Metabolism-influencing light: measurement by digital cameras

Jan Hollan

N. Copernicus and Planetarium in Brno, Kraví hora 2, 616 00 Brno,
tel. +420 541 321 287, hollan(at)ped.muni.cz, http://www.astro.cz/darksky

(Poster at Cancer and Rhythm, Oct 14 - 16, 2004, Graz, Austria)

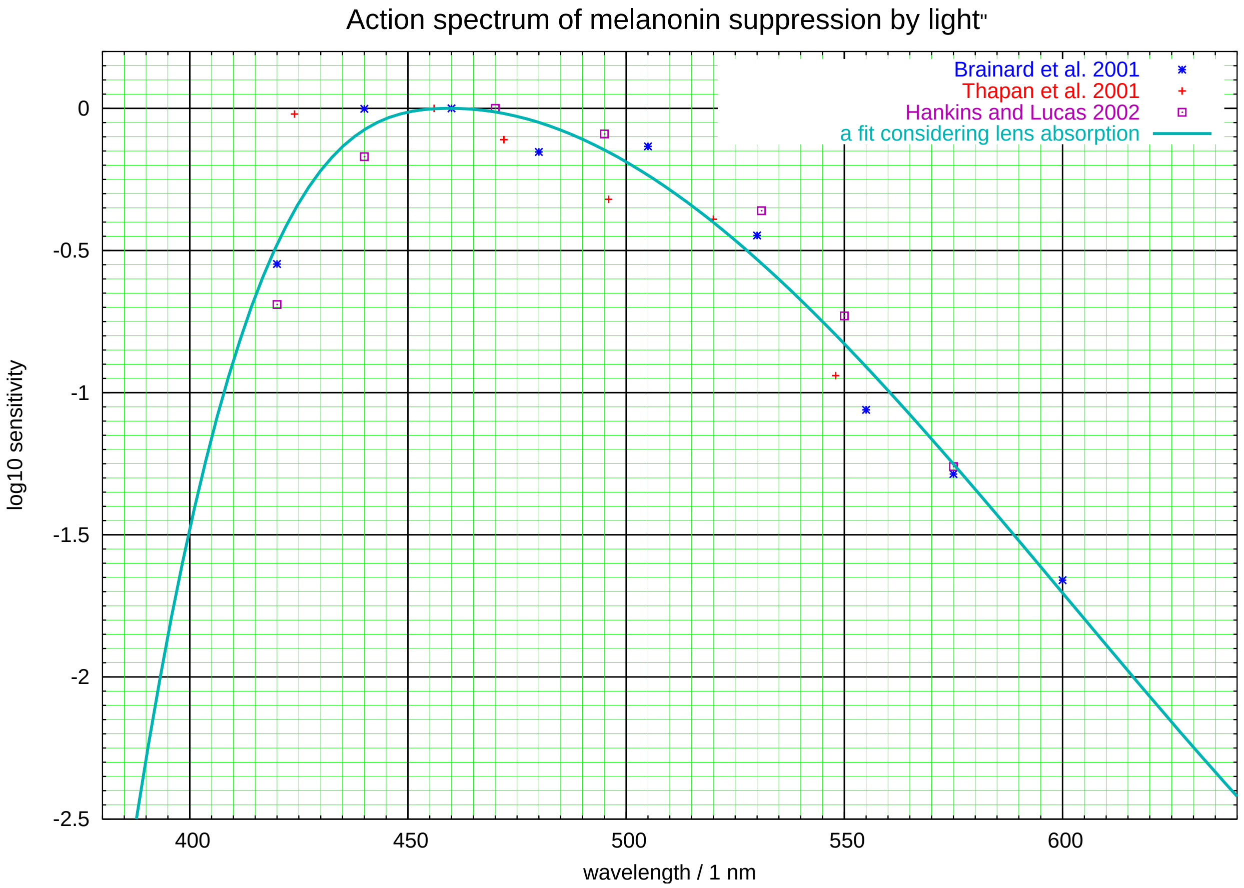
Further development of the methods introduced during a short grant (VaV/740/3/03, by the Czech Environment Ministry, in autumn 2003, Hollan *(ed)* 2004) led to spectral calibration of two common digital cameras. The sensitivity of the blue pixels of one of them matches the action spectrum of the non-imaging human visual system.

