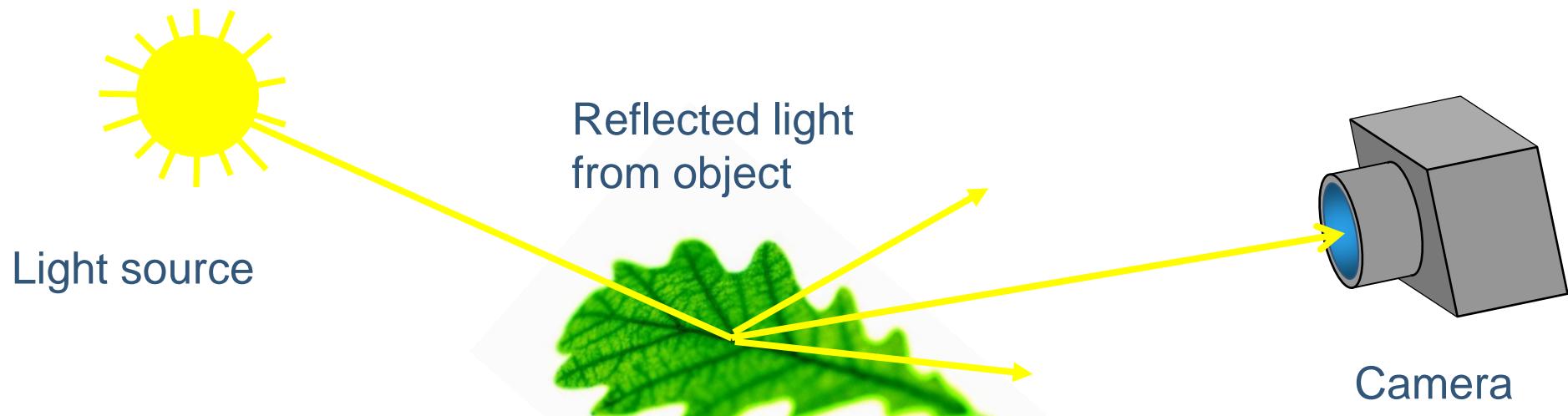


# **Image formation**

## **Lecture 1.1 - Light, camera, optics and colour**

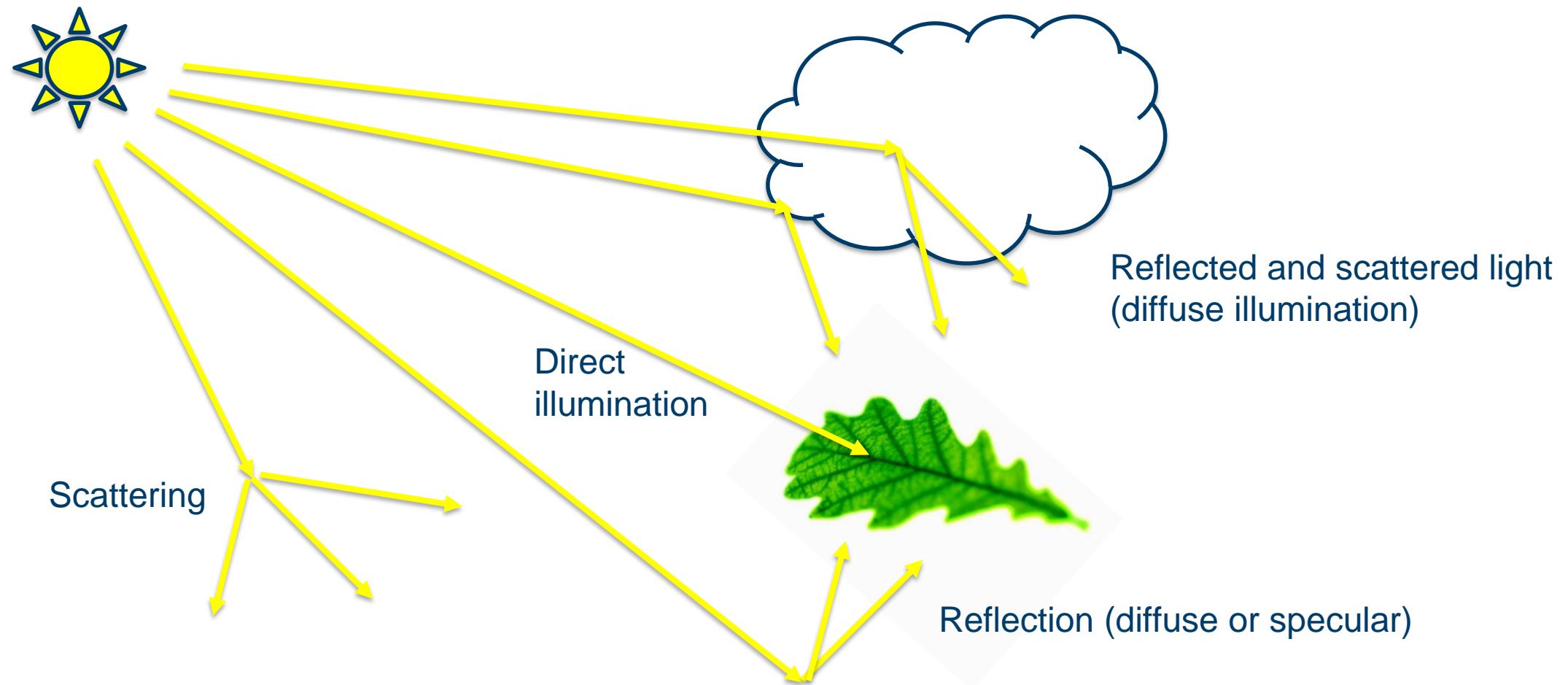
Idar Dyrdal

# Imaging with visible light

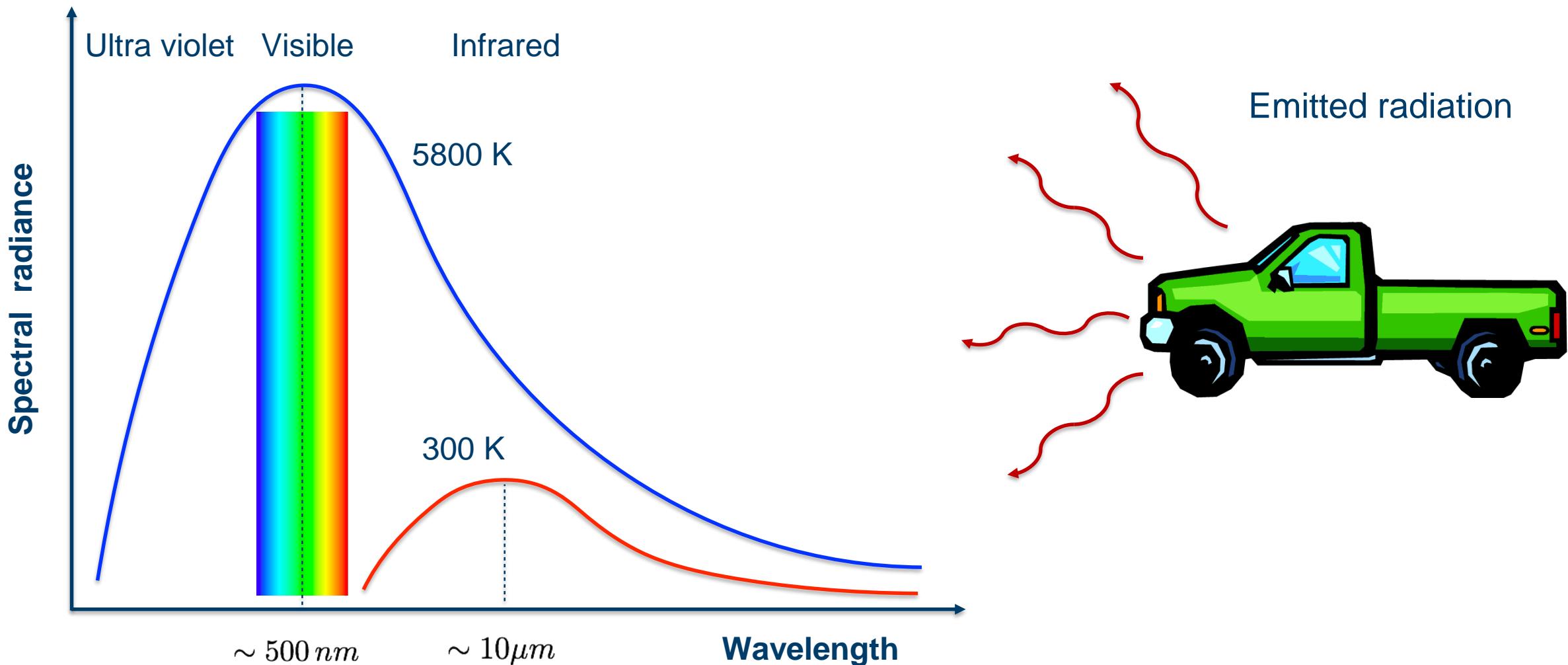


- Direct / indirect illumination
- Point sources / area sources
- Natural / artificial illumination

# Direct and indirect illumination



# Thermal radiation - Planck distribution



# Reflected and emitted radiation



## Image in visible light:

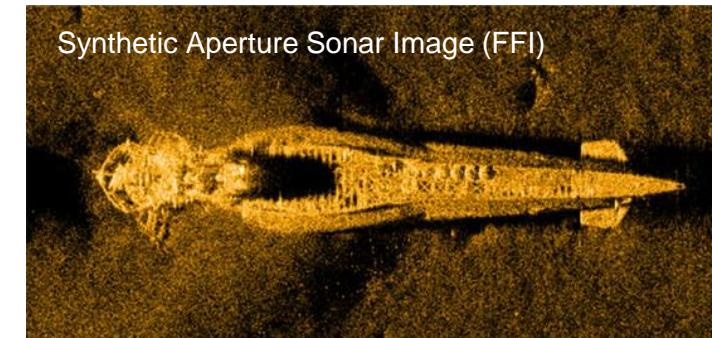
- Imaging with **reflected** (and scattered) radiation from the sun or other natural or artificial sources.

