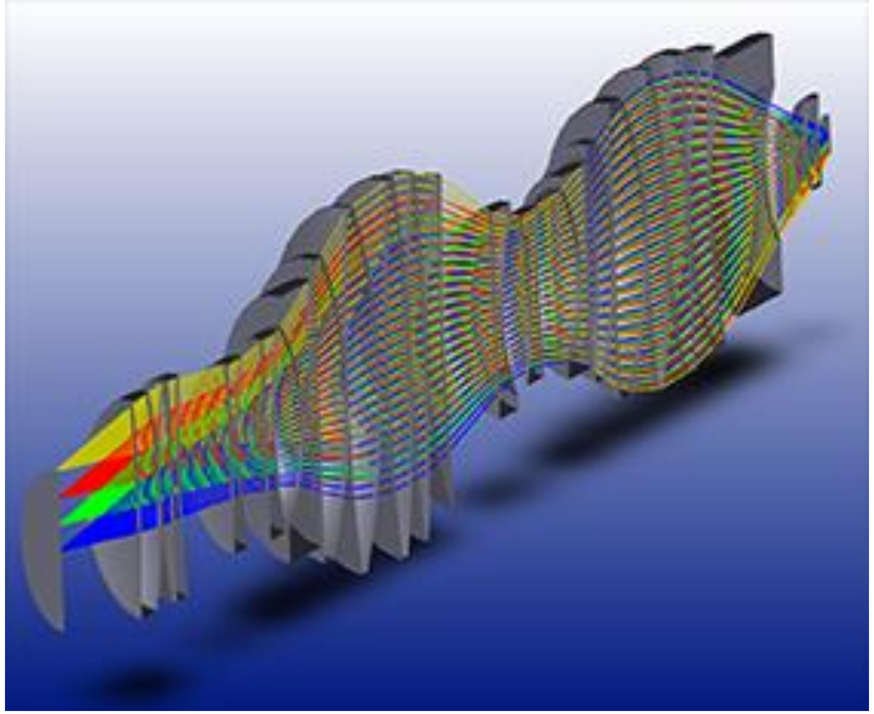
# Introduction to Optical System Design



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# Resources

**Course Web Page:**

http://www1.gantep.edu.tr/~bingul/zemax

**Books:**

http://www1.gantep.edu.tr/~bingul/zemax/OD.zip

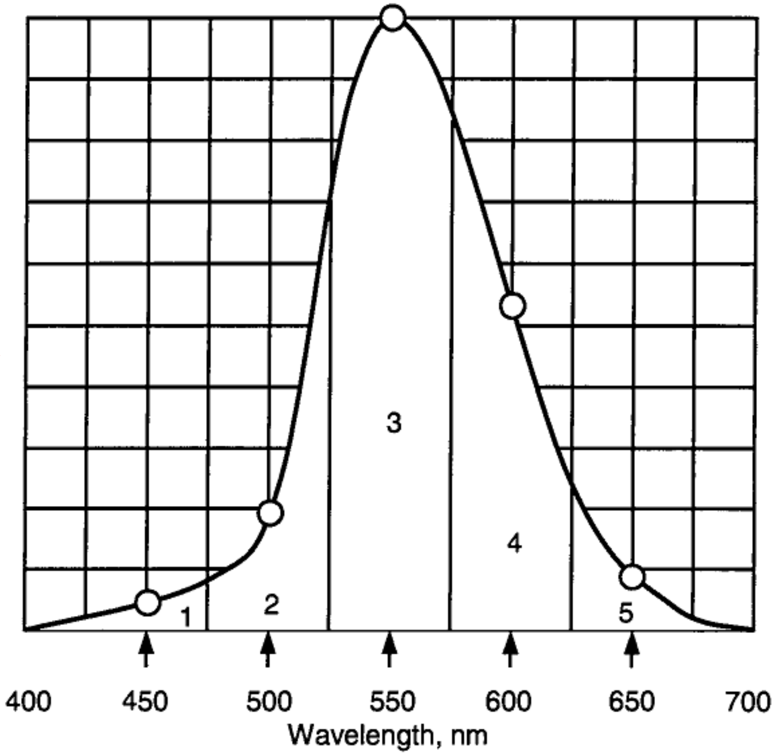
# Electromagnetic Spectra

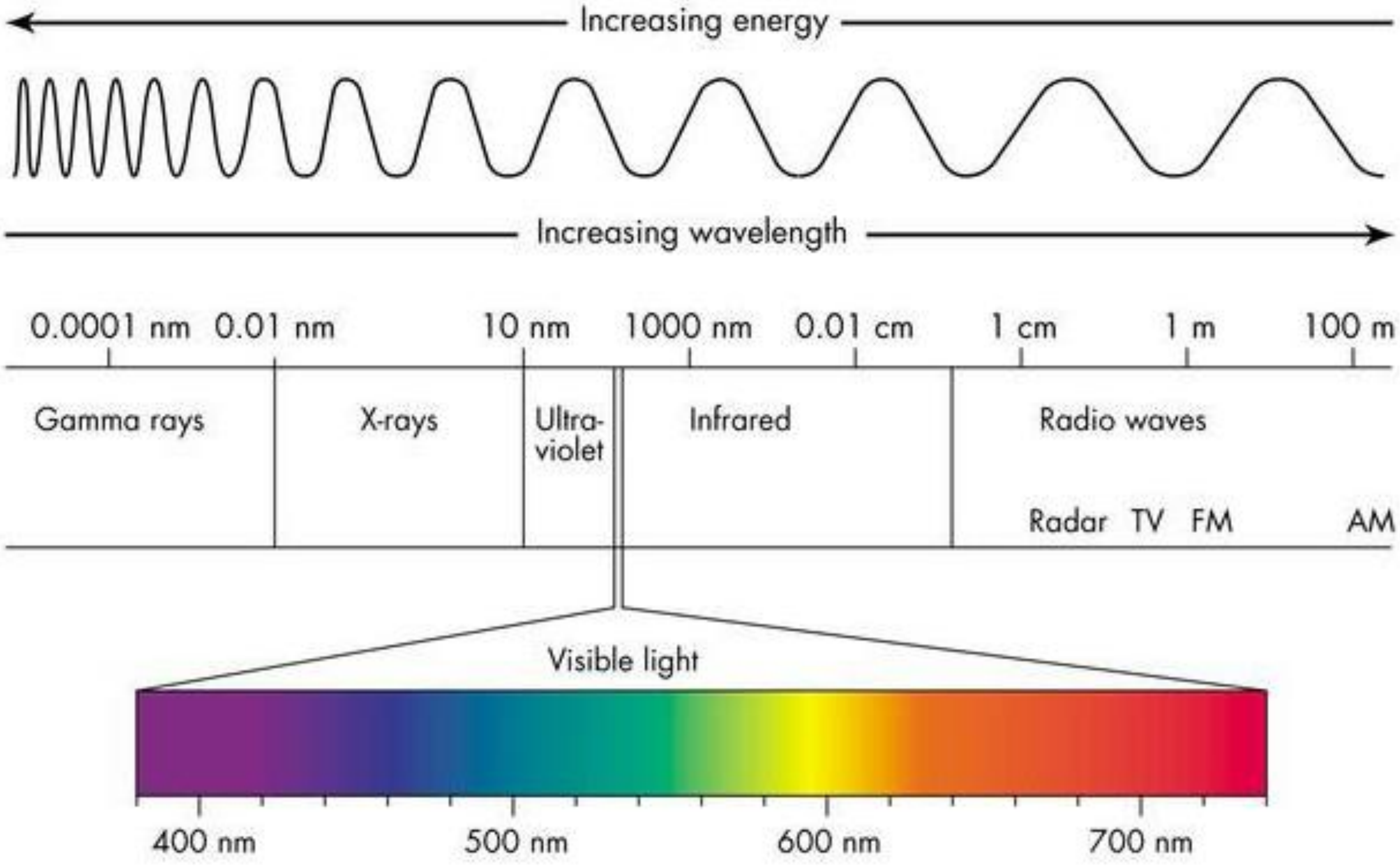
Optics is a branch of physics. It is the science of light.

