# Photographic Technology

PhotoTechEDU series

## Lecture 04: Feb. 14, 2007

Resolution Isn't Everything:

Contrast, MTF, Flare, and Noise

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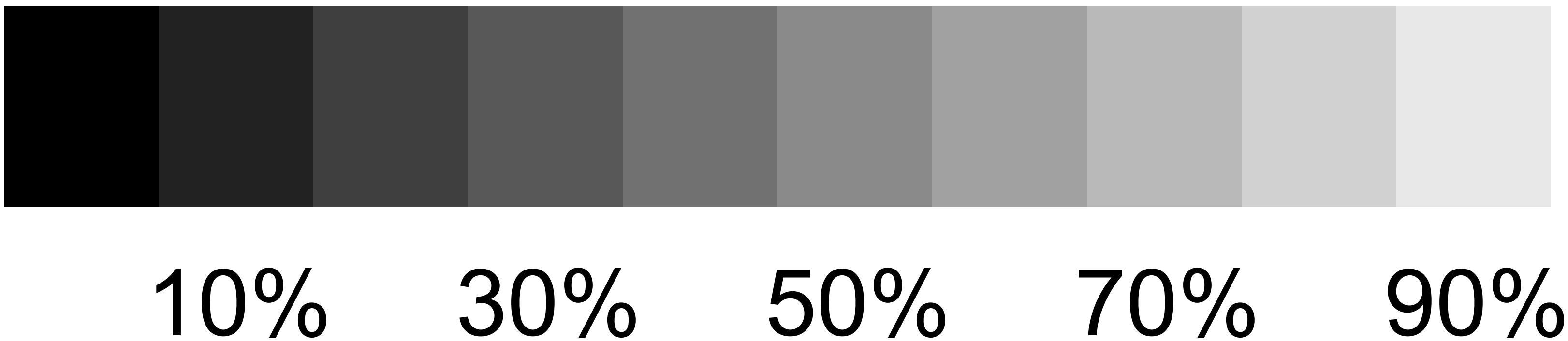
Google Research

# Outline

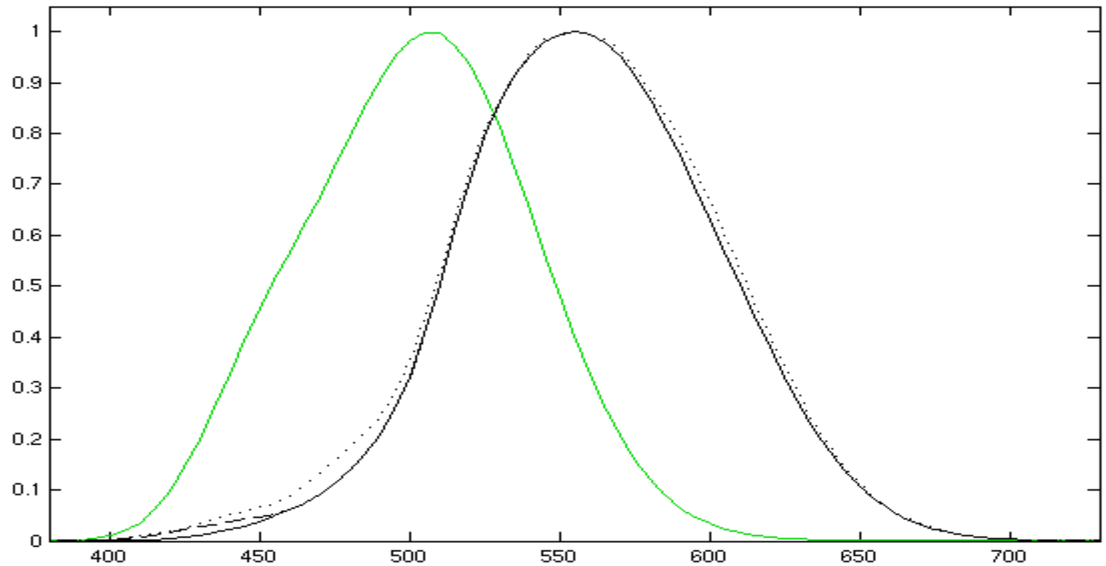
- Luminosity
- Contrast
- Modulation Transfer Function (MTF)
- Flare
- Noise

# Luminance



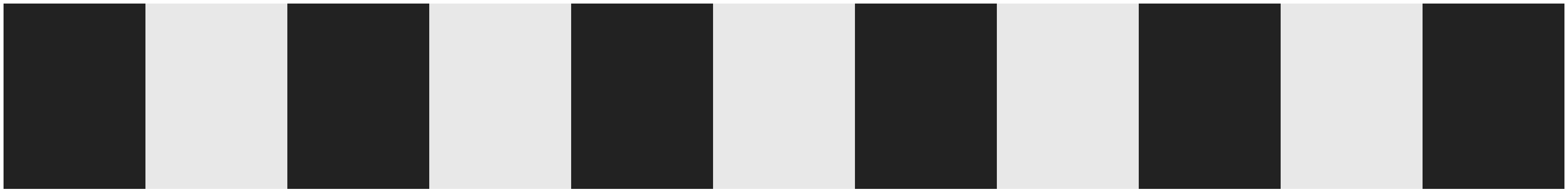

- Luminance is light power from a surface per solid angle

# Luminosity




- Luminosity is weighted sum of spectral power, between 400 and 700 nm
- Peak is 683 lumens/watt at 555 nm

