Chapter 16: 'Windows to the Universe': Starlight, Dark Sky Areas, and Observatory Sites

Cipriano Marín, Richard Wainscoat and Eduardo Fayos-Solá

The sky, our common and universal heritage, is an integral part of the environment perceived by humanity[1]. Starting from this general idea, the Declaration in Defence of the Night Sky and the Right to Starlight, adopted in 2007, states that "an unpolluted night sky that allows the enjoyment and contemplation of the firmament should be considered an inalienable right of humankind equivalent to all other environmental, social, and cultural rights"[2].

Many different factors, but most notably the continued increase in light pollution, are turning this resource—virtually unchanged throughout the history of humankind—into an extremely scarce asset. An essential element of our civilisation and culture is rapidly becoming lost, and this loss is affecting most countries on Earth (see Fig. 16.0.1). Under these conditions, certain places whose sky is still dark, and whose scientific cultural or environmental values depend on starlight, should be recognized and preserved as points of reference to a common heritage in danger.

An eroding nightscape

The importance of preserving places with pristine dark skies not only has repercussions for astronomical observations. It is of vital importance in many different ways. The light of the stars and other heavenly bodies has always enriched the spectacle of terrestrial nature as well as the human habitat, creating reference landscapes traditionally perceived by people as an integral part of their natural and cultural heritage. Starry skies have been one of the most powerful driving forces related to landscape throughout the ages, but in recent times, all over the world, they have been losing their power. The nocturnal 'skyscape' or 'starscape', in spite of its diversity and magnificence, remains the most hidden aspect of the current concept of cultural and natural landscape.

Nightscapes can be very diverse. They include starry landscapes related to rural areas, urban oases, and 'geoparks', as well as natural areas or sites associated with tangible and intangible astronomical heritage. All cultures throughout history have identified the most privileged sites for the observation of the firmament. Each of these places has its own vista of starlight handed down through the generations. These sites and settings should be preserved to prevent them losing their meaning.

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[1] Explanatory Note concerning the Proclamation of 2009 as the International Year of Astronomy (33rd session of the UNESCO General Conference).

[2] The Declaration was adopted on the occasion of the Starlight Conference held in La Palma in 2007. It was promoted by (among others) UNESCO, the IAU, the UN–World Tourism Organisation (UNWTO) and the Instituto de Astrofísica de Canarias (IAC), with the support of several International Programmes and Conventions, such as the World Heritage Convention (WHC), the Convention on Biological Diversity (CBD), the Ramsar Convention and the Convention on Migratory Species (CMS), the MaB Programme, and the European Landscape Convention.

