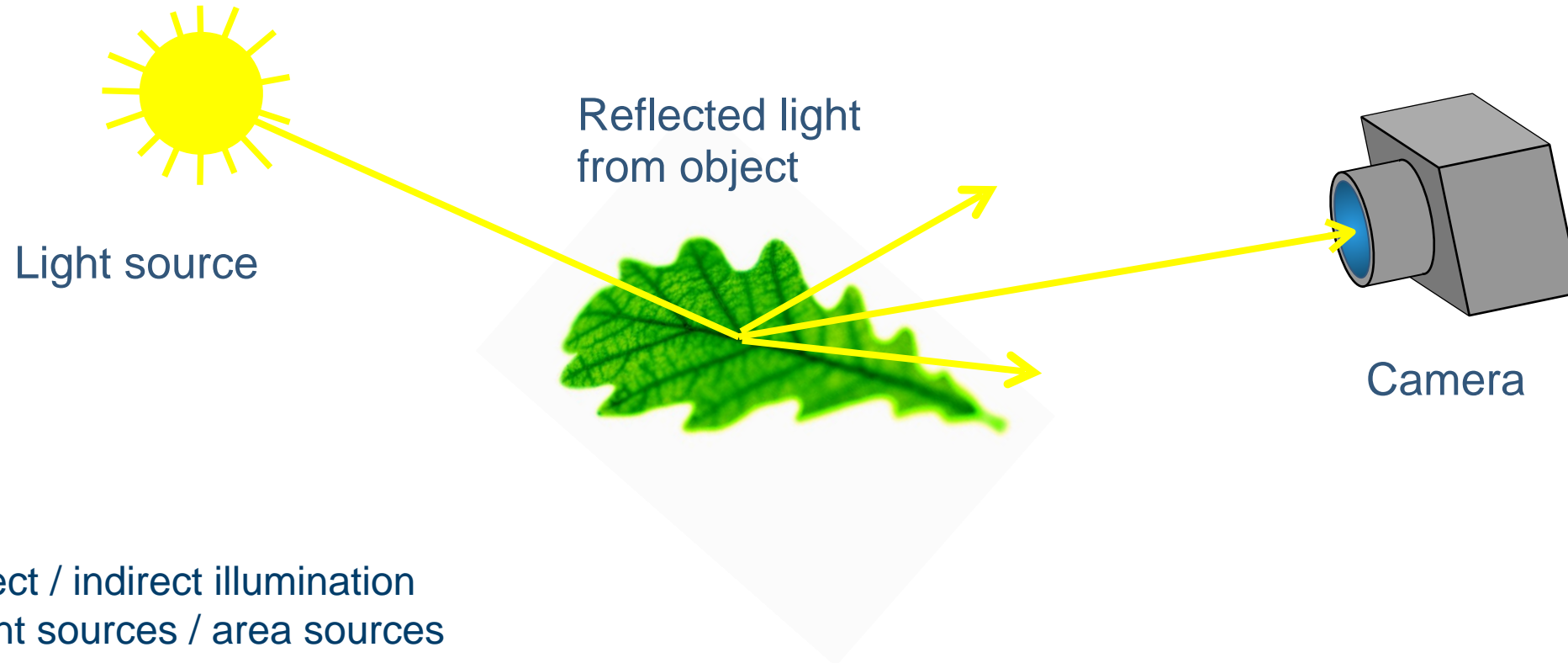


Image formation

Lecture 1.1 - Light, camera, optics and colour

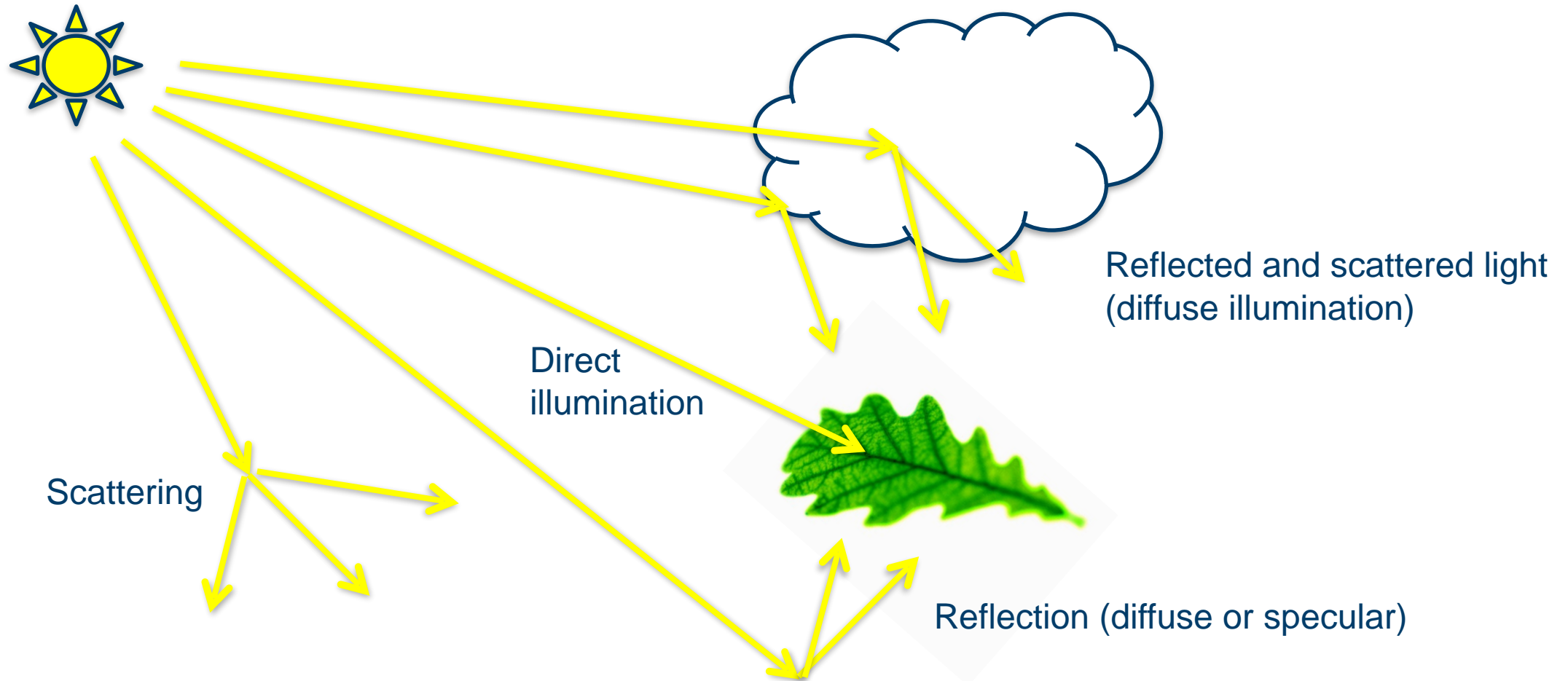
Idar Dyrdal

Imaging with visible light

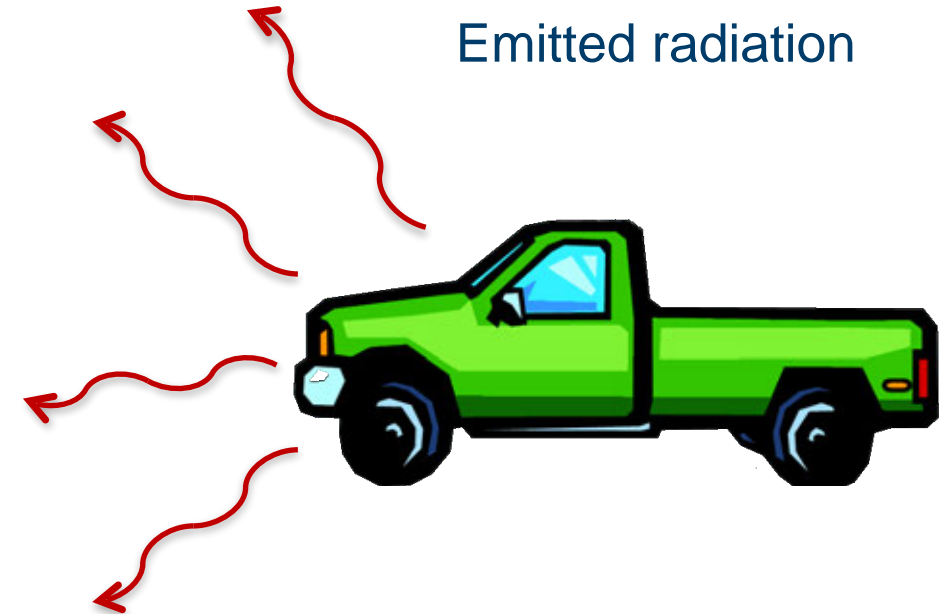
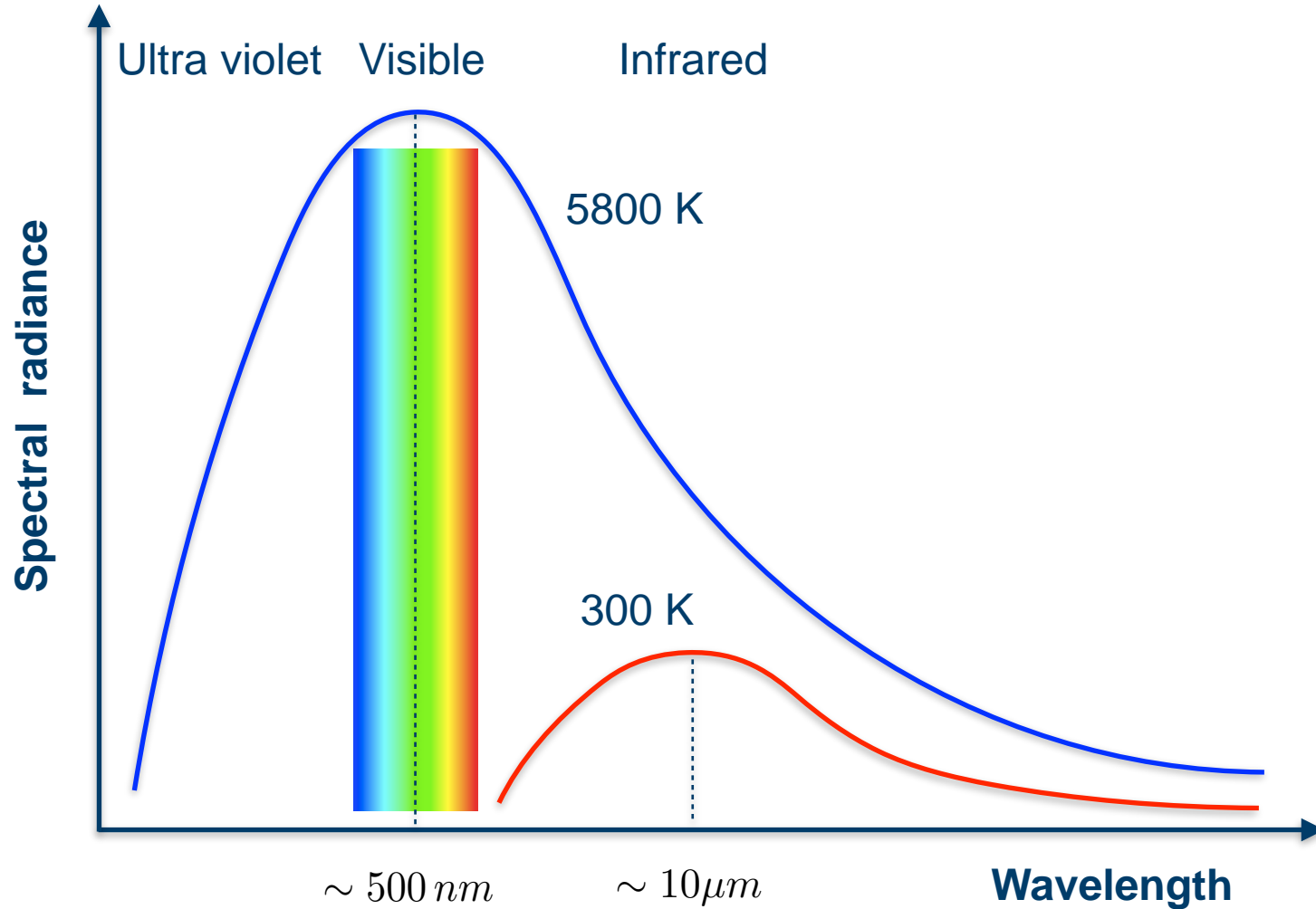


