Observational Astronomy II

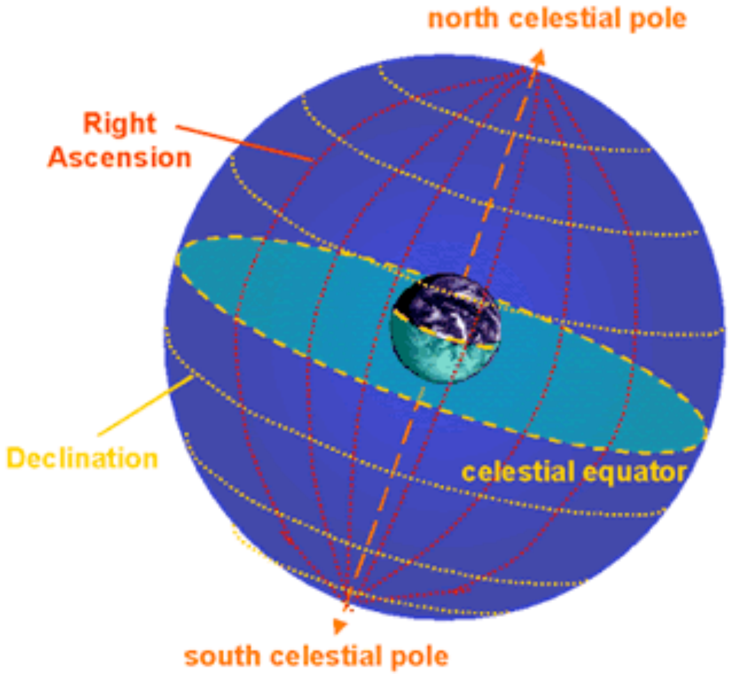
Master/PhD course by
Nikolai Piskunov, Oleg Kochukhov,
Stéphane Sacuto

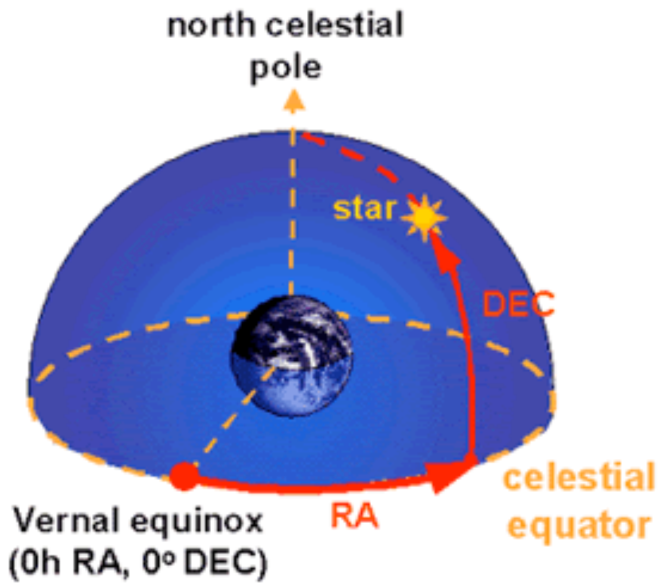
Why do we need telescopes?

- Track objects on the sky
- Collect photons and create image of a region on the sky (FOV)
- Achieve a high angular resolution
- Feed multiple instruments

Equatorial coordinate system

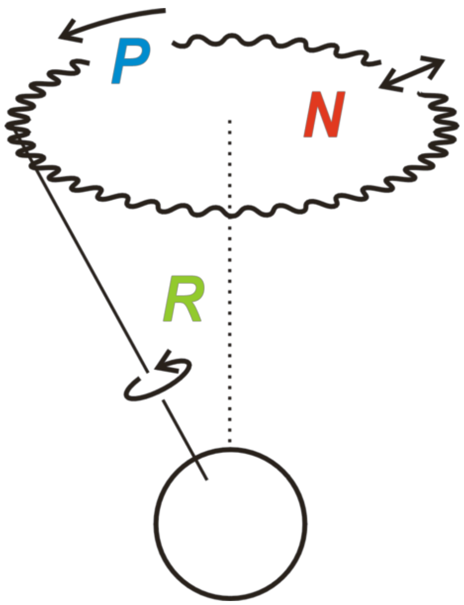
- Declination (DEC, δ): 0-360^o or 0-24h
- Right ascension (RA, α): -90^o to +90^o

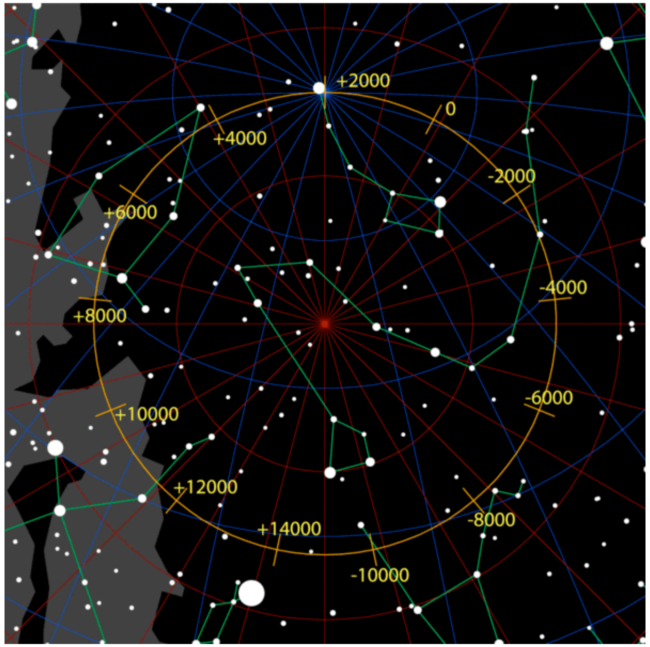




Precession and nutation

- Changes of RA & DEC with ~26000 yr cycle (P) and ~18.6 yr period (N)
- Coordinates are given for a certain **epoch**

