SE 422
Advanced Photogrammetry

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Geometric/ Rays Optics

Four Axioms of Geometric Optics

1. A light ray is a straight line in homogenous material

2. At the border between two homogenous materials, the light is reflected (Fresnel reflection) or refracted (Snell's law)

3. The optical path is reversible

4. Intersecting light rays do not influence each other

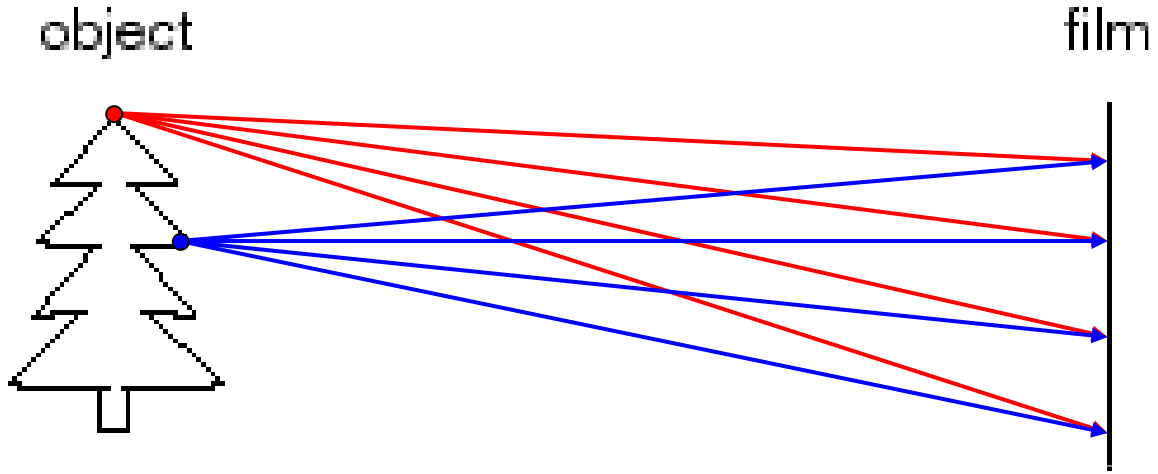
Geometric Optics

- Light propagation is described by rays from the light sources
- Light travels with $c \approx 2.998 \times 10^8 \left({}^{m}/_{s}\right)$ in vacuum
- Different speeds in different materials
- Each material has an index of refraction n
- Speed $v = \frac{c}{n}$
- Light travels along the fastest path

Image Formation

Let’s design a camera

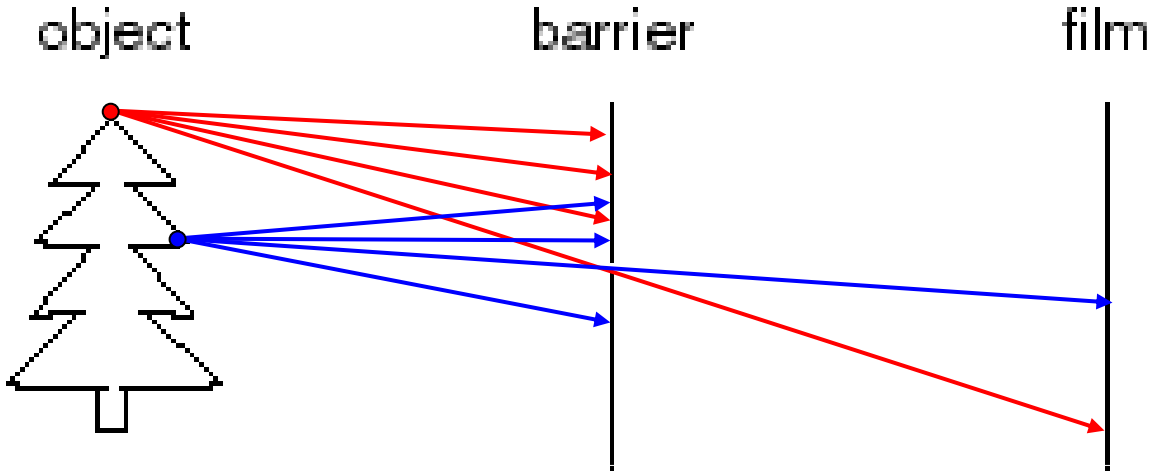
- Idea 1: Put a piece of film in front of an object
- Do we get a reasonable image?



