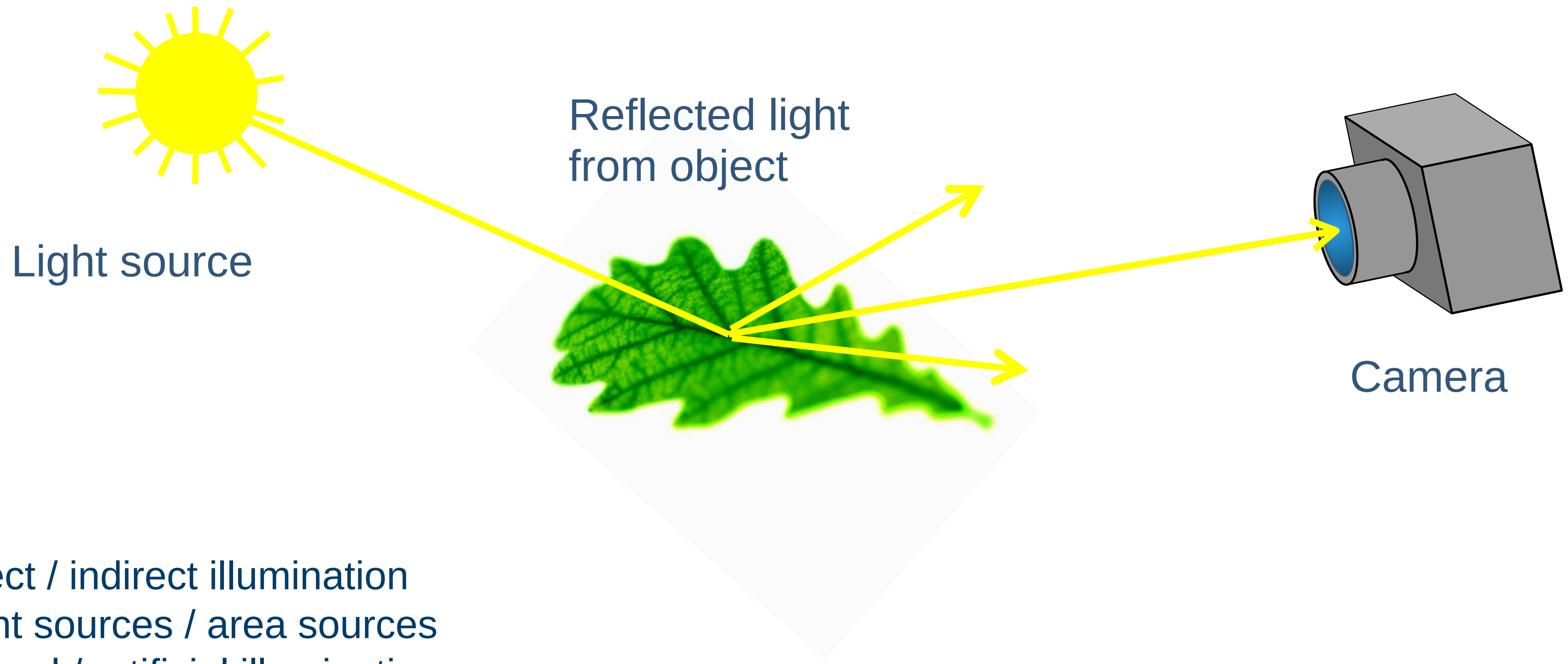
Image formation
Lecture 1.1 - Light, camera, optics and colour

