telescopes

Astronomical Instrumentation course

lecture 8

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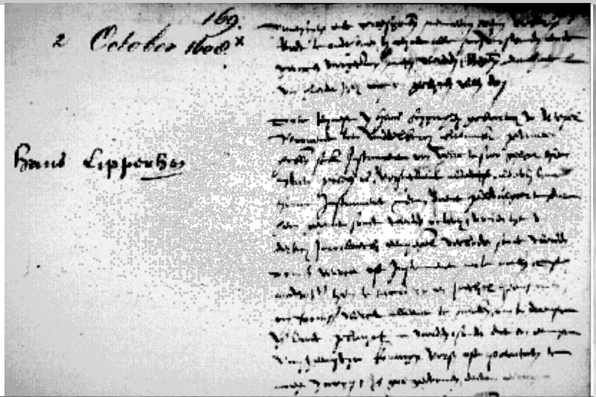
Hollandsche kijker

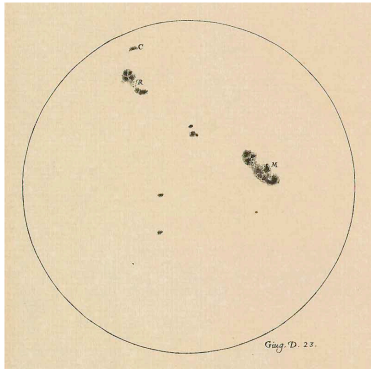
1608

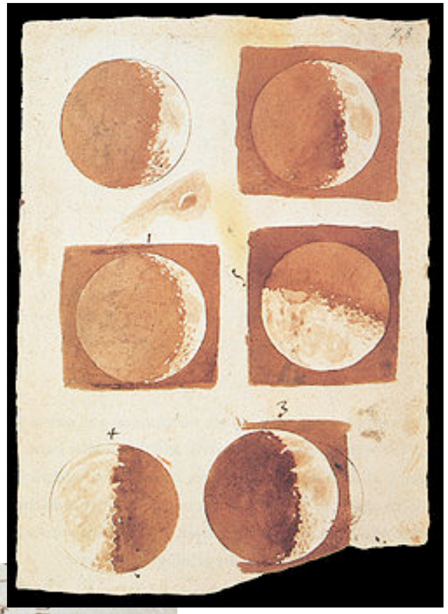


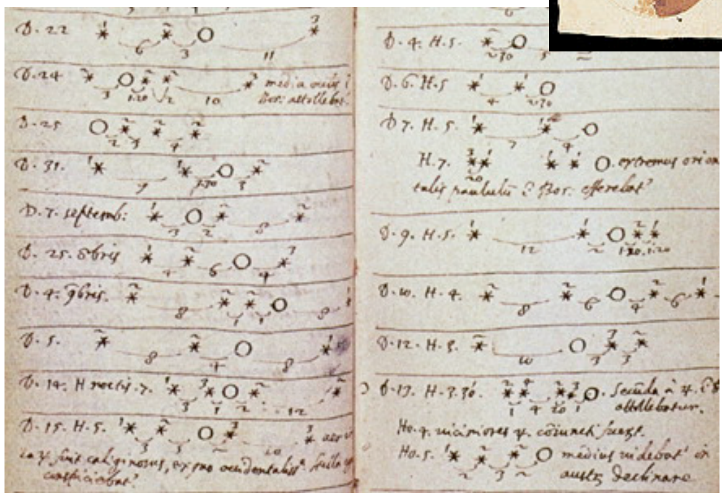
telescopes

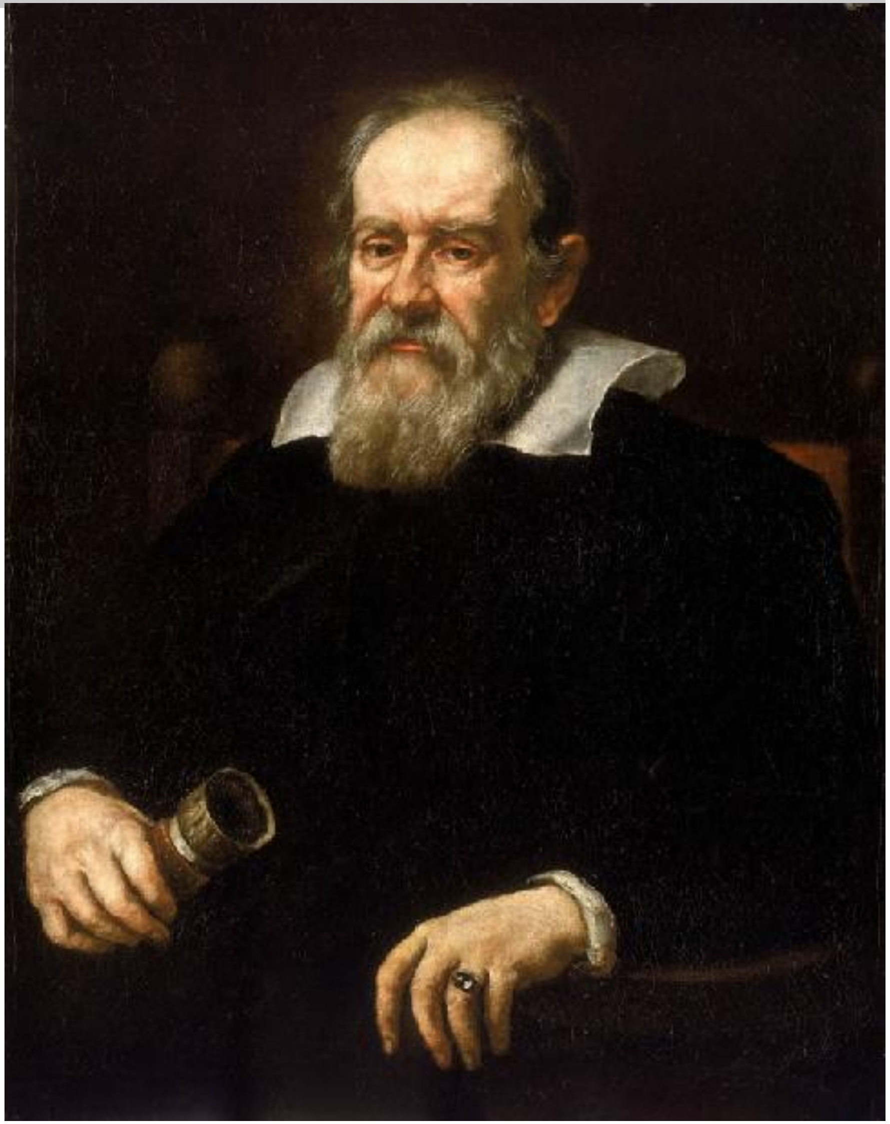
Hollandsche kijker

1609

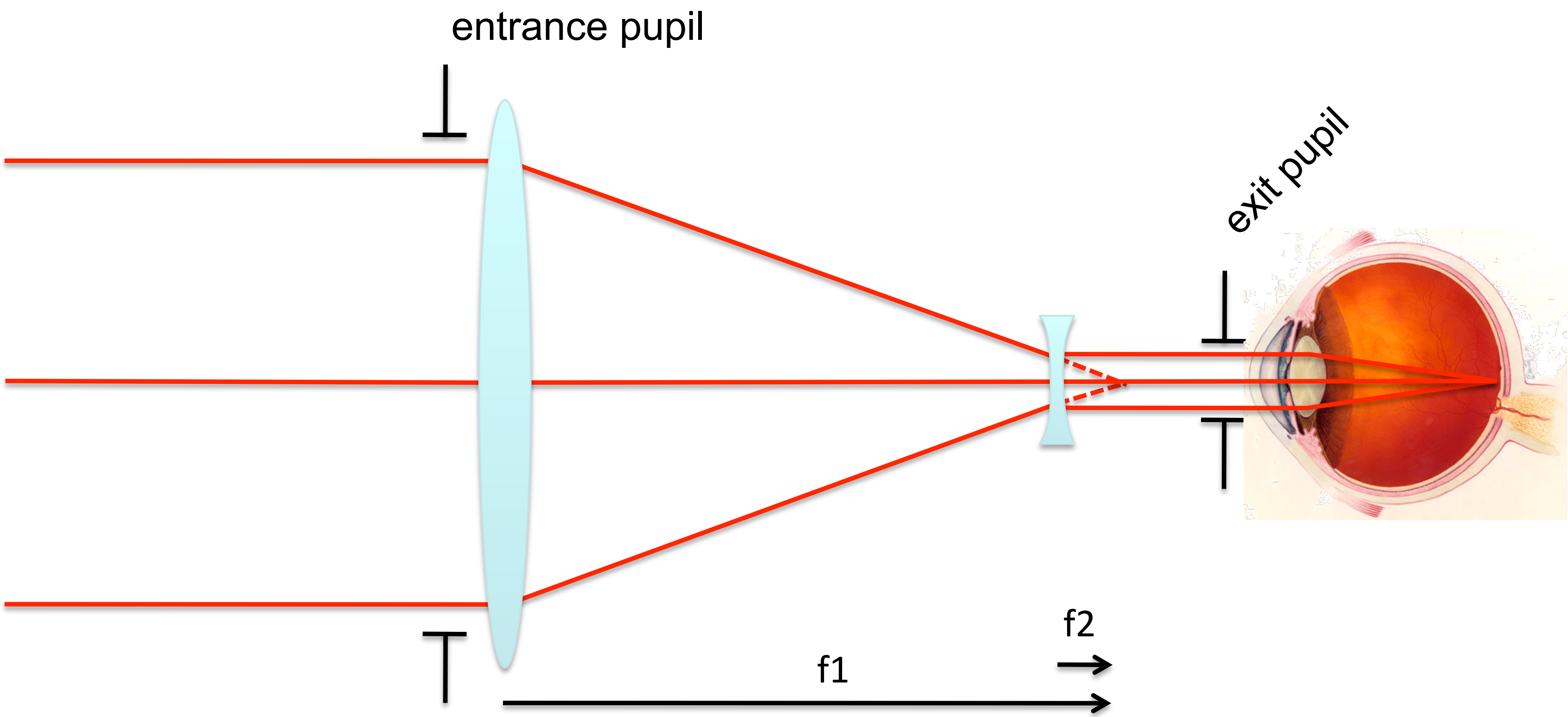








Hollandsche kijker



magnification = f1/f2

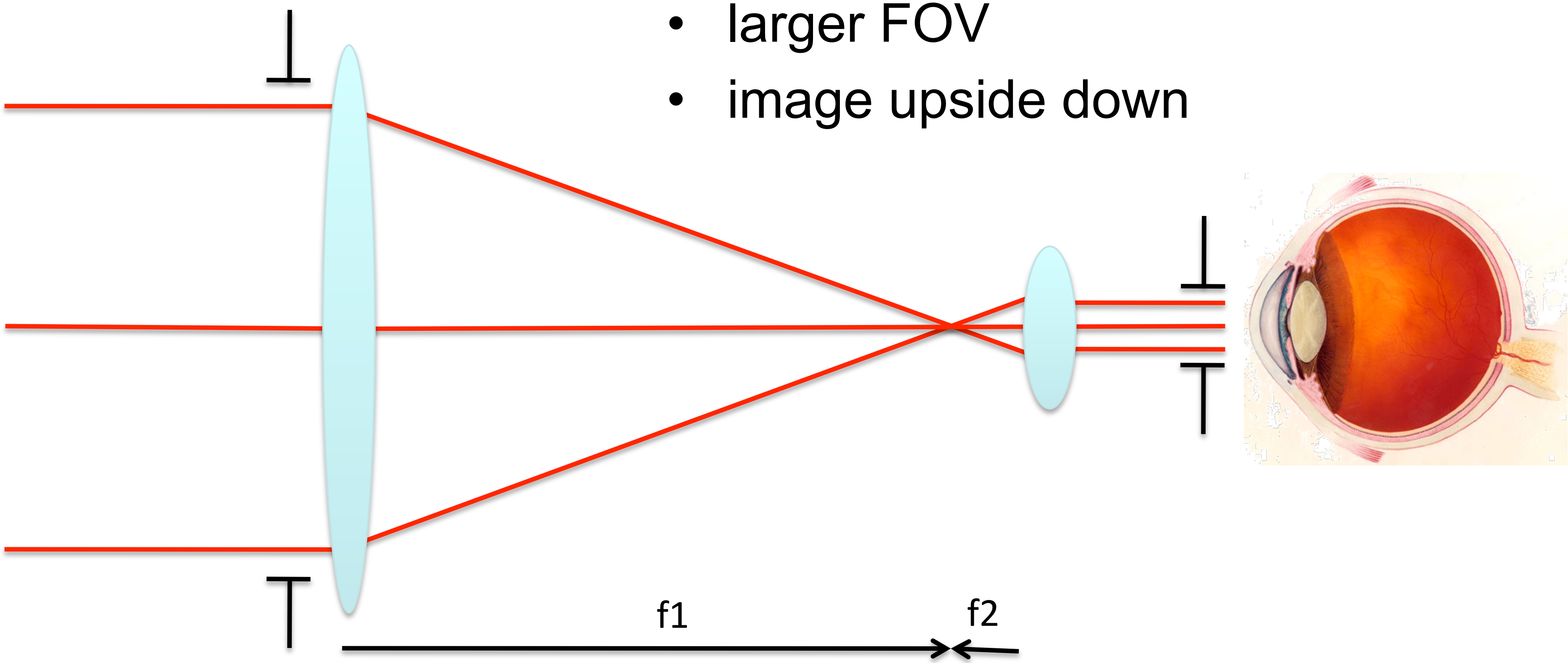
Hollandsche kijker

- limitations:
  - FOV
  - chromatic aberrations
  - magnification: stabilization and guiding

telescopes

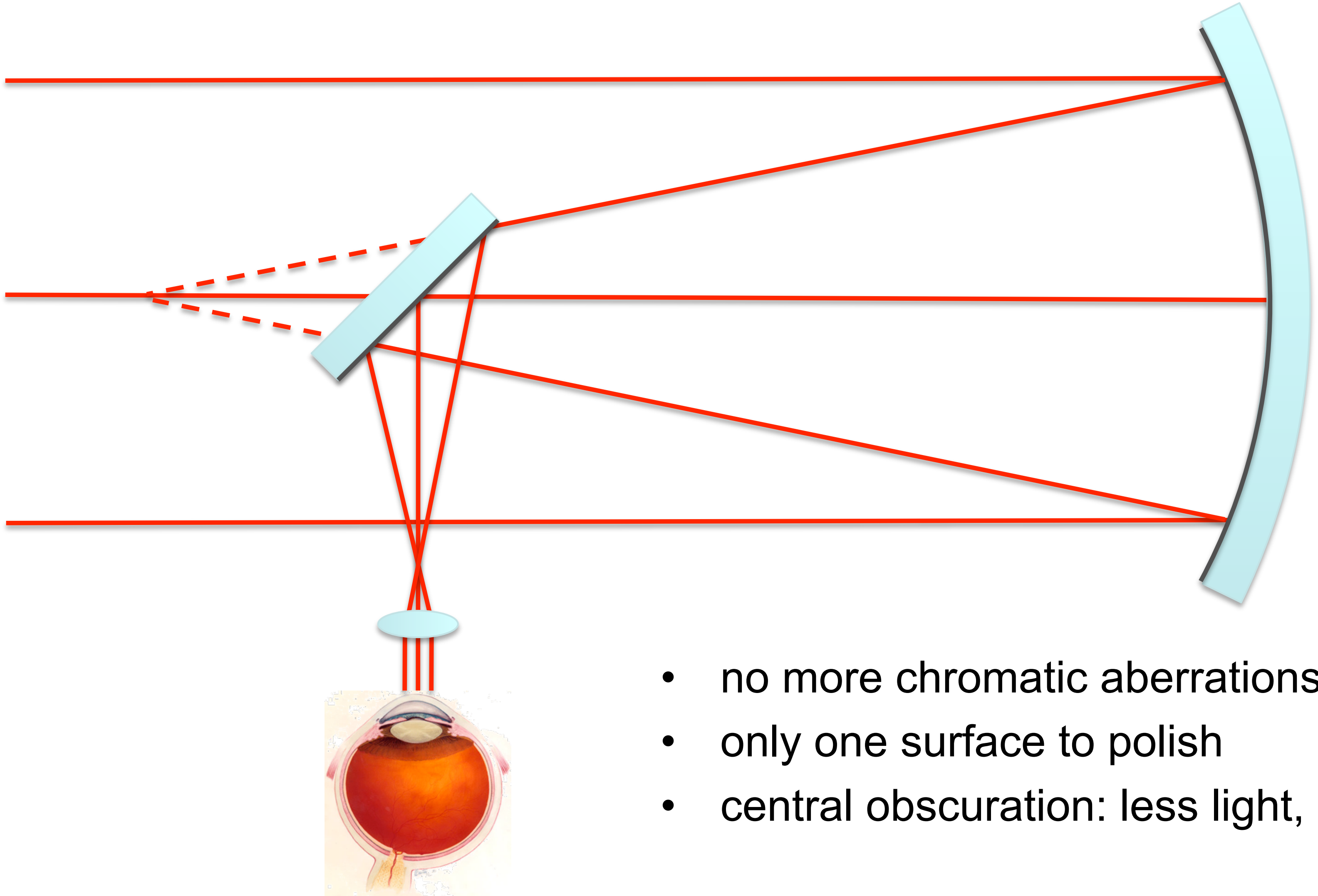
Kepler refractor

- still afocal telescope
- larger FOV
- image upside down



magnification = f1/f2

Newtonian telescope

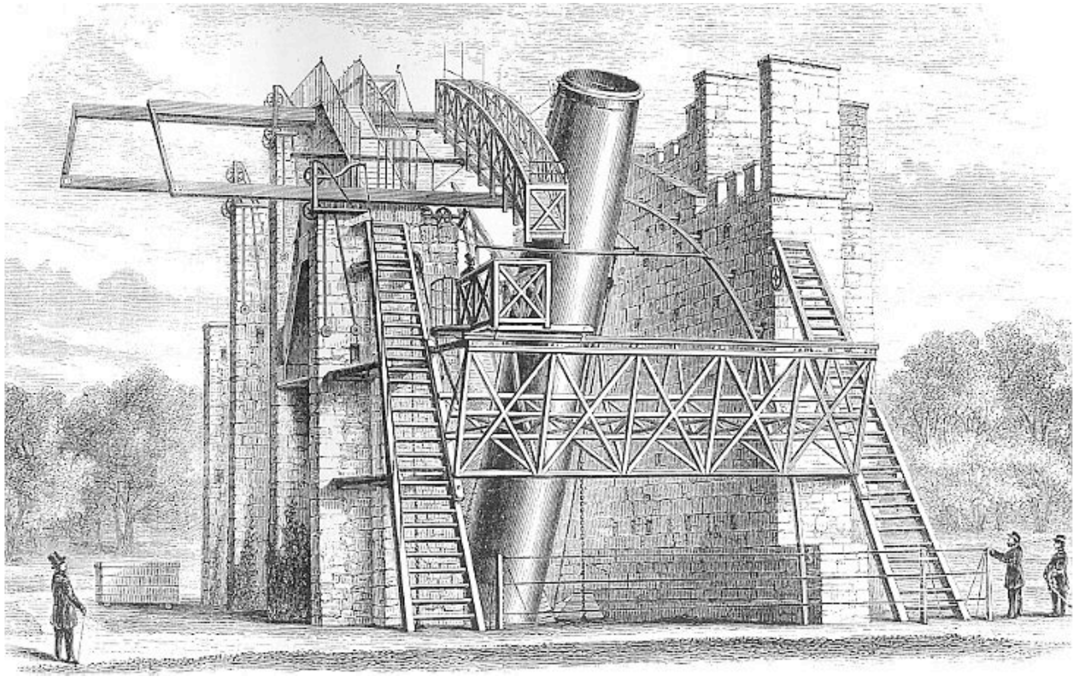


- no more chromatic aberrations
- only one surface to polish
- central obscuration: less light, diffraction

