The night sky brightness at Potsdam-Babelsberg

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Abstract

We analyze the results of a 2 years (2011–2012) time series of night sky photometry performed at the Leibniz Institute for Astrophysics in Potsdam (AIP). This observatory is located on top of a hill ("Babelsberg"), 22 km to the southwest of the center of Berlin. The measurements have been performed with a Unihedron Sky Quality Meter. We find night sky brightness values ranging from 16.5 to 20.3 $\mathrm{mag_{SQM}}$ arcsec^{-2}; the latter (best) value corresponds to 4.7 times the natural zenithal night sky brightness. We discuss the influence of clouds, of the Moon and other factors on the night sky brightness. With respect to the influence of the Moon, it turns out that Potsdam-Babelsberg, despite its proximity to Berlin, still shows a circalunar periodicity of the night sky brightness, although it is much weaker than naturally. The light-pollution-enhancing effect of clouds dominates the night sky brightness by far. Overcast nights with light pollution (up to 16.5 $\mathrm{mag_{SQM}}$ arcsec^{-2}) are brighter than clear full moon nights ($\approx$ 18.5 $\mathrm{mag_{SQM}}$ arcsec^{-2}) in roughly the same proportion as the latter compared to clear nights with light pollution (20.3 $\mathrm{mag_{SQM}}$ arcsec^{-2}).

Keywords: atmospheric effects – site testing – light pollution – techniques: photometric

1. Introduction

In a forthcoming paper (Puschnig et al. [1], also in this volume; henceforth: Paper I), we have presented results of systematic night sky brightness measurements performed at the Vienna University Observatory. Another astrophysical research institute that is relatively close to a metropolis is the Leibniz Institute

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for Astrophysics in Potsdam-Babelsberg. Its geographical position is 22 km to the south-west of the center of Berlin. Here, on top of a hill, 40m above the minimum elevation of Berlin and Potsdam, an observatory was constructed in 1911–13 as a successor to the Royal Observatory of Berlin. The observatory used to be called “Sternwarte Babelsberg” for many decades. Together with its annexes, it harbours one of the largest astrophysical research institutes in Germany.

At the West Dome of this observatory, a 70 cm f/15 reflector was installed in 1957–58 (cf. Notni, P. [2]) and was upgraded in 1994. Using this and other telescopes, measurements such as photometry of variable stars are carried out (e.g. Vogel et al. [3]) at the AIP, which makes it interesting to monitor the local night sky brightness in parallel. More importantly perhaps, the night sky over Potsdam-Babelsberg is representative of the suburbs of the 3.5-million-inhabitants-city of Berlin, which is an additional motivation for the present paper. We want to examine, inter alia, how dark and how bright the night sky may get at such a suburban observatory site. This may have implications extending far beyond the domain of astronomy, since energy consumption, wildlife as well as the human circadian and circalunar rhythm are affected by the brightness of the night sky (see Kyba et al. [4], Davies et al. [5], and references therein).

2. Measurement site and method

All night sky brightness (NSB) measurements presented here were performed on top of the “Schwarzschildhaus” of the AIP – a building that was opened in 2000 and which is located 160 m to the west of the old Babelsberg observatory. The location is sufficiently high to preclude any *direct* irradiation of artificial light on our detector. Hence, it is indeed only the light scattered by the night sky which we measure and the term night sky brightness measurements is justified.

The geographical position of our measurement site is summarized in Table 1.

Table 1: Geographical coordinates of our measurement site Potsdam-Babelsberg. The distance of the sites from the city center of Berlin amounts to 22 km.

Altitude	Longitude	Latitude
70m	13° 06’ 06’ E	52° 24’ 18” N

Systematic NSB measurements at the AIP began already in October 2010 (see `http://verlustdernacht.aip.de`). Thus a data set covering more than 2.5

years has been available for analysis. However, we decided to use the data from the completed calendar years 2011 and 2012 for our analysis.

As in Paper I, we used Unihedron's Sky Quality Meter with an integrated lensing system. The model we used is called "SQM-LE", but for the sake of brevity, we will refer to it as "SQM" here. The instrument was placed into a weatherproof housing and directed into the zenith, thus detecting the zenithal and near-zenithal sky brightness (with a field of view of $\approx 20°$). The device is connected to a computer via ethernet. The sampling rate we used was 2.1 seconds.

