Telescopes

Observational Astronomy

Laboratory of Astrophysics

Telescopes

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1. Collect more light (photons) than human eye
2. Magnify the size of the object and see details

Astronomers generally care more about 1) than 2)!!

Make things brighter rather than large!

Telescopes

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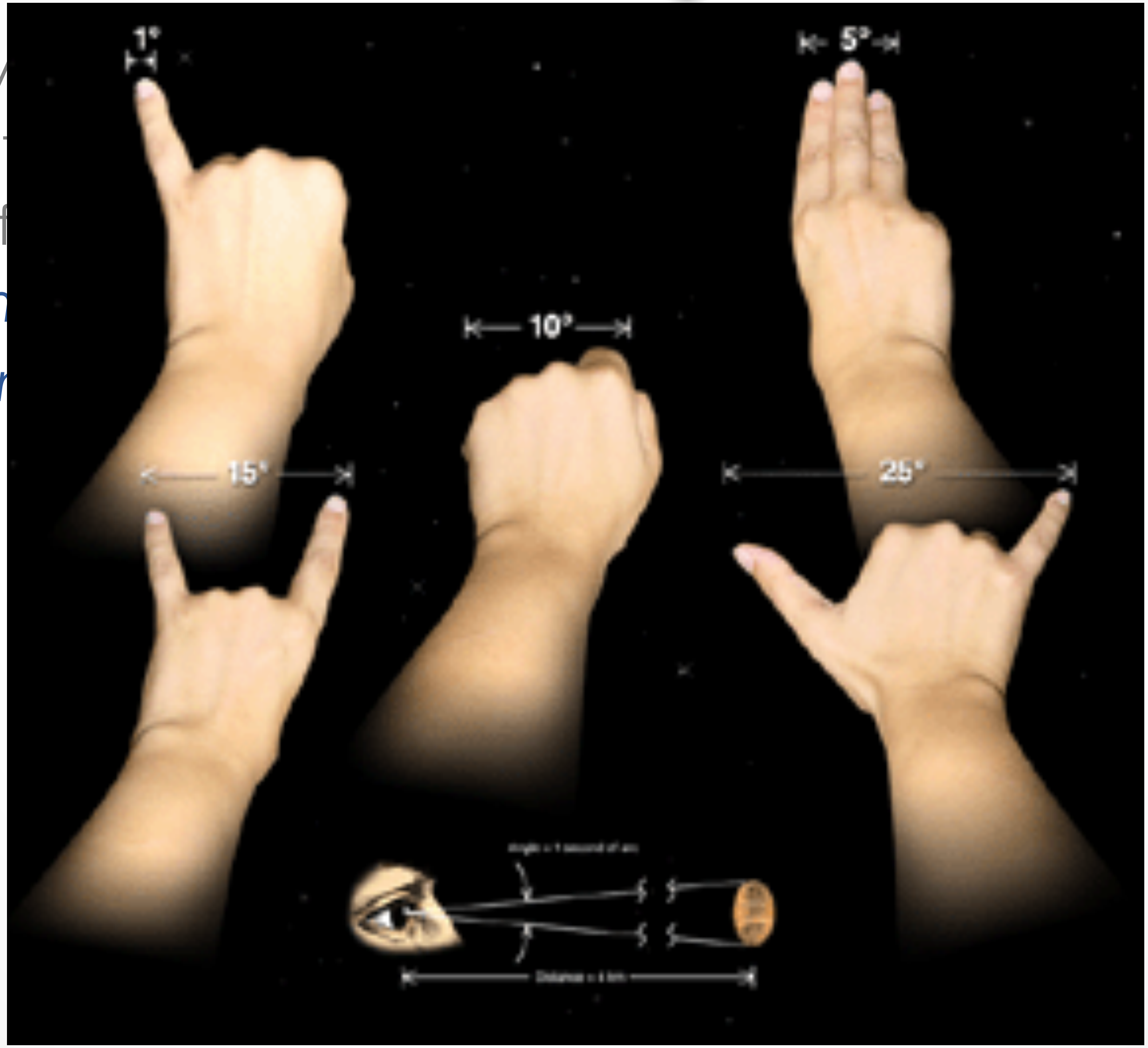

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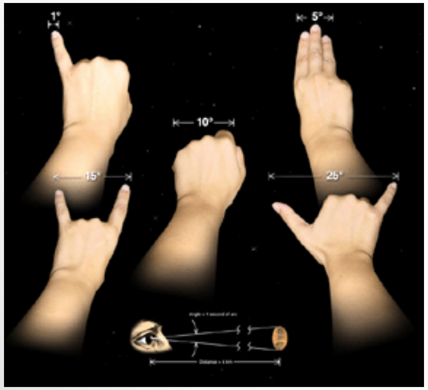
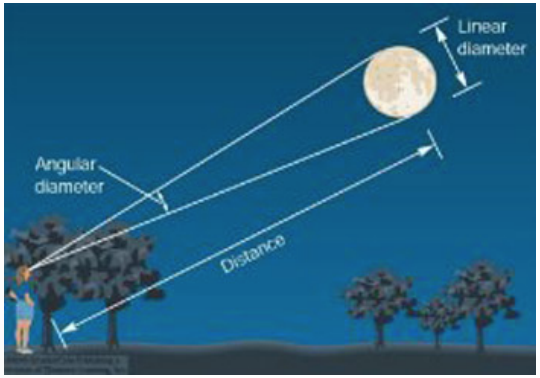
Angular size: Moon
(30arcmin = 0.5deg)





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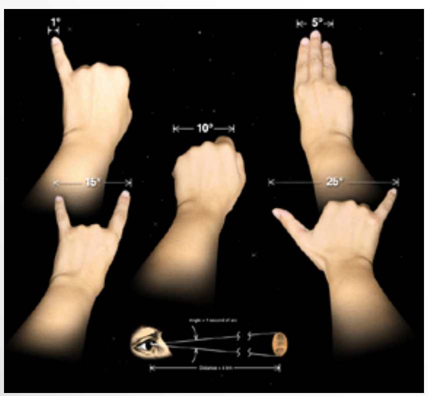
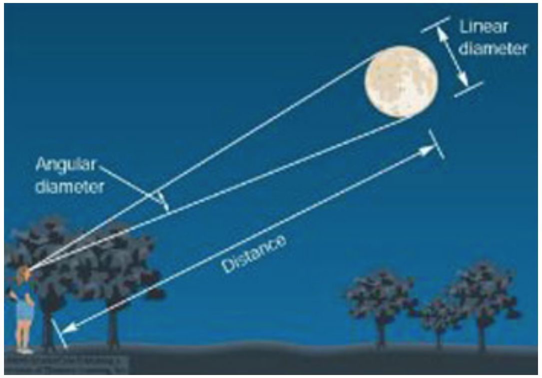




