Optical/IR Observational Astronomy

Telescopes II: Mirrors, Mounts & Enclosures

David Buckley, SALT

Optical/IR Observational Astronomy

Telescopes II: Mirrors, Mounts & Enclosures

Topics Covered

- **Telescope Mirrors**
  - How they are made & supported
  - How they are coated
- **Telescope Mounts**
  - Equatorial mounts
  - Alt-Az mounts
  - Novel mounts
- **Telescope Enclosures**
  - Buildings
  - Domes

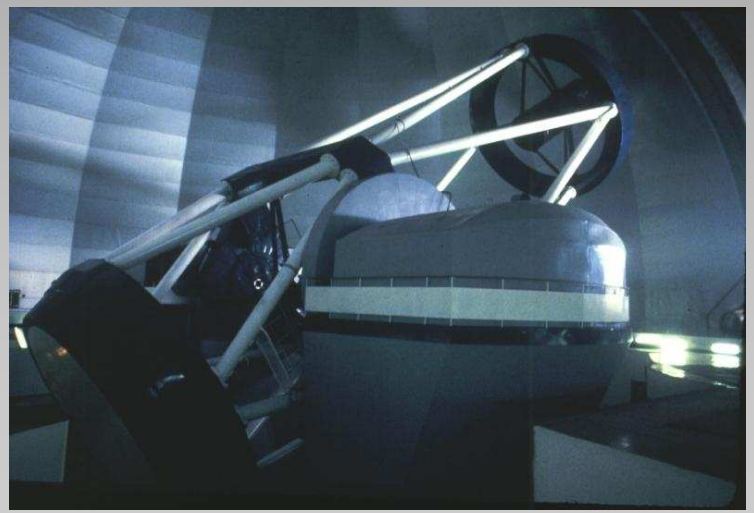
- **Observing sites**
  - The best places for observatories
- **The atmosphere**
  - Seeing, turbulence and Kolmogorov theory
  - Fourier optics, PSFs, MTFs, Strehl ratio
- **Adaptive Optics**
  - Principles
  - Deformable mirrors
  - Laser guide stars

Telescope Mirrors

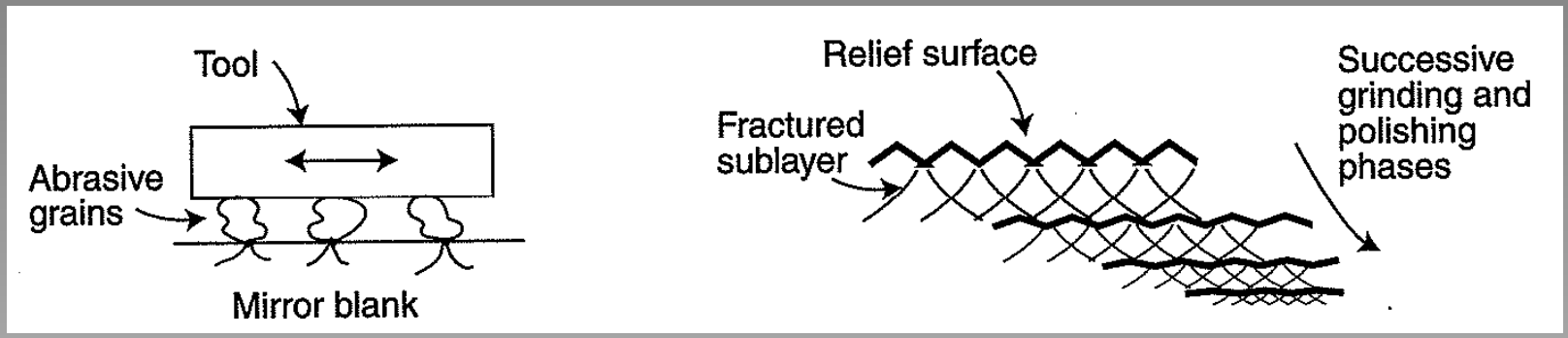
- **Reflecting mirrors**
  - Mirrors bend light due to *reflection*
  - Reflection is wavelength *independent*, so no chromatic effects
- **Use of mirrors pioneered in large telescopes**
  - e.g. the Mt Wilson 100” Hooker telescope, completed in 1917
  - Edwin Hubble discovered the expansion of the Universe with this telescope

Telescope Mirrors

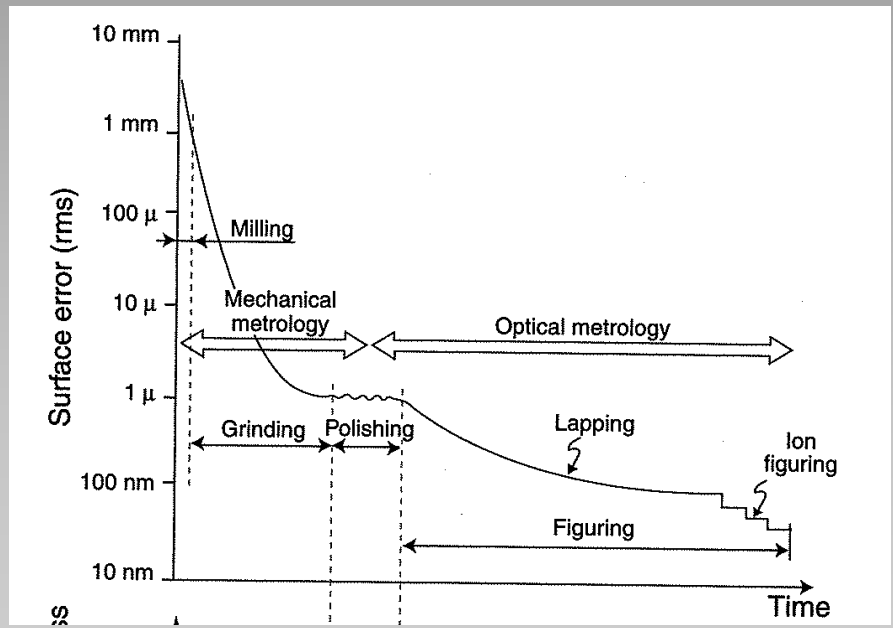
- All major telescopes built from the early 20th Century are reflectors
  - The 200” (5-m) Hale telescope at Mt Palomar, California, was completed in 1948
  - The biggest telescope for ~30 years, until the Russian 6-m BAT



Making Mirrors

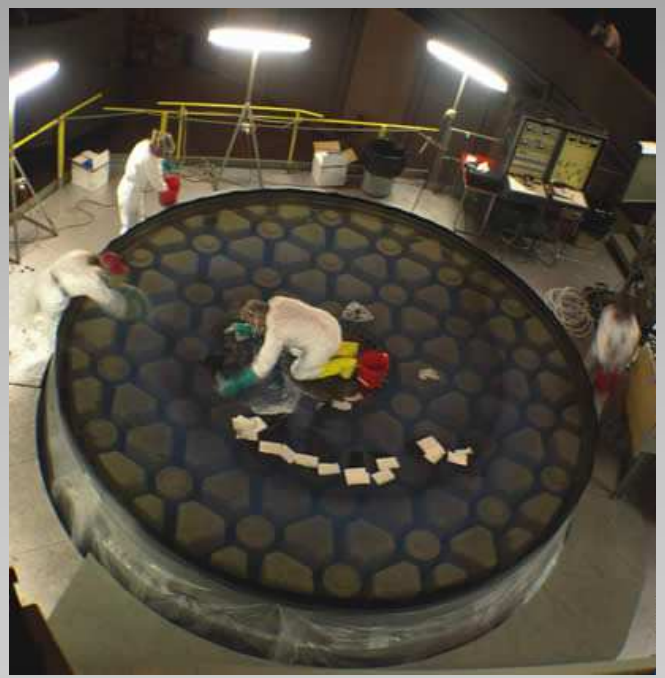


- **Process of grinding and polishing glass with abrasives**
  - **Causes micro-fractures in glass and gradual "erosion" of material**
  - **Eventually surface is smooth and shape approximates ideal (e.g. parabolic or hyperbolic) to within fractions of a wavelength of light**
  - **Typically λ /10 to λ/30, i.e. to ~ 20 nm**
  - **Time consuming process**



Telescope Mirrors

- **Originally mirrors had to be made *thick* in order for them not to sag**
  - **Thickness-to-diameter ratio of typically 1:6**
  - **Mirrors relatively heavy**
    - » **Hale telescope mirror weighs over 20 tons**
  - **Sometimes mirrors were cast with ceramic inserts to decrease the amount of glass**
  - **Mirrors could take literally years to cool after being cast to avoid stresses**

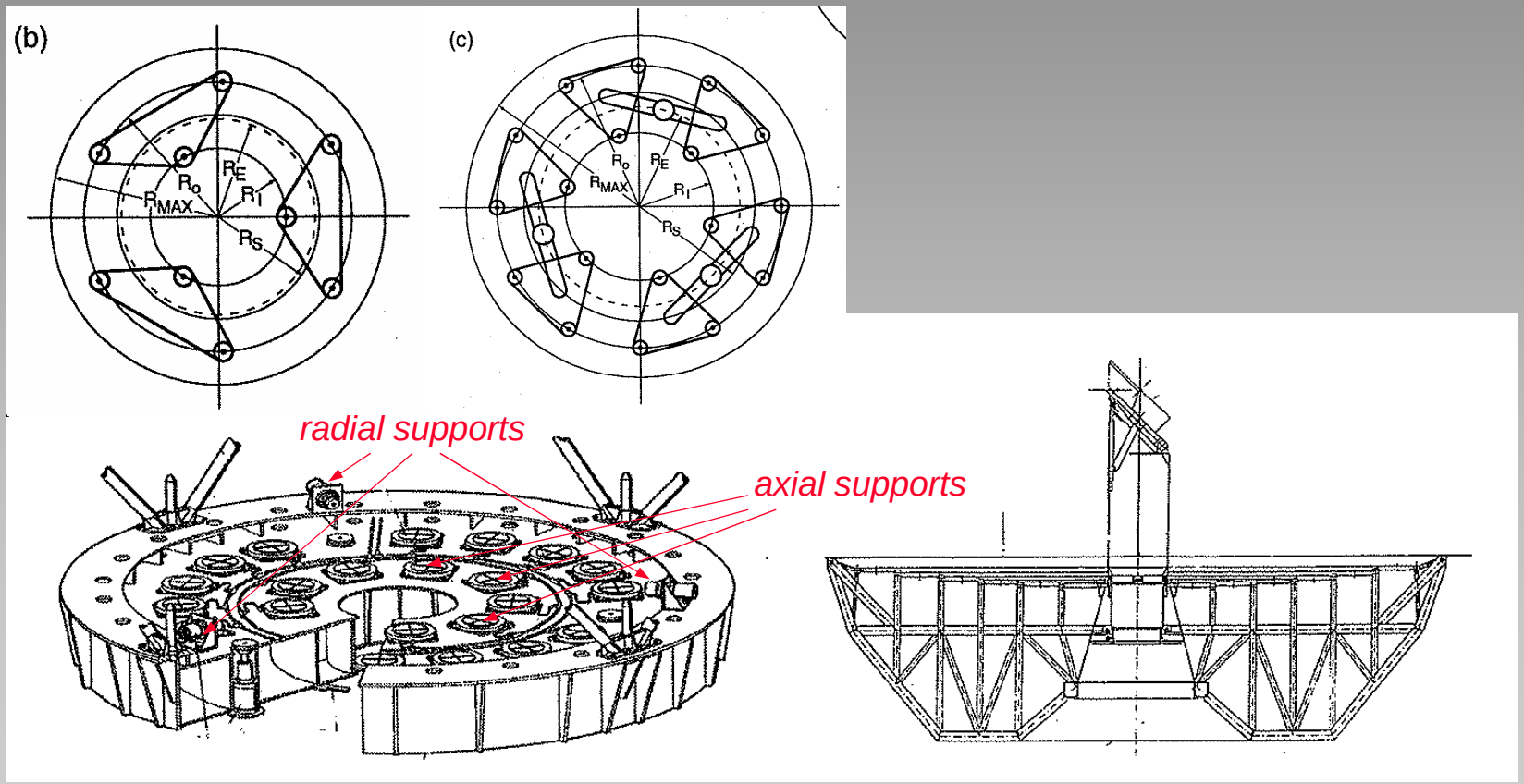


Telescope Mirrors

- Mirrors have to keep their shape
  - » Mirrors held in a “cell” with radial and axial support
  - » System of levers and weights that provide constant force on back and sides of mirror
  - » Used to distribute the weight of the mirror without causing flexure

