Astronomical Observing Techniques

Lecture 3: Eyes to the Skies

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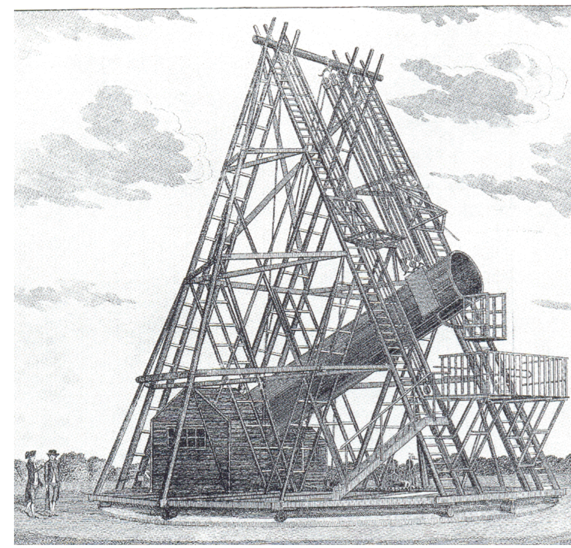
Outline

1. Pointing Telescopes on Earth
2. Space Telescope Orbits
3. Optical Telescopes
4. Radio Telescopes, Interferometers
5. X-ray and Gamma-Ray Telescopes
6. Neutrino Telescopes
7. Gravitational Wave Telescopes

Early Telescopes

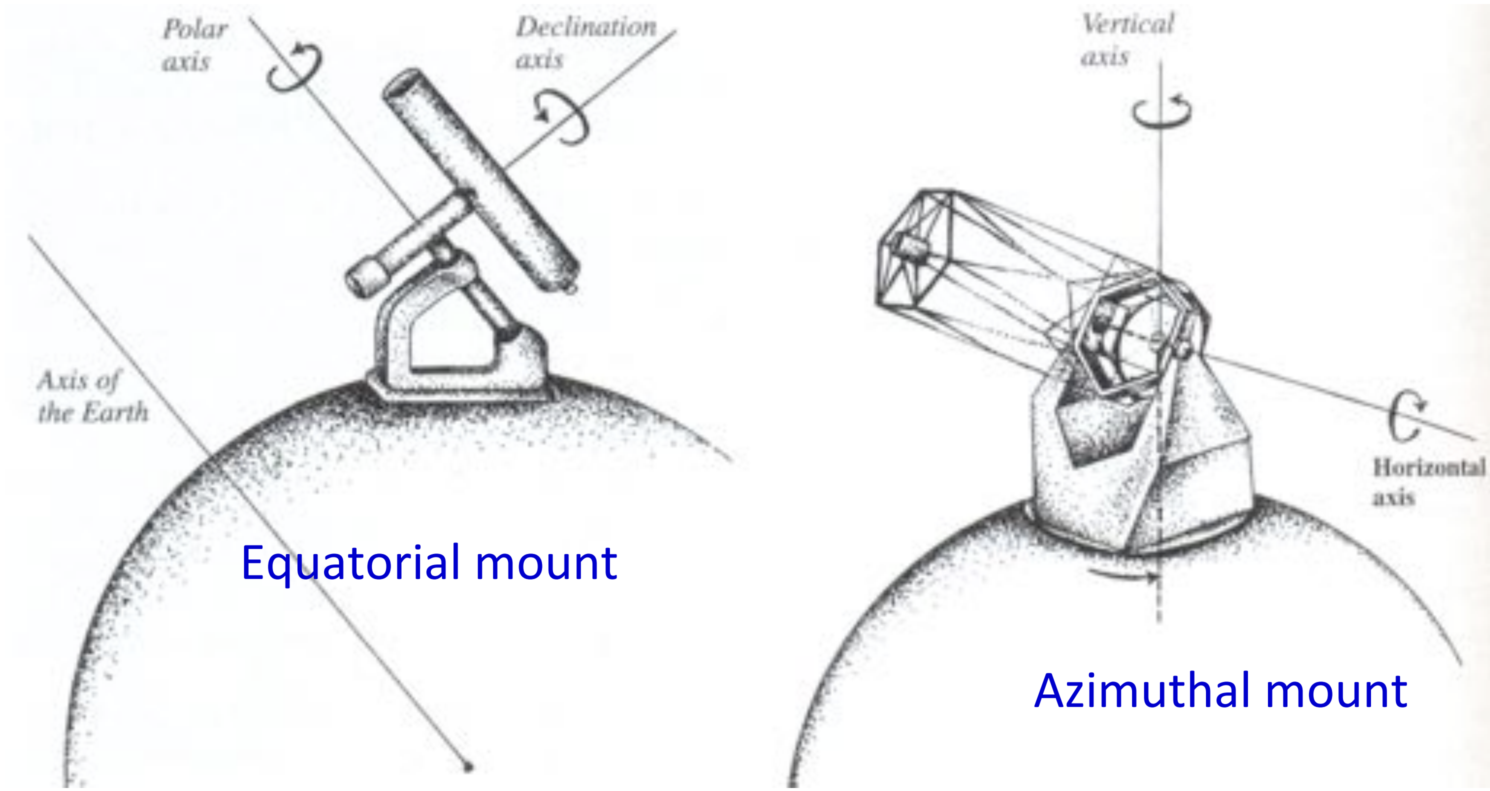


- Hans Lipperhey 1608: spy glasses
- Galileo Galilei 1609: first use in astronomy
- Kepler 1611: improved refractor

Newton 1668:
first reflector

Herschel 1789:
1.22-m diameter, 12-m long

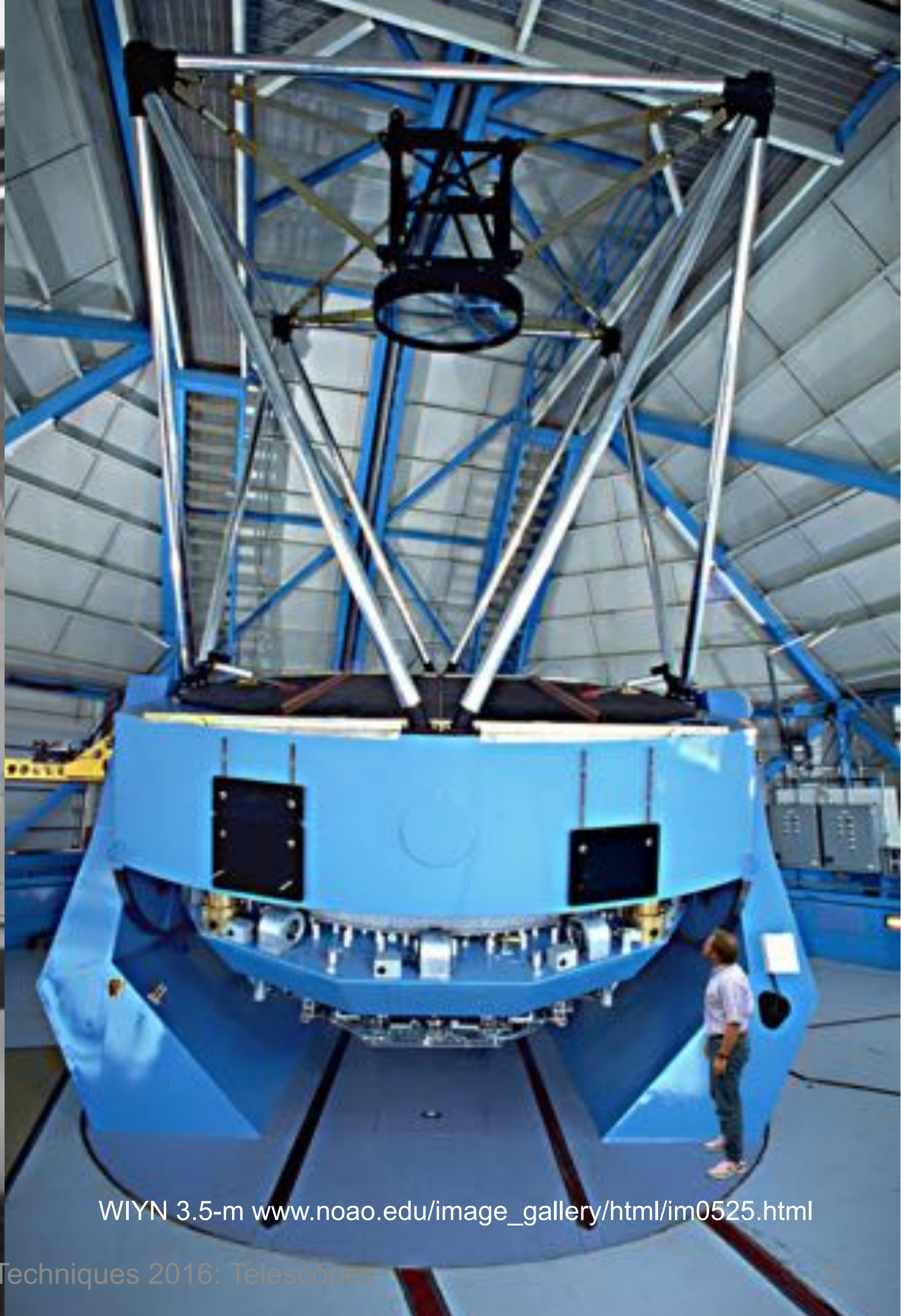
Telescope Mounts



+ single moving axis
+ constant rotation
+ no image rotation
- large, heavy
- instruments: varying gravity

+ light and symmetric
+ fixed gravity on bearings
+ two fixed-gravity ports
- two moving axes
- image rotation

CTIO 4-m, www.noao.edu/image_gallery/html/im0132.html



WIYN 3.5-m www.noao.edu/image_gallery/html/im0525.html

Azimuthal Telescope Mounts

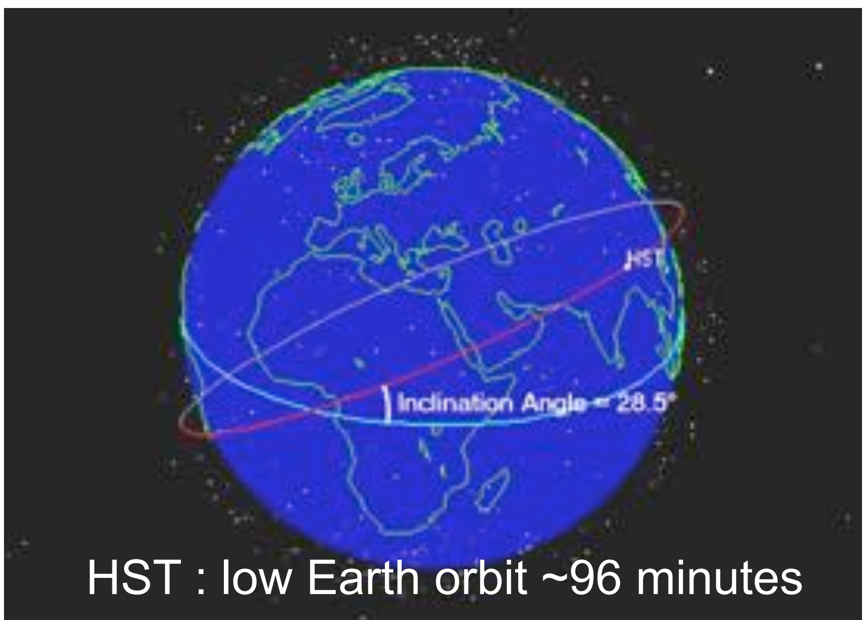
VLT www.eso.org/public/archives/images/screen/vlt-Inside-c-cc.jpg

SALT

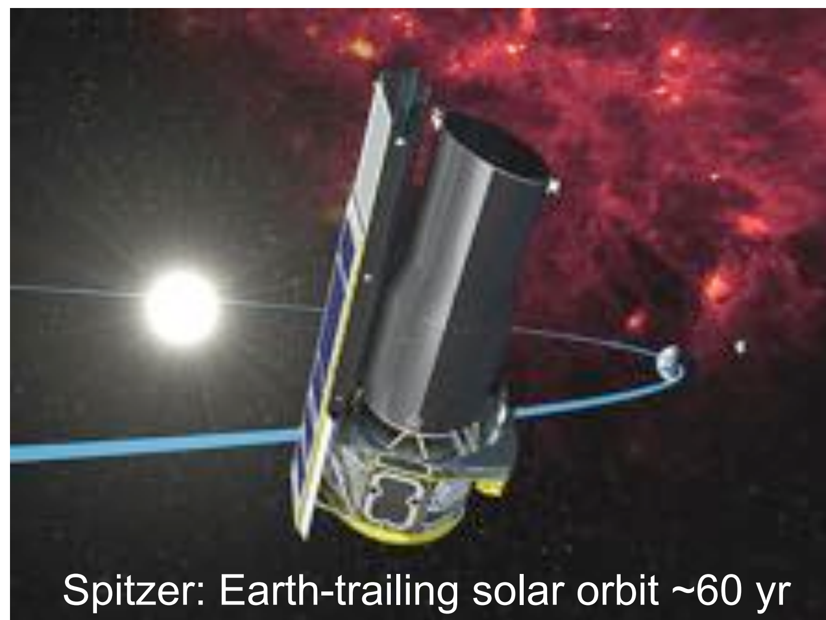
Space Telescope Orbits

Orbits
- low Earth
- sun-synchronous
- geostationary
- Earth-trailing
- L2

Orbit choice influenced by
- communications
- thermal background radiation
- space weather
- sky coverage
- access (servicing)