- Direct / indirect illumination
- Point sources / area sources
- Natural / artificial illumination

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:

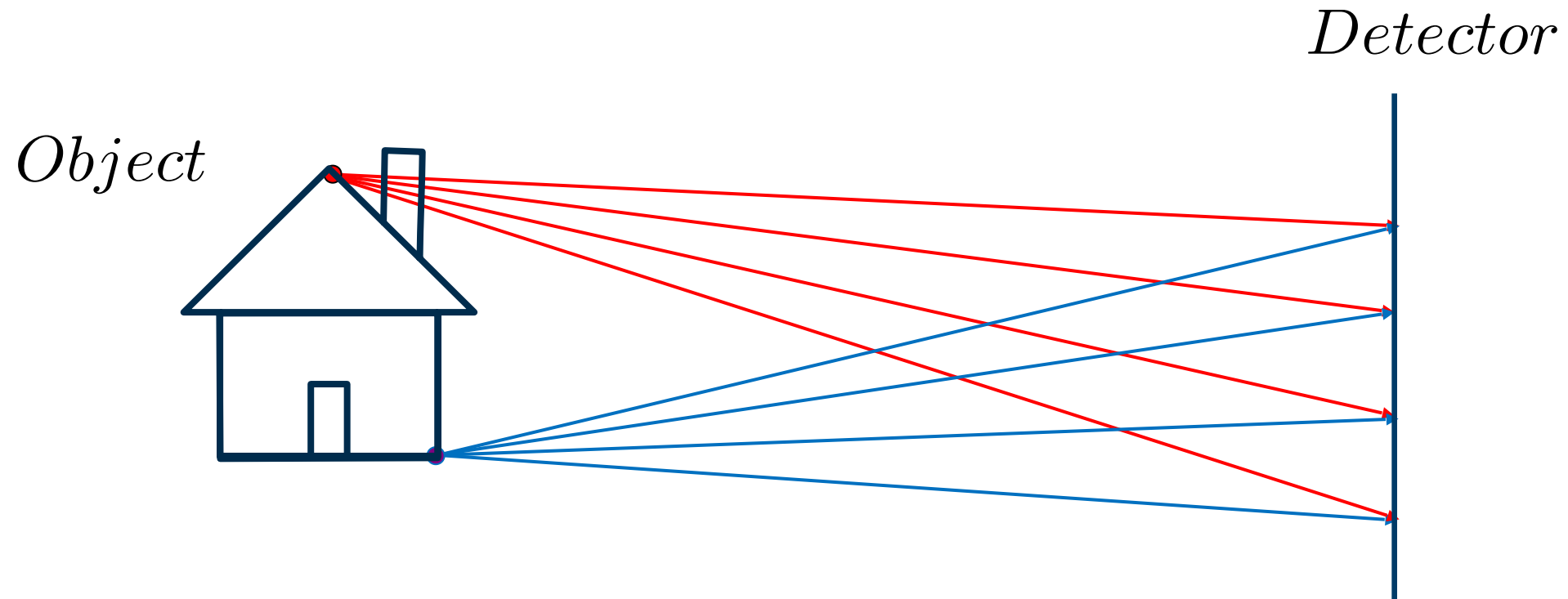
- Imaging with (mainly) the **emitted** thermal radiation from the scene.

Other frequency domains and wave types used for imaging:

- Millimeter waves, x-rays, ... (electromagnetic waves)
- Acoustic (sonar), seismic, ... (mechanical waves)