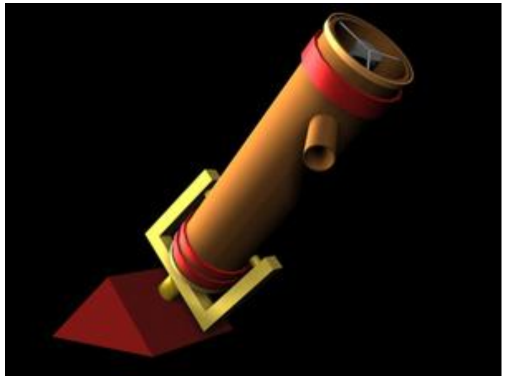




Tracking with telescopes

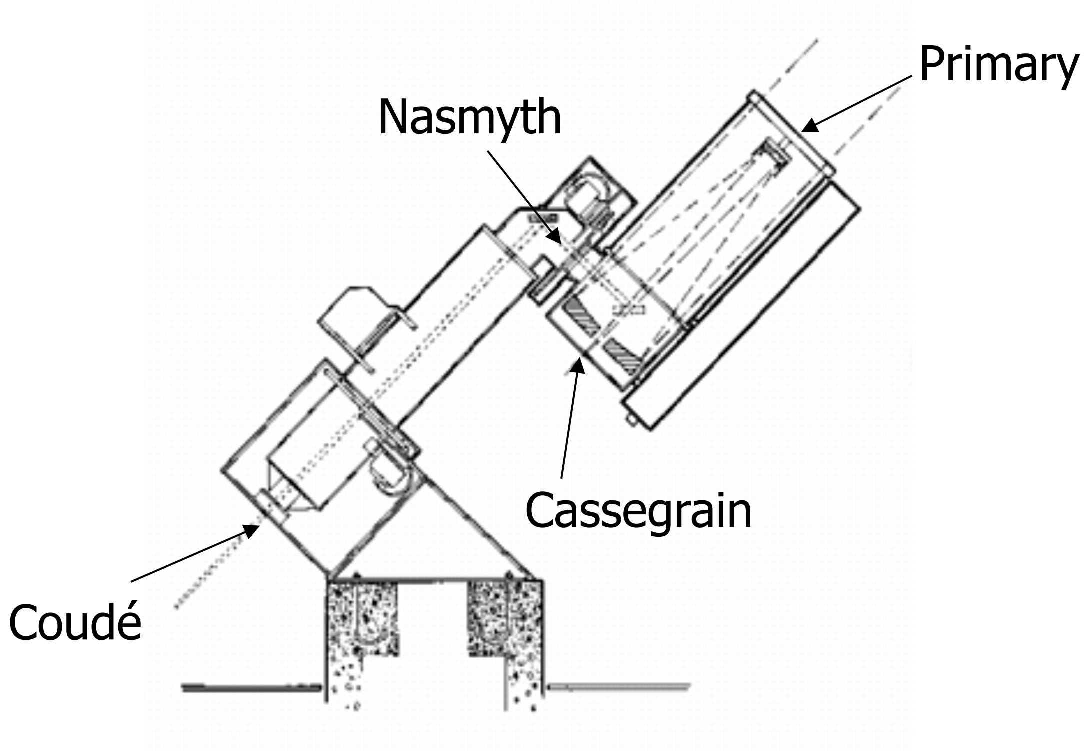
Telescope mounts:

- Equatorial
  - German mount
  - Fork mount
  - English mount
- Alt-Azimuth



Zelentchuk 6m BTA, Russia

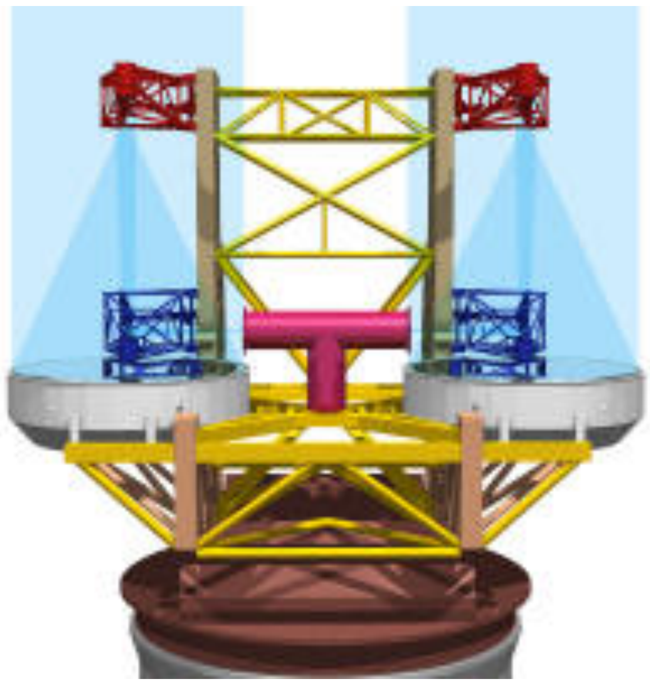
Telescope focii



DAO

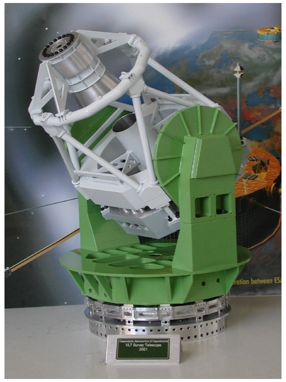
LBT

?



