Dark and Quiet Skies for Science and Society

Report for review

Online workshop 5-9 October 2020

Protection of dark sky oases

Dark Sky Oases

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Dark and Quiet Skies Conference

Dark Sky Oases Working Group

Report to COPUOS

Executive Summary

This chapter discusses the nature and causes of a bright night sky resulting from light pollution. In particular, a bright night sky arising from artificial light at night (ALAN) impairs our ability to see the stars at night. This has an adverse effect for professional astronomers, for amateur astronomers, for astro-tourists and for those who want to admire the beauty of a pristine and dark night sky.

Light pollution also has a number of additional adverse effects which are briefly discussed; they include reduced safety at night, wasted electric power, environmental harm and a probable adverse effect on human health. Other chapters in this report cover some of these topics in more detail.

This chapter focusses on mitigating the effects of ALAN in dark sky oases, also known as dark sky places. These are areas where the night sky has some form of legislative protection from the effects of ALAN, through the means of lighting ordinances or local or national protocols or bye-laws. Such protected areas have been granted accreditation by one of several internationally recognized accreditation organizations, notably the International Dark-Sky Association (based in Arizona) and the Starlight Foundation (based in the Canary Islands).

The International Union for the Conservation of Nature (IUCN) has classified dark sky oases into six classes, based on the type of use to which the oasis dark skies are put (such as astronomical research, astro-tourism, heritage values, wilderness areas used for public education and outreach etc.). The IUCN classification scheme has been adopted here. In May 2020 there were 223 dark sky oases covering more than 20 million hectares with accreditation for their dark skies. The number is growing strongly every year.

Light pollution and bright night skies are a significant problem in eastern North America, Western Europe, India and eastern China. Many people in these places are unable to see the Milky Way at all. In the most populated places only a few stars may be visible to the naked eye at night, compared to several thousand in dark sky oases.

The work of the International Dark-Sky Association and of the Starlight Foundation is outlined, and the dark sky oases they have accredited (or certified) are summarized. The Aoraki Mackenzie International Dark Sky Reserve in New Zealand, with IDA accreditation, and the La Palma Starlight Reserve in the Canary Islands, with Starlight Foundation certification, are presented as typical case studies.

Light pollution has increased dramatically in many countries since the end of WW2 as a result of the proliferation of outdoor street lighting and the use of lighting for commercial locations such as factory yards, ports and sports facilities and the floodlighting of buildings of heritage value.

The effects of light pollution depend very much on the type of lamp and light source used. A short survey of different lamp types is given. The dominant rise of light-emitting diode (LED) lamps in the last decade is noted. Many LEDs have significant blue emission which is largely absent from sodium arc lamps. (Here blue light is defined as that with a wavelength less than 500 nm.) The harmful effects of ALAN in brightening the night sky are considerably greater for blue light, as a result of the wavelength dependence of light scattering in the atmosphere. In this respect, LED light sources present an increased hazard for light pollution and enhanced sky brightness, unless the most recent types of low colour-temperature amber LEDs are used, which have much reduced blue light emission.

The need to mitigate the effects of ALAN have been recognized by a number of countries and localities over the last fifty years, and this has resulted in lighting ordinances or lighting bye-laws to be enacted. These regulations often require exterior lights to shine below the horizontal, and they may place limits on the blue-light emission and require lights only to shine where and when they are required for safety or other essential reasons.

The value of dark sky oases for the economy, for science, for promoting culture, for environmental protection, for human wellbeing and for promoting astro-tourism is discussed.

For the six classes of dark sky oasis recognized by IUCN, values of the maximum desirable night sky brightness are proposed. These are aspirational values, and in particular locations may not be attainable or in others, they may be exceeded with yet darker skies. The values range from 10 per cent more sky brightness than the naturally occurring airglow (applicable in the vicinity of astronomical research observatories) to four times the natural airglow for protected dark sky sites near more urban areas.

Finally, a number of technical lighting recommendations are made which will assist dark sky locations to realize the sky brightness limits advocated here. These recommendations are based on the principles that exterior lighting should only be used where and when it is absolutely necessary; that exterior lighting should shine down and not above the horizontal; and that the emission of blue light should be strongly curtailed.

Dark Sky Oases

Report from UNOOSA/IAU conference, La Palma, Canary Islands

October 2020

to COPUOS

Final version 21.09.2020

N.1. What is light pollution?

Light pollution is a sum of all adverse effects of artificial light at night, more accurately known as obtrusive light - spill light emitted by a lighting installation which falls outside the boundaries of the property for which the lighting installation is designed and because of quantitative or directional attributes, gives rise to annoyance, discomfort, distraction, or a reduction in ability to see essential information.

Light pollution of the night sky occurs when photons from artificial light at night (ALAN) travel up into the atmosphere and are then scattered back down by air molecules or aerosol particles in the Earth's atmosphere. The result is a brightening of the night sky, increasing its brightness over the naturally occurring value. The bright background of the sky makes stars less visible, given that stars are masked by the sky brightness as a background illumination. The fainter stars disappear first from naked eye vision as a result of reduced contrast against the bright sky, and an increasingly greater number become undetectable the brighter the night sky from ALAN. Light pollution which brightens the night sky is generally referred to as skyglow. Various methods exist to measure and monitor the brightness of the night sky, including both natural and artificial light contributions; these are detailed in Appendix 2 of Chapter N.

Scattering is an essential process for the sky to brighten. The effect is much exacerbated if light sources are shining upwards, but even for lights only directing photons below the horizontal, reflection off the ground can still contribute to sky brightness. Photons emitted almost horizontally, even if just below the horizontal, can contribute more to skyglow than those emitted straight up, as these latter may escape into space.

Scattering also renders stars fainter than they would be if observed from the ground instead of from space. At the zenith they are typically about 16 per cent fainter, a phenomenon known as atmospheric extinction. The strength of light scattering in the atmosphere depends on the colour, or wavelength, of light. Short-wavelength ('blue') light is scattered most during its transit through the atmosphere, and tends to contribute the most to night sky brightness as seen at large distances from light sources. (Luginbuhl, Boley and Davis 2014)

The sky brightness from ALAN is termed skyglow, which distinguishes the sky brightness from natural sources of light, which include airglow, zodiacal light, auroral light, moonlight, gegenschein and the light from the Sun near dawn or dusk. Scattered starlight can also contribute. The night sky has a certain natural brightness known as airglow, as a result of emissions from the air molecules in the upper atmosphere, generally the recombination of photo-dissociated nitrogen and oxygen molecules to form nitric oxide (NO) and reactions involving the hydroxyl radical (OH). The brightest emission is green 558 nm light from oxygen atoms in a layer 90-100 km high. Vibrationally and rotationally excited OH radicals emit red and infrared photons in a narrow layer centred at about 86-87 km. Another airglow component is the familiar yellow light from sodium atoms in a layer at 92 km. There are also weak blue emissions from excited molecular oxygen at about 95 km. (Roach and Gordon 1973).

In urban environments, the intensity of skyglow at night usually far exceeds any natural sources of sky brightness, and the result is that stars progressively disappear from view. In the most polluted cities no stars at all may be visible, a common situation in most of the mega-cities (10 million or more inhabitants) in the northern hemisphere. The light pollution is partly the result of poorly installed streetlights that may put as much as 30 per cent of their light output above the horizontal. This represents wasted electrical power to generate that light, much of which goes on upwards into space. In the United States, it has been estimated that poorly installed ~~lights~~ luminaires which brighten the night sky waste $US3.5 billion in electrical power annually (IDA energy waste, 2020). The global figures must be at least an order of magnitude higher. The situation could be greatly improved by suitable shielding of streetlights and ensuring they are mounted horizontally. Full-cutoff luminaires are those where light only shines below the horizontal. They must have flat glass screens under the light source and no diffusing lens to spread the light. However, such ~~light~~ streetlights tend to be the exception rather than the rule.

N.2. Six reasons for good lighting

There are multiple reasons for wanting to protect dark skies and keep them dark. The benefits fall into four main categories, and within each category there are several related benefits. Here we discuss the adverse impact of ALAN and the converse benefits of its absence, which results in dark night skies.

The four main categories are as follows:

- ALAN may have an adverse impact on human health.

- ALAN can be damaging to the bio-environment and to biodiversity
- Poorly installed outdoor lighting, especially installations that allow light to be projected upwards, wastes electricity and hence there is an adverse economic impact.
- ALAN brightens the night sky and this makes it more difficult to see the stars.

In addition to these four main reasons for wanting to maintain dark skies, there are additional benefits believed to arise from good outdoor lighting that is carefully designed. These are:

- Good outdoor lighting installations promote greater public safety (Schreuder, 1998).
- Dark skies can be a resource of a sustainable economy through astrotourism.

Here, 'good lighting' often implies less light and especially the absence of glare, which is the result of direct illumination from a light source into our eyes. Safer lighting is therefore also lighting which often promotes darker skies; however, we note that the evidence basis for specific lighting recommendations is often unclear (Fotios and Gibbons 2018).

All five of these reasons are central to the theme of the Dark and Quiet Skies conference. Hence, the remainder of this chapter is an analysis of some of these factors in more detail, especially in relation to dark sky oases.

N.3. Measuring the brightness of the night sky

N.3.1 The Bortle Scale of light pollution

The Bortle scale of night sky brightness was introduced by the American amateur astronomy John E Bortle in an article published in *Sky and Telescope* in 2001 (Bortle 2001). It uses a nine-point scale to subjectively characterise the quality of the night sky at a given location, Bortle class 1 being for the very darkest sites and Bortle class 9 for the most light-polluted.

Bortle recognised the limitations of the limiting magnitude method of categorizing sky brightness. However, he ascribed approximate limiting magnitudes to each class on his scale; they ranged from m_V = 7.6 to 8.0 for class 1 to 4.0 for the most light-polluted inner-city skies (Bortle class 9).[1] For many observers these faint magnitude limits are unrealistically faint, and few people have the visual acuity to detect eighth magnitude (or even seventh) even in the darkest of locations. Certainly such faint stars would require exceptional eyesight, a fully dark adapted eye of a younger person, and experience in using

[1] Stellar magnitude corresponds to the apparent visual brightness of stars. The brightest stars in the sky are typically magnitude 1 and the faintest discernible by a naked-eye observer are about magnitude 6. The magnitude scale is an inverse logarithmic scale, with each increment of one magnitude corresponding to stars 2.512 times fainter. Larger positive magnitude values correspond to progressively fainter stars, which can be seen with a telescope.

averted scotopic vision, in which the more sensitive peripheral regions of the retina are used, where a greater density of rods (retinal scotopic cells) are located.

In one sense, the Bortle scale does not make estimating sky quality and darkness any easier, as it only ascribes an arbitrary class number to a given site and set of observing conditions. Determination of the Bortle class relies partly on the limiting magnitude of stars, though it also is based partly on the visibility of faint natural sources of light such as the zodiacal light, gegenschein and airglow and on diffuse celestial objects. In the final analysis, Bortle class is the subjective qualitative estimate of a given observer and location, and is not a quantitative objective measurement.