Tom Buckley -Houston

Telescopes

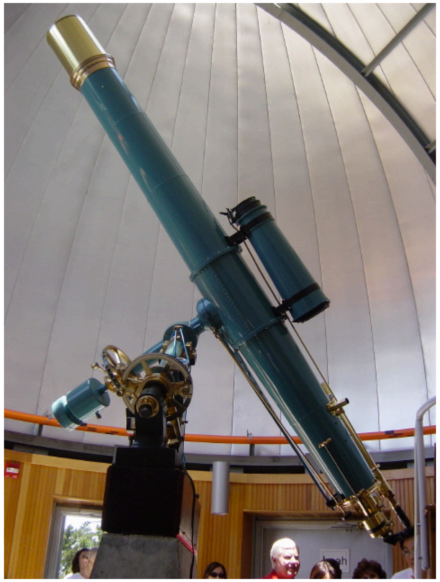
What are the types of telescopes?

Optical telescopes

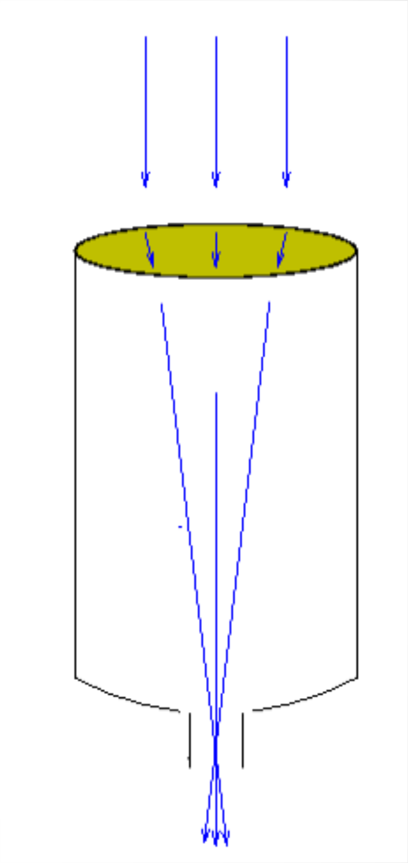
What are the types of telescopes?

1. **Refractors**: use of lenses to focus light

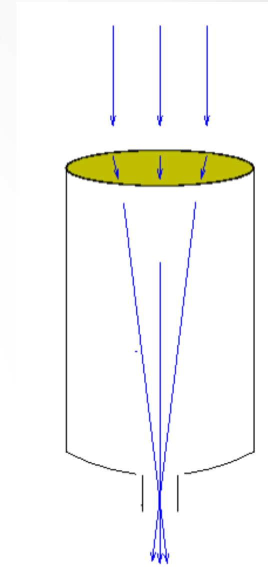
Eyepiece is a lens attached to the telescope located near the focal point.



20cm Chabot space center



Optical telescopes

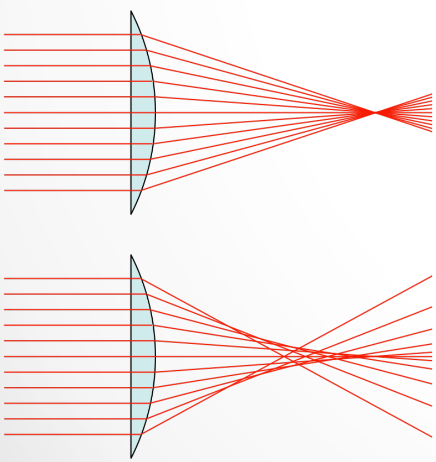


What are the types of telescopes?

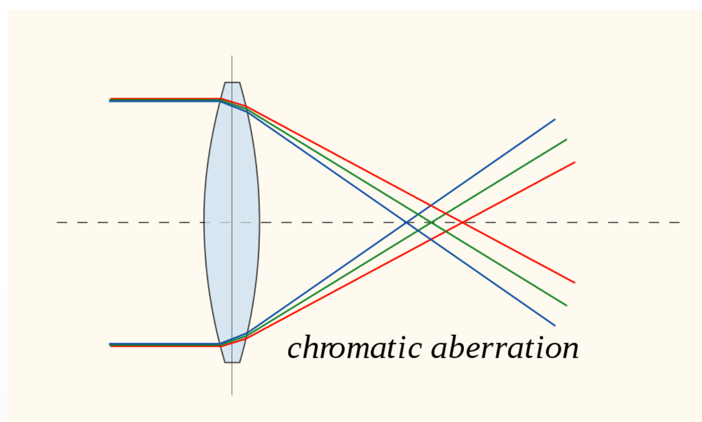
1. **Refractors**: use of lenses to focus light

Problems:

- Suffer from chromatic and spherical aberration
- In large apertures, lens sagging: deformation of lens by gravity



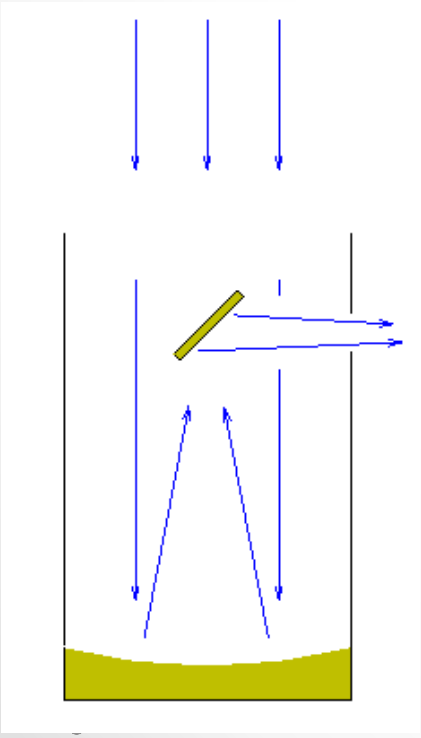
spherical aberration



Optical telescopes

What are the types of telescopes?

