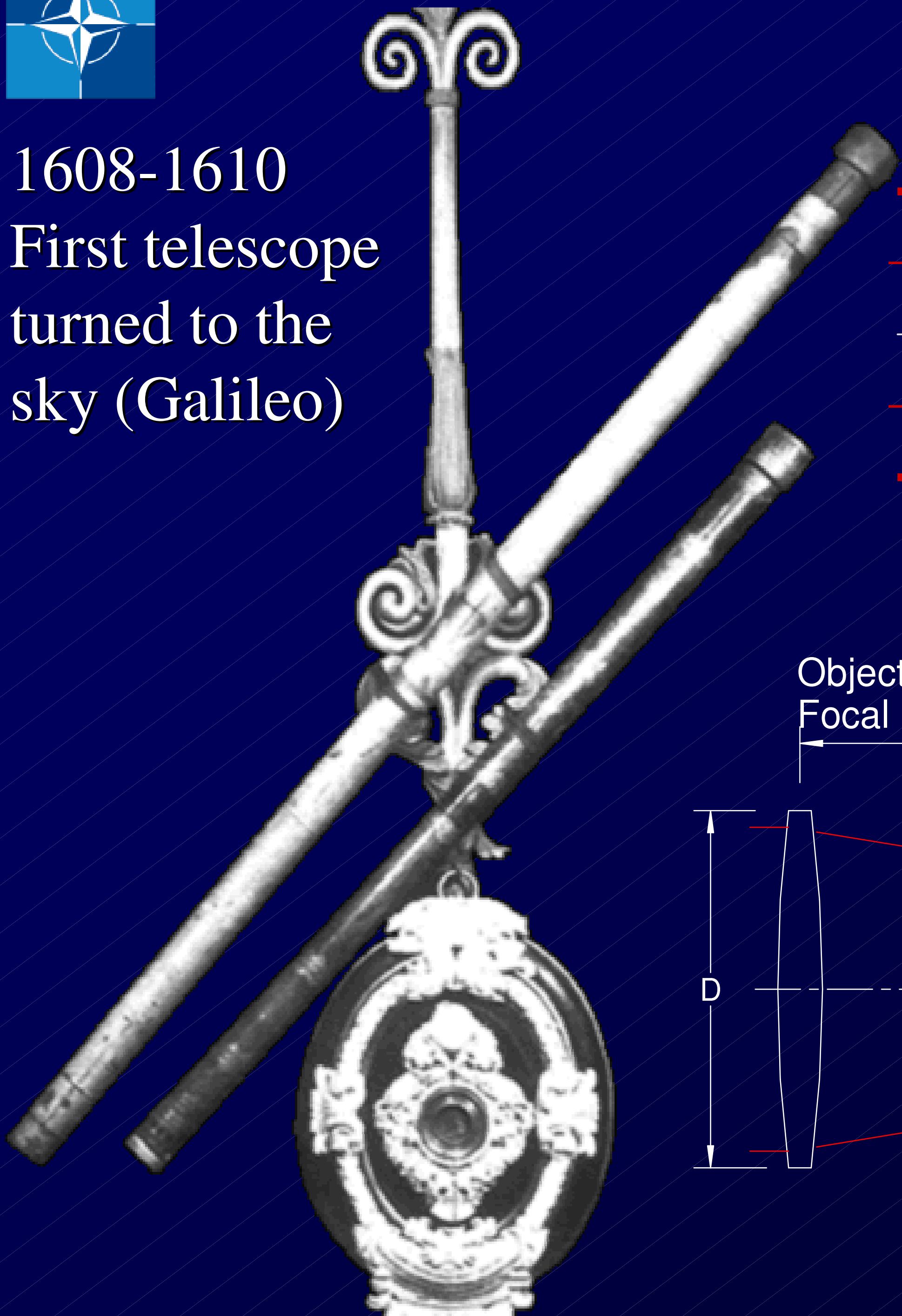
Astronomical telescopes
A brief history

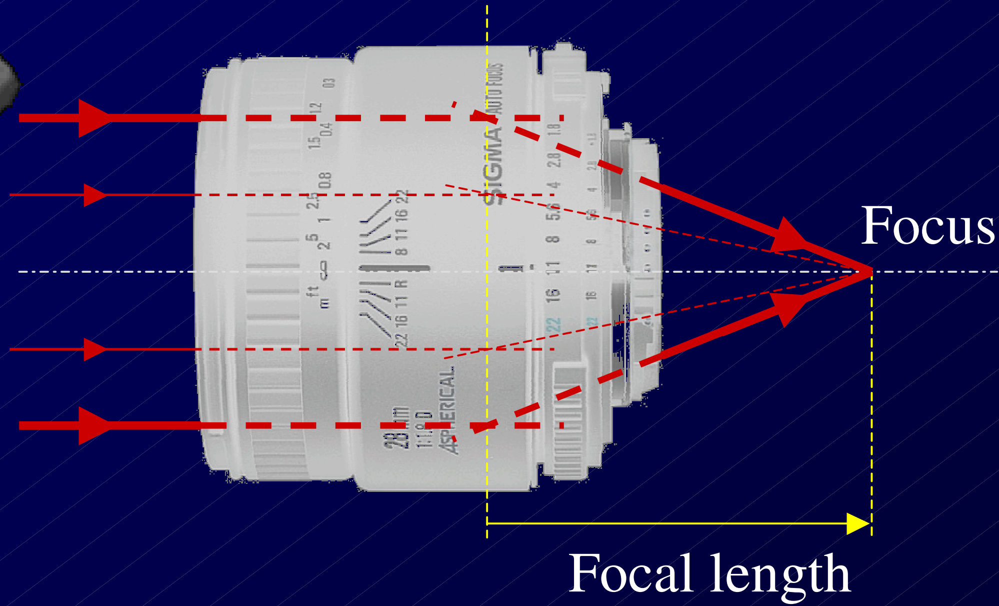
P. Dierickx

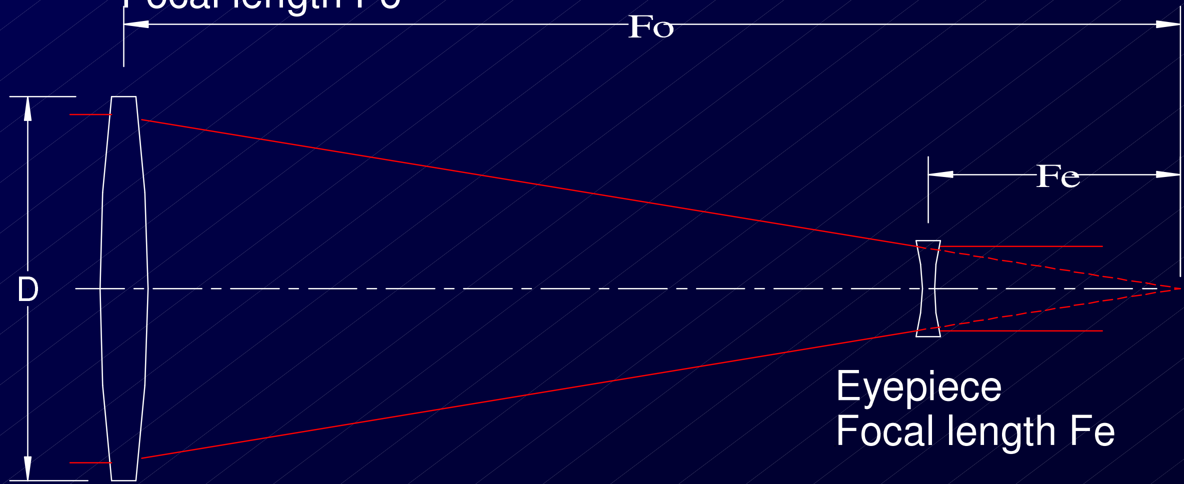
European Southern Observatory

The early years 1608-1672

1608-1610
First telescope turned to the sky (Galileo)





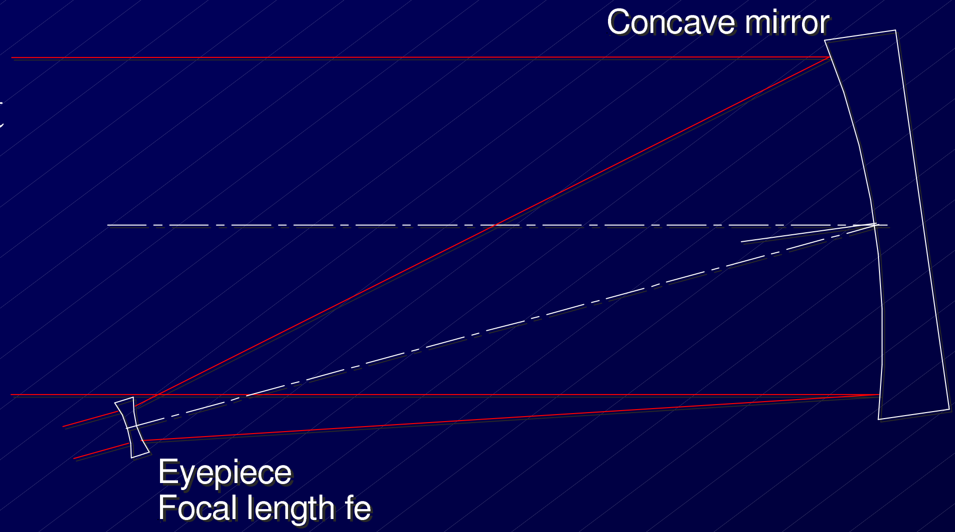


Angular magnification G=Fo / Fe
Focal ratio of objective N=Fo / D

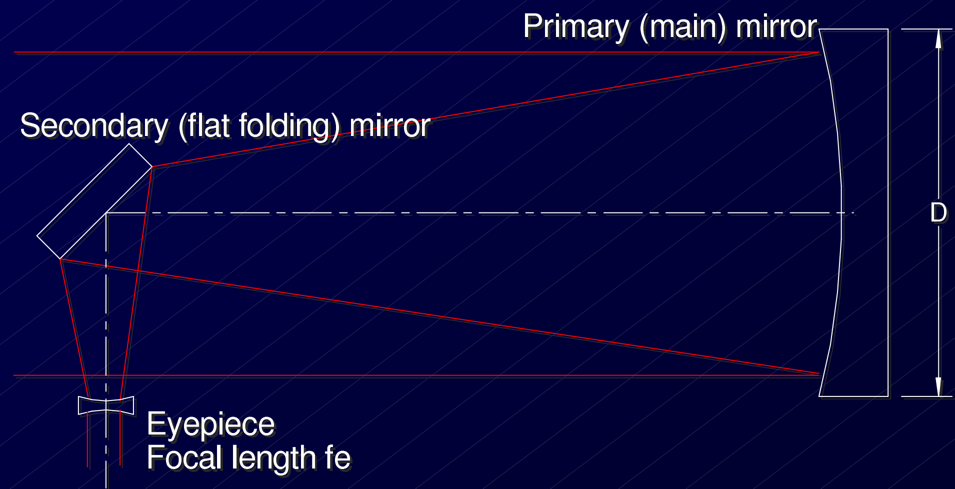
The early years 1608-1672

1616 - Zucchi's (unsuccessful) attempt at making a reflecting telescope

- Field aberrations
- Quality probably not sufficient



1668 - Newton's reflecting telescope (speculum mirror)

