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Guide lines for minimizing Urban Sky Glow near Astronomical Observatories

by

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FIGURE 1. A night time view of the United States composed from US Air Force satellite data. Reproduced with permission from reference 4.

Guidelines for Minimizing Urban Sky Glow Near Astronomical Observatories Joint CIE/IAU publication

The extremely rapid increase of outdoor lighting in most urban areas over recent decades has resulted in levels of sky glow which seriously affected several astronomical observatories and which are threatening others, even where they have been purposely located at more than 100 km from large cities. The International Astronomical Union (IAU) and the CIE have worked together to prepare these guidelines to promote collective action to minimize the degradation of the environment of astronomical observing sites.

The problem and its solutions are stated in a manner that provides a basis for understanding, cooperation, and action by astronomers, lighting engineers and public authorities. The report explains the effect of man-made sky glow, the degree of glow likely to be produced by lighting near an observatory, the level above which sky glow should not be allowed to rise, and how it can be contained by good lighting practice and public ordinances.

Richtlinien zur Minimierung städtischer Himmelsaufhellung in der Nähe astronomischer Observatorien Gemeinsame Publikation CIE/IAU

Der rasche Anstieg der Außenbeleuchtung in den meisten Stadtgebieten in den letzten Jahrzehnten verursachte eine Himmelsaufhellung, die einige astronomische Observatorien ernsthaft beeinträchtigte und andere gefährdete, auch wenn diese absichtlich mehr als 100 km von großen Städten entfernt errichtet wurden. Die International Astronomical Union (IAU) und die CIE bereiteten gemeinsam diese Richtlinien vor, um die gemeinsame Arbeit zur Minimierung der Verschlechterung der Umweltbedingungen astronomischer Beobachtungsstationen zu fördern.

Die Darstellung des Problems und seiner Lösung liefert eine Basis für Verständnis, Zusammenarbeit und Aktionen von Astronomen, Lichttechnikern und Behörden. Der Bericht erklärt die Wirkung der von Menschen verursachten Himmelsaufhellung, den Grad der Aufhellung, der von Beleuchtung in der Nähe eines Observatoriums verursacht wird, den höchstzulässigen Grad der Himmelsaufhellung, und zeigt, wie sie durch gute Beleuchtungspraktiken und behördliche Vorschriften eingedämmt werden kann.

Guide pour minimiser la lueur du ciel urbain à proximité des observatoires astronomiques Publication jointe CIE/IAU

L'augmentation extrêmement rapide de l'éclairage extérieur dans la plupart des sites urbains qui s'est produit dans les dernières décennies a provoqué un niveau de la lueur du ciel qui a sérieusement affecté quelques observatoires astronomiques et a menacé d'autres, même s'ils ont été construits, intentionnellement, à une distance de plus de 100 km de grandes villes. La IAU (International Astronomical

Union - Union Astronomique Internationale) et la CIE ont collaboré pour préparer ce guide dans le but de promouvoir une action collective pour minimiser la dégradation de l'environnement de sites d'observation astronomiques.

Le problème et ses solutions sont présentés de manière à fournir une base pour la compréhension, la coopération et l'action des astronomes, des ingénieurs d'éclairage et des autorités publiques. Le rapport explique l'effet de la lueur du ciel produite par l'homme, le degré de lueur provoquée par l'éclairage à proximité d'un observatoire, le seuil admissible maximum de la lueur du ciel, et une façon de la limiter par une bonne pratique de l'éclairage et par des ordonnances publiques.

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1. INTRODUCTION

Advances in astronomy depend heavily upon observations of very faint objects which can be detected only with large telescopes located on sites away from industrial pollution and city lights. For example, observations of cosmological interest deal with extremely remote sources, galaxies, or quasars at such distances that the light has travelled several billions of years, sometimes twice the age of our solar system, before reaching us. Observations of such very faint extragalactic sources, and even of most galactic gaseous nebulae, can be done only during the dark moon, the sky background being much too strong when moon light is present. Man-made lighting of the sky due to urban lighting has, unfortunately, the same adverse effect on sky background in limiting observations. The sky background is referred to from hereon as sky glow.