The spectral sensitivity of the SQM, which has been studied by Cinzano [6]), differs from the transmittance of a Johnson V filter in three respects (see also Paper I, Fig. 1):

- The peak of the SQM sensitivity is at 540 nm.
- While the Johnson V filter largely cuts off radiation with a wavelength smaller than 470 nm, the SQM does detect a significant amount of blue light, even down to wavelengths smaller than 400 nm.
- Beyond 550 nm, the SQM sensitivity and the Johnson V transmittance are fairly similar, but the SQM has a "broader" transmittance also at these wavelengths.

These differences motivated us to introduce an artificial unit called "$\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$" in order to prevent an interpretion of our sky brightness values as $\mathrm{mag_V}$ $\mathrm{arcsec^{-2}}$; in the present paper, we will follow the same convention. The difference between $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$ and $\mathrm{mag_V}$ $\mathrm{arcsec^{-2}}$ values depends on the colour of the night sky and remains yet to be studied in detail. It is smaller than half a magnitude for most meteorological and sky radiance conditions.

2.1. Data storage and web interface

All data presented and analyzed in this paper can be found as plots on the website `http://verlustdernacht.aip.de`. The data are also available at http://astro.univie.ac.at/en/institute/light-pollution/ under the location code "BA1" (for Babelsberg). The plots of the zenithal NSB shown on these websites will be called 'scotographs' in the following (derived from the Greek word 'skotos' = dark).

3. Data analysis

3.1. Comparison to the 'Landolt-Börnstein values'

'Landolt-Börnstein' (LB) is a well reputed encyclopedia and database for astronomical, physical and chemical data. In its printed edition from 1965, it contains tables of the zenithal luminance for clear skies as a function of the depth of the Sun below the horizon, based on measurements performed in the late 1940s. This data set will be referred to as Hellwege [7] or simply 'LB' in the following. Its advantage is to very nearly represent the natural NSB, since it is based on measurements done at a time with a very limited influence of light pollution.

A comparable data set has been published by Seidelmann [8]; however, it efers to the *illuminance* on a horizontal surface, again for clear conditions and without light pollution. Since horizontal illuminance cannot be converted into zenithal luminance without additional assumptions, we did not use Seidelmann's data set in the present paper.

It is useful to compare a typical clear-sky scotograph measured at Potsdam-Babelsberg to the 'light-pollution-free' LB zenithal luminance data, e.g. to find out for which depth of the Sun below the horizon the anthropogenic contribution to the measured NSB becomes noticeable. For this purpose, we converted the LB zenithal luminance data into zenithal sky brightness data in mag arcsec^{-2} by using the equation:

$$\text{NSB}\,[mag_V arcsec^{-2}] = 12.6 - 2.5\log\left(\text{luminance}\,[cd/m^2]\right) \qquad (1)$$

We refer to (Cinzano [9], p. 112) and (Garstang [10], 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}.

Figure 1 shows a scotograph measured during a very clear night close to the summer solstice, namely from 26th to 27th of June 2012, as compared to the NSB which would have been expected based on the Hellwege data. It can be seen that for an NSB larger (darker) than 18 mag_{SQM} arcsec^{-2}, the measured values deviate from the LB values. This zenithal sky brightness is reached when the Sun reaches a depth of 10.2 degrees below the horizon. The darkest NSB recorded during the chosen night was 20.1 mag_{SQM} arcsec^{-2}. This corresponds to h_{sun} = -12.7 degrees, a value reached shortly after the end of the nautical twilight.

