‘Windows to the Universe’: Leading Optical Observatories and their Dark Skies Chile, United States of America and Spain

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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.

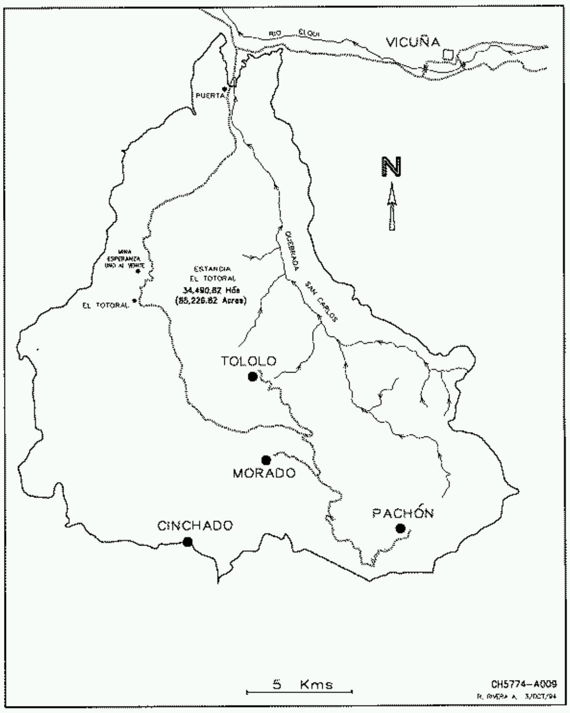


Fig. 10.1. The area of the El Totoral Reserve (Image: NOAO/AURA/NSF)

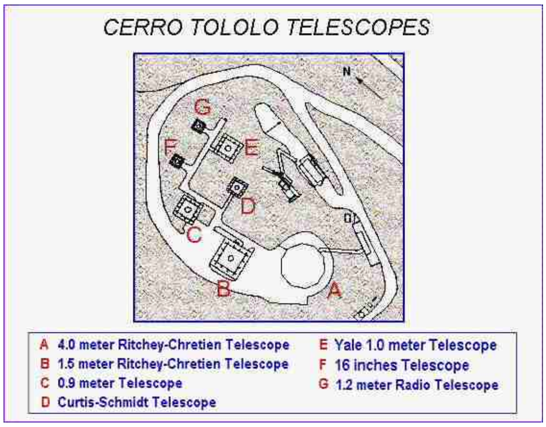


Fig. 10.2. The summit of Cerro Tololo (Image: NOAO/AURA/NSF)

