"Blue" Light and Its Effect on Circadian Rhythms, Sleep, Alertness and Cognition

Presented by:

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UPK Universitäre Psychiatrische Kliniken Basel

Universität Basel

"Blue" Light and Its Effect on Circadian Rhythms, Sleep, Alertness and Cognition

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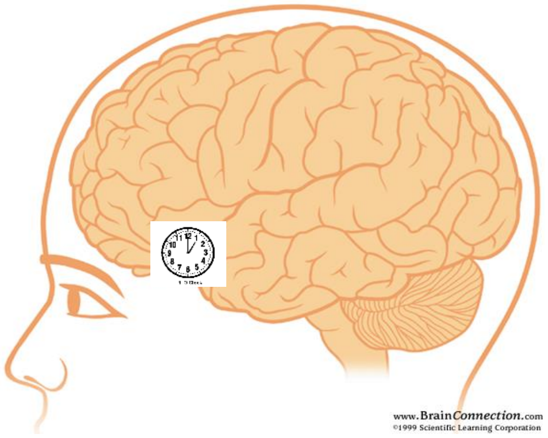
Centre for Chronobiology

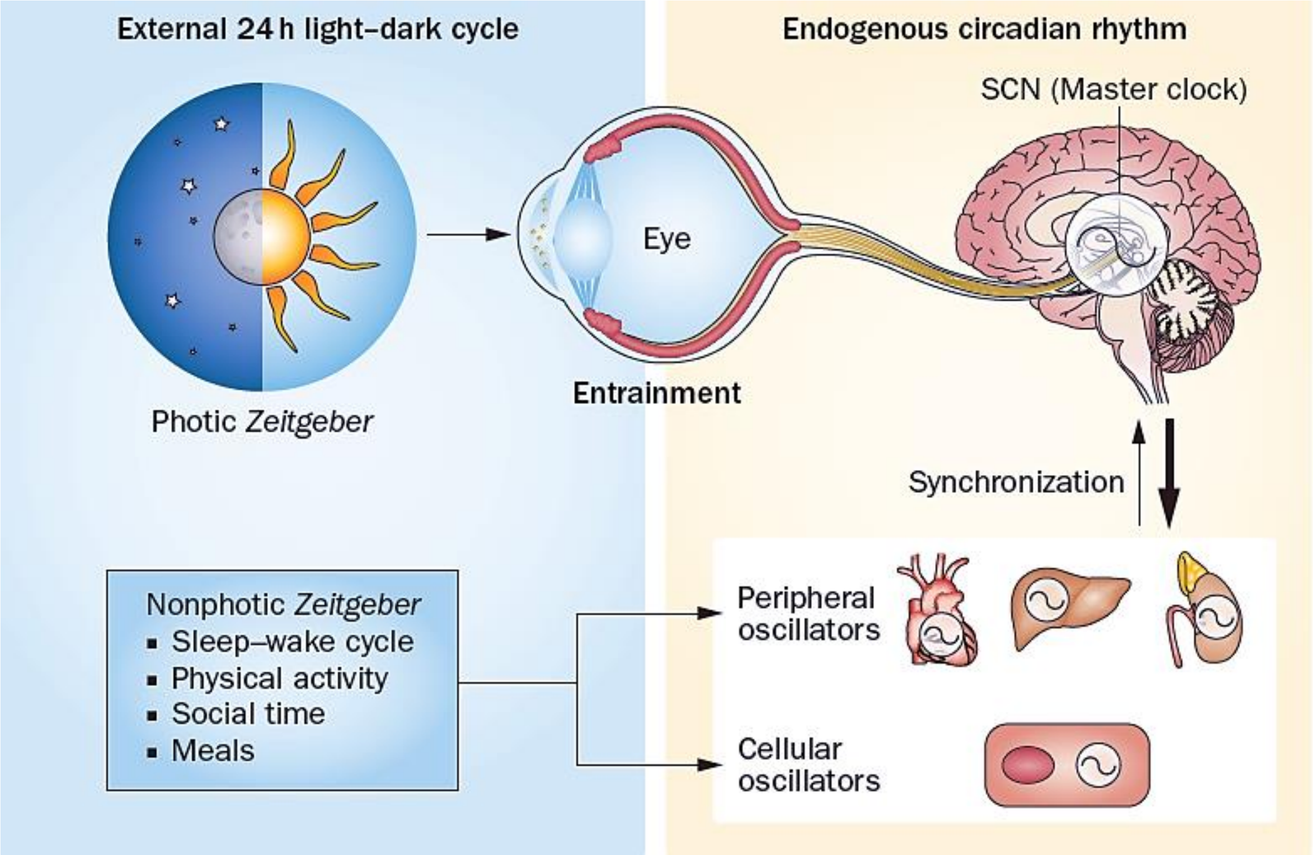
Webinar OSA Technical Group
08.04.2020

OSA The Optical Society | 100 Since 1916

Two «rice grains» in the brain



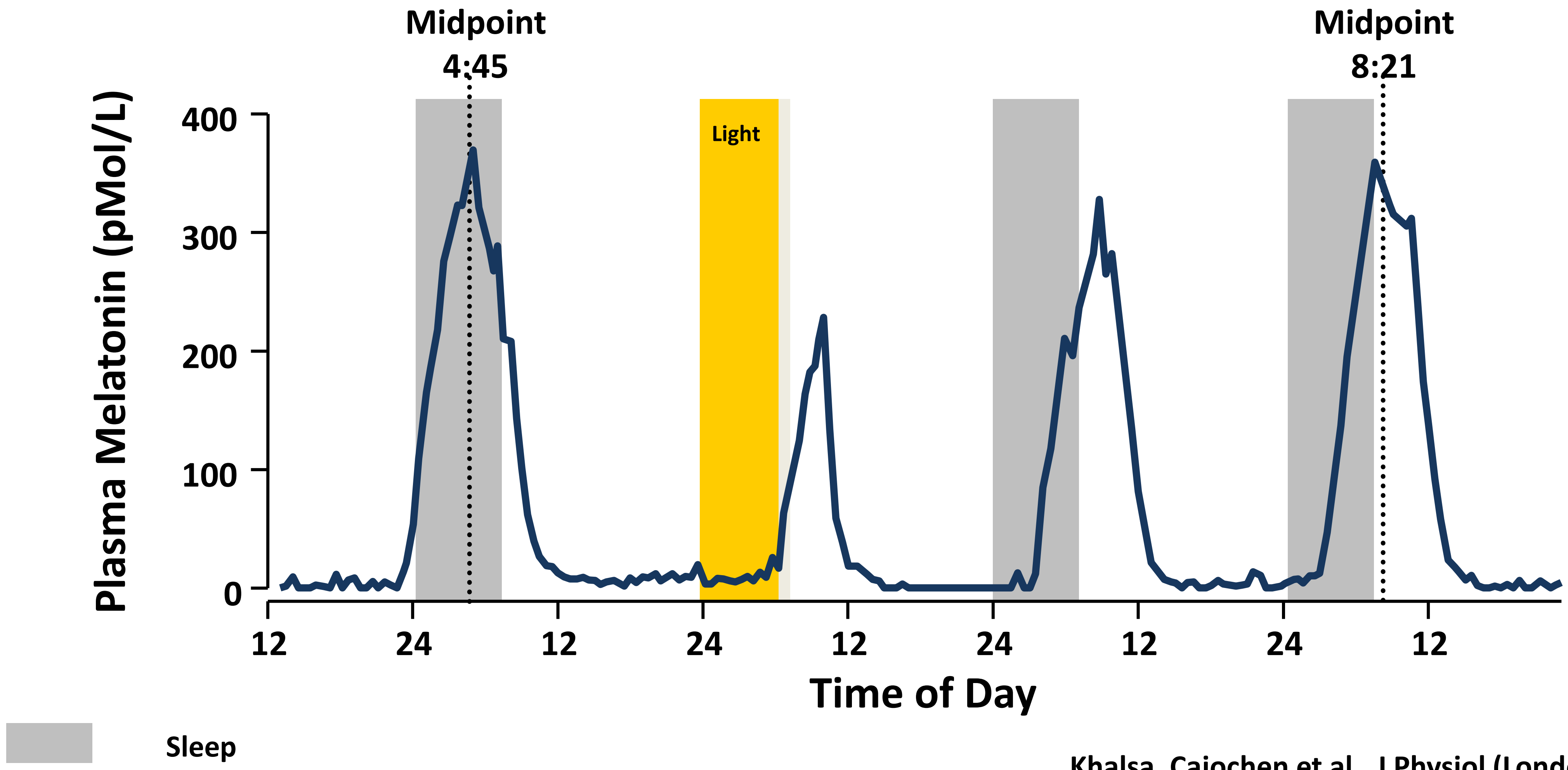
Light is the most important Zeitgeber !



Buttgereit, Smolen, Coogan, Cajochen, Nat Rev Rheumatol, 2015

Light and circadian rhythms

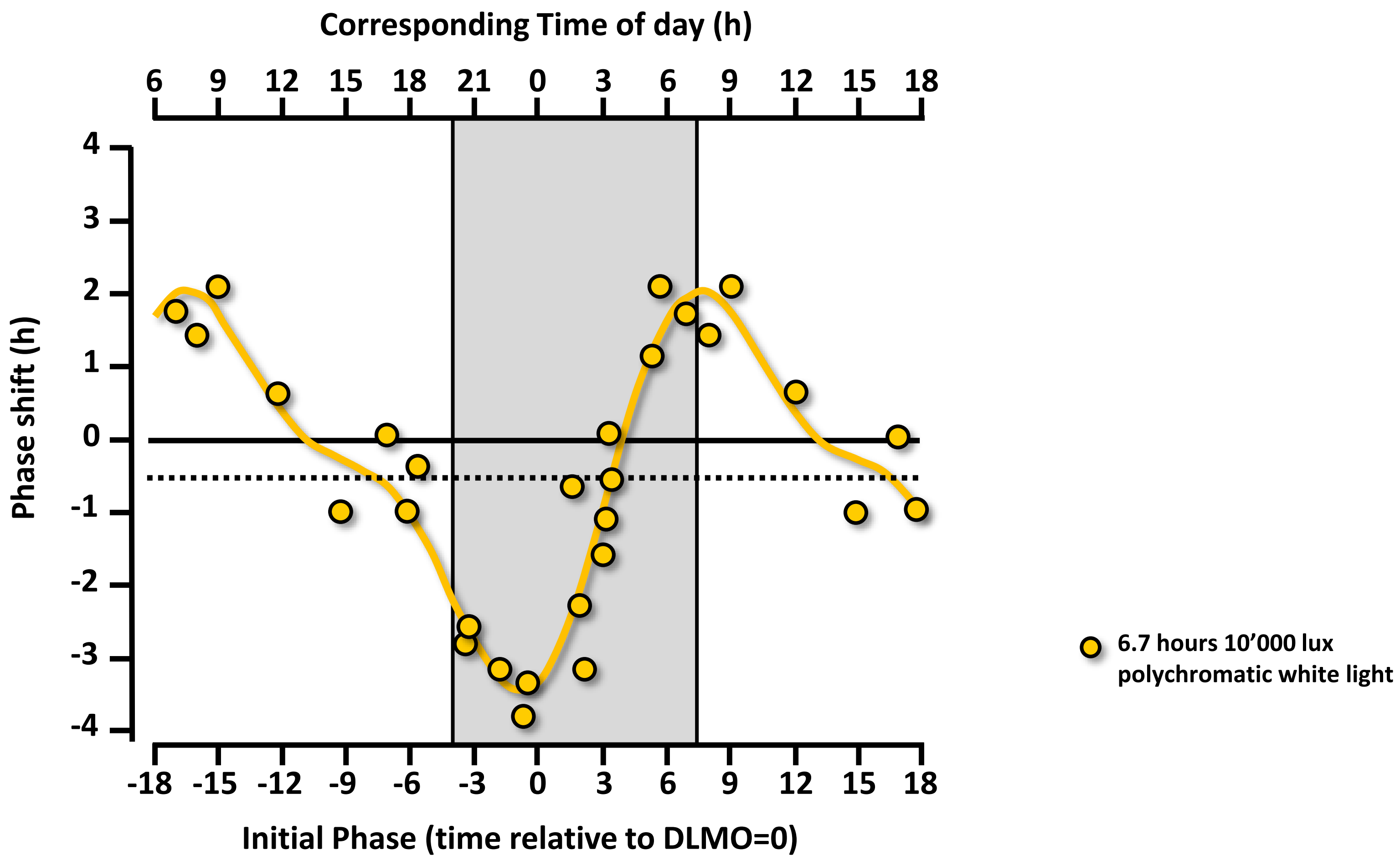
Melatonin the best marker for human circadian phase (hands of the clock)



Khalsa, Cajochen et al., J Physiol (London) 2003

Light and circadian phase

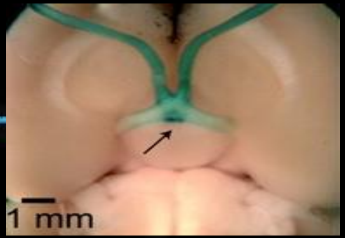
Phase-Response Curve



Khalsa, Cajochen et al., J Physiol (London) 2003

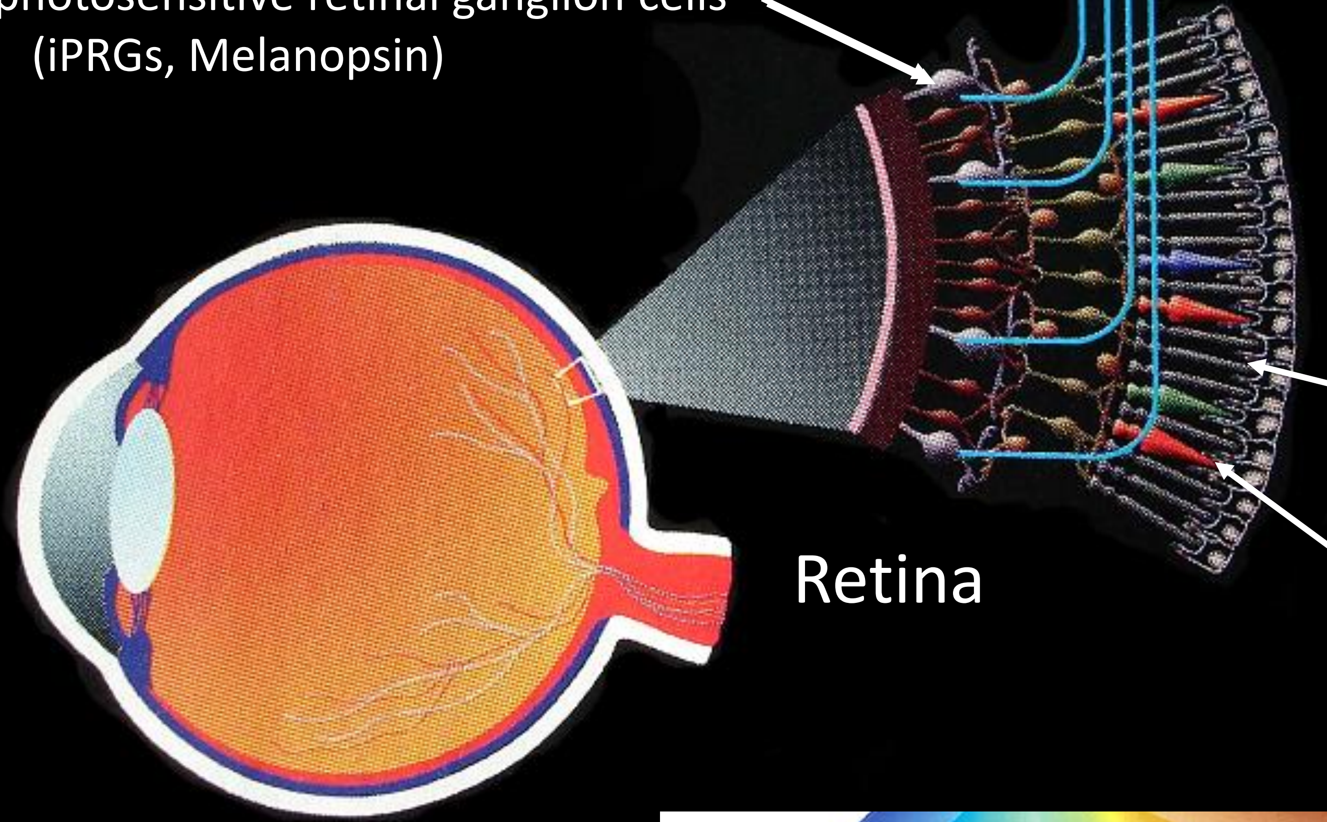
Non-classical Photoreceptors

intrinsically photosensitive retinal ganglion cells
(iPRGs, Melanopsin)