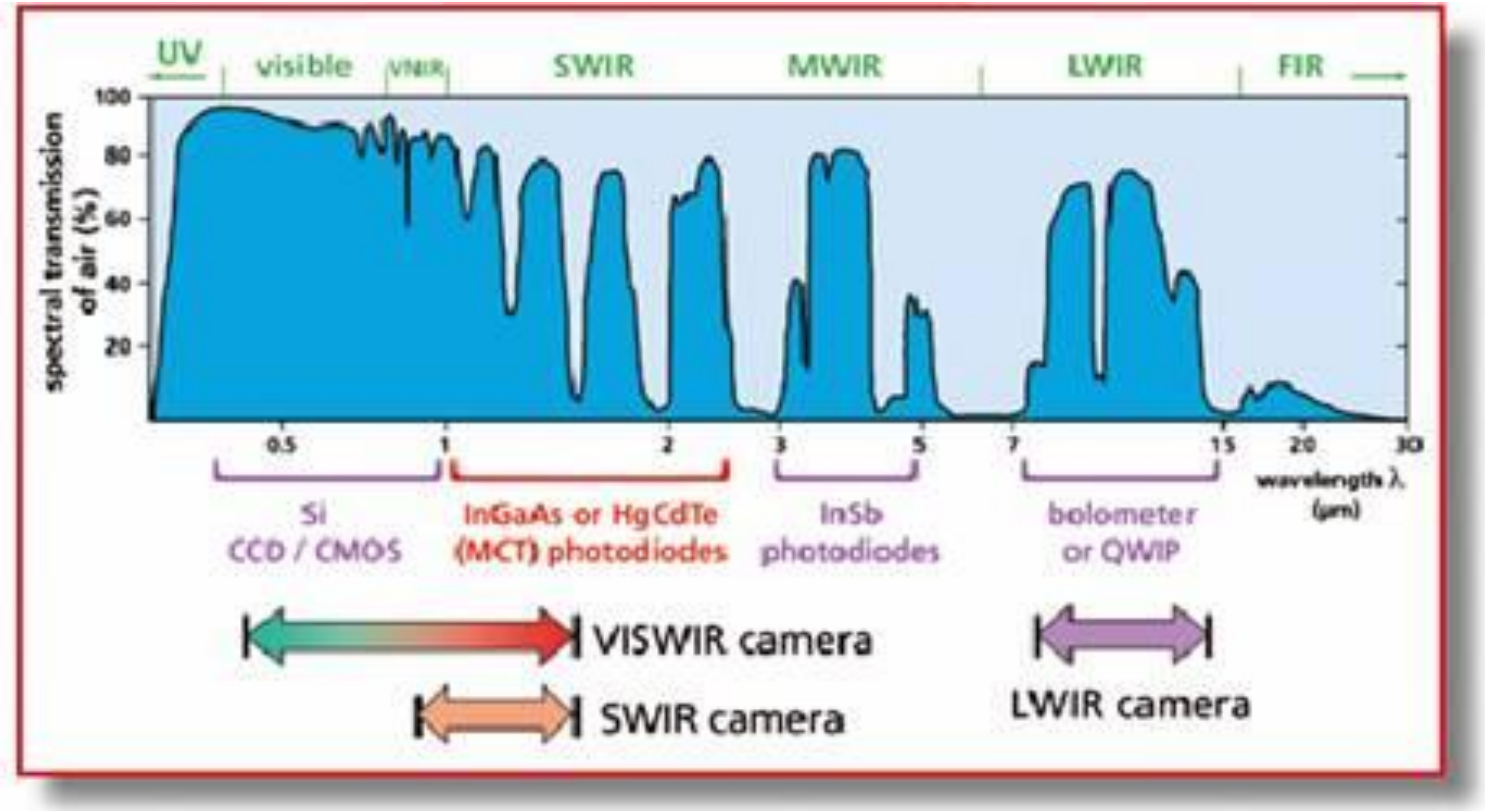
It covers the wavelength (λ) range of electromagnetic spectrum from 10 nm to 1 mm.