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

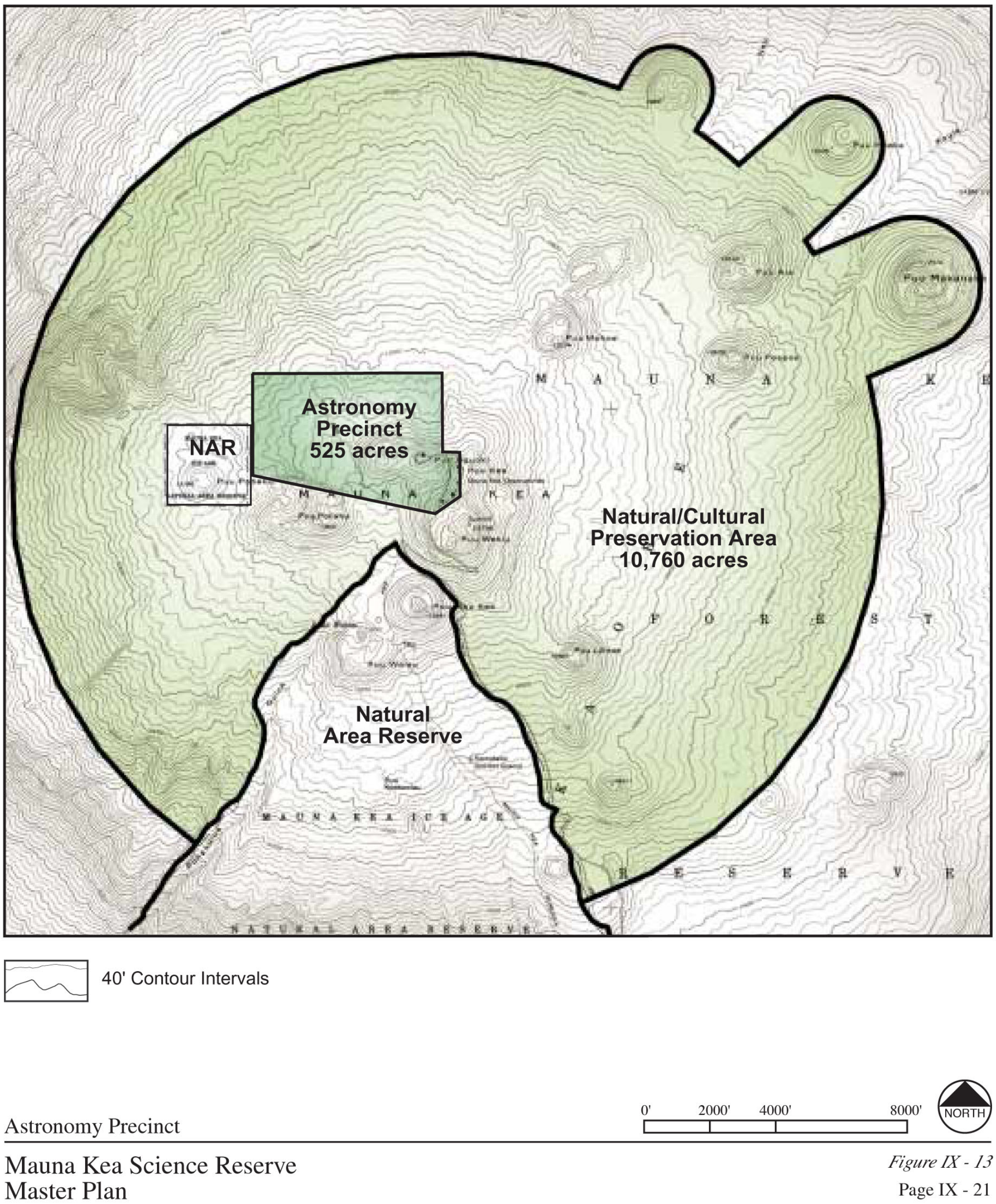


Fig. 10.5a. The astronomy precinct in relationship to the Mauna Kea Science Reserve (colored green), and the Mauna Kea Ice Age Reserve (labeled as "Natural Area Reserve")