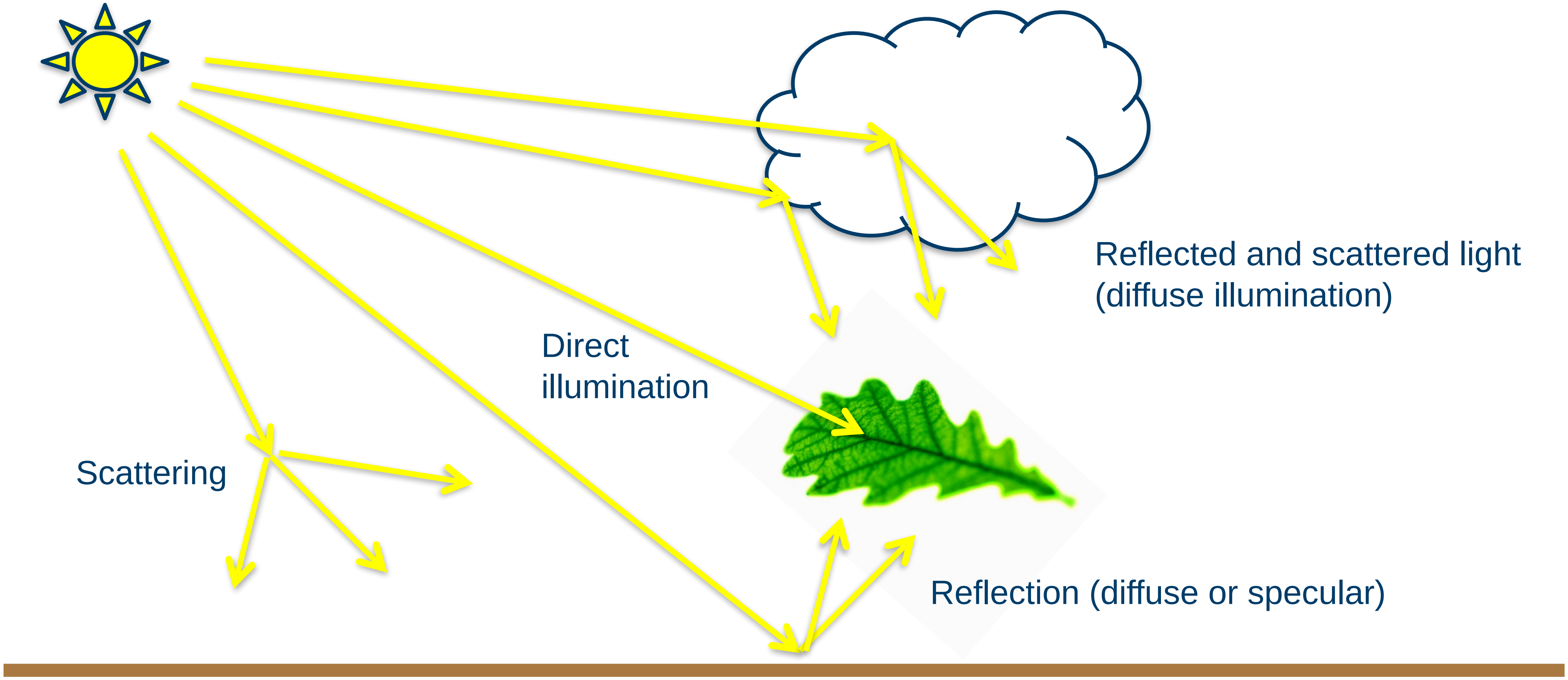
Idar Dyrdal

Imaging with visible light

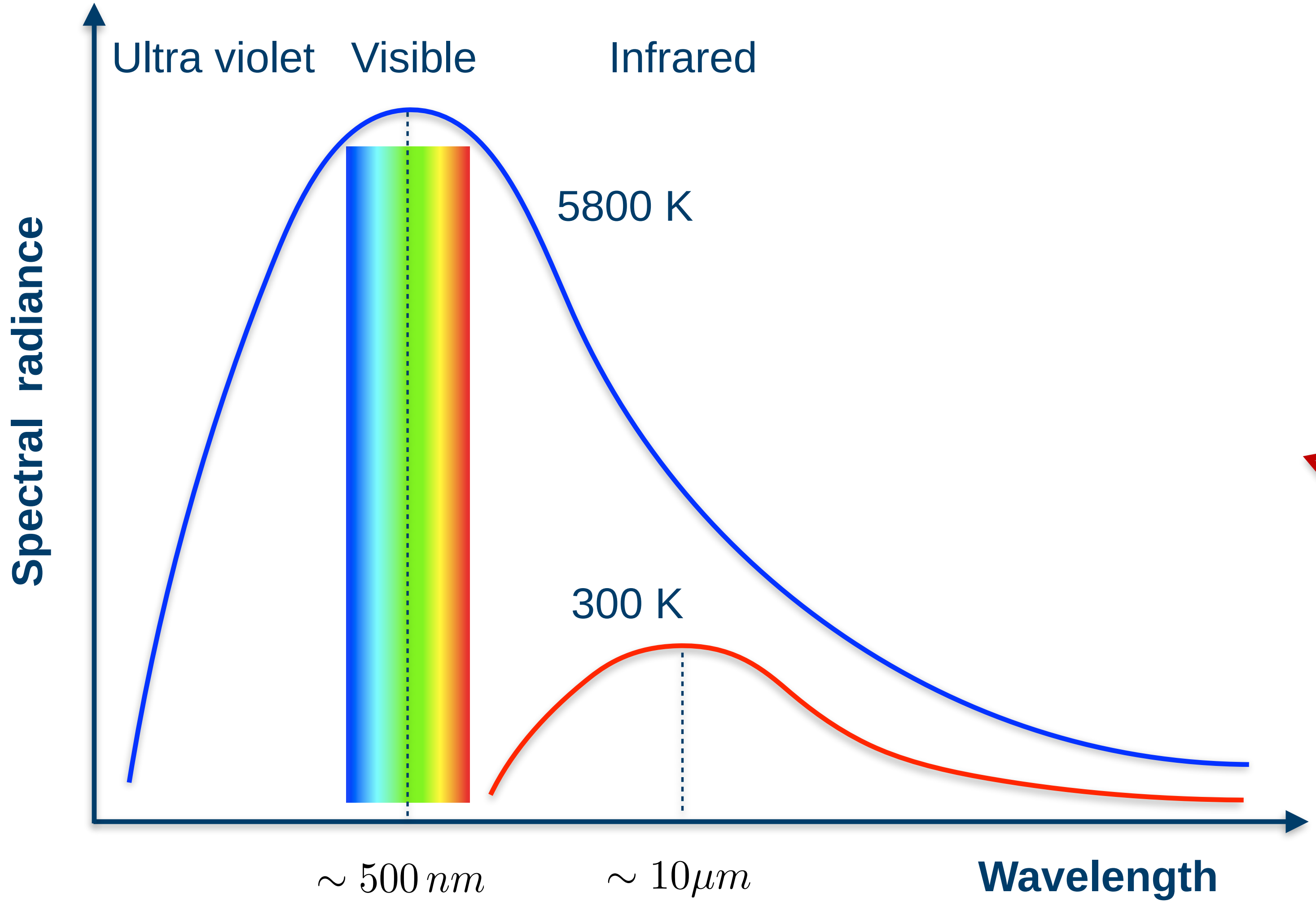


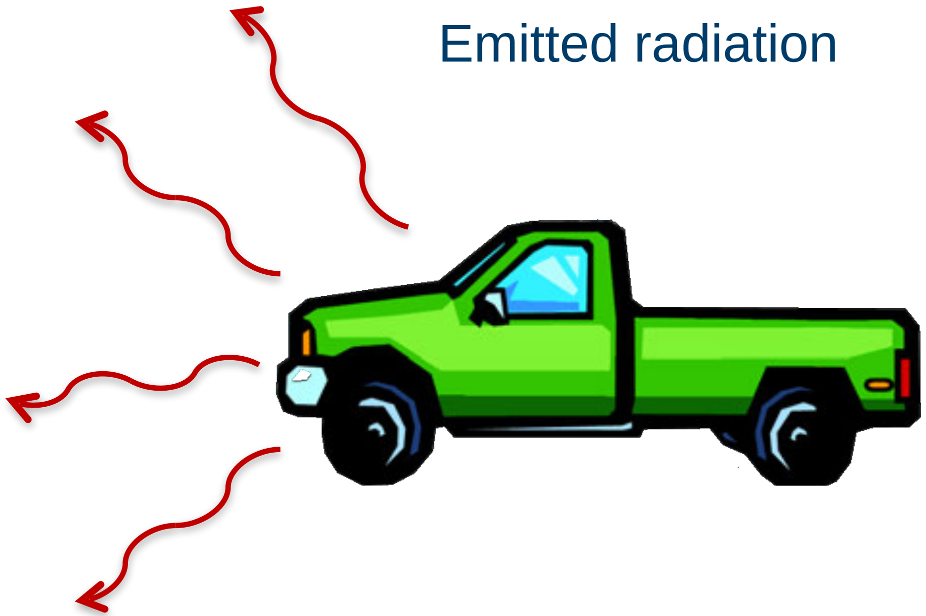
- Direct / indirect illumination
- Point sources / area sources
- Natural / artificial illumination

Direct and indirect illumination



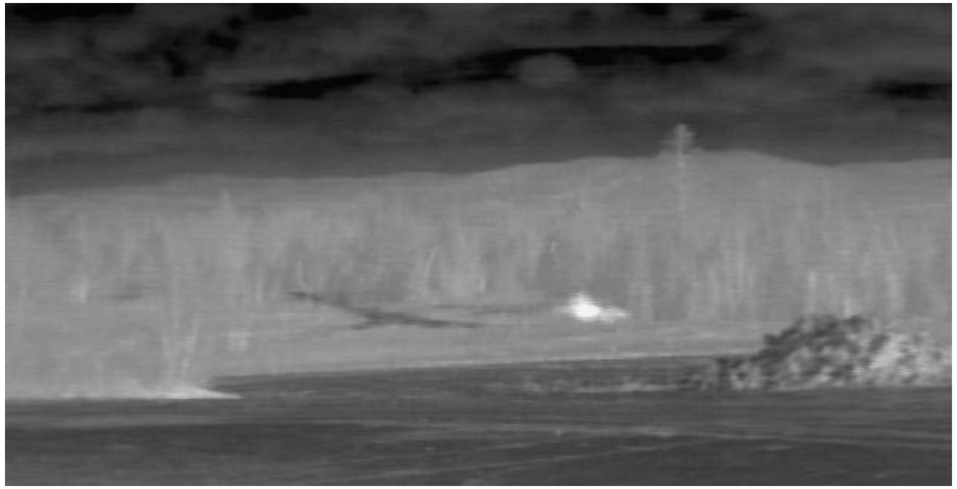
Thermal radiation - Planck distribution





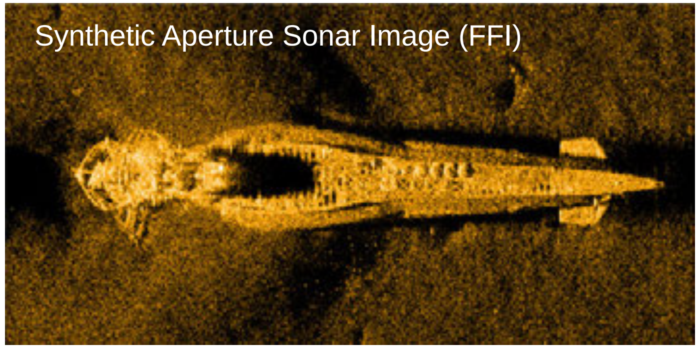
Reflected and emitted radiation

Image in visible light:
- Imaging with **reflected** (and scattered) radiation from the sun or other natural or artificial sources.



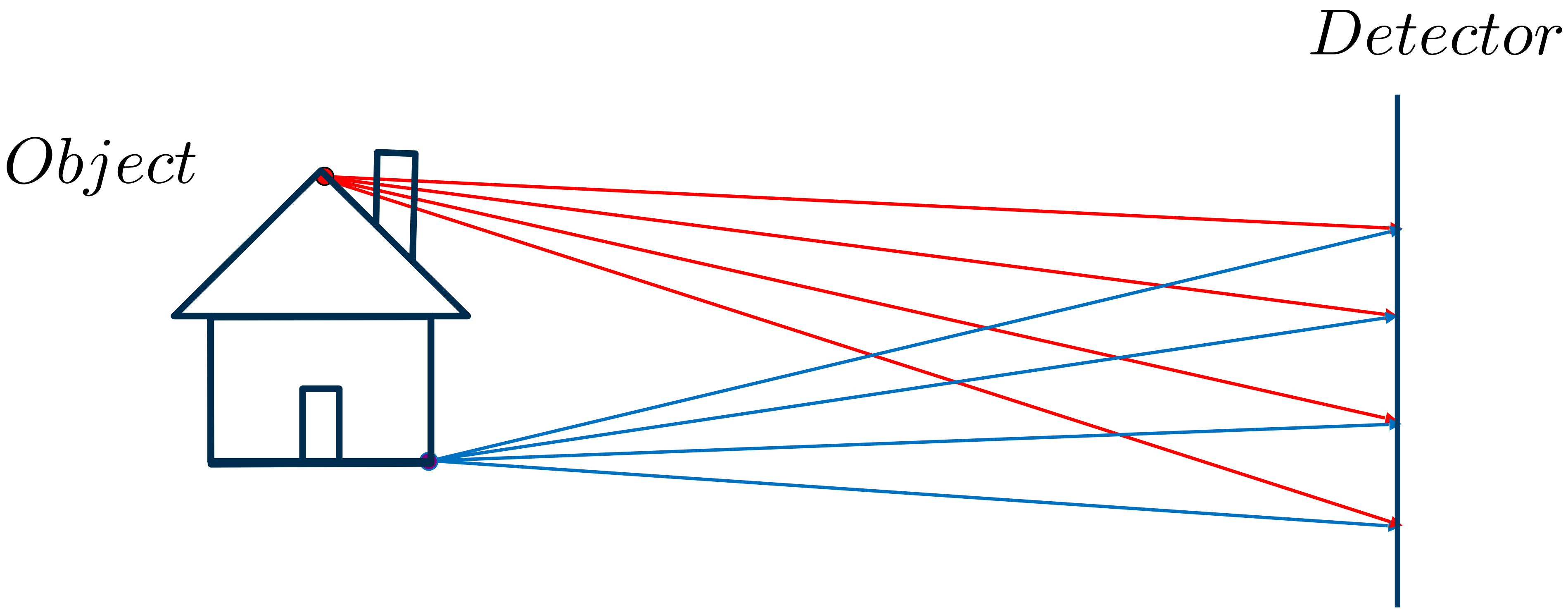
Infrared (thermal) image:
- Imaging with (mainly) the **emitted** thermal radiation from the scene.

Other frequency domains and wave types used for imaging:
- Millimeter waves, x-rays, … (electromagnetic waves)
- Acoustic (sonar), seismic, … (mechanical waves)



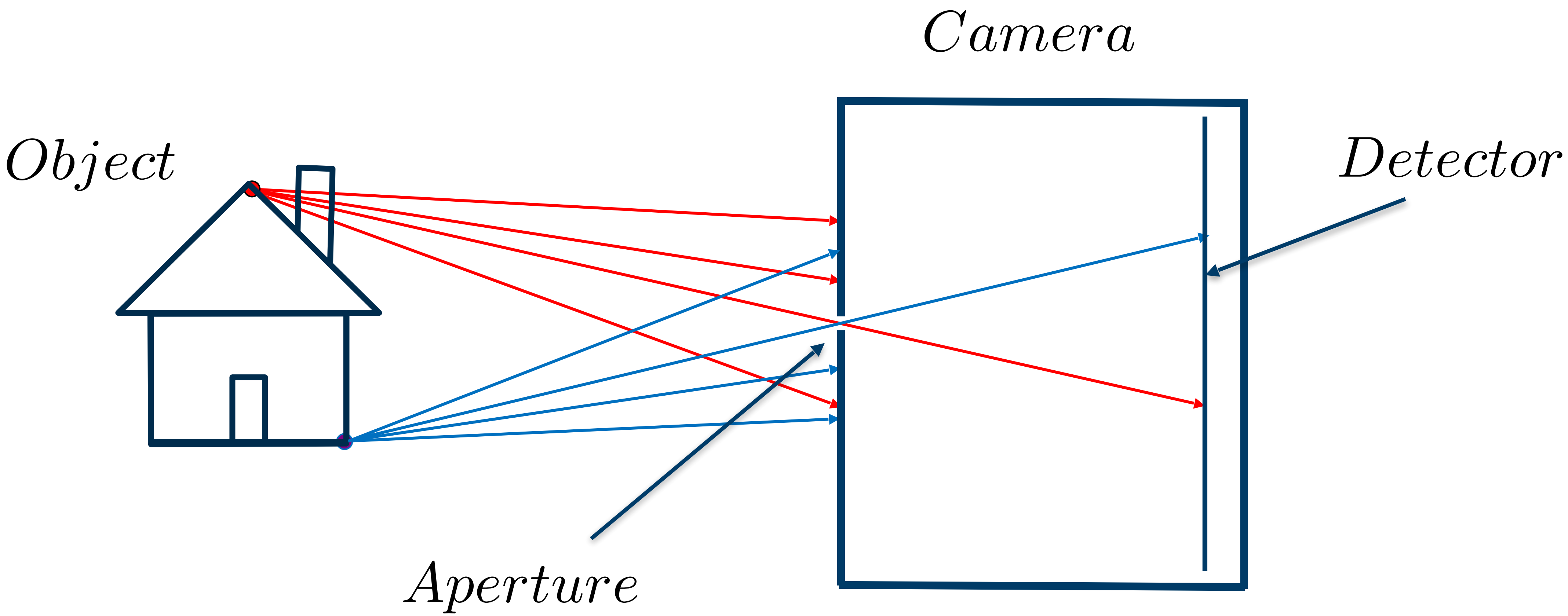
Synthetic Aperture Sonar Image (FFI)

