Artificial Sky Brightness and Human Vision

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METHOD & BASIC FACTS

We measured the **artificial sky brightness** both in **Brno** (370.000 inhabitants) and **Vienna** (1.550.000 inhab.) at different meteorological conditions, aiming at a quantification of the pollution of the night environment by upward directed light.

To be able to detect fainter signals than commercial luxmeters do, we used solar panels with amplifiers and ADC converters. Thereby we achieved a sensitivity better than 1 millilux. For calibration, an illuminance meter has been used.

Our measurements have been carried out in the **absence of direct artificial light**, i.e. the refer only to the **total upward light flux scattered back by the clear or clouded night sky**.

In Vienna, our measurements have been carried out at a distance of 4 km from the center of the city; in Brno, they have been carried out at a distance of 2km from the center. The illuminances which we find **represent minimal nocturnal illuminances**: Many bedrooms will be exposed to much larger light pollution due to unshielded lights shining into them; but the **artificial night sky brightness is always present** as long as much of our light sources are shining to the sky.

Without artificial light, the clouded sky would be much darker than the clear sky. With light pollution, the situation is the other way round: the clouded sky is much brighter (up to 10 times brighter) than the clear sky.

At both places where we measured, we found that the illuminance produced by the clouded sky reaches values comparable to the situation of full moon. Hence, under clouded skies, each bedroom near the locations of the measurements is **permanently exposed to an illuminance equivalent to that at full moon.**

BRIGHTNESS OF THE CLOUDED SKY

During summer 2002, several measurements of the illuminance from the sky have been made at the indicated locations. We found an illuminance from the sky before midnight of **120 millilux** (⇒ Fig. 1).

During nights with a very low cloud cover, illuminances up to **550 millilux** have been measured at the Vienna University observatory (e.g. on 3rd of March 2004).

The **reduction of public illumination** – which is performed between 23.55h and 0.05h CEST/CET – reduces the sky brightness significantly, i.e. **by 30% to 50%,** depending on the consistency of the clouds (⇒ Fig. 2). Hence, in order to reduce unwanted illumination of bedrooms, the curfew should be at 22-23h CEST/CET.

CLEAR SKY vs. CLOUDED SKY

Compared to the sky brightness during clouded nights, the illuminance from the clear (but light-polluted) sky is much smaller (⇒ Fig. 3).

At cloudless conditions, the background illuminance is now **regularly monitored** at the Vienna University Observatory. We find illuminances at clear skies of **20-30 millilux**, depending on the water vapour and aerosol content of the atmosphere. These values are still far above the limit for full dark adaption of the human eye.

In **Brno**, values of the sky brightness down to **7 millilux** have been recorded under clear skies. The darkest skies measured in the Czech republic with the "solar panel technique" produces an illuminance of **slightly less than 1 millilux.** This corresponds to about 4x the natural sky brightness, but the **fully dark-adapted** human eye **can still read** 12mm large digits (black on white) at this illuminance!

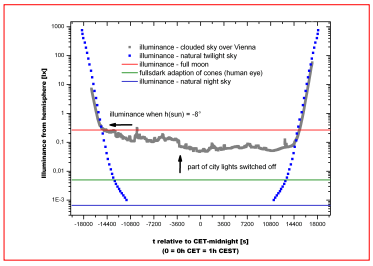

Fig. 1: Illuminance produced by the clouded, light polluted sky. For comparison, the illuminance of the natural twilight sky is also shown (blue squares).

Material	Polycrystalline Si
Area	95 cm²
Max. sensitivity	650 nm
Sensitivity	0.001 lx

Relevant parameters of the detector used by J. Hollan

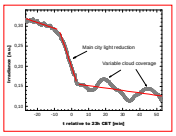

Fig. 2: Decline of irradiance from the light-polluted sky during city light reduction

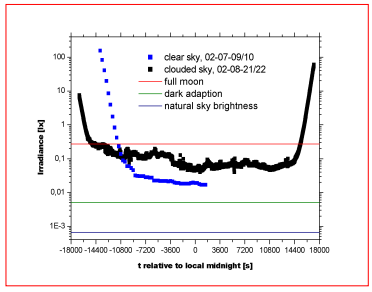

Fig. 3 Comparison of the illuminance from the clear (blue squares) and the clouded sky (black squares) over Vienna.