2. **Reflectors**: use of curved mirrors to reflect light
   - Most current major world telescopes are reflectors

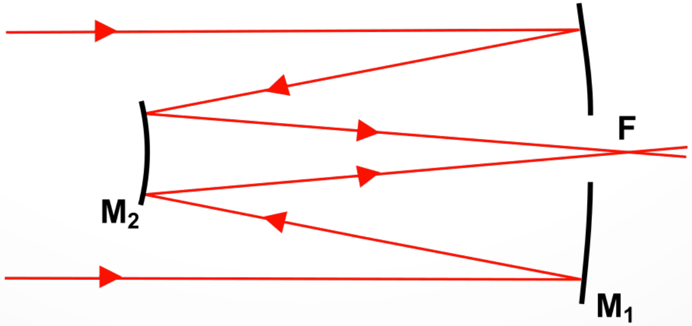


Newtonian

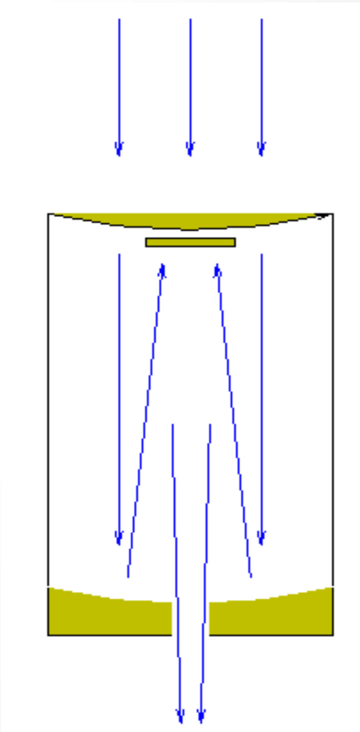
Newtonian: parabolic primary mirror sends light to secondary flat mirror that sends to instrument

Schmidt-Cassegrain: (weak lens) parabolic primary, and hyperbolic secondary

Ritchey-Chrétien: hyperbolic primary and secondary



Ritchey-Chrétien



Schmidt-Cassegrain

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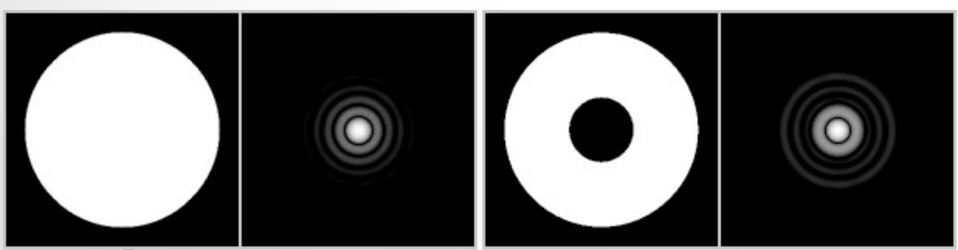
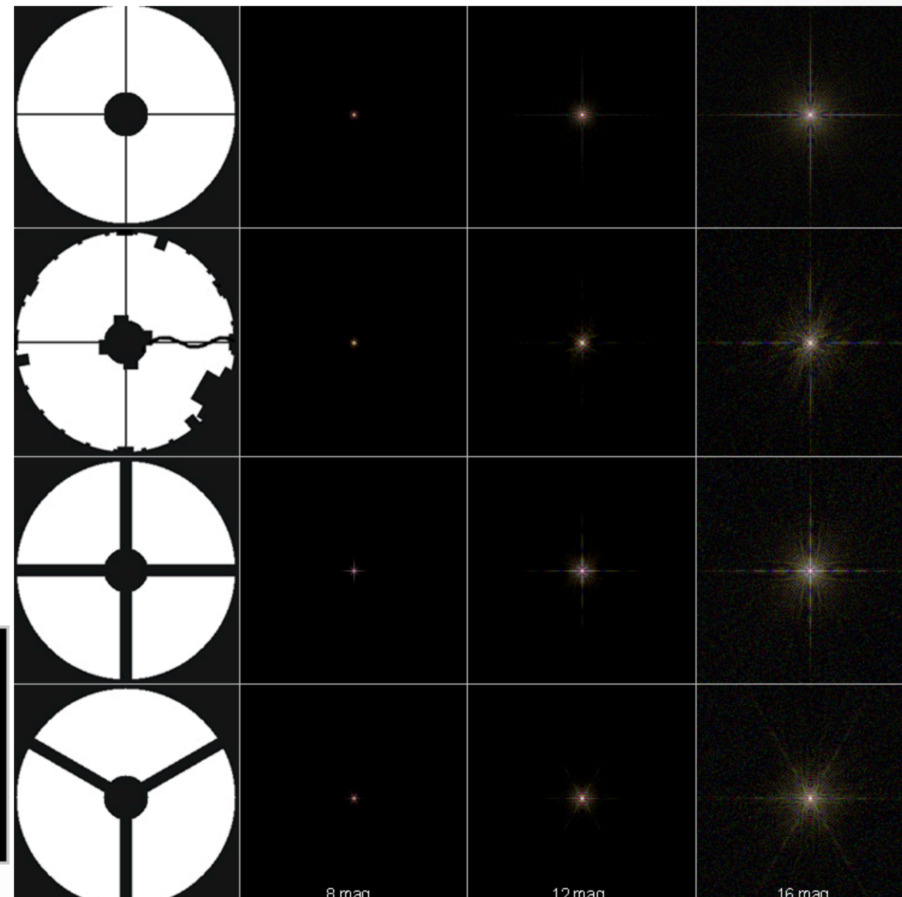
- No chromatic aberration
- No spherical aberration with parabolic/hyperbolic mirrors

Optical errors:

- Secondary mirror: reduction of some incoming light + contrast loss from diffraction effects of obstruction





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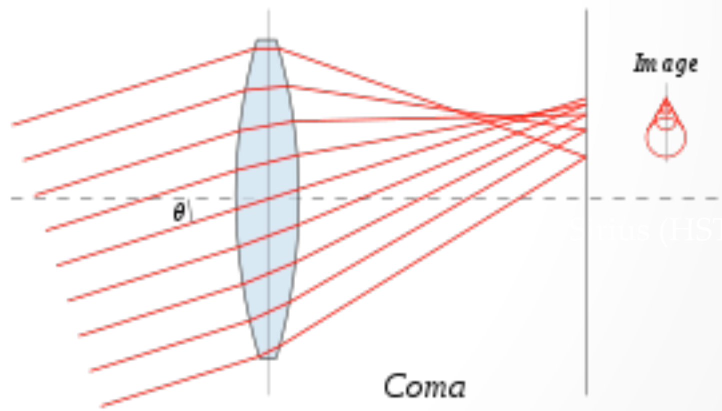
- Others like coma, astigmatism, distortion. They are corrected with more optical elements or image post-processing



Telescopes

Some telescope characteristics:

- Collect light: **light-gathering power**
- See small details: **angular resolution**
- **Magnification** makes object appear larger
- **Focal length** and **focal ratio**

