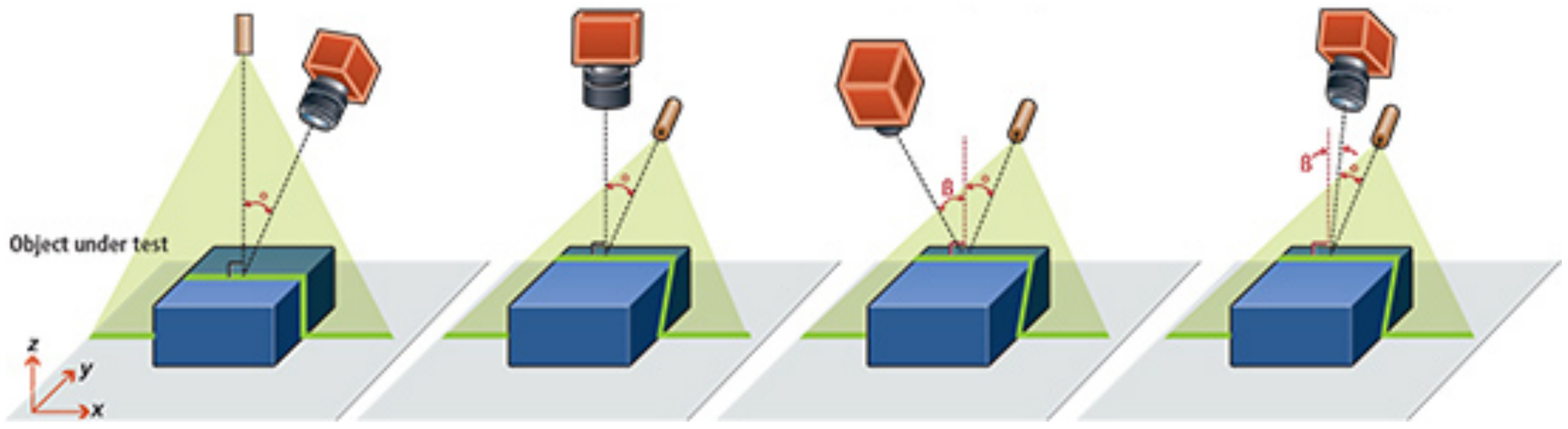
THE UNIVERSITY OF BRITISH COLUMBIA

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 14, 2020**)

Topics:

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

Readings:

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

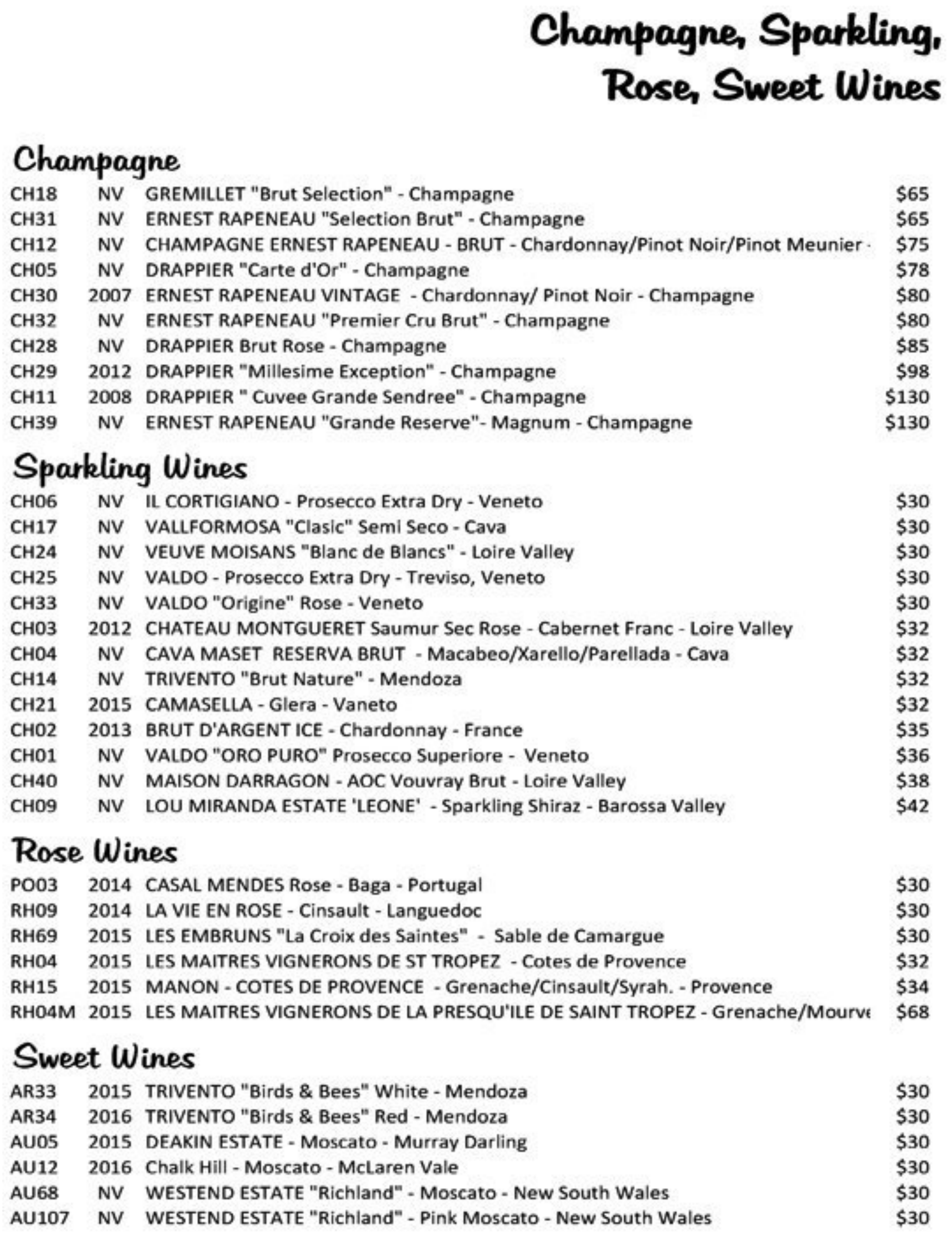
Reminders:

- Complete **Assignment 0** (optional, ungraded) due **September 16th**
- Google Colab **tutorial video** (thank you **Suhail**!) is available in Canvas
- Office hours start **today**

Today’s “**fun**” Example: Nudging

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

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

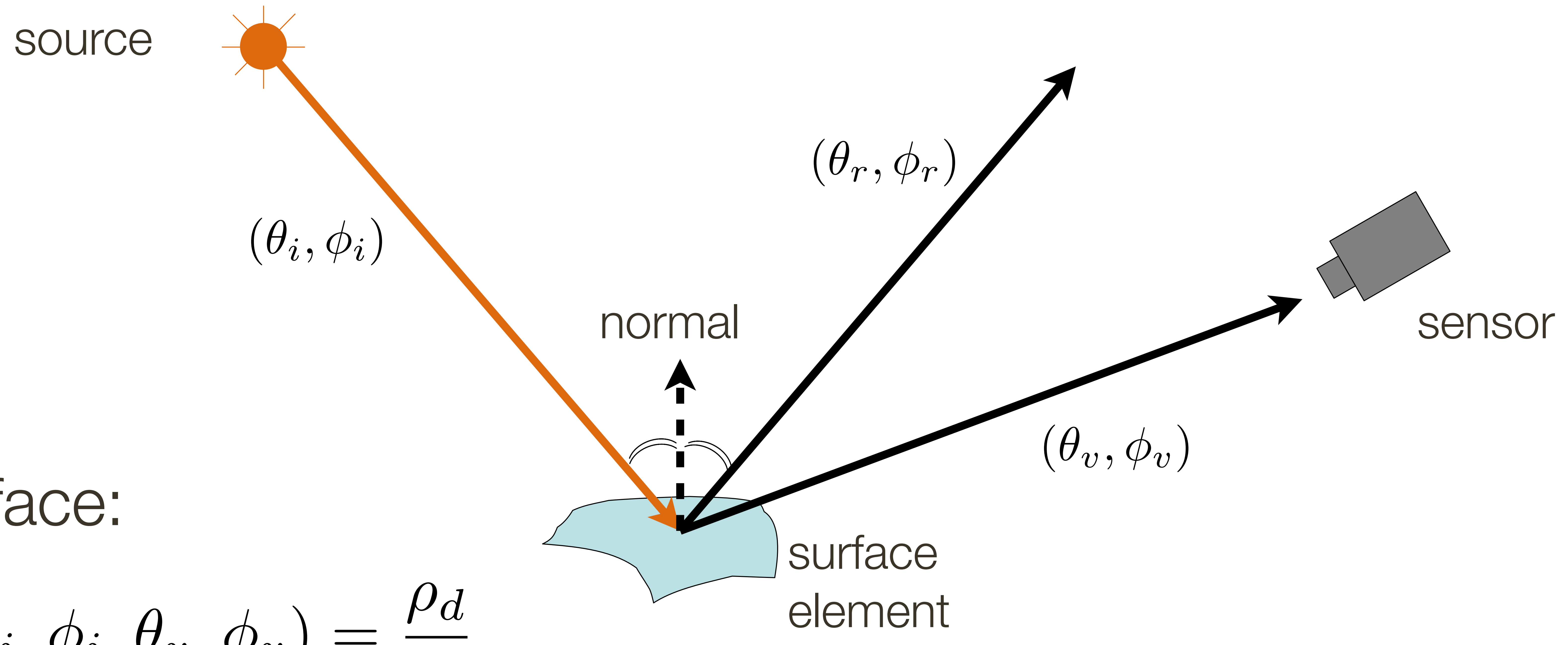
PO03	2014	CASAL MENDES Rose - Baga - Portugal	$30
RH09	2014	LA VIE EN ROSE - Cinsault - Languedoc	$30
RH69	2015	LES EMBRUNS "La Croix des Saintes" - Sable de Camargue	$30
RH04	2015	LES MAITRES VIGNERONS DE ST TROPEZ - Cotes de Provence	$32
RH15	2015	MANON - COTES DE PROVENCE - Grenache/Cinsault/Syrah.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

Lecture 2: Re-cap

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:

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

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

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

Lecture 2: Re-cap

At a **microscopic** level, the process is **stochastic** (e.g., photon bouncing/being emitted in a random direction for a Lambertian surface), which (in part) causes **noise** in images under very low light scenarios; other sources of noise:

- electronic circuits
- variation in the number of photons sensed (quantum efficiency)
- quantization noise

Lecture 2: Re-cap

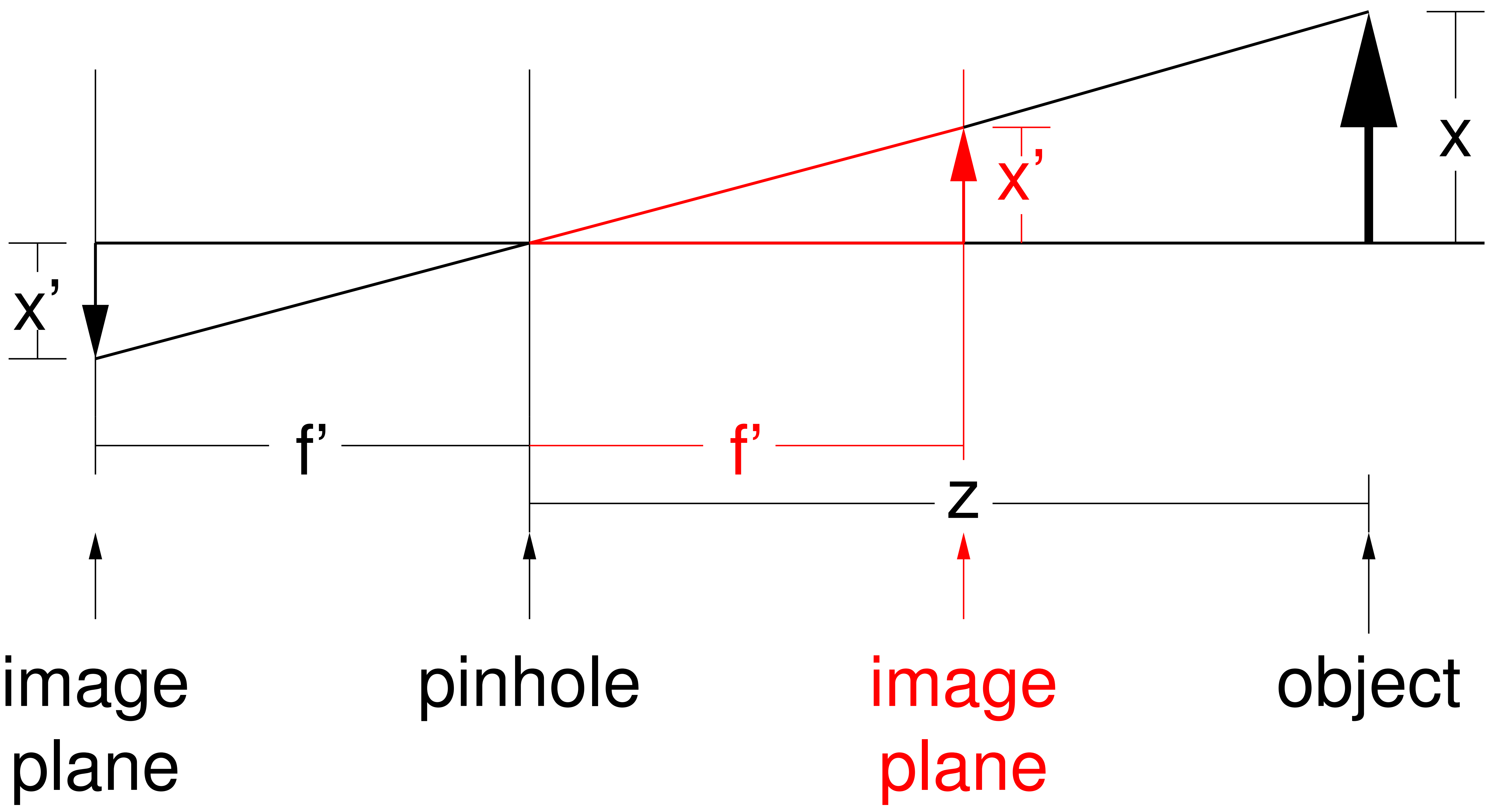
We take a "physics-based" approach to image formation
— Treat camera as an instrument that takes measurements of the 3D world

Basic abstraction is the **pinhole camera**

When **maximum accuracy** required, it is necessary to model additional details of each particular camera (and camera setting)
— Aside: This is called camera calibration

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	$x' = x$ $y' = y$

Why **Not** a Pinhole Camera?

— If pinhole is **too big** then many directions are averaged, blurring the image

— If pinhole is **too small** then diffraction becomes a factor, also blurring the image

— Generally, pinhole cameras are **dark**, because only a very small set of rays from a particular scene point hits the image plane

— Pinhole cameras are **slow**, because only a very small amount of light from a particular scene point hits the image plane per unit time

