High Dynamic Range Images

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CS194: Image Manipulation & Computational Photography
Alexei Efros, UC Berkeley, Fall 2014

…with a lot of slides stolen from Paul Debevec

Why HDR?

Problem: Dynamic Range

1

1500

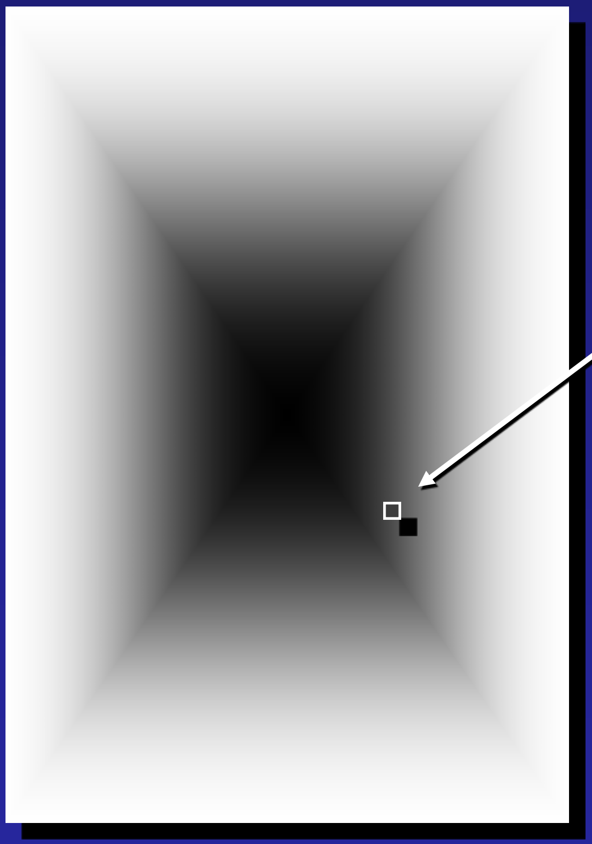
25,000

400,000

2,000,000,000

The real world is high dynamic range.

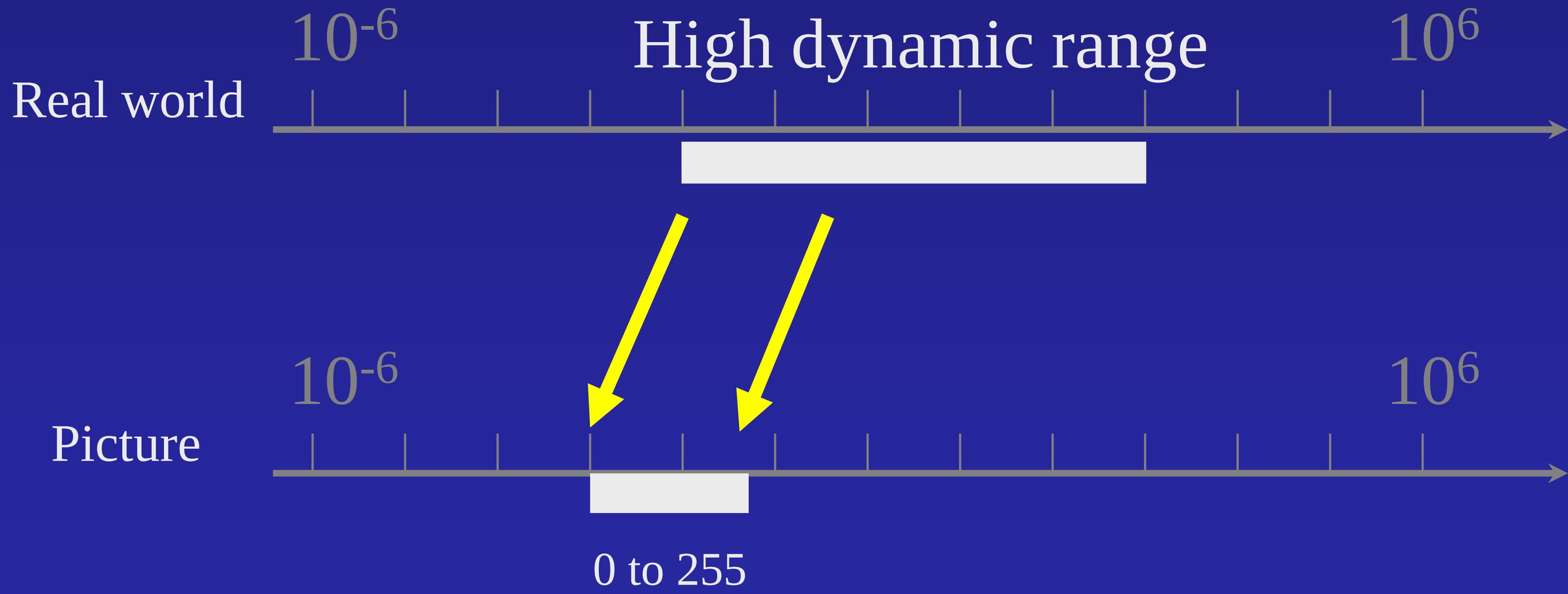
Image



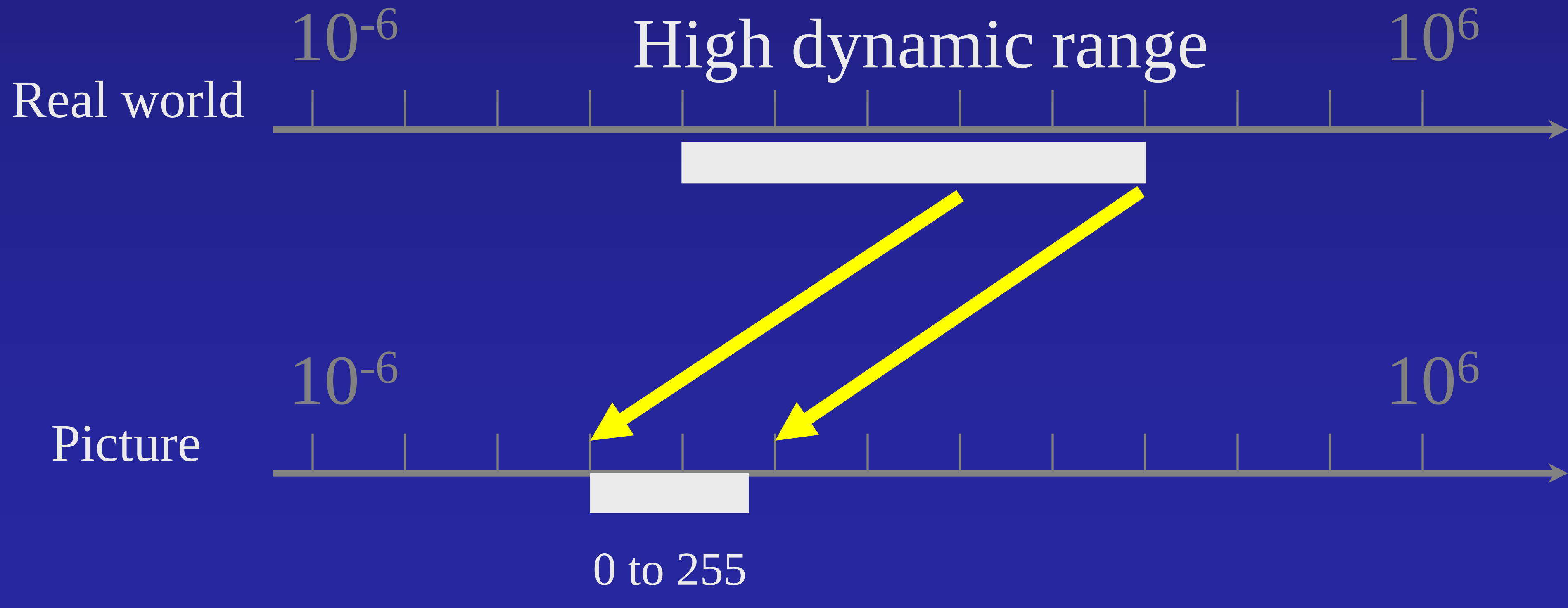
pixel (312, 284) = **42**

42 photos?