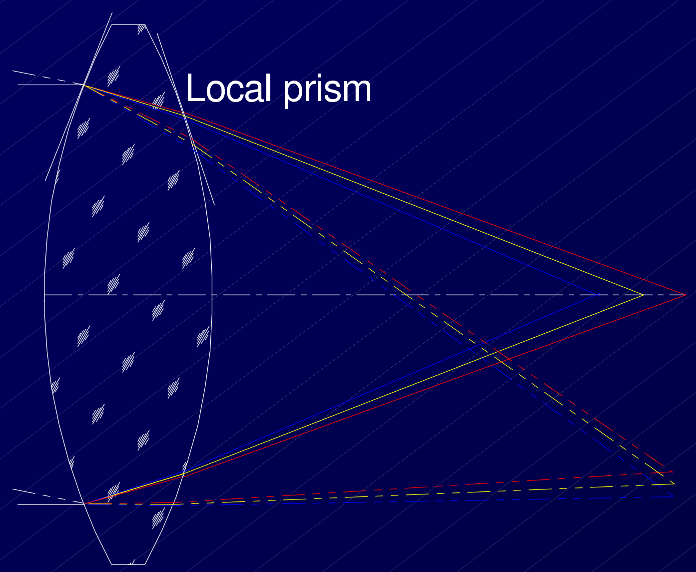


Focal length of primary mirror	$f_1=R/2$
Angular magnification	$G=f_1/f_e$
Focal ratio	$N=f_1/D$