Action spectrum of melatonin-suppresing light

The action spectrum for humans has been published by Brainard *et al.* 2001, Thapan *et al.* 2001, and by Hankins and Lucas 2002. From their data, a compound graph has been made.[1]

As the current data are sparse in the violet wing of the sensitivity curve, a simple hypothesis has been used. Assuming the receptor sensitivity being constant from 460 nm toward ultraviolet, the left wing of the curve was plotted as a lens transmissivity curve taken from Stockman *et al.* 1999. Then a fit has been made using a simple analytical formula.

[1]having no direct access to the latter paper, I used a slide from Foster 2004 lecture to digitise them... the uncertainty of data is far greater than uncertainty of digitization.



The formula consists of two parts, for violet (V) and green (G) wing separately. The wings match at the maximum sensitivity (in the energy domain, not a photon domain) at a wavelenght of $maxS$ nanometres, $maxS = 460$. For $x =$ wavelength / 1 nm,

$$actspV(x) = aV * (x - maxS)^2 + bV * (x - maxS)^3$$

$$actspG(x) = aG * (x - maxS)^2 + bG * (x - maxS)^3$$

– the constants are

$$aV = -7.57e - 5$$
$$bV = 5.59e - 6$$
$$aG = -1.30e - 4$$
$$bG = 3.06e - 7$$

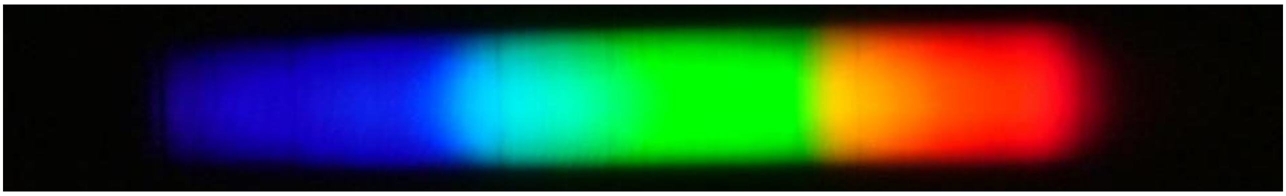
The violet wing may reach farther to UV for children with more transparent lens, and would be much broader for aphakic eyes with removed lens. Otherwise the curve seems to be rather reliable, as a very similar curve matches rodent sensitivity as well (Foster 2004).