Image formation

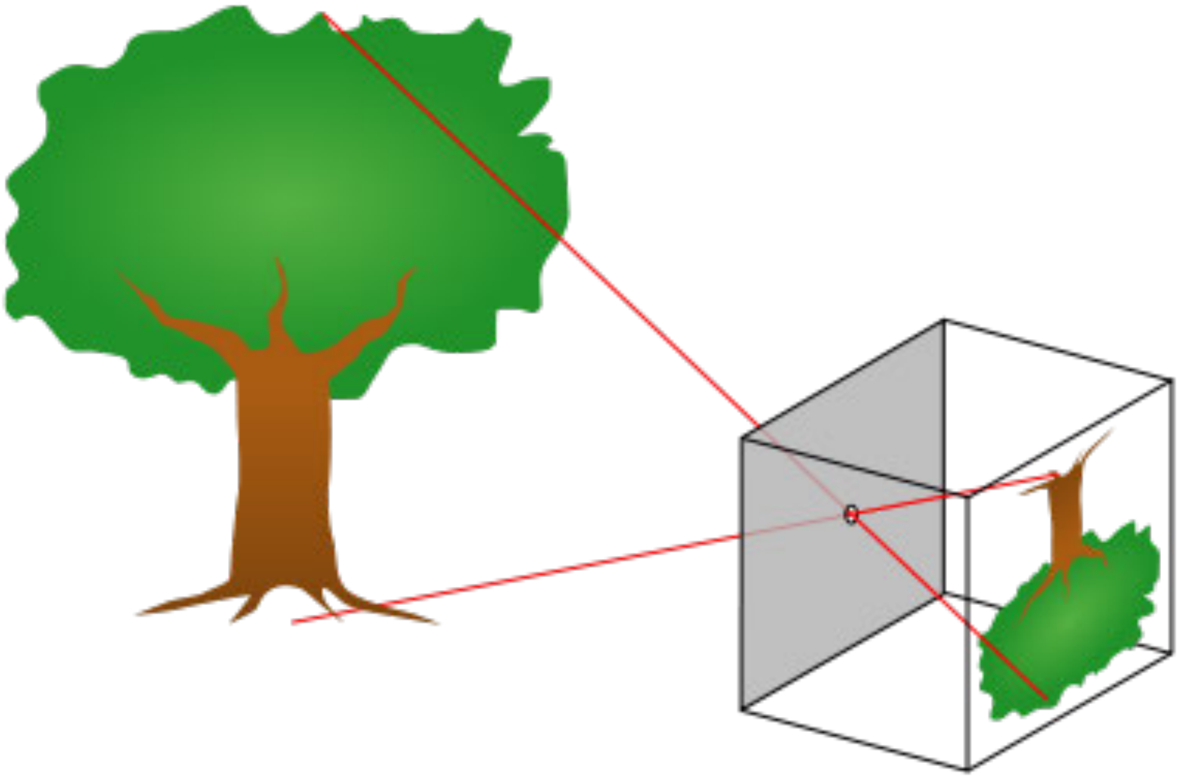


No image is formed!

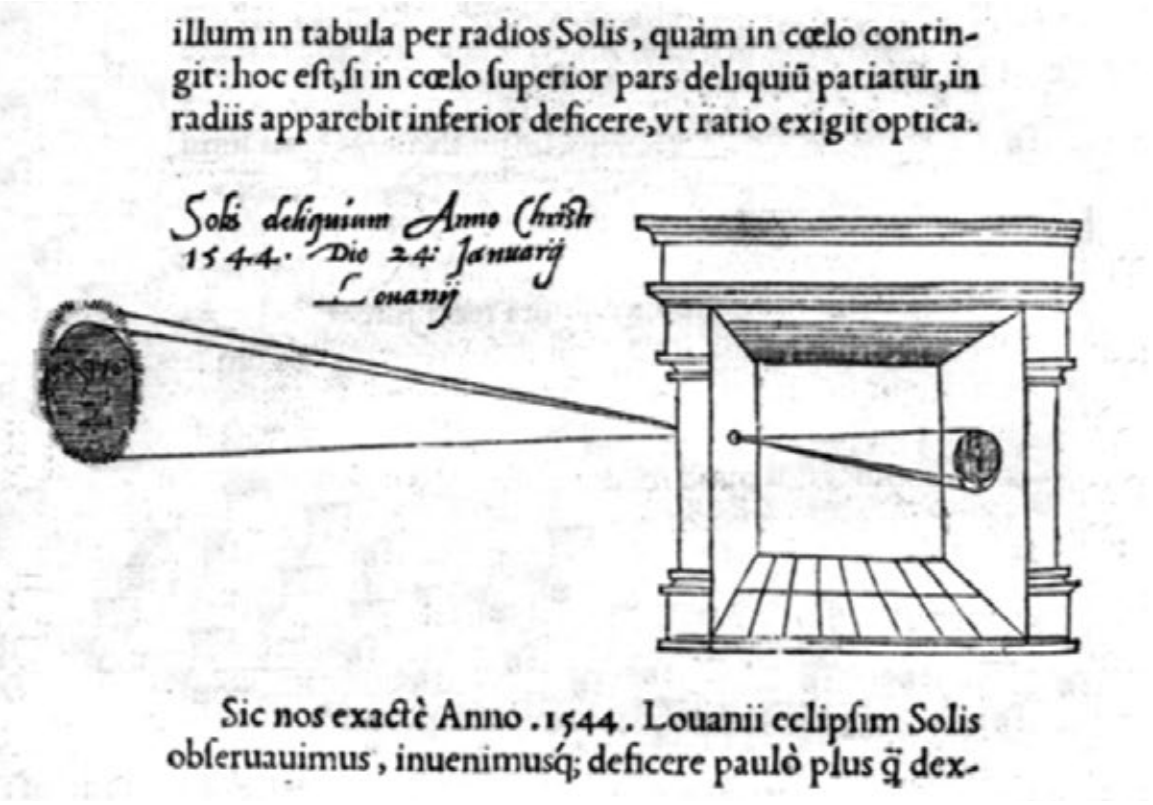
Simple camera - Pinhole camera



Pinhole camera



Camera obscura



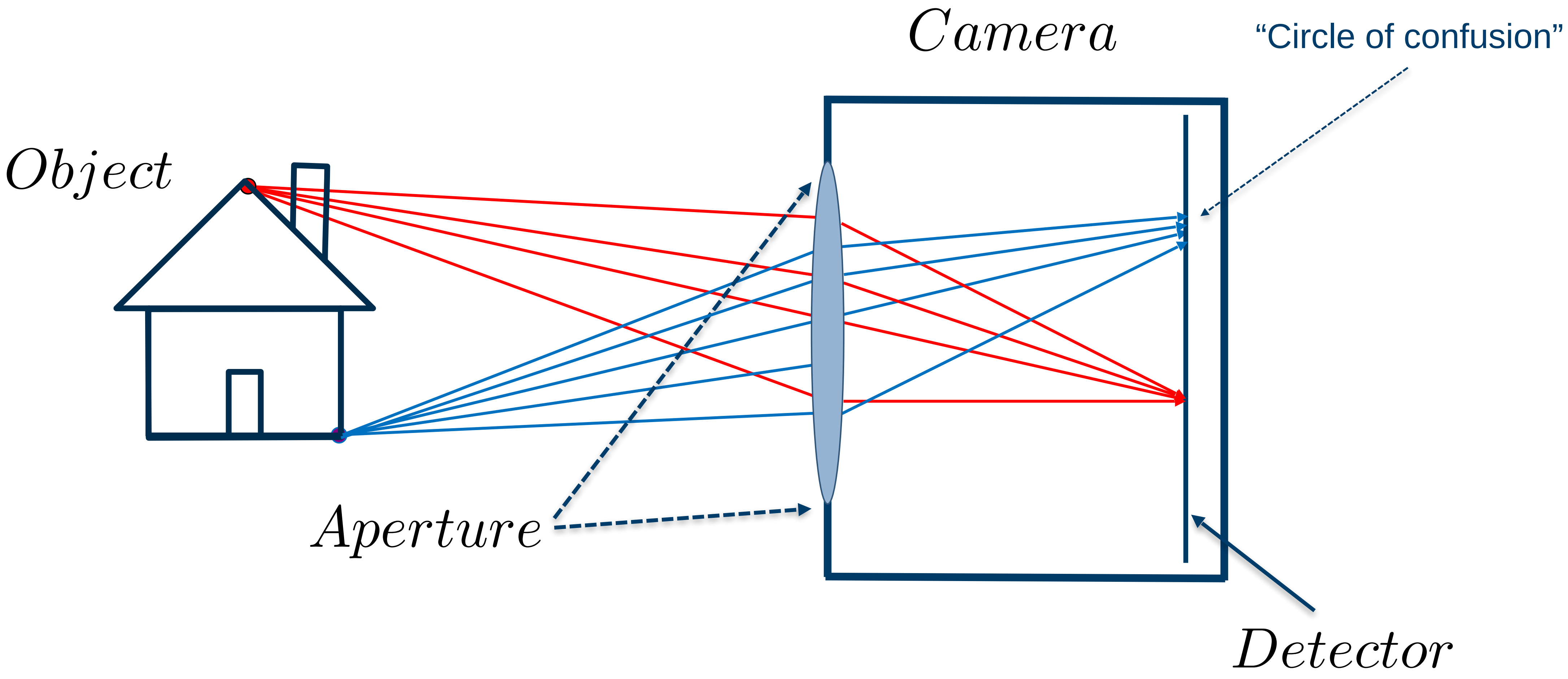
illum in tabula per radios Solis, quàm in cœlo contingit: hoc est, si in cœlo superior pars deliquiũ patiatur, in radiis apparebit inferior deficere, vt ratio exigit optica.

