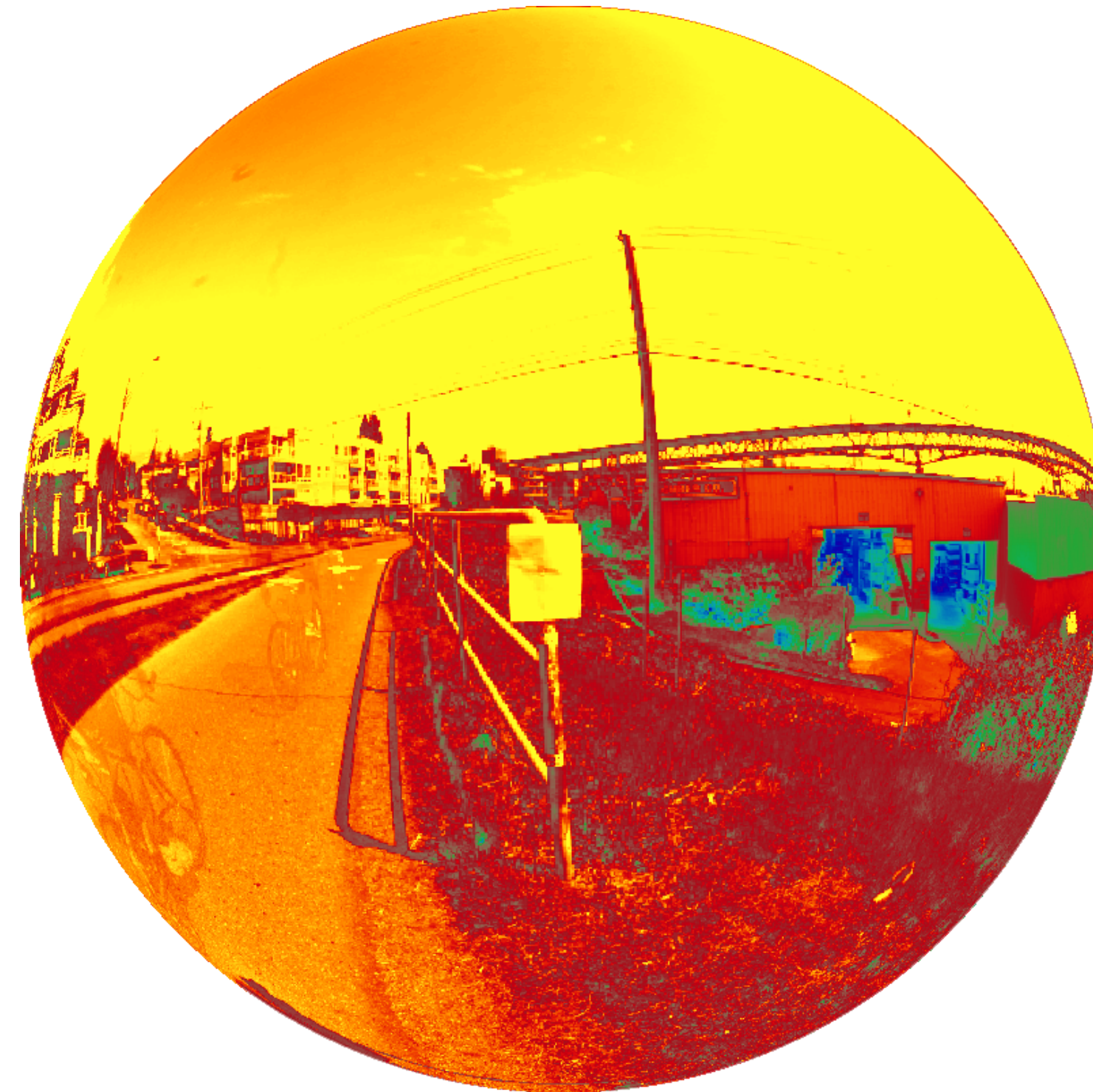


capturing non-visual (circadian) light through HDR photography

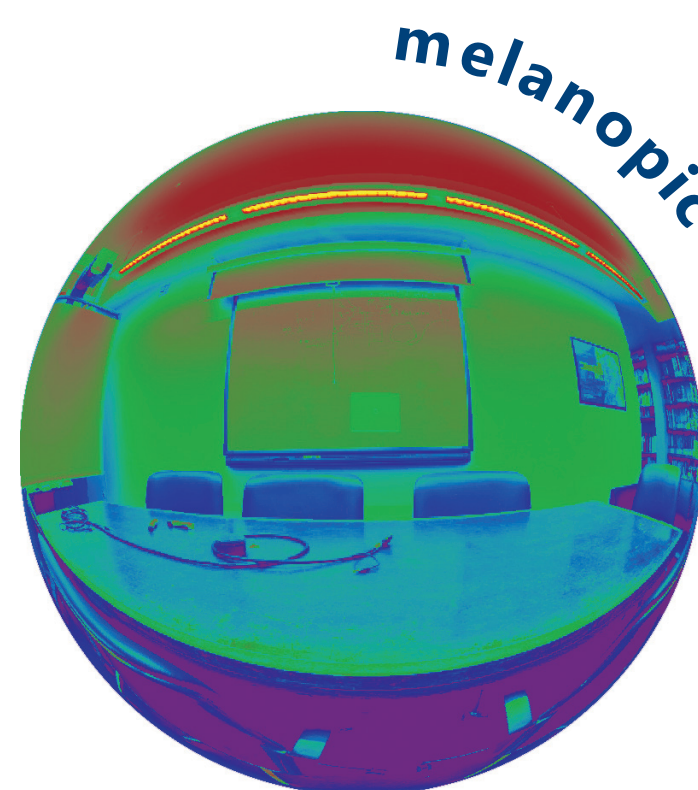
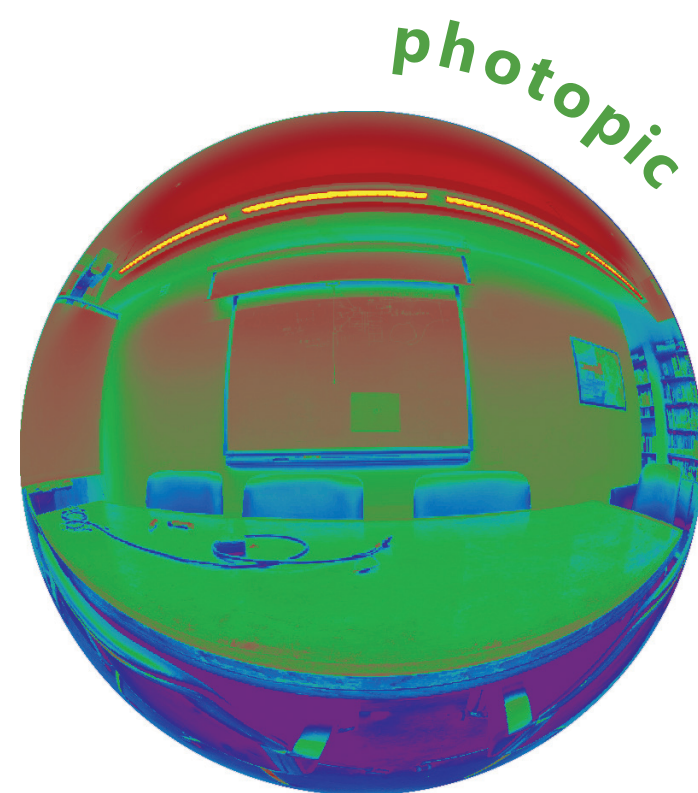


Radiance Workshop . Portland . 2017

University of Washington . Department of Architecture

Bo Jung . Mehlika Inanici

byj20 @ uw.edu



Outline

1. Background

understanding non-visual (circadian) light

2. Methodology

data collection
post processing
calibration
melanopic units

3. Results

4. Discussion

conclusions & future work

non-visual (circadian) light

Circa

dies

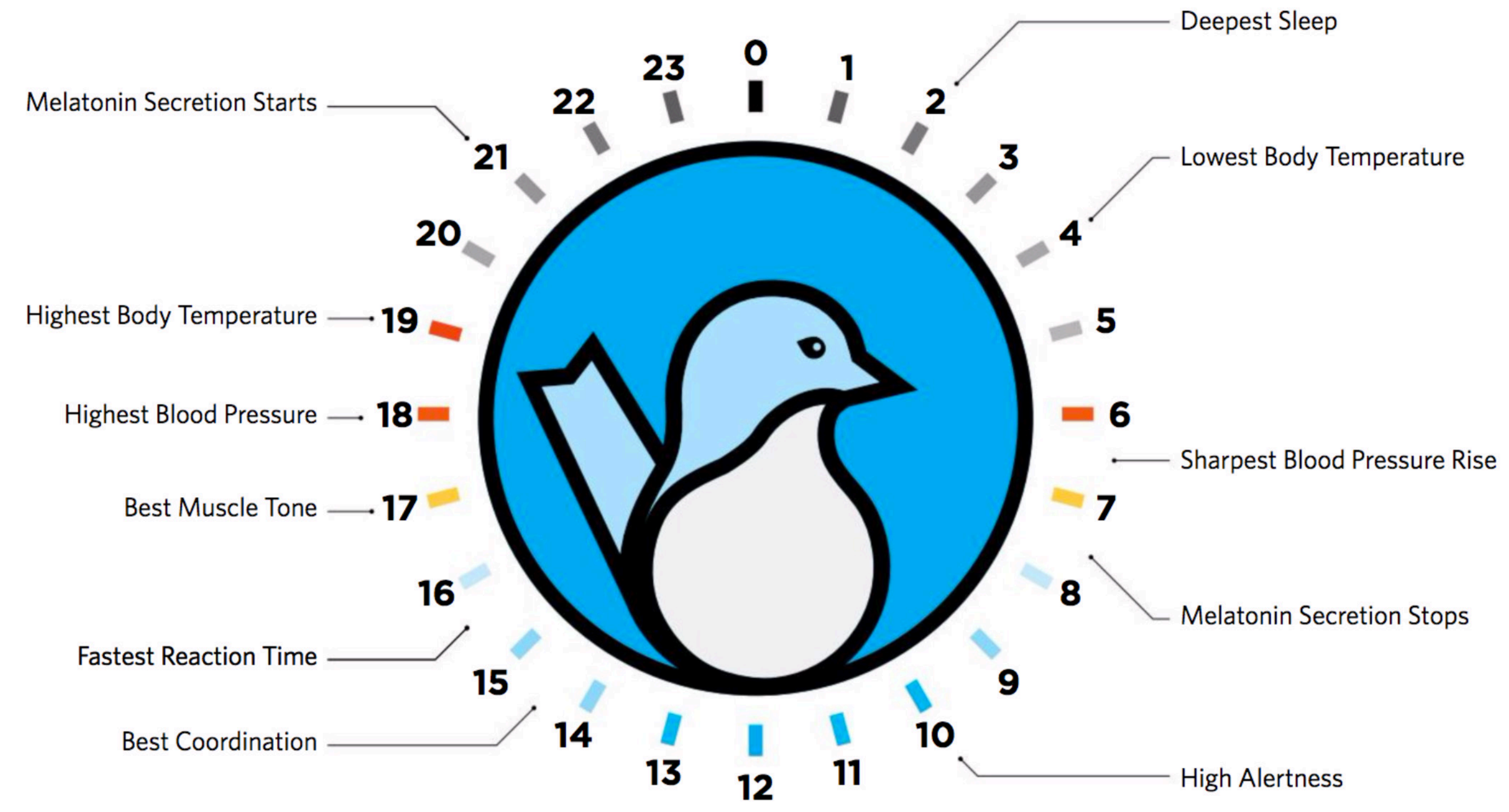
+

Rhythm

“About”

“day”

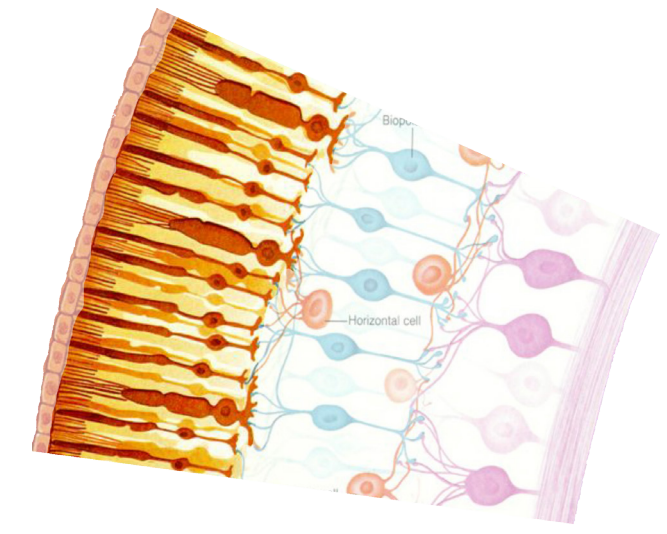
non-visual (circadian) light



non-visual (circadian) light

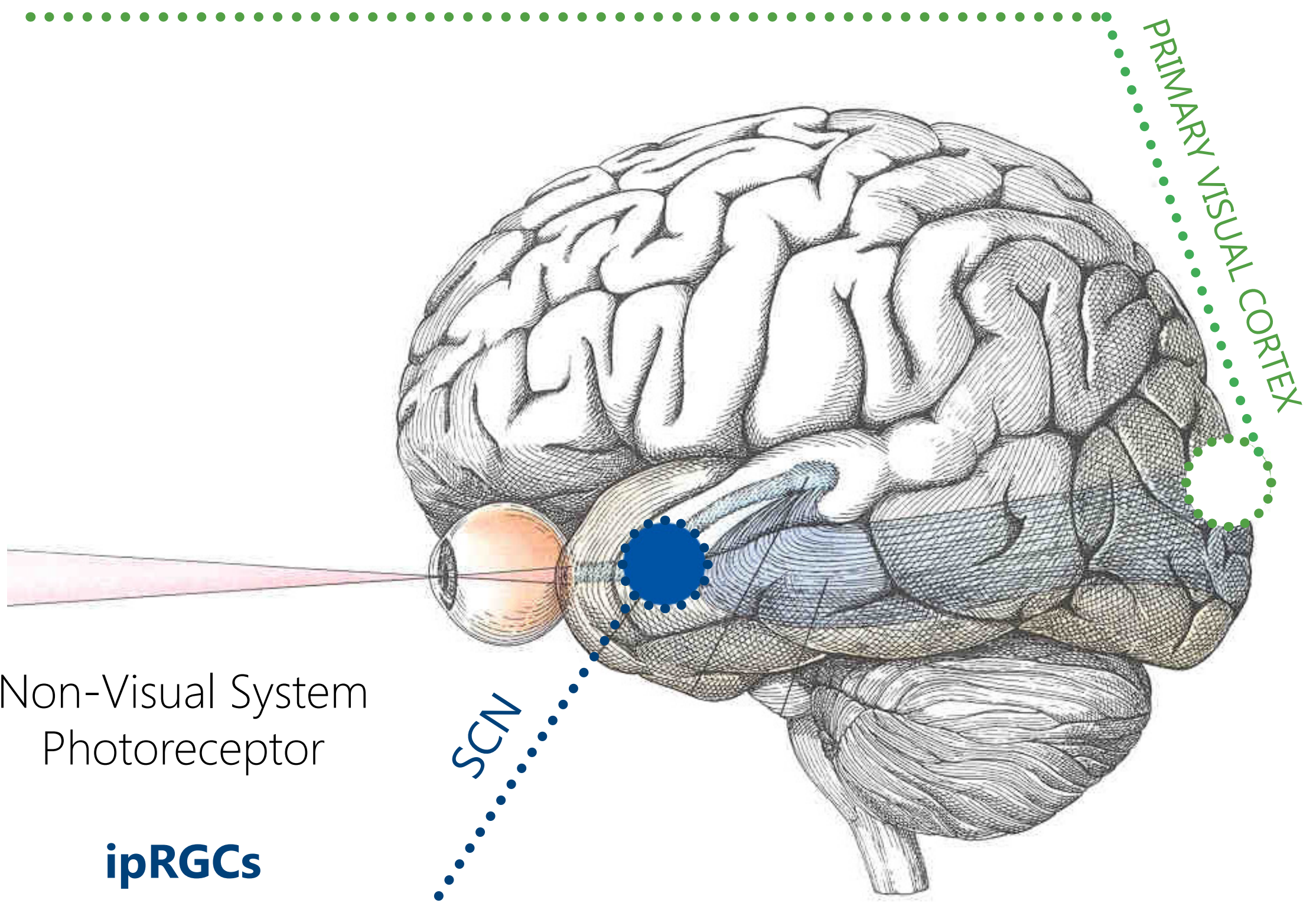
Processing Optical Radiation

- 1. Visual system (photopic)
- 2. Non-Visual system (circadian)