Spectral calibration of digital cameras

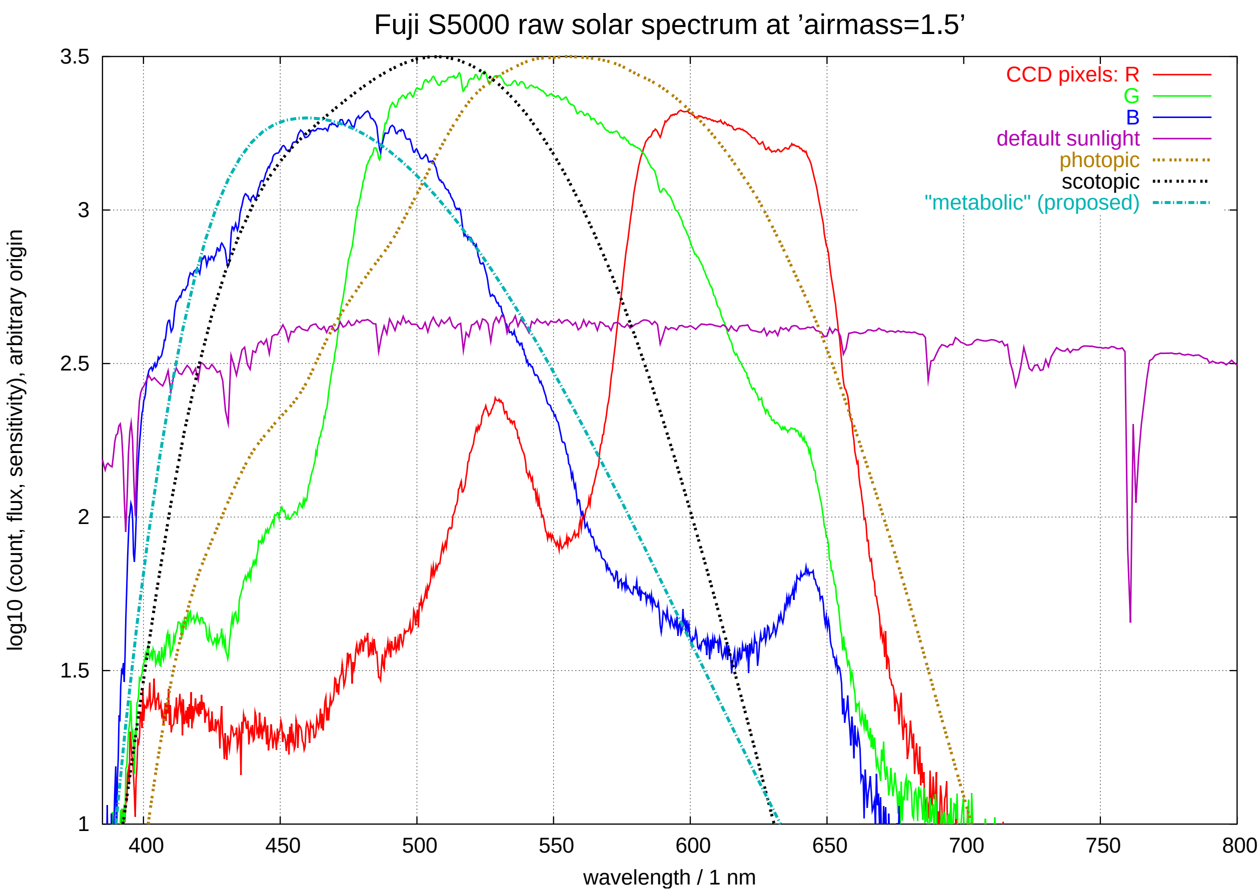
The action spectrum for melanonin suppression lies mostly in blue or blue-green. It is attempting to try to match it by blue pixels of CCD cameras.