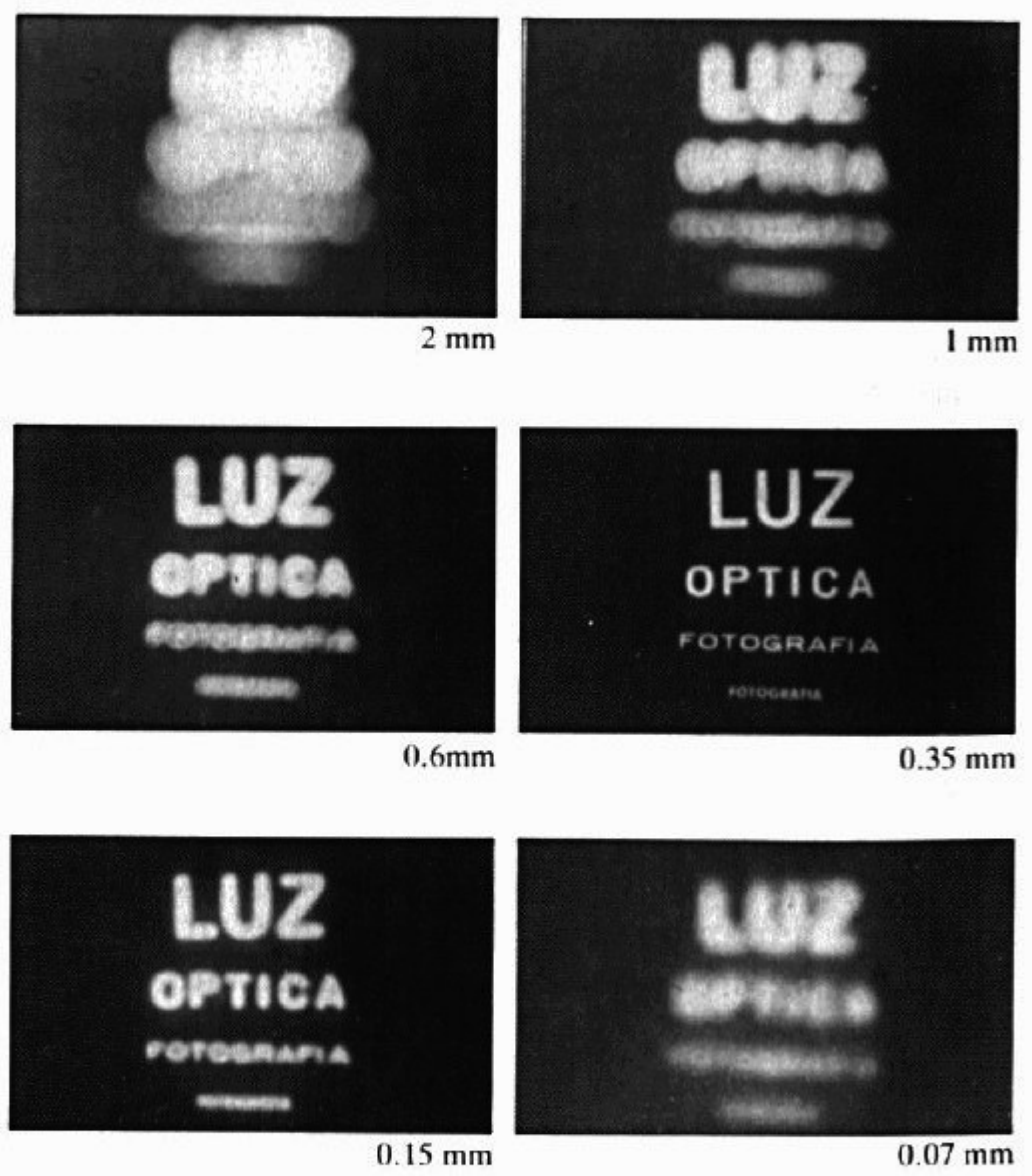
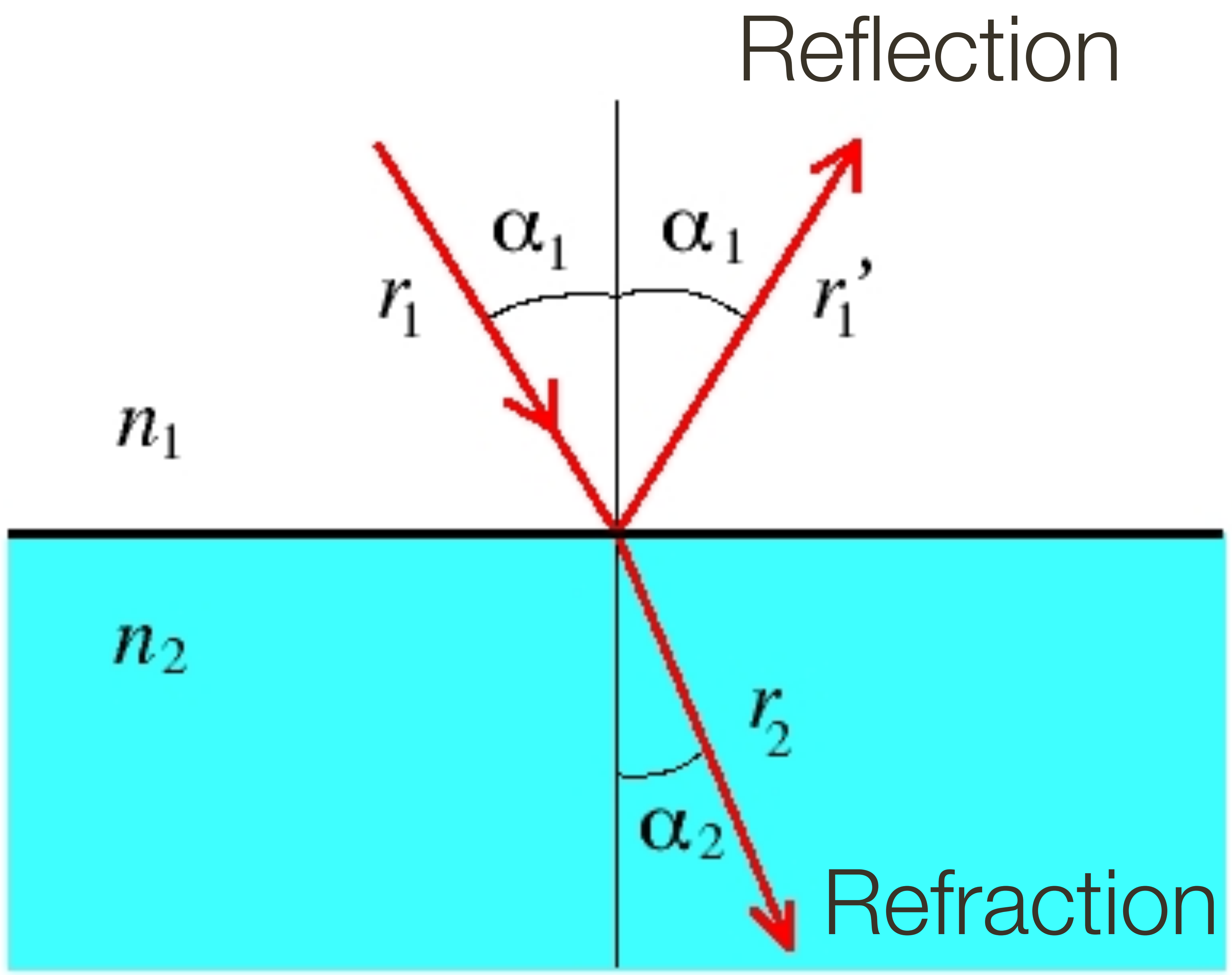


Image Credit: Credit: E. Hecht. “Optics,” Addison-Wesley, 1987

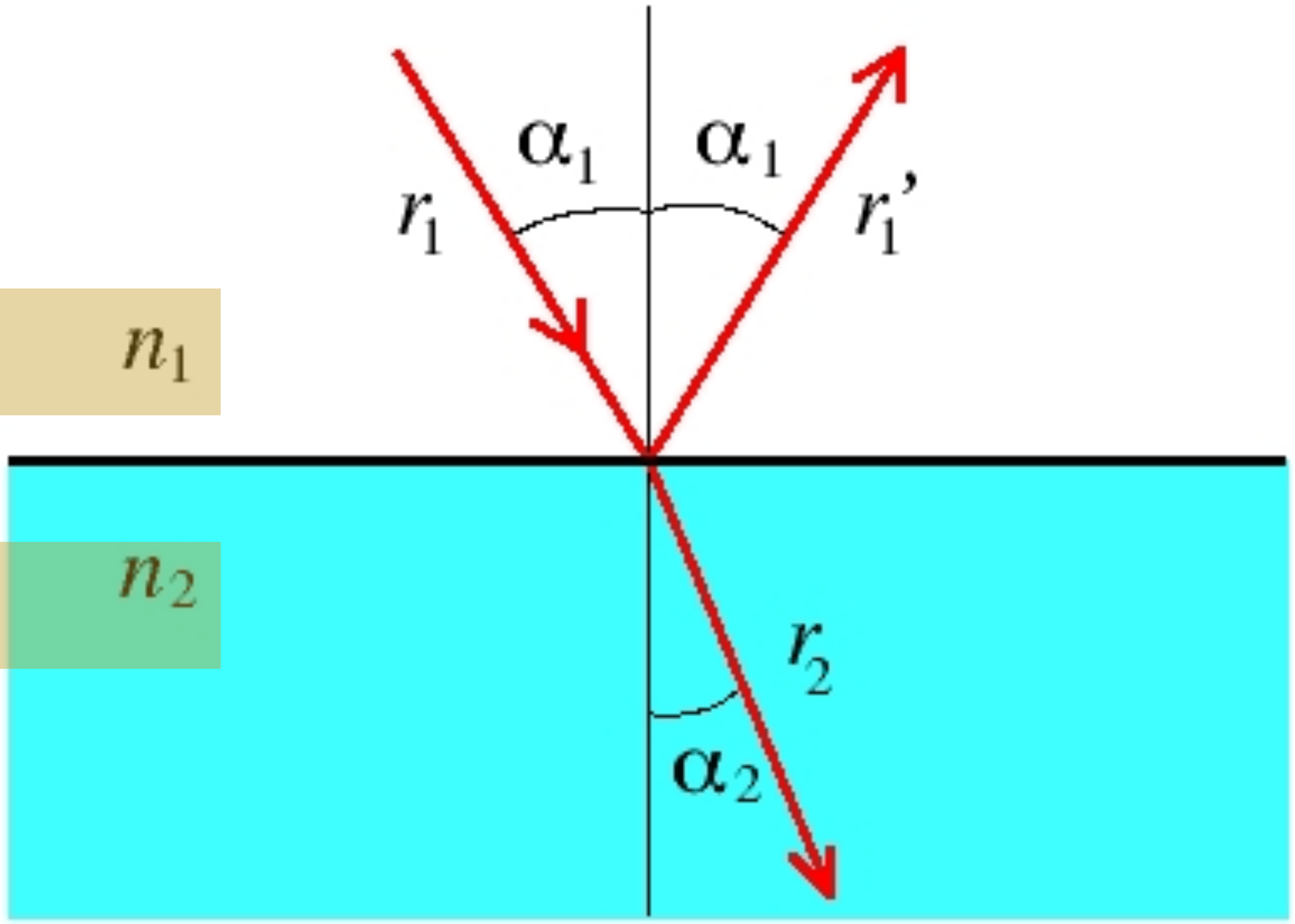
Snell's Law



$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

Snell's Law

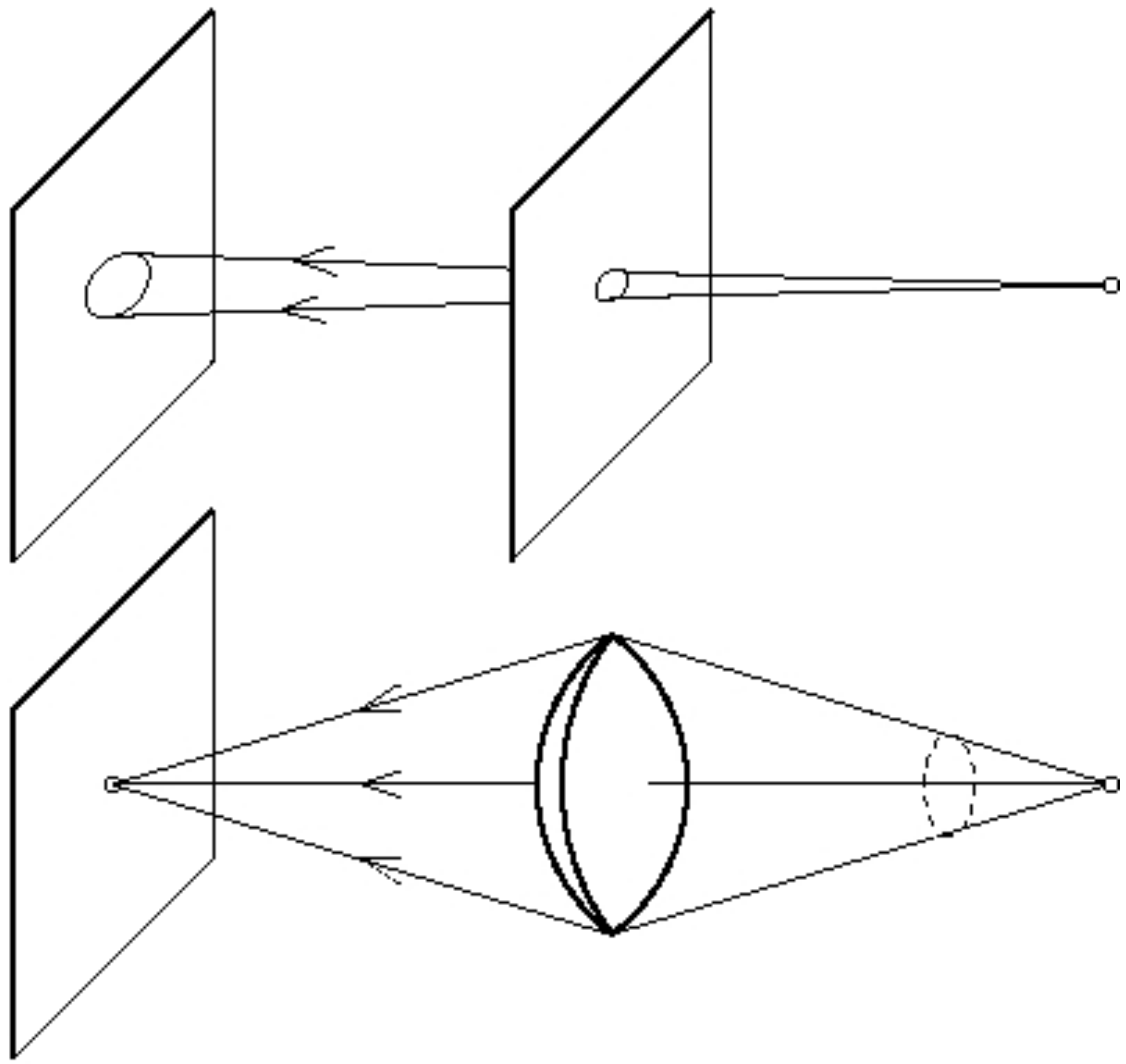
Index of **refraction**



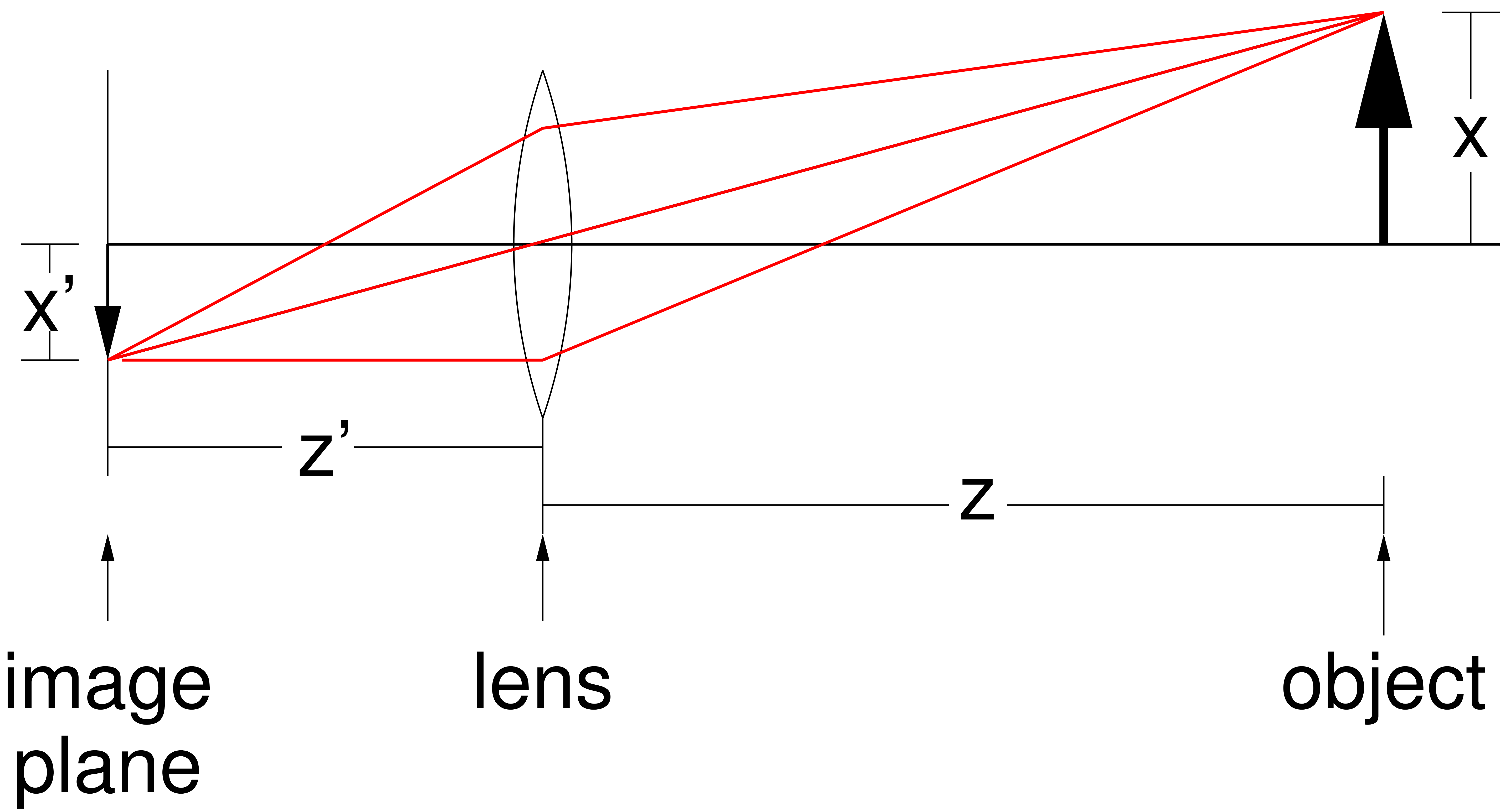
$$n_1 \sin \alpha_1 = n_2 \sin \alpha_2$$

