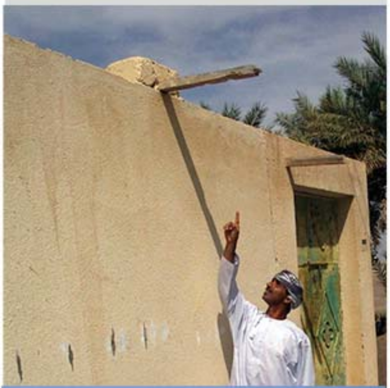
ICOMOS
international council on monuments and sites

IAU
International Astronomical Union




Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention

Thematic Study no. 2

Edited by Clive Ruggles

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In cooperation with
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Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention

Thematic Study, vol. 2

Clive Ruggles and Michel Cotte

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Preface

This Thematic Study is the second volume in a gradual development of themes and issues relating to astronomical heritage in particular and science and technology heritage in general. It also represents progress towards a “global thematic study on science and technology heritage”, a complex topic that can only be approached step by step in the context of a broader, gradual development of ideas.

This Thematic Study results from a collaborative project between the International Council on Monuments and Sites (ICOMOS), an advisory body to UNESCO for cultural heritage, and the International Astronomical Union (IAU), the world’s foremost professional organization for astronomy, through its Commission (C4) on World Heritage and Astronomy. It is published on behalf of both ICOMOS and the IAU.

The main aims of the project are to gain an improved understanding of the character and composition of different forms of astronomical heritage and to identify optimal methods for, and potential problems in, defining this type of heritage in the context of the World Heritage Convention. As a result of the collaboration, the international team of authors is drawn from two complementary scientific and professional communities both of whom have provided invaluable input and expertise. The need to combine methodologies and develop common lines of approach has presented a range of challenges and each of the contributing authors named on various chapters and case studies has played a vital role in helping us to rise to them.

These contributing authors provided the first drafts of their articles working to a common specification. In some cases, the articles have been heavily reorganized and amended in order to impose a suitable degree of consistency of approach and style and depth of analysis (as well as of length).

Versions of the case studies are also available on the UNESCO–IAU Portal to the Heritage of Astronomy (http://www.astronomicalheritage.net/). Updates, together with and further reports and case studies, will also be posted on the portal from time to time, forming part of an electronic resource that will continue to be developed into the future.

The overall aim of the ICOMOS–IAU Thematic Studies on astronomical heritage is to highlight issues that might arise if State Parties were to prepare nomination dossiers concerned with the astronomical values of the properties concerned. This second volume in the series builds upon the first by exploring in more detail some of the unresolved issues raised there. In order best to do this, the case studies presented here are structured in the form of segments of draft dossiers. It must be strongly emphasized, therefore, that the presence or absence of any property as a case study in this volume carries no implications whatsoever regarding the outcome of the nomination process should it ever be put forward for inscription on the World Heritage List, either alone or through a serial nomination.

Clive Ruggles and Michel Cotte, March 2017

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Illustrative materials

Further information

Further information relating to astronomy and archaeoastronomy and/or the context of the World Heritage Convention can be found on the following websites:

UNESCO Astronomy and World Heritage Initiative	whc.unesco.org/en/astronomy
Portal to the Heritage of Astronomy	www.astronomicalheritage.net
UNESCO World Heritage Centre	whc.unesco.org
International Council on Monuments and Sites (ICOMOS)	www.icomos.org
International Astronomical Union (IAU)	www.iau.org
IAU Commission on World Heritage and Astronomy	www.astronomicalheritage.org
International Union for the Conservation of Nature (IUCN)	www.iucn.org
International Society for Archaeoastronomy and Astronomy in Culture (ISAAC)	www.archaeoastronomy.org

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Introduction

Clive Ruggles and Michel Cotte

Article 1 of the World Heritage Convention (http://whc.unesco.org/en/conventiontext) defines as relevant cultural heritage monuments and groups of buildings “which are of outstanding universal value from the point of view of history, art or science”. Article 2 recognizes natural features “of outstanding universal value from the aesthetic or scientific point of view”, geological and physiographical formations “of outstanding universal value from the point of view of science or conservation”, and natural sites “of outstanding universal value from the point of view of science, conservation or natural beauty”. In view of these statements it is extraordinary that criteria for assessing science heritage are so underdeveloped: underdeveloped to the extent, in fact, that the thematic study on *The Heritage Sites of Astronomy and Archaeoastronomy in the Context of the World Heritage Convention* (Ruggles and Cotte 2010 [hereinafter “TS1”]) was the first in any field of science heritage.

Consequently, our efforts to identify and clarify some of the key issues that arise when assessing astronomical heritage have broader value in helping to clarify some of the fundamental issues that apply to science heritage more generally. UNESCO’s Thematic Initiative on Astronomy and World Heritage (whc.unesco.org/en/astronomy) was created in 2003 with the aim “to establish a link between Science and Culture towards recognition of the monuments and sites connected with astronomical observations dispersed throughout all the geographical regions, not only scientific but also the testimonies of traditional community knowledge” (UNESCO 2012).

The Astronomy and World Heritage Initiative sets out to identify, safeguard and promote significant cultural properties connected with astronomy. The places in question do not just include sites (such as observatories) important in the development of modern scientific astronomy, but also much older constructions whose design or location relate to celestial objects and events, reflecting the ways in which ancient cultures attempted to make sense of the world—the cosmos—within which they dwelt (Ruggles 2009; 2012).

In 2008 a formal Memorandum of Understanding (MoU) was signed between UNESCO and the International Astronomical Union (IAU) agreeing a number of ways in which the two organizations would work together to advance the Astronomy and World Heritage Initiative. The IAU promptly set up a Working Group charged with fulfilling the IAU’s commitments under the MoU. One of the first deliverables of the IAU WG, working in collaboration with ICOMOS International, was the global Thematic Study on astronomical heritage, mentioned above. This was published in June 2010 and presented at the 34th session of UNESCO’s World Heritage Committee (34COM) in Brasilia. A downloadable electronic version is available at no charge from the Portal to the Heritage of Astronomy (www.astronomicalheritage.net).

The MoU between UNESCO and the IAU was renewed in 2013. In April 2015, following a major restructuring exercise, the IAU approved the creation of a new Commission on World Heritage and Astronomy, one of four Commissions within a new Division on Education, Outreach and Heritage, thus significantly raising the profile of world heritage among professional astronomers and placing the IAU’s commitment to world heritage on a firmer, longer-term basis. In September 2015 UNESCO and the IAU entered into an Official Partnership agreement (consultative status).

According to the statement of Working Methods and Formal Processes for the Implementation of Activities within the Framework of the renewed MoU, agreed between UNESCO and the IAU, the IAU Commission will, among other things, continue to work on behalf of the IAU with ICOMOS International to define a common vision on astronomical heritage and develop robust general principles for assessing the value of different types and categories of scientific and technological sites relating to astronomy, whether or not they represent potential Outstanding Universal Value (OUV) under the terms of the World Heritage Convention. This will assist State Parties in the identification of properties of significance, and potentially of Outstanding Universal Value, in relation to astronomy.

The 2010 Thematic Study represented a first stage in this process. Its subject matter ranged from early prehistory to modern astrophysics and space heritage, including working observatory sites and dark-sky places. In view of the existence of a 2009 report on classical observatories produced by ICOMOS–Germany and the University of Hamburg (Wolfschmidt 2009), it was not considered necessary to give special emphasis to classical observatories from the renaissance to the mid-20th century, which were treated in equal measure to 14 other cultural heritage themes.

This Thematic Study continues the development of a common vision and robust general principles by presenting a selection of case studies in greater depth, structured as segments of draft dossiers, that raise and help explore key issues relating to astronomical heritage that had first been identified in the 2010 work. It originated from a request in October 2011 from the IAU to its (then) Working Group on Astronomy and World Heritage to develop in more detail some of the case studies included in the 2010 thematic study. WG members, working with other interested parties as appropriate, duly drafted a number of “extended case studies” highlighting the astronomical values of the properties concerned. These were presented and discussed at a Forum held in New Zealand in June 2012, and again at the IAU’s 28th General Assembly in Beijing, China in August 2012. Over the ensuing months and years, various of the case studies were finalized and released publicly on the Portal to the Heritage of Astronomy.

The aim of these “extended case studies” was always, and remains, to explore how significance in relation to astronomy might be used to demonstrate OUV. In particular, they seek to provide

- help and guidance relating to properties that might have a strong claim for inclusion on national tentative lists; and
- guidance for State Parties and stakeholders where it is considered that the property might have the capacity to demonstrate OUV.

Specific extended case studies might well facilitate the eventual preparation of a full nomination dossier should a State Party decide to prepare one, but it is fully recognized that this process must involve a wide range of stakeholders and must cover a range of legal and management issues as well as the scientific and heritage ones.

We also recall that the advice of ICOMOS’ panel is officially required for the value assessment of cultural heritage properties by the World Heritage Committee, including cultural landscapes and archaeological sites. This happens for every cultural property nominated for World Heritage recognition, as part of the process organized by the World Heritage Convention in order to ensure a collective and balanced evaluation. At each year’s World Heritage Committee session, ICOMOS is required to prepare an assessment by its experts and its final evaluation panel. The World Heritage Committee examines the assessments and recommendations by ICOMOS for cultural properties, IUCN for natural properties, and both for cultural landscapes, and then takes the final positive or negative listing decision.

Scope of the Case Studies

The case studies contained in the chapters that follow, together with the main issues that they highlight, are summarized in Table 1.1.

Table. 1.1. Case studies included in this volume and issues raised

Property	**State(s)**	**Main themes and issues**
Seven-stone antas	Portugal, Spain	Potential for serial nomination of a group of prehistoric monuments whose astronomical significance is only evident from the group as a whole
Stonehenge World Heritage Property	United Kingdom	Management issues given due recognition of astronomical values
Chankillo	Peru	Values of specific site in relation to astronomy as against broader values of archaeological landscape and related sites
Astronomical timing of irrigation in Oman	Oman	Cultural practices explicitly dependent upon dark night skies
Observatoire de Paris	France	Relative strength of individual v. serial nomination of classical observatory sites
Royal Observatory, Cape of Good Hope	South Africa	Importance of movable and intangible heritage in strengthening value of fixed heritage
Pic du Midi de Bigorre Observatory	France	High-mountain observatories
Leading optical observatories: AURA Observatory Canarian Observatories Mauna Kea Observatory, Hawai‘i	 Chile Spain USA	)) Modern optical observatory sites under) direct threat from light pollution)
Aoraki–Mackenzie International Dark Sky Reserve	New Zealand	Pristine dark-sky area with broad cultural connections
Eastern Alpine and Großmugl starlight areas	Austria	Relatively dark dark-sky areas with few or no direct cultural connections

The various case studies (Chapters 3–12) elaborate upon a range of issues raised in the 2010 Thematic Study. The major ones include:

- The relative strength of single-property as opposed to serial (typically transnational) nominations. This is explored both in the context of archaeoastronomical sites (seven-stone antas), classical observatories (Observatoire de Paris; Royal Observatory, Cape of Good Hope) and modern working observatories (Pic du Midi de Bigorre Observatory; Leading optical observatories).
- The importance of movable and intangible heritage in strengthening the value of fixed heritage (Royal Observatory, Cape of Good Hope and all other classical and modern working observatories).

- Recognizing and preserving the value of dark skies within cultural landscapes (Astronomical timing of irrigation in Oman), at cultural sites such as those used for modern scientific astronomy (Pic du Midi de Bigorre Observatory; Leading optical observatories) and natural sites (Aoraki–Mackenzie International Dark Sky Reserve; Eastern Alpine and Großmugl starlight areas).
- Recognizing, managing and protecting astronomical values at archaeological sites (Seven-stone antas; Stonehenge; Chankillo).

The “dark skies” issues are particularly complex as it is clear that dark sky places cannot, in themselves, be recognized as specific types or categories of World Heritage property, either cultural or natural. For this reason we include a specific discussion of the issues involved, and the potential for protecting dark skies associated with cultural or natural sites within the World Heritage Convention, in Chapter 2.

Given a strong interest in science and technology heritage related to space exploration, an attempt has also been made to develop a case study on Baikonur Cosmodrome in Kazakhstan. This attempt highlighted the inherent difficulties in obtaining relevant information, for example on protection and management, as well as the complexity of identifying criteria under which nomination might be proposed and in drafting a viable potential statement of OUV. The material developed so far is included in Chapter 13, but not in the “draft dossier” format. It is clear that the theme of science and technology heritage related to space exploration requires much more extensive attention, and it is possible that this could be the subject of a future thematic study in itself. The example of Baikonur is useful to consider in the present context, for example to explore relationships between science heritage and technology heritage.

For reference we include below an abbreviated list of the World Heritage Committee’s criteria for the assessment of OUV (Table 1.2; for the complete criteria see the *Operational Guidelines*).

Table. 1.2. Criteria for the assessment of OUV (abbreviated)

(i)	Masterpiece of human creative genius
(ii)	Exhibit an important interchange of human values on developments in architecture, technology, monumental arts, landscape design
(iii)	Unique/exceptional testimony to a cultural tradition, either living or disappeared
(iv)	Outstanding example of architecture, technology or landscape that illustrates significant stage(s) in human history
(v)	Settlement or land use that represents human interaction with the environment, especially where vulnerable owing to irreversible change
(vi)*	Something directly or tangibly associated with events, living traditions, ideas, beliefs etc. of OUV
(vii)	Superlative natural phenomenon/a or area of exceptional natural beauty and aesthetic importance
(viii)	Outstanding examples representing major stages of earth’s history
(ix)	Outstanding examples representing significant ongoing ecological and biological processes
(x)	Significant natural habitats for in-situ conservation of biological diversity

* “The Committee considers that this criterion should preferably be used in conjunction with other criteria”

Structure of the Case Studies

The Case Studies in this volume are structured according to categories identified in UNESCO's *Operational Guidelines*, Annex 5. The reason for this is to draw out the astronomical heritage issues that might arise if such a site were nominated for inscription on the World Heritage List. Since our case studies focus particularly on these astronomical heritage issues, many of the categories will be only partially relevant, and sometimes completely irrelevant, in any individual case study. Obviously there is a need to refer as clearly and as fully as possible to broader issues that are not directly astronomical, but we do not need to elaborate them as if we were actually writing the dossier. It is also vital to try to identify the most appropriate category or categories under which to raise and elaborate upon specific types of issue, for example those relating to dark sky preservation.

One major difference between the structure of our case studies and that of actual dossiers as specified in the *Operational Guidelines* occurs in the "Justification for Inscription" section. We place the *Comparative Analysis* (3.c) and *Statement of integrity and/or authenticity* (3.d) before, not after, the *Potential criteria under which inscription might be proposed* (3.a) and the *Suggested statement of OUV* (3.b). This is because the comparative analysis and the consideration of integrity and authenticity must precede, and support, the consideration of the criteria under which OUV might be demonstrated and the development of the proposed statement of OUV.

In Table 1.3 below, we list the categories together with a preliminary indication of how relevant they are likely to be.

Table. 1.3. Structure for case studies in this volume, with an indication of the likely relevance of each category

Operational Guidelines Annex 5 [UNESCO]	***Section no.***	***Included?***
Identification of the property:		
Country/State Party	1.a	Always
State/Province/Region	1.b	Always
Name	1.c	Always
Geographical co-ordinates to the nearest second and/or UTM to the nearest 10m	1.d	Always
Maps and plans, showing the boundaries of the property and buffer zone	1.e	As relevant
Area of property and buffer zone	1.f	As relevant
Description:		
Description of the property	2.a	As relevant
History and development	2.b	As relevant
Justification for inscription:		
Criteria under which inscription is proposed	3.a	Always
Proposed statement of OUV	3.b	Astronomical part always; rest optional
Comparative analysis	3.c	As relevant
Integrity and/or authenticity	3.d	As relevant
Present state of conservation	4.a	As relevant

Factors affecting the property:		
Development pressures	4.b.i	As relevant
Environmental pressures	4.b.ii	As relevant
Natural disasters and risk preparedness	4.b.iii	As relevant
Visitor/tourism pressures	4.b.iv	As relevant
No. of inhabitants	4.b.v	If relevant
Protection and management:		
Ownership	5.a	If relevant
Protective designation	5.b	If relevant
Means of implementing protective measures	5.c	If relevant
Existing plans	5.d	As relevant
Property management plan	5.e	As relevant
Sources and levels of finance	5.f	Only if relevant
Sources of expertise and training	5.g	Only if relevant
Visitor facilities and statistics	5.h	As relevant
Presentation and promotion policies	5.i	As relevant
Staff levels	5.j	Only if relevant
Monitoring:		
Key indicators for measuring state of conservation	6.a	As relevant
Administrative arrangements	6.b	Only if relevant
Results of previous reporting exercises	6.c	Only if relevant
Documentation:		
Photos and other AV materials	7.a	As relevant
Texts relating to protective designation	7.b	Only if relevant
Most recent records or inventory	7.c	Only if relevant
Agencies holding inventory records	7.d	Only if relevant
Bibliography	7.e	As relevant

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Windows to the Universe and potential criteria in the World Heritage Convention context

Michel Cotte

What follows is conceived as a systemic approach linking the idea of 'Windows to the Universe' to the recommended use of current World Heritage concepts such as 'Outstanding Universal Value' (OUV), criteria expressing it, integrity and authenticity, etc. These concepts are defined and regularly updated by the World Heritage Committee and publically expressed through the *Guidelines for the implementation of the World Heritage Convention*[1]. This is very useful for preparing a World Heritage dossier, which must strictly follow the nomination format; moreover it also offers an efficient and global methodology for every place playing the role of a 'Window to the Universe' with diverse associated values. Practically it relies upon the author's experience of the nomination evaluation as carried out by the ICOMOS[2] organization for the World Heritage Committee annual sessions.

To be listed as World Heritage Site with a well-fitted OUV requires a strict analysis of the place: first building a credible dossier, second being accepted by the advisory bodies in charge of the implementation of the WH Convention[3]. We propose here a conceptual approach combining the two fields so as to develop a credible demonstration of the OUV for a 'Window to the Universe' place and to choose adapted WH criteria. We recall that there are 10 official criteria to express the potential OUV of a given place, 6 for cultural attributes and 4 for natural ones (see Table 1.1).

Basic features

We can represent the 'Windows to the Universe' concept schematically using three main tangible elements briefly defined here but easily identified by everyone.

The first is the sky itself in the broadest sense, in other words the physical universe comprising stars, planets, galaxies, dark matter, etc. The second is the idea of a 'window', which means basically a frame and a pane of glass. In this sense, the frame of the window represents the local place with its environmental features, and the glass in the window represents the atmosphere through which we have to observe the sky. The third element is the human eye together with the optical instruments or other artefacts that can amplify its observational capabilities. Links with the human brain must also be mentioned here, as they are responsible for rational knowledge (science) and social representations (beliefs, religions, etc.) and uses (practical applications of astronomy to architecture and urbanism).

Of course these three basic issues of sky observation are intimately related to one another. But they are not of the same nature, generally speaking, nor are they directly related to the WH Convention concept of inscription of a given property. What is the most spontaneously adapted to the WH Convention goal is the place itself, as a local tangible property. We can define it by its physical boundaries; we can identify the owner, the manager and we can make an inventory of its tangible evidence and of its specific environmental qualities (e.g. atmosphere qualities that frequently determine the observation position itself).

The presence of the human observers and astronomers of course gives meaning and life to the place, bearing important additional intangible value through the history of knowledge

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1 UNESCO World Heritage Centre, Paris, latest edition 2013.

2 The International Council of Monuments and Sites.

3 ICOMOS for the cultural value and the International Union for the Conservation of Nature (IUCN) for the natural value.

and representation related to it. Observers alone don't make sense in the way of the WH Convention (it is not the Nobel List!).

Can 'Dark Sky' alone be taken into consideration?

The sky is obviously the goal of the observation from the site, and every device and artefact of the observatory is made for that. But the sky itself cannot be defined as a given site, and not at all as belonging to a State party! These are clear requirements for a WH Listing: place of the property, owners, State party responsible, etc. It is not a place in a juridical sense, or even a part of a place. The difficulty of recognizing the sky itself clearly occurred there: it is impossible to define it in WH Convention terms. It can be considered as environmental quality of a place through its exceptional visibility; but it can't be considered as a fully delimited place having OUV by itself.

Of course, the sky must be considered as a major natural feature of the terrestrial environment; but would seem a bit strange to give an 'OUV' to the Universe; in other words to associate a human label of universality to the Universe! This is clearly a paradox. In philosophical terms, it opens questions dealing directly with an anthropocentric approach to the Universe. In such a case, this would mean that humankind allows itself to give a human recognition and value to its global astrophysical environment. In doing so, it would join antique cosmologies and medieval descriptions of the Earth as the Centre of the Universe, and humankind with its gods as ruler of the Universe. It is precisely contemporary astrophysics that shows us the tiny place that humankind actually occupies within the Universe, so that to give human value to the Sky, let alone 'OUV', seems really nonsensical.

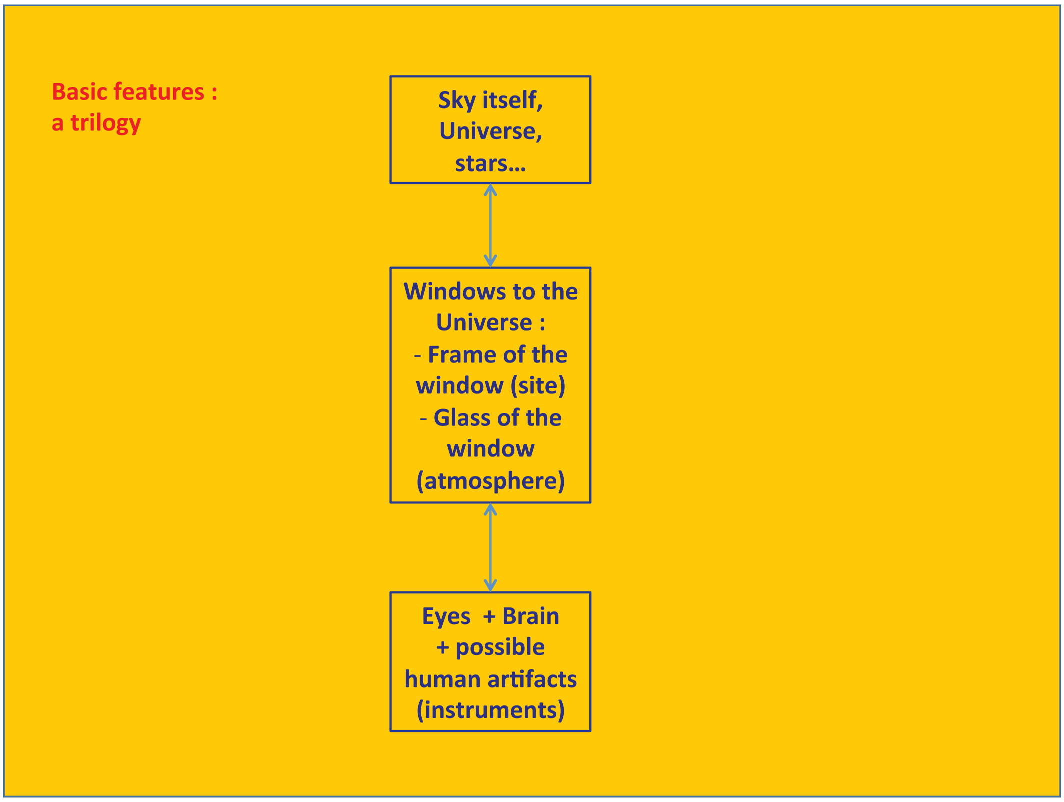

Fig. 2.1. Basic features shaping the 'Windows to the Universe' concept are: Sky itself (object of the observation), Site as a property in local permanent context (geography, atmosphere, architecture, landscape, nature…) and Humankind using the observation place eventually with artefacts/instruments.

If all this seems too theoretical, we can ask practical questions dealing directly with the *Operational guidelines* for the management of WH places: What is the owner of the Sky? What is the management policy to conserve the OUV of the Universe? Obviously, there is no answer to these questions and, even more absolutely, no meaning. That underlines the nonsense of the OUV concept applied to Universe. The Universe or any component of the Sky cannot be nominated in itself. In heritage terms, the Universe is only an element of the landscape we can observe from a given place on the Earth. Consequently, we can only talk about relationships we have with the Universe and not of the Universe itself as a human property.

In WH Convention terms, this leads us back to the site, to the 'frame of the window', and to study its attributes and qualities as a cluster of local elements for a possible nomination. Clearly a Dark Sky alone does not meet the WH requirements. But it could be an essential attribute among others supporting the exceptionality of a place.

Natural and cultural attributes of a given place

We understand that the 'frame of the window' means, firstly, the physical environmental features we have locally, as tangible attributes supporting or surrounding the human observation of the sky at a given place. So, the Window frame presents a series of physical attributes constituting the originality of the site, with consequences for its natural meanings as well as for featuring the landscape. All these attributes indicate the natural and physical originality of the place. In this way it has natural value, in the sense given to this term in the WH Convention. The assessment of local natural value may be done prior to others, by the classical evaluation of natural attributes trough scientific methodology. Relationship with the sky could be handled in this sense and the quality of the sky view 'through the window' appears as one of the landscape and/or major natural attributes of the place. These local natural attributes always exist for a given place, independently of its value and possible OUV, i.e., the top-quality recognition at the higher international level.

A 'Windows to the Universe' site could also carry important cultural evidence related to human observation of the sky. For example, it could be a monument of observation (observatory), some archaeological remains (archaeoastronomical site), architectural features or urban patterns, or a cultural landscape from an ancient civilization that was directly linked with the observation of the sky from the place. These local attributes do not exist systematically, and a site could be exclusively natural. In that sense, cultural attributes are additional to the natural layout of the place. Accordingly, they appear as second issue in the study of its attributes. They could be tangible attributes or intangible ones, conveying the human value associated with a given place. Such intangible additional value could be scientific but not necessary, as we have seen in the first Thematic Study[4].

In every case, the combination of natural and cultural attributes offers a specific landscape; we can easily recognize it for modern observatories in context, and that could be a mixture between cultural and natural attributes.

Dark sky quality as a local environmental attribute

After the frame, the second element of the 'window' is the glass, in other terms the atmosphere. It is an obvious intermediate physical matter between the human eye and the sky, with transparency properties. Dark-sky quality mainly results from the local quality of the atmosphere. In this sense, it is one of the physical attributes giving a specific value to the place,

[4] *Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention*, (ICOMOS & IAU) edited by Clive Ruggles and Michel Cotte. E-book 2010; printed edition 2011.

or its eventual lack of value in the case of light pollution. The quality of the atmospheric transparency depends firstly upon the location of the site with its geographical and climatic dimensions. It is also a variable parameter, given variable cloud-cover, variable moonlight depending upon the phase of the moon, or other typical natural factors. The need for a global and scientific description of these features joins the need for attribute description in the WH dossier sense.

Transparency is an objective physical datum for the atmospheric description of a given place, and can be determined scientifically by means of instruments and regular observations (wetness, density of microscopic dust, turbulence, day-by-day diaries and statistics of the atmosphere, etc.). These experimental results can be compared from one place to another so that the objective quality of a given place can be established with certainty. Of course, some sites are more favoured by nature than others and the objective natural value of such places may be established. Indeed, astronomers have done this for a long time and we have a history of astronomical sites dealing directly with the quality of the local atmosphere and its changes with the rise of urban development and artificial light ever since the 'industrial revolution'. This kind of attribute measurement is typical for the natural description of a given place, even when it is threatened by human lighting factors such as pollution by dust and fog. This human stress upon the natural pattern is not specific to atmosphere transparency, and it is an issue among others as regards human threats upon nature.

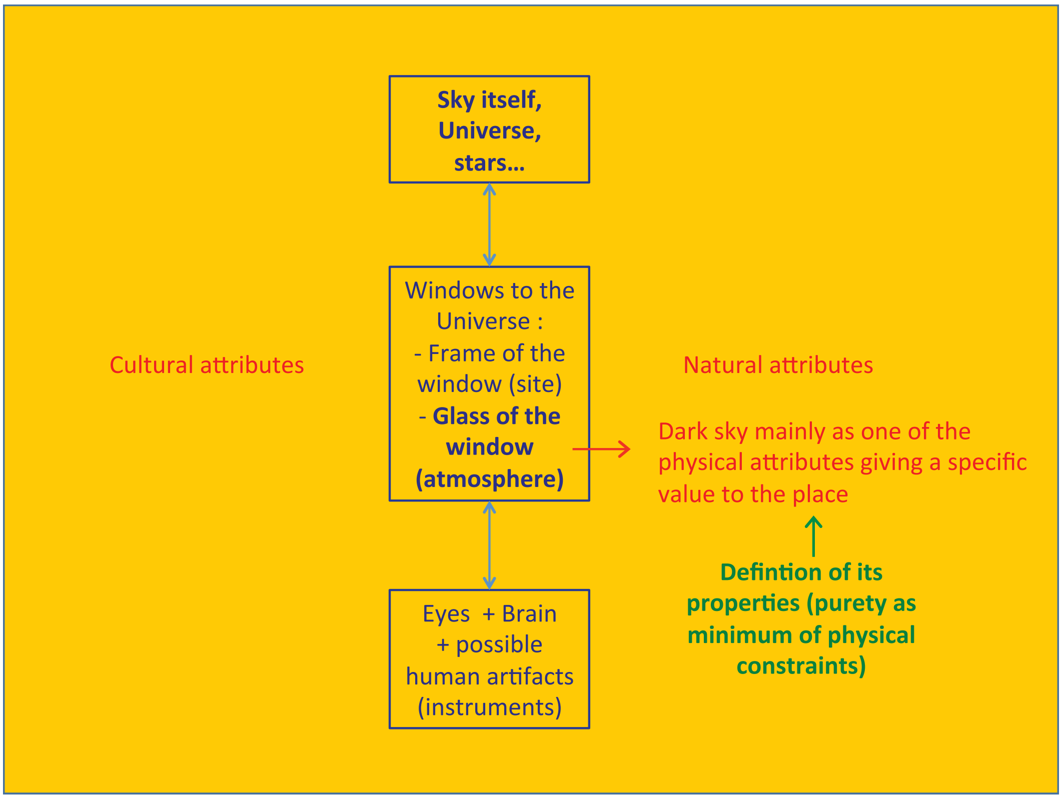

Fig. 2.2. Generally speaking, a given place has natural attributes and cultural attributes; clearly intrinsic Dark Sky quality is a natural attribute of the place among others.

Dark sky as management of Nature

The conservation of dark sky qualities for a given place is a relatively recent initiative but with some important successes as underlined by the international 'Dark Sky Reserve' awards. It remains permanently a challenging goal related to the control of light pollution, which needs strong collective concerns both for local communities' councils and for the inhabitants of a significant geographical area. For instance, it can be important to maintain good conditions for astronomical observations or for improving the quality of the night-and-day cycle for the conservation of natural living species in danger.

The maintenance of dark sky quality can be a strong management issue in itself for an astronomical site. It is necessary in order to maintain good conditions for doing the science and/or for a more natural night environment.

As a cultural attribute it mainly concerns the history of the observatory site as a scientific establishment. The other Dark Sky value relates to the conservation of nature and the establishment of human rights to access the visibility of the natural night sky. These points are important, but recent, and could be not considered as a cultural heritage attribute of the place, only as natural features. They could be seen as issuing from a recent, modern trend of environmental sensibility—a typical feature of today's social movement for political and scientific ecology aiming to defend the conservation of natural value versus uncontrolled human economic and urban development.

The best way to promote Dark Sky initiatives today in relation to the WH Convention is probably not to try to get OUV recognition for this natural feature, but to demonstrate that it could be an efficient and durable way of managing Nature. In that case it is a well-managed environmental quality of the 'window glass', within the specific efforts of local communities and site managers. It is a quality among others that allows a good expression of all the attributes together, especially a global landscape associating features on the earth and in the sky. In the case of observatories, the surest sign of maintaining the dark sky value is the permanence of important scientific programmes of observation. This global landscape expression of an ensemble of attributes supports what we call 'integrity' and 'authenticity' factors of the site. The concept of integrity expresses the completeness of different attributes constituting the value of the place and the easy expression of their relationships. Authenticity expresses the conservation of design, structures, appearance and function of the place.

Today, we can examine the possibility that there is a lack of glass in the window; this definitively bypasses problems due to the atmospheric filter! In this sense, the satellite telescope Hubble is evidence of human progress in the observation of the sky. It represents a crucial and final stage in the story of the location of observatories, moving beyond efforts to build them in mountain locations with the most favourable dark sky conditions throughout the year. In this sense, the Hubble space telescope has an exceptional value, but the question of its examination in a WH context remains a complex one because of its location and its status as a moveable instrument in the sky. The intrinsic scientific value of the Hubble telescope and its family of similar observatories in future is really outstanding.

Dark Sky among a cluster of natural attributes

Globally speaking, if we return first to the natural dimension of the 'Windows to the Universe', Dark Sky quality contributes to the global natural context of a given place. It belongs to a larger group of natural attributes of the site, forming its natural environment components. Of course, these natural attributes could have exceptional value together, and this way examining the combination of a group of natural attributes must be seriously considered through the concept of 'Natural Starlight Reserves'. Thus, the value of a given 'Window to the Universe' place in a global natural sense is a possible way to define potential OUV. That interweaves exceptional dark sky properties with other exceptional or unique natural attributes of the place, forming for instance an outstanding ‘monument of nature’.

Note that the dark sky alone as a natural attribute remains problematic, because it could not be seriously attributed just to one given place, or even to a limited series only relying upon dark-sky quality, without controversy. Furthermore, that isolated attribute suggests a global sky value not really linked with a given place, except is so far as we can do a comparative demonstration showing that it is absolutely better than others. On the other hand, a complete lack of other attributes drastically reduces the credibility of OUV justification because it will rely upon too narrow a base and it will appear as not really supported by a clearly identified site. It will be seen as a theoretical concept out of any context.

Clearly, whether or not the starlight of a given place has exceptional quality, it constitutes one of the natural attributes forming its global value. In this case, the quality of the window glass significantly reinforces the natural qualities of the window frame. It bears one specific attribute among other remarkable natural ones. Dark-sky quality contributes to the global natural exceptionality of the place, both as a natural site and as a “window to the Universe”, and it contributes to its beauty as well as for its intrinsic scientific properties favourable for professional or amateur views of the Universe. In that way, one or some of the natural WH criteria could be appropriate for supporting possible OUV. If a group of natural attributes for a given place may be described with possible OUV, natural WH criteria must be examined, especially criterion (vii) for OUV as a “monument of nature”. Contrariwise, if the only attribute reaching the top level is the quality of the dark sky, then that is problematic. A dark-sky attribute for a site, alone, without any other natural or cultural attribute at OUV level, encounters the strong reservations we have presented above for the sky and the Universe, which could not be presented in OUV terms.

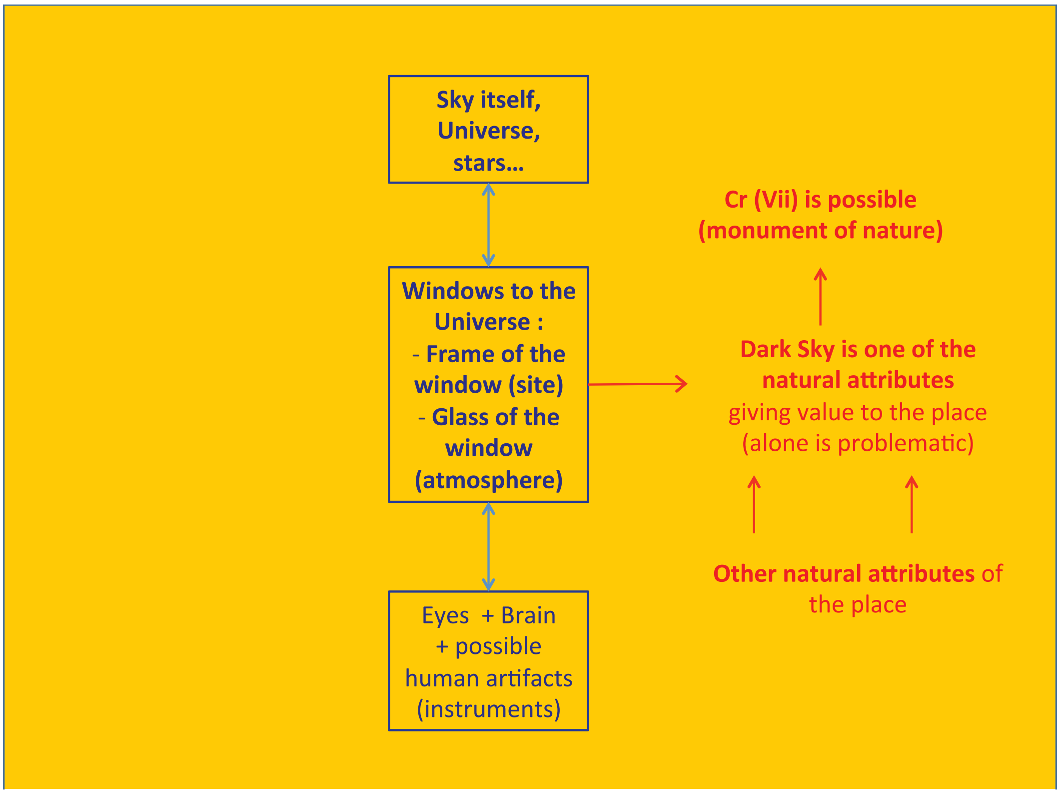

Fig. 2.3. One of the best ways to use ‘Dark Sky’ value is among a set of other natural attributes, making a generally remarkable landscape during both night and day; potential OUV results from the combination of attributes.

For instance the World Heritage List, since 1990, already includes the *Te Wahipounamu – South West New Zealand* natural zone. Its OUV declaration mentions a large and diversified set of natural attributes expressing many natural dimensions, which is recognized by the use of four natural criteria mentioned by the *Operational Guidelines*—(vii), (viii), (ix) and (x):

(vii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;

(viii) be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;

(ix) be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;

(x) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation." [5]

Such diversity for one given place is exceptional.

The brief description of the site and the text justify the criteria: they accurately describe the remarkable diversity of mountain landscapes, natural features for geology, biodiversity, etc. However, they do not mention dark-sky quality. Yet in the adjacent District of Mackenzie and Tekapo Lake in the north-eastern part of the natural park, we can observe the sky with exceptional visual atmospheric quality. The district offers today one of the world's most highly rated Dark Sky Reserves. The district is under collective rules that strictly control all artificial lighting, in a durable perspective and giving an absolute priority to dark-sky conservation. For us, it makes sense to propose an extension of the already listed mountain park to the Mackenzie District and Tekapo Lake, with the addition of Dark Sky value to the others, e.g. to reinforce criterion (vii) ('monument of nature').

Fig. 2.4. Tekapo Lake at night. ©TWAN, http://www.terrastro.com/galleries/lake-tekapo/

[5] World Heritage Center, *op. cit.*, 2013.

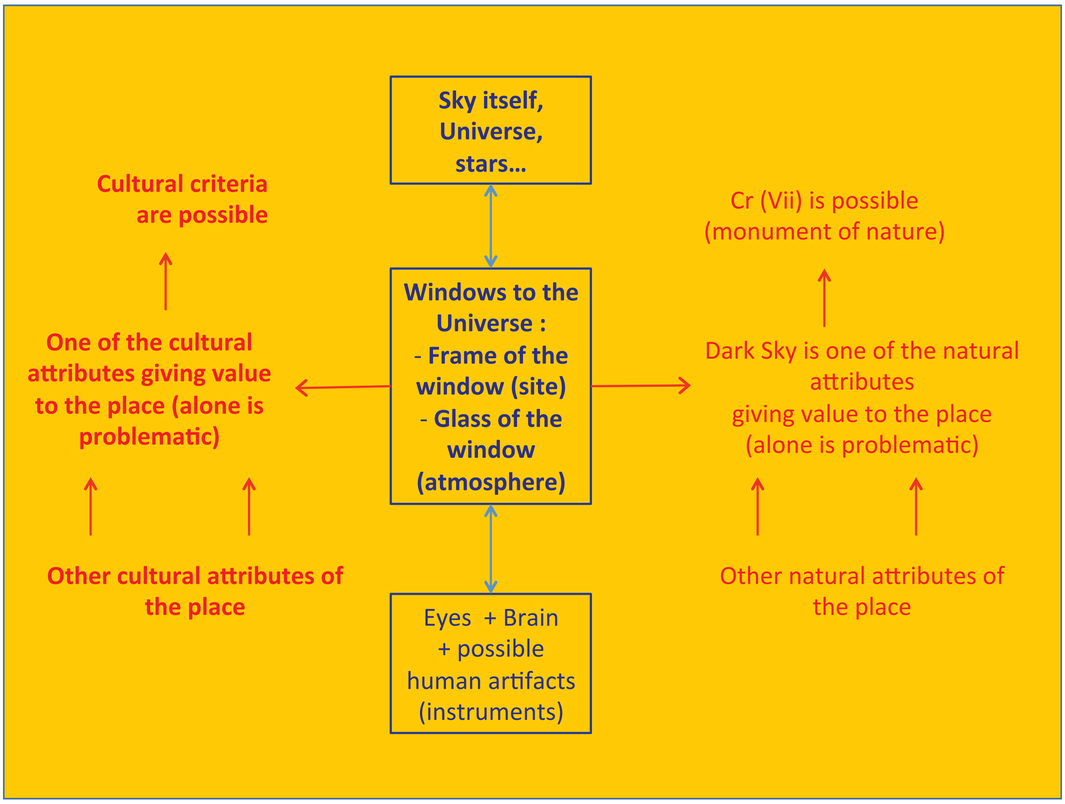

Fig. 2.5. The other good way to use 'Dark Sky' value is to link it to a set of remarkable cultural attributes, or—equally often—to a mixture of cultural and natural features.

Dark Sky among a cluster of cultural attributes or mixed attributes

In a similar way, dark-sky quality could be considered as a cultural attribute in the context of the history of the observatory place. In other words, a remarkable starlight property for a given 'Window to the Universe' could strongly reinforce the value of the observatory site and explain its implementation and its scientific history. Similar remarks about the exceptional quality of the cultural attributes must be made if there is an expectation to reach the level of demonstrating OUV: alone, dark-sky quality remains problematic and will appear out of any context (which is the exact opposite of cultural significance!).

However, dark-sky value associated with a series of other cultural attributes could produce strong global significance and meet possible OUV. Such global value could be expressed by one or more of the different cultural criteria, (i) to (vi). We have to discuss that choice in the context of the site in question and in a comparative view with other similar sites in the World.

We also have to remember that, in any case, Dark Sky forms a management issue. This means that we have to pay great attention to the preservation and conservation of the darkness of a place, through regulation and a collective attitude inside the buffer zone—a strongly recommended management issue. But we have to avoid confusing a possible attribute supporting OUV (exceptional quality of Dark Sky at a given place) with the good environmental management of light pollution (Buffer zone, lightning regulation…). Indeed, this is a mistake frequently made when studying a place without a sufficient attention to what constitutes a heritage site, especially in the WH context.

In the context of the High Mountain Observatories serial nomination project, the case of Pic du Midi in front of the Pyrenean Mountains (France) offers a remarkable example of combined attributes, both cultural and natural. Among them, atmosphere quality plays a significant role because of its stability and its clarity due both to the altitude (2877 m) and the isolated position of the Pic. In historical terms, it is one of the pioneering high-mountain observatories in the World (end of 19th Century) and probably the oldest of this type to be continuously used up until today. It offers by its artificial shaping at the top of the Pic a really impressive view and can be seen from very far distances from a great part of the surrounding valleys, out to cities like Toulouse when the weather is clear. It forms one of the strongest images of the regional identity of Languedoc. On the natural side, the remarkable geology of the Pic contributes to thermal properties that are linked with the stability of the local atmosphere. But what is probably the most impressive is the panorama it offers, as a Northern belvedere, of the central part of the Pyrenean chain, due to its isolated position. The landscape view on the mountain skyline is exceptionally wide owing to the purity of the atmosphere in a place where sunny days are the most numerous in Europe. In short, Dark Sky and landscape qualities are intimately associated[6].

Fig. 2.6. Pic-du-Midi Observatory, France, offers a remarkable combination of cultural value (more than one century of continuous high mountain observation of the sky), identity landmark (one of the strongest and the most visible symbol of the Languedoc region), natural value among them quality of atmosphere and Dark Sky, and the ensemble offering an outstanding mountain landscape. © Courtesy of Régie du Pic-du-Midi, 2009.

[6] See Chapter 9.

Conclusion

To conclude, the Dark Sky by itself is, of course, an important natural feature for a given place, especially in the context of astronomical observations. It can be studied in scientific terms aiming to describe the local atmospheric properties (clarity, stability, average of sunny days, etc.). We have to note that such qualities do not only allow the exceptionality of the dark sky, but also the quality of the landscape by day. Nonetheless, it is really challenging to try to use dark-sky quality alone as an 'exceptional natural attribute supporting potential OUV'. This is firstly because it emphasizes the sky itself more than the local context, and the sky itself cannot be considered in the scope of the WH Convention, as we have seen, because it is not a 'property' in the juridical sense, with mapped limits, an owner and conservation policy, etc.

We absolutely need to place the Dark Sky in context. This means that we need to consider other natural or cultural attributes of the given place, i.e. the completion and correlation of diverse attributes that (generally speaking) make complete sense for the site, with important mutual reinforcement of meanings and global value.

In cultural terms, Dark Sky quality supports one of the fundamental and permanent patterns of the Heritage of astronomy and archaeoastronomy. By itself, it forms the basic and initial condition for choosing a sky observation site. In some way, the other tangible attributes result from it, as a subsidiary human development with its fixed or moveable instruments, its architecture, for the history and socio-anthropology of the place, etc. In other words, it defines a basic requirement for launching human activities in a diversified sense: not only sky observation for knowledge purposes, but also for human and social representation, symbolic and religious issues, and applied astronomy to time measurement, architecture and urbanism, individual and collective prediction of future, navigation, etc. It supports and recalls to us the history of exceptional observations, precious records and of some major scientific discoveries. It also informs us of the history of its initial settlement and scientific developments. Astronomical and archaeoastronomical heritage is a subject by itself, notably explored by the first ICOMOS–IAU Thematic Study with its 18 chapters covering both long historical times from prehistory to present and every large civilization area in the World[7]. In every civilization, all people have a vision of the sky and a cosmology.

Another important issue must be taken into account with the regulation of light pollution aiming to preserve Dark Sky quality. In this sense, Dark-Sky Reserves with specific regulations adopted by local communities to regulate and control lighting, both public and private, are really important. This promotes durable development that respects nature and offers human and social value by itself. In WH terms it is clearly a 'management issue'—a really virtuous one—and it could easily be added to other ways of respecting nature and for a conservation policy of the local cultural components. It could be an important part of the cultural landscape conservation plan or/and an issue for the buffer zone regulation, thus wider than merely 'astronomical or archaeoastronomical places'. In any case, the Dark Sky approach offers us a long-term preservation policy and a basic management issue for the place.

In any case—natural, cultural or mixed—the quality of the local 'Window to the Universe' presents a basic attribute among a set of attributes and a virtuous management issue. This could support potential OUV in the WH sense as well as supporting a regional or national value of a given place. It is also very important to share that group of values with inhabitants and visitors by way of valorization plans, especially for young people.

[7] Clive Ruggles & Michel Cotte, *op. cit.,* 2010 and 2011.

Seven-stone antas, Portugal and Spain

Juan Belmonte, Luís Tirapicos and Clive Ruggles[1]

1. Identification of the property

1.a Country/State Party: Portugal; Spain

1.b State/Province/Region:

Alandroal, Arraiolos, Estremoz, Évora, Mora, Reguengos de Monsaraz, and Redondo municipalities, **Évora district,** central Alentejo region, Portugal

Castelo de Vide, Crato, Elvas, Nisa, and Ponte de Sor municipalities, **Portalegre district**, central Alentejo region, Portugal

Ourique municipality, **Beja district**, Baixo Alentejo region, Portugal

Santiago do Cacém municipality, **Setúbal district**, Baixo Alentejo region, Portugal

Agualva, Loures, and Sintra municipalities, **Lisboa district**, Grande Lisboa region, Portugal

Barcarrota, Jerez de los Caballeros and Mérida municipalities, **Badajoz province**, Extremadura region, Spain

Cedillo and Valencia de Alcántara municipalities, **Cáceres province**, Extremadura region, Spain

Aroche and Rosal de la Frontera municipalities, **Huelva province**, Andalusia region, Spain

1.c Name: 186 individual names as listed in Table 3.1 below.

1.d Location:

The seven-stone antas identified in Table 3.1 occupy 186 separate locations concentrated in the central Alentejo region, Portugal, and the provinces of Badajoz and Cáceres, Extremadura region, Spain. Their latitudes vary from 37.8° to 39.6° N, their longitudes vary from 8.2° to 7.0° W, and their elevations range from c. 200m to 580m above mean sea level.

The Portuguese sites are mostly located within the limits of the Évora and Portalegre districts, an area to the south and west of Elvas, close to the Spanish frontier, and just below the latitude of Lisbon.

1.e Maps and Plans:

See Figs 3.1 and 3.2.

1.f Area of the property:

Seven-stone antas are distributed over an area approximately 100km east to west, from about 50km from the coast near Lisbon to the Spanish border provinces, and a little over 200km from south to north, from Ourique to the River Tejo (Fig. 3.1).

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[1] JB wishes to express his gratitude to Juan Pedro Hilanderas, Concejal de Cultura of the Valencia de Alcántara municipality for his support in locating the necessary documentation to produce this report and to Margarita Sanz de Lara for her photographs. On the Portuguese side, LT wishes to thank Cândido Marciano da Silva and Leonor Rocha for sharing their thoughts and an unpublished manuscript on the topics addressed in this report.

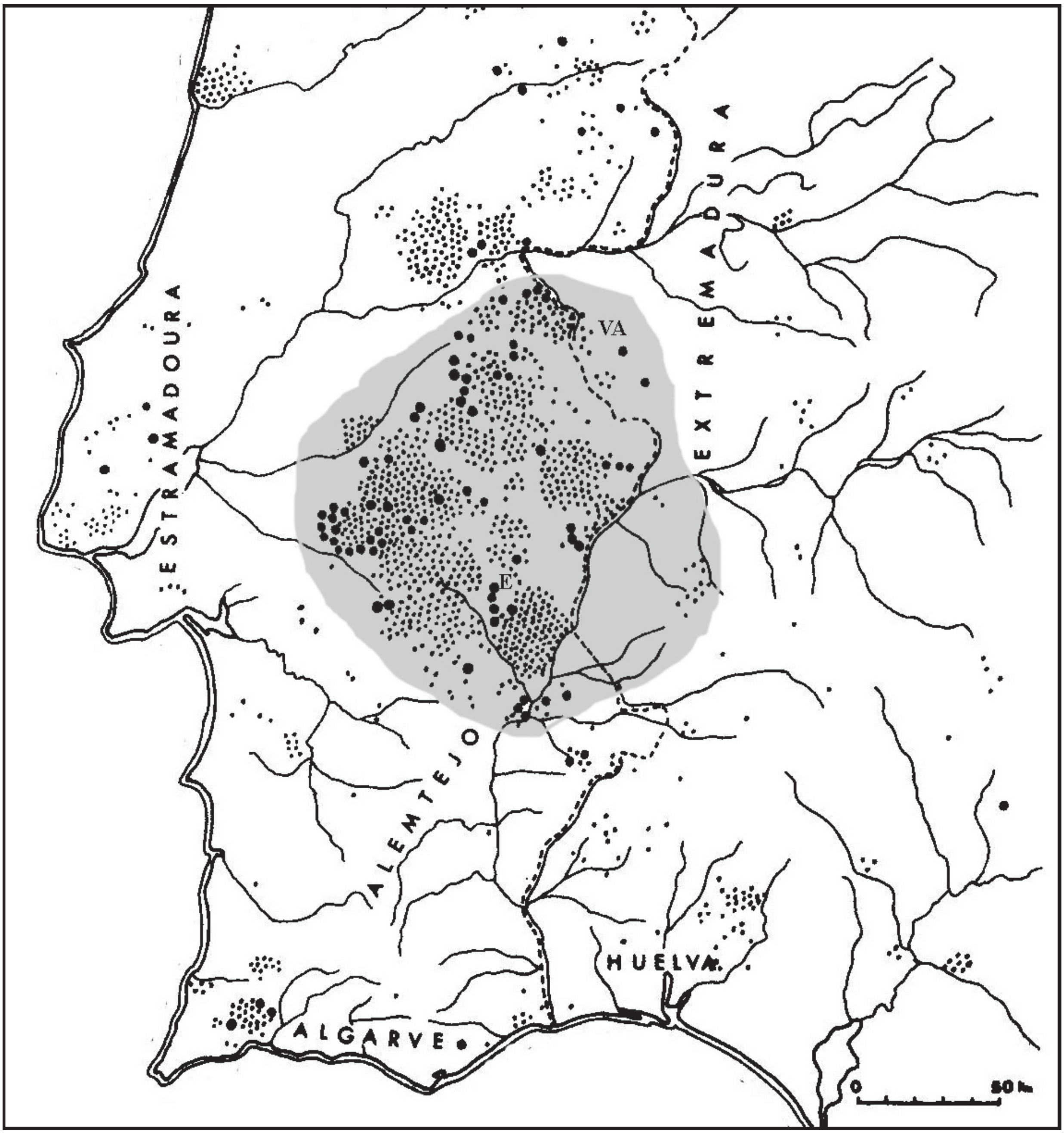

Fig. 3.1. The neighbouring regions of Alentejo (Portugal) and Extremadura (Spain) where seven stone antas can be found. The vast majority are in Portugal (notice the huge concentration around Évora, E in the map), hence the common name of *Antas Alentejanas* by which they are also known. The Spanish town of Valencia de Alcántara (VA) is also shown on the map. Adapted from Belmonte and Hoskin (2002), fig. 2

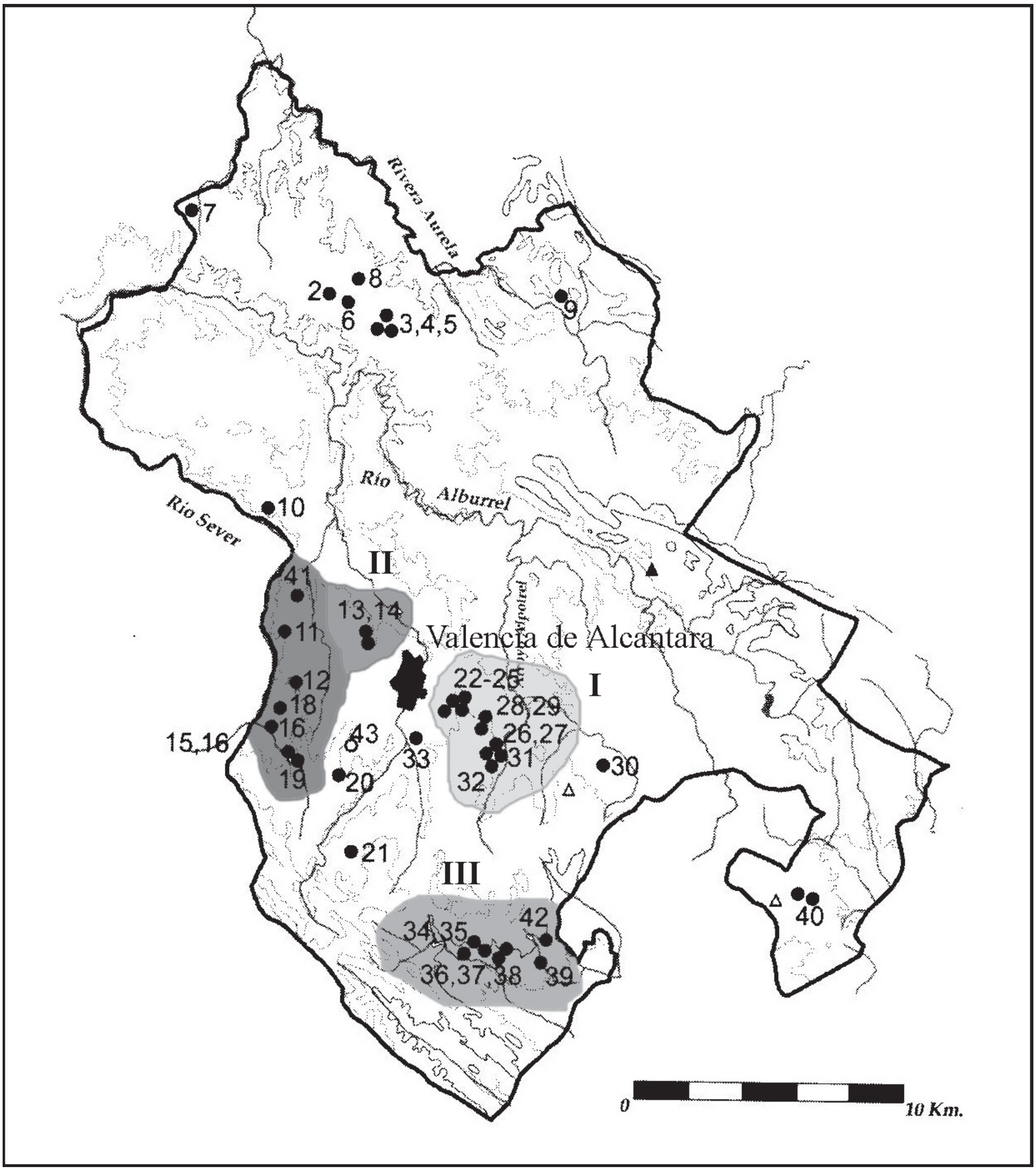

Fig. 3.2. Map of the Valencia de Alcántara municipality showing the areas discussed below where well-preserved groups of seven-stone antas, conforming to the 'standard' design and orientation pattern, are located. These are (I) Collados de Barbón, (II) Río Sever banks and (III) the granite outcrop of Santa María de la Cabeza (in light, dark and middle tone grey respectively). Dolmens 2 to 9 were built of schist and poorly preserved. The river Sever forms the frontier between Spain and Portugal. A handful of antas can be found on its west (Portuguese) bank. For details see Table 3.2. After Bueno Ramírez and Vázquez Cuesta (2008)

2. Description

2.a Description of the property

General description

The seven-stone antas are a distinctive form of megalithic tomb. The 177 examples whose principal orientation has been reliably determined all, without exception, face within the arc of sunrise—the part of the horizon where the sun rises at some time during the year (or moonrise) (see Fig. 3.7). The extraordinary consistency in an orientation pattern that extends over hundreds of kilometres provides an exceptionally clear indication of its astronomical origin.

They were built over a wide area extending over the present-day regions of Alentejo in Portugal, where most of the antas are located, and Extremadura in Spain (see Fig. 3.1). The main concentrations of sites within the group, including the best preserved and some of the most impressive monuments, are around the towns of Évora (Portugal) and Valencia de Alcántara (Spain).

The name *anta* is the Portuguese term for dolmen and will be loosely used as a synonym throughout this case study, although the Spanish counterparts are normally denoted as dolmens in the corresponding archaeological or tourist literature.

The seven-stone antas can easily be described as standard corridor dolmens but their most impressive features are that

(i) they were constructed using a surprisingly consistent architectural design (see Figs 3.3, 3.4, 3.5) over an extended period of time (hence their common name); and

(ii) they manifest a pattern of orientations that place them among the oldest monuments on Earth with indisputable astronomical orientations.

Fig. 3.3. Tapias 1 (no. 143 in Table 3.1), a good example of a seven-stone anta, well preserved, in the vicinity of Valencia de Alcántara. Spain. Photograph courtesy of Margarita Sanz de Lara

Form and construction

The seven-stone antas (dolmens) were mostly constructed using tall blocks of granite, typically 3m or more in height. In some areas to the north the builders used smaller blocks of schist but as a result these examples are mostly in a poor state of preservation. Seven-stone antas are distinguished from other megalithic tombs found in the same and neighbouring regions by two factors. The first is the presence of a passage—shorter or longer depending on the date of construction: the seven-stone antas are thought to have been constructed from c. 4000 BC onwards, with longer corridors appearing around 3200 BC.

The second factor is their distinctive method of construction. This involved erecting a backstone and then leaning three uprights in succession on each side so as to form a chamber typically some 4m to 5m in diameter with a clearly defined entrance to which a passage of smaller orthostats was attached (see Fig. 3.4). In very few cases, an eighth orthostat, acting as a sort of front stone, has been preserved; it is unknown if this component was more frequent than the present state of preservation of many monuments may indicate (see Fig. 3.5). In any case, the dominant feature is the seven-orthostat chamber, as the name suggests.

Among the Alentejo antas are a few exceptional monuments, in particular the Anta Grande do Zambujeiro, a huge dolmen with a chamber 6m high and orthostats measuring nearly 8m. Another is the complex monument at Olival da Pega 2 (Reguengos de Monsaraz), excavated by Victor S. Goncalves in the 1990s, where a corridor 16m long was found. The excavations here demonstrated various reutilizations and structures added at different times.

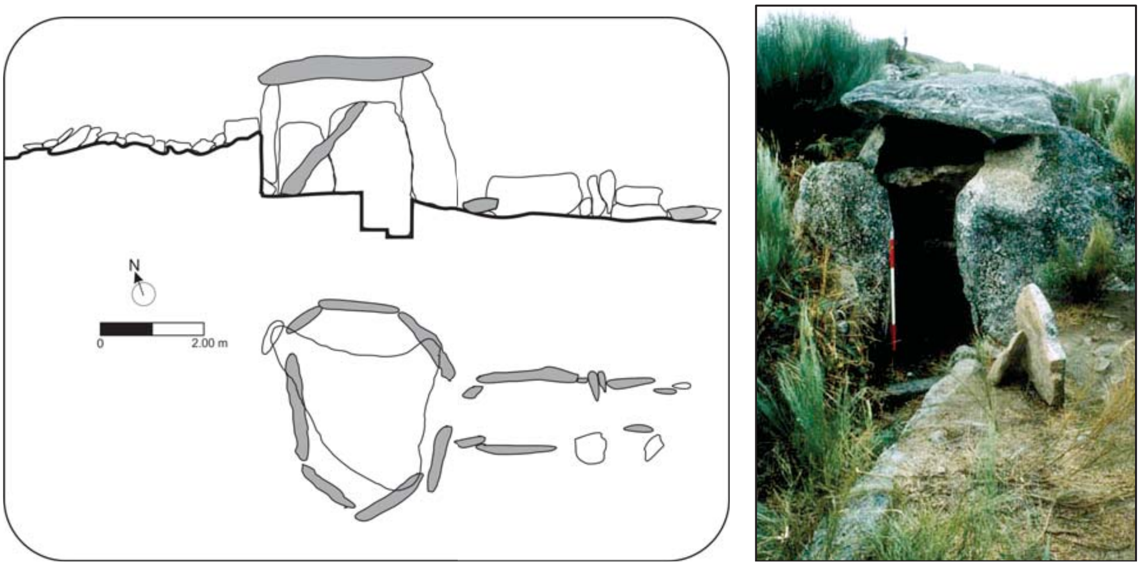

Fig. 3.4. Huerta de las Monjas (no. 3 in Table 3.1), a typical long-corridor seven-stone anta on the eastern bank of the river Sever. Plan (left) adapted from Bueno Ramírez (1988). Photograph (right) courtesy of Margarita Sanz de Lara.

Fig. 3.5. Anta de la Marquesa, also known as Mellizo (no. 101 in Table 3.1), a good example of a short-corridor seven-stone anta with the addition of an eighth orthostat blocking the corridor. Photograph © Clive Ruggles

Landscape

Most of the region in which the seven-stone antas are found comprises low hills with scattered granite outcrops, the latter being where the quarries are usually located. However, to the north-east, in the Spanish sector and on the Portuguese side close to the border, the terrain is scarped by small mountain ranges and large granite outcrops (see Fig. 3.6).

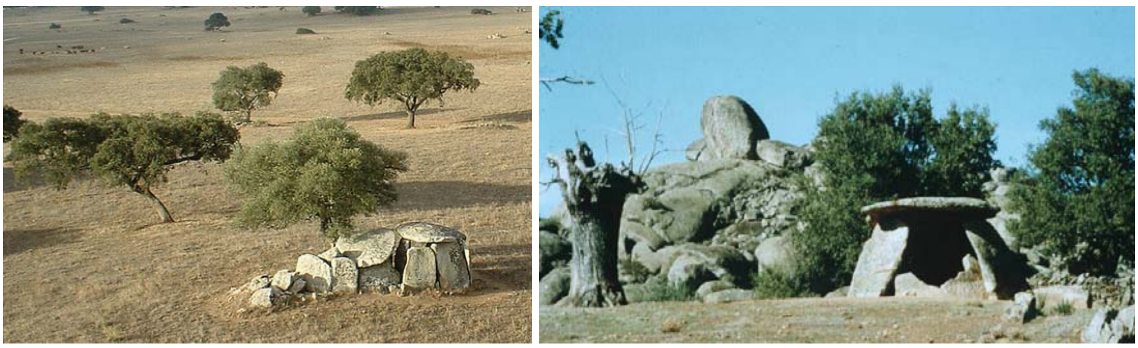

Fig. 3.6. The typical landscapes where seven-stone antas can be found: the plains of central Alentejo (left) and the granite outcrops of the north-east (right), including the Spanish sector close to Valencia de Alcántara. Photographs © Luís Tirapicos (left) and Juan Belmonte (right)

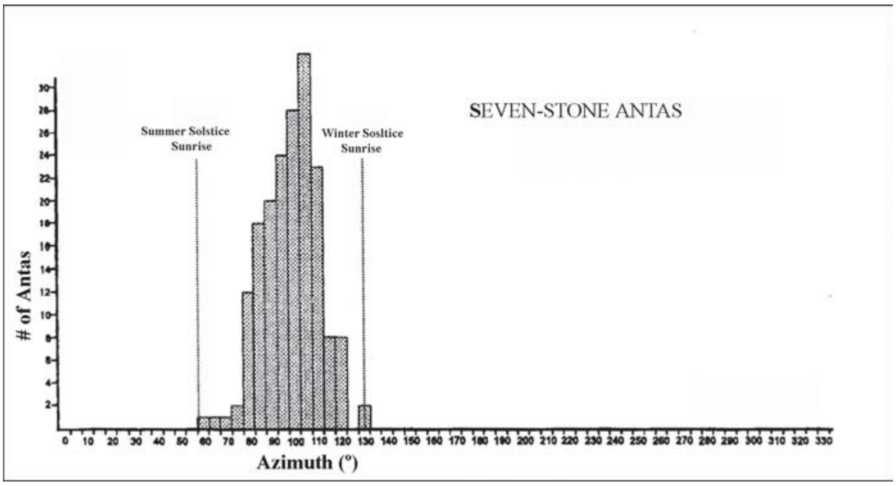

Fig. 3.7. Orientation histogram of 177 seven-stone antas as obtained by Hoskin and collaborators after several years of fieldwork in the region. How every single monument fits within the sector of sunrise (or moonrise) is clearly illustrated. The strength of this evidence makes the seven-stone antas the oldest group of monuments for which there is incontrovertible proof of their connection to astronomy. Adapted from Hoskin 2001, p. 98.

Orientation

The orientation of each of these monuments can be determined (according to the state of preservation) either from the alignment of the stones forming the corridor or from the direction perpendicular to the backstone, or both. All of them point towards the eastern half of the horizon, within about 25° of due east. Such a strong consistency in orientation could not have been achieved using topographic referents such as conspicuous distant mountain peaks: the Alentejo region, in particular, is a very flat area. This implies that the target used to determine the orientations was a celestial object.

The range of the 177 measured orientations corresponds almost exactly to the range of possible rising positions of the sun. In other words, every tomb in the group without exception is oriented within the arc of sunrise, corresponding to about one sixth of the available horizon (Figs. 3.7, 3.8). In almost all cases the orientations fall between azimuths of 61° (29° north of east) and 122° (32° south of east); there are two exceptions, which are oriented more towards the south (azimuth 128°–129°), but these are within a deep valley with a higher eastern horizon, and so still face sunrise. This remarkable statistic provides the strongest possible indication of an association between these tombs and the sun. If the tombs were oriented to face sunrise on the day when construction began, then the distribution of azimuths would suggest that this took place predominantly in the spring or autumn, but the fact that orientations span the entire solar rising range implies that in some cases construction was commenced in the middle of summer or winter. The 'exactness of fit' between the range of tomb orientations and the arc of sunrise suggests that the tombs were aligned with a precision of about 1–2 degrees (2–4 solar diameters). This is indeed the easiest explanation applying Ockham´s Razor.

It is possible to argue that the moon rather than the sun was used to determined the orientations, since any possible solar orientation can also be interpreted as a lunar one (the lunar rising arc on the horizon being somewhat wider than the solar one). In 2004, using the data collected by Hoskin and collaborators, Cândido Marciano da Silva proposed a new interpretation explaining the orientations of the antas. According to da Silva's statistical analysis the entrance of seven-stone antas of Alentejo, and neighbouring regions, may have been oriented to the full moon rise near the vernal equinox – when the positions of the rising sun and moon “cross-over” on the horizon. This idea can be further supported by historical and ethnographical sources. It must be emphasized, however, that the solar explanation fits the observed orientation data closely and simply, and the fact that scientific debate continues about the precise nature of the astronomical target does not in any way cast doubt upon the assuredly astronomical character of the alignments of the seven-stone antas.

Inventory

Table 3.1 lists the 177 seven-stone antas listed by Hoskin (2001, Table 6.2), for 173 of which measured orientations were obtained by Hoskin (2001), together with an additional 9 sites in the Valencia de Alcántara area identified more recently. The sites are ordered by their direction of orientation (azimuth). Where necessary, the name has been corrected from that provided by Hoskin. The latitude and longitude is given correct to the nearest 1'' (approx. 25m) where available (sources C, D, R as below); otherwise the latitude is given to the nearest 0.1° (approx. 150m) as provided by Hoskin (H). Azimuth, altitude and orientation data are also taken from Hoskin’s table; T under azimuth indicates that, although the exact orientation was unmeasurable, this dolmen faced a "typical direction" (i.e., in the solar rising range) according to Hoskin (2001: 232).

Table 3.1. List of seven-stone antas.

Column headings
No. = Reference number in this case study
N4 = Number shown in Fig 3.2
Group = Group as shown in Fig. 3.2
Dist/Prov = District [Portugal] or Province [Spain]
Lat = Latitude (N) in degrees to the nearest 0.1°, supplied where more accurate information unavailable
Lat N = Latitude (N) in deg/min/sec, to the nearest second
Long W = Longitude (W) in deg/min/sec, to the nearest second
S = Source for co-ordinate information (see key below)
az = (true) azimuth in degrees
alt = horizon altitude in the direction of orientation, in degrees
dec = astronomical declination in the direction of orientation, in degrees

Sources for co-ordinate information
B = Juan Belmonte
C = Calado 2004, converted from Coordenadas Militares (Lisbon datum)
D = de Oliveira 1997 and/or Google Earth
H = Hoskin 2001, Table 6.2
R = Clive Ruggles, hand-held GPS, 2005

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
1		Dehesa Bollai 1		Jerez de los Caballeros	Badajoz	Spain	38.3							H	61	1	+23
2		Contada		Elvas	Portalegre	Portugal		38	57	57	7	18	46	D	64	1	+20½
3	17	Huerta de las Monjas	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	24	18	7	18	8	B	70	4	+18
4	13	Lanchas 1	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	25	19	7	15	57	R	76	0	+10½
5		Gonçala 2		Mora	Évora	Portugal		38	56	40	8	0	27	C	77	0½	+10
6		Remendo 1		Mora	Évora	Portugal		38	53	17	7	58	51	C	79	1	+9
7		Pero d'Alba		Castelo de Vide	Portalegre	Portugal		39	28	13	7	27	10	D	79	2½	+10
8	35	Datas 1	Santa María	Valencia de Alcántara	Cáceres	Spain		39	19	57	7	13	36	R	81	3½	+9
9		Sobral		Castelo de Vide	Portalegre	Portugal		39	24	1	7	29	26	R	81	6½	+11
10		Coureilos 3		Castelo de Vide	Portalegre	Portugal		39	26	40	7	28	11	R	81	0½	+7
11		Pedra d'Anta		Ourique	Beja	Portugal	37.8							H	82	0	+6
12		Caeira 3		Mora	Évora	Portugal		38	53	5	7	57	13	C	82	0	+6
13	15	Tapada del Anta 1	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	23	48	7	18	1	B	82	2	+7½
14		Herdade do Duque		Reguengos de Monsaraz	Évora	Portugal		38	27	6	7	26	26	C	82	0	+6
15		Patalim		Évora	Évora	Portugal		38	37	12	8	4	32	C	82	0	+6
16		Coureilos 2		Castelo de Vide	Portalegre	Portugal		39	26	39	7	28	12	R	82	0	+6
17		Torrão 1		Elvas	Portalegre	Portugal		38	58	30	7	16	17	D	82	–0½	+5½
18		Coureilos 4		Castelo de Vide	Portalegre	Portugal		39	26	42	7	28	19	R	82	0	+8
19		Caeira 4		Mora	Évora	Portugal		38	53	3	7	57	9	C	83	0	+5
20		Cré 1		Mora	Évora	Portugal		38	51	51	7	58	15	C	83	3	+5½
21	39	La Morera	Santa María	Valencia de Alcántara	Cáceres	Spain		39	19	2	7	11	17	B	83	0	+5
22		Olival do Monte Velho		Elvas	Portalegre	Portugal	39.0							H	84	3	+6½
23		Silval		Évora	Évora	Portugal		38	40	59	8	2	27	C	84	0	+4½
24		Coureilos 1		Castelo de Vide	Portalegre	Portugal		39	26	35	7	28	12	R	84	0	+4½
25		Paredes		Évora	Évora	Portugal		38	39	46	8	2	21	C	84	1	+5
26		Defesinhas 1		Elvas	Portalegre	Portugal		38	47	10	7	10	23	D	84	0	+4½
27		Cré 2		Mora	Évora	Portugal		38	52	5	7	58	23	C	85	0½	+4

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
28		Bota 1		Évora	Évora	Portugal		38	29	54	7	54	36	C	85	0	+3½
29		Camino de los Bombonas		Barcarrota	Badajoz	Spain	38.5							H	86	2	+4
30		Hermosina		Barcarrota	Badajoz	Spain	38.5							H	86	2	+4
31		Currais do Galhordas		Castelo de Vide	Portalegre	Portugal		39	27	49	7	32	34	D	86	2½	+4½
32	23	Zafra 2	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	24	21	7	13	16	R	86	0	+2½
33	29	Tapias 2	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	24	15	7	12	36	B	86	5	+6
34		Claros Montes 1		Arraiolos	Évora	Portugal		38	53	21	7	54	40	C	86	1½	+4
35		Dehesa de la Muela		Mérida	Badajoz	Spain	39.1							H	87	1	+2½
36		Caeira 1		Mora	Évora	Portugal		38	52	33	7	56	57	C	88	–0½	+1
37	20	La Barca		Valencia de Alcántara	Cáceres	Spain		39	23	28	7	16	4	B	88	0½	+1½
38		Pinheiro do Campo 1		Évora	Évora	Portugal		38	36	9	8	5	13	C	88	1	+2
39	31	Huerta Nueva	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	23	39	7	11	53	B	89	0½	+1
40	19	(La) Miera	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	23	37	7	17	46	B	89	4	+3
41		Freixo de Cima 1		Évora	Évora	Portugal		38	24	39	7	51	18	C	89	0½	+1
42		Pavia		Mora	Évora	Portugal		38	53	39	8	1	2	D	89	0	+0½
43		Gonçala 6		Mora	Évora	Portugal	38.9							H	89	4	+3
44		Figueirinha 2		Mora	Évora	Portugal		38	56	47	8	0	12	C	90	1½	+0½
45		Portela		Mora	Évora	Portugal	38.9							H	90	0½	+0½
46		Farisoa 4		Reguengos de Monsaraz	Évora	Portugal	38.4							H	91	0	–1
47		Cabeção		Mora	Évora	Portugal	38.9							H	91	0	–1
48		Entreáguas		Estremoz	Évora	Portugal		38	47	7	7	37	53	C	91	1½	0
49		Aldeia da Mata		Crato	Portalegre	Portugal		39	18	3	7	42	39	D	91	0	–1
50		São Lourenço 1		Crato	Portalegre	Portugal	39.2							H	91	0	–1
51		Rana		Barcarrota	Badajoz	Spain	38.5							H	91	1	–0½
52		Tapadões		Crato	Portalegre	Portugal	39.2							H	91	0	–1
53		Pombal		Castelo de Vide	Portalegre	Portugal		39	26	19	7	27	25	D	92	3	0
54		Torre das Águias 1		Mora	Évora	Portugal		38	52	18	8	6	52	C	92	1	–1

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
55		Pasada del Abad		Rosal de la Frontera	Huelva	Spain	38.0							H	93	1	–2
56		Herdade da Anta		Évora	Évora	Portugal	38.6							H	93	1	–2
57		Cré 3		Mora	Évora	Portugal		38	52	4	7	58	42	C	93	1	–2
58	24	Zafra 3	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	24	4	7	13	18	B	93	4	0
59		Monte dos Frades		Elvas	Portalegre	Portugal	39.0							H	93	–0½	–3
60		Aguiar		Évora	Évora	Portugal	38.6							H	94	0½	–3
61		Torre das Águias 2		Mora	Évora	Portugal		38	52	27	8	6	53	C	94	1½	–2½
62		Adua 1		Mora	Évora	Portugal		38	54	18	8	1	33	C	94	0	–3½
63		Caeira 2		Mora	Évora	Portugal		38	53	31	7	56	55	C	94	0½	–3
64		Sauza 4		Évora	Évora	Portugal	38.6							H	94	0½	–4½
65		Tajeno		Barcarrota	Badajoz	Spain	38.5							H	95	2½	–1
66		Serrinha		Crato	Portalegre	Portugal	39.0							H	95	2	–3
67		Vale d'Anta		Redondo	Évora	Portugal	38.6							H	95	0	–4½
68	25	Zafra 4	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	23	59	7	13	16	B	95	5	–1
69		Claros Montes 2		Arraiolos	Évora	Portugal		38	53	30	7	54	58	C	95	2	–3
70		Cebolinhos 3		Reguengos de Monsaraz	Évora	Portugal		38	23	27	7	29	10	C	95	0	–4½
71		Gonçala 1		Mora	Évora	Portugal		38	56	23	8	1	2	C	95	0	–4½
72		Bota 2		Évora	Évora	Portugal		38	30	11	7	54	37	C	95	0	–4½
73		Colmeeiro		Redondo	Évora	Portugal		38	41	32	7	38	9	C	96	0½	–4½
74		Alcalaboza		Aroche	Huelva	Spain	37.9							B	96	4	–2½
75		San Blas		Barcarrota	Badajoz	Spain	38.5							B	96	2	–3½
76		Cabeças		Évora	Évora	Portugal		38	40	59	7	53	46	C	96	–0½	–5½
77		Vale Carneiro 1		Reguengos de Monsaraz	Évora	Portugal		38	23	12	7	27	57	C	98	–0½	–7
78		Sardinha		Elvas	Portalegre	Portugal	38.8							H	98	1	–6
79		Sauza 3		Évora	Évora	Portugal	38.6							H	98	1	–6
80		Paço 1		Redondo	Évora	Portugal		38	46	13	8	13	31	C	98	0½	–6
81		Monte Abraão		Sintra	Lisboa	Portugal	38.8							H	98	0	–6½

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
82		Olheiros		Castelo de Vide	Portalegre	Portugal		39	28	34	7	27	17	D	99	10½	0
83		Zambujalinho		Évora	Évora	Portugal		38	40	18	7	46	6	C	99	–0½	–8
84	14	Lanchas 2	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	25	23	7	16	4	B	100	5	–4½
85		Gonçala 4		Mora	Évora	Portugal		38	56	26	8	1	10	C	100	0½	–8
86		Vale de Moura 1		Évora	Évora	Portugal		38	31	39	7	51	32	C	100	1	–7½
87	37	Cajirón 1	Santa María	Valencia de Alcántara	Cáceres	Spain		39	19	37	7	12	32	B	100	0½	–7½
88		Silveira		Redondo	Évora	Portugal		38	40	32	7	31	8	C	100	1	–7½
89		Lapita		Barcarrota	Badajoz	Spain	38.5							H	101	1½	–8
90		Paço das Vinhas		Évora	Évora	Portugal		38	37	24	7	52	43	C	101	0	–9
91		Horta do Zambujeiro		Redondo	Évora	Portugal		38	37	51	7	35	5	C	101	0½	–8½
92		Monte Ruivo		Elvas	Portalegre	Portugal	38.8							H	101	0	–9
93		Gáfete 1		Crato	Portalegre	Portugal	39.4							H	101	0	–9
94	38	Cajirón 2	Santa María	Valencia de Alcántara	Cáceres	Spain		39	19	46	7	12	20	B	101	5½	–5
95	22	Zafra 1	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	24	21	7	13	28	B	101	6½	–4½
96		Anta Grande dos Antões		Mora	Évora	Portugal		38	54	31	8	0	31	C	101	0½	–8½
97		Cebolinhos 2		Reguengos de Monsaraz	Évora	Portugal		38	23	27	7	29	3	C	101	0	–9
98		Pão Mole		Alandroal	Évora	Portugal		38	41	57	7	18	43	C	102	4	–7
99		Candeeira		Redondo	Évora	Portugal		38	42	16	7	33	11	C	102	1	–9
100		Torre das Arcas 1		Elvas	Portalegre	Portugal		38	51	50	7	13	4	D	102	–0½	–10
101	34	Anta de la Marquesa	Santa María	Valencia de Alcántara	Cáceres	Spain		39	19	47	7	13	8	B	102	0	–9½
102		Gáfete 2		Crato	Portalegre	Portugal	39.4							H	102	0	–9½
103		Lacara		Mérida	Badajoz	Spain	39.0							H	102	0	–9½
104		Casas do Canal		Estremoz	Évora	Portugal		38	46	18	7	36	23	C	103	2	–9
105		Farisoa 1		Reguengos de Monsaraz	Évora	Portugal		38	23	2	7	31	51	C	103	–0½	–11
106		Azaruja 2		Évora	Évora	Portugal	38.6							H	103	1	–9½
107		Azaruja 1		Évora	Évora	Portugal	38.6							H	103	0	–10½
108		Gorginos 3		Reguengos de Monsaraz	Évora	Portugal	38.4							H	103	0	–10½

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
109		Barrosinha 1		Évora	Évora	Portugal		38	37	55	7	46	32	C	103	0	–10½
110		Olival da Pega 2		Reguengos de Monsaraz	Évora	Portugal		38	27	6	7	23	56	R	103	2½	–8½
111		Bernardo		Ponte de Sor	Portalegre	Portugal	39.3							H	104	0½	–11
112		Anta do Crato		Crato	Portalegre	Portugal	39.3							H	104	2½	–9½
113		Anta Grande do Zambujeiro		Évora	Évora	Portugal		38	32	21	8	0	52	D	104	0½	–11
114		Monte Novo 2		Reguengos de Monsaraz	Évora	Portugal		38	23	36	7	31	46	C	104	0	–11½
115		Anta Grande, Olival da Pega		Reguengos de Monsaraz	Évora	Portugal		38	27	5	7	24	4	R	104	3	9
116		Freixo de Cima 2		Évora	Évora	Portugal		38	24	49	7	51	23	C	104	0½	–11
117		São Gens		Nisa	Portalegre	Portugal		39	27	0	7	40	30	D	104	1	–10½
118		Farisoa 5		Reguengos de Monsaraz	Évora	Portugal		38	23	24	7	31	59	C	104	0	–11½
119		Dom Miguel		Elvas	Portalegre	Portugal		38	59	19	7	19	48	D	104	2	–9½
120	11	Fragoso	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	26	23	7	18	0	B	105	3½	–9½
121		São Rafael 1		Elvas	Portalegre	Portugal	38.8							H	105	1	–11½
122		Farisoa 2		Reguengos de Monsaraz	Évora	Portugal		38	23	10	7	31	59	C	105	0	–12
123		Matanga		Ponte de Sor	Portalegre	Portugal	39.3							H	105	–0½	–12½
124		Sauza 1		Évora	Évora	Portugal	38.6							H	105	1	–11½
125		Milano		Barcarrota	Badajoz	Spain	38.5							H	105	6	–8
126		Monte das Oliveiras		Mora	Évora	Portugal	38.9							H	105	1	–11
127		Pau		Évora	Évora	Portugal		38	38	23	7	46	44	C	106	–0½	–13
128		Santa Luzia		Alandroal	Évora	Portugal		38	35	32	7	18	50	C	106	0½	–12½
129	36	Datas 2	Santa María	Valencia de Alcántara	Cáceres	Spain		39	20	2	7	13	37	R	106	5½	–9
130		Briços		Mora	Évora	Portugal		38	52	11	8	5	53	C	106	1½	–11½
131		Cebolinhos 1		Reguengos de Monsaraz	Évora	Portugal	38.4							H	106	0	–13
132		Vidigueiras 2		Reguengos de Monsaraz	Évora	Portugal		38	23	9	7	30	20	C	106	0	–13
133		Galvães		Alandroal	Évora	Portugal	38.7							H	107	2½	–11½

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
134		Sauza 2		Évora	Évora	Portugal	38.6							H	107	0½	–13
135		Gonçala 3		Mora	Évora	Portugal		38	56	38	8	0	32	C	108	1	–13½
136		Pedra Branca		Santiago do Cacém	Setúbal	Portugal	38.1							H	108	1	–13½
137		Defesinhas 2		Elvas	Portalegre	Portugal	38.8							H	108	0	–14½
138	—	Sobral		Elvas	Portalegre	Portugal		38	40	15	7	55	43	C	108	0	–14½
139		Pombal 5		Elvas	Portalegre	Portugal	38.9							H	109	1	–14½
140		Azinheiras		Évora	Évora	Portugal		38	32	20	7	52	59	C	109	–0½	–15½
141		Paço 1		Reguengos de Monsaraz	Évora	Portugal		38	23	54	7	27	47	C	109	1	–14½
142		Pena Clara 1		Elvas	Portalegre	Portugal	38.9							H	109	0	–15
143	28	Tapias 1	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	24	15	7	12	41	B	110	2	–14
144		Lapeira		Mora	Évora	Portugal		38	53	22	8	0	41	C	110	0	–16
145		Gonçala 5		Mora	Évora	Portugal	38.9							H	110	1	–15
146		Carrascal		Agualva	Lisboa	Portugal	38.8							H	110	1	–15
147		Vale de Rodrigo 3		Évora	Évora	Portugal		38	30	9	8	3	46	C	110	0	–16
148		Forte das Botas		Elvas	Portalegre	Portugal	38.8							H	111	1½	–15½
149		Conto do Zé Godinho		Castelo de Vide	Portalegre	Portugal		39	28	52	7	31	0	R	111	2	–15
150		Quinta das Longas		Elvas	Portalegre	Portugal	38.9							H	111	0	–16½
151		Carcavelos		Loures	Lisboa	Portugal	38.9							H	111	2	–15
152		Monte dos Negros		Elvas	Portalegre	Portugal	38.9							H	112	0	–17½
153		Palacio		Barcarrota	Badajoz	Spain	38.5							H	112	4½	–14
154		Vale de Moura 2		Évora	Évora	Portugal		38	31	7	7	50	53	C	112	0	–17½
155		Vale de Rodrigo 2		Évora	Évora	Portugal		38	29	44	8	3	35	C	112	0	–17½
156		Hospital		Redondo	Évora	Portugal		38	39	43	7	36	3	C	113	0½	–18
157		Farisoa 7		Reguengos de Monsaraz	Évora	Portugal		38	23	11	7	31	31	C	113	0	–18
158		Gorginos 1		Reguengos de Monsaraz	Évora	Portugal		38	24	19	7	30	38	C	113	0	–18
159		São Rafael 2		Elvas	Portalegre	Portugal	38.8							H	114	0	–19
160	18	Corchero	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	24	49	7	17	25	B	114	0½	–18½

No.	N4	Name	Group	Municipalty	Dist/Prov	Country	Lat	Lat N			Long W			S	az	alt	dec
161		Corticeira		Estremoz	Évora	Portugal		38	45	28	7	36	24	C	116	10	–13
162		Vidigueiras		Redondo	Évora	Portugal	38.6							H	116	0½	–20
163		Casas Novas		Redondo	Évora	Portugal		38	41	1	7	38	1	C	117	2	–19½
164		Torre das Arcas 2		Elvas	Portalegre	Portugal	38.9							H	118	–0½	–22
165		Valmor		Elvas	Portalegre	Portugal		38	50	25	7	11	16	D	118	1	–21
166		Vidigueiras 1		Reguengos de Monsaraz	Évora	Portugal		38	23	40	7	31	9	C	118	0	–22
167		Roca Amador		Barcarrota	Badajoz	Spain	38.5							H	121	2½	–22
168		Melriça		Castelo de Vide	Portalegre	Portugal		39	25	59	7	30	7	R	121	2½	–22
169		Barrosinha 2		Évora	Évora	Portugal		38	37	59	7	46	14	C	122	–0½	–25½
170		Avessadas		Elvas	Portalegre	Portugal	38.8							H	122	0	–25
171		Pinheiro do Campo 2		Évora	Évora	Portugal		38	35	50	8	4	57	C	122	0	–25
172		Tierra Caída 2		Cedillo	Cáceres	Spain		39	38	42	7	31	26	R	128	9	–21½
173		Tierra Caída 1		Cedillo	Cáceres	Spain		39	38	41	7	31	25	R	129	10	–21½
174		Monte Novo 1		Reguengos de Monsaraz	Évora	Portugal		38	35	50	8	4	57	C	T	0	
175		Monte Novo 4		Reguengos de Monsaraz	Évora	Portugal		38	23	40	7	31	45	C	T	0	
176		Vale Carneiro 5		Reguengos de Monsaraz	Évora	Portugal		38	23	12	7	31	29	C	T	0	
177		Paço 2		Redondo	Évora	Portugal		38	23	36	7	27	51	C	T	0½	
178	26	Barbón 1	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	23	29	7	12	25	B	Unmeasured		
179	27	Barbón 2	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	23	28	7	12	30	B	Unmeasured		
180	21	El Palancar		Valencia de Alcántara	Cáceres	Spain		39	21	15	7	15	25	B	Unmeasured		
181	12	Changarilla	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	25	38	7	18	3	B	Unmeasurable		
182	41	El Caballo	Río Sever banks	Valencia de Alcántara	Cáceres	Spain		39	26	43	7	17	36	B	Unmeasurable		
183	40	El Torrejón		Valencia de Alcántara	Cáceres	Spain		Unavailable							Unmeasurable		
184	32	Huerta Látigo	Collados de Barbón	Valencia de Alcántara	Cáceres	Spain		39	23	20	7	12	2	B	Unmeasurable		
185	30	San Antón		Valencia de Alcántara	Cáceres	Spain		39	23	24	7	9	36	B	Unmeasurable		
186	33	Tapada del Puerto		Valencia de Alcántara	Cáceres	Spain		39	23	38	7	14	20	B	Unmeasurable		

Fig. 3.8. Aldeia da Mata, Crato (no. 49 in Table 3.1) facing the rising sun. Photograph © Luís Tirapicos

2.b History and development

Seven-stone antas were built in the southwest of the Iberian Peninsula over a period of about one thousand years spanning the 4th millennium B.C. for the burial of people belonging to a pastoralist culture.

The dolmen cluster is very consistent, with all the monuments being built with seven huge slabs of granite (orthostats) up to 3.5m high, of which the largest is the so-called backstone, which by architectural logic would be the first slab to have been put in place (Figs 3.3–3.6). The resulting polygonal chamber was approached by a corridor of variable length that can be used to date the structures: short corridor dolmens date from the beginning of the fourth millennium (c. 4000 B.C.), while the long corridor dolmens are, on average, about 800 years younger. The structures were continually reutilized: they remained "in use" until the beginning of the Bronze Age, towards the end of the 3rd millennium B.C., and perhaps much later. The whole structure would have been covered by a huge mound of earth and pebbles, which has nearly completely disappeared in the vast majority of cases.

The Alentejo region is exceptionally rich in megalithic remains (enclosures, menhirs, dolmens, etc.). According to recent surveys by Manuel Calado and Jorge de Oliveira (Calado 2004; de Oliveira 1997) the number of megalithic funerary monuments in the region exceeds 1000, with the number of seven-stone antas exceeding 800.

These monuments were used as collective tombs, and it is likely that they were sacred places associated with a cult of ancestors and/or some tutelary divinity. Excavations at some of the dolmens not only uncovered artefacts such as arrowheads and ceramics but also highlighted a series of fragments, and some complete copies, of what have been called plate-idols, decorated with extremely abstract representations of a deity related to a funerary cult, and which may have had calendrical connotations (see Fig. 3.9). Additionally, it is possible that the dolmens served as reference points in the landscape, marking the territory of the community in question.

A consistency in the orientation of megalithic enclosures in central Alentejo implies that, like those of the seven-stone antas, these too were astronomically determined (e.g, Pimenta et al. 2009). If, as Calado (2004) has argued, the antas represent a continuity of the basic horseshoe plan of the older enclosures, then an orientation custom based upon celestial targets may have had even deeper roots in the region.

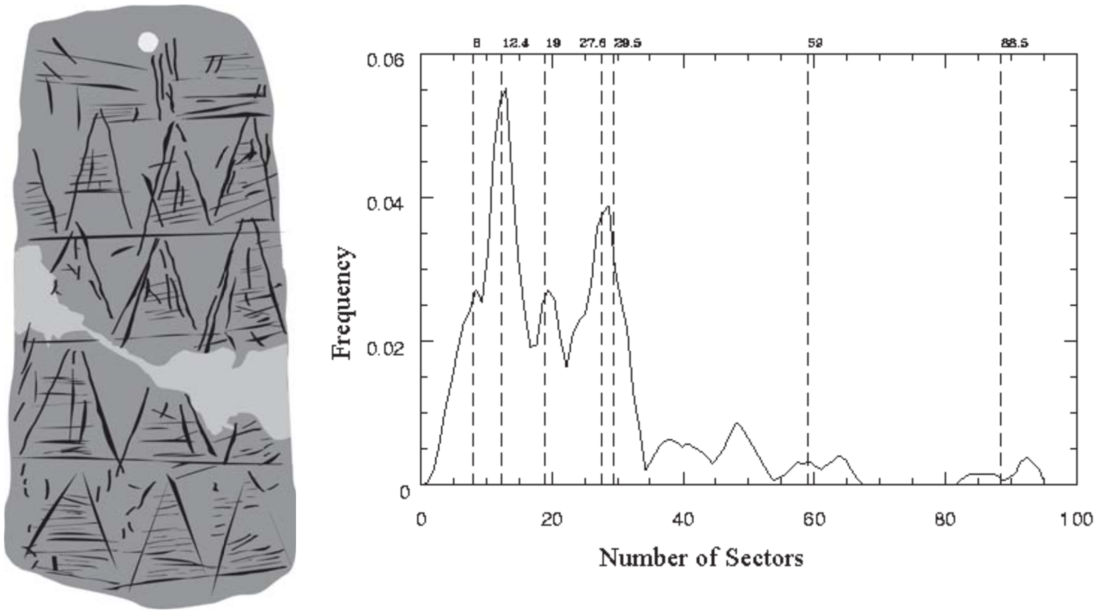

Fig. 3.9. Left: a typical plate-idol found precisely in one of the dolmens of Valencia de Alcántara. Photograph adapted from Bueno (1988). **Right:** Graph showing the number of decorative elements found on 130 plate-idols discovered in megalithic monuments of the south-west of the Iberian Peninsula, including seven-stone antas. There are statistically significant peaks centred at around 12½ and 29½, close to the number of lunar (synodic) months in a seasonal (solar) year and the number of days in a lunar (synodic) month.

In Portugal, the study and protection of the antas dates back to the activities of the *Academia Real da História Portuguesa* (Royal Academy of Portuguese History), created by King D. João V in 1720. In fact, the first inventory produced in Portugal (now lost) was presented to the Royal Academy in 1734, written by Father Afonso da Madre de Deus Guerreiro, and included 315 antas – 66 in the Évora region. Subsequent studies have shown the richness of the megalithic heritage of the country and in particular of the Alto Alentejo Province. At the end of the 19th and beginning of the 20th centuries the work of José Leite de Vasconcellos, Nery Delgado, Carlos Ribeiro, Gabriel Pereira, Emile Cartailhac, Mattos Silva and Filipe Simões made contributions to the inventory and knowledge of the antas of the Évora and Montemor-o-Novo areas. More systematic studies developed in the first half of the 20th century through the identifications, excavations and interpretations of Vergílio Correia and Manuel Heleno. Nevertheless the climax, in the 1940s and 1950s, was the monumental work of Georg and Vera Leisner documenting and studying hundreds of antas in the Alentejo. A more recent archaeological survey has been carried out by Jorge de Oliveira since Hoskin's archaeoastronomical studies were completed in the area. Other recent archaeological studies include those of Victor S. Gonçalves, Philine Kalb, Martin Höck and Mário Varela Gomes. These focus upon local contexts and complement the study of dolmens with the investigation of other megalithic monuments and contemporary (or at least prehistoric) settlements, mainly within the areas of Montemor-o-Novo, Évora and Reguengos de Monsaraz.

The dolmens of the region of Valencia de Alcántara, on the Spanish side of the border, were studied in detail in the 1980s by Jorge de Oliveira and others. Some of them were excavated, this being the main objective of the PhD thesis of Primitiva Bueno, of the University of Alcala de Henares, published in 1988. Further archaeological and restoration work has been carried out since that date.

Interestingly, a century before the quantitative fieldwork of Hoskin and his collaborators, José Leite de Vasconcellos, a Portuguese archaeologist and ethnologist, argued in his book *Religiões da Lusitania*, published in 1897, that the orientations of dolmen entrances, which were “very frequently facing East”, were related to a sun cult.

