# Melanopic HDR capture

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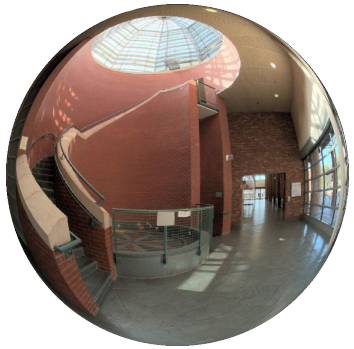
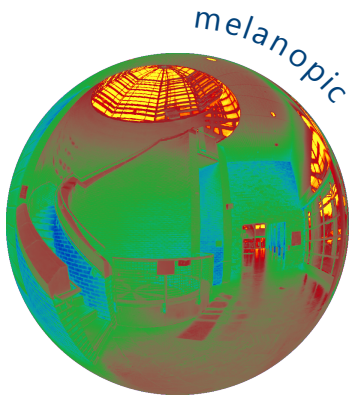





# Outline

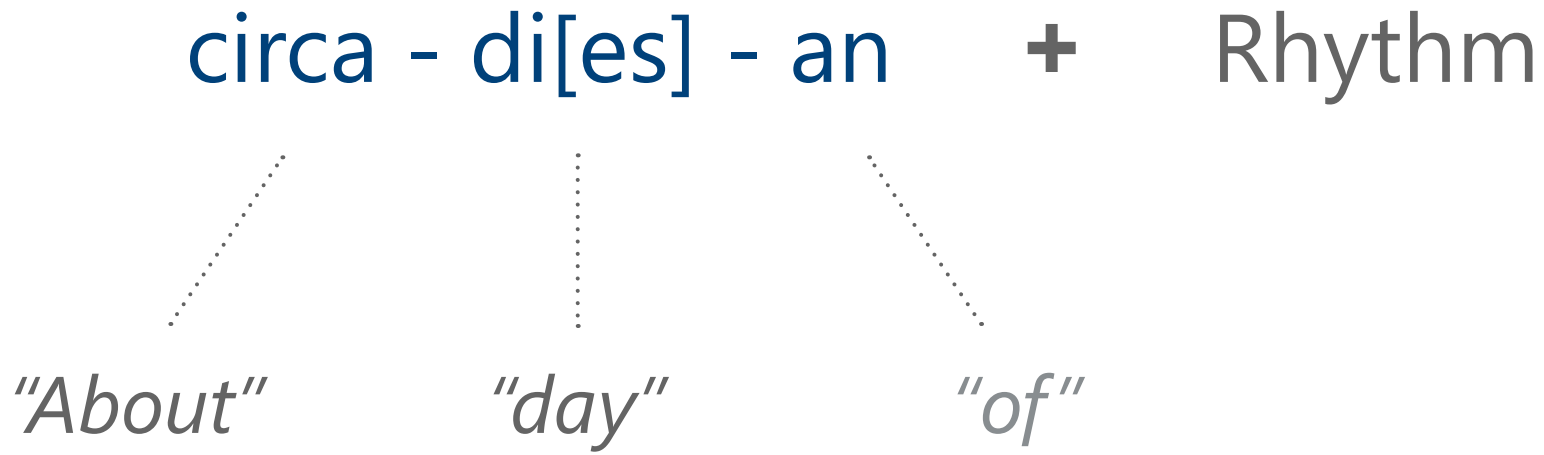
1. Background

   Understanding non-visual (circadian) light

2. Image Capture
3. Post Processing
4. Discussion

# Background

# Non-Visual (Circadian) Light



# Visual (Photopic) Light

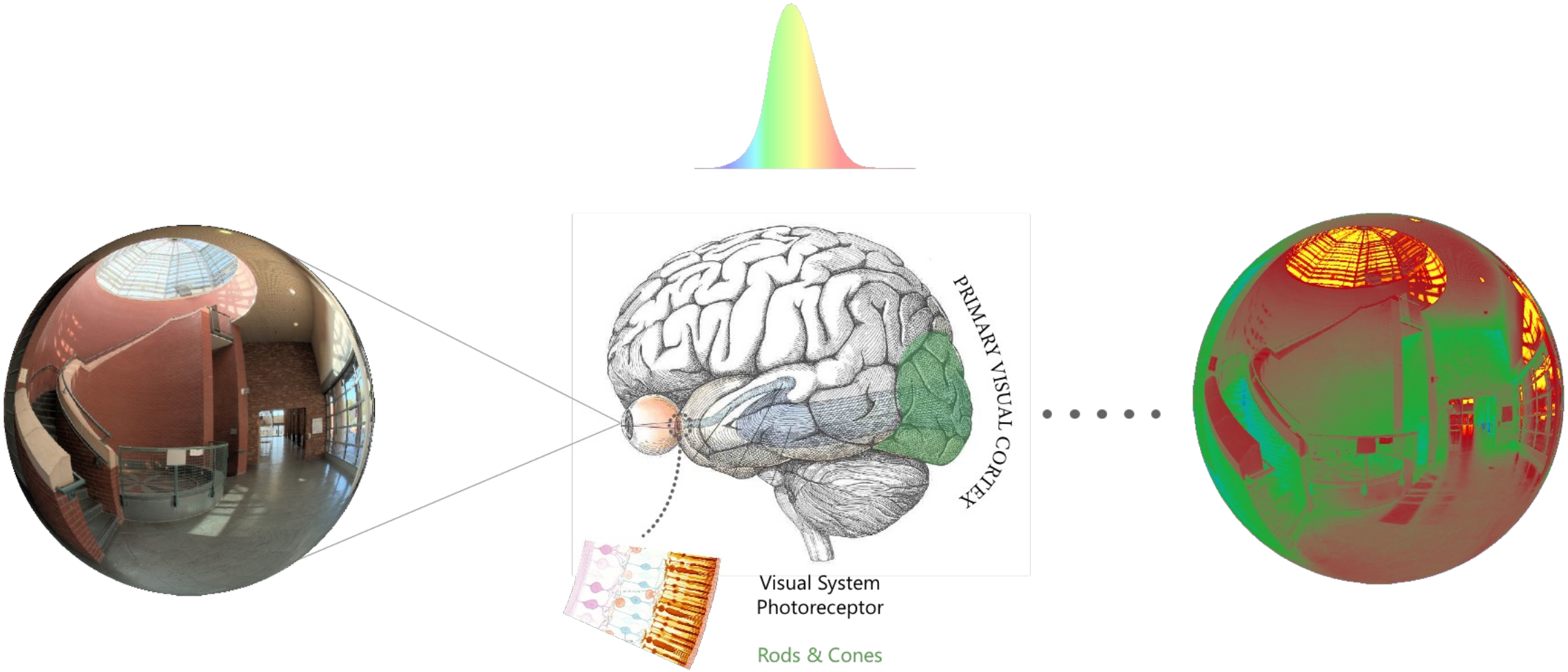



Image modified from: Hubel, D. H. (1988). Eye, brain, and vision. New York: Scientific American Library

# Non-Visual (Circadian) Light

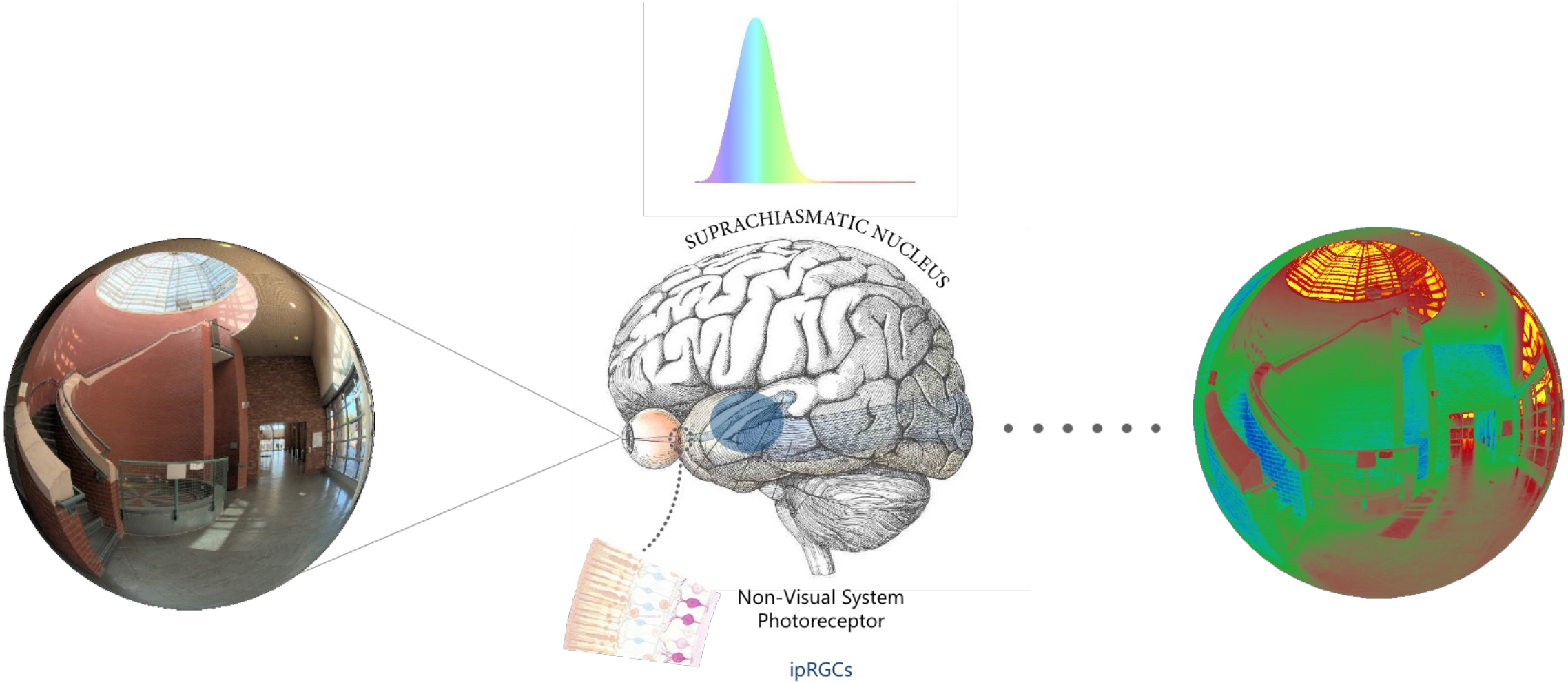



Image modified from: Hubel, D. H. (1988). Eye, brain, and vision. New York: Scientific American Library

# Non-Visual (Circadian) Light

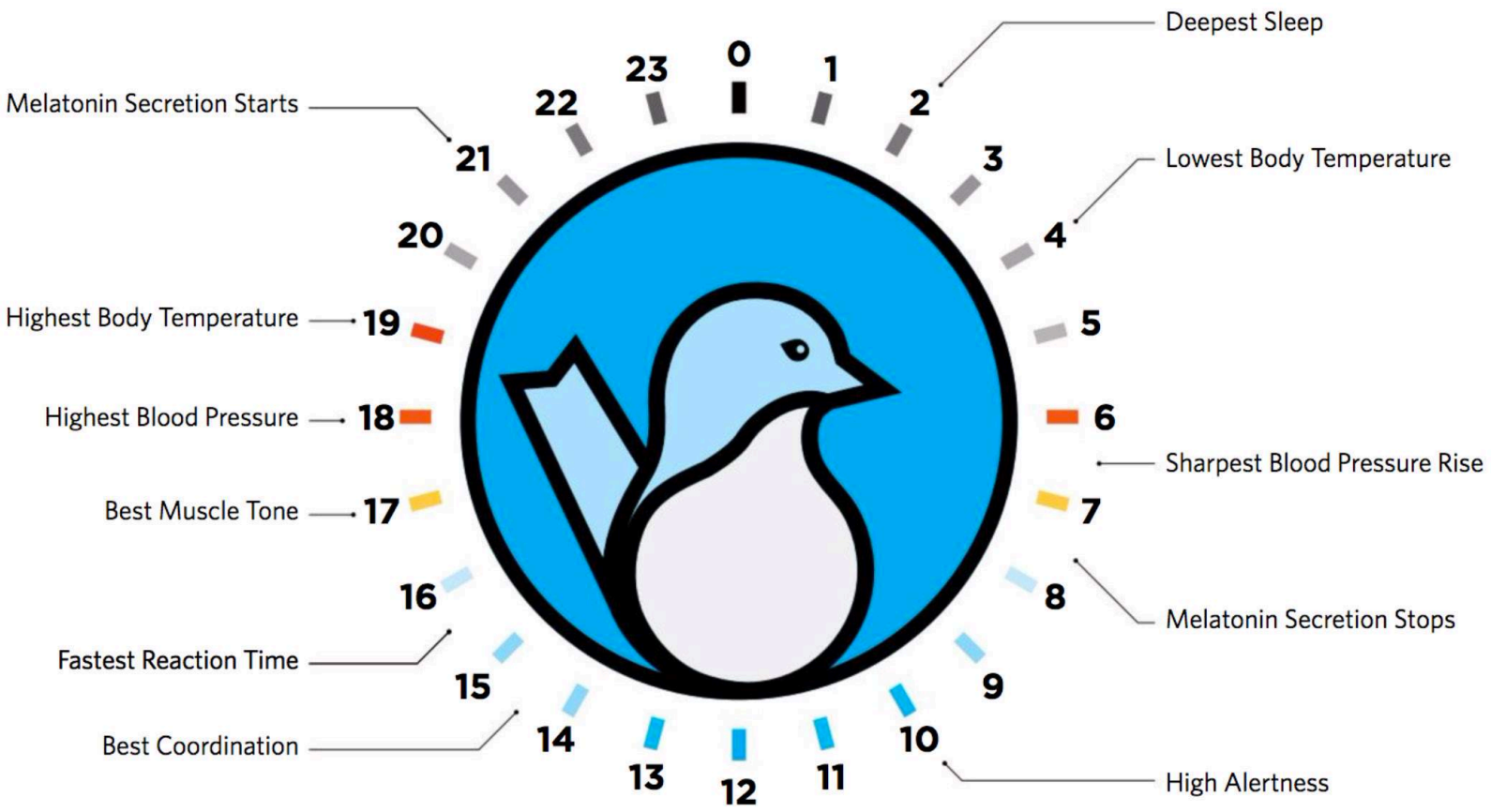



Image: ZGF

# Non-Visual (Circadian) Light

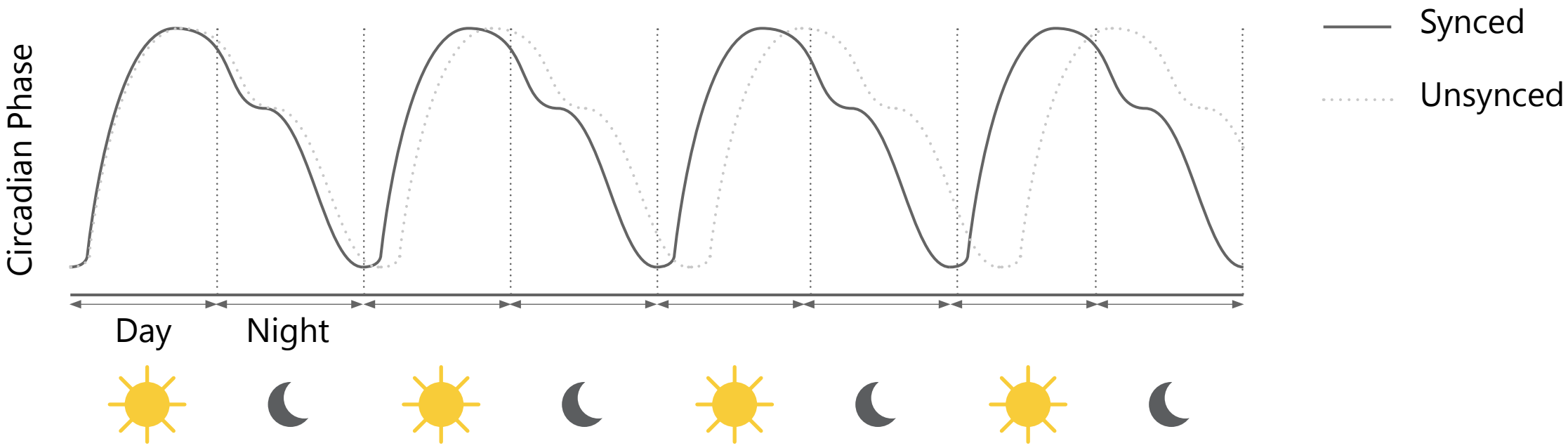



Image adapted from: Vitaterna, M. H., Takahashi, J. S., & Turek, F. W. (2001). Overview of circadian rhythms. Alcohol Research and Health, 25(2), 85-93.

# Non-Visual (Circadian) Light

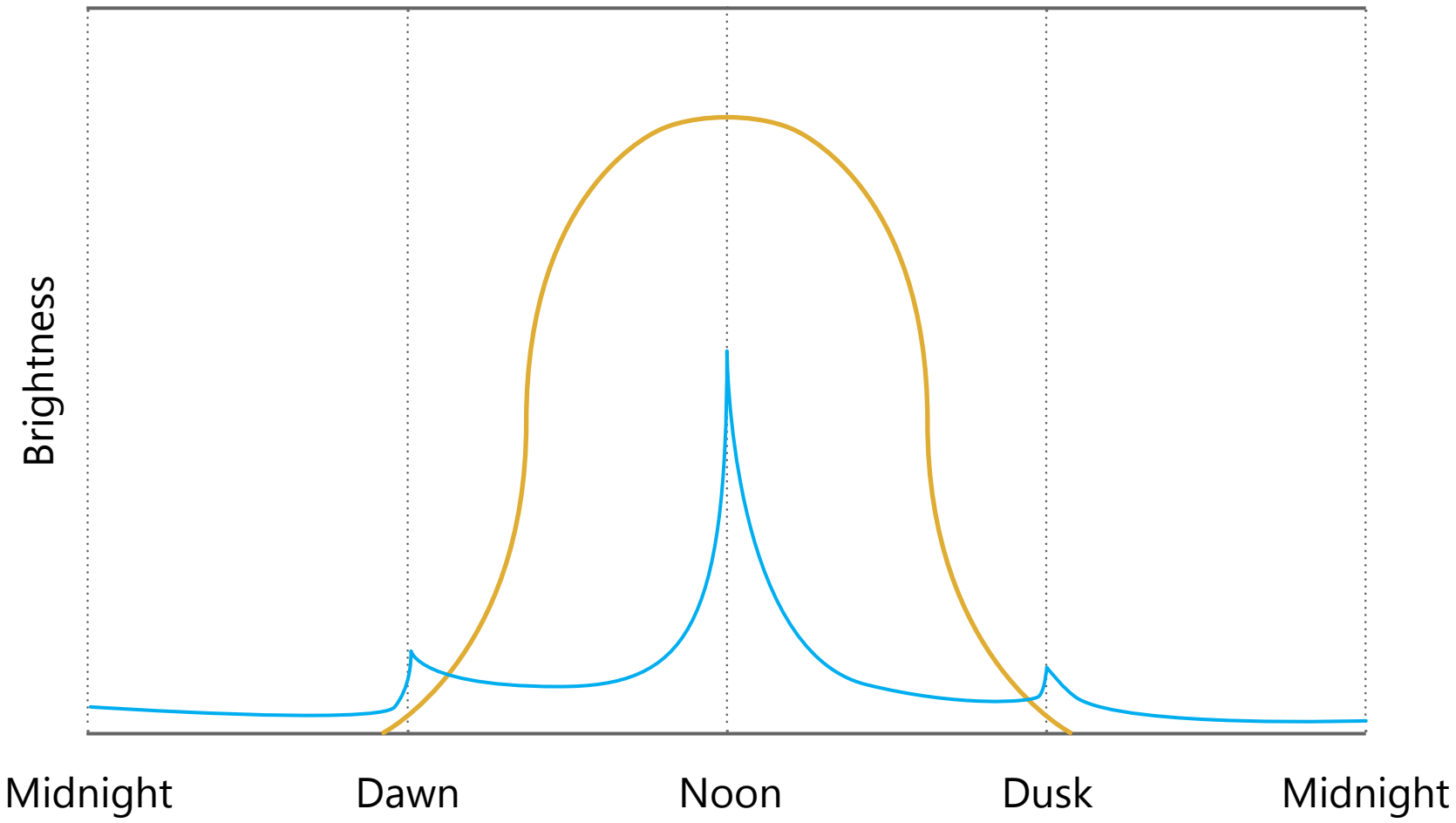
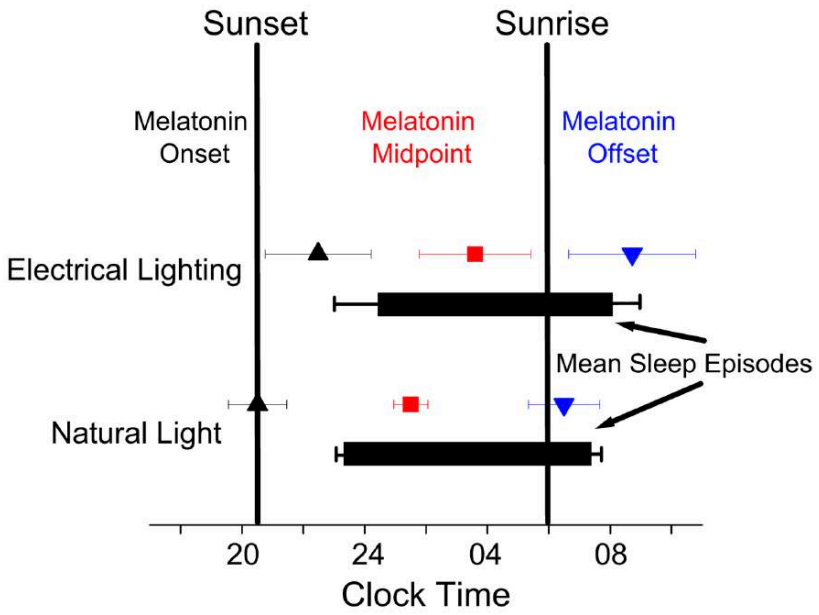



Image adapted from: Figuroa. M.