The early years 1608-1672

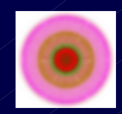
Refracting

- Chromatic aberrations
- Spherical & field aberrations

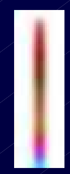


Reflecting

- Spherical & field aberrations
- 4 times tighter manufacturing tolerances

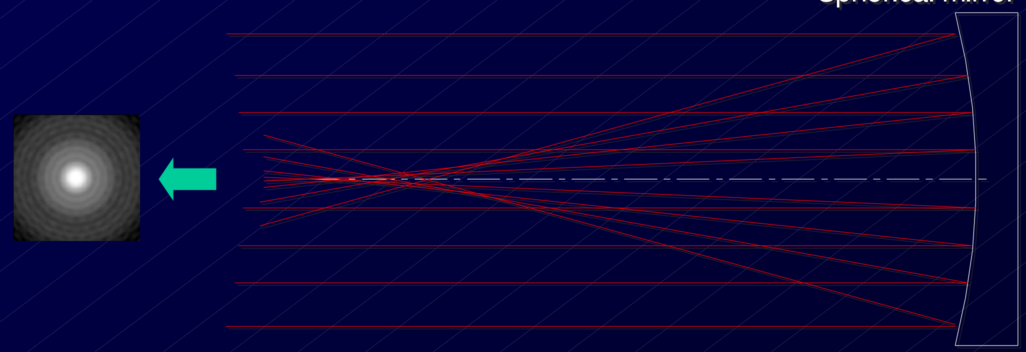


Axial chromatism

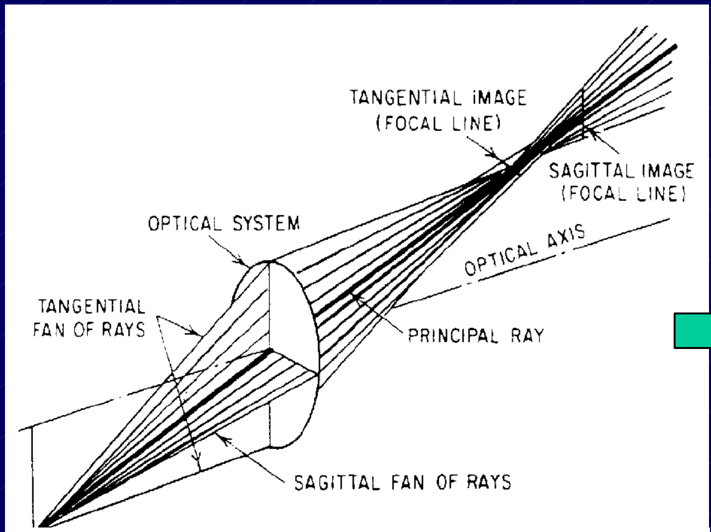


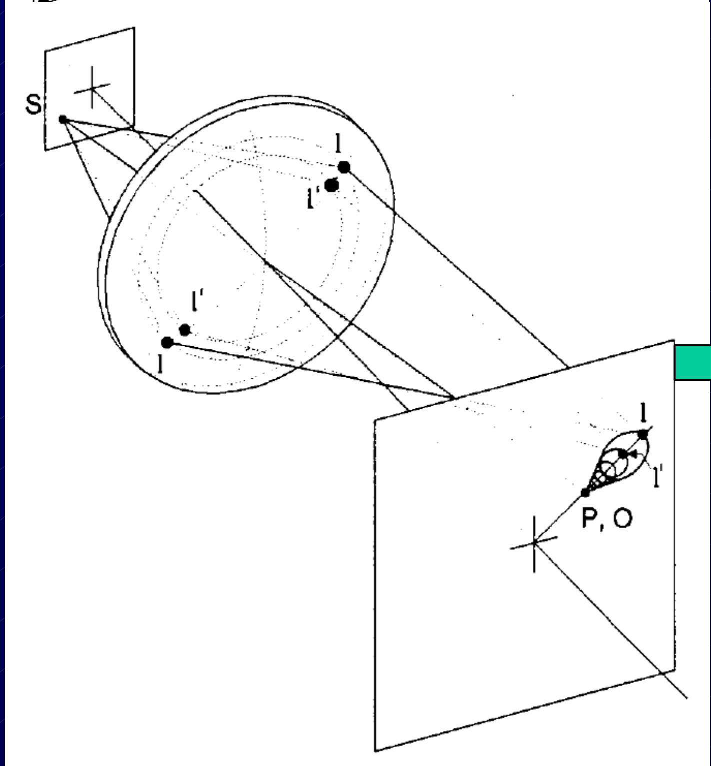
Lateral chromatism

Spherical aberration

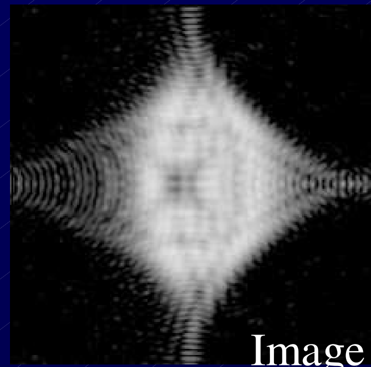


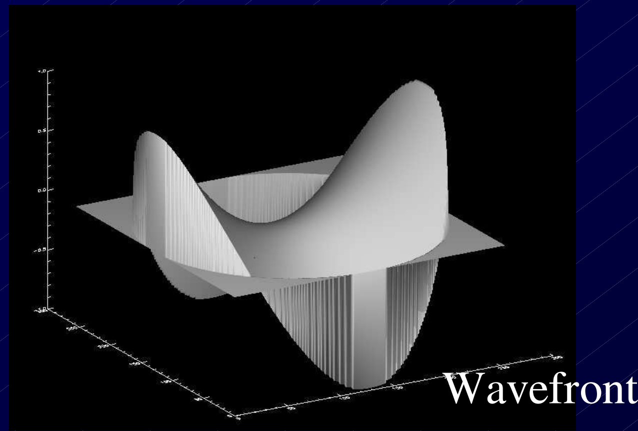
Field aberrations



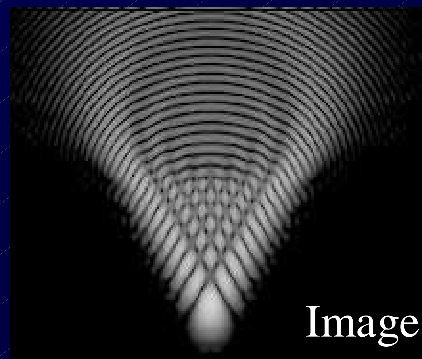


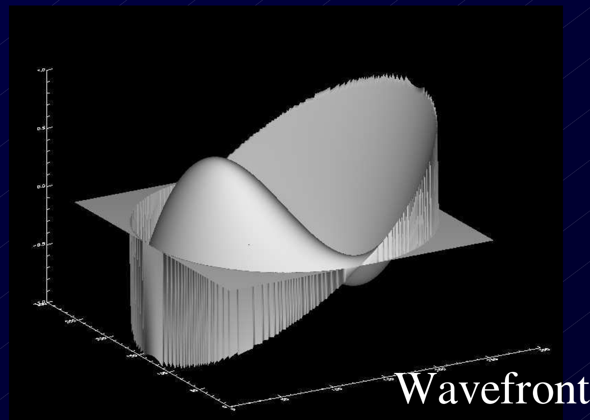
Astigmatism





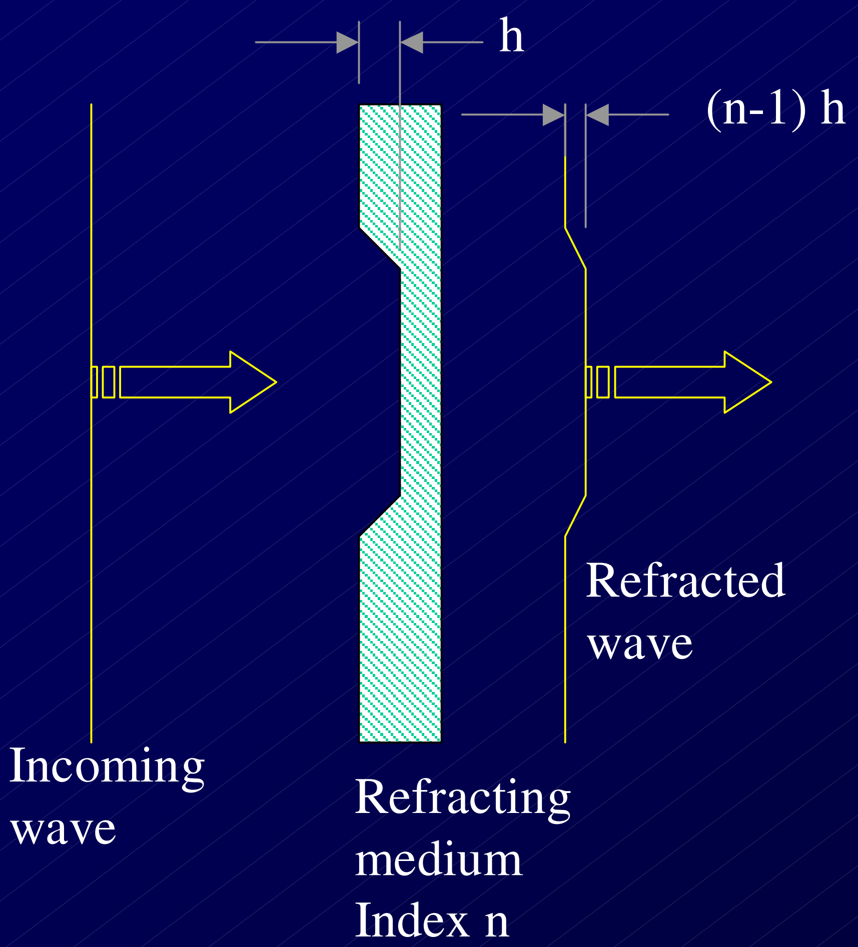
Coma



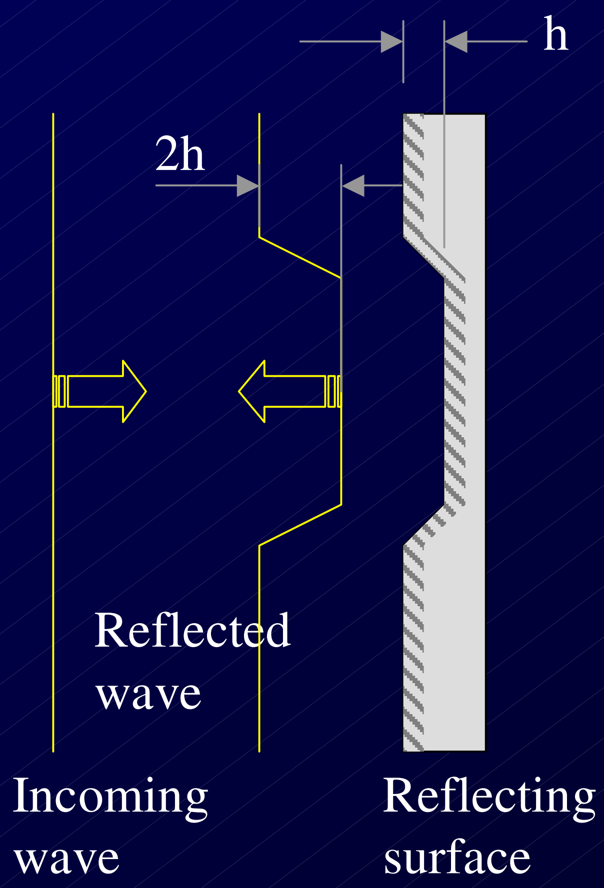


Surface tolerances

- Refractors



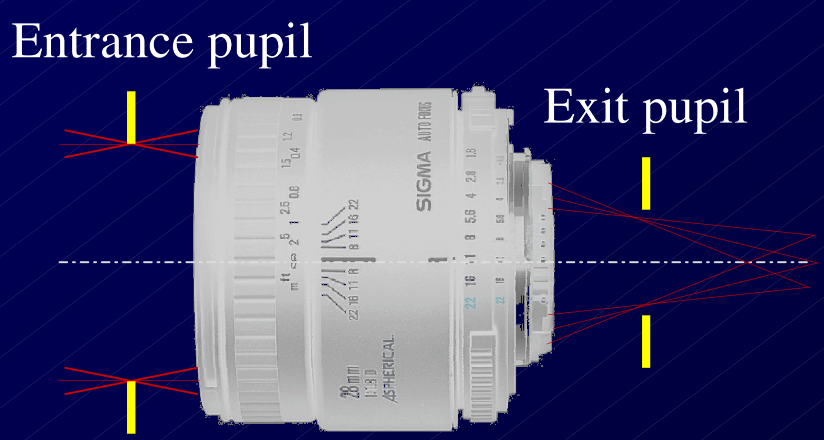
- Reflectors

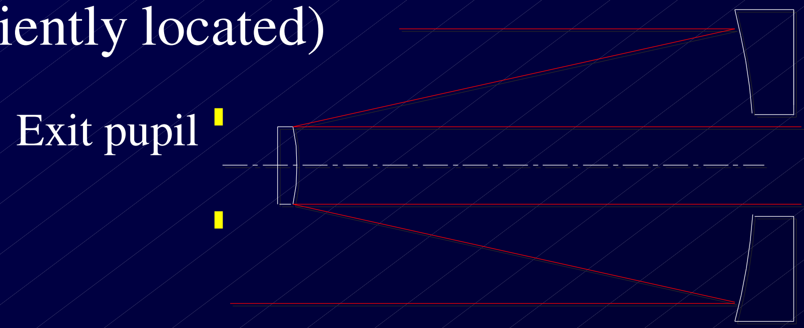


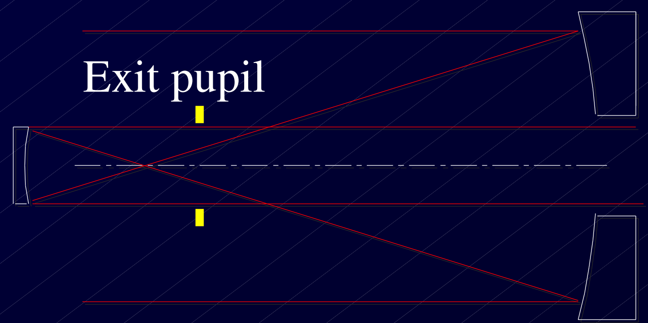
Surface quality requirement for a reflecting surface ~ 1/4th of surface quality requirement for a refracting one

The early years 1608-1672

- Descartes, 1634 & 1636
  - Theory for the elimination of spherical aberration ⇨ aspheric surfaces
  - Chromatic aberrations not understood
  - Successive efforts at making aspheric lenses –but technology not ready, and chromatic effects more detrimental anyway
- Marin Mersenne, 1636
  - Afocal designs; use of a curved secondary mirror as eyepiece
  - Unpractical (exit pupil inconveniently located)