3. Justification for inscription

3.c Comparative analysis

The seven-stone antas found in the central Alentejo region in Portugal and the adjacent border provinces of the Extremadura region in Spain represent one of the largest and best-preserved groups of megalithic monuments in the Iberian Peninsula. The great majority are built with granite slabs, frequently including a corridor. The concentrations around Évora and Valencia de Alcántara are easily located, representative, and contain some of the most impressive individual examples.

Many other groups of European later prehistoric monuments show patterns of orientation that were certainly determined astronomically and in most cases were probably related to the sun (Hoskin 2001, Ruggles 2010).

The range of astronomical declinations of the horizon points towards which the seven-stone antas face is from –24° to +24° (see Table 3.1 and Fig. 3.7). This corresponds to the range of declinations reached by the sun over the course of the year; in other words, each monument is oriented towards a point where the sun rises at some time in the year, with the various monuments effectively covering the entire range. Hence, applying Ockham’s Razor, this appears to be very strong indication of a custom of orientating monuments towards sunrise, with no particular preference for specific times within the seasonal year. Among the many groups of European later prehistoric monuments, only the seven-stone antas manifest a clear and consistent practice of orientation related specifically to the rising arc of the sun over the course of a year. They are quite exceptional in this respect.

3.d Integrity and/or authenticity

As regards the astronomical significance of this group of monuments, a critical issue is the extent to which the intended, or original, direction of orientation is accurately represented and well preserved.

The sites are in various states of repair. Some are well preserved (Figs 3.3, 3.5, 3.6). In other cases the chamber has collapsed leaving only the backstone, the stone put in place first, but the direction perpendicular to this backstone still gives a reliable estimate of the orientation (see Fig. 3.10). In other cases just a few stones are preserved, often the backstone or some stones of the corridor, but this still permits a potential measurement of the orientation (see Fig. 3.11).

Some of the Spanish examples, such as Cajirón 2 (see Fig. 3.12), have been reconstructed since their orientations were determined in the 1990s. In Portugal, especially near Évora, Montemor-o-Novo and Castelo de Vide, a limited number of seven-stone antas have been cleaned, excavated and/or restored.

A few of the antas in the Valencia de Alcántara group have been restored but where this has happened it has been done cautiously, using the original slabs found scattered in situ. Thus very little “reconstruction” has taken place and only a few of the stones have been moved back to their “original” position. Where, as at Cajirón 2 (Fig. 3.12), the capstone has been replaced on top of the structure, this has been achieved without altering its overall orientation.

Fig. 3.10 (left). Coureleiros 4 (no. 18 in Table 3.1), as seen in 2005. The chamber has completely collapsed. Photograph © Clive Ruggles **Fig. 3.11 (right).** (La) Miera (no. 40 in Table 3.1). One of the authors (JB) is measuring the horizon altitude in the direction of the only surviving corridor orthostat. This would give a loose, but still valid, orientation of the partly destroyed dolmen. Photograph courtesy of Margarita Sanz de Lara

Fig. 3.12. Cajirón 2 (no. 94 in Table 3.1) before (left) and after (right) excavation and restoration; in this particular case, the reconstruction was carried out with much caution and the orientation of the monument was preserved. Photographs © Juan Belmonte (left) and Clive Ruggles (right)

3.a Potential criteria under which inscription might be proposed

Criterion (iii). The seven-stone antas bear unique testimony to a cultural practice dating back between five and six thousand years whereby tombs were oriented upon the rising position of the sun. In doing so, they bear exceptional witness to prehistoric cultural traditions and beliefs relating death and ancestors to the sun and seasonality.

3.b Suggested statement of outstanding universal value

The seven-stone antas are a distinctive form of megalithic tomb constructed more than 5000 years ago. They represent the oldest group of monuments on the planet that provide statistically defensible evidence of practices and beliefs linking monumental constructions with the skies. The 177 examples whose principal orientation has been reliably determined all, without exception, face within the arc of sunrise (the part of the horizon where the sun rises at some time during the year). The extraordinary consistency in an orientation pattern that characterises a set of monuments scattered over hundreds of kilometres provides an exceptionally clear indication of an astronomical relationship so significant to the builders that it was implemented unswervingly during the construction of hundreds of monuments, possibly over a period spanning several centuries. This offers a unique insight into the minds of the builders of some of the earliest later prehistoric monuments on the planet still conspicuously visible in today's landscape.

4. Factors affecting the property

4.a Present state of conservation

Almost 200 seven-stone antas are known but somewhat fewer than this number are in a sufficiently good state of preservation that alignments studies can be performed. The monuments have been re-used through history, and even today, for purposes varying from pig shelters to Christian chapels (see Fig. 3.13).

About 40% of the granite-built seven-stone antas (dolmens) of Valencia de Alcántara (Spain) are considered to be in either an excellent or a good state of preservation (see Table 3.2); this number rises to 52% when only the dolmens in the 3 groups shown in Fig. 3.2 (I – Collados de Barbón; II – Río Sever banks; III – the granite outcrop of Santa María de la Cabeza) are taken into consideration. Tapias 1, Zafra 3 and Anta de la Marquesa are among the best preserved, and most impressive, dolmens in the Iberian Peninsula.

Fig. 3.13. Left: Pombal (no. 53 in Table 1). Located in the Portuguese countryside, this anta has been used as a pig-shelter, which has in fact ensured its preservation. **Right:** Pavia (no. 42 in Table 1). This anta, in the centre of the village of Pavia, was converted in the 17th century into a Christian chapel, the Capela de São Dinis, which is still in use. Photographs courtesy of Margarita Sanz de Lara.

Table 3.2. State of preservation of the granite-built seven-stone antas of Valencia de Alcántara (Spain). The table presents the reference number and name as in Table 3.1. The site number shown in Fig. 3.2 is also given, in brackets.

	Group			
State of pre–servation	**Río Sever banks**	**Collados de Barbón**	**Santa María granite outcrop**	**Other**
Excellent	3 (17) Huerta de las Monjas 13 (15) Tapada del Anta 1	58 (24) Zafra 3 143 (28) Tapias 1	101 (34) Anta de la Marquesa 94 (38) Cajirón 2	
Good	4 (13) Lanchas 1 84 (14) Lanchas 2 120 (11) Fragoso	39 (31) Huerta Nueva 68 (25) Zafra 4	8 (35) Datas 1 129 (36) Datas 2	37 (20) La Barca
Moderate	40 (19) (La) Miera 160 (18) Corchero	32 (23) Zafra 2 178 (26) Barbón 1 179 (27) Barbón 2	87 (37) Cajirón 1	180 (21) El Palancar
Poor	181 (12) Changarilla 182 (41) El Caballo	33 (29) Tapias 2 95 (22) Zafra 1 184 (32) Huerta Látigo	21 (39) La Morera	183 (40) El Torrejón 185 (30) San Antón 186 (33) Tapada del Puerto
Destroyed	— (16) Tapada del Anta 2			

4.b.i Developmental pressures

Generally, the monuments are scattered in a rural landscape and there are few developmental pressures. For example, Valencia de Alcántara is a small town of nearly 7000 inhabitants surrounded by a “dehesa” landscape, typical for Extremadura. The climate is mild and the land use is mainly agricultural with a small amount of pastoral (sheep, Iberian pigs and cattle). In the Alentejo there are also some hunting reserves. Field clearance remains a major threat to the conservation of the antas, the destruction of some of which continues to be reported by archaeologists. In some areas it has been estimated that one third of the monuments have disappeared in the last 50 years (Leonor Rocha and Cândido Marciano da Silva – priv. comm.).

4.b.iv Visitor/tourism pressures

Being a set of small, isolated monuments located in a variety of land-use situations, the seven-stone antas face various potential threats, but they are generally safe from the damage that might be caused by large numbers of visitors.

Even in the Valencia de Alcántara area, where the granite-built seven-stone antas constitute one of the major tourist attractions (see below), visitors only put small pressure upon the sites.

5. Protection and management

5.a Ownership

The vast majority of the seven-stone antas are located on privately owned farmland.

5.b Protective designation

In Portugal, the antas are protected as classified archaeological sites by the Ministério da Cultura under Heritage Law no. 107/2001. A number of them have been classified as National Monuments for many years, in most cases since the first half of the 20th century, and the archaeological guide published in 1994 by Ana Paula dos Santos lists 21 such sites.

In Spain, the antas are *Bienes de Interés Cultural* (BIC) protected under Articles 14–25 of Law 16/1985 on Spanish Historical Heritage.

5.h Visitor facilities and infrastructure

Several municipalities have reached agreements with the owners so that free access (*servidumbre de paso*, permission to cross) exists to most of the sites. In particular, this is true for all the dolmens in certain localities, such as Valencia de Alcántara and several villages of Portugal, especially near Évora. Nonetheless, in many other places, notably in Portugal, the antas are only accessible to the public with the landowner’s permission.

All of the three groups of well-preserved dolmens within the municipality of Valencia de Alcántara (see Fig. 3.2) are open to visitors, easily reachable (being located close to well established tracks), and clearly marked. High-quality rural tourism is an important source of income in the Valencia de Alcántara area (see, e.g., http://www.virgencabeza.com/espanol/Dolmenes.htm) with environmentally aware visitors. There is a special agreement between the municipality’s *Consejería de Cultura* and the landowners so that free access to the dolmens is allowed in every case, providing that visitors apply minimum care and observe basic procedures (close fences, avoid jumping walls, etc.). In some areas, such as the Zafra–Tapias sector, to the east of the village, and in the Aceña de la Borrega area to the south, special tourist routes have been arranged and appropriately marked, making tours with an adequate guide–book a real pleasure for interested visitors. The municipality can arrange visits for groups under special circumstances upon demand.

Fig. 3.14. Sign marking the entrance to one of the four megalithic tours run by the Municipal Museum of Coruche. Photograph © Luís Tirapicos

In Portugal, especially near Évora, Montemor-o-Novo and Castelo de Vide, a limited number of seven-stone antas have been cleaned, excavated and/or restored, and are accessible to the general public. Four tours are managed by the Municipal Museum of Coruche near Montemor-o-Novo (Água Doce, Azinhal, Vale de Gatos e Chapelar, and Martinianos). At one entrance a panel invites visitors to follow four tracks through the numerous antas (about 25) of the region (see Fig. 3.14). However, in the same fence a small sign in red prohibits public entry. In practice, visits are authorized but only in small groups, organized and guided by the Museum.

5.i Presentation and promotion policies

A number of local authorities, including those at Évora, Castelo de Vide, Marvão, Montemor-o-Novo, Cedillo and Valencia de Alcántara, have produced booklets, pamphlets and web pages for tourists and more interested visitors, with information about the nature and whereabouts of some of the sites in their area.

The Historic Centre of Évora, inscribed on the World Heritage list in 1986, is located in the heart of one of the major concentrations of antas in the Alentejo. The region has also seen important investments in rural tourism, in particular near the great lake created by the Alqueva dam, around which the first dark sky reserve in Portugal was established: this was also the first site in the world to receive “Starlight Tourism Destination” certification (http://www.darkskyalqueva.com/en/).

7. Documentation

7.c Most recent records or inventory

Some of the seven-stone antas in both countries have been excavated. The orientations of the seven-stone antas were first systematically measured by Michael Hoskin together with Spanish and Portuguese collaborators between 1994 and 1998, as part of a 12-year fieldwork campaign measuring the orientations of many hundreds of tombs and temples in the western Mediterranean. An extended scientific bibliography has been produced on the topic.

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Stonehenge World Heritage Property, United Kingdom

Amanda Chadburn and Clive Ruggles[1]

1. Identification of the property

1.a Country/State Party: England, United Kingdom

1.b State/Province/Region: County of Wiltshire

1.c Name: Stonehenge, Avebury and Associated Sites

1.d Location:

Monument	NGR	Latitude (N)	Longitude (W)	Elevation
Stonehenge	SU 1225 4219	51° 10′ 44″	1° 49′ 34″	102m
Woodhenge	SU 1505 4338	51° 11′ 22″	1° 47′ 10″	98m
Southern Circle, Durrington Walls	SU 1514 4366	51° 11′ 31″	1° 47′ 05″	88m

1.e Maps and plans, showing the boundaries of the Property and buffer zone

The current boundary is as shown in Map 1 in the Stonehenge WHS Management Plan 2009 (Young, Chadburn and Bedu 2009: 175) (see Fig. 4.1). There is no buffer zone but the current Stonehenge WHS Committee considers that a setting study should be carried out (Simmonds and Thomas 2015: Policy 2b/ Action 15). Earlier policies had considered that a buffer zone was not needed if current government guidance was followed (Department for Communities and Local Government and Department for Culture, Media and Sport, 2009; Department for Communities and Local Government, 2012; English Heritage, 2009).

A minor boundary review is currently under way (2015), being one of the actions recommended in the 2009 Stonehenge Management Plan (Young, Chadburn and Bedu 2009: 120).

The Avebury part of the World Heritage Property is not considered further here, as there is no secure evidence for astronomical importance, other than the general one which is noted in southern Britain, that most of its long barrows are roughly aligned towards the sun-climbing or sun-rising parts of the sky (Ruggles 2012).

1.f Area of the property and buffer zone

Stonehenge World Heritage Property (WHP) currently comprises an area of 2,665 hectares (26.6 km^2) of land with Stonehenge at its approximate centre. There is no buffer zone.

2. Description

2.a Description of the property

Stonehenge WHP is one half of the Stonehenge, Avebury and Associated Sites WHP (whc.unesco.org/en/list/373), which is internationally important for its complexes of outstanding prehistoric funerary and ceremonial monuments of the Neolithic and Early Bronze Age.

[1] **Note.** This case study represents the views of the authors, and not necessarily those of Historic England or its predecessor English Heritage, for whom the first author works.

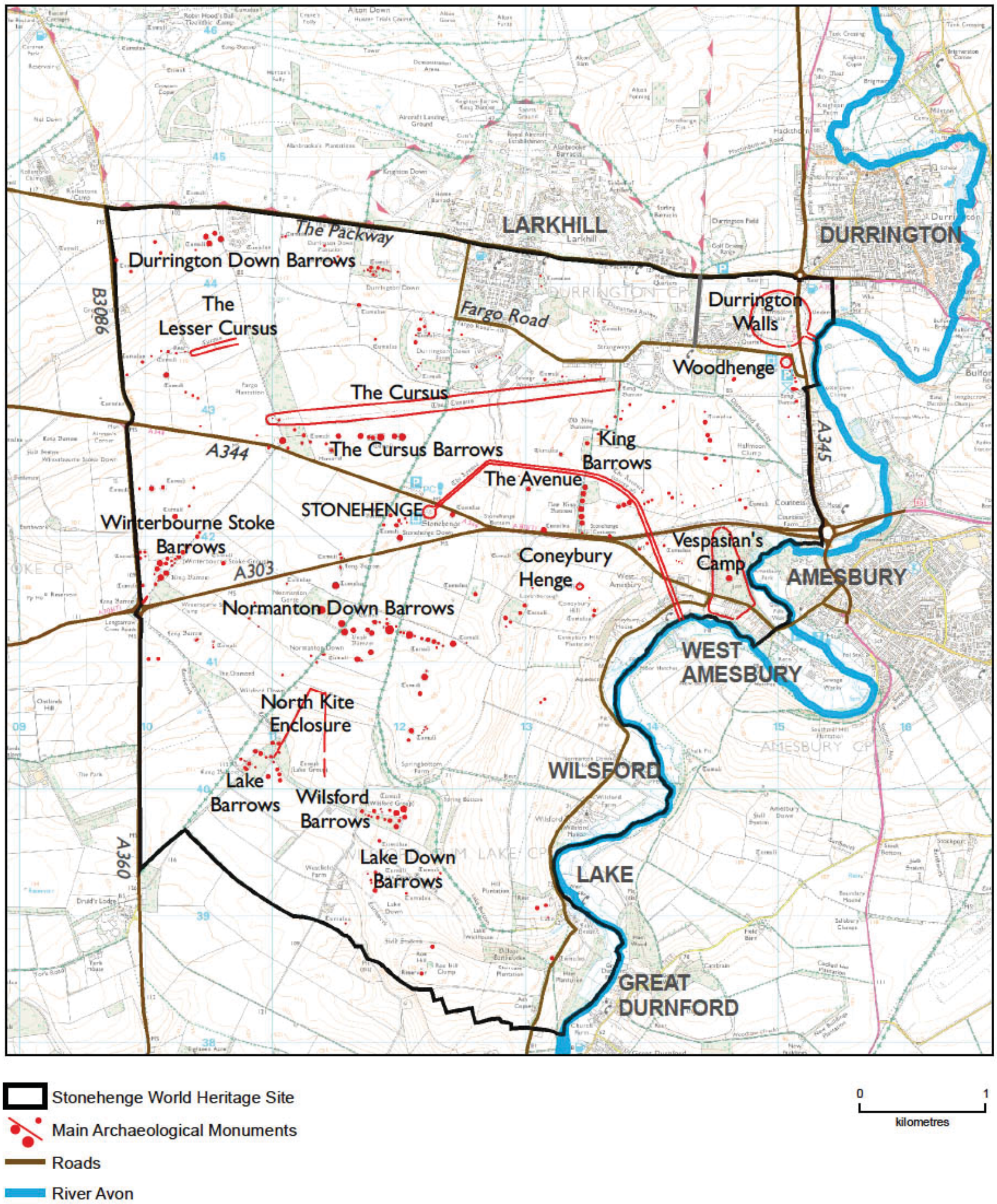

Fig. 4.1. Map of the Stonehenge World Heritage Site. Based on scheduled monument information from the Historic England (formerly English Heritage) GIS combined with features drawn from Ordnance Survey mapping data. © Historic England

Stonehenge is the most architecturally sophisticated prehistoric stone circle in the world and, in addition, the WHP around it contains many hundreds of archaeological sites and monuments, many of which are prehistoric too. These monuments in their associated landscapes help us to understand Neolithic and Bronze Age ceremonial and mortuary practices in England and indeed in north-west Europe. They demonstrate around 2000 years of continuous use and monument building between c. 3700 BC and 1600 BC.

One of the most important features of Stonehenge – one that has been recognised since the 18th century when it was noted by the antiquarian William Stukeley – is that its principal axis of symmetry is aligned upon winter solstice ("midwinter") sunset in one direction and summer solstice ("midsummer") sunrise in the other. We now know that a number of other prehistoric sites in the Stonehenge WHP also have astronomical significance, with some monuments oriented towards midwinter sunset and/or midsummer sunrise and others towards midsummer sunset or midwinter sunrise (Ruggles 2006; 2014). This contrasts with Avebury, where there are no known sites that convincingly demonstrate deliberate alignment in any of the solstitial directions.

See also the official brief description of the property that was agreed by UNESCO in July 2008 (quoted in Young, Chadburn and Bedu 2009: 21, section 3.2). A more detailed description of the Stonehenge WHP is set out in Appendix G (*ibid.*).

Six monuments in the Stonehenge WHP are considered to have significant astronomical alignments:

1. Stone settings at Stonehenge (Bluestone horseshoe, Trilithon horseshoe, Bluestone Circle, Sarsen Circle, Slaughter Stone and its companion, Heel Stone and its companion)
2. Stonehenge Avenue (straight segment closest to Stonehenge)
3. Woodhenge (timber circles rings C–F and grave)
4. Southern Circle, Durrington Walls
5. Southern Circle Avenue, Durrington Walls
6. Stonehenge Station-Stone rectangle

More details on these sites and alignments can be found in the section below and in Table 4.1.

2.b History and development

The first "monument" at Stonehenge WHP comprised an alignment of three Mesolithic pits (c. 8,000 BC) located just to the north-west of Stonehenge monument, which apparently contained huge timber posts. But the area became more intensively used from the early and middle Neolithic onwards (c. 4,000-3,000 BC), with the construction of a number of funerary and ceremonial monuments such as Neolithic long barrows (communal burial mounds) and a causewayed enclosure known as Robin Hood's Ball. Two long earthwork enclosures known as Cursuses – the Greater and Lesser – were also built towards the end of this period.

The lengthy history of Stonehenge itself started around 3,000 BC with the construction of a circular enclosure formed by a bank and ditch, containing the 56 pits known as the Aubrey Holes. Later, stones were added to the monument c. 2,500 BC, culminating in the construction of the stone circle, the remains of which we see today.

This stone-circle phase of the monument is the one that has the most readily apparent astronomical importance, with the axis of symmetry through the Bluestone and Trilithon horseshoes, between the Slaughter Stone and its companion, and between the Heel Stone and its companion, being aligned towards midwinter sunset in one direction and midsummer sunrise in the other (Ruggles 2006). Additionally, it is clear that the Sarsen Circle and Bluestone Circle are not completely regular, and were arranged and worked to respect the solstitial alignment, particularly the Midwinter Sunset alignment (Abbott and Anderson-Whymark 2012; 18, 20–22, 25, 50–53). It may also have been significant that the rectangle of four Station Stones just outside the bank and ditch, which may pre-date the Sarsen Circle, is broadly aligned lengthways upon the most southerly possible rising position and the most northerly setting position of the moon, as well as following the main solstitial axis across its width in the perpendicular direction (Ruggles 1997: 219–220). It is interesting and almost certainly not a coincidence that the width of the Station-Stone rectangle just exceeds the diameter of the Sarsen Circle, so it is possible that these lunar alignments could have been viewed even with the Sarsen Circle in place (Ruggles 2014: 1235).

Table 4.1. Summary of significant astronomical alignments in the Stonehenge WHP, with reference to the sites and components that might carry the OUV of the WHP in relation to astronomy.

ATTRIBUTE OF OUV	COMPONENT	LIKELY ALIGNMENT AND DATE OF CONSTRUCTION
4. The design of Neolithic and Bronze Age funerary and ceremonial sites and monuments in relation to the skies and astronomy	Stone settings at Stonehenge (Bluestone and Trilithon horseshoes, Bluestone Circle, Sarsen Circle, Slaughter Stone and its companion, Heel Stone and its companion), and the relevant sightlines and horizons	Midwinter sunset (but could also be midsummer sunrise) c. 2500 BC
	Stonehenge Avenue (straight segment closest to Stonehenge) and the relevant sightlines and horizons	Midwinter sunset (but could also be midsummer sunrise) c. 2,300 BC
	Woodhenge and the relevant sightlines and horizons	Midwinter sunset (but could also be midsummer sunrise) c. 2,500 BC
	Southern Circle, Durrington Walls and the relevant sightline and horizon	Midwinter sunrise c. 2,500 BC
	Southern Circle Avenue, Durrington Walls and the relevant sightline and horizon	Midsummer sunset c. 2,500 BC
	Stonehenge Station-Stone rectangle and the relevant sightlines and horizons	Most southerly moonrise/ most northerly moonset and Midsummer sunrise/ midwinter sunset c. 2,500 BC

The builders dragged stones for Stonehenge weighing up to 40 tonnes, from distances up to 240km away. They engineered the monument exactly so that the midwinter sun set between the two largest stones (the great trilithon and its fallen companion), and probably between the Heel Stone and its now-lost companion, and the Slaughter Stone and its lost companion, if one were viewing this sunset from the Avenue (Fig. 4.2). The midsummer sunrise may also have been important to the original builders. Standing with their backs to the largest trilithon, and looking down the Stonehenge Avenue, they could have seen the sun rise over the horizon to the north-east. Although the summer solstice is the main focus for modern celebrations, most scholars consider it much more likely that the stones were originally used mainly at midwinter (Fernie 1994: 155–156). This view has recently been strengthened by the results of a laser-scan at Stonehenge commissioned by English Heritage in 2011 and a subsequent archaeological analysis of the results in 2012. These have revealed that much more care was taken in dressing the stones that would be visible when approaching the monument from its Avenue: the stones in the Sarsen Circle at this point were all completely pick-dressed to remove the uneven surface. By contrast, the stones at the very "back" of the monument (for example, the outer faces of the sarsen stones on the south-west side of the circle) were not dressed or shaped with the same care and attention (Abbott and Anderson-Whymark 2012).

Part of the Stonehenge Avenue (c. 2,300 BC) is itself aligned along the main "solstitial axis" of Stonehenge (Fig 4.3), and this part is still visible as an earthwork. Excavations and recent geophysical surveys along its length (Fig. 4.4) have revealed buried linear geological features known as periglacial stripes, which might have been visible above ground during prehistory, for example through differential vegetation growth. In places, some of these stripes appear to be aligned on the solstitial axis, and the Avenue may have been built to formalise this natural phenomenon: this may be one of the reasons why the area was special to prehistoric peoples (Parker Pearson 2012: 240–248; Ruggles 2014: 1234).

Also built during this period around 2,500-2,300 BC were a number of other monuments, including Durrington Walls henge and Woodhenge, which also appear to contain solstitial alignments. Woodhenge is interesting because the solstitial alignment is manifested in the oval shape of its concentric timber rings, rather than the position of the earthwork henge entrance. A closer examination of the plan (see Fig. 4.5, left) reveals that the outer two rings (A and B) appear to be less regular in plan and have entrances that appear to match the henge entrance rather than being on the solstitial alignment. The outer rings A and B appear less regular in plan than the inner rings, and are also placed at a slight distance from them. When one considers the archaeological evidence for the post-holes, Rings A and B are variable in depth whereas the others are more consistent in their depths and dimensions. The inner four timber rings (C, D, E and F) are oval in shape and are certainly solstitially aligned. This suggests that Rings A and B are likely to be of a different date from rings C–F. While the dating evidence

Fig. 4.2. The midwinter sunset at Stonehenge taken from the Stonehenge Avenue, and showing the setting winter solstice sun seen through the monument. Photograph by James O. Davies, © Historic England (Photo Library N030018)

Fig. 4.3. The Stonehenge Avenue is aligned on the solstitial axis. In places, periglacial stripes appear to run parallel with it – one stripe is apparently visible as a shallow linear depression just to the left of the Avenue on this photograph. © 1994 Crown Copyright, Historic England NMR 15041_26

Fig. 4.4. Two views of the Stonehenge Avenue ditches under excavation, August 2013. Photographs by Adam Stanford, Aerial-Cam. © English Heritage

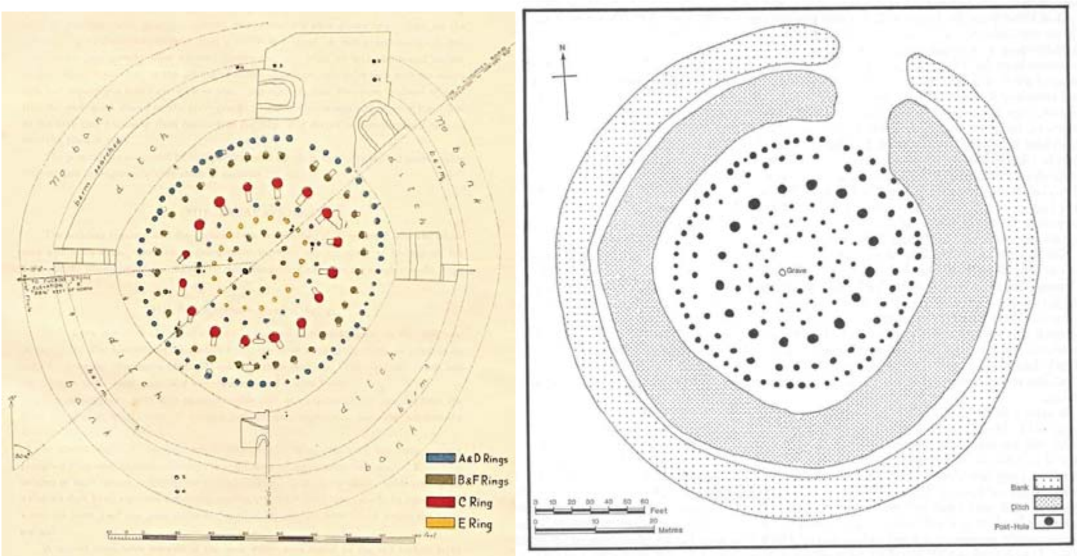

Fig. 4.5. Plans of Woodhenge showing the bank and ditch: **(left)** by Cunnington (1929, plate 3) and **(right)** by Wainwright & Longworth (1971, fig. 85, p. 208) (reproduced by kind permission of the Society of Antiquaries of London, © reserved)

currently available for this monument is insufficiently precise to prove this conclusively, it seems likely that there are two phases of timber rings, and that only the inner rings can be considered to be of astronomical importance.

The entrance of the Southern Circle, a set of six concentric timber rings that stood within Durrington Walls (see Fig. 4.5, right), was aligned south-eastwards towards midwinter sunrise, whereas the short Avenue (the "Southern Circle Avenue") was approximately aligned upon (within 1.5 degrees of) midsummer sunset towards the north-west (Ruggles 2006; 2014: 1232–1233). These two solstitial directions deviate by several degrees from being opposite to each other at this location because of the high horizon to the north-west.

The remains of small houses – perhaps seasonally occupied – were discovered in 2005 around and under the henge banks of Durrington Walls. These also date to c. 2,500 BC (Parker Pearson *et al.* 2005; Parker Pearson 2007: 132–140), but appear to relate to the timber circles enclosed by the henge banks rather than to the slightly later henge earthworks. About 500 years after these henge monuments were built, many burial mounds known as round barrows were constructed, some in linear cemeteries, particularly on the tops of the ridge lines overlooking Stonehenge.

It is difficult to be precise about the uses of the many monuments within the WHP, particularly as they were sometimes in use for many hundreds of years. It is certainly the case that large numbers of monuments in the area have a funerary element to them: the long barrows and round barrows were places of burial, and Stonehenge itself was used as a cremation cemetery, with the ashes of the dead placed in the Aubrey Holes. But other monuments do not appear to have had a primary function as a place of burial. For example, Robin Hood's Ball, the Lesser and Greater Cursus, the timber circles and the henges are more likely to have had ceremonial or meeting-place functions.

It is unclear what function the solstitial alignments at Stonehenge and other monuments in the WHP may have had. However, their significance is not in doubt and it is clear that they reflected the importance of the heavens to prehistoric peoples. Archaeologists have made various attempts to understand the cosmologies of these ancient peoples by studying these monuments. The intentionality of the lunar alignment of the Station-Stone rectangle is much less certain, and it has been claimed that Stonehenge was also important for other solar, lunar and even stellar events, but the evidence for this is even more tenuous.

Other sites for which solstitial alignments have been claimed include Coneybury henge (SU 1344 4160) and a "new henge" discovered in 2010 by the University of Birmingham. However, the possible alignments at both of these sites are very broad and it is difficult to be sure that they were intentional; Coneybury has recently been discounted in any case (Ruggles, 2006: 17). Nor is there strong evidence that the earthwork enclosures themselves (e.g. at Woodhenge and Durrington Walls) were deliberately aligned (ibid.: 20). It has also been suggested that the Northern Circle at Durrington Walls (SU 1518 4379) may have solstitial alignments, but there is not enough evidence to consider them further. A setting of six timber postholes known as Durrington 68 (SU 1513 4325) has also been claimed to face midwinter sunrise, but this has recently been discounted (Ruggles 2014: 1233). Other monuments such as the Greater Cursus have recently been claimed to have alignments: Gaffney et al. (2012: 154) consider that there are two large pits that line up with the Heel Stone to form solstitial alignments. However, as it is also clear that there are other pits within the Cursus, and as the relevant fieldwork has not yet been fully published, it is not easy to assess these claims. None of these alignments will be considered further here, although it is possible—perhaps even likely—that other astronomical alignments and sites existed within the WHP and are waiting to be discovered.

3. Justification for inscription

3.c Comparative analysis

Stonehenge WHP can and should be seen within a regional context of sites in the Neolithic and Bronze Age in north-west Europe that have astronomical alignments. These include monuments such as the Newgrange passage tomb, part of the Brú na Bóinne—Archaeological Ensemble of the Bend of the Boyne WHP (whc.unesco.org/en/list/659) (Prendergast 2014: 1273–1275), and various stone circles and monuments. All seem to have had some sort of funerary or ceremonial function, although astronomical practices in domestic contexts are also noted on occasion. This is more fully discussed elsewhere (Ruggles 2010, 28–34).

The monuments of the Stonehenge WHP provide the earliest evidence in Britain or Ireland of a consistent local practice of aligning monuments with some precision upon sunrise or sunset around the solstices. This is in contrast, for example, to the solstitial orientation of Newgrange, a "one-off" alignment among the Boyne Valley tombs (see Prendergast 2014); to the very broad pattern of orientation clustered around the intercardinal directions observed among Neolithic tombs and houses in the Orkney Islands (Parker Pearson and Richards 1994); and to evidence that Early Neolithic long barrows in the Salisbury Plain area, in the vicinity of Stonehenge—which preceded the construction of the Stonehenge stone circle by about a millennium—followed a broad pattern of orienttation within the sun-rising/sun-climbing arcs, between north-east and south (Ruggles 1997: 212).

3.d Integrity and/or authenticity

There is a statement of integrity and authenticity in the retrospective Statement of Outstanding Universal Value prepared for the Property in 2011 and recently adopted by UNESCO, which does set out some of the damage to astronomical alignments and sightlines. The relevant passages are quoted below:

> *Integrity*
>
> *… The presence of busy roads going through the WHP impacts adversely on its integrity. The roads sever the relationship between Stonehenge and its surrounding monuments, notably the A344 which separates the Stone Circle from the Avenue.*
>
> *Authenticity*
>
> *… At Stonehenge, several monuments have retained their alignment on the Solstice sunrise and sunset, including the Stone Circle, the Avenue, Woodhenge, and the Durrington Walls Southern Circle and its Avenue.*
>
> *Although the original ceremonial use of the monuments is not known, they retain spiritual significance for some people, and many still gather at both stone circles to celebrate the Solstice and other observations …*

We now consider these issues in more detail.

We have seen how the design of a number of monuments within the Stonehenge WHP had an astronomical significance. Some of these monuments are now largely or wholly buried and their astronomical significance is not readily apparent on the ground. Nevertheless, their remains are preserved underground and their authenticity and integrity are not affected. It is generally agreed that the solstitial alignments that form such a key element of the design at Stonehenge itself have not been impaired by intrusive modern structures, although the companions to the Heel Stone and Slaughter Stone are missing, as are some stones in the Sarsen Circle.

However, three monuments with astronomical significance have been directly damaged, all by roads. These are the Durrington Walls Avenue, the Durrington Walls Southern Circle, to which it leads, and the Stonehenge Avenue. The 200-year-old A344 road, which cut off the Stonehenge Avenue from Stonehenge itself (see Fig. 4.3), was of concern to UNESCO at the time of inscription in 1986, and the British Government promised to close the road. Happily, this took place in 2013 as part of the Stonehenge Environmental Improvements Project, and Stonehenge is once again connected with its Avenue for the first time since at least the 18th century, when the turnpike road that became the A344 was first constructed. A modern embanked road (the A345) cuts across the Durrington Walls Avenue, and also buries part of the Southern Circle. The integrity of these important monuments is badly compromised by the presence of this road.

In prehistory, one or more observers would probably have stood at an appropriate point and viewed the sun or moon appearing or disappearing behind a distant horizon at specific times of the year. Thus, clear and unobstructed sightlines and horizons are important to aid our understanding of how these monuments functioned. Although the sightlines from the six monuments listed above are generally understood, it has not always been a straightforward matter to identify the ridge-line or horizon that would have originally been used, especially where intervening woods, road embankments and/or buildings currently block the view.

Table 4.2 assesses the integrity of the astronomical components of the WHP, with the proviso that the relevant horizons are not yet fully understood. This detailed work needs to be done as part of the setting study and boundary review.

Table 4.2. Integrity of the astronomical components of the Stonehenge WHP.

ATTRIBUTE	COMPONENT	INTEGRITY
4. The design of Neolithic and Bronze Age funerary and ceremonial sites and monuments in relation to the skies and astronomy	Stone settings at Stonehenge (Bluestone and Trilithon horseshoes, Bluestone Circle, Sarsen Circle, Slaughter Stone and its companion, Heel Stone and its companion), and the relevant sightlines and horizons	Generally good
	Stonehenge Avenue (straight segment closest to Stonehenge) and the relevant sightlines and horizons	Bisected for 200 years by the A344; this road was removed in 2013
	Woodhenge and the relevant sightlines and horizons	Generally good
	Southern Circle, Durrington Walls, and the relevant sightline and horizon	Partly under the large A345 road embankment
	Southern Circle Avenue, Durrington Walls and the relevant sightline and horizon	Partly under the large A345 road embankment
	Stonehenge Station-Stone Rectangle and the relevant sightlines and horizons	Generally good

The integrity of sightlines within the Stonehenge WHP

In assessing the integrity of these sightlines today, we make the assumption that they were largely kept clear in the Neolithic and Bronze Age, so that the monuments could be used in the way in which we presume they were used, with the sun or moon rising or setting behind distant horizons visible from the monuments themselves. The sightlines are shown in Figs. 4.6 and 4.7. For a summary of the integrity of astronomical sightlines within the Stonehenge WHP, see Table 4.3.

Sightline from Stonehenge looking south-west (midwinter sunset). There is a growing consensus that the midwinter sightline was more important than the midsummer one, as discussed in Section 2b above. Today the integrity of this sightline, and its intermediate ridgelines and final horizon, is marred. Looking out from Stonehenge, the first problem is the A303 (0.5 km), which runs relatively close to the monument, and presents a considerable visual and noise intrusion to this alignment. Moving further south-west, the round barrow known as the Sun Barrow—which is on the alignment and on the Normanton Down ridge line—is intact (0.9 km), but the sightline then quickly runs into the plantation known as Normanton Gorse (1.1 km), which obscures it. Still further south-west is another plantation known as The Diamond (2.2 km), before the alignment continues towards the place that would form the visible horizon from Stonehenge in the absence of intervening vegetation, a hill WNW of Druid's Lodge to the west of the A360 road (and outside the WHP) (4.4 km). This horizon is also obscured by yet another plantation, at The Park. The sightline appears to end just to the north of a much later Iron Age/ Romano-British oval enclosure, probably a settlement, which is situated near the hilltop. It is difficult to determine the exact place because the various obstructions mean that we must rely upon computer modelling.

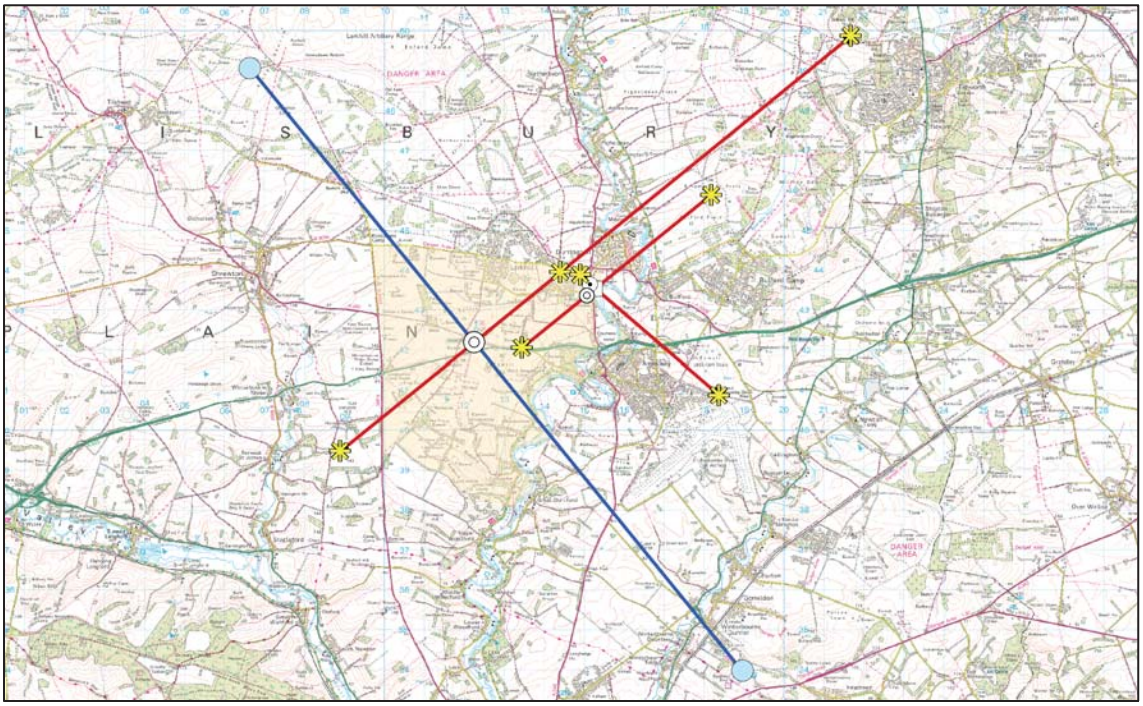

Fig. 4.6. Astronomical sightlines at Stonehenge World Heritage Site and the surrounding area, with their end-points on horizons. These should be treated as indicative rather than necessarily exact. The WHS area is shaded in yellow. Produced by Nick Hanks, Historic England, February 2015. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

The Stonehenge Avenue looking south-west (midwinter sunset) shares the same alignment, and the same issues apply regarding its integrity. On the initial approach towards Stonehenge along the Avenue from the "elbow" at Stonehenge Bottom, Stonehenge itself forms the horizon; the more distant landscape only appears during the final stages of the approach.

Sightline from Stonehenge looking north-east (midsummer sunrise). The A344 has now been closed to traffic and, once the grass has regenerated, visitors will be able to walk uninterrupted from Stonehenge to its Avenue for the first time in centuries. The integrity of this sightline is good for 1.7km until it hits the line of trees to the immediate north of the Cursus which obscure it (these were planted to screen the view of the Steel Houses from Stonehenge). Further to the north-east, by good fortune it avoids buildings within the Larkhill Garrison (although not some garrison roads), and its final horizon is probably the ridge along which the Packway road runs (3.0 km). Alternately, it may continue into the Salisbury Plain Training Area, with the visible horizon formed by a ridge just to the south of Sidbury Hill hillfort, some 12km from Stonehenge. It is difficult to check which ridge forms the final horizon because of the Cursus Northern Plantation, which compromises all views further to the north-east: again, computer modelling is needed.

The Stonehenge Avenue looking north-east (midsummer sunrise) shares the same alignment, and the same issues apply regarding its integrity.

Sightlines from the Stonehenge Station-Stone rectangle looking south-east (southernmost moonrise). (This is assessed as a single line in the landscape, not two parallel lines.) Today the integrity of this sightline, and its intermediate ridge lines and final horizon, is marred. Looking out from Stonehenge, the first problem is the A303 (0.2km), which runs relatively close to the monument, and presents a considerable visual and noise intrusion to this alignment. Further south-east, it is obscured by the Luxenborough Plantation (1.0 km), which obscures the first ridge line it hits at Coneybury Hill. The alignment continues over the Avon Valley and outside the WHP boundary. It just misses the Field Barn Buildings (4 km) on the east side of the Avon, but is further obscured by the Cocked Hat plantation (5 km), which lies near another ridge line on which the A345 runs. After crossing the A345 (where there is some new planting which will also grow and obscure the line more in future), the alignment runs as far as the chalk ridge on which the hillfort of Figsbury Ring sits (10.5 km), where its original horizon was probably located (but passing just north of Figsbury Ring itself, and to the south of the highest point of the ridge). Again, computer modelling is needed to construct the exact sightlines, as the obstructions make it difficult to check on the ground, but the view back from Figsbury Ring into the WHP is helpful.

Sightlines from the Stonehenge Station-Stone rectangle looking north-west (northernmost moonset). (This is assessed as a single line in the landscape, not two parallel lines.) This sightline has relatively good integrity for some distance. The A344 has been closed, and from Stonehenge the alignment runs north-west through the WHP to the Lesser Cursus ridge-line, then runs outside the WHP into the Salisbury Plain Training Area with few interruptions. It is obscured by the caravan park at the Bustard Inn (5 km), and its final horizon may have been the ridge at Westdown Artillery Range (12 km), subject to confirmation by computer modelling.

Sightline from Woodhenge looking north-east (midsummer sunrise). This is a relatively well-preserved alignment. Although it runs through groups of buildings in the village of Durrington, these are relatively low-lying and do not obscure it. The final horizon appears to be outside the WHP at Silk Hill in the Salisbury Plain Training Area (5.3 km).

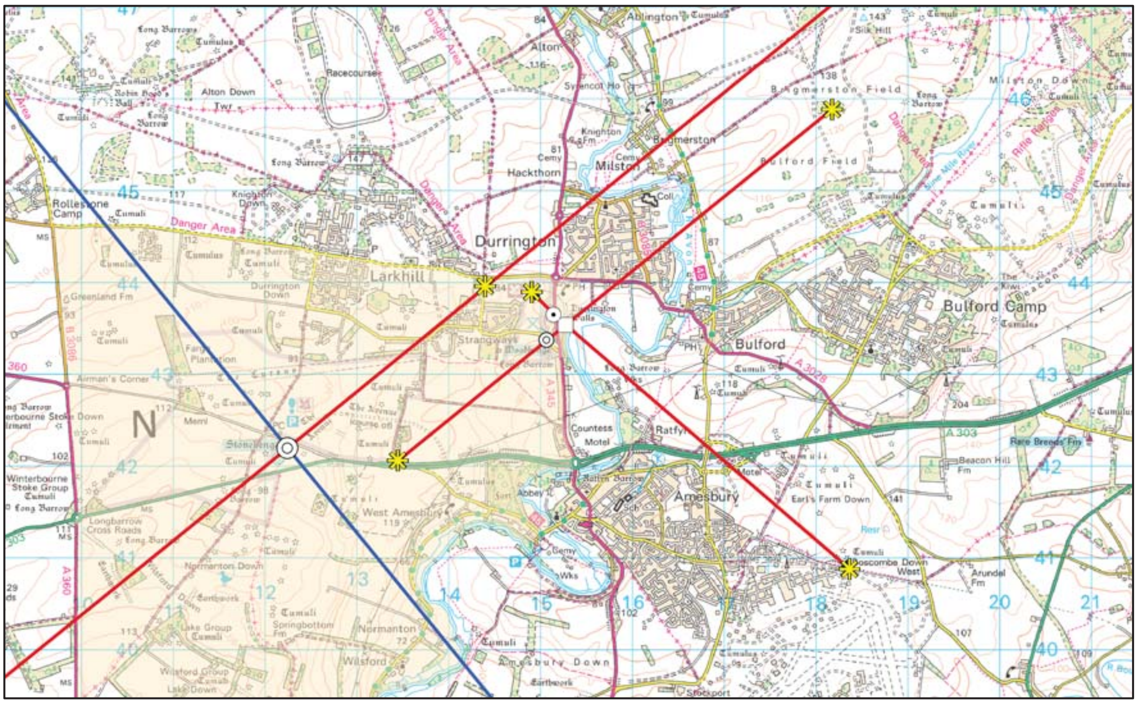

Fig. 4.7. Astronomical sightlines at Stonehenge, Woodhenge, and Durrington Walls Southern Circle and Avenue. These should be treated as indicative rather than necessarily exact. The WHS area is shaded in yellow. Produced by Nick Hanks, Historic England, February 2015.

Table 4.3. Summary of the integrity of astronomical sightlines within the Stonehenge WHP.

	Sightline (alignment)	Integrity	Horizon
1	Stonehenge looking south-west (midwinter sunset)	Line obscured by A303 and several plantations.	Probably hill ~1km to WNW of Druid's Lodge (4.4 km).
2	Stonehenge looking north-east (midsummer sunrise)	A344 now closed, but line obscured by a plantation and the Packway road.	Packway ridge (3.0 km) or Sidbury Hill, south of hillfort (12 km). The latter intact, the former obscured.
3	Stonehenge Avenue looking south-west (midwinter sunset)	Line obscured by A303 and several plantations.	Probably hill ~1km to WNW of Druid's Lodge (4.4 km).
4	Stonehenge Avenue looking north-east (midsummer sunrise)	A344 now closed, but line obscured by a plantation and the Packway road.	Packway ridge (3.0 km) or Sidbury Hill, south of hillfort (12 km). The latter intact, the former obscured.
5	Stonehenge Station-Stone rectangle looking south-east (southernmost moonrise)	(This is assessed as a single line in the landscape, not two parallel lines). Line obscured by A303 and several plantations.	Probably the ridge line on which Figsbury Ring hillfort sits (10.5 km). Intact.
6	Stonehenge Station-Stone Rectangle looking north-west (northernmost moonset)	(This is assessed as a single line in the landscape, not two parallel lines). Relatively good for several km.	Probably Westdown Artillery range (12 km). Intact.
7	Woodhenge looking north-east (midsummer sunrise)	Relatively good for several km.	Silk Hill (5.3 km). Intact.
8	Woodhenge looking south-west (midwinter sunset)	Good.	Probably King Barrow Ridge (2.0 km). Exact point obscured by trees.
9	Southern Circle, Durrington Walls, looking south-east (midwinter sunrise)	Destroyed by A345 embankment.	Earl's Farm Down ridge (4.2 km). Intact.
10	Southern Circle Avenue, Durrington Walls, looking north-west (midsummer sunset)	Destroyed by A345 embankment.	Durrington Walls henge banks (0.7 km). Intact.

Sightline from Woodhenge looking south-west (midwinter sunset). This is a relatively well-preserved sightline as far as its horizon, which is probably at King Barrow Ridge (2.0 km), which sits slightly higher than Woodhenge. It is difficult to be precise about this because today there are numerous trees on the ridge that forms the horizon, together with the Stonehenge Cottages and also the New King Barrows themselves, although the sightline is well preserved up until this point. If the alignment continued, it would eventually hit the Lake Barrow Group (5 km).

Sightline from the Southern Circle, Durrington Walls, looking south-east (midwinter sunrise). This is wholly destroyed by the embankment of the A345, which sits over half the monument. If it were not destroyed, the alignment would swiftly run south-east outside the WHP over the Avon Valley and into the modern industrial development of Solstice Park (whose name is coincidental). The horizon for this alignment is the Earl's Farm Down ridge (4.2 km), near to round barrow group SM 28925 and Bowl Barrow SM 28946. Despite much development in this area, this horizon appears to be intact, with large modern buildings currently sitting below it.

Sightline from the Southern Circle Avenue, Durrington Walls, looking north-west (midsummer sunset). This is wholly destroyed by the embankment of the A345, which sits over part of the Avenue, severing the Avenue from the Southern Circle. If the road were not there, the horizon for this sightline would be the north-westerly banks of Durrington Walls henge (0.7 km).

The integrity of sightlines and the boundary of the Stonehenge WHP

It is recommended here that the minor boundary review and setting study for the WHP (see Section 1.e), and any for a buffer zone, should also consider the solstitial alignments of those monuments that are known to have had them, to ensure that the relevant and appropriate horizons and sightlines are taken into account within any new boundary or future buffer zone. This will probably require some computer modelling (which should be done using topographic modelling excluding vegetation and buildings) and ground-truthing by field observation and measurement as required. We know that not all the relevant horizons and sightlines are captured within the existing boundary, but this needs to be checked in detail Any extensions needed should fall within the scope of a minor boundary review (UNESCO 2011: paras 163–4), because UNESCO's Statement of Outstanding Universal Value (OUV) for Stonehenge already recognises its astronomical importance, or could come within the scope of a new buffer zone, as at Studley Royal and Fountains Abbey WHP (whc.unesco.org/en/list/372)—see Fig. 4.8.

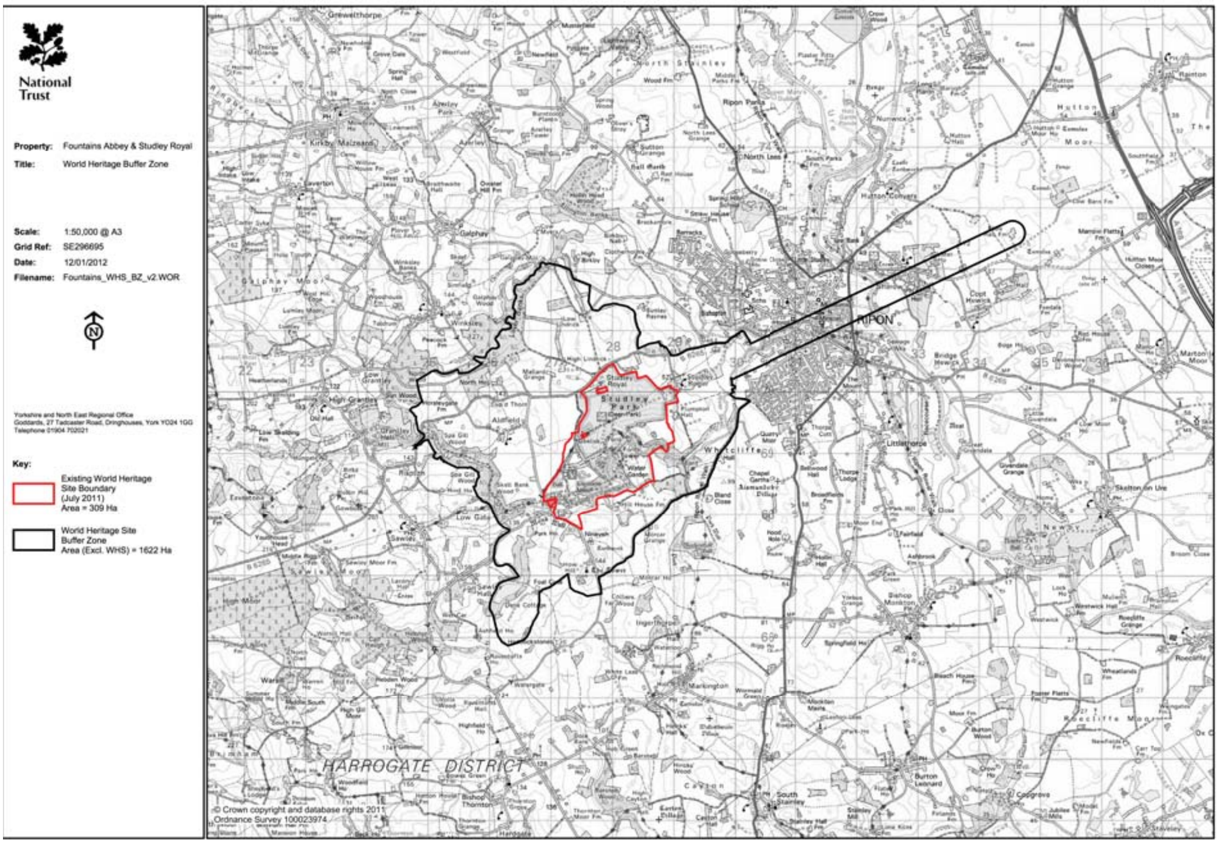

Fig. 4.8. The UNESCO-adopted Fountains Abbey buffer zone, which includes a (non-astronomical) sightline. © National Trust.

3.a Potential criteria under which inscription might be proposed

Stonehenge is inscribed under three criteria (using the definitions current in 1985/6):

- Criterion (i): It represents a unique artistic achievement, a masterpiece of human creative genius.
- Criterion (ii): It has exerted great influence, over a span of time or within a cultural area of the world, on developments in architecture, monumental arts or town planning and landscaping.
- Criterion (iv): It bears a unique or at least exceptional testimony to a civilization that has disappeared.

These are fully set out in the UNESCO Statement of Outstanding Universal Value for Stonehenge. It is additionally considered that Stonehenge might meet two more criteria with respect to its astronomical importance:

- *Criterion (iv): "be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history".*

  The most famous elements at Stonehenge – the Stone Circle and Stone Settings – were built c. 2,500 BC, and are the first elements of the monument that can definitely be considered to have astronomical importance. This date is on the cusp of a major technological change in Southern Britain, at the very end of the Neolithic and the start of the Chalcolithic or Copper Age (c. 2,500 BC to c.2,200 BC). It may be significant that the date of an apparent change in ritual behaviour associated with astronomy is also the date of the introduction of metals to the country. The other monuments of astronomical importance in the Stonehenge WHP also appear to date to the Chalcolithic period, and this surely is no coincidence.

Criterion (vi): "be directly or tangibly associated with events or living traditions, or with beliefs, with artistic and literary works of outstanding universal significance".

The influence of Stonehenge on a variety of people is already recognised in Attribute 7 (Young, Chadburn and Bedu 2009: 28): "the influence of the remains of Neolithic and Bronze Age funerary and ceremonial monuments, and their landscape settings on architects, artists, historians, archaeologists and others". This attribute would sit better under Criterion (vi), than with the existing three criteria.

3.b Suggested statement of outstanding universal value

There is already a Statement of Significance, agreed by UNESCO in 2008 (quoted in full in Young, Chadburn and Bedu, 2009: 26-7). A retrospective Statement of Outstanding Universal Value (SOUV) was prepared for the Property by the State Party in 2011 and has been approved by UNESCO. The relevant parts of that SOUV in relation to astronomy are quoted here and elsewhere (see Integrity and Authenticity [above] and Protection and Management [below]):

Statement of Significance

The Stonehenge, Avebury and Associated Sites WHP is internationally important for its complexes of outstanding prehistoric monuments…

They provide an insight into the mortuary and ceremonial practices of the period, and are evidence of prehistoric technology, architecture and astronomy…

The complexes of monuments at Stonehenge and Avebury provide an exceptional insight into the funerary and ceremonial practices in Britain in the Neolithic and Bronze Age. Together with their settings and associated sites, they form landscapes without parallel.

The design, position and inter-relationship of the monuments and sites are evidence of a wealthy and highly organised prehistoric society able to impose its concepts on the environment. An outstanding example is the alignment of the Stonehenge Avenue (probably a processional route) and Stonehenge stone circle on the axis of the midsummer sunrise and midwinter sunset, indicating their ceremonial and astronomical character…

4. Factors affecting the property

4.a Present state of conservation

The present state of the monuments is generally good, although the integrity of some monuments is compromised as set out above. The WHP generally still has sites "at risk" due to the plough, and the increasing numbers of burrowing animals, particularly the badger, which is legally protected. The sites of astronomical importance listed above are in permanent grassland and are well cared for by their relevant owners. However, it is possible that some as-yet-undiscovered sites may be at risk from the plough or from burrowing.

The night sky is compromised in some places owing to lights from cars on the roads, street lights, housing, and Larkhill Garrison, Amesbury town and Durrington village. Although the dark skies are not part of the WHP, it is considered important to try and preserve the dark-sky setting for these monuments, as this is how they would have originally been viewed.

4.b.i Developmental pressures

There are strong policies in local and national plans (set out in Section 1e above) to protect the WHP from adverse development. However, there is still the potential for adverse effects, particularly from lighting spill. Recently planning applications have started to take the dark skies into consideration, but some damage in and around Larkhill Garrison has already been done.

Unless the relevant horizons and sight-lines are known for the sites of astronomical importance, it may be possible that some future development may adversely affect these. It is therefore essential to identify these as soon as possible.

4.b.ii Environmental pressures

Stonehenge and other monuments are vulnerable to erosion from natural processes such as weathering. However, natural processes do not appear to have markedly changed them, and the fact that there is such a well-preserved colony of lichens on the Stones suggests that the air is very clean and that emissions are not a problem. Light pollution from the neighbouring military settlements and installations at Larkhill and Boscombe Down are more of a problem. The dark skies which once existed in prehistory are often difficult to see today because of light spillage from these areas.

4.b.iii Natural disasters and risk preparedness

There are risk management plans written for Stonehenge. The WHP property is at a very low risk for flooding and hurricanes, and an even lower one from such natural disasters as earthquakes etc.

4.b.iv Visitor/tourism pressures

Stonehenge monument is visited by over a million paying visitors each year, not including those visiting at the summer solstice, but this does not adversely affect its astronomical importance. The centre of the monument is not available for general visiting, but only for small numbers via the "Stone Circle Access" scheme which runs before and after the normal opening hours.

4.b.v No. of inhabitants

There are some local inhabitants, particularly in and around Larkhill Garrison and the Countess Road, Amesbury, and also the villages in the southern parts of the WHP including Lake and West Amesbury.

5. Protection and management

There is a statement of protection and management requirements in the Statement of Outstanding Universal Value for the Property. The relevant passages are:

> *Protection and Management Requirements*
>
> *…. At the time of inscription, the State Party agreed to remove the A344 road to reunite Stonehenge and its Avenue and improve the setting of the Stone Circle. The impact of roads and traffic and the need to improve visitor facilities remain the biggest challenge.*

5.a Ownership

The WHP is a living landscape in multiple ownership. Much of it is in private hands, and most of it is farmland. However, a large part of the WHP is now owned or managed by conservation bodies, although no single body has overall responsibility for the whole WHP. The National Trust owns 827 hectares in the northern and central parts of the WHP. Part of the WHP is owned by the Ministry of Defence, where it forms part of Larkhill military garrison, and additionally, at Amesbury, Durrington and the Woodford Valley, there are a number of private houses within the WHP.

Stonehenge itself is owned by the State Party and in the care of English Heritage, a charity that cares for the National Heritage Collection of more than 400 historic properties and their collections.

5.b Protective designation

The Stonehenge WHP is protected as a WHP, which is a “material consideration” in UK planning law, and many individual elements within it are also protected by law. For example, there are 180 scheduled monuments which include over 415 archaeological sites and monuments within the scheduled areas, which are all protected by the 1979 Ancient Monuments and Archaeological Areas Act. There are also various listed buildings, registered parks and gardens and conservation areas within the WHP.

5.c Means of implementing protective measures

The Property is managed by multiple owners, although there is the Stonehenge WHS Management Plan 2009, which sets out main, agreed overall goals for managing the WHP, and a Stonehenge World Heritage Committee (comprising key stakeholders) who oversee this management framework (Young, Chadburn and Bedu 2009). A new Management Plan was published in 2015 (Simmonds and Thomas 2015).

The legally protected archaeological sites and listed buildings and other heritage assets are protected through the UK’s spatial planning system and specific heritage laws. These are administered by relevant planners, conservation officers and archaeologists in local government and Historic England, the national state heritage agency. Further details are set out in section 4.0 of the Stonehenge WHS Management Plan 2009 (Young, Chadburn and Bedu 2009, 37-41).

5.d Existing plans

See Young, Chadburn and Bedu 2009; Simmonds and Thomas 2015.

5.e Property management plan

See Young, Chadburn and Bedu 2009; Simmonds and Thomas 2015.

5.f Sources and levels of finance

Various stakeholders set out in the Stonehenge WHS Management Plan 2009 (Young, Chadburn and Bedu 2009; Simmonds and Thomas 2015) contribute towards the repair and maintenance of the Property.

5.g Sources of expertise and training

Historic England, English Heritage, the National Trust and Wiltshire Council all employ archaeologists to advise on the WHP and its monuments.

5.h Visitor facilities and infrastructure

English Heritage opened a new Stonehenge Visitor Centre in 2013 which has educational facilities and an interpretation centre with museum objects. Interpretation has also been improved at various sites around the landscape including Durrington Walls and Woodhenge. There is a café, shop, car and coach park, and all the usual facilities one would expect to find.

5.i Presentation and promotion policies

A new Visitor Centre was opened in 2013, as above. The WHP is not actively promoted because visitor numbers are so high anyway.

5.j Staffing levels and expertise

The main stakeholders (e.g. Historic England, English Heritage, the National Trust and Wiltshire Council) all employ appropriate numbers of staff, although there is always room for improvement. There is a dedicated Stonehenge WHS Coordinator funded by Historic England, and employed in the World Heritage Site Coordination Unit at Wiltshire Council.

6. Monitoring

6.a Key indicators for measuring state of conservation

With regard to astronomy, these are not all yet in place. Although the sites are directly protected, their sightlines and horizons are not yet fully understood, and are therefore not yet fully protected. For this reason we append the discussion in Appendix I.

6.c Results of previous reporting exercises

Two Periodic Reports have been prepared for the Property (2005-6 and 2012-14), of which the main recommendations in relation to astronomy were those to close the A344. This has now been undertaken. See

http://whc.unesco.org/archive/periodicreporting/EUR/cycle01/section2/373-summary.pdf

7. Documentation

7.b Texts relating to protective designation

1979 Ancient Monuments and Archaeological Areas Act.

http://www.legislation.gov.uk/ukpga/1979/46

Stonehenge WHS Management Plan 2009.

http://www.stonehengeandaveburywhs.org/assets/Full-MP-2009-low-res-pdf.pdf

Stonehenge and Avebury WHS Management Plan 2015.

http://www.stonehengeandaveburywhs.org/management-of-whs/stonehenge-and-avebury-whs-management-plan-2015/

7.c Most recent records or inventory

Held by the local Historic Environment Record of Wiltshire Council, and the archives and GIS of Historic England.

7.d Agencies holding inventory records

Stonehenge and the key monuments of the WHP are prehistoric and so, by definition, there is no surviving original documentation relating to them. However, there are a number of important museum and archive collections relating to the WHP, most notably at Salisbury and South Wiltshire Museum and Wiltshire Heritage Museum in Devizes, where a number of antiquarian archives are housed, along with important finds from the WHP. There are also very important collections of data in the Wiltshire and Swindon History Centre (including the Wiltshire Sites and Monuments Record), the National Monuments Record of Historic England and The National Archives.

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APPENDIX I

The management of astronomical values – how can this be achieved in practice?

Table 4.4 below sets out a possible way of monitoring the astronomical values, and potential OUV, of the Stonehenge WHP, with two worked examples. Unless the components of each attribute are identified fully, one cannot monitor them, nor ensure they are taken into account in planning and development. Possible impacts also need to be fully identified. Each component is not only directly vulnerable: its setting can also be damaged, particularly its horizons and sightlines. If these are obscured by trees or buildings, this can damage the astronomical importance of the site in question.

The main action needed now is to ensure that these horizons are captured within the boundaries of the WHP or a Buffer Zone, and are fully understood by the WHP's managers, curators and by local planners.

Each relevant sightline and horizon needs to be identified. When this is done, barriers and obstructions on the sightlines, and preventing a clear view along them, need to be specifically identified. These might include trees and buildings. Ideally, all the monuments of astronomical importance should have the relevant sightlines and horizons clear, allowing visibility as it was presumably originally intended. Recommendations for action and management need to be made on a case-by-case basis, once there is a full and detailed understanding of the impacts. Some barriers, e.g. scrub, may be easy to remove and manage. Other impacts, particularly roads (e.g. the A303 and A345) may be difficult or impossible to remove, although we have already noted that the A344 has been closed and is being returned to grass.

Assuming that these were once largely clear in the Neolithic and Bronze Ages, it is important to try and ensure that the sightlines are as clear as possible today. All plans should ensure that no further planting or development takes place along them. Consideration should be given to cutting view-lines through plantations to maintain the alignments unless there are reasons for retaining them (e.g. the screening of buildings), and any Woodland Strategies for the WHP should consider the alignments and how best to manage them.

Table 4.4. Suggested way of monitoring the astronomical values, and potential OUV, of the Stonehenge WHP: two worked examples.

Attribute	**Component**	**Impacts, e.g.**		
		On sightlines and horizons	**Direct impacts (e.g. development, agriculture, burrowing animals)**	**From lighting**
4. The design of Neolithic and Bronze Age funerary and ceremonial sites and monuments in relation to the skies and astronomy	Stonehenge (Bluestone and Trilithon horseshoes, Bluestone Circle, Sarsen Circle, Slaughter Stone and its companion, Heel Stone and its companion), and the relevant sightlines and horizons	**A303**. Recommended action: remove road from surface	**Visitor erosion.** This is already carefully managed	**Vehicle headlights on A303.** Recommended action: remove road from surface
	Stonehenge Avenue and the relevant sightlines and horizons		**Part of the Avenue (not the aligned part) is under the plough.** Recommended action: remove it from arable	**Lights at Larkhill.** Recommended action: explore removing lights and reducing light spill

The roads and buildings that exist along alignments today are a difficult issue. Although the A344 has been closed to great effect, the A303 remains a major problem for some of these sightlines and a road tunnel would be an excellent solution. On 1 December 2014, the British Government announced that it would invest in a fully-bored tunnel of at least 2.9km to remove part of the A303 road from the Stonehenge WHP. At Durrington Walls, the A345 embankment is extremely damaging, and the only obvious physical solution (short of closing the road and redirecting it elsewhere, which would be very difficult to achieve) is that a pedestrian underpass is built along the solstitial alignment through the embankment. This would have the effect of visually linking the Southern Circle and its Avenue once more. However, this would be very expensive, and with two different landowners on either side of the road and currently no public access, would be problematic to achieve. At present, the best we can do is to improve interpretation and intellectual access, and this should be prioritised.

The alignments should be protected via future WHS management plans, policies in spatial planning documents, and consideration should be given to extending the WHP boundaries where appropriate, or managing them via a Buffer Zone (as at Studley Royal and Fountains Abbey WHP (whc.unesco.org/en/list/372).

Chankillo, Peru

Iván Ghezzi

1. Identification of the property

1.a Country/State Party: Peru
1.b State/Province/Region: Ancash region, Casma province, Casma district
1.c Name: Chankillo
1.d Location: 803325 E, 8942566 N, UTM Zone 17S, elevation 300m above MSL.
1.e Maps and Plans: See Figs. 5.1, 5.2 and 5.5.
1.f Area of the property: 17.41254 km^2.

2. Description

2.a Description of the property

Like many of Peru's coastal valleys, Casma has long been an 'oasis' for human settlement in an otherwise inhospitable environment. The Casma-Sechin river basin runs down the western slopes of the Andes mountain range through one of the world's driest deserts, an arid landscape of barren foothills, sandy plains, and narrow valleys that has geologically remained relatively unchanged since the Pleistocene.

Despite this extreme environment, sites such as Las Haldas, Sechin, Pampa de las Llamas-Moxeke, Chankillo, El Purgatorio, and Manchan demonstrate a long period of occupation (4500 years) from the Archaic period to the Incas, suggesting that the area has always been an important regional ceremonial center. Formative period sites in Casma are unequalled nationally in terms of their size, quality, and public architecture. It is now only the ceremonial structures that survive, generally using spaces that would not compromise maximum use of the riverside land for agriculture. The less robust residential sites and cemeteries, perhaps more closely associated with the cultivation zone along the rivers, are no longer visible.

Chankillo is a ceremonial site with complex ritual, administrative, and defensive functions found 365 km north of Lima and 15 km from the Pacific coast (Fig. 5.1). It is adjacent to the irrigated valley of the southern branch of the Casma/Sechin river basin, facing the rugged foothills of the western slopes of the Andes. Dozens of ^{14}C dates, all in the range 2350–2150 CalBP, place the construction, occupation, and abandonment of Chankillo within the late Early Horizon period (500–200 BC) in central Peruvian chronology (Burger 1995).

In 2008, Peru´s Ministry of Culture determined Chankillo to be a "monumental archaeological zone", spread over 17.4 km^2 (Fig. 5.2). A buffer zone was not determined. This area includes archaeological evidence from various periods of occupation, but is characterized by late Early Horizon period monumental stone and mortar constructions, originally plastered and painted with ochre, tan, yellow, and white pigments, sometimes decorated with relief, graffiti, or textured with finger impressions.

These constructions define three main site sectors. The most outstanding feature of Sector 1 is an oval-shaped hilltop building known as the Fortified Temple (Fig. 5.3). A massive construction, located strategically 180 m above the valley floor, it is composed of three central structures surrounded by concentric defensive walls. At its center, two identical buildings with circular ground plan and a rectangular building are surrounded by a platform with parapets, which serves as the innermost defensive wall as well. The twin buildings are composed of pairs of concentric circular walls with three restricted-access gates. They may have served as a last level of refuge.

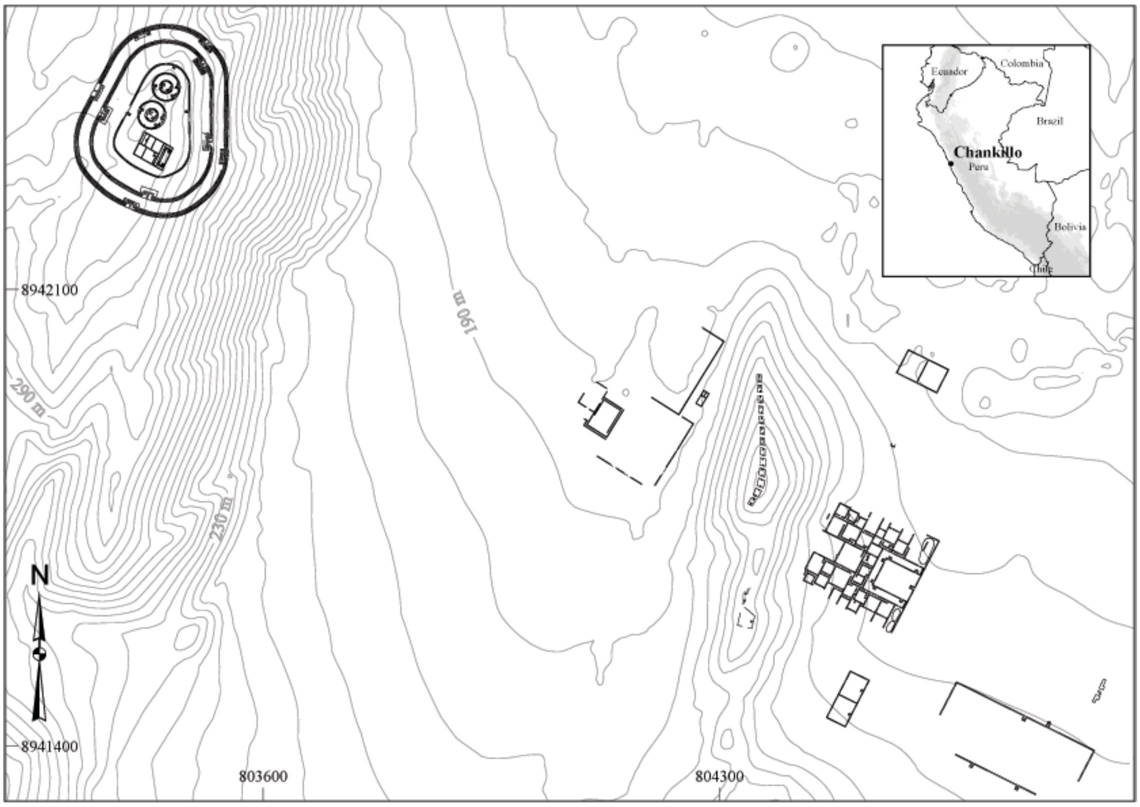

Fig. 5.1. Plan of Chankillo. © Iván Ghezzi

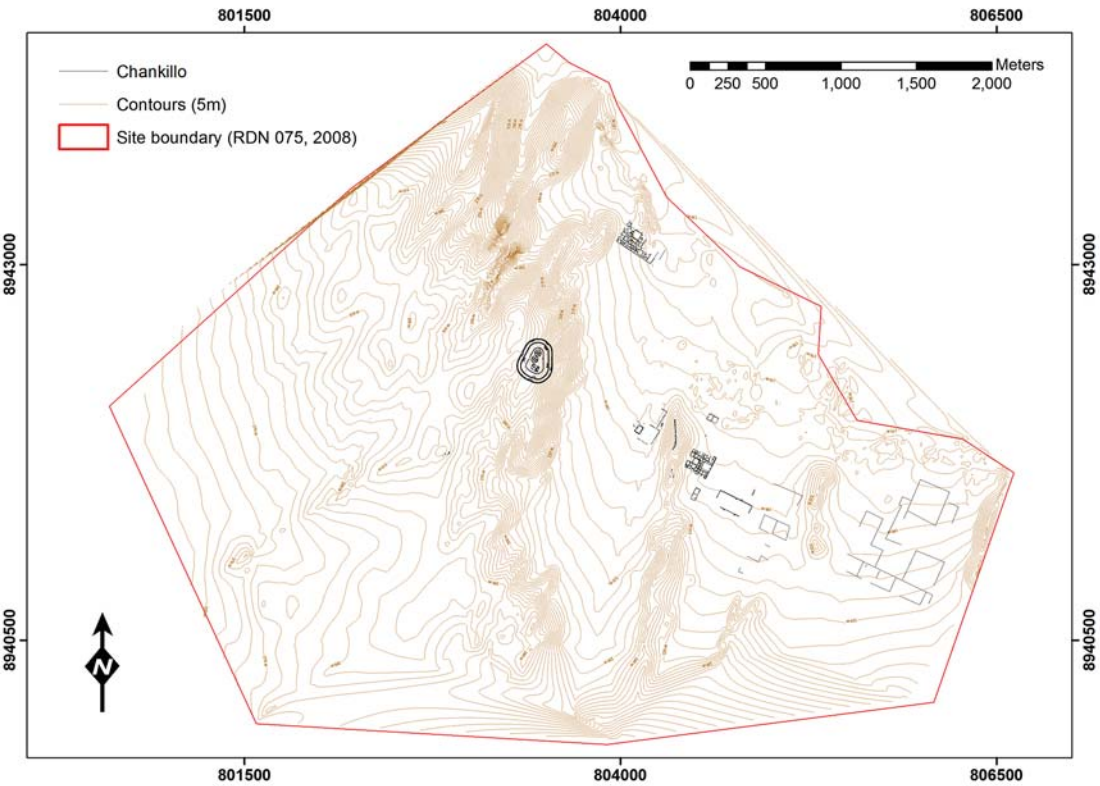

Fig. 5.2. The “monumental archaeological zone” at Chankillo, spread over 17.4 km^2. © Iván Ghezzi

Fig. 5.3. Aerial view of the fortified temple at Chankillo. Photograph © Servicio Aerofotográfico Nacional, Lima

The rectangular building is a temple or palace oriented to the December solstice sunrise. Its front atrium is a U-shaped two-tiered platform with dual staircases on each level. The rooms behind it, sometimes bearing mural decoration (Fig. 5.4), were used for ritual and possibly elite habitation.

The walls surrounding the inner buildings and platform are massive, standing in places up to 8 m. These are complex walls, made up of several parallel wall sections with in-between fill. The wall tops were accessed through staircases spread around the perimeter at regular intervals. There were nine baffled gates, protected with parapets, top rooms hidden from outside view, false corridors, and other strategic measures. Though their defensive function has been ably questioned (Topic and Topic 1997), the available evidence indicates the main purpose of these walls was to provide protection, while regulating traffic, to the interior of the fort.

Excavations at the rectangular building within the central platform revealed the intentional destruction of its walls, pillars, and religious images, the possible looting of objects, and its entombment under a thick layer of rock and debris. It was probably due to conflict, causing the forced abandonment of the site (Ghezzi 2006).

East of the Fortified Temple are Sectors 2 and 3, a large ceremonial area with buildings, plazas, storage facilities, and the Thirteen Towers, the main feature of Sector 2 (Fig. 5.5B). These are a row of thirteen constructions placed along the ridge of a low hill at the center of the site, whose summit is reached by inset staircases on their north and south sides (Fig. 5.6). Their groundplan varies from rectangular to rhomboidal. Their size (75–125 m^2) and height (2–6 m) vary widely: the northernmost towers are taller, apparently to compensate for the drop in elevation of the natural hill on which they rest. Nonetheless, they are regularly spaced: the gaps between the towers range from 4.7 to 5.1 m.

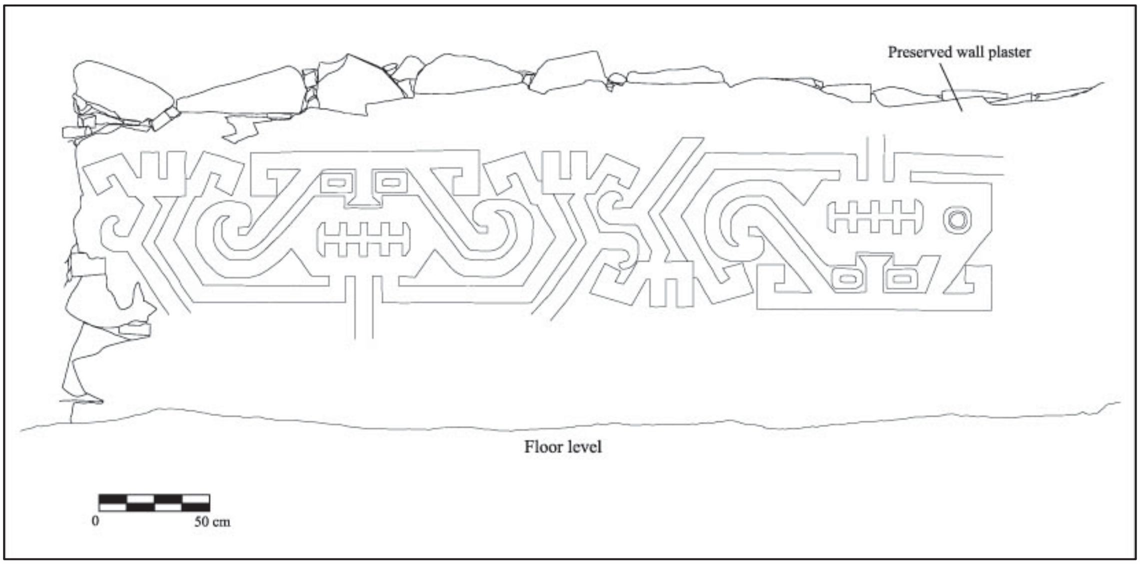

Fig. 5.4. Mural decoration in one of the rooms of the rectangular building within the fortified temple at Chankillo. © Iván Ghezzi

The towers were flat-topped, originally forming a smooth, "false" horizon as viewed from the lower ground to the west or east. No artifacts remain on the summits, yet the staircases strongly suggest that these surfaces were occupied at special times. The ascension to the summits may have been ritually important, yet since the staircases are narrow (1.3–1.5 m wide), and their length (1.3–5.2 m) and height (2–6 m) vary in proportion to tower dimensions, several of them are too steep to climb. The importance of the concept of duality has been amply discussed for the Central Andes, and its manifestation in the dual staircases at the towers, the layout of rooms within buildings, and the use of the double step-motif in sacred architectural elements and pottery vessels at Chankillo reflect the great symbolic importance of the Thirteen Towers.

The line of towers runs north-south, although towers 11–13 are twisted around towards the south-west (Fig 5.5B). In addition, Towers 11-12 cover the largest area. This may suggest that Tower 13 was intentionally "hidden" from some eastern viewing positions. Yet the azimuths of the gaps between the towers, which vary progressively, north to south, from approximately 90°–270° to 120°–300°, indicate that the purpose of the variations in the orientation of the tower axes was to orient the gaps between them towards a group of buildings within a walled enclosure to the west.

The best preserved of these buildings, known as the West Observatory, is 53.6 m long, 36 m wide, and has an outer corridor running 40 m along its south side (Fig. 5.5C). This corridor connected a restricted doorway on the southwest side of the building with a southeast opening that directly faced the Thirteen Towers 235 m away. However, the southeast doorway, unlike every other doorway at Chankillo, did not have the typical barholds, or niches where a stone pin was firmly tied into the masonry, presumably used to attach a door. In other words, it was a doorless opening. This corridor was a unique construction that ran alongside the building, but never led into it. Its purpose was to channel movement from its restricted gateway to its doorless opening directly facing the Thirteen Towers.

Sector 3 is a public area composed of a *plaza* surrounded by buildings, among them a complex of interconnected rooms, corridors, and patios, with associated facilities for the serving and storage of drinks directly southeast of the Thirteen Towers (Fig. 5.5). A small staircase on the eastern perimeter wall is apparently the single point of access to this building´s interior, and leads into a large *patio* surrounded by a U-shaped platform with inset staircases that distribute traffic towards the different rooms and courtyards. The pattern of circulation suggests a complex spatial organization. Towards the interior of the building, the rooms are reduced in size, but gain in elevation and wall height, and have a more restricted control of access. This building, the adjacent plaza, and other small buildings in Sector 3 were a setting for ceremonial feasts. In several places within the *plaza* were found offerings of panpipes and thorny oyster (*Spondylus*) shells. Middens near it contain the remains of serving vessels, panpipes, and maize.

The Thirteen Towers of Chankillo have been interpreted as horizon markers for astronomical observations (Ghezzi and Ruggles 2007). From several locations around Chankillo, the towers are the dominant feature in the horizon and could be used as solar horizon markers, but two buildings are of particular interest. From the doorless opening of the West Observatory, known as the west observing point, the spread of the towers along the horizon corresponds very closely to the range of movement of the rising and setting positions of the Sun over the year. This in itself argues strongly that the towers were used for solar observation. From this observing point, the southern slopes of Mucho Malo mountain, at a distance of 3 km, meet the nearer horizon (formed by the nearby hill on which the towers are constructed) just to the left of the northernmost tower (Tower 1), providing a 13th “gap” of similar width to those between each pair of adjacent towers down the line. During the June solstice, the sun rises in this position (Fig. 5.7); conversely, during the December solstice, it rises directly to the left of the southernmost tower (Tower 13).

In Sector 3, there is a small, isolated structure (Fig. 5.5D). Only the incomplete outline of a rectangular room, 6 m wide, is preserved. Its position in relation to the towers mirrors almost exactly the west observing point: the two lie on the same east-west line, have similar elevation, and are at the same distance from the Thirteen Towers. When viewed from inside this building, the spread of the towers forms an artificial horizon as well. Like the corridor leading to the western observing point on the opposite side of the towers, we hypothesize that this room contained an eastern observing point, though its exact position cannot be known, due to poor preservation, with the same certainty as that of the western observing point. From this eastern observing point, the southernmost tower (Tower 13) would not have been visible, and the top of Tower 12 would only just have been visible (it is only partially visible now due to its ruinous condition). From

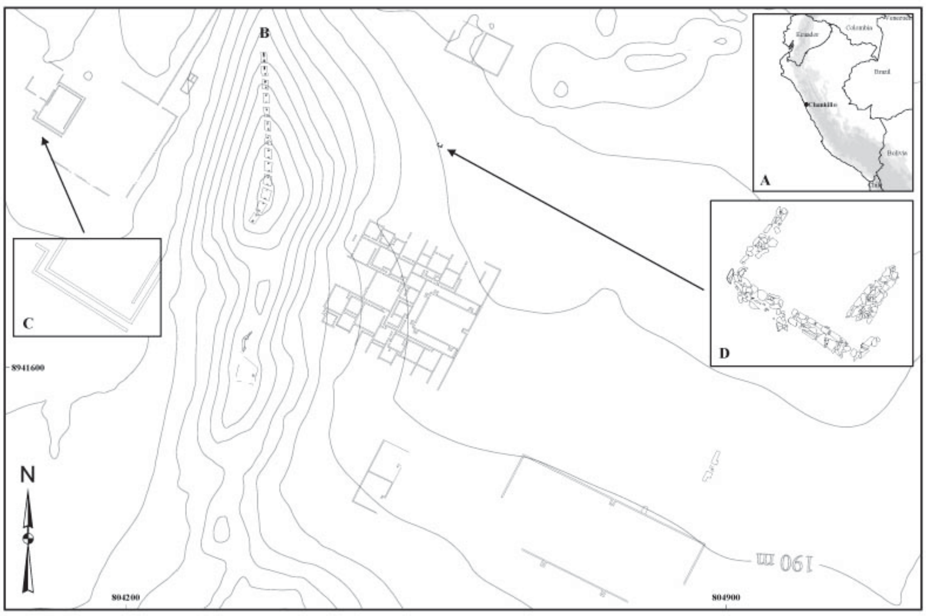

Fig. 5.5. Plan of the area in the vicinity of the thirteen towers. © Iván Ghezzi

Fig. 5.6. The thirteen towers as seen from the fortified temple. © Iván Ghezzi

Fig. 5.7. June solstice sunrise viewed from the western observing point. Photograph © Iván Ghezzi

here, the December solstice Sun set behind the left side of the southernmost visible tower (Tower 12), whereas the June solstice Sun sets directly to the right of the northernmost tower (Tower 1).

From each observing point, once the Sun had begun to move appreciably away from either of its extreme rising positions a few days after each solstice, the towers and gaps would have provided a means to track the progress of the Sun up and down this artificial horizon to within an accuracy of two or three days.

2.b History and development

Chankillo was occupied in 350-100 BC, during the late Early Horizon period of Peruvian prehistory. Research suggests it was devoted to regulating seasonal ritual events, such as religious festivals, solar worship, and the staging of ritual or real battles, maintaining a ceremonial calendar through solar observations.

To judge from the available evidence, the entire site was built and used within a relatively short period. A unique axis of orientation and the functional interconnections between sectors of the site suggest that its layout is the result of a master design. Preliminary dendrochronological research, though unable to provide calendar dates at present, indicates that all wooden lintels used in the construction of gates and doorways are contemporaneous. Radiocarbon date ranges, though broad for this period owing to calibration, does not differentiate at all between site sectors. Finally, excavations reveal that all buildings, save for one peripheral construction, were completed and in use by the time of Chankillo's abrupt abandonment.

No significant developments or modifications to the site are obvious from its surface, or from excavation. For example, there is no evidence that any of the lintels were ever replaced. Walls or floors were often repaired, but rooms were not remodeled, thus reinforcing the impression that Chankillo was occupied briefly, and not significantly modified in regard to its form, function, and use.

Excavations at the Fortified Temple clearly revealed the intentional destruction of its inner temple and religious images, the possible looting of objects, and its entombment under a thick layer of rock and debris. This attempt at erasing the temple from cultural memory was probably due to a violent conflict with an outside power, which ended in the defeat of Chankillo and an abrupt abandonment of the site (Ghezzi 2006).

There is some evidence of later occupations in the form of Early to Late Intermediate period temporary habitations and human burials. However, the significance of Chankillo may have persisted for a long time in the area, as suggested by numerous graffiti of warriors on the Fortified Temple walls, Late Intermediate period figurine offerings at the gates, and, most notably, an Inca 'fertility' offering recovered precisely from the tower clearly associated with the date of harvest festivals in prehistoric Peru (Fig. 5.8). Similarly, Early to Late Intermediate period cemeteries around the Thirteen Towers and the northern periphery of the site may have taken advantage of what was thought of as sacred ground long after its abandonment.

No mention of Chankillo has been found in colonial-era documents. The earliest references belong to the second half of the 19th century, when some of the most famous explorers and naturalists of the time published accounts and drawings of the site (Squier 1877; Raimondi 1874, 1909; Middendorf 1973). Julio C. Tello, who explored the site in the 1930s, led the first archaeological investigations (Tello 1956). Other scholars published additional reports, but Fung and Pimentel, who carried out a research and conservation project, offered the most comprehensive description of Chankillo to date (Collier 1962, Fung and Pimentel 1973; Kroeber 1944; Kosok 1965; Pozorski and Pozorski 1987; Roosevelt 1935; Thompson, 1962, 1974; Topic and Topic 1978, 1997; Wilson 1995).

Fig. 5.8 Inca 'fertility' offering recovered from Tower 1. © Iván Ghezzi

In 2008, by resolution RDN #075, January 15, 2008, Peru´s National Institute of Culture declared the "Chankillo Monumental Archaeological Zone" a national cultural heritage site, and approved a map that establishes its protected boundaries (Fig. 5.2). A buffer zone was not determined. Recent encroachment on the site, through agricultural, mining, and commercial activities, highlights the urgent need for a buffer zone, which is now under consideration by the Ministry of Culture.

3. Justification for inscription

3.c Comparative analysis

Monumental remains from pre-literate cultures can exhibit relationships to the sky in many different ways, but one of the most extensively investigated is where they incorporate structural alignments upon the horizon rising and setting points of celestial objects. A problem in assessing the significance of such alignments is to establish beyond reasonable doubt, in the absence of corroborating cultural evidence other than that available from the archaeological record itself, that such alignments were likely to have been intentional. There always exists the possibility that any oriented structure could align purely fortuitously upon an apparently significant rising or setting point.

Alignments upon the rising or setting positions of stars, while possibly commonplace in prehistory, can only rarely be demonstrated in the absence of corroborating historical evidence. This is because of the large number of bright stars in the sky and the fact that, owing to precession of the equinoxes, their rising and setting positions shift significantly over the centuries (there are further problems owing to atmospheric effects such as extinction: see Ruggles 1999: 52). This means that there is a high chance of being able to fit an astronomical explanation to any random direction by choosing a suitable star and a suitable date within the chronological range suggested by the archaeological evidence. A typical example is the discovery that an offering chamber in a temple complex at Buena Vista, Peru, is aligned so as to face the star Girtab (κ Sco), the 84th brightest star in the sky, on the basis of which the site has widely but very unwisely been reported in the media as "the oldest calendar in the New World". Claims to have dated sites astronomically based on stellar alignments are especially suspect, being usually based on dangerously circular arguments.

The rising and setting positions of the sun, moon and planets, while changing on a day-to-day basis, are not affected by precession, although they are subject to a much smaller systematic change on a timescale of millennia. Apart from this, the sun's motions are essentially straightforward (it swings steadily to and fro over an annual cycle between limits at the two solstices), the moon's are more complex (moonrise and moonset move up and down the horizon once each month, with the limits themselves varying over a cycle of 18.6 years), and those of the planets more complex still. Since simplicity in the motions of a heavenly body means that there are relatively few plausible "targets," it is primarily solar, and to a lesser extent lunar alignments, which can be established with the greatest confidence from the disposition of archaeological remains.

There are two ways of establishing the likely intentionality of a putative astronomical alignment: statistical and contextual (Ruggles 2000). The statistical argument is only applicable where there exists a group of similar monuments that can be shown to be consistently aligned, when paying due care and attention to the fair selection of evidence. Excellent examples exist from the Neolithic in western Europe, such as the 177 seven-stone antas of central Portugal and western Spain which are aligned without exception upon sunrise (Hoskin 2001: 95–100) and the 58 recumbent stone circles of eastern Scotland, which are consistently aligned in relation to the midsummer moon (Ruggles 1999: 91–99). No sites such as these are yet included on the World Heritage List, since no individual site in either group stands out as particularly significant, although they are candidates for serial nomination.

The contextual approach is more subjective but has two distinct advantages: 1) it can help identify 'one-off' instances of deliberate astronomical orientation; and 2) it can help to address questions of motive and meaning. Thus at the Neolithic passage grave at Newgrange in Ireland, part of the "Archaeological Ensemble of the Bend of the Boyne" World Heritage Site (#659), the presence of the famous 'roof-box' argues that the alignment of the passage upon winter solstice sunrise was intentional; and the fact that the primary purpose of the site was as a tomb argues that the solstitial alignment expressed some perceived connection between the sun and seasonal cycles and death and ancestors: this was clearly not an 'observatory' or calendrical device (Ruggles 1999: 12–19). On the other hand, the solstitial orientation of the Dacian fortress of Sarmizegetusa Regia in Romania, part of the "Dacian Fortresses of the Orastie Mountains" WHS (#906), was 'ideal' rather than practical. It assumes a flat rather than a mountainous horizon; if deliberate, it does not result from direct observations of sunrise but reflects the influence of geometrical concepts from Hellenistic Greece (Ruggles 2005: 370–372).

Unfortunately, at many sites where numerous putative solar and/or lunar alignments and alignments have been identified, providing the basis on which the site has been claimed to be an ancient astronomical 'observatory', it has not turned out to be possible to substantiate the evidence archaeologically or statistically. This includes Stonehenge in England, part of the Stonehenge, Avebury and Associated Sites WHS (#373) (Ruggles 1999: 35–41), where only the solstitial alignment of the main axis of the Phase 3 (stone) monument is securely established, being repeated at several similar contemporary monuments in the immediate vicinity (Ruggles 2007; see also Chapter 4).

At many sites around the world, including all of those above mentioned, their significance in relation to the sky is evident through a single astronomical alignment. In contrast, the Chankillo towers span (to within a couple of degrees) the entire solar rising and setting arcs as seen from two observing points, each clearly defined by a unique structure with no other apparent purpose. Thus we are not selecting putative astronomical targets from innumerable possibilities, but seeing direct indications of all four solstitial rising and setting points together with the means to observe and uniquely identify every other day in the year by observing sunrise or sunset against the intervening towers (Ghezzi and Ruggles 2007). The broad significance across cultures of the solstices as astronomical 'targets' is self-evident and widely attested. In this sense, Chankillo is unique, not just in Peru or in the Americas but in the entire world.

It is clear from a range of evidence at Chankillo that direct observations were made of the annual movement of the rising or setting sun along the horizon for the purposes of regulating seasonal events such as religious festivals, and very possibly for maintaining a seasonal calendar. In this sense, the site can truly be referred to as an 'observatory' despite the ethnocentric connotations this term has acquired in recent years. In this sense, it even stands out from the so-called Group E structures, one of the most significant sets of monuments in the Americas with regard to their relationship to the motions of the sun. These fifty structures in the Mayan heartlands of the Petén, Guatemala, are named from their similarity to the structure known as Group E at the city of Uaxactun, which incorporates architectural alignments upon both solstices and the equinoxes, and has become renowned as a solar observatory. However, the remaining Group E structures, although broadly contemporaneous and similar in form, do not generally exhibit the same precise alignments as at Uaxactun. Furthermore, the Uaxactun structure was itself modified later, which had the effect of rendering it useless for precise observations. A possible interpretation is that, while some of the Group E structures incorporated functional solar alignments, others were 'non-functioning' replicas whose importance—even in so far as this related to calendrical rituals and ceremonials—did not need to be reinforced by actual observations of the sun.

3.d Integrity and/or authenticity

Integrity

Chankillo was a ritual complex devoted to a solar cult, by means of a ceremonial calendar structured through precise astronomical observation of the alignments between the Thirteen Towers and observing points. The comprehensive research carried out at the site testifies to its integrity, specifically the constructions that make up the fabric on which these exceptional values rest.

The Thirteen Towers are a row of cubic constructions along the ridge of a hill at the center of the site (Figs. 5.5B and 5.6). Their purpose was to be used as horizon markers, providing multiple alignment positions when viewed from the observing points. Survey and excavations show that many walls have collapsed partially, yet enough is preserved to estimate each tower's dimensions. They are subject to deterioration from unregulated visits, wind erosion, and occasional seismic activity.

The West Observatory contains a special-purpose corridor that channeled traffic to a doorless opening directly facing the towers. From this observing point, the spread of the towers along the horizon corresponds very closely to the range of movement of the rising positions of the Sun over the year. The condition of this building is relatively good. It is almost completely covered by sand. The excavations show that although all walls have lost their upper section, the rubble rests at a stable angle, and the wall plaster is exceptionally preserved, retaining its original pigment.

