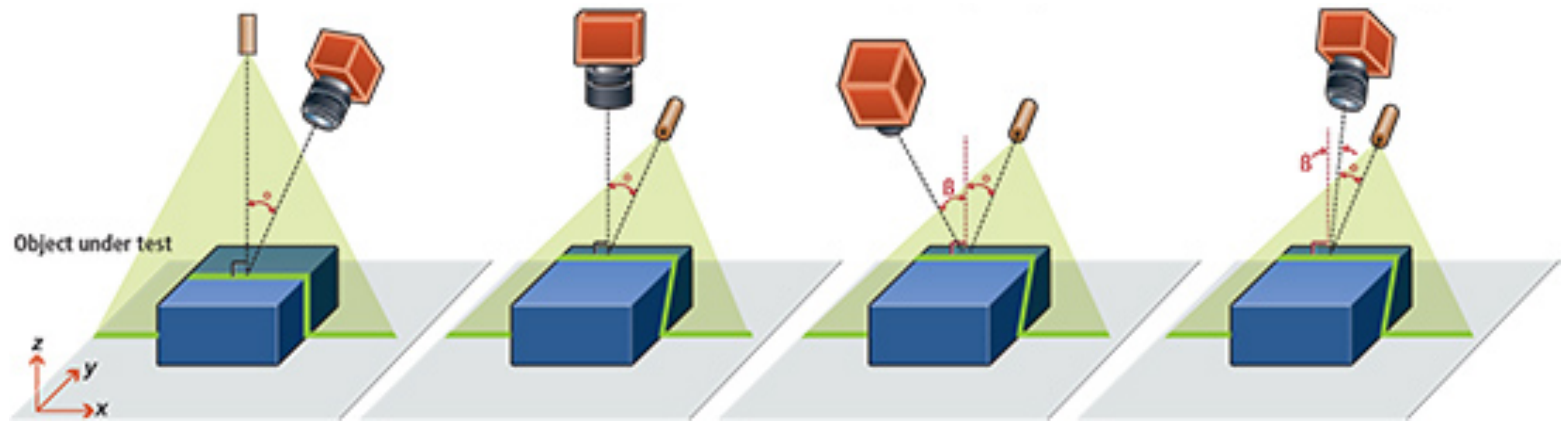
THE UNIVERSITY OF BRITISH COLUMBIA

CPSC 425: Computer Vision



Lecture 3: Image Formation (continued)

(unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung**)

Menu for Today (**September 11, 2024**)

Topics:

- **Lenses**
- Human **eye** (as a camera)
- Image as a **function**
- **Linear filtering**

Readings:

- **Today's** Lecture: Forsyth & Ponce (2nd ed.) 4.1, 4.5
- **Next** Lecture: none

Reminders:

- Complete **Assignment 0** (ungraded) by Wednsday, **September 11**
- **Assignment 1** (graded) is out Wednsday, **September 11**

Today's "**fun**" Example #1: Nudging

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Aerial view of the white stripes at the lake shore drive in Chicago.

Today's "**fun**" Example #1: **Anchoring** and Ordering

Champagne, Sparkling, Rose, Sweet Wines

Champagne

CH18	NV	GREMILLET "Brut Selection" - Champagne	$65
CH31	NV	ERNEST RAPENEAU "Selection Brut" - Champagne	$65
CH12	NV	CHAMPAGNE ERNEST RAPENEAU - BRUT - Chardonnay/Pinot Noir/Pinot Meunier -	$75
CH05	NV	DRAPPIER "Carte d'Or" - Champagne	$78
CH30	2007	ERNEST RAPENEAU VINTAGE - Chardonnay/ Pinot Noir - Champagne	$80
CH32	NV	ERNEST RAPENEAU "Premier Cru Brut" - Champagne	$80
CH28	NV	DRAPPIER Brut Rose - Champagne	$85
CH29	2012	DRAPPIER "Millesime Exception" - Champagne	$98
CH11	2008	DRAPPIER " Cuvee Grande Sendree" - Champagne	$130
CH39	NV	ERNEST RAPENEAU "Grande Reserve"- Magnum - Champagne	$130

Sparkling Wines

CH06	NV	IL CORTIGIANO - Prosecco Extra Dry - Veneto	$30
CH17	NV	VALLFORMOSA "Clasic" Semi Seco - Cava	$30
CH24	NV	VEUVE MOISANS "Blanc de Blancs" - Loire Valley	$30
CH25	NV	VALDO - Prosecco Extra Dry - Treviso, Veneto	$30
CH33	NV	VALDO "Origine" Rose - Veneto	$30
CH03	2012	CHATEAU MONTGUERET Saumur Sec Rose - Cabernet Franc - Loire Valley	$32
CH04	NV	CAVA MASET RESERVA BRUT - Macabeo/Xarello/Parellada - Cava	$32
CH14	NV	TRIVENTO "Brut Nature" - Mendoza	$32
CH21	2015	CAMASELLA - Glera - Vaneto	$32
CH02	2013	BRUT D'ARGENT ICE - Chardonnay - France	$35
CH01	NV	VALDO "ORO PURO" Prosecco Superiore - Veneto	$36
CH40	NV	MAISON DARRAGON - AOC Vouvray Brut - Loire Valley	$38
CH09	NV	LOU MIRANDA ESTATE 'LEONE' - Sparkling Shiraz - Barossa Valley	$42

Rose Wines

PO03	2014	CASAL MENDES Rose - Baga - Portugal	$30
RH09	2014	LA VIE EN ROSE - Cinsault - Languedoc	$30
RH69	2015	LES EMBRUNS "La Croix des Saintes" - Sable de Camargue	$30
RH04	2015	LES MAITRES VIGNERONS DE ST TROPEZ - Cotes de Provence	$32
RH15	2015	MANON - COTES DE PROVENCE - Grenache/Cinsault/Syrah. - Provence	$34
RH04M	2015	LES MAITRES VIGNERONS DE LA PRESQU'ILE DE SAINT TROPEZ - Grenache/Mourve	$68

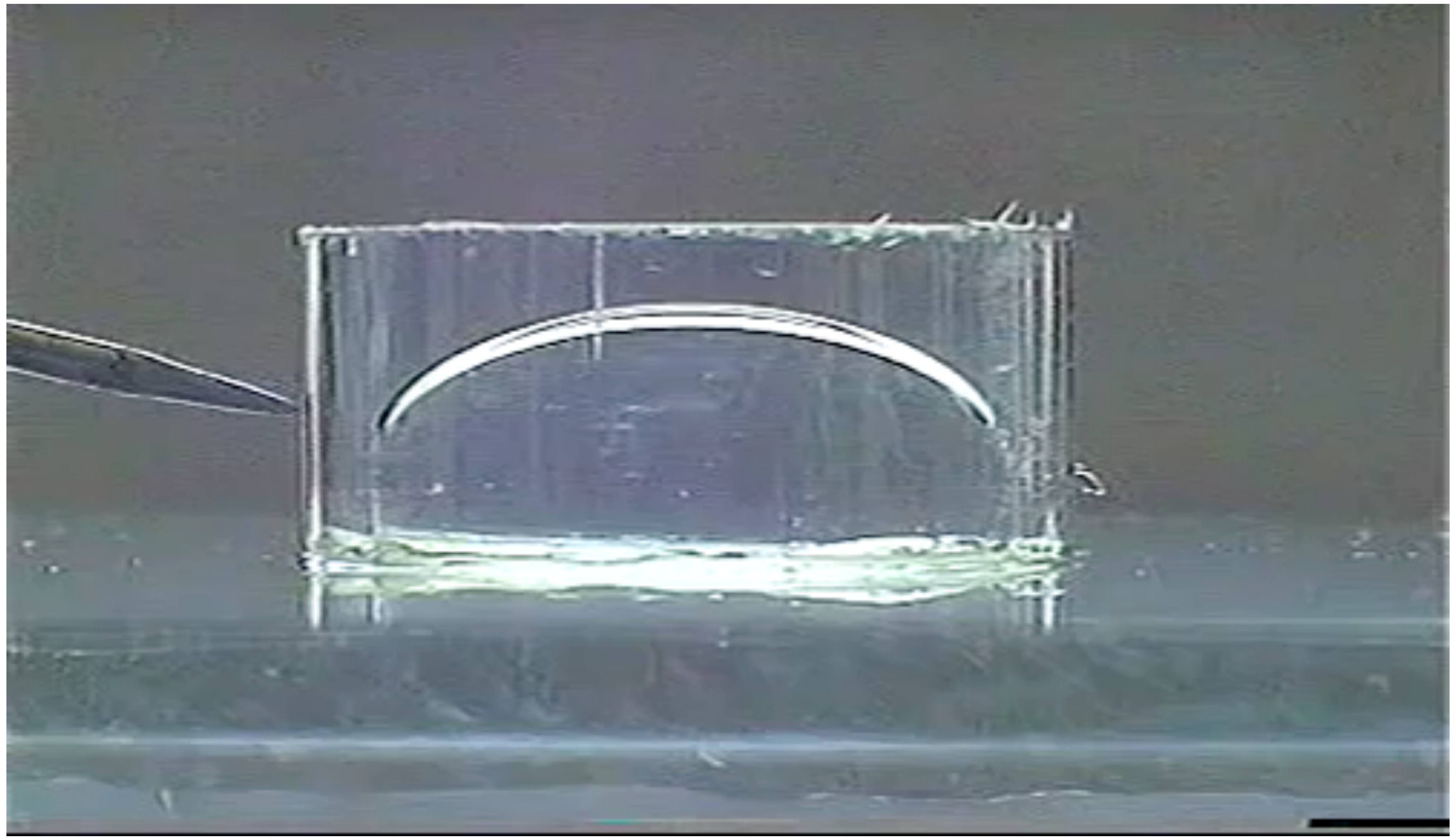
Sweet Wines

AR33	2015	TRIVENTO "Birds & Bees" White - Mendoza	$30
AR34	2016	TRIVENTO "Birds & Bees" Red - Mendoza	$30
AU05	2015	DEAKIN ESTATE - Moscato - Murray Darling	$30
AU12	2016	Chalk Hill - Moscato - McLaren Vale	$30
AU68	NV	WESTEND ESTATE "Richland" - Moscato - New South Wales	$30
AU107	NV	WESTEND ESTATE "Richland" - Pink Moscato - New South Wales	$30

Today's "**fun**" Example #2:

Developed by the French company **Varioptic**, the lenses consist of an oil-based and a water-based fluid sandwiched between glass discs. Electric charge causes the boundary between oil and water to change shape, altering the lens geometry and therefore the lens focal length

The intended applications are: **auto-focus** and **image stabilization**. No moving parts. Fast response. Minimal power consumption.



Video Source: https://www.youtube.com/watch?v=2c6lCdDFOY8

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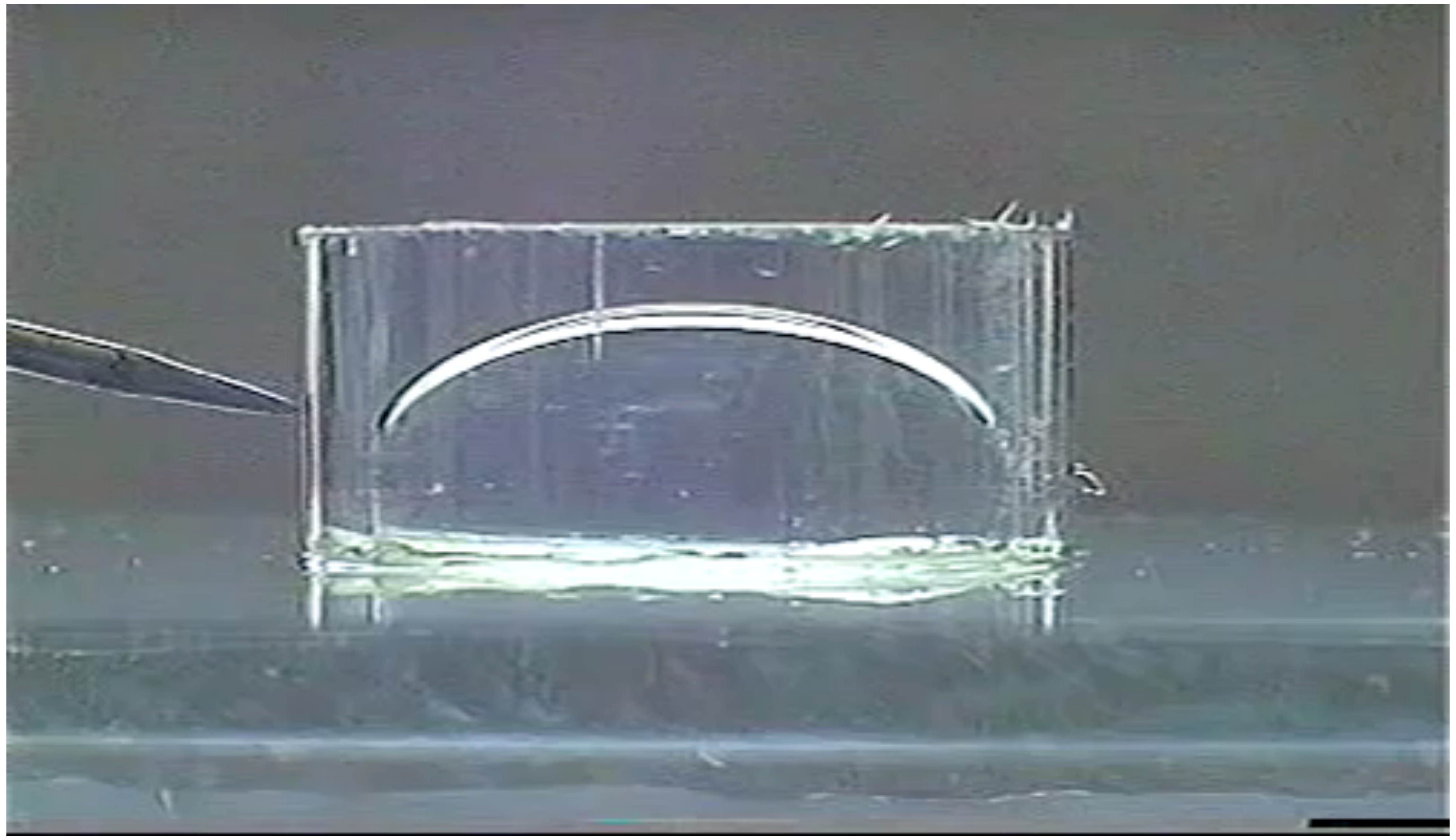

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Today's "**fun**" Example #2:

Electrostatic field between the column of water and the electron (other side of power supply attached to the pipe) — see full video for complete explanation

Video Source: https://www.youtube.com/watch?v=NjLJ77IuBdM

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As one example, in 2010, **Cognex** signed a license agreement with Varioptic to add auto-focus capability to it DataMan line of industrial ID readers (press release May 29, 2012)

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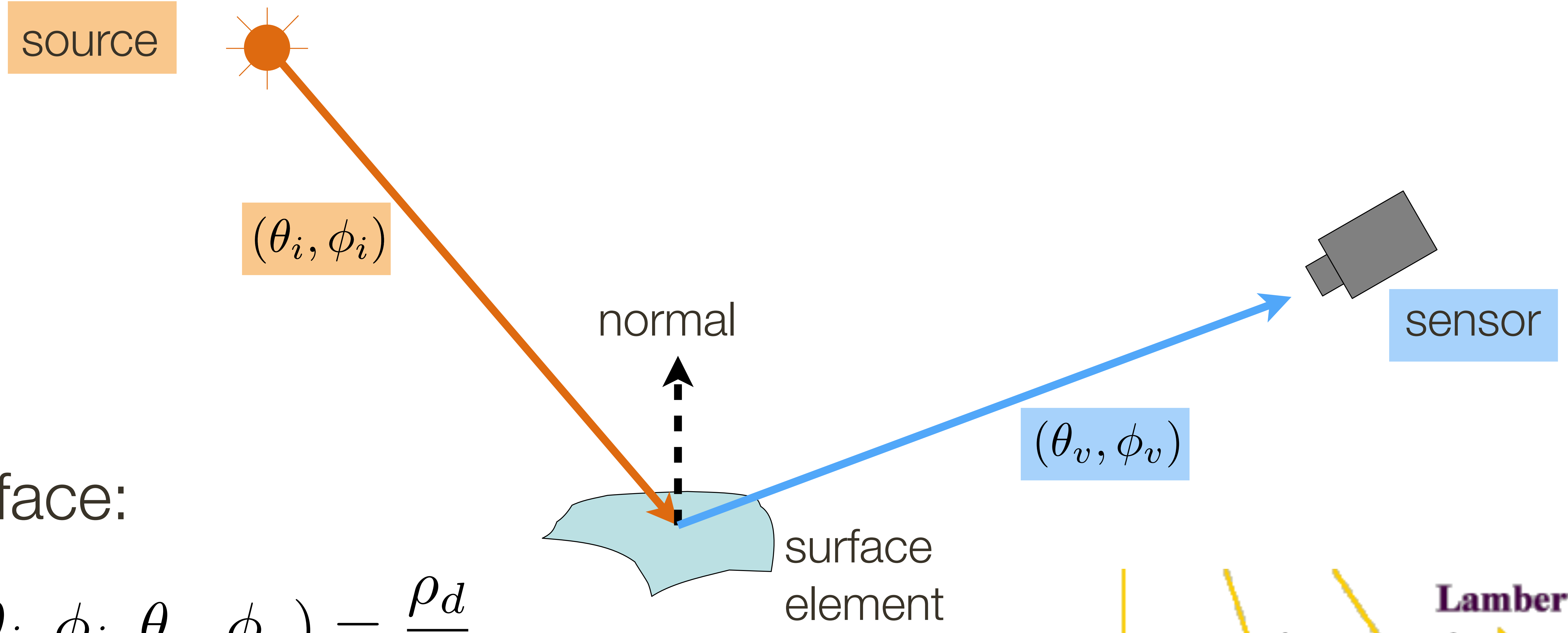
Lecture 2: Re-cap Light and Reflection