Even where the location of large observatories, built during or after the second world war, had been carefully selected, far from large cities, problems have arisen because of the remarkable growth of light output from urban areas. This has been as high as 20 per cent per year over a couple of decades (1) representing a 38-fold increase in artificial illumination of the sky in twenty years. A dramatic picture of the USA by night taken from a spacecraft clearly demonstrates the significance of the fact (Figure 1).

It was mainly for this reason that the IAU decided in 1973 to establish a permanent commission in charge of identification and protection of existing and potential observatory sites (Commission 50).

At the 1976 General Assembly the International Astronomical Union adopted the following resolution:

"The IAU notes with alarm the increasing levels of interference with astronomical observations resulting from artificial illumination of the night sky, radio emission, atmospheric pollution, and the operation of aircraft above observatory sites.

The IAU therefore urgently requests that the responsible civic authorities take action to preserve existing and planned observatories from such interference. To this end, the IAU undertakes to provide through Commission 50 information on acceptable levels of interference and possible means of control."

The information on acceptable levels of interference and possible means of control was issued in 1977 and can be found in Appendix 1. The reports of Commission 50 (2, 3) contain other useful information. The pioneering work (4) made at Kitt Peak Observatory by Hoag and Peterson must also be mentioned here. Lighting technologists have become aware of these problems (6, 7, 8, 12, 13).

Later, in June 1978, the CIE adopted a statement acknowledging the problems caused by uncontrolled outdoor lighting near the best observatory sites and agreeing that all possible action should be taken to protect these sites from such interferences. The CIE statement is given in Appendix 2. The present guidelines are the result of further discussions between Commission 50 of the IAU and Technical Committee 4.6 of the CIE.

The guidelines are concerned only with sky glow and are intended to give guidance to agencies which have funded large astronomical facilities; to lighting technologists responsible for or engaged in designing public lighting in the vicinity of astronomical observatories; and to public authorities concerned with a coherent use of public funds in districts encompassing astronomical observatories. Cooperation between these three parties is needed if the possibility that ground-based astronomy will be eventually untenable, because of a polluted environment, is to be avoided.

The argument that space astronomy will make this problem obsolete is not correct: the largest telescopes are still and will continue to be ground-based for a long time because of cost. The experience of two decades of space astronomy is that space observations have renewed and triggered more programmes from the ground rather than making them obsolete.

2. NATURAL AND ARTIFICIAL SKY GLOW

2.1 Natural sky glow

Most of the brightness of the night sky is due to:

- (i) intrinsic emission of the upper atmosphere (night glow) occurring both at the specific wavelengths of emission lines and in a continuum;
- (ii) unresolved star light when the angular resolution of the instrument is not very large;
- (iii) the zodiacal light, which is sun light scattered by dust particles in the solar system outside the earth's atmosphere;
- (iv) light scattered by the earth's atmosphere coming from the sources mentioned above;
- (v) light scattered by the atmosphere coming from artificial lighting on earth.

It is this last component which is of concern and over which some control can be achieved. As long as it remains weak compared to the other ones it is acceptable. Thus, the natural background is the standard by which man-made sky glow is judged. The average natural brightness or luminance of the night sky, integrated over the visible range, is about 2×10^{-4} cd.m⁻², equivalent to 300 stars of magnitude 10 per square degree or to one star of magnitude 21.6 per square arc second (5). This is the value quoted in the IAU recommendations (Appendix 1). However, it should be noted that darker conditions can be expected under some circumstances, for the following reasons:

- (i) the unresolved starlight (stars fainter than magnitude $m_v = 6.0$) which is conventionally counted as part of the night sky, and accounting for about 25 per cent of it, should not be included in the background for observation with large telescopes, since it is actually resolved down to at least magnitude 20 by large telescopes;
- (ii) the zodiacal light, which can account for 35 per cent of the total background, varies with angular distance to the sun and to the ecliptic plane. It may be larger or smaller according to the direction of the target object.