SCN
(circadian Pacemaker)

Eye
A dual sensory organ

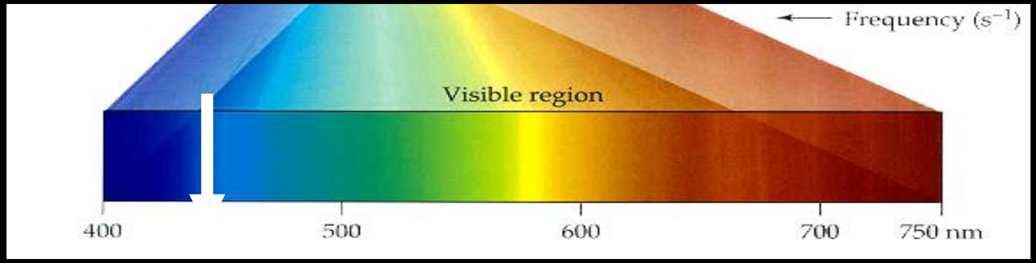


Retina

Rods

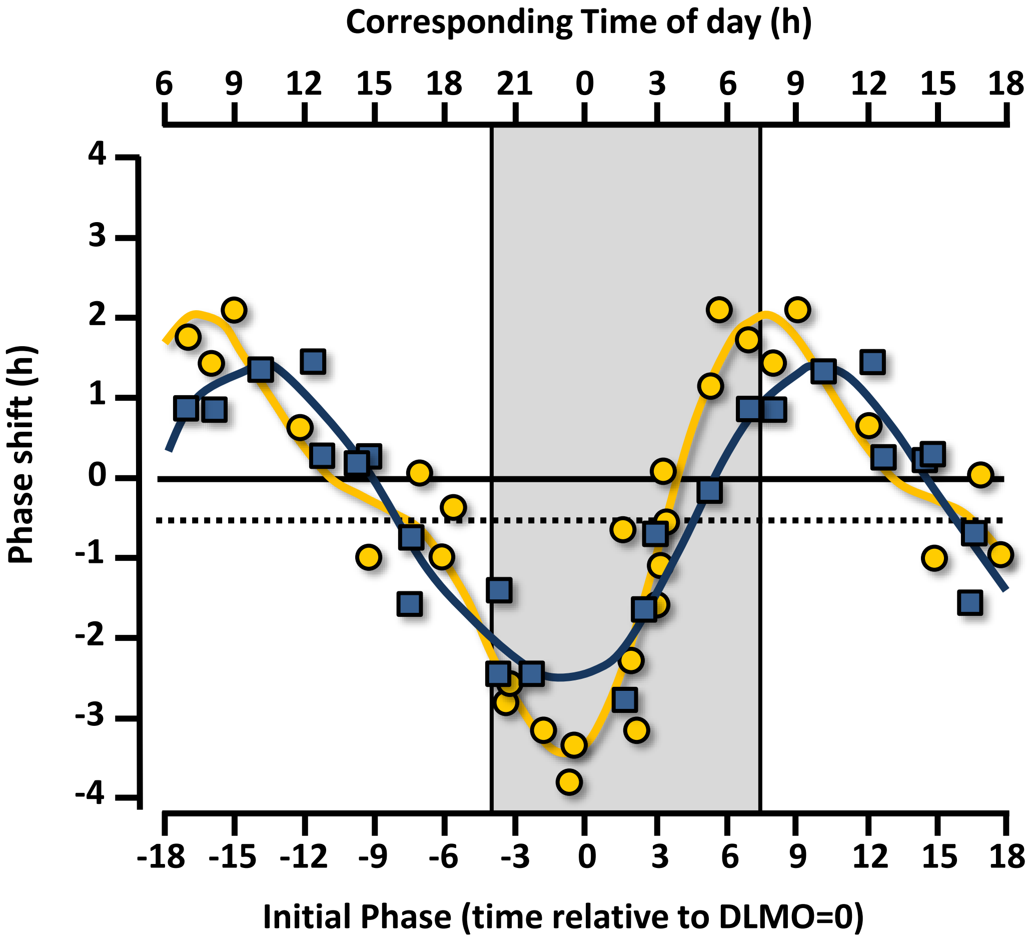
Cones

Hattar et al. Science, 2002
Berson et al. Science, 2002



Light and circadian phase

Phase-Response Curve

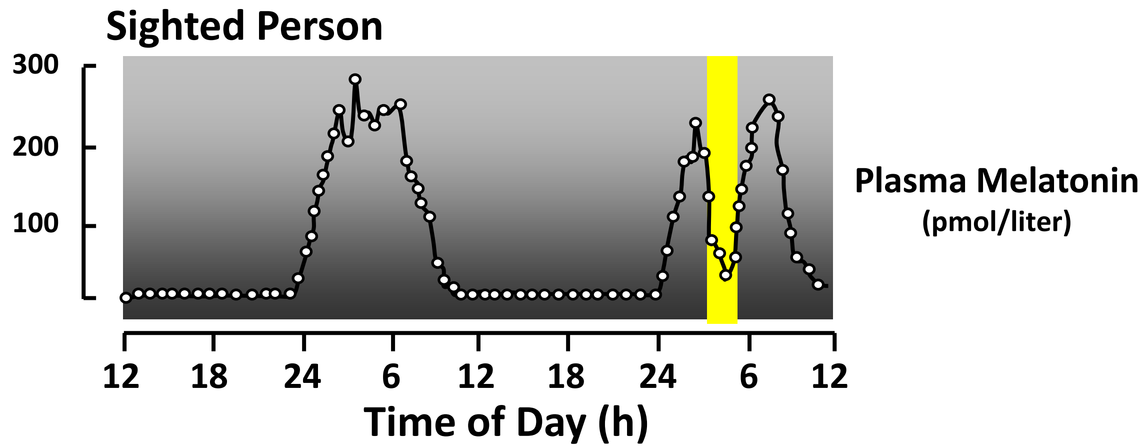


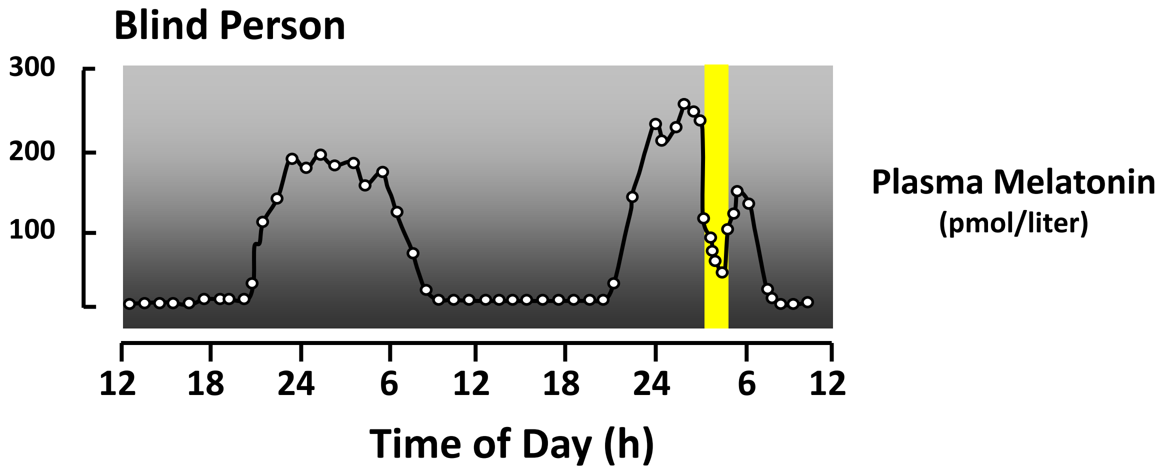
75 % of the resetting response

- 6.7 hours 10'000 lux polychromatic white light
- 6.5 hours blue light (480 nm) 11.8 μWcm^{-2}, 11.2 lux)

Khalsa, Cajochen et al., J Physiol (London) 2003
Rüger, et al., J Physiol (London) 2013

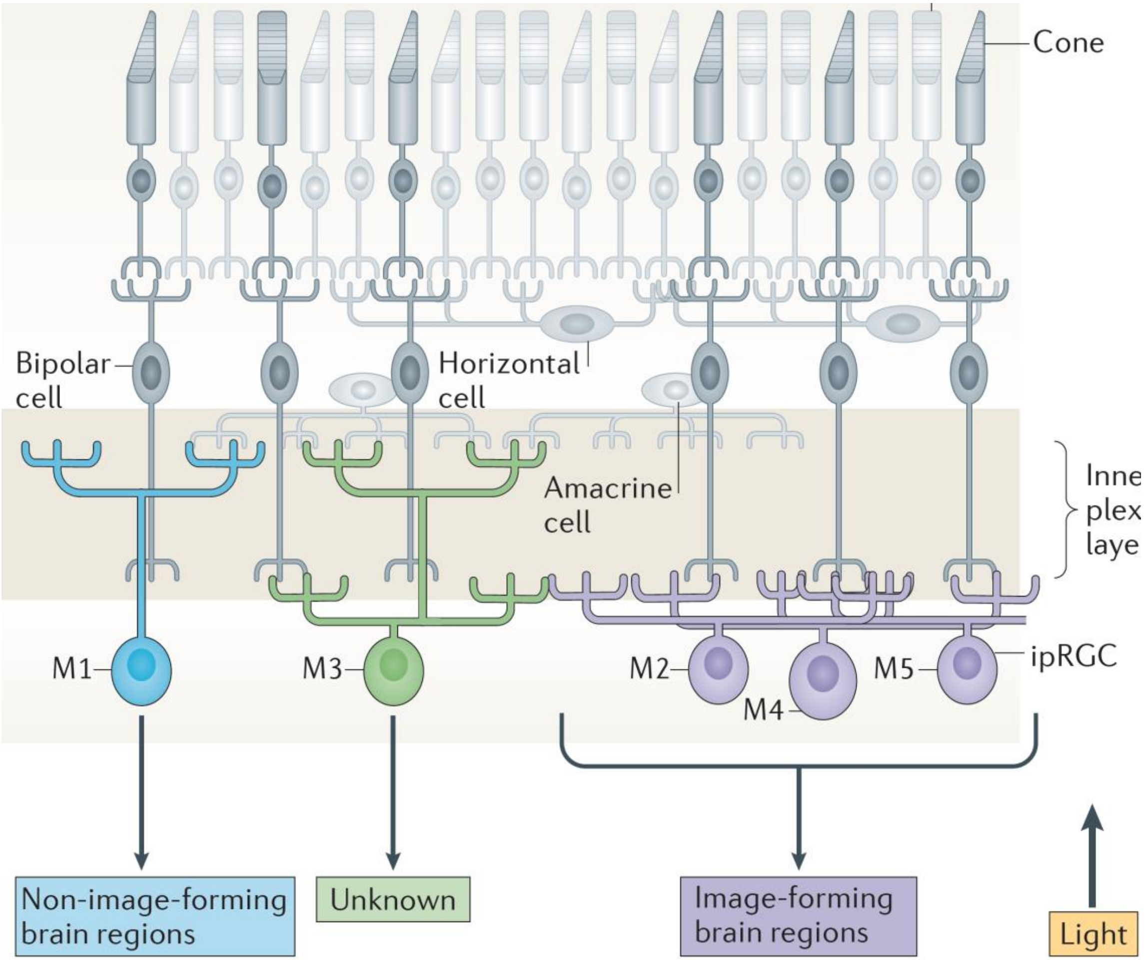
Suppression of melatonin in a totally blind person with bright light





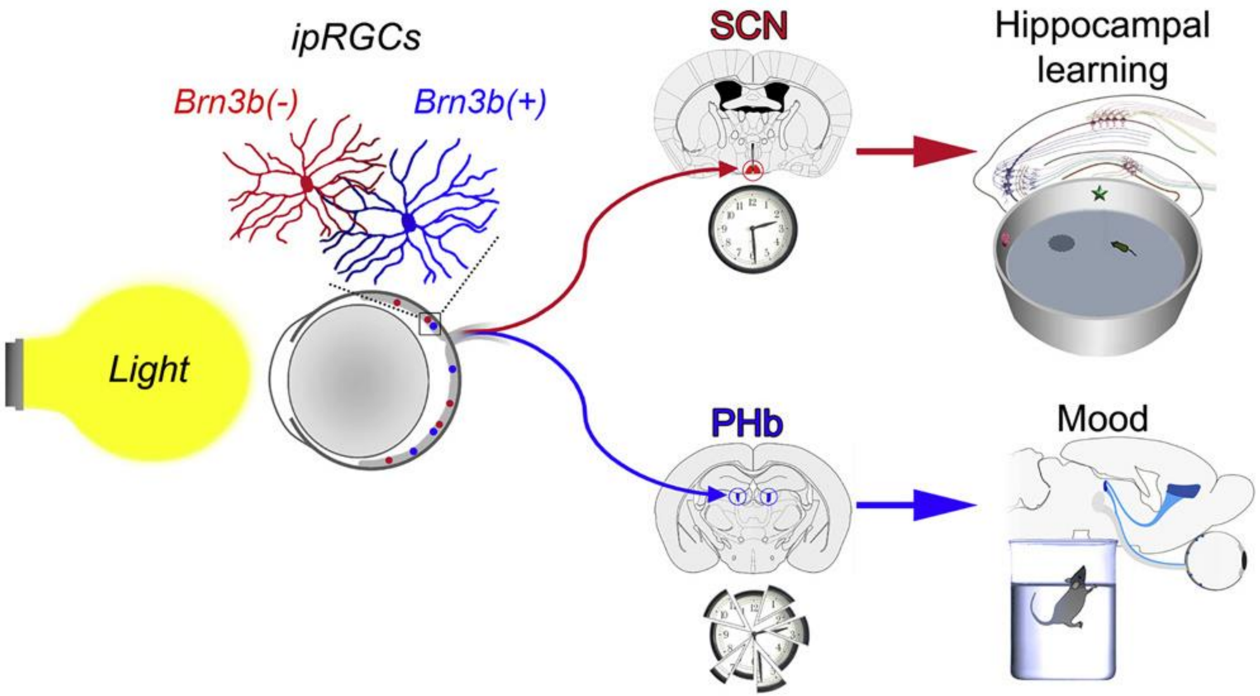
Czeisler et al., New Engl Med 1995

There are at least five subtypes of ipRGCs (M1–M5)