Slide Courtesy: Seitz

Pinhole Camera

- Add a barrier to block off most of the rays
- This reduces blurring
- The opening is known as the aperture
- How does this transform the image?



Pinhole Camera

- Pinhole camera is a simple model to approximate the imaging process
- If we treat pinhole as a point, only one ray from any given point can enter the camera

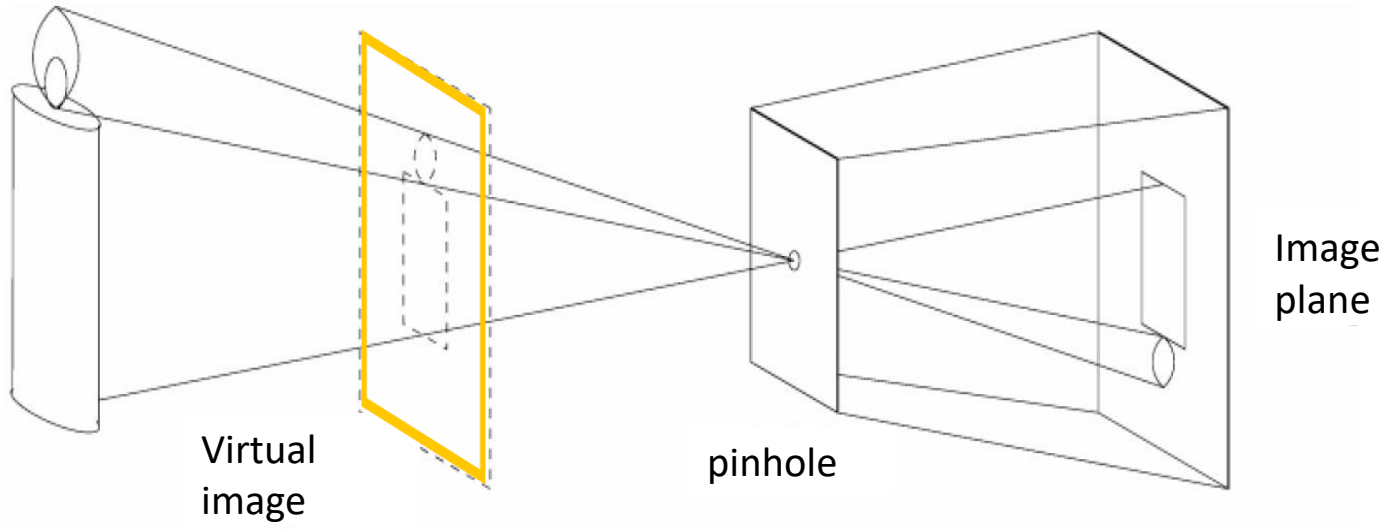
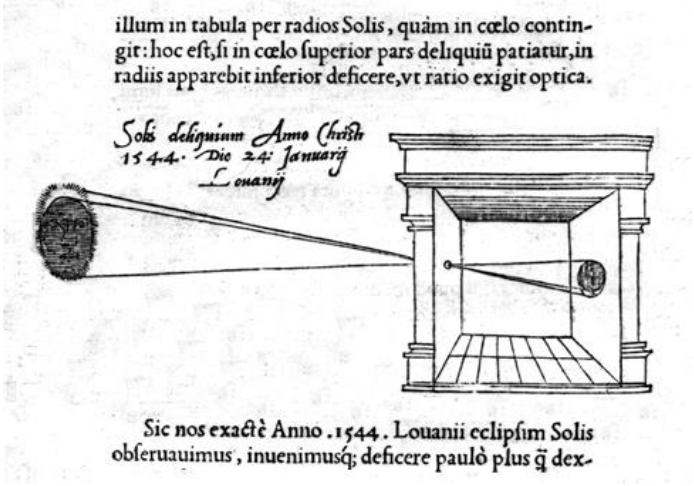


Image Courtesy: Forsyth and Ponce

Camera Obscura (1544)