- **Ultraviolet UV: λ = (0.01 μm, 0.380 μm)**
  - UV-A (0.380-0.315 μm)
  - UV-B (0.315-0.280 μm)
  - UV-C (0.280-0.010 μm)
- **Visible, VIS: λ = (0.380 μm, 0.750 μm)**
- **Infrared, IR: λ = (0.750 μm, 1000 μm)**
  - Near IR [NIR] : (0.75 - 0.9 μm)
  - Short-Wavelength IR [SWIR]: (0.9 - 1.7 μm)
  - Mid-Wavelength IR [MWIR]: (3-8 μm)
  - Long-Wavelength IR [LWIR] : (8-15 μm)
  - Far Infrared [FIR]: (15-1000 μm)

Spectral Sensitivity of Eye

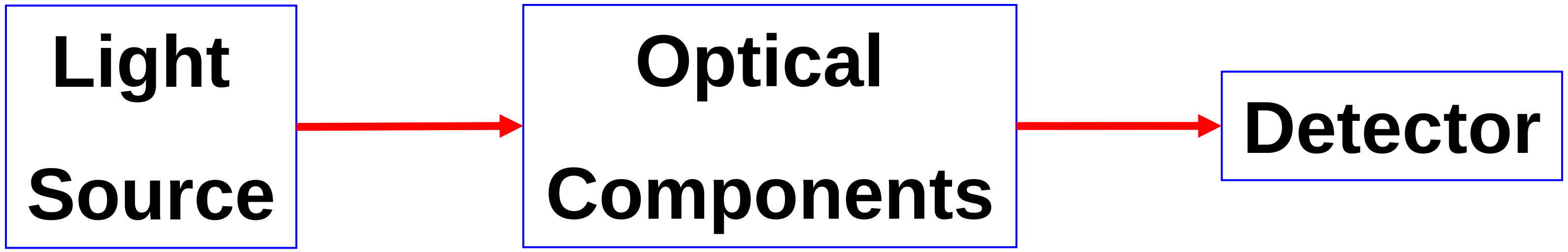



Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-
violet
Infrared
Radio waves
Radar
TV
FM
AM
Visible light
400 nm
500 nm
600 nm
700 nm


UV
visible
VNIR
SWIR
MWIR
LWIR
FIR
spectral transmission of air (%)
100
80
60
40
20
0.5
1
2
3
5
7
15
20
30
wavelength λ (µm)
Si
CCD / CMOS
InGaAs or HgCdTe
(MCT) photodiodes
InSb
photodiodes
bolometer
or QWIP
VISWIR camera
SWIR camera
LWIR camera

# Optical System

There are mainly three components of an optical system:



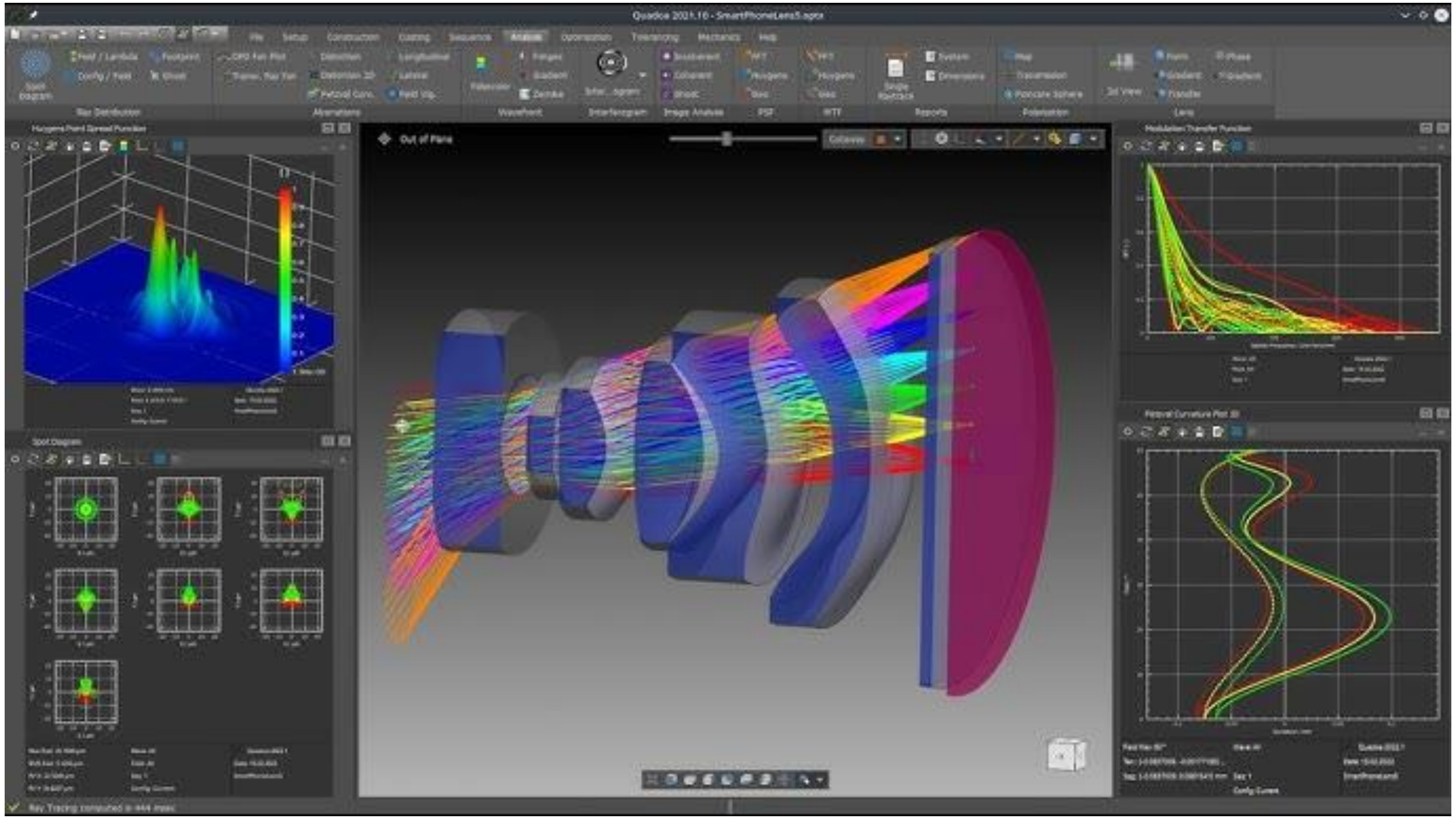

*Laser*
*LED*
*Lamb*
*Star*
*Heat Source*
*Scenery*
*…*

*Lens*
*Mirror*
*Prism*
*Grating*
*Polarizer*
*…*

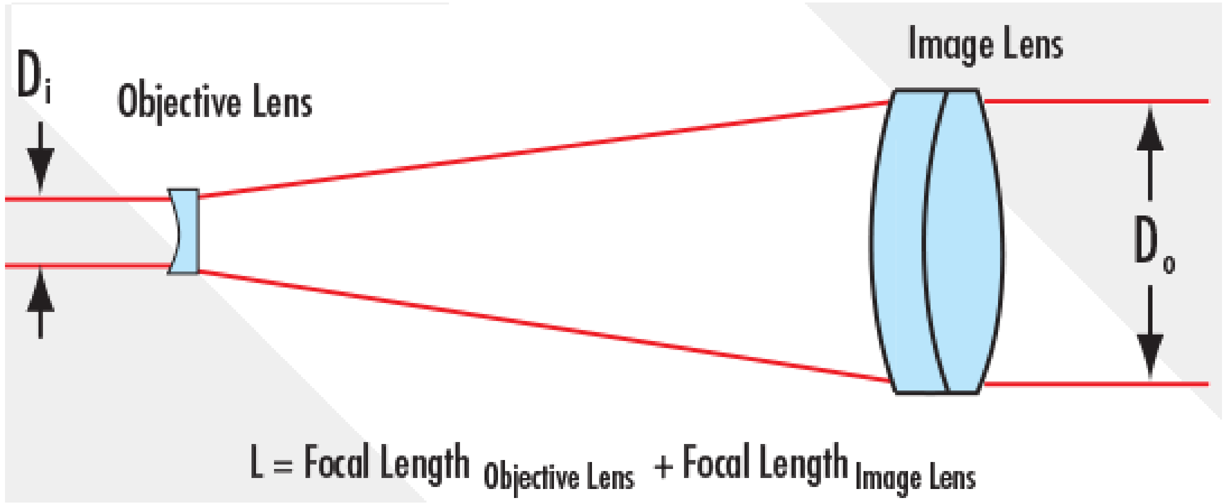
*Eye*
*CCD*
*CMOS*
*Photo Diode*
*Wall*
*…*

# Optical System Design

- Optical Design is the process of designing optical components to meet a set of performance requirements and constraints, including cost and manufacturing limitations.

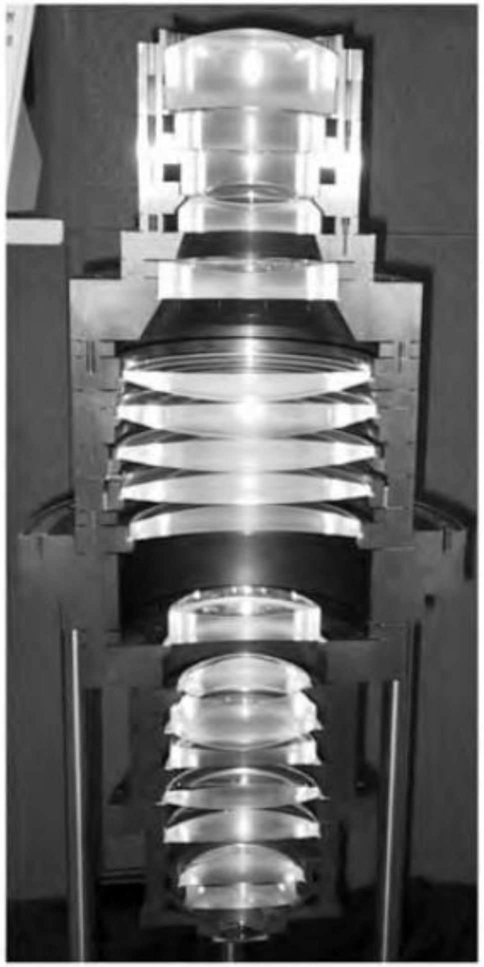


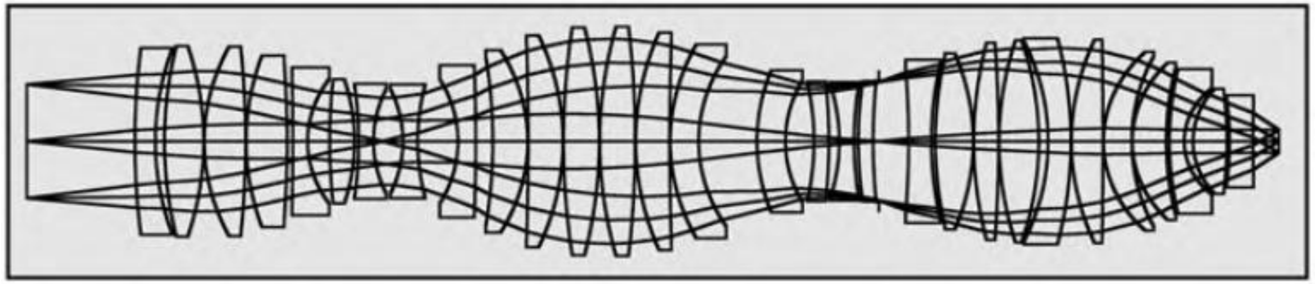
A system may contain a few lenses like a beam expander




or many lenses!

*This is a 30-Element Lithography Lens from the Patent Literature*

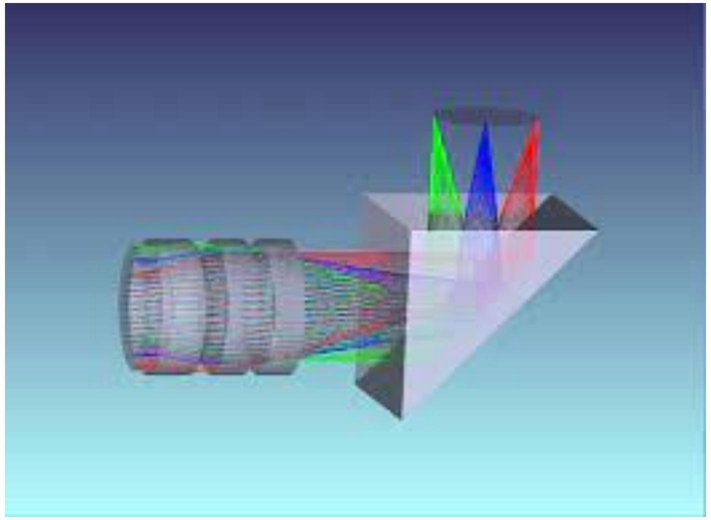


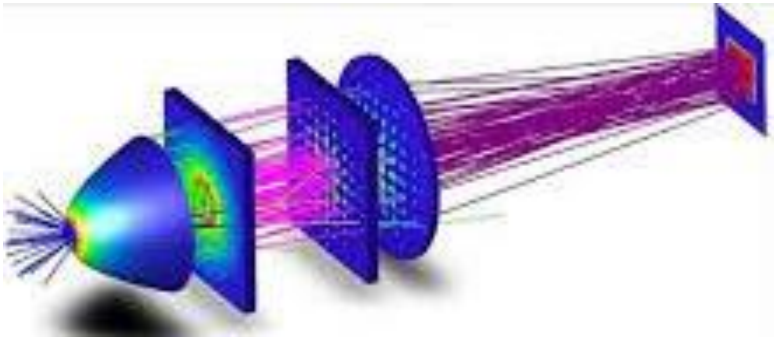
# Types of Optical System

There are two categories:

- **Imaging Optical Systems**
  is concerned with resolving a specified minimum-sized object over a desired field of view.
  Main goal is to form sharp images.
  - Camera
  - Telescope
  - Microscope

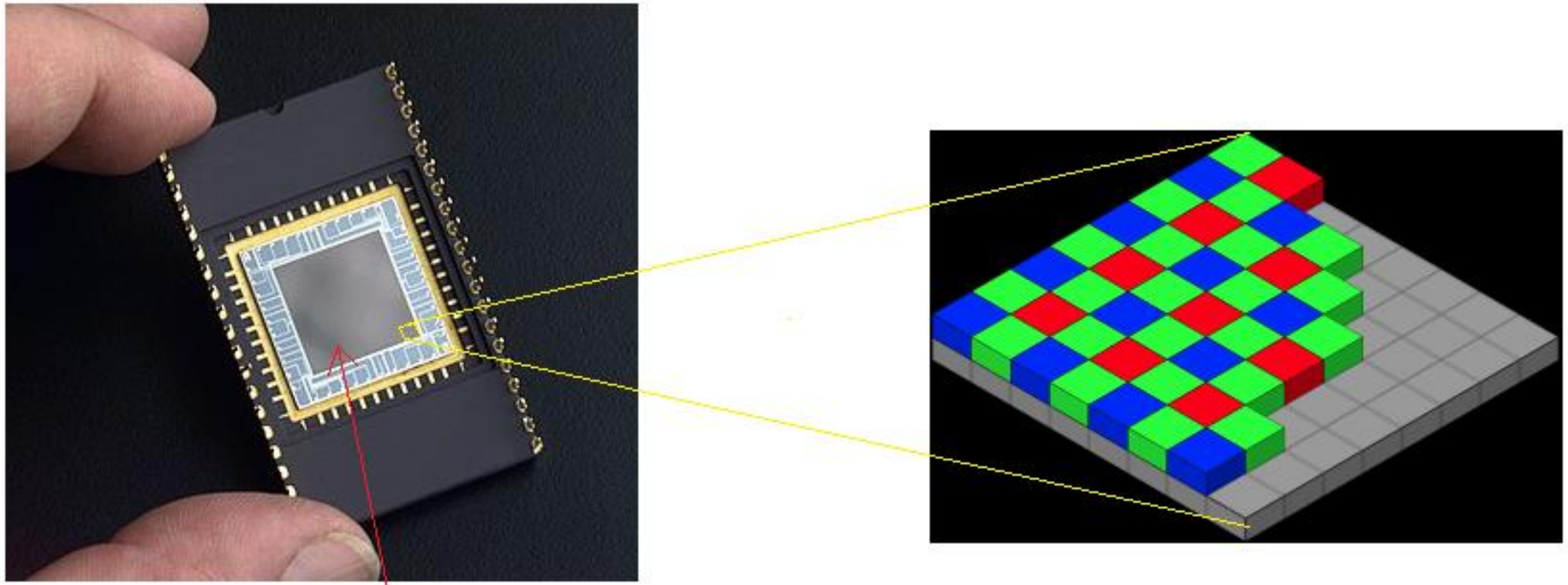


- **Non-imaging Optical Design**
  is concerned with the optimal transfer of light radiation between a source and a target.
  - Tunnel, Street or Automotive illumination
  - Focusing Sun Energy
  - Free-Form Lens Design



# Detectors

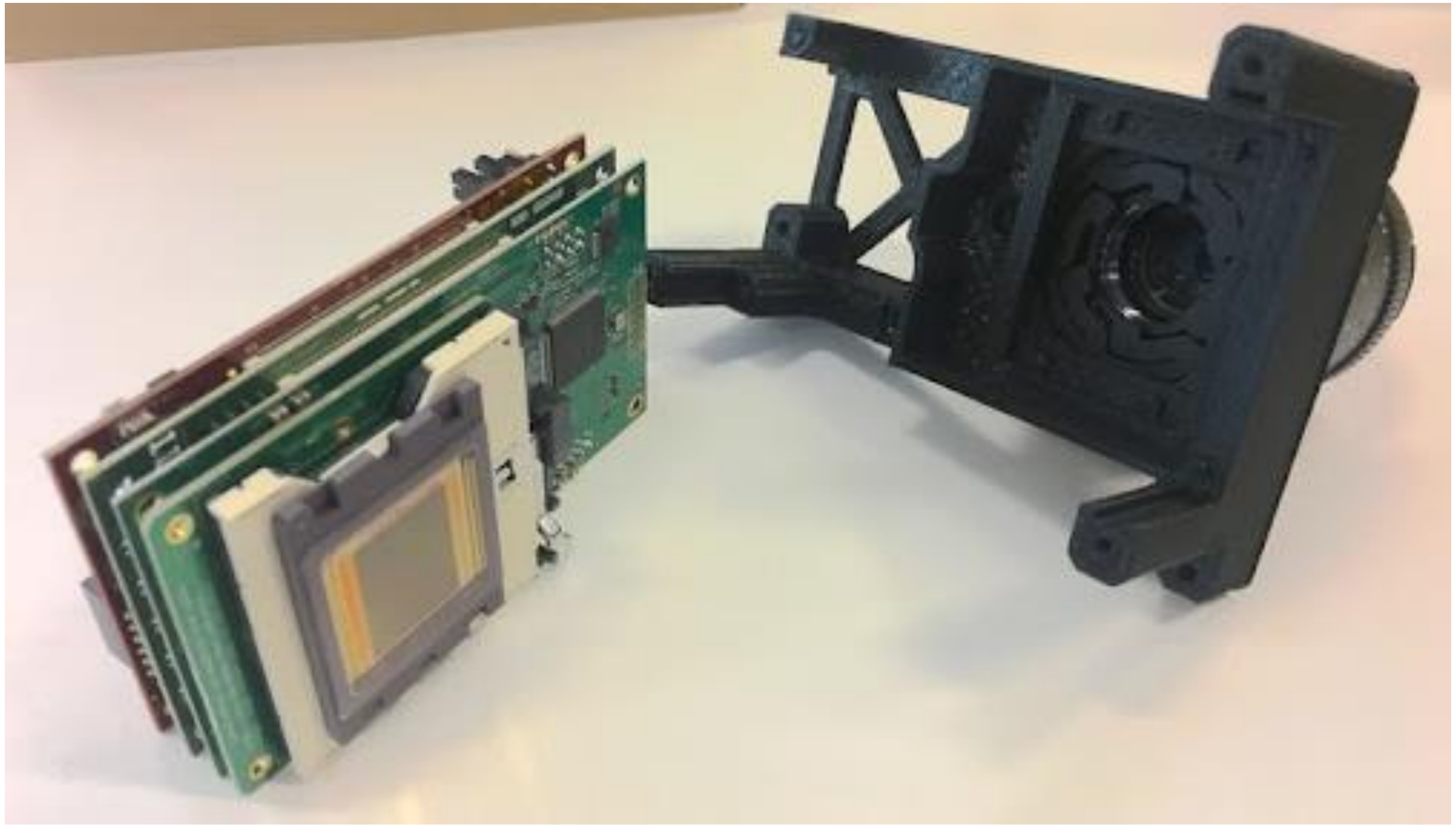
- Final element of an imaging system can be Eye, CCD, CMOS sensor or photodiode.