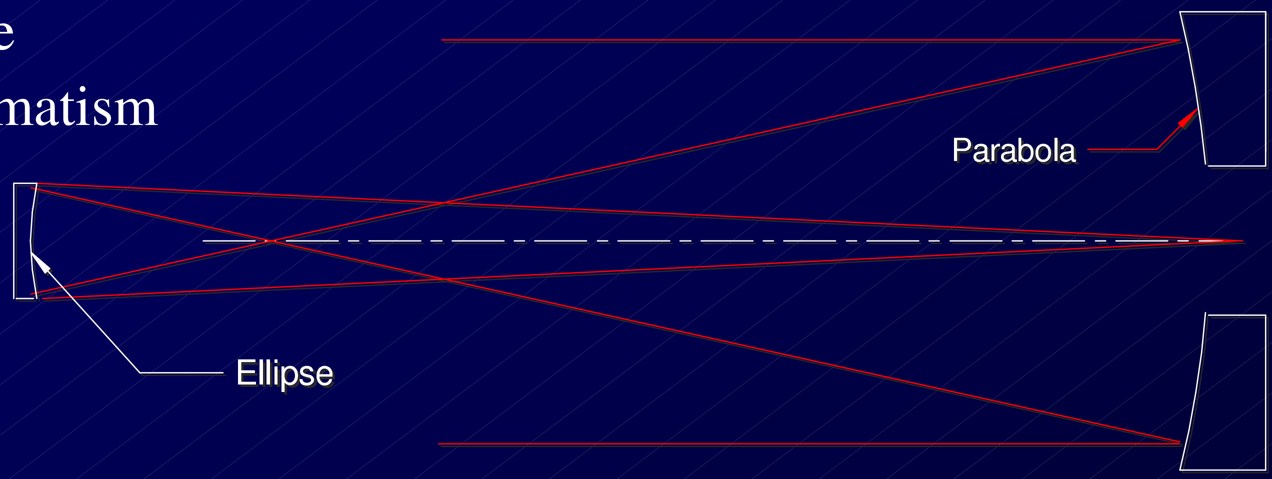




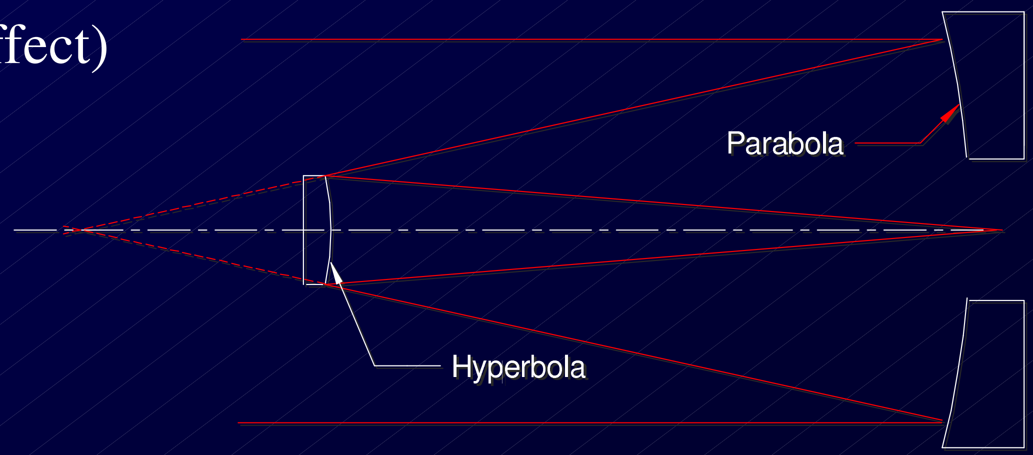


The early years 1608-1672

- Gregory telescope
  “Easier” to make
  Has coma, astigmatism



- Cassegrain telescope
  Compact (best telephoto effect)
  Has coma, astigmatism



Theory of reflectors remains unchanged until 1905 …

The achromatic objective

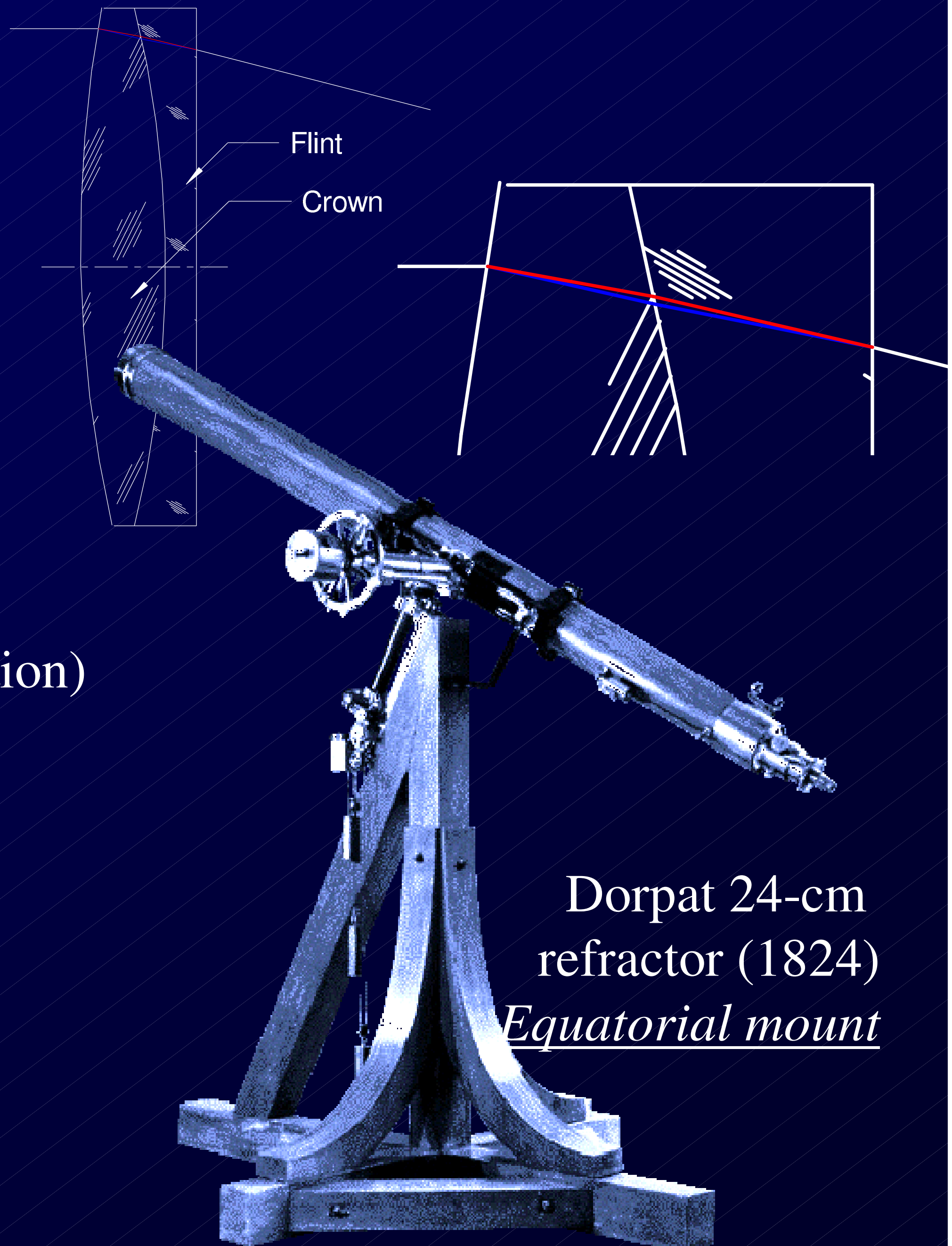
- Chromatism incorrectly quantified by Newton
- Challenged by David Gregory in 1695
- Chester Moor Hall, 1729: basic theory of achromatic doublet
- 1758: John Dollond makes the first successful achromatic doublet
- 1761: Clairaut, modern form (axial chromatism and spherical aberration)
- 1814: Fraunhofer refractors

Advantages of the refractor

Closed tube

Higher efficiency than speculum mirrors

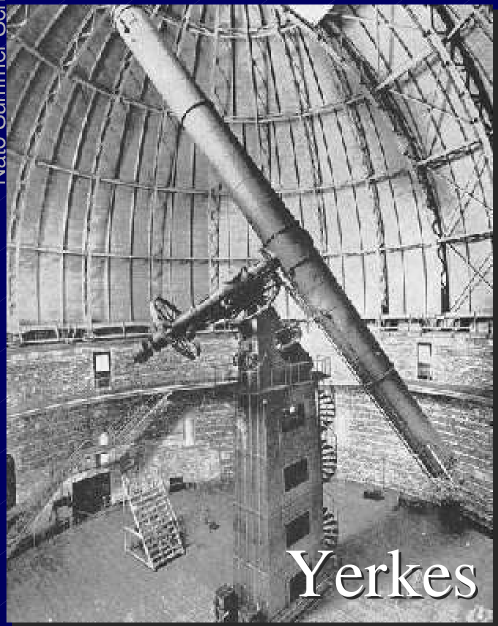
Relaxed surfacing tolerances



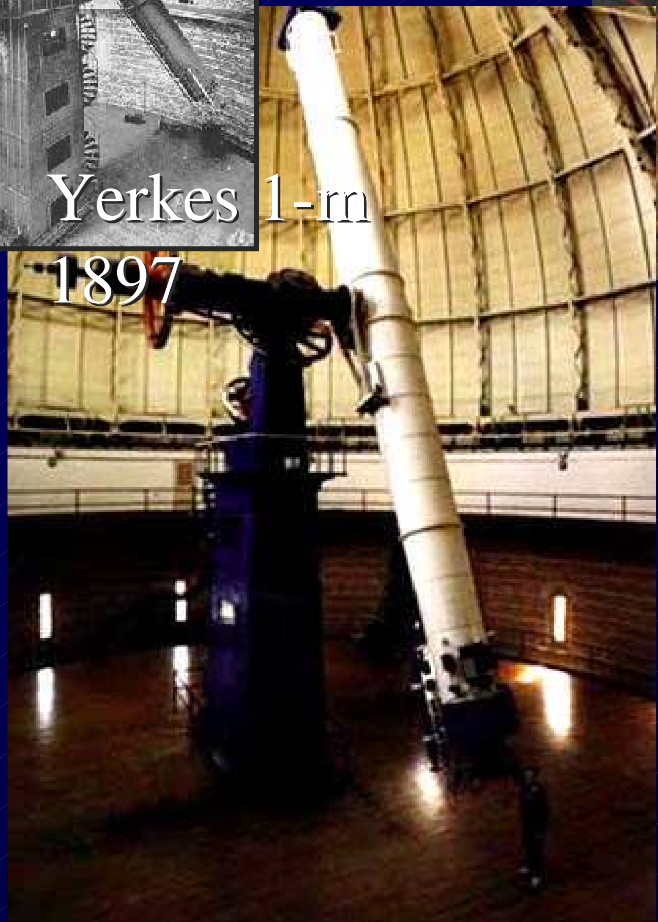
Dorpat 24-cm refractor (1824)

Equatorial mount

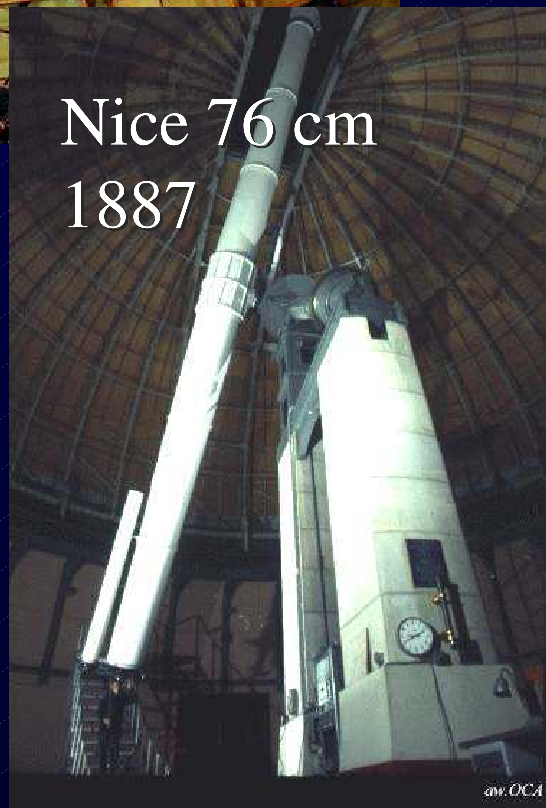
The largest refractors



Lick 91 cm
1888



Yerkes 1-m
1897



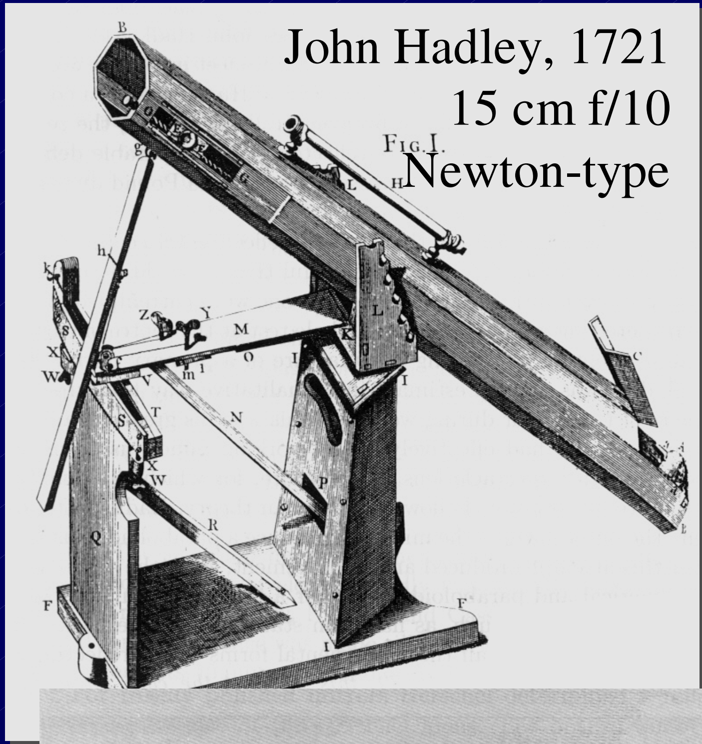
Nice 76 cm
1887

Reflectors after 1672

Mirror manufacturing
- Difficulty to make asphere ~ $(f/D)^{-3}$
  ⇨long focal ratio, long tube
- Testing: no reliable, quantitative optical test
- Heavy mirrors (density of speculum >> glass)
- Large castings often crack during cooling

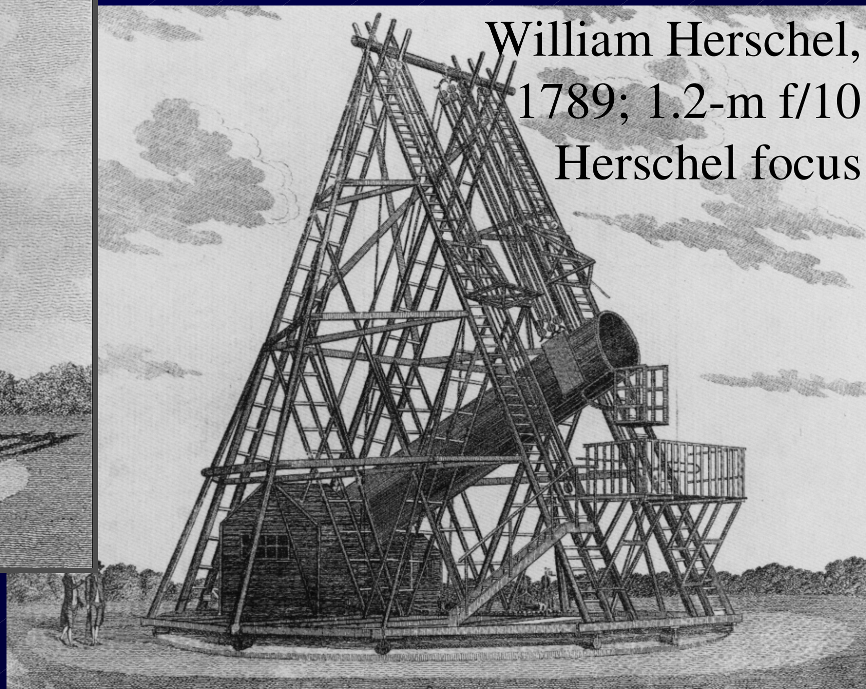
Low efficiency (~65% speculum reflectivity)