# Non-Visual (Circadian) Light




*'after exposure to only natural light, the internal circadian clock synchronizes to solar time such that the beginning of the internal biological night occurs at sunset and the end of the internal biological night occurs before wake time just after sunrise.'*

Wright, K.P., McHill, A.W., Birks, B.R., Griffin, B.R., Rusterholz, T. and Chinoy, E.D. (2013) Entrainment of the Human Circadian Clock to the Natural Light Dark Cycle. Current Biol., 23(16), 1554-1558.

# Non-Visual (Circadian) Light

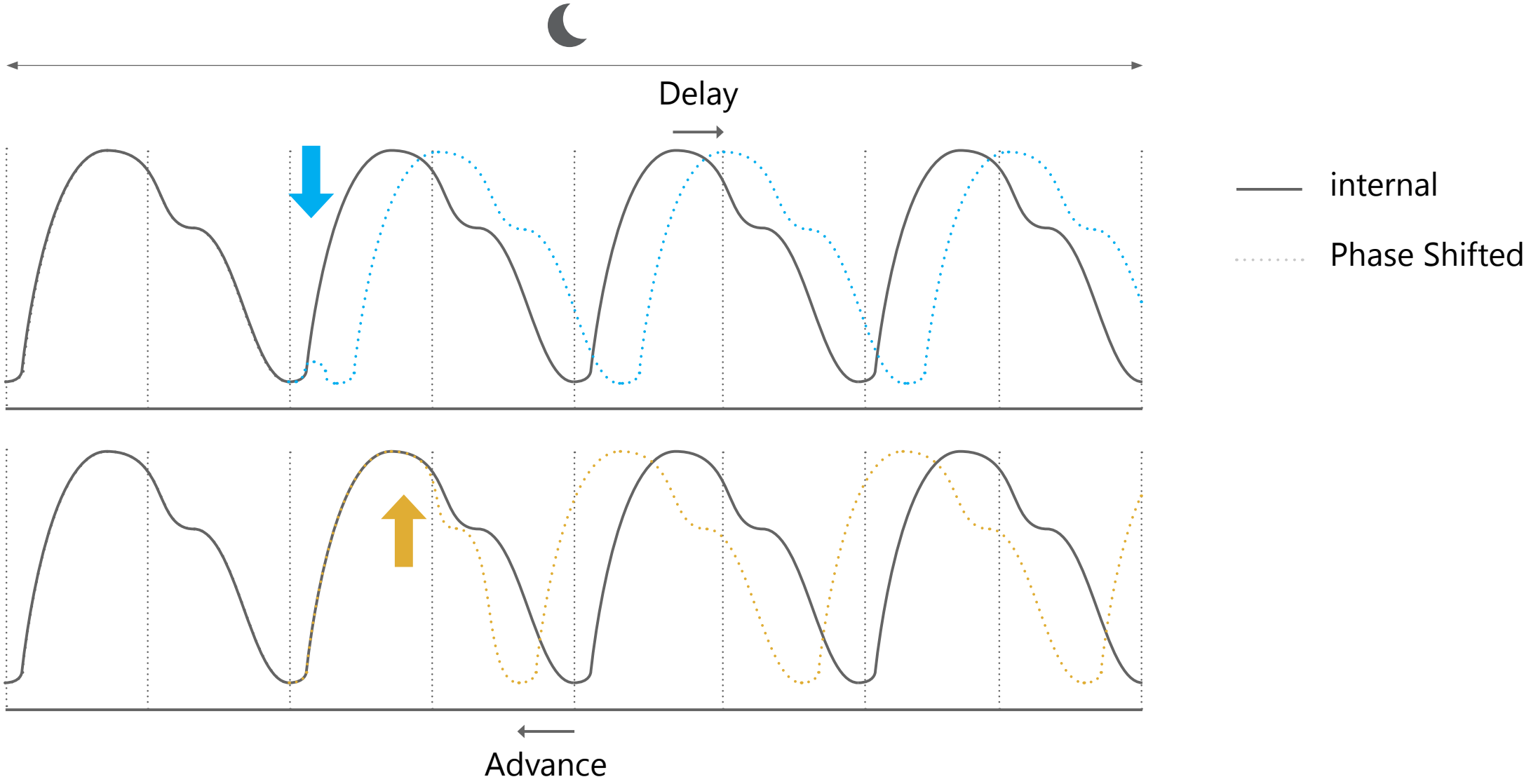



Image adapted from: Vitaterna, M. H., Takahashi, J. S., & Turek, F. W. (2001). Overview of circadian rhythms. Alcohol Research and Health, 25(2), 85-93.

# Non-Visual (Circadian) Light

Biological Darkness = ***No*** Circadian Entrainment

Image: Judith Heerwagen

# Non-Visual (Circadian) Light

Executive Summary of "Adverse Health Effects of Nighttime Lighting":

*"...potential carcinogenic effects related to melatonin suppression, especially **breast cancer**. Other diseases that may be exacerbated by circadian disruption include **obesity**, **diabetes**, **depression**, **mood disorders**, and **reproductive problems**."*

Stevens, R. G., Brainard, G.C., Blask, D.E., Lockley, S.W., and Motta, M.E. (2013) Adverse Health Effects of Nighttime Lighting. American Journal of Preventive Medicine 45(3), 343–346.

# Non-Visual (Circadian) Light

What properties of light affect non-visual system?

photic history

timing

spectra

intensity

duration

# Non-Visual (Circadian) Light

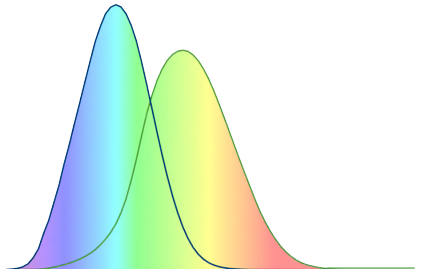
What's happening in the built environment?



# Non-Visual (Circadian) Light

## Visual (Photopic) Light

Calibrated with:
Luminance and / or
Illuminance Meters



## Non-Visual (Circadian) Light

Can be calibrated with:
Spectrophotometers (expensive) or
Colorimeters (CIE XYZ) (feasible)

Jung and Inanici, 2019

# Image Capture

# Image Capture - Equipments

Camera
+ Fisheye Lens
+ Tripod

Spectrophotometer
Colorimeter
(Color calibration)

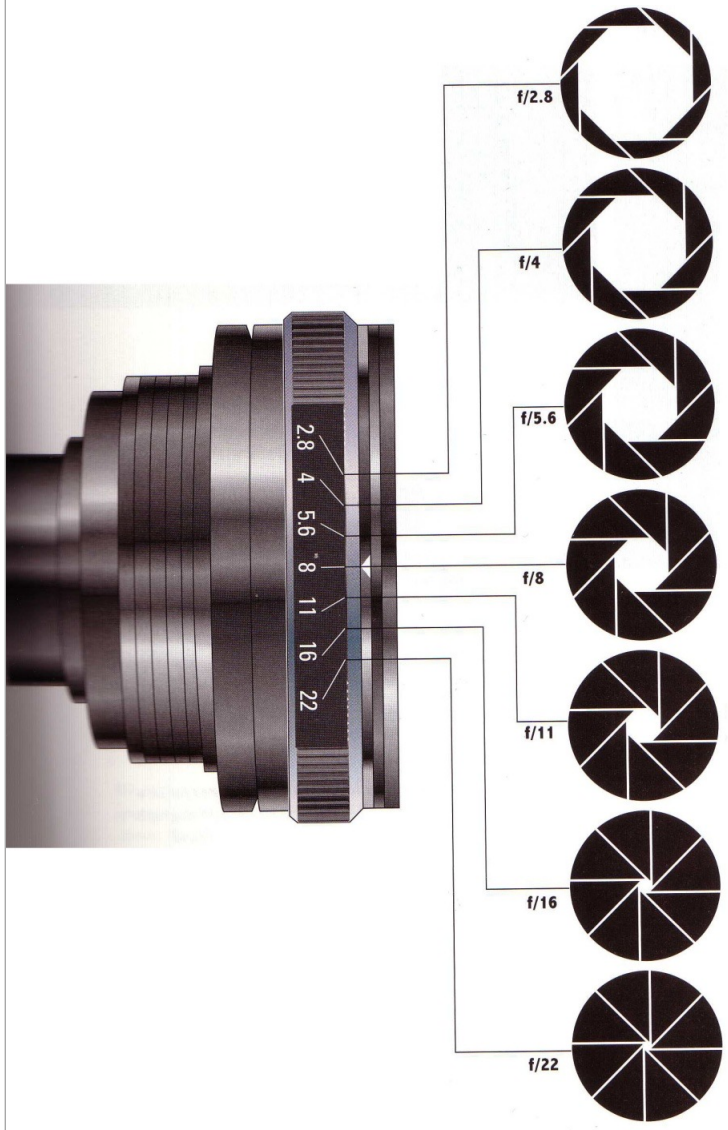
Luminance Meter
(Luminance calibration)

Recommended best practice for HDR Capture:
Jakubiec, van den Wymelenberg, Inanici, Mahic, 2016
Jakubiec A, Inanici M, van den Wymelenberg K, Mahic, 2016
Inanici, 2006

# Image Capture - Equipments

Use Tripod!

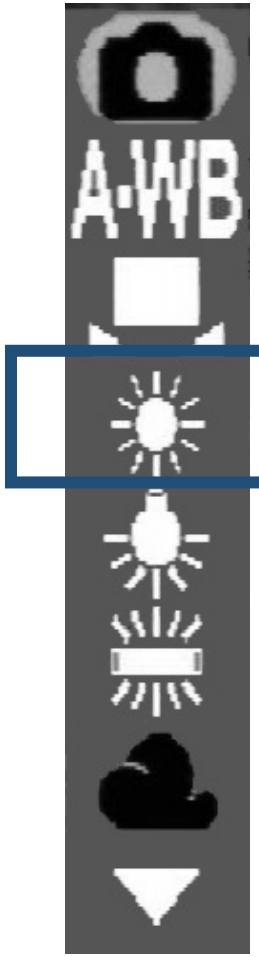
# Image Capture – Recommendations for Interior Views




Accuracy of common interior surfaces vs. the sun

- **f/11 is the recommended aperture size**
- f/11 captures approximately 1,000,000 cd/m$^2$ as max. luminance
- f/4 captures approximately 100,000 cd/m$^2$
- f/22 captures approximately 3,200,000 cd/m$^2$
- f/22 causes significant amount of lens flare, impairing accuracy for the rest of the scene

# Image Capture – Recommendations for interior views




Auto

White Bal Preset

Daylight

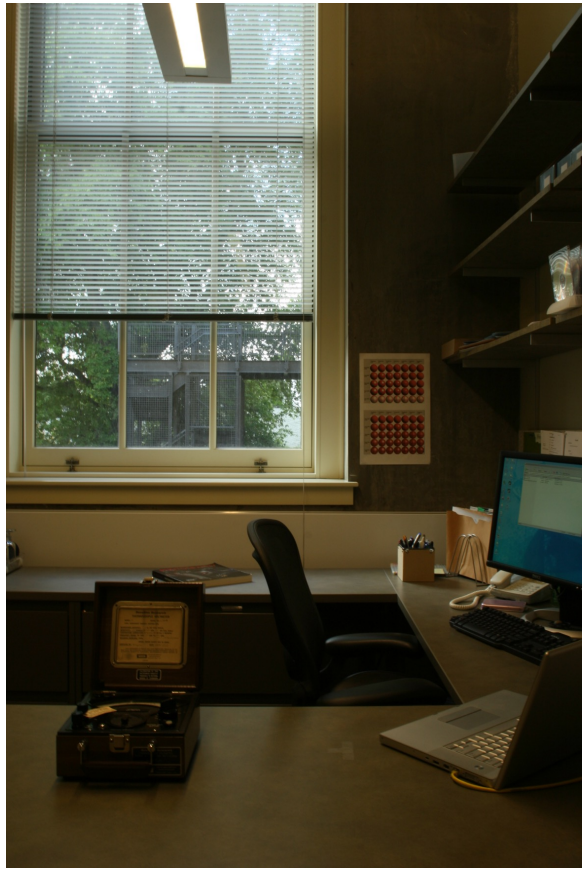
Incandescent

Fluorescent

Cloudy

Set White balance to **Daylight**

# Image Capture – Recommendations for interior views



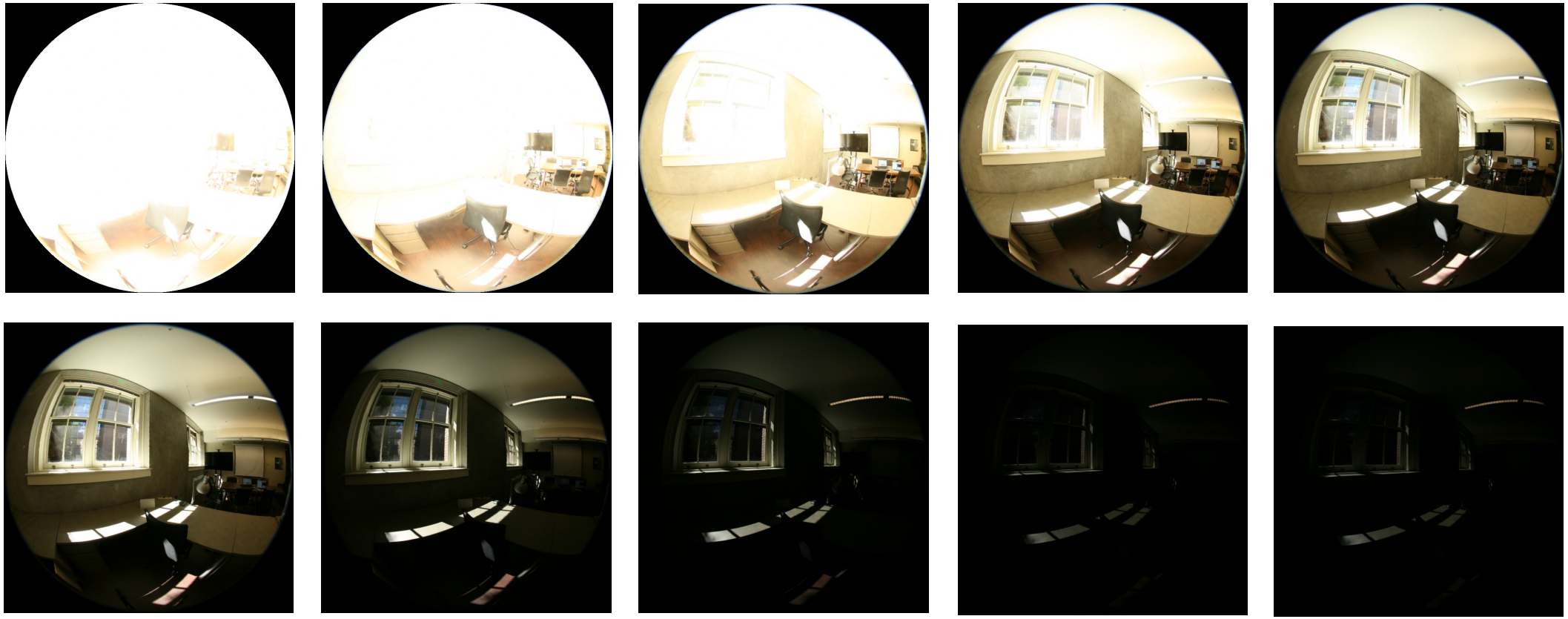
ISO 100

ISO 400

ISO 1000

Set film speed to ISO 100

# Image Capture – Recommendations for interior views



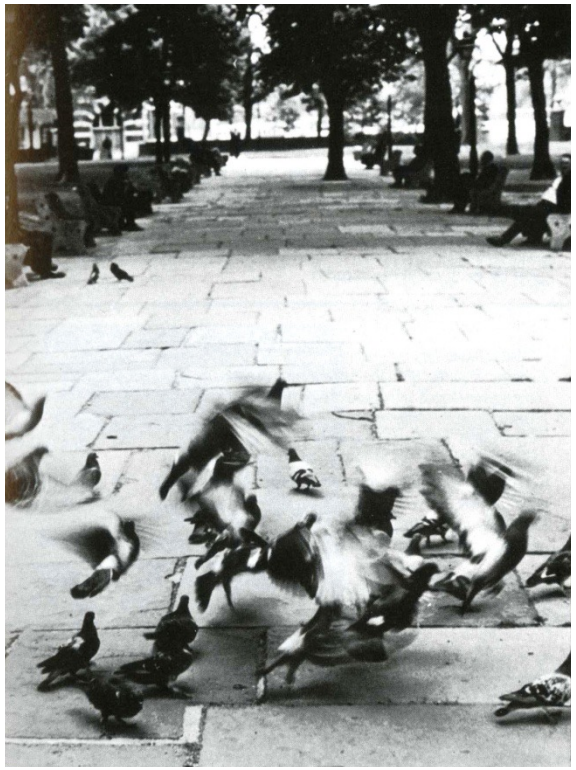
The **overexposed image should not be totally washed with light** and the **under exposed image should not be totally black!**

# Image Capture – Recommendations for interior views

- 1/8000 s
- 1/4000 s
- 1/2000 s
- 1/1000 s
- 1/500 s
- 1/250 s
- 1/125 s
- 1/60 s
- 1/30 s
- 1/15 s
- 1/8 s
- 1/4 s
- 1/2 s
- 1s
- ….
- Bulb

- **Recommended to use full range** (go all the way up to the shortest exposure in the camera). **Extra exposures can be discarded** while merging images
- **Start with a long exposure and take 8+ exposures to cover the range**

# Image Capture – Recommendation



Take photos in **stable environment** (no movement / limited light change)

From “Photography”, by London, Upton, Kobre, Brill

# Image Capture – Calibration Measurements

- Measure a gray card in the scene

  from the position of the camera

# Image Capture – Calibration Measurements

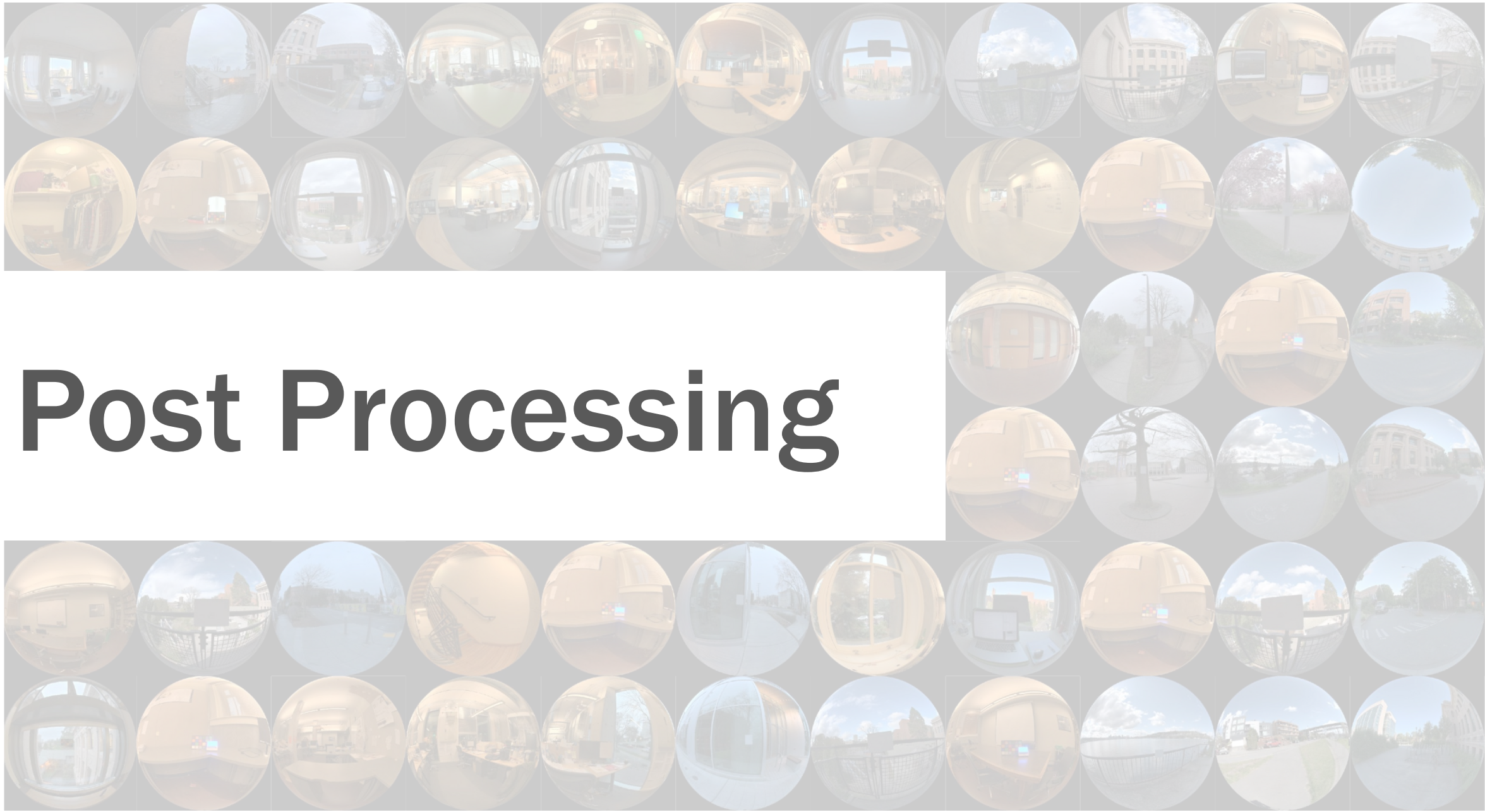
- Measure CIE XYZ at the camera lens

# Image Capture – Calibration Measurements

- Save measurements

# Image Capture – Recap

- Use tripod
- Fix the aperture size (f/11)
- Vary only the shutter speed
- Fix white balance to daylight
- Fix the film speed to ISO 100
- Take photographs in a stable environment (motionless, stable lighting conditions)
- Capture multiple exposures as quickly as possible!