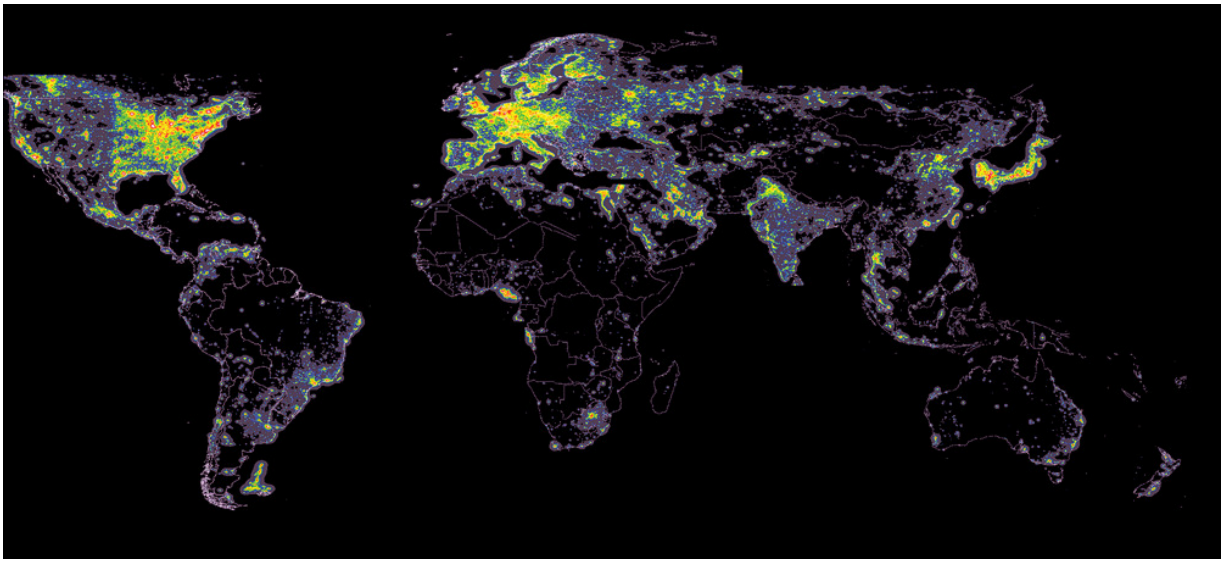

Fig. 16.0.1. The World Atlas of Artificial Night Sky Brightness, by P. Cinzano, F. Falchi (University of Padova) and C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). © Royal Astronomical Society. Reproduced from the *Monthly Notices of the Royal Astronomical Society* [328 (2001), 689–707] by permission of Blackwell Science.

Examining starry night landscapes soon leads to the recognition that it is imperative to protect dark skies in order to preserve essential parts of our common heritage. In fact, there are several reasons to protect the natural night sky:

The preservation of starscapes related to geology. Some geological landscapes are at their most impressive in combination with the nocturnal sky. Sites like Cerro Ventarrones in the Atacama (Chile), the natural bridges at Arches National Park and the Alabama Hills (USA), Mount Norikura (Japan), Arkaroola Wilderness Sanctuary (Australia) and Pic du Midi (France), provide just some examples of how geological landscapes blend with starlight, creating emblematic natural spaces at night.

Commemorative integrity, or the authenticity of historic sites, monuments and cultural-ritual skyscapes. The quality of the night sky can often affect the integrity of the tangible cultural heritage of astronomy. Starry-sky settings are inherent to the perception of cultural landscapes relating to the view of the firmament, and the degradation of this element at sites such as Rapa Nui (Chile) and Montaña de Tindaya (Spain) would result in the decontextualisation of the protected heritage itself. A similar consideration applies to prehistoric monument ensembles associated with the vision of the firmament, such as Zorats Karer (Armenia) and Stonehenge (UK; see Case Study 2.1). The loss of integrity that has already taken place is even more evident at historical observatories such as Cheomseongdae (Korea; see Case Study 5.4) and Jantar Mantar (India; see Case Study 6.1), as well as at more recent ones, such as Armagh (UK) and Mount Wilson (USA; see Case Study 12.4).

The preservation of cultural traditions, both modern indigenous and classical, that relate to the night sky. The relentless increase in light pollution causes the disappearance of starry skies, not only physically but also culturally. This can result in the irrevocable loss of intangible heritage—legends, folk tales, children's stories, old pilgrimage routes, and traditional festivals relating to the night sky—across the globe. This situation suggests that this dimension could be considered for inter-convention recognition, in particular with the Convention for the Safeguarding of the Intangible Cultural Heritage.

Ecological integrity of natural environments. The experience accumulated in protected dark-sky areas such as Torrance Barrens (Canada), Galloway Forest Park (UK) and Hortobágy National Park (Hungary), in emblematic places for nature conservation such as Doñana (Spain) and the East Alpine Starlight Reserve (Austria), and exceptional landscape areas like the MacKenzie Basin (New Zealand), forces us to consider very seriously the importance of night-sky quality for conserving nature and the remarkable values that certain places have with regard to the night. Darkness and natural lighting at night are indispensable for the healthy functioning of a range of species and ecosystems. We tend to forget that life goes on for 24 hours a day and that ecosystems have adapted themselves to the natural rhythms of the moon and stars in the course of millions of years of evolution. As over half of the creatures living on this planet are nocturnal, any degradation in the quality of the sky, by day or by night, is having a profound effect on their behaviour and on the equilibrium of the biosphere.

For reasons related to the conservation of nature, and in recognition of the other benefits of dark skies, the Dark Skies Advisory Group of the IUCN's Cities and Protected Areas Task Force supports the inclusion of night sky protection and appreciation in world heritage considerations, either as one of the outstanding universal values of a heritage site, or as part of a new class of protected area.[3,4] In this context, and in view of the different approaches to this issue, it is worth recalling the appeal made by the Starlight Declaration (2007):

> "The Conference requests the five Conventions in the Biodiversity Liaison Group to examine the outcomes of its deliberations and, if appropriate, take to their governing bodies a combined view of the role of the conventions in helping increase protection for the night sky, understanding that this action will have positive effects on landscape conservation and the wise use of biodiversity".

