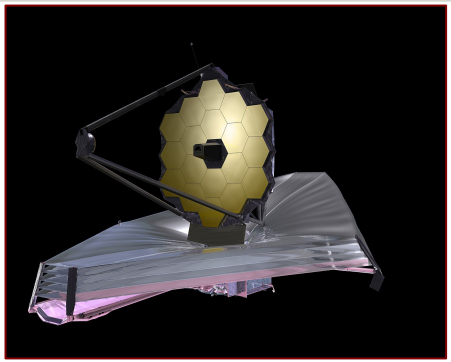
How Astrophysicists see the Universe

Christoph Welling

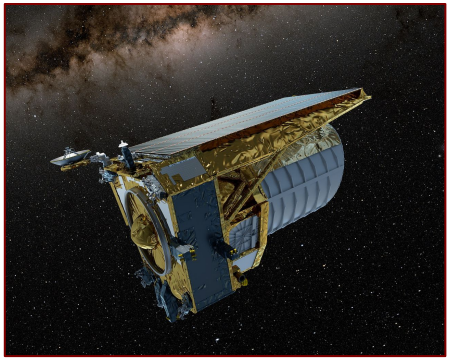
The Problem with Astrophysics

Telescopes!

- It is a great time to be an astrophysicist right now!
- Lots of new observatories operational or coming up soon



James Webb Space Telescope



Euclid

Very Large Telescope

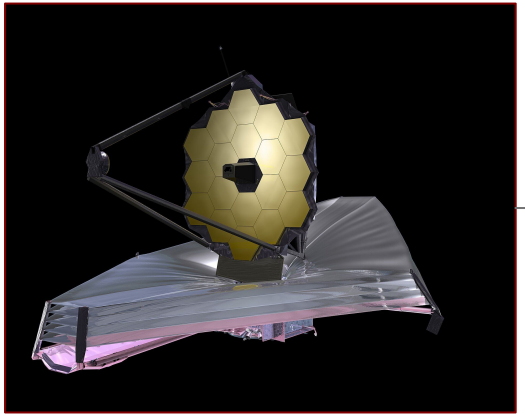
Vera C. Rubin Observatory

So many pretty pictures!

Perseus Cluster (Euclid)

Crab Nebula (JWST)

The Oversimplified Story

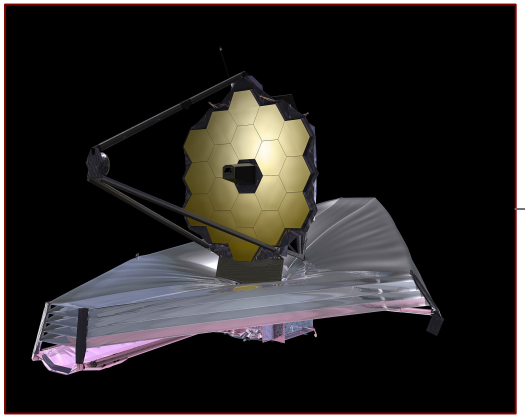


New Telescope

Pretty Pictures

Discovery

The Oversimplified Story



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New Telescope

Pretty Pictures

Discovery

Not just about pretty pictures

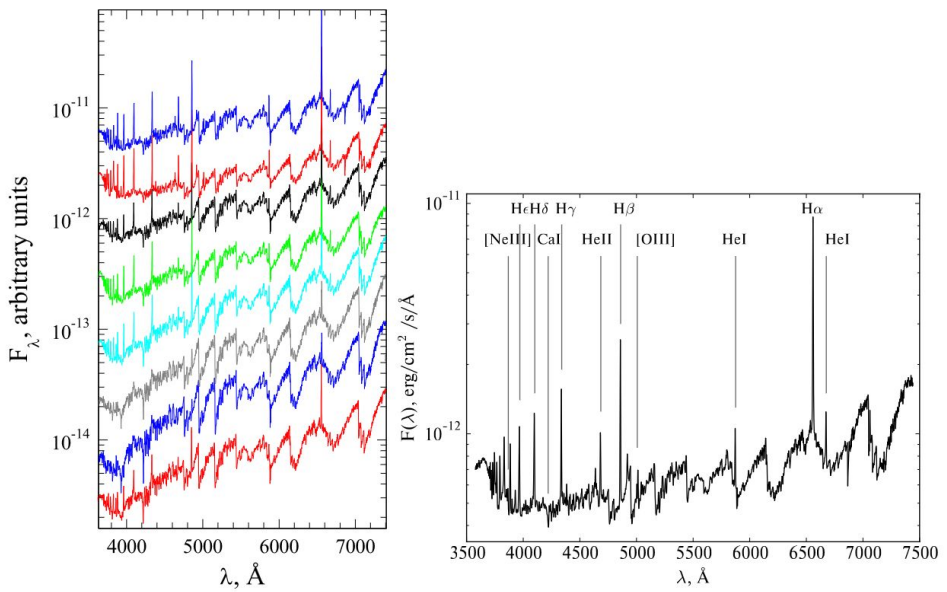
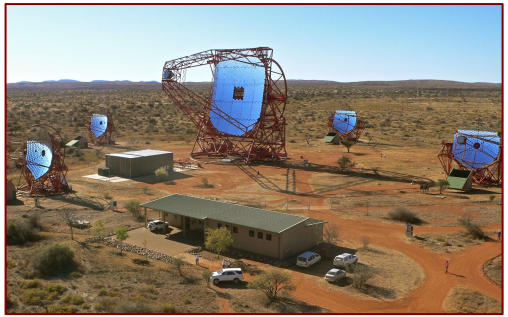


Figure 4: The observed spectra for T CrB (left panel) obtained on (from top to bottom) 22.03.2020, 05.01.2022, 27.01.2023, 26.02.2023, 09.03.2023, 24.06.2023, 26.05.2023, 14.07.2023. The fluxes are multiplied by an arbitrary constant for clarity. The right panel shows the spectrum of T CrB obtained on 05.01.2022 with the most prominent lines identified.

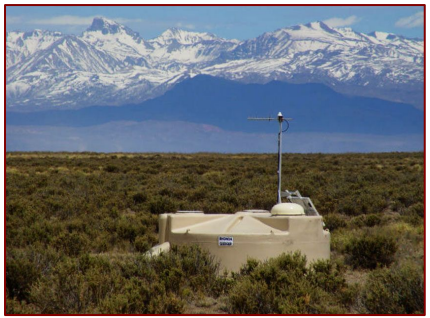
More than just telescopes

ALMA

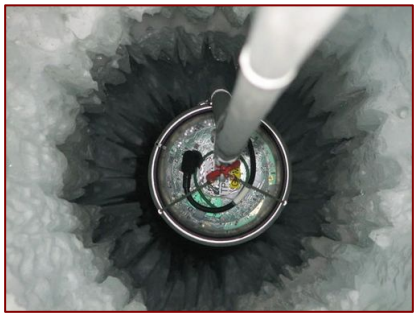
LOFAR



H.E.S.S.



Pierre Auger Observatory



IceCube

LIGO

What is this series going to be about?

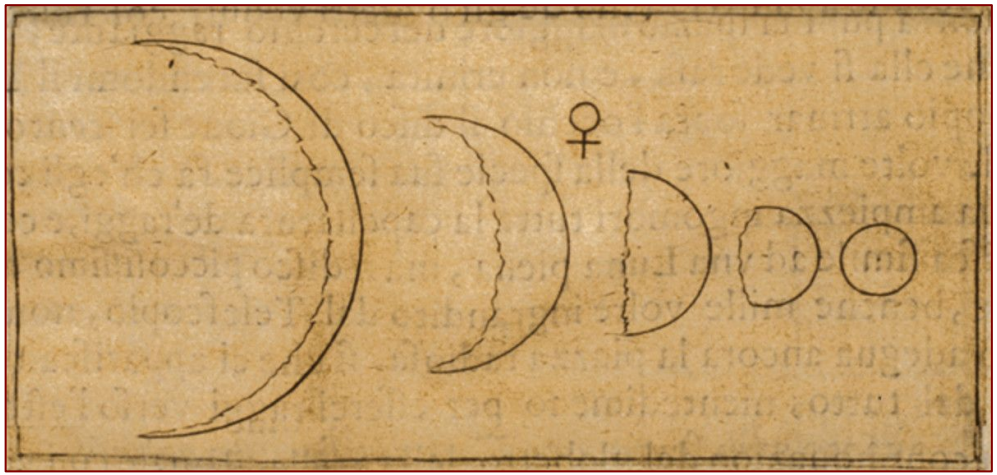
"How do we find out about things in space?"

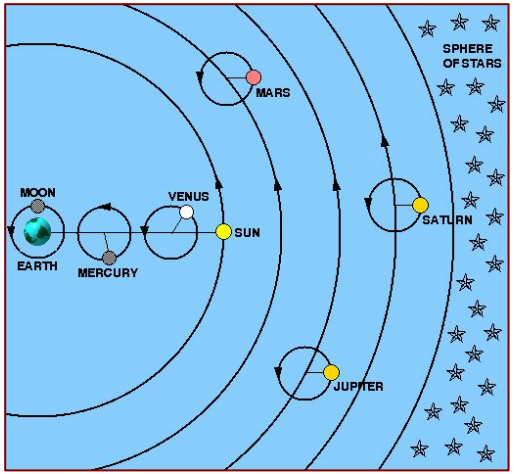
1. Introduction & Telescopes
2. Spectroscopy
3. Distances
4. Microwave & Radio Astronomy