Visual System
Photoreceptor

Rods & Cones



Non-Visual System
Photoreceptor

ipRGCs

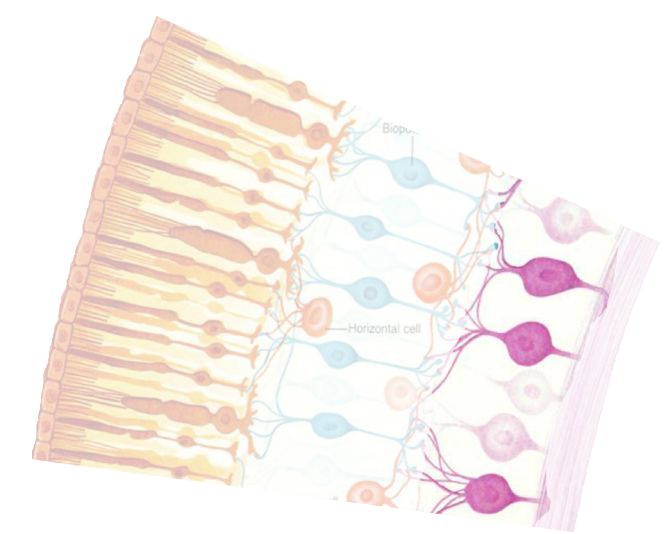
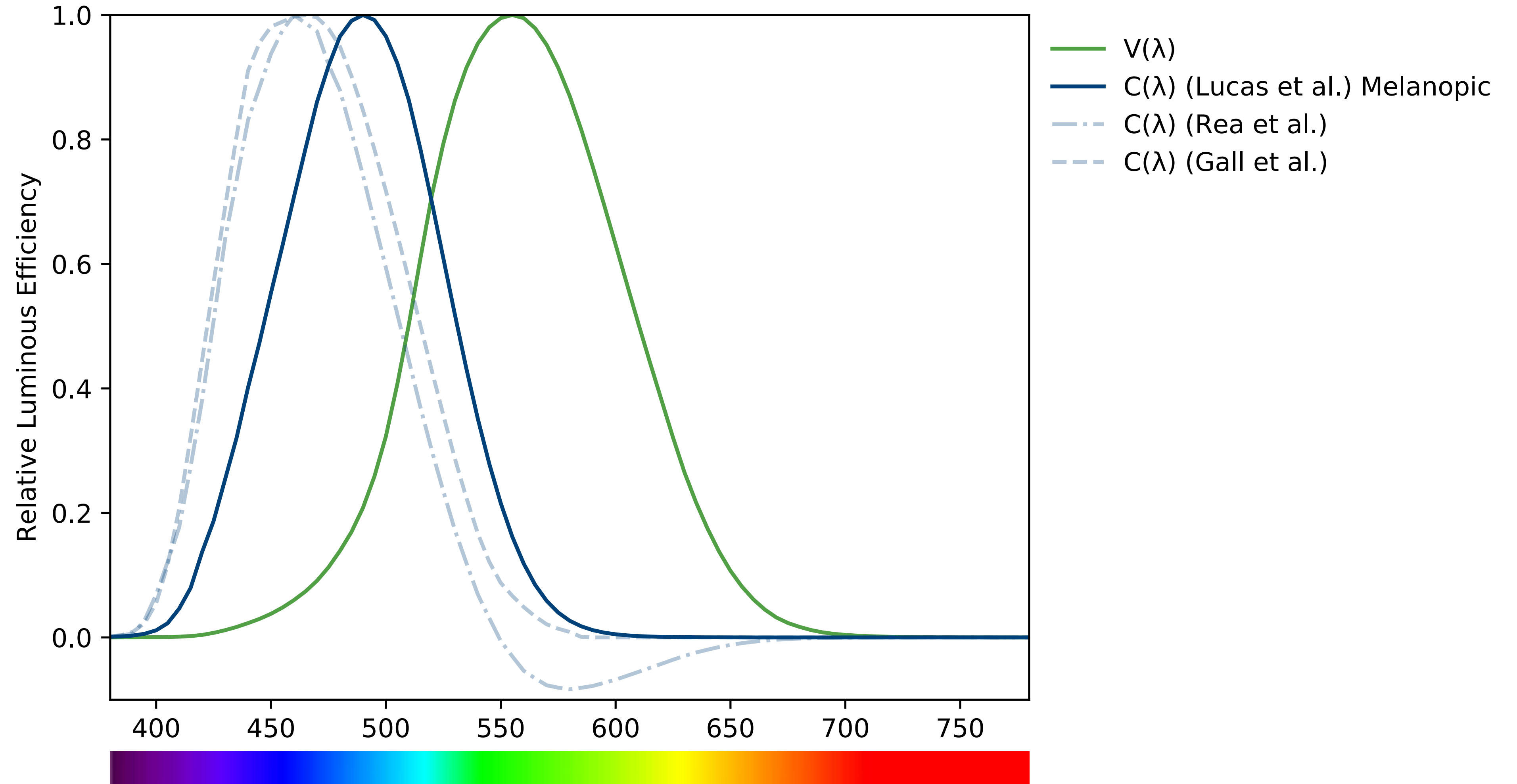
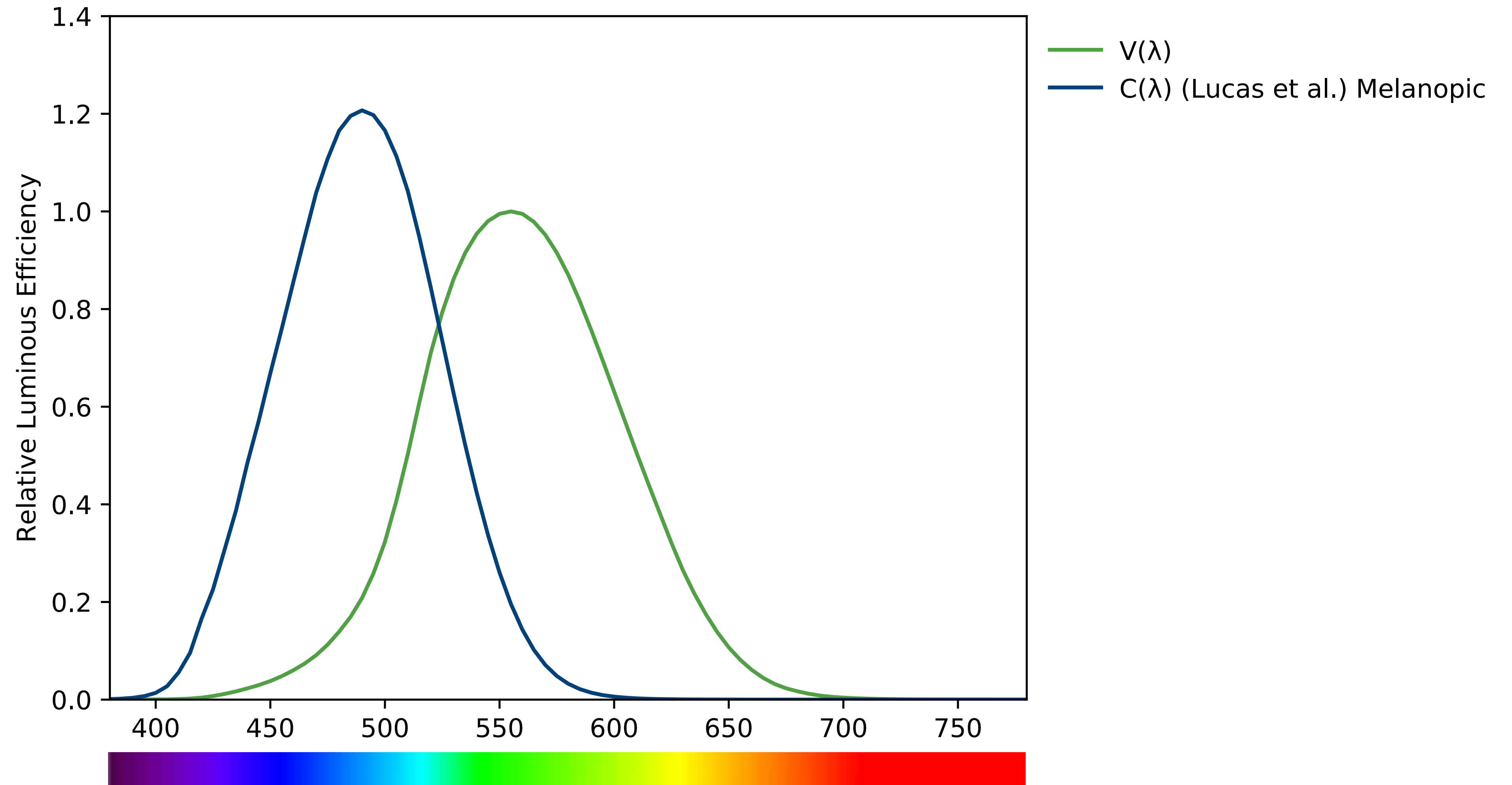


Image modified from: Hubel, D. H. (1988). Eye, brain, and vision. New York: Scientific American Library.

non-visual (circadian) light



non-visual (circadian) light



non-visual (circadian) light

How is light affecting non-visual system?

- photic history
- timing
- spectra
- intensity
- duration

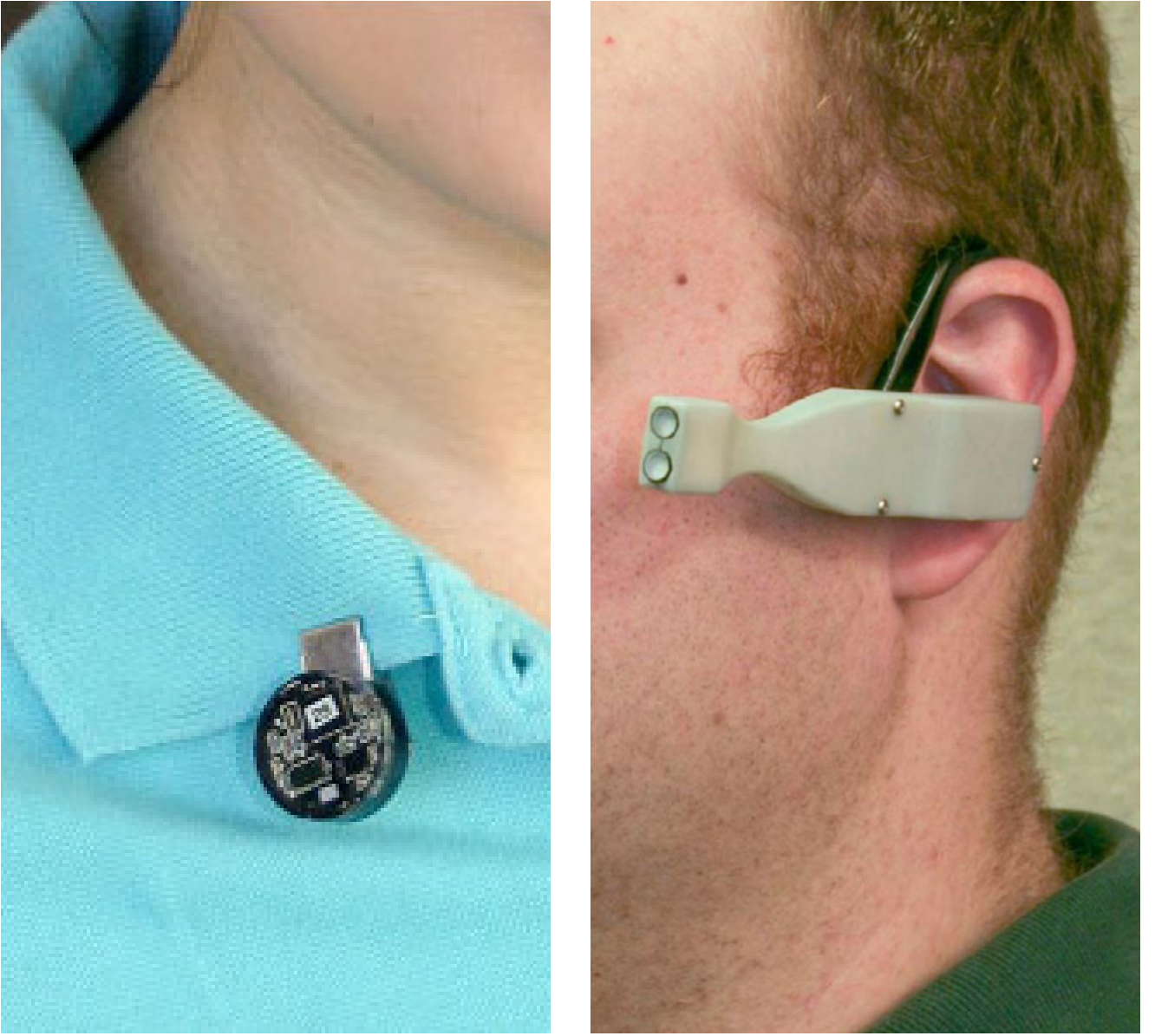
Objective

What's happening in the built environment?



Objective

circadian light measuring devices



Dimensimeter / Daysimeter



Camera Like light Sensor (CLLS)

Image: <http://www.lrc.rpi.edu/programs/lightHealth/projects/Dimesimeter.asp>
 Rea, M. S., Figueiro, M. G., Bierman, A., & Bullough, J. D. (2010). Circadian light. *Journal of Circadian Rhythms*, 8, Art. 2.
 Image modified from : Borisuit, A., Kampf, J., Munch, M., Thanachareonkit, A., Scartezini, J.L., Monitoring and rendering of visual and photo-biological properties of daylight-redirecting systems. (2016). *Solar Energy*, 129, 297–309.

Objective

HDR Photography



Photopic Light

- Calibrated with Luminance or Illuminance meters
- Photopic Luminance accuracy is evaluated and validated

Circadian Light

- What can be used to calibrate?
- The goal is to calibrate with an accessible / inexpensive device