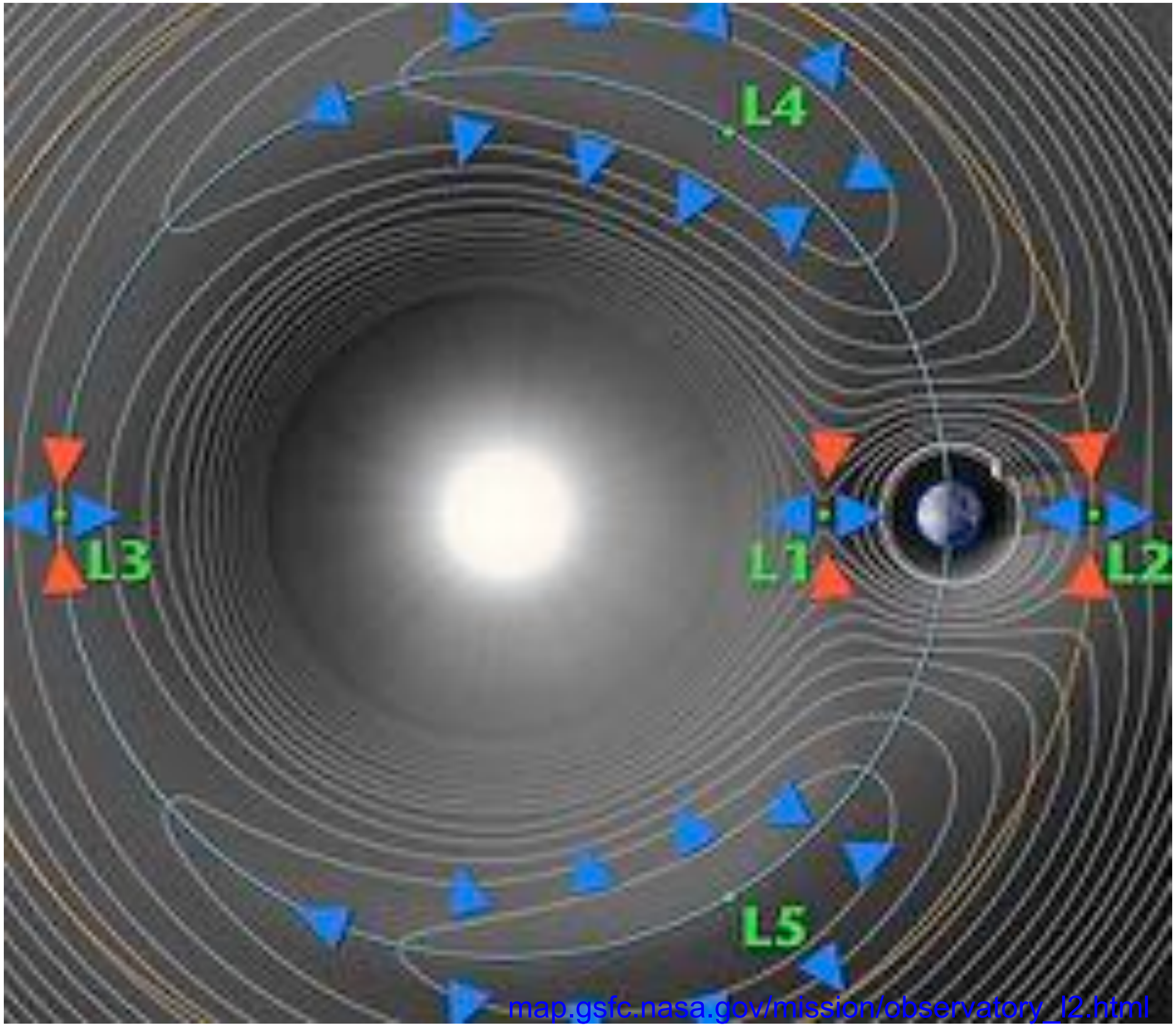


HST : low Earth orbit ~96 minutes



Spitzer: Earth-trailing solar orbit ~60 yr

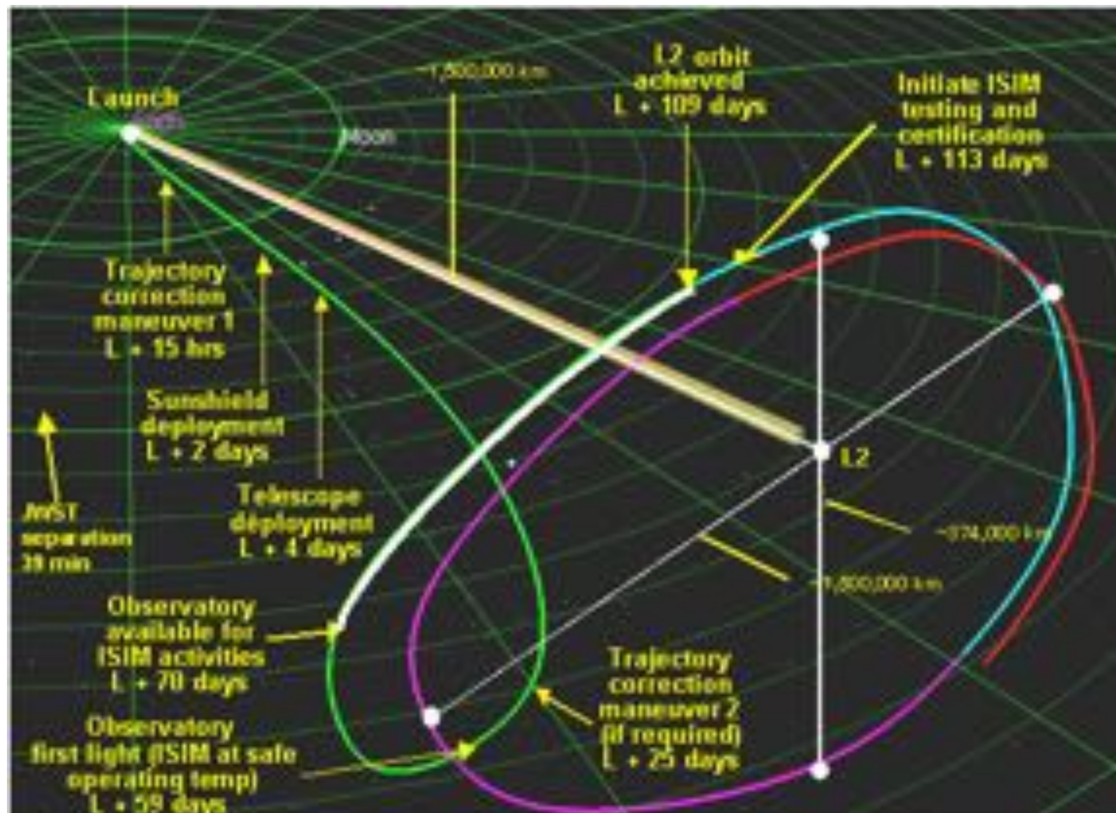
Lagrangian Points



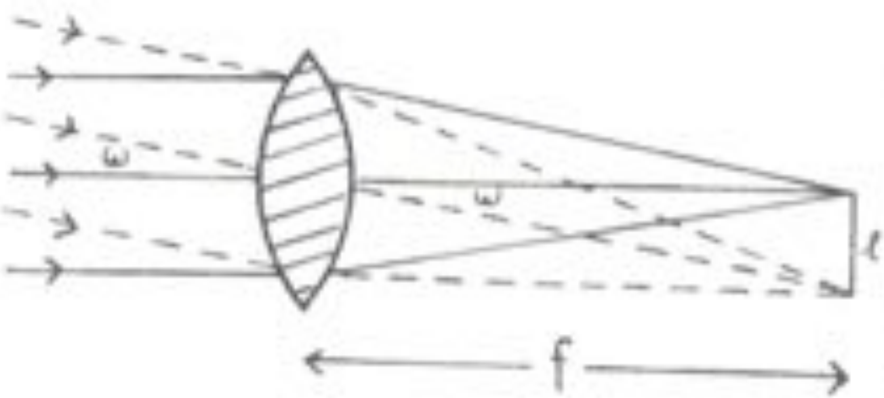
map.gsfc.nasa.gov/mission/observatory_l2.html

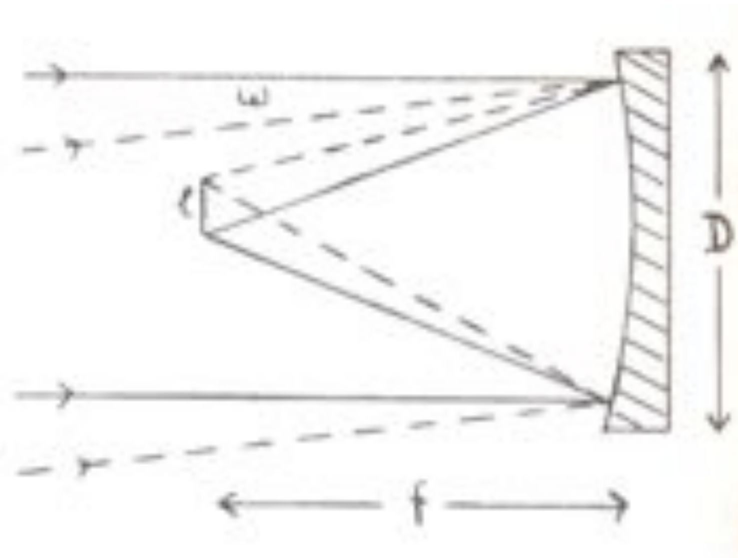
JWST, WMAP, GAIA, Herschel in orbits around L2

+ sun-shields
- orbit around L2
- radiation

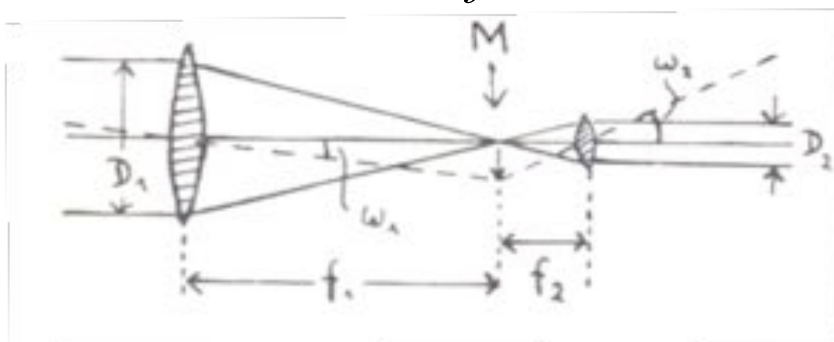


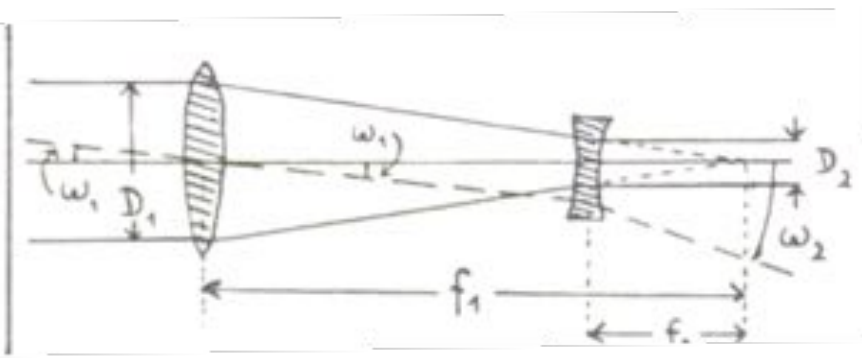
Telescope Optics





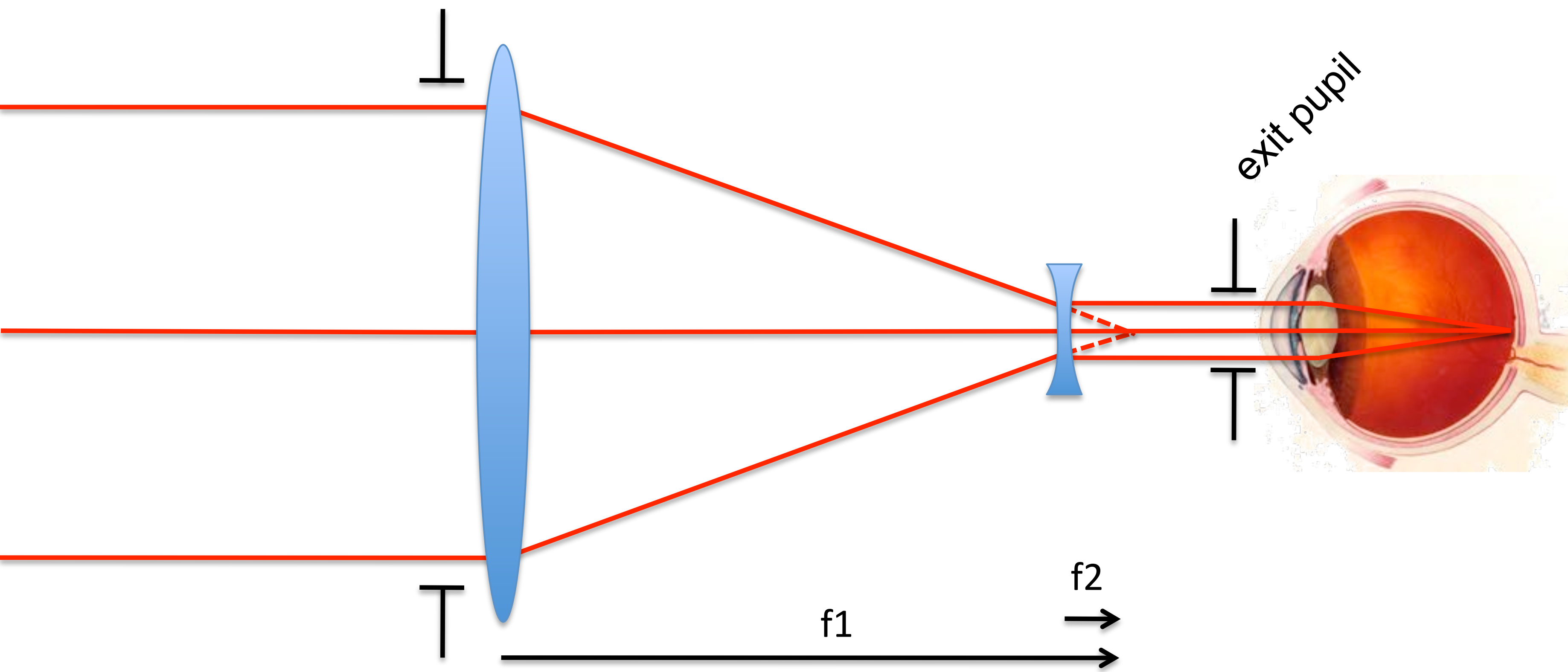
Scale: $\tan\omega = \dfrac{l}{f}$ and for small ω: $l \approx 0.0175\,\omega f$





