# MEASURING LIGHT POLLUTION ON LA PALMA

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The mix of street-lamp types on La Palma, and the characteristic spectral features of each type, are known. Deep spectra of the night sky taken before, during and after a 1995 blackout of the island's street lamps were used to determine at each wavelength the contribution of light pollution. In the continuum, light pollution increases the surface brightness of the night sky above La Palma by < 3% at all wavelengths. The brightest spectral line from street lamps is that of sodium at 5890/6 Å, and this increases the wavelength-averaged brightness of the La Palma night sky in the affected imaging bands (V and R filters) by ≈ 7%. The effect in other bands is much smaller. The La Palma night sky is as dark as at other prime observing sites, B = 22.7, V = 21.9 and R = 21.0 mag arcsec$^{-2}$. This note summarises results from Benn & Ellison (1998).

## Introduction

In most sciences, the phenomena under investigation are explored by changing the experimental conditions and observing what happens. Astronomers don't have this luxury. They can't tinker with a star's atmosphere, or drop one galaxy on another, to see what effect this has. Instead, they rely heavily on making observations of experiments already in progress, e.g. the explosion of a supernova, or the gravitational lensing of light from a distant galaxy. These observations typically entail accurate measurements of the brightness of an object or objects as a function of position on the sky (imaging) and/or as a function of wavelength (spectroscopy). In optical astronomy, the accuracy of these measurements is often limited by the foreground brightness of the night sky. Specifically, if the *average* number of foreground photons arriving from a small area of the sky, in a given wavelength range, during a given time, is N, the *actual* number will vary randomly from measurement to measurement, by ~ $\sqrt{N}$. If this random variation swamps the signal from the as tronomical object being observed, little can be learned about the object.

In the absence of moonlight, the brightness of the night sky is dominated by the components listed in *Table 1*, and described briefly below.

## Airglow

Airglow is light emitted by atoms and molecules in the upper atmosphere which are excited by solar UV radiation during the day. A typical spectrum of the night sky is shown in Fig. 1. Some of the airglow lines (e.g. that at 6300 Å from OI) decay rapidly after twilight, most (e.g. 5577 Å from OI) do not. The brightness of the OH bands in the red and near-IR can vary by a factor ~2 during the night. The airglow is a factor

| Contribution | Brightness in $S_{10}$ units |
|---|---|
| Airglow | ≈ 145 -275 |
| Zodiacal light | ≈ 60 -140 |
| Stars V > 20 | < 5 |
| Scattered starlight | ≈ 10 -100 ? |
| Light pollution | ? |
| Total (typical) | 220 |

*Table 1.* The unit of surface brightness $S_{10}$ corresponds to one 10th-magnitude star per square degree (i.e. 27.78 mag arcsec$^{-2}$). The quoted total of 220 $S_{10}$ corresponds to V = 21.9 mag arcsec$^{-2}$, a typical sky brightness well away from the ecliptic (zodiacal light) and the MilkyWay (scattered starlight), at solar minimum (airglow), and with negligible light pollution.

≈2 brighter at solar maximum than at solar minimum. The brightness of the airglow varies (up to a few 10s %) with position on the sky.

## Zodiacal light

Zodiacal light is sunlight scattered by interplanetary dust. It is generally fainter than the airglow, with the fractional contribution peaking at a wavelength ≈ 4500 Å.

## Starlight

The Milky Way appears bright to the eye, but the average surface brightness of the sky *between* stars, down to some limiting brightness of star, is much darker. For typical observing programmes with modern telescopes, the contribution of unresolved stars to the surface brightness of the sky will be very small, <5 $S_{10}$, even at low galactic latitudes.

Starlight scattered by interstellar dust, however, contributes ~10-100 $S_{10}$ units, depending on galactic latitude.

## Light pollution

Light pollution at observatory sites arises principally from tropospheric scattering of light emitted by street lamps.1 Some of this light arrives at the troposphere directly from the lamp, some of it via reflection from the road surface beneath the lamp. Common lamp types include low-pressure sodium, high-pressure sodium, mercury and incandescent.

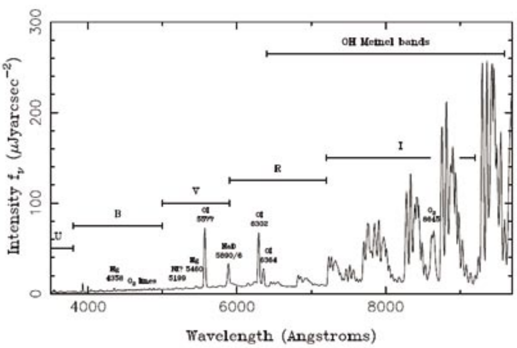



*Figure 1.* Typical spectrum of the La Palma sky on a moonless night, taken with the faint-object spectrograph of the William Herschel Telescope in March 1991. Most of the distinctive features of the night-sky spectrum are due to airglow. The sodium (NaD) emission at 5890/6 Å is partly from street-lighting, the mercury emission at 4358, 5461 Å wholly so. Most of the features dominating the spectrum redward of 6500 Å are the Meinel rotation-vibration bands of atmospheric OH.