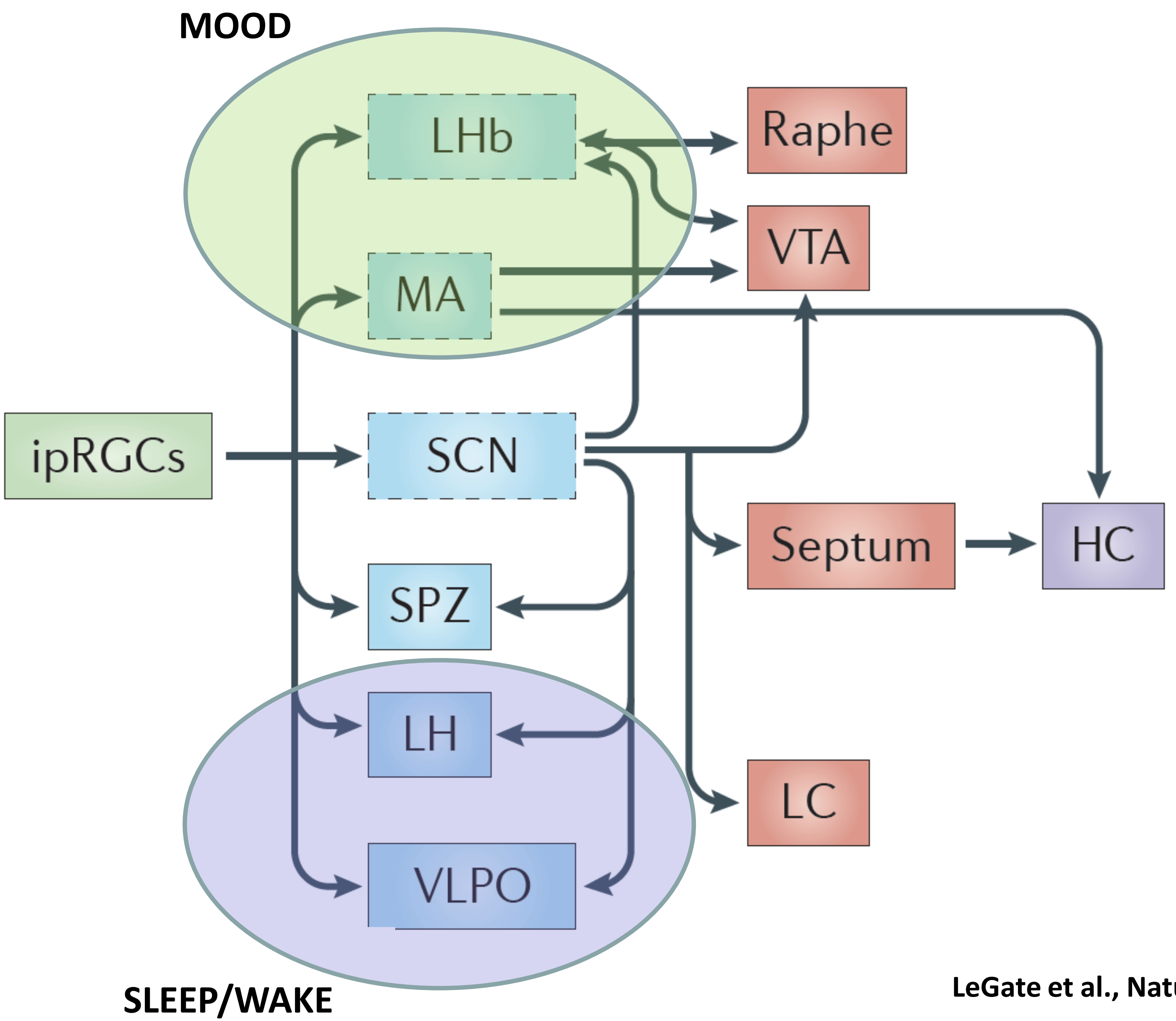
LeGate et al., Nature Reviews Neuroscience, 2014

Light affects mood and learning through distinct retina-brain pathways



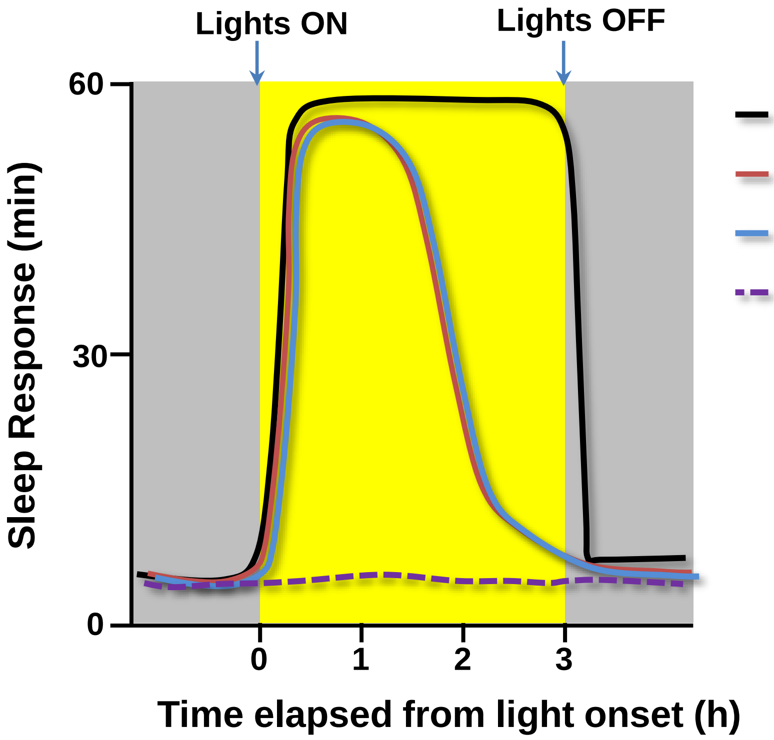
Fernandez et al., Cell 2018

Brain circuits underlying the effects of light on non-image-forming visual functions



LeGate et al., Nature Reviews Neuroscience, 2014

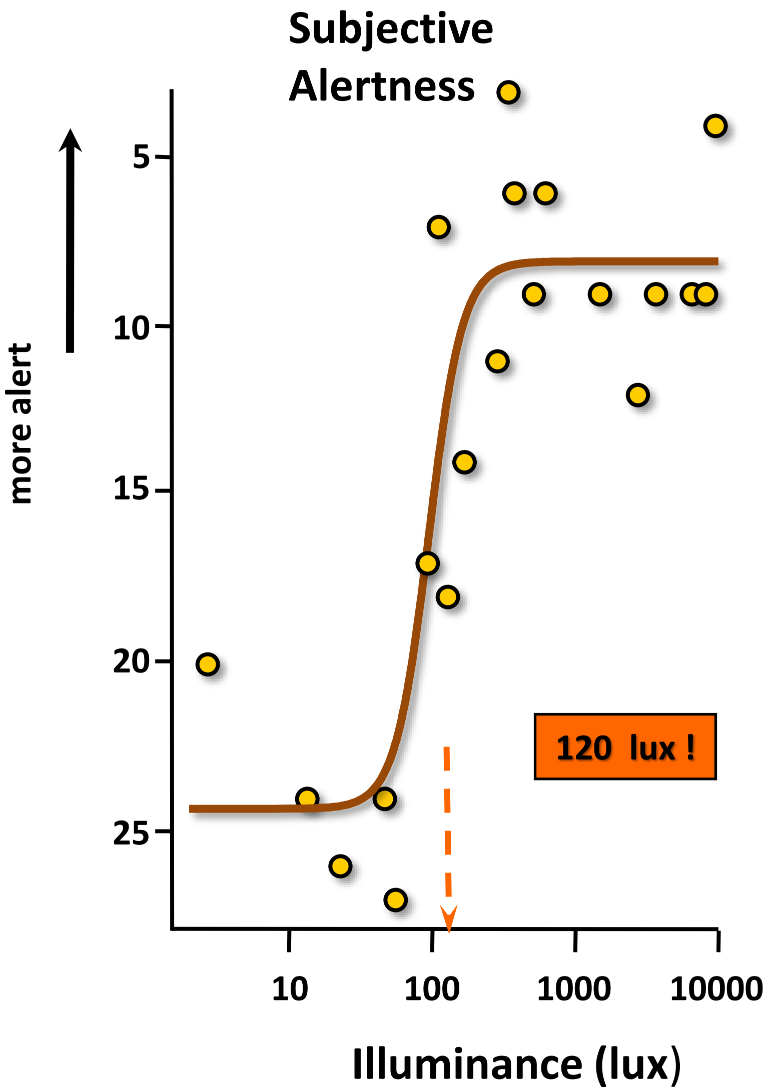
Light evoked sleep induction and sleep maintenance across different genotypes (mice)



This suggests that these cells serve as an exclusive pathway for mediating the acute effects of light

According to Muindi et al., Front Syst Neurosci, 2014

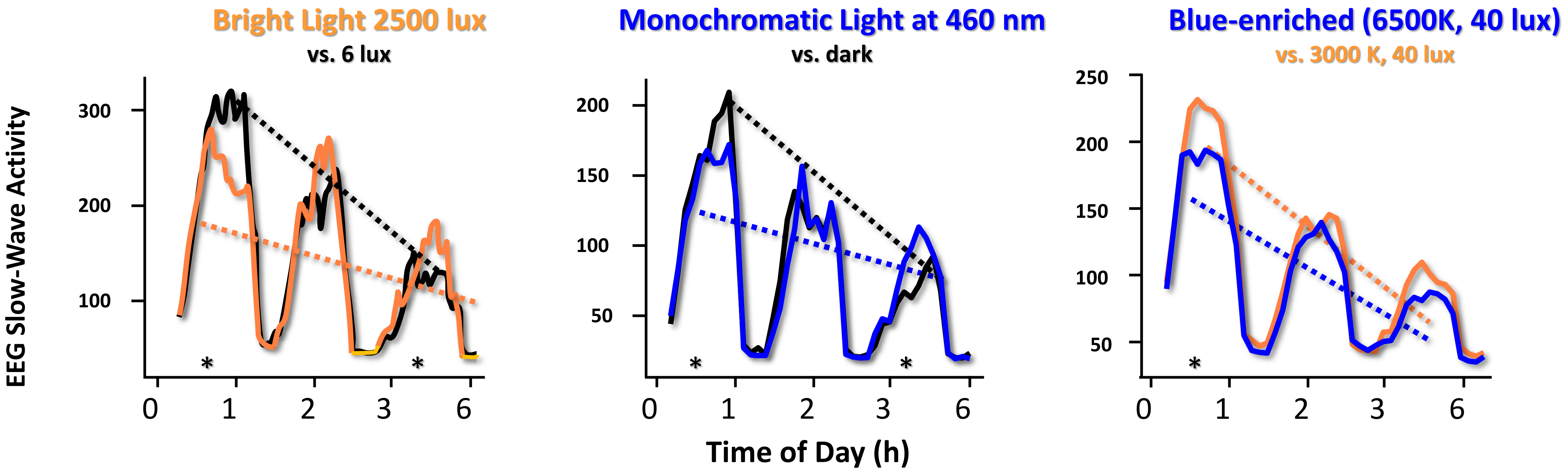
Acute alerting effects of light in diurnal humans