Newtonian telescope

1668

1842

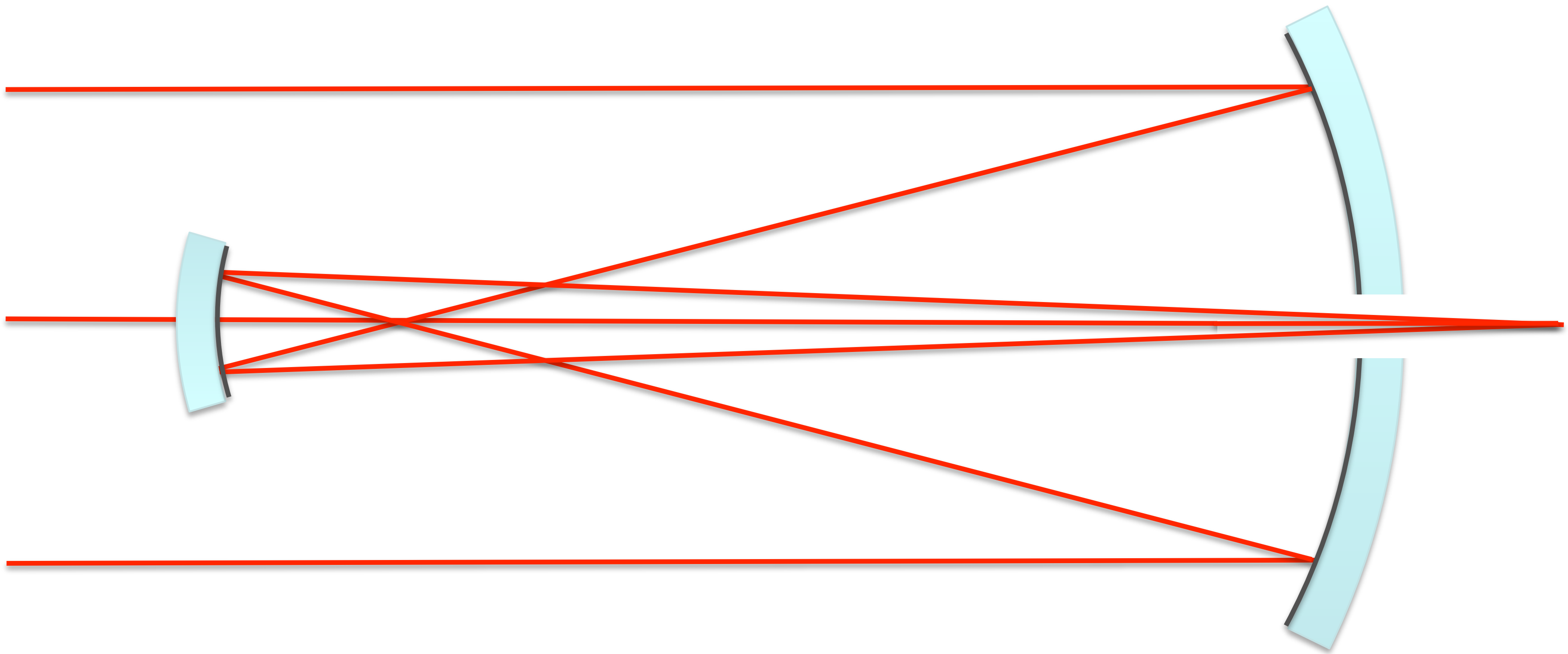


1721: parabolic primary mirror
to reduce spherical aberration

telescopes

secondary mirror

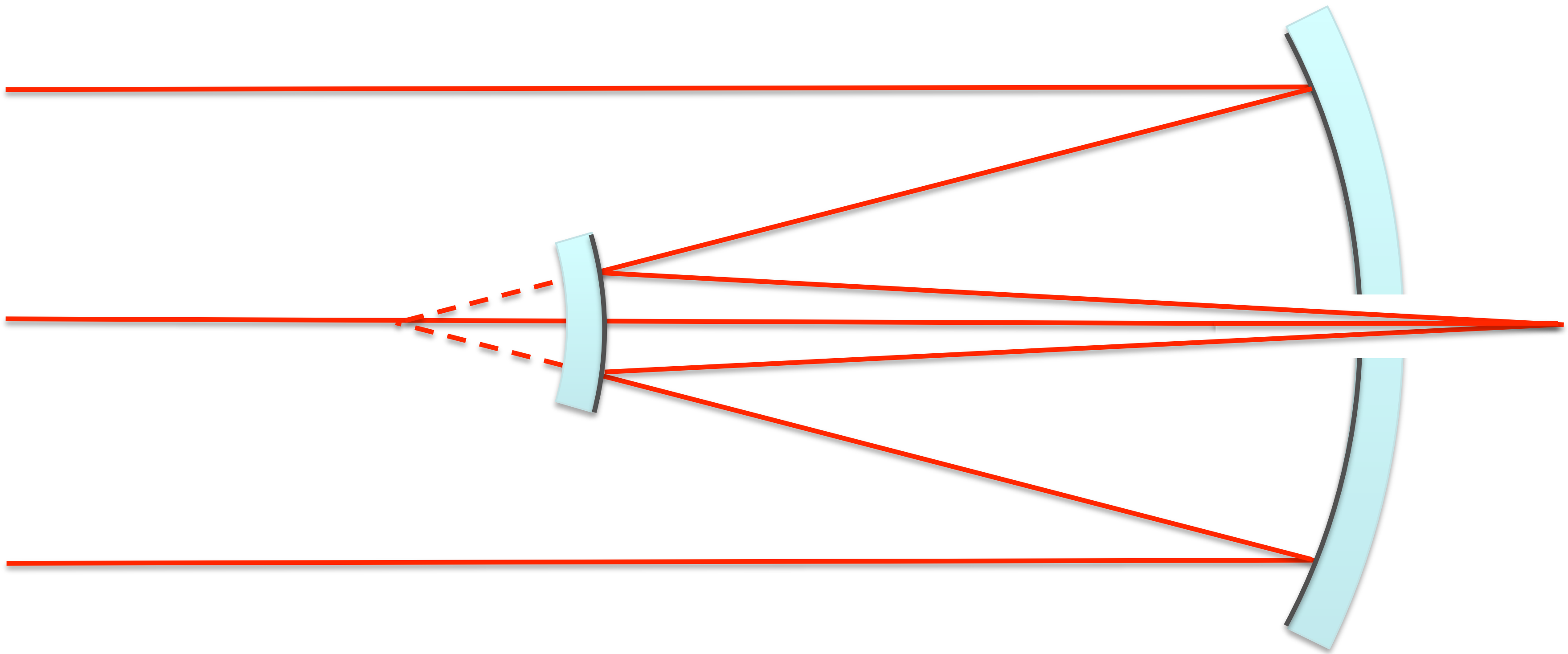
Gregorian telescope



telescopes

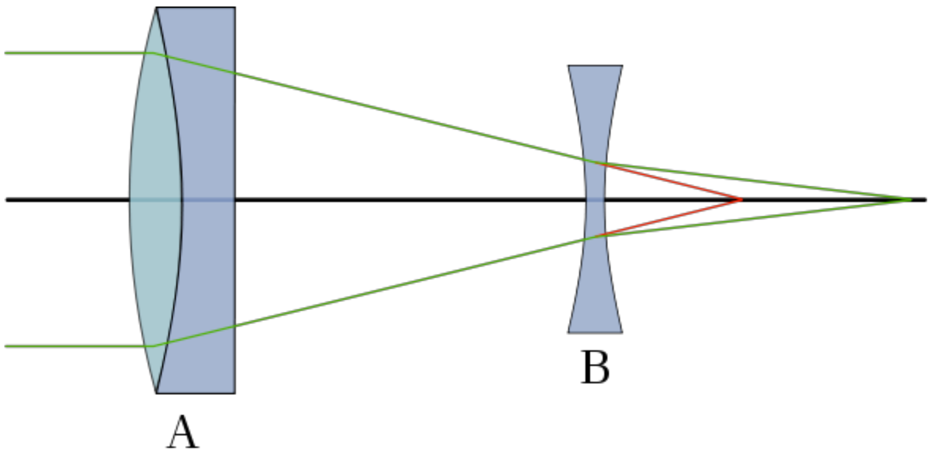
secondary mirror

Cassegrain telescope

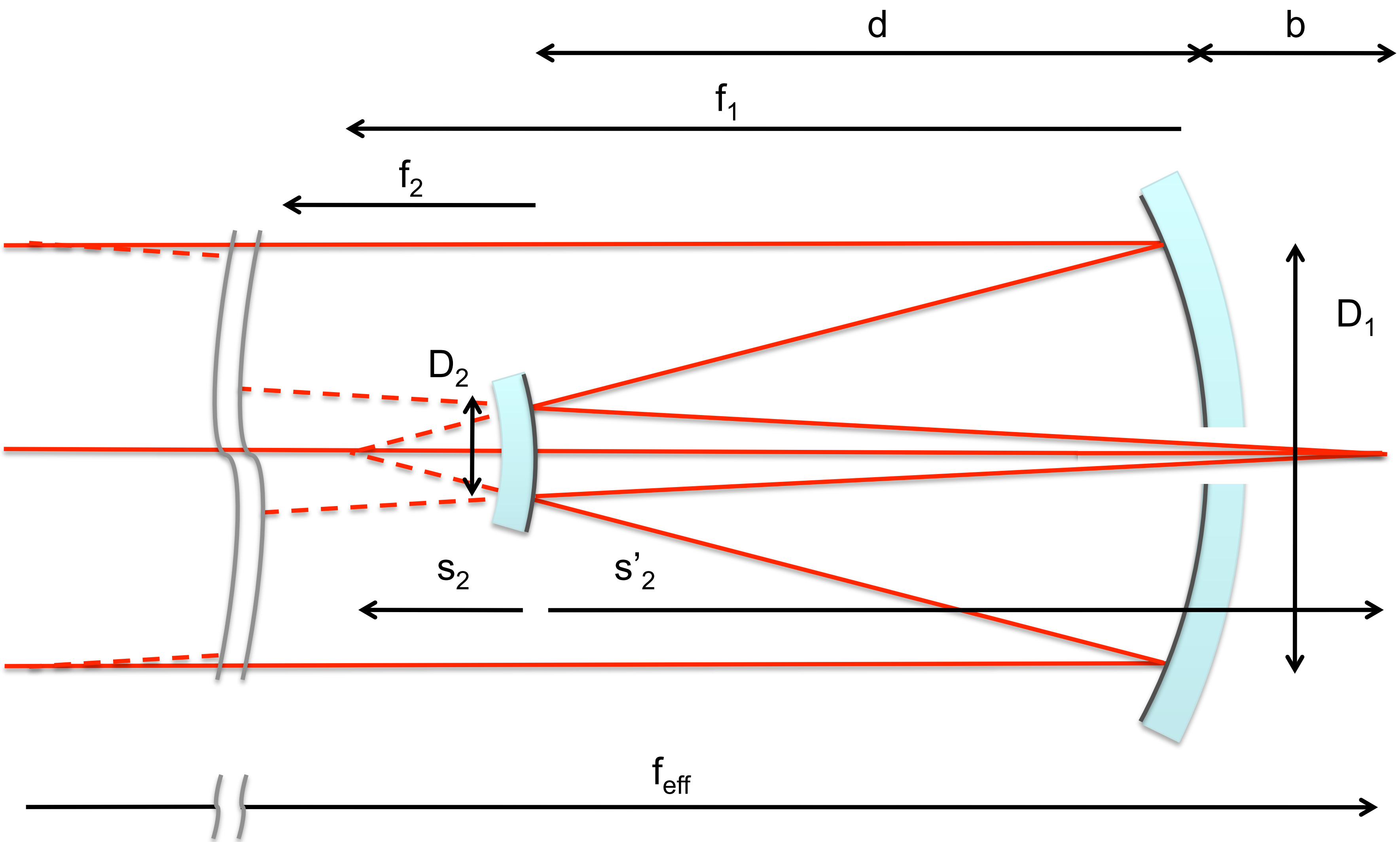


secondary mirror

- relay of focus
- focusing mechanism
- reduction of aperture surface
  - off-axis telescope
- equivalence with Barlow lens