Given the fact that ~ 20 mag_{SQM} arcsec^{-2} can be considered as a typical 'maximum value' of the NSB at Potsdam-Babelsberg during clear nights, this can also

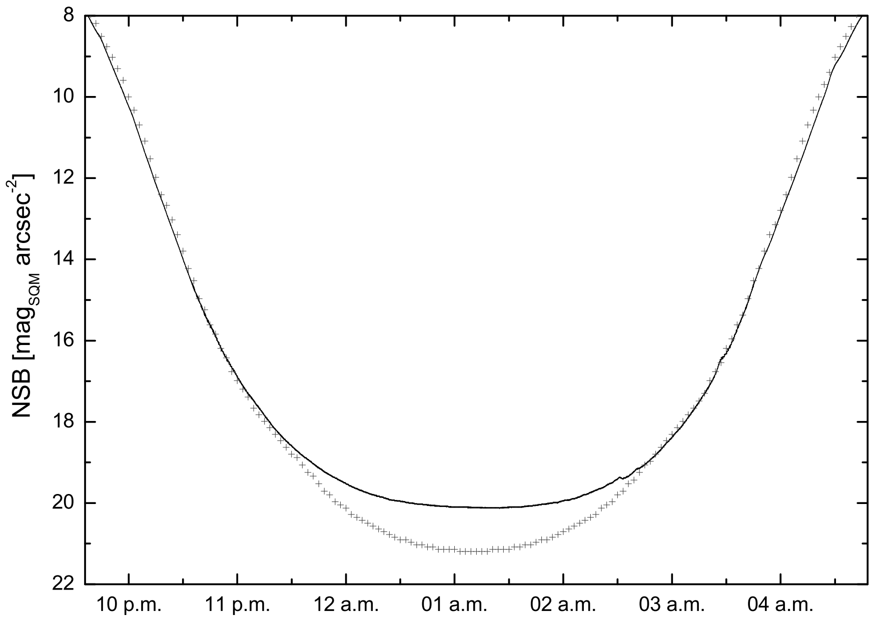

Figure 1: Comparison between standard literature values of the zenithal NSB (after Landolt-Börnstein, black crosses) and the NSB actually measured at Potsdam-Babelsberg during the clear night from 26th to 27th of June 2012 (black solid line).

be expressed in the following, ostensive way: *The skyglow at Potsdam-Babelsberg corresponds to permanent nautical twilight. The sky luminance range which is typical of astronomical twilight is barely reached at this location.* At the same time, it has to be recalled that Potsdam, with its distance of only 22 km from the city of Berlin, provides still relatively dark skies relative to the conditions that probably prevail close to other cities with more than 3 million inhabitants.

On the other hand, since Babelsberg is located at a northern latitude of 52.405 °, the Sun reaches a depth below the northern horizon of only -14 ° at the summer solstice. This is 4 ° less than required for the end of the astronomical twilight. Hence, even without light pollution, there would be more than 70 summer nights per year at Babelsberg during which astronomical darkness is not reached (namely when the declination of the Sun larger is than ~ 19.5 °: 17th May to 26th July).

Finally, it should be noted that the agreement between our measured scotograph and the light-pollution-free LB data is quite good for sky luminances smaller (brighter) than 18 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$ – mainly during the times of civil and nautical twilight.

3.2. *Typical ranges of the night sky brightness at Babelsberg*

The next question of interest is: if we include times other than summer nights and include also overcast nights, how dark and how bright can nights get at Potsdam-Babelsberg? What is the range of *mean* NSBs?

As for mean night sky brightnesses in each individual night, we calculated it the following way:

$$< \mathrm{NSB} > [mag_{SQM} arcsec^{-2}] = \frac{\sum_{t=1}^{n} a_t}{n} \qquad (2)$$

We were using only measurements a_t within the time interval [1,n] starting from the end of the nautical twilight when the sun's height was lower than -12 degree until the beginning of the nautical twilight at time n. By a statistical analysis of more than 14 million individual measurements from 2011 and 2012, we found the following results:

- For clear and moonless skies, the mean night sky brightness at Potsdam-Babelsberg can reach values down to 20.3 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$. Given that the natural *zenithal* night sky brightness is 22 mag $\mathrm{arcsec^{-2}}$ (see Paper I), 20.3 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$ corresponds to 4.7 times the natural sky brightness.

- For clear nights close to full moon, we typically find mean NSBs between of 18.5 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$, with maximum NSB values (close to the full moon's culmination) of up to 18.0 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$.Cloudy nights close to full moon are even brighter than that. Note that for the examined location the Moon is always far enough away from the zenith as not to shine any direct light into the SQM.

