# High Dynamic Range Images

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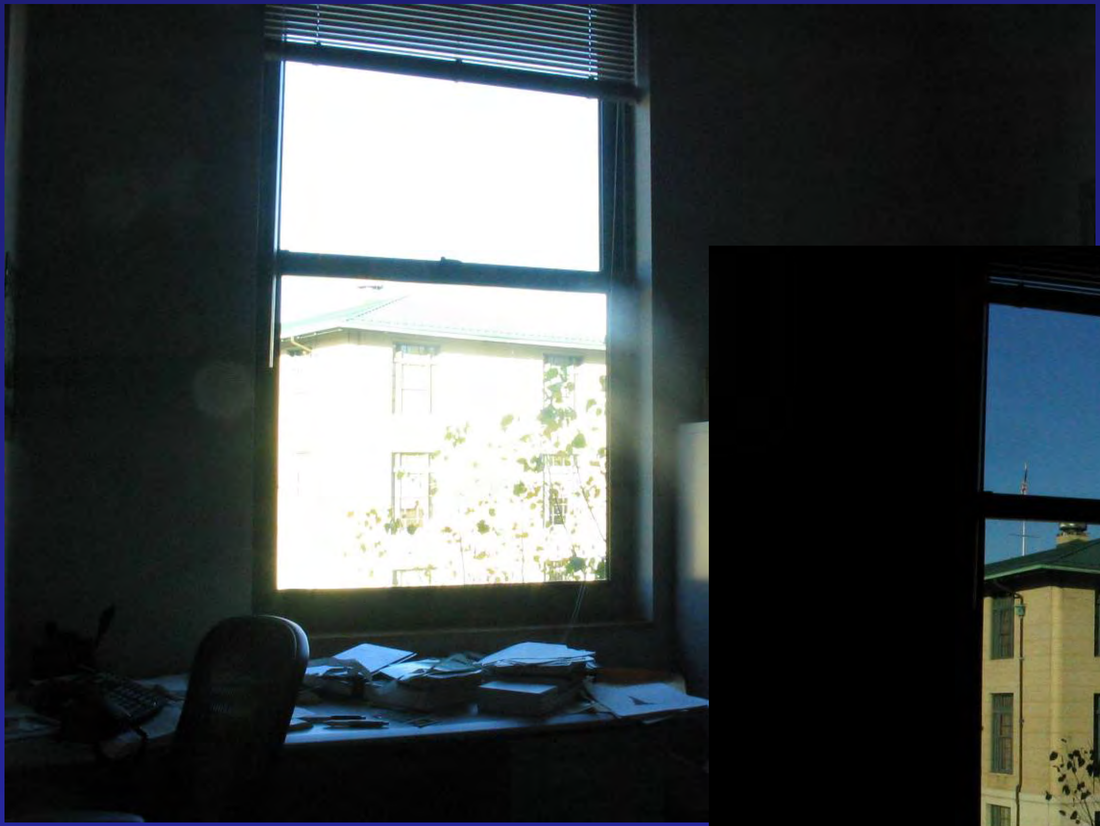
*…with a lot of slides stolen from Paul Debevec and Yuanzhen Li,*

15-463: Computational Photography
Alexei Efros, CMU, Fall 2007

# The Grandma Problem



# Problem: Dynamic Range

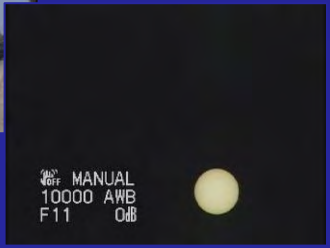
**The real world is high dynamic range.**