Telescope mounts: equatorial versus alt-azimuth

ESO VST

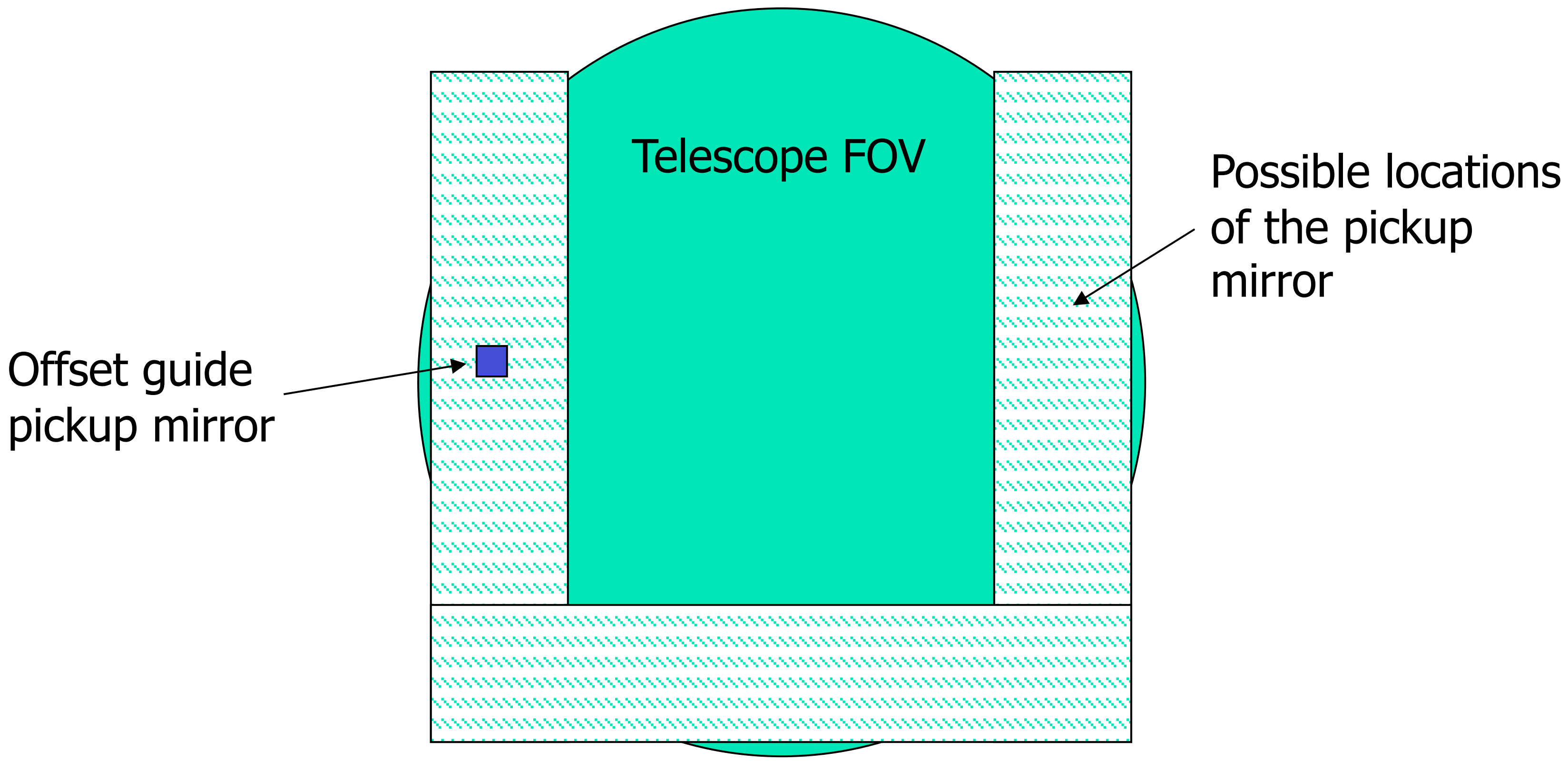


- **Gravity center location and flexure**
  in alt-azimuth mount the support force passes precisely through the gravity center thus canceling any torque: very important for large and heavy telescopes

- **Field of view behavior while tracking**
  in any focus located on the tube of an equatorially mounted telescope the field of view does not rotate

ESO 3.6m La Silla

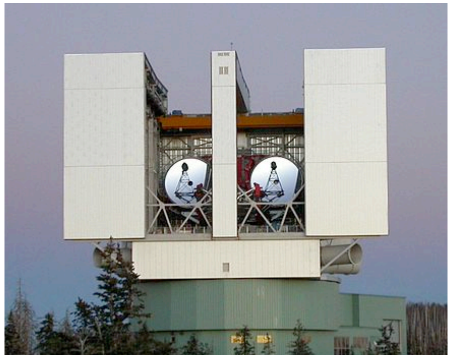
Tracking: offset guiding

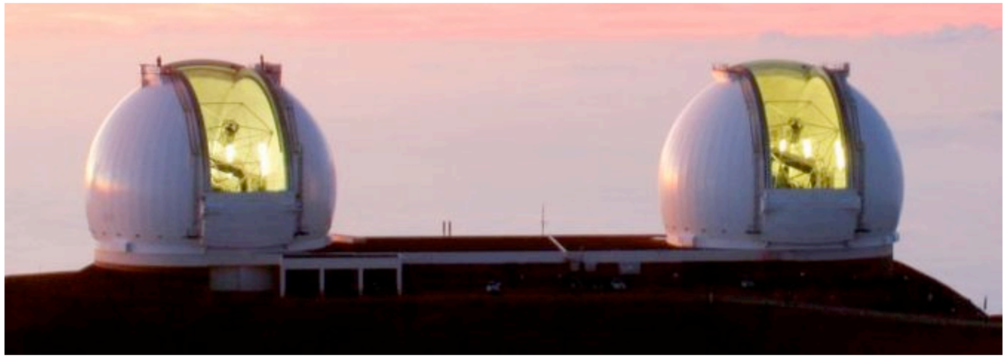


Telescope focal plane

Collecting photons

LBT	2 x 8.4m	Mount Graham, USA	Currently the largest
GTC	10.4m	La Palma, Spain	Spanish main telescope
Keck I & II	2 x 10.0m	Mauna Kea, Hawaii	Segmented telescopes, interferometer.
HET & SALT	9.2m	Mt Fowlkes, Texas Karoo, South Africa	Fixed elevation, low cost telescopes.
Subaru	8.3m	Mauna Kea, Hawaii	Active telescope made in Japan.
VLT	4 x 8.2m	Cerro Paranal, Chile	ESO flagship.
Gemini	8.0m	Mauna Kea, Hawaii Cerro Pachon, Chile	Twin 8-m telescopes in the Northern and Southern hemispheres.