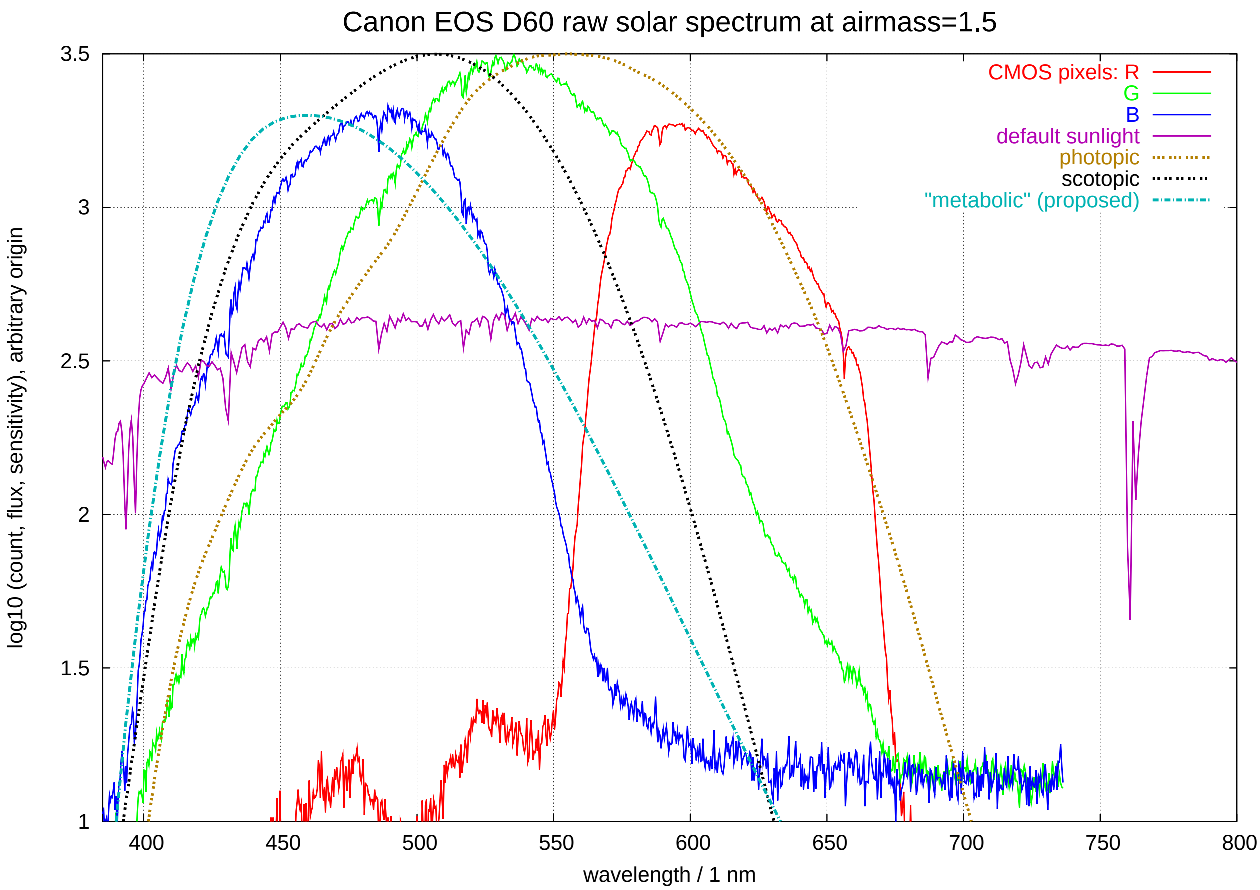
For two common camera types which offer raw data this has been examined using a solar spectrum for calibration. The images have been taken with the appropriate angular height of the Sun in the sky, so that its light went through 1.5 times the thickness of the atmosphere. A CD-based cardboard spectroscope (with a slit from two razors) had been used, after a series of attempts.

The spectrum taken with Fuji S5000 camera:



Solar spectrum has a lower intensity at a handful of wavelengths, so-called spectral lines. After processing the images, the solar spectrum graph as recorded by the three types of camera pixels has been obtained:

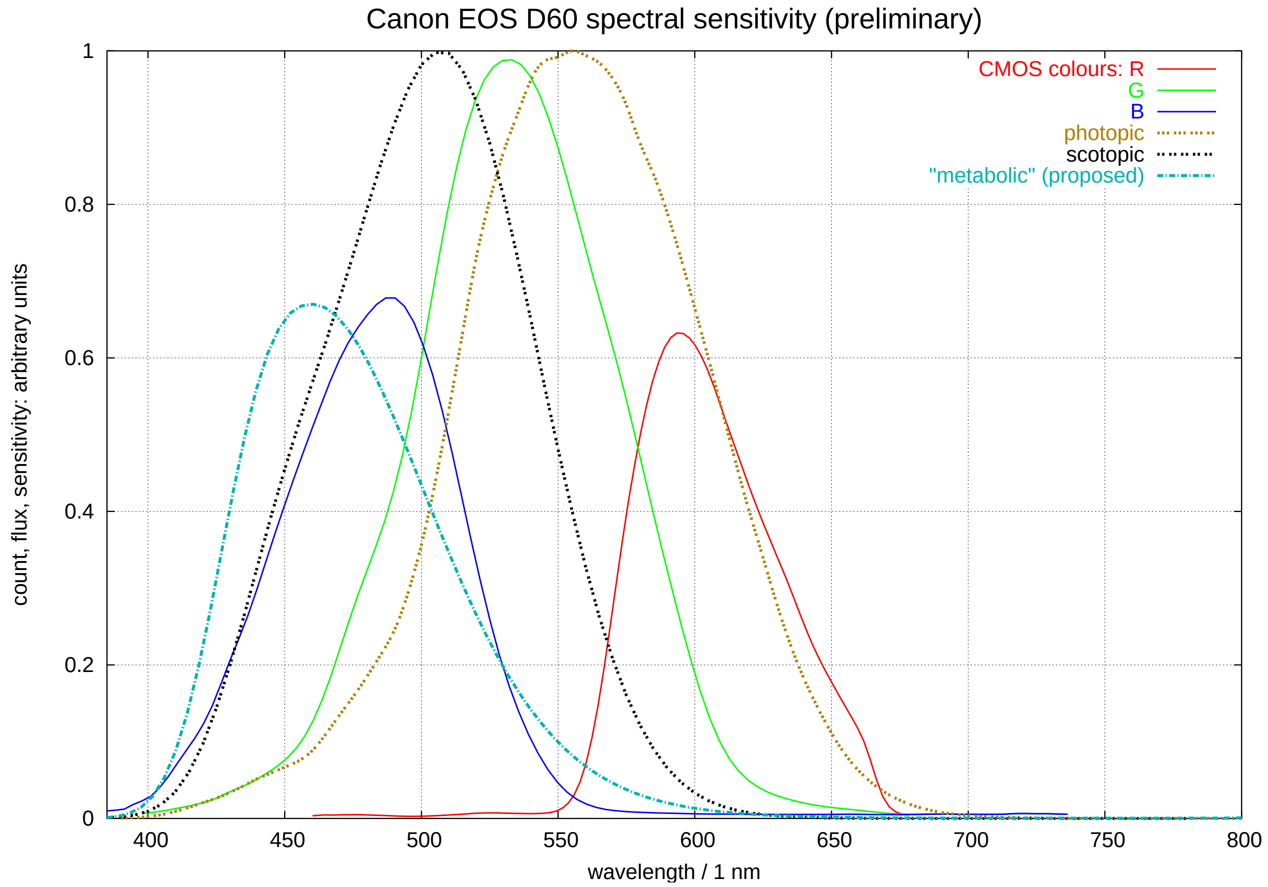

Fuji S5000 raw solar spectrum at 'airmass=1.5'
CCD pixels: R
G
B
default sunlight
photopic
scotopic
"metabolic" (proposed)
log10 (count, flux, sensitivity), arbitrary origin
wavelength / 1 nm
3.5
3
2.5
2
1.5
1
400
450
500
550
600
650
700
750
800

