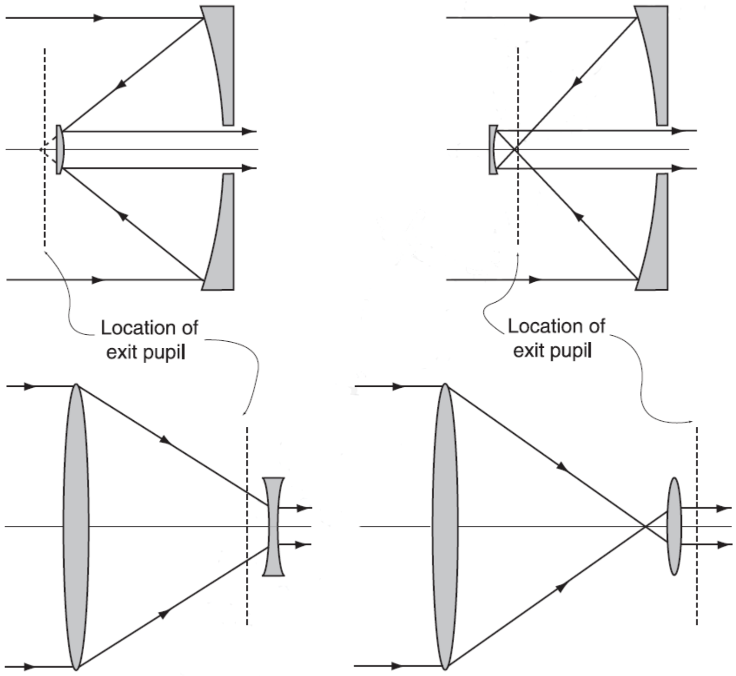
Astronomische Waarneemtechnieken (Astronomical Observing Techniques)

3rd Lecture: 17 September 2012



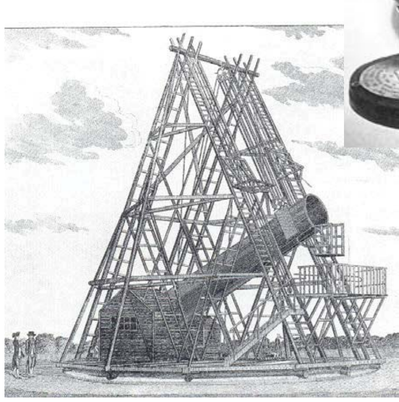
1. History
2. Mounts
3. Orbits
4. Basic Optics
5. Foci
6. Mass, Size, ...
7. Non-optical Tel.

1. History of Telescopes

- Hans Lipperhey 1608 – first patent for “spy glasses”

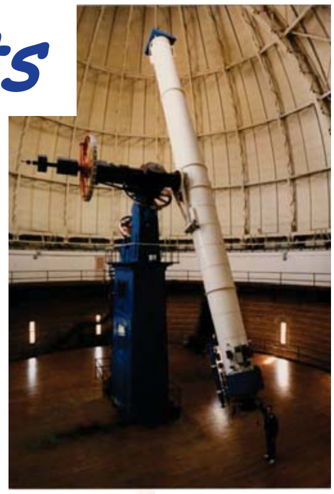
- Galileo Galilei 1609 – first use in astronomy

- Newton 1668 – first refractor

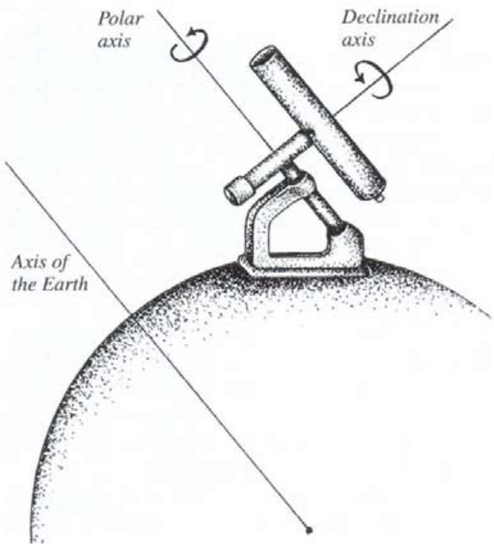


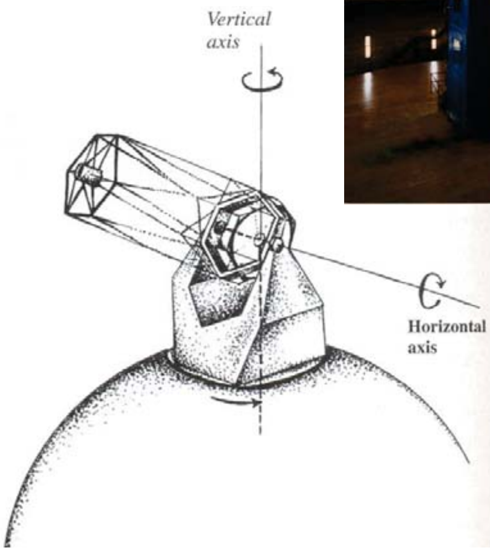
- Kepler – improves reflector
- Herschel 1789 – 4 ft refractor
- ...

2. *Ground-based Telescopes:* **Mounts**



Two main types:
1. Equatorial mounting
2. Azimuthal mounting





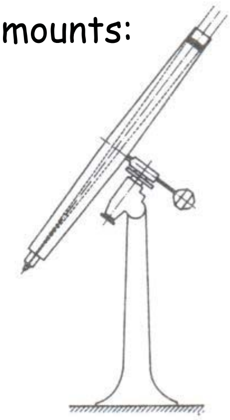
Equatorial:
+ follows the Earth rotation
- typically much larger and massive

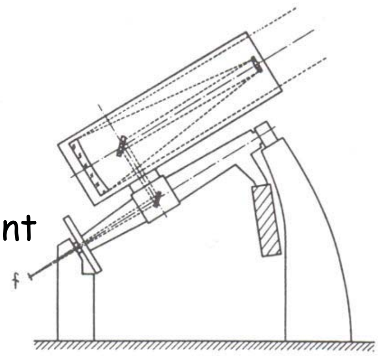
Azimuthal:
+ light and symmetric
- requires computer control

Telescope Mounts (2)

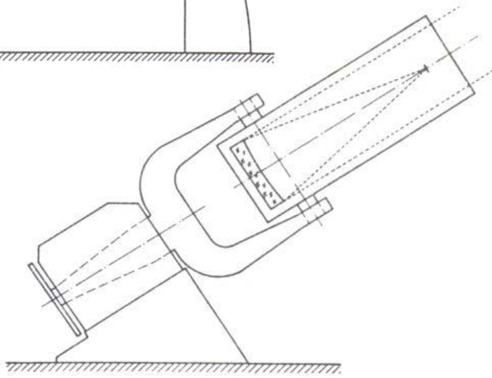
Variations of equatorial (or parallactic) mounts:

- German mount





- English mount

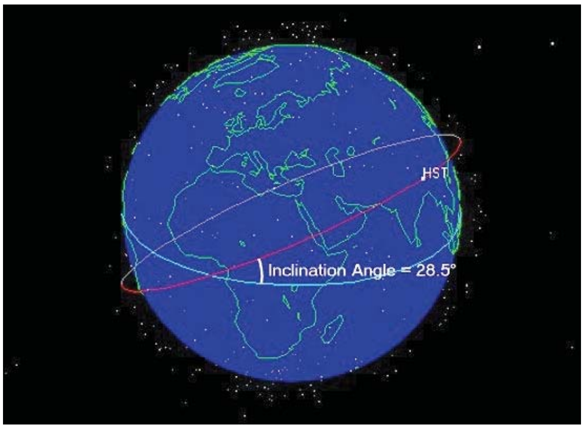


- Fork mount

3. Space Telescopes: Orbits

Choice of Orbits:

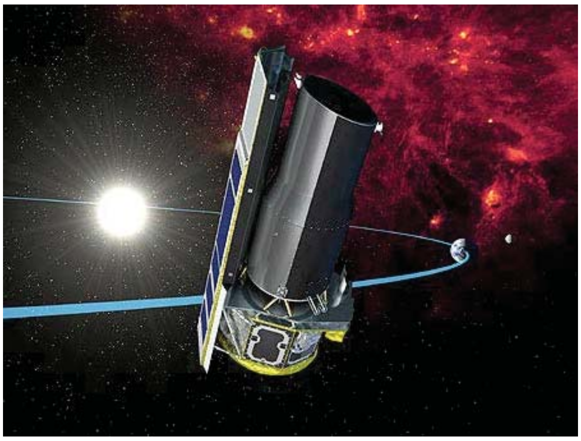
- communications
- thermal background radiation
- space weather
- sky coverage
- access (servicing)



Two Examples:

HST : low Earth orbit ~96 minutes

Spitzer: Earth-trailing solar orbit ~60 yr

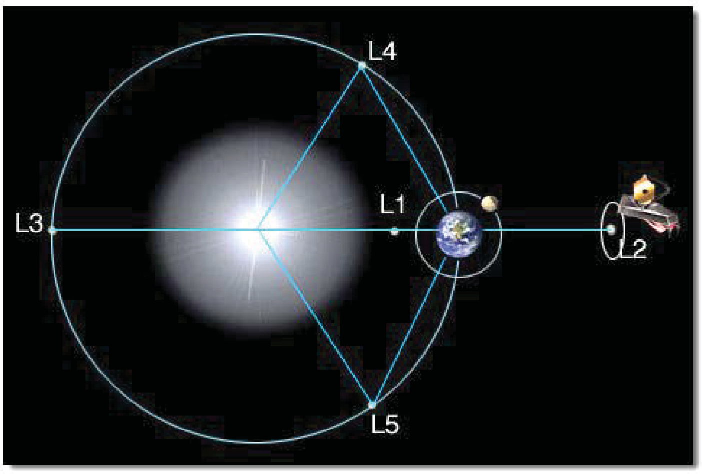


Lagrange Points

Joseph-Louis Lagrange: mathematician (1736 – 1813)

Is there a stable configuration in which three bodies* could orbit each other, yet stay in the same position relative to each other?

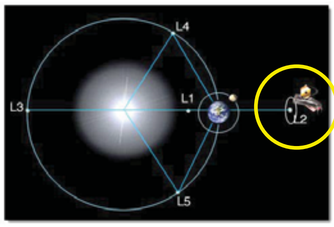
→ five solutions, the five Lagrange points.



*Sun-Earth-Satellite

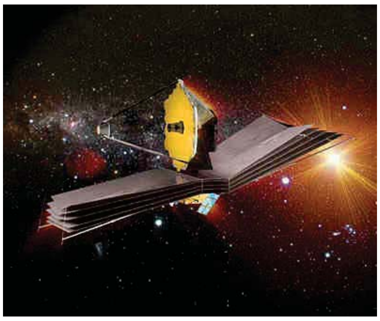
An object placed at any one of these 5 points will stay in place relative to the other two.

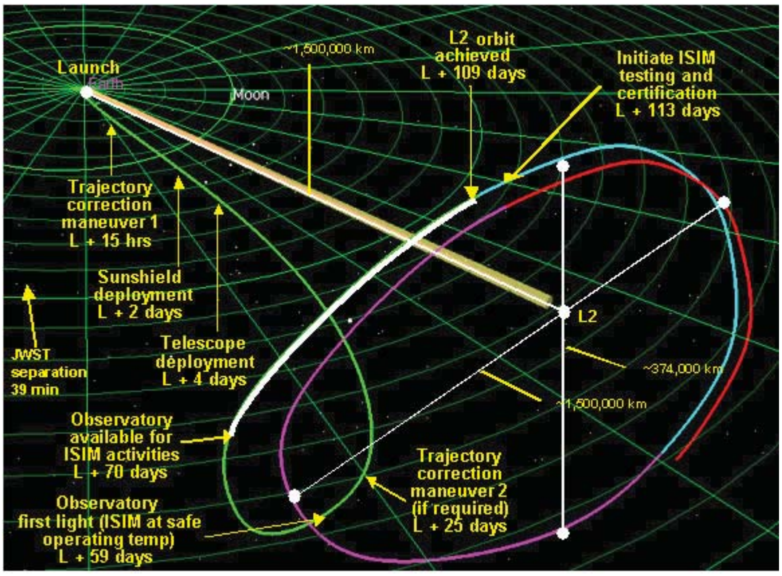
The L2 Orbit



JWST, WMAP, GAIA and Herschel are/will be in orbits around the L2 point:

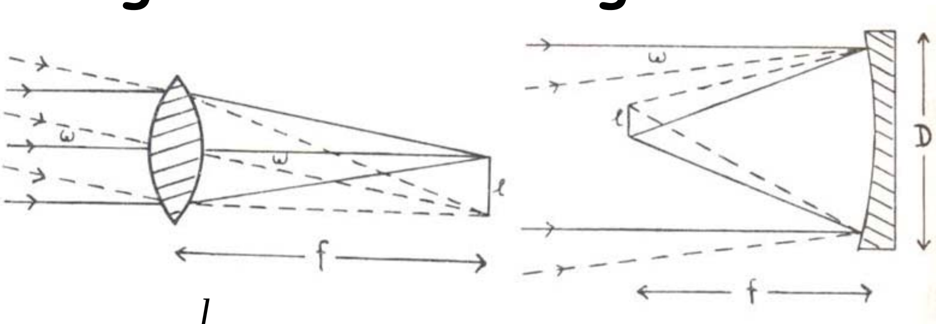
+ sun-shields
- radiation



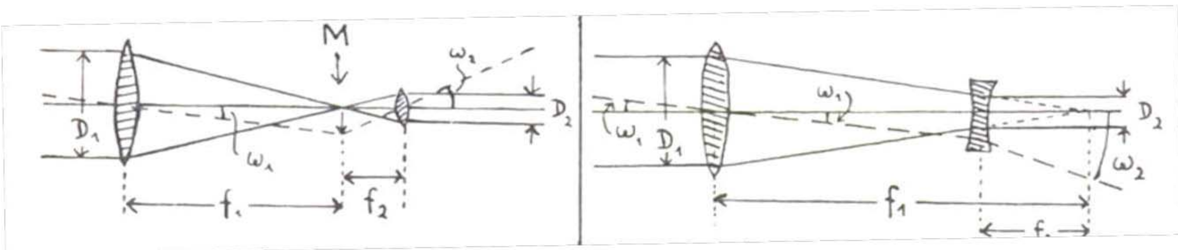


4. Basic Telescope Optics

Image Scale and Magnification



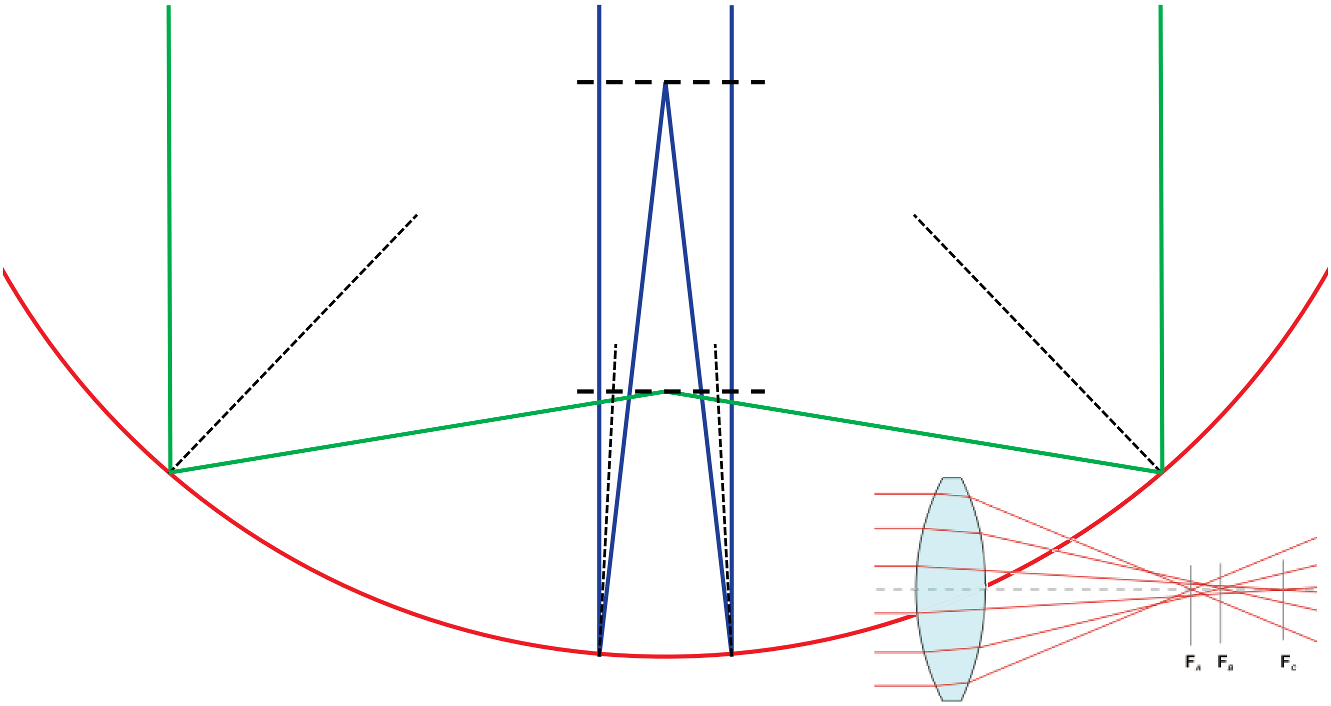
Scale: $\tan\omega = \frac{l}{f}$ and for small ω: $l \approx 0.0175\omega f$



Magnification: $V = \frac{f_1}{f_2} = \frac{D_1}{D_2} = \frac{\omega_2}{\omega_1}$

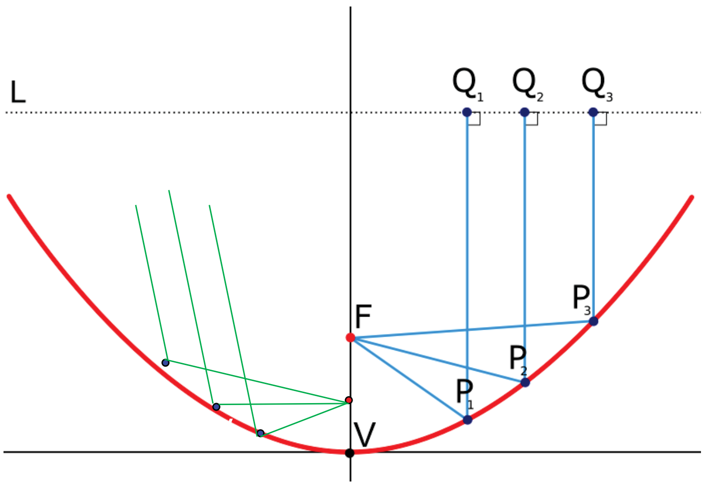
Spherical and Parabolic Mirrors

Spherical primary mirrors provide a large field of view (FOW) but rays more distant from the optical axis have a different focal point → aberrations → limited size, curvature!



Spherical and Parabolic Mirrors (2)

Parabolic primary mirrors focus all rays from the same direction to one point.
But: different directions have different focal points.

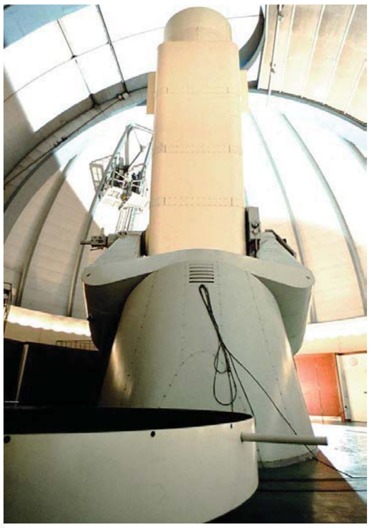


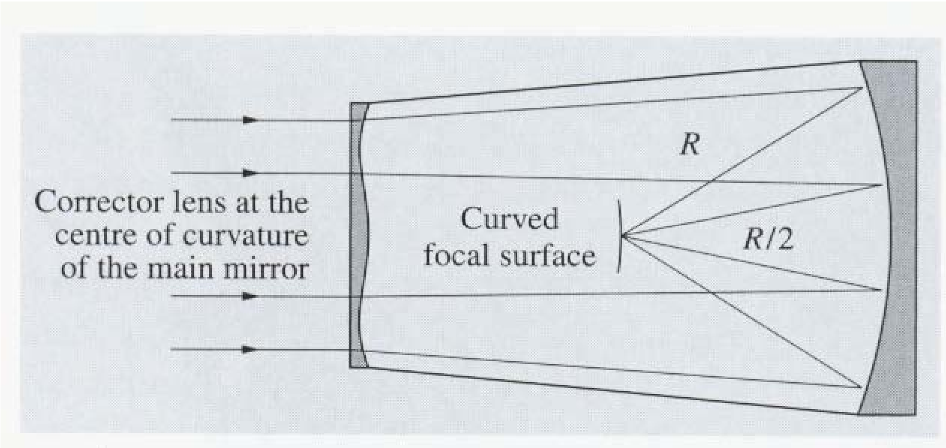
→ FOV is limited by aberrations: the bigger the mirror the bigger the difference [parabola – sphere] near the edge → bigger telescopes have smaller FOVs (~<1 deg).

The Schmidt Telescope

Idea:

1. Use a spherical primary mirror to get the maximum field of view (>5 deg) → no off-axis asymmetry *but* spherical aberrations, and
2. correct the spherical aberrations with a corrector lens.