# Contrast



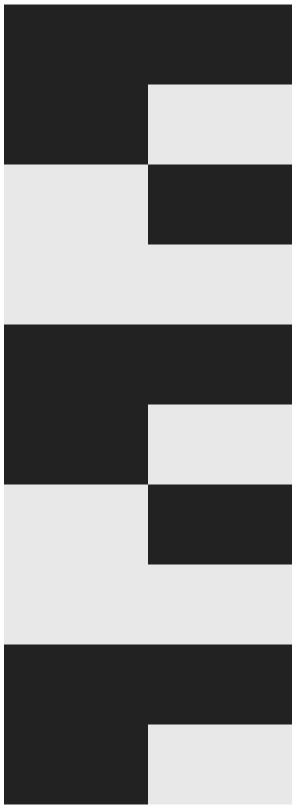
- 90% vs 10% luminosity

# Modulation Transfer Function


90%-10% = 80%

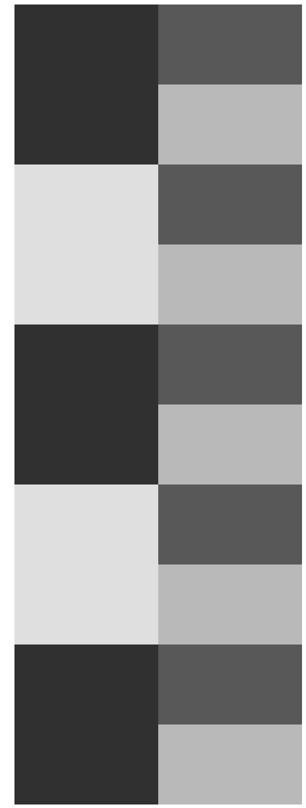
70%-30% = 40%

# Modulation Transfer Function



MTF@20 lp/mm=90%

MTF@40 lp/mm=50%



90%-10% = 80%

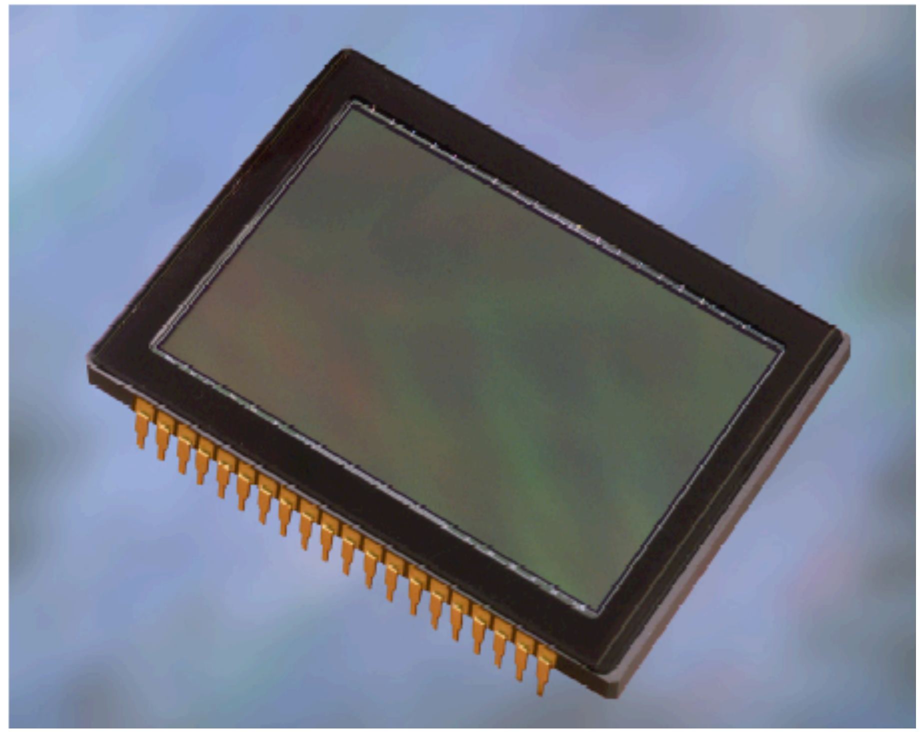
86%-14% = 72%

70%-30% = 40%

# Line pairs per mm

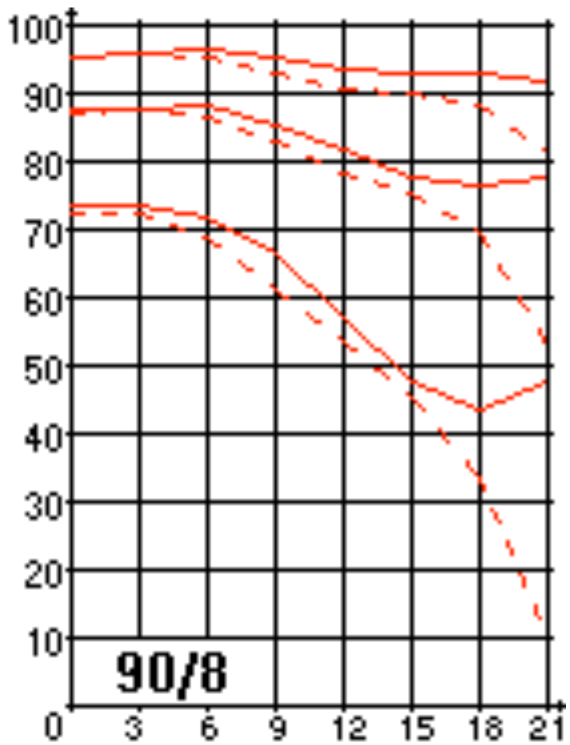
- Full Frame CCD is 36 mm x 24 mm
- Pixels are 6 to 9 microns on a side
- Nyquist frequency is 55 to 83 lp/mm
- Bayer color filter