The combined effect of these factors gives the darkest background level as about 1.5×10^{-4} cd.m⁻² when integrated over the visible range, or 1.5×10^{-6} cd.m⁻² per unit wavelength interval (nm), taking the effective bandwidth of eye sensitivity as about 100 nanometers.

2.2 Limitations on astronomical observations caused by sky glow

Sky glow would not be a significant limiting factor if it could be subtracted with an unlimited accuracy from the total light signal, made up of light from the source of interest and from the sky glow. There is, however, a fundamental and inescapable difficulty in this subtraction, which is the result of the photon nature of light. The uncertainty in any measurement of light intensity is determined by the statistical fluctuations in the total light rather than in the source alone. The sky glow must therefore be kept as low as possible.

The IAU recommends (Recommendation 1) that the man-made sky glow above the best observing sites be kept below 10 per cent of the natural level. For a very faint astronomical source, this is equivalent to saying that it is acceptable that man-made sky glow increases the observing time by 10 per cent to get the same signal/noise ratio as obtainable when only the natural sky background is present. A doubling of the sky glow by man-made lighting means that the efficiency of the telescope is halved; for example, a 4-metre telescope becomes as slow as a 2.8-metre telescope, the 4-metre telescope having cost about two and a half times more. This is already a very serious level of interference, both technically and economically.

