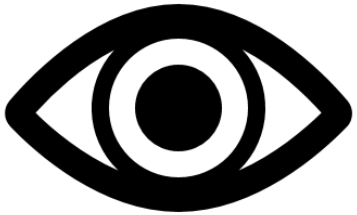


Advanced Image Processing

Cameras, Light and Color

SYDE 671

Bela Borsodi

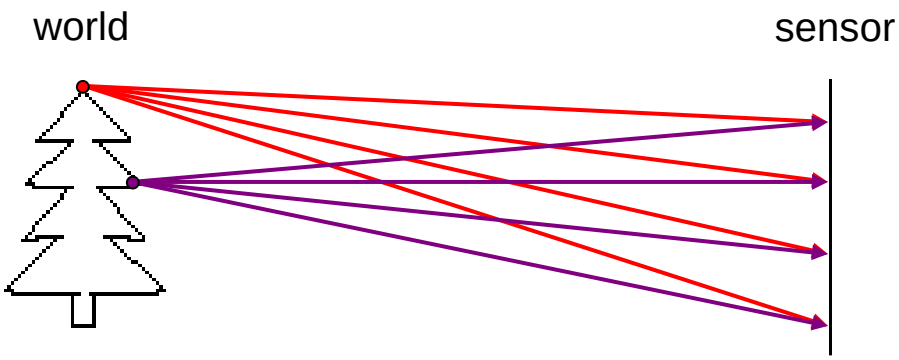
https://www.youtube.com/watch?reload=9&v=oJGN6sX5Ekg

Bela Borsodi

The Image formation process: Part 1 - Geometry

Let’s design a camera

Idea 1: Put a sensor in front of an object
Do we get a reasonable image?

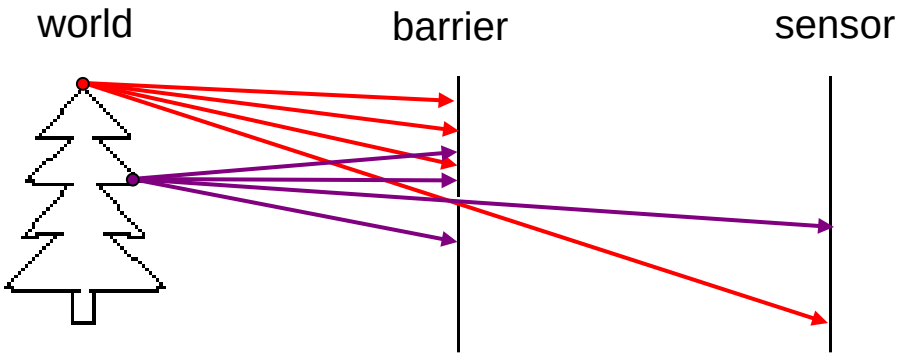


Slide source: Seitz

Let’s design a camera

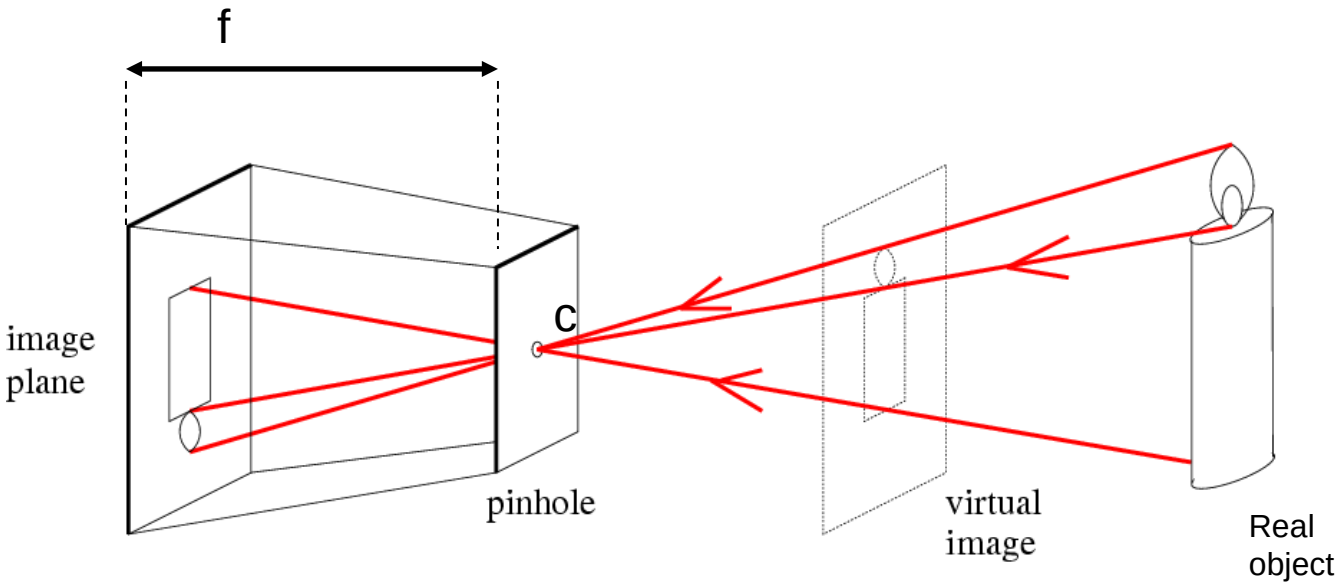
Idea 2: Add a barrier to block most rays

- Pinhole in barrier
- Only sense light from one direction.
  - Reduces blurring.
- In most cameras, this **aperture** can vary in size.