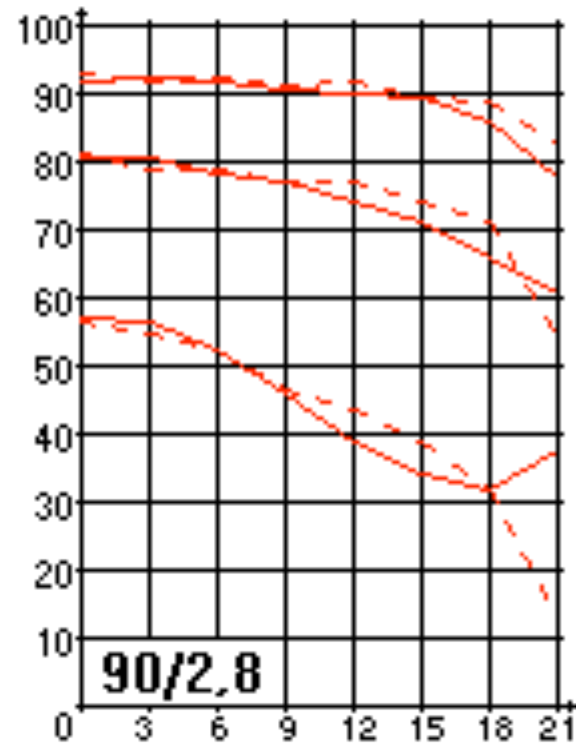
  => 30 to 45 lp/mm



# Measured MTF

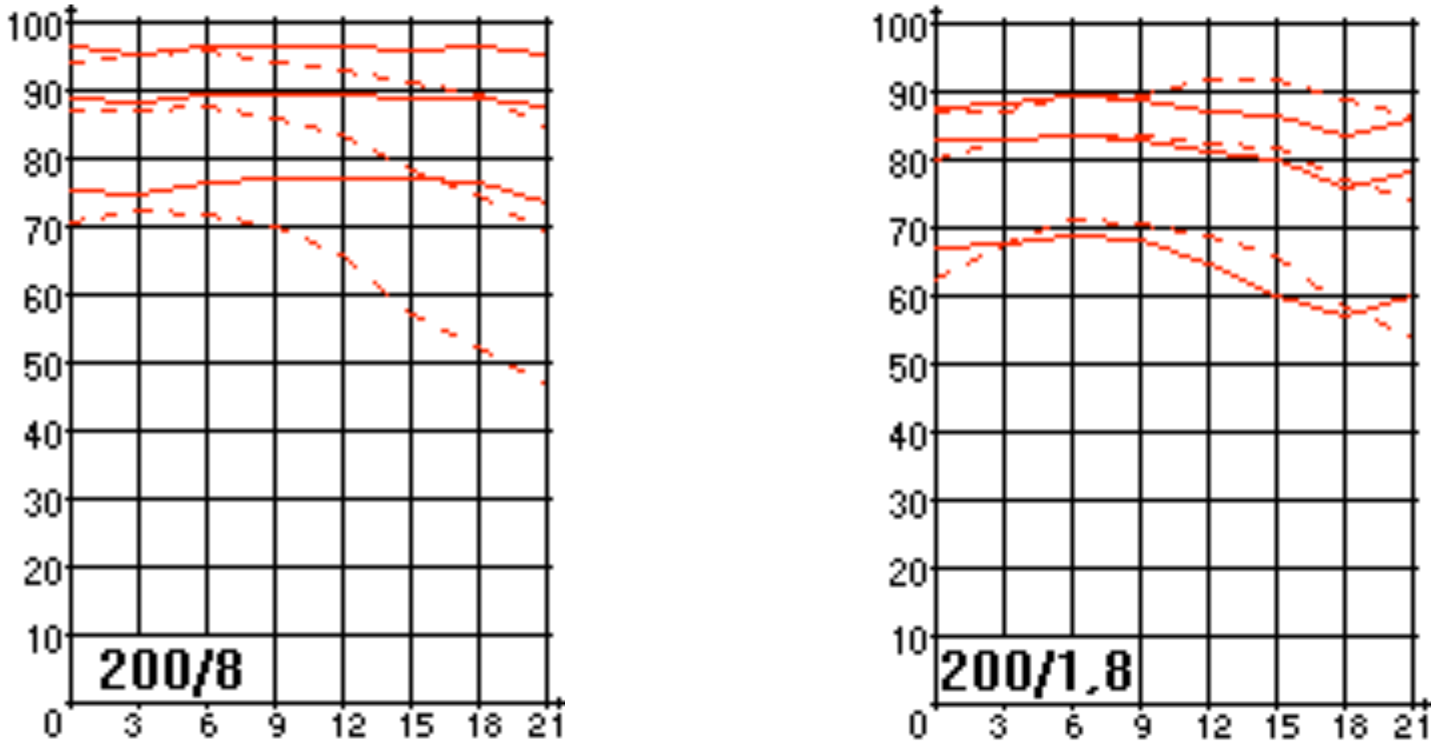
## Tamron 90mm/2.8: $489



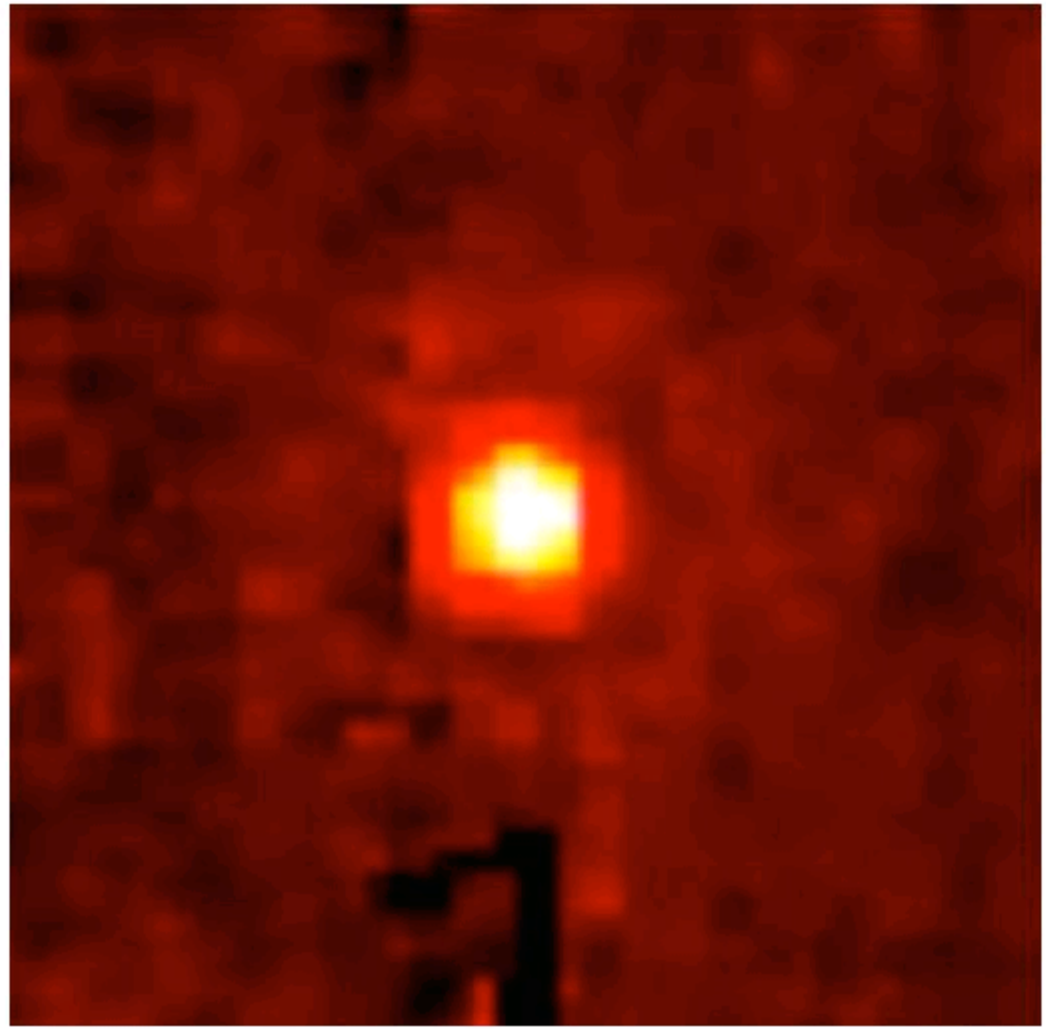
# Measured MTF

## Canon 200mm/1.8 L: $4600



# Point Spread Function

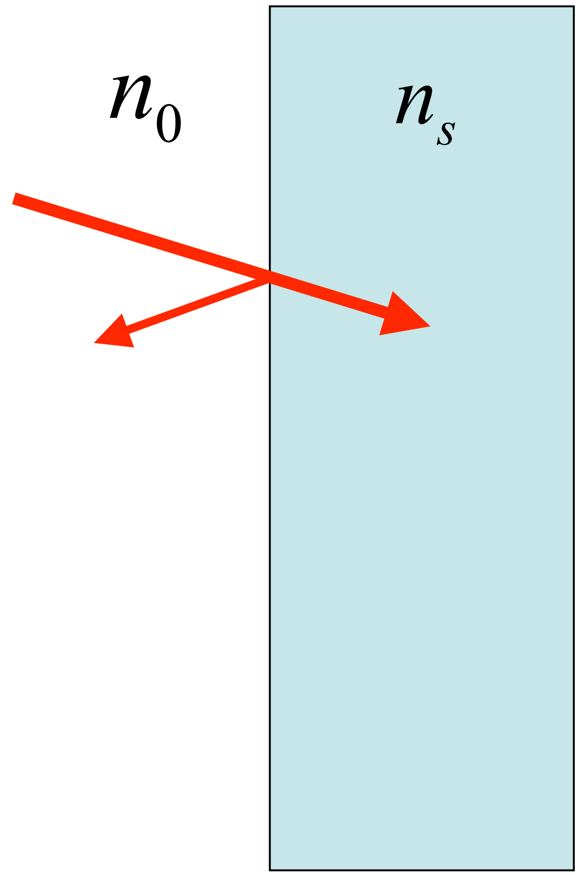
- PSF is image created of point source
- MTF is Fourier transform of PSF
- Aberrations and Flare