Tarnish ⇨ must be periodically repolished

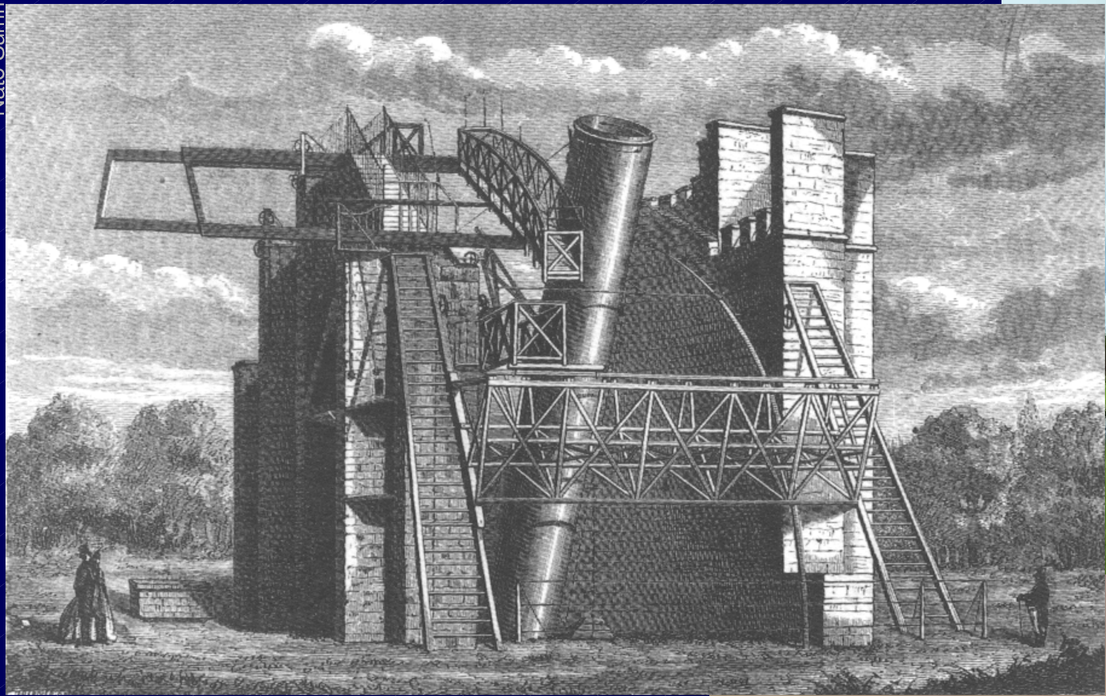


John Hadley, 1721
15 cm f/10
Newton-type


William Herschel, 1784
50 cm f/12.8
Herschel focus

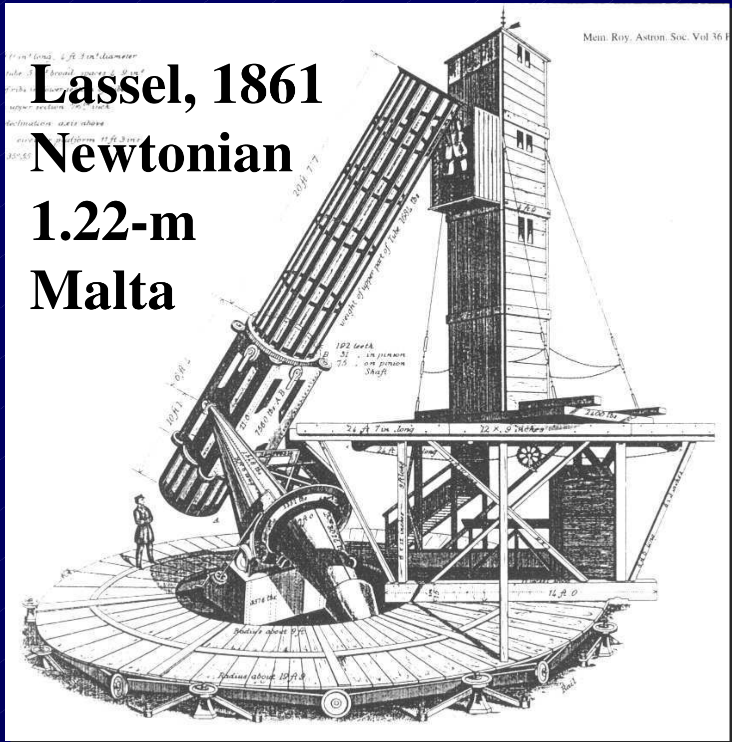

William Herschel,
1789; 1.2-m f/10
Herschel focus

The largest telescope of the 19th century

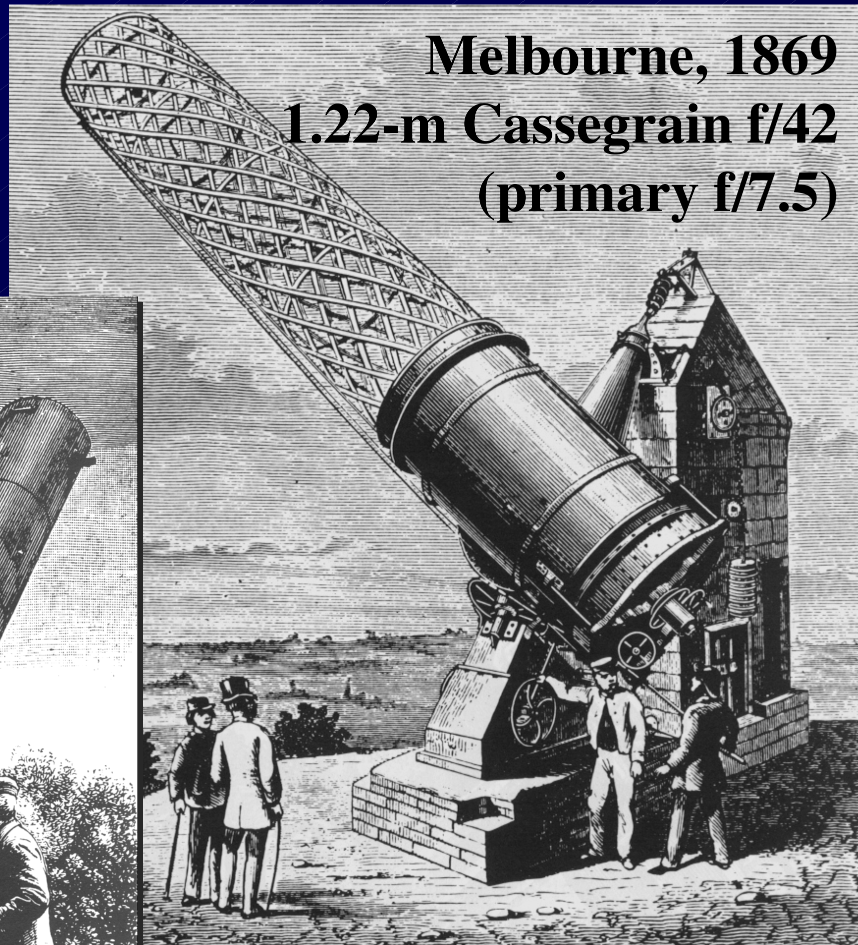


Lord Rosse 1.82-m, 1845
F/9 Newtonian
27-points whiffle-tree
mirror support

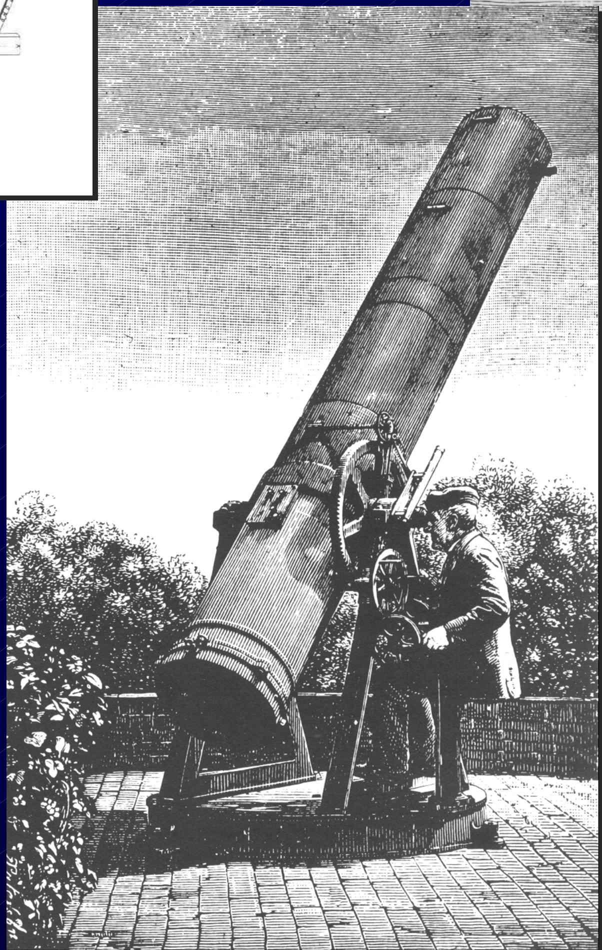
Reflectors from 1672 to about 1900



Lassel, 1861
Newtonian
1.22-m
Malta

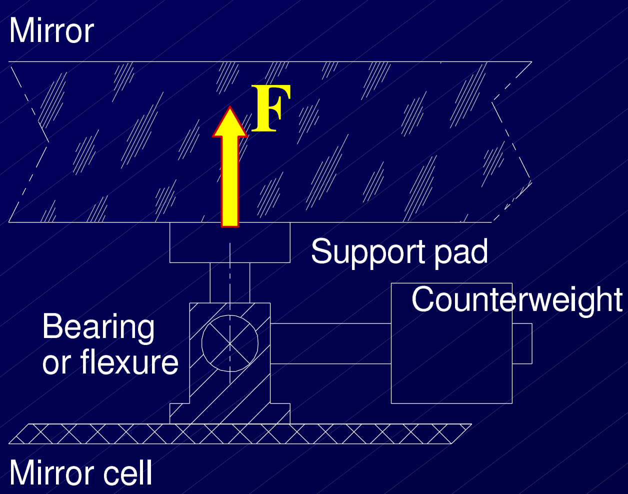


Melbourne, 1869
1.22-m Cassegrain f/42
(primary f/7.5)