Slide source: Seitz

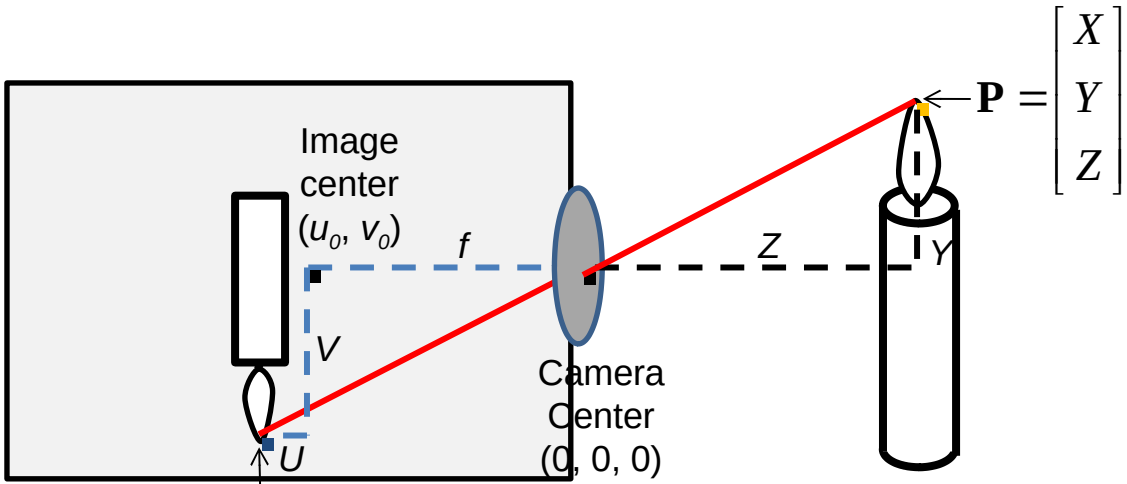
Pinhole camera model



f = Focal length
c = Optical center of the camera

Figure from Forsyth

Projection: world coordinates→image coordinates



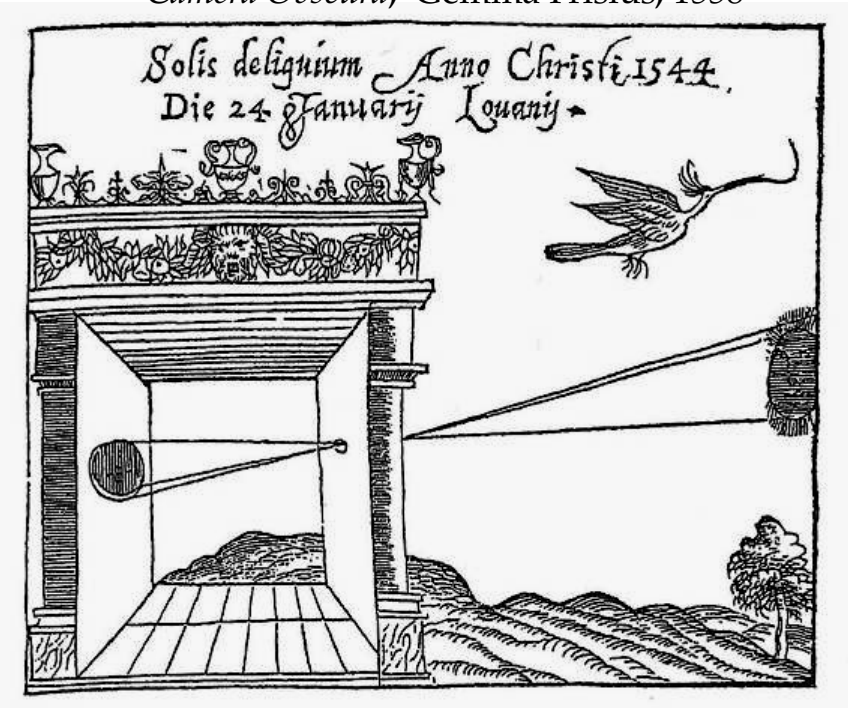
p = distance from image center

$$U = - X * \frac{f}{Z} \qquad V = - Y * \frac{f}{Z}$$

What is the effect if f and Z are equal?

Camera Obscura

Camera Obscura, Gemma Frisius, 1558



The first camera

Known to Aristotle (300 B.C.) – inverted the image of the sun by passing sunlight through a pinhole

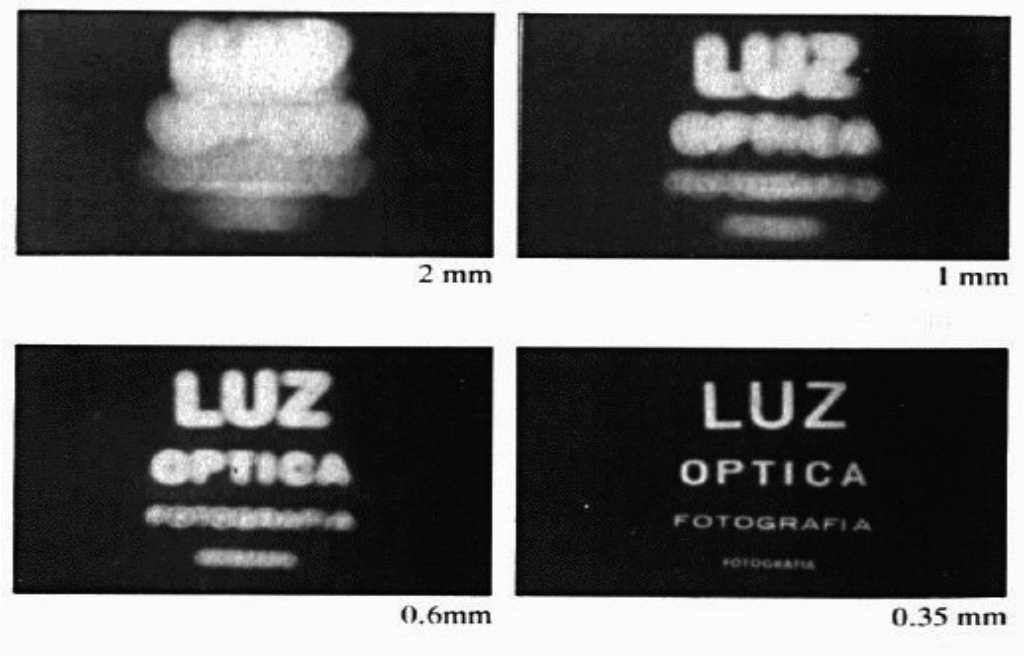
Depth of the room is the effective focal length

Home-made pinhole camera

Why so blurry?

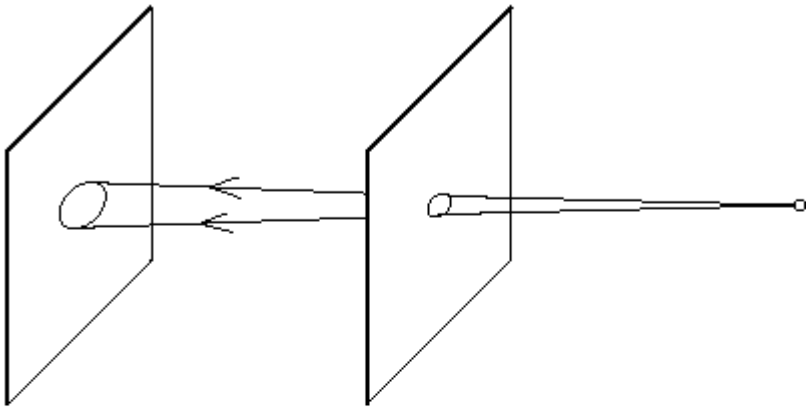
http://www.debevec.org/Pinhole/

Shrinking the aperture



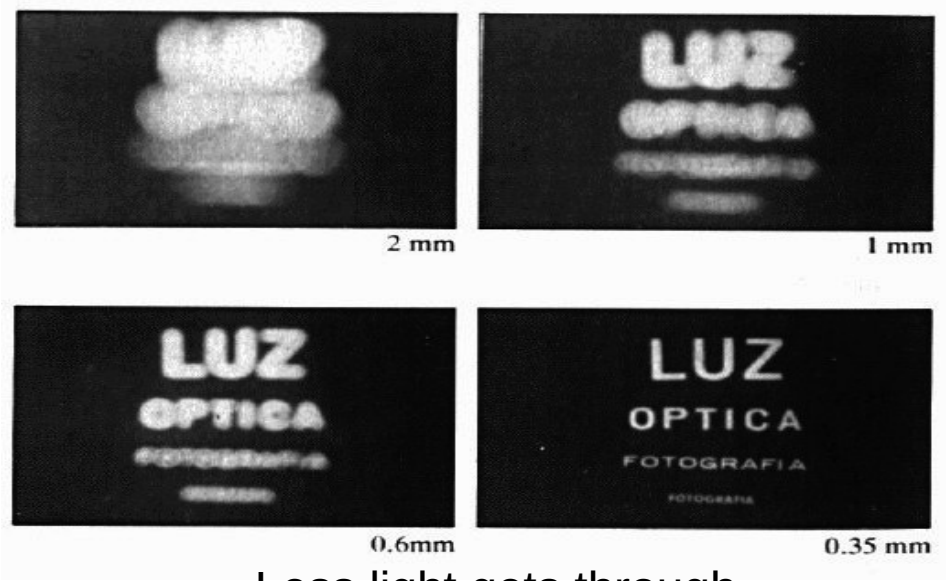
Why not make my aperture tiny?

Integrate over fewer angles



[Steve Seitz]

Shrinking the aperture



Less light gets through

Why not make the aperture as small as possible?

- Less light gets through
- Diffraction effects…

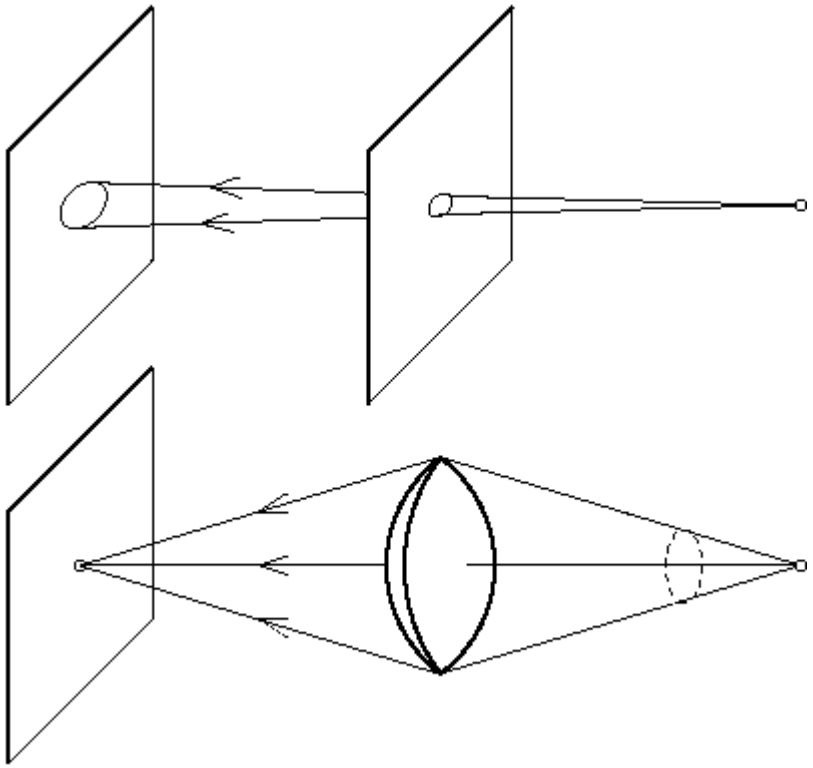
[Steve Seitz]