Other telescope related concepts

- Create image of a region of the sky: **field of view**
- Move to a another object: **slewing**
- Point to a particular object/region: **pointing**
- Track objects on the sky: **tracking**
- Direct light to instruments: you need an **instrument**

Light-gathering power

Light gathering power or aperture gain is directly related to the size or aperture of the main optical element

Difference in capacity to collect photons between two telescopes:

$$P = \frac{A_1}{A_2} = \left(\frac{D_1}{D_2}\right)^2$$

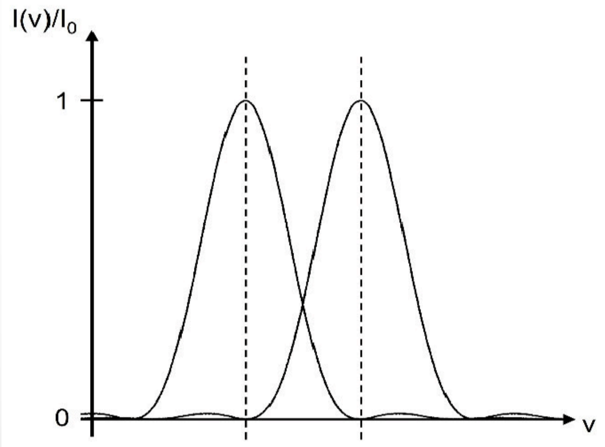
Compared with eye's pupil (D_p = 7mm), a telescope of D = 40cm has P = 3.3×10^5

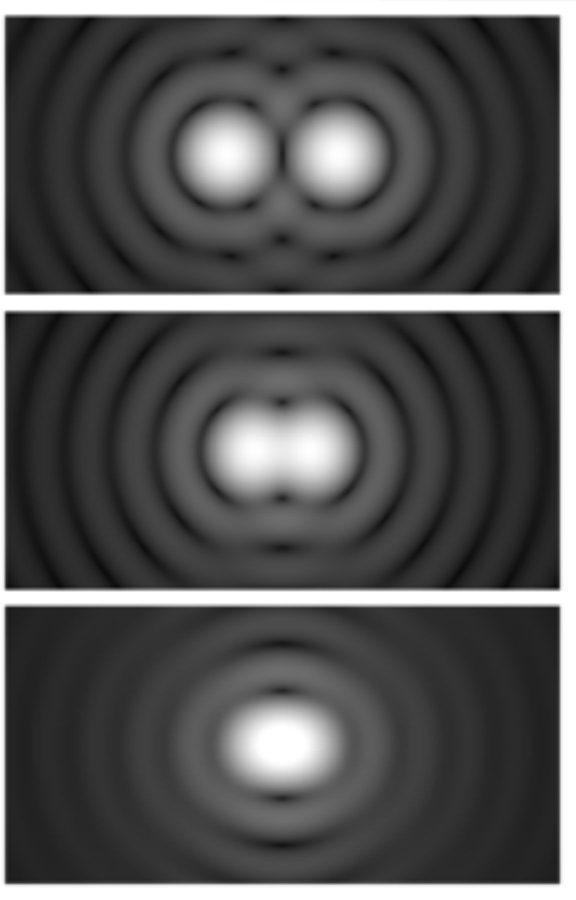
Angular resolution

Ability of a telescope to distinguish small details of an object improving **image resolution**.

Rayleigh criterion:

Two point sources are regarded as just resolved when the principal diffraction maximum of one image coincides with the first minimum of the other





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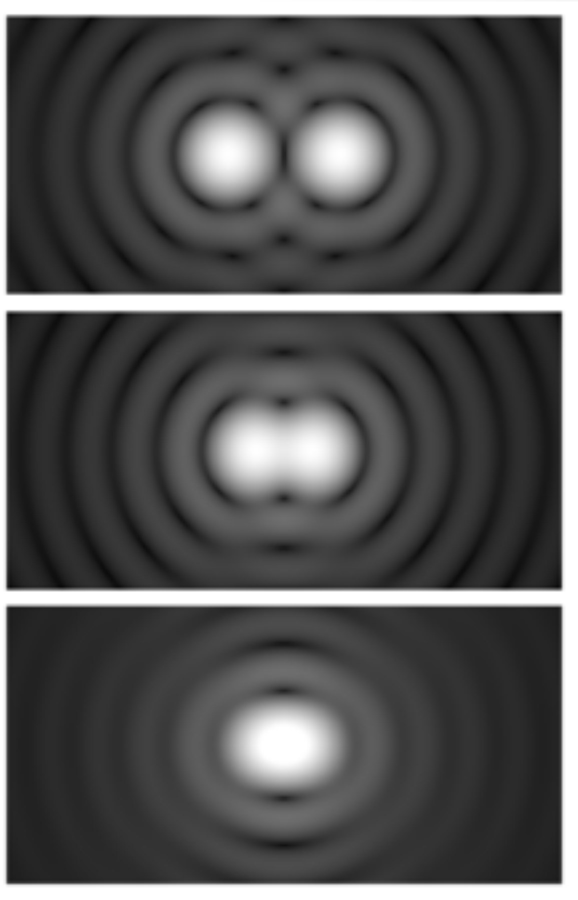
Ability of a telescope to distinguish small details of an object improving **image resolution**.

Rayleigh criterion: $\sin(\alpha_{min}) = 1.22\frac{\lambda}{D}$

Angular resolution

Wavelength

Aperture diameter



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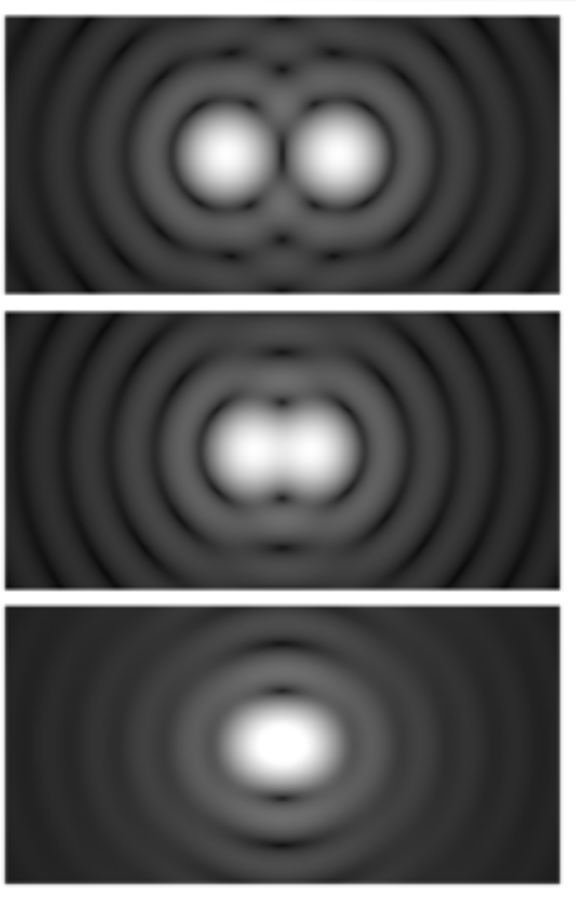