Cassegrain telescope



Cassegrain telescope

- short system with long focal length

- effective focal length $f_{eff} = \dfrac{f_1 \cdot f_2}{f_1 - f_2 - d}$

- secondary magnification:
  $M_2 = f_{eff} / f_1 = s'_2 / s_2$

- $f_{eff} = d + b + M_2 * d$

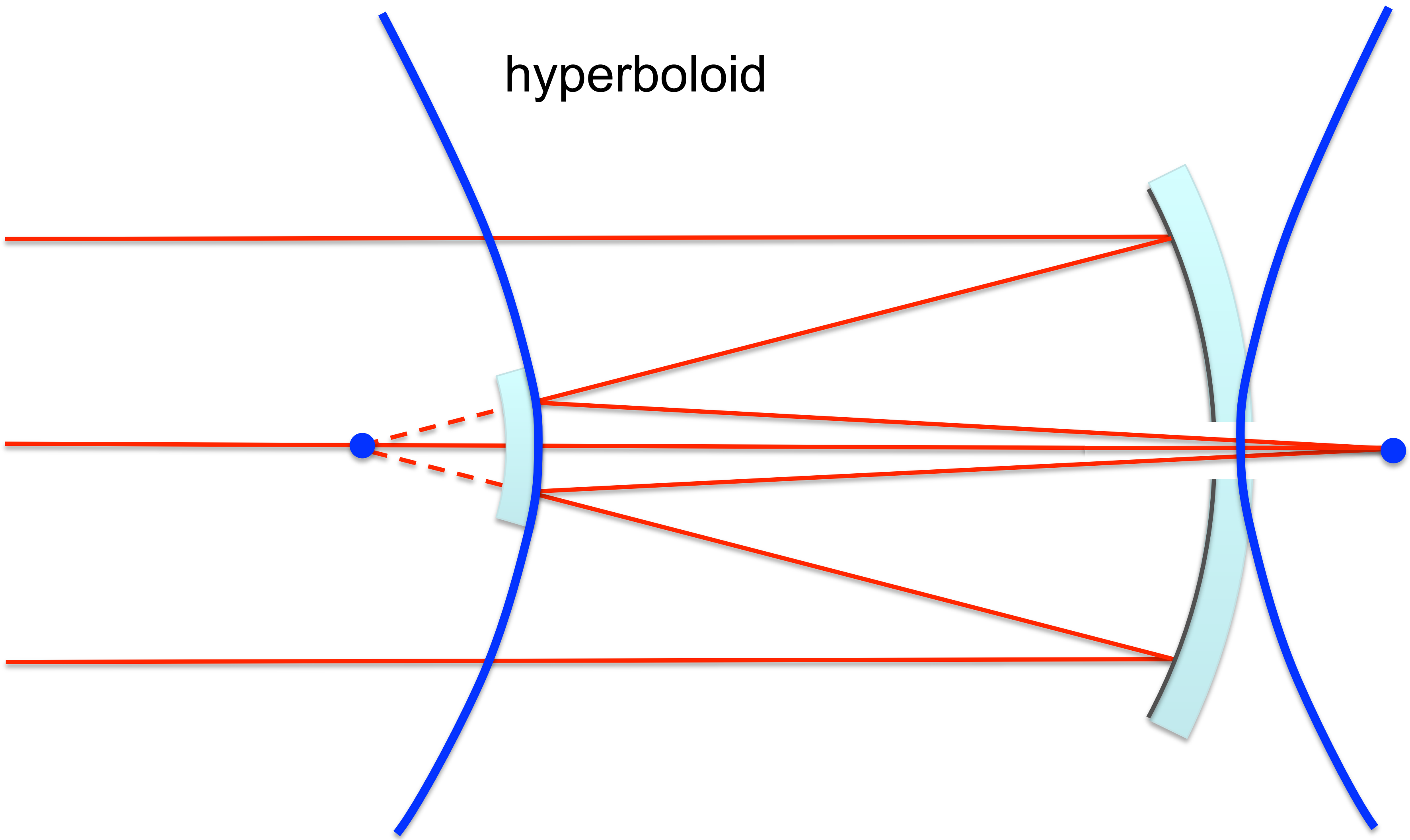
two-mirror telescope aberrations

- field curvature

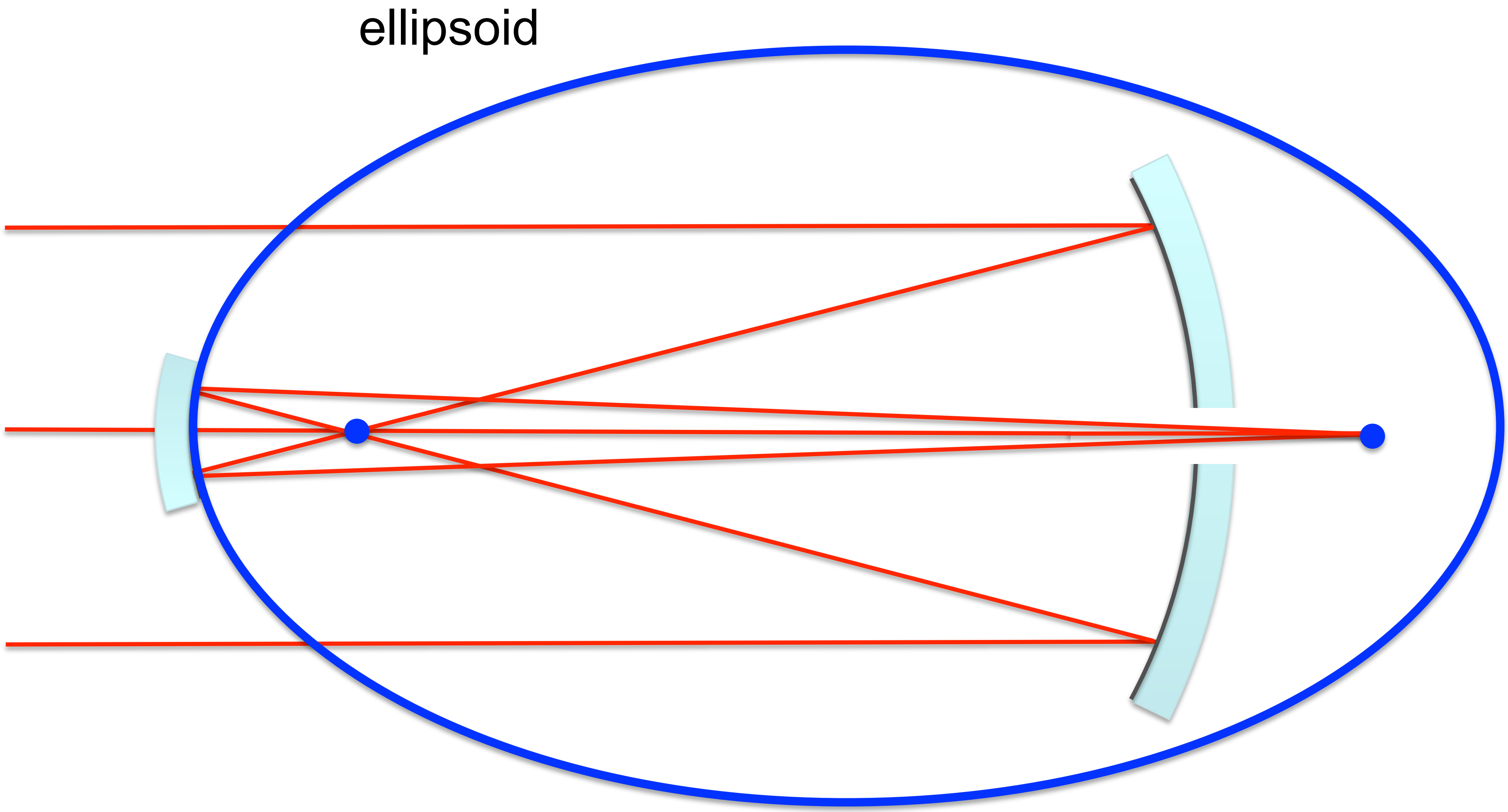
$$\frac{1}{r_f} = \frac{2}{R_1} - \frac{2}{R_2}$$

- concave towards the sky
- always present in real two-mirror telescopes

two-mirror telescope aberrations



two-mirror telescope aberrations



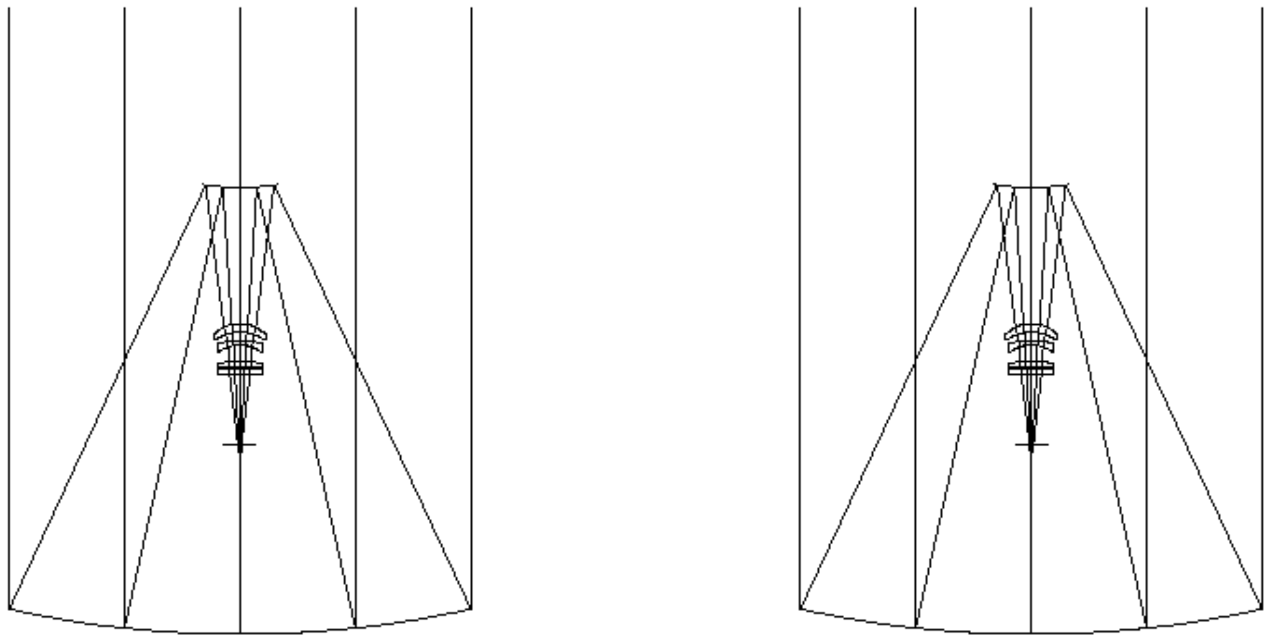
two-mirror telescope aberrations

- Seidel aberrations
- solutions for conic constants to cancel spherical aberration; $\Sigma S_I = 0$
- classical Cassegrain: parabolic M1 and hyperbolic secondary with conic constant

$$K_2 = -\left(\frac{M_2 + 1}{M_2 - 1}\right)^2$$

- residual coma and astigmatism…

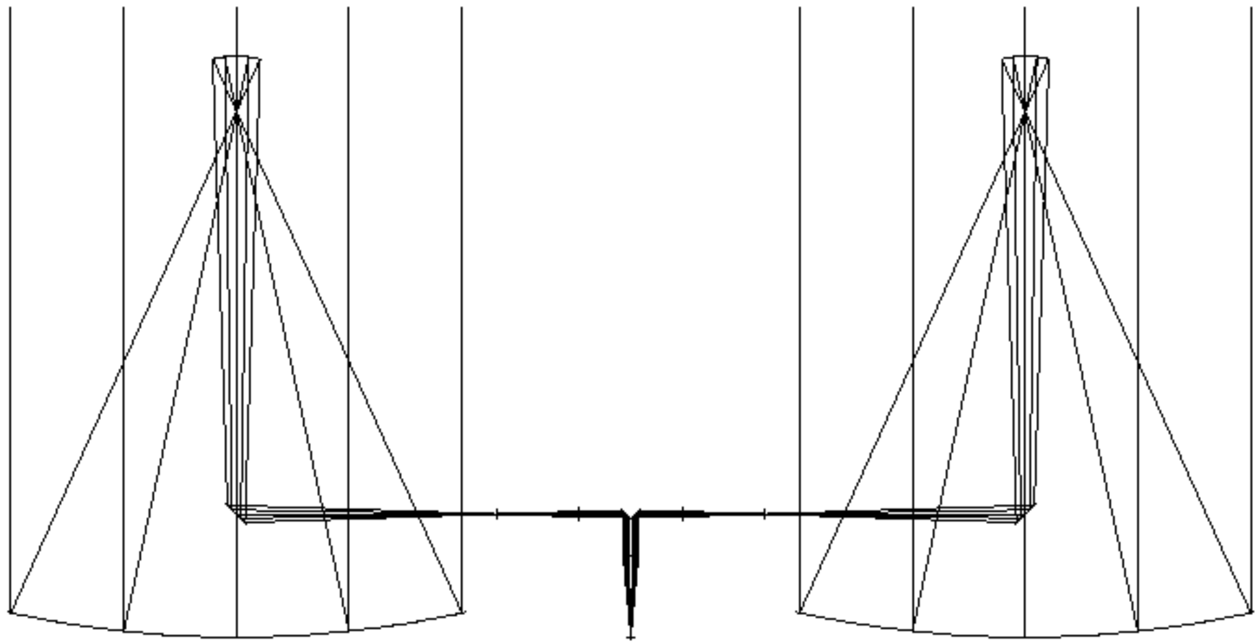
two-mirror telescope aberrations



LBT

two-mirror telescope aberrations

- equations also for Gregorian: elliptical secondary

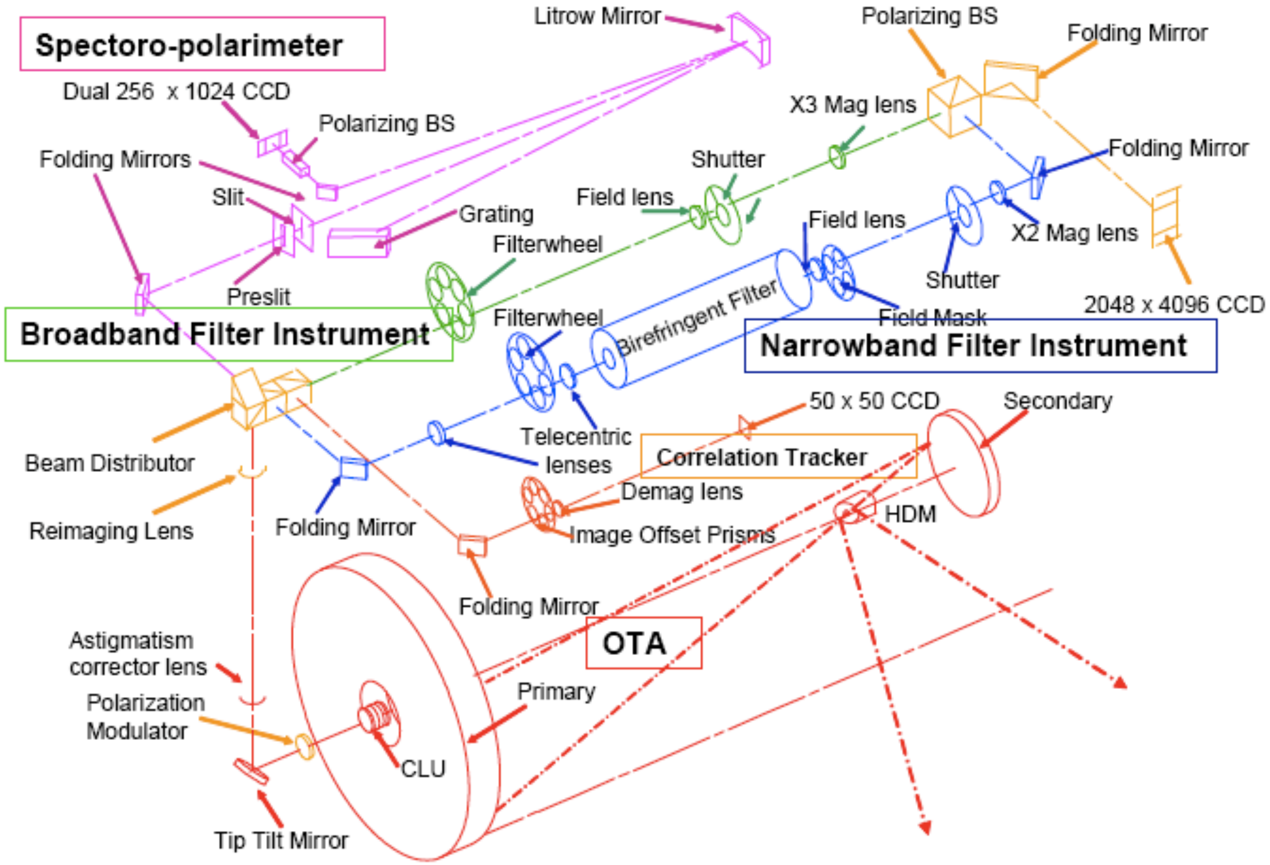


adaptive secondary calibrated from intermediate focus

LBT

two-mirror telescope aberrations

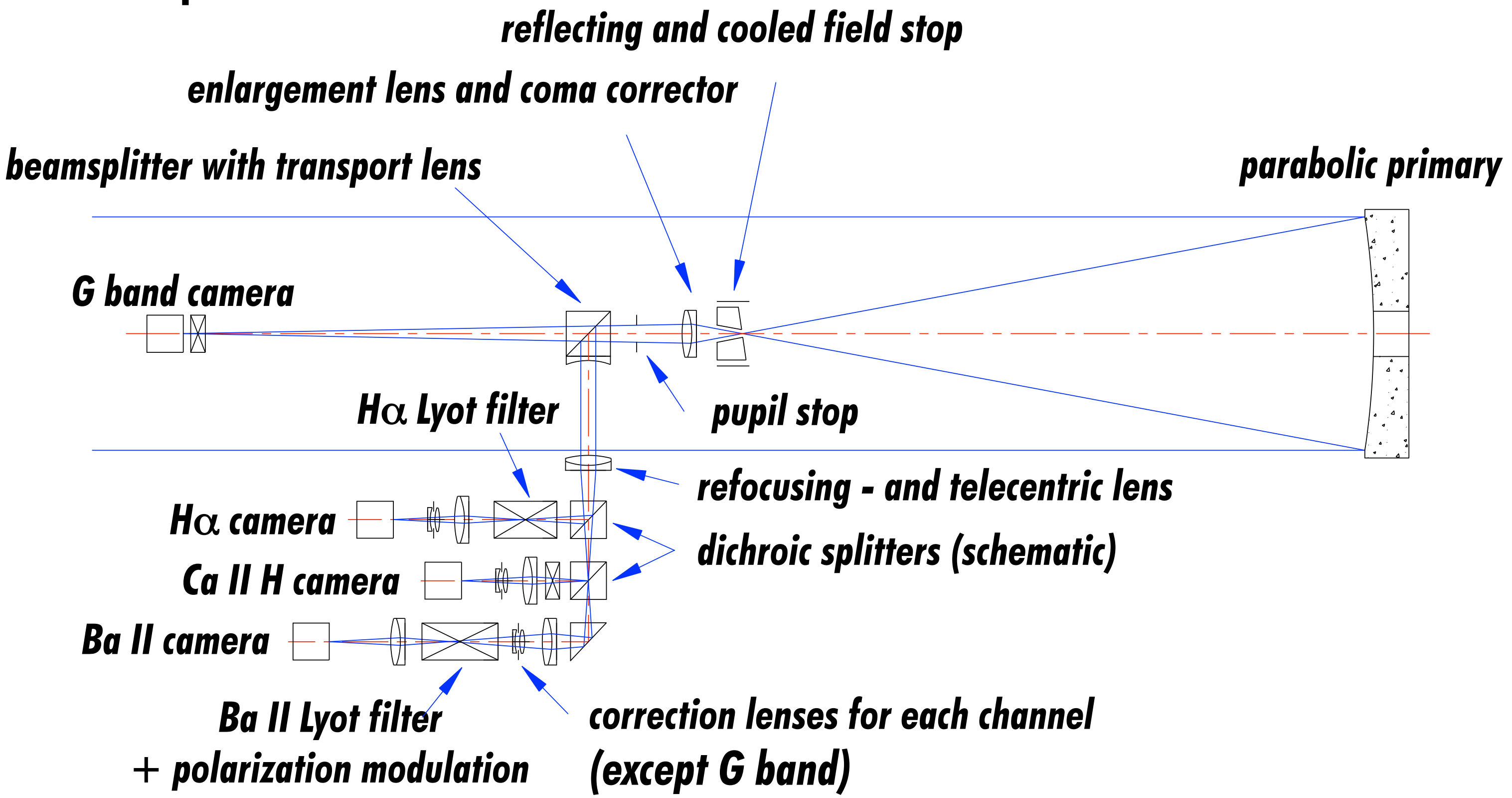
- many solar telescopes are Gregorian
  - heat stop