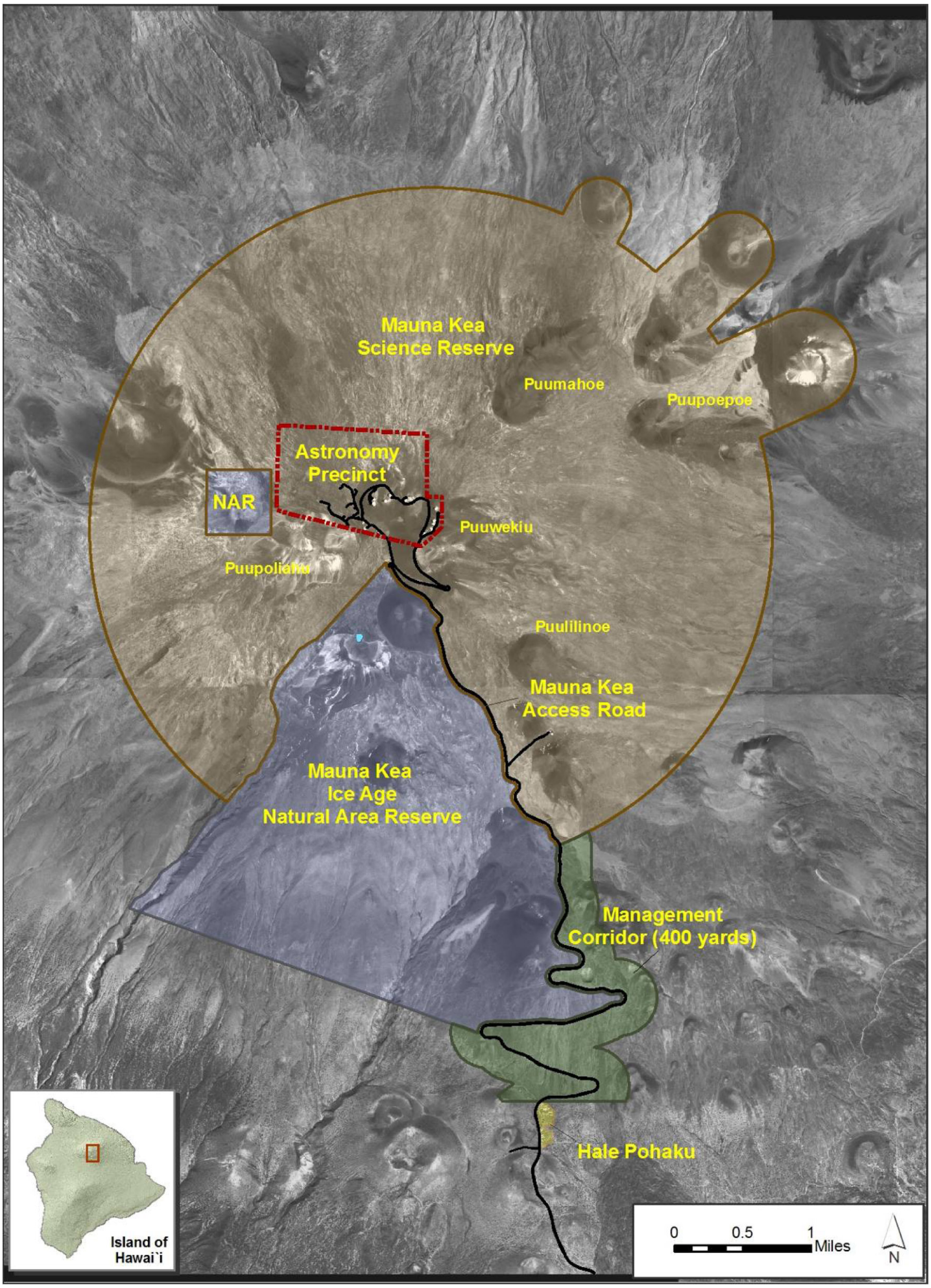


Fig. 10.5b. The Management Corridor, Hale Pohaku, the Mauna Kea Science Reserve, and the Mauna Kea Ice Age Natural Area Reserve