5. Cosmic Rays
6. Gamma Rays
7. Neutrino Astronomy
8. Gravitational Waves

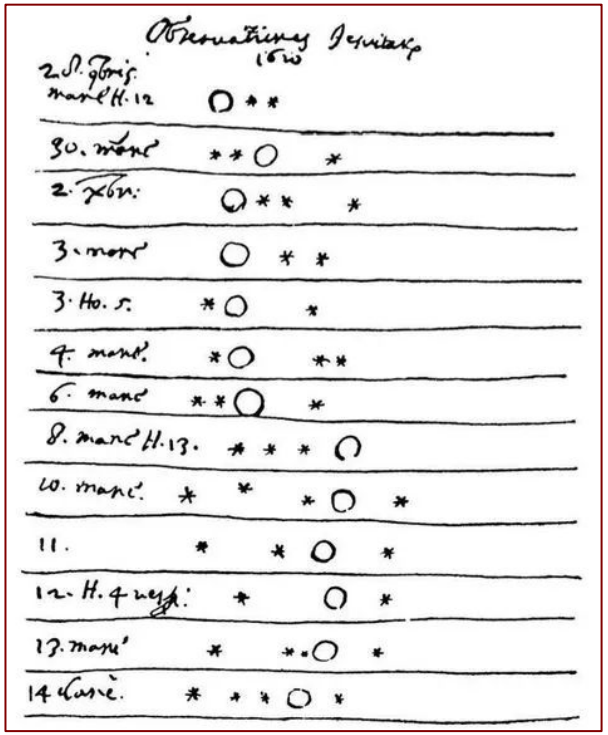
Galileo Galilei

Galileo Galilei





Galileo Galilei

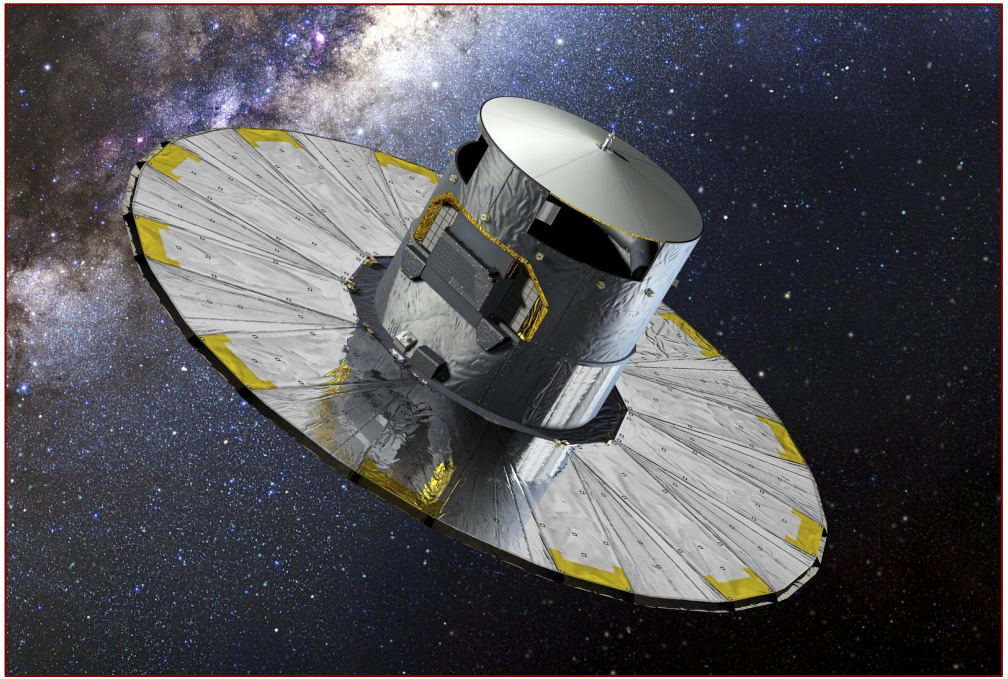


Tycho Brahe & Johannes Kepler

Tycho Brahe

Tycho Brahe & Johannes Kepler

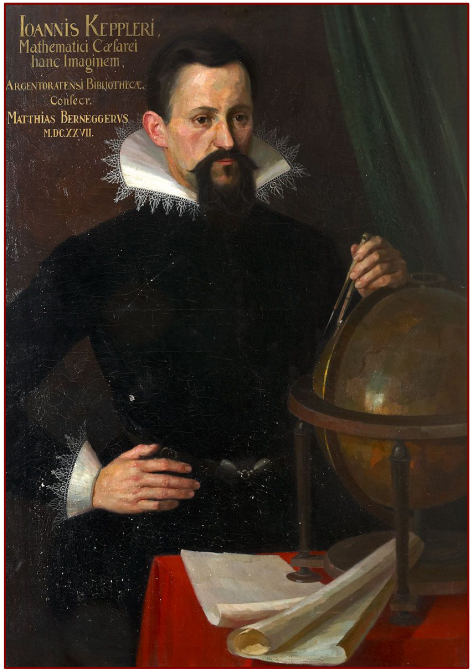
Tycho Brahe



Gaia

Tycho Brahe & Johannes Kepler

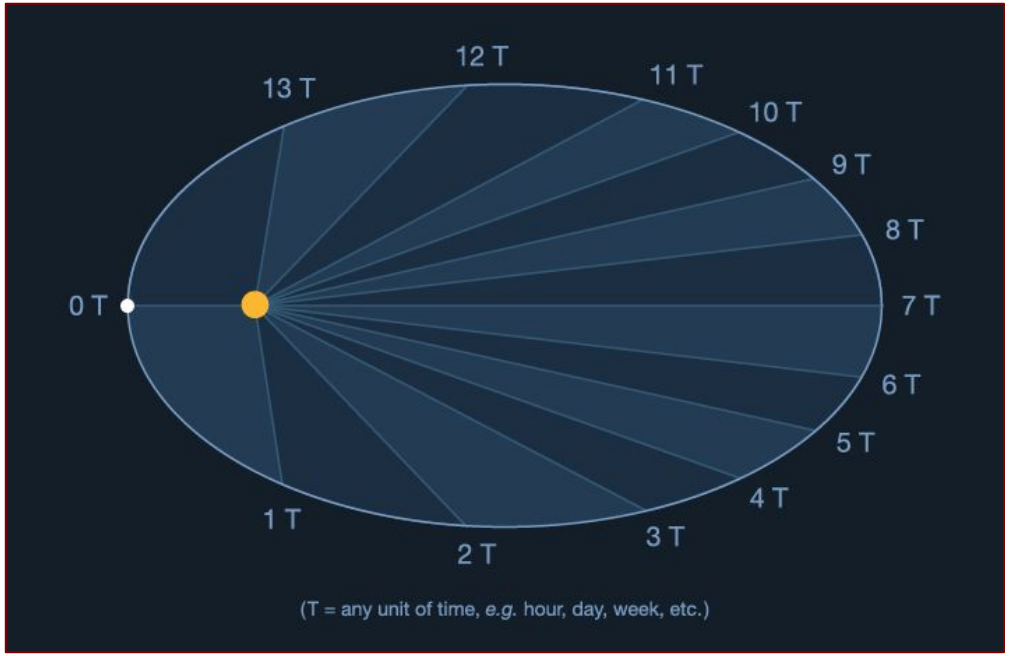
Tycho Brahe



Johannes Kepler

Kepler's Laws of Motion

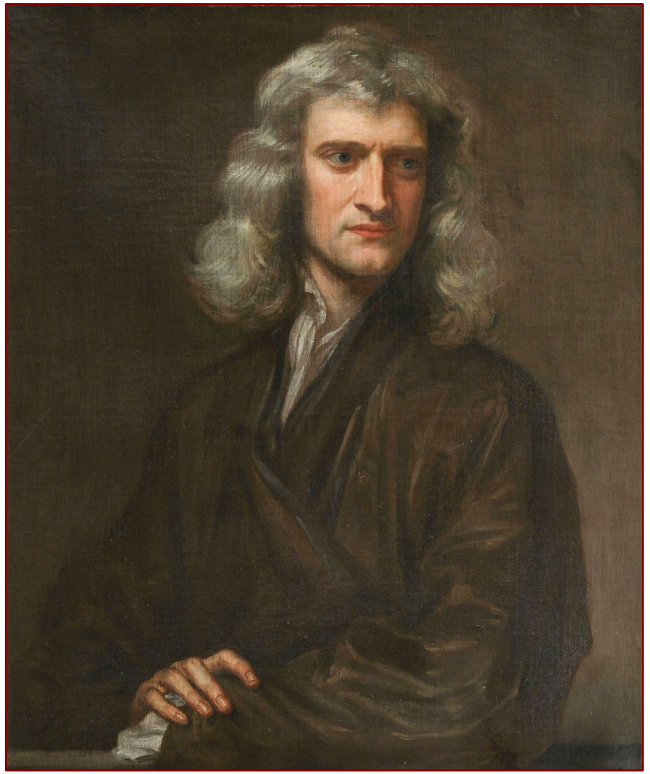
1. Orbits are ellipses, with the sun at one focus.
2. The line between sun and planet always sweeps the same area per time.
3. The square of the orbital period is proportional to the cube of the distance.



Isaac Newton

- Newton's Laws of Motion:
  - An object moves in a straight line, at constant speed, unless a force acts on it.
  - $F = m * a$
  - For every force, there is an equal, but opposite, reaction force.
- Newton's theory of Gravity:

$$F = G * m_1 * m_2 / d^2$$



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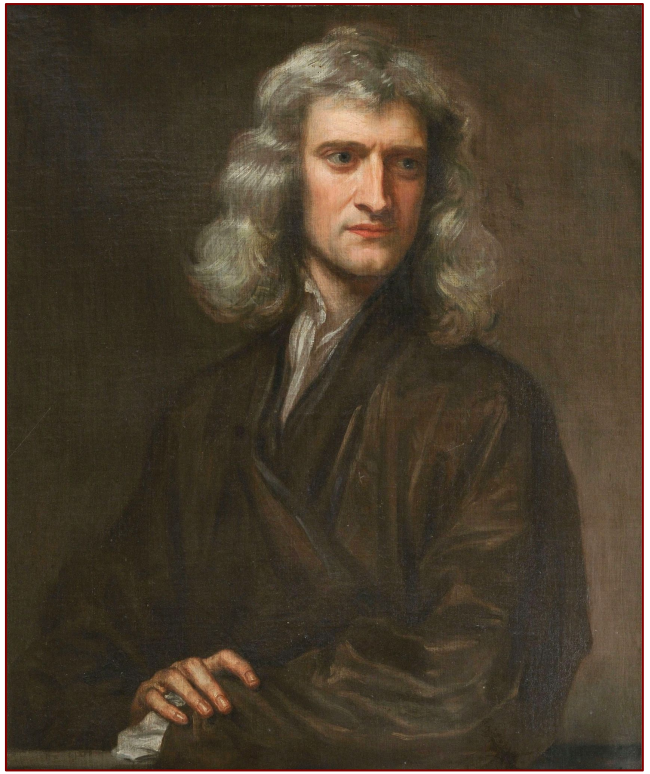
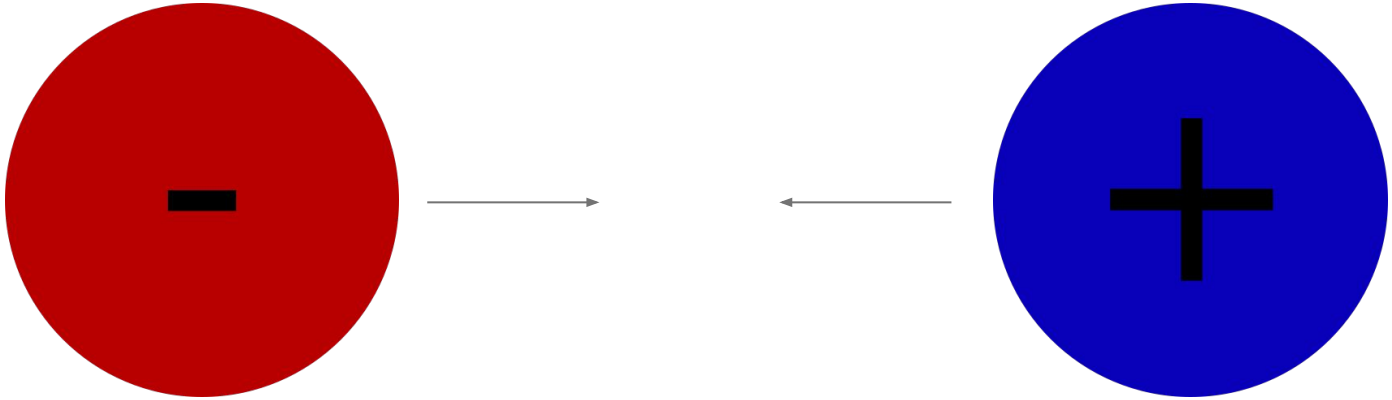
The planets are following the same laws as things on earth!



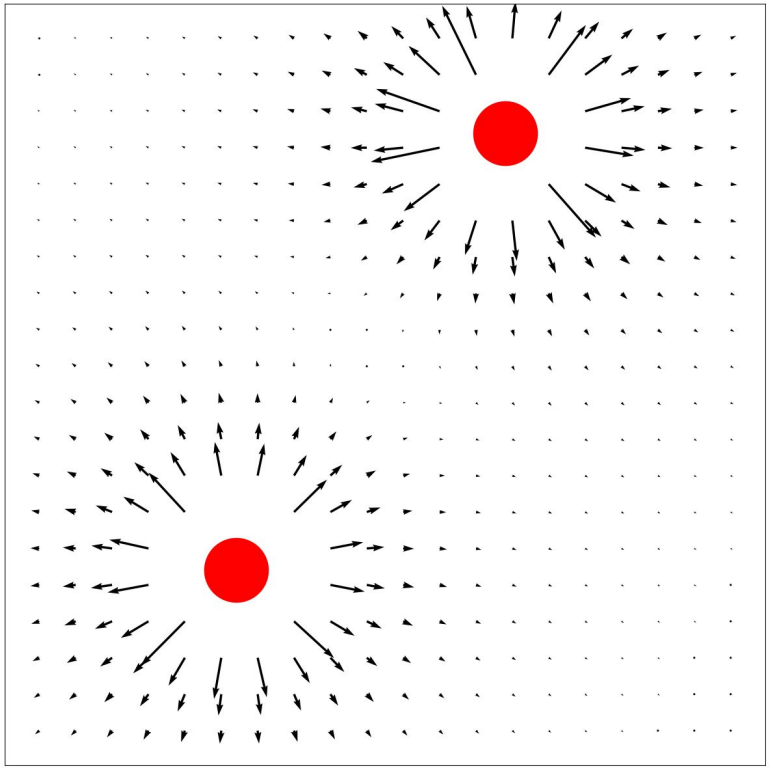
Telescopes

What is Light exactly?