- "**Reinerus Gemma-Frisius**, observed an eclipse of the sun at Louvain on January 24, 1544, and later he used this illustration of the event in his book De Radio Astronomica et Geometrica, 1545. It is thought to be the first published illustration of a camera obscura..."
- Hammond, John H., The Camera Obscura, A Chronicle



In Latin, means "dark room"

Image Courtesy: http://www.acmi.net.au/AIC/CAMERA_OBSCURA.html

Pinhole Camera Model

- Similarity of the gray triangles
- Image scale $s = \frac{d}{D}$
- Mapping $x = -s\,X$

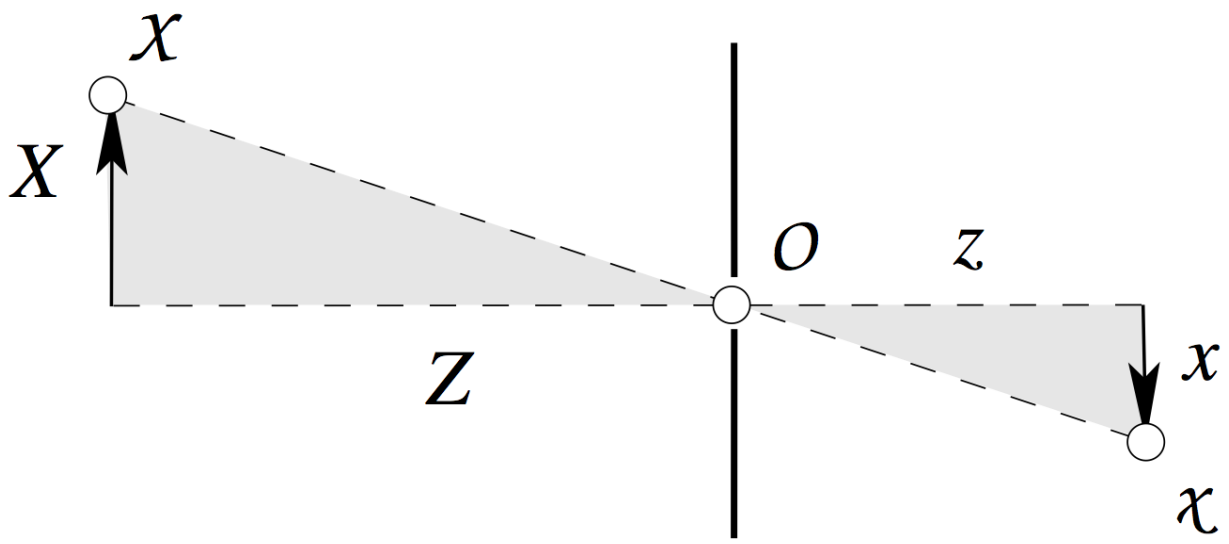


Image courtesy: Förstner

Pinhole Camera Model

- Small hole: sharp image but requires large exposure times
- Large hole: short exposure times but blurry images
- Solution: replace pinhole by lenses