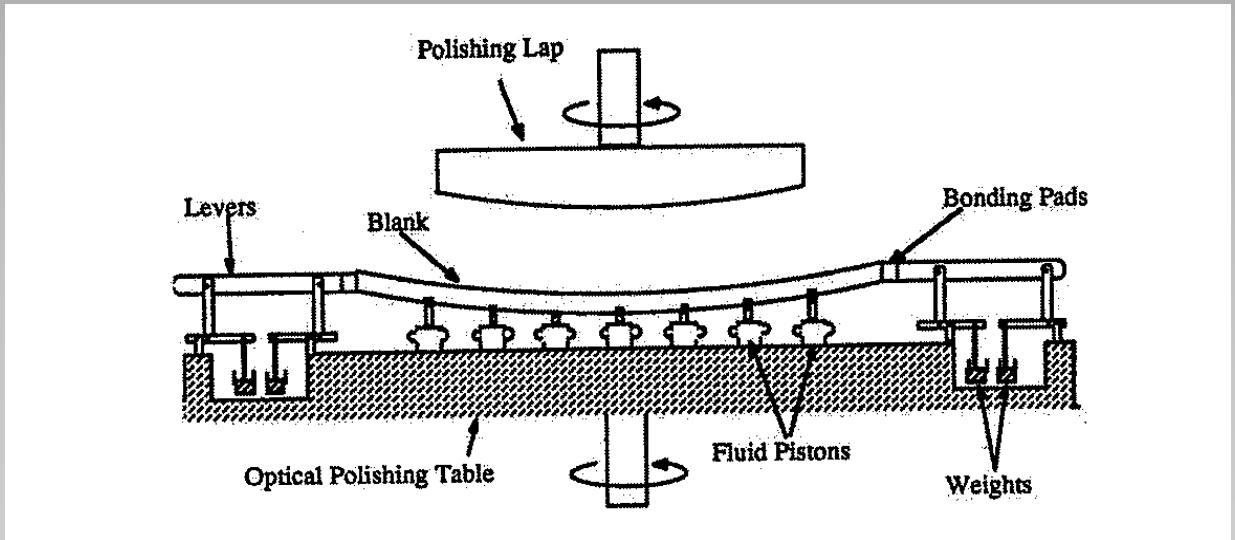
Telescope Mirror Cells

- Mirrors have to keep their shape
  - » Mirror experience varying gravitational force as telescope moves in altitude
  - » Mirror need to be well supported (e.g. multi-point “wiffle tree”)



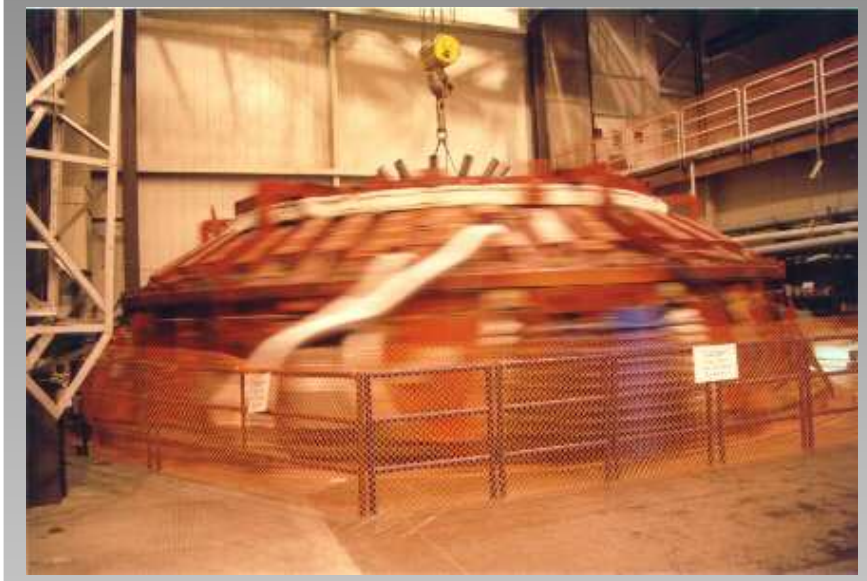
Telescope Mirrors

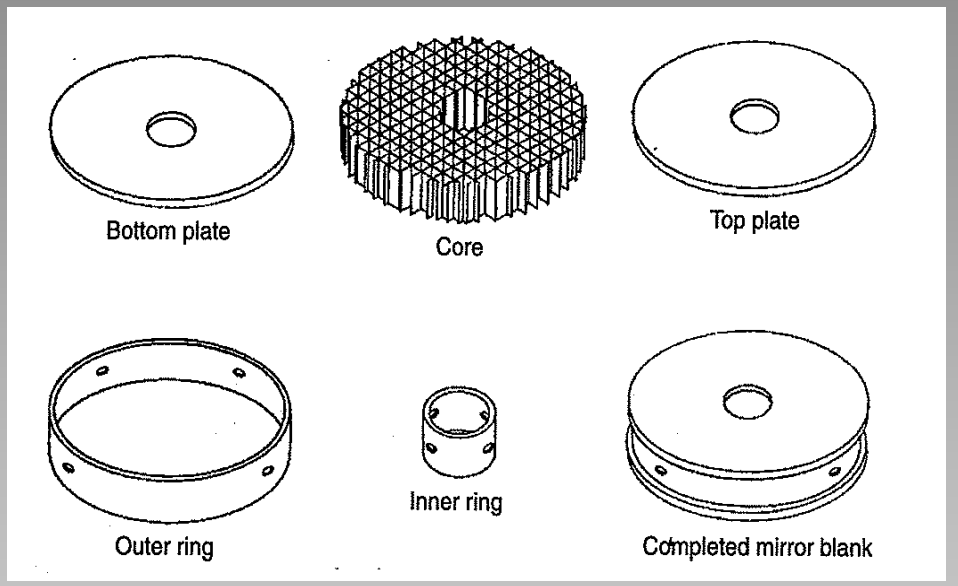
- **New *materials* and *methods* developed for mirrors that minimize temperature effect**
  - **Low expansion glass-ceramic materials (e.g. Cervit, Zerodur, Astro-Sitall)**
  - **Fused silica (e.g. Corning Ultra Low Expansion (ULE) glass)**
  - **"Meniscus" mirrors have been produced for many of the major 8-m class telescopes**
    - » **Thickness-to-diameter ratio is 1:47 (cf. 1:6 for thick mirrors)**



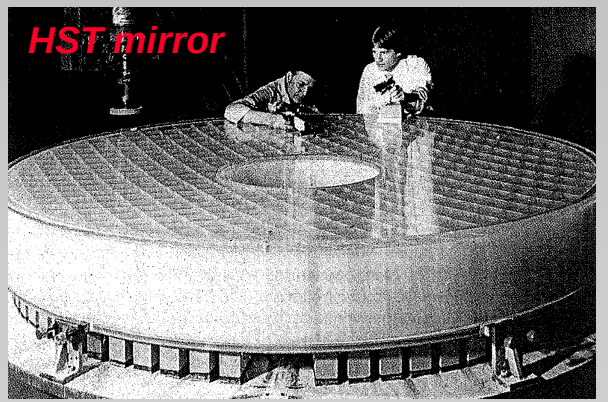
Telescope Mirrors

- Light-weighted mirrors
  - » Caste into “honeycomb” structures or water jet cutting
  - » Air gaps allow good ventilation and temperature equilization





- Spin-casting mirrors in rotating furnace
  - » Parabolic surface
  - » Cheaper material (Pyrex)



Optical/IR Observational Astronomy

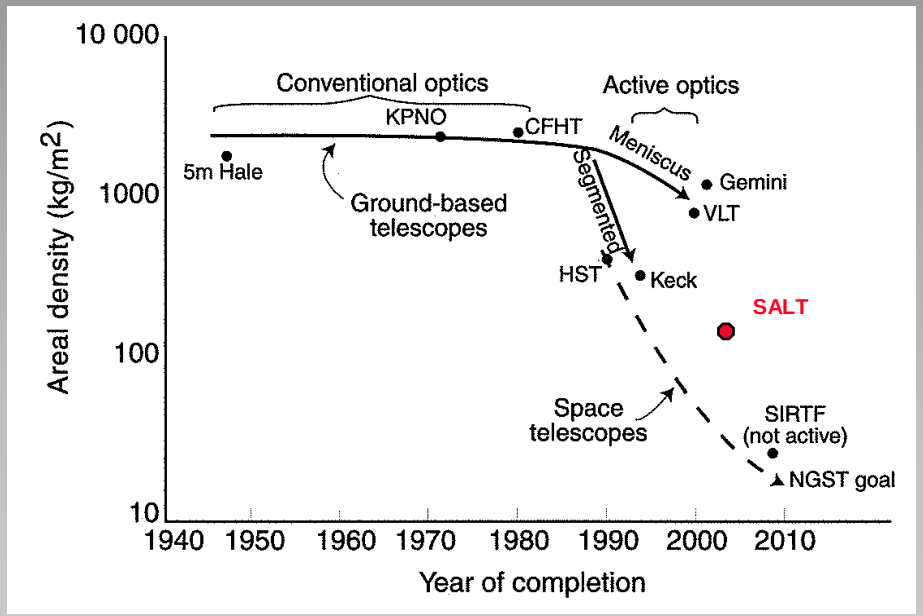
Telescopes II: Mirrors, Mounts & Enclosures

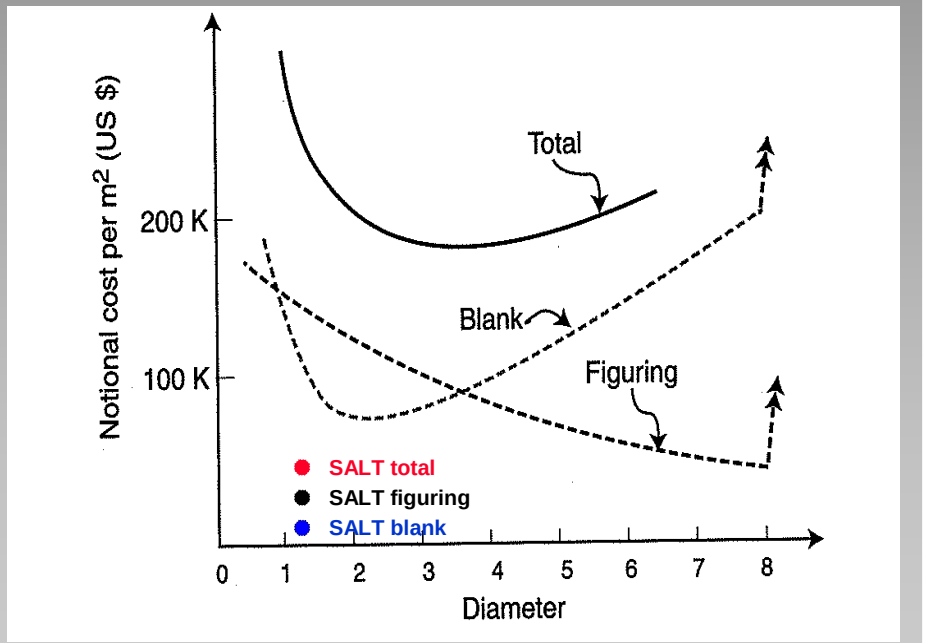
New innovations in telescope mirrors

- **Meniscus mirrors**
- **Spun-cast mirrors**
- **Segmented mirrors**

Mirror Costs

- **New technologies developed in the 1980s to allow *thinner* mirrors to be made**
  - ***Less material, so cheaper and quicker to make***
  - ***But more sophisticated support mechanisms required***