# Post Processing

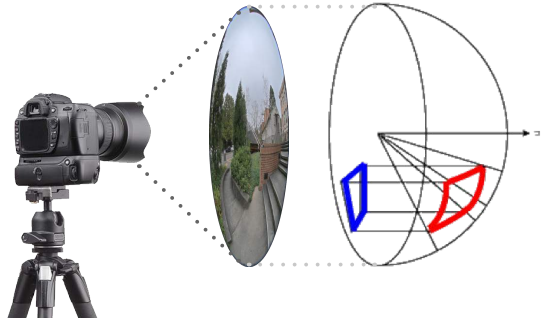
# Post Processing

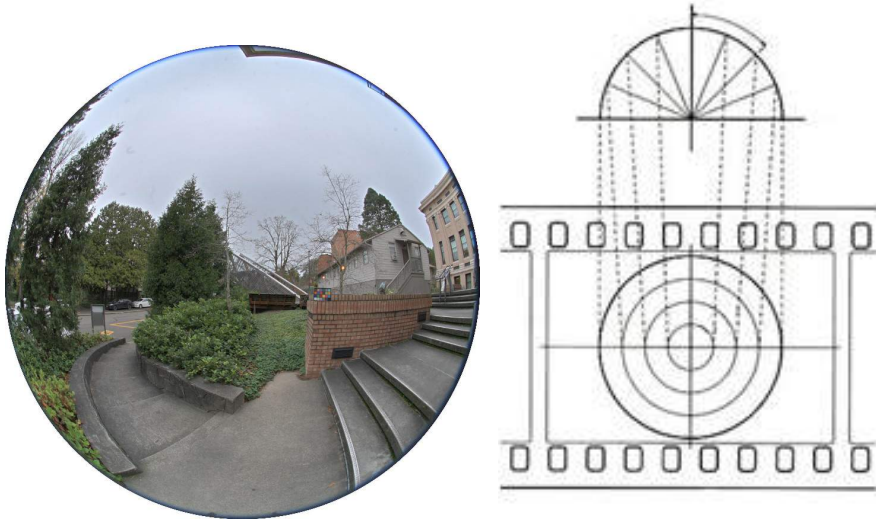
1. Correct for geometric aberrations **LENS SPECIFIC**
2. Original HDR merge + Luminance calibration **CAMERA SPECIFIC**
3. Exposure set to 1
4. Vignetting correction **LENS SPECIFIC**
5. Edit Header
6. Luminous overflow correction (Illuminance calibration – CIE Y)
7. Clean Header
8. Color calibration **CAMERA SPECIFIC** (only for camera specific calibration method)
9. Calculate Melanopic Luminance
10. Clean Header
11. Calculate Melanopic Illuminance

*Going through these steps produces both photopic and melanopic HDR*

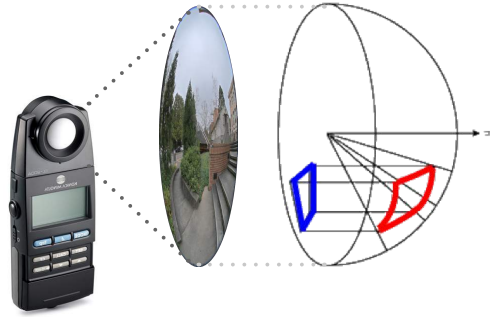
# Post Processing – 1. Correct for Geometric Abberations

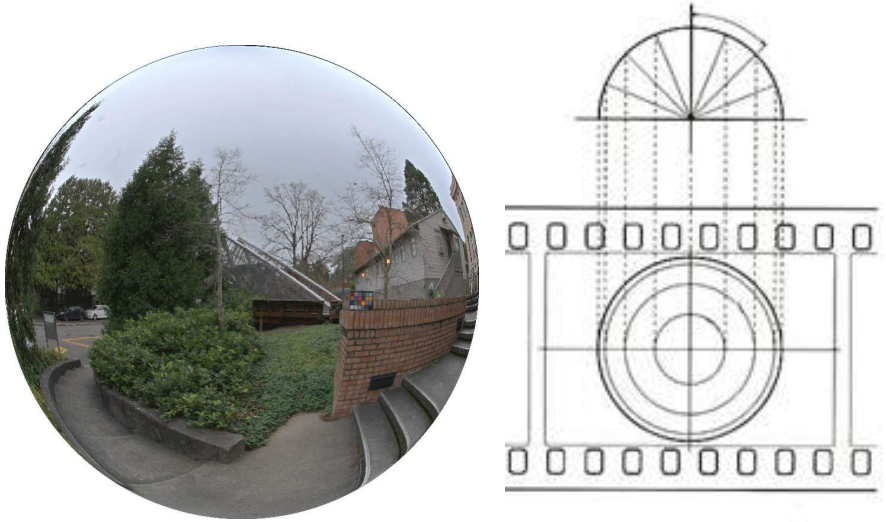
**Equidistant** Projection





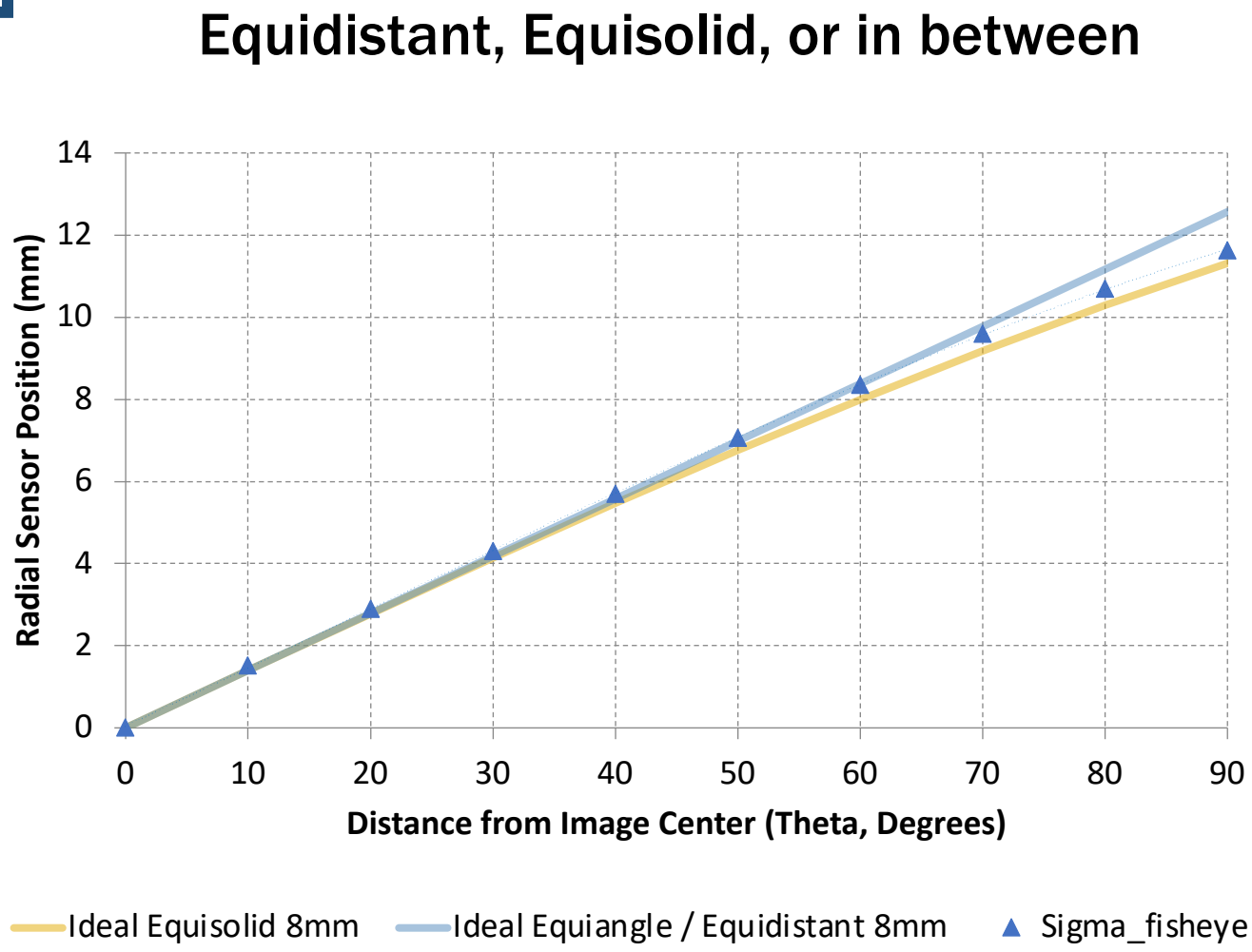
**Equisolid** Projection
**Hemispherical** / **Cosine corrected**



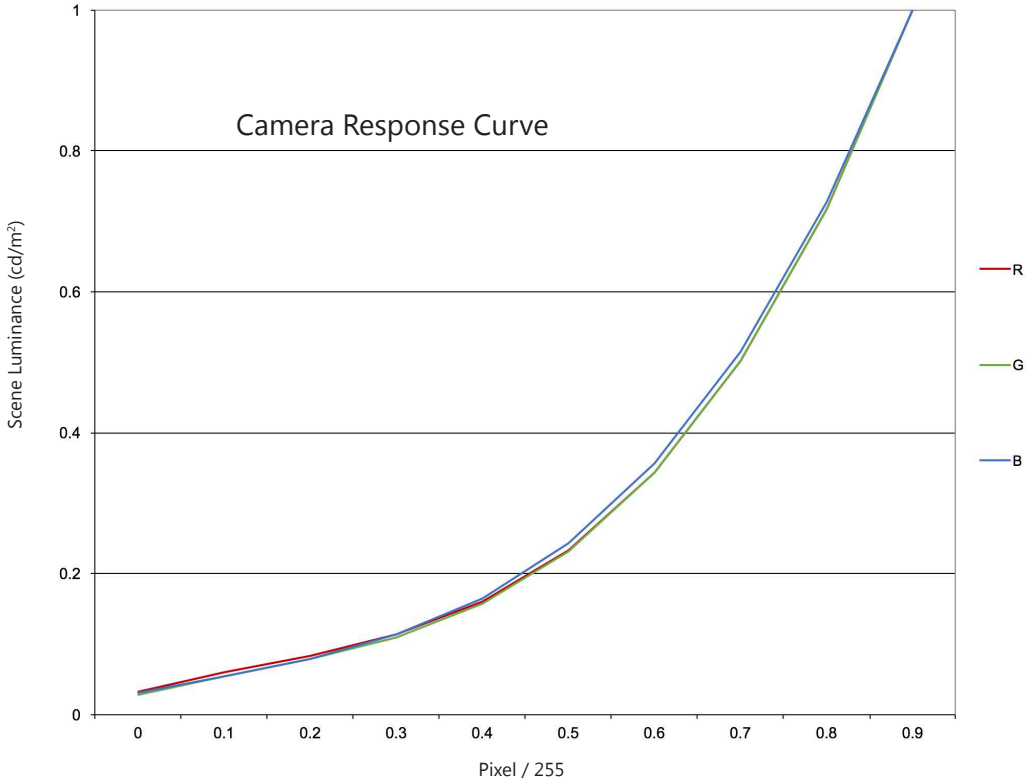


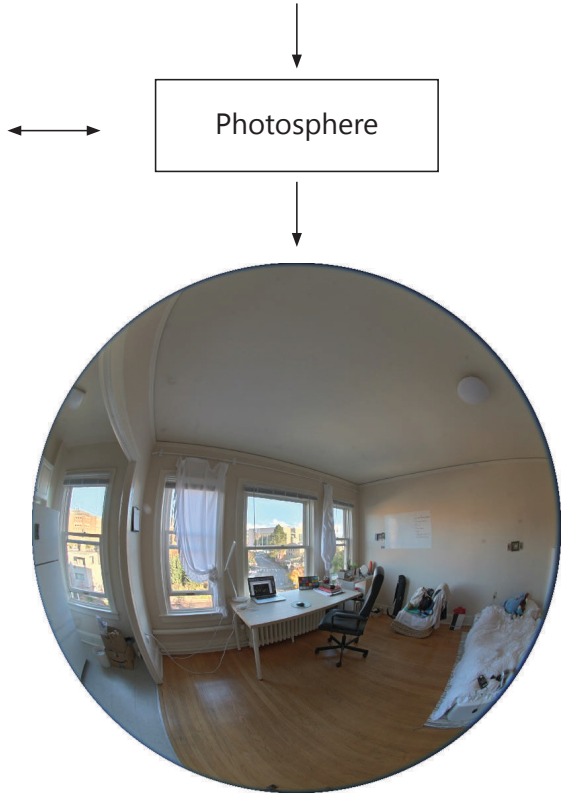
# Post Processing – 1. Correct for Geometric Abberations

LENS SPECIFIC



# Post Processing – 2. Merge HDR + Luminance Calibration

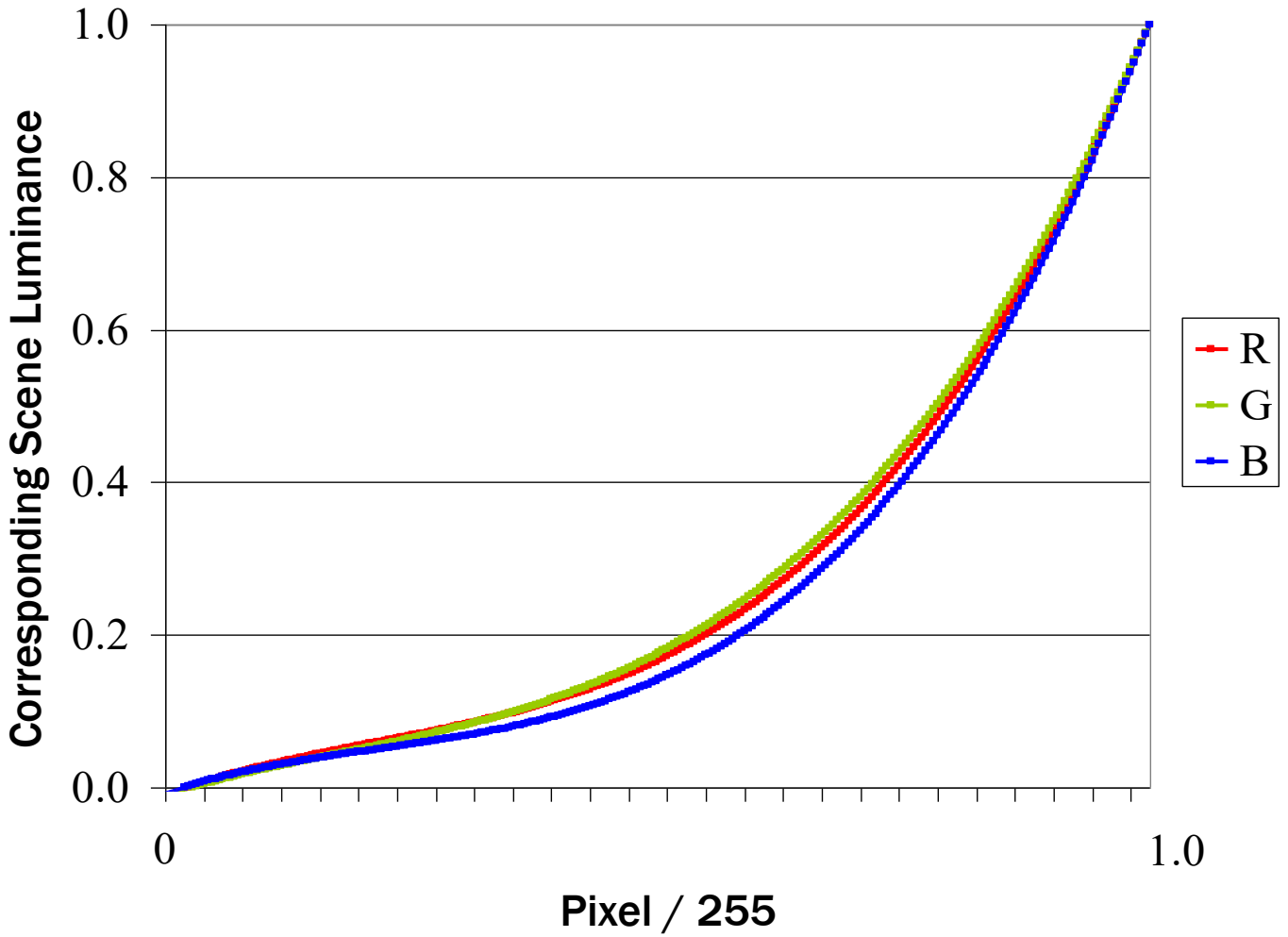


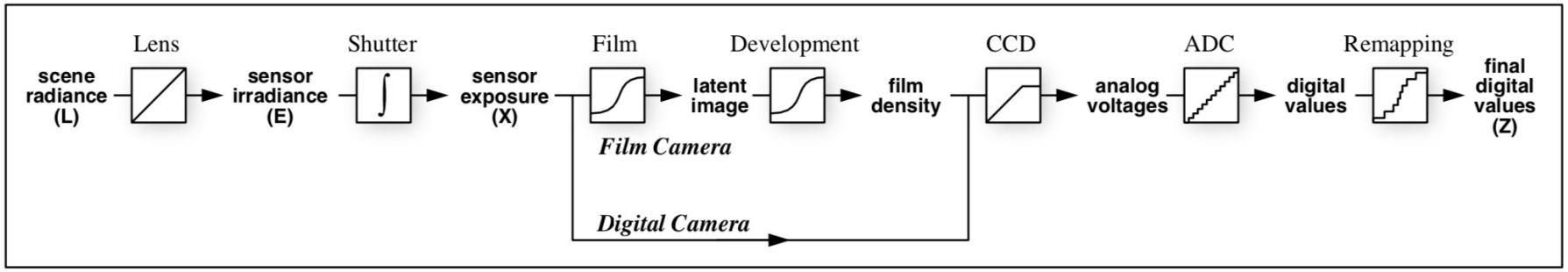
# Post Processing – 2. Merge HDR + Luminance Calibration