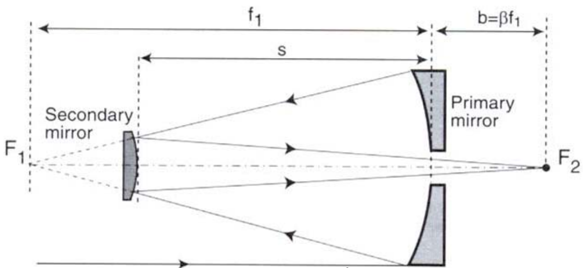


Two meter Alfred-Jensch-Telescope in Tautenburg, the largest Schmidt camera in the world.

The Ritchey-Chrétien Configuration

Astronomers George Willis Ritchey and Henri Chrétien found in the early 20th century that the combination of a hyperbolic primary mirror and a hyperbolic secondary mirror eliminates (some) optical errors (3rd order coma and spherical aberration).

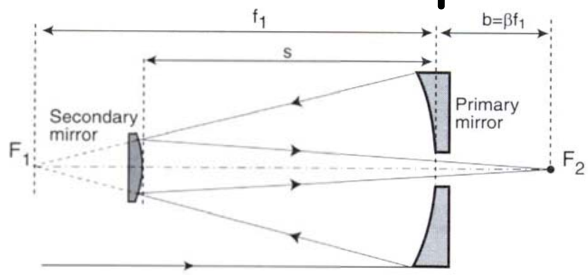
RC telescopes use two hyperbolic $\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$ mirrors, instead of a parabolic $y - ax^2 = 0$ mirror.



→ large field of view & compact design (for a given focal length)

→ most large professional telescopes are Ritchey–Chrétien telescopes

Parameters of a Ritchey-Chrétien Telescope



Optical parameters	
Primary mirror diameter	D_1
Primary mirror f-ratio	N_1
Primary mirror focal length	$f_1 = N_1 D_1$
Backfocal distance	$b = \beta f_1$
Normalized back focal distance	$\beta = b/f_1$
Magnification of secondary mirror	$m = f/f_1$
Primary–secondary separation	$s = (f-b)/(m+1)$
Secondary mirror focal length	$f_2 = m(f_1+b)/(m^2-1)$
Primary mirror conic constant	$\kappa_1 = -1 - \frac{2(1+\beta)}{m^2(m-\beta)}$
Secondary mirror conic constant	$\kappa_2 = -\left(\frac{m+1}{m-1}\right)^2 - \frac{2m(m+1)}{(m-\beta)/(m-1)^3}$
Secondary mirror dia. (zero field)	$D_2 = D_1(f_1+b)/(f+f_1)$
Obscuration ratio (no baffling)	D_2/D_1
Final f-ratio	N
Final focal length	$f = ND_1 = \frac{f_1 f_2}{f_1+f_2-s}$
Field radius of curvature	$\frac{f_1 f^2 (f_1-s)}{f f_1^2 + s(f^2-f_1^2)}$
Aberrations	
Angular astigmatism	$\frac{\theta^2}{2F}\frac{m(2m+1)+\beta}{2m(1+\beta)}$
Angular distortion	$\theta^3 \frac{(m-\beta)}{4m^2(1+\beta)^2}(m(m^2-2)+\beta(3m^2-2))$
Median field curvature	$\frac{2}{R_1}\frac{(m+1)}{m^2(1+\beta)}(m^2-\beta(m-1))$

Light Gathering Power and Resolution

Light gathering power

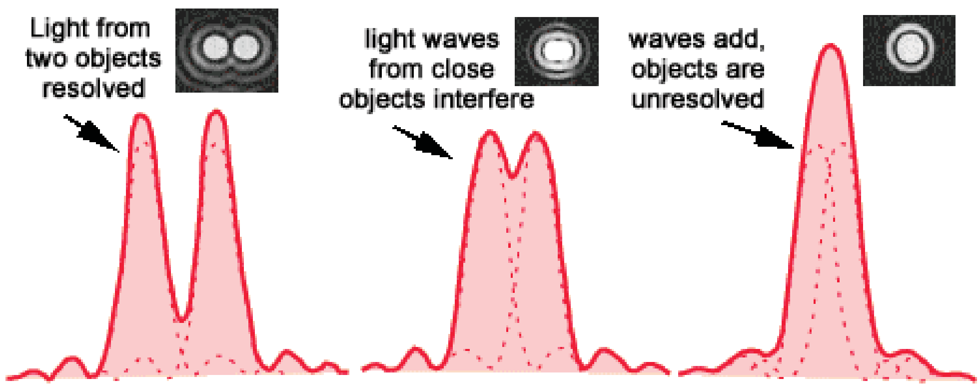
For extended objects: $S/N \propto \left(\frac{D}{f}\right)^2$ (see lecture on S/N)

For point sources: $S/N \propto D^2$

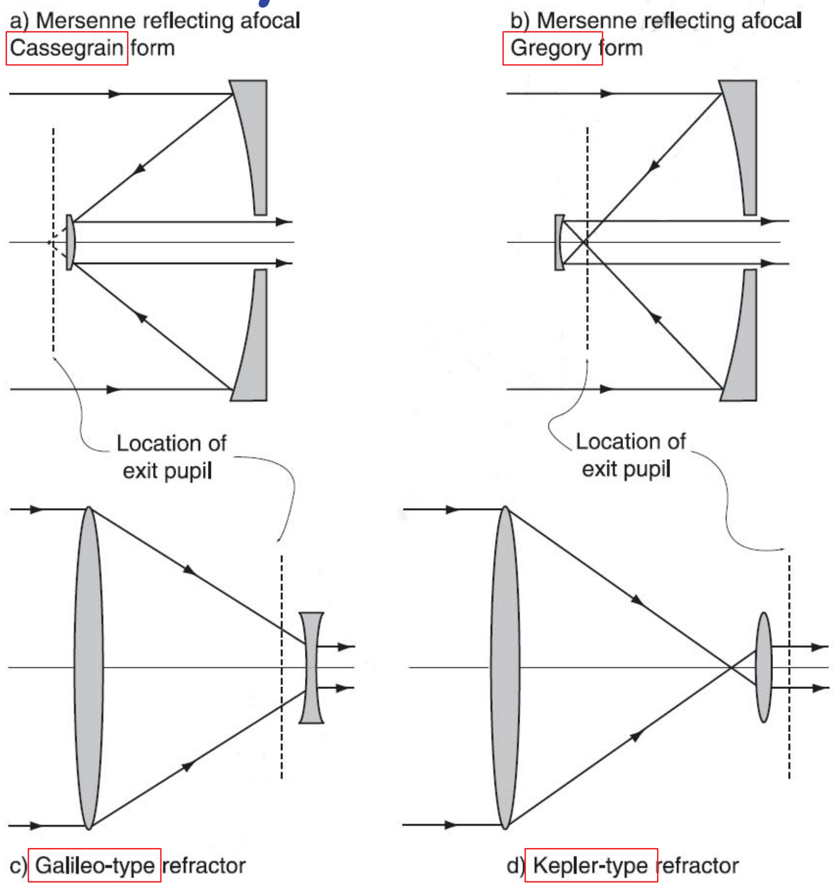
Angular resolution

$$\sin\Theta = 1.22\frac{\lambda}{D} \quad \text{or} \quad \Delta l = 1.22\frac{f\lambda}{D}$$

(given by the Rayleigh criterion)



