Introduction to High Dynamic Range Photography

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Outline

❶ Lighting Measurements

❷ Measurement with HDR Photography

- Image Capture
- Image Generation
- Data validation

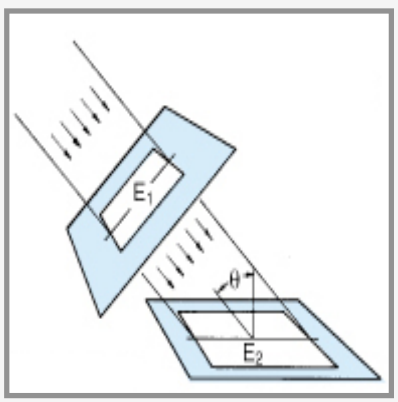
❸ Applications

❹ Numerical versus Visual Data

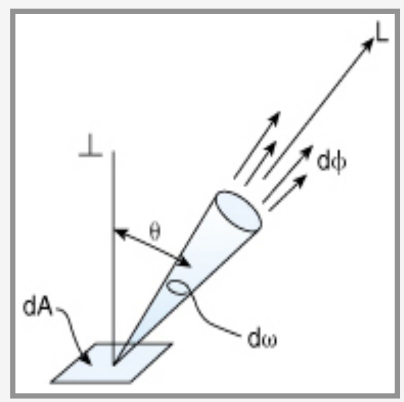
❶

Lighting Measurements

Illuminance

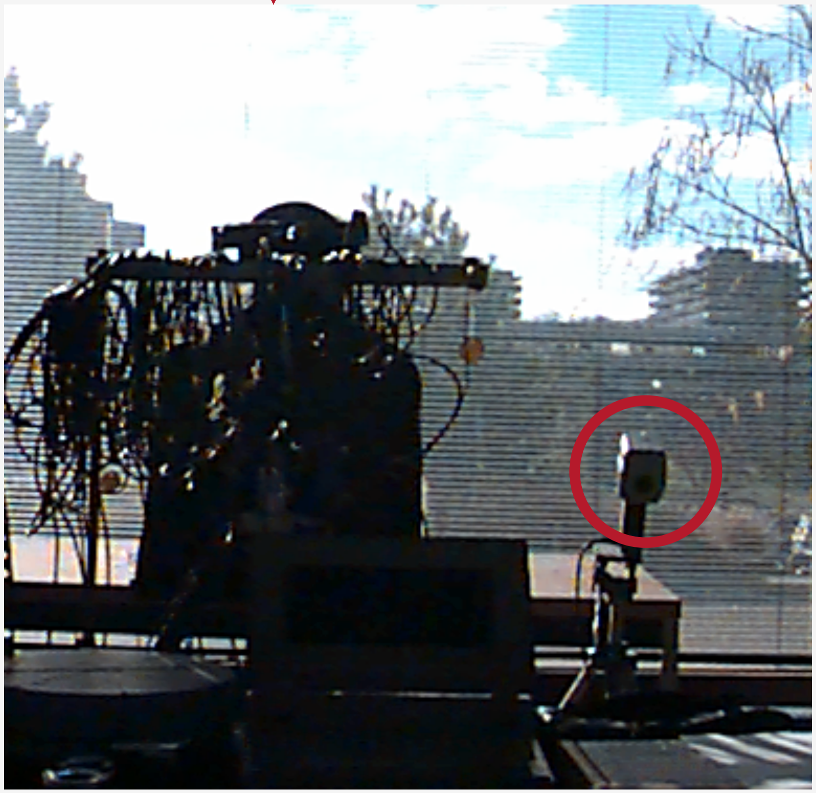


Luminance



Luminance

Luminance Meter



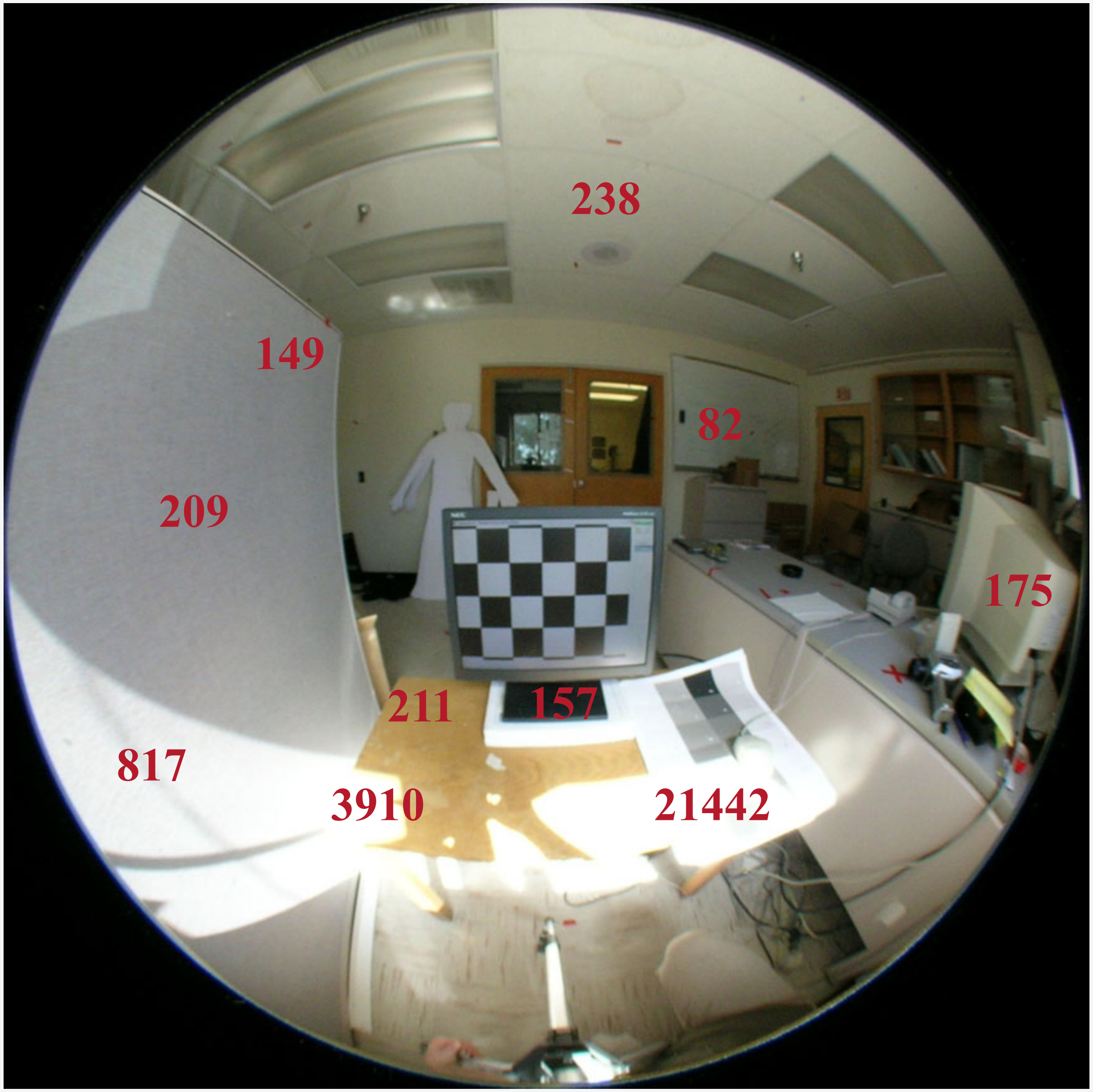
Lighting Dynamics

Sky conditions and sun movement

Glazing and Shading Systems

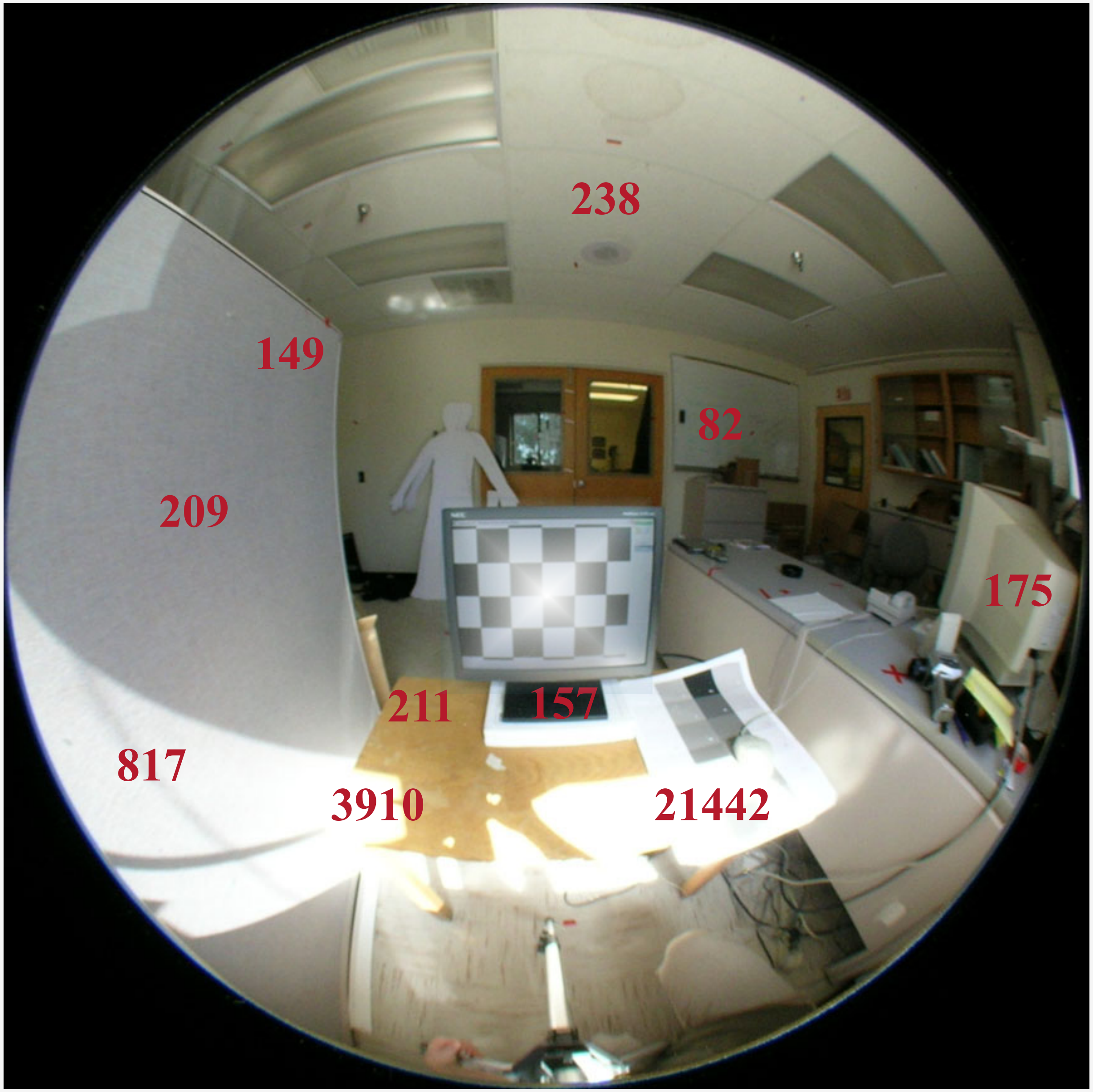
Electric Lighting and Daylighting Controls

Spatial Dynamics



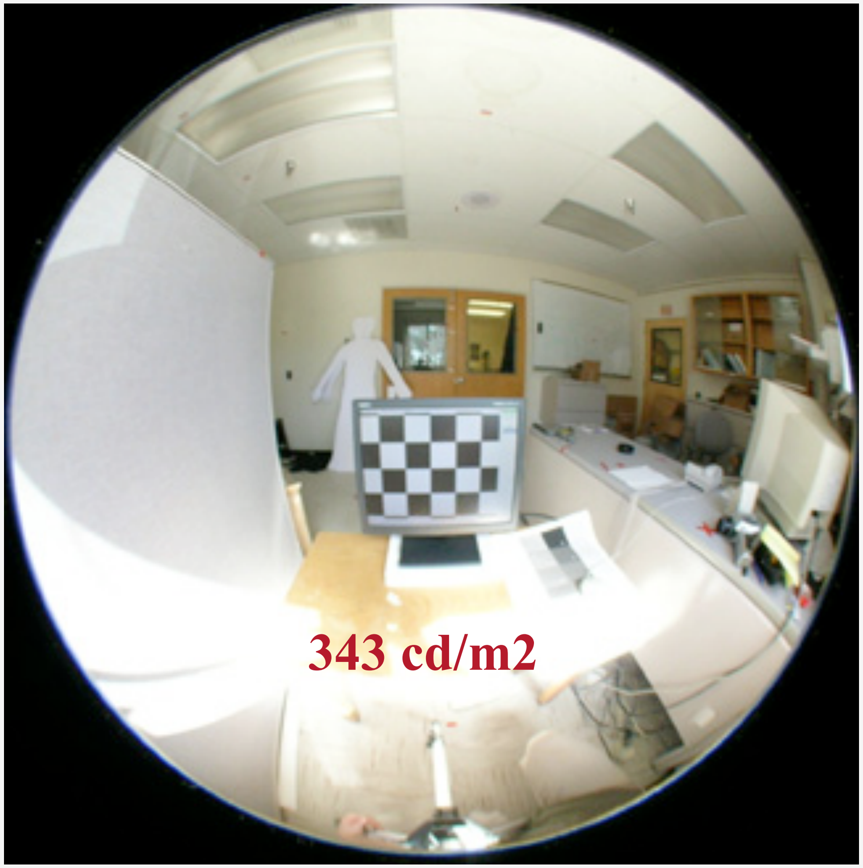
Nits
cd/m²

Spatial Dynamics



Nits
cd/m²

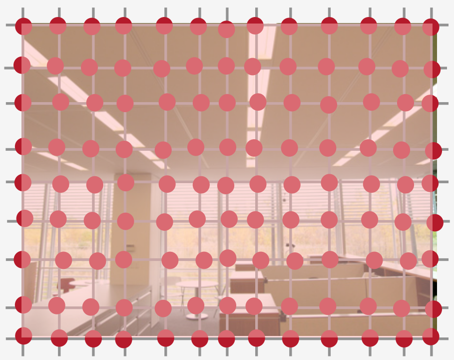
Temporal Dynamics



3:16 pm

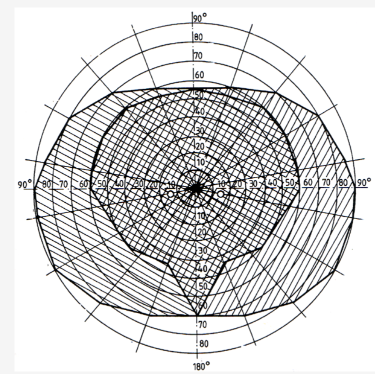
4:48 pm

Measurement & Analysis



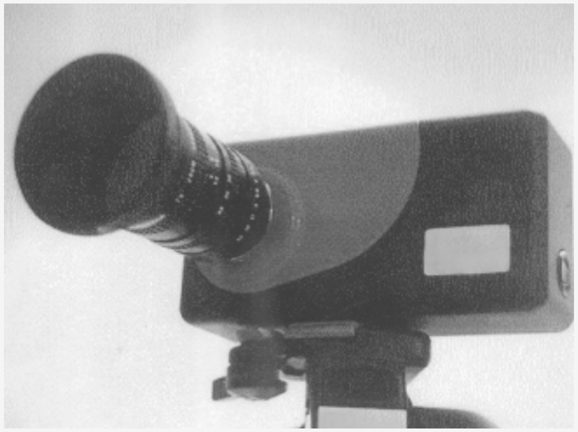
High Resolution

High Dynamic Range



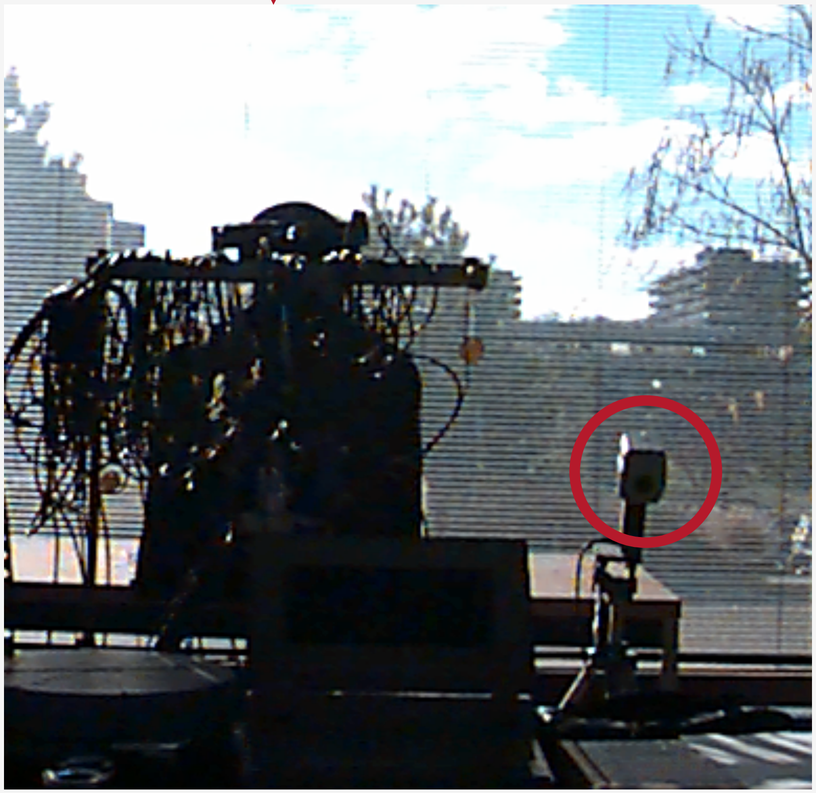
Large field of view

Luminance



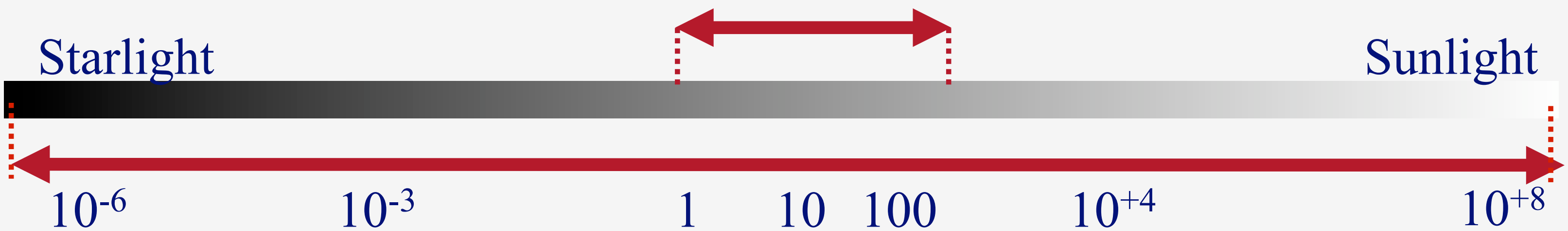
CCD Camera

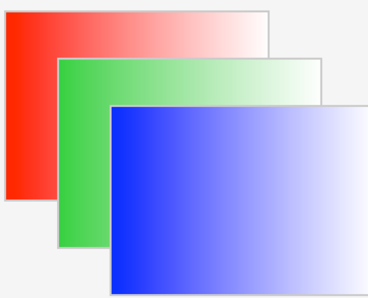
Luminance Meter



❷

Photography based Photometry

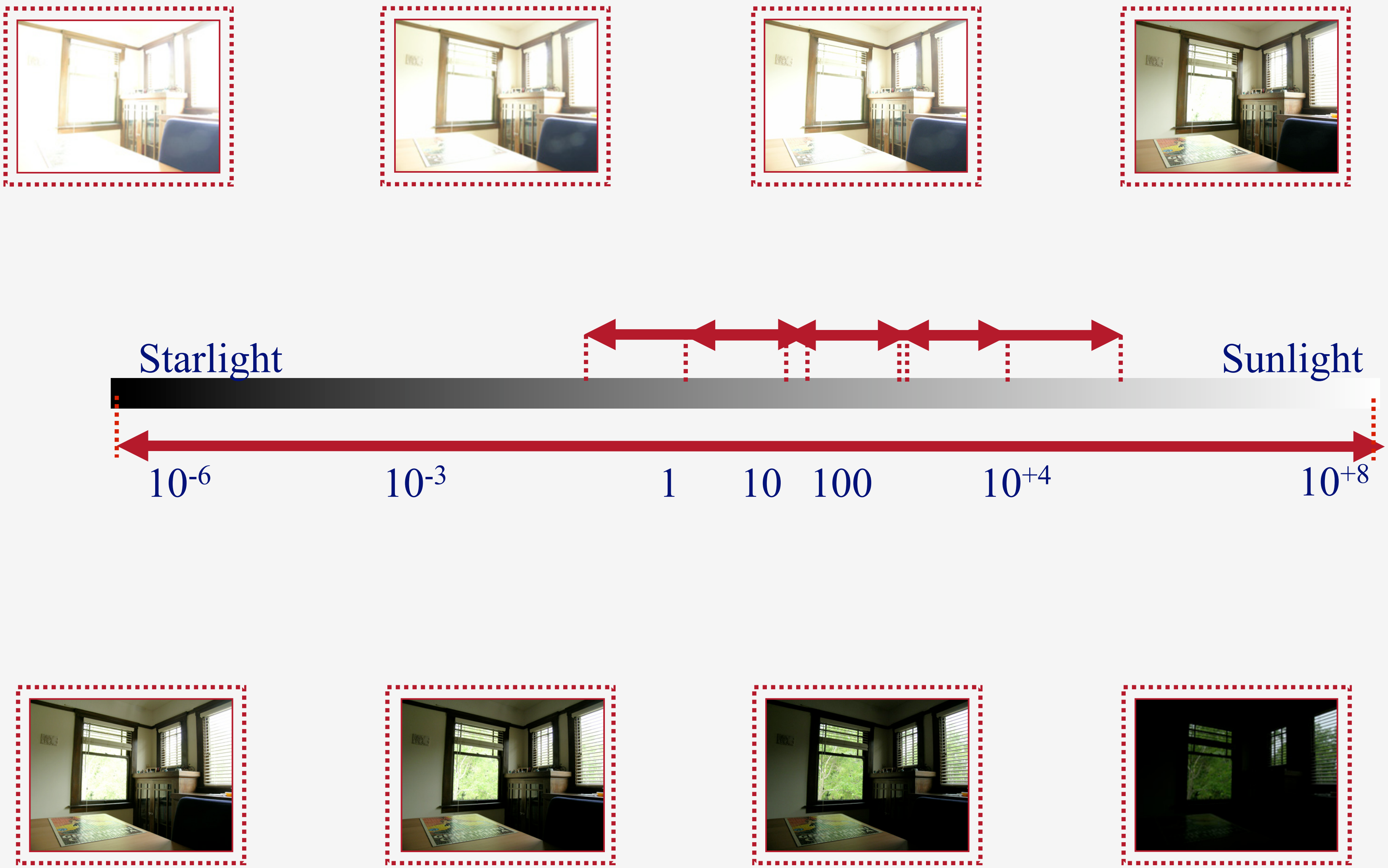




- Digital and chemical photography
- Conventional display devices
- Low Dynamic Range Image formats

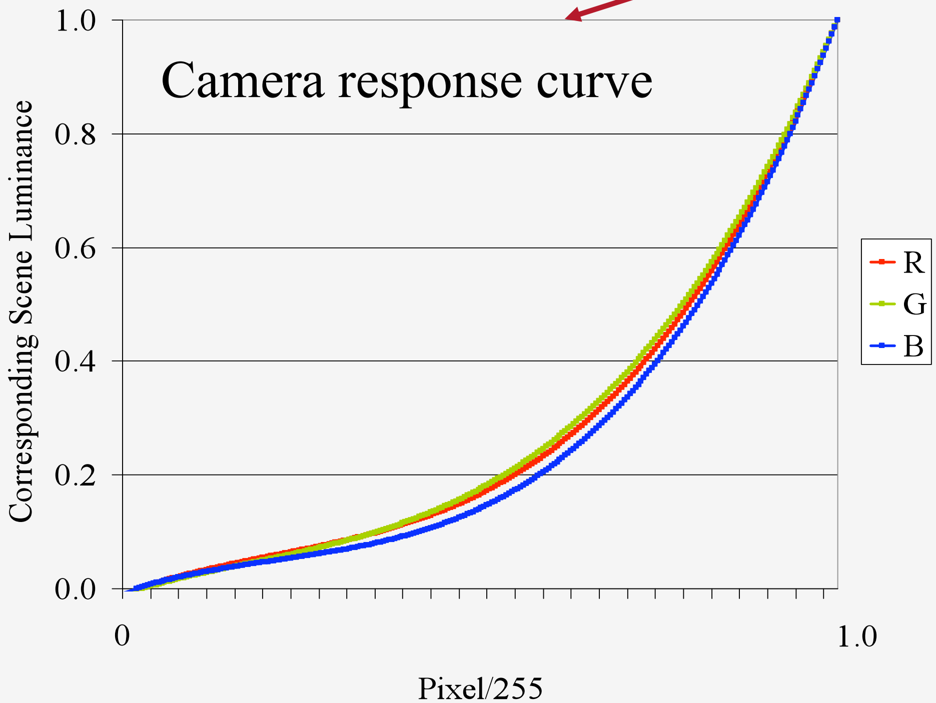
RGB [0 - 255]