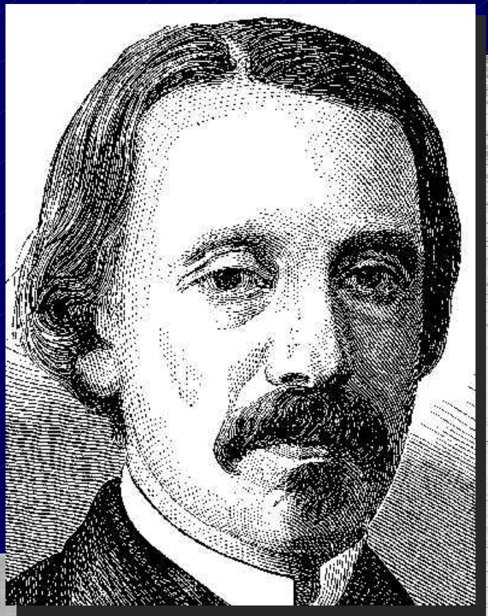
⇦ **Nasmyth, 1845**
50-cm “folded” cassegrain

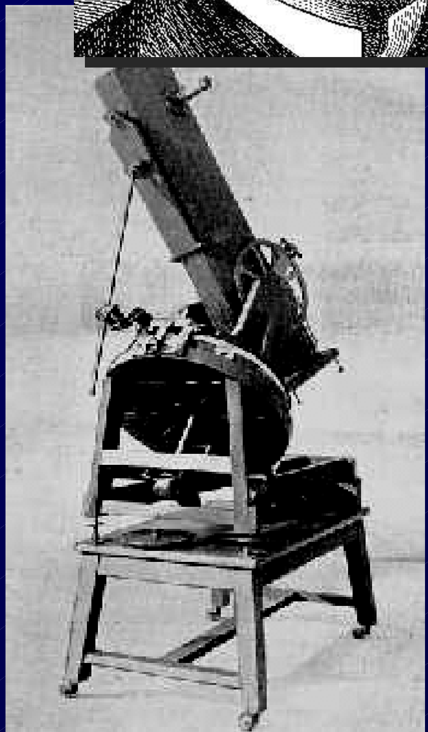
Astatic support

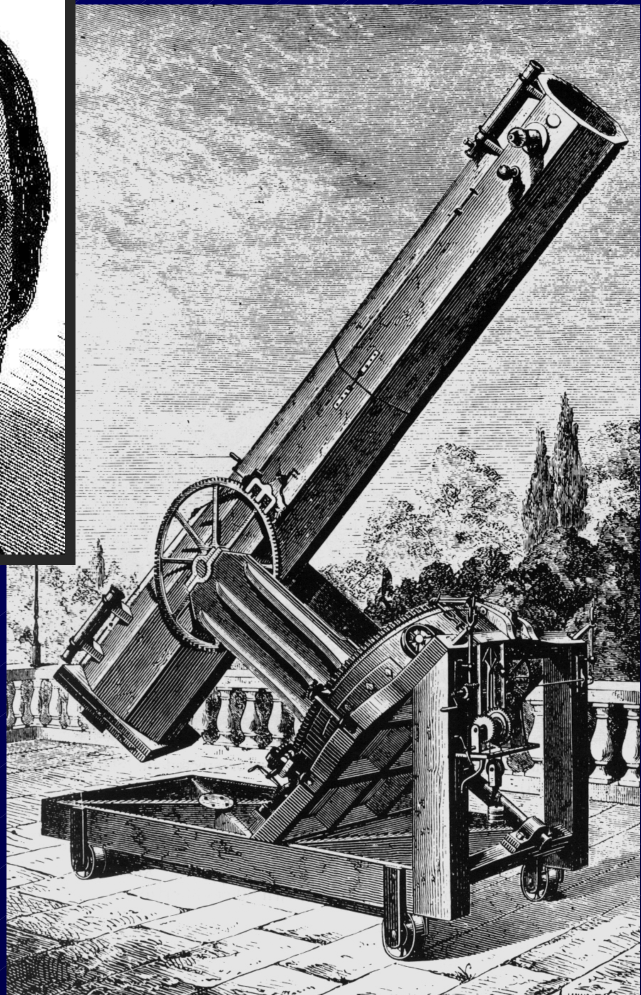


$F \propto \cos z$

Refractors vs reflectors: glass mirrors





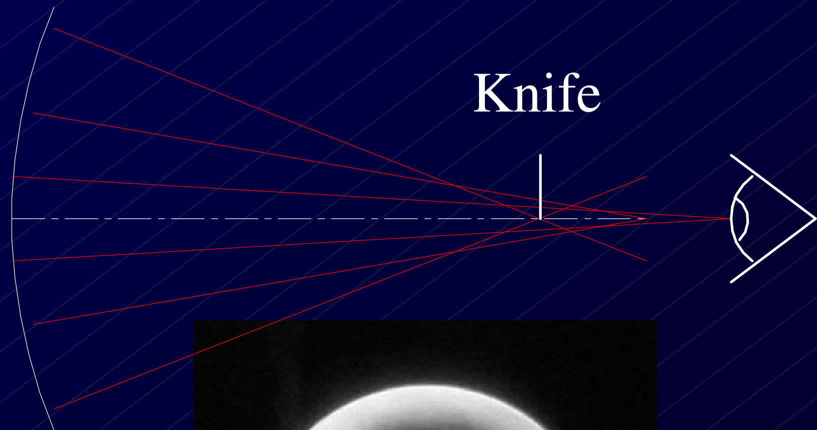


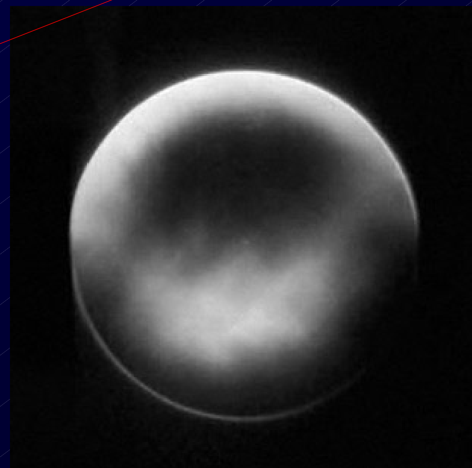
80 cm silver on glass
1862

Foucault

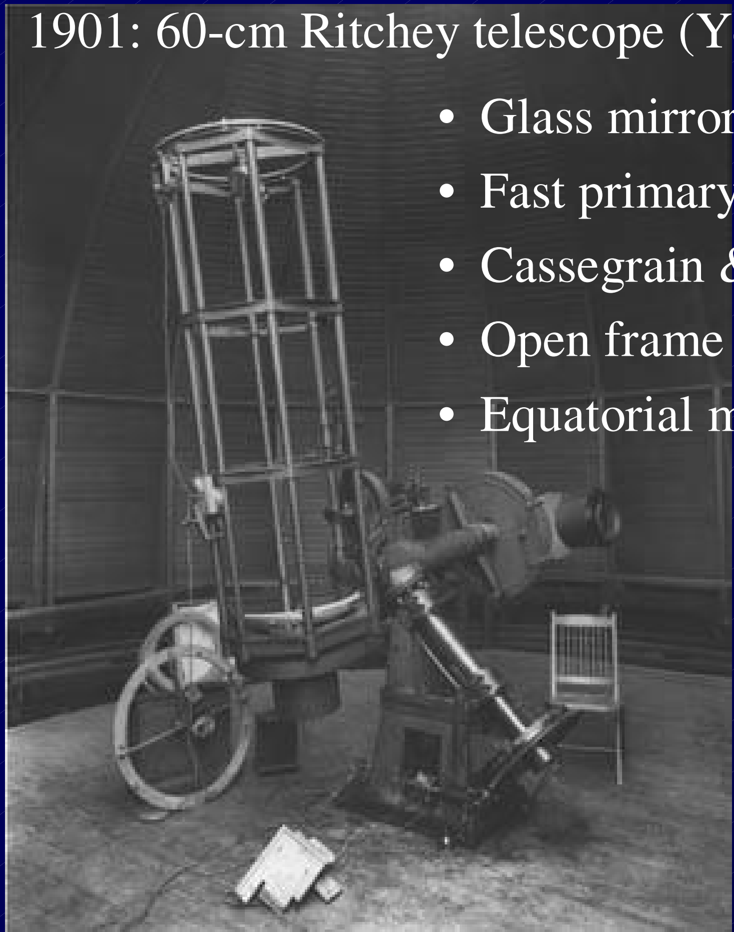
1857: silver coating
(10-cm mirror)