Data collection



HDR Camera
EOS 5D | Sigma EX DG Fisheye8mm



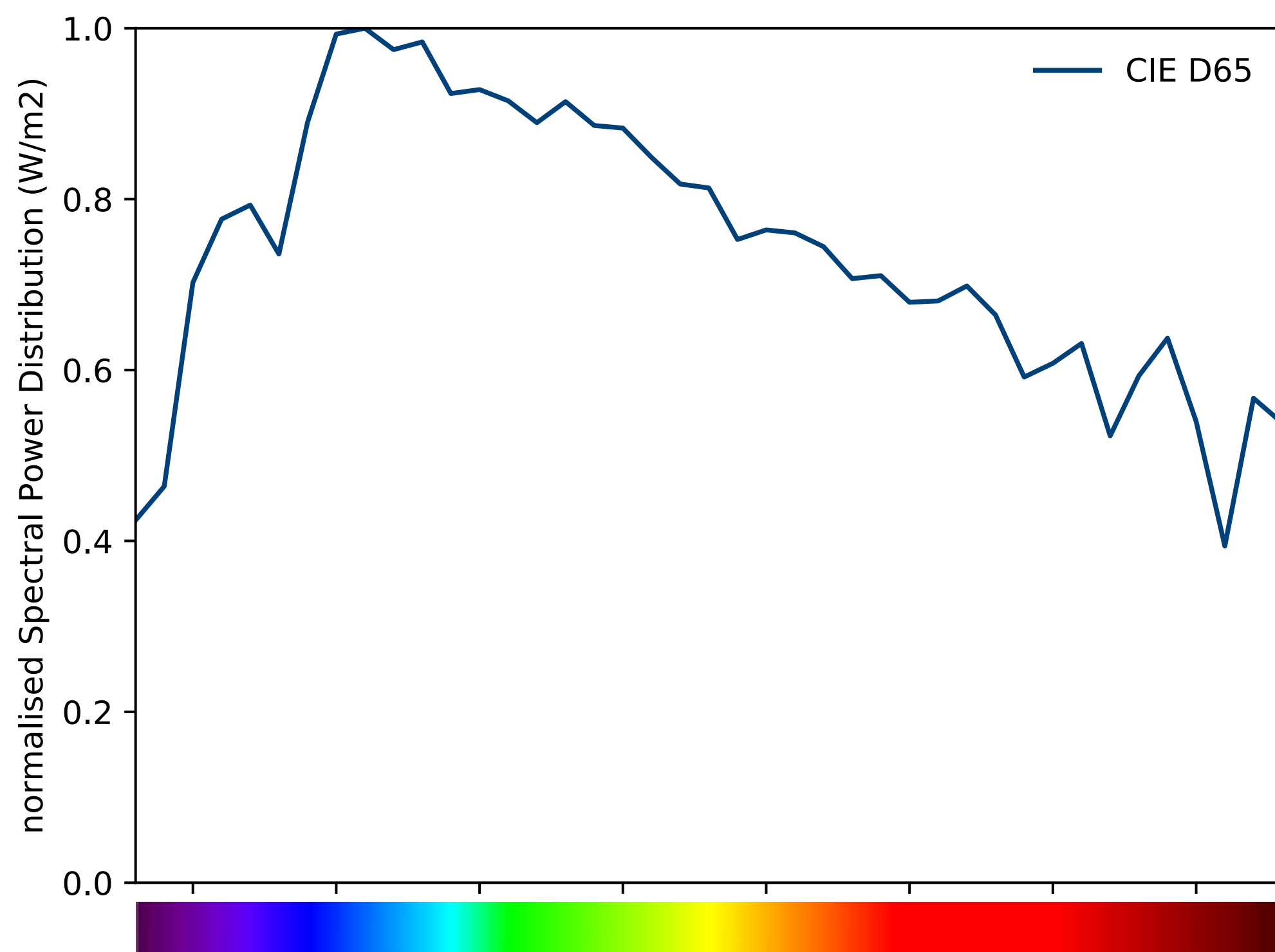
luminance meter
Konica_Minolta_LS-110



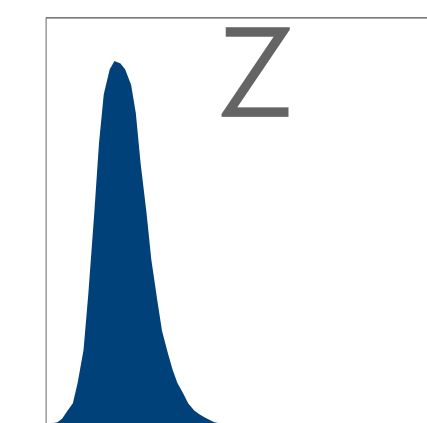
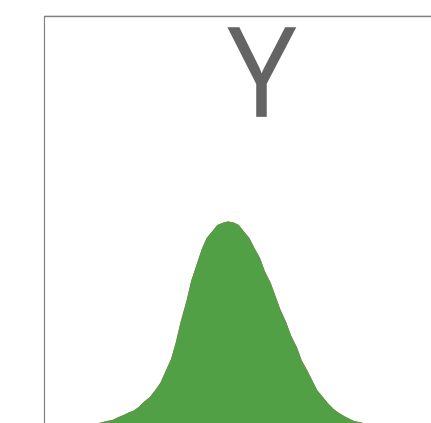
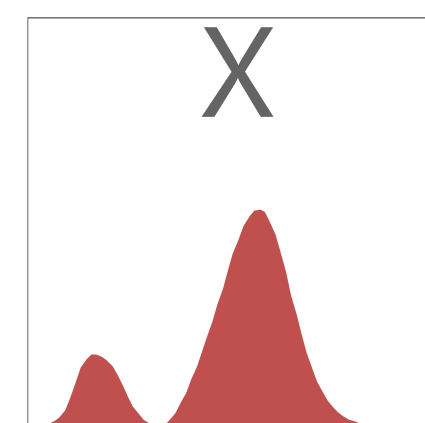
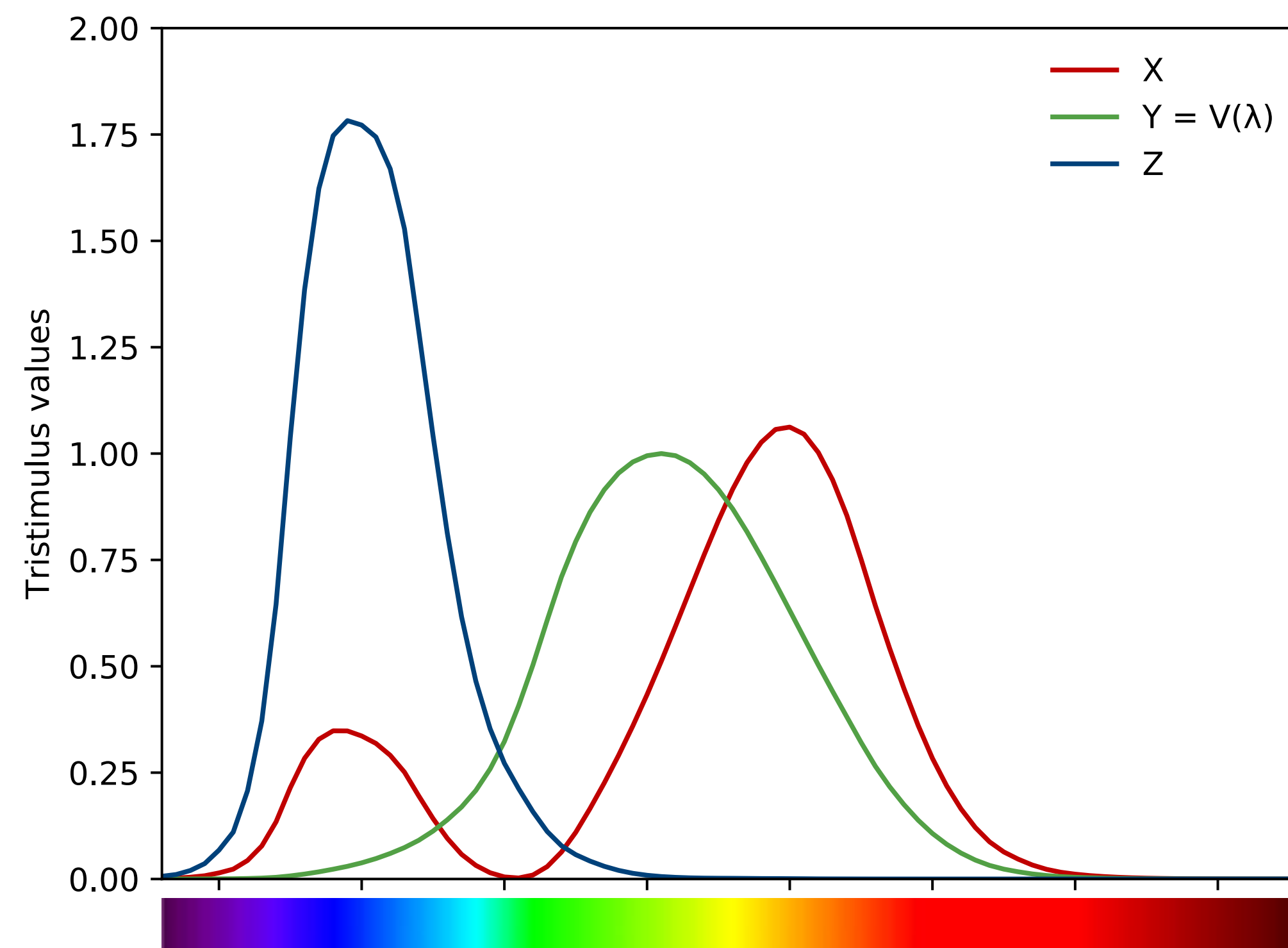
Illuminance Color meter
Konica_Minolta_CL-200A

Data collection

full spectrum

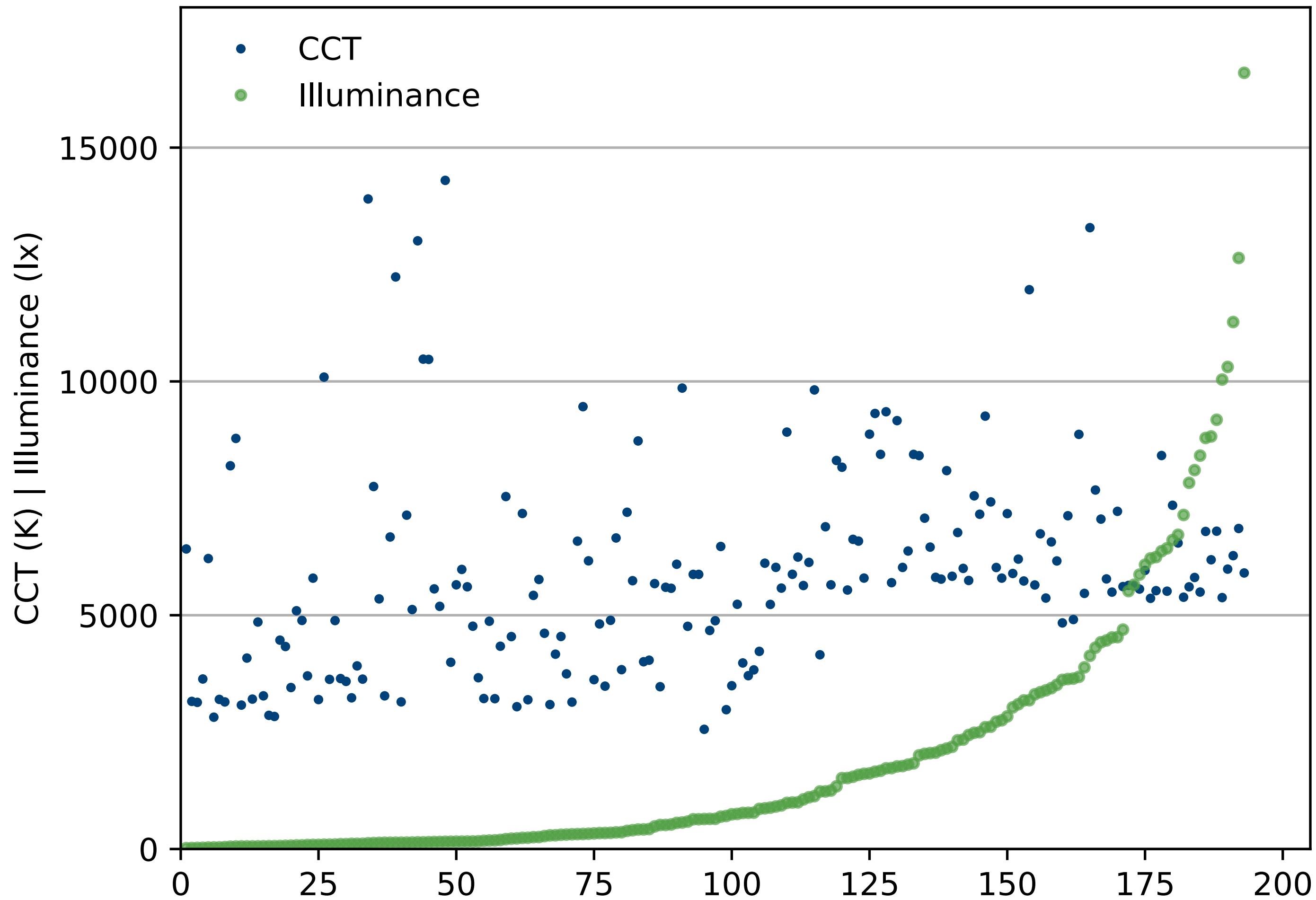


CIE XYZ





Data collection - CCT* and Illuminance



collection period : 9 months
total no. data : 205
weather cond. : Seattle

* McCamy, C.S. (1992) Correlated color temperature as an explicit function of chromaticity coordinates. Color Research and Application. 17(2), 142-144.

Post Processing - calibration method 1



Vignetting + Cosine Correction



Illuminance Calibration (CIE Y)



Extract Pixel RGB value



R	G	B
.	.	.
8.906e-001	9.531e-001	5.328e+000
8.281e-001	1.016e+000	5.578e+000
8.906e-001	1.078e+000	5.766e+000
8.594e-001	1.141e+000	5.953e+000
8.906e-001	1.234e+000	6.234e+000
8.906e-001	1.297e+000	6.391e+000
9.531e-001	1.359e+000	6.641e+000
9.531e-001	1.516e+000	6.766e+000
5.859e-001	4.922e-001	2.648e+000
6.016e-001	5.078e-001	2.805e+000
:	:	:

```
pvalue -d -h -H -o image.hdr > data.txt
```



convert image RGB to XYZ

$$X = (0.4124 * R) + (0.3576 * G) + (0.1805 * B)$$

$$Y = (0.2127 * R) + (0.7151 * G) + (0.0722 * B)$$

$$Z = (0.0193 * R) + (0.1192 * G) + (0.9505 * B)$$

(sRGB) reference primaries



compare measured and captured XYZ values



Post Processing - calibration method 2



Vignetting + Cosine Correction



Illuminance Calibration (CIE Y)



Extract Pixel RGB value



R	G	B
.	.	.
.	.	.
8.906e-001	9.531e-001	5.328e+000
8.281e-001	1.016e+000	5.578e+000
8.906e-001	1.078e+000	5.766e+000
8.594e-001	1.141e+000	5.953e+000
8.906e-001	1.234e+000	6.234e+000
8.906e-001	1.297e+000	6.391e+000
9.531e-001	1.359e+000	6.641e+000
9.531e-001	1.516e+000	6.766e+000
5.859e-001	4.922e-001	2.648e+000
6.016e-001	5.078e-001	2.805e+000
:	:	:

```
pvalue -d -h -H -o image.hdr > data.txt
```



convert measured XYZ to RGB

$$\begin{aligned} R &= (3.2406 * X) - (1.5372 * Y) - (0.4986 * Z) \\ G &= -(0.9689 * X) + (1.8758 * Y) + (0.0415 * Z) \\ B &= (0.0557 * X) - (0.2040 * Y) + (1.0570 * Z) \end{aligned}$$