East of the Thirteen Towers, a small, isolated structure has been interpreted as the east observing point. Its position in relation to the towers mirrors almost exactly the west observing point: the two lie on the same east-west line, have similar elevation, and are at the same distance from the towers. When viewed from inside this building, the spread of the towers forms an artificial horizon as well, and their spread also matches closely the annual range of movement of the setting positions of the Sun. Nevertheless, only the incomplete outline of a rectangular room, is preserved, possibly due to stone robbing for nearby constructions of a later period.

Further research is needed to characterize the nature of occupations at Chankillo to the east and north of the Thirteen Towers, and assess their integrity. Similarly, more studies are required to define the extent to which the horizon visible to the east from the Fortified Temple and the Thirteen Towers contained natural features that could also be exploited for astronomical purposes (Ghezzi & Ruggles 2011). This proposed cultural landscape is outside of the current protection zone, and its extent remains to be defined.

Authenticity

The archaeological evidence affirms the authenticity of the solar observation installation at Chankillo (Ghezzi & Ruggles 2007). We find direct indications of the solstitial rising and setting points, together with the means to observe and uniquely identify the time of the year with a precision of 2-3 days, by observing sunrises/sunsets against the towers.

No conservation or restoration has been attempted to date on the features bearing the universal value of this site. In the 1960s, archaeologist Rosa Fung and conservator Victor Pimentel drafted plans for a conservation and restoration project at the Fortified Temple. Currently, the Chankillo project, with support from international, national and regional sponsors, is preparing a conservation intervention of the entire site, including the most outstanding features, such as the Thirteen Towers and its observing points.

3.a Potential criteria under which inscription might be proposed

Criterion (i): The Chankillo solar observation device is a masterful example of *landscape timekeeping*, a practice of ancient civilizations worldwide that used visible natural or cultural features. At Chankillo, we find direct indications of all four solstitial rising and setting points, together with means to observe and uniquely identify the time of year, with a precision of 2-3 days, by observing sunrises or sunsets against the intervening towers. In this sense, the astronomical facilities at this site represent a masterpiece of human creative genius.

Criterion (iii): Ancient Andean peoples often structured their actions within a particular view and understanding of the landscape, including the sky. The solar observation device at Chankillo reveals a great deal about the ways in which, in this part of the world—people before the advent of written records—perceived, understood, and attempted to order and control the world they inhabited through astronomy. Therefore, Chankillo and its astronomical installations bear unique and exceptional testimony to a cultural tradition that has disappeared.

3.b Suggested statement of outstanding universal value

The solar observation facility at Chankillo is the earliest example known to date in the Americas of a monument devoted to an astronomical function (Ghezzi and Ruggles 2007). The carefully chosen location (in a place of exceptional natural beauty, with an appropriately low natural horizon for sky observation), the construction of an artificial horizon, and the precise design of the observing points and markers constitute an extraordinary example of the cultural transformation of a natural landscape, and of the vital role of astronomical knowledge within ancient civilizations.

At this site we find direct indications of all solstitial rising and setting points, together with the means to observe and uniquely identify the time of year, to a precision of 2-3 days, by observing sunrises or sunsets against the Thirteen Towers. This is an example of *landscape timekeeping*, a practice of ancient civilizations that used visible natural or cultural features to keep track of the cyclical passage of celestial bodies, and represents a masterpiece of human creative genius.

The Chankillo solar observation device represents an early developmental stage of native astronomy in the Americas (Aveni 2008). In this part of the world, there is a long-standing relationship between humanity and the sky. Ancient Andean peoples, like other ancient civilizations, often structured their actions within a particular view and understanding of the landscape, including the sky. Chankillo reveals a great deal about the ways in which people, before the advent of written records, perceived, understood, and attempted to order and control the world they inhabited through astronomy.

Like many other ancient civilizations, Andean peoples imprinted their particular worldview onto their sacred buildings. At Chankillo, they incorporated specific features for astronomical observation and timekeeping. Thus, in the category of architectural monuments incorporating astronomical functions (see *Comparative Analysis*), Chankillo is unique and exceptional, bearing testimony to a cultural tradition that has disappeared.

4. Factors affecting the property

4.a Present state of conservation

Chankillo, although relatively shielded from threats of cultural origin, is exposed without any control to the damaging action of winds, daily thermal variation, seasonal humidity, earthquakes, and uncontrolled visits. Aeolian erosion causes a severe loss of wall mortar, weakening its stone masonry and causing a gradual fall from wall tops, the appearance of cracks, sometimes running all the way down, and, thus, gradual collapse. The structural instabilities caused by these physical-mechanical flaws increase the risk of collapse due to earthquakes, a common event in Peru.

The general neglect suffered by the site causes greater exposure to the above-mentioned threats, and a significant increase in their rate of action, compounded with the effects of unsupervised tourism, which is growing slowly but steadily.

A total site condition survey is under way. Coupled with increased stakeholder interest, this baseline study will offer a chance to reverse Chankillo´s deterioration. It will require planning, infrastructure, management, and education for local populations. Presently there are no issues of competing research interests, or accessibility. However, as the significance of the site becomes more widely known, development pressures on Chankillo´s buffer zone are mounting.

5. Protection and management

5.a Ownership

The Peruvian government is the sole owner of archaeological sites in Peru. Its “Law on National Cultural Patrimony” (www.bnp.gob.pe/portalbnp/pdf/ley28296.pdf) charges branches of the government, headed by the recently created Ministry of Culture, with the protection and management of these sites, such as Chankillo.

5.b Protective designation

By resolution RDN #075, January 15, 2008, the National Institute of Culture of Peru declared the “Chankillo Monumental Archaeological Zone” a national cultural heritage site, and approved a map that establishes its boundaries (Fig. 5.2). For full protection under Peruvian cultural heritage laws, this map must be registered with SUNARP, Peru´s official agency for public records. However, the Ministry of Culture of Peru has a very poor record of officially inscribing archaeological site boundaries.

5.c Means of implementing protective measures

The Ministry of Culture of Peru is charged with the protection and management of all archaeological sites. Unfortunately, it is severely underfunded and generally can only react to imminent threats to the best-known sites. The local Casma province office does not have the resources to monitor Chankillo, or any of the major sites in the area. However, recent administrative changes will place regional cultural authority within the regional government of Ancash, which has one of the largest revenues in the country.

The Chankillo Project, through a partnership with the World Monuments Fund, receives expertise and funding from national and international sources. However, local matching is always required to get any activities approved, and this is a great challenge in Peru. At this initial stage in the project, no permanent structure or staff is in place for conservation or management efforts, much less to open the site to visitors, but these are valued goals of the project.

The Chankillo project’s site investigation and conservation have led to its being considered by the Ministry of Culture for inclusion in Peru´s WHS tentative list. As such, it would be afforded the highest level of protection and management from the office in charge of world heritage sites in the country. Even if the site were not included in the tentative list promptly, it is likely that the regional culture office will assume the responsibility for its protection.

5.d Existing Plans

Besides global plans from the Ministry of Culture to protect archaeological sites, if Chankillo is included in Peru´s WHS tentative list, it will be afforded a specific level of protection and management from the ministry´s office in charge of such sites. On the other hand, the Chankillo project plans to carry out in coming years the conservation and restoration interventions necessary to preserve the site and prepare it for tourism.

5.e Property Management Plan

There is no property management system yet. However, as the most valued goal of the Chankillo project, its development will begin in late 2012, under an agreement with the Ministry of Culture. In the near term, the Chankillo project and its sponsors provide all the human and financial resources necessary to develop the plan and begin its implementation. Meanwhile, an agreement with the regional government of Ancash, in progress, seeks to secure long term funding for the management system.

5.f Sources and levels of finance

The Chankillo Project, through a partnership with the World Monuments Fund, receives funding from national and international sources. WMF has set up a special fund for the project. However, local matching is required to get any activities approved, and this is a great challenge in Peru.

Private sector support has been essential to carry out the required site condition survey. In regards to the public sector, the regional government of Ancash and the national government of Peru are in the early stages of providing funding for the public presentation and conservation of Chankillo.

5.g Sources of expertise and training

The World Monuments Fund is the main technical partner for the Chankillo project, providing when necessary expertise, local and international consultants, and training, in all aspects of research and conservation activities.

6. Monitoring

6.a Key indicators for measuring state of conservation

A condition survey of Chankillo, including low-altitude aerial photography with kite and balloon, photogrammetry, laser scanning at 5-10 mm resolution, High Dynamic Range photography, and conservation annotations on forms and orthophotos, covering every single standing architectural element at the site, was completed in 2010-12 by the Chankillo project. Such a comprehensive study is the baseline for adequately planning upcoming conservation interventions, as well as monitoring this site´s current and future state of conservation. A key indicator is the 3D point cloud of all structures obtained through 3D laser scanning, surveyed with a permanent control network. In the future, laser scans could be accurately repeated to monitor changes.

7. Documentation

7.a Photos and other AV materials

The World Monuments Fund has acquired the reproduction rights to a collection of photographs from 1967-8 by Peruvian conservator Victor Pimentel. As part of the condition survey carried out at the site, the Chankillo project obtained high-resolution satellite imagery and low-altitude aerial photographs, scanned the site in 3D, carried out a High Dynamic Range photographic survey, and documented excavation/conservation activities with high-resolution photographs. This documentation will be made available through publications and web sites of the cooperating institutions (see 7.d).

7.b Texts relating to protective designation

Peru´s general law of national cultural heritage grants the state the exclusive property of all archaeological sites. The recently created Ministry of Culture is charged with their protection and management, which includes officially declaring properties as cultural heritage. By resolution RDN #075, January 15, 2008, the National Institute of Culture declared the “Chankillo Monumental Archaeological Zone” a cultural heritage site and approved the official map that establishes its boundaries. Nevertheless, for full protection under Peruvian cultural heritage regulations, this map must be inscribed with SUNARP, Peru´s official agency for public records. There are no regulations at the regional or local government level that protect specifically cultural heritage in the area where Chankillo is located.

7.c Most recent records or inventory

The Chankillo project carried out a condition survey in 2010-2, which included: review of high-resolution satellite images and government aerial photographs and maps; low-altitude aerial photography survey with kites and balloons; High Dynamic Range photographic study; 3D laser-scanning at 5-10 mm resolution; total station survey at 3" angular precision; and excavations, thoroughly documented in photographs, drawings, forms, and 3D models. Photogrammetric processing of aerial/hand-held photographs, as well as 3D laser scanning, have yielded point clouds and 3D models covering all the architecture at the site. These were used to create orthophotos of every single standing architectural element at the site. The orthophotos were used as base maps for detailed conservation annotations, in combination with varied recording forms, sketches, photos, etc. All of these data were analyzed in a geographical information system environment to produce a Condition Survey Report covering 100% of the site.

7.d Agencies holding inventory records

Instituto de Investigaciones Arqueologicas (www.idarq.org), World Monuments Fund (www.wmf.org), and Ministerio de Cultura del Peru (www.mcultura.gob.pe).

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Astronomical timing of irrigation in Oman

Harriet Nash

1. Identification of the property

1.a Country/State Party: Sultanate of Oman

1.b State/Province/Region: Northern Oman

1.c Name: Various settlements, as identified in Table 6.1 below.

1.d Location: The area of Northern Oman containing *falaj* irrigation systems extends from 55° 30′ E to 59° 55′ E and from 22° 0′ N to 25° 0′ N.

1.e Maps and plans

Fig. 6.1 shows the rough outline of the area in which the sun and stars were (and in some cases still are) used for timing irrigation water. This includes the five areas listed in the nomination file for the *Aflāj* Irrigation Systems of Oman World Heritage Property (whc.unesco.org/en/list/1207). Villages where detailed information has been collected and stars used identified are shown in Fig. 6.2.

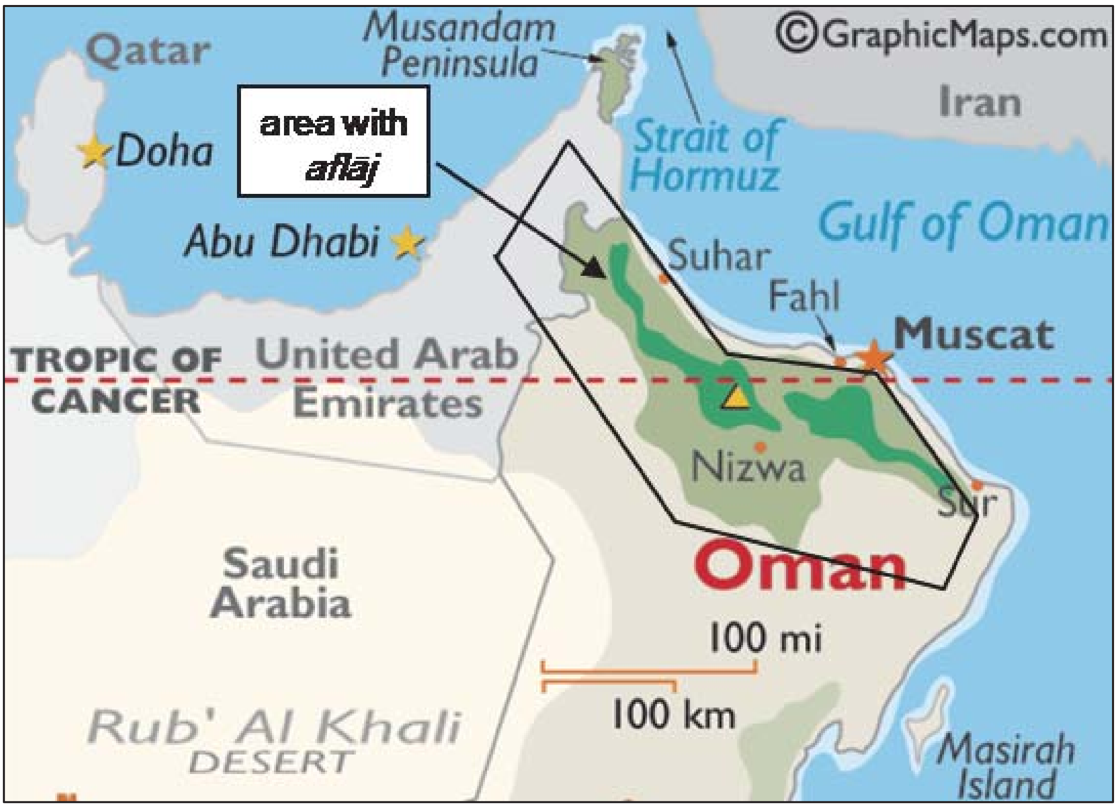


Fig. 6.1. Area of Oman with *aflāj*. Base map from www.worldatlas.com. Reproduced by permission

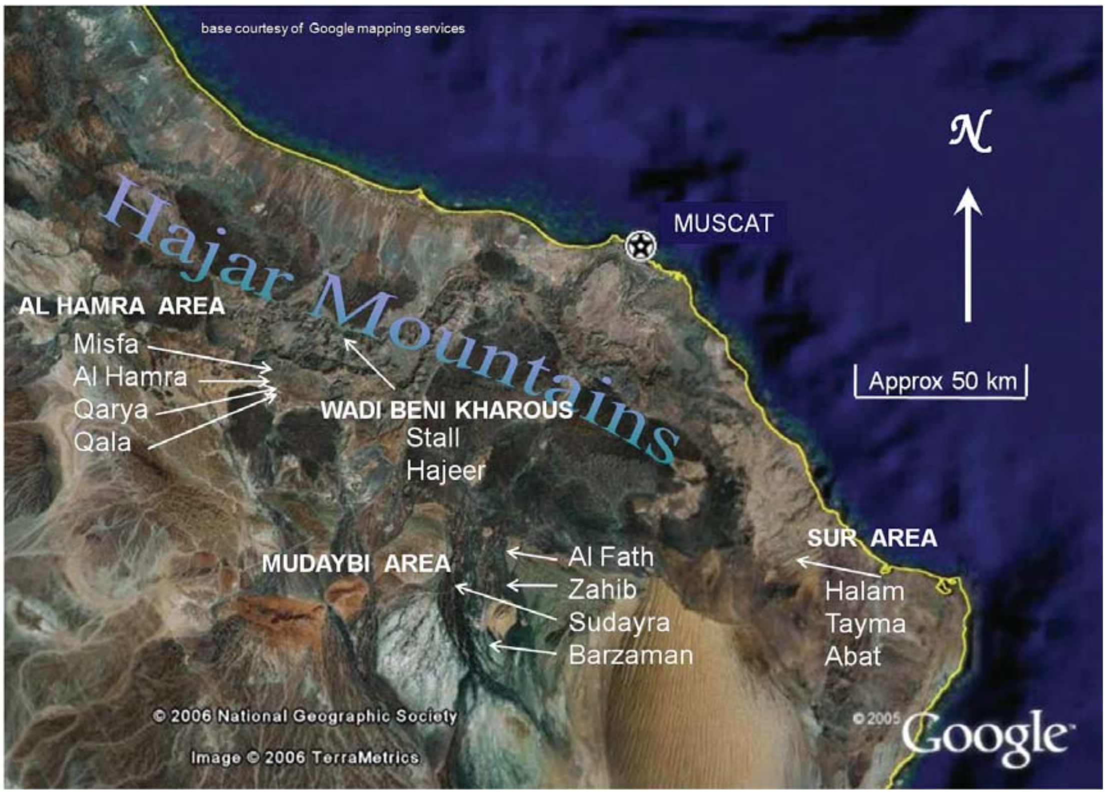


Fig. 6.2. Settlements where the current and past use of stars for timing irrigation water has been studied.

2. Description

2.a Description of the property

The core intangible heritage is a practice (or, rather, a set of practices) of using the sun or stars to tell the time for the division of water shares from traditional irrigation systems called *aflāj* (the singular is *falaj*).

The property comprises material attributes linked to these practices. Such material can be classified into three main types:

1. *Sundials*. These generally comprise a vertical pole and lines on the ground demarcating time intervals defined by the movement of the shadow of the tip of the pole.
2. *Foresights for stellar observations*. These may be natural (e.g. a marker on the horizon) or man-made (e.g. a mosque wall) against which the appearance or disappearance of a star can be timed as seen from a fixed observing point.
3. *Observing points for watching stars*. These may be marked or unmarked, although the latter are culturally acknowledged as part of the astronomical timing 'system'. Marked observing points are generally used in conjunction with man-made foresights. In the Mudaybi area (Zahib and Al Fath), indicator stars are watched from marks on walls, rising or setting above/below a horizontal marker, often the top of a wall.

The property includes:

1. The whole area with *falaj* irrigation systems. Most of these would have used the sun and stars for timing water shares, the exceptions being a few in the mountains that used the water clock.

2. Individual villages known to be using the sun and stars in, say, 2007.

3. Individual villages where details of star use have been collected.

For (2) and (3), see the location maps and Table 6.1. In all the settlements listed in the Table, the great majority of stars used or formerly used have been identified. In each case, the use of the sundial either continues or stopped at the same time as the use of stars. In many other villages in Oman, the sundial is still used even though people stopped using stars around 1970.

Table 6.1. Settlements where the use of stars in timing water shares has been documented in detail.

Area	Settlement	Stars	Sun	Method
Al Hamra	Al Hamra	Stopped c. 1968	Stopped c. 1968	Natural horizon, rising
	Misfat-Al-Abryeen	Stopped c. 1970	Stopped c. 1970	Natural horizon, rising
	Qarya Beni Subh	In use	In use	Natural horizon, rising
Mudaybi	Barzaman	In use	In use	Local horizon (wall), rising
	Sudayra	Stopped c. 1970	In use	Local horizon (tops of trees), rising
	Zahib	In use	In use	Complex markers + buildings
	Al Fath	Stopped 2011	Stopped 2011	Complex markers + buildings
Wadi Beni Kharus	Stal	In use by a few	In use	Natural horizon, rising
	Hajeer	In use by a few	In use	Natural horizon, rising
Sur	Halam	In use	In use	Natural horizon, setting
	Tayma	In use	In use	Natural horizon, setting
	Abat	In use	In use	Natural horizon, setting

Examples follow from a selection of those villages studied in some detail. There are many more with sundials.

Qarya Beni Subh

Sundial comprising:

- Pole, lines, metal studs, stones or other items used as personal markers, tree for shade (see Fig. 6.3).

Stars:

- Foresight: natural horizon to east (see Fig. 6.4).
- Observing points: 3 official observing points.

Between the main *falaj* stars Vega (α Lyr) and Deneb (α Cyg), there are three *athar*s with four official dividers (i.e. stars named as dividers) and one unofficial divider, none of which coincides with the *athar* divisions. It is not known why these particular stars were selected: possibly there are no alternative easily recognised stars visible from the observation point; possibly the selection was based on actual divisions of water ownership, which may not coincide with *athar* divisions. This serves to illustrate just how many stars must be known and that the system will only survive as long as the official stargazer remains to resolve any disputes among farmers.

Fig. 6.3. The sundial in Qarya Beni Subh. Photograph: Harriet Nash

Fig. 6.4. Horizon for watching stars in Qarya Beni Subh from one of the three official observing locations. Photograph: Harriet Nash

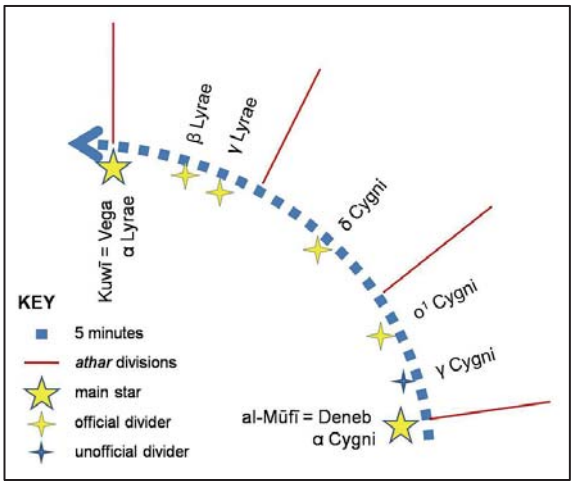


Fig. 6.5. Example of divisions of water share by *athar* and stars in Qarya Beni Subh. Drawing: Harriet Nash

Fig. 6.6. The sundial in Barzaman. Photograph: Harriet Nash

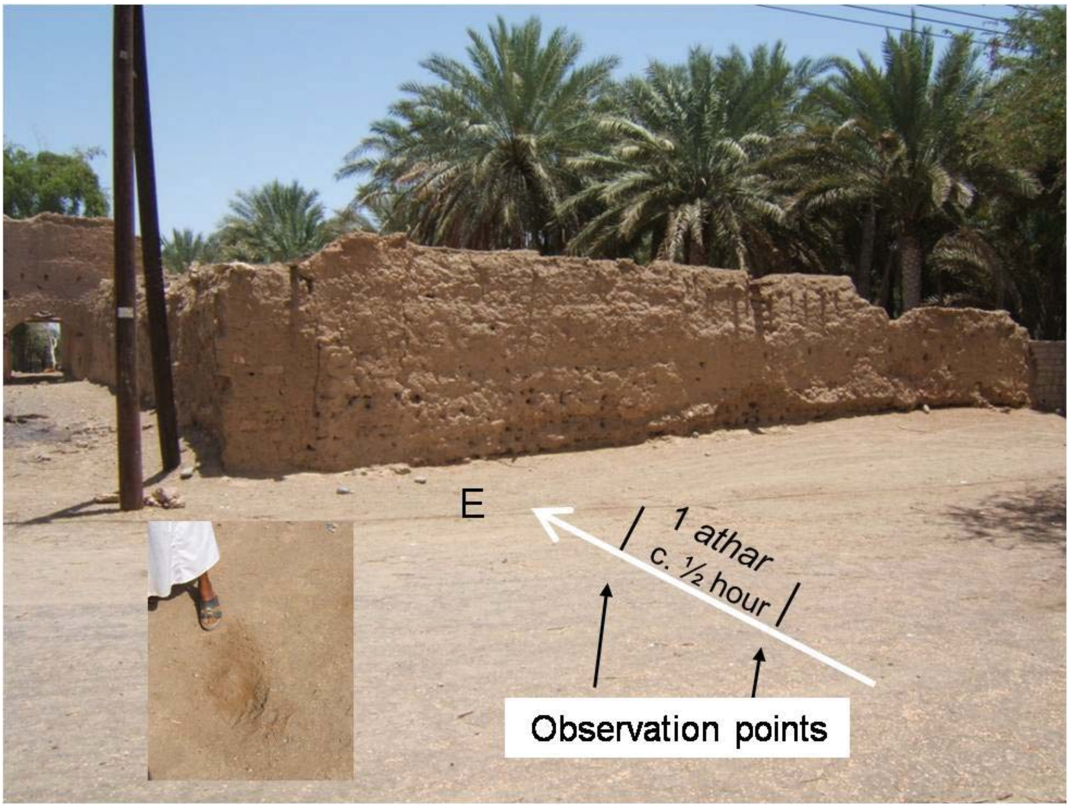


Fig. 6.7. Wall for watching stars in Barzaman. **Inset:** A stone marking an observation point. Photographs and annotations: Harriet Nash

Barzaman

Sundial comprising:

- Pole, lines scored in ground, walls of adjacent buildings, personal markers (see Fig. 6.6).

Stars:

- Foresight: 2 walls (one used before c. 1970 and that used now). For the latter (see Fig. 6.7):
- Observing points: stones in ground; Steps of mosque to wait one's turn.

Zahib

Sundial comprising:

- Pole, lines scored in concrete, shelter from sun, stones as personal markers (see Fig. 6.8).

Stars:

- Foresights: tops of walls, wooden post attached to wall.
- Observing points: numerous marks on walls (see Fig. 6.9).

Fig. 6.8. The sundial in Zahib. Photograph: Harriet Nash

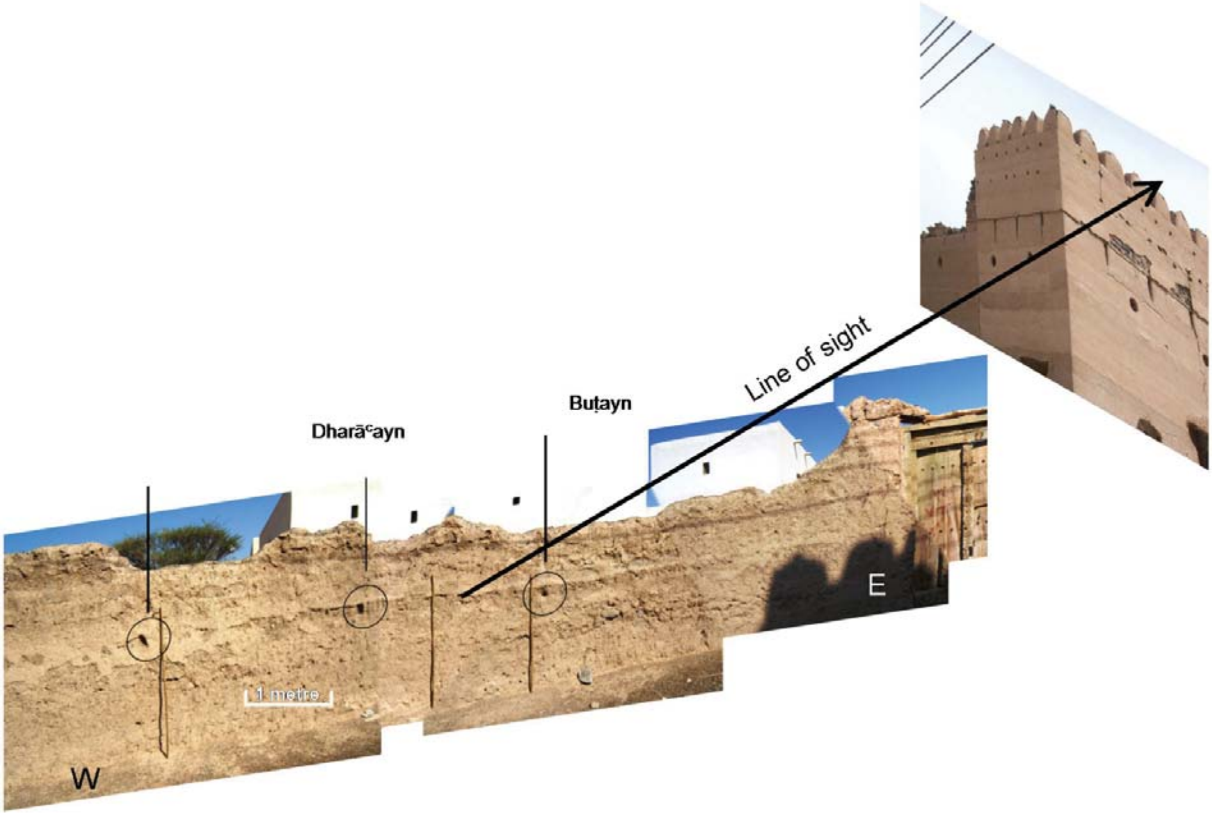


Fig. 6.9. Example of star observing point and foresights in Zahib. Photographs and annotations: Harriet Nash

Fig. 6.10. The sundial in Al Fath. Photograph: Harriet Nash

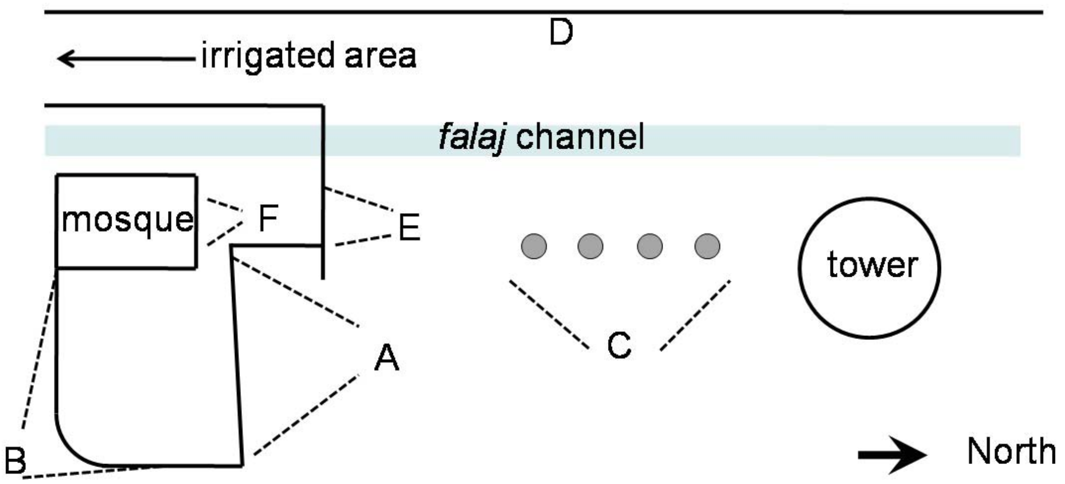


Fig. 6.11. Layout of star "clock" in Al Fath. A–F are observing points. Drawing: Harriet Nash

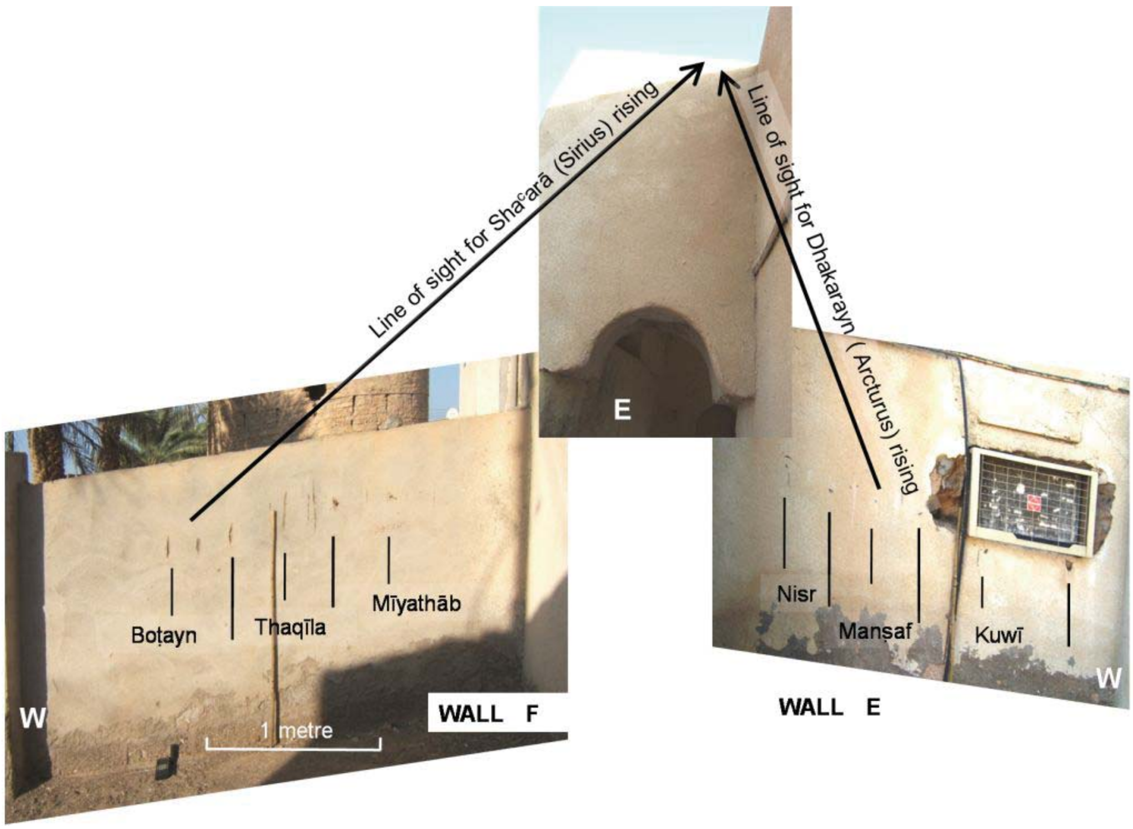


Fig. 6.12. Example of observing points and foresights in Al Fath. The names of stars between marks on the wall relate to the main *falaj* stars rising above the horizon when observing Sirius or Arcturus. Photographs and annotations: Harriet Nash

Al Fath

Sundial comprising:

- Pole, lines scored in ground, personal markers (see Fig. 6.10).

Stars:

- Foresights: tops of walls (mosque buildings and a tower).
- Observing points: numerous marks on walls; stones on ground (see Figs 6.11 and 6.12).

There are also portable artefacts relating to this practice, notably the use of a conch shell to inform farmers at a distance from a sundial that the time has come to take their water. This has been attested at two villages, Tayma and Abaat (see Fig. 6.13) near the town of Sur, in the east of the region.

Fig. 6.13. The sundial in Abaat, with use of conch shell. Photographs: Harriet Nash

Other sundials

Fig. 6.14. Part of the "sundial" in Halam, where natural features of the landscape are used. Photograph: Harriet Nash

Fig. 6.15. Studious use of personal markers (date palm fronds) at a sundial in the town of Adam (approx. 60km west of Barzaman). Photograph: Harriet Nash

Other observing points for watching stars

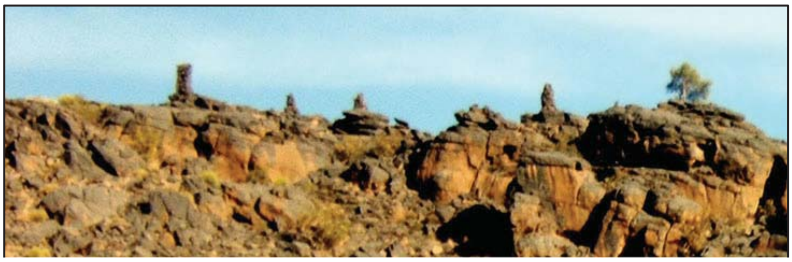


Fig. 6.16. Horizon formerly used for watching stars in Misfat-Al-Abryeen. Towers were built as foresights for some of the main stars, apparently to assist people with poor eyesight. Photograph: Harriet Nash

2.b History and development

The practice of using the sun and stars for timing water shares was once widespread in semi-arid and arid areas of the Middle East and Central Asia—the heartland of *falaj* development. The history of *falaj* development is relatively well documented: they date from at least 1000 BC (e.g. al-Tikriti 2002), before Oman was controlled by the Persian Achaemenids (c. 6th century BC).

The use of sun and stars is not so well documented, but it is possible that it goes back as long as the *falaj* systems in communities where divisions of shares less than about 6 hours each was needed. Their use in Iran has been documented (Nash et al. 2012), and it is likely that they were used in Afghanistan and elsewhere in the region. In Iran, their use stopped in about 1960. In Oman, many communities also stopped using them when wristwatches became widely available in the late 1960s-early 1970s. However, the sun is still widely used and in a few places, where the community prefers to continue with tradition and where light and dust pollution are not too severe, the use of stars also continues.

Many of the star names are pre-Islamic, and the practitioners have no knowledge of the stellar Stations of the Moon.

3.Justification for inscription

3.d Integrity and/or authenticity

Authenticity

The authenticity of the astronomical timing system is demonstrated by:

1. *Use and function*. The practice of timing water shares by astronomical means is untouched by modern influences outside the community. The use and function is dependent on the *falaj* irrigation systems, which have not changed in thousands of years.
2. *Traditions, techniques and management systems.* The tradition has been passed down from generation to generation. There may have been historical changes in the form of the sundials and in the particular stars used and the method of watching them, but there have been practically no changes due to outside influences in modern times. This is demonstrated by the lack of knowledge in one settlement of the method, stars and star names used in nearby villages.
3. *Location and setting*. The practice was limited to the heartland of *falaj*/*qanat* development and use. Since the ready availability of wristwatches, it has become confined to Oman.
4. *Language*. In Oman, the letter *jeem* is almost invariably pronounced as a hard ‘g’. However, the star gazers use a soft *jeem* for the word *najam* for star, and for some star names. This indicates that some aspects of this practice could have originated outside Oman.

5. *Spirit and feeling*. Villagers' strong sense of tradition ensures that the continued use of these practices results in the fair distribution of water and the avoidance of disputes. Over the generations they have contributed to the cohesion of the community and Omanis consider the *falaj* systems as a whole to be an important part of their national identity.

Integrity

Since these practices are handed down orally, the documents describing them are mainly based on interviews with village elders and farmers and first-hand observation by ethnographers, mostly during the last ten years. One written document has been found describing the star system used in the town of Al Hamra, on the southern edge of the Jebel Akhdar mountains; another document is an illustration of the star cycle in the town of Mudayrib. See Nash and Agius (2011).

3.a Potential criteria under which inscription might be proposed

Criterion (iii): The material evidence relating to the astronomical timing of irrigation in Oman bears testimony to a unique cultural tradition part of which (mainly to do with sun observations) is still living but the remainder of which (including nearly all the practices relating to star observations) has disappeared.

Other criteria. Five *falaj* systems were inscribed in 2006 under criterion (v) (whc.unesco.org/en/list/1207/) and the ICOMOS evaluation (see p.51 in the nomination file) recognises that criteria (ii) and (iv) might also be justified on the basis of further information.

3.b Suggested statement of outstanding universal value

The use of observations of stars for timing shares of irrigation water in Oman bears outstanding testimony to the way in which observations and understanding of the celestial bodies can help human communities adapt to and survive in harsh environments. This practice demonstrates a direct cultural connection between subsistence economy and the dark night sky that may well be unique in surviving almost to the present day, and is still not quite extinct. Related practices of solar observation that apply the same astronomical system of time apportionment during daylight hours continue in a number of communities, perhaps as many as a hundred. By continuing uninterrupted for hundreds, if not thousands, of years, the system in Oman has become perhaps the only surviving example of practices relating astronomical timing to subsistence economy that in all probability were once widespread.

4. Factors affecting the property

4.a Present state of conservation

There are conservation issues relating both to the intangible practice itself and to the material associations (human constructions and natural landscape) used in a few places:

- The use of stars is almost extinct and is unlikely to last more than a decade or so. As the older generation dies, and younger people are not willing to learn the system thoroughly, there will be no one to check correct usage and people will change to using watches. In addition, the continued erosion of dark skies by light pollution is making it increasingly difficult to undertake the necessary stellar observations.
- The buildings comprising the star clock in Al Fath are still in good condition.
- In Zahib the buildings are still used, and in fair condition, but one wall, belonging to a private individual, was rebuilt a few years ago and the markers were not replaced. Watches are now used during the 1–1.5 hours that the wall represented.

- In Barzaman, the wall used (see Fig. 6.7) is in a fair state of repair. While stars are still used, this is unlikely to continue for very long.
- Where sundials are still in use, they are well maintained.

4.b.i Developmental pressures

The oral tradition is dying out because young people are generally not prepared to continue this, in the face of the availability of formal education and job opportunities outside the village.

In Al Fath, stargazing (and the use of the sundial) stopped in about 2011, when the person with most knowledge of the star timing system died, even though up to that time every farmer had used the stars. It is unlikely that any special efforts are being made to maintain the star clock. This means that some features, such as stone markers on the ground are likely to be lost quickly. Marks on the mosque walls may be lost if the mosque is repaired at some point.

4.b.ii Environmental pressures

Light pollution is one reason that many communities stopped using stars. The continued erosion of dark skies by light pollution means that this situation is likely to get worse.

Dust pollution and cloudy skies from changing climate are also factors that may get worse.

4.b.iv Visitor/tourism pressures

Non-existent. Some pressure from this quarter could actually be helpful in limiting the potential for destruction of buildings used for stargazing.

5. Protection and management

5.a Ownership

The *falaj* system as a whole is owned by the community. The buildings used for observing points and foresights are generally in individual ownership, with the exception of public buildings such as mosques. However, the sundials and related artefacts, and some artificial foresights, are owned by the community.

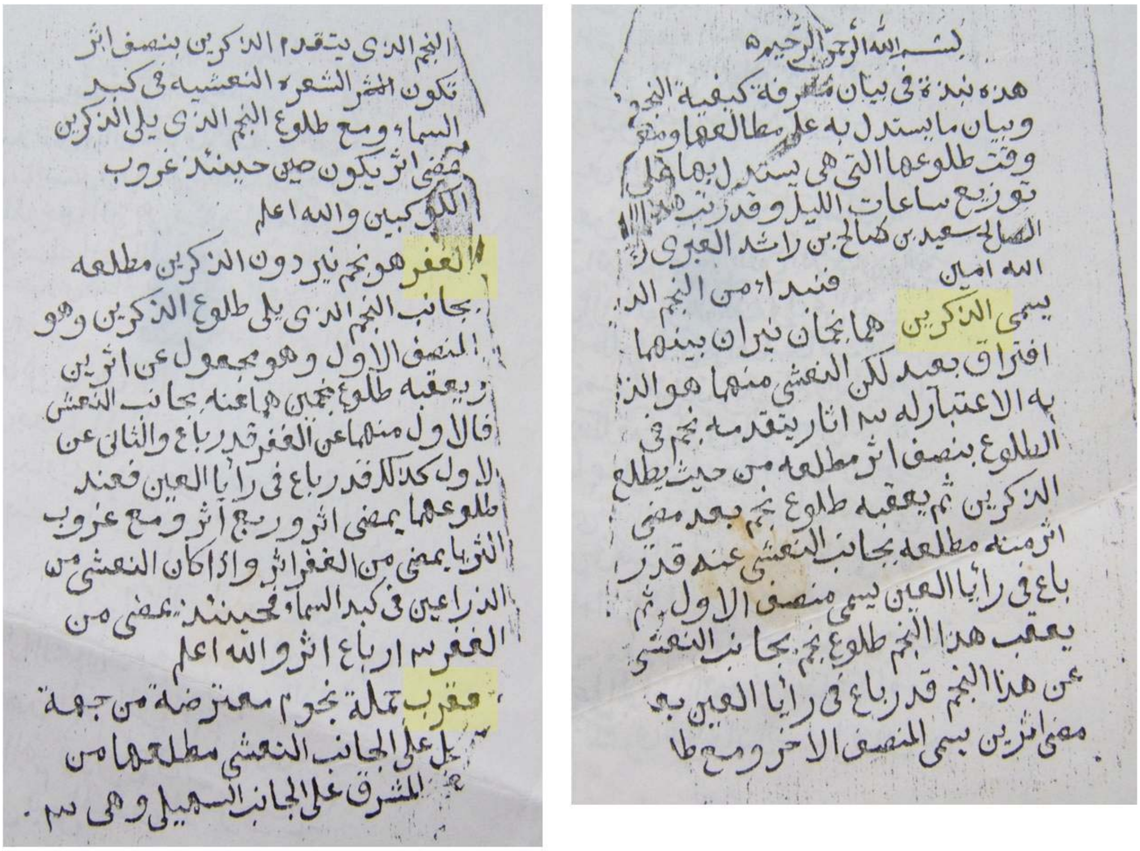
Ownership of the star timing system and knowledge rests with the individuals/communities applying the system.

5.b Protective designation

It is understood that all mud-brick buildings in Oman are protected by law implemented by the Ministry of Heritage and Culture. However, implementation of the law appears to be ineffective.

5.c Means of implementing protective measures

While timing water shares by astronomical means cannot be continued beyond the point that the community wishes without becoming an artificial enterprise, the knowledge and detail can be preserved by recording and publishing it, and the structures and buildings, together with the details of how they were used, could be protected and preserved for future generations. This would need to be linked with preservation policies for the World Heritage Site already inscribed. The protection of traditional buildings is likely to be ineffective unless there is explicit agreement from the community.



Originator: Sheikh Sa^{c}īd b. Sāleh al-^{c}Abrī d. 1921
Copyist: Muḥammad b. ^{c}Āmar al-^{c}Abrī c. 1941

Fig. 6.17. A manuscript from Al Hamra. Names of main stars are highlighted. Author Skeikh Said bin Saleh Al-Abri (d. 1921); copyist Muhammed bin Amar Al-Abri c. 1947. Reproduced by permission.

7. Documentation

7.c Most recent records or inventory

The tradition of astronomical timing of *falaj* water in Oman is oral: the knowledge is handed down from generation to generation. One example of a book describing the *falaj* systems, which includes a general description of the use of sun and stars, is al-^{c}Abrī (c. 1980). However, the prime source of information is the communities themselves. A few villagers and researchers have written down lists of the stars used and the number of days each "main" star is the first to rise, and these are collated in Nash (2011: 97–98). There is little documentation related to the use of the sun and stars. Two rare examples related to stars are shown below (Figs 6.17 and 6.18).

7e. Bibliography

Information was collected from the communities in the settlements listed in Table 1, including the stars used and their identifications, by Harriet Nash in the period 2005–2011. That on the Al Hamra and Mudaybi areas has been published (Nash 2011), as has that from Wadi Beni Kharus (al-Ghafri et al. 2013). That from the area near Sur has yet to be published. A summary of methods of watching the stars and their names and identifications is given in Nash and Agius (2011).

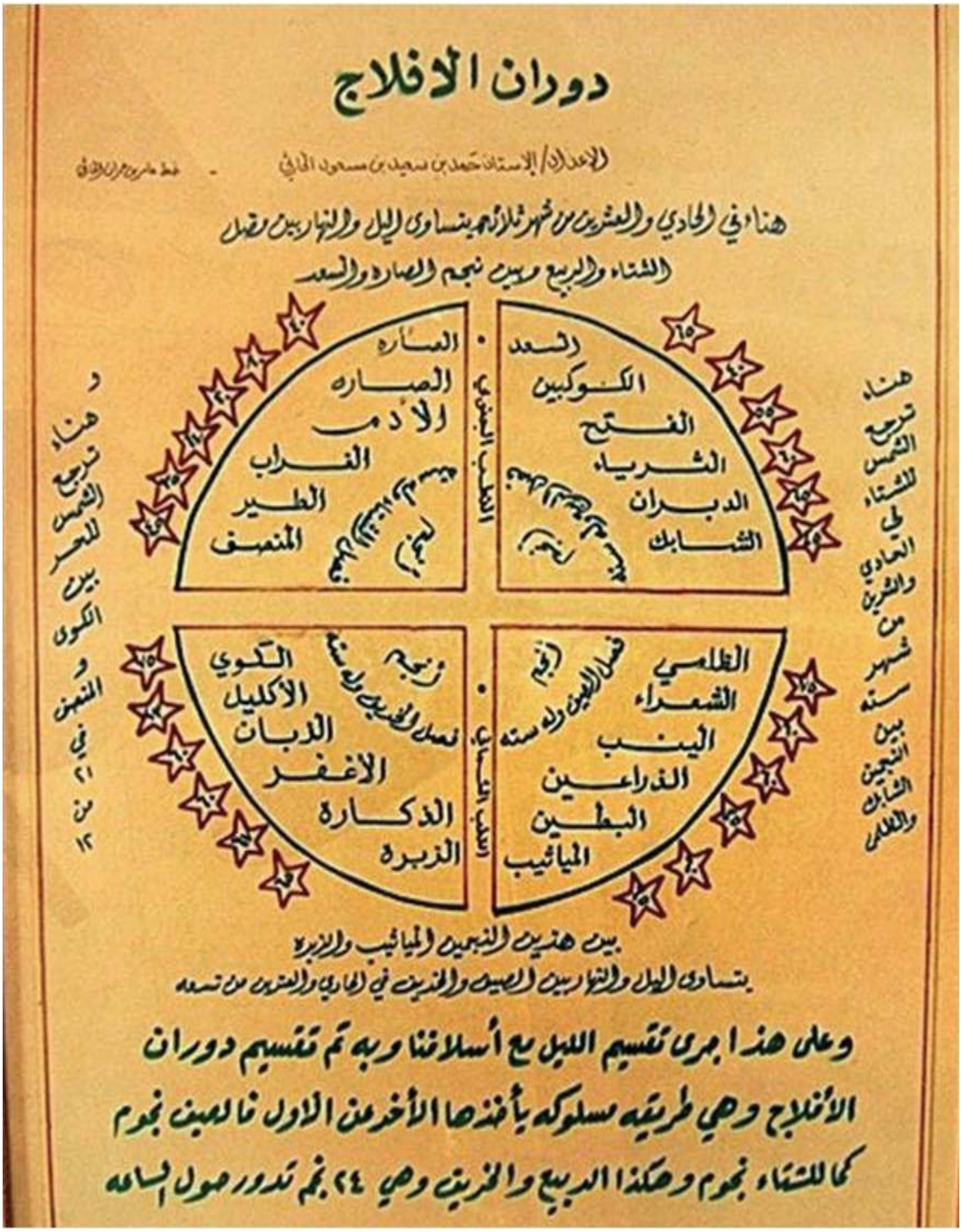


Fig. 6.18. Star chart from Mudayrib painted by Hamad bin Saeed Al-Harthi c. 1986. Reproduced by permission.

al-ᶜAbrī, Badr (c. 1980). *Al-bayān fī baᶜḍ aflāj ᶜUmān* [A Description of some of Oman's *Aflāj*], Muscat. (Publisher not known, out of print; there is a copy in the Oman Studies section of the library at Sultan Qaboos University, Oman.)

al-Ghafri, A., H. Nash, & M. al-Sarmi (2013). Timing water shares in Wādī Benī Kharūs, Sultanate of Oman. *Proceedings of the Seminar for Arabian Studies* 43, 1–10.

al-Tikriti, Walid Y. (2002). The south-east Arabian origin of the falaj system. *Proceedings of the Seminar for Arabian Studies*, 32, 117–138.

Nash, Harriet (2011). *Water Management: the Use of Stars in Oman*, Society for Arabian Studies Monographs No. 11, Archaeopress, Oxford. (This includes photographs of buildings used, copies of star lists and one manuscript from c. 1947, describing the stars used in Al Hamra.)

Nash, Harriet & Dionisius A. Agius (2011). Folk astronomy in Omani agriculture. *The Role of Astronomy in Society and Culture (Proceedings of IAU Symposium S260)*, D. Valls-Gebaud & A. Boksenberg (eds), pp. 166–171. Cambridge University Press, Cambridge.

Nash, Harriet, Majid Labbaf Khaneiki & Ali A. Semsar Yazdi (2012). Traditional timing of qanat water shares. In *International Conference on Traditional Knowledge for Water Resources Management*, 21–23 February 2012, Yazd, Iran. (Downloadable from media.astronomical heritage.net/media/astronomicalheritage.net/entity_000046/Nash_et_al._2012.pdf)

L'Observatoire de Paris, France

Danielle Fauque et Michel Cotte[1]

1. Identification du bien

1.a État partie de la Convention du patrimoine mondial (1972): France

1.b État, province ou région: Région de l'Île-de-France, département de Paris (75), commune de Paris, 14e arrondissement

1.c Nom du bien: Observatoire de Paris (XVIIe-XXe siècles)

1.d Coordonnées géographiques: latitude 48° 50′ 11,32″ N, longitude 9 min 21 sec (2° 20′ 11,4874″) E, altitude 67m (repère IGN).

1.e Cartes et plans:

Cadastre: www.cadastre.gouv.fr,

Commune Paris 14 (75),

000AQ01: parcelle 10 – plan AQ 01.

1.f Surface du bien: Ces données ne sont pas accessibles actuellement, mais l'étendue du domaine propre à l'Observatoire de Paris est d'environ 2,5 hectares.

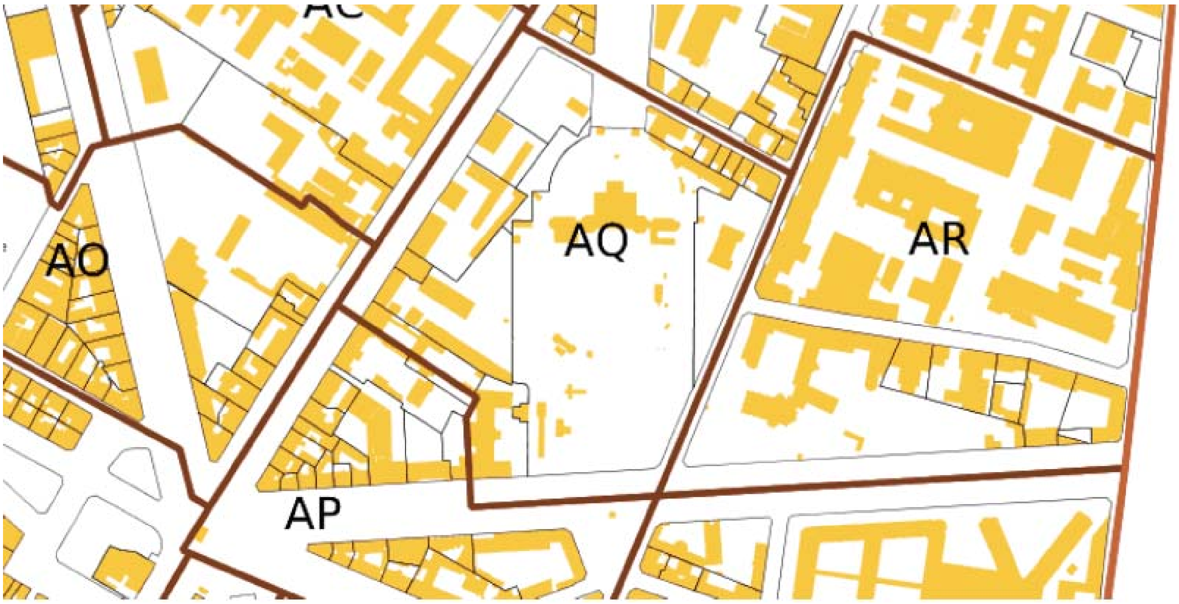


Fig. 7.1. Plan cadastral de l'Observatoire de Paris, parcelle AQ. © Ministère de l'Économie et des Finances.

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[1] La partie descriptive et les sections historiques ont été rédigées par Mme Danielle Fauque, Université de Paris Sud – Orsay, qui a également fourni l'ensemble de la documentation nécessaires aux autres sections.

2. Description

2.a Description du bien

Situé au sud de Paris, avenue de l'Observatoire, dans le XIVe arrondissement, l'Observatoire de Paris, fondé en 1667, est resté inchangé durant deux siècles. Il lui fut adjoint deux coupoles au XIXe siècle, et des bâtiments annexes au XXe siècle. Son domaine fut étendu au XIXe et au XXe siècles. Dépendant de l'Académie royale des sciences sous l'Ancien régime, il fut placé ensuite sous la tutelle du Bureau des longitudes au XIXe siècle avant de devenir autonome au milieu du XIXe siècle. Aujourd'hui, il a le statut d'un Établissement public de coopération scientifique. Les bâtiments et les jardins sont protégés au titre des Monuments historiques français depuis 1926. Les archives, de statut public exercé par les Archives nationales, sont également protégées.

Le bâtiment historique (1667–1672) dû à l'architecte Claude Perrault comporte trois niveaux de hauteur croissante du rez-de-chaussée à la plate-forme supérieure, afin de donner un effet visuel de perspective harmonieuse. Le rez-de-chaussée s'ouvre au nord, le premier étage s'ouvre sur une terrasse dallée au sud, le deuxième étage comporte la grande salle dite salle Cassini, où la grande méridienne (1729) concrétise la trace du méridien de Paris. Le troisième étage forme une terrasse dallée. Ce bâtiment abrite aujourd'hui les services administratifs de l'Observatoire de Paris, la bibliothèque et les archives; la collection des instruments et autres objets historiques sont exposés dans ce bâtiment accessible au public sur rendez-vous.

Dans les jardins arborés fermés ont été installées deux petits observatoires dont l'un fut dédiée au programme international de la Carte du ciel (1887–1970), et un bâtiment aujourd'hui en mauvais état qui abritait le grand équatorial coudé, maintenant démonté (1891–1939). En bordure de terrain, à l'ouest, sur un terrain acquis en 1970, un nouveau bâtiment fut adjoint pour abriter l'Institut national d'astronomie et de géophysique créé en 1967, qui après plusieurs transformations administratives fut définitivement rattaché à l'entité Observatoire de Paris depuis 1998.

Primitivement placé en campagne, l'ensemble est aujourd'hui situé en ville, dont les jardins constituent une zone tampon entre la cité et les bâtiments historiques, sur une surface d'environ 2,5 hectares. Les contraintes environnementales sont strictes, ce qui rend les projets de nouvelles constructions ou de reconstructions d'immeubles très contrôlés et rares. Dans tous les cas, la hauteur des bâtiments reste limitée, conditions qui ont contribué à protéger les capacités astronomiques du site.

L'ensemble de l'Observatoire de Paris avec son jardin d'origine, constitue toujours un ensemble particulièrement complet et qui témoigne de manière lisible et compréhensible de son architecture d'origine; il est complété par une série de strates aux dates, origines et fonctions scientifiques parfaitement identifiables. L'environnement des jardins du bien forme avec les bâtiments un ensemble à la fois complet et authentique d'un lieu scientifique majeur sur la longue durée historique.

2.b Historique et développement

Sous l'Ancien Régime

Construit sur un terrain acheté par Colbert au nom roi Louis XIV, le 7 mars 1667, le bâtiment central (1667–1672) est dû à Claude Perrault, un des plus importants représentants du renouveau de l'architecture française à l'époque de l'absolutisme royal en France au XVIIe siècle. Ses conceptions néo-classiques sont basées sur l'harmonie des proportions. Au jour du solstice d'été 1667, Adrien Auzout, Jean Picard et leurs collègues, dessinèrent le méridien de Paris sur une pierre, et imposèrent cette ligne comme axe de symétrie du futur édifice.

Ce bâtiment initial se compose d'un bloc central presque carré de 31m de long sur 29m de large du côté sud. Il est flanqué de deux tours octogonales encastrées, l'une à l'est, l'autre à l'ouest. Au nord une tour carrée surmontée d'un tympan triangulaire fait saillie au milieu de la façade. Le bâtiment de Perrault comporte trois niveaux de hauteur croissante du rez-de-chaussée à la plate-forme supérieure, afin de donner un effet visuel de perspective harmonieuse. Le rez-de-chaussée s'ouvre au nord vers la ville. Le premier étage s'ouvre de plain-pied au sud sur une terrasse dallée, prolongée ultérieurement d'une seconde terrasse aujourd'hui arborée. Des murs de soutènement furent construits à l'est et à l'ouest.

Le second étage est essentiellement constitué d'une grande salle voutée, traversant le bâtiment du nord au sud. Cette salle s'ouvre au sud par trois grandes fenêtres. Dès qu'il fut en charge de l'Observatoire, Jean-Dominique Cassini (Cassini I) voulut faire dans cette salle une grande méridienne qui donnerait le temps solaire vrai du lieu. Il fit percer un trou dans le mur sud au-dessus de la fenêtre centrale, le trou du gnomon, par lequel la lumière projetait l'image du Soleil sur le sol. La méridienne définitive fut réalisée par Jacques Cassini (Cassini II), en 1729. Elle est constituée de 32 règles en laiton graduées chacune en dixièmes et en centièmes de leur longueur. La longueur de chaque règle est égale au dixième de la hauteur séparant le sol de la salle de la base du trou du gnomon. Cette hauteur avait été elle-même déterminée de façon à faire dix fois la longueur du pendule à seconde utilisé par l'astronome Jean Picard, longueur mesurée sur la toise de référence de l'époque scellée dans un mur du Chatelet, et dite ensuite toise de Picard. Ainsi, la méridienne est-elle, elle-même, l'étalon de mesure française des dimensions d'avant la Révolution ; elle a de ce fait une importance historique. Toutes les observations de Picard peuvent donc être ramenées aux observations ultérieures de façon satisfaisante. Les restaurations successives ont su préserver cet ouvrage de référence exceptionnel. La salle est donc un véritable instrument astronomique.

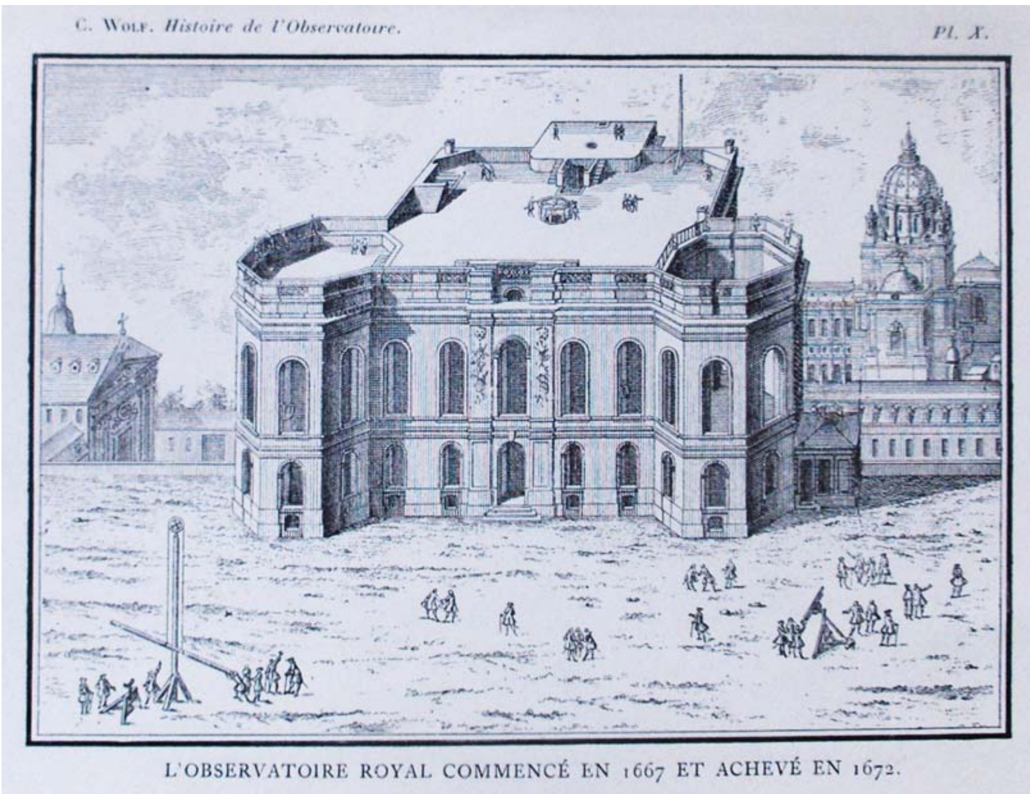

Fig. 7.2. Vue en perspective cavalière de l'architecture du bâtiment principal due à Claude Perrault. D'après C. Wolf, *Histoire de l'Observatoire de Paris de sa fondation à 1793* (Paris, 1902), HPIM.5426.

Ce second étage fut surmonté d'un toit en terrasse plane bordée d'une balustrade d'un mètre de haut. Cette terrasse dallée, supportée par des voûtes, a remplacé la plate-forme d'origine en 1787. Les pans est et ouest des tours octogonales étaient ouverts de façon à observer respectivement les lever et coucher du Soleil aux solstices, d'autres pans ouverts permettaient d'observer le lever et le coucher du Soleil aux équinoxes. Le bâtiment indique donc par sa construction les principaux moments de l'année solaire.

Un puits de 45m traversait le bâtiment, plongeant dans les anciennes carrières de calcaire, prévu pour observer au zénith, mais il fut très peu utilisé. La tour orientale est ainsi restée ouverte au-dessus du second étage jusqu'au milieu du XIXe siècle.

En 1730, 1742 et 1760, des petits cabinets d'observation furent adjoints à la tour orientale, à l'est, pour une observation continue. Ces nouvelles constructions, de structure légère, durent être restaurées en 1776, puis modifiées en 1780. Les salles du grand bâtiment furent aussi transformées en logements, ou utilisées pour des observations temporaires.

À la fin du XVIIIe siècle, lorsque Jean-Dominique Cassini (Cassini IV) prit la direction de l'Observatoire, il eut à cœur de restaurer le bâtiment, de renouveler la collection d'instruments et d'enrichir l'Observatoire d'une bibliothèque. Cette remise en état commença dès 1786 et se poursuivit durant plusieurs années. En 1795, l'observatoire devenu Observatoire de la République fut mis sous la tutelle du tout récent Bureau des longitudes.

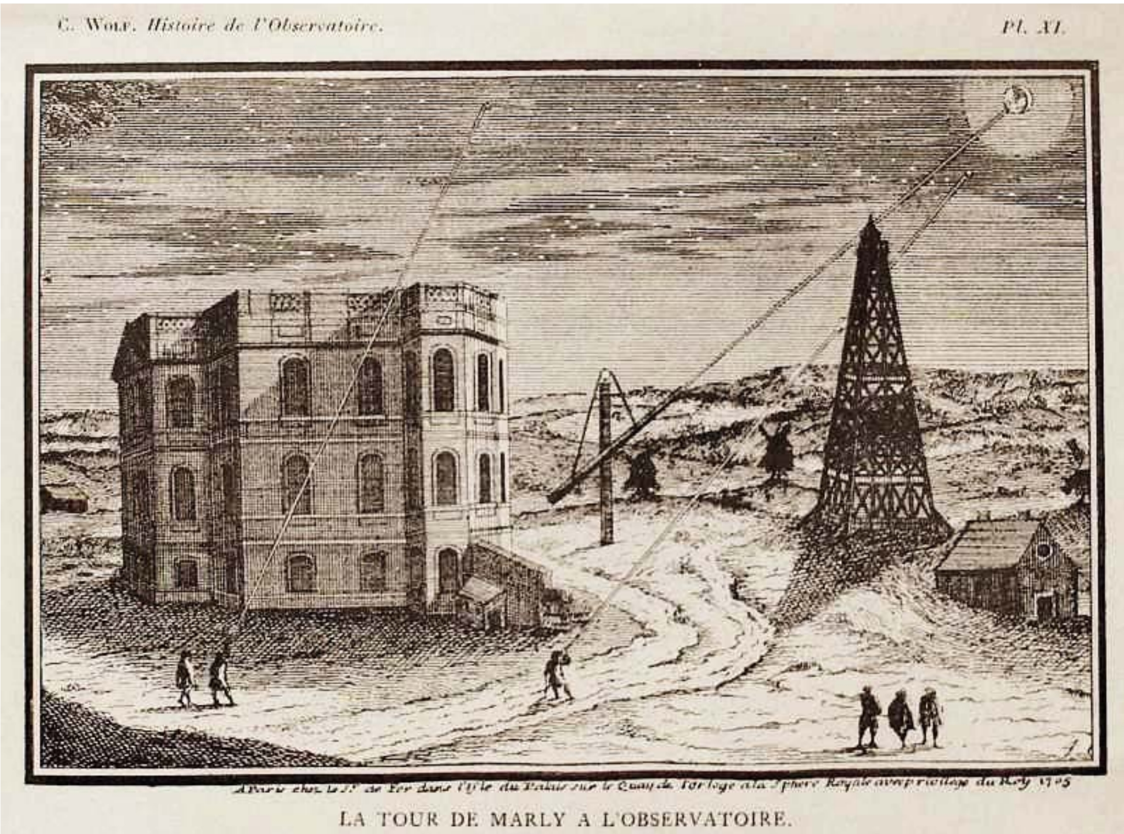

Fig. 7.3. L'Observatoire de Paris en 1705. D'après C. Wolf, *Histoire de l'Observatoire de Paris de sa fondation à 1793* (Paris, 1902), plate XI.

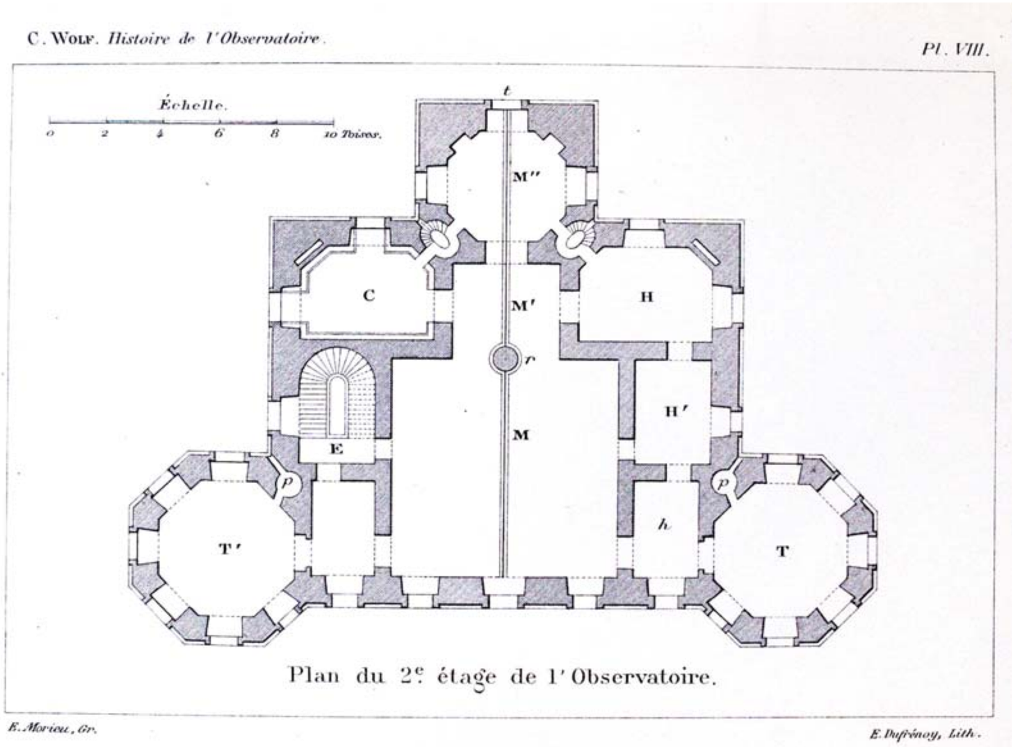

Fig. 7.4. Plan de l'Observatoire. D'après C. Wolf, *Histoire de l'Observatoire de Paris de sa fondation à 1793* (Paris, 1902), plate VIII.

Les nouvelles constructions, XIX^{e}–XX^{e} siècles

En 1801, on élargit la porte centrale donnant sur la terrasse sud, pour permettre le passage d'un instrument d'observation. Cette terrasse sud fut en partie dallée en 1843. À l'origine, les jardins des couvents entouraient l'Observatoire. En 1796, on voulut réunir les deux bâtiments l'Observatoire au sud et le Palais du Luxembourg au nord, par une avenue. Cette nouvelle voie fut ouverte en 1811. Elle donna l'occasion de déplacer l'entrée principale de l'Observatoire, primitivement rue du Faubourg Saint-Jacques côté est. Elle fut placée au bout de la nouvelle avenue de l'Observatoire. Deux petits pavillons (l'un servit de logement au concierge) furent construits de part et d'autre de l'entrée. Des grilles et un grand portail fermaient maintenant le terrain de l'Observatoire au nord. Au delà des deux pavillons, des nouveaux murs en arc de cercle ajoutèrent à l'harmonie de la cour nord. L'avenue donnait une perspective élégante sur le palais du Luxembourg vu de l'Observatoire, et sur l'Observatoire, vu du Luxembourg, et ajoute de la monumentalité au site.

Arago modifia les bâtiments côté est, puis en 1845 il fit ajouter une grande coupole au dessus de la tour orientale alors ouverte vers le ciel. Elle ne fut opérationnelle qu'en 1855. En 1857, une seconde coupole plus petite fut ajoutée au dessus de la tour ouest. Elle fut démontée en 1974. On aperçoit, du côté nord, une petite coupole dédiée à la météorologie. Dans la partie ouest, Arago fit aussi construire un grand amphithéâtre de 800 places, dans lequel il donnait ses cours d'astronomie; Le Verrier le détruisit quelques années plus tard pour y installer ses appartements.

À la fin du XIXe siècle, deux bâtiments et un laboratoire photographique furent installés sur le côté ouest de la seconde terrasse sud, dans la partie ancienne. La coupole d'un des pavillons abritait l'équatorial du grand projet international de la Carte du ciel, la seconde reçut l'équatorial dit de la Sorbonne. Entre les deux pavillons, le laboratoire photographique permettait de développer les plaques de verre.

Fig. 7.5. Le bâtiment à deux dômes de la Carte du ciel. Photo © Danielle Fauque

En 1881, le domaine de l'Observatoire s'étendit au sud par l'acquisition de terrains situés en contrebas. Une partie de ces terrains dits terrains Arago, jouxtant le nouveau boulevard Arago ouvert en 1866, fut convertie en jardin public, dans un espace séparé du domaine propre à l'Observatoire.

Deux amputations ont été effectuées au XXe siècle. D'une part, un terrain de 2800 m^2 fut cédé, côté rue du Faubourg Saint-Jacques, à l'est, à la Société des Gens de lettres qui y reconstruisirent l'Hôtel de Massa, une «folie» du XVIIIe siècle, située primitivement avenue des Champs-Élysées et démontée pierre à pierre. D'autre part, à l'ouest, un terrain primitivement prévu pour l'extension de l'Observatoire, fut finalement attribué, en 1937, au futur Institut d'astrophysique, dépendant aujourd'hui de l'Université Pierre-et-Marie Curie. L'Observatoire put ensuite acquérir un terrain plus à l'ouest, en façade sur l'avenue Denfert-Rochereau, en 1970. Des bâtiments (dits bâtiments Denfert) y furent érigés. Ils abritèrent des bureaux et des laboratoires de recherche de l'Observatoire dont le Bureau international de l'heure (BIH) et les Services du calcul et de mécanique céleste du Bureau des longitudes. L'Observatoire a ainsi pu accueillir des travaux scientifiques importants provenant d'autres lieux devenus plus propices aux observations, participants de programmes internationaux, par exemple des observatoires d'altitude comme celui du plateau de Bures (Hautes-Alpes) et celui de Tenerife (Îles Canaries), ou de l'hémisphère sud comme l'Observatoire européen du Chili, traitement des données de radioastronomie de Nançay et d'observatoires spatiaux comme Hubble, etc.).

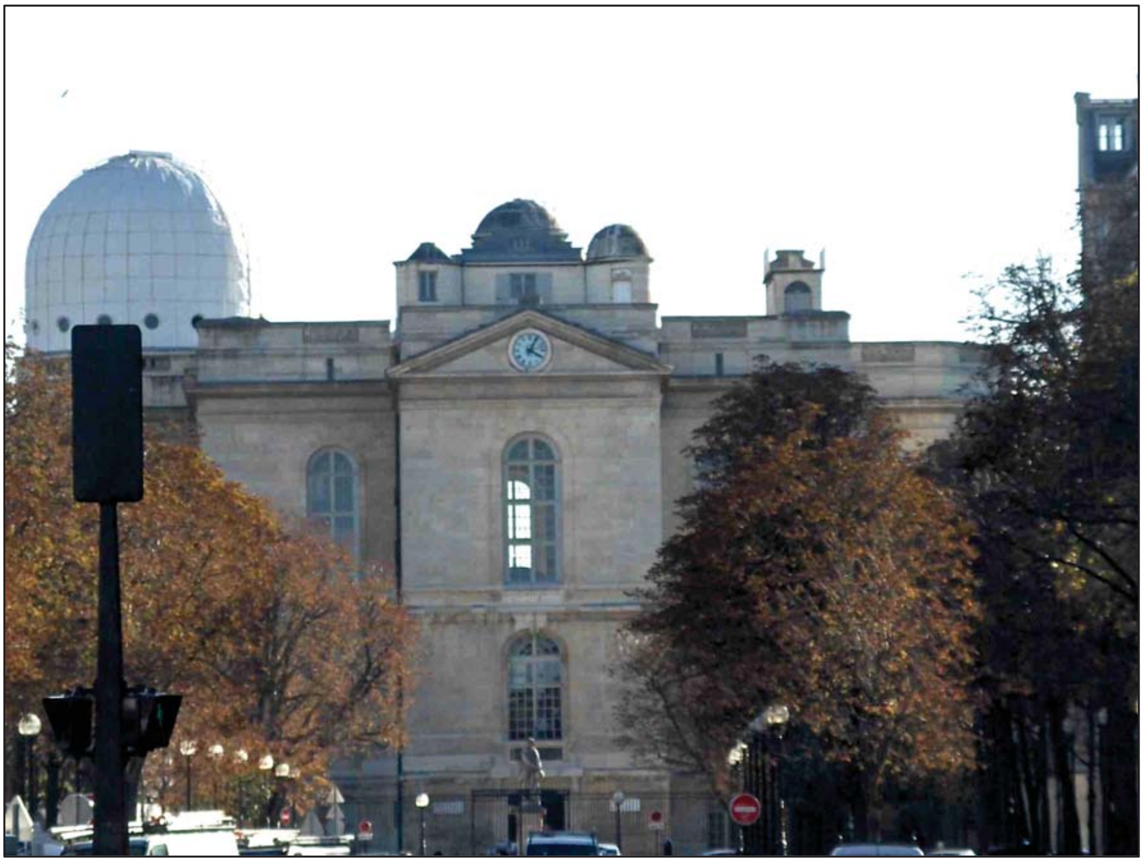

Fig. 7.6. La façade nord de l'Observatoire. Photo © Danielle Fauque

3. Justification de l'inscription

3.c Analyse comparative

Ainsi, depuis la fin du XVIIe siècle jusqu'à aujourd'hui, au sein d'un ensemble architecturel bien préservé, l'Observatoire de Paris avait été et restait l'un des centres principaux où s'élaborait la science astronomique occidentale, de manière continue. L'Observatoire de Paris a été et est toujours aujourd'hui au centre d'un réseau international essentiel à la construction des théories astronomiques, à leur vérification expérimentale, à l'application de l'astronomie à la mesure du temps, à la navigation et à la connaissance de la Terre. Il fut suivi de la construction de l'observatoire de Greenwich (1675). Puis au XIXe siècle, des observatoires de Poulkovo et de Berlin.

En effet, d'un point de vue historiographique, l'Observatoire de Paris est souvent associé à l'observatoire royal de Greenwich, ou celui de Berlin. Ces deux derniers sont intégrés dans des ensembles fonciers et immobiliers plus vastes que les seuls observatoires historiques. L'observatoire de Greenwich fait partie du site inscrit au Patrimoine mondial (PM par la suite) *Maritime Greenwich* (inscrit en 1997, bien 795, critères (i) (ii) (iv) (vi)). Il comprend le Royal Naval Collège (1873–1998), occupant l'ancien Royal Hospital for Seamen at Greenwich, construit entre 1696 et 1712 sur les plans de Christopher Wren, la Queen's House (1616–1635), et l'observatoire (ROG) lui-même comprenant plusieurs bâtiments dont Flamsteed House, et Meridian Building, dédié originellement aux progrès de la navigation astronomique (Ruggles et Cotte 2010: 195–198). La publication par Nevil Maskelyne, astronome royal, du *Nautical Almanach* à partir de 1767 devait faire la réputation de ce lieu. Ce lieu est aujourd'hui un musée, et le méridien international de référence décidé en 1884 qui le traversait n'est plus lié aujourd'hui au méridien international de référence (International Reference Meridian: IRM), sans réalité physique. Au XXe siècle, l'observatoire fut déplacé plusieurs fois, puis fermé définitivement en 1998.

L'observatoire de Berlin, construit à Babelberg dans un quartier de Postdam entre 1831 et 1835 a permis à Johann Galle de découvrir la planète Neptune en 1846 sur les indications d'Urbain Le Verrier, directeur de l'Observatoire de Paris. On peut noter que les différents observatoires de Potsdam sont à proximité immédiate du site inscrit sur la Liste du patrimoine mondial des *Châteaux et Parcs de Potsdam* (inscrit en 1990 puis étendu en 1992 et 1999, bien 532 ter, critères (i) (ii) et (iv)). Si la présence de l'observatoire est très brièvement mentionnée parmi les attributs du bien au moment de l'inscription, il semble que les installations astronomiques à caractère patrimonial ne soient pas dans le périmètre du bien qui a été précisé seulement en 2005. Dans la présentation actuelle de ce bien, seules les valeurs de l'architecture et des jardins sont mentionnées comme contribuant à sa valeur universelle exceptionnelle. On peut noter dans cet ensemble scientifique remarquable la tour Einstein, construite entre 1920 et 1922 par l'architecte Erich Mendelsohn (1887–1953), et consacrée à l'observation du Soleil (Ruggles et Cotte 2010: 209–212).

On peut associer à ces deux sites patrimoniaux, *l'Arc géodésique de Struve* (inscrit en 2005, bien 1187, critères (ii) (iii) et (vi)), qui s'étend de la Norvège à la Mer noire, impliquant une série de biens dans 10 pays différents. Son but initial était de donner une origine géographique à la détermination des limites des états après le traité de Vienne de 1815, mais dont on retient seulement dans la valeur universelle exceptionnelle actuelle qu'il permettait de déterminer la forme exacte de la Terre. La mesure de cet arc de méridien le plus long jamais effectué avait été commandée par l'Empire russe d'une part et le royaume de Suède-Norvège d'autre part, dont l'autorité couvrait alors l'ensemble des territoires traversés. Le projet se déroula de 1816 à 1856, et s'étendit sur 2800 km. Il fut dirigé par les Struve, astronomes titulaires de l'observatoire de Poulkovo dont la construction s'acheva en 1839. Cet observatoire est inscrit au Patrimoine mondial dans un ensemble plus large, intitulé *Centre historique de Saint-Petersbourg et ensembles monumentaux annexes* (inscrit en 1990, modifié en 2013, bien 540 bis, critères (i) (ii) (iv) et (vi)), il reste situé assez nettement en dehors de la ville actuelle, sur l'une des rares hauteurs de la région; l'observatoire est inscrit sous le numéro 540–009. Il s'agit donc ici d'un site patrimonial dont la composition est tout-à-fait différente du site architectural et scientifique de l'Observatoire de Paris, dont les spécificités et l'histoire sont en outre bien plus anciennes. La tradition de Poulkovo ne se rattache pas directement à celles de ces trois autres sites présentés (Paris, Greenwich, Berlin-Potsdam) mais elle la complète.

En effet, à la différence des autres sites historiques majeurs de l'histoire de l'astronomie que nous venons d'évoquer, l'Observatoire de Paris constitue un site en soi, entièrement et exclusivement dédié à l'astronomie. Il réunit des qualités architecturales concrétisant les aspirations à la rationalité du XVIIe siècle, définissant la Révolution scientifique de cette période. Il est le lieu où sont conservées les archives relatives aux grandes expéditions astronomiques et géodésiques du XVIIe au XIXe siècles, ainsi que celles des programmes internationaux comme la Carte du ciel ou la détermination internationale de l'heure.

Un programme des plus anciens menés par l'Observatoire de Paris a été la mesure de la Méridienne de France qui s'étend de Dunkerque à Perpignan et dont le premier morceau avait été mesuré par Jean-Dominique Cassini (Cassini I) sous Louis XIV, puis poursuivi et étendu par les Cassini successifs au XVIIIe siècle, et à nouveau sous la Révolution et au début du XIXe siècle. Elle a été le premier arc de méridien mesuré dont on espérait la réponse sur la forme de la Terre au début du XVIIIe siècle. Cette méridienne, gravée dans le dallage du premier étage, représente l'axe de symétrie du bâtiment historique. Là encore, l'Observatoire de

Paris a montré le chemin par les techniques de triangulation employées qui ont ensuite été utilisées pour toutes les autres entreprises géodésiques. Comme institution d’une part, et par les travaux entrepris d’autre part, son rôle scientifique et historique n’a cessé de s’affirmer tout au long des siècles. Depuis son origine, il y a continuité de l’occupation du site et de son utilisation à des fins astronomiques de référence jusqu’à aujourd’hui. Les données acquises depuis l’origine sont toujours utilisées dans le monde entier. Le bâtiment historique de l’Observatoire de Paris est le mieux conservé, et n’a jamais été détruit; il est toujours en activité, constamment adapté et bien entretenu dans son originalité. La continuité de la mission depuis l’origine est donc patente, et s’est déroulée dans des lieux dont l’architecture d’origine a été conservée.

3.d Intégrité et authenticité

Les bâtiments et leur environnement de terrasses et de jardins forment un ensemble monumental et paysager similaire à ceux du projet initial d’observatoire astronomique, sur un parcellaire général bien conservé et bien lisible, entouré de murs. Les bâtiments plus récents du quartier Denfert sont suffisamment éloignés pour ne pas modifier l’aspect architectural de l’Observatoire ancien et de son environnement arboré. Ils restent par ailleurs de hauteur contrôlée par l’administration de la ville de Paris. L’espace de l’Observatoire s’est densifié pour accompagner le développement même de l’astronomie, autour et dans un profond respect du bâtiment central originel de Perrault. Cet ensemble monumental et paysager forme un paysage significatif, témoignant de l’activité scientifique dans le Monde moderne et contemporain d’un observatoire parmi les plus anciens si ce n’est le plus ancien ensemble scientifique conservé à ce jour en Europe. L’intégrité d’usage de l’Observatoire a été continue depuis sa création jusqu’à aujourd’hui.

Placé sur une colline proche du quartier latin, à l’altitude de 67 m au repère IGN (longitude 9min 21s Est, latitude 48° 50′ 11,32″ Nord), lieu historique de l’université de Paris, avec un large espace dégagé vers le sud, l’Observatoire a contribué à l’urbanisation, au XIX^{e} siècle, de la ville de Paris, capitale de la France. Primitivement placé en campagne, l’ensemble est aujourd’hui situé en ville, dans un jardin arboré fermé, constituant une zone tampon entre la cité et les bâtiments historiques, sur une surface d’environ 2,5 hectares. Les contraintes environnementales sont strictes, de par l’application des règles d’urbanisme de la ville de Paris: l’urbanisation du quartier doit rester aérée, ce qui rend les projets de nouvelles constructions ou de reconstructions d’immeubles très contrôlés et rares. Dans tous les cas, la hauteur des bâtiments reste limitée, conditions qui ont contribué à protéger les capacités astronomiques du site.

Les modifications apportées au cours des trois siècles de son existence n’ont pas modifié l’Observatoire dans sa structure architecturale d’origine, mais elles ont contribué à une meilleure utilisation astronomique, notamment en fonction des progrès apportés aux instruments. Le plan général de l’Observatoire a été conservé et même agrandi.

L’authenticité architecturale des bâtiments est bonne (structure, formes, matériaux), seulement affectée légèrement par des transformations successives à chaque fois justifiées par des raisons scientifiques. Ces dernières sont plus à considérer comme des adaptations et des compléments nécessaires à la conservation de l’usage que comme une atteinte à l’ensemble.

L’ensemble de l’Observatoire de Paris est toujours dans son jardin d’origine, une propriété qui a d’ailleurs été étendue au cours de son histoire comme mentionné plus haut. Il constitue toujours un ensemble particulièrement complet et qui témoigne de manière lisible et compréhensible de son architecture d’origine; il est complété par une série de strates aux dates, origines et fonctions scientifiques parfaitement identifiables. L’environnement des jardins du bien forme avec les bâtiments un ensemble à la fois complet et authentique d’un lieu scientifique majeur sur la longue durée historique.

Fig. 7.7. La limite sud de l'Observatoire, le long du boulevard Arago. Photo © Danielle Fauque

3.a Critères selon lesquels l'inscription pourrait être proposée

Critère (i): L'Observatoire de Paris concrétise un projet fondateur majeur pour le développement de la science rationnelle moderne en Occident, dont il témoigna durant trois siècles et demi de fonctionnement scientifique ininterrompu et conforme à sa vocation initiale.

Critère (ii): Il témoigne d'un échange d'influences considérable depuis sa création, dans le domaine de l'astronomie, de la géodésie et de la détermination de l'heure universelle. Il fut un pôle international majeur de diffusion de la connaissance et d'animation de la communauté scientifique internationale.

Critère (iii): L'Observatoire de Paris est un témoignage fondateur particulièrement intègre et authentique de la tradition de construction des observatoires astronomiques de la science moderne occidentale et de la vie scientifique et culturelle qui lui a été associée au cours d'une histoire séculaire et continue.

Critère (iv): L'Observatoire de Paris, par l'architecture novatrice et fonctionnaliste de Perrault, contribue au renouveau des principes architecturaux antiques de Vitruve, dans le cadre du néoclassicisme propre à la France du XVII^{e} siècle. C'est un exemple éminent d'un nouvel esprit esthétique qui sera imité dans d'autres pays européens, mettant en valeur l'axe de symétrie d'un bâtiment, illustrant par ailleurs le méridien, comme axe majeur d'organisation des façades extérieures.

Critère (vi): L'Observatoire de Paris demeura pendant plusieurs siècles, et jusqu'à aujourd'hui, un lieu central du développement des connaissances scientifiques dans le domaine de l'astronomie d'observation et dans celui de l'astronomie théorique. Il fut à de nombreuses reprises le lieu par excellence de la coordination de la coopération scientifique internationale pour l'observation et la connaissance du ciel, dont il fut un centre d'archivage parmi les plus anciens et les plus complets du Monde moderne. C'est un lieu emblématique fondamental de l'histoire de l'astronomie scientifique. Il a été choisi par l'Union astronomique internationale pour y tenir son siège permanent.

3.b Proposition de déclaration de valeur universelle exceptionnelle

Au cœur du XVII^{e} siècle, l'Observatoire de Paris est une réalisation matérielle totalement novatrice, comme projet issu de la volonté de rationalité au sein du Monde occidental. Un projet d'une telle envergure concrétise l'émergence des nouveaux grands Etats nations du Monde occidental à la transition de la Renaissance et de l'Epoque moderne, dont il sera le premier symbole scientifique majeur et universellement reconnu. Il est caractéristique de l'émergence de l'Etat français à l'époque de Louis XIV et contemporain d'autres grandes œuvres symboliques du pouvoir royal: le *Palais et parc de Versailles* (Liste PM, 1979, réf. 83, critères (i) (ii) et (vi)), du *Canal du Midi* (Liste PM, 1996, réf. 770, critères (i), (ii) (iv) et (vi)) et de l'Académie des sciences.

Il s'agit de mieux connaître le ciel afin de mieux connaître le territoire de l'Etat nation afin de le cartographier et de le maitriser de la manière la plus scientifique possible. Sa matérialité physique définira et abritera le point référence du territoire (longitude zéro). Pour la première fois, la méridienne est tracée dans la pierre, le jour du solstice d'été 1667, pour former l'axe de symétrie de l'Observatoire. Le Monde britannique prendra rapidement la suite avec la création de l'Observatoire de Greenwich ouvert en 1675. Il faudra attendre le XIX^{e} siècle pour voir se développer des observatoires d'une importance comparable à celui de Paris.

À l'origine placé sous la tutelle de l'Académie royale des sciences fondée en 1666, l'Observatoire devait abriter les salles destinées aux expériences des académiciens, comme la salle de dissection et le laboratoire de chimie, le cabinet des machines, et comporter des salles de réunion ainsi que quelques logements. Il s'inspirait clairement de l'observatoire de Tycho Brahé à Uraniborg. Mais placé alors en pleine campagne, éloigné du centre actif de la ville, il ne fut guère utilisé que pour des observations astronomiques, confortant ainsi son statut d'observatoire.

Créé de par la volonté du roi, l'Observatoire devait en illustrer la puissance par la maîtrise scientifique à une époque de renouveau pour l'étude de la nature et d'une façon générale pour le monde, né à la Renaissance, et concrétisé de façon forte par la révolution copernicienne; il portait en lui-même l'idée de l'unité du savoir. L'observation systématique et régulière du ciel qui avait été effectuée par Tycho Brahé (1546–1601), l'exploration croissante du monde terrestre par les voyages et la cartographie, commençait d'enrichir considérablement l'inventaire du ciel et de la Terre au XVII^{e} siècle; l'Observatoire de Paris fondé en 1667 voulait répondre à cette demande. À l'origine, les futures fonctions de l'Observatoire avaient été définies par les astronomes du roi, Adrien Auzout et Jean Picard (1620–1682), inventeurs de nouveaux instruments d'observation, et de nouvelles procédures d'observation. C'est dans ce cadre que Picard se rendit à Uraniborg (situé sur l'île de Ven (Hven), proche de Copenhague, actuellement en Suède) pour relever précisément la différence de longitude entre l'observatoire de Tycho et celui de Paris, en 1671. Il s'agissait ensuite de dresser les tables astronomiques en référence au méridien de Paris, défini par la position de l'Observatoire. Le programme envisagé fut modifié par Cassini I quelques années après, qui ajouta l'observation des surfaces planétaires et des satellites de Jupiter, et la cartographie de la Lune. Les astronomes entreprirent aussi la triangulation du royaume initiée et poursuivie par les Cassini, au XVIII^{e} siècle.

Colbert, au nom du roi, confia la conception de l'Observatoire à Claude Perrault (1613–1688). Ce dernier était membre de l'Académie des sciences, récemment créée. C'était un physiologiste, un anatomiste, autant qu'un architecte. Ses recherches personnelles portent sur les questions de son temps: la physique des corpuscules, l'anatomie révélant l'harmonie d'un corps vivant, dont l'organisation intérieure répond à des fonctions établies et coordonnées. Le roi venait de lui confier la traduction des œuvres de Vitruve. À cet effet, il effectua un travail considérable de recherches et d'analyse critique, et nul doute que l'architecture de l'Observatoire de Paris en garde les traces. Ce bloc sobre, dénué d'ornementations superflues, était bien destiné à un usage différent de celui de tous les monuments de l'époque. La pureté des lignes, la symbolisation de ses orientations, la répartition des pièces et des couloirs, favorisant la circulation des hommes et des instruments entre les quatre points cardinaux, l'envolée de l'escalier tournant magistral, sans pilier central, à la courbe mathématique, tout concours à voir dans l'Observatoire, le corps architectural synthétisé de la pensée scientifique du XVII^e siècle. Jusqu'à la méridienne, conservant la longueur du pendule battant la seconde de Picard, qui ne rappelle l'idée de mesure universelle affirmée que celle-ci représentait dans l'esprit de l'astronome.

Paris devient alors le lieu de référence de l'observation du ciel dans le Monde occidental, et l'Observatoire le symbole tangible de cette révolution scientifique, tant dans son esprit savant et son ambition politique que dans l'affirmation d'une architecture monumentale propre à cet esprit de rationalité au service du roi. Il est construit entièrement en pierres de taille d'une qualité remarquable, sans charpente et uniquement avec des voûtes. Le style architectural est typique du néoclassicisme français, il est conçu pour durer.

Le grand œuvre du XVIII^e siècle est probablement la Carte des Cassini, cet arpentage métré en fin, par triangulation du royaume que suivirent à leur suite toutes les nations éclairées. Mais ce que l'on retiendra, ce sont ces expéditions, l'une au Pérou, l'autre en Laponie, qui montrèrent que la Terre était bien aplatie aux pôles. Le Bureau des longitudes, en charge de l'Observatoire, va poursuivre ce travail de triangulation dans le grand projet d'unification des mesures. L'unité de longueur devait-elle être basée sur la longueur du pendule battant la seconde, ou sur une portion du méridien terrestre? On retint la dernière proposition: le mètre serait le quart de la dix-millionième partie du méridien. Ce fut l'objet de grandes expéditions géodésiques avec les Delambre, Méchain et autres Arago. La toise du Pérou, toujours conservée à l'Observatoire, restait la longueur de référence.

Mais le monde s'ouvre, les connaissances s'élargissent, et l'Observatoire s'agrandit en évoluant dans le même sens. De plus en plus de personnes circulent et de plus en plus rapidement. Au milieu du XIX^e siècle, l'arrivée du chemin de fer et le développement du télégraphe rapprochent les hommes, compriment le temps. Urbain Le Verrier comprend tout le parti que l'on peut tirer du télégraphe pour transmettre et diffuser l'information, en l'occurrence, les informations météorologiques. Il construit ainsi peu à peu un réseau régional, national, puis européen. Il put ensuite dresser des tables de prévision météorologiques. L'Observatoire était alors dans les années 1850 tout à fait innovant dans le domaine. L'Angleterre et les Pays-Bas lui emboîtèrent le pas, et développèrent de tels réseaux en liaison avec la marine.

La transmission des signaux d'informations météorologiques exigeait aussi un système électromécanique de synchronisation des signaux temporels. De même, Les chemins de fer obligeaient d'avoir des montres « à l'heure », synchronisée sur une horloge de référence. Le temps solaire vrai n'est plus le temps des hommes. La question du temps, de quelle mesure de temps avons-nous besoin pour nous accorder, et donner de la cohérence à nos mesures?

La mesure du temps, la synchronisation des horloges, est également liée aux coordonnées géographiques. Voilà la troisième période de l'Observatoire. Le Service de l'heure, depuis les signaux électromagnétiques partis de l'Observatoire, et émis par la Tour Eiffel, permet à Paris de tenir un premier rang sur la scène internationale à partir de 1910 dans ce domaine. Après l'adoption du méridien de Greenwich par la France en 1911, Paris accueille sur son initiative, la Conférence internationale de l'heure en 1912. Le Bureau international de l'heure (BIH), qui en naît et dont le siège est fixé à l'Observatoire, ne fonctionnera effectivement qu'après la Première guerre mondiale. Le développement du service de l'heure à l'Observatoire conduit à la première horloge parlante au monde, en 1933.