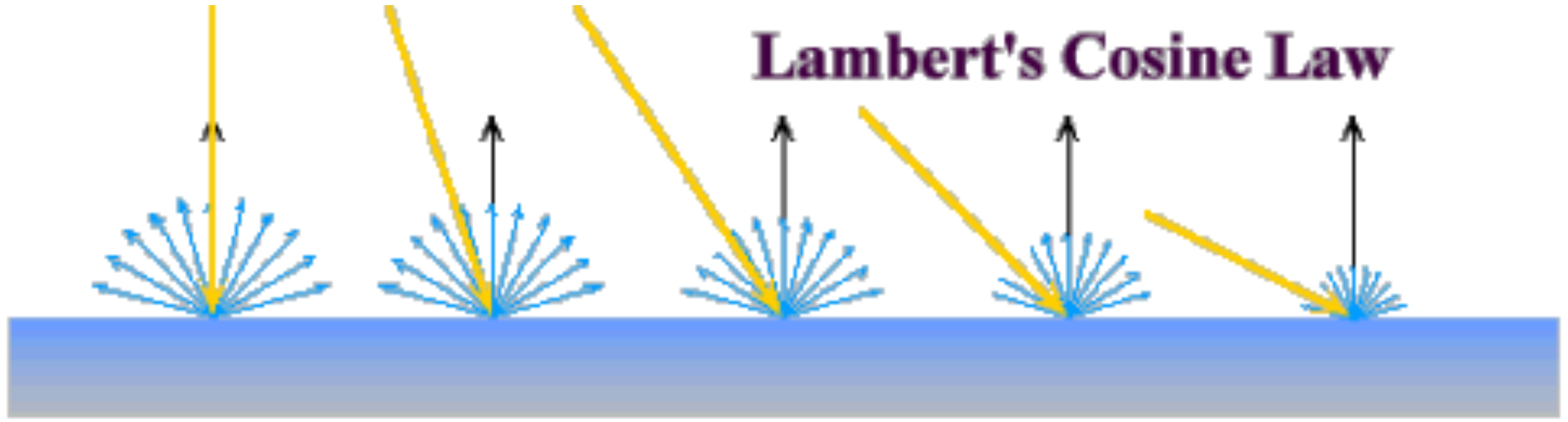
Surface reflection depends on both the **viewing** (θ_v, ϕ_v) and **illumination** (θ_i, ϕ_i) direction, with Bidirectional Reflection Distribution Function: $\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v)$



Lambertian surface:

$$\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{\rho_d}{\pi}$$

$$L = \frac{\rho_d}{\pi} I(\vec{i} \cdot \vec{n})$$



Slide adopted from: Ioannis (Yannis) Gkioulekas (CMU)

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To sum up: For a perfect **lambertian** surface reflected light is

(1) amount and color of incident light — I

(2) fraction of light being reflected (material) — ρ_d

(3) angle between the light and the surface (geometry) — $(\vec{i} \cdot \vec{n})$

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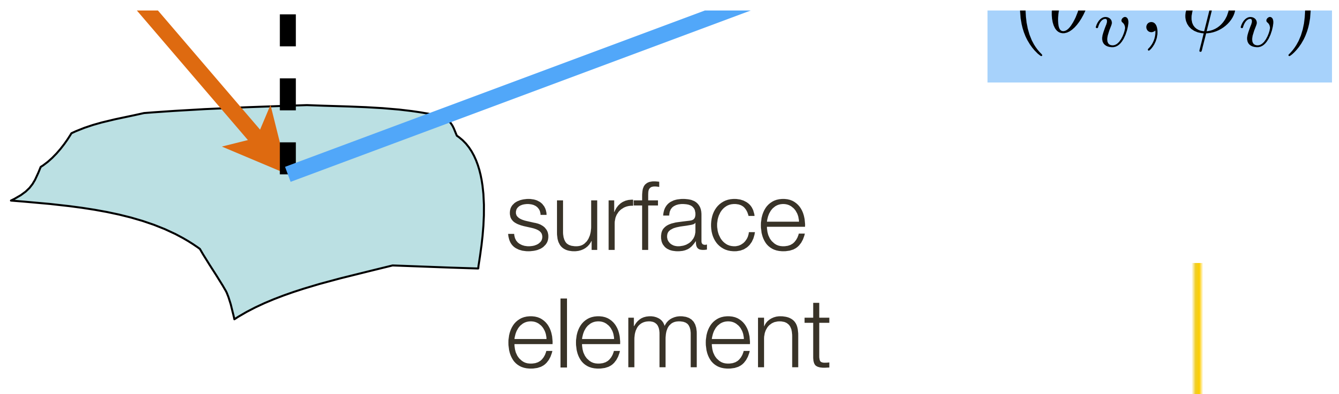

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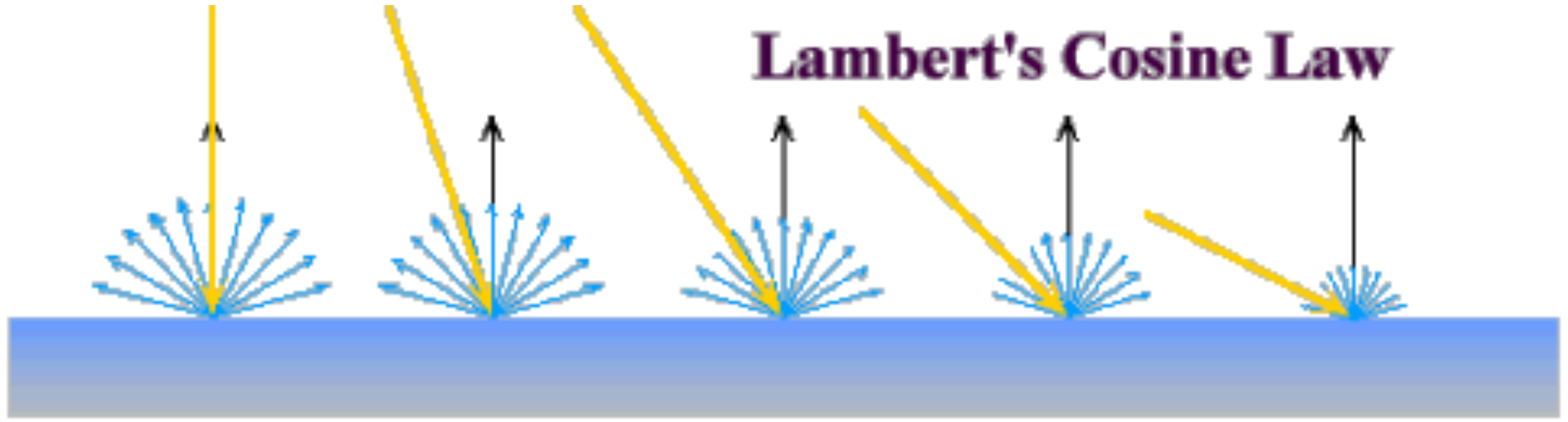

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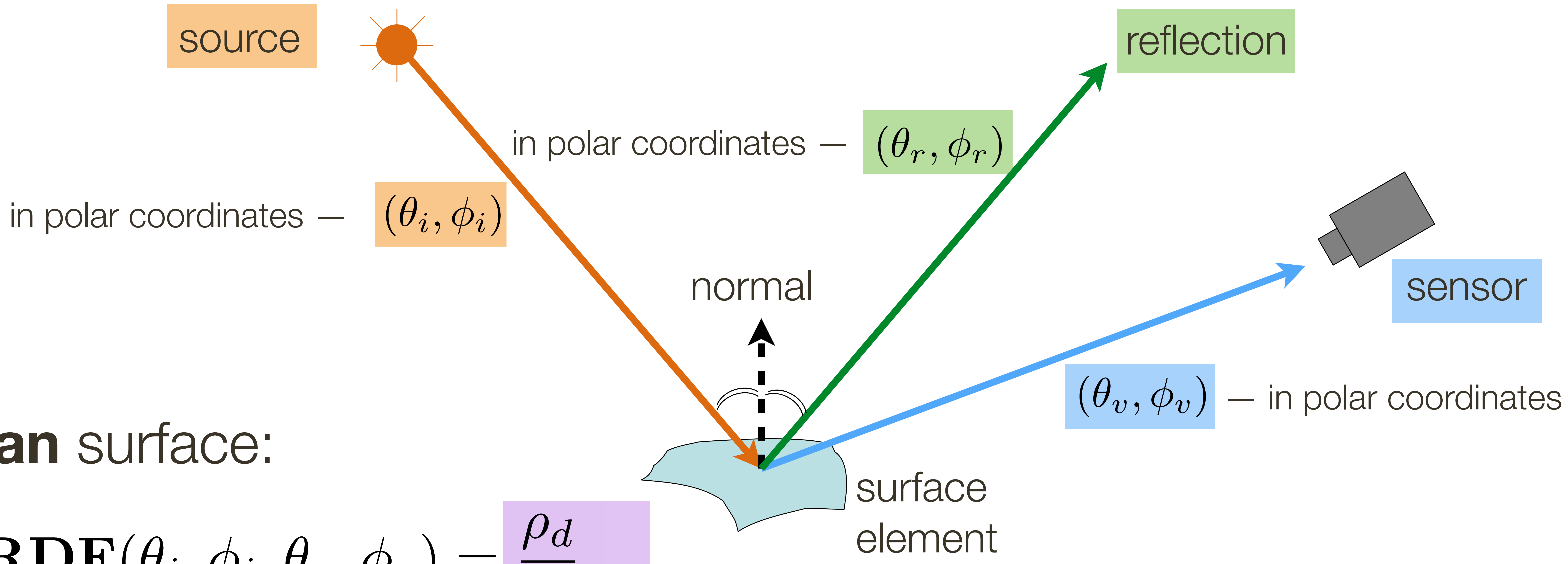

Lambertian surface:

$$\mathbf{BRDF}(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{\rho_d}{\pi}$$

constant, called **albedo**

Mirror surface: all incident light reflected in one directions $(\theta_v, \phi_v) = (\theta_r, \phi_r)$

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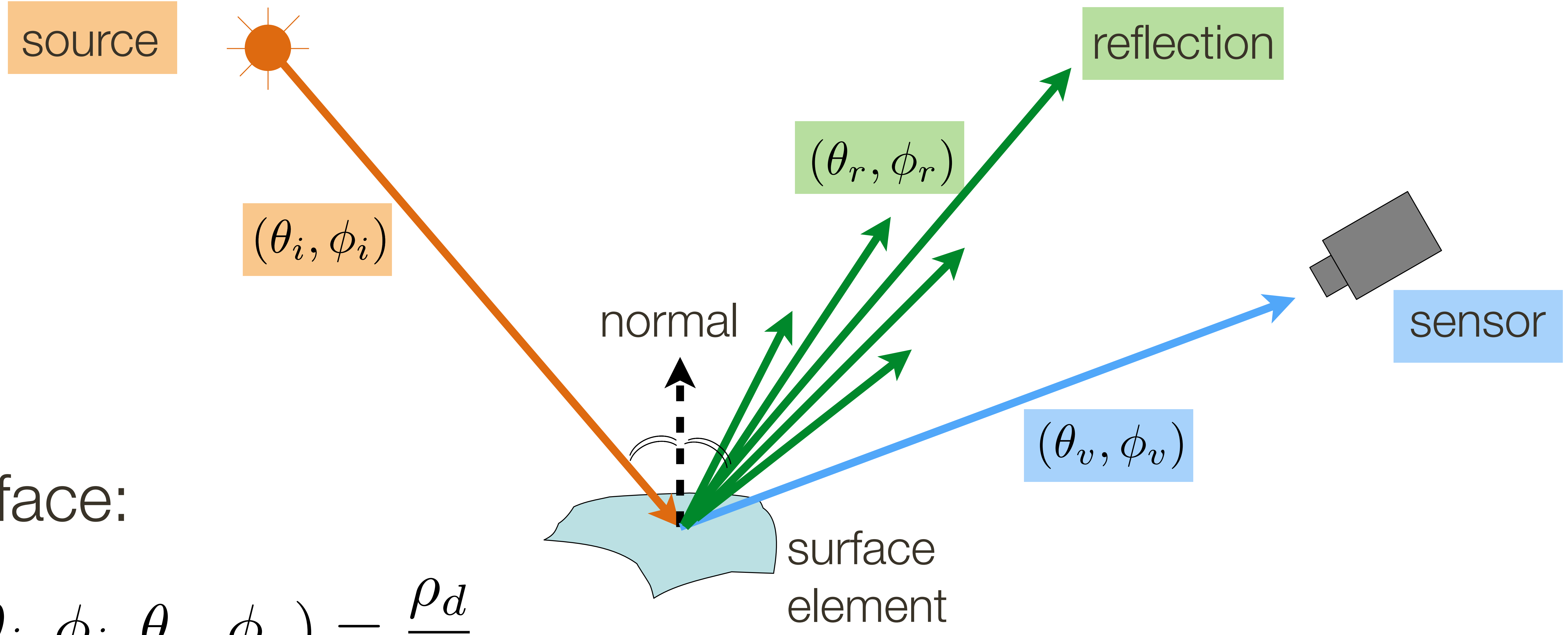

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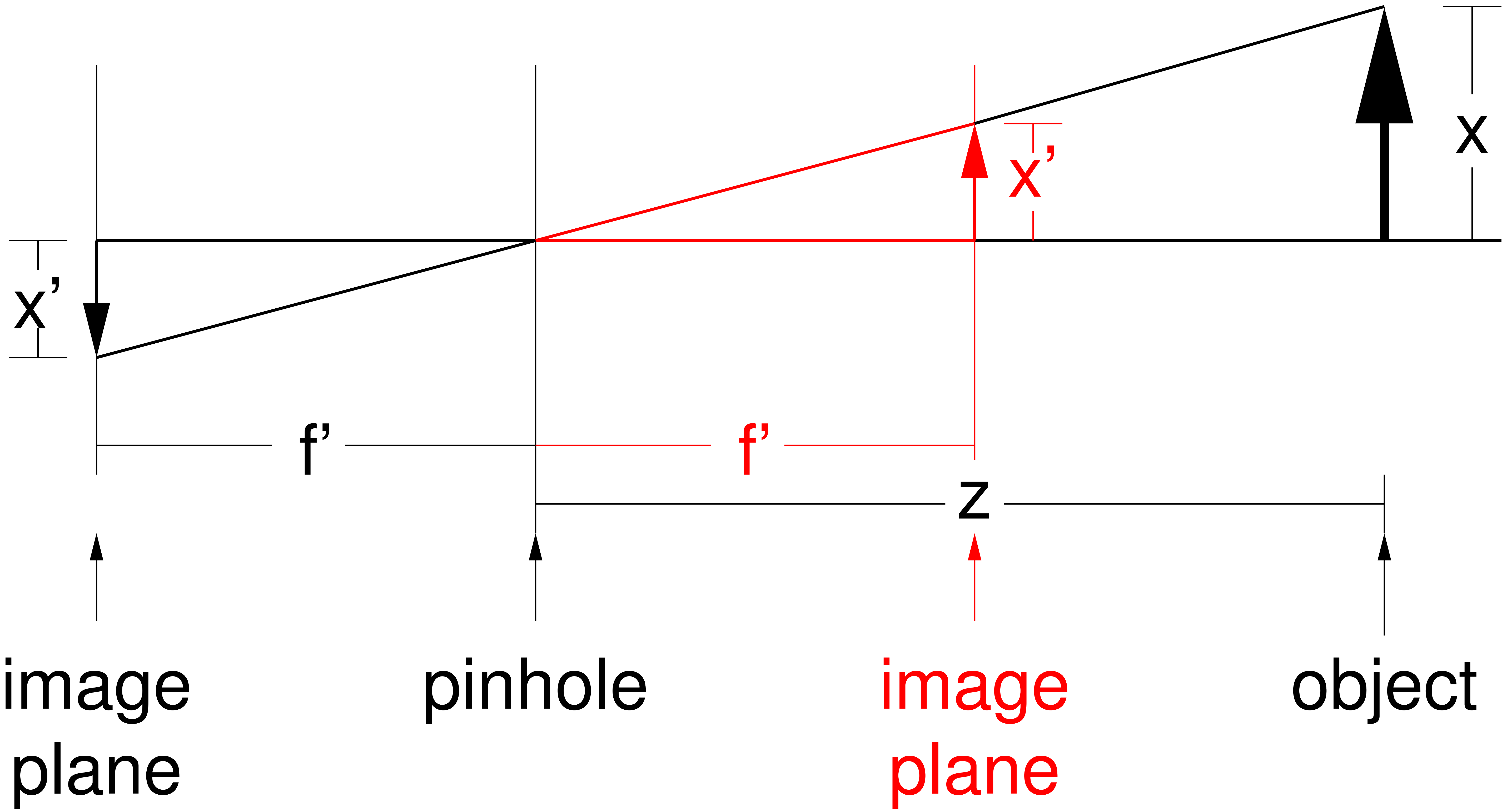
Lecture 2: Re-cap Pinhole Camera Abstraction