Shrinking the aperture - diffraction

Light diffracts as wavelength of aperture equals wavelength of light

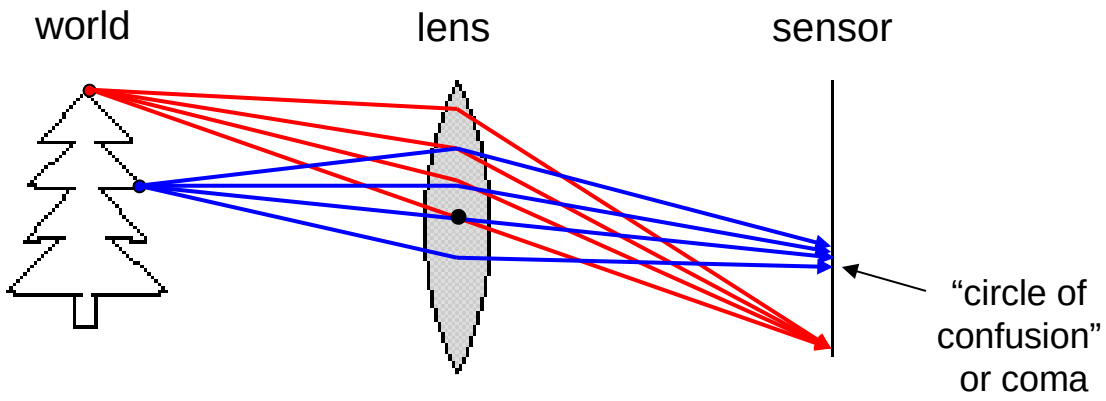
Shrinking the aperture - diffraction

The reason for lenses



Slide by Steve Seitz

Focus and Defocus

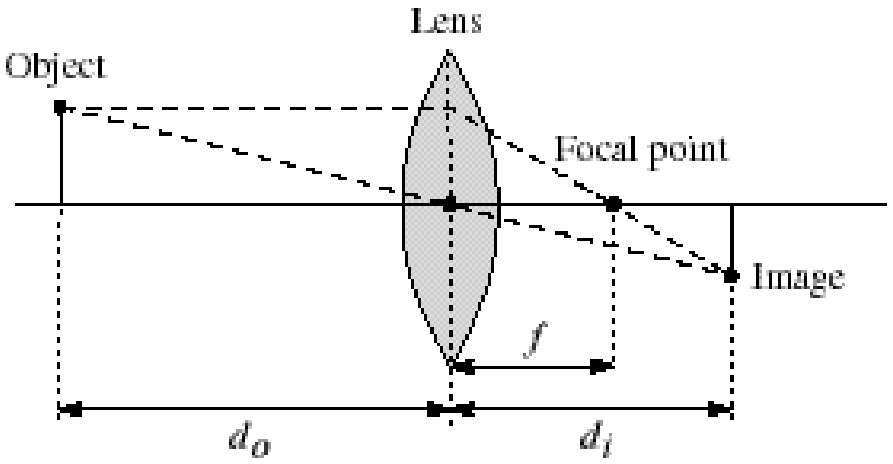


A lens focuses light onto the film

- There is a specific distance at which objects are “in focus”
- } other points project to a “circle of confusion” in the image
- Changing the shape of the lens changes this distance

Slide by Steve Seitz

Thin lenses



Thin lens equation:

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

Let's rearrange:

$$\frac{1}{f} - \frac{1}{d_i} = \frac{1}{d_o}$$

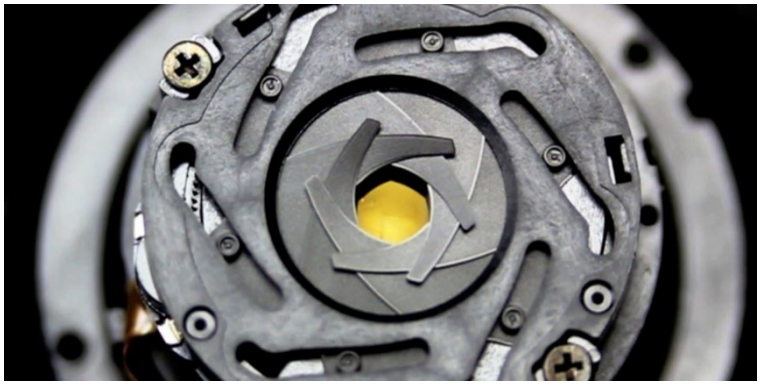
Any object point satisfying this equation is in focus

What is the shape of the focus region?

How can we change the focus region?

Thin lens applet(doesn't work without adobe flash unfortunately):
https://sites.google.com/site/marclevoylectures/applets/operation-of-a-thin-lens
(by Andrew Adams, Nora Willett, Marc Levoy)

Slide by Steve Seitz



Beyond Pinholes: Real apertures

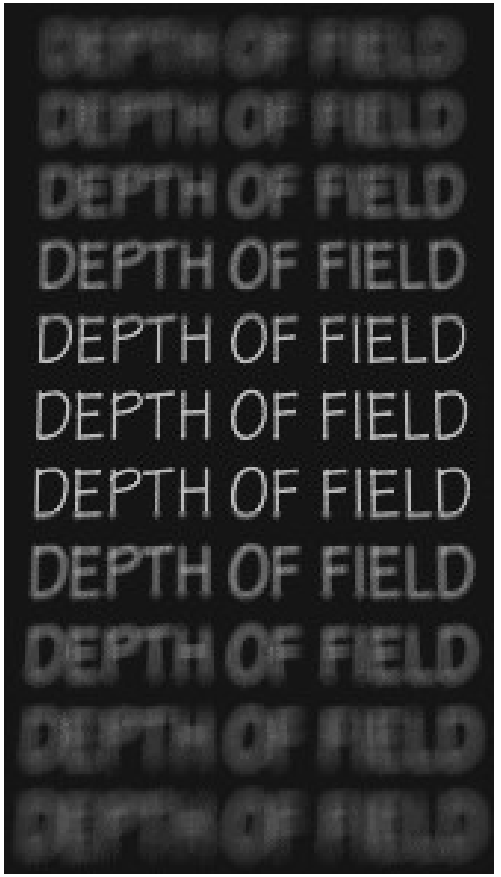
Bokeh:

[Rushif – Wikipedia]