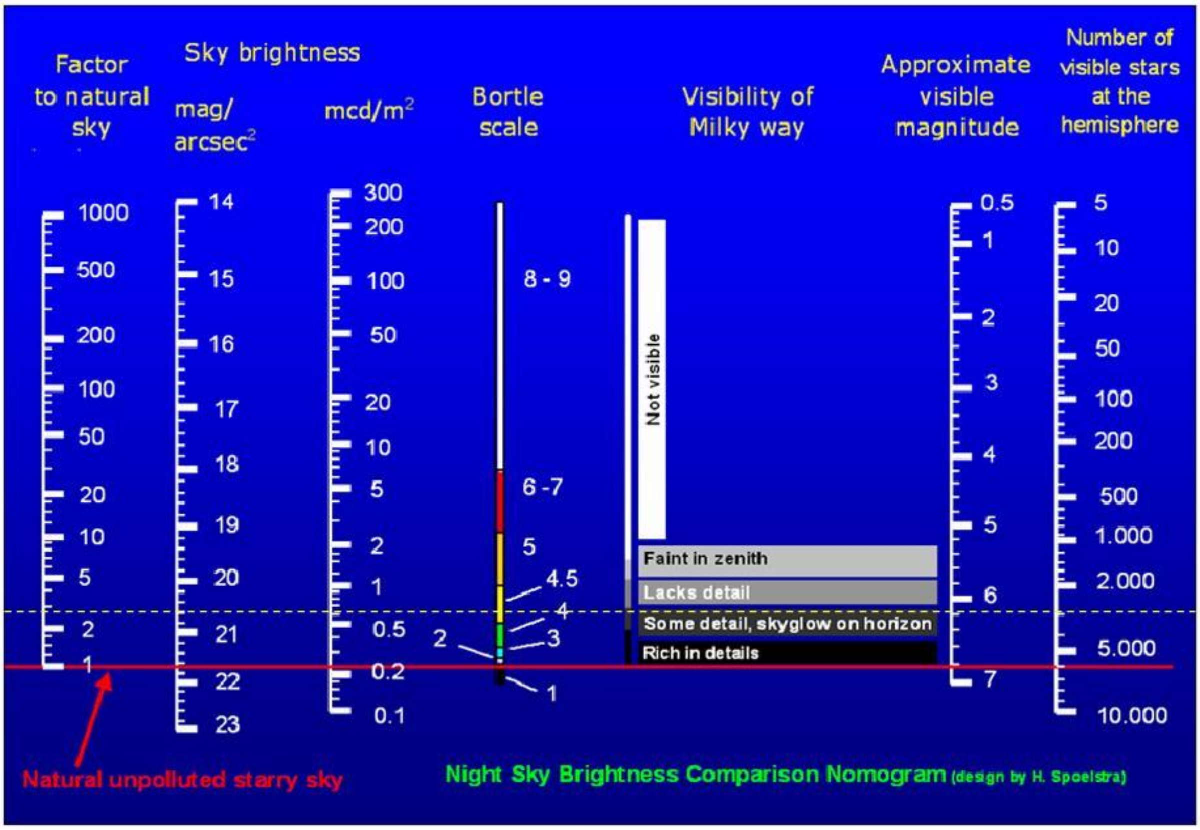

Figure N.1. Spoelstra's sky brightness nomogram (courtesy of H. Spoelstra)

Henk Spoelstra (2002) in the Netherlands has produced a well-known nomogram that illustrates the Bortle scale (column 4) and relates it to the visibility of the Milky Way (column 5), limiting visual magnitude (column 6) and the number of stars visible above the horizon (column 7). A horizontal line across the diagram indicates the characteristics of a given observing location (such as the dashed line shown as an example).

N.3.2 Magnitudes per square arc second and S10 units

A more quantitative way of expressing night sky brightness is to use physical units for surface brightness, given that the night sky can be considered as a hemispherical surface with the observer at the centre.

One popular unit of night sky brightness is magnitudes per square arc second (mag/sq arcsec). First consider a star of magnitude $m_V = 21$, which is exactly a million times fainter than a naked eye star of magnitude 6. Although stars are essentially point sources of light, we can imagine that light being spread over a tiny square in the sky, whose side in angular measure is 1 arc second (there are 3600 arc seconds in a degree). A hemisphere comprises 2.7×10^{11} square arc secs, so 1 square arc second is a very tiny area of the sky. If the whole sky had the same surface brightness as this tiny area, then the sky brightness would be written 21 mag/sq arc sec. This corresponds to a fairly dark sky, about 4 on the Bortle scale. This is shown in the second column of the Spoelstra nomogram (Fig. 1).

The darkest possible skies are at about 21.7 mag/sq arc secs, and this figure represents a typical value of the natural airglow which is always present, though somewhat variable in direction and in time. A sky which is 20 times brighter than this natural airglow background would be at about 18.5 mag/sq arc secs and this would be a typical value in many urban environments. If the sky is 100 times brighter than the natural airglow background, then the brightness would be 16.7 mag/sq arc secs, a value found in the central areas of the world's large cities with Bortle class 8.

Of course the unit of mag/sq arcsec are an inverse logarithmic scale, and not therefore very intuitive for those not used to dealing in stellar magnitudes. Sometimes it is more convenient to use a linear scale in which larger numbers represent brighter skies. One such unit sometimes used is S_{10}, the number of tenth magnitude stars per square arc minute, assuming their light were spread uniformly over this small area. One S_{10} unit corresponds to 27.78 mag/sq arcsec, which is darker than any night sky. Typically unpolluted airglow will be at about 145 S_{10}, while zodiacal light would be 60 S_{10} and scattered starlight would contribute just 15 S_{10}. A very polluted sky at 16.7 mag/sq arcsec would correspond to about 27,000 S_{10}.

N.3.3 Photometric SI units for night sky brightness

Light sources often radiate in all directions and the luminous intensity determines the lumens radiated into unit solid angle, and is measured in candela (cd), which is a lumen per steradian. For some light sources, such as a laser, the distribution of intensity is highly directional, so the intensity has a high value in that direction, but low or zero elsewhere.

The surface brightness or luminance of a light-emitting surface is measured in candelas per square metre (cd/m^2), sometimes referred to as a nit (nt). For the night sky, the millicandela per square metre is a more useful unit (mcd/m^2). The natural airglow is at about 0.25

mcd/m^2. Any sky brightness above 1 mcd/m^2 is significantly light-polluted. The Spoelstra nomogram (Fig. 1) column 2 shows the typical sky brightness values in mcd/m^2. The mean surface brightness of the Sun's disk is about 1.6×10^9 cd/m^2 (though it varies over the solar disk, being higher in the centre). One property of the surface brightness of any radiating surface is that its value is an intrinsic property of the radiating surface and is independent of distance. The surface brightness of the Sun would have the same value for an observer on Mars or any other planet in the solar system. For that reason, specifying the surface brightness of the night sky does not require specifying the distance to the light scattering hemispherical surface of the sky.

The surface brightness of the night sky (*S*) in mcd/m2 can be calculated from a given value in visual magnitudes per square arc second. The equation relating these two parameters is[2]:

$$S\ (\text{mcd/m}^2) = 1.08 \times 10^8 \times 10^{(-0.4\ \text{mag/sq arcsec})}.$$

Note that one S_{10} unit is close to 1 micro candela/m^2.

N.4. What is a Dark Sky Oasis?

A dark sky oasis (also often referred to as a 'dark sky place') is a location where the night sky is protected by an outdoor lighting policy, or in legal terms, *a lighting ordinance* which limits the amount and the wavelengths of light that shine upwards into the sky. Most dark sky oases will have controls on street lighting (CIE 2010; CIE 2019 ~~CIE 115, CIE 236~~), and where required, on the lighting of sports facilities at night (CIE 2019 ~~CIE 083 and others~~), on outdoor lighting of commercial facilities such as ports and factory yards, and limits on flood lighting of buildings for decorative purposes (CIE 1993 ~~CIE 094~~).

A number of bodies are currently giving accreditation for dark sky oases based on the submitted evidence that the sky is protected and that outdoor lighting complies with these basic criteria. The largest organisation offering such accreditation is the International Dark-sky Association (IDA), based in Tucson, U.S. (IDA, 2018). They offer accreditation in five different categories, namely International Dark Sky Reserves, Sanctuaries, Parks and Communities, and Urban Night Sky Places. These all have slightly different criteria.

Another international organisation with an accreditation programme is the Starlight Foundation, based in Tenerife, Canary Islands (Starlight Foundation, 2020). The Starlight Foundation recognises starlight reserves, starlight tourist destinations and they also have a category of starlight rural hotels and houses. These last are individual establishments with good lighting practices and offering information to their customers on the night sky. The criteria to be met are a little different in each case, being a bit less stringent for the Starlight Tourist Destinations than the Starlight Reserves, as shown in Section 7.2.

[2] The constant of 1.08×10^8 is approximate, and depends on the night sky spectrum (Bará et al, 2020).

The Starlight Foundation has criteria based not only on night sky brightness, but also the requirement for clear skies, good transparency and excellent seeing (a measure of image diameter, and hence of the lack of turbulence in the Earth's atmosphere) (Varela et al. 2012). These criteria are generally more stringent than those from the IDA, where dark skies are the main criterion.

UNESCO Starlight reserves and IDA Dark Sky parks are classified as environmental zone E0 and described as intrinsically dark lighting environments. (CIE 2017) For environmental zone E0 the most stringent requirements apply on maximum values of upward light ratio of luminaires (0 %), luminous intensity in different directions (0 cd), building facade luminance and sign luminance (0,1 $cd.m^{-2}$).

Some national bodies also offer dark-sky place certification, most notably the Royal Astronomical Society of Canada (RASC, 2020).

N.4.1 The IUCN Dark Skies Classification Scheme

The International Union for the Conservation of Nature operates the Dark Skies Advisory Group (IUCN-DSAG). The aims of this group are to:

- Preserve the ecological integrity of natural environments;
- Ensure the full enjoyment of a wilderness experience;
- Appreciate the integrity, character and beauty of rural landscapes;
- Protect and present the authenticity of cultural sites (tangible heritage);
- Help preserve cultural practices and ceremonies related to the night sky;
- Help preserve the intangible heritage that relates to mythology, traditional navigation and cultural heritage related to the night sky;
- Protect human health, both medical and psychological;
- Contribute to energy efficiency;
- Benefit scientific and amateur astronomy (starlight tourism) and the right for all people to enjoy a clear, unpolluted night sky; and
- Improve personal security through non-glare lighting in urban areas.

The DSAG was established in 2009 and has 18 members, including the current and founding chair, Dr David Welch in Ottawa. The DSAG website (DSAG, 2020) gives more information about the IUCN-DSAG.

Part of the work of the Dark Skies Advisory Group is to maintain a world list of dark sky places. This list is to be found at the site DSP (2020) and is regularly up-dated.

At the present time (31 May 2020) there are 223 dark sky oases (or places) in 27 different countries with accreditation in most cases from IDA, the Starlight Foundation or the Royal Astronomical Society of Canada. These dark sky oases have been classified into six main categories as well as several subcategories according to the scheme proposed by the International Union for the Conservation of Nature (IUCN) Dark Skies Advisory Group (DSAG) (Welch 2013). These in turn refer to the IUCN categories of protected natural areas (Dudley 2008; Stolton, Shadie, and Dudley 2013).

The definitions of the IUCN DSAG Dark Sky Places Class system follow both from the IUCN categories of protected natural areas and a set of additional criteria identified by the DSAG. To be classified within this system, a place should:

- be an officially protected area in the sense understood by the IUCN;
- have management policies and practices in place to protect or restore natural darkness; and
- be recognised either by an authoritative body at arm's length from the protected area agency itself, or by legislation, regulation or policy of the appropriate national, territorial, state or provincial jurisdiction.

