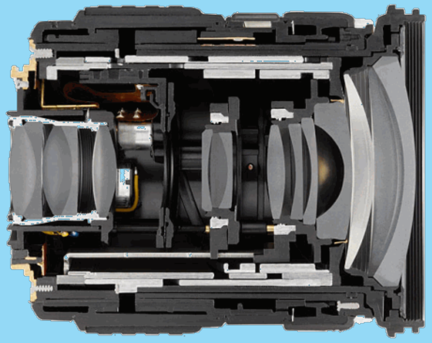
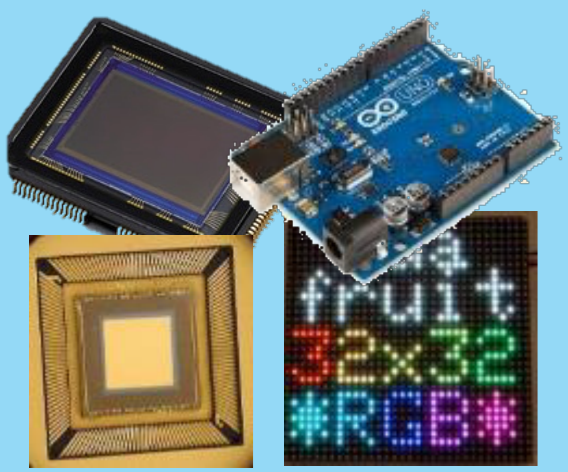


Optics

+



Sensors
&
devices

+

Signal
processing
&
algorithms

COMPUTATIONAL METHODS FOR IMAGING (AND VISION)

LECTURE 26: INTRODUCTORY OPTICS

PROF. JOHN MURRAY-BRUCE

WHERE ARE WE

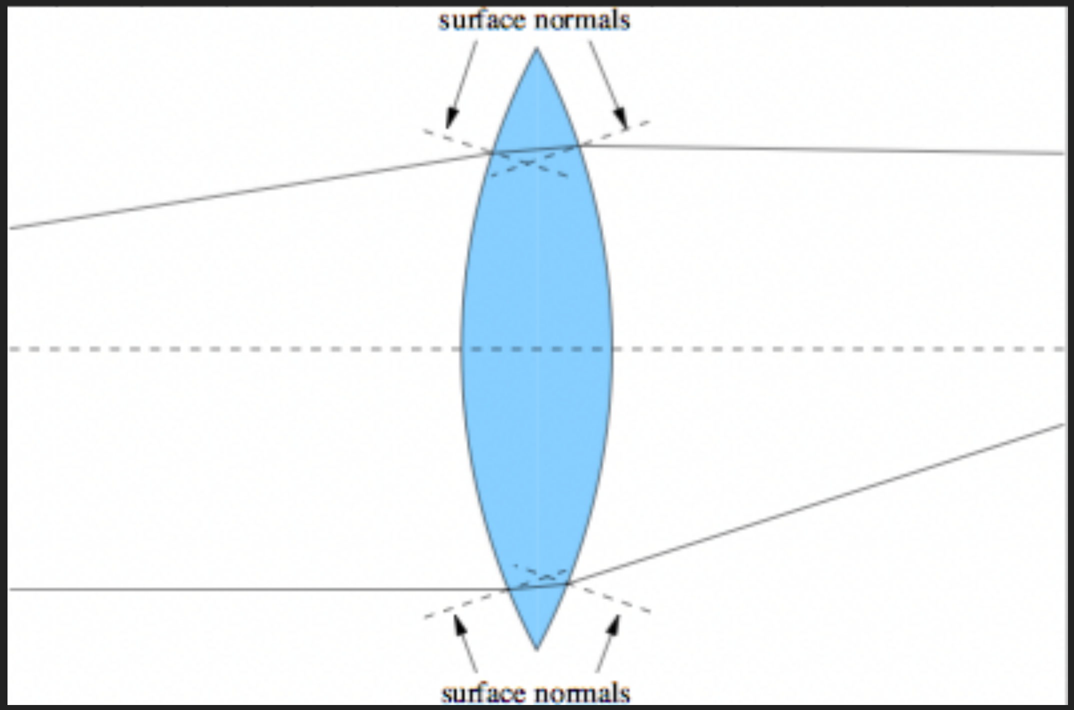
WE ARE HERE!

10	15-Mar-21	Forward Models and Inverse Problems	Linear Inversion - Inverse problems - Deconvolution and Denoising	IIP 4, Appendix E	**HW 4**	
	17-Mar-21		Intro to Regularized Inversion I - Tikhonov	IIP 5, Appendix E		
11	22-Mar-21	Regularization	Intro to Regularized Inversion II - Iterative methods - Steepest descent	IIP 6		
	24-Mar-21		Statistical methods I - ML estimation - Bayesian estimation	IIP 7.1 - 7.5		
12	29-Mar-21	Forward models and Inverse Problems II	LSV imaging systems: Forward problem - SVD - Inversion	IIP 8.1, 9, 10		
	31-Mar-21	Non-linear Regularization	Beyond L_2-regularization - Sparsity (l_0- and l_1-priors) - TV prior	SMIV 1.1 - 1.5 Papers & Handout		**HW 4**
13	5-Apr-21		Algorithms overview - ISTA/FISTA - ADMM	Papers & Handout		
	7-Apr-21	Introductory Optics	Geometrical/Ray Optics - Rays & pinhole cameras - Lenless imaging and Coded apertures	IIP 8.2, 8.3, 9.5 Papers & Handout		
14	12-Apr-21 14-Apr-21	**Spring Break (no classes)**				
15	19-Apr-21	Applications of Comp. Imaging	INTRO OPTICS CODED-APERTURE	Papers & Handout		
	21-Apr-21			Papers & Handout		
16	26-Apr-21 28-Apr-21	**Group Presentations (Teams)**				
17	3-May-21	***no class**				
	5-May-21	**Final Exam: 12:30 PM - 2:30 PM**				

LENS TYPES

Positive Lenses

- Thicker middle
- Bend rays toward axis
- Forms a real focus



Negative Lenses

- Thinner middle
- Bend rays away from axis
- Form virtual focus

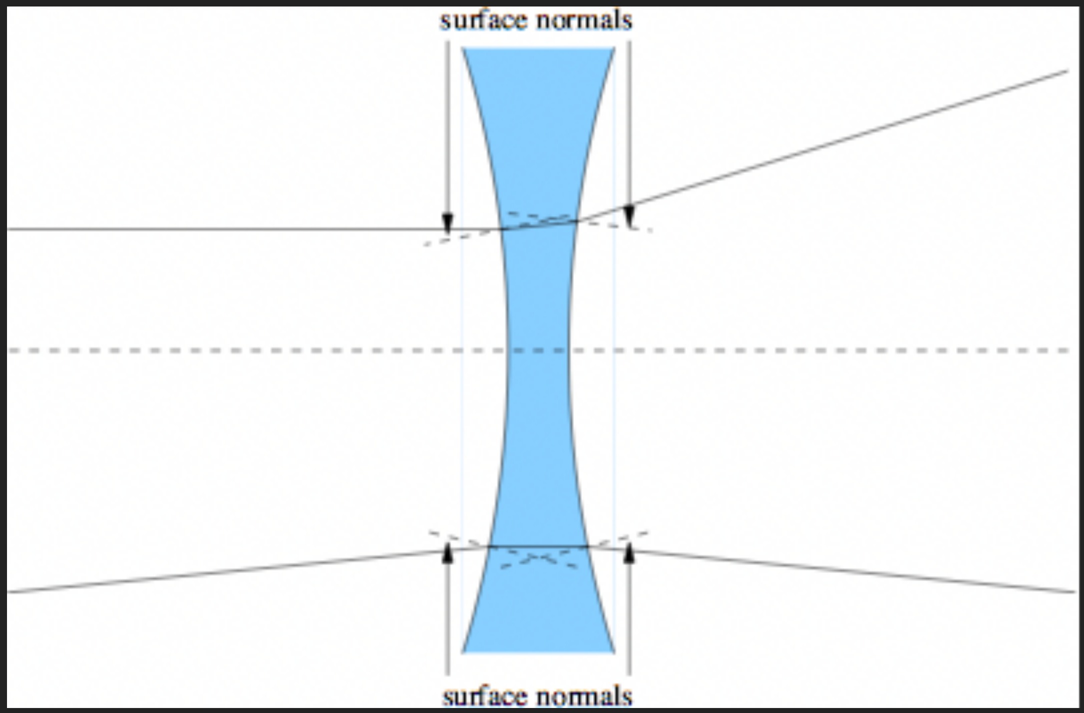
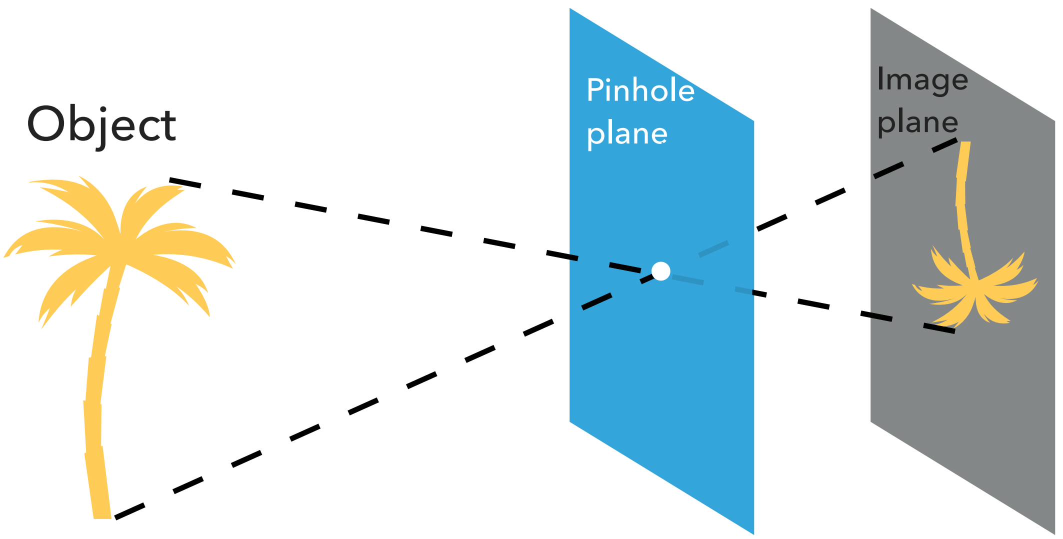
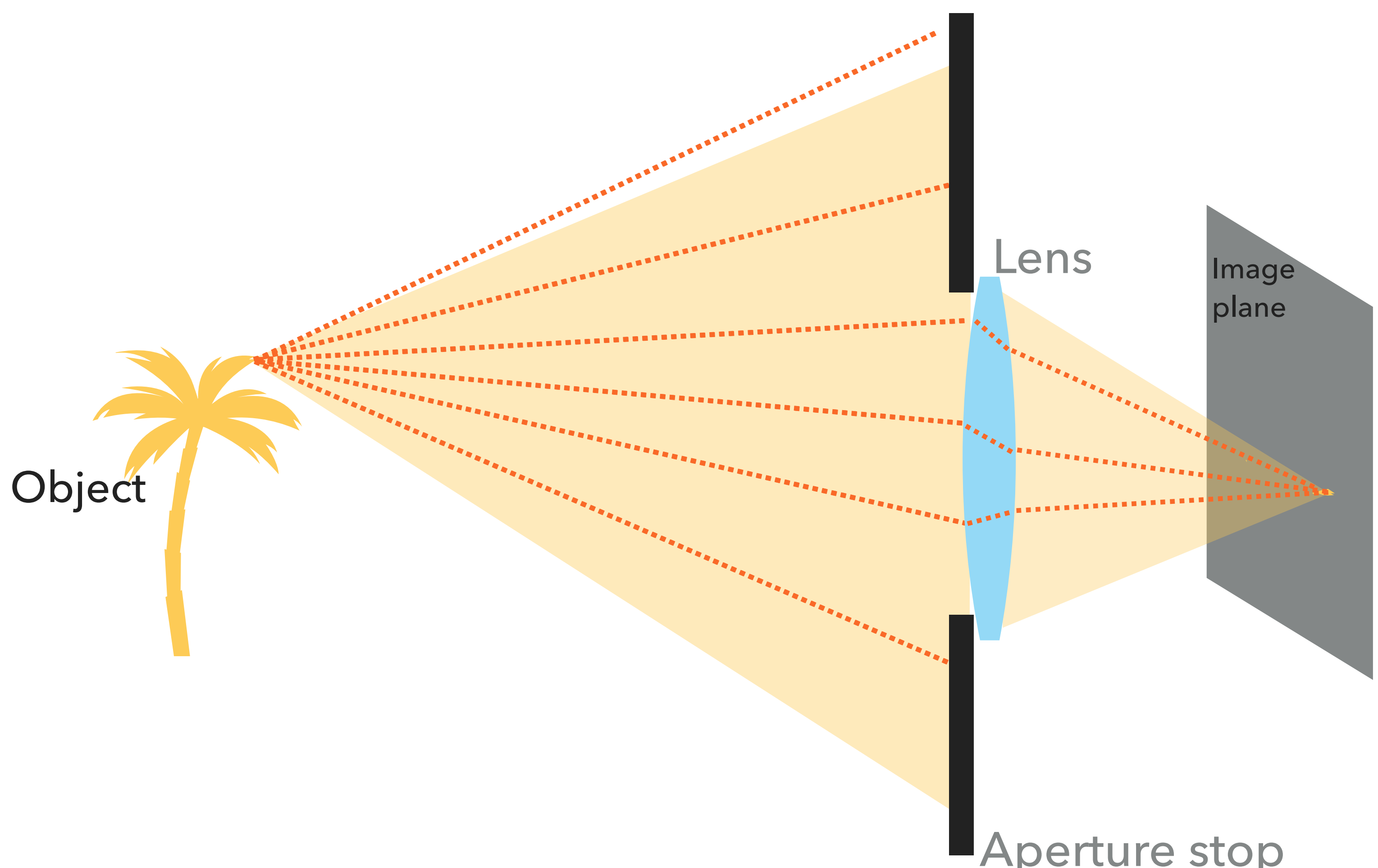