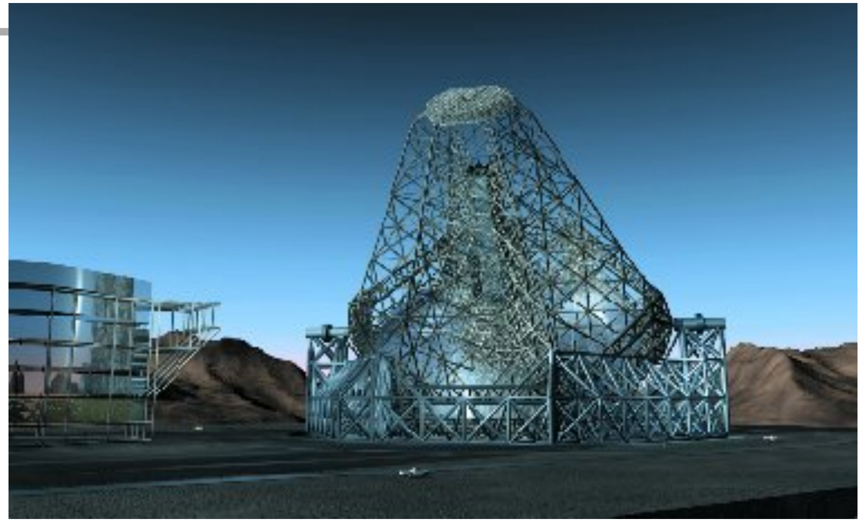




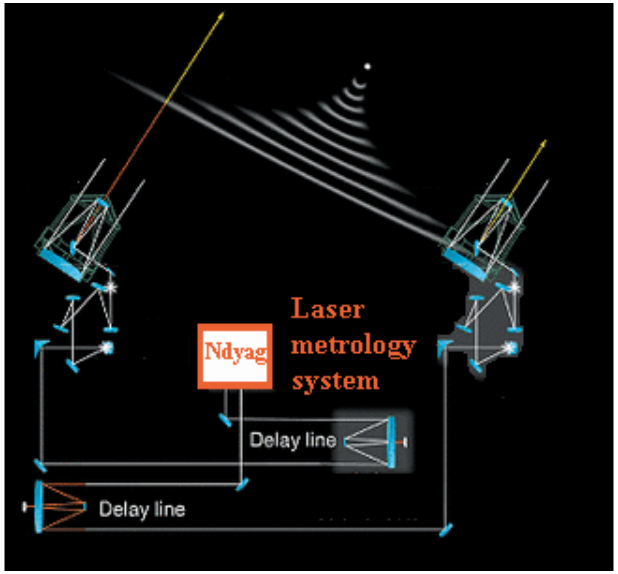
Angular resolution

- Angular resolution goes as wavelength/diameter or baseline

ESO OWL 100m design



- Interferometers

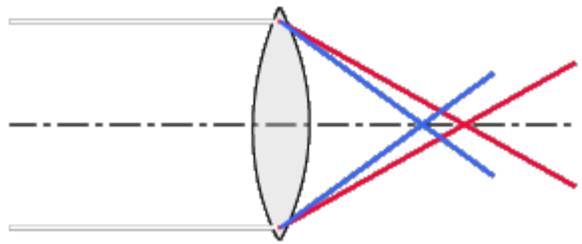


Refractors

Refractors are based on lenses

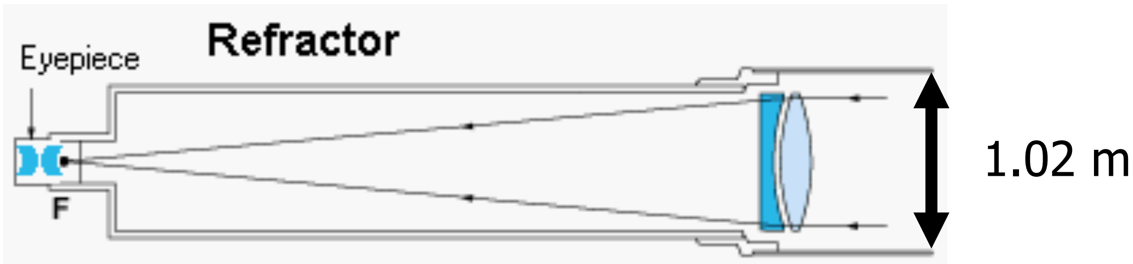
Easy to make, can combine several elements

Chromatic aberrations:



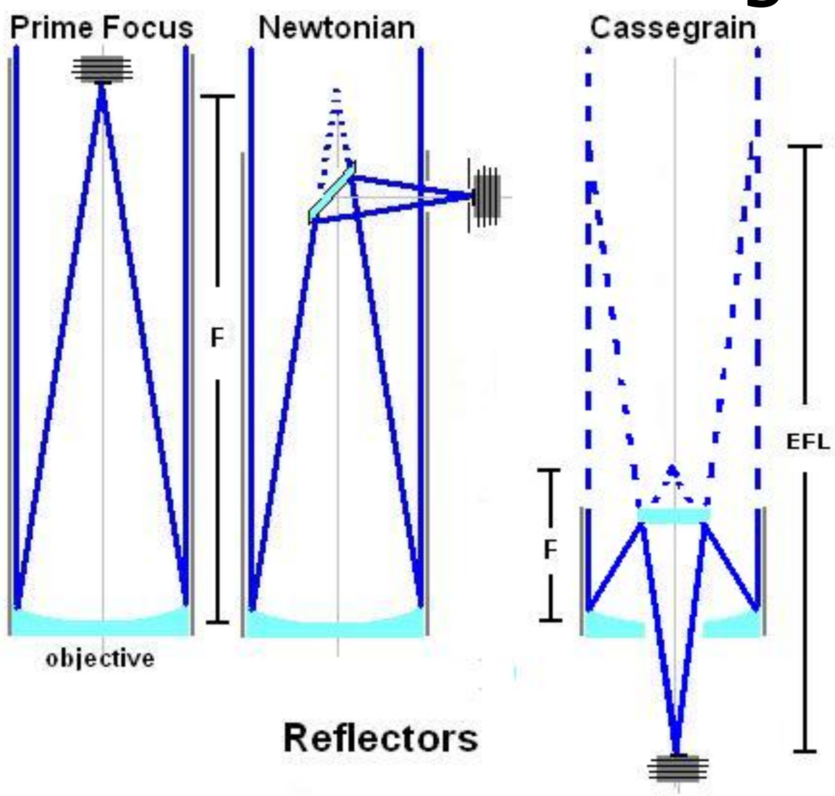
Largest refractor (1897):

Yerkes Obs. 40”, f/19



Reflectors

Lots of options: from basic single mirror to Newtonian and Cassegrain



Summary: refractors

- Axial symmetry
- Combination of multiple elements
- Compact
- Cheap for small sizes
- Chromatism
- Difficult making many meter size lenses
- Heavy
- Impossible to make segmented lenses