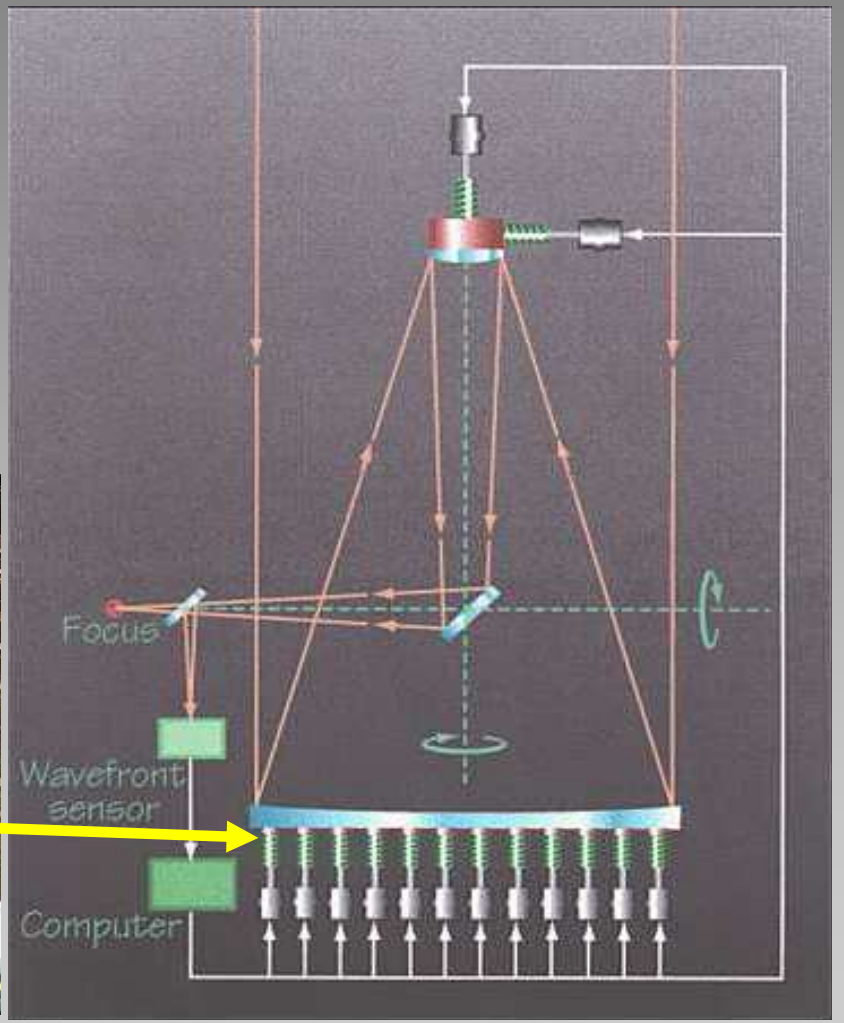




Supporting Thin Mirrors

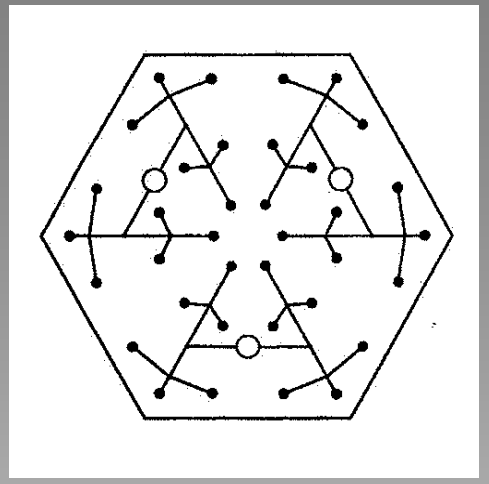
Thin mirrors bend due to *gravity* and *temperature*:

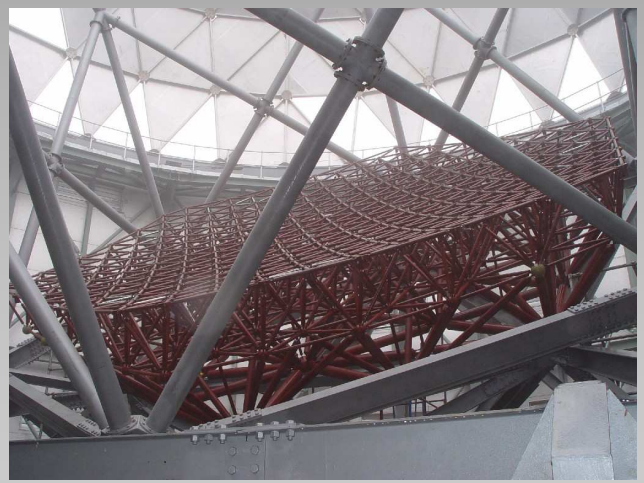
- **Correct with *active optics***
- **Allows distortions to be removed locally on surface**
- **Uses push-pull *actuators***
- **Correction done dynamically using**

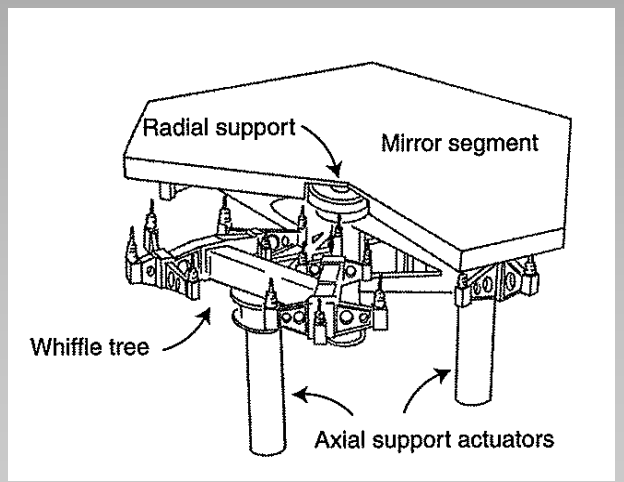


Supporting Segmented Mirrors

- Each mirror segment is supported independently
- "Wiffle tree" distributes weight equally
- 3 actuators are used to ***tip, tilt & piston*** mirrors to align
- If pistoning is done to accuracy of $n\lambda/4$ mirror can be ***phased*** (e.g. Keck telescope)
  - Acts like a single surface, so resolution is $1.44\lambda/D$ (rads)

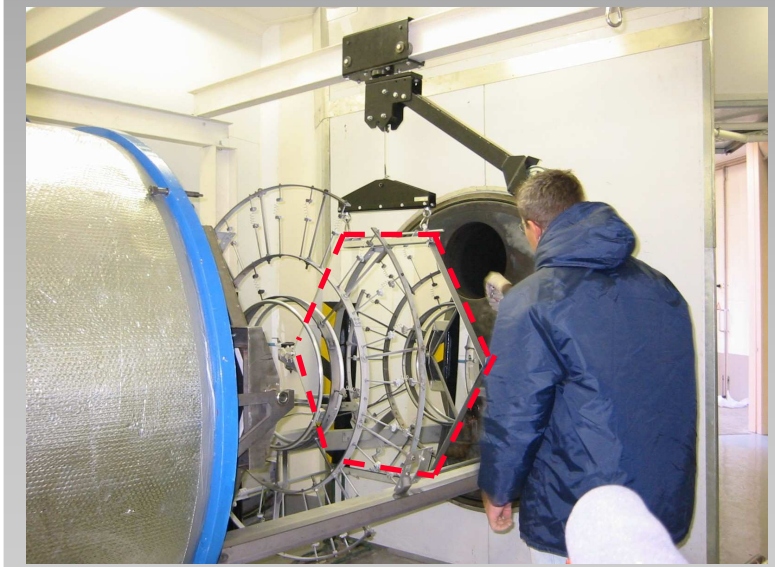


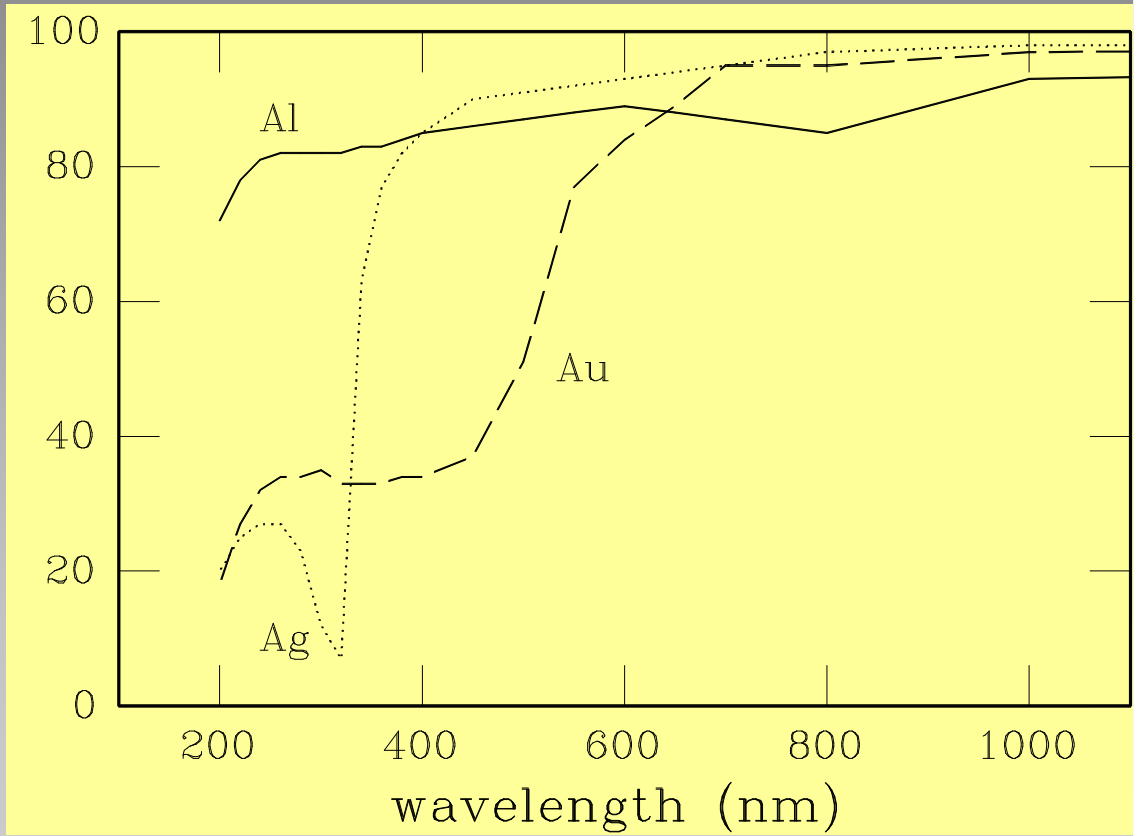




Mirror Coatings

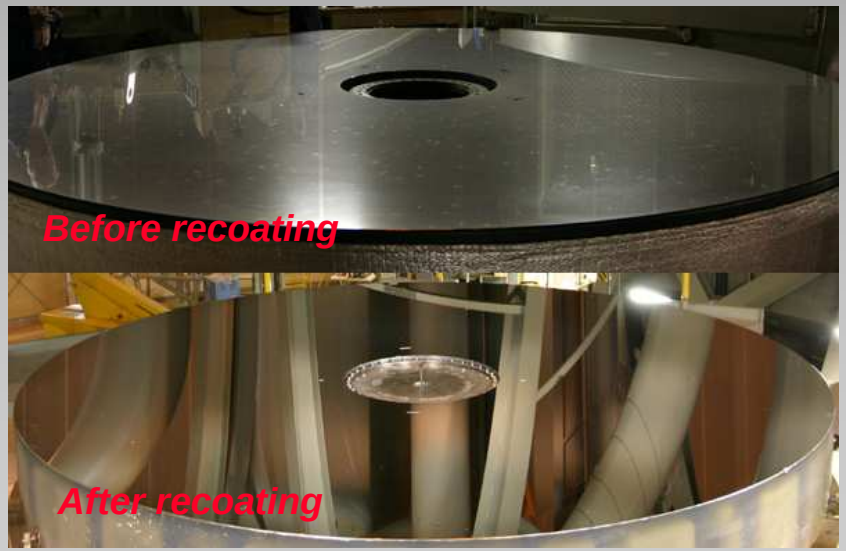
- **Mirrors have to be coated with reflective metal**
  - **Silver (better in red), Aluminium (better in blue), Gold (better in IR)**
  - **Vacuum deposition**
    - » **Evaporation**
    - » **Ion or e-beam deposition**
    - » **Sputtering**
    - » **Thickness ~100-200nm**