Long Exposure

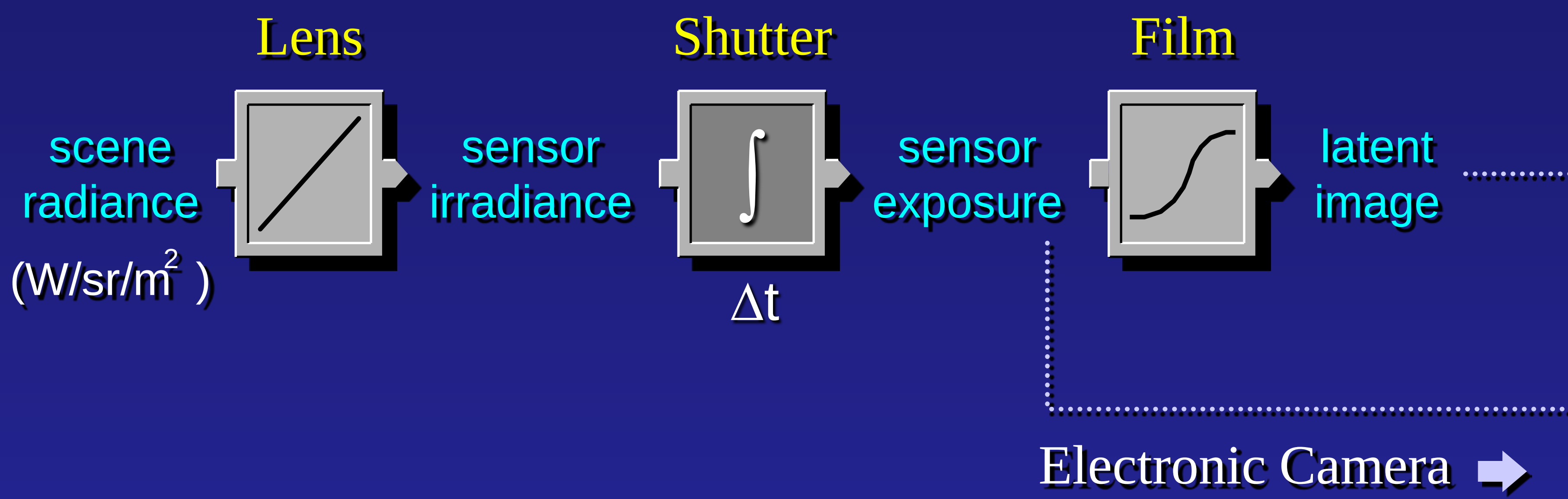


Short Exposure

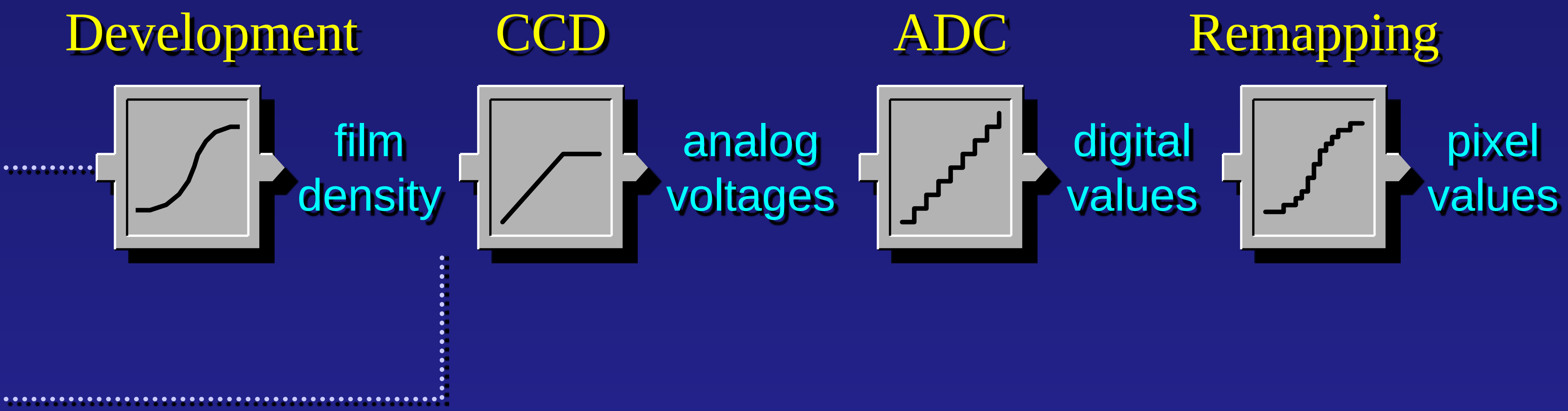


Camera Calibration

- Geometric
  - How pixel **coordinates** relate to **directions** in the world
- Photometric
  - How pixel **values** relate to **radiance** amounts in the world

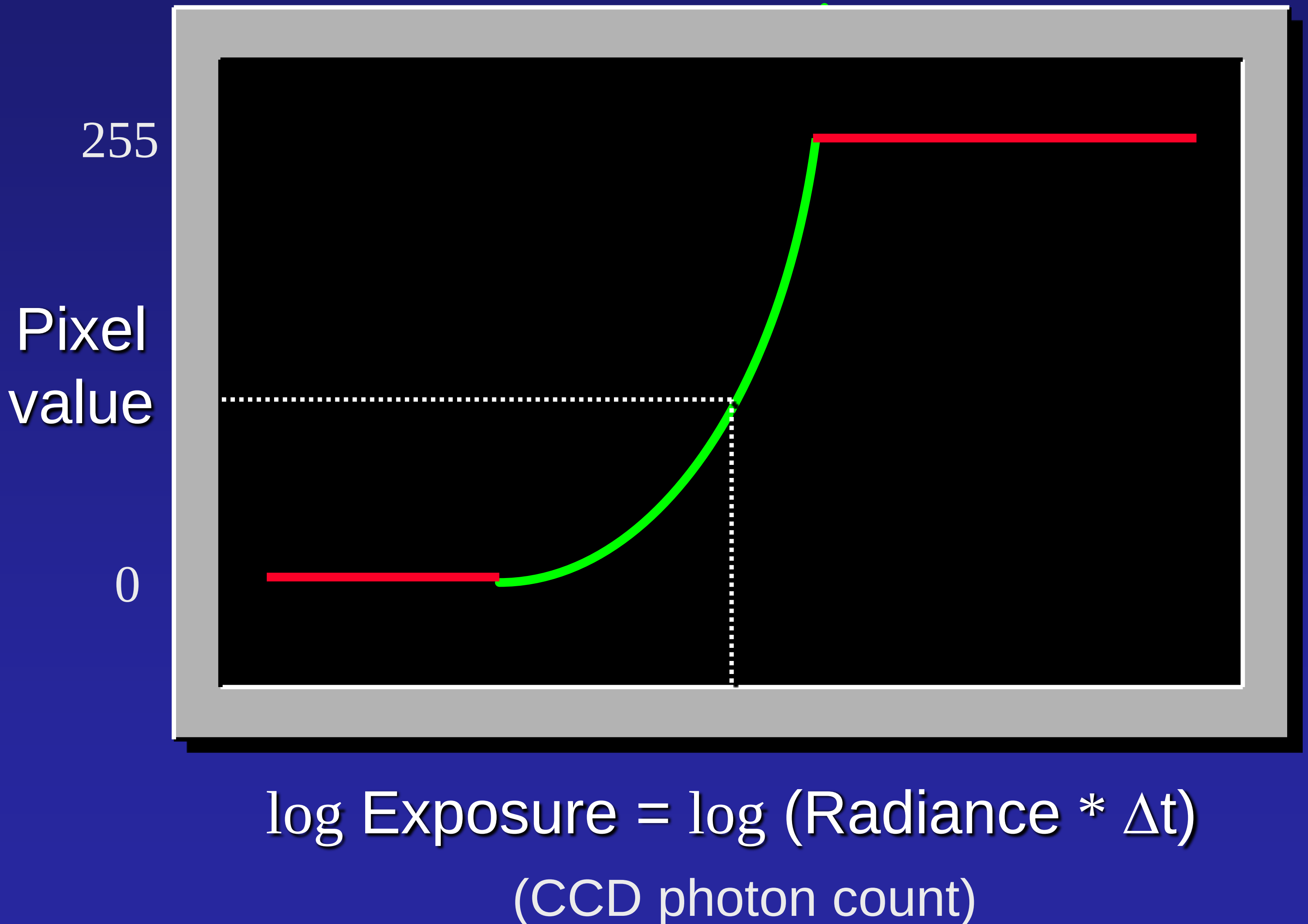


The Image Acquisition Pipeline



Development
CCD
ADC
Remapping
film
density
analog
voltages
digital
values
pixel
values

Imaging system response function



Varying Exposure

Camera is not a photometer!