Summary: reflectors

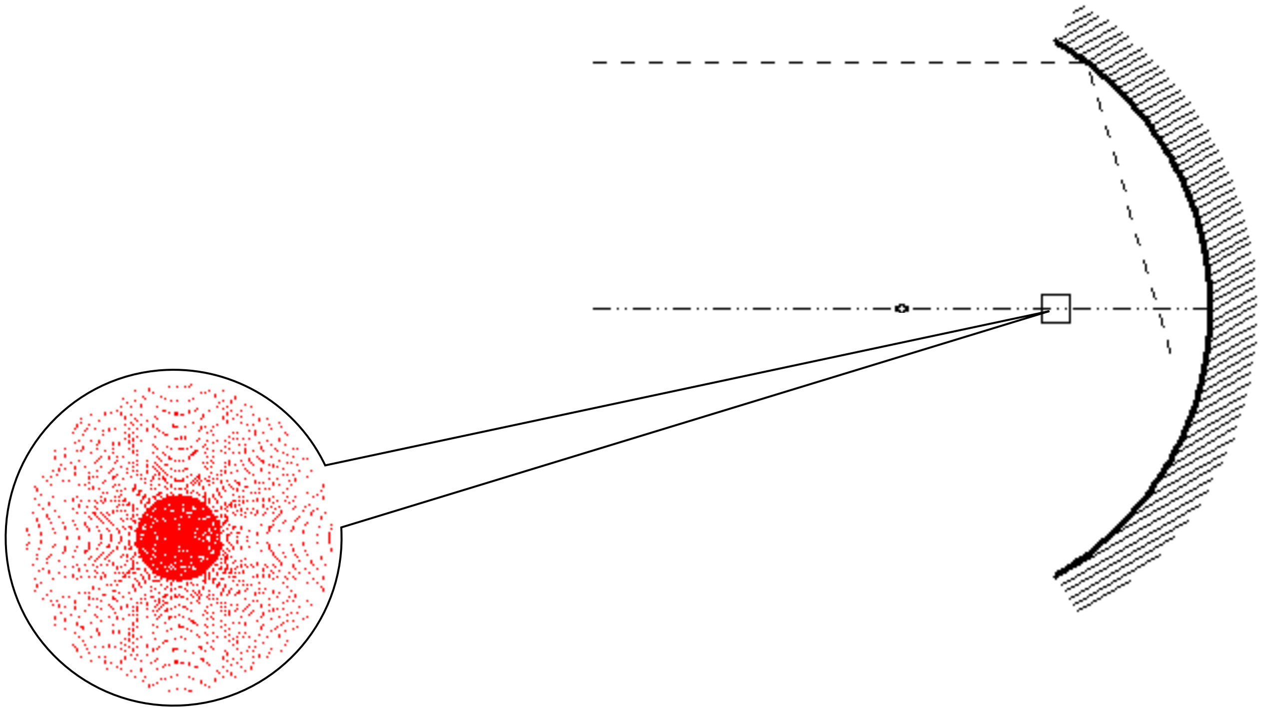
- Light (high surface/weight ratio)
- Can be made in large sizes from temperature insensitive materials
- Can be made in large sizes
- Can be made segmented
- Shape can be adjusted (“flexible” mirrors)
- Difficult to combine
- Hard to make axial systems (vigneting)

Specialized telescopes:

1. Wide field (Schmidt camera)
2. Infra-red (coatings, thermal control)
3. Automatic/robotic telescopes (complex telescope control system)
4. Solar telescopes (heat)
5. With fixed primary (large & cheap)
6. Space telescopes (three axes, thermal gradients, power consumption, pointing)

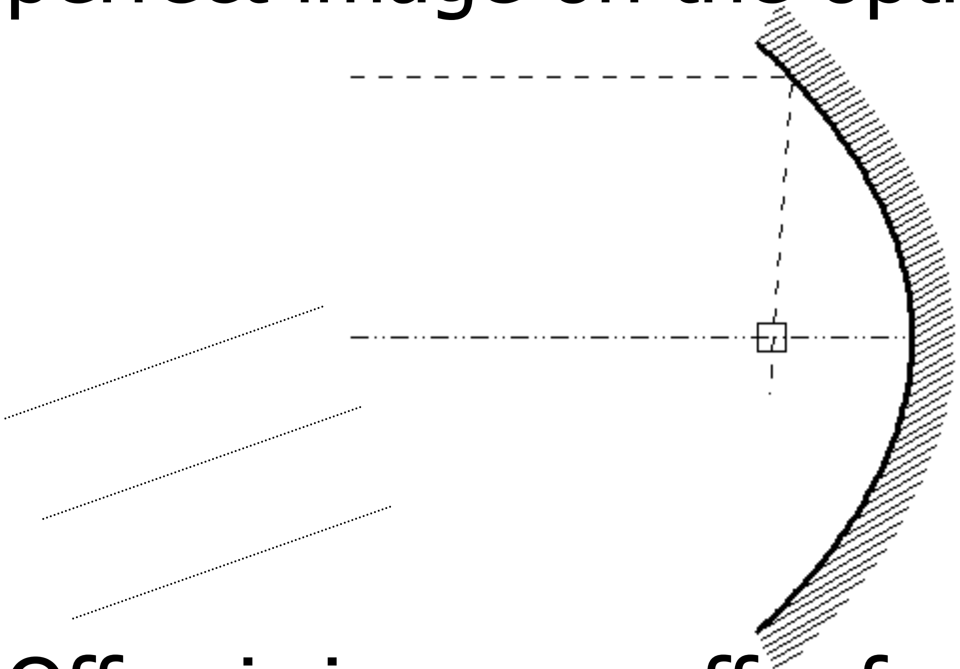
Optical Schemes

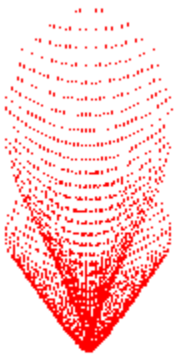
Spherical mirrors cannot focus light properly due to spherical aberrations:



Optical Schemes

… but a single parabola can produce perfect image on the optical axis:





Off-axis images suffer from coma.

Ritchey-Chrétien telescope

Hyperbolic primary and hyperbolic secondary solve main aberration problems (spherical and coma) in a rather large field of view (few arcminutes) in Cassegrain focus