An additional class recognizing the built environment is added to enable inclusion of the IDA International Dark Sky Community designation category. The IUCN DSAG Dark Sky Places Classes are:

1 **Dark sky astronomy site:** protected areas that include an astronomical research observatory.

2 **Dark Sky Park**: protected natural area

2a Park, reserve, habitat, natural area or other ecological protection;

2b Unpopulated area set aside for traditional or sacred practices related to the sky;

2c Rural area, area of outstanding landscape beauty.

3 **Dark Sky Heritage Site**: protected heritage physical works of mankind.

4 **Dark Sky Outreach Site**

4a Urban or suburban site;

4b Rural site.

5 **Dark Sky Reserve**: mix of cooperating community, rural and natural area jurisdictions.

6 **Dark Sky Community**: an entire village, town or city

6a Urban;

6b Rural.

The classifications are summarised below along with the total number of places in each category recognised to date by IUCN-DSAG.

Class	**Class type and subtypes**	**Class description**	**Number world-wide (in brackets, subtype numbers)**

1	**Dark Sky Astronomy Site**	Sites having a science-quality astronomical observatory	15
2	**Dark Sky Park**	Sites which are protected natural areas	114
2a	Park, reserve, habitat, natural area or other ecological or geological protection		(85)
2b	Unpopulated area set aside for traditional or sacred practices related to the sky		(4)
2c	Rural area, area of outstanding landscape beauty		(25)
3	**Dark Sky Heritage Site**	Sites which are protected heritage, physical works of mankind	9
4	**Dark Sky Outreach Site**	Sites where astronomical outreach is carried out, often in or on outskirts of a city or conurbation.	25
4a	Urban or suburban site		(6)
4b	Rural site		(19)
5	**Dark Sky Reserve**	Sites with a core protected area and a sustainable development buffer ma of cooperating community, rural and natural area jurisdictions	21
6	**Dark Sky Community**	A rural area, village, town or city	39
6a	City, town or village		(33)
6b	Populated rural area without a formal protected area		(6)
	Global total		**223**

Table N.1. IUCN dark sky place classes

These 223 dark sky oases, which have received accreditation and therefore enjoy some level of protection for the night sky, constitute a total land area of just over 20 million hectares (in fact, 20,395,000 ha), or an average of about 900 sq km each in land area. This is just 0.14 per cent of the total land area present on the Earth’s surface, excluding oceans. They comprise, therefore, a tiny fraction of the global land area that is under any kind of protection for the night sky above.

N.4.2 The World Atlas of Artificial Night Sky Brightness

In 2001 an important publication by Pierantonio Cinzano at the Italian Light Pollution Science and Technology Institute and his colleagues mapped for the first time the effect of light pollution on night sky brightness on a global scale (Cinzano et al. 2001). This was the first 'World Atlas of Artificial Night Sky Brightness.' It was produced by measuring from space the upwards-travelling light from the whole Earth in the years 1996-97. Modelling was then done to calculate the resulting night sky brightness at the zenith for an observer at sea level, based on the expected scattering in the Earth's atmosphere by air molecules and aerosols. The United States Defense Meteorological Satellite Program (DMSP) made observations of light going into space on cloudless nights in the wavelength range 440-940 nm, which covers the emissions from most common street-lights (Elvidge et al. 2009; Huang et al. 2014). The map's ground resolution was 0.93 km.

In the World Atlas, the natural sky brightness background was taken to be b_n = 21.6 visual magnitudes per square arc second[3] and the skyglow from light pollution was plotted using six colour-coded levels from 0.11-0.33 b_n (dark and almost unpolluted sky) to more than 27 b_n for the most polluted cases.

Sky brightness was also tabulated for every country in the world to show what fraction of the population of each nation is living under skies for each level of pollution. The most polluted regions of the world were found to be the eastern half of North America, Western Europe and Japan. Countries in the southern hemisphere were much less severely affected.

The data for the first World Atlas were taken in the late 20th century, and today the situation has considerably worsened as anticipated by Cinzano and his colleagues. This was shown in the New World Atlas of Artificial Night Sky Brightness (Falchi et al. 2016) produced using Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS-DNB) data from the *Suomi* National Polar-orbiting Partnership satellite (Lee et al. 2006). The data were from 2013 and 2014 and with the results calibrated with photometric data of sky brightness from the ground. High resolution maps with 14 levels of light pollution were plotted.

The new world atlas showed that 80 per cent of the world and more than 99 per cent of the U.S. and European populations live under light-polluted skies. The Milky Way is hidden from more than one third of humanity, including 60 per cent of Europeans and nearly 80 per cent of North Americans. These figures are based on a night sky brightness of greater than 14 μcd

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[3] This corresponds to a background airglow natural sky brightness of 8.61×10^7 visual photons $cm^{-2}\ s^{-1}\ sr^{-1}$, or 252 $\mu cd\ m^{-2}$. This was revised to 174 $\mu cd\ m^{-2}$ in the new world atlas of Falchi et al (2016).

m^{-2}, or eight per cent of the natural airglow. The plotted maps showed dramatic increases in skyglow in many countries, especially so in eastern China, India and South Korea.

If we limit our attention to the most heavily light-polluted skies with the artificial night sky brightness of 87 µcd m^{-2} or greater (50% of the natural airglow), then 83.2 per cent of the world's population live under these heavily polluted skies, and 8.6 per cent of the world's land area is affected. The polluted land area is vastly greater than the tiny area in protected areas as dark sky oases. What is more, the polluted land area is growing at two per cent annually, or doubling in about 35 years (Kyba et al. 2017).

Unfortunately the New World Atlas was based on satellite data which recorded light pollution on the ground in the wavelength region 500-900 nm. It therefore omitted the blue peak emission ($\lambda \sim 450$ nm) from the numerous LED street-lights that had been installed in the early 21st century, and it is this blue light that scatters most in the atmosphere. The night sky brightness calculated from the satellite data will therefore be an underestimate of the true situation for those localities with a substantial LED component to street-lighting.

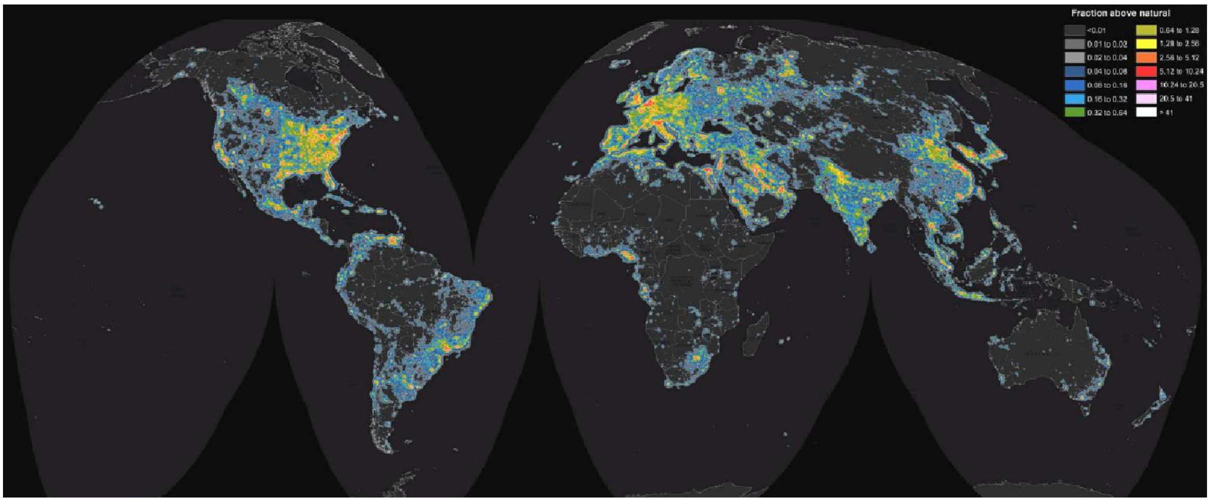

Figure N.2: Artificial night sky brightness at ground level from the New World Atlas of Artificial Night Sky Brightness by Falchi et al (2016).

N.5. Impacts of light pollution on the visibility of stars

Given that light pollution is a risk that can threaten the practice of astronomical research, curtail star-gazers' view of the night sky and limit the effectiveness of astro-tourism, it is important to have means of measuring light pollution at any location. One simple method is to estimate the number of stars visible on a given clear moonless night, or to estimate the limiting magnitude of the faintest stars visible to a naked eye. The two parameters are closely related.

The number of stars visible on a clear moonless night to different magnitude limits is given in the table below. The data are adapted from Haworth (2003).

Magnitude	**Range**	**Number of Stars per Range**	**Cumulative Stars**	**Number of stars visible above 10°**
-1	-1.50 to -0.51	2	2	1
0	-0.50 to +0.49	6	8	3
1	+0.50 to +1.49	14	22	9
2	+1.50 to +2.49	71	93	38
3	+2.50 to +3.49	190	283	116
4	+3.50 to +4.49	610	893	368
5	+4.50 to +5.49	1,929	2,822	1165
6	+5.50 to +6.49	5,946	8,768	3621
7	+6.50 to +7.49	17,765	26,533	10958
8	+7.50 to +8.49	51,094	77,627	32059

Table N.1: Number of visible stars in the sky as a function of magnitude

In practice, in most locations stars are only visible to about 10 degrees from the horizon, so at a given location we can only see about 40 per cent of a full sphere, less than a hemisphere. The last column gives the total number of stars visible above 10° elevation to different limiting magnitudes for a dark-sky location. The numbers are approximate.

In practice few people can see below magnitude 6.5 even in the best conditions, and more likely the practical limit is closer to 6 in the absence of light pollution on a clear moonless night. The numbers are very approximate, but indicate that at any given place and time we are unlikely to see more than three and a half thousand stars.

If there is light pollution, the brighter sky lowers the limiting magnitude to perhaps 3 or 4, typical of many urban environments. The table shows that only a few hundred stars can be detected with a naked eye in such conditions. In the most light-polluted cities the limiting magnitude might be only zero or one. In that case, the number of stars visible could be in single figures.

Instead of counting stars, we can find the faintest stars visible under given conditions, and thereby estimate the sky brightness. For every ten-fold increase in sky brightness, the limiting magnitude will reduce by 2.5 magnitudes (i.e. it will go from 6.5 to 4.0), which corresponds to about ten times fewer stars being visible.

The limiting magnitude depends on many factors in addition to light pollution, including sky transparency, phase and position of the Moon, time since sunset or before sunrise, age of the observer and whether complete eye dark adaptation has occurred. All these factors combined make star counts or estimating the limiting magnitude a very crude indicator of light pollution.

N.6. The International Dark-Sky Association and designation of International Dark Sky Places

N.6.1 Mission and organisation

The International Dark-Sky Association is a U.S.-based non-governmental organisation whose mission is to preserve and protect the nighttime environment and our heritage of dark skies through environmentally responsible outdoor lighting. The organisation was established to protect the night sky for astronomers in southern Arizona, U.S., from the light pollution of the nearby city of Tucson, but its mission has expanded enormously to become a world-wide organisation to promote good lighting practices which help protect dark night skies and minimise light pollution everywhere, not just near professional observatories. The recognition that light pollution is not only damaging for astronomers, but potentially also harmful to the environment and to human health has greatly increased the role of IDA in mitigating all these harmful consequences of artificial light at night.