Reason for **Lenses**

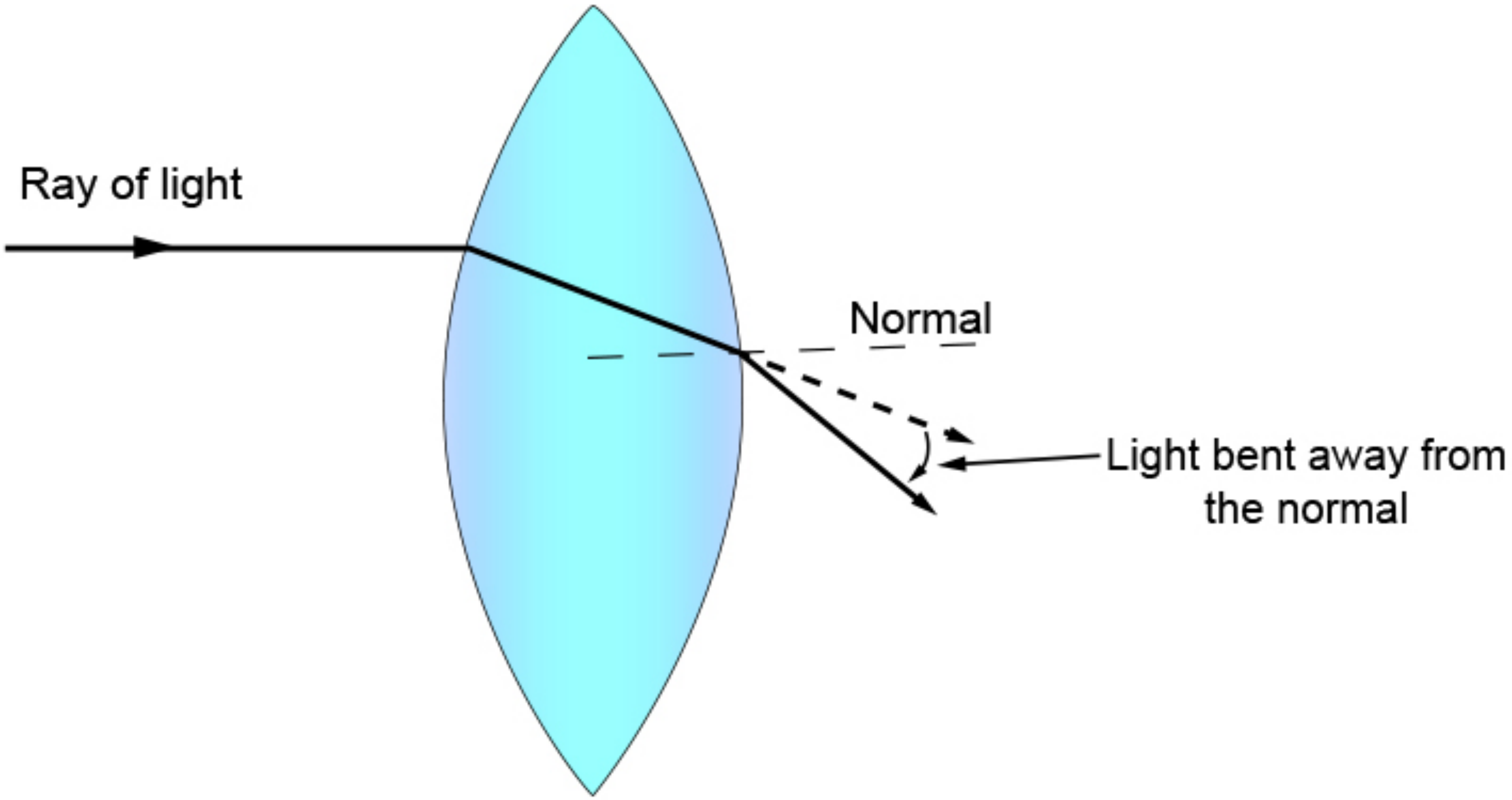
The role of a lens is to **capture more light** while preserving, as much as possible, the abstraction of an ideal pinhole camera.



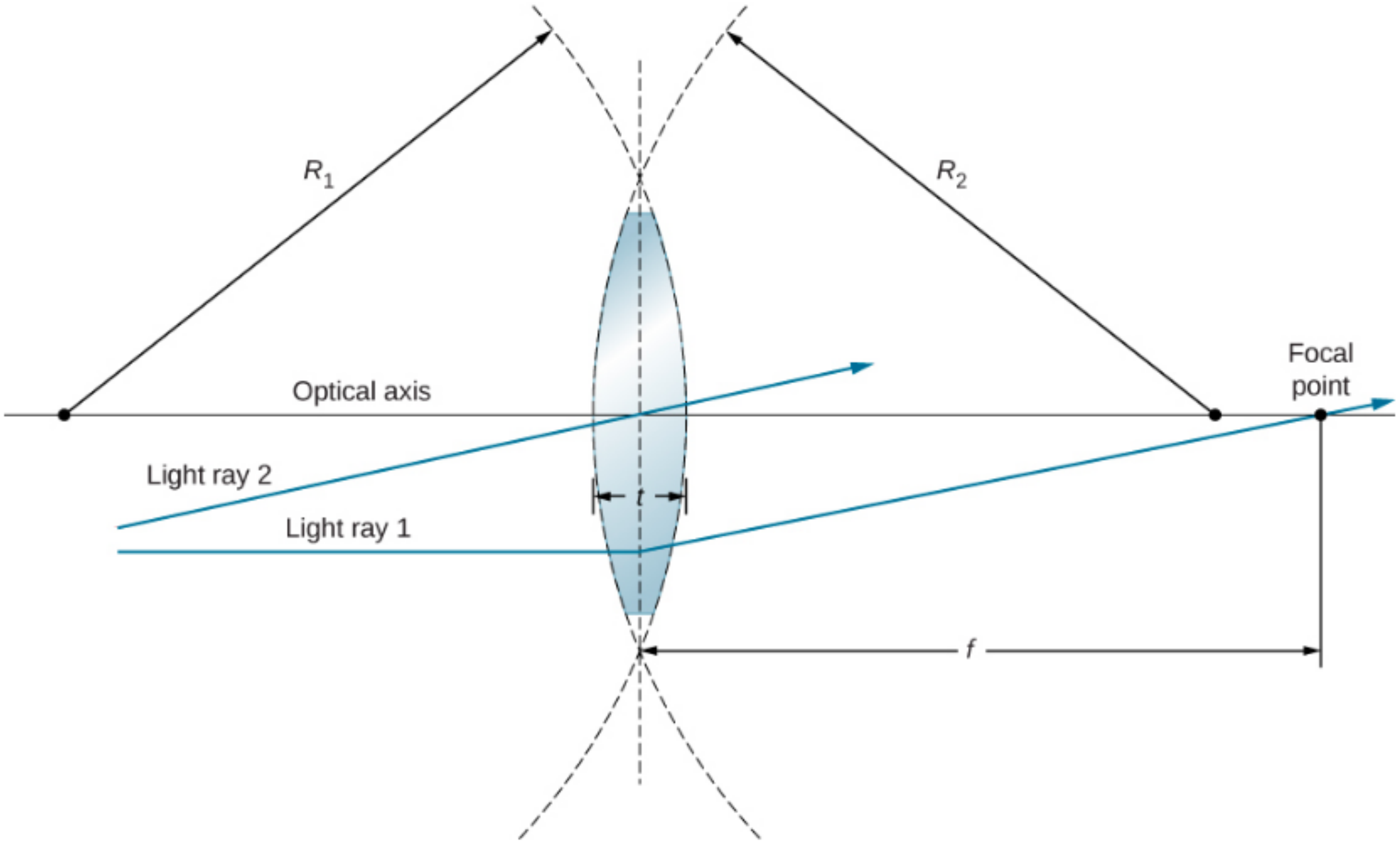
Pinhole Model (Simplified) **with Lens**



General Lens

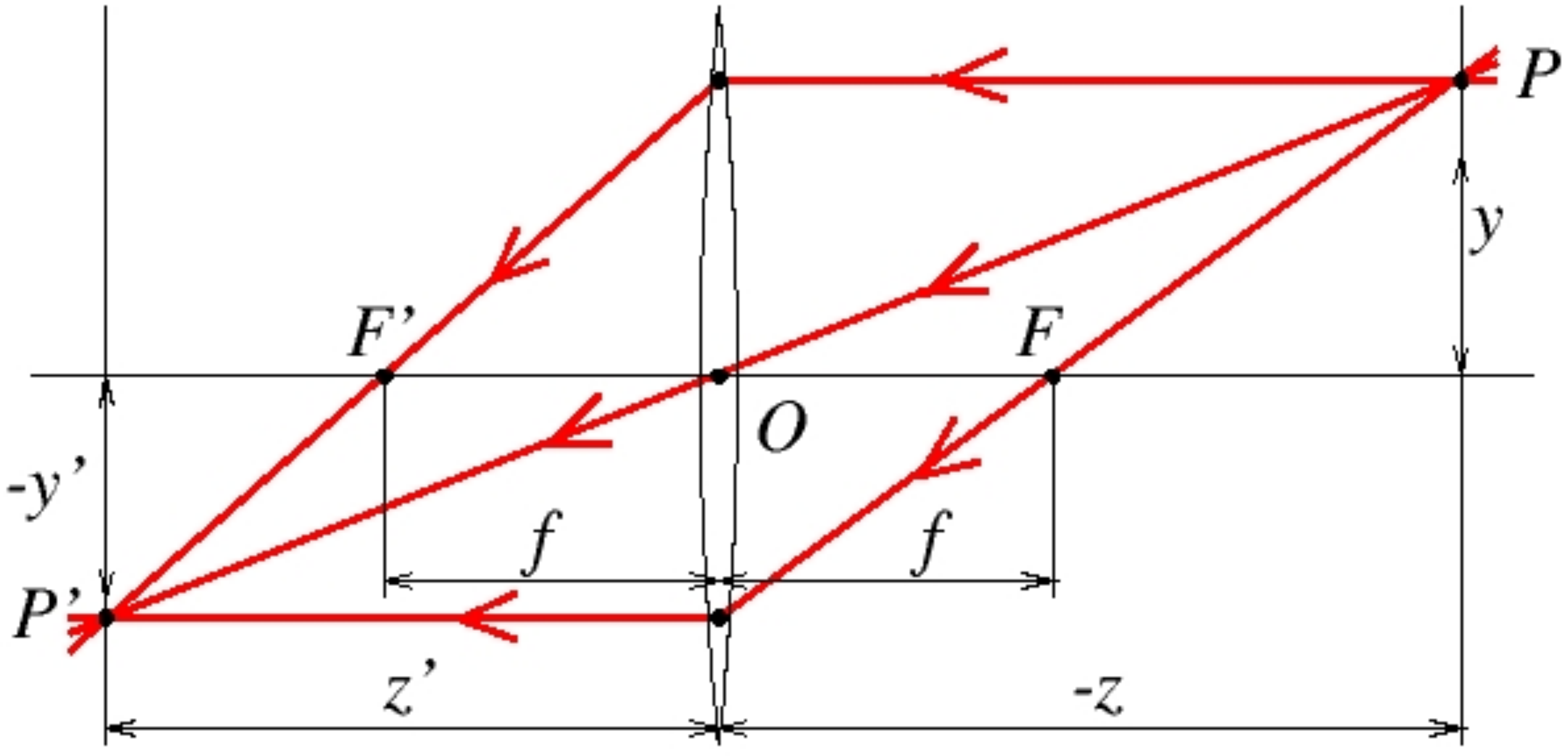


Thin Lens



https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_University_Physics_(OpenStax)/Map%3A_University_Physics_III_-_Optics_and_Modern_Physics_(OpenStax)/02%3A_Geometric_Optics_and_Image_Formation/2.05%3A_Thin_Lenses