Sic nos exactè Anno .1544. Louanii eclipsim Solis obseruauimus, inuenimusq; deficere paulò plus q̃ dex-

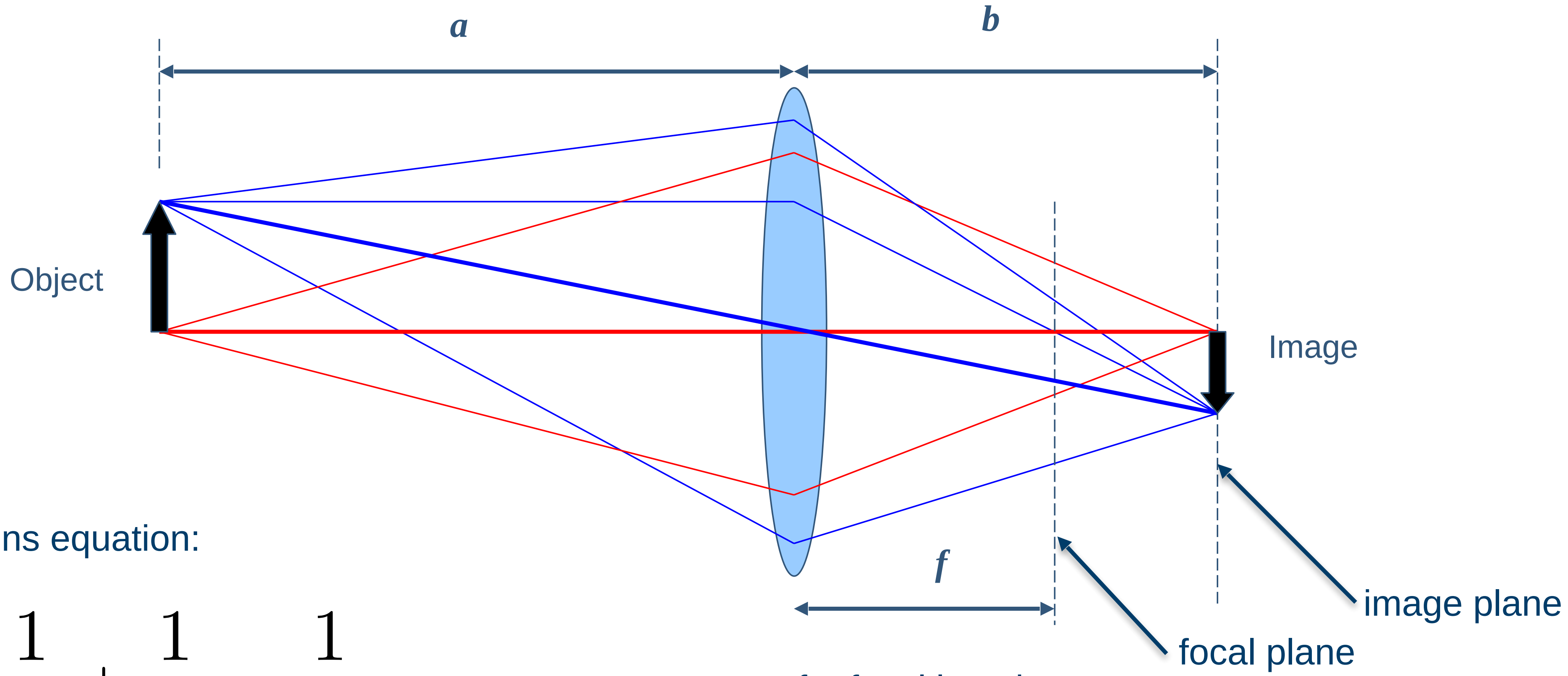
Small aperture → Dark image

Large aperture → Image out of focus

Camera with a lens



Imaging with a lens

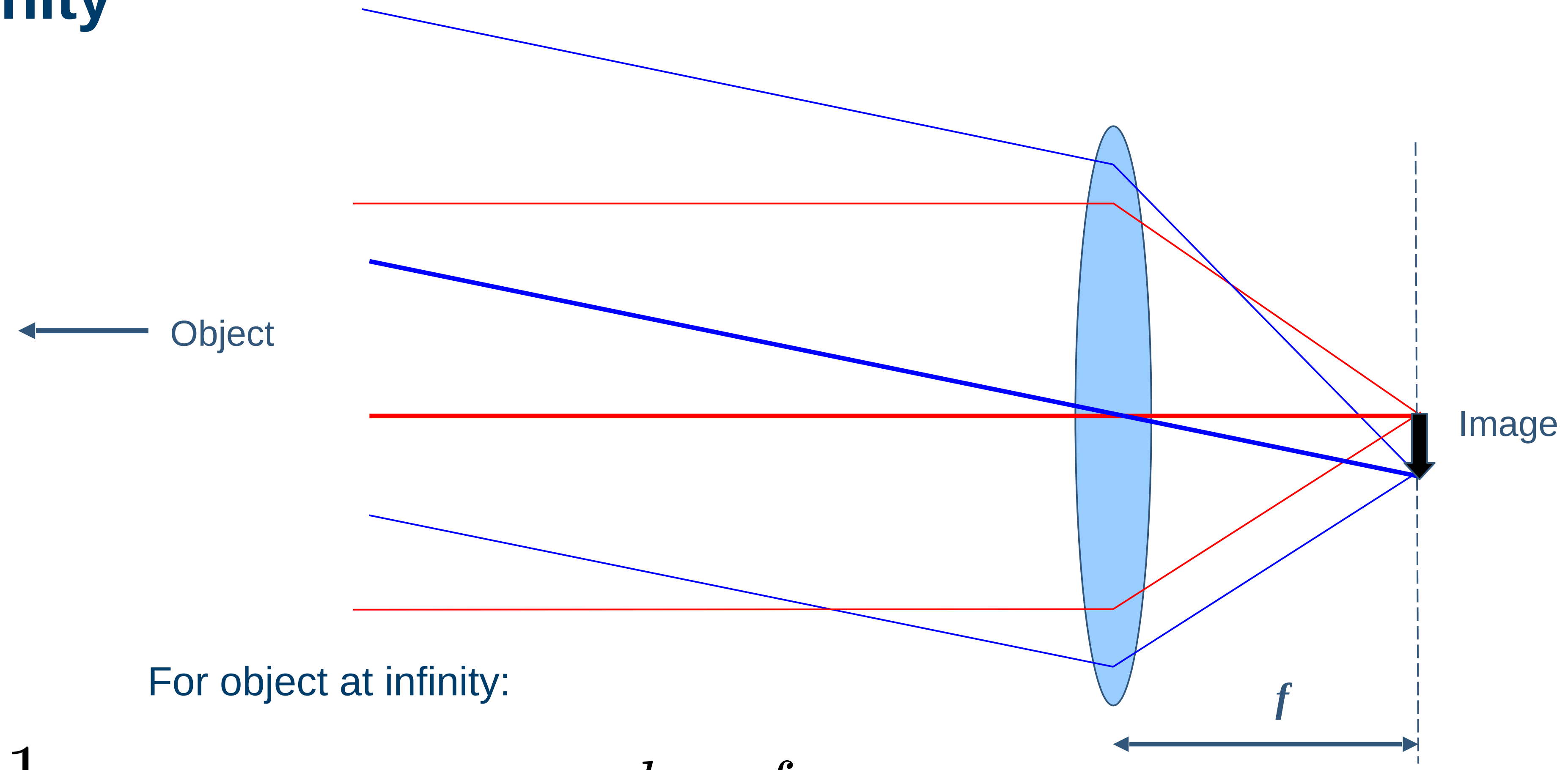


f = focal length

Lens equation:

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

Object at infinity



Lens equation:

$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

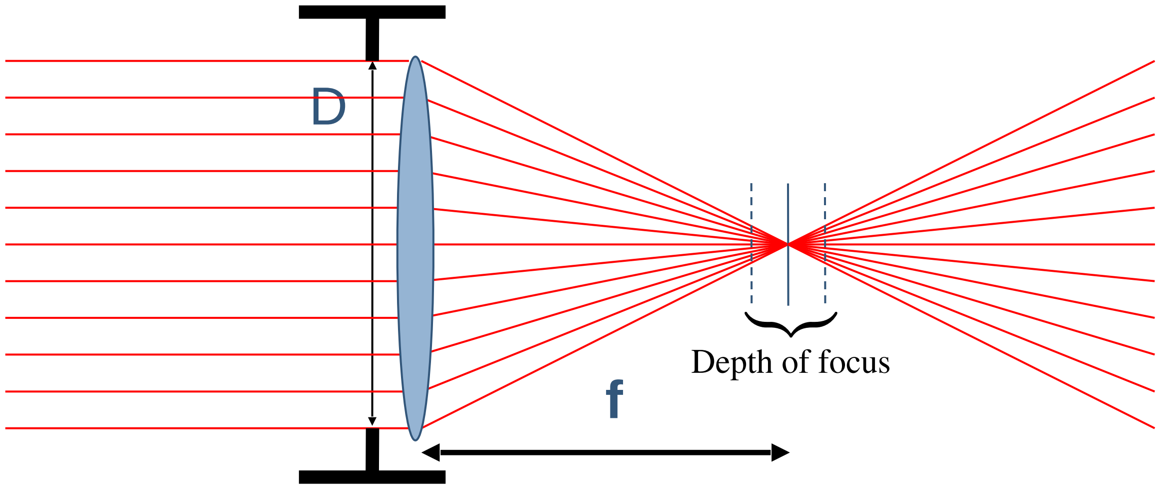
For object at infinity:

$$a = \infty \quad \Rightarrow \quad b = f$$

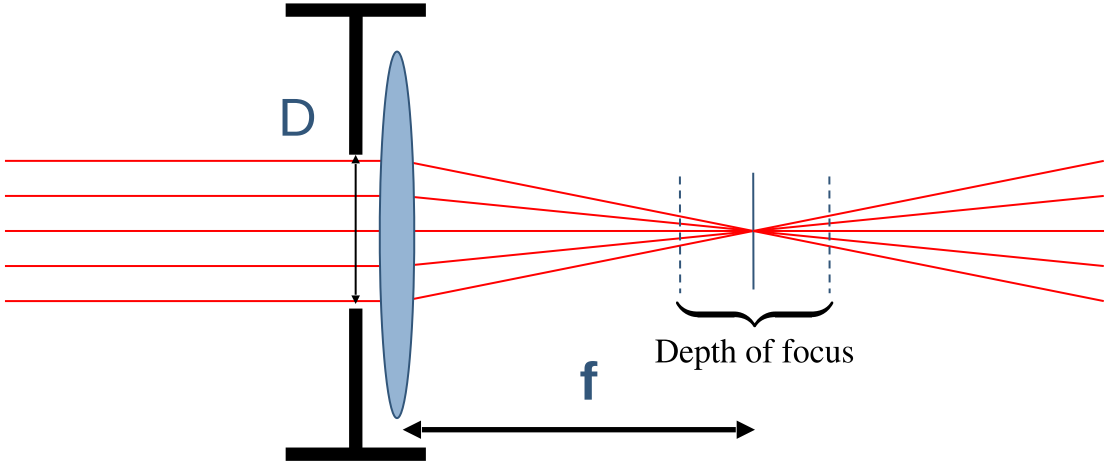
i.e. image is formed in focal plane.