IDA’s goals are to advocate for the protection of the night sky; educate the public and policymakers about night sky conservation; promote environmentally responsible, quality outdoor lighting; and empower the global public with the tools and resources to help bring back the night. It pursues these goals by engaging a distributive network of members, advocates and volunteers around the world to lead efforts to create change from the grassroots.

N.6.2 International Dark Sky Places Programme

In 2001, IDA initiated its International Dark Sky Places Programme to encourage communities, parks and protected areas around the world to preserve and protect dark sites through responsible lighting policies and public education. This programme considers two settings for recognition of outstanding efforts to pursue the goal of preserving dark skies: conservation sites and the built environment. Designation is offered to parks and protected areas with credible lighting controls and active public outreach and education programmes in place for protecting dark skies, as well as communities that enact quality outdoor lighting policies, ensure publicly owned lighting complies with those policies, and engage residents toward bringing private lighting into compliance. International Dark Sky

Places are recognised in several categories, including International Dark Sky Parks, International Dark Sky Reserves, International Dark Sky Communities, International Dark Sky Sanctuaries and Urban Night Sky Places. (Dalton, del Solar and Barentine 2021a)

At the time of writing, there are 86 International Dark Sky Parks, 16 International Dark Sky Reserves, 29 International Dark Sky Communities and 13 International Dark Sky Sanctuaries. The newest IDA designation category, Urban Night Sky Places (UNSP), consists of municipal parks, open spaces, observing sites, and similar lands in urban or peri-urban settings. One UNSP has been designated since the category was introduced in 2018.

International Dark Sky Reserves are the most complex designation type recognised by IDA. An IDA International Dark Sky Reserve is "a public or private land possessing an exceptional or distinguished quality of starry nights and nocturnal environment that is specifically protected for its scientific, natural, educational, cultural, heritage and/or public enjoyment." (IDA 2018) Reserves consist of a core area meeting minimum criteria for sky quality and natural darkness, and a peripheral area that supports dark sky preservation in the core.

N.6.3 The Aoraki Mackenzie International Dark Sky Reserve as a case study for light pollution mitigation

The Aoraki Mackenzie International Dark Sky Reserve (AMIDSR) was created in April 2012 with recognition as a reserve from IDA. The reserve is located in the centre of New Zealand's South Island and comprises most of the Mackenzie Basin and all of Aoraki/Mt Cook National Park. The Mackenzie Basin lies to the east of the main range, the Southern Alps, and to the west of a lower range called the Two Thumb range. The coordinates of the centre of the reserve are about 44 degrees south and 170.3 degrees east (AMIDSR 2020).

The application document to IDA discussed the geography, topography, population, ecology, climate, fauna, flora, settlement history of the region, the Mackenzie Lighting Ordinance in the District Plan, Maori astronomy, Mt John Observatory, astro-tourism, land ownership, conservation, local governance and it gave a complete catalogue of all external street lighting in the proposed Reserve.

The decision by IDA to grant the Reserve, just the third to be recognised in the world, the first in the southern hemisphere and the first to be accorded gold tier status (Barentine 2016), was a major step forwards. At 4367 square km, AMIDSR is also the world's second largest dark sky reserve of the 16 reserves currently recognised.

The aims of the reserve are first to protect the exceptionally dark skies we have in the Mackenzie and at Aoraki/Mt Cook National Park. Dark skies free of light pollution help those who come to the Mackenzie for star-gazing, as well as research astronomers at the University of Canterbury's Mt John Observatory. A lighting ordinance was first enacted in 1981 to protect the astronomical research at the observatory.

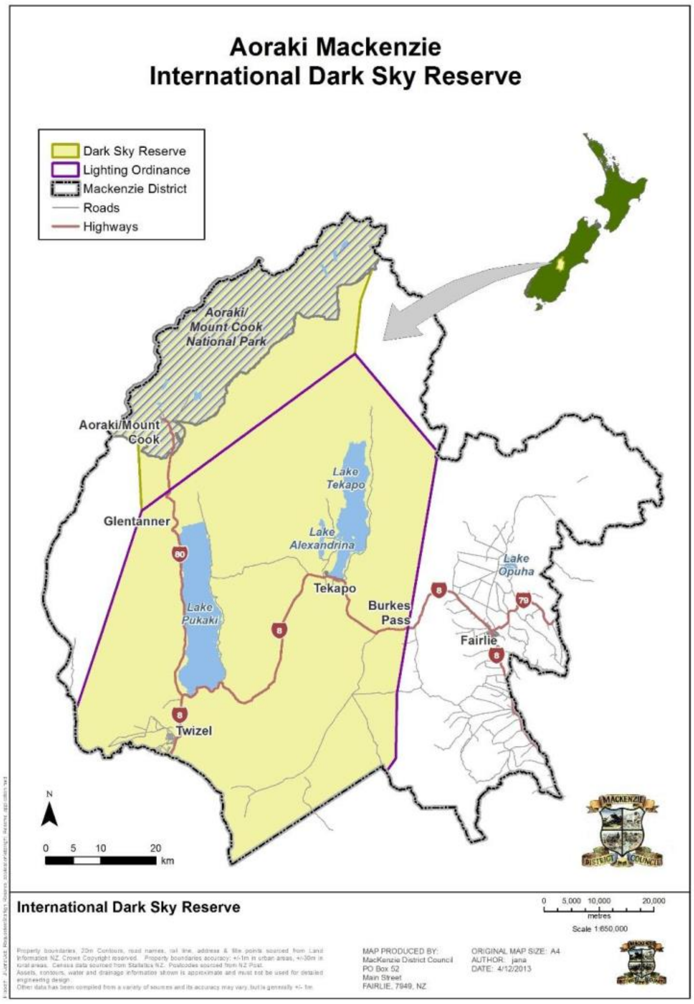

Figure N.3: Map of the Aoraki Mackenzie International Dark Sky Reserve

The reserve is run by a board of a dozen members who operate as a registered charity, and the Board's aim is to educate the public about the dangers of light pollution as well as the benefits of dark skies. Public outreach is a major aspect of the Board's work. Over the last six years there have been three Starlight Festivals, which have entailed public lectures by international visiting speakers, videos on light pollution, star-gazing sessions, exhibitions and cultural activities run over three days. International conferences to promote dark skies were held in the reserve in 2012 and 2019.

Figure N.4: Road sign at Burkes Pass, the entry to AMIDSR (courtesy Maki Yanagimachi)

The success of the reserve is shown by the rapid rise of astro-tourism in the Mackenzie and at Aoraki/Mt Cook. About 1.5 million tourists[4] come through the Mackenzie District annually and an estimate is that about ten per cent come explicitly to see the beauty of the pristine starlit skies at night or to visit Mt John Observatory by day. Many tourists are from Asian countries with severe light pollution who have never seen the Milky Way from their home towns or cities.

Astro-tourism companies such as the Dark Sky Project at Tekapo and Big Sky Stargazing at Mt Cook have been thriving for the last decade, and tourist numbers with these companies jumped about 20 per cent after the reserve was established. Other companies are now springing up inside the reserve at Tekapo and Twizel to show our visitors the night sky.

In 2019, the New Zealand Transport Agency agreed to replace all the streetlights in Mackenzie District with warm amber-coloured LED lights (with a colour temperature[5] of 2200 K).

N.7. The Starlight Foundation: the commitment to the Declaration in Defence of the Night Sky and the Right to Starlight (La Palma Declaration).

N.7.1 Background to the Starlight Foundation

The Starlight Initiative was born with the "Declaration in Defense of the Night Sky and the Right to Starlight" (2007), in which representatives of the Astrophysics Institute of the

[4] These are pre-covid pandemic figures.

[5] The correlated colour temperature (CCT) of a light source is the temperature of a radiating black body that presents the same apparent colour to the human eye as the light source.

Canaries (IAC), United Nations Educational Scientific Cultural organisation (UNESCO), the United Nations World Tourism organisation (UNWTO), the International Astronomical Union (IAU), United Nations Environmental Programme-Convention on the Conservation of Migratory Species of Wild Animals (UNEP-CMS), Comité Olímpico Español (COE), Secretariat of the Convention on Biological Diversity (SCBD), Man and Biosphere Programme (MaB), European Community (EC) and Ramsar-Convention launched this international movement in defense of the night sky, promoting the dissemination of astronomy and sustainable, high-quality tourism in those places where the night sky is cared for (Marín & Jafari, 2007). The Starlight sites incorporate the preservation and observation of the night sky as a part of natural, scenic, cultural and scientific heritage; encourage "Star Tourism"; and promote infrastructure, products, activities and training of specialised guides in sustainable tourism.

The Starlight Foundation (known in Spanish as *Fundación Starlight*) is a legal non profit entity created in 2009 by the Institute of Astrophysics of the Canary Islands and the consulting Corporación 5 as the body in charge of the Starlight Initiative, providing human resources and means for its development and promotion.

The XXVIIth IAU General Assembly in August 2009, in Rio de Janeiro (Brazil), unanimously passed Resolution B5 in Defence of the Night Sky and the Right to Starlight, recognizing the principles expressed in the Starlight Declaration. Since then, the IAU has been significantly increasing its work in this line, particularly through the Division C (Education, Outreach and Heritage), or with the creation of commissions and working groups such as the Commission C4 (World Heritage and Astronomy), WG Dark and Quiet Sky Protection, WG Astronomical heritage in danger and WG Achieving Sustainable Development within a Quality Lighting Framework.

The Foundation has four main objectives:

1.- Protection of the night sky from light pollution
2.- Cultural dissemination of astronomy, through outreach
3. Promotion of astro-tourism
4. Adoption of intelligent lighting and innovation, energy saving

N.7.2 The Starlight Certification System

The Starlight Foundation has created an international certification system whereby those areas that have excellent sky quality and represent an example of protection and conservation are accredited.

The **Starlight Reserve** concept was established in the UNESCO World Heritage Centre, Paris (October 2007), *Astronomy and World Heritage*. But the criteria were well determined in the *International Seminar and World Heritage* (London) and at *the World Heritage Committee*

(Quebec), 2008. It is a protected natural area where a commitment to protecting the quality of the night sky and providing access to starlight is established to preserve the quality of the night sky and the different associated values, whether cultural, scientific, astronomical, or the natural landscape. The Starlight Reserve concept is accompanied in each case by a Participatory Action Plan and a set of recommendations To date they cover the following categories: Heritage Sites, Astronomy Sites (Ruggles & Cotte (2010), Natural Sites, Landscape, Starlight Oases - human habitats and Mixed Starlight Sites.

Starlight Tourist Destinations are locations with ideal conditions for observing the stars and where light pollution is controlled. This makes them logical destinations for tourism based on the appreciation of the sky as part of the natural world. It must not only prove the quality of its air, and the means to ensure its protection but they must also have appropriate tourism infrastructure and its integration into nocturnal nature. The criteria were established in December 2010, at the UNWTO Centre in Madrid, with representatives of UNESCO, UNESCO-Mab and IAC.

There exist other modalities described in the Starlight Foundation webpage: **Stellar Parks and Stellariums**; **Villages**, **Wilderness**, **Rural Hotels and Houses, camps, Inns, monasteries and abbeys, etc.** The Starlight Foundation offers its experience and the ability to offer specific **advice and consultancy** for each destination so as to develop its full potential in this type of tourism. The sky quality parameters and thresholds required for Starlight Reserves and Starlight Tourist Destination are summarised in Table 2.