## Other frequency domains and wave types used for imaging:

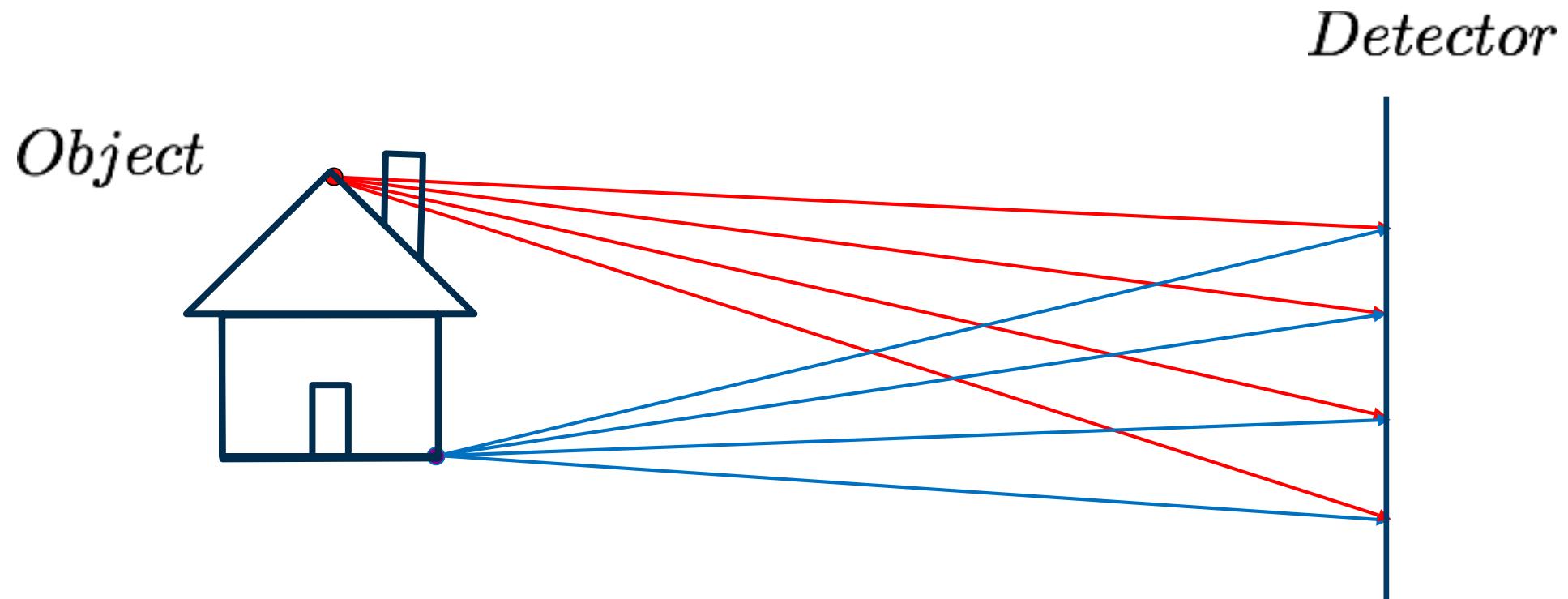
- Millimeter waves, x-rays, ... (electromagnetic waves)
- Acoustic (sonar), seismic, ... (mechanical waves)

## Infrared (thermal) image:

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

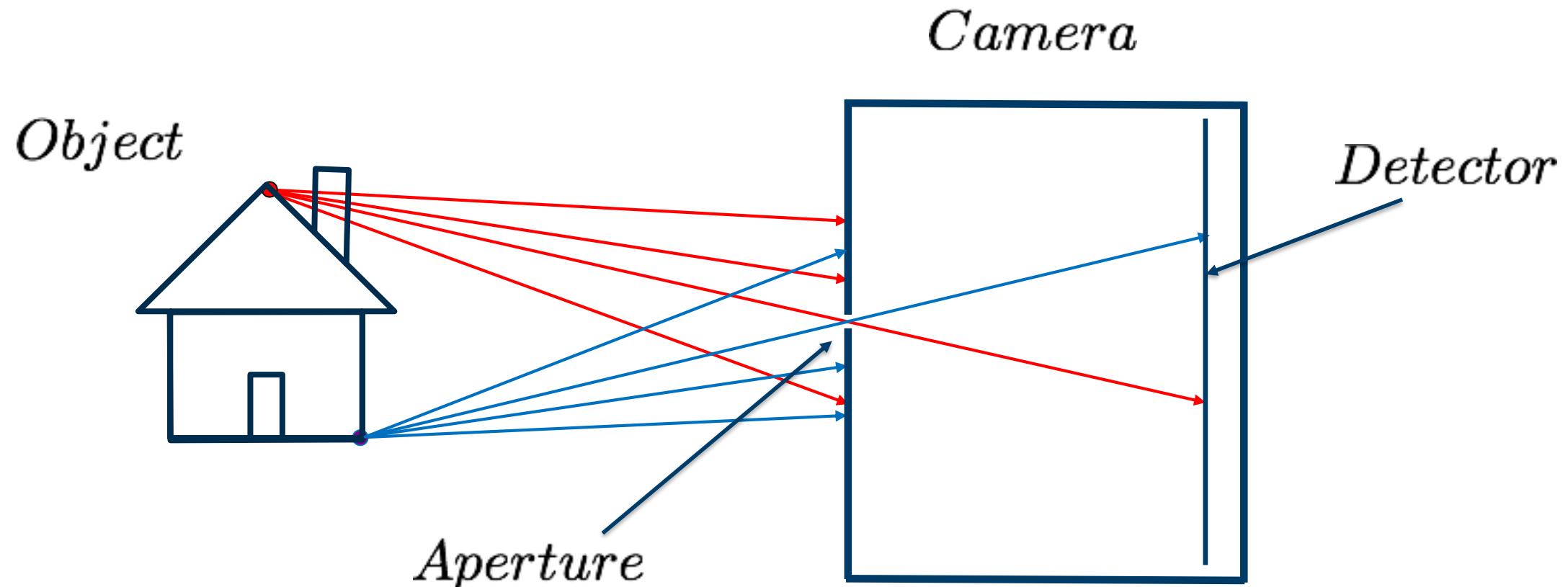


# Image formation

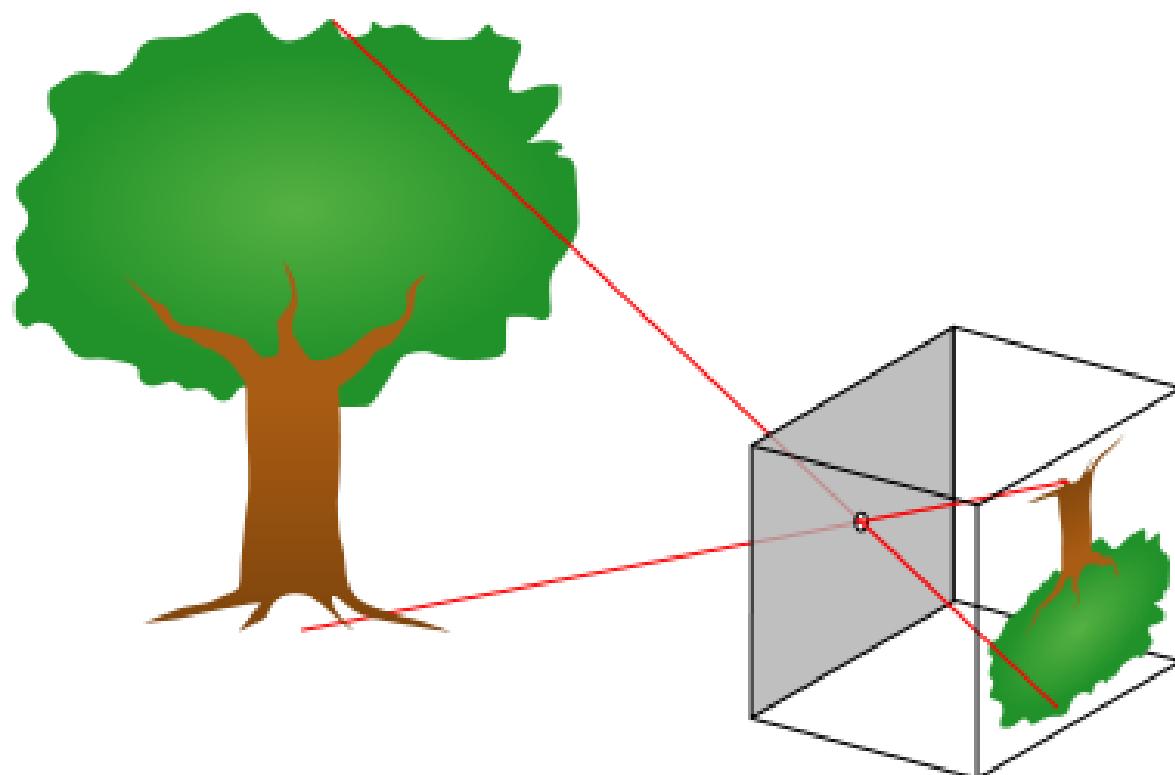


No image is formed!