Depth Of Field

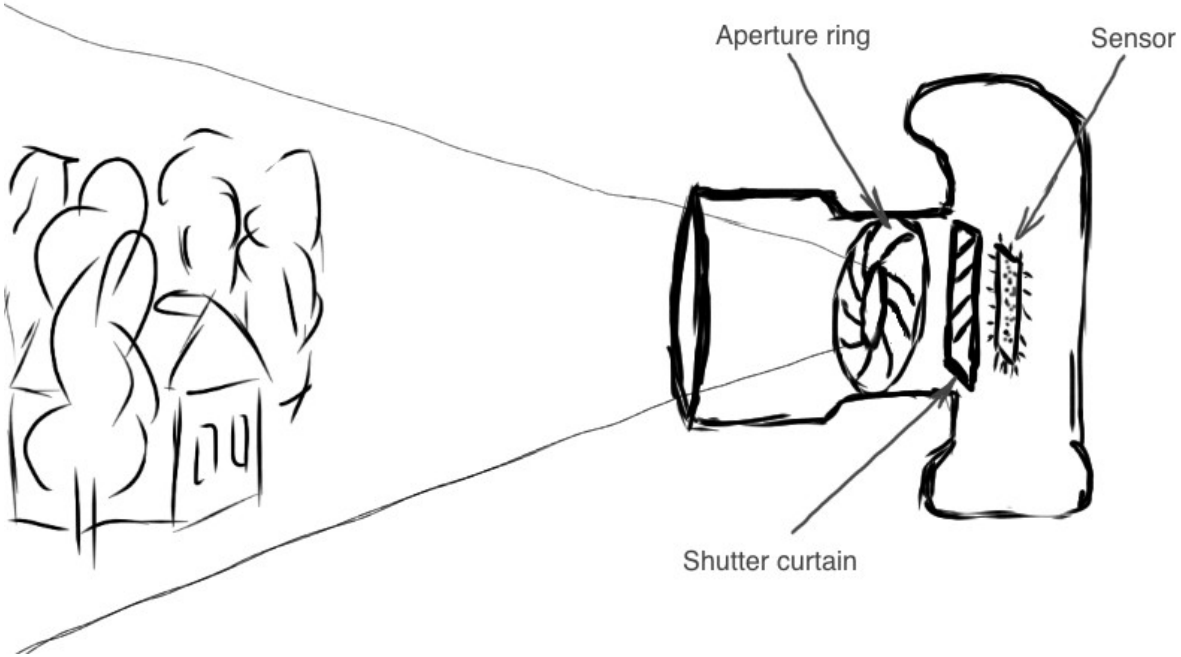
Depth of Field

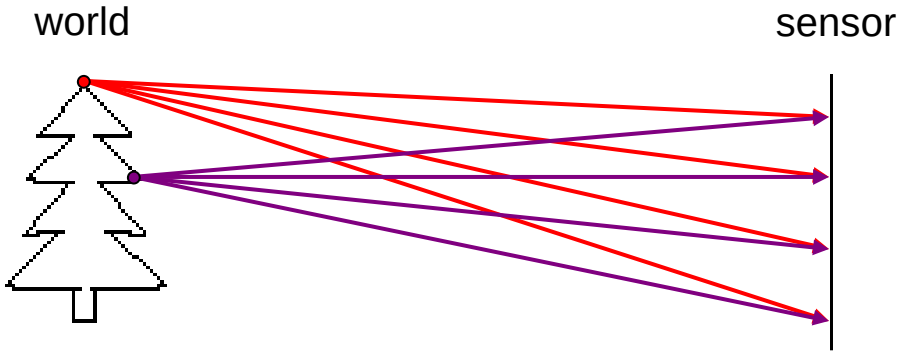
Depth of Field



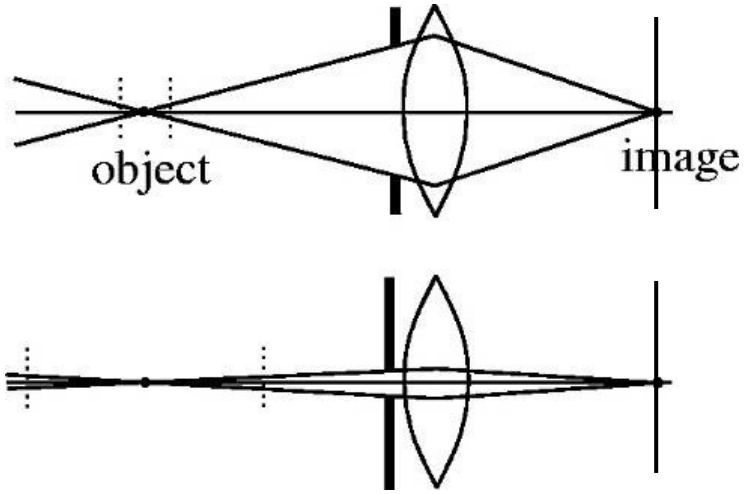
http://www.cambridgeincolour.com/tutorials/depth-of-field.htm

Camera simplified anatomy





Aperture controls Depth of Field



Changing the aperture size affects depth of field

- A smaller aperture increases the range in which the object is approximately in focus
- But small aperture reduces amount of light – need to increase exposure

