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Night sky photometry and spectroscopy performed at the Vienna University Observatory

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A B S T R A C T

We present night sky brightness measurements performed at the Vienna University Observatory and at the Leopold-Figl-Observatorium für Astrophysik, which is located about 35 km to the southwest of Vienna. The measurements have been performed with Sky Quality Meters made by Unihedron. They cover a time span of roughly one year and have been carried out every night, yielding a luminance value every 7 s and thus delivering a large amount of data. In this paper, the level of skyglow in Vienna, which ranges from 15 to 19.25 mag_{SQM} $arcsec^{-2}$ is presented for the very first time in a systematic way. We discuss the influence of different environmental conditions on the night sky brightness and implications for human vision. We show that the circalunar rhythm of night sky brightness is almost extinguished at our observatory due to light pollution.

Additionally, we present spectra of the night sky in Vienna, taken with a 0.8 m telescope. The goal of these spectroscopic measurements was to identify the main types of light sources and the spectral lines which cause the skyglow in Vienna. It turned out that fluorescent lamps are responsible for the strongest lines of the night sky above Vienna (e.g. lines at 546 nm and at 611 nm).

1. Introduction

Until recently, astronomers have mainly been measuring the brightness of the night sky (in magnitudes $arcsec^{-2}$) at dark sites, especially at modern mountain observatories, or at potential observatory sites as a part of “site-testing” and “site-monitoring”. Within the past few years, it has become evident that increasing night sky brightness and light pollution have far-reaching consequences for many branches of human life as well as wildlife (e.g. [1]).

Therefore, it is desirable to measure and monitor the night sky brightness not only at remote mountaintop observatory locations (as done, e.g. by Patat [2]), but also close to the centers of modern civilization, and to do so every night, in a reproducible way, with the aim of performing long-term studies (such as in climate research). Only in this way can the impact of skyglow on biological rhythms on animal behavior, and human health be assessed (see [3–5]).

This is the aim of our ongoing night sky brightness measurements in Vienna and at the “Leopold-Figl-Observatorium für Astrophysik” (LFOA) on Mount Mitterschöpfl. We complemented our measurements with spectroscopic studies of the night sky at the Vienna University Observatory, which hosts the “Institut für Astrophysik” (IfA).

It should be noted that all our measurements refer to scattered light. We measured only brightness values and spectra of the sky background, while we explicitly avoided to measure any direct radiation from streetlamps. This is what we call “night sky brightness” (NSB). In other words: the brightness values and the spectra presented in this paper refer to the total backscattered light of the night sky. Its origin is the whole ensemble of streetlamps, facade illuminations, illuminated billboards, etc. at the respective observing site and in its near and far surroundings. The natural nocturnal radiation from Earth's atmosphere, which is produced by

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different processes such as recombination of atoms that have been ionized by Sun's radiation during daytime, contributes very little to the NSB that we measured at our observing sites, since the latter is dominated by the influence of artificial light.

2. Measurement sites and methods

2.1. Measurement sites

First measurements began in November 2011 at the IfA. Since April 2nd, 2012 the measuring device (label "IFA") has been mounted at its ultimate place and points exactly to the zenith. About the same time (March 21st, 2012) we started measuring the NSB at our remote mountaintop site too. Currently we use three devices in total, two of which are located at LFOA (label "FOA" and "FOA2"). The geographical positions of our sites are given below (Table 1).

Table 1
Geographical coordinates of our measurement sites. The distances of the sites IfA and LFOA from the city center are 3.5 km and 35 km, respectively.

Location (altitude)	Longitude	Latitude
IfA (240 m)	16°20′03′E	48°13′54″N
LFOA (880 m)	15°55′24″E	48°05′03″N

2.2. Photometric measurements

2.2.1. Units used for our photometric measurements

The devices that we use for our NSB measurements yield data in a unit which is very widespread in astronomy, namely magnitudes per square arcsecond (mag arcsec^{-2}). This unit corresponds to a luminance, but is a logarithmic measure derived from stellar photometry, where larger values correspond to fainter objects. In the same way, larger NSB values in mag arcsec^{-2} indicate darker skies (with less light pollution). Eq. (1) gives the conversion from mag arcsec^{-2} to cd m^{-2} and Table 2 lists selected pairs of corresponding values

$$Luminance\ [\text{cd/m}^2] = 10.9 \times 10^4 \times 10^{(-0.4 \times [\text{mag arcsec}^{-2}])} \quad (1)$$

We refer to [6, p. 112] and [7, Eq. 19] for a derivation. Note that this relation has been derived for the NSB measured in mag$_V$ arcsec^{-2}, while it is only an approximation (but quite an accurate one) for the NSB measured in mag$_{SQM}$ arcsec^{-2}.

Table 2
Conversion between mag arcsec^{-2} and mcd m^{-2}.

mag arcsec^{-2}	mcd m^{-2}	Comment
14	271.000	
15	108.000	
16	43.000	
17	17.100	
18	6.810	
19	2.710	
20	1.080	
21	0.430	
21.75	0.215	Value we assume for the *overall* natural clear sky brightness
22.0	0.172	Value we assume for the *zenithal* clear sky brightness

For the purpose of monitoring the night sky brightness over a long period of time, we use Unihedron's Sky Quality Meter with an integrated lensing system. The model is called "SQM-LE", but hereafter we will refer to it as "SQM". All our devices are connected via ethernet. According to the manufacturer's manual, the integrated lens narrows down the field of view to only $\approx 20^\circ$ full width at half maximum (FWHM), thus at an off-axis distance of $\approx 10^\circ$, the sensitivity declines by a factor of 2. At higher angles the response decreases rapidly, so that a point source located $\approx 19^\circ$ off-axis contributes a factor of 10 less to the measured brightness than on-axis. We have chosen the lensed version because we also use the devices in urban regions where the field of view is limited due to surrounding buildings. A wide beam width then could result in lower accuracy due to the possible influence of nearby lights (Table 3).

An advantage of the ethernet version is that with network cables far greater distances can be reached than with USB cables and by making use of the "Power over Ethernet" (PoE) technology also power supply at remote sites is easier to handle. Furthermore, the PoE device directly attached to the SQM leads to a sufficient amount of heating so as to avoid the formation of dew.

2.2.2. Spectral response function of the SQM and comparison to the Johnson V band

Sky Quality Meters are equipped with a photo diode, a filter and a temperature sensor for thermal stabilization. The manufacturer provides information on the sensitivity curve of the photo diode and the filter, but not the resulting response function. Previous reports indicated that the night sky brightness values measured by SQMs do not differ strongly from those from systems equipped with a Johnson V filter. Nevertheless, given that SQM magnitudes are not the same as V magnitudes, we will use the unit "mag$_{SQM}$ arcsec^{-2}" throughout this paper in order to make this difference clear.

The spectral sensitivity of the SQM was measured by Cinzano [8]. A comparison between the SQM response function and the Johnson V band shows that the SQM is much more sensitive to light below ≈ 520 nm. At a first glance the difference seems to make a calibration between the Johnson V band and the SQM response function difficult, but considering the spectral distribution of the night sky over Vienna which is dominated by emission

Table 3
Selected (strong) spectral lines detected in Vienna's night sky.

Peak position [nm]	Assignment (see text)	Remark
544	FL	Blend with HPS
546	FL	
558	Atm. OI	
569/588/598	HPS	
611	FL	
630	Atm. OI	
819	HPS	