Pinhole Camera Abstraction



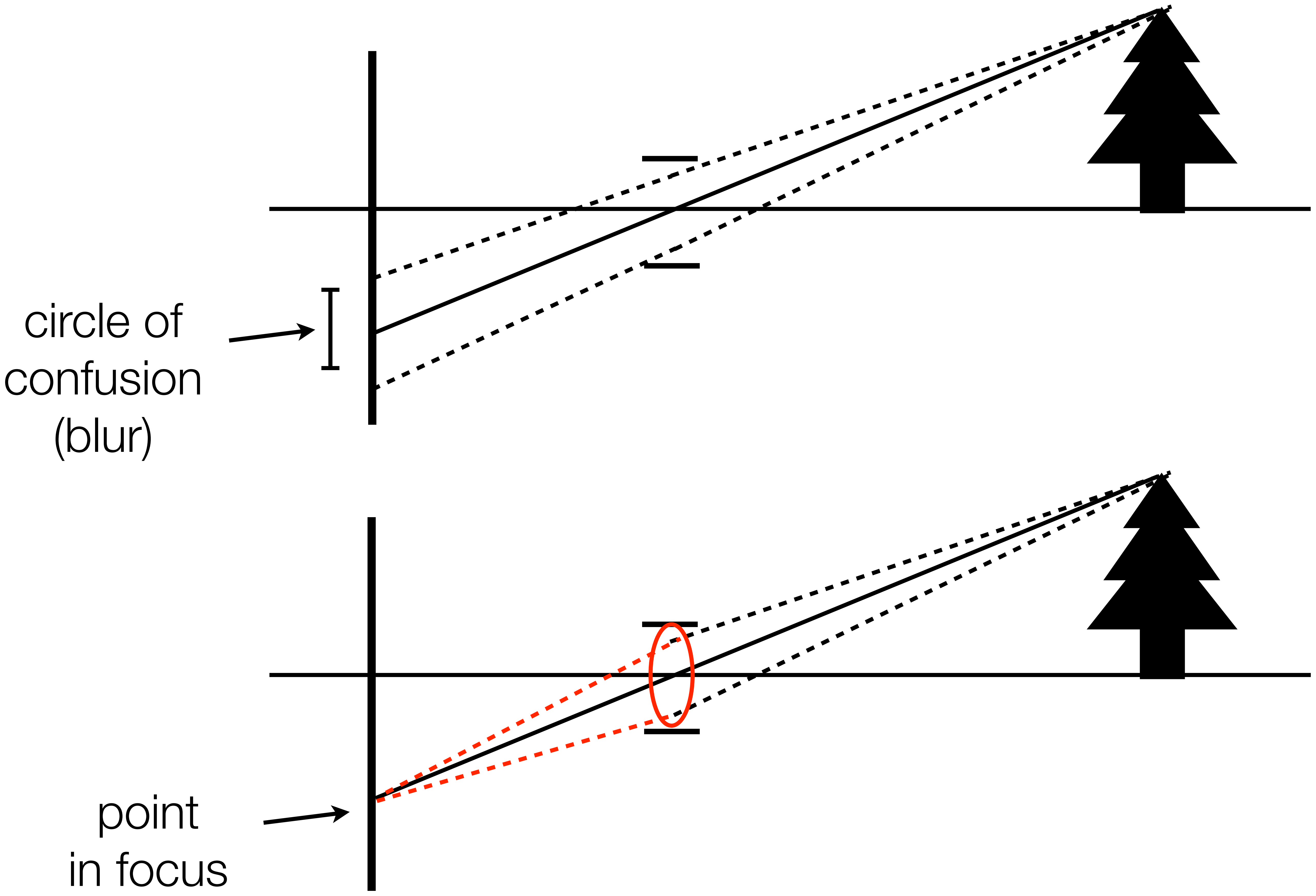
Lecture 2: Re-cap Projection

3D object point $P = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$ projects to 2D image point $P' = \begin{bmatrix} x' \\ y' \end{bmatrix}$ where

Perspective	$x' = f' \frac{x}{z}$ $y' = f' \frac{y}{z}$
Weak Perspective	$x' = m\,x$ $y' = m\,y$ $m = \frac{f'}{z_0}$
Orthographic	$x' = x$ $y' = y$

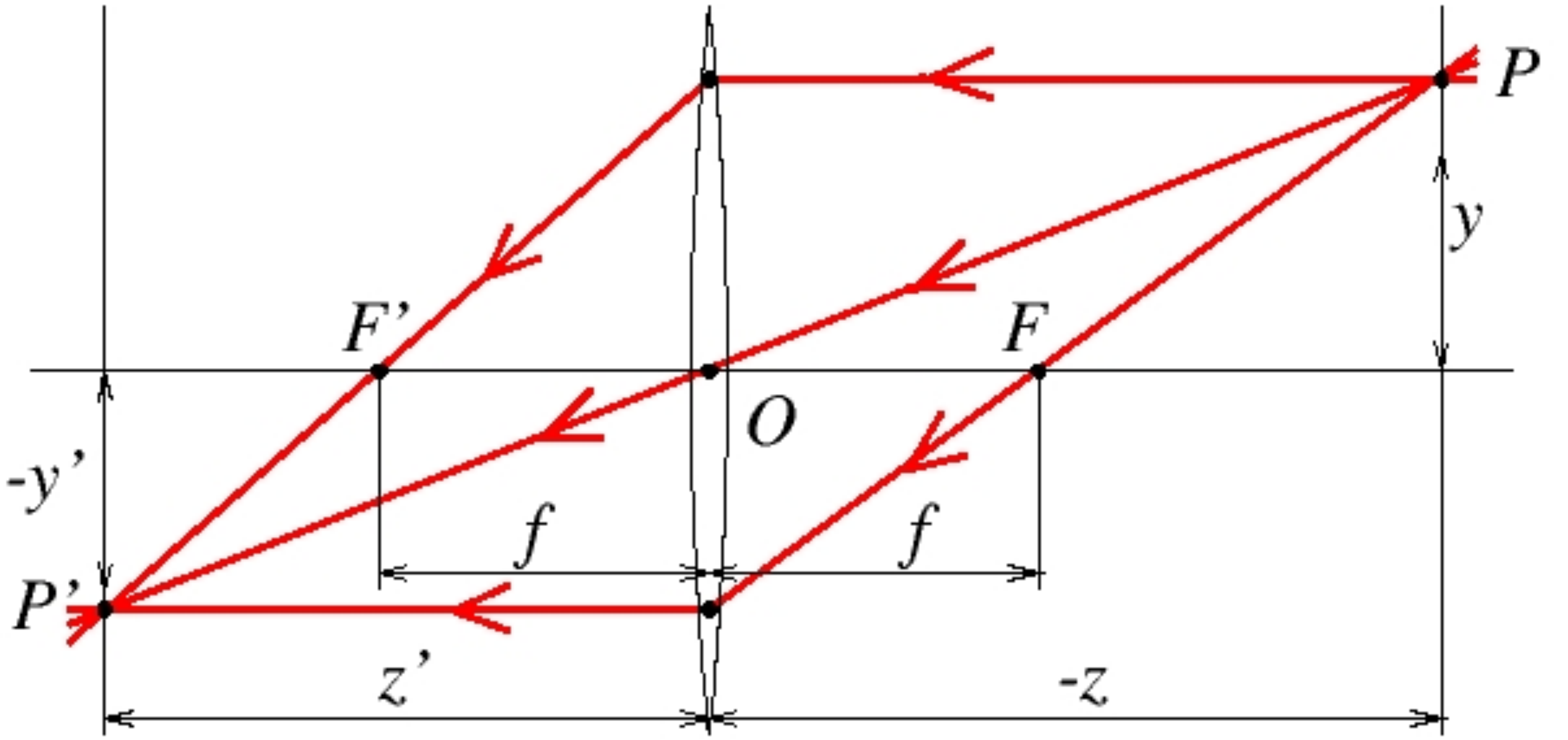
Lecture 2: Re-cap Reason for Lenses

A real camera must have a finite aperture to get enough light, but this causes blur in the image



Solution: use a **lens** to focus light onto the image plane

Lecture 2: Re-cap Thin Lens Equation

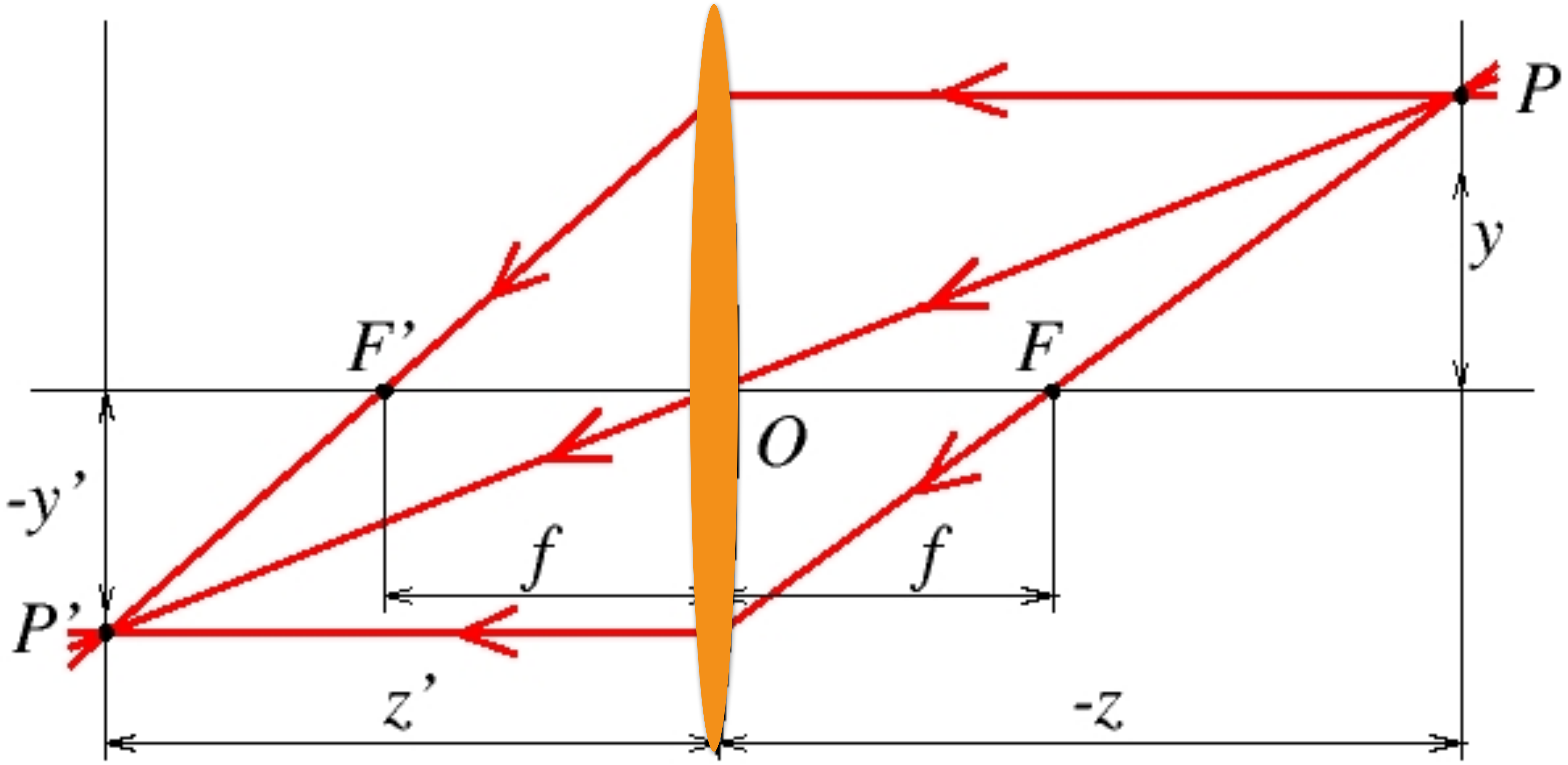


Forsyth & Ponce (1st ed.) Figure 1.9

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

Lecture 2: Re-cap Thin Lens Equation

Focal Length: Property of the lens (geometry and refraction index)



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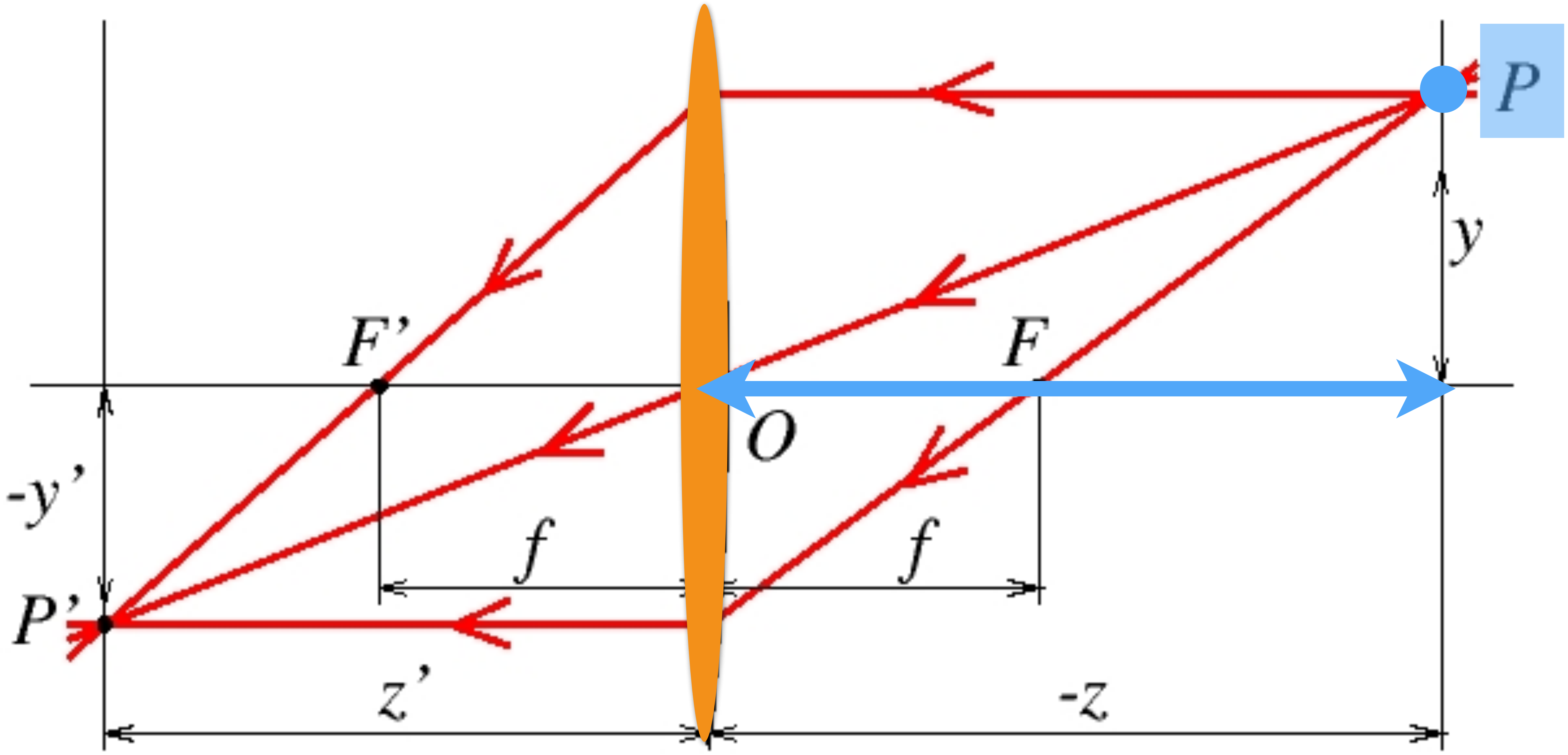

Depth of the point (P) in the world

Forsyth & Ponce (1st ed.) Figure 1.9

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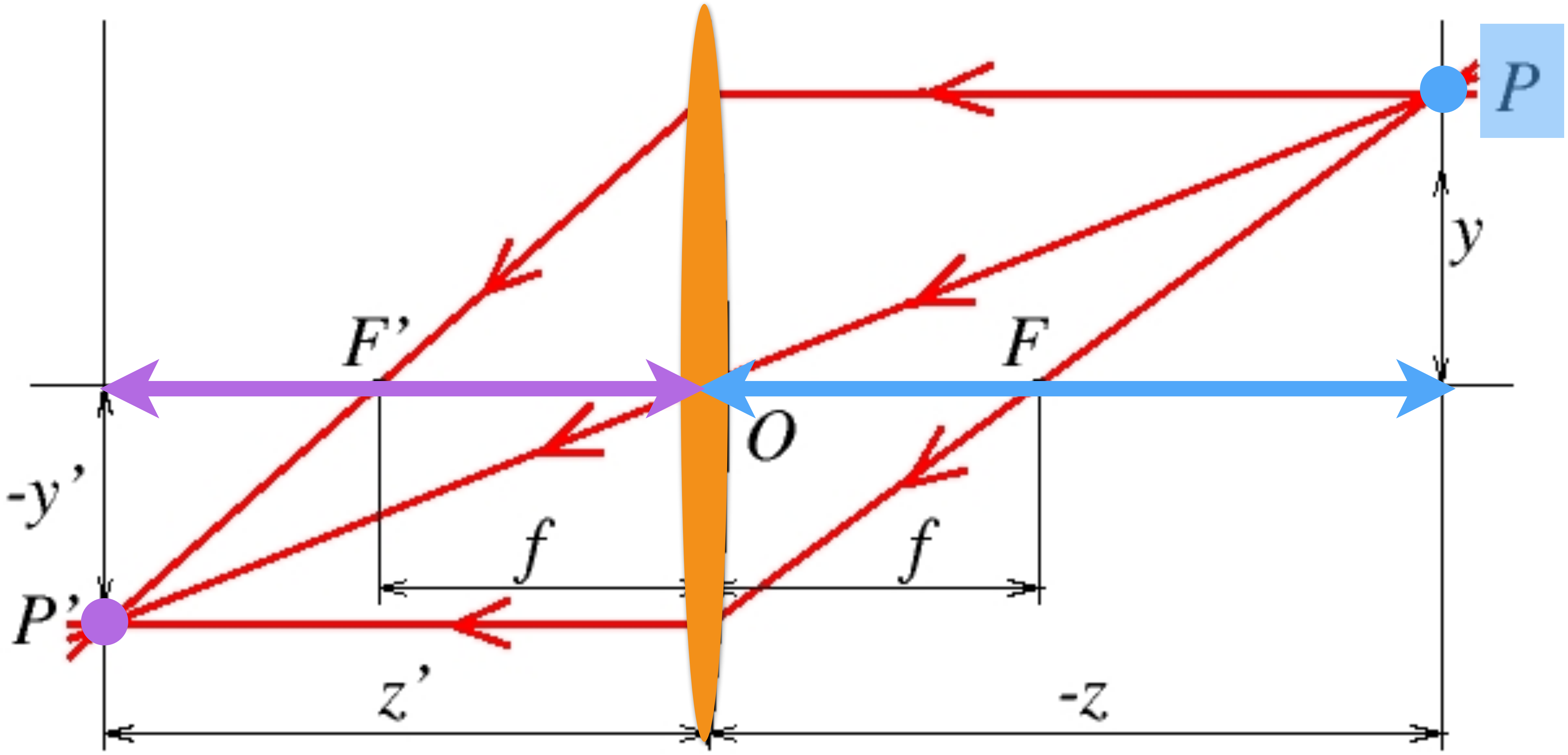
Lecture 2: Re-cap Thin Lens Equation

Focal Length: Property of the lens (geometry and refraction index)

Location of the imaging plane where the projection of this point (P) will be in focus



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Pinhole Camera with a **Lens**