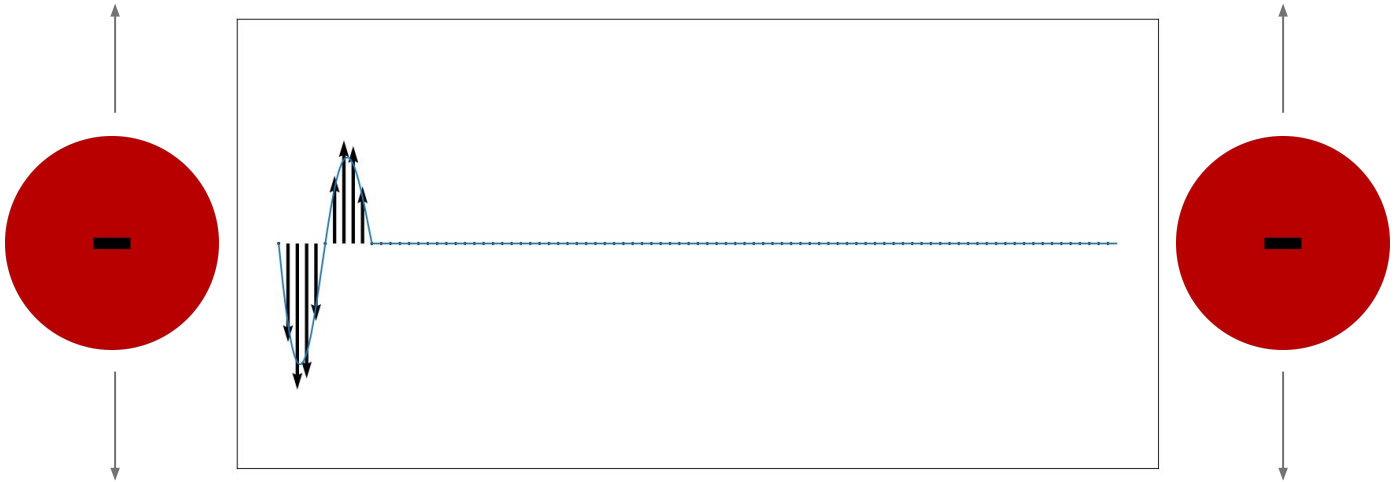
What is Light exactly?