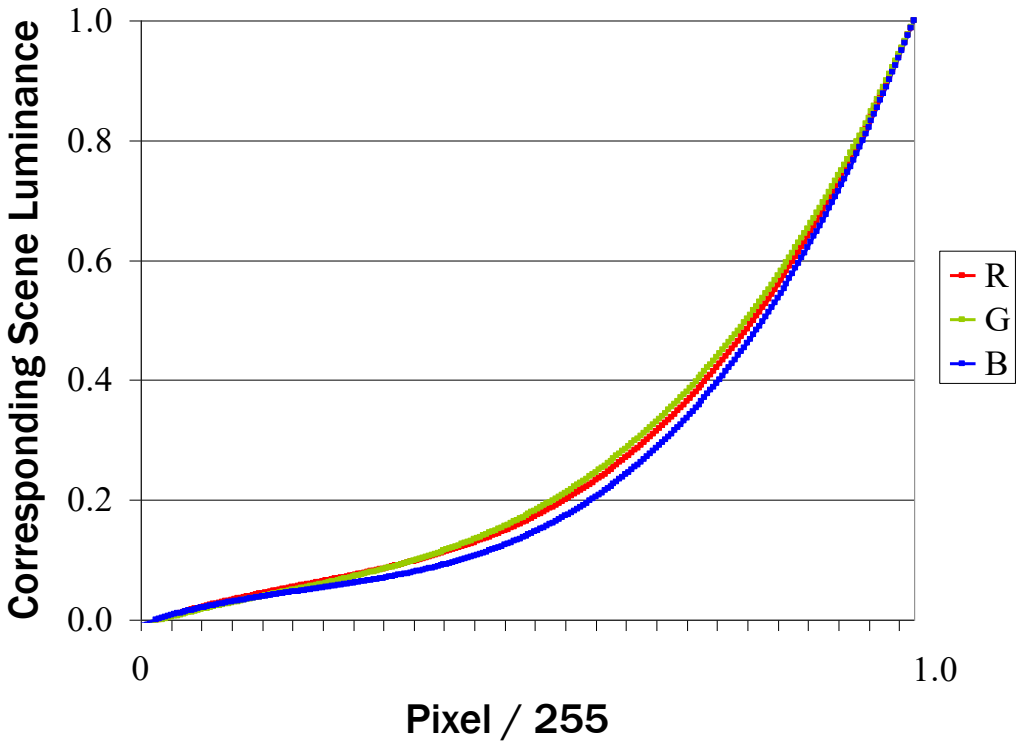
**CAMERA SPECIFIC**

$$R = 1.53994x^3 - 0.99492x^2 + 0.46536 - 0.01037$$
$$G = 1.31795x^3 - 0.69784x^2 + 0.38994 - 0.01005$$
$$B = 1.67667x^3 - 1.09256x^2 + 0.42334 - 0.00745$$



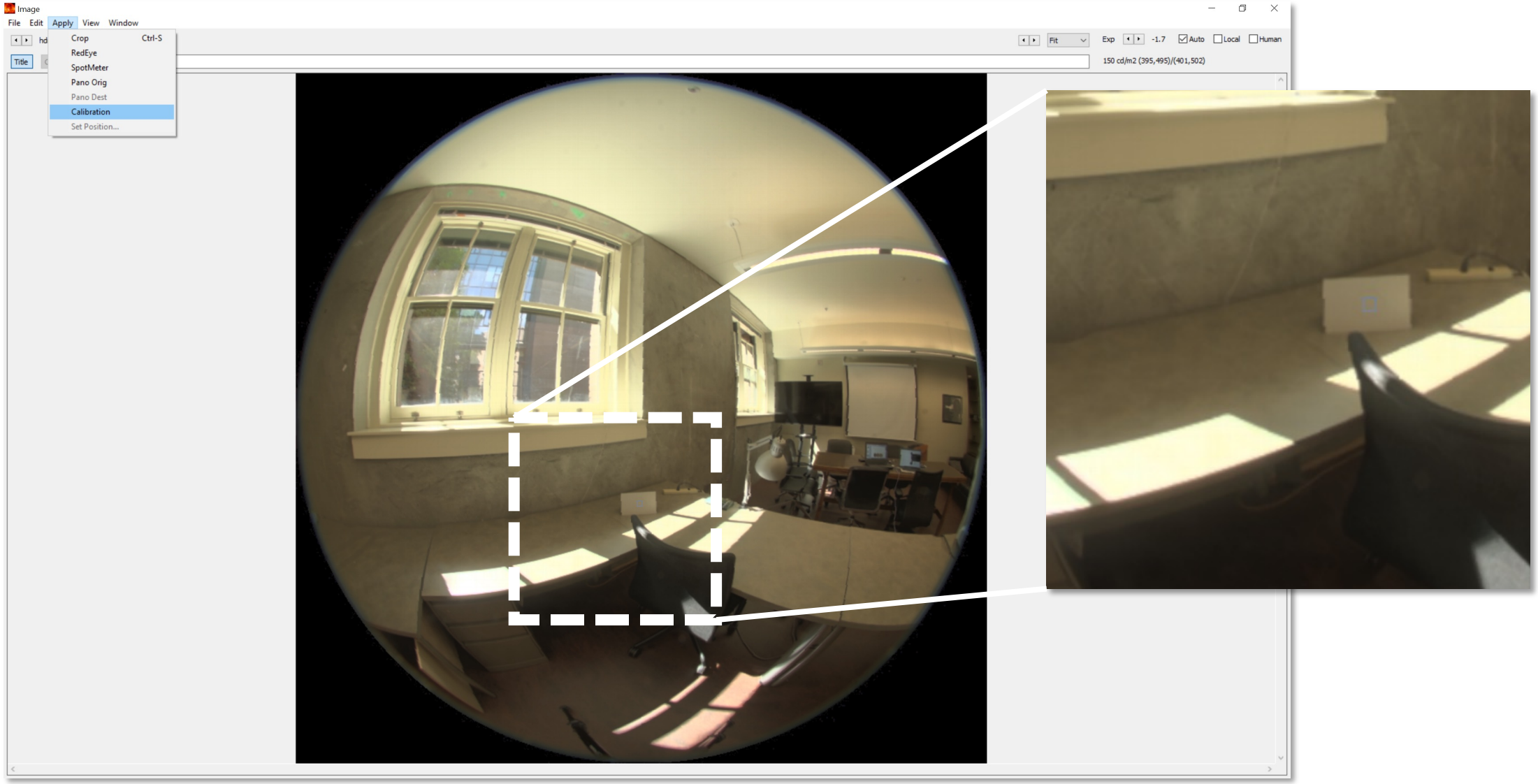
# Post Processing – 2. Merge HDR + Luminance Calibration




Debevec, P.E., Malik J., (1997). From Recovering high dynamic range radiance maps from photographs. *Proceedings of the 24th annual conference on computer graphics and interactive techniques*, 369-378.

# Post Processing – 2. Merge HDR + Luminance Calibration



# Post Processing – 2. Merge HDR + Luminance Calibration

If fixing geometric aberration is not needed:

1. merge the HDR (through Photosphere)
2. crop the image

***pcompos -h -x 800 -y 800 file_name.hdr -525 0 > new_file_name.hdr***

crop size

x-axis cut pixel point
(lower left corner)

3. resize the image

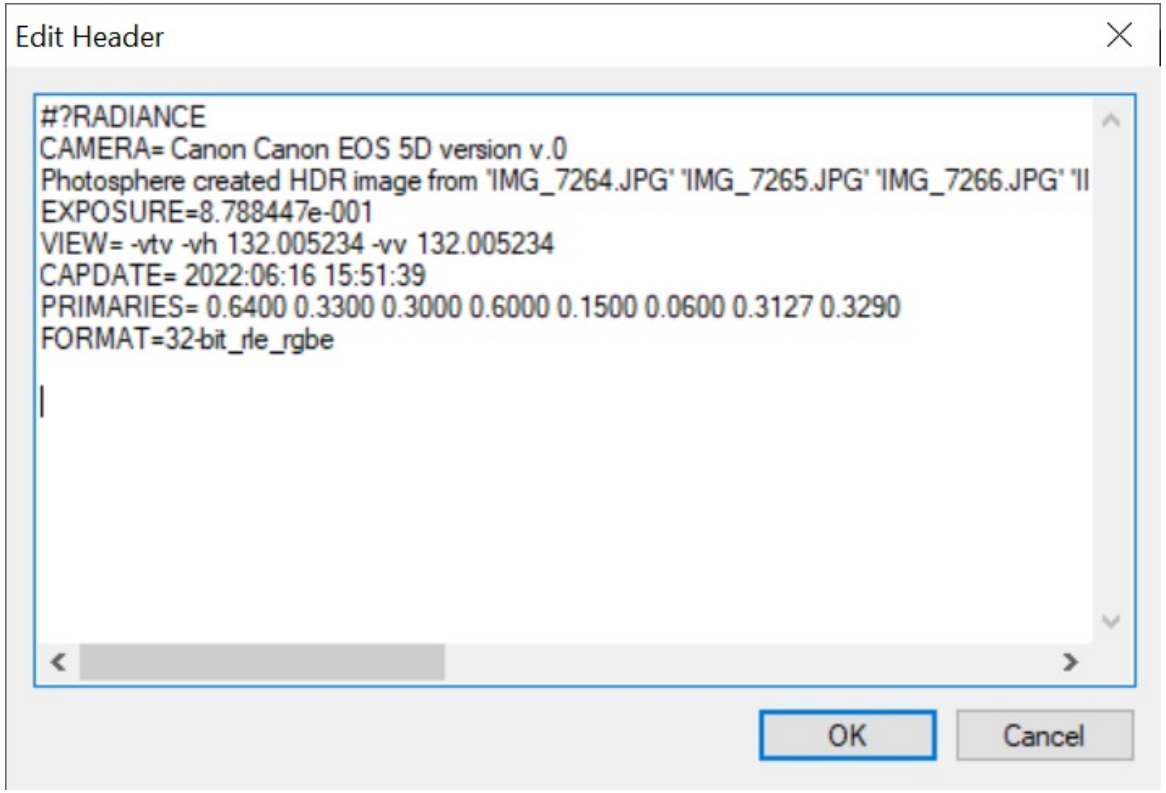
***pfilt –x 800 –y 800 –e 1 file_name.hdr > new_file_name.hdr***

Note that the location of the crop varies based on camera and lens

# Post Processing – 3. Set Exposure to 1

**Exposure set to 1**

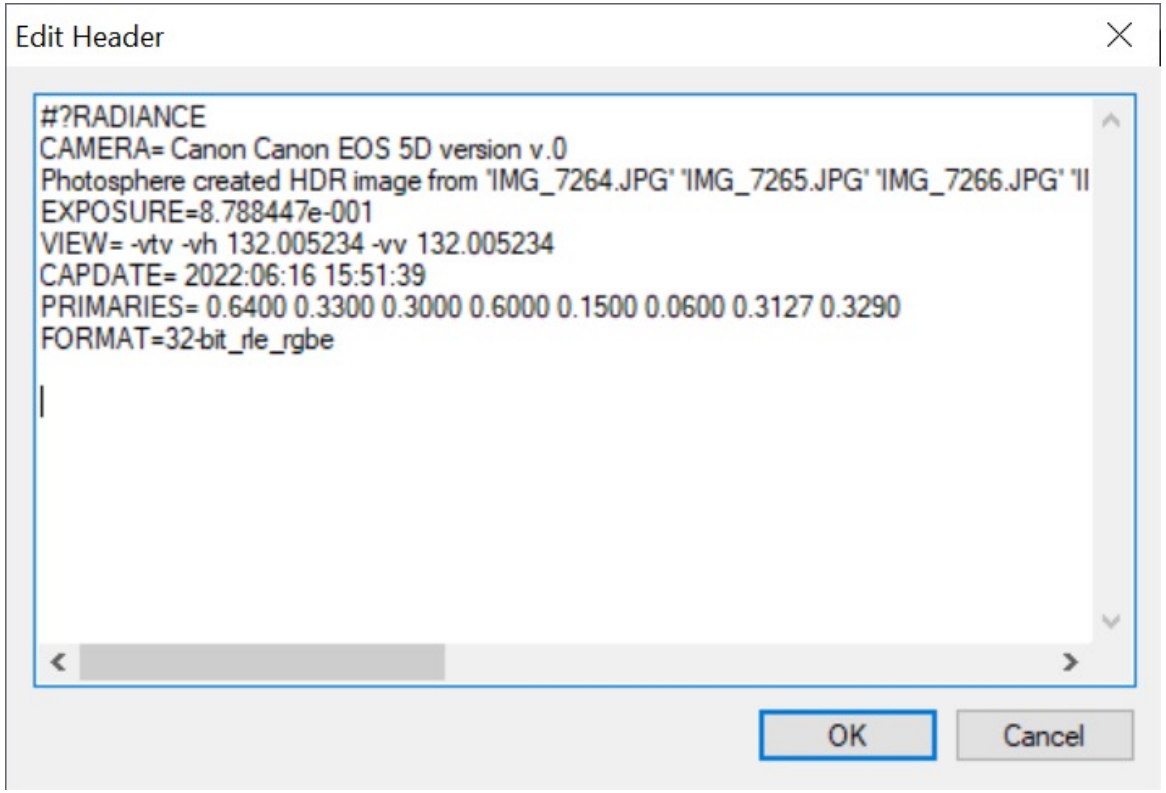
ra_xyze -r -o image.hdr > exp_image.hdr



# Post Processing – 3. Set Exposure to 1

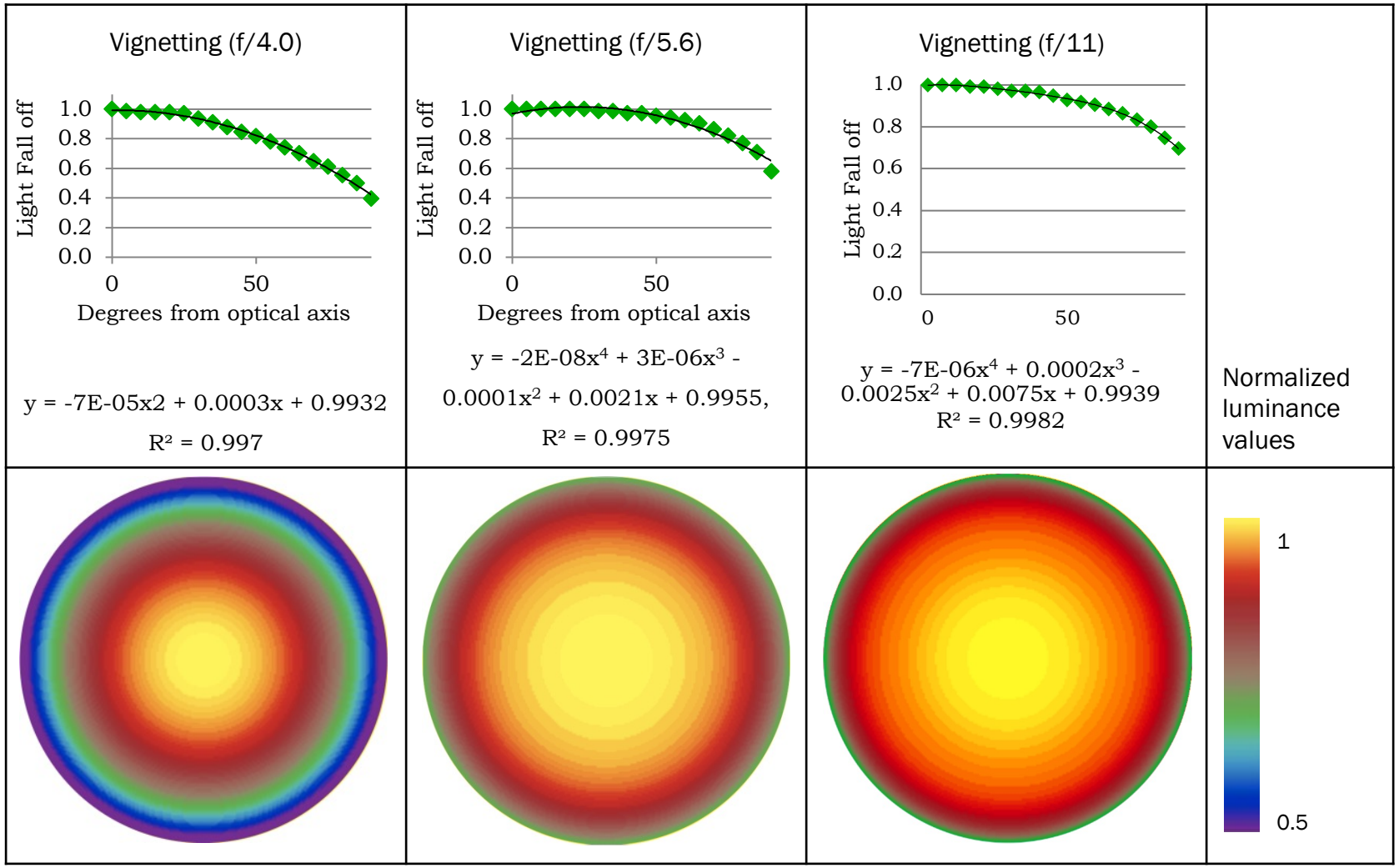
**Exposure set to 1**

ra_xyze -r -o image.hdr > exp_image.hdr



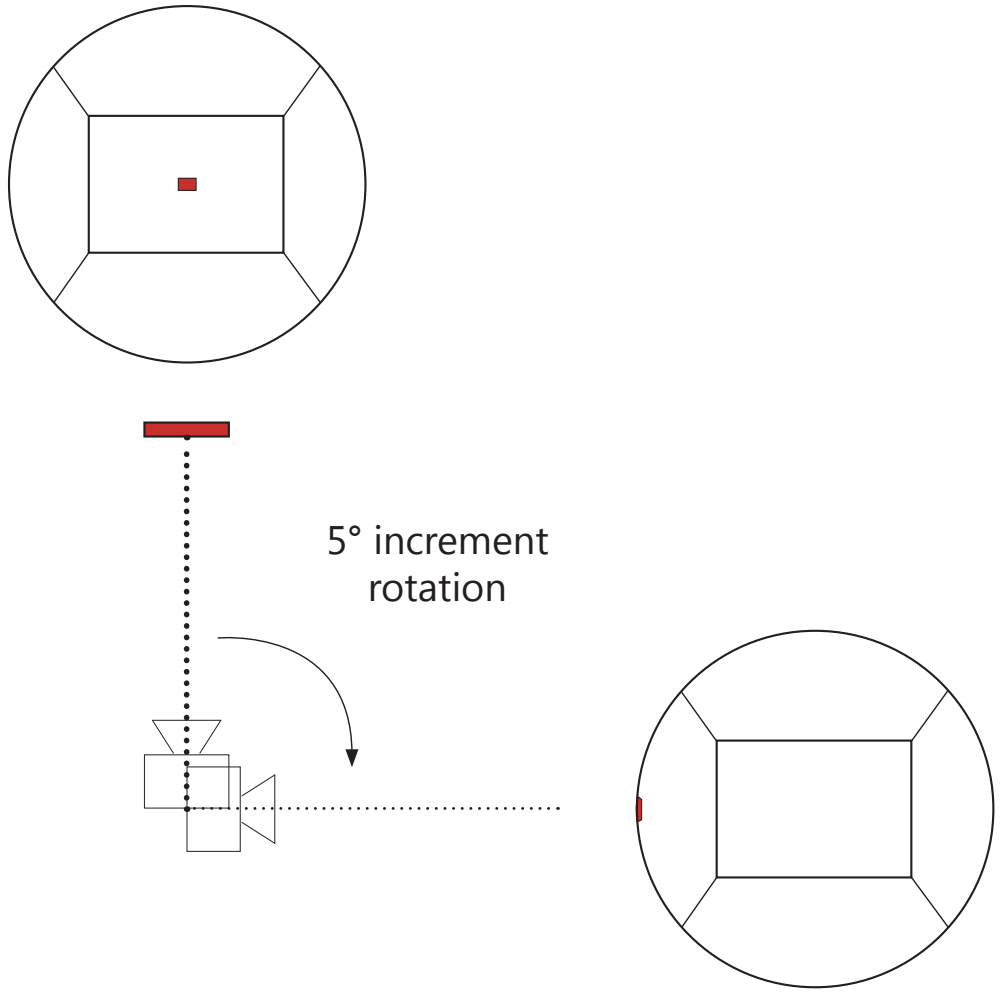
# Post Processing – 4. Vignetting Correction