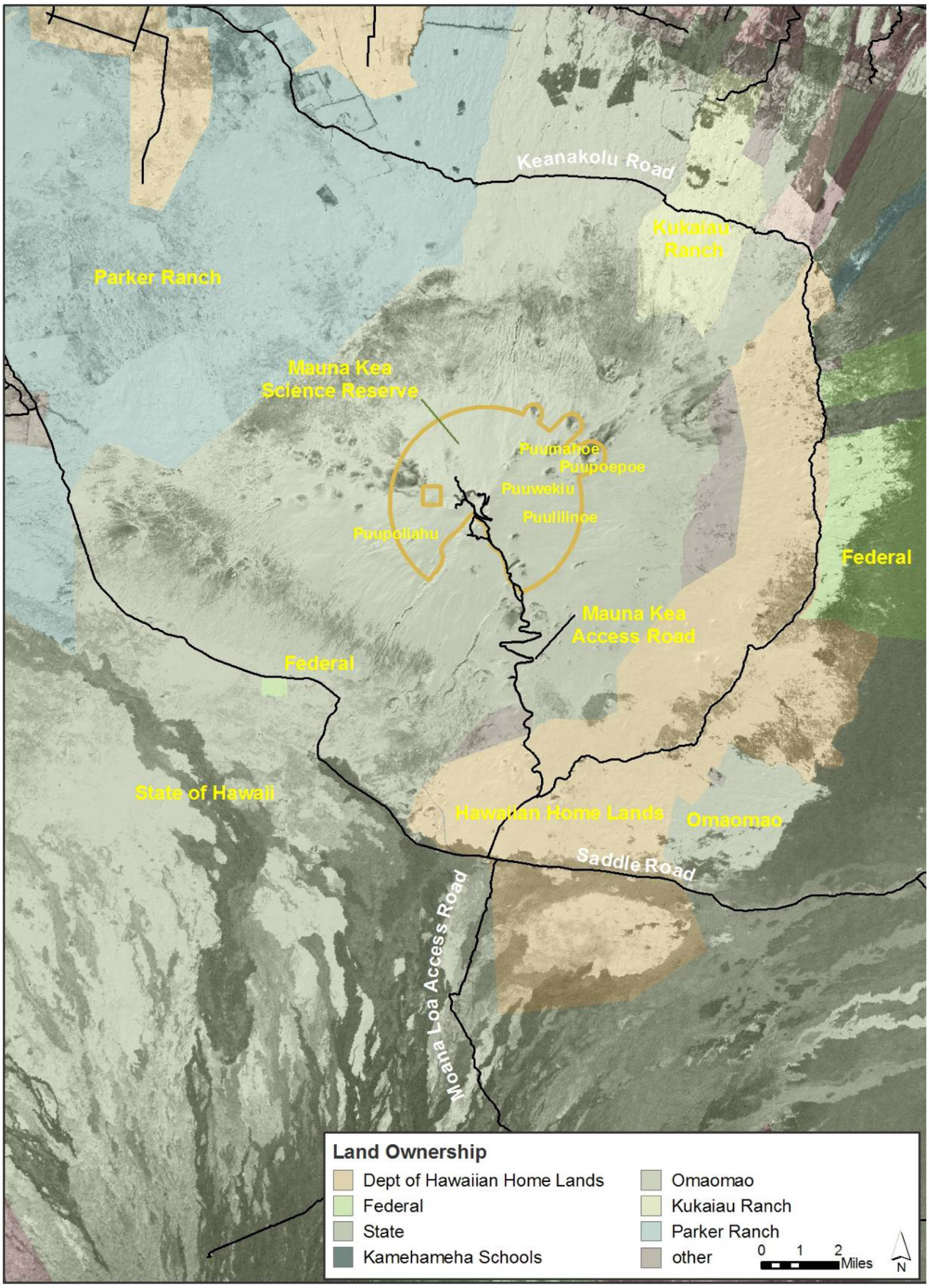


Fig. 10.5c. Land ownership around Mauna Kea

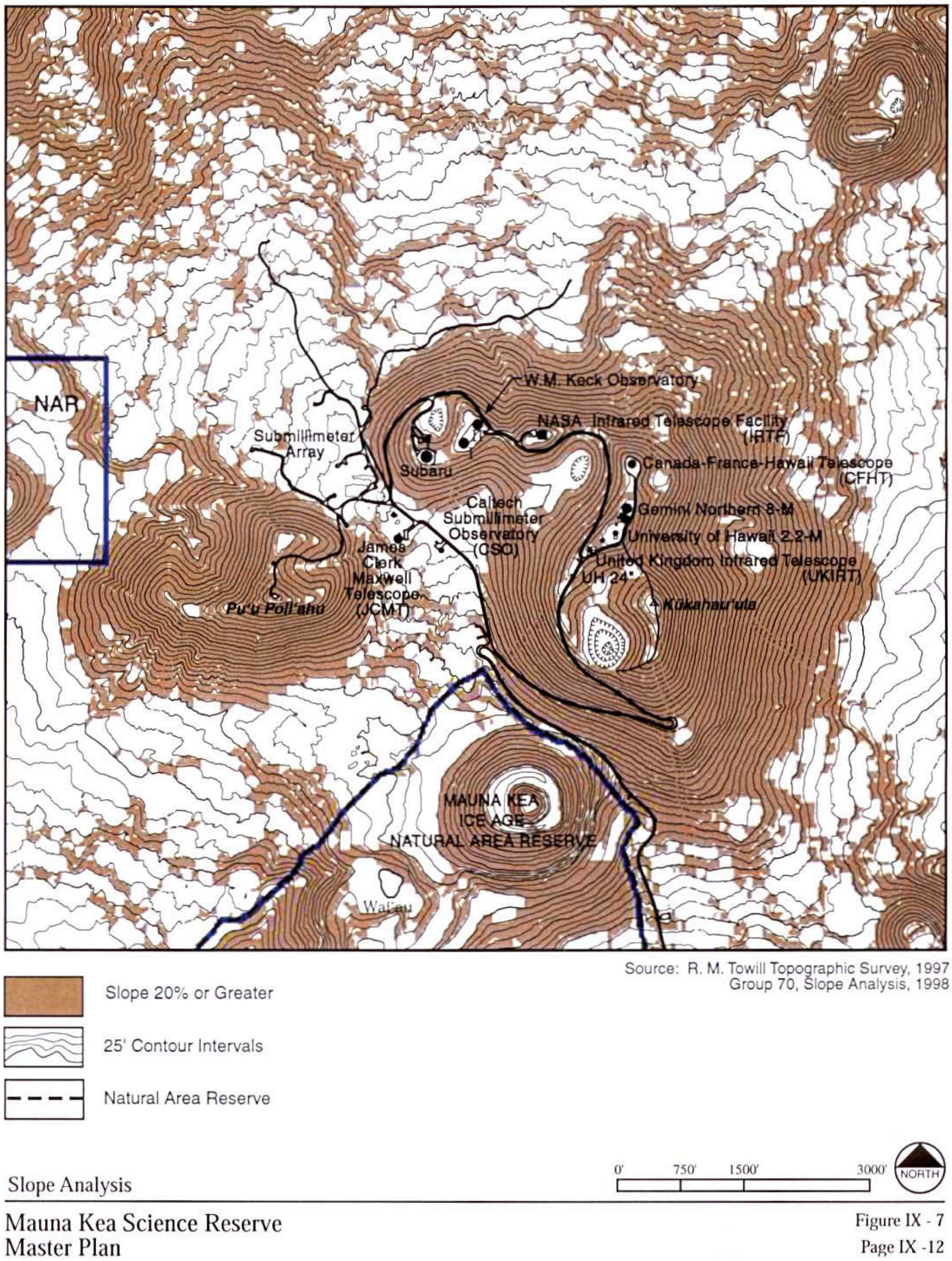


Fig. 10.6. Locations of observatories near the summit of Mauna Kea