Perspective Projection: location in the image where a 3D world point projects

$$x' = f' \frac{x}{z}$$
$$y' = f' \frac{y}{z}$$

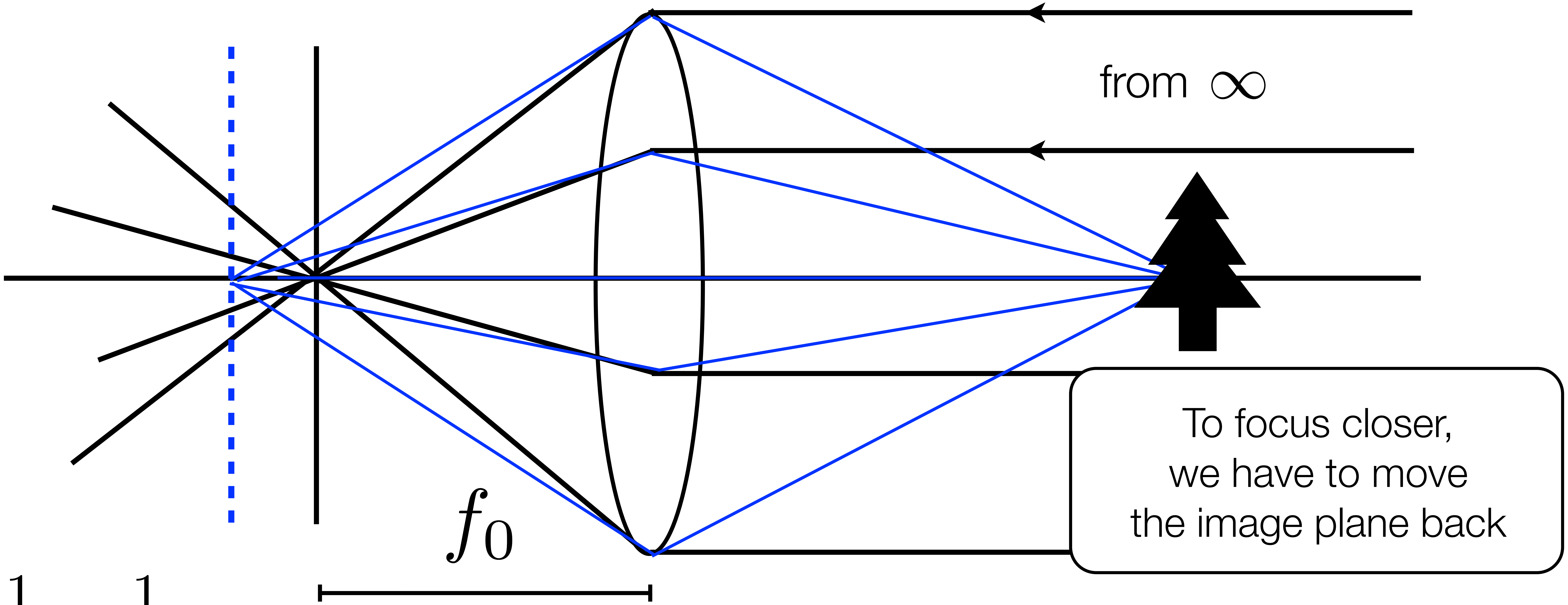
Thin Lens Equation: depth of the imaging plane itself where this point will be in focus

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

Lens Basics

A lens focuses parallel rays (from points at infinity) at focal length of the lens

Rays passing through the center of the lens are not bent



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Lens Basics

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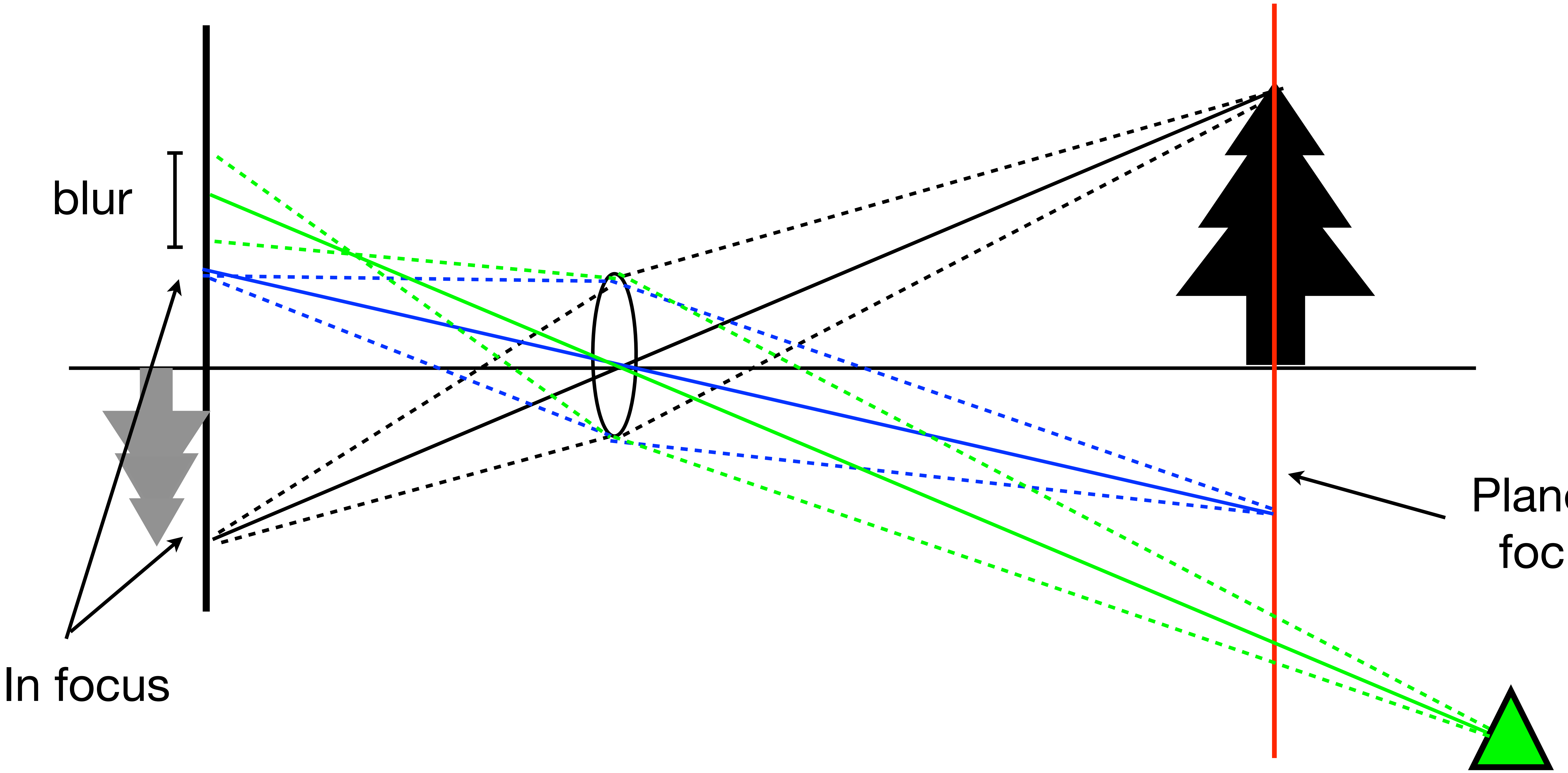
Lenses focus all rays from a (parallel to lens) plane in the world



Objects off the plane are blurred depending on the distance

Perspective Projection + **Thin Lens** Examples

Where would the focusing plane be for various positions of the object?

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

https://www.physicsclassroom.com/class/refrn/Lesson-5/Converging-Lenses-Object-Image-Relations

Perspective Projection + **Thin Lens** Examples

Where would the focusing plane be for various positions of the object?

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

$$z' = \frac{zf}{z+f}$$

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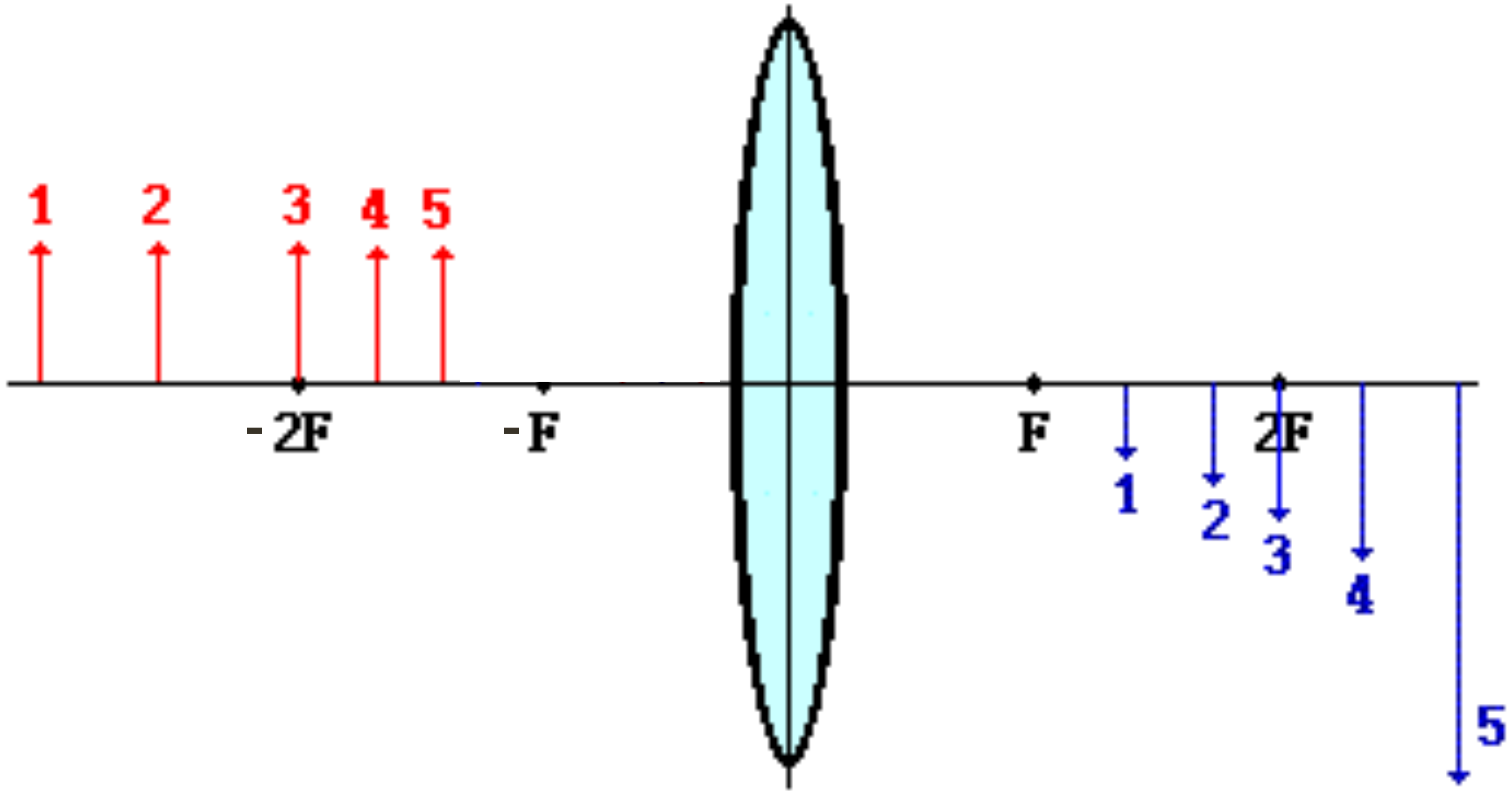

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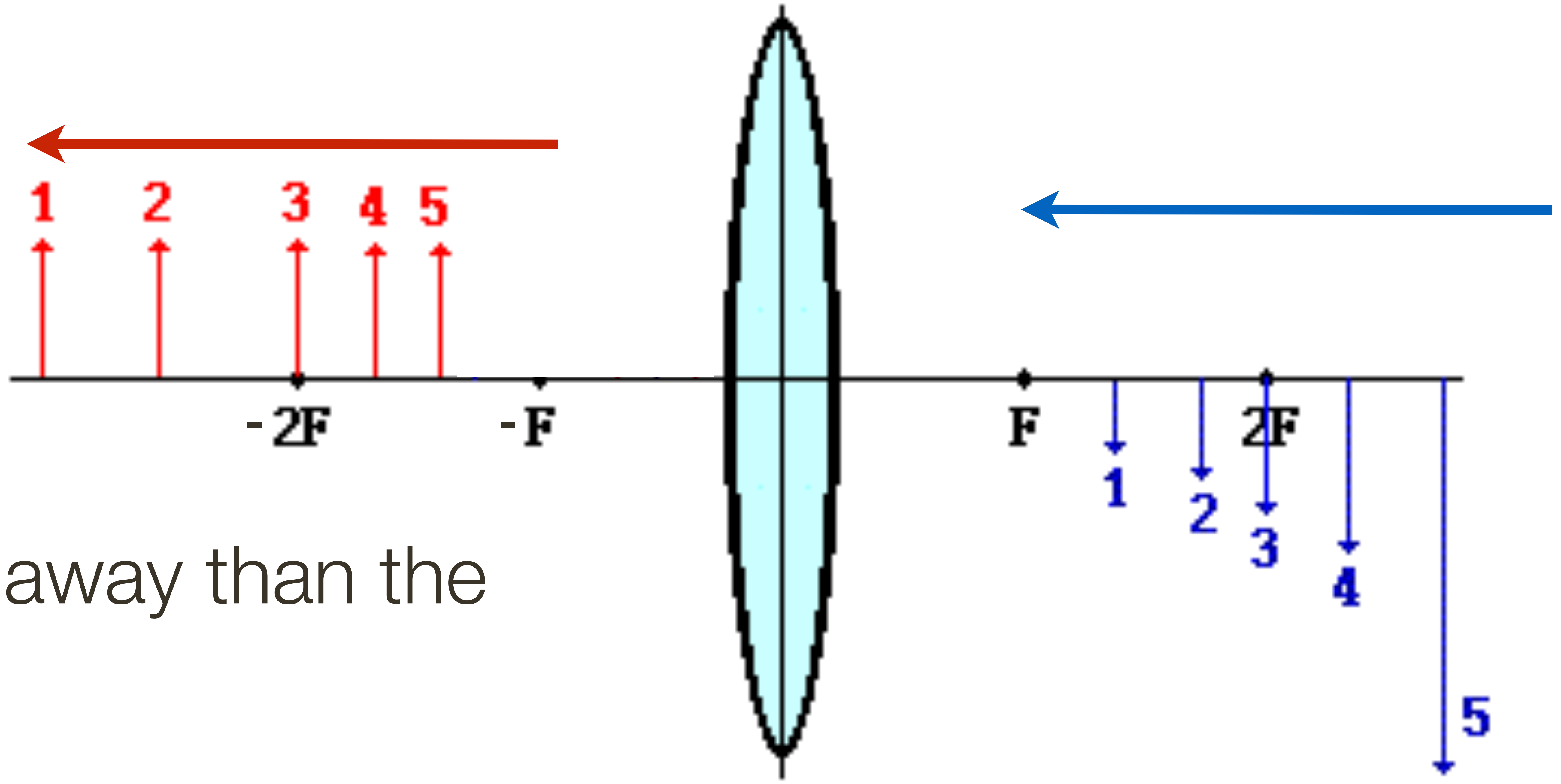

Objects **further** away than the **focal length**

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Where would the focusing plane be for various positions of the object?

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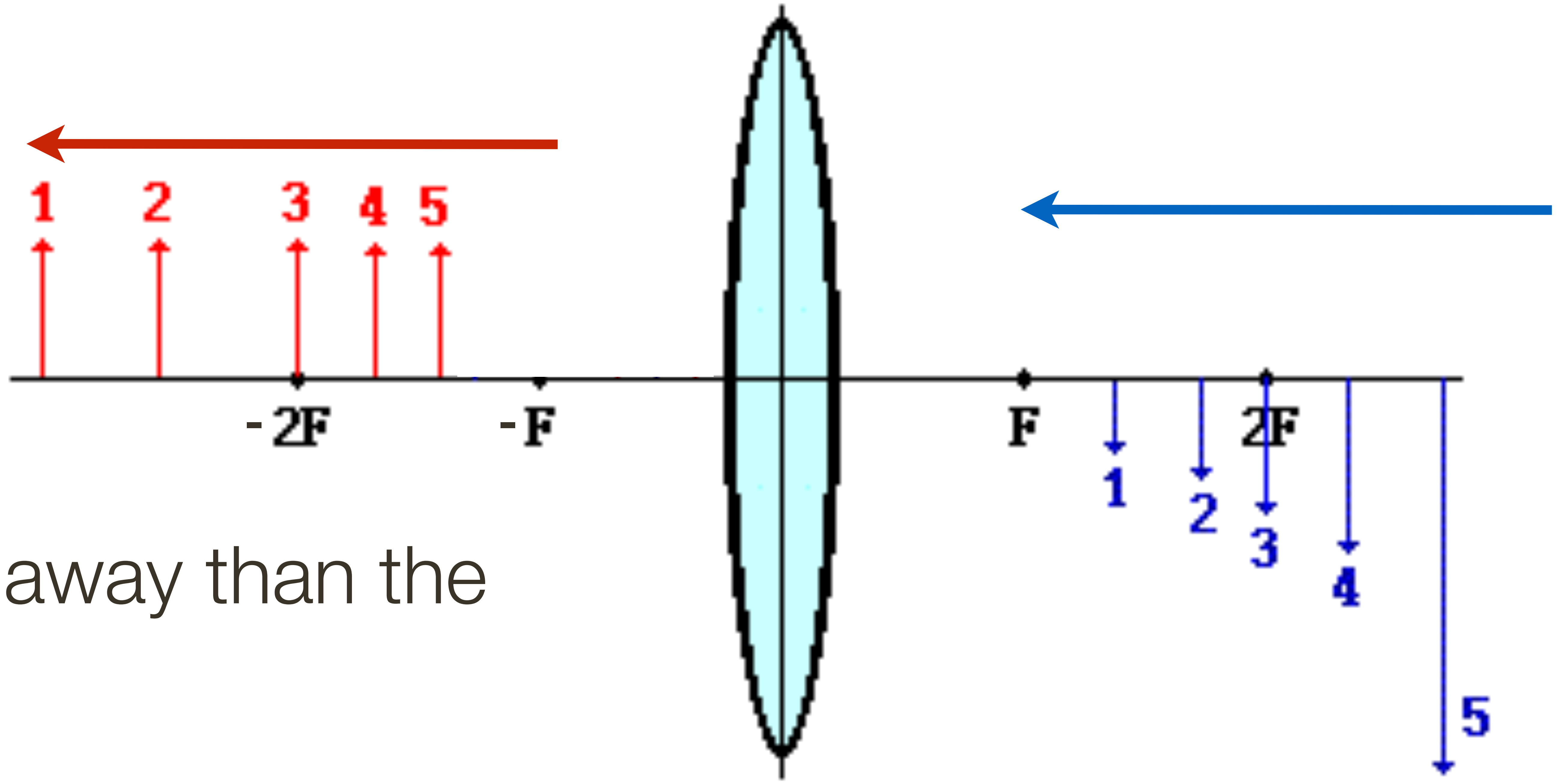
$$\lim_{z \to -\infty} \frac{zf}{z+f} = f$$