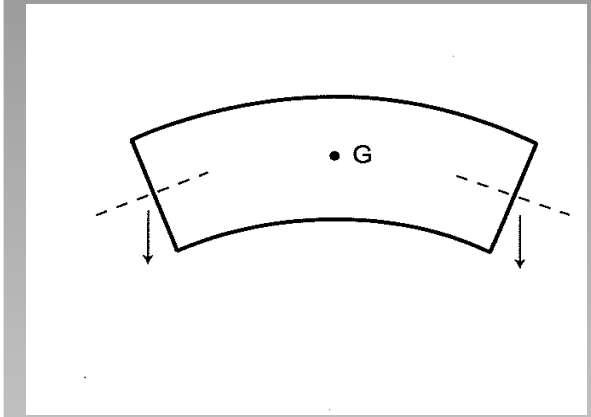
Mirror Coatings

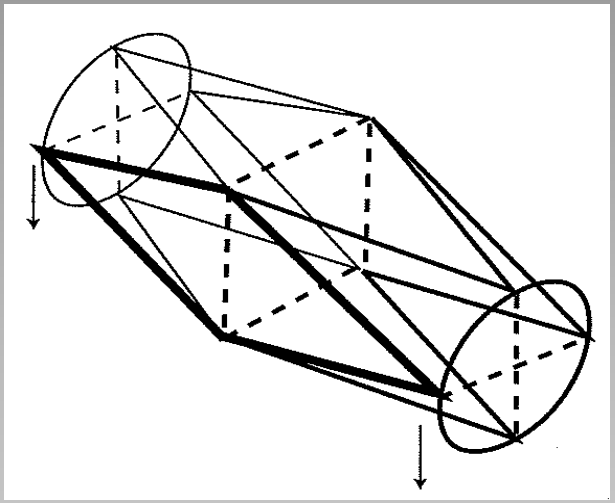
- Mirrors typically need to be recoated every 1-2 years
  - Can be big job for large mirrors
  - Some 8-m mirrors are coated in-site with Bell jar type tank
- Cleaning is also done more frequently to remove dust
  - CO_2 "snow" blows of dust without damaging coating
  - Sometime wet clean with detergents too

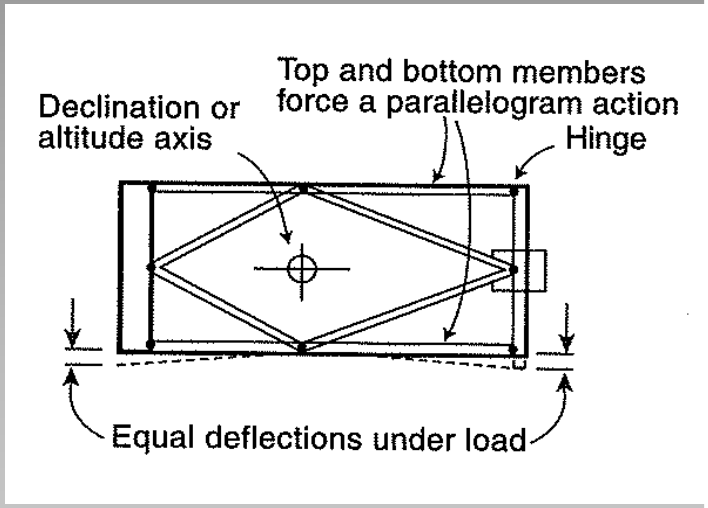


Telescope Tubes & Mounts

- Telescopes have to support mirrors and keep them aligned
  - "Tubes" keep mirrors & instruments co-aligned through varying gravity
  - Serrurier truss keeps primary and secondary mirrors co-aligned
    - » *Relative* movement between mirror eliminated







- Telescopes need to follow objects across the sky due to Earth's rotation

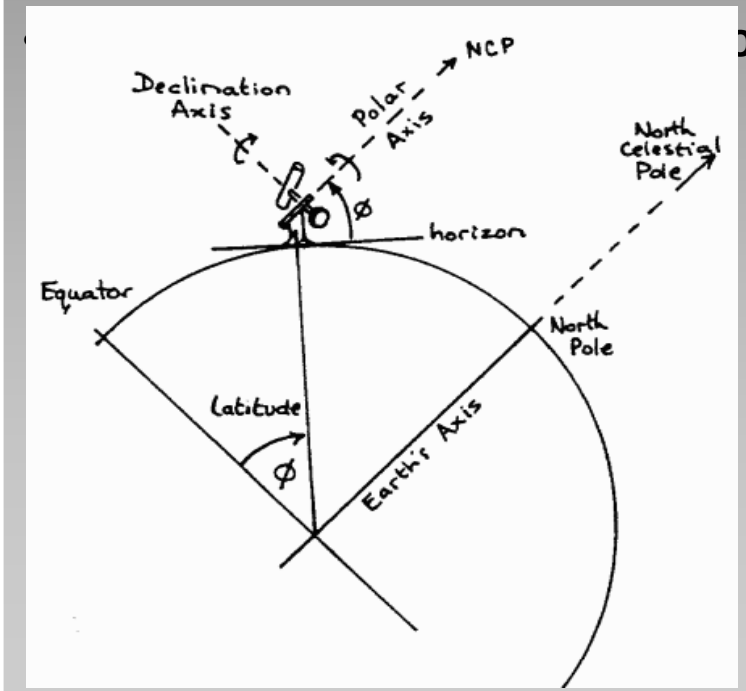
Telescope Tubes & Mounts

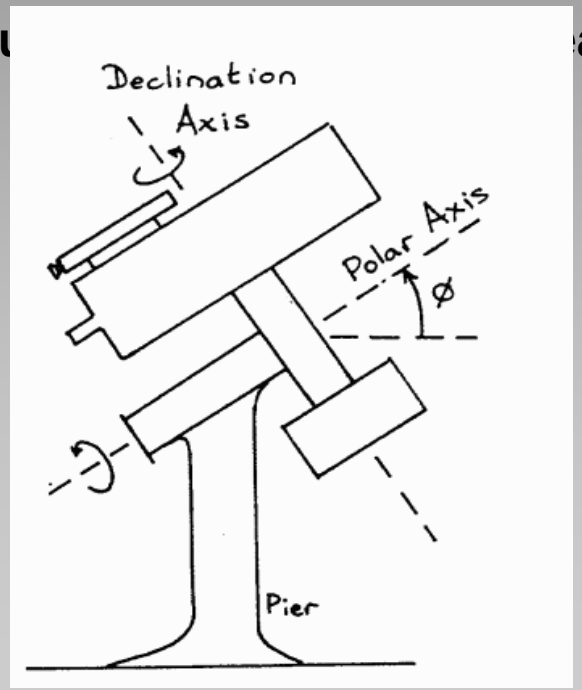
Telescopes need to follow objects across the sky due to Earth's rotation

How?

1. Equatorial Mount

- **Simplest & easiest method for tracking (used in all major telescopes pre-1980s)**
- **Telescope rotation axis (polar axis) is parallel to Earth's rotation axis**





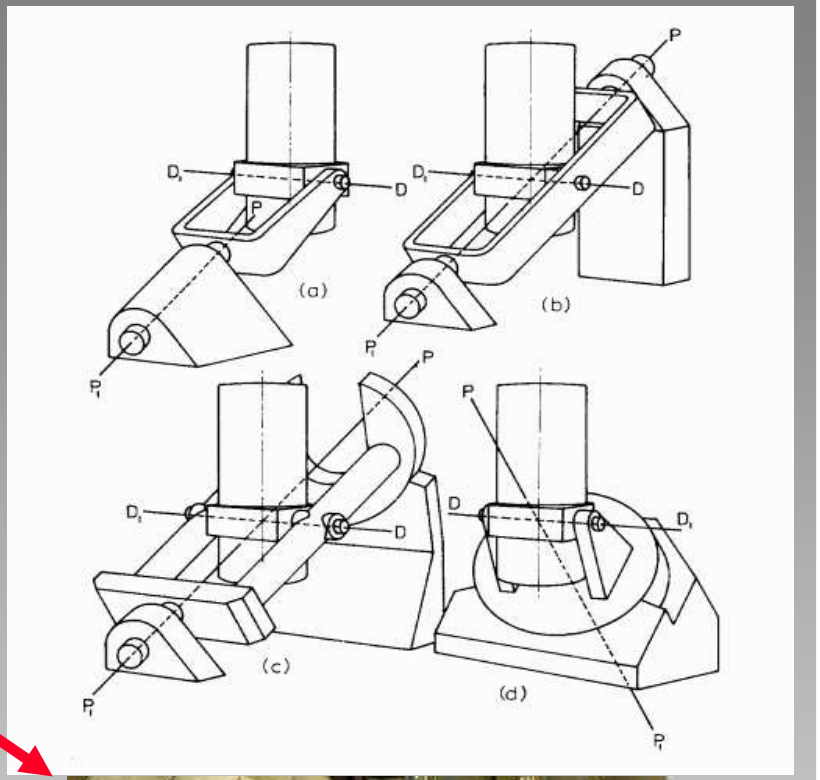
Optical/IR Observational Astronomy

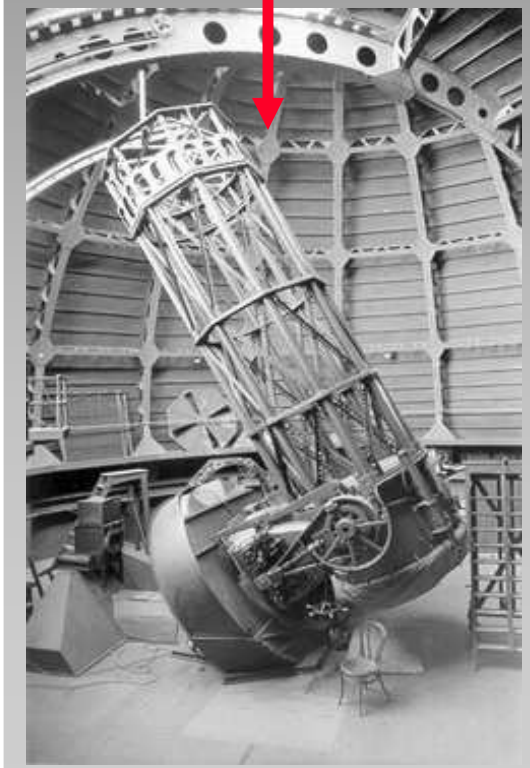
Telescopes II: Mirrors, Mounts & Enclosures

Telescope Tubes & Mounts

Different Equatorial Mounts

- Fork (a)
- Yoke (b)
- Horseshoe (c)
- Polar disc (d)





Telescope Tubes & Mounts

Different Equatorial Mounts

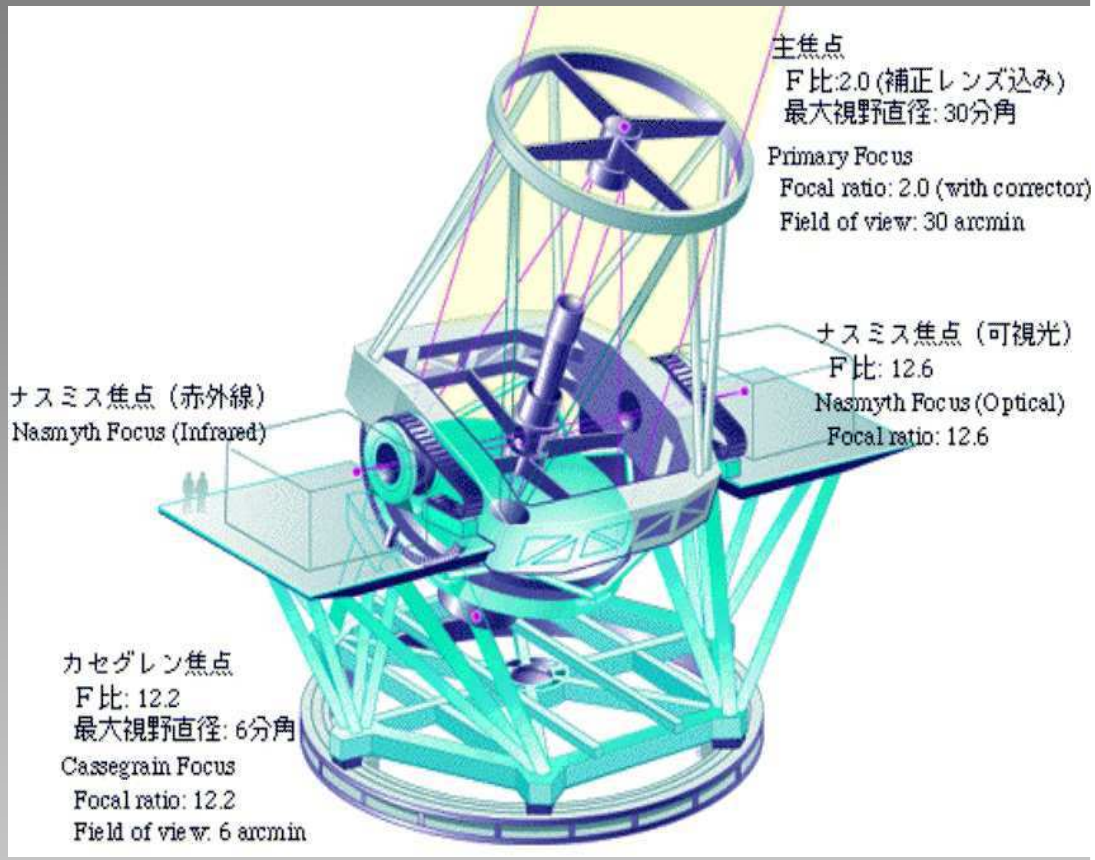
- English mount
- German mount
- Horseshoe mount