IMAGE GENERATION
PINHOLE VS LENS

- **Pinhole camera**: small hole means that light hitting any particular point on the image plane must have come from a particular direction outside the camera





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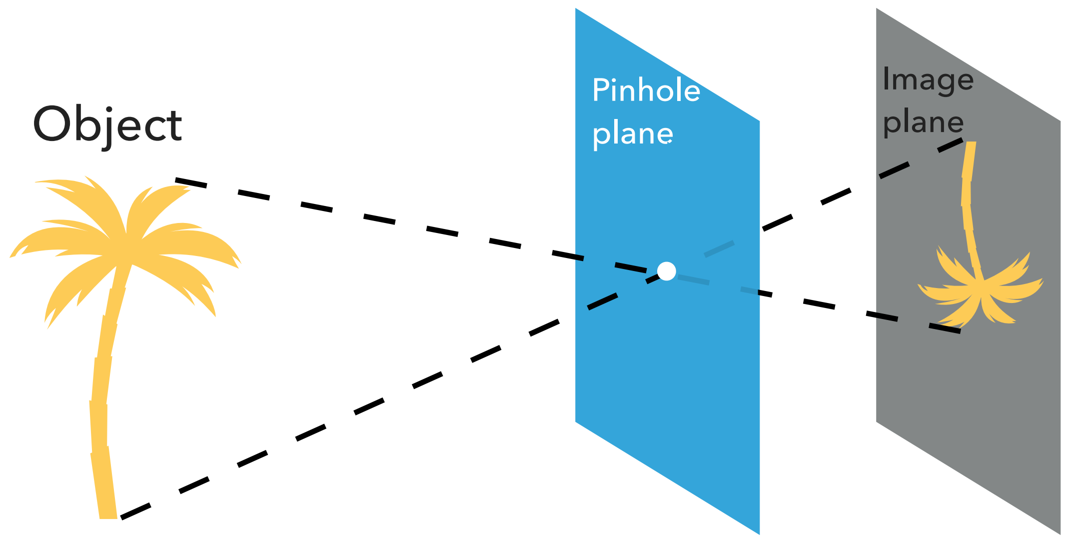

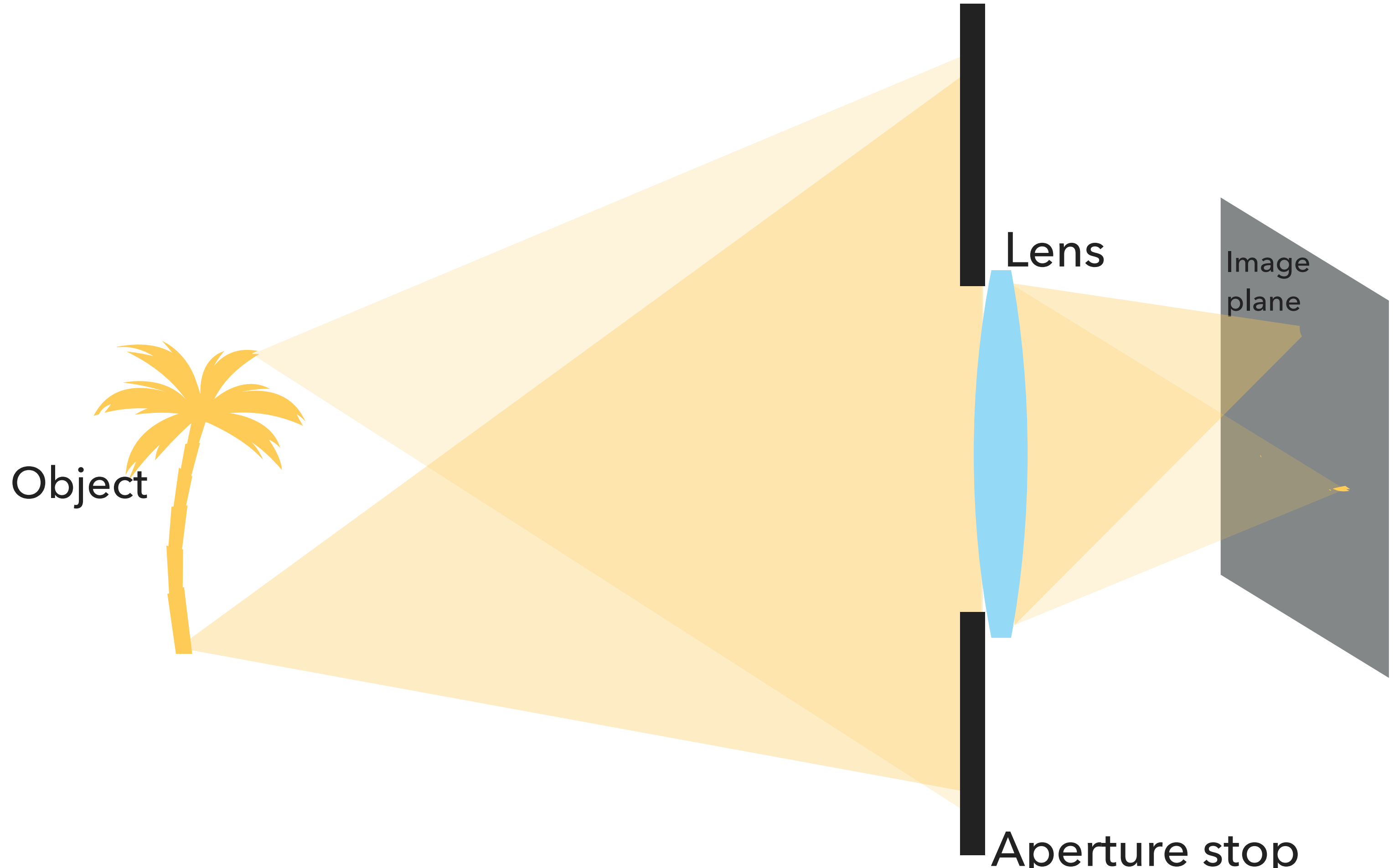

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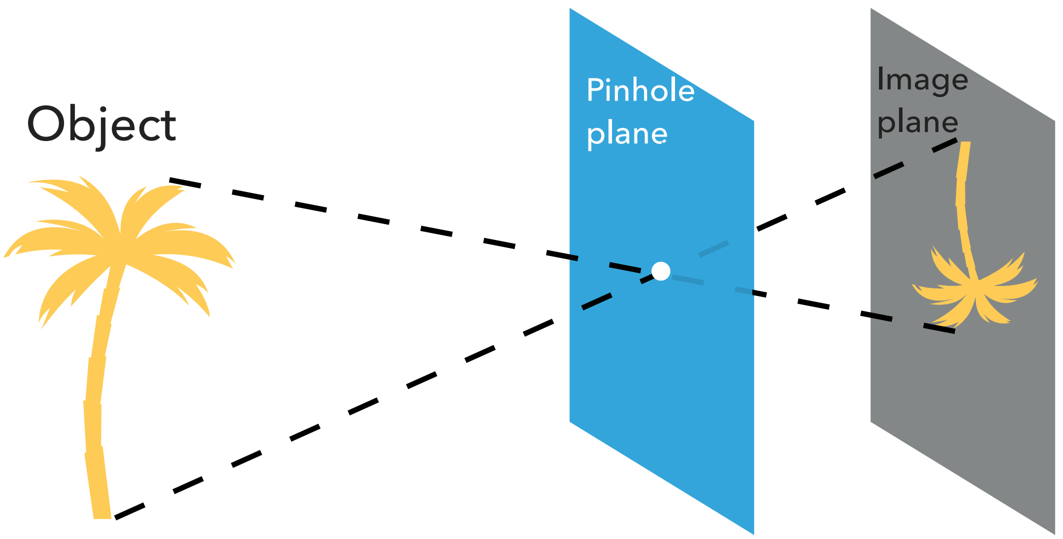