*There are many phostodiodes as in matrix form*

# Detectors

The first step of the system engineering for an electro-optic camera development is **selecting a proper imaging sensor** according to the mission requirements.
(In general, imaging sensor specification is a leading input for an optical design)

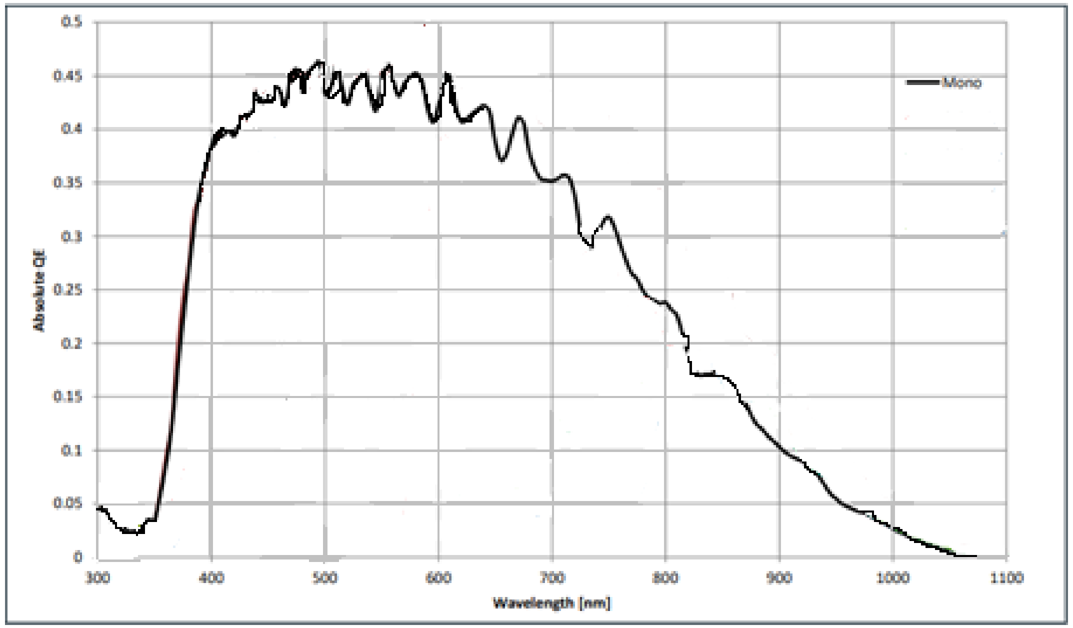


# e.g. Osram CMV12000 CMOS Image Sensor

## Specifications:

| Parameters | Symbol | Value |
|---|---|---|
| Detector Type | - | CMOS |
| Pixel Pitch | $p$ | 5.5 µm |
| Spectrum | λ | 450 - 700 nm |
| Quantum Efficiency (@500 nm) | $QE$ | >46% |
| Dimension | Pixel x Pixel | 4096(H) X 3072 (V) |
| | | 22.5($H'$) X 16.9 ($V'$) |
| Readout Noise | $\sigma_{read}$ | 13 ē |
| Full Well Charge | $N_{FWC}$ | 13,500 ē |
| Modulation Transfer Function | $MTF$ | 58% |

## Quantum Efficiency*




**QE represents the ratio of the number of incident photons that are transformed into electrons concerning the wavelength*