Depth of focus

Large aperture



Small aperture

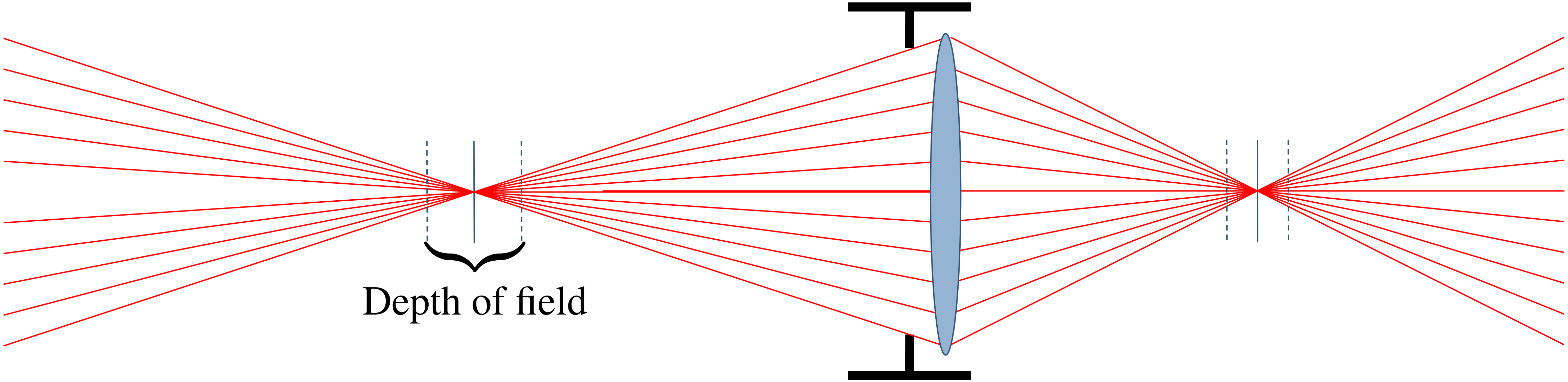


F-number: f/D (examples: f/2.8, f/4, f/5.6, f/8, f/11, f/22)

Small f-number → Narrow depth of focus

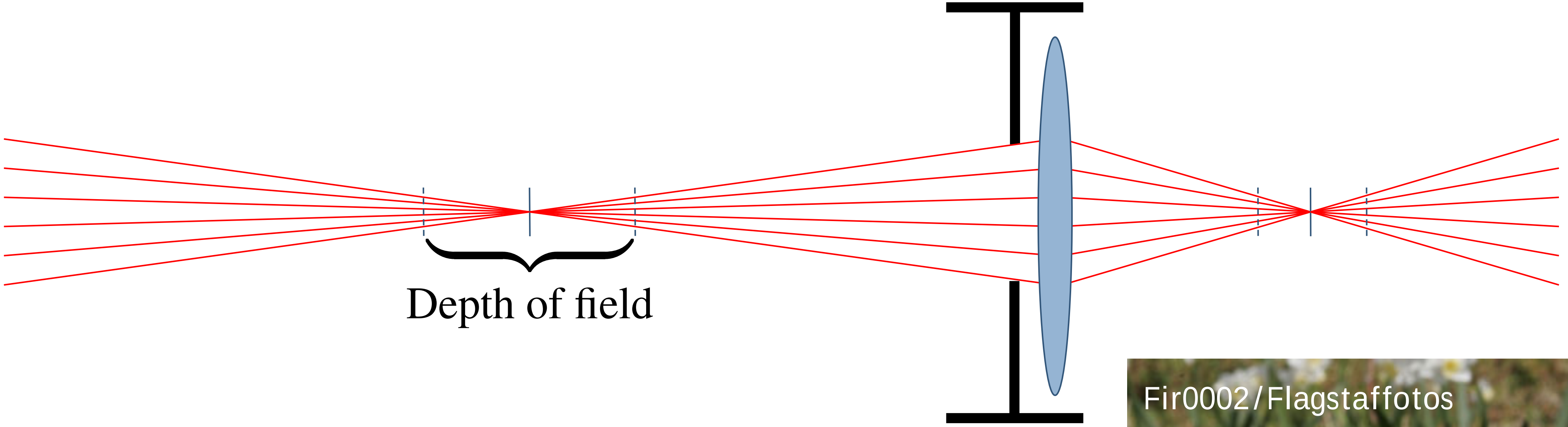
Large f-number → Large depth of focus

Depth of field – large aperture



Large aperture → Narrow depth of field

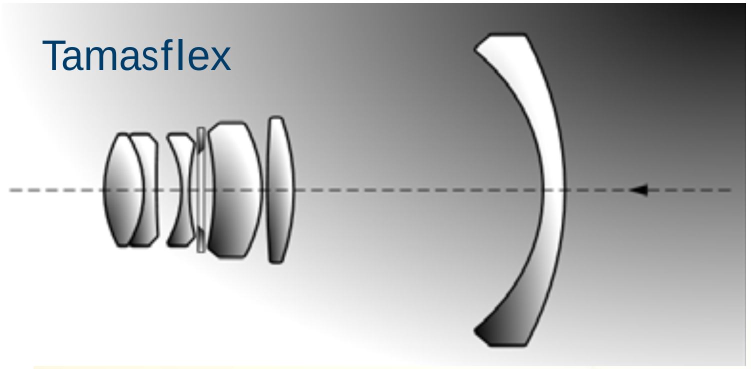
Depth of field – small aperture



Small aperture → Large depth of field

Too small aperture will lead to *diffraction* and loss of sharpness

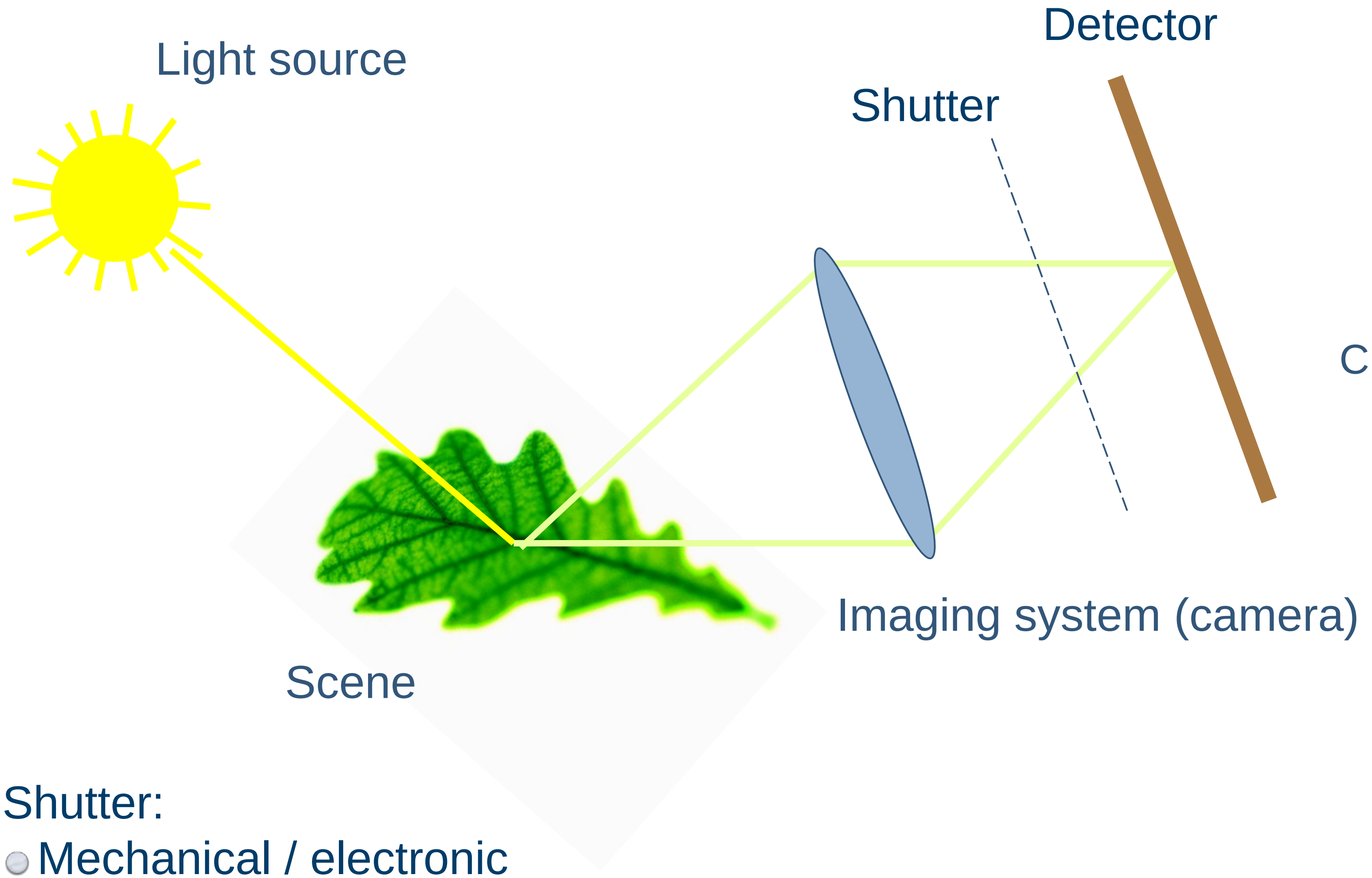
Practical lenses

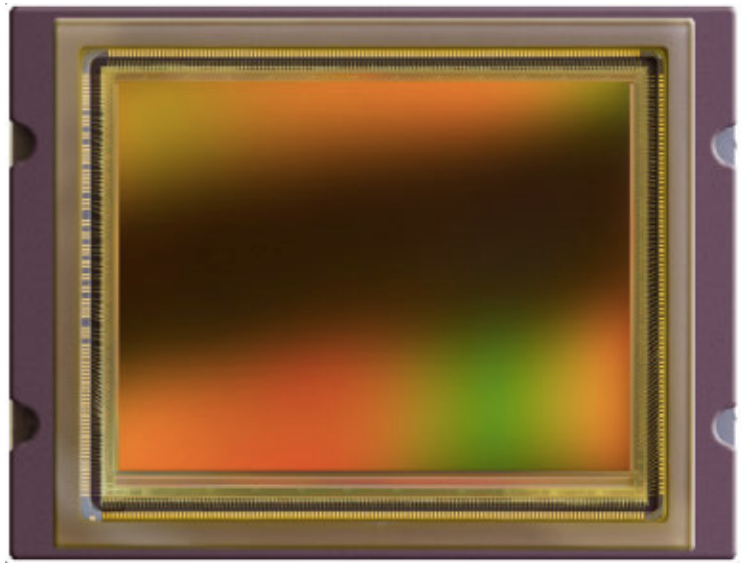


Fixed focal length lens

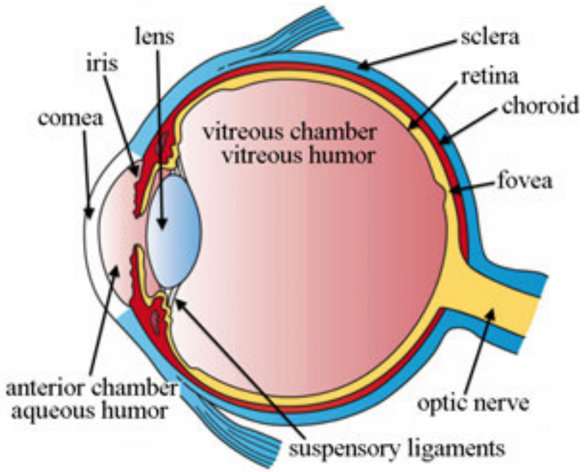
Zoom lens (variable focal length)