1859: knife-edge test



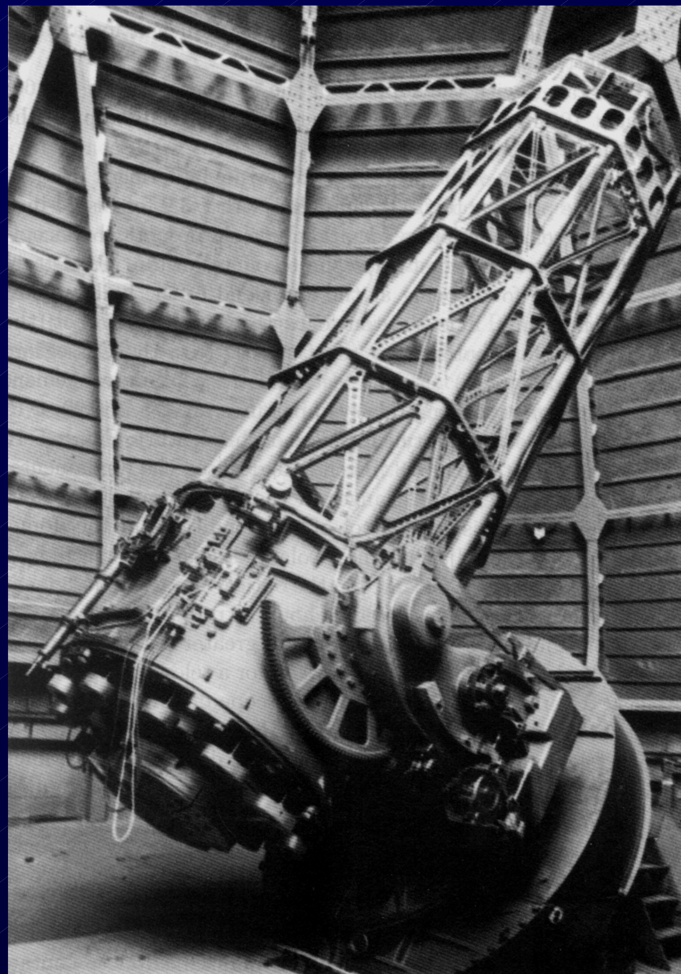


The 20th century until 1988



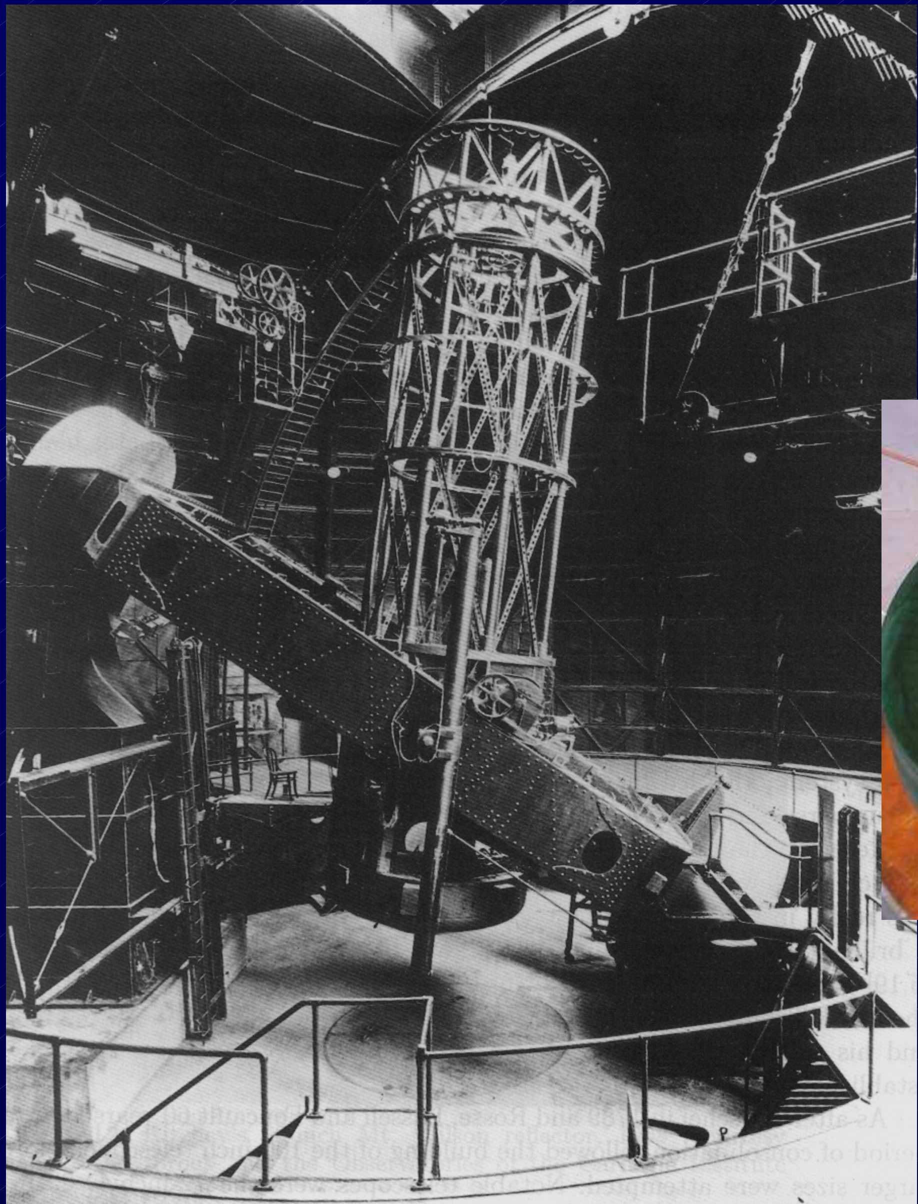
1901: 60-cm Ritchey telescope (Yerkes)

- Glass mirror (silvered)
- Fast primary (f/3.9)
- Cassegrain & Newton foci
- Open frame
- Equatorial mount

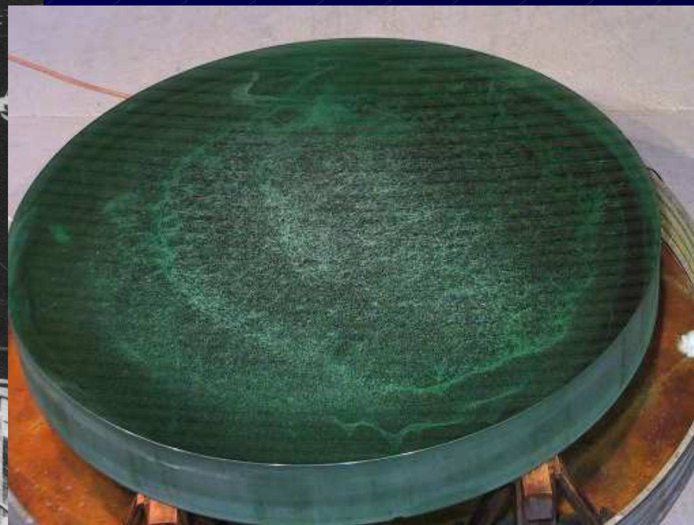


1908: Ritchey
Mt Wilson 1.5-m
Several foci
(Newton,
Nasmyth, Coudé)
Mercury flotation

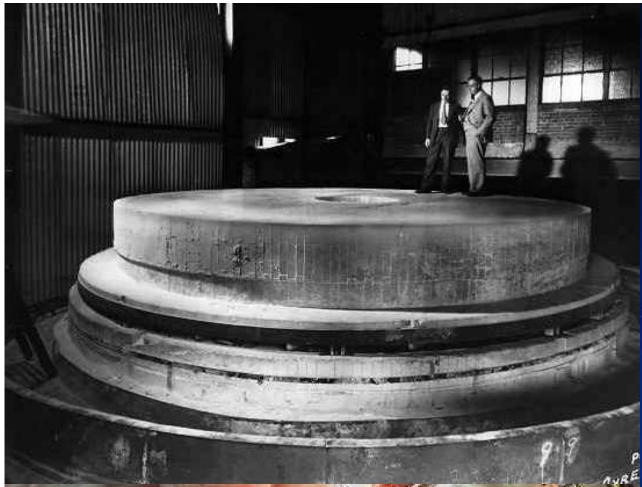
The 20th century until 1988

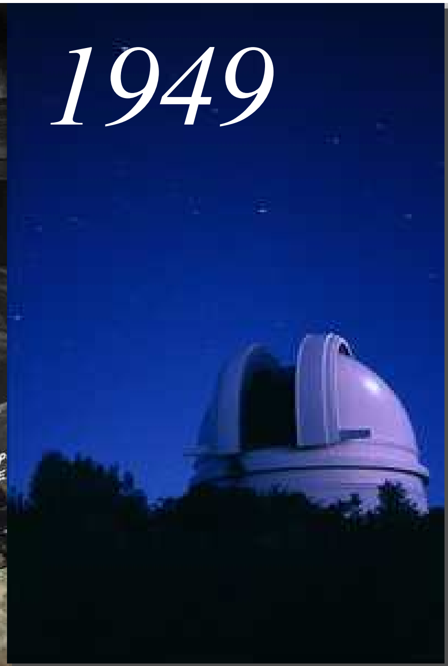


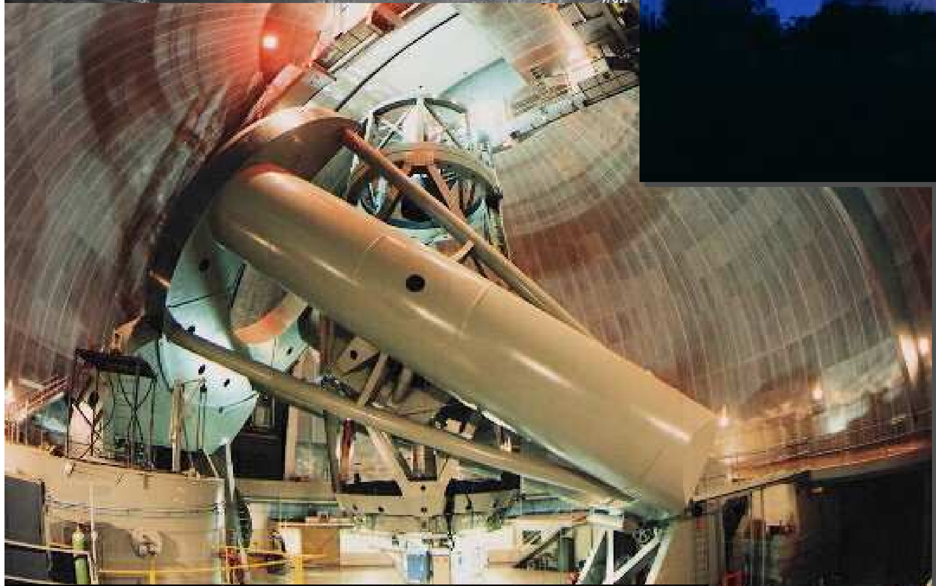
- 1917 Mt Wilson Hooker telescope
- 2.5-m, f/5.1 primary mirror
- Newton, Cassegrain & Coudé foci
- Glass mirror, large bubble content
- Performance degraded by severe thermal inertia

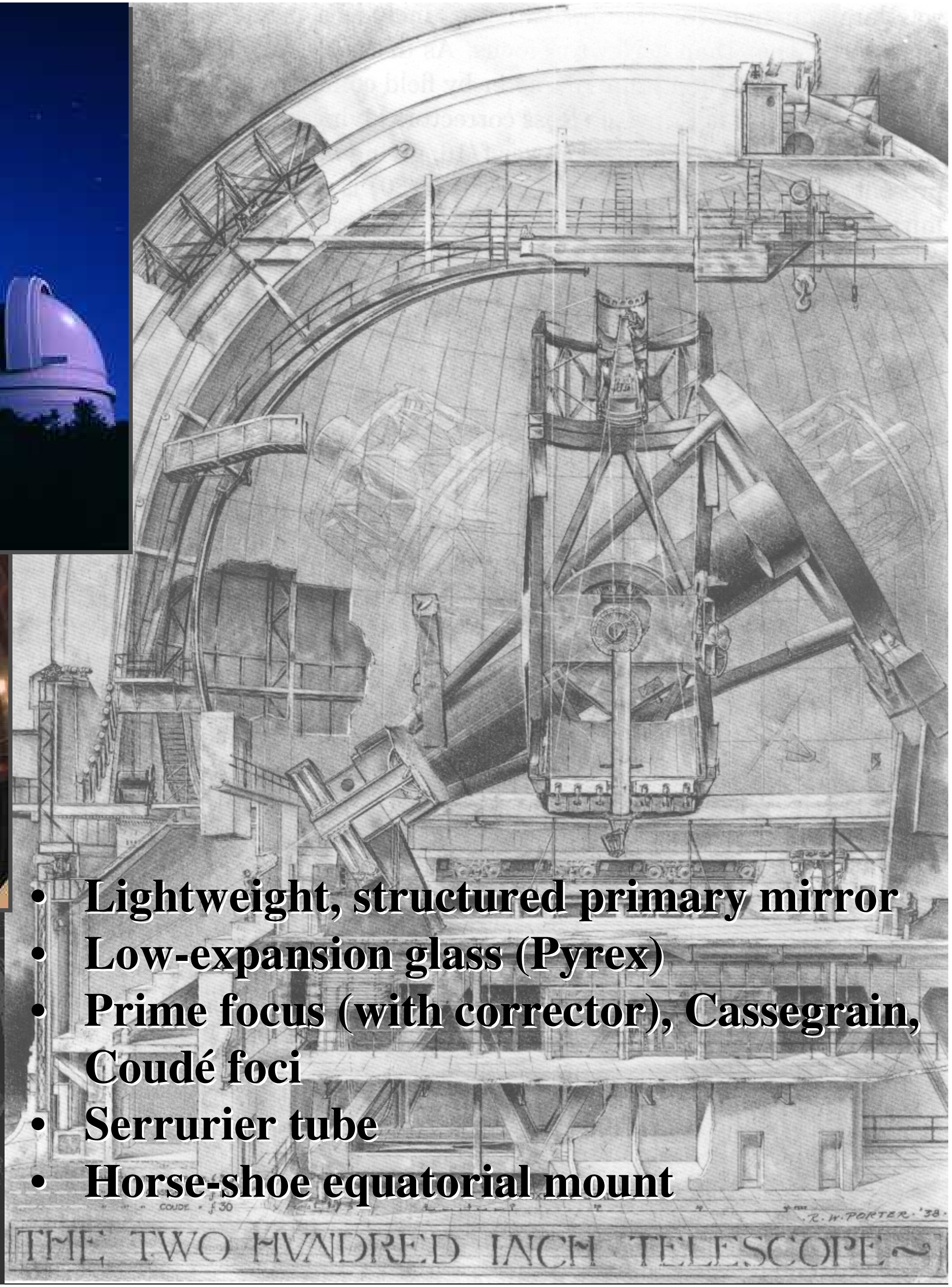


Learn more at:
http://www.astro.wisc.edu/~jsg/astro335/class_pdf_materials/Mt_wilson_hist.pdf