Angular resolution is increased with **interferometry**: use of several telescopes:

$$\alpha_{\min} \approx \frac{\lambda}{B}$$

Baseline: distance between two farthest telescopes

Angular resolution

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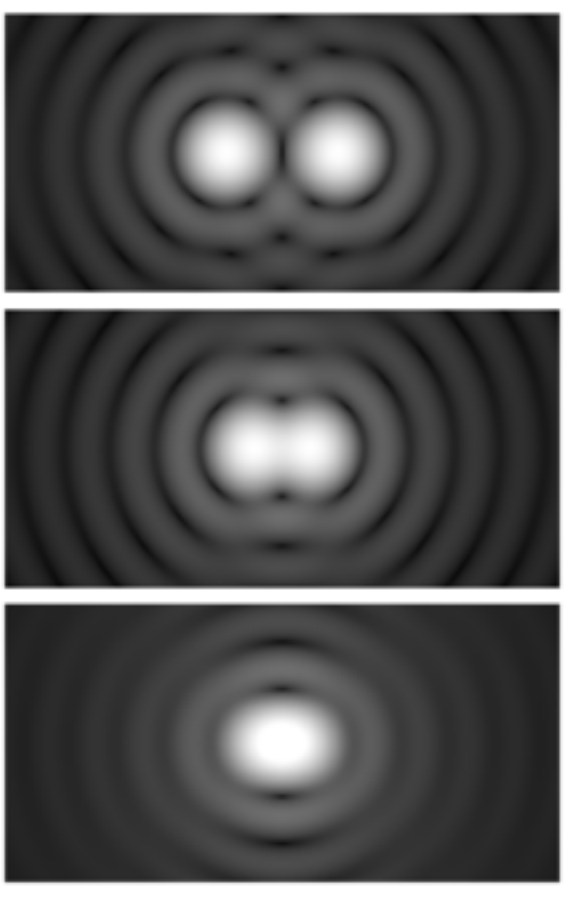
Rayleigh criterion: $$\sin(\alpha_{\min}) = 1.22\frac{\lambda}{D}$$

Human eye: D=5mm, λ =550nm

$\alpha_{\min} \approx 27''$

In reality it's worse cause not the entire pupil diameter is used



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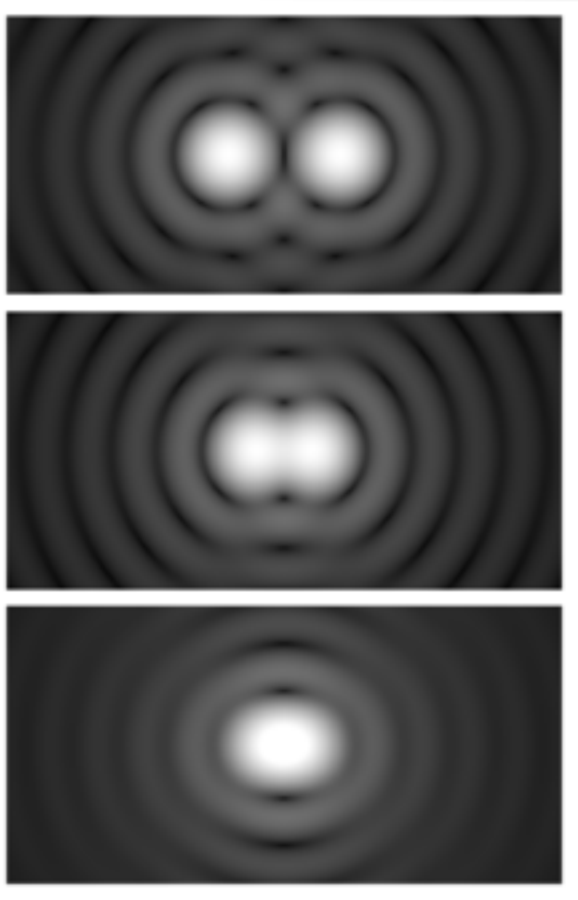


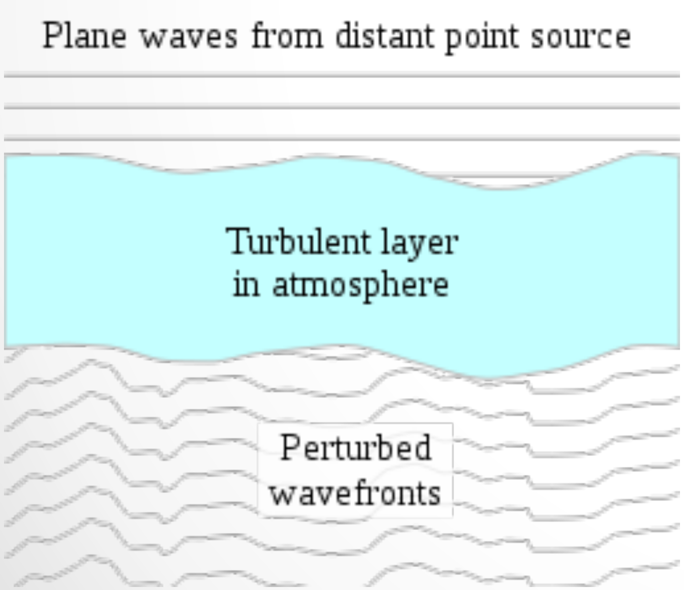
Human eye: D=5mm, $\alpha_{min} \approx 27''$
Small telescope: D=10cm, $\alpha_{min} \approx 1.4''$
Medium telescope: D=1m, $\alpha_{min} \approx 0.14''$
Large telescope: D=8m, $\alpha_{min} \approx 0.02''$

Only true outside of the Earth's atmosphere!

Seeing

Rayleigh criterion: $\sin(\alpha_{\min}) = 1.22\frac{\lambda}{D}$

In reality, on the ground resolution is limited by atmospheric turbulence (**seeing**), optics, etc.