Cajochen et al., Beh Brain Res. 2000

Carry-over effect of the light's alerting in the evening

Evening Light Exposure and EEG Slow-Wave Activity Dynamics across Sleep Cycles

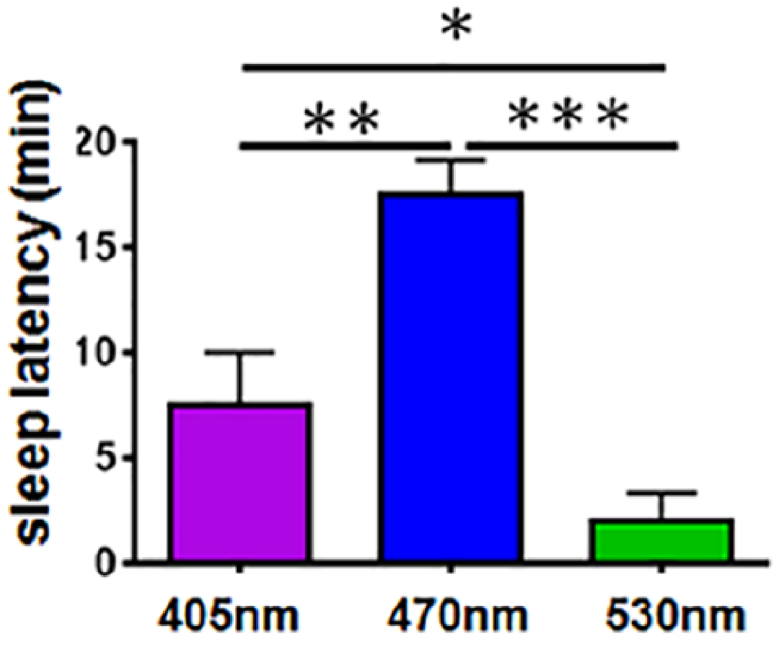


Cajochen et al., Sleep 1992

Münch et al., Am J Physiol. 2006

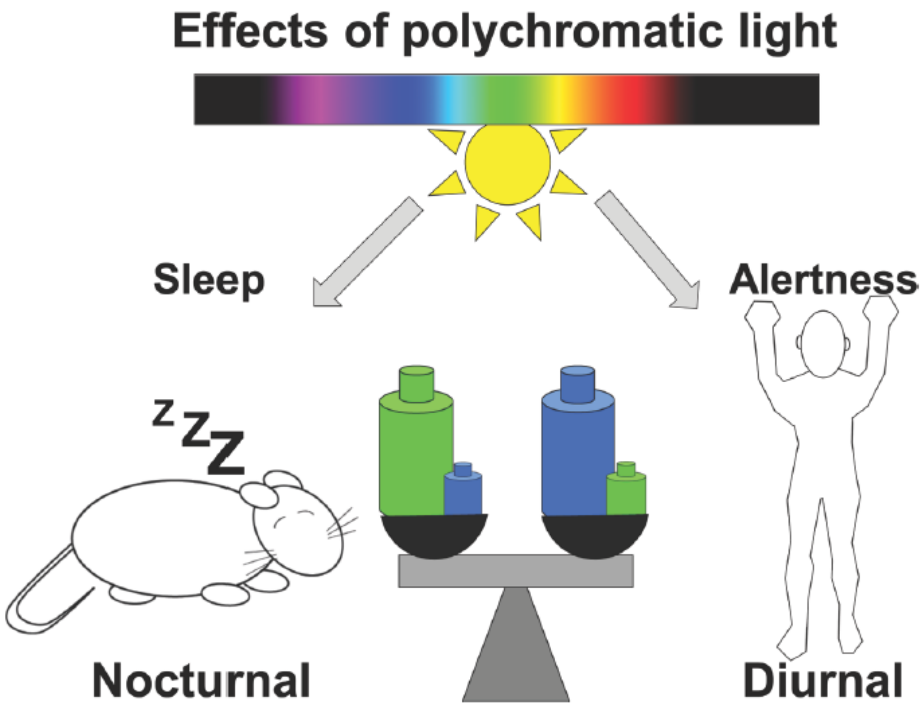
Chellappa et al., J Sleep Res. 2013

Wavelength-dependent sleep induction in a nocturnal animal



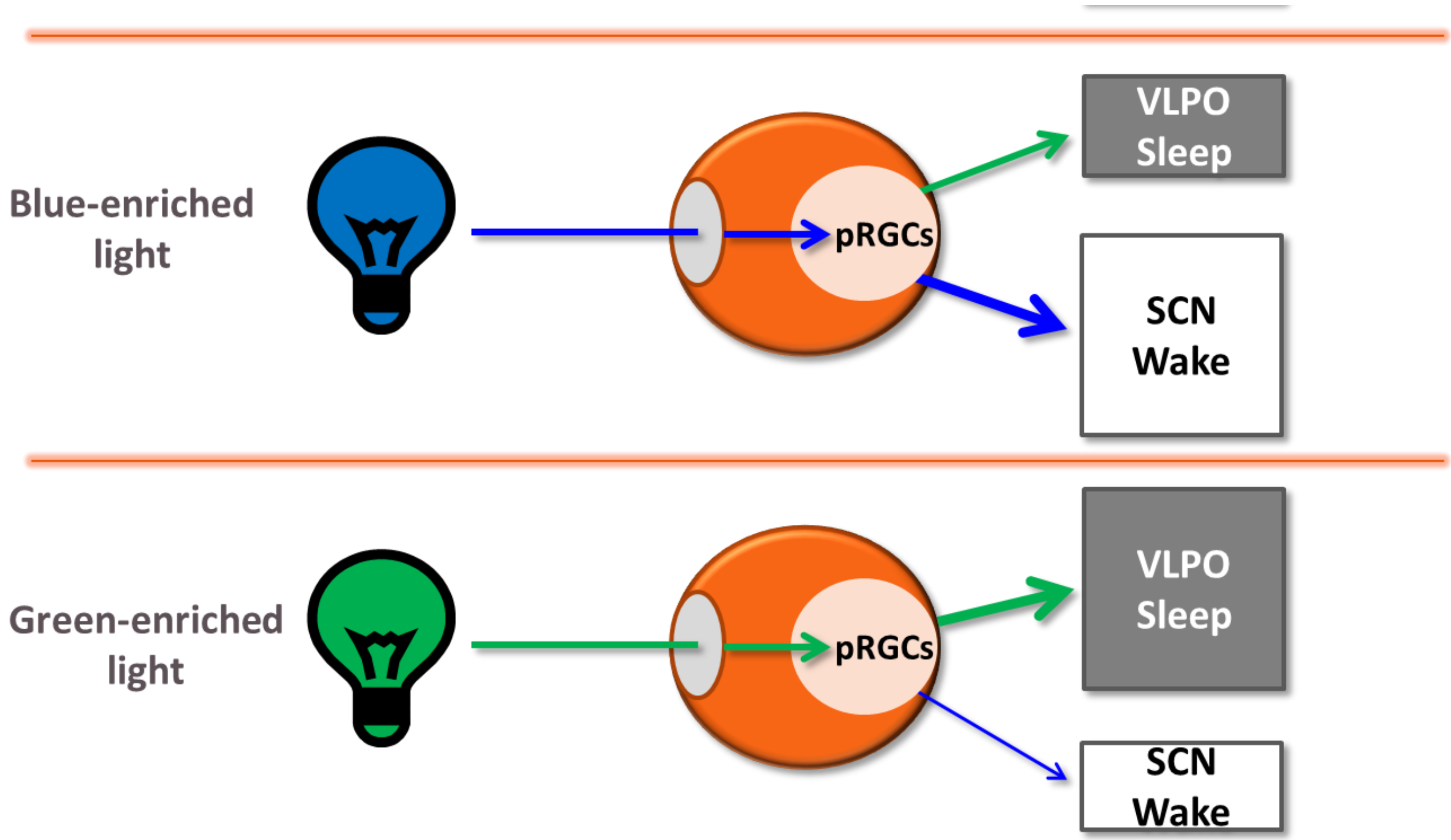
Pilorz et al., Plos Biol 2016

Polychromatic light and diur-/nocturnality



Bourgin and Hubbard, Plos Biol 2016

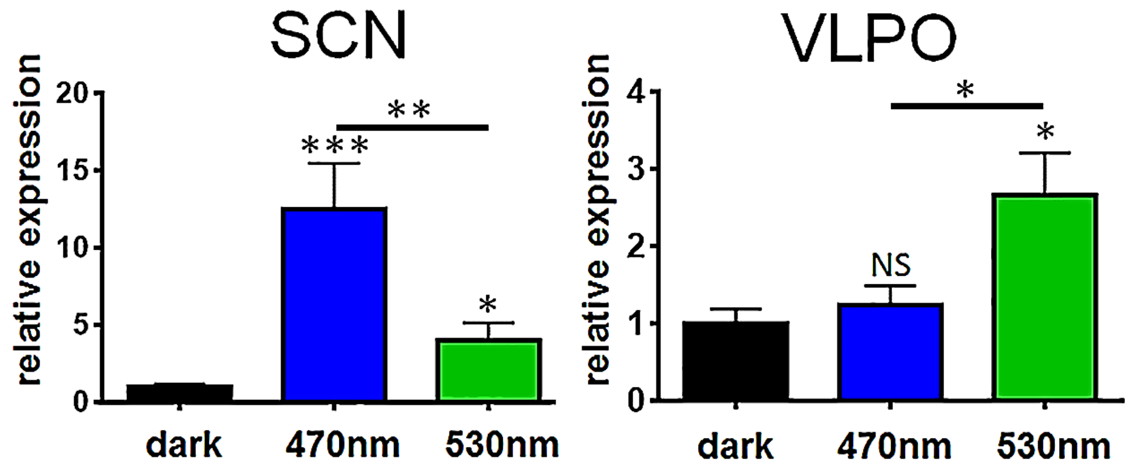
Blue- vs. green enriched light



Cajochen and Chellappa, Front Neural Circuits. 2016

Molecular responses to light in SCN and VLP are wavelength-dependent

Fos



Pilorz et al., Plos Biol 2016

Is this relevant to everyday life ?

http://journal.media-culture.org.au/index.php/mcjournal/article/view/1009

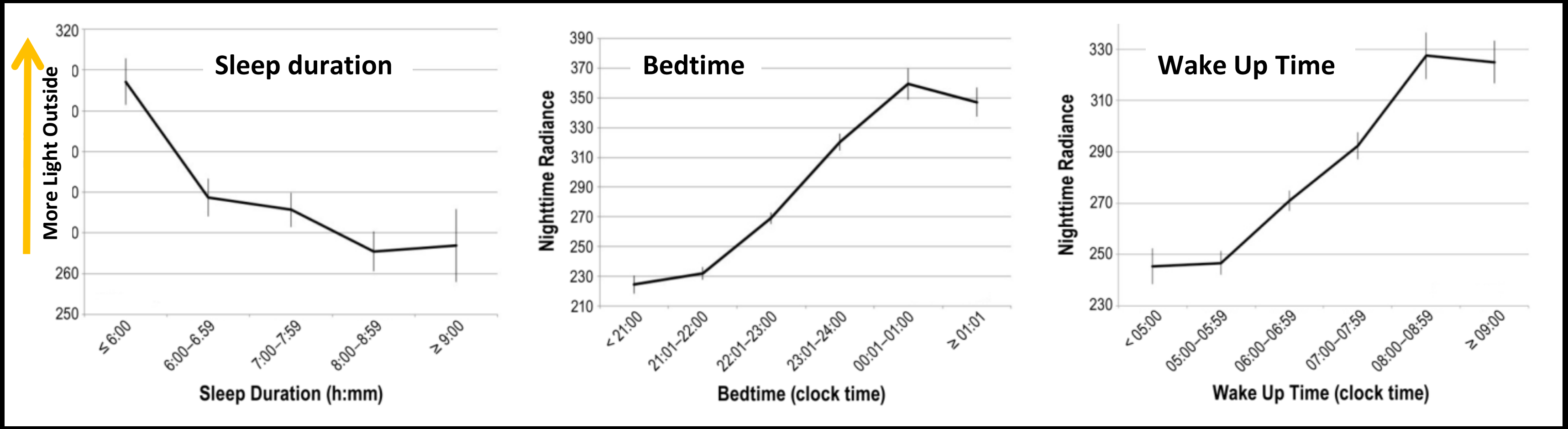
MOTIVATION FOR BETTER LIGHTING SOLUTIONS

We spend more than 90% of our time indoors

The world gets brighter at night

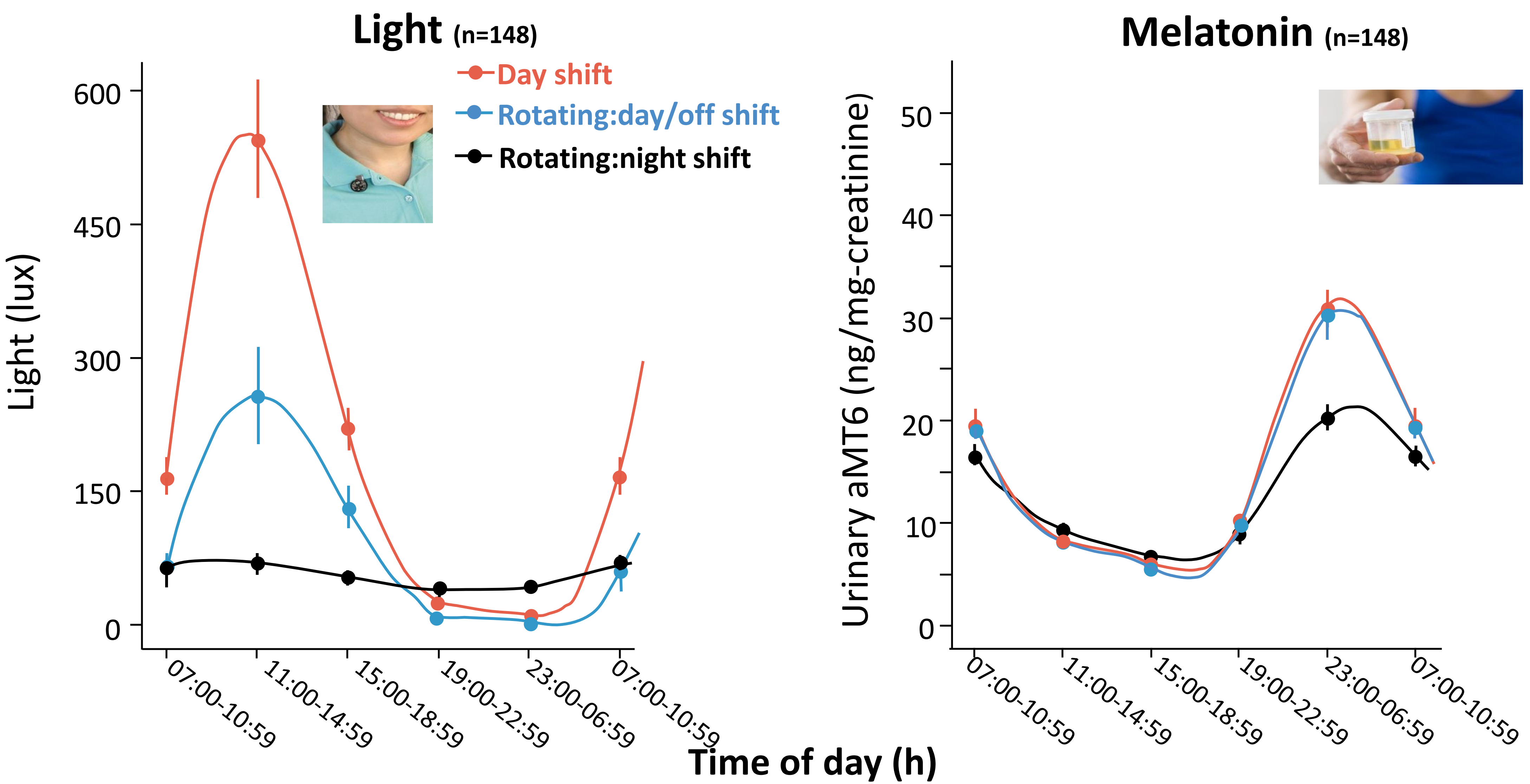
Artificial outdoor light levels correlate with human sleep-wake behavior in the US (n=19'136)

Distribution of nocturnal outdoor illuminance



Ohayon and Miles, Sleep, 2016

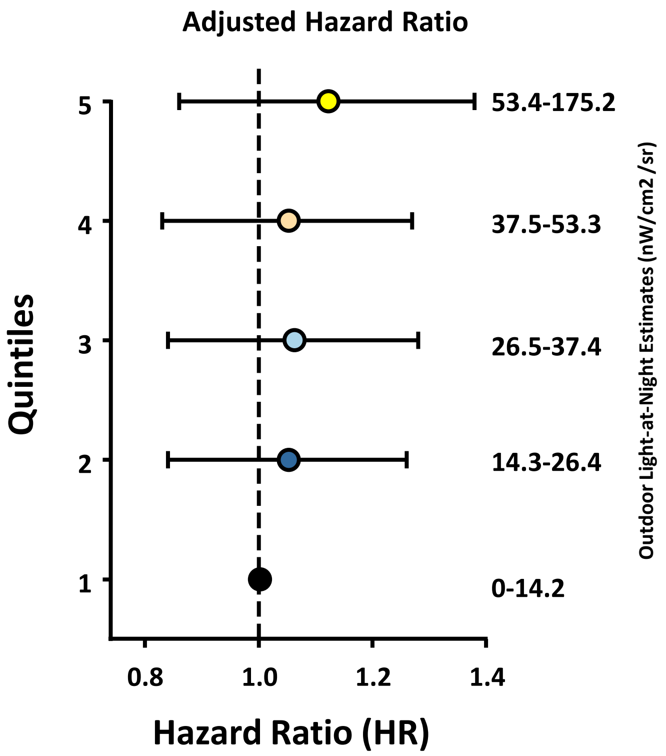
Light exposure and urinary melatonin levels across shift work schedules



Razavi et al. Cancer Epidemiol Biomarkers Prev 2019

Light at Night and Cancer

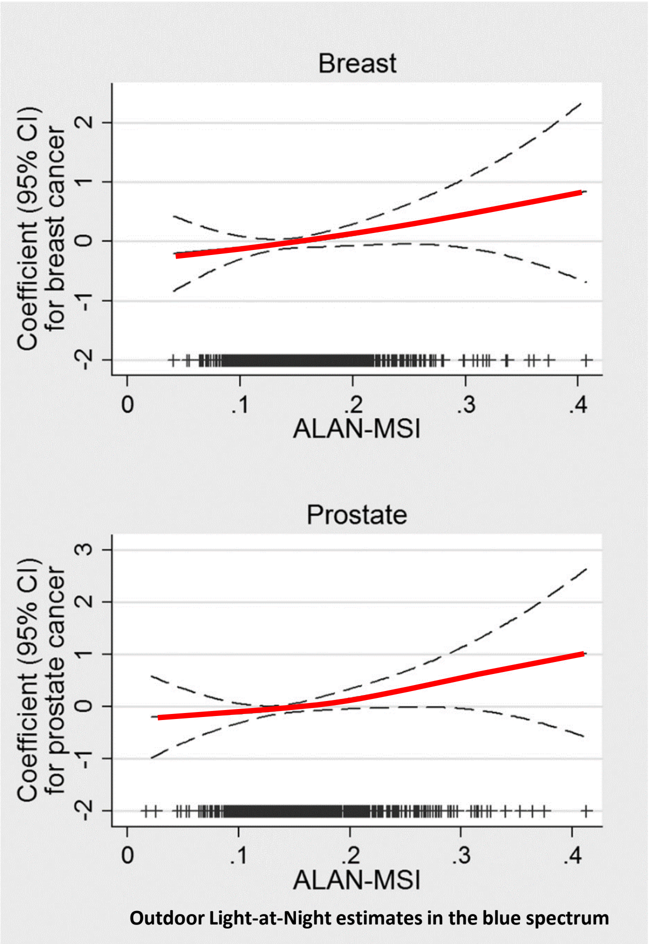
Women living in areas with high levels of ambient light at night may be at an increased risk of breast cancer