Electric Fields

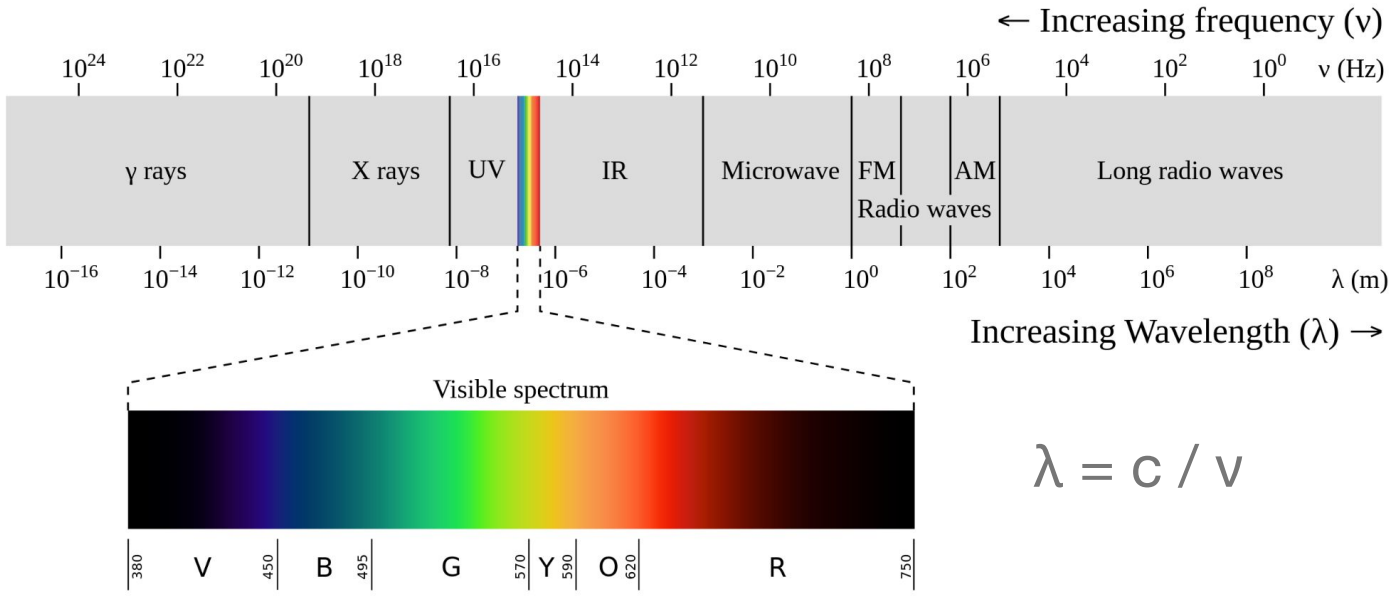


Electromagnetic Waves

Electromagnetic Waves

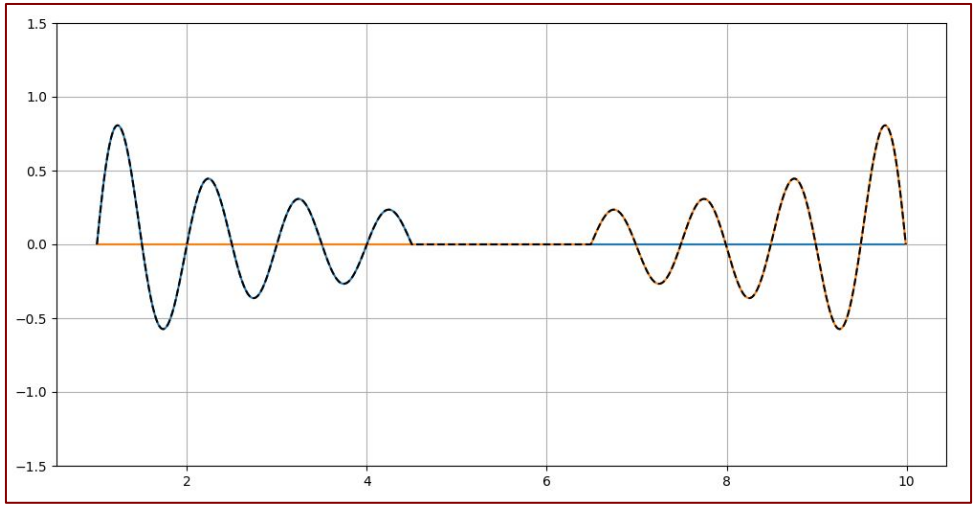


Electromagnetic Waves

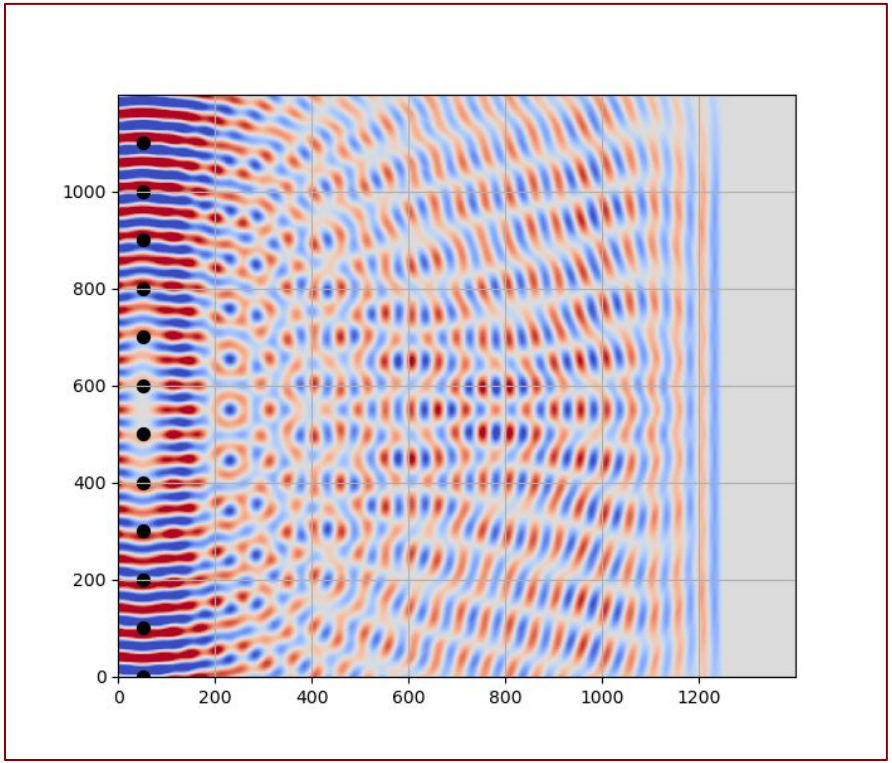


$$\lambda = c / \nu$$

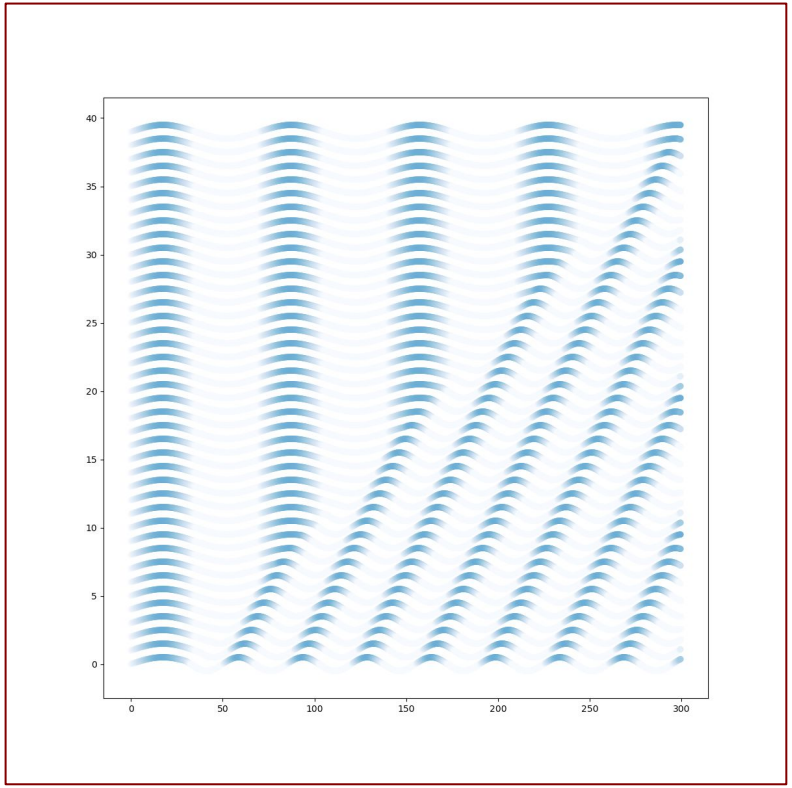
Interference



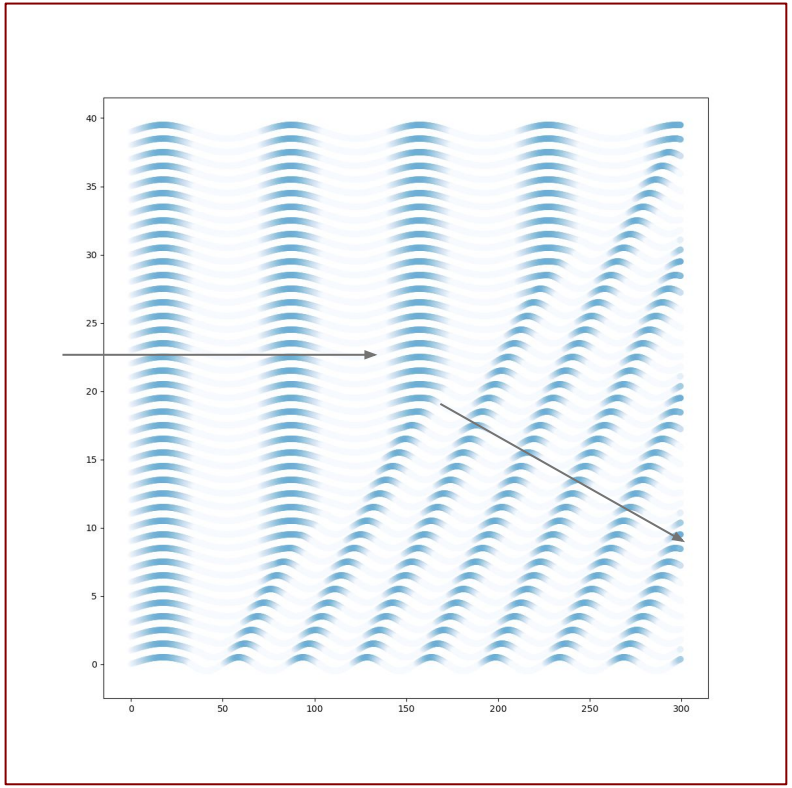
Wave optics



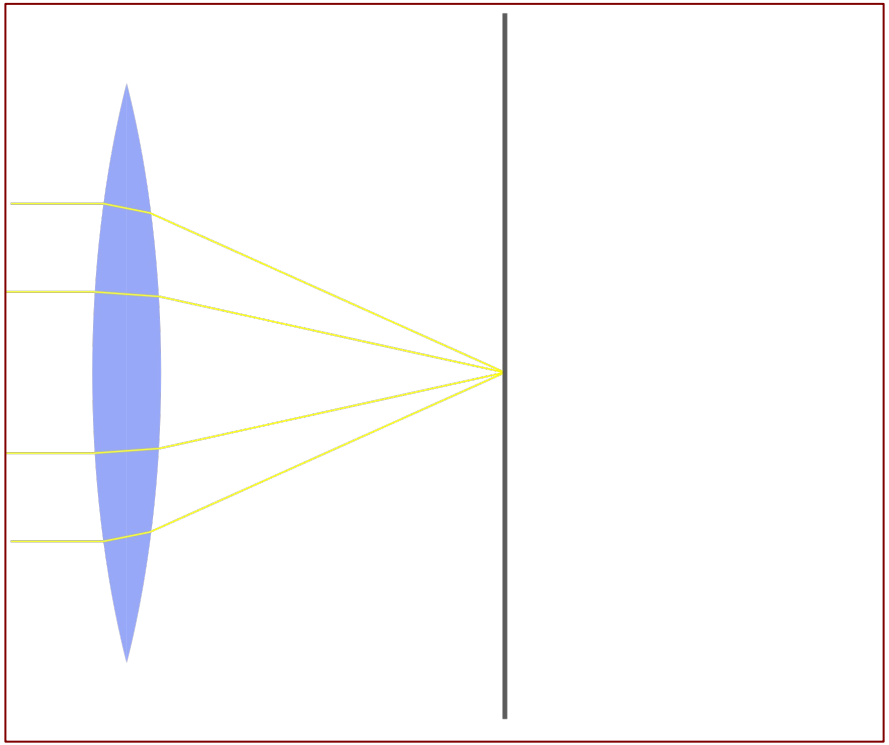
Refraction



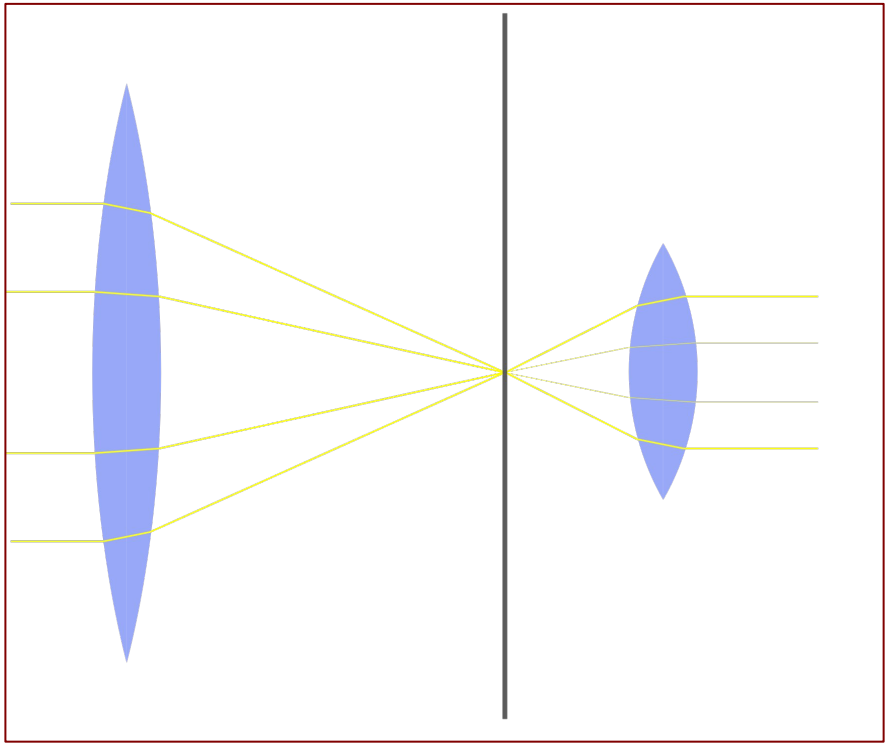
Refraction



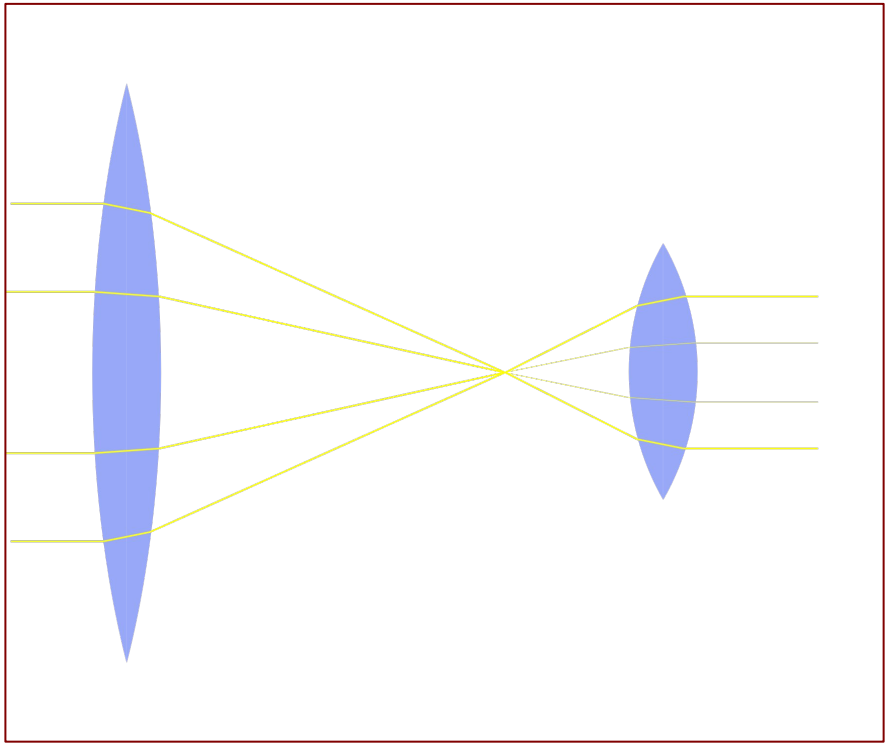
Ray optics and lenses



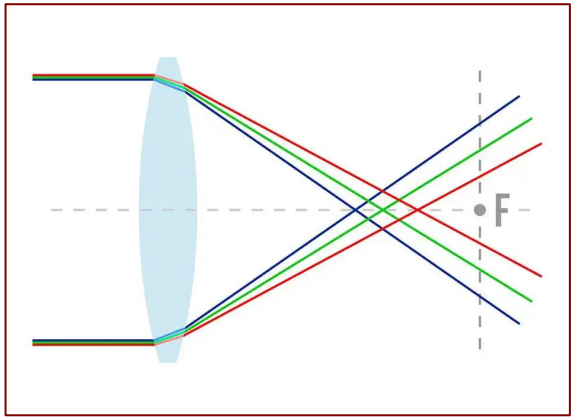
Ray optics and lenses



Ray optics and lenses

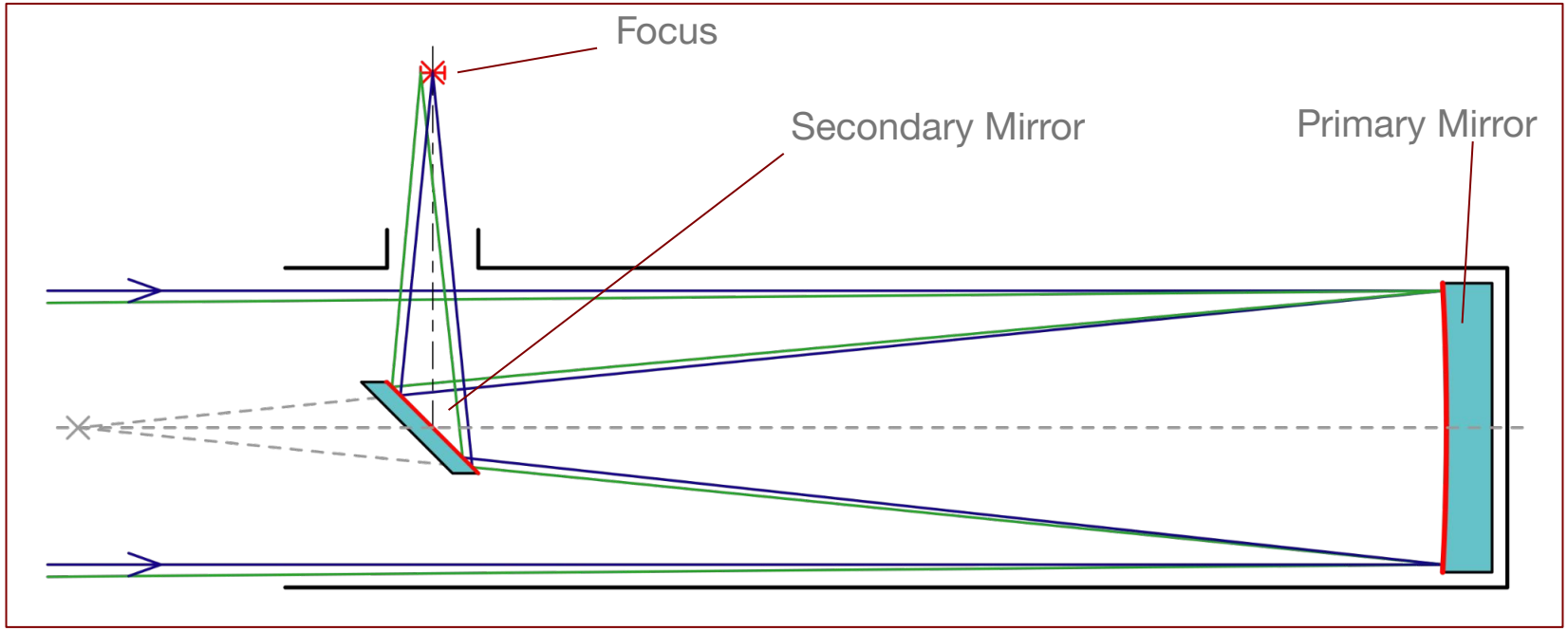


Chromatic Aberration

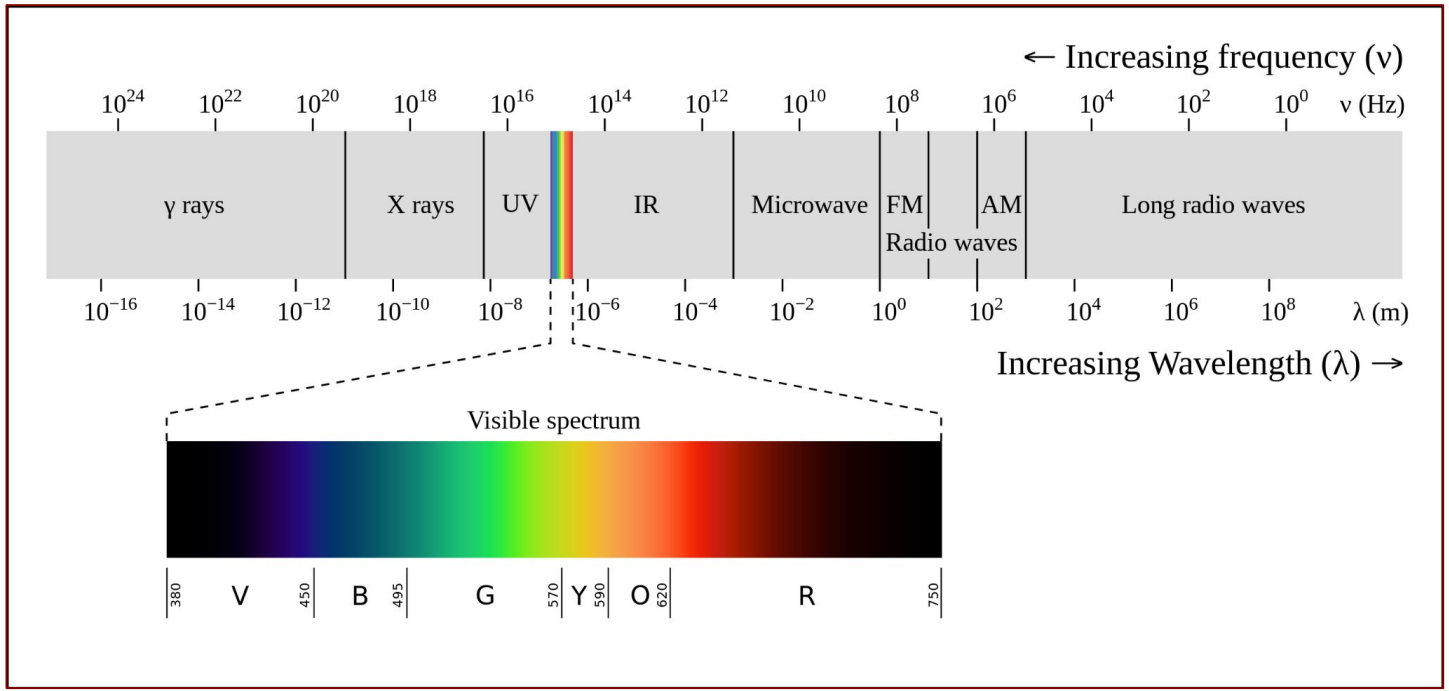


This text is hard to read!