Reliée à l'évolution du monde, à la globalisation en marche, aux exigences de standardisation de toute grandeur quantifiable dont témoignent l'apparition puis la fréquence des congrès internationaux, l'astronomie, elle-même, n'est plus une question d'individu, mais répond à un programme de plus en plus collectif, d'abord par observatoire, ensuite par réseaux d'observatoires nationaux puis internationaux. À ce titre, le projet de la Carte du Ciel est tout à fait représentatif. Créée par initiative française au cours d'un congrès international réuni à l'Observatoire en 1887, cette entreprise réunit à ses débuts dix-huit observatoires européens et sud-américains. L'entreprise se termine en 1970 quand le développement des satellites artificiels peut la remplacer. Elle marqua un moment essentiel de l'histoire internationale de l'astronomie contemporaine.

Une nouvelle période commence, caractérisée par l'internationalisation générale des travaux astronomiques, montrant que l'Observatoire de Paris reste au cœur des actions, tout en gardant son identité d'origine. Son centre d'archives astronomiques reste l'un des plus importants et des plus complets au monde (voir ci-dessous). L'Union astronomique internationale, créée en 1919, élit Benjamin Baillaud, directeur de l'Observatoire de Paris comme premier président. Le secrétariat permanent est actuellement à l'Institut d'astrophysique.

En conséquence, la valeur universelle exceptionnelle de l'Observatoire de Paris peut s'exprimer par les critères (i), (ii), (iii), (iv) et (vi) (voir ci-dessus).

4. État de conservation du bien et facteurs affectant le bien

4.a État actuel de conservation

Le bâtiment Perrault est en excellent état, ayant toujours été occupé et continuellement entretenu depuis le XIX^{e} siècle. Cependant, les petits bâtiments (carte du ciel et équatorial) situés à l'ouest sont à restaurer. Le bâtiment de l'équatorial coudé tombe en ruine.

4.b.i Pressions dues au développement

D'après les informations actuelles, aucune menace extérieure ne touche aux bâtiments historiques. La protection légale française est maximale (Monument historique, voir paragraphe suivant). Les constructions dans l'environnement et dans la zone tampon sont pérennes et leur hauteur, comme déjà indiqué, ne sont pas susceptibles de changer dans l'avenir. Le quartier est essentiellement un quartier résidentiel assez arboré. Une architecture typique du XIX^{e} siècle domine, avec quelques bâtiments d'habitation du XX^{e} siècle. Récemment, la maternité de Port-Royal a construit de nouveaux bâtiments en bordure du domaine foncier du bien (53 avenue de l'Observatoire), mais leur hauteur respecte le cahier des charges car ces bâtiments sont dans le périmètre protégé par la loi française.

4.b.ii Contraintes liées à l'environnement

Comme dans toutes les grandes villes, le ciel parisien souffre d'une pollution constante, attaquant la pierre et qui nécessite un entretien régulier des façades. Le sous-sol est percé de nombreuses anciennes carrières, le RER passe également très en dessous du terrain de l'Observatoire, du côté est.

Fig. 7.8. L'aile orientale du bâtiment principal de l'Observatoire. Photo © Danielle Fauque

Les locaux de l'Observatoire de Paris sont en principe tous équipés aux normes incendies, conformément à la réglementation française pour ce type de bâtiments, simultanément historiques et d'utilité publique. D'importants moyens techniques sont en place en cas de sinistre (incendie, accident majeur, attentat…), dans le cadre du SDIS 75 (service d'intervention incendie et de secours) de la ville de Paris et du département de la Seine. La présence de deux grands boulevards et de deux rues importantes le long de la propriété assure une intervention rapide en cas de sinistre.

4.b.iii Catastrophes naturelles et planification préalable

Par ailleurs, la région parisienne est une zone sismique de faible risque. Du fait de la situation de l'Observatoire sur le sommet d'un léger promontoire, il n'y a pas de risque d'inondation. Enfin, les impacts du changement climatique en cours ne sont pas sensibles pour l'instant au niveau de l'Observatoire.

4.b.iv Contraintes dues aux visiteurs et touristes

L'entrée des locaux est strictement réglementée et contrôlée, n'étant autorisée qu'aux personnes accréditées ou aux visiteurs dûment enregistrés. Des employés de gardiennage font partie du personnel de l'Observatoire.

5. Protection et gestion

5.a Droit de propriété

L'Etat est propriétaire de cet établissement. Le Ministère de tutelle est celui de l'Enseignement supérieur et de la recherche; suivant les gouvernements, il peut être inclus dans un grand Ministère de l'éducation. Son usage et sa gestion sont confiés à une Institution publique autonome, dite « Observatoire de Paris » qui a le statut d'établissement public de coopération scientifique (EPCS) au sein d'une Fondation de coopération scientifique, dénommée Paris Sciences Lettres – Quartier latin (PSL) depuis 2012. Il a rang d'université et peut délivrer des diplômes de thèse et de master dans les différents domaines scientifiques afférant à l'astronomie, à l'astrophysique et aux sciences associées.

5.b Classement de protection

Le bâtiment central et les jardins avec leurs clôtures (murs, grilles, et pavillons d'entrée) ont été classés « monument historique » par un arrêté du 12 juin 1926, dans les conditions d'application du décret du 18 mars 1924 de la loi du 31 décembre 1913, et est, de ce fait, un site protégé au plus haut niveau de la législation française. Elle implique en particulier une zone de protection supplémentaire dans un rayon de 500 m, qui impose un avis obligatoire et suspensif de l'administration du Ministère de la culture sur le projet. L'instruction du dossier et l'avis de conformité sont réalisés par l'Architecte des bâtiments de France (ABF) en charge du secteur urbain. Les ABF constituent un corps de fonctionnaires de l'État depuis le XVII^{e} siècle. Nous avons vu que la restructuration de la maternité voisine avait suivi et respecté cette disposition de la loi de 1913. La décision de protection de l'ensemble a été actualisée par un arrêté modificatif de classement en date du 14 décembre 2009. Un arrêté du 23 décembre 2009 inclut les édicules placés sur le site dont le bâtiment du grand équatorial coudé et celui de la Carte du ciel.

Au-delà des jardins (concept de Zone Tampon), comme déjà indiqué, l'urbanisme parisien voisin de l'Observatoire date essentiellement de la seconde moitié du XIX^{e} siècle et du début du XX^{e} siècle. Il a les qualités bien connues de l'architecture haussmannienne et forme à ce titre un écrin significatif du site classé Paris Rives de la Seine (Liste PM, 1991, réf. 600), au sud de la rive gauche. Ce quartier continue l'extrémité ouest du vaste ensemble scientifique et éducatif bâti par la France à Paris, sur la Montagne Sainte-Geneviève, depuis la Sorbonne médiévale jusqu'au milieu du XX^{e} siècle. Ses règles de protection sont celles du centre urbain de Paris. Il s'y applique en particulier la loi de 1913 sur les monuments historiques assortie de nombreux décrets complémentaires circonstanciés monument par monument. La densité des monuments historiques rend de manière presque automatique l'application de la règle des 500 m. Ces dispositions sont en outre reprises et systématisées par quartiers, dans le cadre du plan d'urbanisme régulièrement actualisé de la ville de Paris et en conformité avec le Code de l'urbanisme français. Aucun immeuble de taille élevée ou de façade trop anachronique en regard de son environnement visuel ne peut y être envisagé. Tout projet doit être soumis à la ville de Paris et au Ministère de la culture, direction des Monuments historiques, pour un avis de conformité rendu par les ABF. Cette servitude s'applique aux immeubles et aux espaces situés à la fois dans un périmètre de cinq cents mètres de rayon autour de l'Observatoire et dans son champ de co-visibilité (c'est à dire visible depuis l'Observatoire ou en même temps que lui) (loi du 25 février 1943). Ces dispositions légales et réglementaires constituent *de facto* une zone tampon, au sens du Patrimoine mondial, et elles contribuent à conserver l'intégrité visuelle du bien, et elles lui donnent un environnement qui permet une bonne expression de son authenticité scientifique et culturelle.

5.e Plan de gestion du bien

Conservation et gestion des bâtiments, des collections et des archives

Comme déjà indiqué, le gérant et usager du bien est l'institution publique et scientifique autonome de l'Observatoire de Paris, ayant rang d'université. Son activité exclusivement dédiée à l'astronomie est garantie par ce statut. Cela induit une attention particulière pour la conservation de la collection d'instruments, la conservation documentaire et archivistique. Les archives sont également protégées par leur statut d'archives publiques exercé par les Archives nationales; elles sont gérées par des personnels professionnels spécialisés, sous le double contrôle de l'Observatoire de Paris et des Archives nationales.

Il s'agit d'une gestion d'un patrimoine bâti et de jardins dans la continuité directe de la vocation historique de l'Observatoire, ce qui en fait un patrimoine vivant. La conservation de long terme du bien est garantie par la présence permanente d'astronomes professionnels, d'une administration dédiée à cet usage, d'une conservation professionnelle tant des archives que des instruments anciens et modernes. L'entretien des bâtiments et des jardins est assuré par un personnel professionnel permanent attaché à l'Observatoire et de statut public. Le statut de bâtiment public et monument historique lui assure une conservation qui bénéficie du suivi et de l'aide des services spécialisés de l'Etat (Monuments historiques et architecte des Bâtiments de France), ainsi que de d'aides du Ministère de la culture en cas de besoins de restauration.

La collection d'instruments

La collection d'instruments anciens est l'une des plus significatives qui soit, en référence avec des utilisations majeures pour l'histoire de l'astronomie moderne et contemporaine (inventaire en ligne). Ils sont entretenus, voire pour certains encore utilisés. Leur présence renforce l'authenticité scientifique du lieu (quelques-uns comme la lunette Arago, le cercle méridien et l'équatorial de la Carte du ciel sont des instruments fixes toujours sur leur site d'origine). Plus largement, ils témoignent, sur la longue durée de l'histoire des sciences, d'un lieu authentique de la production scientifique en Occident.

À ce titre, la collection d'instruments dont plusieurs sont fixes contribue à l'intégrité du lieu en tant que composante de la complétude scientifique du bien proposé et de démonstration de la continuité comme de l'évolution de ses usages depuis sa fondation. Elle contribue à démontrer et à illustrer l'importance de l'Observatoire de Paris en tant que lieu scientifique majeur pour une durée exceptionnelle d'utilisation dans le domaine de l'astronomie instrumentale. Elle permet une bonne compréhension de ses fonctions historiques dans un contexte presque toujours international et à la pointe tant des progrès techniques de l'astronomie que de la recherche observationnelle et théorique.

Fig. 7.9. L'entrée principale de l'Observatoire. Photo © Danielle Fauque

Archives, documentation

Il en va de même pour les archives historiques, dont beaucoup de documents sont uniques et souvent autographes d’astronomes considérés comme majeurs dans l’histoire des observations comme des théories astronomiques propres à l’histoire scientifique du Monde occidental. Elles couvrent de manière homogène et continue près de quatre siècles d’histoire de l’astronomie, ce qui est exceptionnel et peut-être unique. L’Observatoire a reçu également des documents authentiques rassemblés par les astronomes eux-mêmes dont des papiers de Johannes Hevelius (1611–1687), puis à la Révolution des collections confisquées vinrent enrichir ses fonds.

Leur contribution à la valeur universelle de l’Observatoire de Paris est essentielle; elle est complémentaire de l’apport déjà évoqué des collections. Il s’agit d’une contribution majeure et unique en tant qu’ensemble scientifique par le nombre, l’ancienneté et la qualité des archives rassemblées, ainsi que par leur exhaustivité et leur état de conservation actuel. Ces archives constituent autant de témoignages d’observateurs que de savants de premier plan à des moments différents des progrès de la connaissance humaine dans son environnement astronomique et cosmique. Leur caractère est exceptionnel tant par la durée de la compilation recueillie que par son amplitude en tant que collection de documents scientifiques historiques de première main. Ils apportent également une dimension de contenu scientifique à l’authenticité de longue durée du bien proposé et une preuve matérielle et intellectuelle de son rôle historique comme d’une science très tôt internationale en train de se constituer, en lien avec les meilleurs sites d’observation des différentes périodes de l’histoire de l’astronomie moderne et contemporaine. Les archives et collections documentaires apportent une base exceptionnelle pour l’analyse comparative non seulement de l’Observatoire de Paris en tant que monument scientifique, mais de toutes les grandes contributions observationnelles et théoriques ayant participé à la construction du corpus de l’astronomie scientifique dans le Monde, du milieu XVII^{e} siècle à la seconde partie du XX^{e} siècle.

On doit à Jean-Dominique Cassini (Cassini IV, 1748–1845), la fondation du centre d’archives. Il déposa à l’Observatoire les papiers conservés dans sa famille, et une grande partie de sa bibliothèque. Le Bureau des longitudes recueillit un certain nombre d’instruments. L’amiral Mouchez poursuivit cette entreprise et retrouva nombre d’instruments anciens, créant ainsi la base du Musée et des collections historiques d’aujourd’hui.

L’imposante bibliothèque conserve les archives concernant l’Observatoire dans des conditions strictes d’usage depuis sa création. Les données ainsi réunies (recueils manuscrits de données d’observations originaux, correspondances d’astronomes de toutes nationalités, pendant plus de trois siècles, documents des périodes antérieures à la création) sont d’une valeur inestimable, toujours utilisées aujourd’hui par les astronomes du monde entier pour les besoins de leurs recherches ou de l’astronomie spatiale. Citons l’exemple des documents manuscrits d’observation des éclipses des satellites de Jupiter des XVII^{e} et XVIII^{e} siècles, dont celles de Römer, et qui n’avaient pas été publiées. En 1976, le *Jet Propulsion Laboratory* (NASA) fit décrypter ces manuscrits, les fit microfilmer, les remis à un temps uniforme calé sur les satellites, afin de les utiliser pour la préparation des missions des sondes Voyager.

De 1985 à nos jours: un Observatoire au cœur des recherches internationales

L’Observatoire participe à des programmes internationaux, ou utilise des moyens d’observation internationaux partagés, comme l’Observatoire européen austral (ESO), les radiotélescopes de l’Institut de radioastronomie millimétriques (IRAM), dont le siège social est à Grenoble, ou les satellites de la NASA et de l’ESA. Une visite des sites internet de l’Observatoire de Paris (http://www.obspm.fr), renseignera sur ces programmes.

Rappelons cependant que la coopération et les échanges internationaux furent établis dès l’origine.

L'Observatoire de Paris a été et reste le centre d'une vaste coopération internationale. Donnons quelques exemples. Dès le XVIII^{e} siècle, Joseph-Nicolas Delisle commençait en centralisant les données d'observation du passage de Vénus devant le disque solaire en 1761, exploitées ensuite par Jérôme de Lalande. Ce dernier poursuivit l'entreprise et réunit 120 observations du second passage en 1769; pendant plus de cinquante ans, il tissa un réseau de correspondants et d'observateurs dont les observations contribuèrent à l'établissement de ses tables des planètes et des étoiles, mais il ne travaillait pas à l'Observatoire. Il fallut attendre Le Verrier pour une première entreprise internationale menée depuis l'Observatoire, et qui commença dès 1854. Ce fut le premier réseau national puis européen de météorologie, permettant l'émergence d'une météorologie prédictive.

L'établissement de la Carte du ciel fut donc le véritable premier programme astronomique international mené à partir de l'Observatoire. L'astronome David Gill, de l'observatoire du Cap, désirait établir une série photographique de tout le ciel austral, dont on établirait un catalogue; il fit part de cette idée à l'amiral Mouchez en 1885. Or les photographies du ciel étoilé, prises jusqu'à cette date, avaient déçu tous les espoirs. Peu de progrès apparaissaient par rapport aux procédés traditionnels. Cependant, les frères Paul et Prosper Henry, opticiens à l'Observatoire de Paris depuis 1879, venaient d'obtenir des photographies satisfaisantes d'étoiles jusqu'à la 14^{e} grandeur avec un nouvel objectif spécialement adapté pour la photographie sur un instrument de Gautier.

Le projet prit d'abord forme en France; les observatoires d'Alger, de Toulouse et de Bordeaux formèrent un réseau national. Mouchez sollicita l'avis de ses collègues étrangers pour étendre l'entreprise au ciel entier, divisé en secteurs, puis organisa à Paris un congrès international sous l'égide de l'Académie des sciences en 1887. Une commission internationale permanente pour le suivi de l'entreprise de la Carte du ciel fut instituée. Chacun des dix-huit observatoires associés devait être équipé d'un instrument Gautier-Henry (deux lunettes couplées, l'une avec un objectif visuel, l'autre avec un objectif photographique) ou de mêmes performances techniques. Les frères Henry inventèrent une machine spéciale pour mesurer les clichés. Il y avait unification des instruments et des techniques d'observation ainsi que du traitement des clichés. Mais les méthodes de réduction des données dépendaient d'une table de constantes fondamentales, qui n'étaient pas quant à elles encore unifiées. Ce fut au congrès de 1896, que l'accord sur ce dernier point fut obtenu. L'avancée du projet fut donc lente. À partir de 1919, l'UAI soutint la publication de plusieurs catalogues tirés de la Carte du ciel. L'entreprise fut close en 1970, sans avoir été terminée, mais l'avancée des technologies ne justifiait plus sa maintenance. Dans cette entreprise, la place de l'Observatoire fut primordiale. Le directeur de l'Observatoire coordonnait les travaux internationaux; le Comité se réunissait à Paris.

Presque comme une conséquence, la nouvelle UAI fondée en 1919 eut comme premier président, Baillaud, directeur de l'Observatoire. Ses archives, conservées à Paris, furent utilisées pour des missions satellitaires dont celle d'Hipparcos (ASE, 1989–93), dont on tira les catalogues d'étoiles Hipparcos, Tycho et Tycho-2 (1997–2000).

Au tournant du XX^{e} siècle, la demande internationale pour une normalisation des méthodes, une unification de présentation des résultats, une détermination des constantes fondamentales était formulée dans la plupart des domaines scientifiques. Pour l'astronomie, cela devenait crucial pour la mesure du temps et ses corollaires. L'Observatoire joua avec le Bureau international de l'heure un rôle de premier plan. En 1912, on voulut unifier l'heure, et pour cela, il fallait synchroniser les signaux émis par les différents pays. Fondé en 1912, et grâce à l'action de Baillaud, le BIH fut installé dans les locaux du Service de l'heure dans la tour orientale du bâtiment Perrault, mais la guerre survint avant qu'une convention internationale ne fût signée. Il ne commença donc à réellement fonctionner qu'à partir de 1919 sous la responsabilité de l'UAI (commission 19), et fut dirigé par Bigourdan. Cette entreprise nécessitait de reprendre par télégraphie des mesures plus précises des longitudes, que l'Observatoire centralisa. Les signaux horaires étaient émis de la Tour Eiffel. En 1933, la première horloge parlante mise en service public dans le monde égraina ses tops à la précision au dixième de seconde (le millième aujourd'hui) à partir de l'Observatoire de Paris. Le BIH fonctionna jusqu'en 1987, où il fut supprimé en même temps que le Service international du pôle.

7. Documentation

7.a Documentation photographique et audiovisuelle

Netothèque

http://www.obspm.fr/-histoire-du-site-de-Paris.html?lang=fr. Ce site donne une histoire de l'Observatoire de Paris jusqu'à la fin du XX^e siècle, basée sur les archives et des études historiques de haut niveau.

http://www.bibli.obspm.fr/. Les catalogues en ligne permettent de saisir la richesse de la bibliothèque et des archives de l'Observatoire de Paris.

http://alidade.obspm.fr/sdx/alidade/. Pages pour les instruments, documents et archives de l'astronomie de l'Observatoire de Paris.

http://www.obspm.fr/la-restauration-du-batiment-perrault.html?lang=fr. Cette page concerne le bâtiment de l'architecte Perrault et sa conservation.

http://patrimoine.obspm.fr/Instruments/Instruments/Instruments.html. Ce site (nécessite un code d'accès à demander à l'Observatoire de Paris) présente le catalogue des instruments conservés à l'Observatoire de Paris.

7.b Textes relatifs au classement à des fins de protection

Législation concernant l'Observatoire de Paris. Voir le site Legifrance:

- *Statut PSL*
- *Statut EPCS*
- *Protection du patrimoine culturel* (Loi du 31/12/1913; Loi du 25 février 1943)

7e. Bibliographie

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Le livre de Charles Wolf reste la référence en langue française pour la période pré-révolutionnaire. Le dernier ouvrage paru, de L. Bobis et J. Lequeux, présente l'histoire de l'Observatoire jusqu'à nos jours dans une présentation magnifiquement illustrée. Les actes des colloques, cités ci-après, proposent un large éventail des activités qui se sont déroulées à l'Observatoire de Paris depuis sa fondation. Enfin, des monographies éclairent l'histoire de l'Observatoire dans un contexte plus large. Les travaux de Michael Petzet, sur les travaux d'architecture de C. Perrault sont essentiels. Antoine Picon s'y réfère dans sa belle étude sur Perrault. Les informations sur la vie et les travaux de Claude Perrault ajoutent ainsi plus de cohérence à la compréhension du projet d'observatoire réalisé à la fin du XVII^e siècle.

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Royal Observatory, Cape of Good Hope, Republic of South Africa

Ian Glass

1. Identification of the property

1.a Country/State Party: Republic of South Africa

1.b State/Province/Region: Western Cape

1.c Name: The *Royal Observatory, Cape of Good Hope* is the original name for the headquarters of the present-day *South African Astronomical Observatory*.

1.d Location: latitude 33° 56′ 4″ S, longitude 18° 28′ 39″ E, elevation 15m above MSL.

1.e Maps and Plans: Property diagrams and other maps of the Royal Observatory property exist from many epochs. See also Figs 8.1 and 8.13.

1.f Area of the property: 9 hectares

2. Description

2.a Description of the property

Introduction

The Royal Observatory occupies a small wooded hill about 6 km east of central Cape Town, within a conservation area known as the Two Rivers Urban Park. Its location was originally chosen to be within view of the Table Bay, the anchorage in front of the City, to permit the visual signalling of time to visiting ships. The property is one of the last remaining places close to the city centre where the original ecology of the area is preserved. Its low-lying portions are subject to occasional flooding.

Some sixty or more structures occupy the site at present. Many of these date from the nineteenth century. The Greek Revival Main Building of 1825–8 still dominates the hill and faces a lawn to the south which forms an axis along which are many smaller edifices such as domes and dwelling houses, most dating from the Victorian period and forming a pleasant coherent whole. The only large modern building is inconspicuously located at the back (north) of the Main Building towards the northern end of the property.

The property is situated adjacent to the Cape Town suburb of Observatory, which grew up beside it, towards the east, in the late nineteenth century. Cape Town is the capital city of the Western Cape Province, Republic of South Africa. Founded by the Dutch East India Company in 1652, it is regarded as the 'mother city' of present-day South Africa.

The proximity to the centre of Cape Town and the availability of parking space makes the Royal Observatory site a convenient and valued meeting place for the astronomical and some other scientific communities.

Fig. 8.1. Google image of the Royal Observatory. The H-shaped main building was completed in 1828. North is at the top. To the north, north-east and east is swampy land. A canalised river runs along the western boundary and a mental institution lies to the south. © 2012 Google

Environment

The land in this area is underlain by greywacke, quartzitic limestone and shale. Before it was acquired for the Observatory, the landscape was rocky, treeless and windswept, but nonetheless supported a remarkable variety of seasonal grasses and bulbs. No longer barren, over the nearly two centuries of its existence the site has been planted extensively with shrubs and trees to act as windbreaks.

Although it is the habitat of many interesting flora and fauna, the site is particularly noted for being the last remaining natural habitat of a rare Iris *Moraea aristata* and the northern limit of the Western Leopard Toad *Bufo pantherinus*, an endangered species.

The site is no longer dark and rural. Beyond the boundaries of the Two Rivers Urban Park, which encircle it, the Observatory site is surrounded by freeways, major roads, office buildings etc.

Intangible heritage

For most of its existence the Royal Observatory was the major contributor to positional astronomy in the southern hemisphere. Among its most important achievements were:

- The first successful measurement of the distance of a star by Thomas Henderson (1832-3), announced in 1839. He detected the parallax of Alpha Centauri against the background of more distant objects as the earth moved around its orbit. The search for the parallax of the stars was almost the ‘Holy Grail’ of astronomy, having been a prediction of Copernicus’s heliocentric theory of the Universe published in his *De Revolutionibus* of 1543. This discovery and the slightly later work of F.W. Bessel were described by Sir John Herschel in 1841 as ‘the greatest and most glorious triumph which sidereal astronomy has ever witnessed’.
- Maclear’s repeat and extension of the geodetic measurements carried out by N-L de La Caille that showed that his conclusion that the shape of the earth was significantly different in the southern and northern hemispheres was wrong.
- The first use of photography to make a systematic sky survey, by David Gill from 1885. From photographic experiments made around 1882 Gill realised that photography was the method of choice for mapping the sky. Photographic plates gave a permanent and impersonal record of star positions that could be consulted forever. Refused support from official sources, Gill financed at great personal sacrifice the Cape Photographic Durchmusterung, the first catalogue of stars observed by photographic means. A few years later, Gill was the leader of the Astrophotographic Congress with Admiral Mouchez of Paris. This meeting, which led to the international sky-mapping project known as the Carte du Ciel, is often regarded as the precursor of the International Astronomical Union.
- The measurement of the ‘Astronomical Unit’ made by Gill using observations of minor planets yielded the most accurate value of this fundamental quantity for several decades.
- The design and instruction of a new type of Transit Circle by Gill, which inspired many later instruments of this kind until the field was taken over by artificial earth satellites in the 1990s.
- The measurement of stellar angular diameters by means of Lunar occultations by David S. Evans in the 1950s.
- The measurement of standard star brightnesses (magnitudes) by Alan W.J. Cousins from the 1940s to the 1990s. This ultra-careful work is fundamental to many areas of astronomy including the cosmic distance scale. He was also responsible for introducing the current system of VRI photometry.
- Verification by J. Churms of the rings around the planet Uranus in 1977 by observation of the occultation event also seen by the Kuiper aeroplane.

It is also the location of the oldest photographs taken in South Africa and the photograph of the main building is the oldest of any observatory (excluding that of Herschel’s outdoor telescope).

Fig. 8.2. The Main Building. Photograph © Ian Glass

Tangible heritage—a partial inventory

Immovable items—buildings and grounds

The property was for many years maintained to a very high standard by the local branch of the British Office of Works, which caused it to be regarded as a showpiece. Much remains of the general appearance of the campus is as it was around 1900 and many of the buildings—even the more peripheral ones such as the Victorian residences—have been classified by specialised heritage architects as worthy of preservation. Certain of them have considerable architectural merit.

- *The Royal Observatory complex as an entity in itself*

  The observatory campus forms a coherent enclave of scientific buildings. It was administered at first by the Royal Navy and, even following the Simonstown agreement (when the Royal Navy withdrew from South Africa), enjoyed extraterritorial rights. This led to a certain unique atmosphere and a feeling that it was a special outpost of empire. The buildings are all white-painted in the general style of Cape Town, with its Dutch colonial heritage. For much of the twentieth century there was little change or development, leading to a unique atmosphere preserved up to the present day. Many visitors comment on its 'rus in urbis' feel.

- *The Main Building*

  The Main Building of the Observatory (see Figs 8.1 and 8.2) was completed in 1828. The architect of this Greek Revival structure was John Rennie the Elder (1761–1821). He was born in East Lothian, Scotland and worked for James Watt at Soho before opening his own engineering business in 1791. He was considered to be 'a man of unbounded resource and originality'. He designed many canals, bridges, docks, breakwaters and even a lighthouse. Among his most famous works was Waterloo Bridge, London. Two of his sons also became notable engineers.

  His designs for the Royal Observatory, dated 1 March 1821, are located today in the Public Record Office (UK) and have been reproduced by Warner, B., 1979, in 'Astronomers at the Royal Observatory, Cape of Good Hope', Balkema, Cape Town and Rotterdam. Some copies of these exist at the Observatory.

Rennie was Chief Engineer to the Admiralty. Unfortunately, he died before the construction commenced. The Admiralty sent out John Skirrow as Clerk of Works. Building commenced in 1825 and was completed early in 1828. The choice of building materials was left to Skirrow.

The walls are made of plastered-over uncut stone and the floors, doors, window frames, stairs and shutters, which still remain, were made of teak. The ironwork of the shutters is still in place. The impressive Doric pillars were constructed of brick with wooden cladding.

The upstairs window sashes of the residential wings are unusual in that they can be raised into the walls completely to allow free air circulation on hot days. The corners of the cornices feature small plaster flowers.

The first instruments, a mural circle and a transit telescope, were installed and ready for operation by the end of 1828. The only relics of these instruments still at the Observatory are their objective lenses. However, the Hardy clock that was used in connection with Right Ascension determinations is still there.

In 1829 the domes made of copper and brass arrived (see Fig. 8.12). However, they turned out to be unwieldy. Instruments within them were only supported by the roof and were subject to severe vibrations. They remained unused and were removed in 1883. The last instrument within the Main Building, an Airy Transit Circle similar to that at Greenwich, was removed in 1950, though its eye-end and objective have been preserved. The 'chases', or openings in he walls and roof, through which the Circle viewed the sky were also filled in at this time. The central 'lantern' structure was removed in 1961 and replaced by a skylight.

At the present time, the central rooms of the building are used to house the national library for astronomy. The bookcases date from the nineteenth century. The rooms in the wings, which were originally used as residences, are now mostly offices for the astronomers.

- *The McClean Building*

The next building of special architectural significance is the McClean, officially the Victoria, Telescope (Fig. 8.3). This was completed in 1896.

The building was designed by (later Sir) Herbert John Baker, the best-known colonial architect to have worked in South Africa. It is one of his earlier designs, following his rapid success after being patronised by the financier and politician Cecil Rhodes.

Baker executed several large projects, such as the Union Buildings in Pretoria. There are many examples of his work throughout South Africa, including private houses, churches and various government buildings. This observatory was an early project and one of a kind.

Baker combined some elements of Dutch colonial architecture with British ideas. His use of stone courses and his unusual door shapes are characteristic. He often specified artistic details such as the rainwater box-funnels above the downpipes, which carry the date 1896.

The Observatory possesses two of Baker's original drawings of this building.

The rotating dome was built by Cooke of York. The latter was originally rotated by a hydraulic motor, but this was later abandoned in favour of electricity. The dome features a rising floor, still powered hydraulically. The original 3-cylinder hydraulic pump (Fig. 8.4) is still in use, powered by an A.C. motor of 1920s vintage. The previous D.C. motor has been preserved. Adjacent to the dome is a battery house (1897) that stored energy generated during the day from a steam-powered plant for use at night.

Fig. 8.3. Exterior of the McClean Building (dome and laboratory). Photograph © Ian Glass

The telescope was made by Howard Grubb of Dublin. Considerable difficulties were experienced during the construction. These have been documented by Glass (1997).

As the McClean building was being constructed, it was decided to add an astrophysical laboratory. This still exists, with its original cupboards, benches and fittings. It was the first spectroscopic laboratory in South Africa. It saw use in the period 1972–1987 as an infrared instrument laboratory and has been used since then as a museum.

The telescope was used over the years for spectroscopy and parallax work, with many publications resulting. An item of special interest was the determination of the diameter of Arcturus in the 1950s by David S. Evans using high-speed photometry during a lunar occultation.

The telescope is nowadays used on open nights for public viewing and, very occasionally, for special occultation events.

- *The photo-heliograph building* of 1848 (see Fig. 8.5) was originally built to house a 7.5-inch Merz telescope. The most interesting feature of this building is that it has a pre-fabricated wooden dome that runs on cannon balls.

- *The old workshops and engine room*, though architecturally of little interest, originally contained a steam-powered electricity generating plant dating from 1888, one of the first such installations in South Africa.

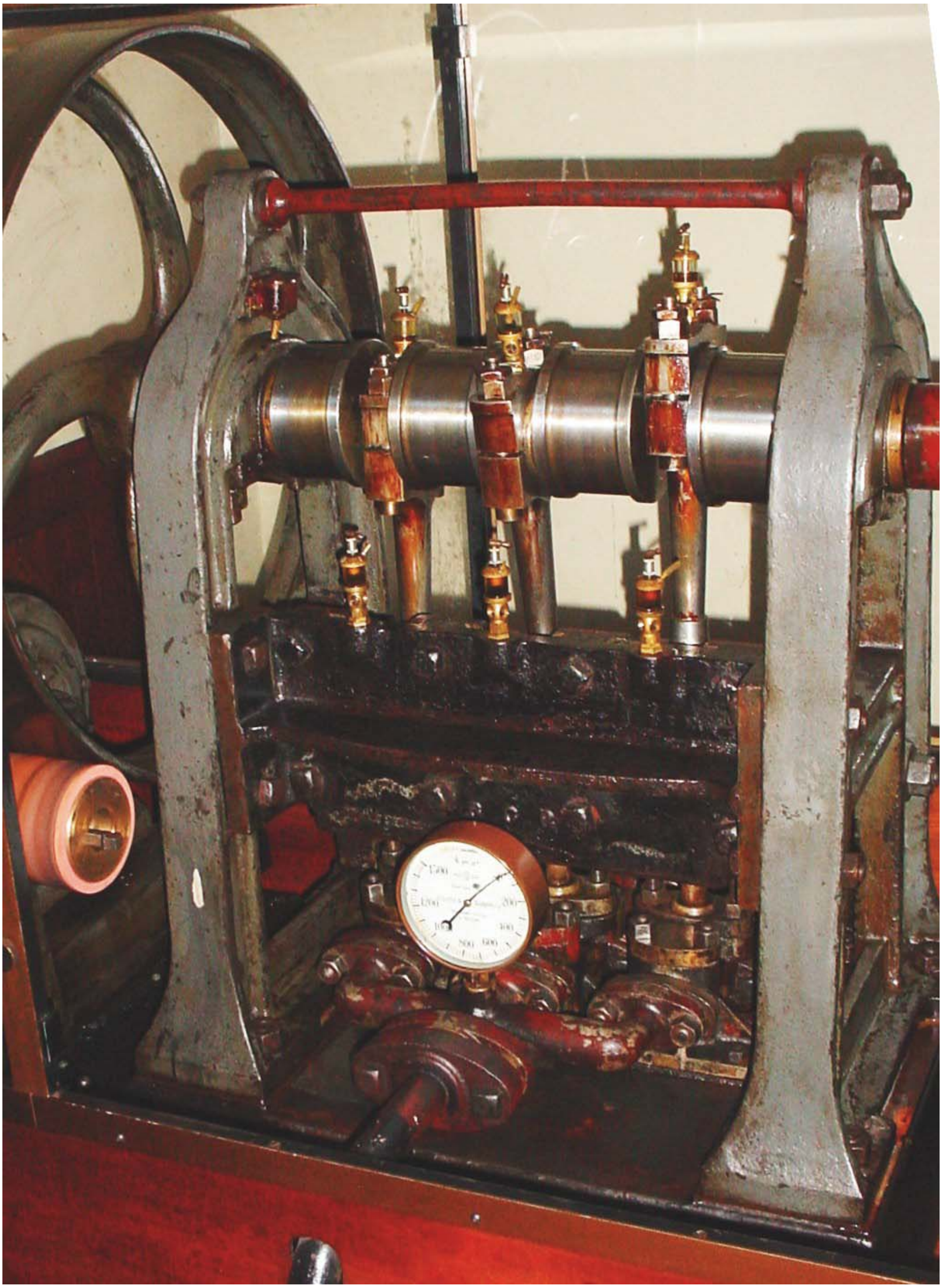

Fig. 8.4. McClean dome: the three-cylinder hydraulic pump (1896) that provides power for the rising floor. Photograph © Ian Glass

Fig. 8.5. Photoheliograph dome (1848). The wooden prefabricated dome, made in England, originally housed a Merz 7-inch telescope (1848) and now contains the De la Rue or Kew Pattern Photoheliograph made by Dallmeyer in 1875, mounted on a stand by Troughton and Simms (1874). Photograph © Ian Glass

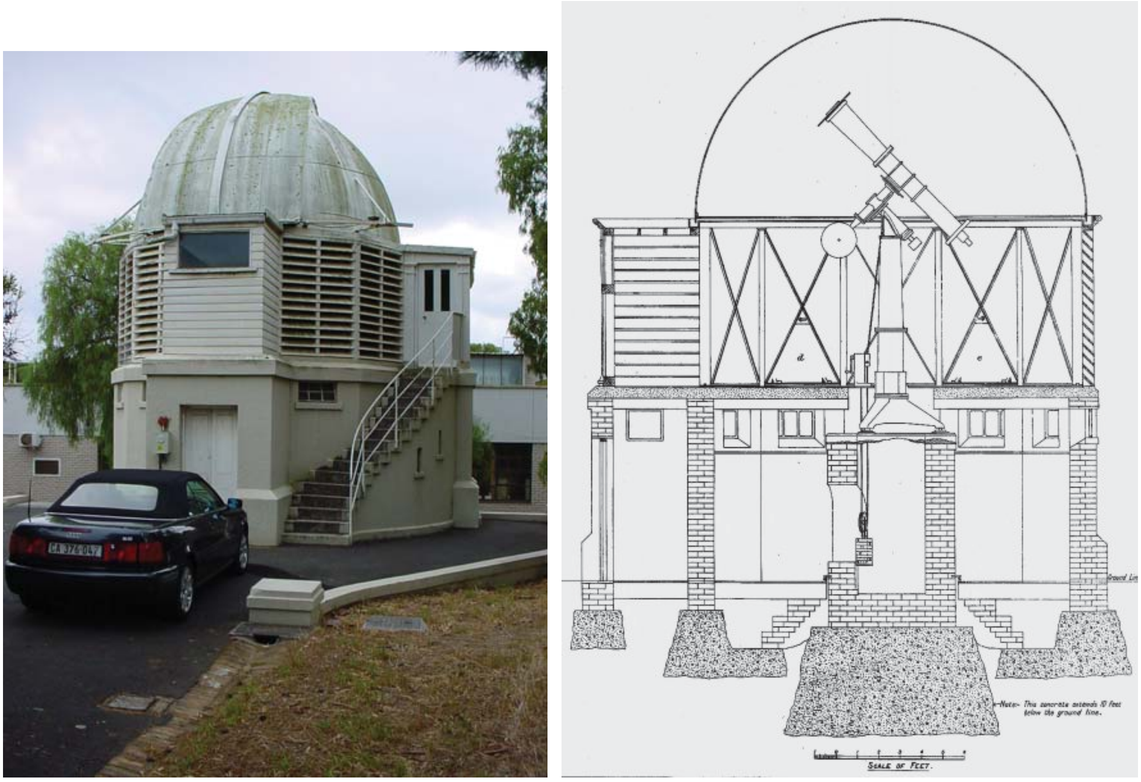

Fig. 8.6. Left: Heliometer dome with louvres for cooling and openable sides (1887). This dome houses the 18-inch reflector (1955), mounted on the original heliometer stand by Repsold. Photograph © Ian Glass. **Right:** Drawing of Heliometer dome as originally designed. Copyright © SAAO

- *The 18-inch building* (see Fig. 8.6), originally used for a Repsold heliometer, was designed by Gill with louvres and openable sides to allow for rapid equalization of inside and outside temperatures, a very modern idea. The metal skeleton of the upper part of the building and the dome were by Howard Grubb of Dublin. The only similar Grubb construction is a building at Armagh Observatory in Ireland of about the same period.

- *The Astrographic (Carte du Ciel) building* of 1890 still exists, with its telescope.

- *The Reversible Transit Circle building* of 1905 is in a double (inner and outer) steel building, designed to keep it cool during the day. It is accompanied by interesting collimator and mark houses.

- *Two nineteenth-century graves* of astronomers are located on the grounds: the first Royal Astronomer, Fearon Fallows, and that of Sir Thomas Maclear, together with his wife.

In addition, there are a number of 19th century observers' residences, meridian marks, small outbuildings, etc.

Movable heritage objects

Introductory note

The remainder of the tangible heritage consists of movable heritage objects, of which there are vast numbers given the length of time that the Royal Observatory has been functioning. Note, however, that the domes, and the rising floor of the McClean building, have not been included in this list. They were taken to be parts of the buildings, even though strictly speaking they are movable.

Telescopes

- *7-inch (18cm) telescope* by Merz (1849). Used for the Transit of Venus 1882. Used also by RTA Innes (later the discoverer of the nearest star, Proxima Cen) who discovered with it 'Kapteyn's Star' and for double star work. Its Repsold stand was discarded at an early stage in its history as being too flimsy and it was probably then placed on the Troughton and Sims stand now used for the photoheliograph in its original dome. It is currently mounted as a guide telescope for the 18-inch described below.
- *'Kew Pattern Heliograph'* by Dallmeyer (1875). This telescope was used to take pictures of the Sun to monitor sunspots on behalf of the Royal Greenwich Observatory. Originally it was mounted on its own stand in a wooden revolving building whose foundation can be seen near the Astrographic building. It was moved to its present location in 1929.
- *6-inch (15cm) telescope* (Grubb, 1882). Though in a 1930s building, this telescope has an interesting history. It was with this that the bright comet of 1882 was first examined by Finlay, an assistant at the Observatory. The first astronomical photographs were taken on site with a camera mounted on this telescope so that it could be guided. It was also used by W. de Sitter for early photoelectric photometry.
- *Astrographic telescope* (Grubb, 1889). This was one of twelve telescopes of equal aperture (33cm) and 3.43m focal length, giving a plate scale of 1 arc min per mm, that were used for the international *Carte du Ciel* project. Its guider has an aperture of 10 inches.
- *McClean (Victoria) telescope* (Grubb, 1897). Three telescopes, a photographic refractor of 61cm aperture, a visual refractor of 46cm aperture and a guider of 20cm aperture, all having focal lengths of 6.8m, were provided. The first work with it used an objective prism for spectroscopy. Later, there was a 4-prism spectrograph and after 1925 it was devoted mainly to photographic parallax observations.

  The telescope is still functional and is used for public viewing.

  In 2011 the dome was extensively overhauled and parts of the hydraulic floor mechanism were renewed.
- *Gill transit circle* (15cm, 1905). Gill's design had a profound influence on later Transit Circles. The instrument was constructed by Troughton and Simms and the building was by Cooke of York. It was last used around 1980 and is complete, though in need of restoration.
- *18-inch telescope* (actually 49cm; Cox, Hargreaves and Thompson, 1955) on Heliometer mount by Repsold (1885). This telescope was used for setting up photometric standard stars by AWJ Cousins from the 1950s to the 1990s. His work was valued worldwide.

Small instruments

Very large numbers of small instruments remain in the possession of the Observatory and are displayed in a museum formed from the spectroscopy laboratory attached to the McClean Telescope building. Smaller numbers of antique measuring machines etc. are in storage on-site. A few items from the collection are listed below:

- A repeating transit by Dollond (see Fig. 8.7), described in a publication of 1820. (It was used by the first astronomer before the completion of the main building.)

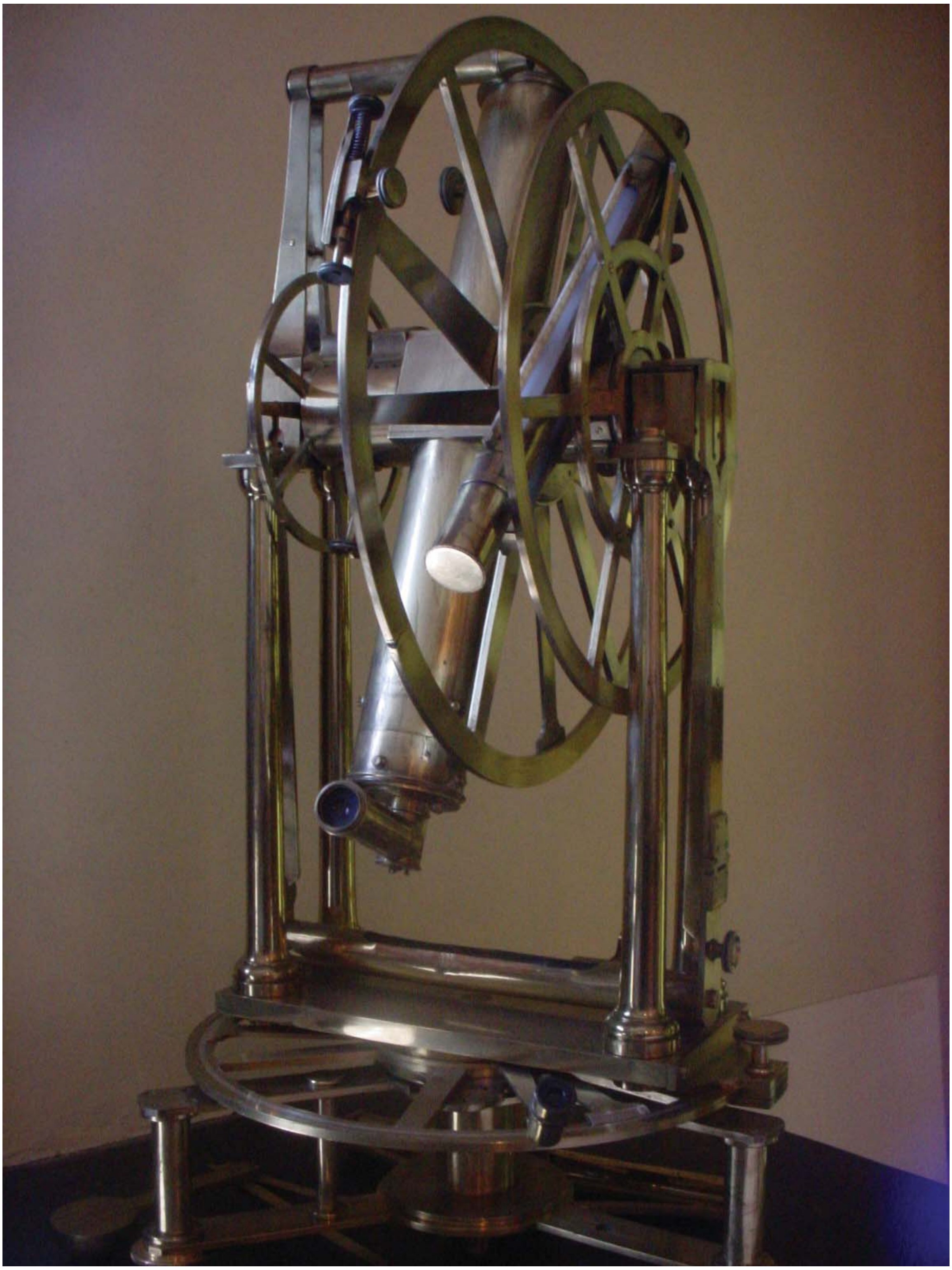

Fig. 8.7. Dollond Repeating Transit (ca 1820). Photograph © Ian Glass

Fig. 8.8. Dallmeyer Portrait lens (1880s) used for making the Cape Photographic Durchmusterung, the first photographic sky survey. Photograph © Ian Glass

- A speculum metal mirror by W Herschel (1811). This, with a telescope that no longer exists, was purchased second-hand from Glasgow around 1820.
- Time signal pistol (ca 1833). This flare pistol was fired by the HM Astronomer from the roof of the Main Building at a set time each day to enable sea captains in Table Bay to set their chronometers.
- Regulator clocks by Molyneux, Hardy, Dent and Riefler (total: 9). The Hardy clock, which dates from the 1820s or slightly earlier, was in the Transit Room and was used by Henderson in his α Cen work; the Molyneux clocks (one each sidereal and mean) date from about the same time.
- Six nautical chronometers, by various 19th Century makers, some set to run on sidereal time.
- Ross lens used by Gill for his epoch-making photography of Great Comet of 1882.
- Large Dallmeyer portrait lens (see Fig. 8.8) used for Cape Photographic Durchmusterung – the first photographic sky survey.
- Eyepiece and lens of Airy Transit circle (installed 1854).
- Victorian Standard Weights and Measures Box (see Fig. 8.9—the contents are said to be in a storeroom of the Iziko South African Museum in Cape Town).

Books

The library (Fig. 8.10), which is the national library of astronomy, is the most comprehensive astronomical library in the country, both for antique and contemporary material. It occupies the central room of the Main Building.

An early inventory of library books dating from 1830 still exists and essentially all of these are still present. In addition some of the past directors collected interesting editions of antique books, which today form part of a special collection.

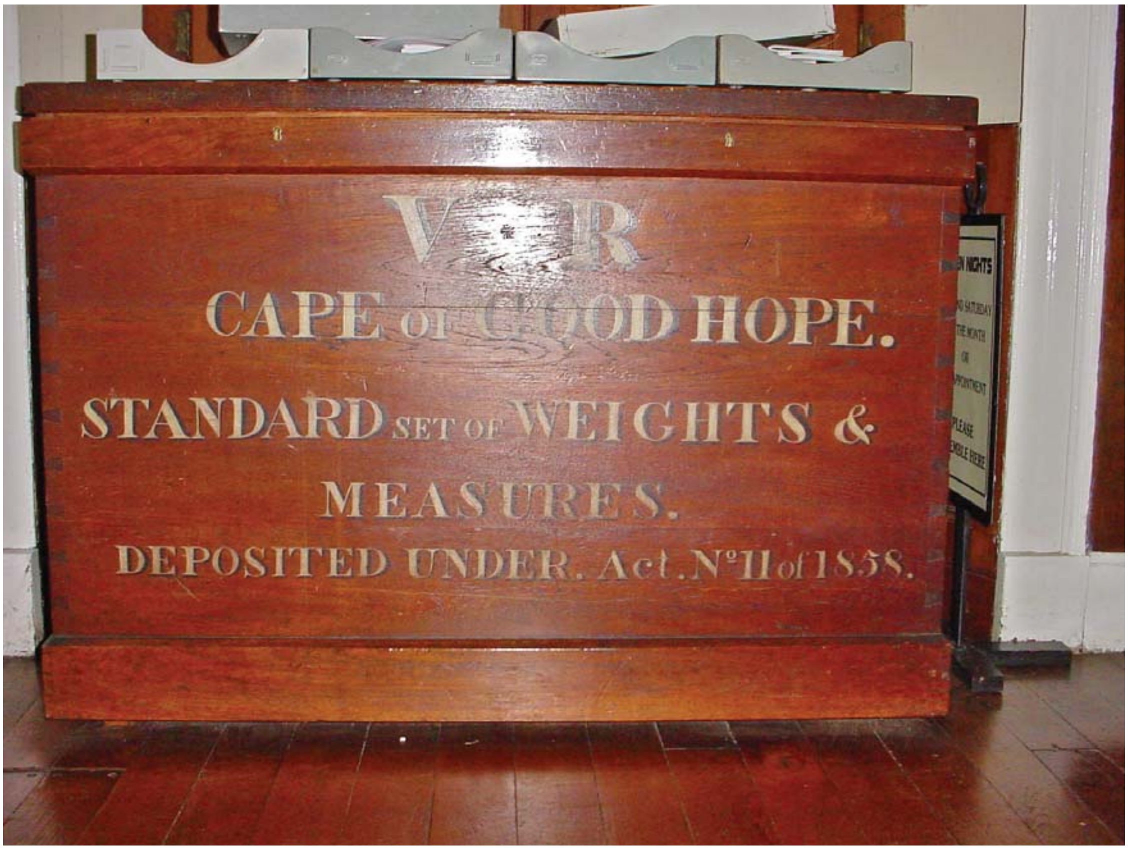

Fig. 8.9. Box that contained the standard weights and measures for the Cape Colony. Copyright © Ian Glass

The library contains many interesting series of journals, believed complete, such as the Royal Academy of Sciences (Paris, starting in the 17th century), The Royal Astronomical Society (Monthly Notices and Memoirs), The Observatory, Astrophysical Journal, Astronomical Journal, Royal Society, Philosophical Magazine etc. These series are unique in South Africa.

Archives

The Archive Room contains thousands of records dating from all periods of the Observatory's existence. Certain sections of these were removed and merged with the Royal Greenwich Observatory records (now in Cambridge University Library) when the site was transferred to the South African Astronomical Observatory in 1972.

Though the selection seems to have been somewhat haphazard, the main items to have been removed seem to have been the astronomical correspondence.

Pictures

The Observatory contains a number of original artworks. Especially noteworthy are a number by the early Cape artist Thomas Bowler, who worked for a time at the Observatory. In addition there are 27 ink and wash drawings of scenes encountered during a geodetic surveying project around 1842. They are by Charles Piazzi Smyth, one of the assistant astronomers, later Astronomer Royal for Scotland. A fine portrait in oils of Sir David Gill (see Fig. 8.11) is shown here.

In addition there are small numbers of prints – engravings, lithographs etc.

Fig. 8.10. The central room of the library, Main Building. Photograph © Ian Glass

Fig. 8.11. Portrait of Sir David Gill by G.M. Winkles (1897), 116cm × 97cm. Copyright © SAAO

Other movable heritage objects

- The observatory possesses large numbers of *mechanical drawings and blueprints* concerning the telescopes and accessories. Certain of these date from the 19th century and are from the Grubb firm of Dublin.

- Many original *architectural drawings* of the buildings and drawings of modifications are still present. Plans of almost all the buildings from the late nineteenth century are preserved.

Photographic records: paper prints and plates

Many of the glass stellar image plates were disposed of on the grounds that they were not being made use of and occupied space that could be used for current research. Only representative samples and images of some unique objects such as comets were retained. However, all the spectra taken with the McClean telescope are still extant. Plates from Radcliffe Observatory are also stored.

Large numbers of glass plates of scenes, people, buildings etc. dating from the Gill period are still extant. Many of these have been digitized at high resolution.

Photographic prints of scenes, people, observatories etc. also exist in large numbers. Some date from the nineteenth century. By and large these items are stored rather casually and are only partially catalogued.

2.b History and development

In pre-colonial times the site was probably used for grazing by the indigenous San (Khoina) pastoralists (also sometimes referred to as Bushmen) who preceded the Bantu peoples in Southern Africa. During the first decades of the Dutch East India Company Colony it was on the boundary of the secured area. Later, but before it was acquired for the Observatory, the area was farmland, though it remained rocky, treeless and windswept.

The Royal Observatory, Cape of Good Hope, was created on 20 October 1820 by an Order of King George IV of the United Kingdom, of which the Cape was by then a colony. The first building was completed in 1828.

It was the first scientific institution of the Cape Colony, which had been established by the Dutch East India Company in 1652 and taken over by the United Kingdom in the early nineteenth century without much attention being given at first to things such as education and scientific matters. Increasing numbers of immigrants stimulated the development of schools, libraries and a greater scientific interest in the environment.

Though intended to serve primarily the interests of the Royal Navy, by the mid-nineteenth century the Royal Observatory, Cape of Good Hope, had come to be regarded as a source of advice to the colonial government on scientific matters, mapping and standards. For much of the 19th century it occupied an important position in the Cape Colonial hierarchy, His or Her Majesty's Astronomer (HMA) being called upon to give advice and to serve on the boards of cultural and educational institutions. To the general public it was known as the supplier of time services, firing a noonday cannon in the harbour (as it still does) and time balls at various places in the Cape Colony. It was also the repository of standard weights and measures for the colony: the weather records are the longest-running in South Africa.

Development of the site proceeded slowly at first. Certain basic amenities were lacking thanks to a budget cutback in 1826 and items such as the provision of proper sanitation and security fencing were delayed by several years. In the fourth decade of the nineteenth century a number of buildings were erected to form a magnetic observatory of which nothing now remains. Two additional domes were erected around this time (of which one is still extant). However, dating from Gill's time, i.e. from 1879 to 1907, the site began to take on its present appearance.

The Heliometer, Astrographic, McClean and Reversible Transit Circle domes or housings, besides a number of the dwelling houses for staff, were built during his regime. The twentieth century saw the erection of a new office building around 1930 as well as buildings for a 0.75m telescope, a 1m telescope (since demolished), a Lyot Coronagraph, an engineering workshop and residences. The large 'Technical Building' was erected around 1987 to house the technical departments; today it also includes the headquarters of the South African Large Telescope at Sutherland (a separate legal entity from the South African Astronomical Observatory).

The observing rooms of the Main Building ceased to be used as such during the second half of the nineteenth century and the first half of the twentieth. The wings of this building, which were originally the residences of His or Her Majesty's (HM) Astronomer and the main assistants, were converted to office use in the second half of the twentieth century.

The main telescopes continued in research use until around 1980, by which time most observing activities had become concentrated at Sutherland. The increasing light pollution from the surrounding city was largely responsible for this. However, a notable exception was the 18-inch (49cm), where A.W.J. Cousins carried out photometric standard work on bright stars that found worldwide acceptance. Today, the telescopes are only rarely used for research but form a valuable resource for interesting the public in astronomy.

As time went on, it became possible for the successive astronomers to diversify away from the purely utilitarian measurement of star positions and the provision of a time service as envisaged by the Observatory's founders and take an interest in broad scientific questions. By the last quarter of the 19th century the Royal Observatory had become for the most part a research institution. Today it forms the headquarters of the South African Astronomical Observatory, where astronomers have their offices, data reductions are carried out and instruments are constructed. The current observational activities of the SAAO are centred in Sutherland, about 400km into the interior.

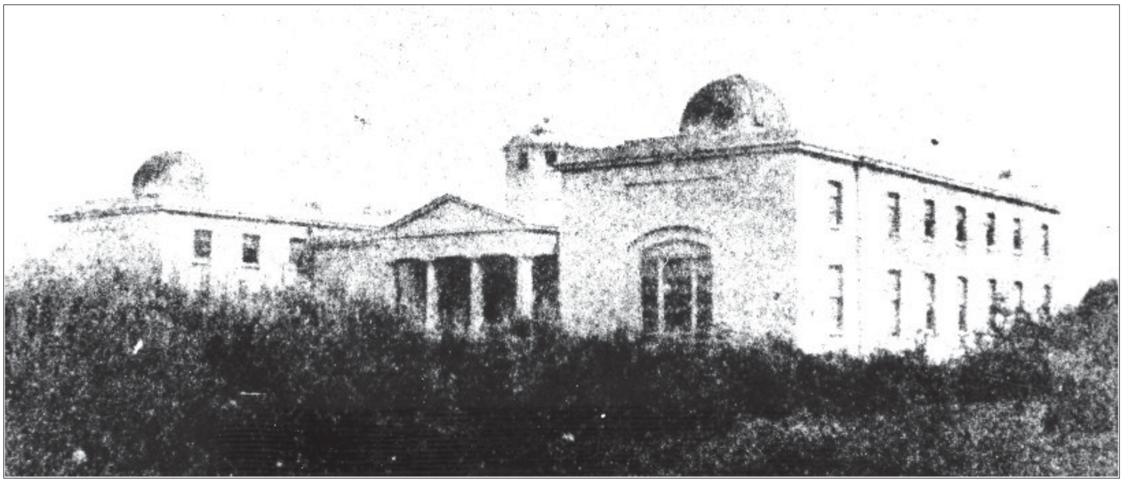

Fig. 8.12. Calotype of the Royal Observatory by C.P. Smyth, dated ca 1842. This is the oldest photo of an observatory and one of the oldest photographs taken in South Africa. It is owned today by the Royal Society of Edinburgh. Courtesy Brian Warner

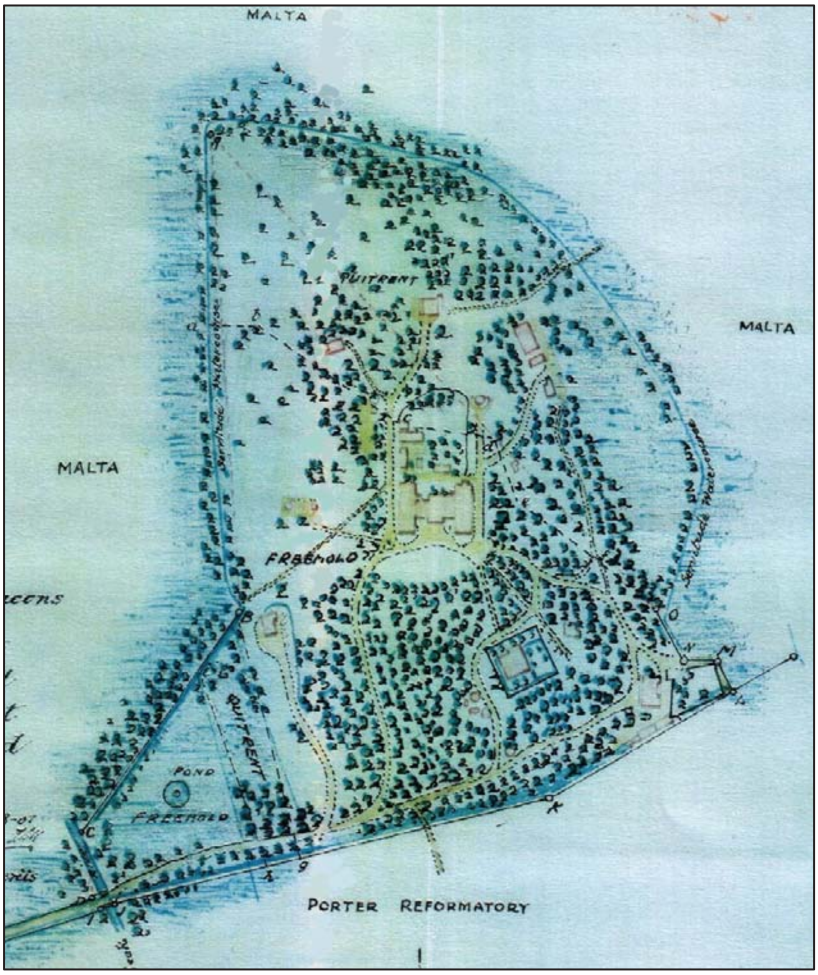

Fig. 8.13. Map of the Royal Observatory dated 1888. Copyright © SAAO

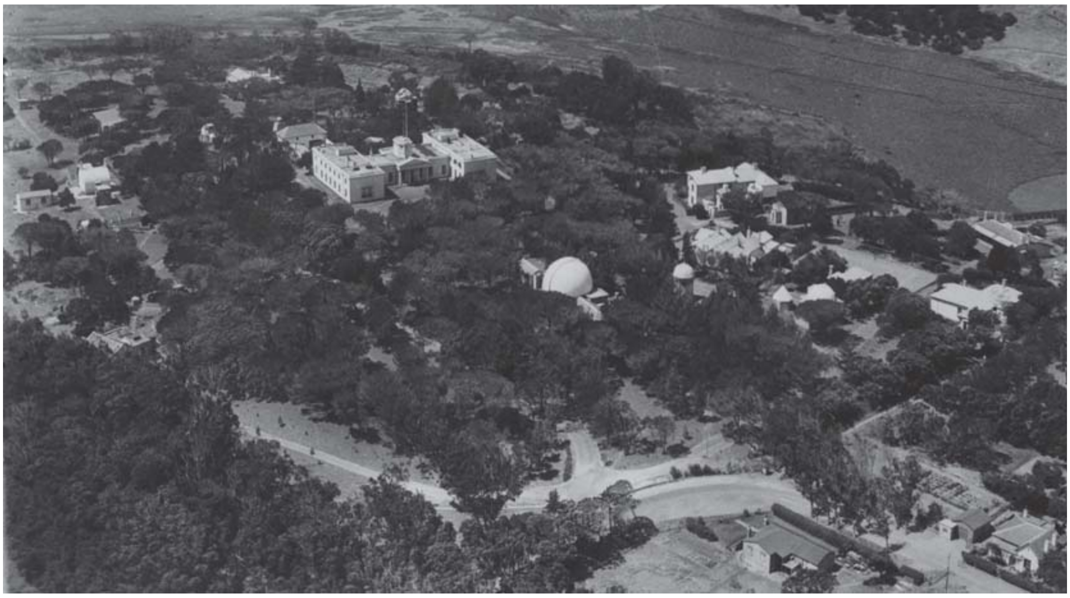

Fig. 8.14. The Royal Observatory in the early twentieth Century. Photograph © SAAO

3. Justification for inscription

3.c Comparative analysis

Initially, the tasks of the Royal Observatory Cape of Good Hope were largely similar to those of the Royal Observatory Greenwich (ROG) in England. Though to some extent a daughter institution, it was essentially parallel to it in purpose and fell, like ROG, under the direction of the Hydrographer of the Royal Navy. During his tenure as Astronomer Royal (head of ROG), the dominant G.B. Airy managed to exert considerable influence on the running of the Cape Observatory. However, the Hydrographer worked directly with Gill during his time as HMA, following perceived hostility (possibility originating from jealousy) on the part of Christie, the Astronomer Royal at Greenwich.

Like the ROG, the Royal Observatory Cape of Good Hope was usually—especially at first— directed by a graduate with mathematical knowledge and the remainder of the staff were not expected to be intellectually independent. While well-educated Assistant astronomers were appointed from time to time, most of the rest of the staff were expected to be routine workers, even 'harmless drudges'. A great many human computers were employed there over the years and several of these (usually temporary employees) found fame elsewhere in later life.

The Royal Observatory was similar in purpose to many others founded in the late eighteenth and early nineteenth centuries. That period saw a rapid improvement in sidereal position-measuring technology and the instruments that were installed in 1828 represented the state of the art. The astronomers and their assistants spent most of their time in 'grinding the meridian', i.e., in positional measurements, though at various times they had to conduct geodetic surveys in the field. This unusual feature of the Royal Observatory's work was conducted mainly under Thomas Maclear and David Gill. In the early 1900s, survey work was transferred to a separate institution.

Though other observatories were set up in the southern hemisphere, the Royal Observatory managed to attain a pre-eminent position by the end of the nineteenth century. This may partly have been due to its relative proximity to Europe and the clarity of the Cape atmosphere. However, by the end of its existence, its limited involvement in astrophysics and the increase of light pollution rendered it of less central relevance to astronomical research.

The visit of Sir John Herschel to the Cape for a few years in the 1830s involved considerable collaboration with Maclear's Royal Observatory, though he worked at a different site a few kilometres distant.

The productivity of the Royal Observatory in the late nineteenth century was relatively high when compared with many of its contemporaries, thanks to the energy of Gill as director. He was able to attract a number of eminent scientific collaborators, among whom can be mentioned von Auwers, de Sitter, Kapteyn, Innes, McClean and Franklin-Adams.

The obvious comparison from an architectural point of view is to the Cambridge Observatory of 1823, another building, similar to the Royal Observatory's Main Building, in neo-classical style. Both observatories housed transit-style instruments which looked through 'chases' in the walls and roofs and had wings that were used as residences for the astronomers. The Cambridge Observatory was founded by the University and was not a government institution.

In Australia, the Parramatta Observatory was established by Sir Thomas Brisbane in 1822 but existed only until 1848. It was a much smaller building, about 8.5m square, and did not enjoy significant official support.

3.d Integrity and/or authenticity

We are fortunate in having a number of drawings of the Observatory dating to ca 1833 by Thomas Bowler and even photographs dating from 1842 (see Fig. 8.12). The latter, taken by C.P. Smyth, are the oldest photographs originating in South Africa and the oldest of any observatory anywhere excepting J.F.W. Herschel's photograph of his father's 48-inch telescope.

Many of the buildings on the site are unaltered. The Main Building, commenced in 1825 and completed in 1828, is still extant and has been modified only marginally. Two copper domes, shown in the 1842 photograph, were removed in 1883 and the central lantern structure was removed in 1961.

The Royal Observatory, as a living institution, has evolved continuously since its foundation. The original instruments, consisting of a transit and a mural circle, were located in the Main Building. By 1855, these had been replaced by a transit circle designed by Airy. In 1849 a 7-inch Merz telescope with dome was added. A magnetic observatory, comprising several buildings, was established in 1841 but none of these survives today.

Still within the 19th century, a photo-heliograph designed by de la Rue was installed in 1876.

During the régime of David Gill, one of the greatest astronomers of the 19th century, activity on the site reached its zenith. Numerous buildings from Gill's time are extant, including the Astrographic dome (1888), the Heliometer dome (1888), the McClean dome (1895) and the Gill Transit Circle (1905). Also during this period several houses were constructed to house astronomers and their families.

The 20th century saw the New Offices (ca 1920), the WWII Optical Workshop (now lecture theatre), the Lyot coronagraph (1958) and the Technical Building (ca 1988).

Numerous other small buildings have come and gone during this period, including the Franklin-Adams telescope (ca 1909), the 40-inch (Elizabeth) Telescope (1964) and the Astrolabe Hut (ca 1960s).

3.a Potential criteria under which inscription might be proposed

Criterion (ii): The Cape Observatory represents a supreme example of the interchange of scientific and technological expertise that allowed 'state-of-the-art' working observatories to begin to be constructed around the world during the early nineteenth century. Its continuing connectivity with its European counterparts together with its location in the southern hemisphere and hence its unimpeded view of the southern sky ensured that the Cape Observatory rapidly established itself as *the* major contributor to positional astronomy in the southern hemisphere, a position it maintained until for over a century. The observations carried out here made an outstanding contribution to the fundamental celestial catalogues of successive epochs.

3.b Suggested statement of outstanding universal value

The Royal Observatory was the first major scientific institution to be erected on the continent of Africa. It is also the first permanent Observatory to have been constructed in the southern hemisphere. For most of its existence it has been *the* major contributor to positional astronomy in the southern hemisphere. Working in collaboration with its European counterparts, observations of the southern sky not possible from northern latitudes helped to complete several successive projects to map the entire celestial sphere, including the first systematic photographic sky survey instigated by David Gill in 1885.

The Cape Observatory has been the setting for a series of seminal scientific achievements, among them the first successful measurement of the distance of a star (by Thomas Henderson in 1832–3); the first use of photography to make a systematic sky survey (by David Gill from 1885); the accurate measurement of the 'Astronomical Unit' (distance of the earth from the sun) made by Gill at around the same time; and, more recently, the measurement of stellar angular diameters by means of lunar occultations (by David S. Evans in the 1950s).

The Cape Observatory is an outstanding example of the buildings, telescopes, instruments and paraphernalia of the working 19th century observatory—an ensemble of immovable and movable items that, together, typify the 'machine of science' that was used at this time for the determination of time and the systematic mapping of the cosmos. It also includes some exceptional elements, most notably the Greek Revival Main Building, which is almost unique among observatories worldwide, and the McClean or Victoria building of 1896, designed by the famous colonial architect Sir Herbert Baker in his own unique style.

4. Factors affecting the property

4.a Present state of conservation

Most of the buildings are regularly maintained but certain of those not in use for current astronomical projects require restoration. In particular, the Gill Reversible Transit Circle building of iron and steel is in poor condition. The archives and retired instruments are generally well-protected from environmental damage.

Some workshop time is committed to maintaining the telescopes and domes, though a greater commitment would be desirable.

Certain of the old instruments have recently been restored. These include the Merz 7-inch telescope and the de la Rue photoheliograph.

Some of the buildings require reasonably frequent maintenance, particularly those (most of them) that have painted exterior walls. Obtaining funds for this purpose is usually difficult except for those used for current research, such as the Main Building. However, due to a fortunate combination of circumstances, it was possible recently to commission a major refurbishment of the McClean building, with special attention to its shutters and the hydraulic power storage cylinder.

A museum in the former McClean laboratory contains a selection of the smaller antique instruments no longer in use, ranging from the Dollond Repeating Transit (1820) (Fig. 8.7) used by Fearon Fallows to the photometry equipment of Alan Cousins, in use until about 2000.

4.b.i Developmental pressures

The main threat to the Royal Observatory site lies in the ever-increasing pressure on open urban land from real-estate developers.

4.b.ii Environmental pressures

The sky is already too bright for many types of astronomical work. However, it remains free of particulate pollution much of the time. This fact enabled bright standard star work to be carried out until the end of the 20th century. However, since most observing activities have been transferred to Sutherland, sky conditions have almost ceased to be relevant.

4.b.iii Natural disasters and risk preparedness

The most likely natural disaster would probably be flooding from the nearby rivers. Urban development upstream has increased the speed of water run-off after heavy rain and this leads to occasional flooding of the lower reaches of the Observatory property. Only the Victorian workshop and an uninspiring house of ca 1960s vintage are at risk. The tendency towards flooding can even be regarded as a form of protection against development.

Fires from dried-out reed beds close to the property are an occasional risk in summer. The site residents have been trained in fire protection and the vegetation near the buildings is kept low to prevent fires from approaching. There is an extensive network of fire hydrants.

Earthquakes are rare and have generally been quite weak.

4.b.iv Visitor/tourism pressures

The numbers are manageable at present.

4.b.v Number of inhabitants

The houses on the site typically accommodate about 30 people including spouses and children.

5. Protection and management

5.a Ownership

The property is owned at present by the National Research Foundation (NRF) of South Africa, the umbrella agency of which the SAAO and a number of other scientific institutes form part. The NRF itself is part of the Ministry of Science and Technology. It is expected that the NRF as the controlling agency will be replaced by a new astronomical agency in the near future.

The site is used exclusively for astronomical purposes.

5.b Protective designation

The property is surrounded by the Two Rivers Urban Park, a conservation area established by the City of Cape Town. This offers some degree of protection against urban development. The Observatory is bordered to the east and north by wetlands, and as such is protected in principle from encroachment, but a limited area of the site lies above the flood line.

Classification as a National Heritage Site is imminent.

Another type of protection is the requirement that heritage objects are secured from theft. While theft by ‘collectors’ has not yet become a significant problem, metal thieves are a threat, especially in a poor community. Alarms, protective measures and security staff are undergoing constant review.

5.h Visitor facilities and infrastructure

The principal facilities devoted to visitors at present are a lecture room with a seating capacity of about 100 persons, an Astronomical Museum, access to the McClean and 6-inch telescopes, and the library. Besides being of service for in-house lectures and seminars, the auditorium is useful venue for student courses. In the evenings various external societies including the local Astronomical Society and some other scientific societies meet there. The auditorium includes a display area suitable for poster presentations and a small kitchen. Small conferences are often held there. Daytime visitors have the opportunity to look at sunspots using the photoheliograph (equipped with a ground glass screen).

For many decades there has been a public outreach programme. Open nights are held twice monthly or more often, in which members of the public are given free of charge an introduction to the Observatory, a lecture on an astronomical topic and sky-viewing opportunities. In addition, many school and other groups tour the establishment during the daytime. Special tours including the technical workshops and other facilities are sometimes arranged. A ride on the rising floor of the McClean telescope is something that many Capetonians remember from their schooldays.

Typically there are at present about 6000 visitors per year (from schools and the general public) who specifically come to view the site. This does not include those whose purpose is only to attend meetings or conduct business etc.

5.i Presentation and promotion policies

There is a keen interest in the history of the site and recently an independent 'Friends of the Observatory' group has been organised, with restoration of old instruments and domes as a major theme.

An application to the South African National Heritage Agency is currently in progress. If approved it would be the first SA cultural property designated for its scientific research history.

7. Documentation

7.a Photos and other AV materials

Photographic inventories of heritage objects are in course of preparation, partly in order to increase awareness among the astronomical staff and partly for security reasons.

7.b Texts relating to protective designation

Baumann, N. and Winter, S., 2011 *The South African Astronomical Observatory: A Heritage Survey*, SAAO, Cape Town. This survey was commissioned from heritage architects primarily to understand the value of the built environment of the Observatory. The buildings have been classified in terms of the criteria employed by the South African Geritage Resources Agency.

Van der Walt, L., Strong, N., Mustart, P., 2010. *Observatory Landscape Framework*, SAAO, Cape Town. A study commissioned to identify the ecologically sensitive areas of the Observatory and the scope for further construction without causing environmental damage.

Glass, I.S., 2012. *Intangible Heritage of the South African Astronomical Observatory*, SAAO, Cape Town. Prepared in order to assist the South African Heritage Resources Agency.

7.c Most recent records or inventory

The Royal Observatory is well documented historically in books by David Gill and Brian Warner and by many articles in books and journals. Research on historical matters by various interested parties is fairly continuous.

The site has not been investigated archaeologically.

7e. Bibliography

Baumann, N. and Winter, S., 2011. *The South African Astronomical Observatory: A Heritage Survey*, SAAO, Cape Town. This survey was commissioned from two heritage architects primarily to understand the value of the built environment of the Observatory.

Forbes, G., 1916. *David Gill, Man and Astronomer*, London, John Murray.

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Glass, I.S., 2008. *Proxima, the Nearest Star (Other than the Sun)*, Mons Mensa, Cape Town. Covers the activities of Henderson (parallax of Alpha Centauri) and Innes.

Laing, J.D., 1970. *The Royal Observatory at the Cape of Good Hope 1820-1970, A Sesquicentennial Offering*, Cape Town, Royal Observatory. A useful pamphlet that describes the activities of the Observatory around the end of its time under British control.

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Ruggles, C. and Cotte, M., 2011. *Heritage Sites of Astronomy and Archaeoastronomy in the context of the UNESCO World Heritage Convention, A Thematic Study*, ICOMOS, Paris, and IAU, Paris.

Van der Walt, L., Strong, N., Mustart, P., 2010. *Observatory Landscape Framework*, SAAO. A study commissioned to identify the ecologically sensitive areas of the Observatory and the scope for further construction without causing environmental damage.

Warner, Brian, 1979. *Astronomers at the Royal Observatory, Cape of Good Hope*, Balkema, Cape Town and Rotterdam.

Warner, Brian, 1983. *Charles Piazzi Smyth, Astronomer-Artist. His Cape Years 1835-1845*. Balkema, Cape Town and Rotterdam.

Pic du Midi de Bigorre Observatory, France

Nicolas Bourgeois

Photograph © Haute Pyrénées Tourisme Environnement

1. Identification of the property

1.a Country/State Party: France

1.b State/Province/Region: Midi Pyrénées Region, Hautes-Pyrénées Département

1.c Name: Pic du Midi de Bigorre Observatory

1.d Location: Latitude 42.9374 N, longitude 0.14106 E; UTM (Zone 31N) E 266729 N 4757829. Elevation 2830m above MSL.

1.e Maps and Plans: See Figs 9.1 and 9.2.

1.f Area of the property: The observatory takes up the entire surface of the Pic du Midi de Bigorre summit, that is 3500 m^2.

2. Description

2.a Description of the property

Introduction

The Pyrenees form a natural border almost 400 km long, both separating France and Spain and joining the Atlantic and the Mediterranean. As we approach this indented wall of snow-capped peaks, one of them immediately catches the eye: the Pic du Midi. Benefitting from an exceptional, seemingly privileged geological location, this mountain stands at nearly 3000 m above sea level in the line of the Pyrenean foothills. It thus appears to dominate all the mountains surrounding it.

The mountain's very position and presence has long captivated mountain dwellers, and later scientists. It has been home to history and human adventure for hundreds of years. But as Graham Greene said, there is no beginning or end to history; it is because of arbitrary decisions that we fix it in the river of time.

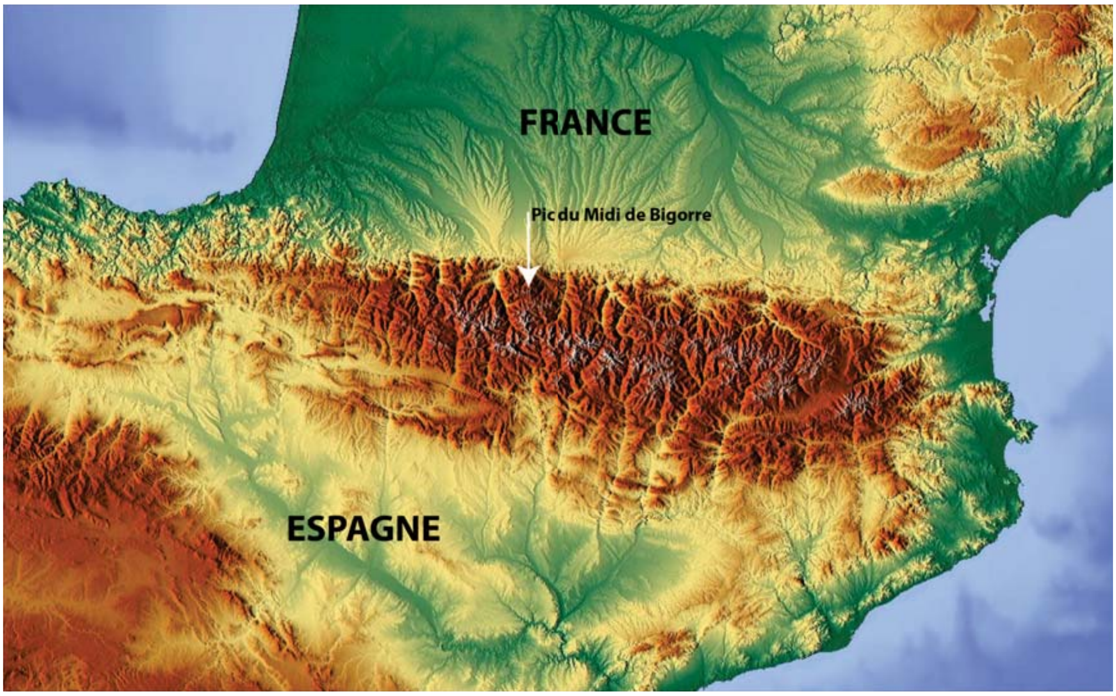

Fig. 9.1. Locality of the Pic du Midi de Bigorre within the Pyrenean Chain. Source: geographdumonde (geographie.blog.lemonde.fr)

Fig. 9.2. Extract from the IGN map, scale 1:50,000. The cable-car line to access the Pic du Midi, leaving from La Mongie, crosses over the Taoulet before reaching the summit. Source: géoportail (www.geoportail.gouv.fr)

Fig. 9.3. The Pic du Midi de Bigorre Observatory by night, in December 2013, facing the eastern horizon. Photo © Nicolas Bourgeois

As we continue towards the Pic du Midi, it is no longer the mountain alone which holds our attention, but the budding domes and grand aerial on its summit. Finally the Pic du Midi Observatory is revealed, a high-mountain scientific fortress that has stood strong for over 130 years.

Our arbitrary decision comes into play here. A new beginning, in 1870: the birth of the observatory and of human and scientific adventure. And now, not an end but an opening: 2014, the year in which the Pic du Midi decided to value and preserve what makes it an treasured inheritance, namely that it is the oldest mountain observatory still working today.

Despite its total isolation, the observatory has made significant contributions in a number of scientific fields that depend on findings at high altitude or in a very pure atmosphere. This is shown by data such as scientific results, publications and prizes, and the number of researchers who have succeeded one another. In so doing it has itself evolved, keeping pace with the development of scientific knowledge.

The unique identity of the Pic du Midi goes beyond the purely scientific realm. Above all, it is a matter of a human adventure that is still continuing today. It is this that accounts for the scale of the heritage described below.

Environment

The Pic du Midi de Bigorre, an exception in Pyrenean geology

The Pic du Midi stands at 2877 m. Nowhere on the northern side of the Pyrenees is there another mountain of comparable altitude so close to the plain. The surrounding peaks reach 2500 m at best.

Fig. 9.4. The Pic du Midi and the Observatory, aerial view, 2010. Photo © Haute Pyrénées Tourisme Environnement

The Pic du Midi owes this characteristic to its geological structure. The rocks that form the pyramid are variable in nature: limestone massif, silicate minerals and schist on the top. This combination has been very much affected by intense metamorphism (the rocks have undergone temperatures of 600°C at pressures of tens of kilobars). The result of this metamorphism was a hardening of the rocks, a recrystallising of them. The limestone massif thus became more resistant to erosion than its surrounding neighbours.

Another outstanding result of the metamorphism is the presence of geological formations known as "barégiennes", in reference to the local town of Barèges. The barégiennes appear to be significant distortions of the geological domain. They are derived from the alternating siliceous beds (which deform rigidly) and carbonate beds (which deform plastically) having been subjected to the increase in temperature and pressure that occurred during the Hercynian period. These barégiennes look like huge, stone snakes and are at the origin of the tale of the legend of Python, the guardian of the Pyrène tomb.

The atmospheric quality and the scale of the panorama

The geological characteristics of the Pic du Midi mean that it benefits from two major assets: excellent atmospheric quality and stability, and a spectacular panoramic view.

The Pic du Midi's altitude rises above the lower layers of the atmosphere where we find dust, droplets and other particles. The summit is situated in the lower troposphere, an atmospheric layer that establishes itself between 2500 and 3500 m above sea level, reversing the natural temperature curve and keeping condensation blocked below. When this limit of this layer is below the summit, the observatory stands above a sea of clouds, allowing access to a sky entirely devoid of particles and light pollution.

The position and elevation of the peak have another beneficial effect: atmospheric stability. The dynamics of the layers of air found in the upper troposphere (3000 to 10,000 m above sea level) depend upon geomorphology. A mountain causes turbulence in much the same way as a stone falling into water disturbs the water's surface. However, when the wind comes from the north or north-east, the first mountain that the air mass reaches is the Pic du Midi. The flow of the airstream is thus laminar, with no turbulence between the summit and the stars.

It was this exceptional atmospheric quality that the first Pic du Midi astronomers took note of in the early twentieth century, and which continues to allow us to conduct many research programmes on the properties of the atmosphere.

From the summit, which rises up above all surrounding landmarks, one enjoys an exceptional view. Count Russel liked to say that from the peak you could see the foothills of the Massif Central by day and the lights of the Biarritz lighthouse by night. His successors, contemplating this, could only confirm it.

The characteristics of this view are such that in 2003 the Pic du Midi was registered by the French government for the beauty of its landscapes. Indeed, on a clear day, the spectacular view offers up all 400 km of the Pyrenean chain.

The properties of this natural viewpoint were, in a way, the first foundations of the Pic du Midi Observatory. Almost a century and a half later, it continues to use them in order to enrich both science and mountaineering in the Pyrenees.

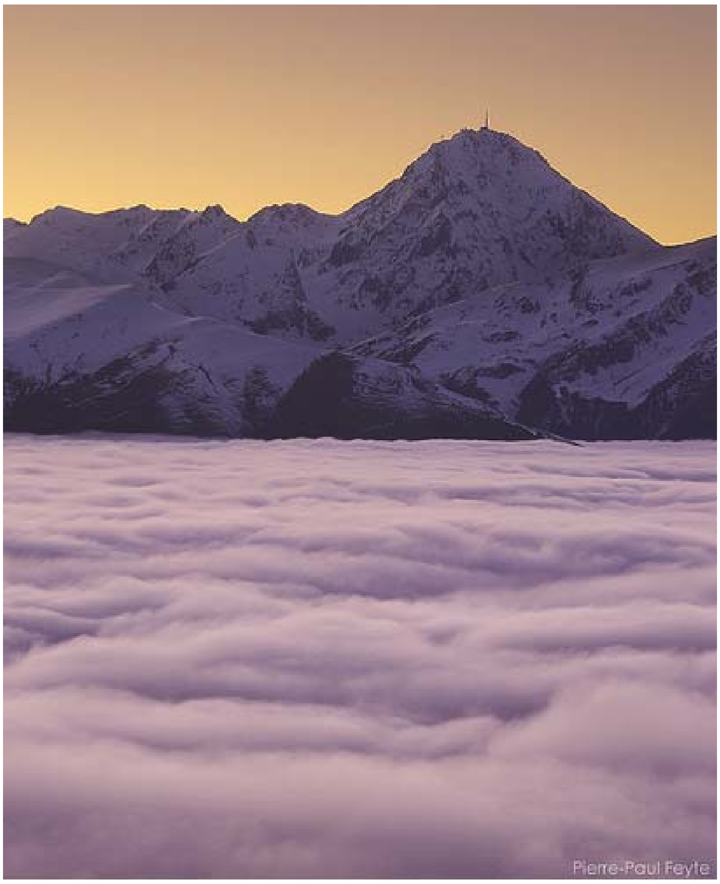

Fig. 9.5. Le Pic du Midi above the sea of clouds, 2009. Photo © Pierre Paul Feyte

Intangible heritage

The Pic du Midi Observatory's contribution to the scientific knowledge of humanity over the 130 years it has existed is very rich indeed and covers a wide range of natural sciences.

The Pic du Midi has been and remains a first class astronomical site owing to the quality of the seeing and the transparency and purity of its sky both by day and night. This quality is now guaranteed by the commitment of all the people working to preserve the sky above the peak following the recognition of Pic du Midi as an International Dark Sky Reserve in 2013.

The Pic du Midi plays a central role in spreading knowledge to visitors from around the world, as much about the quality of its preserved geological landscape as the quality of its night sky. This is open to professional astronomers, amateur astronomers, university students, schoolchildren and the general public.

The use of the Pic du Midi as a place of scientific observation is rooted in the Enlightenment period, well before any building took place on the summit. Some of the great names in exploration made some interesting observations from the peak. These observations were used in developing the topographical map of France and for pioneering new ways to measure atmospheric pressure at altitude (Cassini III in 1740; Monge and Darcet in 1774; Lapeyrouse in 1782).

The Pic du Midi is known worldwide for many modern discoveries, including the following:

Aerology

- The first measurements of ozone at high altitude using chromatography (Marchand in 1874 and 1909). These measurements serve as a reference for the contemporary evolution of anthropogenic ozone pollution (tropospheric increases evaluated over 100 years by the current service). The Pic du Midi remains an international reference site for the quality of the troposphere, chemical measurements of CO, CO_2, O_3, NOx, mercury vapour, aerosols, and mass spectrometry of traces of radioactive elements (Pyrenean Atmospheric Observation Platform: Gheusi in 2012). The Pic du Midi detected, using mass spectrometry, traces of radioactive elements from Fukushima six months after the accident in 2012 (Van Beek in 2012).

- Pioneering studies of atmospheric electricity and lightning (Dauzère in the 1920s and 1930s). The Pic du Midi is now an international site for the study of Transitory Luminous Phenomena (or Sprites): these are the flashes that appear above thunderstorms (Soula in 1990).

Cosmic rays and particle physics

- The first measurements of cosmic rays and atmospheric electricity (Nodo in 1907) five years before the discovery of cosmic rays by V. Hess in 1912.

- The Pic du Midi became a hotspot for research on cosmic rays (Daudin, 1948–53) and particle physics after preliminary measurements (Cosyns from 1937; Auger in 1938). The site welcomed international teams managed by P. Blackett (Nobel Prize, 1948)—it was the location for the fundamental discoveries of the pion (pi meson) by Occhialini in 1947 and the hyperon in 1950—and then Leprince-Ringuet (1951–53) with the installation of a bubble chamber and particle physics detector. The Pic du Midi was the main site for research in this area up until the foundation of CERN in 1958.

- The study of cosmic rays is experiencing a revival at the Pic du Midi with the recent installation of a Bonner high-resolution, spherical spectrograph (Hubert in 2013, ONERA, INRS) for studying the spectrum of telluric and cosmic neutron disintegration.

Solar astronomy

- Pioneering photographs of the eclipse of 18 July 1860 by Maxwell-Lyte from the meteorological station in Sencours; observations of the low solar corona using the coronographic technique, a technique invented and tested by Bernard Lyot at the Pic du Midi from 1930 to 1940. See the Paris Observatory's digital base, notably the first films of the solar flares taken by Lyot between 1935 and 1937 and films on sunspots and solar granulation taken by Lyot in 1943 (www.obspm.fr/films-de-bernard-lyot.html).
- Pioneering discoveries on solar granulation: the most precise solar observations from Earth using the Jean Rösch Telescope from 1961 to 1990. Also, the work of R. Muller on observations within the G band wavelength range (430.5 nm) at very high resolution (seeing = 0.3 arc sec) and that of T. Roudier and M. Rieutord on the dynamics of sunspots and magnetism (1990–2009).
- Today, the solar corona observation service continues to observe the Sun with a Lyot coronograph (rebuilt in 2009), continuing a tradition that began almost a century ago on the Pic du Midi. The findings are stored in international databases managed by the Observatoire Virtuel du Grand Sud Ouest, for the use of astronomers worldwide.

Planetary astronomy

- Observations of planetary surfaces (Henri Camichel, Audoin Dollfus, Jean Focas, Edward Bowell and John Murray, 1943–1963): some of the best images of the planets in our solar system taken from the Earth have been produced using the 60 cm Telescope in the Baillaud dome and then the 1m Telescope. The measurement of planetary diameters; the measurement of the retrograde rotation of Venus' atmosphere (Boyer 1957-1967). The mapping of the moon and preparations for the Apollo mission (1964–1966: over seventy thousand shots, Manchester Lunar Programme).
- Pioneering measurements of the distance between the Earth and the Moon using laser shots (Calame in 1969).

Stellar astronomy

- Today, the Bernard Lyot Telescope (2m) is the worldwide leader in the observation of stellar magnetism using the instruments MUSICOS (Boehm, Catala, Donati 2000-2007) and NARVAL (Semel, Donati, since 2007). Many pioneering discoveries were made and continue to be made in the study of magnetic fields across the HR diagram.
- Current projects are moving towards monitoring the impact of magnetic fields on exoplanetary systems both nascent (SPIP project, Donati) and at the end of their lives (Boehm, Neo-Narval).

Instrumental development

- The Pic du Midi has served, and continues to serve, as a testbed for many different instruments. Examples include developments in coronography (a technique invented at the Pic du Midi by Bernard Lyot in 1930-1931) and polarimetry (pioneering instruments were developed by French teams—Semel, Leroy, Donati), and the first CCD, now in use in digital photo devices. Semiconductor matrix detectors have been most notably developed and tested by Toulouse teams at the Pic du Midi (Strong in 1980). The early development of instruments that correct for atmospheric disturbances (telescopes isolated from dome turbulence, Lyot, Rösch; Prieur tavelograph, 1991–1993) also took place at Pic du Midi.

Tangible heritage—a partial inventory

Immovable items—buildings and grounds

The Pic du Midi Observatory building represents the culmination of 140 years of organisation and development, resulting in a complex and massive infrastructure which has been devoted to science and also, since the 2000s, to tourism.

The general architecture of the Observatory is a direct result both of this long history and of the continuity in its function. There is typical mountain architecture (ogival roofs and walls built of stone extracted from the summit itself) but also, uniquely, more contemporary architecture, developed and designed specifically for the Pic du Midi (the Jean Rösch dome and the Bernard Lyot Telescope observatory).

The size, complexity and diversity of the activity on this platform oblige us to focus solely on the heritage developed on the summit, but elements such as the Plantade Station on the Col de Sencours and the Observatory of Bagnères de Bigorre were fundamental elements of the Pic's life.

Evidence of the desire to preserve the heritage of the Pic du Midi can be found in the excellent conservation of the scientific buildings, which is largely due to tourist activity. Our description will therefore focus on these buildings.

Fig. 9.6. Aerial view of the Observatory after the "Pic 2000" project in 2000. The new elements of infrastructure are visible: the cable car station, the footbridges, the new coronograph building, and the modernising of the weather tower (2009). Photo © Claude Etchelecou

The key periods in the evolution of the infrastructure are presented in the “History and development ” section below.

General description and key facts and figures in the Pic du Midi’s tangible heritage

We can imagine the Pic du Midi to be a small independent town perched on a peak at almost 3000 m above sea level. The general description that follows expresses this idea.

The Pic du Midi comprises:

- A terrace covering 750 m^2
- 5 km of inland corridors for link buildings and basements
- 10,000 m^2 of covered surfaces
- 5 floors (8 if we include the floors in the Interdepartmental building: the equivalent of 10 storeys)
- Annual electricity consumption equal to that of a French village of 600 people

General infrastructure:

- On the summit this is of three types: scientific infrastructure (buildings and observatories); tourist infrastructure (museum, restaurant, reception and constructions for managing the movement of people); and the Interdepartmental building and its aerial.
- The scientific infrastructure and tourist infrastructure are interdependent whilst remaining dissociated. The observatories are only accessible to tourists under certain conditions and on certain occasions, in order not to disrupt their scientific activities.

The platform consists of the following:

- 4 scientific and historic buildings on the terrace: the Vaussenat building, the Nanssouty building, the Marchand laboratory, and the Dauzère building.
- 7 astronomical observatories, 5 of which house scientific instruments that are still in use: the Bernard Lyot Telescope dome and observatory, the 1 m Telescope dome and observatory, the Jean Röcsh dome and observatory, the Coronograph dome and observatory, the 60 cm Telescope dome and observatory, the Charvin dome and, finally, the Baillaud dome.

The scientific buildings of the Pic du Midi Observatory

- *The Baillaud Dome (1908)*

  The Baillaud dome was the initiative of Benjamain Baillaud, the director of the Toulouse Observatory at the beginning of the century. It was the first permanent astronomical facility to be installed on the Pic du Midi. Almost unused until the 1930s, it later became the centre of the Observatory’s astronomical activity. Indeed it was under this dome that Bernard Lyot invented and subsequently tested his coronograph. Later, in the 1950s, the dome housed powerful instrumentation, allowing us to take advantage of the transparent sky above the Pic du Midi. The Pic du Midi’s international prestige originated from the Baillaud Dome. Most of the scientific discoveries and contributions towards both planetary science and the study of the sun were made in this building.