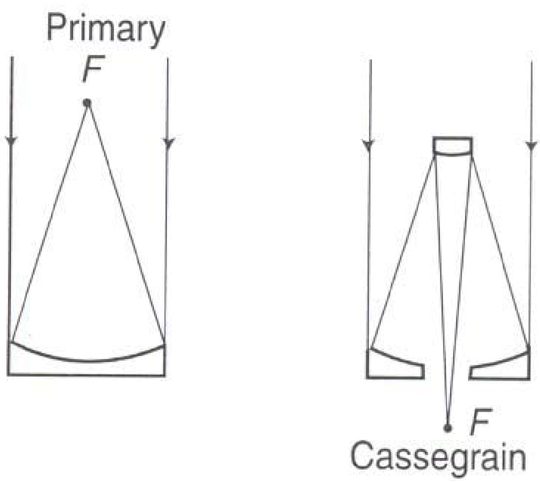
5. Telescope Foci

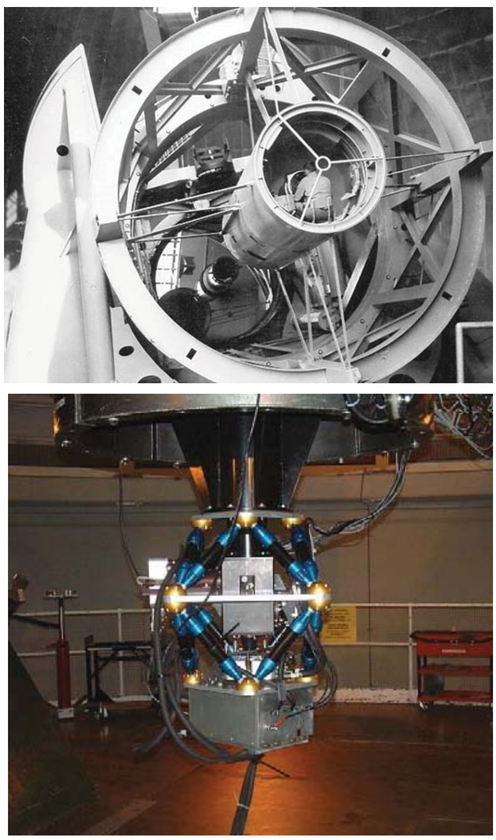


2 fundamental choices:

- Refractor ⇔ Reflector
- Location of exit pupil

Telescope Foci – where to put the instruments

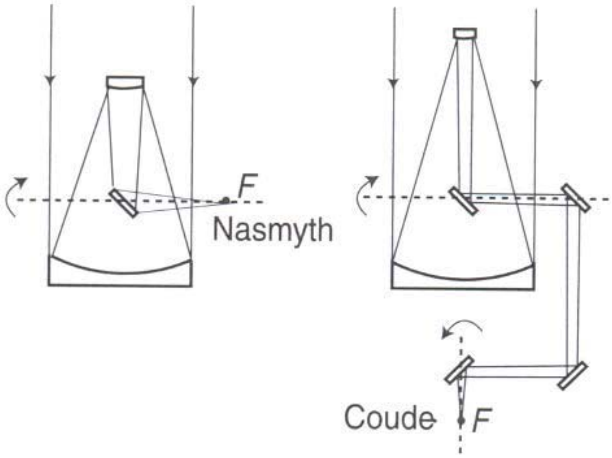




Prime focus – wide field, fast beam but difficult to access and not suitable for heavy instruments

Cassegrain focus – moves with the telescope, no image rotation, but flexure may be a problem

Telescope Foci – where to put instruments (2)



Nasmyth – ideal for heavy instruments to put on a stable platform, but field rotates

Coudé – very slow beam, usually for large spectrographs in the "basement"

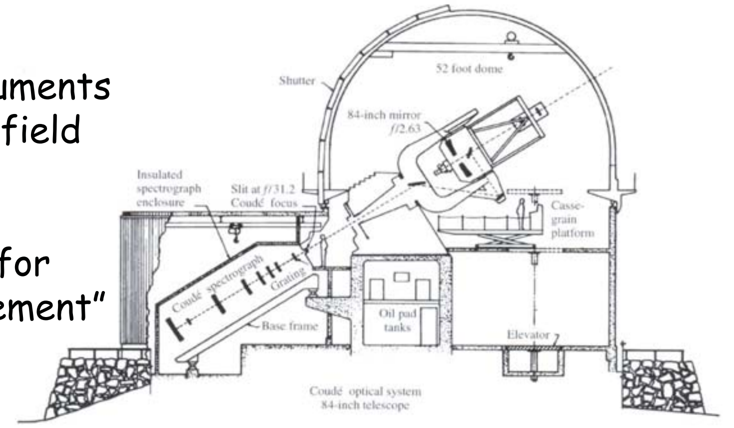
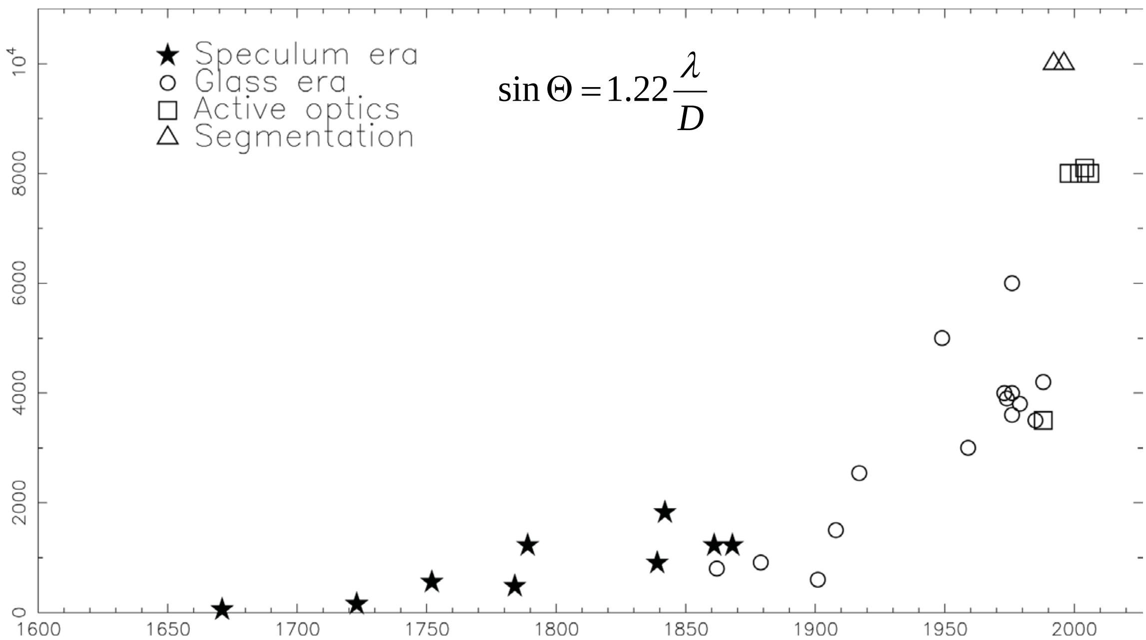


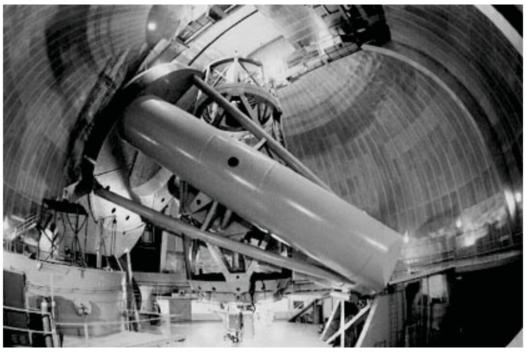
Fig. 3.13. The coudé system of the Kitt Peak 2.1 m reflector. (Drawing National Optical Astronomy Observatories, Kitt Peak National Observatory)