Appreciation of the integrity, character and beauty of urban and rural landscapes. Nowadays it is unthinkable that minds such as Vincent van Gogh would create works of art such as 'Starry Night'. The loss of the dark sky is not only affecting cities, because the adverse effects of light pollution can extend for hundreds of kilometres. The European Landscape Convention, as well as initiatives such as the Campaign to Protect Rural England (CPRE)[5], have now started to address this issue.

When speaking of the possibility of preserving pristine dark skies, we are not only referring to locations far away from cities and bright areas, remarkable natural landscapes at night, and unique settings related to astronomical activity in human culture. There are also areas near cities, towns and villages whose value in relation to natural or cultural heritage cannot be considered exceptional, and whose sharpness parameters do not meet the required standards for astronomical observation, but which do, nonetheless, offer excellent opportunities for education in astronomy and the possibility of enjoying (relatively) dark skies. In areas such as Großmugl Starlight Oasis (Austria) (see Case Study 16.2), Monfrague National Park (Spain) and the various public observatories in the Coquimbo Region of Chile (see Case Study 16.3), the dark night sky provides a critical element in the natural outdoor experience in relatively accessible places. Here, people can still have easy access to a type of heritage at risk: starlight.

Certain sites combine several different qualities and exceptional values in the same place: they are multifunctional windows to the universe. This is the case at Lake Tekapo–Aoraki–Mount Cook (see Case Study 16.1). This region has outstanding natural landscapes of

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[3] Welch, D., Trzyna, T. and Lopoukhine, N.. Prologue by the IUCN's Dark Skies Advisory Group (DSAG) to the Report of the 'Starlight Reserves and World Heritage' Expert Meeting, March 2009.

[4] Note [MC & CR]: This support for the inclusion of night sky protection and appreciation in world heritage considerations is not necessarily shared by ICOMOS.

[5] With the support of British Astronomical Association's Campaign for Dark Skies (CfDS).

exceptional scenic beauty, enhanced by a starry sky setting. Both the quality and the clarity of the night sky are very high, which has led to the establishment of an observatory and to significant stargazing tourism. It also is a place of significance for the Maori, who visited the area for generations for food gathering and to observe the regular 'night visitors'—the constellations. Another example is Onk Jamel (camel neck) in southern Tunisia, a landscape of great dunes under the stars historically crossed by caravans, which includes exceptional troglodyte settlements. Places such as this, where multiple natural and cultural values converge, deserve special attention when considering the preservation of the dark night sky.

The World Heritage Convention refers to science in Articles 1 and 2. More specifically, in Article 2 it establishes that the following shall be considered as natural heritage: "natural sites or precisely delineated natural areas of outstanding universal value from the point of view of science, conservation or natural beauty". Nevertheless, as in other Conventions, the most emblematic dark sky areas and their associated scientific, cultural or natural heritage, are not taken into account as an indivisible whole, regardless of how exceptional they are. In terms of heritage identification to date, the day is considered immutable, while night is ephemeral.

Where the Earth meets the universe

The scientific aspect of a starry night is an essential part of the legacy of the sky. The ability of the planet's astronomical sites and observatories to detect and interpret data from outside the world we live in should be considered as a resource of extraordinary value for the progress of knowledge, as it has been throughout history. Dark skies are still the windows to our knowledge of the greater universe.

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 offering good conditions for the development of astronomy, and of optical and infrared astronomy in particular. There are only a few places on the planet where we find this unique combination of environmental and natural circumstances: well-conserved spaces with very little alteration to natural starlight.

The quality of astronomical observation is influenced in many ways by the Earth's atmosphere. Although these effects can be eliminated by launching telescopes into space, space astronomy is extremely expensive, very large telescopes cannot be launched into space, and servicing and maintaining space telescopes is difficult or impossible.

The identification of windows on the Earth for the observation of the universe is a task where several limiting factors come into play (Table 16.0.1). Most of them affect the sharpness of images, something that is of paramount importance in astronomical observation. Blurry images cause confusion, and nearby stars cannot be resolved from each other. Faint stars take much longer to detect if the images are blurry.[6]

At mid-latitudes, the wind direction in the upper atmosphere is from west to east. This arises from Earth's rotation and the Coriolis force. As a result, the air arriving at the west coast of a continent or isolated island flows in a non-turbulent manner. It is in such places that we obtain the sites that have the best image quality, since they lack turbulence caused by phenomena such as the mixing of cooler and warmer air that causes blurring of stellar images.