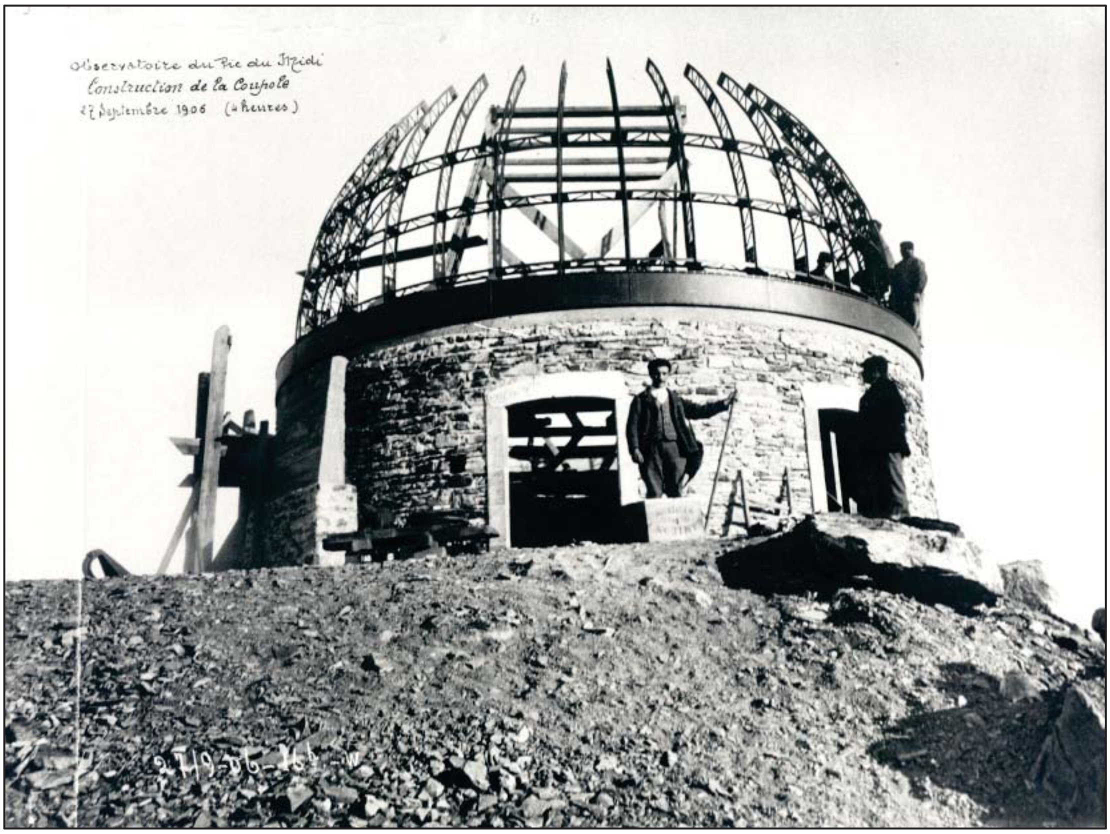

Fig. 9.7. Construction of the Baillaud Dome in 1907. Photo © Alix, Fond Eyssalet

Fig. 9.8. The Baillaud Dome in 2013. It houses the museum and the 1/1 scale model of the coronograph. Photo © Nicolas Bourgeois

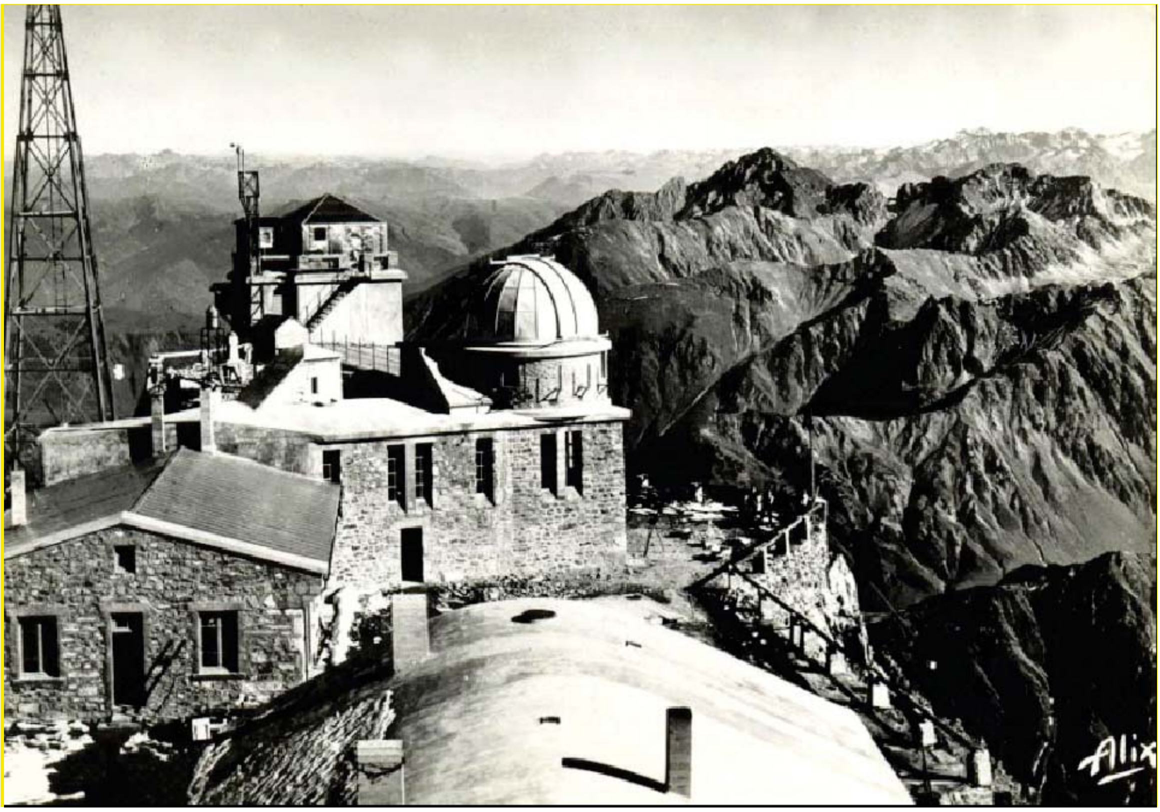

Fig. 9.9. The Dauzère building, where the Gentili dome was placed in 1947. Photo © Alix, Fond Eyssalet

Fig. 9.10. The Dauzère building and the Gentili dome in 2013. The integrity of the building has been fully preserved. Photo © Nicolas Bourgeois

Between 1904 and 1905, the dome was built and assembled for the first time in Toulouse, in the gardens of the Jolimont Observatory. During 1906 and 1907, it was transported first by train, then by men and mules, to the summit. On 14 September 1907, the dome was finished. Measuring 8 m in diameter, the dome is large enough to accommodate a 500 mm telescope with a 230 mm guider on the top.

For nearly 130 years, the Pic du Midi has been expanding with further constructions being added around the first domed buildings. In the late 1990s, the Baillaud Dome ceased its scientific activity. Preserved in its original state, it is now the highlight of the observatory museum space. Presented here for visitors are Lyot's first coronograph and other instrumentation.

- *The 1 m Telescope Observatory and Dome (1947)*

The 1 m Telescope dome has been at the summit since 1947. Made in 1925 and based in Paris, the dome was donated by Marcel Gentili, in recognition of the years he spent on the Pic during World War II, where he was protected from the Nazis. This dome, installed on the Dauzère building, originally housed the Gentili 60 cm telescope.

In March 1962, the new 1 m Telescope was installed to support the Manchester Lunar Programme. At this time, use of the dome proved to be an excellent opportunity for the NASA-financed programme. Indeed, the experience gained on the Pic du Midi concerning the necessary conditions to obtain good images allowed us to highlight the need for a small dome so that the thermal balance between the instrument and the air outside/inside would take place quickly. Owing to a lack of resources to build a new dome, Gentili's gift was accepted and served only to reinforce the project.

This dome, which today is over a century old, has housed one of the Pic du Midi's most efficient instruments for 50 years: the 1 m Telescope.

- *The Jean-Rösch Dome and observation point, or Tourelle dome (1961)*

The Tourelle dome is one of Jean Rösch's pioneering and experimental projects at the Pic du Midi. This observation point complements and reinforces the work following the sun done under the Billaud dome. Rösch's ambition was to create a unique type of observatory in order to benefit from the high atmospheric quality that the Pic offers whilst reducing the constraints inherent to solar observation with a conventional device (increase in dome temperature, image deterioration due to instrumentation, internal turbulence).

In order to create this dome, Jean Rösch called upon Jacques Pageault. Pageault designed and constructed the dome in the Bagnères Observatory workshop.

The dome has been installed on the extreme eastern end of the summit, which is the ideal place to make the most of observational conditions in the morning, the best time of day. The dome was inaugurated on 15 February 1961, a day when a partial solar eclipse was visible.

The dome measures only 5 m in diameter, but its design is such that it can accommodate an instrument 6 m long. The instrument's lens is 2.5 m outside the dome, which allows it to escape the structure's internal turbulence. It is also equipped with a cooling system for draining away the energy produced by the light beam. In addition, the interior walls of the dome are isolated by a lining. The characteristics of this dome have been included in most solar telescopes built around the world subsequently.

Fig. 9.11. The Tourelle dome was installed on the extreme eastern end of the Pic du Midi platform in order to make the most of optimal observation conditions early in the day (2013). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Fig. 9.12. The Bernard Lyot Telescope tower and dome. The cap is open and pointing eastward. The building is located to the south-west of the summit (2013). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

- *The Bernard Lyot Telescope dome and observatory (1978)*

The Bernard Lyot Telescope dome and observation point were developed by Jean Rösch's team in order to accommodate the largest national telescope. This project came into being in

1966. Its location and architecture were determined by two conditions which are dear to the Pic du Midi astronomers: maximum use of the atmospheric stability offered by the Pic du Midi and creating the best possible balance between the structure and the instrument it houses (in the manner of the Tourelle dome and the Jean Rösch Telescope).

In order to take advantage of all the benefits the summit has to offer, the position of the structure was determined using a wind tunnel. This was the first time such a method was used in deciding where to place an astronomical site. Following this analysis, the south-west of the summit was chosen. In order to escape the turbulence caused by the floor heating up during the day, it was decided that the dome should be placed on a tower 28 m high and 14 m in diameter. The tower has 5 floors, the first floor being the room for aluminising the telescope mirror.

The dome's characteristic form is explained by Jean Rösch's desire to minimise the disruptions linked to air exchange between the instrument and the inside/outside air. To do this, Jean Rösch wanted to connect the telescope tube directly to the dome opening, which explains the very small size of the latter. Due to a lack of budget, and a disagreement between the team and future users of the instrument, this technical solution did not turn out well. In order to preserve the quality of the image, engineers applied the solutions adopted in Hawaii to the Observatory telescope: a cooled floor and perforated tube.

This imposing structure was built between 1970 and 1978. The building site proved extremely difficult because of the conditions imposed by the high altitude.

This building is a product of the modern era of astronomy. It means that today the Pic du Midi is a pioneer in observations of stellar magnetism and maintains a leading position in international research.

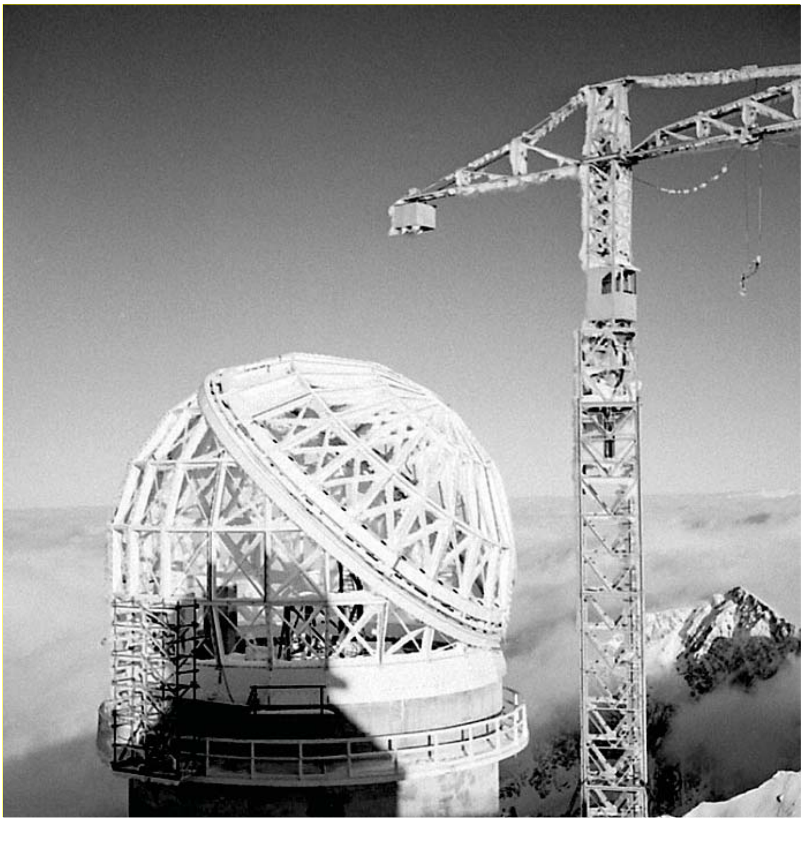

Fig. 9.13. The construction of the dome in 1974. The difficult conditions the mountains are clearly visible: frost covered the buildings and the construction machinery. Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Movable heritage objects—telescopes

- *The first coronograph in the world, invented by Bernard Lyot in 1933*

  This coronograph was invented and tested during the 1930s. The first films and images of the solar corona were created by Bernard Lyot at the Pic du Midi as early as 1935.

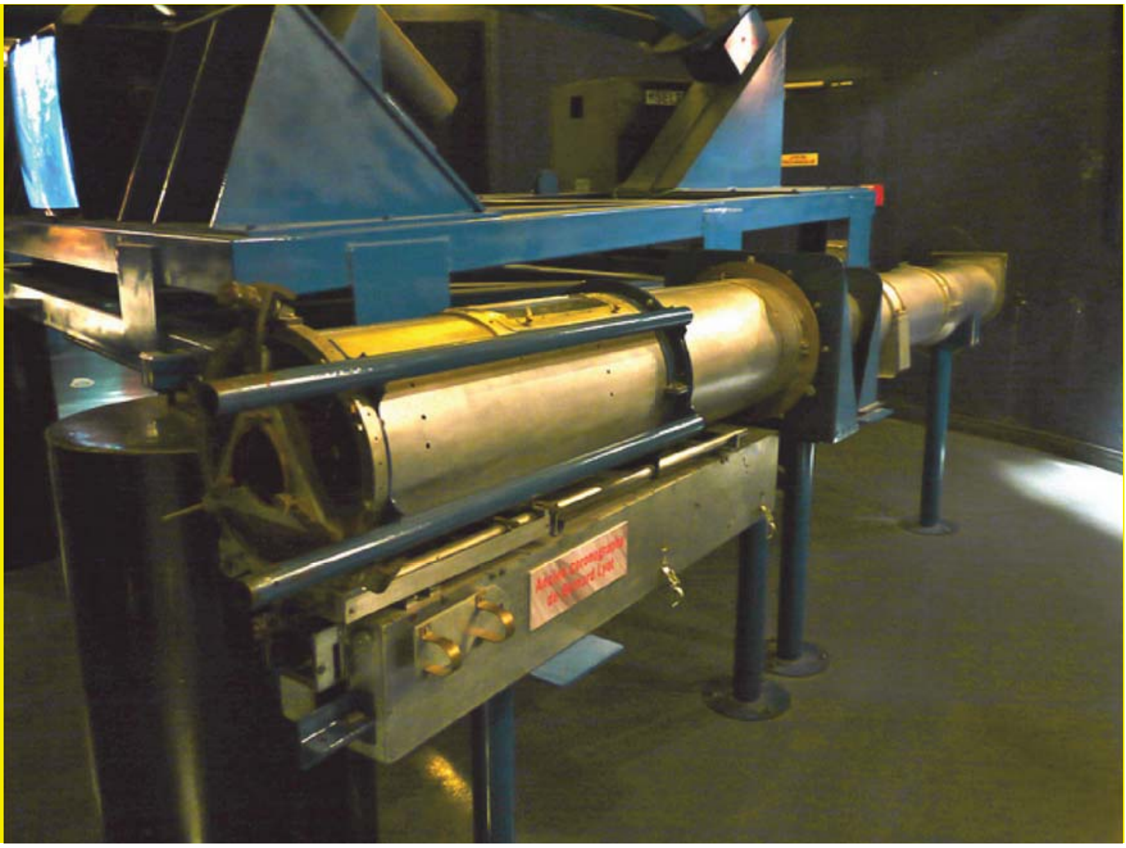

Fig. 9.14. The first coronograph in the world. Invented and tested by Bernard Lyot at the Pic du Midi. It is displayed in the museographic space in the observatory (2013). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

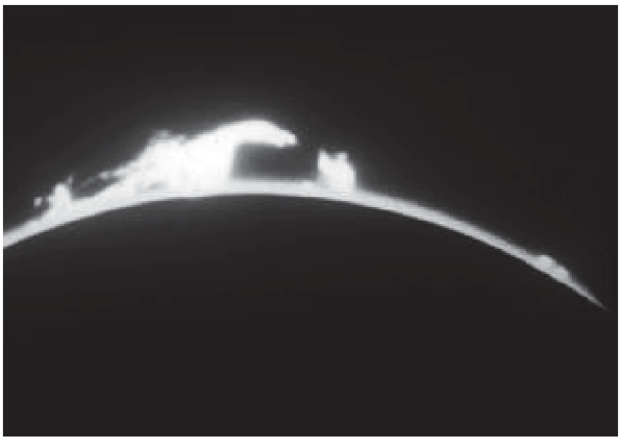

Fig. 9.15. Image from a film of the solar corona taken by the Pic du Midi chronograph in 1935. Photo © Vidéothèque du CNRS

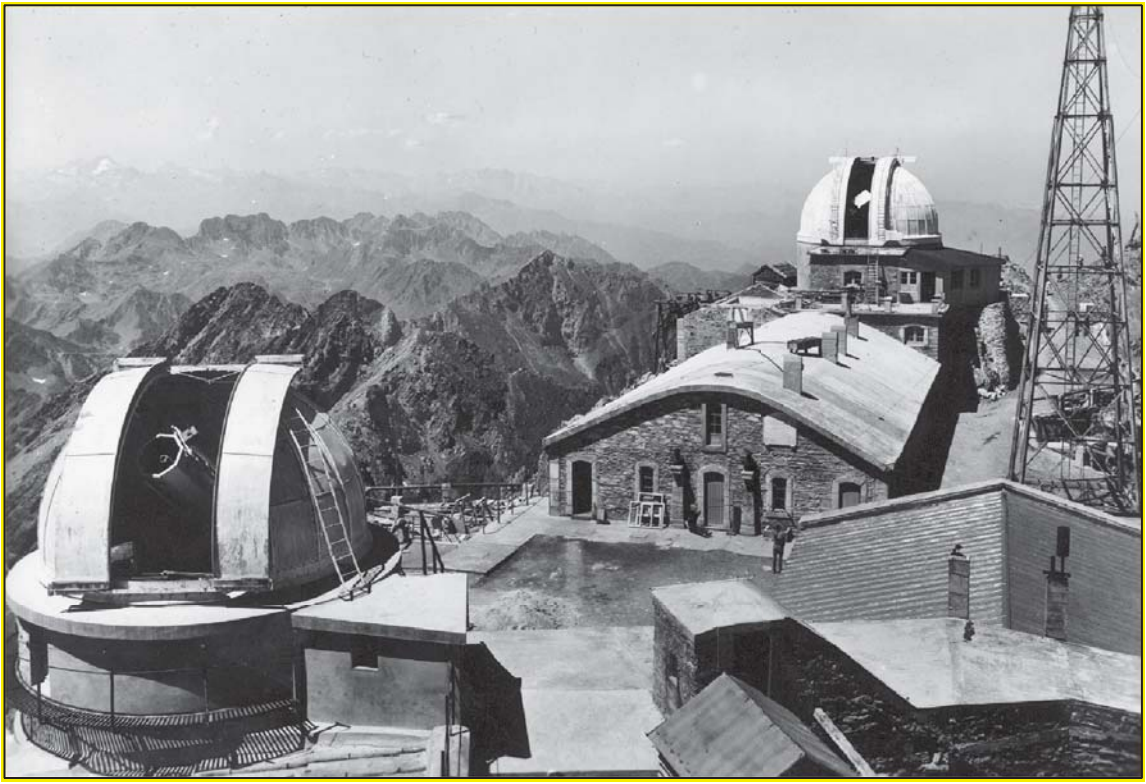

Fig. 9.16. The 60cm Telescope in 1947 (on the left of the picture). At this time, it was placed under the dome that would house the 1 m Telescope. Photo © Alix, Fond Eyssalet

- *The 60 cm telescope (1922)*

The T60 was installed in 1947 at the Pic du Midi. At the time, it was the instrument with the greatest diameter in the observatory. Today, it is the oldest telescope still in working order. In the 1950s, it was used mainly for photometry. With the arrival of the 1 m Telescope in 1963, the T60 was placed in the smallest dome on the same floor as the terrace and was principally used for the study of extragalactic nebulae. In 1982, the Toulouse Observatory created a committee of amateur and professional astronomers who would manage the new research programmes for the T60. This initiative allowed us to test the participation of amateur astronomers in professional research programmes. Given the success of this initiative, the T60 association was created in 1985. Today, an important associative network supports the association responsible for maintaining and developing the operation of the telescope. Incidentally, it was on the T60 that the first CCD amateur camera was placed in 1985.

- *The Jean-Rösch telescope (1961)*

The current Jean Rösch Telescope (JRT) is the result of several years of evolution. It is used to observe the photosphere (solar surface) at very high resolution. The distinctive feature of the instrument lies in the originality of its construction. It is directly linked to the structure that protects it: the Tourelle dome. It is the combination of the telescope and dome, as it were, that forms the real instrument. We have already described the Tourelle in the previous section.

The JRT was initially equipped with a 38 cm lens, but in 1972 Jean Rösch received supplementary funds to increase the strength of the lens. A 50 cm lens was fashioned in the Observatory in Paris by Jean Texereau. This lens is today considered the masterpiece of the optician's career. Up until 1987 the JRT, associated with the atmospheric qualities of the Pic du Midi, was the best performing instrument used to observe the sun in the world.

The research carried out by the JRT in the 1970s had an important impact on the evolution of solar physics, especially on the interaction between granulation and the cycles of solar activity.

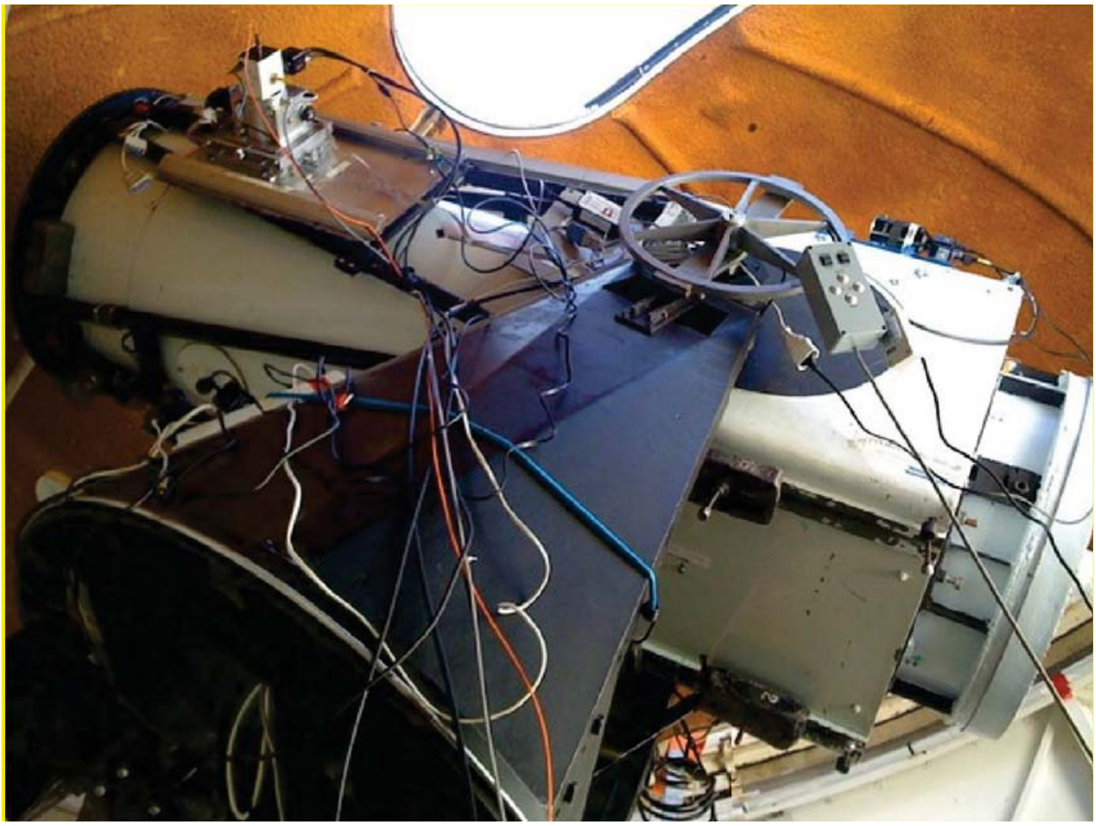

Fig. 9.17. The 60cm Telescope and its modern equipment (2012). Photo © Association T60

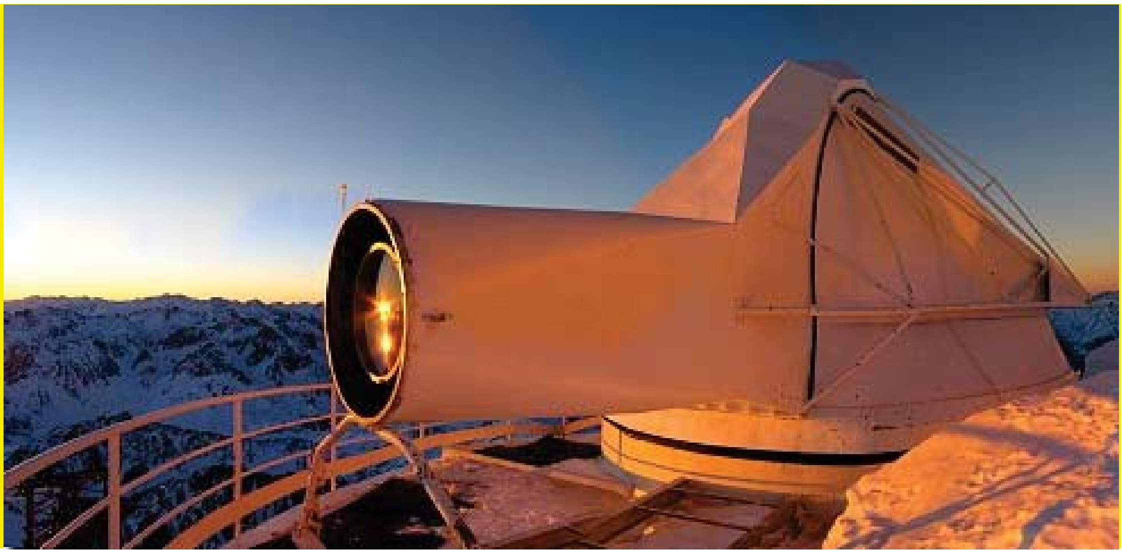

Fig. 9.18. The Jean Rösch Telescope 50cm lens (2012). Photo © Observatoire Midi Pyrénées

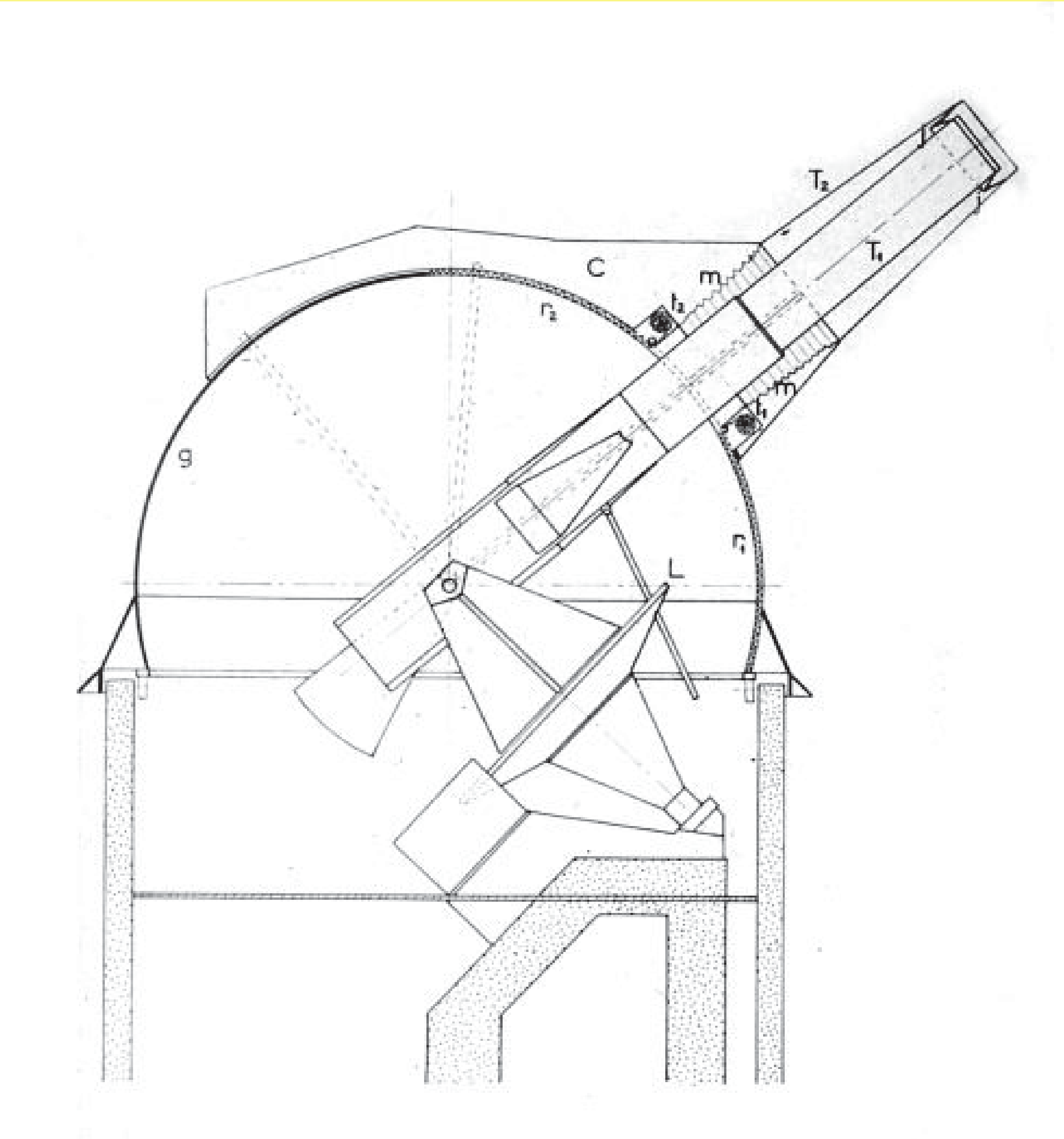

Fig. 9.19. Plan of the Tourelle Dome and Jean Rösch Telescope. It can be seen that these two together form one single instrument. Photo © Observatoire Midi Pyrénées

The JRT today forms part of an international solar observation network, on the ground and in space. The largest instrumentation field of the telescope has no competition for the time being, which allows it to remain complementary to major international space observatories.

- *The 1 m Telescope (1962)*

As with the JRT, the T1M benefitted from several instrumental improvements over the course of its history. NASA encouraged its construction in 1959 so as to increase the instrumental power of the Manchester Lunar Programme and thus to obtain the best possible images of the moon for the Apollo Programme Lunar Atlas. In 1974, the old optics were replaced by a new Pyrex mirror built by Jean Texereau, one made from a material that is not too sensitive to heat.

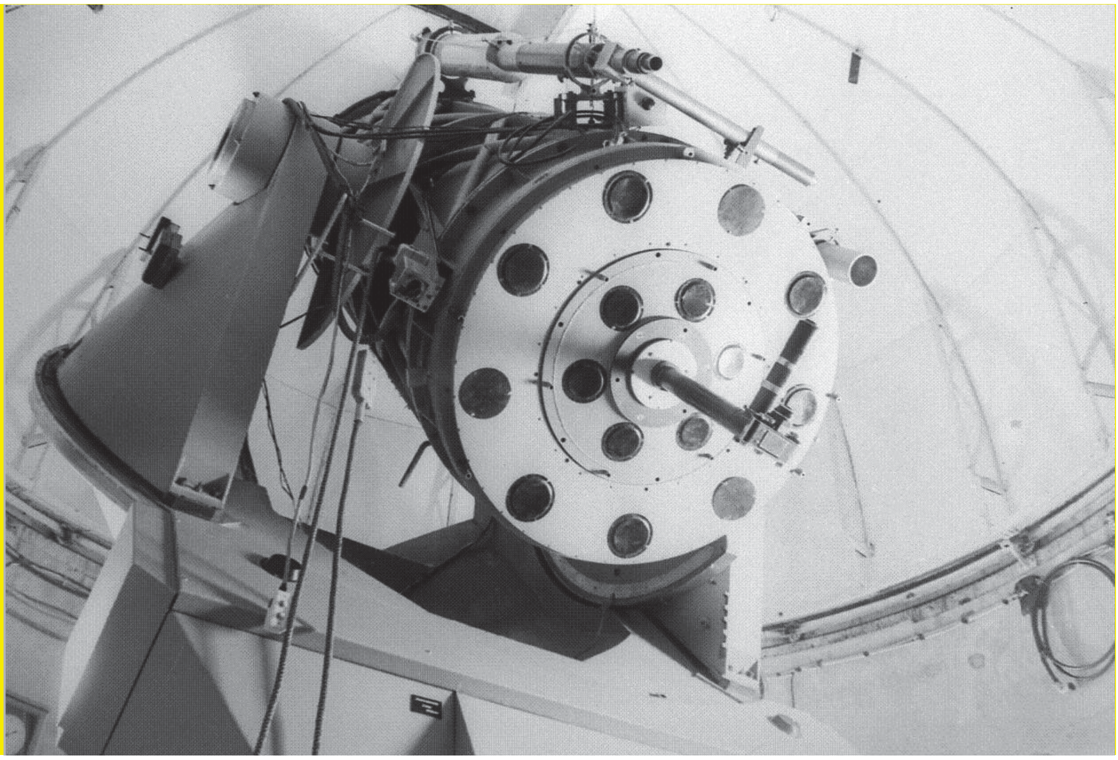

Fig. 9.20. The 106 cm Telescope in the 1950s. It is equipped with material for silver shots using its cassegrain focus. Photo © Observatoire Midi Pyrénées

During the telescope's first ten years of service, it was used in inverse mode as a transmitter as well as a receiver of light. A network of great scientific institutions created a project (École Polytechnique, CNES, CNRS) whose goal was to measure the distance between the Earth and the moon by firing a laser. The first echoes were measured in 1969 following the placing of reflector panels on the moon by the Apollo 11 astronauts.

Today, the T1M is equipped with a CCD camera and is managed by the Institut de Mécanique Céleste et de Calcul des Ephémérides in the Paris Observatory. It is used to study the planets and small bodies of the solar system.

- *The Bernard Lyot 203 cm Telescope (1976)*

The Bernard Lyot Telescope is considered by its founders the greatest achievement of the human and scientific adventure at the Pic du Midi. Even though the difficulties faced during its development and creation meant that the initial project could not be carried out, the Bernard Lyot Telescope remains today the most important telescope on French soil and occupies a unique place on an international scale.

The double focus telescope (cassegrain focus open at f/25 and strand at f/5) is installed on a 16-ton horseshoe-shaped structure resting on an oil bath.

During the first 30 years of its service, the BLT was a generalist instrument used to serve the international astronomical community (infrared-visible imagery, photometry, polarimetry, spectroscopy). In 2006, the BLT was equipped with a spectro-polarimeter, named NARVAL, installed on a network with the Canada-France-Hawaii Telescope for continuous monitoring.

Fig. 9.21. View of the interior of the Bernard Lyot Telescope dome. The red structure is the horseshoe-shaped setting which supports the 2 m telescope. The NARVAL system can be seen, installed at the telescope's focus (2009). Photo © Paul Compère

Thanks to NARVAL and the BLT, the Pic du Midi Observatory is currently the most important contributor in the study of stellar magnetism. Among its key findings are the characterisation of the magnetic field of various stars (small and massive) and the inversion of the magnetic field in several stars.

Finally, the BLT was one of the main factors that led astronomers and public workers to initiate the Pic 2000 project and thus save the scientific work of the observatory.

Movable heritage objects—small instruments, books, archives and photographs

All small items, books, archives and photographs related to the Pic du Midi are preserved in various heritage collections and are currently undergoing an inventory.

These pieces of heritage are shared between the National Centre for Scientific Research (CNRS), the Paris Observatory, the Heritage Commission of the Midi Pyrénées Observatory, the Departmental Archives of Tarbes, the Ramond Society Heritage Fund in

Bagnères de Bigorre, and the Eyssalet Photography Fund which is part of the Haute-Bigorre Community of Communes.

A common fund is being created in order to bring these iconic pieces of heritage together and thus display them in the museum area of the Pic du Midi.

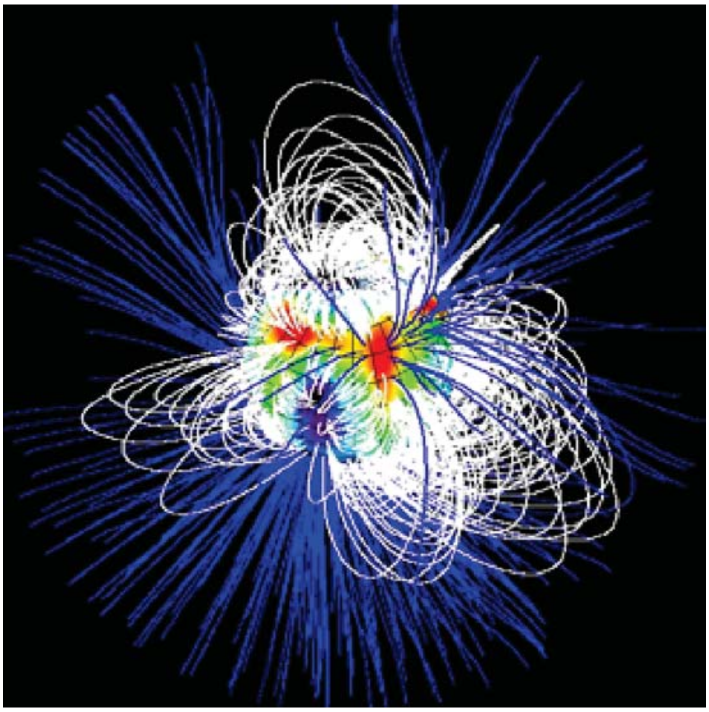

Fig. 9.22. Model of the magnetic field of the star SU Aurigae, created using the NARVAL and ESPADON systems (2007). Photo © Observatoire Midi Pyrénées

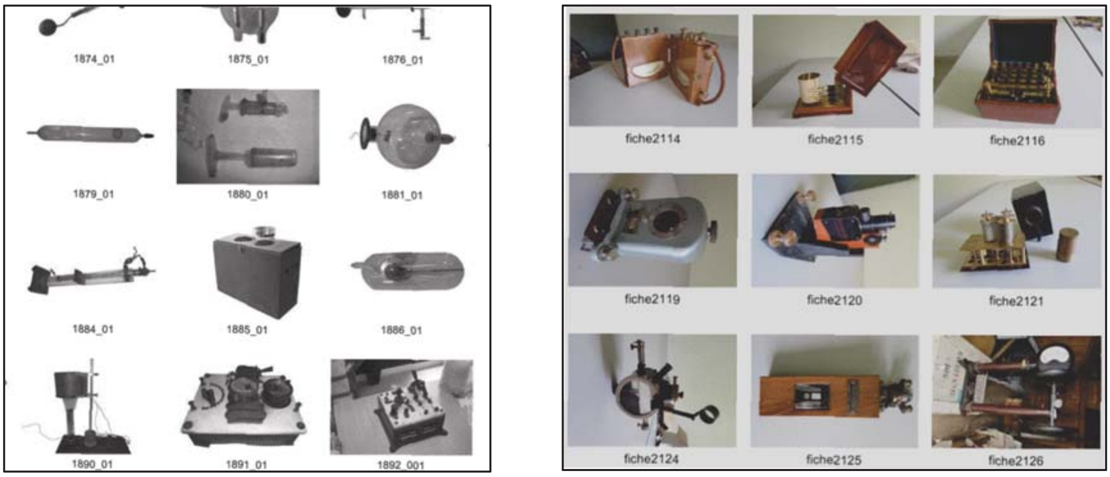

Fig. 9.23. Extracts from the inventories of the Pic du Midi's heritage objects. Images: Ramond Society Heritage Fund in Bagnères de Bigorre. Photo © Société Ramond

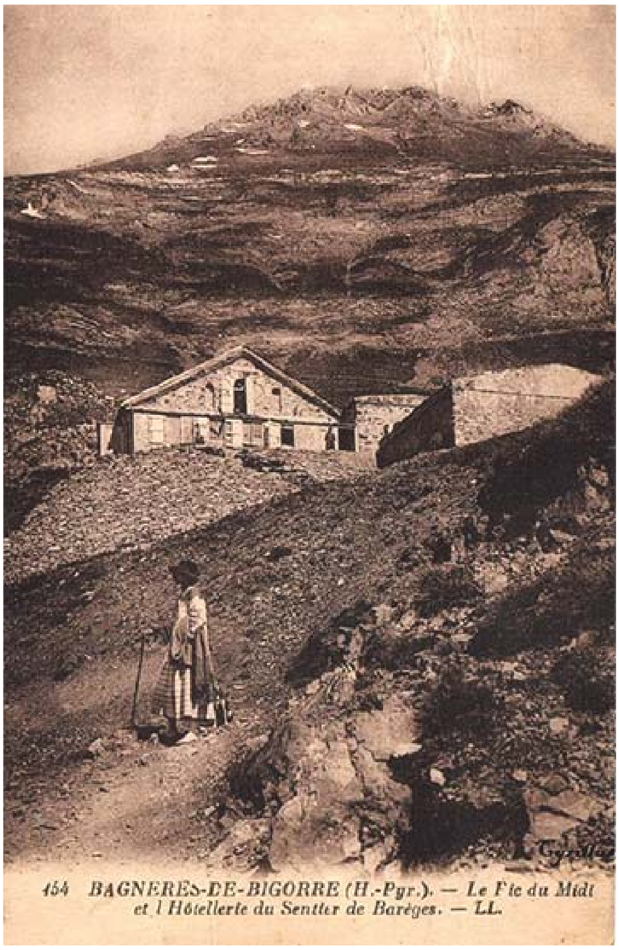

Fig. 9.24. The Plantade station on the Col de Sencours in 1875. The summit of the Pic du Midi in the background is still devoid of any development. Photo © Alex, Fond Eyssalet

Fig. 9.25. The same view as in Fig. 9.24, in 2013. The Plantade station is currently in ruins and undergoing renovation. A hundred and forty years on, the most important working observatory in France stands on the summit of the Pic du Midi. Photo © Nicolas Bourgeois

2.b History and development

140 years of life and science in the high mountains*

The history and development of the Pic du Midi Observatory are primarily guided by three ideas.

The first is a contemporary mountain approach, which asserted itself in the 19th century. For members of the Ramond Society, the founders of the Observatory, the Pyrenees represent a world created to defy temerity, elevate the soul, explore and discover. This culture may explain in part the many risks taken for the good of the observatory.

The second is that the Pic du Midi, by its very geographical position and its atmospheric quality, has seen itself become a centre for research and a science hub. Even if astronomy later became an important uncontested element, science itself has reigned for over 60 years. The observatory is also a scientific platform where various different domains of research are carried out: meteorology, climatology, cosmic rays, botany, medicine, etc. This led to the significant development of the Pic's infrastructure in order to meet the influx and expectations of a growing number of increasingly diverse researchers.

Finally, the Pic has always been threatened. Whether by the ever-difficult mountaineering conditions, budget constraints or competition from major international observatories, the growing threat of closure is very real indeed. But the Pic has always resisted. From the first stakeholders to the scientists and finally to the elected officials, there has been a chain of supporters and a human adventure continuously upholding this threatened heritage.

We will address the Pic du Midi's history in six periods, through the facts, events and the scientific work. Details of dates, facts and scientific results will be accompanied by a mention of the key people that shaped the Pic and built its history.

From Genesis to the first stone (1865–1891)

The question of building an observatory on the summit of the Pic du Midi arose in the 18th century. But it was in the mid-19th century that the project really started to take shape thanks to members of a newly formed Pyrenean company: the Ramond Society. Its founders define it as a Pyrenean exploration company, grouping together scientists and mountaineers. For these men, the Pic du Midi would be the perfect host for a high-quality observatory. France learned about the impending creation of the observatory in 1869 via the Official Journal.

The war of 1870 caused the project to be suspended, then two years later, added weight to the argument that the work should restart: indeed in a country bruised by defeat, the observatory presented a way of raising the morale of the French people.

Two men will forever mark the history of the Pic du Midi. This is because they are at once the founders of the observatory and the guarantors of its Pyreniste identity. They are General Charles Champion du Bois de Nanssouty and the engineer Célestin-Xavier Vaussenat. Thanks to their efforts and research grant, the Pic du Midi project was voted in on 8 April 1873 and it was executed on 21 May 1878. Thirty workers worked on the summit until 1881, under the direction of General Nanssouty's wife, Lucie Abadie.

On 27 July 1882, Vaussenat and Nanssouty donated the observatory to the French State in order to ensure its management, obtain finance and reimburse the debts. Xavier Vaussenat died on 16 December 1891, a date that marks the end of the first period in the history of the Pic du Midi.

Scientific work and results

During this period, the Pic du Midi was the centre for many experiments and meteorological readings, in particular for the central weather bureau.

Many of these experiments proved and presaged the quality of the observations that it would be possible to carry out.

Fig. 9.26 The men's ongoing battle on the summit during the winter of 1908. Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

The first decade of the Pic du Midi Observatory was thus a period of material expansion. Vaussenat, as well as setting up and securing the site, also contributed to publicising the summit by inviting scholars there during the summer period.

Infrastructure

In 1882, the observatory comprised a house (the Nanssouty building) connected to a small building by a narrow path (the future Vaussenat building), leaning against a blockhouse where the weather instruments were installed. A blacksmith's, a stable and some shops were also built on the summit.

Celestin Vaussenat, up until his death, sought to level out the peak and build sheltered passages to facilitate travel in winter, when snow covers the station.

Work at this time was only possible for three months each year, from July to September, when there was no snow on the summit and the caravans and mules could access it.

Systematic observations and the trials of the First World War (1892–1920)

From the arrival of the new director Emile Marchand in 1892 onward, the Pic gradually became a centre of multidisciplinary scientific observations, for which data in meteorology, atmospheric physics, seismology, astronomy and botany would be collected daily.

In 1900, the Pic saw the arrival of the Toulouse Observatory and its director, Benjamin Baillaud, who would encourage the building of the first dome and its grand telescope.

The Pic du Midi had a hard time during the First World War (1914–1918). Emile Marchand died in 1914 and so the Pic found itself with no director and no maintenance, a state of abandonment from which it only insecurely emerged in 1920 with the arrival of its third director, Camille Dauzère.

Fig. 9.27 The Pic du Midi Observatory in 1891. From left to right: the blockhouse, the Vaussenat building and the Nanssouty building. The construction of the terrace had not yet begun. Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Fig. 9.28 The men from the infantry regiment in Tarbes carrying the Baillaud Telescope materials up to the summit (1906). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

From 1903 to 1908, the main stages of construction of the first astronomical observatory of the Pic du Midi took shape. In 1906, the dome was built on the summit. After this the 50 cm Telescope, built in a Parisian workshop, was brought by rail to Bagnères, then by oxen and cart to the Col du Tourmalet. From there, a dozen soldiers of an artillery regiment from Tarbes were to persevere for more than a year to get the 22 boxes of material up to the summit.

In September 1907, the telescope was atop the Pic; another summer would be required to assemble it and make it operational. During the first 20 years of its use, the astronomical observatory held a place that was both paradoxical and representative of the Pic du Midi's history. The observations made there were considered to be excellent. But the conditions faced by the observers (cold, snow, difficult access, temperamental weather), were such that motivated astronomers were rare indeed. The telescope remained practically unused until the 1930s.

Scientific work and results

During the 22 years of his directorship, Emile Marchand and his teams collected a considerable number of daily measurements: the mapping of the Sun, planetary surfaces and cloud cover, meteorological recordings, atmospheric electricity, terrestrial magnetism and seismology.

During this time, Marchand published 35 articles on geophysics, 20 on astronomy, 9 on botany and 6 on the relationship between the Sun and the Earth. Unfortunately, most of the articles only appeared in the journal of a local society and in progress reports for conferences.

We must go beyond the "anonymous" nature of these results in order to see the emerging intensity of observation at the Pic du Midi, foreshadowing its arrival at true scientific maturity from 1920 onwards.

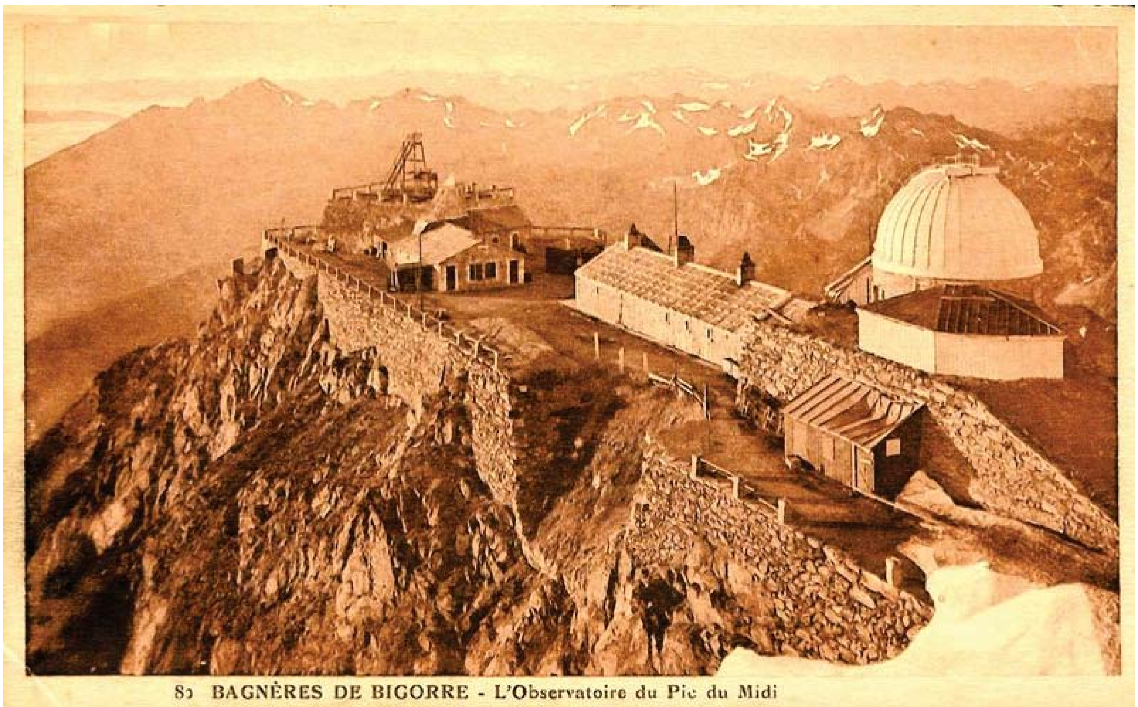

Fig. 9.29 The Pic du Midi Observatory just after the First World War. We can see the Baillaud dome and observatory building on the right, built between 1906 and 1908. The north terrace crumbled following several years without maintenance (1920). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

The thirty years described here mark a new complexity and intensity in the history of the Pic du Midi. The observatory gained a paradoxical reputation. Its size and potential fascinated people, but equally it repulsed them with the tough conditions it imposed on them and their observations.

Infrastructure: landscaping, development of means of observation, construction of the Baillaud observatory building

Before the First World War, the main construction efforts were turned towards increasing the effective surface area of the Observatory by landscaping, and the development of its instrumental capabilities. The greatest additions to the Pic du Midi's infrastructure at this time were the installation of the astronomical observatory in 1908, with the Baillaud Dome, the 50 cm Telescope and a building for accommodating astronomers.

The "Dauzère years", the first real threats for the Pic and scientific maturity (1920–1937)

Camille Dauzère was appointed Deputy Director by Toulouse on 31 August 1920. Under his leadership, the Pic's strong, symbolic identity materialised, which gave it the power of resistance. Only just out of the First World War, the Observatory experienced its first major crisis. The platform was in a fragile state and its future greatly threatened by a report from the inspection of French observatories in 1922.

Against all the odds, these vulnerabilities and threats were a blessing to Camille Dauzère. They raised great support from the public, local elected officials and the people in charge of the Pic. This large mobilisation provided substantial funds to the observatory, which would be renovated and expanded, over fifteen years.

Under Dauzère, the Pic's research assured its position and became internationalised. From 1920 to 1935, geophysics and meteorology were the queens of sciences.

Astronomy was still a rather secondary element until the arrival and intervention of several important figures in and after 1930. Those figures firmly pushed the Pic towards the stars for the following 60 years.

From 1930 to 1937, astronomy made its progressive comeback. Bernard Lyot, astronomer at the Paris Observatory, made the most of the transparent sky above the Pic du Midi in order to develop the first coronograph in the world. A few years later, the first images of the solar corona were being produced under the Baillaud dome.

Scientific work and results

From 1920 to 1935, the Pic du Midi acquired a certain maturity and an international reputation in terms of scientific research. It was to geophysics that the Observatory owed its reputation.

Meteorologist Joseph Devaux produced his thesis on the thermal assessment of snowfields and glaciers. Camille Dauzère, interested in both lightning and hail, completed and put to good use a remarkable database on the impact of lightning upon the summit. The reputation Dauzère acquired for this work strengthened his conviction to build a terrestrial physics laboratory on the summit.

The "Dauzère years" revealed the symbolic and mythical dimension of the Pic du Midi. Cornered, the observatory raised awareness and goodwill while preparing for its own renewal. The summit showed, despite its harsh location, that it was a great observation site, allowing for both versatility and excellence. At the end of the Dauzère era, all the conditions were met to be able to plan and fund the major projects of the Pic du Midi.

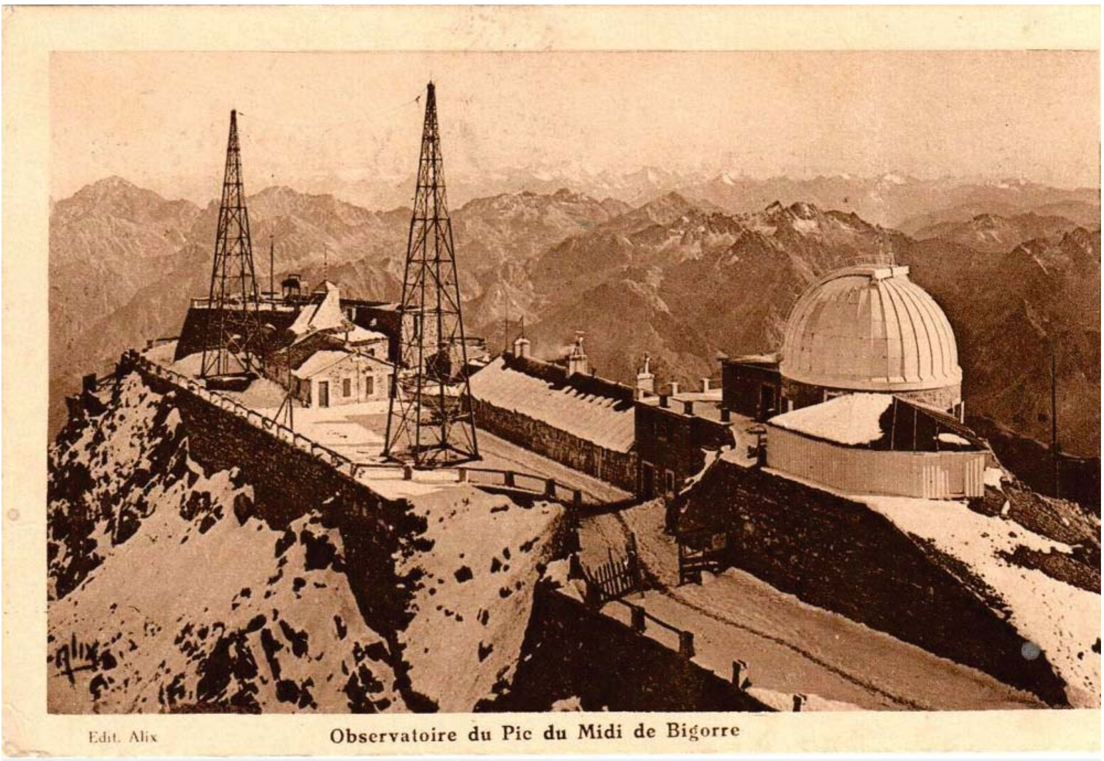

Fig. 9.30 The Pic du Midi Observatory in 1925. The two TSF aerials have been placed on the summit. The crumbling northern ravine started to be reinforced. Photo © Alix, Fond Eyssalet

Infrastructure: modernisation of communication and facilities for terrestrial physics

- 1926: installation of the TSF. Two 25 m pylons were built on the Pic for broadcasting. The Observatory gradually emerged from its isolation.
- From 1926 to 1933, a route was constructed between the Col du Tourmalet and the Col de Sencours, which continued on to Laquet, allowing for easier transportation of people and materials. A hotel was to be built as the end of this road.
- 1928 to 1936 saw the protracted construction of the Terrestrial Physics laboratory known as the Dauzère building, which would come to house the Pic's laboratories and the 1 m Telescope.

The major projects (1937–1947)

Jules Baillaud, director of the Paris Observatory, succeeded Camille Dauzère in 1937. He devoted his directorship to the planning of the Observatory's major projects.

Baillaud was very aware of the great difficulties imposed by the Pic on scientists who, inevitably, emphasised its fragile situation when faced with councillors and national astronomers. His priority in the pre-war years was to take on an ambitious renovation programme to make life easier on site, together with the construction of a cable car to revolutionise access, and finally the installation of a power line to resolve energy problems. "The Baillaud Decade" provided the foundations needed by the observatory to enter the modern era.

Bernard Lyot, astronomer at the Paris Observatory, supported Jules Baillaud in his astronomical projects. It is to him that they owe their original and audacious character.

In 1942, new 60 cm optics were installed on the Pic. The large 18 m focus is folded up on itself twice, transforming the telescope into a refracto-reflector. Rechristened the "Baillaud Telescope", this instrument was used with a great deal of success in the 1960s and would become the instrumental flagship of the Pic.

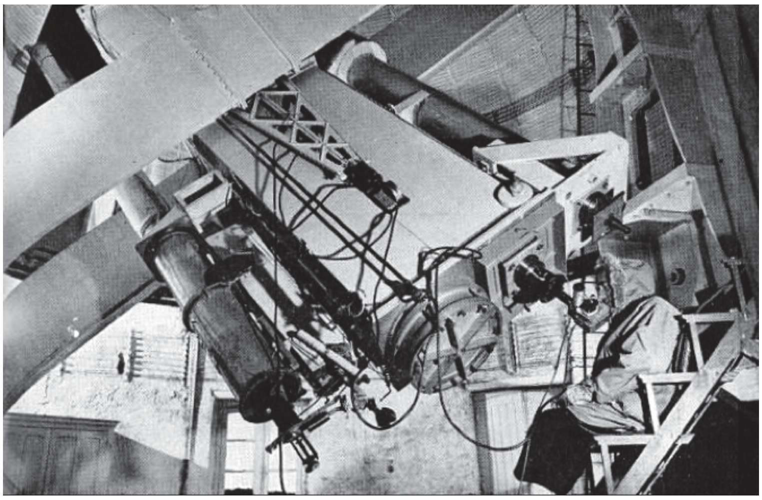

Fig. 9.31 The refracto-reflector, named the Baillaud Telescope, under the Baillaud dome in 1947. It was with this instrument that the main planetary and solar observations from 1950–60 were made. The instrument was dismantled in 1970 and replaced by a coronograph. Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

After the war, the main projects that had been prepared by Jules Baillaud and catalysed by Bernard Lyot would finally be completed. The rise and influence of the Pic du Midi could begin.

Infrastructure: renovation of the first buildings and completion of the Dauzère building

- 1937: The Nanssouty building was renovated and received a new roof: a reinforced concrete vault. This roof would be more resistant to the conditions experienced on the summit (the weight of the snow and the violent winds are still present today).
- 1946: The wealthy amateur astronomer Marcel Gentili gave the observatory a dome (the future dome of the 1 m Telescope) and a 60 cm telescope, in order to thank its members for hiding him from the Nazis during the war. The new dome was installed on the Dauzère building whose construction began in 1935 and was completed in 1948.
- 1947: The observatory was connected to La Mongie by a cable car exclusively reserved for transporting equipment. The arrival point of the cable car was located southwest of the Baillaud dome.

The rise of astronomy and the international influence of the observatory (1947–1981)

Astronomer Jean Rösch was director of the Pic du Midi over the course of these prosperous years. In order to describe this long period under his directorship, he divided it into three parts:

- 1947 to 1952 saw major infrastructure work and the arrival of the cosmic ray specialists.
- 1953 to 1964, the decade following the construction of the cable car, saw the all-round expansion of scientific work and the internationalisation of the Pic du Midi's reputation.
- 1965 to 1981 saw the project to increase the instrumental power of the observatory with the 2 m Telescope, Jean Rösch's largest investment.

The "Rösch years" represent a fundamental break with the observatory's first 50 years. There was a surge in all its components: personnel, infrastructure, instrumental capabilities, and topics of scientific research.

The major infrastructure work and arrival of the cosmic ray specialists (1947–1952)

The arrival of the cosmic ray specialists from Manchester in 1949 brought about a revolution at the observatory. Their presence, their needs and the results of their work allowed Jean Rösch to boost all the major infrastructure projects that would transform the Pic forever. In particular, they needed a means of transportation to bring their electro-magnet to the summit and a high-powered electric current to operate it.

Fig. 9.32 The Pic du Midi Observatory in 1948. We can see the extension of the Dauzère building to the left of the image, the installation of the Gentili dome, and the Nanssouty building's new roof. Photo © Yan, Fond Eyssalet

Fig. 9.33 Construction of the first cable car station on the south side of the Observatory, 1950. Photo © Alix, Fond Eyssalet

Scientific work and results

In 1950, a new particle was discovered at the Pic by the cosmic ray specialists from Manchester. It was named the "Hypéron" during the International Congress of Cosmic Rays in Bagnères de Bigorre in 1953. This discovery was rewarded with a Nobel Prize.

Infrastructure: major works as the Pic du Midi enters the modern era

- Between 1945 and 1949, the high tension line was built. This 10,000-volt line came into service on 18 November 1949. The unlimited electrical current attracted many heavy usage experiments. The supporting cable greatly facilitated building extension work.
- In June 1949, a funicular was built in order to connect the hotel in Laquet to the observatory. The installation of this framework on the incline was justified by the Manchester cosmic ray specialists' need to transport the electro-magnet. The series of mules that had been marching up the Pic du Midi for 75 years disappeared forever.
- On 15 August 1952, the first cable car docked at 2877 m above sea level. The observatory emerged out of isolation for good, bringing with it a complete development of the infrastructure that would accommodate the increase in personnel and meet the expectations of the researchers.

Fig. 9.34 The first Pic du Midi cable car, the symbol of its entry into modernity (1952). Photo © Alix, Fond Eyssalet

All-round expansion of scientific work and the internationalisation of the Pic du Midi's reputation (1953–1964)

From this period on, the scientific work is such that it becomes the main factor in the history and development of the Pic du Midi. The facts and events in this section will therefore be explained in terms of scientific work.

Scientific work and results

- *The cosmic rays decade (1949–1959)*

Throughout these ten years, several internationally renowned teams brought to the Pic advanced experiments on cosmic rays. Priority was given to high-altitude observatories at this time because they reduce the destructive effect of the atmosphere on these particles. Furthermore, interest in cosmic rays increased after the 1950s. Indeed, their study provided an indirect way to undertake nuclear physics. The cosmic ray specialists at the Pic can be separated into two categories.

The Manchester team was joined in 1951 by others from the Polytechnic School, led by Louis Leprince-Ringuet. In 1951 he installed equipment that performed better on the summit than that of the Manchester team. According to Leprince-Ringuet, the Wilson Chamber was the largest of its kind in the world. With this instrumentation, they discovered new particles in subatomic matter, which earned them the Cognac-Jay Prize from the Academy of Sciences in 1962. In 1959 and 1960, the accelerators of CERN and Brookhaven brought about the departure of the Polytechnic team from the Pic.

- *The Sun*

Monitoring of the solar corona with the Lyot coronograph in the 1930s was both the starting point and catalyst for solar research undertaken at the Pic in the second half of the 20th century.

Jean Rösch equipped the observatory building with new instruments in order to study the solar atmosphere in its entirety. Alongside the solar corona, it was now possible to study the photosphere and the chromosphere. This work, and its potential, attracted many scientists: Lyot's "heirs" at the Meudon Observatory and foreign researchers.

In 1955, the study of solar granulation was at the cutting edge of global scientific research on the Sun and the photographs from the Pic were considered the best available. Up until 1987, when the Roque to the Muchachos Observatory opened in the Canary Islands (see Ch. 10), the Pic du Midi was the most important solar observation site in the world.

- *The Moon*

The infrastructure at, and high quality images available from, the Pic secured its selection in 1956 to carry out the "Manchester Lunar Programme". In 1959, thousands of lunar images taken at the summit impressed the US Air Force so much that they decided to fund the observatory to map the Moon. This work contributed directly to the Apollo programme launched in 1961. Placed under American management, the mapping of the Moon required the work of more than 50 people at the Pic. In 1964, a 1 m telescope, funded in part by NASA, was installed under the Gentili dome and took over from the Baillaud Telescope for lunar observations. The American Orbiter probes 1-5 were launched between 1966 and 1967, and marked the decline of the "Manchester Lunar Programme".

- *The planets and their satellites*

As with the Sun and Moon, the quality of the research and planetary images have contributed to the worldwide reputation of the Pic du Midi. The intense development of planetary exploration in the 1950s and 1960s was mainly due to Andoin Dolfus.

Detailed cartography of Mars took place for more than a decade. Henri Camichel was able to determine the length of the Martian day, the diameter, the levelling of the planet, the polar alignment and the orientation of its rotational axis with great accuracy.

Fig. 9.35 Aerial view of the Observatory in 1960. The western part of the summit is not yet taken up with the interdepartmental building. In the centre, we can see the new cable car station at the top. Photo © La Pie servie aérien

The exploration of Saturn at the Pic also provided important contributions to planetary science. In 1966, Dolfus was involved in the discovery of one of the outer rings of the planet, as well as that of one of its small satellites, which he proposed to name Janus.

Venus was also the target of many observations. The work conducted by Dolfus helped highlight the retrograde rotation of the planet, and the four-day "hyper-rotation" of its atmosphere, confirmed in 1972 by the Mariner 10 probe, is considered to be one of the most important discoveries to which the Pic du Midi has contributed.

The study of the soil and atmosphere of the planets and their satellites is the most original contribution that the Pic has made in the field of planetary science. By using a polarimeter, an instrument rarely used at the time, Dolfus was able to deduce the composition of planetary surfaces, notably those of Mars and of the Galilean satellites of Jupiter. The results on the Galilean satellites were confirmed in the 1970s by the Voyager probes.

The 1970s heralded the era of such space probes, and thus planetary research at the Pic—which had hitherto been considered unrivalled—gradually declined.

Infrastructure: expansion in response to the intensification and diversification of scientific and technical demands

Work on the infrastructure at the beginning of the 1950s, and the observatory's increase in power, led to the extension and construction of several buildings. The Marchand Laboratory was built in 1956, and the Labardens building completed in 1957.

- 15 February 1961 marked the inauguration of the Tourelle Dome, installed on the eastern part of the platform.

Fig. 9.36 The face of the Pic du Midi changes for good with the arrival of the 103 m-high aerial and the inter–departmental building (1963). Photo © Alix, Fond Eyssalet

- 1962–1963: The summit welcomed the structure which today makes it recognisable to all: the interdepartmental building with its 103 m-high aerial, which rises to over 3000 m above sea level. These buildings are not part of the Observatory and handle services related to broadcasting, civil and military communications. The astronomers' influence at the time was such that they succeeded in banning the installation of a light on the aerial.
- 1964: The 1m Telescope, financed by NASA, was placed in the Gentili dome. The Pic du Midi's great nocturnal telescope era began here.

The increase in instrumental power of the observatory (1965–1981)

In 1965, John Rösch began the 2 m telescope project in order to afford the Pic its place in an astronomical context where the reputation of an observatory depends on the power of its instruments. This also served to make the most of the conditions offered by the summit.

The BLT, built from 1970 to 1981, is available to the international community. As the largest national telescope, for several years it was used as one of the tools in an immense research strategy in a multitude of projects across a range of topics.

The John Rösch years marked the highest point in the history of the Observatory. During these three decades, the Pic was consistently placed at the forefront of various themed astronomical observations and contributed hugely to scientific progress in this area.

The years 1970 and 1980 marked a set of technological and international revolutions to which the Pic has tried to adapt. It gradually yielded to the space probes and the giant international and spatial telescopes. Nonetheless, the Pic du Midi's robust scientific core endures, as the Bernard Lyot Telescope demonstrates.

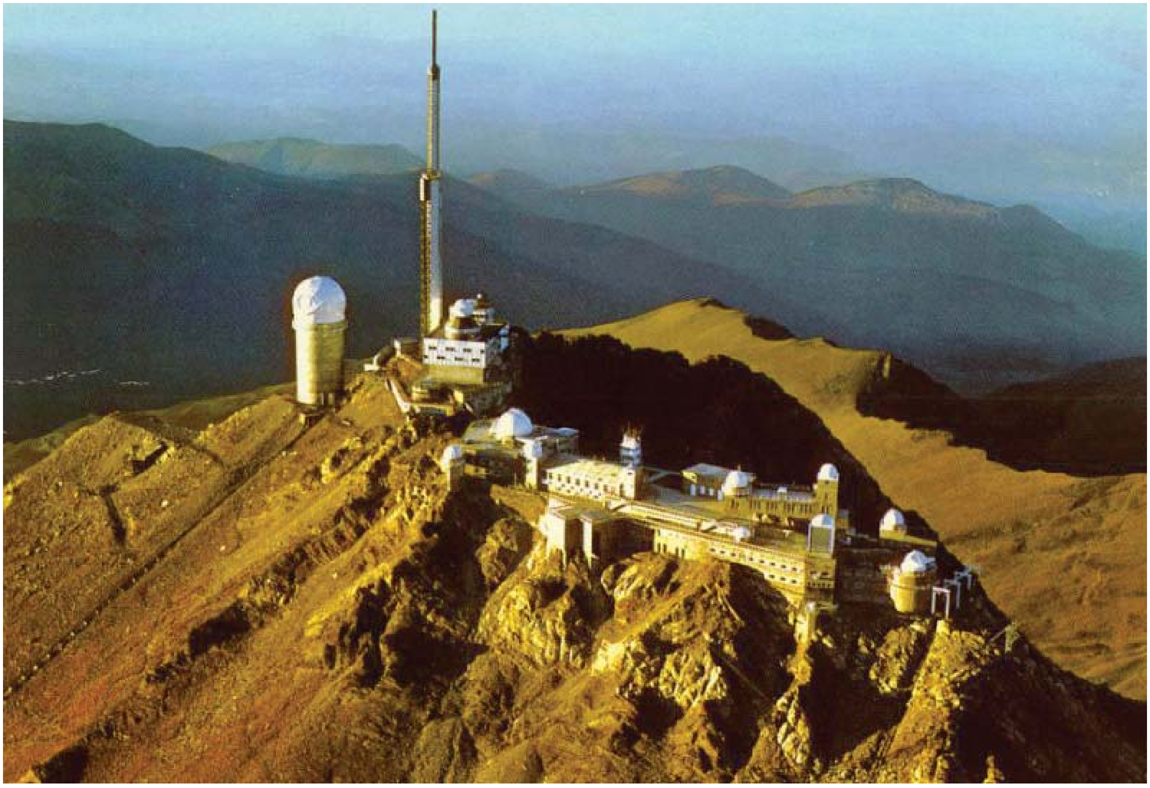

Fig. 9.37 Aerial view of the Pic du Midi Observatory in 1990. The scientific infrastructure was at its height before the reconfigurations during the 2000s. Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Infrastructure

- 1970–1981: the construction of the Bernard Lyot Telescope and its observatory building comprises the last phase of scientific infrastructure development on the summit. The initial landscaping work began in 1970, the building was completed in 1976 and the telescope was fully operational in 1981. The construction of the BLT and the aerial are the most important and iconic features of the Pic du Midi.

The dark years to come (1982–2000)

During the 1980s, France redirected its astronomical policies in order to prepare for the advent of major international observatories such as the VLT. The development of these projects required transforming the management and financing of national observatories. As with the crisis of the 1920s, the continued functioning of the observatory was deemed too expensive and its closure was announced for 1998.

In 1993 the new director, Michel Blanc, presented the "Pic 2000" project. This project was a challenge of reconfiguration: to locate the Pic du Midi on a new technology-oriented university campus and redevelop the site in order to sustain the scientific work at the summit whilst opening it up to tourism. A public coalition was set up in the same year, and the Syndicat Mixte for tourism development at the Pic du Midi was created. A set of public and private partners came forward to help fund what would become the highest construction site in Europe, the work starting in 1996.

In June 2000, the Pic opened its doors to tourism. Since then, its 100,000 visitors a year have allowed the Pic to cover its own operating expenses and continue its scientific work. The observatory has since been asked to develop both these aspects. The tourist activity must reinvent and enrich itself while always preserving the identity and integrity of the site. The scientific work, meanwhile, should be situated in specific fields and excel at these on an international level.

Scientific work and results

Even during the dark years of the Pic 2000 project, the astronomical work never ceased. From 1980 to 2000, the BLT was a universal telescope, available to the international community. After 2000, the instrumentation and fields of investigation of the BLT were rationalised in order to maintain its place in the scale of world astronomy. In 2007, the telescope was specialised for use in stellar spectro-polarimetry using its NARVAL system. This was such a new field of study that the only telescopes practising it were the BLT in collaboration with the Canada-France-Hawaii Telescope.

Alongside the BLT, other telescopes carried on their observation programmes. The 1 m Telescope was operated by the Institute of Celestial Mechanics and Ephemeris Computation (MCCE) in Paris. It specialises in monitoring planetary surfaces and in the study of small solar system bodies. The Rösch Telescope and Tourrelle dome were managed by the PMO and were used specifically for the training of PhD students in astrophysics for observing the solar photosphere. The continued monitoring of the corona was ensured via instrumentation and infrastructure recently installed for the Pic 2000 project. The observers and monitoring were entirely funded by sponsorship.

With the Pic 2000 project, the PMO was able to expand the range and direction of the Pic's fields of research, including atmospheric sciences. The observatory contributed to the study of atmospheric pollution and transient luminous phenomena.

Fig. 9.38 Since 2007, the Pic du Midi has been opening its doors to tourists at night for evenings dedicated to observation and the discovery of the observatory. The astronomers and facilitators enhance the public experience (2014). Photo © Nicolas Bourgeois

Fig. 9.39 The new cable-car station at the summit and the high-capacity cable car (2000). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Fig. 9.40 The Pic du Midi museum space, telling the Observatory's scientific and human history (2005). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Fig. 9.41 The new dome and coronograph ensuring continuous monitoring of the solar corona (2008). Photo © Régie du Pic du Midi and Observatoire Midi Pyrénées

Infrastructure

The latest work on the Pic du Midi's infrastructure was done in order to accommodate tourism whilst preserving the scientific work. This was all done between 1996 and 2000.

- Installation of a high-capacity cable car (300 people/hour).

- Reconfiguration of the platform with infrastructure modifications and the installation of services dedicated to tourists: a museum space in the Baillaud dome buildings to display 140 years of life and science on the Pic du Midi; a restaurant accommodating 80 people; facilities to manage the flow of people, safety and movement on the terraces; refurbishment of all rooms and premises.
- Installation of a new coronograph observatory building on the south-east terrace.

3. Justification for inscription

3.c Comparative analysis

The Pic du Midi's profile is unique in the great family of worldwide scientific observation stations. Firstly, its history is rooted in the early development of the application of scientific method to nature in the 17th century. It is one of the last high-altitude resorts built in the 19th century that is still used as a window on the geophysical and astrophysical universe. This vibrant site has witnessed evidence of the human desire to gain knowledge in fields as diverse as meteorology, aerology, botany, geophysics, astronomy, and particle physics over the years of its existence.

There are a fair number of observation stations at altitude around the world, but the stations on high mountains can be counted on one hand. The Alpine station, Jungfraujoch in Switzerland, is the last one still open, and the Californian observatories, amongst some of the oldest, are not in the high mountains. The great Andean astronomical observatories are recent.

In addition, the scientific work of all these other sites is dedicated to a particular subject area (aerology for Jungfraujoch, astronomy for the others) or is being severely compromised by adjacent human activities (as is the case for Palomar and all the observatories in urban and peri-urban areas).

The major active sites, the island observatories (Hawaii and the Canary Islands [see Ch. 9]) and the astronomical sites in the Chilean Andes (AURA [also see Ch. 9], Las Campanas, La Silla, Paranal, and ALMA), all have a relatively recent history, starting in the late 1960s for the oldest ones and the 2000s for the most recent. While all these sites convey the feeling of exceptional human adventure, they do not convey the closeness to the historical roots of scientific exploration that is found at the Pic du Midi.

The Pic du Midi uniquely illustrates the power of humanity. Thanks to the perseverance of men and women from diverse starting points (rich sponsors, Pyrenean mountain enthusiasts, committed scientists, shepherds from the valley who love their mountain)—with a variety of motivations but driven by the same enthusiasm—the Pic du Midi has become, and will continue to be, a space where culture, science and art cross paths and complement one another by making the unspoilt beauty of the site and landscape available to everyone.

3.d Integrity and/or authenticity

Integrity

The *integrity of composition* is satisfactory because all major historical activities are present (foundations from the early 20th century, historic domes, etc.) or represented in the Pic du Midi's site and its surroundings (buildings with 19th century origins, historical paths, etc.) by correctly identified material evidence. It is therefore possible for the visitor to have a clear enough idea about the past and present of the site.

Today's *structural integrity* truly represents the overlapping and correlation of functions historically assigned to the Pic. These activities have been continued since the foundation of the observatory, and the renewal of individual components in accordance with new requirements has always been undertaken in keeping with the original elements.

The *functional integrity* is marked by the fact that the Pic's various main activities—scientific observations of the sky and the atmosphere, the welcoming and lodging of tourists and mountaineers, broadcasting functions—have been in harmony with one another right from the beginning and have always complemented one another and been organised around the Astronomical Observatory. The buildings and infrastructure form a whole that serves the well-being of the Pic so that it can continue in its original, historical role.

The quality of the panorama and the night sky are such that the *celestial landscape integrity* of the Pic du Midi reflects one of the most remarkable, natural properties of the site. The origin of this lies as much in its vocation as a scientific station at high altitude as with its popularity and tourist success (Pyrenees, mountaineering, snow sports, visiting for the view, amateur astronomy, etc.). The conservation of this dual integrity, both by night and day, today presents one of the major challenges for the conservation of the site.

Authenticity

The *authenticity of its design* rests upon a continuity of scientific, technological and civil engineering initiatives since the first projects came into being towards the end of the 19th century. They can only be understood within the dynamics of the site and the renewal of techniques in order to benefit site development: the creation of domes and scientific instruments, its current evolution, the creation of cable car access, the construction of the great broadcasting tower, and so on.

The *authenticity of the components and materials* is again based on this dynamic, specific to a scientific station that has had multiple purposes throughout its history: the introduction of reinforced concrete, progress in dome construction, the evolution of architectural structures. A specific feature marking this aspect of authenticity is the respect for existing buildings and the sympathetic superimposition of new structures upon older ones. This has been particularly true ever since the equipment of the early 20th century was installed on the summit: all strata of building constructions and historical scientific equipment are present.

The *architectural and landscape authenticity* is an issue that can only be understood in terms of other closely complementary aspects. It is a matter of understanding a place of science and tourism that is continuously taking on new forms. It is not possible to judge the authenticity of such a place as one would for classical heritage sites and monuments. The renewal both of the equipment and of the construction framework for both the scientific station and the tourist resort has always been undertaken in a spirit of restructuring the old, but two main components represent a split:

- the construction of the cable car (1950–52), which totally changed the access to the Pic and allowed the site to welcome in the public and remain open all year;
- the construction of the DFT tower (1953) in the second half of the 20th century, which gave the Pic its visual signature as seen from the valley or the adjacent mountain.

The property therefore has a visual authenticity that has evolved alongside its history. The *perceived authenticity* of the Pic du Midi today seems most important: the newcomer's first, strong impression while riding the cable car is that of an authentic and original scientific mountain station. One could even say that the image portrayed by the Pic, with its broadcasting tower surrounded by observatory domes, forms the ideal model and symbol of the high altitude Observatory.

The *environmental authenticity* reflects one of the great values of the property: the quality of its atmosphere and its clear skies. These values are intrinsic to the Pyrenees and are the source of the romantic appreciation of their outstanding tonal range compared to other major

European mountain ranges, which motivated the first foreign visitors, notably British, and local élites behind the proposed observatory at the Pic du Midi (see History and Development, above). This sparked the notion that we should have a seasonal and then permanent human presence on the Pic, enabling high-quality astronomical observations (substituting for the Paris Observatory, in partnership with NASA), and finally allowed the development of tourism dedicated largely to the Pyrenean panorama, and more recently to the appreciation of its night sky. The long-term preservation of panoramas, at the highest level of French legislation (see Protection and Management, below), and more recently a major initiative to protect against light pollution (International Dark Sky Reserve project, 2009–2013), the largest in France to date, guarantee the highest degree of environmental authenticity and its future protection.

3.a Potential criteria under which inscription might be proposed

Criterion (ii): In terms of the history of its construction and development, the Pic du Midi is primarily a national programme that brings together important human, scientific and financial capabilities, on both a regional and national level. Owing to the quality of its night sky, the Pic took over from and substituted for the Paris Observatory, itself a leader and promoter of very important international scientific programmes (see Ch. 7). From the 1930s, and especially during the second half of the 20th century, the Pic du Midi Observatory developed international collaborations in astronomy. In particular, it served in the 1960s as an observation centre associated with NASA and the conquest of space.

Criterion (iv): Today, the Pic du Midi represents the ideal model and symbol of a high-mountain observatory. It belongs to the older generation of such observatories, designed and built towards the end of the 19th century. Over time it has gradually changed its use and today it offers a veritable landscape and cultural icon, visible from far away, showing both the human presence at altitude and the scientific use of the high mountains. The quality of its climate and atmospheric environment is responsible both for its daytime panoramas and its exceptional night sky, qualities that underpin its scientific value as much as its tourist reputation.

Fig. 9.42 Winter at the Pic du Midi. The buildings are imprisoned under the frost and the snow (2008). Photo © Nathalie Strippe

3.b Suggested statement of outstanding universal value

In terms of UNESCO categories, it seems reasonable to consider "Cultural Landscape" for the Pic du Midi. This would fit well with the value assigned to the site, its situation as a mountain peak, and its general shape as symbolic value. It is also consistent with two very important environmental values: the view of the central chain of the truly remarkable Pyrenees by day, and an equally outstanding situation by night owing to the quality of the night sky.

Potential "Outstanding Universal Value" (OUV) could be based on the following:

- The Pic is a high-mountain observatory amongst some of the oldest (the comparative analysis will be important on this point).
- It includes a comprehensive set of material testimony to its different historical periods of occupation (domes, instruments, technical equipment) spanning more than a century of scientific use in the high mountains.
- Beyond this, it is a pioneering scientific and technical station at altitude with a number of other uses (weather observations, broadcasting, etc.).
- The Pic has had continuous scientific use, particularly for astronomy, and has always been a place alive with astronomy.
- The importance of the scientific work at the Pic du Midi, world-class innovations (coronagraph), and international cooperation.
- It represents a major natural and cultural landmark in regional history. Its silhouette is unforgettable, as important a symbol of the Pyrenees as physical geography manuals. It is a symbol of the peaceful relationship between humankind and the high mountains.
- It is a place of exceptional observation by day and night, to which the Pyrenean panoramas and the quality of the night sky are testament.

4. Factors affecting the property

4.a Present state of conservation

The buildings and observatories are regularly maintained. However, this maintenance is extremely complex and sensitive. See §4.b.ii below for more information.

4.b.i Developmental pressures

The exceptional location of the Pic du Midi means that it escapes most of the pressures linked to urban or industrial development.

However, the presence of the nearby ski resort of La Mongie has, on occasion, resulted in the Pic being exposed to expansion projects to enlarge the skiable area. But the desire of the local elected officials to preserve the observatory's integrity has always succeeded in keeping these attacks at bay.

4.b.ii Environmental pressures

The first is the high altitude and strong assaults it inflicts on buildings. Rain and melting snow seep into buildings. When temperatures drop, the water freezes and shatters the masonry. There are also very strong winds that can reach nearly 300 km/h, or thermal amplitudes reaching nearly 60°C. Without permanent maintenance work, the Pic would fall into ruin in fewer than 5 years (as happened during the First World War).

The second reason is the complexity and variety of the buildings. One hundred and forty years of facilities and construction are superimposed on the summit. Modern concrete buildings are mixed with stone structures from the beginning of the 20th century and the whole assemblage spreads over 1 hectare of ground and reaches nearly 8 floors in height. The maintenance of an edifice of this size and diversity at nearly 3000 m above sea level demands considerable attention and resources. These are not sufficient to ensure the homogenous integrity of the whole platform.

The final reason, also related to the altitude, is the seasonal maintenance. Throughout its history, major work on the Pic du Midi could only be carried out during the summer (July to September) and modern methods can do nothing to change this.

The Pic du Midi's night sky today is still of very good quality. However, the increase in light pollution observed for more than twenty years in this region has alarmed both astronomers and elected officials of the Pic du Midi. In order to counter this threat, the International Dark Sky Reserve project was launched in 2009. The Pic du Midi, accompanied by an extensive network of partners, is committed to completing this process, which goes beyond just the issue of access to the stars.

The 251 municipalities that make up the Reserve in the Hautes-Pyrénées are currently mobilising to support the sustainable development approach. Among the main actions that characterise this project are the establishment of a new mode of economical, sustainable and cleaner lighting, the protection of the sky and the nocturnal environment, and tourism development. On 19 December 2013, the Pic du Midi IDSR was accredited by the International Dark Sky Association, making this Dark Sky Reserve the first in France and the second largest in the world. Today, 40,000 public street-lights are involved in the programme to improve the lighting. The monitoring carried out by this programme measured an 85% decrease in the luminous flux emitted upward in converted villages. Since 2012, approximately 3000 lights have been improved each year.

4.b.iii Natural disasters and risk preparedness

Natural disasters in the Pyrenees affect the Pic du Midi indirectly. They disrupt the flow of tourists upon which the observatory's work now depends. In June 2013, heavy floods affected the Hautes-Pyrénées, destroying many access roads and making them impassable for several months. The Pic du Midi in general, already very sensitive to bad weather, saw its attendance drop by more than 30% that year.

4.b.iv Visitor/tourism pressures

Tourism is now essential to the work of the Observatory. The "Pic 2000" project was the fruit of collective work between astronomers and local public authorities, helping to redesign the platform and its access in order to welcome the public without transforming or disrupting the scientific work. Most of the tourists visit during the summer. However, the Pic stays open for visits all year round and only closes for maintenance periods in November and April.

4.b.v No. of inhabitants

The observatory has 10 permanent residents and an average of 5 researchers on the summit. However, the number of staff members that allow the Pic du Midi to operate is much greater. The Syndicat Mixte of the Pic du Midi and its technicians have over 50 employees. The Midi Pyrénées Observatory platform technique team is made up of 20 people. The Pic, as a university training centre, also welcomes many trainees and PhD students.

Fig. 9.43 Pic du Midi IDSR. The IDSR, with its core and buffer zones, takes up 65% of the territory of the Hautes-Pyrénées' département. Photo © Agence Hotel Republique, Régie du Pic du Midi

5. Protection and management

5.a Ownership

Currently, two agencies manage the Pic du Midi Observatory and its infrastructure.

The buildings carrying out the scientific work are in the public domain of the French state. Their management is provided by the Paul Sabatier University in Toulouse via the Midi Pyrénées Observatory. The MPO is thus responsible for 4000 m² distributed amongst the various observatories and technical areas related to science.

Since 1996, the Syndicat Mixte du Pic du Midi has been the new observatory concessionary. It is in charge of tourism infrastructure, technical elements (purification of the summit station, pumping station, generator), access to the site (and cable car stations) and human resources (rooms, staff rooms, meeting room). This also represents 4000 m².

There is one final concession at the summit, which is outside the Pic du Midi Observatory. This concerns the Interdepartmental Building, which is the property of the State and managed by the French broadcasting organisation Télédiffusion De France. This makes up 2000 m².

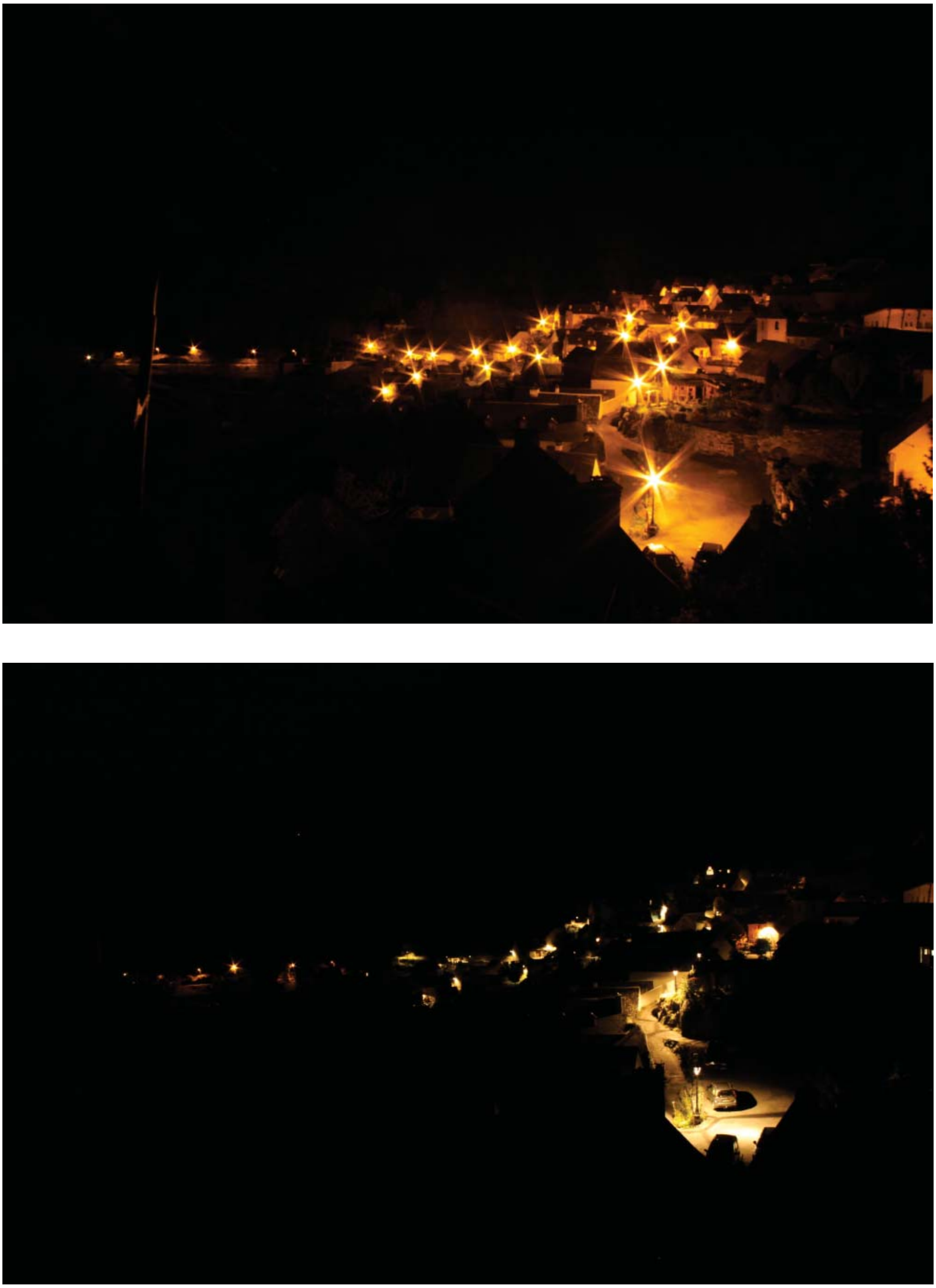

Fig. 9.44 Lighting in the village of Aulon, before and after the improvements made to the lighting under the Pic du Midi IDSR project (2013). Photos © Léa Salmon

5.b Protective designation

In 2003, the Pic du Midi became a "National Natural Site" under the heading "Landscape Beauty". This document, issued by the Ministry of Ecology and Sustainable Development, protects the integrity of the panorama terraces accessible from the observatory.

Since 2007 the observatory has been involved in a voluntary environmental quality programme in order to reduce its impact on the natural environment. It obtained the international "quality, safety, environment" certificate via the ISO 14001 standard.

The Pic du Midi is also the only tourist attraction at altitude to have achieved, on its own, the level of security required for an establishment to open its doors to the public. The observatory is certified to ISO 9001 Version 2000 in security, infrastructure maintenance and public management.

In 2013, it received International Dark Sky Association accreditation for the preservation of its night skies (see §4.b.ii above for more information).

5.h Visitor facilities and infrastructure

The observatory is equipped to accommodate an average of 100,000 visitors per year while preserving the architectural integrity of the site and its scientific work. For details, see §2.a "Tangible Heritage", §2.b and §3.d.

5.i Presentation and promotion policies

The Pic du Midi is considered a Mecca and geosymbol of the Pyrenees, of human adventure and of science. Because of this, it is the subject of several development and protection policies.

In 2010, the Pic du Midi was chosen to be part of the "Grands Sites de la Région Midi-Pyrénées" (the Midi-Pyrénées' Great Sights). This label values natural and cultural sites as well as the most iconic architecture of the Region.

Fig. 9.45 The terrace on top of the Pic du Midi in the summer. Tourists today have access to 750 m² of terrace, the museum space under the Baillaud Dome, and the restaurant in the Vaussenat Building (2013). Photo © Nicolas Bourgeois

7. Documentation

7.a Photos and other AV materials

A photographic inventory of the Pic du Midi property is being developed within the Ramond Society and the Pic du Midi Observatory.

7.c Most recent records or inventory

See §2.a "Movable heritage objects—small instruments, books, archives and photographs" for the Pic du Midi Observatory heritage inventories.

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‘Windows to the Universe’: Leading Optical Observatories and their Dark Skies
Chile, United States of America and Spain

Cipriano Marín, Malcolm Smith and Richard Wainscoat

1. Identification of the property

1.a Country/State Party: Chile / United States of America / Spain
1.b State/Province/Region: Coquimbo Region / State of Hawaii / Canary Islands
1.c Name: AURA Observatory / Mauna Kea Observatory / Canarian Observatories

1.d Location

AURA OBSERVATORY
Cerro Tololo:
Latitude 30° 10′ 09″ S, longitude 70° 48′ 23″ W, elevation 2240m above MSL.
Cerro Pachón:
Latitude 30° 14′ 27″ S, longitude 70° 44′ 12″ W, elevation 2700m above MSL.
(For more detailed information see *Accurate Geodetic Coordinates for Observatories on Cerro Tololo and Cerro Pachón*, a Technical Report for CTIO by Eric Mamajek [v3, May 2013].)

MAUNA KEA OBSERVATORY
Latitude 19° 49.4′ N, longitude 155° 28.4′ W, elevation 4190m above MSL.
(See below for details of the precise locations of individual telescopes.)

CANARIAN OBSERVATORIES
ORM – La Palma:
Latitude 28° 46′ N, longitude 17° 53′ W, elevation 2396m above MSL.
OT – Tenerife:
Latitude 28° 18′ N, longitude 16° 30′ W, elevation 2390m above MSL.

1.e Maps and Plans

See Figs 10.1–10.2 (AURA Observatory), 10.5a–10.5c (Mauna Kea Observatory) and 10.8 and 10.10 (Canarian Observatories).

1.f Area of the property and buffer zone

AURA OBSERVATORY
The area of AURA property surrounding Cerro Tololo and Cerro Pachón is 34,491ha (85,227 acres). This property, now known as the El Totoral Reserve, serves as the inner buffer zone for protection against light pollution and mining.

Three northern Regions of Chile—one of which is the Coquimbo Region, where the AURA observatory is sited—are protected to some extent against light pollution by Decreto Supremo 686/98 which was signed into effect in 1999 by the then President of Chile. These Regions serve as outer buffer zones for reducing light pollution within these Regions. (Poorly-designed exterior lighting within a buffer zone of typically 300km radius can affect the purity of the natural night sky.) The Fray Jorge UNESCO Biosphere Reserve, comprising the Fray Jorge, Talinay and Punta del Viento National Parks, is located in the Coquimbo Region, ~100km southwest of the observatory, within the outer buffer zone.

MAUNA KEA OBSERVATORY

The region of Mauna Kea designated for astronomical research has an area of 2.125 km² (525 acres). This “Astronomy Precinct” is contained within the “Mauna Kea Science Reserve” which has an area of 45.7 km² (11,288 acres). The science reserve has strict controls on usage. A pie-shaped sector of it is preserved as the “Mauna Kea Ice Age Reserve”. See Figs 10.5a and 10.5b.

Fig. 10.5c shows land ownership around Mauna Kea. A large area around the science reserve is preservation land owned by the state of Hawaii. Few people live within 25 km of the summit. Mauna Loa is a large active volcano located to the south of Mauna Kea and its upper slopes are uninhabited.

CANARIAN OBSERVATORIES

ORM – La Palma

The Roque de Los Muchachos Observatory is located in an area of some 200 ha. In terms of nature and landscape conservation, the Caldera de Taburiente National Park covering 4,354 ha together with the Special Protection Area (SPA) “Cumbres y acantilados del Norte de La Palma”, covering 22,701 ha, are considered as a buffer zone.

In terms of protection against light pollution, there is a core zone around the ORM void of any source of light pollution of 25,434 ha (radius 9 km) (Fig. 10.8). A Buffer Zone has been established, covering an area of 19,400 ha, including the north of the island, the dorsal ridge and large areas of the west and south of the island. Finally, an external zone of protection from light pollution was established in the Sky Law of 1988, which practically includes the whole island of La Palma and the north of Tenerife island directly visible from the site.