Hinode
Solar Optical Telescope

two-mirror telescope aberrations

- many solar telescopes are Gregorian
  - heat stop



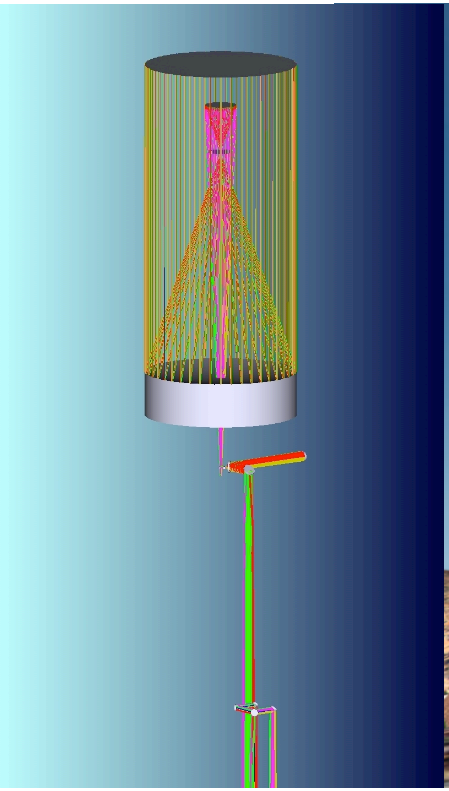
DOT

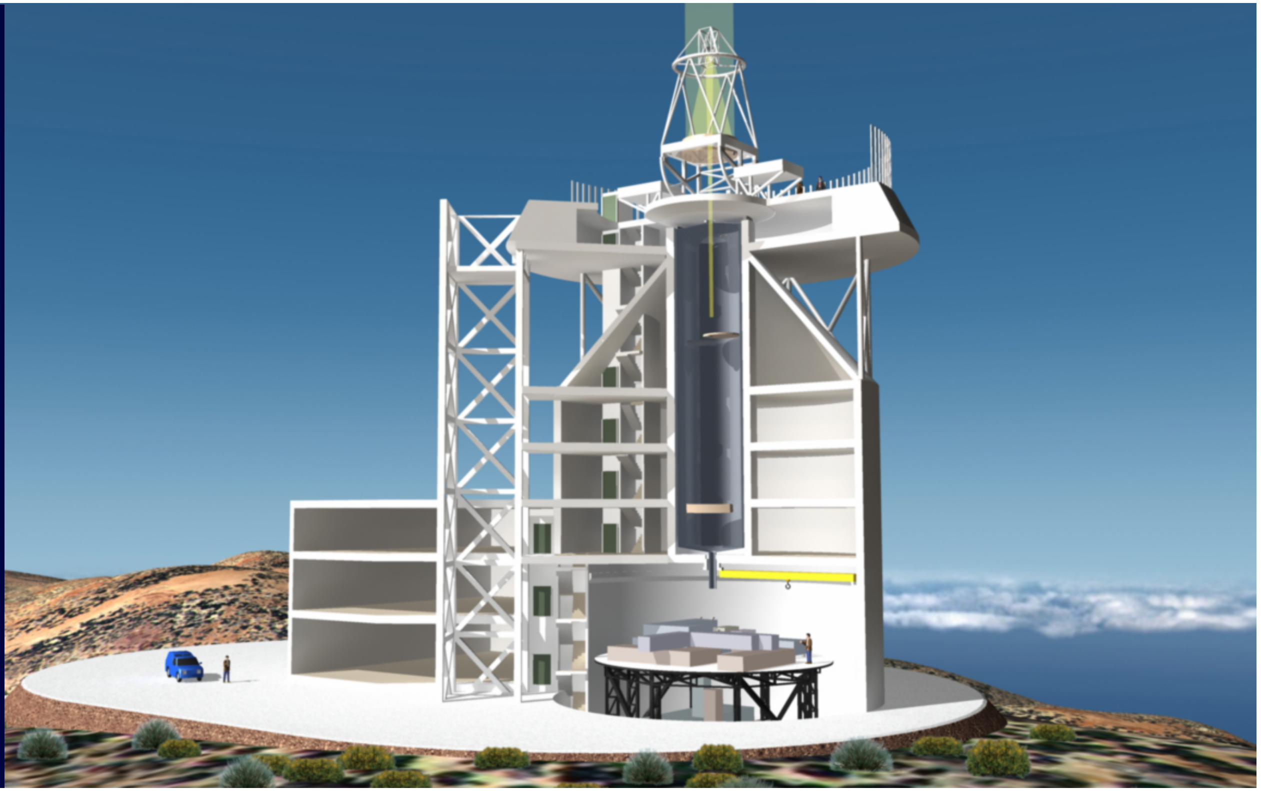
telescopes

two-mirror telescope aberrations

- many solar telescopes are Gregorian
  - heat stop

EST





Ritchey-Chrétien telescope

- cancel spherical and coma:
  $\Sigma S_I = 0$ and $\Sigma S_{II} = 0$

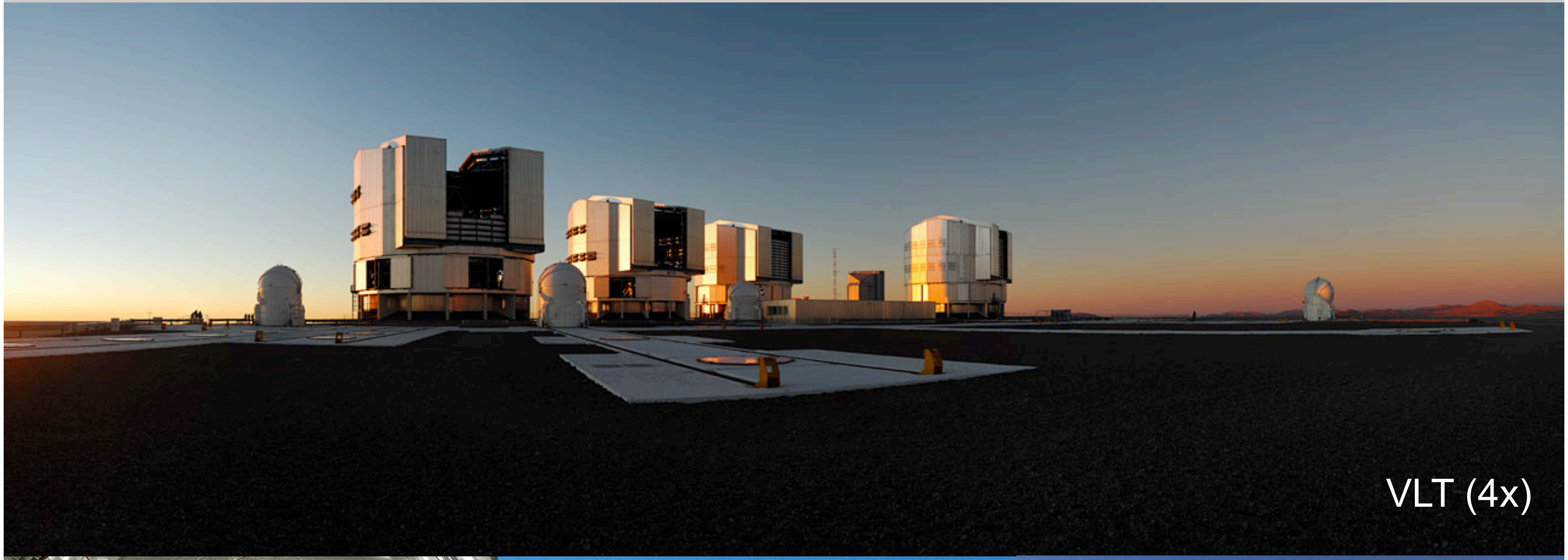
$$K_1 = -1 - \frac{2}{(M_2)^3} \cdot \frac{b}{d} < -1$$

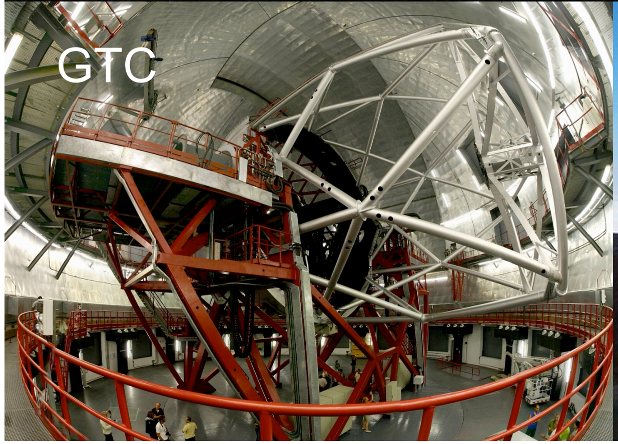
$$K_2 = -1 - \frac{2}{(M_2 - 1)^3}\left(M_2(2M_2 - 1) + \frac{b}{d}\right) < -1$$

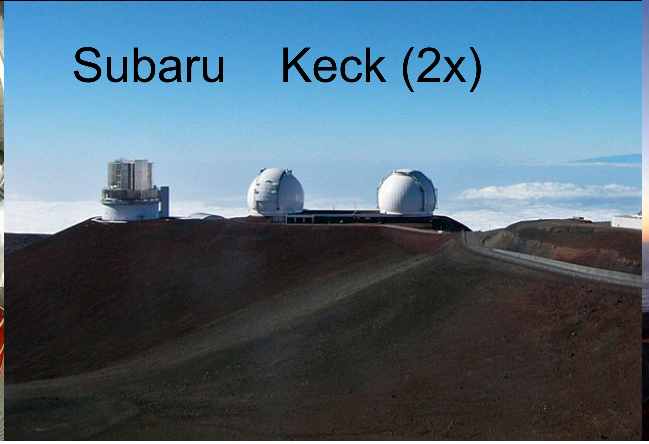
- both M1 and M2 hyperbolic

telescopes

Ritchey-Chrétien telescope





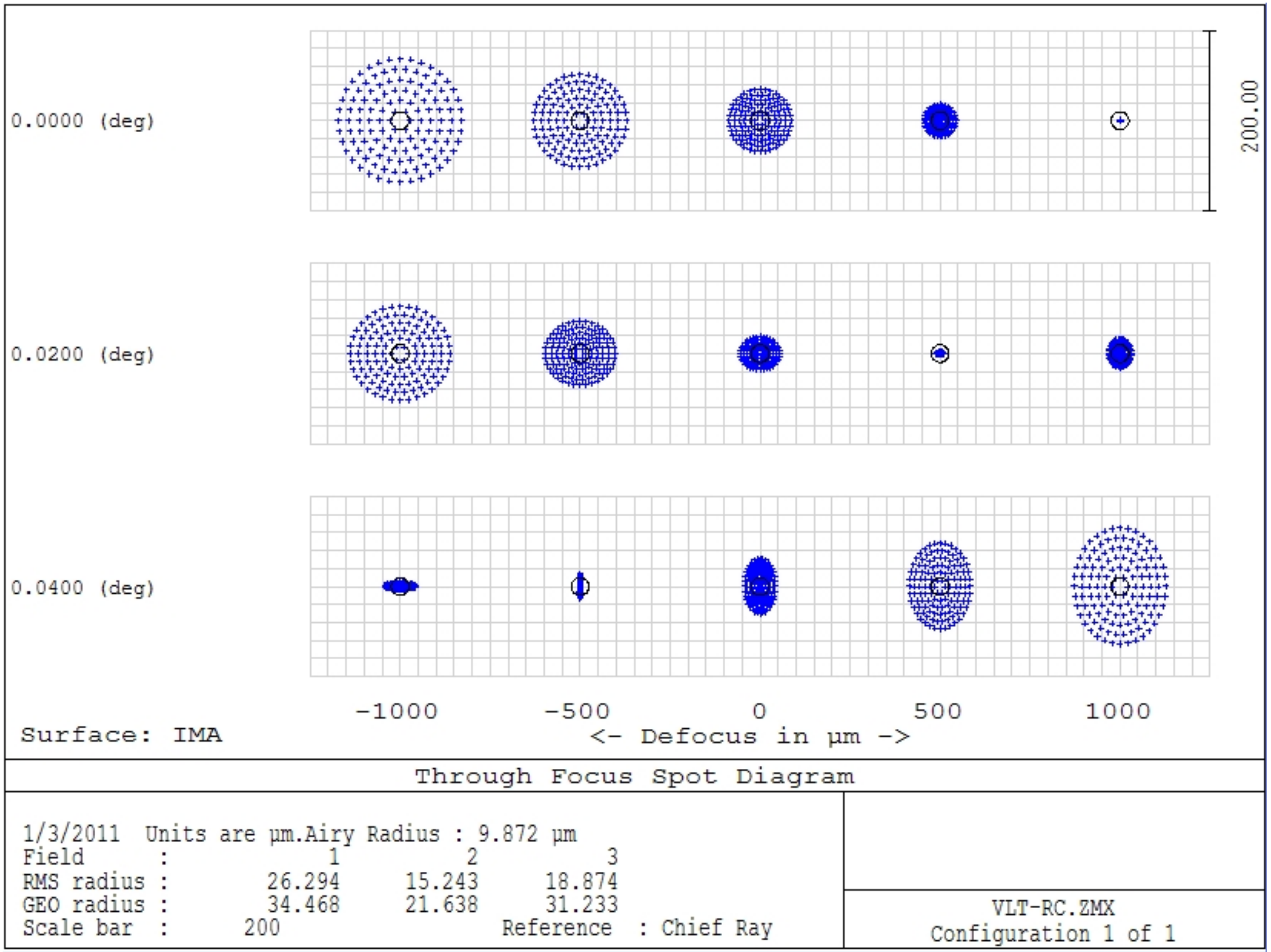


Ritchey-Chrétien telescope

Ritchey-Chrétien telescope

VLT

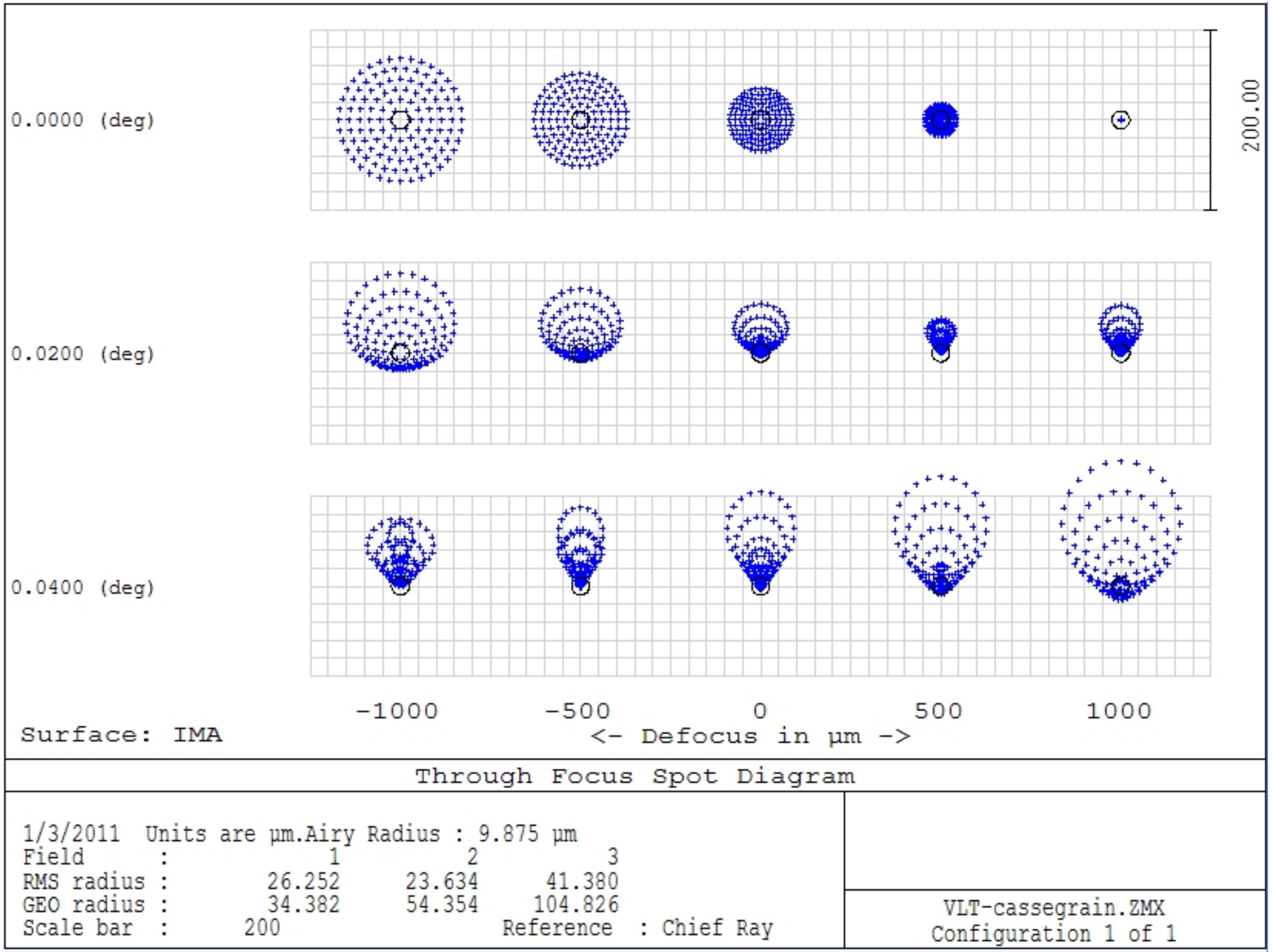
$K_1 = -1.0046$
$K_2 = -1.66926$



Ritchey-Chrétien telescope

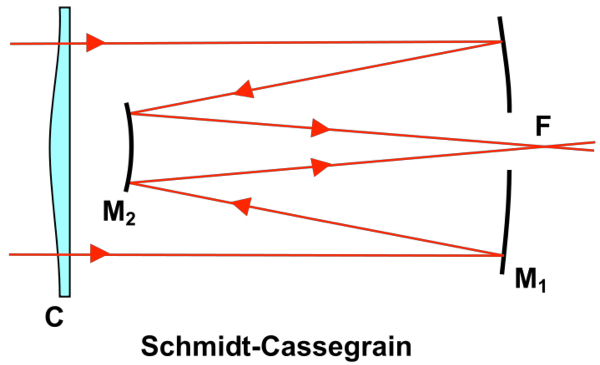
VLT as classical Cassegrain

$K_1 = -1$
$K_2 = -1.62$



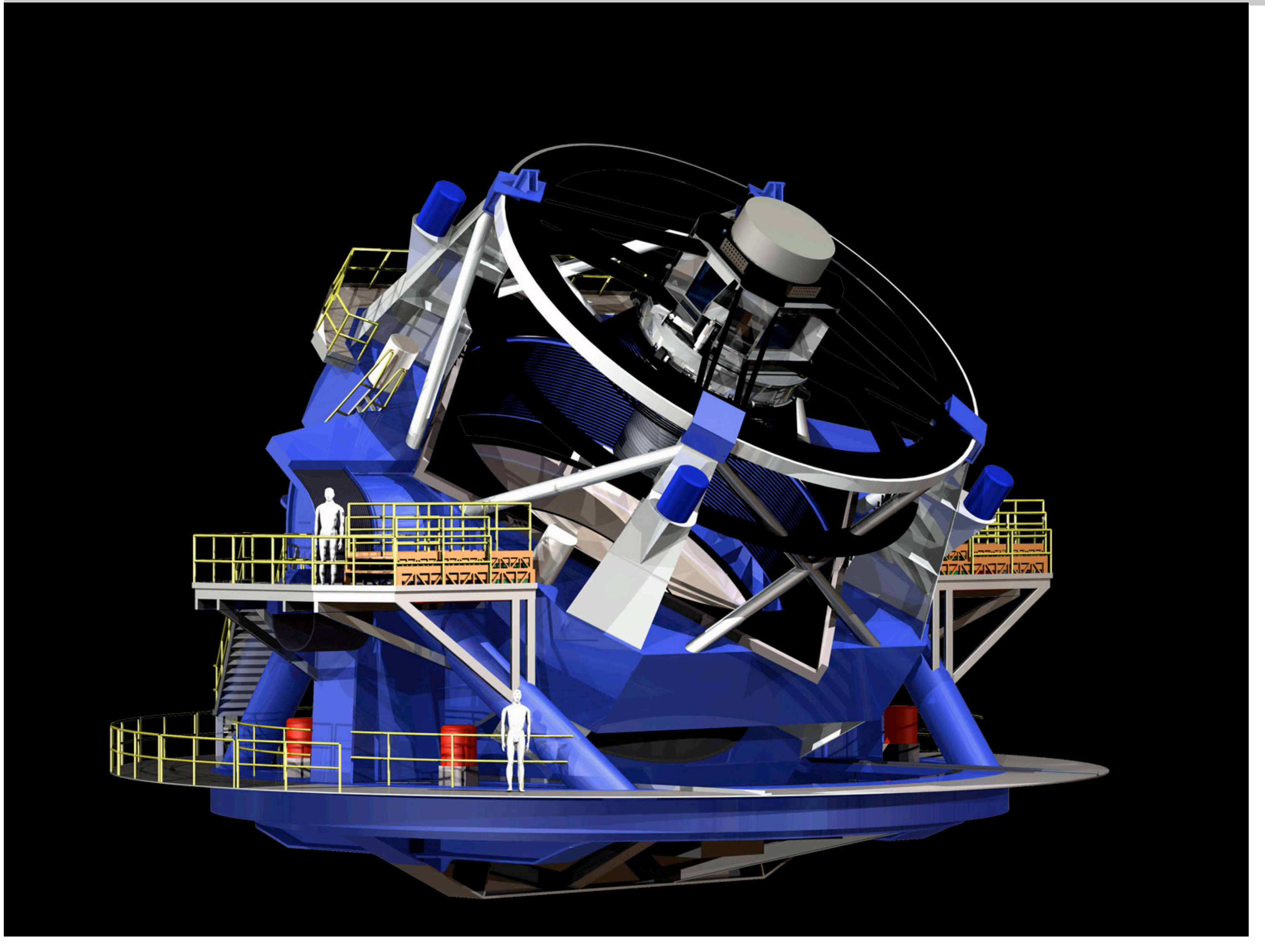
wide-field telescopes

- add degree(s) of freedom
- corrector plate (Schmidt, Maksutov)