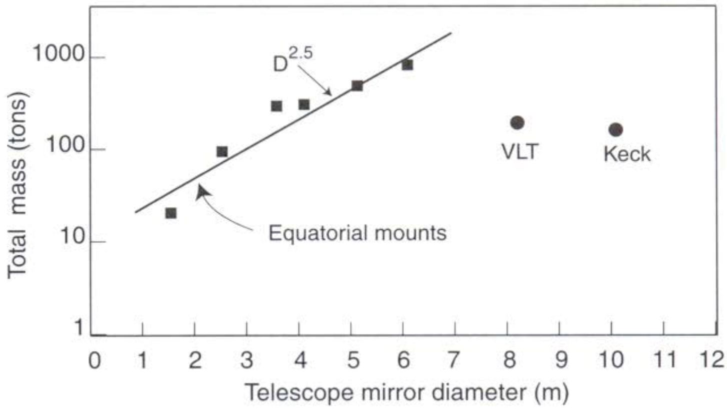
6. Mass, Size, etc.

The Growth of Telescope Collecting Area



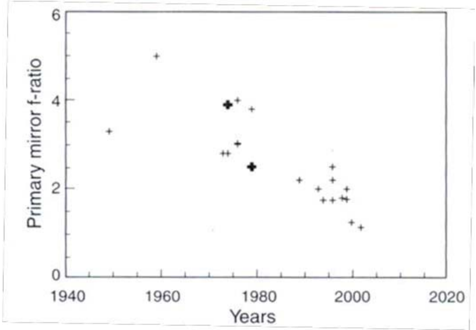
Mass Limitations





Most important innovations:

1. faster mirrors → smaller telescopes → smaller domes
2. faster mirrors ← new polishing techniques
3. bigger mirrors ← thinner / segmented mirrors ← active support



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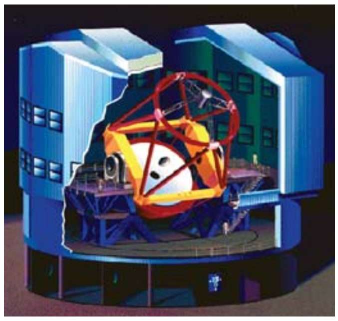
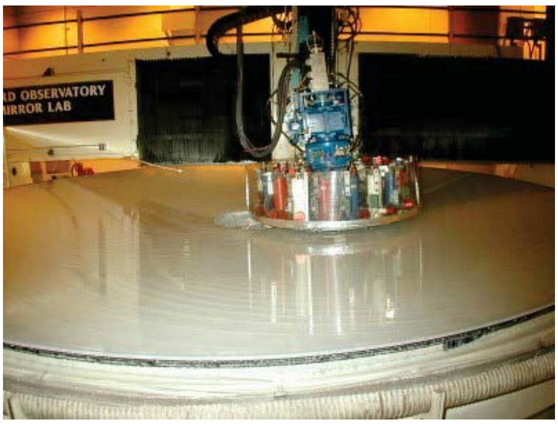


Polishing Techniques

Stressed mirror polishing. 1: A technique for producing nonaxisymmetric mirrors

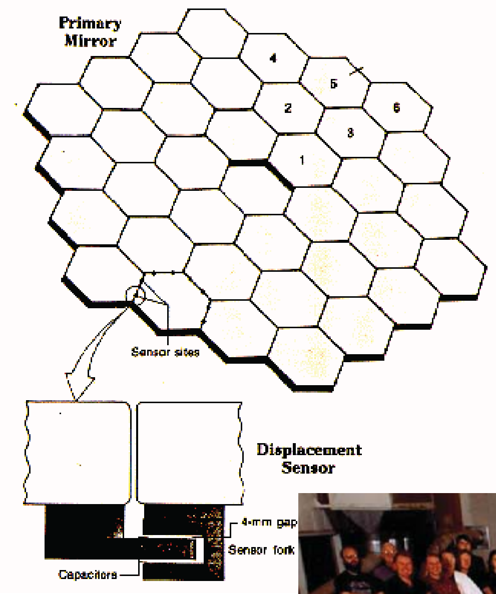
Jacob Lubliner and Jerry E. Nelson (OSA, 1980)

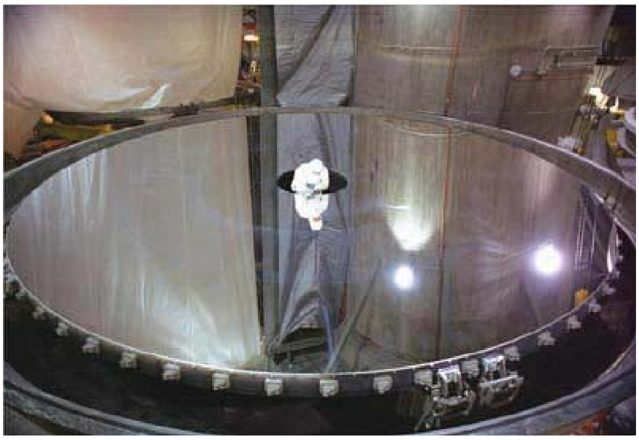
The theoretical basis is developed for a technique to fabricate nonaxisymmetric mirrors. Stresses are applied to a mirror blank that would have the effect of elastically deforming a desired surface into a sphere. A sphere is then polished into the blank, and upon release of the applied stress, the spherical surface deforms into the desired one. The method can be applied iteratively, so arbitrary accuracy should be possible. Calculations of the stresses and deformations are carried out in detail for an off-axis section of a paraboloid. For a very general class of surfaces, it is sufficient to only impose appropriate stresses at the edge of the blank plus a uniform pressure on the back.