[6] With a good detector, the signal-to-noise ratio is: Signal-to-noise = N^* / sqrt (N^* + *npix*(*Ns*)), where N^* is the number of photons from the star, *npix* is the number of pixels containing the star and sky, and *Ns* is the number of photons per pixel from the sky. Sharp images reduce *npix*, and therefore allow observations to be acquired more quickly. An elevated sky background from artificial light makes astronomical observations more difficult and slower.

Table 16.0.1. **ATMOSPHERIC FACTORS AFFECTING ASTRONOMICAL OBSERVATION**
Turbulence in the atmosphere air blurs images of stars and other objects — turbulence causes mixing of cooler and warmer air, and the turbulent air acts like a lens, blurring images of astronomical objects.
Weather (e.g., clouds, rain) prevents observations some of the time.
Water vapour and carbon dioxide absorb infrared light at some wavelengths, making the atmosphere opaque.
Air molecules and aerosols scatter artificial light, making the sky bright.
Molecules and atoms high in the atmosphere absorb sunlight during the day and re-emit it at night, creating a dim glow from the atmosphere at night.

Observatories must be located at sites with good weather. Tropical rain forests and temperate rain forests are clearly not good locations for observatories. In general, trees are not consistent with good observatory sites. The equatorial region has (meteorological) convergence and hence a lot of rainfall. Latitudes close to 60 degrees are also regions of convergence, and are poor locations for observatories. However, latitudes close to 30 degrees (north or south) are regions of subsidence (dry air) and are good locations for observatories.

Wind is also an important consideration. High altitudes have strong winds while mid altitudes have gentler winds. Low altitudes have more air pollution, and there is a low moist marine layer in coastal locations. Lower altitudes also have more atmospheric turbulence, because there is more air to look through. A temperature inversion often traps the moisture and air pollution at lower altitudes.

The dominant west-to-east airflow means that mountains on the west coast of continents, or isolated islands with moderately high mountains, are ideal locations for observatories. The mountains allow the observatory to be located above the turbulent lower atmosphere. In addition, clouds at lower altitudes can blanket artificial light sources, reducing light pollution.

Observatory sites must also be accessible. They cannot be too high, since higher altitudes are very difficult to work at. Antarctica is an excellent site for astronomy, but is not easily accessible, and the northern sky cannot be seen from there. Observatory sites should also be geo logically stable. High-seismicity zones, active volcanoes and glaciers must therefore be avoided.

Collisions of Pacific and American plates have created mountain ranges along the west coast of North and South America. At mid-latitudes, these mountains are in California, Baja California, and northern Chile. The mountains in California are located too close to major light sources, and are no longer good observatory sites. Instead, several areas in Northern Chile and Baja California (Mexico) have excellent qualities and feature appropriate locations for observatories. Other continents, such as Australia, do not have suitable mountains on the west coast.

Volcanic hotspots have created the Hawaiian and Canary Islands. These isolated islands each have excellent observatory sites, most notably Mauna Kea Observatory in Hawaii, and Teide and Roque de los Muchachos Observatory in the Canary Islands. The South Island of New Zealand has suitable high mountains along its west coast, but is located further south in the ‘Roaring Forties’ zone, so that weather conditions along this coast are not optimal, although on the east side of the mountains there is a protected high-country plateau, the Mackenzie Basin, which is moderately good for optical astronomy. Observatory sites in South Africa (SAAO Site), Arizona and Texas are also good, but not as good as the Chilean, Hawaiian and Canary Island sites, because they are located further from the coast.

The above-mentioned sites are characterised by extraordinarily good sky-quality parameters that determine exceptional windows to the Universe. These are:

- Useful Time (of clear sky).
- Sky background (darkness)
- 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.]

Having identified the best locations for astronomical observation throughout the planet, it is critically important to try to conserve and protect them. It is essential to include sites in each hemisphere, since northern sites cannot see parts of the southern sky and southern sites cannot see parts of the northern sky. In addition, there are natural and man-made threats to the observatory sites that make it essential to protect several of them in each hemisphere. These threats include volcanic eruptions, major earthquakes, mining and atmospheric pollution as well as light pollution. For these reasons it is critical not to concentrate exclusively on the most outstanding observatories in isolation, but to develop a collective vision of an ensemble of windows open to the universe, needing to be kept open and protected appropriately.