- Limited dynamic range
  ⇒ Perhaps use multiple exposures?
- Unknown, nonlinear response
  ⇒ Not possible to convert pixel values to radiance
- Solution:
  – Recover response curve from multiple exposures, then reconstruct the ***radiance map***

Recovering High Dynamic Range Radiance Maps from Photographs

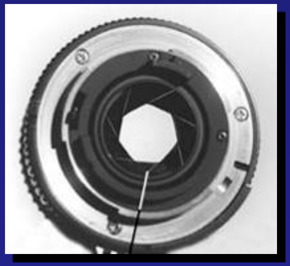
Paul Debevec
Jitendra Malik

Computer Science Division
University of California at Berkeley

August 1997

Ways to vary exposure

- Shutter Speed (*)
- F/stop (aperture, iris)




- Neutral Density (ND) Filters

Shutter Speed

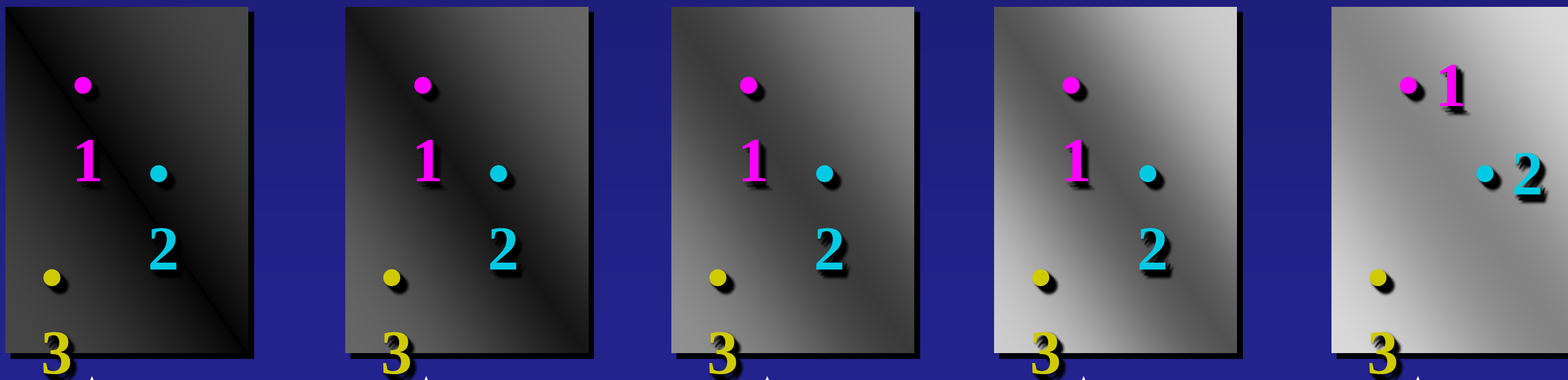
- Ranges: Canon D30: 30 to 1/4,000 sec.
- Sony VX2000: ¼ to 1/10,000 sec.
- Pros:
- Directly varies the exposure
- Usually accurate and repeatable
- Issues:
- Noise in long exposures

Shutter Speed

- **Note: shutter times usually obey a power series – each "stop" is a factor of 2**
- **¼, 1/8, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500, 1/1000 sec**
- **Usually really is:**
- **¼, 1/8, 1/16, 1/32, 1/64, 1/128, 1/256, 1/512, 1/1024 sec**

The Algorithm

Image series



Δt = 1/64 sec	**Δt = 1/16 sec**	**Δt = 1/4 sec**	**Δt = 1 sec**	**Δt = 4 sec**

Pixel Value Z = f(Exposure)

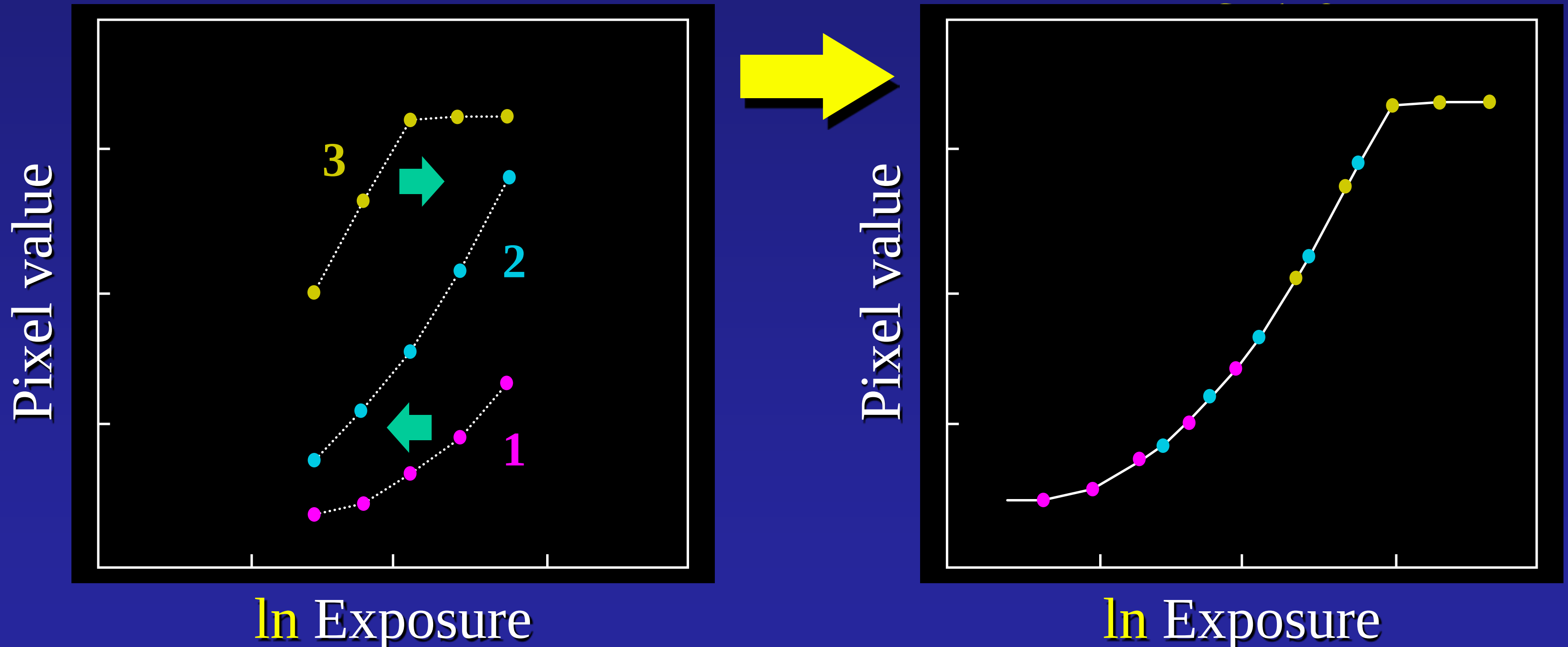
Exposure = Radiance ´ Δt

log Exposure = log Radiance + log Δt

Response Curve

Assuming unit radiance for each pixel

After adjusting radiances to obtain a smooth response



The Math

- Let *g(z)* be the *discrete* inverse response function
- For each pixel site *i* in each image *j*, want:

$$\ln Radiance_i + \ln \Delta t_j = g(Z_{ij})$$

- Solve the overdetermined linear system:

$$\sum_{i=1}^{N} \sum_{j=1}^{P} \left[\ln Radiance_i + \ln \Delta t_j - g(Z_{ij}) \right]^2 + \lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2$$