1


1500

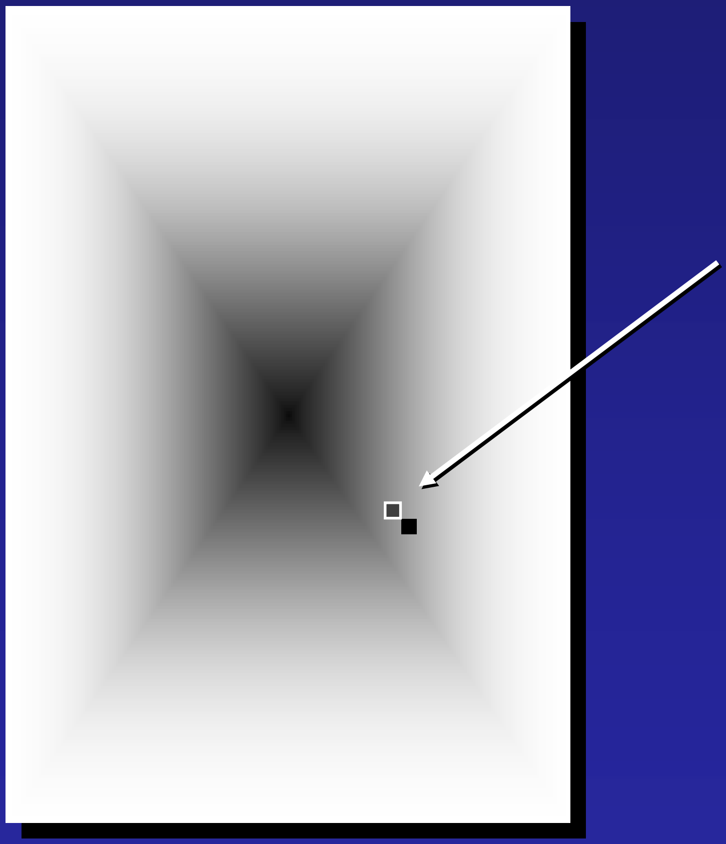

25,000


400,000




2,000,000,000

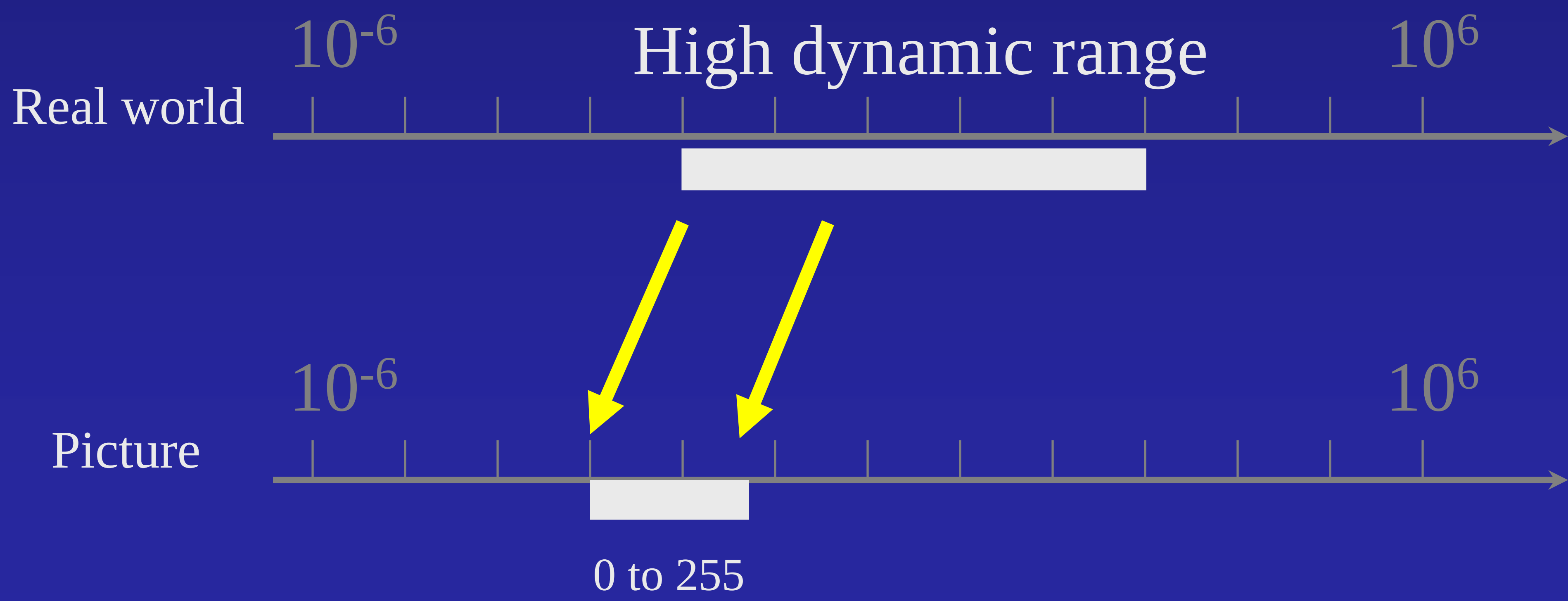
Image



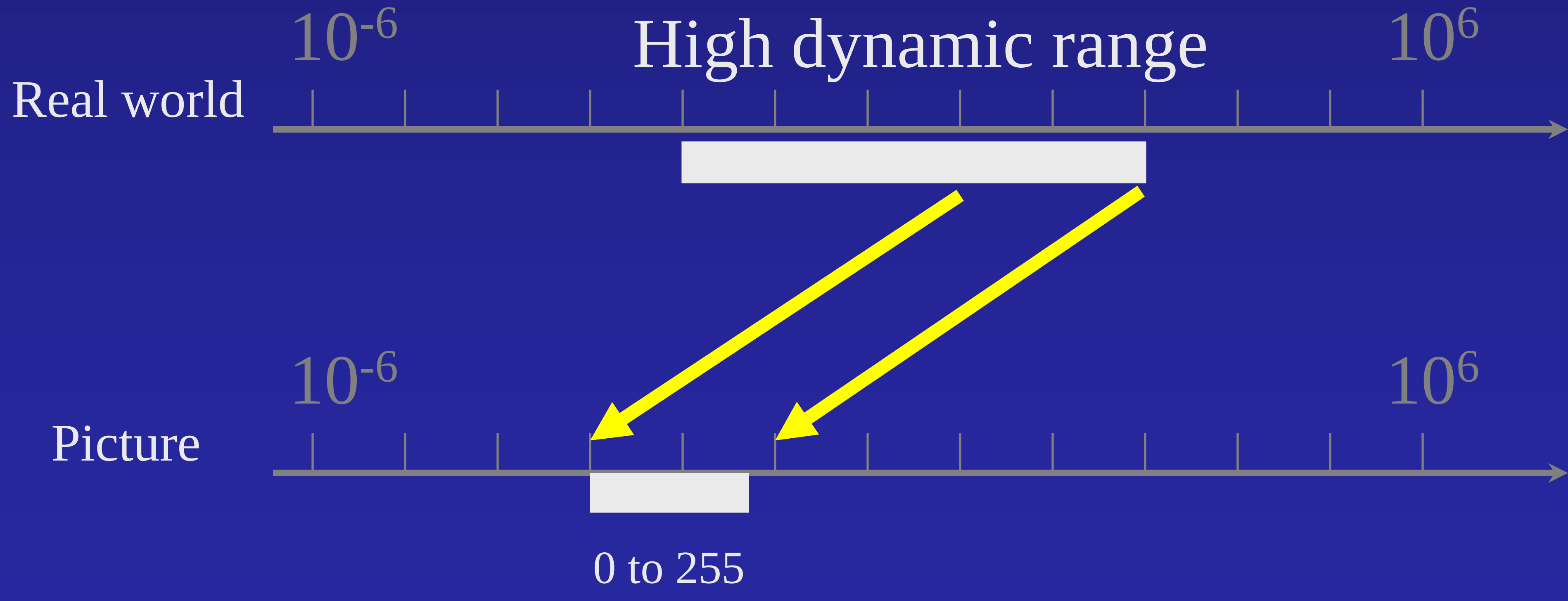
pixel (312, 284) = **42**

**42 photos?**

# Long Exposure

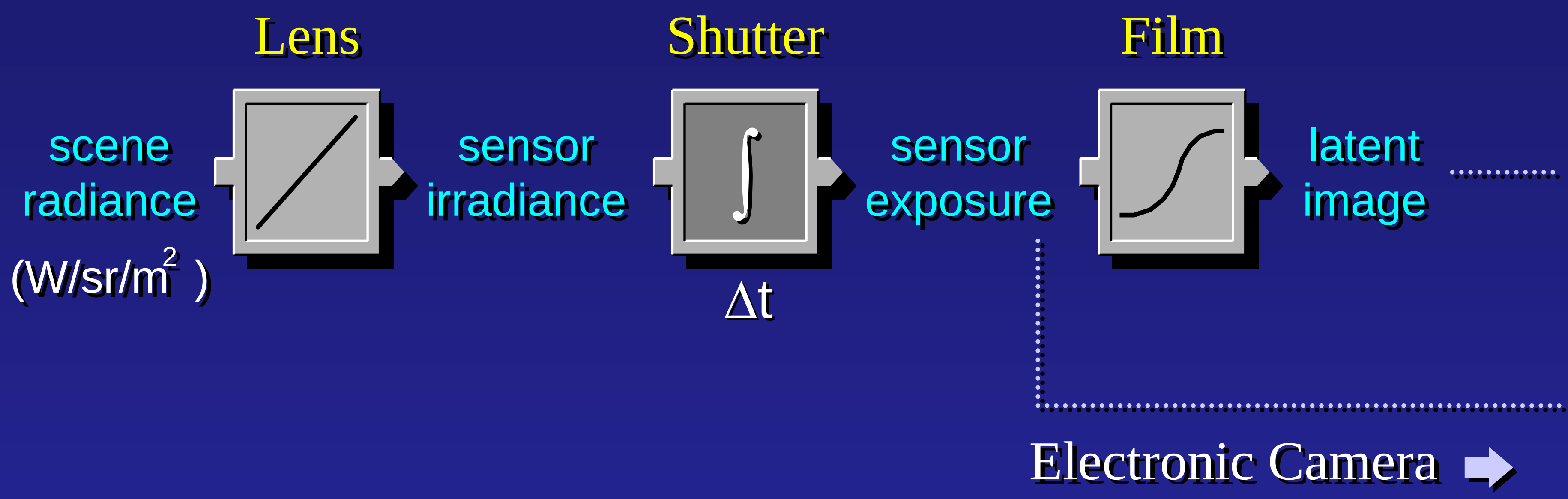


# Short Exposure

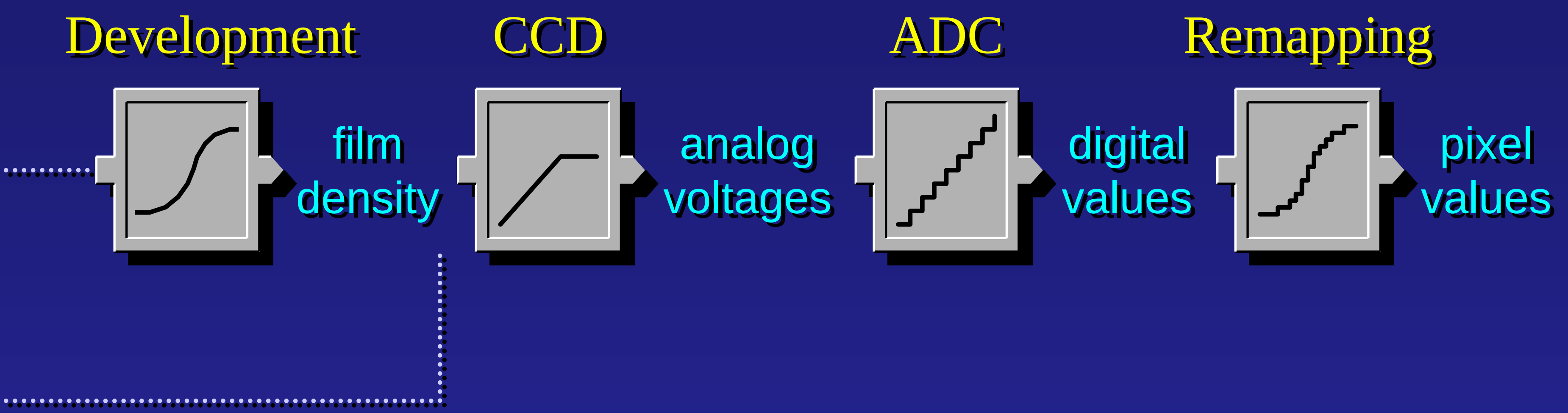


# Camera Calibration

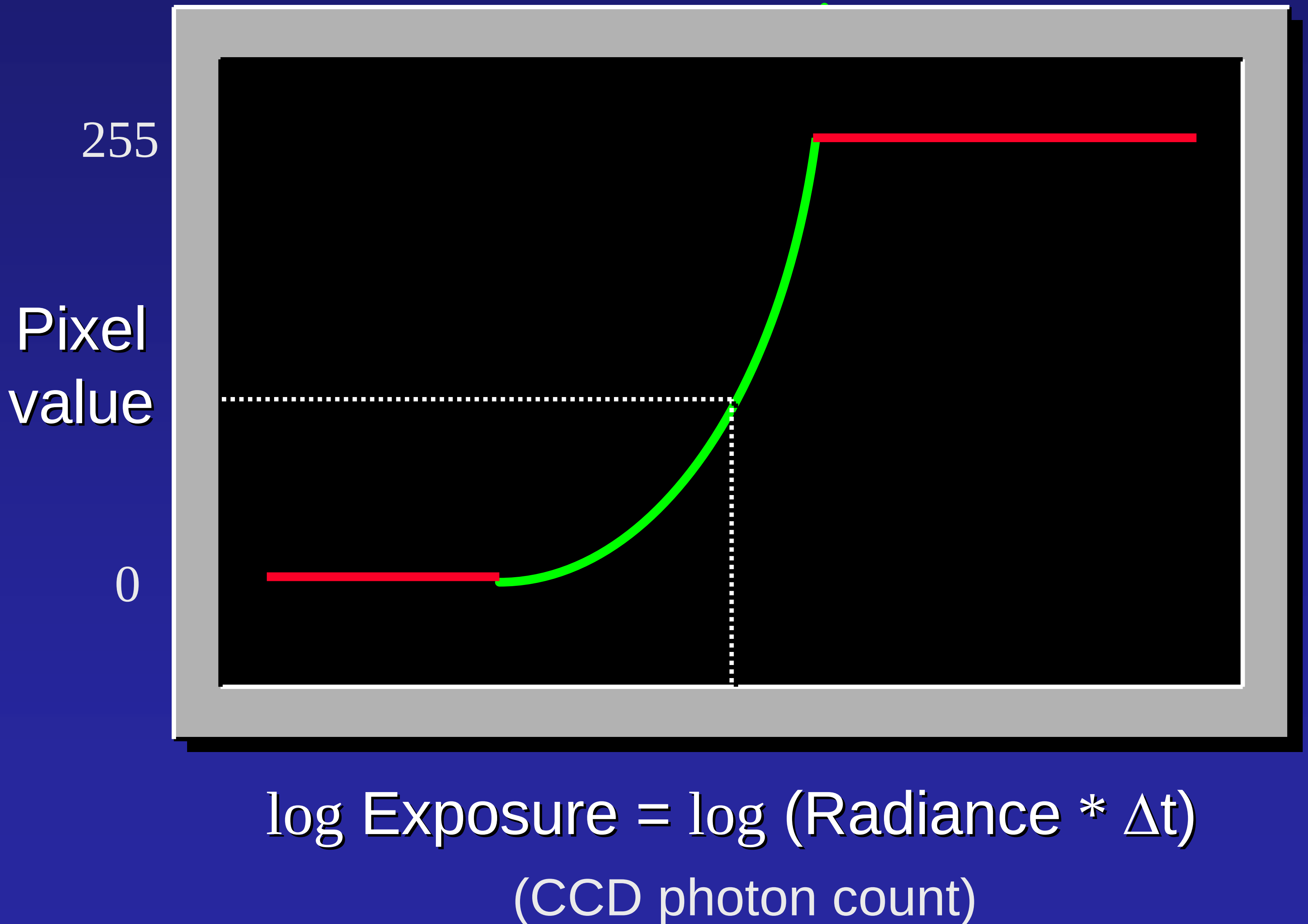
- Geometric
  - How pixel **coordinates** relate to **directions** in the world
- Photometric
  - How pixel **values** relate to **radiance** amounts in the world




# 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

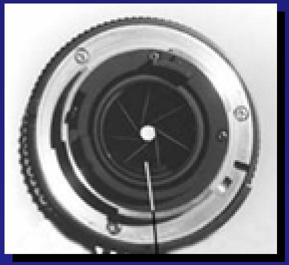
Paul Debevec
Jitendra Malik

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

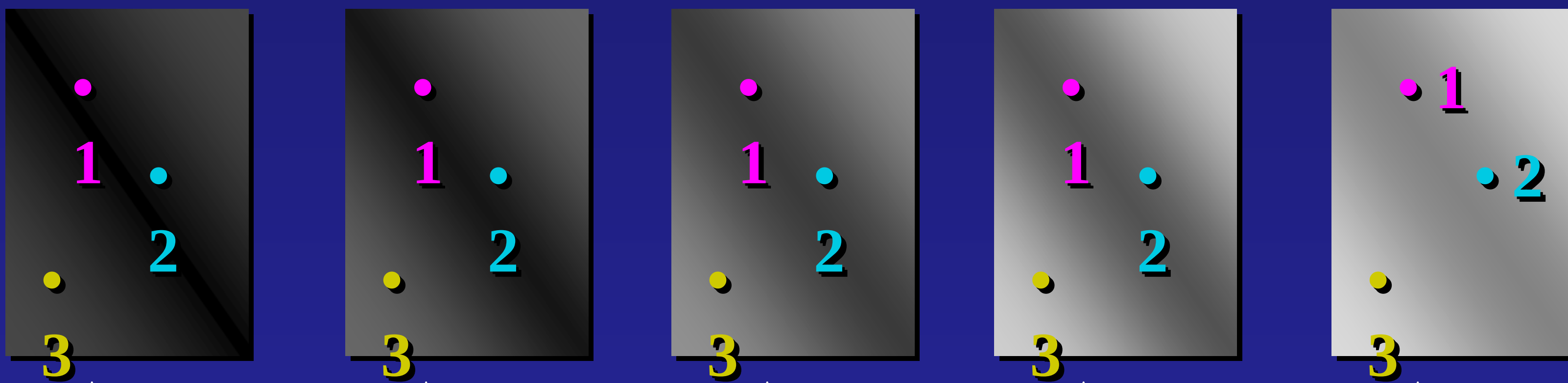
- **Ranges: Canon D30: 30 to 1/4,000 sec.**
- **Sony VX2000: ¼ to 1/10,000 sec.**
- **Pros:**
- **Directly varies the exposure**
- **Usually accurate and repeatable**
- **Issues:**
- **Noise in long exposures**

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

Pixel Value Z = f(Exposure)