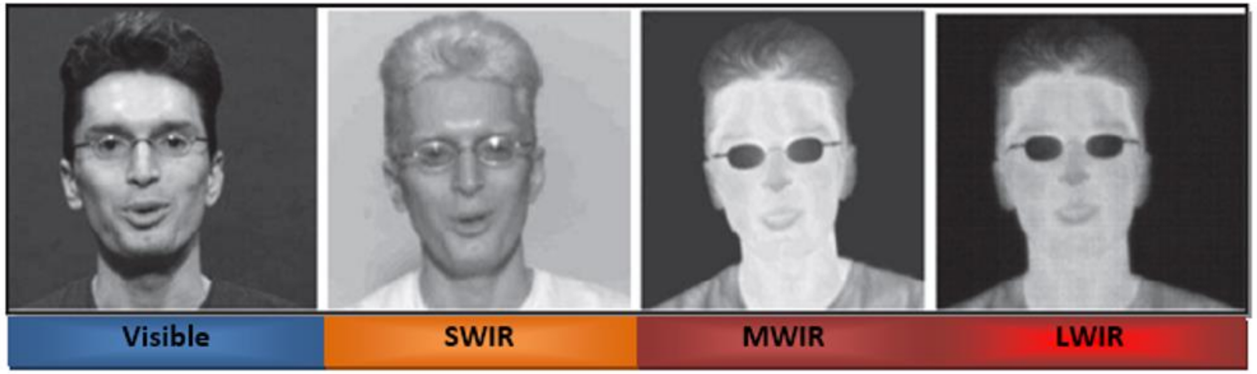
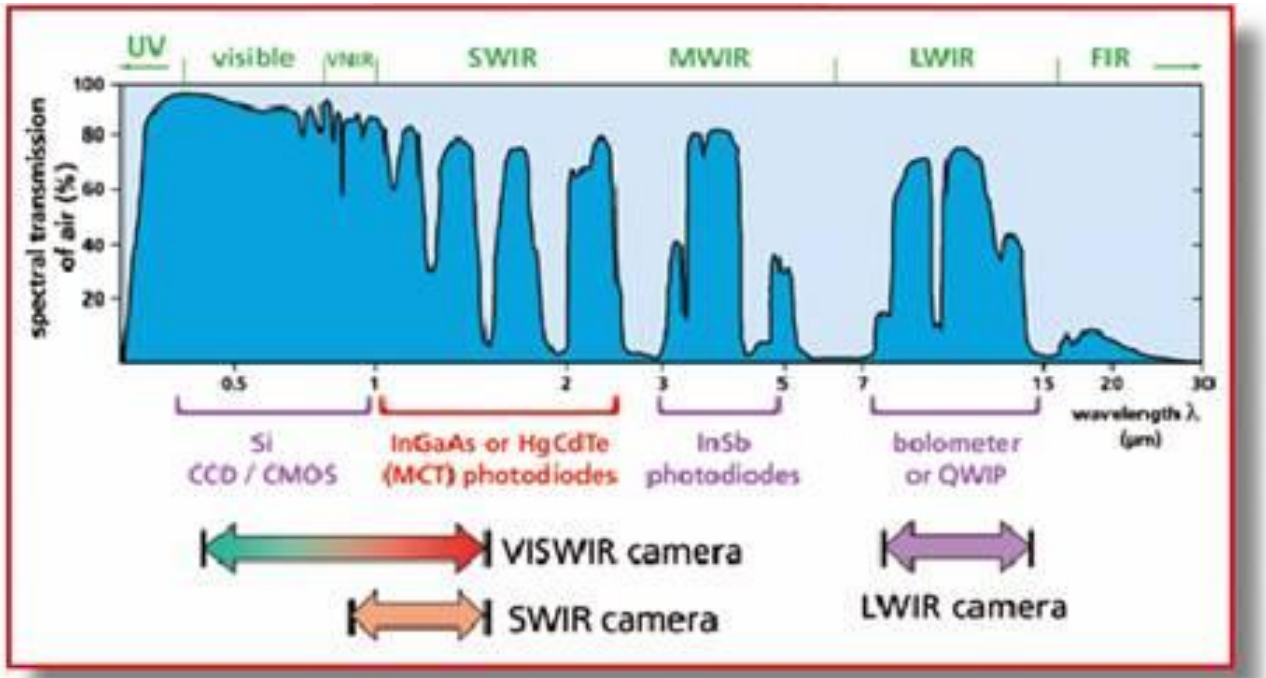
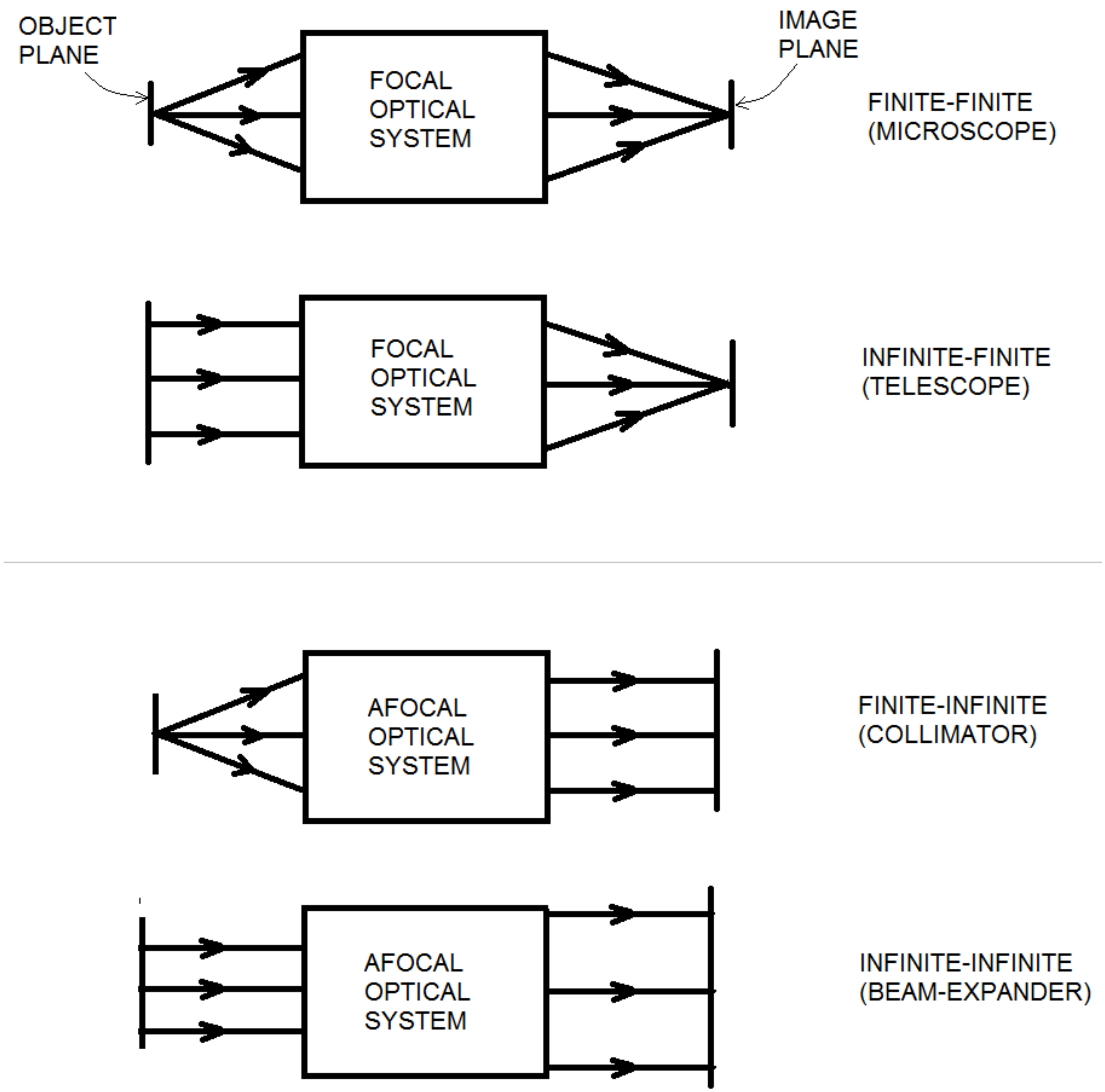




Figure 4 Example of a visage in differents ranges



# Generalized Imaging Systems



# Specifying the Image Quality

*The following list contains some of the more common ways of specifying the image quality.*
*Each of  these will be discussed later.*

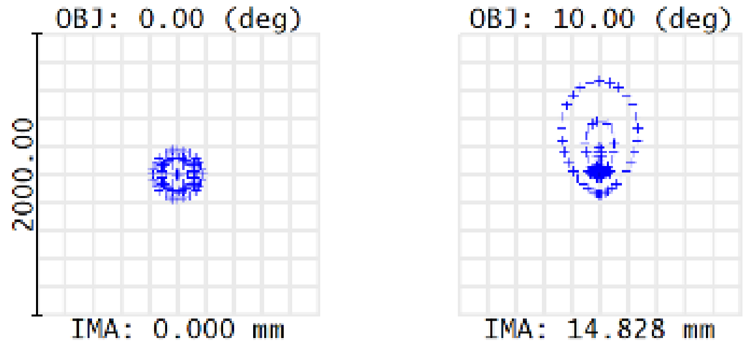
- **RMS blur diameter**
  The diameter of a circle containing approximately 68% of the energy imaged from a point source.