fitting term

smoothness term

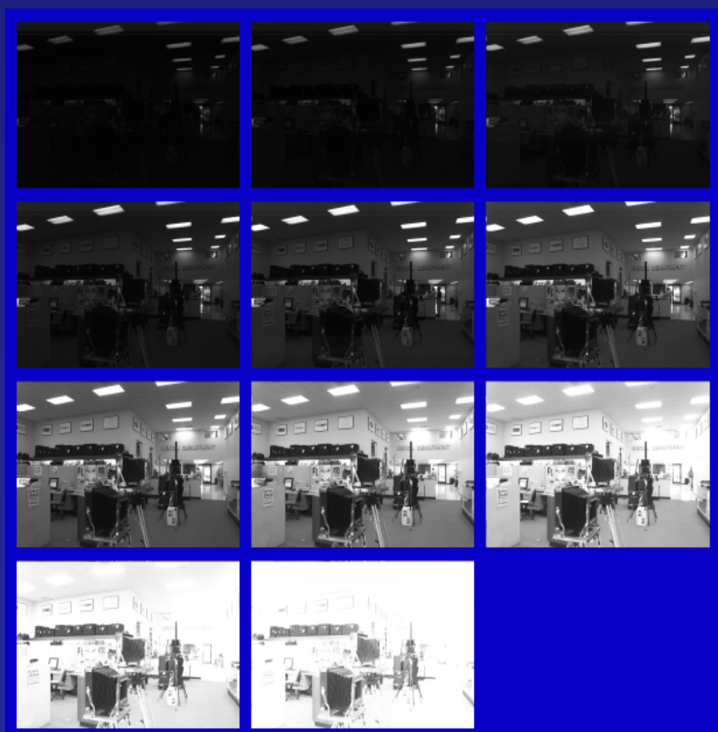
Matlab Code

```
function [g,lE]=gsolve(Z,B,l,w)

n = 256;
A = zeros(size(Z,1)*size(Z,2)+n+1,n+size(Z,1));
b = zeros(size(A,1),1);

k = 1;                    %% Include the data-fitting equations
for i=1:size(Z,1)
  for j=1:size(Z,2)
    wij = w(Z(i,j)+1);
    A(k,Z(i,j)+1) = wij; A(k,n+i) = -wij; b(k,1) = wij * B(i,j);
    k=k+1;
  end
end

A(k,129) = 1;             %% Fix the curve by setting its middle value to
k=k+1;

for i=1:n-2               %% Include the smoothness equations
  A(k,i)=l*w(i+1); A(k,i+1)=-2*l*w(i+1); A(k,i+2)=l*w(i+1);
  k=k+1;
end

x = A\b;                  %% Solve the system using SVD

g = x(1:n);
lE = x(n+1:size(x,1));
```