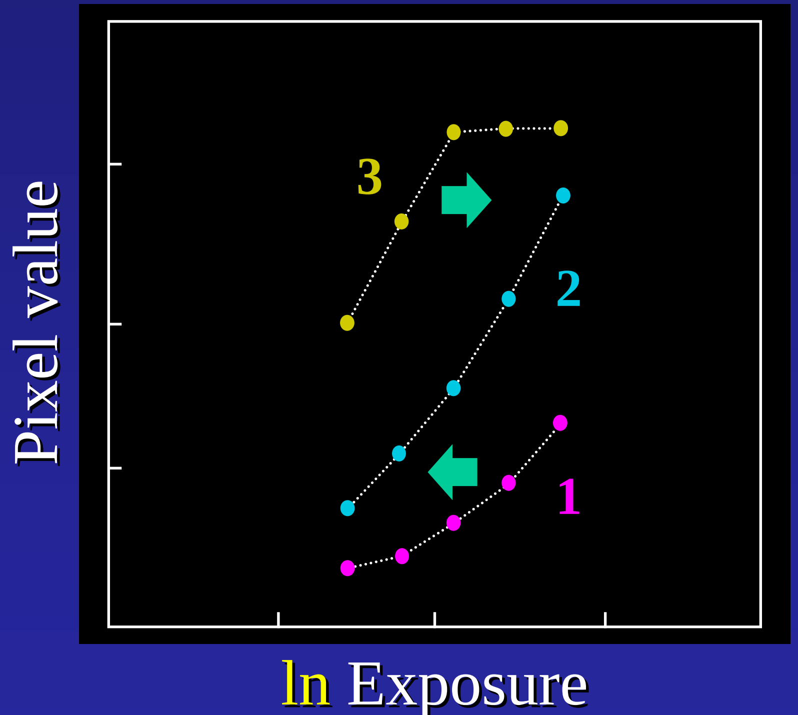
Exposure = Radiance × Δt

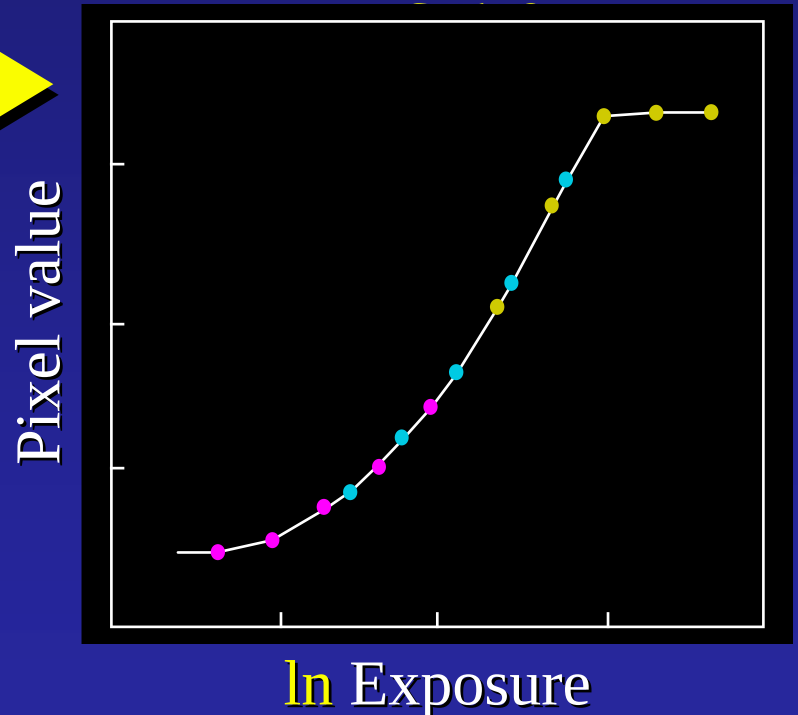
log Exposure = log Radiance + log Δt

# 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:

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

- Solve the overdetermined linear system:

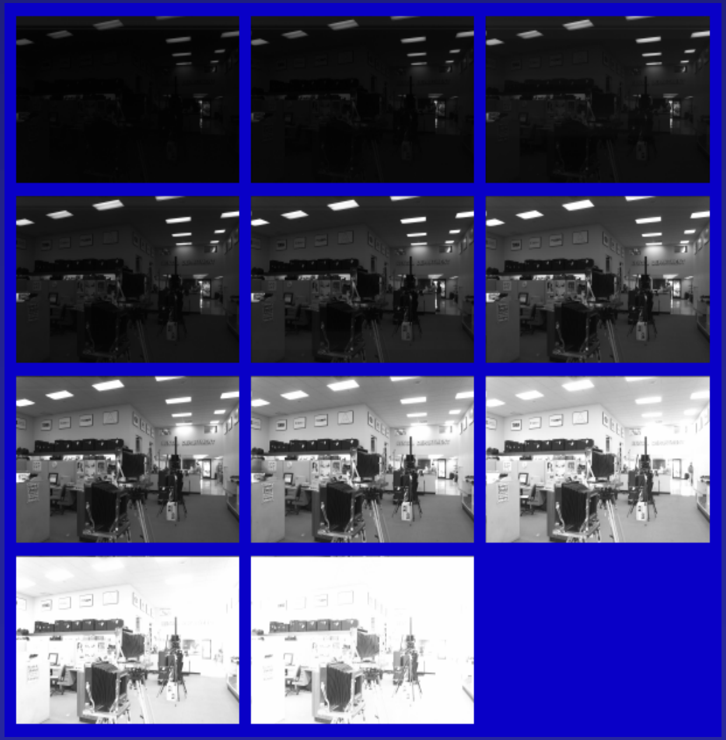
$$\underbrace{\sum_{i=1}^{N}\sum_{j=1}^{P}\left[\ln Radiance_i + \ln \Delta t_j - g(Z_{ij})\right]^2}_{\text{fitting term}} + \underbrace{\lambda \sum_{z=Z_{min}}^{Z_{max}} g''(z)^2}_{\text{smoothness term}}$$