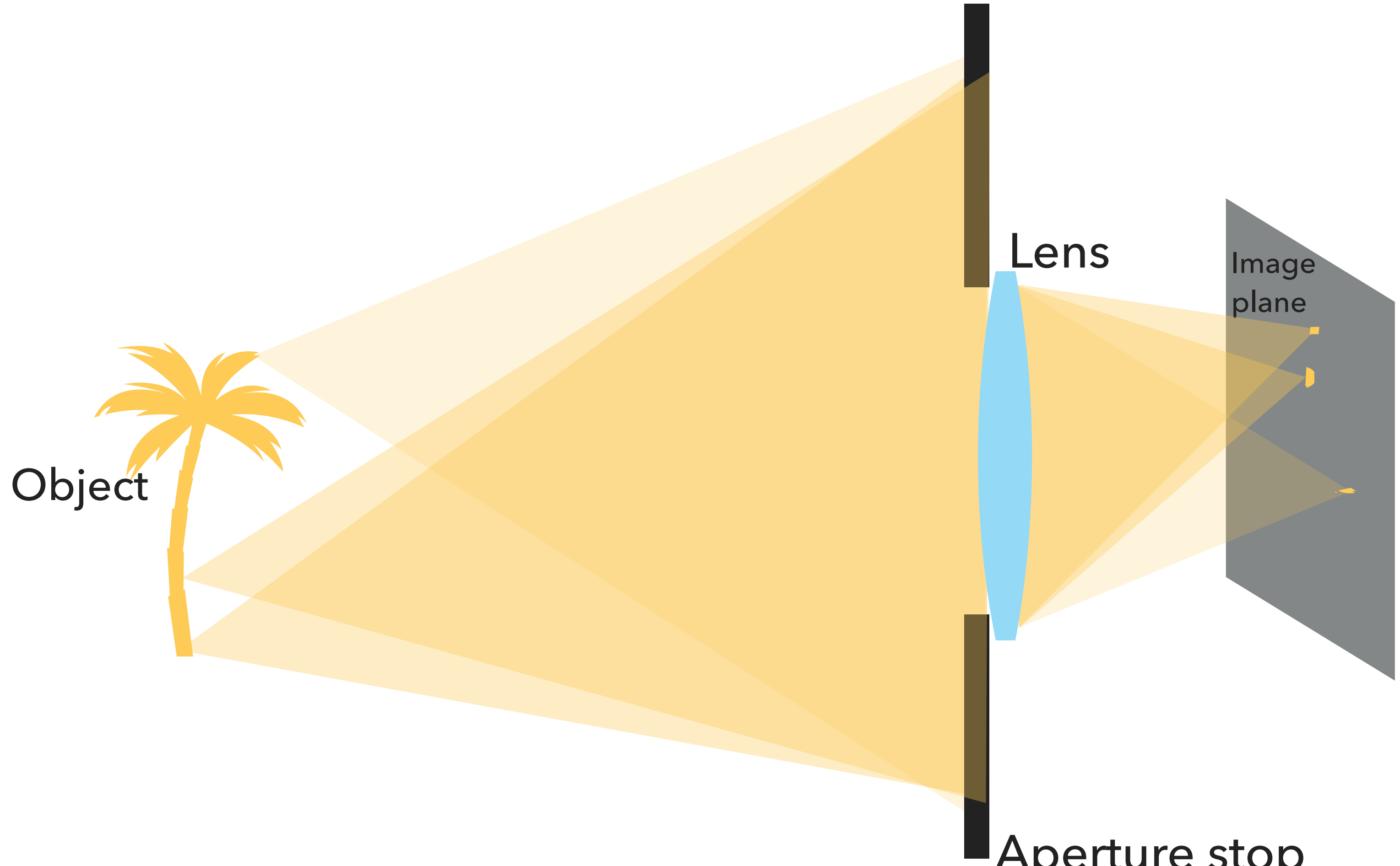
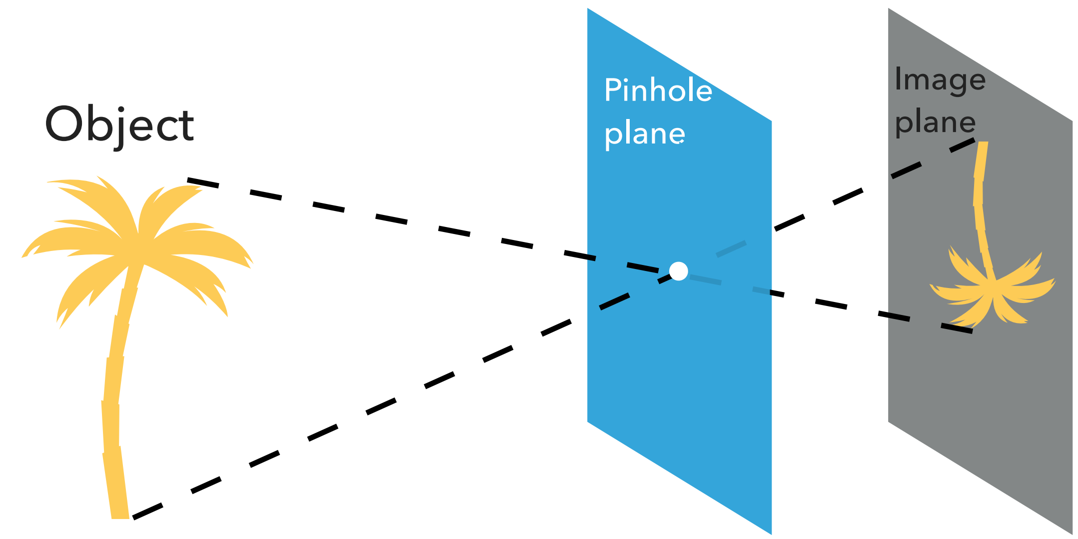


IMAGE GENERATION

PINHOLE VS LENS

- **Pinhole camera**: small hole means that light hitting any particular point on the image plane must have come from a particular direction outside the camera



- **Lens-based camera**: any particular point on the image plane corresponds to a particular direction outside the camera.

- **Lenses** have an additional important advantage of collecting more light than a pinhole.

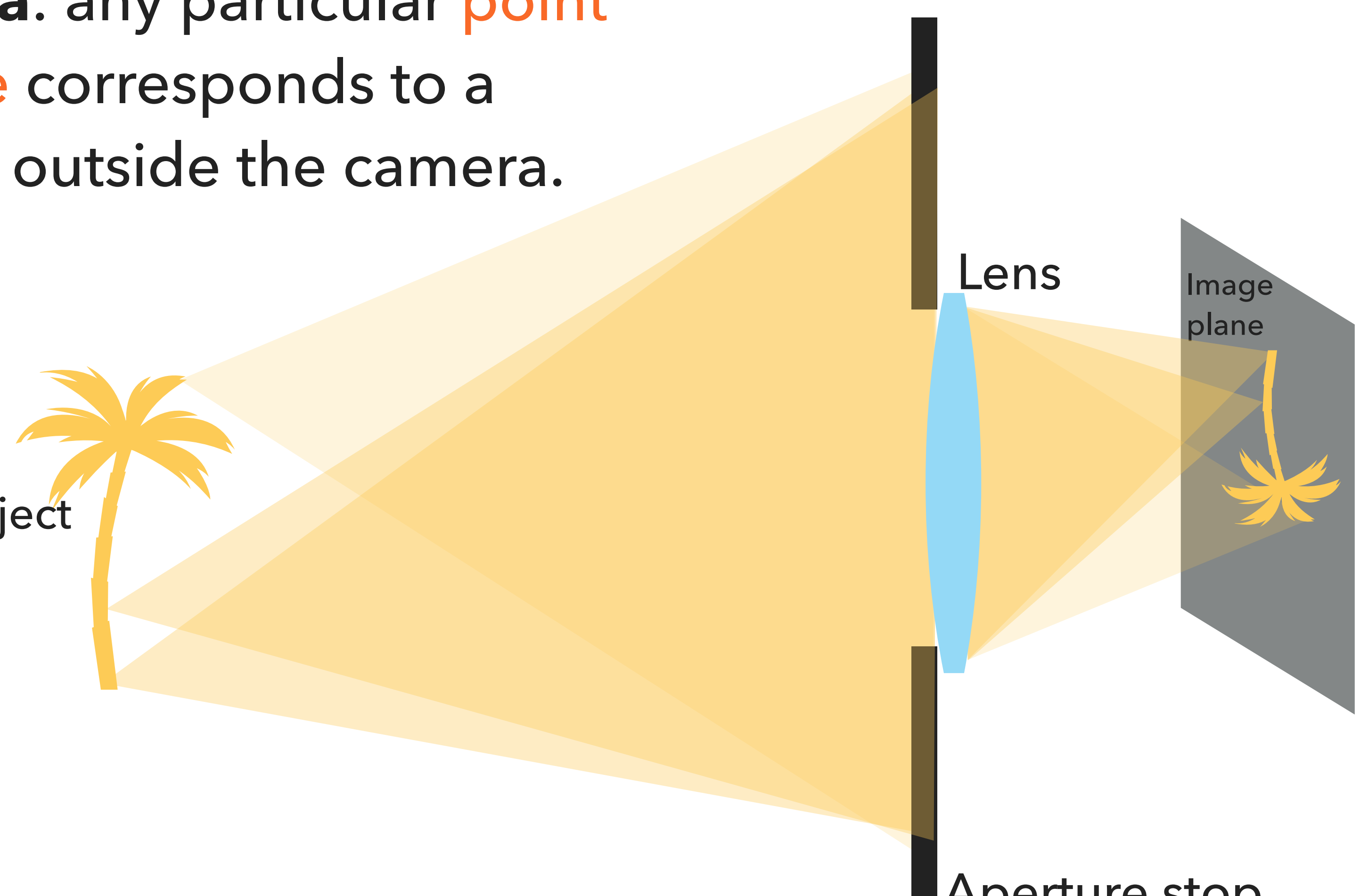
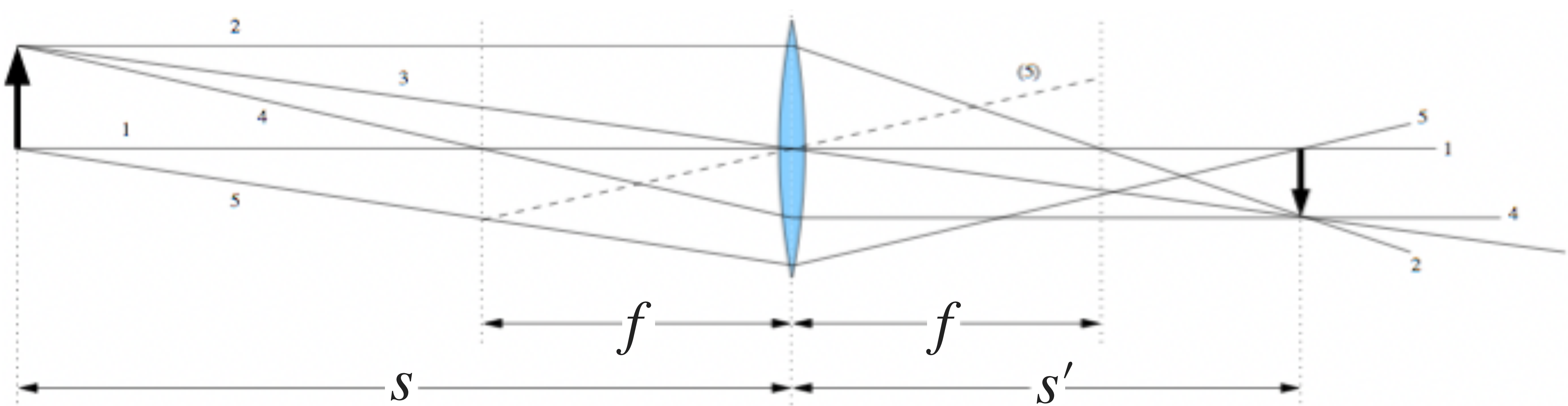


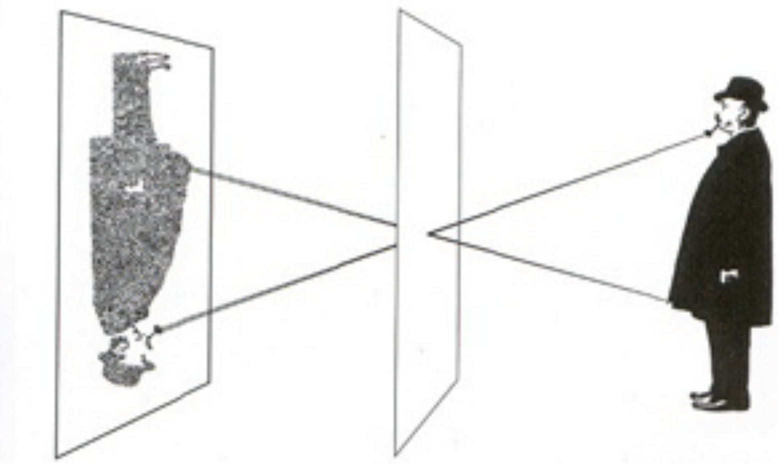
IMAGE FORMATION

- Place arrow (object) on left, trace through image:
  (1) along optical axis (no deflection – optical axis);
  (2) parallel to axis (marginal ray), goes through far focus with optical axis ray;
  (3) through lens center (chief ray);
  (4) through near-side focus, emerges parallel to optical axis;
  (5) arbitrary ray with helper