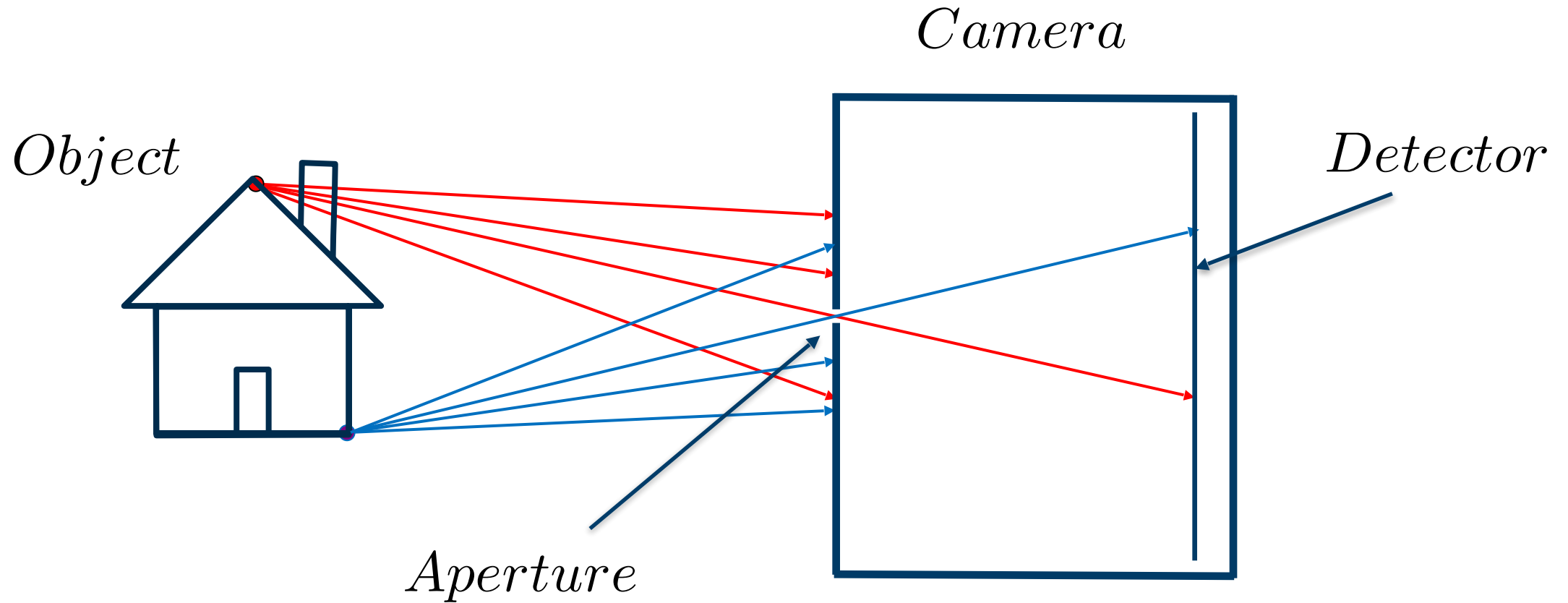


Image formation

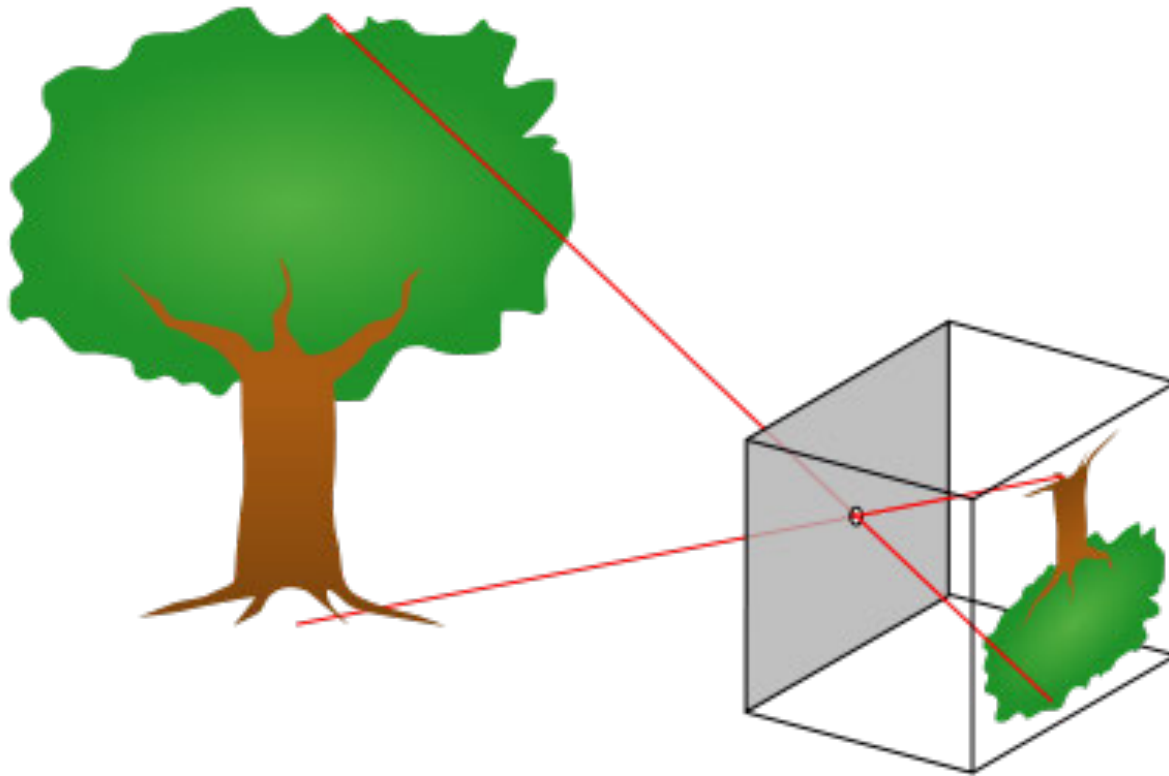


No image is formed!