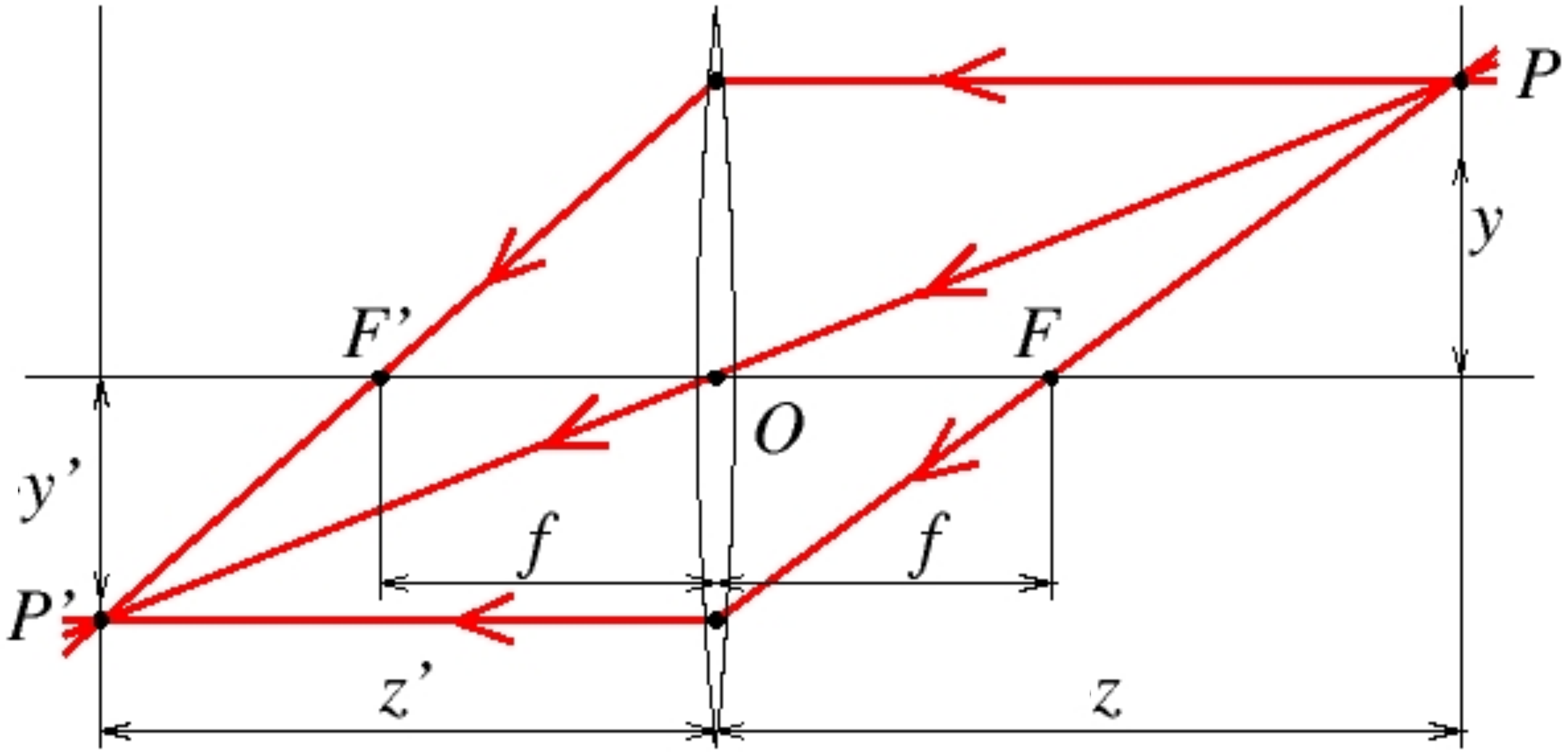
Thin Lens Equation



Forsyth & Ponce (1st ed.) Figure 1.9

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

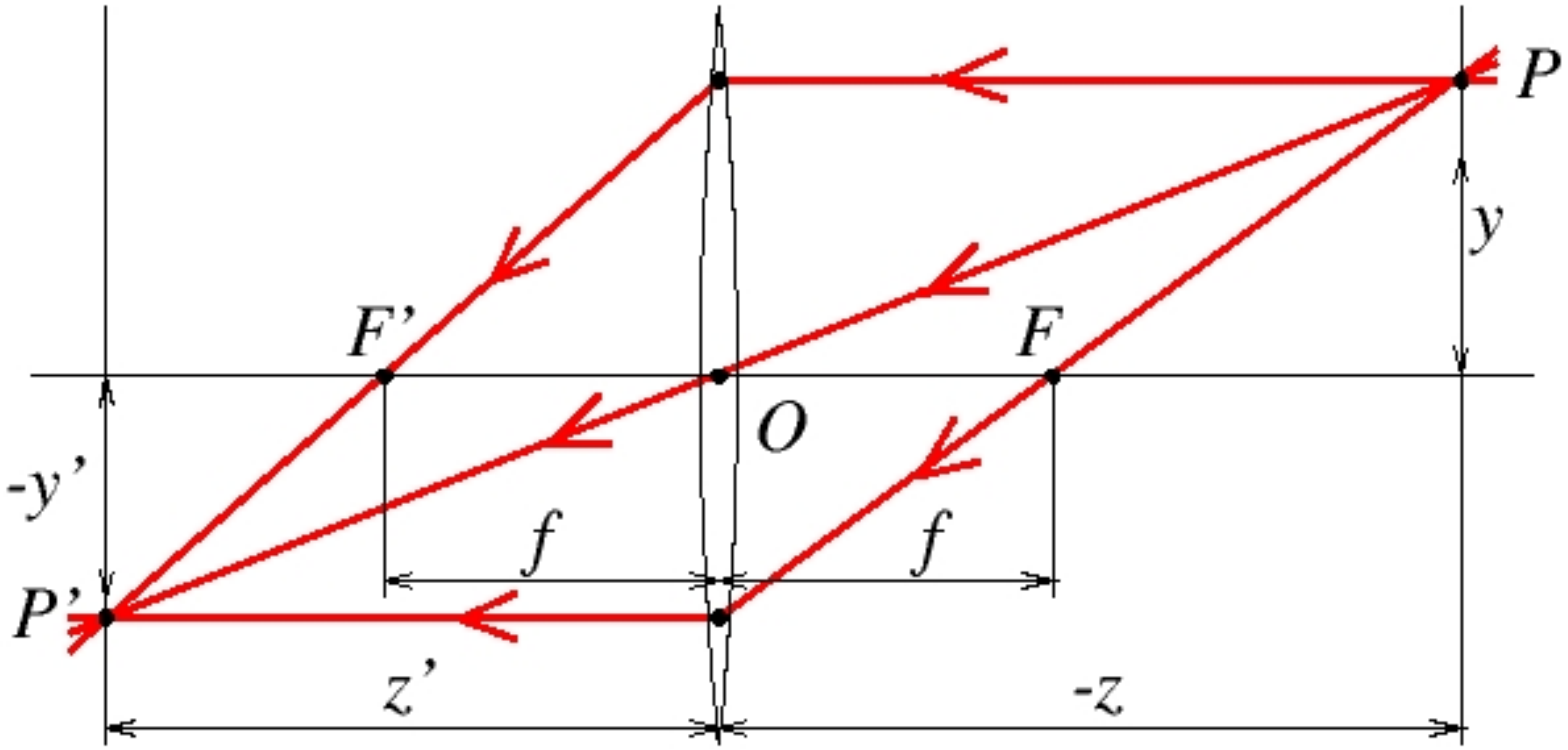
Thin Lens Equation



Forsyth & Ponce (1st ed.) Figure 1.9

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

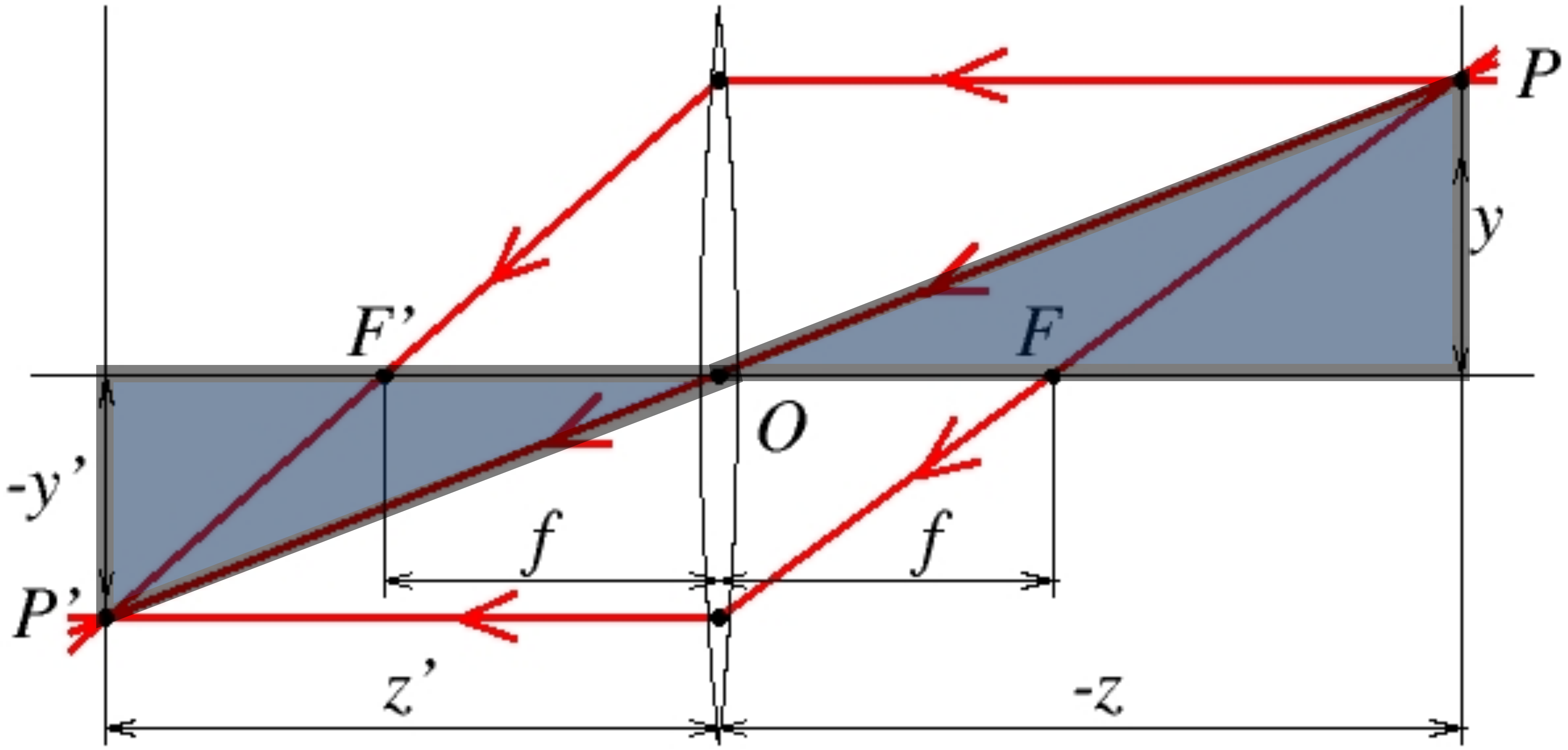
Thin Lens Equation



Forsyth & Ponce (1st ed.) Figure 1.9

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

Thin Lens Equation: Derivation



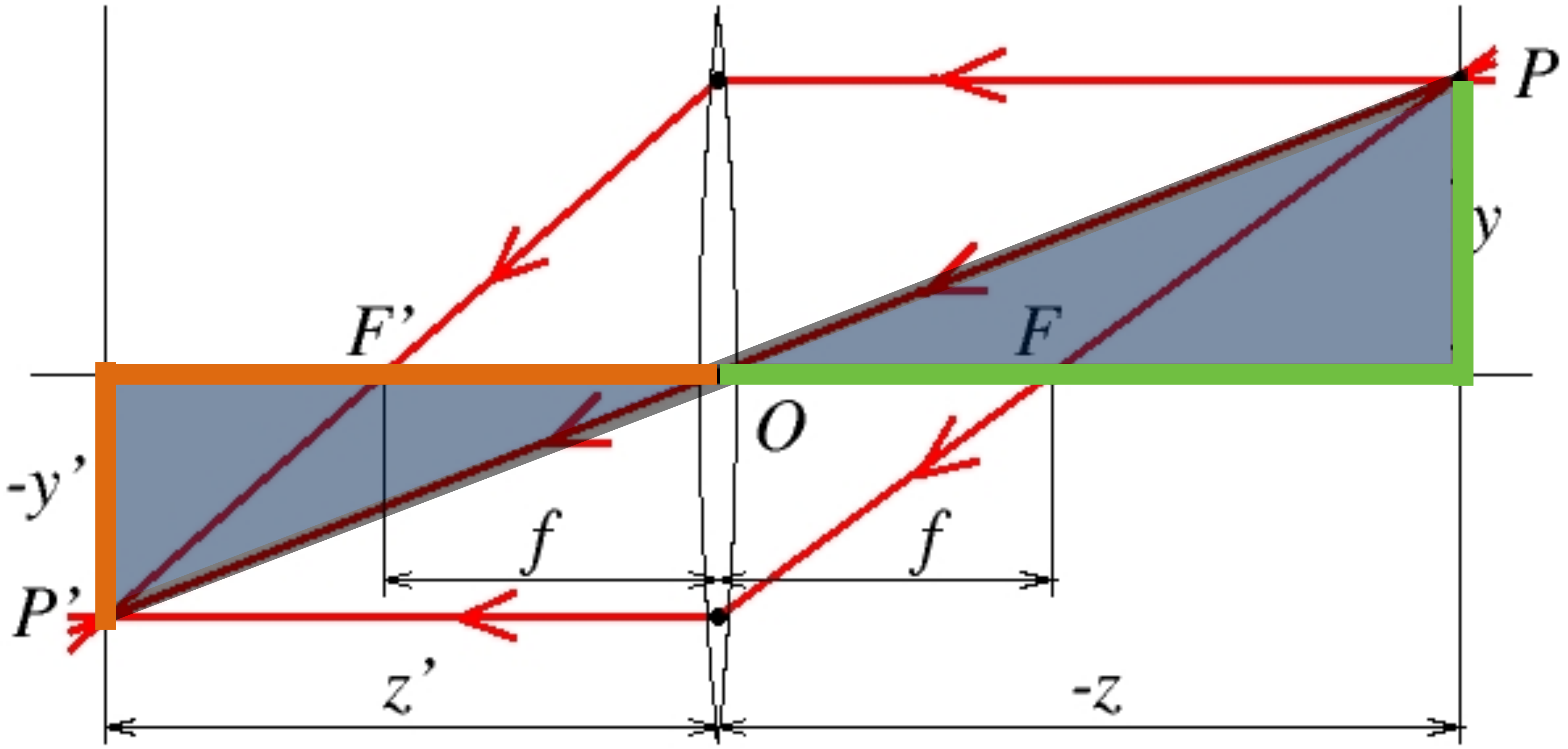
Forsyth & Ponce (1st ed.) Figure 1.9

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

Thin Lens Equation: Derivation

$$\frac{y}{-z} = \frac{-y'}{z'}$$

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



Forsyth & Ponce (1st ed.) Figure 1.9

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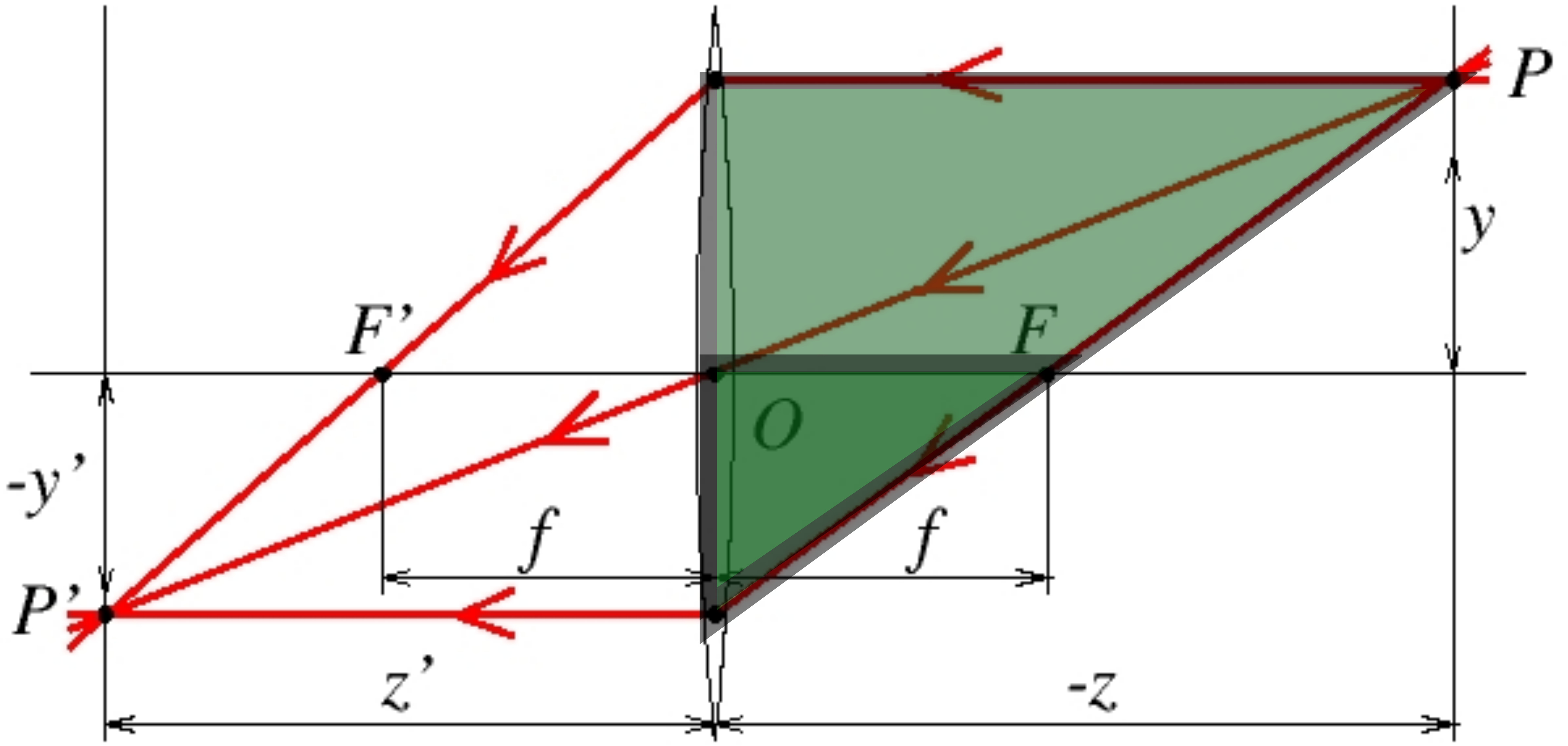

Forsyth & Ponce (1st ed.) Figure 1.9

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

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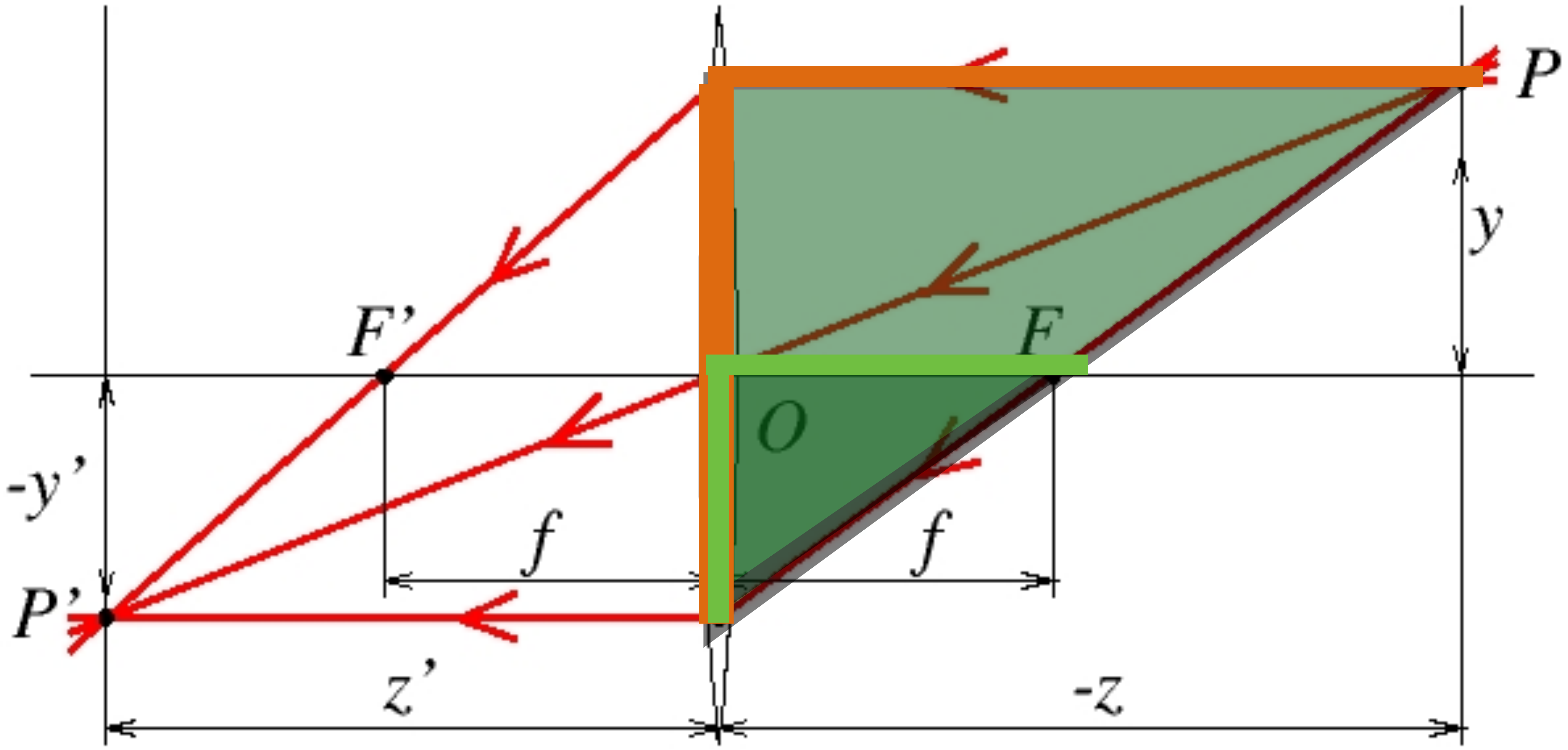