Varying the aperture

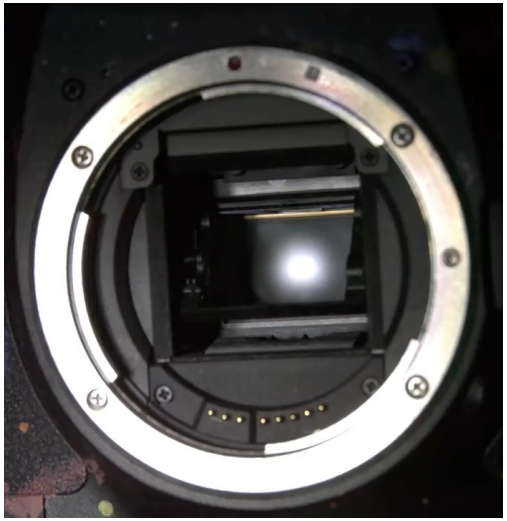
Large aperture = small DOF

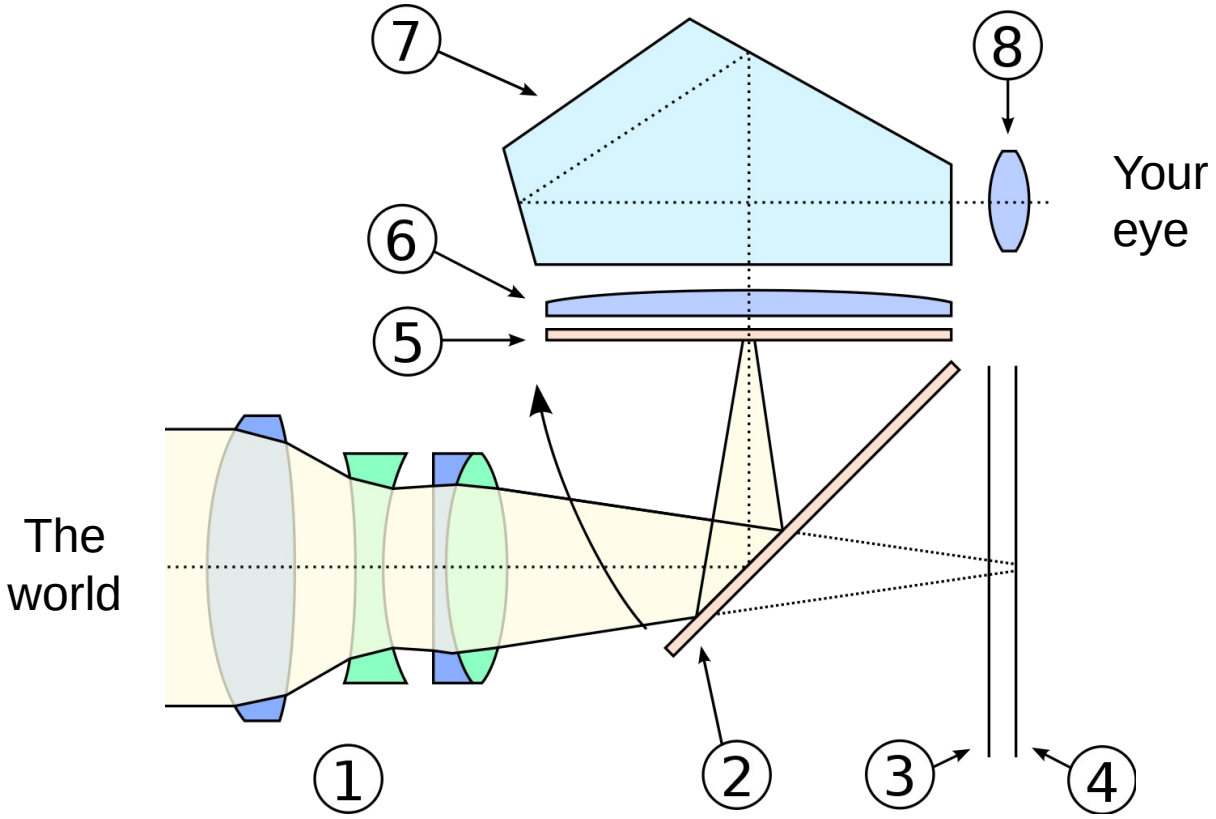
Small aperture = large DOF

DSLR – Digital Single Lens Reflex Camera

DSLR – Digital Single Lens Reflex Camera

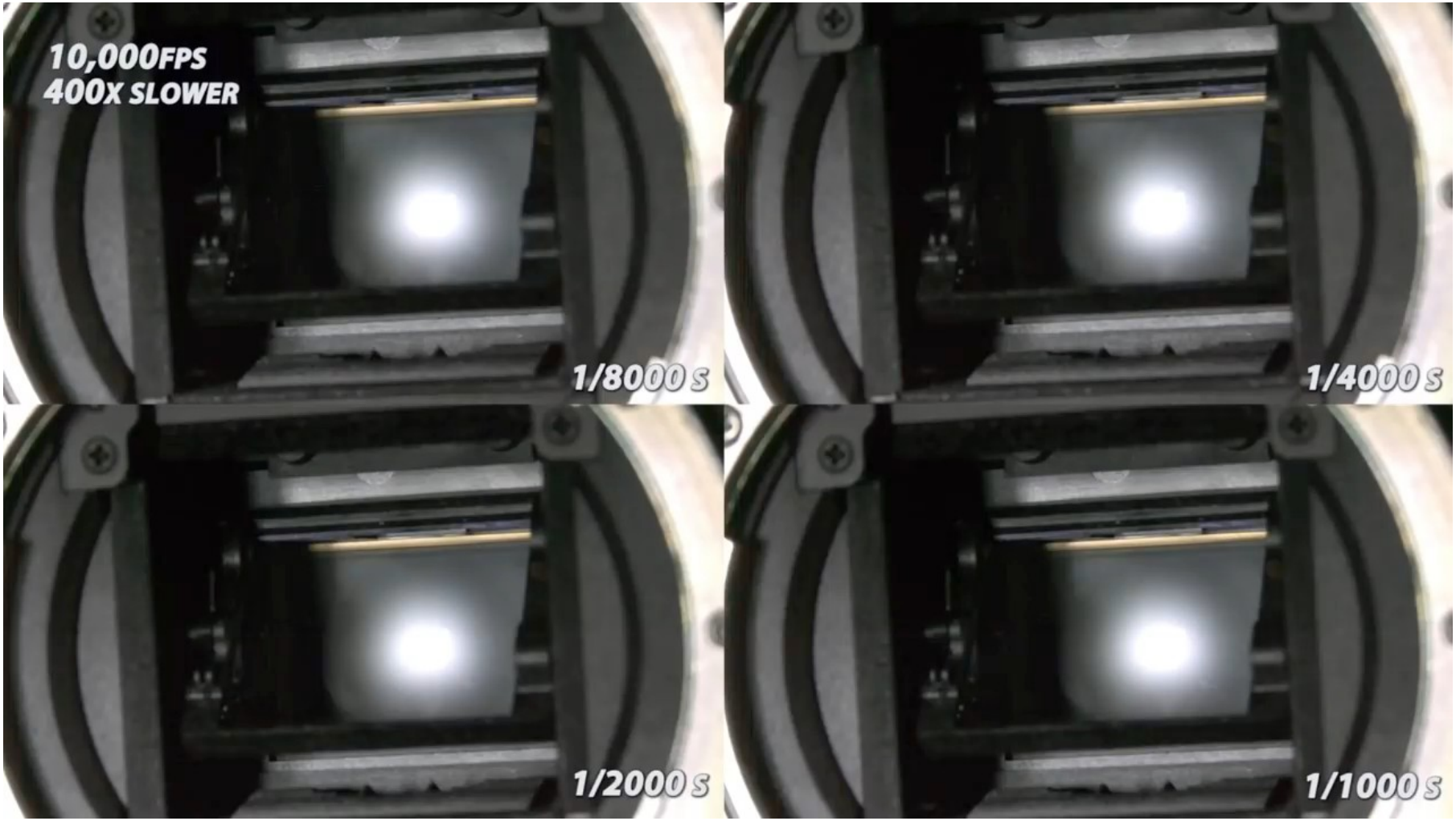
"See what the main lens sees"





1. Objective (main) lens
2. Mirror
3. Shutter
4. Sensor
5. Mirror in raised position
6. Viewfinder focusing lens
7. Prism
8. Eye prescription lens

Shutters



https://youtu.be/CmjeCchGRQo?t=160

[The Slo-Mo Guys]

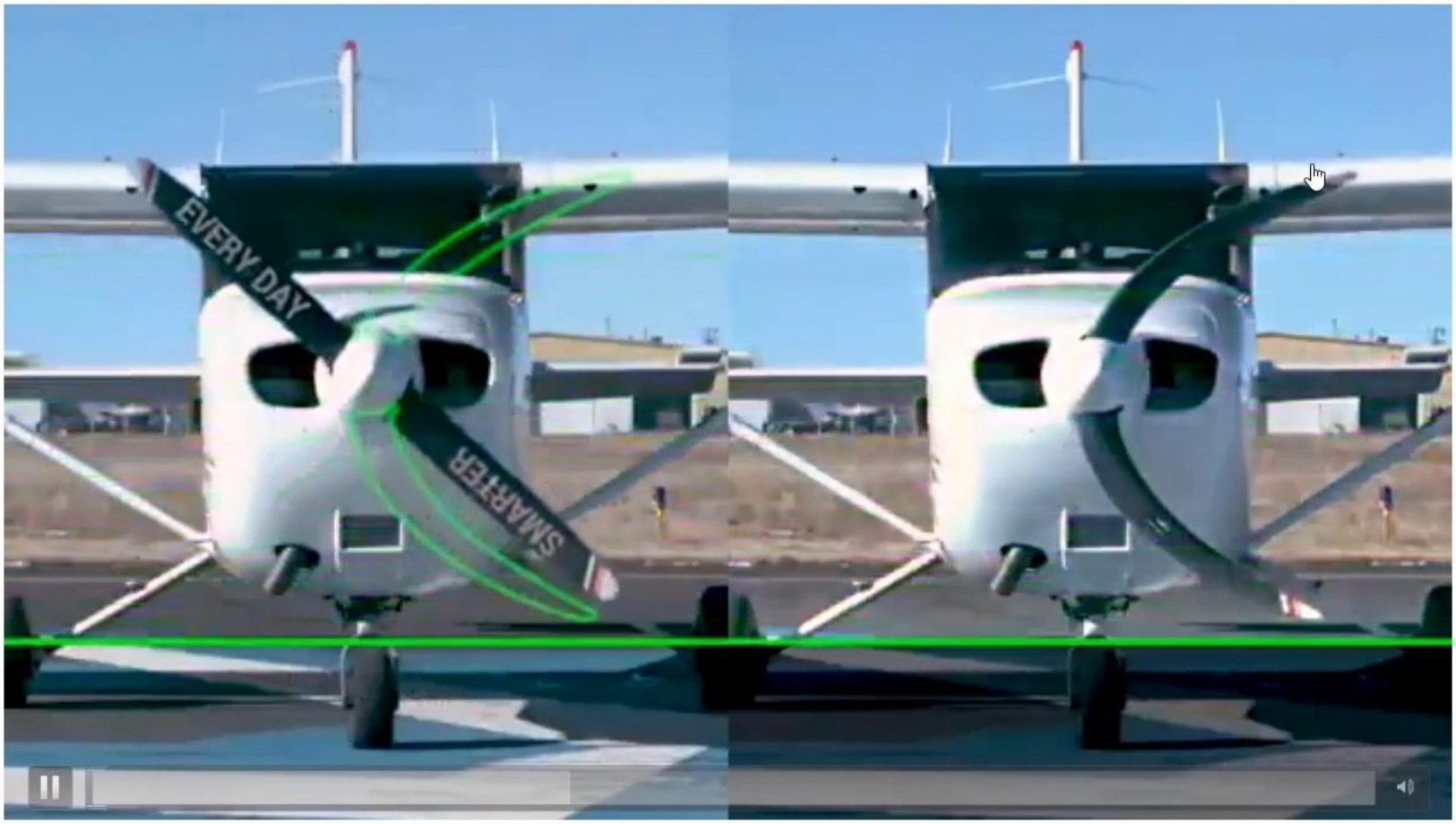
Shutters

https://youtu.be/CmjeCchGRQo?t=267

[The Slo-Mo Guys]

Sensors: Rolling shutter vs. global shutter

Most modern cameras have purely digital shutters.