# Matlab Code

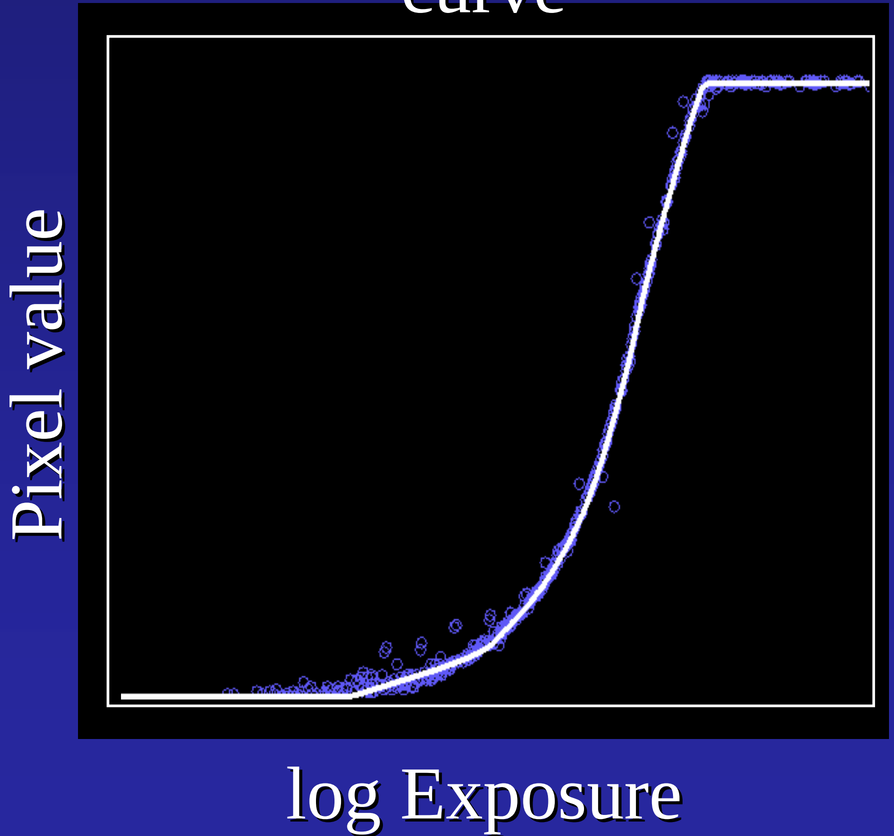
```
function [g,lE]=gsolve(Z,B,l,w)

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

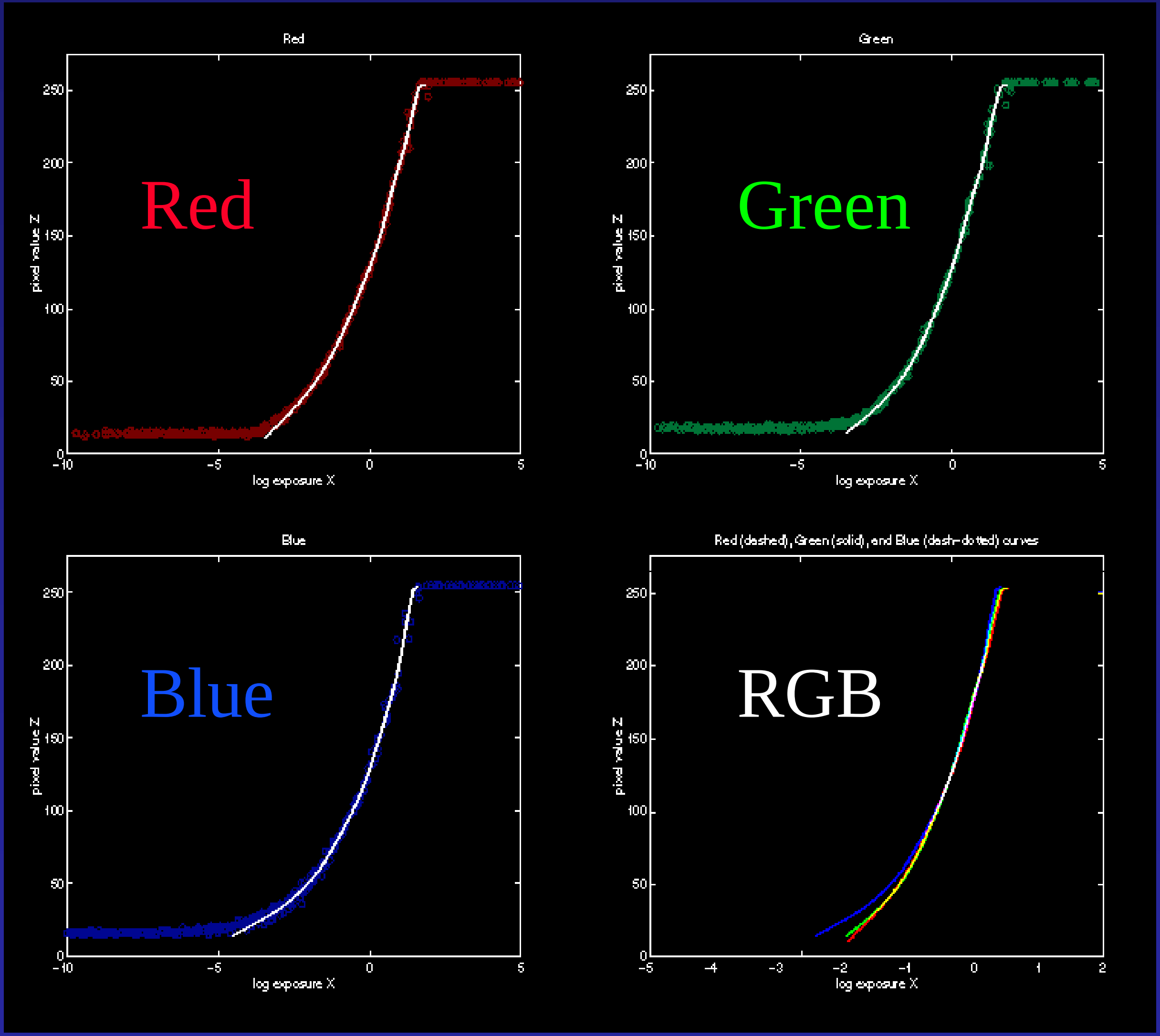


# Reconstructed radiance map

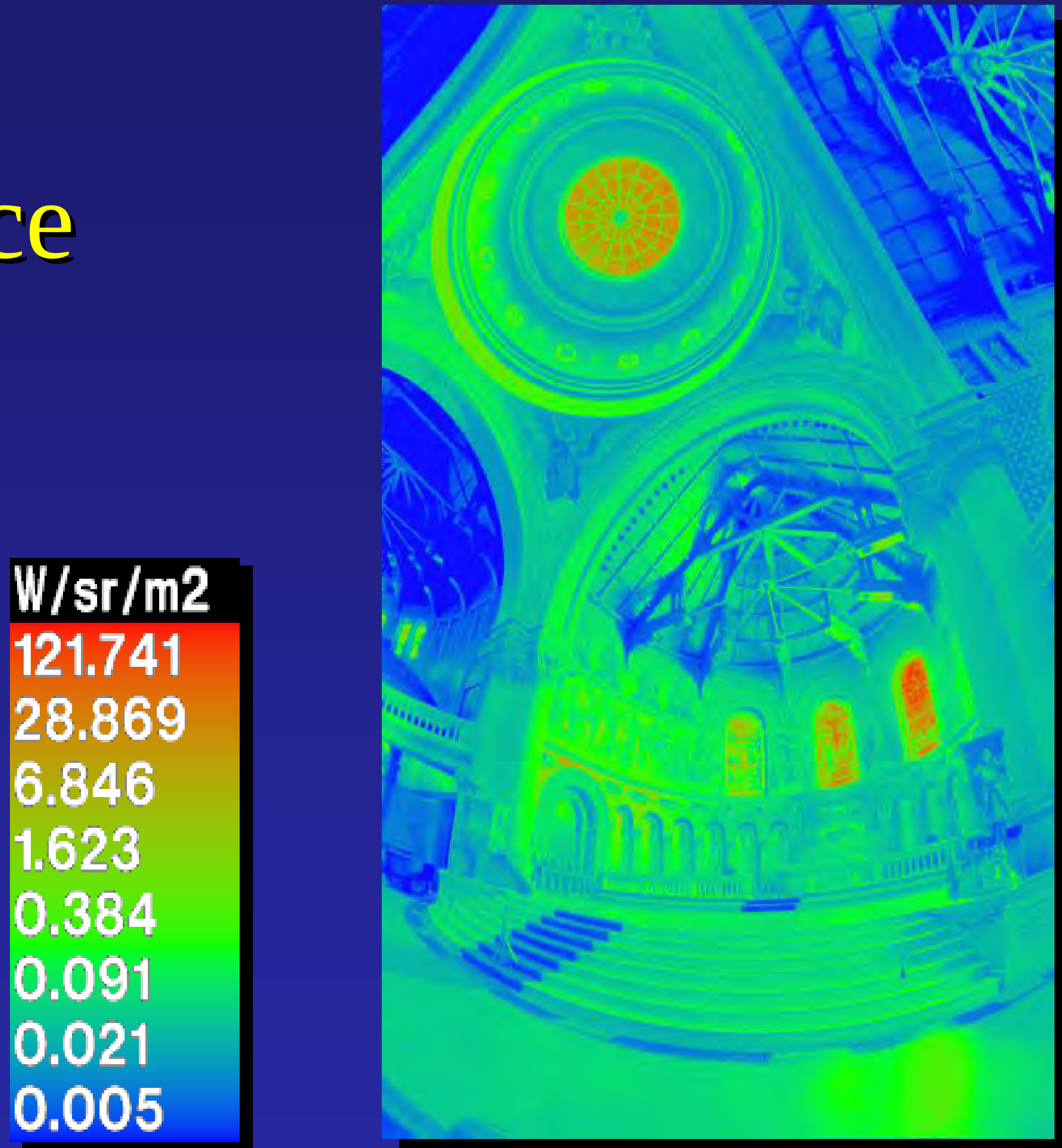
# Results: Color Film

- Kodak Gold ASA 100, PhotoCD

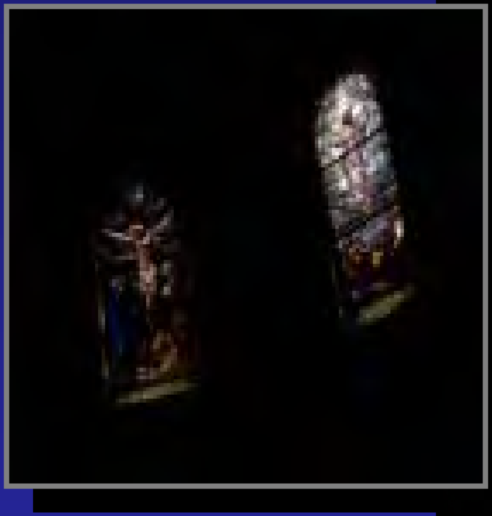
# Recovered Response Curves

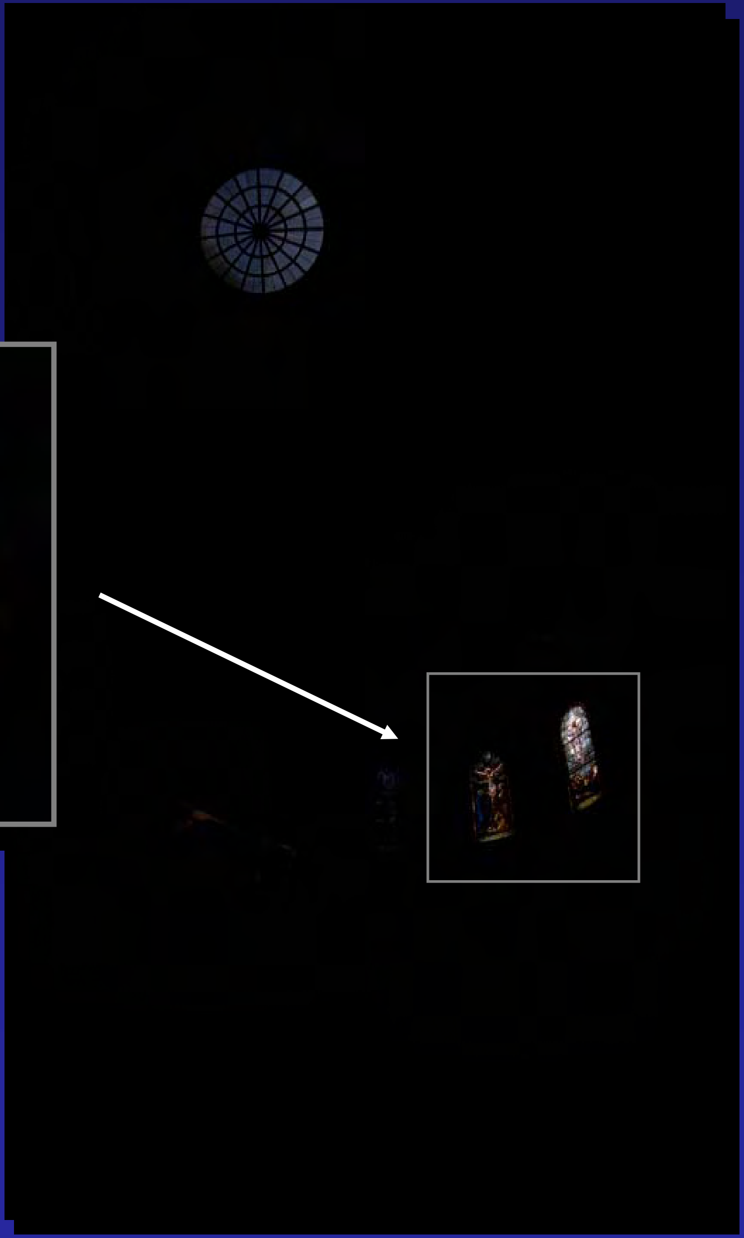


# The Radiance Map



# The Radiance Map

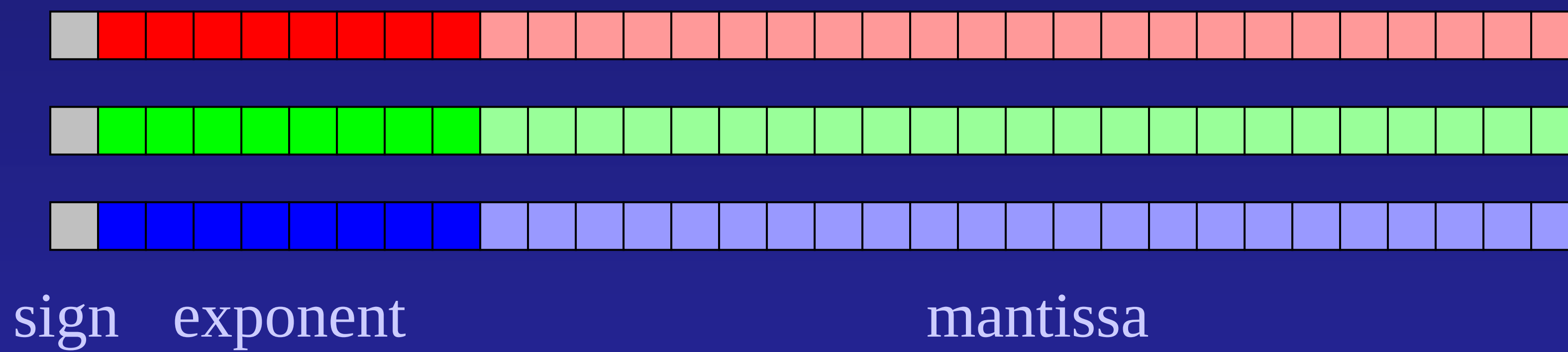




Linearly scaled to display device

# Portable FloatMap (.pfm)

- 12 bytes per pixel, 4 for each channel



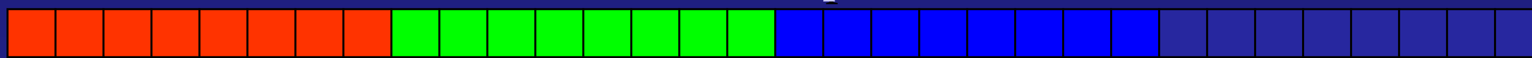

Text header similar to Jeff Poskanzer’s .ppm image format:

```
PF
768 512
1
<binary image data>
```

Floating Point TIFF similar

# *Radiance* Format
# (.pic, .hdr)

32 bits / pixel



Red Green Blue Exponent

(145, 215, 87, 149) =

(145, 215, 87) * 2^(149-128) =

(1190000, 1760000, 713000)

(145, 215, 87, 103) =

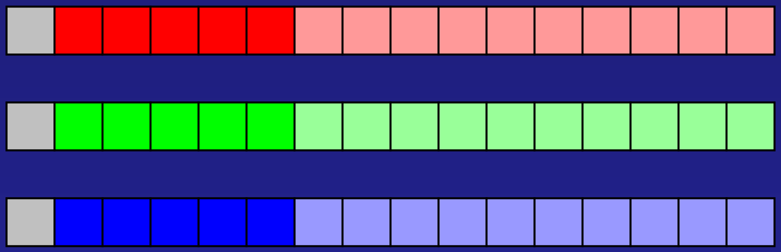
(145, 215, 87) * 2^(103-128) =

(0.00000432, 0.00000641, 0.00000259)

Ward, Greg. "Real Pixels," in Graphics Gems IV, edited by James Arvo, Academic Press, 1994

# *ILM*’s OpenEXR (.exr)

- 6 bytes per pixel, 2 for each channel, compressed

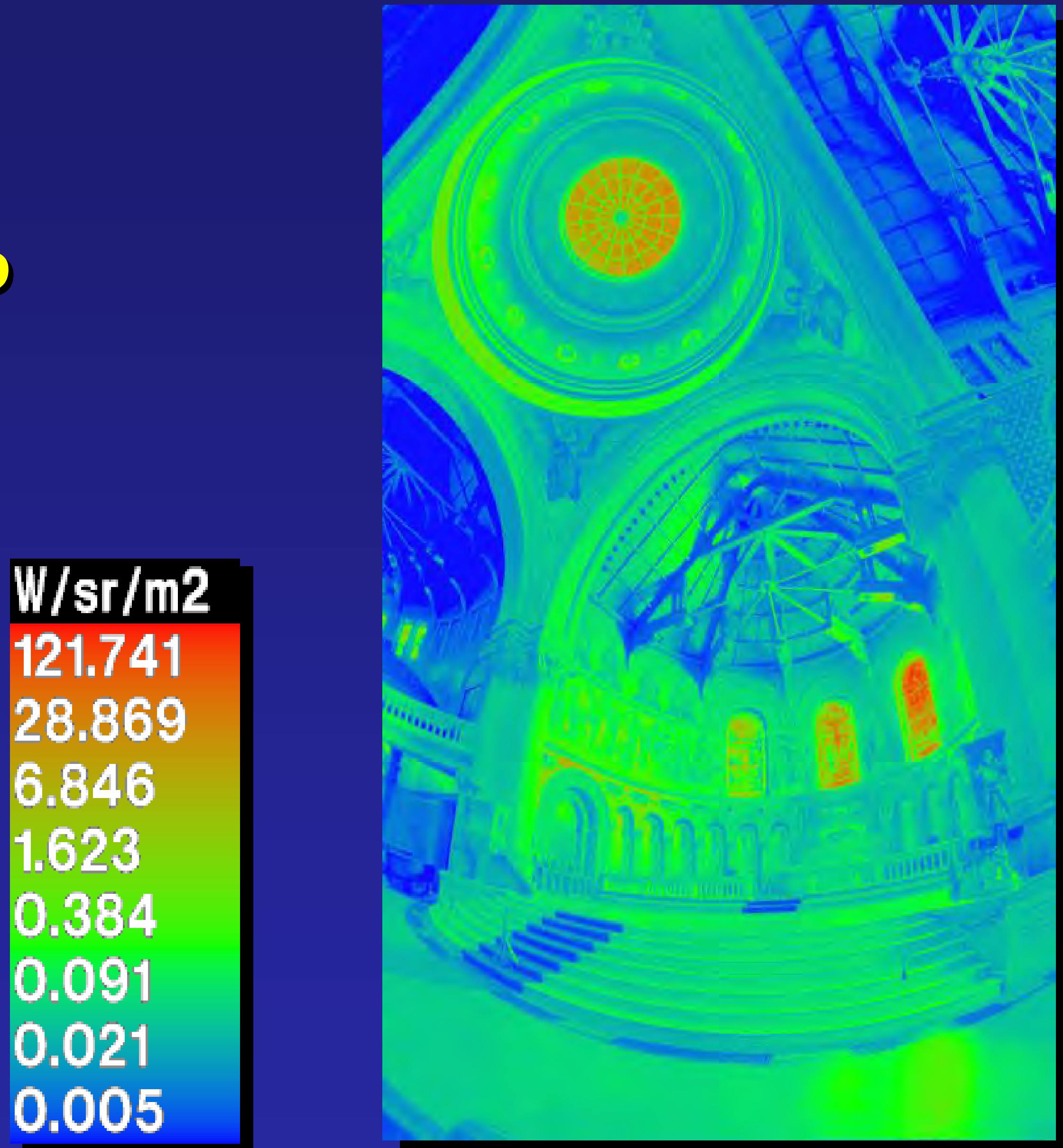


sign exponent mantissa

- Several lossless compression options, 2:1 typical
- Compatible with the “half” datatype in NVidia's Cg
- Supported natively on GeForce FX and Quadro FX

- Available at http://www.openexr.net/