Telescope Mounts

2. Alt-Az Mounts

- Two axes are Altitude & Azimuth
- Mechanically easier to build
- More complex to track
  - Both axes have to move at differing rates
  - Field rotates, so instruments or images de-rotate

6-m BTA: first big AltAz telescope (1978)

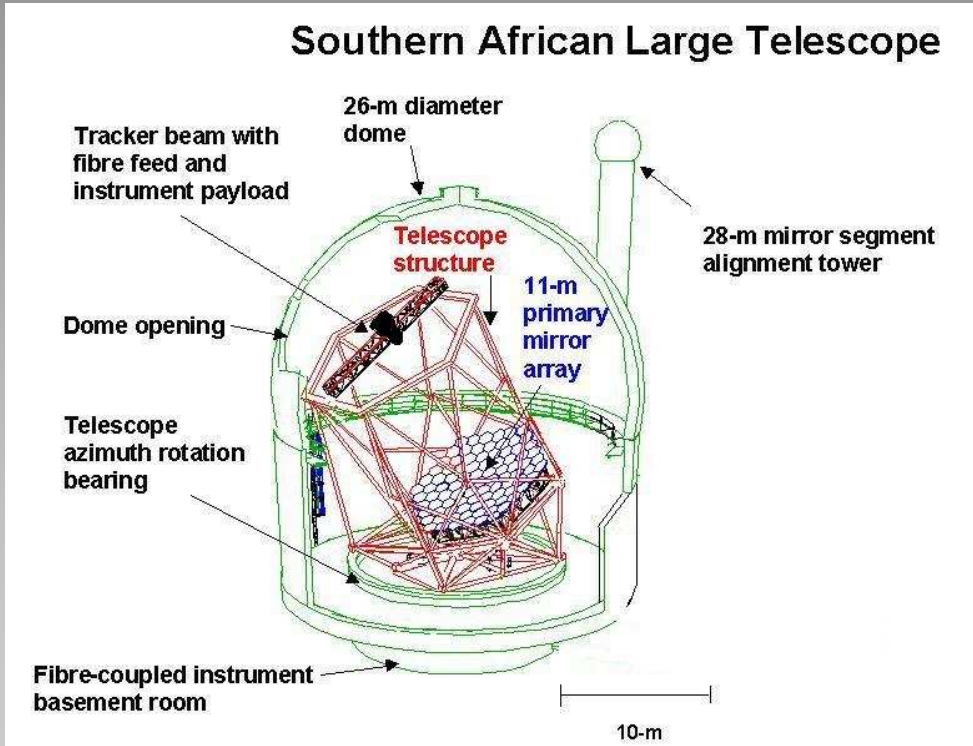


8.3-m Subaru telescope (2000)

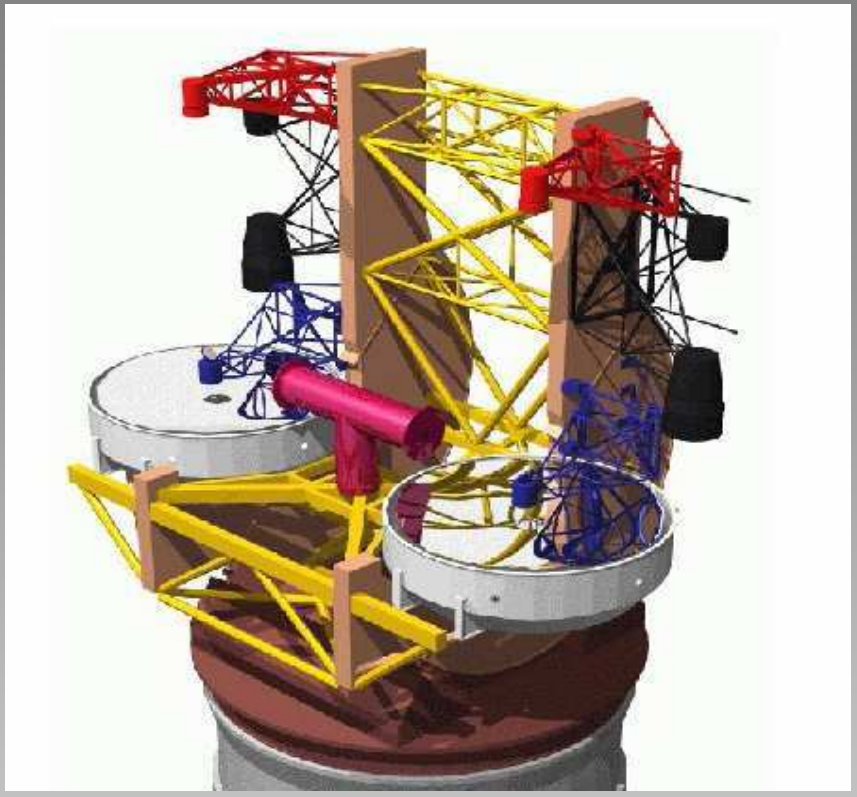
Novel Telescope Mounts

New types of Alt-Az mounts

- **Large Binocular Telescope (LBT)**
- **SALT & HET**



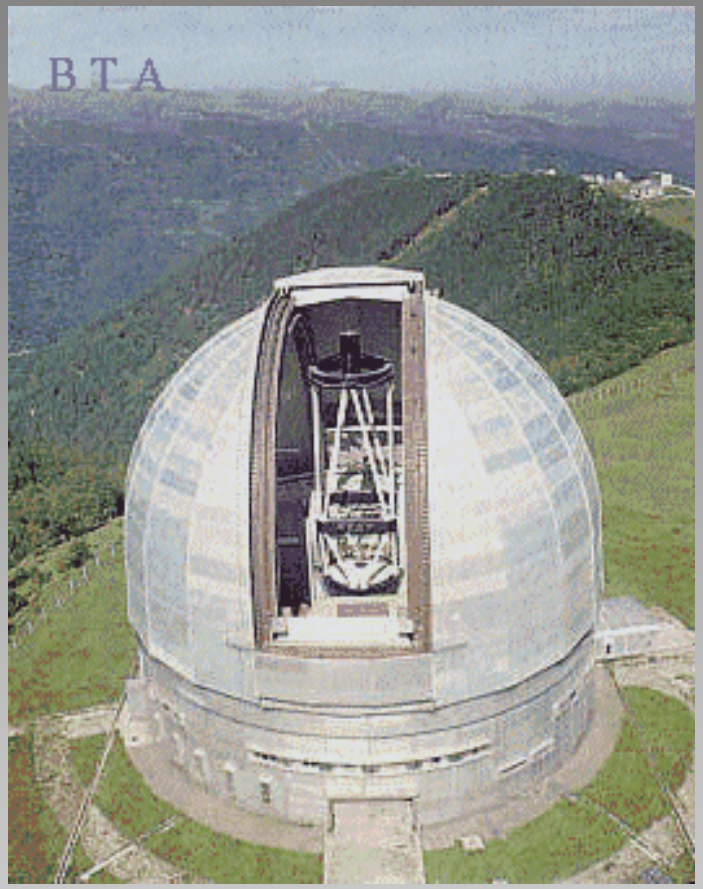
SALT (2005)



Twin 8.4-m LBT (2006)

Telescope Enclosures

- Weather proof building design to protect telescope
- Domes or turrets with openings (shutters) protect the telescope from wind shake
- Designed to produce smooth non-turbulent airflow over building
- Buildings designed to avoid solar heating
  - Painted with white TiO paint or use of reflective louvres

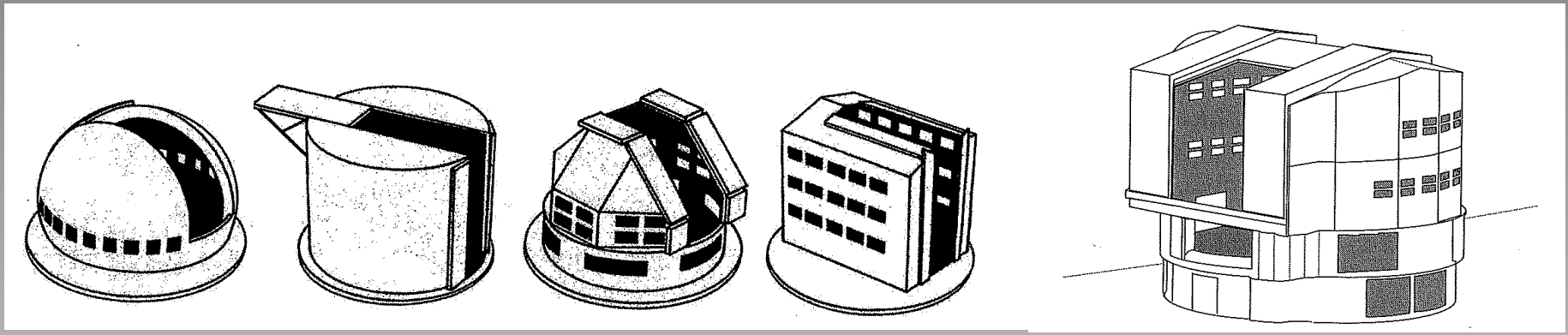


Optical/IR Observational Astronomy

Telescopes II: Mirrors, Mounts & Enclosures

Telescope Enclosures

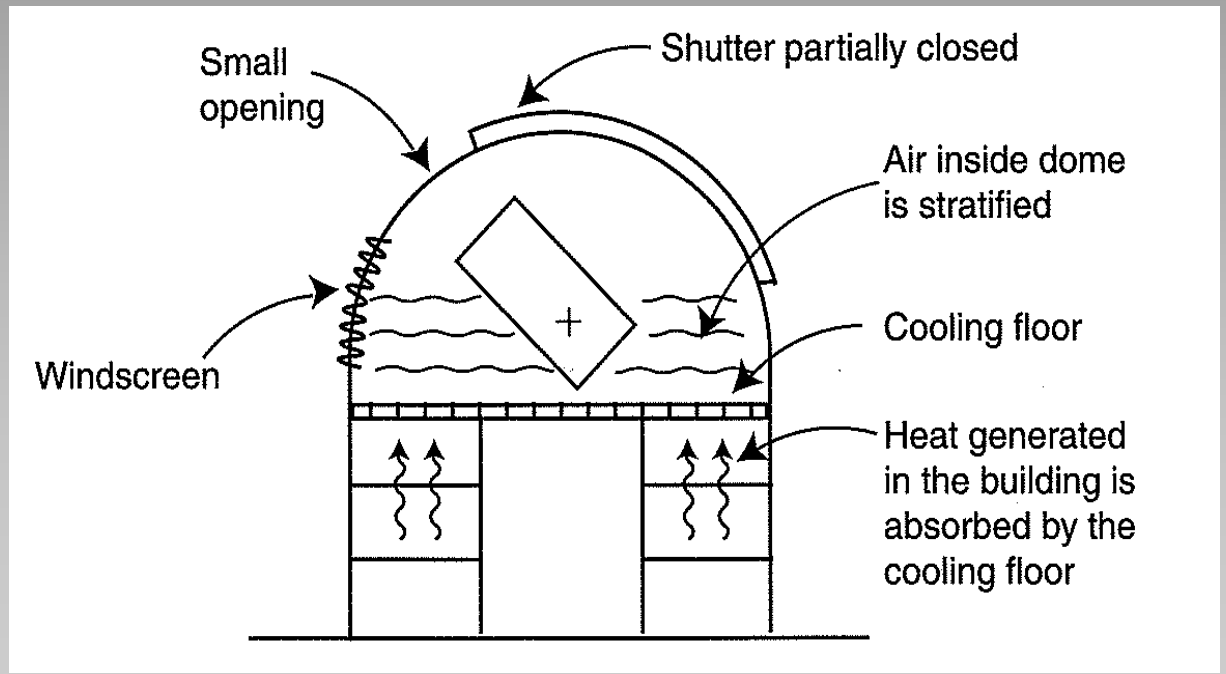
- Evolved from simple domes (minimum volume for a telescope) to turrets with better ventilation properties