Forsyth & Ponce (1st ed.) Figure 1.9

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

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

$$\frac{1}{f} = \frac{y - y'}{zy'}$$

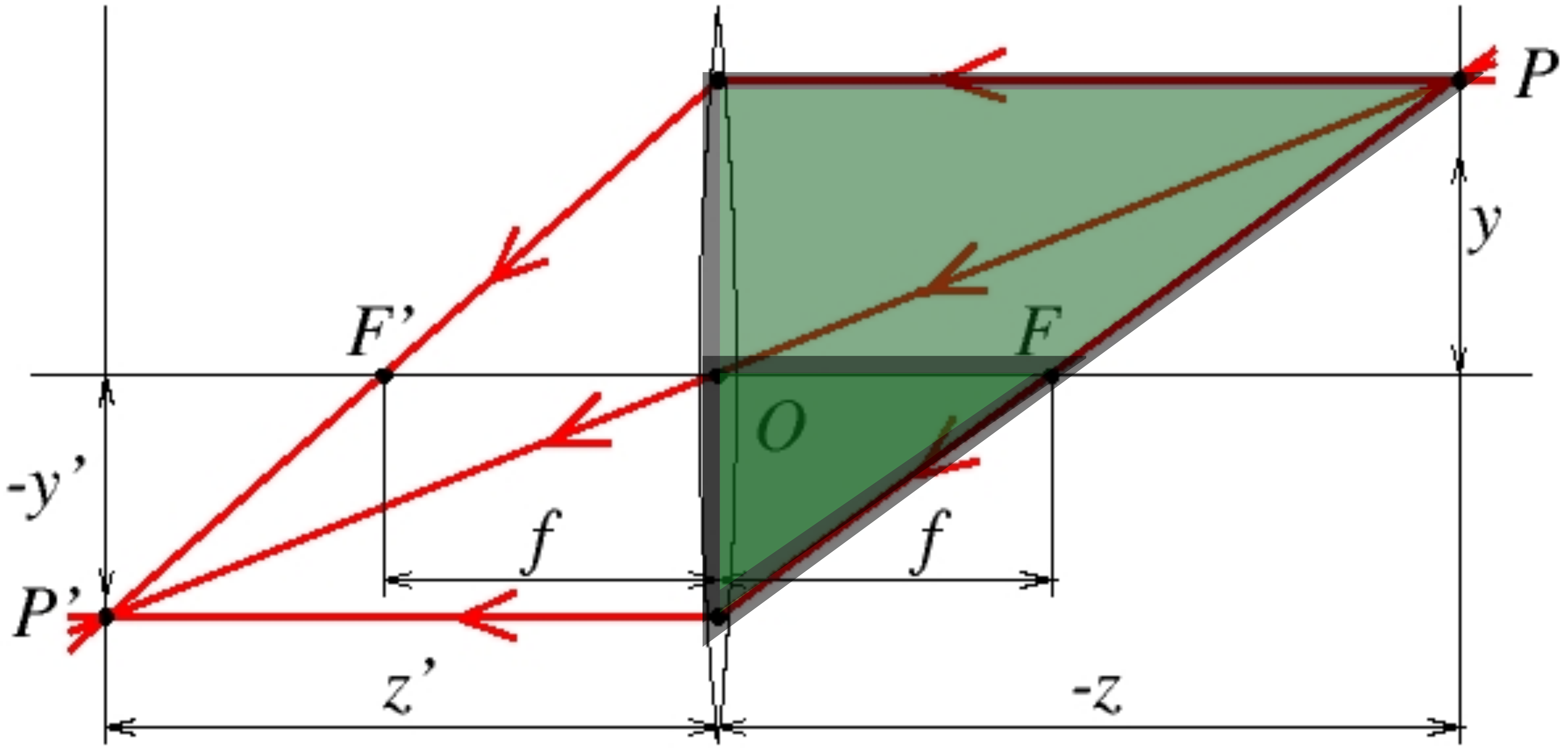
$$= \frac{y}{zy'} - \frac{y'}{zy'}$$

$$= \frac{y}{zy'} - \frac{1}{z}$$

Thin Lens Equation: Derivation

$$\frac{y}{-z} = \frac{-y'}{z'}$$

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



Forsyth & Ponce (1st ed.) Figure 1.9

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

$$\frac{1}{f} = \frac{y - y'}{zy'}$$

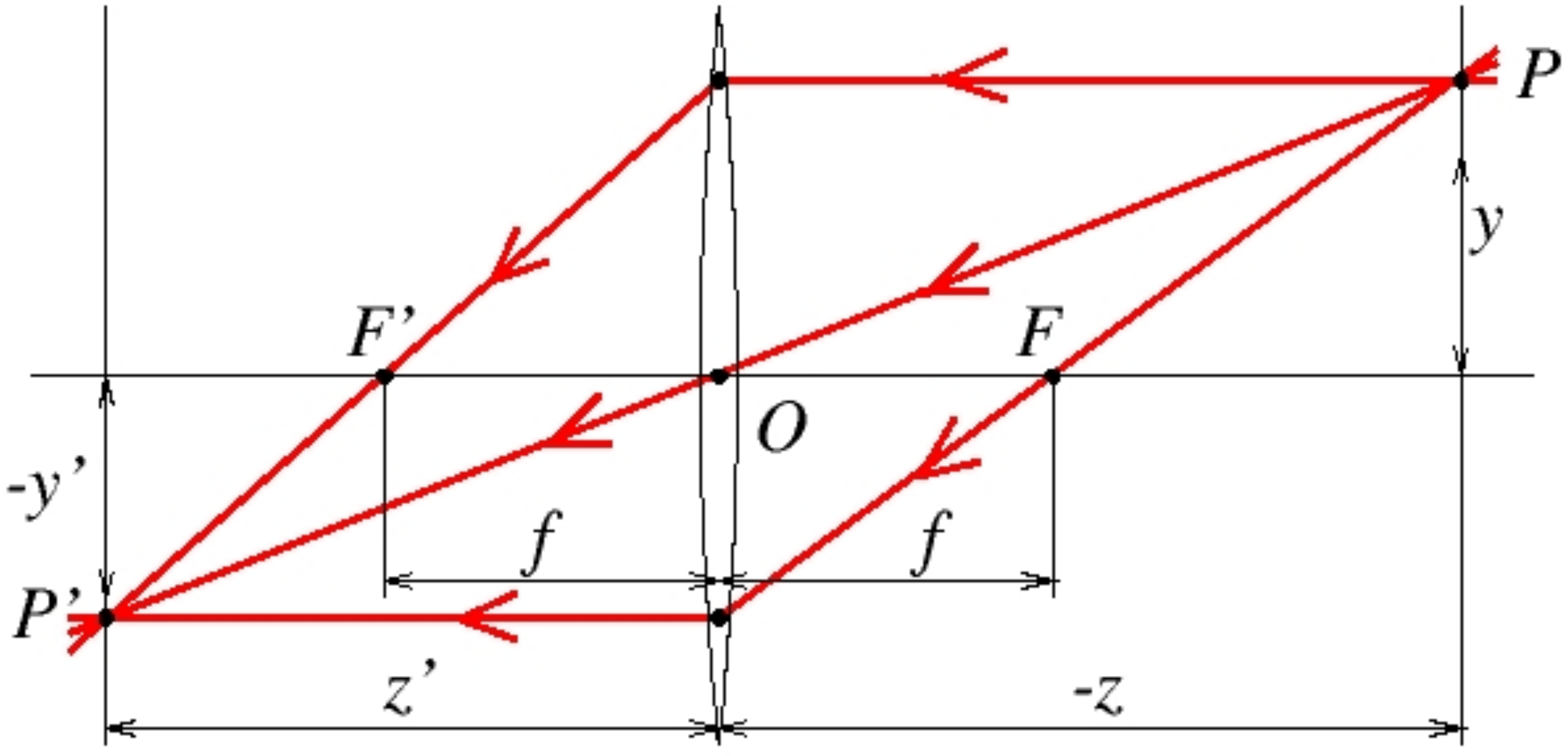
$$= \frac{y}{zy'} - \frac{y'}{zy'}$$

$$= \frac{y}{zy'} - \frac{1}{z}$$

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

Substitute: $\frac{1}{f} = \frac{1}{\cancel{z}}\frac{\cancel{z}}{z'} - \frac{1}{z}$

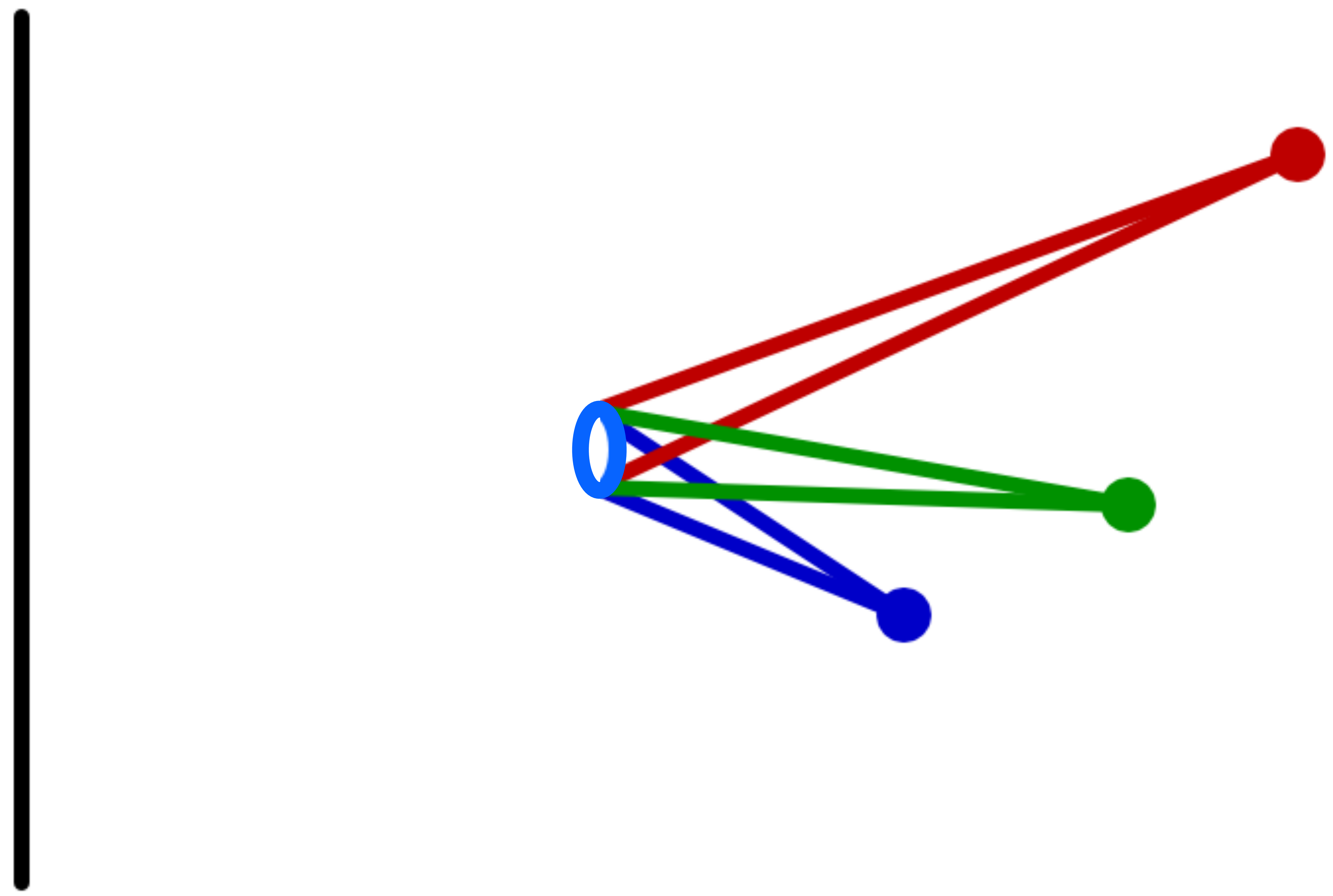
Possible Uses of Thin Lens Abstraction



Forsyth & Ponce (1st ed.) Figure 1.9

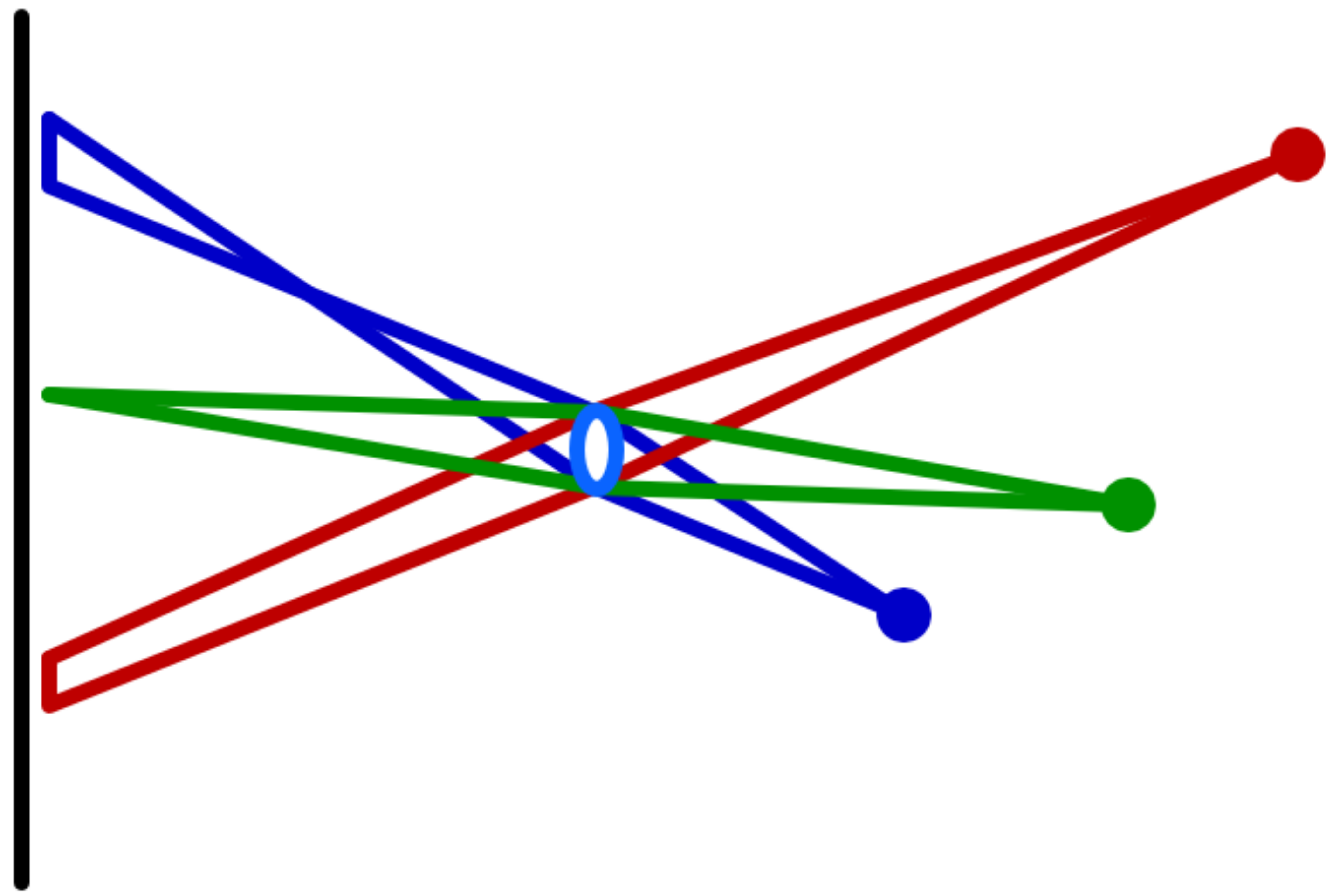
$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f}$$

Thin Lens Equation: Points at different depths



* image credit: https://catlikecoding.com/unity/tutorials/advanced-rendering/depth-of-field/circle-of-confusion/lens-camera.png

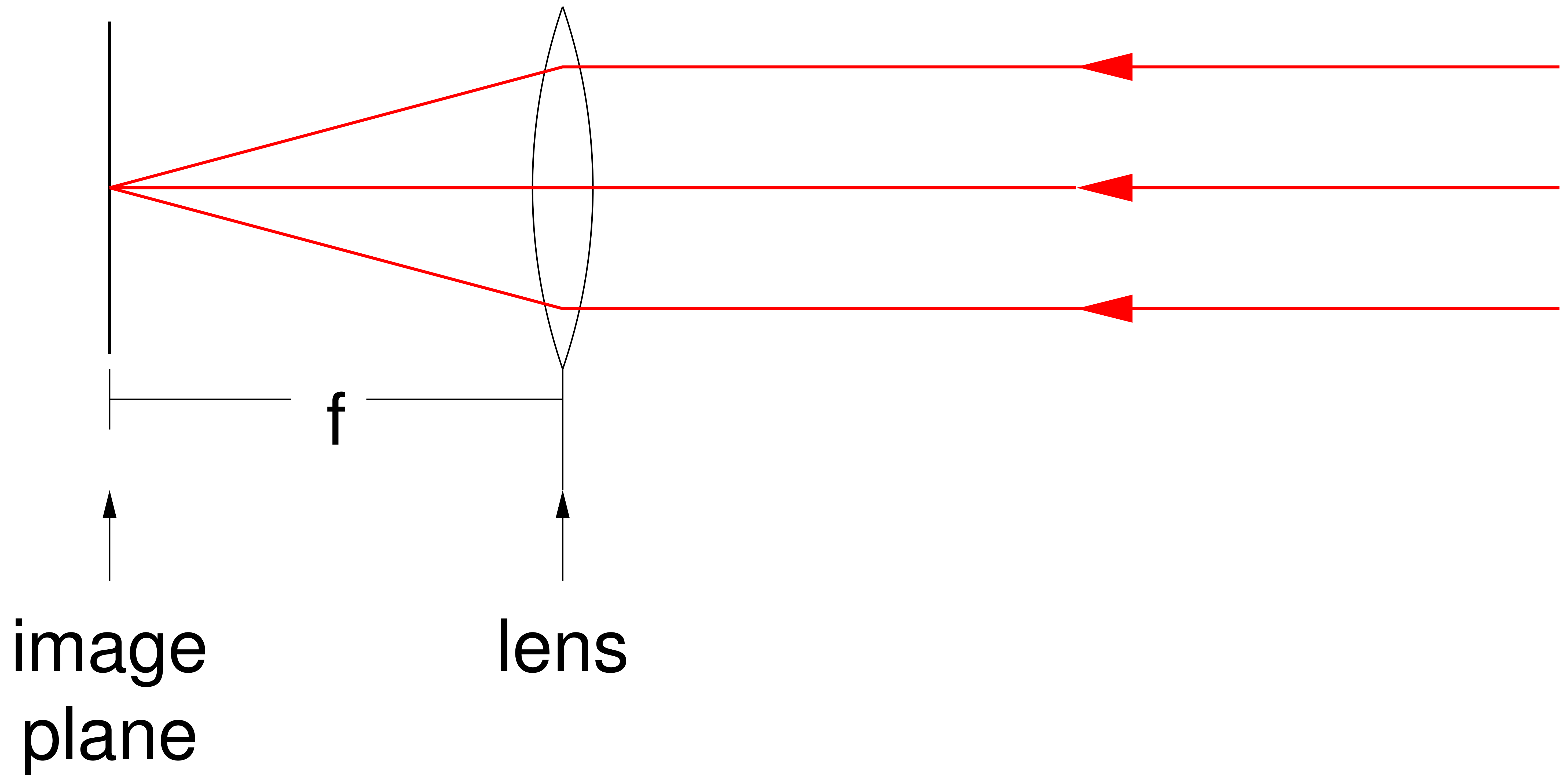
Thin Lens Equation: Points at different depths