- For clouded to overcast skies, mean NSB values up to 16.5 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$ can occur due to the enhanced backscattering of urban lights (sometimes with additional influence of the Moon). Typical values of the NSB for nights with clouds over Babelsberg are around 17.5 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$.

- In summary, the range of the mean night sky brightness at the examined location is 16.5–20.3 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$. Individual (as opposed to mean) NSB values brighter than 16.5 and darker than 20.3 $\mathrm{mag_{SQM}}$ $\mathrm{arcsec^{-2}}$ do occur at Babelsberg, but especially the latter case it very rare and limited to the early morning hours.

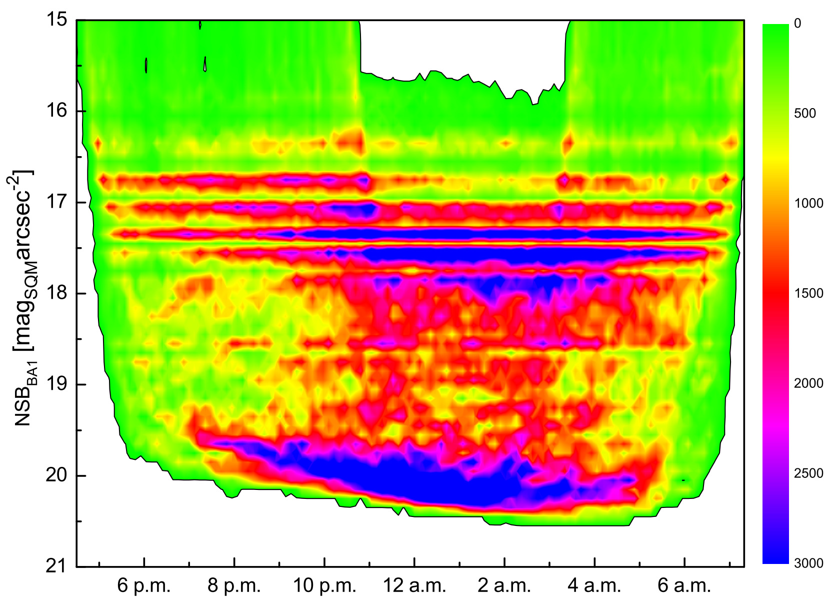

Figure 2: Density plot of the SQM measurements performed at Potsdam-Babelsberg in 2011. Two dominant NSB ranges can be seen, one for cloudy and overcast skies (16.5–18 mag$_{\mathrm{SQM}}$ arcsec^{-2}) and one for clear skies and small influence of the Moon (19.5–20.3 mag$_{\mathrm{SQM}}$ arcsec^{-2}).

The most instructive way to show NSB ranges which we found so far are false-colour cumulative plots (= density plots). We did such plots for two completed calendar years where we have data from almost every single night, namely for 2011 and 2012: see Figs. 2-3. Each of these figures contains about seven million individual data points.

The most conspicuous feature of Figs. 2-3 is the bifurcation between clear and cloudy nights (like in Fig. 4 of Paper I). Clear nights again turn out to be darker by almost 3 magnitudes (a factor of more than 15 in luminance) compared to overcast nights. (Without artificial illumination, overcast nights would be *darker* of course than clear nights due to the blocking of any natural light coming from the high atmosphere (airglow) and from the stars.)

The decrease of the NSB (= increase of the darkness of the night sky) towards later hours is less evident in the Potsdam-Babelsberg data than in the data from the Vienna University Observatory presented in Paper I. While we found a typical gradient of 0.1 mag$_{\mathrm{SQM}}$ arcsec^{-2} per (dark) hour for the latter site, the present data sets indicate 0.08 mag$_{\mathrm{SQM}}$ arcsec^{-2} per hour for clear nights at Babelsberg, and still less for overcast nights. One reason for the smaller improvement of the night