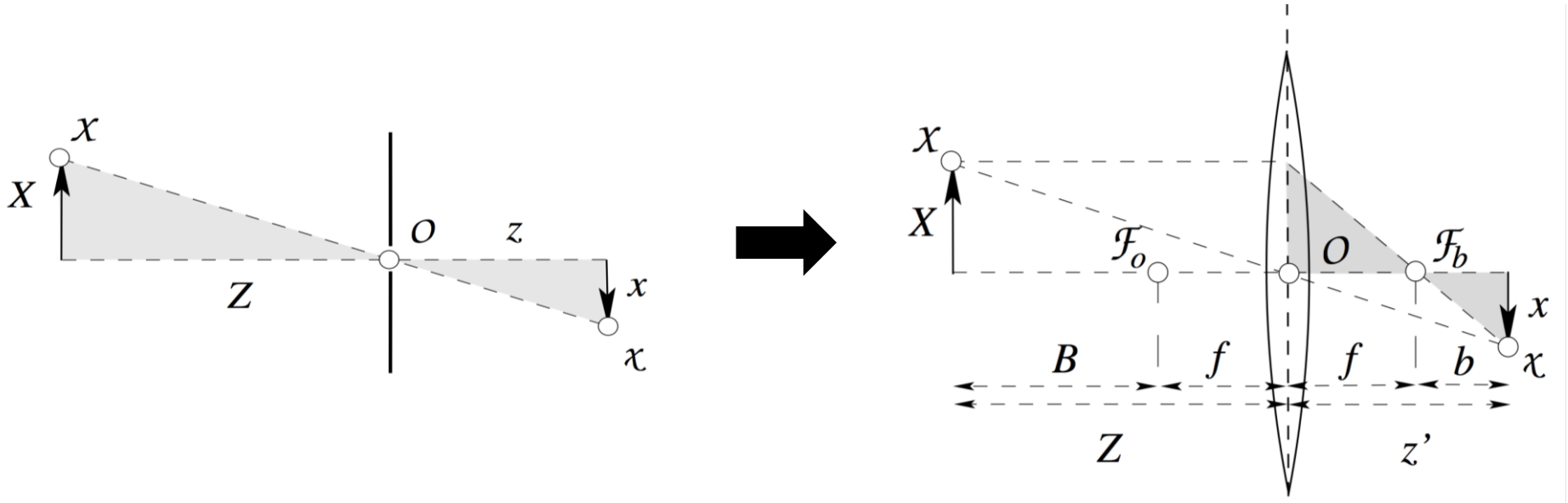
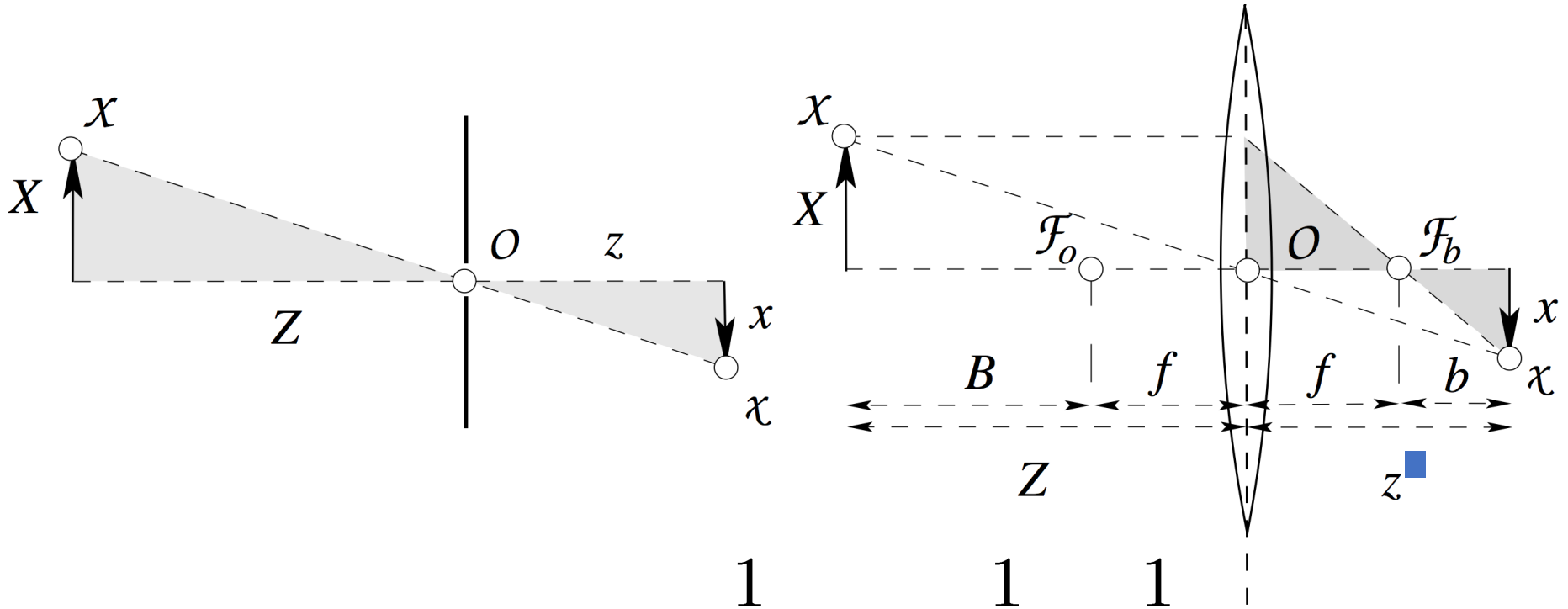