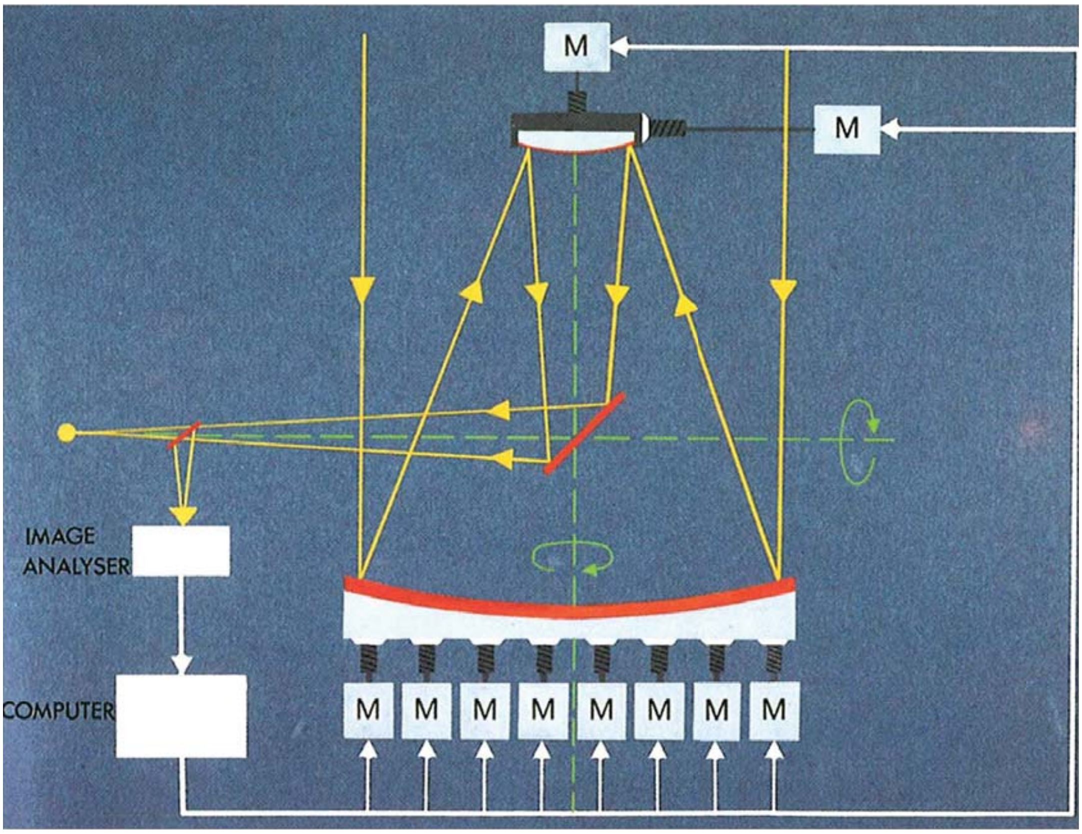
Polishing a 6.5-m mirror on the Large Optical Generator (LOG) using the stressed-lap polishing tool. The lap changes shape dynamically as it moves radially from center-to-edge of the mirror to produce a paraboloid. Our 6.5-m mirrors are typically figured to a focal ratio of f/1.25 with a finished precision of ± 15-20 nanometers.
http://mirrorlab.as.arizona.edu/TECH.php?navi=poli

Segmented, Thin and Honeycomb Mirrors

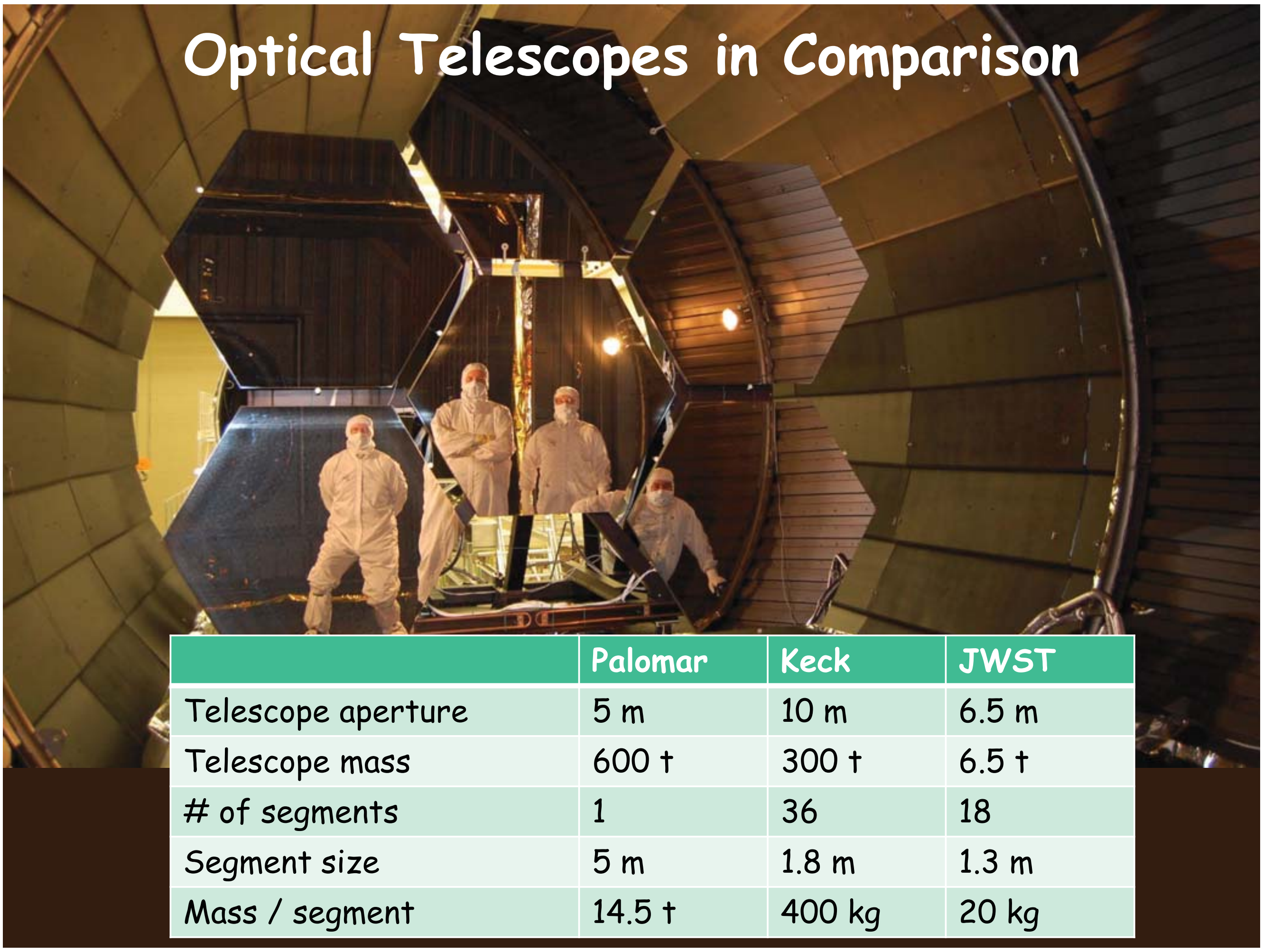




Active Optics (Mirror Support)