- Some smaller telescope have enclosures that fold away so telescope is in “free air”, but need to protect against wind shake

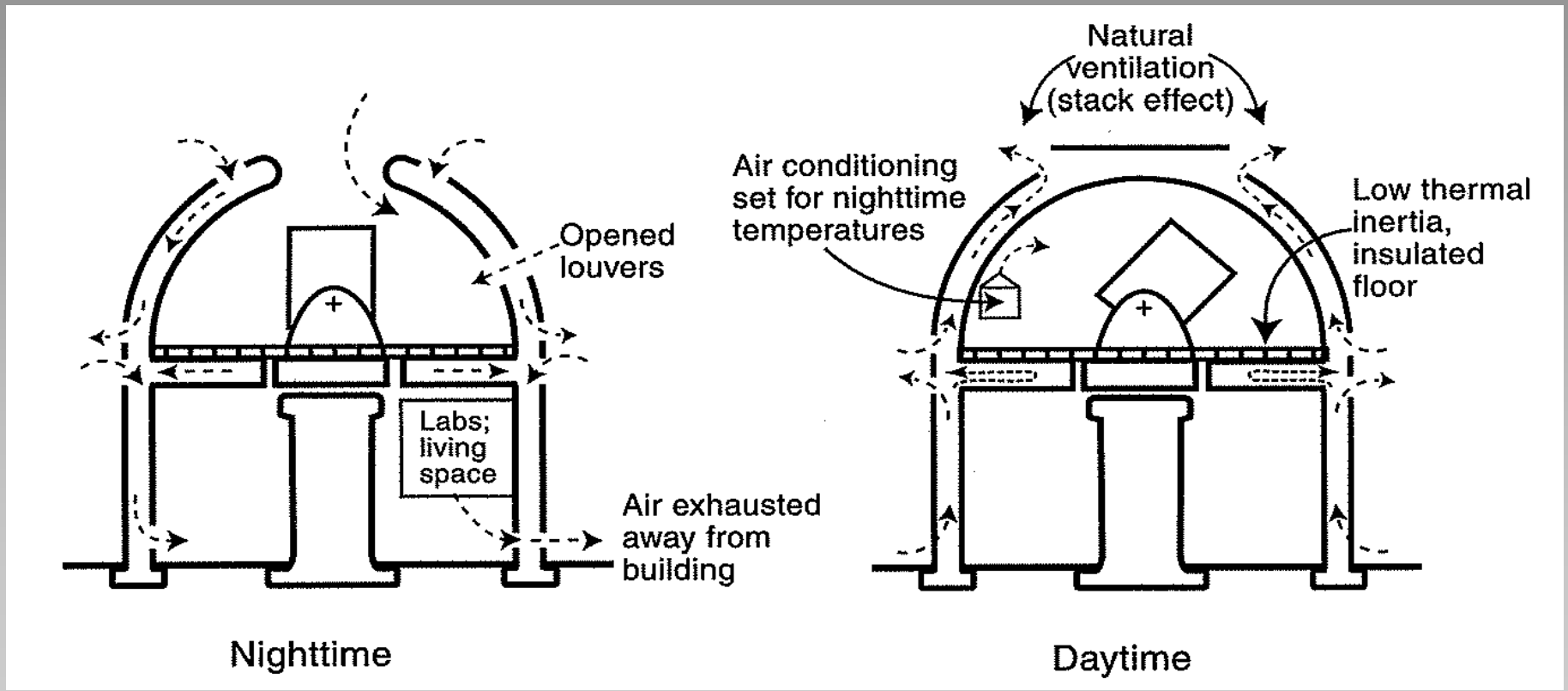
Telescope Enclosures

- Telescope buildings were often poorly designed
  - Prior to 1980s, telescope buildings were designed with lots of heated offices, work areas, libraries, etc.
  - Heat from these rose up and caused air around telescope to be warmed leading to turbulence and bad 'dome seeing', degrading image quality
  - Mitigated by ventilating dome (louvres and fans)

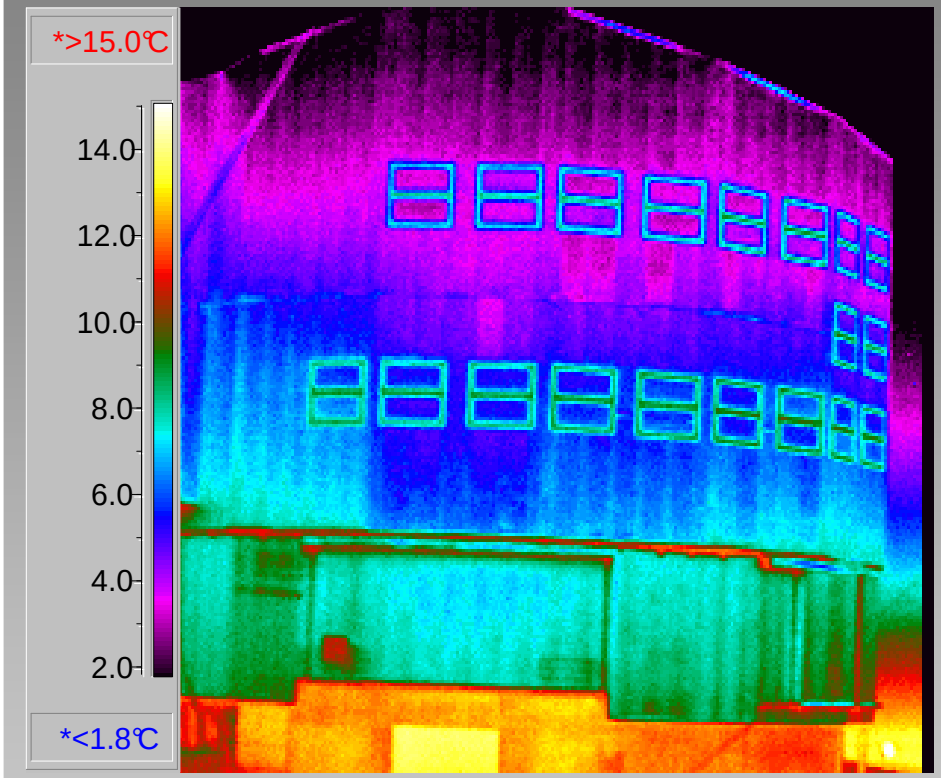


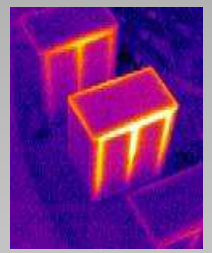
Telescope Enclosures

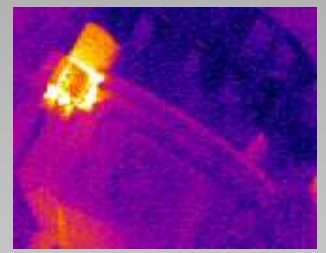
- Buildings have evolved to be less heat emitting
- New telescopes now have less office space and have ventilated voids under floors to remove hot air



Thermal Effects







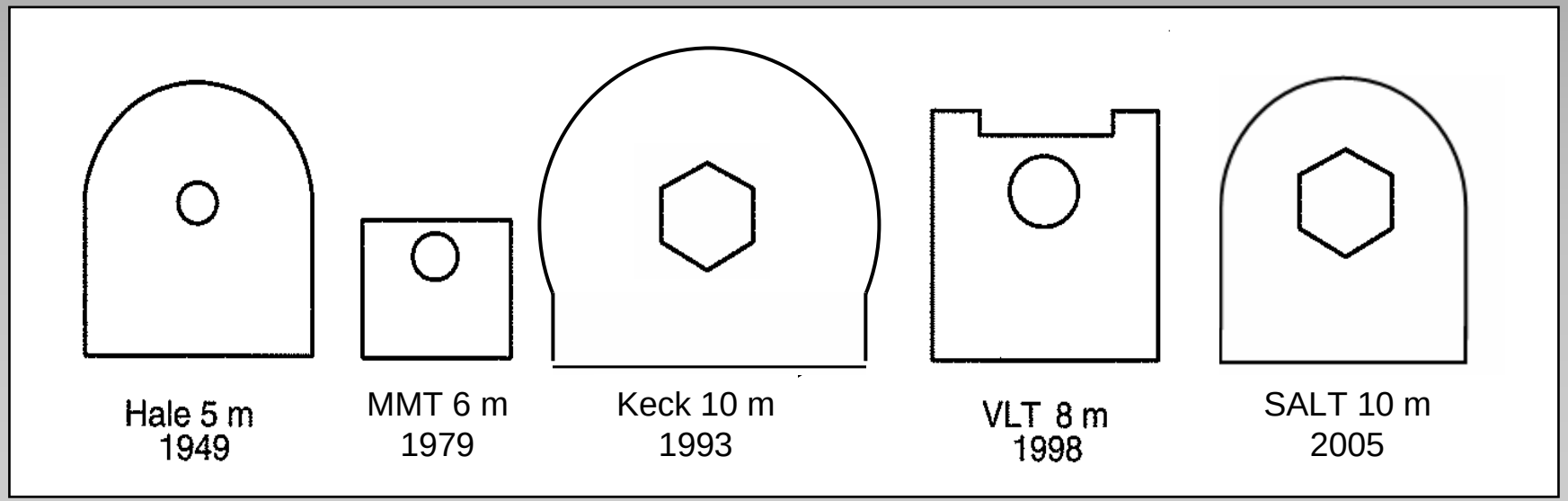
VLT UT3 Enclosure

- **19 Feb. 1999, 00h34 Local Time**
- **Need to balance heating & cooling**
- **Avoid thermally driven air currents**

Thermal images of SALT

Mirror / Enclosure Sizes

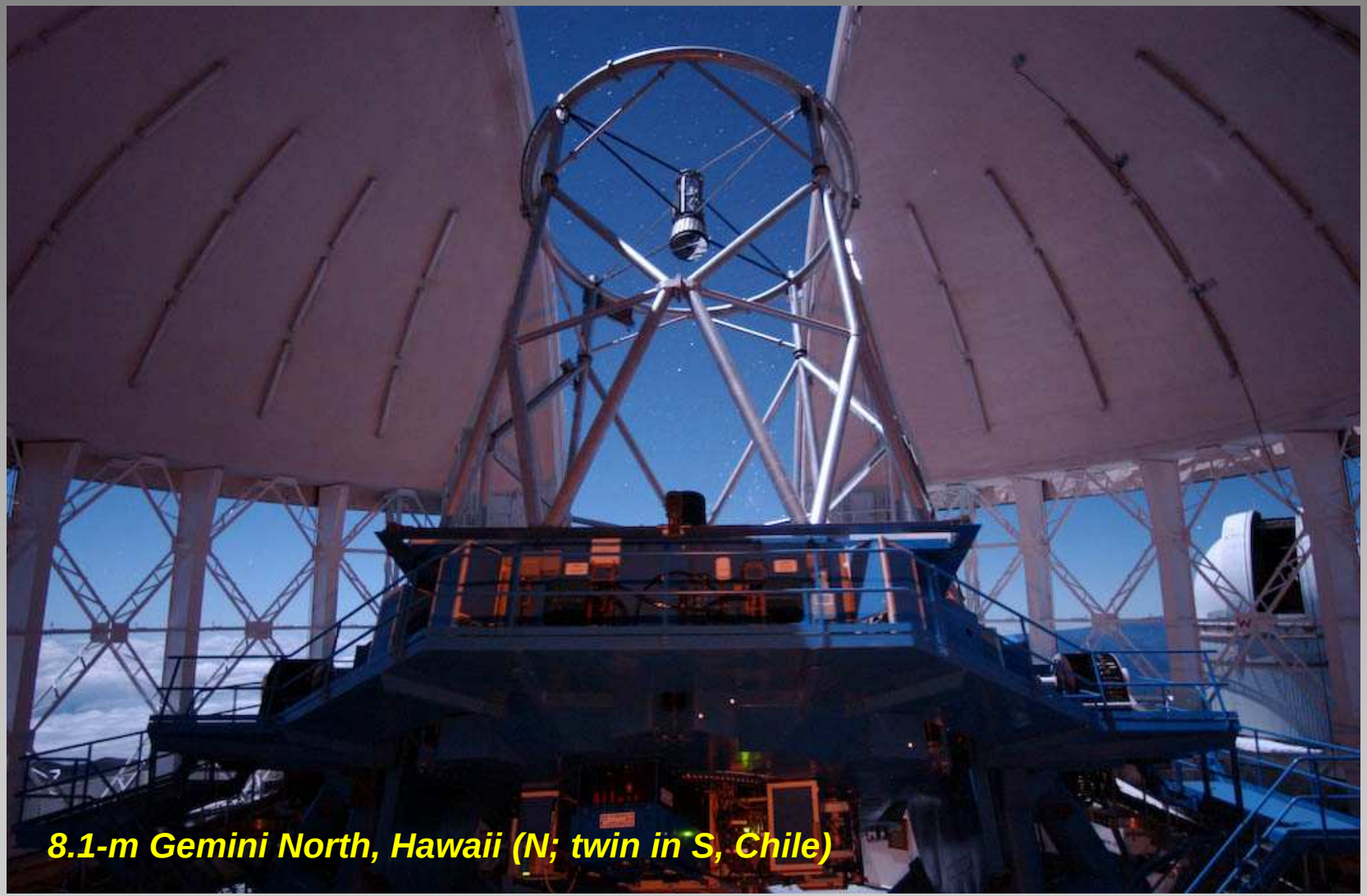
- **Ratio of building size to mirror diameter has been decreasing with time**
  - **Relative building cost decrease**
  - **Easier & cheaper to air condition and ventilate**