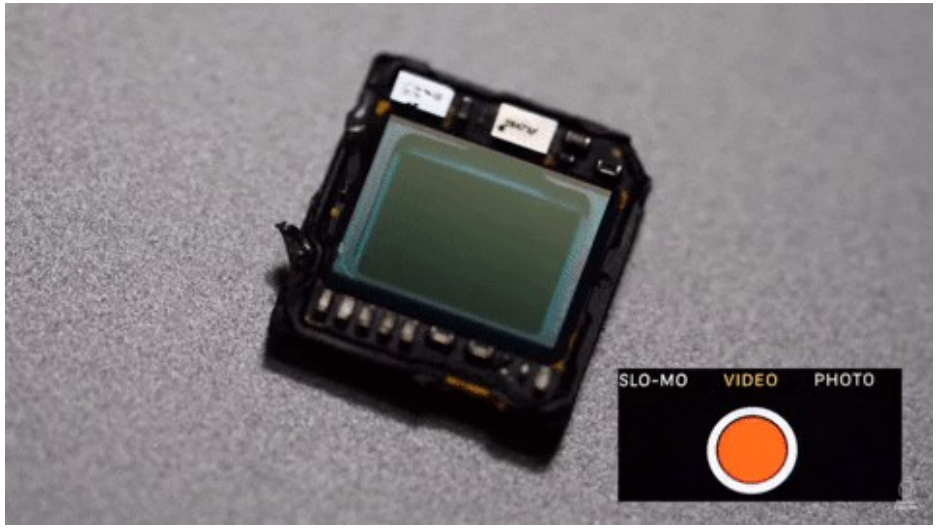


https://youtu.be/dNVtMmLlnoE?t=181

SmarterEveryDay/YouTube

Sensors: Rolling shutter vs. global shutter

Most modern cameras have purely digital shutters.



https://youtu.be/dNVtMmLlnoE?t=23

Image by SmarterEveryDay/ YouTube

Sensors: Rolling shutter vs. global shutter

Why not use Global Shutter always??

- Lower sensitivity
- Lower dynamic range
- Requires memory cells on the sensor
- Induces fixed pattern noise (especially with low light)
- Generates more heat (challenging calibration over time due to temp increase)

Sensor ISO

Analogue Photography:

ISO = old film terminology

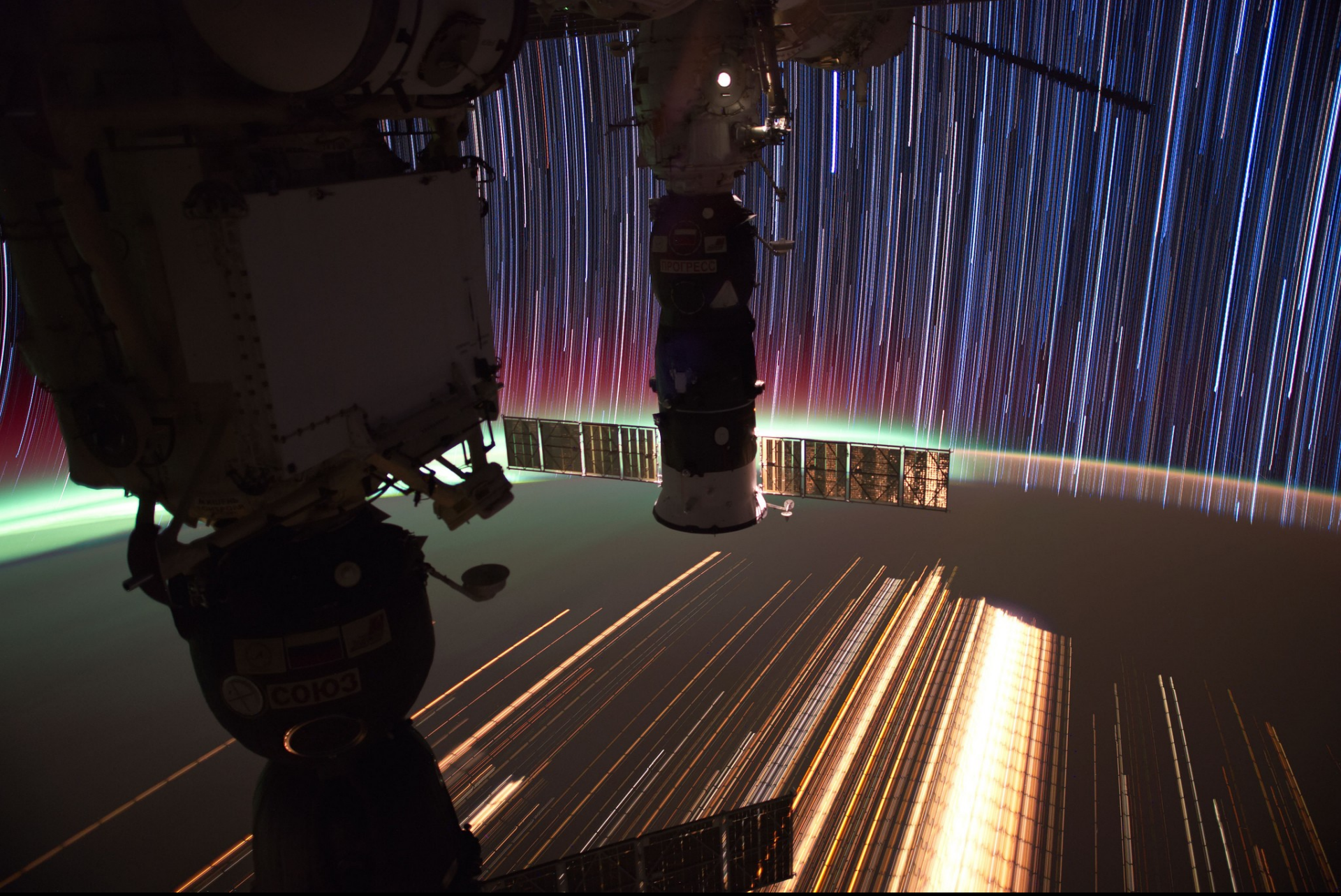
= sensitivity to light

ISO 200 is twice as sensitive as ISO 100.

Digital Photography:

ISO = ‘gain’ or amplification of sensor signal

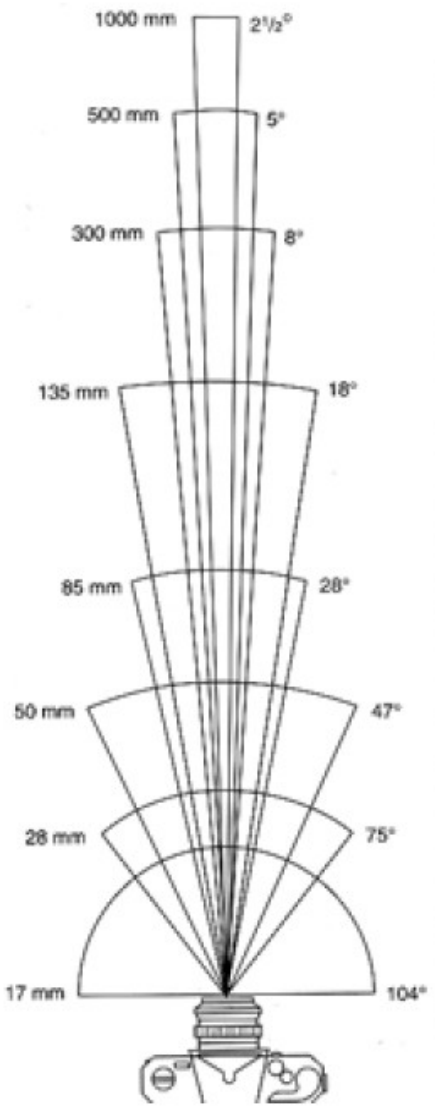
[Don Pettit]



[Don Pettit]

Field of View (Zoom)

Field of View (Zoom)