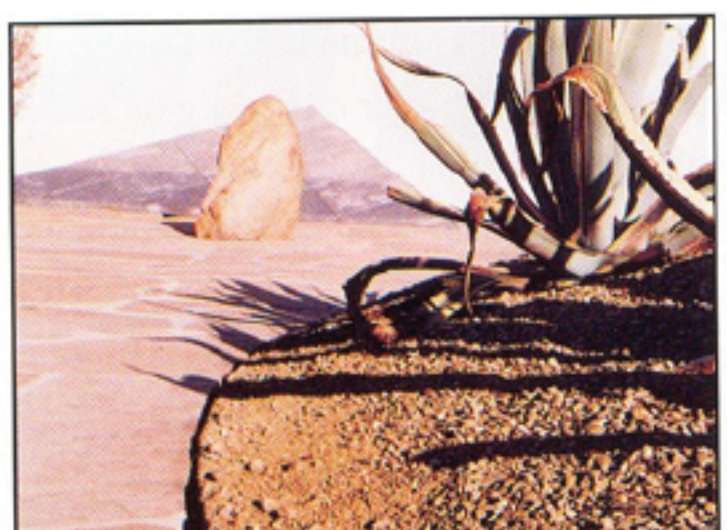
PINHOLE VS LENS IMAGING

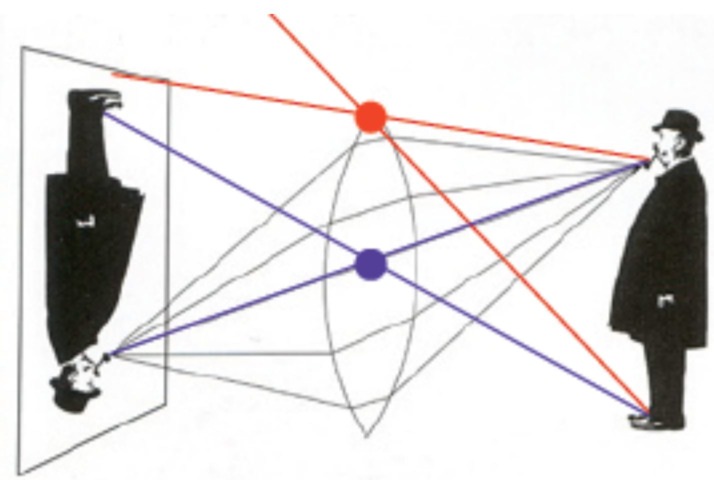
Pinhole camera



To make this picture, the lens of a camera was replaced with a thin metal disk pierced by a tiny pinhole, *equivalent in size to an aperture of f/182. Only a few rays of light from each point on the subject got through the tiny opening, producing a soft but acceptably clear photograph. Because of the small size of the pinhole, the exposure had to be 6 sec long.*

Lens-based camera





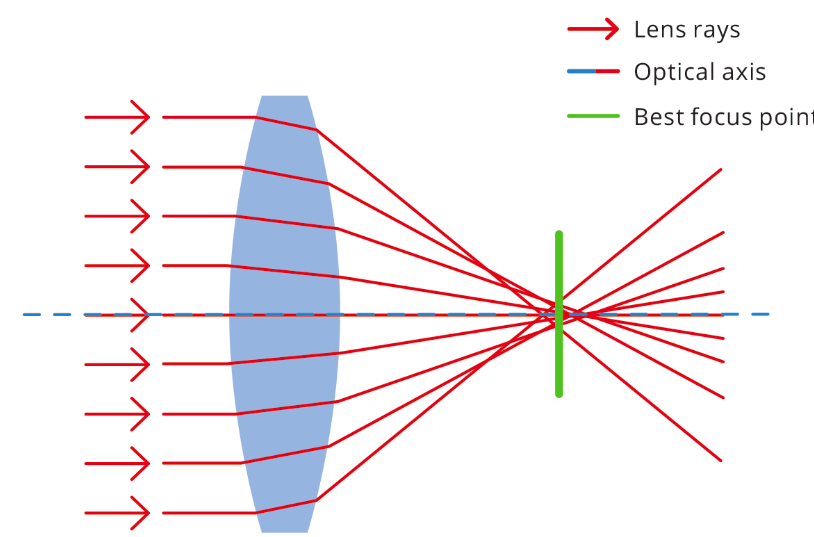
This time, using a simple convex lens with an f/16 aperture, *the scene appeared sharper than the one taken with the smaller pinhole, and the exposure time was much shorter, only 1/100 sec.*

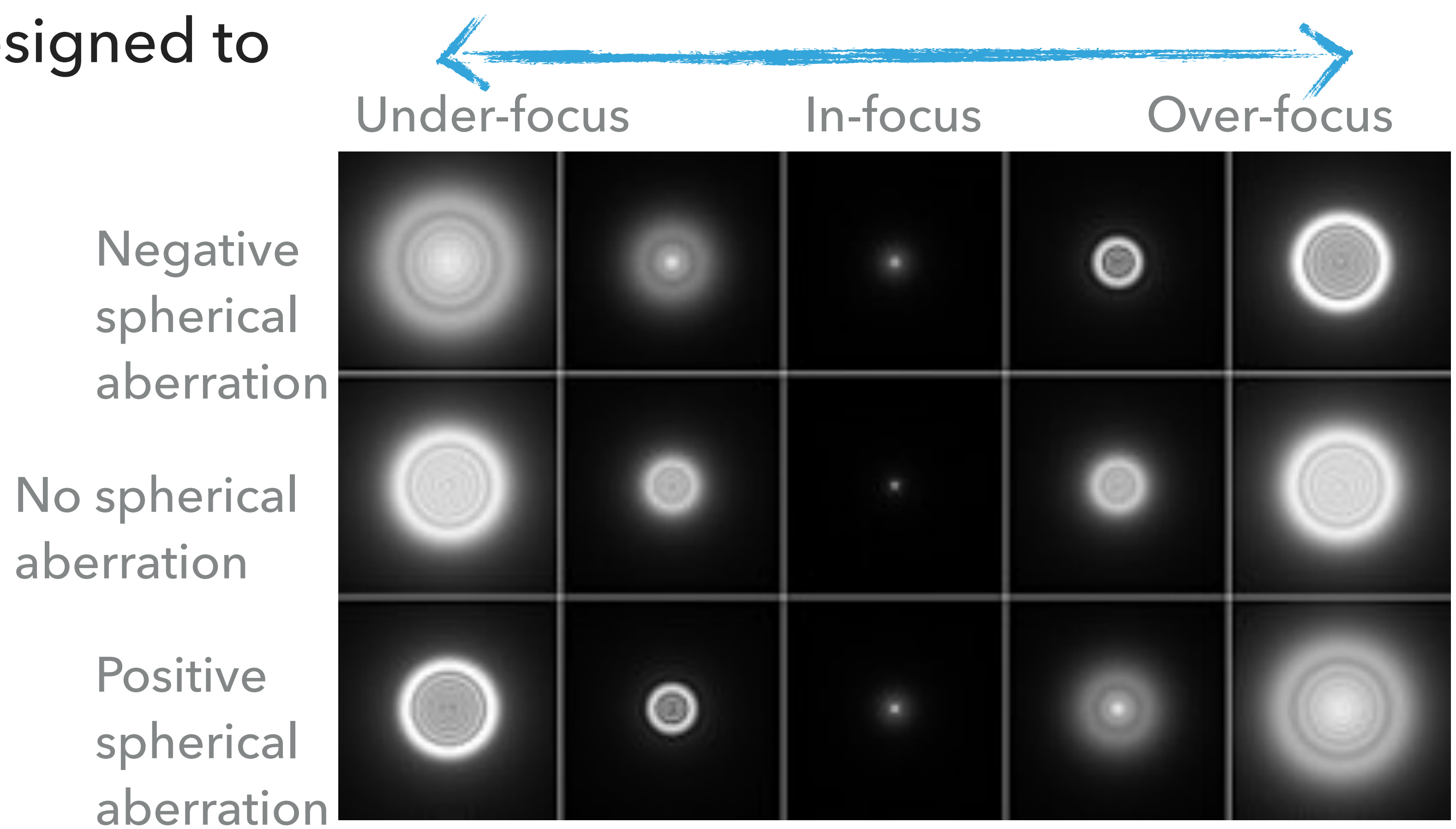
The lens opening was much bigger than the pinhole, letting in far more light, but it focused the rays from each point on the subject precisely so that they were sharp on the film.

From Photography, London *et al.*

ABERRATIONS

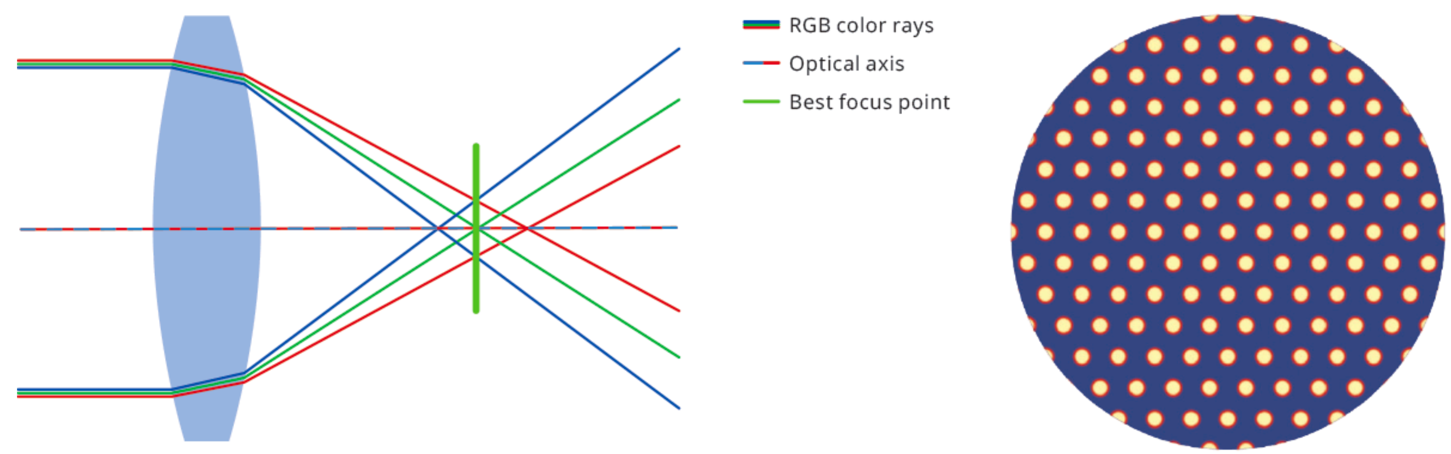
- **Spherical Aberration** -- causes light rays passing through a lens (or reflected from a mirror) at different distances from the optical center to come to focus at different points on the axis. This causes a star to be seen as a blurred disk rather than a sharp point. Most telescopes are designed to eliminate this aberration.



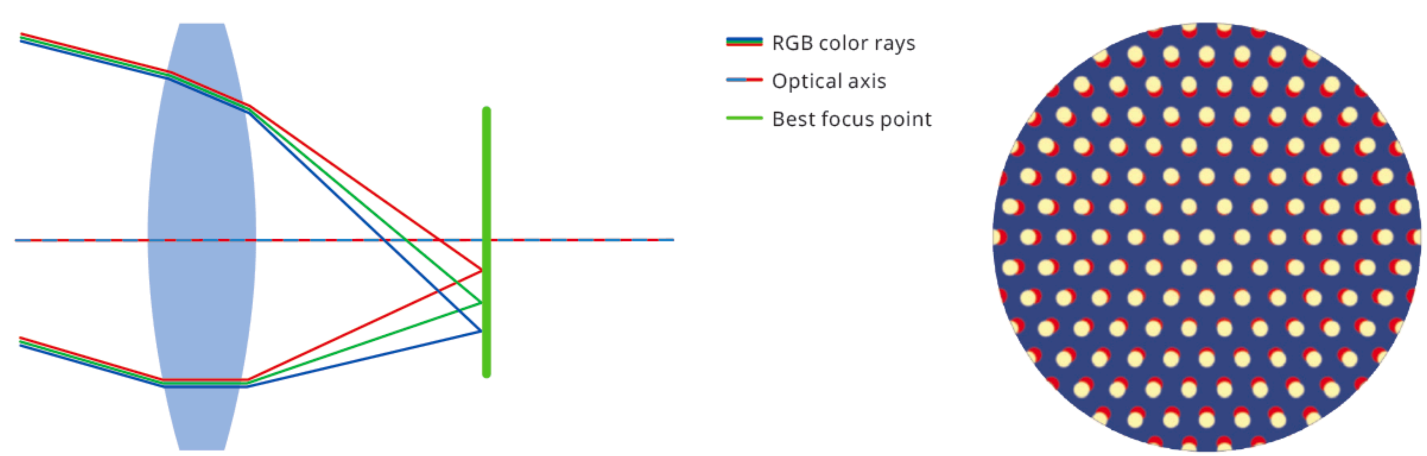


CHROMATIC ABERRATIONS

- **Chromatic Aberration** -- usually associated with objective lenses of refractor telescopes. It is the failure of a lens to bring light of different wavelengths (colors) to a common focus. This results mainly in a faint colored halo (usually violet) around bright stars, the planets and the moon. It also reduces lunar and planetary contrast. It usually shows up more as speed and aperture increase. Achromat doublets in refractors help reduce this aberration and more expensive, sophisticated designs like apochromats and those using fluorite lenses can virtually eliminate it.