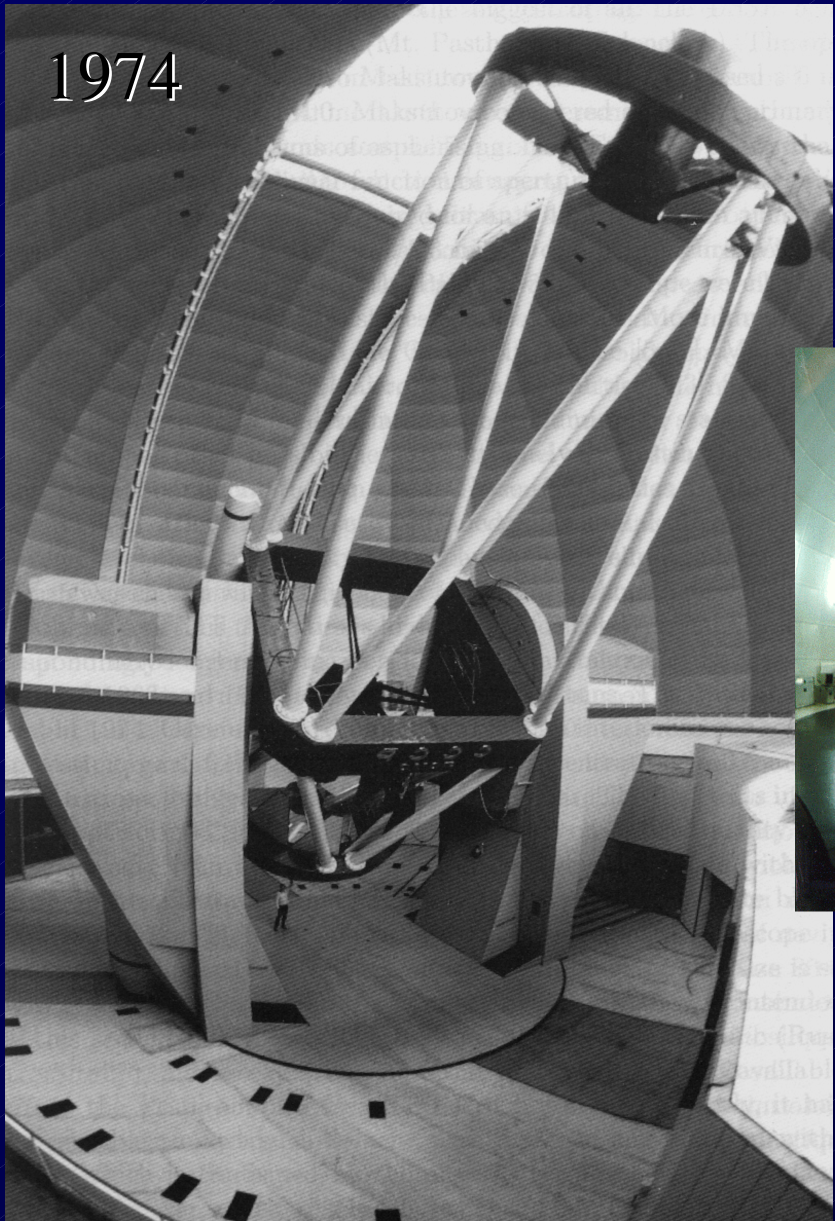


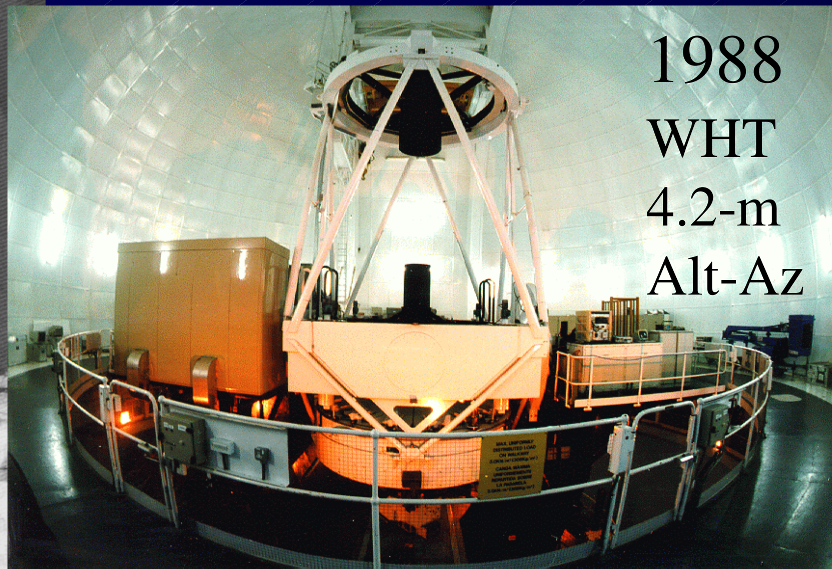


- Lightweight, structured primary mirror
- Low-expansion glass (Pyrex)
- Prime focus (with corrector), Cassegrain, Coudé foci
- Serrurier tube
- Horse-shoe equatorial mount

Trying bigger …

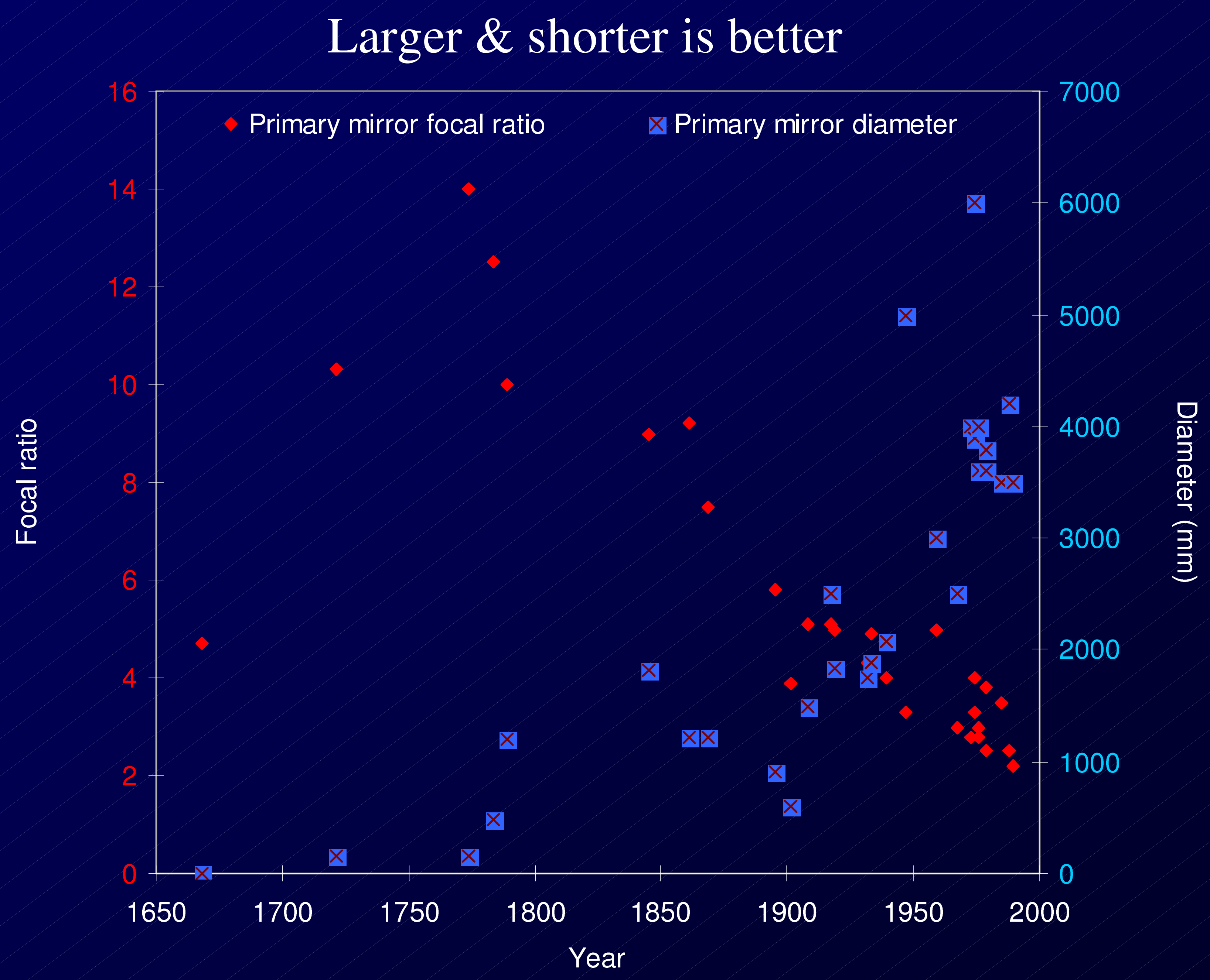
- 1974: Nizhny Arkhyz (Zelenchuk) 6-m
- F/4 primary mirror
- Massive mirror
- First computer-controlled Alt-Az mount





With these exceptions, the period 1949-1988 saw consolidation of the Palomar concept: telescopes of 3-4 m class (Lick, Kitt Peak, ESO 3.6-m, CFHT, MPIA …)

Design evolution



Major progress in the 20th century

- Ritchey-Chrétien design (suppression of field coma)
- Serrurier tube structure ⇨ lower decenters under gravity
- Alt-az mounts
  - Compact, lighter designs
  - Smaller enclosure ⇨ cheaper, lower air volume
- Low-expansion glasses / ceramics
  - Near-zero thermal expansion
  - Low / very low residual stresses
- Huge increase in detector efficiency
  - photographic plates to CCD: from 1-4% to near-100%
- In the 80's and 90's:
  - Better understanding of site quality
  - Control of fabrication processes & metrology (computer-assisted polishing, high resolution / accurate optical testing) ⇨ shorter focal ratio (< f/2 !!!)
  - **Active optics (NTT, 1989)**
  - **Optical segmentation (Keck, 1993)**