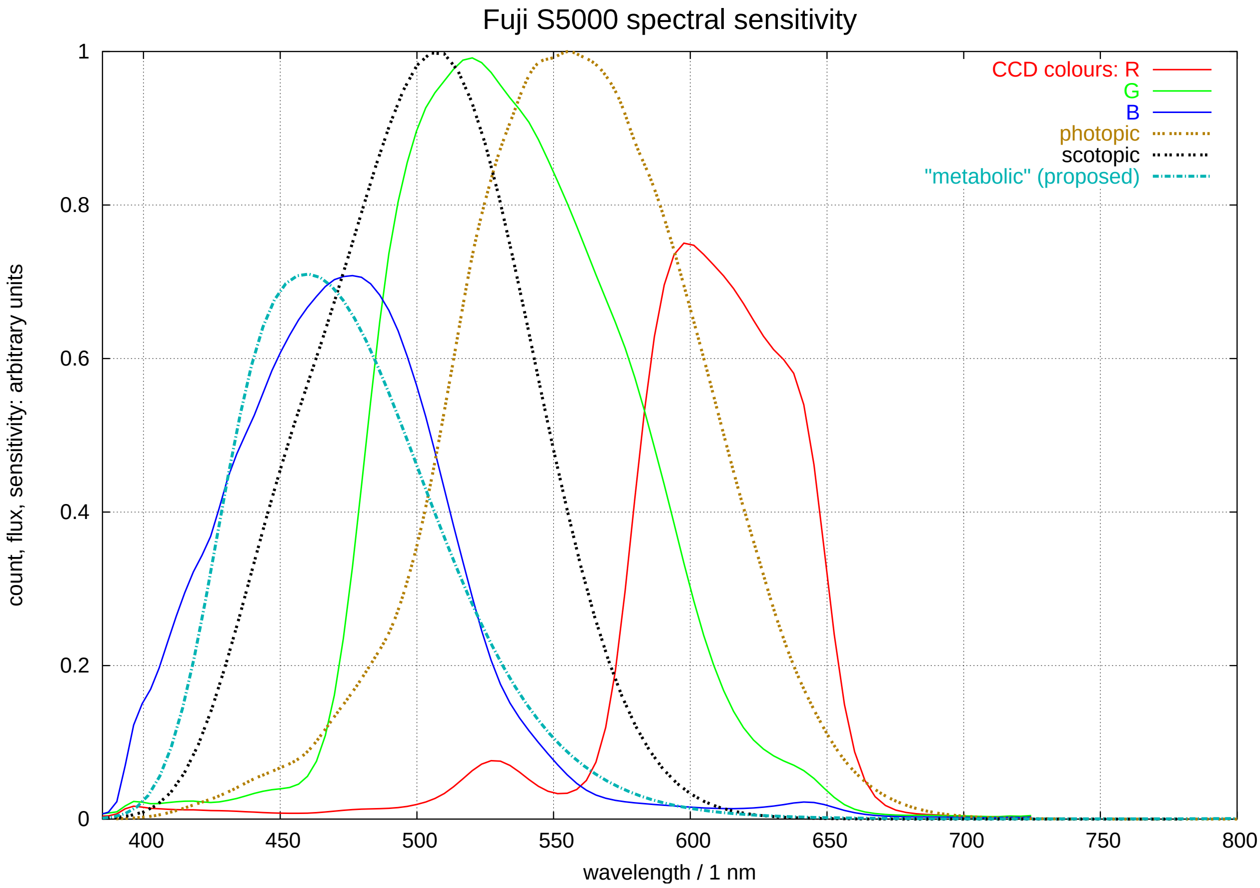

Canon EOS D60 raw solar spectrum at airmass=1.5
CMOS pixels: R
G
B
default sunlight
photopic
scotopic
"metabolic" (proposed)
log10 (count, flux, sensitivity), arbitrary origin
wavelength / 1 nm
3.5
3
2.5
2
1.5
1
400
450
500
550
600
650
700
750
800

A canonic solar spectrum as arriving through "1.5 airmasses" is shown as well (ASTM, 2003). It helped to match the wavelengths. The three sensitivities of human eye are plotted for comparison: photopic, scotopic, and the novel "metabolic" one (I called it "melanoptic" earlier, but it seems to be premature, as it is still not sure which pigments work here). The photopic and scotopic curve are taken from Stockman and Sharpe 2000.

Apparently Fuji S5000 blue sensitivity matches the assumed non-imaging eye sensitivity rather well. The blue peak of Canon EOS D60 seems to be a bit too narrow in its violet wing.

Curves made by dividing the recorded spectra by the canonic solar spectrum are given in a linear scale in the next graphs.





So, at least some CCD cameras can measure melatonin-affecting light rather well. But how to express the amount of effective radiation?

This should be an analogy to expressing scotopic-effective radiation. There are “scotopic luxes” (lumens, candelas) for this purpose. The definition is based on the demand that at 555 nm monochromatic radiation there is always 683 lumens per watt. For a flat spectrum this means that scotopic illumination is some 2.5 times the scotopic one, given the sensitivities as shown in the graphs.

For melatonin suppression, the sensitivity at blue-green maximum is almost ten times larger than at 555 nm. We could then say that a flat spectrum light would give ten times more metabolic lumens than photopic lumens. However, this would be misleading. Sensitivity of non-imaging system seems to be much less than sensitivity of imaging systems. So it would be more appropriate to set the lumens for flat (equal energy per nanometre) spectrum the same for photopic and non-imaging visual systems

Sunlit white surfaces have not a really flat spectrum, but for the green and blue filters it works almost like that. **By setting their B luminance to photopic one** (measured by a luxmeter, or computed astronomically), **the camera is simply calibrated.** Of course, the photopic luminance can be also obtained from digital images, esp. if the camera colour sensitivities are known as in our case.