Longitudinal/axial chromatic abberation



Lateral/transverse chromatic abberation

FIELD OF VIEW
NUMERICAL APERTURE
DEPTH OF FOCUS

FUNDAMENTAL IMAGING CONSIDERATIONS

FIELD OF VIEW

NUMERICAL APERTURE

DEPTH OF FOCUS

FUNDAMENTAL IMAGING CONSIDERATIONS

FIELD OF VIEW (FOV)

- **Field of view (FOV):** the maximum area of a scene that a camera can image.

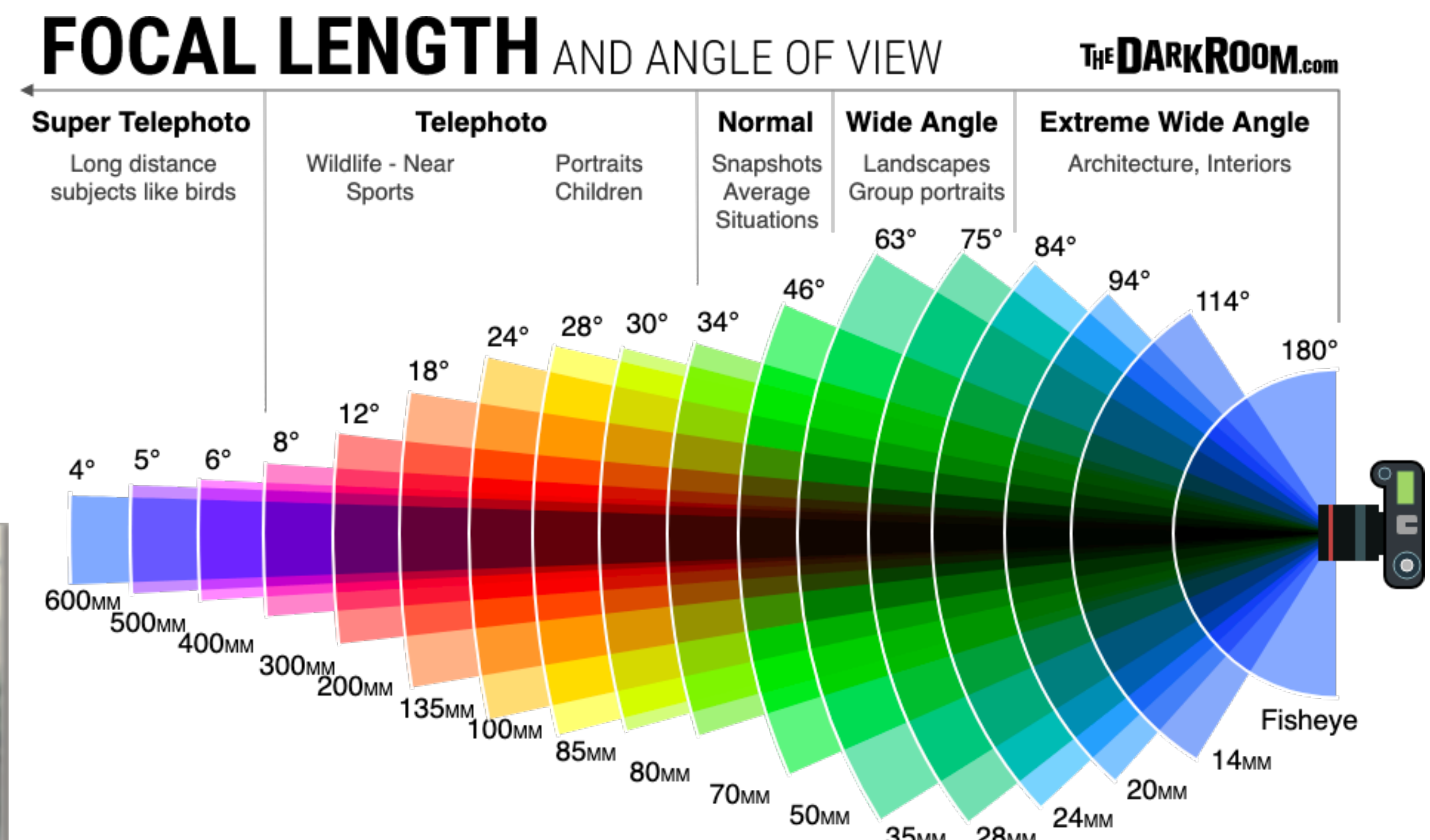
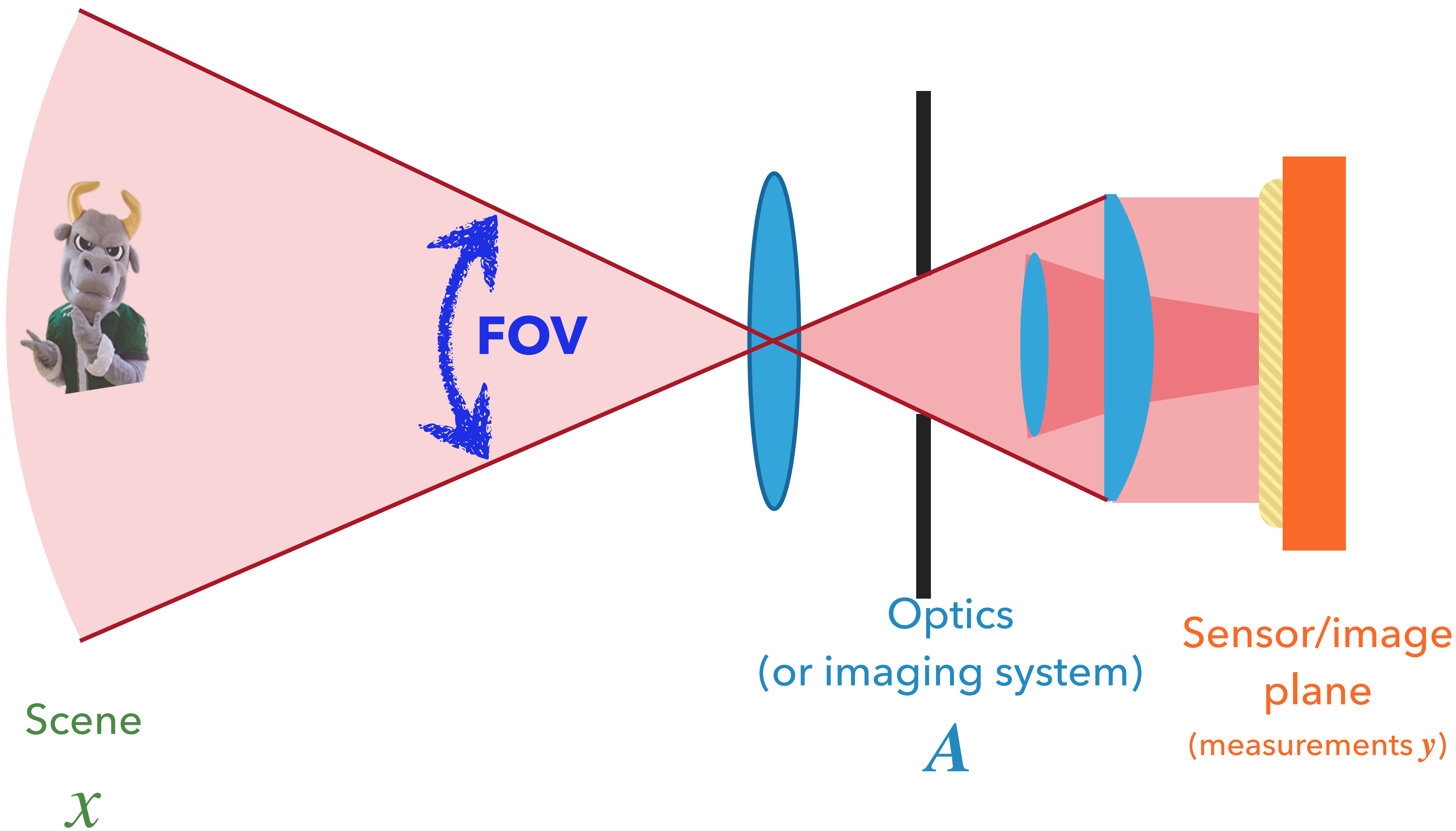


Image credit: Andrew McWilliams

FIELD OF VIEW (FOV)

- **Field of view (FOV):** the maximum area of a scene that a camera can image.

Why is FOV measured in terms of angle?



FIELD OF VIEW

NUMERICAL APERTURE

DEPTH OF FOCUS

FUNDAMENTAL IMAGING CONSIDERATIONS

NUMERICAL APERTURE

- **Numerical Aperture (NA):** describes the range of angles over which the system can accept light.

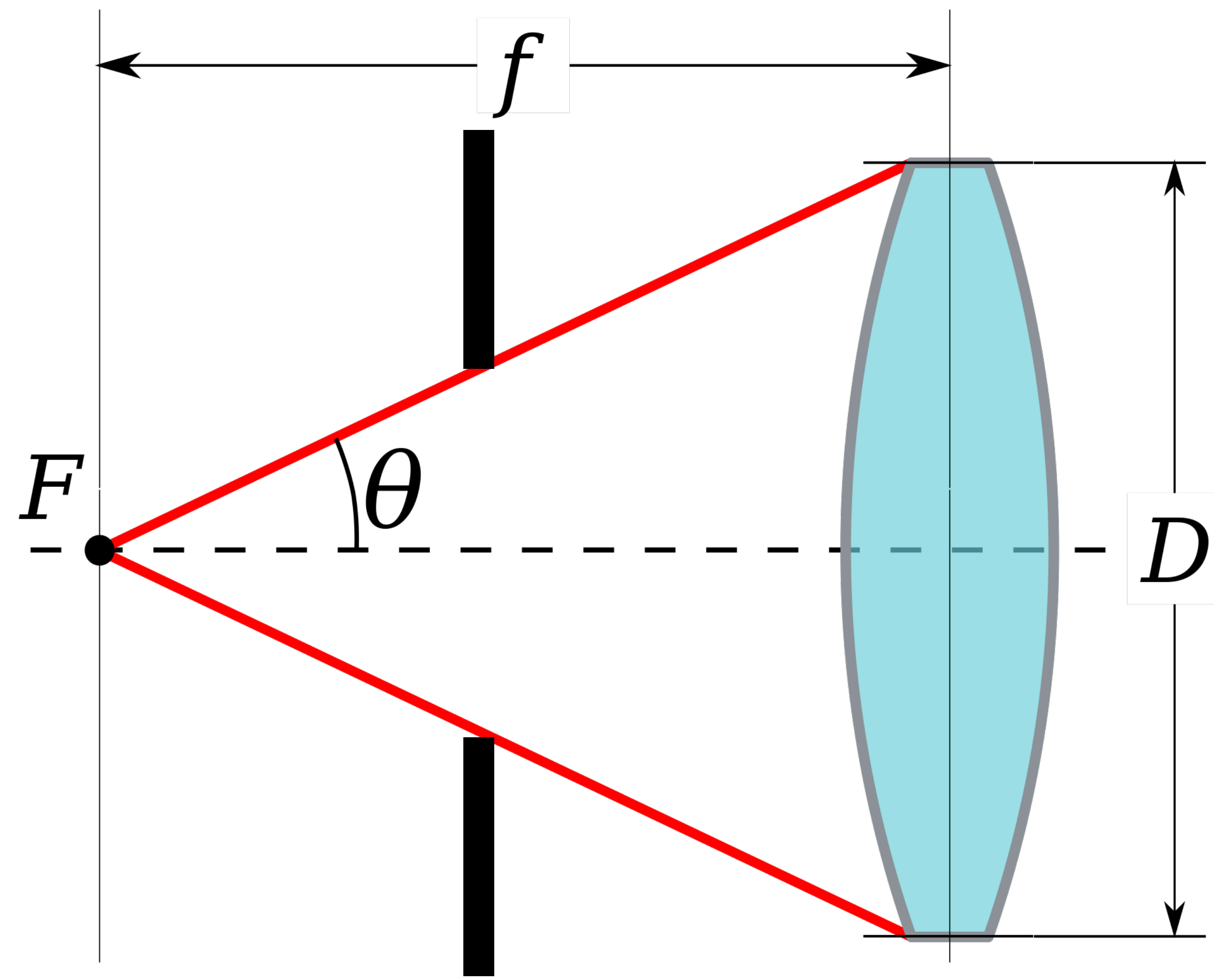
$$\mathrm{NA} = n \sin\theta$$

θ is the **half-angle subtended** by the imaging system from an *axial object.*

n is the refractive index of the medium

In photography, typically use the **f-number** ($f/\#$) instead:

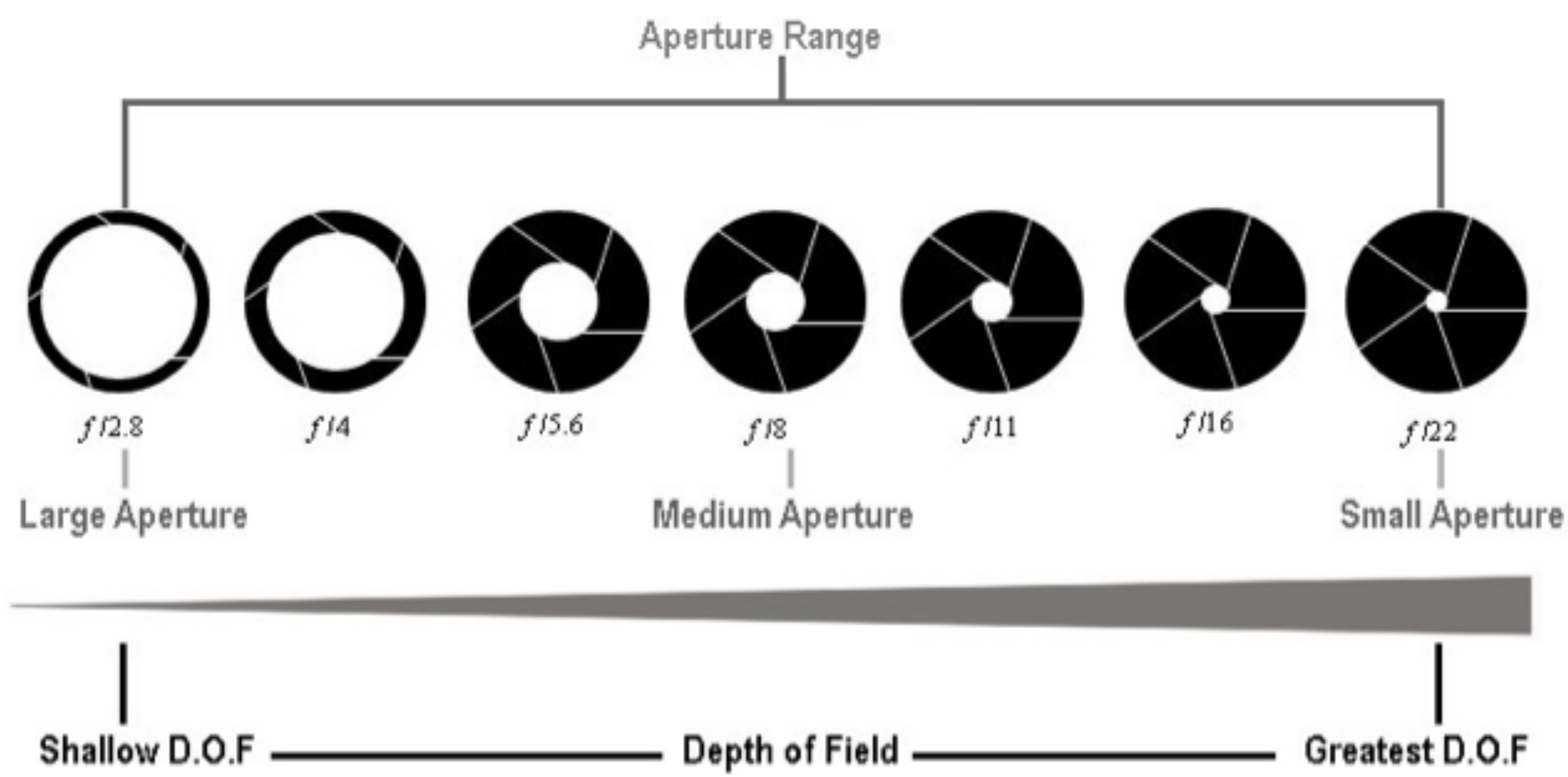
$$f/\# = \frac{1}{2\,(\mathrm{NA})}$$



PHOTOGRAPHY

- The aperture stop controls many things

Lets in more light



Lets in less light

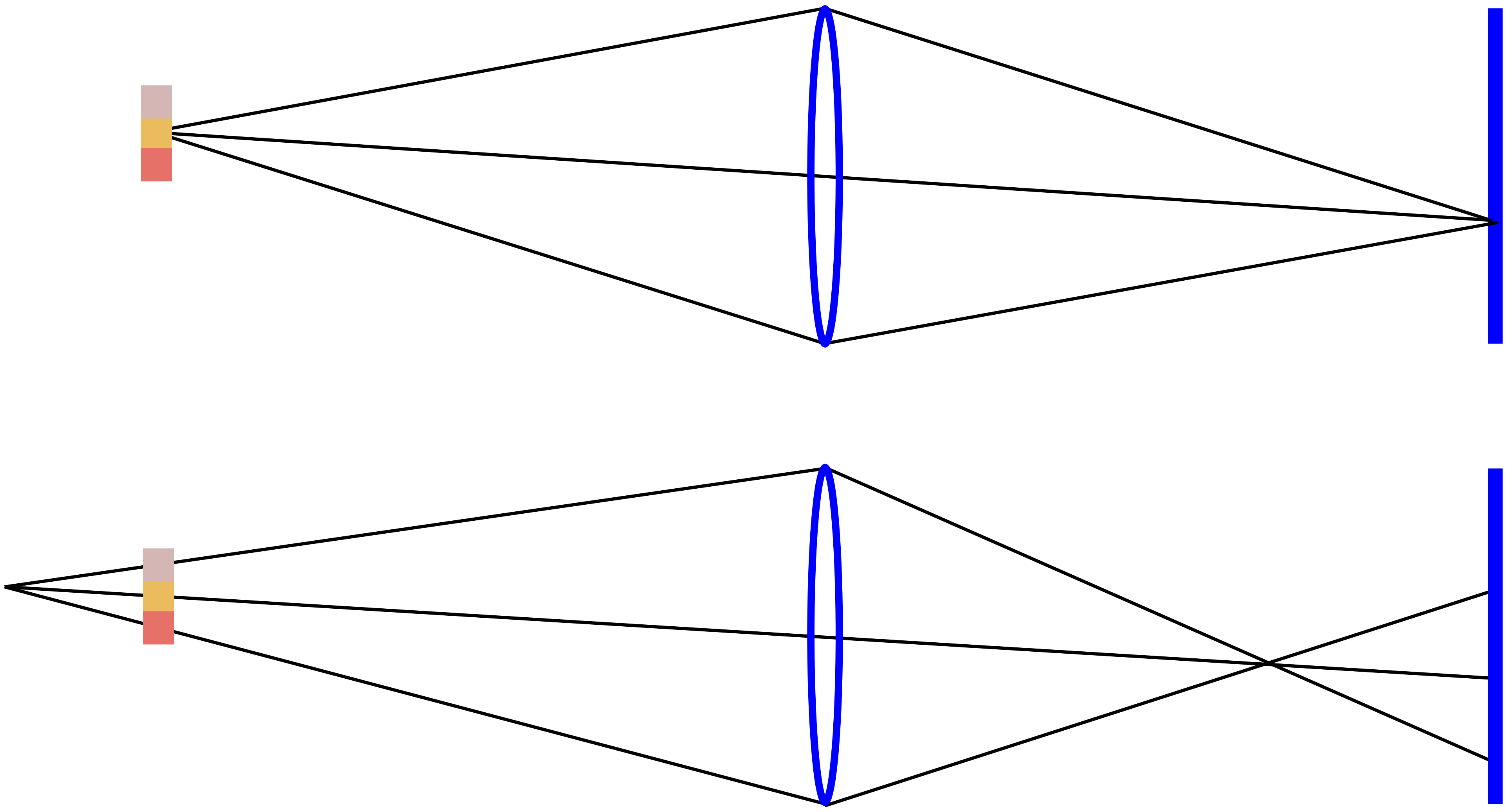
FIELD OF VIEW

NUMERICAL APERTURE

DEPTH OF FOCUS

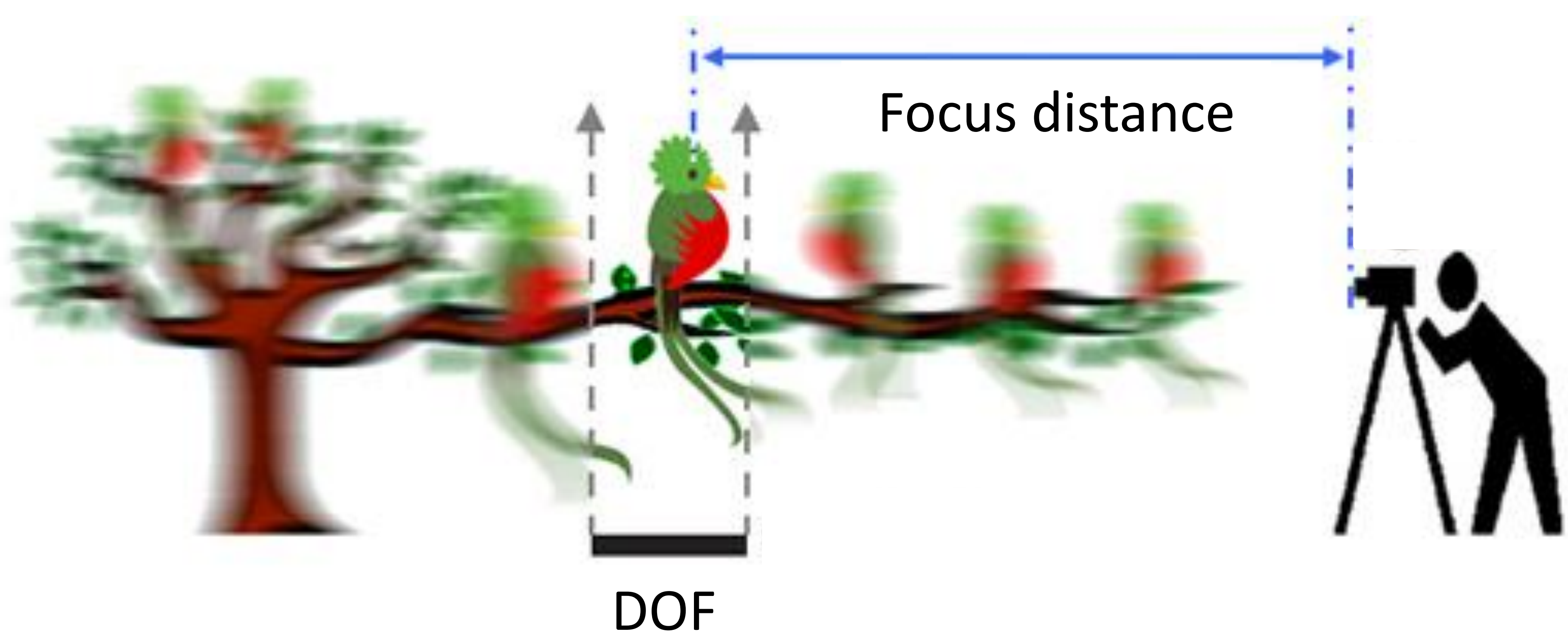
FUNDAMENTAL IMAGING CONSIDERATIONS

IN-FOCUS AND OUT-OF-FOCUS



DEPTH OF FIELD

- For a given image distance, the **depth of field** is the range of object distances for which the object stays in focus