Reflector Telescopes



What Wavelengths do you want to see?

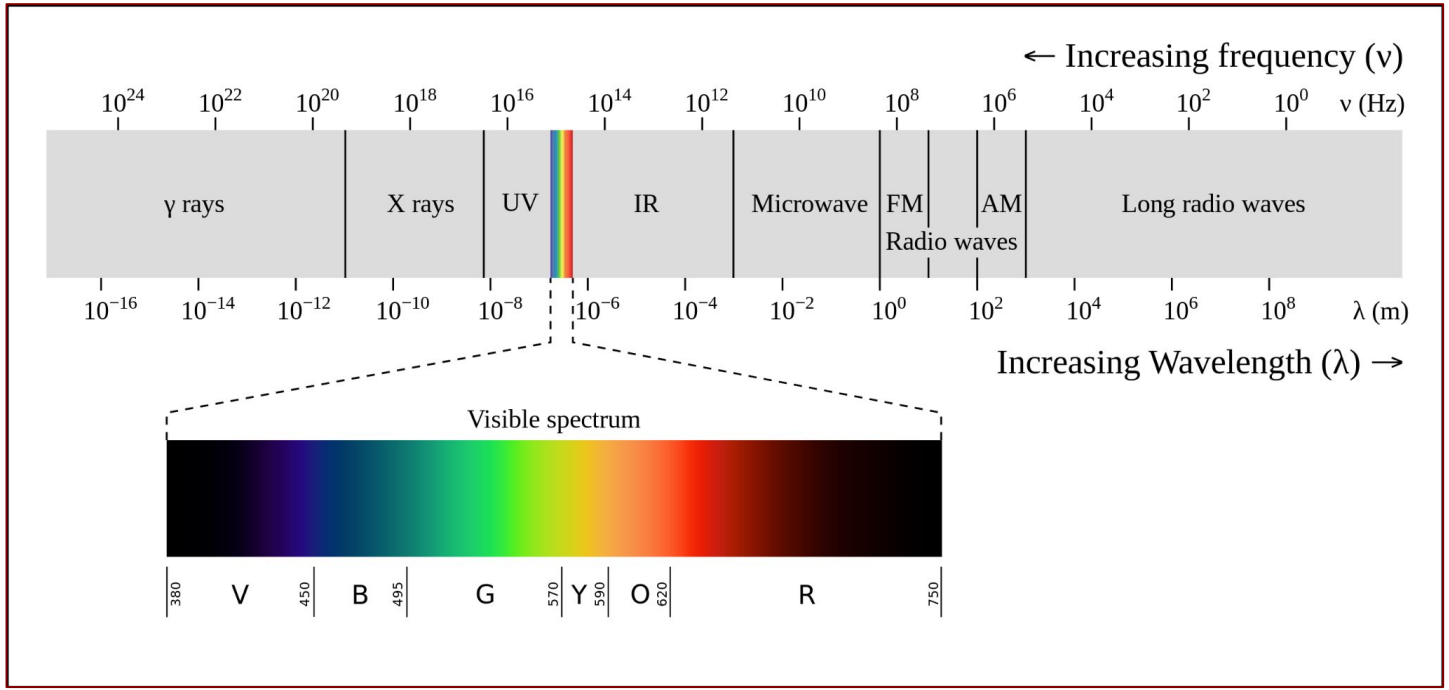


What Wavelengths do you want to see?

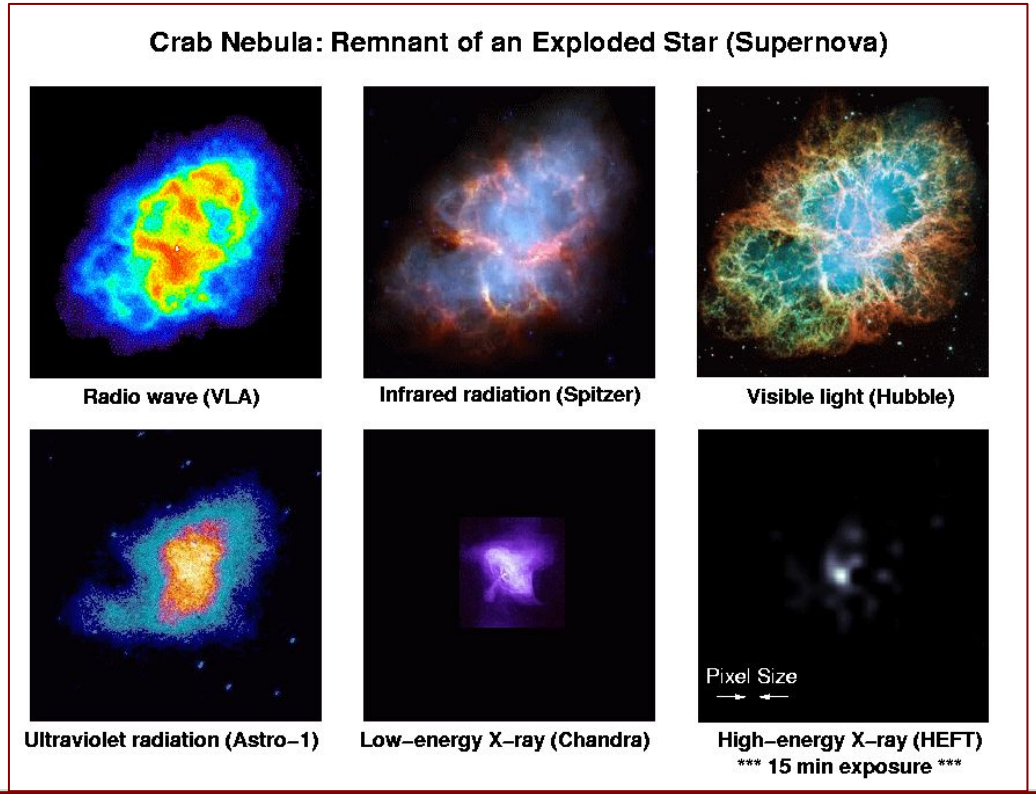
In 5 Weeks

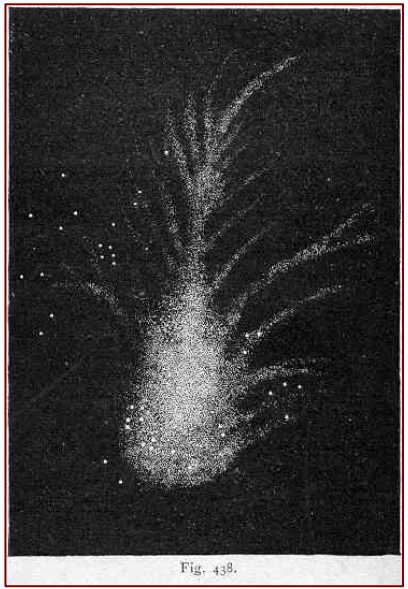
Today + 2 weeks

In 3 Weeks



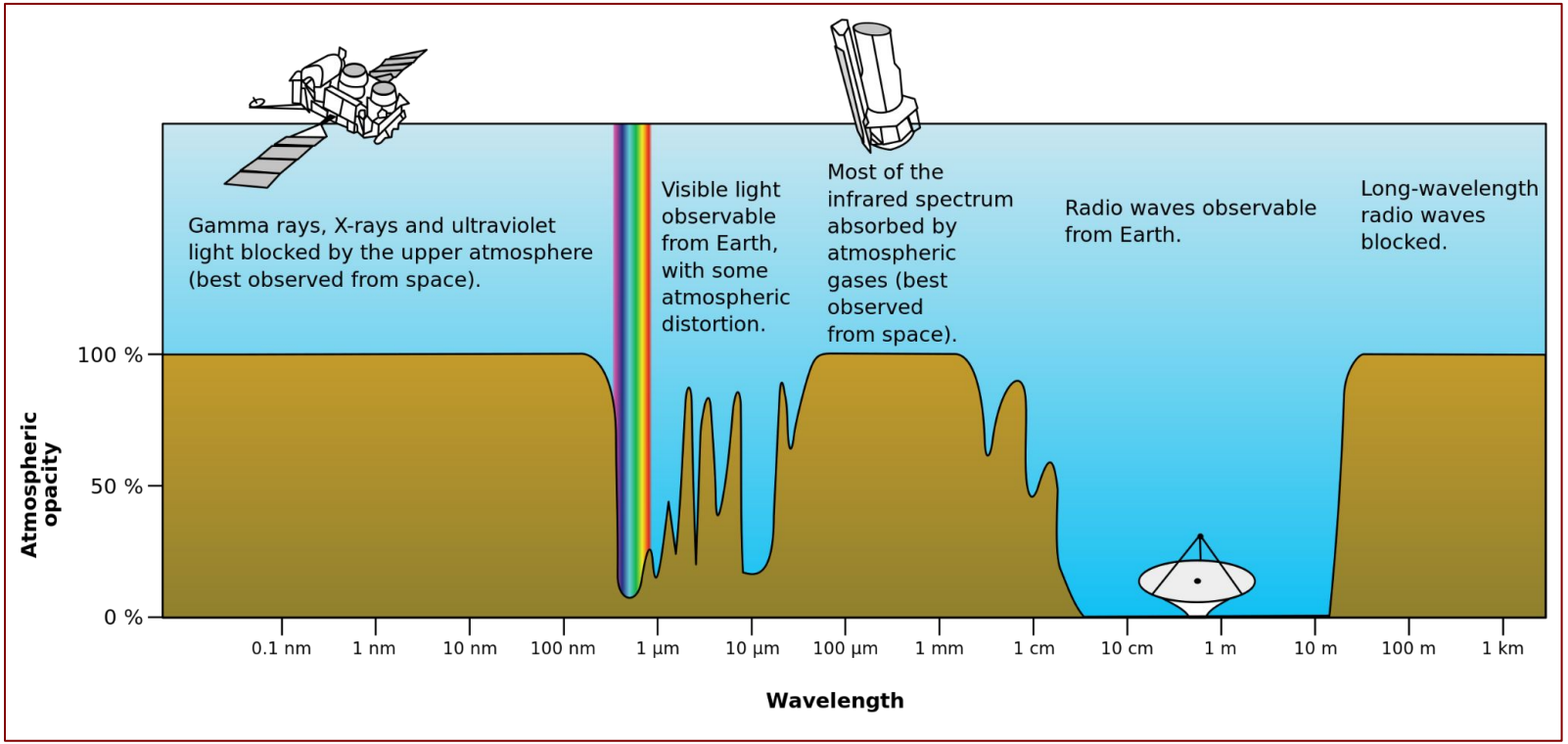
What Wavelengths do you want to see?



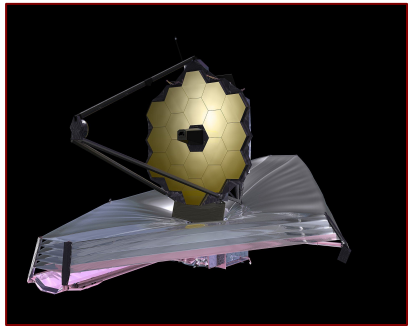


William Parsons

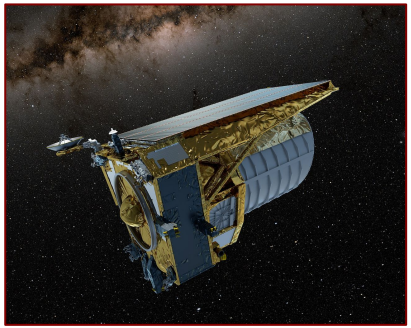
Atmospheric Absorption



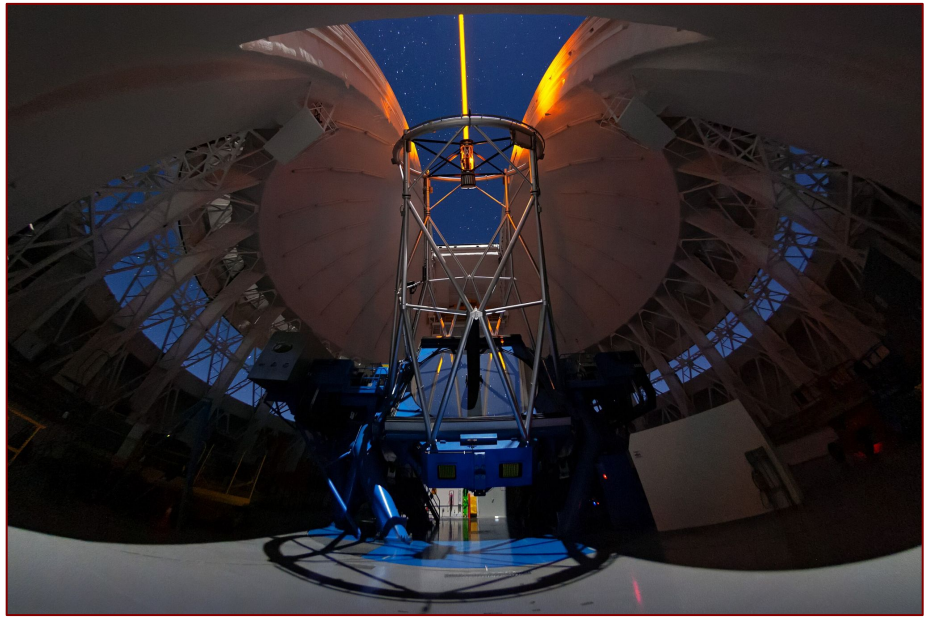
What about space telescopes?