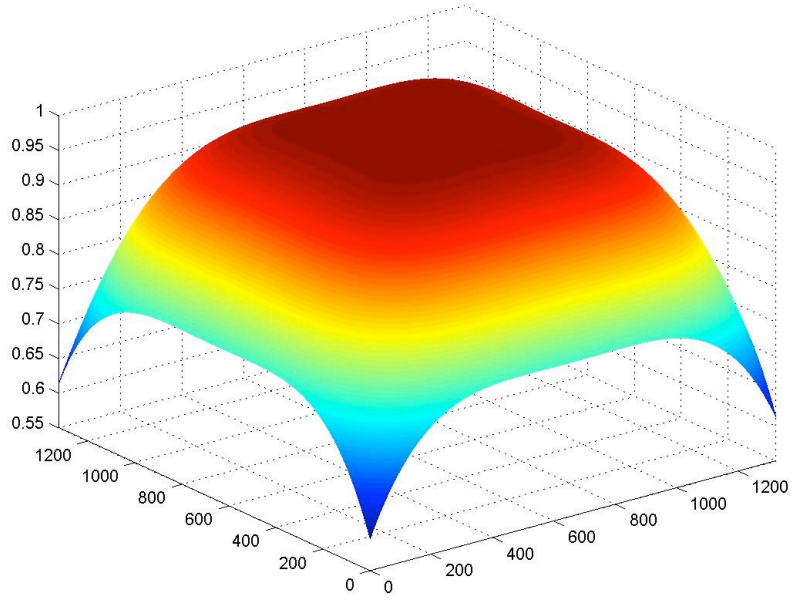
LENS SPECIFIC



# Post Processing – 4. Vignetting Correction

**LENS SPECIFIC**



# Post Processing – 4. Vignetting Correction

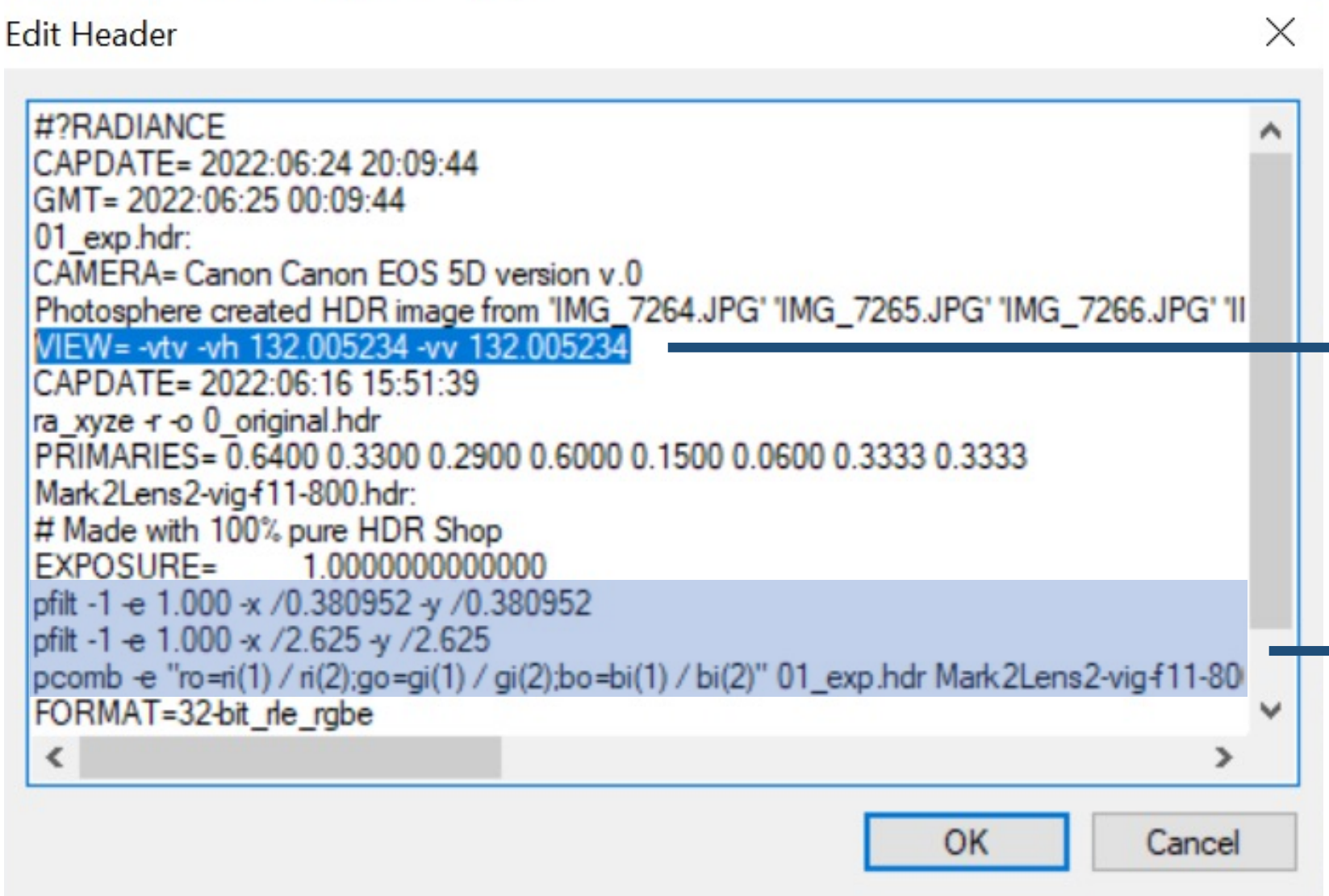
If the vignetting function is:

**y = -0.0000005x3 + 0.000004x2 + 0.0002x + 0.9991**

An example correction for 800 pixel image is:

**pcomb -e "ro=vign;go=vign;bo=vign;vign=if(dist-400.0,1,eq);eq=-0.0000005*deg^3+0.000004*deg^2+0.0002*deg+0.9991;deg=(dist/400.0)*90.0;dist=sqrt((x+0.5-400-.0)^2+(y+0.5-400.0)^2);" 800_vta.pic > vignetting.pic**

# Post Processing – 5. Change Header

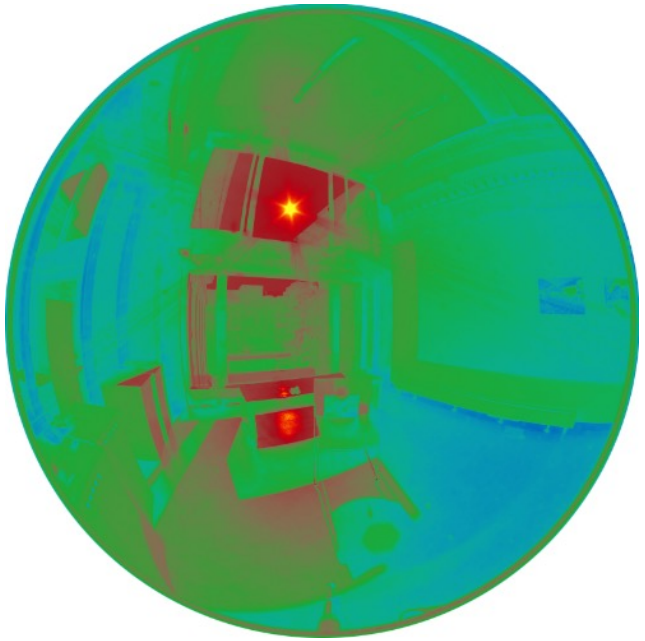



View Info - Change

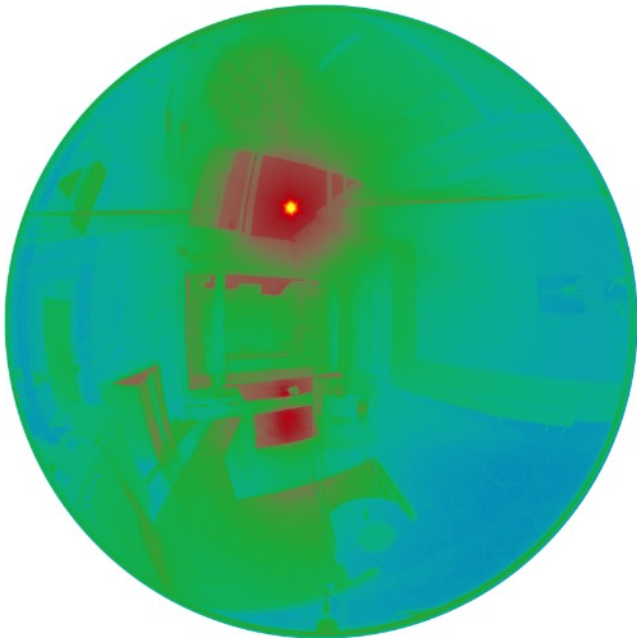
Additional Info - Delete

# Post Processing – 6. Luminous Overflow Correction

Max Captured Luminance
around circumsolar region



f/11 & No Filter
~1 million cd/m$^2$



f/11 & ND3
~272 million cd/m$^2$


*Jakubiec, Inanici, van den Wymelenberg, Mahic 2016*

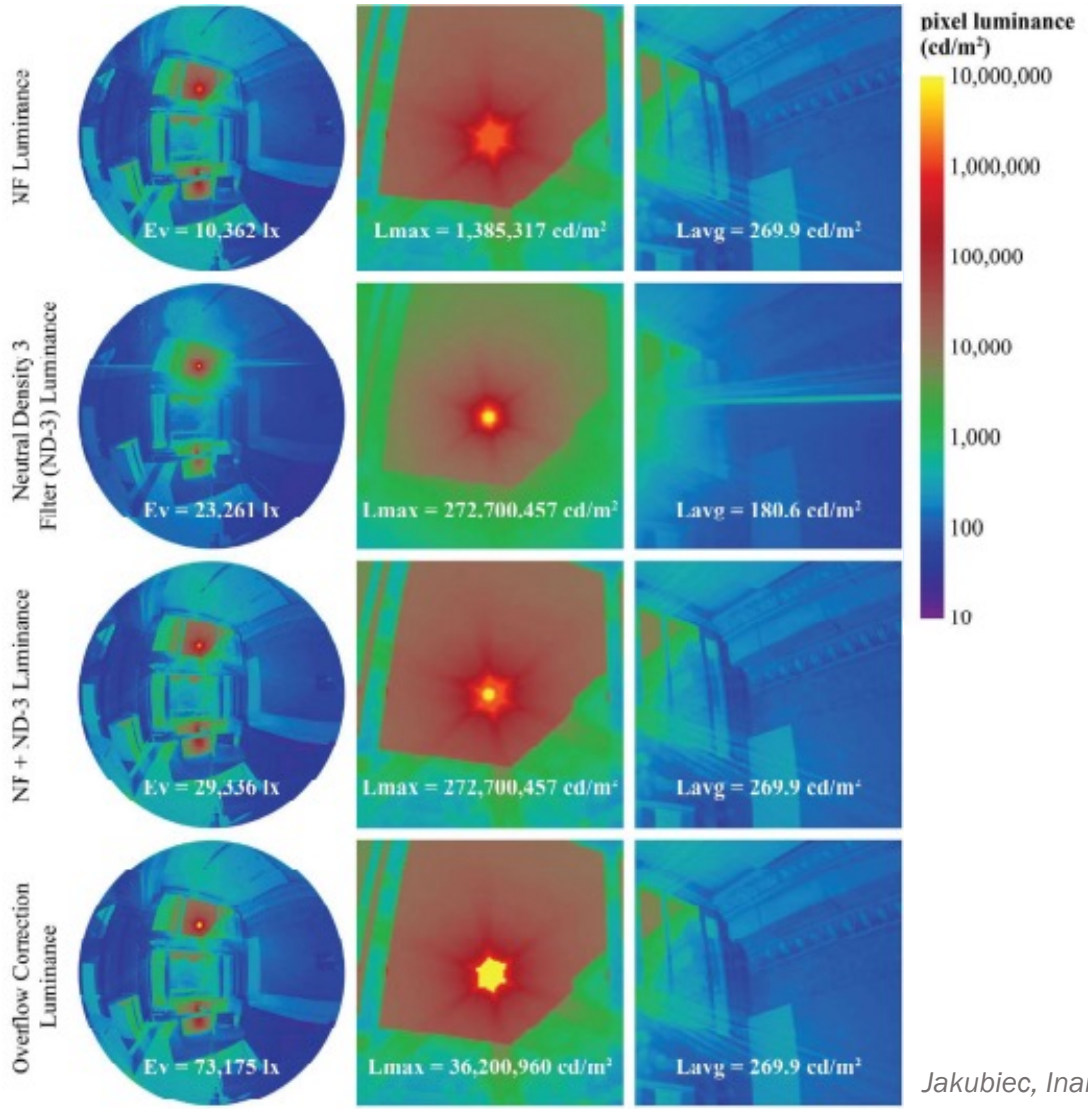
# Post Processing – 6. Luminous Overflow Correction

A. No filter f/11

B. ND3 with f/11

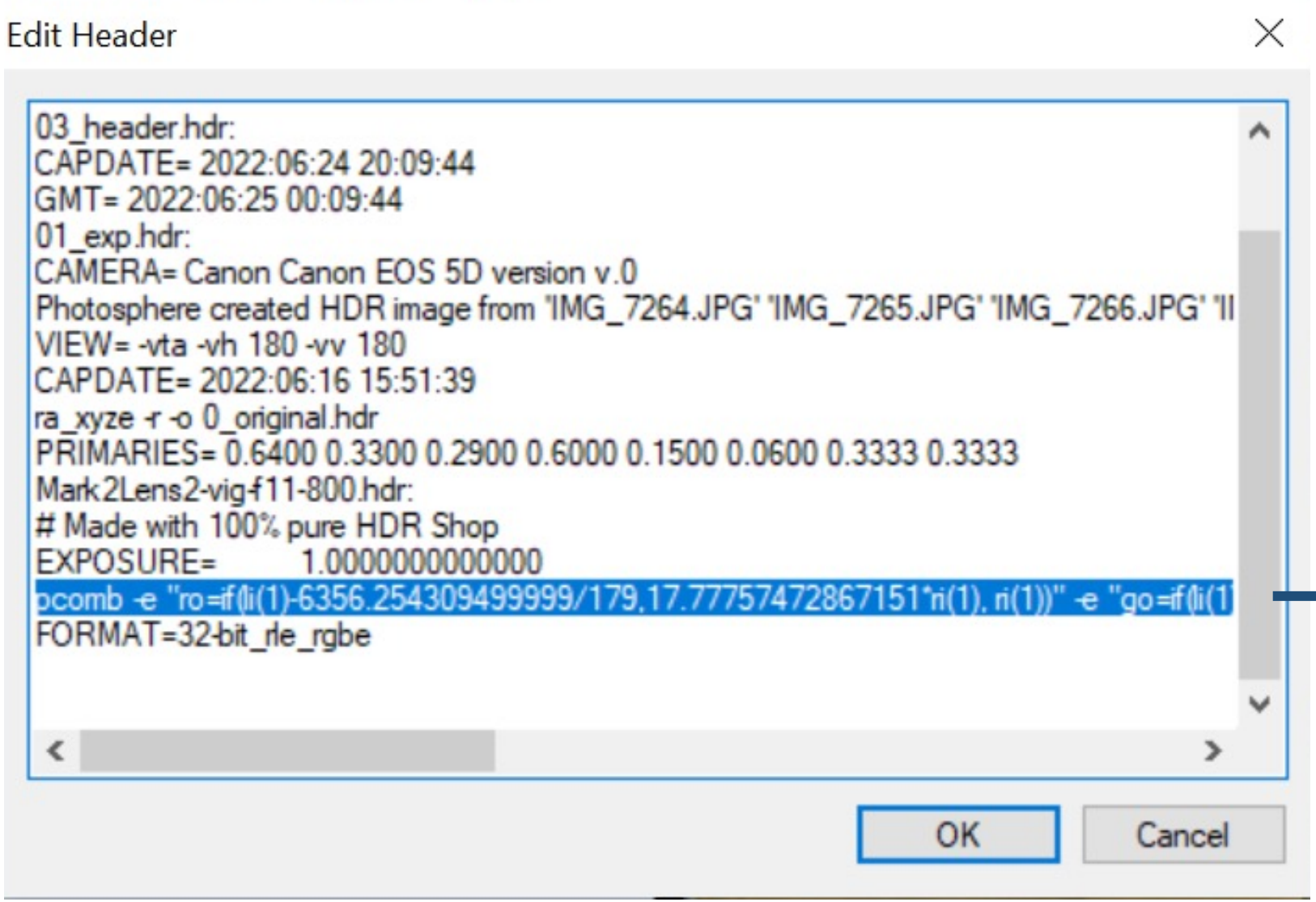
C. Partial combinations of
no filter and ND3 with f/11

D. Luminous overflow correction




*Jakubiec, Inanici, van den Wymelenberg, Mahic 2016*

# Post Processing – 7. Header Clean up



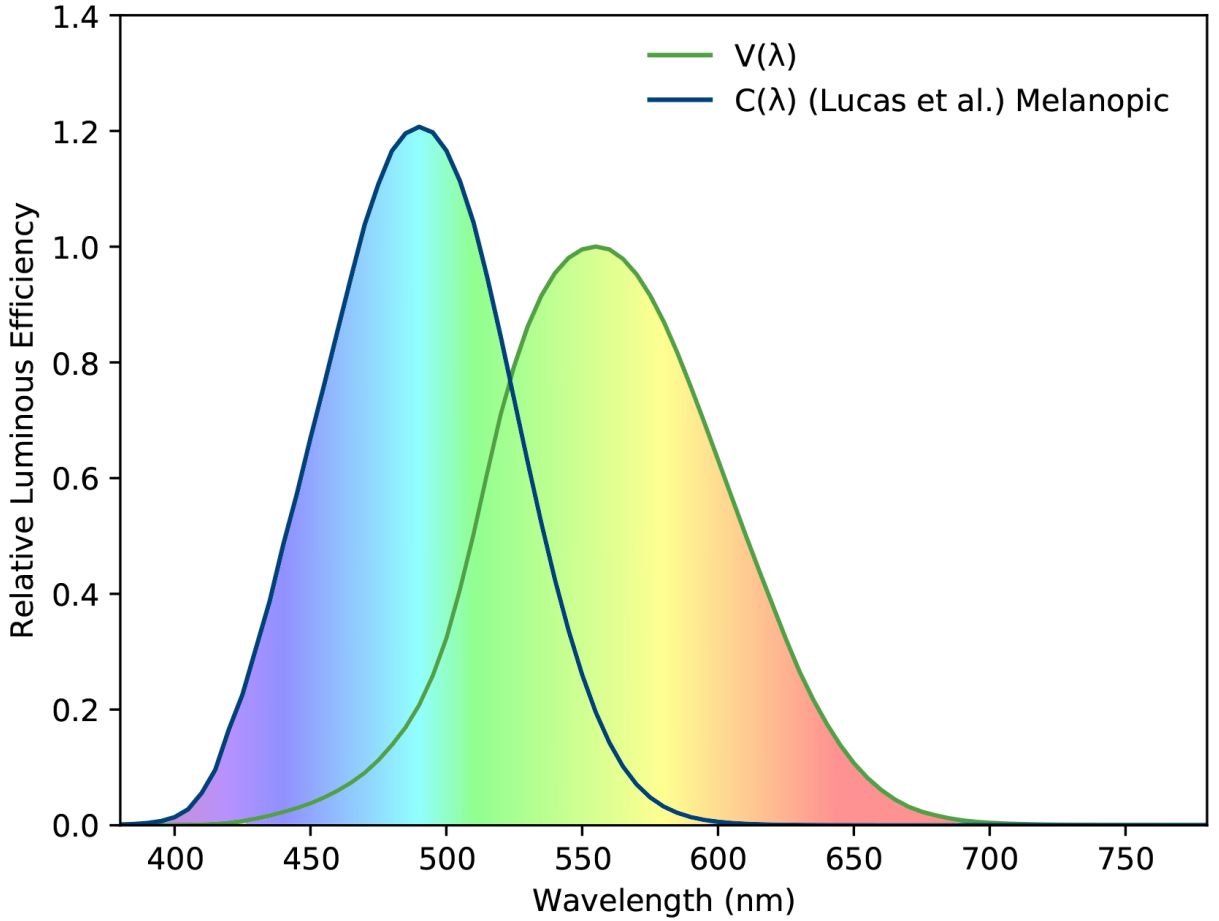

Additional Info - Delete

# Post Processing – 8. Color Calibration

sRGB

vs.