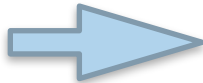
Simple camera - Pinhole camera



Pinhole camera



Small aperture



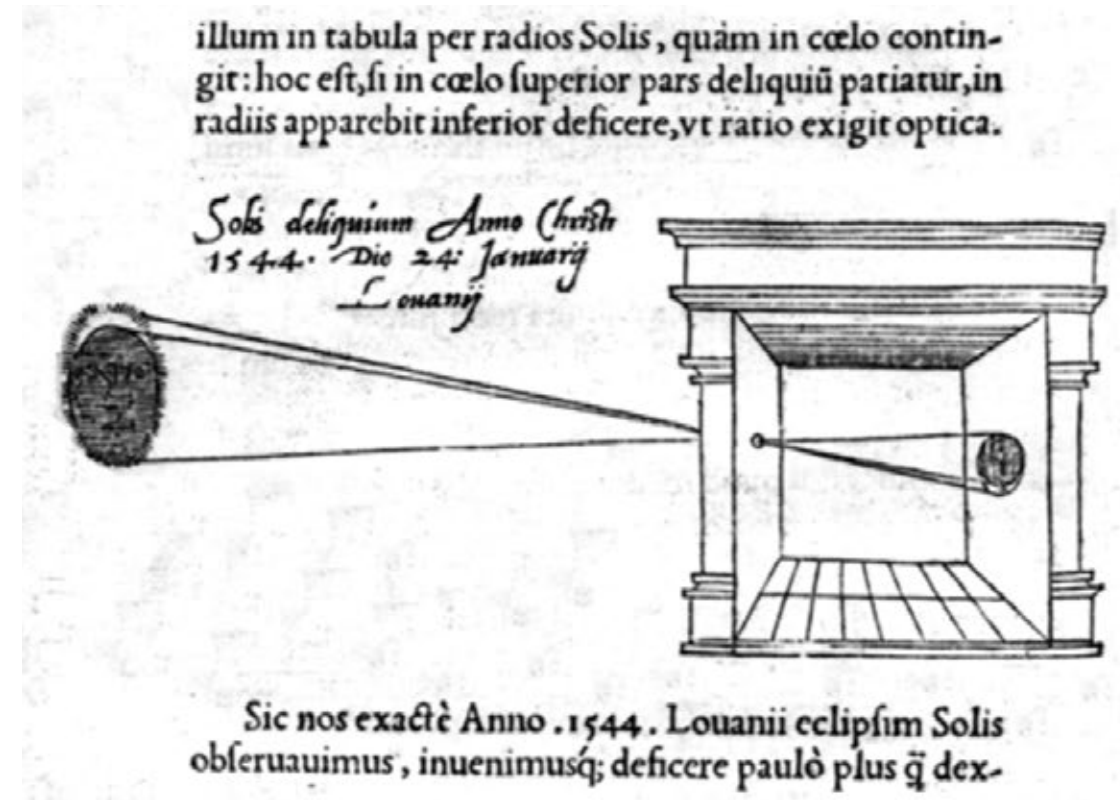
Dark image

Large aperture

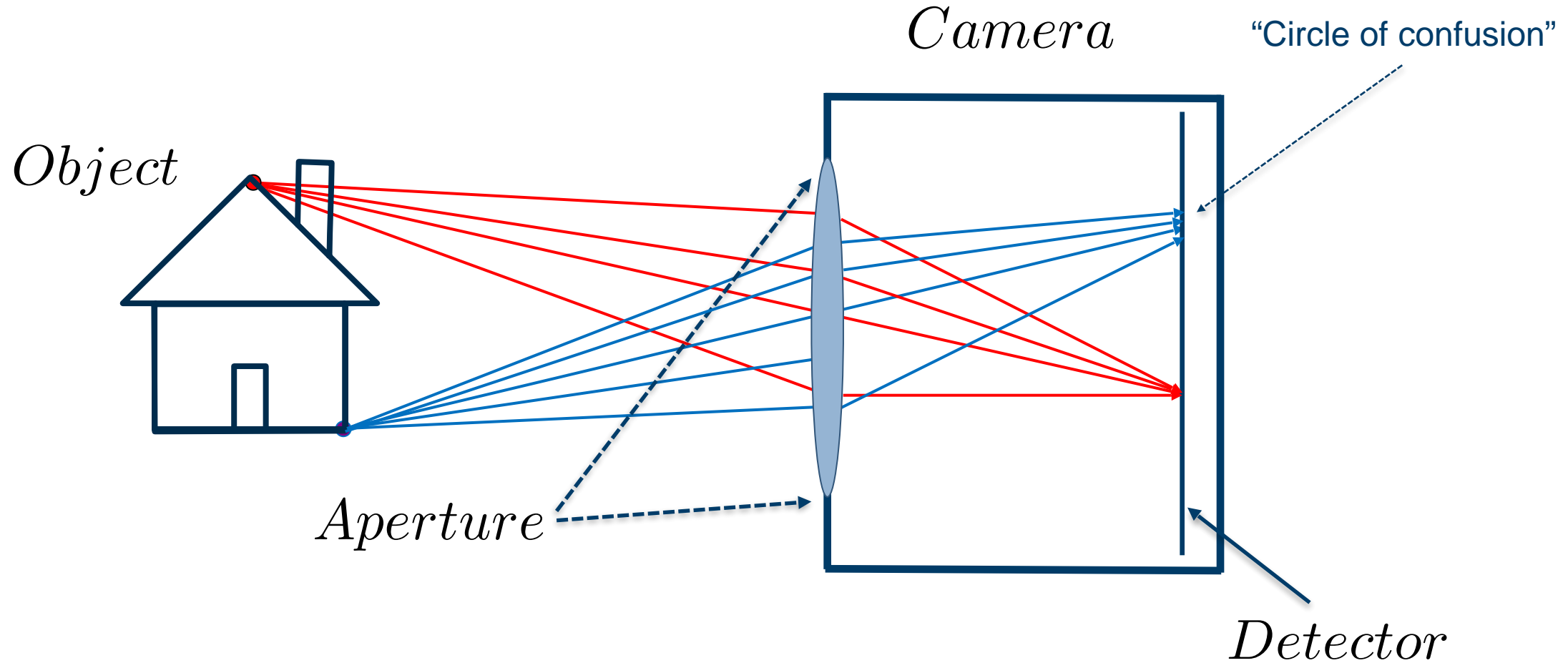


Image out of focus

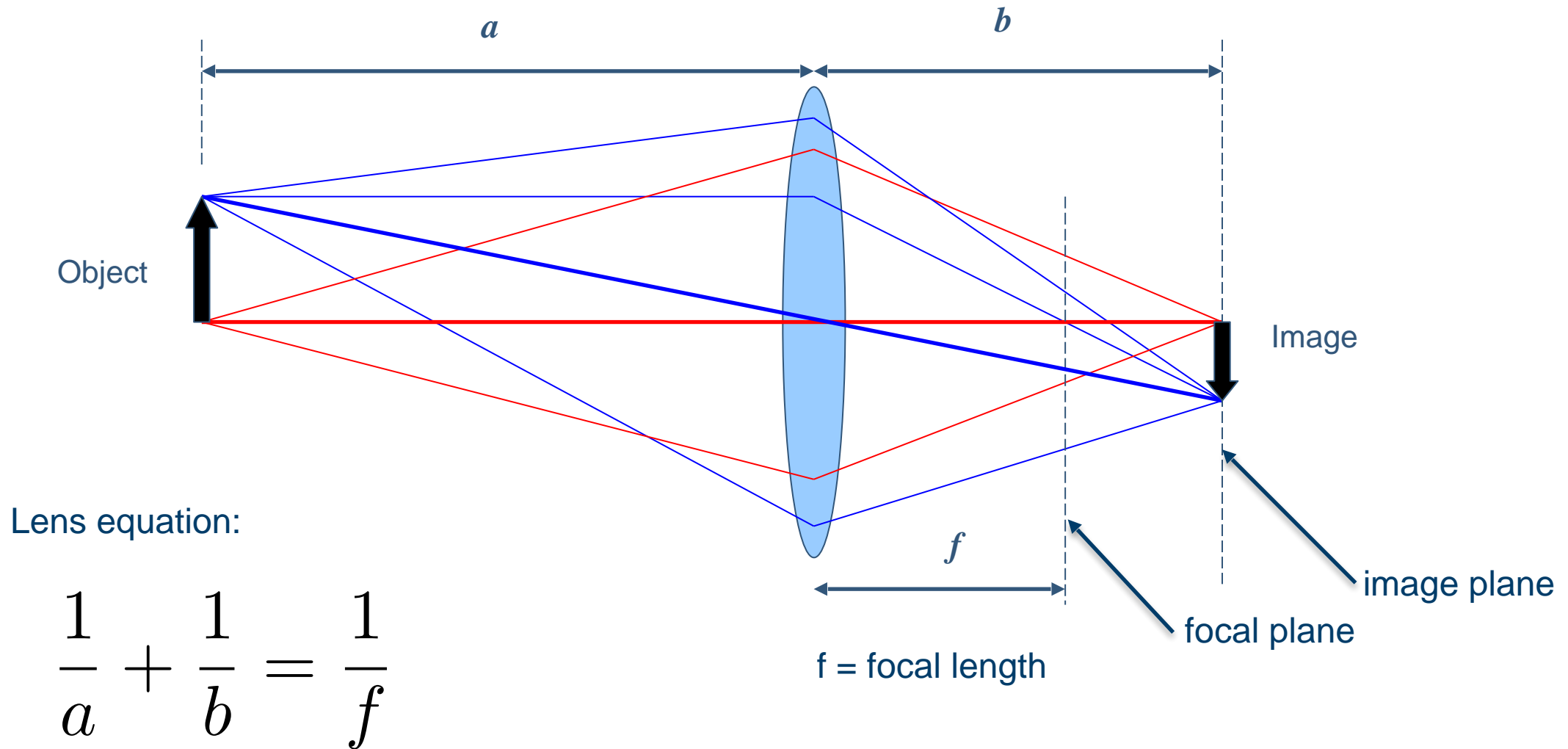
Camera obscura



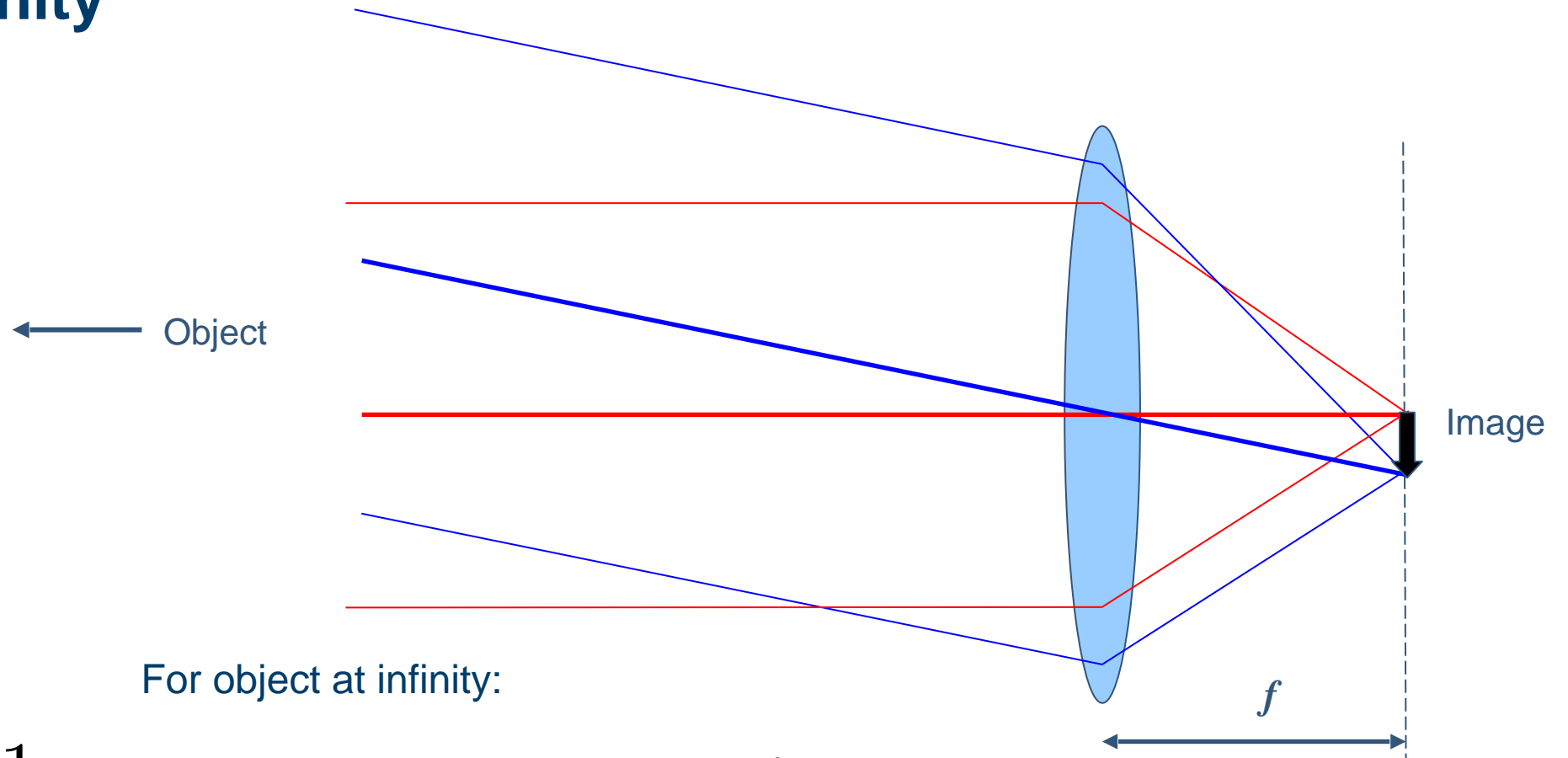
Camera with a lens



Imaging with a lens



Object at infinity



Lens equation:

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

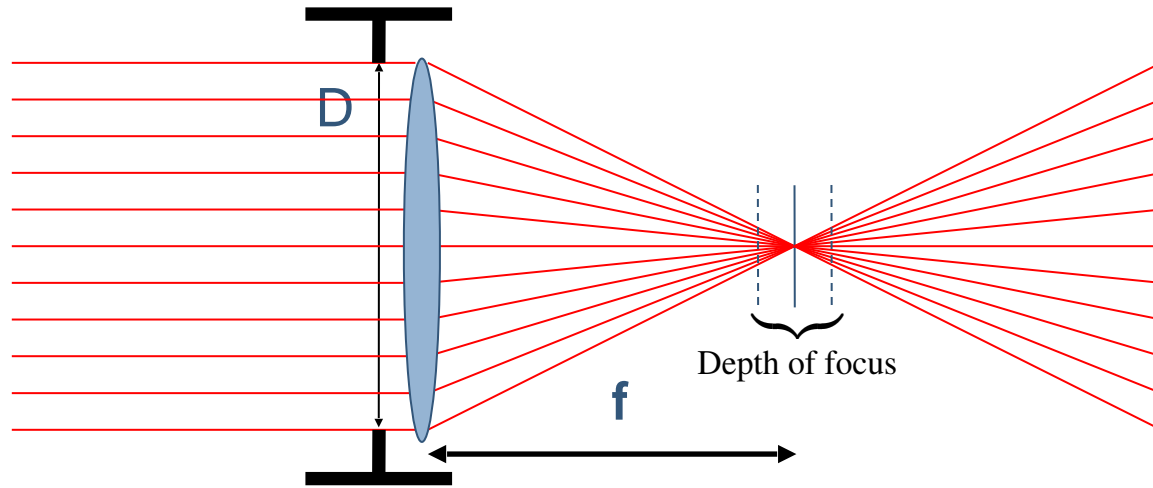
For object at infinity:

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

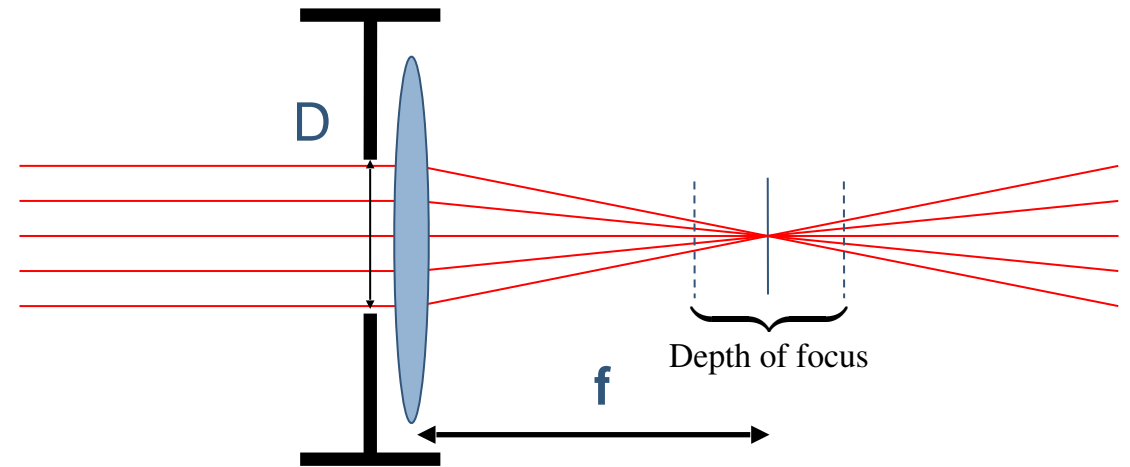
i.e. image is formed in focal plane.