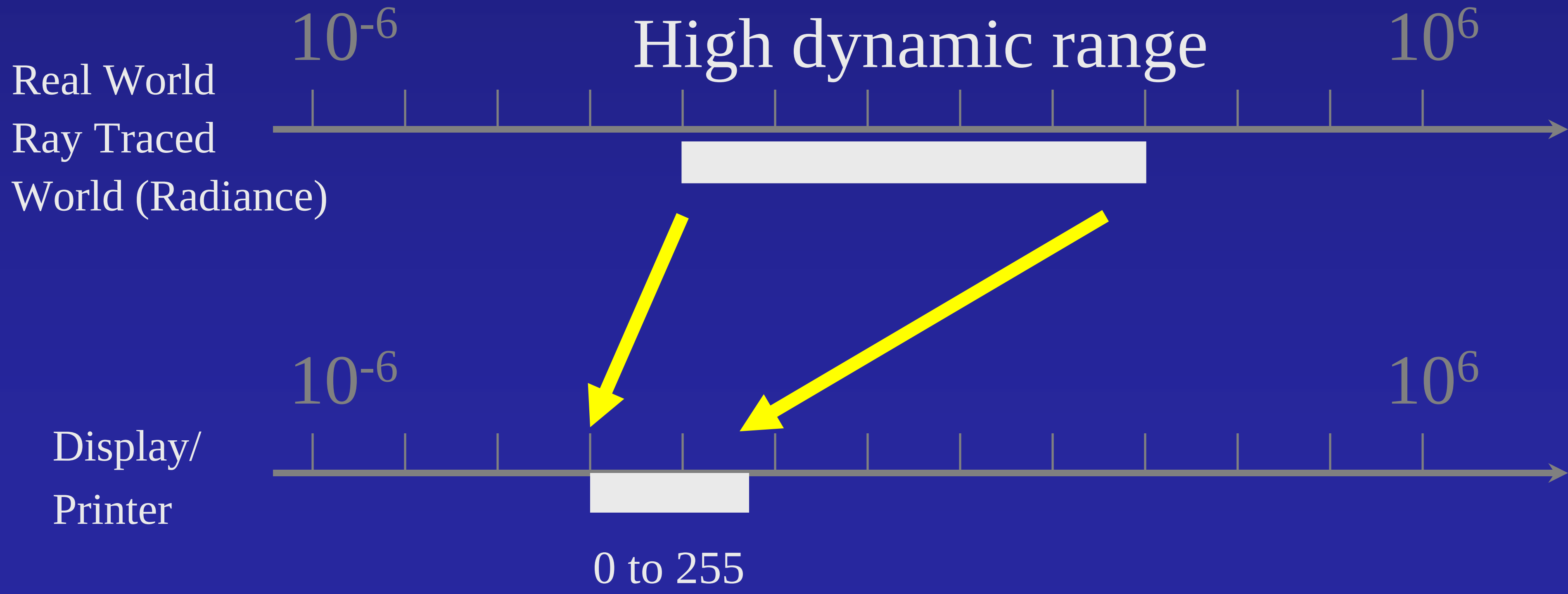
# Now What?



# Tone Mapping

- How can we do this?

  Linear scaling?, thresholding?  Suggestions?

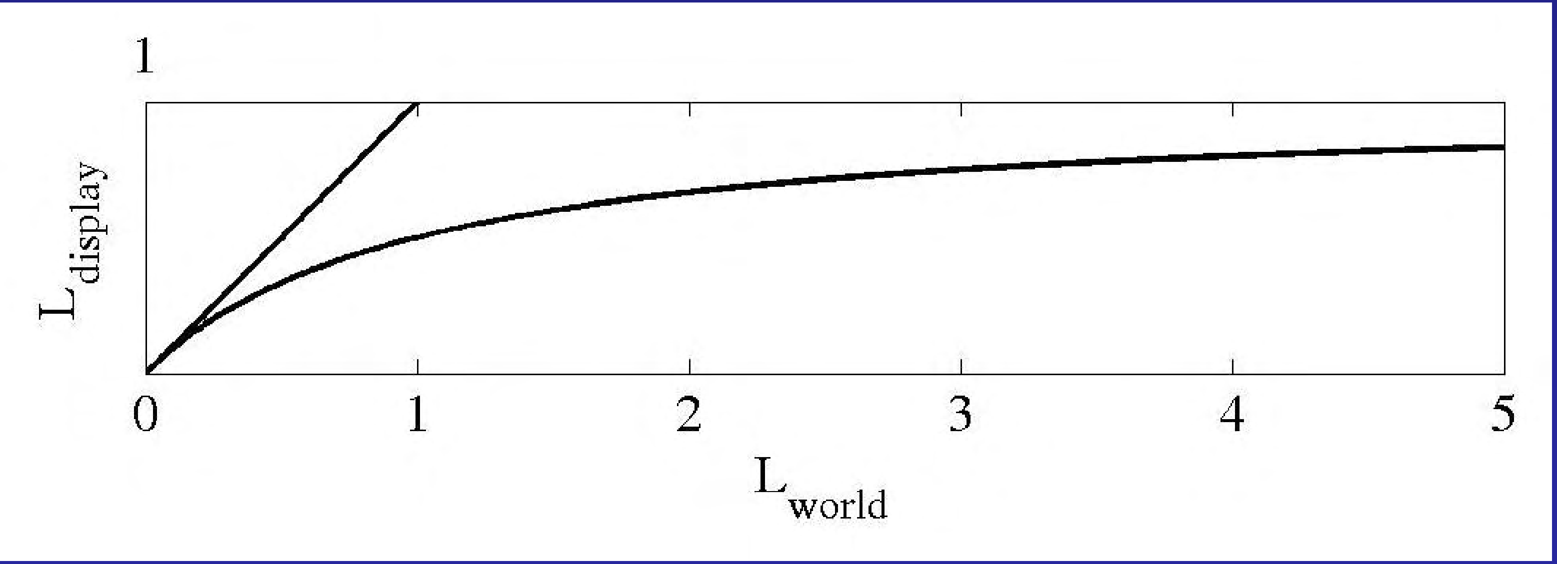


# Simple Global Operator

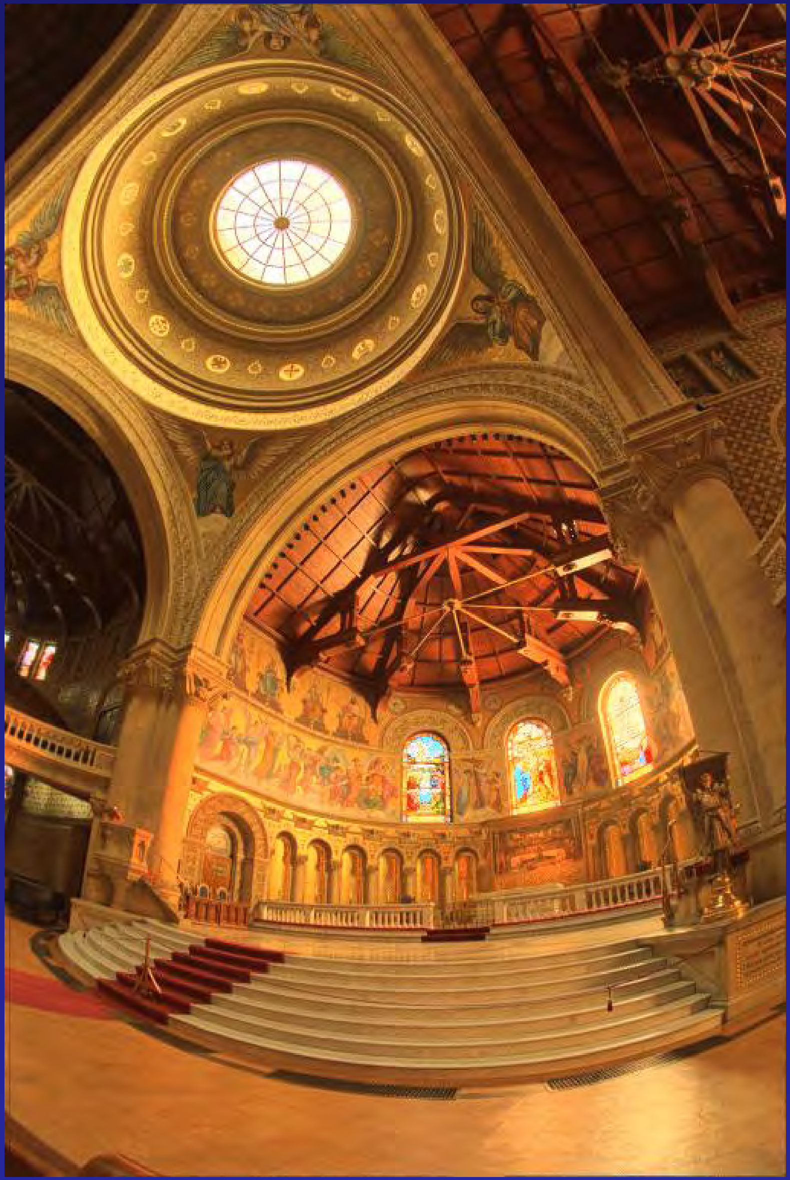
- Compression curve needs to
  - Bring everything within range
  - Leave dark areas alone
- In other words
  - Asymptote at 255
  - Derivative of 1 at 0

# Global Operator (Reinhart et al)

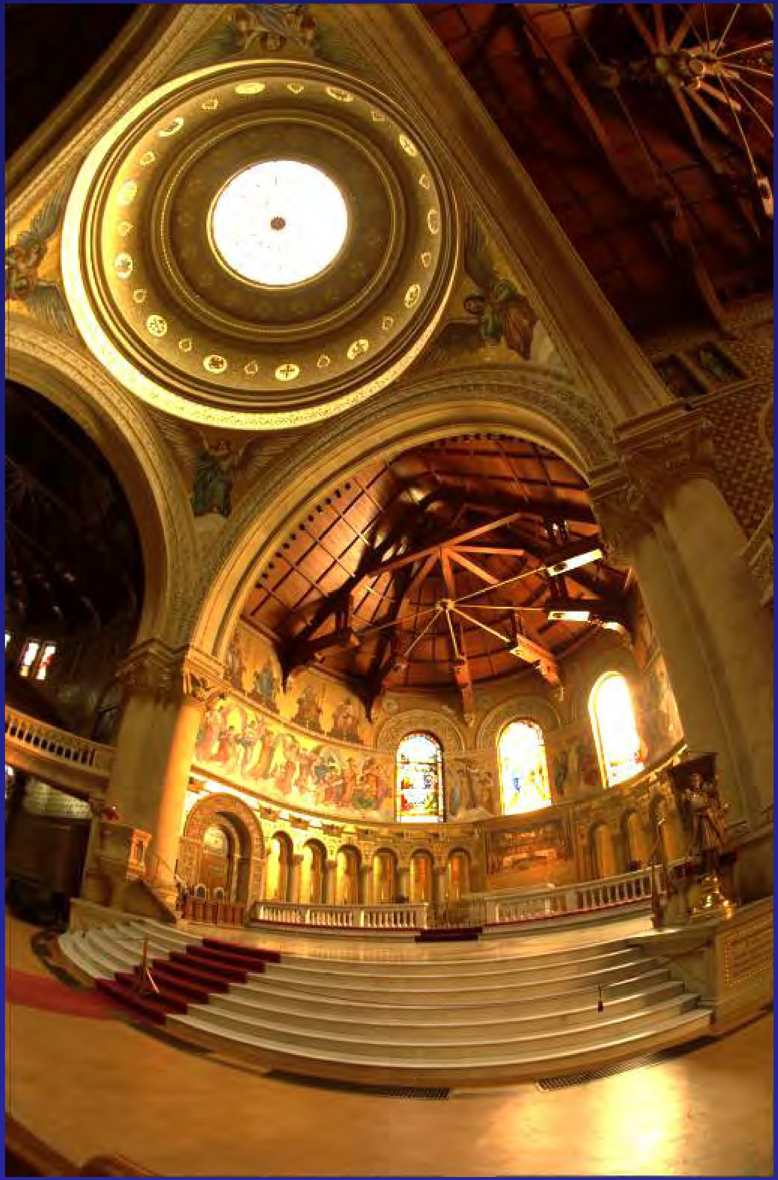
$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



# Global Operator Results



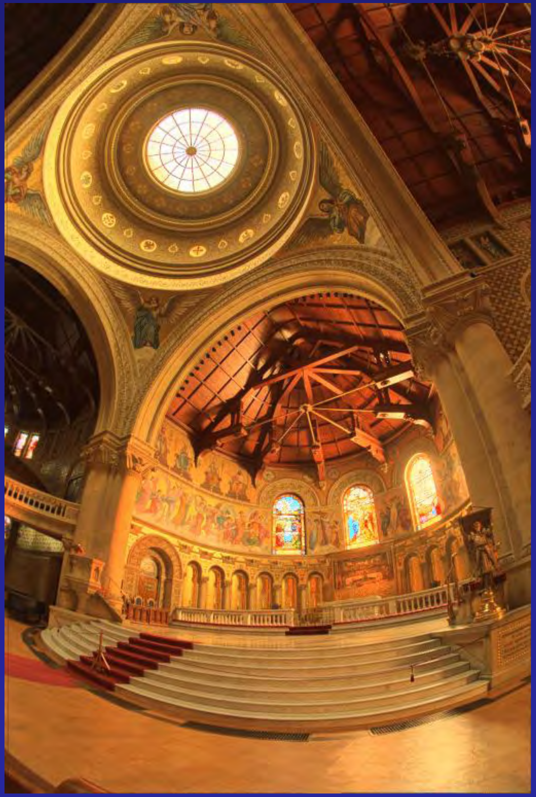
Reinhart Operator



Darkest 0.1% scaled
to display device

# What do *we* see?


Vs.



# What does the eye sees?

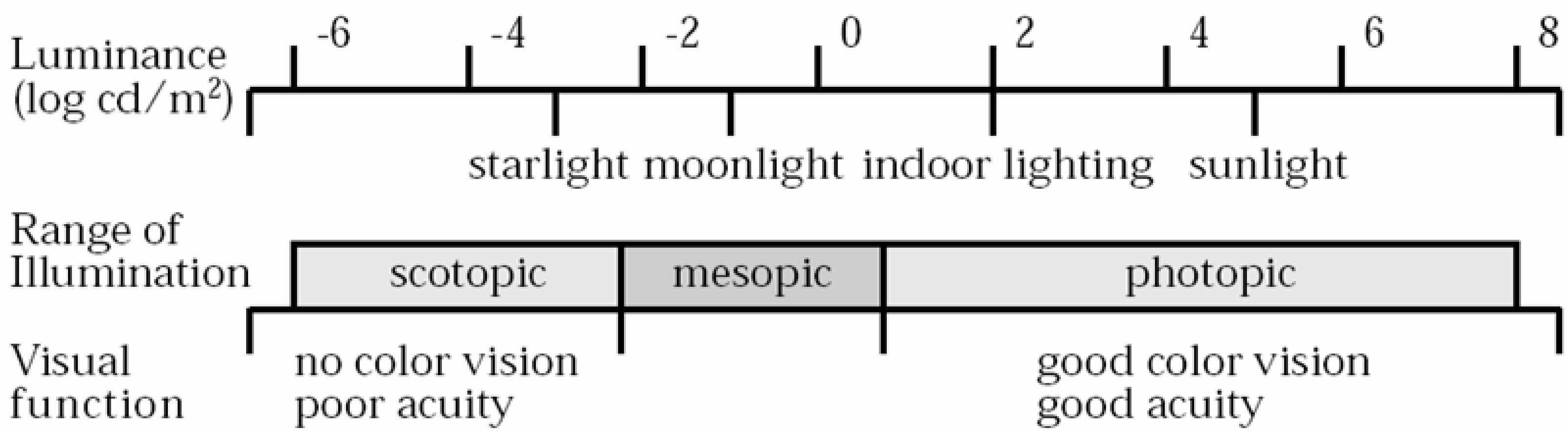
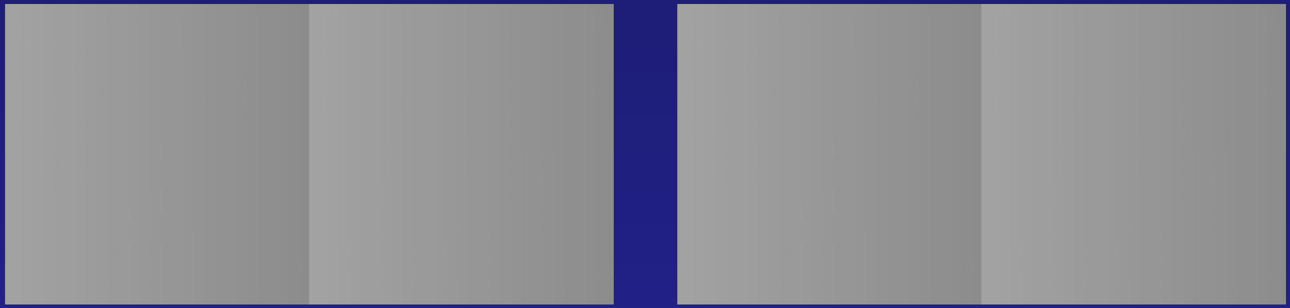