# Flare

Light reflects off refractive index changes

$$R = \left( \frac{n_0 - n_s}{n_0 + n_s} \right)^2 = 4\%$$



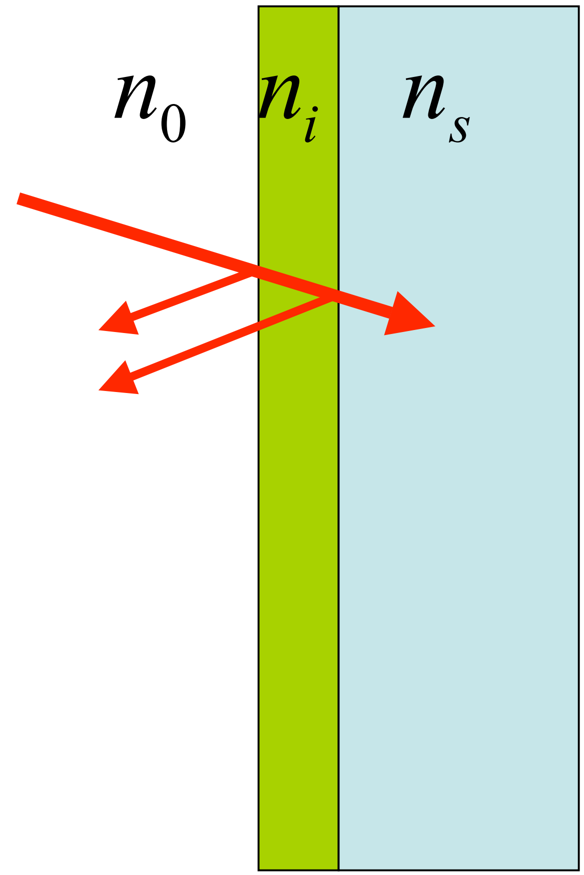

This would make multi-element lenses impractical…

# Anti-reflective Coatings

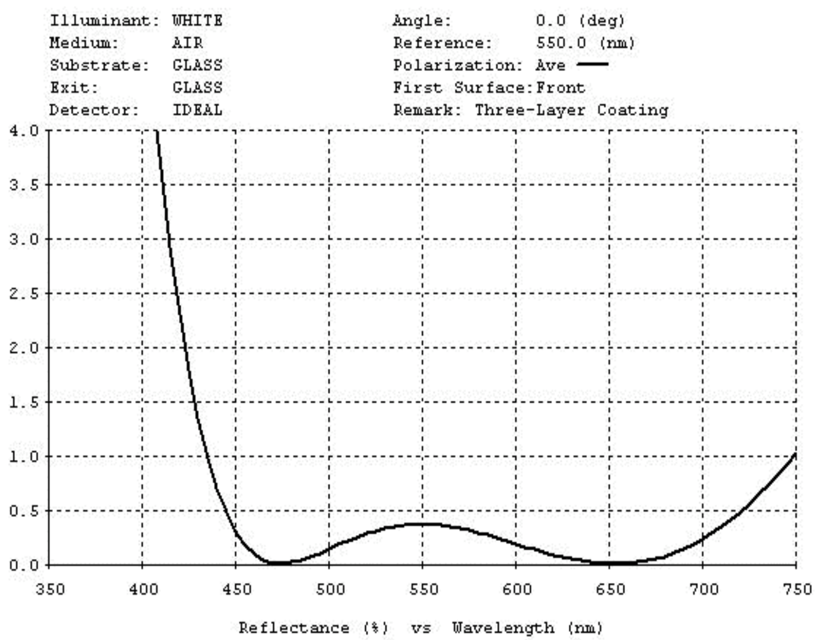
- Coat glass with quarter-wavelength $MgF_2$

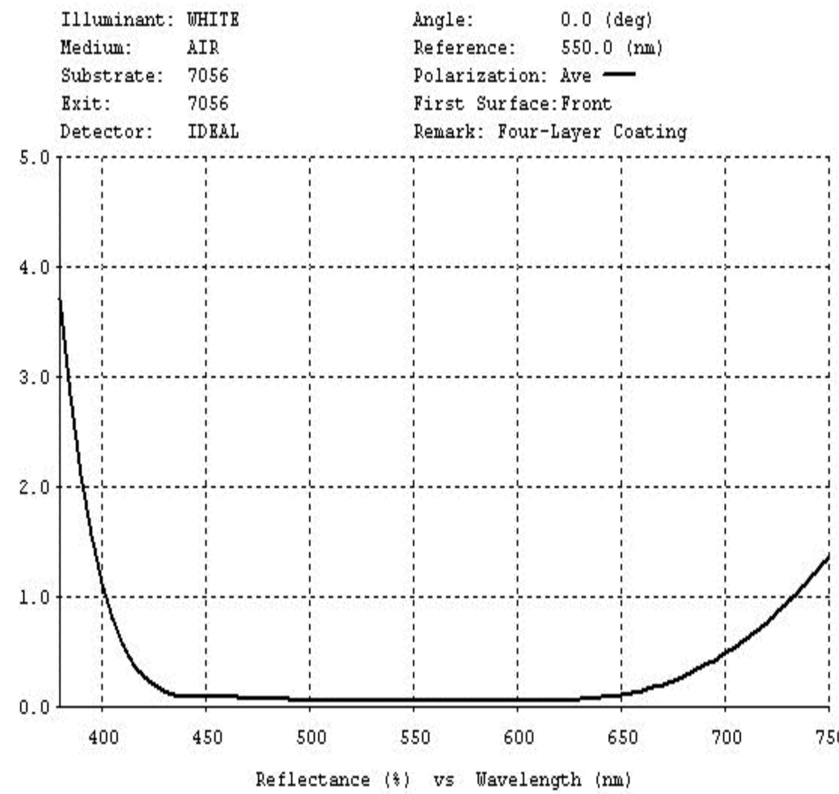
$$n_i = 1.38 \cong \sqrt{n_0 n_s} = 1.23$$

- Two reflections are smaller, almost equal in magnitude, half-wavelength separated, and mostly cancel