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

Hollandsche Kijker

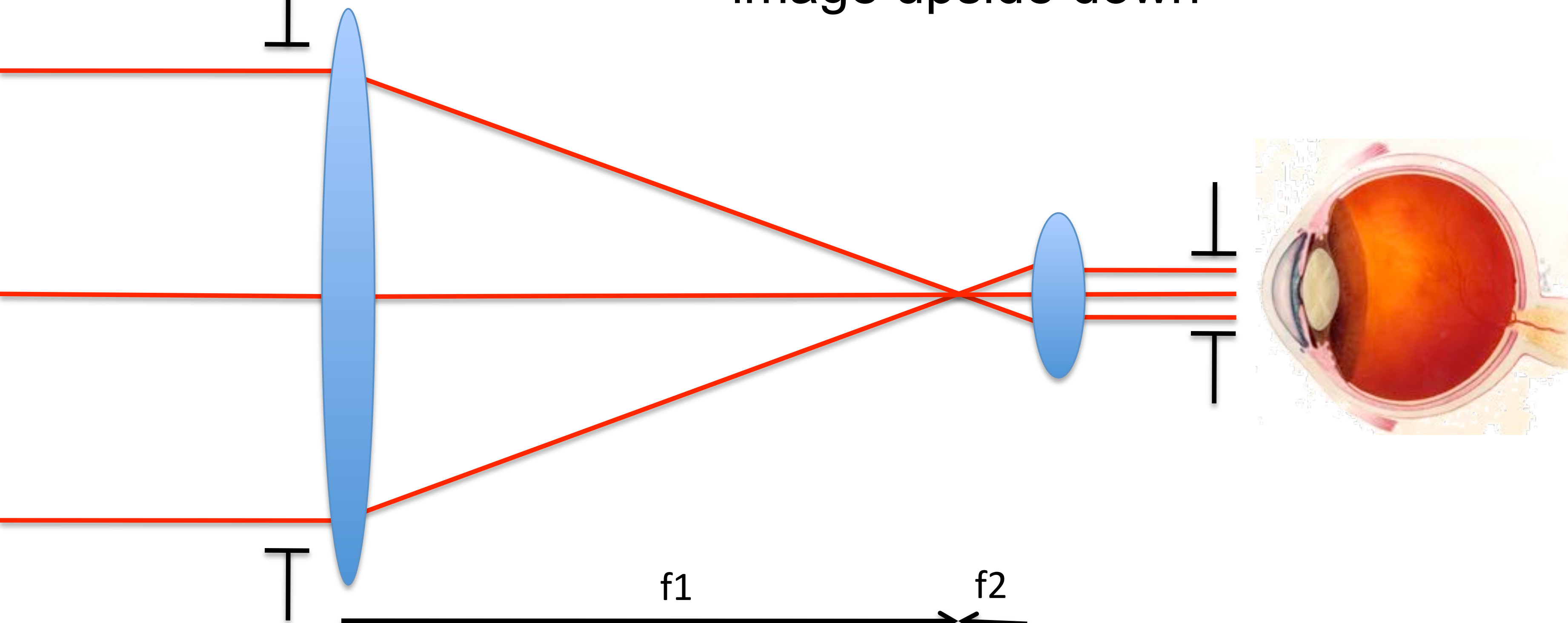


magnification = f1/f2

limitations: field, chromatic aberrations

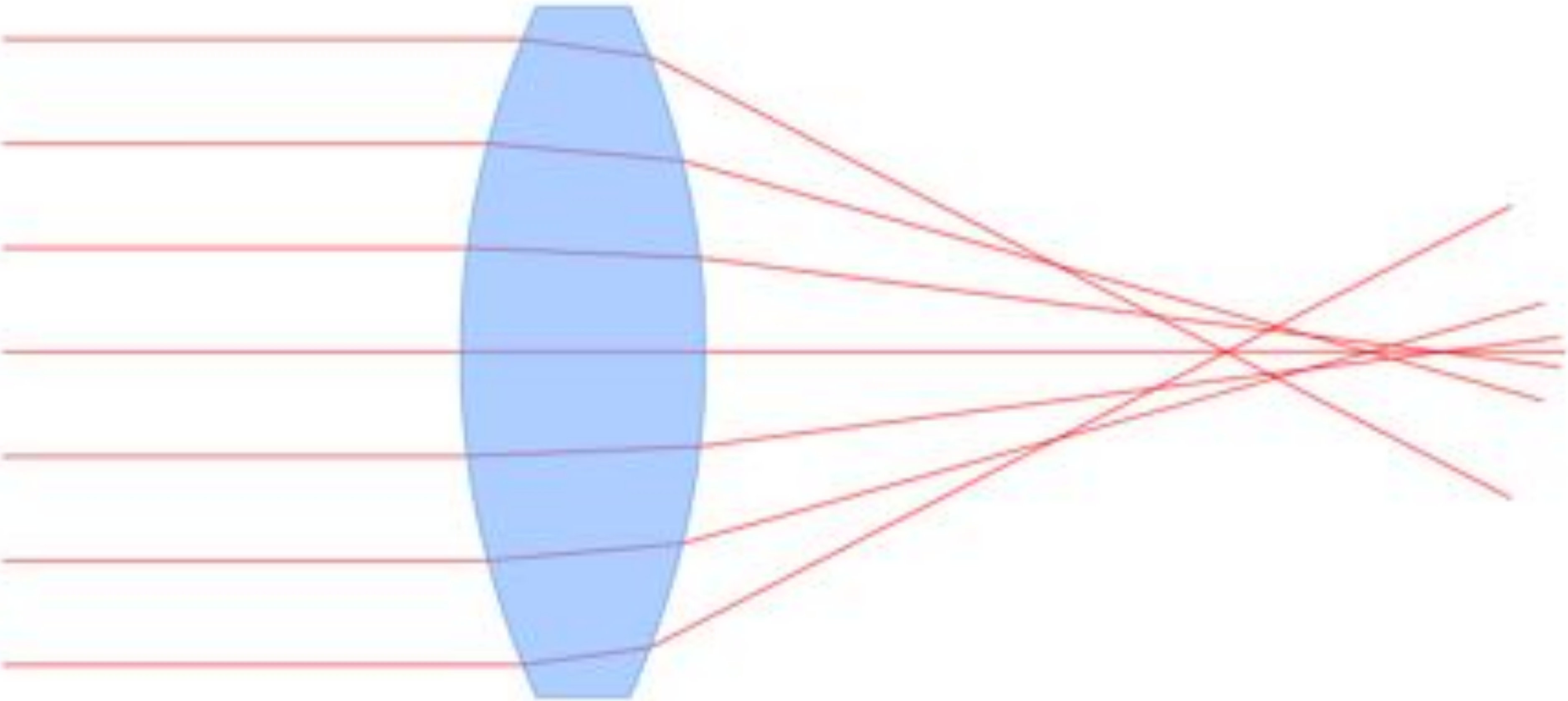
Kepler Refractor

- larger FOV
- image upside down



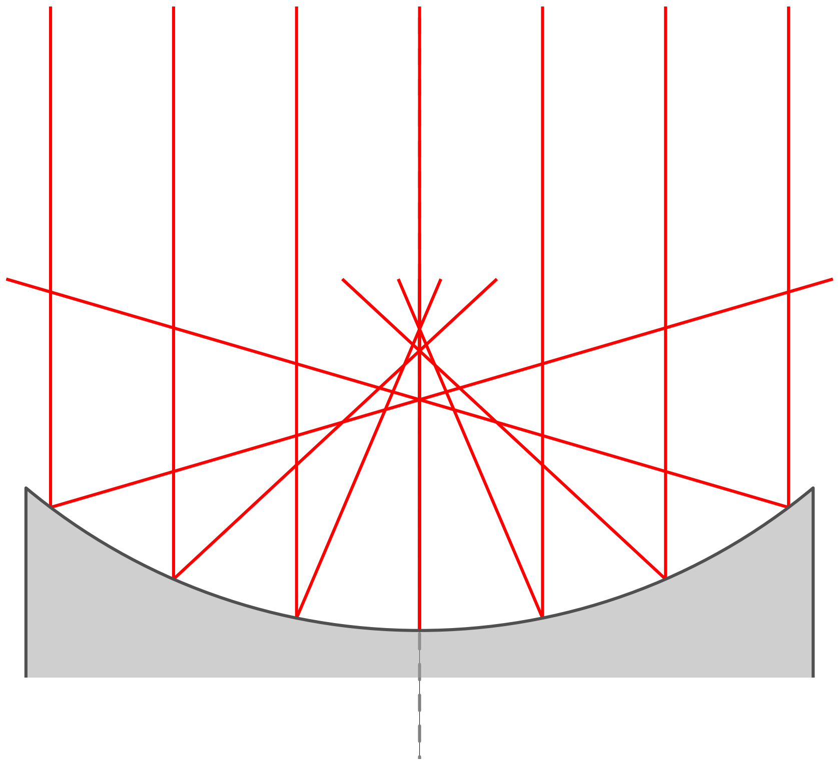
magnification = f1/f2

Spherical Lenses



Spherical Aberration: Beams away from center have shorter focal lengths

Spherical Mirrors

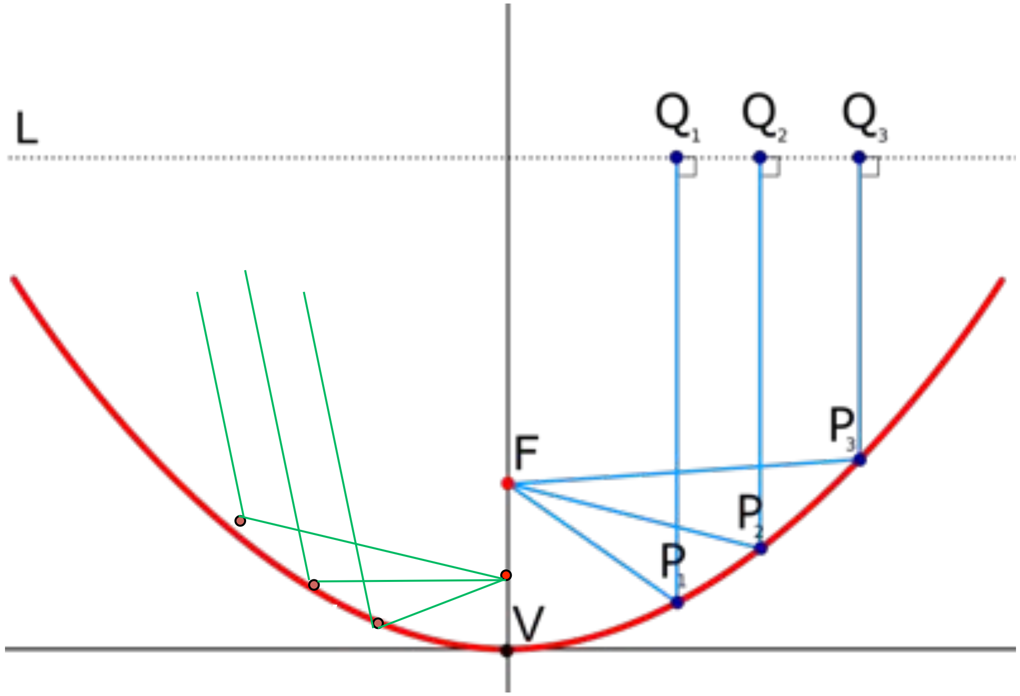


- provide large field of view (FoV)
- rays more distant from optical axis have a different focal point

Parabolic Mirrors

Parabolic primary mirrors focus all rays from the same direction to one point.

But: different directions have different focal points.