Depth of focus

Large aperture

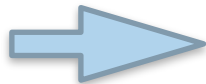


Small aperture



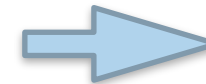
F-number: f/D (examples: $f/2.8$, $f/4$, $f/5.6$, $f/8$, $f/11$, $f/22$)

Small f-number



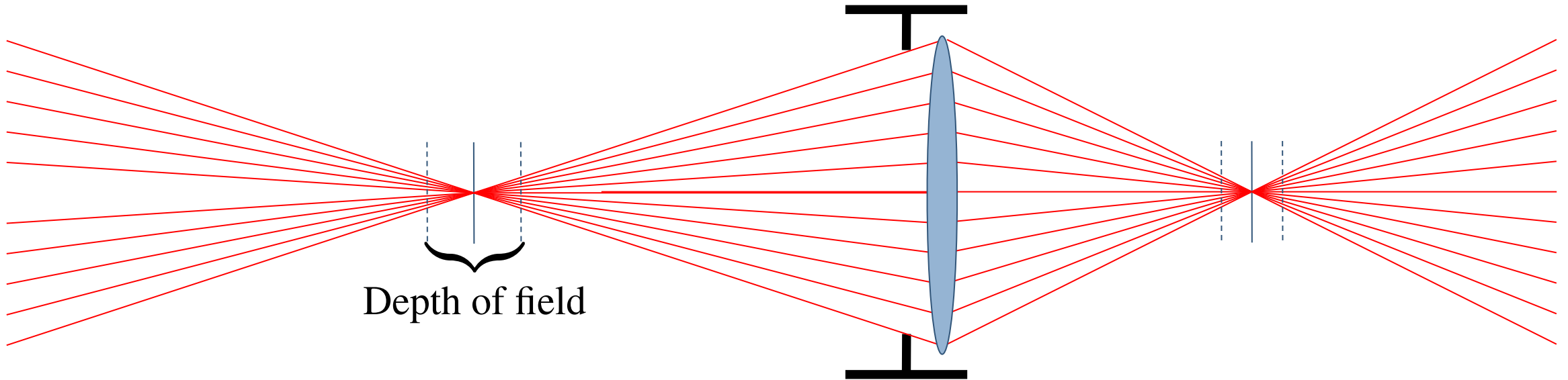
Narrow depth of focus

Large f-number

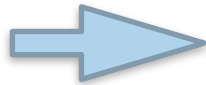


Large depth of focus

Depth of field – large aperture



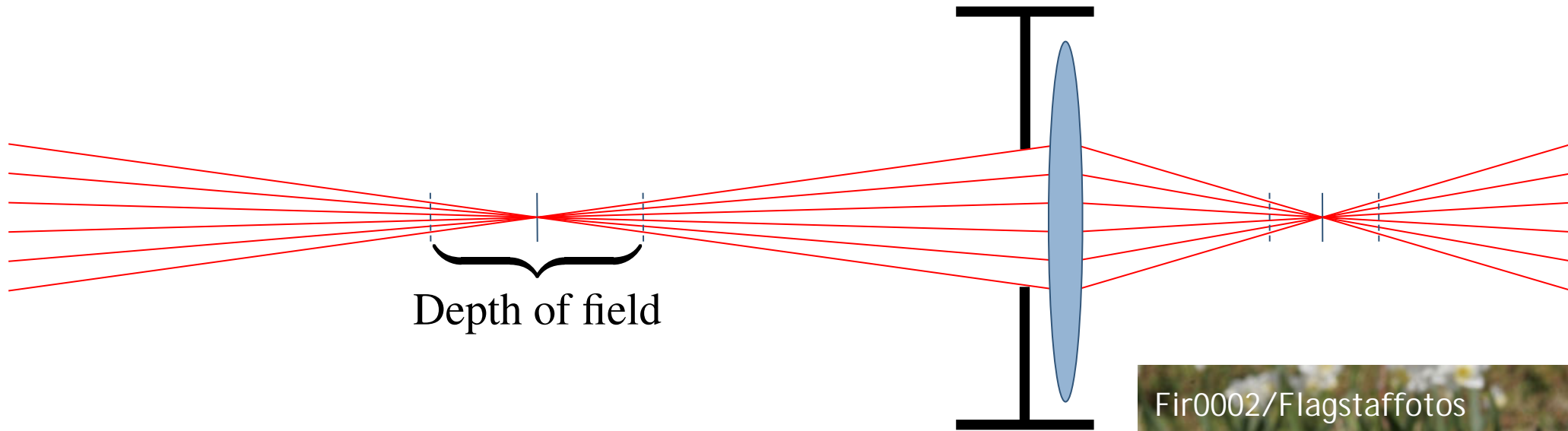
Large aperture



Narrow depth of field



Depth of field – small aperture



Small aperture → Large depth of field

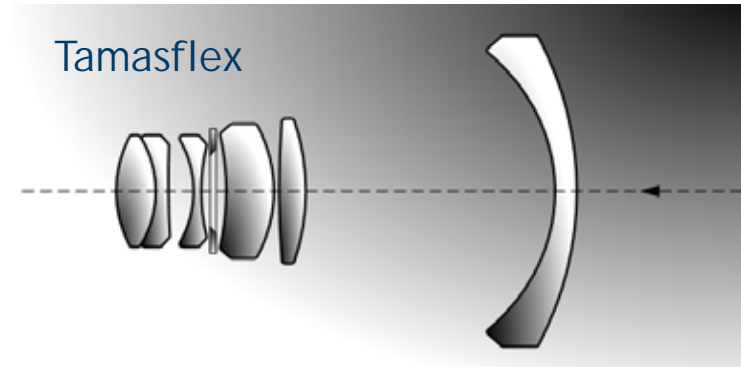
Too small aperture will lead to *diffraction* and loss of sharpness



Practical lenses

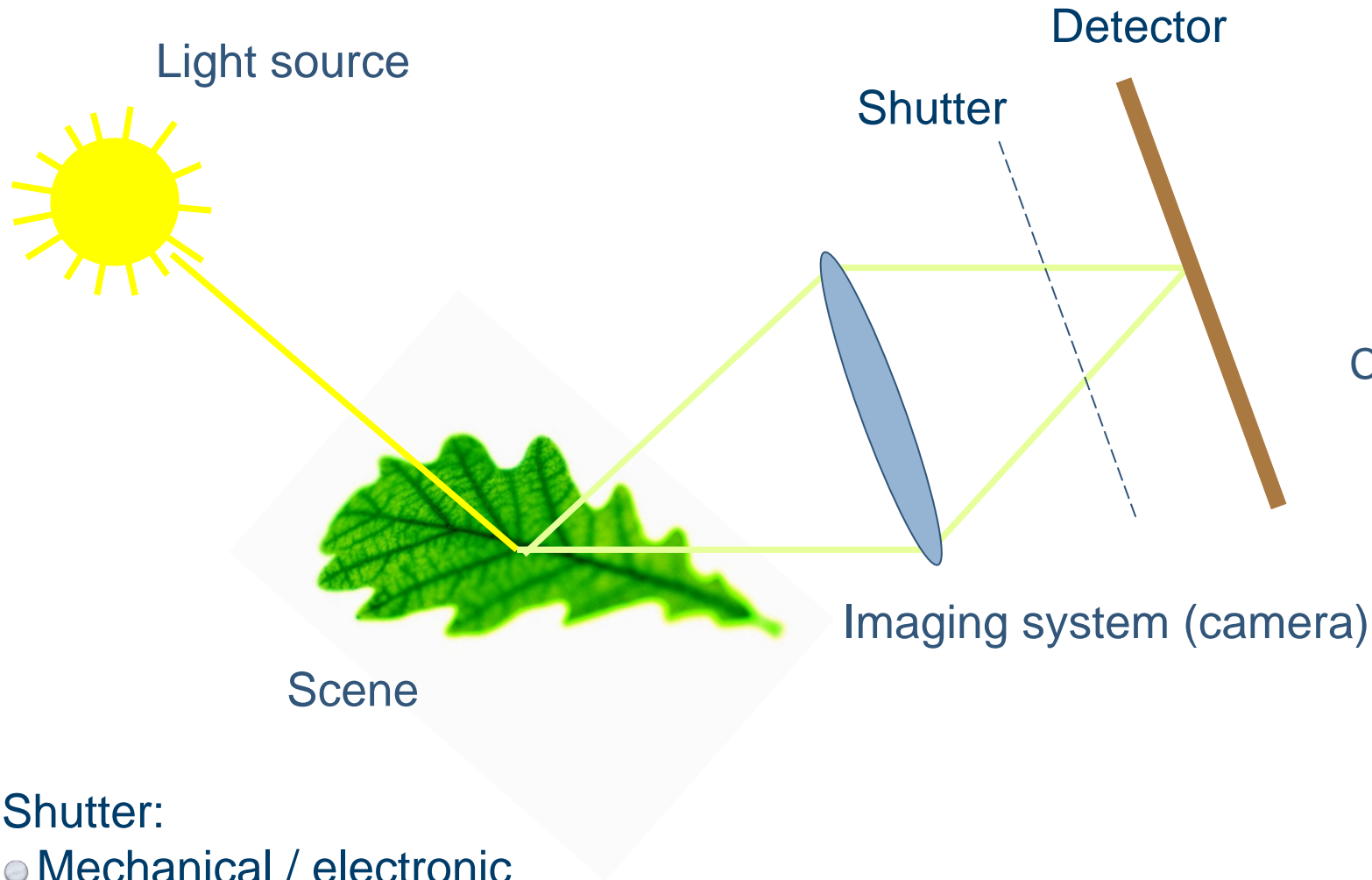


Fixed focal length lens



Zoom lens (variable focal length)

Image capture

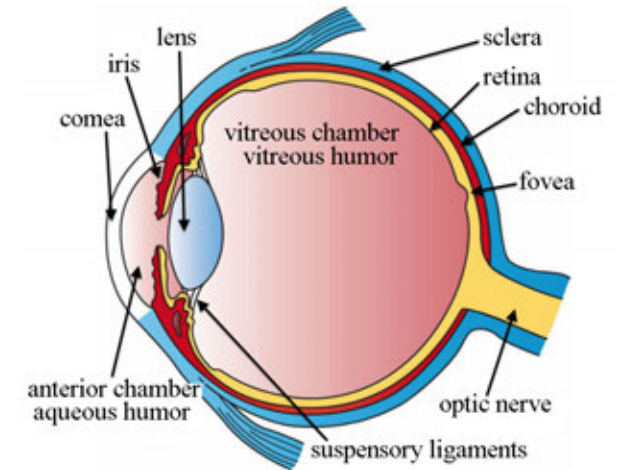


Shutter:

- Mechanical / electronic
- Global / rolling



CMOS image sensor (CMOSIS 48Mp)



(Artwork by Holly Fischer)