(sRGB) reference primaries

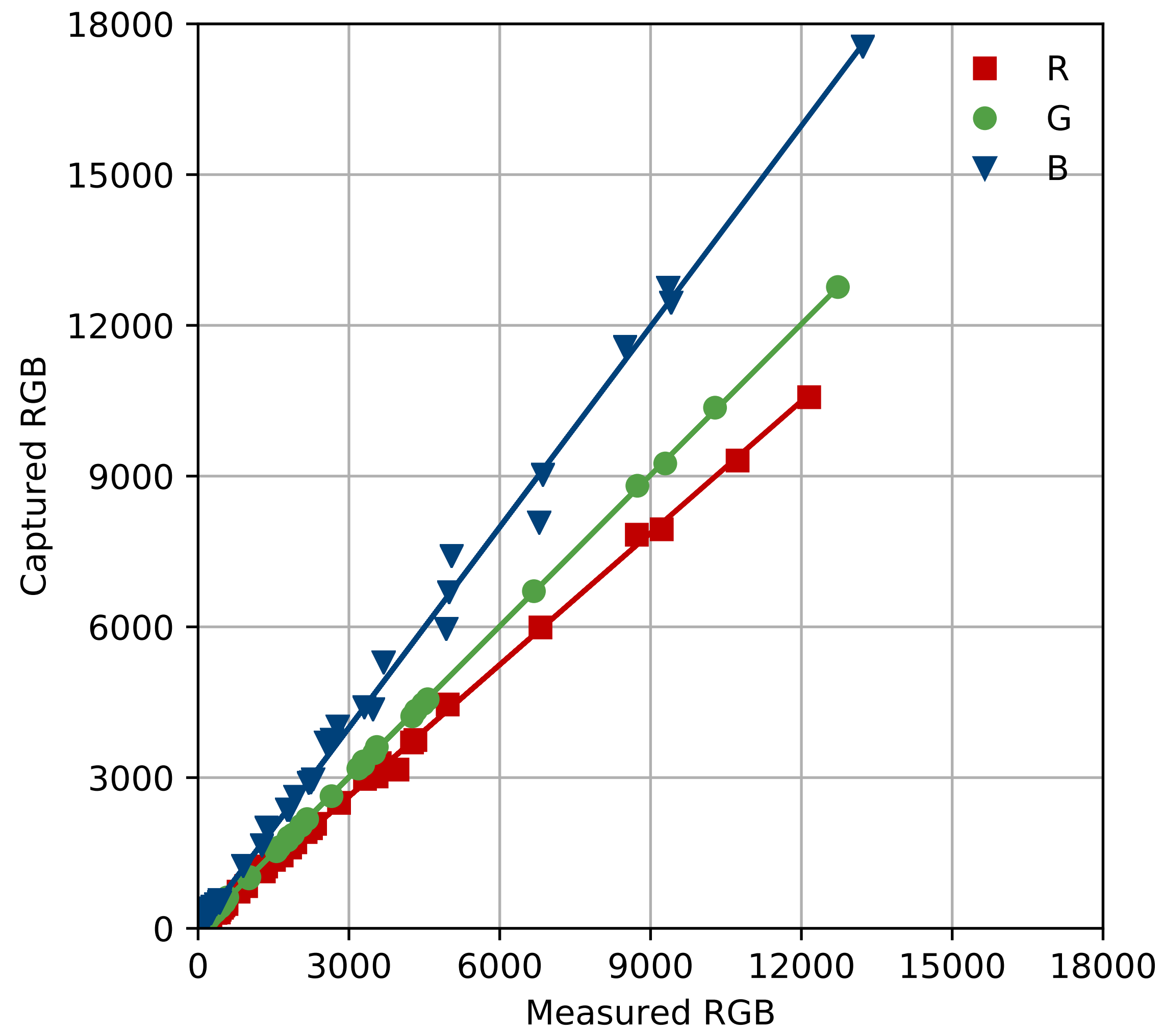


compare measured and captured RGB values



Calibration

Regression line equation



original img data

$$R = 0.8743 x$$
$$R^2 = 0.99721$$

$$G = 1.0022 x$$
$$R^2 = 0.99995$$

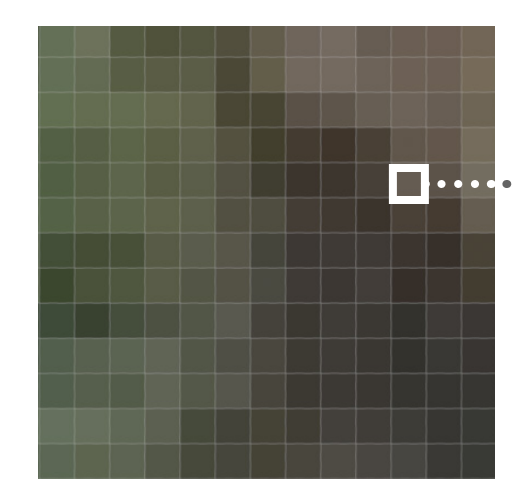
$$B = 1.3308 x$$
$$R^2 = 0.99922$$

calibrated img data

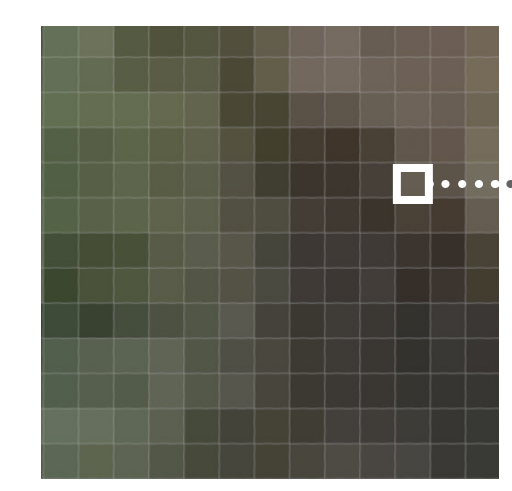
$$R = 1 x$$
$$R_{cal} = 1.1438 * R$$

$$G = 1 x$$
$$G_{cal} = 0.9978 * G$$

$$B = 1 x$$
$$B_{cal} = 0.7514 * B$$

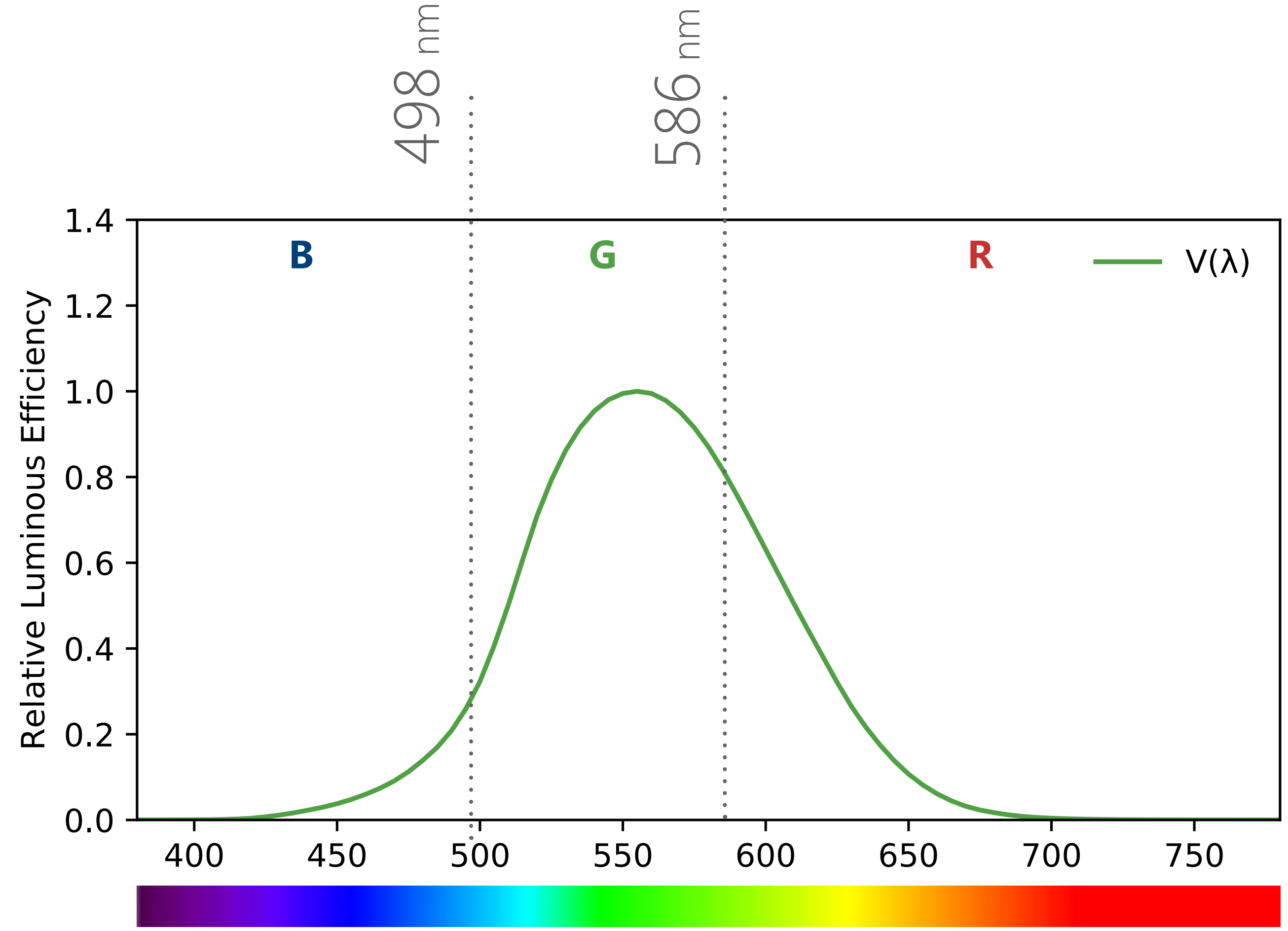


R = 100
G = 91
B = 83



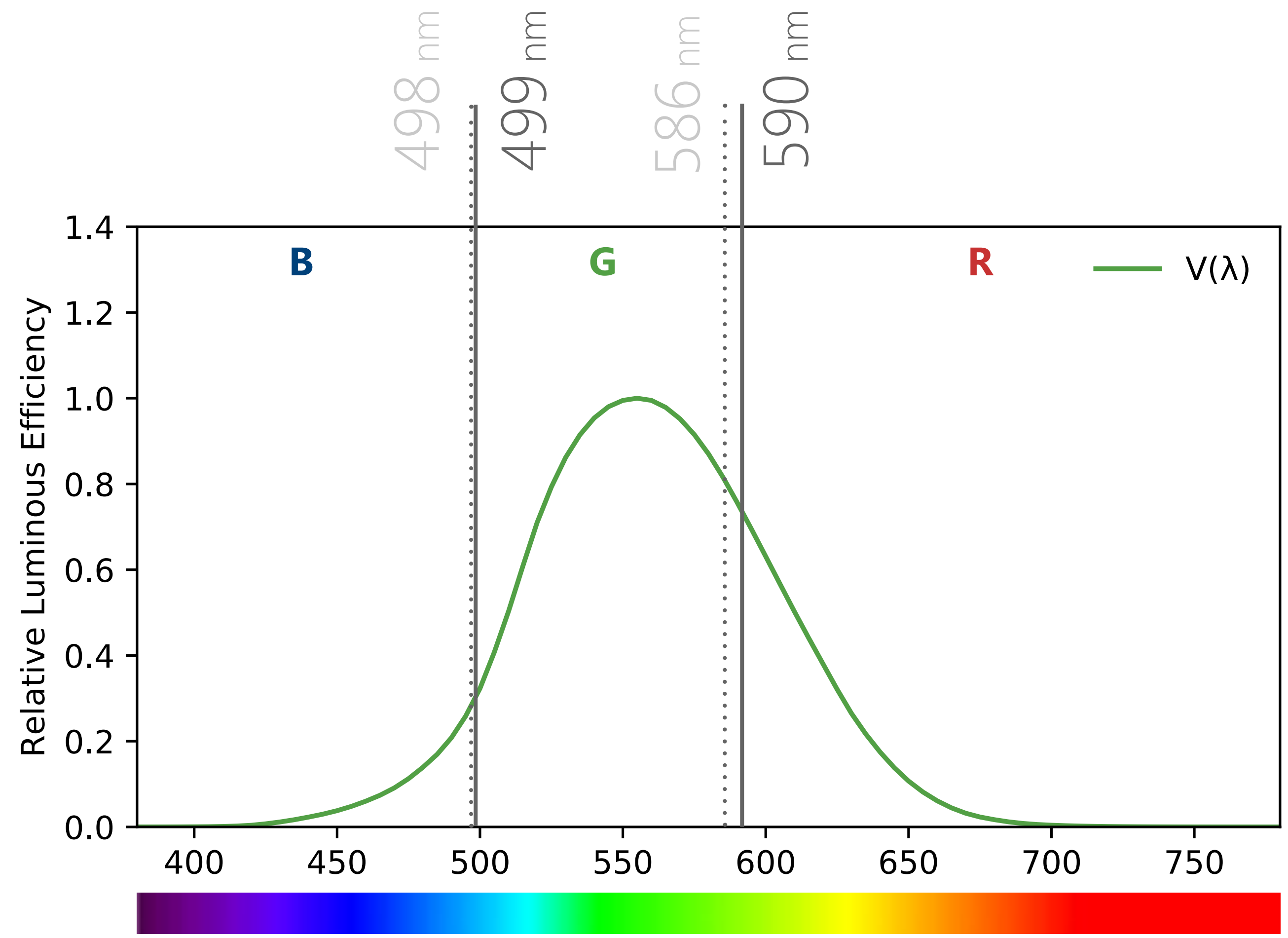
R = 114
G = 91
B = 62

Melanopic Units



Radiance **Photopic luminance** = $179 * ((0.2651 * R) + (0.6700 * G) + (0.0650 * B))$

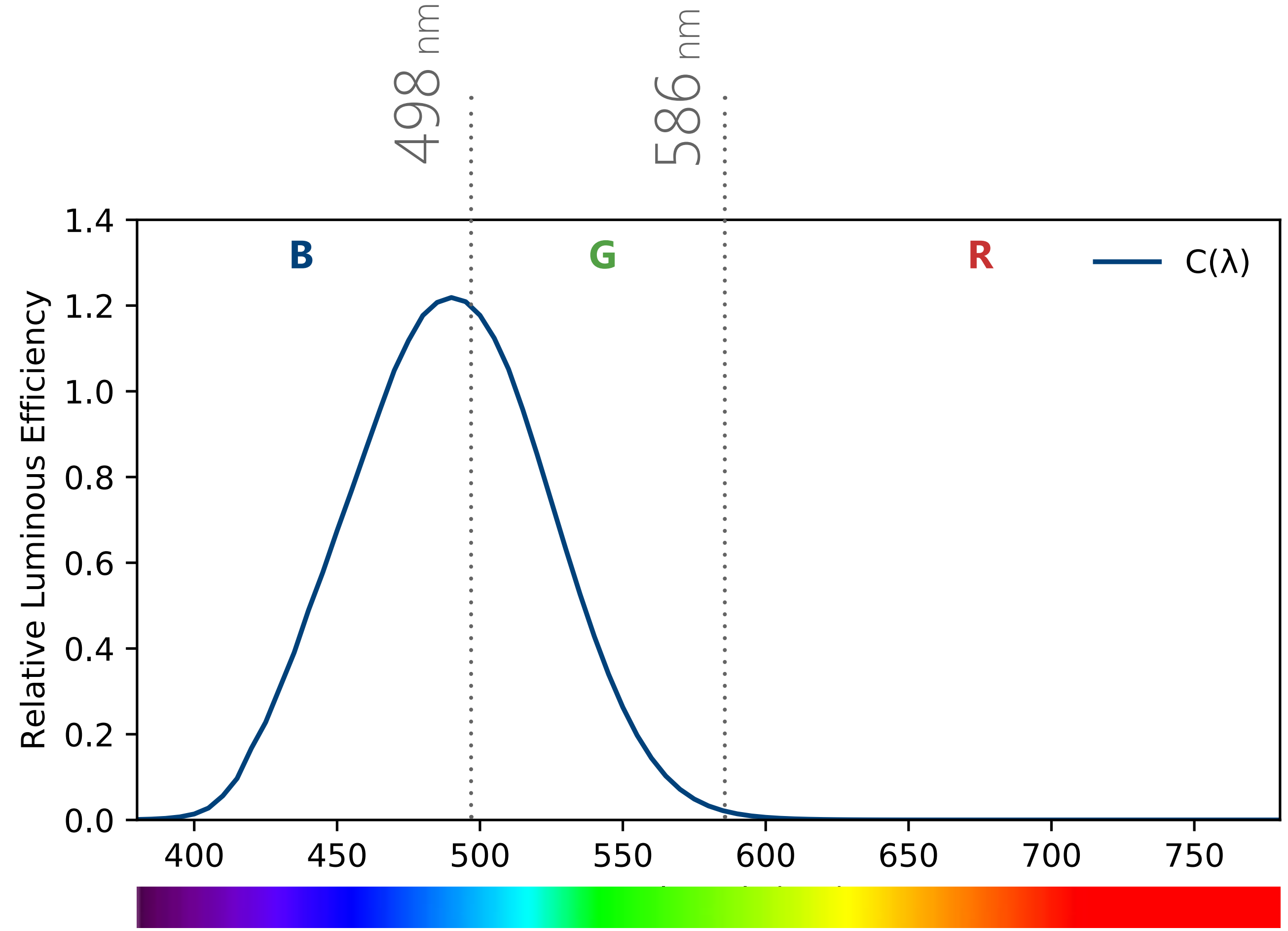
Melanopic Units



Radiance Photopic luminance = $179 * ((0.2651 * R) + (0.6700 * G) + (0.0650 * B))$

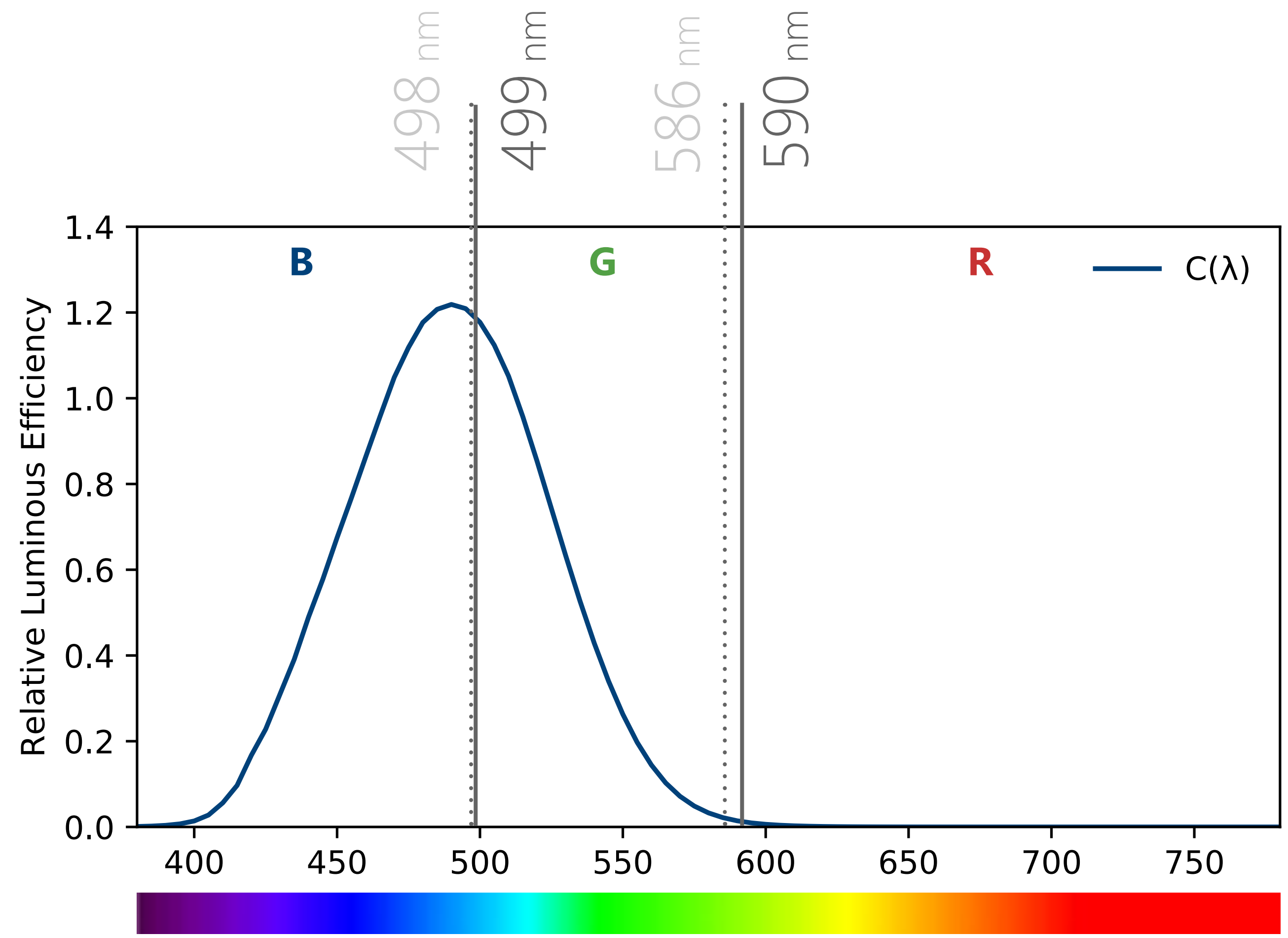
sRGB Photopic luminance = $179 * ((0.2127 * R) + (0.7151 * G) + (0.0722 * B))$

Melanopic Units



Radiance Melanopic luminance = $179 * ((0.0130 * R) + (0.3812 * G) + (0.6175 * B))$

Melanopic Units

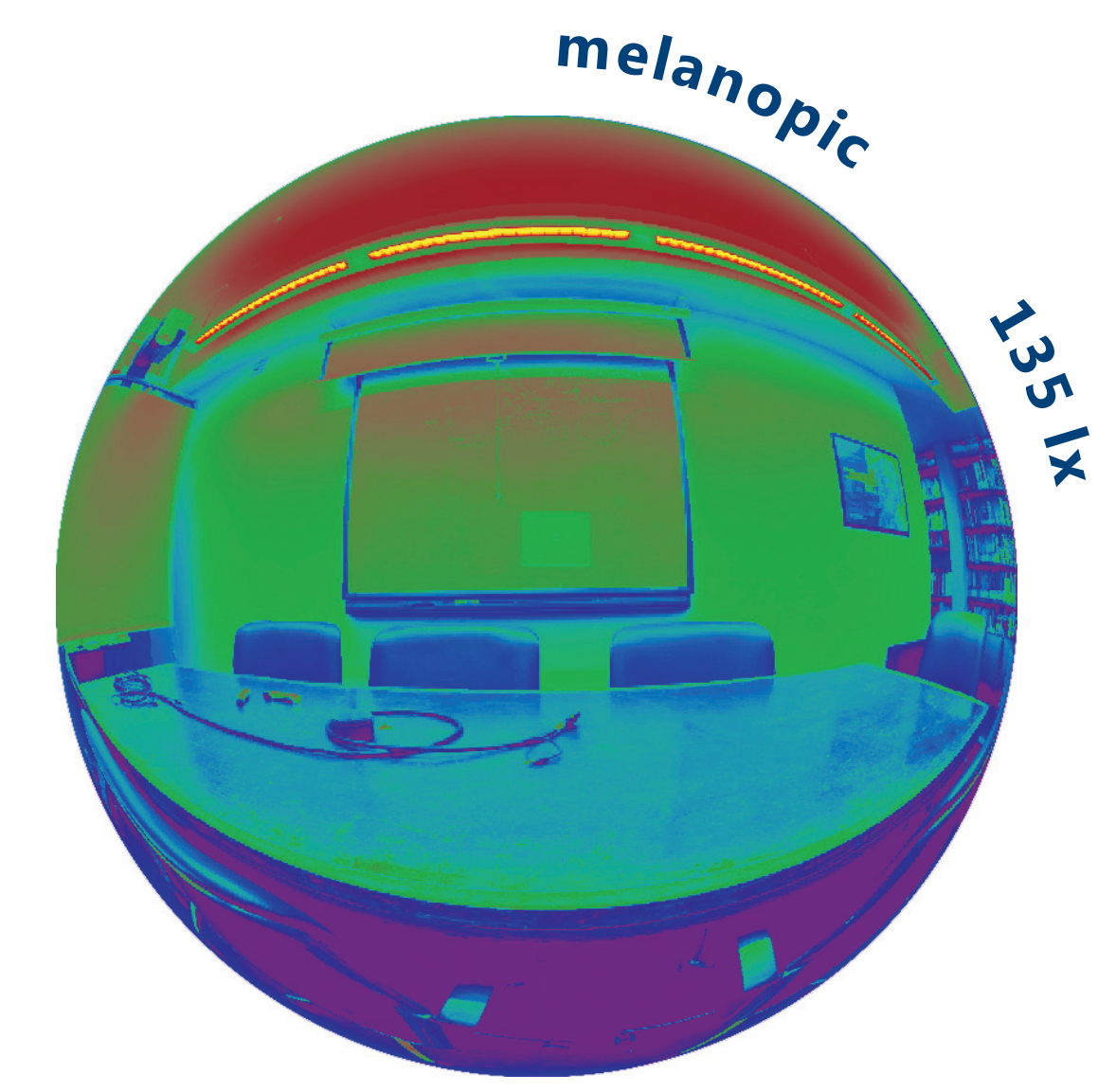
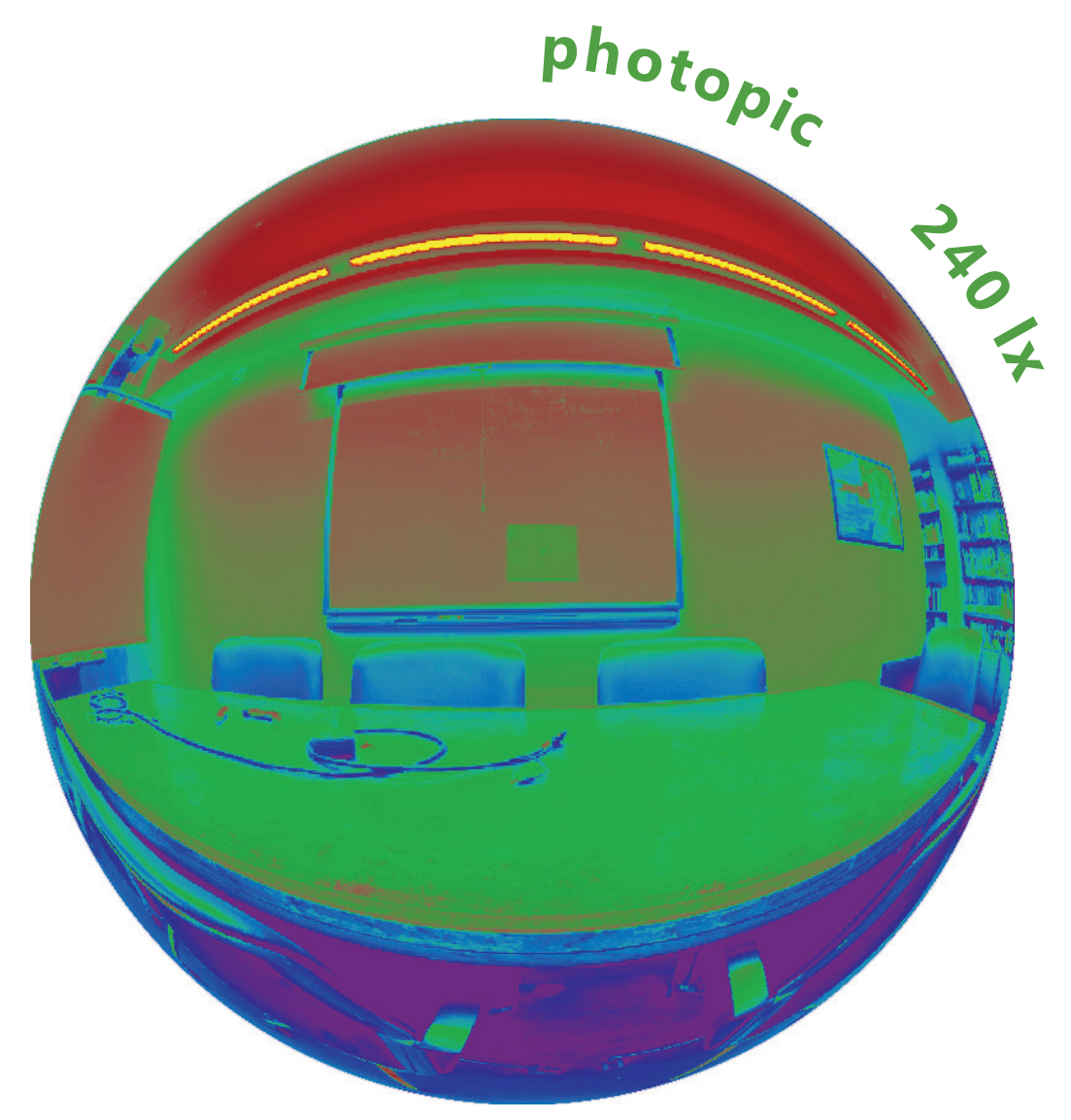