Image capture





CMOS image sensor (CMOSIS 48Mp)



(Artwork by Holly Fischer)

Shutter:
- Mechanical / electronic
- Global / rolling

Digital image

$j \rightarrow$

$i \downarrow$

255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255
255	255	255	0	0	255	255	255	255	255
255	255	255	0	0	85	255	255	255	255
255	255	0	85	85	0	255	255	255	255
255	255	0	85	85	170	170	255	255	255
255	85	85	0	170	170	85	85	255	255
255	255	170	170	85	85	85	255	255	255
255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255

$$image(i, j)$$

Colour images

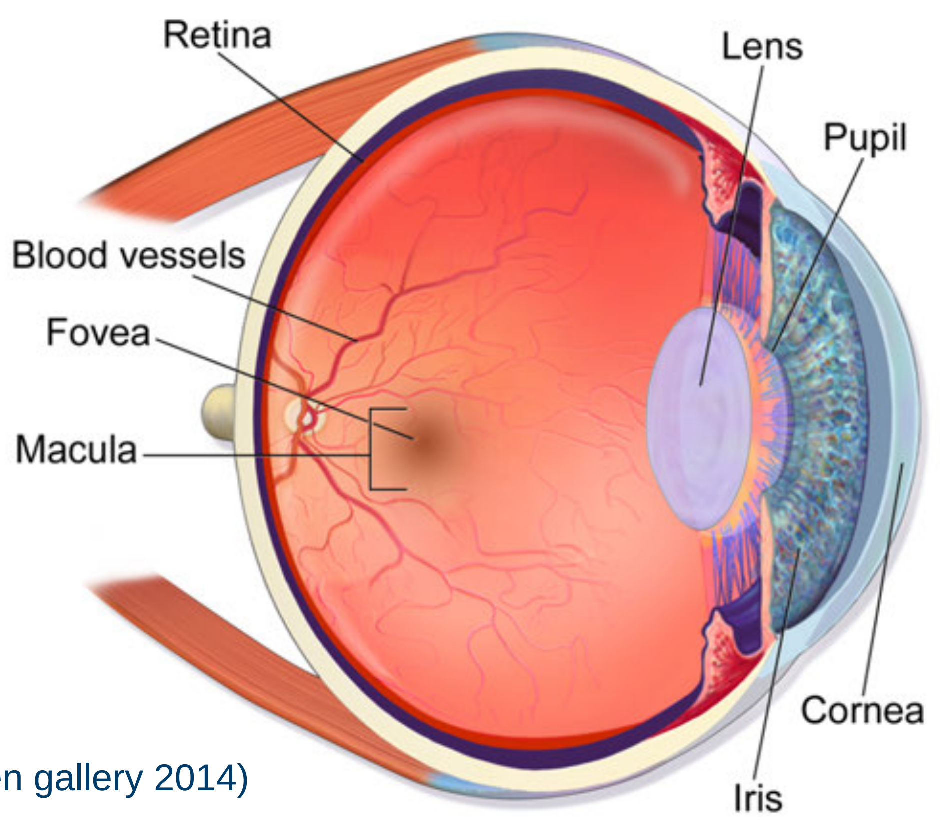
RGB colour image

Red

Green

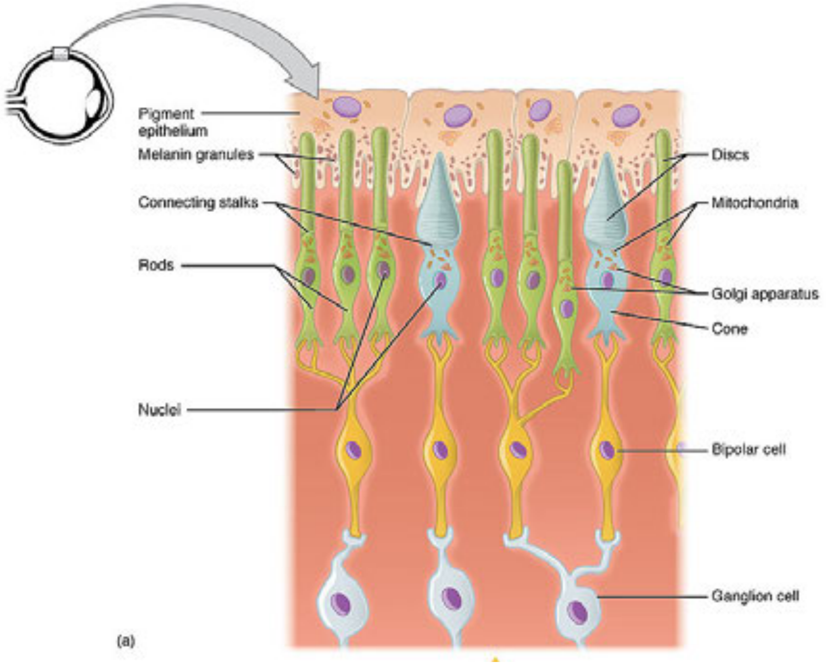
Blue

Human Vision

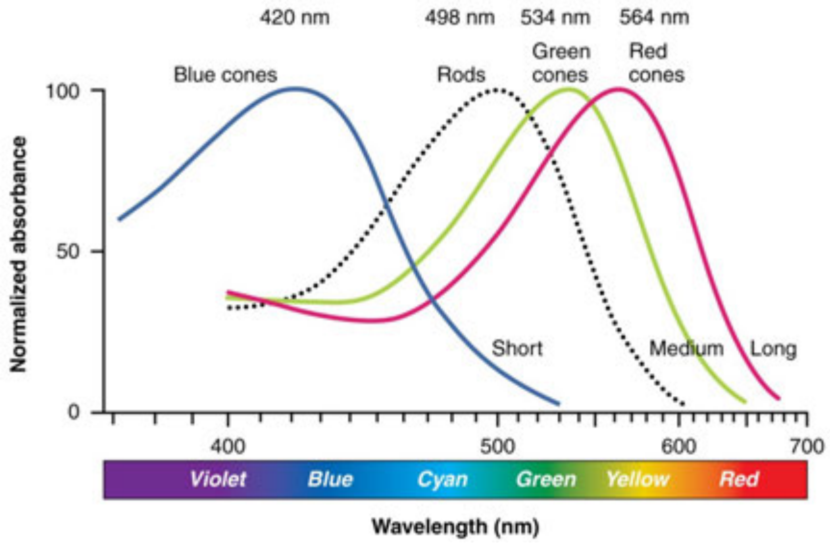


(Blausen gallery 2014)

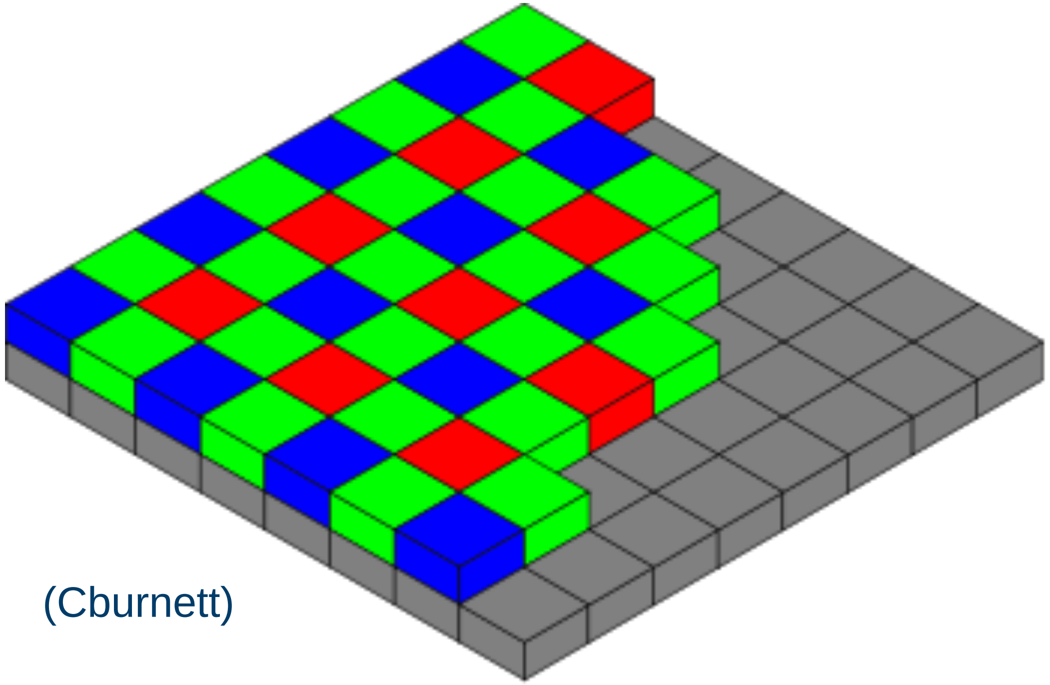
Eye Anatomy



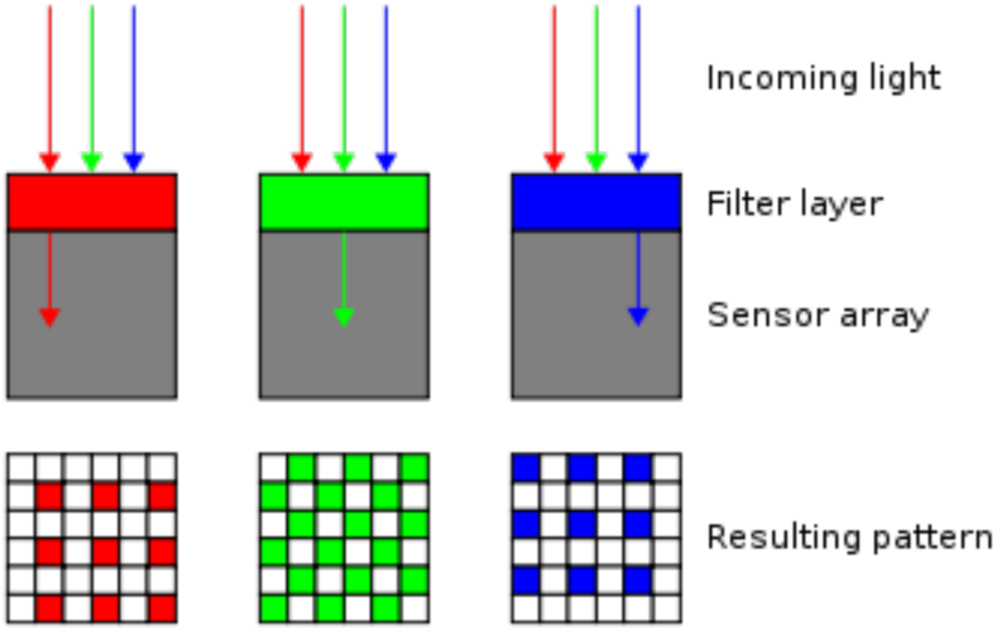
(OpenStax College - Anatomy & Physiology)