CIE XYZ



# Post Processing – 8. Color Calibration

**1. Camera-based (using series of HDR photographs)**

- Approximately within 10% error margin
- Doesn’t need colorimeter after calibration

**2. Scene based (using simultaneous XYZ measurements)**

- Approximately within 1-2% error margin
- Requires colorimeter for each scene for calibration

# Post Processing – 8. Color Calibration: (a) Camera Based

collection period : 2 month
total no. data : 33
collection location : Seattle

# Post Processing – 8. Color Calibration: (a) Camera Based


Extract Pixel RGB value

Calculate Mean RGB * π

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

| 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 |
| . | . | . |
| . | . | . |

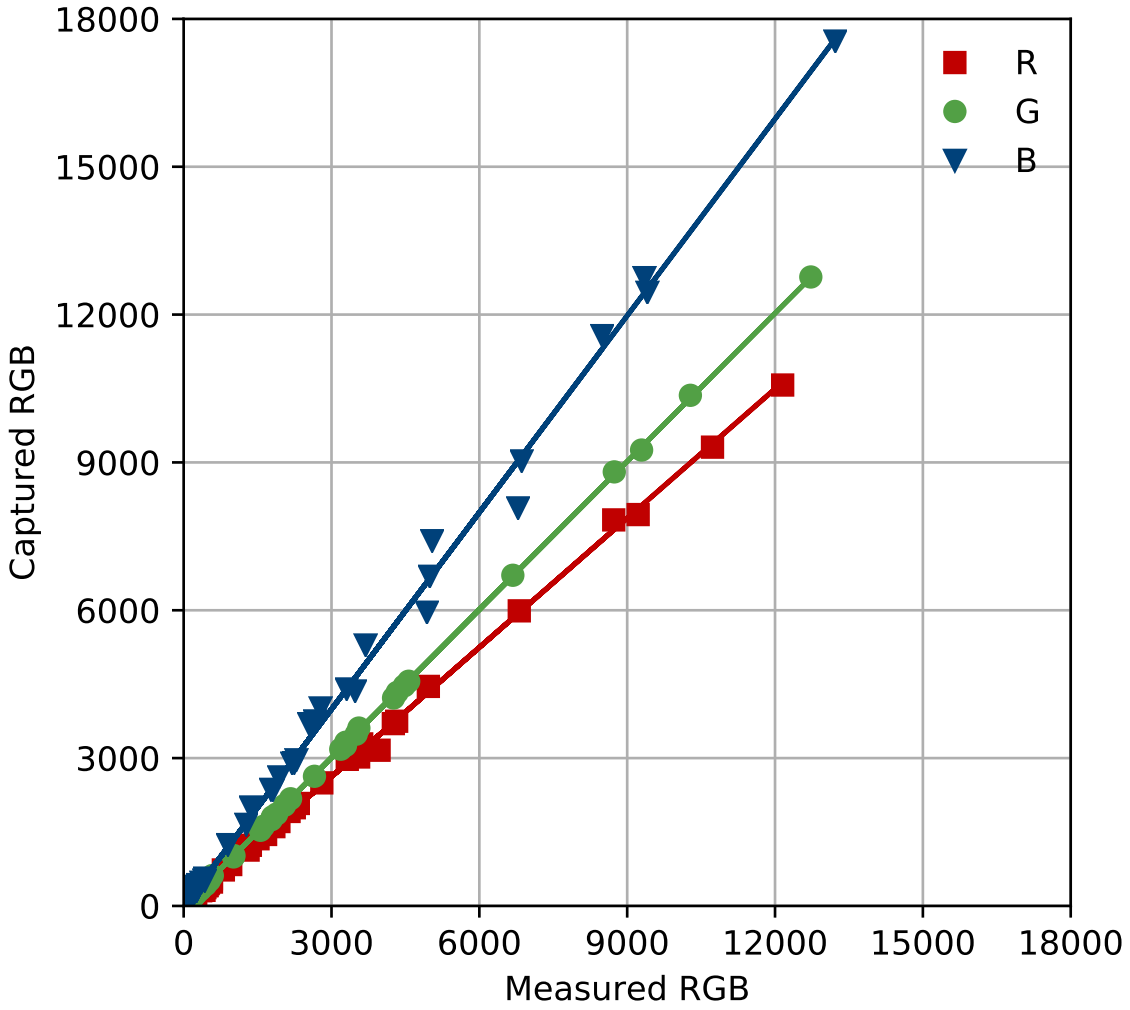
convert measured XYZ to RGB

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)

(sRGB) reference primaries

compare measured and captured RGB values

# Post Processing – 8. Color Calibration: (a) Camera Based




original img data

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

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

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

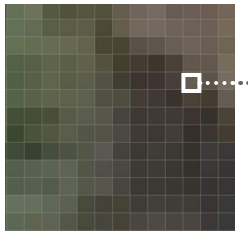
*Correction Coefficient*

calibrated img data

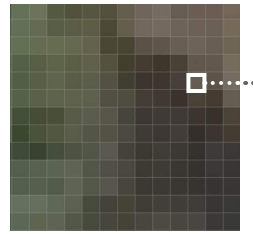
$R = 1\ x$
$R_{cal} = 1.1438 * R$

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

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



R = 100
G = 91
B = 83



R = 114
G = 91
B = 62

# Post Processing – 8. Color Calibration: (b) Scene Based

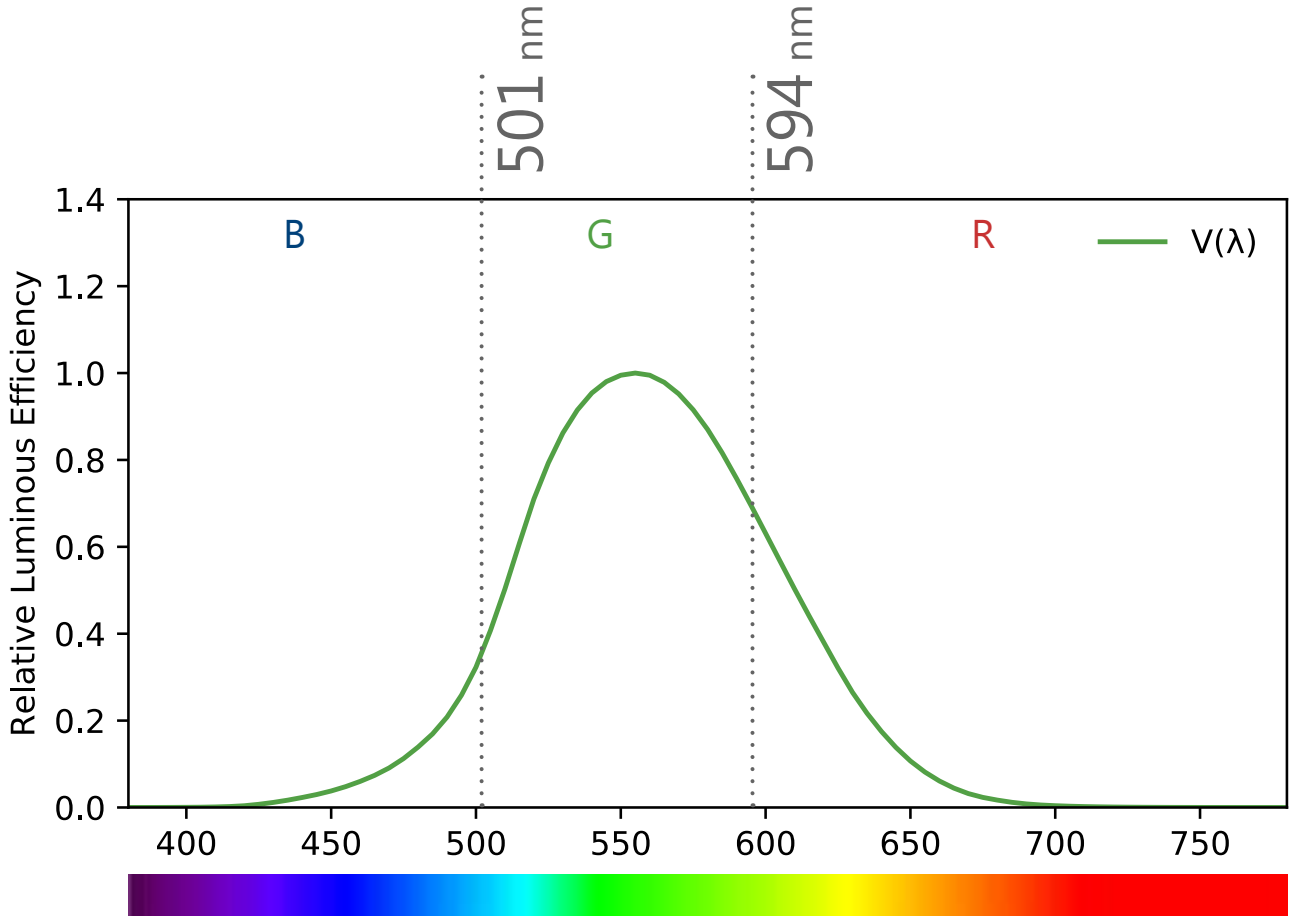
## XYZ is calculated from images (cosine corrected) - for verification

```
pcomb -e "lo=X*Sang*cosCos;X=(179*(ri(1)*0.4124 + gi(1)*0.3576 + bi(1)*0.1805));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total > XYZ.txt

pcomb -e "lo=Y*Sang*cosCos;Y=(179*(ri(1)*0.2127 + gi(1)*0.7152 + bi(1)*0.0722));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total >> XYZ.txt

pcomb -e "lo=Z*Sang*cosCos;Z=(179*(ri(1)*0.0193 + gi(1)*0.1192 + bi(1)*0.9505));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total >> XYZ.txt
```

## RGB is calculated from images (cosine corrected) – for correction factors

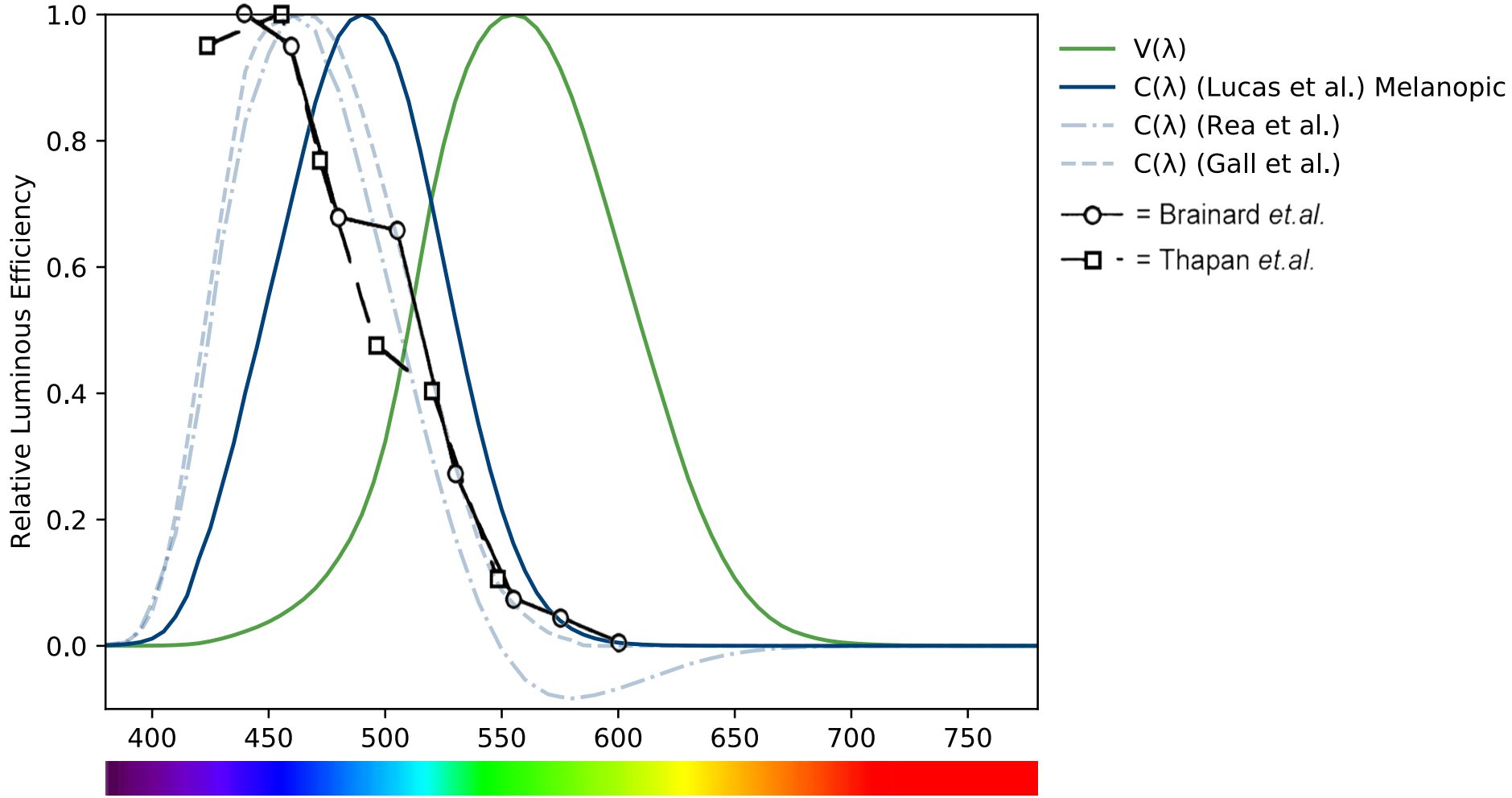
```
pcomb -e "lo=R*Sang*cosCos;R=(179*(ri(1)));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total > RGB.txt

pcomb -e "lo=G*Sang*cosCos;G=(179*(gi(1)));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total >> RGB.txt

pcomb -e "lo=B*Sang*cosCos;B=(179*(bi(1)));Sang=S(1);cosCos=Dy(1);" -o 04_overflow_cor.hdr |pvalue -d -b -h -H | total >> RGB.txt
```

# Post Processing – 9. Calculate Melanopic Luminance

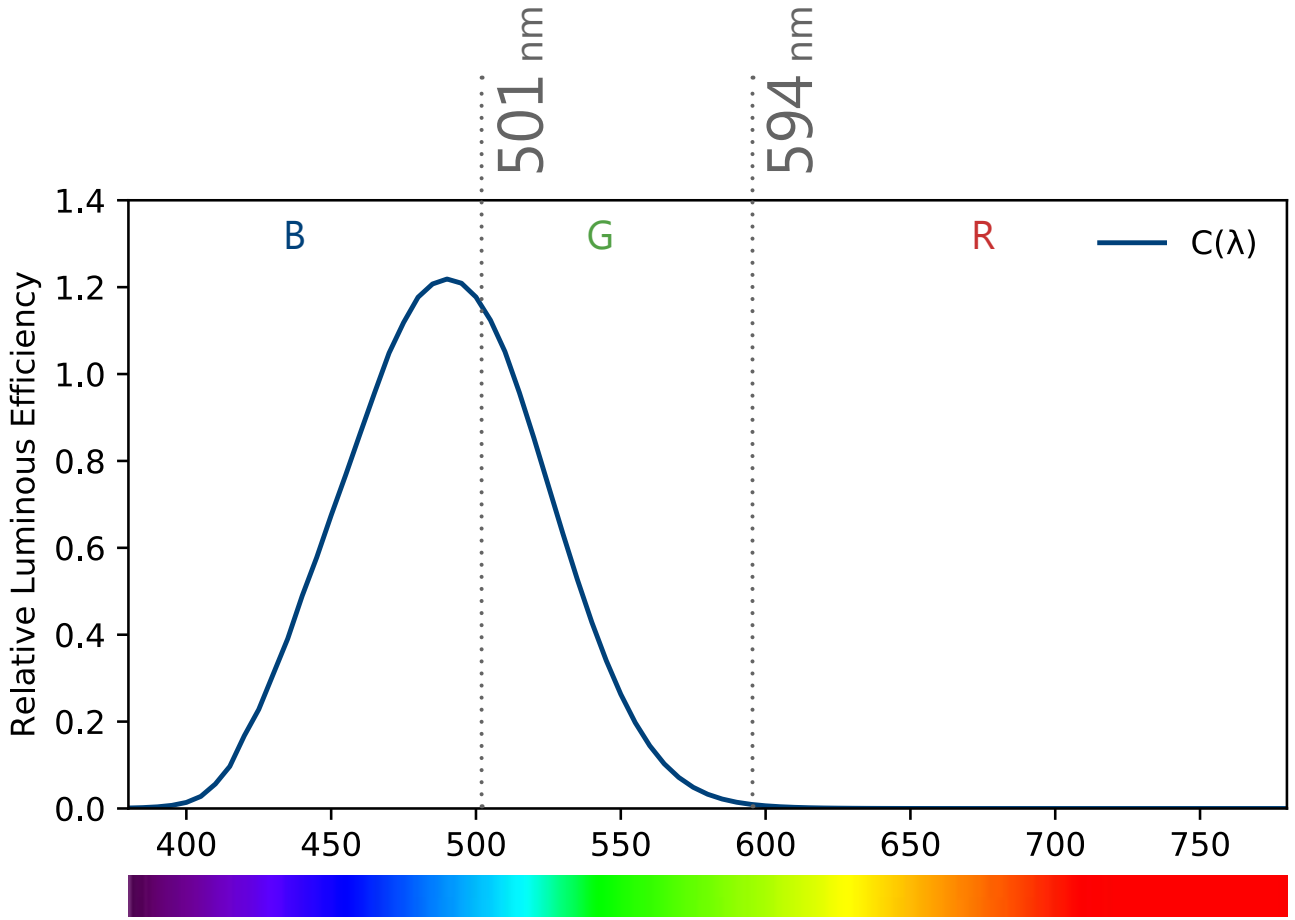



Photopic luminance = 179 * ((0.2621 * R) + (0.7166 * G) + (0.0713 * B))

# Post Processing – 9. Calculate Melanopic Luminance



# Post Processing – 9. Calculate Melanopic Luminance

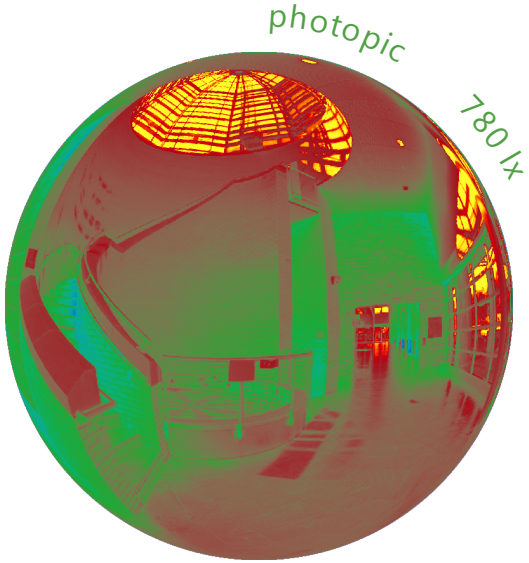


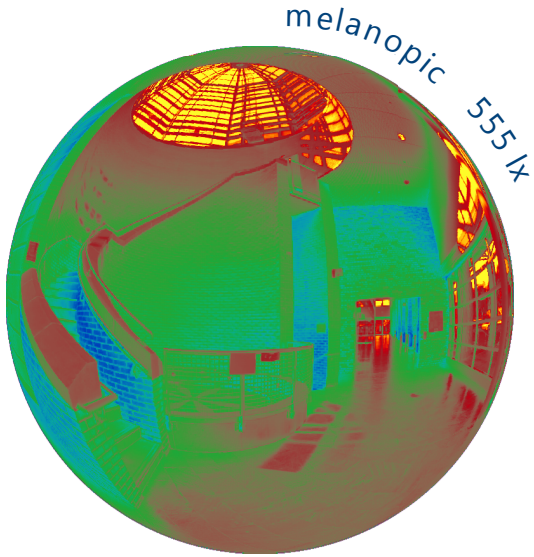

Melanopic luminance = 179 * ((0.0013 * R) + (0.3812 * G) + (0.6175 * B))

# Post Processing – 9. Calculate Melanopic Luminance

photopic

179 * ((0.2121 * R) + (0.7166 * G) + (0.0713 * B))



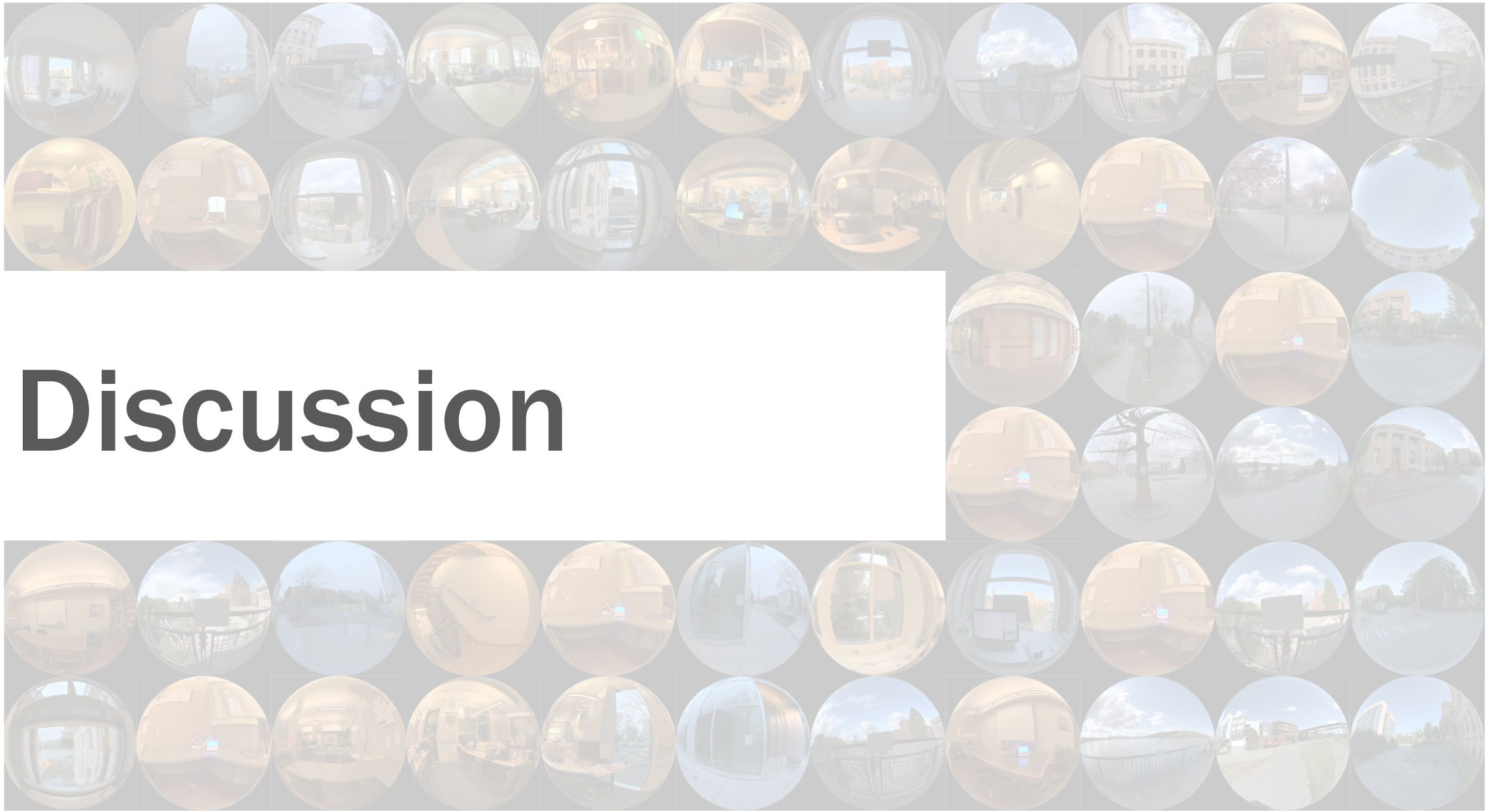

Melanopic

179 * ((0.0013 * R) + (0.3812 * G) + (0.6175 * B))