Image courtesy: Förstner

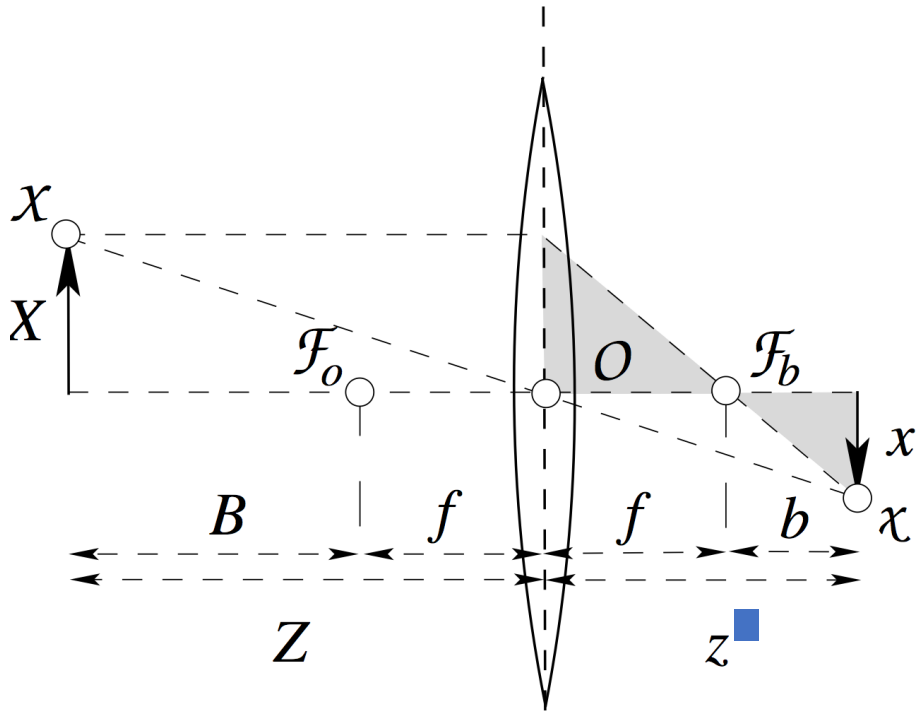
Camera with a Thin Lens



law for thin lenses: $$\frac{1}{f} = \frac{1}{z} - \frac{1}{Z}$$

Image courtesy: Förstner

Camera with a Thin Lens



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

$$\frac{x}{z-f} = \frac{X}{f}$$

Newtonian lens equation (f>0)

$$\underbrace{(z-f)}_{b}\underbrace{(Z+f)}_{B} = -f^2$$

Image courtesy: Förstner

Lens Approximates the Pinhole

- A lens is only an approximation of the pinhole camera model
- The corresponding point on the object and in the image and the center of the lens should lie on one line
- The further away a beam passes the center of the lens, the larger the error
- Use of an aperture to limit the error (trade off between the usable light and price of the lens)

Three Assumptions Made in the Pinhole Camera/Thin Lens

1. All rays from the object point intersect in a single point

2. All image points lie on a plane

3. The ray from the object point to the image point is a straight line

Wave Optics

- Considers light as an electromagnetic wave described by the Maxwell equations
- Describes interference und diffraction
- Visible light from 400nm to 700 nm
- Electro magnetic waves cover a large spectrum of wave lengths