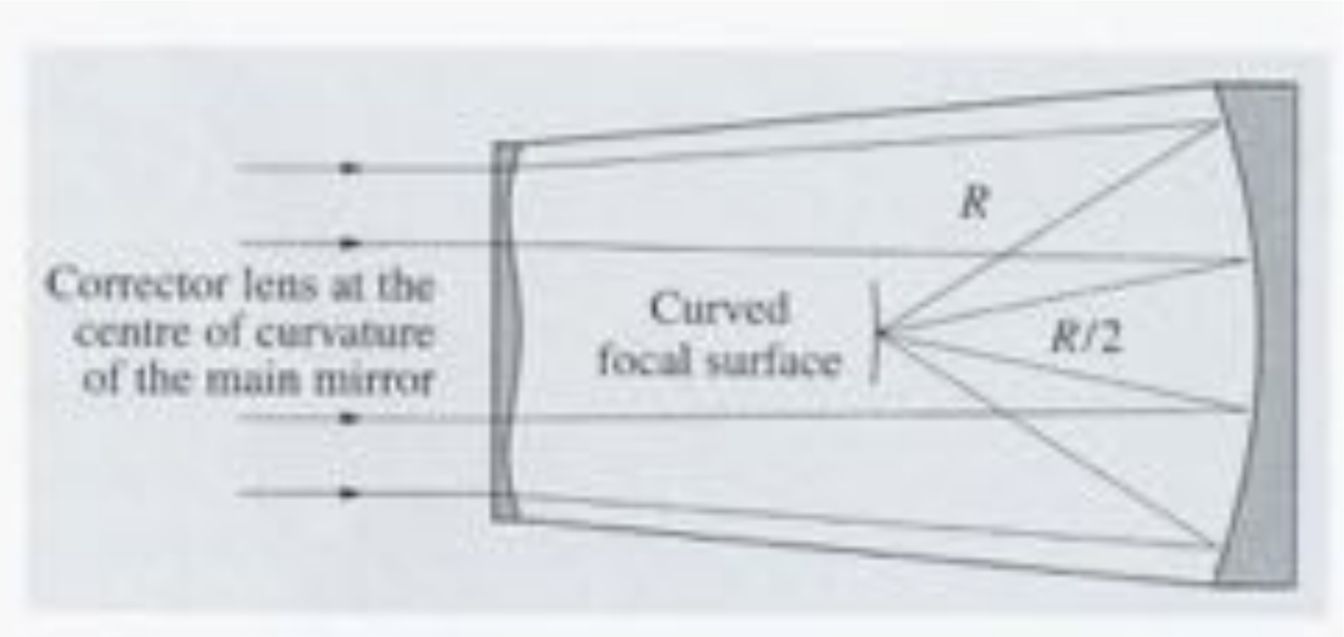


→ Field of view limited by aberrations: the bigger the mirror the bigger the difference [parabola – sphere] near the edge → bigger telescopes have smaller FOVs (~<1 deg)

Schmidt Telescope

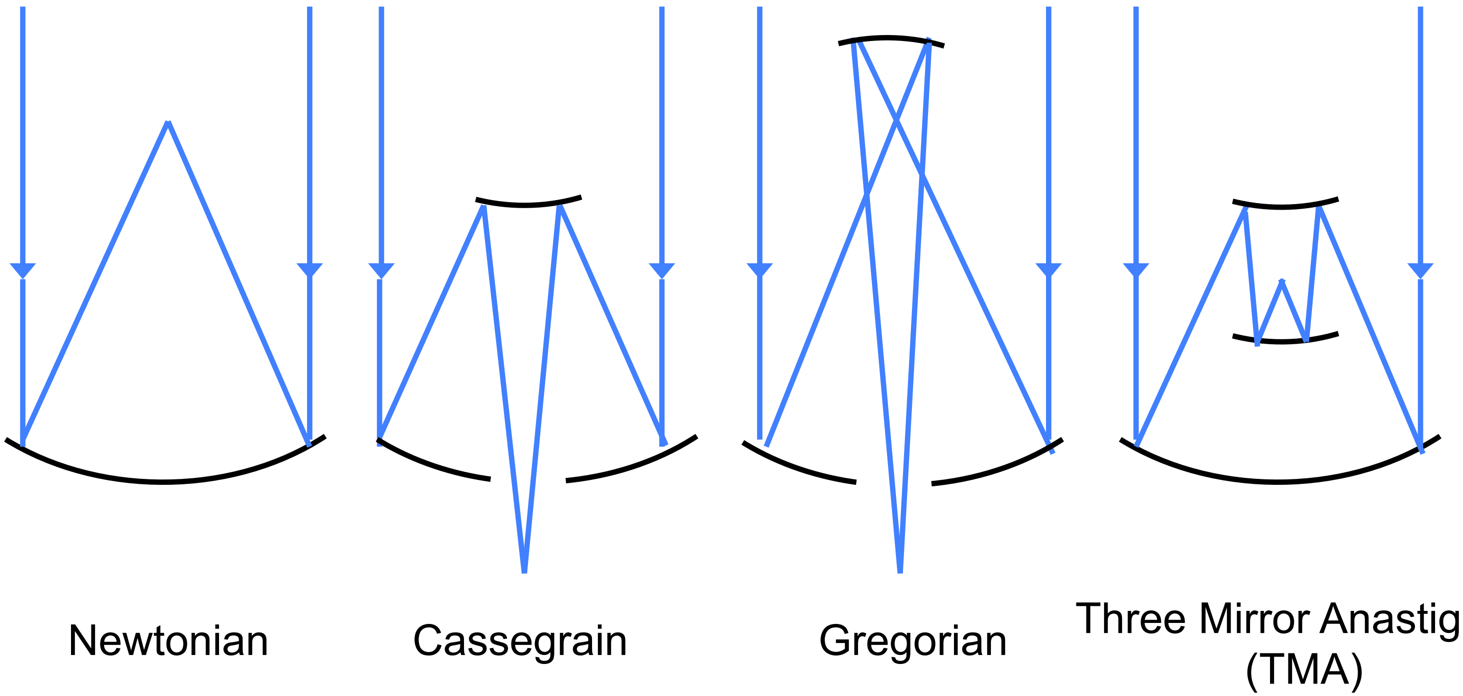
Idea:

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



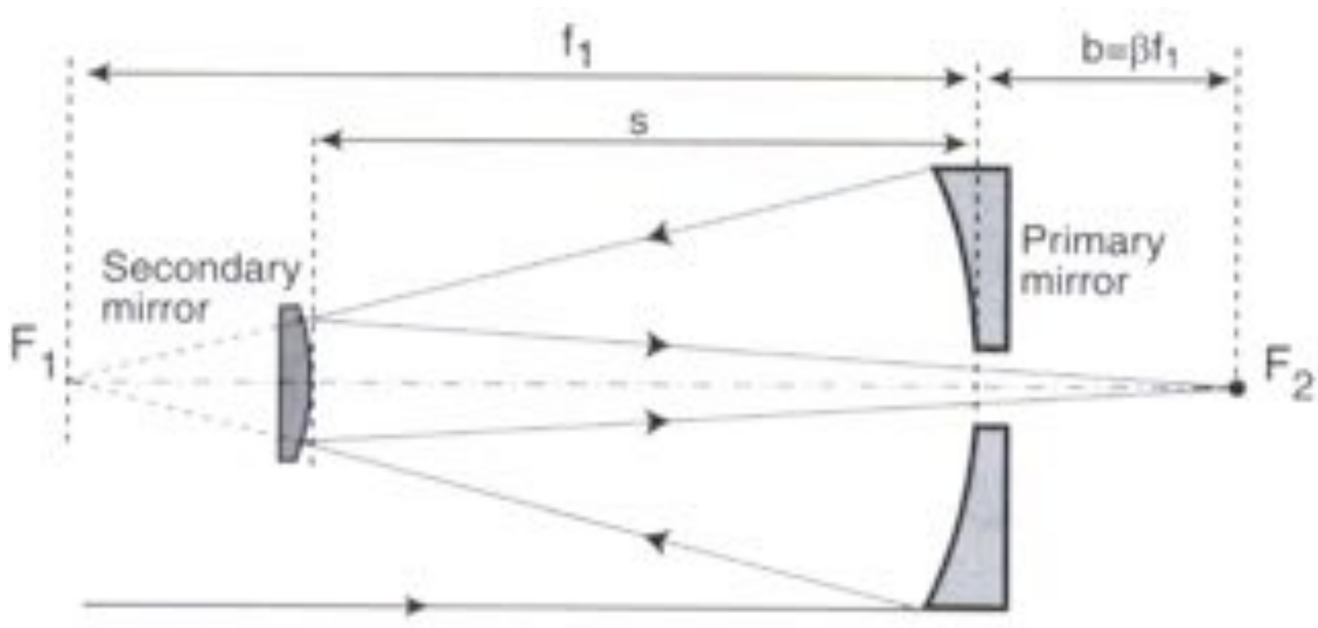
Two meter Alfred-Jensch-Telescope in Tautenburg, the largest Schmidt camera in the world.

Two-Mirror Telescopes



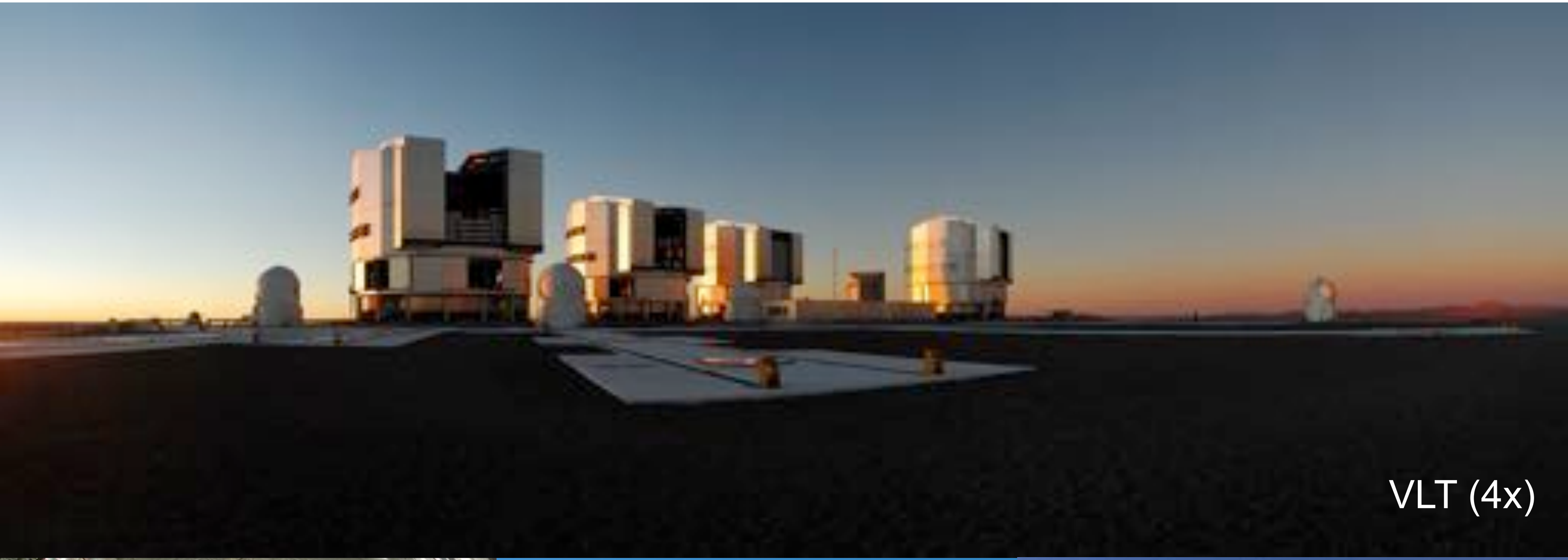
Ritchey-Chrétien Configuration

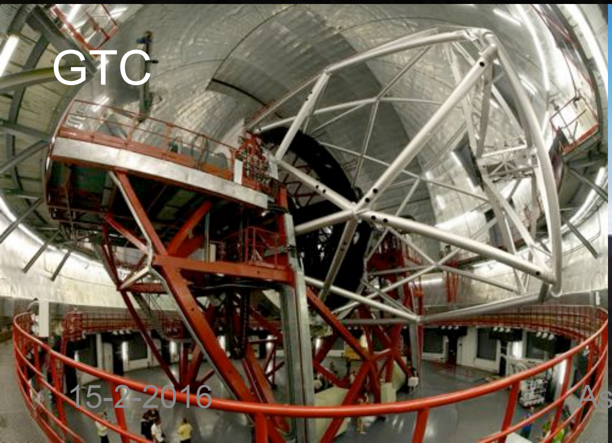
Modification of Cassegrain configuration (parabolic primary, elliptical secondary): Hyperbolic primary mirror (almost parabola) and hyperbolic secondary mirror eliminates (some) optical errors (3rd order coma and spherical aberration).

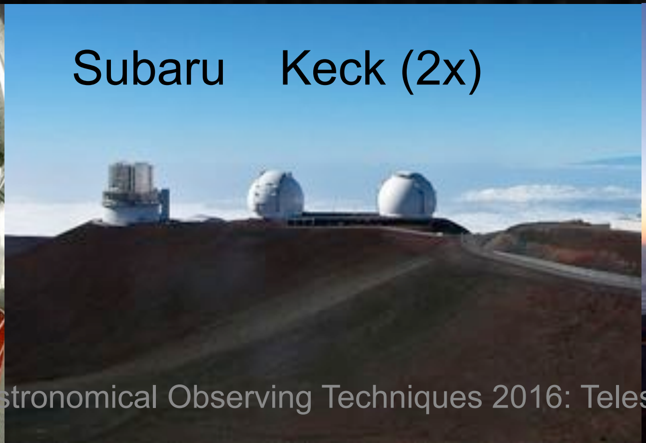


→ large field of view & compact design (for a given focal length)

Ritchey-Chrétien Telescopes



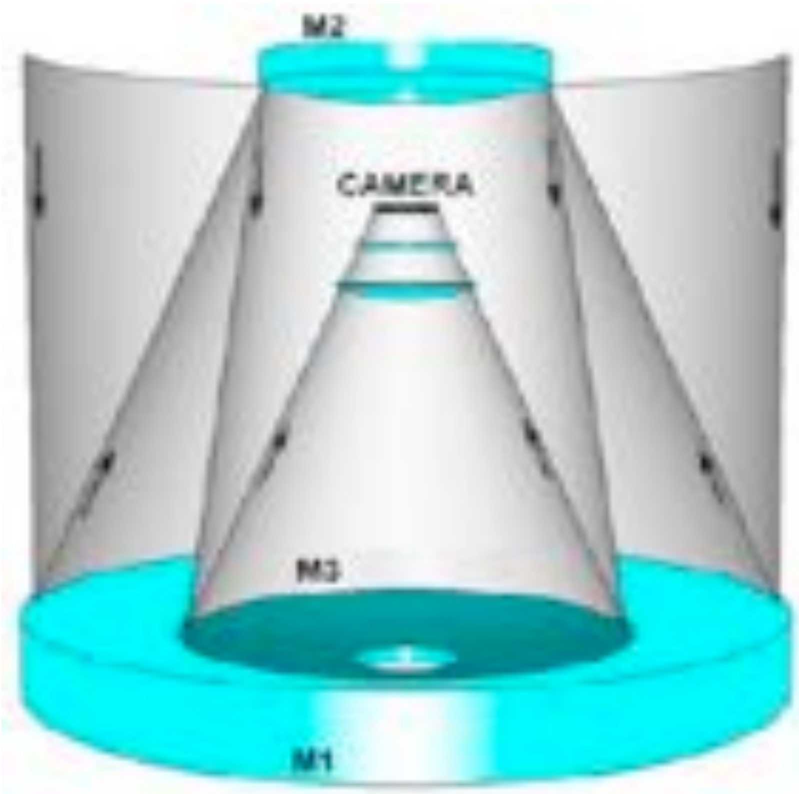




Ritchey-Chrétien Telescope

HST

TMA Wide-Field Telescope



Large Synoptic Survey Telescope (LSST)