$10 billion

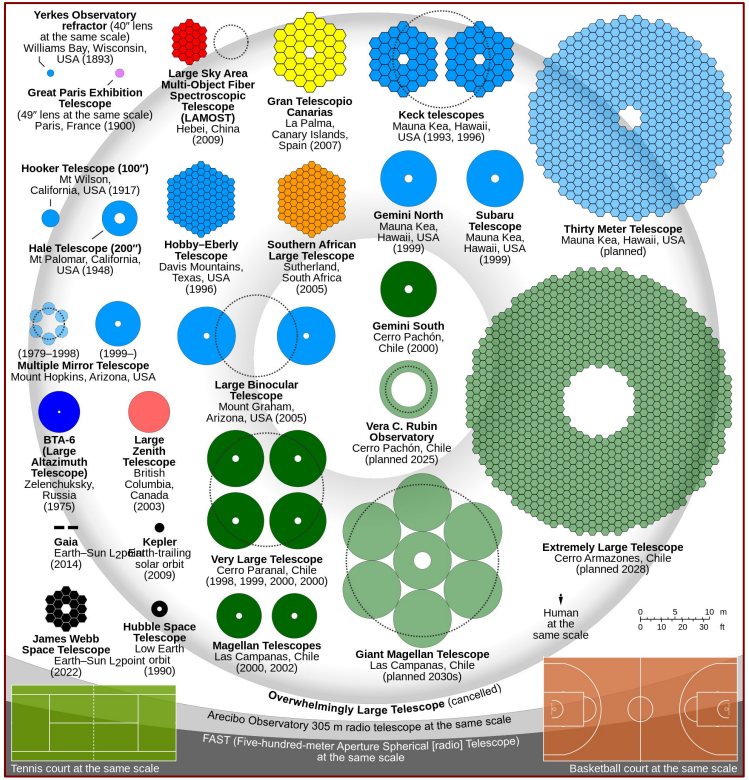


$1 billion

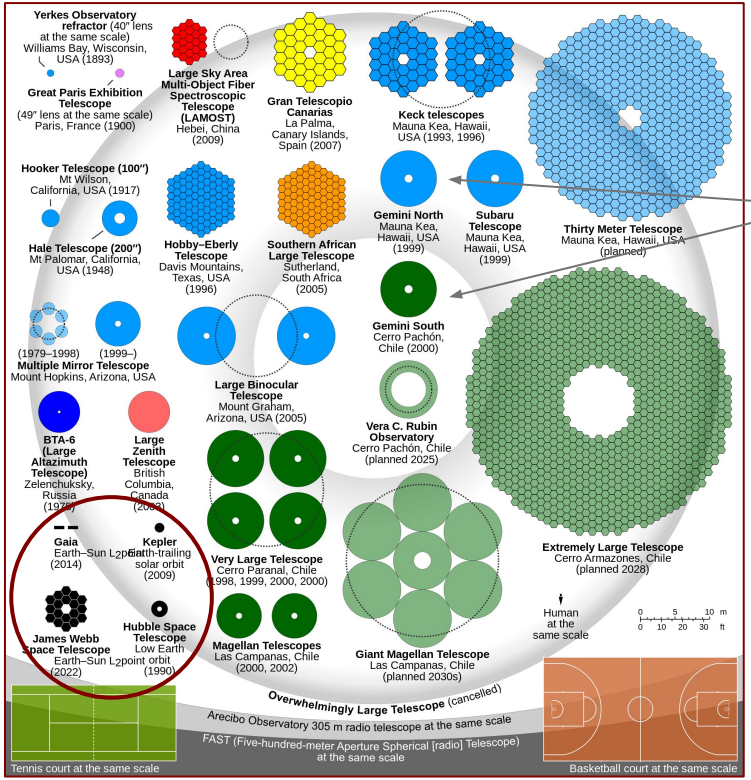


Gemini: $187 million (2 telescopes)

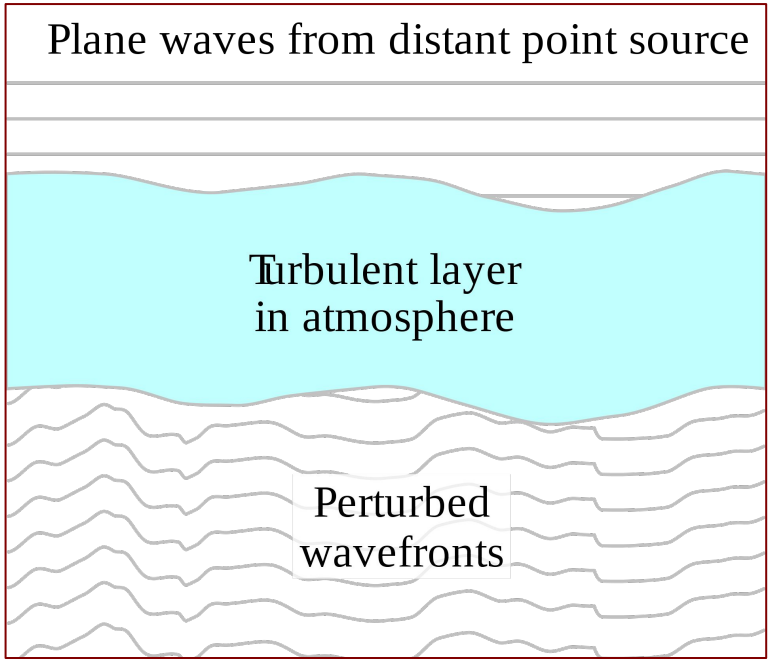
Telescope Sizes



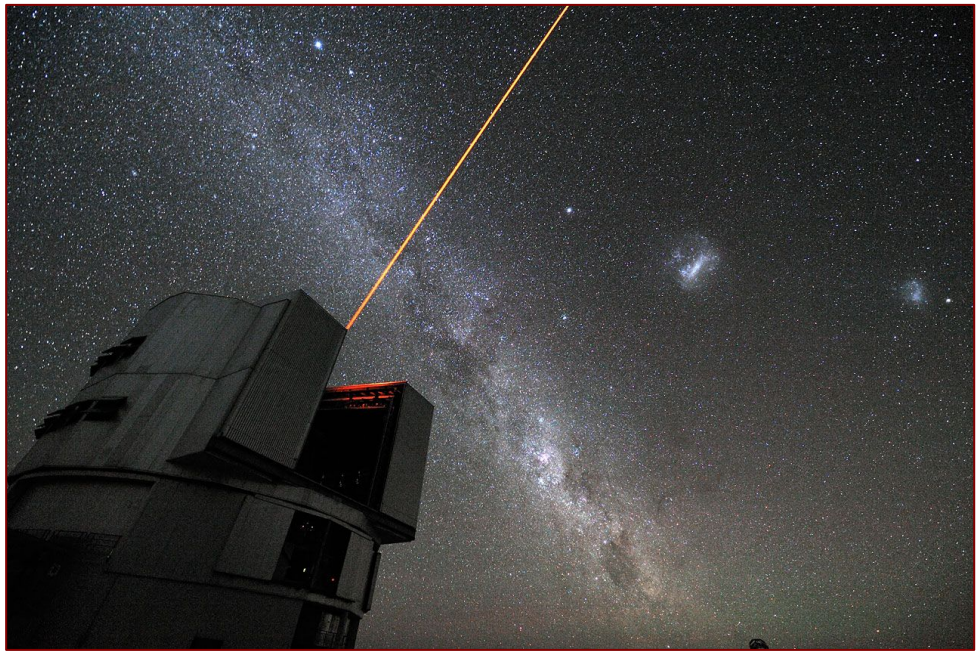
Telescope Sizes

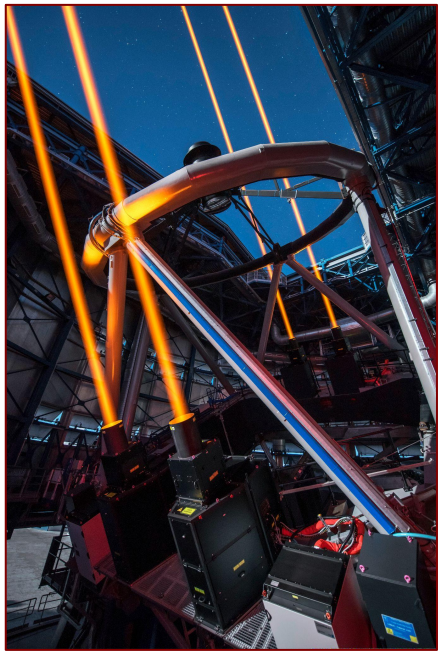


“Seeing”

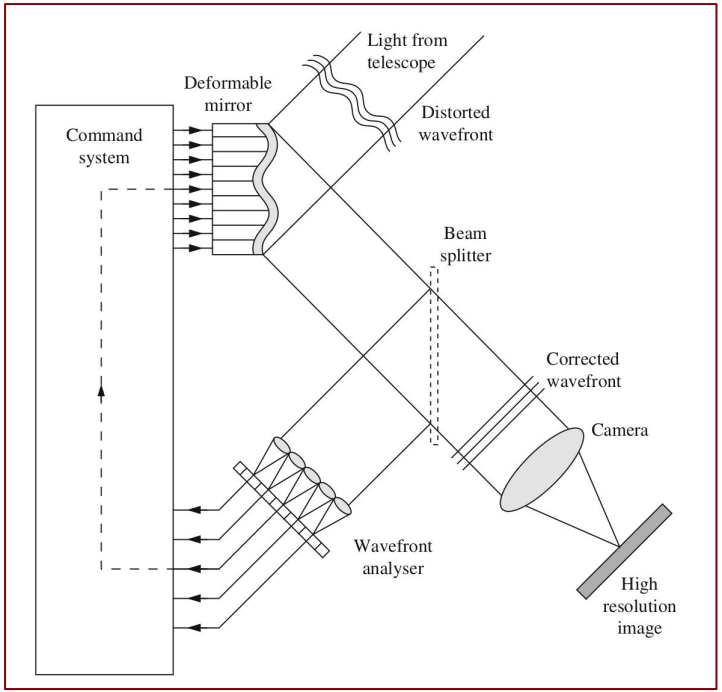

Plane waves from distant point source
Turbulent layer
in atmosphere
Perturbed
wavefronts