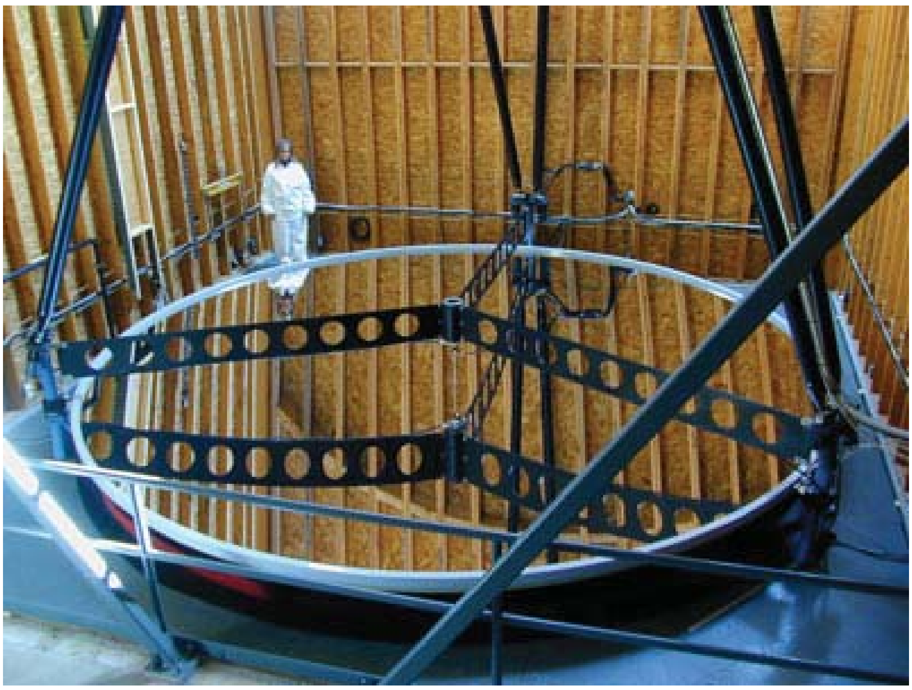
Optical Telescopes in Comparison

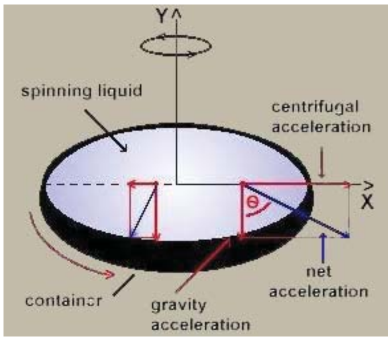


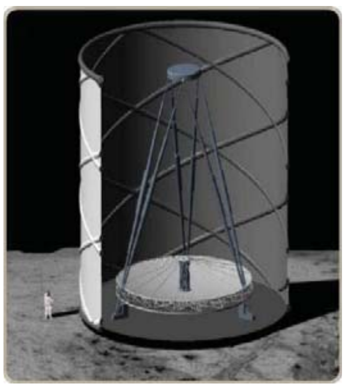
	Palomar	Keck	JWST
Telescope aperture	5 m	10 m	6.5 m
Telescope mass	600 t	300 t	6.5 t
# of segments	1	36	18
Segment size	5 m	1.8 m	1.3 m
Mass / segment	14.5 t	400 kg	20 kg

Liquid Mirror Telescopes

- First suggestion by Ernesto Capocci in 1850
- First mercury telescope built in 1872 with a diameter of 350 mm
- Largest mirror: diameter 3.7 m

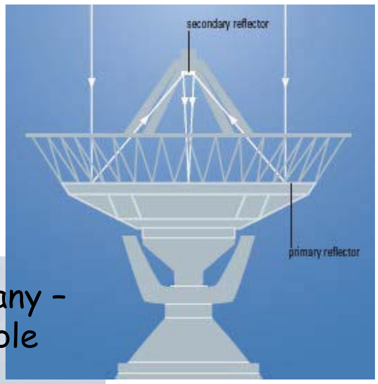




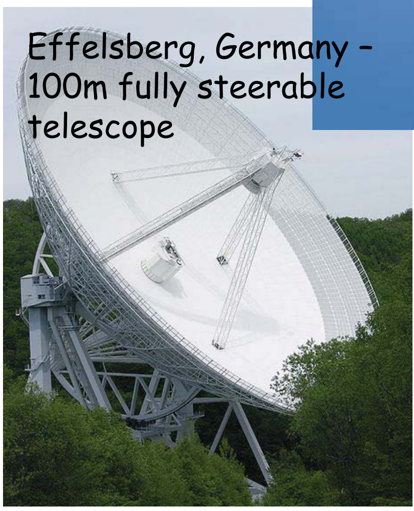


7. "Non-Optical" Telescopes

Dishes similar to optical telescopes but with much lower surface accuracy



Arecibo, Puerto Rico – the largest (305m) single-aperture telescope

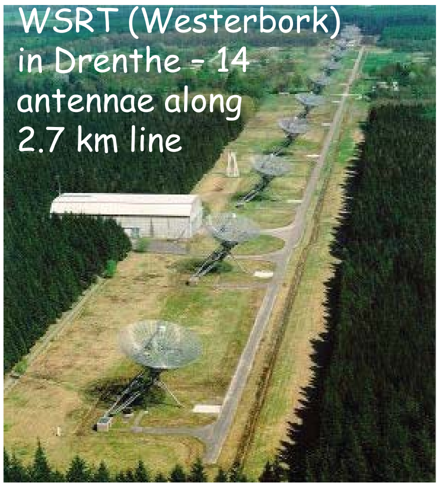


Effelsberg, Germany – 100m fully steerable telescope

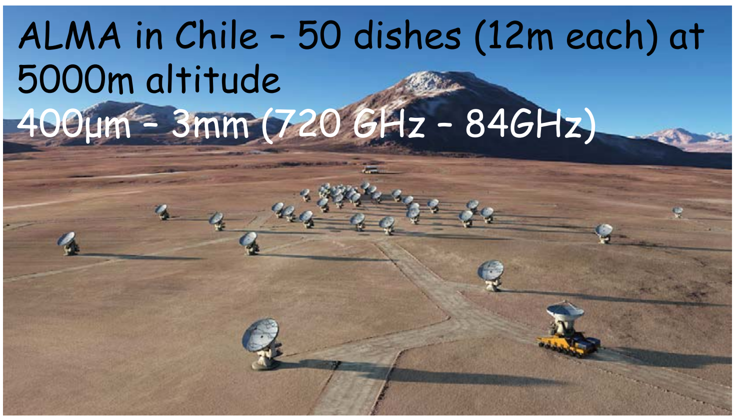
Greenbank, USA – after structural collapse (now rebuilt)

Arrays and Interferometers

VLA in New Mexico – 27 antennae (each 25m) in a Y-shape (up to 36 km baseline)



WSRT (Westerbork) in Drenthe – 14 antennae along 2.7 km line



ALMA in Chile – 50 dishes (12m each) at 5000m altitude
400μm – 3mm (720 GHz – 84GHz)

LOFAR in the Netherlands

The LOw Frequency ARray uses two types of low-cost antennas:

- Low Band Antenna (10-90 MHz)
- High Band Antenna (110-250 MHz).

Antennae are organized in 36 stations over ~100 km. Each station contains 96 LBAs and 48 HBAs

Baselines: 100m – 1500km

Main LOFAR subsystems:

- sensor fields
- wide area networks
- central processing systems
- user interfaces

X-ray Telescopes

- X-rays impinging perpendicular on any material are largely absorbed rather than reflected.

- ➔telescope optics is based on glancing angle reflection (rather than refraction or large angle reflection)

- typical reflecting materials for X-ray mirrors are gold and iridium (gold has a critical reflection angle of 3.7 deg at 1 keV).

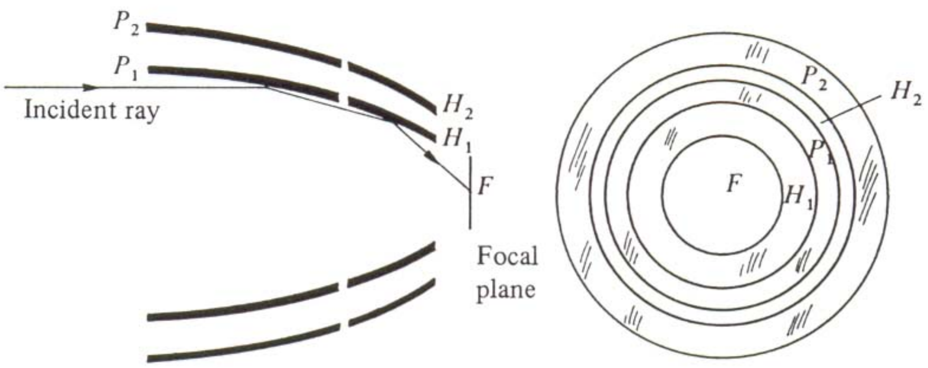


Fig. 4.33. Side and front views of a Wolter X-ray telescope. P and H denote parabolic and hyperbolic surfaces of revolution, whose common axis points to the source