1 5 14 36 109 326 973 3000 cd/m²

# Post Processing

1. Correct for geometric aberrations **LENS SPECIFIC**
2. Original HDR merge + Luminance calibration **CAMERA SPECIFIC**
3. Exposure set to 1
4. Vignetting correction **LENS SPECIFIC**
5. Edit Header
6. Luminous overflow correction (Illuminance calibration – CIE Y)
7. Clean Header
8. Color calibration **CAMERA SPECIFIC** (only for camera specific calibration method)
9. Calculate Melanopic Luminance
10. Clean Header
11. Calculate Melanopic Illuminance



# Discussion

# Unit Reference


**Work Areas**

**200 EML**

**(Daylight + Electric Light)**

@ 75% or more workstations on vertical plane with daily exposure between 9am and 1pm

**150 EML**

**(Electric Light Only)**

@ 100% workstations on vertical plane

**Living Areas**

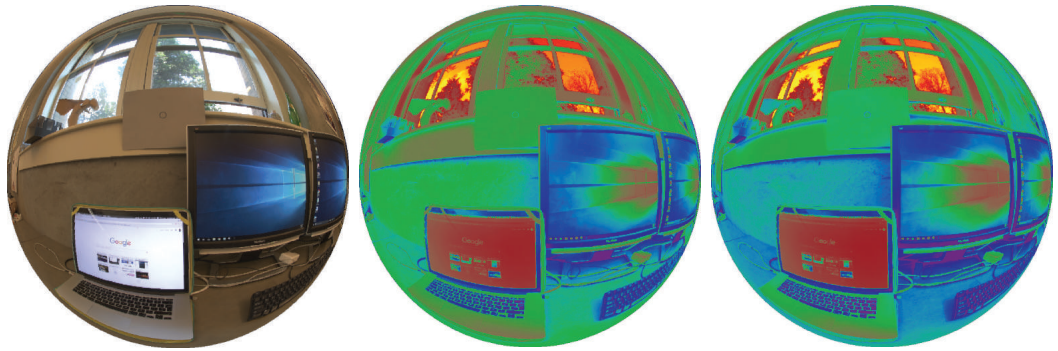
**Maintain 200 EML during day**

**Provide < 50 EML during night**

*Image: WELL Building Standard*

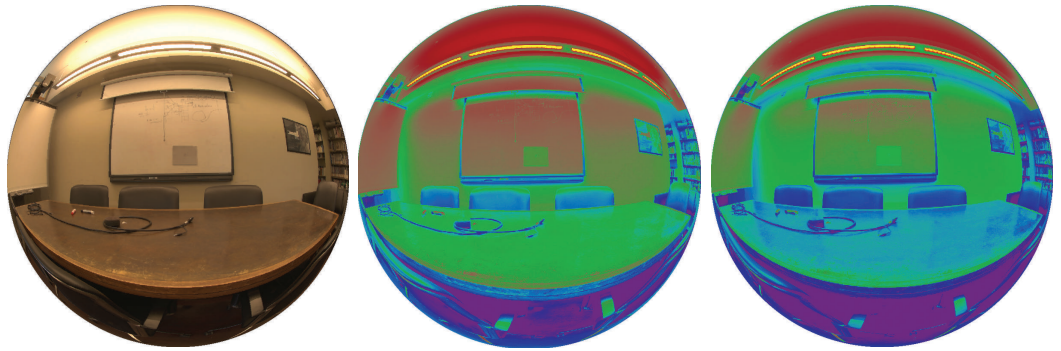
# Architectural Context


MAY 4 11:29 am



CCT | 7176 K  Photopic | 238 lx  Melanopic | 258 lx

MAY 4 11:33 am

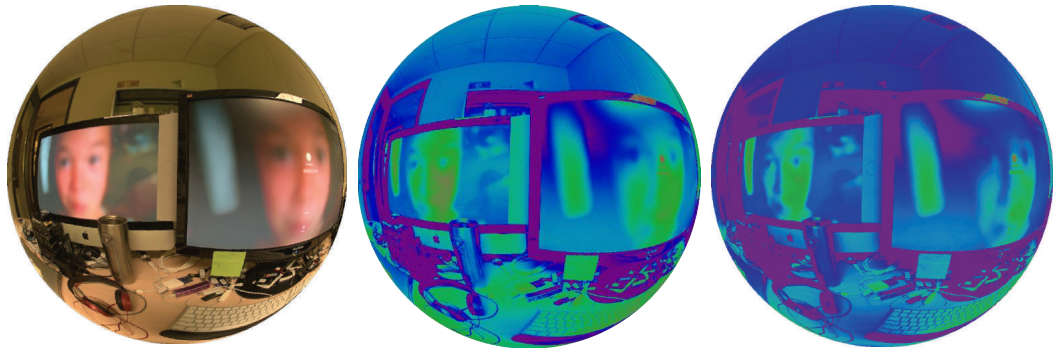


CCT | 3192 K  Photopic | 240 lx  Melanopic | 135 lx

MAY 4 11:22 am

CCT | 5495 K  Photopic | 8413 lx  Melanopic | 7884 lx

MAY 4 14:27 pm

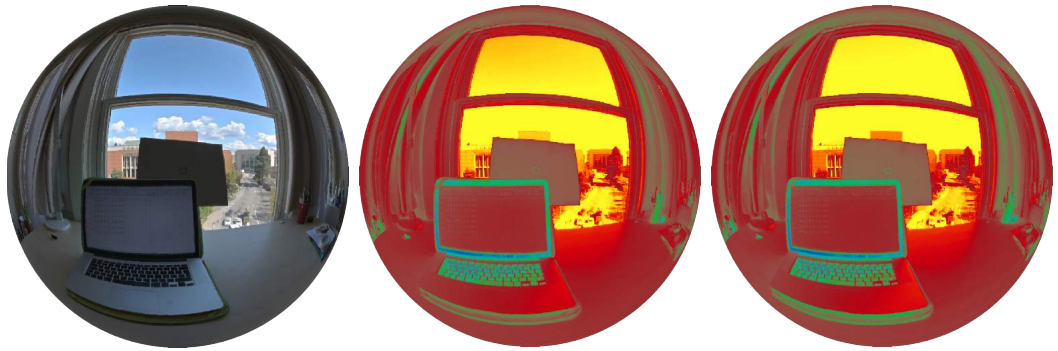


CCT | 3157 K  Photopic | 22 lx  Melanopic | 13 lx

# Weather

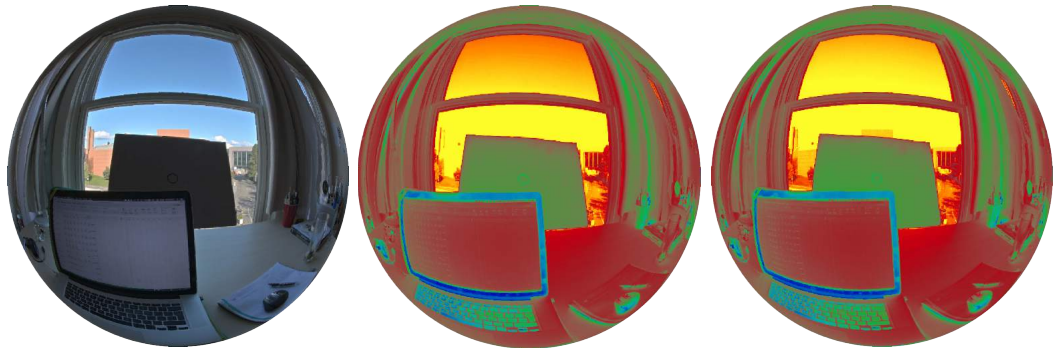
1 5 14 36 109 326 973 3000 cd/m²

APR 15 1:31 pm



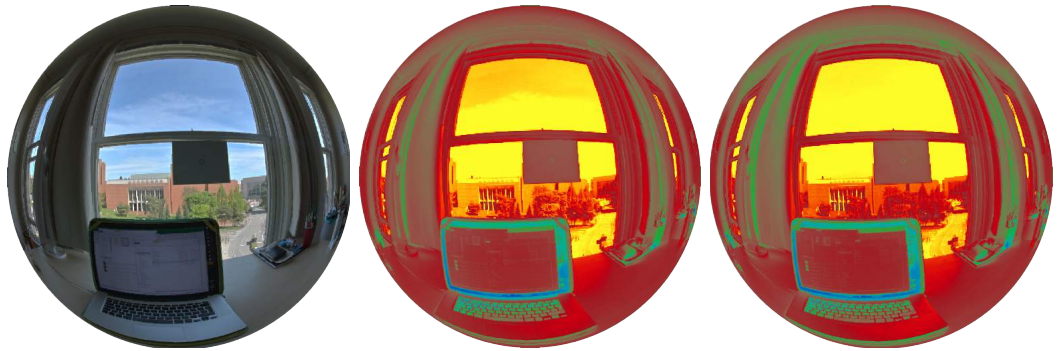
CCT | 7423 K | Photopic | 2615 lx | Melanopic | 2822 lx

APR 15 4:32 pm



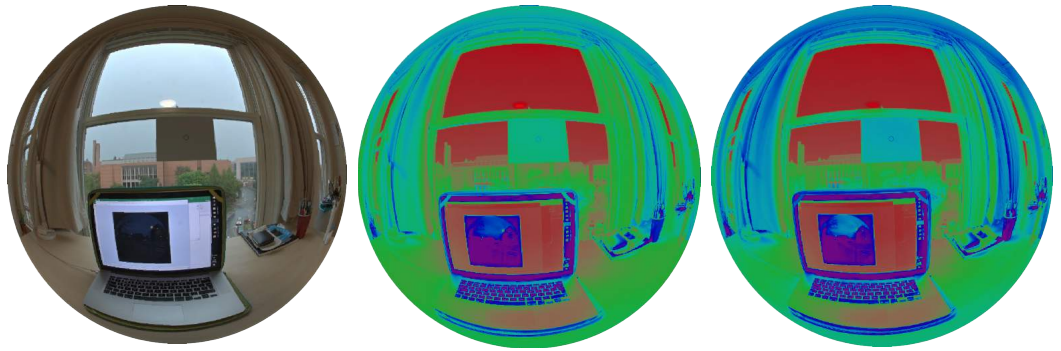
CCT | 9162 K | Photopic | 1766 lx | Melanopic | 2029 lx

MAY 4 1:22 pm



CCT | 7159 K | Photopic | 2498 lx | Melanopic | 2727 lx

MAY 4 4:29 pm

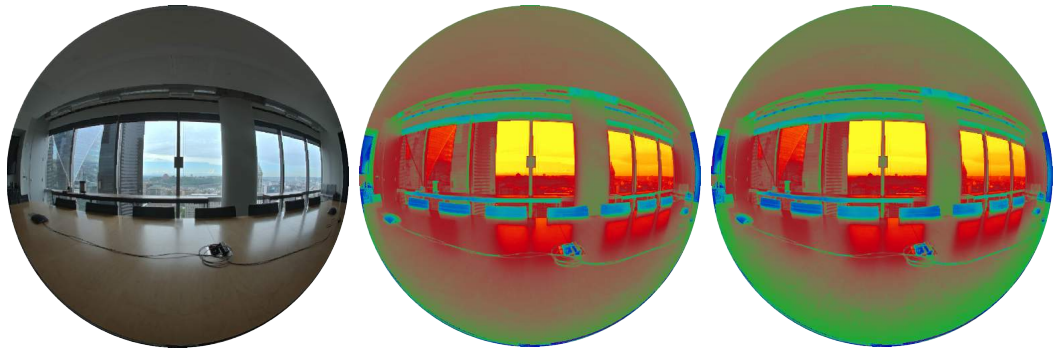


CCT | 5979 K | Photopic | 158 lx | Melanopic | 151 lx

# View Direction

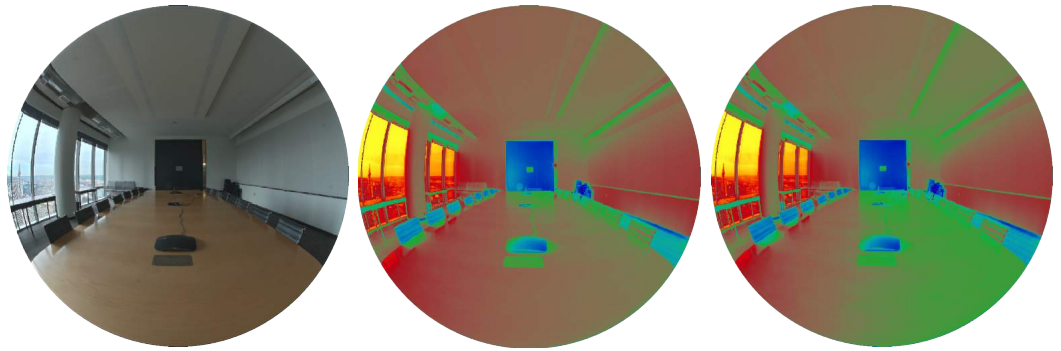
1 5 14 36 109 326 973 3000 cd/m²

MAY 19 8:07 am



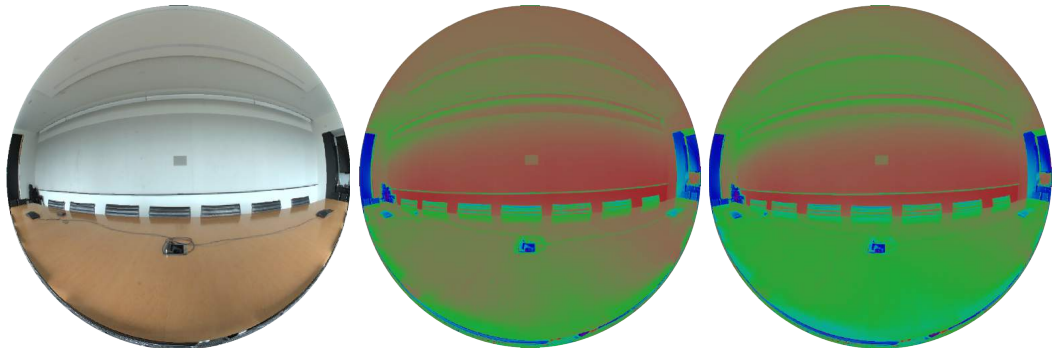
CCT | 6023 K  Photopic | 909 lx  Melanopic | 870 lx

MAY 19 8:11 am



CCT | 5598 K  Photopic | 515 lx  Melanopic | 473 lx

MAY 19 8:03 am

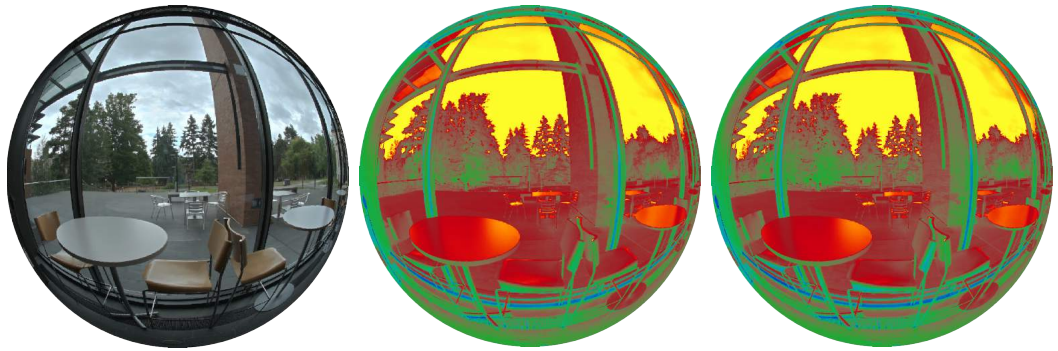


CCT | 4765 K  Photopic | 161 lx  Melanopic | 131 lx

# Building Depth

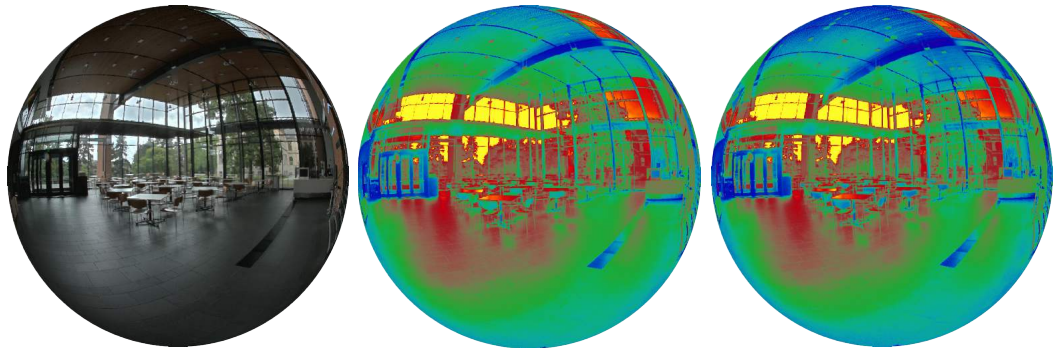
1 5 14 36 109 326 973 3000 cd/m²

AUG 13 1:27 pm



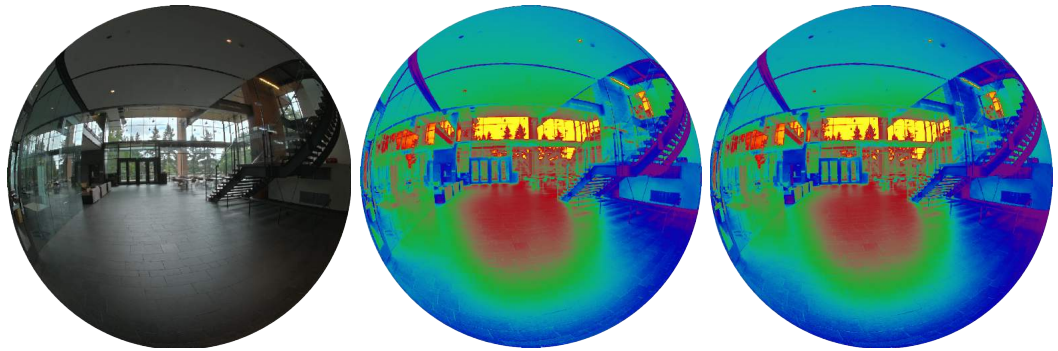
CCT | 5793 K | Photopic | 2753 lx | Melanopic | 2582 lx

AUG 13 1:34 pm



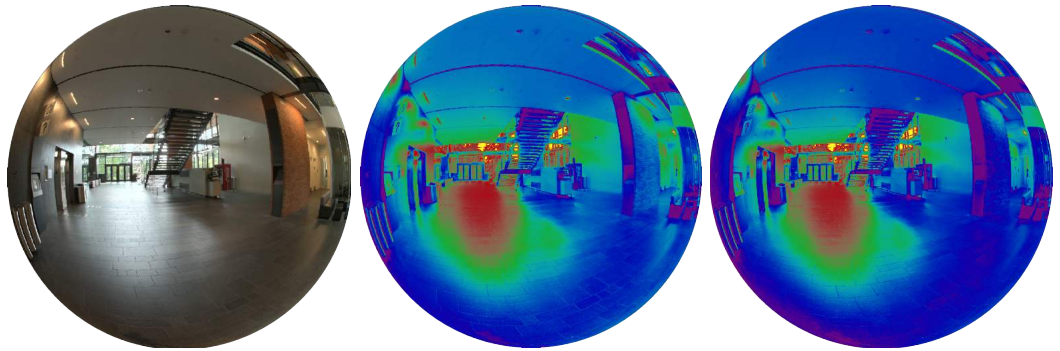
CCT | 5579 K | Photopic | 932 lx | Melanopic | 849 lx