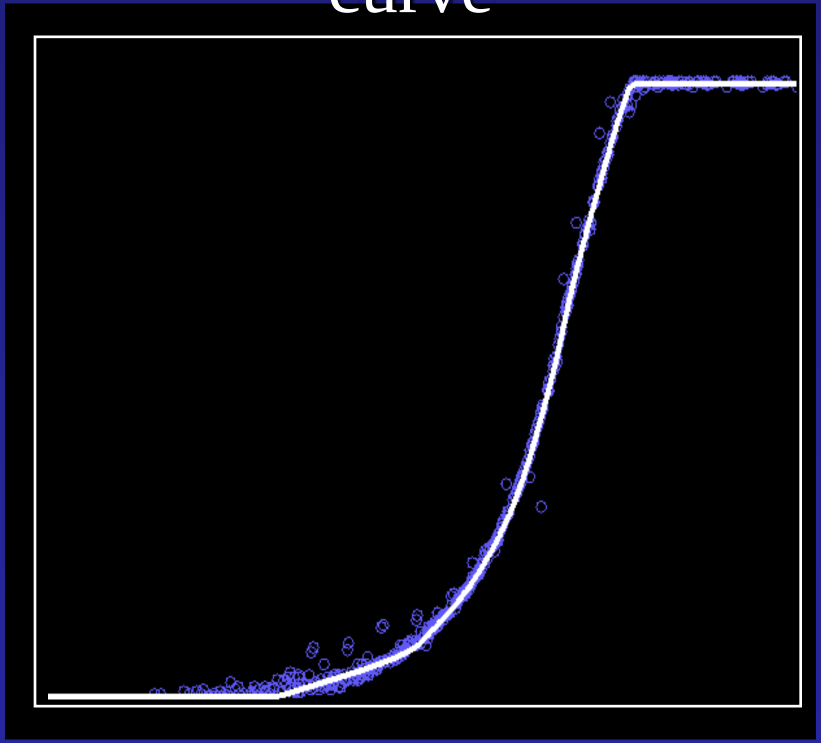
Results: Digital Camera

Kodak DCS460

1/30 to 30 sec



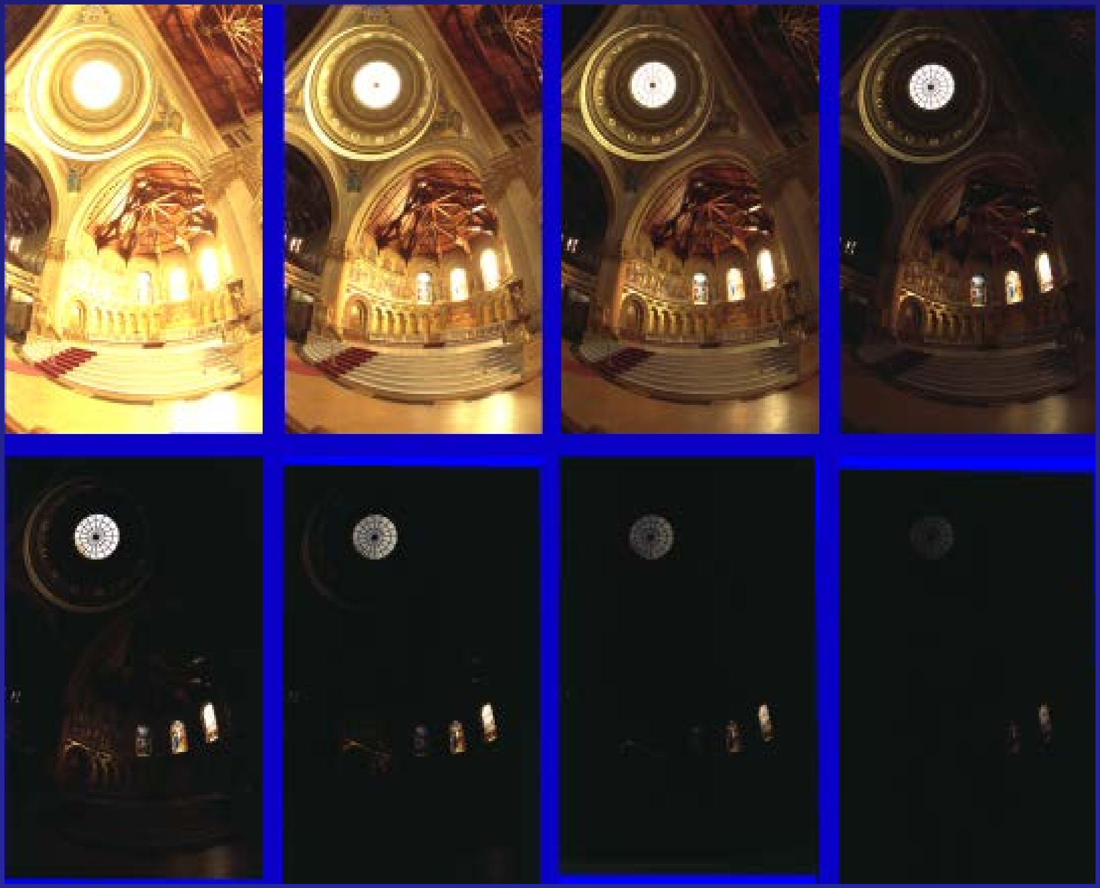
Recovered response curve



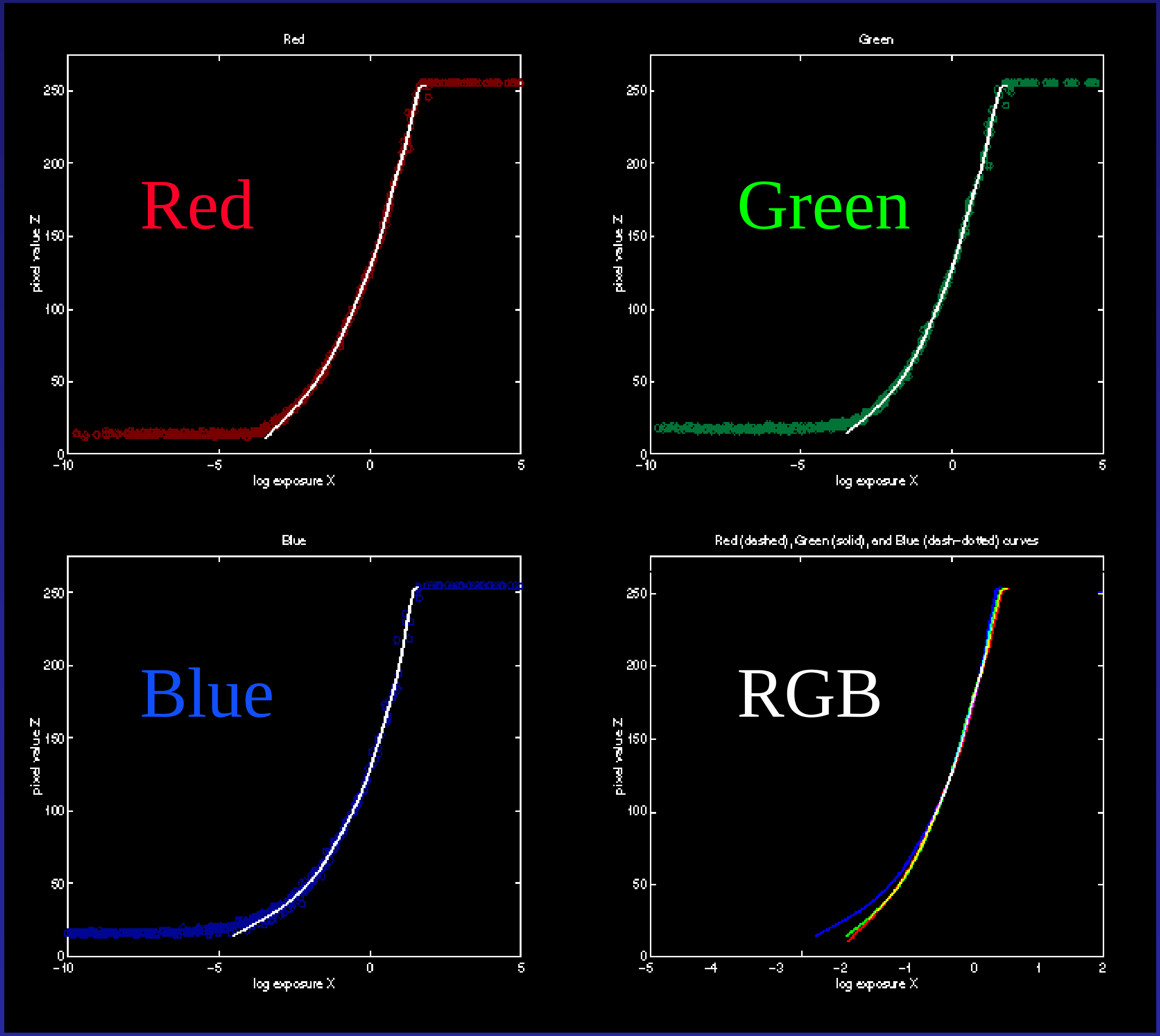
Reconstructed radiance map

Results: Color Film

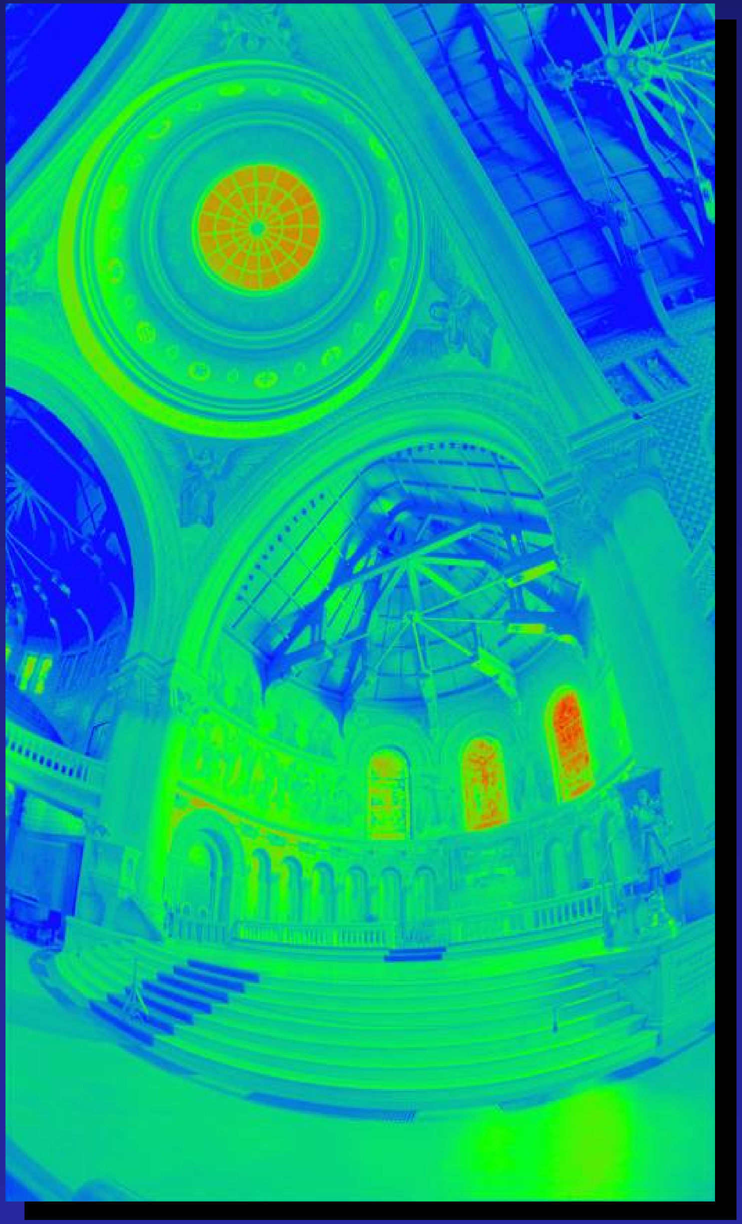
- Kodak Gold ASA 100, PhotoCD