# BBAR Coatings

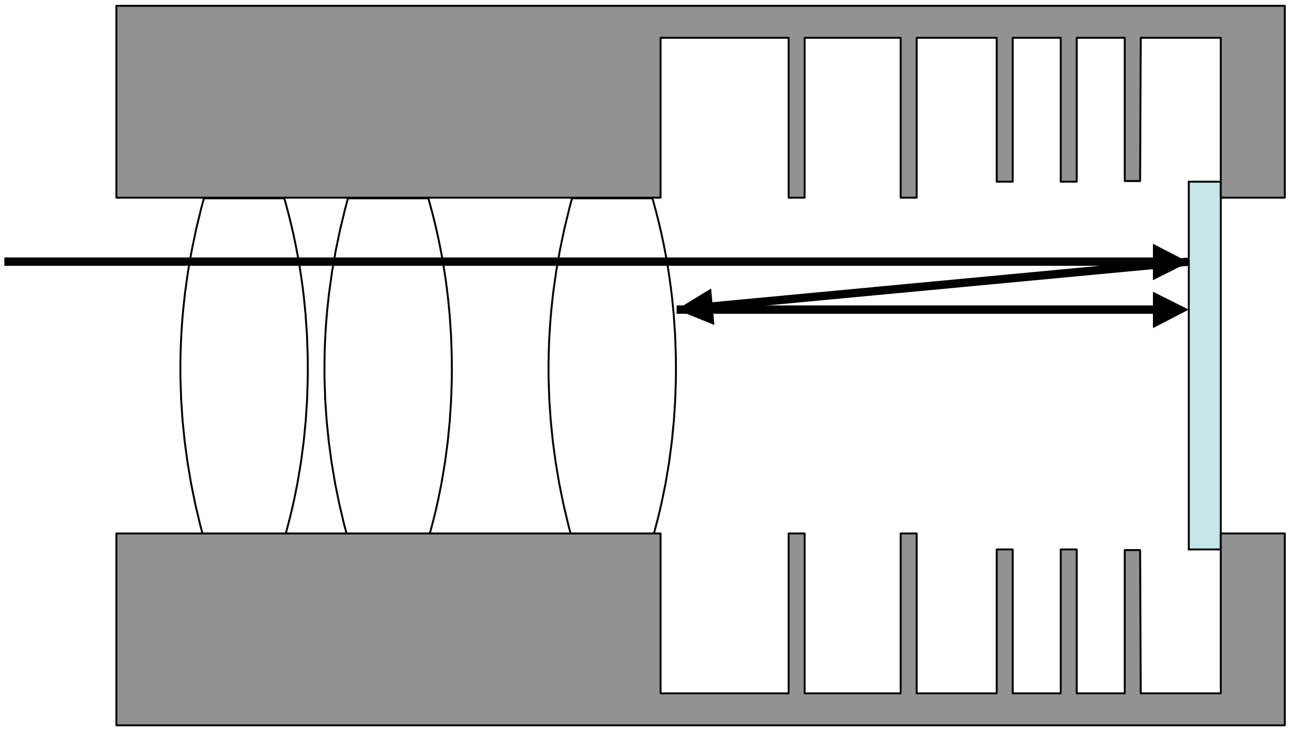



3 layer
No optimization

4 layer
Optimized

# Flare

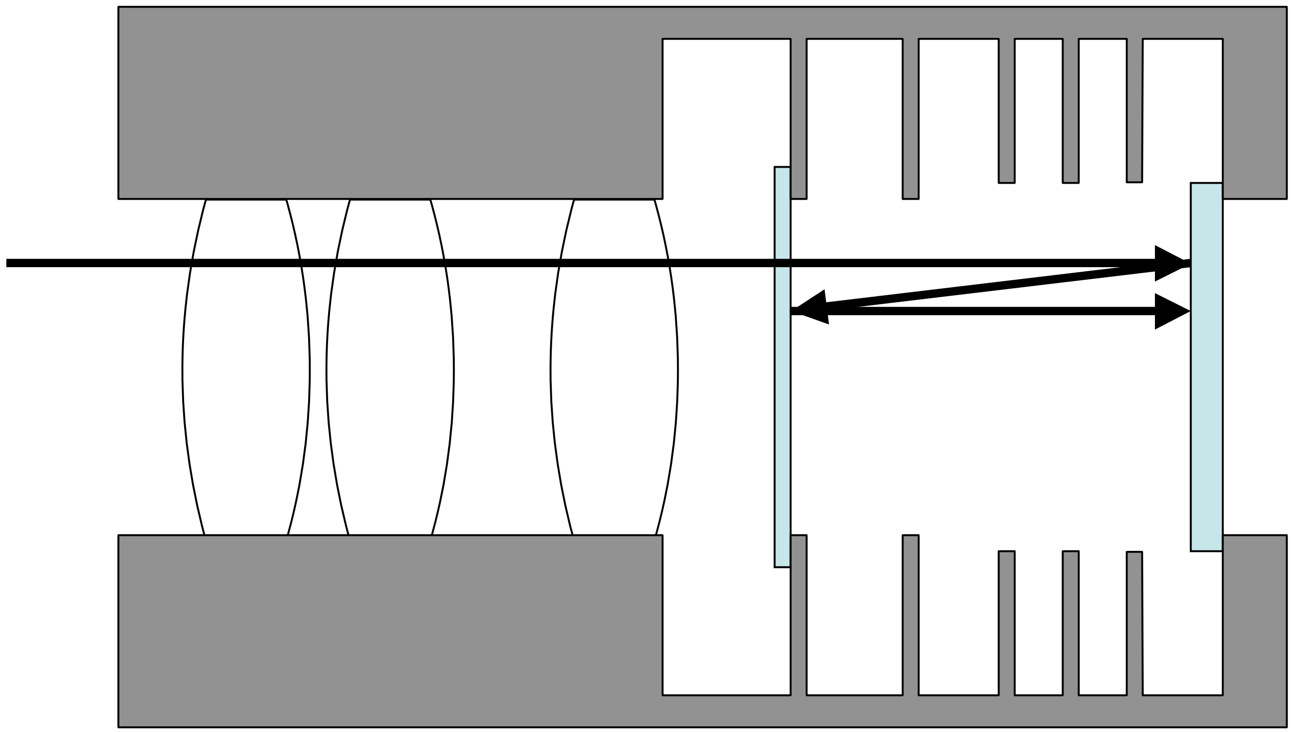


Sensor is 30x – 100x more reflective than glass surfaces

# Sensor Reflectivity

- $SiO_2$ has $n = 1.5$
- Si has $n = 3.0$
- Reflection off this interface is 11%
- Bayer filters reduce, metal increases
  - Overall reflectivity is around 10%
- No AR coatings on the active surface
  - Backside, thinned CCDs!