Telescope Enclosures

- Telescope also raised above ground level to be above boundary layer
  - More laminar airflow and better seeing
- New telescope enclosures are as open as possible to promote good ventilation and temperature equilization

Telescopes II: Mirrors, Mounts & Enclosures



8.1-m Gemini North, Hawaii (N; twin in S, Chile)

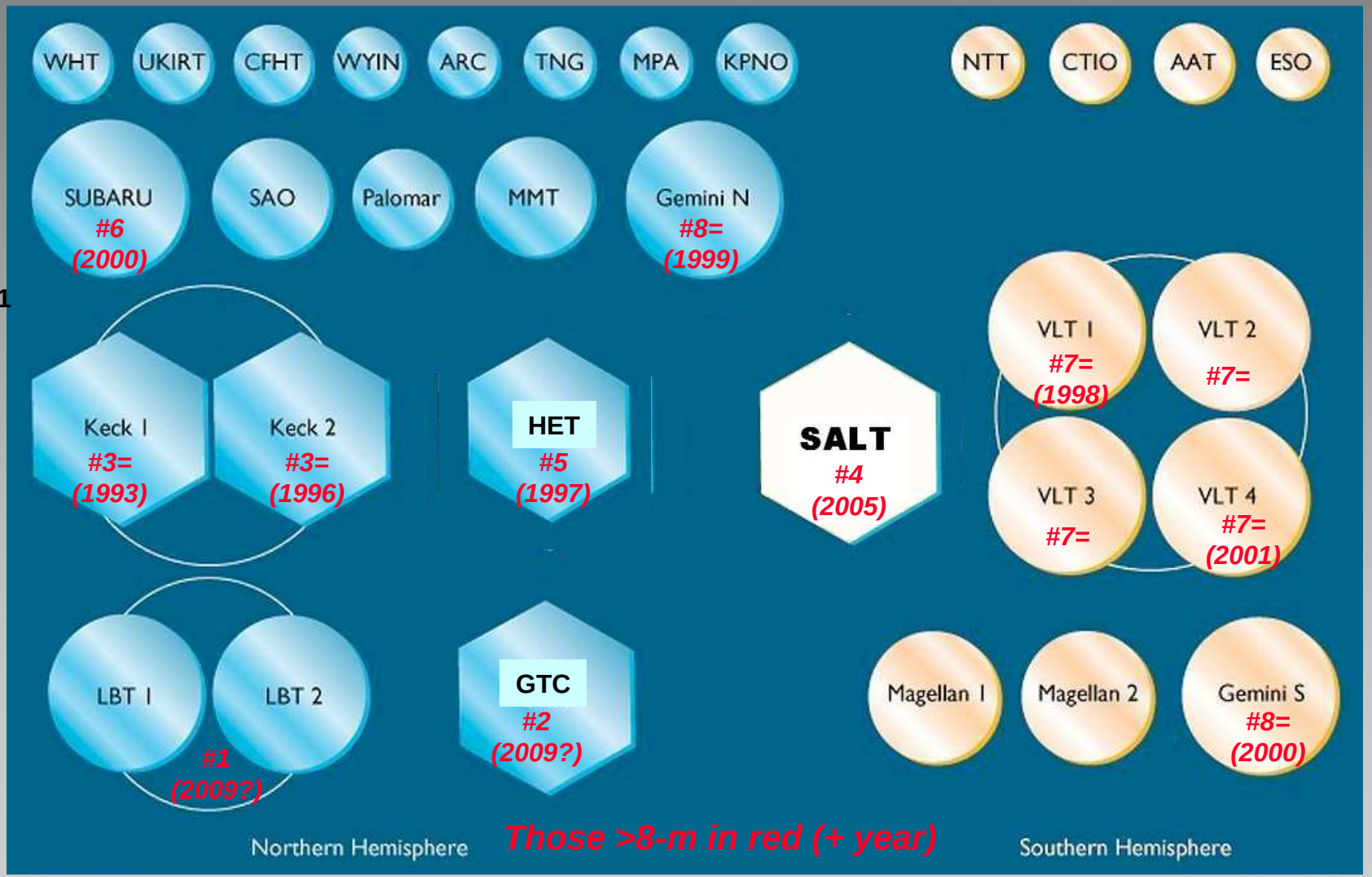
Optical/IR Observational Astronomy

Telescopes II: Mirrors, Mounts & Enclosures

Telescope Mirror Sizes

Rankings:

LBT 2 x 8.4
GTC 10.4
Keck 9.8
SALT 7 - 9.2
HET 7 - 9.0
Subaru 8.3
VLT 4 x 8.2
Gemini 2 x 8.1



The "Big Five": Segmented Mirror Telescopes

- **Keck I (1993) & Keck II (1996):** **Hawaii, USA**
- **HET (1999):** **Texas, USA**
- **SALT (2005):** **South Africa**
- **GRANTECAN (2009:)** **Canary Islands, Spain**

These telescopes have the largest light grasp

Some also use *adaptive optics* to get sharper images, particularly at longer wavelengths (IR)

Optical/IR Observational Astronomy

Telescopes II: Mirrors, Mounts & Enclosures


10.4-m GTC: La Palma (N)

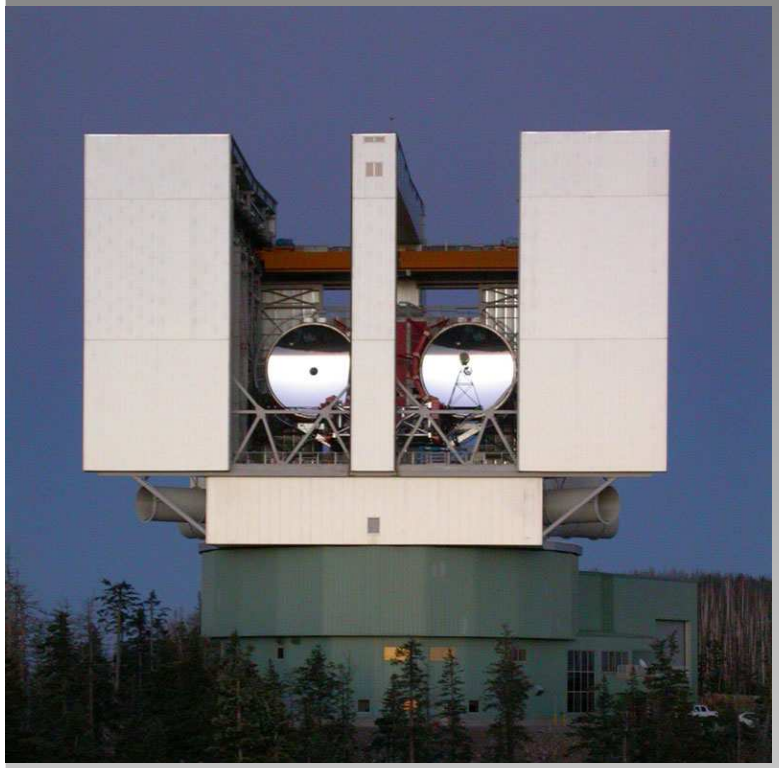
The 10-m Club

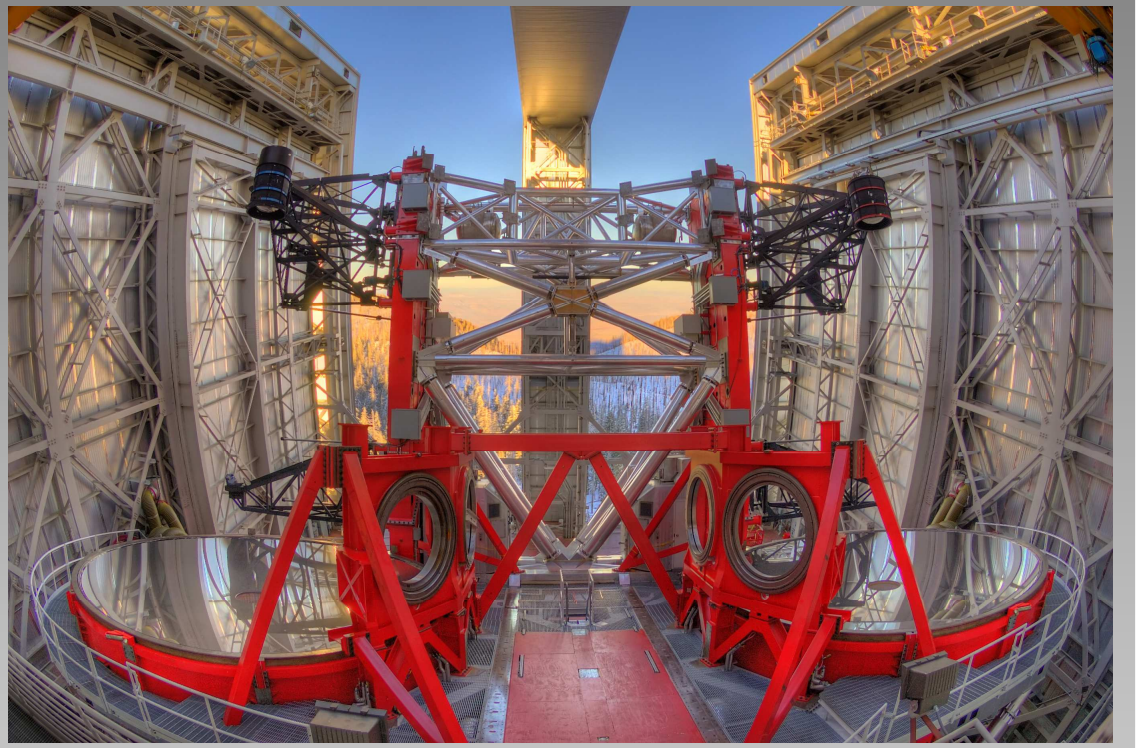

2 x 9.8-m Keck Telescope: Hawaii (N)


9.0-m HET: Texas (N)


9.0-m SALT (S)