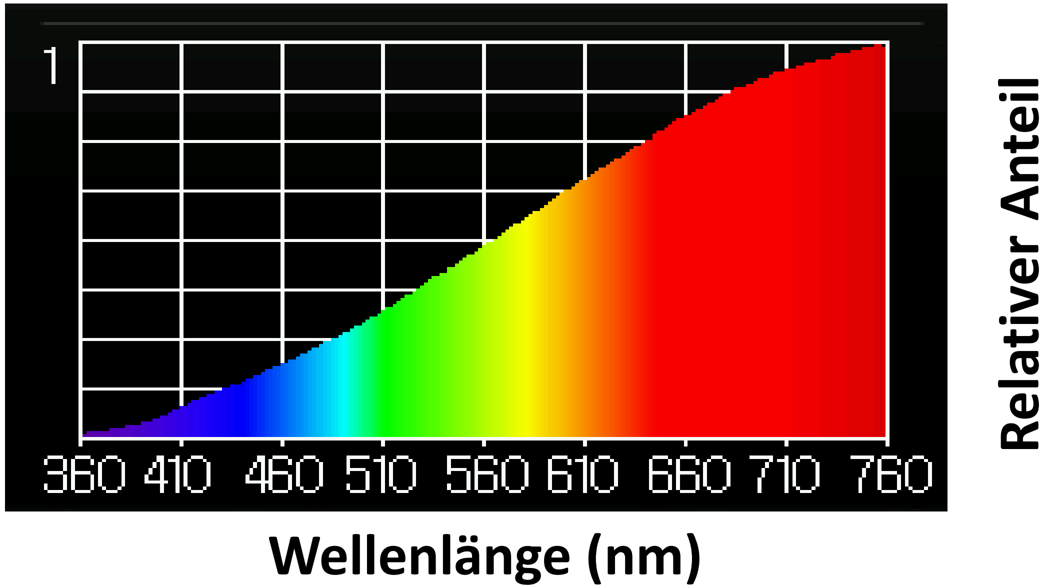
Risk of Invasive Breast Cancer Associated with Outdoor Estimates of Light at Night Among **106,731 Study Participants**: Adjusted HRs and 95% CIs Estimated from Cox Proportional Hazard Models

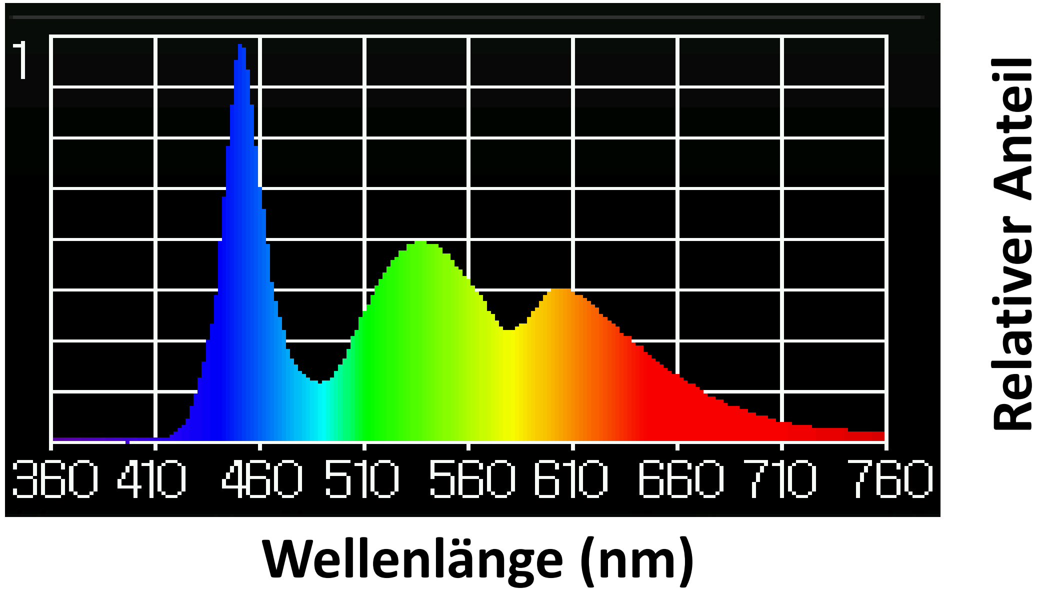
Hurley et al., Epidemiology, 2014

Both prostate and breast cancer were associated with high estimated exposure to outdoor light at night in the blue-enriched light spectrum



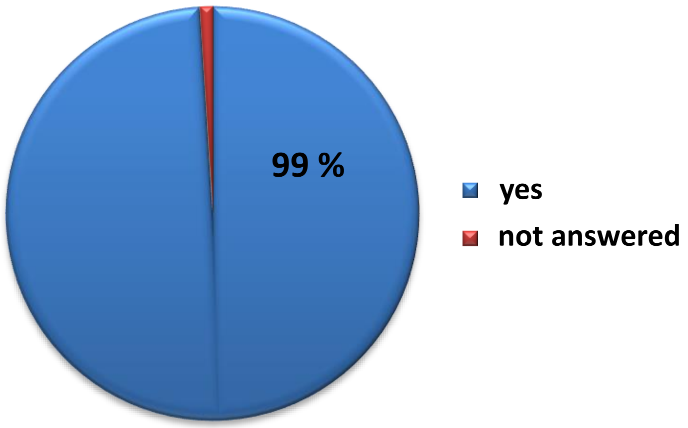
Garcia-Saenz et al., Env Health Persp, 2018


1
360 410 460 510 560 610 660 710 760
Wellenlänge (nm)
Relativer Anteil


1
360 410 460 510 560 610 660 710 760
Wellenlänge (nm)
Relativer Anteil

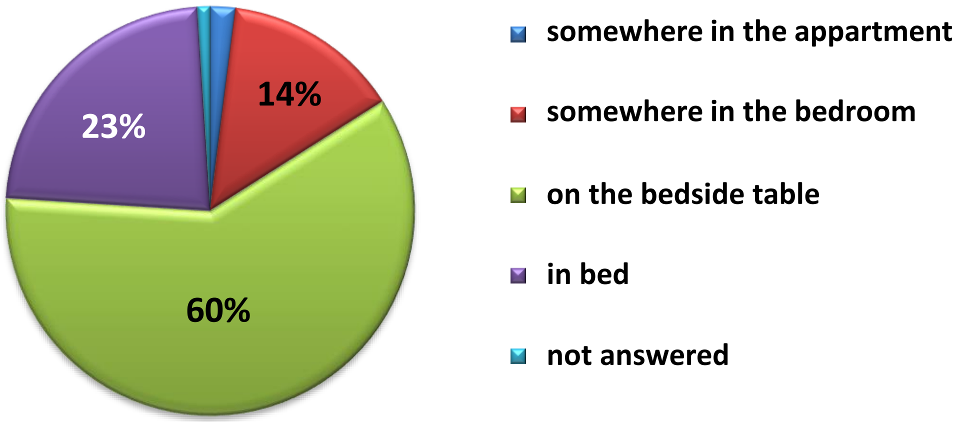
Smartphone use in adolescents (14-20 years)

Use of smartphones 1 hour prior bedtime



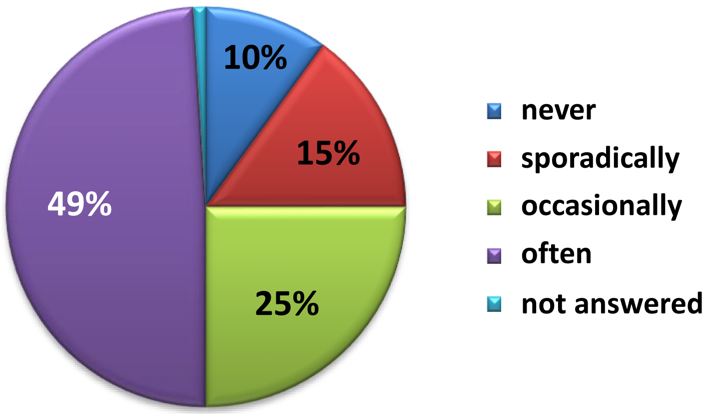
99% yes

Where do you keep your smartphone during night?



97% in bedroom

How often do you use your smartphone after «Lights off»



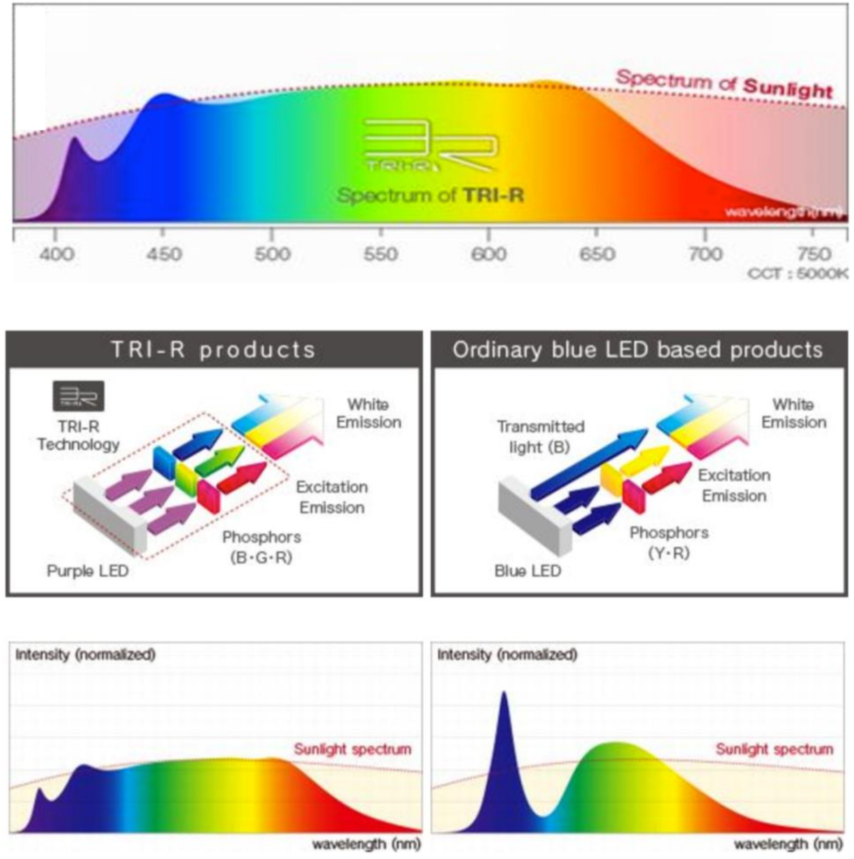
74% occasionally-often

Strube et al. Somnologie, 2016

Daylight-LED vs. conventional LED

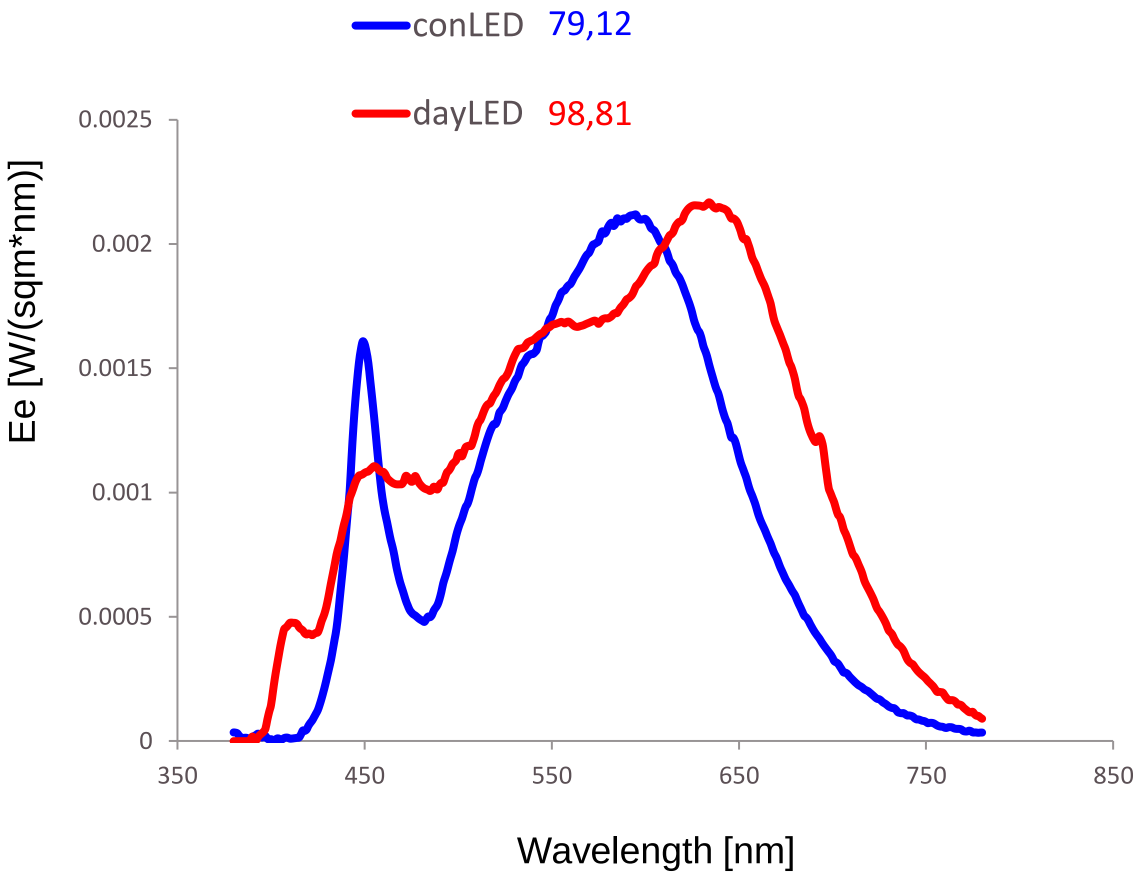
100 Lux, 3700 Kelvin

Intensity [normalized]



http://www.toshiba-tmat.co.jp/eng/case_tri_r/index.htm

Colour rendering, R_a different:



Farbtemperatur von 3700K = sonniger Tag kurz nach Sonnenaufgang während "goldener Stunde” gemessen in der Sonne

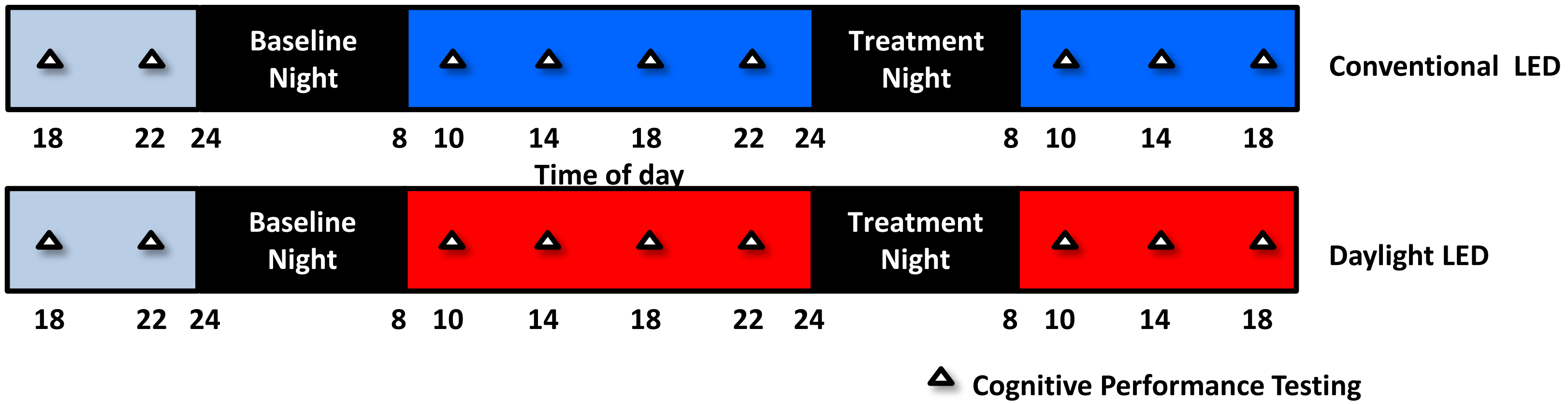
https://www.nrel.gov/ grid/solar-resource/smarts.html