L'Hopital's Rule



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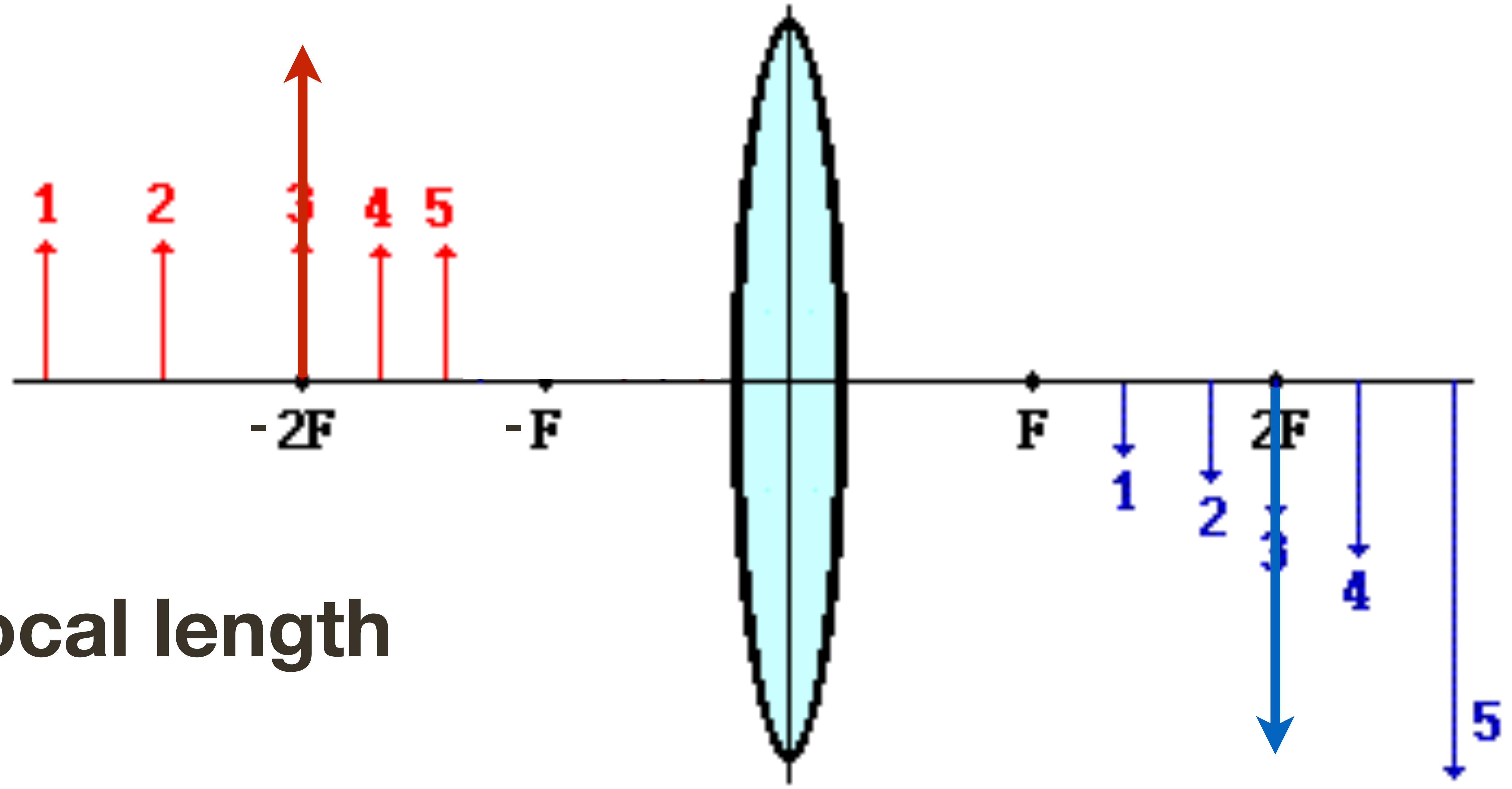

Objects at 2 x **focal length**

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Perspective Projection + **Thin Lens** Examples

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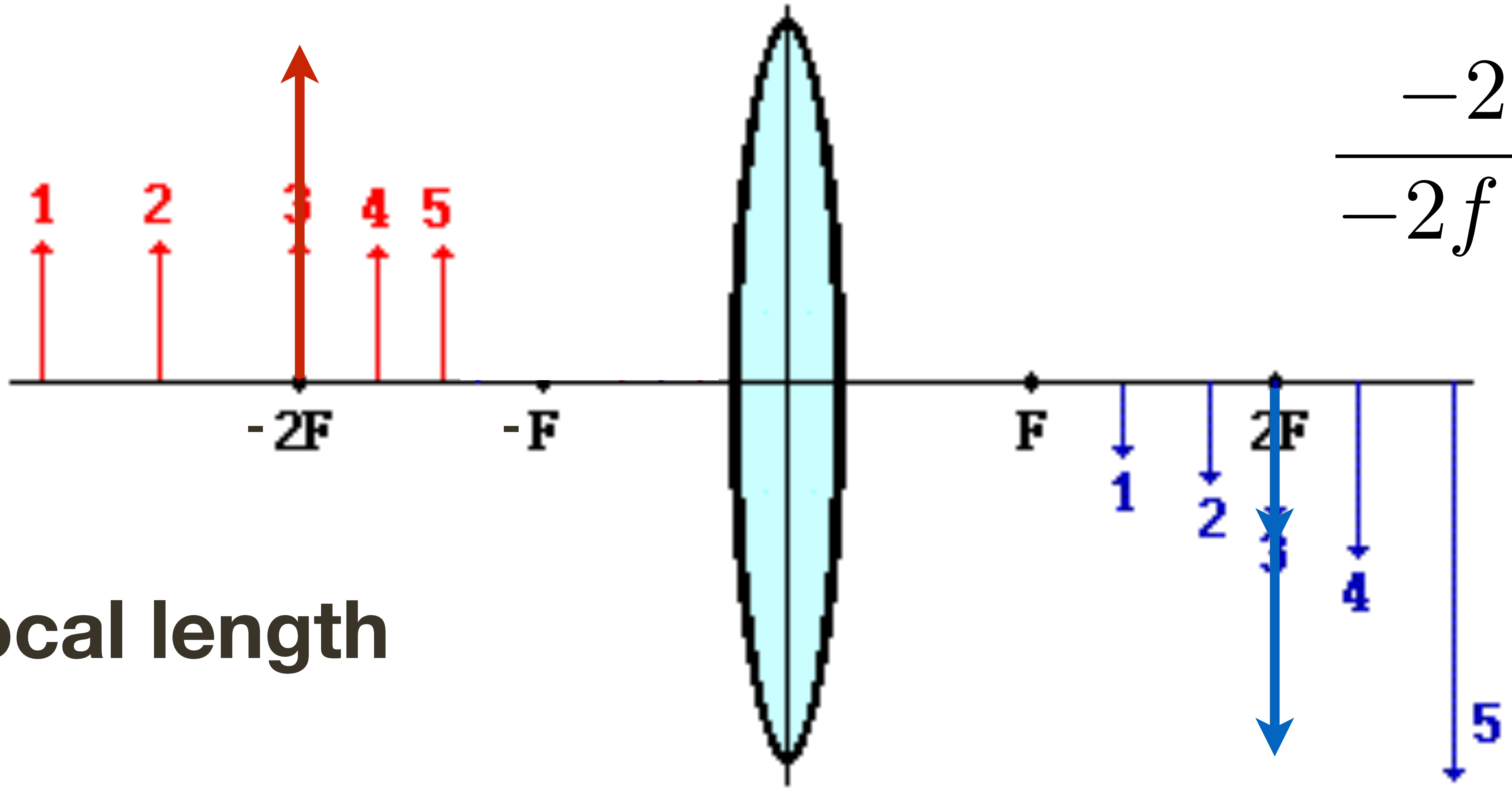
$$\frac{-2f^2}{-2f+f} = \frac{-2f^2}{-f} = 2f$$



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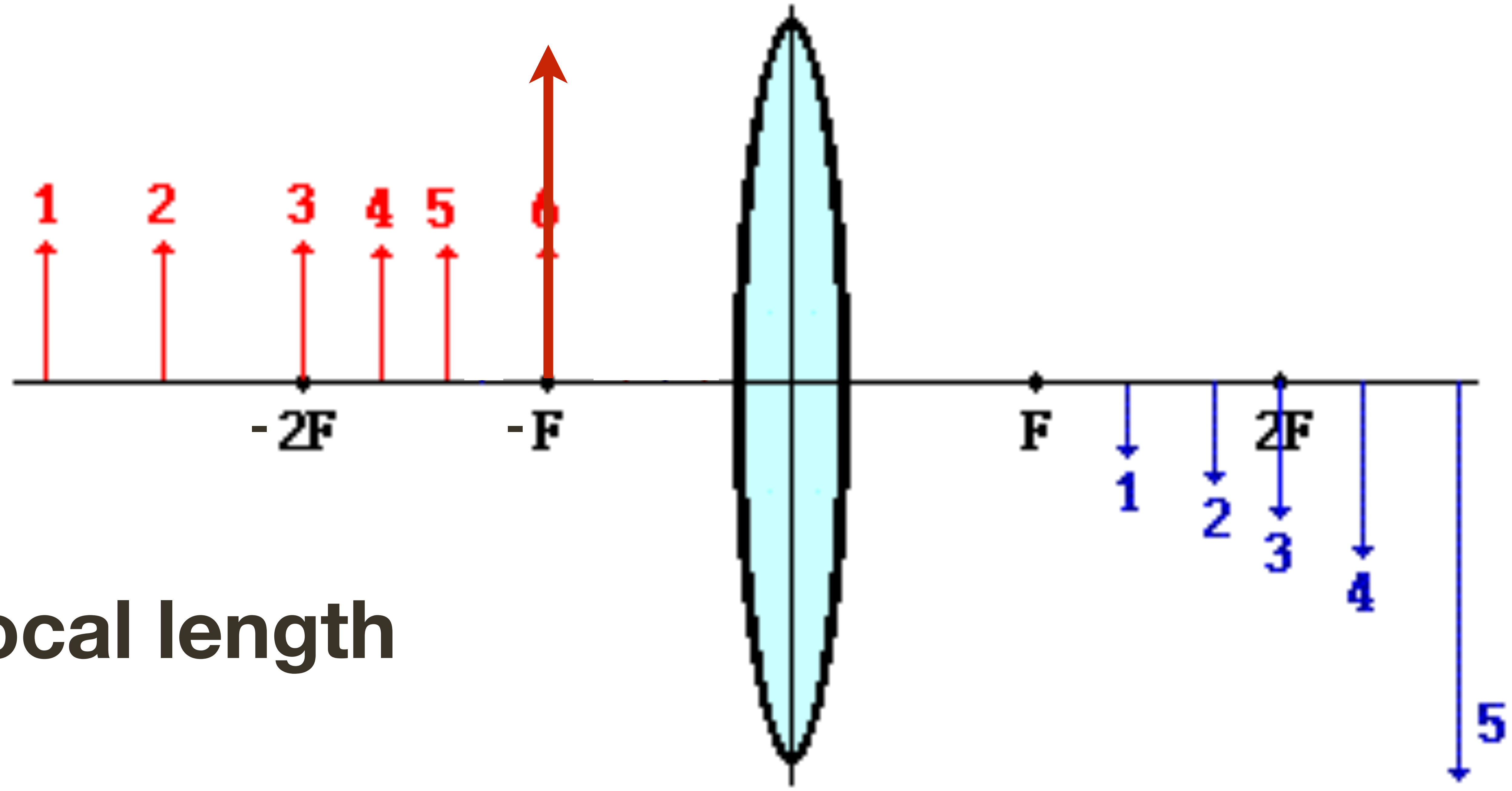

Objects at the **focal length**

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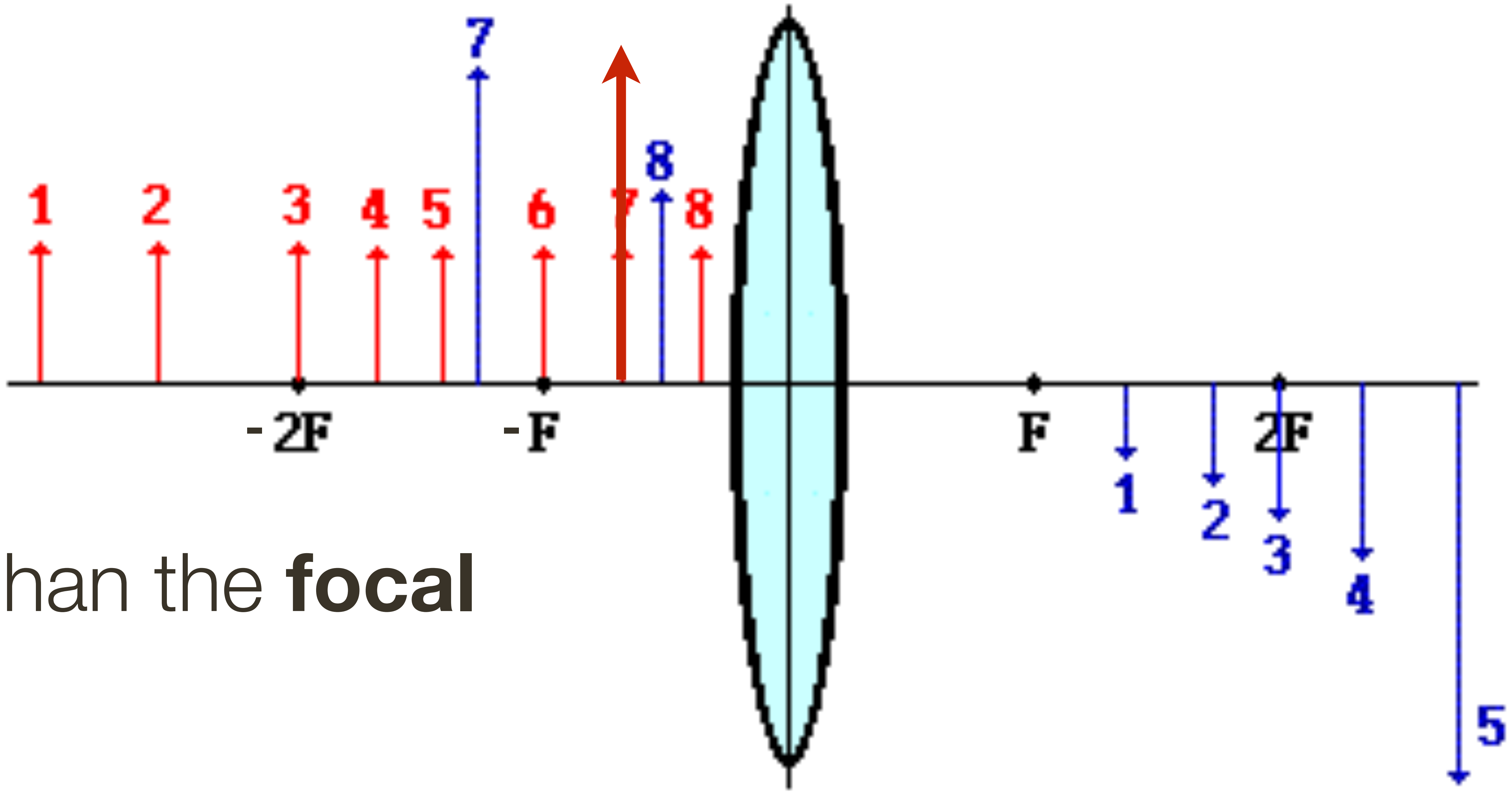