Spectrum

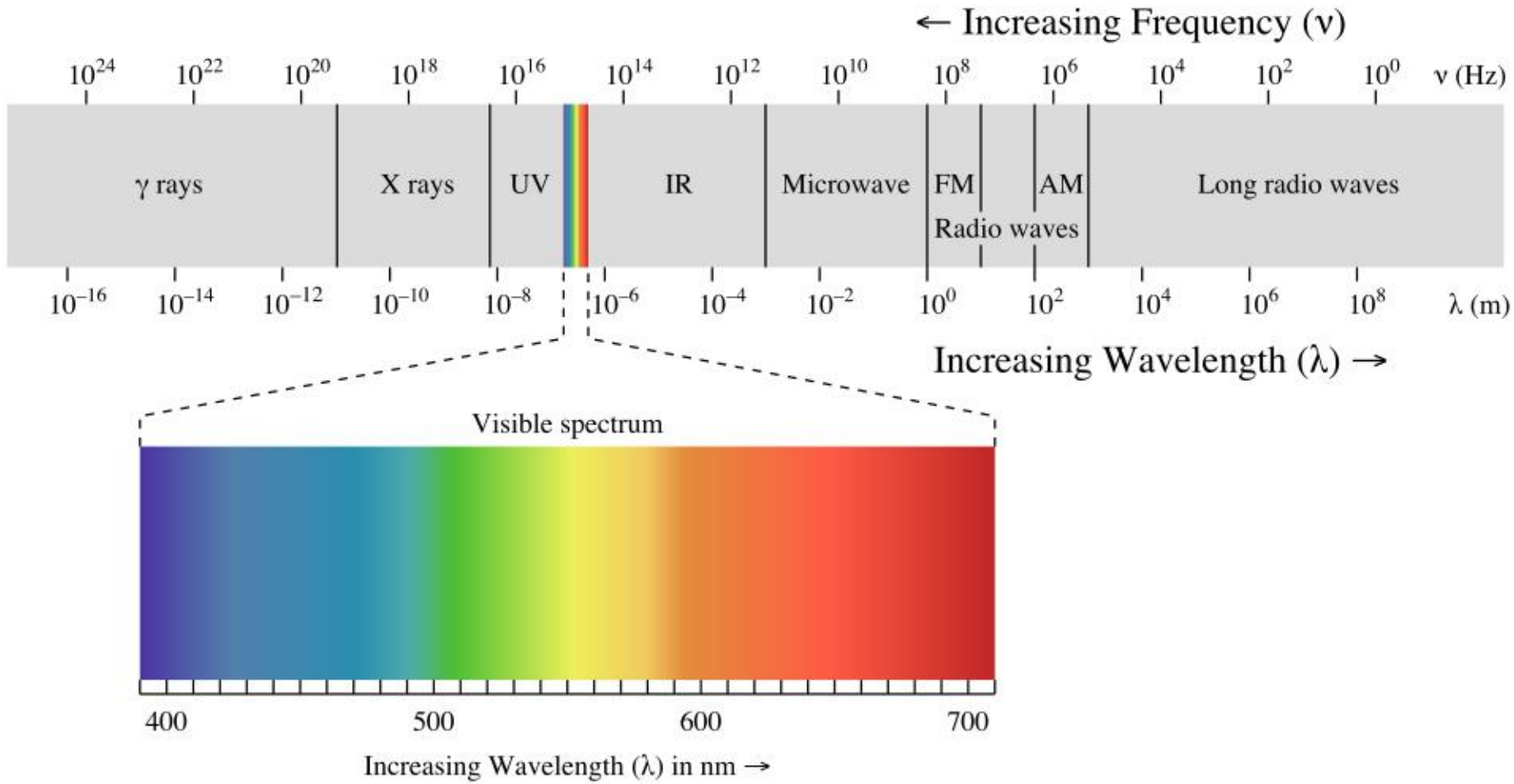


Image courtesy: Wikipedia

Frequency

- The frequency v is defined as

speed of light (vacuum)

$c \approx 2.998 \times 10^8 \frac{m}{s}$

$$\nu = \frac{c}{\lambda}$$

wave length

$$\nu = \frac{c}{\lambda n}$$

refraction index

Near the Visible Spectrum

- Infrared light (λ≈1mm) is strongly reflected by chlorophyll and thus often used for monitoring vegetation

Image courtesy: Wikipedia (left), Förstner (right)

Microwaves

- Microwaves ($\lambda \approx 1$cm) can “look” through clouds
- Can be used for weather-independent monitoring
- Can be used for estimating the water content of soil
- Used in radar systems

Summary

- Basic elements of a camera
- Pinhole camera model and thin lenses
- Three models to describe the propagation of light