* image credit: https://catlikecoding.com/unity/tutorials/advanced-rendering/depth-of-field/circle-of-confusion/lens-camera.png

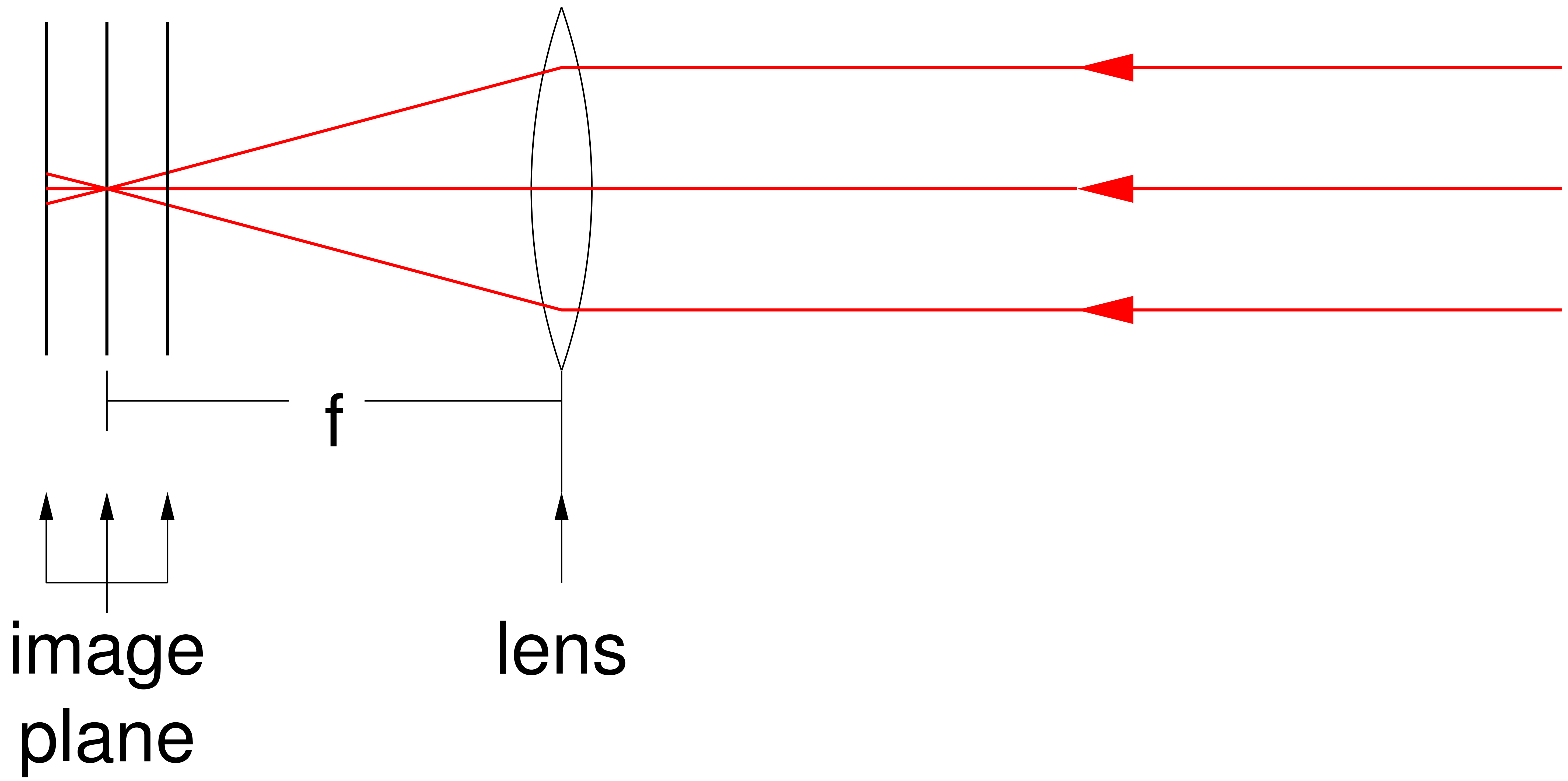
Focal Length

Another way of looking at the **focal length** of a lens. The incoming rays, parallel to the optical axis, **converge to a single point a distance f behind the lens**. This is where we want to place the image plane.

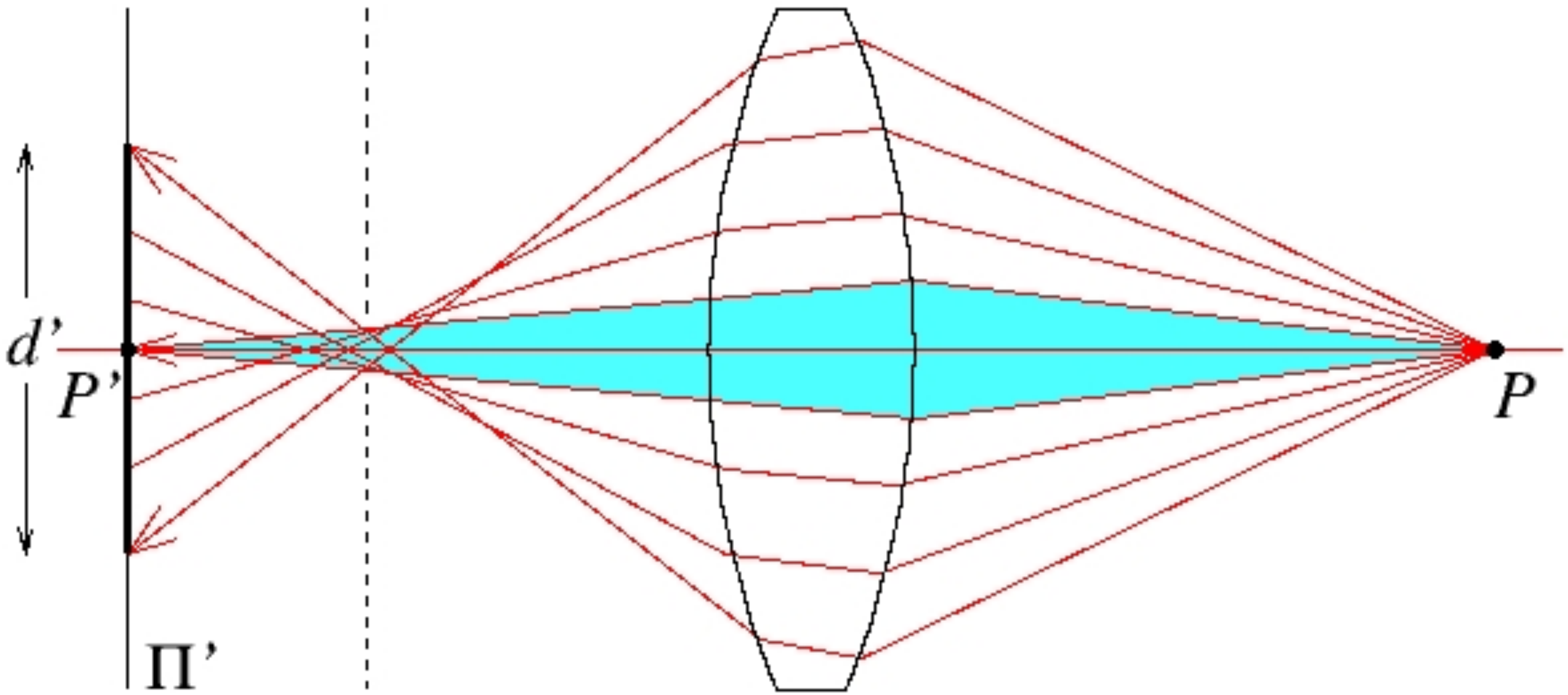


Out-of-Focus

The image plane is in the wrong place, either slightly closer than the required focal length, f, or slightly further than the required focal length, f.



Spherical **Aberration**



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

Spherical **Aberration**

Un-aberrated image

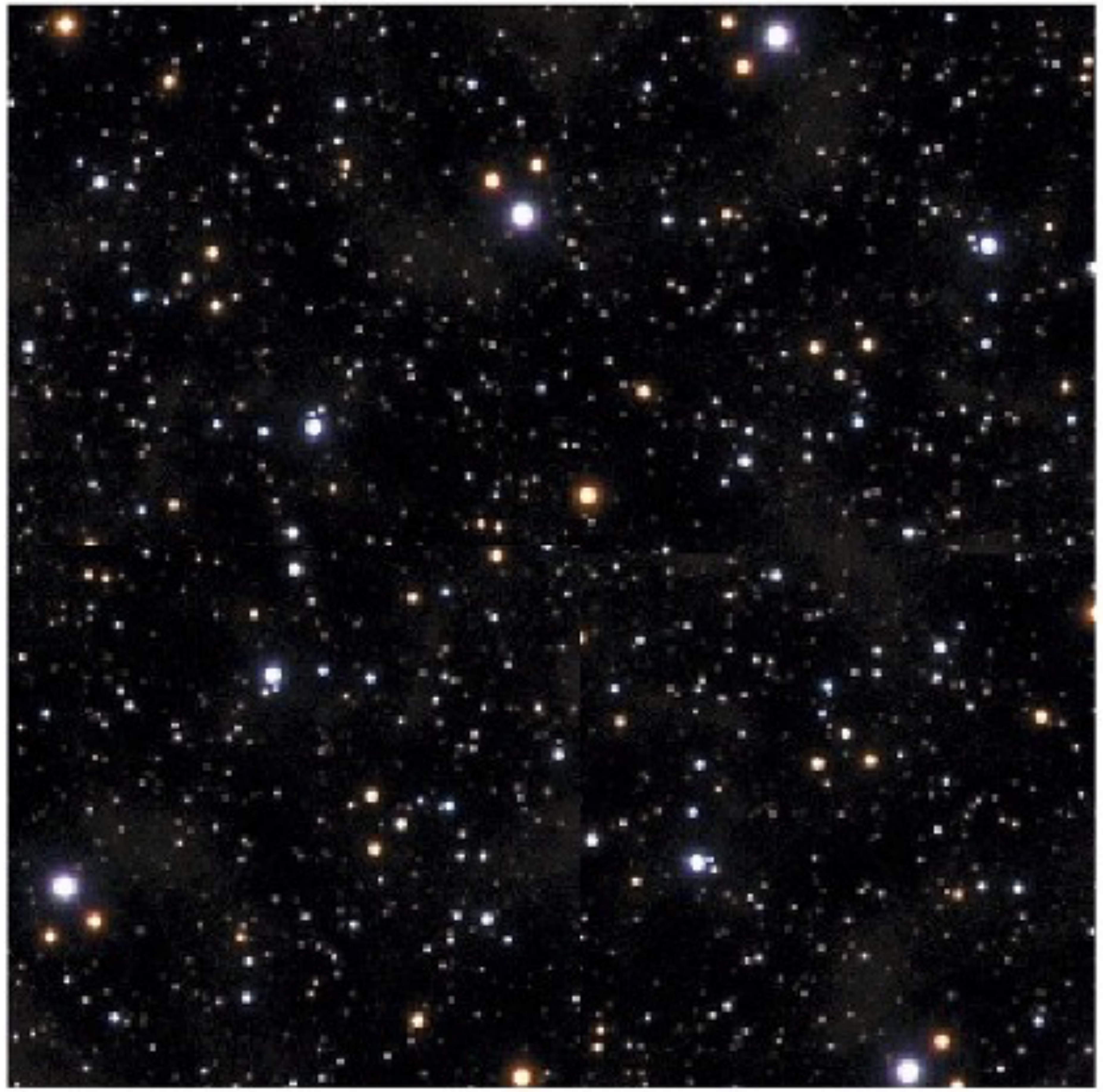
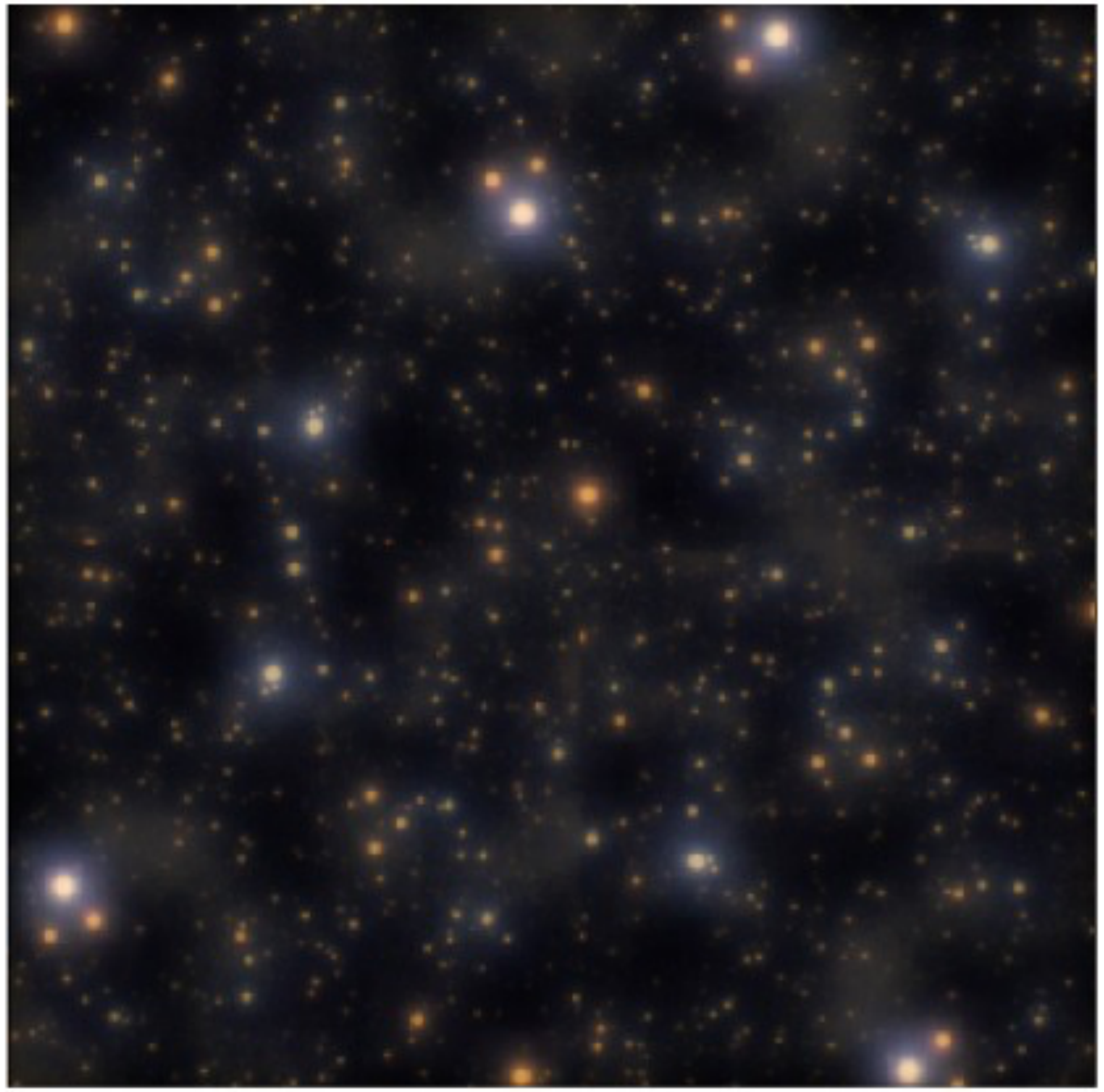
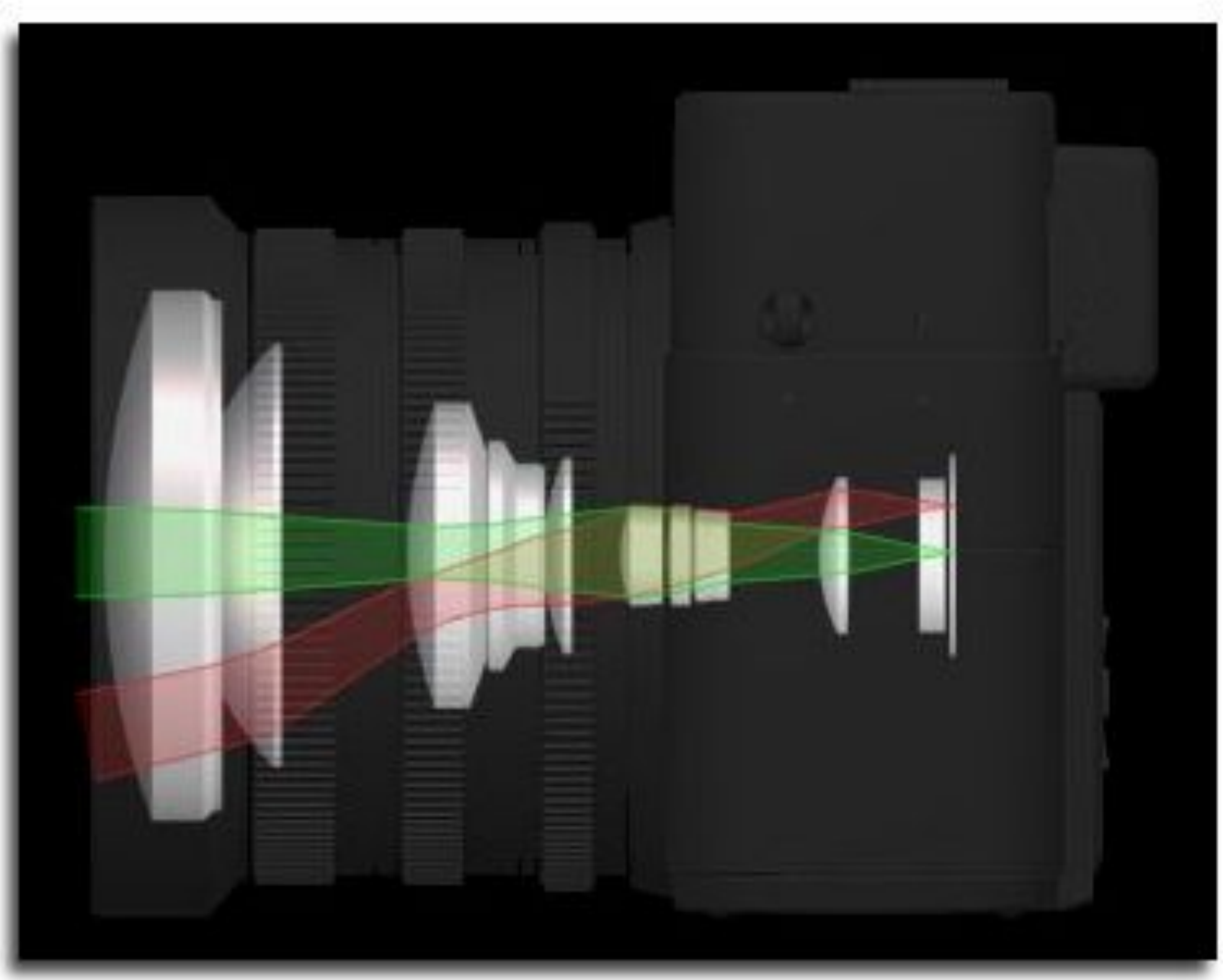
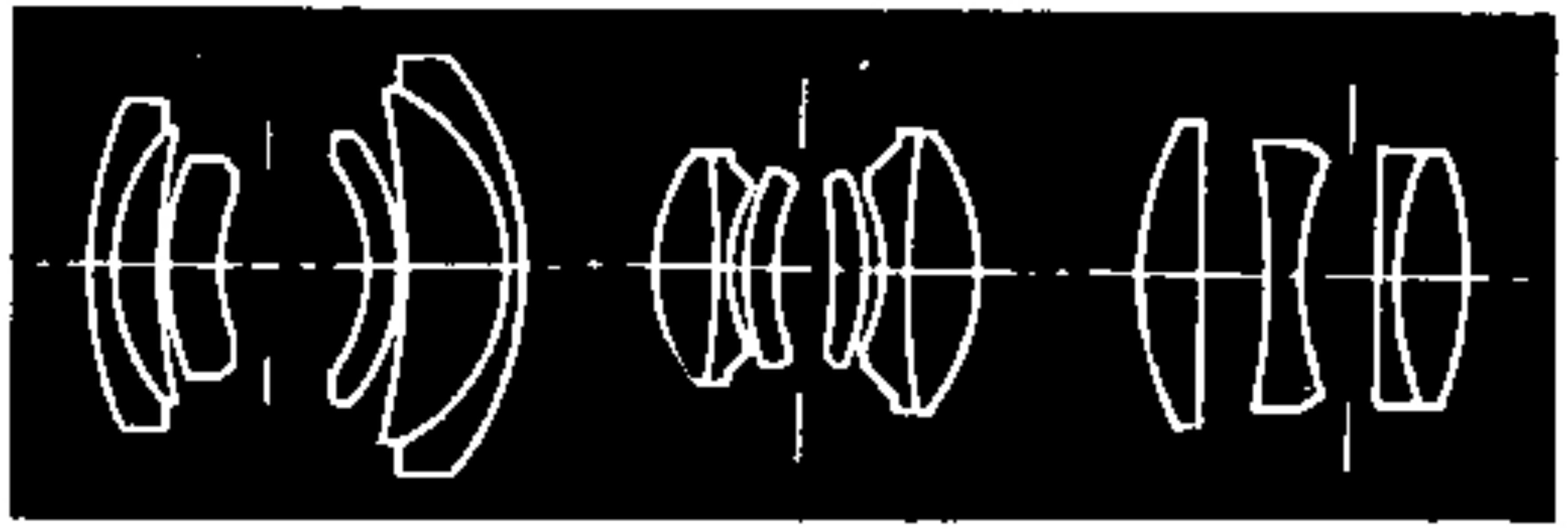