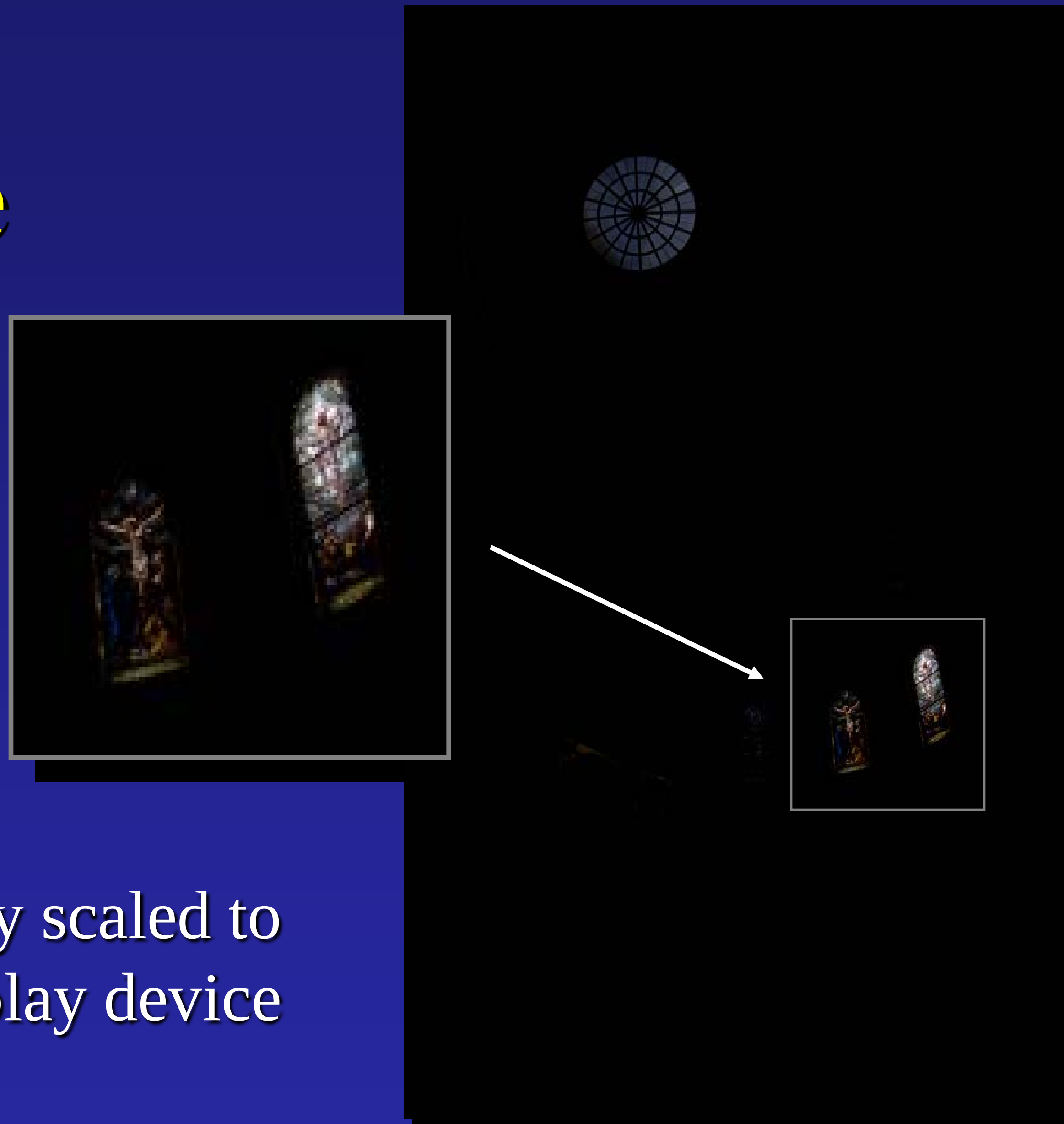
Recovered Response Curves



The Radiance Map

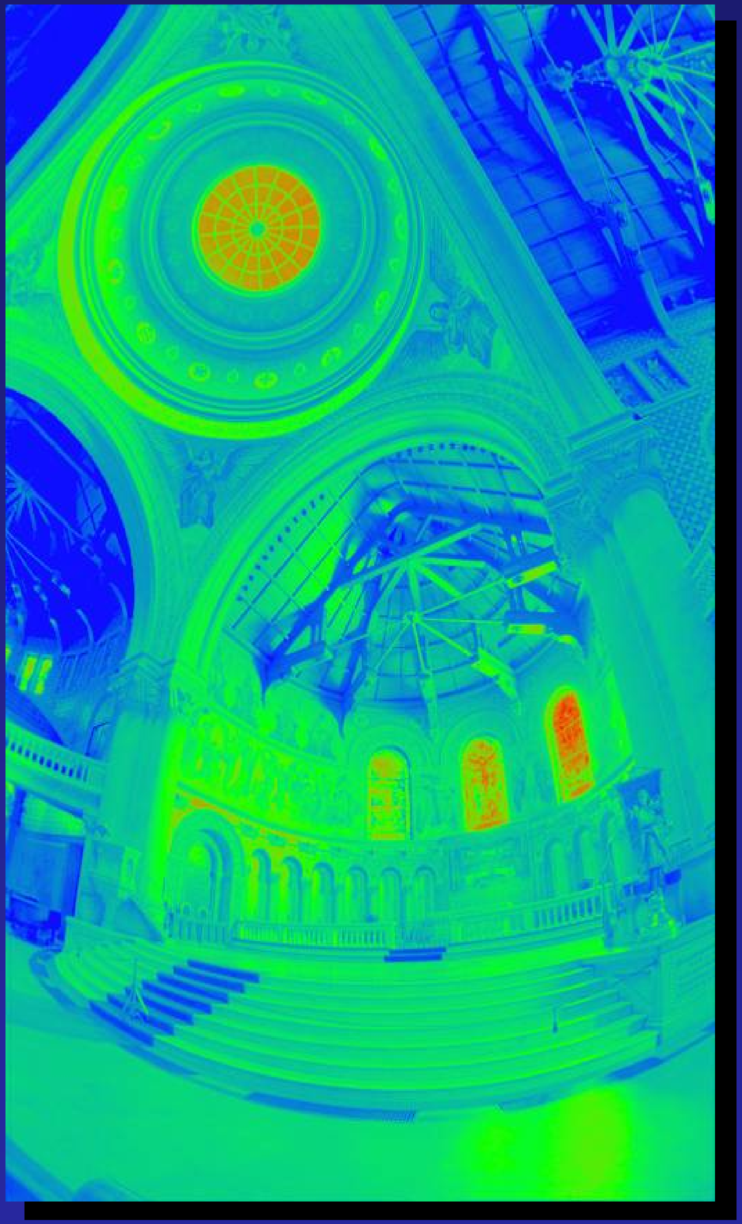


The Radiance Map



Linearly scaled to display device

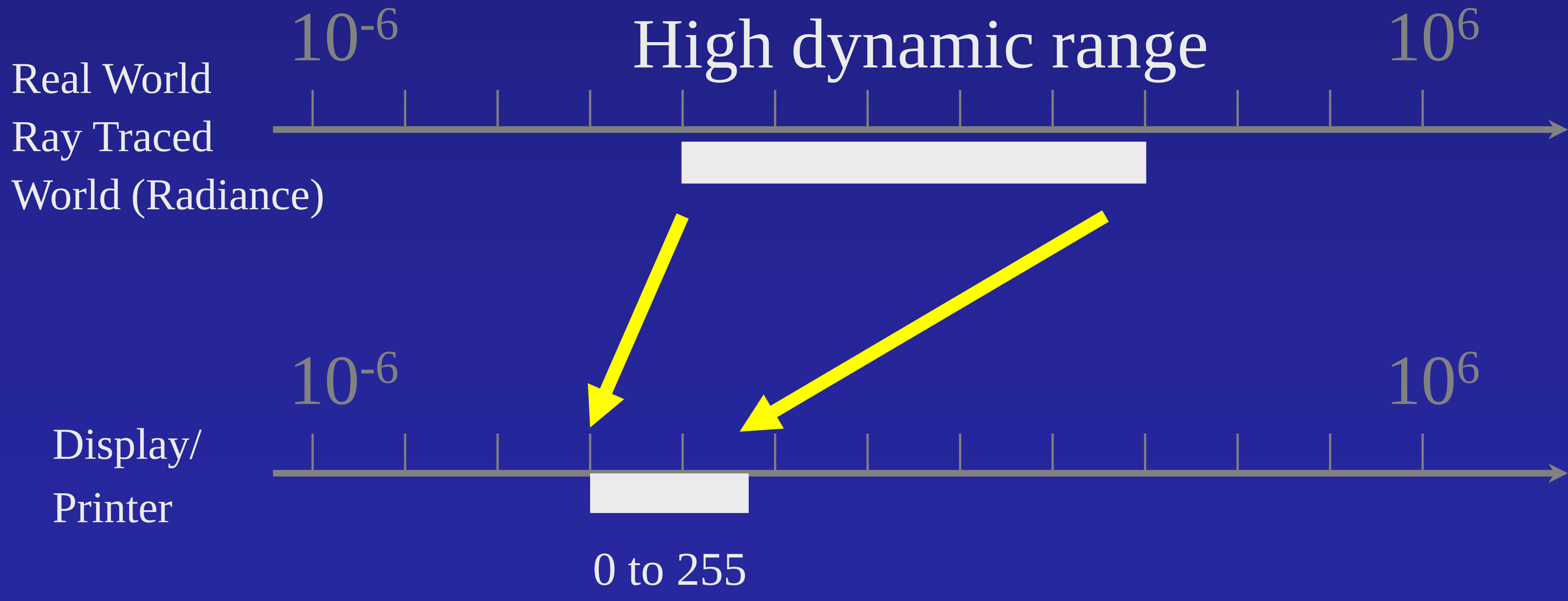
Now What?



Tone Mapping

- How can we do this?

  Linear scaling?, thresholding? Suggestions?