Conventional LED vs. daylight LED

Room equipped with daylight LED

Room equipped with conventional LED

Daylight LED vs. conventional LED



Night sleep between
± 1 hours of usual bedtime

Within participant design with a counterbalanced order of the light conditions:

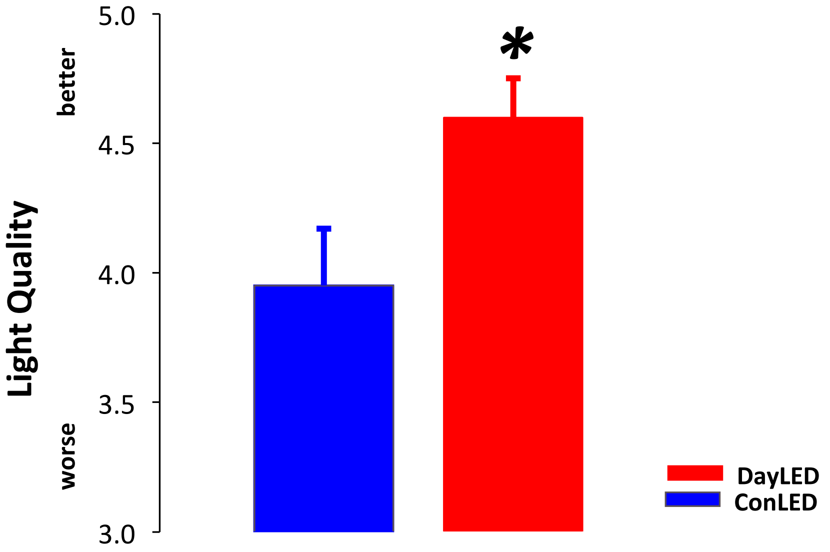
- Each participant reported two times to the lab for two light conditions (conLED and dayLED)
- The order of the light conditions was balanced among the study participants

Conventional LED vs. daylight LED

Visual comfort ratings

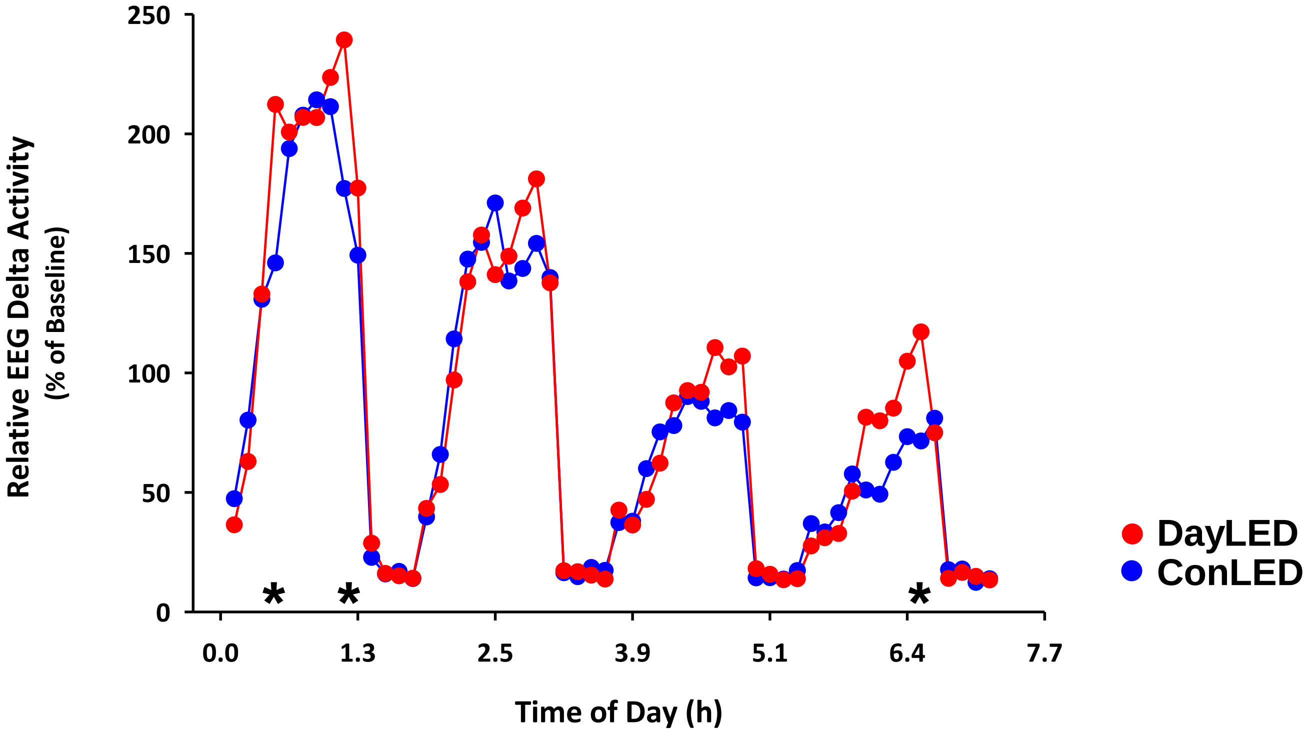
Subjective Rating of Light Quality

(Brightness and Colour Temperature)



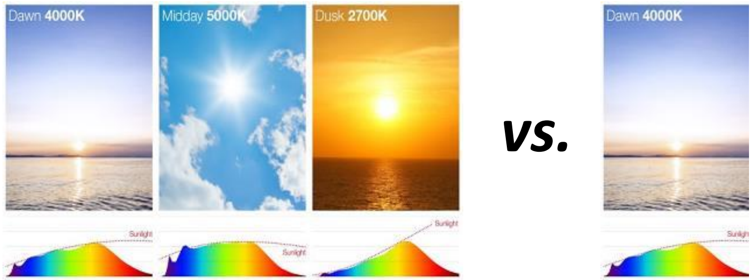
Sleep

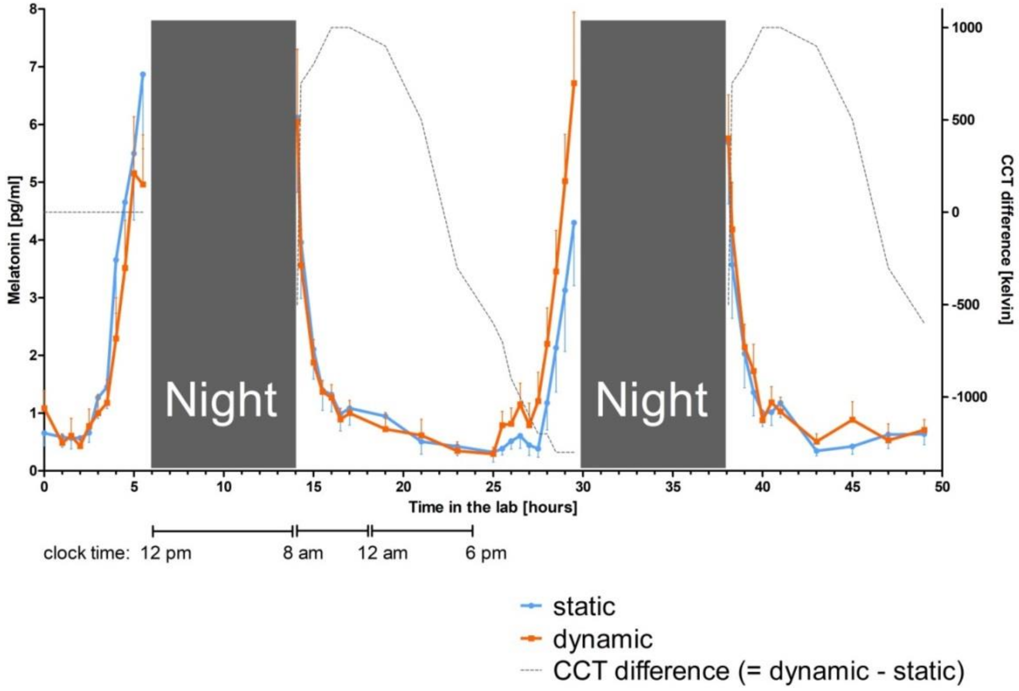
Dynamics of delta-EEG activity during sleep

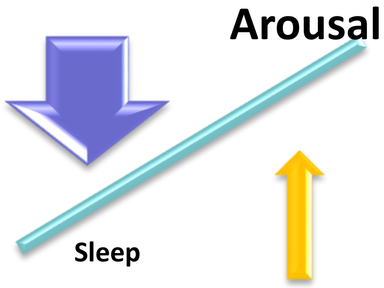


Cajochen et al. Lighting Res. Technol., 2019

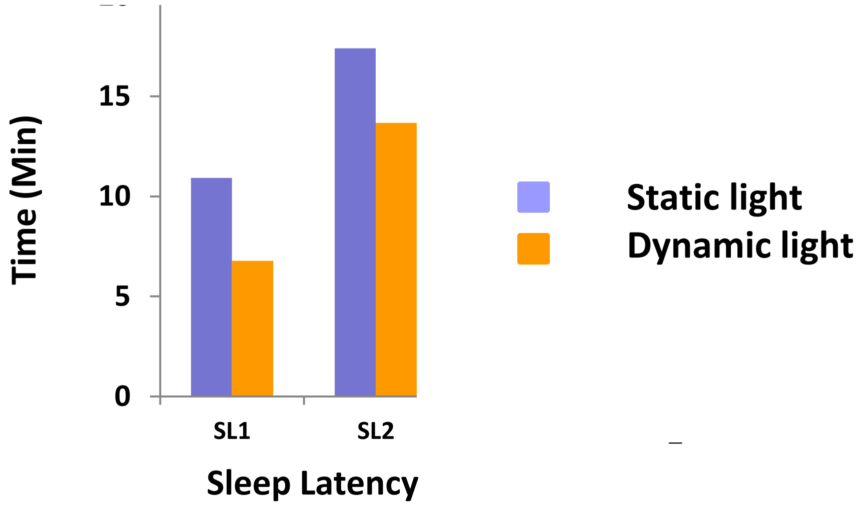
Dynamic "Daylight" LED impacts on melatonin secretion and sleep





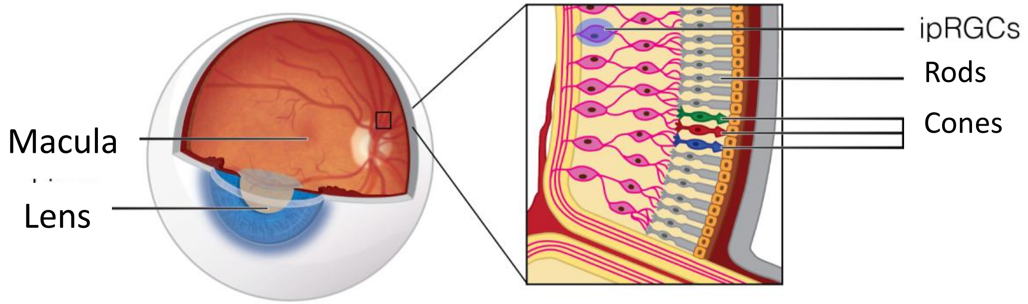


Dynamic light: 38% reduction in latency to sleep stage 1

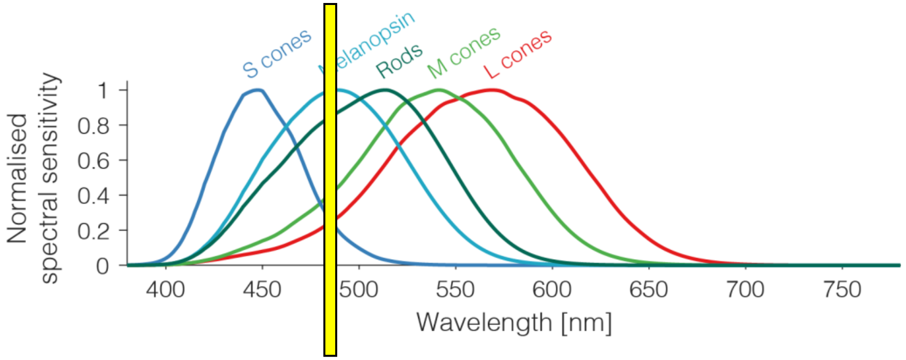


Stefani et al., in prep.

Processing of light in the human eye takes place through five photoreceptors.



These photoreceptors integrate light according to their spectral sensitivity.



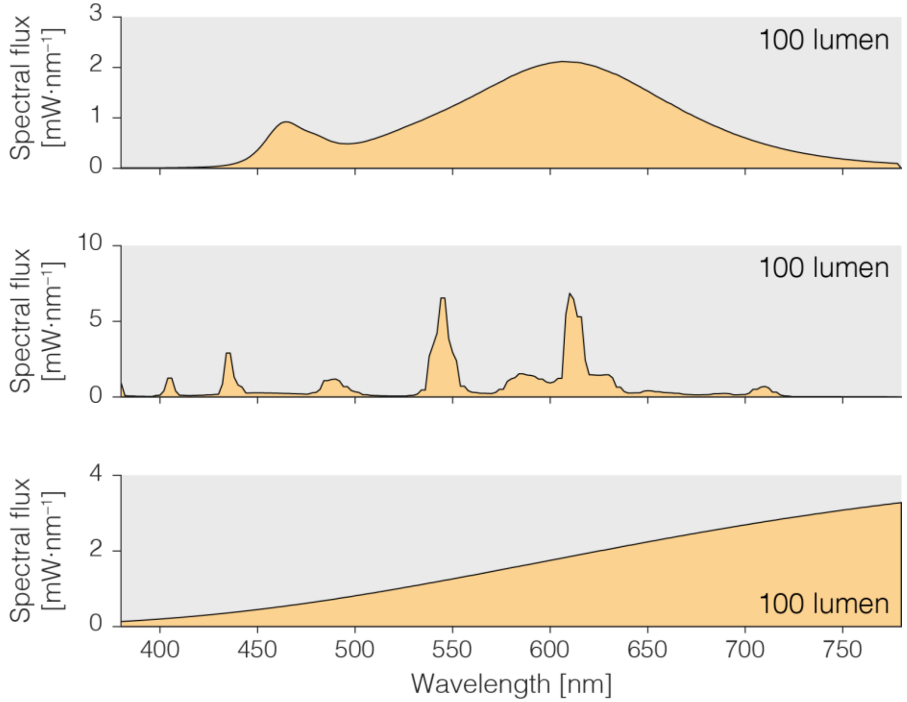
Because of this integration, information about the light spectrum is lost.

Lights with different spectra can look the same.