Light Gathering Power and Resolution

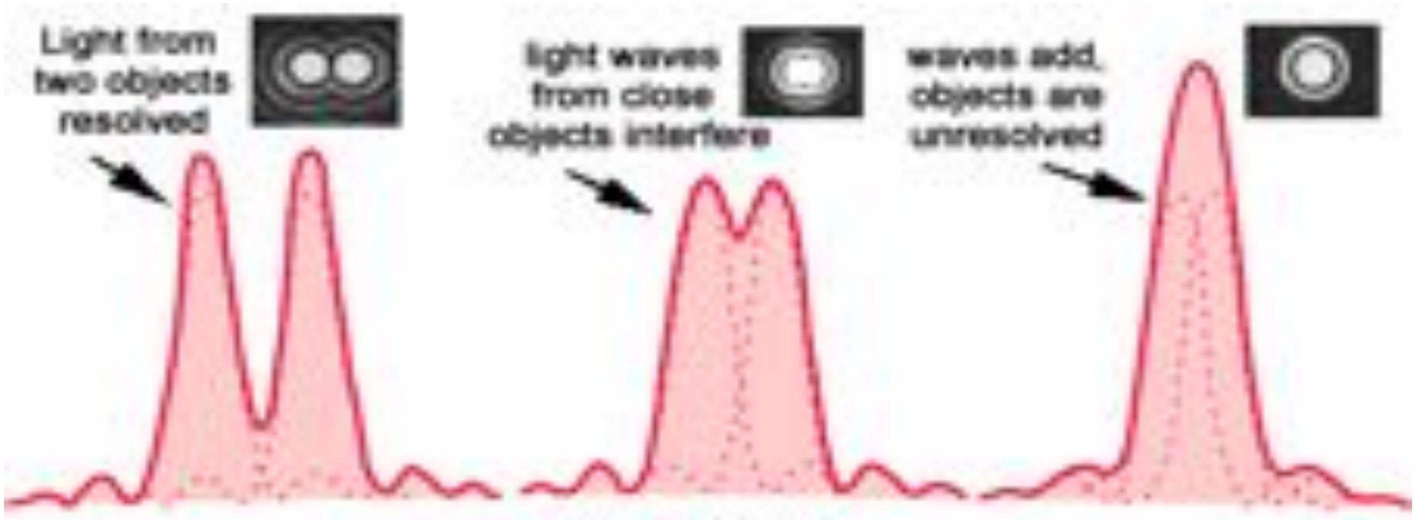
Light gathering power

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

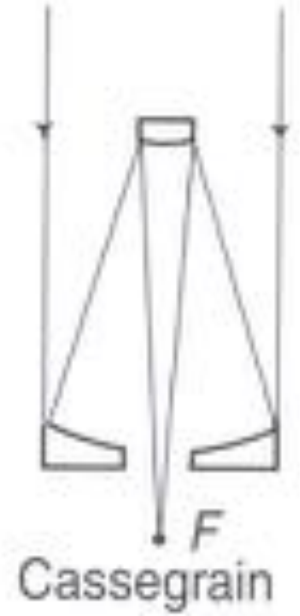
For point sources: $$S/N \propto D^2$$

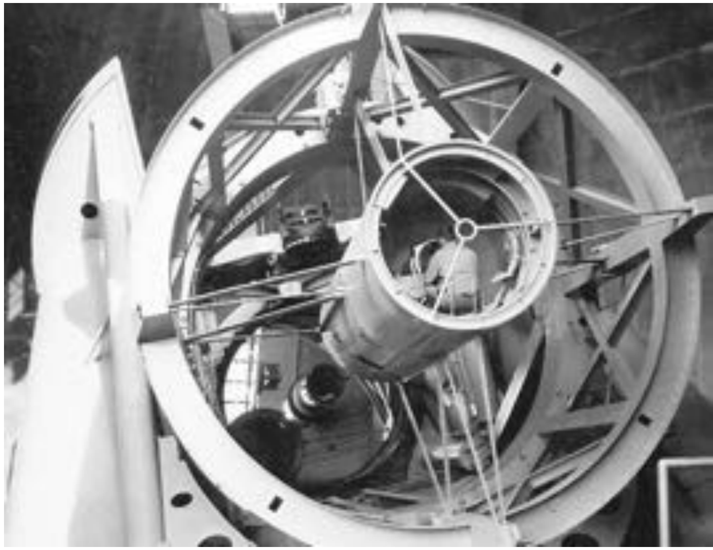
Angular resolution $$\sin\Theta = 1.22\frac{\lambda}{D} \quad \text{or} \quad \Delta l = 1.22\frac{f\lambda}{D}$$

(given by the Rayleigh criterion)



Telescope Foci – where to put the instruments

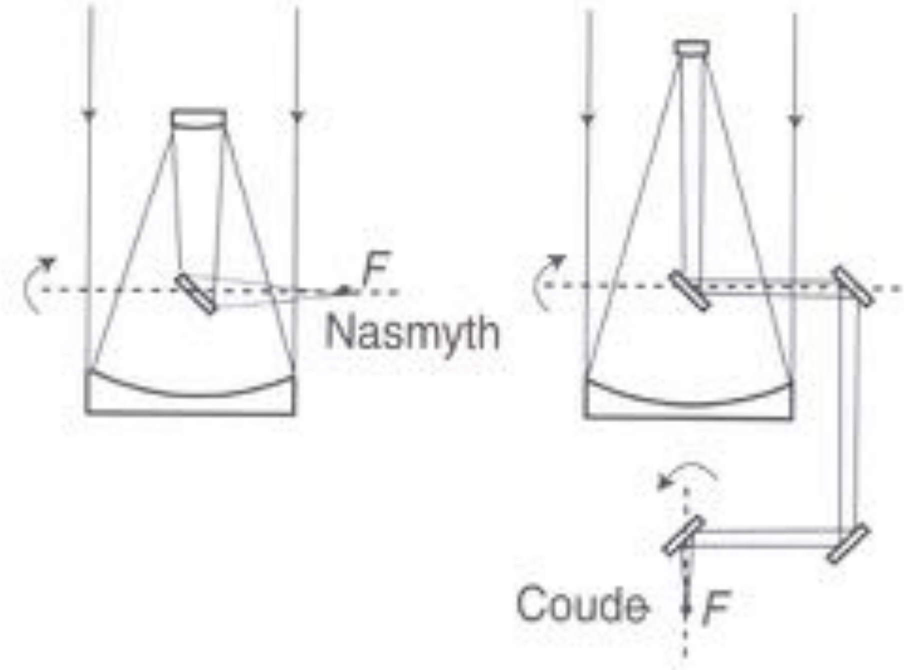




Prime focus – wide field, fast beam but difficult to access and not suitable for heavy instruments

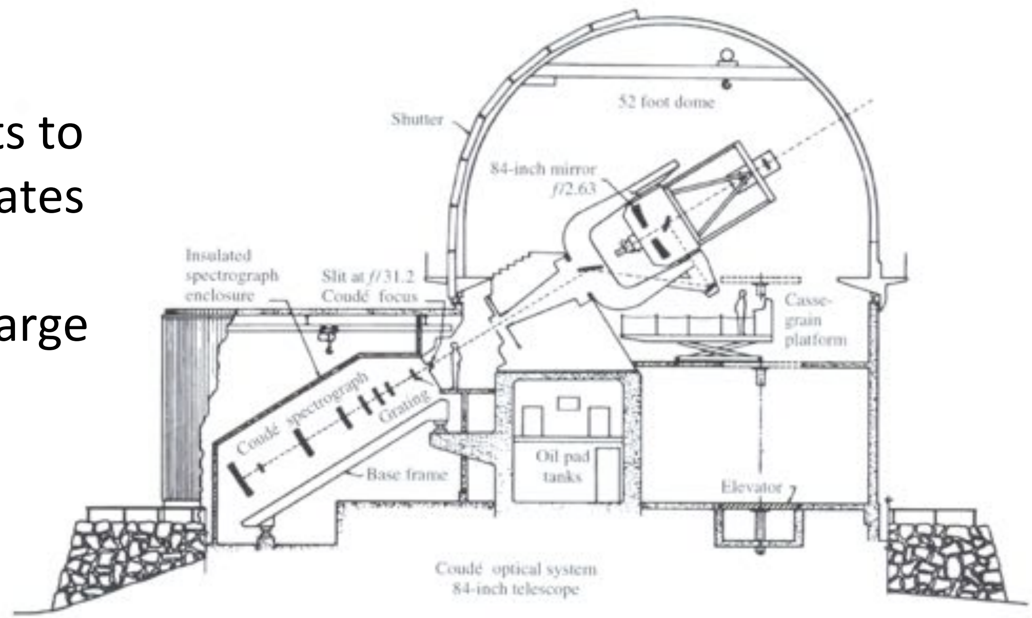
Cassegrain focus – moves with telescopes, small field

Telescope Foci – where to put instruments (2)

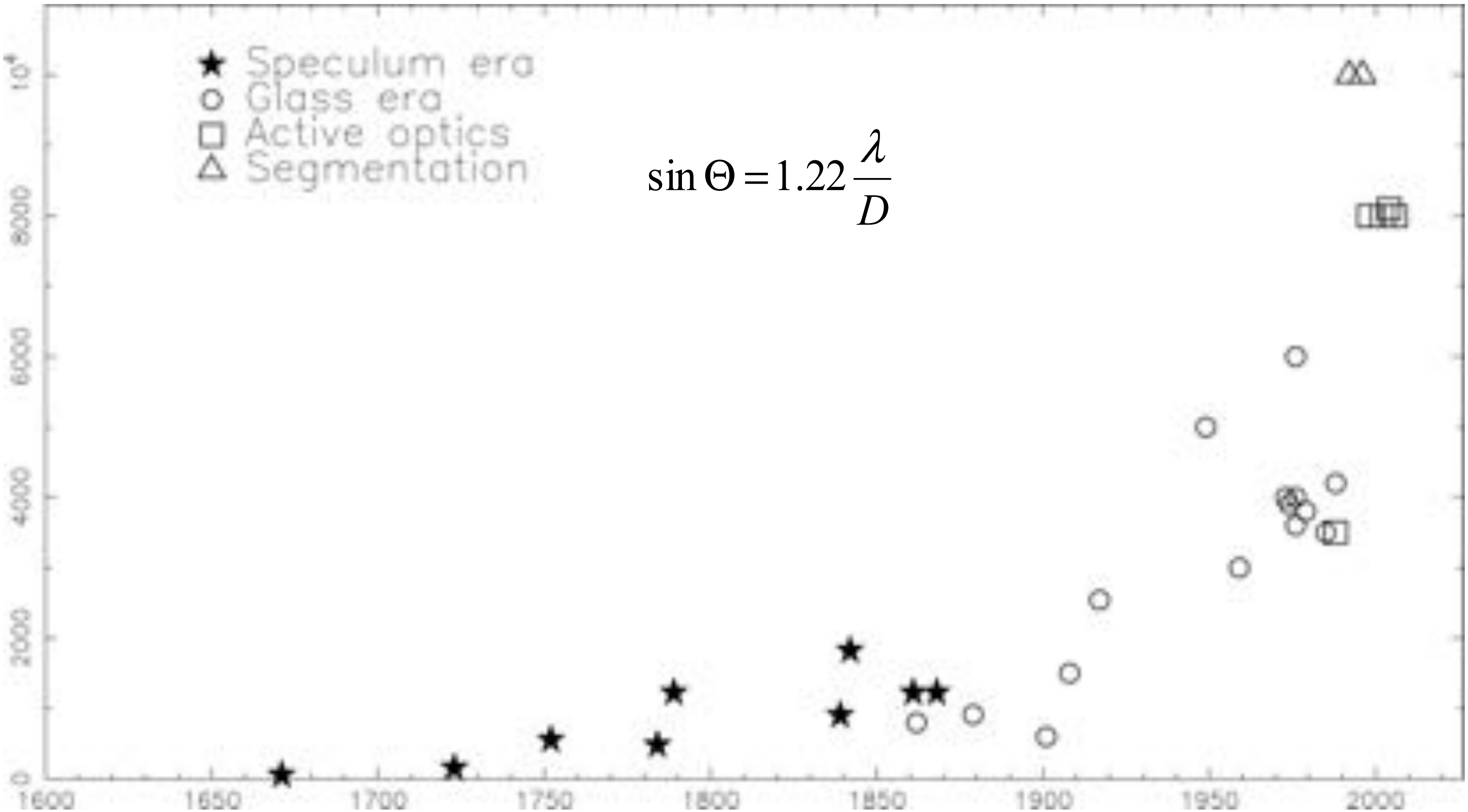


Nasmyth – ideal for heavy instruments to put on a stable platform, but field rotates