Radiance Melanopic luminance = $179 * ((0.0130 * R) + (0.3812 * G) + (0.6175 * B))$

sRGB Melanopic luminance = $179 * ((0.0180 * R) + (0.4024 * G) + (0.5950 * B))$

Melanopic Units

$$179 * ((0.2127 * R) + (0.7151 * G) + (0.0722 * B))$$



$$179 * ((0.0180 * R) + (0.4024 * G) + (0.5950 * B))$$



Melanopic Units



226 photopic lux (D65)
250 Equivalent Melanopic Lux

@ 75% or more workstations on vertical plane with at least 4 hour exposure daily on annual basis

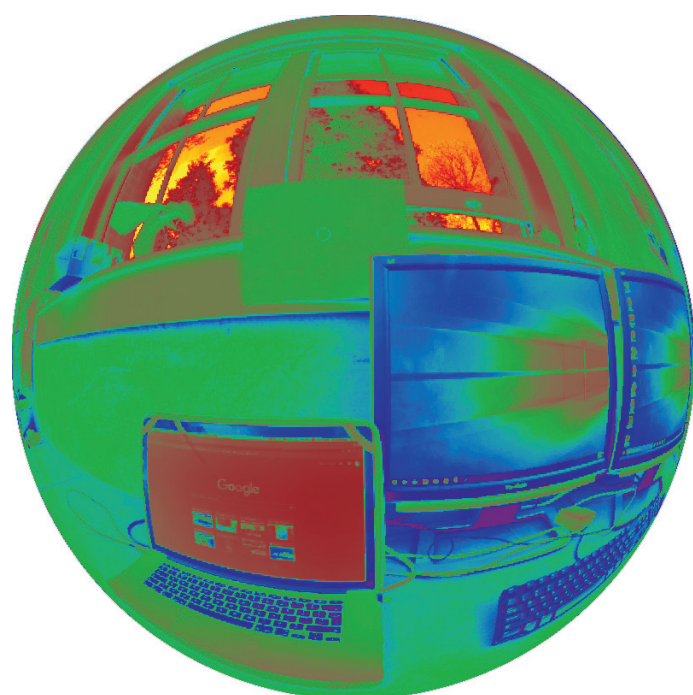
architectural context



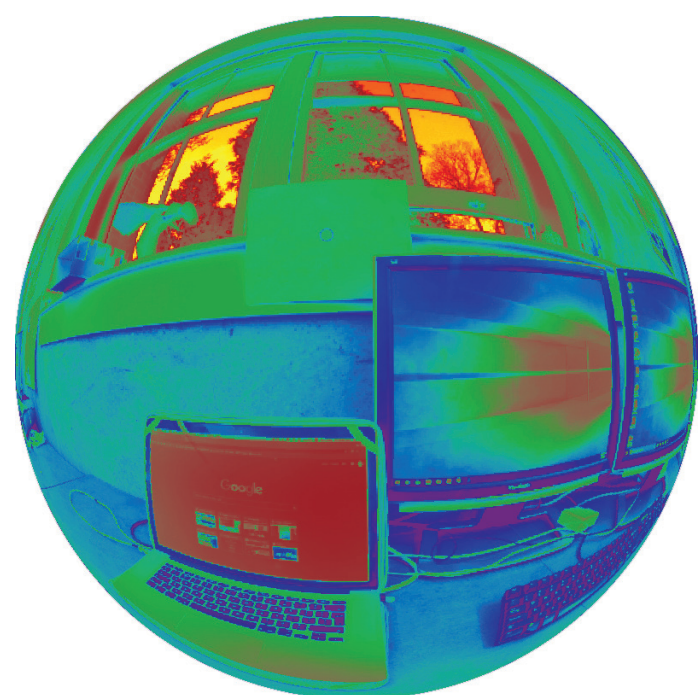
MAY 4 11:29 am



CCT | 7176 K



Photopic | **238 lx**



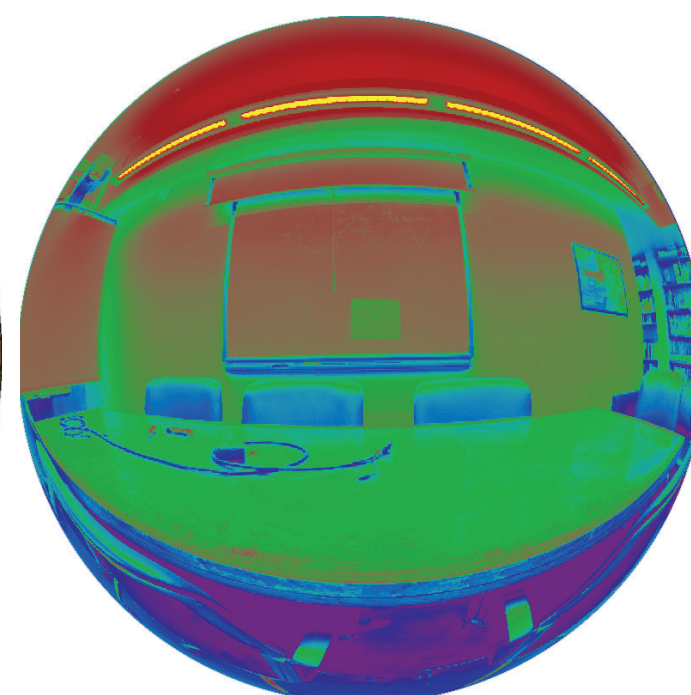
circadian | **258 lx**



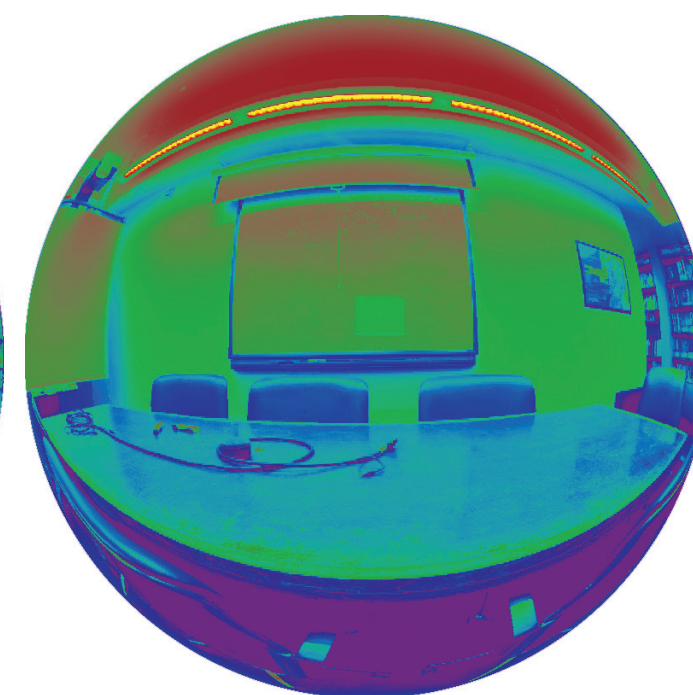
MAY 4 11:33 am



CCT | 3192 K



Photopic | **240 lx**



circadian | **135 lx**



MAY 4 11:22 am



CCT | 5495 K



Photopic | **8413 lx**



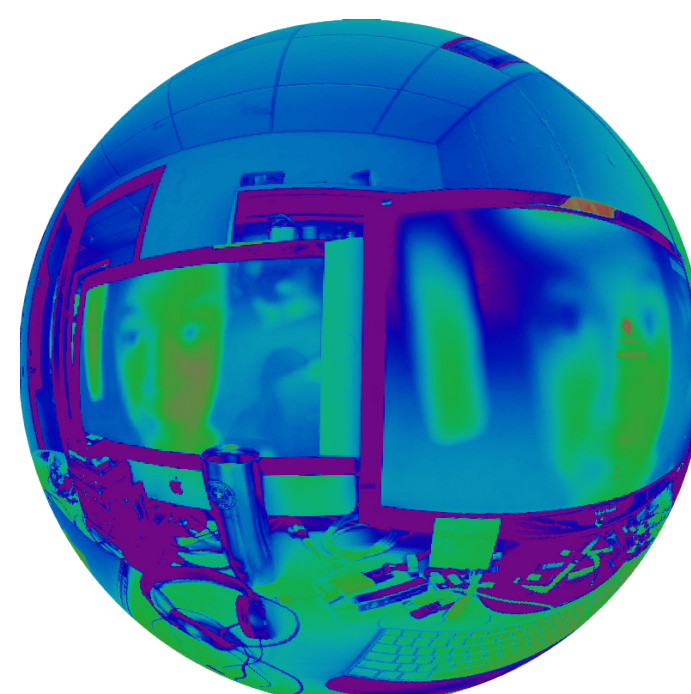
circadian | **7884 lx**



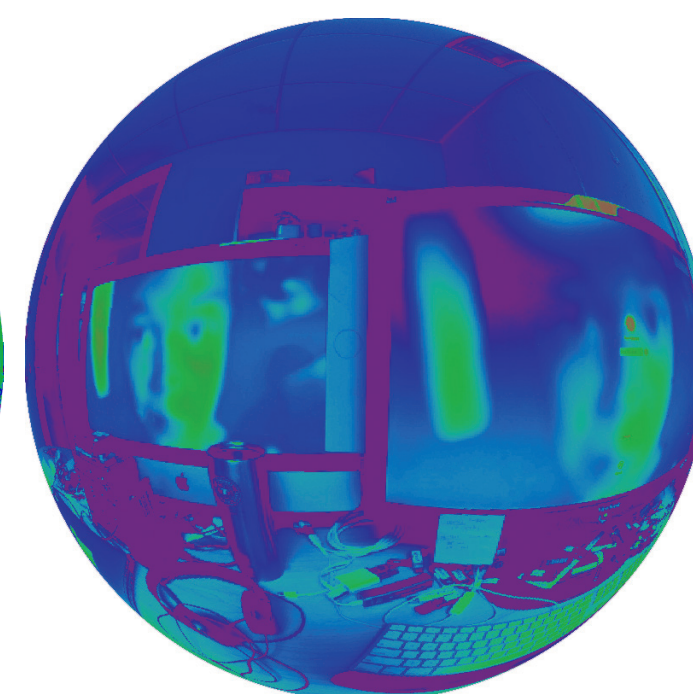
MAY 4 14:27 pm



CCT | 3157 K



Photopic | **22 lx**



circadian | **13 lx**



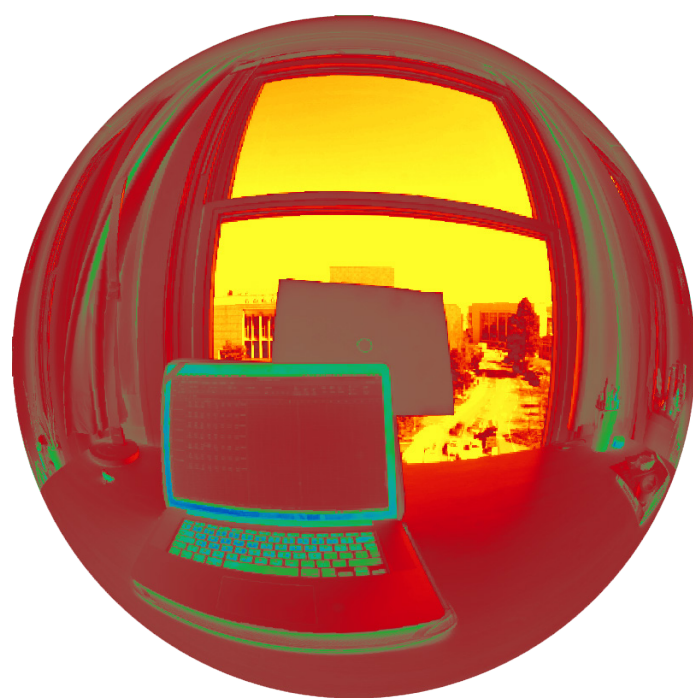
weather

1 5 14 36 109 326 973 3000 cd/m²

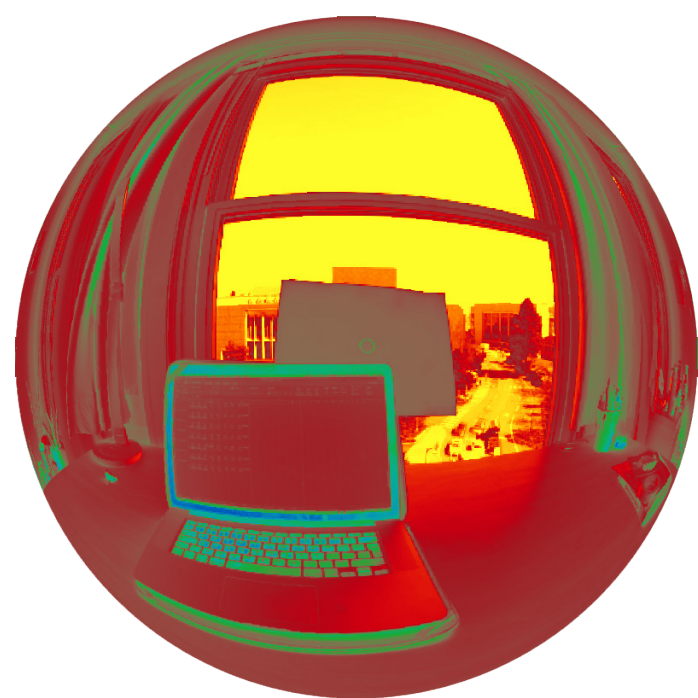
APR 15 1:31 pm



CCT | 7423 K



Photopic | **2615 lx**

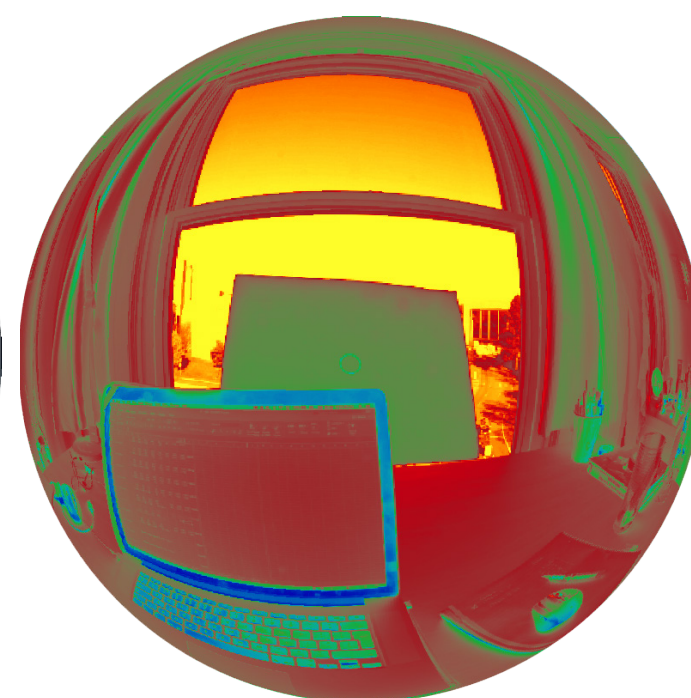