High Dynamic Range Photography

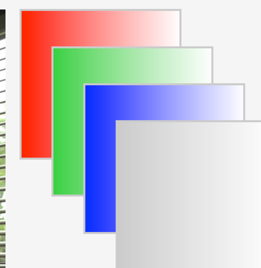


High Dynamic Range Photography

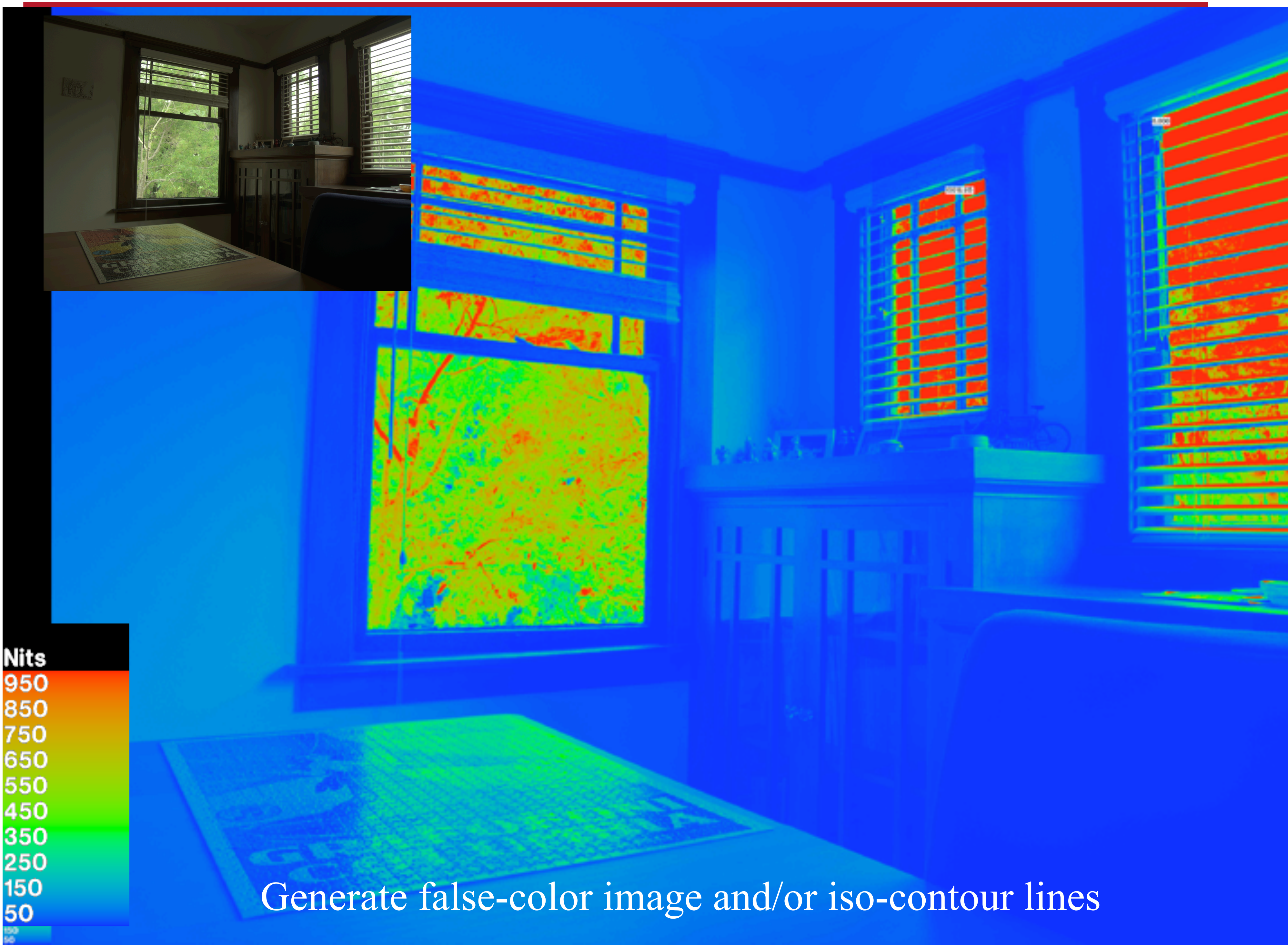
HDRI Software - Photosphere



HDRI

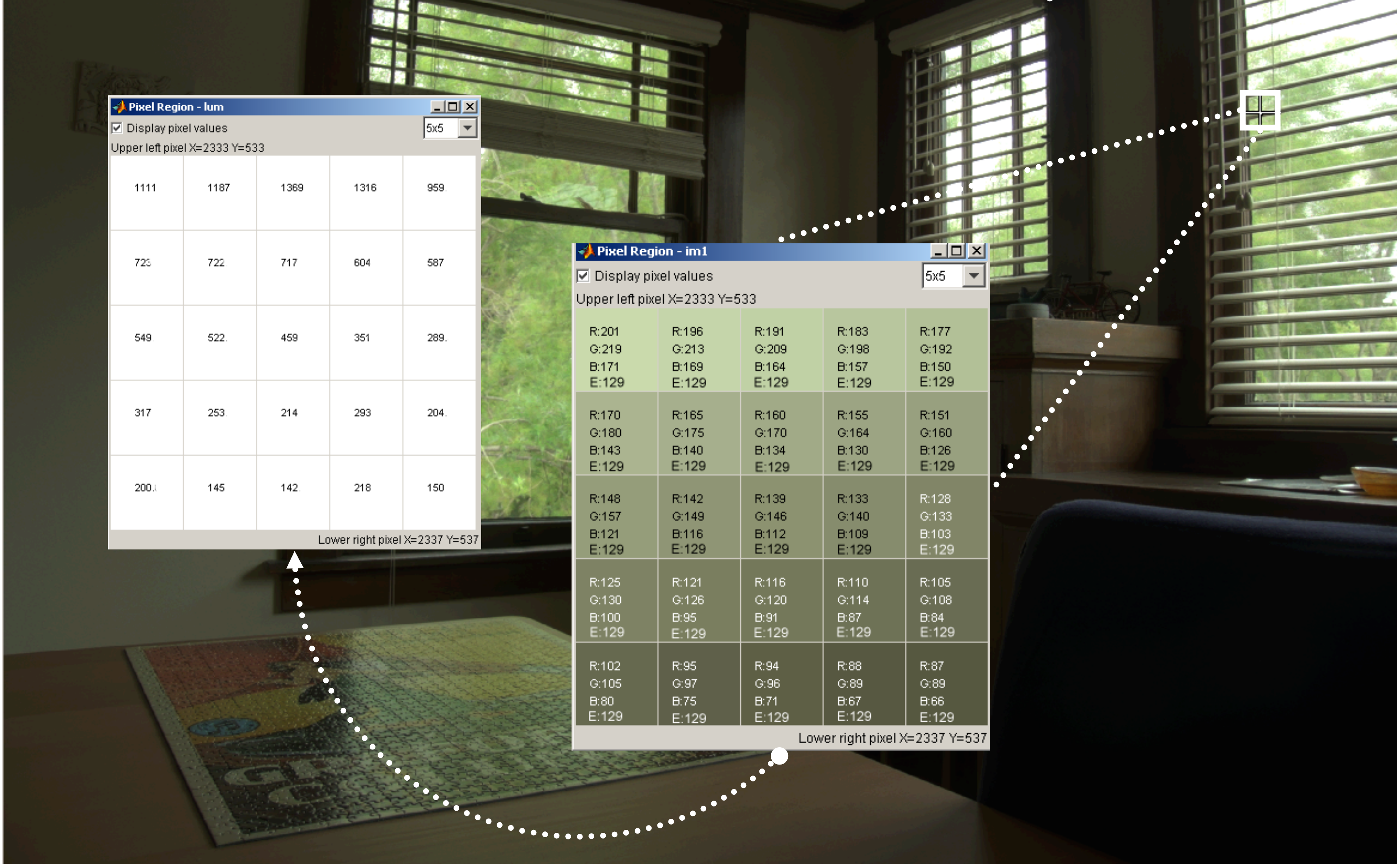


Demonstration



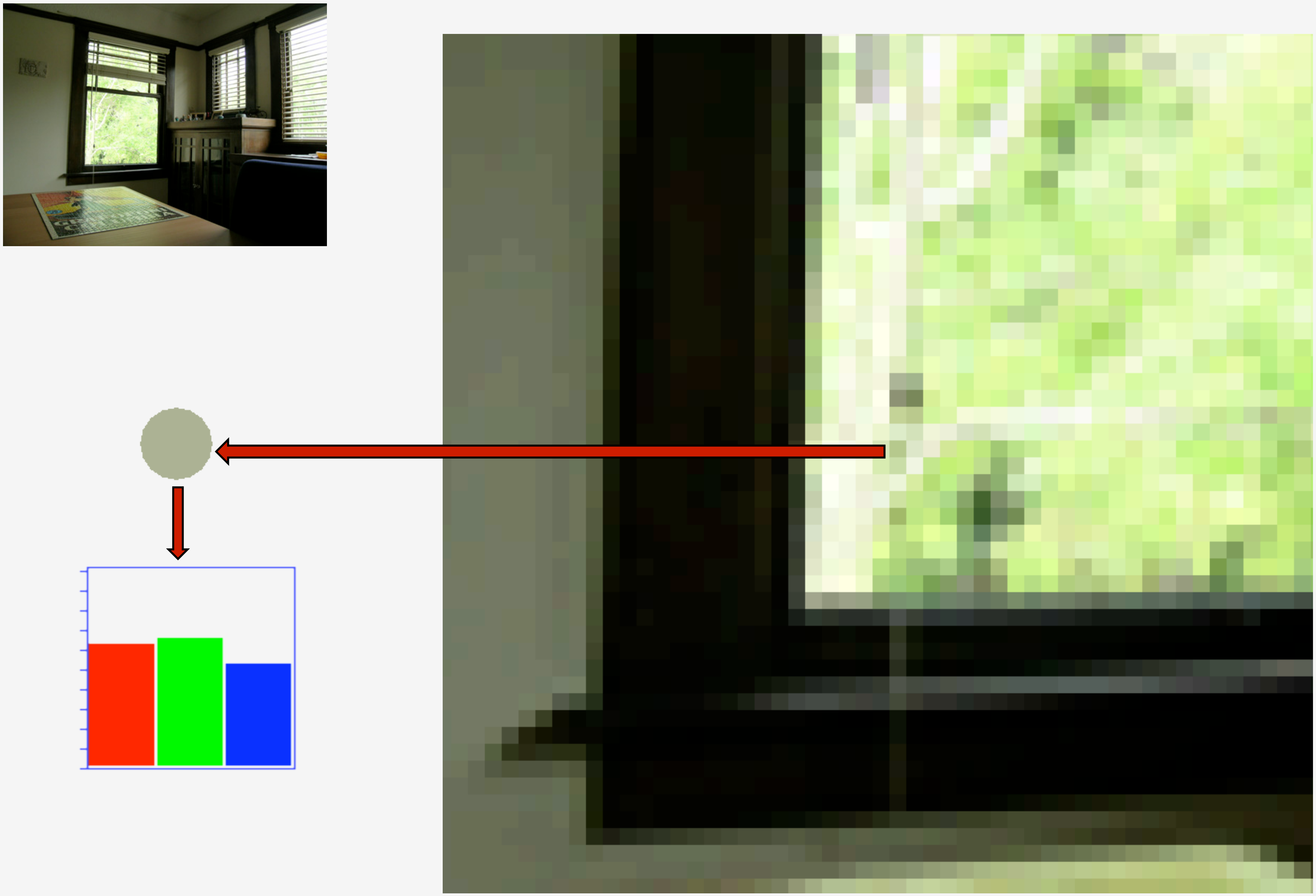
Generate false-color image and/or iso-contour lines

An HDR photograph can be post-processed to extract photometric information on a pixel scale; this information can be utilized for statistical and mathematical analysis

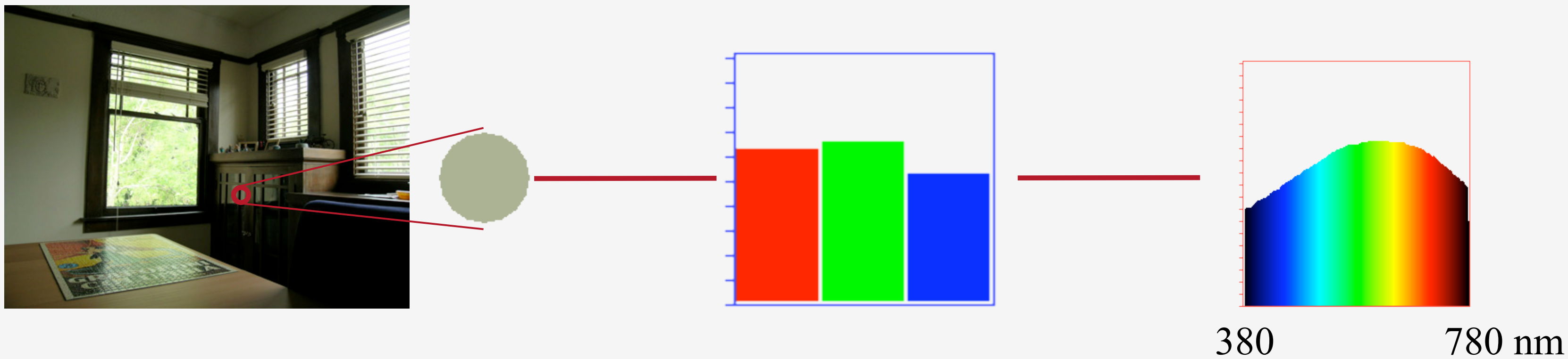


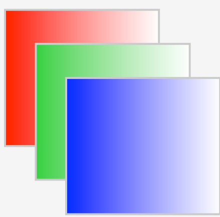
Some of the HDR Image Formats

- RGBE (Radiance .pic = .hdr) 1989
- LogLuv TIFF
- ILM OpenEXR
- HDR-JPEG

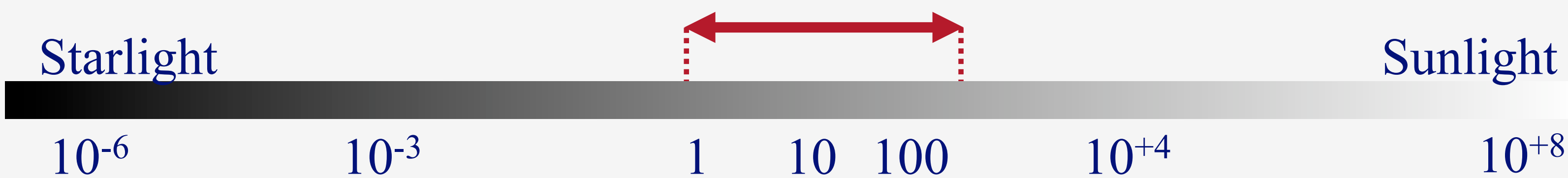


High Dynamic Range Imagery



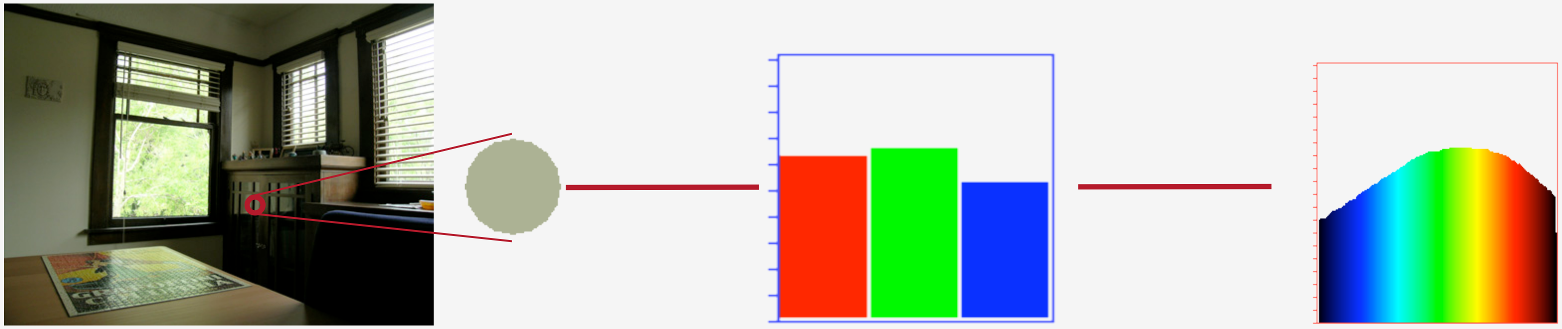


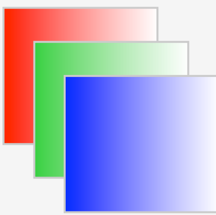
Traditional image formats (Low Dynamic Range Imagery)
24 bit image formats e.g. TIFF, JPEG, GIF…
[0 - 255]



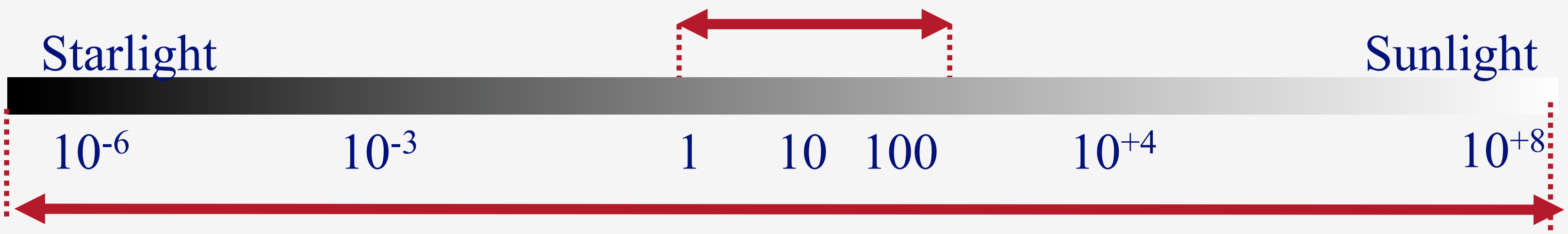
256 * 256 * 256 ~ 16 million colors

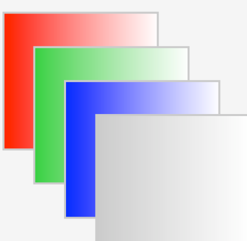
High Dynamic Range Imagery





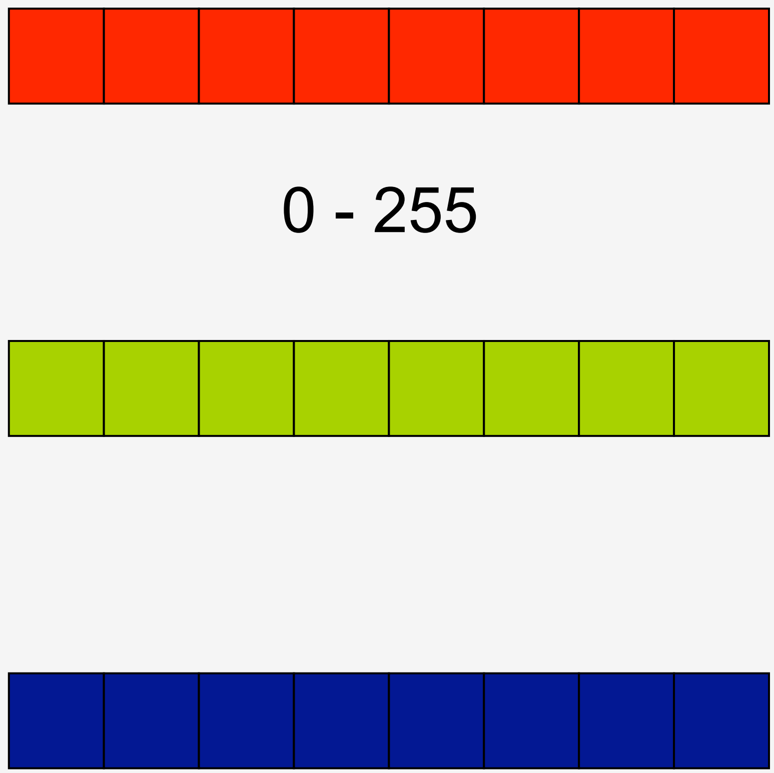
Traditional image formats (Low Dynamic Range Imagery)
24 bit image formats e.g. TIFF, JPEG, GIF…
[0 - 255]





High Dynamic Range Imagery
32 bit image formats e.g. HDR (RGBE, Radiance .pic, .hdr)
[10^{-38} - 10^{38}]

24 bit Image Format
(Low Dynamic Range Format)



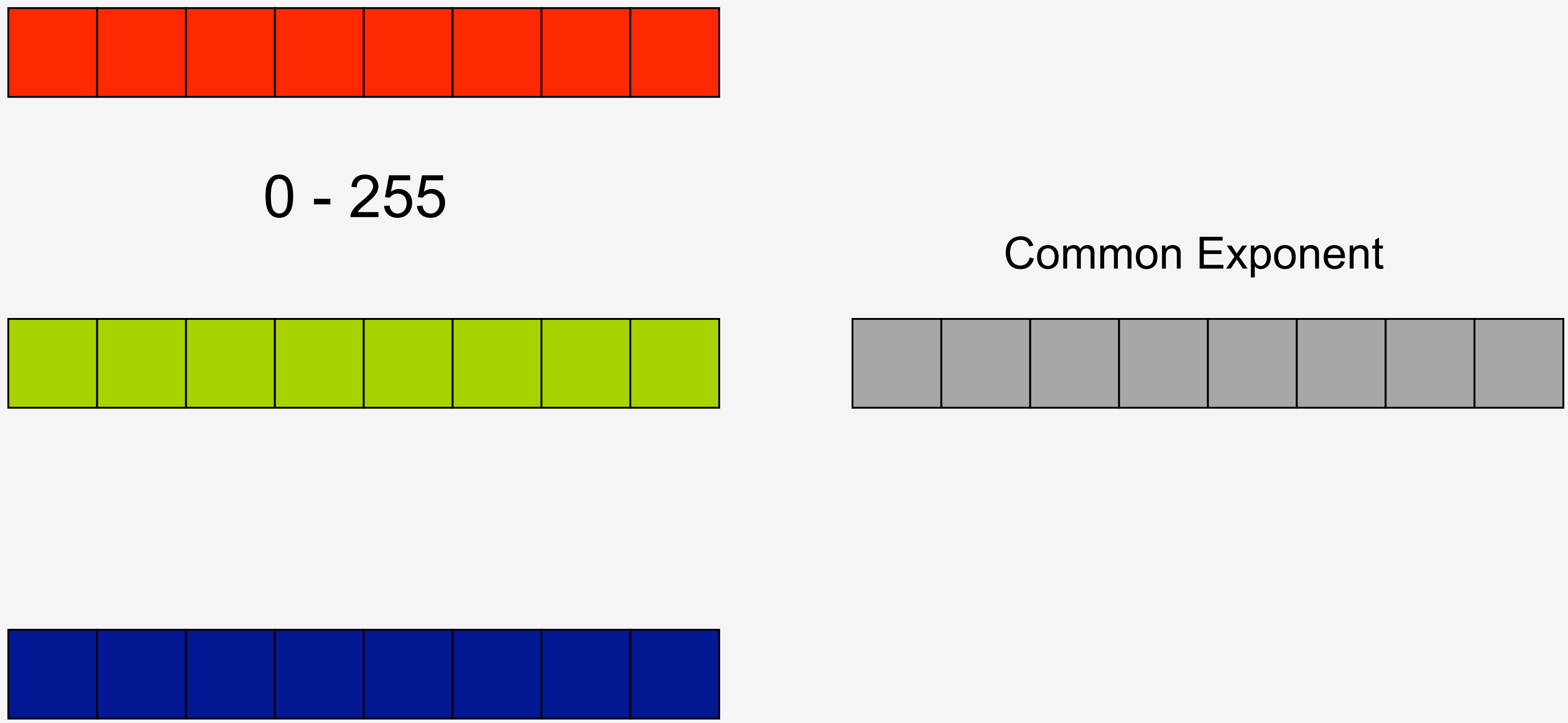
TIFF

JPG

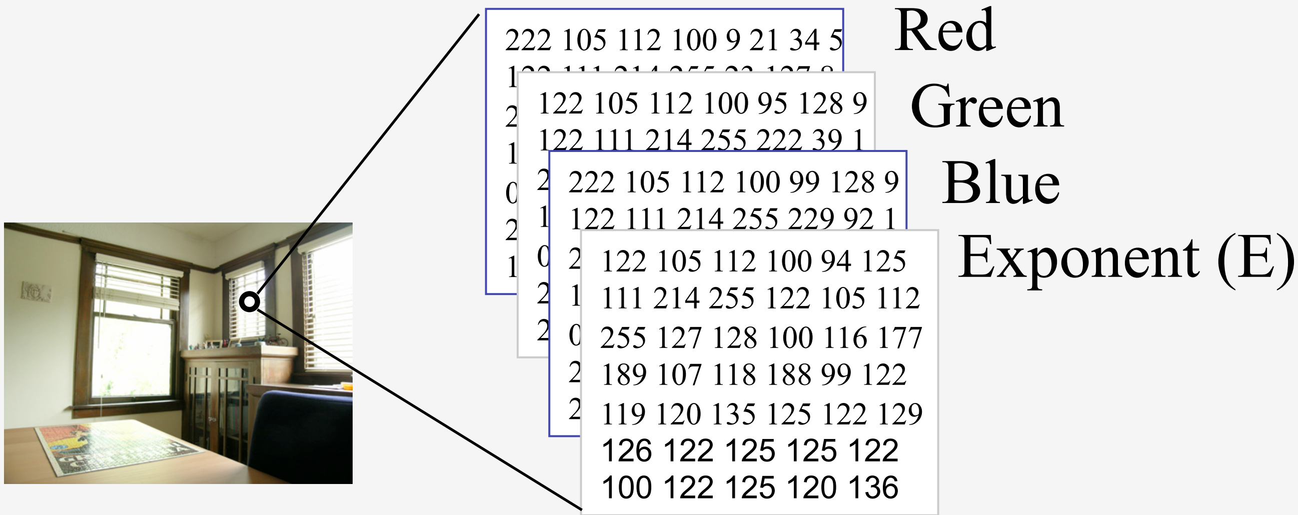
GIF

…

32 bit Image Format
Radiance .pic Format = .hdr



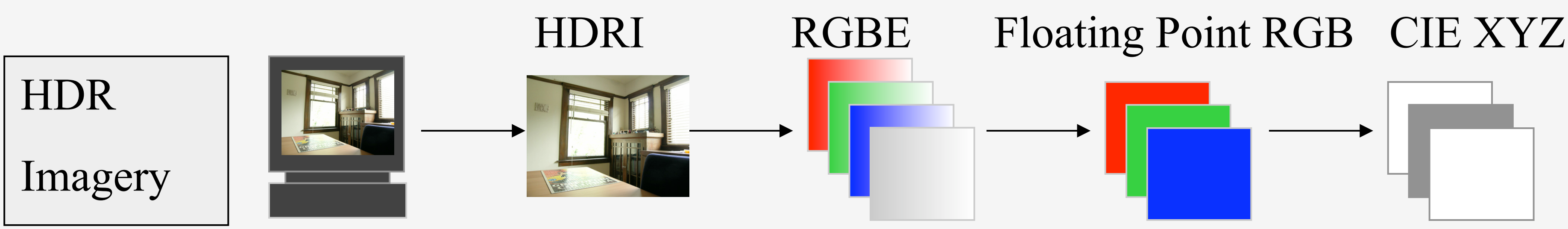
Per-pixel Luminance Measurement



$$red = \frac{R}{255} * 2^{(E-128)}$$

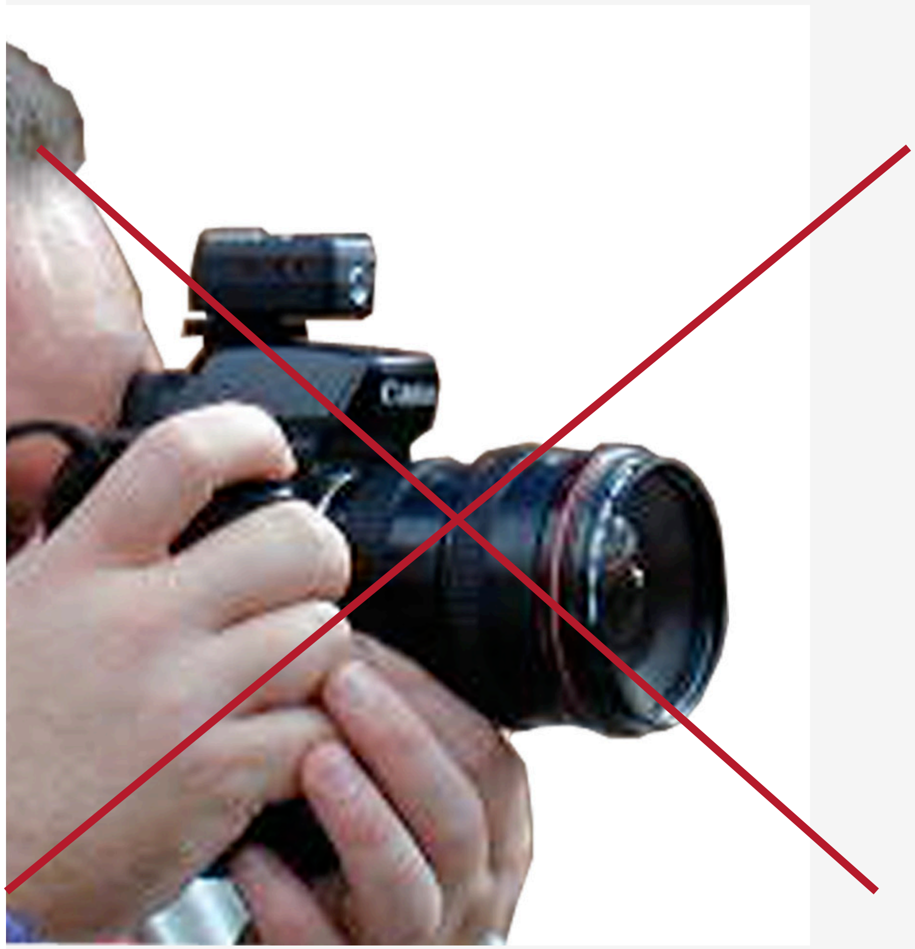
$$green = \frac{G}{255} * 2^{(E-128)}$$

$$blue = \frac{B}{255} * 2^{(E-128)}$$



2a

HDR Image Capture



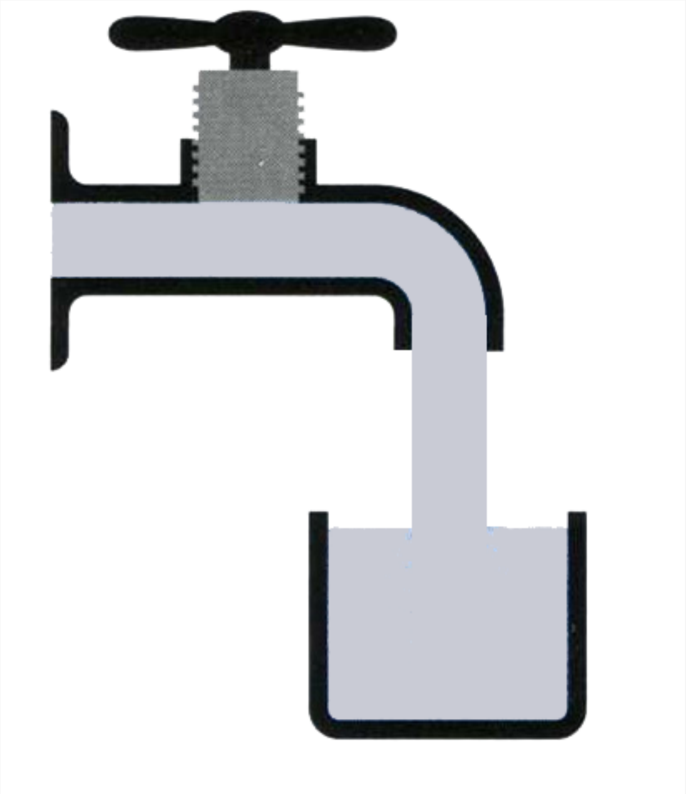
Use a tripod to take multiple exposure photographs!

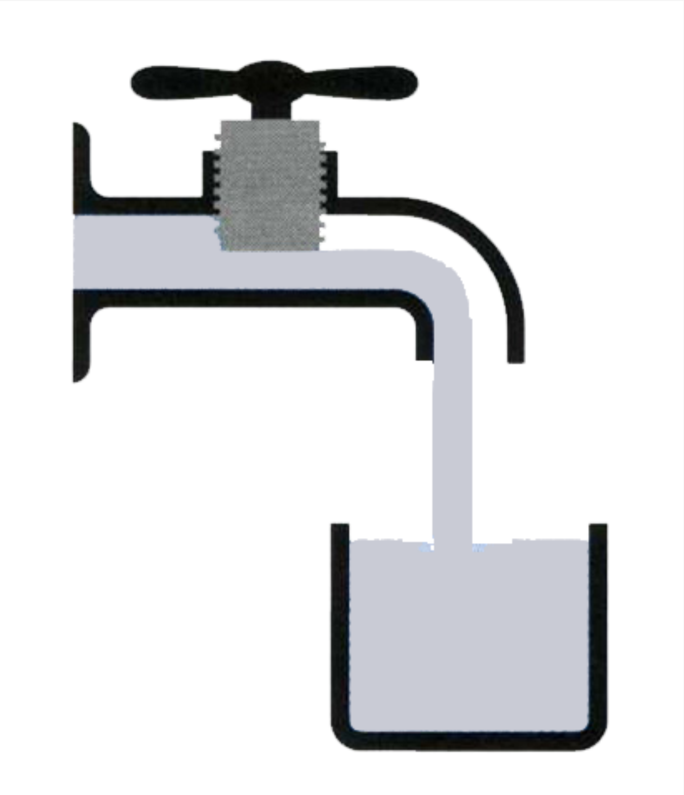
Exposure

- Aperture size (F-stop)

- Shutter speed (Seconds)

Bucket of Light





Larger aperture size
Shorter shutter speed

Smaller aperture size
Longer shutter speed

- Aperture size: size of the lens opening
  - The smaller the aperture opening, the greater the depth of field.

Large aperture, less depth of field

Small aperture, more depth of field

- Aperture size: size of the lens opening
  - The smaller the aperture opening, the smaller the vignette effect.
  - Lenses exhibit noticeable light falloff (vignetting) for the pixels far from the optical axis

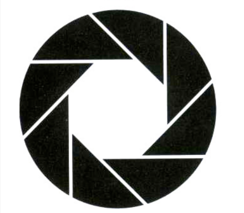
Shutter Speed (second)

- 1/8000 s
- 1/2000 s
- 1/500 s
- 1/125 s
- 1/30 s
- 1/8 s
- 1/2 s

1/4000 s
1/1000 s
1/250 s
1/60 s
1/15 s
1/4 s
1s

Shutter speed is a more reliable measure than aperture size in changing the exposure values!