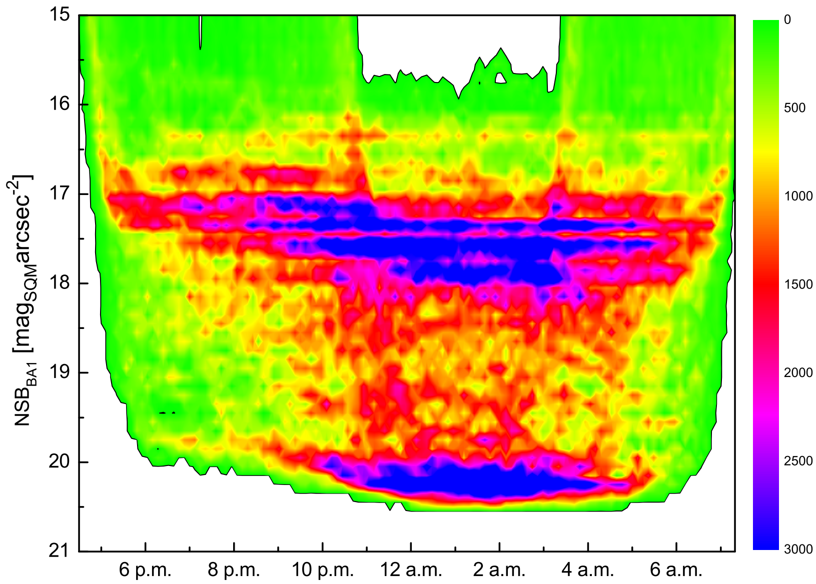

Figure 3: Density plot of the SQM measurements done at Potsdam-Babelsberg in 2012. The NSB values at which the measurements strongly cluster are very similar as for the previuos year.

sky quality within each night at Babelsberg, as compared to Vienna, is the lack of a city-wide curfew at Potsdam and in Berlin.

Figures 2-3 do not permit to derive any significant *annual light pollution increase rate*. As we shall show in Figs. 6, the measurements from 2012 even point towards slightly darker skies than the data from 2011, but this is likely due to meteorological conditions.

3.3. Circalunar variation of the night sky brightness at Babelsberg

Due to the publications of Puschnig et al. [1] and Davies et al. [5], the following question came more into the focus of research: to which extent is the natural variation of the night sky brightness with the phase of the Moon ('circalunar variation') still significant in urban congestion areas? This question may have far-reaching consequences for wildlife and even for human health, since many species are known to ajust their internal clocks to circalunar rhythms.

Puschnig et al. [1] have shown that the circalunar NSB variation is close to extinction at the Vienna University Observatory, located 3.5 km from the city of Vienna (≈ 1.8 million inhabitants). Davies et al. [5] have shown that the natural rhythm of the lunar sky brightness is no longer evident at the city center of Plymouth (≈ 250.000 inhabitants).