circadian | **2822 lx**

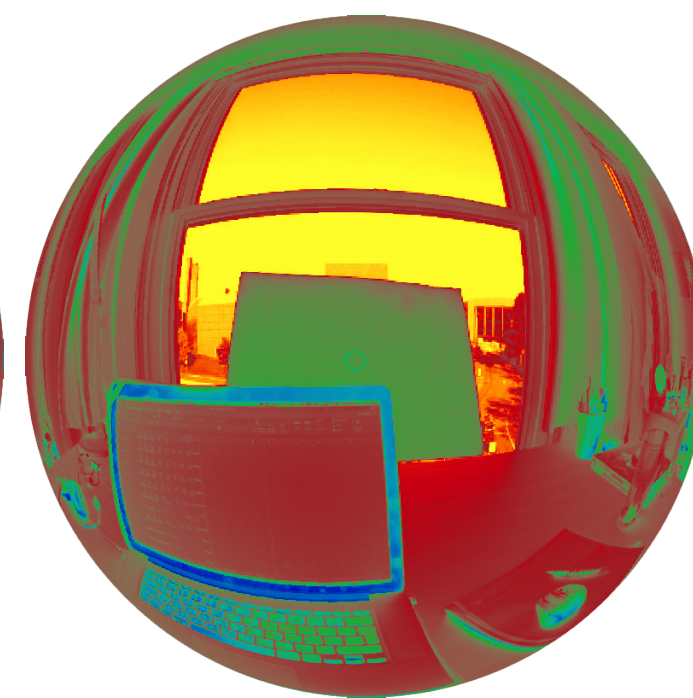
APR 15 4:32 pm



CCT | 9162 K

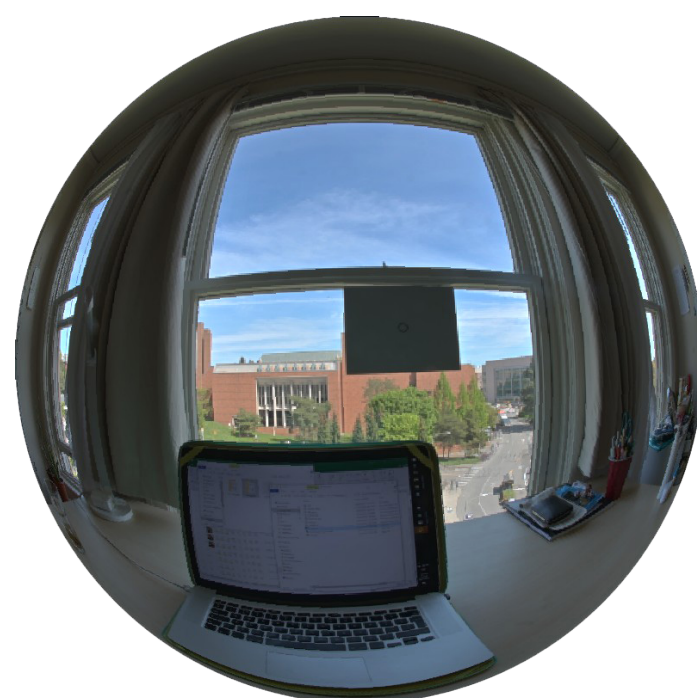


Photopic | **1766 lx**

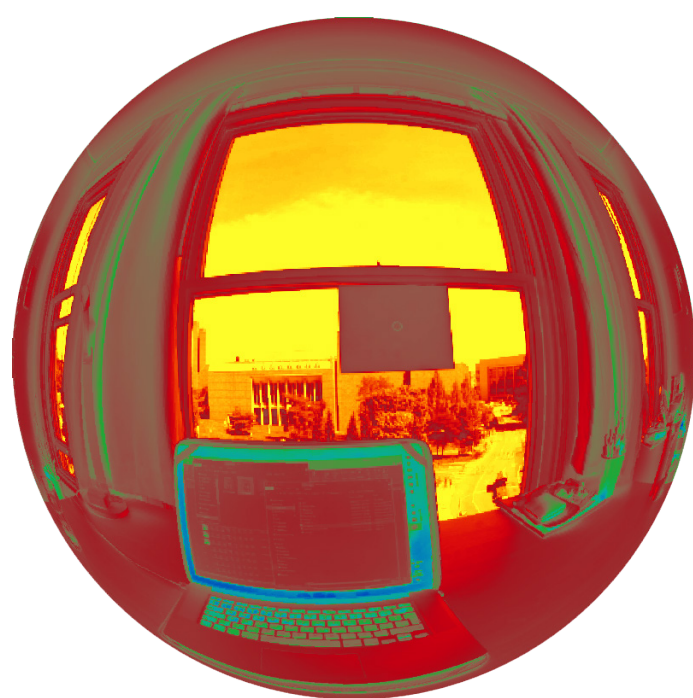


circadian | **2029 lx**

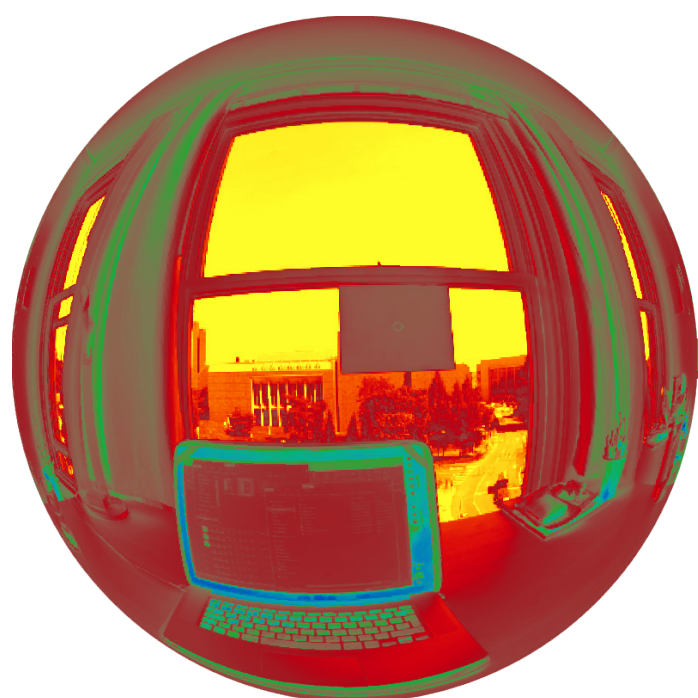
MAY 4 1:22 pm



CCT | 7159 K

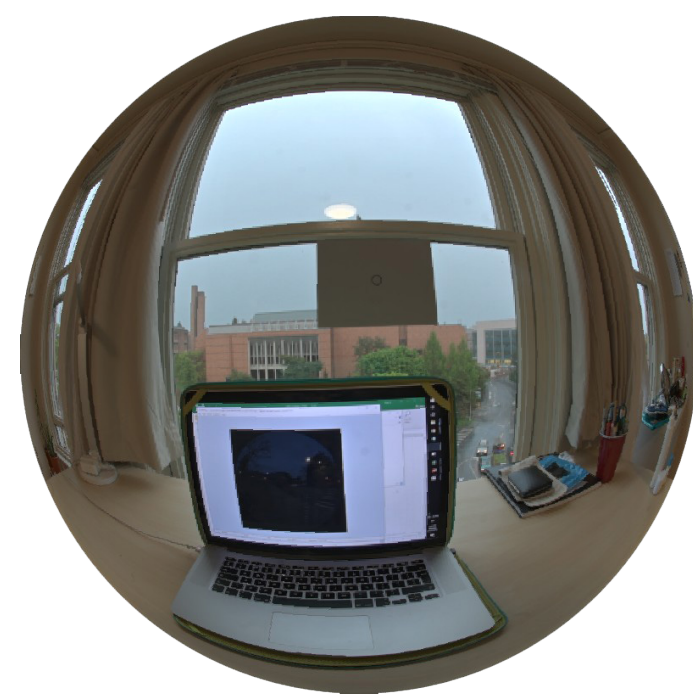


Photopic | **2498 lx**

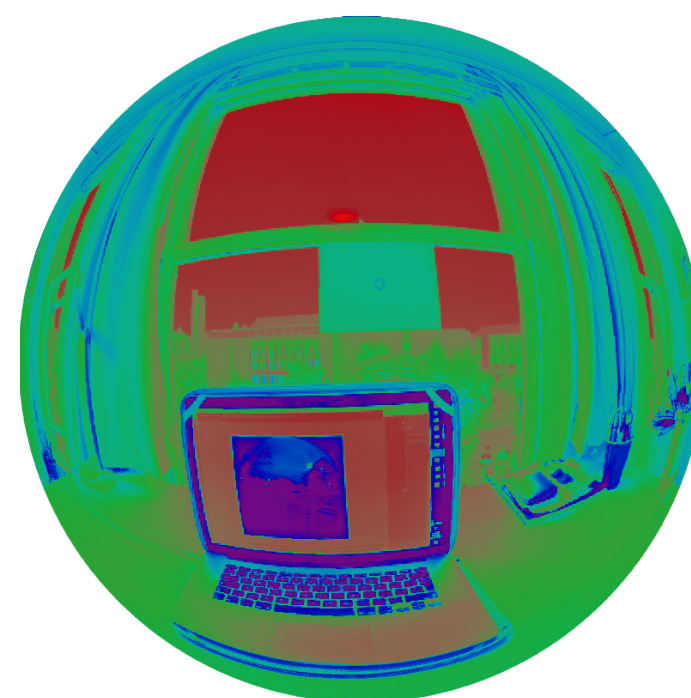


circadian | **2727 lx**

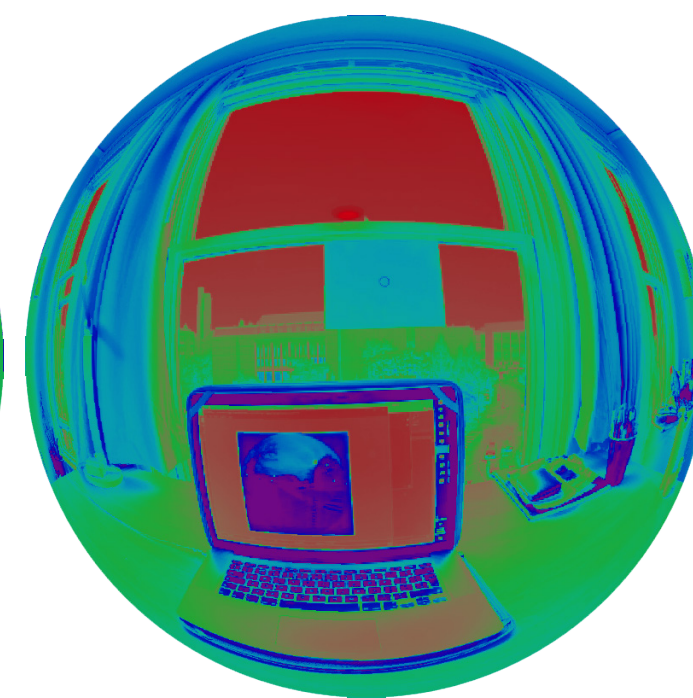
MAY 4 4:29 pm



CCT | 5979 K



Photopic | **158 lx**



circadian | **151 lx**

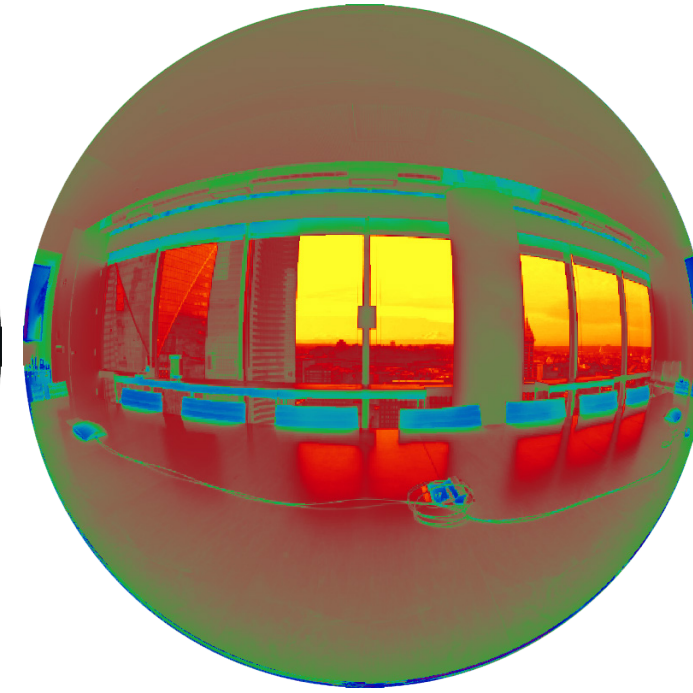
view direction



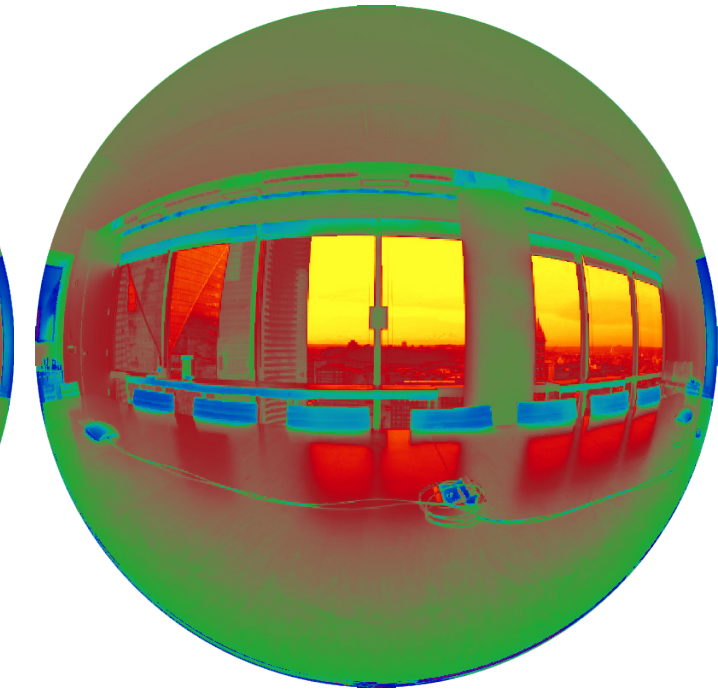
MAY 19 8:07 am



CCT | 6023 K



Photopic | **909 lx**



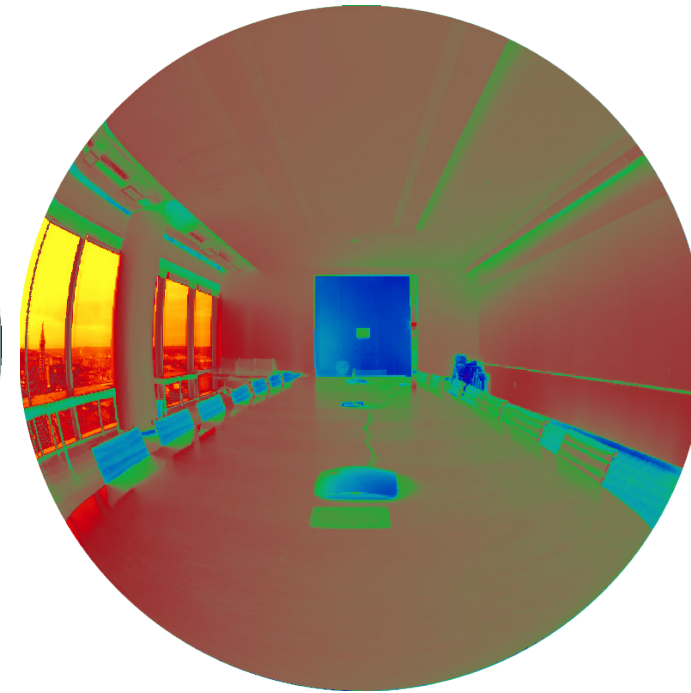
circadian | 870 lx



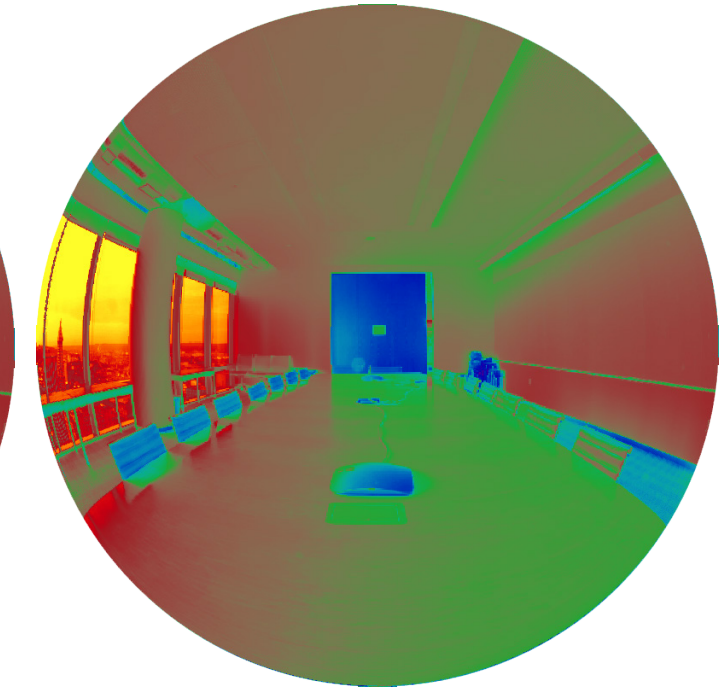
MAY 19 8:11 am



CCT | 5598 K



Photopic | **515 lx**



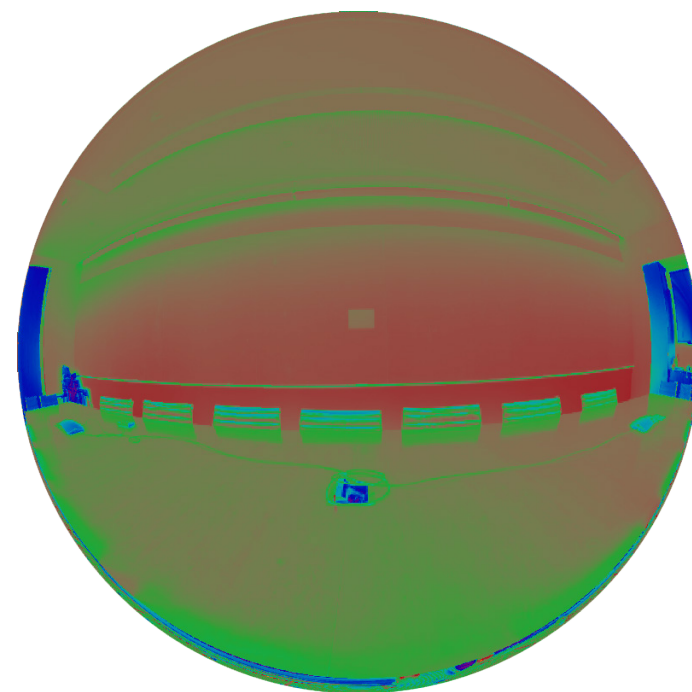
circadian | 473 lx



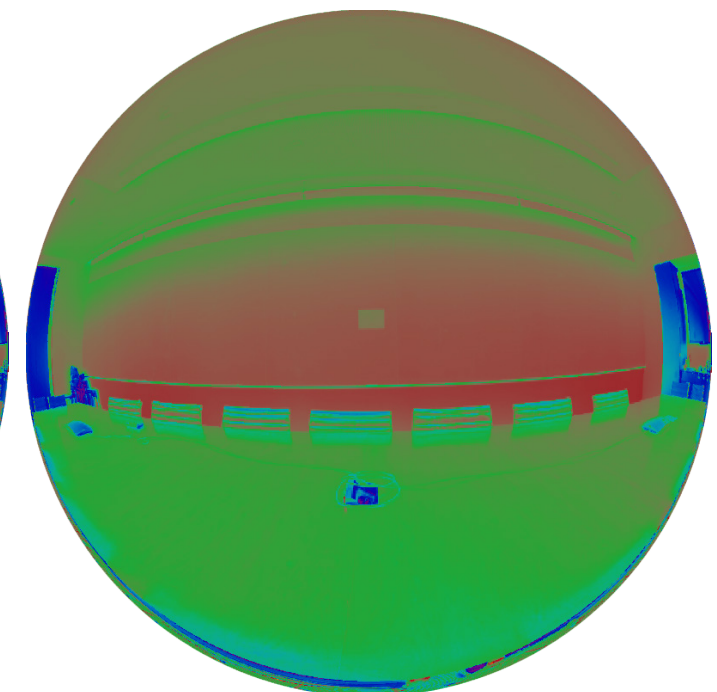
MAY 19 8:03 am



CCT | 4765 K



Photopic | **161 lx**



circadian | 131 lx



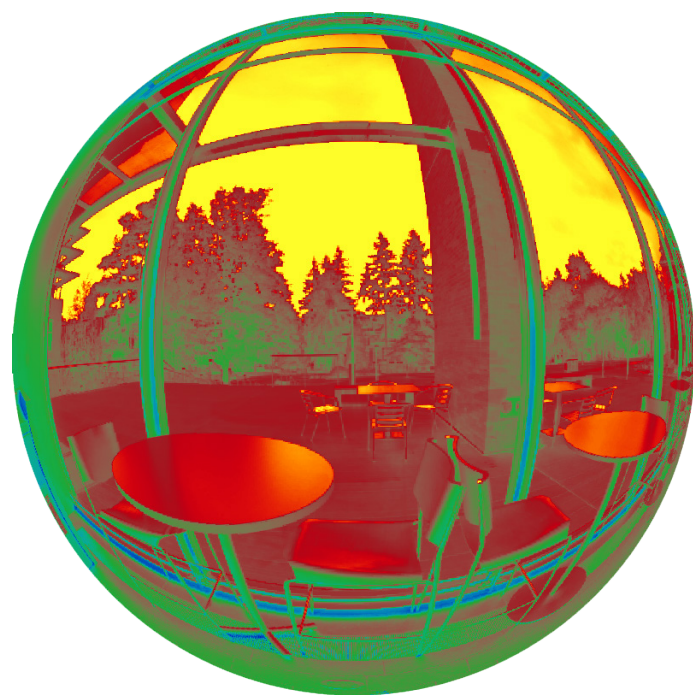
building depth

1 5 14 36 109 326 973 3000 cd/m²

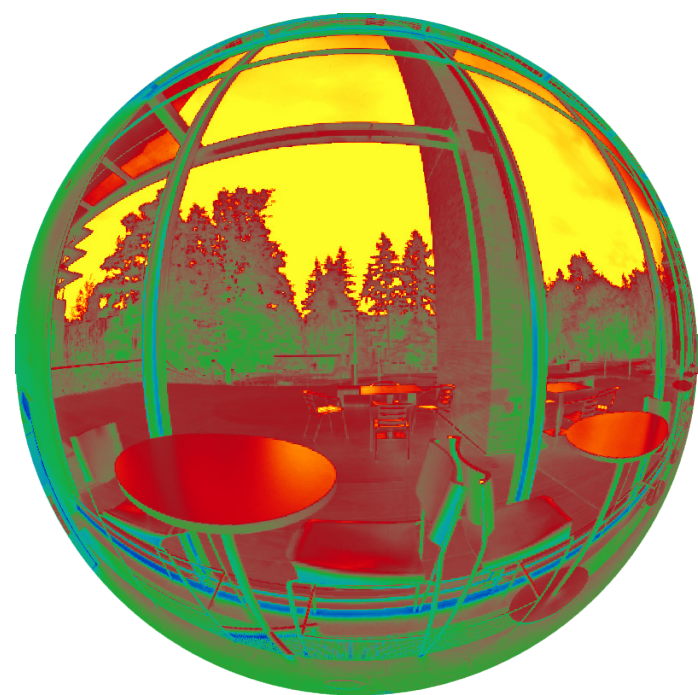
AUG 13 1:27 pm



CCT | 5793 K



Photopic | **2753** lx



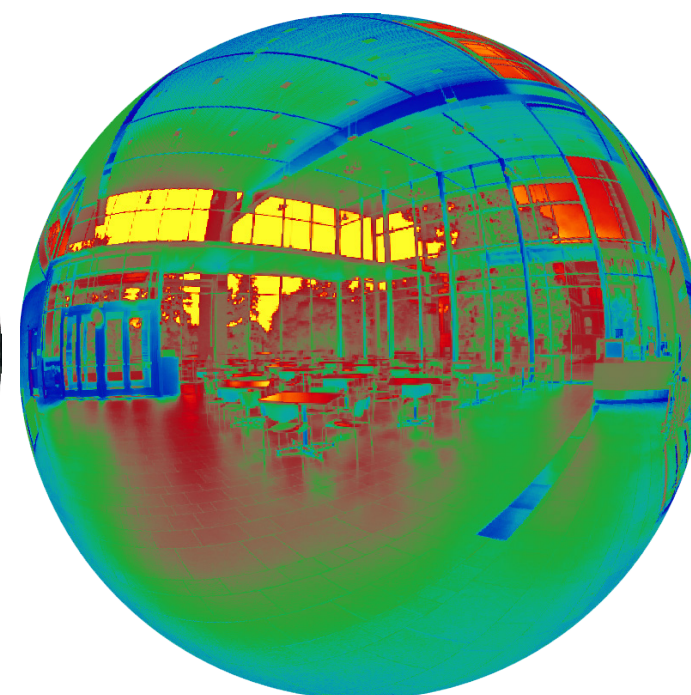