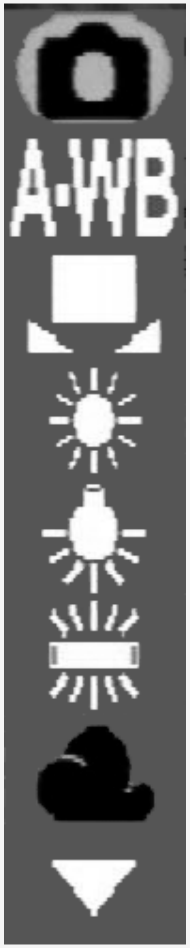
Aperture size (f stop)



#2:

Use fixed aperture size and vary the shutter speed to change exposure!

White balance



Auto
White Bal Preset
Daylight
Incandescent
Fluorescent
Cloudy

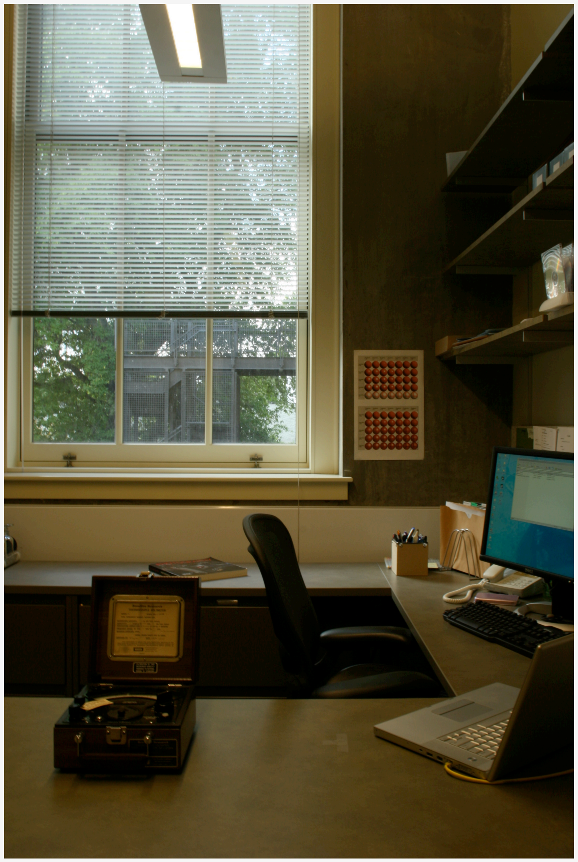
White balance

Auto
White Bal Preset
Daylight
Incandescent
Fluorescent
Cloudy

#3:
Set white balance, preferably to Daylight.

Film Speed

Film speed describes a film's sensitivity to light.



ISO 100

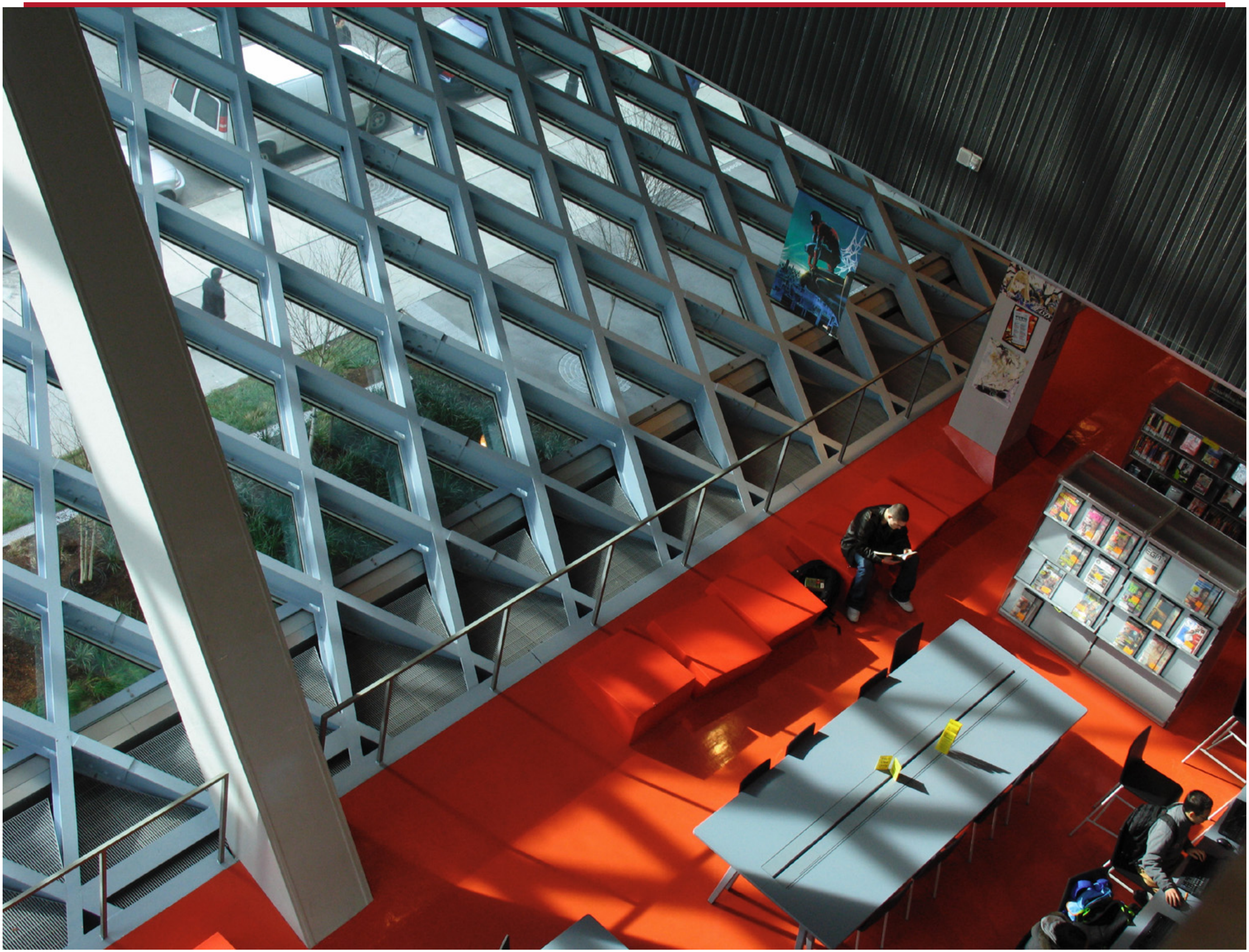
ISO 400

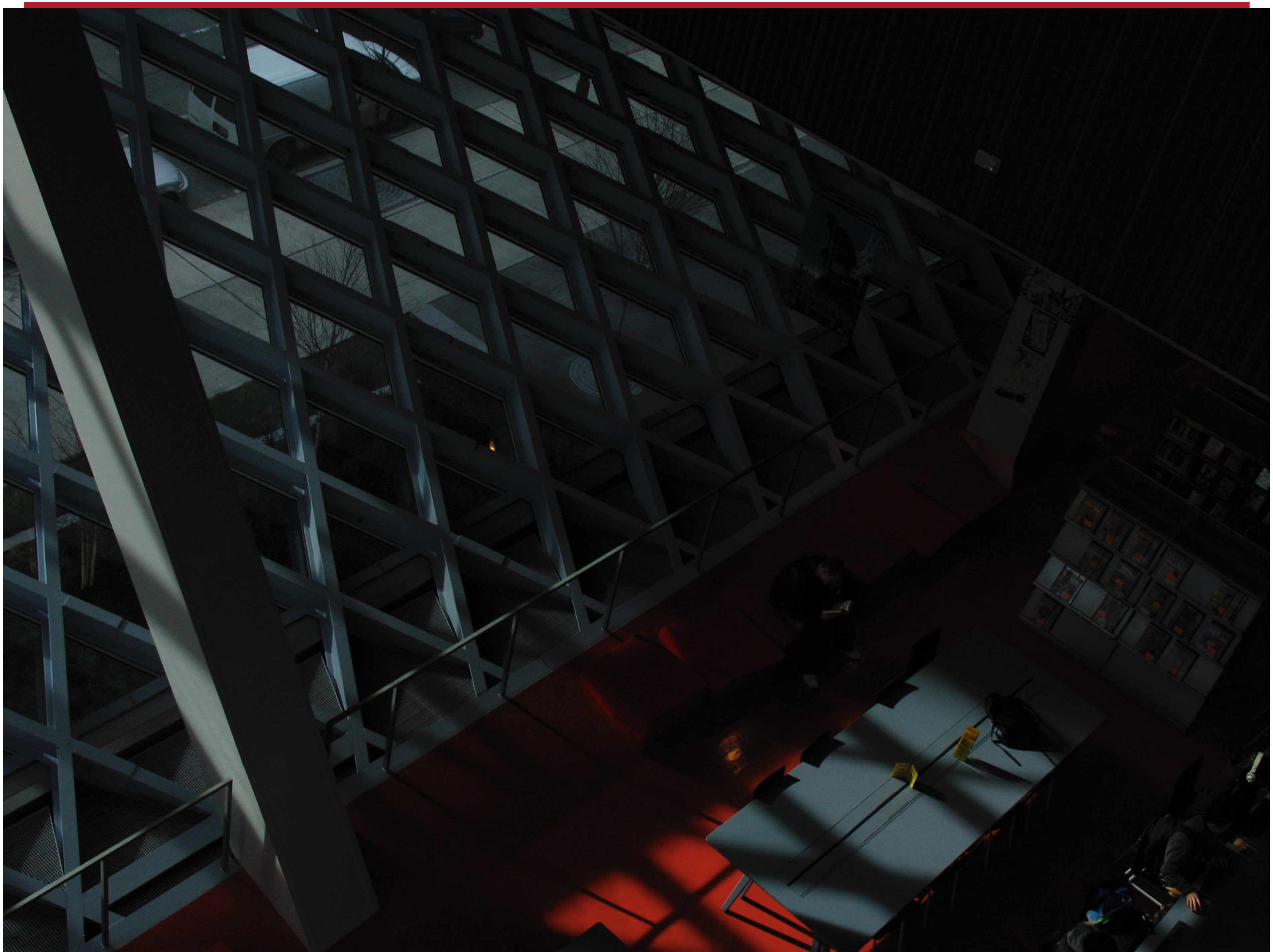
ISO 1000

#4: Set film speed to ISO 100

Capturing process

- Use tripod
- Fix the aperture size
- 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!



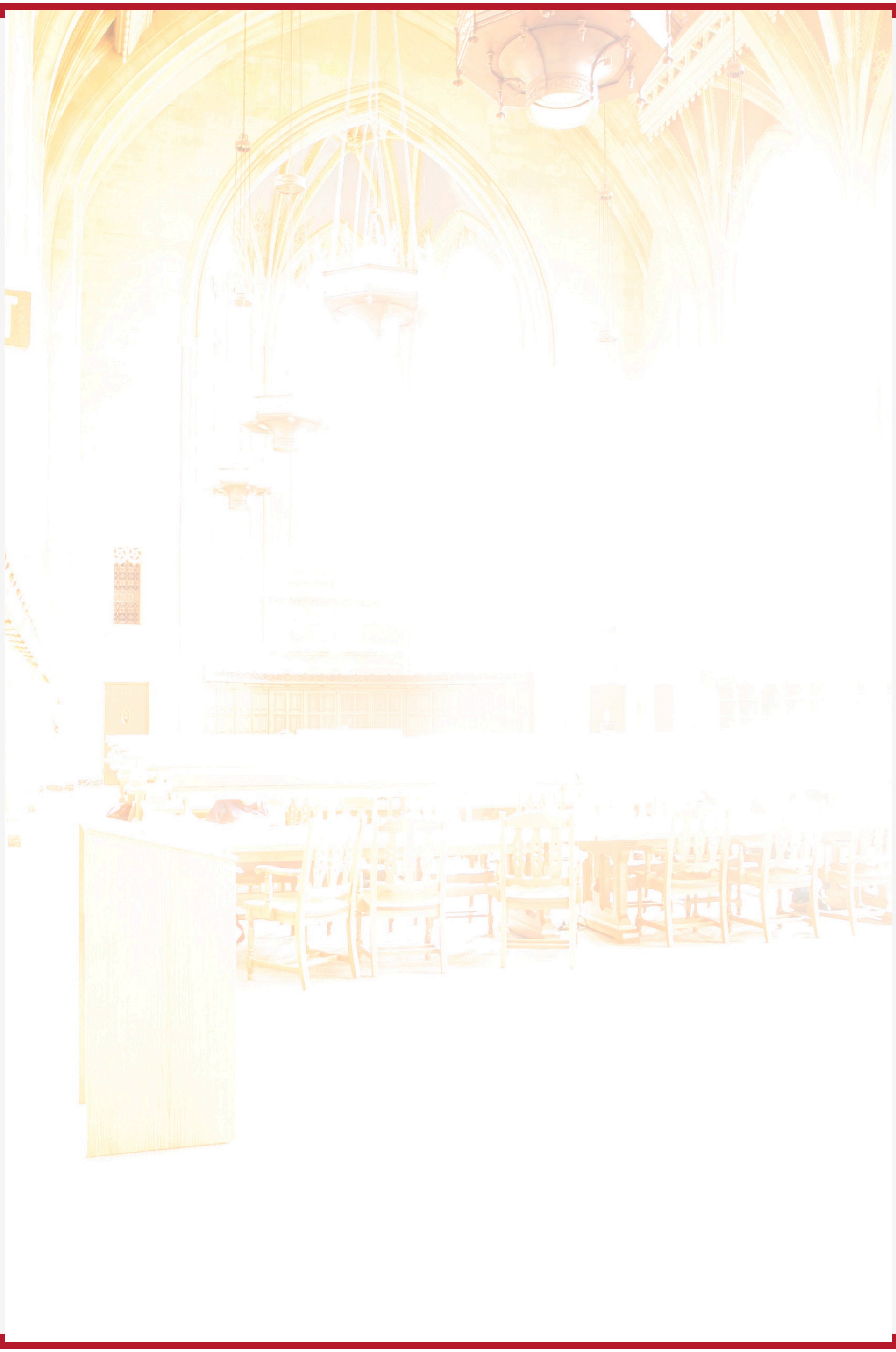


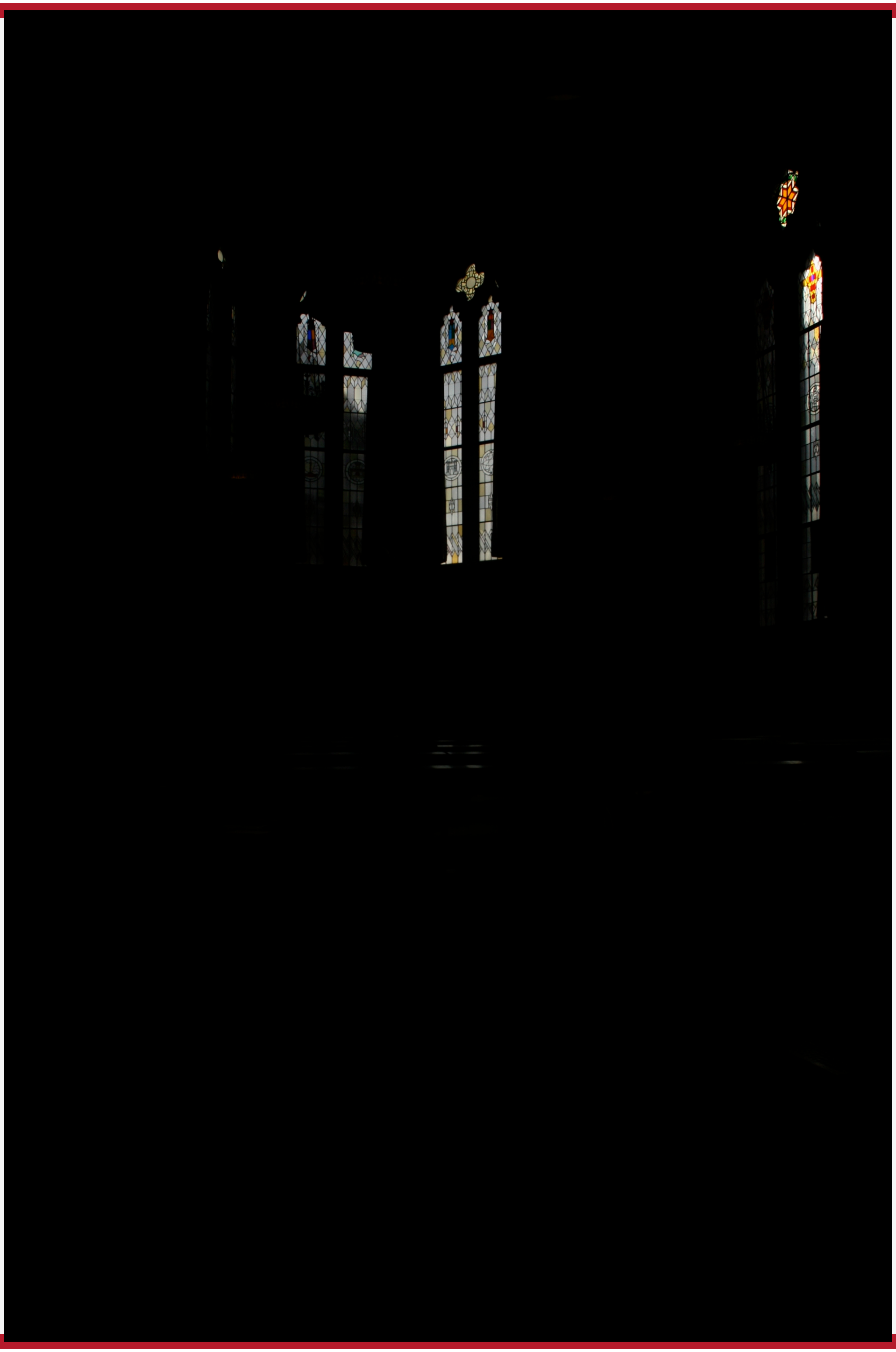
#5:

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

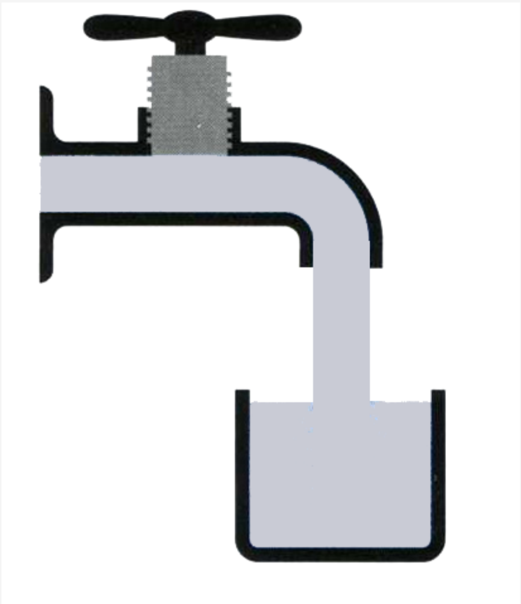
#6:

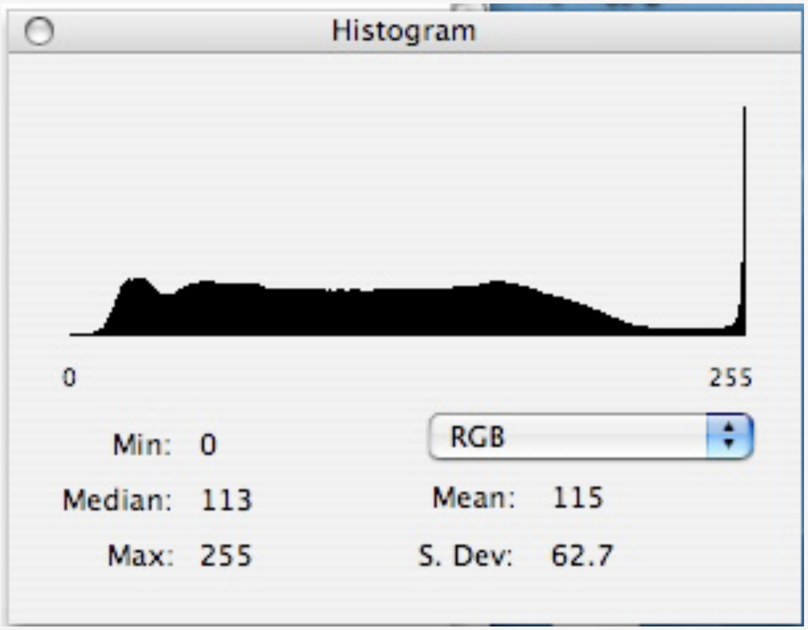
For a regular HDR assembly, take 6 - 8 exposures to cover the range.

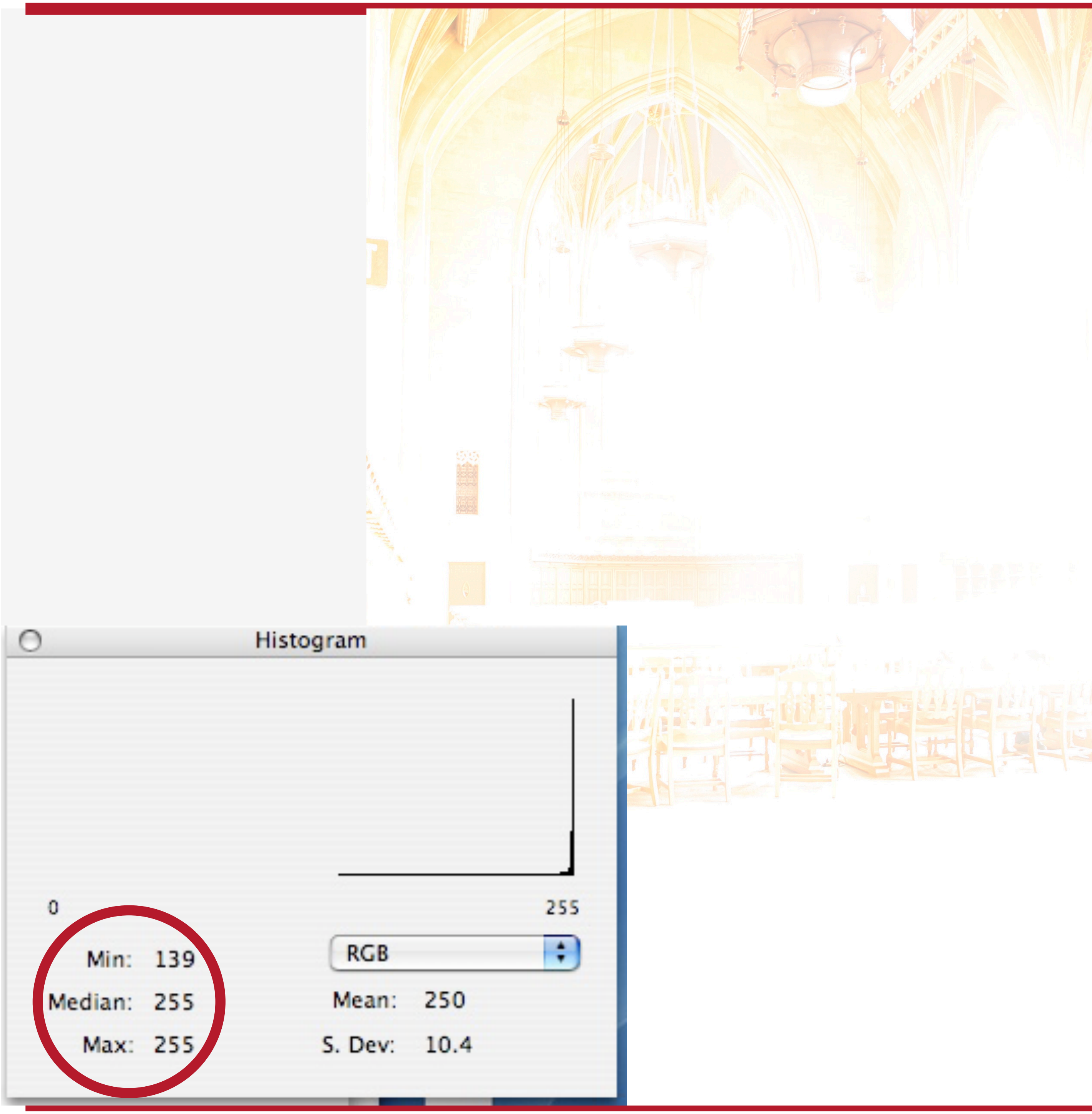




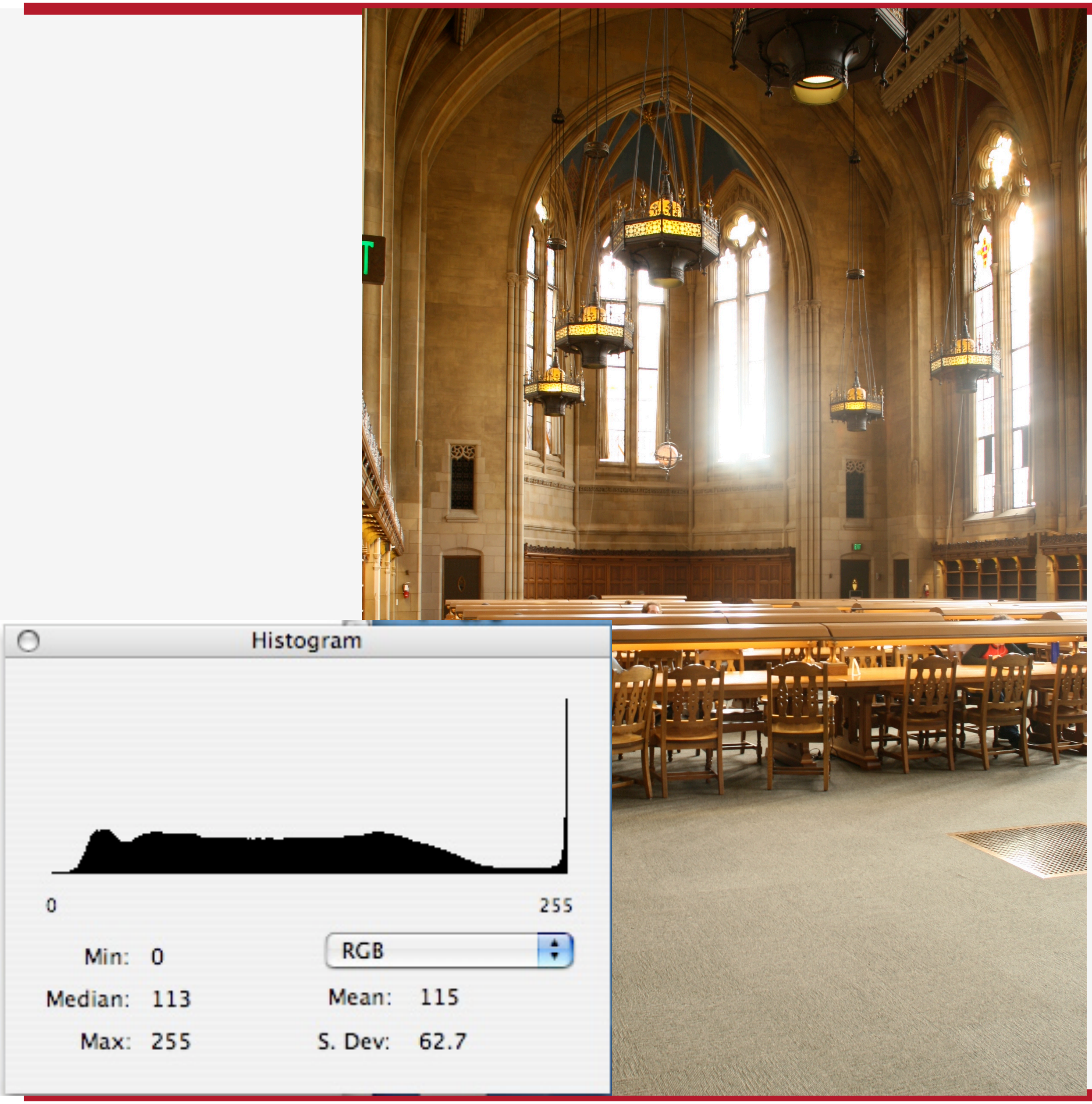
Is the bucket of light full?