Colour Sensing in digital cameras - Bayer filter



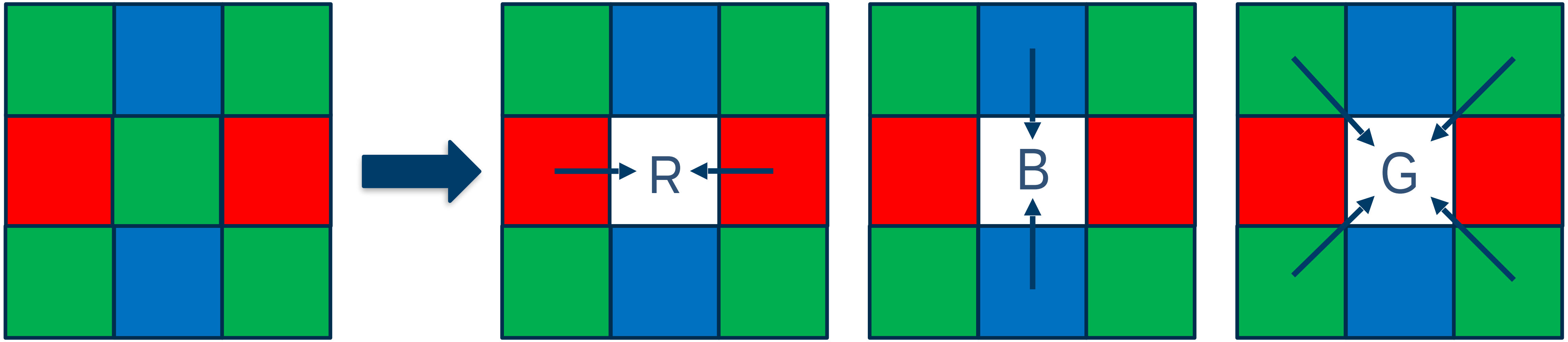
(Cburnett)



Undersampled (incomplete) colour information

Demosaicing (debayering)

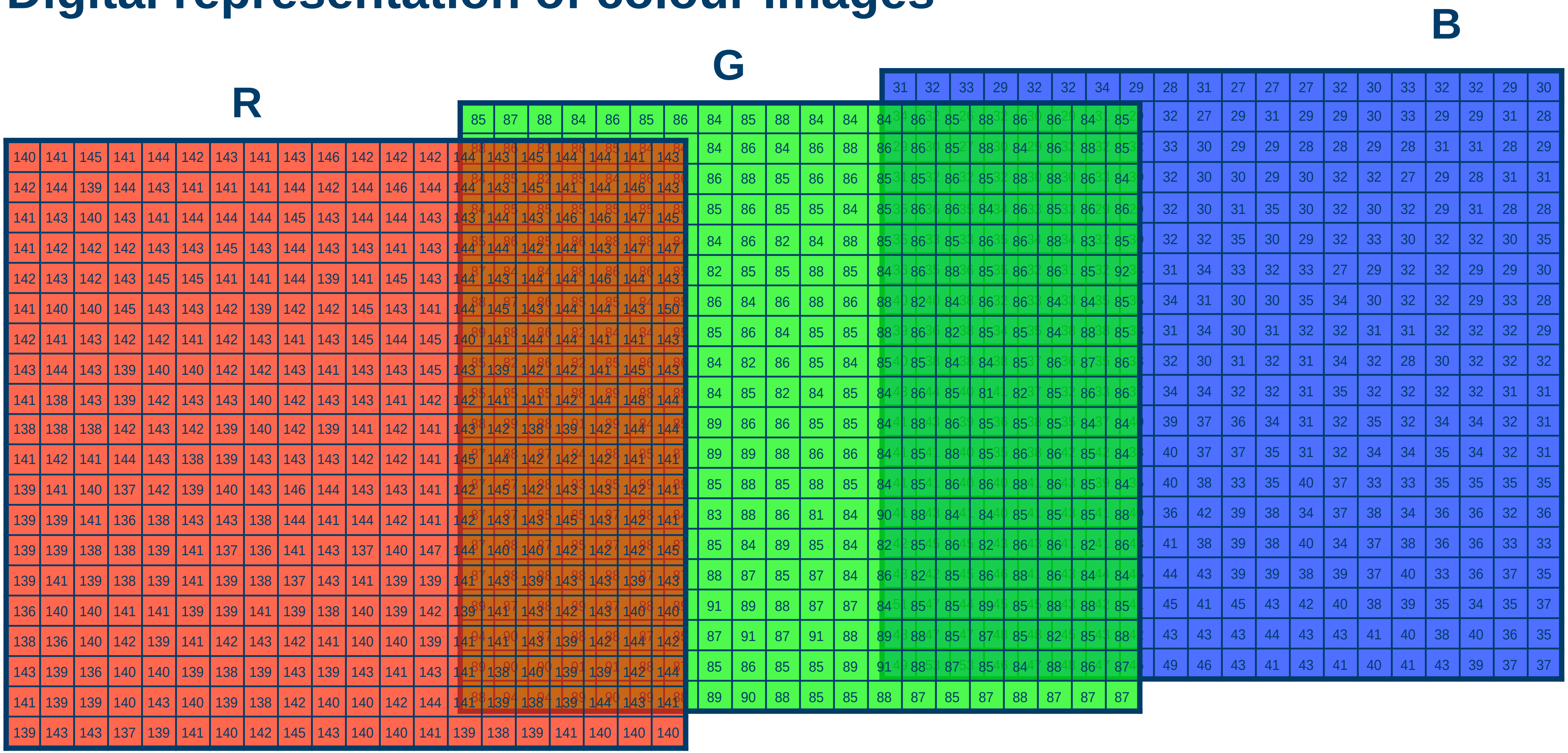
Reconstruction of full colour image from incomplete colour information from the image sensor.



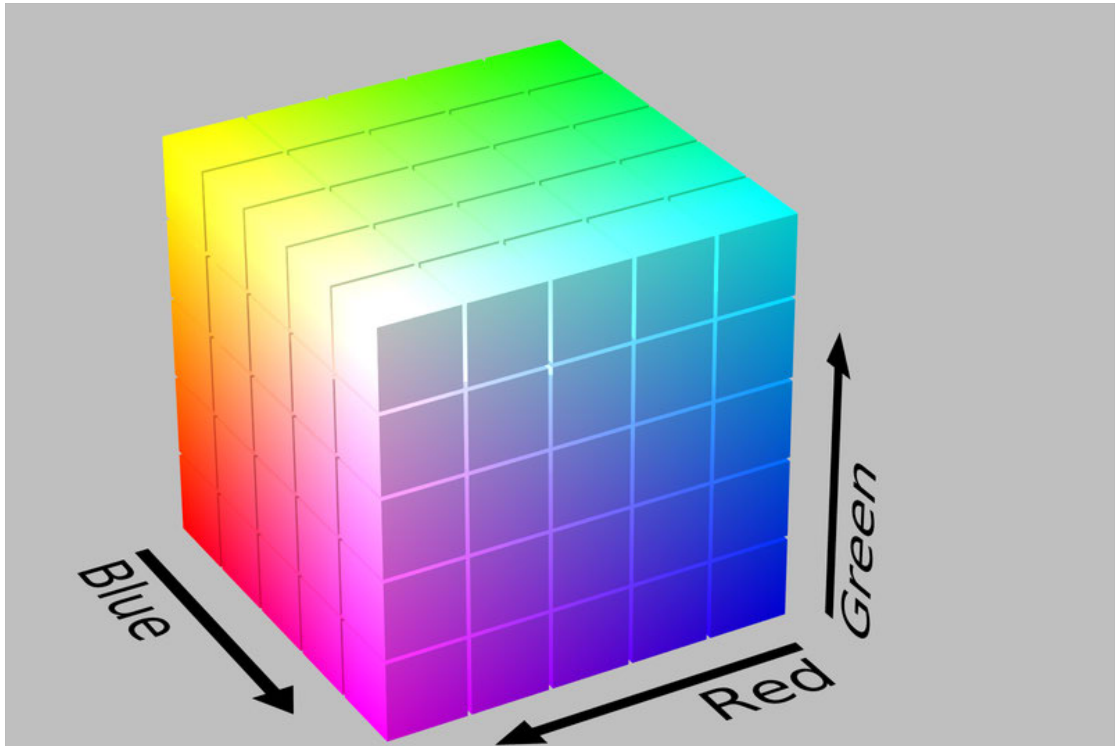
Algorithms:
- Nearest-neighbor interpolation
- Bilinear interpolation
- Bicubic interpolation

Other methods:
- Splines
- Lanczos resampling
- Methods utilizing pixel values

Digital representation of colour images



RGB colour space



(Horst Frank)

Normalized RGB values:

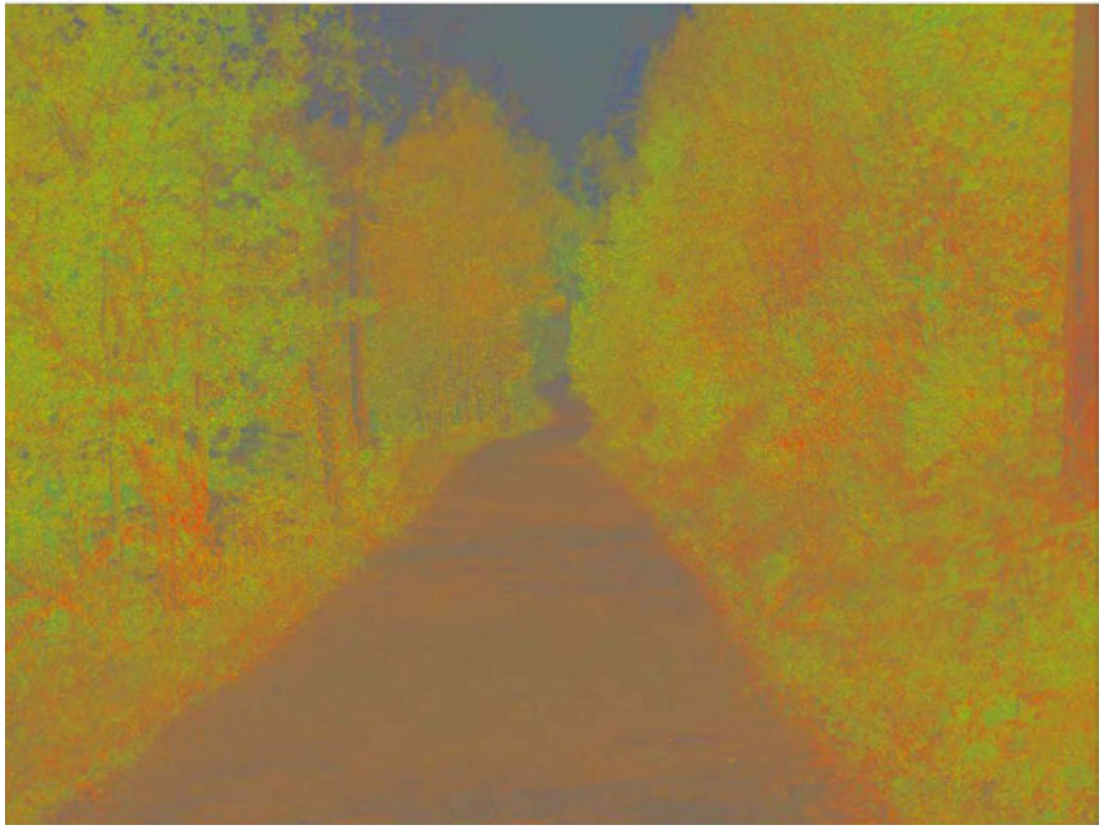
$$r = \frac{R}{R+G+B}$$
$$g = \frac{G}{R+G+B}$$
$$b = \frac{B}{R+G+B}$$