OT – Tenerife

The Teide Observatory is located within an area of some 100 ha inset in the Teide National Park World Heritage Site (#1258), whose size is 18,990 ha. A natural and landscape protection belt surrounds the National Park, named Parque Natural de Corona Forestal. It is considered as a buffer zone and covers an area of 46613 ha (Fig. 10.10).

2. Description

2.a Description of the property

AURA OBSERVATORY

General Description

The AURA (Association of Universities for Research in Astronomy) Observatory in Chile comprises two mountain-top groups of telescopes: on Cerro Tololo and Cerro Pachón.

Cerro Tololo is the site of the first of the various major, international observatories that are now operating in Chile. Attracted by the pristine night skies, the world’s astronomers have since made northern Chile the primary centre for major astronomy research observatories in the southern hemisphere. The wide-field, 4m, Blanco telescope was the largest telescope in the southern hemisphere during the period 1975–1997. Clear, dark skies over the Blanco telescope were crucial to its selection by the two groups who used it to make the initial discovery of the acceleration of the Universe, which was announced in 1998. This discovery, awarded the 2011 Nobel Prize for Physics, was one of the major discoveries made in astrophysics during the second half of the 20th century. There are numerous smaller telescopes on Cerro Tololo, funded mainly by the Small and Moderate Aperture Research Telescope System (www.ctio.noao.edu/noao/content/smarts-consortium).

Cerro Pachón is the site of the international 8m Gemini South and 4.2m SOAR telescopes and the future site for the 8.2m, very-wide-field Large Synoptic Survey Telescope.

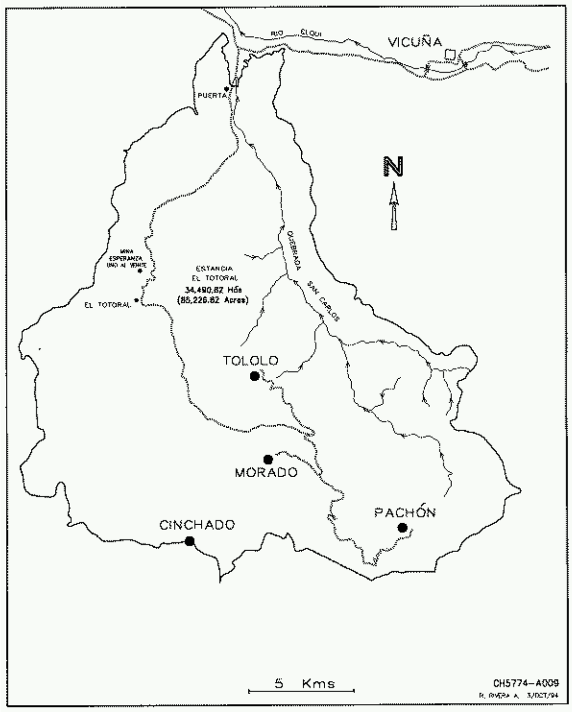


Fig. 10.1. The area of the El Totoral Reserve (Image: NOAO/AURA/NSF)

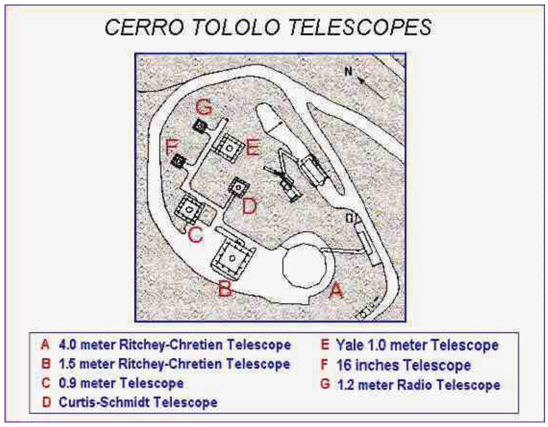


Fig. 10.2. The summit of Cerro Tololo (Image: NOAO/AURA/NSF)

The El Totoral Reserve, Cerro Tololo and Cerro Pachón

The Cerro Tololo Inter-American Observatory is located about 500km north of Santiago, Chile, about 52km east (80km by road) of La Serena, at an altitude of 2200 meters. It lies near the centre of a 34,491ha (85,227-acre) site known as Estancia El Totoral (Fig. 10.1), which was purchased by AURA on the open market in 1967 for use as an astronomical observatory.

Roughly in the center of the property lies Cerro Tololo on which is located a still-increasing number of working optical astronomical telescopes, the largest of which is the 4m Victor M. Blanco (Figs 10.2–10.3).

On the southeast side of the property lies Cerro Pachón where the Southern Hemiphere Gemini 8m and the 4.2m SOAR telescopes are located (Fig. 10.4).

MAUNA KEA OBSERVATORY

Mauna Kea Observatory is a collection of astronomical research telescopes located close to the geographic summit of Mauna Kea on the Island of Hawai‘i (Figs 10.5a–10.5c). The locations of the telescopes are shown in Fig. 10.6 and their geographical coordinates are listed below. The coordinates were determined from an aerial survey made on Sep 25, 1996, that used GPS techniques for reference points. Altitudes for the optical telescopes were determined from telescope construction plans.

The Submillimeter Array (SMA) is not shown in the table because it consists of 8 movable antennae with positions that change.

The Hawaii antenna of the Very Long Baseline Array is located away from the summit region, at 19° 48′ 05″ N, 155° 27′ 21″ W at an altitude of approximately 3,732 meters (12,240 feet). The proposed Thirty Meter Telescope (TMT) will be built on the plateau to the north of the main collection of telescopes near the summit, at a location of approximately 19° 49′ 57″ N, 155° 28′ 55″ W, at an altitude of approximately 4,007 meters (13,150 feet).

Fig. 10.3. Cerro Tololo from the south-east (above) and north (below). Photographs: NOAO/AURA/NSF

Fig. 10.4. (Top) In this picture, looking up at the face of Pachón from the northwest, the Gemini dome can be seen when it was under construction. The SOAR site is behind the promontory in the top center of the picture. **(Bottom)** A broader view of Cerro Pachón years later (2011), where SOAR (left) and Gemini (right) can easily be distinguished. Two bumps further to the right of the Gemini site mark where rock-blasting preparation work on the site for the LSST is currently under way. Photographs: NOAO/AURA/NSF

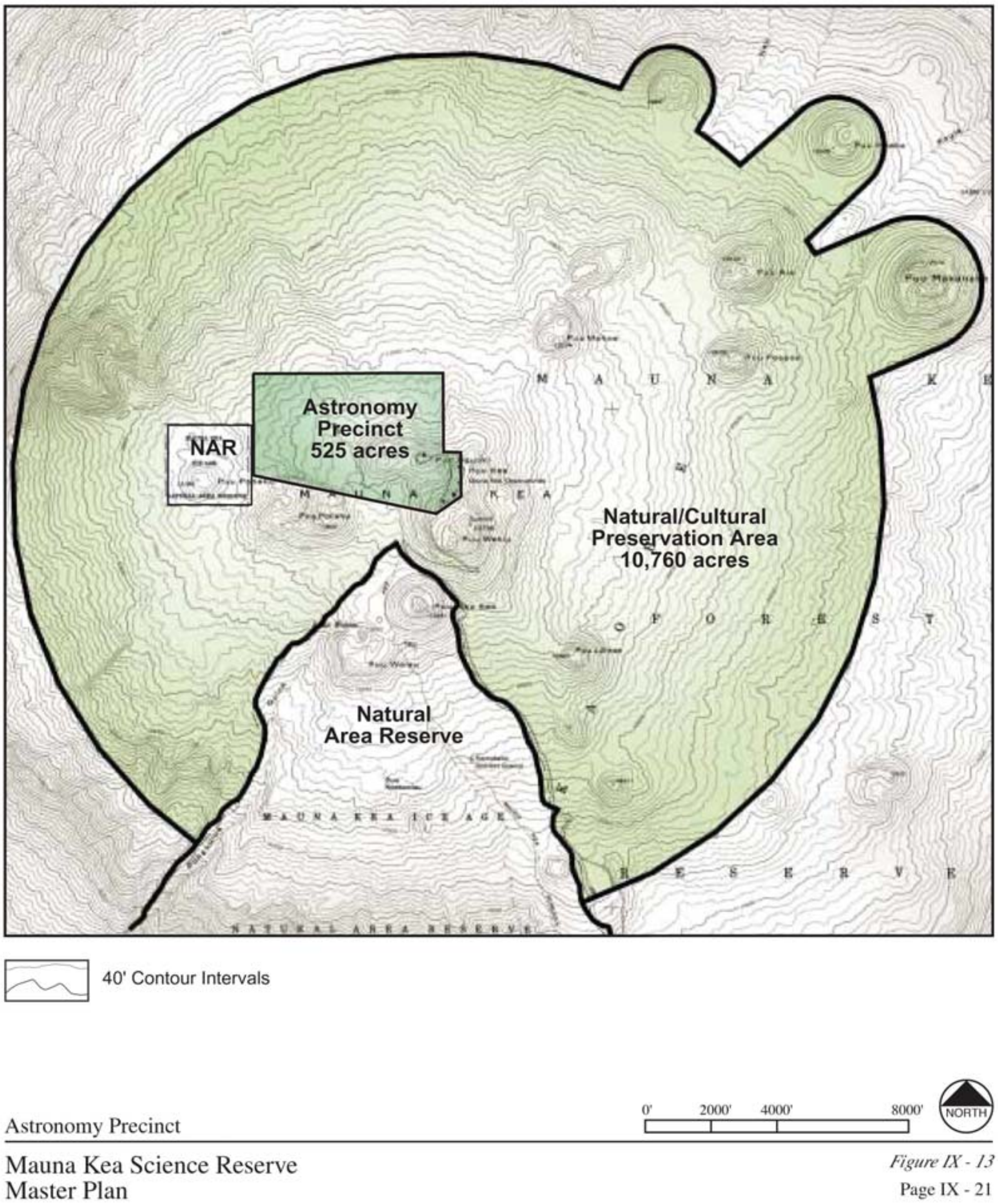


Fig. 10.5a. The astronomy precinct in relationship to the Mauna Kea Science Reserve (colored green), and the Mauna Kea Ice Age Reserve (labeled as "Natural Area Reserve")

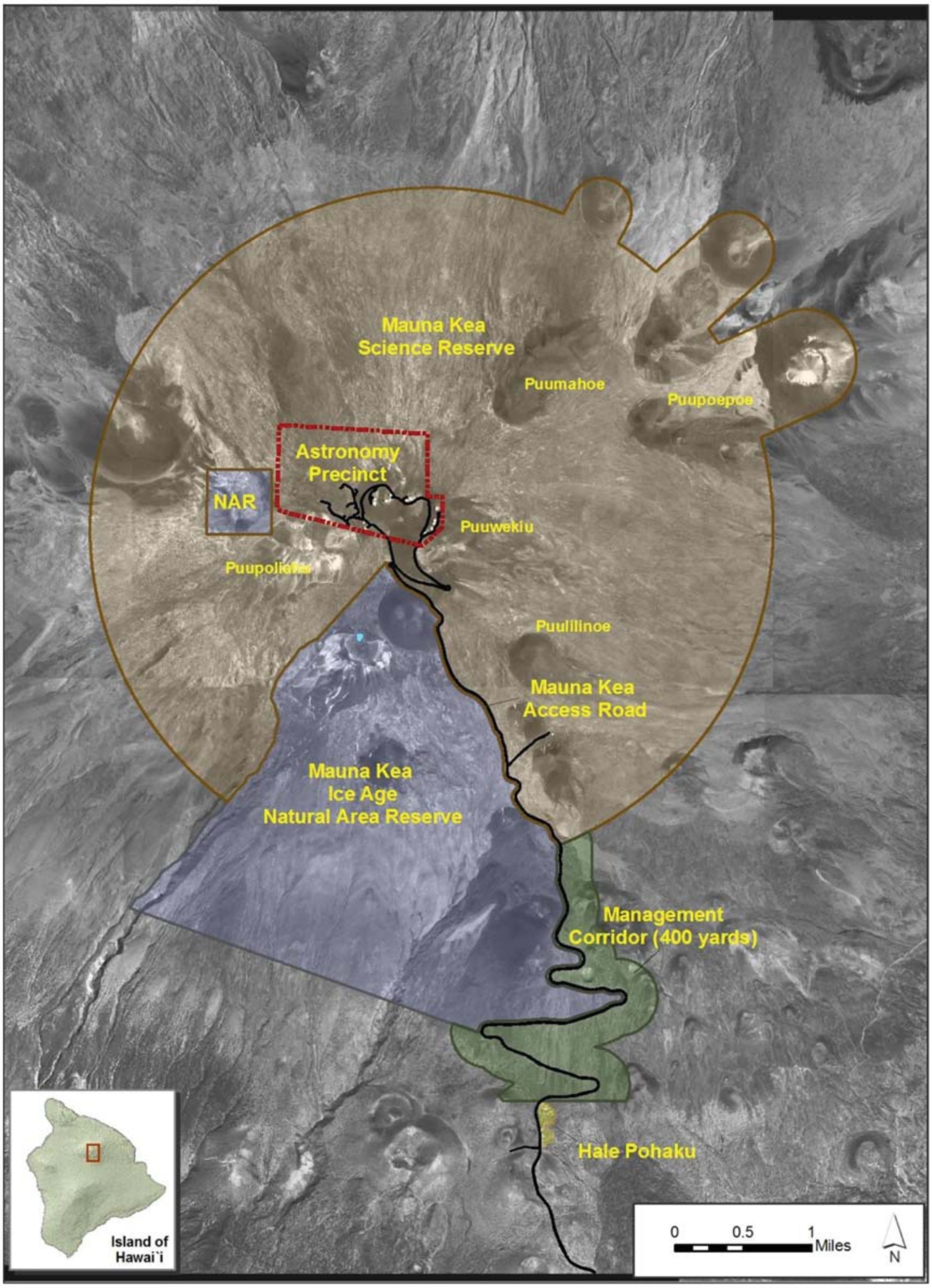


Fig. 10.5b. The Management Corridor, Hale Pohaku, the Mauna Kea Science Reserve, and the Mauna Kea Ice Age Natural Area Reserve

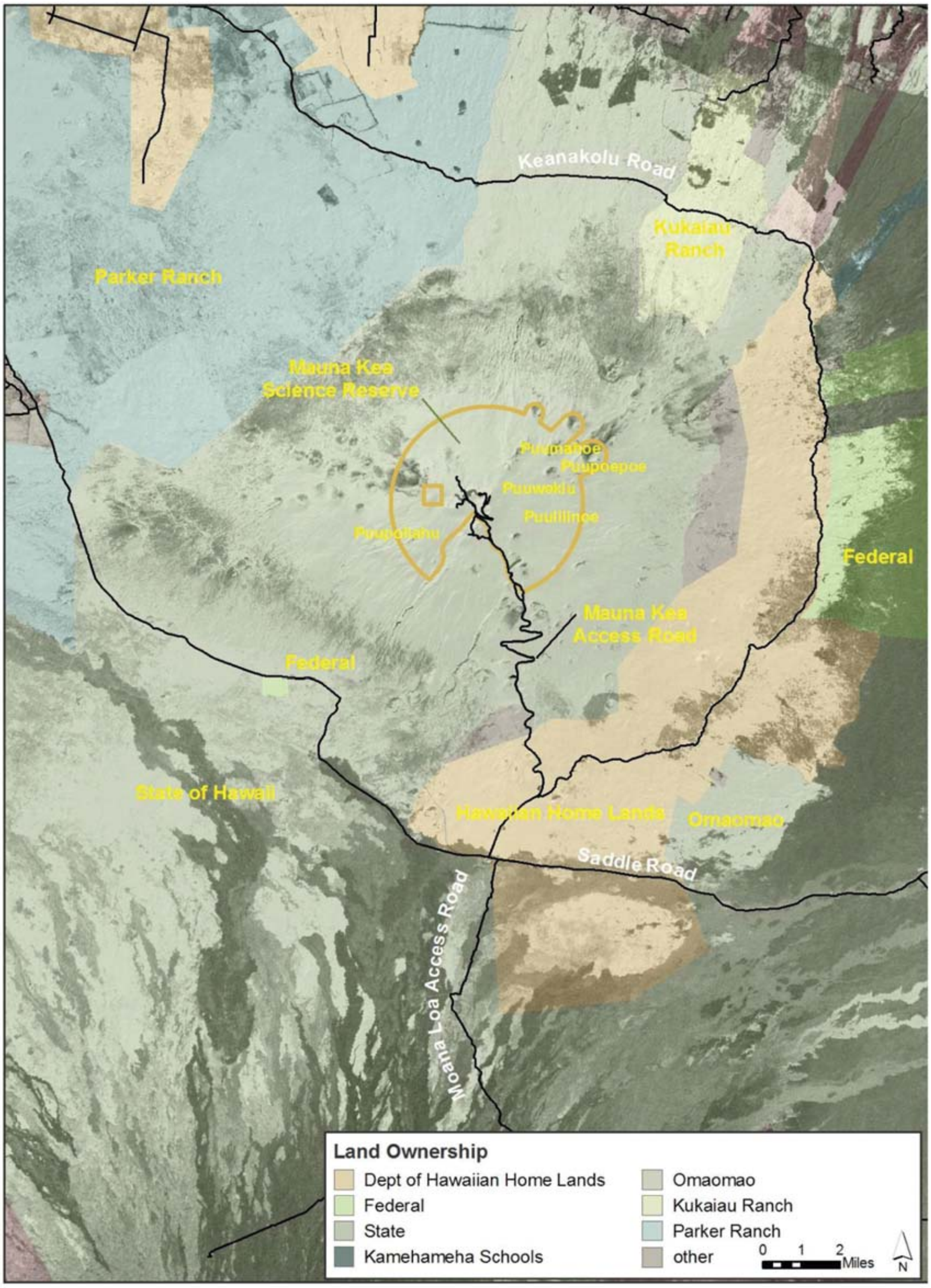


Fig. 10.5c. Land ownership around Mauna Kea

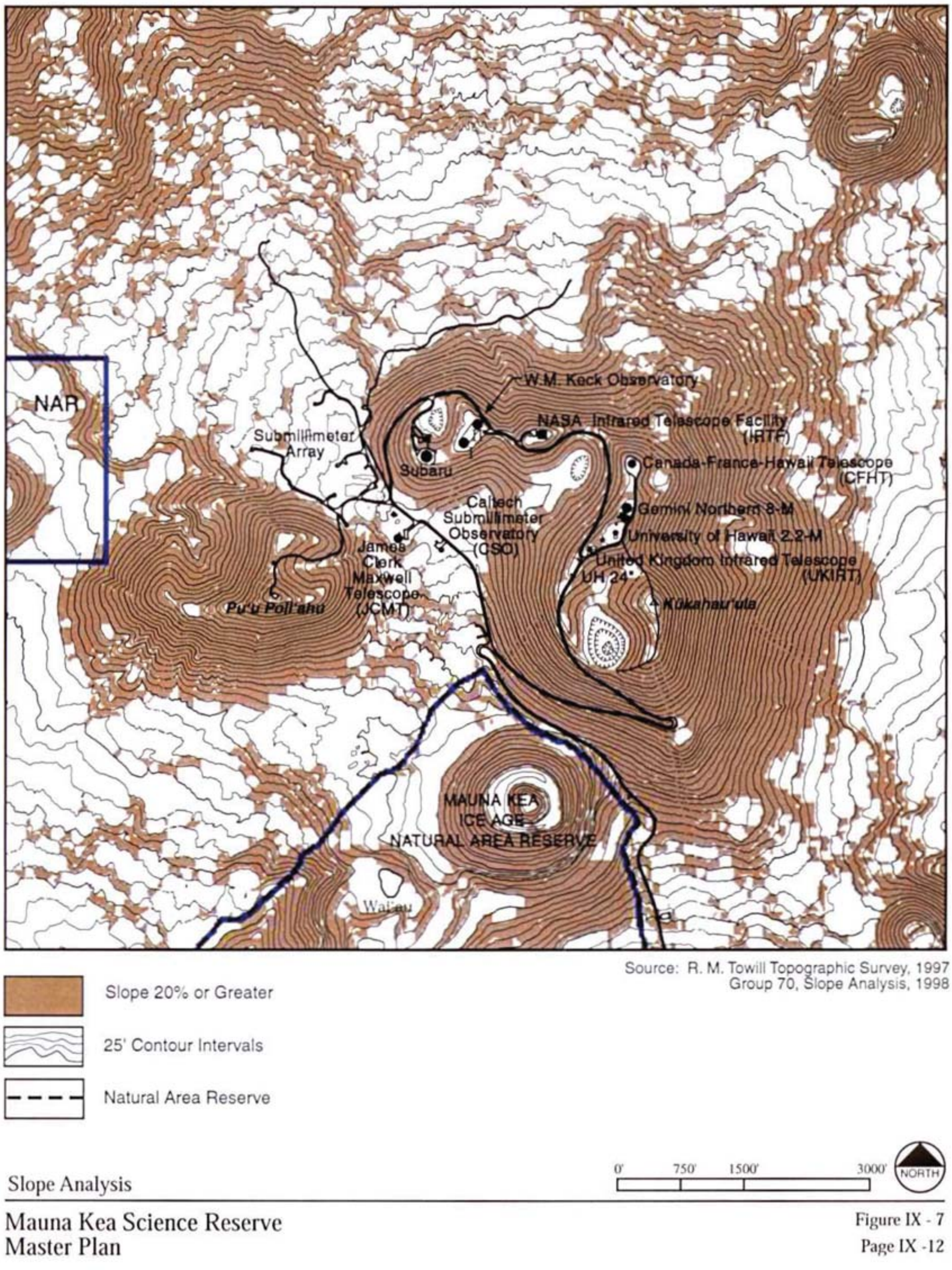


Fig. 10.6. Locations of observatories near the summit of Mauna Kea

	NAD83		
Telescope	**Latitude (North)**	**Longitude (West)**	**Altitude (feet)**
0.9-m	19 49 17.81149	155 28 15.46587	13734.67
2.2-m	19 49 22.76784	155 28 09.96073	13824.00
CFHT	19 49 30.90648	155 28 07.95258	13793.00
IRTF	19 49 34.38594	155 28 19.19564	13674.76
UKIRT	19 49 20.75334	155 28 13.17630	13774.60
JCMT	19 49 22.10741	155 28 37.20394	
CSO	19 49 20.77658	155 28 31.78945	
Keck 1	19 49 33.40757	155 28 28.98665	13646.92
Keck 2	19 49 35.61788	155 28 27.24268	13646.92
Subaru	19 49 31.81425	155 28 33.66719	13658.14
Gemini	19 49 25.68521	155 28 08.56831	13823.62

The area of Mauna Kea designated for astronomical use stretches north to the TMT site, and encompasses the area already developed with telescopes. Existing cinder cones near the summit that do not have telescopes on them, such as the Pu'u Wekiu (the summit), Pu'u Poliahu (to the west) and Pu'u Hau Kea (to the south) will not be used for telescopes.

CANARIAN OBSERVATORIES

The two observatories of the Instituto de Astrofísica de Canarias (IAC)—the Roque de los Muchachos Observatory (ORM) on the island of La Palma and the Teide Observatory (OT) on the island of Tenerife—constitute an 'astronomy reserve' that has been made available to the international community. The Canary Islands sky quality for astronomical observation has long been recognised worldwide. They are near to the equator yet out of the reach of tropical storms. The whole of the Northern Celestial Hemisphere and part of the Southern can be observed from them. The observatories are located 2400 m above sea level, above the temperature-inversion layer produced by the trade winds. This ensures that the installations are always above the so-called 'sea of clouds', where the atmosphere, stabilised by the ocean, is clean and turbulence-free.

The two observatories are currently home to telescopes and other instruments belonging to 60 scientific institutions from 19 different countries. These observation facilities, together with the scientific and technological resources of the IAC at La Laguna (Tenerife) and Centro de Astrofísica en La Palma (CALP) at Breña Baja (La Palma), make up the *European Northern Observatory* (ENO).

Both observatories are located in areas of the utmost value from an environmental point of view, with exceptional natural scenery. The ORM (Fig. 10.7) is situated at the edge of the Caldera de Taburiente National Park (Fig. 10.8), a spectacular erosion caldera covered by vegetation. It is located at 2,396 m above sea level in the municipality of Garafía. It is home to one of the most extensive fleets of telescopes to be found anywhere in the world. A number of archaeoastronomical sites, such as Lomo de las Lajitas, are also located within its area.

The ORM is located within the core zone of the La Palma Biosphere Reserve (www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/ europe-north-america/spain/ la-palma/) declared in 2002 by UNESCO. This is the first case of Biosphere Reserve zoning that includes areas of exceptional sky quality in its core zone. It is also included within the Special Protection Area (SPA) (Natura 2000) called "Barlovento, Garafía, El Paso y Tijarafe".

Fig. 10.7. The Gran Telescopio Canarias (GTC), part of the Roque de los Muchachos Observatory (ORM) on La Palma. © Pablo Bonet/GTC

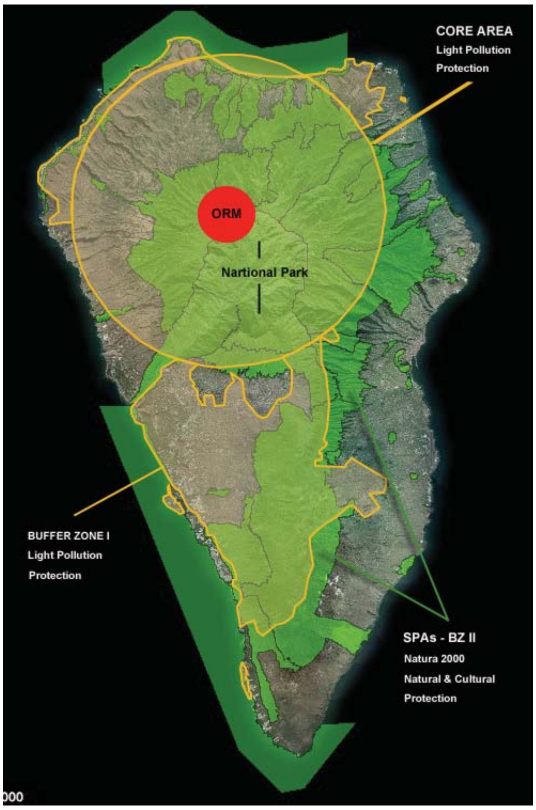


Fig. 10.8. Roque de los Muchachos Observatory (ORM), La Palma, zoning

The Teide Observatory (OT) (Fig. 10.9) is located on the border of the Teide National Park World Heritage Site (#1258) (Fig. 10.10). As the inscription text states (statement of Outstanding Universal Value under criterion (vii)): "Mount Teide is a striking volcanic landscape dominated by the jagged Las Cañadas escarpment and a central volcano that makes Tenerife the third tallest volcanic structure in the world. Within this landscape is a superlative suite of landforms that reveal different phases of construction and remodelling of the volcanic complex and highlight its unique geodiversity. The visual impact is emphasized by atmospheric conditions that create constantly changing textures and tones in the landscape and a 'sea of clouds' that forms a visually impressive backdrop to the mountain". At night, the landscape is dominated by the stunning clearness of the starry sky and the profile of Mount Teide itself.

Administratively it is not included within the National Park, for reasons of territorial management, but yet it shares all the natural and scenic values of its surroundings. That is why the OT area is within the SPA "Parque Nacional del Teide". It is situated 2,390 m above sea level in Izaña, an area of Tenerife that lies across three municipal districts: La Orotava, Fasnia and Güímar.

Its geographical location (between the eastern and western solar observatories), together with the clarity and excellent quality of the sky, make the Teide Observatory ideally suited for studying the sun. For this reason it is home to Europe's finest solar telescopes.

The main telescopes are:

- **ORM**: 10.4m Gran Telescopio CANARIAS (GTC), 4.2m William Herschel Telescope (WHT), 3.5m Telescopio Nazionale GALILEO, 2.56m Nordic Optical Telescope (NOT), 2.5m Isaac Newton Telescope (INT), 2m Liverpool Telescope, 1.2m MERCATOR, 0.45m Dutch Open Telescope (DOT), 1m Solar Telescope (SST), MAGIC I and II (which detect very-high-energy gamma rays), SuperWASP-North (robotic observatory).
- **OT**: 1.55m CARLOS SÁNCHEZ, 1m OGS, 0.8m IAC-80, 0.5m MONS, 0.4m OTA, 1.5GREGOR (Solar), 0.9m THEMIS (Solar), 0.7m VTT (Solar), 0.3m Bradford Robotic Telescope, 1.2m Robotic telescopes STELLA.

Fig. 10.9. Teide Observatory (OT) at night. © Daniel López

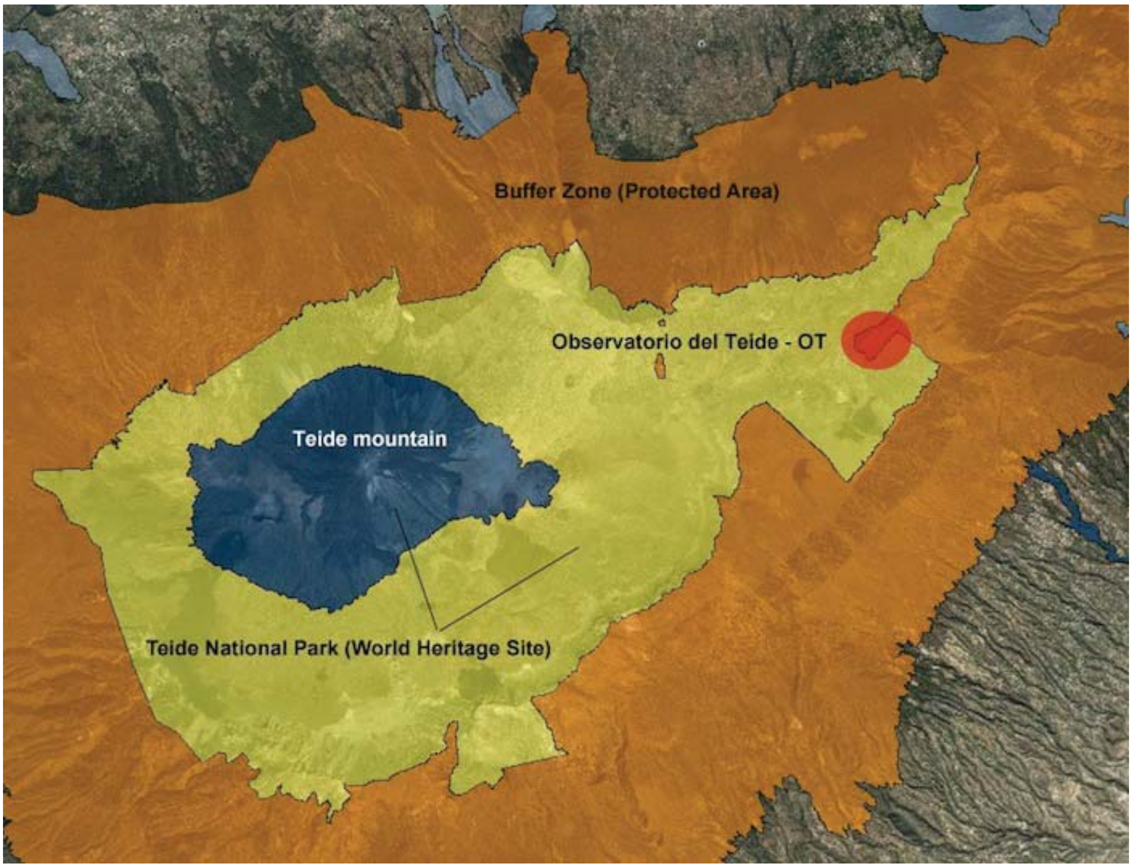


Fig. 10.10. Teide Observatory (OT), Tenerife, zoning

2.b History and development

AURA OBSERVATORY

Archaeological/historical/heritage research

The Diaguita and Molle cultures in the immediately surrounding area are extinct. There are two examples of rock art (not necessarily connected with astronomy) on Cerro Pachón. A statistical study of Molle sites might reveal further astronomically relevant information.

CTIO historic highlights

The Cerro Tololo Interamerican Observatory, on the AURA property near La Serena, was the first of the large, modern, international, astrophysical observatories to be set up in Chile. The following is a detailed, decade-by-decade list of historic and development highlights since the late 1950s.

1950s

Jun 1958	Prof. Federico Ruttlant of the U. of Chile visits Yerkes Observatory and proposes a cooperative observatory project to Drs. Kuiper and Hiltner.
Jul 7, 1958	Dr. Kuiper contacts Dr. Shane to explore possible AURA interest in the co-operative observatory. AURA is not then in a position to consider the project.
Jan 8, 1959	U. of Chicago applies to the U.S. Air Force for funds for a 40-inch telescope in Chile to be located near Santiago. The Air Force expresses interest and agrees to fund site testing program.

May-Jun 1959	Dr. J. Stock, later CTIOs first Director, travels to Chile and with U. of Chile personnel and equipment, a site testing program is organized. The first sites tested were near Farellones and Cerro El Roble.
Jun 1, 1959	The Universities of Chile, Chicago, and Texas sign an agreement for a cooperative observatory to be funded by the U.S. Air Force. The 40-inch telescope project becomes a 60-inch telescope project. Dr. Clemence suggests the project title: The Inter-American Observatory in Chile.
Aug 19, 1959	Dr. I. Epstein of Columbia U. starts another site testing program in Chile with NSF funding. This program aimed at comparing sites in Chile, Argentina, Australia, and South Africa. A month later Drs. Stock and Epstein coordinated their programs. Eventually, the U. of Columbia and Yale U. established an astrometric observing station near San Juan, Argentina.
Oct 19, 1959	Dr. G. Keller of the NSF expresses the interest of the NSF in supporting the Chilean Observatory project. A policy advisory committee with AURA, NSF, Air Force, and Universities of Chile, Chicago, and Texas representatives is formed to consider the future of the project.
May 25, 1960	AURA is asked to take over construction and operation of a joint Chilean Observatory.
Jun 30, 1960	AURA assumes reponsibi1ity of site surveys for U.S. observatory in Chile under the auspices of the U.S. Air Force and subsequently the National Science Foundation.

1960s

Feb–Aug 1960	Site surveys extended northward to include Tololo, Morado, and other mountains near Vicuña.
Aug 1961	0.41-m telescope hauled to Cerro Tololo on mule back for tests of site.
Dec 1961	AURA and the U. of Chile sign an agreement for establishment of the observatory in Chile.
Dec 1961	CTIOs first administrative office opens at the Chilean National Observatory at Cerro Calán, Santiago.
Oct 11, 1962	Eight hectares lot is purchased in La Serena.
Nov 23, 1962	Cerro Tololo chosen as site and the Cerro Tololo Interamerican Observatory's current name adopted.
Nov 25, 1962	AURA buys the property El Totoral, 30,000 ha, with Cerro Tololo near its center.
Dec 2, 1962	Traditional flag-raising ceremony held on Tololo in company of Chilean officials who climbed the mountain on horseback.
Jan 1963	Chilean Congress, with sponsorship of the U. of Chile, approves duty-free importations by AURA. Such importations were to be handled by the U. of Chile.
Feb 1963	NSF approves the funding of a 0.92-m telescope for CTIO.
Apr 1963	Dr. J. Stock is appointed first Director of CTIO.
Sep 1963	First vehicle driven to Tololo on the primitive, but passable, 38-km access road.

Mid-1963	Temporary powerhouse, warehouse, and maintenance shops completed, and 25 years later, the temporary structures are still in use.
Jun 1963	Representatives of ESO and AURA meet to discuss possibility of the European Southern Observatory being located in CTIOs grounds. In 1965 ESO decides on La Silla for its location, further north and closer to the Atacama desert.
Dec 63 – Feb 64	Dr. H. Babcock, director of Mt. Wilson and Palomar Observatories, visits CTIO to initiate a site survey on AURA’s grounds for a Carnegie Southern Observatory. After initial tests at Cerro Pachón, further testing was limited to Cerro Morado. Eventually the Carnegie Observatory is established on Las Campanas, a mountain between Cerro Tololo and Cerro La Silla, much closer to the latter.
Jan 1964	Construction initiated of the Headquarters building in La Serena.
Feb 1964	First radio messages sent between CTIO and KPNO. The University of Chile allowed CTIO to use its assigned wavelengths and call letters.
Mar 1964	AURA Board approves five-year master plan for development of CTIO.
May 1964	First 800 books acquired for Library.
Jan–Jun 1964	Leveling of the top of Cerro Tololo carried out.
Mid-1964	The U. of Chile, La Serena Branch, on a cost-free basis, allows CTIO to build an access road to CTIOs headquarters across its property.
Jun 1964	Water being pumped to Tololo from a spring at Los Placeres.
Jul 1964	Within weeks of leveling the summit of Tololo, housings started for the 0.41m, 0.92m, and 1.5-m telescopes.
Jun 30, 1965	The CTIO staff consists of seven employees, two of which were stationed in Tucson, Arizona. By January 1976 when the 4-m telescope is put into operation the staff numbered 175, probably close to its historical maximum.
Dec 1965	First 50,000-gallon water storage tank installed on Tololo.
Dec 1965	An additional hectare containing a house added to the La Serena compound at its western end (Calle Cisterna).
Mid-1966	Five houses completed on Tololo.
Oct 26, 1966	AURA concludes agreement with the University of Michigan to install the Curtis Schmidt telescope on Tololo on a 10-year loan basis; the agreement was extended for 25 years in 1975.
Dec 1966	Ford Foundation decides to donate $5 million on matching-grant basis with NSF for construction of a 4-m telescope in the Southern Hemisphere.
Mar 1967	0.92-m telescope acquired and installed outdoors; moved to its permanent housing in Kay.
Apr 3, 1967	The housing for the Curtis Schmidt telescope is completed.
Apr 1967	At Punta del Este, Uruguay, U.S. President Johnson and Chilean President Frei jointly announce that the Ford-NSF 4-m telescope would be installed on Cerro Tololo.
May 1967	Housings for the 0.4l-m and 0.92-m telescopes are completed.

Sep 1967	Previously planned houses on Cerro Tololo for the CTIO Director and a Mountain Superintendent, as well as three other houses, are eliminated from the Master Plan.
Oct 1967	1.5-m telescope installed.
Oct 1967	The administrative/scientific (round) office building is completed on Tololo.
Oct 1967	Astronomers' Dormitory and Dining Hall first occupied.
Nov 3, 1967	The U. of Chile and CTIO jointly sponsor a conference on Astrophysical Photometry in Santiago as part of the CTIO inauguration program.
Nov 6, 1967	First light on the 1.5-m telescope.
Nov 7, 1967	Official inauguration of CTIO. The benediction is given by Msgr. Fresno, later Cardinal Fresno. Chilean President Frei visits Tololo.
Nov 1967	Tololo instrument shop completed; it subsequently becomes the electronic shop, and eventually the visitors' center.
Late 1967	Late in the year, the decision is made to locate in La Serena all CTIO service shops not needed on Tololo: e.g., the instrument shop, ETS offices and shops, the library, receiving warehouse, main garage and computer center.
Dec 1967	Excavation started for 4-m telescope housing.
Mar 1968	An additional eight hectares are added to the La Serena compound at its eastern end (hilltop).
Mid-1968	Negotiations initiated to modify importation procedures of CTIO shipments.
Jul 1968	The first prefabricated houses for U.S. hired
Aug 7, 1968	With AURA approval, the CTIO Director and the Rector of the U. of Chile sign an agreement allowing telescope time for U. of Chile astronomers.
Dec 1968	The Government of Chile extends to CTIOs U.S. Hires certain benefits enjoyed by foreign employees of the United Nations branch office in Santiago.
Mar 1969	Lowell 24-inch telescope installed.
May 21, 1969	Harvard and Yale Universities and MIT plan possible installation on Cerro Morado of a 90-inch, a 36-inch, and a l6-inch telescope.
July 25, 1969	The 4-m Cervit mirror blank is cast by Owens-Illinois Company of Toledo, Ohio. The l7-ton casting is the largest casting ever made.
Sep 1969	Passage by the Chilean Congress of a law modifying importation procedures and freeing CTIO from certain taxations and limitations of its operations.

1970s

Jun 1970	The U. of Chile and AURA award the first jointly-financed fellowship for Chilean graduate students in Astronomy.
Mar 1971	NASA, the U. of Chile, and the Smithsonian Institution install on Cerro Morado a station to observe barium clouds injected into the upper atmosphere by Germanys Max Planck Institute.
Mar 1971	The U. of Chile puts into operation a seismograph station on Cerro Tololo.
Mar 1972	4-m telescope housing completed.

Jun 1972	Yale University agrees to lend its 1-m telescope to CTIO. The telescope is put into operation one year later.
Mid-1974	A low wattage microwave relay station is erected on a side spur of Cerro Tololo by the Chilean Telecommunications Agency, ENTEL, per agreement with AURA.
Dec 1975	Completion of fine tuning of, and addition of the cassegrain secondary to the 4-m telescope.
Jan 1, 1976	First visiting astronomers use the 4-m telescope.
1977	At the request of CTIO, the Government of Chile declares Cerro Tololo a privileged scientific sanctuary where mining is prohibited without permission of the President of Chile.

1980s

Nov 1982	Columbia University starts operation at CTIO of a 1-m diameter, millimeter radio telescope.
Nov 1982	The AURA Board of Directors agrees on a reorganization whereby CTIO becomes part of NOAO along with KPNO and the US National Solar Observatory.; NOAO comes into existence officially on February 1, 1984.
Jan 1986	Dr. Robert Williams is appointed CTIO Director until July 1993.
Feb 23, 1987	Supernova 1987A explodes in the Large Magellanic Cloud (a satellite galaxy of the Milky Way). It is first naked eye supernova in four centuries, and sparks intense investigation with CTIO telescopes (e.g. Phillips et al. 1988).

1990s

Nov 1993	Dr. Malcolm G. Smith is appointed CTIO Director until October 2003.
Nov 1993	In response to a request for guidance, CTIO receives advice from Senator Edgardo Boeninger that Chile is about to set up a Chilean equivalent of the US Environmental Protection Agency (CONAMA) and recommends putting CTIOs interest in protection against light pollution on its early agenda.
1997	The 1.3m (50-inch) IR survey telescope begins the southern component of the Two Micron All Sky Survey (2MASS), mapping the sky in the near-infrared, with sensitivity limits of J = 15.8, H = 15.1 and K = 14.3. The 2MASS survey produced a catalog of over 470 million infrared point sources (mostly stars), 1.6 million extended sources (mostly galaxies), and helped in detecting hundreds of the nearest substellar objects (brown dwarfs) to the Sun.
1998	President Frei Ruiz Tagle signs the Supreme Decree 686/98, now more normally referred to as the norma luminica, which provides a legal foundation for the effort to protect astronomy in northern Chile. This action probably gained an increase of a couple of decades in the useful future lifetime of the sites in northern Chile for astronomical research.
Dec 18, 1998	Science Magazine recognizes discovery of the accelerating universe as the Science Breakthrough of the Year for 1998. Given the then wide-field capability of the telescope the clear dark site and efforts to maintain pixel-

	limited imaging performance, much of the early work by the two main groups who made the discovery was carried out on Cerro Tololo at the Blanco 4m telescope. Important calibration work for using Type Ia supernovae as distance indicators was carried out by CTIO staff in Calan/Tololo supernova survey with the Michigan Curtis Schmidt telescope (e.g. Hamuy et al. 1996). In the Riess et al. 1998 study demonstrating the existence of the dark energy, the 10 Type Ia supernovae analyzed with redshifts $0.16 < z < 0.62$ were all discovered with the prime-focus CCD camera on the Blanco 4-m telescope.
Aug 1999	Event “The Sun, Our Star” heralds the formation of a local schools network RedLaser and organized local public outreach from Cerro Tololo.
Oct 1999	The norma luminica Chilean law to protect the future of astronomy in northern Chile (DS 686/98) comes into force.

2000s

2000	Michigan State University becomes a partner in the SOAR 4.1m telescope, finalizing the partnership formation process led with tenacity and patience by the University of North Carolina. It took UNC 18 years to get the telescope built after multiple partners had bowed out.
2000	Given the greater medium-term risk of light pollution at Cerro Tololo and Cerro Pachón, the national office for the protection of the skies of northern Chile (OPCC) is set up and the former Regional director of CONAMA is hired as the first director of the OPCC.
March 2002	International Conference on Light Pollution held in La Serena.
November 2003	Dr. Alistair R. Walker is appointed CTIO Director until October 2008.
April 17, 2004	Dedication ceremony for the SOAR 4.1m telescope held on Cerro Pachón.
2006	In response to increasing pressure on CTIO to reduce its support of the small telescopes on Cerro Tololo, the community-led SMARTS consortium—set up a few years earlier to provide balance for the installation of Gemini South and SOAR on Cerro Pachón—begins operation of the SMARTS telescopes (0.9m, 1.3m, 1.5m).
May 17, 2006	El Peñón summit on Cerro Pachón is selected as the future site for the 8.4-m Large Synoptic Survey Telescope (LSST).
November 2008	Dr. Robert C. Smith is appointed CTIO Director.

2010s

2011	In the context of humanity’s ability to see dark skies in the future and carry out optical observational astronomy from the ground, Cerro Tololo and Cerro Pachón are highlighted as case studies in the IAU/ICOMOS/UNESCO World Heritage Centre book on Heritage Sites of Astronomy and Archeoastronomy as one of five Windows on the Universe (along with dark-sky sites in Hawaii, La Palma, New Zealand and the East Alpine Starlight Reserve).
March 8, 2011	LSST first blast: initiation of site leveling of the El Peñón summit of Cerro Pachón in preparation for the LSST.

Oct 4, 2011	2011 Nobel Prize in Physics won by three astronomers, for the discovery that the expansion of the Universe is speeding up. Saul Perlmutter (Lawrence Berkeley National Lab) led the Supernova Cosmology Project while Brian Schmidt (Australian National University) and Adam Riess (Johns Hopkins/Space Telescope Science Institute) were leading members of the High-z Supernova Search team. Present (Chris Smith) and past (Mark Phillips, Nick Suntzeff, Mario Hamuy, Bob Schommer) CTIO staff members were members of the High-z team. Both teams announced their results in 1998. Both teams used the Blanco 4m telescope and prime focus imagers in the period 1994-1998 for some of their most critical observations. And prior to this, important precursor observations were made on the Curtis Schmidt telescope by Mario Hamuy and Jose Maza (U. Chile). CTIO staff, both scientific and technical, were crucial in providing the support that allowed these very difficult observations to be made successfully. At that time, the Blanco telescope plus Big Throughput Camera was the most powerful CCD camera in the world. The unexpected discovery that the expansion of the universe is speeding up led to the concept of dark energy and that the Universe we see (stars etc) represents only a very minor constituent of the mass-energy budget of the universe.
2012	Commissioning scheduled for the Dark Energy Camera (DECam) wide-field imager on the Blanco 4-m, and the anticipated start of the Dark Energy Survey — a comprehensive program to characterize the evolution of the dark energy over cosmological time.
Nov 23, 2012	50th anniversary of Cerro Tololo Inter-American Observatory.

MAUNA KEA OBSERVATORY

After a several-year period of site testing in the 1960s, two small telescopes (0.6-m diameter) were built in 1968 and 1969. A larger 2.2-m telescope was completed in 1970. This telescope was managed by the University of Hawaii, and built using funds from NASA. The 2.2-m telescope showed that Mauna Kea was an excellent site for astronomy. In 1979, thee larger telescopes—the 3.6-m United Kingdom Infrared Telescope, the 3.8-m Canada-France Hawaii Telescope, and the 3.0-m NASA Infrared Telescope Facilty—began observations from Mauna Kea. These were followed by two submillimeter telescopes: the James Clerk Maxwell Telescope and the Caltech Submillimeter Observatory. The 10-m Keck-1 Telescope began observations in 1990, and its success led to the completion of the adjacent Keck-2 telescope in 1996. The Gemini-North and the Subaru telescopes were then constructed each has a monolithic primary with a diameter slightly larger than 8-m. The Gemini Northern 8-m telescope was built on the site of one of the original 0.6-m telescopes, and the 0.6-m telescope was removed. The most recent major telescope to be completed is the Submillimeter Array, which consists of 8 movable antennae, each with a diameter of 6 m.

The University of Hawaii at Hilo has replaced the other 0.6-m telescope with a slightly larger aperture 0.9-m telescope in the same structure. The main purpose of this telescope will be for teaching. This telescope is still in development, and is not functioning properly at the present time.

The only telescope presently under development is the Thirty Meter Telescope. The Caltech Submillimeter Observatory is expected to be shut down and removed within 4 years.

CANARIAN OBSERVATORIES

Both Canarian observatory sites are areas where the past astronomical culture of the ancient inhabitants combined with the birth of modern astronomy in the 18th century.

High mountains were typically regarded as sacred by Mediterranean cultures, and this was also common among protohistoric societies of the Maghreb area. The idea of the *Axis Mundi* can also be applied to Mount Teide. This great volcano supported the belief that the sky was maintained by a pillar supporting the two physical realities, sky and earth, and by extension the two worlds (upper and lower), where good spirits and evil beings were located.

In the Guanche cosmogony (the "Guanches" were the ancient inhabitants of Tenerife island) Mount Teide was the prime sacred mountain and provided a symbolic reference to the aboriginal inhabitants of the other Canary Islands, such as the *awara* people living on the neighbouring island of La Palma. It also was a reference for *majos* people living on the remote island of Fuerteventura, as shown by the exceptional foot-shaped engravings found in their sacred mountain Tindaya. The archaeoastronomer Juan Belmonte has shown that the orientation of these was determined both astronomically (to the winter solstice and other celestial phenomena) and topographically (orientation to Mount Teide).

The Roque de los Muchachos was also of crucial importance within the ancient awara culture on La Palma, as is clear from the archaeological evidence at a number of sites such as 'Lomo de Las Lajitas', located within the observatory area. This site consists of more than a dozen sacrificial altars and a series of rock carvings with evident astronomical significance.

The Teide mountain is world-renowned for its contribution to science in modern times, especially in the field of geology and the study of the atmosphere. The Teide National Park was inscribed on the World Heritage List in 2007 under natural criteria (vii) and (viii). Its connection with science is evident from the inscription text: "The area is a major centre for international research with a long history of influence on geology and geomorphology especially through the work of von Humboldt, von Buch and Lyell, which has made Mount Teide a significant site in the history of volcanology".

One thing not mentioned in the case for inscription to the World Heritage List was the fact that some members of scientific expeditions to the Canaries, such as Humboldt in 1799, made pioneering atmospheric observations. Mount Teide was a priority objective of the about thirty scientific expeditions to the Canary Islands that took place between 1770 and 1830.

In his book *Opticks* (1730), Isaac Newton suggested that telescopes should be installed where the atmosphere was calmer and more stable, that being what happens upon the highest mountain peaks, above the cloud layer. Following this suggestion, the British astronomer Piazzi Smyth (1856) first demonstrated that high-altitude sites offered clear advantages for astronomical observation. He reached this conclusion after making observations at several altitudes on Tenerife, from sea level up to the mountains of Guajara (2,717 m) and Altavista (3,250 m) on the Teide volcano. These experiences can be considered the starting point of the development of the large advanced observatories of the present day—the "Windows to the Universe"—that have revolutionized our understanding of the cosmos.

Piazzi Smyth presented these findings to the British Government and to the Royal Society, before publishing them in 1857 in its book *Teneriffe: An Astronomer Experiment*. These works show the clear advantages of these mountain areas, including the detection and measurement of faint stars and the quality of the diffraction rings in the telescope focus (low seeing). In June 1895, Knut Angström and his collaborators settled upon the former site of Piazzi Smyth, at Altavista, 3,252m above MSL. At that time the first "reliable" measurements were made of solar radiation at different altitudes (Altavista, Las Cañadas, Puerto de la Cruz, Santa Cruz, and Güímar) (Angström, 1901).

Fig. 10.11. Jean Mascart Observatory installed on Guajara mountain, near Mount Teide, in 1910. Image from the publication *Impressions et observations dans un voyage à Ténérife* by Jean Mascart (Ernest Flammarion, Editeur, Paris, 1910). Digitised by the University of La Laguna.

In 1910 the French astronomer Jean Mascart travelled to the Canary Islands specifically to observe the passage of Halley’s Comet (Fig. 10.11). He then proposed the creation of an international observatory on the Teide, on Guajara Mountain, very close to the present site. However, the idea was shelved owing to World War I.

Five decades later, in 1959, the total eclipse of the sun, visible from the Canaries, once again attracted the attention of numerous investigators and astronomers and the idea of creating an astronomical observatory on these islands resurfaced. In 1960, Prof. Fran-cisco Sánchez and Prof. Torroja y Romaña laid the groundwork for today’s Canarian Observatories, exploring both the areas that subsequently became the ORM and OT.

The Observatorio del Teide was founded in 1959, and the first telescope arrived in the area in 1964, thanks to an agreement with the University of Bordeaux. In 1975 the Instituto de Astrofísica de Canarias was founded by the Instituto de Astrofísica, as part of the University of La Laguna. In 1979, Spain signed the “Agreement and Protocol of Cooperation in Astrophysics” with Denmark, Sweden, and the United Kingdom, which brought modern telescopes to the observatories. Presently, both observatories offer facilities for night-time study as well as solar studies, using telescopes and other astronomical instruments from 19 countries.

The ensemble of observatories on the Canary Islands has played an important role in astronomy, being the place where, for example, the optical counterpart of a Gamma Ray Burst was first observed, the first unequivocal evidence for a stellar-sized black hole in the Galaxy was obtained (something that had been sought for decades), and the first brown dwarf was discovered.

The GTC (Gran Telescopio Canarias), at present the largest optical and infrared telescope in the world, will “see” the farthest and faintest objects in our Universe, and will help provide answers to many questions about how the known universe was created.

3. Justification for inscription

3.c Comparative analysis

Modern astronomy has mostly been developed in a few exceptional places on our planet where a unique set of natural circumstances converge. These sites have been chosen for decades by the international scientific community to develop the most important groups of telescopes in the world.

Historically, ground-based observatories have provided the vast majority of our knowledge of outer space. However, present-day technical and scientific requirements restrict suitable areas to very specific and limited locations: those that offer good conditions for the development of astronomy, and of optical and infrared astronomy in particular. There are only a few places on our planet featuring this unique combination of environmental and natural circumstances: well-conserved spaces with very little alteration to natural starlight.

The importance of the Windows to the Universe lies not only in the uniqueness of each site and group of telescopes, but also in the fact that, taken together, they cover both the northern and southern parts of the celestial dome.

3.d Integrity and/or authenticity

Authenticity

The Windows to the Universe meet several conditions of authenticity that are expressed through the following attributes:

- *Each observatory contains a group of telescopes whose form and design is quite unique.* The development and construction of the telescopes represent the state of scientific and technological developments at the time when they were built. Their form and design is unique and unrepeatable.
- *In each case, the development of specific instruments represented true technological micro-revolutions.* The list of new materials that appeared in these observatories with the creation of the telescopes is impressive, and, in many cases, those technologies and materials have been replicated in applications of great social importance, including medicine.

Fig. 10.12. A selection of remarkable observing sites. Based on "The process of selection of exceptional observing sites", by Richard Wainscoat; elaboration on CIA's Physical Map of the World, 2004 (available on wikimedia commons).

- *The observatories and telescopes are a continuous representation of the state of the art in astronomy as it developed through time.* The telescopes were designed for specific functions, according to the observational priorities for which they were created. These functions correspond to key aspects of our knowledge of the universe at the time in question.
- *The observatories have given rise to a particular form of technological and scientific management.* Unlike many other human activities, they are usually managed by scientific community consortia or agreements, representing a form of management based on international cooperation.
- *The Windows to the Universe have contributed invaluably to the intangible heritage of humankind.* The sites under consideration have produced most major discoveries about the universe in modern times. Some of these discoveries have fundamentally altered the course of science.
- *The Windows to the Universe only occur in places with exceptional natural conditions,* which are only found in very few places on the planet.

Integrity

The conservation status of the designated case study areas qualifies as “intact” in relation to the applicable criteria.

The three “Windows to the Universe” selected include the world's most important representation of the telescopes that have marked the history of modern astronomy throughout decades. All the telescopes, even the oldest ones, are in good condition. Under no circumstances have the telescopes been demolished. If they lose their original function because of scientific and technological progress, they are adapted to other functions, whether scientific, educational, or astro-tourist. In some cases the buildings and instruments have also been conserved.

The identity and unique construction features of the buildings and groups of telescopes have been maintained and will be kept intact, except for instrumental modifications or readjustments.

Exceptional sky quality and an environment undisturbed by external activities unrelated to sky observation are the natural conditions that determine its uniqueness as a superlative natural phenomenon, by application of criterion (vii). These conditions have remained practically unchanged over the past decades. This is demonstrated by the continuous records carried by the three identified sites, in relation to all air quality factors. The three sites keep continuous measurements of sharpness, seeing, and the natural darkness conditions of the night sky, concluding that natural conditions have remained practically unchanged to date.

The influence of light pollution beyond the areas under consideration, or the possible occupation of land by other activities are effects that can compromise the integrity of resources. These effects are being mitigated in every case.

Permitted activities in the selected areas are fully compatible with resource conservation. Only professional astronomical observations, occasional research and astro-tourism activities are allowed, ensuring the sustainable use of each area.

The selected areas and their protection zones are of an appropriate size to ensure resource integrity. Furthermore, the areas under consideration are surrounded by quite large protected areas.

- The site of the Chilean observatories covers an area of 34,491 ha. It is located in a large territory without any human intervention or land-use projects.
- The Mauna Kea Science Reserve, where the observatories are located, covers an area of 4,520 ha. Included in its surroundings is the Ice Age Reserve covering an area of 1,576 ha.

- In the case of Mount Teide, the observatories would constitute the central zone of an area of 18,000 ha, with a buffer zone of 40,000 ha. With regard to the observatories of La Palma, the area under consideration measures 8,873 ha, which are included in a natural protection area that exceeds 41,000 ha.

3.a Potential criteria under which inscription might be proposed

Criterion (i): Each telescope is a one-of-a-kind masterpiece in which a range of disciplines and expertise converge, reflecting state-of-the-art technology and scientific understanding at each stage in the evolution of modern astronomy.

Each telescope or group of telescopes constituting the Windows to the Universe expresses, in several different ways, both human creative genius and the state of the art in technology, as well as reflecting our extraordinary knowledge of the Universe.

The combined know-how accumulated through international scientific cooperation has enabled some of these telescopes to contribute decisively—either individually or in combination—to the huge advances in astronomical knowledge that have taken place in recent times.

Criterion (iii): The observatories and their telescopes bear unique and exceptional testimony to the culmination of observational astronomy in the 20th century.

During the 20th century, our knowledge of the universe has been revolutionized thanks to the development of earth-based observatories. Many of the extraordinary advances in our knowledge of the cosmos that have now become part of our collective culture—such as the expansion of the universe and the discovery of many exotic objects including quasars, pulsars, blazars, and radio galaxies—were based on observations made at these places.

The Windows to the Universe are therefore icons representing one of the greatest scientific revolutions known in the history of humankind. They are also emblematic of a new culture for the development of science based on international cooperation.

Criterion (iv): Observational arrays and groups of telescopes are unique ensembles of complex design that represent the different stages of humankind's recent technological evolution in several key areas, from optics to new materials. Many of the technological advances achieved at each stage of the observatories have had, and continue to have, a major impact on society.

Each telescope and element built in each observatory represents a milestone, both in architectural terms and in engineering development. Each of these extraordinary built elements and technological ensembles is quite unique.

Criterion (vii): The exceptional sky quality in these locations results from a unique combination of atmospheric, meteorological and microclimatic factors that only occurs at fewer than a dozen sites on Earth.

The Windows to the Universe are characterised by superlative natural conditions that not only ensure long periods of useful observing time (clear sky), but are also exceptional in terms of sky background (darkness), atmospheric extinction (transparency), and seeing (for sharp images).

The places where the observatories are located, and the surrounding areas, lay claim to some of the most spectacular starry sky sceneries in the world. Besides their importance for the development of astronomy, the Windows to the Universe are characterised by the extraordinary scenery of the starry firmament, whose magnificence is enhanced by the nature and geology of these sites. These places have traditionally been of symbolic importance to local communities.

3.b Suggested statement of outstanding universal value

The Windows to the Universe are groups of telescopes located in unique environments with unrivalled natural characteristics. There are no better places on the planet from which to observe the skies in optical and infrared wavelengths. The major advances in astronomy that have been made at these places have come to form part of the collective memory of humankind.

During the 20th century the observatories of Chile, Hawaii, and the Canary Islands have come to represent the peak of earth-based observational astronomy and a crucial period for the development of science. They contributed decisively to many of the most important advances and discoveries in modern astronomy throughout the century, and continue to do so.

The Windows to the Universe are also emblematic of one of the biggest international cooperative efforts in the history of astronomy, reaching beyond the borders of countries and cultures.

The Windows to the Universe thus represent a unique combination of three factors:

- The observatories at each site are a group of complex technological buildings that have played and still play a key role in the history of modern science.
- All the scientific and technological developments that have taken place at these sites represent the results of extensive cooperation between many different nations.
- The natural areas where the observatories are located benefit from exceptional atmospheric conditions which make their skies the clearest in the world.

4. Factors affecting the property

4.a Present state of conservation

AURA OBSERVATORY

The buildings and telescopes at the AURA observatory are well maintained, consistent with the operation of a major research facility.

Sky brightness caused by the current level of lighting from nearby cities (La Serena, Coquimbo, Ovalle, Andacollo, and Vicuna) is not worrisome at present. According to recent surveys (Kriscuinas et al. 2007; 2010: see especially figs 1 and 3), the broad-band, artificial sky background is, even in the worst directions, still only detectable in broad-band measurements within 10–15 degrees of the horizon, and does not (yet) interfere with any observatory research.

MAUNA KEA OBSERVATORY

The buildings and telescopes at the Mauna Kea observatory are well maintained, consistent with the operation of a major research facility.

One of the main factors affecting astronomy on Mauna Kea is artificial lights that cause light pollution. The specific form of light pollution that affects the telescopes is increased sky glow. Artificial light sources increase the sky background level above the natural background. This diminishes astronomers' ability to see faint objects, and effectively decreases the effective size of the telescope. Light pollution affects optical astronomy—astronomy at wavelengths where the human eye is sensitive. Light pollution does not affect infrared astronomy. However, the window of the electromagnetic spectrum where the human eye is sensitive is one of the most valuable windows available to astronomy, because Earth's atmosphere has high transparency. The sky is particularly dark at blue and green wavelengths, below 555 nm (see Fig. 10.13).

Fortunately, a strong lighting ordinance that was enacted in 1989 has provided good protection for the telescopes from light pollution. As a result, the sky background on Mauna Kea is very close to the natural level. Fig. MK.3 shows a spectrum of the night sky seen from Mauna Kea.

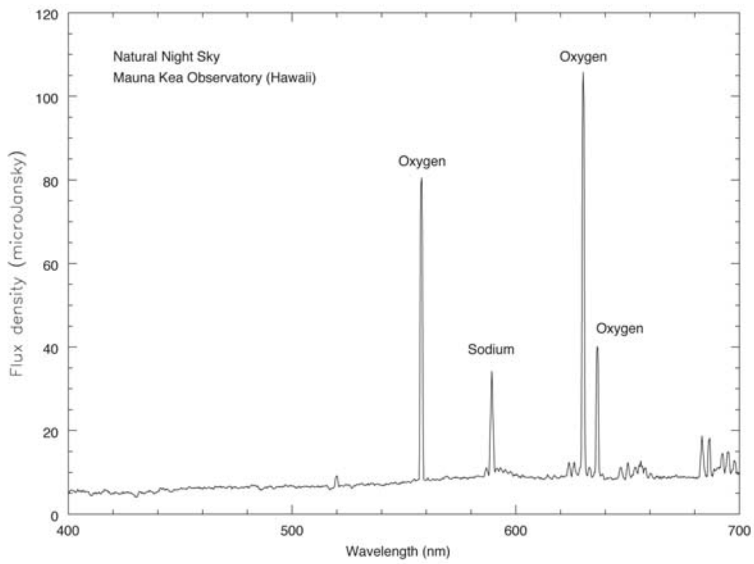


Fig. 10.13. A spectrum of the night sky seen from Mauna Kea. Nearly all of the flux shown here is natural. Sodium emission from low-pressure sodium street lights forms part of the emission near 589 nm.

The eastern side of the island is frequently covered by clouds, and these clouds help to suppress artificial lights from populated areas such as Hilo in the eastern part of the island.

The submillimeter, radio and optical telescopes on Mauna Kea also need to be protected from radio frequency interference. There is a ban on fixed radio transmitters on Mauna Kea. There is one low power radio repeater located on Mauna Kea and used by the Hawaii Volcanos Observatory for safety reasons. A second repeater can be activated in the event that the Governor of Hawaii declares an emergency.

CANARIAN OBSERVATORIES

The sky protection law has been in place for 24 years, and has provided good protection for the night sky, especially on the island of La Palma. The Instituto de Astrofísica de Canarias (IAC), long aware of the importance of promoting initiatives to protect the ORM and OT, created a Sky Quality Group in the late 1980s and a technical office for sky protection (OTPC) in 1992 to provide advice on the application of the Sky Law.

The level of protection has been increasing in recent years, overcoming the initial reluctance of the local population. Better enforcement is expected in the future. The present level of light pollution does not compromise research, maintaining the high level of excellence of the sky quality parameters.

4.b.i Developmental pressures

AURA OBSERVATORY

Of the major observatories in Chile, the AURA Observatory is currently the most threatened by the gradual encroachment of light pollution and therefore serves as a marker for gaining experience over the next two or three decades in how to protect the dark skies not only over this observatory but also over other sites in Northern Chile, including the site of the European Extremely Large Telescope (E-ELT, the largest ground based optical telescope currently planned anywhere in the world).

A CTIO study in 2004 (www.ctio.noao.edu/noao/sites/default/files/Night Sky Brightness at Cerro Pachon.pdf) discussed predictions for night sky brightness at Cerro Pachón, in the context of planning for the LSST. It presents the relevant numbers and several projections, depending on population growth and the success of lighting controls. The study demonstrates that with successful lighting awareness campaigns, such as that which CTIO/AURA has launched, Cerro Pachón and Cerro Tololo can continue to be prime astronomical sites for at least 3 decades even under the assumption that the dramatic population growth of the La Serena/Coquimbo conurbation (32% between 1992 and 2002) continues into the future.

That assumption may be proving to be the correct one—the rapid growth over the last 30 years of La Serena and Coquimbo is a concern. The current population is 412,586 (according to preliminary census figures for Chile released in August, 2012) and large mining projects in northern Chile have accelerated the arrival of inhabitants to the conurbation. This 27% growth over the last decade compares fairly closely with the predictions of the constant-growth model used in the CTIO study, which, in 2004, predicted a population of 425,000 for 2012. Currently 19 infrastructure projects totalling US$277,000,000 are being planned for this conurbation.

This rapid growth is in the context of half of humanity now living in cities. According to *National Geographic Magazine* (December 2011 issue, pp. 138–139), in 1800 there were only three cities of one million or more, in 1900 16 such cities and in 2010 442 of them, with 21 having more than 10 million and several exceeding 20 million. Thus the earlier assumptions about city development made in the CTIO study—that the rapid-growth model for La Serena and Coquimbo was unlikely to continue for more than two decades—remain uncertain.

With regard to street lighting, the recent increase in population in La Serena/Coquimbo has increased the number of vehicles. Traffic licences for La Serena/Coquimbo are increasing at a rate of 9.2% each year (compared with Chile's national rate of increase, which has reached 7.5%). There are currently 90,000 vehicles in La Serena. The Ministry of Transport expects this number to double by the year 2020—about the time that LSST will begin operations.

It is fortunate indeed that light pollution control was begun in earnest in Chile 20 years ago. It is also particularly fortunate that most of the current conurbation is shielded by a range of coastal mountains which still block a direct view of most of the conurbation from Cerro Tololo and Cerro Pachón.

Pressure continues to develop a bi-oceanic corridor through Argentina, under the Andes (the Agua Negra tunnel) and down the Elqui valley near the AURA observatory, in support of trade between Brazil and China. It is important to learn the lessons provided by Los Angeles plus the Palomar and Lick Observatories in the USA. Los Angeles grew in a hundred years from an urban center about ⅔ the size of the current La Serena-Coquimbo conurbation to a city of 5,000,000 people. Protection of the northern Chilean sites needs continued attention—we cannot afford to be complacent.

MAUNA KEA OBSERVATORY

Population growth on the Island of Hawaii is relatively rapid, particularly on the western side of the island that is less frequently covered by clouds. Growth in lighting associated with this growth in population is one of the largest concerns for preservation of the dark sky over Mauna Kea, and the ability to continue to do optical astronomy from Mauna Kea.

The adjacent Pohakuloa Training Area, used by the United Stated Army for military training is of particular concern as a source of artificial light. Expansion of this facility is presently occurring. Because it is located only 10 km from the observatory, lights at this location have a much higher impact than more distant lights. Additionally, because this is a federal facility, it is not regulated by the County lighting ordinance. However, the army has cooperated with the University of Hawaii by following the lighting ordinance whenever possible, and by reducing lighting to the minimum levels required.

Fig. 10.14. The night sky at Cerro Tololo (Photograph: Arturo Gomez/NOAO/AURA/NSF).

CANARIAN OBSERVATORIES

In neither of the two cases is any territorial or environmental pressure recorded, since they are located within protected areas. The only exception in these areas is for astronomical use or uses related to education and low-impact ecotourism.

4.b.ii Environmental pressures

AURA OBSERVATORY

When the El Totoral area was purchased by AURA, the land supported a number of subsistence farmers and goat herders. They were allowed to continue to live on the reserve after it was purchased by AURA and have gradually been leaving voluntarily for more lucrative jobs in the nearby towns.

As a result of the departure of most of its human inhabitants and a policy combining environmental protection with benign neglect on the part of the Observatory, the property sees little human activity except for the roads and relatively small areas on the tops of Cerro Tololo and Cerro Pachón. As a result, much of the reserve is gradually returning to its natural state. Many native species of plants and animals, long thought in danger of extinction, are now returning. The last half of the trip to Tololo is an excellent opportunity to see a reasonably intact Chilean desert ecosystem. During the first portion of the journey, to a few km beyond El Totoral, the effect on the environment of humans, bad farming practices and the remaining goats is easily seen. That damage will take many years to heal.

MAUNA KEA OBSERVATORY

Conservation groups are frequently opposed to astronomical development on Mauna Kea. Environmental and cultural pressures have limited future astronomical use as outlined in the Mauna Kea Master Plan.

The wekiu bug is a small insect that inhabits cinder cones close to the summit. Several of the cinder cones near the summit have been developed for astronomical use, and concerns have been expressed about whether this insect has been threatened by the astronomy development. Studies of the wekiu bug are ongoing. The wekiu bug currently is not listed as a threatened or endangered species.

CANARIAN OBSERVATORIES

There are no significant environmental pressures since both areas are well preserved.

The main pressure may come from light pollution that affects sky quality. The big problem of light pollution is that it can have an impact at tens or even hundreds of km from the polluting source, both directly and by contributing to sky glow. This pressure is especially important on Mt Teide, where in the last two decades there has been a considerable increase in light pollution in Valle de La Orotava, Santa Cruz metropolitan area, and in the tourist resorts of the south of the island.

This factor has a lower impact in the case of La Palma, especially after much work being done to improve and replace the older outdoor lighting with less polluting systems, following the provisions of the Sky Law. In any case this is a process of continuous innovation and improvement to achieve the minimum pollution levels. It should be emphasized that sky protection is strictly linked to higher efficiency and more sustainable use of energy. La Palma figures indicate that the introduction of non-polluting luminaires and lamp types will lead to an energy saving of around 40% from the current scenario. This will result in a significant reduction in CO_2 emissions and an effective contribution in the fight against climate change.

4.b.iii Natural disasters and risk preparedness

MAUNA KEA OBSERVATORY

The Island of Hawaii is a very high seismic risk zone and the telescopes at the observatory are at risk from damage from earthquakes. A magnitude 6.7 earthquake on Oct 15, 2006 caused significant damage to most of the telescopes on Mauna Kea. Historical records show a magnitude 7.9 earthquake occurring on the island of Hawaii on April 2, 1868.

Mauna Kea is classified as a dormant volcano. It has not erupted since the last ice age. Any future eruption is expected to be on the south flank, and not at the summit.

The Island of Hawaii has three active volcanos—Kilauea, Mauna Loa and Hualalai. Kilauea is presently undergoing an extended eruption that is producing large amounts of volcanic gases. The volcanic gases are nearly always trapped in the lower levels of the atmosphere, and do not affect Mauna Kea. Mauna Loa erupts infrequently. An eruption from Mauna Loa may have some temporary adverse effects on the observatory, including volcanic gases and temporary sky glow. Hualalai erupts more infrequently, and is less likely to have adverse effects on Mauna Kea.

4.b.iv Visitor/tourism pressures

AURA OBSERVATORY

Cerro Tololo is open to the public every Saturday, summer and winter, weather permitting. For safety and security reasons, the number of visitors on any given day is limited to two groups of 40 people. One group meets at the gatehouse at 9am and the other at 1pm. Because the number of visitors is limited, advance reservations are essential. During the tourist season from mid-December to March, reservations must be made several weeks in advance. Permits must be picked up in La Serena before proceeding to the mountain. Access to the mountain is by private vehicles only. There is no public transportation.

Fig. 10.15. Cerro Tololo domes reflected in the eye of a condor (Photograph: Arturo Gómez/NOAO/AURA/NSF)

Permits are free and may be obtained from the Reception Desk in La Serena. Tours are conducted at no charge by a professional guide. Total elapsed time from leaving the gatehouse until returning to the highway is approximately three hours.

AURA has worked with local tourism agencies and municipalities in support of the development of 7 public observatories. This successful program has relieved the pressure on the AURA observatory, which is not open to the public at night, while creating employment and educational opportunities for local people. The Coquimbo Region is now known as La Region Estrella largely as a result of these initiatives.

More information on public access to CTIO is available at www.ctio.noao.edu/ noao/content/ public-access. As Fig. 10.15 shows, not only human visitors are interested in visiting the summit of Cerro Tololo...

MAUNA KEA OBSERVATORY

The road to the observatory is a public road that is always open unless weather conditions make it unsafe. Excessive numbers of visitors at night can cause problems from car headlights shining into telescope domes. Fortunately, at present, most visitors depart the summit area shortly after sunset, and few people travel to the summit for sunrise. The summit area is cold, often windy, and there is only limited shelter for tourists. Visits to the summit area by tourists are therefore usually of short duration.

CANARIAN OBSERVATORIES

The ORM and the edge of the Caldera de Taburiente National Park are both prime tourist attractions on the island. However, visits to the observatory area are regulated. In particular, nocturnal visits are very limited due to restrictions related to the operability of the telescopes.

In general, there are no significant tourist pressures in the observatory and its surroundings, since visitor flow is well regulated by the IAC and the National Park administration. There is also a set of requirements that are updated through the Public Use Plan of La Palma Biosphere Reserve.

Visitor pressure on Mount Teide is very significant, as it is among the most visited National Parks in Europe and worldwide. The park's Use and Management Master Plan and the

Park Management Trust address its regulation as a priority. However, visits for educational and astro-tourism purposes in the observatory area are also well regulated by the Observatory Management Board. Moreover, astro-tourist activities at night in its surroundings comply with minimal pressure criteria, as they are concentrated in the park's hosting facilities that minimize their impact.

4.b.v No. of inhabitants

AURA OBSERVATORY
See "Developmental pressures" and "Environmental pressures" above.

MAUNA KEA OBSERVATORY
There are no permanent inhabitants at Mauna Kea Observatory. Visiting astronomers stay at Hale Pohaku, located at an altitude of approximately 2,830 m on the southern flank of Mauna Kea, approximately 7 km from the telescopes. Hale Pohaku can accommodate up to 72 temporary residents, but occupancy has been diminishing recently because of increasing amounts of remote usage of the telescopes. Typical occupancy is now less than 30.

CANARIAN OBSERVATORIES
There is no permanent population in either of the two observatories. The presence of people is limited to the observatories' maintenance personnel, scientists and operators.

5. Protection and management

Overview
The selected locations rely on management and protection mechanisms and systems that ensure their long-term survival, guaranteeing the conditions of integrity and/or authenticity. This concerns both the sets of observatories themselves and their natural environments, especially air quality and sky clearness.

In the case of the two Chilean locations, the areas around both them have been declared 'of Scientific Interest' by the Chilean Government, which protects them against incursion by mining interests. Any mining activity within this area, including prospection work, would require the written permission of the President of the Republic of Chile. The buffer zones are protected from mining operations via a formal program of constant monitoring of requests for mining activity.

The Region of Coquimbo is one of three Regions in northern Chile where artificial lighting is governed by the requirements of the new Norma Lumínica (Lighting Ordinance) of Chile. This protects against light pollution with the maximum enforceable restriction. On the property, AURA has even increased the environmental requirements of the Chilean government.

The two locations of the Canarian observatories enjoy maximum protection both of atmospheric conditions and sky quality, and of the surrounding territory. Each of the observatories is located within a European Special Area for Conservation, and within areas protected as National Parks. In the Teide case, the location is mostly included within the World Heritage Site. The astronomical quality of the Canary Islands' observatories is guaranteed under a specific national 'Sky Law' ('Ley del Cielo'—Law 31/1988) approved in 1988.

Relying upon this regulatory development, a high-sensibility 'core area' has been established around the La Palma Observatory, extending 9 km in each direction. The rest of the island of La Palma (25 km around the Observatory) is considered a high-protection buffer zone, while the external zone is the area visible from La Palma, 100–160 km around the Observatory, which includes to the island of Tenerife. The protection also covers radio and atmospheric pollution (prohibiting emission sources above 1500m elevation), and air traffic.

In the case of the observatories of Hawaii, the zone around the observatory is called the "Mauna Kea Science Reserve" and has strict controls on usage. A subset of this reserve is designated for astronomical usage. A pie-shaped sector of the zone around the observatory is preserved as the "Mauna Kea Ice Age Reserve". A lighting ordinance for the island of Hawaii has been established to limit artificial light and its damaging effects on the observatories. The lighting ordinance has been in place for 20 years, and has provided good protection for the night sky.

5.a Ownership

AURA OBSERVATORY

The entire 34,491ha (344.9km²) site is owned by AURA, the Association of Universities for Research in Astronomy. AURA is recognized by the Chilean Government as an accredited International Organization, with a variety of diplomatic privileges. The stakeholders are the 40 international member institutes of AURA Inc.

MAUNA KEA OBSERVATORY

The land where Mauna Kea Observatory is located is owned by the State of Hawaii. The Mauna Kea Science Reserve is leased to the University of Hawaii.

CANARIAN OBSERVATORIES

Both observatory areas are municipality-owned and administrated by the Instituto de Astrofísica de Canarias (IAC).

The IAC is constituted administratively as a Public Consortium, with involvement from the Spanish Government, the Government of the Canary Islands, the University of La Laguna and Spain's Science Research Council (CSIC).

5.b Protective designation

AURA OBSERVATORY

The El Totoral Reserve around Cerro Tololo and Cerro Pachón has been declared "of Scientific Interest" by the Chilean Government, which protects it from incursion by mining interests.

The Region of Coquimbo is one of three Regions in northern Chile where artificial lighting will be governed by the requirements of Supreme Decree 43/2013—already signed by the President of Chile on 3 May 2013 and which will come into effect on 3 May 2014—as an updated revision of Supreme Decree 686/1998 (the "norma lumínica"). This protects against light pollution.

MAUNA KEA OBSERVATORY

The Mauna Kea Science Reserve and the Mauna Kea Ice Age Natural Reserve are state conservation lands.

CANARIAN OBSERVATORIES

The whole area where each observatory is located enjoys a high level of protection. Each of the observatories is located within a European Special Area for Conservation (SPA—Natura 2000 Network), and lies at the edge of a National Park.

The astronomical quality of the Canary Islands' observatories is guaranteed under a specific national 'Sky Law' ('Ley del Cielo'—Law 31/1988) approved in 1988.

Relying upon this regulatory development, a high-sensibility ‘core area’ has been established around the ORM, extending 9 km in each direction. The rest of the island of La Palma (25 km around the Observatory) is considered a high-protection buffer zone, while the external zone is the area visible from La Palma, 100–160 km around the Observatory, which includes the island of Tenerife. The protection also covers radio and atmospheric pollution (prohibiting emission sources above 1500m elevation), and air traffic.

One of the IAC’s greatest successes in its work to protect the observatories was the designation of the airspace above them as an "Ecological Protection Zone” on 17th May 1998.

5.c Means of implementing protective measures

AURA OBSERVATORY

Any mining activity within this area, including prospection work, would require the written permission of the President of the Republic of Chile. The buffer zone is protected from mining operations via a formal program of constant monitoring of requests for mining activity.

On the property, AURA voluntarily complies with and exceeds all environmental protection requirements of the Chilean government, including of course, the norma luminica.

Outside the property, AURA carries out education work via its membership of the consortium which supports the Office for the Protection of the Quality of the Skies of Northern Chile (OPCC) and through activities in local schools. The OPCC has the mission to carry out public education and to assist the Chilean government in the protection of this natural resource.

Under supervision of the Superintendents Office of Electricity and Fuel (SEC, Chile) and local municipalities, about 50% of all street lights in the Region of Coquimbo have now been modified or replaced in order to comply with the requirements of the norma luminica.

The observatory has formed a network of 200+ schools and support organization in collaboration with the Municipality of La Serena, the University of La Serena and the national Libraries, Archives and Museums directorate (DIBAM). The Coquimbo Region has developed an extensive astro-tourism initiative, which has flourished because of the contrast between the polluted skies of much of Europe, Japan and the USA and the skies as seen through the Windows to the Universe. Seven public and private observatories have opened in the Region in response to demand from networks of schools and from tourists. Recognizing this natural and cultural heritage, the motto of the Coquimbo Region of Chile is now “Coquimbo—the Star Region”.

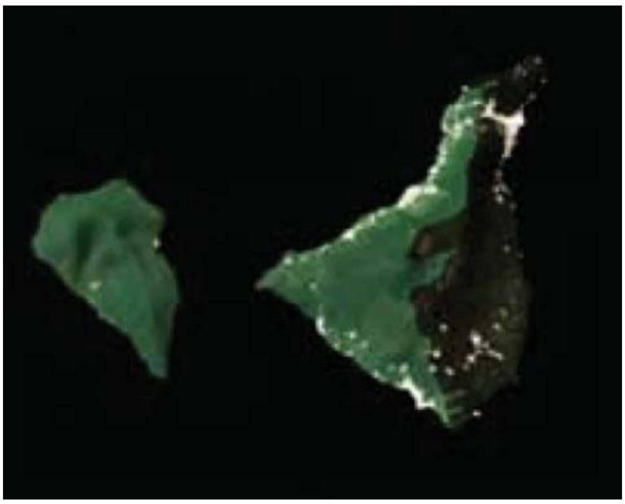


Fig. 10.16. Protection area under the Canarian ‘Sky Law’. © IAC-OTPC (Instituto de Astrofísica de Canarias)

MAUNA KEA OBSERVATORY

A lighting ordinance is in place that restricts artificial lighting in the County of Hawaii (which encompasses the entire Island of Hawaii, where Mauna Kea Observatory is located). A state lighting law requires the state department of transportation to follow the county lighting ordinance. A new state lighting law is presently under consideration by the 2012 Hawaii State Legislature. If passed, this bill will afford further protections to the dark night sky over Mauna Kea. A state "Starlight Reserve Committee" has been established to recommend further legislation to the state government to protect the night sky over Mauna Kea and Haleakala Observatories.

A staff of Mauna Kea Rangers patrols the Mauna Kea Science Reserve. They are tasked with preservation of the natural and cultural environment, and also provide assistance to persons in trouble. Law enforcement assistance is available from the State of Hawaii Division of Conservation and Resources Enforcement, and from the County of Hawaii Police Department.

CANARIAN OBSERVATORIES

The exceptional quality of the sky for observation over the Canaries is protected by Law 31/1988, which is known as the "Sky Law".

Sky Quality Group

A team of scientists within the IAC (Sky Quality Group) is responsible for the 'Characterisation of the Canarian Observatories'. The SQG ensures that the atmospheric parameters determining the astronomical quality of observations are continually monitored and updated. The objectives of this group were the determination and characterisation of optical-infrared quality, as well as meteorological conditions, at the observatories. These studies were completed with geophysical tests.

The Observatories in Chile, Hawaii and the Canaries are the only ones to have conducted intensive astronomical prospecting campaigns; Chile and the Canaries are unique in that they have developed extensive and reliable databases.

Sky Quality Protection Technical Office

The Sky Quality Protection Technical Office (OTPC) was set up by the IAC in January 1992 to provide advice on the application of the Sky Law (Law 31/1988), which protects the astronomical quality of observatories in the Canaries from

- light pollution,
- radioelectrical pollution,
- atmospheric pollution, and
- aviation routes.

The OTPC provides advice on the application of regulations contained in the Law and produces technical reports for lighting projects and radioelectric stations, as well as issuing lighting certificates.

5.d Existing Plans

AURA OBSERVATORY

AURA has been working via the OPCC with the Chilean Ministry of the Environment to develop an updated version of the Norma Lumínica. This will limit proliferation of blue-rich Light Emitting Diodes. The blue region of the optical spectrum is currently without significant pollution (Kriscuinas *et al*. 2010), even from Cerro Tololo looking at the sky directly over the La Serena/Coquimbo conurbation (largely as a result of using sodium lighting fixtures). An additional advance under the new Norma will be to limit the amounts of light allowed and to have external lighting upgraded to full cut-off (full shielding above the horizontal).

The longer-term aim is to have the Norma Lumínica upgraded to a Chilean law, rather than a set of environmental rules.

MAUNA KEA OBSERVATORY

The Mauna Kea Science Reserve Master Plan was adopted by the University of Hawaii Board of Regents on June 16, 2000.

The Comprehensive Management Plan (malamamaunakea.org/management/comprehensive-management-plan) (CMP) provides a management framework for the University of Hawaii (UH) to address existing and future activities in the UH Management Areas on Mauna Kea. The CMP was approved by the state Board of Land and Natural Resources (BLNR) in April 2009 on the condition that UH complete four sub-plans addressing: public access, cultural resources management, natural resources management, and decommissioning. On March 25, 2010, the BLNR voted unanimously to approve the CMP's four sub-plans, along with the management framework and implementation for project development. The sub-plans are:

a. Mauna Kea Public Access Plan (www.malamamaunakea.org/uploads/management/plans/CMP_PublicAccessPlan_2010.pdf)
b. Mauna Kea Decommissioning Plan (www.malamamaunakea.org/uploads/management/plans/CMP_DecommissioningPlan_2010.pdf)
c. Mauna Kea Natural Resources Management Plan (www.malamamaunakea.org/uploads/management/plans/CMP_NRMP_2009.pdf)
d. Mauna Kea Cultural Resources Management Plan (www.malamamaunakea.org/uploads/management/plans/CMP_CRMP_2009.pdf)

5.e Property Management Plan

MAUNA KEA OBSERVATORY

The Mauna Kea Science Reserve Master Plan established the Office of Mauna Kea Management (OMKM), which is charged with the day-to-day management of the Mauna Kea Science Reserve.

The Mauna Kea Management Board (MKMB) provides advice to OMKM. The Board is comprised of seven members of the community, nominated by the Chancellor of the University of Hawaii at Hilo, and approved by the Board of Regents of the University of Hawaii.

Kahu Ku Mauna (Guardians of the Mountain) is a nine-member council named by the MKMB. The council advises OMKM, MKMB, and the University Chancellor in Hawaiian cultural matters affecting the Mauna Kea Science Reserve.

The Mauna Kea Ice Age Reserve is managed by the State of Hawaii Department of Land and Natural Resources (DLNR).

DLNR is headed by the Board of Land and Natural Resources and manages the state's public lands. Several divisions within DLNR share management responsibility for Mauna Kea lands, including the Division of Aquatic Resources (DAR), Division of Conservation and Resource Enforcement (DOCARE), the Division of Forestry and Wildlife (DOFAW), the Natural Area Reserves Commission, the Land Division, the Office of Conservation and Coastal Lands (OCCL), and the State Historic Preservation Division (SHPD).

The Mauna Kea Observatories Oversight Committee, composed of representatives from all of the observatories including those operated by IfA, oversees MKSS activities. Each observatory pays into accounts held by The Research Corporation of the University of Hawaii that are used to fund MKSS activities including road maintenance, snow removal, facilities maintenance and management at Hale Pōhaku, common utilities and the VIS.

Mauna Kea Observatories Support Services (MKSS) provides food and lodging facilities and common infrastructure support for the observatories.

MKSS also supports, under the direction of OMKM, ranger services.

5.f Sources and levels of finance

MAUNA KEA OBSERVATORY

The University of Hawaii at Hilo provides funding for the Office of Mauna Kea Management. User fees from commercial tours of Mauna Kea also provide some funding for OMKM.

The State of Hawaii paid for the road that goes up the southern side of Mauna Kea to the summit region where the telescopes are located, with a contribution from the Keck Observatory. The telescopes on Mauna Kea collectively fund maintenance of the roadway, and snow removal operations. The telescope organizations also provide funding for the Visitor Station.

5.g Sources of expertise and training

MAUNA KEA OBSERVATORY

Astronomers working for the University of Hawaii and the other telescopes on Mauna Kea are experts on the astronomy needs of the observatory. Guidance on cultural matters comes from Kahu Ku Mauna.

5.h Visitor facilities and infrastructure

AURA OBSERVATORY

The Coquimbo Region has developed an extensive astro-tourism initiative, which has flourished because of the contrast between the polluted skies of much of Europe, Japan and the USA and the skies as seen through the Windows to the Universe. Seven public and private observatories have opened in the Region in response to the demand from networks of schools and from tourists: see www.ctio.noao.edu/noao/content/ astro-tourism-chile. Recognizing this natural and cultural heritage, the motto of the Coquimbo Region of Chile is now “Coquimbo—the Star Region”.

MAUNA KEA OBSERVATORY

A Visitor Station is located at an altitude of 2,800 m (9,200 ft), and is part of the Hale Pohaku facility. The Visitor Station conducts nightly stargazing, and is open every day of the year. There is presently no charge for visitors.

CANARIAN OBSERVATORIES

The ORM is a focal point for star tourism development and a unique attraction on the island of La Palma. The Observatory allows organized groups from schools, universities, professionals or interested tourists to visit its telescopes and facilities. The ORM receives about 5000 visitors annually. However, in order to satisfy the demands of the increasing number of visitors, the Roque de Los Muchachos Cultural Park will be completed in a few years not far from the observatory itself, and it will allow visits to be channelled to the Roque. Apart from its astronomical content this Cultural Park will emphasize the natural and cultural heritage of the area.

Outreach and educational activities carried out by the IAC for many years are the reason behind the present boom in star-tourism on the island. In order to consolidate an advanced, sustainable, and scientifically supported tourist destination, the best areas of the island enjoying excellent sky conditions have been certified as a *Starlight Tourist Destination*.

Within the framework of the Starlight strategy, the island Government of La Palma has developed a network of star-viewpoints and thematic trails, which give great support to this new dimension of tourism. An added benefit is that part of the flow of this tourist activity is diverted to other areas, ensuring a maximum level of protection around the ORM. Guides are required to possess a Starlight accreditation in order to guarantee an appropriate scientific and interpretive level, and best-practice guidelines have been developed so as not to threaten the resource.

Studies of rural tourism on La Palma give a good idea of the level of demand for star-tourism. In the 2008 survey on “Main leisure and recreational activities”, star observation is in fourth place with a surprising 80.38% of positive responses. This is a very significant number, that puts star observation higher than other activities related to cultural and nature tourism. In other words, tourists identify the sky of La Palma as a prime tourist attraction.

Teide National Park is the most visited protected natural area in Spain; it receives around 3.5 million visitors a year, i.e. an average of 9,600 people a day. However, the figure for nocturnal visits related to the observation of stars is significantly lower, averaging 60,000 visitors. Most astro-tourist night activities take place outside the area of the Observatory.

Visits to the Teide Observatory are regulated, and they are mainly educational, but open days take place and are quite often crowded. The OT relies on advanced educational and interpretive resources such as the Cosmos trail and the Dome for the popularisation of astronomy. Innovative measures such as educational projects with Robotic Telescopes (PETER) or the Virtual Telescope (IAC-80 located in the OT) have been added.

5.i Presentation and promotion policies

MAUNA KEA OBSERVATORY

The Visitor Station is operating at capacity, and is not actively being promoted. Various tourist publications and the internet promote the Visitor Station and its stargazing program to local residents and to tourists.

5.j Staffing levels and expertise

CANARIAN OBSERVATORIES

The Instituto de Astrofisica de Canarias (IAC) is an internationalized Spanish research centre. It has two headquarters and two observatories. Altogether about 400 people work here, this number comprising researchers, technology developers, engineers, project managers, and administrative staff.

6. Monitoring

6.a Key indicators for measuring state of conservation

AURA OBSERVATORY

Measurements of broad-band magnitudes per square arcsecond alongside regular photography provide a first-order guide to the source and extent of light pollution sufficient for most purposes including setting local priorities for protective action. The zodiacal light (sunlight reflected off dust in the plane of our solar system) is easily seen from first-class dark-sky locations, but not from even fairly mildly polluted sites. Major observatories, such as those included in the Windows to the Universe, usually support studies every few years to check the status of light pollution from their surroundings. An effort to introduce international, continuous monitoring on an intercomparable basis at many sites is currently being attempted by the International Dark Sky Association (www. darksky.org); the Cerro Tololo site has been used for one year as one of three beta test sites for this work, which will take and send measurements taken automatically each night for processing and display on the web, in a graphical form, readily accessible to the public. One plan is to have one detector pointed at the zenith, the other pointed over the source of most serious local light pollution, at each of the Windows to the Universe.

Measuring the night sky brightness in order to quantify contamination in the directions in which we are interested (e.g. zenith distances less than 60 degrees) is difficult at world-class sites owing to the necessity of measuring an effect that may be only 1–2% of the sky brightness. Additionally, interpretation of the results may not be straightforward. The natural brightness varies on timescale of minutes to years with amplitudes of several tenths of a magnitude (Patat 2006). The choice of sky position is important. Lavasseur-Regourd and Dumont (1980) model the increase in background as the ecliptic plane (and its zodiacal light) is approached. In the V band the effect is 0.3 magnitudes at ecliptic latitude 0 and falls by roughly 0.05 mag for each 10 degree increase in ecliptic latitude.

Two of the most recent monitoring papers for Cerro Tololo are Kriscuinas et al. (2007; 2010). Cerro Tololo is closer to La Serena-Coquimbo and Vicuña than Cerro Pachon and is roughly estimated to suffer 65% more light contamination than Cerro Pachon. It will be necessary to analyze a lot more data before we have any hope of measuring long-term trends in light pollution over Cerro Tololo. It is particularly important to support efforts to fund a second epoch of the World Atlas of the Artificial Night Sky Brightness (Cinzano et al. 2001)—see Fig. 10.18 (Northern Chile and the world reproduced from that Atlas).

Significant modelling extensions have recently been reported by Cinzano and Falchi (2012). However, more computing power will be needed to include the beneficial screening effect of coastal mountains which protect the summits of Cerro Tololo and Cerro Pachón from a direct view of most of the lights in the La Serena/Coquimbo conurbation.

Another approach is being followed based on taking many less precise, simple measurements of the zenith sky brightness using Sky Quality Meters closer to the cities and other major sources of light pollution. The Globe at Night program involves citizen scientists from the general public in this increasingly useful, world-wide monitoring effort—as explained on the program website, www.globeatnight.org.

CANARIAN OBSERVATORIES

Environmental and nature conservation

The Canary Islands' Biodiversity Data Bank is constantly monitoring parameters related to biodiversity conservation and potential impacts on the integrity of the areas containing both observatory sites, since both are Special Areas of Conservation (SAC) and Special Protection Areas (SPA). These indicators include the numbers of endangered species and other trends important for conservation purposes, such as the introduction of invasive alien species. The first data on nocturnal wildlife species are being obtained. Their best protection depends upon the absence of light pollution, since this would decrease their distribution and abundance.

Archaeoastronomical heritage

Indicators relating to archaeoastronomical heritage are deduced from the archaeological maps of both islands, which set out an assessment of existing heritage.

Sky quality

Sky quality indicators are monitored continuously, in particular astronomical quality parameters related to darkness, atmospheric conditions, seeing, and transparency.