White-LED

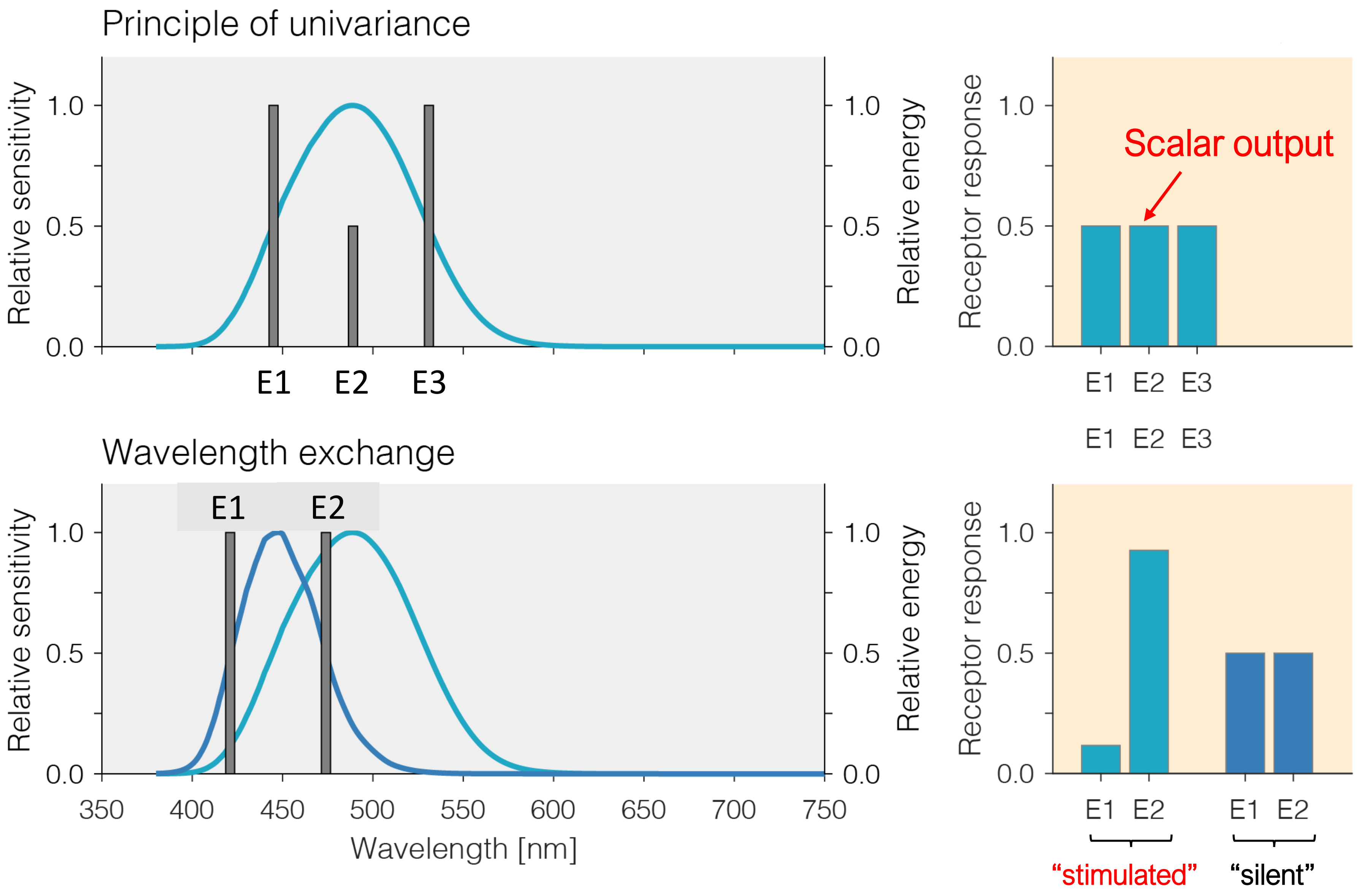
Fluorescent lamp

Incandescent lamp



Slide kindly provided by Manuel Spitschan

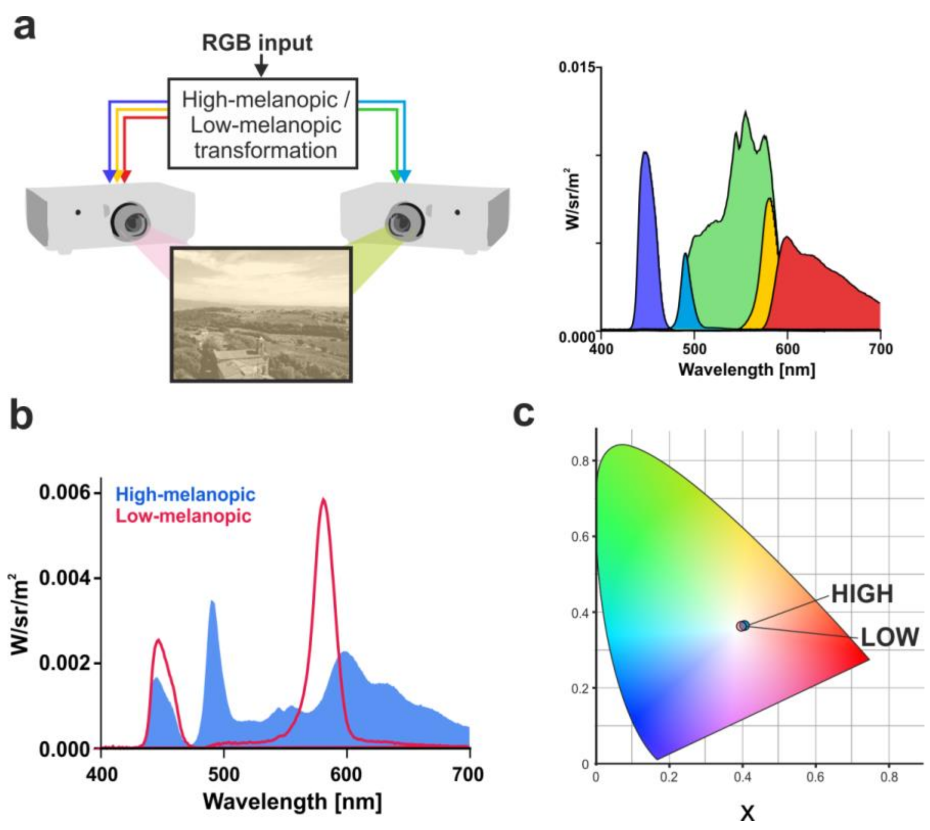
Metameric light stimuli

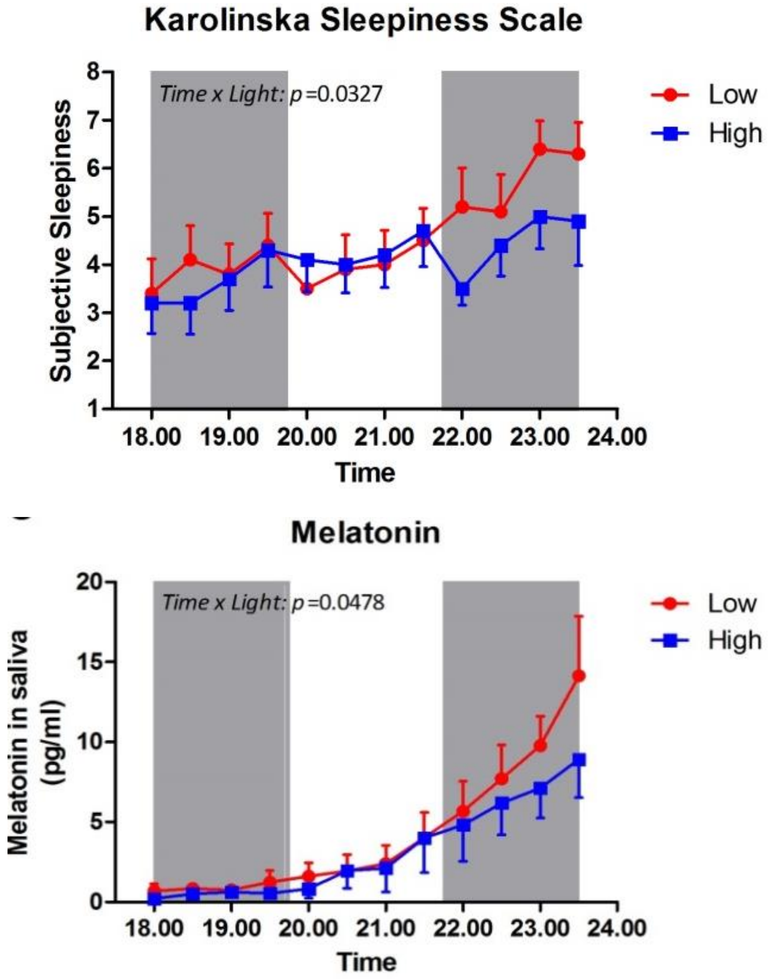


Goal:
2 lights with spectral power distributions
that do not differ in the amount they activate the cones, but
the amount they activate melanopsin

Spitschan and Woelders, Front in Neurol, 2018

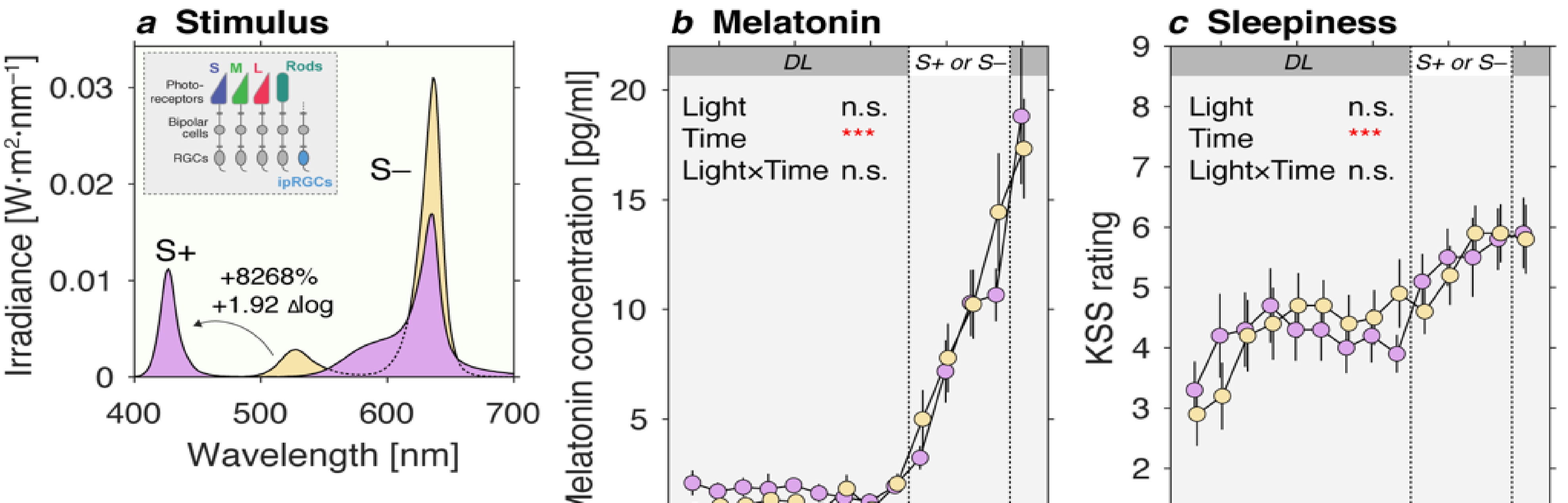
Exploiting metamerism to regulate the impact of a visual display on alertness and melatonin suppression independent of visual appearance





Allen et al., Sleep 2018

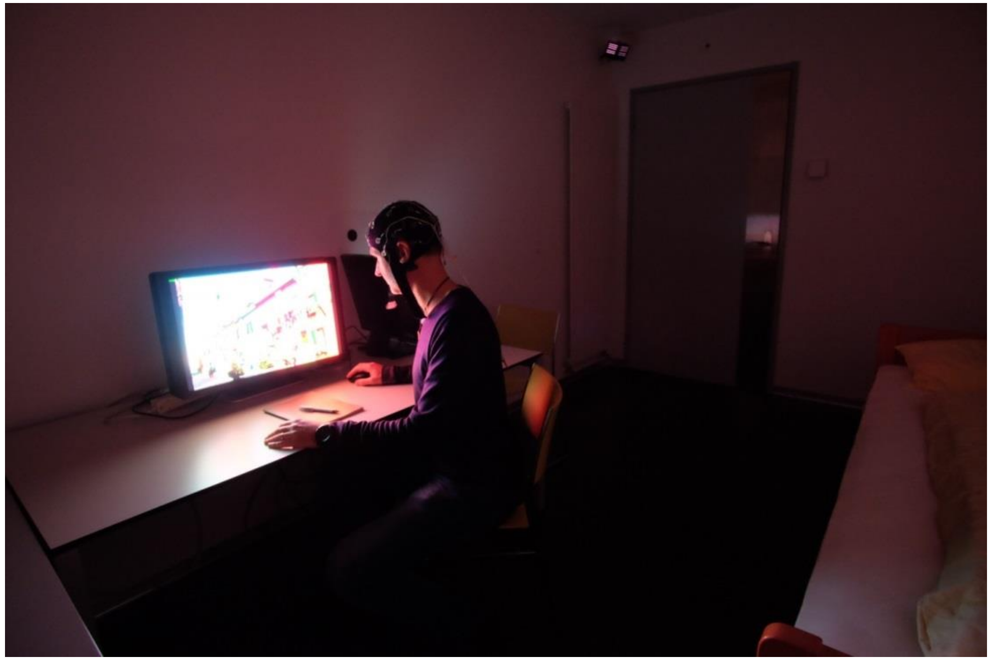
No evidence for an S cone contribution to the human circadian response to light

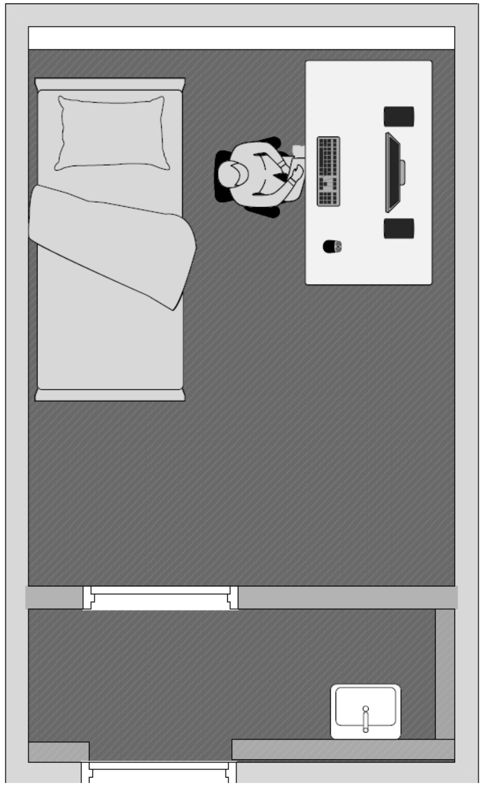


[mW/m²]	S	M	L	Rod	Mel
S–	2	134	313	80	53
S+	136	130	311	66	59
Contrast	**8268%**	–3%	–1%	–18%	11%
Factor	**83.68×**	0.97×	0.99×	0.82×	1.11×
Δlog	+1.92	+0.01	–0.00	–0.09	+0.05

Spitschan et al. Curr Biol, 2019

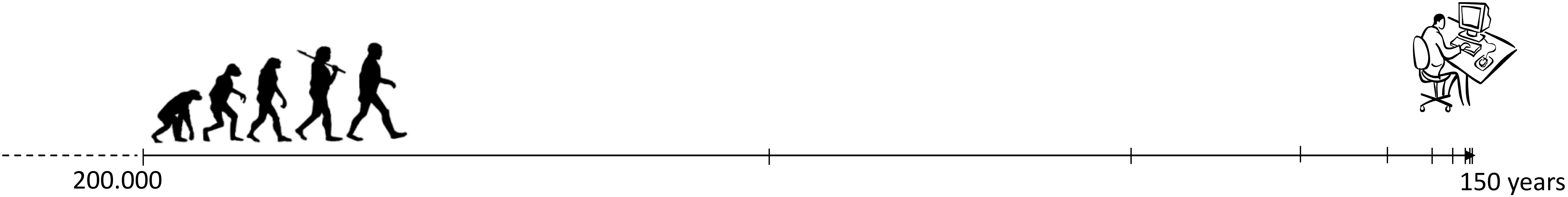
Using a visual display controlling melanopic irradiance to regulate sleep





Evolutionary adaptation to natural light

22.25 hours per day in buildings [1]



Slide kindly provided Oliver Stefani

[1] Schweizer et al. 2007

Impact of blue- and non-blue enriched white light on circadian physiology and alertness during sustained wakefulness in young and older individuals