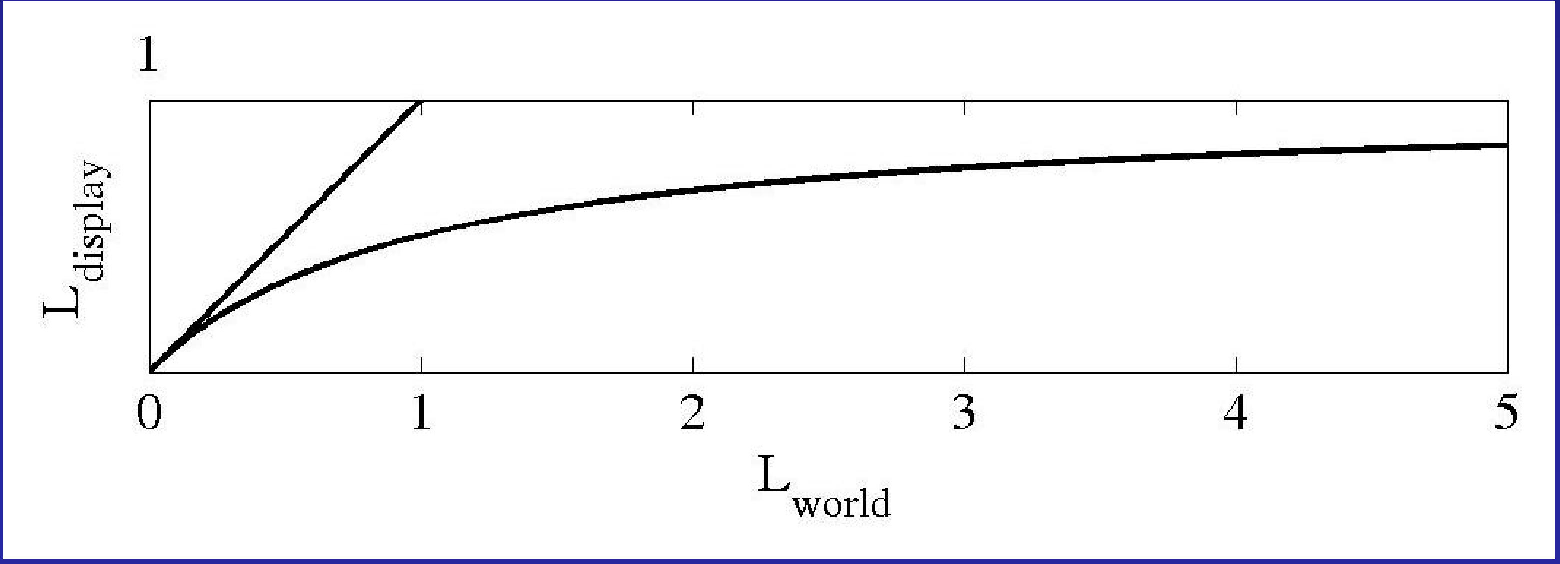


Simple Global Operator

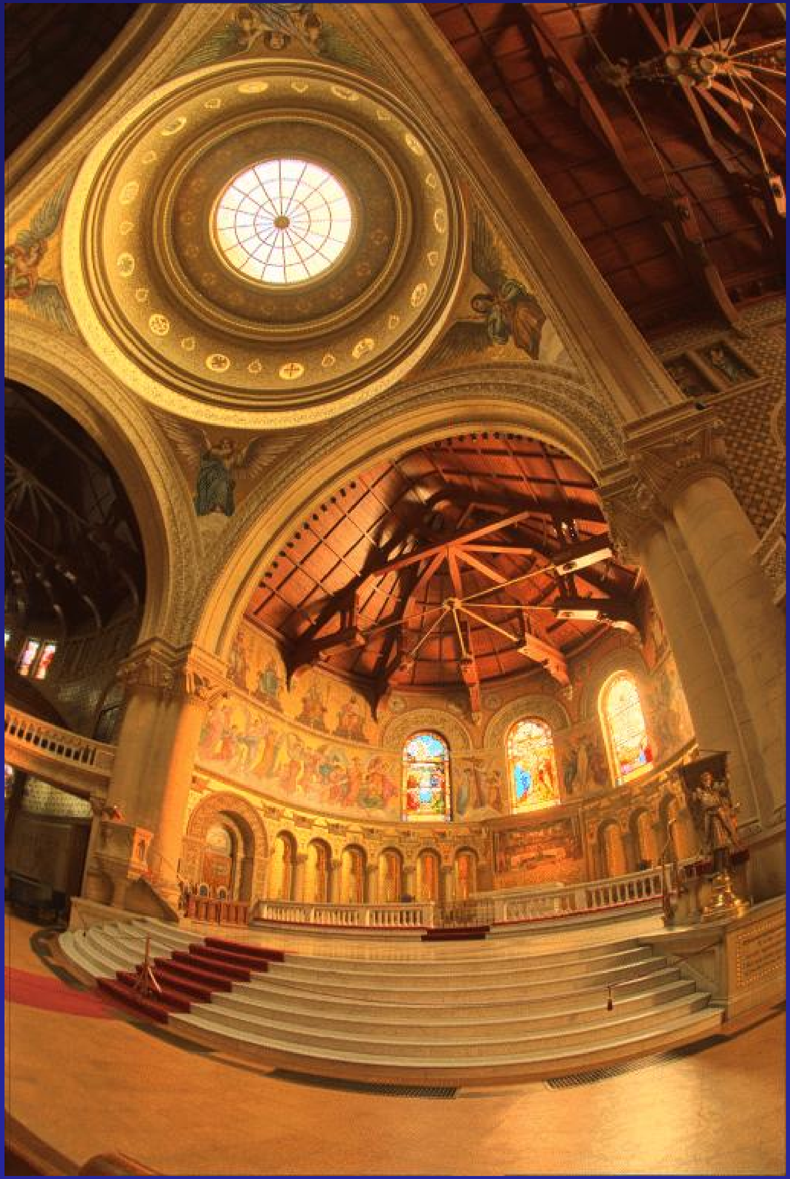
- Compression curve needs to
  - Bring everything within range
  - Leave dark areas alone
- In other words
  - Asymptote at 255
  - Derivative of 1 at 0

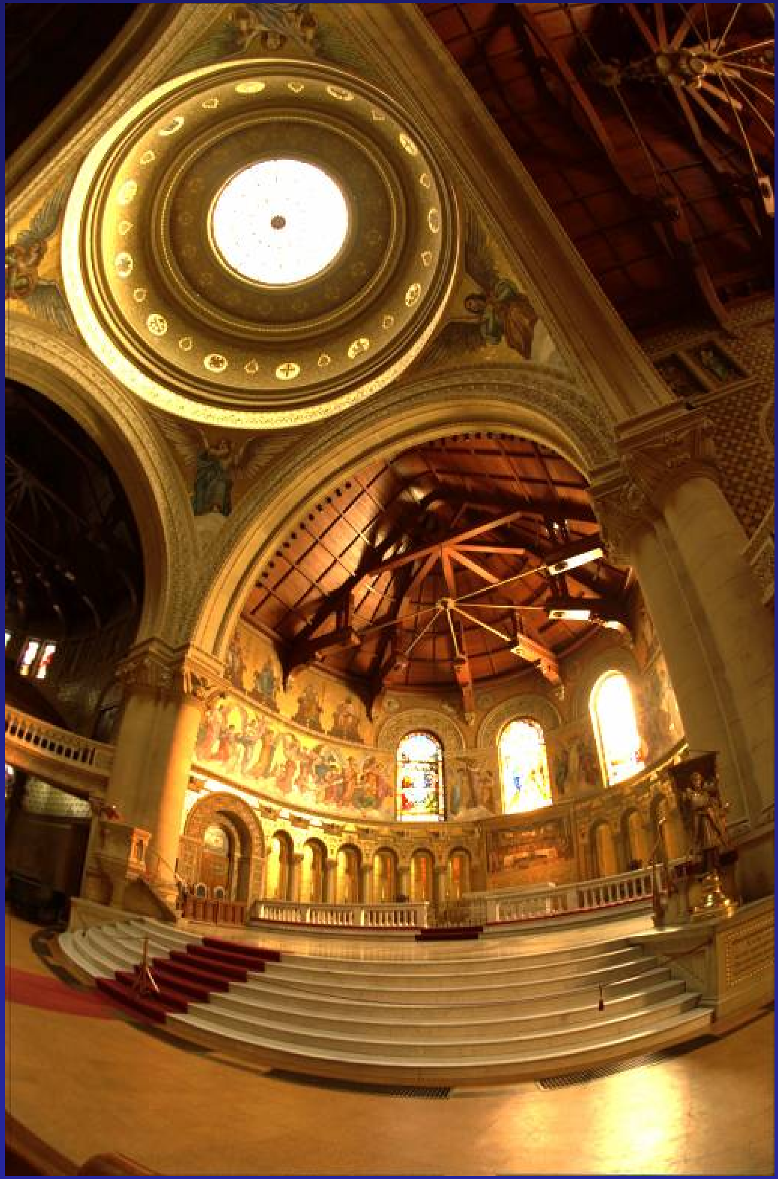
Global Operator (Reinhart et al)