These exceptional sites, including their natural components, can be considered as 'landscapes of science and knowledge'. It is no surprise that the world's largest contemporary observatories are located in these places: Keck I and II, Subaru, and Gemini North in Hawaii; Gran Telescopio Canarias in La Palma; Very Large Telescope 1,2,3 and 4, Magellan 1 and 2 and Gemini South in Chile; the Giant Binocular Telescope and Multiple Mirror Telescope in Arizona; the South African Large Telescope in South Africa; and the Hobby Eberly Telescope in Texas.

These are true scientific monuments, and we recall that Article 1 of the Convention defines cultural heritage as monuments and groups of buildings that "are of outstanding universal value from the […] scientific point of view". At the same time the locations of these observatories are all, to a greater or lesser extent, important historically in the context of indigenous cultures and their astronomy. Case Studies 16.3–16.5 (northern Chile, Hawaii, and the Canary Islands) present prominent examples in more detail.

Fig. 16.0.2. 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.

The management of dark sky sites

The effective preservation of dark areas requires the establishment of appropriate criteria for their management, especially with regard to the mitigation or elimination of light pollution. It is important to identify and establish 'umbral' zones, together with 'penumbral' zones around them, depending on the level of impact on the type(s) of value to be preserved in the dark sky area concerned. Different approaches might be needed, in other words, depending upon whether the aim is to preserve clear skies for astronomical observations, the scenic context of cultural sites related to astronomy, dark skies for wildlife conservation, natural areas or nightscapes, or any combination of these. According to the function of each site, the requirement level will be higher or lower. The zoning systems proposed to date are similar, in terms of night-sky quality, to those established in areas such as biosphere reserves or other protected entities.

The Starlight Reserve concept, developed in cooperation with the 'Astronomy and World Heritage' Thematic Initiative, establishes a zoning scheme of this type, consisting of a core zone, a buffer zone and an external zone. A set of requirements and general recommendations on total exclusion or the intelligent use of artificial lighting has been specified for each area, and these have been compiled into a Guide.[7] This guide has been proposed and developed as a general reference document for World Heritage Sites and in particular for those related to astronomy. Similar considerations are found in the application criteria developed for International Dark Sky Parks and Reserves by the International Dark Sky Association (IDA) (http://www.darksky.org/).

The dark sky should also be considered as an additional criterion for existing World Heritage Sites. This does not just include those having astronomy-related values, but any cultural landscapes and natural areas sensitive to alterations to the natural lighting. Furthermore, reducing light pollution at cultural sites connected with astronomy can be considered, at the very least, an exercise in coordination that helps to safeguard the integrity of the site.

With regard to legal issues, it should be noted that some of the most important areas for astronomical observation were also important in pioneering the development of regulations and laws to ensure the adequate protection of sky quality. The first attempts to regulate light pollution were made in the USA (for example, at Arizona), but the first national law that explicitly protects the sky for astronomical observation is the 1988 'Ley del Cielo' ('Sky Law') that protects the Canary Islands' observatories. Chile subsequently developed its 'Norma Lumínica' and Hawaii an ordinance for the Mauna Kea Observatory. Lake Tekapo is also governed by an ordinance: this dates from 1981 and is a pioneer of its type. These issues are dealt more in depth within the case studies.

These pioneering initiatives have provided an example that has been copied progressively in the last decade, spreading out to other areas, and from protected sites to cities. More than 200 initiatives have commenced in the last decade, culminating in advanced laws and regulations on intelligent lighting, such as the most recent law against light pollution passed in the Lombardy Region (Italy). Some of these legal instruments have been designed to face simultaneously the dual challenges of protecting the quality of the night sky and supporting energy-saving intelligent lighting systems—both fighting against climate change and recovering starry skies.

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[7] This Guide was finalised at the International Workshop and Expert Meeting on 'Starlight Reserves and World Heritage: scientific, cultural and environmental values', held in Fuerteventura in March 2009. The Starlight Reserve Guidelines were prepared with the participation of over 100 international experts and developed in cooperation with the World Heritage Centre and organizations such as the International Astronomical Union (IAU), the IAC (Instituto de Astrofísica de Canarias), UN–World Tourism Organization, the International Commission on Illumination (CIE) and the MaB Programme, with inputs from IDA (International Dark Sky Association) representatives.