AUG 13 1:37 pm



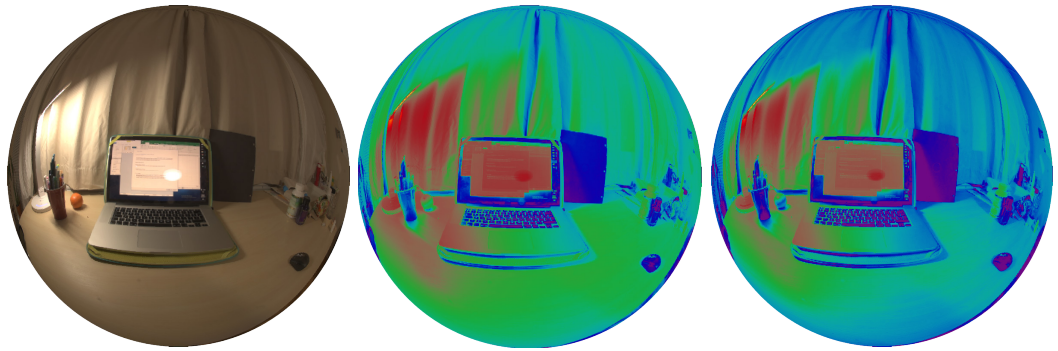
CCT | 5676 K | Photopic | 483 lx | Melanopic | 440 lx

AUG 13 1:43 pm

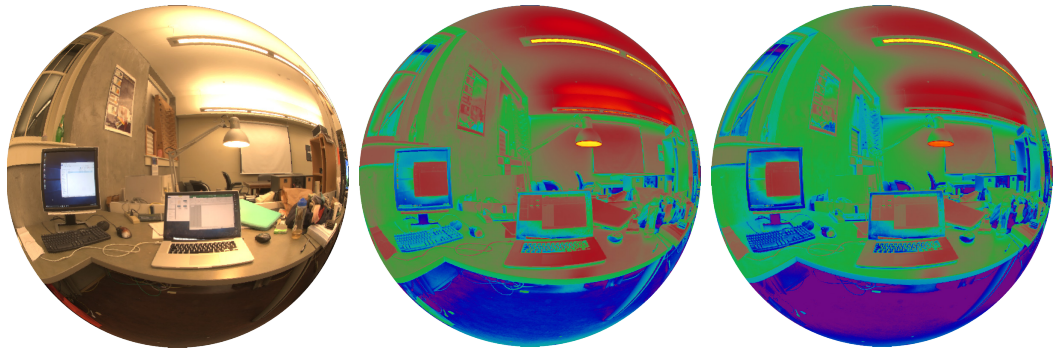


CCT | 5095 K | Photopic | 77 lx | Melanopic | 65 lx

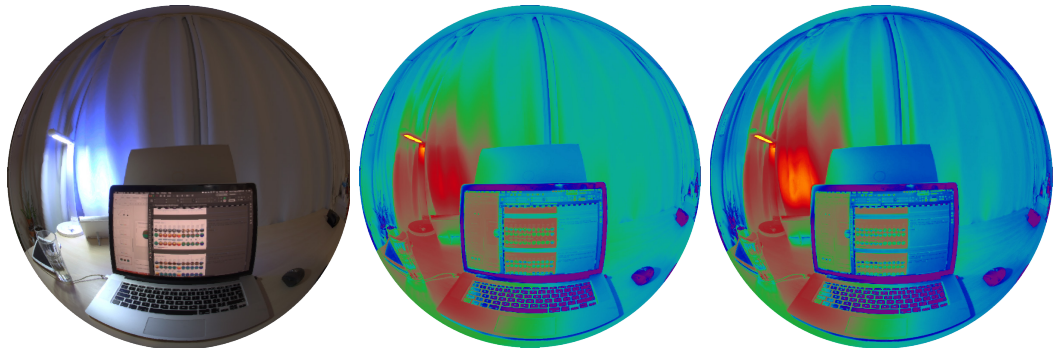
# Night Exposure

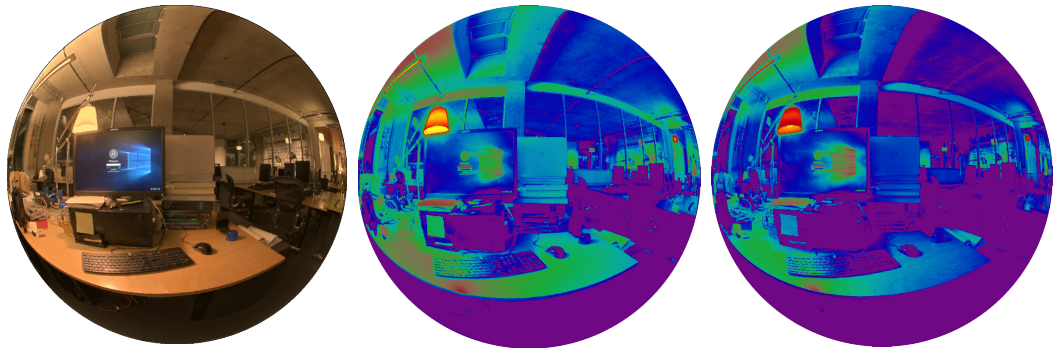
CCT | 3628 K  Photopic | 94 lx  Melanopic | 60 lx



CCT | 3142 K  Photopic | 315 lx  Melanopic | 171 lx

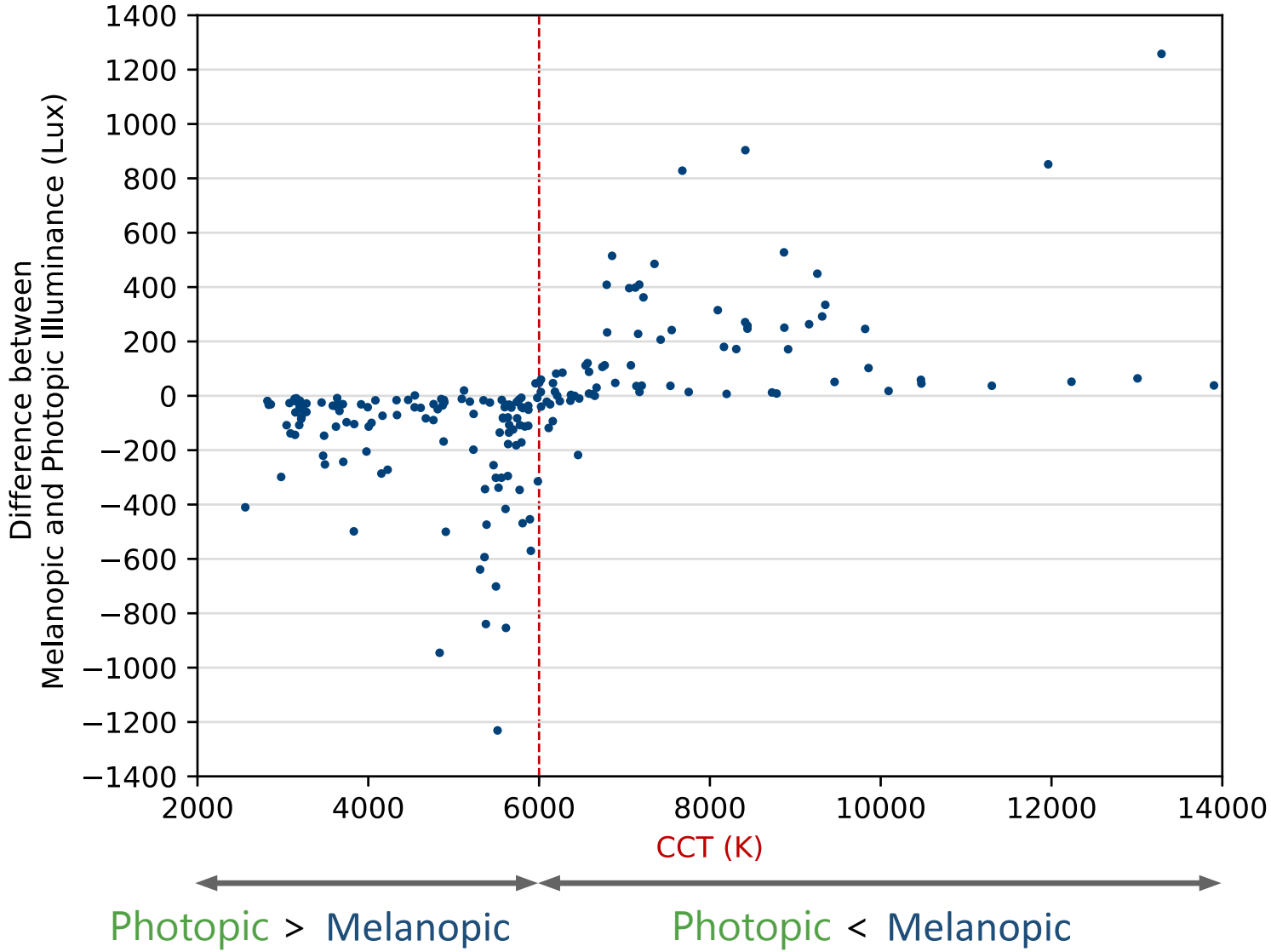


CCT | 11301 K  Photopic | 113 lx  Melanopic | 150 lx

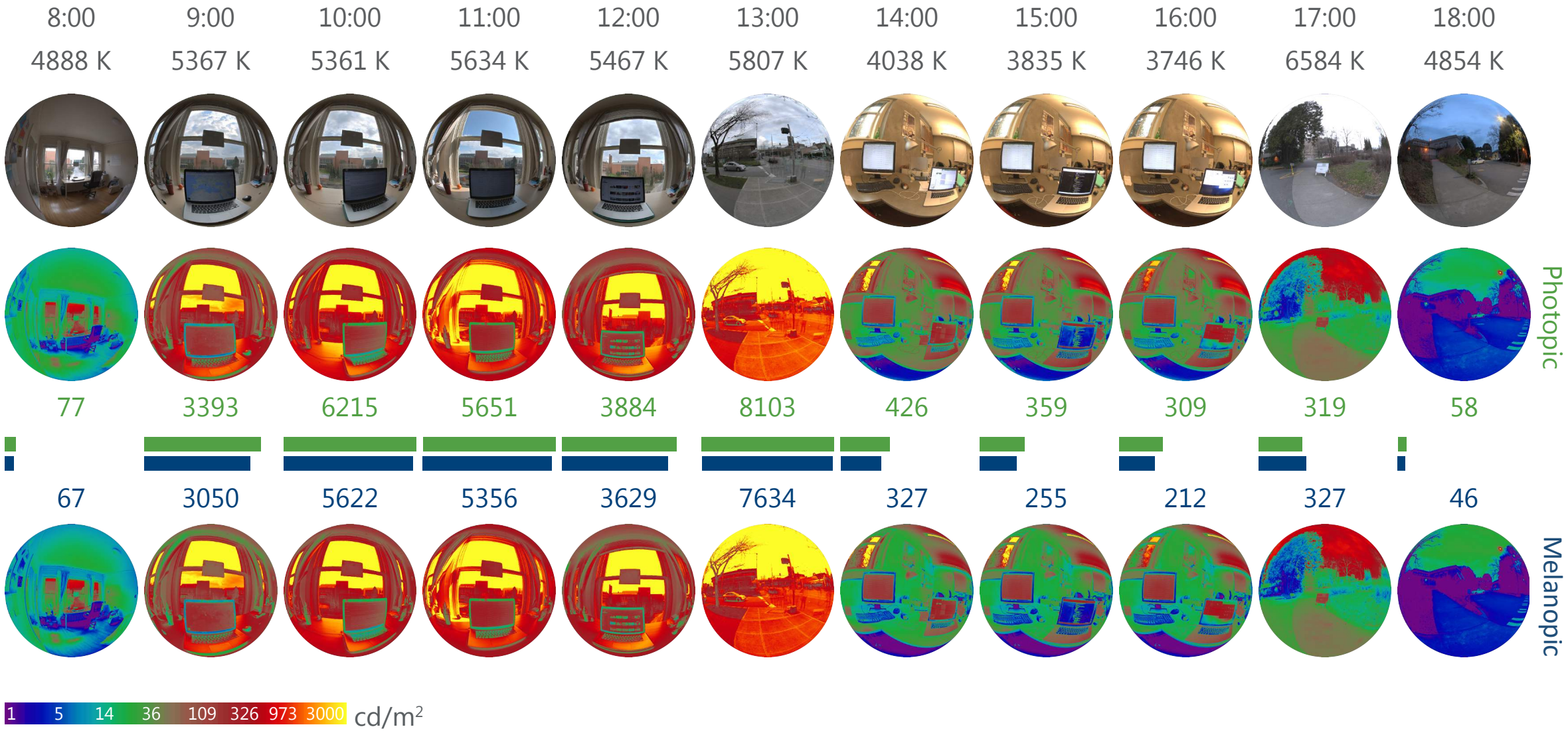


CCT | 2859 K  Photopic | 61 lx  Melanopic | 30 lx

# Photopic and Circadian Illuminance

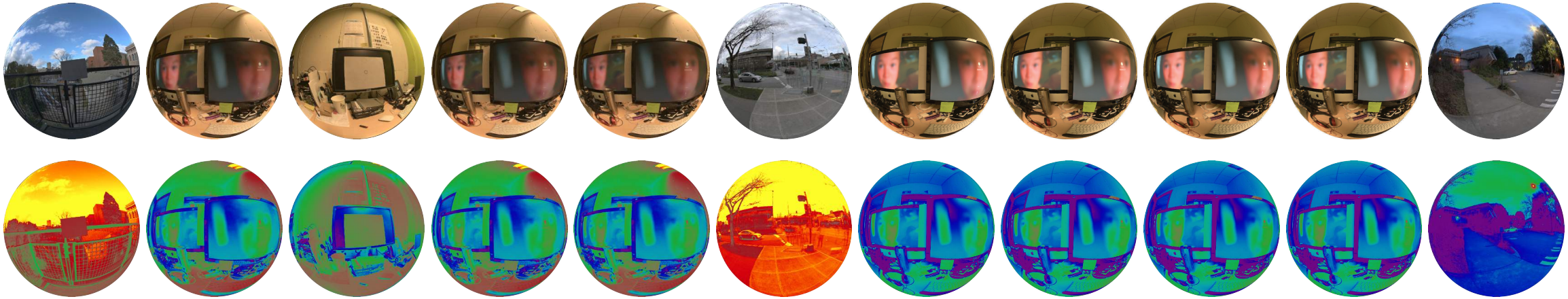


# Example Day | FEB 25



# 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 K | 3157 K | 3157 K | 5807 K | 3275 K | 3275 K | 3275 K | 3275 K | 4854 K |



Photopic

| 7677 | 135 | 111 | 135 | 135 | 8103 | 22 | 22 | 22 | 22 | 58 |
|---|---|---|---|---|---|---|---|---|---|---|

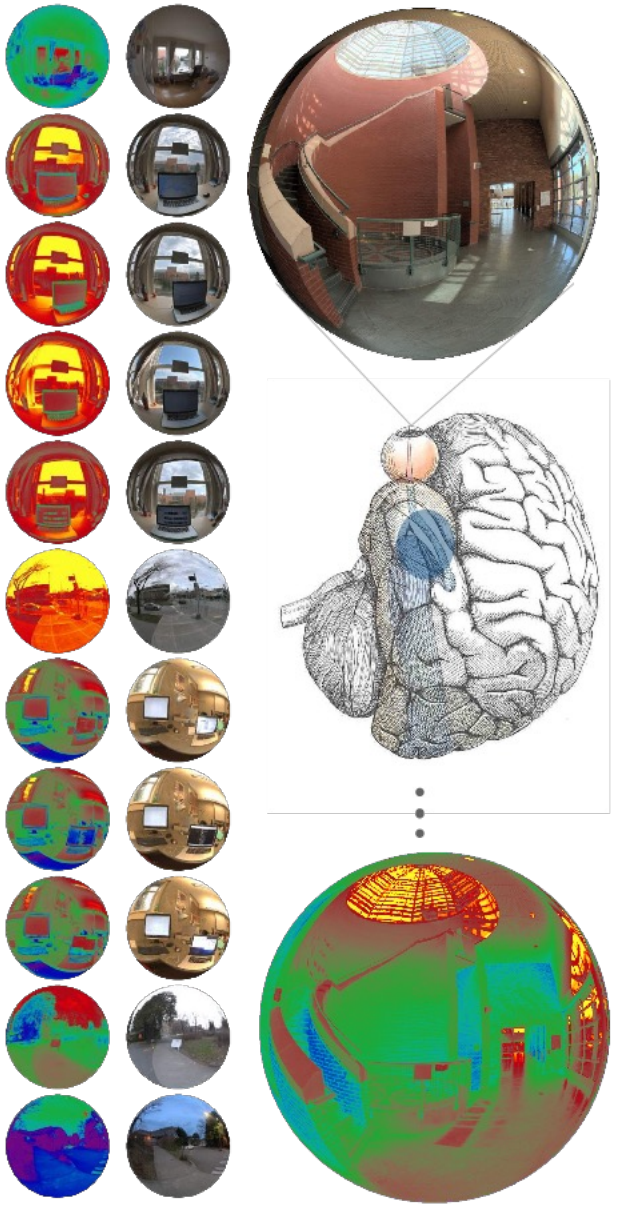
| 5134 | 75 | 59 | 75 | 75 | 7634 | 12 | 12 | 12 | 12 | 46 |
|---|---|---|---|---|---|---|---|---|---|---|

Melanopic

1 5 14 36 109 326 973 3000 cd/m²

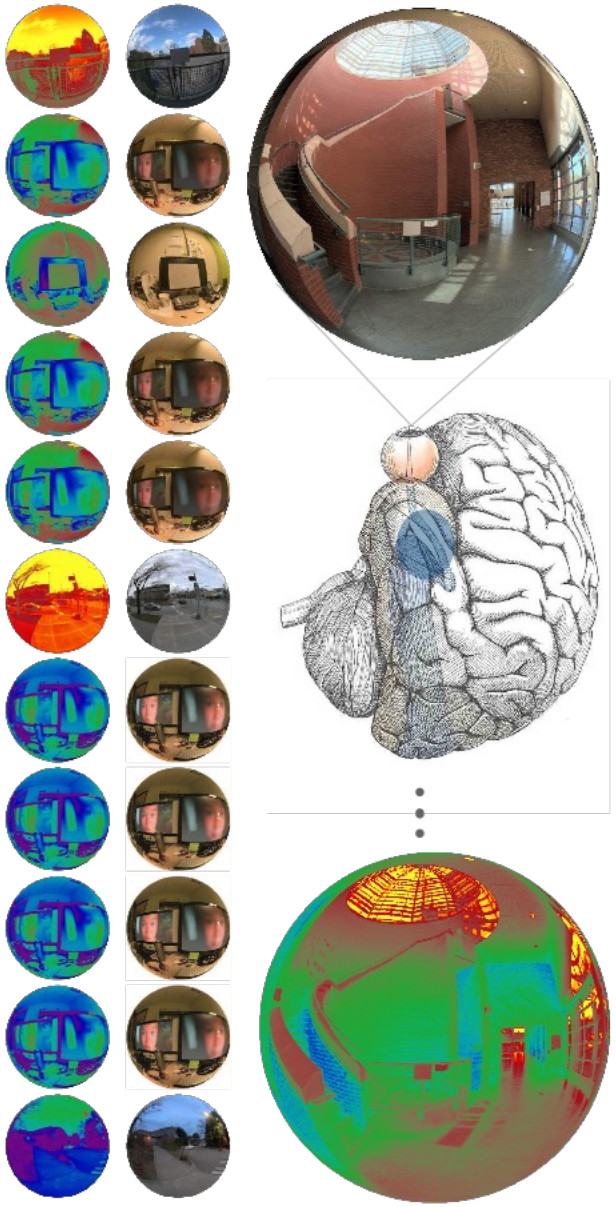
# Conclusions

- Circadian lighting conditions within built environments are not well known
- HDR photography can be used for measuring both photopic & circadian light
- Accessible to all lighting professionals
- Provides rich data to create circadian metrics and guidelines



# Conclusions

- Further studies needed to test color calibration in other cameras
- More biological studies are required to develop time and duration guidelines



# Main References

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Jakubiec A, Inanici M, van den Wymelenberg K, Mahic A. “Improving the Accuracy of Measurements in Daylit Interior Scenes using High Dynamic Range Photography,” Proceedings of Passive and Low Energy Architecture Conference, Los Angeles, CA, 1: 649-656, July 11-13, 2016. http://www.plea-arch.org/index.php/plea-proceedings/

Jakubiec A, van den Wymelenberg K, Inanici M, and Mahic A. “Accurate Measurement of Daylit Interior Scenes using High Dynamic Range Photography,” Proceedings of the CIE (International Commission on Illumination) Lighting Quality and Energy Efficiency Conference, Melbourne, Australia, March 3-5, 2016.

Inanici M. “Evaluation of High Dynamic Range Photography as a Luminance Data Acquisition System,” *Lighting Research and Technology*, 38(2): 123-136, 2006. https://doi.org/10.1191/1365782806li164oa

# Melanopic HDR Capture

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