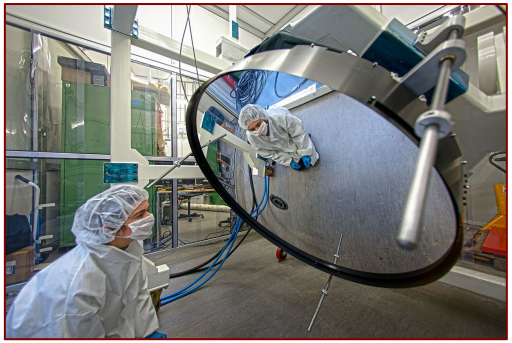
Adaptive Optics

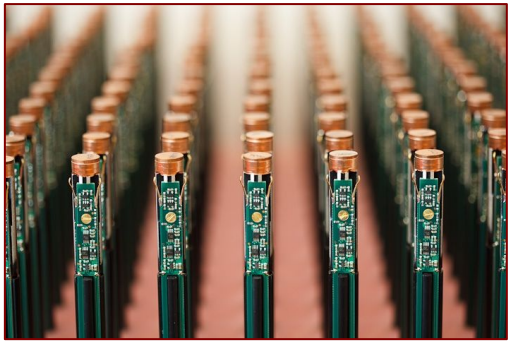


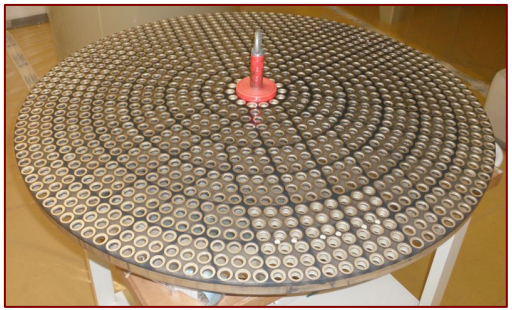


Adaptive Optics

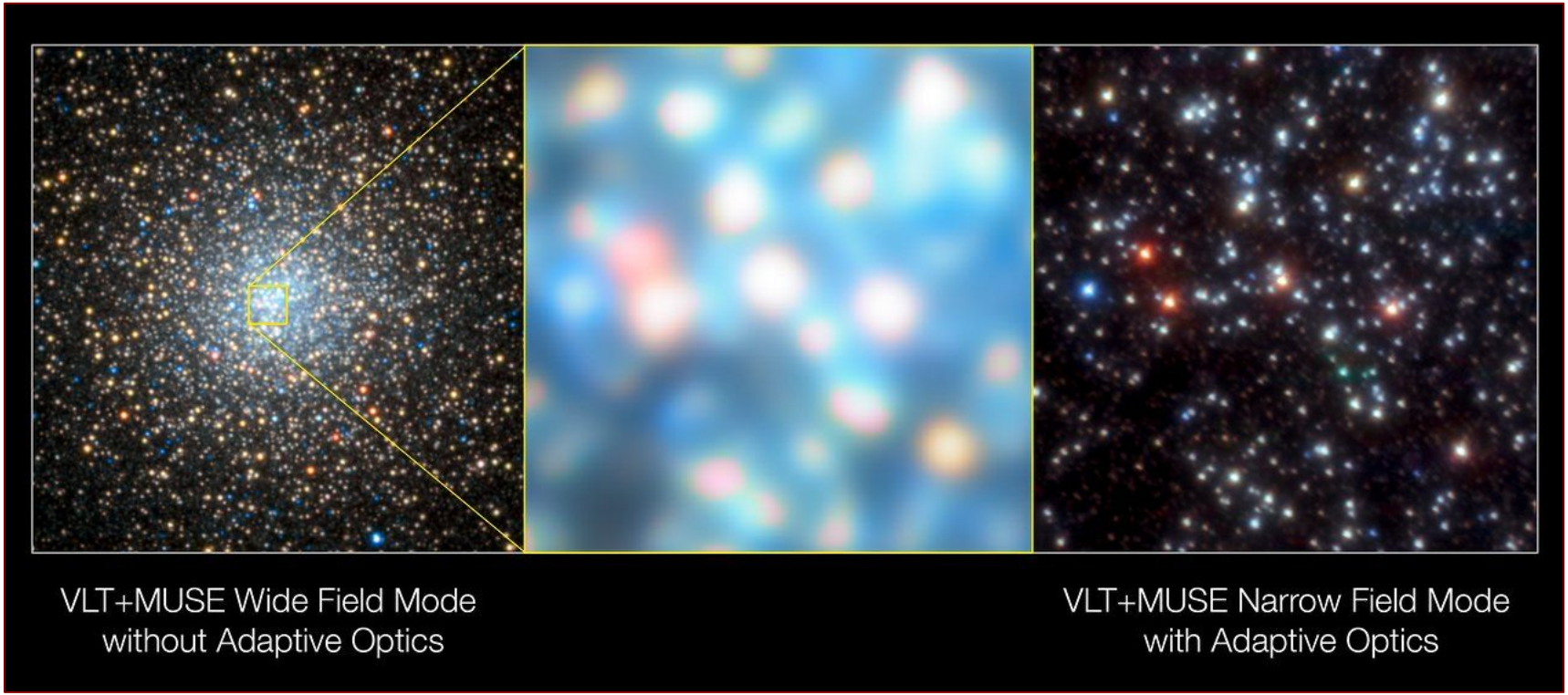






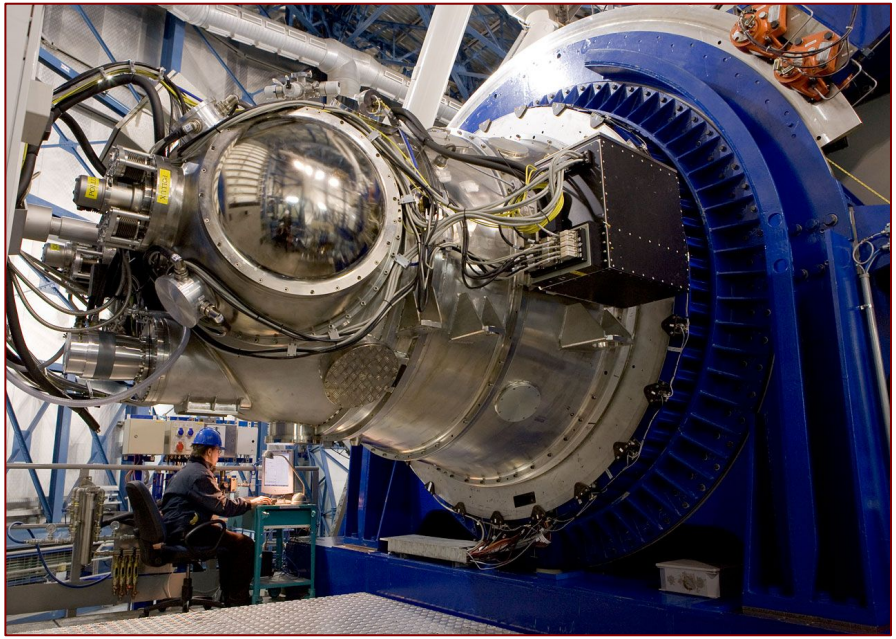


Adaptive Optics



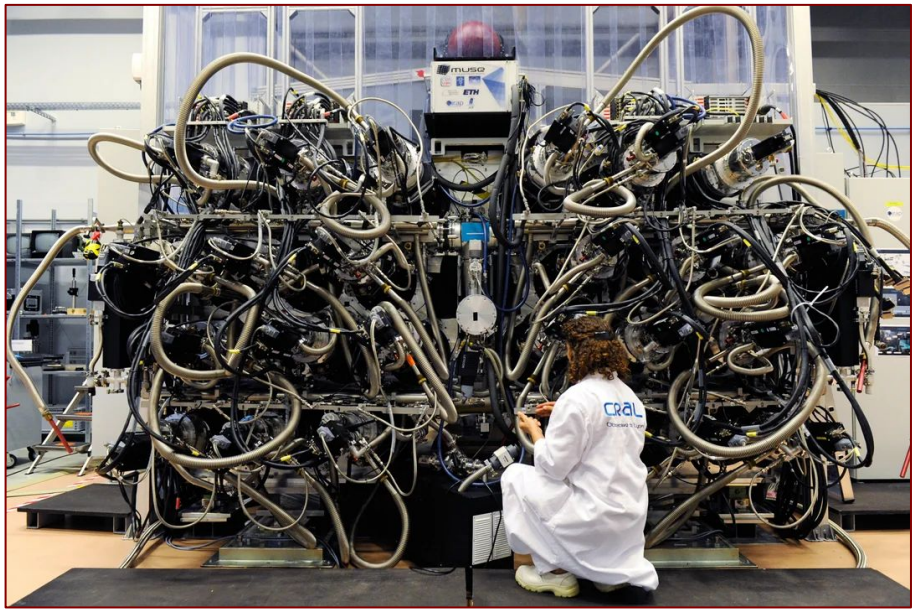
Instruments: VLT Unit Telescope 4

- High Acuity Wide-field K-band Imager
  - Near infrared
  - Wide field of view



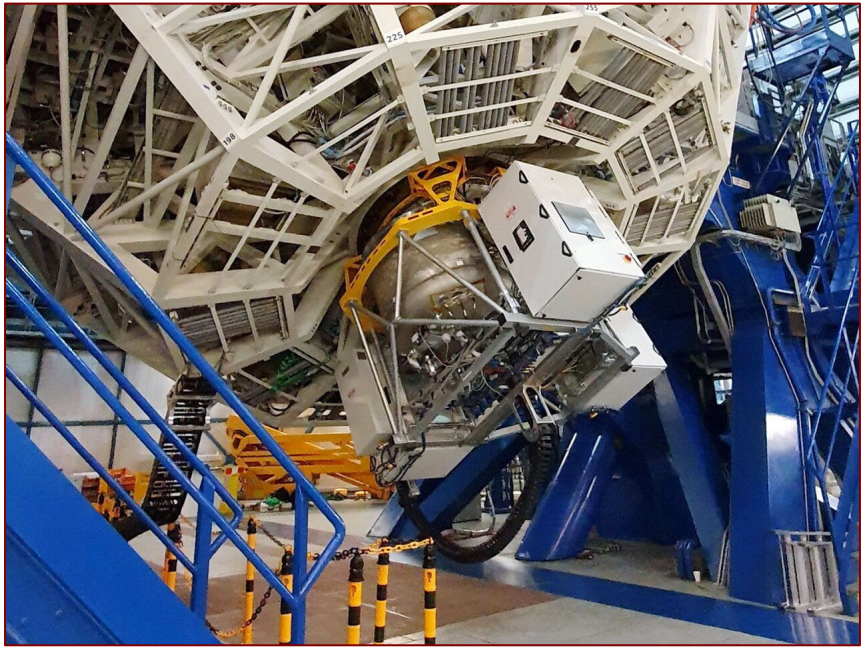
Instruments: VLT Unit Telescope 4

- High Acuity Wide-field K-band Imager
  - Near infrared
  - Wide field of view
- Multi Unit Spectral Explorer
  - Visible to near infrared
  - Integral field spectroscopy

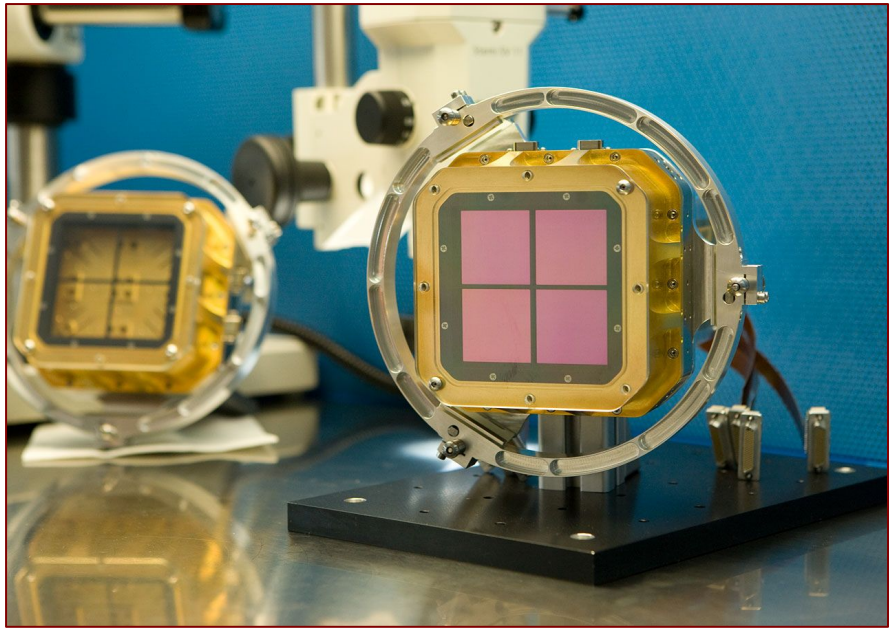


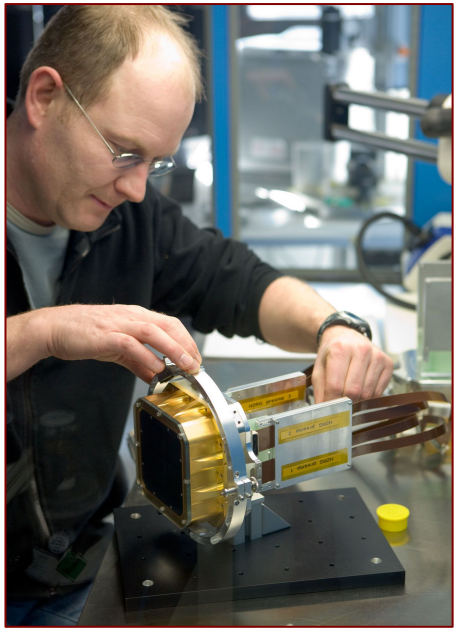
Instruments: VLT Unit Telescope 4

- High Acuity Wide-field K-band Imager
  - Near infrared
  - Wide field of view
- Multi Unit Spectral Explorer
  - Visible to near infrared
  - Integral field spectroscopy
- Enhanced Resolution Imager and Spectrograph
  - Near infrared
  - Integral field spectroscopy
  - Imaging
  - Coronagraph