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

Red



Green

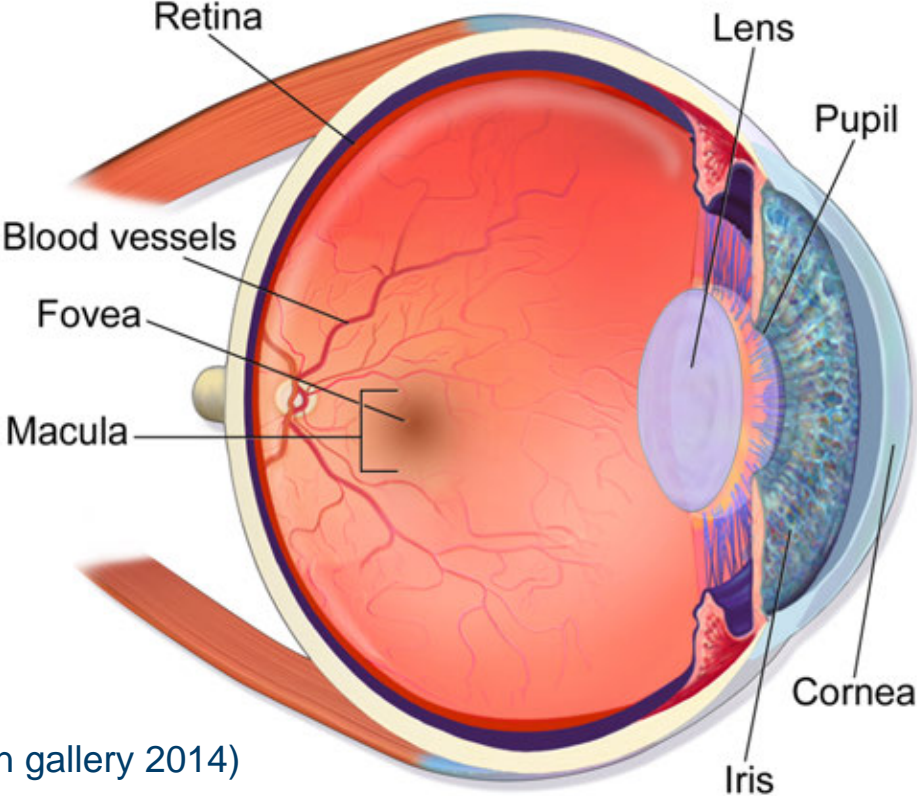


Blue



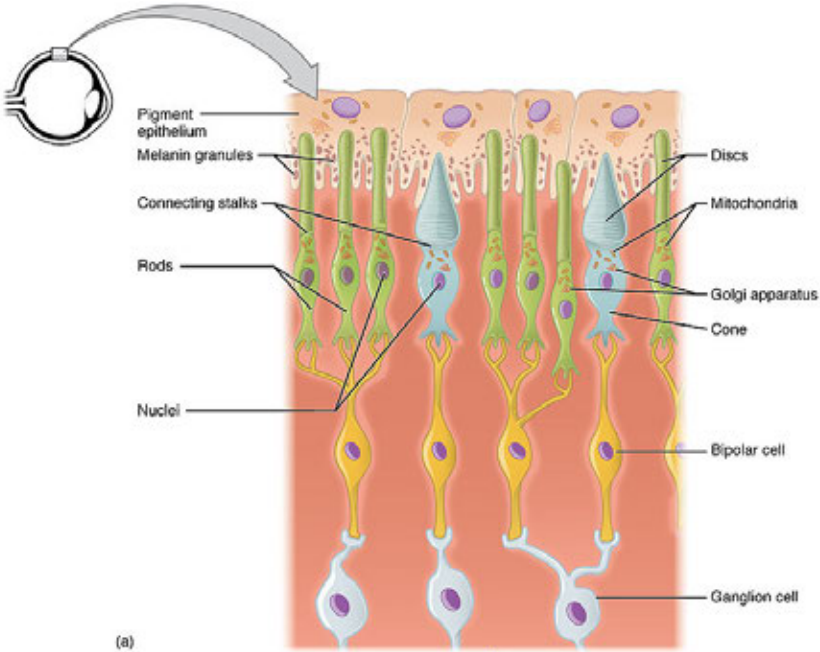
RGB colour image

Human Vision

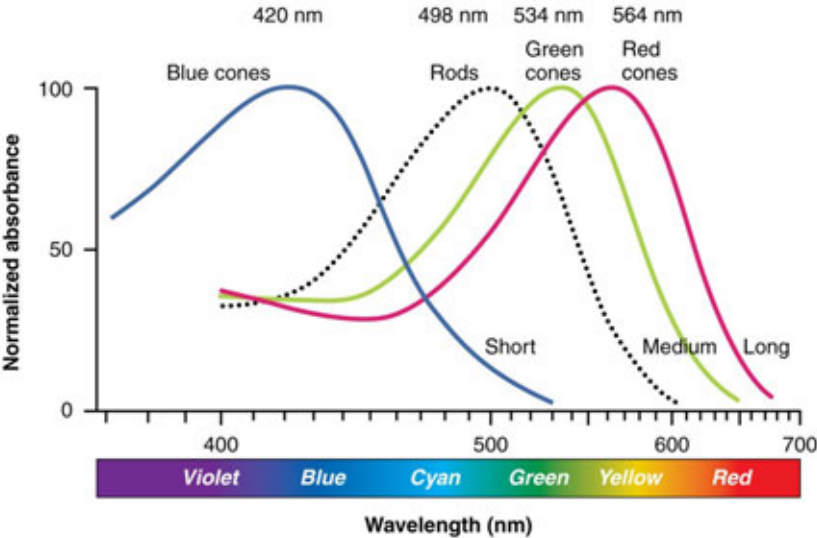


(Blausen gallery 2014)

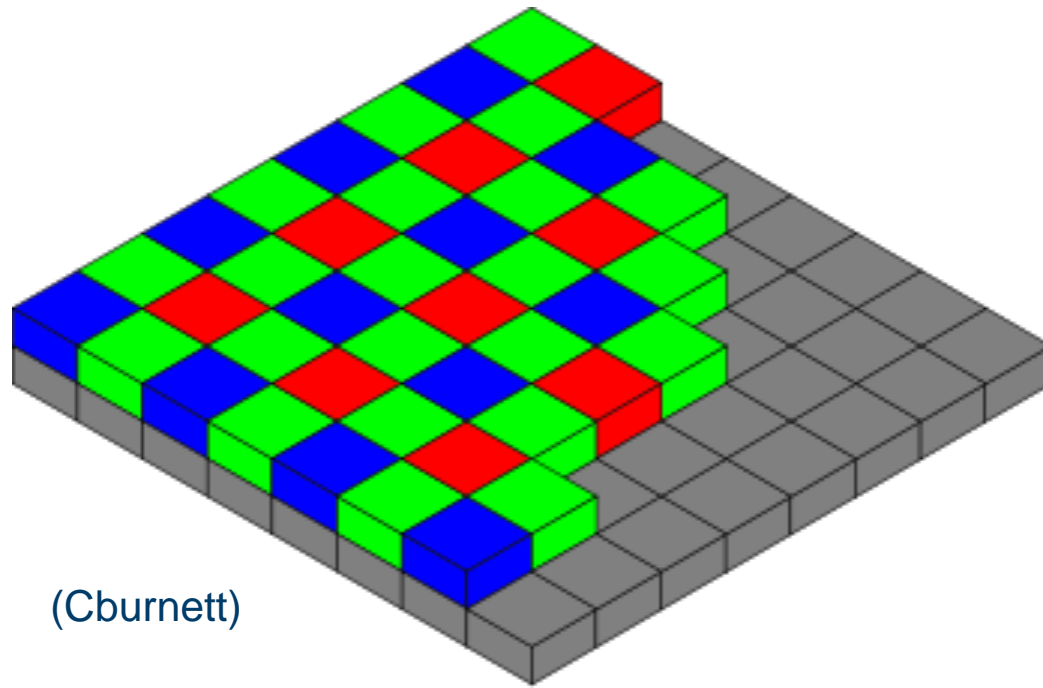
Eye Anatomy



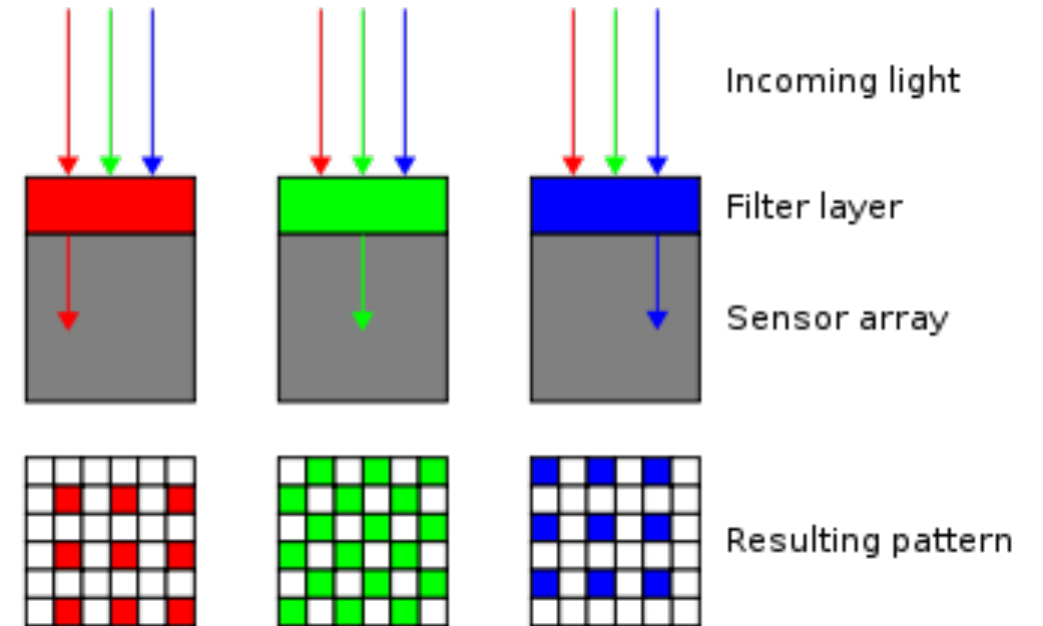
(OpenStax College - Anatomy & Physiology)