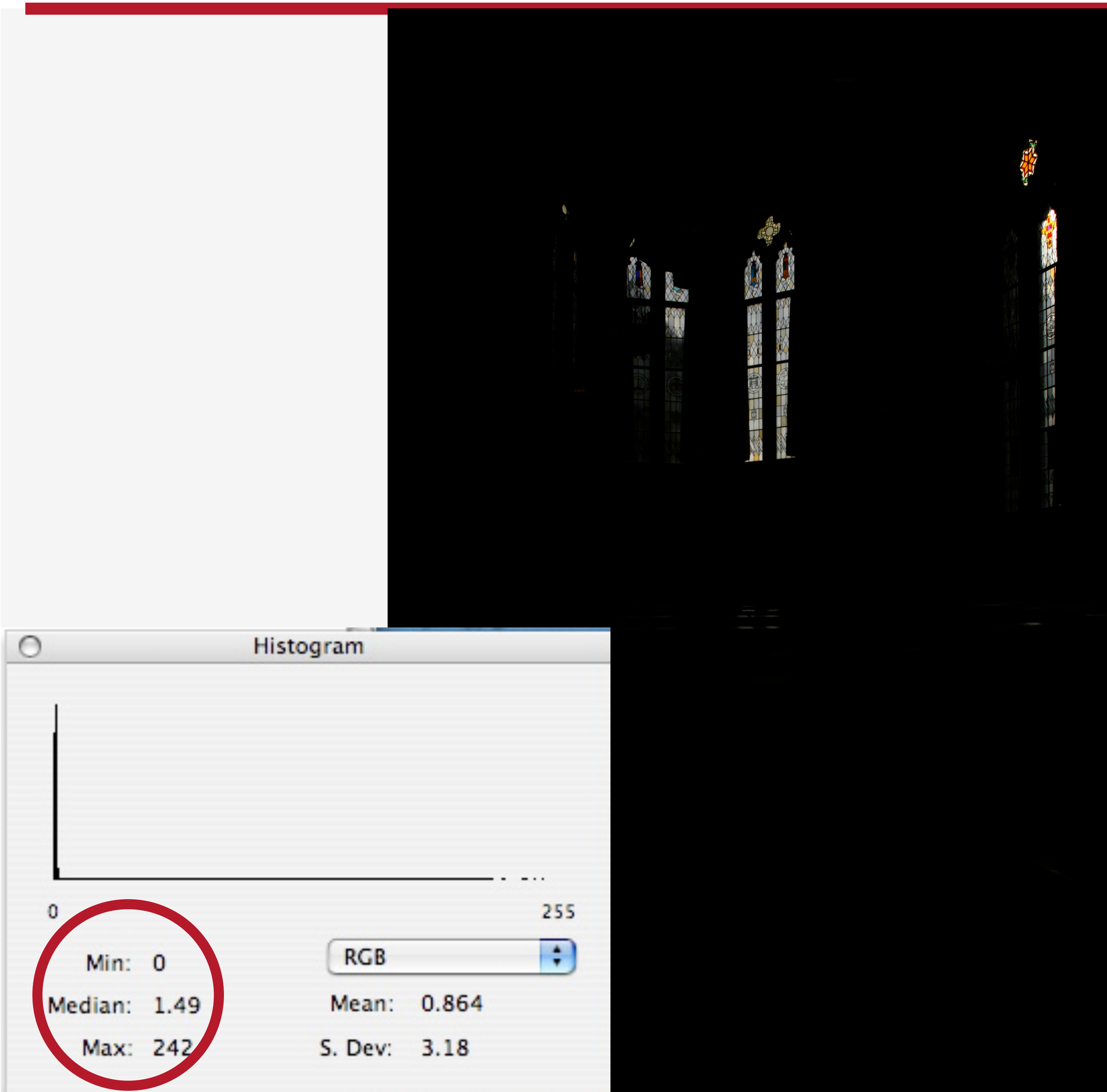


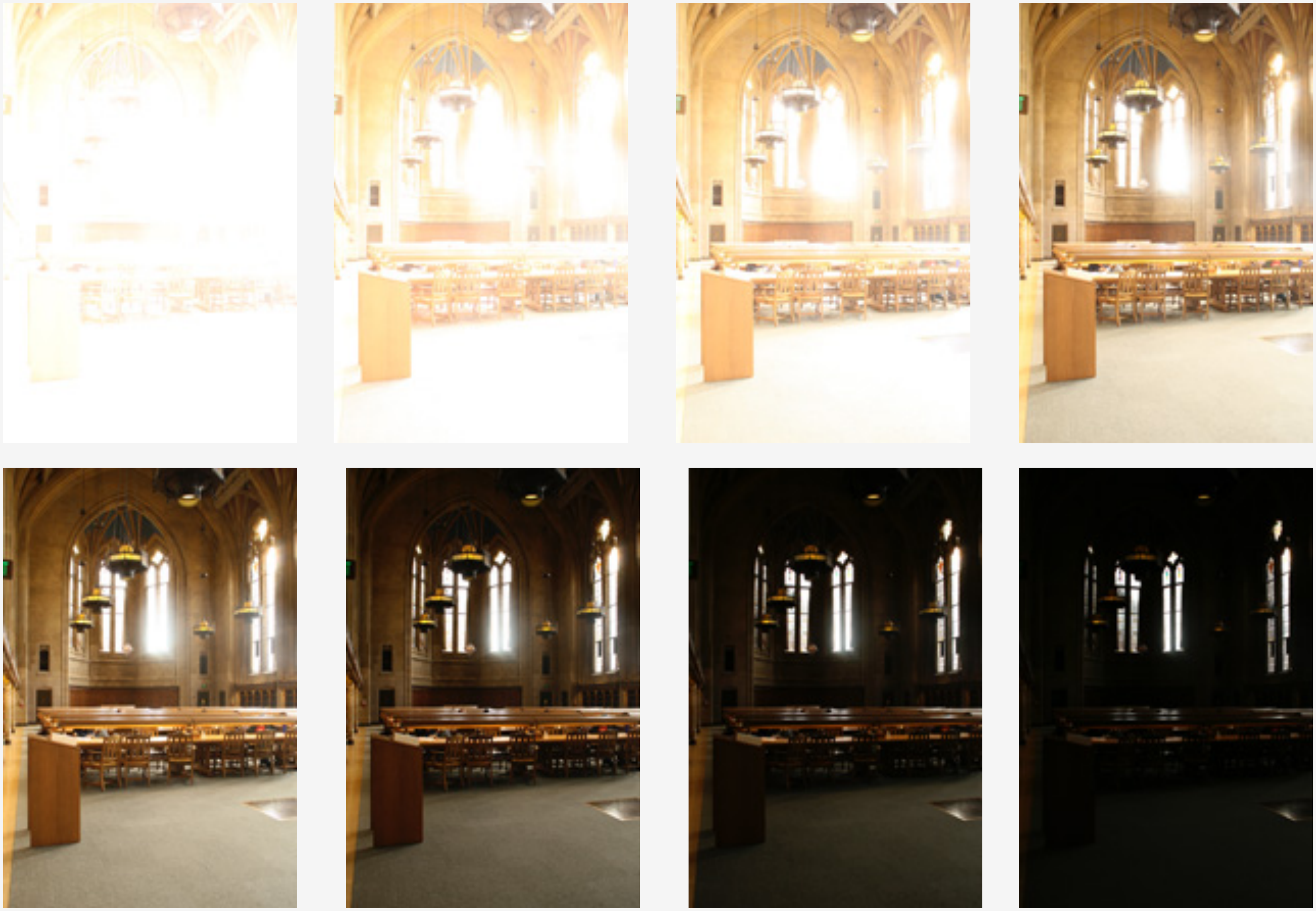




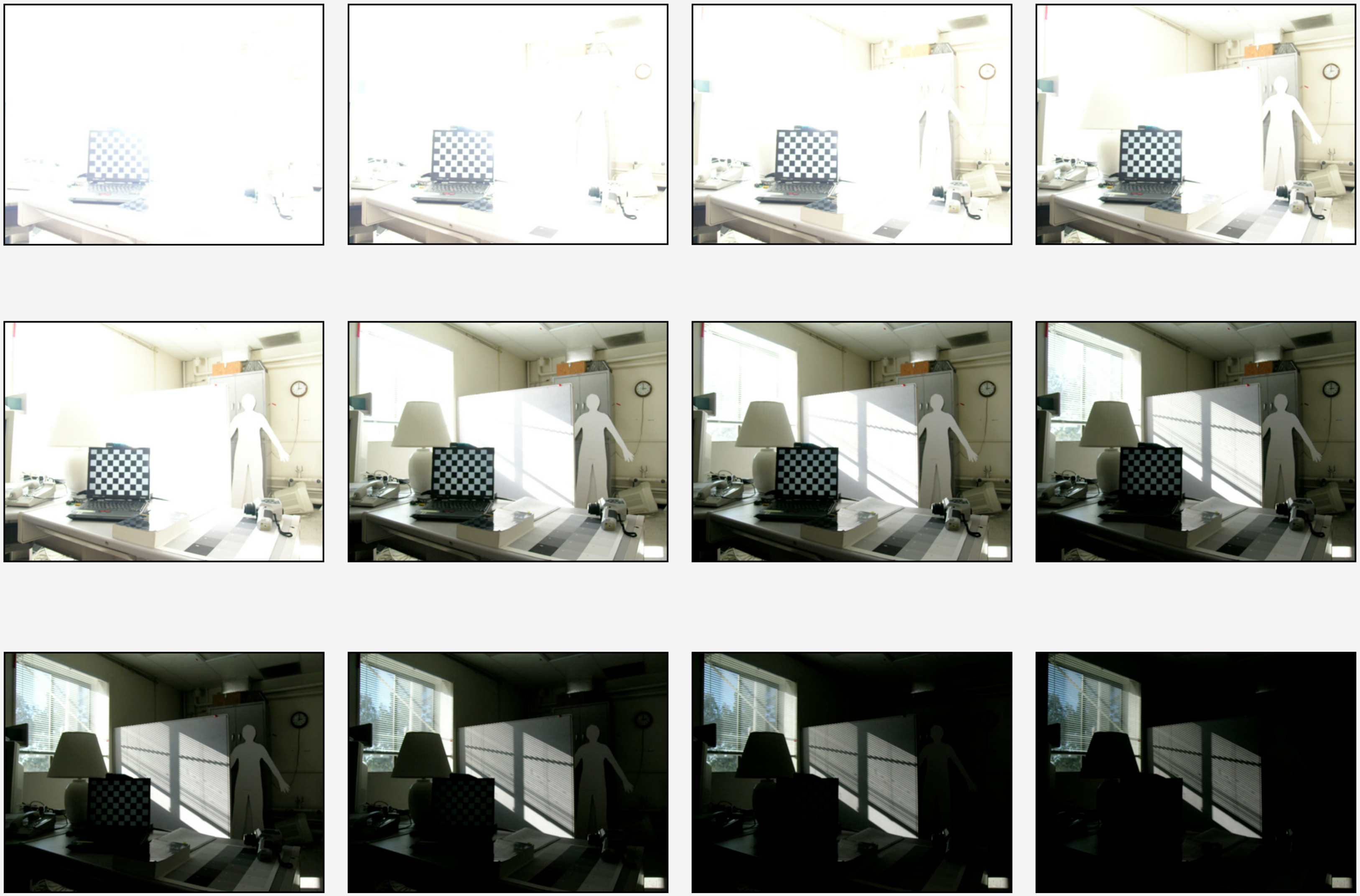
Histogram
0
255
Min: 139
Median: 255
Max: 255
RGB
Mean: 250
S. Dev: 10.4


Histogram
0
255
Min: 0
Median: 113
Max: 255
RGB
Mean: 115
S. Dev: 62.7


Histogram
0
255
Min: 0
Median: 1.49
Max: 242
RGB
Mean: 0.864
S. Dev: 3.18

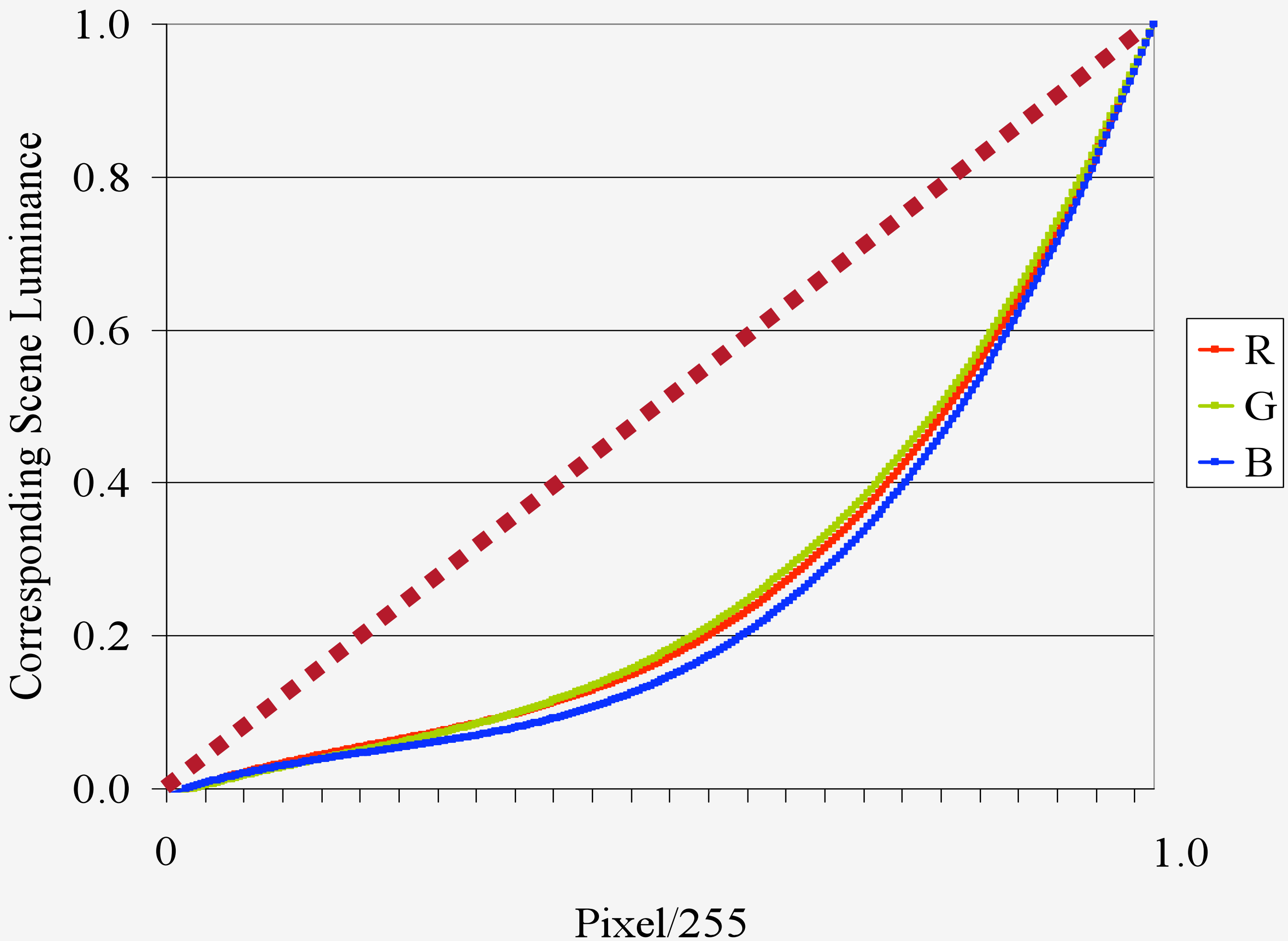


Camera Response Function



2b

Camera Response Curve

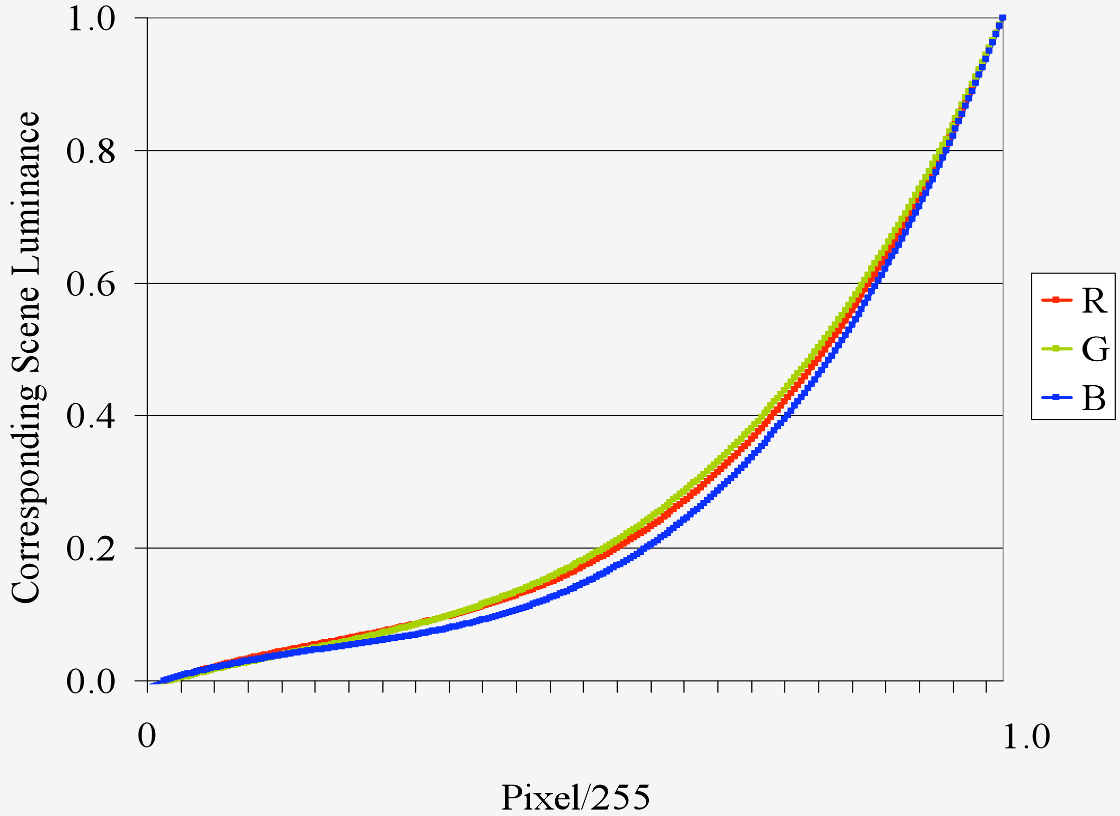


Every camera has a different calibration curve

Camera Response Curve

"Polynomial functions that model the accumulated radiometric non-linearities of the image acquisition process, without addressing the individual source of each non-linearity".

Source: Mitsunaga and Nayar

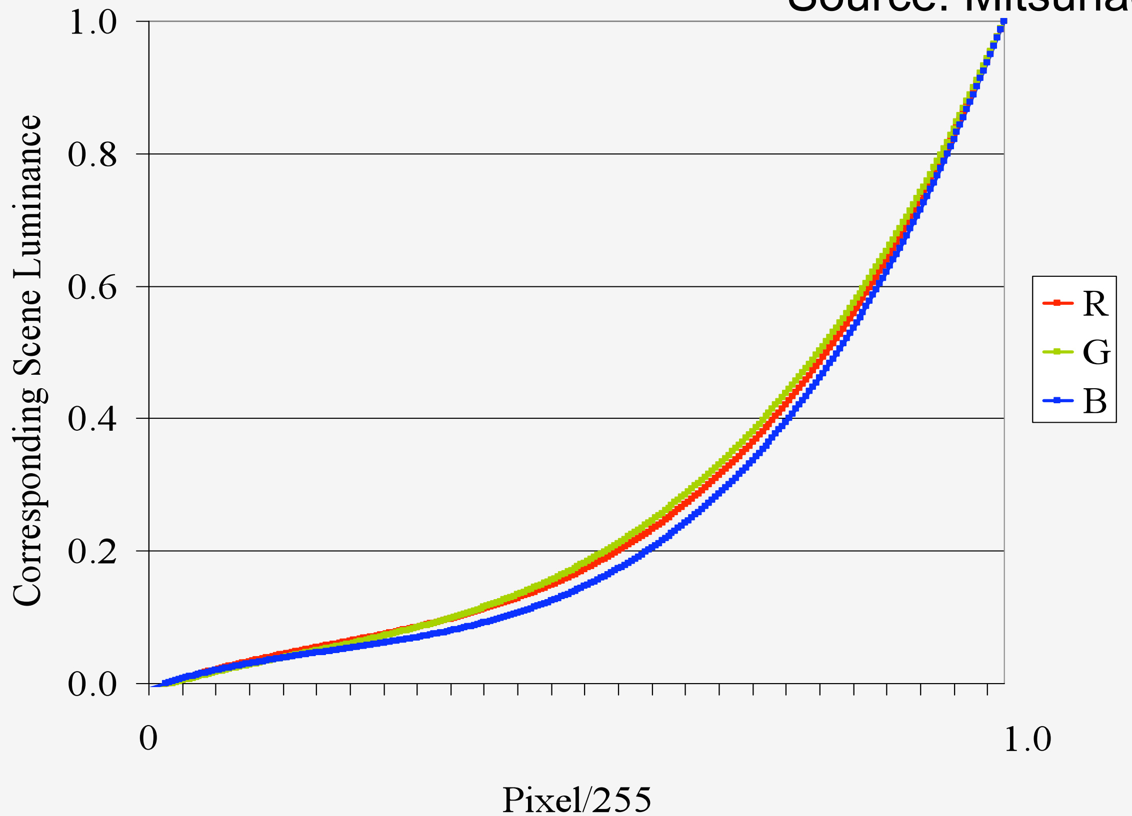


Every camera has a different calibration curve

Camera Response Curve

Radiometric self-calibration is a computationally derived calibration process that is used to relate the pixel values to the real-world luminances.

Source: Mitsunaga and Nayar



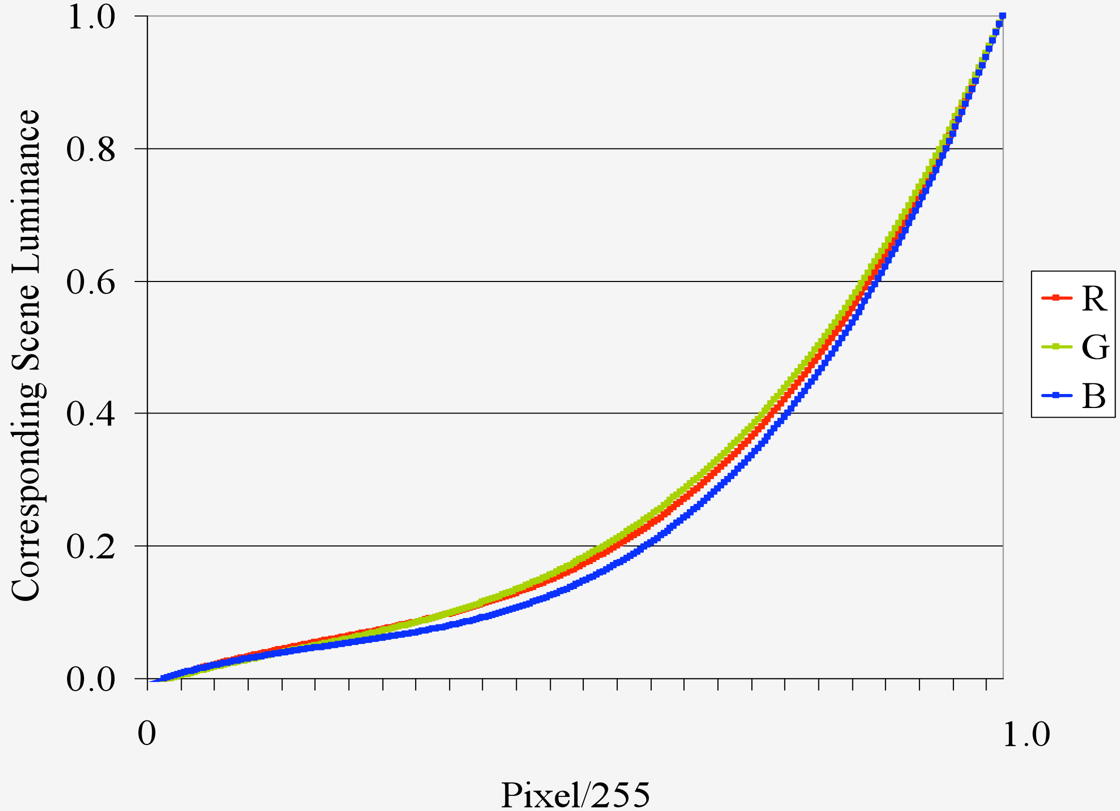
Every camera has a different calibration curve

Camera Response Curve

$$R = 1.53994x^3 - 0.99492x^2 + 0.46536 - 0.01037$$

$$G = 1.31795x^3 - 0.69784x^2 + 0.38994 - 0.01005$$

$$B = 1.67667x^3 - 1.09256x^2 + 0.42334 - 0.00745$$



Every camera has a different calibration curve

#7:

For determining the camera response curve, select a scene that has both low and high luminance values and gradual change within the scene.

#8:

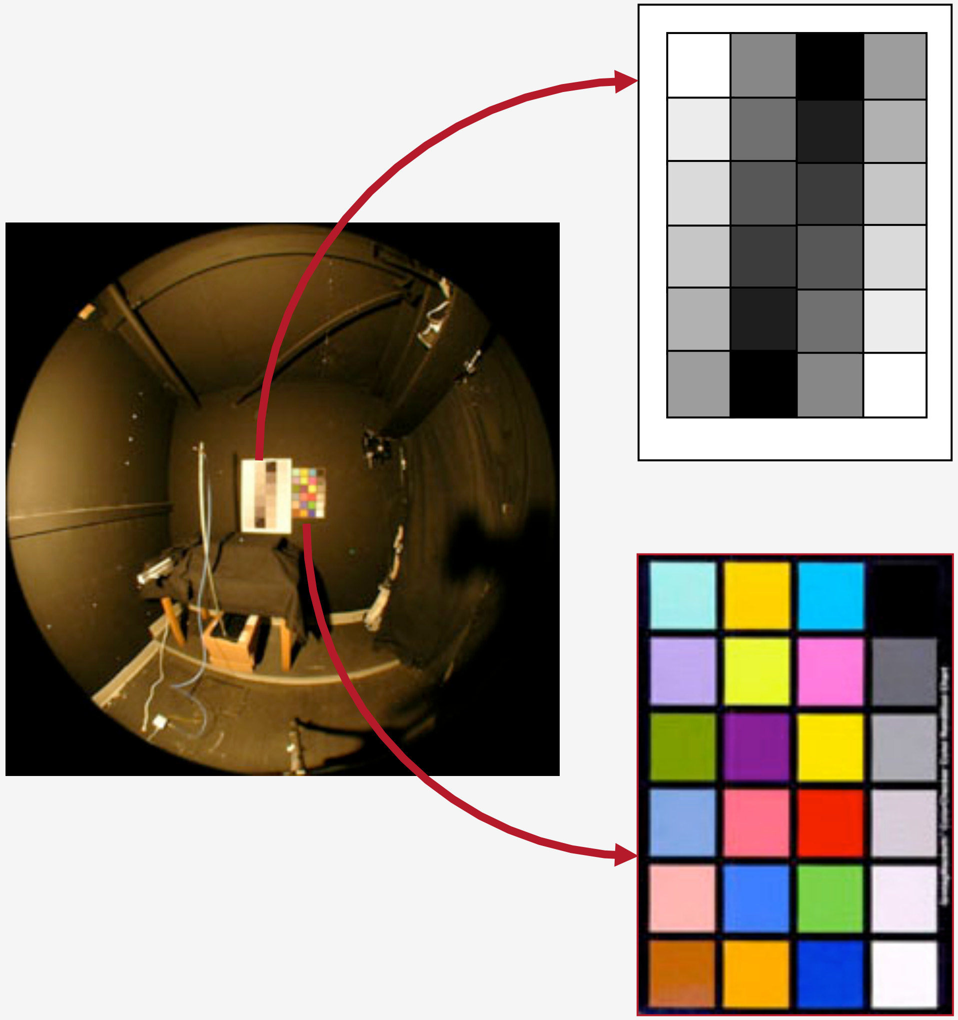
For determining the camera response curve, take as many exposures as you can take with your camera (12+).