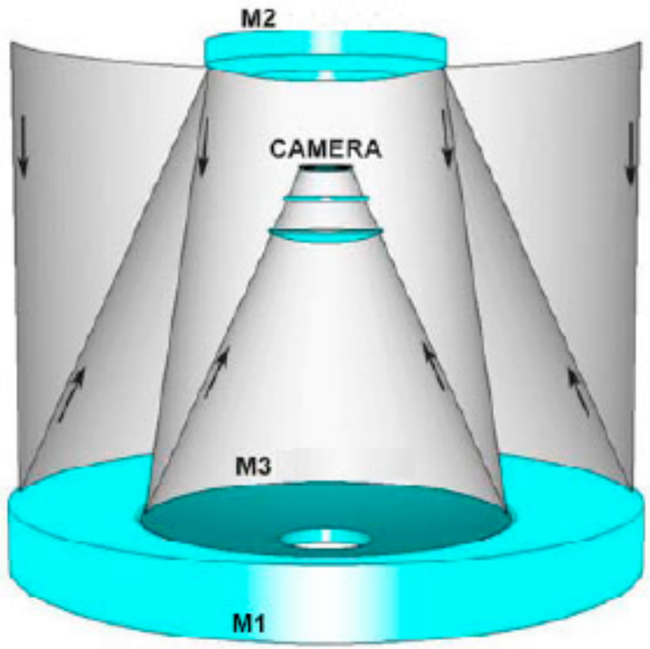
- three-mirror anastigmat (TMA):
  - three conic constants to fix spherical, coma, astigmatism

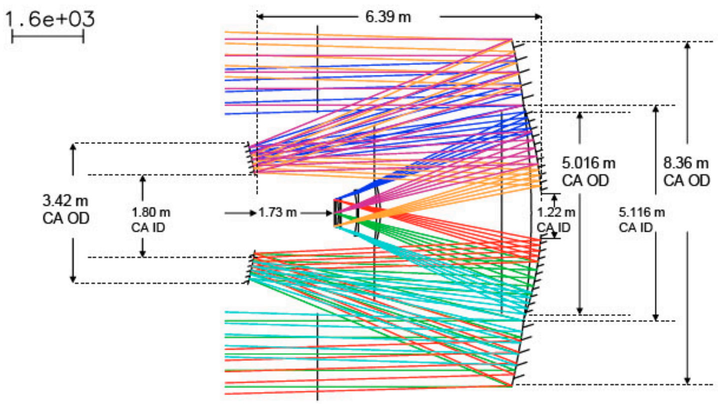
wide-field telescope



LSST

wide-field telescope

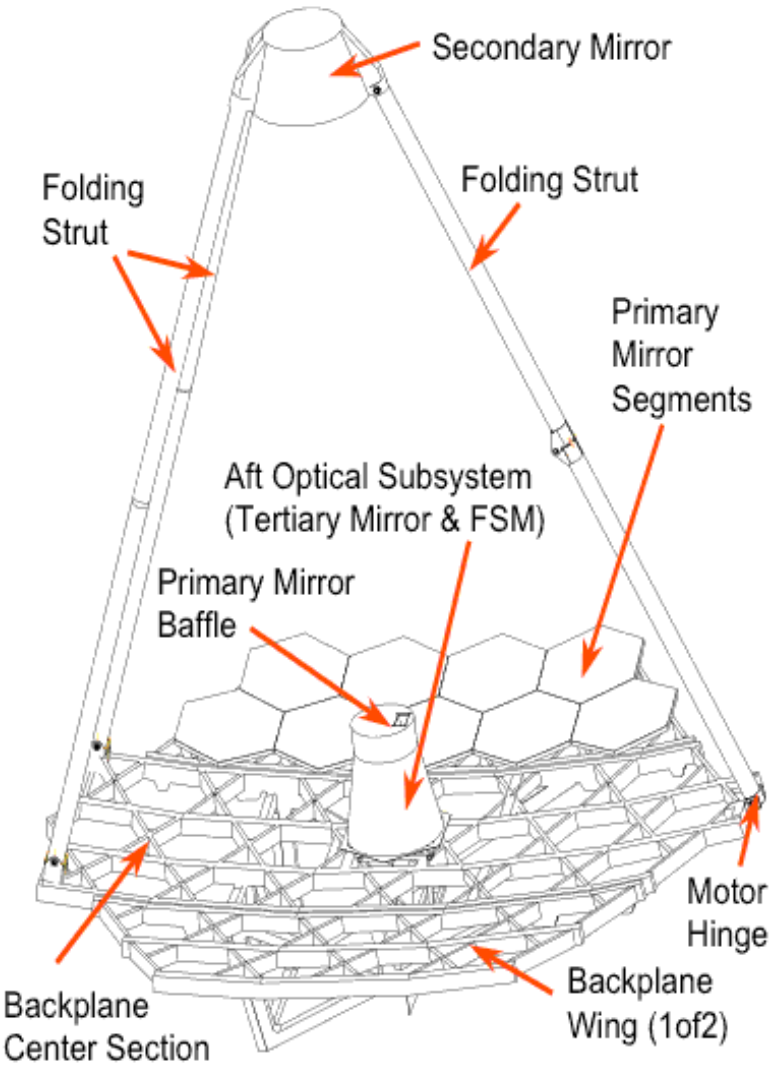




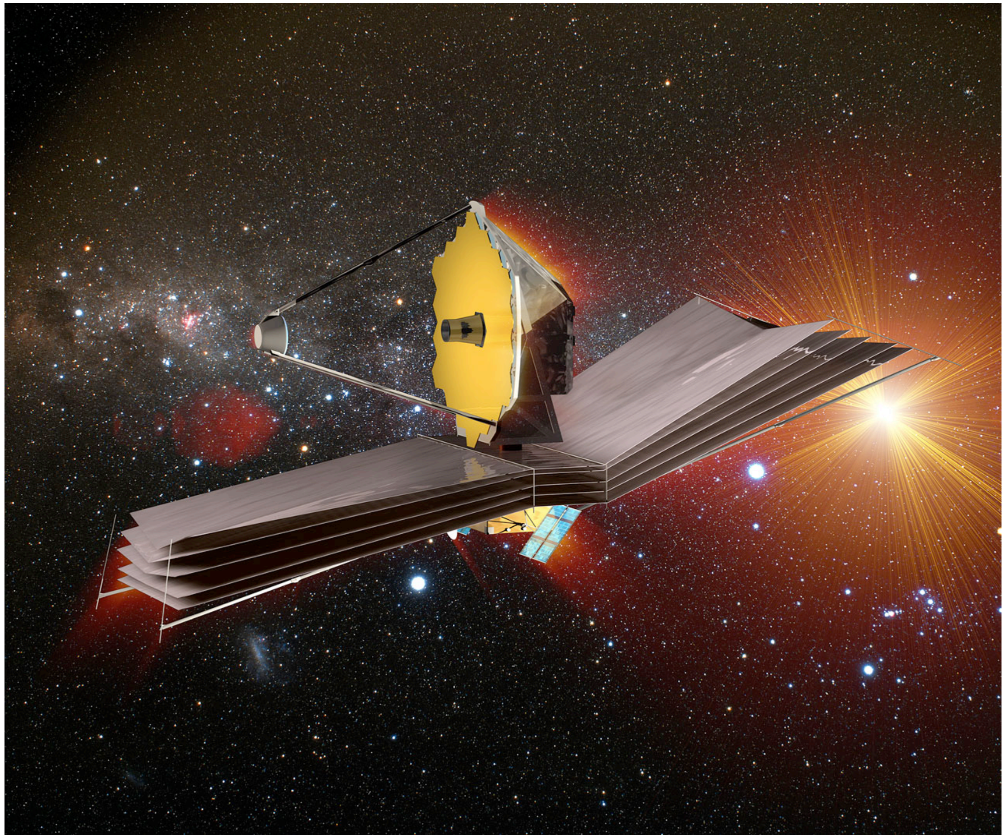
LSST

telescopes

wide-field telescope

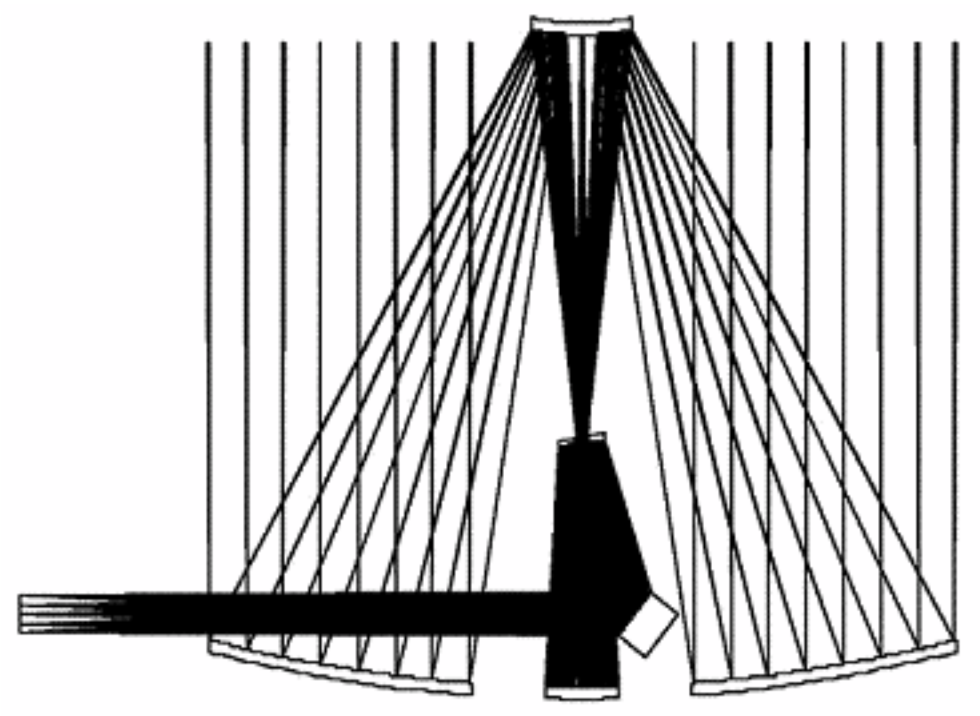


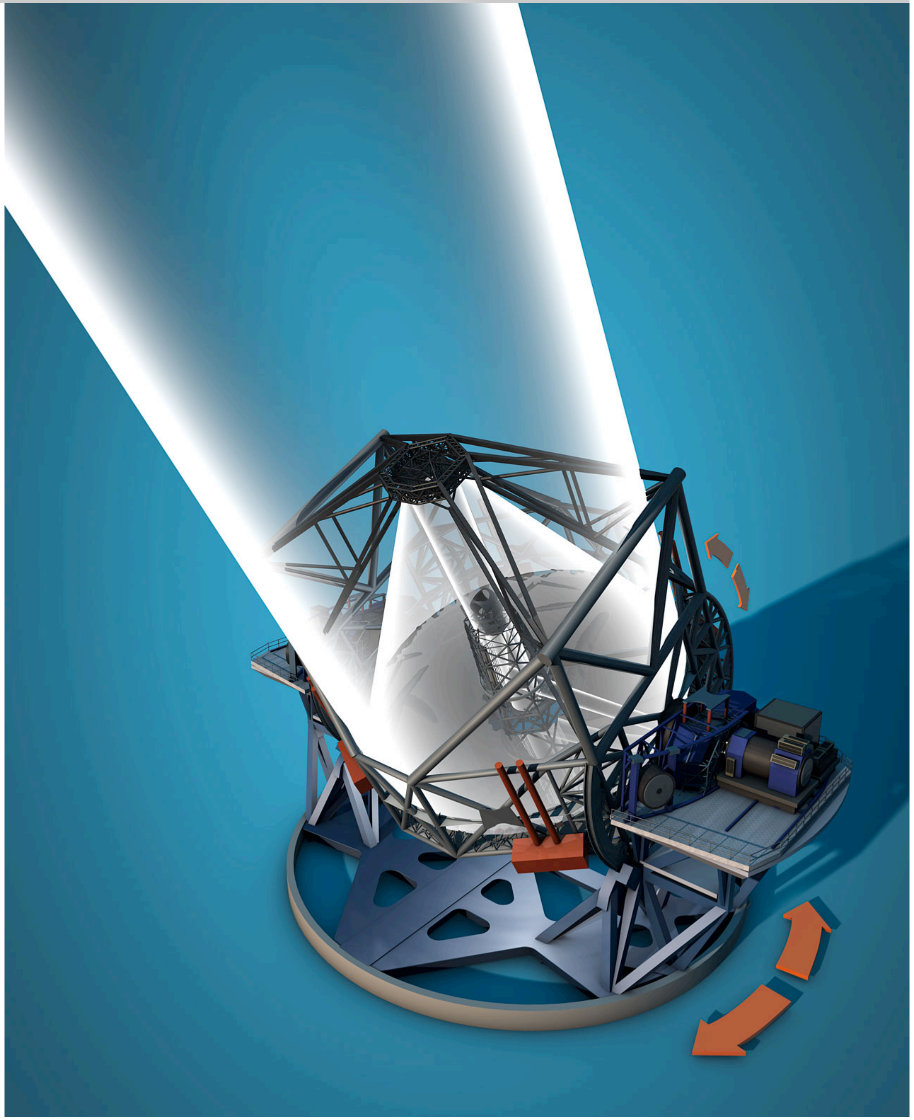
JWST



wide-field telescope

E-ELT





telescope size

- Airy disk: λ/D
- D^2 photon flux

- D^4 point source detection limit for diffraction-limited performance
  - D^2 more photons in an area of a factor D^2 smaller