Colour Sensing in digital cameras - Bayer filter



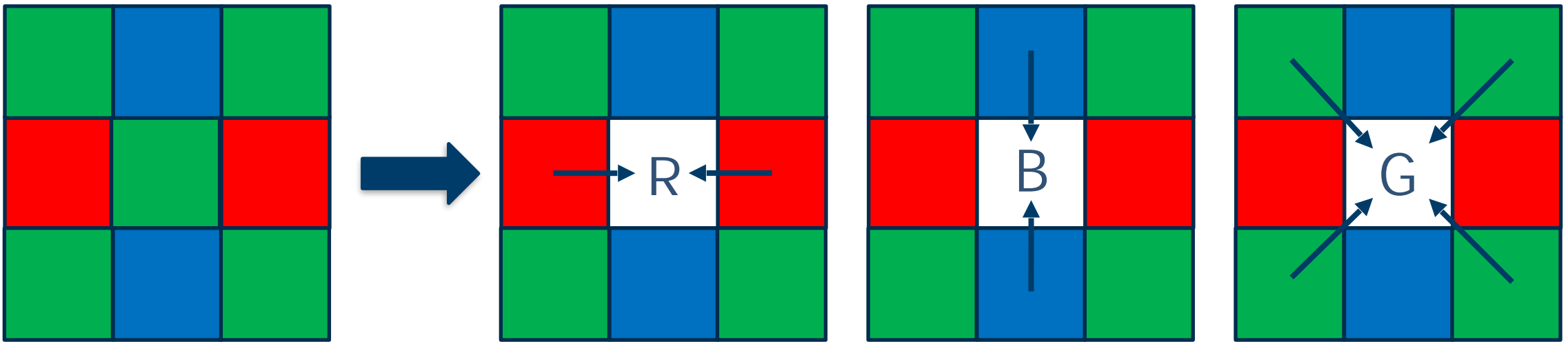
(Cburnett)



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

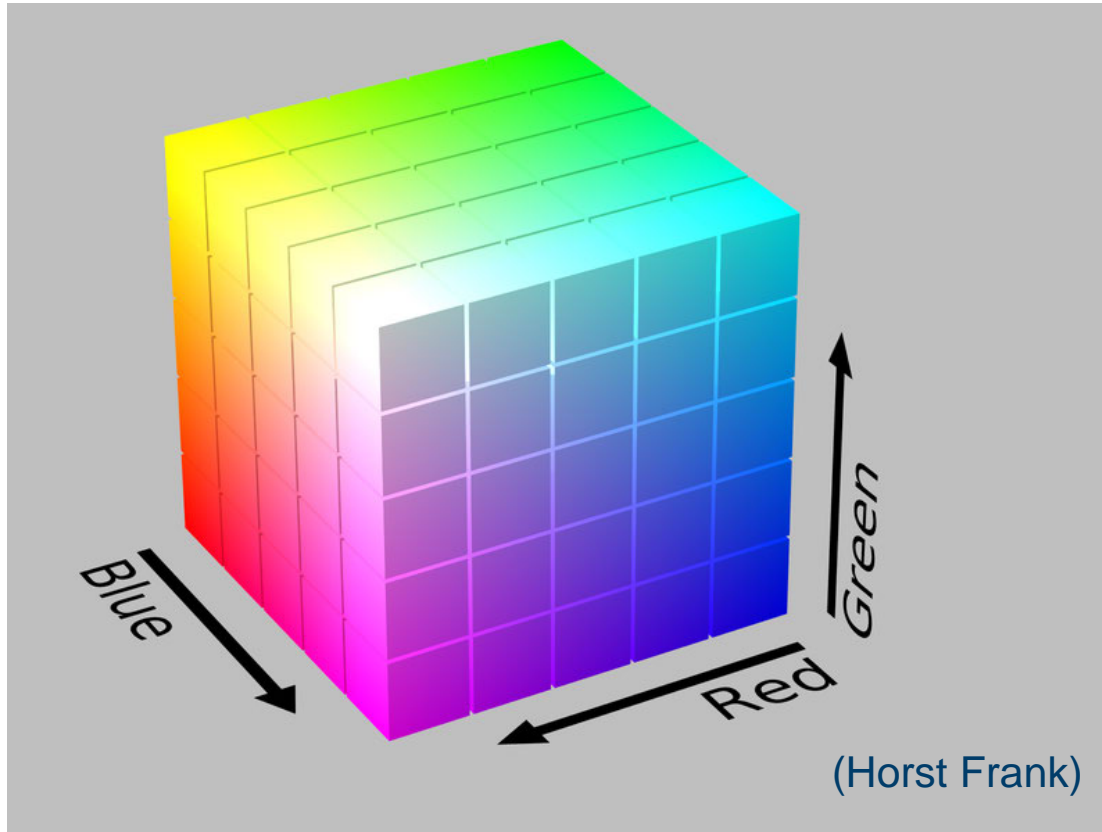
B

G

R

R														C														31	32	33	29	32	32	34	29															28	31	27	27	27	32	30	33	32	32	29	30			
														85	87	88	84	86	85	86	84	85	88	84	84	84	84	86	86	84	86	88	86	86	84	86	84	85															32	27	29	31	29	29	30	33	29	29	31	28
140	141	145	141	144	142	143	141	143	146	142	142	142	144	143	145	144	144	141	143	84	86	84	86	88	86	86	85	86	85	88	86	86	84	85	32	30	29	29	28	28	29	28	31	31	28	29																		
142	144	139	144	143	141	141	141	144	142	144	146	144	144	143	145	141	144	146	143	86	88	85	86	86	85	83	85	86	85	88	88	88	86	83	32	30	30	29	30	32	32	27	29	28	31	31																		
141	143	140	143	141	144	144	144	145	143	144	144	143	143	144	143	146	146	147	145	85	86	85	85	84	85	86	86	86	84	86	83	85	86	86	32	30	31	35	30	32	30	32	29	31	28	28																		
141	142	142	142	143	143	145	143	144	143	143	141	143	144	144	142	144	143	147	147	84	86	82	84	88	85	86	86	85	86	86	88	83	83	85	32	32	35	30	29	32	33	30	32	32	30	35																		
142	143	142	143	145	145	141	141	144	139	141	145	143	144	143	144	144	146	144	143	82	85	85	88	85	84	86	86	88	86	86	85	85	92	31	34	33	32	33	27	29	32	32	29	29	30																			
141	140	140	145	143	143	142	139	142	142	145	143	141	144	145	143	144	144	143	150	86	84	86	88	86	88	88	84	82	84	86	86	84	84	85	34	31	30	30	35	34	30	32	32	29	33	28																		
142	141	143	142	142	141	142	143	141	143	145	144	145	140	141	144	144	141	141	143	85	86	84	85	85	88	83	86	86	82	85	85	84	88	85	31	34	30	31	32	32	31	31	32	32	32	29																		
143	144	143	139	140	140	142	142	143	141	143	143	145	143	139	142	142	141	145	143	84	82	86	85	84	85	85	85	84	85	86	87	86	32	30	31	32	31	34	32	28	30	32	32	32																				
141	138	143	139	142	143	143	140	142	143	143	141	142	142	141	141	142	144	148	144	84	85	82	84	85	84	40	86	40	85	40	81	82	85	86	34	34	32	32	31	35	32	32	32	32	31	31																		
138	138	138	142	143	142	139	140	142	139	141	142	141	143	142	138	139	142	144	144	89	86	86	85	85	84	40	88	40	86	30	85	30	85	30	84	30	39	37	36	34	31	32	35	32	34	34	32	31																
141	142	141	144	143	138	139	143	143	143	142	142	141	145	144	142	142	142	141	141	89	89	88	86	86	84	40	85	40	88	40	85	30	86	30	86	40	85	40	84	30	40	37	37	35	31	32	34	34	35	34	32	31												
139	141	140	137	142	139	140	143	146	144	143	143	141	142	145	142	143	143	142	141	85	88	85	88	85	84	40	85	40	86	40	88	40	86	40	85	30	84	30	40	38	33	35	40	37	33	33	35	35	35	35														
139	139	141	136	138	143	143	138	144	141	144	142	141	142	143	143	145	143	142	141	83	88	86	81	84	90	40	88	40	84	40	85	40	85	40	85	40	84	30	36	42	39	38	34	37	38	34	36	36	32	36														
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139	141	139	138	139	141	139	138	137	143	141	139	139	141	143	139	143	143	139	143	88	87	85	87	84	86	40	82	40	85	40	86	40	86	40	84	40	84	40	44	43	39	39	38	39	37	40	33	36	37	35														
136	140	140	141	141	139	139	141	139	138	140	139	142	139	141	143	142	143	140	140	91	89	88	87	87	84	50	85	40	85	40	89	40	85	40	88	40	88	40	45	41	45	43	42	40	38	39	35	34	35	37														
138	136	140	142	139	141	142	143	142	141	140	140	139	141	141	143	139	142	144	142	87	91	87	91	88	89	40	88	40	85	40	87	40	85	40	82	40	85	40	43	43	43	44	43	43	41	40	38	40	36	35														
143	139	136	140	140	139	138	139	143	139	143	141	143	141	138	140	139	139	142	144	85	86	85	85	89	91	40	88	50	87	50	85	40	84	40	88	40	86	40	49	46	43	41	43	41	40	41	43	39	37	37														
141	139	139	140	143	140	139	138	142	140	140	142	144	141	139	138	139	144	143	141	89	90	88	85	85	88	87	85	87	88	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87																
139	143	143	137	139	141	140	142	145	143	140	140	141	139	138	139	141	140	140	140	84	86	84	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88	86	88																

RGB colour space



Normalized RGB values:

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

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

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

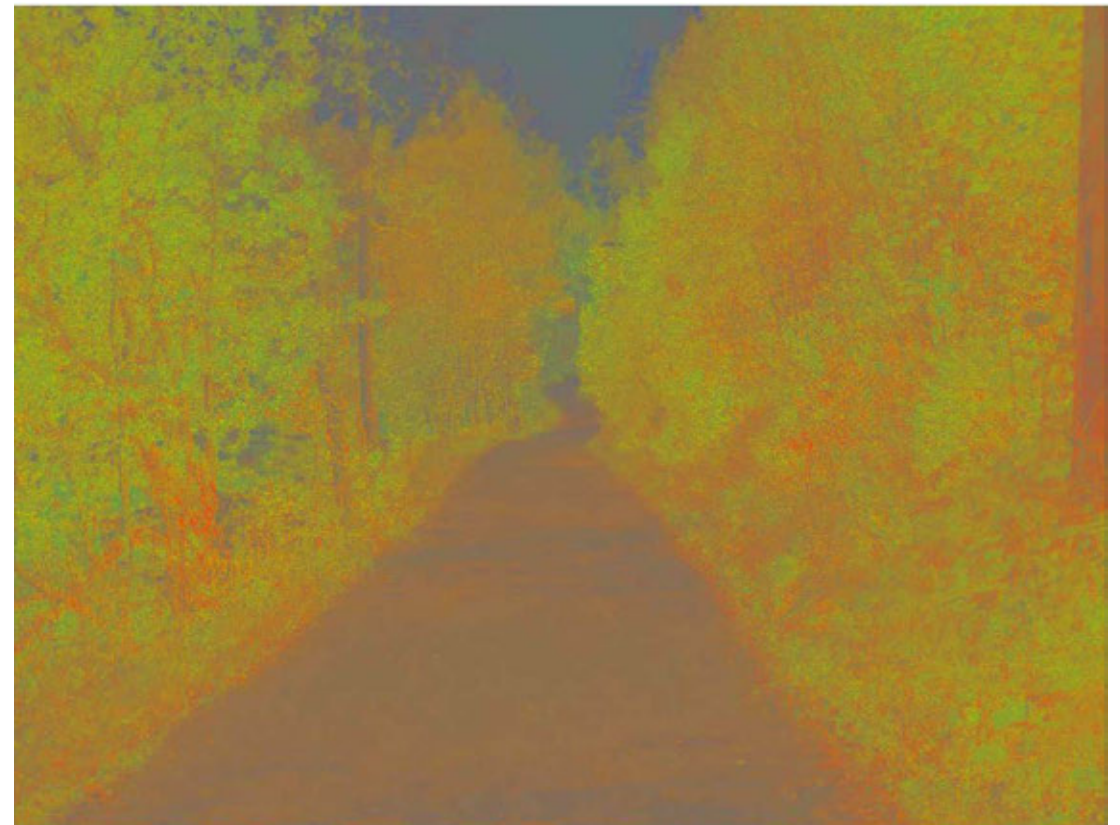
(Illumination invariance)

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

RGB normalization (example)

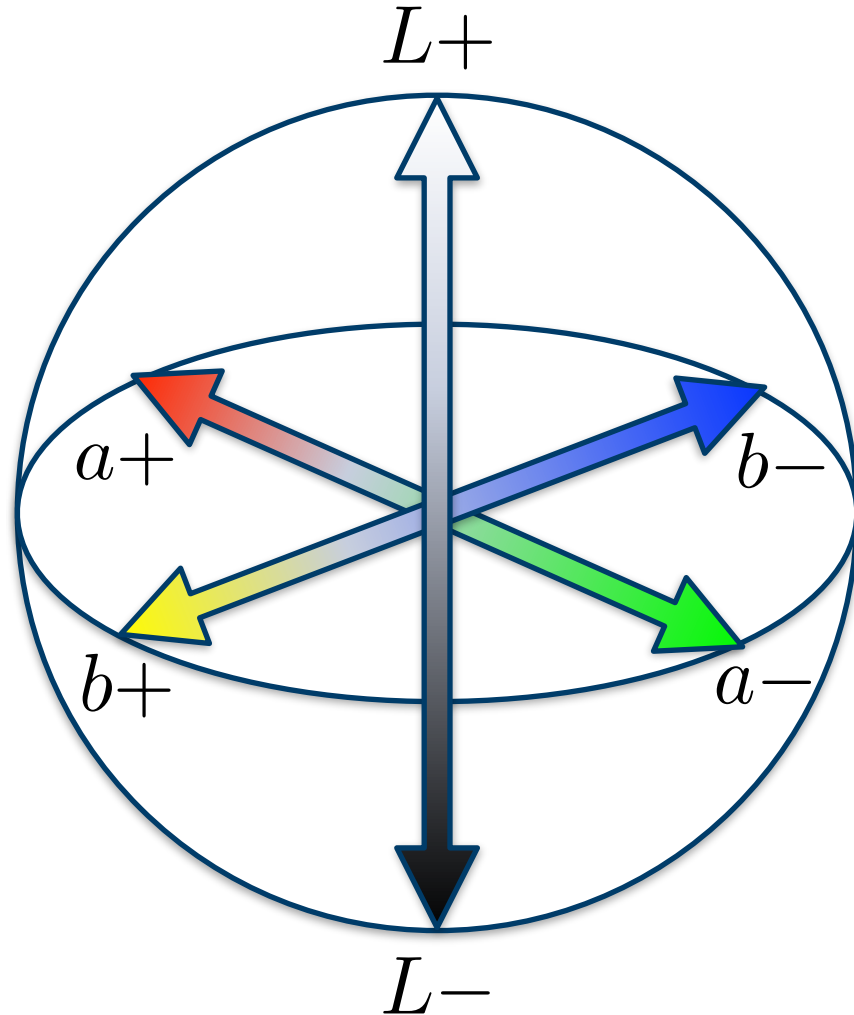


RGB original



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)

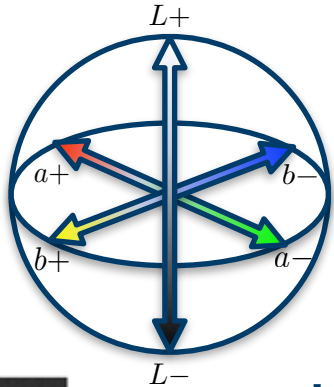
Lab - example

L

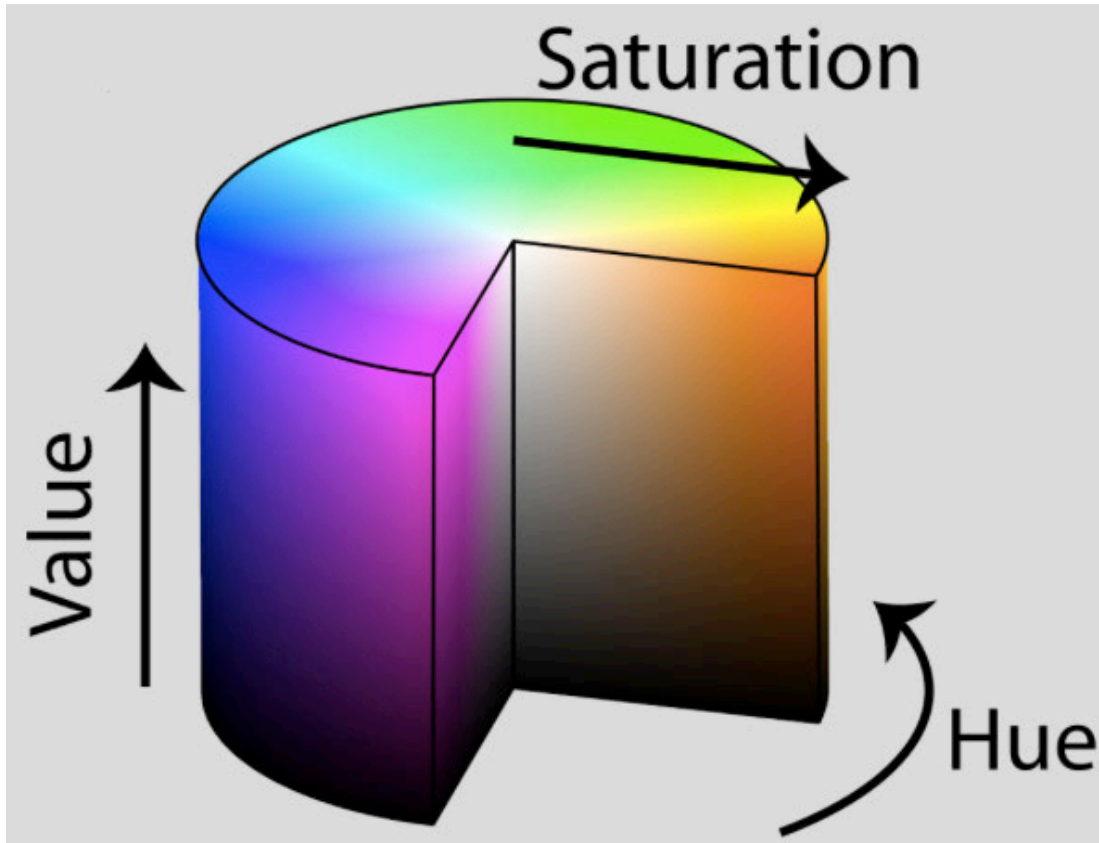


a

b



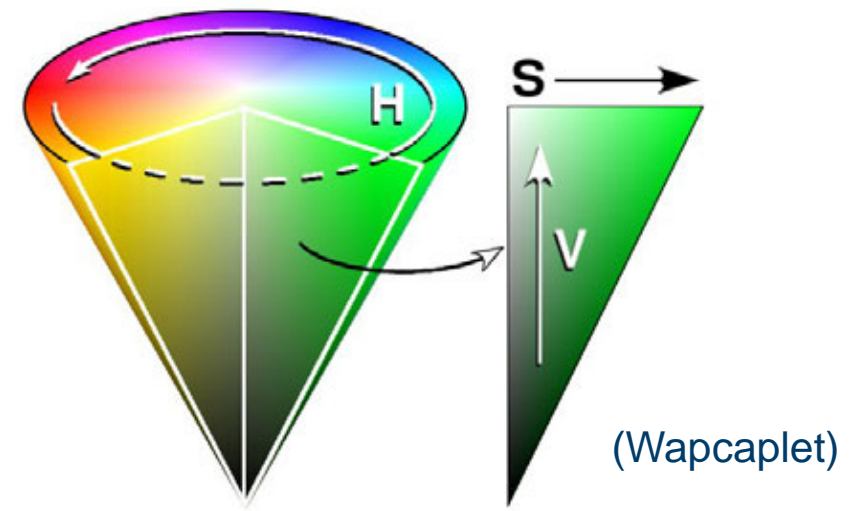
HSV colour space (Hue, Saturation, Value)



(Jacob Rus, 2010)

Intuitive colour space:

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



HSV



Hue



Saturation



Value

Summary

Image formation:

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

More information: Szeliski 2.2 and 2.3