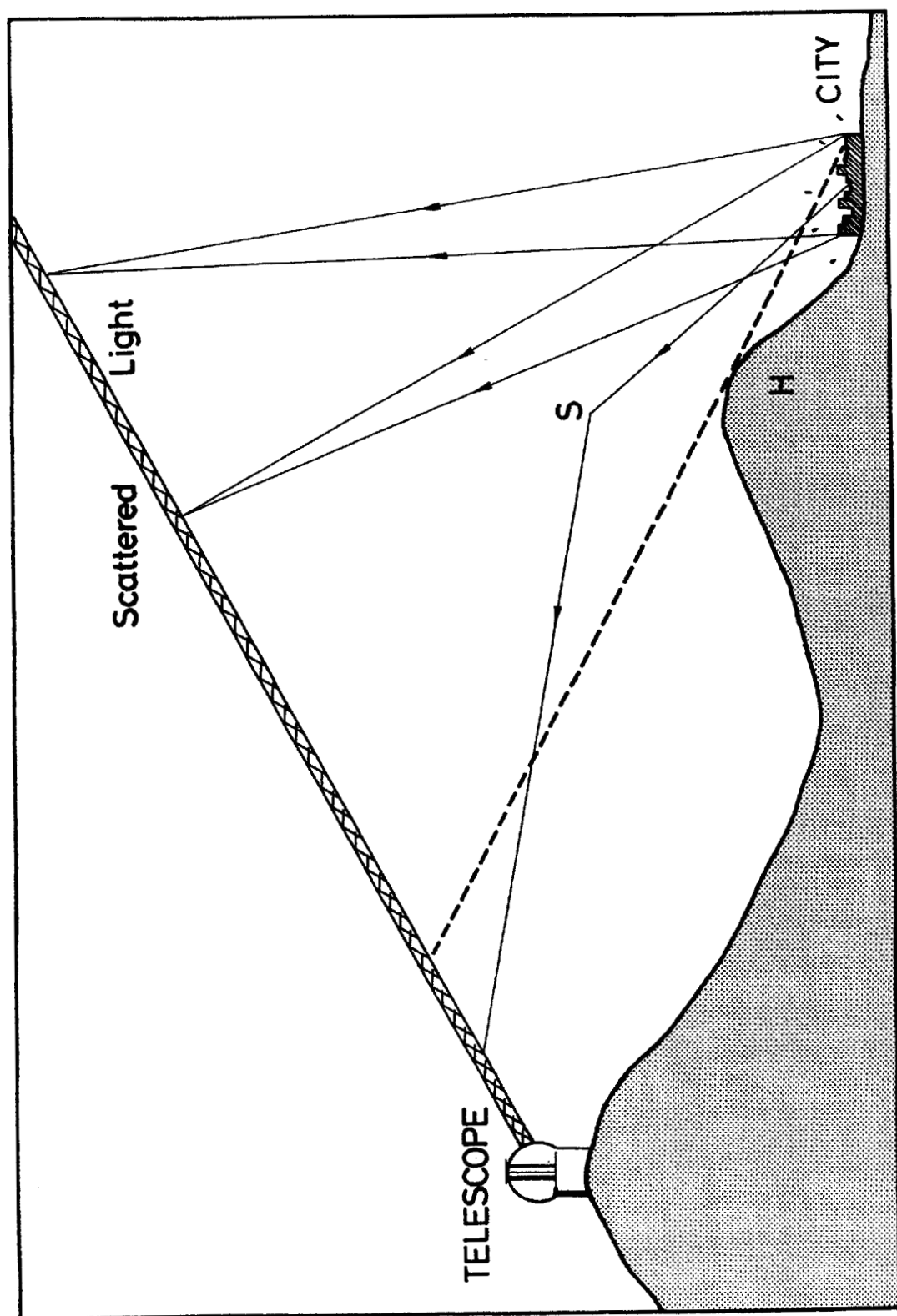


FIGURE 2. Mechanism of sky illumination by artificial lights. Light emitted by the city can reach the telescope either by direct scattering involving air molecules and aerosols located in the telescope field of view, or by multiple scattering in indirect paths such as that shown via the point S. Note that the hill H protects part of the telescope beam from direct illumination.

The 10 per cent recommended by the IAU is necessarily somewhat arbitrary, it is meant to characterize a degradation still one order of magnitude below the unavoidable degradation due to the natural sky glow. A more general statement is that if the artificial sky glow is f times the natural sky glow, the time needed to get the same quality of observation at the telescope is multiplied by $1+f$, or the telescope becomes slower by a factor $(1+f)$.

A different situation exists at the specific wavelengths of the emission line of the natural sky glow. These lines emit much more energy per unit wavelength than the continuum and are variable in intensity. In the visible, the emission is concentrated at the wavelengths 557.7, 630.0 and 636.4 nm. (oxygen lines) and 589.0 - 589.6 nm. (D-lines of sodium).

Against this variable background the detectivity is no longer controlled by the photon statistics and the limitation on man-made sky glow can therefore be relaxed. The IAU recommends (Recommendation 2) that the artificial increase in sky brightness over the wavelength band 588.8 nm to 589.8 nm should not exceed the minimum natural level in this band, whereas Recommendation 1 requests that the increase be not more than 10 per cent at other wavelengths.

This relaxation, by a factor of ten, compared with the continuum, suggests a greater tolerance for low pressure sodium lamps than of other types of discharge lamps (there are no existing lamps whose radiation coincides with the oxygen lines of the natural sky glow). It must be noted that this relaxation does not apply where an observatory is carrying out a programme of monitoring the natural night sky emission in the D-lines. Also, it must be realized that, as explained in section 7.2 of Appendix 1, the tolerance of 10 per cent of the natural sky glow over the entire visible range allows more lumens in upward stray light than does the tolerance of 100 per cent of the natural glow just over the 1 nm around the D-lines.

2.3 Mechanism of artificial sky glow

The reason why artificial light contributes to the sky glow is its scattering by the earth's atmosphere. Each molecule, or dust particle, or drop of aerosol contained in the beam of an observing telescope intercepts a small fraction of the light coming from artificial lighting and scatters some of it into the solid angle covering the field of view of the telescope, as shown in Figure 2.