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

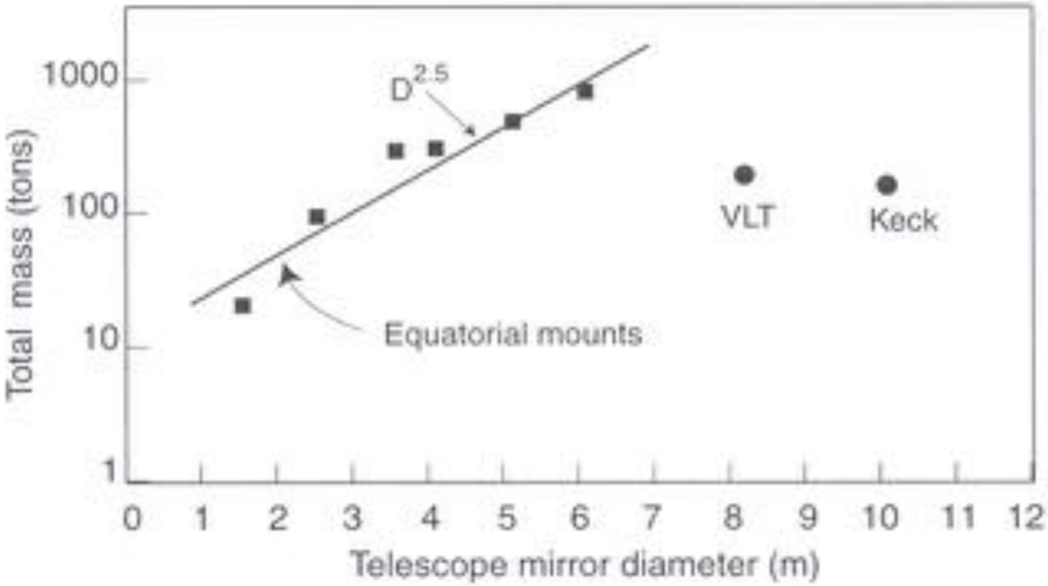


Growth of Telescope Collecting Area



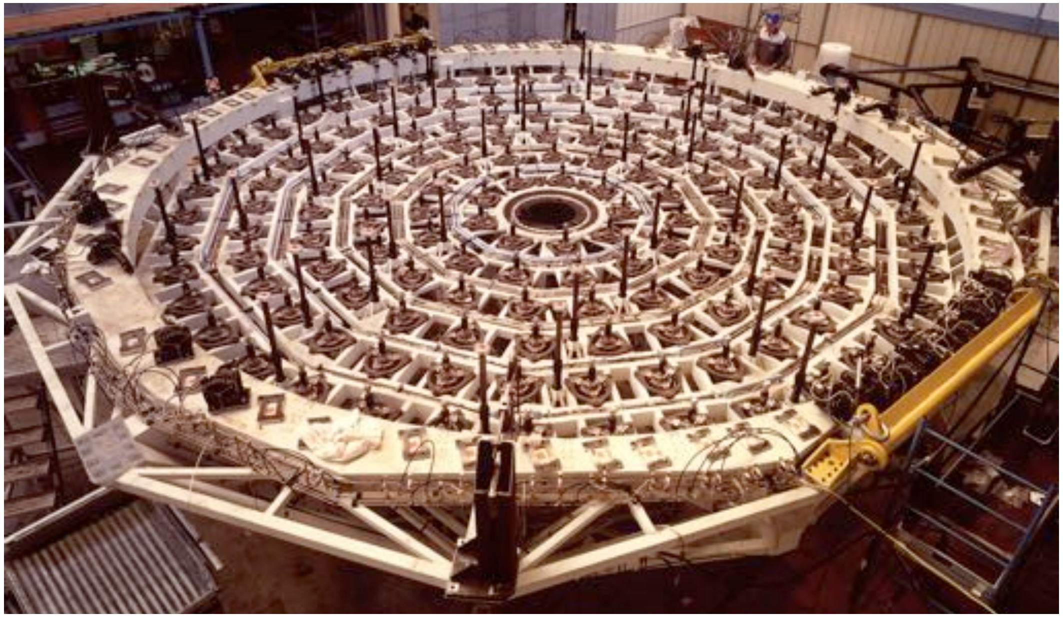
$$\sin\Theta = 1.22\frac{\lambda}{D}$$

Mass Limitations

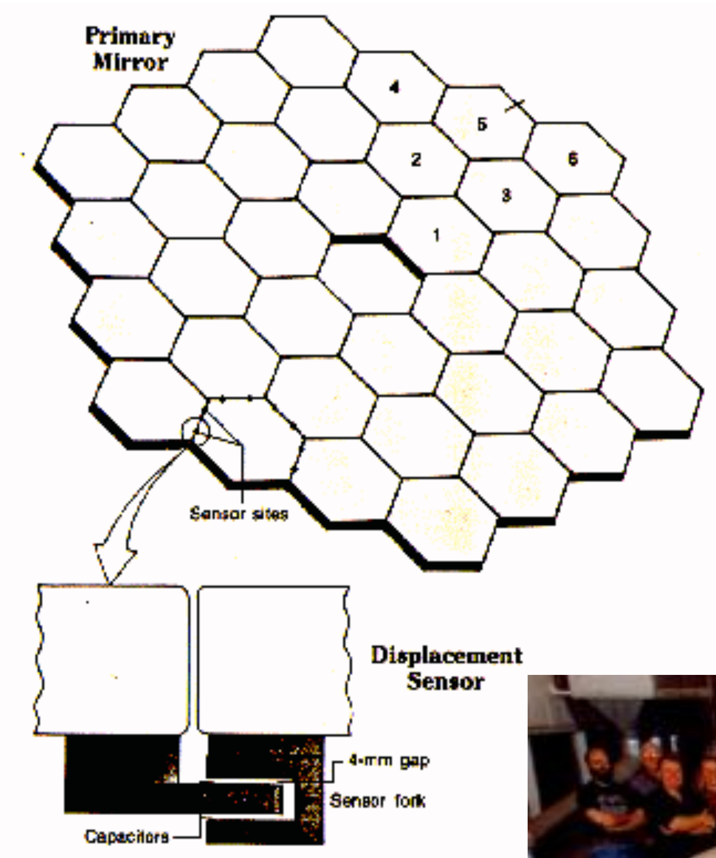


bigger mirrors require

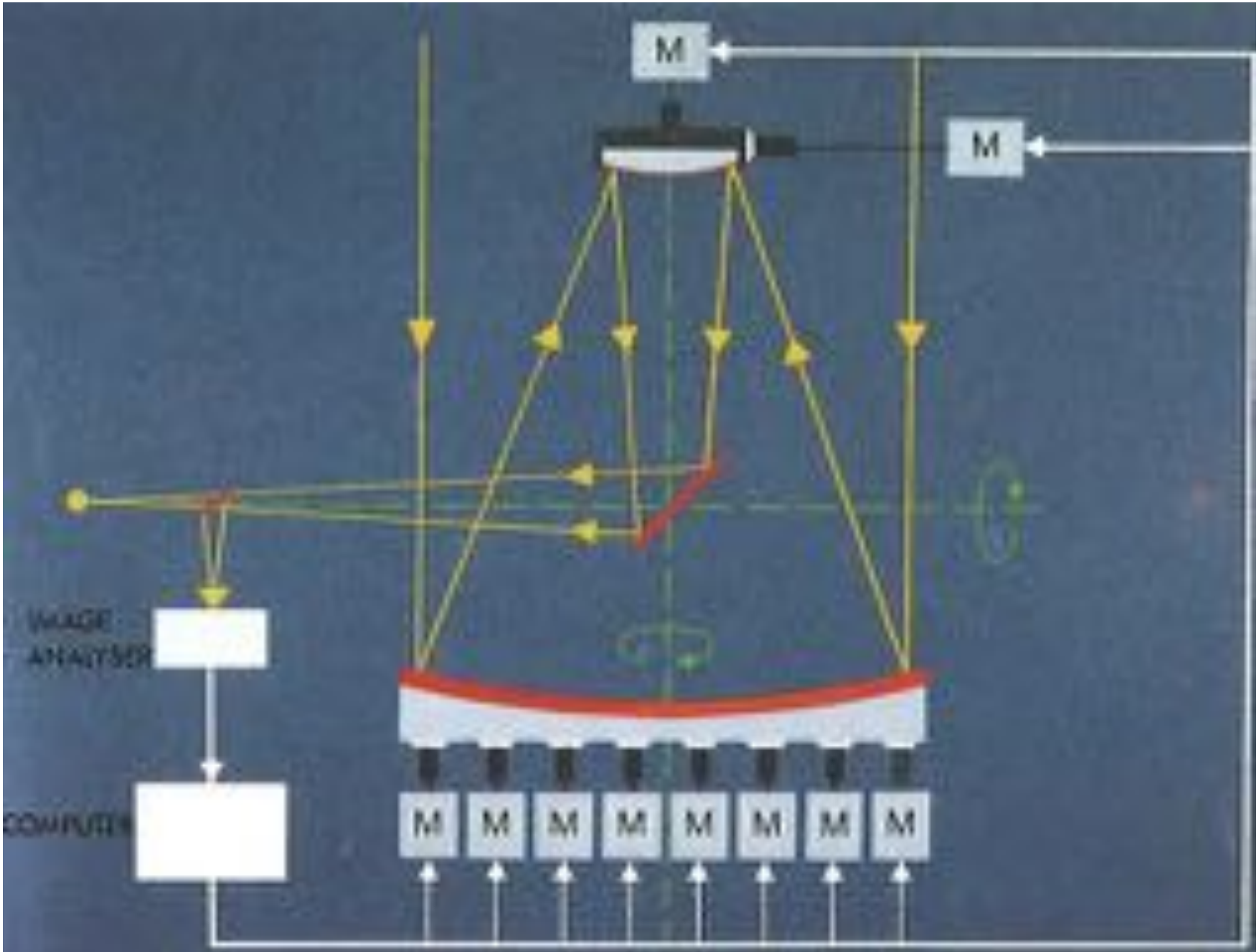
- thinner / segmented mirrors
- active support



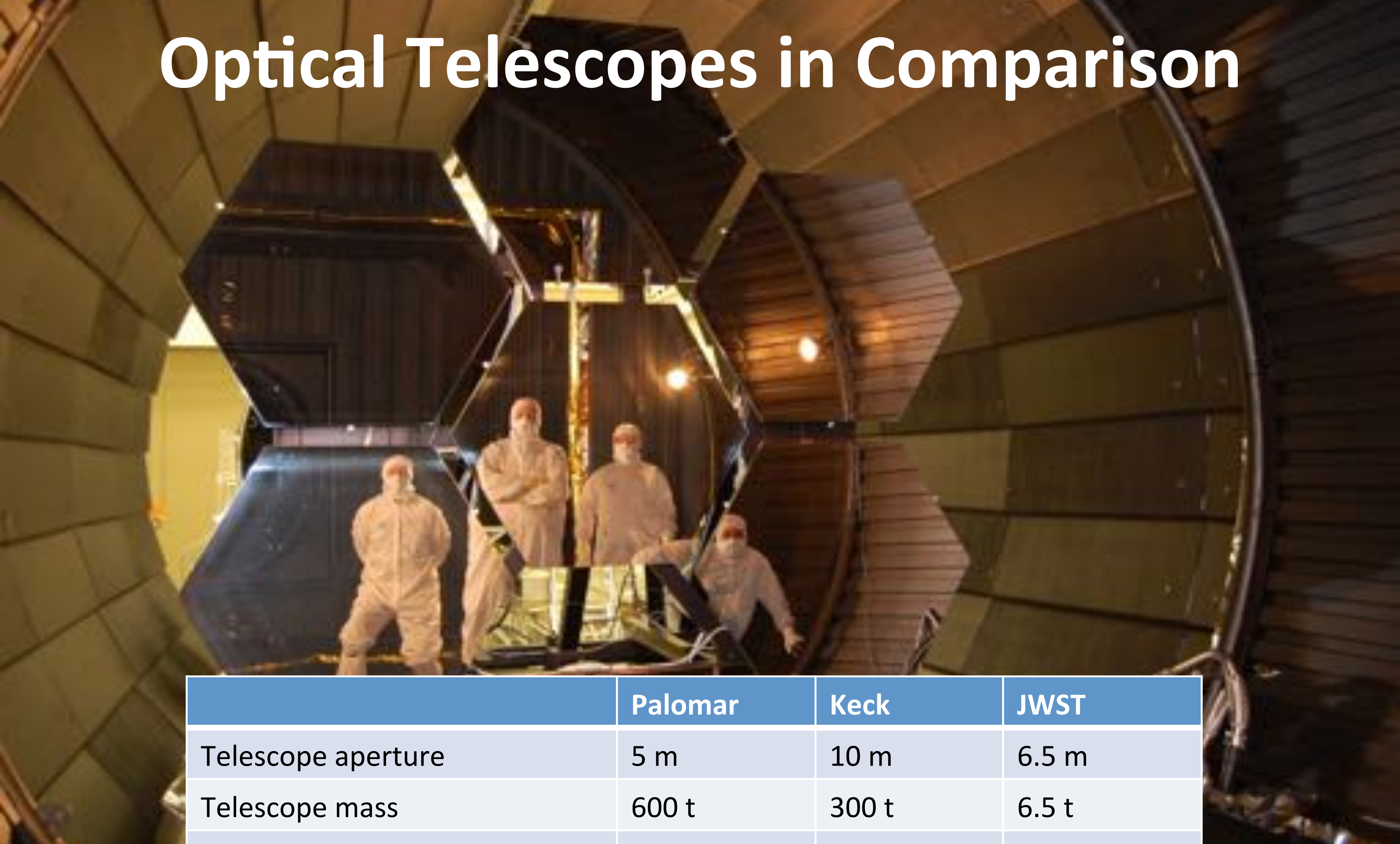
Segmented, Thin and Honeycomb Mirrors



Active Mirror Support



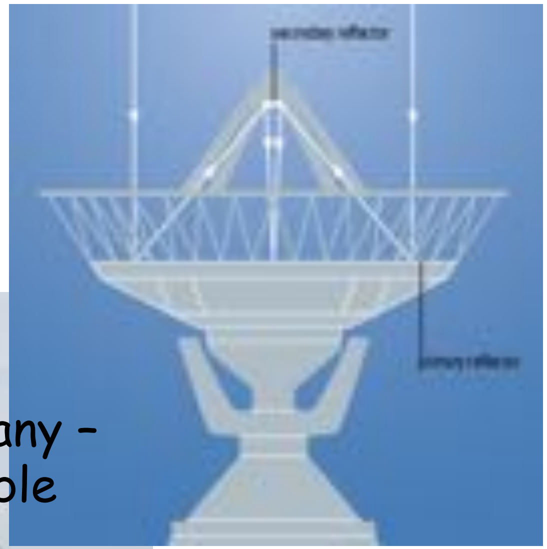
Optical Telescopes in Comparison



	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	14’500 kg	400 kg	20 kg

Radio 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

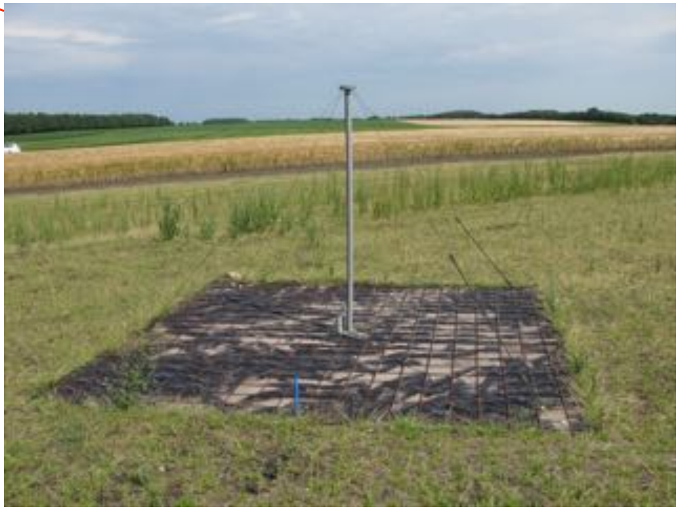
VLA in New Mexico – 27 antennae (each 25m) in a Y-shape (up to 36 km baseline)

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

- LOw Frequency ARray uses two types of low-cost antennae:
  - Low Band Antenna (10-90 MHz)
  - High Band Antenna (110-250 MHz).