# Simple camera - Pinhole camera



# Pinhole camera



Small aperture



Dark image

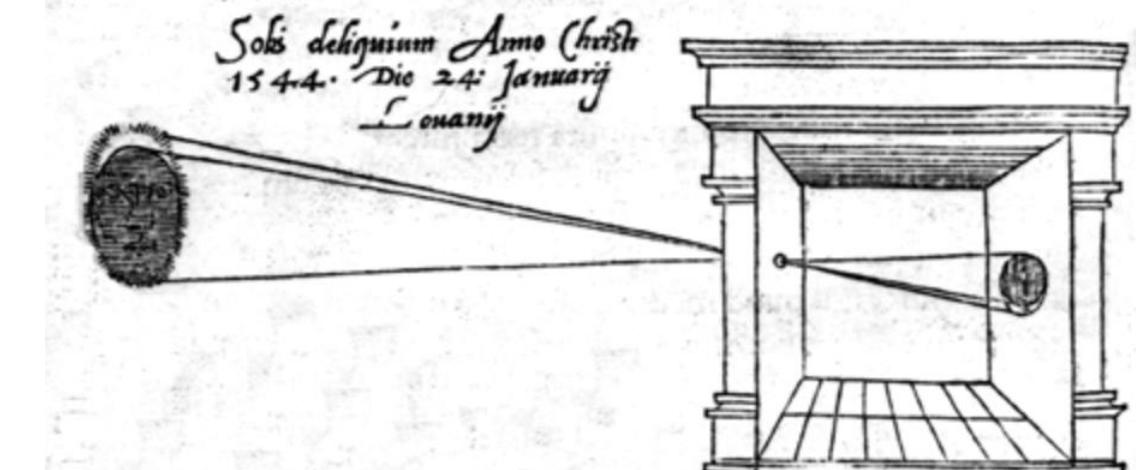
Large aperture



Image out of focus

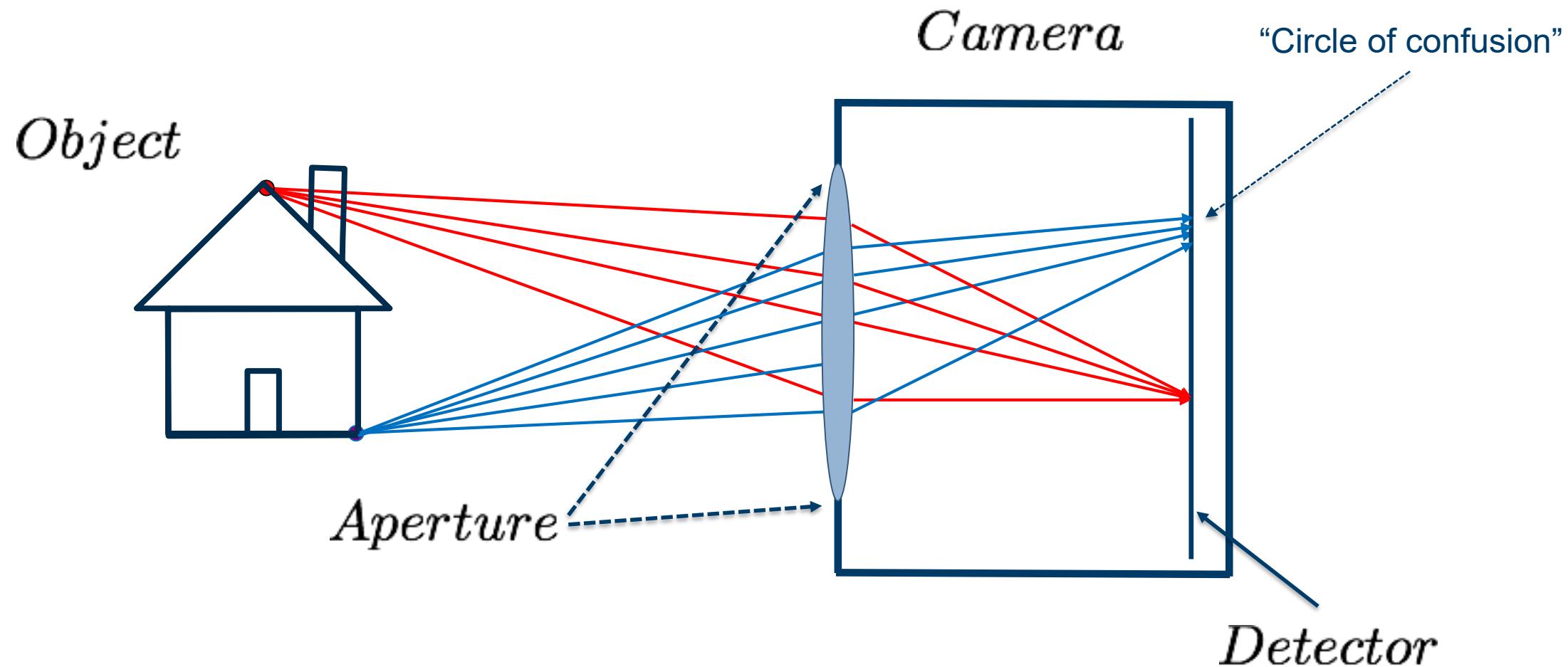
# Camera obscura

illum in tabula per radios Solis , quam in cœlo contin-  
git : hoc est, si in cœlo superior pars deliquiū patiatur, in  
radiis apparebit inferior deficere, ut ratio exigit optica.

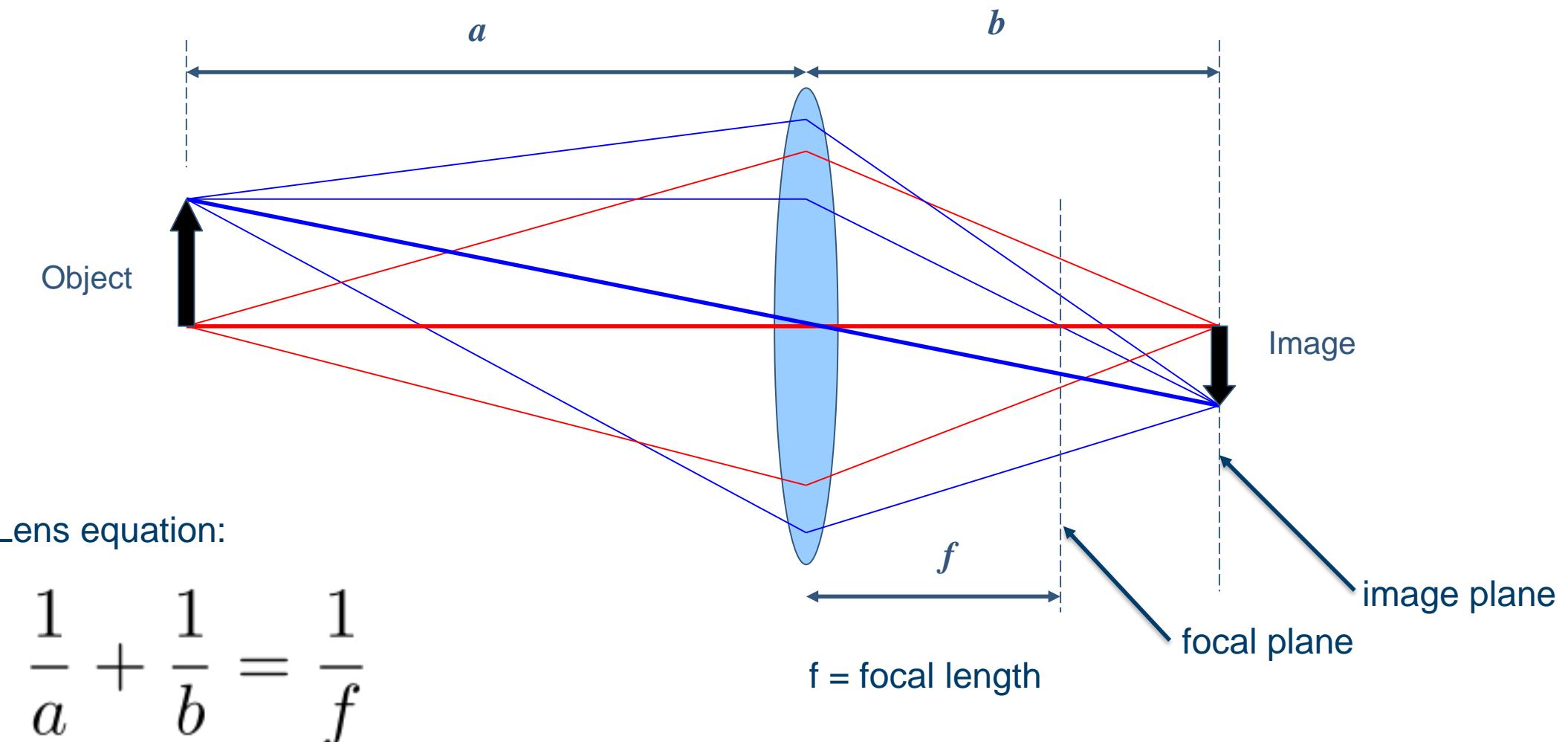


Sic nos exactè Anno .1544 . Louanii eclipsim Solis  
obseruauimus , inuenimusq; deficere paulò plus q̄ dex-