Parameter	**Starlight Reserve**	**Starlight Tourist Destination**
Sky brightness (V mag/sq arc second)	>21.4	> 21.0
Seeing	<1 arc second	< 3 arc seconds
Transparency/ limiting magnitude for stars	m_{limit} ~ 6	m_{limit} ~ 6
Clear time	> 60 per cent	> 50 per cent

Table 2: Starlight Foundation criteria for reserves and tourist destinations

The criteria are based not only on night sky brightness, but also the requirement for clear skies, good transparency and excellent seeing (a measure of image diameter, and hence the lack of turbulence in the Earth's atmosphere). These criteria are generally more stringent than those from the IDA, where dark skies are the main criterion.

At the time of writing (July 2020) there were 14 Starlight Reserves, 30 Starlight Tourist Destinations, seven Starlight Stellar Parks and more than sixty Starlight Hotels and Rural Houses. In 2020 the number of international Starlight certification requests grew by 300 per cent (addressing Costa Rica, Puerto Rico, México, Perú, Argentina, Chile, Rusia, France, Portugal, Maroc, Australia, etc.)

N.7.3 Starlight Training

This new concept of Star Tourism requires specialised training for the professionals in the existing tourism sector in the area, especially those working in the field of nature tourism.
A "Starlight Astronomical Monitor" (60 hours´duration) is a guide who is trained and able to accompany groups complementing their enjoyment of nature with knowledge about the Universe seen either with the naked eye or through simple observation instruments "Starlight Tourist Guides" qualification is awarded to those who complete the Courses in La Palma and Tenerife (of 120 hours' duration) and whose purpose is to train the Guides to accompany groups round the Teide Astrophysical Observatory (Tenerife) and Roque de los Muchachos (La Palma) and their telescopes. The Starlight Guides are the only professionals accredited by the IAC to do the guided tours in their observatories. There are a total of about 600 Starlight trained people of more than 15 nationalities.

N.7.4 Tenth Anniversary of the Starlight Declaration (2017)

In this Congress held in La Palma (18-21 April 2017), it was commemorated the tenth Anniversary of the "Declaration on the Defense of the Night Sky and the Right to the Stars Light", where the institutions signing the same, as well as other institutions invited, adopted resolutions and made a call facing the future. It was acknowledged the full validity of the "Starlight Declaration", signed in the island of La Palma in 2007 and the whole population, the local communities and the governments were encouraged to adopt their principles and guidelines.

Both IDA and the Starlight Foundation have a considerable overlap in their goals of protecting dark sky places through accreditation. They work independently but with some collaborative exchanges. The Starlight Foundation at present is very much focussed on Spain and Latin America, but has the ambition to become more global in its reach in the future. It has links with international organisations such as UNESCO, UNWTO and IAU and a strong emphasis on astrotourism and on dissemination of astronomy.

N.7.5 Impact of astrotourism in numbers

-According to data from the Teide National Park, there are some 200,000 visitors/year for stargazing

-Parc Astronòmic del Montsec (PAM) generates an annual income in 2018, of €2.5 million in the territory.

-La Palma …more than 70 business or registered projects, 29 millions €/year (from TIDES, Cabildo de La Palma).

- AIRBNB DATA: in "some of the main places identified by the Starlight Foundation, in which it is possible to observe the stars, which are becoming trend destinations, the year-on-year growth in arrivals of travelers are": La Palma (Spain), with 90%; Kiruna (Suecia) 134%; Alqueva (Portugal) with 64%; Pic du Midi (France) with 99%; Antofagasta (Chile) with 327% or Acadian Skies & Mik'Maq Lands (Nova Scotia, Canada) with 221%.

Mitchell and Gallaway (2019) recently evaluated the economic impact potential of astrotourism on the colourado Plateau in the western United States, finding that non-local tourists who value dark skies will spend in excess of USD 5.8 billion in the next decade, generating USD 2.4 billion in higher wages and creating over 10,000 additional jobs each year in the region.

N.8. Lamp technologies and their contribution to light pollution

N.8.1 Conventional light sources

Even public outdoor lighting has its origin back in the 15th century, it was only near the 19th century where artificial light sources were widely industrialized. The two major groups of lamp types were based on filament or on arc discharge technologies respectively. A comprehensive analysis on the evolution of light sources can be found in Appendix 2. THe most common traditional light sources that can be found either today, are High and Low Pressure Sodium, Metal Halide, Mercury Vapor and Tungsten Incandescent.

The key motivation of developing new light sources was to increase their efficiency while reducing associated manufacturing costs. The evolution of lamp efficiency from few lm/W to more than 100lm/W in recent years demonstrates the technology advances in the lighting industry. Each lamp technology is associated with specific material and gas types. This association affects one of the most important properties of each type of light source which is the spectral power distribution (SPD). SPD describes the relative emissions of light of different colours (throughout the visible range of spectrum) by a given light source and it has an important bearing on light pollution and night sky brightness.

Early lighting technologies such as incandescent filament lamps emit a continuous spectrum that includes all colours of light, but are especially strong in red and near-infrared wavelengths. On the other hand, the SPD of carbon arcs has a strong blue-violet peak at a wavelength of about 389 nm and only weak emission in the red. Given that blue light is the main contributor to night-sky brightness, incandescent street-lights would certainly be better for astronomy than carbon arc lamps, although this issue was hardly ever debated in the early 20th century.

To demonstrate the noticeable difference between the conventional light sources used for street and outdoor lighting, their spectral power distributions are shown in Fig. 5 (taken from Lamptech (2020)). They are compared with the continuous spectrum of sunlight. Many of these lamp types are currently phased out in certain countries but can already be found in existing lighting installations all around the world.

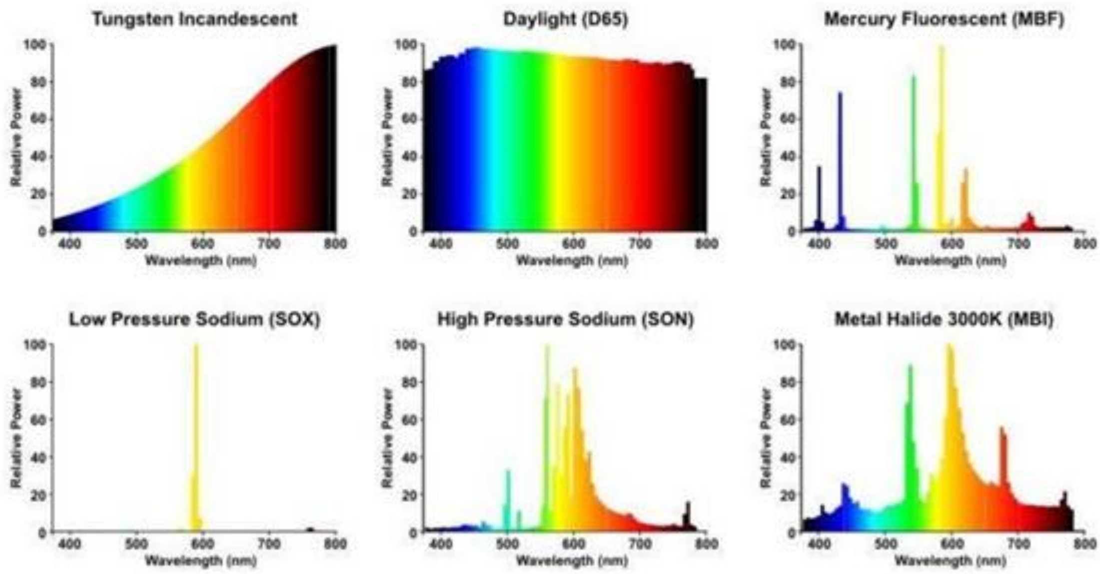

Figure N.5: Spectral power distributions of some common types of lamp (from Lamptech, 2020)

N.8.2 The rise of the light-emitting diode (LED) as a light source

The new technology that revolutionized the lighting industry was the Light Emitting Diode (LED). LED is a solid-state, semiconductor chip that emits light under a low voltage (typically about 10 volts). The first LED was developed by Nick Holonyak at General Electric in Michigan in 1962. It was based on gallium arsenide phosphide. The first LEDs emitted red or infrared radiation. Modern LED technology can produce lights of any wavelength from ultraviolet to infrared. In particular blue LEDs using gallium nitride were developed from 1993. In general, LEDs are lightwright, long-lived and highly energy efficient, which are significant advantages for many applications.

Traditional luminaire manufactures adopted LED technology by introducing new products or updating their existing lineup. Due to its low cost of materials and the fast development process, a lot of new manufactures appeared in the market, especially from the Asian region. Market penetration of LED was so vast that regulations and standardization of the technical specifications could not follow this stream.

Today, large cities all over the world are changing over from legacy lighting technologies such as HPS and LPS to LEDs. For example, Anchorage, Alaska, had installed 4000 LED luminaires by 2008; Los Angeles, California, 140,000 by 2009; and Seattle, Washington, 40,000 by 2010. The low power consumption and maintenance needs represent a huge cost saving for many municipalities. LED technology offers the possibility of easy and efficient control (local or remote), enabling possibilities such as dimming in the early morning hours after midnight.

The SPD of the first LEDs used for street-lights shows a strong peak at wavelengths between 450 nm -470 nm in the blue, corresponding to the gallium nitride-based LED to which is added the broad continuous spectrum at longer wavelengths (500 nm -700 nm) of the Ce:YAG phosphor. The colour temperature of these first white LEDs was often at or above 5000 K, which is usually deemed to be an unattractive harsh white with a high percentage of blue emission. A white LED at 5000 K colour temperature emits about 35 % to 40 % of its energy in the blue region, as represented by the area under the blue peak in Fig. 6.

It is the blue emission which scatters in the atmosphere far more efficiently than longer wavelengths, thereby contributing to excessive skyglow. The blue peak of LED street luminaires has therefore a major influence on the current environmental concerns of light pollution. A useful resource on lamp types, including LED lights giving technical data for each, is to be found in the Lamps Spectral Power Distribution database (LSPDD, 2020). The database gives for each commercially available lamp the percentage of blue light emitted, the colour temperature, the spectral energy distribution , the light output (in lumens) and indices for melatonin suppression, for induced photosynthesis and a starlight index, which measures the amount of light pollution contributing to skyglow for a scotopic dark-adapted eye.

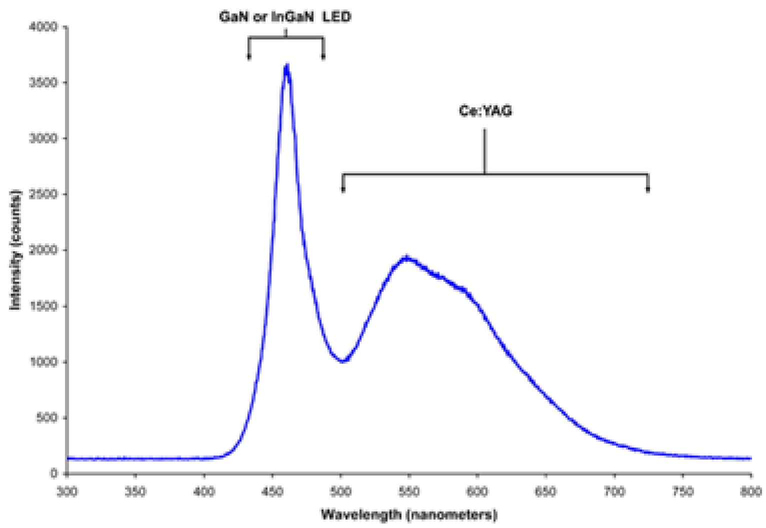

Figure N.6: Spectral energy distribution of a typical high-correlated colour temperature (CCT) white LED with a strong peak in the blue at wavelength about 465 nm. Wavelength ranges above the SPD indicate the colors for which the LED semiconductor material (GaN and InGaN) or phosphor coating (Ce:YAG) are responsible. (reference???)