Objects **closer** than the **focal length**

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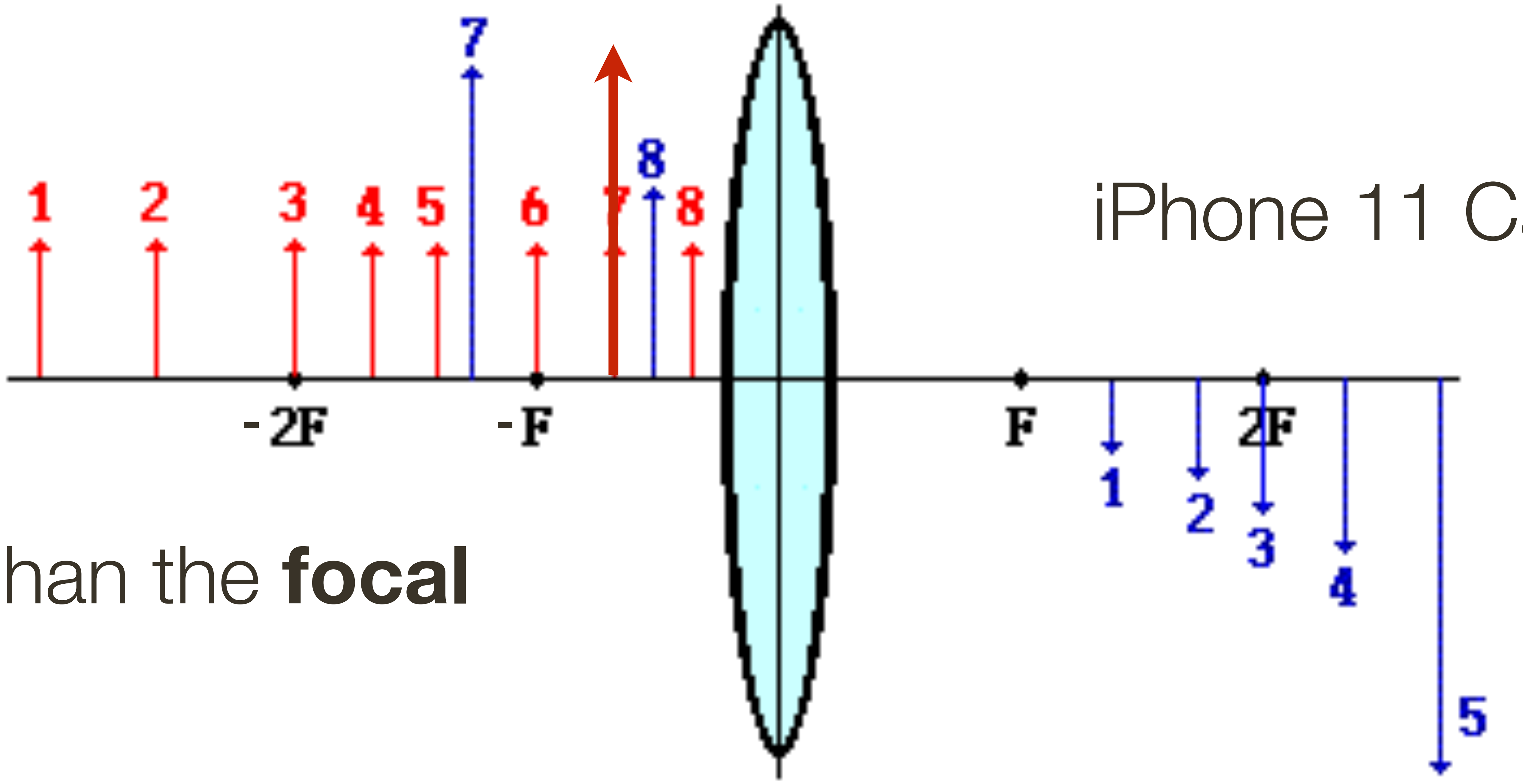
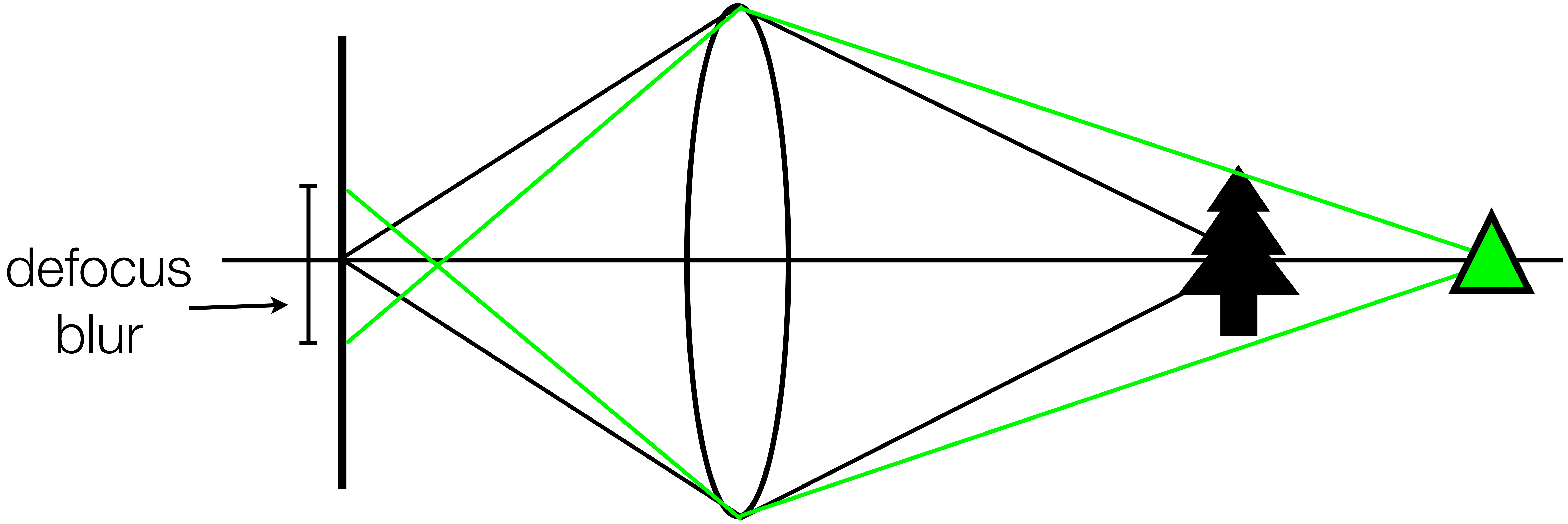


iPhone 11 Camera Lens: **26mm**

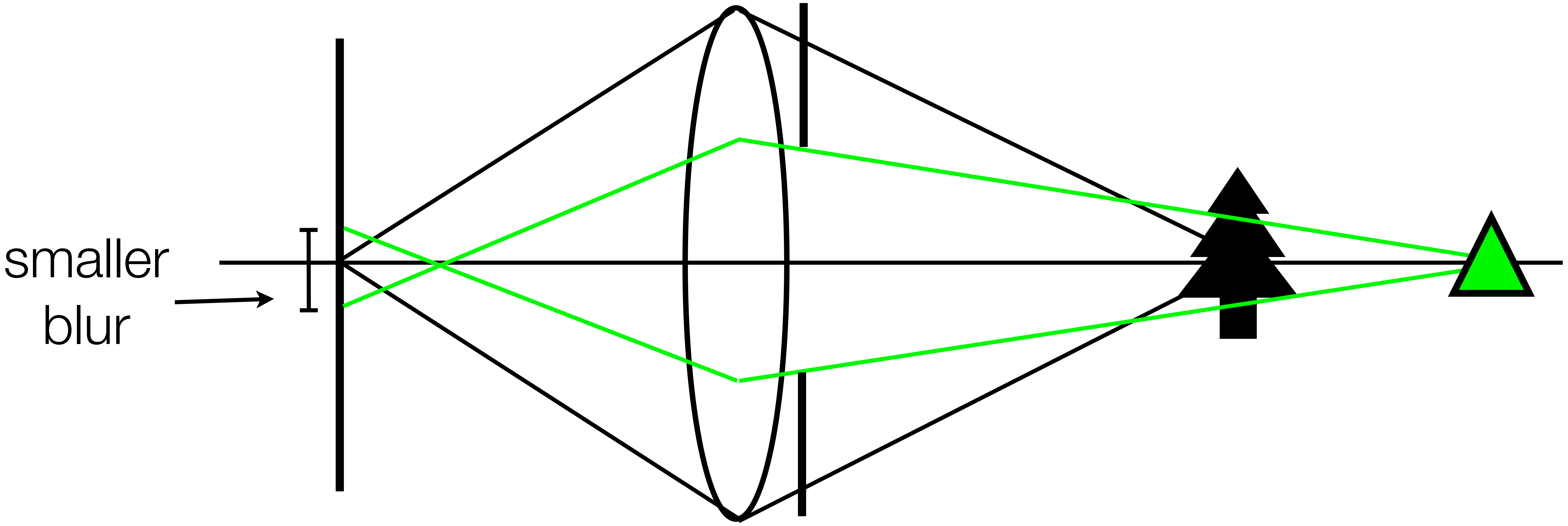
Objects **closer** than the **focal length**

https://www.physicsclassroom.com/class/refrn/Lesson-5/Converging-Lenses-Object-Image-Relations

Effect of **Aperture** Size



Smaller aperture ⇒ smaller blur, larger **depth of field**



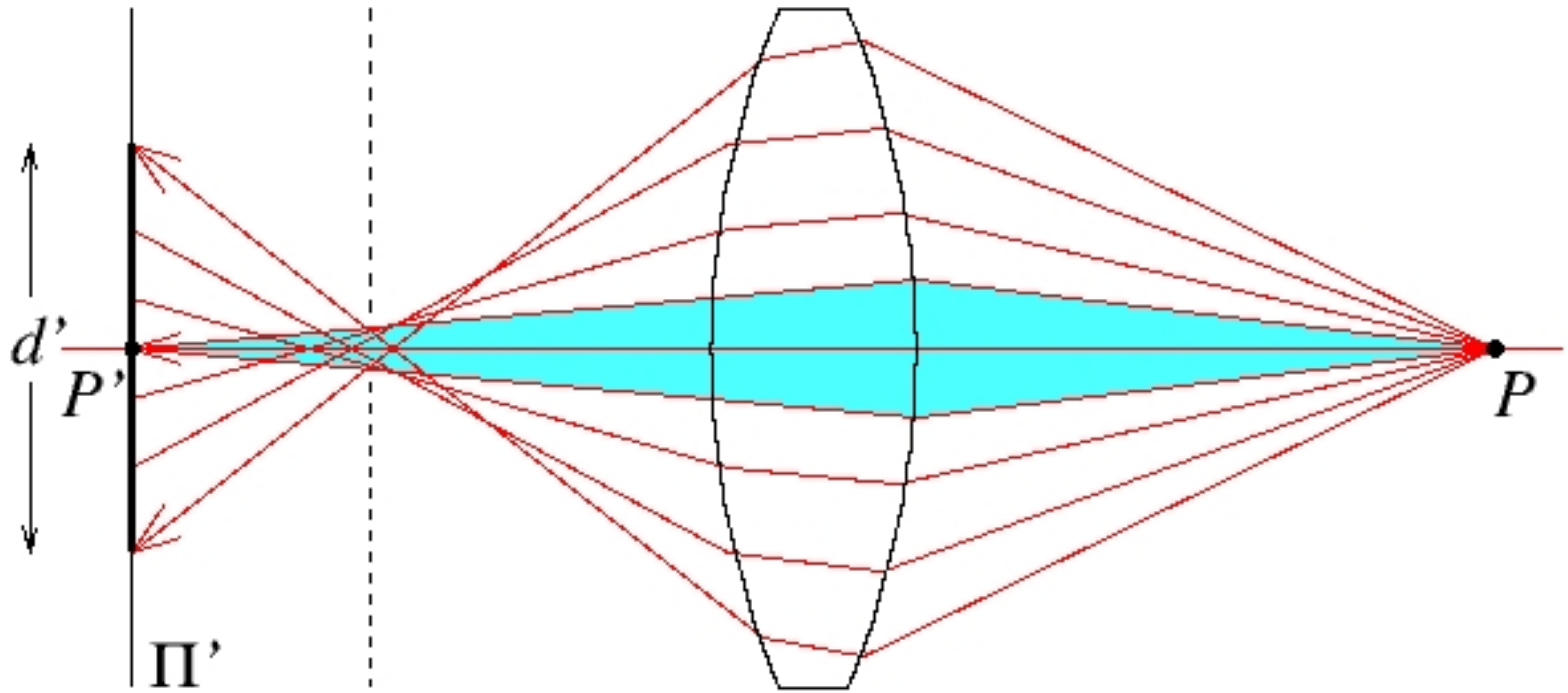
Depth of Field

Aperture size = f/N, ⇒ large N = small aperture

Real Lenses

- Real Lenses have multiple stages of positive and negative elements with differing refractive indices
- This can help deal with issues such as chromatic aberration (different colours bent by different amounts), vignetting (light fall off at image edge) and sharp imaging across the zoom range