$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



Global Operator Results

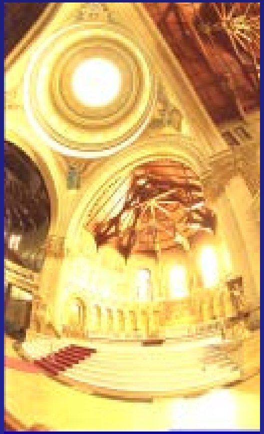




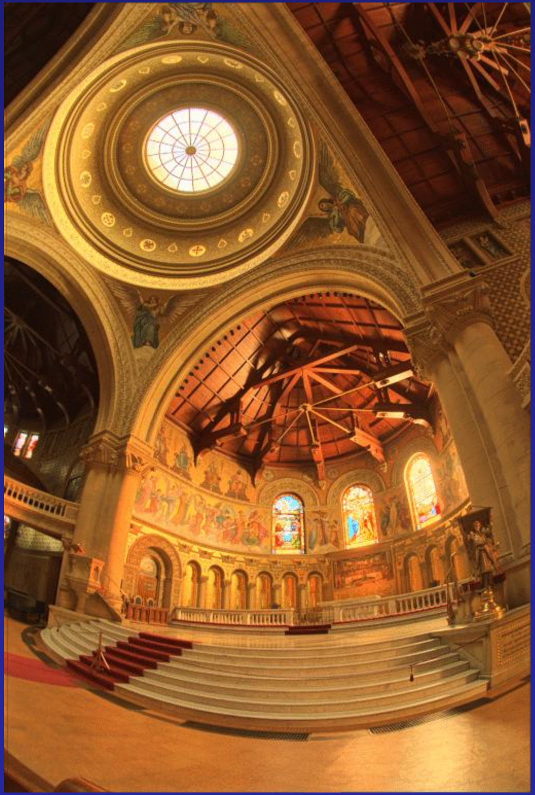
Reinhart Operator

Darkest 0.1% scaled to display device

What do *we* see?



Vs.



What does the eye sees?

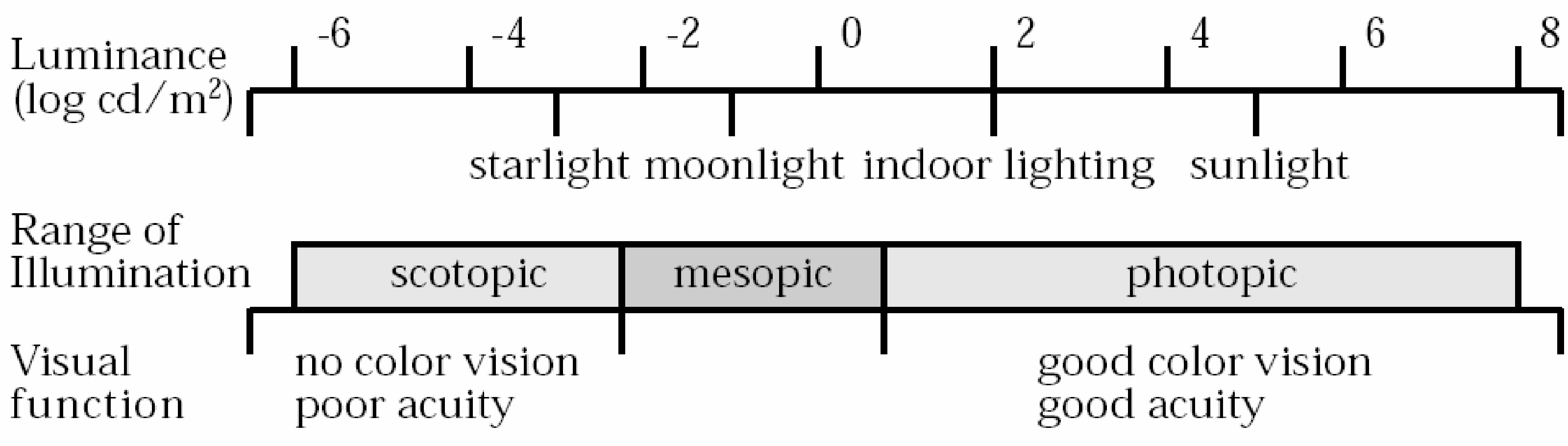
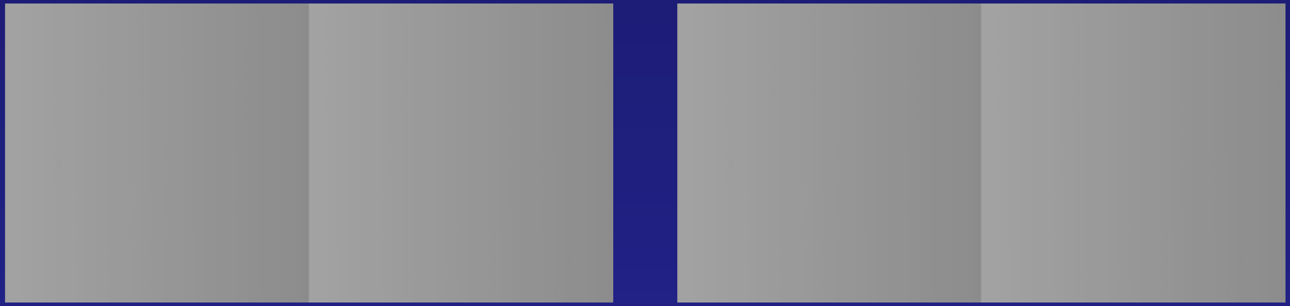


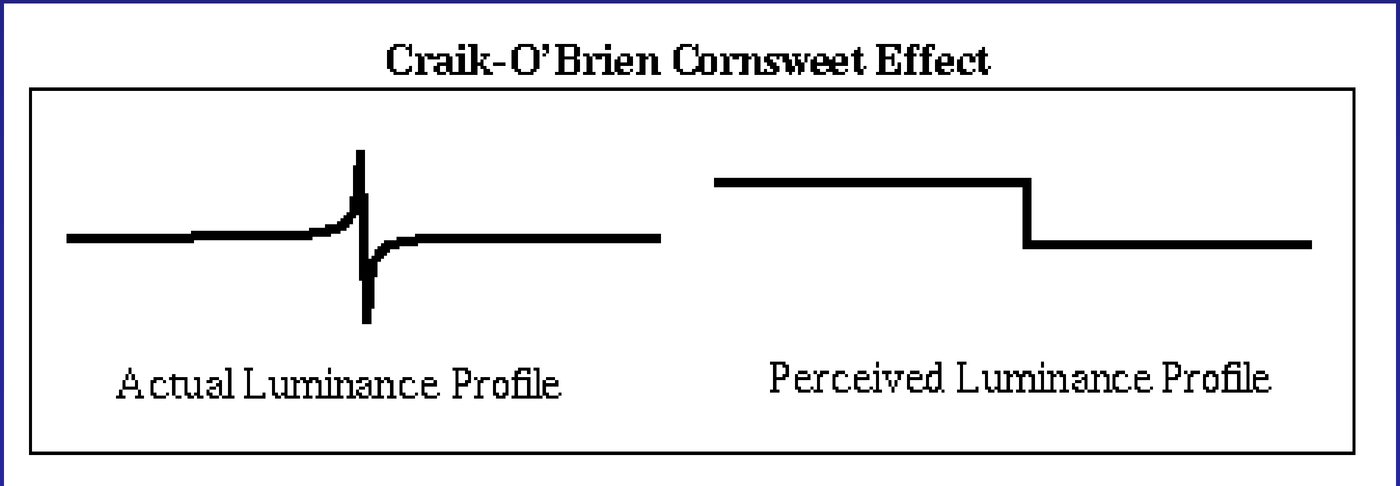
Figure 1: The range of luminances in the natural environment and associated visual parameters. After Hood (1986).

The eye has a huge dynamic range

Do we see a true radiance map?

Metamores





Can we use this for range compression?

Compressing Dynamic Range