Image from lens with Spherical Aberration



Compound **Lens Systems**

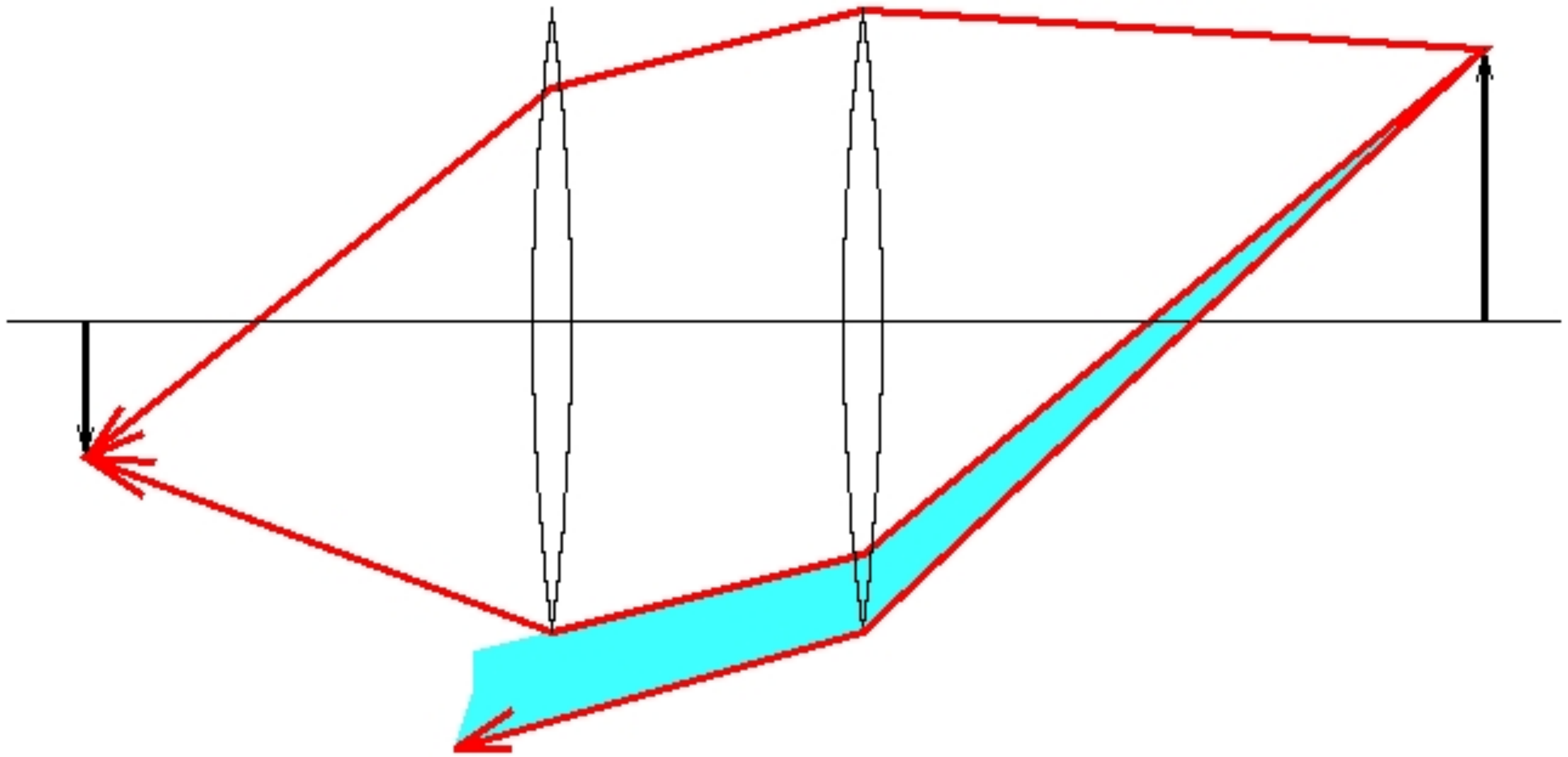




A modern camera lens may contain multiple components, including aspherical elements

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

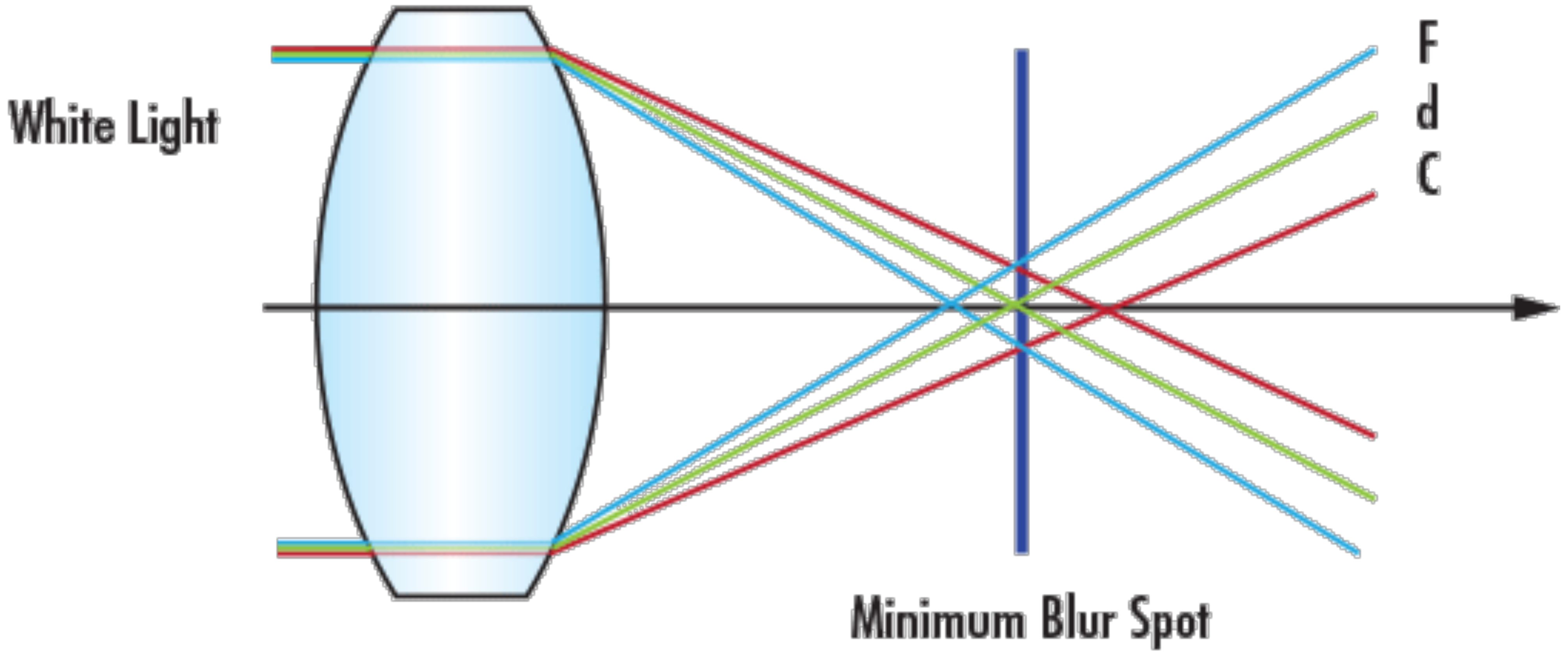


Image Credit: Trevor Darrell

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!