DEPTH OF FIELD

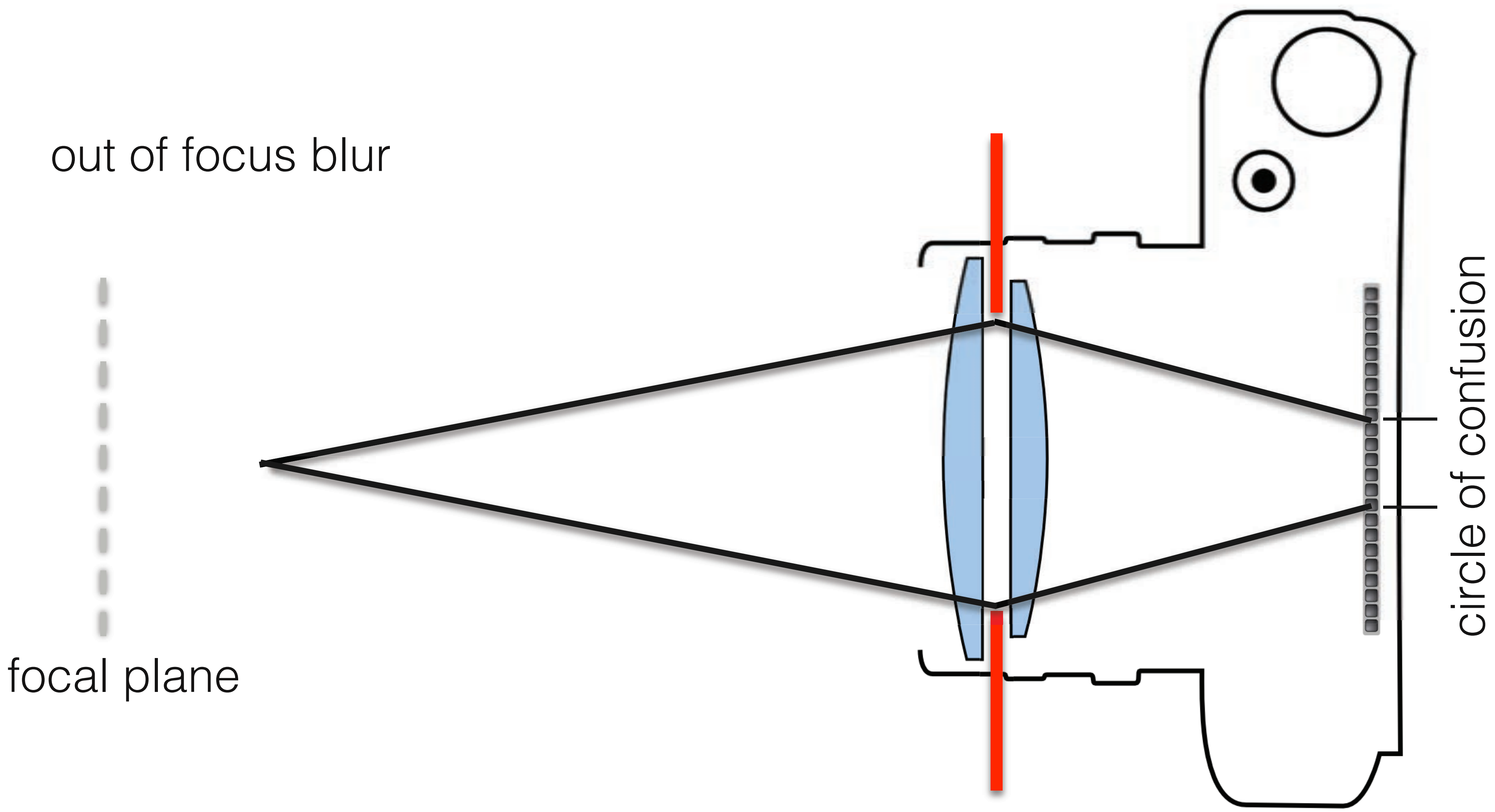
- DOF is proportional to the numerical aperture