	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

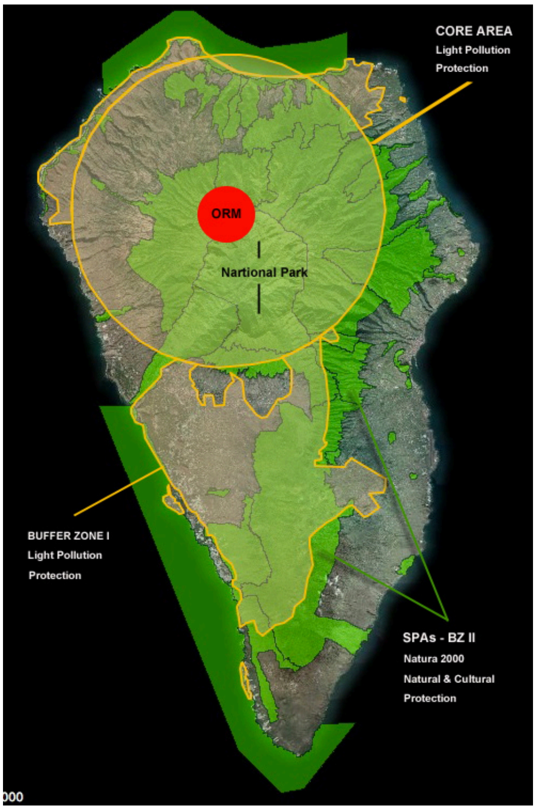


Fig. 10.8. Roque de los Muchachos Observatory (ORM), La Palma, zoning