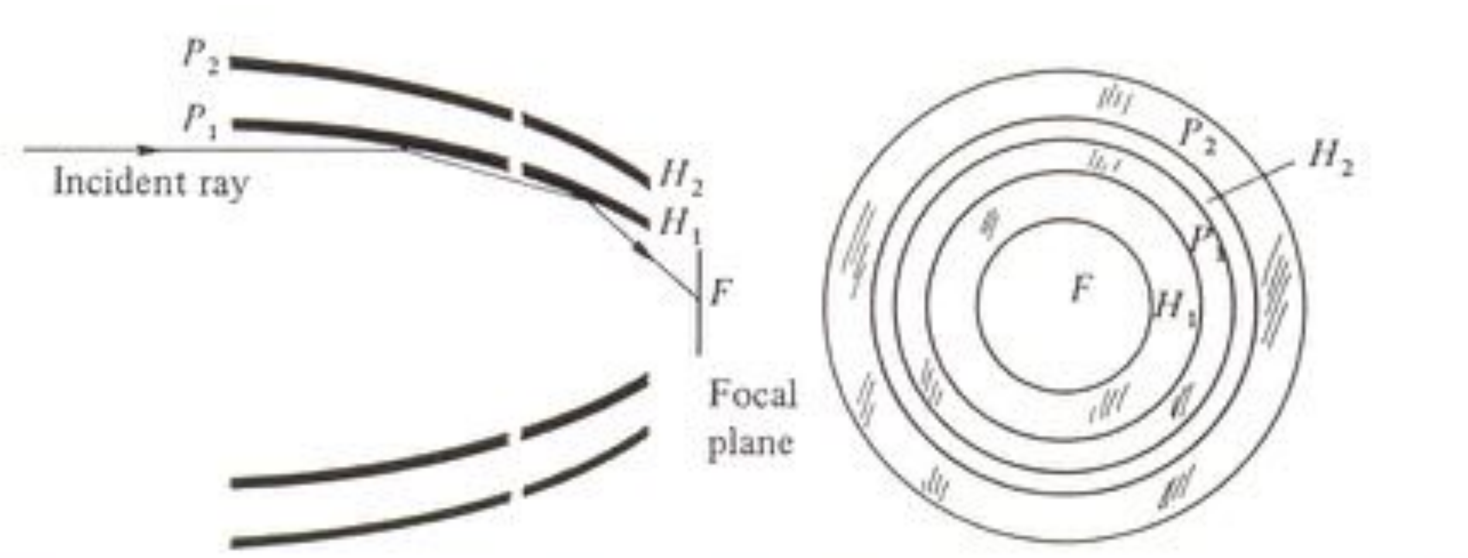
- Antennae are organized in 36 stations
- over ~100 km. Each station contains
- 96 LBAs and 48 HBAs
- Baselines: 100m – 1500km
- Main LOFAR subsystems:
- sensor fields
- wide area networks
- central processing systems
- user interfaces

X-ray Telescopes

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

• telescope optics 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).



Gamma-Ray Telescopes

FERMI satellite

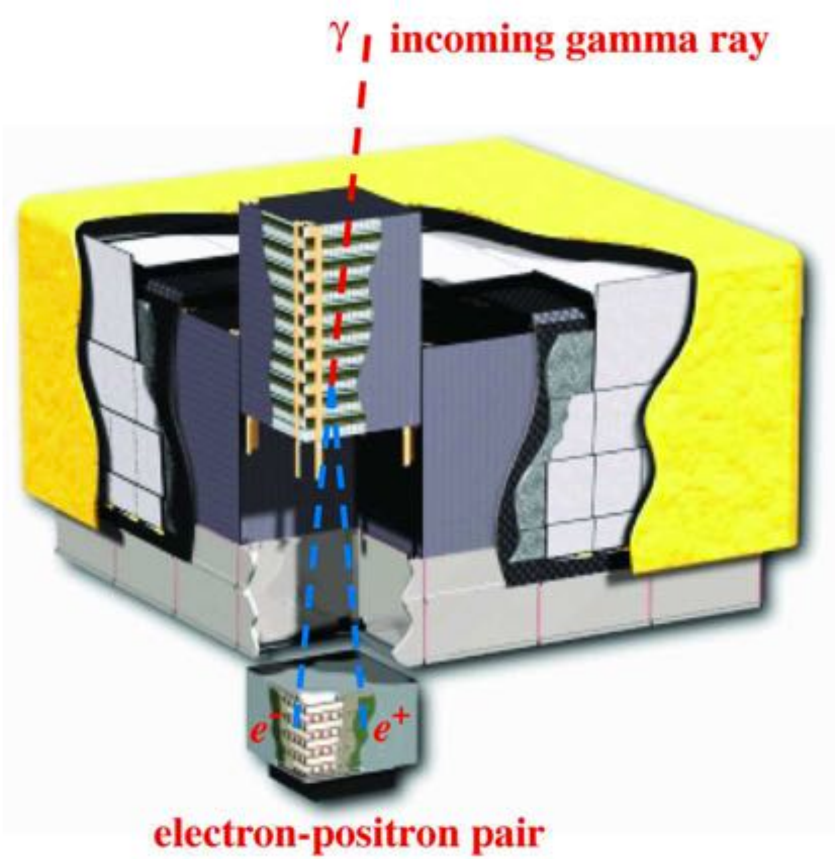
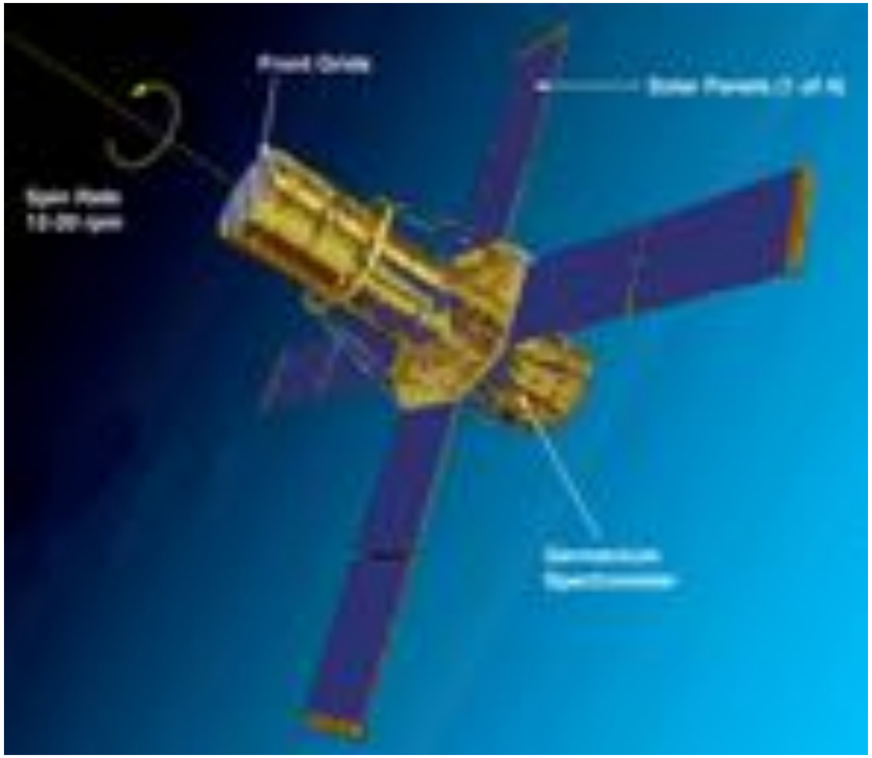