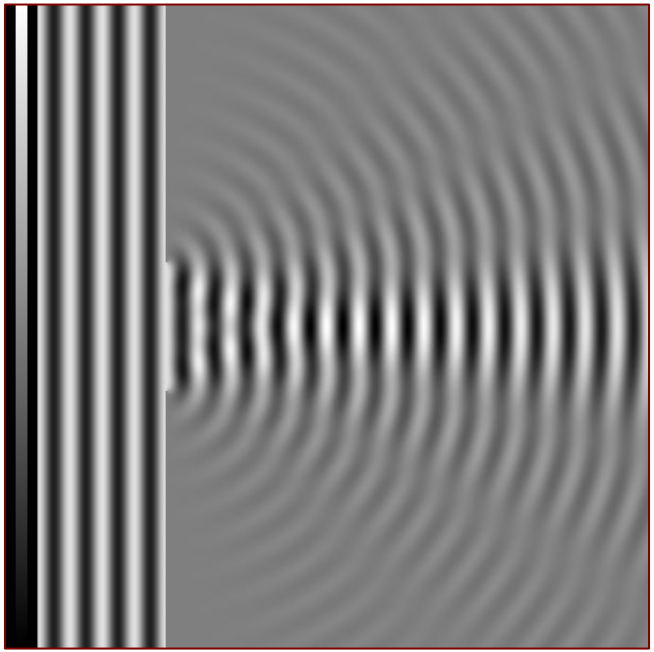


Charge Coupled Devices

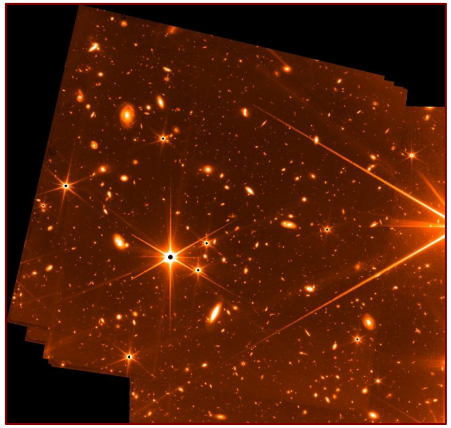


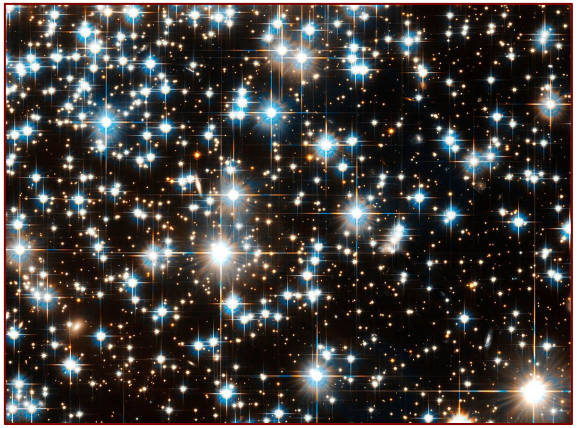


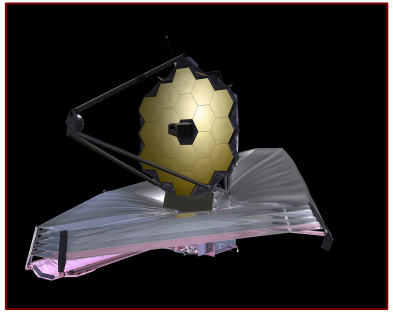
Diffraction



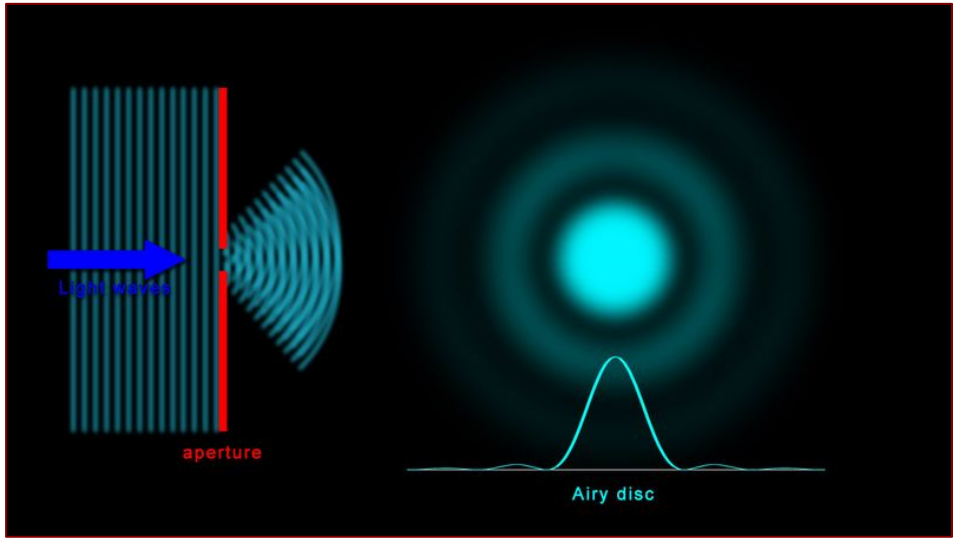
Diffraction



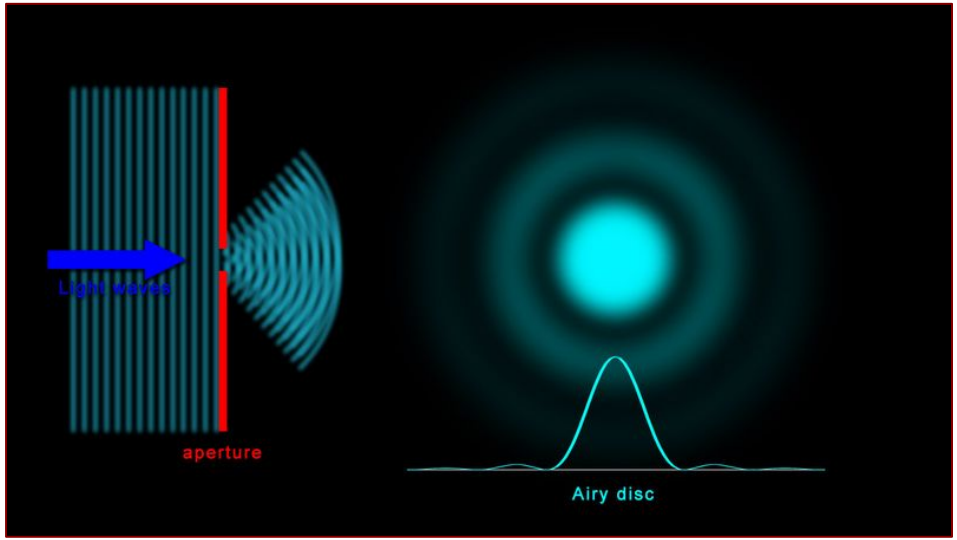


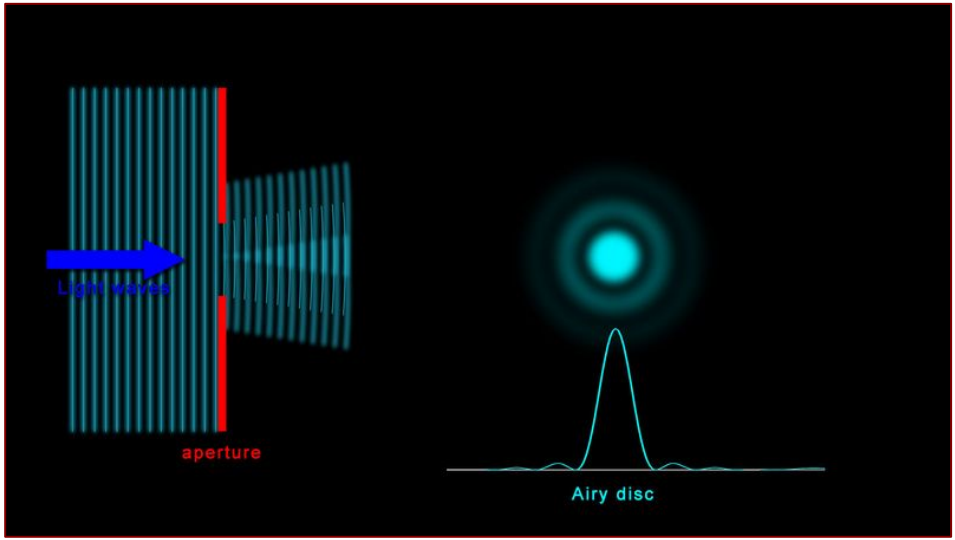


Airy Disk



Airy Disk

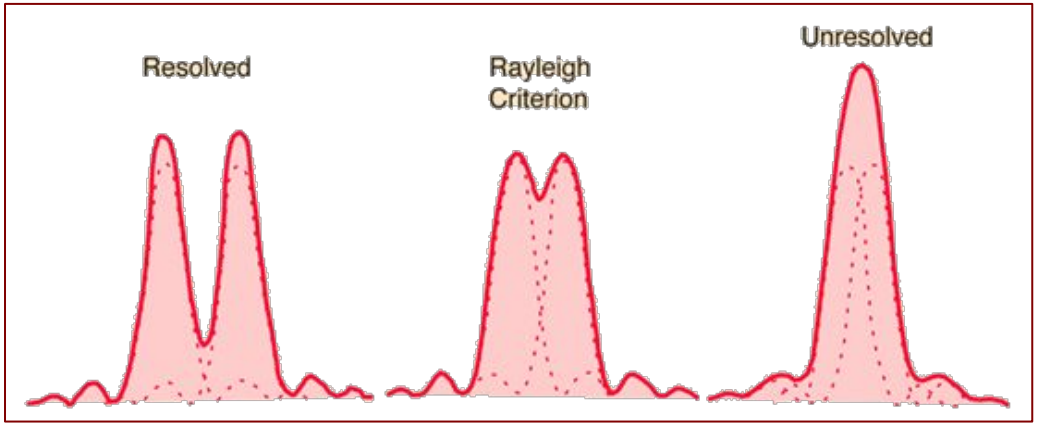

Light waves
aperture
Airy disc


Light waves
aperture
Airy disc

Rayleigh Criterion

- Resolution limit from diffraction:

$$\theta \approx 1.22\ \lambda / D$$



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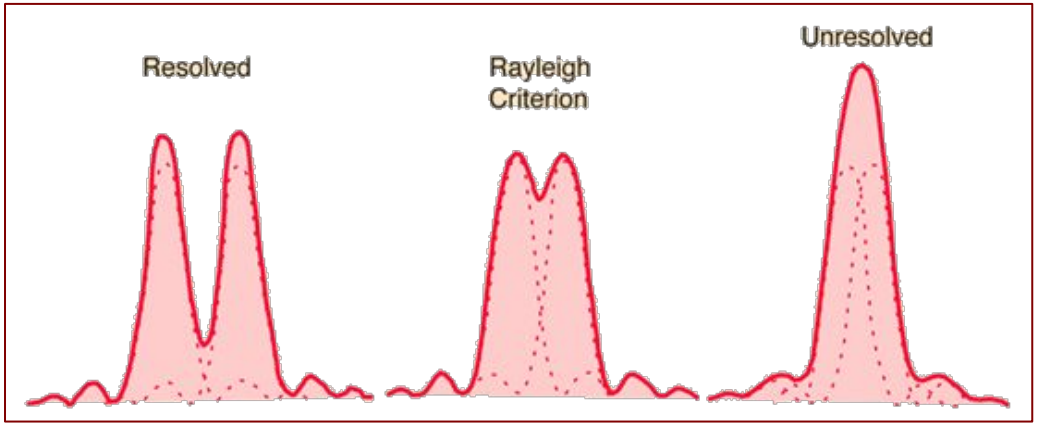

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  - 8m mirror diameter
  - ~ 1μm wavelength
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  - ~ 1μm wavelength
  - 10 lightyear distance

Required size: $1.4*10^{10}$m

Sun diameter: $1.4*10^{9}$m

Distance earth-sun: $1.5*10^{11}$m

See you next week!