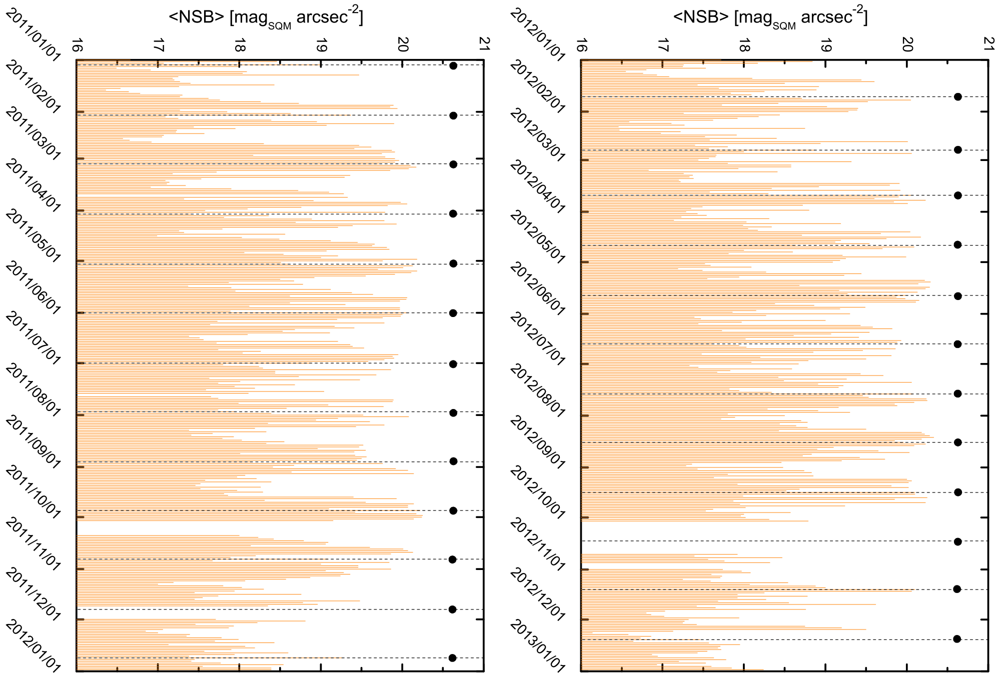

Figure 4: Mean NSBs for all nights in 2011 and 2012 for which our SQM at Potsdam-Babelsberg delivered data. The circalunar rhythm is still clearly seen in both plots, as the black filled circles and dashed vertical lines (= times of new moon) indicate.

For Potsdam-Babelsberg, the calculation of mean NSB values for each night in 2011 and 2012 (except for some nights where our device did not deliver any useful data, e.g. due to the coverage of the detector by snow) yields the interesting pattern shown in Fig. 4. The brighter full moon nights can be identified in both plots. However, we can also see that there are many nights close to new moon where the mean NSB reaches values close to those typical for full moon.

In summary, we do detect a circalunar periodicity of the night sky brightness at Potsdam-Babelsberg, but a highly ‘spoiled’ one – spoiled by the influence of artificial light. Note that we only analyze the influence of *scattered* artificial lights on the night sky brightness here. The radiation from streetlights *directly* reaching trees, bushes, water surfaces and many other animal and human habitats is still by far stronger than the influence of scattered (skyglow) light.

3.4. Variations of the sky brightness within a night

During clouded nights, the variation of the NSB typically amounts to 1 magnitude, but with strongly varying cloud coverage (see Fig. 5), it may also reach 3 magnitudes (corresponding to a factor of more than 16 in the sky brightness).

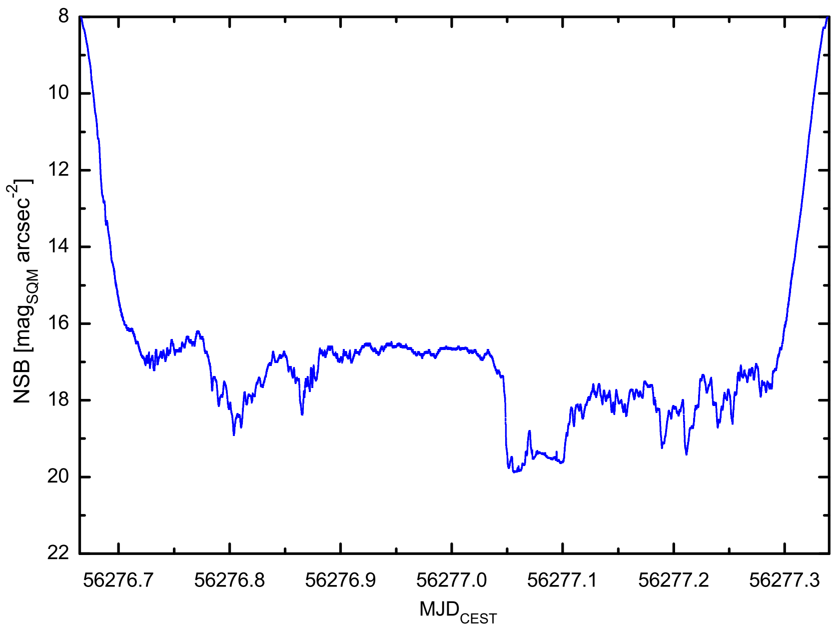

Figure 5: Scotograph measured during the night from Dec 15 to Dec 16, 2012 showing variations of up to 3 mag$_{SQM}$ arcsec^{-2} due to overcast sky.