N.9. Local, Regional and National Regulations

To date, a number of countries including Spain, France, Czech Republic, Slovenia, Croatia, Italy and Chile have enacted regional or national legislation for the control of outdoor lighting in order to reduce light pollution. (Barentine 2021) Others have attempted some form of rulemaking through executive action. For instance, the environmental impact assessment process in many countries requires applicants for development permits to show that adequate steps to mitigate light pollution impacts have been taken even if no particular statute requires it.

There is little empirical evidence showing that particular policies are more or less effective at reducing or preventing light pollution than others; rather, a sense of emergent lighting policy best practice stems from scientific knowledge about lighting designs and practices that result in varying degrees of night sky impacts, with the goal of codifying into law the elements that seem to be most effective. However, given the global rate of growth of light pollution in recent decades, it is arguable that outdoor lighting policies in many jurisdictions are ineffectual. That is thought to result in part from an overall lack of consistent implementation and enforcement of lighting control laws. With this in mind, policies may be written in ways so as to be more readily enforceable, the ultimate success of this approach relies on broad public support for those policies.

The kinds of policies that are thought to have the greatest potential to make meaningful reduction of light pollution have to do with limiting wasted light, much of which ends up in the night sky. IDA and the Illuminating Engineering Society have identified a series of five principles for responsible outdoor lighting that can be incorporated into legislation and regulations. The principles hold that outdoor lighting should only be used when a clear purpose or need for the light is identified. Once the need for outdoor lighting is firmly established, it should be installed and operated such that its light output is:

1. Directed only where it is needed, illuminating an object or task performance area, avoiding light spill;
2. Used only at times when it is useful, and actively reduced or extinguished during times when users of lighting are not present;
3. No brighter than necessary to perform the intended task, and deployed in such a way as to reduce glare; and
4. Designed to release the least fraction of short-wavelength emissions possible in order to minimise specific impacts to the night sky and biological systems.[6]

[6] For general purposes, 'short-wavelength' light is any electromagnetic radiation between 350 and 500 nanometers in wavelength.

These principles are summarised below in Figure 7. Their proper implementation results in lighting that is functional and safe, decreases the incidence of glare, preventing conditions of intrusive 'light trespass', and minimises the amount of artificial light released into the nocturnal environment. Regulations following from the principles can be made increasingly prescriptive by adding lighting technical details as needed.

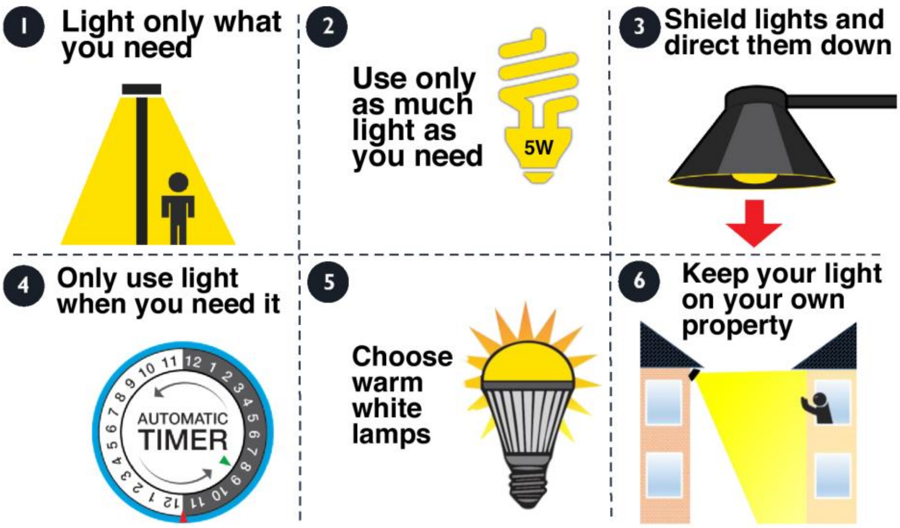

Figure N.7: Graphical representation of the IDA-IES Principles for Responsible Outdoor Lighting. Graphic by IDA, used with permission.

N.10. The value of Dark Sky Oases

The value of a resource like natural nighttime darkness stems in part from the perception of its comparative (and increasing) rarity as an everyday experience among humans. The converse begs the question of whether people who have never had access to a particular resource, such as natural nighttime darkness, can value it highly enough to actively support its conservation. As the world's human population becomes increasingly urban, it may be progressively more difficult to build and sustain coalitions aimed at reducing light pollution.

Some scholars have critically evaluated the value of natural darkness beyond what it represents in terms of potential material benefit and the extent to which it is impacted by light pollution, which perhaps devalues the resource. In particular, Stone (2017) asked "that we reconsider darkness, not as an opponent of lighting, but as an equal consideration in the design of nighttime spaces." The suggested approach is therefore holistic and transcends the simple question of whether or not one can see the stars at night.

Here we examine different dimensions of "value" as regards places where night skies have protected status.

N.10.1 Economic value

It is hypothesised that the conservation of dark night skies generates economic value by encouraging tourism and supporting property values if such dark places are considered desirable locations to visit or live. Because the resource of darkness is fully renewable, this value can be sustained indefinitely with good management practices. Further discussion of this subject may be found in Appendix 3.

The economic value of natural darkness may be indicated by the degree to which residents and property owners in and around protected areas agree that public resources should be spent on conservation programs. Simpson and Hanna (2010) applied the Contingent Valuation Method (CVM) to light pollution in terms of survey respondents' Willingness To Pay (WTP) both to improve night sky visibility and to prevent deterioration in visibility. They found that "a larger improvement in night-sky conditions has a significantly higher average WTP, suggesting that larger expenditures for light pollution projects with greater effects may be economically efficient. Gallaway (2010) argued that nighttime darkness has 'instrumental value' (as a means to an end), rather than intrinsic value (an end unto itself)."The passive enjoyment of beauty is fundamental to the value of dark skies, and prevailing economic doctrines make it difficult to appreciate and articulate the importance of beauty and other passive pleasures."

N.10.2 Scientific value

Human understanding of the nighttime environment, and the ways artificial light at night alters it, are still far from complete. To the extent that researchers look to light-polluted cities as environments to study the deleterious effects of light pollution, they need protected dark places to serve as experimental "controls". This is especially important when biological systems are under study. Protected dark-sky places are themselves natural laboratories for studying the natural light of the nighttime environment; as an example, see the recent work in Grauer et al. (2019) resulting from a collaboration between two IDA International Dark Sky Sanctuaries: the Cosmic Campground (U.S.) and Aotea/Great Barrier Island (New Zealand).

Beyond their advantages for research relating directly to darkness itself, protected dark places enable other kinds of science. In recent decades, ground-based astronomical observatories have been situated progressively further from cities in order to limit the impact of skyglow on science observations. To prolong the useful lifetime of these facilities, some observatories have successfully sought protections for territories surrounding their sites. Examples include Mont-Mégantic Observatory in the Mont-Mégantic International Dark Sky Reserve, Québec; Mt. John Observatory in the Aoraki Mackenzie International Dark Sky Reserve, New Zealand; and the AURA Observatory in the Gabriela Mistral International Dark Sky Sanctuary, Chile, Roque de los Muchachos Observatory (La Palma, Starlight reserve and Starlight Tourist Destination) and Teide Observatory (Tenerife, in National Park of Teide, Starlight Reserve and Starlight Tourist Destination), Parc Astronòmic del Montsec (Catalonia, Starlight Reserve and Starlight Tourist Destination) or Pic du Midi (Starlight certification in progress).

Windows to the Universe (Marín et al. 2015).

The scientific dimension 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. Unfortunately current areas devoted to astronomical observation do not enjoy appropriate recognition and some of them are threatened by light pollution. Present-day technical and scientific requirements restrict suitable areas to very specific and limited locations offering good conditions for the development of astronomy, and for 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. These exceptional sites, including their natural components, can be considered as "landscapes of science and knowledge". Having identified the best locations for astronomical observation throughout the planet, it is critically important to try to conserve and protect them. The case of Hawaii, the Canaries, Namibia and northern Chile are an ensemble of discrete sites that, within this context, have outstanding universal significance as a group (Ruggles & Cotte, 2010).

N.10.3 Cultural value

The close and perpetual interaction between astronomy and its role within human culture is a vital element of the outstanding universal value of the dark sky.

There is a lengthy human history and prehistory terms of astronomical themes in art and architecture, arising as early as the Paleolithic. (Sweatman and McCoombs, 2019) Deliberate alignment of artificial structures to the rising and setting points of astronomical objects points to human use of the night sky as a calendric device by the Neolithic period.

They are places of mystery and wisdom based on the "knowledge of stars". Teotihuacán, Stonehenge, Giza, Carnac, Chichen Itza, Delos, and Jaipur are only a few examples symbolizing this legacy made up of an infinity of artistic, scientific and ethnographic manifestations conserved at all latitudes. (Marín et al. 2015).

Furthermore, the night sky has inspired numerous great works of art, literature, poetry and music across all human cultures, religions and societies.

Although UNESCO has so far declined to recognise the night sky itself in the context of its World Heritage Programme, it has conferred World Heritage status on many monuments and sites associated with both historical astronomy activity and archaeoastronomy.

The cultural and religious practices of many people, especially those in indigenous societies, rely on access to the night sky. Detailed examples are given by Ruggles and Cotte (2010) and by Ruggles (2017).

N.10.4 Environmental value

Dark Sky Oases offer the possibility of controlling and minimizing, or even, eliminating the artificial illumination into their territories. Consequently, they are literal refuges for wildlife under the stress of increasing human territorial intervention, including environmental light pollution -ELP.

The loss of the natural darkness because of ELP has become a serious threat for many species, disturbing their habits and habitats, as well as the basic functions of ecosystems. Darkness and natural light are indispensable for the healthy functioning of organisms and ecosystems. Wildlife has been adapted to the natural cycles of the moon and stars during millions of years of evolution. As over half of the creatures living on this planet are nocturnal, any insignificant degradation in the quality of the sky is having a profound effect on the behaviour and on the equilibrium of the biosphere. (Marín et al.(2015). In addition, many diurnal species adjust their vital cycle according to night duration. Light pollution, in particular, has been shown to have a widespread, negative impact on many different species and also covering large portions of territory. Scientific evidence for this impact in migratory birds, wilderness fauna, hatchling sea turtles, oceanic species and insects is striking, because of the large-scale mortality that has occurred as a result of artificial night lighting, a phenomenon which is increasing worldwide, also because of the increased negative impact of the blue rich LED; a technology that has been replacing the traditional electric discharge sources of illumination.

Most natural protected areas and sites of importance for conservation were not originally designed or placed to ensure maintenance of ecological processes without disturbance from artificial light or skyglow from distant cities or industrial zones. Dark Sky Oases offer both concrete and successful examples on how to control the ELP in their territories and surroundings.

