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LIGHT AS A DISRUPTOR TO BE QUANTIFIED

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Day and night cycle, what's more natural than that? And what aspect of nature has been lost more than this one, in our civilisation? It appears, that the present light amounts we're using at night 'thanks' to electric lighting are far over the safe levels. Not only wildlife, but our own health is damaged a lot. Bad and shorter sleep, reduced melatonin production controlling the night-mode metabolism result. The very roots of our civilisation vanish. However, hard numbers are a must in debating those issues. And a broad citizen involvement. Bringing light-at-night photometry to everybody's hands is feasible, instruments for that exist now. We present an overview of technologies, results and their implications. Restoring healthy darkness and still being able to live comfortably is well within our reach. Quantitative approach helps to overcome the business parole 'the more light the better' Light can be a good servant again, not a bad lord.

Keywords: darkness, circadian cycle, sleep disruption, radiometry, photometry, faint light

1 Introduction

Alteration of day and night was a matter of course during all geologic history of the Earth. Humans began to change it by using fire at night, from about 200 ka ago [1]. However, only after the invention of petroleum, gas and electric lamps, artificial lighting at night was able to offer daylight intensities indoors and large-scale illumination outdoors.

Light amounts we use are unsustainable in several aspects. Electricity consumption for lighting, relying on fossil-fuel power plants, contributes to the global climate disruption and has to be diminished by an order of magnitude – also to avoid a bad example for poor countries lacking electric grid. Electricity-based light should not be the very symbol of welfare. Alteration of day and night is far from being obsolete. Light at night is a problem, disrupting our metabolic day-night cycle, sleep, wildlife habitats, and the night landscape in general, including its worse visibility due to glare.

The old wish of 'seeing light in darkness', based in fear of darkness led to a world where many people don't know and appreciate the natural night environment at all. This has huge consequences for our culture and civilization.

Much lower amounts of light than those used in rich countries would give us the needed services entirely well. However, such sustainable lighting is to be administered by educated citizens and competent environmentalists, not by industry, whose business concern is to sell ever more. To control it, people should understand various quantities concerning light and should be able to measure them.

2 Light as a pollutant

There is no doubt that artificial lighting is needed in modern society. However, when we add anything to the environment, altering its state from a natural one, we have to denote it as pollution. It's but a technical term with no moral aspect. Some kinds and levels of pollution may be innocent, some disastrous, in many cases we don't know. See a thorough discussion of the definition of light pollution in [2]; there is also a list of quantities by which this type of pollution can be expressed. Shortly, for outdoor environment, pollution is always the change from the state which would exist without introducing the pollutant, i.e., light from artificial sources. It can be measured in absolute terms, but in many cases, relative change is more important, being much larger at night. For indoors, there is mostly no natural environment, and it is common to speak about pollution just in case that health is compromised.

Traditional approach for artificial lighting has been: the more light the better. Centuries ago, most people stayed outdoors during the day, having plenty of natural light. Nowadays, most people stay in buildings all working days; offering them as much daylight as possible even indoors had been considered desirable, therefore the large, tall windows of schools etc. And whenever the technology enabled stronger lighting to supplement or replace daylight, it had been employed or even made obligatory. During daytime, it has no drawback apart from electricity consumption. But as twilight deepens toward night, usual indoor lighting becomes too strong. Much more than really needed to perform various tasks, so strong, that it prevents the onset of melatonin production. It was not until this millenium that it has been recognized as a serious problem. There is evidence that it causes increased occurrence of several types of cancer (breast, prostate) in humans. And it's certain it works this way for small short-lived animals, like mice. For humans, obesity and 2nd type diabetes are further probable consequences. For them, shorter sleep duration may be the causal link, the delayed moment of going to bed is probably partly due to reduced production of melatonin, the sleep hormone (another cause being, there are so many possible nighttime activities thanks to cheap lighting, TV and now especially Internet). Average sleep is hours shorter than a century ago [3] [4].

Sleep itself is disturbed by lack of darkness for almost half of the population – this is not due to interior lighting, but to outdoor lighting penetrating the bedrooms. Most people don't realize there is little if any reason to leave all outdoor lighting on late at night.

Why do people use so much light almost everywhere at night? Two superstitions are behind it. The first one: ‘dim light harms your eyes’. No, it may just cause fatigue when reading a long time with very little light, and a desire to go to sleep – not bad [5] [6]. There is no mechanism how diminished light amounts could harm the vision system. People lived under much lower light intensities at night before, without being impaired from it.

The second myth is ‘light reduces crime’. No, crime is not close to zero in broad daylight. And outdoor lighting seems to promote crime rather then reduce it. Switching light off diminishes crime, an extreme example being large blackouts [7].