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

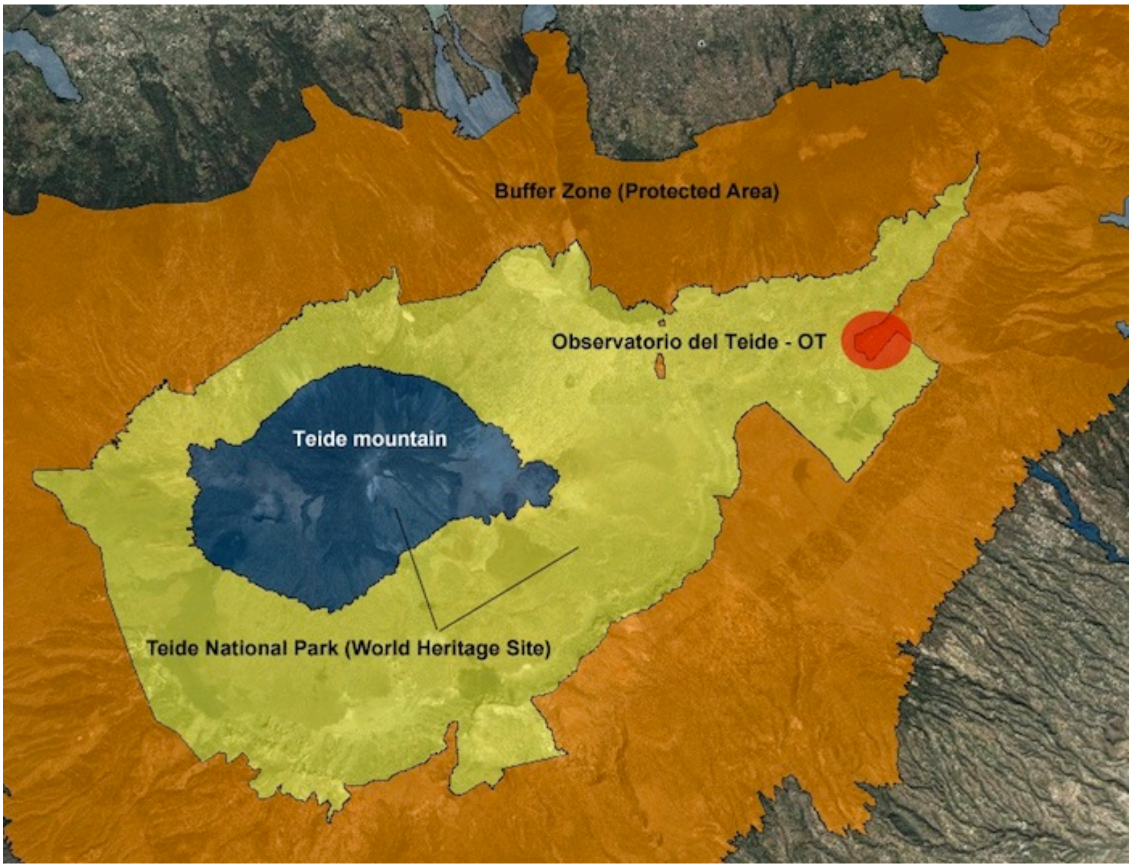


Fig. 10.10. Teide Observatory (OT), Tenerife, zoning

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.