17mm

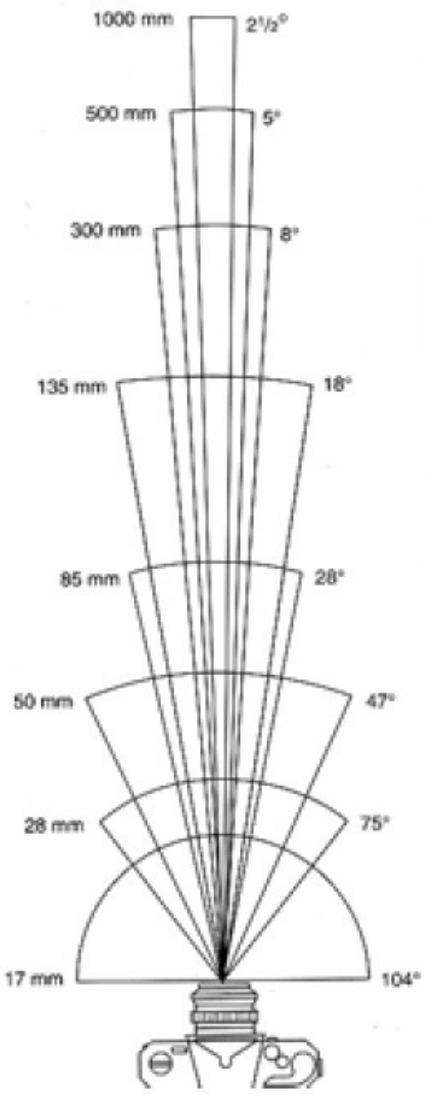
28mm

50mm

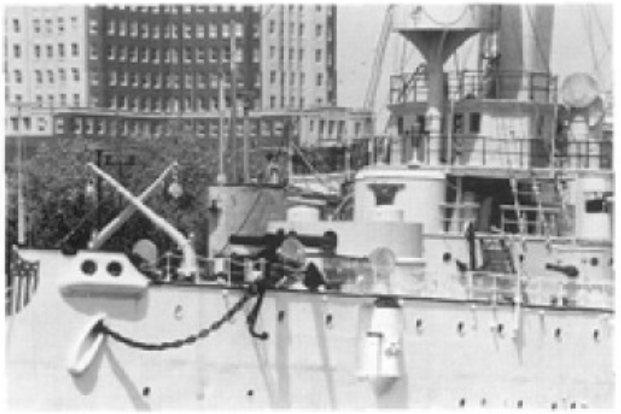
85mm

From London and Upton

Field of View (Zoom) = Cropping



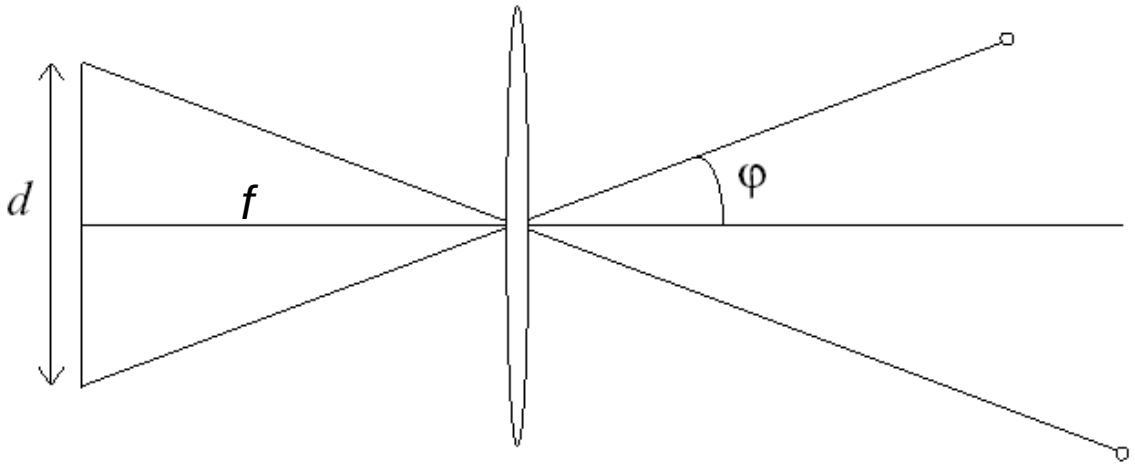
135mm



300mm

From London and Upton

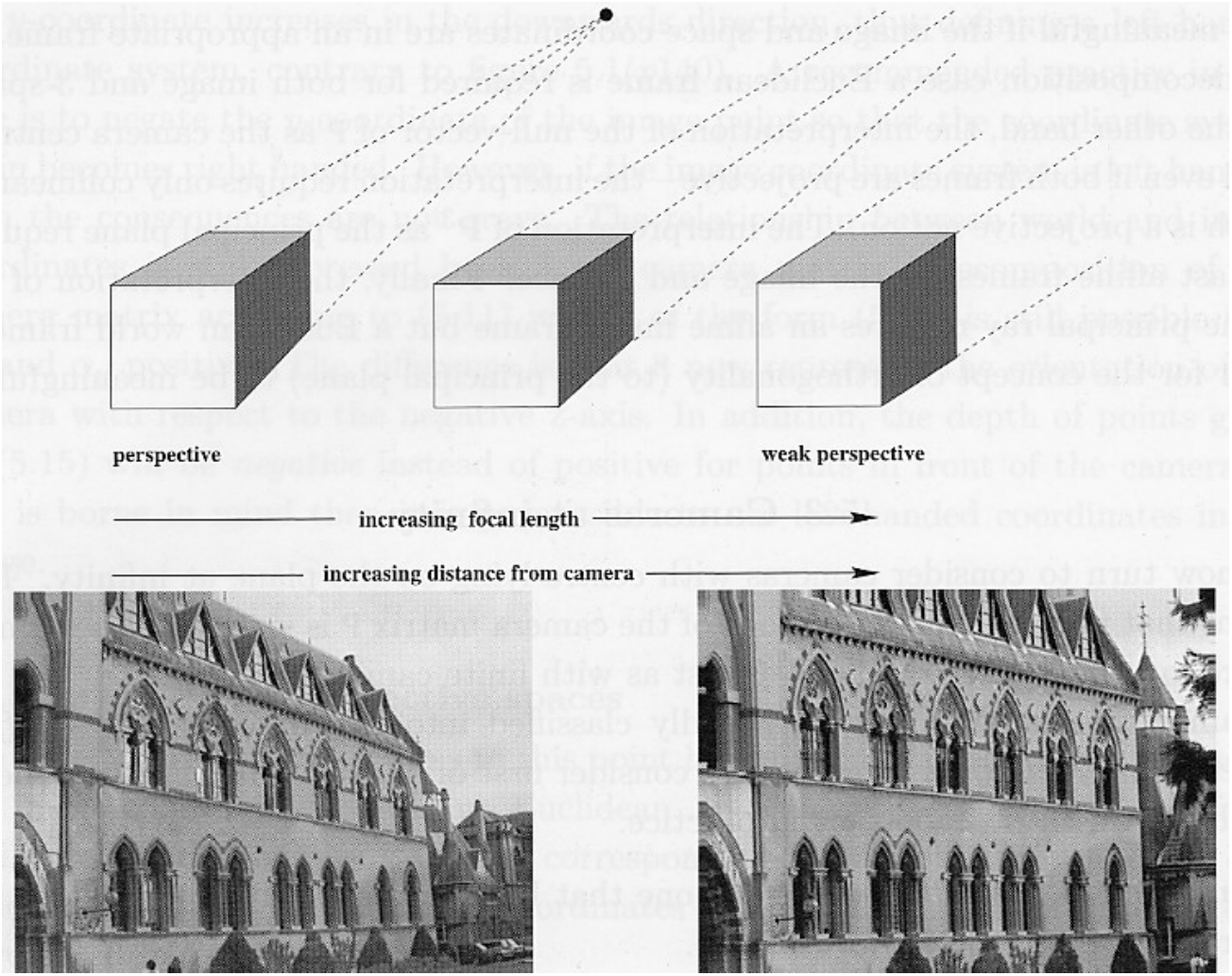
FOV depends of Focal Length



$$\varphi = \tan^{-1}(\frac{d}{2f})$$

larger Focal Length = Smaller FOV

Effect on Perspective Geometry



From Zisserman & Hartley

Field of View / Focal Length

Large FOV, small f
Camera close to car

Small FOV, large f
Camera far from the car

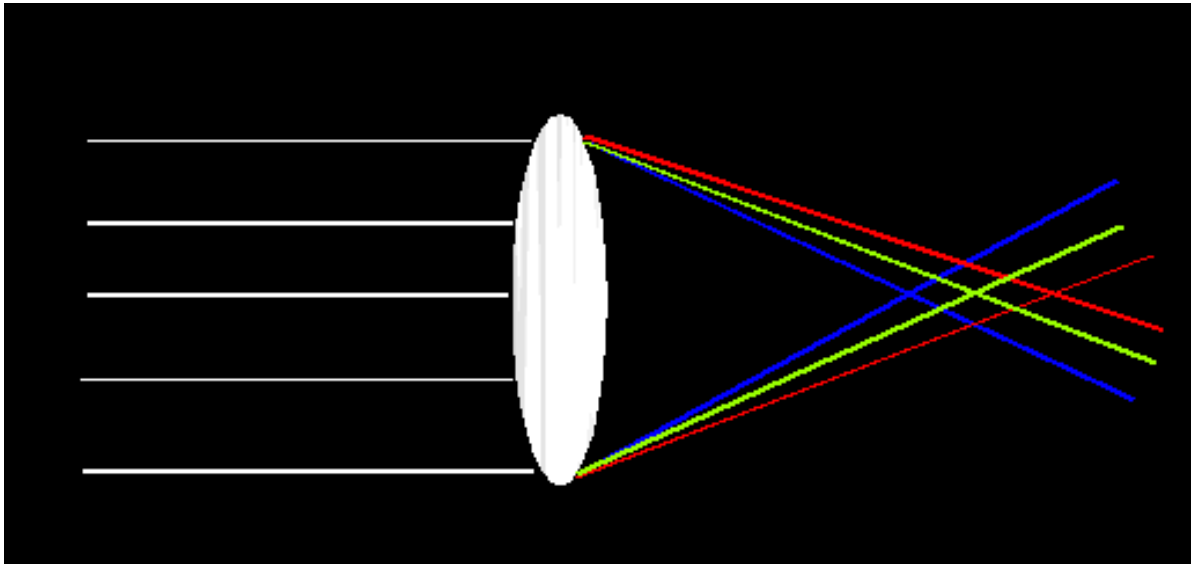
Lens Flaws

Lens Flaws: Chromatic Aberration

Dispersion: wavelength-dependent refractive index

(enables prism to spread white light beam into rainbow)

Modifies ray-bending and lens focal length: f( )