Spherical **Aberration**



Forsyth & Ponce (1st ed.) Figure 1.12a

Spherical **Aberration**

Un-aberrated image

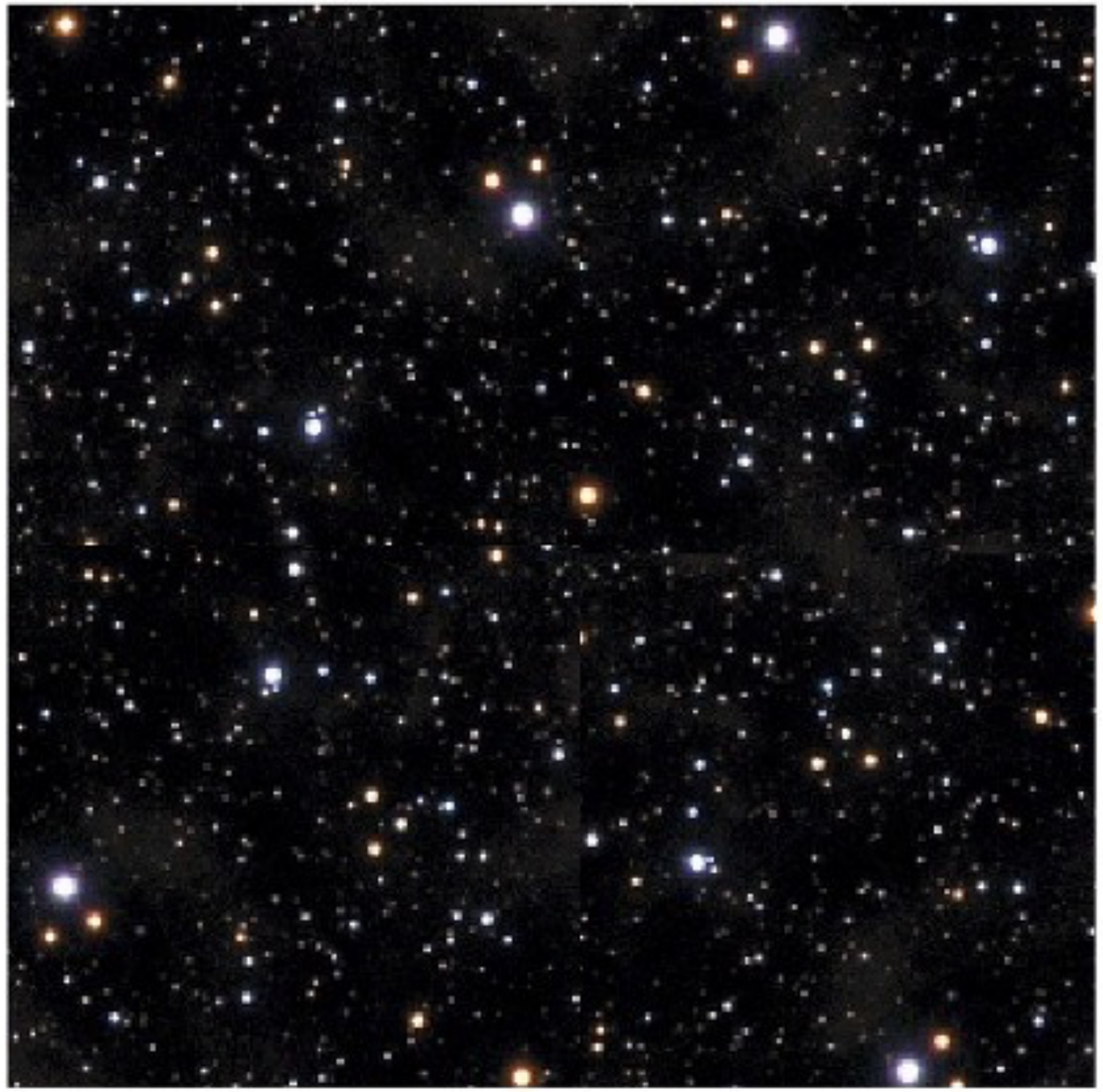
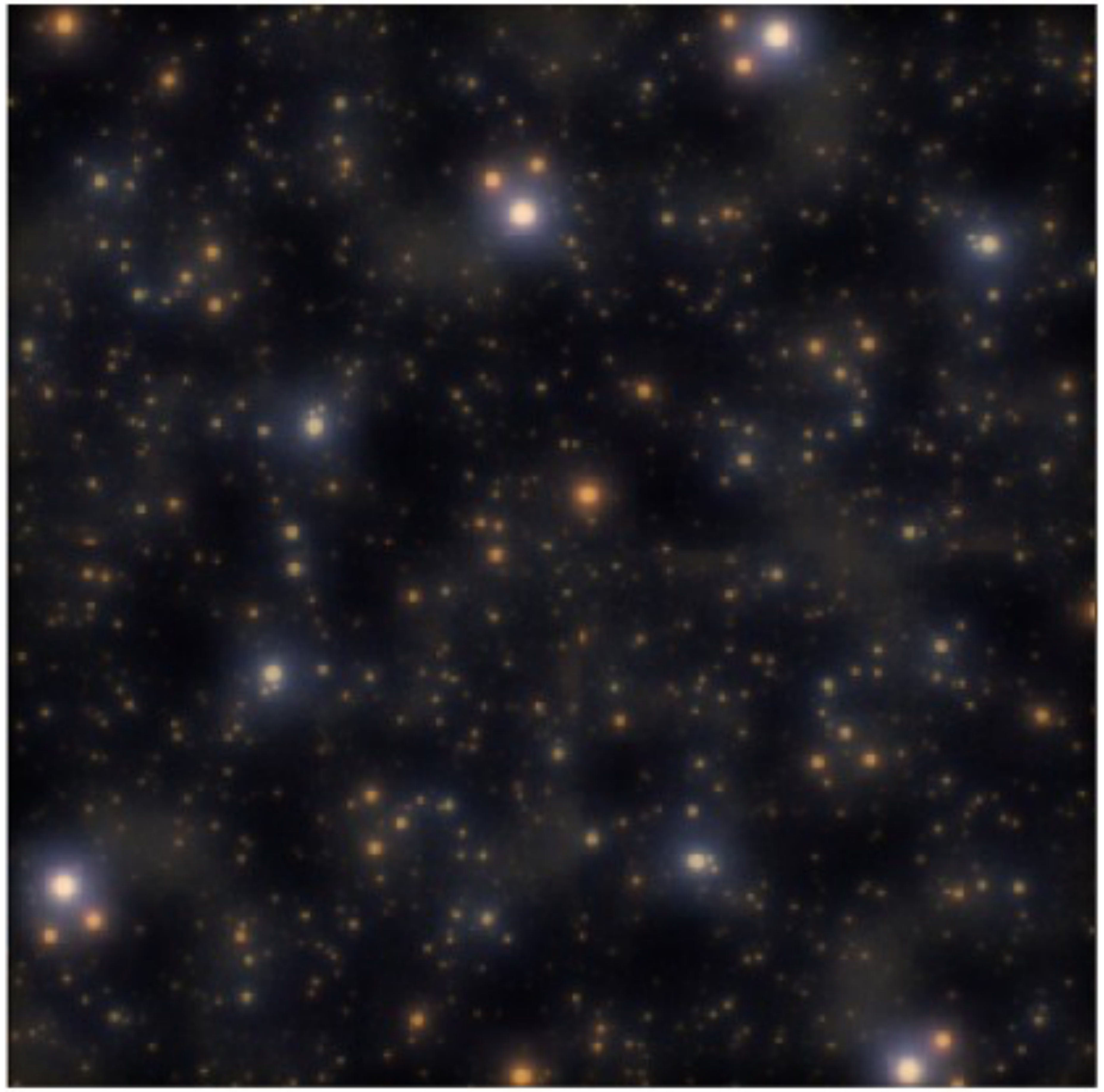
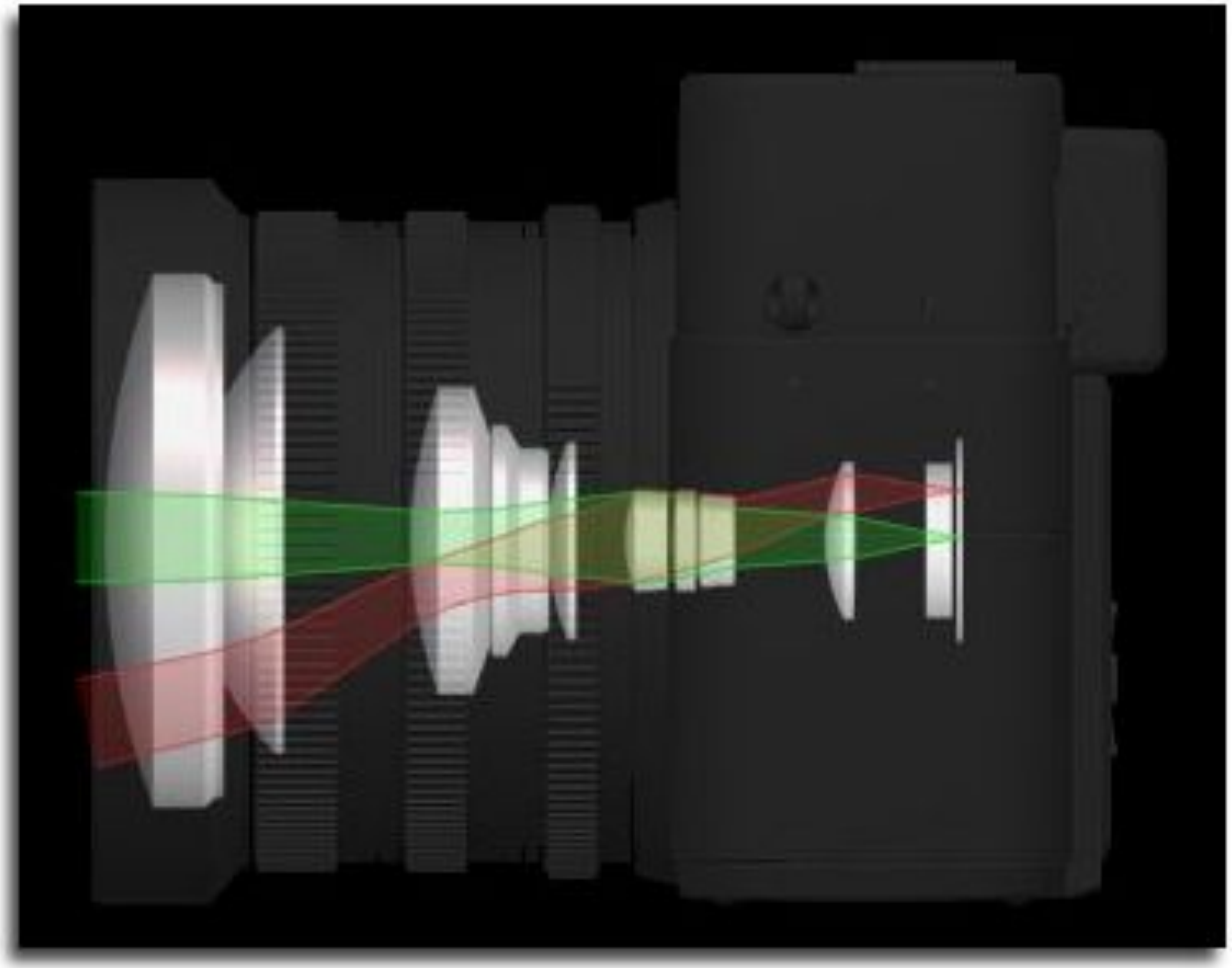
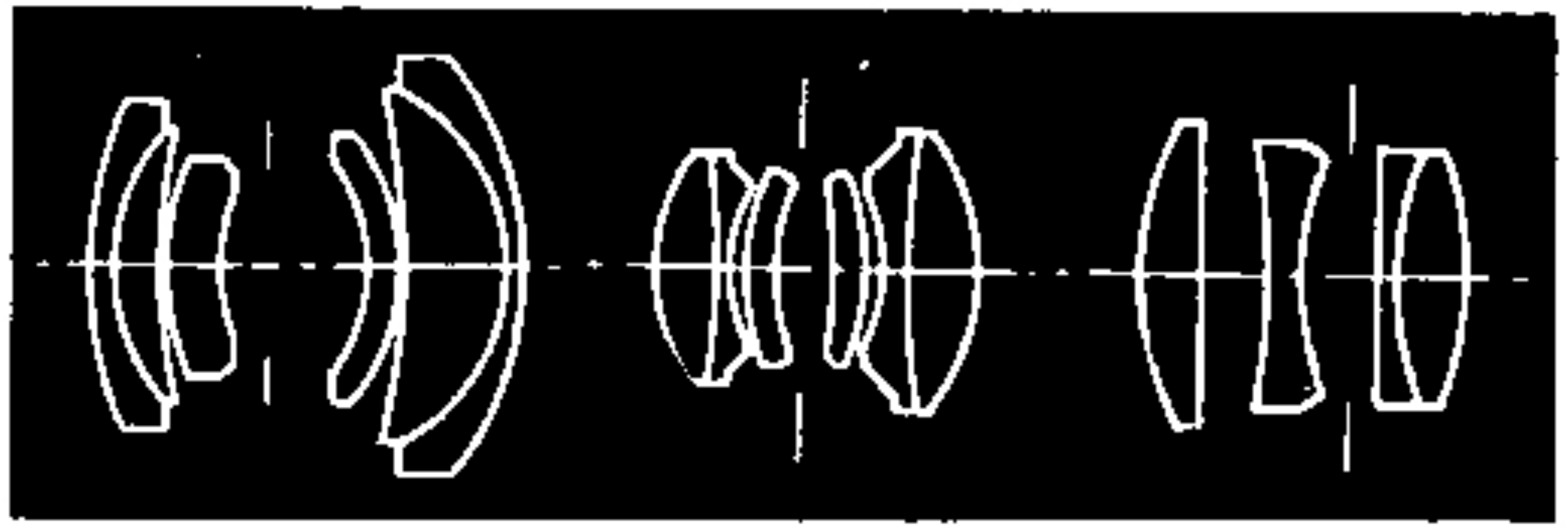


Image from lens with Spherical Aberration



Compound **Lens Systems**

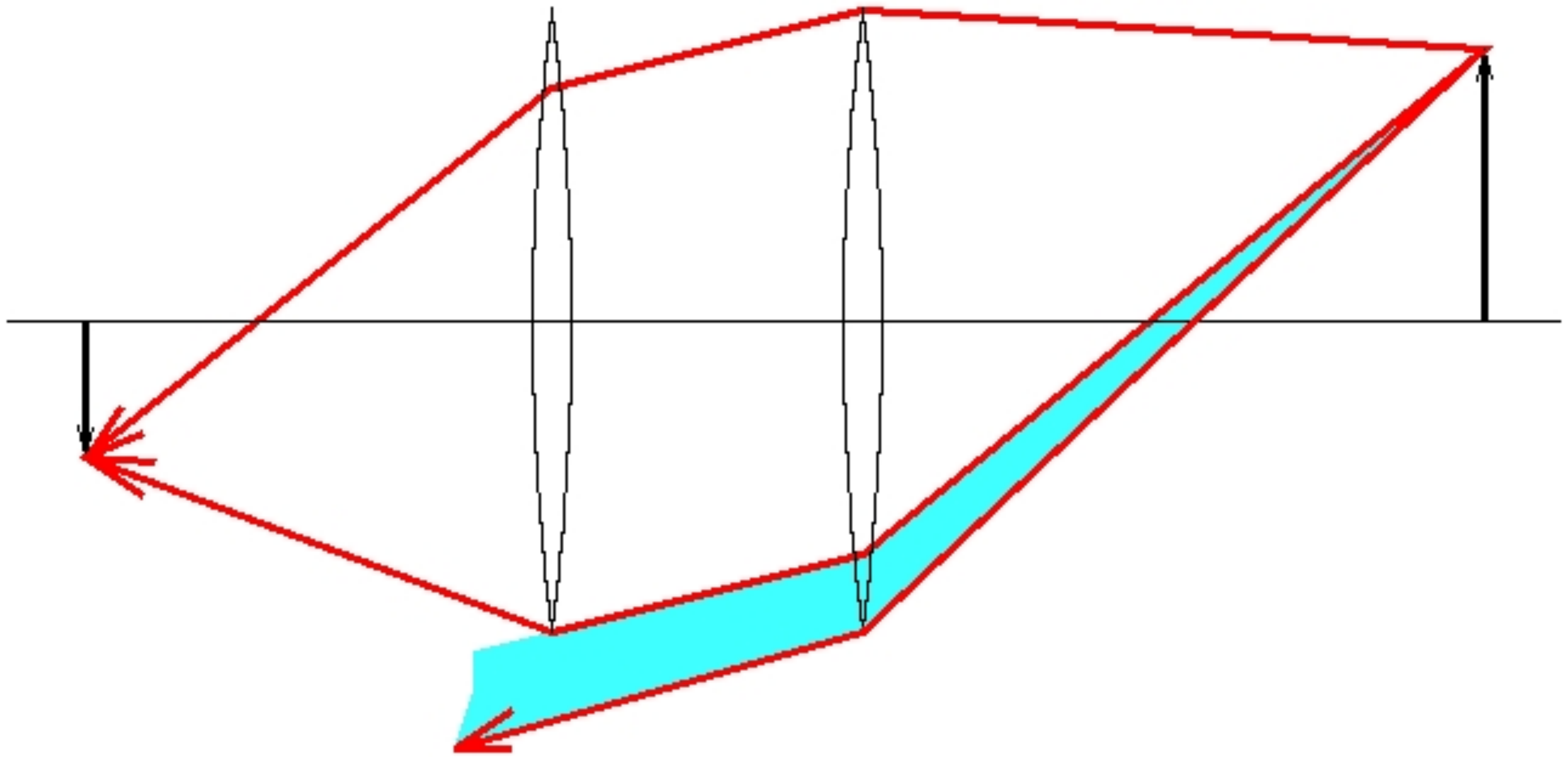




A modern camera lens may contain multiple components, including aspherical elements

Vignetting

Vignetting in a two-lens system



Forsyth & Ponce (2nd ed.) Figure 1.12

The shaded part of the beam **never reaches** the second lens

Vignetting

Image Credit: Cambridge in Colour

Chromatic **Aberration**

— Index of **refraction depends on wavelength**, λ, of light

— Light of different colours follows different paths

— Therefore, not all colours can be in equal focus

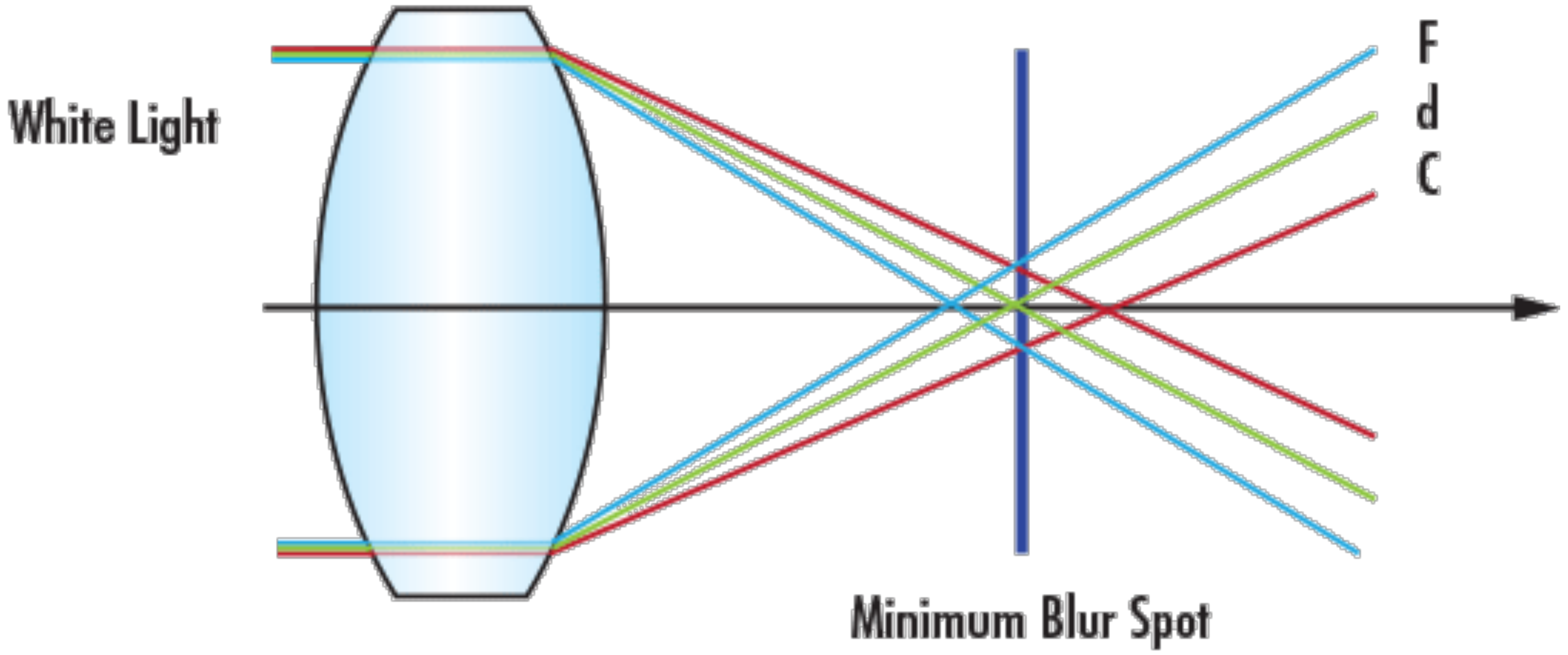


Image Credit: Trevor Darrell

Other (Possibly Significant) **Lens Effects**

Chromatic **aberration**

— Index of refraction depends on wavelength, λ, of light

— Light of different colours follows different paths

— Therefore, not all colours can be in equal focus

Scattering at the lens surface

— Some light is reflected at each lens surface

There are other **geometric phenomena/distortions**

— pincushion distortion

— barrel distortion

— etc

Lens **Distortion**

Fish-eye Lens

Szeliski (1st ed.) Figure 2.13

Lines in the world are no longer lines on the image, they are curves!

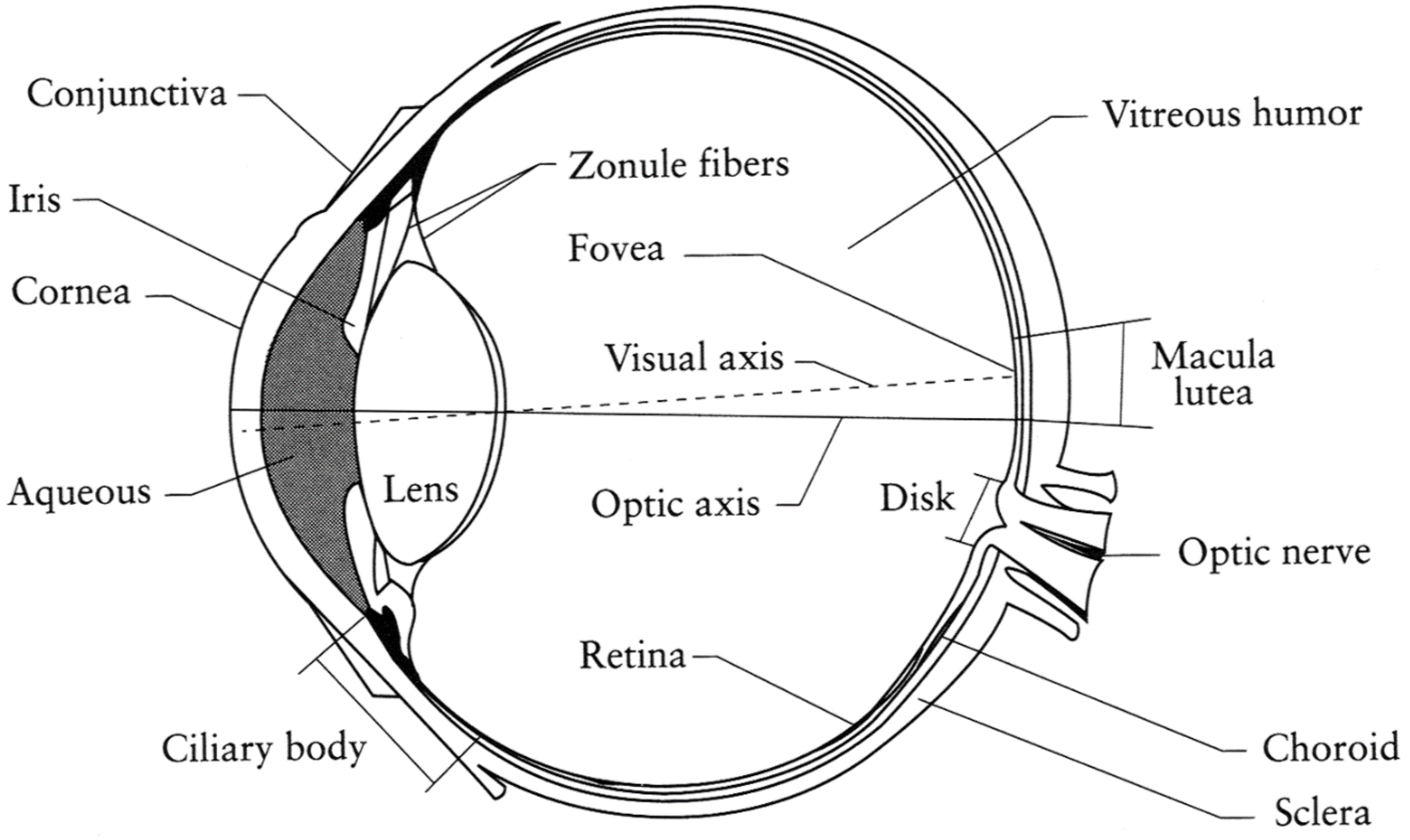
Human Eye

— The eye has an **iris** (like a camera)