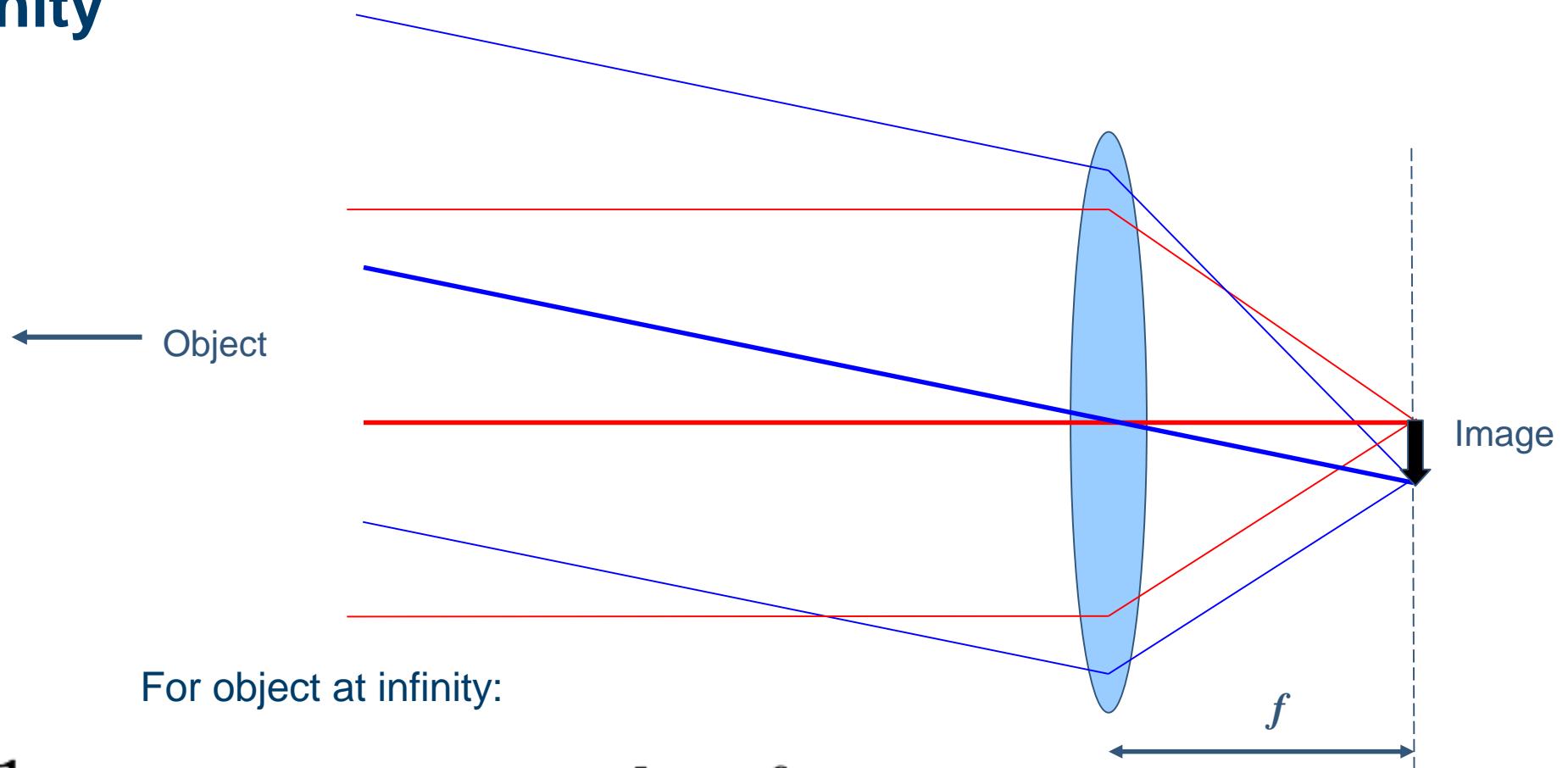
# Camera with a lens



# Imaging with a lens



# Object at infinity



Lens equation:

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

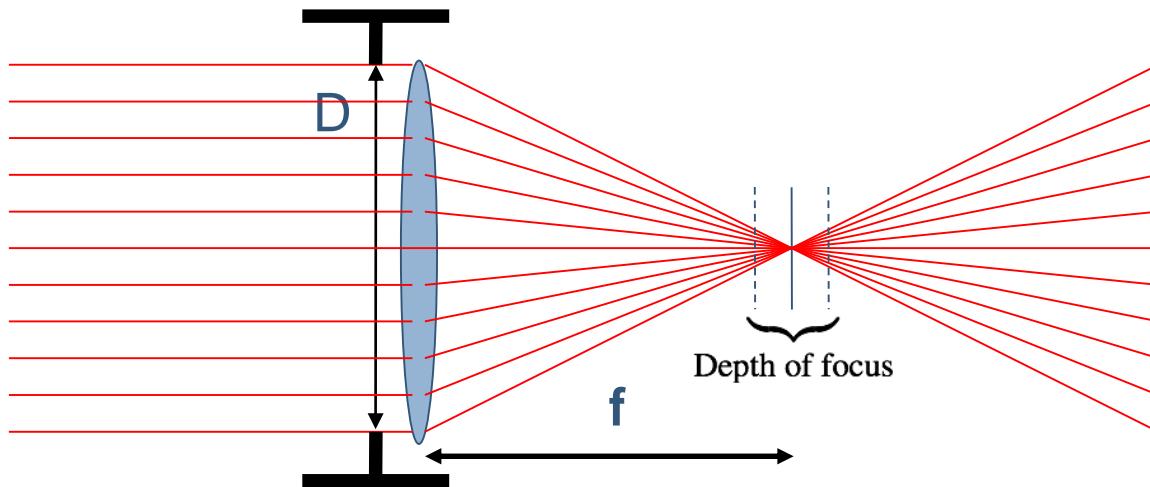
For object at infinity:

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

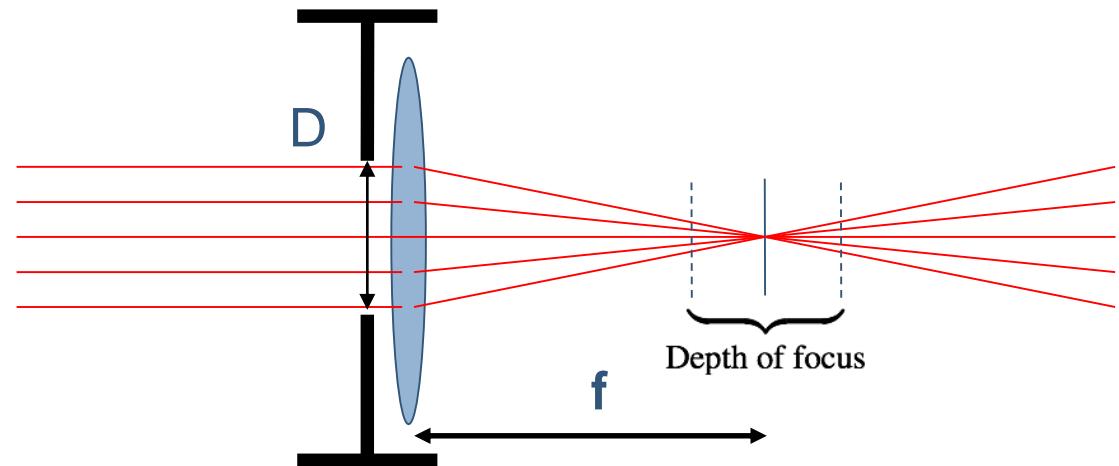
i.e. image is formed in focal plane.