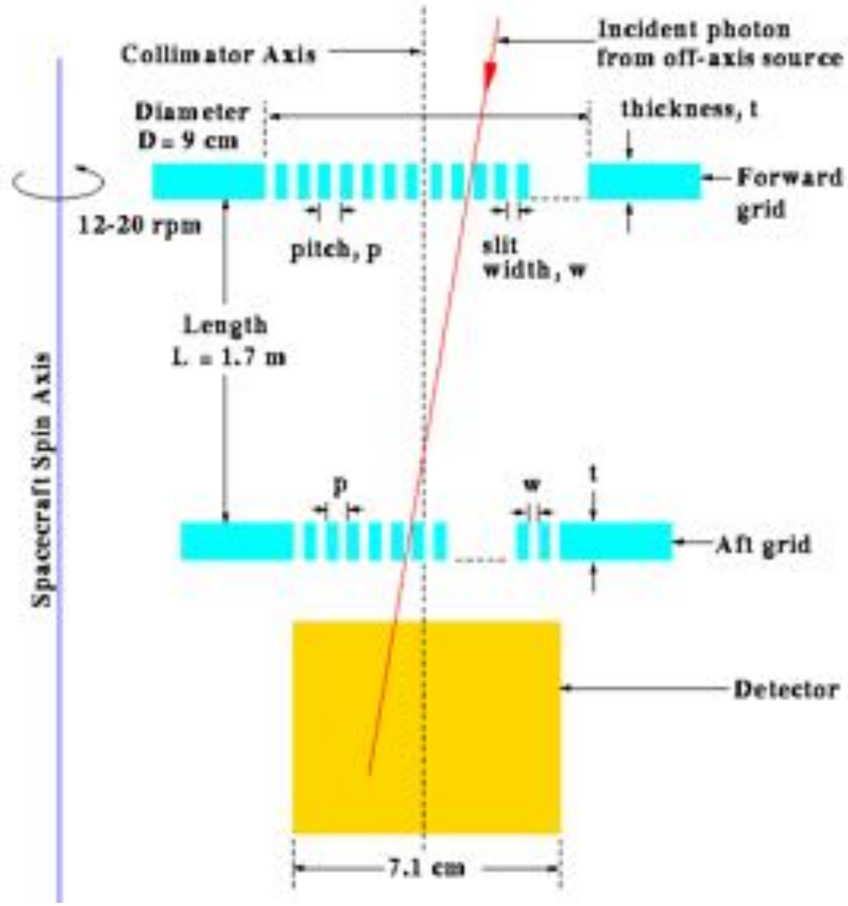
Fig. 1 in arxiv.org/pdf/0902.1089v1.pdf

MAGIC Cerenkov telescopes

magic.mpp.mpg.de/newcomers/introduction/

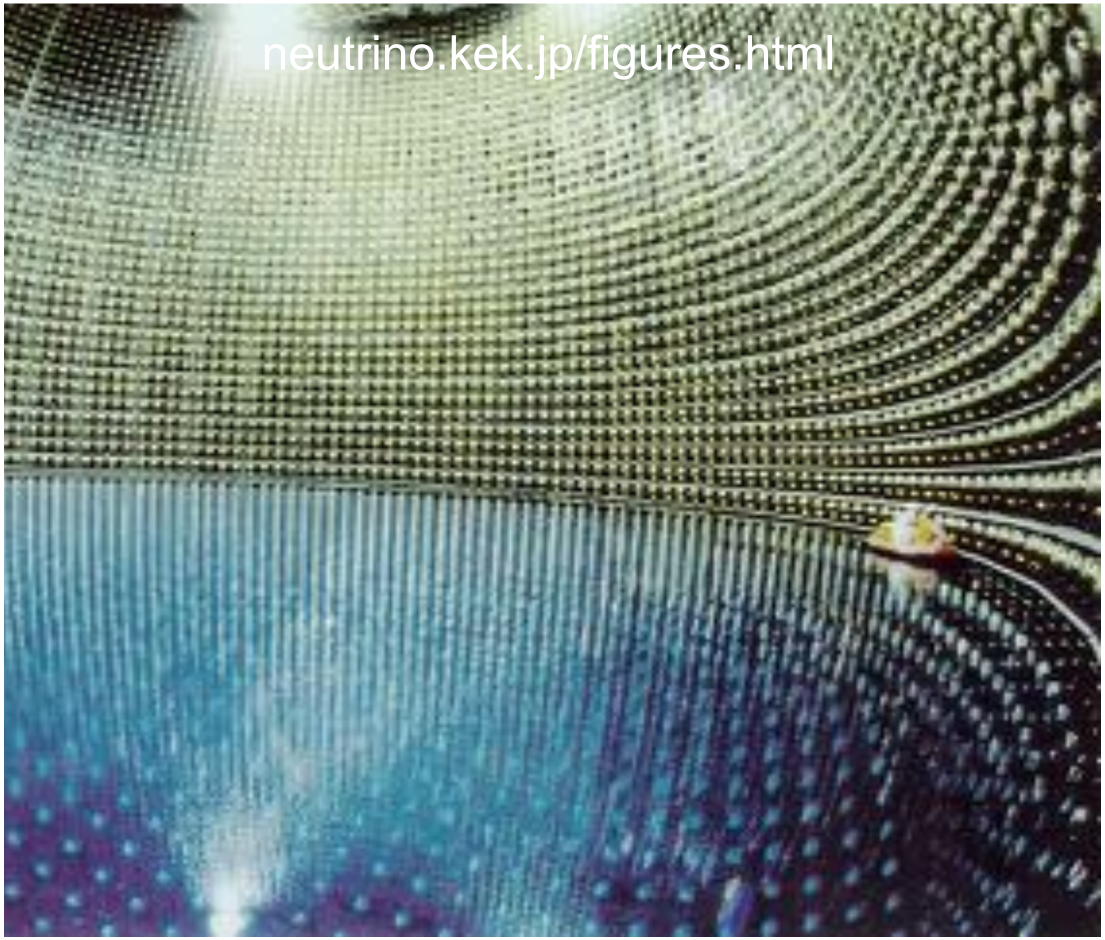
RHESSI Gamma-Ray

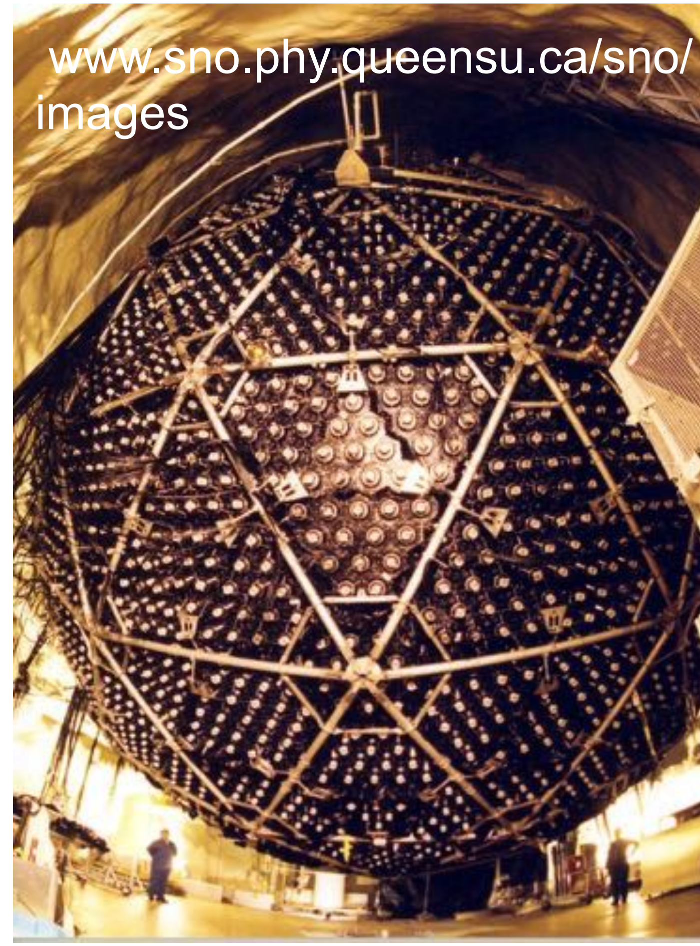




hesperia.gsfc.nasa.gov/rhessi3/mission

Neutrino Telescopes



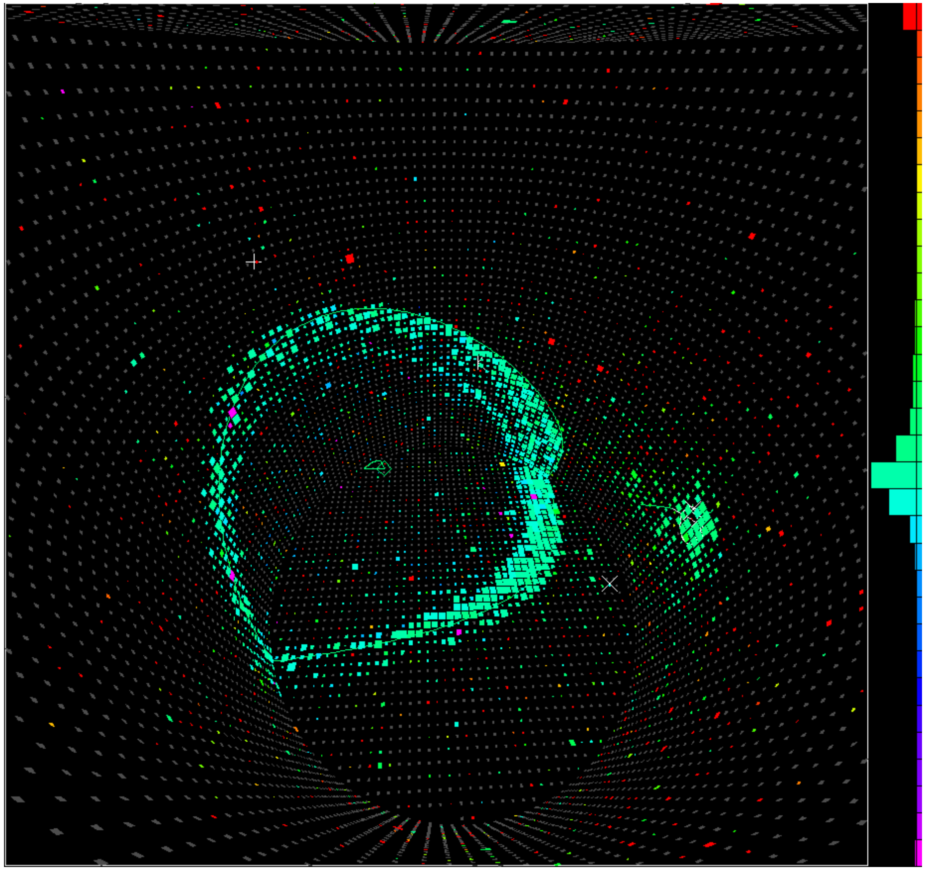


Super-Kamiokande, 50,000 tons of water

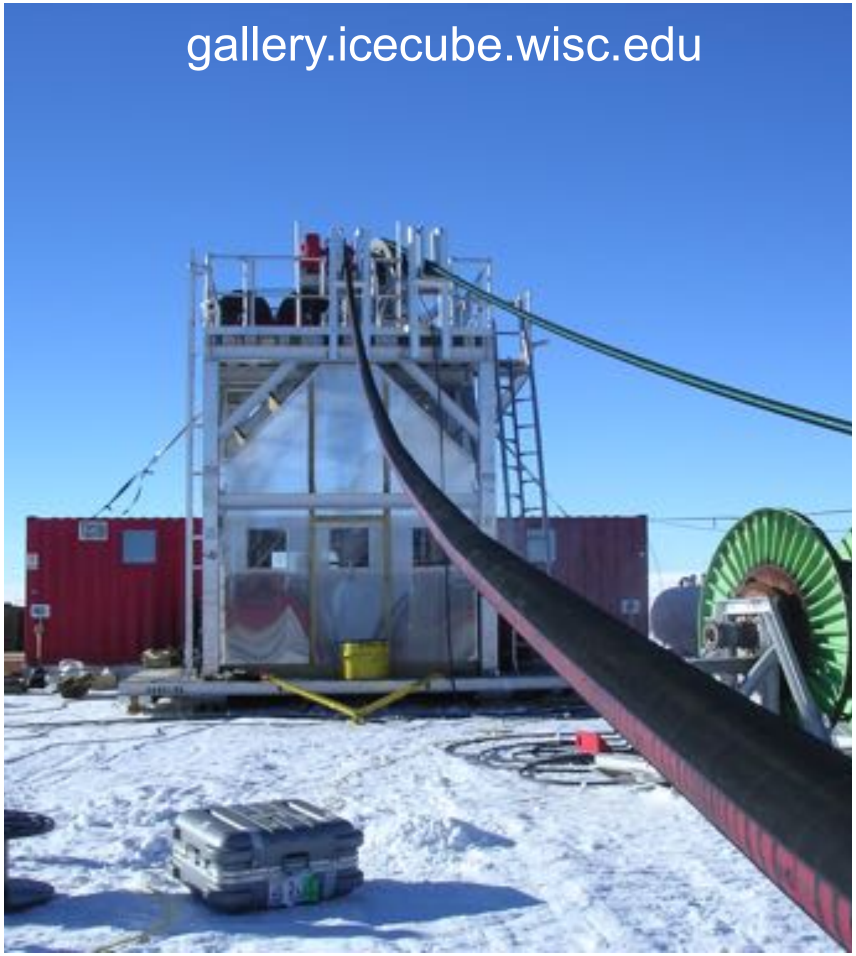
Sudbury Neutrino Observatory, 1000 tons of D_2O

Neutrino Detection

- scattering of neutrinos on electrons: $e^- + \nu_e \rightarrow e^- + \nu_e$
- electron accelerated to $v > c$ ➔ Cerenkov radiation
- solar neutrinos
- neutrino oscillations
- neutrinos from SN1987A



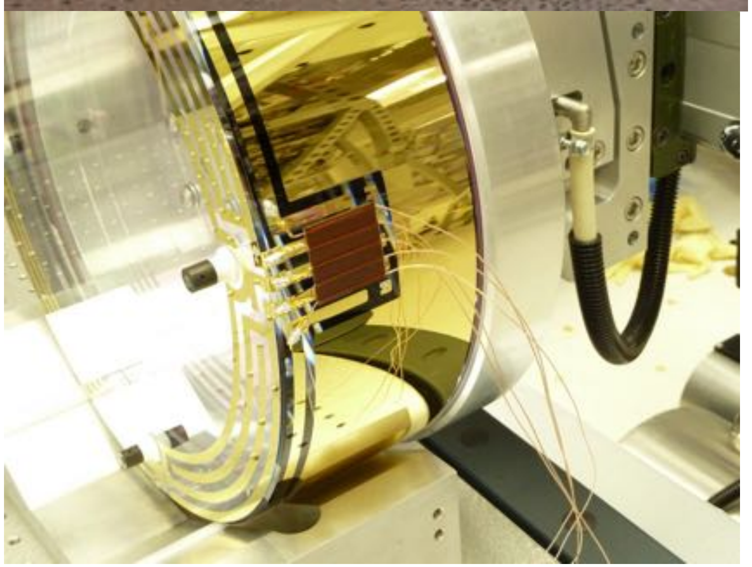
Neutrinos in Ice and Water



IceCube at the South Pole

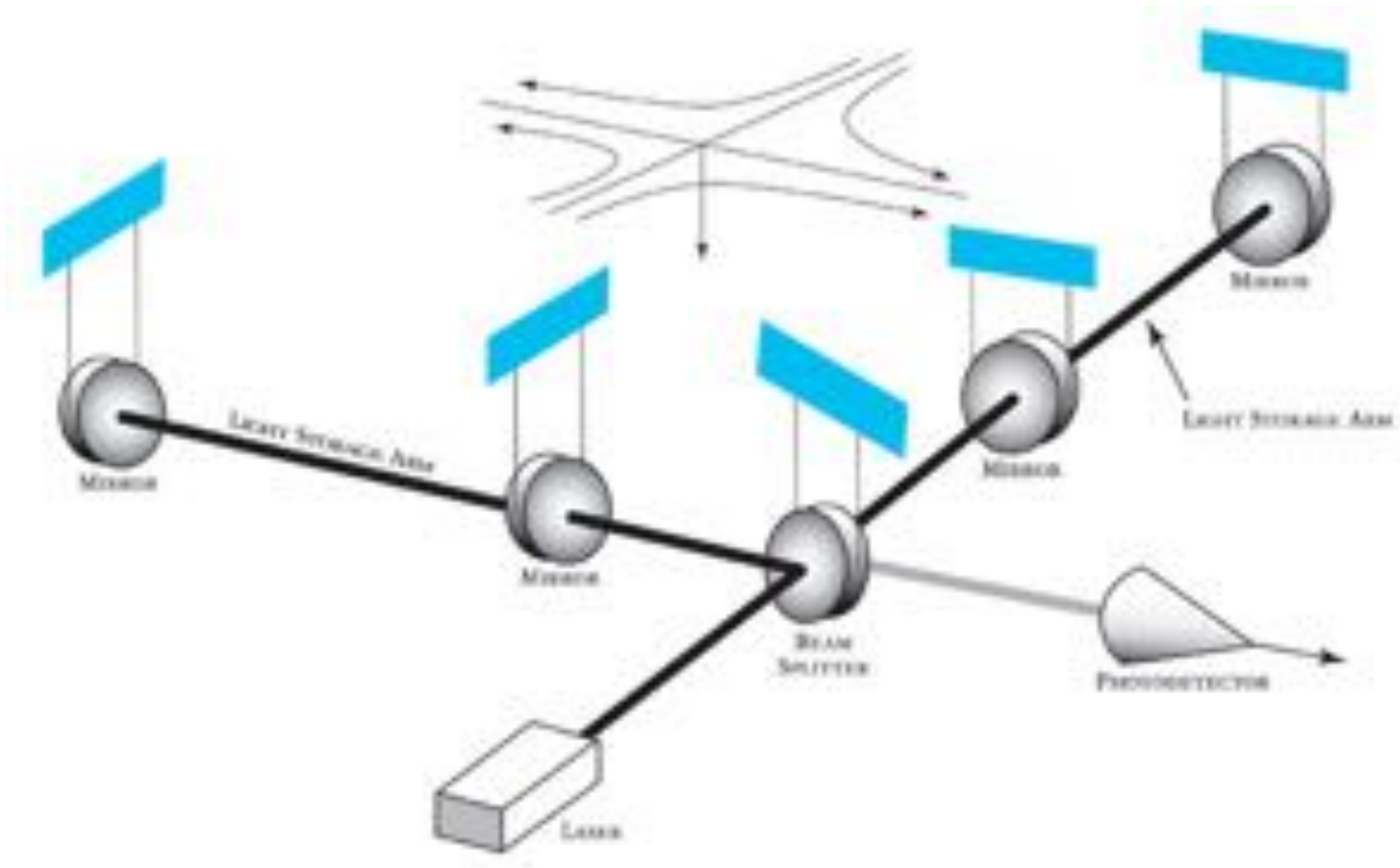
ANTARES in Mediterranean Sea

Gravitational Wave Detectors



ligo.org/multimedia/gallery

GW Measurement Principle



ligo.org/science/GW-Overview/images/IFO.jpg