Color fringes near edges of image

Corrections: add ‘doublet’ lens of flint glass, etc.

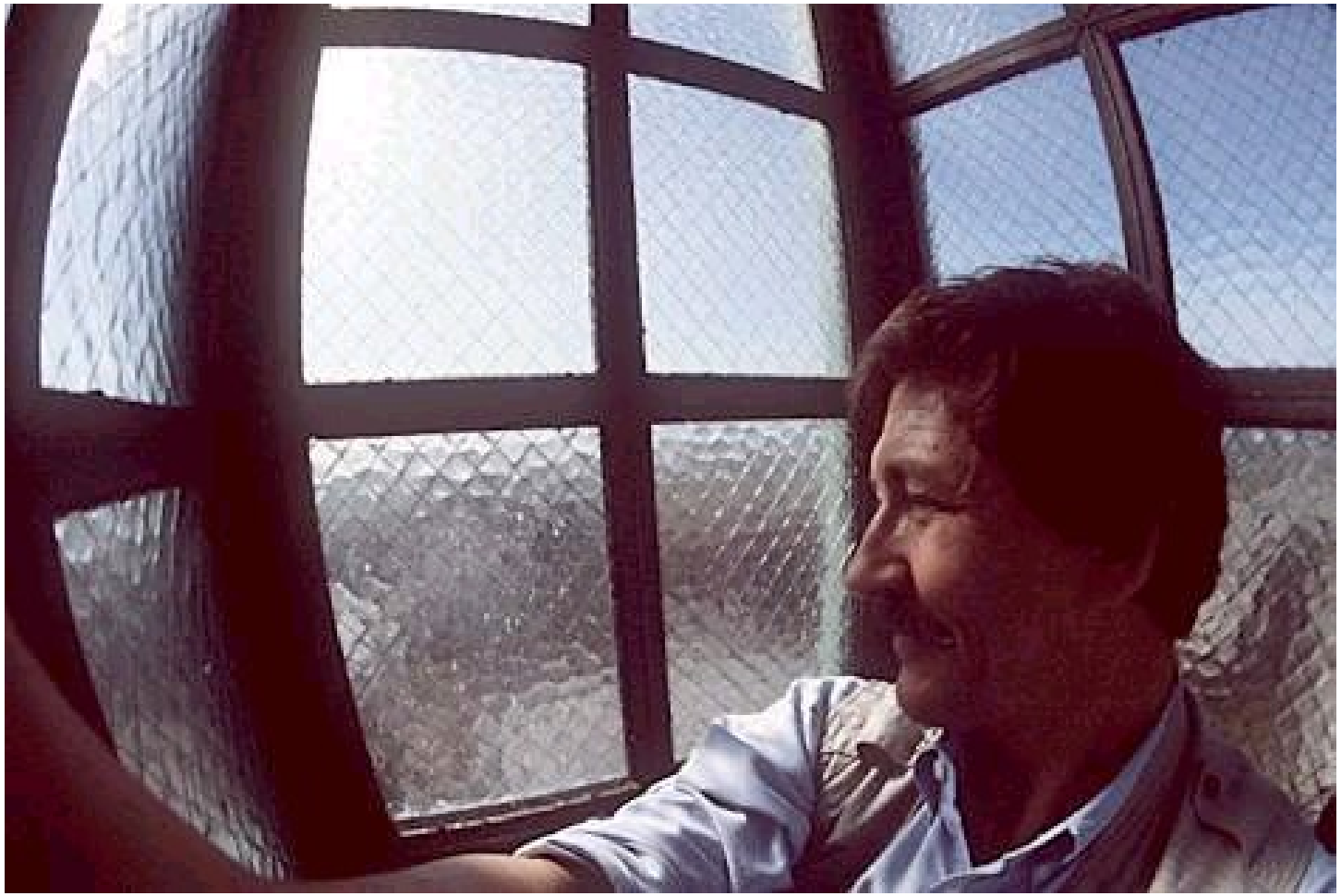
Chromatic Aberration

Near Lens Center

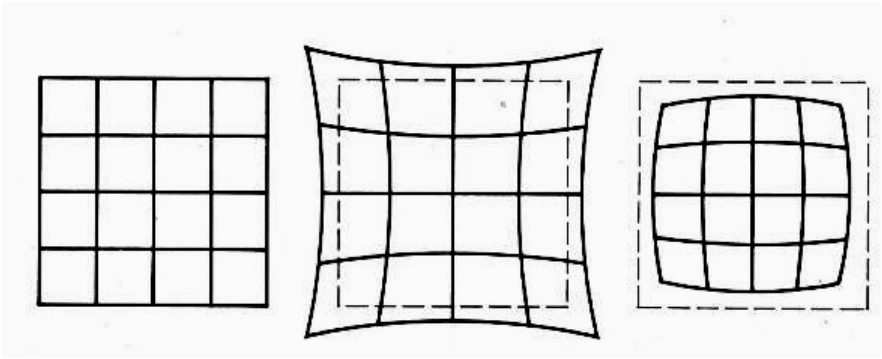
Near Lens Outer Edge

Radial Distortion (*e.g.* ‘barrel’ and ‘pin-cushion’)

Straight lines curve around the image center



Radial Distortion



No distortion Pin cushion Barrel

Radial distortion of the image

- Caused by imperfect lenses
- Deviations are most noticeable for rays that pass through the edge of the lens

Corrected Barrel Distortion

Image from Martin Habbecke

Vignetting

Optical system occludes rays entering at obtuse angles.

Causes darkening at edges.

‘Old mode’ - but WHY?

Computer-aided lens design (optimization) and manufacturing made removing (all) these flaws _much_ easier.