# 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



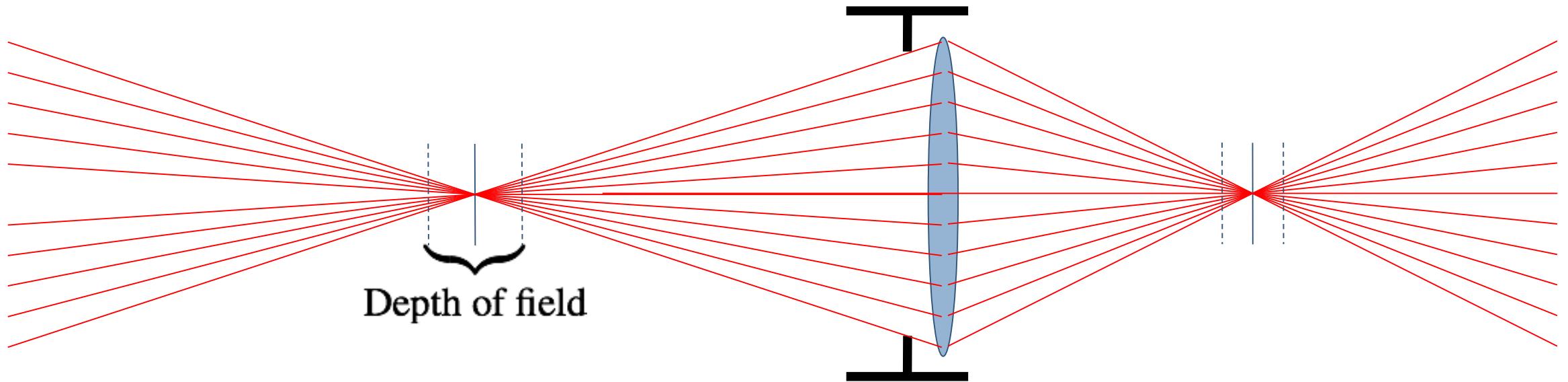
Narrow depth of focus

Large f-number



Large depth of focus

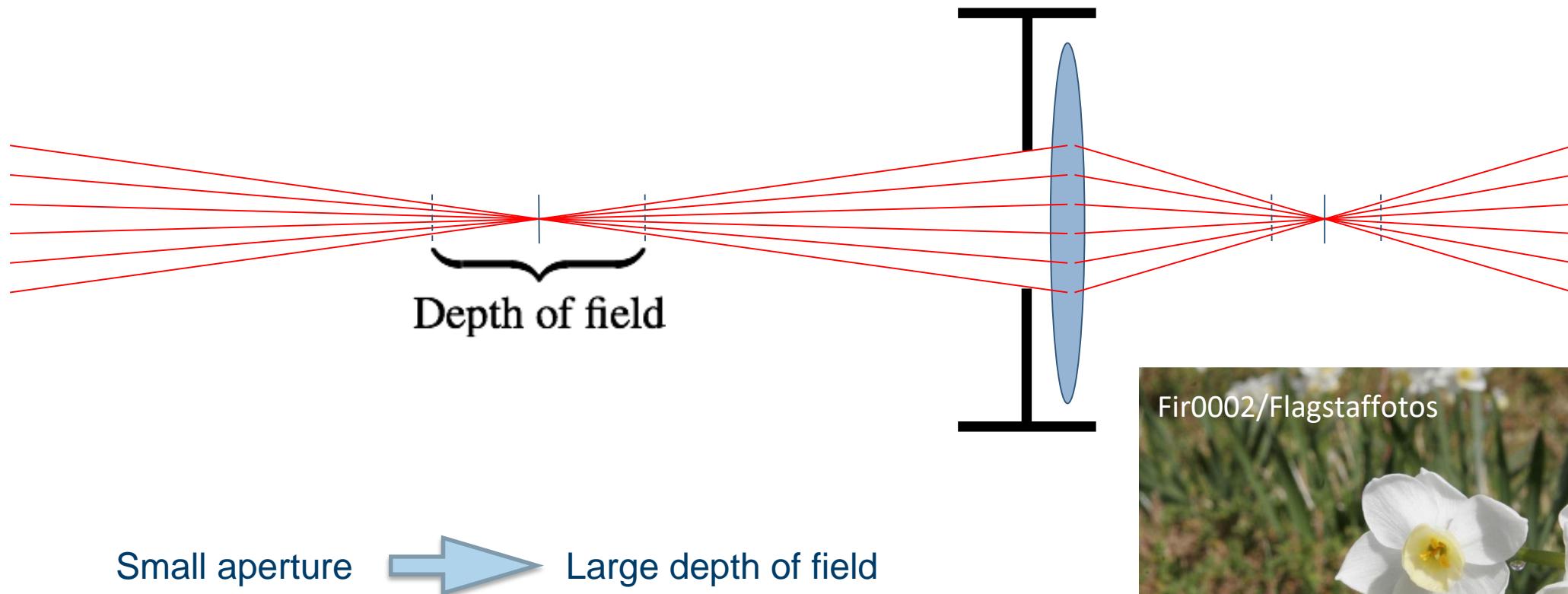
# Depth of field – large aperture



Large aperture → Narrow depth of field



# Depth of field – small aperture



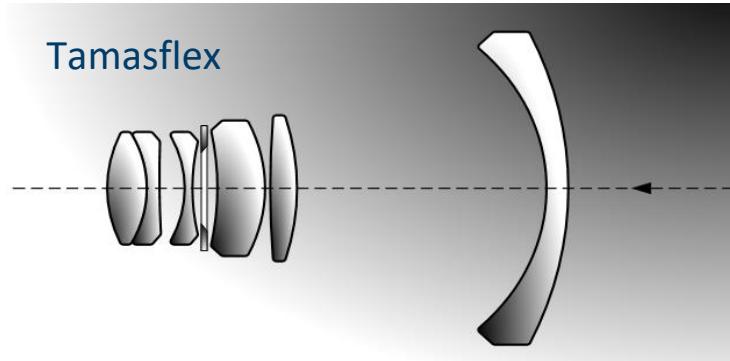
Too small aperture will lead to *diffraction* and loss of sharpness



# Practical lenses

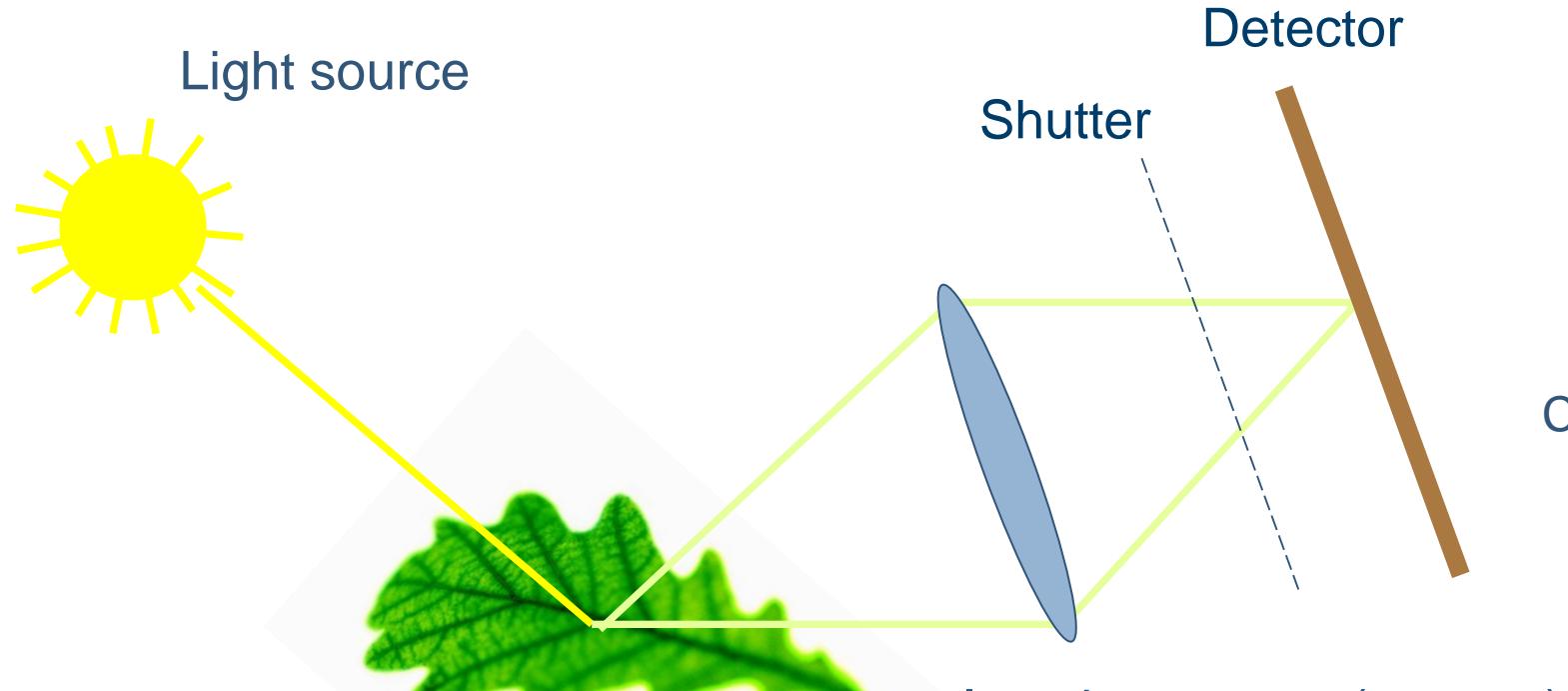


Fixed focal length lens



Zoom lens (variable focal length)

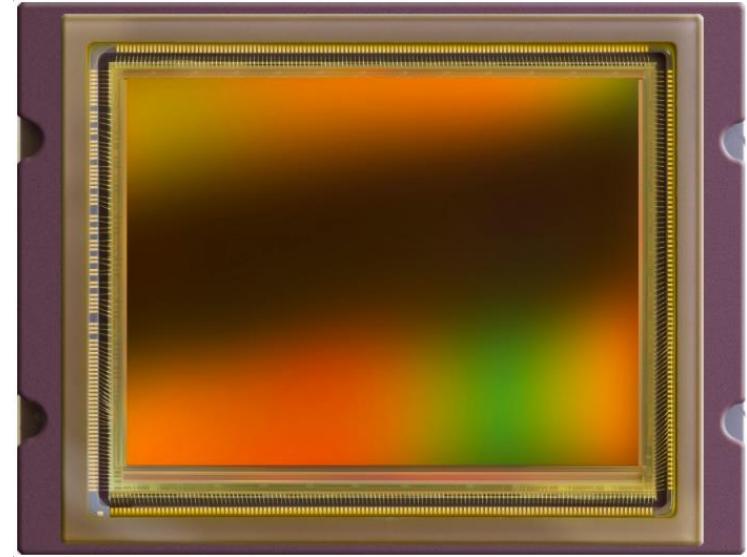
# Image capture



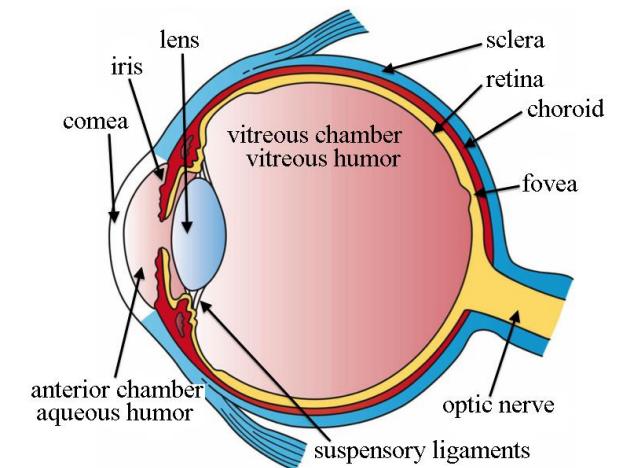
Imaging system (camera)