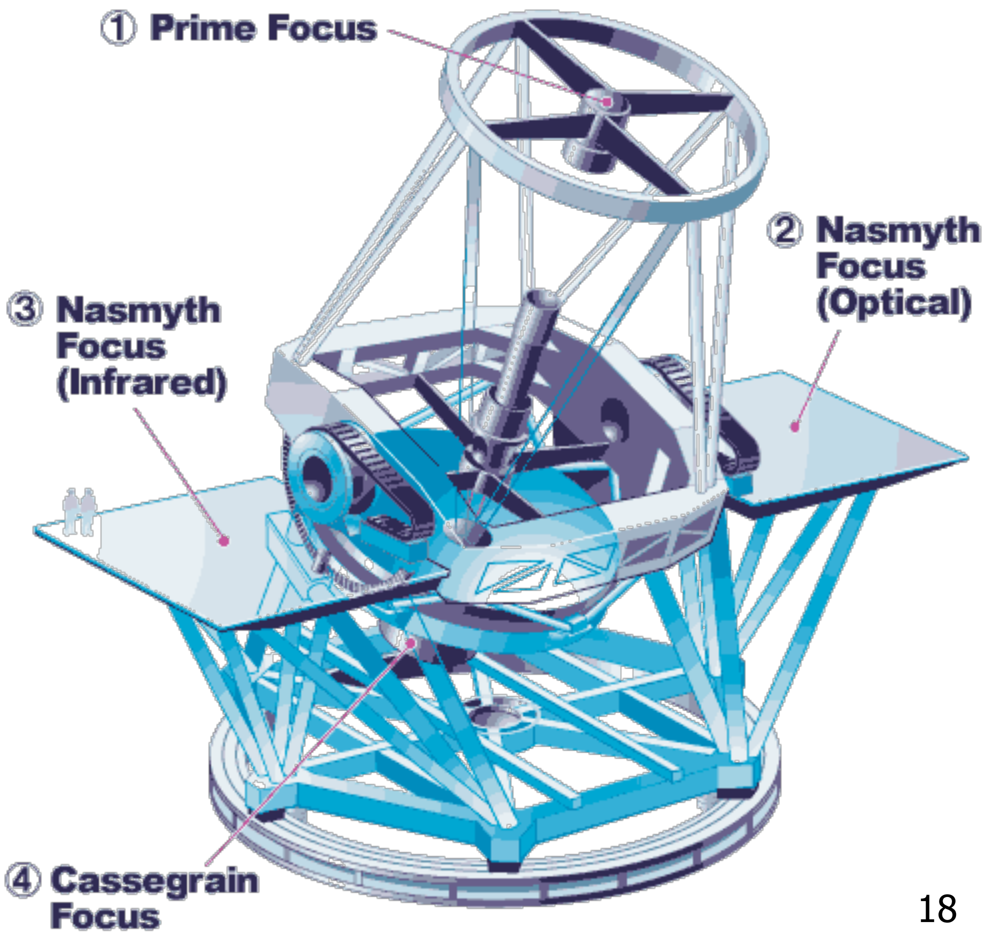


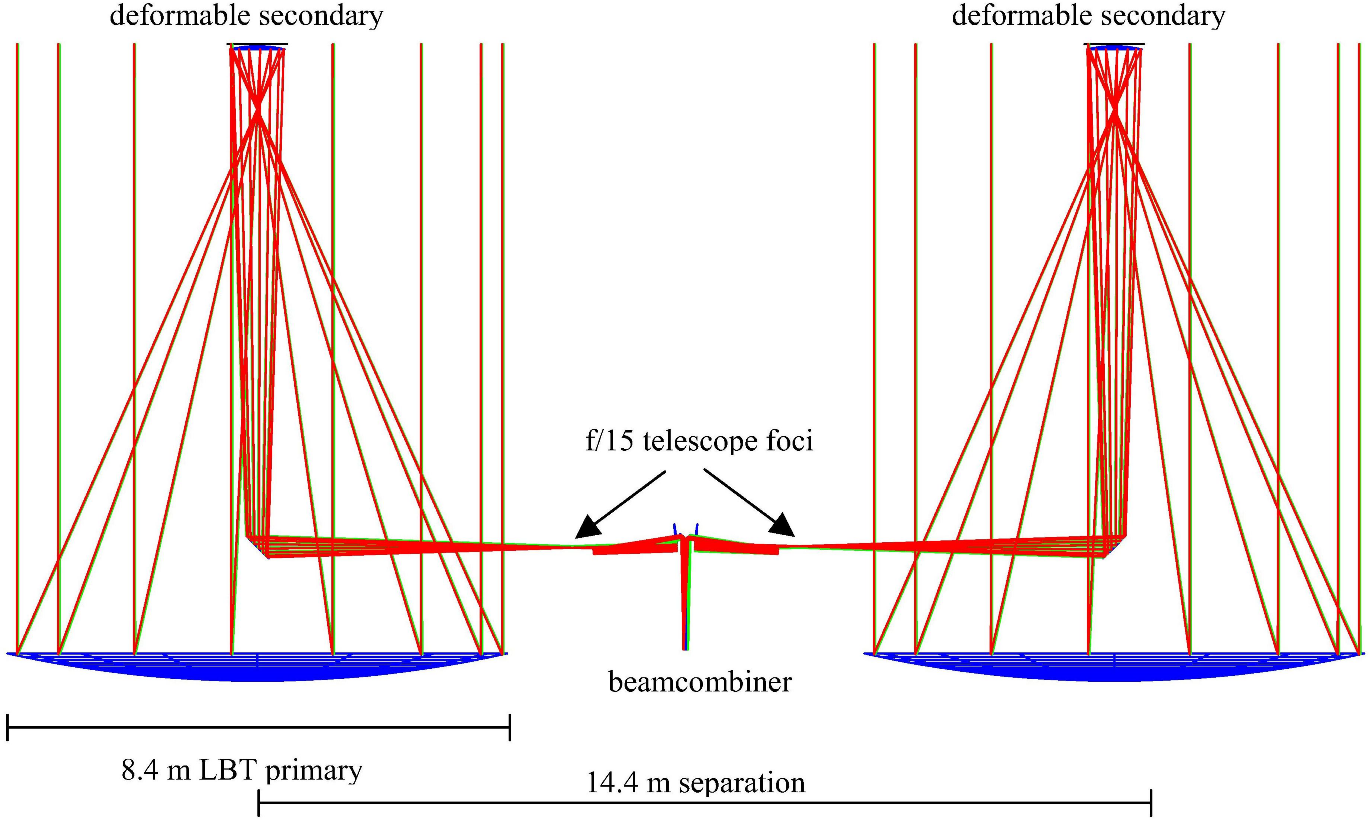
Illustration by Takaetsu Endo, taken from Nikkei Science 1996

Schmidt-Cassegrain

- RC provides very good image quality in a relatively small field
- When large FoV (up to 5º) is need Schmidt-Cassegrain is the preferred design:

Alternatively Gregorian system

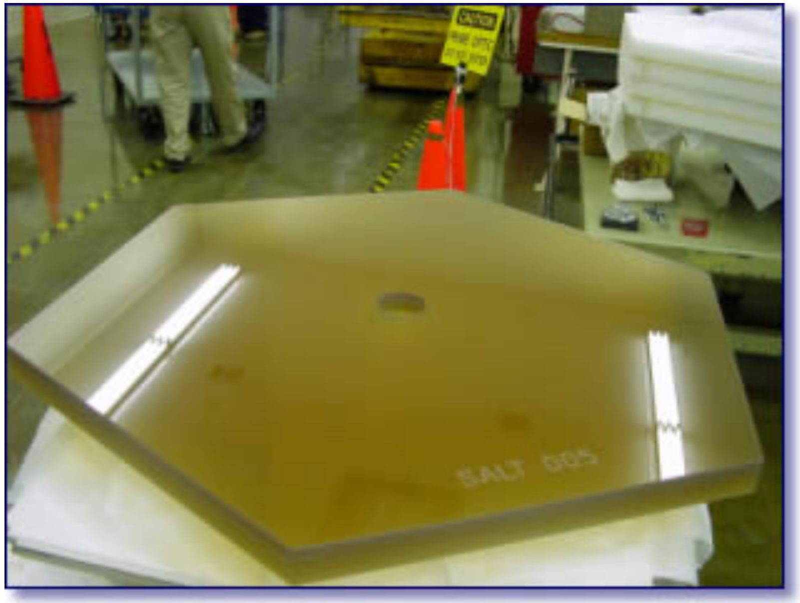
Concave secondary after the primary focus:



Courtesy of MPI Potsdam

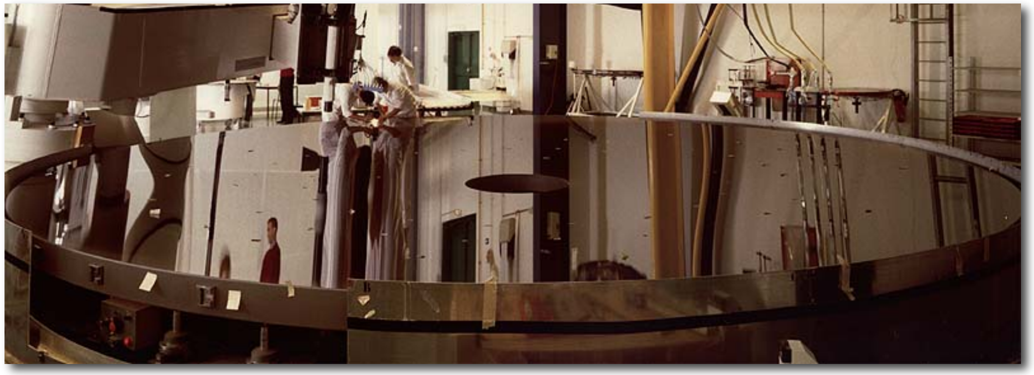
Materials

- Low thermal expansion: zerodur & sitall



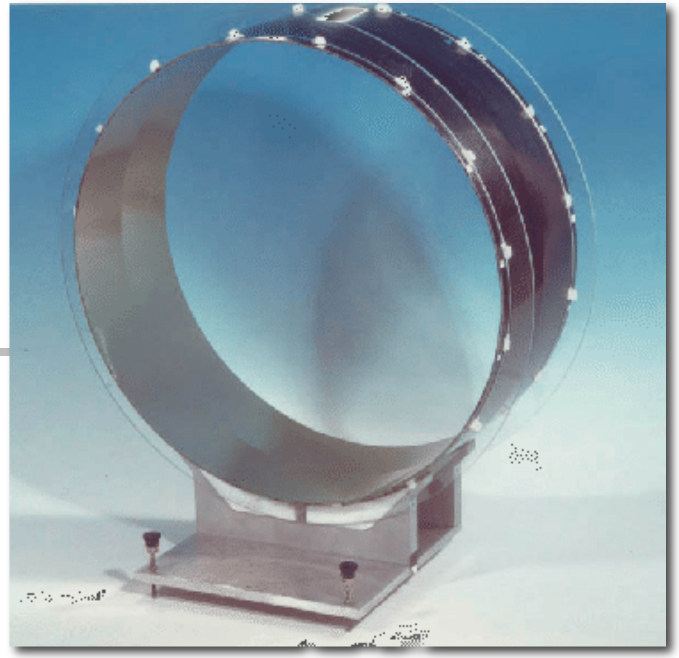
Astro-sitall blank at LZOS
(VST, VISTA, SALT, LAMOST)

mean linear coefficient of thermal expansion within temperature range -60^{o} to $+60^{o}$ C is $<10^{-8}$ cm $^{o}C^{-1}$



Zerodur VLT primary at REOSC

More materials



SiC 60 cm X-ray mirror
Weight: 6.2 kg

Silicon Carbide

- Low thermal expansion (not as good as glass)
- Very light
- Very hard, keep the shape well
- Hard to make in large pieces
- Fragile, hard to process