#9:

Use the same response curve for generating subsequent HDR images

2c

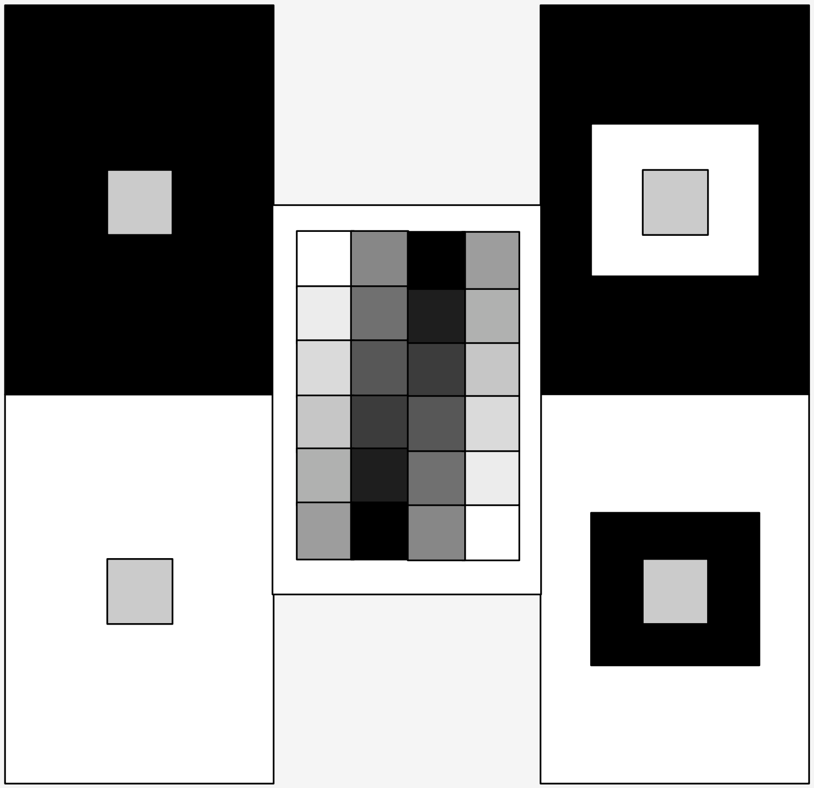
Accuracy of HDR Data Acquisition

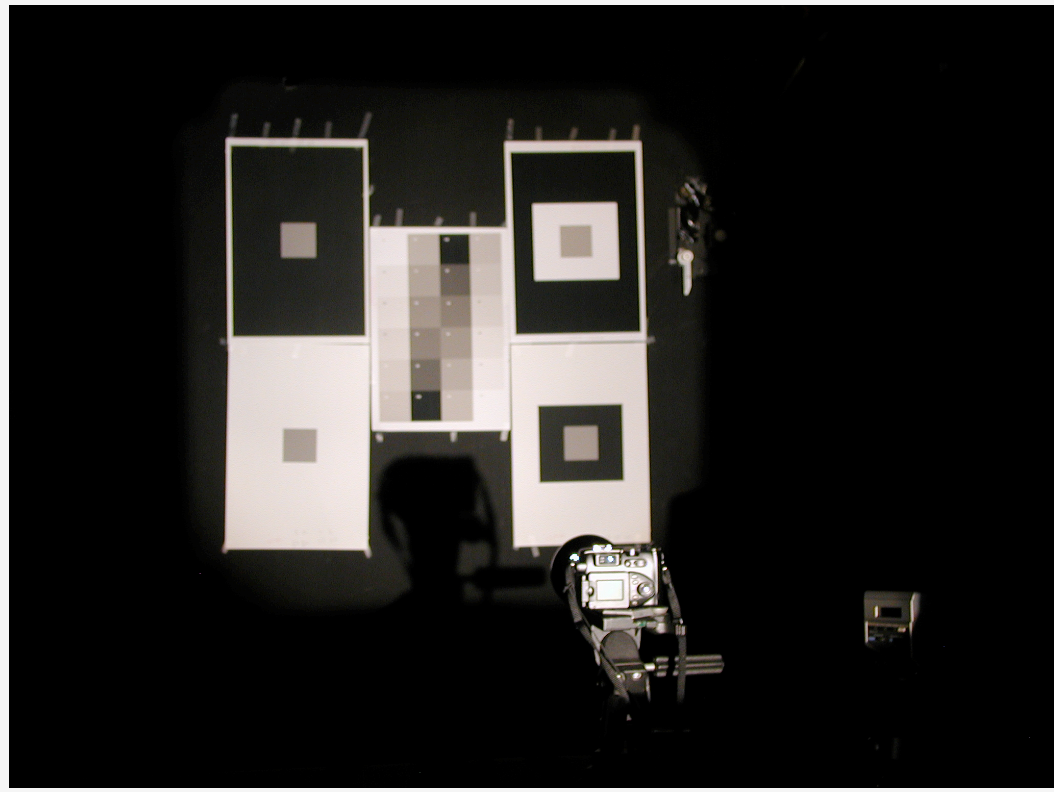


Photosphere

- Developed by Greg Ward
- Based on “Self Calibration Algorithm” developed by Mitsunaga and Nayar
- Free
- Available from: http://www.anyhere.com

Accuracy of HDR Data Acquisition





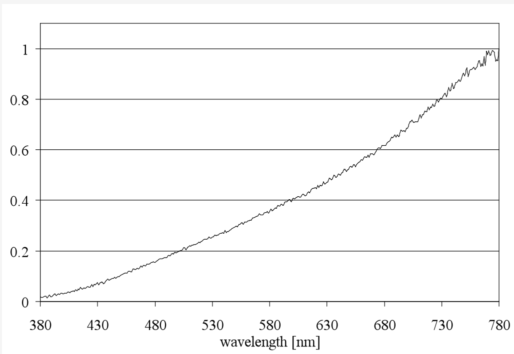
Accuracy of HDR Data Acquisition

- Incandescent lamp
- Fluorescent Lamp

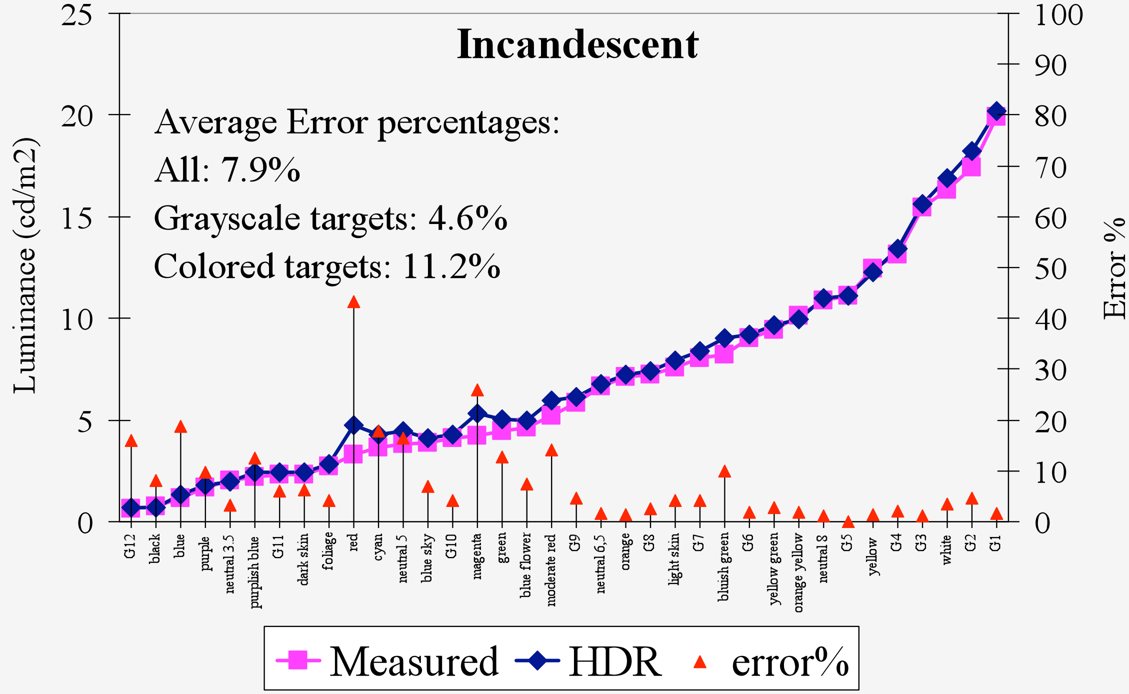
  (T5, T8, T12 w/ CCT 3000-6500°K)
- High Pressure Sodium
- Metal Halide
- LED