3.5. Fraction of nights darker than 3 mcd m^{-2}at the zenith

In Paper I, we examined the fraction of nights during which the average sky brightness becomes smaller than 18.9 mag$_{SQM}$ arcsec^{-2}, corresponding to a zenithal luminance of 3 mcd m^{-2}. This is to some extent an arbitrary number, but it can be taken as a rough measure of Milky Way visibility at the zenith and transition from mesopic to scotopic vision (even though different values for this transition can be found in the literature).

At AIP, 40 percent of all nights have mean NSB values beyond (=darker than) 18.9 mag$_{SQM}$ arcsec^{-2}. This is a surprisingly high fraction of relatively dark nights. It is probably related to the fact that the Berlin-Potsdam area is still more moderately lit (or more efficiently lit, with a higher fraction of downward-directed lights) than other metropolitan areas of a comparable size. (Note that the city of Paris, e.g., spends more than twice the number of kilowatt hours per person and year on public illumination than Berlin; Hänel, priv. comm.).

Figure 6 shows the distribution of mean NSB values in the form of histograms.

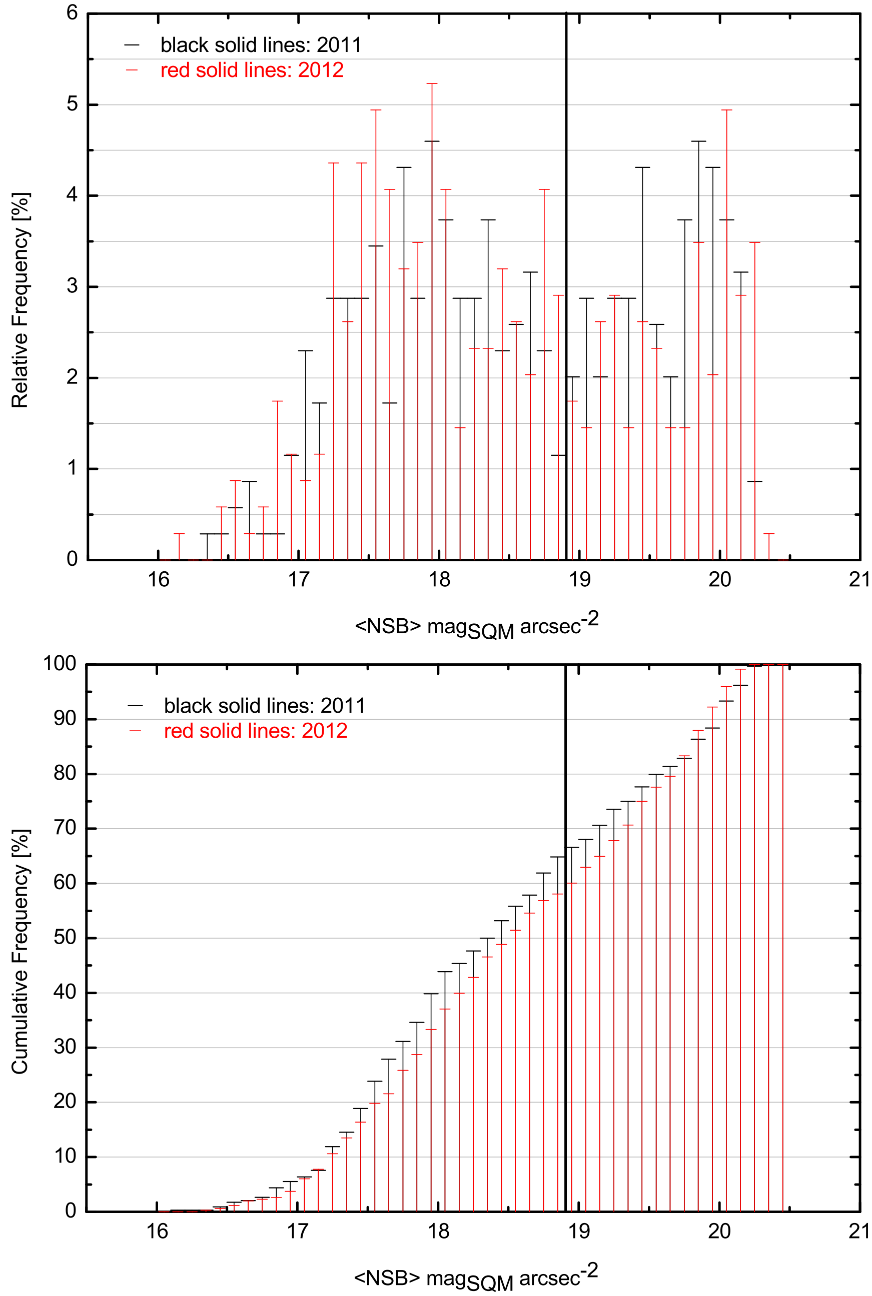

Figure 6: Histogram showing the relative (top) and cumulative (bottom) distribution of the mean NSB measured at AIP from 2011 to 2012. The vertical line corresponds to 18.9 mag$_{SQM}$ arcsec^{-2}.

4. Conclusions

Based on photometric measurements performed in 2011 and 2012 with a Sky Quality Meter installed at Potsdam-Babelsberg, we find that the most decisive factor for the night sky brightness is – as for most urban and surburban sites – the cloudiness of the night sky and not the phase of the Moon.

The circalunar periodicity of the night sky brightness, however, is still seen at Potsdam-Babelsberg, even though in a much less pronounced form than at sites with dark skies.

Overcast skies with their enhanced backscattering of city lights lead to a mean NSB of up to 16.5 mag_{SQM} $arcsec^{-2}$ at Potsdam-Babelsberg, corresponding to a zenithal luminance of 27.1 mcd m^{-2} or 157 times the natural zenithal sky brightness. Under clear and moonless skies and during the late night hours, the mean NSB may reach 20.3 mag_{SQM} $arcsec^{-2}$ corresponding to 0.82 mcd m^{-2} or 4.7 times the natural zenithal sky brightness. In contrast, clear full moon nights at the AIP site have a typical zenithal