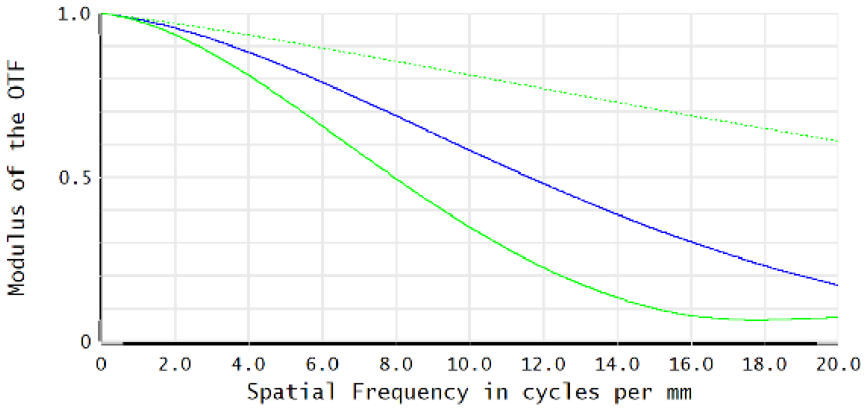
- **Modulation transfer function (MTF)**
  The modulation (contrast) versus the number of line pairs per millimeter in the image.

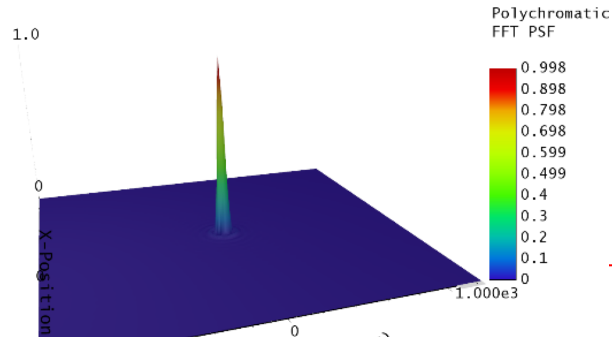
- **Encircled energy (or ensquared energy)**
  The diameter of a circle (or side of a square such as a pixel) containing a given percent of energy.

- **Root-mean-square (rms) wavefront error**
  The rms departure of the real wavefront from a perfect wavefront.

- **Other**
  Depending on the functional requirements of the system, there may be other performance requirements relating to image quality, for example, point spread function (PSF), control of specific aberrations, etc.

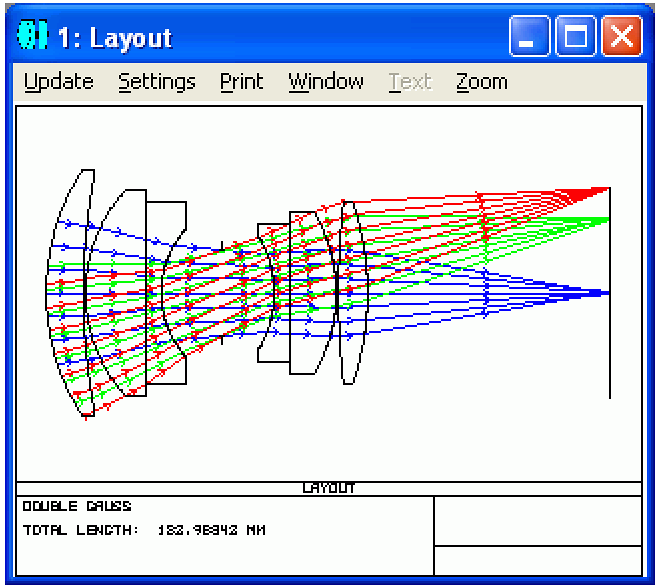


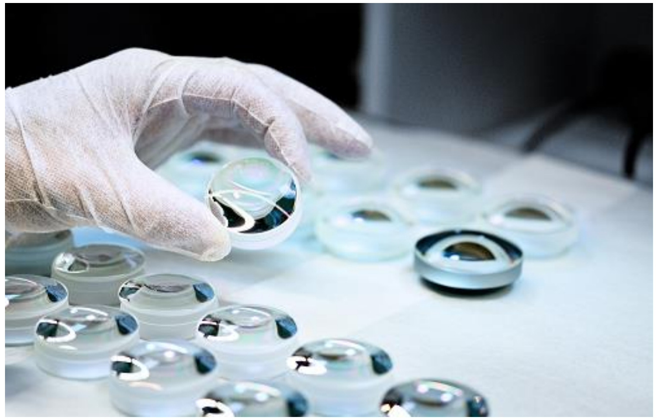



# Summary of Optical Design Steps

1. Define the problem
2. Determine pre-design (detector, componets, etc)
3. Select starting point (design form, patent, etc)
4. Perform initial analysis (implement your starting issues)
5. Optimize the system (use software)
6. Fulfill final analysis (thermal, tolerencing, mechanical)
7. Prepare for fabrication



## Some Reference Books


1. R. E. Fischer, **Optical System Design**, Mc Graw Hill 2nd Ed (2008)
2. R. Kingslake, **Lens Design Fundamentals**, Spie Press 2nd Ed (2010)
3. D. C. O'Shea, **Elements of Modern Optical Design**, John Wiley (1985)
4. J.M. Geary, **Lens Design**, Willmann-Bell, Inc (2002)


## News

1. Optical Society of America (OSA)
   https://www.osa.org
2. Applied Optics
   https://opg.optica.org/ao/home.cfm
3. International Journal for Light and Electron Optics
   https://www.journals.elsevier.com/optik