Lightsource	Luminance Illuminance from hemisphere
Integrated starlight	83 µcd/m² 0.261 millilux
Darkest sky ever measured	171 µcd/m² 0.537 millilux
Natural background level (NBG)	250 µcd/m² 0.785 millilux
Milky Way	3.700 µcd/m² (≈ 15*NBG) 11.6 millilux
Sensitivity limit of the human eye rods	4.700 µcd/m² (≈ 19*NBG) 14.8 millilux
Typical sky of Vienna-Währing under clear conditions	38.000 µcd/m² 120 millilux
Typical sky of Vienna-Währing with cloud cover	Up to 175.000 µcd/m² Up to 550 millilux

Tab. 1: Luminances (in units of µcd/m² = 10⁻³ cd/m²) and illuminances (in units of millilux) of selected lightsources which are contributing to the brightness of the night sky. The values have been taken from Refs. **(1)** and **(5)** and from our own measurements. According to IAU Commission 50 guideline, the definition "light polluted night sky" applies to a value of L > 275 µcd/m² (at h=45°), i.e. to the case that the sky is just 10% brighter than the NBG level **(7)**.
The rods of the human eye begin to be dominant in light detection only below 10.000µcd/m². The faintest luminances detectable by the cones are ~1.000µcd/m². The faintest luminances detectable by the rods are ~1 µcd/m² **(10)**.

RELATION TO HUMAN VISION

The **adaption of the cones** of the human eye reaches its limits at illuminances of the order of **about 5 millilux** (green horizontal line in Fig. 1).

The **adaption of the rods** begins at about 30 millilux and proceeds down to illuminances which are smaller by a factor of 2000, i.e. down to **some 10^{-6} lux or 1µcd/m²** (10).

(The **full moon** can illuminate a window onto which it is shining vertically with **300 millilux**. Half moon, under the same circum-stances, illuminates a window with up to 30 millilux.)

In order to enable effective operation of the cones, illuminances in the range of a few millilux would be required. As shown in Figs. 1 and 3, the **artificially illuminated night sky of Vienna** is **always too bright as to permit the cones to come into operation**.

The **levels of light relevant for disturbing** the fully dark adapted organism and for **affecting melatonin production** have not yet been sufficiently explored (however, see posters by J. Hollan et al.). Interestingly, blue light (~420nm wavelength) is much more disturbing with respect to melatonin production.

SATELLITE DATA

According to satellite measurements from 1997, Vienna emits **2000 kW upward flux power** within an area of 1080 km² **into the atmosphere** (9). This is equivalent to **1.85 kW/km²** !

A first guess of the mean irradiance in a clouded Vienna - under the assumption that all the upward light flux is scattered back by the clouds - yields (130000 lx / 1.35 kW/m²) * 1.85 × 10^{-3} W/m² = **180 millilux**. This refers to the average illuminance of the clouded night sky in a very simplified backscattering scenario.

A refined calculation would have to take into account.

(a) the difference between the solar spectrum and the average spectrum of the lamps illuminating Vienna;

(b) the albedo of the clouds;

(c) the average increase in the upward flux of European cities, which is about 10% per year (6) ;

(d) the dependence of the illuminance on the distance from the (light emission) centre of Vienna.

INSTRUMENT CALIBRATION

For the calibration of our instrument, we used various commercial luxmeters, including those in the laboratory of the public lighting magistrate department of Vienna (MA 33). The luxmeters and, in parallel, our solar panels, were exposed to the radiation of different light sources such as a **high pressure mercury lamp** and a **high pressure sodium lamp**.

Different conversion factors between the solar panel voltage and the illuminances as measured by the luxmeters have been found. The linearity of the relation between voltage and illuminance was very good in the range below 100mV.

For the light polluted night sky, we assumed that its integrated spectrum is intermediate between the spectrum of sodium and mercury lamps.

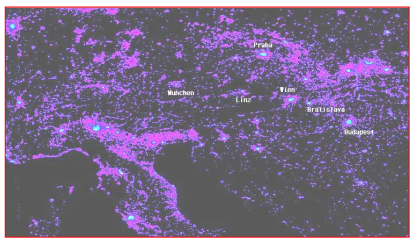

Fig. 4: Upward light flux from of central european cities derived from Satellite data (9)

REFERENCES

(1) B. E. Schaefer, Vistas in Astronomy, Vol. 36, p. 311 (1993)
(2) M. Jackel (Univ. Koblenz): Vorlesung Medientechnik, WS 2000/01 http://mitarbeiter.kobland.de/Folien/Default.htm
(3) A. Ryer (International Light Inc.): Light Measurement Handbook http://www.intl-light.com/handbook/
(4) P. Schlyta (Stockholm): Radiometry and photometry in astronomy http://home.tiscali.se/peschl/comp/radfpa.html
(5) P. Cinzano: Inquinamento luminoso e protezione del cielo notturno, Venezia 1997 (ISBN 88-8166-48-6)
(6) P. Cinzano, F. Falchi, C.D. Elvidge, MNRAS 328, p. 689 (2001)
(7) F.G. Smith: Report and Recommendations of IAU Commission 50, Reports on Astronomy, IAU Trans. XVIIA, 218 (1979)
(8) E. Barti, F. Börngen, W. Häupl, et al., Astron. Nachr. 300, 209 (1979)
(9) S. Isobe, S. Hamamura, SPIE Proceedings, vol. 4151, p. 237 (2001)
(10) H.-J. Hentschel (Hg.), Licht und Beleuchtung, Heidelberg 2002

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