All needed software is available at `http://amper.ped.muni.cz/light/luminance`. It’s not easy to use, but what’s important: by taking several images by a suitable camera, the effective amount of radiation affecting melatonin secretion can be documented for further use.

Examples of metabolic efficiency of different light sources

With the Fuji S5000 camera, several light sources have been investigated. Unlike daylight, some artificial sources have a lower shortwave component. For a common compact fluorescent, incandescent and even candle, the B luminance is thrice lower than a photopic one. For HPS (high pressure sodium discharge) lamps, those orange ones common in outdoor lighting, the non-imaging light component is ten times lower than the photopic one.

Limits to avoid circadian rhythm disruption

Having a low blue-green component is an advantage, if we want to avoid melatonin production suppression.

For white light (daylight, and probably some white discharge sources), some 3 or 4 lx suppress the melatonin production non-negligibly (by five per cent, according to Thapan *et al* 2001). Some people may be more sensitive, the sensitivity might depend also on the daytime light exposure (it might be lower after strong sunshine summer days and higher in cloudy winter days – as the task of the system is to recognise day and night). A safe limit is surely not over 1 lx, taking 0.25 lx should be entirely safe: this is the maximum illumination by the Moon, i.e. a maximum natural nighttime one.

For yellow light sources mentioned above, almost 1 lx could be entirely safe. With additional filtering by yellow, or even orange filters, more photopic light can be at hand, with no increase in the amount of that light which affects the non-imaging system.

Filtering the light for night

Plastic foils may do the job well, for non-hot sources as the fluorescent ones, paints for glass surfaces may work for hot incandescent bulbs. As much as 10 lx, enough for evening reading, may be obtained without confusing the circadian rhythm.

High pressure sodium lamps should not be a problem at illuminations of up to three photopic lux. There exist faint discharge sources filled with neon, these are purple-orange and with some paint blocking blue would be good for corridor illumination etc. And of course, yellow LEDs. Most promising are the neglected low pressure sodium lamps, shining almost exclusively at 589 nm – these are 30 times less “metabolic” efficient than white lights and up to ten lux by then illumination might be tolerable. They can be obtained at 18 W, and are suitable even for indoor purposes.

Filtered or monochromatic sources don’t enable colour perception like daylight. This has to be accepted – natural night has little colour, and if we need light indeed, we should resign to rich colours when they are not absolutely necessary.

References

American Society for Testing and Materials, 2003, Solar Spectral Irradiance: Air Mass 1.5. http://rredc.nrel.gov/solar/spectra/am1.5/

Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner G., et al., 2001, Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. *J. Neurosci.* **21**(16), 6405-6412.

Foster RG, 2004, Novel insights into photoreception, phototransduction and biological rhythms – how might this impact on carcinogenesis? Lecture at *Childhood Leukaemia*, London. Abstract is available at http://leukaemiaconference.org.

Hankins MW, Lucas RJ, 2002, The primary visual pathway in humans is regulated according to long-term light exposure through the action of a nonclassical photopigment. *Curr Biol*, **12(3)**, 191–198.

Hollan J (ed), 2004: *Mapping of light pollution and negative influences of artificial lighting on living nature at the territory of Czech Republic.* Research report, available as http://amper.ped.muni.cz/noc (in Czech; some posters based on it are in the subdirectory *english*).

Thapan K, Arendt J, Skene DJ, 2001, An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *J.Physiol*, **535**, 261–267.