circadian | **2582** lx



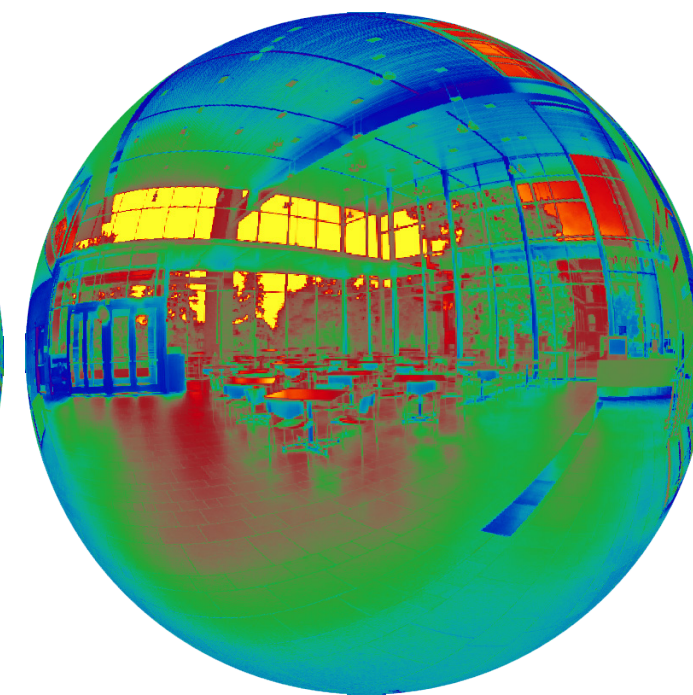
AUG 13 1:34 pm



CCT | 5579 K



Photopic | **932** lx



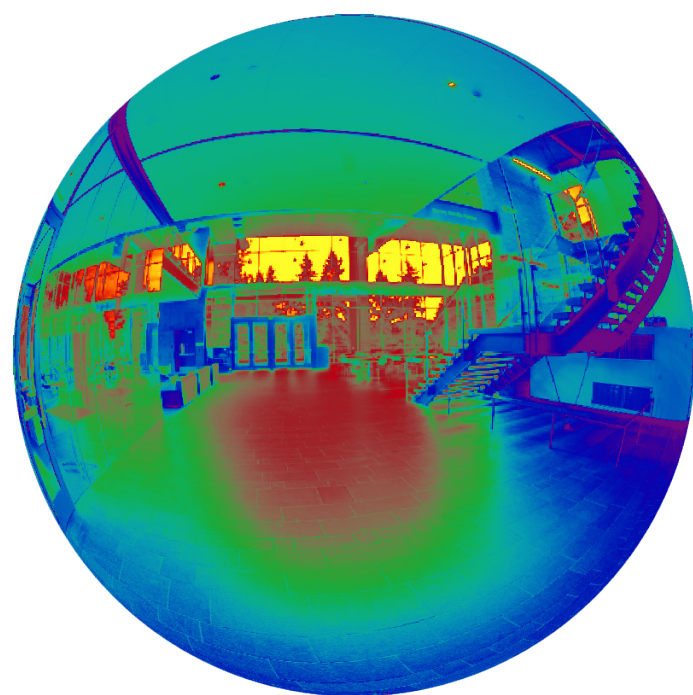
circadian | **849** lx



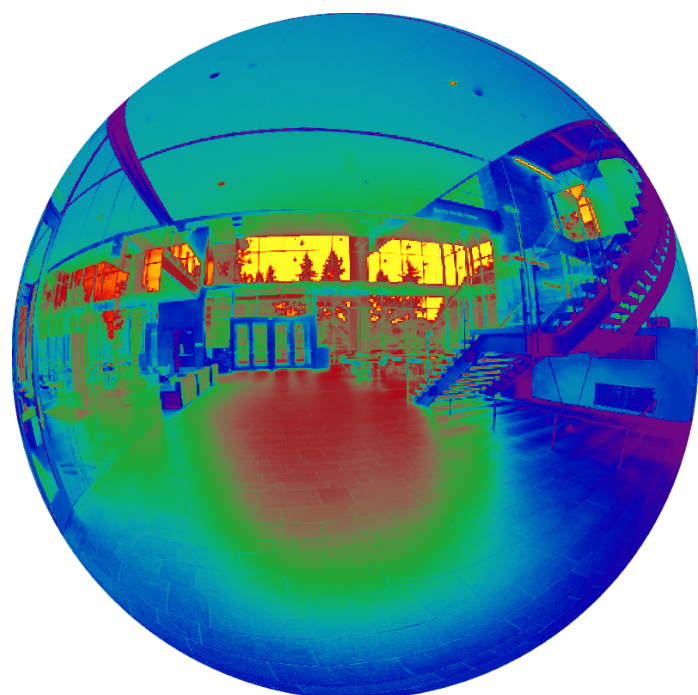
AUG 13 1:37 pm



CCT | 5676 K



Photopic | **483** lx



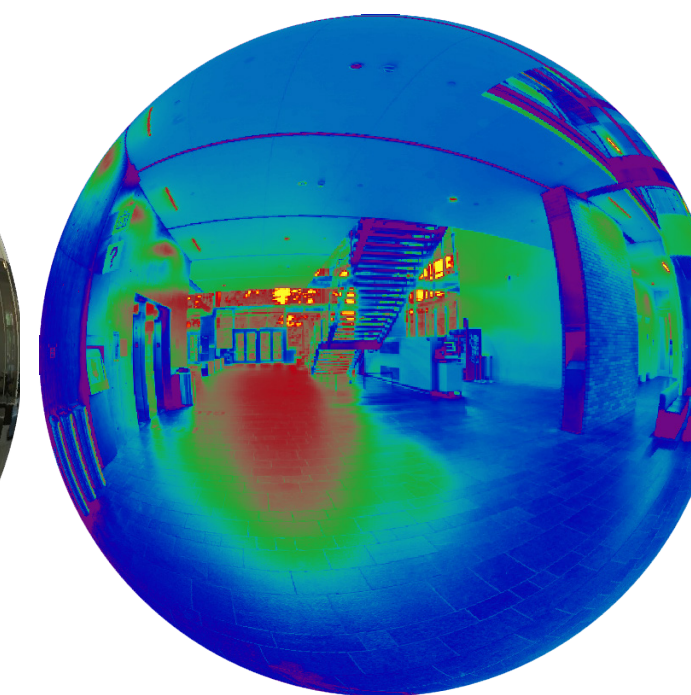
circadian | **440** lx



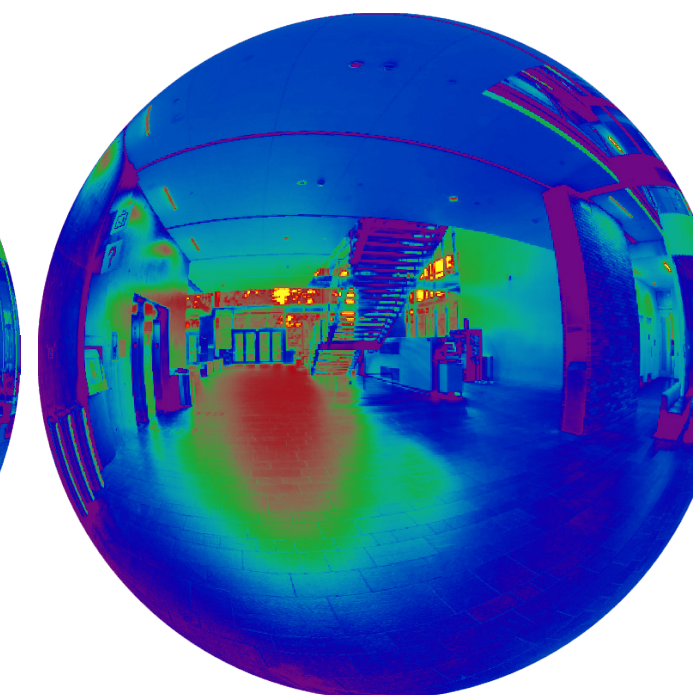
AUG 13 1:43 pm



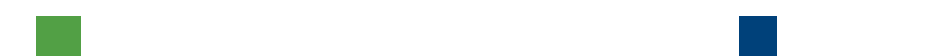
CCT | 5095 K



Photopic | **77** lx



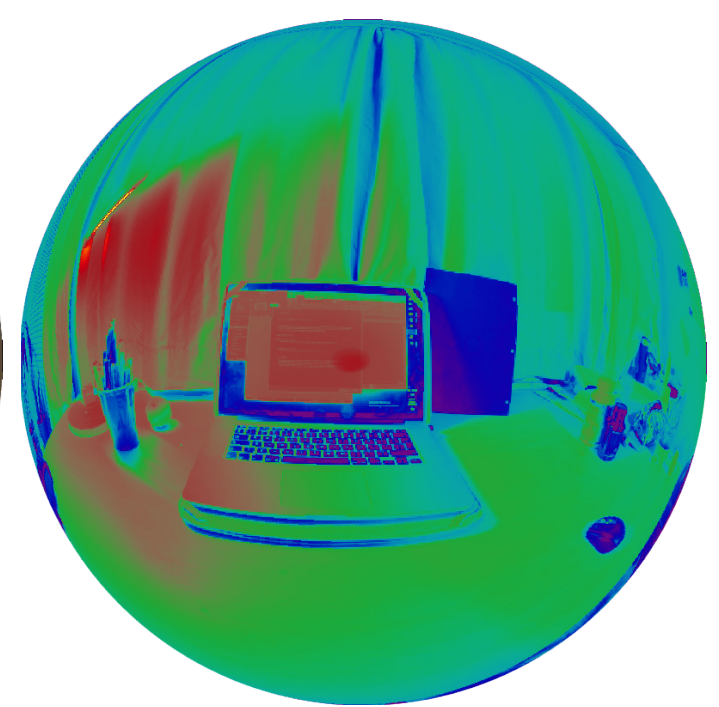
circadian | **65** lx



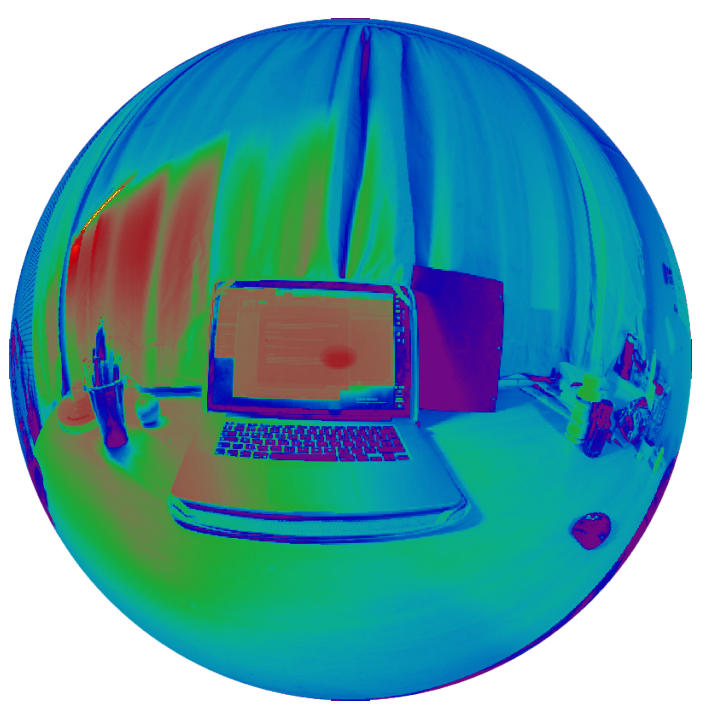
night exposure



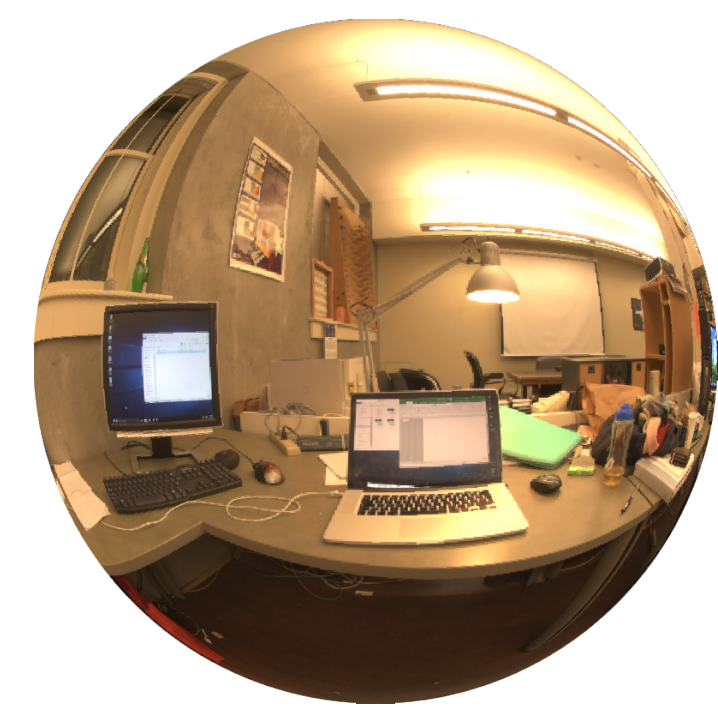
CCT | 3628 K



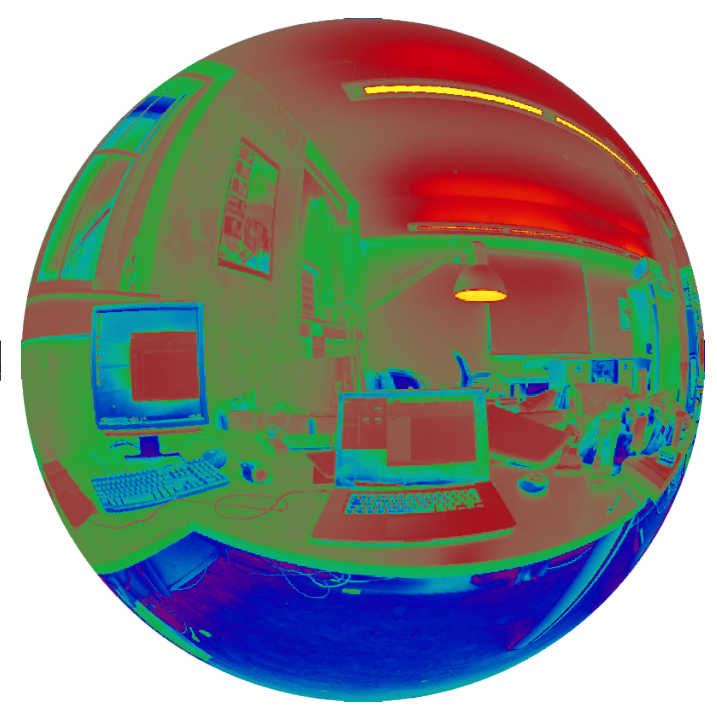
Photopic | **94** lx



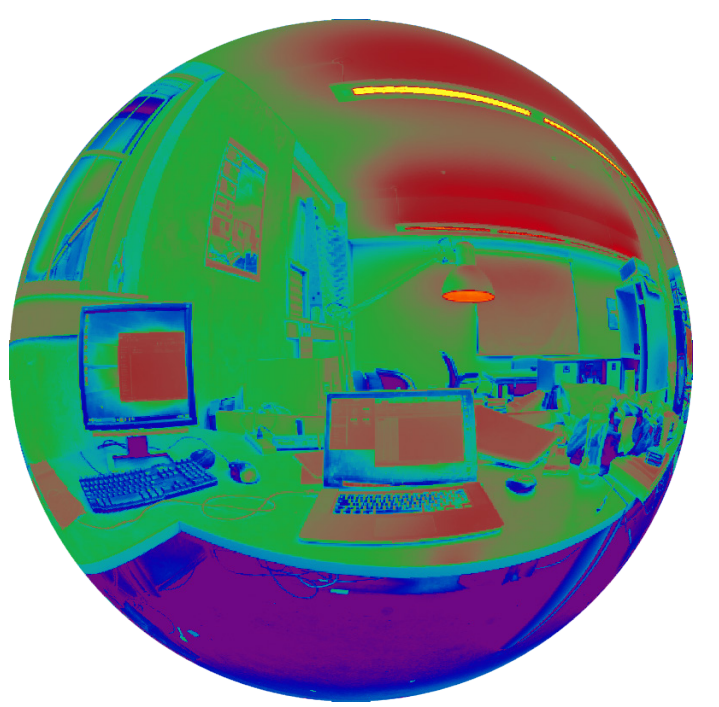
circadian | **60** lx



CCT | 3142 K



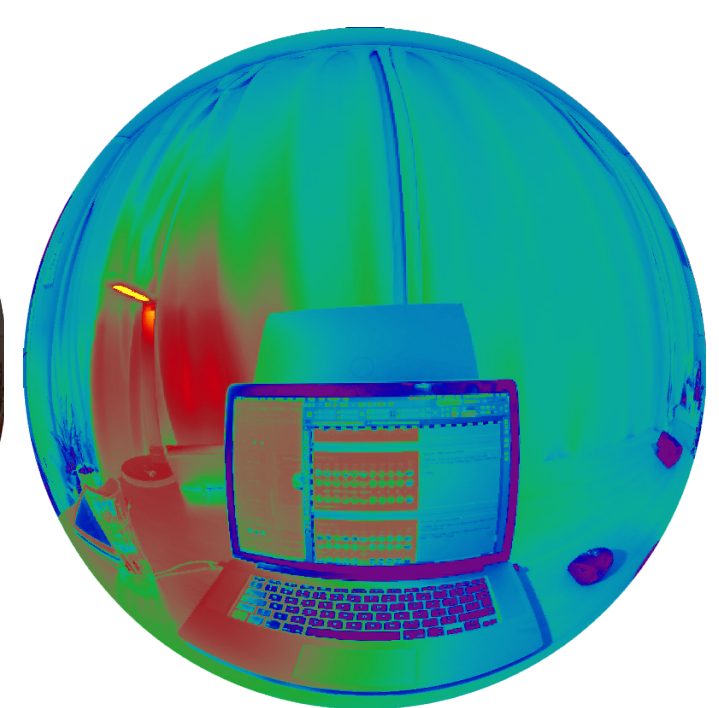
Photopic | **315** lx



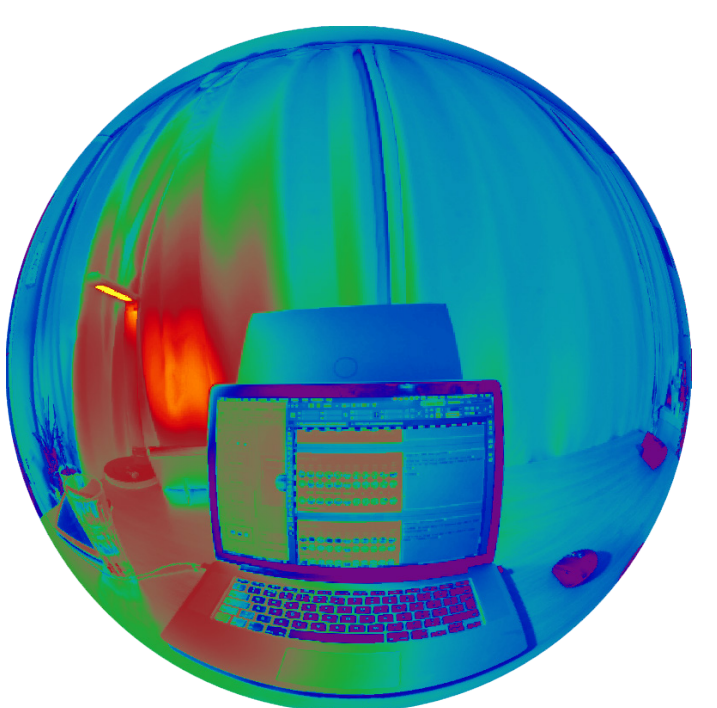
circadian | **171** lx



CCT | 11301 K



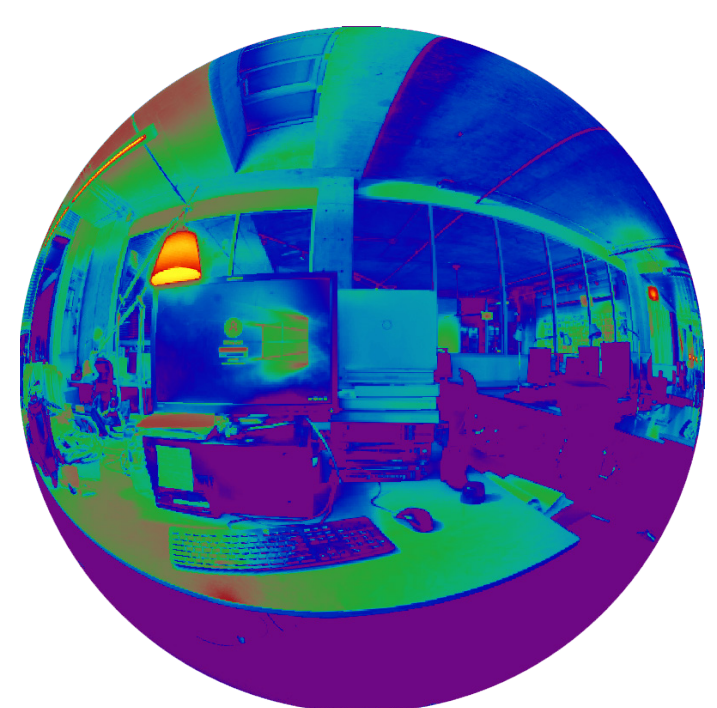
Photopic | **113** lx



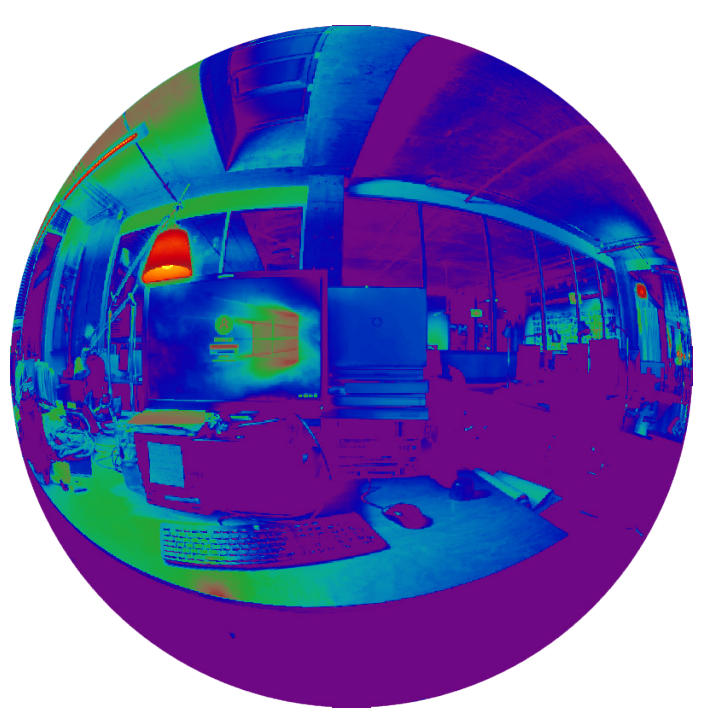
circadian | **150** lx



CCT | 2859 K



Photopic | **61** lx

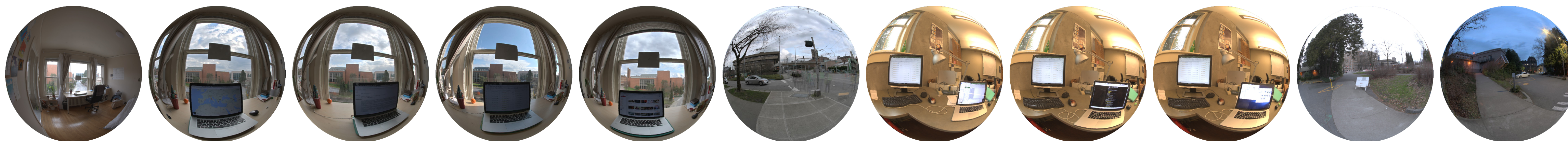


circadian | **30** lx

example day

FEB 25

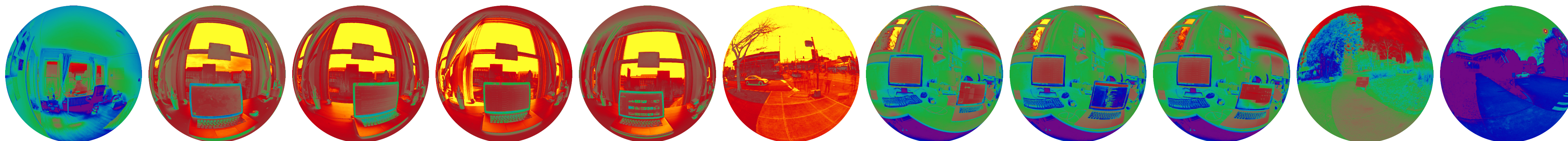