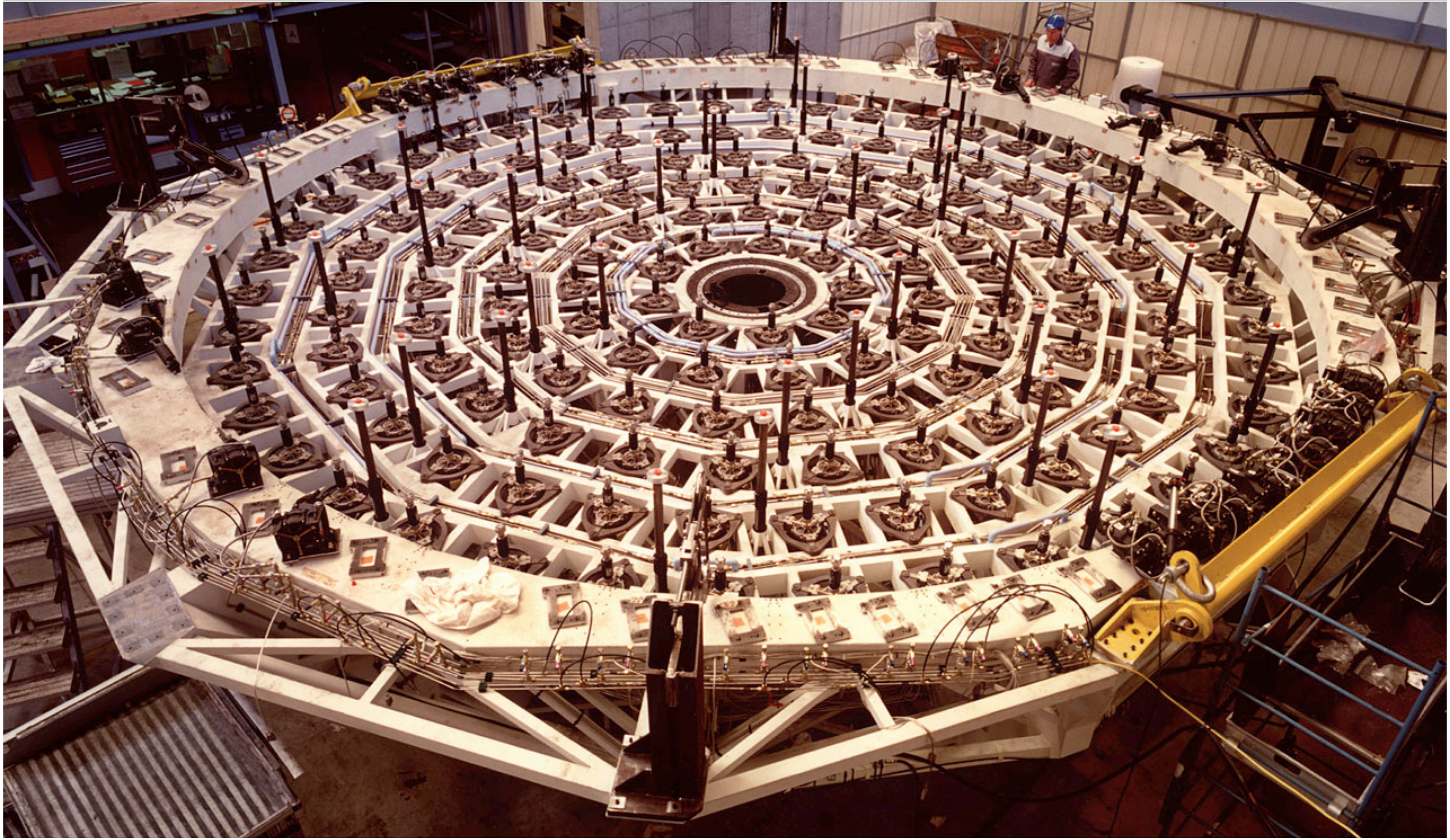
larger primary mirrors

- “membrane” mirror
- honeycomb structure spincasting

- active optics to
  - bring mirror in shape
  - correct for gravitational sag

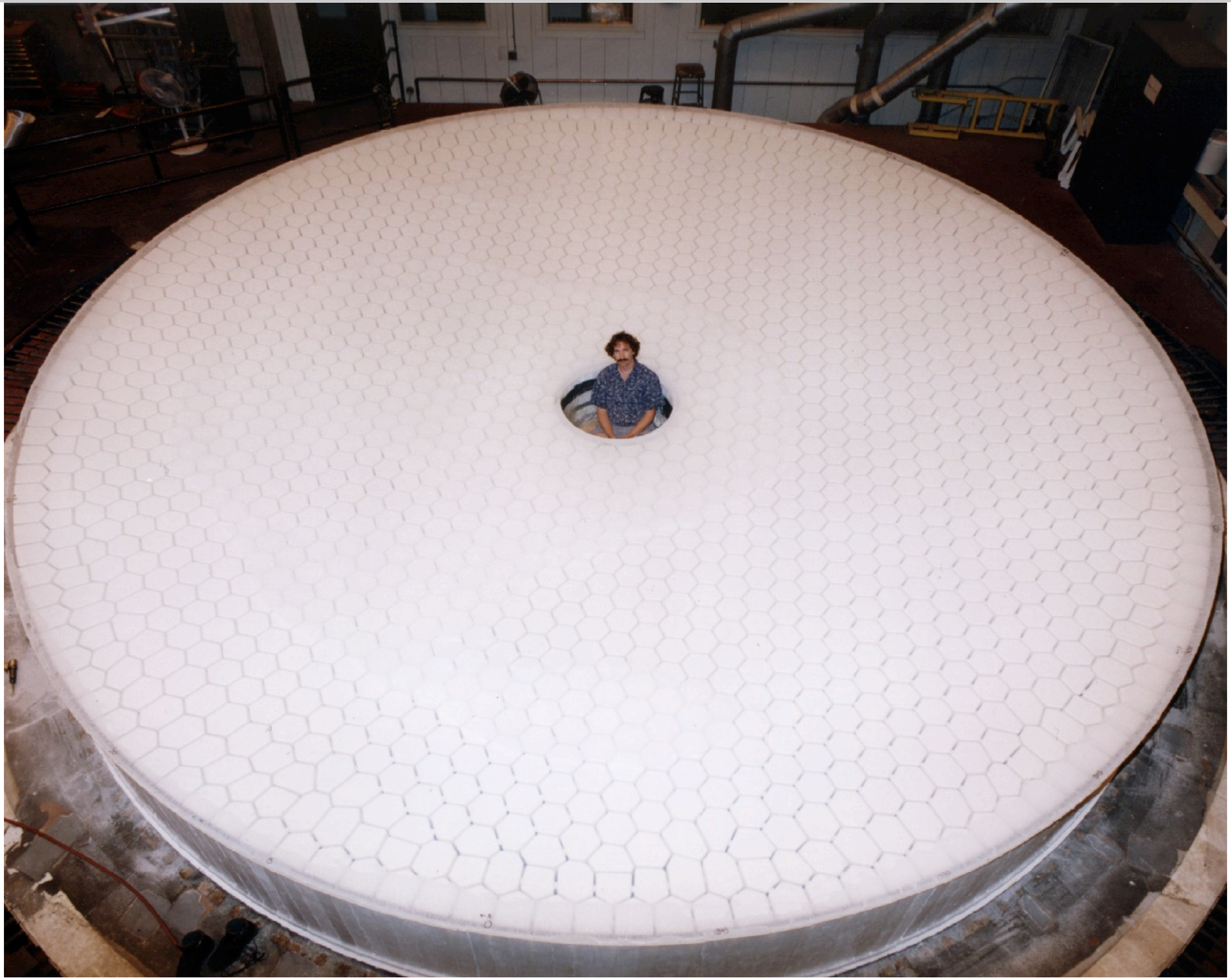
telescopes

larger primary mirrors



telescopes

larger primary mirrors



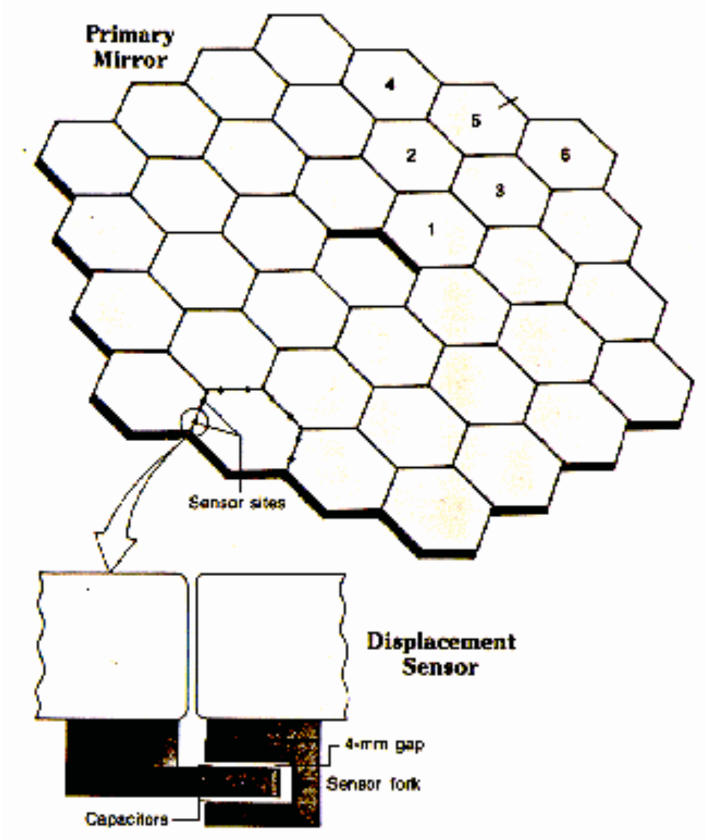
larger primary mirrors

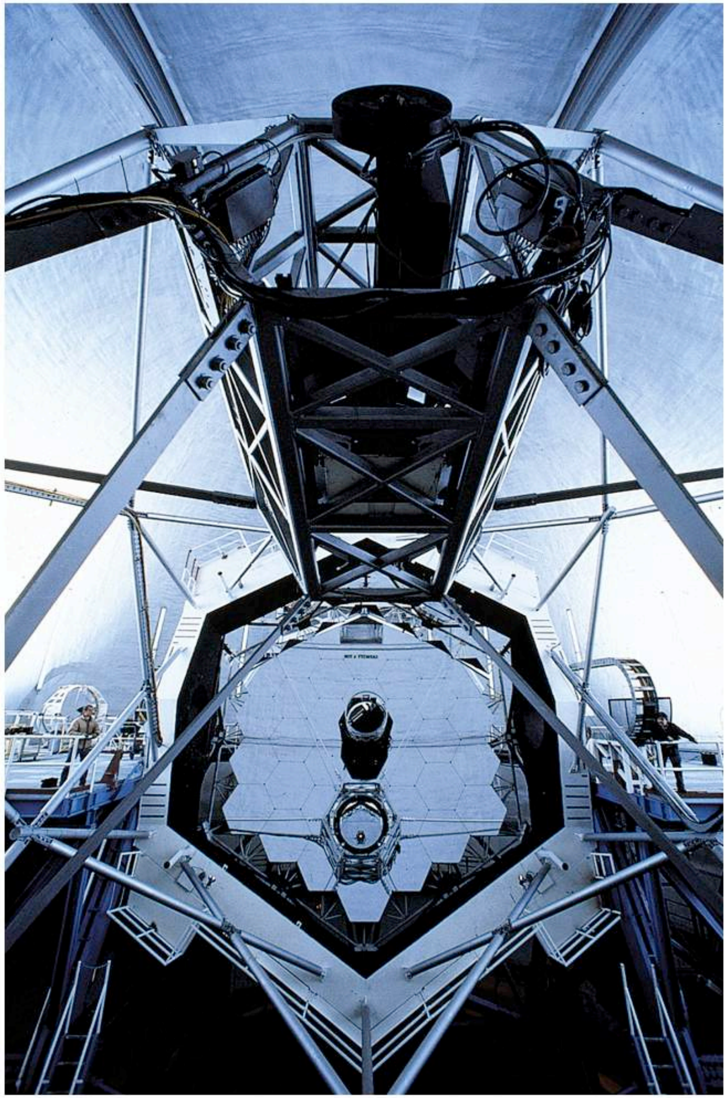
- segmented mirrors
- most segments have different off-axis distance and therefore different conic constant to be measured

telescopes

larger primary mirrors

Keck

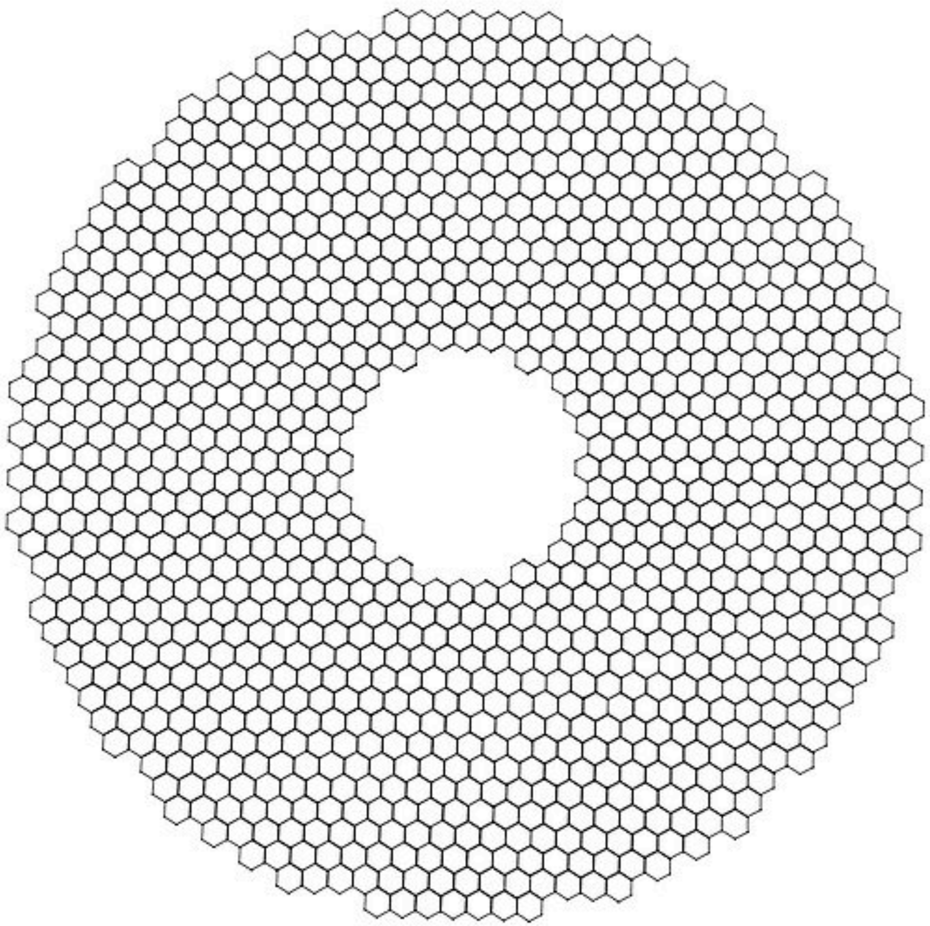


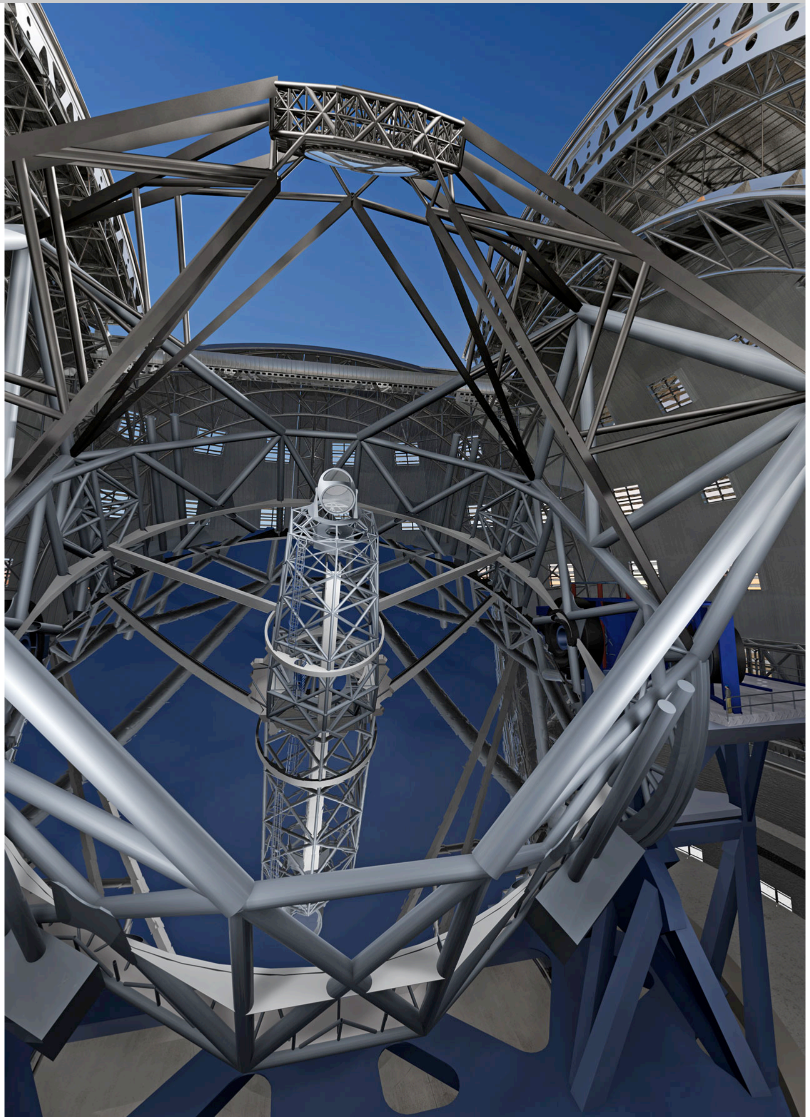


telescopes

larger primary mirrors

E-ELT: 984 1.4-m segments



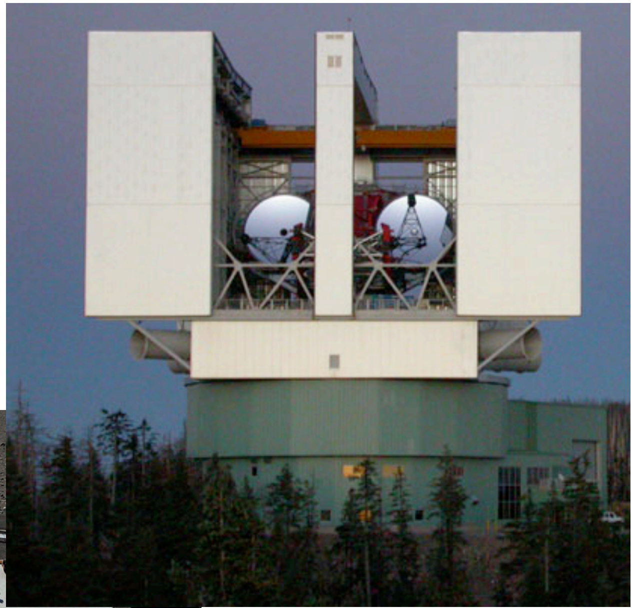


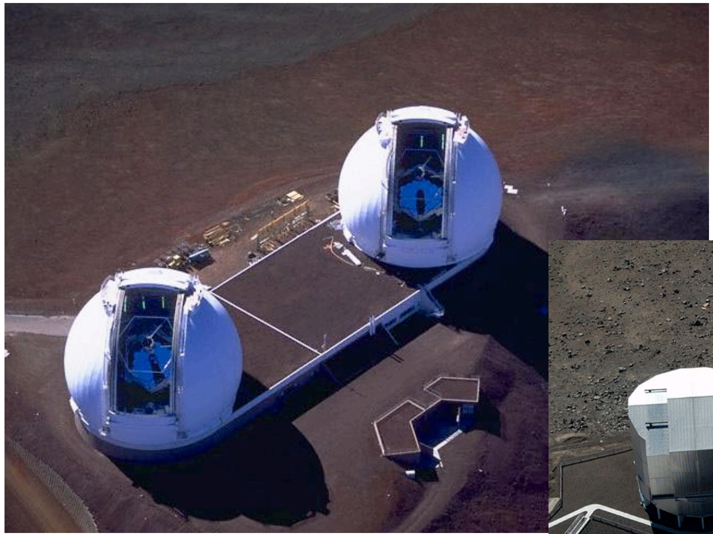
telescopes

larger primary mirrors

- interferometry (lecture 12)