Accuracy of HDR Data Acquisition

Spectral data

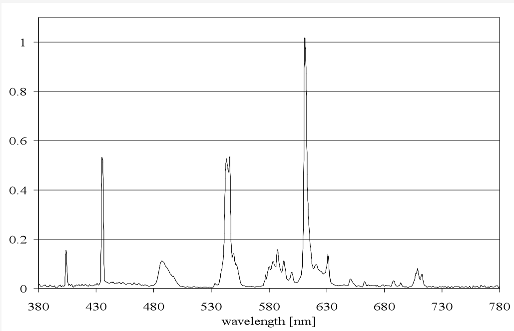


Luminance measurements

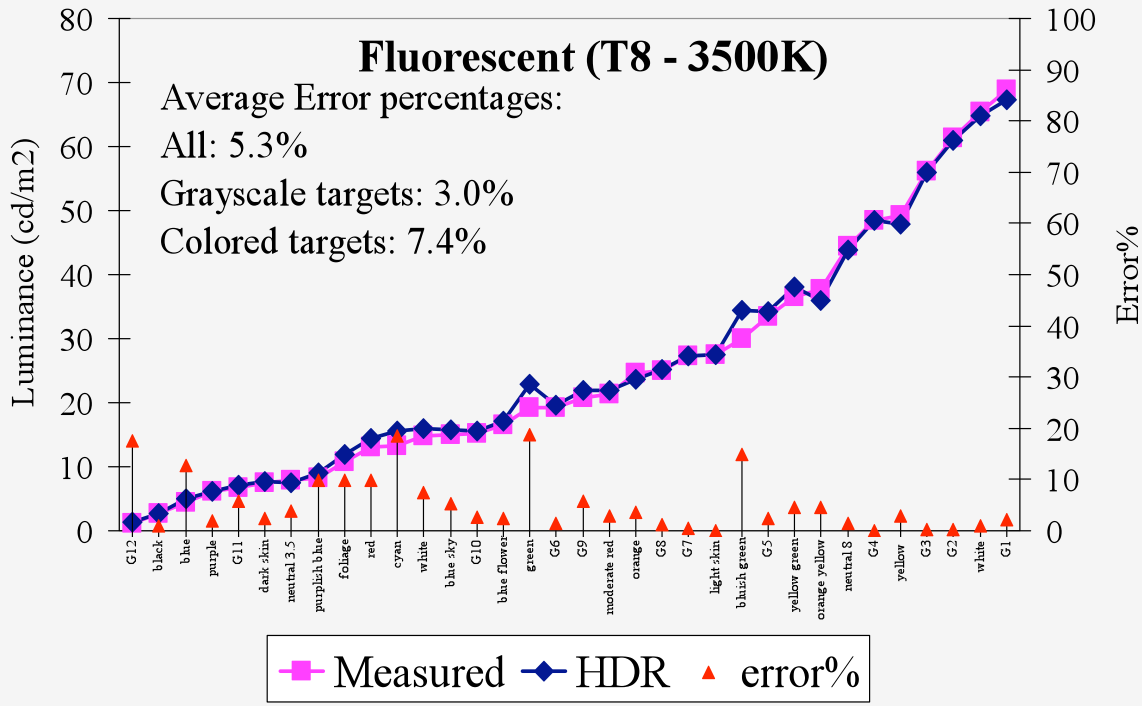


Accuracy of HDR Data Acquisition

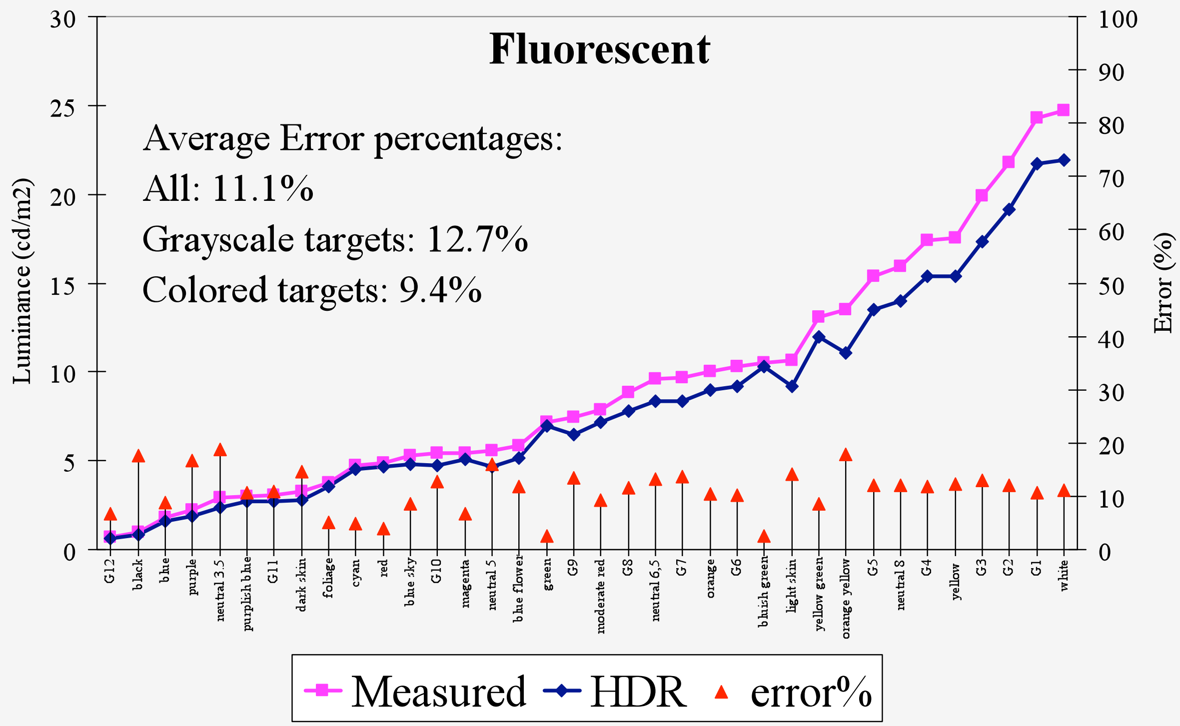
Spectral data



Luminance measurements

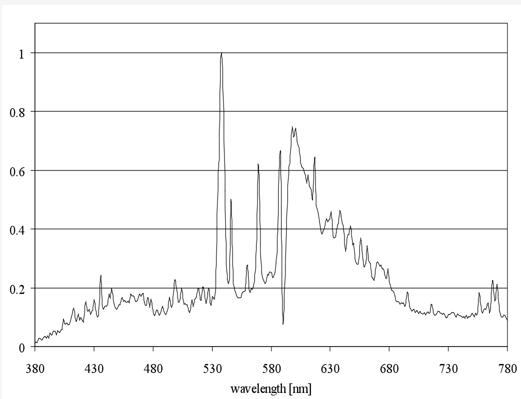


Accuracy of HDR Data Acquisition

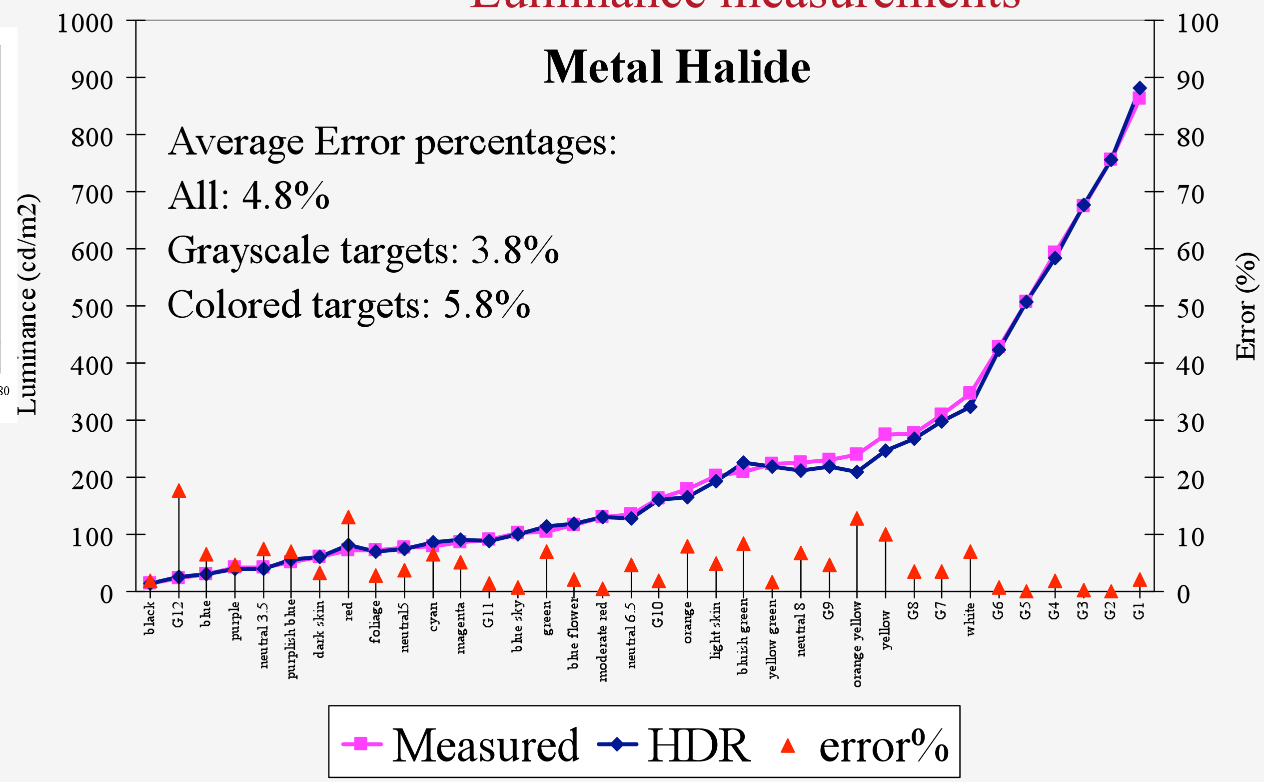


Accuracy of HDR Data Acquisition

Spectral data

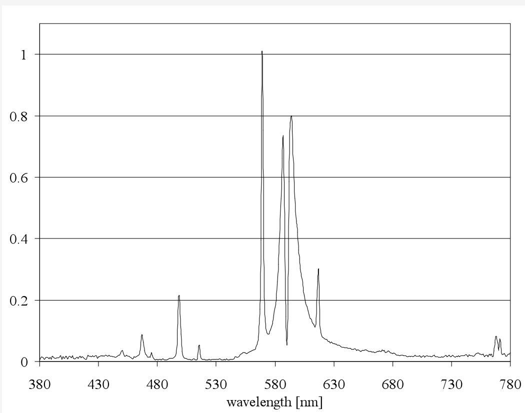


Luminance measurements

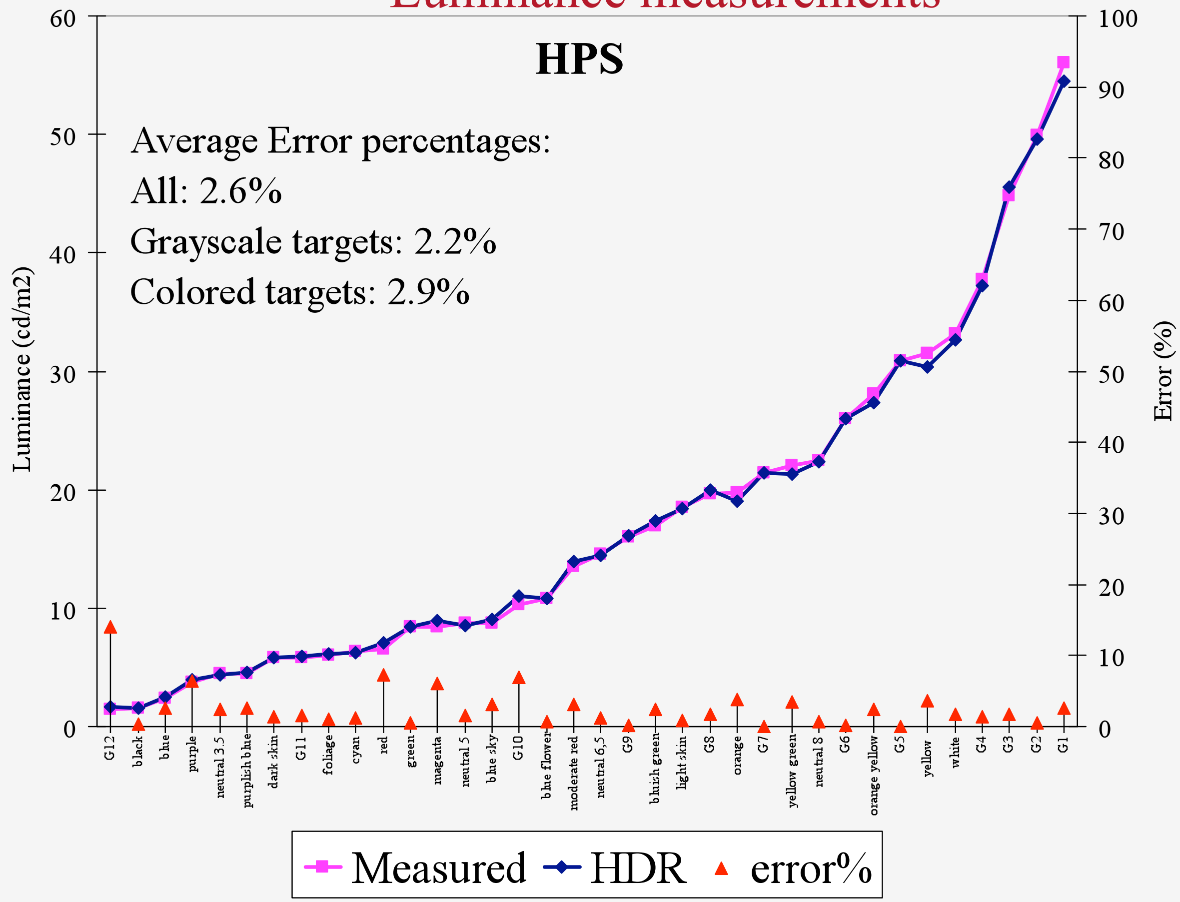


Accuracy of HDR Data Acquisition

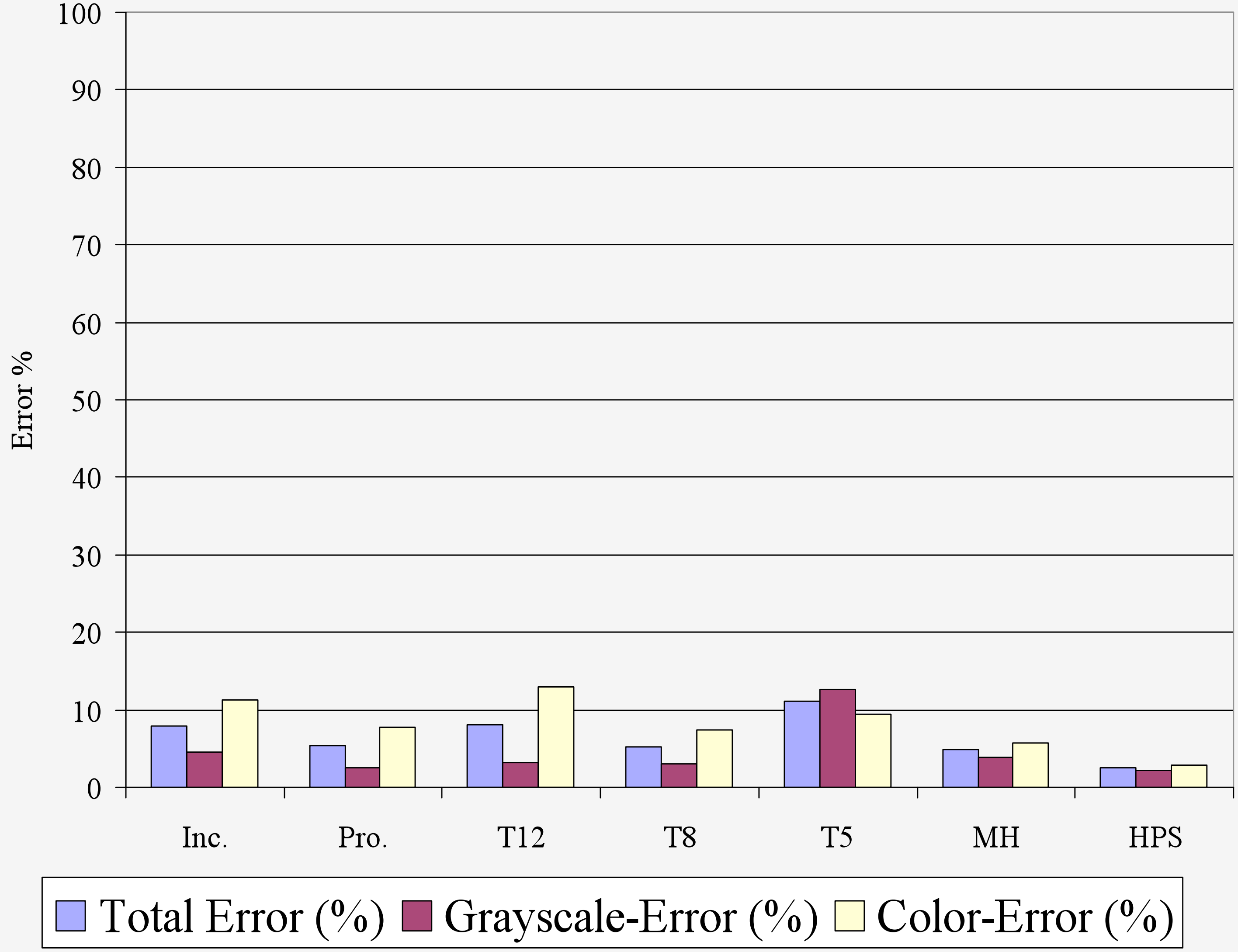
Spectral data

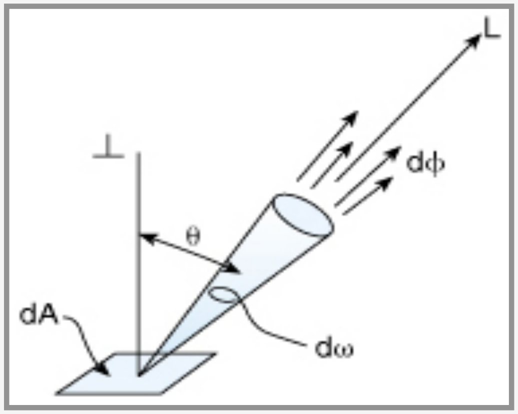


Luminance measurements

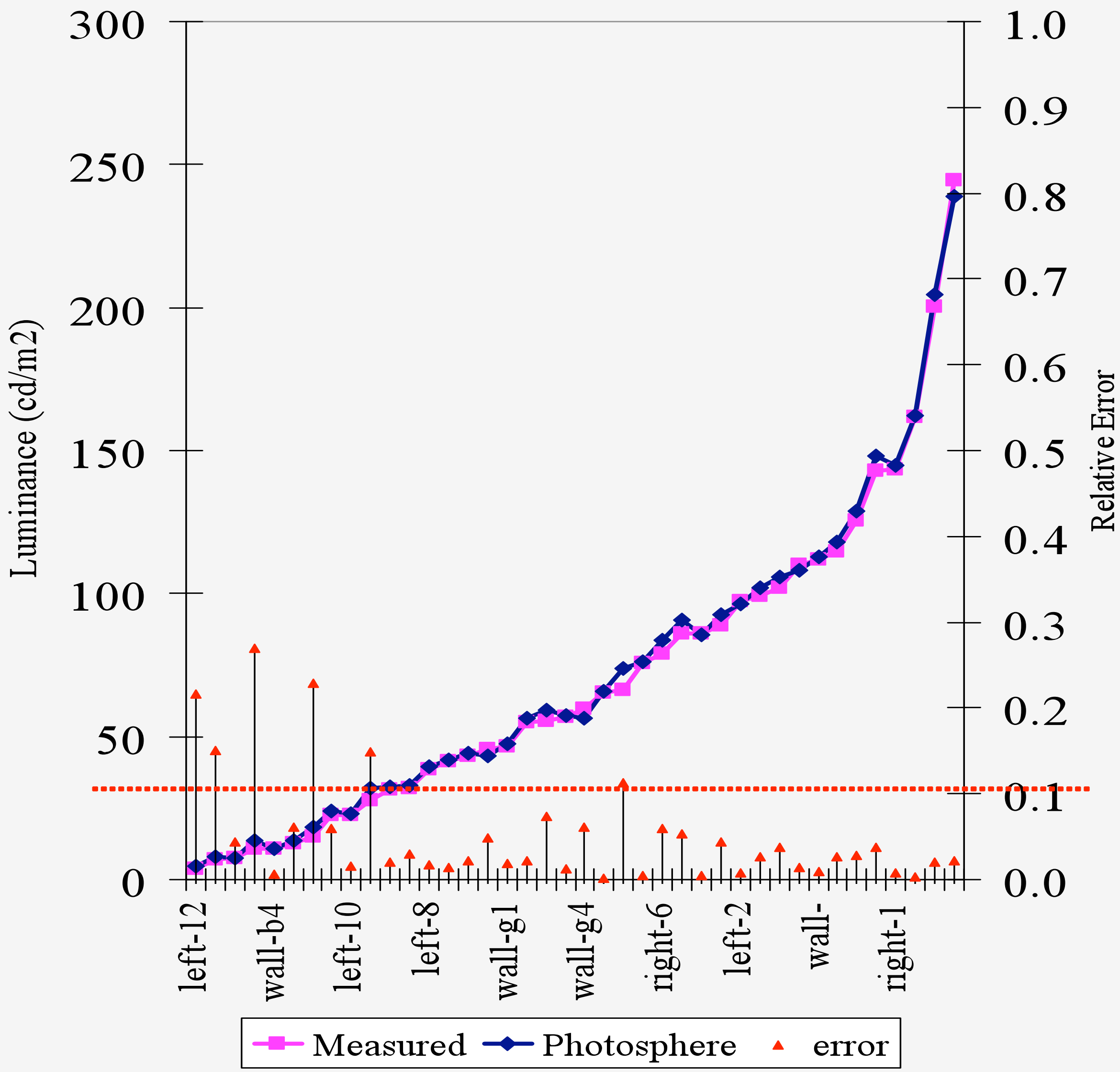


Accuracy of HDR Data Acquisition



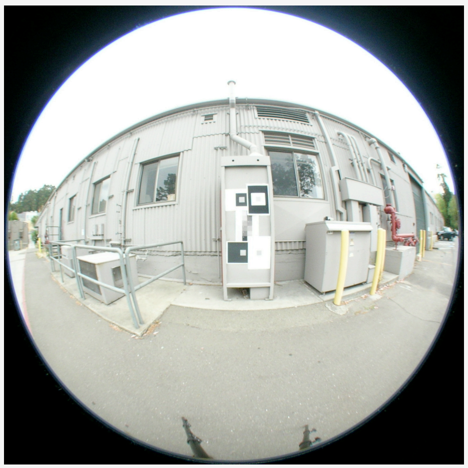

L
⊥
dϕ
θ
dA
dω

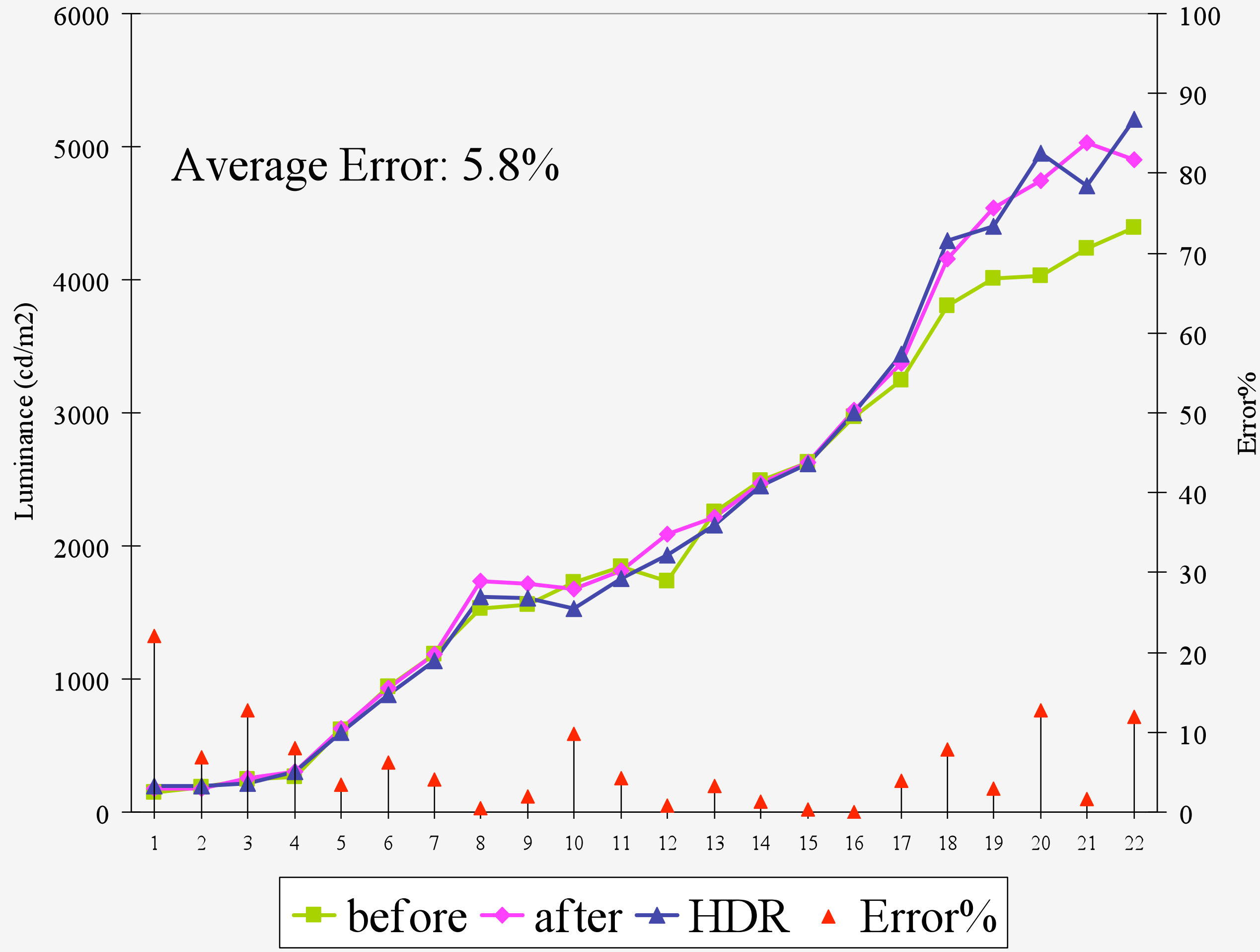
Accuracy of HDR Data Acquisition



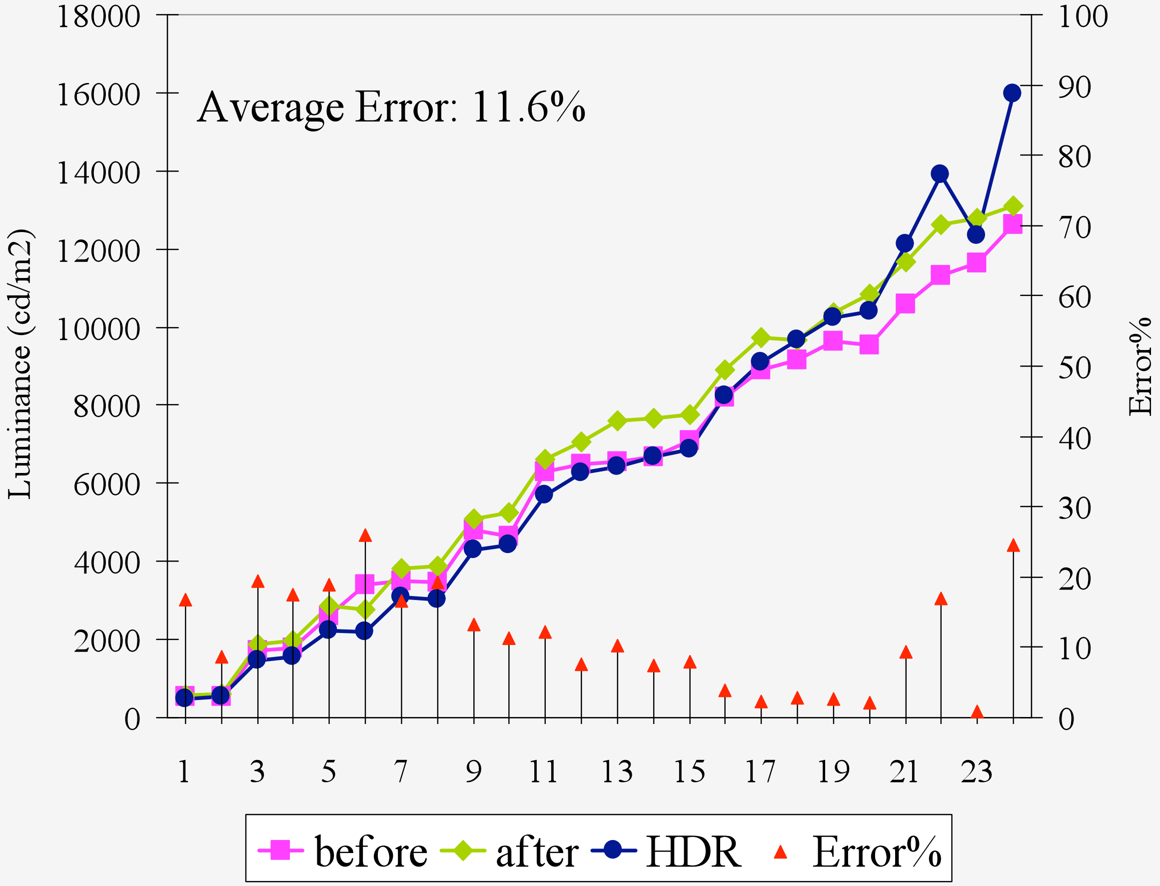
Accuracy of HDR Data Acquisition

Accuracy of HDR Data Acquisition

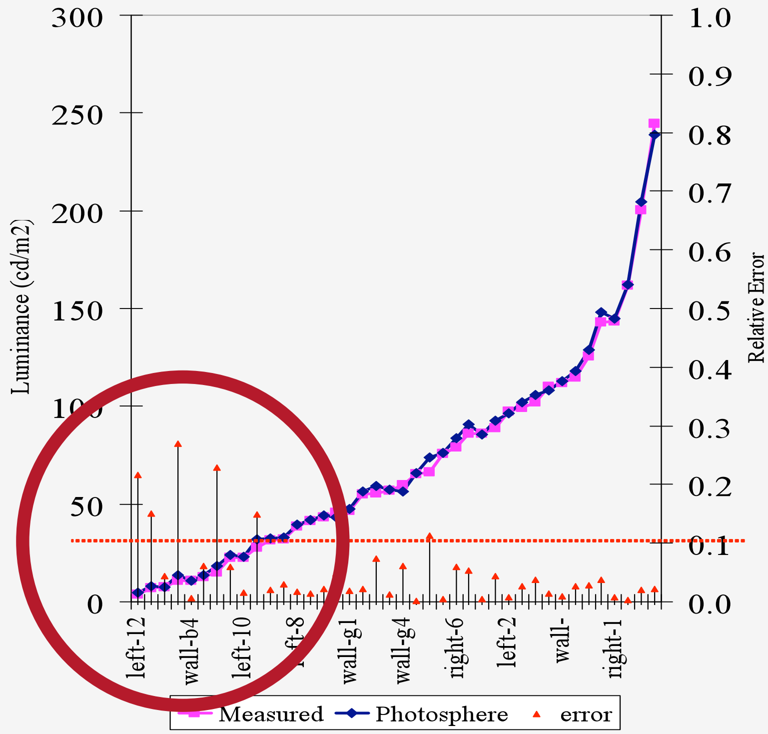


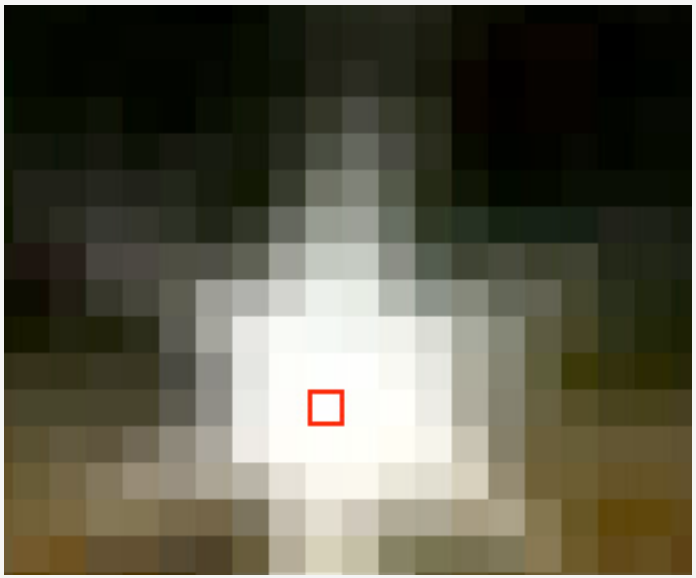


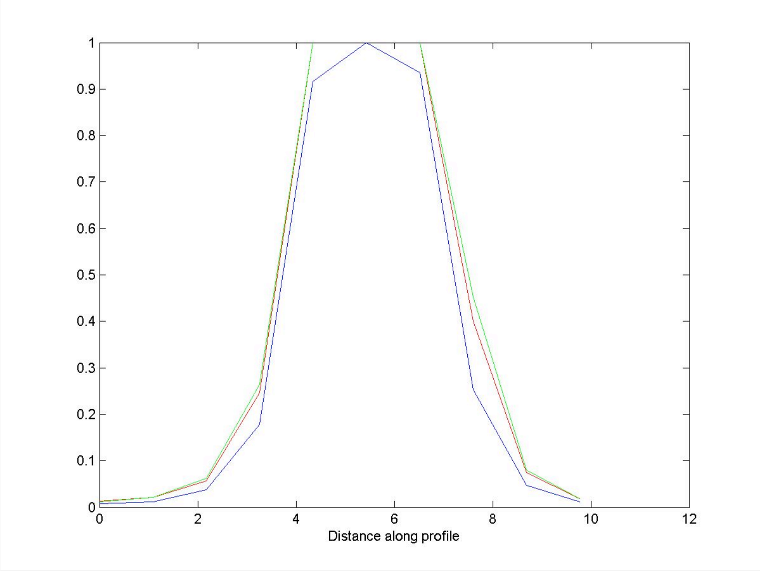
Accuracy of HDR Data Acquisition



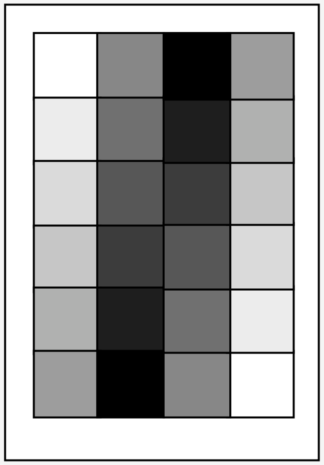
Point Spread Function

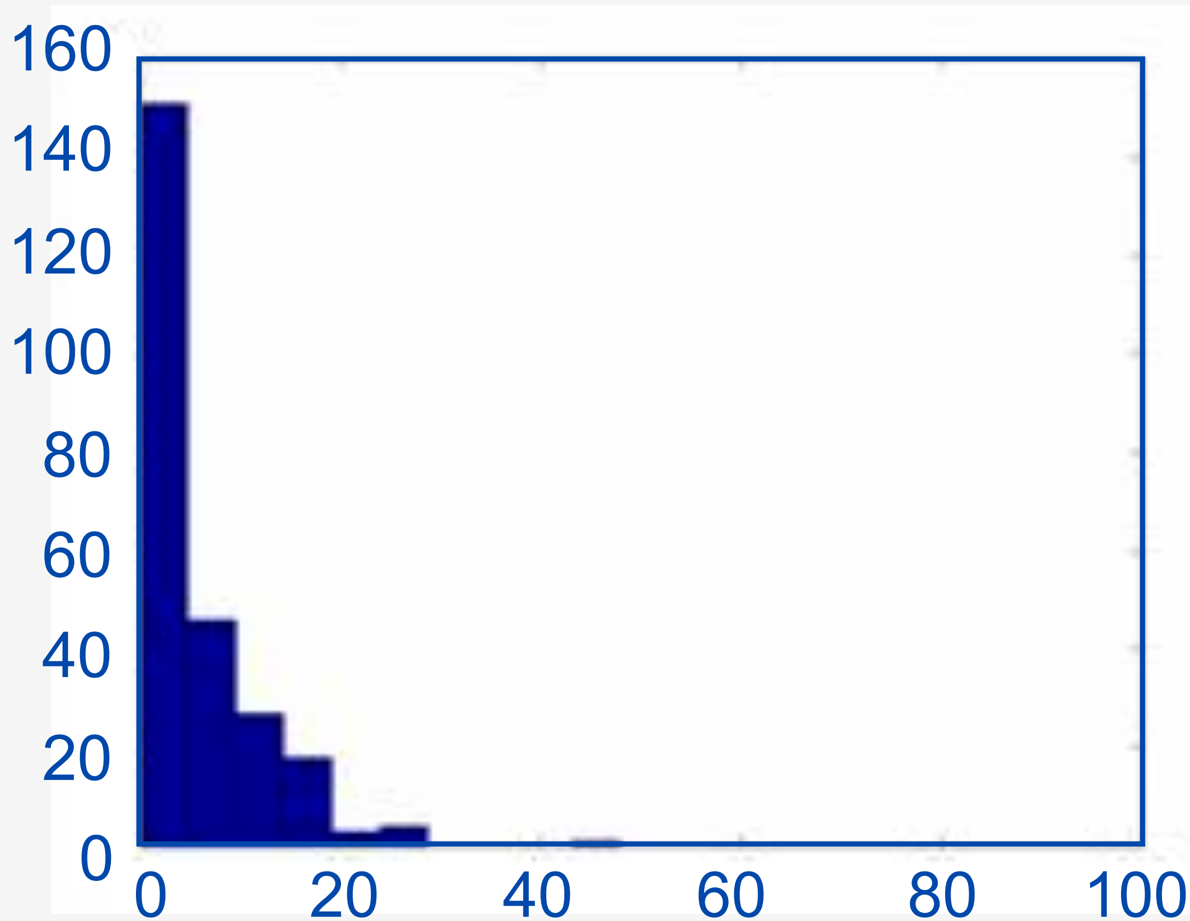




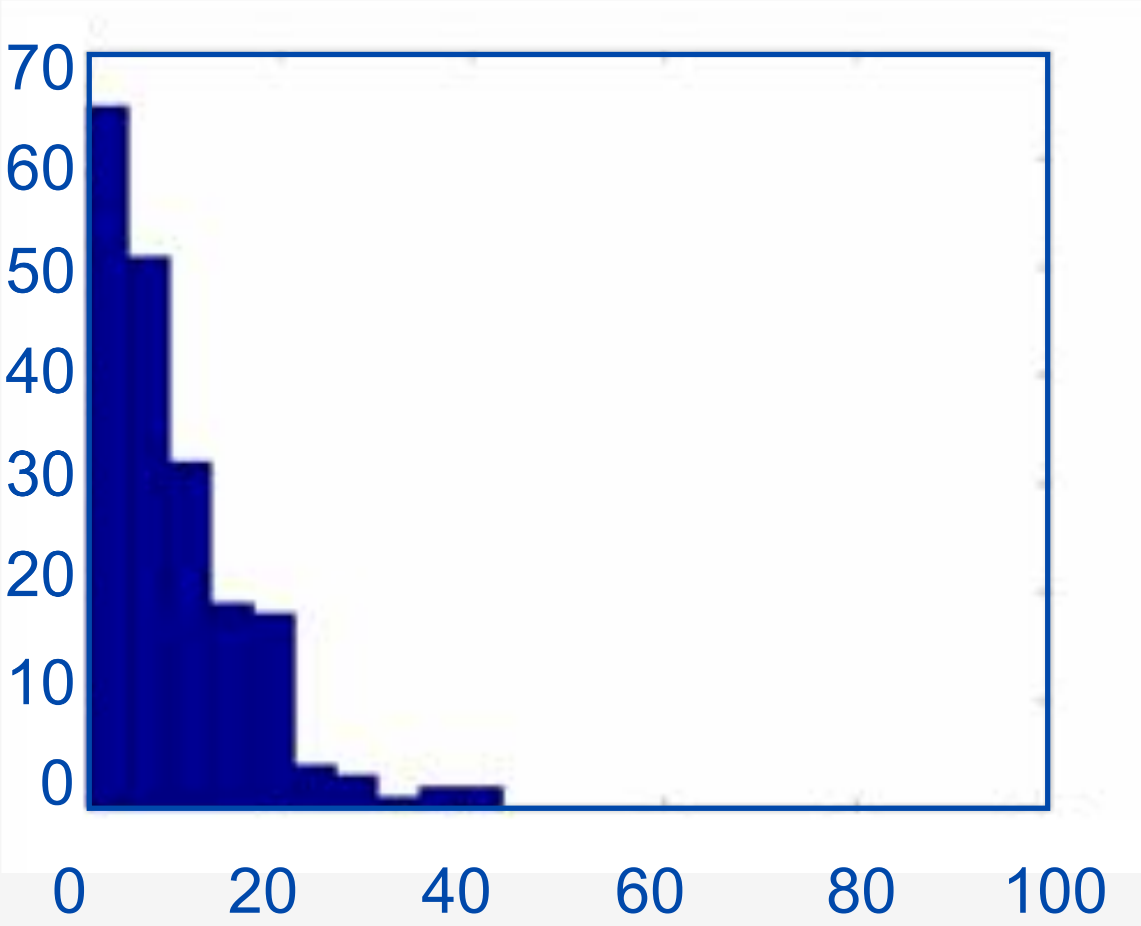


Grayscale





Saturated Colors



Assembly process

For good accuracy:

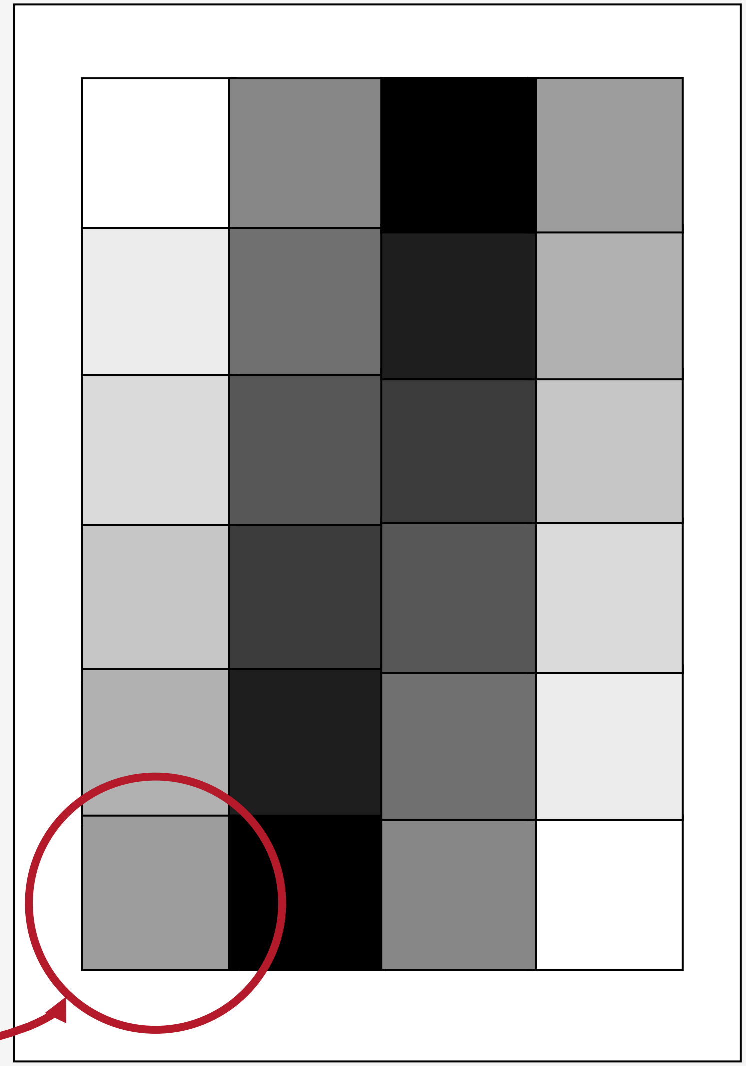
calibrate HDR photographs

with

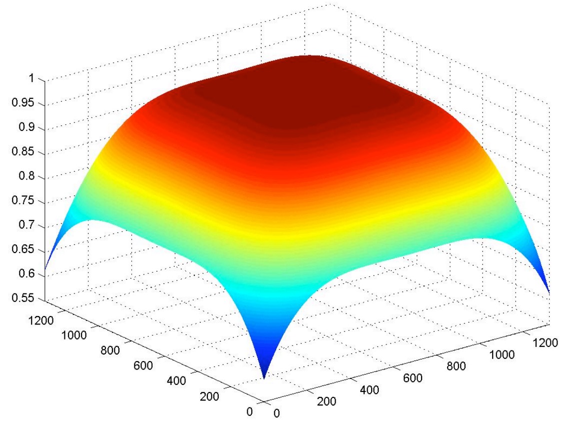
a **single** luminance measurement of

a mid level grey patch in the scene.

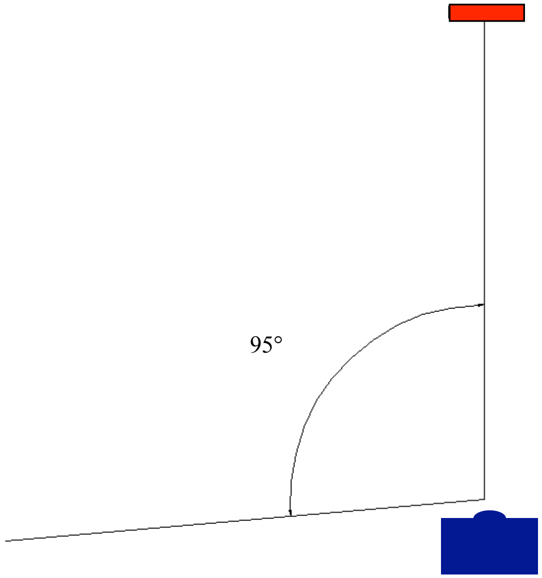
Calibration



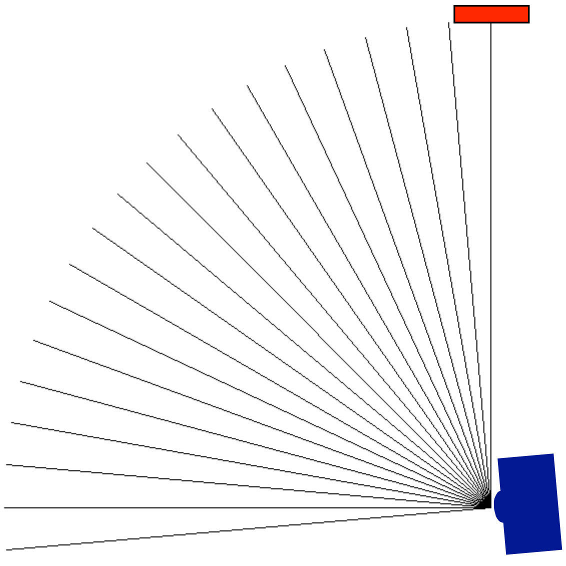
Vignetting



1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200



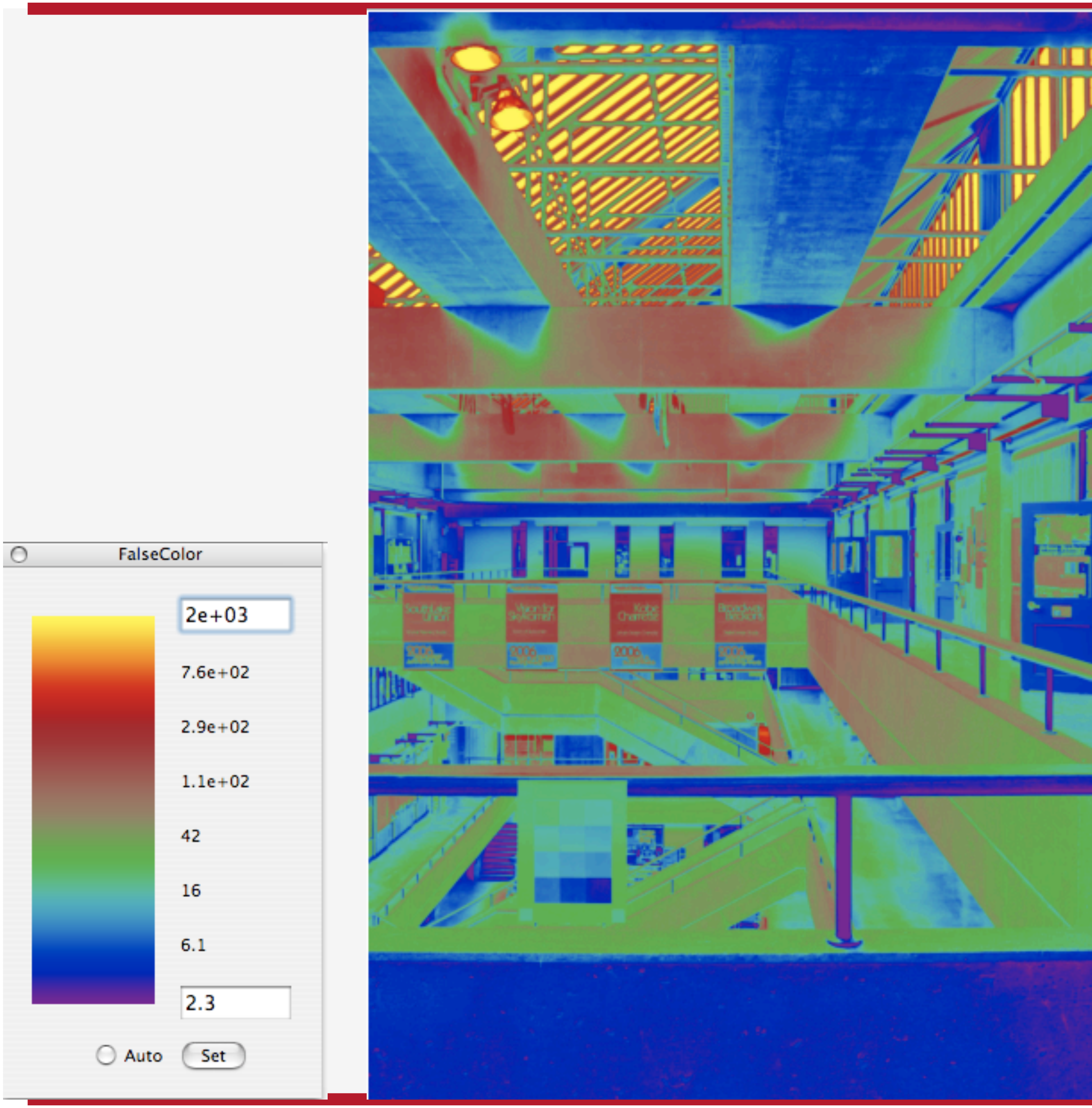
95°

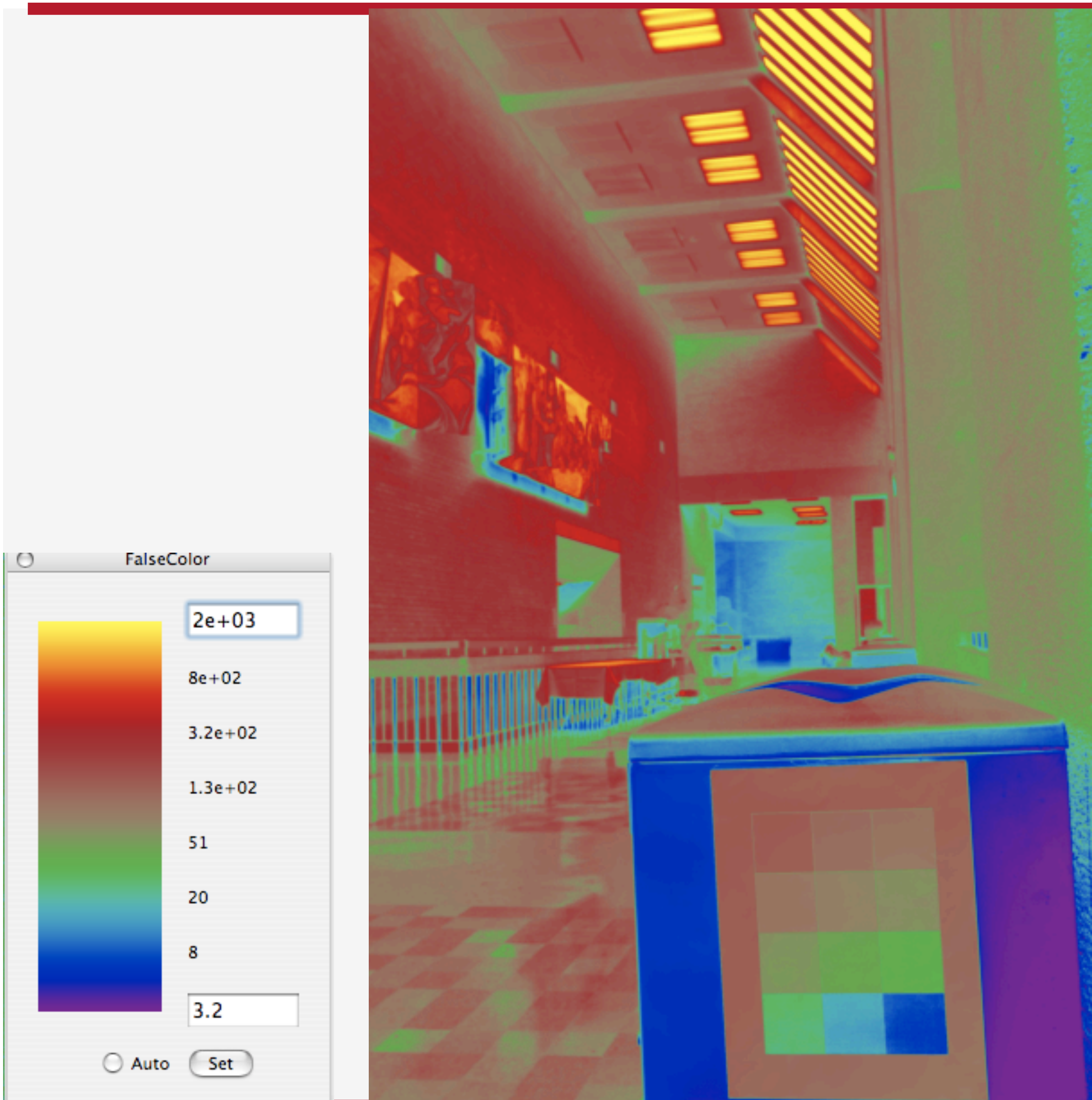


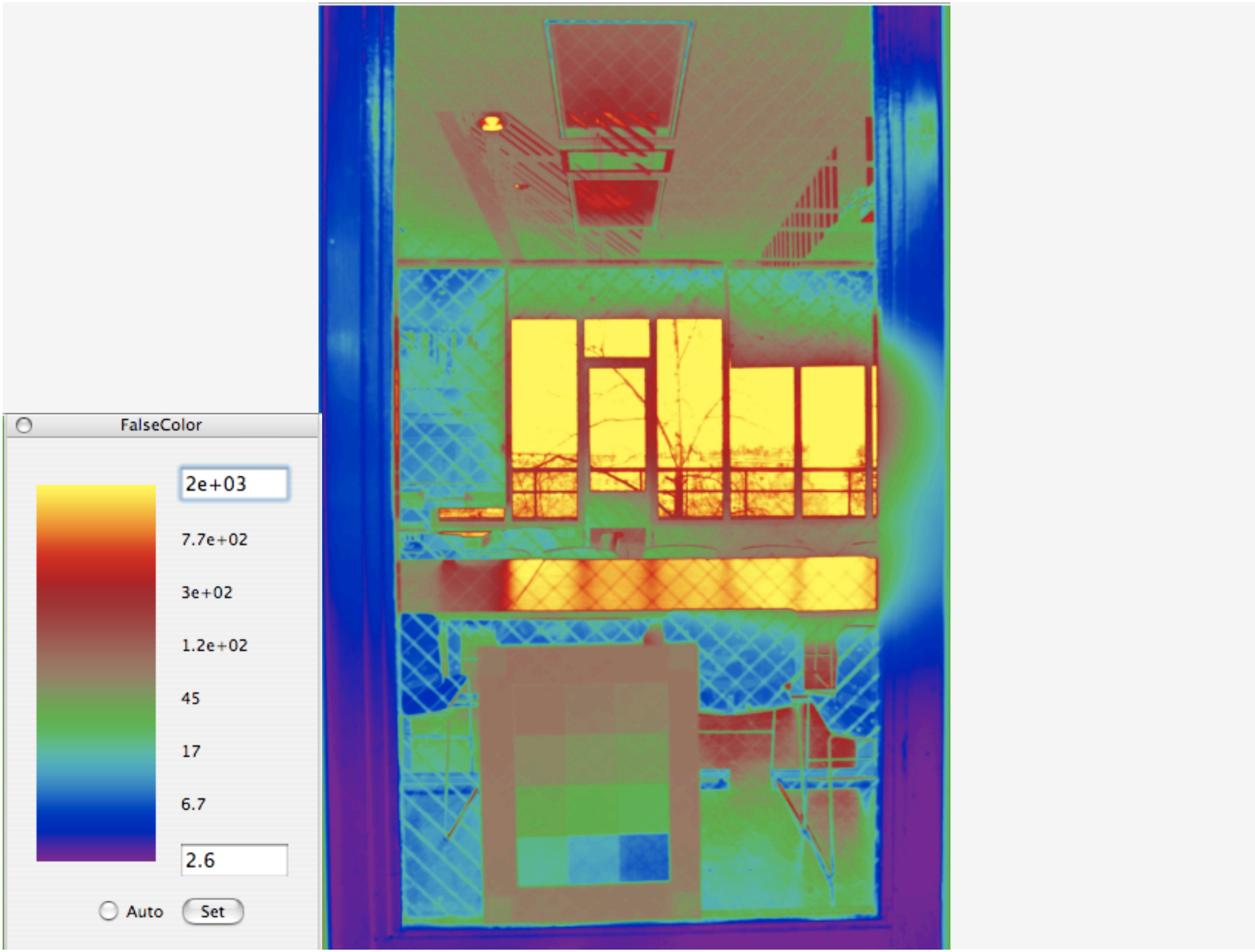
Applications of HDR

- Numeric Data
  - False color images / Iso contour lines
  - Detailed mathematical and statistical analysis
- Visual Data
  - Change exposure to demonstrate the wide luminance range
  - Tone mapping
  - HDR Displays
- Image based Lighting