f/22

f/8

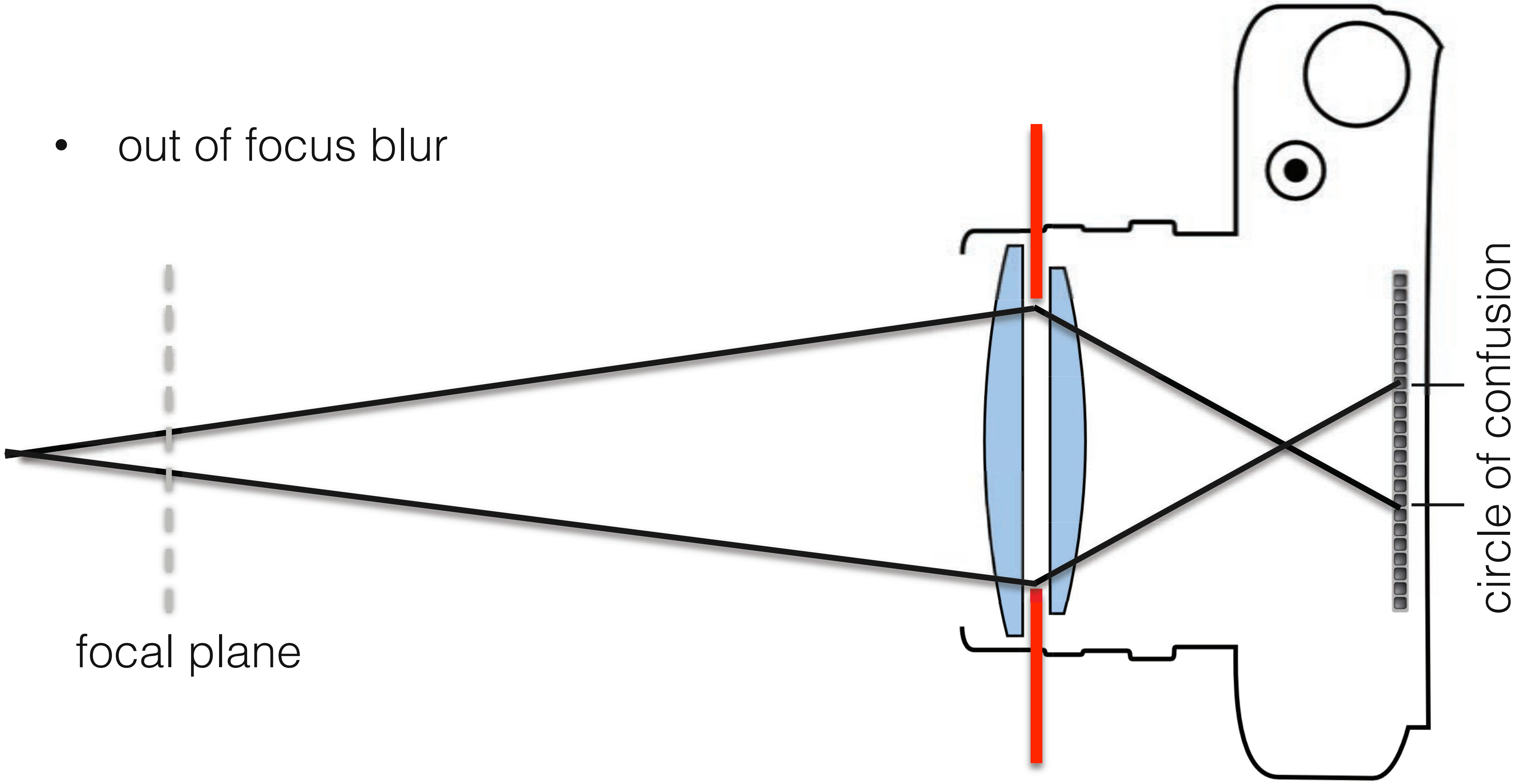
$$f/\# = \frac{1}{2\,(\mathrm{NA})}$$

UNDER FOCUS

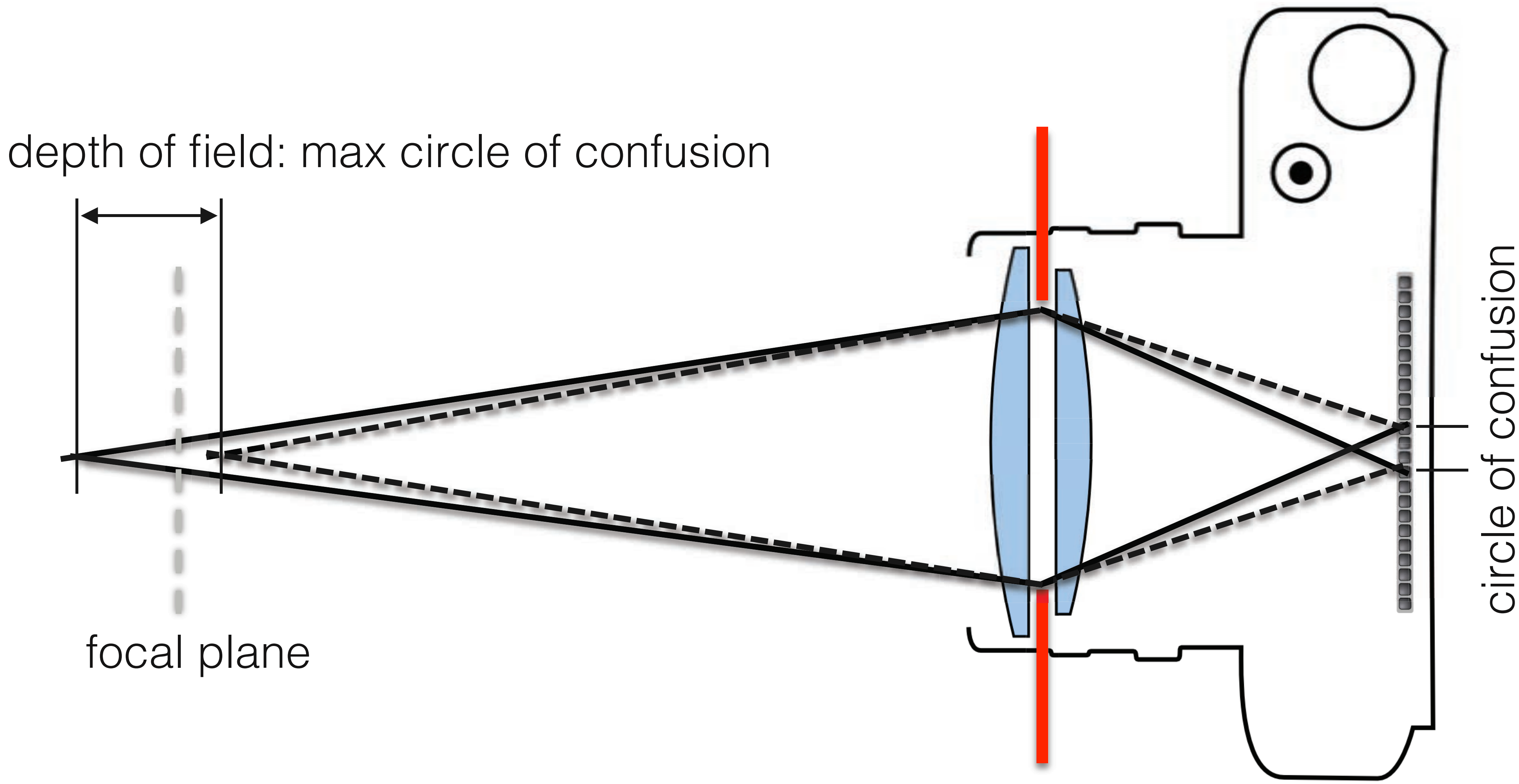


OVER FOCUS

- out of focus blur



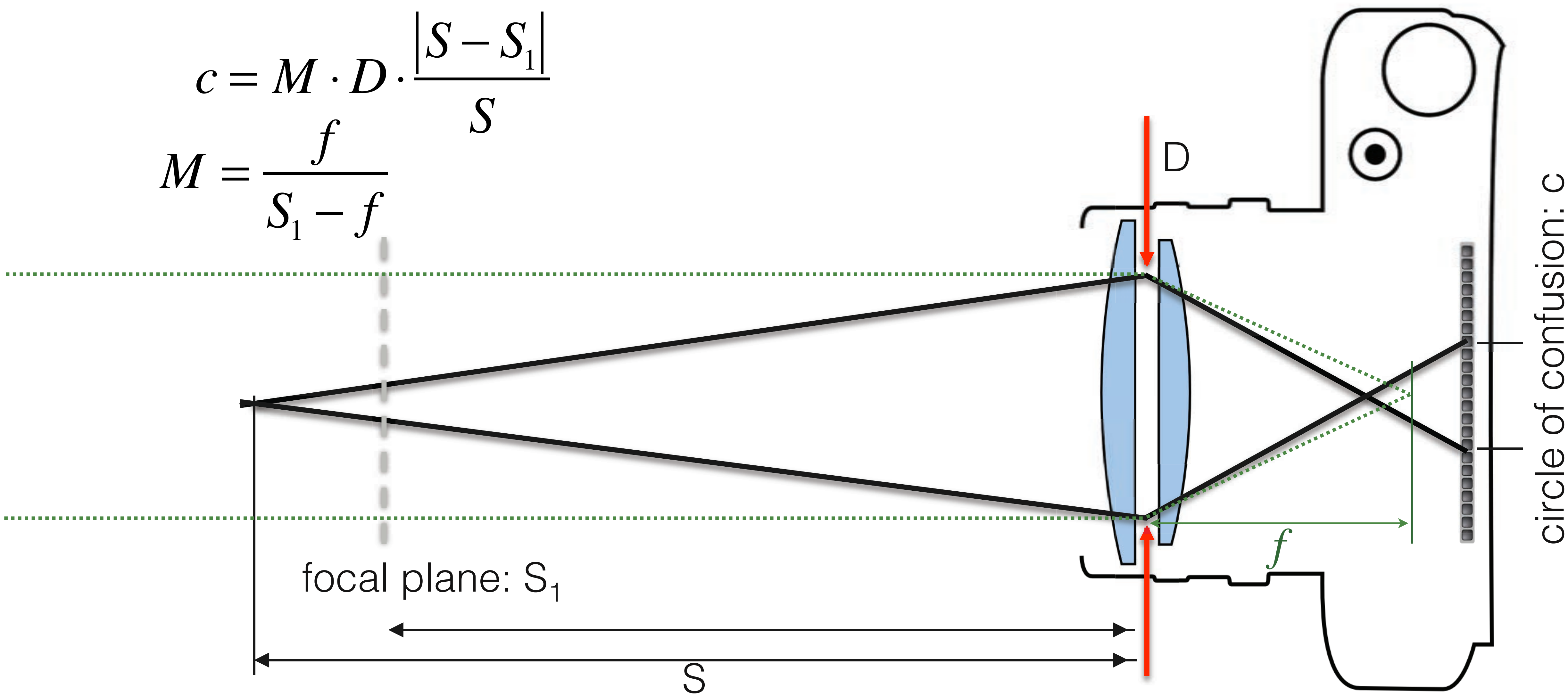
DEPTH OF FIELD



CIRCLE OF CONFUSION

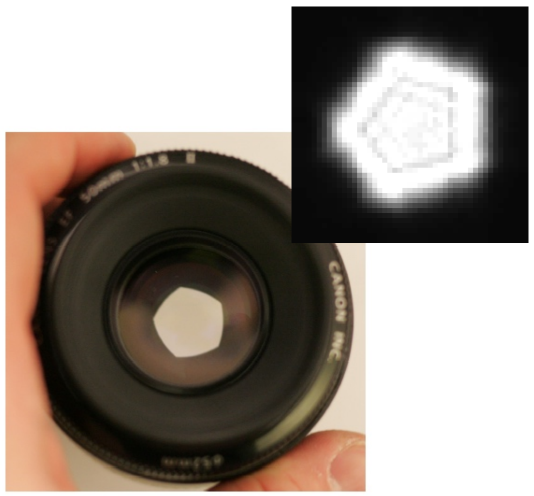
$$c = M \cdot D \cdot \frac{|S - S_1|}{S}$$

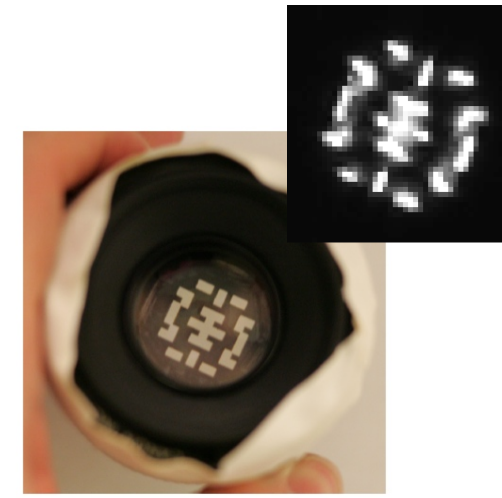
$$M = \frac{f}{S_1 - f}$$



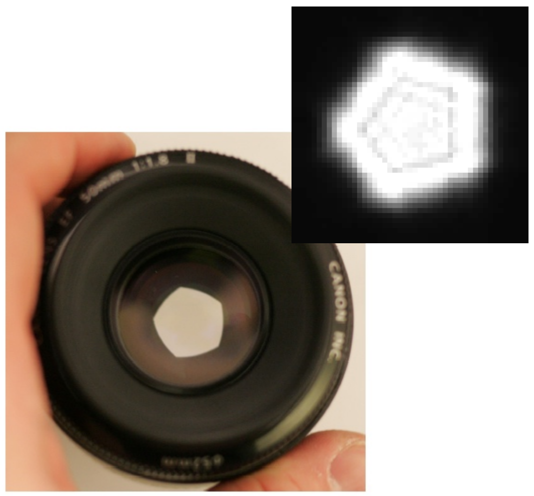
f is the focal distance of the lens

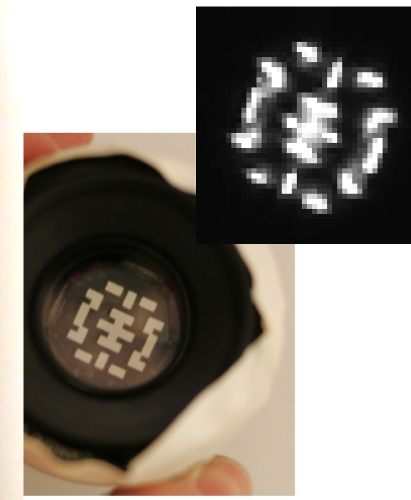
CODED-APERTURE FOR 3D IMAGING

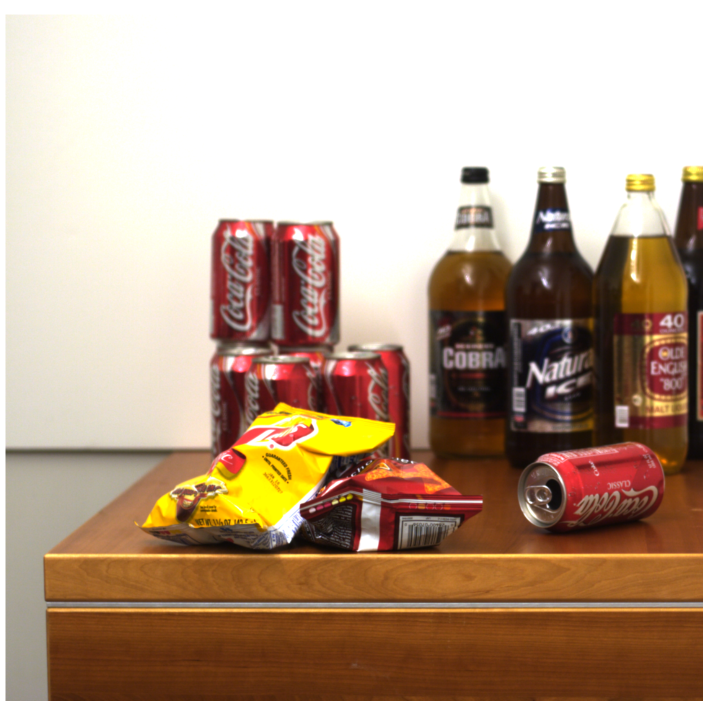


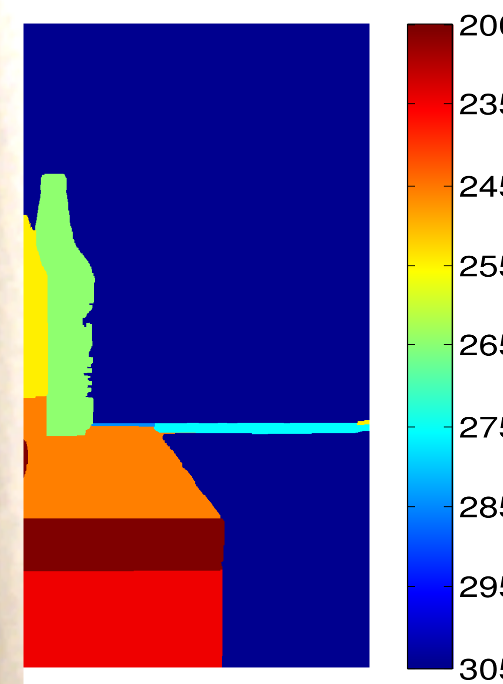


CODED-APERTURE FOR 3D IMAGING









CODED-APERTURE

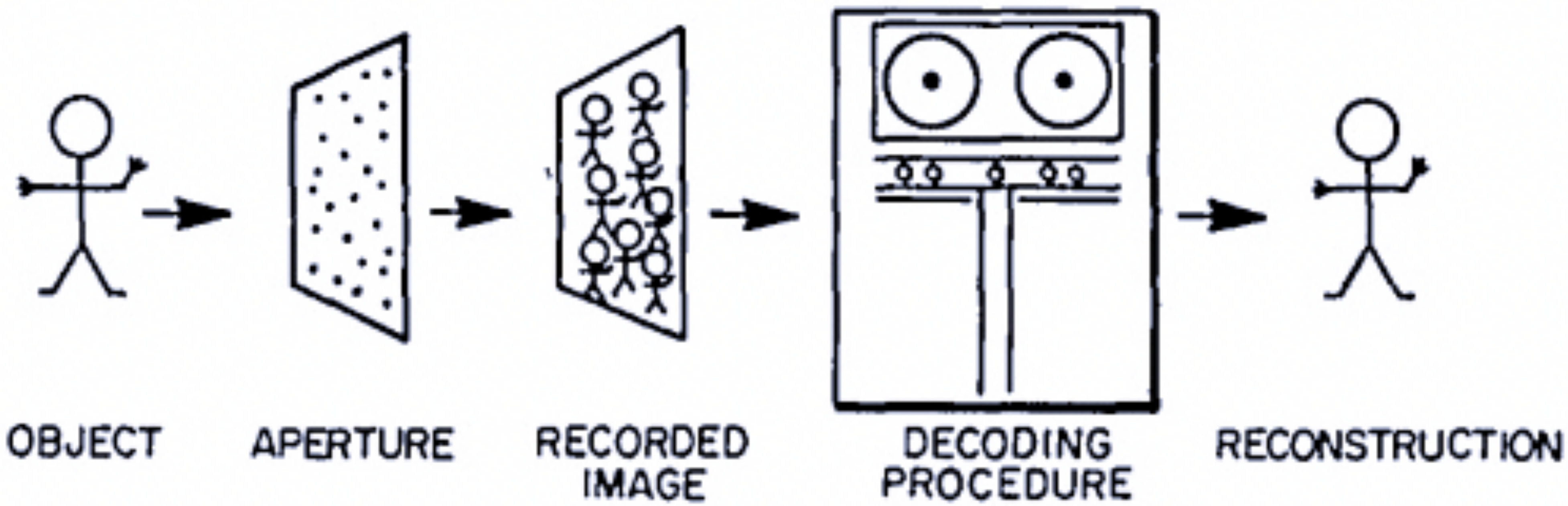
CODED-APERTURE

APPLICATION

CODED APERTURE IMAGING

CODED-APERTURE IMAGING

APPLICATION OF PINHOLE



- Widely used in x-rays, gamma rays
  - High-energy rays cannot be focused with lenses or mirrors
  - Blocking light with a known pattern, a coded "shadow" is cast upon a plane
  - Computational reconstruction of original object

E. E. Fenimore and T. M. Cannon, "Coded aperture imaging with uniformly redundant arrays," Appl. Opt. 17, 337-347 (1978)

ASSUMPTIONS

- The aperture is very close to the detector
- The aperture holes are assumed to be square and match the sensors of the detector
- Scene is in the far field – so no fall-off effects

Please complete the Student Assessment of Instruction Survey

NEXT TIME!

GROUP PRESENTATIONS