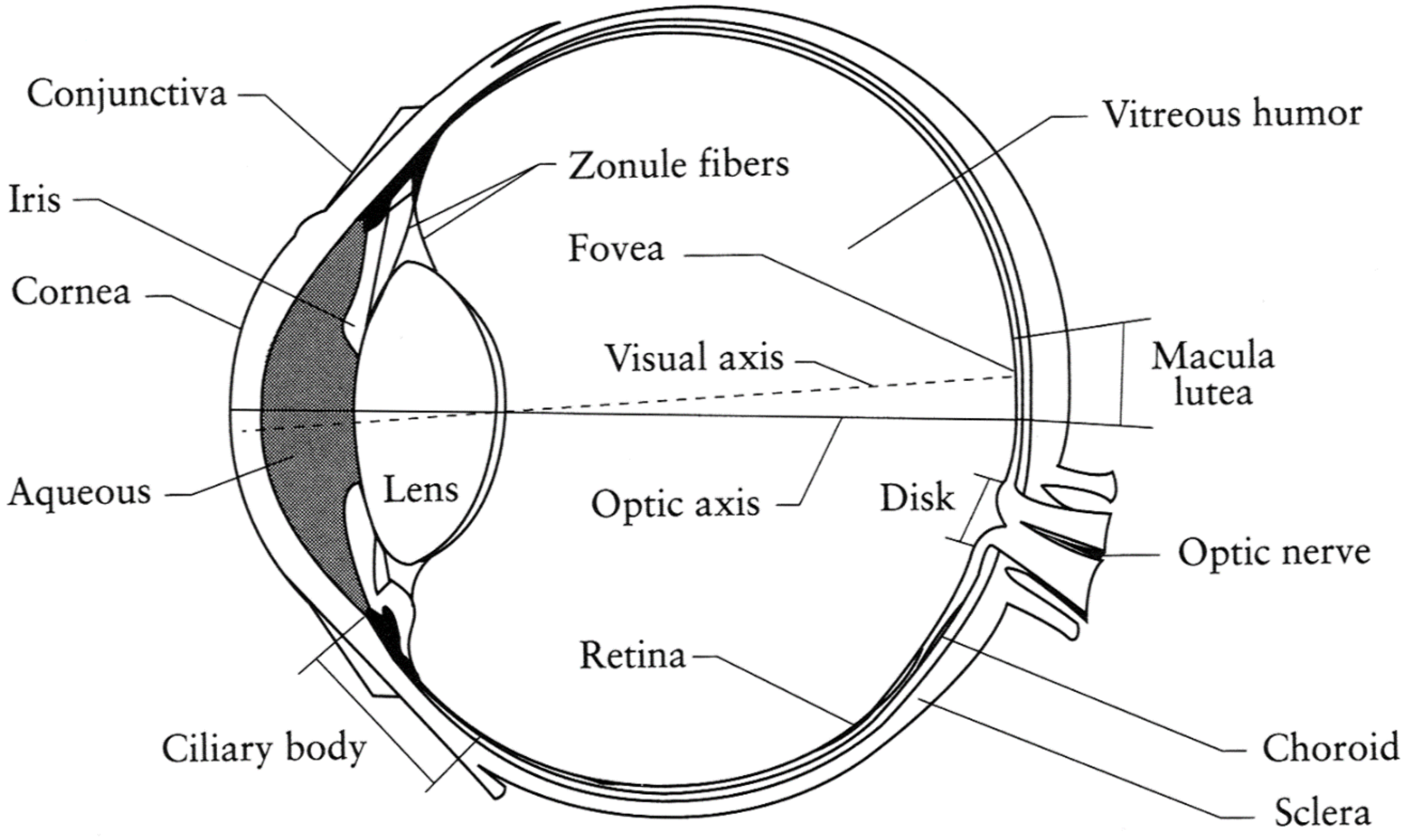
Human Eye

— 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**

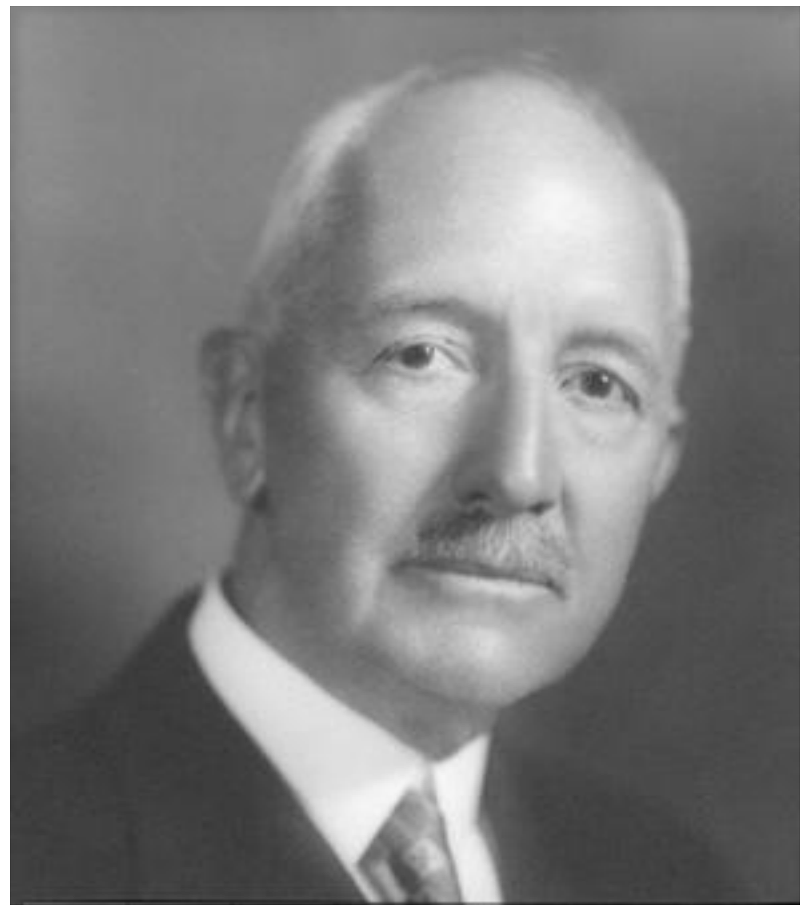


pupil = pinhole / aperture

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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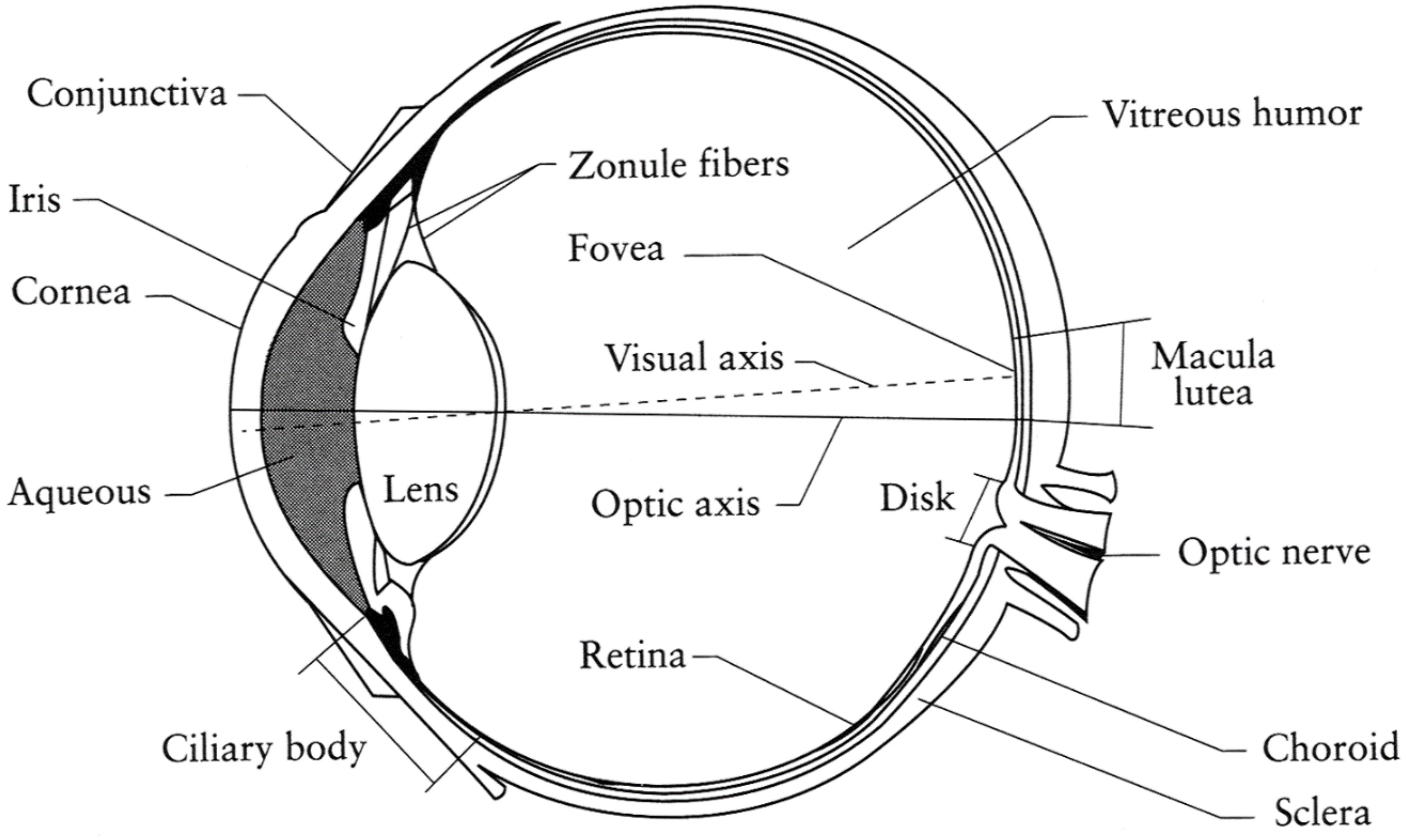

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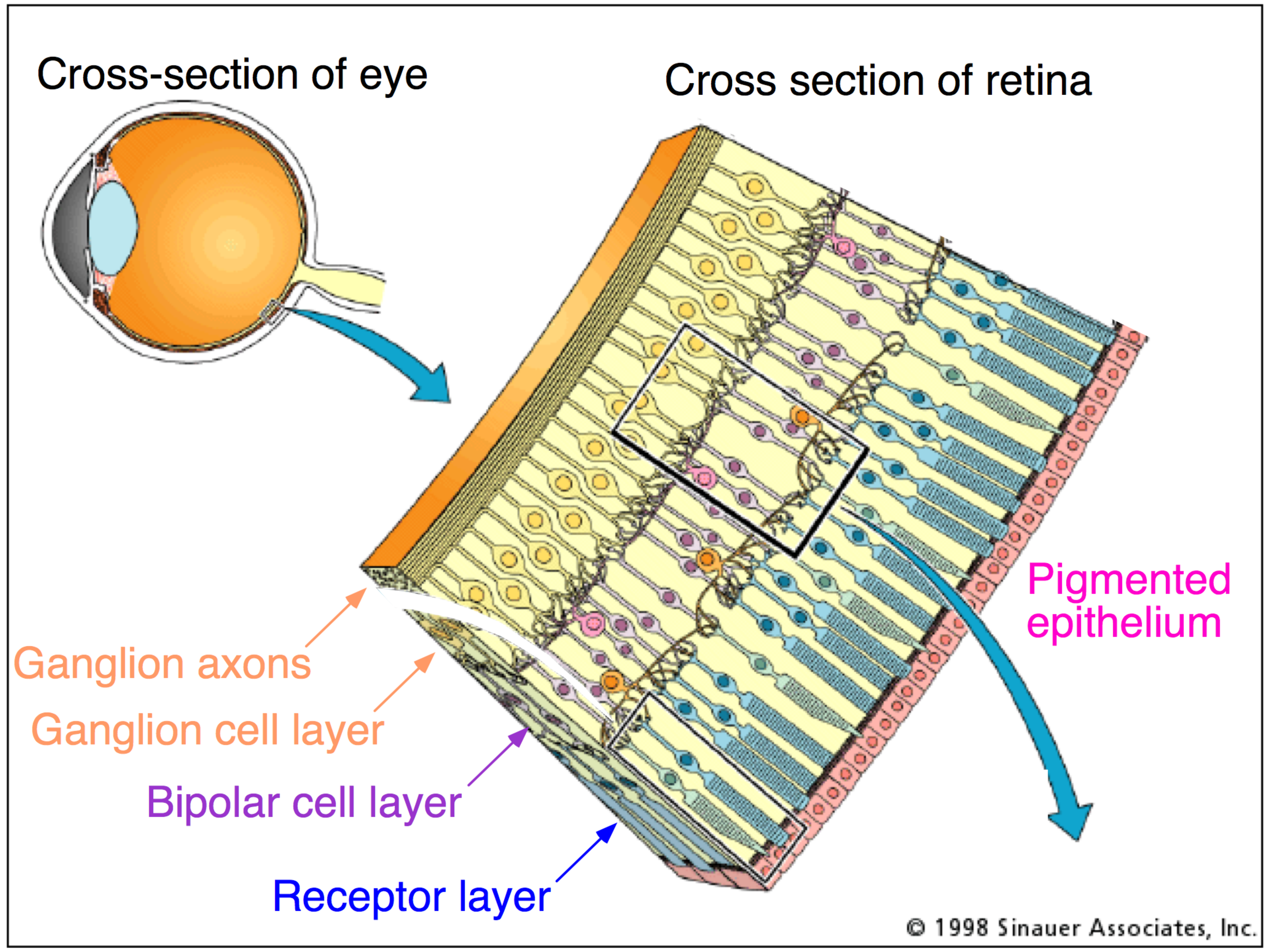

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Slide adopted from: Steve Seitz

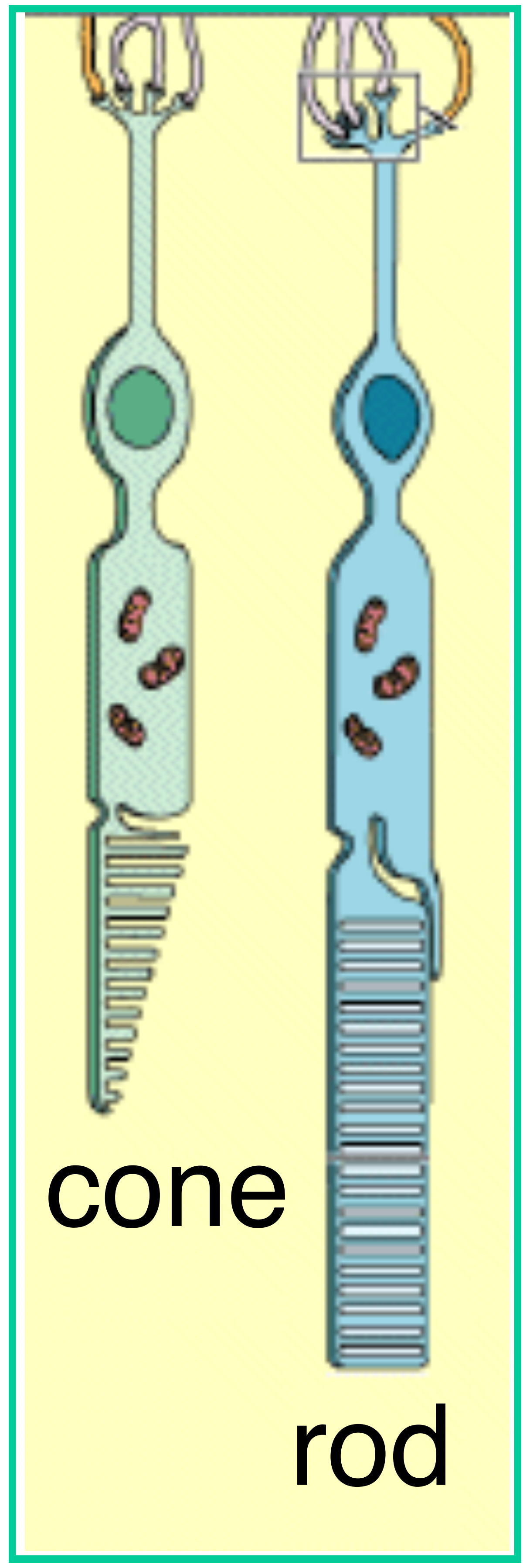
Two-types of **Light Sensitive Receptors**

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

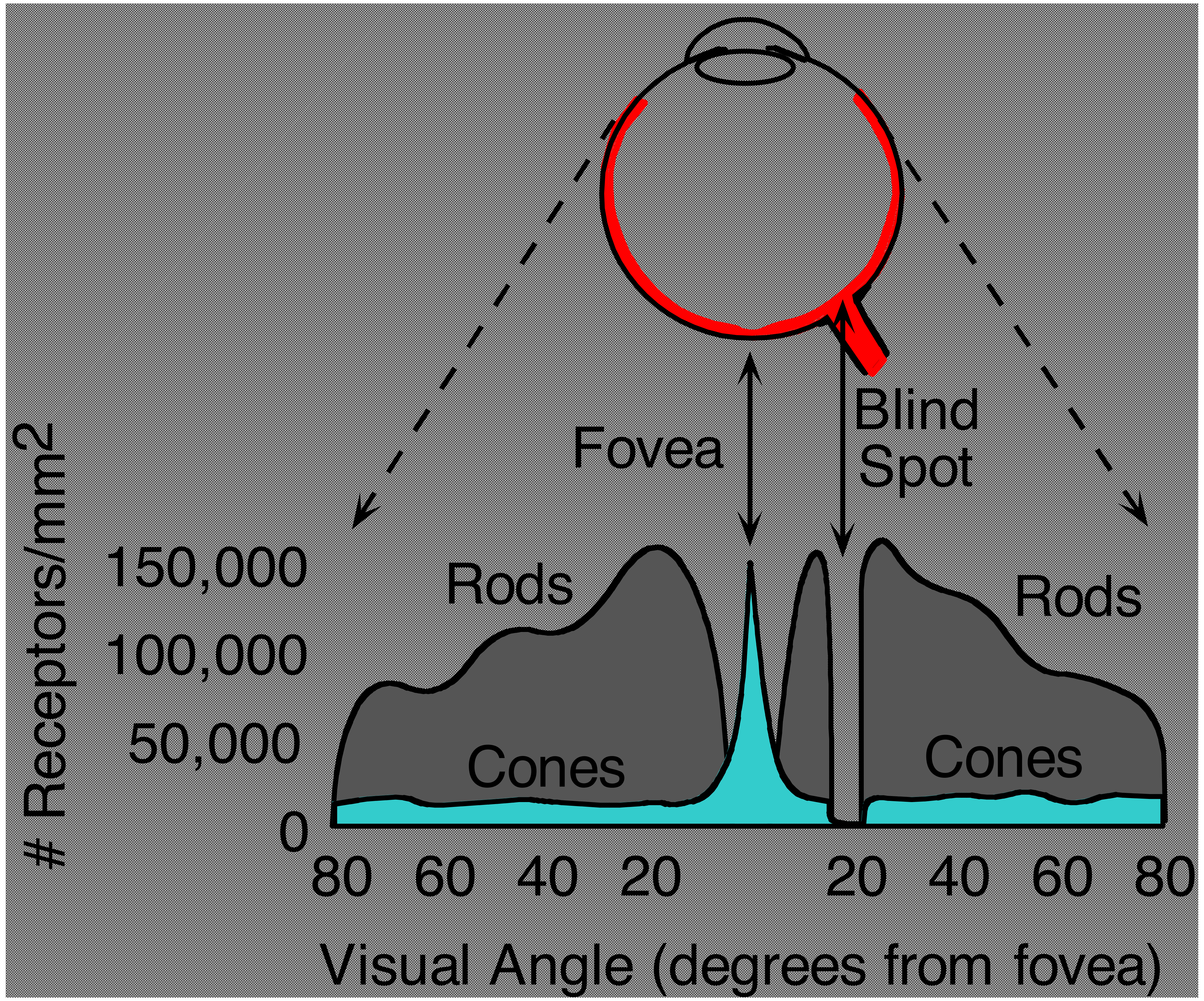
6-7 million cone-shaped receptors
color vision
operate in high light
less sensitive
yield higher resolution



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

What is **Computer Vision**?

Compute vision, broadly speaking, is a research field aimed to enable computers to **process and interpret visual data**, as sighted humans can.

Image (or video)

Sensing Device

Interpreting Device

Image Credit: https://www.flickr.com/photos/flamephoenix1991/8376271918

Interpretation

blue sky,
trees,
fountains,
UBC, …

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Compute vision, broadly speaking, is a research field aimed to enable computers to **process and interpret visual data**, as sighted humans can.

Image (or video)

Sensing Device

Interpreting Device

Image Credit: https://www.flickr.com/photos/flamephoenix1991/8376271918

Interpretation

blue sky,
trees,
fountains,
UBC, …

Discretization (spatially and and in terms of photon counts), camera **hardware** and **low-level processing** … we will talk about these topics next week

Perception and encoding of **color** … we will talk about this in a few weeks

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Image (or video)

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What is **Computer Vision**?

Compute vision, broadly speaking, is a research field aimed to enable computers to **process and interpret visual data**, as sighted humans can.

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