# Flare

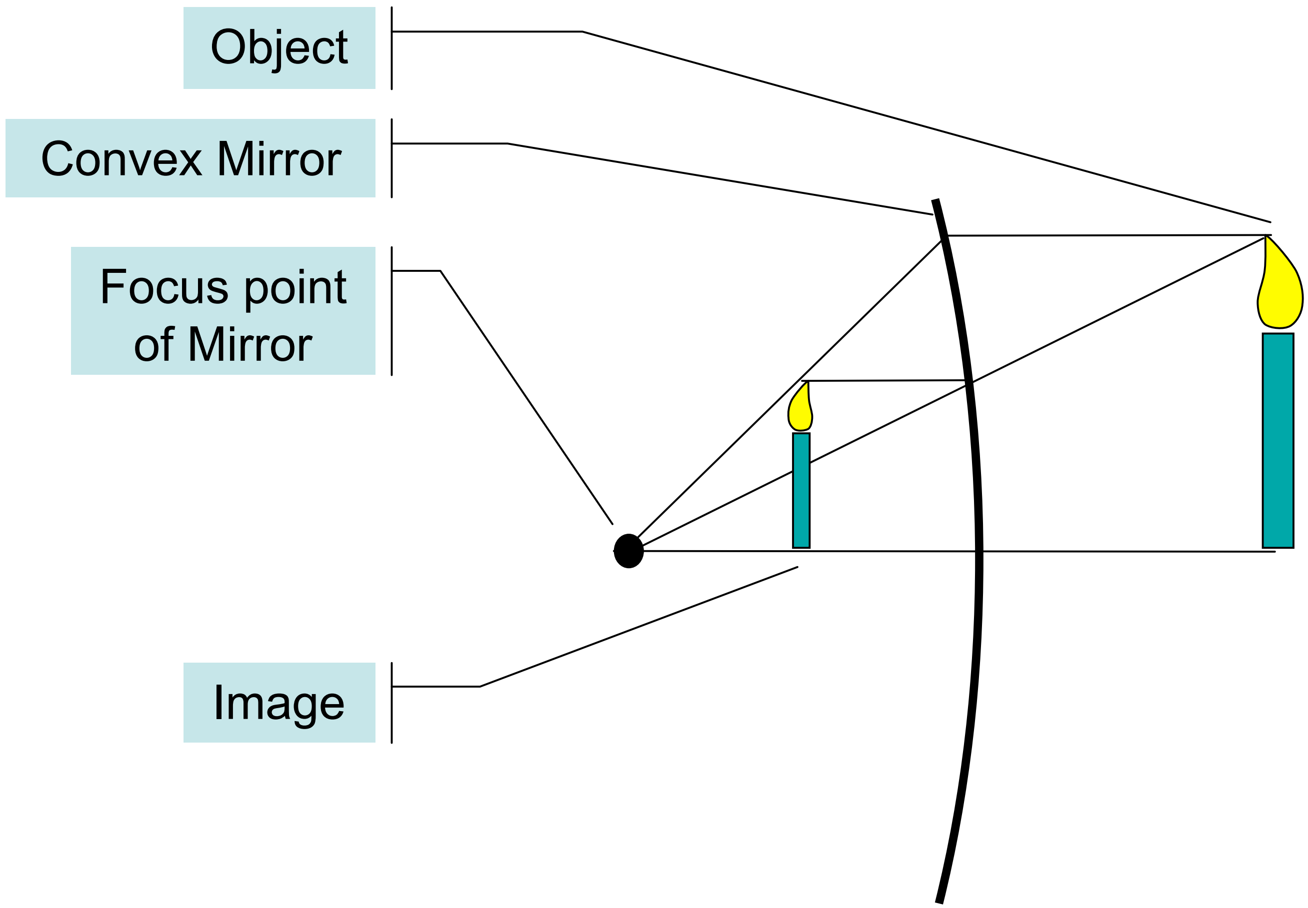


IR cut filter is 10x – 20x more reflective than glass surfaces

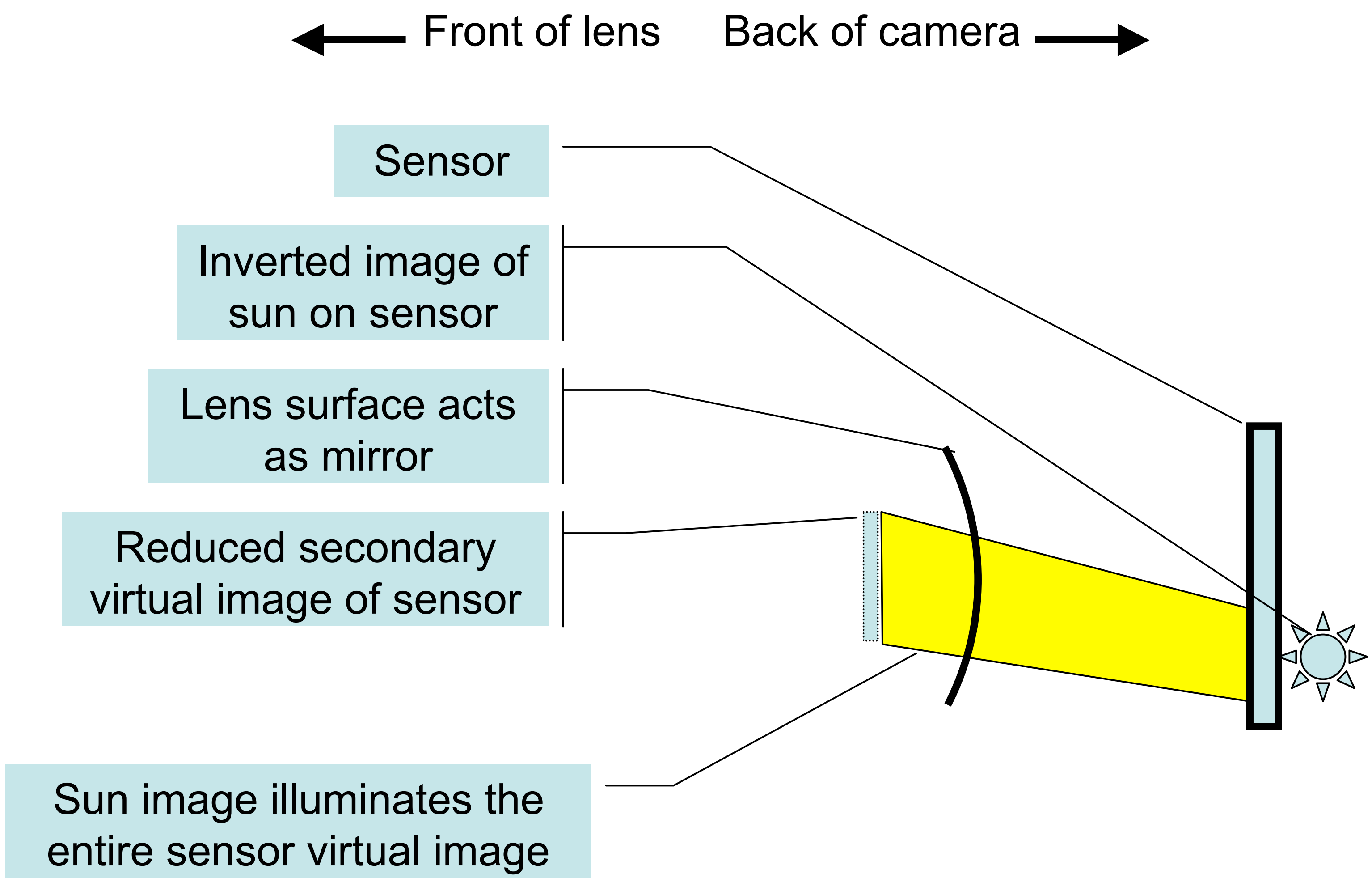
# IR Cut Filter

- In front of lens?
  - Color shift in wide angle lenses
- Between lens and sensor?
  - Strong reflection
- Internal lens elements?
  - Hard to coat