Low-pressure sodium lamps (orange to the eye) emit most of their light in the (narrow) NaD 5890/6-Å doublet, with weak narrow emission at 5683/8 Å and 6154/6 Å, and negligible emission in the continuum.

High-pressure sodium lamps (pinkish-orange to the eye) emit most of their light in a broadened NaD line, ~ 400 Å wide, with a deep central reversal. There is significant continuum emission between 5500 Å and the infrared, and narrow emission lines at 4665/9 (violet), 4979/83 (blue), 5149/53 (blue), 5683/8 (green) and 6154/61 (red) Å.

Mercury lamps are white to the eye, and emit most of their light in narrow lines at 3651/63, 4047, 4358, 5461, 5770 and 5791 Å, with broad features at 6200 and 7000 Å, and weak continuum emission over the whole range.

Incandescent lamps (white or yellowish to the eye) emit a continuum spectrum approximating that of black-body radiation at ~3200 K.

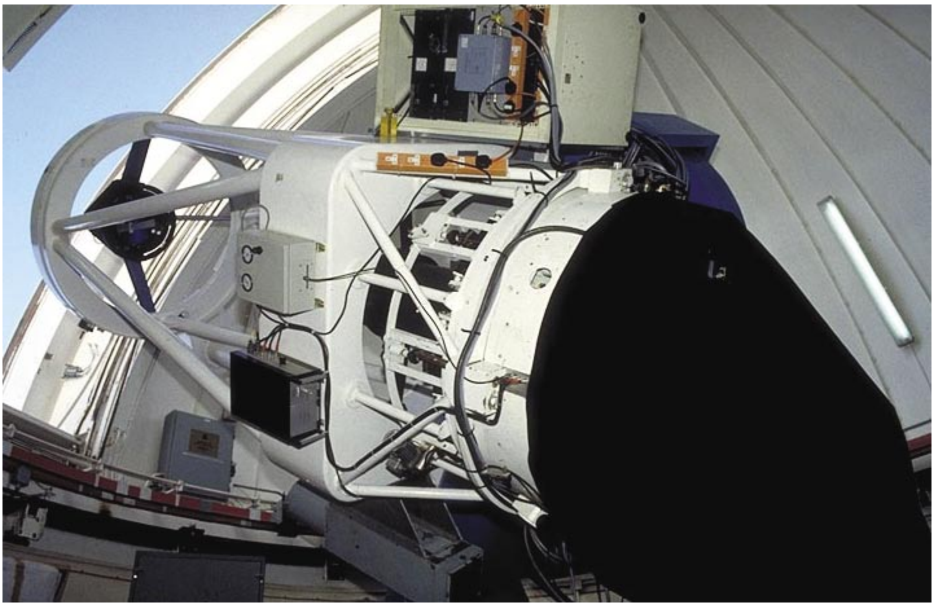
Light pollution in the continuum (i.e. at all wavelengths) reduces the signal-to-noise ratio for both imaging and spectroscopy. Light pollution concentrated in a narrow emission line severely affects spectroscopy at the same wavelength, but it also reduces the signal to noise for broad-band imaging if the filter being used passes light of that wavelength.

**Sky brightness on La Palma**

Benn & Ellison (1998) measured the brightness of the sky on 427 archival science images, mainly from the 2.5-m Isaac Newton Telescope on La Palma. They observed the expected dependencies of sky brightness on ecliptic and galactic latitudes, zenith distance and time during the solar cycle, and measured an average dark-sky brightness of B = 22.7, V = 21.9 and R = 21.0 mag arcsec$^{-2}$ at the zenith, at high ecliptic and galactic latitudes, and at solar minimum. This is similar to the values measured at other good observatory sites (e.g. Hawaii, Chile), which in itself suggests that light pollution is not a serious problem on La Palma.

**Light pollution on La Palma**

80000 people live on the island of La Palma, mostly in or near nine small towns lying between 10 and 15 km from the observatory. The island's 14000 street lamps between



them consume ~ 2 MW of electrical power and emit ≈120 Mlumens, corresponding to ≈180 kW of visible light. About 49% of this is from low-pressure sodium lamps, 21% from high-pressure sodium lamps, 13% from mercury lamps and 15% from incandescent (continuum) lamps.