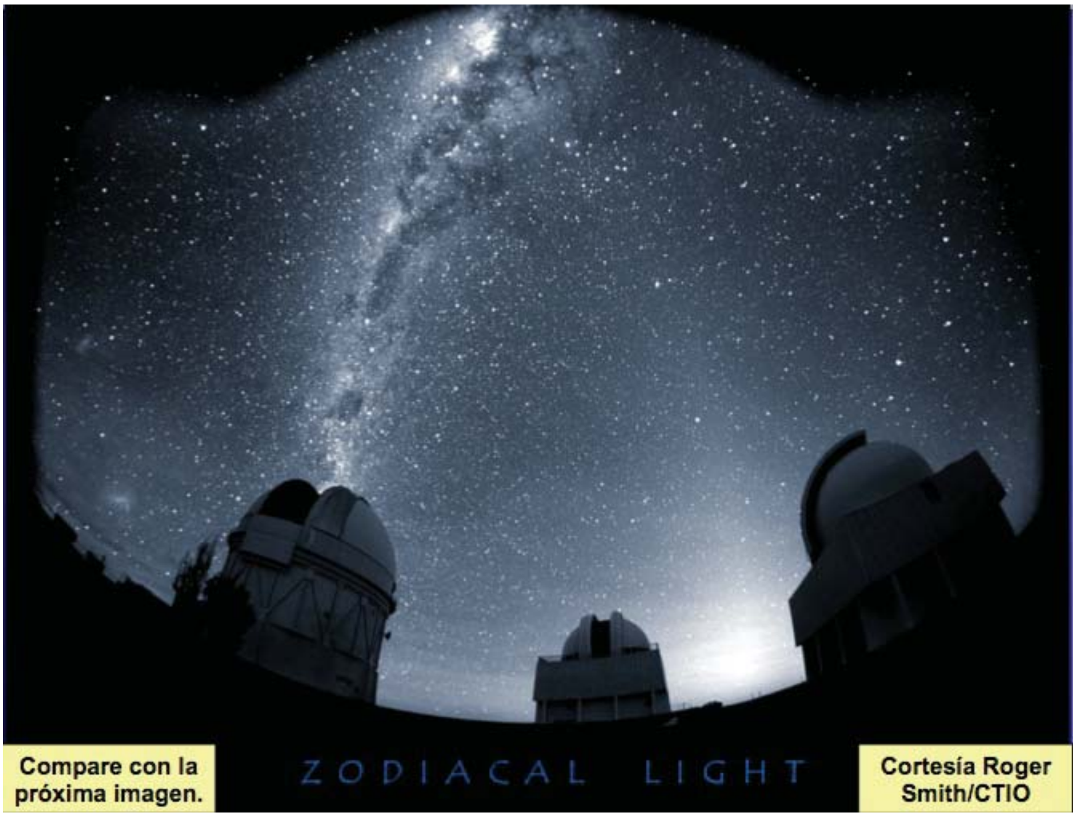


Fig. 10.17. The setting Zodiacal Light as seen looking SW from Cerro Tololo. **(Top):** With the Zodiacal Light still quite high in the sky. **(Bottom):** After the Zodiacal Light has set. Photographs: Roger Smith/CTIO

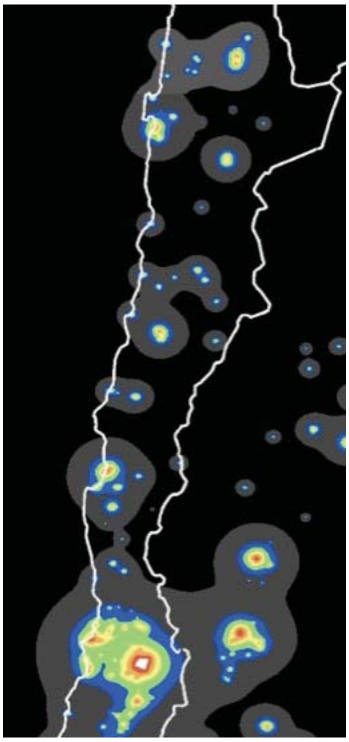
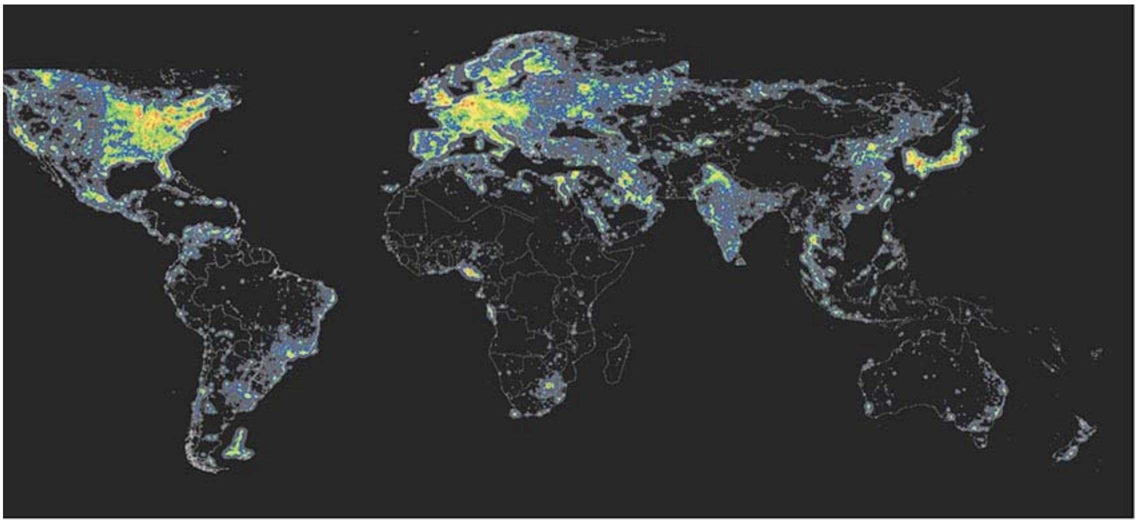


Fig. 10.18. Images based on work done for the *World Atlas of Artificial Night-Sky Brightness* by P. Cinzano, F. Falchi (University of Padova) and C.D Elvidge (NOAA National Geophysical Data Center, Boulder). published in the *Monthly Notices of the Royal Astronomical Society* in 2001. **(Left):** Northern Chile. **(Below):** The world. Reproduced by permission of Blackwell Science.



- *Useful Time (of clear sky) and meteorological parameters*. It is essential to know the local meteorology and climate in the area studied—the presence of cirrus clouds, dust in suspension, air temperature, relative humidity, barometric pressure, rain gauge levels, direction and velocity of the wind, etc.—and its possible correlation with image quality. To do this, there are automatic meteorological stations equipped with standard meteorological sensors. The infrequency of cirrus clouds, moderate temperatures and the semi-presence of trade winds allow for a high percentage of observation hours and contribute to the excellent quality of the astronomical images.

  A key factor is the degree of disturbance caused by *light pollution* on natural *darkness* conditions at night at the site. Both the SQG and the OTPC continuously monitor light pollution trends in order to propose at any moment the corrective measures to deal with any deviation.

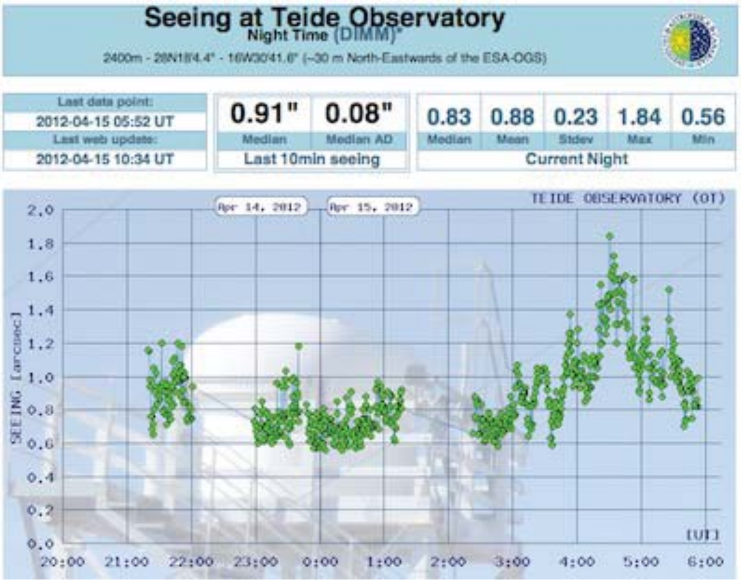


Fig. 10.19. Sky parameters for observing proposals. From the Sky Quality Group web site (www.iac.es/proyecto/site-testing/).

Atmospheric Extinction (transparency). The term ‘extinction’ means the loss of light in the atmosphere from a directly transmitted beam. Two different mechanisms contribute to extinction: absorption and scattering.

Seeing (for sharp images). Astronomical “seeing” refers to the blurring and twinkling of astronomical objects such as stars caused by turbulence in the Earth’s atmosphere. In order to get smaller “seeing” values (only obtained in the best locations) sophisticated techniques and instrumentation which have been developed in the last decade are needed. There are two prototype instruments in existence: one of them was built by the European Southern Observatory (ESO) and the other was created by the IAC in collaboration with the University of Nice (France). They have been calibrated to each other and are producing the most convincing and modern data of the Canarian Observatories as well as those of the ESO in Chile (La Silla and Paranal).

The measurement and statistical analysis of parameters related to atmospheric turbulence are crucial for the selection and characterization of the best astronomical observing sites. These parameters require continuous monitoring and updating. The largest statistical study of atmospheric turbulence profiles in the world was achieved for the ORM.

The SQG web site (www.iac.es/proyecto/site-testing/) has been set up to provide detailed information and statistics about meteorological and seeing data at different locations at the Canarian Observatories, as provided by different instruments and campaigns. Data files and charts are also available, as well as other related information. The Site Characterization Study is funded by the IAC and co-funded by European Commission FP6 programme.

7. Documentation

7.b Texts relating to protective designation

CANARIAN OBSERVATORIES

Law for the Protection of the Astronomical Quality of the IAC Observatories - Law 31/1988
www.iac.es/adjuntos/otpc/leycielo.pdf

Regulations for the law - R.D. 243/1992
www.iac.es/adjuntos/otpc/regcielo.pdf

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http://www.iac.es/adjuntos/otpc/RESUMEN_DE_CRITERIOS_2012-ENERO.pdf
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whc.unesco.org/archive/2007/whc07-31com-24e.pdf
Plan Rector de Uso y Gestión del Parque Nacional del Teide (Teide Management Plan)
www.gobiernodecanarias.org/boc/2002/164/002.html
Special Areas of Conservation (Natura 2000)
http://www.gobcan.es/cmayot/descargas/documentos/zec/Borrador_Orden_ZEC.pdf

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Aoraki Mackenzie International Dark Sky Reserve, New Zealand

Margaret Austin, John Hearnshaw and Alison Loveridge

1. Identification of the property

1.a Country/State Party: New Zealand

1.b State/Province/Region: Canterbury Region, Te Manahuna / Mackenzie Basin

1.c Name: Aoraki Mackenzie International Dark Sky Reserve

1.d Location

The geographical co-ordinates for the two core sites are:

- Mt John University Observatory near Tekapo: latitude 43° 59′ 08″ S, longitude 170° 27′ 54″ E, elevation 1030m above MSL.
- Mt Cook Airport and including the White Horse Hill Camping Ground near Aoraki/Mt Cook village: latitude 43° 46′ 01″ S, longitude 170° 07′ 59″ E, elevation 650m above MSL.

Fig. 11.1. Location of the property in New Zealand South Island. Satellite photograph showing the locations of Lake Tekapo (A) and the Aoraki/Mt Cook National Park (B). Source: Google Earth

1.e Maps and Plans

See Figs. 11.2, 11.3 and 11.4.

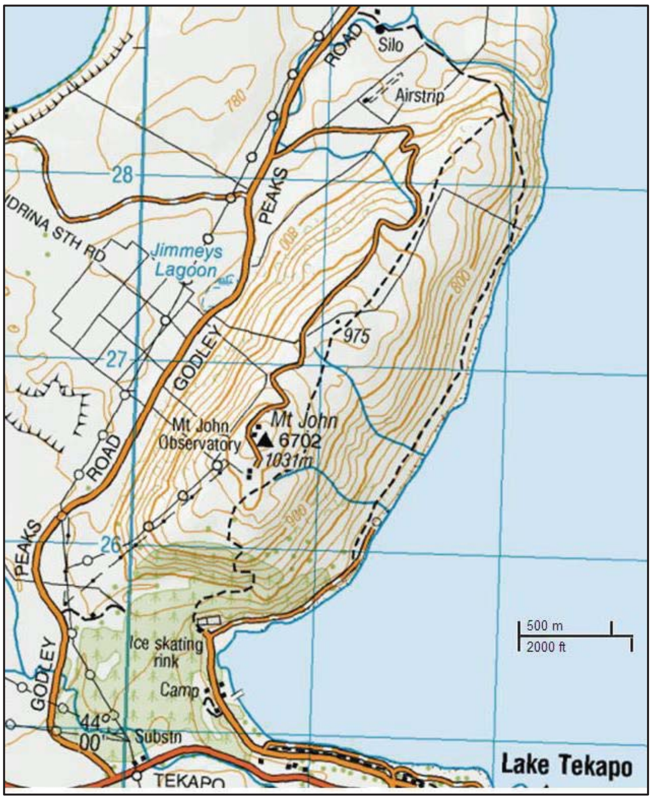

Fig. 11.2. Topographic map showing the primary core boundary defined by the 800m contour line

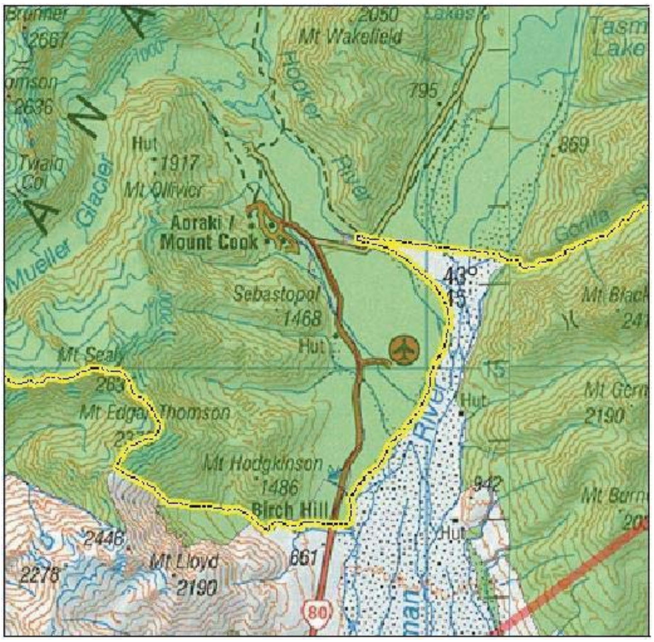

Fig. 11.3. Map showing the boundaries of the secondary core at Mt Cook Airport. The boundaries are clearly defined by State Highway 80, Tasman Valley Rd, and Mt Cook National Park's southern boundary

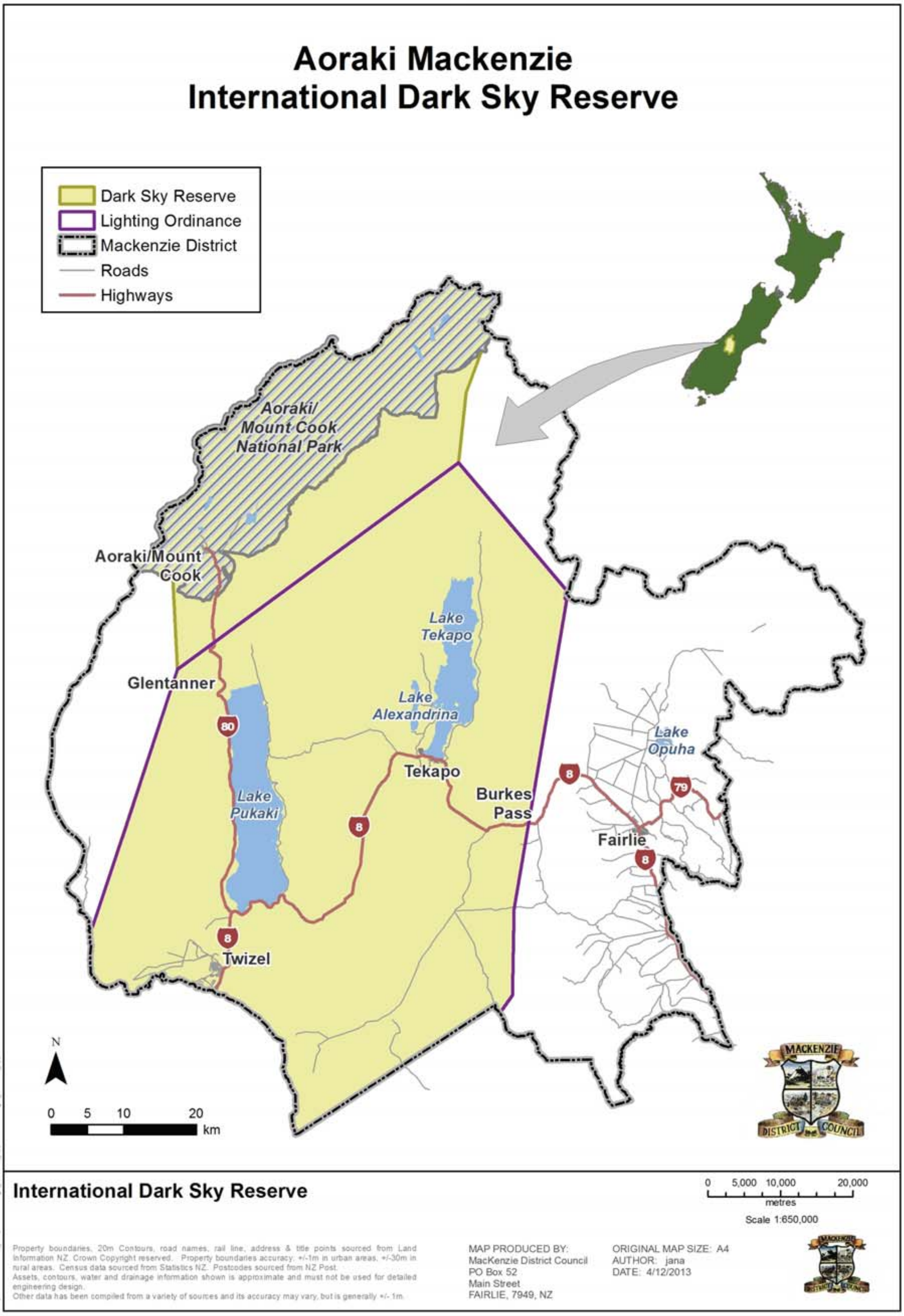

Fig. 11.4. Map showing the boundaries of the secondary core at Mt Cook Airport. The boundaries are clearly defined by State Highway 80, Tasman Valley Rd, and Mt Cook National Park's southern boundary

1.f Area of the property

Aoraki Mackenzie International Dark Sky Reserve is located in the centre of the South Island of New Zealand, in the Canterbury Region, in the place known as Te Manahuna or the Mackenzie Basin (see Fig. 11.1). The property consists of an extensive buffer zone around two core sites at Mount John Observatory and Mount Cook Airport.

Aoraki Mackenzie International Dark Sky Reserve includes

- Lake Tekapo and its tributary, the Godley Valley;
- Lake Pukaki; and
- Aoraki/Mount Cook National Park Village within Te Wāhipounamu – South West New Zealand World Heritage Site (#551).

Aoraki Mackenzie International Dark Sky Reserve extends approximately 70 km (43 miles) from north to south and 90 km (56 miles) from east to west at its longest and widest points (see Fig. 11.1). The Southern Alps and Aoraki/Mount Cook National Park, which is also within Te Wāhipounamu – South West New Zealand World Heritage Site (#551), constitute its western edge.

The buffer zone of *Aoraki Mackenzie International Dark Sky Reserve* includes the whole of the Aoraki/Mount Cook National Park (see Fig. 11.4).

The areas concerned are:

Mount John University Observatory Core	23 hectares
Mount Cook Village Airport Core	c. 15 km²
Buffer zone in Mackenzie Basin including Aoraki/Mount Cook National Park	4,367 km²
Aoraki/Mount Cook National Park	70 km²

2. Description

2.a Description of the property

Significant Features of the Property

Aoraki Mackenzie International Dark Sky Reserve is described as a Mixed Starlight Reserve as defined by the *Starlight Reserve: Concept, Dimensions, Categories, Criteria, Recommendations* criteria (Marín and Orlando 2009), where two or more different categories of Starlight Sites are combined. These could be astronomical and scientific sites of significance, natural sites and Starlight Landscapes, and human inhabited Starlight Oases. Additionally, the ICOMOS/IAU Thematic Study (Ruggles and Cotte 2010) describes the Reserve as a "multifunctional" window to the universe as the site exhibits several significant qualities and exceptional natural and cultural values in one location. A "layering" approach is used to build a case for a Mixed Starlight Reserve whereby the natural, cultural, scientific and astronomical heritage values of the site are interwoven.

Natural Property – Important Physical Attributes

The Mackenzie Basin is a large, dry, flat area of land covered in grasses and tussocks ringed with high snow-capped mountains. The many lakes of glacial origin, tarns and kettleholes define the character of the whole area. Pastoral farming introduced fauna and flora and hydroelectricity developments have altered the landscape over the last 150 years. The Mackenzie Basin experiences extremes of cold, drought and wind. It has shallow, stony, porous and infertile soil. Tough, slow-growing grasses and woody plants make the most of the formidable soil. The Mackenzie has a very low risk of fire, despite the dry, drought-prone terrain. This unique environment means there are a number of important ecosystems which were relatively uncommon even before the arrival of Māori and European settlers. Access to irrigation water will determine the spread of landscape change in the future. Given the variability of income from dryland farming, some “run holders” (holders of Crown pastoral leases) supplement their incomes from farming with tourism and other businesses and this may increase.

Natural Beauty

The Mackenzie Basin is an immense golden tussock-covered floodplain wide open to a vast sky surrounded by soaring mountain peaks. Volumes of glacial water pour into long braided rivers and deep lakes. The *Canterbury Regional Landscape Study Review* (Environmental Canterbury 2010: 142) recently identified the entire Mackenzie Basin, including the valley floor and surrounding slopes and ridgelines, as an Outstanding Natural Feature and Landscape (ONF/L). Only a small section around and to the south of Twizel has been excluded owing to high levels of modification in this area. This means that the Aoraki Mackenzie International Dark Sky Reserve site bounded by the current Outdoor Lighting Restriction area falls within this area of ONF/L. ONF/L was granted on the basis of several key landscape values, including aesthetic values such as the striking colour of Lakes Tekapo and Pūkaki forming “one of the most memorable landscapes in the country”. The sky is a crucial element by day as the open plains mean that the dramatic cloud effects of “norwester” weather are more vividly experienced than anywhere else in the country. The mountains of the Te Wāhipounamu World Heritage Site ring the western and northern boundaries of the International Dark Sky Reserve. The contrast between these mountains and Aoraki/Mt Cook itself and the plains is considered a highlight of the view.

The landscape as it appears now has been altered by human activity. With the arrival of Māori (750–1300 CE) the landscape began to undergo a process of change, converting from a mixture of forest, scrub and tussock grassland to predominately dense tall and short tussocks (Walker 2010). This process of change was intensified by the pastoral grazing techniques of Pākehā (European) settlers since the late 19th century and the introduction of foreign species of flora and fauna. This resulted in the more sparsely covered tussock landscape present today, though essentially the landscape looks as it would have when the first Pākehā (Europeans) arrived in the area. Farming sheep and cattle maintains landscape features such as the extensive tussock grasslands and it is these features that contribute to the natural beauty of the area. UNESCO’s *Operational Guidelines for the Implementation of the World Heritage Convention* indicate that human activity of “traditional societies” (Māori) and “local communities” (pastoral farmers) is acceptable as it is consistent with the OUV of the area. The man-made features such as the open tussock grassland combined with natural features such as glacial lakes and braided rivers provide the scenic beauty and aesthetic importance of the landscape.

Tekapo and Aoraki/Mt Cook are major tourist destinations between Christchurch and Queenstown. As well as providing inspiration for artists and writers, the Basin’s natural beauty features prominently in local television commercials and international marketing campaigns promoting New Zealand as a tourist destination. The general absence of people and human activity serve to enhance the area’s natural scenic beauty and aesthetic importance.

The night sky and its celestial bodies are superlative natural phenomena. The lack of light pollution, the clarity of the night sky and the wide open vistas of the Mackenzie Basin are features that make this site special and distinguish it from other locations around the world with

Fig. 11.5. The Milky Way, Mt John, Tekapo. Photograph: Fraser Gunn

equally beautiful night-time vistas. These features combine to create an area in which to view the exceptional natural beauty and aesthetic importance of the night sky. The stars and planets visible in the night sky contribute to a sense of place and the site's natural heritage. The sky is a cultural resource common to all humanity, as outlined in the Introduction of the first Thematic Study (Ruggles and Cotte 2010: 6).

Aoraki Mackenzie International Dark Sky Reserve is appreciated for the integrity, character and beauty of its rural landscape where the natural beauty and the rural beauty of the landscape combine with the area's astronomical heritage. The landscape also has an historical and social context in additional to its ecological and geological context. The issue of past human influence being viewed as "spoiling" the physical attributes of the basin's natural beauty becomes less applicable.

Furthermore, the physical attributes of the geology and biodiversity of Aoraki Mackenzie International Dark Sky Reserve are interpreted here as enhancing the heritage value of the dark night sky.

Geology

The Mackenzie Basin, the largest inter-montane basin in New Zealand, is a geomorphically significant area. Many of the landforms present in the Basin are the result of late Pleistocene glacial advances and retreats occurring 13,000 to 130,000 years ago. A large number of geo-preservation sites exist in the area and can be found listed in the *Mackenzie District Council District Plan 2004* (Mackenzie District Council 2004). The most notable sites within the Lighting Ordinance include G7, G8, G9, G10, G11, G13, G14, G15, G16, G21, G23 and G25. Several of these are situated within the buffer zone for the Aoraki Mackenzie International Dark Sky

Reserve, as delineated by the Outdoor Lighting Restriction area (Fig. 11.4). This is significant for World Heritage status for this particular part of the Basin. These notable sites include the Tasman River Outwash Plain (G7), one of the biggest fluvio-glacial outwash plains in New Zealand; Landslip Creek Lateral Moraine (G8), the best example of a lateral moraine in New Zealand; Glenmore Station Kame (G11), the best example of a large kame in New Zealand; and Mount John itself (G16), which is an excellent example of a rôche moutonnée and provides a superb view of many of the features listed. All sites are identified as having extremely high scientific and educational value. The recent identification of the entire Mackenzie Basin as an ONF/L by the *Canterbury Regional Landscape Study Review* resulted from the legibility of the Basin's formative glacial processes, expressed by landscape features such as moraines, rôches moutonnées, hanging valleys, terraces, fans and the glacial outwash plains. The original Te Wāhipounamu World Heritage Site nomination contended "the only limitation to the integrity of the Pleistocene imprint is the absence of the glacial outwash basins and large lakes along the eastern margin" of the site (Department of Conservation 1989: 57).

Biodiversity

The Mackenzie Basin contains many important naturally rare ecosystems. Naturally rare ecosystems are types of ecosystems that were uncommon even before the arrival of humans in the area. The inland alluvial surfaces, inland dune systems, kettleholes and braided rivers of the Mackenzie Basin provide the habitat for many rare and threatened native and endemic species of flora and fauna. Notably, braided river landscapes are globally rare and the Mackenzie Basin contains the largest concentration of braided river habitat in New Zealand at approximately 20,000 ha. All or parts of the Godley, Macaulay, Cass, Tekapo and Tasman tributaries fall within the buffer zone or Outdoor Lighting Restriction area.

There are conservation areas managed by the Conservation Department scattered throughout the Aoraki Mackenzie International Dark Sky Reserve area. Important endemic and threatened species are found within these reserve areas as well as outside them where they may not be as well protected as they would be under Department of Conservation administration.

The Mackenzie Basin is home to a number of freshwater fish species including Lowland Longjaw Galaxias; Bignose Galaxias; Upland Longjaw Galaxias; Koaro; Longfin Eel; Alpine Galaxias; Canterbury Galaxias; Upland Bully; and Common Bully. There are also significant populations of endemic invertebrates in the Basin: Knobbled Weevil; Robust Grasshopper; Small High Country Grasshopper; Moths and Butterflies; Ground Beetle; Ground Weta and large Dragon Flies. Birds living in the Mackenzie Basin include Black Stilt; Black-Billed Gull; Black-Fronted Tern; Grey Duck; Southern Crested Grebe; Eastern Falcon; Banded Dotterel; Wrybill; Caspian Tern; Rockwren; New Zealand Pipit; South Island Oystercatcher; Kea and Pied Stilt. The Mackenzie is also home to the lizard species Spotted Skink, Scree Skink, Long-Toed Skink, and the rarely seen Jewelled Gecko. Additionally, the Mackenzie Basin is an important habitat for flora, and is home to approximately 39% of threatened flora in Canterbury. There are at least 32 plant varieties in the area that can be classified as threatened, which means these species are considered to be nationally critical, vulnerable, or endangered.

"Project River Recovery" (PRR) was launched in 1991 to mitigate the effects of the hydroelectricity developments on wetland and braided riverbeds. It is funded by Meridian Energy and the Department of Conservation to control weeds, research riverbed predators, undertake ecological monitoring, advocacy, and the construction of new wetlands to encourage native birds to nest there. A review of the project by Brian Caruso (2006) noted that about half of New Zealand's bird habitat on braided riverbed is in the Mackenzie Basin. While braided rivers

Fig. 11.6. Altar window in the Church of the Good Shepherd, designed "to encompass the beauty of God's creation". Photograph: Fraser Gunn

are geologically unusual, "their plant and animal communities make them unique" as birds adapt to this dynamic and complex environment. Biodiversity work is focused on the kakī/black stilt, one of the world's rarest wading birds. Increasing kakī numbers and the strength of the research are among the indicators that this is a world class, effective ecological programme.

Aoraki Mackenzie International Dark Sky Reserve as Cultural Landscape

Aoraki Mackenzie International Dark Sky Reserve is a Cultural Landscape that includes the Dark Sky and Observatories. The sky is very much part of the landscape in the Reserve and is identified by both Māori and Pākehā as an integral part of their natural and cultural heritage.

Both Māori and Pākehā speak of spiritual connections and spiritual places within the Aoraki Mackenzie International Dark Sky Reserve area. Participation and attachments are expressed through food collection and pastoral livelihoods and the meanings given to the sky, the land, the waters and stargazing. These expressions are made visible in literature, drawing, painting, sculpture, oral traditions, scientific endeavour, cultural heritage sites, and tourist and educational interpretations.

Fig. 11.7. Orion nebula. Photograph: Fraser Gunn

Astronomy

Significant sites exist at Mt John University Observatory, Tekapo, Mt Cook Village and Mt Cook Airport for observing the stars. These sites are important for astronomy and science as well as providing access for the general public to pursue wonderment about stars and celestial phenomena in an outstanding rural environment. Because of the clarity of the skies and Lighting Ordinances protecting the dark-sky from village lights, astrophotography is possible from the balconies of accommodation in Tekapo, Aoraki/Mt Cook and surrounds. There are four research telescopes at Mt John. The most recent is a result of collaboration between scientists in New Zealand and Nagoya University in Japan aimed at discovering extrasolar planets using the gravitational microlensing technique. The Microlensing Observations in Astrophysics (MOA) project has had an involvement in all the extrasolar planet discoveries that have used this technique since the first discovery in 2003.

Traditional Māori Culture

Aoraki/Mt Cook, visible from many parts of the Mackenzie Basin, is the ancestor of Ngāi Tahu Whānui (members of the Ngāi Tahu *iwi* or tribe) and contains many powerful messages. The story of Aoraki is told in any important document to do with the area, from tourist websites to resource management plans and a 20-minute 3D digital presentation at Aoraki/Mt Cook Planetarium. It is a notable feature in the Department of Conservation's presentation of the area because of the tōpuni status (an official statement of cultural values) over Aoraki/Mt Cook. The recent Cultural Impact Assessment undertaken for the proposed change to the Mackenzie District Plan highlights the value of unimpeded vistas. “Visual catchments were seen by Ngāi Tahu as essential to maintaining the relationships with these culturally significant landscapes”. “The visual catchments and view shafts between the southern shores of the lakes and the mountains in the north were particularly important to Ngāi Tahu for the purpose of maintaining relationships with those places”. The entire Mackenzie Basin is a significant ancestral landscape to Ngāi Tahu.

Te Manahuna is the traditional name for the Mackenzie Pass and Basin. The nearest *marae* is Arowhenua, near Timaru, but the area is also important to Ngāti Māmoe who travelled to it up the Waitaki River. Māori continue to travel into Te Manahuna to fish and gather food from land and water sources (*mahinga kai*). Access to several Nohoanga sites that are reserves allowing Ngāi Tahu access to natural resources within the agricultural landscape fall within the International Dark Sky Reserve. Like Tōpuni, these have been guaranteed by the Ngāi Tahu Claims Settlement Act 1998.

Pākehā land management has changed Māori relationships to the area, however. Ngāi Tahu, in collaboration with Outward Bound based at Anikiwa, have developed an enterprise with an educational focus. “Aoraki Bound” (www.ngaitahu.iwi.nz/whanau/aoraki-bound/) is a course that combines 8 days at an Outward Bound facility with 12 days on a journey from Anakiwa in the Marlborough Sounds to the base of Aoraki/Mt Cook. One of its main objectives is for students “to experience the majesty of our lands and waters; to gain an understanding of kaitiakitanga [guardianship] … and commit to the protection and enhancement of our environment and its Taonga”. The purpose is to develop an “increased understanding of Ngāi Tahu culture, beliefs, language and history” and to enhance a “sense of connection and identity” among participants. The course is open to anyone; however, its central aim is the cultural revitalization of Ngāi Tahu as individuals and as a collective and is part of reclaiming traditional relationships with the land through participation and asserting control over the interpretation of their heritage landscapes.

Fig. 11.8. Farming requires working dogs. Photograph: Mark Ivey

Māori Rock Art (Tuhituhi Neherā) and Oral History (Tāhuhu Kōrero)

Te Ana Ngāi Tahu Rock Art Centre (www.teana.co.nz) opened in December 2010 and is based within the Timaru Visitor Information Centre. It provides accessible and culturally authentic interpretation of some of the most significant examples of Māori rock art in New Zealand offering insights into the mythology and cultural heritage of Māori from the surrounding region. The Rock Art sites are located on the traditional pathways to Aoraki Mackenzie International Dark Sky Reserve and are connected by these ancient pathways to the sites and knowledge within the Reserve. Visitors follow the journey of the people who created the rock art where attention is drawn to time, seasons, earthly and spiritual worlds through an educational, "virtual" rock art experience. Stories are told by Manawhenua (local Ngāi Tahu people). The Rock Art Centre also contributes to the protection and management of the rock art sites as a commitment to future generations, as part of Ngāi Tahu cultural revitalization and as education for visitors about cultural meanings embedded in the landscape.

Pastoral Farming and Cultural Values

Aesthetic, spiritual and cultural values attached to the Aoraki Mackenzie International Dark Sky Reserve area have inspired expression in drawing, painting, sculpture, photography and written and oral literature. Artists including Grahame Sydney describe the effect the landscape has on those who witness it. He says it has "a particularly powerful grip … imaginations, emotions and memories … profound and mysterious contentment … mystical and complex … in short, we feel spiritually connected" (Sydney 2009: 2).

Dryland pastoral farming began with Pākehā (European) settlement and is orientated around large-scale exports of wool and meat. There is little cropping in the area and the main product is fine wool. Forestry is uncommon and raises concerns over change in the landscape values. Recently deer have also been farmed. The basin was traditionally managed by farmers leasing crown land. Established practices, supported by legislation, maintained this crown property in a difficult environment over the last 150 years. Art tends to emphasise the wilderness values of the landscape or dryland farming and the pioneering element of farming in this difficult and isolated area.

- *Contemporary art — Painting and architecture*

  The painter Esther Hope (1885–1975) lived at "The Grampians", a high-country farm in the Mackenzie Basin. She exemplifies the qualities of much art of the basin. As well as her legacy of paintings from this area, her commissioned drawings and models were turned into design plans by the architect R.S.D. Harman of Christchurch for the Church of the Good Shepherd at Tekapo. The church was built in 1935. As an expression of the relationship between the community and the environment, the church sits on ground left in its natural state covered with matagouri, tussock and rock as requested by the land donor, Mr George

Murray from Braemar Station. Adjoining land was also gifted to ensure the church remained in distinctive isolation.

- *Sculpture*

  Sculptor Innes Elliot also lived on a pastoral farm in the Mackenzie Basin. Her commissioned public sculpture at Tekapo celebrates not only the “collie dog, without the help of which, the grazing of this mountain county would be impossible” but also the history of the Scottish Highland shepherds who helped manage the properties of run holders. Mackenzie, the folk hero who was the first European to find the route into the Basin, and his dog Friday are also remembered with the phrase “Beannachdan Air na Cu Caorach”, which means “Blessings on the sheep dog”, on the monument plaque.

- *Photography*

  Fraser Gunn’s spectacular photography is featured in this Extended Case Study. A remarkable astro-photographer, he captures and interprets the beauty of the dark sky of Aoraki Mackenzie International Dark Sky Reserve. A plethora of photography and digital media — amateur, professional and commercial — is inspired by the outstanding vistas of this area.

- *Writing*

  Alan Curnow and Owen Marshall are two of New Zealand’s most significant writers connected to the Mackenzie Basin, the former a poet and the latter a leading fiction writer: “the affinity he feels with its people and landscapes is evident in much of his writing”.

Fig. 11.9. Sculpture: Innes Elliot. Photograph: John Bisset / Timaru Herald

Fig. 11.10. Matariki. Photograph : Fraser Gunn

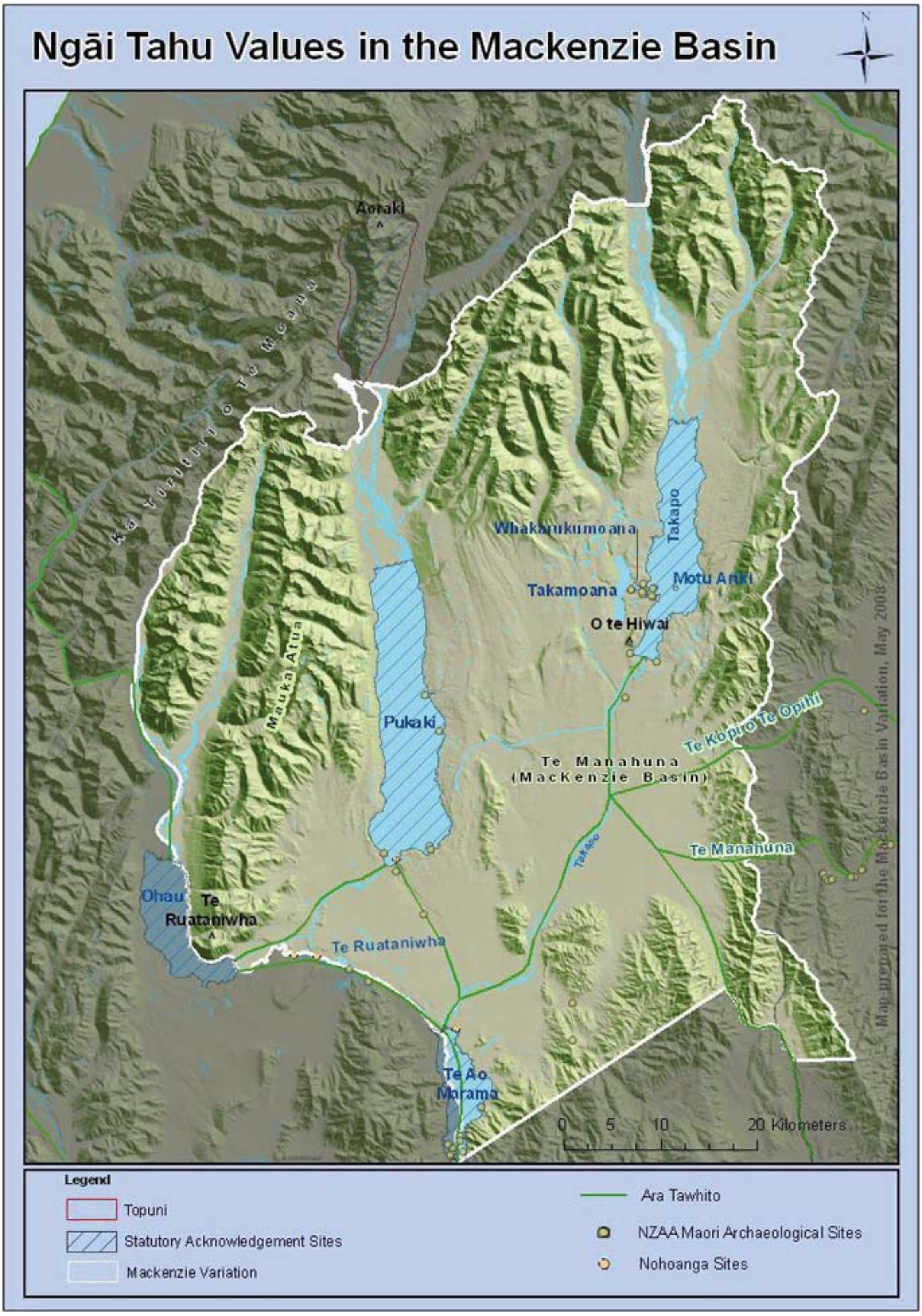

Fig. 11.11. Sites of importance to Maori in the Cultural Impact Assessment carried out for Mackenzie District Council Plan Change 13. This is not a full record of all significant sites.

2.b History and development

Matariki ahunga nui	When Pleiades,
Matariki tāpuapua	The gatherer,
Matariki hunga nui	Is bright in the sky
Ngā kai a Matariki	The year begins.
Nāna i ao ake ki runga.	

(Grace & Grace 2003)

Waitaha Māori are identified as the first people to travel into the Mackenzie Country between 750 and 1300 CE. Other tribal identities later linked to this area include Ngāti Māmoe and Ngāi Tahu. The Mana Whenua (overall guardians or customary authority) at the present time are Ngāi Tahu Whānui. Before European settlement large parties travelled into the Basin to harvest the local resources. Māori from mid-Canterbury travelled through the valleys to Te Kopi o Opihi (Burkes Pass) and Te Manahuna (The Mackenzie Pass). These valleys contain some of the rock art sites thought to be areas where traditional learning took place. From the South, people travelled on the Waitaki river, using craft made from reeds as the rapids were dangerous to heavier wooden canoes. Māori collected stone such as silcrete for tool making, and travelled to the west coast, where greenstone (*pounamu*) was found, or to another greenstone site near the head of Lake Wakatipu.

Travel began while moa were still important to local subsistence and resulted in landscape change, converting the Basin from a mixture of forest, scrub and tussock grassland to predominately dense tall and short tussocks. Moa were large flightless birds, now extinct. Little is known about Waitaha occupation of the Basin until the late 16th and early 17th centuries when a series of skirmishes took place between Waitaha and Ngāi Tahu. While family groups sometimes settled for longer periods, most occupation was seasonal. Māori were not living there permanently when the area was surveyed between 1852 and 1860. Archaeological evidence and first-hand accounts from the 19th century point to small encampments of coastal people clustered on the shores of lakes or waterways. Some settlements have been inundated by the expansion of the lakes for the production of hydroelectricity. Weka, kākāpō and other waterfowl were important. The Cultural Impact Assessment carried out for the *Mackenzie Basin Proposed Plan Change 13* (Boffa Miskell Limited *et al.* 2008) noted “Flora gathered from land adjoining the lake included matagouri, taramea, tutu, tataraheka, manuka, snowgrass, and raupo. The succulent *kiore* (Polynesian rat) was once an important food resource”. Eeling was also important. Ram Island or Take Karaka (now commonly known as Motuariki) in the middle of Lake Tekapo was once the home of the ancestors of Arowhenua. “Such was the reputation of Takapo as a mahika kai that people came from as far away as Kaiapoi, several hundred kilometers to the north, to trade for food.” As Māori moved through the area, each locality was given a name. Important ones are listed in the Cultural Impact Assessment. The Kāi Tahu Ki Otago *Natural Resource Management Plan* (Kāi Tahu Ki Otago 2005) notes in its discussion of cultural landscapes in the Waitaki catchments (including the Mackenzie Basin) that “The value attached to the land is evident from the fact that every part of the landscape was known and named … every hillock, streamlet and valley”. The stories associated with each locality are also listed in statutory acknowledgements in official documents. For instance, the story associated with Lake Pūkaki is:

> Pūkaki is one of the lakes referred to in the tradition of “Ngā Puna Wai Karikari o Rakaihautu” which tells how the principal lakes of Te Wai Pounamu were dug by the *rangatira* (chief) Rakaihautu. Rakaihautu was the captain of the canoe, Uruao, which brought the tribe, Waitaha, to New Zealand. Rakaihautu beached his canoe at Whakatū (Nelson).

> From Whakatū, Rakaihautu divided the new arrivals in two, with his son taking one party to explore the coastline southwards and Rakaihautu taking another southwards by an inland route. On his inland journey southward, Rakaihautu used his famous *kō* (a tool similar to a spade) to dig the principal lakes of Te Wai Pounamu, including Pūkaki.

Māori expeditions into the area overlapped with European settlement, and were interrupted by the establishment of rabbits in the area and the laying of poison, which also killed the birds. Oral testimony by the Maiharoa family in response to development projects confirms that Māori returned to the area:

> We live beside the Waitaki Awa (river) which, as a child, was our playground, we learnt to row a boat, how to make a *mokihi* (reed raft made of raupo), to swim and fish, and we planted by the phases of the moon and stars)... When people say "*Kei hia tou mana e tipu ana?*"... where is your mana tree growing?" they ask where our families came ashore. And we reply: "Tahunanui, 67 generations ago." He was the Ancestor of Waitaha who came with his digging stick or spade. (Tu Whakaroria [the spade] dug and named many lakes — Takapo, Pukaki and Ohau.)

Travels and seasonal activities have been traditionally linked to the stars, which are considered ancestors from whom one receives direction. "We often refer to our ancestors as *rātou kua wheturangitia* (those who have become stars). With the passing of seasons the stars come and go just like people and the seasons." In order to memorize, make sense of, and pass on precise astronomical knowledge, it was often woven into stories that adopted the mythical nature of astrology. Myths, with characters and stories, have helped to preserve knowledge throughout the generations. These stories include references to the sky. There are ten myth cycles or eras, each with its own context, that place different creation events in their own time. "If a feature such as the Milky Way is called Te Waka o Māui, then the correct context in which to consider it is: the discovery of the world, the development of knowledge and the origin of death", and the whole of the Maui Cycle is relevant. In this cycle the Waka or canoe is the South Island, which Maui stood on when he fished up the North Island from the sea. For Māori, "the Milky Way is a more important seasonal marker than the Zodiac" which marks the seasons in 'Western' traditional astronomy.

Māori mythology chronicles the creation of land, water bodies, and sky, attributing spiritual qualities to them. What Europeans would call 'the landscape', for Māori includes the sky and is not merely physical, but is relevant to culture and society as well. Myths provide messages as to how people should live, so 'the landscape', imbued with messages, tells people how to live. As one Māori proverb from the Graces' collection says: "By the forest vines Earth and Sky were bound together". In the Māori creation story, before the time of light, the primal parents Earth and Sky lay together in darkness, bound by vines. They were thrust apart, light came to earth and life as we know it evolved.

In Waitaha, traditional knowledge of the stars was as important as any other knowledge. Ruka Te Korako and Ruka Te Korako (2006) note: "They long held that every child should have a song of the geography of the land sung to them during their infancy". As well as songs and stories, string patterns (*mahi whai*) were created for different constellations and used as a teaching tool to pass on astronomical knowledge. These string patterns are similar to those that Pākehā 'play' with as children, manipulating a continuous piece of string (tied in a circle) into various symmetrical patterns with their fingers. However Māori did not practise this as a child's game; rather, the various patterns resembled specific constellations full of meaning and were taught by adults. Ruka Te Korako and Ruka Te Korako (2006) describe how:

> The elders looked into the heavens and marked the various star houses into the landscape, normally into rock overhangs or scribed into the sides of caves. If the star

> movements indicated that devastation was approaching, they would scribe the star message onto small tablets of clay, and fire them in the umu ukurangi.

The arrival of Matariki (the Pleiades) low in the eastern sky in early June signals the beginning of a new year. The counting of the full moons recommences. Māori have traditionally-set times for planting, making safe journeys across mountains seeking rock and food resources, and fishing and voyaging on the inland lakes and rivers and coastal seas. Anthropologist Elsdon Best stated in 1922 (Best 2002):

> An old saying is, "When Matariki [Pleiades] is seen, then game is preserved"; for it marked the season when such food-supplies have been procured and preserved in fat in certain vessels.

He also claimed Ngāi Tahu said that

> Women awaited the appearance of Rigel and regarded intently its aspect. If when it appeared above the horizon its rays were directed towards the south, then an inclement season followed; products of field, forest, and sea would suffer. If directed to the northward, then a fair season followed; all products were plentiful, floods were not, and merely desirable rains fell.

Lunar cycles were also associated with medicines. The effects of the lunar phases on members of the communities were carefully observed and Waitaha elders noted "at the optimum times of the effects of the moon on some of the patients of the teachers and healers, special medicines were gathered and prepared for use only on these times of critical power of the moon" (Ruka Te Korako and Ruka Te Korako, 2006). The elders believed that the moon affected the water within the body of the patient, much as it does the tides of the sea. Changes in energy levels were also observed to be related to phases of the moon and used to time heavy manual labour.

Context is an important issue. There are no fixed borders in Māori astronomy and constellations and their names may change from season to season. At different times of the year stars may symbolize different things. For example, when Māori observed Orion they also observed its position in the sky and its orientation. The same stars could be used over and over again with different names in different contexts and different symbolism. Different *iwi* have their own star names, which indicate different associations that are appropriate in different contexts. Therefore, a star name is likely to be specific not only to a certain season or related activity, but to a specific tribal region. The boundlessness of Māori astronomy and astrology often ties the land and its features together with the celestial ancestors.

It can be inferred that observing the stars was an integral part of the journey to Tekapo to gather up winter supplies. Astronomy was pivotal for Māori navigation and arrival in New Zealand and further research and input from Māori is being sought with regard to building knowledge and information about the importance of astronomy for terrestrial navigation in relation to Te Manahuna. Pauline Harris, an alumna of the University of Canterbury, is currently writing a book on Māori astronomy.

European History and Development

Astronomy was also related to the European arrival in New Zealand. After observing the Transit of Venus in Tahiti, Captain James Cook first came upon New Zealand in 1769 in his quest to find a great southern continent. He mapped what he found and made extensive astronomical observations for determining latitude and longitude. He came three times in all, bringing explorers, astronomers and botanists.

European settlement and high-country pastoral farming commenced in the late 1800s after Europeans became aware of the Te Manahuna area. Europeans named the area after the

Fig. 11.12. Recreation in the Mackenzie. Photograph: Keith Payne

first European to locate it—the folk hero and Scottish Highlander, James Mackenzie (Seumas MacCoinneach in Scottish Gaelic). He was captured in 1855 for being "in the company of a thousand stolen sheep" as he rustled them with his remarkable dog Friday, through a remote alpine pass into "a plain of immense extent".

Tourism was established at Mt Cook village in the late 19th century. The first Hermitage Hotel was "believed to have been a small cob building" (McIntyre, 2007). This was later sold to the Mount Cook–Hermitage Company, which also ran its own coach service between Fairlie and The Hermitage. It took a visitor 3 days to travel from Timaru to Mount Cook. Later exotic game animals, such as chamois and Himalayan tahr, were introduced to attract wealthy hunters. In 1935 an airstrip was built.

One of the few other enterprises in the early history of the Mackenzie Basin was the design of the Hamilton Jet. Hamilton owned a station at Irishman Creek and the first private hydroelectricity was generated on this run from 1927. In the late 1930s he began an experimental engineering workshop there. Despite the difficult logistics of being 40 miles from the nearest railhead and down a road that was often impassable during winter, Hamilton's team proved efficient enough to compete with imported machinery. Loader dozers, scrapers, road graders and other earth-moving machinery were manufactured there. During the Second World War the factory also produced munitions. After the war the factory was relocated to Christchurch and the original premises devoted principally to experiments, producing the first water-jet prototypes in the 1950s, developed by Hamilton to travel up the shallow local rivers.

The Upper Waitaki Hydroelectric Schemes

Production of hydroelectricity has had a major impact on the landscape of the Mackenzie Basin. Construction of the first dam on the Waitaki River was begun in 1928 and the Upper Waitaki Scheme stage one commenced in 1938. By the 1980s the scheme had expanded to five power stations, on Lakes Ohau, Pūkaki and Tekapo, followed by the construction of Lake Ruataniwha. The greatest visual impact may be from the canals which transfer water between the powerhouses and dams, described for tourists as "like turquoise highways—ribbons of blue on the scorched brown earth". The schemes raised the lake levels of Pūkaki, Tekapo and Ohau and have an ongoing impact on river levels. Despite these controls, a large area of the basin will not be developed because it is designated as flood plain. The Upper Waitaki scheme includes Tekapo B, New Zealand's only powerhouse completely surrounded by water, which stands on "floating" concrete foundations because of the depth of clay and ice covering the bedrock 1.6 km below. Engineers met many challenges to complete the interlinked projects in the harsh climate, at high altitude, working with the gravel of the glacial moraines. The earth dams and canals were New Zealand's largest earthmoving project. Lake Pūkaki is New Zealand's largest single controllable storage reservoir and the scheme as a whole contributes to the supply of power to the North Island over the High Voltage Direct Current Link which was the world's largest and longest when it was built in 1965 and includes the world largest submarine cable (popularly known as the Cook Straight Cable). The link runs from Lake Benmore just south of the Aoraki Mackenzie International Dark Sky Reserve to Wellington. All elements were recognised as contributing to New Zealand's engineering heritage by the Institution of Professional Engineers New Zealand (IPENZ) at the time of the sesquicentenary in 1990 (ipenz.org.nz/heritage/).

Although the early construction camps, which might house up to 500 people, were disassembled as work finished, the last settlement was Twizel, which had a maximum population of 6,000. When the last dam was completed in the mid 1980s, residents argued that housing should be retained and Twizel is now a settlement with about 1,000 people whose main purpose is recreation and tourism. Lake Ruataniwha, like the other lakes, is now a major recreational resource in the area, its speciality being competitive rowing.

3. Justification for inscription

3.c Comparative analysis

Aoraki Mackenzie International Dark Sky Reserve is located far away from cities and currently contains only three small village populations of typically less than 1,000 people. There are no World Heritage Sites with which to compare the Aoraki Mackenzie International Dark Sky Reserve. It would be more meaningfully compared with other International Dark Sky Reserves that have been certified by the International Dark-Sky Association (IDA). As at November 2013, Aoraki Mackenzie is one of just two International Dark Sky Reserves to receive a Gold Tier award, the highest designation possible. The other is NambiRand Nature Reserve in Namibia. Three International Dark Sky Reserves have been designated at the Silver level: Mont-Mégantic in Canada, and Exmoor National Park and the Brecon Beacons National Park in the United Kingdom.

Minimal light pollution—a naturally dark sky combined with human efforts to reduce lighting in its three small villages—makes the Mackenzie a premier location for viewing the stars. Mt John University Observatory has good accessibility (SH 8) and good weather with 68% of nights being useable for astronomical observations including phenomena such as the Magellanic Clouds. It is home to the southernmost observatory in the world apart from the ones at the South Pole. Aoraki Mackenzie International Dark Sky Reserve is a superlative location for stargazing.

3.d Integrity and/or authenticity

Authenticity

The authenticity of the Cultural Heritage of Aoraki Mackenzie International Dark Sky Reserve is upheld in the official documents of the Mackenzie District Council as well as the Treaty of Waitangi Settlement between the Government of New Zealand and the Ngāi Tahu *iwi* of the South Island of New Zealand. Tōpuni status (official statement of cultural value) is given to Aoraki/Mt Cook as the ancestor of Ngāi Tahu Whānui and as the spiritual link between this community and its environment. Māori cultural history embedded in the landscape as names and genealogical heritage is recorded in written form by the Mackenzie District Council District Plan (2004) and is presented to visitors in the area at the Aoraki/ Mount Cook Visitor Centre, the Lake Pukaki Information Kiosk and Te Ana Ngāi Tahu Rock Art Centre at the Timaru Visitor Information Centre. The history of Pākehā, as European settlers in the area and their relationship with the land, is also profiled at these venues through their involvement in the arts, the mountains and farming and with their technological inventions and innovations. There is also an extensive collection of farming and domestic artefacts and buildings at the local museum in Fairlie.

Integrity

The first ICOMOS/IAU Thematic Study views authenticity of use as a key issue for consideration. Scientific use of the Mt John University Observatory and the general public's relationship with both the daytime and night-time skyscape of Aoraki Mackenzie International Dark Sky Reserve mixes both natural and cultural elements. Integrity relates both to the physical features of the site, and to the site's uses. The integrity of the significant geological and biodiversity features of Aoraki Mackenzie International Dark Sky Reserve are protected and managed as a result of the requirements of the *Mackenzie District Council Plan Change 13* and all development must meet the criteria of the regional environmental agency (Environment Canterbury) and the Resource Management Act.

3.a Potential criteria under which inscription might be proposed

Criterion (iii): Te Manahuna (the Mackenzie Basin) is the gateway to Aoraki, ancestor of Ngāi Tahu Whānui and the highest peak in New Zealand and contains ancestral pathways, identity, knowledge and food resources for local Māori associated with the Rūnangas (Māori governance areas related to tribal sub-groups) of Arowhenua, Waihao and Moeraki.

Meanings woven around land and sky are vibrant within their cultural traditions. Contemporary research as well as inclusion of the area within management plans and the presentation to visitors of information about local cultural significance such as Aoraki/Mt Cook or the rock art sites also contribute to the cultural revitalization of Ngāi Tahu Whānui (combined South Island tribal sub-groups) as individuals and as a collective.

Criterion (vi): The Mackenzie Basin is a broad and spacious vista for the powerful physical and spiritual presence of Aoraki/Mt Cook. The beauty of the area impacts on those who live there, those who visit there and those who return time and time again.

Criterion (vii): The openness and extensiveness of the landscape is exceptionally beautiful with an immense expanse of starry night sky. The dark night sky values are enhanced by cultural meanings and remarkable natural attributes. The International Dark Sky Reserve site has multiple layers of importance that when combined together form a compelling argument where astronomy is just one aspect of the significance of this area.

Criterion (viii): in a recent presentation to a High Country Symposium in Twizel, Dr Les Molloy, an expert on natural World Heritage, included a discussion on the heritage values of the Mackenzie Basin, with reference to Te Wāhipounamu World Heritage Site and the possible relationship between the two. The Te Wāhipounamu Nomination contends "the only limitation to the integrity of the Pleistocene imprint is the absence of the glacial outwash basins and large lakes along the eastern margin" of the site (Department of Conservation 1989, p. 57). Such an area along the eastern margin of the existing World Heritage Site would include Lakes Pūkaki and Tekapo with their distinctive Tasman and Godley braided riverbeds respectively. This would complete the representation of the impact of the Pleistocene epoch included as contributing to the superlative natural features of the Te Wāhipounamu site. To date, the Department of Conservation has not considered that the International Dark Sky Reserve area could be formally included in the existing Te Wāhipounamu site, which is a pristine natural environment. However, if the continuity of the cultural aspects of the landscape were given more weight in relation to the landscape and biodiversity values, an extension of Te Wāhipounamu to include the Aoraki Mackenzie International Dark Sky Reserve should be discussed with the Department of Conservation (DOC). Aoraki/Mt Cook National Park is included in the extended buffer zone to the Reserve. Regardless of the final tenure and conservation status of the International Dark Sky Reserve, the relationship between the outstanding geological and geomorphic features that exist within the Reserve site to those features recognised in the Te Wāhipounamu site will be emphasized.

The Te Wāhipounamu World Heritage Site Nomination argues that the glacial lakes of Tekapo and Pūkaki and their surrounding tussock grassland landscapes "act as a scenic access way or visual corridor, allowing the visitor to place the mountains beyond in their true perspective and scale". This argument can also be applied to the night sky. The vast open landscape surrounded by mountains in all directions that characterises this intermontane basin provides perspective and a "scenic access way" to the night sky for those stargazing from the top of Mt John or the basin floor. Likewise, clear pollutant-free days and night skies provide a simple and outstanding backdrop for the geological features of the Basin.

Combining these two important natural features of geology and pristine dark skies opens the door for additional educational or tourism-based activities operating from the site. There is no reason for tourist activities to stop when the sun goes down. Stargazing provides locals and tourists alike an opportunity to appreciate and interpret the geology of the land in a night-time context. The day-time, dusk and night-time tours that Earth & Sky (www.earthandskynz.co.nz) currently operate at Tekapo are well positioned to educate visitors about the geological history of the area. Big Sky Stargazing night-time tours do the same for visitors to Mt Cook Village. Other groups operate in the area using smaller or no telescopes.

Criterion (x): Owing to the global rarity of braided river habitat it could be argued that the International Dark Sky Reserve site has international significance and value from the point of view of conservation. A focus on the nocturnal wildlife of Aoraki Mackenzie International Dark Sky Reserve links the quality of the dark night sky with the ecological integrity and conservation of the natural environment for the purposes of World Heritage Status. Currently, there needs to be more information gathered about the Mackenzie Basin's nocturnal species. The current Outdoor Lighting Restrictions in place to preserve the clarity of the night sky provide an unintentional conservation tool. Potentially, sustainable tourism activities could combine stargazing with walking tours of night-time habitats of nocturnal species (dependent on the type of nocturnal species inhabiting the area and the appropriateness and feasibility of viewing these species in their natural habitat). Incorporating stargazing with conservation would firmly establish Tekapo and the Mackenzie Basin as a Starlight Destination, where people not only come to learn about the night sky and the nocturnal landscape, but also the unique and special biodiversity of the Mackenzie Basin.

3.b Suggested statement of outstanding universal value

Aoraki Mackenzie International Dark Sky Reserve has multiple layers of importance. Natural and cultural heritage values embedded in this area enhance the pristine, dark sky and remarkable astronomical attributes. There is a wealth of scientific knowledge available from the University of Canterbury Mount John Observatory staff. Specific details of the astronomical value and scientific importance of the observatory site are relevant for incorporation as yet another layer of significance.

Aoraki Mackenzie International Dark Sky Reserve is a mixed site that represents astronomical, natural and cultural heritage values as well as being a human-inhabited Starlight Oasis. This type of site can also be considered a "Window to the Universe" where pristine starlit conditions combine with an observatory site protected by outdoor lighting restrictions to create a dark-sky area – in other words a "Night Cultural Landscape".

Fig. 11.13. Visitors in the Astro Café, Mt John, Tekapo. Photograph: Fraser Gunn

4. Factors affecting the property

4.a Present state of conservation

Aoraki Mackenzie International Dark Sky Reserve is a human-inhabited Starlight Oasis where the dark-sky values are protected by quality outdoor lighting systems. Regulation of land use that could impact on the biodiversity and geology of the area is part of ongoing negotiation involving the Regional Council (Environment Canterbury), the Mackenzie District Council and the local community.

The quality of the night sky has been well documented from records at Mt John University Observatory since the 1960s. Useful observation hours amount to an average of 1,600 in any one year at Mt John where photometric, partly photometric and spectroscopic hours are included. Light pollution is comparable to the unpolluted night sky with measurements for sky brightness around 21.6 magnitude per arc-second squared or a Bortle Scale of 2. Recent measurements using Sky Quality Meters were taken for the International Dark Sky application in the core areas and some parts of the buffer zone. Water vapour in the air in the Tekapo area is lower than the New Zealand national average, which is ideal for stargazing. There appear to be no quantitative data on dust in the air in the Mackenzie partly because it is not a problem. Dust issues are brief episodes such as an occasional north-west wind bringing dust down river valleys. Data on general air transparency can be derived from measurements formerly taken at Mt John when photometric programmes were running. The changing brightness and colours of variable stars were measured and the amount of light absorbed by the air in the different colours was calibrated. The results showed that the air at Mt John University Observatory is much clearer than at many northern hemisphere sites. Being able to see distant mountains in daylight is a simpler way of quantifying air transparency and this is one of the exceptional qualities of the Aoraki Mackenzie International Dark Sky Reserve. New land developments generate dust when there is a gale blowing, but as these areas are soon grassed they do not present an ongoing problem. Some ploughing is done on small areas for growing silage; however, dust is rarely a problem from them. Smoke from burn-offs can hang around for a few days but is generally too low to affect the night sky. On the other hand, smoke from Australian bush fires can be a serious problem for a few days and there was a particularly long episode in January 2007. Radio-electric interference tests show no interference with equipment at Mt John. There are three Vodafone antennae, a National Radio FM repeater and an (undocumented) Port FM repeater in the Mackenzie Basin. A radio-noise survey at the bottom of Mt John, near the Godley Peaks gate, showed little noise there. According to the Superintendent at the Mt John University Observatory, Alan Gilmore (meeting with one of the authors in January 2011), there is no significant effect on the night sky at Tekapo from the above factors and there is no reason for him to mitigate or manage any issues with regard to them.

The second core, at Mt Cook Airport, is cut off from Mt Cook Village by the nearby mountains and there is no local development using lighting at night (see Fig. 11.3).

4.b.i Developmental pressures

Land in the Mackenzie Basin is largely crown-owned leasehold or privately owned, so that protection and management of flora and fauna are largely out of the hands of the Department of Conservation (DOC). The Mackenzie Basin's indigenous flora and fauna have suffered significantly from human-related activities and the presence of introduced species of fauna and flora such as wilding pines. The scattered Conservation Areas are managed by the DOC, and a Drylands Park is proposed by sectors of the public who seek to protect this flora and fauna. Crown land is currently subject to a tenure review process that will affect ownership and the management of the Mackenzie Basin. Despite these developments, landowners will continue to be bound by the Lighting Ordinances of the Mackenzie District Council and the conditions of the Resource Management Act. Consequently, change of ownership is unlikely to affect a Reserve based solely on the dark-sky values of the area nor the distinctive beauty of the area.

In 2007, the Mackenzie District Council introduced a change to their 2004 District Plan: *Plan Change 13, Rural Zone – Mackenzie Basin*. Submissions were called for and heard from interest and farming groups since District Plans are one of the key tools for enforcing the Resource Management Act. The outcome of the proposed Plan Change 13 has significant implications for the protection and management of the International Dark Sky Reserve site. In December 2011, an interim decision was made in the Environment Court by Judge Jon Jackson that favoured greater recognition of conservation and the "outstanding natural landscape" of the Mackenzie Basin and protection of the area for future generations (High Country Rosehip Orchards Ltd v Mackenzie District Council, NZEnvC 387, 12 December 2011). The judge was also concerned that the responsibility for conservation and management of the Mackenzie Basin should not fall solely upon the farmers concerned and that ways to share the costs of conservation management with the wider public needed to be addressed. A definitive judgement will eventually be made.

4.b.ii Environmental pressures

The Mackenzie Basin experiences extremes of weather, has relatively poor soils, and is under pressure from introduced species, all of which create considerable challenges to management. It is claimed that pastoral farming techniques require considerable local knowledge and that these are continuing to improve. Environment Canterbury's *Canterbury Regional Environment Report* (2008: 104) states: "There has been a net decrease in bare ground in the Mackenzie Basin between 1994 and 2002." Farming techniques are affected by economic factors as, historically, farm incomes have not always been sufficient to ensure that what has been understood to be best practice can be achieved. For instance, the 1990s saw pressure from rabbit populations explode at a time when prices for fine wool were low. This pressure was relieved by the introduction of Rabbit Calicivirus (RCD), but other challenges may arise in the future. Rabbit numbers are increasing rapidly, as the influence of RCD becomes attenuated. Hawkweed (chiefly *Hieracium pilosella*) is widespread on the lower and drier areas. This introduced weed can restrict the growth of indigenous species. The Parliamentary Commissioner for the Environment's report *Change in the High Country* (2009: 26) describes the high country as follows:

> The high country climate is harsh and unpredictable with long winters and dry summers. Growing seasons are short, frost frequency is high in all seasons, and temperature constraints increase significantly with altitude. Precipitation is high close to the Main Divide, but in the alpine rain shadow to the east the land becomes increasingly arid. Pristine high country headwaters feed the East Coast rivers that power major hydroelectric schemes in the Clutha and Waitaki catchments, and irrigate the lowland plains.

The recent Environment Court decision relating to the Mackenzie District Council's Plan Change 13 notes that wilding pines are currently a major challenge to the environment and that climate change policy (The Climate Change Response Act 2002) has the potential to impact the environment through encouraging tree planting within the Basin.

In general, the impact of climate change as outlined by the Parliamentary Commissioner for the Environment will require ongoing attention (2009: 31):

> Climatic change over the next several decades is projected to increase the contrast between the conditions along the main divide and those on the eastern hill and high country in the alpine rain shadow. Higher rainfall is predicted for the west and the alpine zone, with drier and more drought-prone conditions to the east. The snowline is predicted to rise, and wind and rainfall events to become more intense.

Agricultural intensification to maintain farm income is likely to impact on water quality within the Basin, and though the quality is currently high, there is potential for this to deteriorate. DOC has noted that fertiliser use around Lake Alexandrina is the lake's greatest management issue.

4.b.iii Natural disasters and risk preparedness

The Mackenzie District Civil Defence Emergency Management Local Arrangements 2005 (Mackenzie District Council 2005: 4–5) identify the higher priority hazards as follows.

- Earthquakes – from the Alpine fault line.
- Floods – extremely heavy rainfall can be expected which may block local streams.
- Cyclonic storms are experienced from time to time. The highest recorded wind speed in NZ of 250 km/h (155 mph) was recorded on top of Mt John.
- Snowfalls: "Heavy snowfalls from time to time cause disruptions to telephones, power supply, road traffic and can cause the isolation of townships for several days. While there is seldom any risk to human life, people may need to be rescued from stranded vehicles or from back country stations."

The Mackenzie District Council is a member of the Canterbury Civil Defence Emergency Management (CDEM) Group established under the Civil Defence Emergency Management Act 2002. Its own resources will be supplemented by those of other organisations. Aoraki/Mt Cook Village and the Glentanner area have their own Emergency Response Plan because of their isolation and vulnerability to extreme weather. Emergency headquarters will be set up in Fairlie, with Twizel also hosting a Community Welfare centre. The key local response will come from the Police, Fire Brigade and St John Ambulance. There is no local hospital. The local volunteer Fire Brigades in Fairlie, Lake Tekapo and Twizel are all trained in Basic Rescue and will help with emergencies as required. National Urban Search and Rescue (USAR) Resources will be provided through the Canterbury CDEM team.

4.b.iv Visitor/tourism pressures

The Mackenzie attracted more than 450,000 visitors in 2010 and provided employment for approximately 30% of the population there. 300,000 people visit Mt Cook Village per annum. Approximately two thirds of these are international visitors. Accommodation at Lake Tekapo includes backpackers, farmsteads, homesteads and holiday homes, motels and hotels. The Mackenzie District Council has information on its website for campers with their Independent Overnight Camping Guide (www.mackenzie.govt.nz/Site/A-Z/A-C/Camping.aspx).

Mt Cook village has lodges, motels, chalets, holiday parks and backpackers and the Hermitage Hotel (which organises Big Sky Stargazing tours for its guests and others). Astro-tourism is enjoyed by close to 20,000 people per annum, with possibly twice as many missing a planned trip because of poor weather.

According to Phil Brownie, then manager of the Mackenzie District Tourism and Development Trust, meeting with one of the authors in January 2011, approximately 30% of visitors to Lake Tekapo are aware of the extraordinary opportunities for stargazing in the area. The Japanese market is already well established: a survey conducted in Japan by Air New Zealand showed that 72% of people listed stargazing as the main reason they wanted to visit New Zealand. Lake Tekapo is situated about tenth or eleventh in terms of visitor numbers to New Zealand locations.

4.b.v No. of inhabitants

Approximately 1,900 inhabitants live permanently within the Aoraki Mackenzie International Dark Sky Reserve area, consisting of around 500 in Lake Tekapo, 150 in Mt Cook Village and 1,000 in Twizel with the remainder in the outlying areas. The population fluctuates with the seasonal occupation of holiday homes, tourist-busy periods and related temporary-job, short-term residents working in hospitality (data from Statistics New Zealand, Population by Territory [apps.nowwhere.com.au/ StatsNZ/Maps/default.aspx], retrieved 10/01/2012).

5. Protection and management

5.a Ownership

The Mt John University Observatory core is located on 23.8 hectares of Crown land leased from the Government by the University of Canterbury. This lease is for 33 years and was renewed on Jan. 1 1997. It includes the summit of Mt John, the private access road maintained by the University of Canterbury, which must provide day-time access to Mount John (as stipulated in the lease), plus a small grassed area at the bottom of the road where the Mt John road meets the Godley Peaks Road. This latter road is a public highway leading to Glenmore and Godley Peaks sheep stations. The land surrounding Mt John is freehold and belongs to Mt John Station.

The second core at Mt Cook Airport is located within the Aoraki/Mt Cook National Park and is on land administered by DOC as the local airport and subject to restrictions on its use related to this function.

The vast majority of land situated in the Buffer Zone of the Aoraki Mackenzie International Dark Sky Reserve is or was once in Crown Pastoral Leases. This land has been leased to run holders by the Crown for pastoral grazing since the 1850s. Leases have been for 33 years with a perpetual right of renewal. Since 1998 individual run holders have been able to enter into a Tenure Review process initiated by the Crown Pastoral Land Act 1998, which allows them to gain freehold title to areas of productive land leased from the Crown. The remaining land not converted to private ownership is usually transferred to the Department of Conservation for management. Under the pastoral lease system, run holders have been relatively restricted in the type of agricultural and development activities they can undertake on the land. This has resulted in the general appearance of the landscape remaining relatively unchanged for the past 150 years or so. As run holders gain private ownership of land via Tenure Review, they are free to undertake a much wider range of activities. Tenure review has resulted in some changes to the Mackenzie Basin landscape over the last ten years, especially in the south of the Mackenzie Basin away from the Reserve area. Changes are related to factors such as the availability of irrigation water as well as land tenure and are controlled by the Resource Management Act.

There are approximately 38 pastoral leases in the Aoraki Mackenzie International Dark Sky Reserve area. Some are not in the review process, some are in the consulting phase and some have completed the entire Tenure Review (eight properties). Approximately 80% of the properties have been or will be converted from Crown ownership to a mixture of private ownership and conservation land in the near future.

5.b Protective designation

Mackenzie District Council District Plan 2004, section 12, Signs and Outdoor Lighting

The Mackenzie District Lighting Ordinance (www.mackenzie.govt.nz/includes/download.aspx?ID=118114), first enacted in 1981 in the District Plan of that year and included under the Town and Country Planning Act 1977 (which it is now part of the Resource Management Act 1991). It is the legal document that protects the Mackenzie Basin from light pollution.

Mackenzie District Council District Plan 2004, Plan Change 13, 2007

This document was a response to the Resource Management Act 1991 (RMA) giving local authorities more governance in the sustainable management of regional resources and the designation of what constitutes permissible activities and developments. The primary purpose was to protect the basin from "inappropriate subdivision, development and use". It was also a response to increased development activities in the Mackenzie Basin over the previous five years and was instituted to protect the landscape values of the area.

5.c Means of implementing protective measures

Resource Management Act 1991 (2011) (RMA)

Under the RMA, environmental management is centred on concepts of sustainable and integrated management of resources. Environmental management is mainly achieved through the statement of overall goals in the Act itself, the establishment of a hierarchy of policy statements and plans, the granting of resource consents and the provision of mechanisms for enforcement.

At a regional level, policy statements are compulsory and regional plans are optional, with the exception of a regional coastal plan. District plans must be prepared at a territorial authority level. District plans are generally required to be 'not inconsistent' with regional plans, district and regional plans are required to 'give effect to' regional policy statements, and all these documents are in turn required to 'give effect to' national policy statements. This helps to promote consistency and integration.

The RMA focuses on managing the effects of activities rather than regulating the activities themselves. The RMA adopts an enabling approach that seeks only to intervene where activities are likely to result in unacceptable environmental impacts. This approach has the advantage of focusing on the reduction of environmental impacts.

The overriding purpose of the RMA is ‘to promote the sustainable management of natural and physical resources’. This is defined in section 5(2) as meaning

> managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while
>
> a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations;
>
> b) safeguarding the life-supporting capacity of air, water, soil and ecosystems; and
>
> c) avoiding, remedying or mitigating any adverse effects on the environment.

The conservation land within the buffer zone is managed by the Department of Conservation (DOC), which manages approximately one third of the land in New Zealand, as well as marine reserves, on behalf of all New Zealanders. The Conservation Act 1987, the National Parks Act 1980 and the Reserves Act 1977 set out how DOC should look after this land, water, and vegetation, and the living things that inhabit it. In a manner similar to that prescribed under the RMA, the Conservation Act provides a framework of management policies, strategies and plans for the management of Conservation Land.

Canterbury Conservancy has a management strategy that lists all the reserves and farm parks etc. for which it is responsible and the specific issues that DOC must attend to in each area. National Parks have individual management plans. The Waitaki area covers the area relevant to the Aoraki Mackenzie International Dark Sky Reserve. The Department also prepares other plans that cover specific functions, such as pest management and recreation and public awareness strategies.

5.d Existing Plans

Currently there is no single property management plan for land other than that managed by the Department of Conservation, which has individual plans for its large holdings such as National Parks or Farm Parks and a district-wide conservancy plan which covers smaller areas. Environment Canterbury has a number of relevant plans on landscape values and water quality, has a Biodiversity Strategy for the Canterbury Region, and is generally responsible for monitoring its achievements in relation to these plans. Outcomes are reported through a series of Canterbury Regional Environment Reports, the latest of which came out in 2008. Outcomes are also reported annually. These plans and reports comment specifically on the Mackenzie Basin where relevant.

5.e Property Management Plan

The two Core Zones of the Aoraki Mackenzie International Dark Sky Reserve, Mt John and Mt Cook Airport, are managed in accordance with the requirements of the *Starlight Reserve: Concept, Dimensions, Categories, Criteria, Recommendations* (Marín and Orlando 2009) as an exclusion zone—an area untouched by light pollution where the natural conditions of the night sky are intact. Mt John is heavily protected with no artificial outdoor lighting. The Mt Cook Airport Core Zone only operates during the day as an airport. There is no outdoor lighting at night although it is accessed at night for stargazing tourists by Big Sky Stargazing Tours. The Buffer Zone for the Aoraki Mackenzie International Dark Sky Reserve includes the whole of the Outdoor Lighting Restriction Area and Aoraki/Mt Cook National Park as demonstrated in Fig. 11.4. The Starlight Reserve Concept document calls this area an external zone and defines it as “an area where existing larger human settlements or activities could negatively impact on the night sky quality of the Reserve”. Within the Aoraki Mackenzie International Dark Sky Reserve this wider area is included in the Buffer Zone. The Reserve thus combines the requirements of the *Operational Guidelines* with the requirements of the Starlight Reserve Initiative.

In relation to the natural heritage values of geology and biodiversity, the Department of Conservation Commercial Business Unit was set up in Feb 2010 to foster conservation values through partnerships with the business community. Most of the current partnerships involve funding of specific conservation projects for rare species and regional plans for encouraging the use of conservation land, both of which are consistent with the promotion of an International Dark Sky Reserve. As well as working with eco-tourism operators, DOC has worked with private landowners and expects such partnerships to increase employment and income within specific communities, as well as spreading conservation values among users of the conservation estate. Along with involvement of new people in management DOC expects “benefit from the different ideas and initiatives likely to come from interactions with the commercial sector”. There is potential here for the development of partnerships with landowners in the The Aoraki Mackenzie International Dark Sky Reserve area.

However, if a new category of World Heritage is proposed that recognises the natural heritage of the night sky and night-time landscapes, then it is possible that the issues around other natural heritage values would become less of a challenge, especially if zones drew upon the current guidelines for Starlight Reserves, set out in the various starlight reserve concept documents. Zoning then hinges upon delineated areas that protect night-time light conditions, supported by appropriate areas of intelligent lighting and outdoor lighting restrictions.

5.f Sources and levels of finance

Current funding from various sources is devoted to protection of the night sky and is adequate to continue protection of the two core areas. There is currently no funding set aside to manage a Starlight Reserve in the buffer zone, but other types of funding are available which will ensure that current levels of night-sky darkness continue in the short term. Increased protection of the night sky through international certification should ensure increased attention to this issue and targeted funding.

5.g Sources of expertise and training

Currently, training for management of the night sky is available from the University of Canterbury. Training in management of landscape is available from Lincoln University, which offers a Bachelor of Landscape Architecture and several postgraduate degrees and diplomas. DOC employs staff members who are specialists in conservation management. Other expertise in management of both the cultural and biophysical aspects of the reserve concept is available from the universities, *wananga* (predominantly Māori Further Education Institutes), and Crown Research Institutes. Local government organisations also employ specialists in management of cultural and biophysical resources in order to prepare management plans and to monitor management of resources.

5.h Visitor facilities and infrastructure

International tourists to the Mackenzie Basin originate mainly from Australia, North America, the United Kingdom, Europe and Asia. The average length of time people stay is 1.32 nights and there are approximately 2,400 accommodation beds. Of the 300,000 people who visit Mt Cook Village annually, about one third stay overnight. Mt Cook Village can sleep 600 people. Different types of accommodation are available including lodges, motels, chalets, hotels, holiday parks and backpackers that cater for all accommodation demands and price ranges. Five restaurants in the Mt Cook area cater for a variety of tastes and budgets. There are three main points of information for tourists about the area, at the Aoraki/Mt Cook Visitor Centre, the Lake Pukaki Information Kiosk and Te Ana Ngāi Tahu Rock Art Centre at the Timaru Visitor Information Centre.

5.i Presentation and promotion policies

The Aoraki Mackenzie International Dark Sky Reserve Board, which includes representatives of tourism organisations, confirms that the number of visitors to the area with an interest in the dark sky has increased since the reserve was established in June 2012. Interest is sufficient for plans to be developed to manage pressure on the Mt John visitor facilities with a purpose-built facility in Tekapo with its own telescope.

During the preparation of the application for reserve status, the Aoraki Mackenzie Starlight Working Party collected letters of support for the International Dark Sky Association application from heads of local enterprises such as Genesis Energy and key tourism figures. The supporters included former Prime Ministers and the current Prime Minister John Key also supported the Working Party’s activities. The Chief Executive of the Christchurch International Airport noted that the airport was not only known as New Zealand’s Tourism Gateway to the South Island but was becoming known as the “Gateway to the Stars”.

The protection of the night sky was spontaneously supported by residents at the Lake Tekapo meeting to discuss the future of the area as part of the consultation for the Mackenzie District’s Long Term Community Plan in November 2005. When asked how the existing vision could be enhanced, protection of the night sky was mentioned more often than any other additional element.

In relation to commercial promotion, there are currently two commercial businesses operating within the Aoraki Mackenzie International Dark Sky Reserve that offer extended opportunities for the public to familiarize and educate themselves about the night sky:

- *Big Sky Stargazing* (www.hermitage.co.nz/en/the-sir-edmund-hillary-alpine-centre/big-sky-stargazing) offers educational and public outreach to inform visitors about the night sky with a well established planetarium facility located in the Sir Edmund Hillary Centre at Aoraki/Mt Cook. Digital experiences include “Infinity Express” (pictured), “Space Traveller”, “Black Holes” and other dark-sky digital experiences prior to going ‘out into the field’ with the telescope at the Aoraki/Mt Cook airport observatory.
- *Earth & Sky* (www.earthandskynz.co.nz) based at Tekapo township offer guided day or evening tours for the public to the Mt John University Observatory. The day-time, dusk and night-time tours operated by Earth & Sky are well positioned to educate visitors about the geological history of the area. This fits in well with the education and public outreach priorities of Earth & Sky and with the World Heritage Committee’s goal to educate and raise awareness of World Heritage by involving schools, universities and other local and national education providers.

Other businesses assist tourists wishing to view the night sky on a more informal basis.

5.j Staffing levels and expertise

No staff are engaged in full time administration and promotion of the International Dark Sky Reserve at present.

Fig. 11.14. Digital Dome Planetarium at the Sir Edmund Hillary Centre.
Photograph courtesy of The Hermitage, Aoraki/Mt Cook

Fig. 11.15. View from Mt John with Lake Alexandrina and Lake Tekapo in the background.
Photograph: Fraser Gunn

6. Monitoring

6.a Key indicators for measuring state of conservation

Monitoring is currently carried out by Environment Canterbury as part of its ongoing programmes to maintain or improve the resources within the Canterbury Region and through its approval and monitoring of resource consents. Monitoring occurs around their key areas:

- Air quality
- Coastal environment
- Democratic process
- Energy
- Emergency management
- Hazards
- Land
- Navigation safety
- Pests and biosecurity
- Public passenger transport

- Regional land transport
- Waste, hazardous substances and contaminated sites
- Water quality, quantity and aquatic biodiversity.

The areas most relevant to the Mackenzie Basin are the Regional Pest Management Strategy and Biodiversity Strategy. Water quality is generally good in the large lakes and waterways but will become more important as farming intensifies. Many of the monitoring staff are employed to identify hazards, but can also provide technical information and advice in the areas identified above. The goal of the Environmental Quality and Hazards Section is to be

> "involved in monitoring Canterbury's environment in these areas and in making that information available in a way that can contribute to the maintenance and enhancement of environmental quality … The section carries out both long-term monitoring programmes, designed for such things as identifying the current state of the environment and any trends that may be occurring, and shorter-term investigations relating to specific environmental quality issues."

Monitoring is carried out in conjunction with:

- Other territorial local authorities
- Crown research institutes
- Government departments such as DOC
- Tangata Whenua (Ngāi Tahu and local *runanga*)
- Non-government agencies such as the Queen Elizabeth II Trust, NZ Landcare Trust, Forest and Bird (www.forestandbird.org.nz/), Fish and Game, and Federated Farmers
- Other local organisations such as Landcare groups
- Individual landowners.

6.b Administrative arrangements

The Mackenzie District Council and the Department of Conservation have overall responsibility for the District as outlined in the Case Study. The current Superintendent of the Mt John University Observatory has agreed to undertake management of the Aoraki Mackenzie International Dark Sky Reserve.

6.c Results of previous reporting exercises

The main documentation providing an inventory comprises:

- DOC conservancy and national park management plans;
- Environment Canterbury's various plans and reports;
- The Ngāi Tahu environmental management plans for Canterbury and Otago:
  - Kāi Tahu Ki Otago, *Natural Resource Management Plan 2005* (which specifically mentions the dark sky as a value that could be preserved through planning),
  - Te Whakatau Kaupapa, *Resource Management Strategy for Canterbury – Part A*,
  - Canterbury Iwi Management Plans.

7. Documentation

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Eastern Alpine and Großmugl starlight areas, Austria

Günther Wuchterl

1. Identification of the property

1.a Country/State Party: Austria

1.b State/Province/Region: Lower Austria, Upper Austria and Styria. The Großmugl Starlight Oasis is within the Korneuburg district, Lower Austria

1.c Name: Eastern Alpine Starlight Reserve / Großmugl Starlight Oasis

1.d Location

EASTERN ALPINE STARLIGHT RESERVE

Elliptical area including Dürrenstein Wilderness Area, Gesäuse National Park and Kalkalpen National Park:

Long axis (approx. W–E): 47° 11′ N, 13° 50′ E to 47° 58′ N, 16° 55′ E
Short axis (approx. N–S): 47° 50′ N, 14° 27′ E to 47° 18′ N, 14° 52′ E

Alternative elliptical area additionally including Nockberge National Park (Carinthia):

Long axis (approx. W–E): 46° 52′ N, 13° 35′ E to 47° 58′ N, 16° 55′ E
Short axis (approx. N–S): 47° 50′ N, 14° 27′ E to 47° 18′ N, 14° 52′ E

GROßMUGL STARLIGHT OASIS

Latitude 48° 29′ 18″ N, longitude 16° 13′ 23″ E, elevation 265m above MSL (Large tumulus)

1.e Maps and Plans

Fig 12.1 shows the general location of the proposed core areas of the Eastern Alpine Starlight Reserve and of the Großmugl Starlight Oasis. Fig 12.2 shows the proposed core zone and buffer zone of the Großmugl Starlight Oasis.

1.f Area of the property and buffer zone

EASTERN ALPINE STARLIGHT RESERVE

Core area:

Total 34,304 ha, comprising

- 20,850 ha (Kalkapen National Park),
- 11,054 ha (Gesäuse National Park), and
- 3,500 ha (Dürrenstein Wilderness Area).

Buffer zone:

~ 19,000 km² (~ 100 × 60 km).
Alternative including Nockberge National Park: ~ 41,000 km² (~ 220 × 60 km).

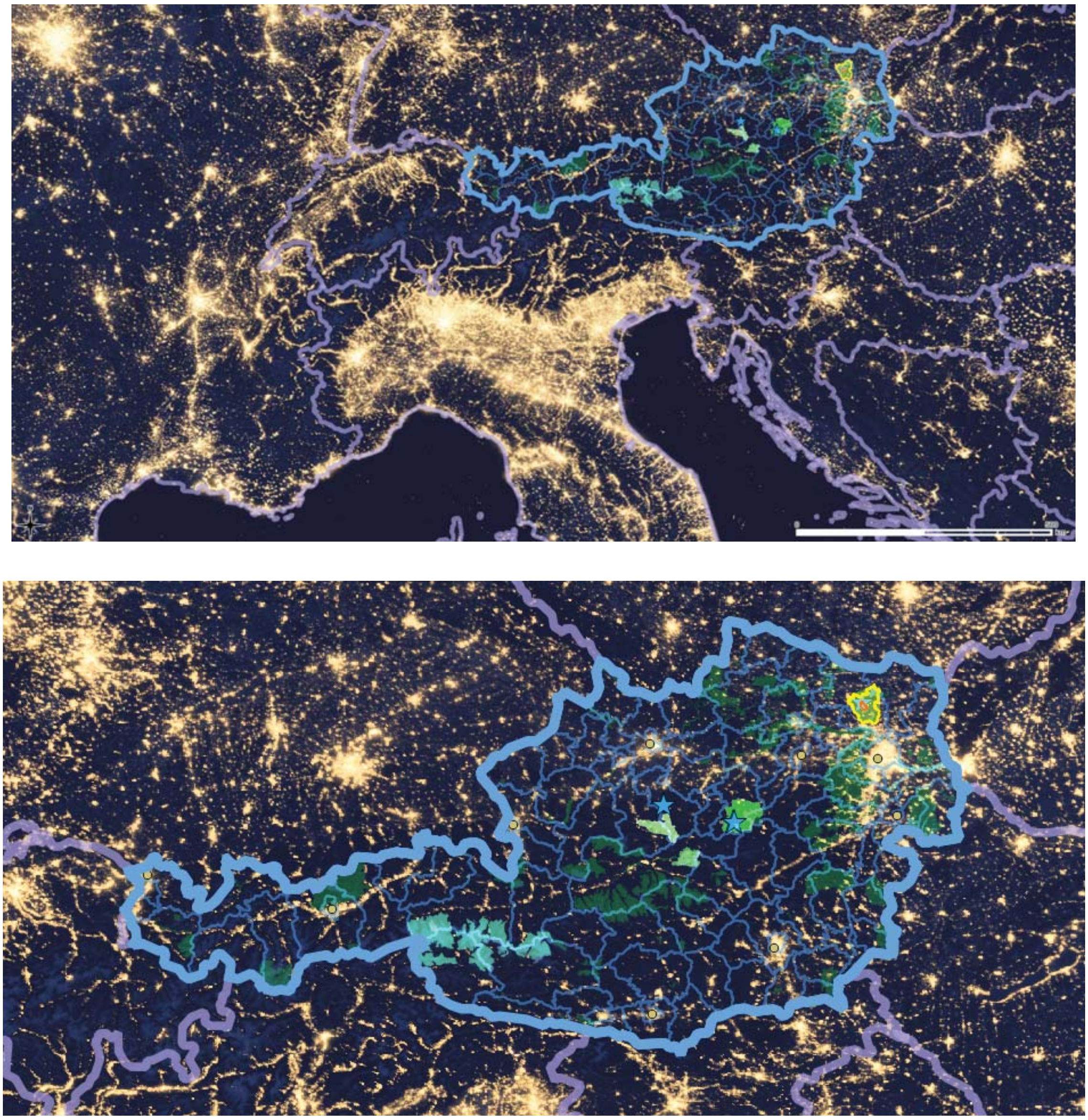

Fig. 12.1: The Alpine Arc and Central Europe at night. **Top:** Upward light from satellite measurements (background image), with state boundaries superimposed in purple, and the Austrian border highlighted in light blue. The bar at the lower right indicates 500 km. **Bottom:** Magnification of the part within Austria. Provincial boundaries are shown in blue. Bright green patches show the proposed Eastern Alpine Starlight Reserve cores and the Großmugl Starlight Oasis (with yellow boundary). Blue-green denotes additional IUCN category I and II protected areas in Austria, while dark green marks selected nature protection areas (for orientation). Blue stars denote light-monitoring stations that were set up for this study. They monitor light levels resulting from light shining downwards onto the sites. Chart and image: G. Wuchterl. Background image: NASA Black Marble

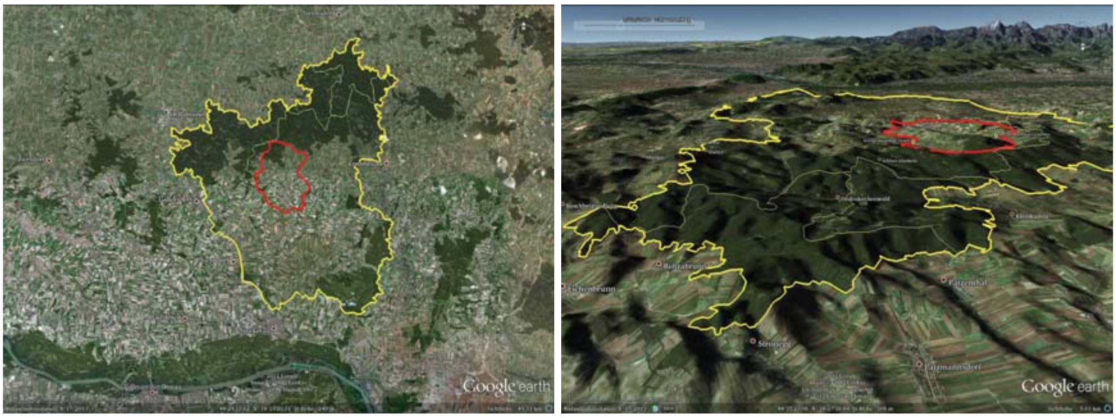

Fig. 12.2: The core-zone (red) and buffer-zone (yellow) of the Großmugl Starlight Oasis. **(Left)** As viewed from overhead. The area shown is about 30 × 40km, 30 km NNW of central Vienna; the Danube is visible at the bottom. **(Right)** As viewed from the north. The Vienna basin is visible at the upper left; the eastern end of the Alps is in the upper right corner.

GROßMUGL STARLIGHT OASIS

- Core area: approx. 25 km²
- Buffer zone: approx. 300 km²

The *core zone* (red line in Fig. 12.2) has a radius of approximately 3km. It covers an area of about 30 × 40km and is situated 30km NNW of central Vienna (the Danube is visible at the bottom of Fig. 12.2 [Left]). It contains some major prehistoric remains—the large tumulus, the Steinabrunn and Linen circular ditched enclosures (Fig. 12.3) —as well as a number of important sky-observing spots and viewpoints.

The *buffer-zone* is an area approximately 10km in radius around the large tumulus at Großmugl. Its border (yellow line in Fig. 12.2) follows the visible landscape horizon, which is largely shaped by the "inner ring" of a natural light protection system created by the topography. In the directions towards the main Alpine chain, where remote high mountains up to 200 km distant may be seen, the horizon is defined by clearly visible mountain peaks. Towards the north and between the south and south-east (the general direction of Vienna) the border follows mountains or ridges. In other directions the buffer zone extends to hill-crests, forests patches and landscape "divides" in order to include the topographical features that shield the area against the influx of light (Fig. 12.2 [Left]; see also Fig. 12.4).

The buffer zone, or high-sensitivity zone, will thus include the nearby area that can be directly seen from the core zone, thereby guaranteeing that the effects of air or light pollution will not affect the core zone (cf. *Starlight Reserve Concept*[1] p. 20). It also protects the wide and unobstructed views towards and above the horizon and, in particular, ensures full access to the celestial hemisphere. This combination provides protection for the entire night-landscape as seen from the tumulus-area and other viewpoints in the core zone.

In sum, the sky-landscape system of the core zone is protected by the buffer zone, which prevents unwanted artificial light intrusion into the site while enabling natural light-flow within it.

1 http://www.starlight2007.net/pdf/StarlightReserve.pdf

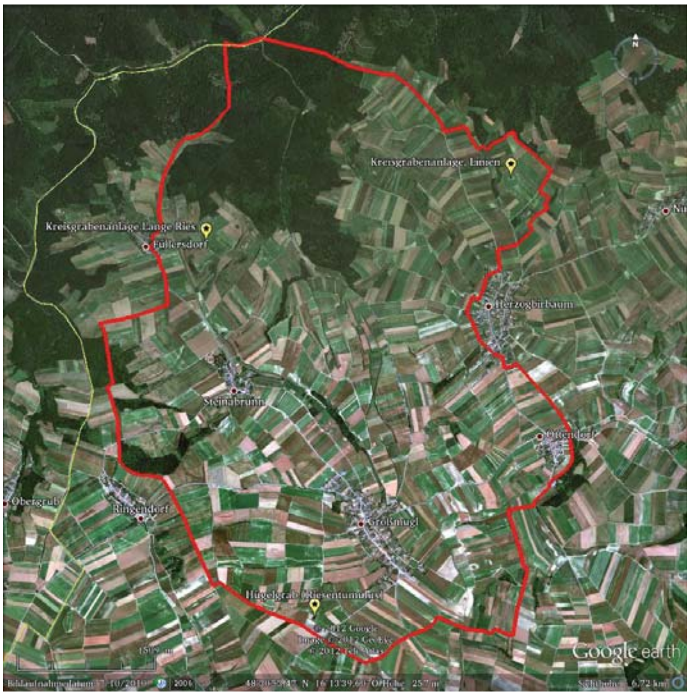

Fig. 12.3: Prehistoric remains (yellow symbols) in the core zone (marked in red) of the Großmugl Starlight Oasis. They include the Großmugl large tumulus (lower centre), the Steinabrunn circular ditch system and the Linen ditch and grave-field.

Fig. 12.4: Bird's eye view (looking south) of the topography at the site that protects the core-zone from the lights of Vienna. The shielding effect against the artificial sky brightening caused by Vienna's lights and light dome can be imagined by looking at the shadows cast by a low morning Sun. The triple hill chains between the core zone (in red) are visible towards the upper left with the Vienna-basin in the corner. Two of the hill-chains are included in the buffer zone that is outlined in yellow. The village of Großmugl is visible in the lower right corner with the large tumulus just above it (yellow marker). The conspicuous mountain in the upper right is the Schneeberg (2076m).