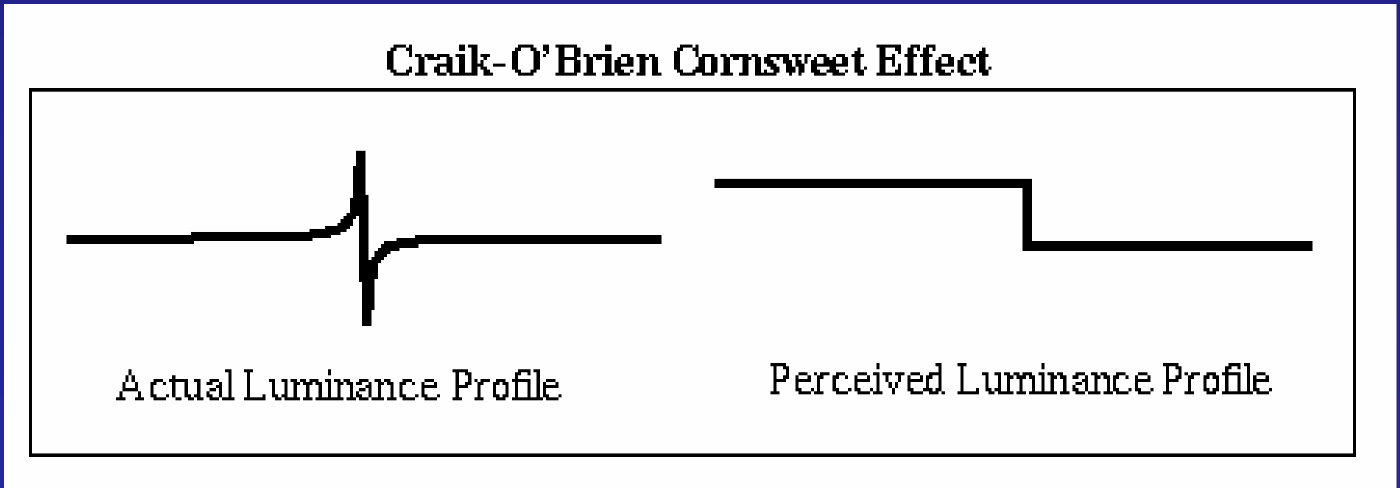

Figure 1: The range of luminances in the natural environment and associated visual parameters. After Hood (1986).

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

SIGGRAPH2005

# Compressing and Companding High Dynamic Range Images with Subband Architectures

Yuanzhen Li, Lavanya Sharan,

Edward Adelson

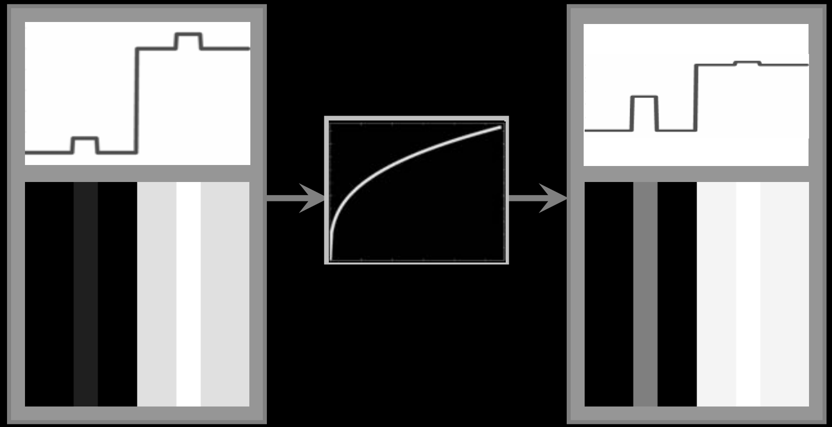
Massachusetts Institute of Technology

# Dynamic Range Problem

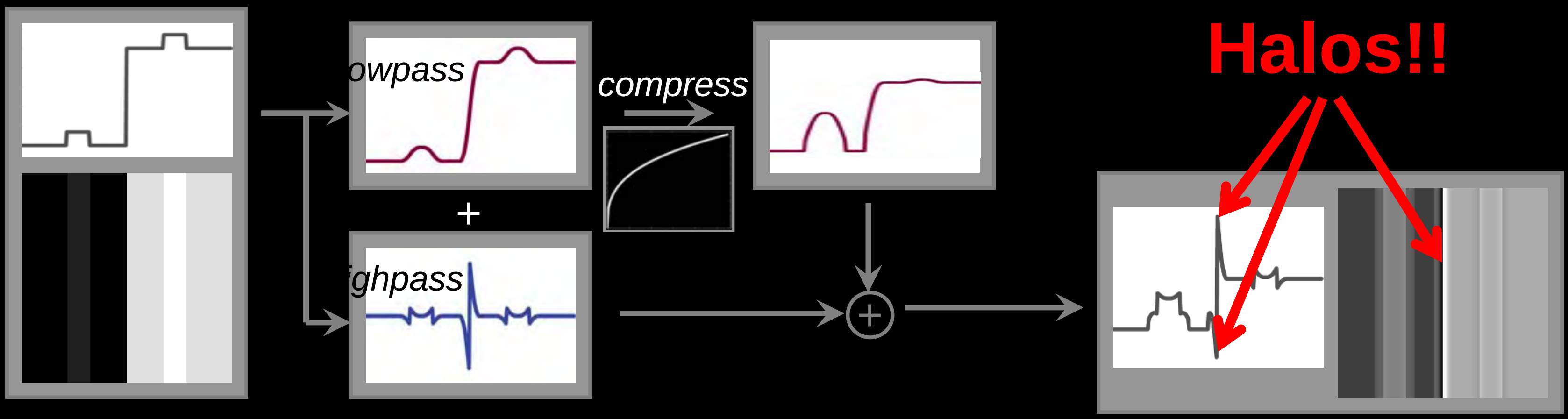
Source: Shree Nayar

# Range Compression

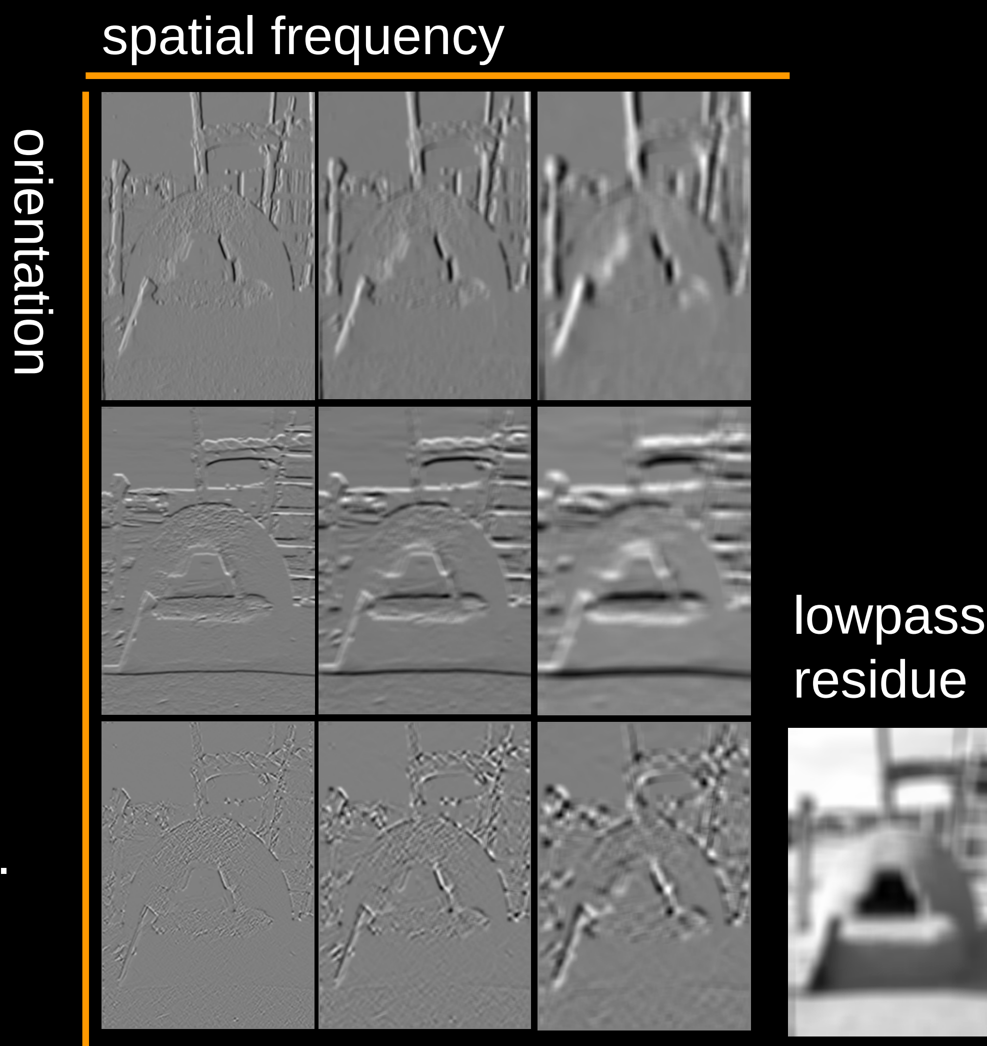
Method: Gamma or log on intensities.
Problem: loss of detail.



Solution: filtering.
Problem: halos.

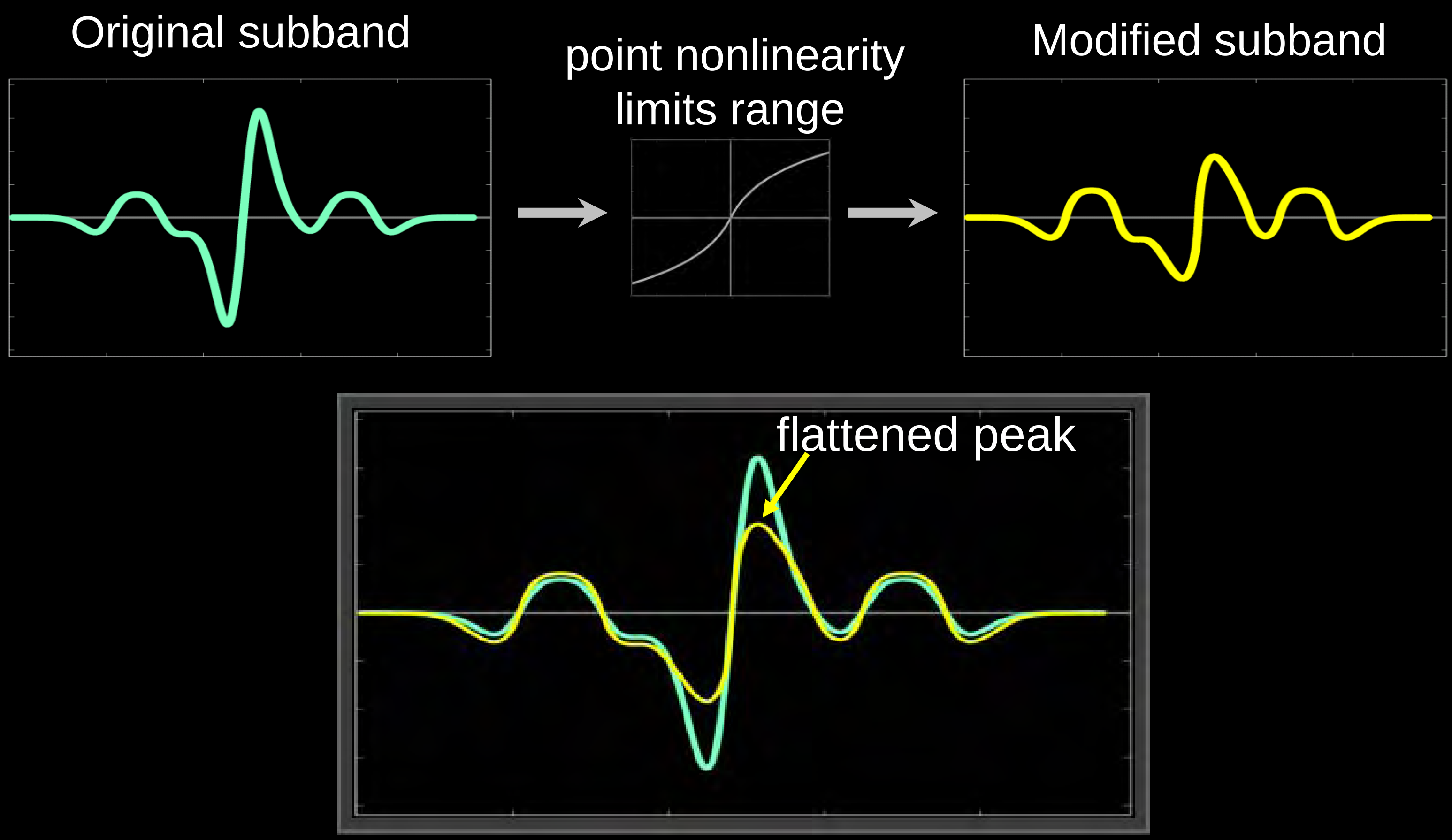


# Multiscale Subband Decomposition



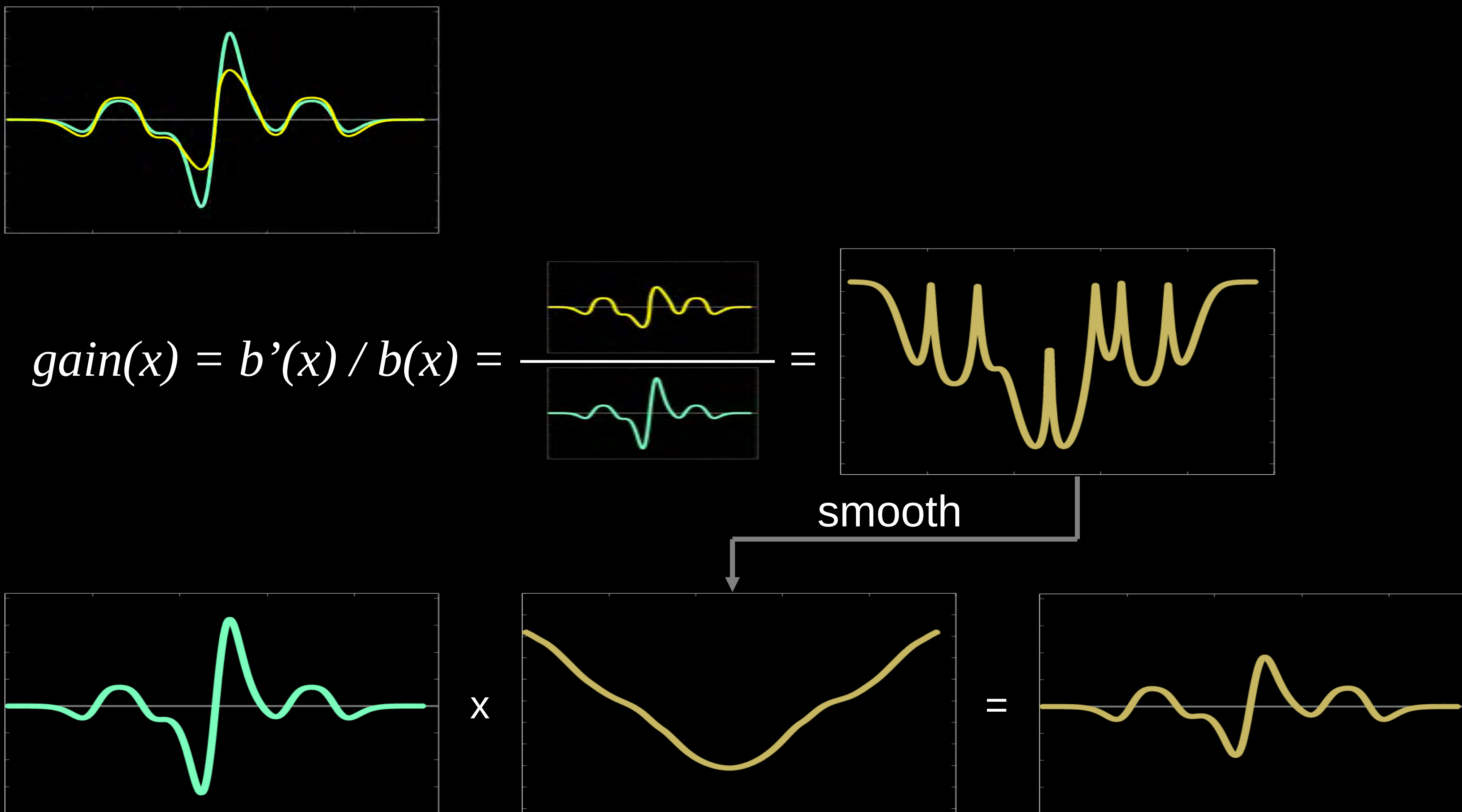