LBT





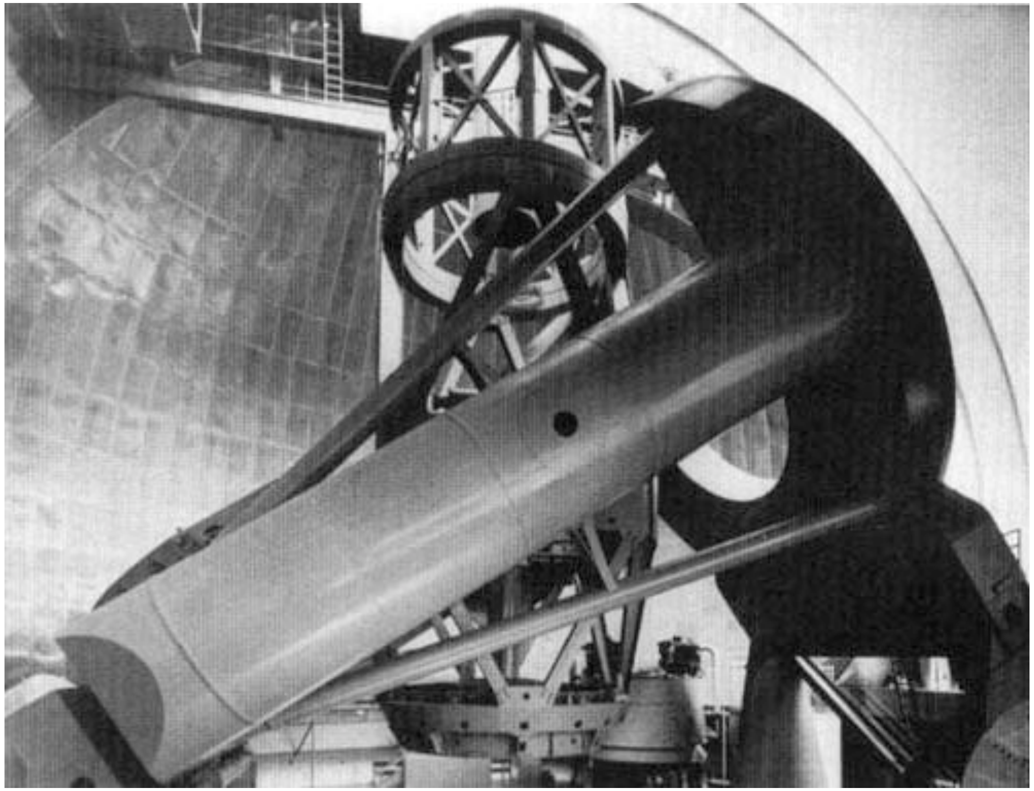
Keck

VLTI

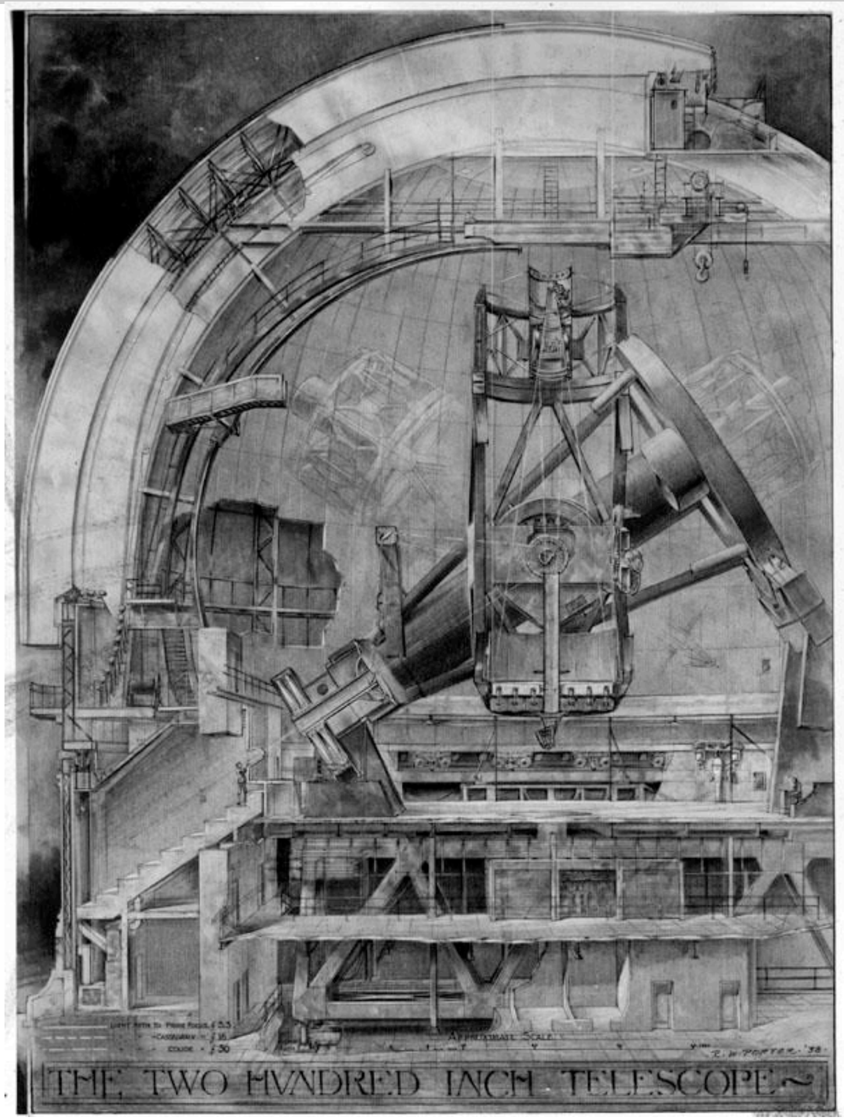
telescopes

pointing

- equatorial (RA, dec)



Hale 200” (Palomar)



telescopes

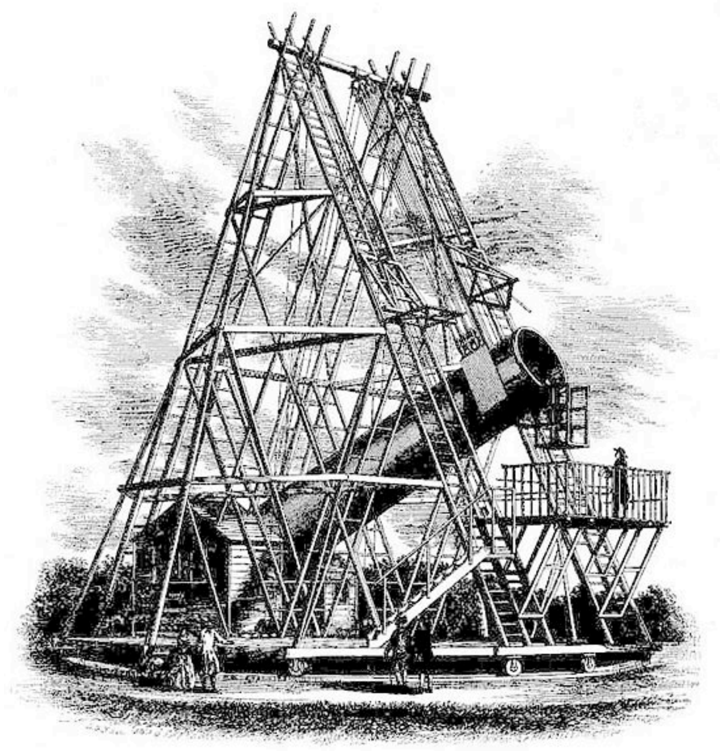
pointing

- equatorial (RA, dec)

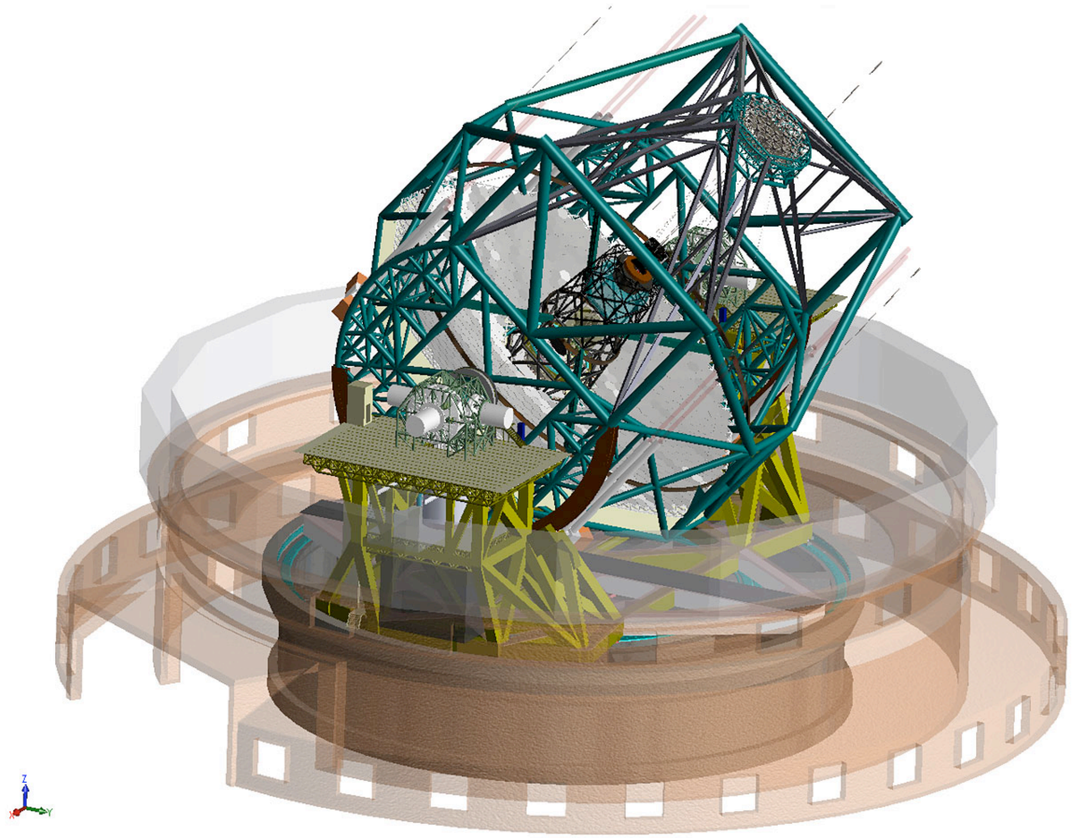
telescopes

pointing

- alt-az



Herschel (1789)



E-ELT (>2020)

pointing

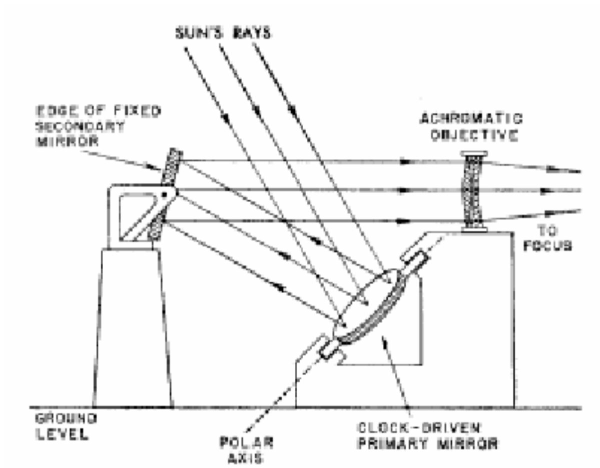
- alt-az

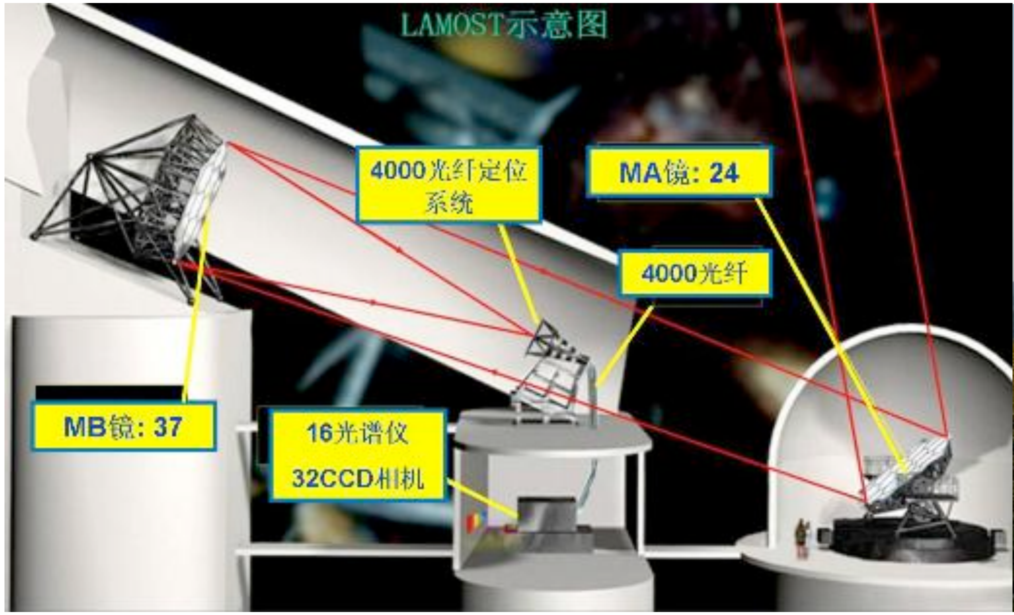
- mechanically much easier
- computer control
- zenith not accessible because drives would spin too fast

telescopes

pointing

- coelostat

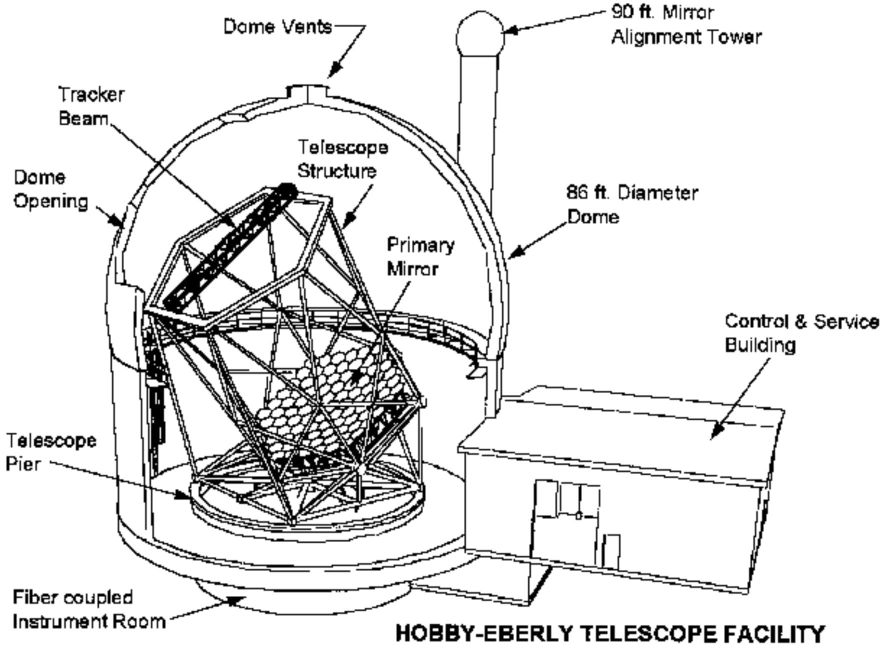


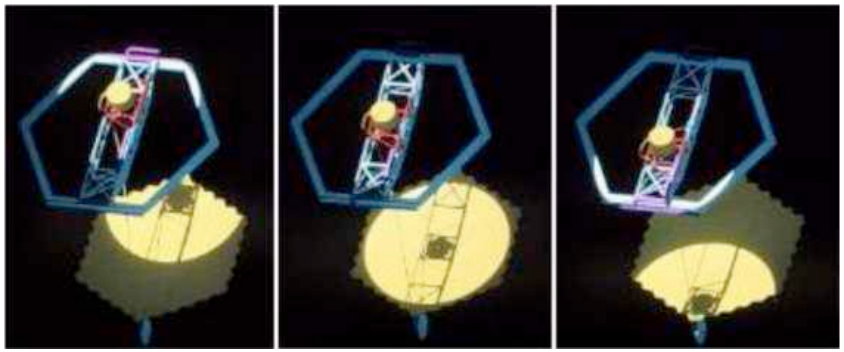


pointing

- Hobby-Eberly style
  – liquid mirror telescopes

SALT





telescopes

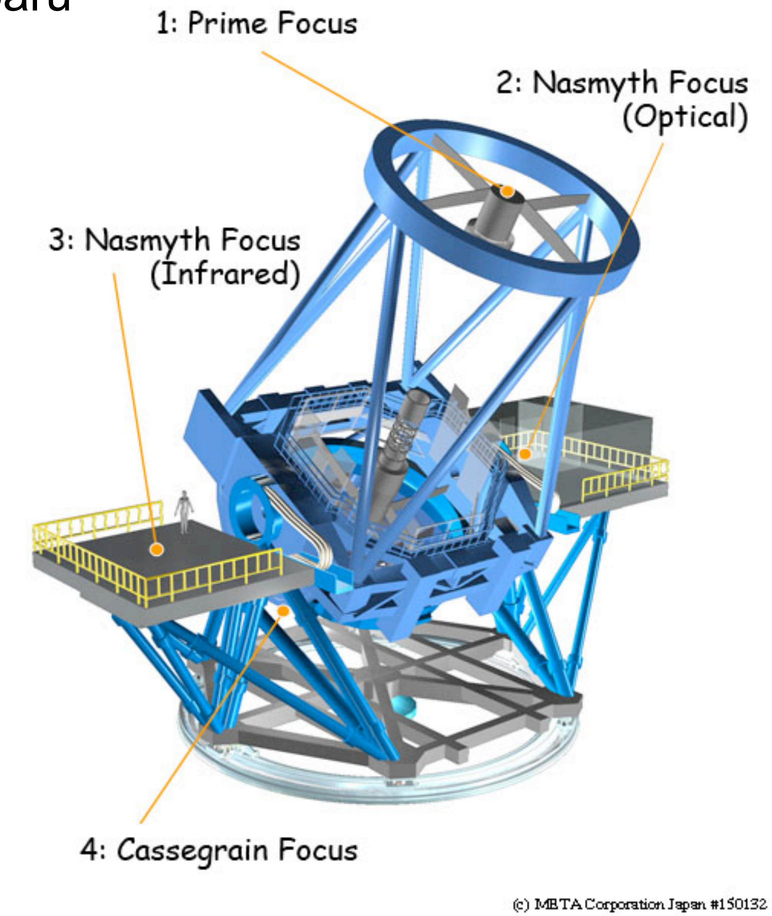
focal stations

- connected to telescope (varying gravity):
  - prime focus
  - Cassegrain
- fixed platforms:
  - Nasmyth
  - Coudé