2. Description

2.a Description of the property

EASTERN ALPINE STARLIGHT RESERVE

The iconic landscape of the Alpine range together with its comparatively less known, very wide eastern third form a ~1000 km² area containing natural skies above a unique mountain landscape.

The core-zone of the proposed Eastern Alpine Starlight Reserve is comprised of three of the most secluded areas in the widest part of the Alpine arc, each of which is an IUCN-recognised Austrian nature conservation area. These are:

1. The Wildnisgebiet Dürrenstein (Dürrenstein Wilderness Area) in Lower Austria (IUCN category I), of which the Urwald Rothwald (Rothwald primary forest) (IUCN category Ia) is a component;
2. The Nationalpark Kalkalpen (Kalkalpen National Park) in Upper Austria (IUCN category II); and
3. The Nationalpark Gesäuse (Gesäuse National Park) in Styria (IUCN category II).

Together they span a "starlight triangle" which is readily visible as a central European dark spot on satellite imagery.

GROßMUGL STARLIGHT OASIS

The Großmugl administrative unit (established in 1970) is a community in the hill-lands of Lower Austria's Weinviertel (Wine Quarter) with an area of 64.38 km². It is a rural, agricultural area to the NW of Vienna with a particular elevated-plane topography and villages in depressions. An "archaeological landscape" extends around the large tumulus at its centre (Fig. 12.3). The main prehistoric remains are:

- the large tumulus from the Hallstatt period (lower centre),
- the Steinabrunn circular ditched enclosure belonging to the mid-Neolithic period (upper left), and
- the Linen circular ditched enclosure and grave-field (upper right).

A full inventory of remains is beyond the scope of this case study and necessarily must involve additional archaeological and conservation studies.

The open landscape features wide horizons that allow access to the entire firmament (almost a full hemisphere) with a dependable deep Milky Way sky that guarantees the visibility of the Zodiac and Western stellar constellations. The site is naturally protected against artificial light at night by the particular village-structure and a unique natural light-rejection system, consisting of three hill-chains shielding the sky-landscape-system from the city of Vienna with its centre at a distance of 33 km (see Fig. 12.4).

The core zone and a large proportion of the buffer zone constitute a rural area whose starry sky view forms part of its recognised identity ("Großmugl an der Milchstraße") and values. It comprises a group of ten small villages ("Katastralgemeinden") keeping the night sky reasonably free from atmospheric and light pollution effects by (at least in part) explicitly realising and following the definition of a *Starlight Oasis* in the *Starlight Reserve Concept*, p.13. The ten villages are Füllersdorf, Geitzendorf, Großmugl, Herzogbirbaum, Nursch, Ottendorf, Ringendorf, Roseldorf, Steinabrunn and Schloß Glaswein.

2.b History and development

EASTERN ALPINE STARLIGHT RESERVE[2]

This remote area, where the borders of three provinces meet, has long proved difficult for human access because its mountains and basins are protected by long and narrow access gorges. It was overlooked by the Alpine tourism that began in the Western Alps in the 19th century and by the hydroelectric power development of the 20th century. The Kalkalpen and Gesäuse National Parks and the Dürrenstein Wilderness Area were declared in the 1990s and early 2000s to protect against more recent development pressures.

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[2] This section is prepared on the basis, and largely following the history chapter, of the *Dürrenstein Wildernis* book by the Reserve's present director, Christoph Leditznig, with kind permission of the author. Information on the Kalkalpen National Park is mostly based on sources from the Park Administration with kind permission of its director Erich Mayrhofer.

Within the Kalkalpen National Park area, stone tools (found in the Ramesch cave) show that hunting practices extended as far back as 65,000 BCE, and bone-tools have also been found (e.g. in Losenstein) dating from 18,000–10,000 BCE. From the Late Neolithic onwards, pastoral farming on seasonal high-elevation meadow meadows—"Alms" or "Alps"—became essential in order to sustain the human presence in this area. During the Bronze Age, cattle were driven into the woods for grazing in the Dürrenstein area and pasturage on the high-elevation meadows of the Dürrenstein commenced in the first century BCE. The first written documents relating to Alm-management date back to the 16th century for the Schaumbergalm and Jörgl-Alm, and to 1647 for the Annerl-Alm in the Kalkalpen National Park.

In all three core areas, mining activities drove humans into the most secluded valleys. Copper melting spots are documented in the Gesäuse from 1800 BCE. Metal tools found within the Kalkalpen National Park area demonstrate the use of the natural north-south passes through the Alps by about 1000 BCE. Iron production drove humans towards the most inaccessible woodlands, the limit being set by their ability to extract it using the waterways. Iron-Age activities in the Alps are recognised in the "Hallstatt-Dachstein/Salzkammergut Cultural Landscape" World Heritage Site (whc.unesco.org/en/list/ 806): *ferrum noricum* (Noric steel) was exploited through antiquity.

Population pressure reached a first peak with medieval deforestation, which also progressed deeply into the valleys. The earliest written records, from the monastic period, show that in 1330 just 2700 ha of primary forest remained in the Dürrenstein Wilderness Area (the Habsburgs' endowment to the Carthusians (Karthäuser)), less than 10% of the stipulated area in the modern communities of Gaming, Scheibbs, St. Anton and Lunz am See.

The "Rothwald" primary forest in the Dürrenstein Wilderness was protected into the 19th century by an enduring gridlock between timber harvesting by the Carthusians in Gaming and the "competing" Benedictine Monastery in neighboring Admont, which had been founded in 1074 by the Archbishop of Salzburg at the western entrance of the Gesäuse valley. (Admont Abbey, which includes the largest monastic library hall in the world, is at the centre of the Eastern Alps and forms the core of the settlements around the Gesäuse National Park.) While the Carthusians at Gaming owned the land use rights, the limited capacity of the waterways would, in practice, only permit the transportation of timber across land owned by the Benedictians in Admont. Nonetheless, a settlement between the monasteries of Admont and Gaming in 1689 did allow further exploitation of wood driven by the huge energy demand of the nearby iron production in the "Eisenwurzen" (literally, "root of iron") area. It is estimated that 25% of Europe's iron production at the time came from that region. The Carthausian monastery was secularized in 1782 by a decree of Emperor Josef II. The Rothwald primary forest was reduced to 1520 ha under the following imperial state ownership. Private ownership commenced in 1825, reducing the Rothwald by a further 950 ha.

By 1750 the wood shortage had become so acute that woodcutting started in the most remote valleys. This happened as late as 1765 in the Jörglgraben, now part of the Kalkalpen National Park. Trees there were only harvested once in history and it is suspected that patches of primary forest survived into the present between the "secondary" forest. In 2000 a total of 37 ha of primary forest could be identified.

With the energy-hungry industrialization, wood was harvested on a large scale, driven in particular by the relative proximity, downstream, of the rapidly growing imperial capital, Vienna, and its demand for firewood. Today, Vienna still takes advantage of this proximity: its water supply comes from the Eastern Alpine mountains with two of the three main source areas overlapping with the cores of the starlight reserve.

Just before industry moved to fossil fuel in the 20th century, a new wave of timber exploitation reached the Alps, halted only by inaccessibility and a water system that could not be controlled by late 19th century technology. The "Aktiengesellschaft für Forstindustrie" (a stock company) acquired a large fraction of the forests in the Dürrenstein area in 1865. It introduced log rafting on the Ybbs river to feed a steam-driven sawmill on the Danube. Massive modifications of the Ybbs river were undertaken in order to allow large-scale timber transportation, which left a devastated landscape plagued by landslides and flooding when the company went into bankrupcy in 1875.

These activities overlapped with the opening of the first large-scale conservation area, the Yellowstone National Park, in 1872. After the bankruptcy large pieces of land, including 420 ha of primary forest, remained and were purchased by Albert Rothschild, who already had held a share of the Forstindutrie AG. Now the sole owner, he realized the value of the untouched wilderness and protected the remaining Rothwald primary forest. It is due to him that the Rothwald survived against both the pressures of technology — which now provided possibilities for timber extraction without using the waterways — and the pressures to improve nature as vocalized by the Academia of the time. (They used the primary forest for teaching, as an example of the chaos and decay that will occur without human intervention and improvement.)

In 1935, parts of the forest — which now constitutes some of the Western areas of the Dürrenstein Wilderness — were sold following the "Creditanstalt Crisis", one of the triggers of the global economic crisis. The remaining properties were appropriated in 1938 after the "Anschluß" of Austria to Nazi Germany. Since the Rothschild family had taken over, only 20 ha of primary forest had been lost, after wind damage. The ecological importance of deadwood was not recognized at the time and thus the area had been cleaned out. This also led to the realization that the untouched forest could not resist all forces of nature.

During the Second World War the primary forest was declared a nature conservation area, with somewhat arbitrary zoning. In 1946–47 the properties were returned to the Rothschild family but some parts in the west were traded by Louis Rothschild to what is now the Second Austrian Republic in exchange for pension duties. In 1988, a modern zoning concept was implemented after the inclusion of the Rothwald II area.

The Dürrenstein Wilderness area was founded in 1997, supported by a European Union nature conservation project. Nature conservation is handled by provincial governments, and in May 2001 the government of the State of Lower Austria finalized legal protection. Recognition by the IUCN as a Category Ia Protected Area following two years later.

The Kalkalpen National Park reached its present area after extensions in 2001 and 2003.

In addition to the areas in the Forstverwaltung Langau that are still owned by the Rothschild family, Austrian National Forestry properties on the south-west slopes of the Dürrenstein mountain-massif were added in 2002, yielding a total of 2,400 ha (24 km²) in 2013. Today's size of 3,500 ha was reached in 2014 by including partially protected neighboring areas and placing the whole Wilderness Area under the legal umbrella necessary for the IUCN category I by a new decision of the provincial government.

GROßMUGL STARLIGHT OASIS

Human presence in Austria's Danube area is witnessed by some of humanity's earliest known pieces of art. Probably the most famous of these is the "Venus of Willendorf", estimated to be 27,000 years old, discovered in 1908 near Willendorf, about 64 km south-west of Großmugl.

The region around Großmugl in north-eastern Lower Austria is recognized to be the oldest cultural landscape in Austria with continuous settlement. Abundant finds in the 19th century had already indicated the area's significance for early human history. In 1871, the archaeologist Matthäus Much first reported the tumuli of the Großmugl area, locally known as *Leeberge* ("grave hills").

The fertile hills around Großmugl with their Löß (loess) soils have been a favoured area for settlement since the first farming cultures developed in central Europe during the 6th millennium BCE. Stone tools of all shapes and sizes together with fragments of Linearband-keramik (LBK) pottery have helped identify numerous early Neolithic settlements in Großmugl, Herzogbirbaum and Roseldorf. Farm buildings of the era were huge houses up to c. 35 m long constructed of timber posts. Goats and sheep were domesticated at first, followed by cattle.

New influences from the lower Danube arriving in the early 5th millennium BCE resulted in the appearance of larger village complexes which became foci for smaller settlements. Agriculture and cattle breeding were practised simultaneously: aurochs still constituted a significant proportion of the cattle. Lengyel Culture settlements are documented in Großmugl, Herzogbirbaum and Steinabrunn.

Kreisgrabenanlagen (circular ditched enclosures), which reached their highpoint in the Middle Neolithic, are among the most impressive prehistoric monuments of Central Europe, although their function is still unclear. Almost all of the 40 examples known in Austria are located in Lower Austria's Wine Quarter. One of the most impressive is Lange Ries, about 1300 m to the North of Steinabrunn. Built between 4800 and 4500 BCE, the maximum diameters of its outer and inner ditches are 88 m and 58 m, respectively.

In the Early Bronze Age, 20th to 16th century BCE, a metal-processing centre apparently existed in the Großmugl area. In the Moravian-Lower-Austrian border region, Bronze was predominantly traded in the form of ingot torcs (ring-shaped bars). Two depots have been found in Geitzendorf. More than 61 ingot torcs were discovered in the Geitzendorf fields in 1910, another 39 in 1949 (as well as six arm-spirals), and another in 1979. Further depots surfaced in Senning and Sierndorf, to the south. In Großmugl, four of the typical Hockergräber (crouched burials) of this era were found as well as a ceramic depot and four Siedlungsgruben (settlement pits) belonging to an extended Early Bronze Age settlement. More settlements are known in Füllersdorf, Herzogbirbaum, Steinabrunn and Roseldorf.

In 2008–09 a burial ground was discovered in Geitzendorf. The fifteen graves were classified as belonging to the classical stage BzA2 of the Únětice Culture. One of them contained an archaeological highlight that brought worldwide attention: the first evidence of a female metal worker in the Early Bronze Age. Together with costume and ceramic remains, her grave contained a stone anvil and hammer and flint chisels as used for metal-processing, in particular the fabrication of jewellery.

In the Middle Bronze Age (16th to 14th century BCE) the Hügelgräberkultur (Tumulus Culture) shaped an area from eastern France to western Hungary. The mounds clearly contain elite burials: the grave-goods typically include many heavy arm-rings and elaborate necklaces for women and weaponry such as axes and daggers for men. Many influences are already apparent from the Minoan-Mycenaean cultures of the Aegean and these left traces in Großmugl. In 1966–67, spectacular caches were uncovered featuring a double-handled amphora and other pottery demonstrating the artistic richness of the era.

At the onset of the 13th century BCE a new cultural complex was spreading into Central Europe characterised by their practice of cremating corpses and burying their ashes in urns. Four Urnfield Culture graves discovered near Großmugl in 1939 contained numerous bronzes together with a famous "violin-bow" fibula. There are also numerous finds from the era in Herzogbirbaum and Steinabrunn. Two grape-seeds from the Urnfield Culture period, dated 992–810 BCE, have been found in Stillfried an der March, east of Großmugl in the Wine Quarter. They provide some of the oldest evidence for the cultivation of grape vines in Central Europe. (Today the Wine Quarter, with 14,000 ha of vineyards, is the largest wine-producing region in Austria.)

For Großmugl the most evident and important prehistoric era is the Hallstatt period (Early Iron Age, 8th to 5th century BCE). The largest tumulus from the Hallstatt Culture in Central Europe, 16m in height, is found less than 1 km outside the village, and gives the village its name. It is first mentioned in 1293 as “Grassemugel” (Slavic *krasa* “beautiful” + mogyla “burial mound”). The mound is untouched; it has never been scientifically investigated. Another tumulus 50 m to the NW, much smaller today, is known locally as the “Queen’s Grave”. Excavations between 1950 and 1956 uncovered the remains of a wooden chamber and numerous large ceramic vessels, but their state of conservation rendered scientific studies impossible. Two further flattened tumuli in the immediate vicinity have been identified on aerial photographs.

A number of Hallstatt Culture sites have been found around Großmugl. Excavations in 1938–39 and 1989 to 1994 uncovered large settlement areas at the “Todtenweg” (way of the deaths), including a fireplace and aligned loom-weights that indicate a weaving hut.

Late Iron Age (5th century BCE to 0) settlements of the La Tène (Celtic) Culture are known in Großmugl, Herzogbirbaum and Roseldorf. The "Fürstensitz Keltenstadt” on the Sandberg ridge near Roseldorf is the largest known Celtic settlement in Austria. The site contains Austria’s oldest known mint: some 1500 gold and silver coins were found here. Typical ceramic potsherds containing graphite have come to light in Großmugl.

Germanic settlement in Lower Austria during the 1st and 2nd century CE was focused in the central and eastern Wine Quarter and was dense north of the Danube. But only stray finds from the Roman imperial period (1st to 4th century) are known from Großmugl. An excavated settlement on the widely visible Oberleiserberg at Ernstbrunn, in the Centre of the Weinviertel about 50 km north of Vienna, contains a residence in the style of a Roman palace and various facilities for the artisanal production, suggestive of a manor house built during the migration period.

The arrival of Slavic population groups during the 5th to 10th centuries is evident from 9th-century burial fields. Little is known about daily life in Slavic settlements, although a socketed lance-head (Tüllenlanzenspitze) has been uncovered in Großmugl.

The Christianization of the Danube area in the 8th century progressed from Passau under Charlemagne; a large mission started up in the Weinviertel between 1000 and 1150. Forest clearance resumed as the population grew in Medieval times, requiring additional farmland. It was at this point that drainage commenced of a landscape characterized until then by abundant standing water such as moors and wetlands. On the other hand, the large-scale regulation of rivers and streams only began in the 19th and 20th centuries.

Lower Austria was quick to develop an awareness of its history and prehistory. In 1970, the Museum of Prehistory was opened in the castle of Asparn an der Zaya, Mistelbach, 22 km NE of Großmugl. It is one of the most important of its kind in Europe. It includes an archaeological open-air exhibition with life-sized reconstructions of buildings from the Neolithic through to the Iron Age, and an artefact collection that, since the addition of Early Medieval objects in 2014, spans 40,000 years.

The Großmugl Oasis is a generic prototype for a “Starlight Oasis”. It was established at an existing observing site of the Kuffner-Sternwarte Society following the adoption in 2007 of the La Palma Declaration for the Right to Starlight both by the Society and by the community of Großmugl. While the area has been used intensively for agriculture and forestry throughout many millennia, one of Europe’s first bat censuses was undertaken in Großmugl and six Natura 2000 areas are now established in the Weinviertel, one overlapping with the proposed buffer zone.

3. Justification for inscription

3.c Comparative analysis

A comparative analysis of natural values other than dark-sky quality, important as they are, is beyond the scope of this case study.

EASTERN ALPINE STARLIGHT RESERVE

Satellite data show clearly that, at least as far as light-sources on the ground are concerned, the Alpine Arc is the largest dark spot in central Europe (see Fig. 12.1). Along this arc, the Eastern Alpine location is optimal because the effects of scattered light on sky quality are minimized: the light-intense regions of northern Italy and the strongly developed western Alps are at the greatest distance that can be achieved within the mountain range.

The extent to which light is reduced depends upon the comparative height and width of the mountain range. A 1000m-height difference reduces a large fraction of the aerosol scattering, and the skies certainly benefit from additional height. That is also true for the light-blocking effect where a mountain system acts as a natural baffle. For that, the width of the mountain range is important. That is a particularity of the Alps. It is shared with the Rocky Mountains, the Northern Andes and the Himalayas.

An additional factor in the Alps is the absence of high-altitude plains that attract human settlement. This reduces light pollution pressure compared to, say, Salt Lake City in the Rocky Mountains. A similar but narrower mountain chain can certainly protect skies of similar quality in less populated areas than Europe, the exceptional sky quality of the Aoraki-Mackenzie region of New Zealand (see Ch. 11), adjacent to the Southern Alps, being a case in point. The Natural Bridges Dark Sky Park located on the high altitude Colorado plateau is also sparsely populated. Sample measurements by the author showed that the sky quality there is broadly indistinguishable from that in the Eastern Alpine Starlight Reserve. However, at this very high level of sky quality, natural seasonal variations in the appearance of the Milky Way, airglow, and extinction (due, for example, to aerosols above the desert) are major factors and many measurements at both sites would be required for a meaningful comparison.

In any case, a comparison based on sky quality alone is insufficient because the night sky—and the twilight—varies with latitude. These latitudinal variations are significant and produce skies of very different character, the most commonly appreciated distinction being that between the Northern and Southern sky.

Nightscapes are as rich and diverse as the landscapes with which they are associated, and a classification of sky-landscape systems is surely necessary for a complete inventory of unique sky-heritage. A first step could be to distinguish, for example, high-elevation plains with open skies from summit-gorge areas such as canyon-lands, or places where parts of the horizon is formed by an ocean. It is evident that more specific comparisons are possible. The value of landscapes under the Moon or seen by the light of a starry night sky is becoming more commonly appreciated.

The latitude of the Alps (both Northern and Southern) together with their height produces a relatively rare feature: icy or snowy summits all year round, which create a particular impression when starlight or moonlight shines on the white ground, maximizing the contrast.

GROßMUGL STARLIGHT OASIS

At Großmugl the night sky quality is not exceptional *per se*, but does stand out strongly, if not uniquely, given its proximity to a city with a population (in the metropolitan area) of some 2.4 million people. Around other cities, as well as in other directions from Vienna, much larger dist-ances (by an estimated factor of 2–5) are generally prerequisite for a sky and night-time environment of comparable quality. The designation as a “starlight oasis” indicates this combination of night-sky quality and ease of human accessibility. The Starlight Reserve document suggests, as a prototype for a Starlight Oasis (see *Starlight Reserve Concept*, pp. 13–15), the skies of inhabited areas, of small villages reasonably free from light pollution. That implies access to the Milky Way in the better cases and roughly reflects the pre-light-pollution situation of the 1960s when the Milky Way still could be seen from cities with more than a million inhabitants.

Key indicators of night-sky quality are as follows.

1. The brightness of the location. Excessive illumination by light pollution threatens the integrity of sky and landscape.
2. The irradiance—energy flux per unit area (in our case) on the ground and through a horizontal surface. This is relevant for the environment, flora and fauna, as well as for humans at night when their perception is naturally in mesopic or scotopic mode.
3. Night-sky emission, natural and artificial. This is typically measured towards the zenith. The light emission per unit area of sky—more precisely per unit solid angle—is often expressed in relation to the magnitude of stars and thus given in magnitudes per square arc-second (mag/″²).
4. The emission of artificial light from the area towards the zenith as seen from satellites. This is a proxy for the artificial light input into the atmosphere (although it actually uses the fraction of the light that escapes directly into space, and so is not a factor degrading the sky quality for an observer on the ground, who is presumably mostly effected by light emitted near the horizontal).

Proximity, as far as artificial sky brightness is concerned, is usually discussed in the context of empirical rules of thumb based on city-population and distance. Typically, 100 km is a plausible distance to get to a fairly good sky with stars visible down to magnitude 6 (for a conspicuous Milky Way and thousands of stars—this value is often quoted as the limit of visibility for naked eye stars) or 7 (a near-natural sky with about three times more stars/less sky brightness) for a city population of 1 million. Vienna, the 9th largest city in the European Union, has a population of about 1.7 million (2.4 million in the metropolitan area).

Großmugl, at 33 km from the city centre, provides a weather-robust, conspicuous and impressive Milky Way. A visual limiting magnitude beyond 6 is typical for moonless nights. Hand-held sky-quality meter (SQM)-measurements[3] yield 21.15 mag/″² in the core zone and around 21 mag/″² through most of the buffer-zone. For comparison, observatory skies are measured around 21.6 with significant natural variations (Patat 2004).

A pioneering study of the large-scale distribution of sky brightness around the city of Perth, Western Australia (Biggs *et al*. 2012) gives 20.5 mag/″² at 30 km from the central business district in the least light-polluted northeasterly direction, which is also located behind a mountain range. Given (i) the differences in climate and consequently the natural variability in extinction, (ii) the fact that Perth is one of the most isolated cities in the world and thus there is no contribution from “neighbouring” cities, (iii) the reduced airglow in Perth due to its lower magnetic latitude, (iv) the fact that measurements in Perth were taken at solar minimum, and (v) that the metropolitan population of Perth is 1.7 million compared with Vienna’s 2.4 million, we can be very confident that the sky quality near the zenith around Großmugl is significantly better than around Perth, by at least 0.5 magnitudes. In addition, coastal extinction (not measured in the Perth study) is expected to decrease the natural sky brightness in low light-pollution environments, as compared to the continental Großmugl site, at an elevation of 300 m.

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3 Using a Unihedron sky quality meter. This measures sky brightness using an instrumental photometric system that is oriented towards but not equivalent to astronomical visual magnitudes. See Biggs *et al.* (2012) for a discussion in the present context.

3.d Integrity and/or authenticity

It is beyond the scope of this case study to attempt a complete, integrated discussion of integrity and authenticity including both astronomical and non-astronomical aspects. Instead, we focus upon the possible connections and relations between astronomically determined environmental factors in a broad sense and potential additional cultural, archaeological and science-historical values.

From a cultural perspective, the authenticity of the night sky must surely concern how well its appearance today reflects its appearance to the cultures that had a connection with it in the past. From a natural perspective, the question is perhaps how well the integrated sky-landscape system conveys the exceptional nature of both together. Either way, a critical factor is sky quality, as discussed in other sections. Complete visibility of the entire firmament is an important factor that can relate to integrity if natural views have been compromised.

While a relatively intact night sky remained in most places long after astronomers first noted light pollution in the 19th century, it is now evident that the night-time situation has significantly changed the appearance of many heritage sites—including World Heritage Sites—at night. Part of this may even result, ironically, from efforts to enhance the appearance of the heritage itself, by lighting it at night. In this context it is significant that the large tumulus at Großmugl, itself intact and unopened, sits beneath an authentic night sky (Fig. 12.5), even though the tomb itself has no evident material connection to the sky. The possibility of such connections has been explored in the case of the Lange Ries circular ditched enclosure near Steinabrunn (Zotti *et al.* 2009) but they have low credibility (Zotti and Neubauer 2015).

Fig. 12.5: Moonrise at Großmugl large tumulus. Note the reddened moon, coloured clouds and blue sky with stars (Cassiopeia and Pegasus). The colours of the moon physically are the colours of the sun, with the same spectrum and the same scattering: the moonlit night sky is as blue as during the day with the same shadow-casting. The unique moonshine appearance is created by the human eye in mesopic (twilight) mode, which perceives bluish colour tones and hard pitch-black shadows. Photograph: Norbert Fiala (kuffner-sternwarte.at)

Fig. 12.6: 1852 painting of Friedrich II playing the flute under the "crown-light", a symbol of ultimate luxury. Creative Commons license.

Given their proximity to the Großmugl site, we can use the two World Heritage Sites in Vienna— its historic centre (whc.unesco.org/en/list/1033) and the Schönbrunn Imperial Castle (/786)—to illustrate what integrity and authenticity, and their loss, may mean at night in a cultural environment.

Today it is impossible to see Schönbrunn Castle or St. Stephen's Cathedral in authentic night-light, but seeing them by starlight or moonlight, especially during the long winter nights, was as normal at the time they were built as the daytime view still is for us now. And much of the representative "luxury" of such sites may well be related to the particularities of night-culture. In "enlightened" courts the ultimate luxury was the crown-light (candelabrum) (Fig. 12.6): one used by King Friedrich II[4] cost the equivalent of 5 annual salaries of his court musician Karl Phillip Emanuel Bach. Being able to afford to sleep during the day and sustain night-time activities against the classic dangers of darkness was one of the highest social privileges. Yet light levels were surprisingly dim (5 Lux for the scene in Fig. 12.6, as measured in a recent reconstruction experiment). The crown-light and all the candles and mirrors were not creating brightness but rather a "Christmas tree" atmosphere, making the room come to life. In those days people came into the royal light from a dark park outside, through a sequence of court-rooms with slowly increasing candle-contingent and smaller crown-lights, not through rooms housing modern ceiling floodlights which reveal all the splendour in something as close to daylight as present-day lighting technology can provide. The dimness seems unnatural to us because we have lost the "art of seeing" at night—we are culturally night-blind.

Regarding the exterior of Schönbrunn Castle, a significant effort has been made to reconstruct the authentic daytime view of the façade in the "Schönbrunn-yellow" colour that was "iconic" in the Austro-Hungarian empire. But what of the night-time view? The Gloriette originally

4 The court of Friedrich II shown in the picture is actually in Potsdam, not in Vienna.

appeared as a moon-lit prominence in the imperial gardens as viewed from a candle-lit mirror ballroom. Nowadays it has to fight for contrast with the modern ballroom illumination, a fight for the attention that can only be won for the viewer inside by using lighting technology on the megawatt scale.

In general terms, a comparatively well-preserved night sky can strengthen the authenticity of astronomical attributes of value not only at a cultural site—including helping to provide a physical context for astronomical narration—but also at a natural one, since the sky forms the upper half of the natural environment, with the landscape below. Genuine night-light contributes to the integrity of the night-time environment (e.g. by allowing the original species to survive and exhibit their authentic behaviour) and is thus a basic contributing factor to the heritage value of a range of natural and cultural monuments and artefacts, both indoors and outdoors. Just as a curator's efforts to better display pieces of art by bringing daylight into the exhibition is action towards the goal of authenticity, the Starlight Reserve or Starlight Oasis is a tool for similar efforts at night. It maintains the natural night-time illumination upon our heritage in places where people still live and conserves important elements of the night-time environment in an inhabited area.

3.a Potential criteria under which inscription might be proposed

Criterion (v): Sustaining human habitability in the extreme Alpine environment has engendered a wide range of cultural activities since the Bronze Age.

The region around Großmugl is the oldest cultural landscape in Austria with continuous settlement, which extends back more than seven millennia. The Großmugl large tumulus is iconic of the early Hallstatt period, and the surrounding archaeological landscape includes the Lange Ries circular ditched enclosure, 88m in diameter, and other monuments and grave-fields that bear witness to human activity on the northern shores of the Danube as far back as the early 5th millennium BCE.

Criterion (vii): In the Eastern Alpine Starlight Reserve, the ragged mountain scenery and the superb sky quality combine to produce nocturnal phenomena of the utmost aesthetic importance.

The Großmugl area, with its wide horizons and remarkable sky quality, contains a sky-landscape system that also provides exceptional day and night-time beauty, including the spectacular sight of the Milky Way arching above the large tumulus.

Criterion (x): The Alpine primary forest within the Dürrenstein Wildernis area contains significant natural habitats for the *in situ* conservation of biological diversity, including threatened species.

3.b Suggested statement of outstanding universal value

The Dürrenstein Wildernis area, with its last remaining stretch of Alpine primary forest, contains the ultimate in-situ conservation area for numerous species, including unique species, supported by and depending on the original soil and dead-wood organisms with their fungi and micro-flora and fauna. The larger species form a prototypical Urwald (primeval forest), where the "Urlicht" (pristine sky) naturally blends in with the ragged mountain scenery resulting in exceptional beauty both by day and by night.

In addition to their own important species, the Gesäuse and Kalkalpen national parks sustain and protect Alp management—the human land-use practices such as high-altitude agriculture that have supported human life over the millennia as well as the other species that have adapted to it.

At Großmugl the combination of sky, prehistory, history and city is exceptional. The Großmugl Starlight Oasis is a sky-landscape system with outstanding remains from the Hallstatt and mid-Neolithic periods including an outstanding large tumulus in an authentic night-time environment of exceptional beauty, including nocturnal phenomena of aesthetic importance such as the arching Milky Way, situated close to Vienna, a city that is itself of considerable significance in the development of Renaissance astronomy.

4. Factors affecting the property

4.a Present state of conservation

EASTERN ALPINE STARLIGHT RESERVE

The Dürrenstein Wilderness Area contains the largest contiguous stretch of primary forest in the Alpine arc. This has not been cultivated or managed since the last Ice Age and thus supports a variety of Alpine flora and fauna (for more detail see www.wildnisgebiet.at). Following IUCN guidelines it is divided into the following zones (see www.wildnisgebiet.at/en/portrait/zoning/):

- A natural zone where no measures are implemented except for the regulation of game. Visitors may enter certain parts of this zone when participating in guided tours. This covers approximately 88% of the Wilderness Area.
- A natural zone with woodland management. For a limited period of time, secondary spruce forests are being transformed into mixed forests with a high proportion of deciduous trees. This comprises less than 5% of the Wilderness Area.
- An Alpine pasture management zone where cattle grazing is permitted to the same extent as prior to the zoning. This maintains the grasslands which provide habitats for a large number of rare species of plants and insects, as well as for black grouse and ptarmigan. This covers about 7% of the Wilderness area.
- A wildlife management zone overlapping the zones above, where the number of deer and other ungulates is regulated in order to protect the balance between forest and game. This comprises about 25% of the Wilderness Area.

The Kalkapen National Park contains Reichraminger Hintergebirge, part of one of the most unspoiled wooded areas in Austria. So far this mountain forest has not been affected and destroyed by public transportation routes or settlements.

The Gesäuse National Park embraces two limestone massifs: the Buchsteinmassiv and the Hochtorgruppe. It is largely untouched and has high biodiversity.

The sky quality in all three areas is exceptional. Light levels generally compare with those for natural skies, both by day and by night. The darkest night skies (Fig. 12.7) are the most frequent and occur under prevailing weather conditions—not just in exceptional circumstances. The brightness of the sky is comparable to the one of the best astronomical sites of the world—though of course not with the same number of clear nights.

These pristine skies above pristine Alpine mountain landscapes sustain biodiversity by providing habitats with natural conditions both by day and by night (Fig. 12.8). They support the nocturnal majority as well as numerous daytime-active rare species and their habitats (Fig. 12.9).

GROßMUGL STARLIGHT OASIS

An assessment of the “non-astronomical” state of conservation of the archaeological sites within the Starlight Oasis is beyond the scope of this text, except to say that the large tumulus is well preserved and unopened.

Under median sky conditions on moonless nights there is a dependable visual limiting magnitude beyond 6, and the Milky Way is impressive, although light pollution from Vienna is noticeable.

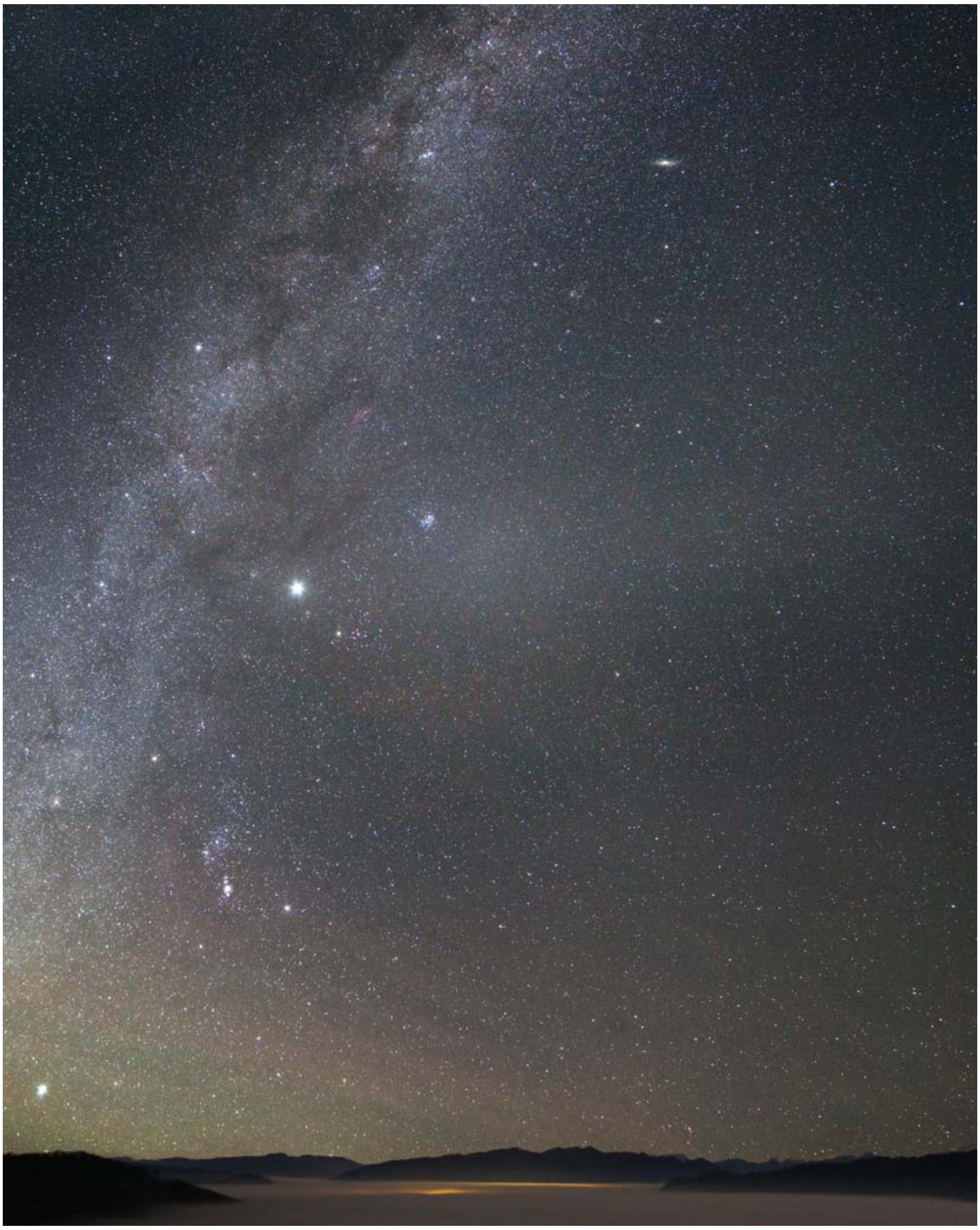

Fig. 12.7: Gegenschein in the zodical band (centre) in the Eastern Alpine Starlight Reserve above the Kalkalpen National park as seen from the “Hohe Dirn” (1000m). The Milky Way is rising on the left. Photograph: R. Dobesberger, Sternfreunde Steyr

4.b.i Developmental pressures

EASTERN ALPINE STARLIGHT RESERVE

The population of the area is shrinking and skiing activities in neighbouring regions have declined, and will decline further, owing to climate change. Thus, fragmentation by urban development is not an issue in this area.

Fig. 12.8: The moon above Gesäuse National Park, showing the point where the River Enns emerges from the canyon (partly obscured by patches of mist) on the left. The bright moonlight brings out colours in this image that are visible in a moderated way to the human eye in mesopic mode. Note the stars in the blue sky. Photograph: Norbert Fiala (kuffner-sternwarte.at)

Fig. 12.9: The boreal owl (*aegolius funereus*, a precious nocturnal species) looking north together with the sky above its frequent hunting and nesting grounds in the Dürrenstein Wilderness Area. Image: P. Buchner, www.birdlife.at (owl), G. Wuchterl (stars), K. Einhorn (montage)

GROßMUGL STARLIGHT OASIS

- The Vienna-Prague road near the west end of the buffer-zone.
- City-dwellers from Vienna: retirement sub-urbanization?
- The possible further development of wind farms.

4.b.ii Environmental pressures

EASTERN ALPINE STARLIGHT RESERVE
There could possibly be an increase in light-pollution from the growth of cities more than 100 km away.

GROßMUGL STARLIGHT OASIS
The development of the Vienna-light-dome.

4.b.iii Natural disasters and risk preparedness

GROßMUGL STARLIGHT OASIS
A new flash-flood management system was installed in 2010.

4.b.iv Visitor/tourism pressures

EASTERN ALPINE STARLIGHT RESERVE
Skiing and other Alpine outdoor activities.

GROßMUGL STARLIGHT OASIS
There are about 3000 visitors per year to events in the area. The site itself is open access and so the actual number of visitors is likely to be significantly greater.

4.b.v No. of inhabitants

EASTERN ALPINE STARLIGHT RESERVE
None in the 3 IUCN-recognised areas; an estimated 100,000 in the buffer-zone.

GROßMUGL STARLIGHT OASIS
617 people live in the core zone (mostly in the village of Großmugl); there are a few thousand inhabitants in the buffer zone.

5. Protection and management

5.a Ownership

EASTERN ALPINE STARLIGHT RESERVE
There is mixed ownership: a large proportion is state-owned land managed by the Austrian Federal Forest Administration (Österreichische Bundesforste). For example, 88% of the Kalkapen National Park is state-owned, with 11% in under private ownership and 1% municipal property.

GROßMUGL STARLIGHT OASIS
The area around the large tumulus is owned by the Erzdiözese Wien (Catholic Archdiocese of Vienna) and leased to the community of Großmugl. The remainder of the core and buffer zones is under mixed ownership.

5.b Protective designation

EASTERN ALPINE STARLIGHT RESERVE
The natural heritage is protected by federal National Park law and by state nature protection law. The area is a Starlight Natural Site in the context of the Starlight Reserve Document.

GROßMUGL STARLIGHT OASIS
The tumuli, Steinabrunn and Herzogbirbaum circular ditched enclosures, and various other archeological sites are protected historic monuments. The Starlight Declaration and Starlight Reserve document are endorsed by the community of Großmugl.

5.c Means of implementing protective measures

EASTERN ALPINE STARLIGHT RESERVE
A set of nature-protection regulations recognized by the IUCN is in place for the conservation of the three components of the core zone. State light-pollution laws, with sections on conservation areas, are in preparation. The spread of national light-pollution laws, already existing in the Czech Republic, Slovenia and many provinces of Italy, could counteract the threat of light-spill from the growth of distant cities.

GROßMUGL STARLIGHT OASIS
A construction codex has imposed a “no-building zone” around the large tumulus, while federal monument protection applies to the prehistoric sites (and other monuments in the area). State light-pollution laws, in preparation, include sections on conservation areas. The protection of the core zone is managed by the community of Großmugl (www.grossmugl.at).

5.d Existing Plans

EASTERN ALPINE STARLIGHT RESERVE
It is planned to increase the existing night-oriented activities, managed by the park administrations in cooperation with astronomical organizations such as the Kuffner Observatory (www.kuffner-sternwarte.at) and Sternfreunde Steyr (www.sternfreunde-steyr.at).

GROßMUGL STARLIGHT OASIS
Plans by the Keltenberg Observatory (www.keltenbergsternwarte.at) include an infrastructure extension for night-sky observation, thematic pathways, a small planetarium, visitor management, and the extension of a public observatory in the village.

5.g Sources of expertise and training

Sources of astronomical expertise and training include

- Institute for Astronomy, University of Vienna (didactics of astronomy education for teachers);
- the Kuffner-Sternwarte Society (amateur and professional astronomers and physicists);
- the Linzer Astronomische Gemeinschaft;
- Sternfreunde Steyr;
- Hochbärneck Observatory; and
- the Keltenberg Observatory (for Großmugl).

National Park institutions provide expertise and training relating to other issues in the Eastern Alpine Starlight Reserve. The Museum of Prehistory at Asparn an der Zaya (www.urgeschichte.at) provides archaeological expertise in the Großmugl area.

5.h Visitor facilities and infrastructure

EASTERN ALPINE STARLIGHT RESERVE
The National Parks and Wilderness Area provide visitor centres and infrastructure. In the conservation zone of the primary forest of the Dürrenstein Wilderness area, human access is only possible under exceptional circumstances.

GROßMUGL STARLIGHT OASIS
The Großmugl community assembly room has facilities and a capacity of 200. Restaurant Schillinger (www.charlys.at) has a lecture/event room with a capacity of 100 that acts as an information base and contact point. The Austrian "rights of way" law guarantees public access throughout the core and buffer zones.

5.i Presentation and promotion policies

EASTERN ALPINE STARLIGHT RESERVE
The National Park and Wilderness Area have already included night-time activities in their programmes.

GROßMUGL STARLIGHT OASIS
See www.starlightoasis.org; www.grossmugl.com.

6. Monitoring

6.a Key indicators for measuring state of conservation

The key indicators are:

- Illumination levels and total radiation.
- Complementary background sky brightness or near zenithal average sky brightness (SQM-measurements) and all-sky brightness distribution.
- An air-quality related value (visibility versus haze):
    - total aerosol optical depth
    - mass fraction of particulate matter with respect to an upper size limit specified by μm
    - ozone (health)

EASTERN ALPINE STARLIGHT RESERVE
Continuous monitoring of the sky quality in the proposed reserve is carried out by the Kuffner-Sternwarte Society in collaboration with the Dürrenstein Wilderness area and the Sternfreunde Steyr.

GROßMUGL STARLIGHT OASIS
Continuous monitoring of day and night total radiation is carried out by the Kuffner-Sternwarte Society and the Großmugl Starlight Task Force of the Großmugl Community Council, chaired by the mayor of Großmugl.

The sky quality at Großmugl and the development of the Vienna light-dome is continuously monitored by a network of Lightmeters (see www.lightmeter.astronomy2009.at), which permits control of the sky quality and an assessment of protective measures. The sky quality above Großmugl itself has been continuously monitored since October 2009 by measuring the horizontal illumination and total radiation using a Lightmeter on the roof of the Schillinger Inn inside the village. There are public street-lights in the village, which is the largest in the core zone, and thus the sky quality at other locations (such as around the large tumulus) will be slightly better due to the complete absence of lights.

7. Documentation

7.a Photos and other AV materials

EASTERN ALPINE STARLIGHT RESERVE
Extensive multilingual documentation is available at www.wildnisgebiet.at (for the Dürrenstein Wilderness Area), www.nationalpark.co.at (for the Gesäuse National Park) and www.kalkalpen.at (for the Kalkalpen National Park).

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Baikonur Cosmodrome, Kazakhstan

Mikhail Marov

Geographical position

Kyzylorda Province, Kazakhstan

Location

Latitude 45.9° N, longitude 63.3° E. Elevation 100m above mean sea level.

General description

Baikonur Cosmodrome has been the global base of operations for the Soviet, and subsequently the Russian, space programme. The first satellite, Sputnik, was launched from Baikonur, as was the first manned spacecraft in human history, Vostok 1, with Yuri Gagarin. So were several generations of cosmonauts, orbital stations, and lunar and planetary space missions.

Introduction

Science and technology heritage is a challenging new initiative involving numerous themes and issues, including specifically those relating to astronomical heritage and space exploration. We are keen to see solid progress towards understanding the principal concepts underlying such a complex topic. This, however, can only be accomplished by a gradual development of ideas. Baikonur's inclusion in this volume is an attempt to undertake the first steps in this process, but it does not constitute a full case study.

Science and innovation are regarded by UNESCO as key activities promoting sustainable development. Astronomical heritage is intrinsically related to the most important breakthroughs in space science and technology, and space exploration has established a new great milestone for human civilization. It is therefore essential to include space technology as an important category of technology heritage that has international significance in terms of humankind's relationships with the sky. Following the international conference on 'Astronomy and World Heritage: Across Time and Continents' held in Kazan, Russia in August, 2009, it became a subject of further discussion and clarification, with an important step towards the goal being taken within the first ICOMOS–IAU Thematic Study (see DeVorkin 2010; Marov 2010).

Outstanding objects of space infrastructure involving the most valuable sites and facilities must be regarded as historically important artefacts of human culture, alongside astronomical observatories and instruments. This includes instruments operating in space, themselves material artefacts of great significance (see Huntress and Marov 2011). There is a synergy between space astronomy and space technology that served to stimulate progress with astronomy and produced numerous technological spin-offs. The goal is therefore to develop a rational and coherent approach enabling us to commemorate various space instruments (e.g. space telescopes), spacecraft (e.g. planetary probes), and other man-made objects in space (e.g. orbital stations) accepted by international bodies such as the IAU, ICOMOS, and COSPAR, as heritage artefacts of global significance in relation to astronomy and space technology.

Space facilities where the most historically valuable spacecraft were designed and manufactured together with launch pads (cosmodromes) are key parts of the overall space infrastructure because they ensured the development and launch of spacecraft and thus historical achievements in space exploration and use. Examples of particular historical value are the RSC "Energiya" (former OKB-1) and NPO Lavochkin in Russia; the Jet Propulsion

Laboratory (JPL) and Johnson Space Flight Center (JSFC) in the USA; the Russian Baikonur Cosmodrome and the American Kennedy Space Center, just to mention a few. These are space facilities responsible for the development and launch of the first satellite; for Yuri Gagarin's first orbital flight in the VOSTOK spaceship; for Neil Armstrong first step on the Moon from the EAGLE capsule; for the first orbital stations (Salyut, Skylab, MIR) which paved the road to the International Space Station (ISS); and for several generations of launchers including the Space Shuttle and Energiya-Buran.

Brief inventory

Baikonur cosmodrome is located at the centre of an elliptically shaped area measuring 90 km from east to west and 85 km from north to south. It comprises nine launch complexes with fourteen launch pads, thirty-four engineering complexes, three fuelling stations for space vehicles and two aerodromes. The location of the main facilities is shown schematically in Fig. 13.1. The town of Baikonur is shown as Ленинск (Leninsk)—see below.

The famous "Launch pad no. 1", known as "Gagarinskiy Start" (Gagarin's launch pad), is some 30 km to the north of Baikonur. The launch complex measures 250 × 100 m with a depth of 45 m. Extraordinary efforts were needed in order to create the necessary infrastructure of concrete foundations, flame duct, steel launch platform, tanks, pumps, drainage pipes etc. in the mid-1950s. The launch pad and an associated assembly building (Site 2) formed the initial facility where military and space developments took place at Baikonur.

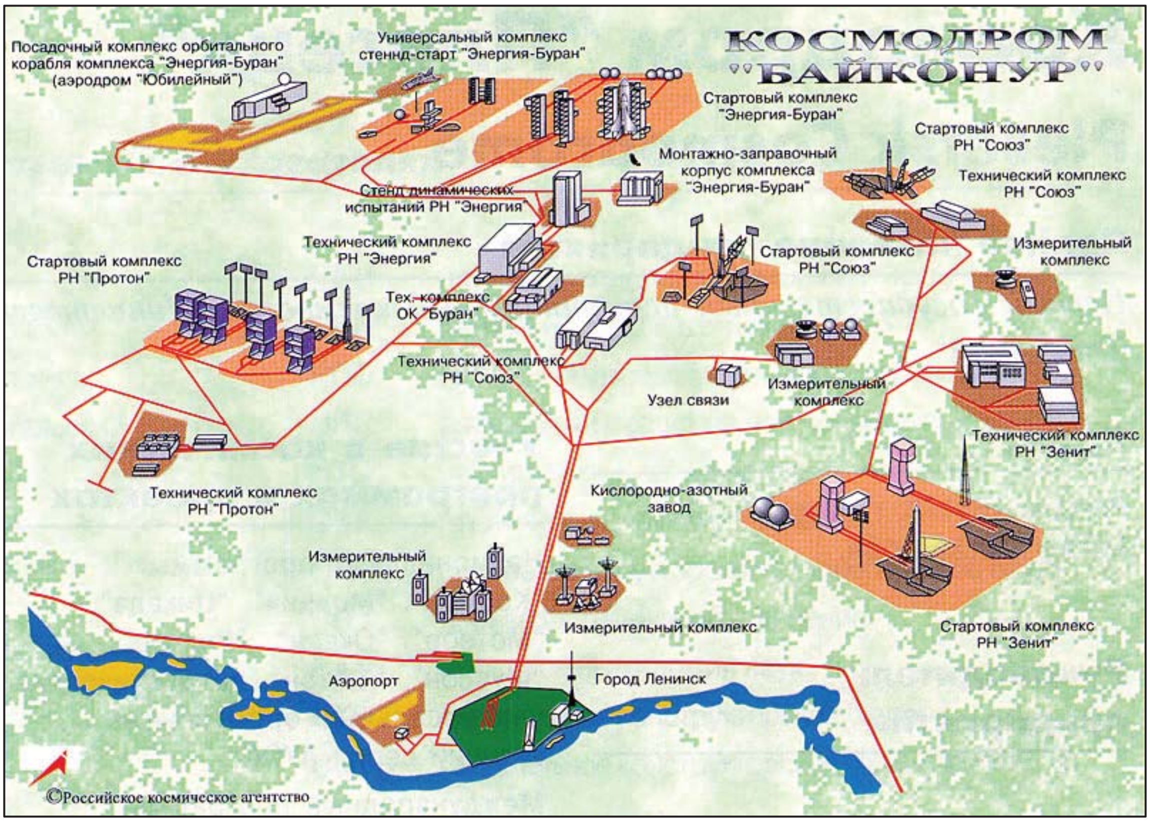

Fig. 13.1. Location of the main facilities at Baikonur Cosmodrome. Courtesy ROSCOSMOS

Fig. 13.2. The Soyuz TMA-10M spacecraft being prepared for launch in September 2013, to take a new crew to the International Space Station. Photograph: NASA/Carla Cioffi

The Энергия–Бура́н (Energia–Buran) general-purpose rocket launch complex is located in the center of the cosmodrome, close to Gagarin's pad, stretching out for 15 km along the main cosmodrome road. It was constructed on the site where the N1 rocket booster, intended for manned flight to the Moon, was developed between the late 1960s and early 1970s. However four launches failed, one of which completely destroyed the launch pad.

The "left flank" portion of the cosmodrome stretches for some 20 km to the west of the Energia–Buran complex, and contains the engineering and launch facilities for the Циклон (Tsyklon/ "Cyclone") and Протон (Proton) rockets. The latter contains four launch pads and two large "processing" (assembly-and-test) complexes, as well as a fuelling facility.

The eastern section ("right flank") of the cosmodrome, which came into operation in 1961, was used for testing a range of ballistic missiles and rocket launchers developed by Mikhail Yangel's Design Bureau. The more northerly of its two launching complexes has been used extensively for the launch of space vehicles, both manned and unmanned, including the extraordinarily successful Союз (Soyuz) spacecraft (see Fig 13.2). The other launch complex, 10 km to the south, was built to develop the Зени́т (Zenith) launch system focused upon putting satellites into earth orbit. It comprises two launch pads, an assembly-and-test building, storage depots and other engineering facilities. A cryogenic centre is situated nearby.

Historical highlights

On Feb 12, 1955, the Soviet Council of Ministers issued a decree that Defence Ministry Research and Trials Field Station no. 5 (NIIP–5) would be sited in the heart of the Kazakh Steppe, north of the Syr Darya river and about 200 km east of the Aral Sea, near to the village of Tyuratam and its railway station. NIIP–5 was a test range for the world's first intercontinental ballistic missile (ICBM), the R–7, which needed to be deployed well away from densely populated areas but also in a location surrounded by desert plains, so that it could receive continuous radio signals from distant ground control stations. NIIP–5 was almost immediately expanded to include launch facilities for space flights. Construction of the first of these began on Jan 12, 1956 and was completed in under one and half years on May 5, 1957. Sergei Korolev, the Chief Designer of the R–7, went on to lead the early Soviet space programme.

According to some sources, Baikonur was a pre-existing name for the Tyuratam area. Most, however, state that the name was chosen in 1961, at the time of Gagarin's flight, in order to mislead the West about the exact location: there is a small mining town called Baikonur some 320 km to the north-east. The present city of Baikonur only came into existence in 1955, when a settlement of wooden buildings ("Ground #10 Zarya") was erected some 30 km away from the cosmodrome facilities in order to provide housing, schools and support infrastructure for employees. From 1966 until 1995 the developing city was known as Leninsk; on 20 December 1995 it was renamed Baikonur by a decree signed by Russian and Kazakh Presidents Boris Yeltsin and Narsultan Nazarbaev.

Among the notable early space missions that were launched from Baikonur are:

- Sputnik 1 (Oct 4, 1957), the first artificial satellite;
- Luna 1 (Jan 2, 1959), the first spacecraft to reach the vicinity of the Moon;
- Vostok 1 (Apr 12, 1961), the first manned spaceflight, which carried Yuri Gagarin into orbit; and
- Vostok 6 (Jun 16, 1963), which carried Valentina Tereshkova, the first woman in space.

On Oct 24, 1960 there was a major disaster when a prototype R–16 ICBM detonated on the launch pad, killing about 150 people.

Between 1978 and 1988, the "Interkosmos" program led to 14 cosmonauts from 13 nations outside the Soviet Union—countries both within and outside the Warsaw Pact (including Bulgaria, Czechoslovakia, Cuba, Vietnam, India and France)—participating in Soyuz missions launched from Baikonur. Following the collapse of the Soviet Union in 1991, Russia began joint missions to the Mir space station with the USA. This led to the development of the International Space Station, which, since the termination of the US Space Shuttle program in 2009, has been supplied solely by Soyuz manned spacecraft and "Progress" cargo transport vehicles launched from Baikonur.

Baikonur continues to be used for launching both manned and unmanned spacecraft. Numerous commercial, military and scientific missions are launched annually as part of the current Russian space programme.

Documentation and archives

Baikonur Cosmodrome has a museum which houses many artefacts, documents and photographs relating to space exploration and, more specifically, to the cosmodrome's history. A Buran shuttle orbiter, tested on a single unmanned spaceflight, has been restored and hosts an interactive presentation for visitors. The museum also includes a Soyuz descent capsule, a variety of rocket engines, early computers, various models, and numerous artefacts relating to Sergei Korolev, Valentin Glushko and Yuri Gagarin. Finally, there is a signed crew photograph for every expedition launched from Baikonur—a tradition that has been maintained without exception.

Located adjacent to the museum building are two small cottages, formerly occupied by Sergey Korolev and Yuri Gagarin, which have been carefully preserved. Their interiors nicely convey the very modest living environment and atmosphere of those few anxious nights before the historic Gagarin flight.

Fig. 13.3. The room where academician Sergey Pavlovich Korolyov, Chief Designer spent the night before Yuri Alexeyevich Gagarin's flight, the first manned spaceflight (April 11 and 12, 1961). Photograph: Alexander Mokletsov (RIA Novosti archive, image #877560)

Justification for inscription

Baikonur is one of the most advanced properties of the space era and its historically important position in human culture is without question. It could well be considered to "represent a masterpiece of human creative genius" (criterion (i)). What follows in this section is simply an attempt to preliminarily address some of the issues that could arise in the comparative analysis and in the discussion of integrity and authenticity.

The comparative analysis should most certainly consider the Kennedy Space Flight Center (KSFC) in the USA, which is arguably of similar historical value to Baikonur. Like Baikonur, it has many globally recognized achievements. Nonetheless, Baikonur holds the historical facilities that provided the launch of the world's first artificial satellite and the first man in space, Yuri Gagarin, the two key events that opened the space era.

The present-day Baikonur cosmodrome is a huge area containing numerous launch pads and facilities, as described above. It has been dramatically extended since the first Sputnik and Vostok flights. In order to satisfy integrity-authenticity requirements, careful consideration must be given to critical historical elements such as the famous "Gagarinskiy Start" (Gagarin's launch pad) and Korolev and Gagarin's cottages.

The facility containing Gagarin's launch pad is well integrated within the functional space technologies used for testing and launching manned craft: many cosmonauts and crews have been launched since the first flight of Gagarin. Nonetheless, nothing has been removed or even partially demolished since the Gagarin's time. The facility's authenticity is beyond doubt and is well documented in the available historical archives. The historical events related to the launch pad are commemorated in an inscription on the stone plate erected *in situ* beside the pad. Certainly the original launch pad and its close environment have experienced some reconstruction in order to utilise modern equipment, but there have been no significant changes that would compromise authenticity. The Gagarin and Korolev cottages have been repaired but have not been altered, and the original furniture and personal belongings have been left in place.

Management

Since the disintegration of the Soviet Union, the Baikonur cosmodrome has been leased to Russia by the Kazakh government. Under an agreement signed by Vladimir Putin and Narsultan Nazarbaev in Astana on Jan 9–10, 2004, and ratified on June 2004 to be extended until 2050 at a fixed rent of US$ 115 million per annum, with each country holding a 50% stake, it is managed jointly by the Russian Federal Space Agency and the Russian Space Forces.

It is not believed that the protection and management of historically significant elements of the cosmodrome such as the Gagarin launch pad (Gagarin start), Baikonur museum, and other sites and facilities that could contribute to potential OUV would impose any political obstacles, despite the fact that Baikonur is under international Russia-Kazakhstan joint jurisdiction. Certainly, various mutual obligations and restrictions would be necessary in order to preserve their integrity. There would also be a need for new procedures and formats concerning continuing utilization, preservation and maintenance, minor modification (if any), and public access to the relevant zones, and these would need to be negotiated with the Roscosmos authorities. The Baikonur management team would be responsible for implementing these procedures.

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Discussion

Clive Ruggles

At any potential World Heritage site relating to astronomy, we have to consider what are the core values and their potential OUV. This leads to a suggested statement of OUV and suggested criteria that support the statement. In most cases not all the core values with potential OUV will be astronomical.

The extended case studies chosen for this volume represent attempts to develop methodologies most likely to provide a demonstration of potential OUV in relation to astronomy. While the case study authors have attempted to define potential OUV in each case, final statements of OUV can only result from the development of nomination dossiers by national authorities, their evaluation by the advisory bodies, and the successful inscription of the property concerned on the World Heritage List (WHL).

The extended case studies chosen for this volume do not in any sense constitute a "pre-listing", despite being structured as segments of nomination dossiers. In other words, the choice of case studies does not reflect any judgement about the likelihood of success if the properties concerned were to be nominated for the WHL.

In this concluding chapter we examine some of the main themes and issues of importance relating to astronomy that are raised by the case studies.

Relating the tangible and the intangible

From a heritage perspective it is clear that astronomy must always be considered in its social context: all astronomy is ultimately cultural astronomy. The significance of astronomical perceptions and knowledge as intangible heritage is that they reinforce or deepen broader cultural understandings. Such knowledge may well be considered "scientific" in a broad sense (see TS1: 6–7) and it can also have (what a Western commentator, at least, would consider) practical benefits, such as in navigation; however, many other types of astronomical knowledge may also have strong cultural value, for example in the realm of religious beliefs and practices, or when used for astrological prognostications.

Since all tangible astronomical heritage must relate to the intangible heritage of astronomical knowledge itself,[1] a general issue running inevitably through all of the case studies, either explicitly or implicitly, is how to assess the relative strength of the attributes of value of the tangible and intangible heritage, and which combination might best demonstrate the potential OUV of the whole. (The same issue arises for all forms of science heritage.) This, of course, concerns the potential application of criterion (vi) but it also raises the question of whether a nomination under UNESCO's Convention for the Safeguarding of Intangible Cultural Heritage, rather than under the World Heritage Convention, or a linked nomination under both conventions, might be more appropriate in particular cases.

Tangible heritage itself comprises two distinct subcategories: fixed ("immovable") and movable, of which only the first is covered directly by the World Heritage Convention. The meaninglessness, on a conceptual level, of separating astronomical heritage by category—tangible immovable, tangible movable and intangible—is an issue discussed at length in TS1.

The Paris Observatory and Royal Observatory, Cape of Good Hope, South Africa case studies strongly underline the interconnectivity of different heritage objects. They also illustrate

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1 Space technology heritage is slightly different in this regard, since it does not necessarily relate to the business of "doing astronomy".

ways in which science heritage sites with strong associations both to movable and intangible heritage items (and more specifically, observatories and similar institutions from the 17th century onwards) could be presented in the context of a nomination dossier.

The balance of tangible and intangible values at a classical observatory site is particularly well illustrated in the case of the Cape Observatory. Architecturally, the Greek Revival Main Building is almost unique among observatories worldwide and is slightly older than the Cambridge University Observatory whose style is somewhat similar. In terms of Cape colonial architecture, only the St Andrews Presbyterian Church in Cape Town is stylistically similar. Another building with exceptional architectural appeal is the McClean or Victoria building of 1896, designed by the famous colonial architect Sir Herbert Baker. This is in the unique style developed by him, with elements of stone, oval windows, varnished wood and pebble-dashed walls. Apart from the architecture, the site is replete with many of the telescopes, instruments and paraphernalia of the working 19th century observatory. The case of the Cape Observatory illustrates the indistinct boundaries between fixed ("immovable") and movable elements—thus, fixed observatory buildings have rotating domes and can have movable floors, and telescopes have movable parts but fixed mounts—as well as the importance of portable instruments and objects. The intangible heritage of scientific achievement, resulting in particular from its location in the southern hemisphere, also contributes significantly to the value of the site.

A stronger weighting towards the intangible is evident in the case of the sun- and star clocks of Oman. Here the actual sky-watching devices are of an ad-hoc nature, often insubstantial, relatively short-lived and constantly being replaced. For example, in the Mudhaybi area, indicator stars are watched from simple markers on walls, rising or setting above or below a second horizontal marker, often on the top of the wall; in many places the natural horizon is used. On the other hand, the use of sun and star observations for timing shares of irrigation water in Oman represents an impressive example of how observations and understanding of the celestial bodies can help human communities adapt to and survive in harsh environments. The practice of night-time star observation also demonstrates a direct cultural connection between subsistence ecology and the dark night sky that may well be unique in surviving to the present day, although it is threatened with extinction. Related practices of solar observation that apply the same astronomical system of time apportionment during daylight hours continue in perhaps as many as a hundred separate communities. Together, they represent vestiges of once-widespread practices relating astronomical timing to subsistence ecology that have continued uninterrupted for hundreds, if not thousands, of years.

Space technology heritage raises further complexities. Baikonur Cosmodrome, examined by Marov in Ch. 13, is recognized worldwide as the foremost operational base for the Soviet/Russian space programme. But, as Marov points out, instruments operating in space are themselves material artefacts of great significance, as are space vehicles (TS1, pp. 234–6) and landing sites on the moon, Mars or elsewhere (TS1, p. 264). Some of the juridical and practical issues raised by this type of heritage—such as what could be considered "fixed" or "movable"—were considered in TS1 (pp. 264–5) and will not be repeated here. The fact that much of the tangible heritage exists beyond the sovereign territory of member states—e.g. on the moon or other bodies in the solar system, in earth orbit or further away in space—may not represent an insurmountable problem in the future. A recent UNESCO report (Freestone *et al.* 2016) raises parallel issues with respect to marine heritage under the high seas. As pointed out there (p. 10), an independent external audit in 2011 recommended that the World Heritage Committee should reflect on appropriate means to preserve sites that correspond to conditions of OUV but are not dependent upon the sovereignty of States. It may be that similar considerations can eventually be applied to off-planet heritage.

The heritage of space exploration is a topic whose investigation has been officially recommended by the World Heritage Committee (36th session, St. Petersburg, 2012) and there is interest from a number of partners in participating, together with ICOMOS and the IAU, in the development of a thematic study devoted entirely to this topic. The organizations concerned include the Committee on Space Research (COSPAR), NASA, the European Space Agency (ESA), and the International Astronautical Foundation (IAF).

Integrity and authenticity issues in relation to places of science

Change is inevitable in a functioning place of science, and tends to increase rather than decrease its value. The same is true for technology heritage, because of the necessity for continual innovation and modification. This implies very careful consideration of integrity and authenticity issues (see TS1: 10–11; 267). The requirements of authenticity (how well the attributes reflect the OUV) and integrity (the completeness or intactness of the attributes that carry OUV) dictate that there should be sufficient genuine and comprehensible evidence remaining from the most significant periods in the history of the place in an adequate state of conservation. On the other hand, observatory directors do not wish to restrict their ability to continue to undertake cutting-edge science and are rarely able to see clearly how future developments might need to impact upon the existing components of their “monument of science” such as particular buildings and instruments.

Science itself can be viewed as a “living” cultural practice, and the importance and the inevitability of change, as science moves forward, is a feature it shares in common with indigenous knowledge and practices that could be recognized either as living components of a site or cultural landscape or in themselves as valuable intangible heritage worthy of potential recognition under the Convention for the Safeguarding of Intangible Cultural Heritage (CICH) (UNESCO 2003). In this case, the intangible heritage is related to a living community and not to a place. Such knowledge and practices are never static but are subject to continual modification and change—a fact that is well known, for example, to cultural astronomers (López 2014)—and is especially true for science and modern technology. In cases where indigenous and modern scientific values both have legitimacy, there is an absolute need to find an expression of value that encompasses both aspects and ensures locally sustainable accordance before proposing international recognition.

In practice, the OUV of a World Heritage Property must be clearly understandable by everyone, and enough tangible components, of sufficient quality, must be protected in order to ensure that this continues to be the case. Individual meanings (attributes of value) must remain clearly identifiable and represented. If the OUV is defined in a series of historical steps, each of them must remain clearly identifiable and represented. In the case of a serial inscription, each historical step must be present in the series as a whole. The details in any particular case could be explored by upstream process missions.

Recommendations

Given that only tangible, immovable heritage can contribute directly to the OUV but that movable objects and intangible evidence can constitute important additional value, it is good practice to present the inventory of attributes in the following order: (1) tangible evidence such as immovable features of the property; (2) visual links between tangible evidence and landscape features or qualities; (3) movable evidence such as small instruments and archives; and (4) intangible evidence and understanding of the place. Intangible evidence also contributes to the section on “history and development” in a nomination dossier.

Protecting dark skies

The discussion of dark sky values in Ch. 2 concludes that, while dark sky places cannot, in themselves, be recognized as specific types or categories of World Heritage property, either cultural or natural (cf. TS1: 266), dark sky values can certainly enhance either the natural or cultural value of a place (or both), and in this sense contribute to potential OUV. Five of the case studies relate directly or indirectly to dark skies issues, reflecting the IAU's particular concerns about such matters. They explore various ways in which dark skies and light pollution issues could be raised in nomination dossiers.

Dark sky reserves

The Dark Sky in itself is an important natural feature of a given place. The Aoraki-Mackenzie region in New Zealand, one of the first to be recognized by the International Dark-Sky Association (IDA) as a gold-tier International Dark Sky Reserve, provides an example where an exceptional pristine dark sky is a vital component of the beauty of the open natural landscape. The Dark Sky Reserve already overlaps with part of the existing Te Wāhipounamu (South-west New Zealand) World Heritage Site (whc.unesco.org/en/list/551), listed under criteria (vii)–(x), and extending the boundary of the latter to include the Mackenzie area, as discussed in the case study, could provide a possible path towards achieving World Heritage recognition, including the dark sky value in close relationship with other natural features of exceptional value.

The dark skies of the Eastern Alpine and Großmugl starlight areas in Austria are not in themselves exceptional on a global scale. Data on sky brightness, irradiance, and night-sky emission set out in the case study do, however, indicate that the Eastern Alpine Starlight Reserve is an area whose dark skies are amongst the darkest in Europe, while the dark skies of the Großmugl "starlight oasis" (covering about 30 × 40km) are exceptional for a location so close to a large city. In the Eastern Alpine case, a possible way forward might be to focus upon other natural values such as the primeval beech forests similar to those whose outstanding value has already been recognised in Slovakia, Ukraine and Germany (whc.unesco.org/en/list/1133), and whose connection to dark skies might be established through links such as sustainable ecosystems. However, dark sky values cannot stand alone and other natural features must be shown to be really exceptional or unique.

Of course, a pristine dark-sky area with natural values may manifest other broad cultural connections. For example, the early Māori inhabitants of the Aoraki-Mackenzie region had strong cultural connections to the sky, stemming from the Polynesian tradition of night-time navigation by the stars that first brought them to Aotearoa (New Zealand). In some cases a better approach could be to consider the contribution of a dark sky to a cultural landscape, which, being a "combined work of nature and of man", can embrace both cultural and natural features. The astronomical timing of irrigation in Oman is a good example of this, being a modern indigenous cultural landscape with cultural practices of star observation, linked to other environmental issues (in this case, water management), that are threatened by the erosion of dark skies.

Cultural landscapes may also contain archaeological sites significant from the historical, aesthetic, ethnological or anthropological points of view. The Großmugl starlight oasis contains the largest and best preserved example of the large tumuli of the region which are characteristic of the Hallstatt period in Lower Austria. However, neither this specific monument nor this class of monument as a whole have any demonstrable connection with astronomy yet identified by archaeoastronomers. The area also contains two older circular ring-ditch enclosures (Kreisgrabenanlage), dating from the Neolithic period, mostly visible only as crop markings seen from the air. Monuments of this type are found over a wide region extending into several countries, and the entrance orientations of such monuments have been claimed to have an astronomical connection. However, this remains unproven, and systematic studies suggest that the principal factors defining the entrance orientation were in fact topographic. The most striking example of a solstitially oriented entrance that might have been intentional is found at Pranhartsberg 2, an enclosure well outside the Großmugl area. Thus, even if potential OUV could be demonstrated for the Großmugl area as a cultural landscape containing important archaeological sites—either alone, as part of a serial nomination, or as an extension to an existing World Heritage property such as Hallstatt-Dachstein/Salzkammergut (whc.unesco.org/en/list/806)—the lack of an explicit material connection between the archaeological remains and the sky would be a problem if one were trying to construct a case for OUV integrating both the cultural and dark sky aspects.

Another approach would be to include the dark sky as one among a wider set of natural features that enhance the cultural value of a place: thus both a mountain landscape and an exceptional sky may contribute to the value of a modern observatory site, as is the case at Pic du Midi. It is less clear, however, whether dark skies could be the only natural attribute of potential OUV (under criterion (vii)) at an otherwise cultural site. It is also conceivable that criterion (vii) could operate in conjunction with criterion (vi), but, again, demonstrating potential OUV under criterion (vi), if based only upon astronomical cognisance, could present a considerable challenge where there are few or no tangible remains with a clear direct cultural connection to the dark night sky. These latter cases would, of course, imply a mixed inscription.

The Hortobágy National Park in Hungary offers another possible approach: here, cultural OUV has been established under criteria (iv) and (v) (whc.unesco.org/en/list/474), while the dark sky value is recognised by the IDA as an International Dark Sky Park. It is also a UNESCO–MAB Biosphere reserve.

A case based on the cultural values could still include a general argument for maintaining a prehistoric cultural landscape in its “authentic light”, including preserving dark starry skies at night. Thus at Stonehenge World Heritage Property in the United Kingdom, it is considered important to try and preserve the dark-sky setting for the monuments within the WHP, as this is how they would have originally been viewed (see case study). This is despite the fact that the astronomical connections recognized by UNESCO in the 2011 retrospective statement of OUV (also see case study) are with the sunrise and sunset, so dark sky values do not directly reinforce the cultural values. Rather, the dark sky serves in a general way to enhance a visitor's broad sense of the connection between the place and the sky.

Modern observatory sites and their dark skies

The world’s leading optical observatories symbolize, and are responsible for many of, the extraordinary advances made by astronomy since approximately the beginning of the 20th century. This value is innately cultural: however, of necessity, these observatories occupy exceptional places on our planet where a unique combination of environmental and natural circumstances occurs, resulting in incomparable sky quality (purity, stability, high average of cloud-free days, etc.) and, in particular, pristine dark skies. Preserving these skies is part of maintaining their heritage value.

For the purposes of a World Heritage application one would need to focus both upon truly exceptional advances in human knowledge and the most outstanding places that represent and symbolize them. One approach (*A*) could be to focus primarily upon the fundamental transformations in humankind’s conception of the cosmos that have been achieved at some of the most exceptional observing places on the planet. For example, at the beginning of the 20th century the Milky Way galaxy was generally believed to constitute the entire universe; at its end, humankind knew of the existence of countless millions of other galaxies; of exotic objects such as quasars, pulsars, and black holes; and of cosmic expansion and the Big Bang—concepts that are now part of our collective culture. Broadly speaking, this transformation of ideas happened between 1920 and 1970. To the list of concepts that are now part of our collective culture one could conceivably add dark matter and dark energy, thus extending the period concerned up to the end of the 20th century. Other developments in 20th-century astrophysics, though plentiful, are likely to seem too narrowly focused from a heritage perspective.

A rather different approach (*B*) would be to emphasize an ensemble of places, structures and technologies as a step in the developments that have enabled fundamental advances to be made in astronomical knowledge during the course of human history. By constructing observatories on mountain summits, astronomers could not only minimize light pollution but also benefit from exceptional atmospheric quality and stability. During most of the 20th century, high mountaintop locations in particularly favourable regions of the planet were unsurpassed for making astronomical observations in optical as well as infrared and millimetre/sub-millimetre wavelengths.[2] This era could be chronologically located as a stage in a historical progression that had started with observatories being built within cities and later being located outside cities to avoid light pollution. This implies a start date in the late 19th century. In 1993, when the Hubble space telescope became operational, such ground-based observatories were complemented for the first time by space telescopes, although these will be unable to exceed what can be achieved from the surface of the planet for many decades to come (because we can build much larger receivers on the ground, and given the success of laser technology in countering the effects of atmospheric turbulence).

Most scientists and historians of science would probably follow approach (*A*), while (*B*) is more in line with the thinking of most heritage professionals. (*B*) could lead to a clear statement of potential OUV under criterion (iv) (an ensemble of the best examples) or (i) (a single outstanding case) with possible supporting values under criteria (ii) and (vi), while approach (*A*) might emphasize pristine skies as a natural value, perhaps to be considered under criterion (vii), strongly supported by criterion (vi). A combined approach could well provide the strongest demonstration of potential OUV, bearing in mind that (as already noted) it is unclear whether dark skies would be acceptable as the only natural attribute of potential OUV among an otherwise cultural nomination. Also, criterion (vi) is normally used in conjunction with other cultural criteria, following the *Operational Guidelines*, rather than natural ones.

Methodologies for assessing science heritage developed in TS1 attempt to combine relevant aspects of both approaches and these are further developed here in the case studies of the AURA Observatory (Chile), Canarian Observatories (Spain) and Mauna Kea Observatory, Hawai‘i (USA), as well as the Pic du Midi de Bigorre Observatory (France). In particular, Chapter 2 develops the "Windows to the Universe" concept in the context of the World Heritage Convention.

Many modern observatory sites, including the AURA Observatory, ORM La Palma (Canaries) and Mauna Kea, are emblematic of international technological cooperation on a grand scale from the 1960s onwards, which enables a wide range of technological developments at the cutting edge. This suggests the possibility of demonstrating attributes of potential OUV under criterion (ii).

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2 This ignores Antarctica, parts of which also has exceptional atmospheric conditions, and where the South Pole Observatory was founded in 1957. While there does exist an international convention relating to Antarctica (the Antarctic Treaty, signed by 12 countries), its land does not constitute the sovereign territory of any one State Party. Thus WHL recognition could only follow changes to the operation of the World Heritage Convention, as is suggested for marine heritage under the high seas (Freestone *et al.* 2016) and would be needed for space technology heritage beyond the surface of the planet, as already discussed.

While the case studies also refer to broader cultural associations such as rock art sites, none of them is closely associated with cultural sites that manifest a direct tangible connection with astronomy, although Mauna Kea in Hawai'i, like the Aoraki-Mackenzie region in New Zealand discussed above, is connected with a cultural tradition emanating from the ancient Polynesians in which star knowledge is deeply embedded and respected. Ironically, instead of reinforcing the case for heritage recognition of the Mauna Kea Observatory, such associations cause potential conflict in that some indigenous groups regard the telescopes as encroaching upon land that is, for them, sacred and should not be used for such purposes. A recent meeting that formed part of the IUCN World Conservation Congress held in Honolulu in 2016, seeking ways in which the conflict might be resolved, drew attention to the unique relationship that exists in the Hawaiian Islands between cutting-edge science and technology and indigenous culture, through the medium of the sky and astronomy, and to their common concern to preserve dark starry skies.

An additional issue with regard to modern observatory sites and their dark skies is whether they are more appropriately considered sites or cultural landscapes (in the World Heritage sense),[3] in that they typically comprise collections of buildings and telescopes scattered over a considerable area, including perhaps more than one adjacent mountain peak (as at AURA). The obvious attraction of the cultural landscapes option is that these are “combined works of nature and of man" which raises the possibility of including of both the observatory and its dark sky in an integrated way. Cultural landscapes also embody both tangible and intangible heritage; they result from cultural and natural processes that began in the past and will continue into the future; and change is inherent in living landscapes, something that also applies to working observatory sites. On the other hand, we can recall the concept of a “monument of science” developed in TS1 (p. 267), which encapsulates the idea that an astronomical observatory is an integrated system linking fixed, movable and intangible heritage, and where change and development is inevitable.

There is no simple theoretical solution as to which approach—sites (groups of buildings) or cultural landscapes—would be more appropriate for modern observatories. But the answer could effect dark sky considerations. If the dark sky were viewed as a characteristic of a cultural landscape, its definition—and regulation—would be more complex than for a cultural site (set of buildings and/or monuments). It would also affect the choice of buffer zone. If a property was nominated as a cultural or natural landscape with the dark skies as an additional value, a large buffer zone would need to be considered for regulation, up to and including the skyline.

Conclusions

The dark sky does not constitute a part of a property in the juridical sense: it is not a tangible feature specific to a location, nor is it an immovable attribute of the place. Yet it can clearly be viewed as a natural attribute that can add to the natural value of a property. In certain cases it can also support important historical and social values; in such cases it could (also) be seen as an intangible cultural attribute. In other words, the dark-sky characteristics of a place can feature

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[3] According to UNESCO’s *Operational Guidelines*, a World Heritage cultural property may comprise sites (“works of man”) or cultural landscapes (“combined works of nature and man”). A site may comprise groups of buildings or monuments, for example “groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of Outstanding Universal Value from the point of view of history, art or science.” A cultural landscape is an area “of Outstanding Universal Value from the historical, aesthetic, ethnological or anthropological points of view” which is “illustrative of the evolution of human society and settlement over time, under the influence of the physical constraints and/or opportunities presented by their natural environment and of successive social, economic and cultural forces, both external and internal.”

among a set of attributes of value, cultural or natural, that could together justify OUV. In this case, maintaining those dark skies would become an important management issue. In any case, the quality of the sky can be regarded as a quality of the global landscape, and its conservation (for example, by regulations to control light pollution) as an aspect of good management of the property.

For modern observatory sites and their dark skies, potential OUV is likely to rely mainly upon presenting a site or ensemble of sites

- as technological and scientific implementations leading to major contributions to the history of astronomy [WH criteria (iv) and (vi)];
- as technological and scientific masterpieces [WH criterion (i)];
- as some of the best places on the planet for sky transparency and atmospheric stability [WH criterion (vii)];
- as outstanding examples of international cooperation for human progress in knowledge and science, forming part of a long-standing and ongoing tradition among the community of astronomers [WH criterion (ii)];

and/or

- as peaceful and sustainable examples of the use of exceptional natural locations for human progress in knowledge and science [WH criterion (iv)].

The cultural landscape concept may merit consideration in some cases. This is because it not only encapsulates the interaction between people and their environment but also represents a category of heritage that is intrinsically evolving. The same is true of places of science, and in particular of still-functioning observatories and their dark skies: concepts such as sustainability—the need to preserve cultural and/or natural values in a context that is inevitably changing—apply equally to both.

Issues relating to serial nominations

Paris Observatory is without doubt a place of the foremost importance for the history of astronomy within the history of European civilization. It demonstrates strong integrity and authenticity, is well conserved, and has a good collection of instruments and outstanding archives. Potential OUV might be demonstrated in various ways, just as the OUV of the Royal Observatory Greenwich, UK, is already recognised in terms of navigation and the measurement of longitude (as part of the Maritime Greenwich WHP, whc.unesco.org/en/list/373) and that of Pulkovo Observatory, Russia, as part of an architectural ensemble (the Historic Centre of St Petersburg and Related Groups of Monuments WHP, whc.unesco.org/en/list/540).

It is also clear that Paris Observatory it is one of a family—classical observatories of the Western world, built both within Europe and in the colonies—that, collectively, are very significant in the history of humankind. This group might well include Greenwich, Pulkovo and the Cape Observatory, South Africa, as well as many others. This suggests that a serial nomination might be an appropriate way forward. What are the relative strengths of the individual and the serial approaches?

General considerations

Taking account of the *Operational Guidelines*, of WH Committee decisions and recommendations, and of the reports of the advisory bodies governing evaluations, we can identify the following general considerations concerning serial nominations:

- The group must comprise those places that best demonstrate the potential OUV of the whole ensemble. Various attributes might demonstrate potential OUV under one or more of

UNESCO's criteria, and not all attributes of value have to be demonstrated at every component property in the series. However, each component must contribute significantly to some facet of the overall OUV, otherwise a serial property could represent little more than a catalogue. The comparative analysis, which forms a crucial part of the nomination dossier, must ensure not only that all properties that best support the statement of OUV are included in the sample but also that no equally important sites are excluded, from a global perspective.

- It is possible to include a place already on the WHL within a subsequent serial nomination. Precedents include the Frontiers of the Roman Empire WHP (whc.unesco.org/en/list/430), inscribed in 2008, which includes the pre-existing Hadrian's Wall WHP (UK), inscribed in 1987. Whatever its existing recognized values, as a component of a new ensemble the place must contribute significantly to the OUV of that ensemble as explained above.
- The components of a serial nomination need to be defined in a common way, with an overall management plan and a global conservation policy. This implies, for example, that no serial property could comprise a mixture of "sites" (collections of buildings, monuments) and cultural landscapes. In practice, there are very few WH serial properties that are sets of extended landscapes, an exception being the two mining areas in Slovenia and Spain that form the Heritage of Mercury WHP (whc.unesco.org/en/list/1313).
- Ideally, all the components of a potential serial inscription will be nominated together, as happened in the case of the Struve Geodetic Arc WHP (whc.unesco.org/en/list/1187). However, where this is not practicable (for example, given the complexities of developing transnational nominations), it is possible to adopt a staged approach in which, although the complete set of components is specified at the outset, only a subset of the component properties is nominated in each stage. For inscription, the set of components proposed at the first stage must demonstrate OUV in itself, and the remaining components need to add to that OUV.
- Integrity considerations dictate that a threat to the OUV of any individual component is a threat to the OUV of the serial property as a whole. Thus, if one component is at risk then the whole serial property will be considered at risk and put on UNESCO's list of World Heritage in Danger.

Ultimately, State Parties must make the decision as to whether a single outstanding example or an ensemble would provide a better demonstration of potential OUV (see TS1: 267–268).

Classical observatories

As regards the classical observatories, there are various possibilities of a serial nomination demonstrating a significant advance in science.

A case could perhaps be made for including *all* observatories from the 17th to the early 20th centuries that might wish to be included, as a serial nomination. They were established for similar reasons and very often were the first research institutions in their various countries. The remarkable number of such establishments and their basic similarity is conveyed by the study *Astronomical Observatories: from Classical Astronomy to Modern Astrophysics* (Wolfschmidt 2009).

If a few such observatories were to be chosen, one would have to ask which ones stand out among the generality. Tangible features might include the architecture, the presence of the first instruments of a particular kind, and so on. Intangible factors might include major discoveries made from the site and the public perception of the ranking of an observatory as a whole among other institutions or historical buildings.

A serial nomination could be considered for several observatories within a given country. For example, within South Africa there are two large optical observatories other than the Cape Observatory: the Boyden Observatory of the University of the Free State (formerly a part of Harvard University) and the Republic Observatory in Johannesburg (no longer doing active astronomical research). Both these institutions have campuses, old instruments and buildings, and are associated with some important discoveries (e.g., of the first dwarf galaxies at Boyden, and of the nearest star, Proxima Centauri, at the Republic Observatory). One might therefore consider these three institutions as an ensemble representing foreign observing stations of northern hemisphere institutions. However, one must identify a strong enough thematic linkage to demonstrate potential OUV as an ensemble, otherwise one faces the danger of producing what is essentially no more than a catalogue of sites (TS1:269–270).

Another relevant issue in relation to observatories is the question of whether outlying meridian marks and other peripheral structures in separate locations should be recognised as part of a thematic ensemble. In the case of the Cape Observatory, for example, there remains a north meridian mark on the hill known as Blaauberg, about 20km away across Table Bay. The observatory was also involved with pioneering geodetic surveys. About 75 km to the north are two pyramids that define the end of a geodetic baseline set out by Thomas Maclear in the mid-19th century, and about 140 km to the north is a monument marking Maclear's efforts to verify the geodetic surveys of N-L de la Caille in 1752. These sites already enjoy protection as National Monuments.

On a related issue, there has also been some interest in promoting as global heritage a geodetic arc following the 30°E meridian down through Africa from Egypt to Port Elizabeth in South Africa. This "30th Meridian Arc", initiated in 1883 but only eventually completed in 1954 (Braun 2003; Smith 2006), has been connected to the more famous Struve Arc (whc.unesco.org/en/list/1187), already a serial World Heritage property spanning 10 countries, and suggested as a possible extension to the existing Struve Arc inscription. Aside from the need to establish heritage value that would add to the existing OUV, the administrative complexities of adding a further 10 countries or so to an existing ensemble of 10 countries would be considerable.

Modern observatory sites and their dark skies

The discussion above suggests that some or all of the modern observatory sites and their dark skies included as case studies in this volume could constitute part of a potential serial nomination. Whichever way potential OUV is to be demonstrated, however, the comparative analysis could raise complex issues. For example, not all high-elevation observatories are on mountain summits, an example being the Observatorio Astronómico Nacional (Colombia), constructed in 1803 at an elevation of approximately 2600m but within the city of Bogotá; places with the most exceptional atmospheric quality on the planet are not necessarily on mountains but may (according to some astronomers) also exist in locations where no observatories have been built, e.g. within Turkmenistan and Uzbekistan; and other high mountain summits around the world—including some where major observatories were built before the second half of the 20th century, such as California (USA) and the Pyrenees (France)—do not have the exceptionally high sky transparency and atmospheric stability that marks out such locations in the Canary Islands, the Hawaiian Islands, or northern Chile.

A productive approach may be to adopt a "chronological differentiation" methodology identifying distinct phases of development with different characteristics, while recognizing a particular ensemble of (late-19th and) 20th-century observatories built on high mountains, as a whole, as an outstanding heritage landmark representing the revolution in humanity's understanding of the cosmos that has taken place through scientific and technological cooperation and achievement at some of the most exceptional locations on the planet. For example, one could identify three phases as follows:

- Phase I (1880–1910): Pioneers first conquer high mountains to set up astrophysical observatories.
- Phase II (1910–1960): Such observatories are responsible for discoveries that revolutionized humanity's perception of the cosmos (e.g. the existence of other galaxies; the expansion of the universe).
- Phase III (1960–2000): Technological masterpieces achieved by international cooperation are constructed at the very best places on the planet, leading the way to even greater discoveries and expansion of the boundaries of human knowledge (e.g. cosmic acceleration and dark energy).

In such a scheme, one can simultaneously recognize the importance of Pic du Midi de Bigorre (established—at first as a meteorological observatory—in 1881, becoming an astronomical observatory in 1908) as a pioneering achievement in Phase I, particularly in terms of its elevation (2900m); that of Mt Wilson (case study TS1:206–208), which is not at a particularly high elevation and where the dark sky has been obliterated by light pollution, in terms of its fundamental contribution to cosmology in the first half of the 20th century; and the three "Windows to the Universe" observatories where extraordinary international technological and scientific cooperation maintain the cutting edge at some of the most exceptional locations on the planet.

Archaeoastronomical sites

The potential for a serial nomination of archaeoastronomical sites is explored below with reference to the case study on seven-stone antas (Portugal and Spain).

Intangible heritage

Serial nominations are also possible under the Convention for the Safeguarding of Intangible Cultural Heritage (CICH), raising the possibility of international nominations relating to key intangible themes such as ocean navigation.

The recognition and management of astronomical values at archaeological sites

While ancient sites may have a strong connection to astronomy, in no cases do the astronomical values exist in isolation. So-called "observatories" (Belmonte 2014) are, if anything[4], invariably temples, tombs or other buildings with connections to the sky manifested in features such as their orientation. Thus while Chankillo in Peru presents a unique example of "landscape timekeeping", as the case study puts it—a monumental device that enabled the calendar to be regulated against the horizon rising and setting positions of the sun throughout the year—this existed as part of a ritual complex evidently devoted to a cult that linked warfare, calendrical regulation, sun worship and social hierarchy. Appreciating the social and religious context is vital to the interpretation of the site and the assessment of its value as a whole. Thus, while the potential OUV may be supported mainly by the astronomy, it is essential to take account of the secondary attributes deriving from this broader context.

Similarly, the seven-stone antas of Portugal and Spain represent the remains of tombs which, by being consistently oriented upon points within the solar rising arc on the horizon, manifest a conceptual connection between death, ancestors or ancestral spirits and the rising sun that prevailed over a remarkably wide area during the 4th millennium BC. Their unique importance, astronomically speaking, derives from the fact they provide the earliest examples of a custom of sunrise orientation that is statistically defensible — in contrast, for example, to the

[4] On the question of the credibility of archaeoastronomical evidence see TS1:270–271.

famous solstitial orientation of Newgrange passage tomb in Ireland (part of the Brú na Bóinne World Heritage Property, whc.unesco.org/ en/list/659), which is a "one-off". But any potential World Heritage nomination would also need to acknowledge the broader archaeological context of these monuments, for instance the remarkable consistency in their architectural design.

The existence of solstitial orientations at several monuments within the Stonehenge World Heritage Property (see case study) reinforces their intentionality, although not at the level of formal statistical support. At Stonehenge, in contrast to the other examples, the astronomical attributes of OUV were only recognised retrospectively, after Stonehenge had already been inscribed on the World Heritage List for over 25 years[5] (as part of the Stonehenge, Avebury and Associated Sites WHP whc.unesco.org/ en/list/373). The case study focuses on the management issues that arise as a consequence.

Given that the Chankillo ritual complex as a whole represents the cultural transformation of a natural landscape covering more than 17 km^2, containing not only the thirteen towers that provide the foresights for the solar observation device but also an extraordinary triple-walled fortified temple and various other monumental constructions, both a site and a cultural landscape approach are open as possibilities here.

In contrast, the seven-stone antas are much more modest constructions scattered over many hundreds of kilometres within a developed landscape, which suggests a serial approach. Indeed, such an approach is necessary since the astronomical significance is only evident from the group as a whole (cf. TS1: 269). While the orientation of any particular monument in the group could have arisen through factors quite unrelated to astronomy, it is the fact that all 177 measured sites face within the arc of sunrise that proves this was intentional. The fact that the monuments are, in the main, situated in a flat landscape lacking prominent topographic landmarks demonstrates beyond doubt not only that orientation was a key architectural consideration in the design and constructions of these tombs but that the correct orientation could only have been achieved by reference to the sky. On the other hand, it is clear that not all of the 177 sites (and perhaps no more than a select few) could contribute significantly to the potential OUV, most obviously because of their poor state of conservation and lack of integrity.

Breaking new ground

World Heritage concepts, definitions and processes are not fixed for all time. Indeed, UNESCO's *Operational Guidelines for the Implementation of the World Heritage Convention* (whc.unesco.org/ en/guidelines/) are continually updated to take account of changing concepts and new experience. A good example is the introduction of the concept of cultural landscapes in 1994. Expert workshops are an essential part of this process, an example being that on serial nominations held in Switzerland in 2010 (whc.unesco.org/document/124861), Thematic Studies and other publications, and nomination proposals that raise new issues, periodically motivate and inform revisions to the overall vision of World Heritage.

5 Amanda Chadburn writes: "There are a number of reasons for this. Firstly, archaeoastronomy has developed significantly as a discipline since the 1980s. In parallel, the discipline of landscape archaeology has also developed, gained in importance and become more recognised. This means that our understanding of ancient sites of archaeoastronomy in their landscape context has altered. Secondly, our understanding of the Stonehenge landscape has dramatically changed in the last 25 years, after years of research that has been particularly intensive since 2000 (Darvill 2005). Some new sites of astronomical importance have been discovered. Thirdly, an appreciation of the settings of sites, buildings and monuments has considerably altered in the UK since the 1980s (see, for example, English Heritage 2011), and finally, and management of WHPs has radically changed and developed, for example through UNESCO's *Operational Guidelines for the World Heritage Convention*."

A number of the case studies discussed in this volume break new ground, or at least push beyond existing boundaries, in various respects. For example, the “Windows to the Universe” observatory sites, dating from 1959 onwards, are more recent than any already currently on the World Heritage List. While there is no “time limit” from a World Heritage perspective—indeed, cultural landscapes can include living (intangible) heritage—it is clear that telescopes still under construction could not be considered as tangible heritage, because their potential (in terms of technological achievement and scientific discovery) has not yet been fulfilled. As regards precedents, there are very few historical observatories on the World Heritage List and no observatories from the 20th century (whether or not still undertaking active science). The most recent example on a National Tentative List at the time of writing is Jodrell Bank (UK), founded in the late 1940s. UNESCO has a Modern Heritage Programme (whc.unesco.org/en/modernheritage/) to promote 19th- and 20th-century architectural heritage: cities and urban planning, monuments and palaces, industrial heritage, etc. Examples on the World Heritage List include Brasilia, created in the late 1950s, and several from the early 20th century (whc.unesco.org/document/117571). Potential value under criterion (vi) is not limited in any absolute sense by time, but the value of recent scientific discoveries as intangible heritage must still be recognized and defined by established World Heritage recommendations and practice.

Even at existing World Heritage Properties, OUV is a living issue: it is not defined for eternity, and the revision of OUV is normal. This raises the possibility of modifying the statements of OUV for existing World Heritage Sites so as to include more explicit recognition of their astronomical values: for example, by altering boundaries and/or the buffer zone, by the inclusion of environmental aspects such as dark sky protection, and adding measures to manage and preserve significant sightlines to horizons. The Stonehenge case study explicitly addresses the last of these issues.

The case study of the sun- and star clocks of Oman describes possible refinements or extensions of existing criteria of OUV at an existing World Heritage Property. The *aflaj* (irrigation channels) of Oman were inscribed in 2006 under criterion (v) and the ICOMOS evaluation on p.51 of the nomination file (whc.unesco.org/en/list/1207/documents) recognises that criteria (ii) and (iv) might also be justified on the basis of further information. One could also envisage enhancements of the value under criterion (v). The collection of *aflaj* irrigation systems represents some 3,000 still functioning systems in Oman. Ancient engineering technologies demonstrate long-standing, sustainable use of water resources for the cultivation of palms and other produce in extremely arid desert lands. Such systems reflect the former total dependence of communities on this irrigation, and the astronomical timing of the apportionment of water represents a time-honoured, fair and effective management and sharing of water resources, underpinned by mutual dependence and communal values.

The need to balance the World Heritage List so as to better represent the heritage of human achievements in the fields of science and technology has been clearly recognized for well over a decade, for example in the establishment of the Astronomy and World Heritage Initiative itself in 2003 (whc.unesco.org/en/astronomy/). Yet such heritage raises fundamental issues and demands innovative approaches to familiar concepts such as integrity and authenticity. Additionally, dark-sky recognition has long been problematic in the World Heritage context. This creates difficulties for State Parties and challenges for UNESCO’s advisory bodies.

This Thematic Study demonstrates the feasibility of such nominations on a technical level. Astronomy has a place on the World Heritage List, but not every site considered important by astronomers has a place on this list. At the time of writing, the International Astronomical Union has resolved to establish its own “outstanding astronomical heritage” certification to be attributed to astronomical sites and institutions that had a significant role in the history of astronomy. This will help establish the credibility of the site from a global heritage perspective and, potentially, provide an important step towards World Heritage List nomination in appropriate cases.

Since January 2015, it has been possible for State Parties to request advisory missions as part of the "upstream processes" whereby UNESCO's advisory bodies can provide advice and assistance to governments who are considering potential nominations. (In the case of properties with a connection to astronomy, the IAU understands that it might also be called upon to provide upstream advice alongside the advisory bodies in its capacity as a Partner Organization to UNESCO.) It seems clear that an early upstream involvement from the advisory bodies could be especially important in the development of nomination dossiers in this challenging but hugely important and underrepresented area of human heritage.

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