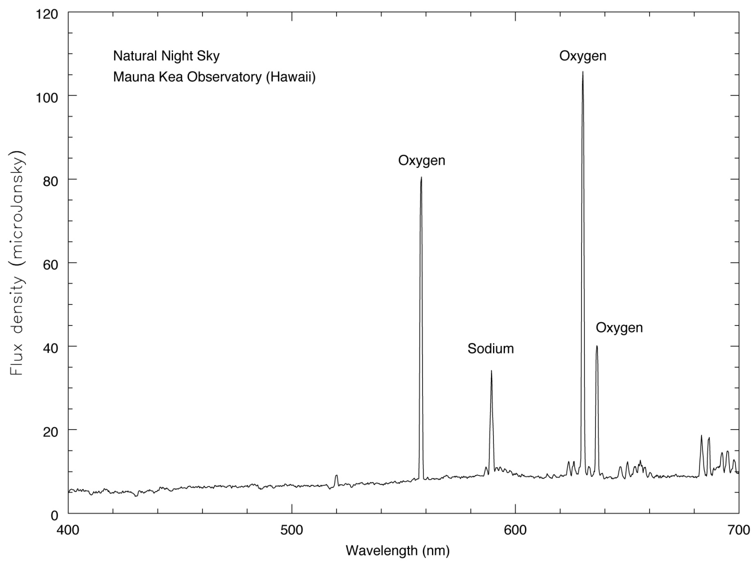


Fig. 10.13. A spectrum of the night sky seen from Mauna Kea. Nearly all of the flux shown here is natural. Sodium emission from low-pressure sodium street lights forms part of the emission near 589 nm.

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”.

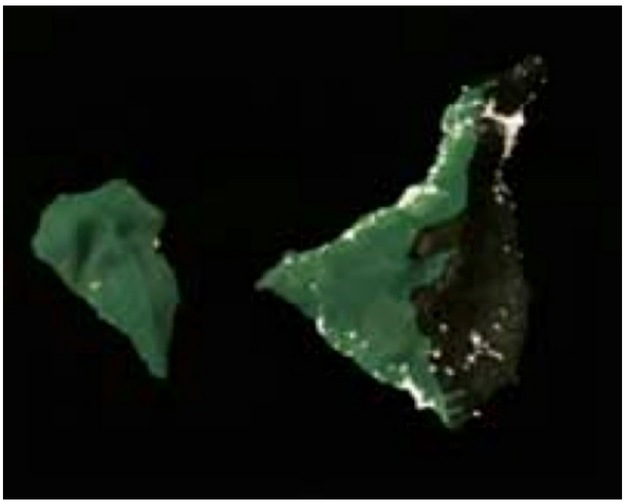


Fig. 10.16. Protection area under the Canarian ‘Sky Law’. © IAC-OTPC (Instituto de Astrofísica de Canarias)