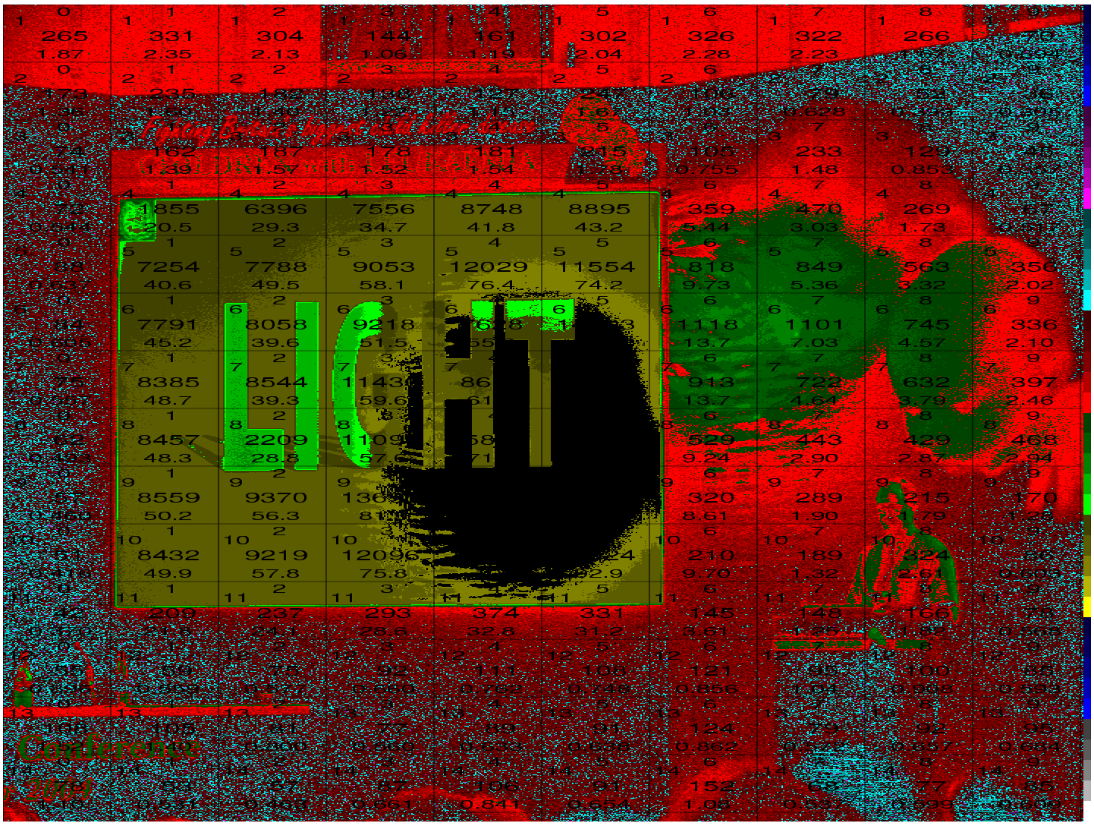
Stockman A, Sharpe LT, Fach CC, 1999, The spectral sensitivity of the human short-wavelength cones. *Vision Research*, **39**, 2901-2927. The lens tranmissivity data can be downloaded at http://cvision.ucsd.edu/.

Stockman A, Sharpe LT, 2000, Spectral sensitivities of the middle- and long-wavelength sensitive cones derived from measurements in observers of known genotype. *Vision Research*, **40**, 1711–1737. The photopic sensitivity data, together with the standard CIE scotopic data, can be downloaded at http://cvision.ucsd.edu/.

Appendix: examples of photopic luminances from digital images

Showing and summing B-luminances of a scene is a task to be yet done. However, it is very similar to that one which has been solved already: showing and summing photopic luminances (for these, just G and R values are important).

The examples of such information obtained from Fuji S5000 images is shown for two scenes photographed in September in London.



A scene from Childhood Leukemia conference. Dr. Richard Stevens gives a lecture.

The second image shows colour-coded luminances, in a logarithmic scale. The black spot means oversaturated pixels. Average luminances of the tiles are given at their bottom, the number in the centre is the average green pixels raw reading.

Middle of the red colour range corresponds to 1 cd/m^2, the green to 10 cd/m^2, yellow to 100 cd/m^2 etc. Luminance of the face around the eyes is about one candela per square metre (or one nit, using a convenient non-SI name of the unit).

Westmisnter Abbey. Its luminances are in one nit and one decinit range. Note the obsolete glaring luminaires at right (the only light which should be visible is the red traffic light...