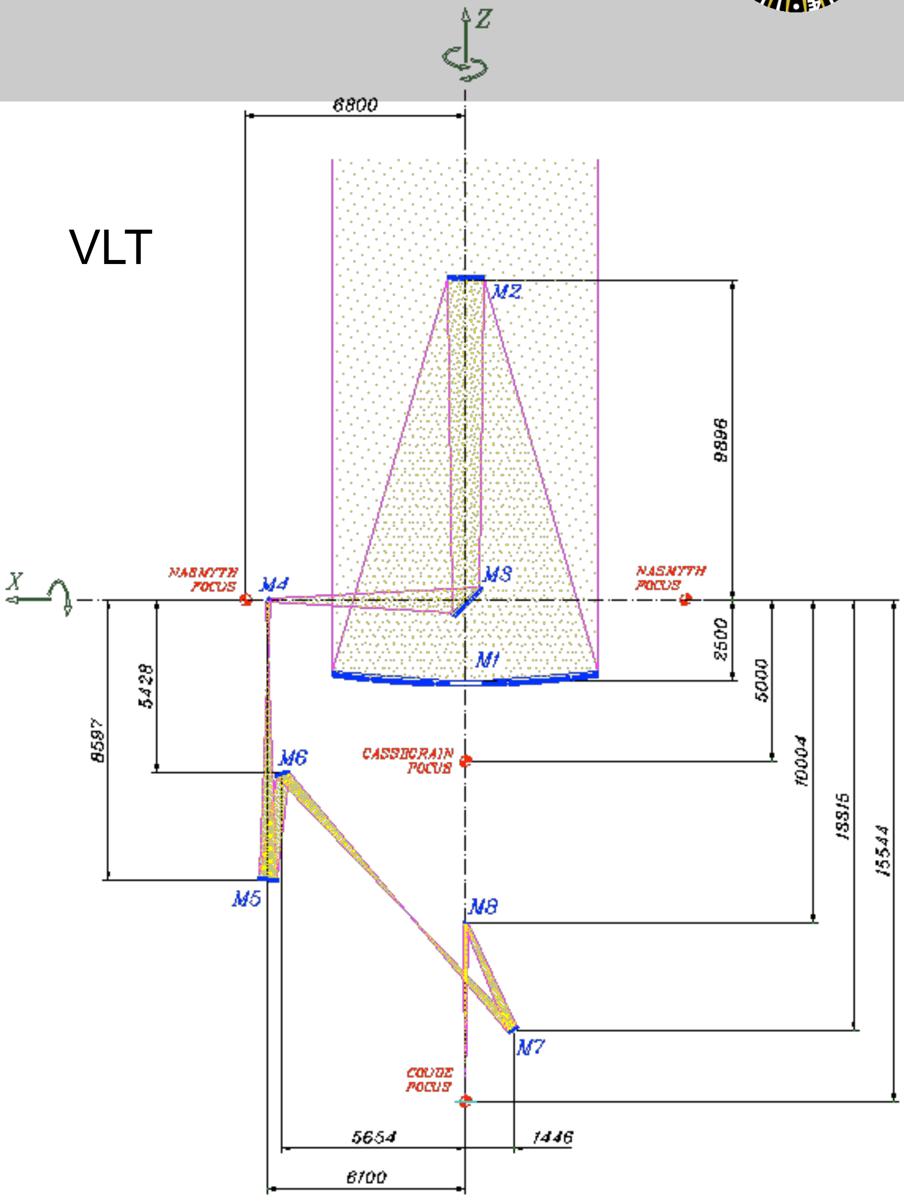
telescopes

focal stations

Subaru

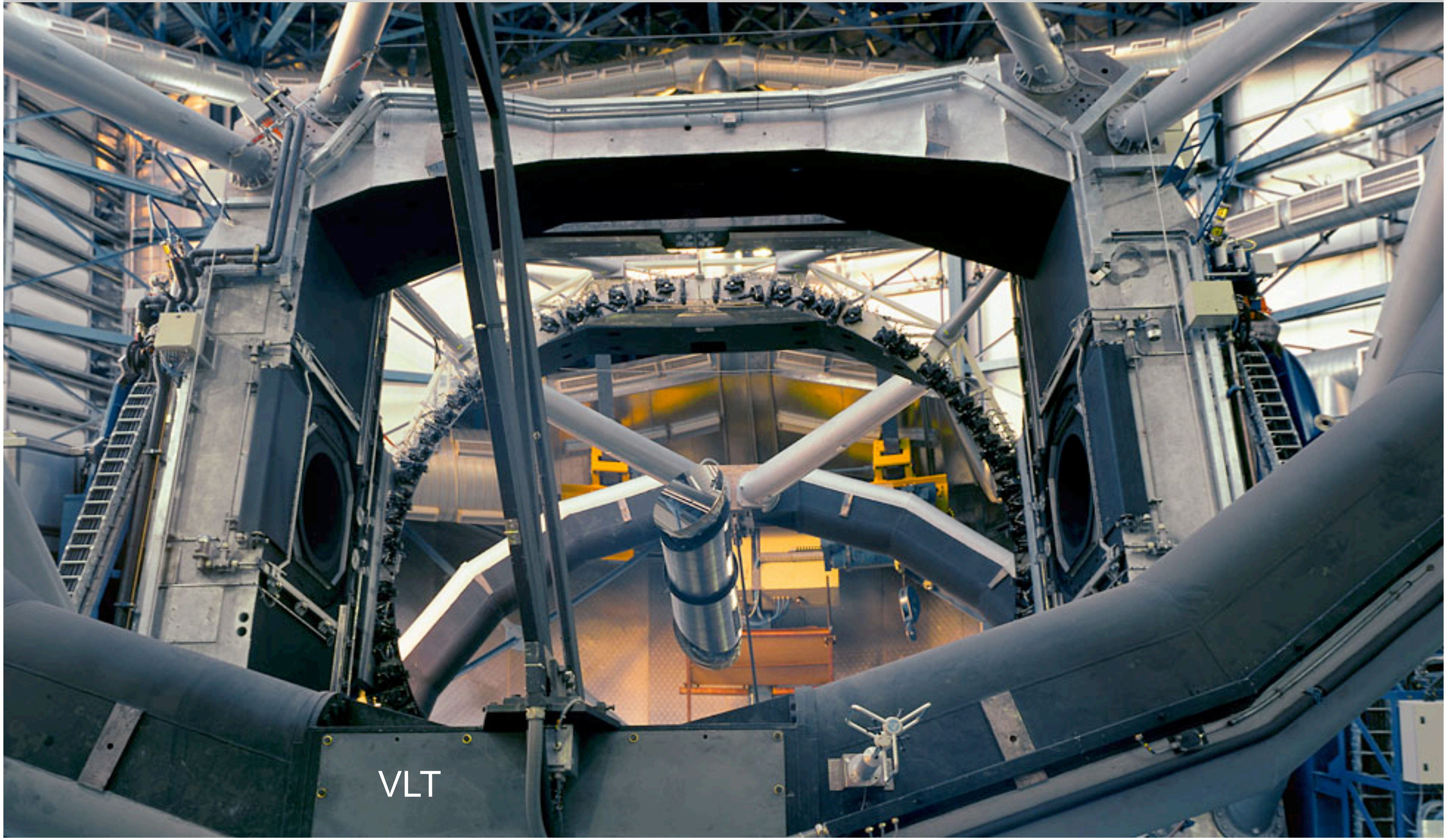


VLT



telescopes

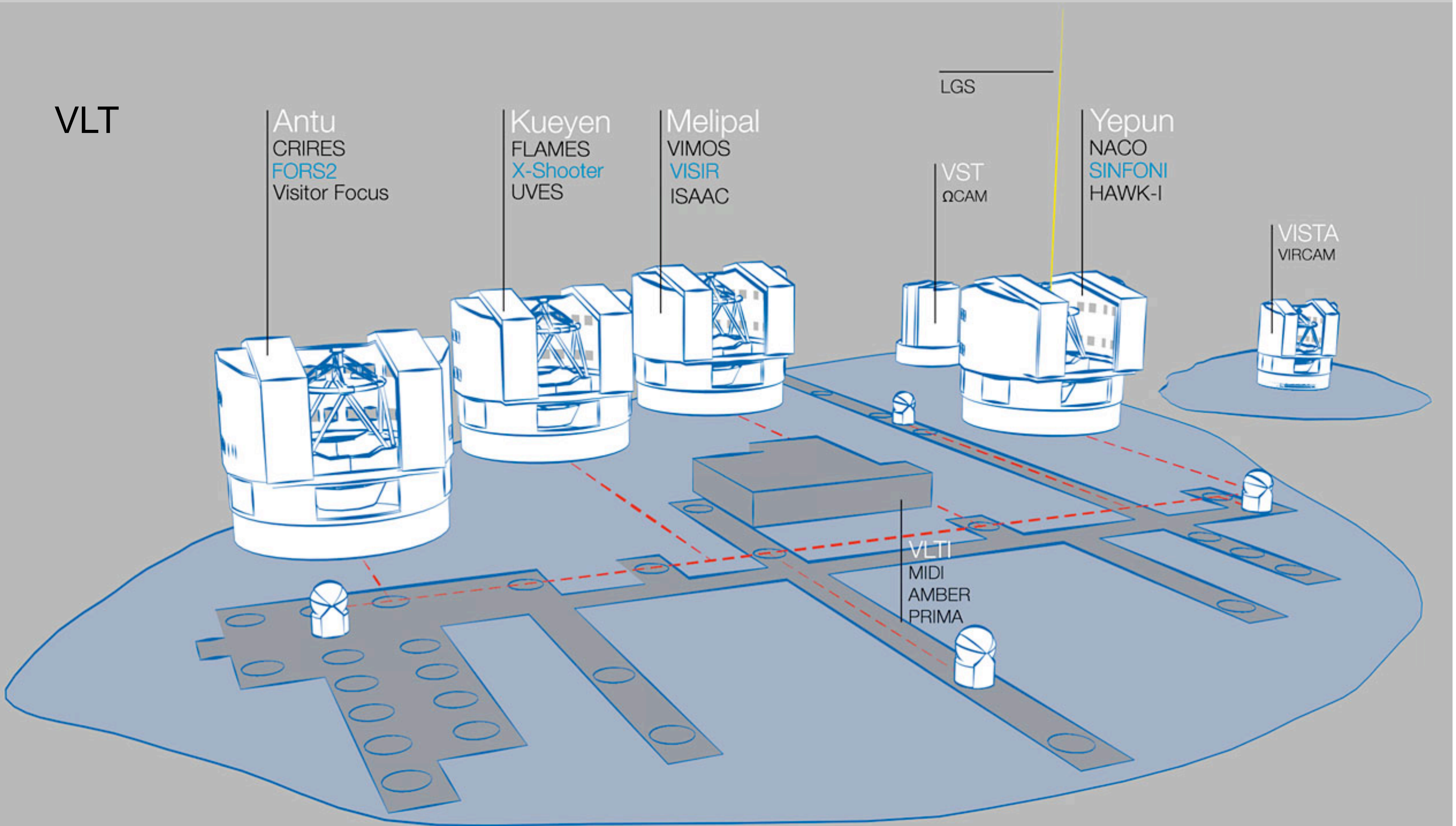
focal stations



telescopes

focal stations

VLT



telescopes

image rotation

- none for Cassegrain or Gregorian focus on equatorial mount

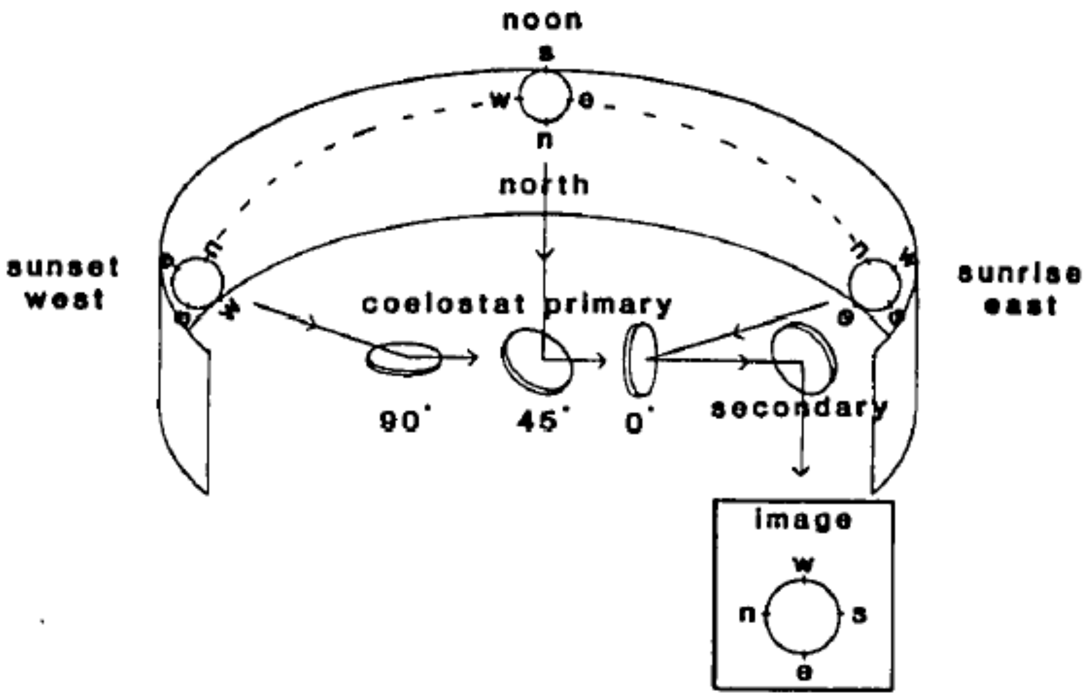


image rotation

- δ = source declination
- φ = telescope lattitude

- alt-az at Cassegrain focus:

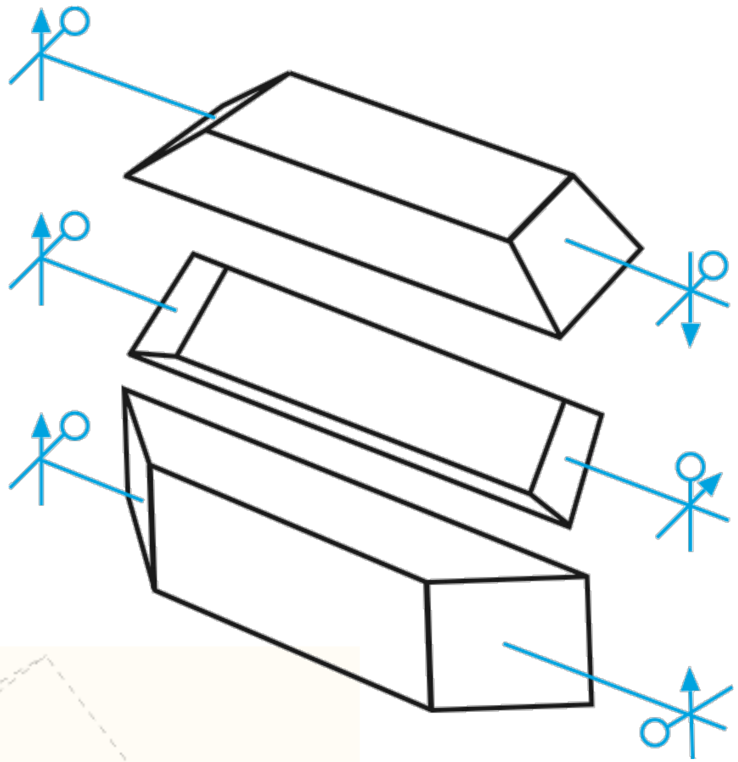
$$\cos\vartheta_{\mathrm{Cass}} = \frac{\sin\varphi - \sin(alt)\sin\delta}{\cos(alt)\cos\delta}$$

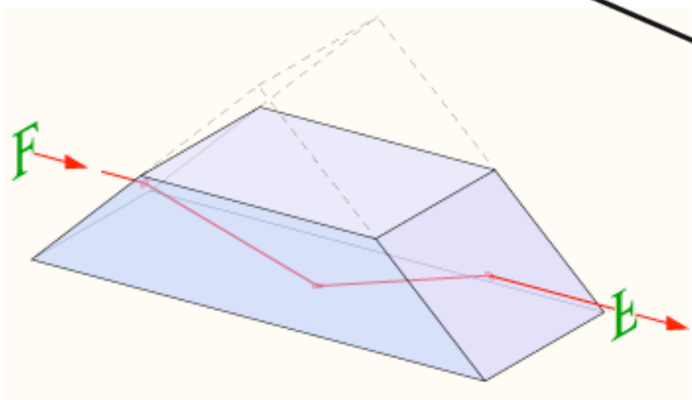
- alt-az at Nasmyth (or Coudé) platform:

$$\vartheta_{\mathrm{Nasmyth}} = alt - \vartheta_{\mathrm{cass.}}\ (-\ az)$$

image rotation

- rotate entire instrument
- derotator
  - K-mirror
  - Dove prism
  - anything rotatable with an odd number of reflections





instrumental polarization

- virtually zero for (rotationally symmetric) Cassegrain or Gregorian focus
- Nasmyth mirror:

$$M_{M\,3} = T \cdot \begin{pmatrix} 1 & 0.03 & 0 & 0 \\ 0.03 & 1 & 0 & 0 \\ 0 & 0 & -0.96 & 0.28 \\ 0 & 0 & -0.28 & -0.96 \end{pmatrix}$$

- Plus rotations of [Q,U] coordinate system
  - crossing and uncrossing mirrors

atmospheric dispersion corrector