## Shutter:

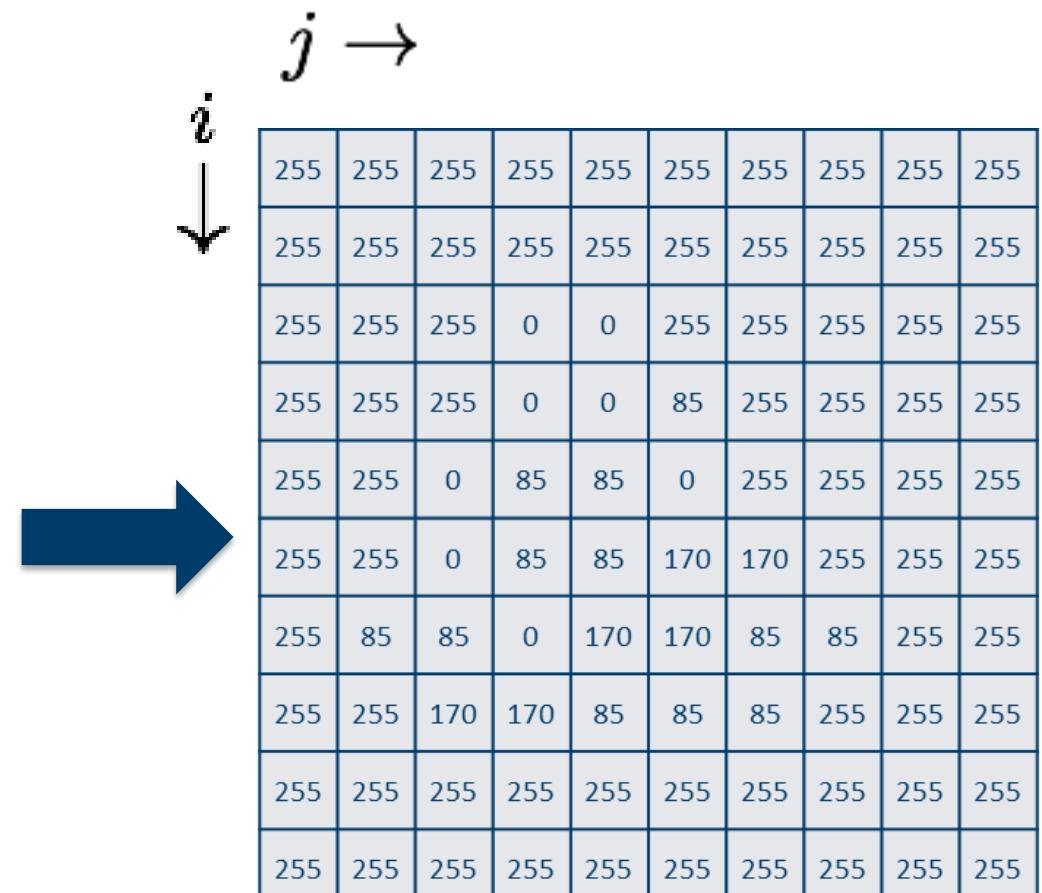
- Mechanical / electronic
- Global / rolling



CMOS image sensor (CMOSIS 48Mp)



# Digital image



$image(i, j)$

# Colour images



RGB colour image

Red



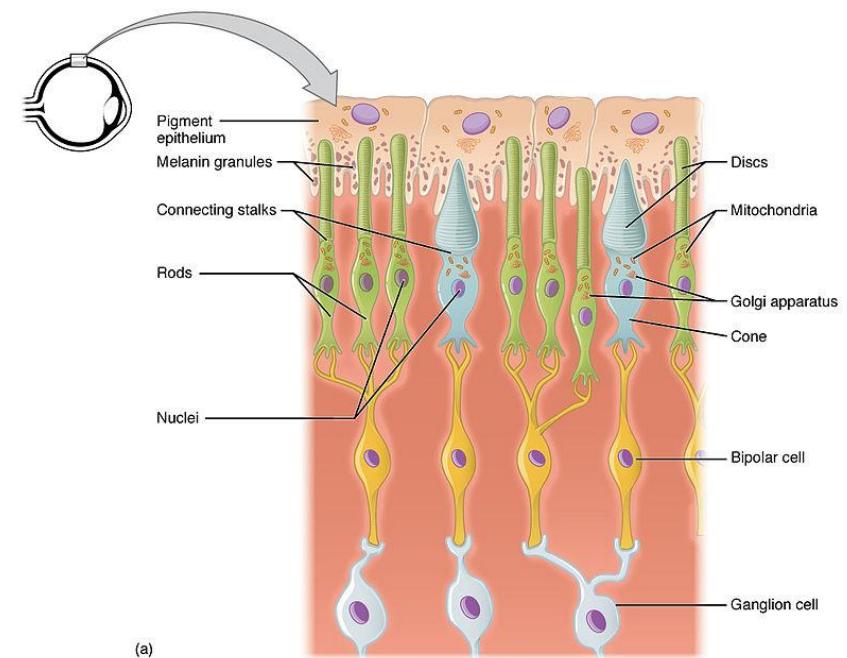
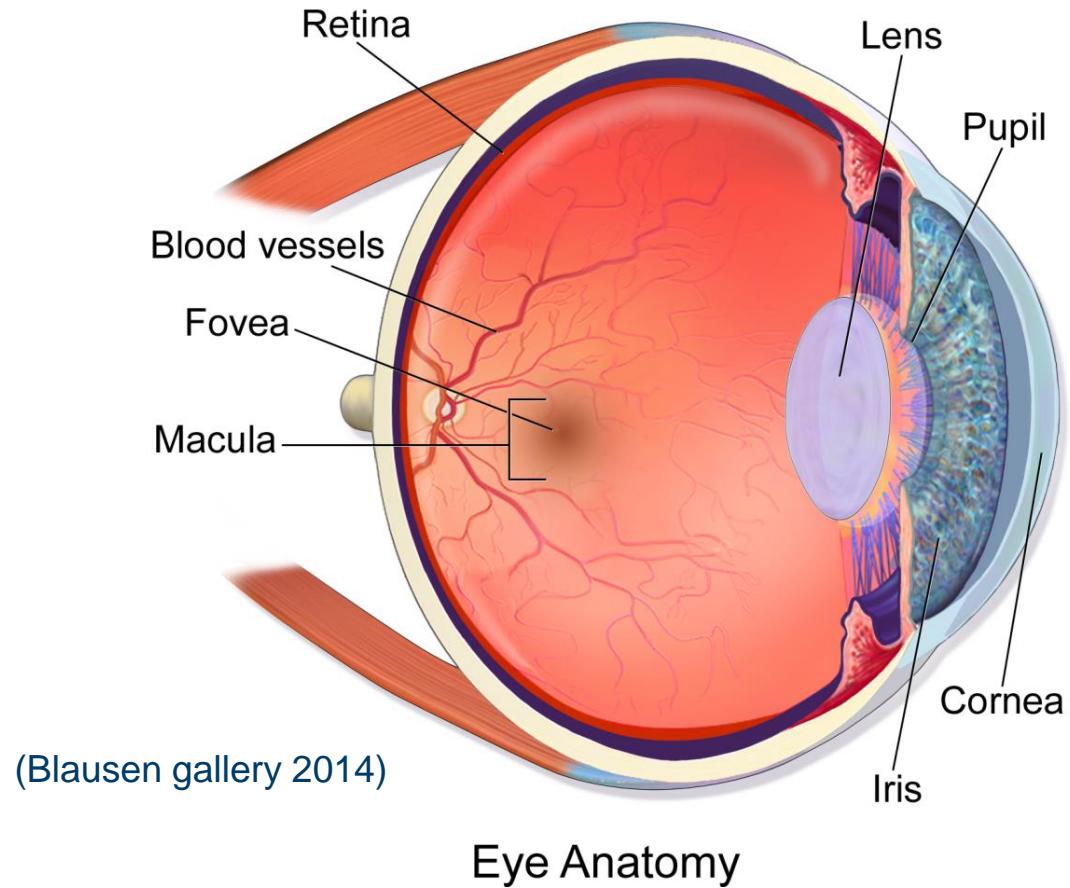
Green