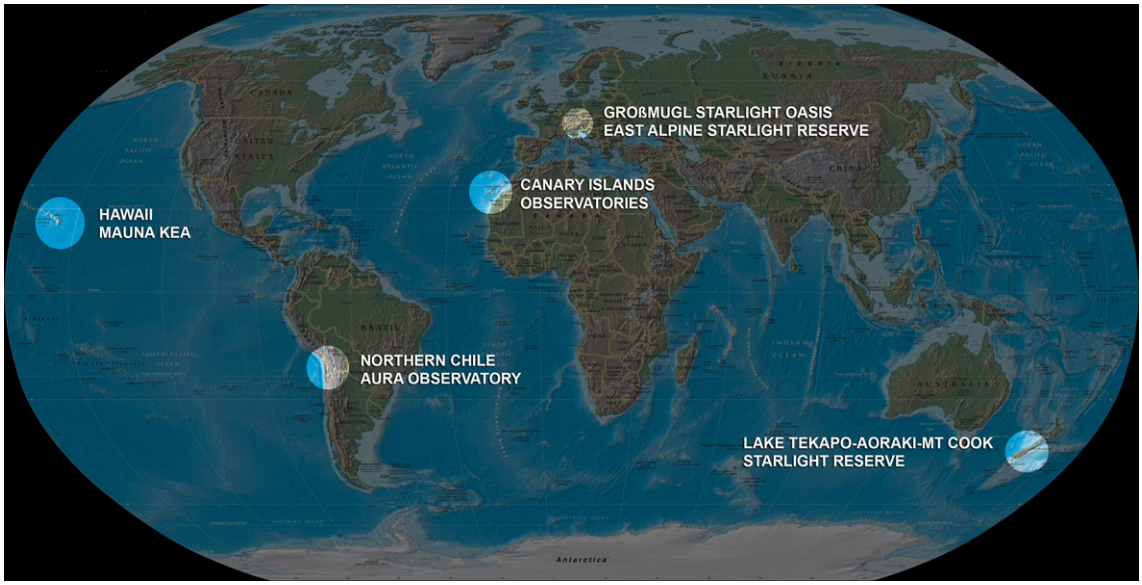

Fig. 16.0.3. The case studies. Elaboration on CIA's *Physical Map of the World*, 2004.

The fragile light of stars can become an engine for sustainable development in local communities. 'Star tourism' opens up new possibilities for responsible tourist destinations, offering such diverse activities as watching starry skies, aurorae and eclipses; visits to astronomical observatories; sailing holidays featuring navigation by the stars; following pilgrimage routes; discovering the nature of the night; or experiencing a desert under the stars. All of these have the potential to become viable, sustainable sources of income and employment, and are already beginning to do so in an increasing number of areas around the world.

Starlight tourism also makes it possible for the first time to bring science and tourism together. Star destinations can be defined as visitable places characterised by their excellent potential for the contemplation of starry skies, and this encourages the development of tourist-educational activities based on this resource. Star tourism not only allows science to be recognised as a tourist product but also, at the same time, develops new working methods in tourism, through science-based standards and procedures. This has been already done in cooperation with UN-WTO for the development of the Starlight certification. This innovation also shows that an appropriate blend of science and tourism can contribute to the global acceptance of the 'green economy' and the 'global sustainable village'.

Starlight destinations are diverse, including observatory sites, landscapes relating to the cultural heritage of astronomy, and natural dark-sky areas of outstanding beauty. The Alpine Starlight Reserve case shows us how night skies are already well embedded in National Park programmes including night hiking and the observation of nocturnal species. Many such programmes rely on the natural night-time environment, integrating astronomical observation and additional night resources. The development of this type of tourism is also important in reducing tension between modern astronomy and indigenous concerns: astronomy becomes a driving force of development in local communities. In the case of Italy's Amalfi Coast, the first customers and recipients in this new era of tourism are the local communities, who avoid the creation of segregated resorts and instead share the enjoyment of a common heritage.

The heritage of science continues to be insufficiently recognized, something that was stressed as recently as 2008 at a UNESCO International Expert Meeting on Science and Technology held in London. A part of the necessary recognition, at least in the astronomical field, may come from a new concept of tourism. In addition, the starry sky can highlight the strong link between tangible and intangible heritage.