N.10.5 Potential human wellbeing value

We know the least about this value. There is no known evidence that people who live in and near these places benefit in terms of health outcomes. However, one example has to do with ‘medical tourism’. The Yeongyang Firefly Eco-Park International Dark Sky Park in the Republic of Korea cultivates the image of a place where people can recuperate from medical procedures in a naturally dark environment, which is thought in some strains of eastern medicine to be beneficial to healing. (Dalton, del Solar and Barentine 2021b)

Another example has to do with an overall sense of well being among people living in dark places, which could be connected to better mental health. Blair (2018) studied the people of Sark, a royal fief among the Channel Islands off the south coast of the United Kingdom that was named an IDA International Dark Sky Community in 2011. She found that residents of Sark place a high value on observing the night sky with others from their island, and that the shared experience supports and extends family and community connections through the transmission of night sky lore. Blair's observations also validate a "widespread belief that observing the night sky spontaneously or intentionally results in positive (and sometimes transformative) feelings" that "impact positively on wellbeing." (Blair 2018)

N.12. Recommendations to COPUOS

While protected area and conservation managers have no direct sway over light pollution and the resulting skyglow, we recommend to COPUOS the levels of sky brightness considered to be appropriate for different dark sky place classes, as defined by the IUCN Dark Skies Advisory Group (DSAG) - see §4.1. The International Astronomical Union and the International Commission on Illumination (Cayrel et al. 1980) recommend that for astronomical observatories it should be no more than 10 % additional brightness beyond the natural background airglow at a zenith angle 45°, airglow being typically 174 to 250 µcd/m^2 (Falchi et al 2016). We have adopted 240 µcd/m^2 here as a nominal value. Rounding this value and extending it to the DSAG classes of dark sky place, we recommend the following values as a basis for seeking support for abatement of light pollution. Recommended limiting values in µcd/m^2 are also quoted in visual magnitudes per square arc second. These recommended values are consistent with those also recommended by IUCN (Welch, 2021).

- Dark Sky Astronomy Site, DSAG class 1: <260 µcd/m^2; >21.7 mag/sq arc sec. 10 % more than airglow
- Dark Sky Park, DSAG class 2: no more than 50 % more than the natural airglow, or <360 µcd/m^2 (>21.4 mag/sq arcsec)
- Dark Sky Heritage Site, DSAG class 3: No more than 2.75 times the natural airglow, or <660 µcd/m^2 (>20.7 mag/sq arcsec).
- Dark Sky Outreach Site, DSAG class 4: given that astro-tourism and amateur astronomy often happen at these places, the recommended limit is 2.0 times the airglow, or <480 µcd/m^2 (>21.0 mag/sq arcsec).
- Dark Sky Reserves, DSAG class 5: similar to outreach sites, <480 µcd/m^2 (>21.0 mag/sq arcsec).
- Dark Sky Community, urban, DSAG class 6a: The recommended limit is 4 times the airglow for protected sites in more urban areas, giving sky brightness <1000 µcd/m^2 (>20.3 mag/sq arcsec).
- Dark Sky Community, rural, DSAG class 6b: The recommended limit is 3 times the airglow for protected sites in more rural areas, giving sky brightness <750 µcd/m^2 (>20.6 mag/sq arcsec).

It is recognised that these recommendations may not be realizable in all protected areas and that each area will have its own challenges and circumstances. Values of sky brightness may be more or less than these recommendations in individual locations.

In addition, we make the following practical recommendations for exterior lighting in protected dark sky oases:

1. In all protected dark sky oases the default condition should be no artificial light. Specific uses justifying light should then be additive once other non-lighting interventions are exhausted.
2. In ecological reserves and similarly sensitive sites with little or no human presence at night, generally speaking, artificial light should not be used. If it is used, it should be a narrowband amber LED or equivalent emitting no light at $\lambda < 500$ nm. Lighting should be strictly controlled and switched on only when it is needed.
3. If phosphor-converted amber LED lights are used, the amount of blue light ($\lambda < 500$ nm) should be below 5 % of the total spectral power. Generally this requires using LED luminaires with a correlated colour temperature of 2200 K or less.
4. All exterior lights should only distribute light below the horizontal, and the upward light output ratio (ULOR) should be no more than 0.5 %. This requires luminaires to be mounted horizontally and have flat screen glass below the light source.
5. No development in or near highly ecologically sensitive sites should be permitted.
6. Monitoring of nighttime conditions in/near dark sky oases is encouraged through a combination of ground-based and remote sensing methods.
7. Active management of natural nighttime darkness as a natural resource is encouraged through recognised conservation best practices.
8. Restoration plans should be implemented when sky brightness thresholds are routinely exceeded.

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Appendix 1. Dark Sky Oasis Classification Scheme

The following table lists, for each of the six fundamental IUCN-DSAG classes, a recommendation for the threshold visual night sky brightness (NSB) at the zenith that defines the class and equivalent designation categories in the dark-sky certification programs of IDA, the Starlight Foundation, and the Royal Astronomical Society of Canada (RASC).

IUCN-DSAG Class	*V*-band Zenith NSB (µcd m^{-2})	*V*-band Zenith NSB (mag $arcsec^{-2}$)	IDA Category	Starlight Foundation Category	RASC Category
1	<264	>21.7	International Dark Sky Sanctuary	Starlight Reserve	Nocturnal Preserve
2	<360	>21.4	International Dark Sky Park	Starlight Landscape; Starlight Wilderness	Dark Sky Preserve
3	<660	>20.7	(none)	Starlight Heritage Site	(none)
4	<480	>21.1	Urban Night Sky Place[7]	Starlight Astronomy Site; Starlight Tourism Destination; Starlight Stellar Park; Starlight Camp	Urban Star Park
5	<480	>21.1	International Dark Sky Reserve	Mixed Starlight Site	(none)
6a	<1000	>20.3	International Dark Sky Community[8]	(none)	(none)
6b	<750	>20.6	International Dark Sky Community	Starlight Oasis; Starlight Village	(none)

Table N: Suggested zenith night sky brightnesses defining the IUCN-DSAG dark-sky place classes

Threshold zenith brightnesses are given in multiples of an assumed dark limit for the luminance of a night sky in the absence of anthropogenic light set only by natural sources.[9]

[7] In practice, no upper limit for zenith NSB is imposed by IDA program guidelines as a requirement for obtaining this certification.
[8] In practice, no upper limit for zenith NSB is imposed by IDA program guidelines as a requirement for obtaining this certification.
[9] This furthermore assumes that the sky is 'astronomically dark' (i.e., the Sun is at least 18° and the Moon at least 10° below the horizon); the air is clear (i.e., the atmospheric optical depth in the middle of the visual band $\tau \lesssim 0.1$); the Milky Way is not in the zenith and the observer is looking away from the ecliptic.

There is some disagreement in the literature as to the value of this minimum zenith brightness in part because there is in some cases significant spatial and temporal variation in natural sources of light in the night sky. Chief among these sources in terms of contribution to night sky brightness is airglow, a chemiluminescent process in the Earth's atmosphere that can contribute as much as ~280 µcd m^{-2} of luminance to the total NSB in any given direction (Sternberg and Ingam 1972). Its intensity and distribution depend on upper atmosphere conditions and solar-geophysical conditions.

In the New World Atlas of Artificial Sky Brightness, Falchi et al. (2016) adopted a 'canonical' value of 174 µcd m^{-2}, or about 22.2 *V* magnitudes per square arcsecond. Crumey (2014) argued that "the darkest skies on Earth" have a zenith luminance of 171 µcd m^{-2}, but "a general approximation … representative of a truly dark sky" considering variations in airglow intensity and sky distribution is 200 µcd m^{-2} (22.0 *V* magnitudes per square arcsecond), "though at a pristine site there may be regions of the sky that are darker than this".

This is, however, a theoretical lower limit that is rarely obtained in nature. In the experience of the authors, having made many measurements of NSB in different parts of the world and under a variety of conditions, the natural night sky is observed to vary in zenith brightness from around 200-250 µcd m^{-2} (22.0-21.8 *V* magnitudes per square arcsecond). We therefore adopt a conservative global average, away from the Earth's polar regions, of 240 µcd m^{-2} (21.8 *V* magnitudes per square arcsecond). We define this as one "night sky unit" (NSU).

Thresholds in multiples of this value are suggested in Welch (2021); we have adjusted the value of the NSU relative to Welch according to our preferred definition.

IUCN-DSAG Class	Threshold (NSU)
1	1.1
2	1.6
3	4.0
4	2.6
5	2.6
6a	4.0
6b	3.0

Table N: IUCN-DSAG dark-sky place class definitions by zenith brightness given in night sky units (NSU).

We note that the values in the above tables are not intended to form the basis of regulations to control the brightness of the night sky over particular areas. Far from sources of light pollution, the brightness of the night sky, controlled by natural sources of light, is known to vary by a factor of two on timescales ranging from hours to years. For the purposes of defining conservation classifications of various sites, the guidelines above should be considered determinative only in the context of long-period night sky brightness monitoring programmes.

Appendix 2. Traditional and modern lamp types used in outdoor installations

In 1417 houses in London were required to hang a lantern outside during the hours of darkness. This was presumably a wax candle, and represents the earliest introduction of street-lighting. Paris followed with a similar ordinance a century later, in 1524.

These early beginnings to municipal lighting would have hardly caused any significant light pollution. Lighting by reticulated coal gas came to London in 1807, to Baltimore in 1816 and to Paris in 1820. The 19th century was therefore the era of gas street-lighting in the major urban centres of Europe and North America. A typical gas mantle was very dim and emitted about 400 lumens, the same as a 25-watt incandescent light bulb.

Thomas Edison in the United States and Joseph Swan in England developed the first electric light bulbs using incandescent carbon filaments. Both were patented independently in 1879. A few years earlier Pavlov Yablochkov in Russia had devised a carbon arc lamp, and it was this lamp which was installed in Paris in 1878, the first city to have electric street-lighting. By 1881 as many as 4000 Yablochkov candles were installed in Paris. Carbon arc lamps were widespread in the United States by 1890. At about the same time, Edison incandescent bulbs were being used from the 1880s for street-lighting. These bulbs had a low efficiency, short life and yellow to orange colour. Edison and Swan each started companies for the manufacture of electric lights. These companies merged in 1883 with the formation of the Ediswan company.

Tungsten filament incandescent lamps were developed in 1904 and patented by Hungarian Sándor Just and Croatian Franjo Hanaman. They had brighter filaments operating at a higher temperature, and were filled with an inert gas such as argon or nitrogen.

Another type of arc lamp is the low-pressure sodium (LPS) lamp, in which light is emitted as the result of passing an electric current through a thin vapour of ionised sodium atoms. LPS technology was developed in the 1930s, and streetlights using this technology became common after World War 2. They emit almost monochromatic light at 589 nm, resulting in the well-known orange glow. Their colour temperature is about 1900 K, insofar as the concept of colour temperature can be applied to a non-thermal source with such a large departure from a black-body SPD. This value is similar to a typical carbon-filament incandescent lamp, but less than that of a tungsten filament (which is about 2450 K). Given their almost complete lack of short wavelength blue light, LPS luminaires have the least impact on night sky brightness among common lighting technologies.