Mirror manufacturing

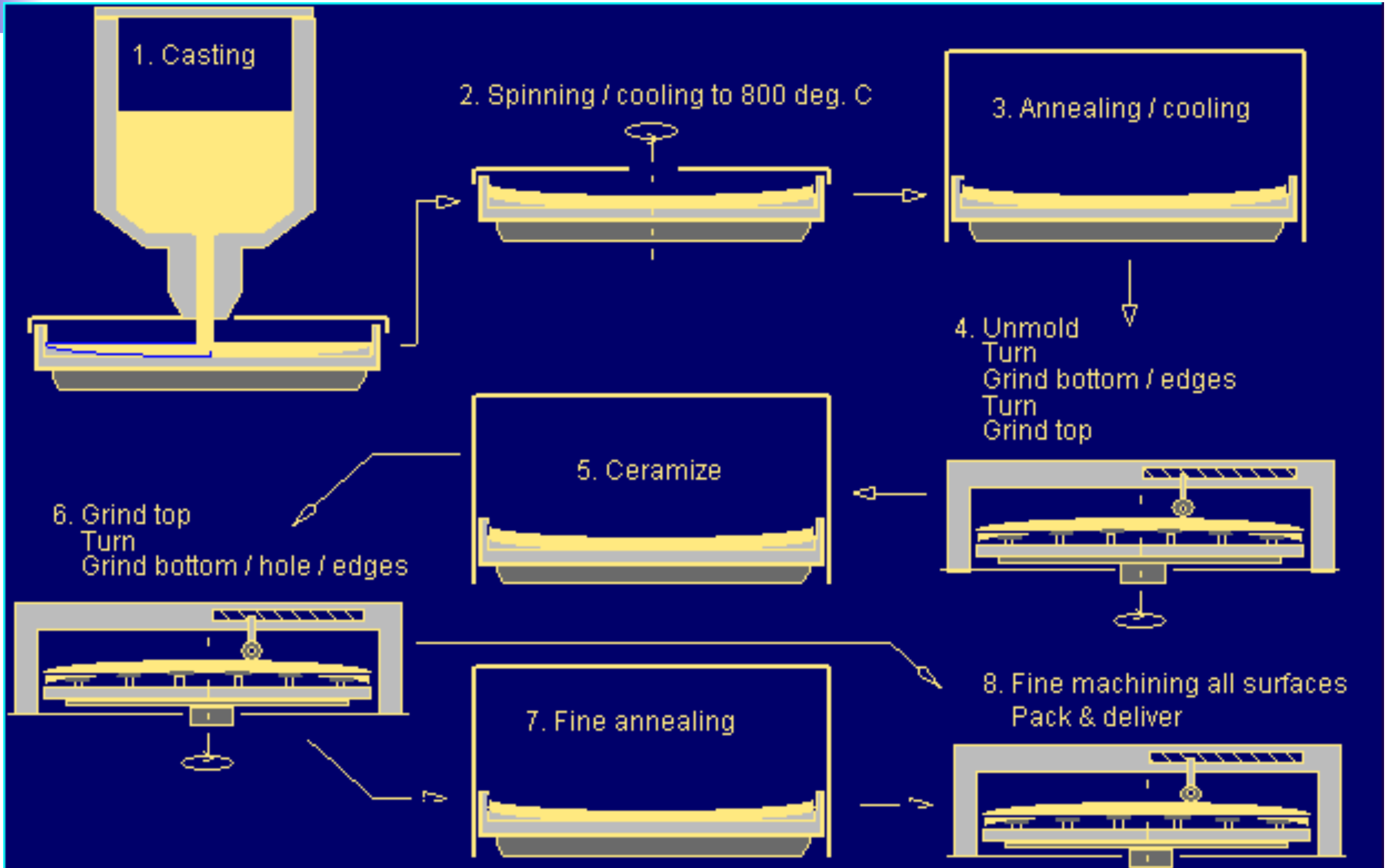


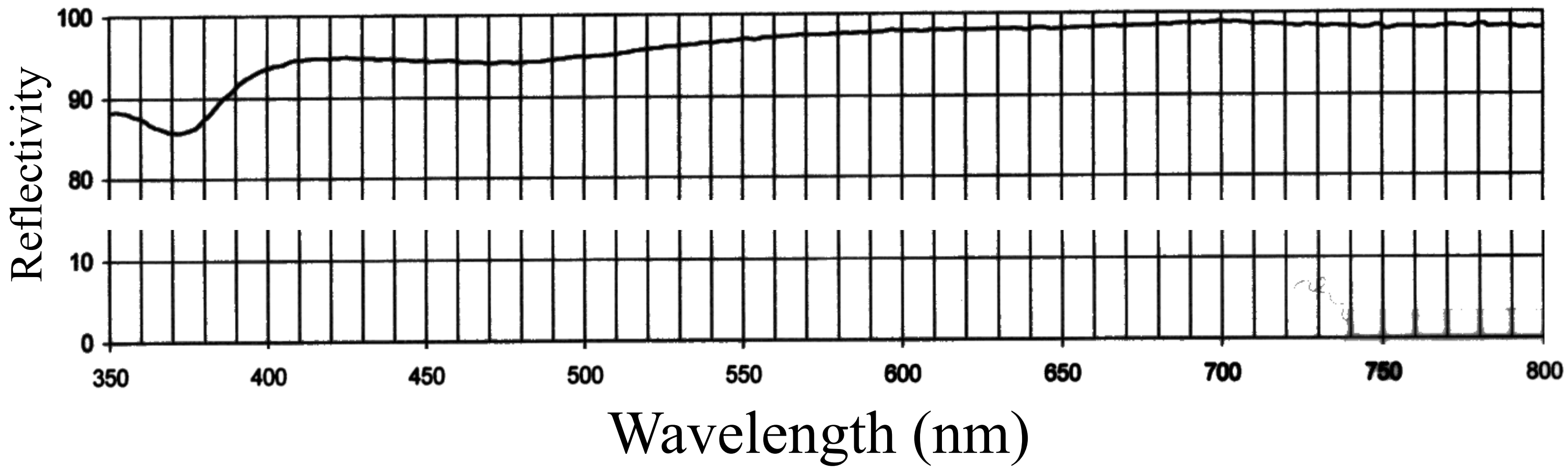
Figure 3. Mirror blanks manufacturing process

Coatings

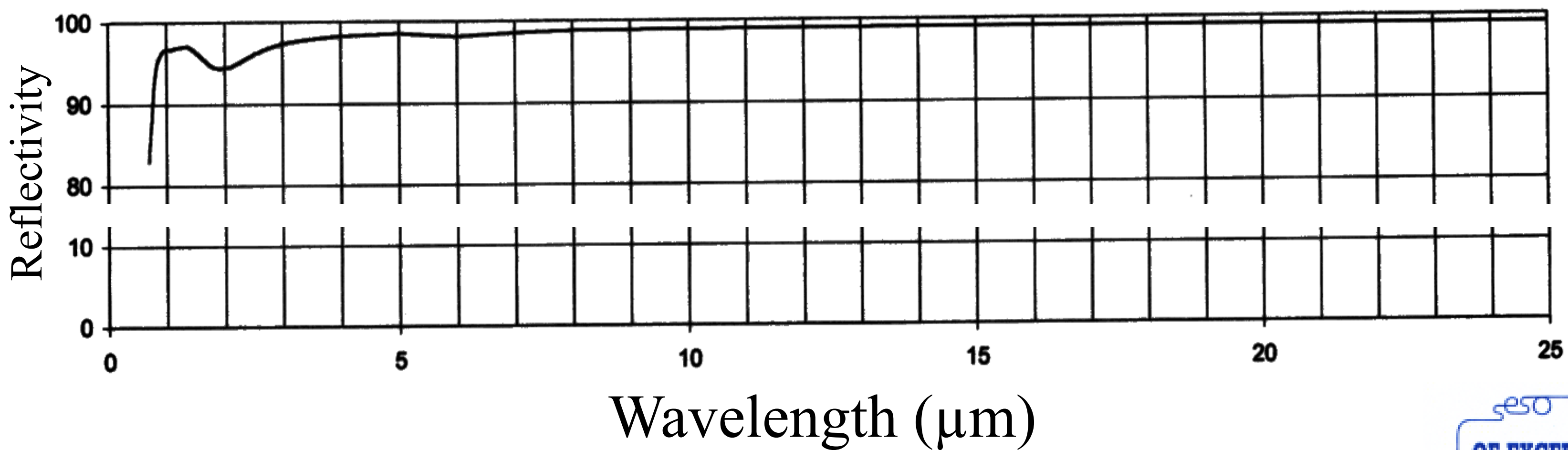
- Mirrors:
  - Aluminum with SiO on the top
  - Silver-based coatings. Needs coating to prevent mechanical damage during washing
- Lenses: MgF_2

EXAMPLES OF OPTICAL COATING

Enhanced Silver coating results (from 350 nm to 800 nm)



Hard Gold coating results (from 0.7 µm to 25 µm)



Home work

- Find online catalogues providing equatorial coordinates for celestial objects
- Find online tools to calculate visibility of stars for given RA & DEC
- For the night Nov 15 estimate RA and DEC ranges of objects observable from Uppsala
- What is the condition for a star to be always visible from Uppsala?