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

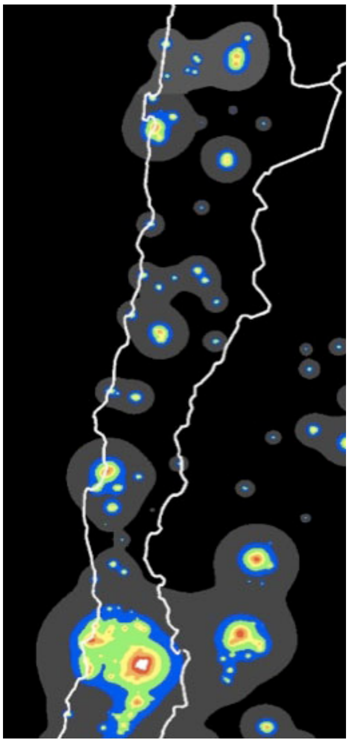
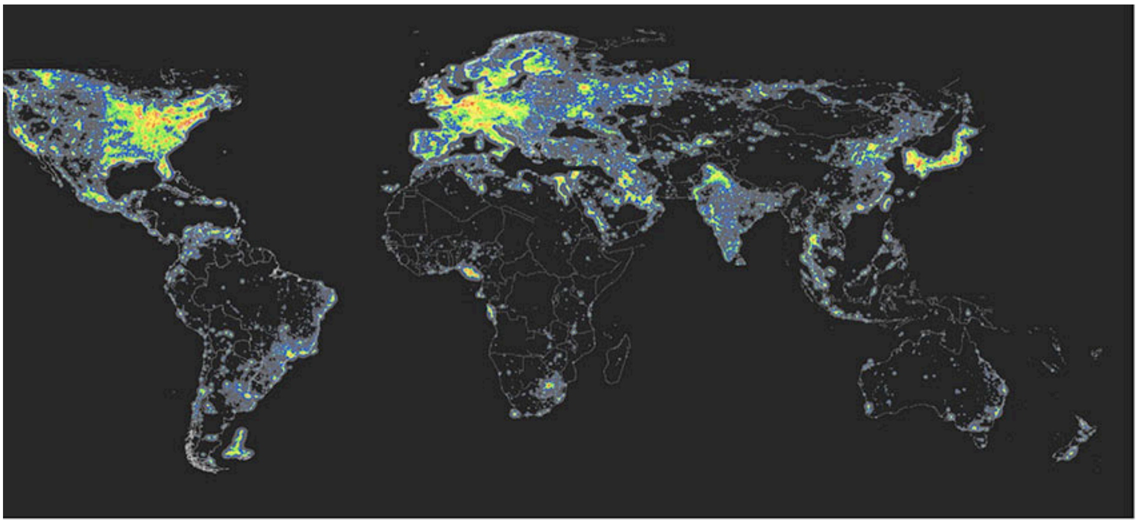


Fig. 10.18. Images based on work done for the *World Atlas of Artificial Night-Sky Brightness* by P. Cinzano, F. Falchi (University of Padova) and C.D Elvidge (NOAA National Geophysical Data Center, Boulder). published in the *Monthly Notices of the Royal Astronomical Society* in 2001. **(Left):** Northern 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.

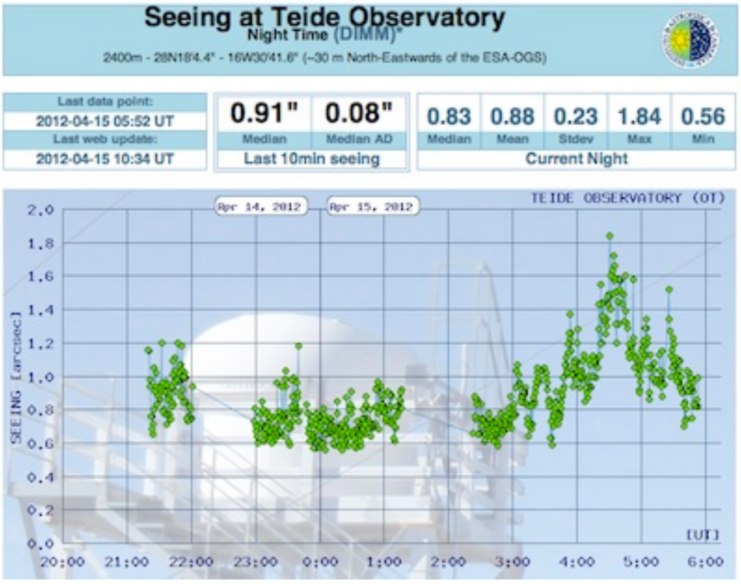


Fig. 10.19. Sky parameters for observing proposals. From the Sky Quality Group web site (www.iac.es/proyecto/site-testing/).

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

Lighting installation criteria
http://www.iac.es/adjuntos/otpc/RESUMEN_DE_CRITERIOS_2012-ENERO.pdf
Protected airspace and occupation procedure, 2001
http://www.iac.es/adjuntos/otpc/esp_prot.pdf
Other overflight restrictions, 2005
http://www.iac.es/adjuntos/otpc/sobrev.pdf
Decision: 31 COM 8B.17. Decisions Adopted at the 31st session of the World Heritage Committee (Christchurch, 2007). Inscription of the Teide National Park, Spain, on the World Heritage List
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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