# Image formation in Convex Mirrors

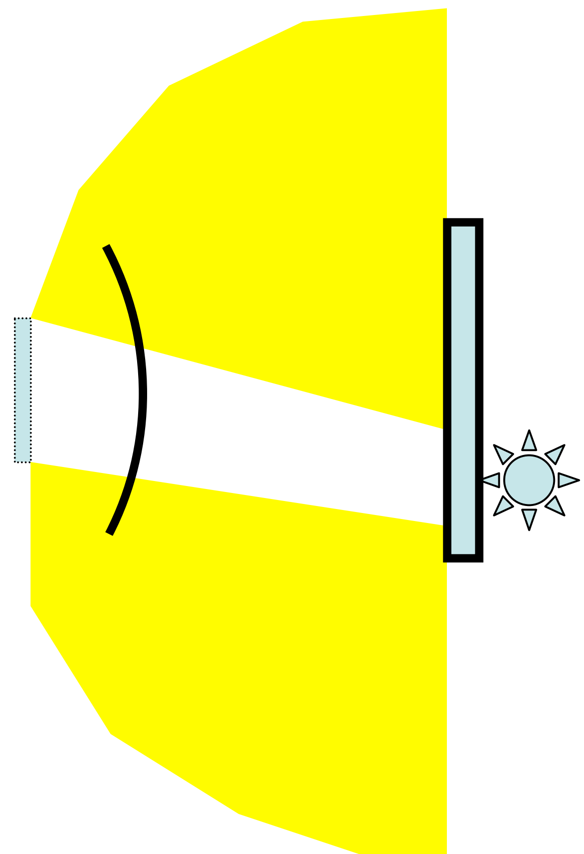


# Veiling Flare, Convex Element

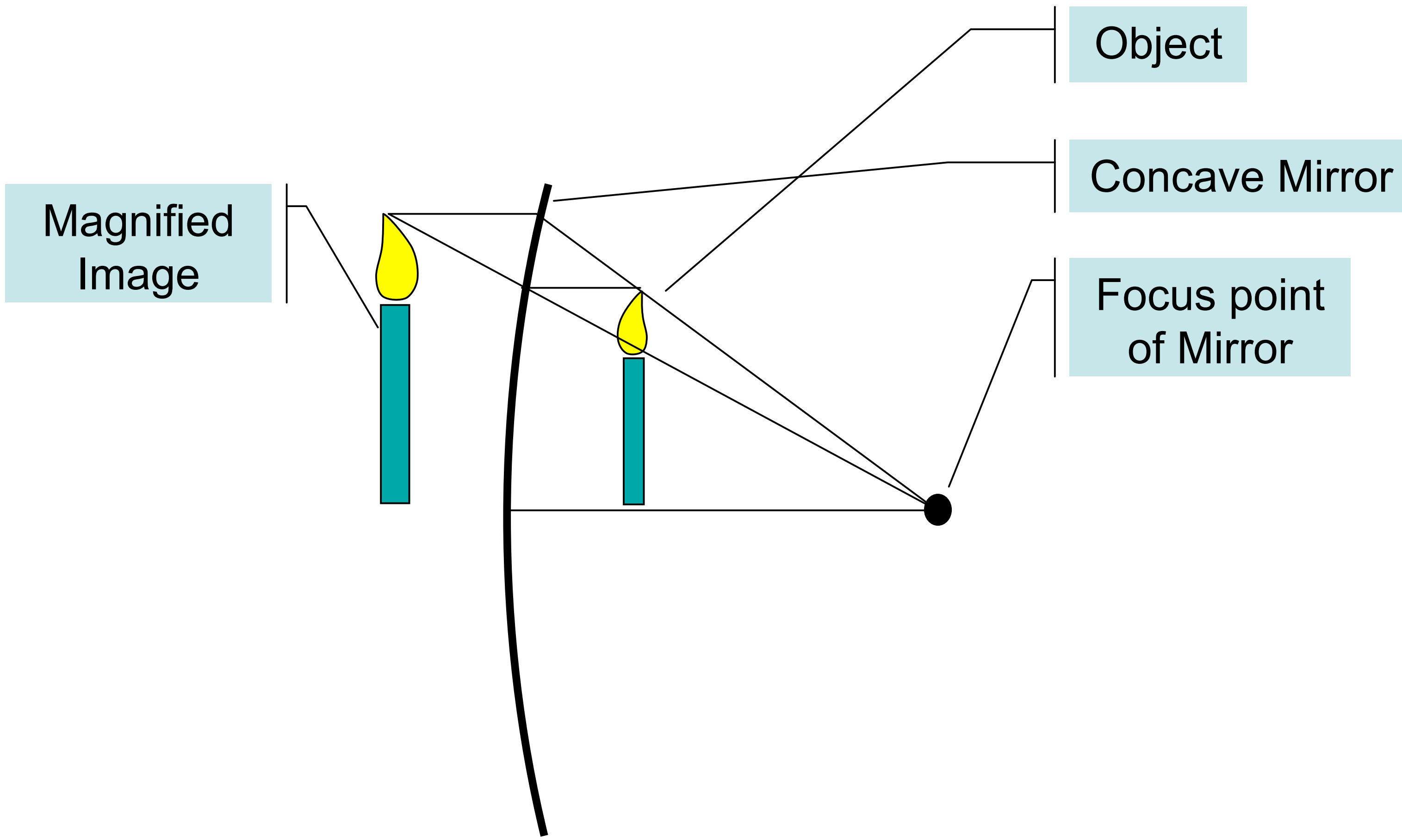


# Veiling Flare, Convex Element

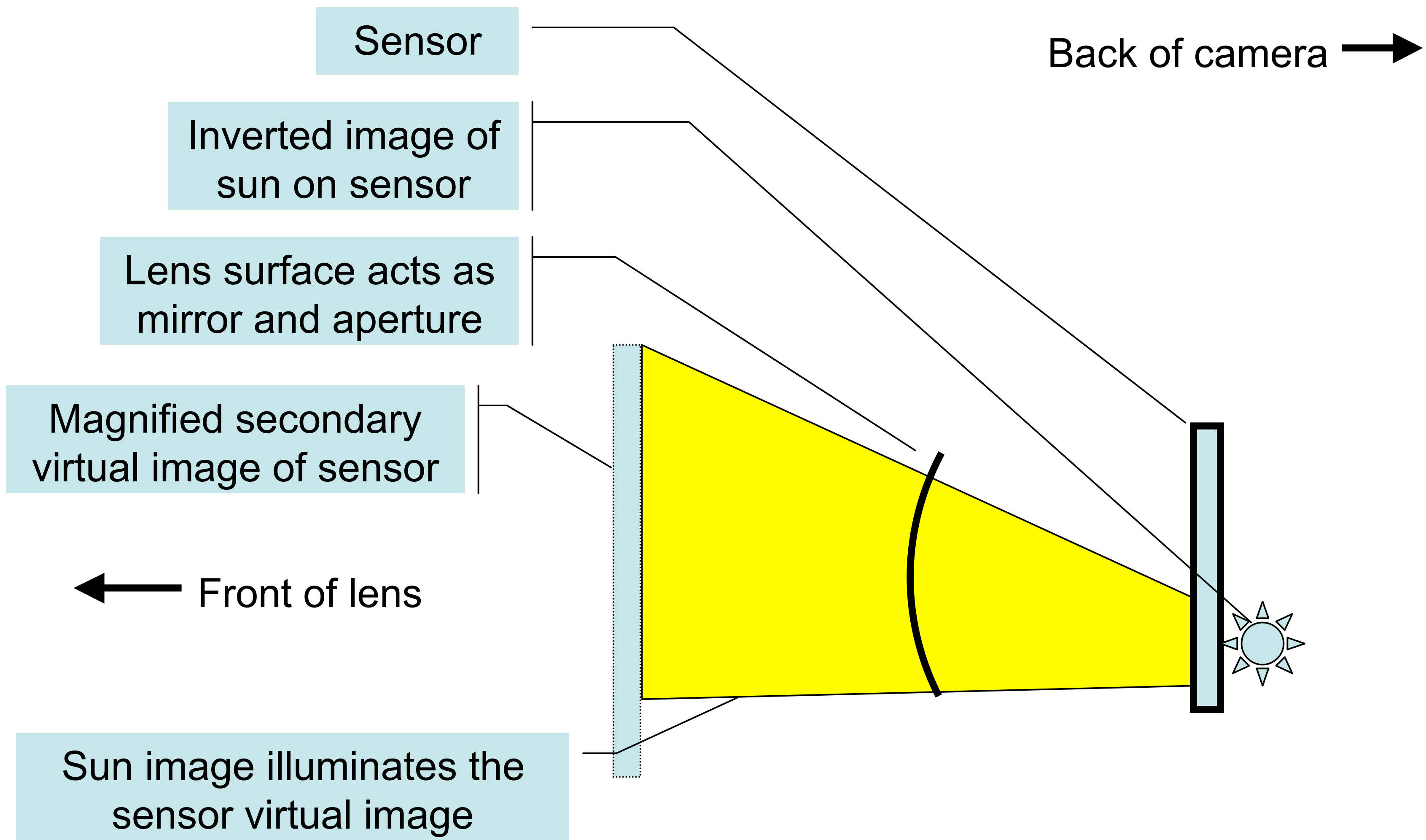
- Most light dumped into baffles



# Image formation in Concave Mirrors

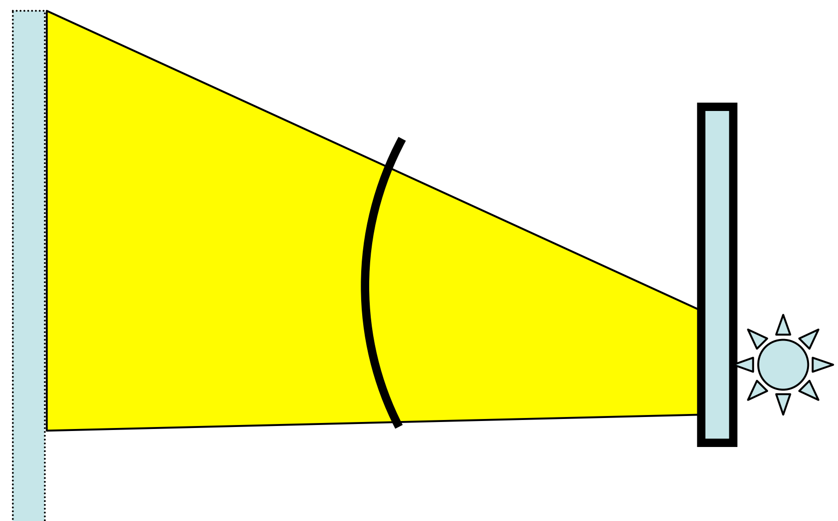


# Veiling Flare, Concave Element

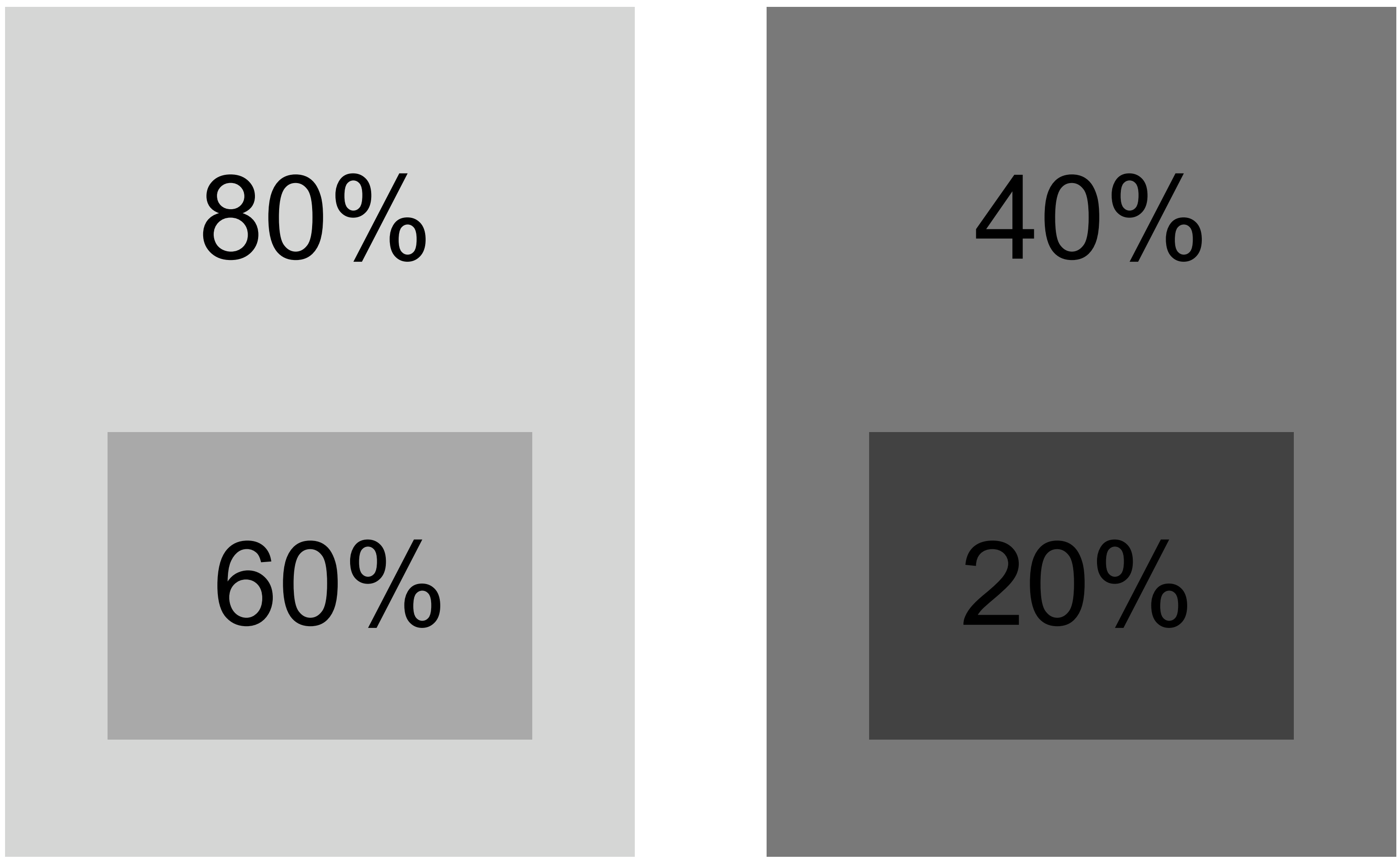


# Veiling Flare, Concave Element

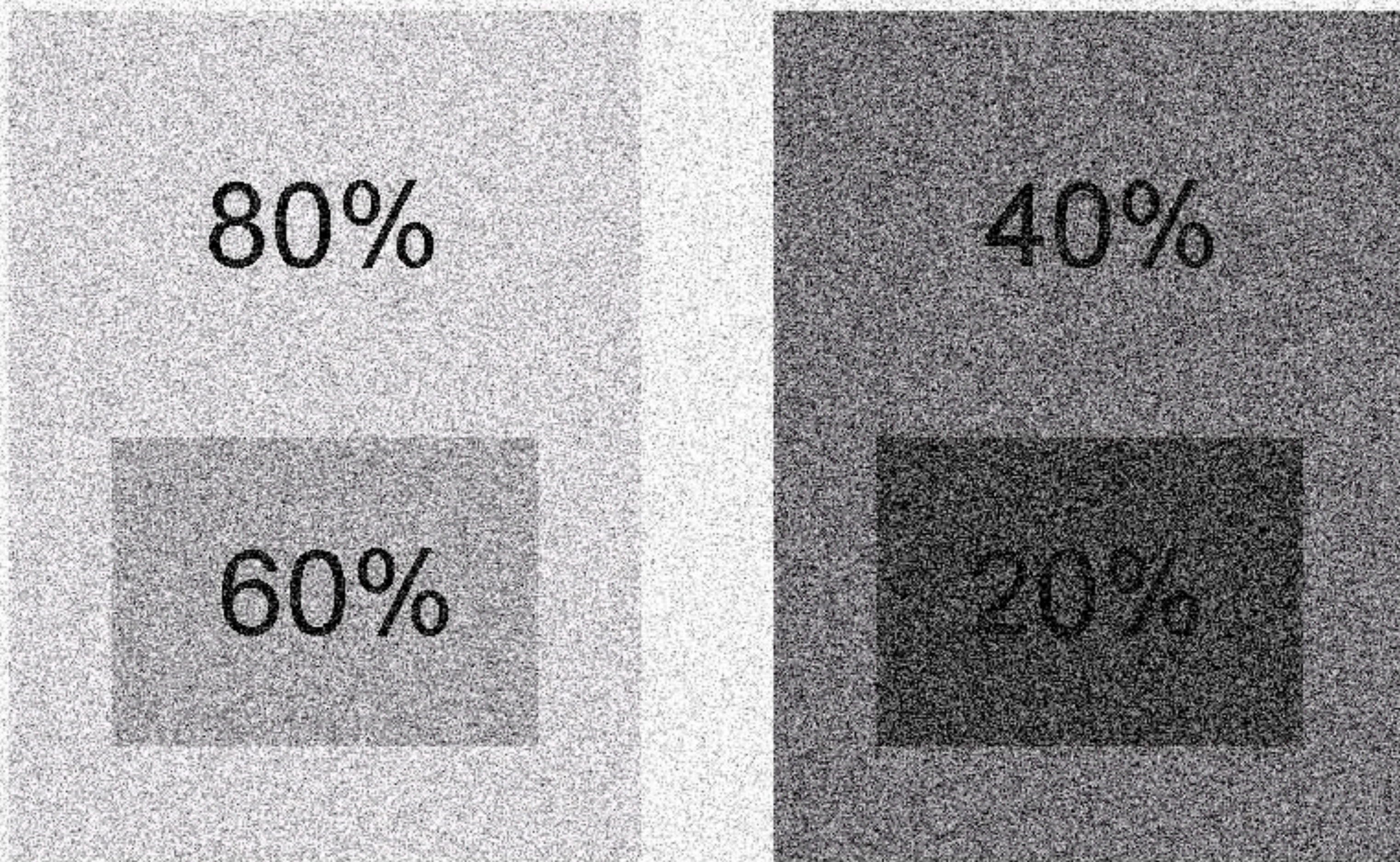
- Limited mostly by aperture of element, not size of sensor image
- ~5x worse than convex elements



# Why Do We Need Contrast?



# Noise



# Contrast versus Noise

| 18 point | 36 point | 48 point |
|---|---|---|
| The quick brown fox | The quick brown fox | The quick brown fox |
| The quick brown fox | The quick brown fox | The quick brown fox |
| The quick brown fox | The quick brown fox | The quick brown fox |

Small text needs $$\frac{RMS(contrast)}{RMS(noise)} \geq 4$$

# Noise Budget

Black text on white background:

| | |
|---|---|
| Scene Contrast | 80% of white response |
| Lens MTF | 50% |
| Required SNR | 4:1 |
| Noise | <10% of white response |

# Photon Shot Noise

- Dominant noise source in modern sensors
- Rises as sqrt(electrons)
- SNR > 10 requires 100+ electrons
  – Sets the low-light limit
- Smaller pixels collect fewer electrons
  – Limits camera resolution