luminance of 18.5 mag_{SQM} $arcsec^{-2}$ or 4.3 mcd m^{-2}or 25 times the natural zenithal sky brightness. This means that overcast nights at the AIP site are brighter than clear full moon nights roughly in the same proportion as the latter compared to moonless clear nights. However, the precise combination of full moon and clear skies is not very frequent in our data, such that the zenithal luminance of 18.5 mag_{SQM} $arcsec^{-2}$ is not a strong cumulation region in our density plots (Figs. 2 – 3).

Especially for clear and moonless skies, a continuous decrease in the NSB is detected at the AIP – without any major (> 0.1 mag) regularly occurring discontinuous 'steps' at any given time (as espected for a curfew, e.g. around midnight). The decrease in the NSB (= improvement of the sky quality) is found to be no larger than 0.08 mag_{SQM} $arcsec^{-2}$ per hour. Only a very small, if any, contribution to this decrease may be from a natural darkening of the night sky in the V band after the end of the astronomical twilight (see Patat [11], Sect. 6).

Compared to the results presented in Paper I for the Vienna University Observatory, the average skies over Potsdam-Babelsberg are significantly darker, namely by more than 1 magnitude. At the same time, the *difference* between the brightest and the darkest mean NSB values is smaller for Potsdam-Babelsberg (3.8 mag_{SQM} $arcsec^{-2}$) than for the Vienna University Observatory (4.25 mag_{SQM} $arcsec^{-2}$). We expect that *sites with larger light pollution tend to have larger spreads between the respective darkest and brightest NSB values* than sites with lower levels of light pollution. Further studies should be made to confirm this.

Table 2 summarizes some of our conclusions.

Table 2: Some benchmark values of the night sky brightness and luminance in mag_{SQM} $arcsec^{-2}$ and mcd m^{-2} for Potsdam-Babelsberg. The assumed value of the natural zenithal NSB is to be understood as a "darkest possible" reference value, measured only at excellent sites and during minima of the solar cycle (see Garstang [10], Patat [11], Patat [12]).

Sky condition	Typical mean NSB [$mag_{SQM}/arcsec^2$]	Corresponding luminance [mcd m^{-2}]
Moonless clear skies	≤20.3	≥0.82
Clear skies with full moon	≈18.5	≈4.3
Overcast skies	≥16.5	≤27.1
Natural zenithal NSB	22.0	0.172

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