Blue

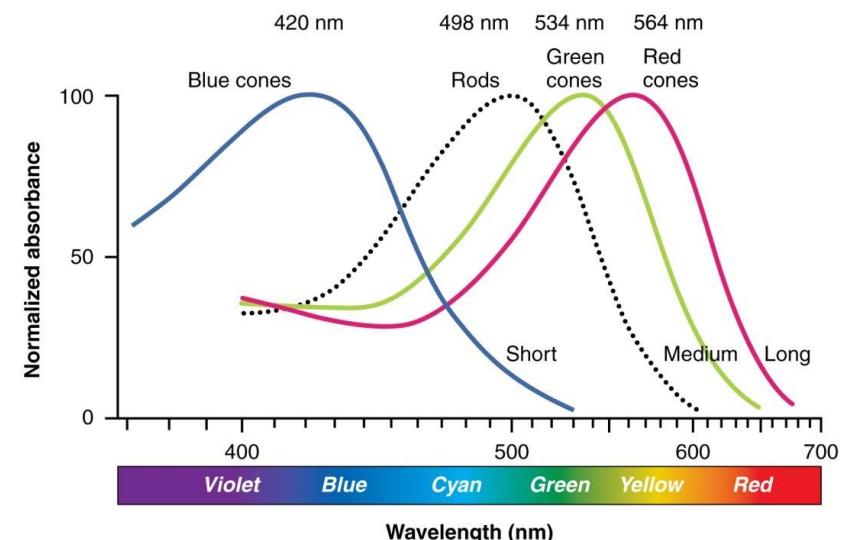


# Human Vision

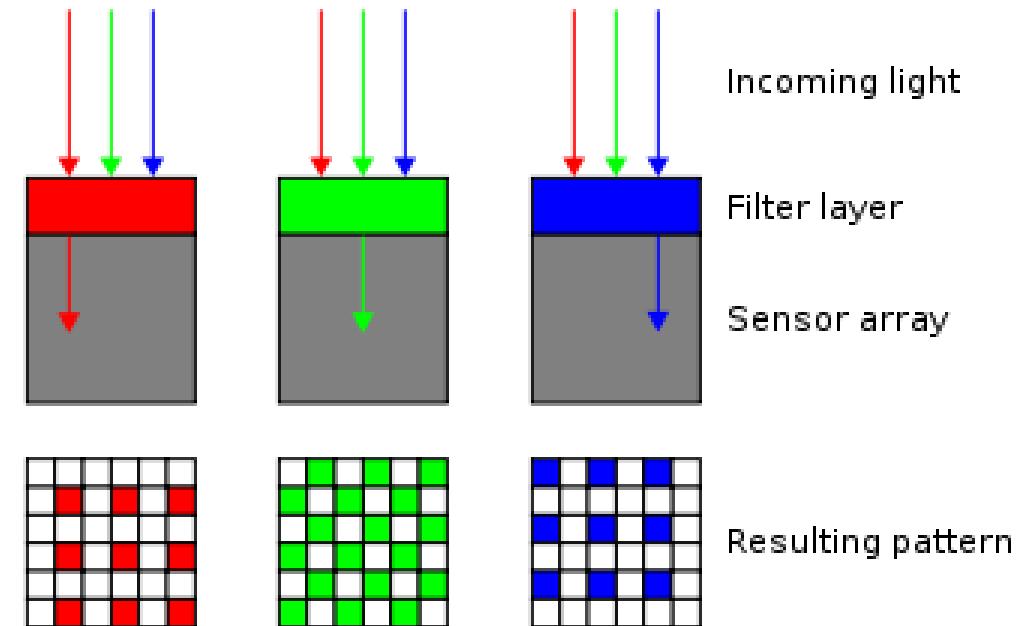
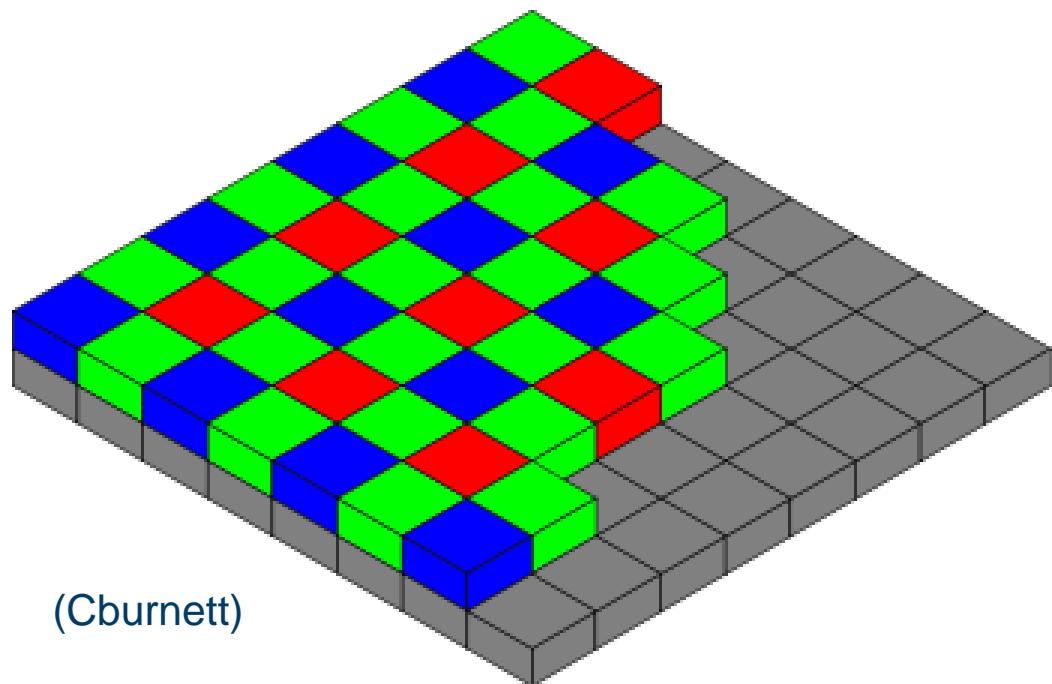


(a)

(OpenStax College - Anatomy & Physiology)



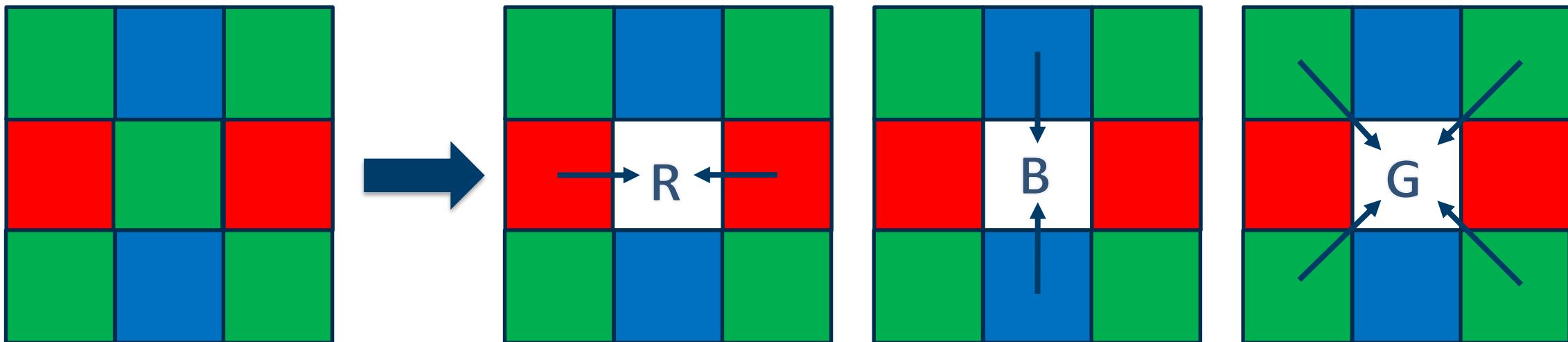
# Colour Sensing in digital cameras - Bayer filter



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:

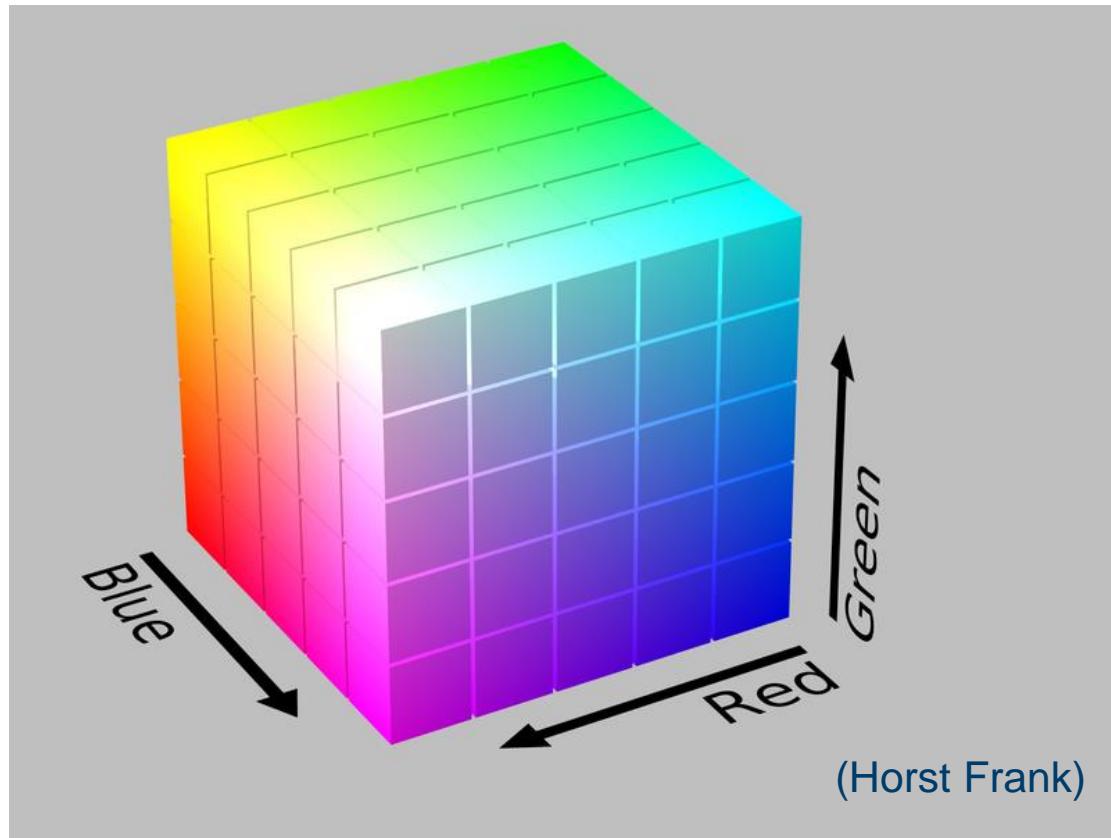
- Splines
- Lanczos resampling
- Methods utilizing pixel values

# Digital representation of colour images

B

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

# RGB colour space



Colour coordinate systems:

Normalized RGB values:

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

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

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

(Illumination invariance)