— **Focusing** is done by changing shape of lens

— When the eye is properly focused, light from an object outside the eye is imaged on the **retina**

— The retina contains light receptors called **rods** and **cones**

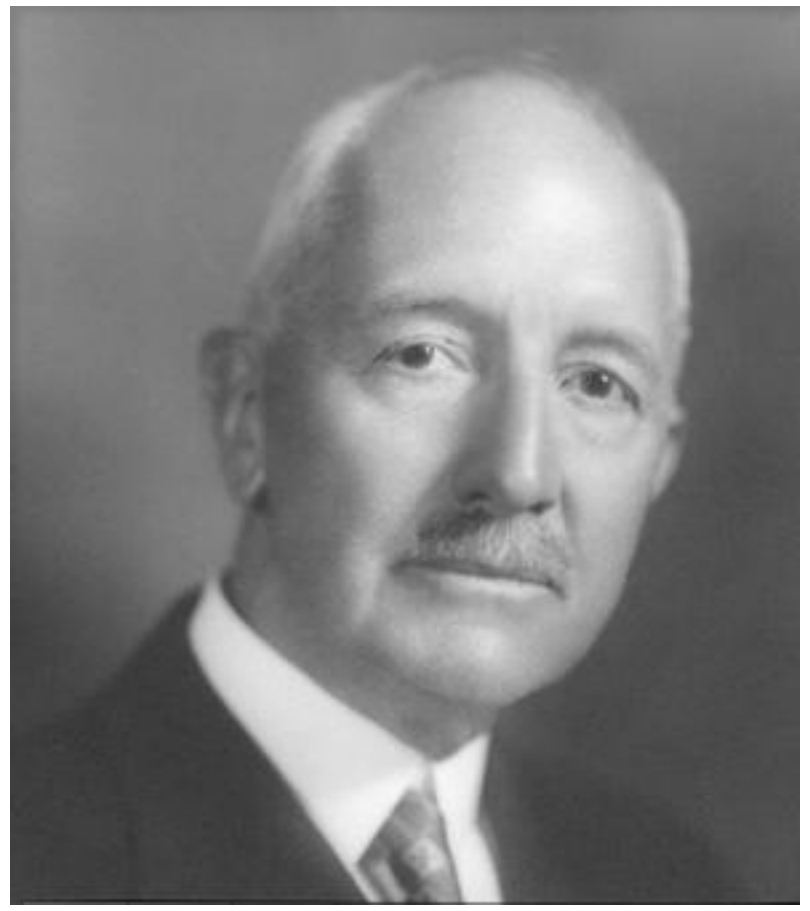


pupil = pinhole / aperture

retina = film / digital sensor

Slide adopted from: Steve Seitz

Fun **Aside**



George M. Stratton

https://io9.gizmodo.com/does-your-brain-really-have-the-power-to-see-the-world-5905180

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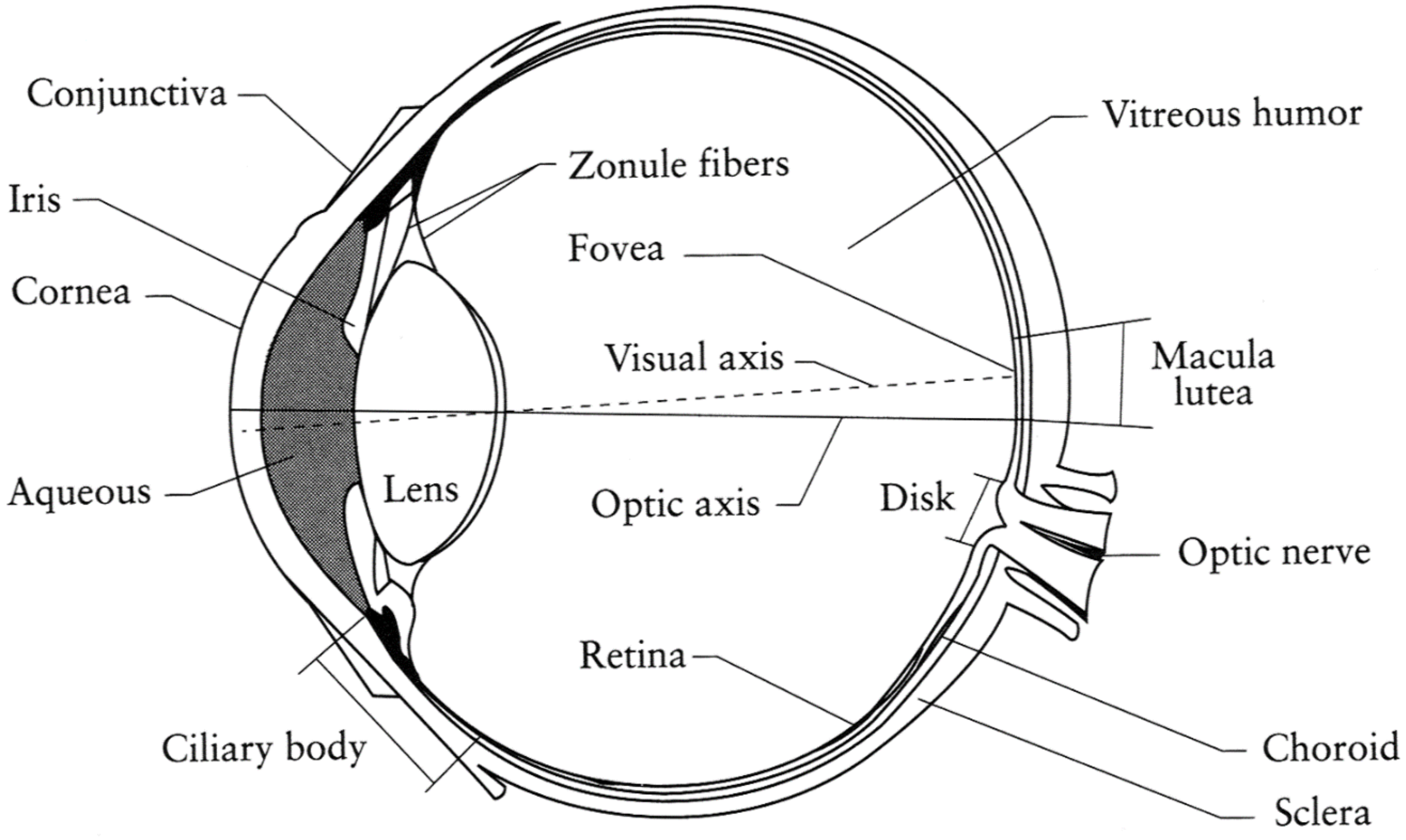

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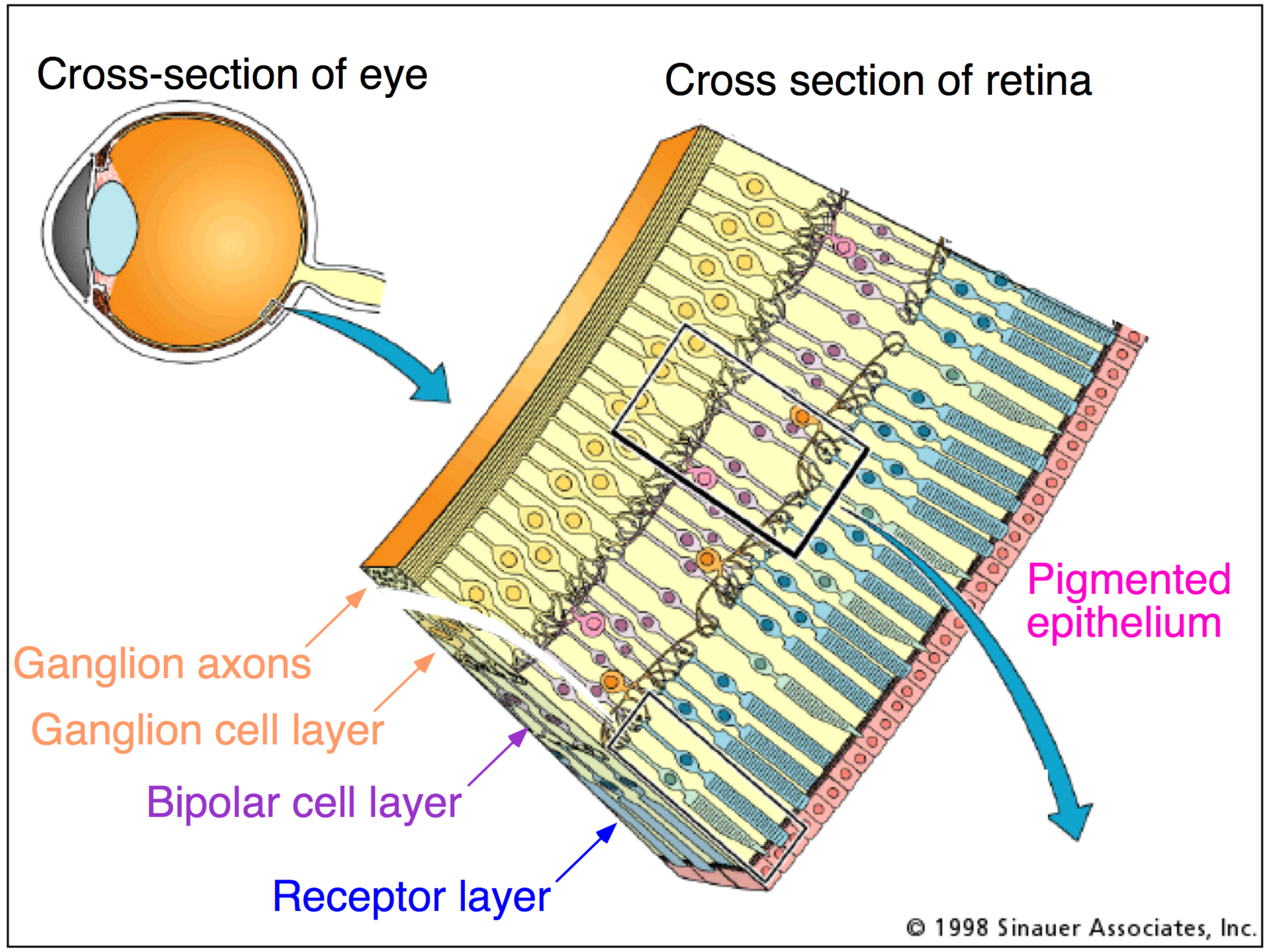

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Slide adopted from: Steve Seitz

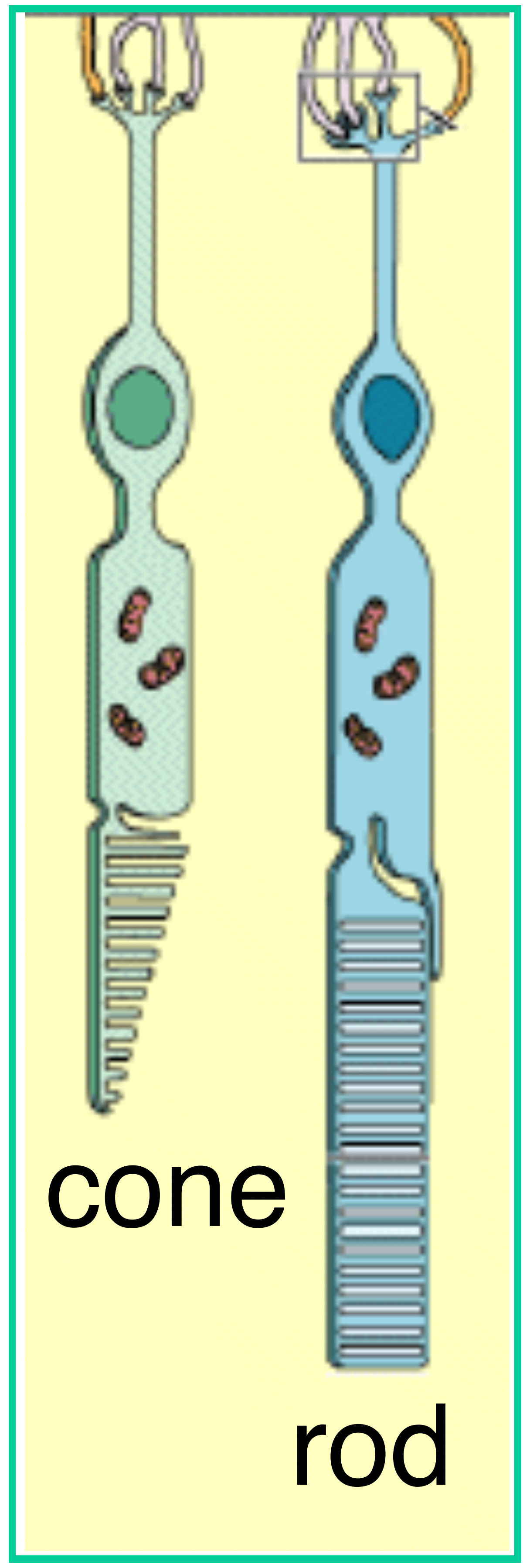
Two-types of **Light Sensitive Receptors**

Rods

75-150 million rod-shaped receptors
not involved in color vision, gray-scale vision only
operate at night
highly sensitive, can responding to a single photon
yield relatively poor spatial detail

Cones

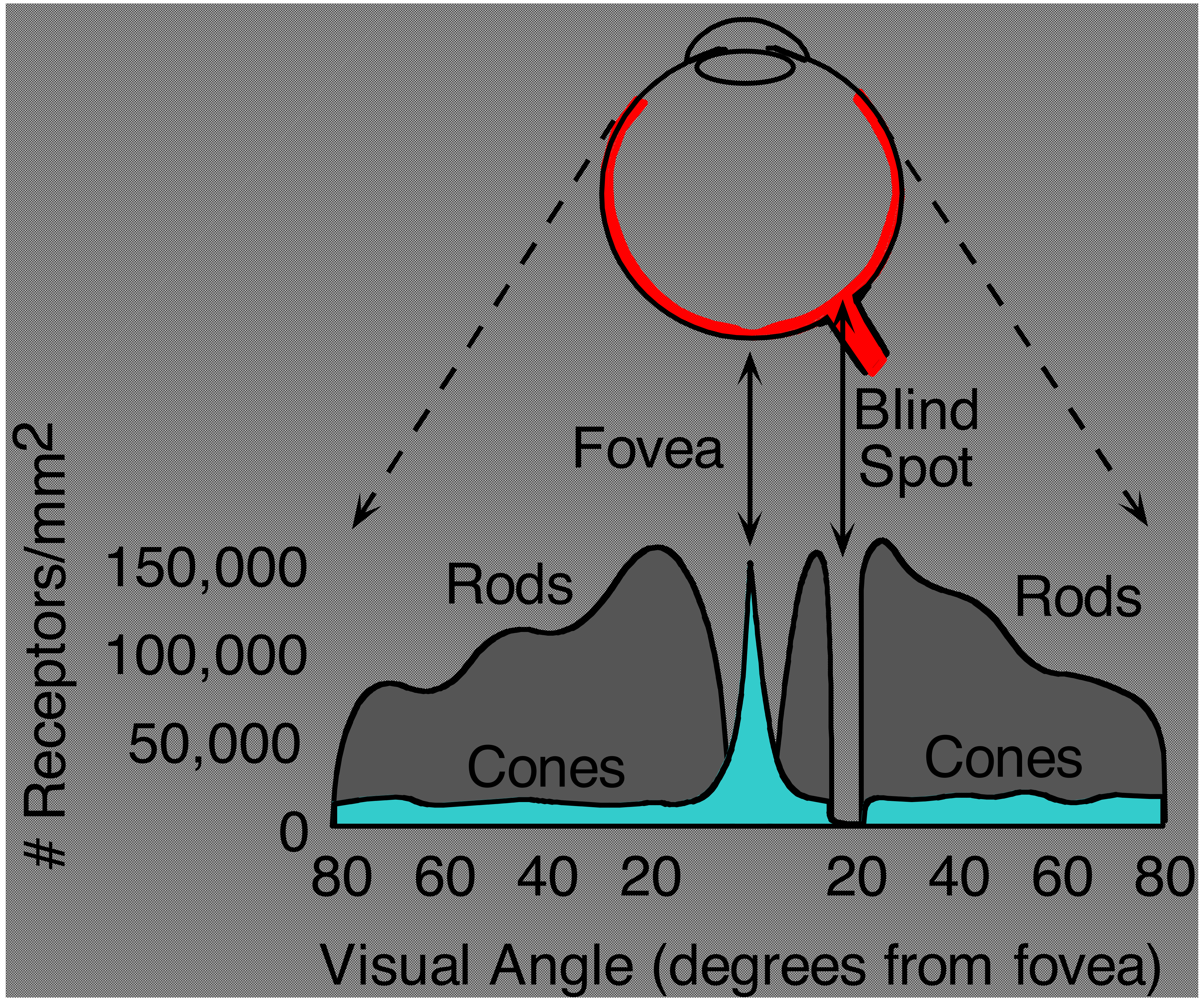
6-7 million cone-shaped receptors
color vision
operate in high light
less sensitive
yield higher resolution



Slide adopted from: James Hays

Human Eye

Density of rods and cones



Slide adopted from: James Hays

Lecture **Summary**

— We discussed a “physics-based” approach to image formation. Basic abstraction is the **pinhole camera**.

— **Lenses overcome limitations** of the pinhole model while trying to preserve it as a useful abstraction

— Projection equations: **perspective**, weak perspective, orthographic

— Thin lens equation

— Some “aberrations and **distortions**” persist (e.g. spherical aberration, vignetting)

— The **human eye** functions much like a camera