Lights visible from large distances, but even the illuminances due to terrestrial light dispersed in the atmosphere, disrupt behaviour of many species. Attraction of insects and even birds, followed with fatalities, is an example. Declines, extinctions of whole populations have been recorded. The reduced visibility of natural phenomena like the starry heavens affect also us. All human cultures stem from its availability on cloudless nights. And all nations have fairy tales about fireflies – unfortunately, children don't see plenty of them every midsummer evening any more. Fireflies need darkness to have their light signals visible, to be able to mate. Their populations did not survive in environments with no night.

For a set of basic recommendation for outdoor lighting see [8]. At night, an opposite rule should hold for lighting: *the less the better* – provided the visual task can still be ac-

complished with proper aids. And its shortwave part below 500 nm should be avoided as much as possible, to enable melatonin production, i.e., light should be deep yellow, not white.

3 Measuring light at night

People don't perceive absolute amounts of light, just the relative changes of luminance, contrasts. Having 10 lx, 1000 lx or 50000 lx at the book makes little difference of its readability. Just the eye pupil is grows twice or thrice larger from day to night, what implies a need for more precise accommodation in dim light, similarly as when using cameras at full opening. People over 50 have to do that by using glasses proper for the distance of the observed scene, as their ability to change dioptric power of their eyes vanishes. Very low illuminances allow us to read, down to decilux level when we keep the text close enough to our eyes. How low? Moonlight is one of the checks, being below 0.3 lx all the time.

Illuminances are commonly measured by luxmeters; their analog types gave hardly any signal at 1 lx or less. Modern devices have a step of 1 clx in dim light, and can be relied on from a decilux level upwards. They are able to register illuminances provided by full Moon. The cheapest ones cost about 100 euro. It is easy to get luminance estimates using them. Holding the sensor close to a screen of a computer, a first guess of its luminance is the reading divided by 3.14 steradians; this assumes that the luminance of the screen is the same in all directions. For old CRTs it was almost the case, for modern flat screens the luminance is lower for large aspect angles, they are so non-lambertian [9], that the factor may decline to 2 sr. Overcast sky is a similar case. But a large facade, under overcast sky, is lambertian enough. Or a terrain covered by snow.

For quantifying light pollution at night, illuminances down to of microlux level are to be measured. Or luminances from several cd/m^2 to μcd/m^2. What options do we have?

For luminance, it is simple: lots of modern CCD or CMOS cameras can give proxies of luminance, of integrals of filtered spectral radiance; actually, they give photon counts through a spectral filter. Even uncooled chips give usable data at the bottom limit of the span given above, those which offer raw data from their A/D conversion. The crude way: take the green pixels, apply exposure settings and find a coefficient of proportion using a luxmeter and some lambertian surface. See more at [10]. Using blue pixels is a good proxy for light affecting melatonin production [11]. Cameras with fish eye may give the best overview of light pollution; however, computer processing of their data is needed. Examples see at [12].

A direct proxy for luminance gives the Sky Quality Meter, http://unihedron.com/, offered in a filter-and-photodiode version and in a version including a lens, sensing from a cone of about 20º diameter. The device collects light, up to one minute at dark night, before reporting a result. Its output is given in a logarithmic inverse scale ‘how many magnitudes has a square arc-second’; its conversion to SI units is (the top and bottom line is out of SQM range):

SQM reading / 1 mag	luminance / 1 cd/m2
5	1080
7.5	108
10	11
12.5	1
15	0.1
20	0.01
22.5	0.001
25	0.0001

Tab. 1. Conversion of ‘faintness’ of 1 square second of arc to candelas per square metre.

SQM is about 100× more sensitive than cheap luxmeters. To be able to measure larger luminances, a gray filter can be put over its entrance, e.g. http://www.dimm-it.com/ (each layer of it dims light about 5×). lum.php at http://amper.ped.muni.cz/jenik/astro/ provides units conversion.

Even more sensitive is an amorphous silicon PV cell equipped with electronics measuring its current, as described at http://lightmeter.astronomy2009.at. This is due to its large area. The signal is a photon flux filtered by the spectral sensitivity of the cell, going about twice further toward UV than the photopic sensitivity of the eye. The instrument has no display, a computer has to log its output via USB. Used as a proxy for illuminance, it registers down to a microlux level, like in a large room with small windows in a dark night. This lightmeter and cheap versions of SQM cost some 100 euro, too.

Neither of them is suitable to register illuminance of human face continuously. Knowing this quantity as a function of time is needed to investigate its influence on melatonin production. An instrument with a small sensor, which can be attached to glasses, with a logger to be held in a shirt pocket, has been developed recently for the author [13]. An example of its output (tiny dots in the ¼ lx to over klx range) is at p. 14 of [14].

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