$RGB \Rightarrow XYZ \Rightarrow LAB$

## RGB normalization (example)

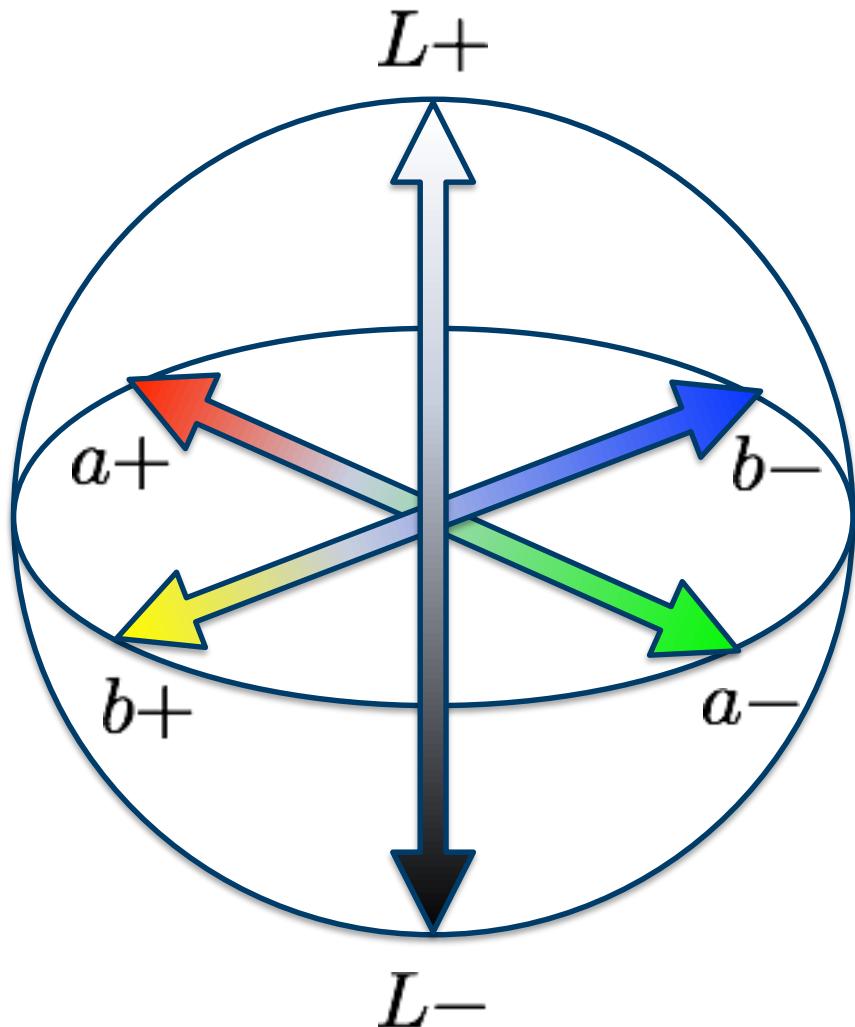


RGB original



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)

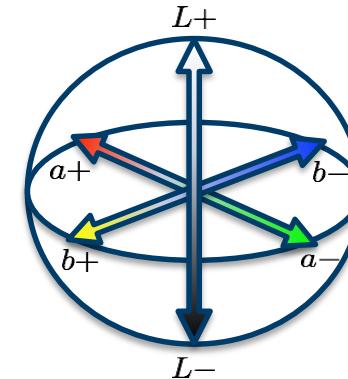
## Lab - example



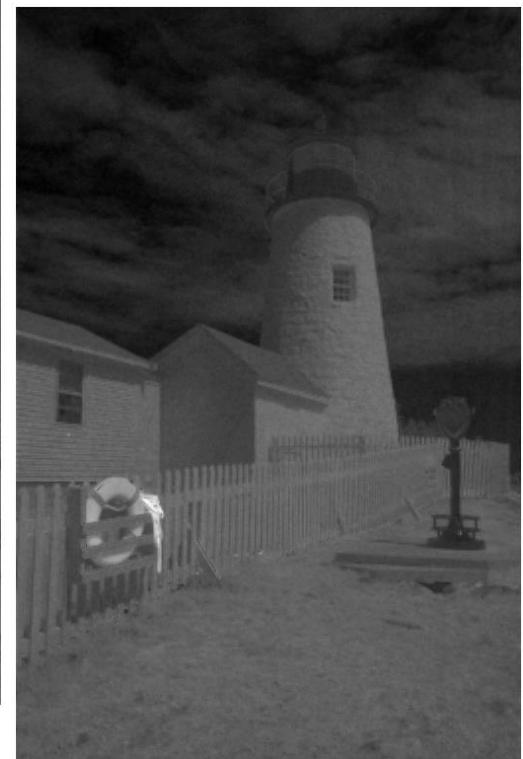
L



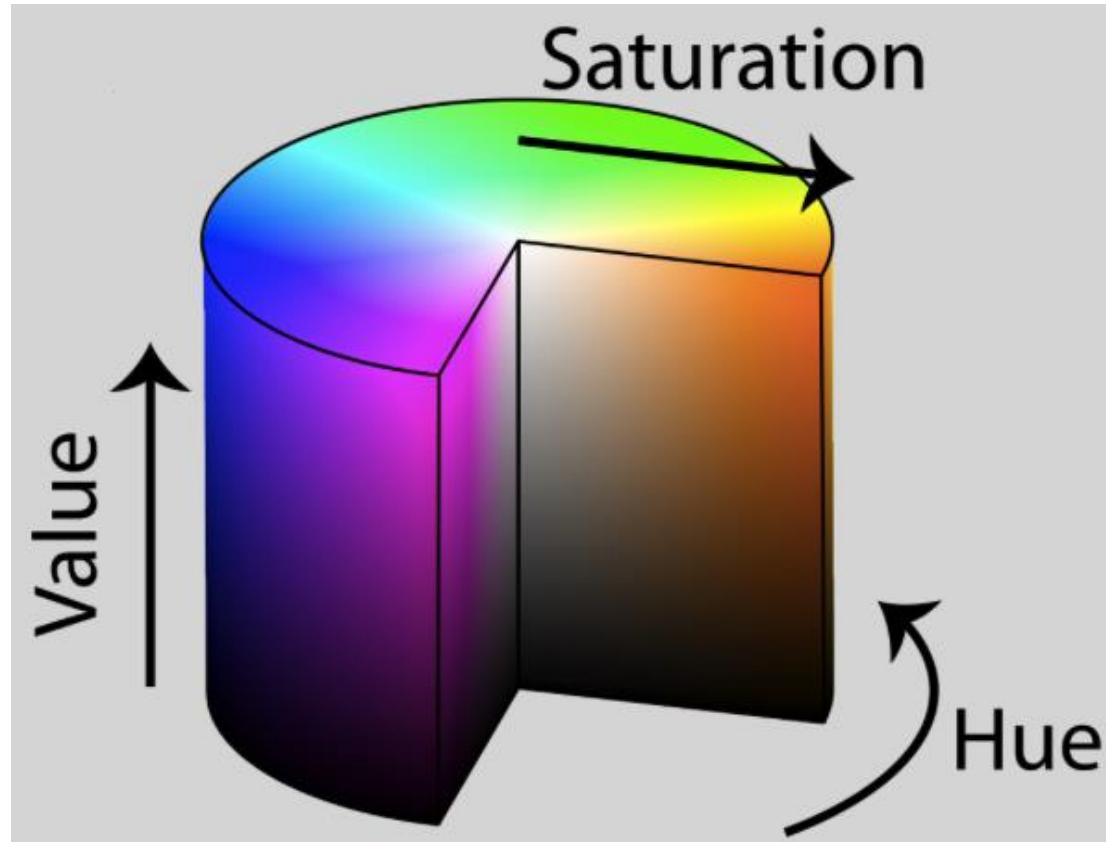
a



b



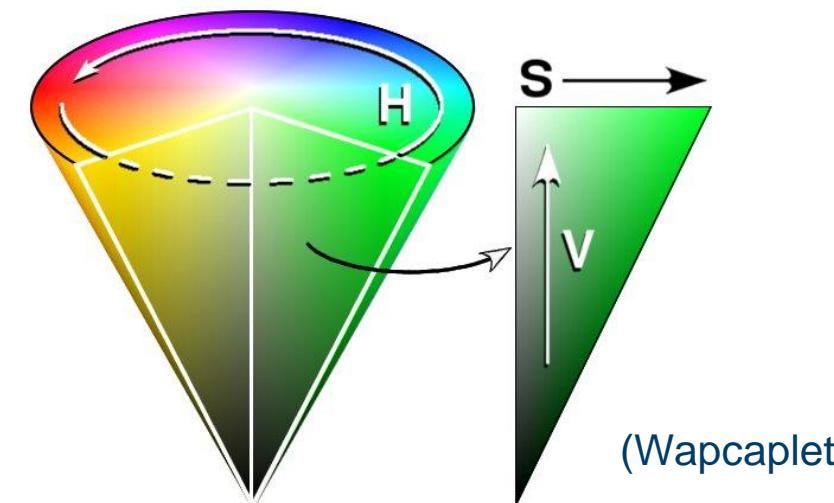
# HSV colour space (Hue, Saturation, Value)



(Jacob Rus, 2010)

## Intuitive colour space:

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

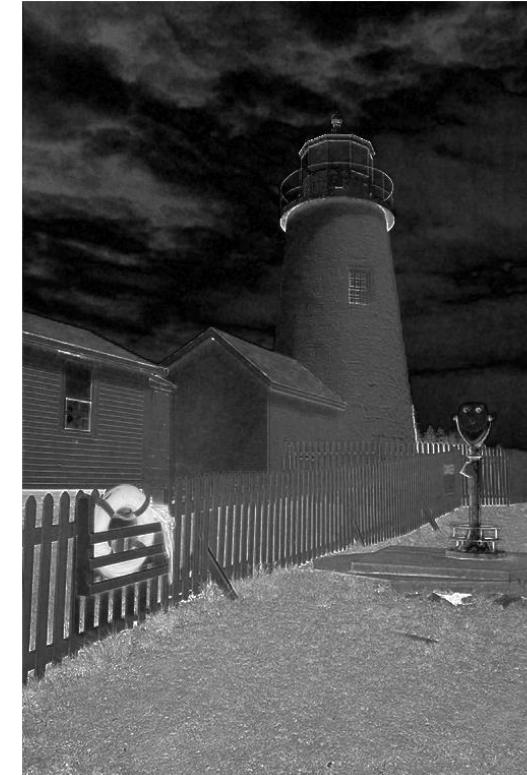


(Wapcaplet)

HSV



Hue



Saturation



Value

# Summary

## Image formation:

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

More information: Szeliski 2.2 and 2.3