The local sky-protection legislation ('La Ley del Cielo') strictly limits outdoor night-time illumination: lamps must not emit above the horizontal; low-pressure sodium lamps must be used except in urban areas; the fraction of UV light emitted by lamps is limited; discharge tube illumination, and most high-pressure sodium lamps, must be extinguished after midnight.

On a dark night, a faint orange glow can be seen on the horizon in the directions of the towns of Santa Cruz, Los Llanos and Barlovento on La Palma. The island of Tenerife, which is more generously illuminated, and has a population of 600000, lies 130 km away, in approximately the same direction from the observatory as Santa Cruz.

Knowing the total power output in the visible (180 kW, above), and assuming that 10% of the light escaping from the lamp is reflected from the ground, one expects that on average ~10 W $km^{-2}$ is emitted upwards from La Palma. This is similar to the ≈10 W $km^{-2}$ inbound from the night sky, so significant back-scattering from the atmosphere will be a light-pollution hazard.

For an idea of which towns contribute the most light pollution, we turned to the model of Garstang (1989), which predicts the change in sky brightness as a function of the populations and distances of nearby towns. For La Palma, the model predicts that the largest contributions will be from the towns of Los Sauces, Santa Cruz, El Paso and Los Llanos. It predicts that the contribution from Tenerife will be very small (3% of the total from La Palma), and that from the other nearby islands (La Gomera and El Hierro) will be negligible.

For an absolute measure of the level of light pollution, we used WHT spectra of the night sky taken before, during and after a 1-hour blackout of the street lamps on 25$^{th}$ June 1995 (celebrating the 10$^{th}$ anniversary of the inauguration of the observatory). In the spectra taken before and after the blackout, faint emission lines from mercury are visible at 4358 and 5461 Å. These are not present during the blackout. The narrow NaD emission at 5890/6 Å is 2.5 times weaker during the blackout than before or after, allowing measurement of the contribution due to light pollution alone (i.e. excluding airglow). There is no detectable change in the brightness of the continuum when the street lamps are switched off. Combining these results with the known relative contributions from the four types of street lamp, we were able to derive the fractional contamination of the sky brightness from each type, in each band

| Type of lamp | Flux % | Contamination of sky brightness (mag) | | | |
|---|---|---|---|---|---|
| | | U 3200-3800Å | B 3800-5000Å | V 5000-5900Å | R 5900-7200Å |
| Sodium low-pressure | 49 | 0 | 0 | 0.05 | 0.04 |
| Sodium high-pressure | 21 | 0 | <0.01 | 0.03 | 0.02 |
| Mercury | 13 | <0.03 | 0.02 | 0.01 | 0.02 |
| Incandescent | 15 | < 0.01 | < 0.01 | 0.01 | 0.02 |
| Total | | <0.03 | 0.02 | 0.10 | 0.10 |

*Table 2.* Contamination of the sky above the observatory by street lamps on La Palma. The first two columns give the lamp type, and fraction of total lumens illumination on La Palma (information supplied by Javier Diaz of the Oficina Técnica para la Protección de la Calidad del Cielo). Fluorescent lamps contribute a negligible fraction of the total illumination, ≈2%. Columns 3-6 give the estimated brightening of the sky above the observatory in mag (a change of 0.1 mag corresponds to ≈10%) for line plus continuum emission.

## Conclusions

- The La Palma night sky is as dark as at other prime observing sites, B = 22.7, V = 21.9 and R = 21.0 mag arcsec$^{-2}$.
- The contribution of continuum light pollution at the zenith is very small, < 0.03 mag (i.e. < 3%) of the natural sky brightness at all wavelengths.
- The NaD (5890/6 Å) contribution from street lamps is brighter than the airglow in the same line, but other street-lamp spectral lines contribute very little.
- The total contamination (line + continuum) at the zenith is < 0.03 mag in U band, ≈ 0.02 mag in B, ≈ 0.10 mag in V, ≈ 0.10 mag in R. La Palma is an excellent dark site.

See Benn & Ellison (1998) for further details.

## Notes an references


1. Lighting wastefully emitted above the horizontal costs the US taxpayer ~ $\$10^9$ year $^{-1}$, more than the cost of funding US astronomy (Hunter & Crawford 1991).
2. BENN C.R., ELLISON S.L., 1998, La Palma technical note 115, http://www.ing.iac.es/Astronomy/observing/conditions/skybr/skybr.html
3. GARSTANG R.H., 1989, PASP, 101, 306.
4. HUNTER T.B. & CRAWFORD D.L., 1991 in 'Light Pollution, Radio Interference and Space Debris', ed. D.L. Crawford (PASP conference vol. 17), p.89.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