University of Washington
SouthLake Union
1st year Planning Studio
2006 APA/PAW Joint Planning Awards
University of Washington
Vision for Skykomish
Town of Skykomish
2006 VISION 2020 Planning Awards
University of Washington
Kobe Charrette
Urban Design Charrette
2006 WASLA Student Awards
University of Washington
Broadway Beckons
Digital Design Studio
2006 APA/PAW Joint Planning Awards


FalseColor
2e+03
7.6e+02
2.9e+02
1.1e+02
42
16
6.1
2.3
Auto
Set


FalseColor
2e+03
8e+02
3.2e+02
1.3e+02
51
20
8
3.2
Auto
Set


FalseColor
2e+03
7.7e+02
3e+02
1.2e+02
45
17
6.7
2.6
Auto
Set

CONTRAST

CONTRAST

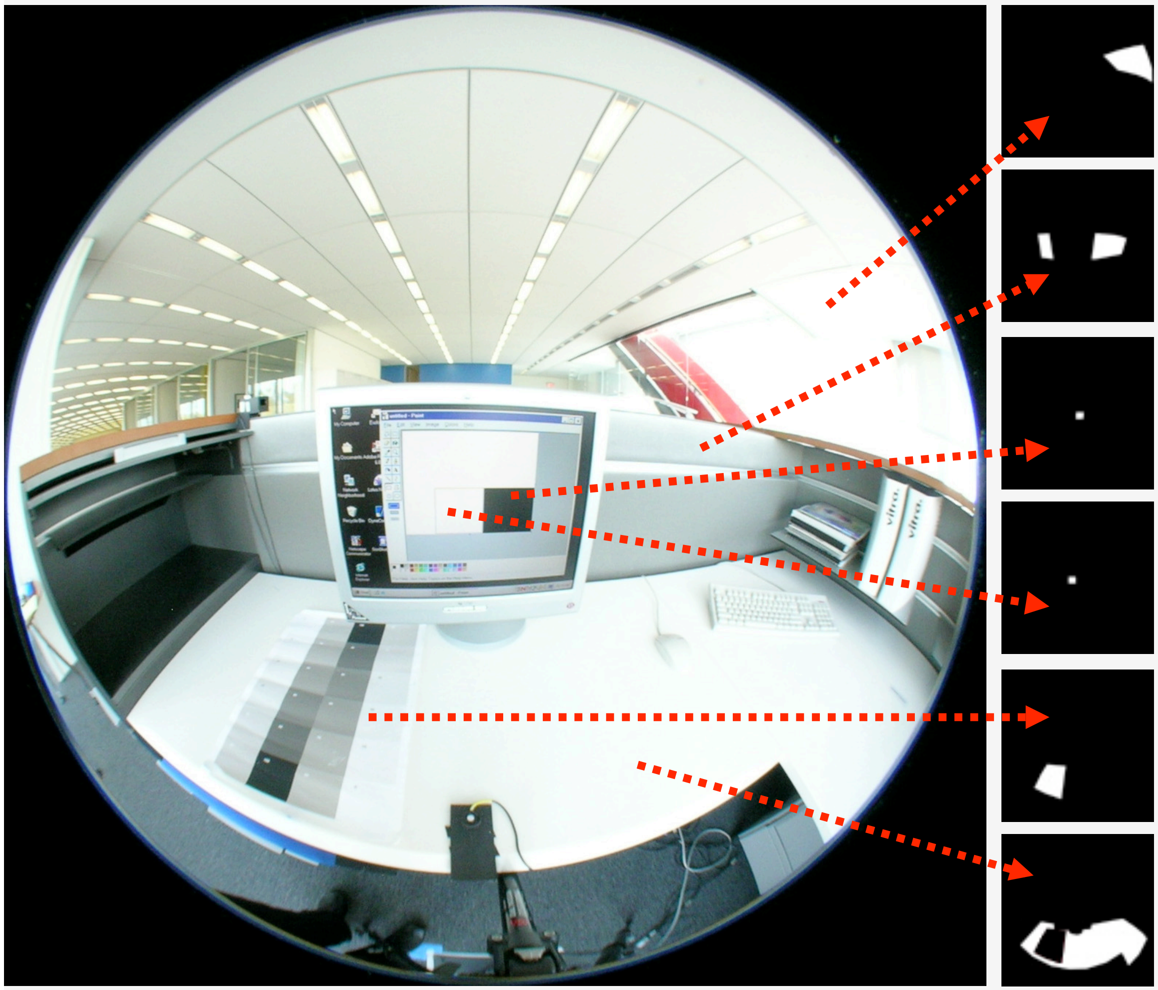
VDT Visibility

Contrast: 0.8

Contrast: 0.2

$$Contrast = \frac{\left| L_{background} - L_{task} \right|}{L_{background}}$$

Data Analysis: Luminance Ratios



Window	Min L Max L Mean L	9 cd/m2 19522 669
Wall	Min L Max L Mean	7 cd/m2 1297 233
Screen	White Black Contrast	230 cd/m2 15 0.93
Paper	White Black Contrast	239 cd/m2 14 0.94
Table	Min L Max L Mean L	1 cd/m2 2051 131

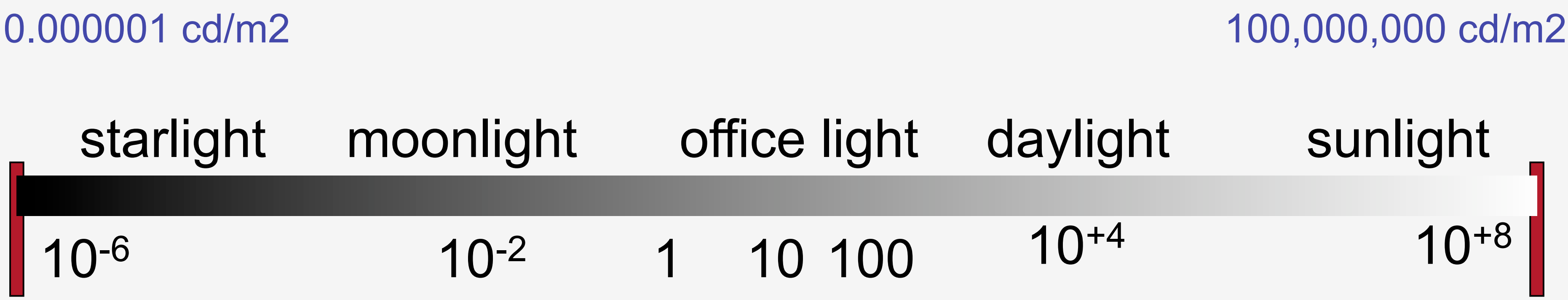
	E (lux)	Max. L (cd/m2)	L ratio (task: surround)	L ratio (task: wall)
IESNA	200-300	850 2000	3:1	10:1, 40:1 max

Image Output

1. Printing (Hardcopy) devices

2. Display (Softcopy) devices
   - Cathode Ray Tubes (CRTs)
   - Liquid Crystal Displays (LCDs)
   - HDR Display Devices

Display Devices

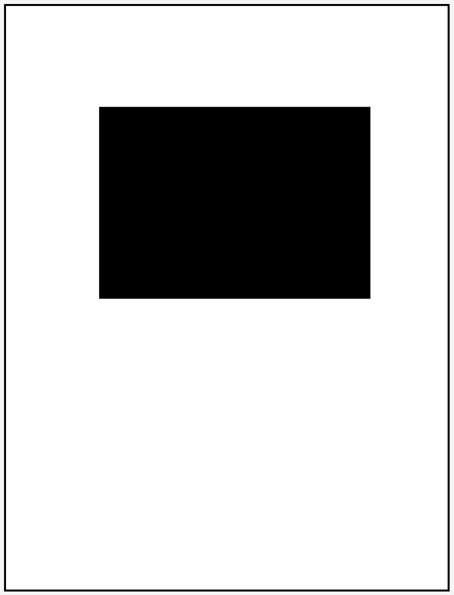


Range of Typical

CRT Displays: 1 : ~100 cd/m^{2};
LCD Displays: from ~1 to ~250 cd/m^{2}

HDR Displays: from ~1 to 3000 cd/m2

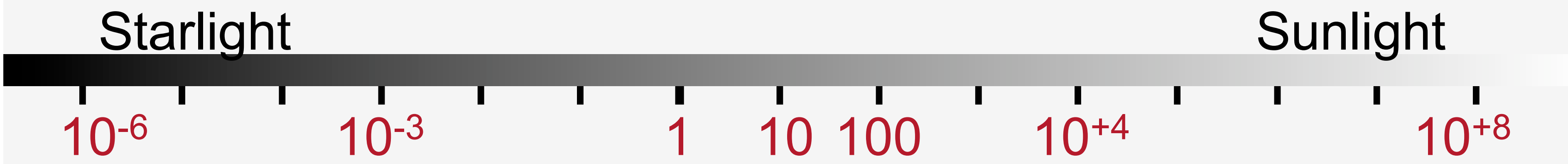
Printed Media



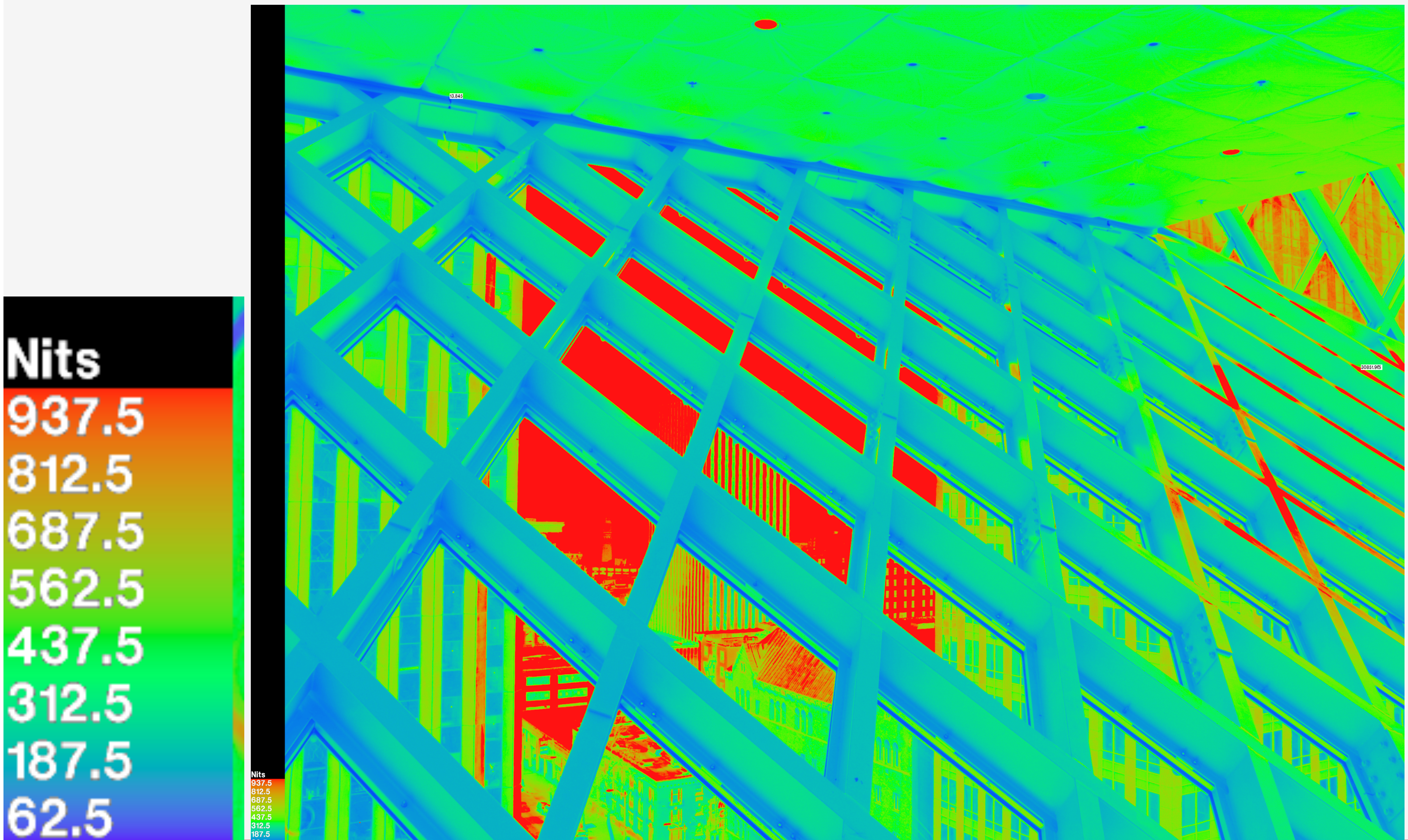
Relies on ambient illumination.

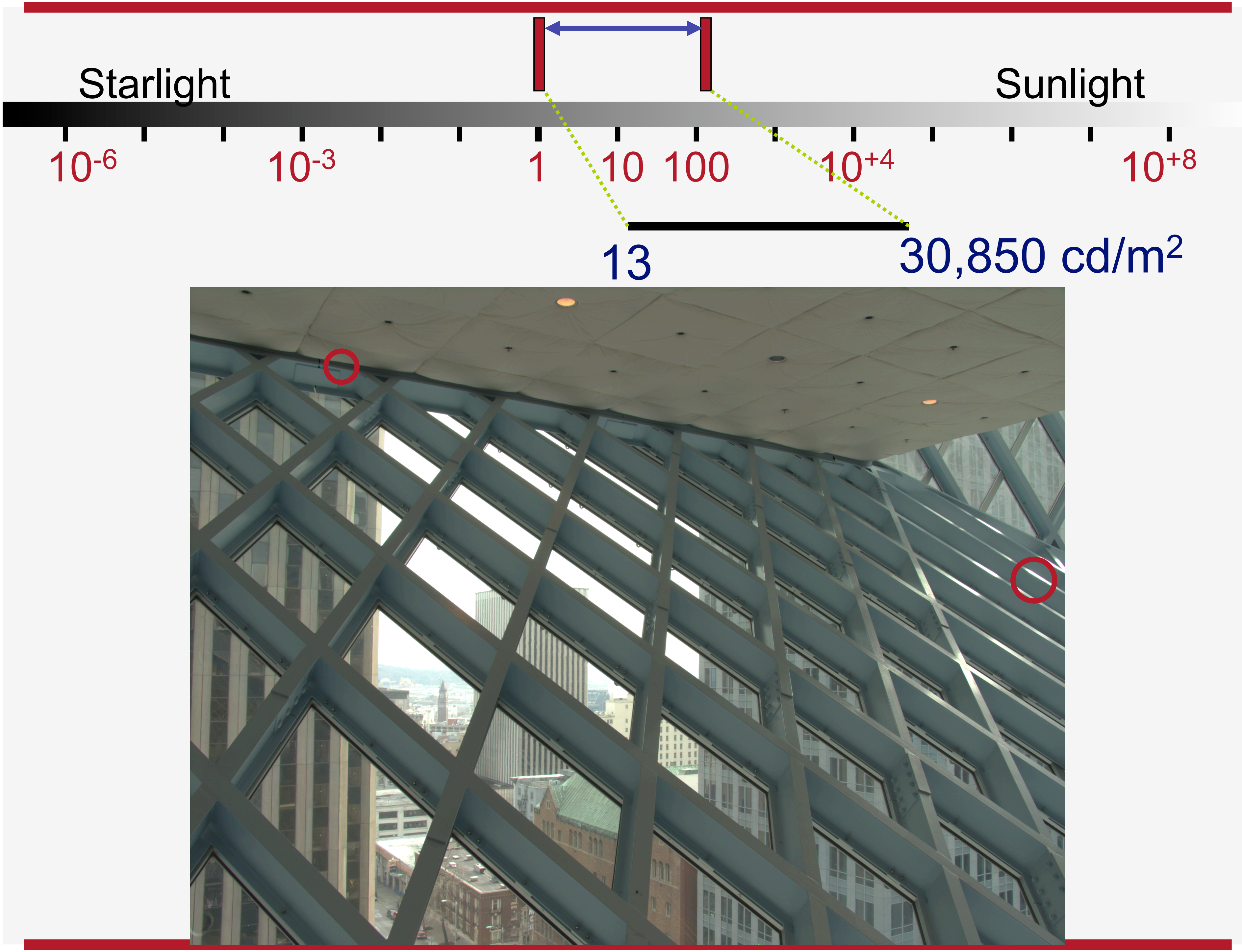
The best contrast: ~100:1

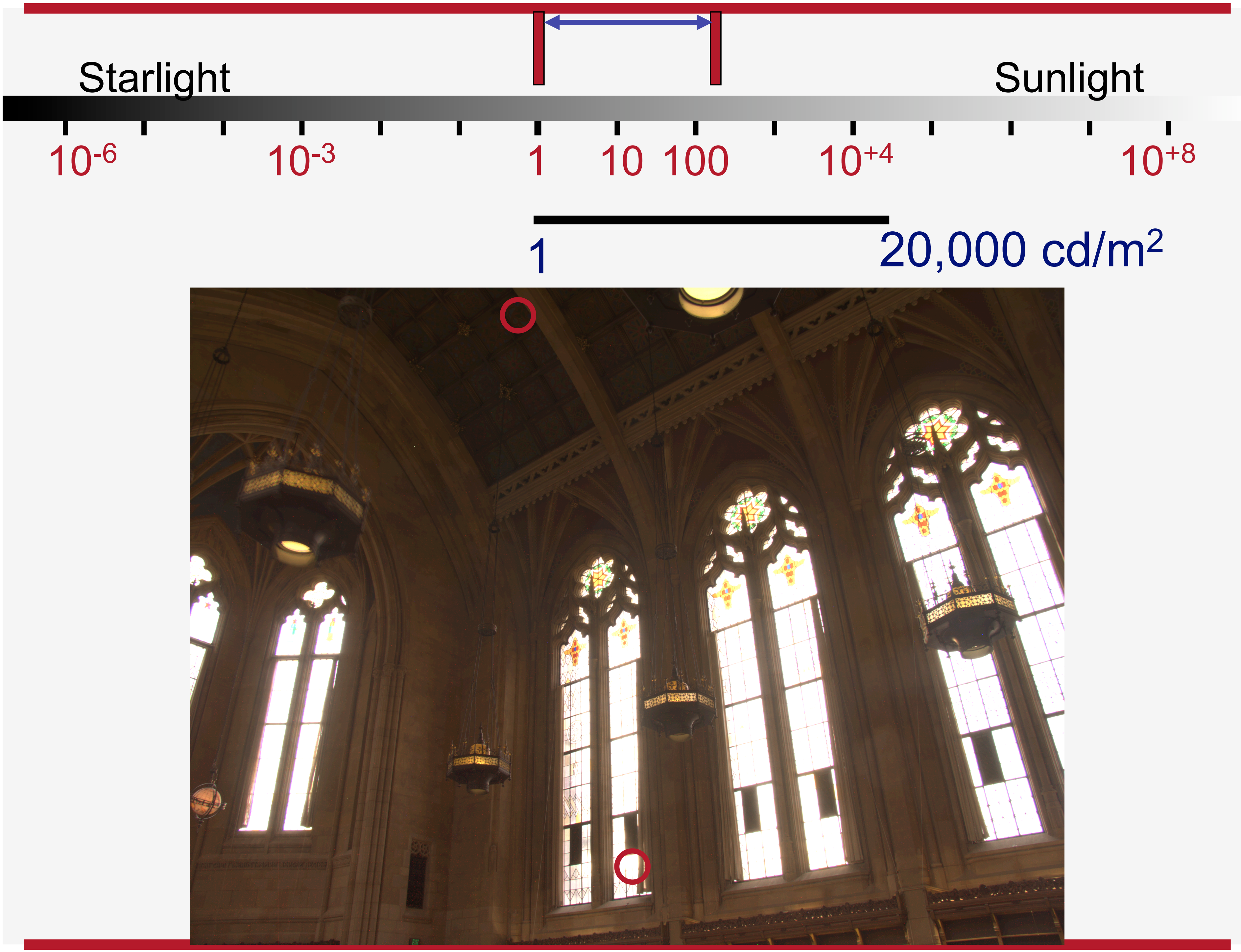
it is often much less.

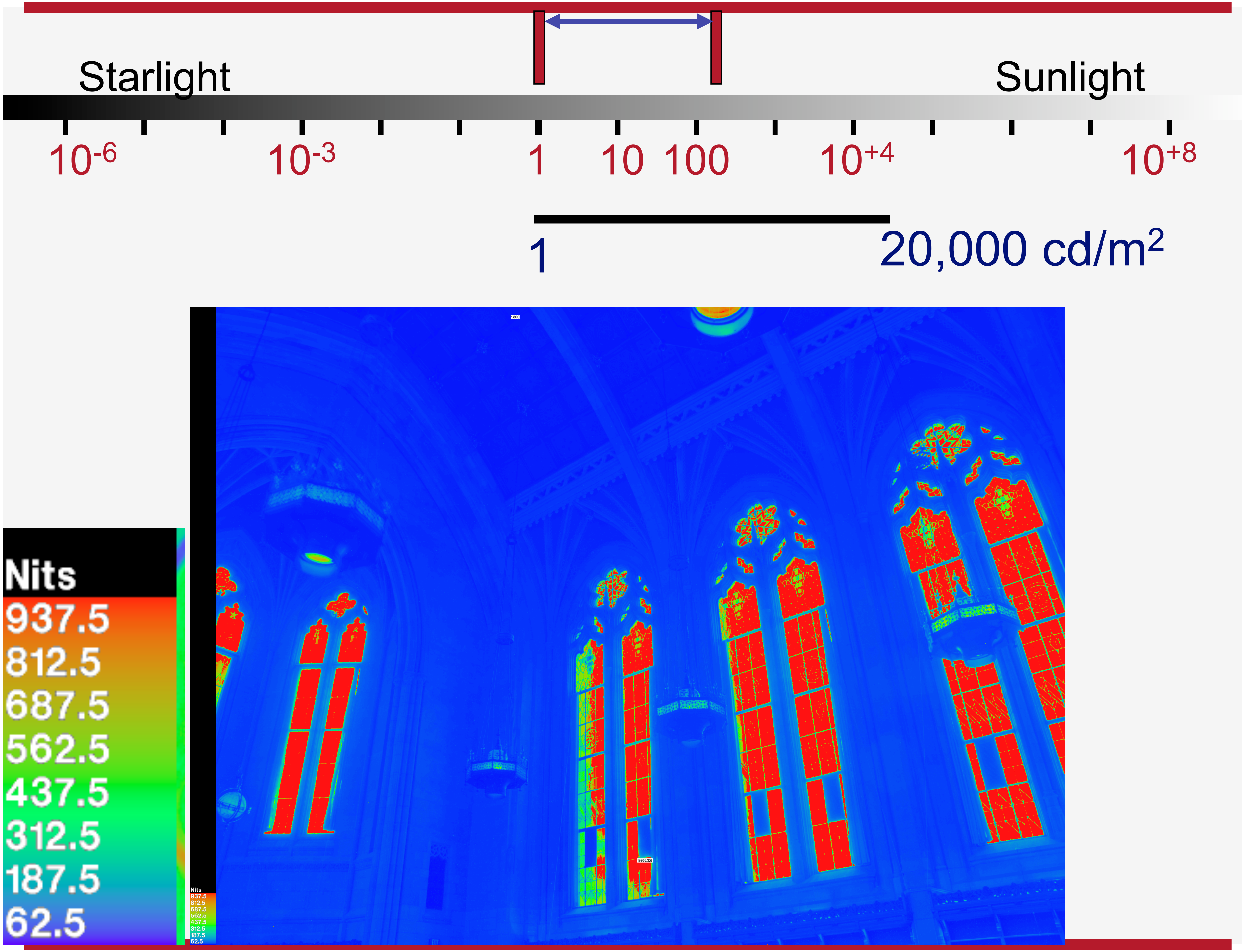


13 — 30,850 cd/m²




Starlight
Sunlight
10-6
10-3
1
10
100
10+4
10+8
13
30,850 cd/m2


Starlight
Sunlight
10-6
10-3
1
10
100
10+4
10+8
1
20,000 cd/m2

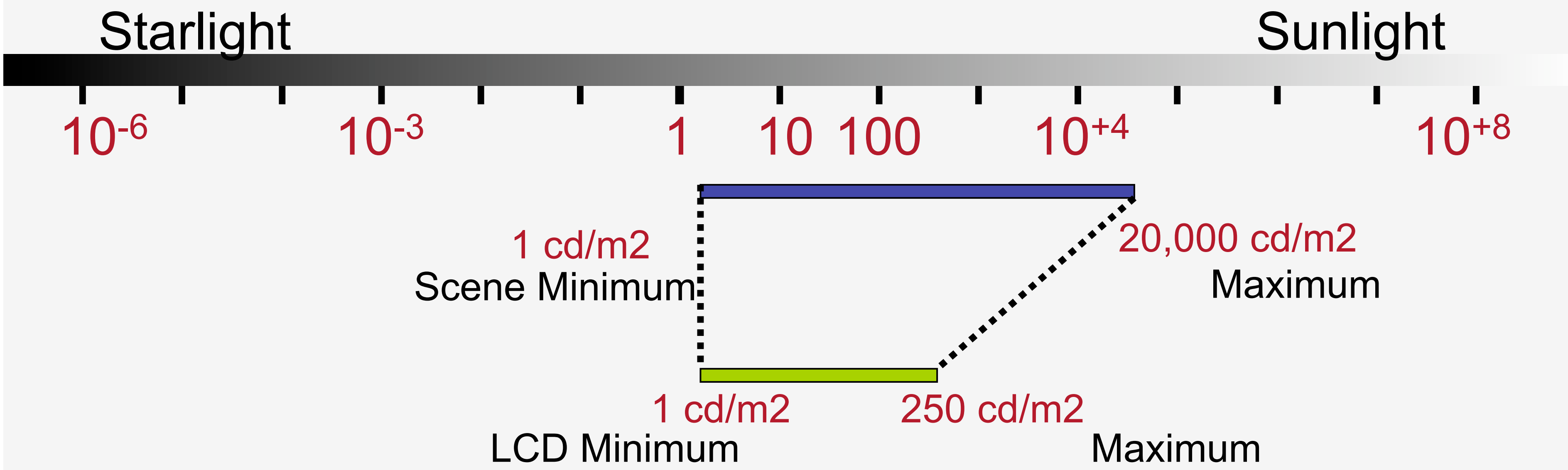

Starlight
Sunlight
10-6
10-3
1
10
100
10+4
10+8
1
20,000 cd/m2
Nits
937.5
812.5
687.5
562.5
437.5
312.5
187.5
62.5

Discrepancy

- The wide ranges of luminances that are captured

and

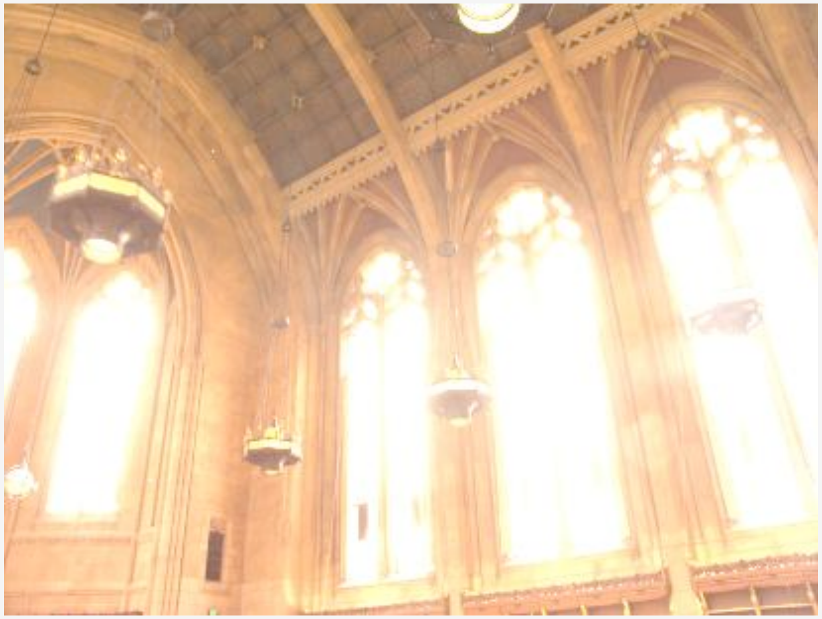
- The small ranges that can be reproduced by existing display devices

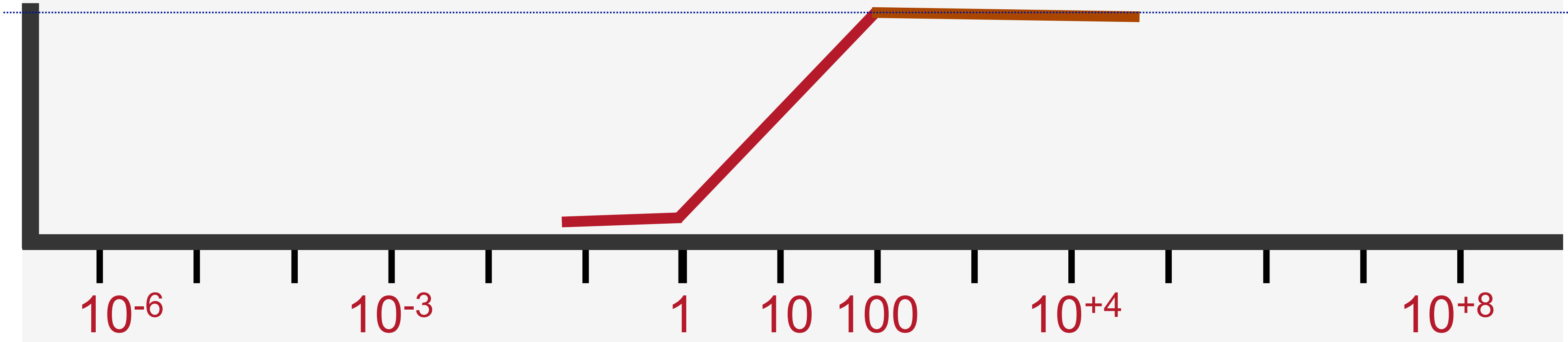


How to compress the dynamic range of HDR image to fit into the display range such that the displayed image would represent the original scene in a meaningful way?