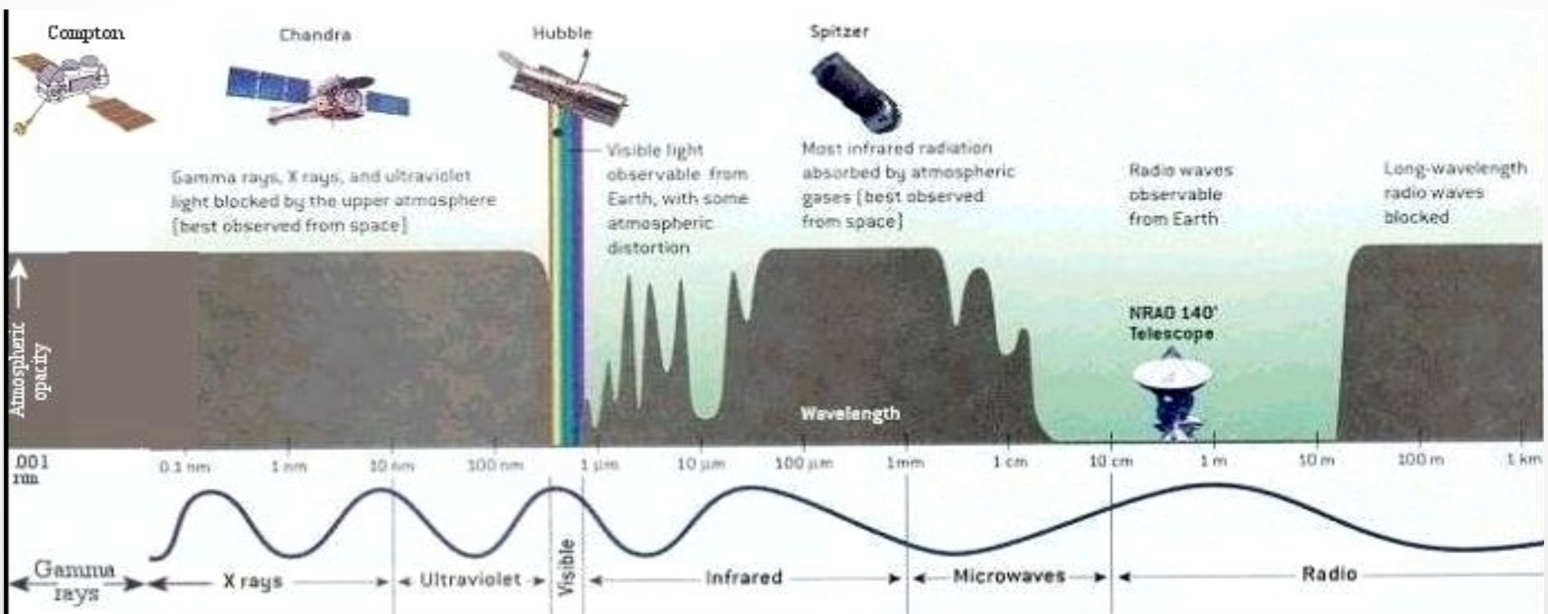
Seeing: blurring and twinkling

Seeing

The images in the atmosphere are blurred because of seeing. Seeing is measured in arcseconds.

- Seeing is **wavelength** dependent

$\alpha_{seeing}(550nm) \approx 1''$ whereas $\alpha_{seeing}(2.2\mu m) \approx 0.75''$



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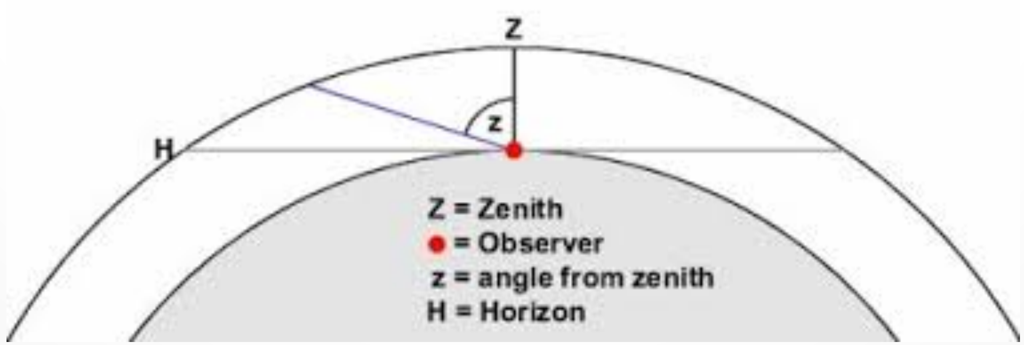
- Seeing is **airmass** dependent: higher airmass means a thicker layer of atmosphere ➔ more turbulence

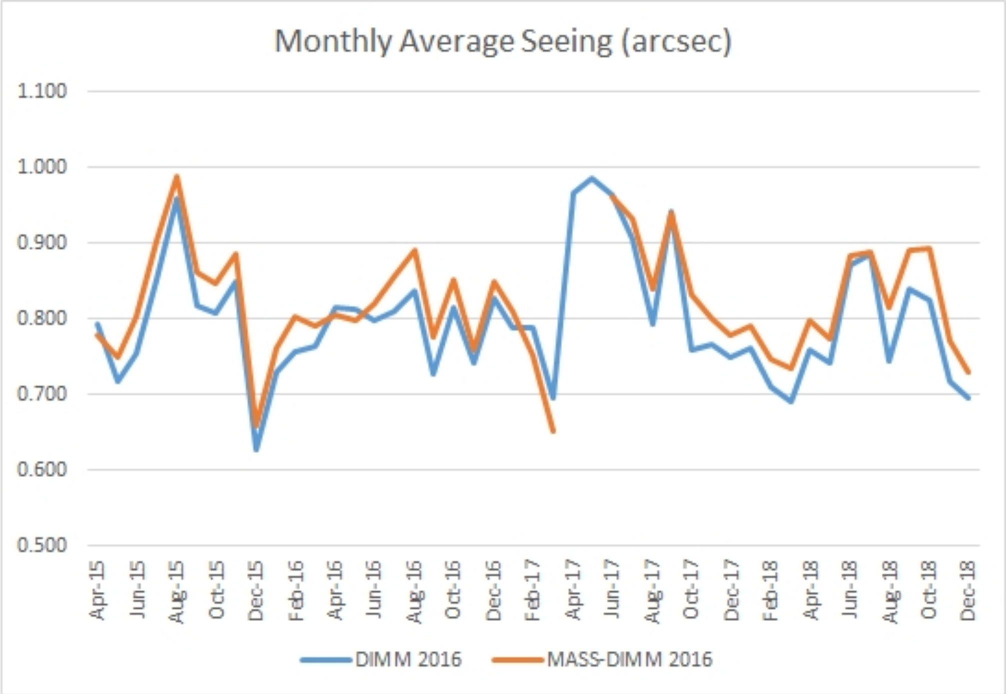


Seeing

The images in the atmosphere are blurred because of seeing. Seeing is measured in arcseconds.