(Illumination invariance)

Colour coordinate systems: $RGB \Rightarrow XYZ \Rightarrow LAB$

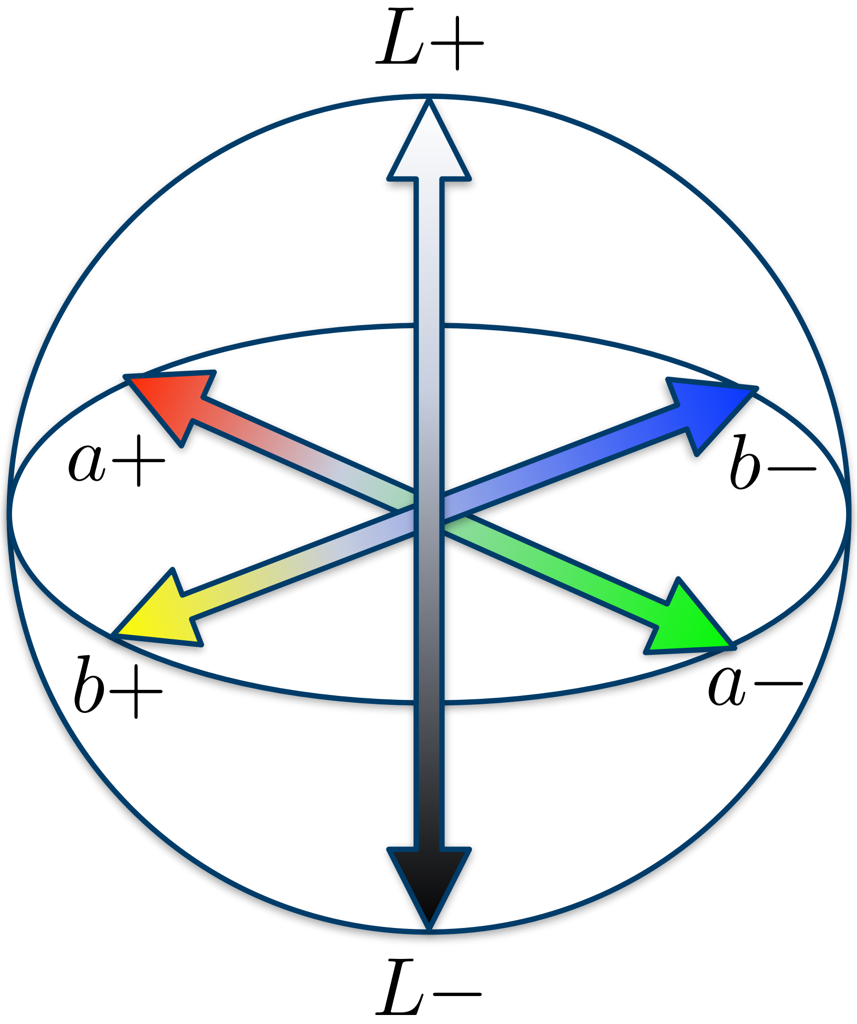
RGB normalization (example)

RGB original



Normalized RGB

Lab colour space (CIE 1976 L* a* b*)



«Perceptually uniform» colour space:

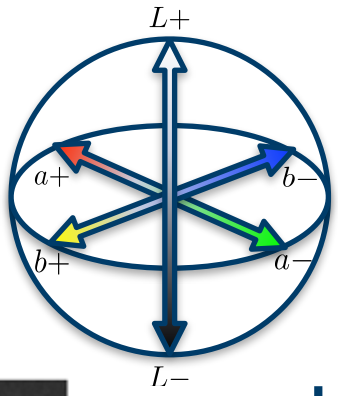
- Approximation to human vision
- L* = Lightness
- a*, b* = Colour opponent dimensions

- L* = darkest black to brightest white (0 - 100)
- a* = green to red (-100 to +100)
- b* = blue to yellow (-100 to +100)

Lab - example

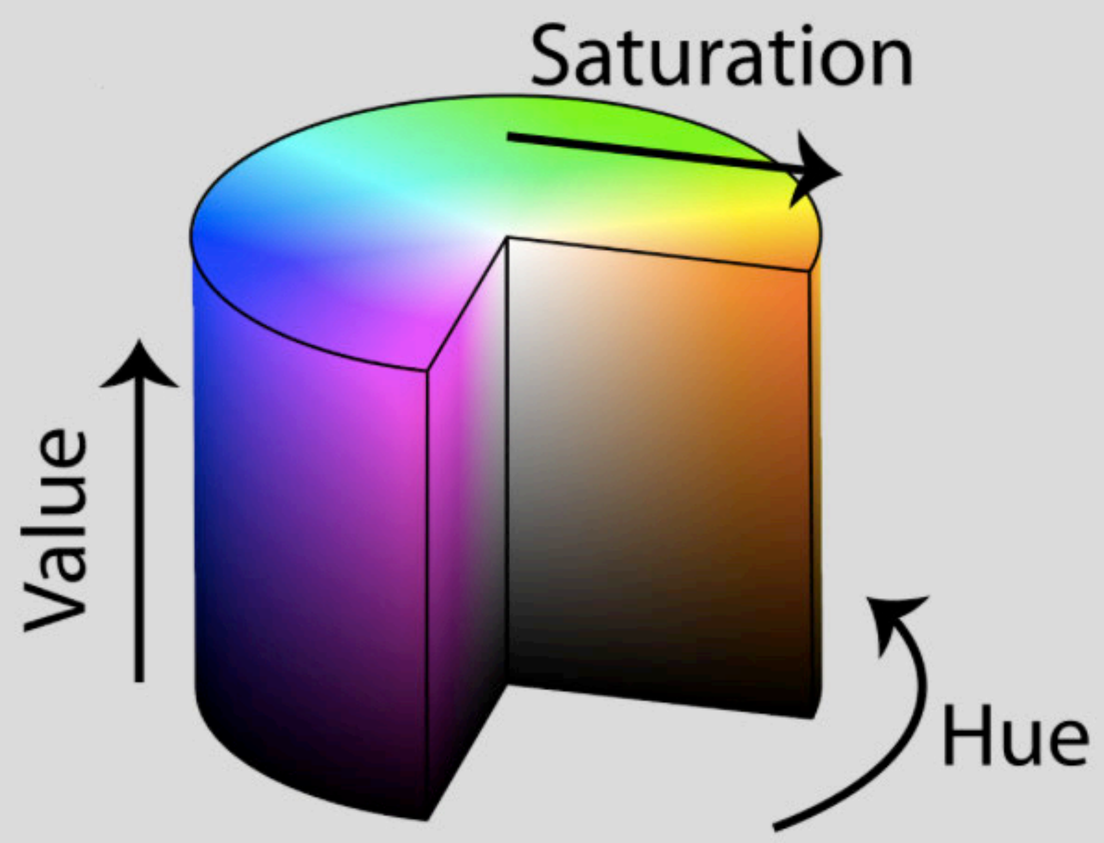
L

a



b

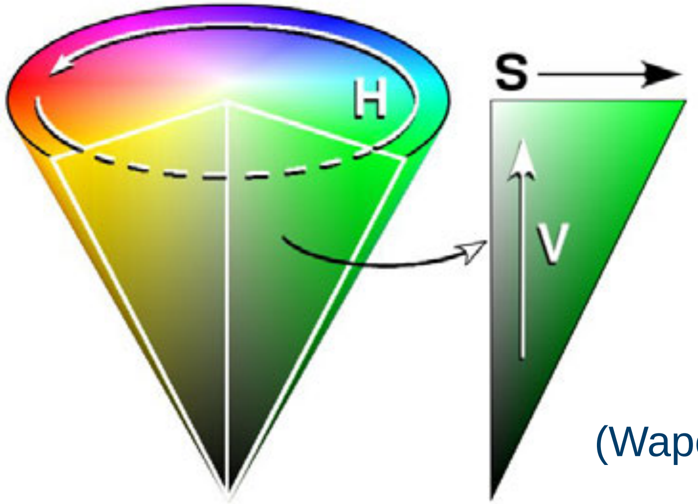
HSV colour space (Hue, Saturation, Value)



(Jacob Rus, 2010)

Intuitive colour space:

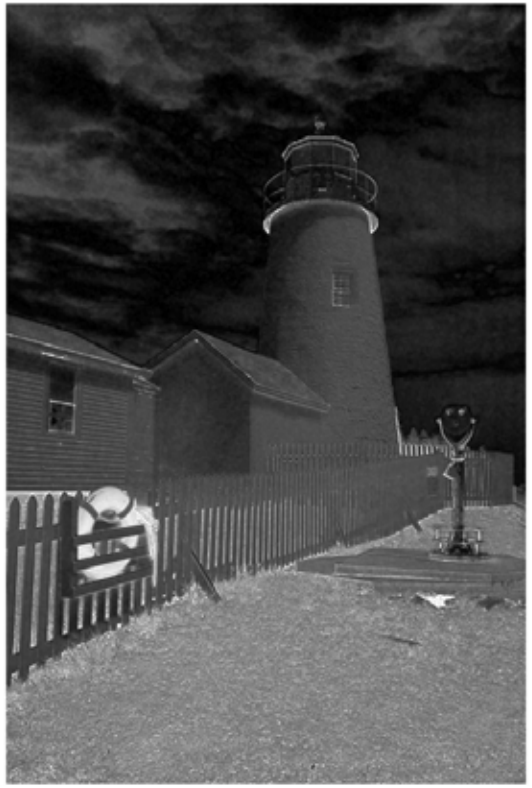
- Cylindrical representation of RGB values
- Hue = angle from 0º to 360º
- Saturation = 0 - 100% (gray to primary colour)
- Value = 0 - 100% (totally black to bright colours)



(Wapcaplet)

HSV

Hue



Saturation

Value

Summary

Image formation:

- Illumination
- Cameras
- Optics
- Image Capture
- Colour Sensing.

More information: Szeliski 2.2 and 2.3