Solution: Tone Mapping

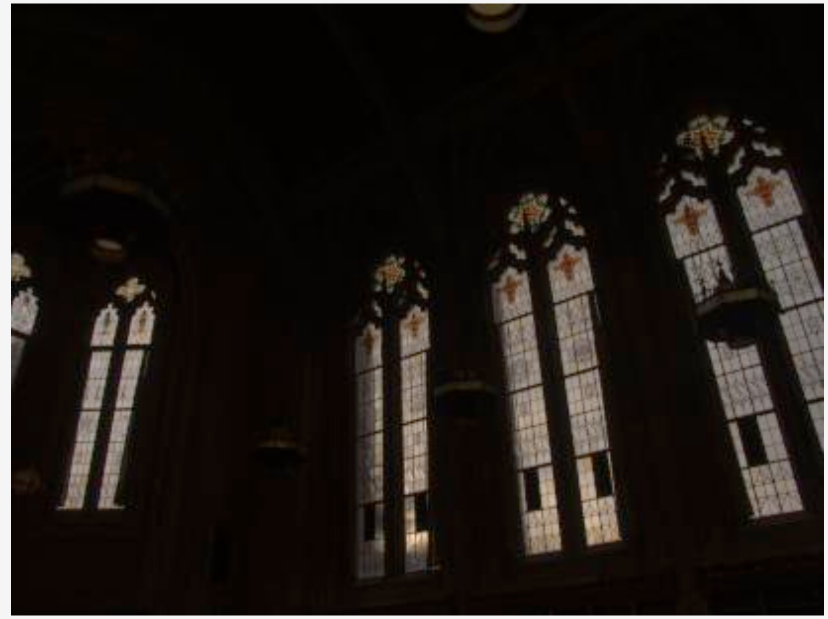
- Clipping data ?

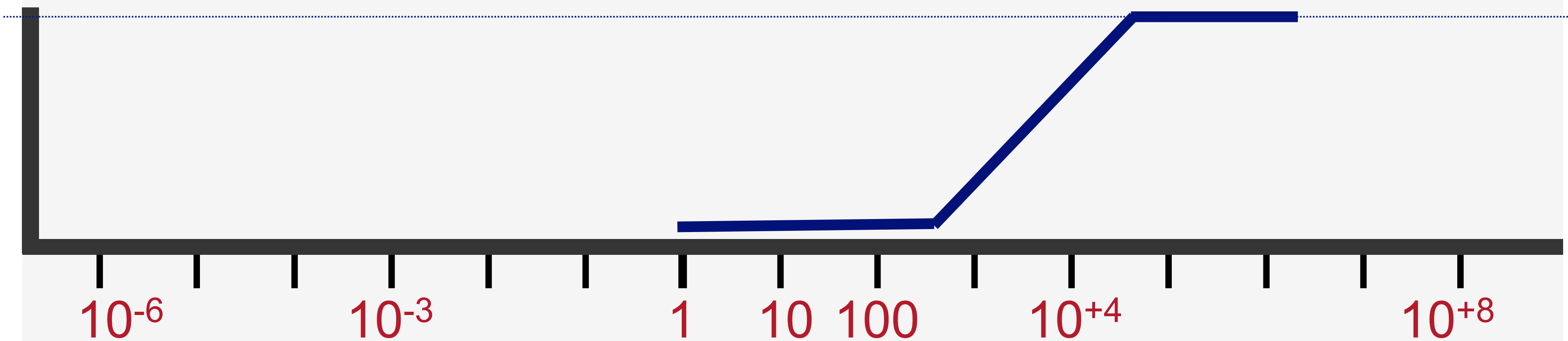




Solution: Tone Mapping

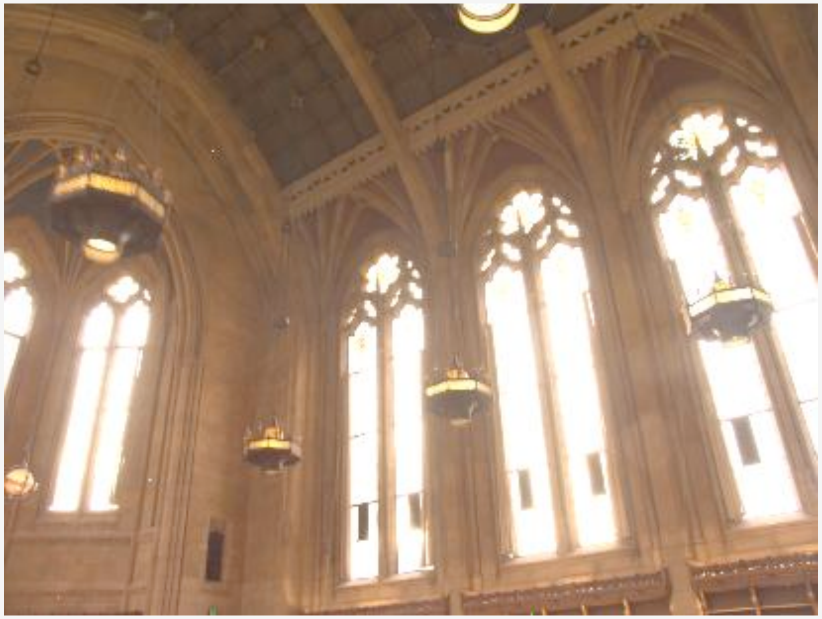
- Clipping data ?

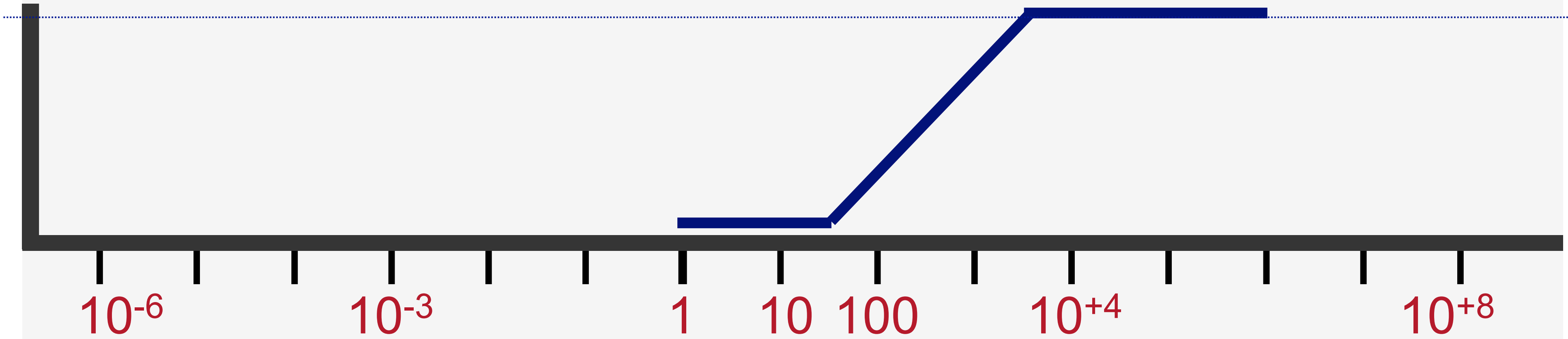




Solution: Tone Mapping

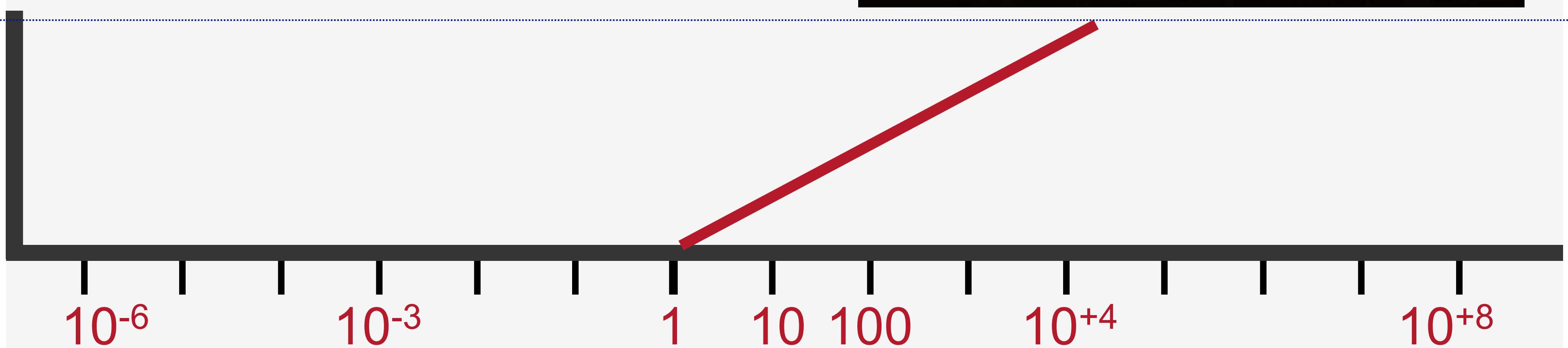
- Clipping data ?





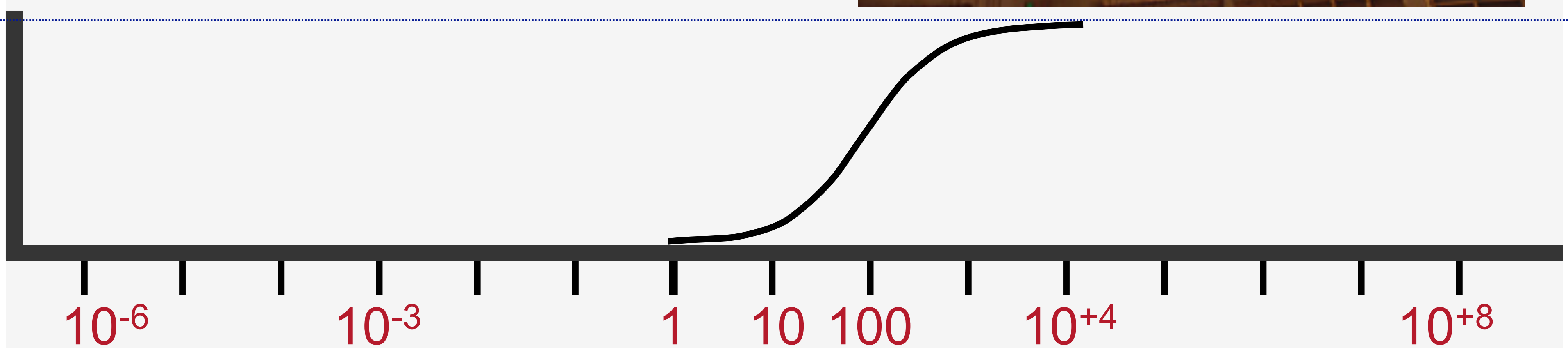
Solution: Tone Mapping

- Linear scaling?



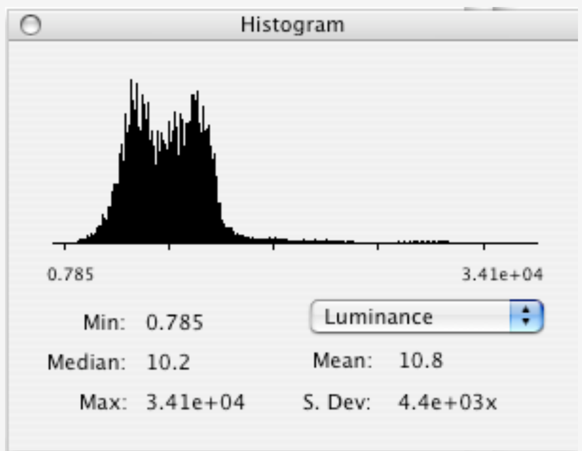
Solution: Tone Mapping

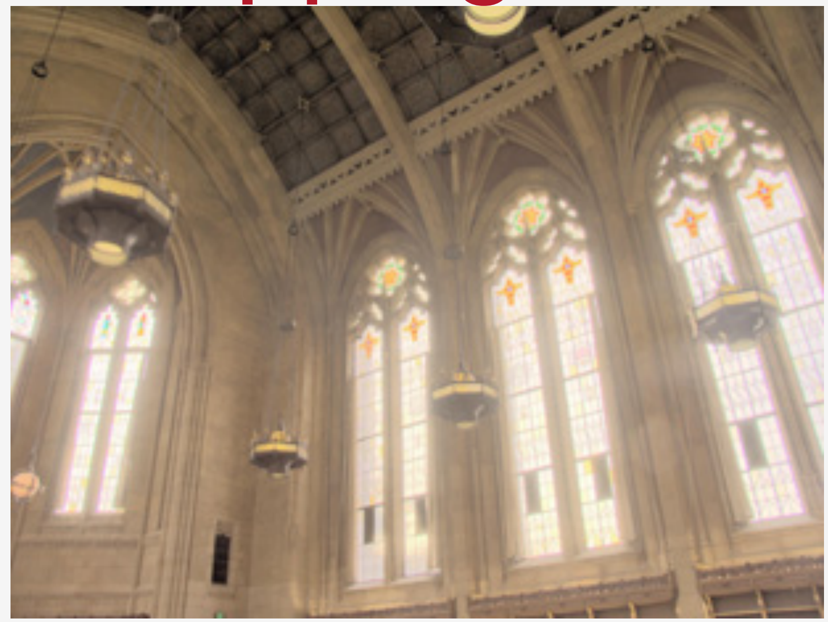
- Film like?

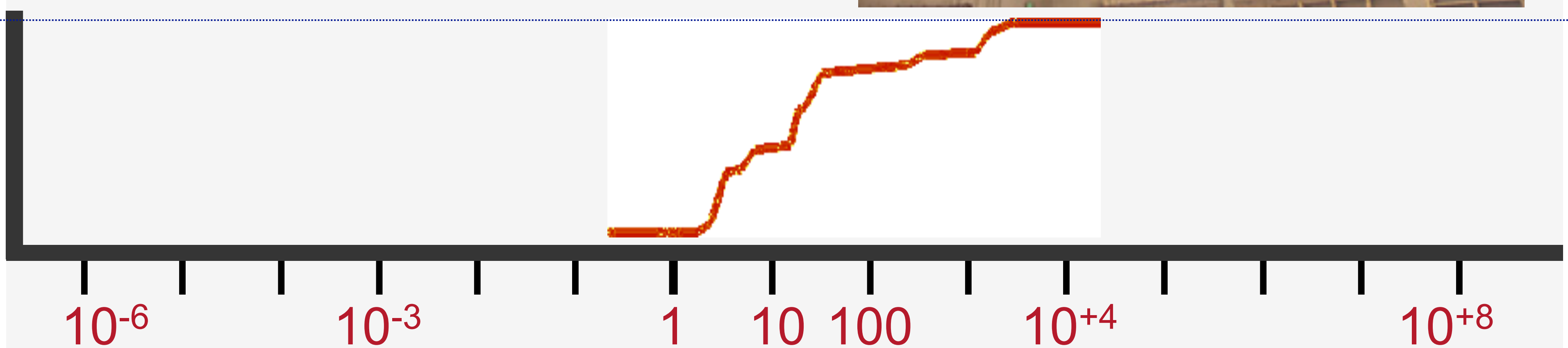


Solution: Tone Mapping

- Histogram

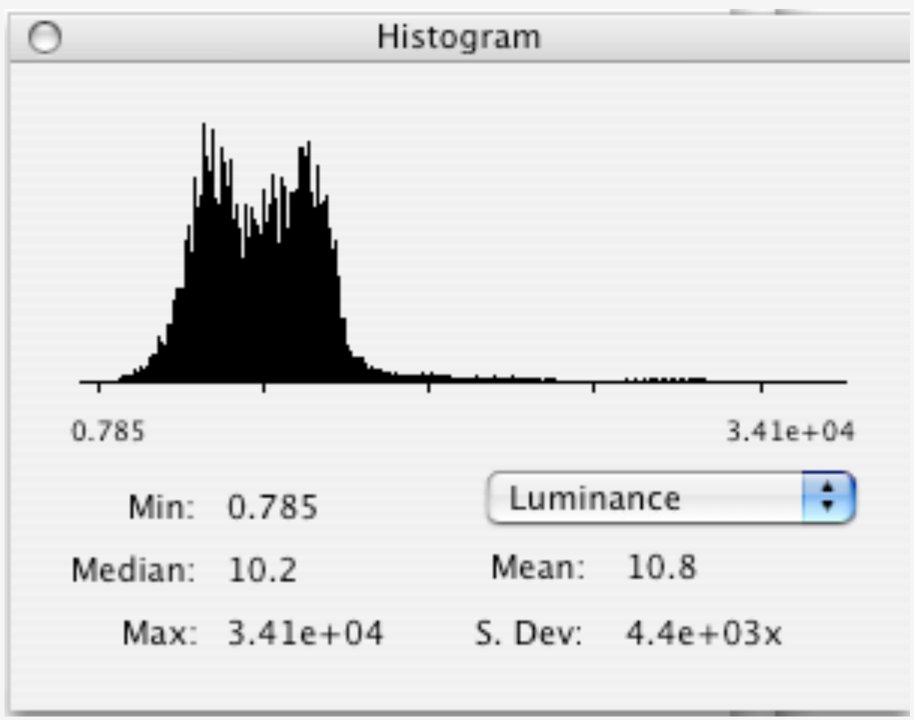


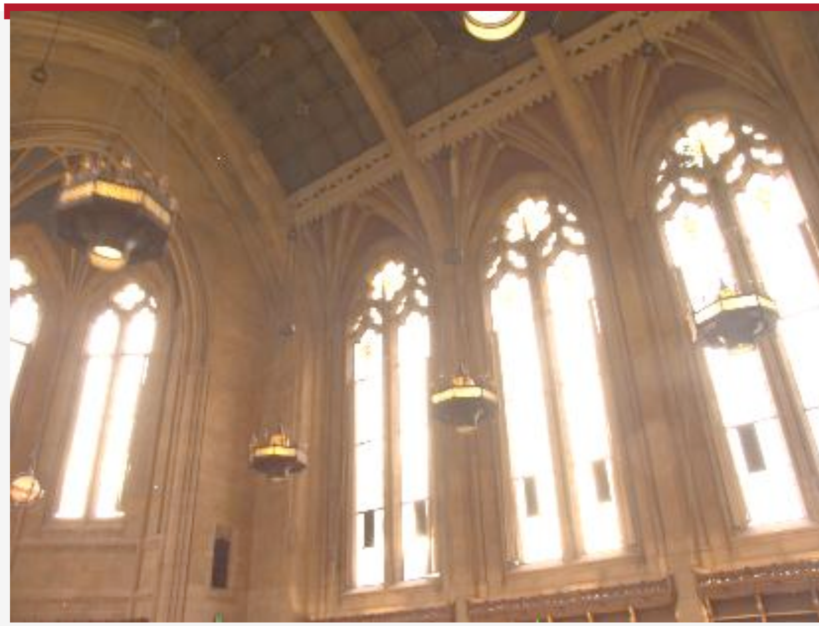




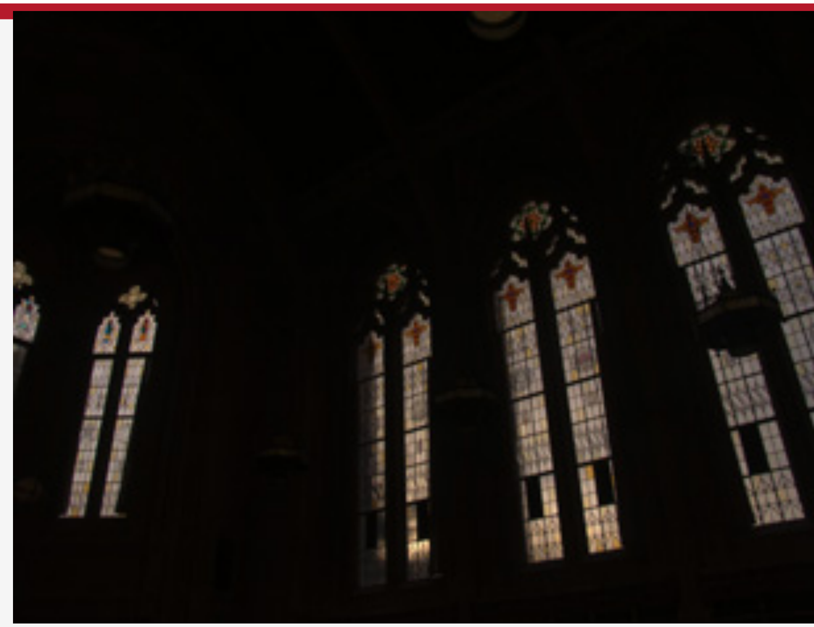
Histogram Adjustment

Light levels in a image are redistributed more evenly to make better use of the range of display device.





Selected exposure (clipped)

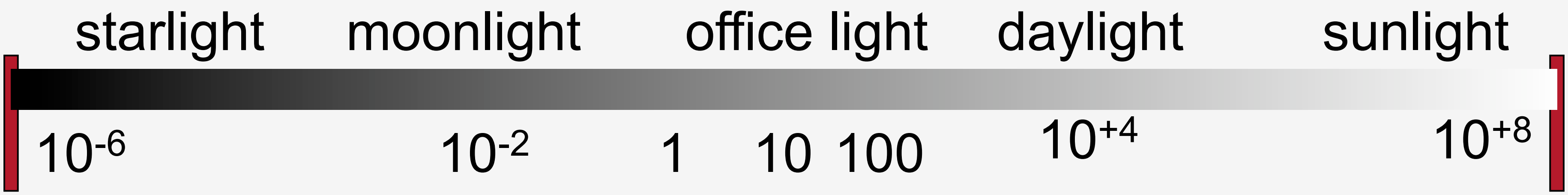


Linear mapping

Film like mapping

Histogram adjustment

Human Visual Adaptation



- The dynamic range simultaneously adapted in a single scene at a given time is around 4 orders of magnitude.

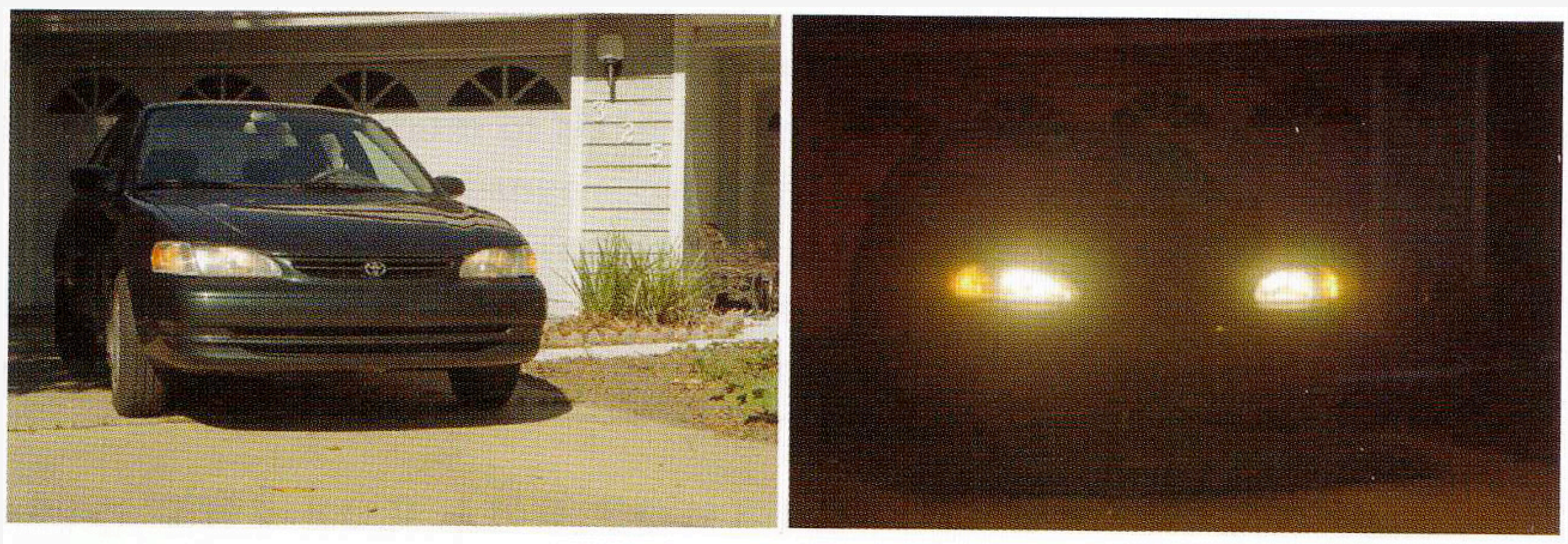
Human Visual Adaptation

- The visual system functions in this range by adapting to the prevailing conditions of illumination.

- Adaptation renders our visual system less sensitive in daylight and more sensitive at night.

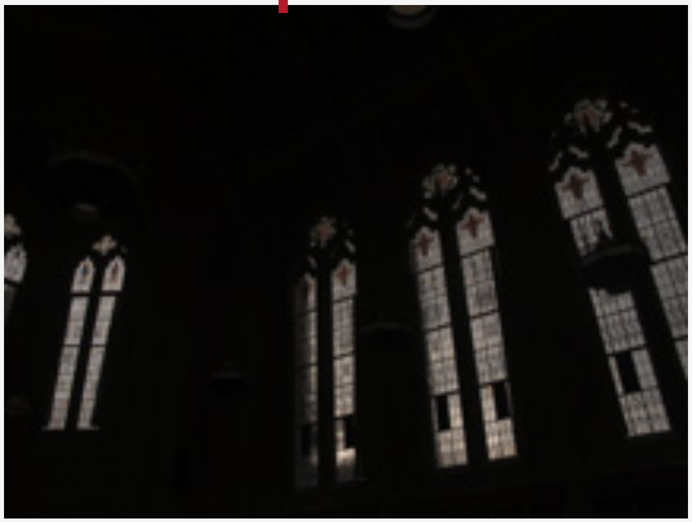
Human Visual System

- Less sensitive in high luminance levels;
- More sensitive at low luminance levels.



Images from: Reinhard E., Ward G., Pattanaik S., and Debevec P. *High Dynamic Range Imaging*. San Francisco: Morgan Kaufmann, 2006.

Comparison of few TM Algorithms



Ferwerda

Tumblin Rushmeier

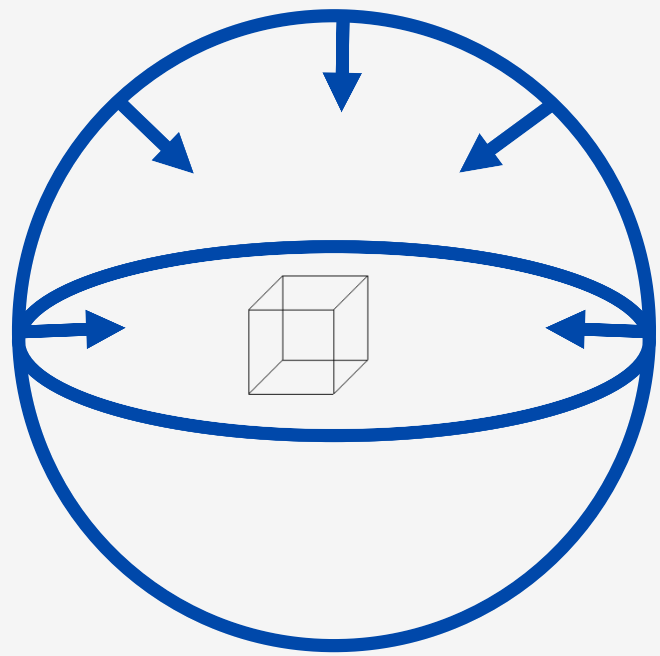
Ward Histogram

Reinhard etal. Photographic

HDR Photography

- Image Capture
- Image Assembly
- HDRI as luminance maps
- HDRI Analysis
- HDRI Display

Image based Lighting (IBL) using HDR Photographs to Light the Scene



IBL: Rendering with Radiance

Acknowledgements

- “Evaluation of High Dynamic Range Photography as a Luminance Data Acquisition” was funded by the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and carried out at the Lawrence Berkeley National Laboratory (2004-05).

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Introduction to High Dynamic Range Photography

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