Median seeing at one of the best astronomical sites in the world is ~ 0.7'' (in Lisbon, seeing is >3-4'')

This is comparable to the angular resolution of a 20 cm telescope!



Seeing

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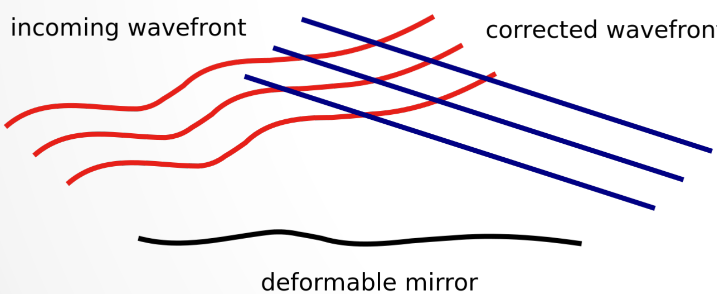
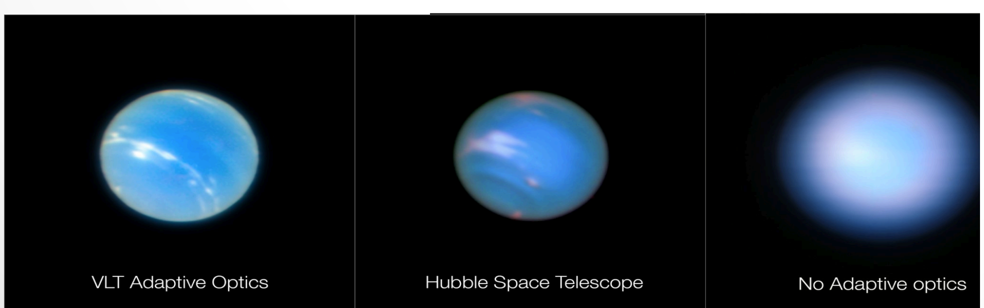
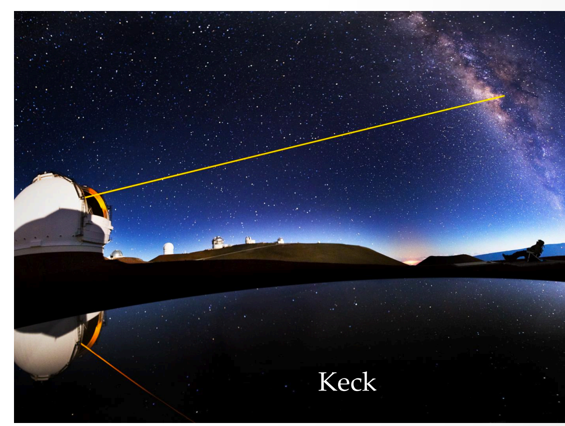
Seeing

If seeing at Paranal does not allow us to see ay better than a telescope of 20cm, why build an 8m telescope?

- Light-gathering power is many times larger, so we can detect much fainter objects
- Modern techniques like **Adaptive Optics** to correct for the effect of atmospheric turbulence







Focal length and ratio

Focal length: measure of strength of convergence/divergence of the light. It is the distance to bring rays into focus.

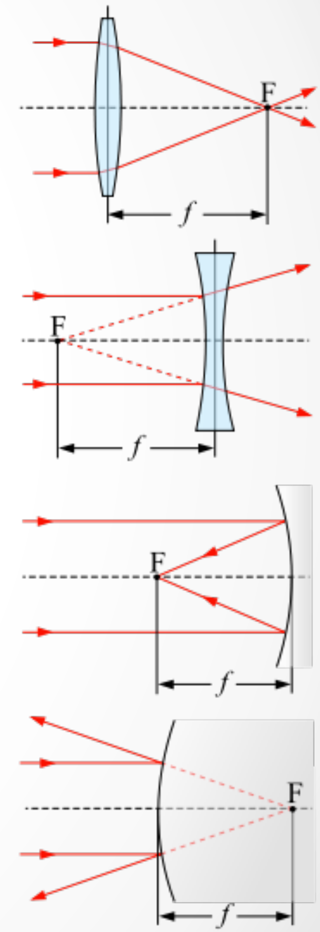
Effective focal length:

$$1/F = 1/f_1 + 1/f_2$$

Focal ratio: ratio of focal length to aperture diameter

$$N = f/D$$

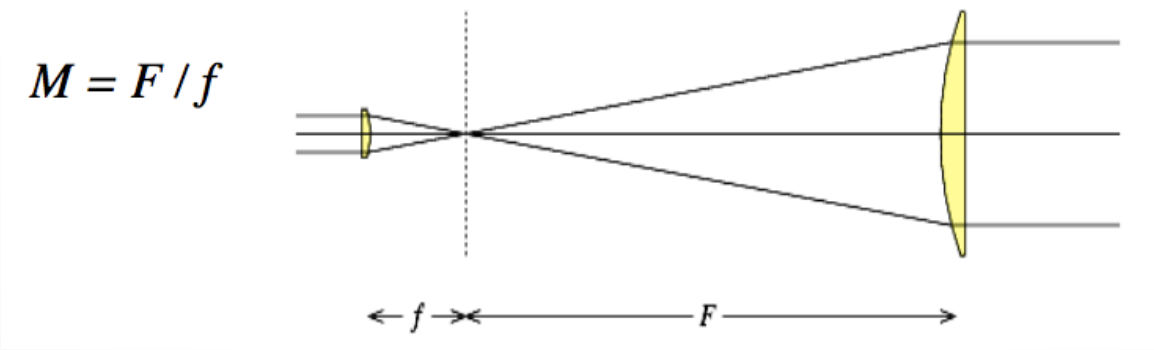
Ex: f=10mm and D = 5mm, N = 2 or "f/2"



Magnification

This is not the most important thing, because detail is limited by amount of light (and seeing). You may magnify an object that is unresolved and it will remain unresolved.