Choice of filters:
Wavelets, QMFs, Laplacian, etc.
They all worked.

# Point Nonlinearity on Subbands



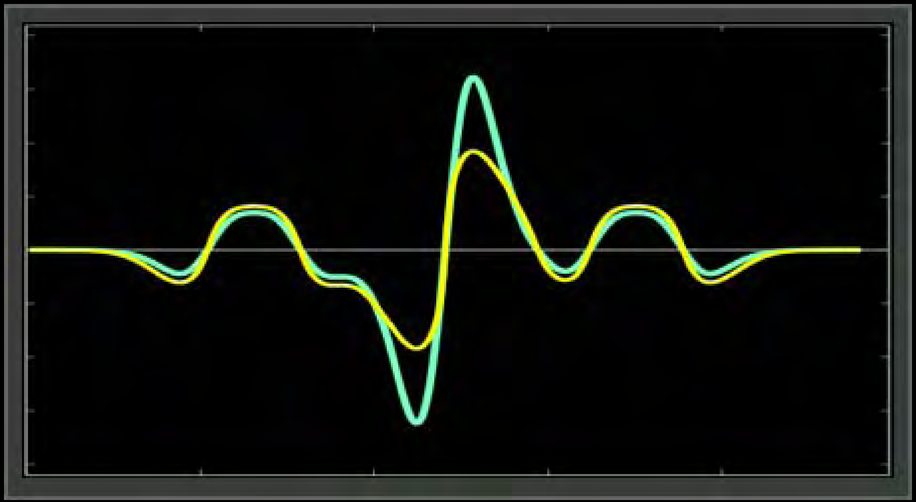

Problem: Nonlinear distortion.

# Smooth Gain Control



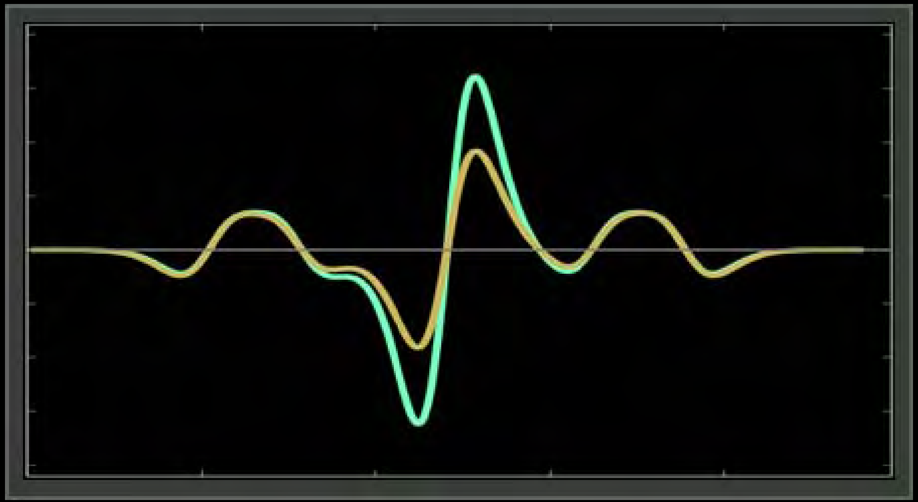
# Smooth Gain Control Reduces Distortion

Point nonlinearity



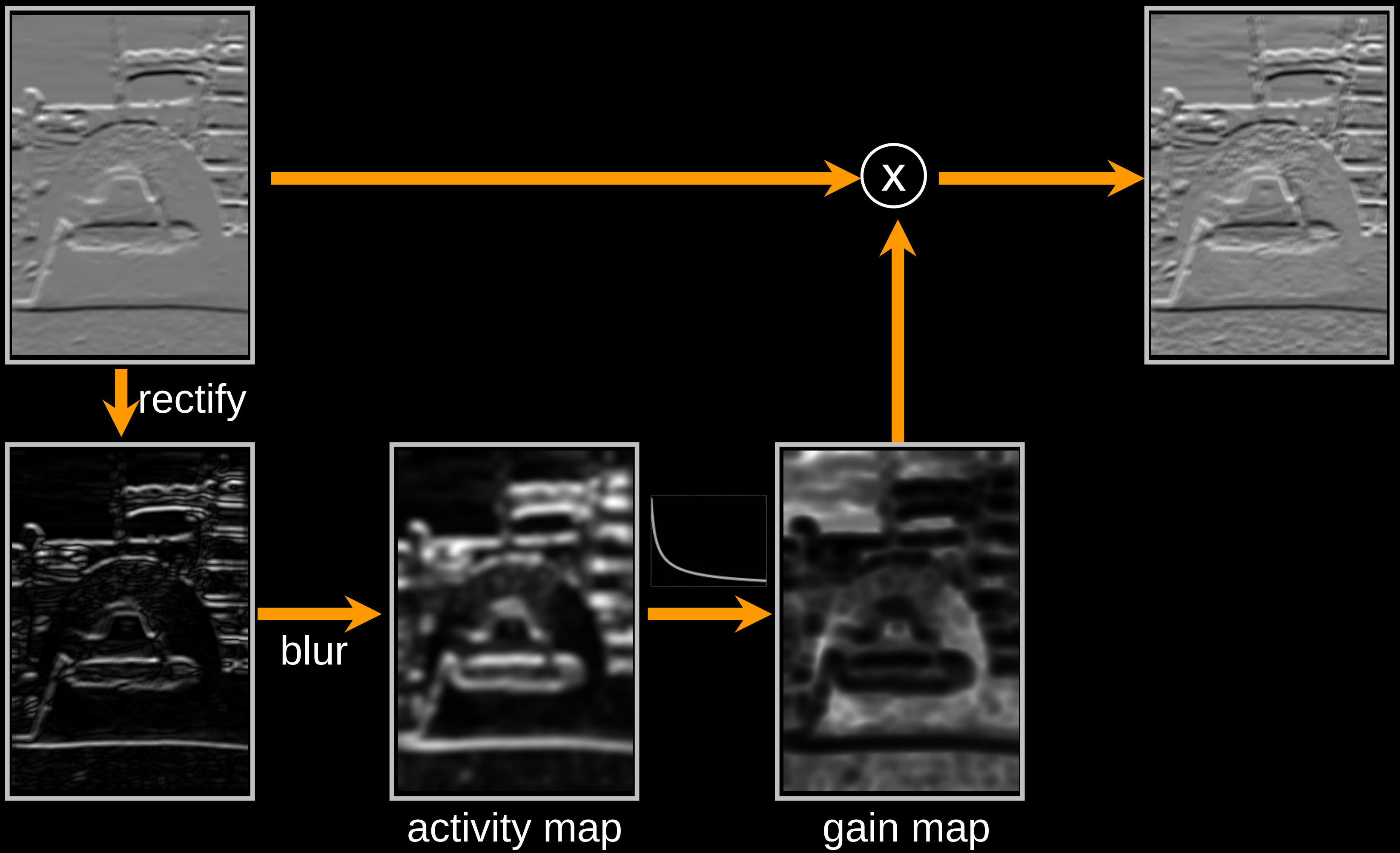
Distorted.

Smooth gain control



Distortion reduced.

# Smooth Gain Control on Subbands



Ours

Fattal et al. 2002

Reinhard et al. 2002

Durand & Dorsey 2002

# Reinhard et al. 2002

Ours

Fattal et al. 2002

Reinhard et al. 2002

Durand & Dorsey 2002

Ours

Fattal et al. 2002

Reinhard et al. 2002

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Ours

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