8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
4888 K	5367 K	5361 K	5634 K	5467 K	5807 K	4038 K	3835 K	3746 K	6584 K	4854 K



77	3393	6215	5651	3884	8103	426	359	309	319	58
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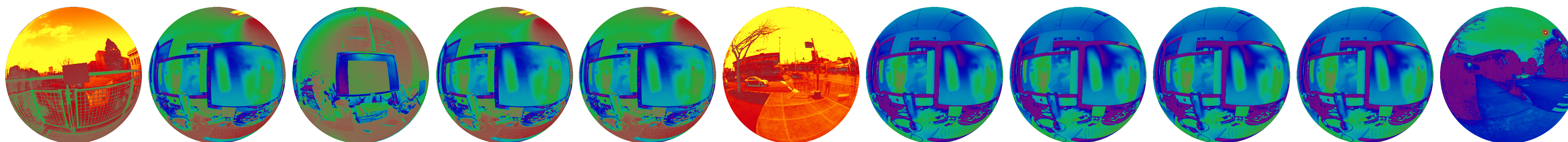
67	3050	5622	5356	3629	7634	327	255	212	327	46
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example day

FEB 25

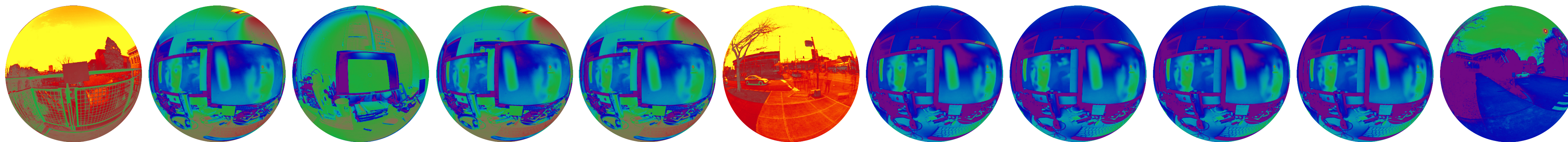
8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
4306 K	3157 K	3233	3157 K	3157 K	5807 K	3275	3275	3275	3275	4854 K



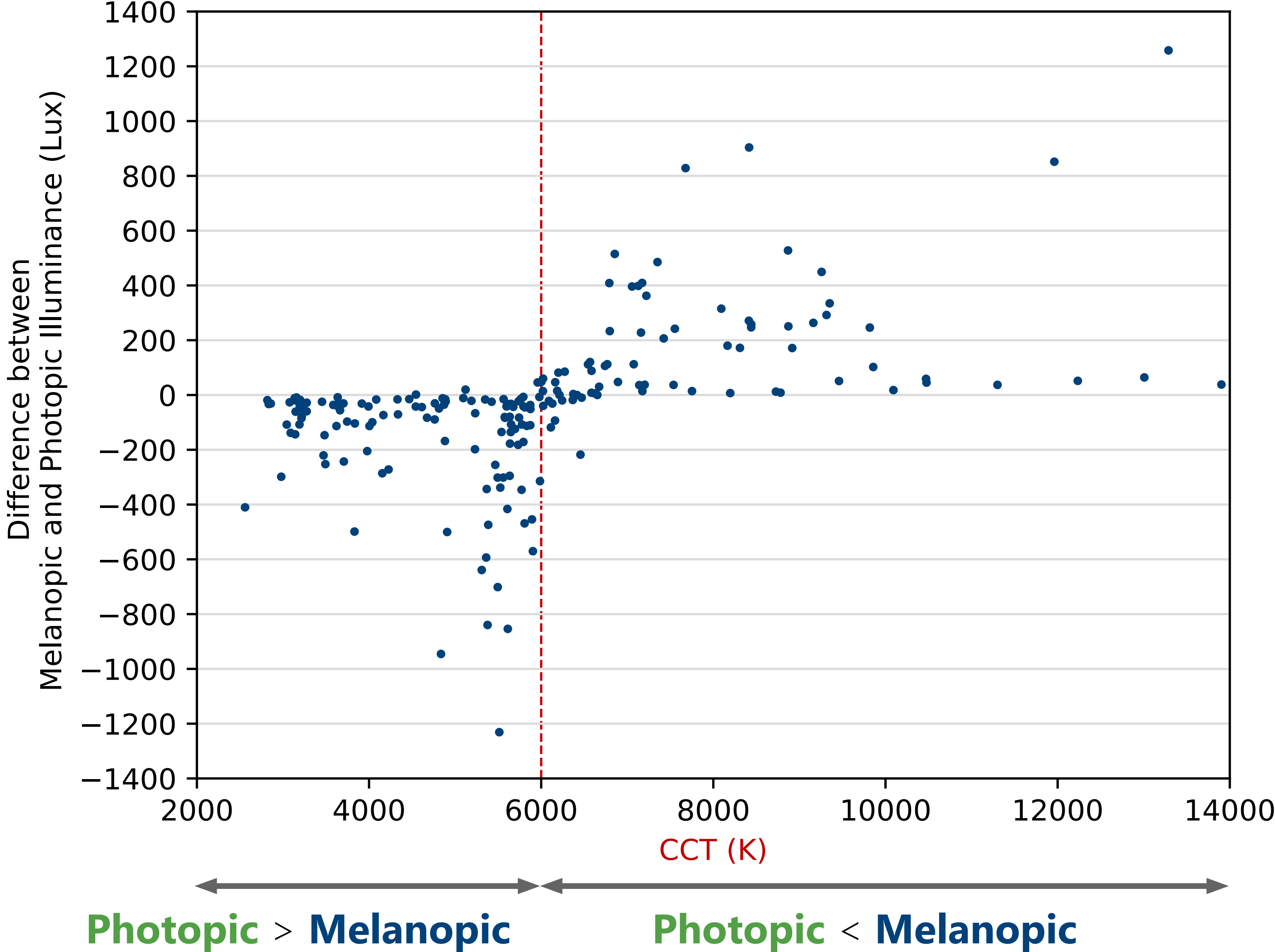
7677	135	111	135	135	8103	22	22	22	22	58
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5134	75	59	75	75	7634	12	12	12	12	46
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CCT, photopic and melanopic illuminance



conclusions & future work

conclusions

- demonstrate utilisation of HDR
- provides rich data for the design and guidelines development of circadian friendly settings

Future Work

- further accuracy testing will be done with spectrophotometer
- further studies needed to test colour calibration in other cameras
- more biological studies are required to develop time and duration guidelines



capturing non-visual (circadian) Light
through HDR photography

Bo Jung | Mehlika Inanici