A high-pressure sodium (HPS) arc lamp broadens the monochromatic orange light SPD of LPS, giving a more pleasing golden-yellow hue with better colour rendering to the human eye. HPS street-light luminaires were developed from 1965 and became widespread from that time. Another type of arc or gas discharge lamp is the mercury-vapour lamp, first patented in the 1890s. Its spectrum consists of a number of emission lines at discrete wavelengths, especially in the blue and ultraviolet; the high pressure under which the gas is maintained broadens the lines, rendering their perceived colour as bluish-white.A variation of the mercury-vapour lamp is the fluorescent lamp, in which the inside surface of a glass tube is painted with a fluorescent substance that converts ultraviolet light to visible light, thereby increasing the luminous efficacy and giving a more pleasing white light. Fluorescent lights were patented in 1931 and were marketed commercially by the General Electric Company in the U.S. from 1938. They were often used for street-lighting in the 1950s and 1960s, as well as for interior spaces such as offices and workshops.

Yet another variation of the mercury-vapour lamp is the metal halide lamp. Here a metal salt such as sodium iodide is added to the mercury vapour. In a metal halide lamp spectrum, orange sodium D lines are added to the line emission of mercury, giving a better luminous efficacy and improved colour rendition. Metal halide lamps are often used to light outdoor commercial or industrial spaces and car parks, as well as for flood lighting. They were first developed in the 1960s.

The first use of LEDs for street-lighting only came in 2006, almost half a century after their first invention. Ann Arbor in Michigan, where LEDs were first developed, was also the first to install LED street-lights. This required the first white LED to be devised, based on using a blue LED made from indium gallium nitride (InGaN) or gallium nitride (GaN) as the main semiconductor material, and coated with a phosphor made from yttrium aluminium oxide doped with cerium (known as Ce:YAG, or cerium-doped yttrium aluminium garnet semiconductor). The phosphor converts some of the blue or violet light into a broad spectrum of green, yellow and red. The result is an LED emitting light which appears as white to the human eye. LEDs are theoretically capable of emitting over 300 lumens of light per watt of electricity consumed, a vast improvement over the 16 lumens per watt efficacy for incandescent filament lamps, and are expected to operate for at least 100,000 hours in the field. For street-lights, this corresponds to about 25 years.

Appendix 3. Astrotourism

'Astrotourism' is sustainable in that it does not involve resource extraction. If darkness is preserved, it is infinitely renewable (Starlight, 2007)

Because natural darkness tends to be concentrated in underdeveloped and/or little-populated areas, astrotourism necessarily contributes to rural economic development and overall development goals.

The biggest threat is often from the development that follows intense tourism interest in dark skies.

The challenge is how to sustainably grow this kind of tourism without damaging the very resource that tourists come to enjoy.

The French astronomer Camille Flammarion (1842-1925) was a great populariser of astronomy, and he had his private observatory at Juvisy-sur-Orge, 18 km south-east of Paris. He installed there a 24-cm refracting telescope where he was able to bring the beauty of celestial objects to the public, and to members of the Société Astronomique de France, which he founded.

In 1880, Flammarion wrote his well-known book *Astronomie Populaire* in which he extolled the beauty of a pristine night sky (Flammarion 1880). He was one of the founders of astro-tourism.

In spite of Flammarion's early recognition of celestial aesthetics, the strong interest in astro-tourism is very much a recent phenomenon, of the late 20th and 21st centuries. Astro-tourism constitutes the travelling of people to dark sky locations to admire the beauty of the night sky, and possibly to participate in a guided night-sky tour.

A3.1 Starlight Tourist Destinations

Astrotourism epitomises the tendencies towards more meaningful tourism experiences, based on conservation of natural resources, knowledge, and science, potentially enriching the traveler and the host communities. In 2009, the Starlight Foundation unveiled for the first time the Starlight Tourism Certification System with the support of UNWTO. In recent years several UNESCO sites have been labelled by the Starlight Foundation as Starlight destinations, such is the case of biosphere reserves of La Palma, La Rioja, Fuerteventura, Sierra Morena, Gran Canaria, Monfragüe, Alto Turia, etc. (Spain), Fray Jorge (Chile) and South West Nova (Canada) or the Teide National Park, the first World Heritage site labelled. Responsible lighting and light pollution control are key requirements for the certification in these sites (Ref. *Alternative Ways of Lighting UNESCO Sites*, 2005).

As an example of good practices on Astrotourism we have chosen La Palma Island, **the world's first Starlight Reserve, was acknowledged in 2012 as a Starlight Tourist Destination;** this guarantees the possibility of enjoyable stargazing while learning something of the associated scientific, cultural, natural and environmental values. On 20 April 2007, **La Palma hosted the signing of the Starlight Declaration** in Defence of the Night Sky and the Right to Starlight (or La Palma Declaration) and on April 2017 hosted the X Anniversary of the Starlight Declaration, where the institutions signing the same, as well as other institutions invited, adopted resolutions and made a call facing the future.

La Palma possesses certain unique environmental features which have won it the distinction of being named a UNESCO World Biosphere Reserve. More than one third of its surface area is protected land, the highlight of which is the Caldera de Taburiente National Park. Its landscape is the result of a dramatic formation process that took millions of years, and houses a multitude of microclimates and surprisingly contrasting vegetation. At its highest point, over 2400m above sea level, the Roque de Los Muchachos Observatory rises above the “sea of clouds” where the atmosphere is clear and stable thanks to the Atlantic Ocean. Consequently, this is considered one of the best places on earth to observe the sky. In addition, La Palma was **the first place in the world to apply the Sky Law** promoted by the Institute of Astrophysics of Canary Island in 1988, a specific law was passed designed to protect the quality of the night sky for the purpose of astrophysical observation, which was a giant step forward in defence of the sky on a world-wide scale. This law protects La Palma from light, atmospheric and radioelectrical pollution, as well as preventing interference from aviation routes.

We can enjoy stargazing activities, guided night trails, visits to the astrophysics observatories of Roque de los Muchachos, etc. For all of them specialised personnel is needed. In La Palma the first course of **Starlight Guides** took place in 2011 and the second one in 2019, but the number of guides dedicated to the activity of stargazing has fallen short, especially when it coincides in dates with the visit of cruise ships. There is a demand for the training of specialised guides by specialised companies that have increased their activity in the last years.

To enjoy a unique experience, La Palma offers: hotels and country cottages that have basic instruments to enjoy our spectacular sky (El Pósito and Casa Emblemática San Sebastian have been awarded as Starlight Rural House and Hotel respectively); companies specialised in Astronomical Tours that have professional guides; organised visits to one of the most important Astrophysical Observatories in the world ; archaeoastronomy activities; night photography; thematic routes (wine and stars, moonlight hikes); solar observations; camping under the stars; activities with solar cooking; or the chance to simply stroll around discovering the sundials or to go shopping in stores where the protagonists are the stars. Some restaurants even include evocative flavours with names of planets, galaxies and constellations in their dishes.

There are more than 70 enterprises dedicated to astro tourism with annual revenues of about 30 million euros.

Astronomical resources:

A.3.1 Stargazing viewpoints network

These spaces located throughout the island’s geography are equipped with information panels designed to interpret the night sky. The viewpoints are divided into 3 categories, depending on the darkness of the night sky. All of La Palma’s municipalities have viewpoints dedicated to the observation of the local landscape during the day and astronomy during night, with themes that range from the interpretation of the sky (with its constellations, planets or the Moon), the calculation of equinoxes and solstices, up to a Solar System to scale, making an outdoor astronomy museum Some of these observation points connect to hiking routes belonging to the nature trail network of La Palma.

A3.2 Stargazing trails

La Palma is an ideal island for lovers of hiking. In combination with the GR 131, four hiking trails have been signposted so you can walk while enjoying routes linked to the stars.

A3.3. Places of astronomical interest

Throughout the island’s geography, places that have a special symbolism or connection with the sky and the stars are referenced: sundials, dark sky sites or places of great symbolism.

A3.4. Archeoastronomy

The Awara, the first settlers of the island, created various rock carvings, cairns, and other elements. According to new research these are related to ancient markers for the solstices, equinoxes and stellar alignments vital to the survival and religious beliefs of the population.

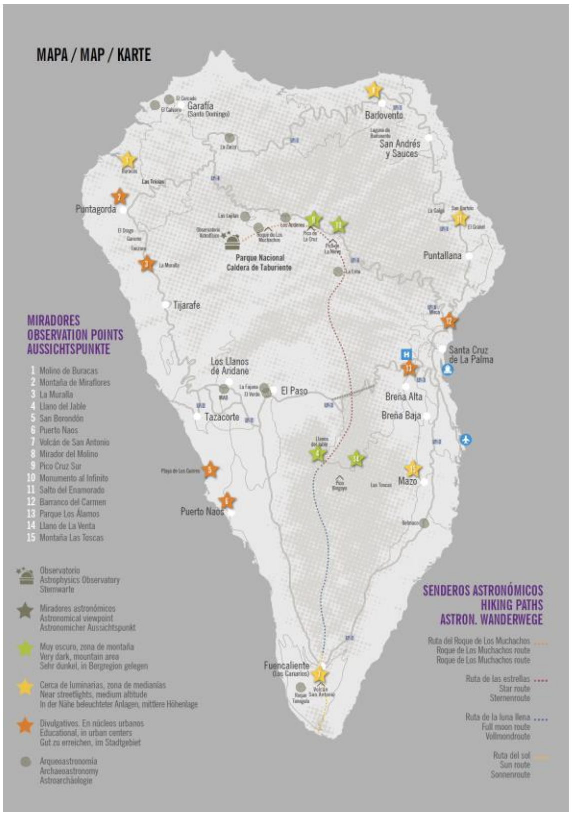

Figure 12. Stargazing resources at La Palma Island: walking and observing (http://www.starsislandlapalma.es/en/walking-and-observing/).

A3.2 Astrotourism in New Zealand

In New Zealand astro-tourism has grown strongly since the creation of the company Earth and Sky at Lake Tekapo in 2004 (since renamed the Dark Sky Project, in 2019). Approximately 1.5 million tourists travel through Tekapo annually, and a rough estimate is that 10 % of them come to see the night sky. In 2019 visitor guest nights in Mackenzie District accommodation reached 900,000 per year, a figure which has doubled in the period 2014 to 2019. Many astro-tourists visit nearby Mt John Observatory, a professional research facility operated by the University of Canterbury.

The growth of astro-tourism is very much a world-wide phenomenon, but New Zealand is seen as a world leader. This is a result of relatively unpolluted night skies, the Mackenzie District ordinance to control light pollution (first introduced in 1981), the presence of numerous astro-tourism companies in the Mackenzie Basin and the desire of many other communities in New Zealand to emulate the success of astro-tourism in the Mackenzie Basin.

In August 2019 Forbes magazine asked the question: 'Is Astrotourism the next Big Thing? – Incredible night-time outdoor adventures for Stargazers' (Forbes, 2019). The article urged tourists to visit a dark sky place to view the Milky Way, or an aurora or even an eclipse. Lonely Planet have jumped onto the band-wagon and published their first guide for astro-tourism (Stimac, 2019). The guide-book features many of the world's top locations for dark skies and star-gazing, including those in New Zealand and Australia.

Travel writers have also been quick to extol the delights of this new brand of educational scientific tourism. One of those is UK travel writer Anna Hart in the Telegraph (Hart 2018). She mentioned the top stargazing locations in the world, including the Aoraki Mackenzie in New Zealand.

In Italy, the website AstronomItaly, which has an English version (AstronomItaly, 2020) advises tourists how to find the best locations on Earth for stargazing. They also offer a certification programme for new dark sky localities, with applications solicited from observatories, planetariums, hotels and lodges, nature and national parks and villages, with a handful of certified places in each category.