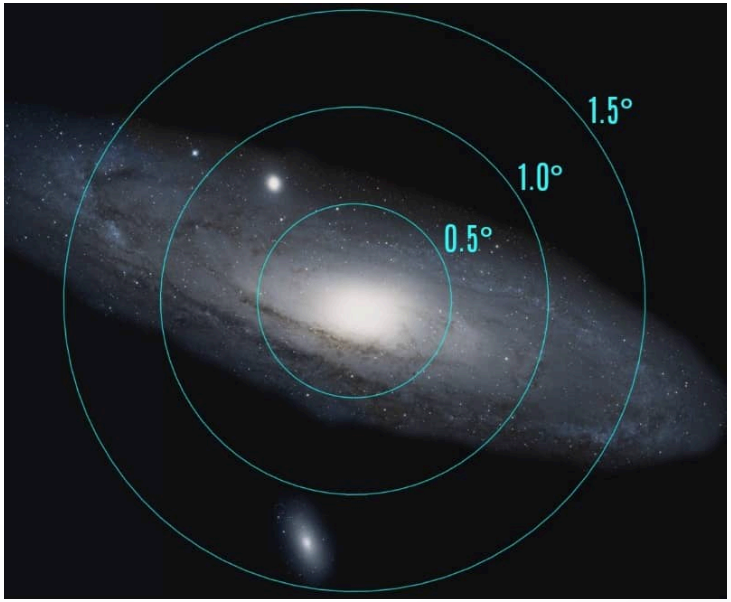
Magnification = telescope focal length / eyepiece focal length



Field of view

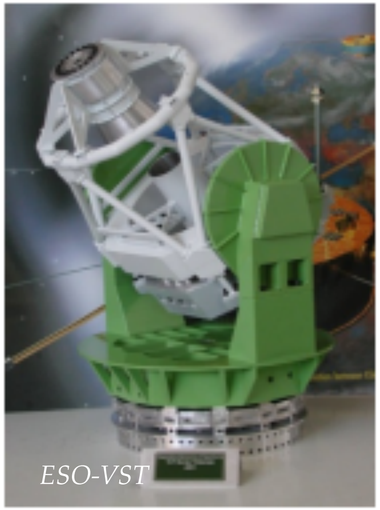
Field of view (FOV): observable angular area an optical device can see

Maxium FOV: Due to diffractions of the optics of a telescope



Telescope mounts

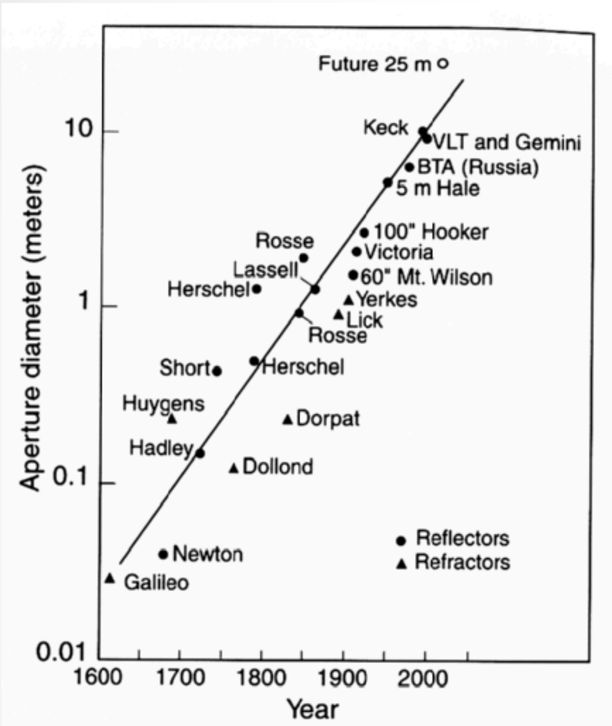
1. **Alt-azimuth mount**: one axis for azimuth and another for altitude. Simple design but complex two-axis movement to follow Earth rotation. For large telescopes support goes through center of mass and there are less torques
2. **Equatorial mount (RA,DEC)**: one axis aligned to the rotational axis of Earth (celestial pole). It can easily follow objects as they move through the sky

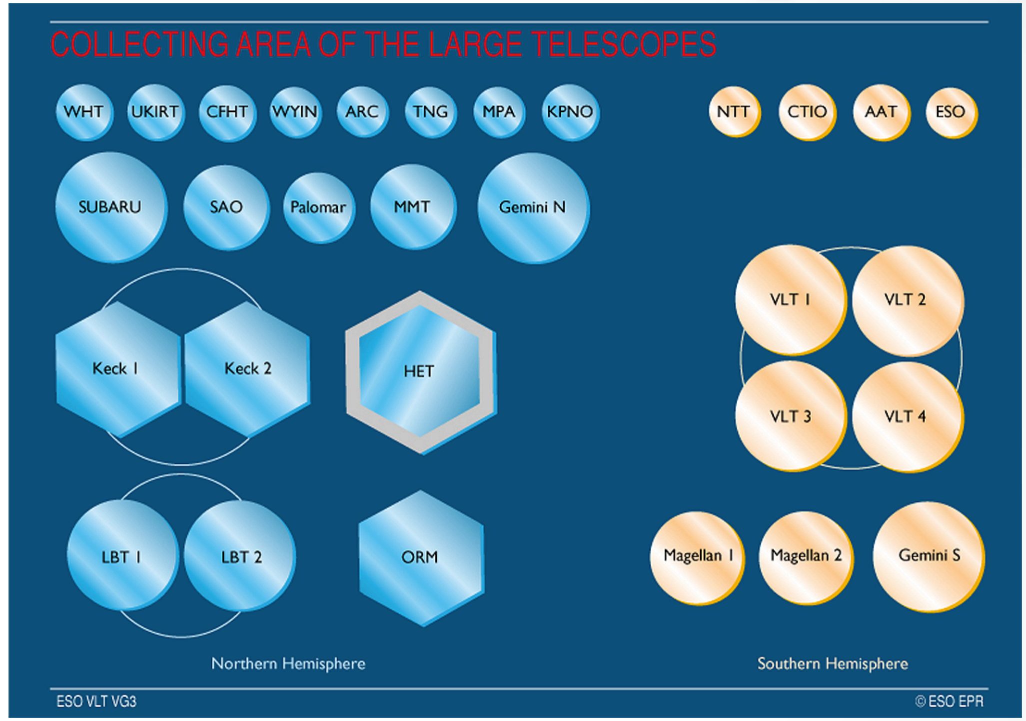


Telescope movement

- **Slewing:** movement of the telescope
- **Tracking**: a device that moves the mount at sidereal rate (Earth rotation), so that there are no star trails
- **Pointing**: Precision of telescope to target an object
- **Guiding**: more accurate pointing by using a star to keep telescope pointing fixed. This need another camera that takes shorter exposures.

World optical telescopes





Future telescopes:

E-ELT (39m), GMT (24.5m), TMT (30m)