8h | 40h light exposure | 8h

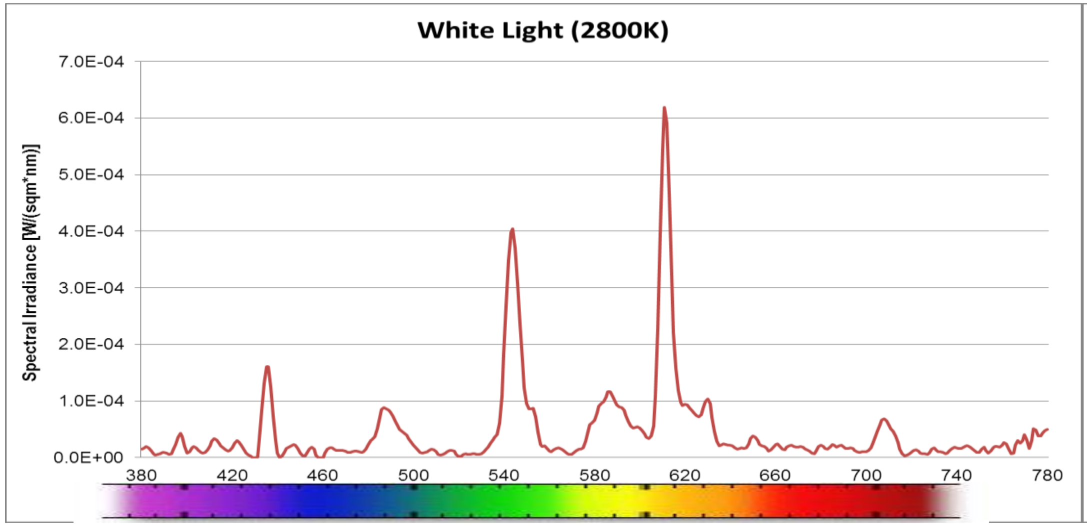
Virginie Gabel, PhD

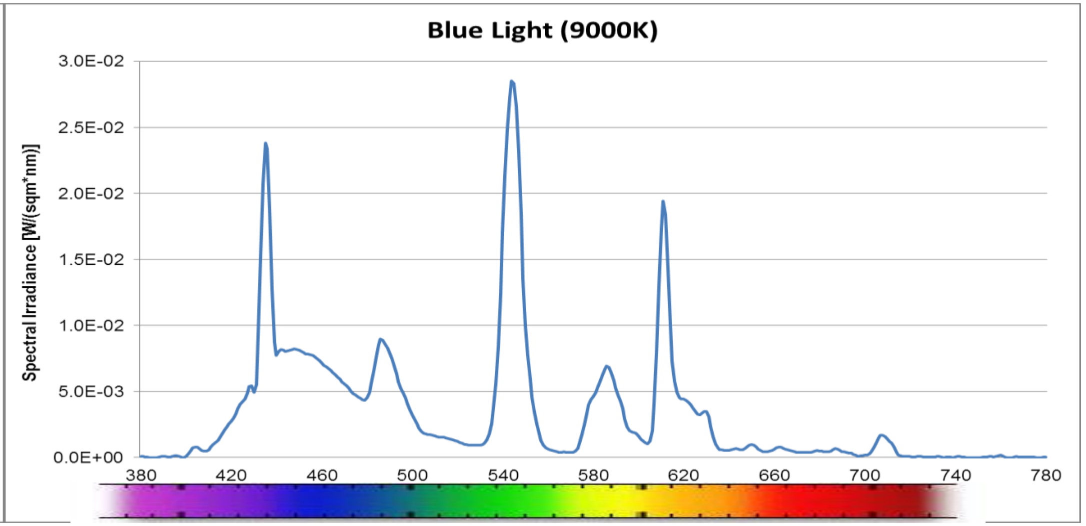
250 lux

White Light
(2800K)

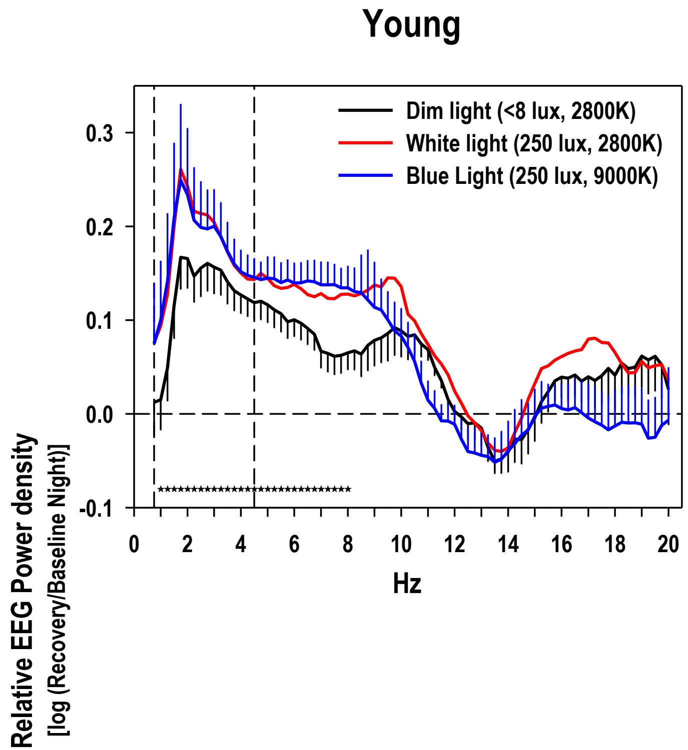
250 lux

Blue - enriched white Light
(9000K)





Evidence that homeostatic sleep regulation is modulated by prior light intensity



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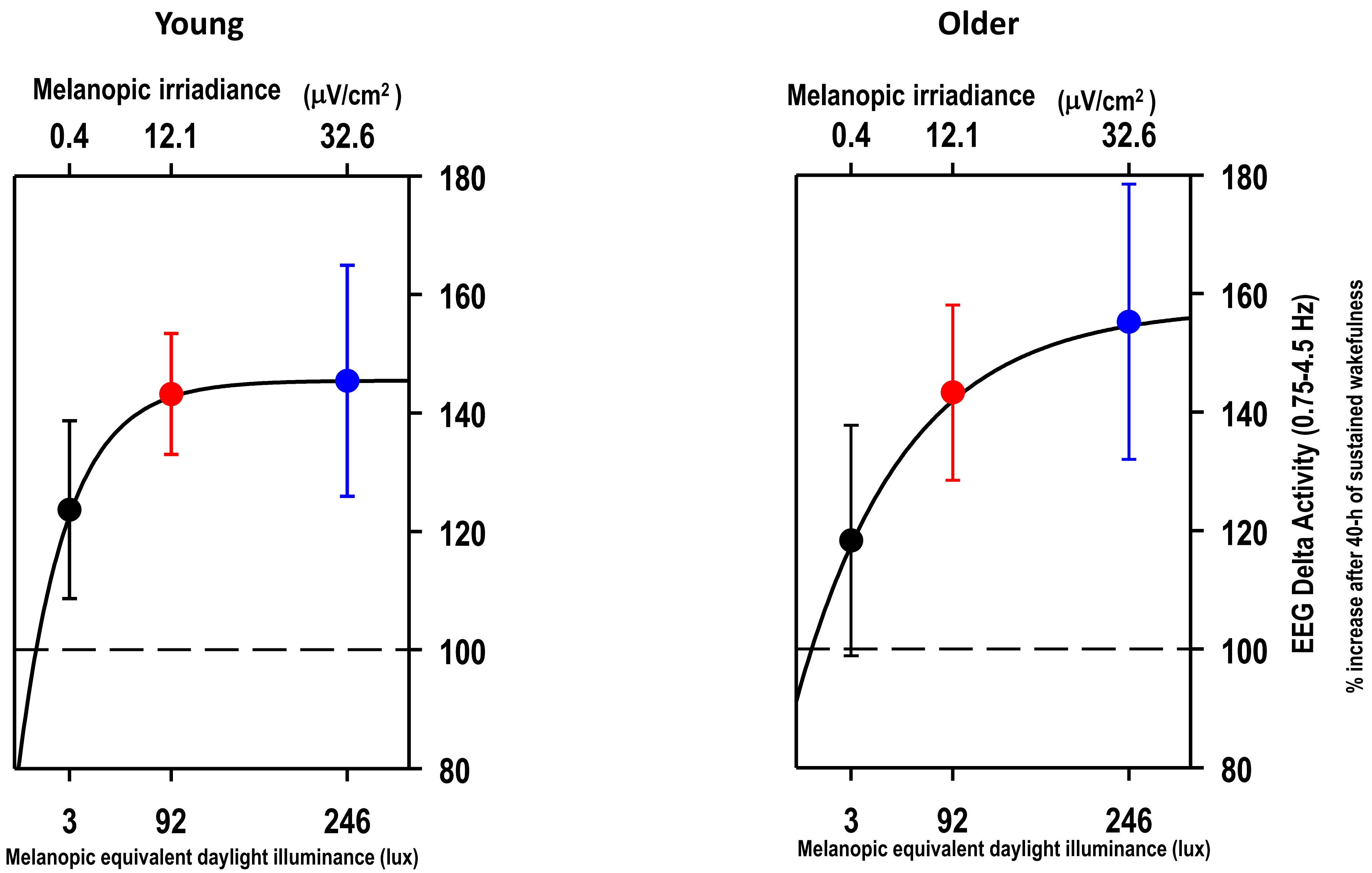
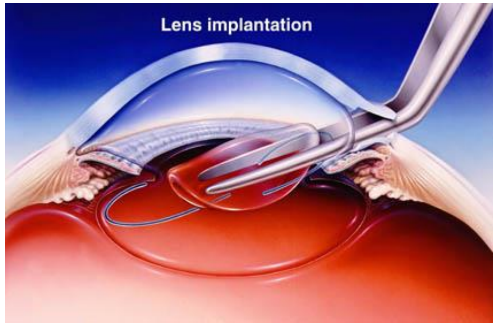
Cajochen et al., Clocks&Sleep, 2019

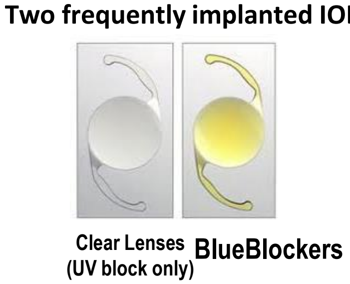
More light during daytime increases sleep pressure (deep sleep)

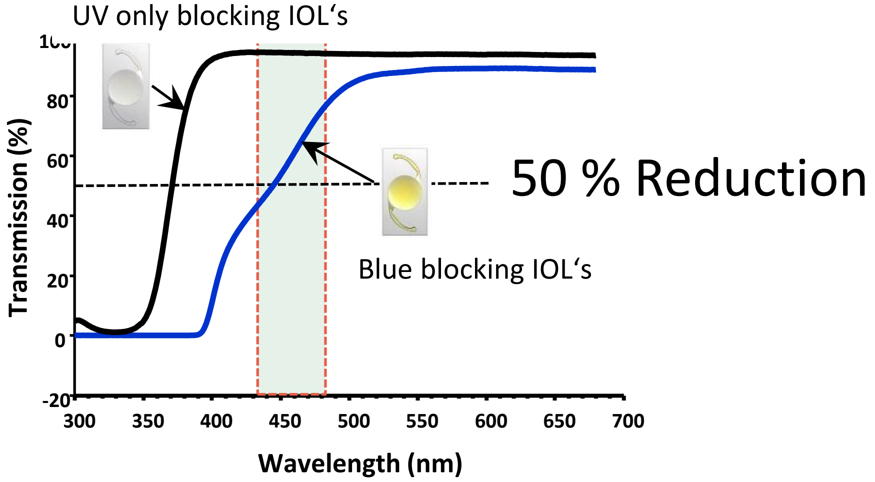


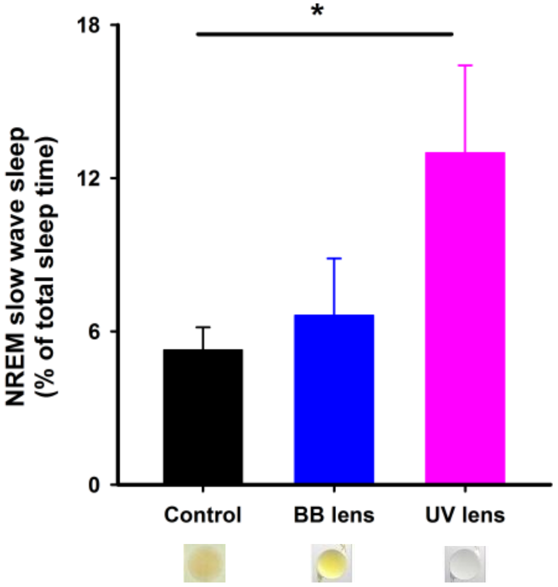
Cajochen et al., Clocks&Sleep, 2019

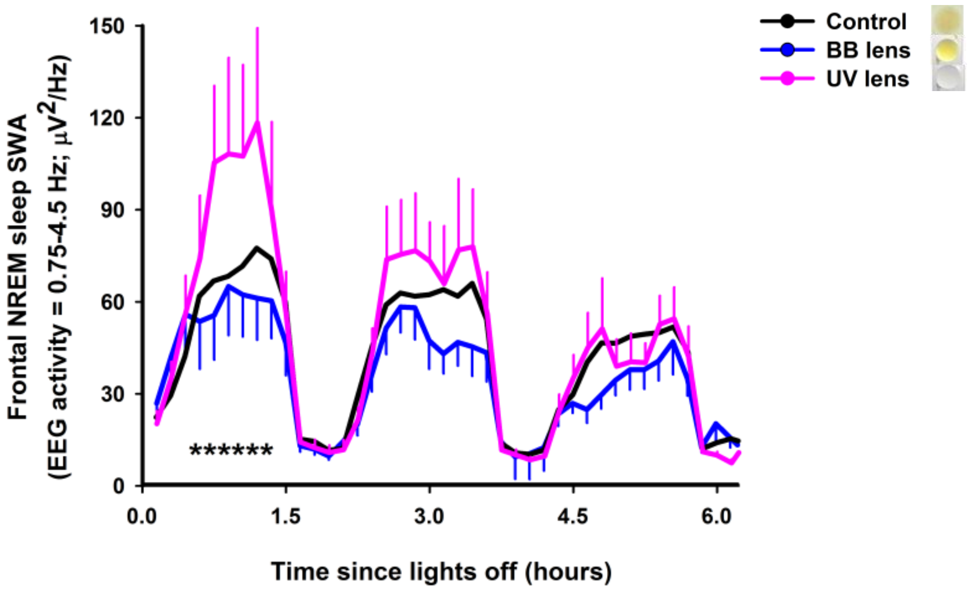
Intraocular cataract lens replacement improves circadian rhythms, cognitive function and sleep in older adults











Chellappa et al., Jama Ophthalmology, 2019

Summary

- Non-visual forming effects of light are ipRCGs driven and light's effect on mood, learning and sleep are separate from a pacemaker dependent role of the suprachiasmatic nucleus
- There are wavelength-dependent effects of light on sleep in both: nocturnal animals and diurnal humans, with alerting short-wave length light in both
- The quality of artificial lighting, as indexed by its spectral and dynamic similarity to daylight has beneficial effects on human sleep
- The impact of light on alertness and melatonin production can be controlled independently of visual experience (metameric displays)
- Experienced illuminance levels during wakefulness impact on homeostatic sleep regulation in humans (i.e. deep sleep)
- Non-blue blocking IOLs may be useful in older cataract patients as a "stimulant" to increase delta-EEG activity in nonREM sleep (i.e. deep sleep)

Thank you

Centre for Chronobiology

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- Dr. Ruta Lasauskaite, Psychologist
- Dr. Oliver Stefani, Engineer
- Dr. Manuel Spitschan, Psychologist
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TOSHIBA

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