It must be noted that:

- (i) direct light from a city luminaire emitted above the horizontal can be scattered;
- (ii) light reflected from the ground can be scattered, in this case the reflectance of the ground enters into the determination of the reflected light;
- (iii) multiple scattering in the atmosphere can also occur.

This last case becomes important only if the direct or reflected light has undergone strong extinction after traversing a distance longer than 50 km. or so. The curvature of the earth must also be taken into account when the horizontal distance between the observatory and the city is longer than 50 km. Intervening high ground between the light sources and the observatory may screen part of the beam as it is in the case for hill H in Figure 2.

Unfortunately, the detailed computation of the scattered light is complicated, on one hand by the characteristics of dust and aerosols contained in variable quantity by the atmosphere, and on the other hand by the photometric characteristics of the luminaires (in particular the polar diagrams of light emission above the horizontal), by the reflectance of the ground, etc.

Nevertheless, modelling has been made of the effects of urban road lighting on Mount Stromlo Observatory at Canberra (6, 7), and on University Observatory, St. Andrews, Scotland (8). Such modelling is needed if one intends to determine the relative contributions of the different districts of a city to sky glow. The method of computation of scattered light is discussed in more detail by Cayrel (15).

2.4 Estimate of artificial sky glow

It is important to have some simple way of telling if the density of artificial lighting is likely, or not, to cause an appreciable sky glow for an observatory.

Using theoretical arguments, Treanor (9) suggested a relationship of the form:

$$L(r)/L_N = \left(\frac{A}{r} + \frac{B}{r^2} \right) \exp(-kr) \quad (1)$$

where $L(r)$ is the luminance of the sky at zenith above the observatory, due to the light of a city at distance r . L_N is the natural luminance of the sky and A , B and k are constants derived from observations of Italian cities.

Walker (10) suggests a power law

$$L'(r)/L'_N = C r^{-2.5} \quad (2)$$

$L'(r)$ being the luminance of the sky at a 45° elevation, in the azimuth direction of a city at distance r , and L'_N being the natural luminance of the sky in the same direction, derived from observations of cities on the west coast of the USA.

Both authors find that the luminance of man-made sky glow is, to first approximation, proportional to the population of the city with:

$$\left. \begin{aligned} A &= 1.8 \times 10^{-5} \frac{P}{P} \\ B &= 13.6 \times 10^{-5} \frac{P}{P} \\ k &= 0.026 \end{aligned} \right\} \quad (\text{Treanor})$$

$$C = 0.01 \frac{P}{P} \quad (\text{Walker})$$

P being the population of the city and r being expressed in km. The details on how these coefficients have been determined can be found in references (9) and (10).

As the IAU recommendations specify light levels at 45° elevation (implicitly in the direction of the source of interference), it is usually more practical to use Walker's formula (2). As a rule of thumb, the 10 per cent level recommended by the IAU will be exceeded if the observatory is within the following distances from the following populations (Table 1):

Table 1

Distance (km)	10	25	50	100
Population (number of inhabitants)	3,200	31,000	180,000	10^6

These numbers are only valid as long as the lumen output in road lighting is of the order of 500 lumen per inhabitant as found by Walker (10) in California.

The study of Fisher and Turner (6) for Canberra quotes a total lumen output of 110×10^6 lumen for 200,000 inhabitants, giving a very similar value. It should be noted, however, that small towns tend to have a lower level of lighting per inhabitant than big towns.

Table 1, or formula (2), supplies a useful guideline for estimating if a city is likely to cause a problem for the night sky over a given observatory. Due to the uniqueness of each site (type and number of luminaires used in a city, composition of the atmosphere, possible partial screening of city lights by the local relief, kind of research carried out by the observatory, etc.), it is highly recommended that the level of interference be actually measured in each particular case, both initially and later to check that the situation is under control.