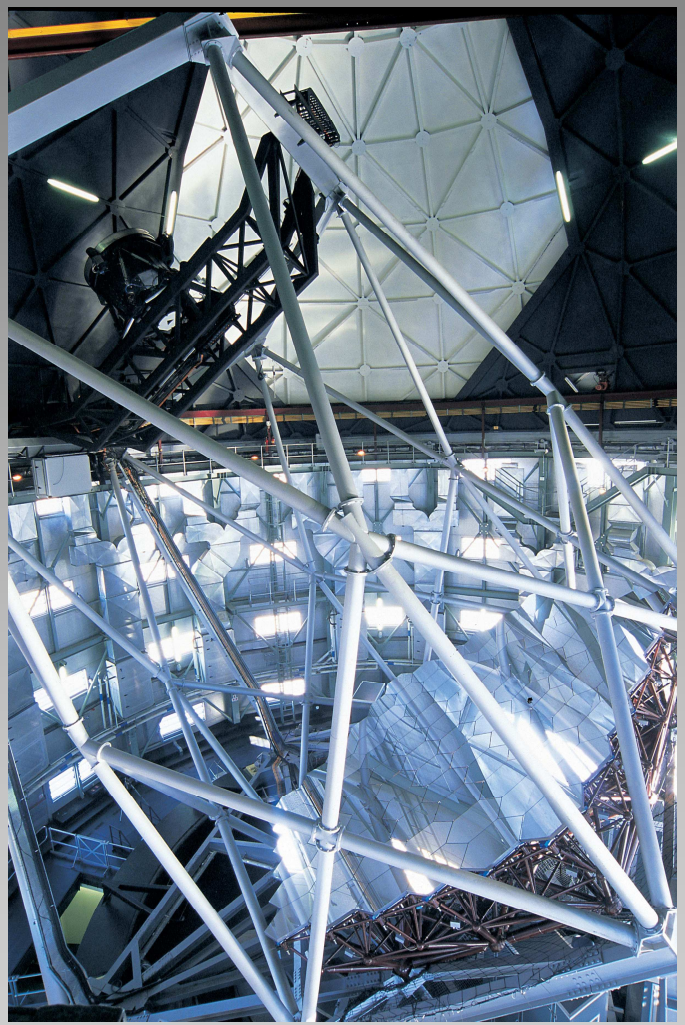
Novel Telescope Mounts

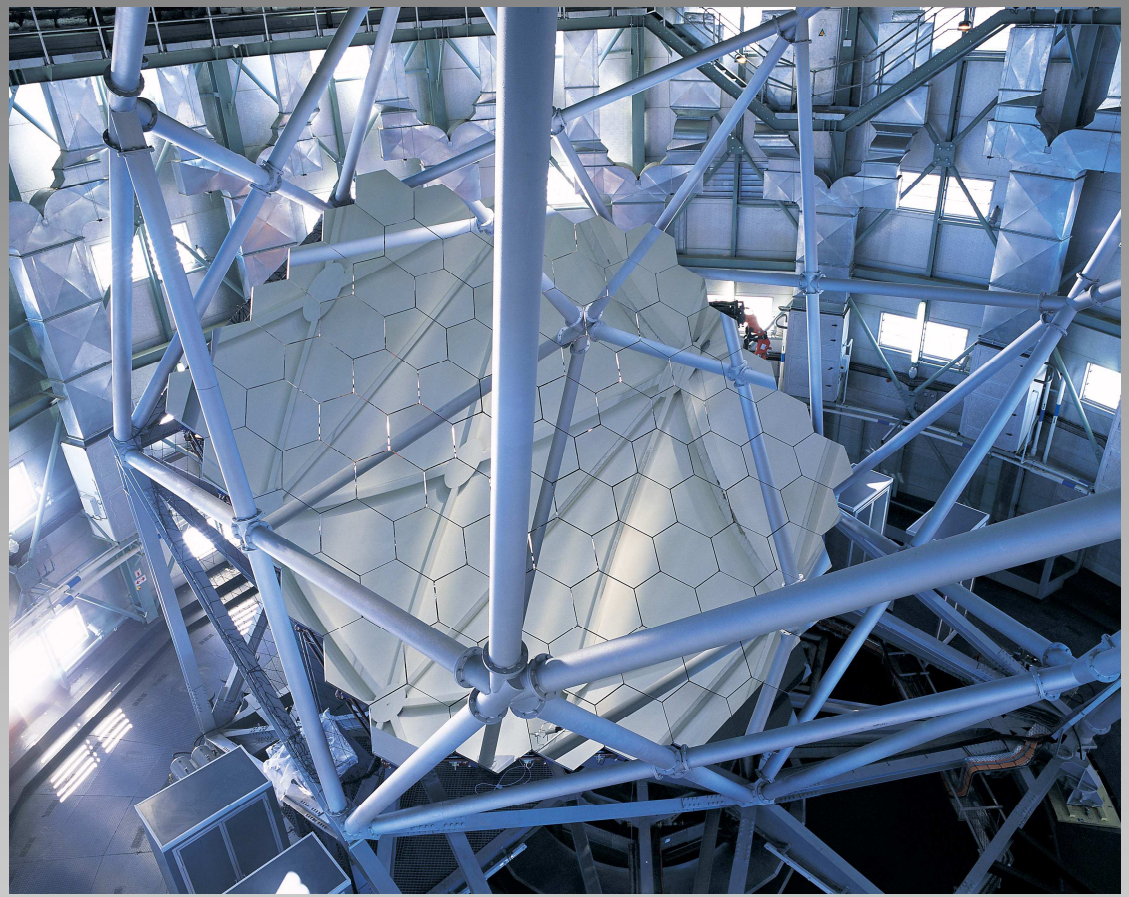




Twin 8.4-m Large Binocular Telescope

Novel Telescope Mounts





10-m Southern African Large Telescope (SALT)

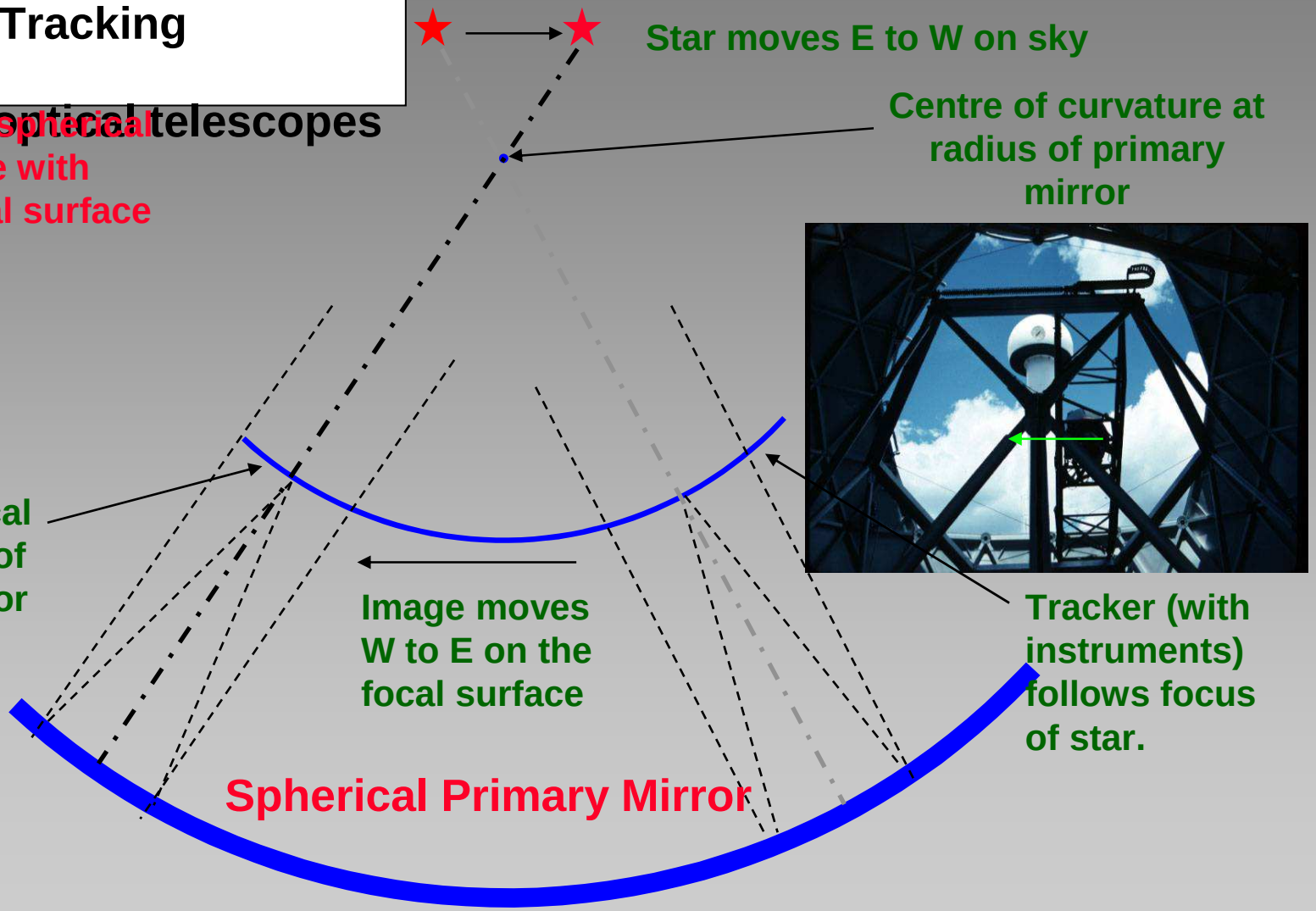
SALT: A 'fixed' Altitude Telescope

SALT is the optical analogue of the (zenith pointed) Arecibo radio telescope, except its tilted to Z.D. = 37°

The Arecibo Tracking Concept:

extended to optical telescopes

Fixed elevation spherical mirror telescope with tracking on focal surface



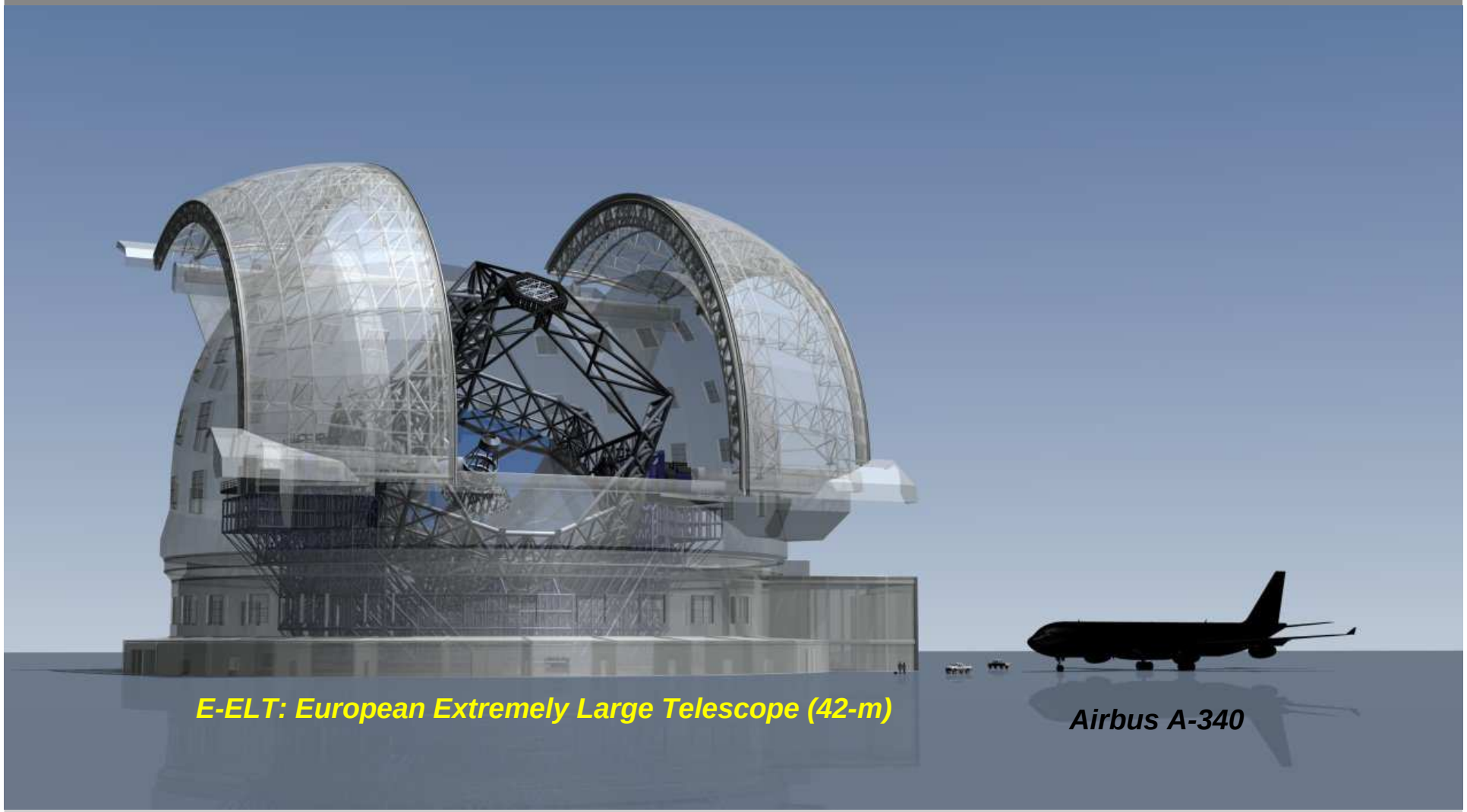
Giants of the Future: Extremely Large Telescopes

The Giant Magellan Telescope (USA/Australia/Korea consortium) [to be built in Chile]

Giants of the Future: Extremely Large Telescopes

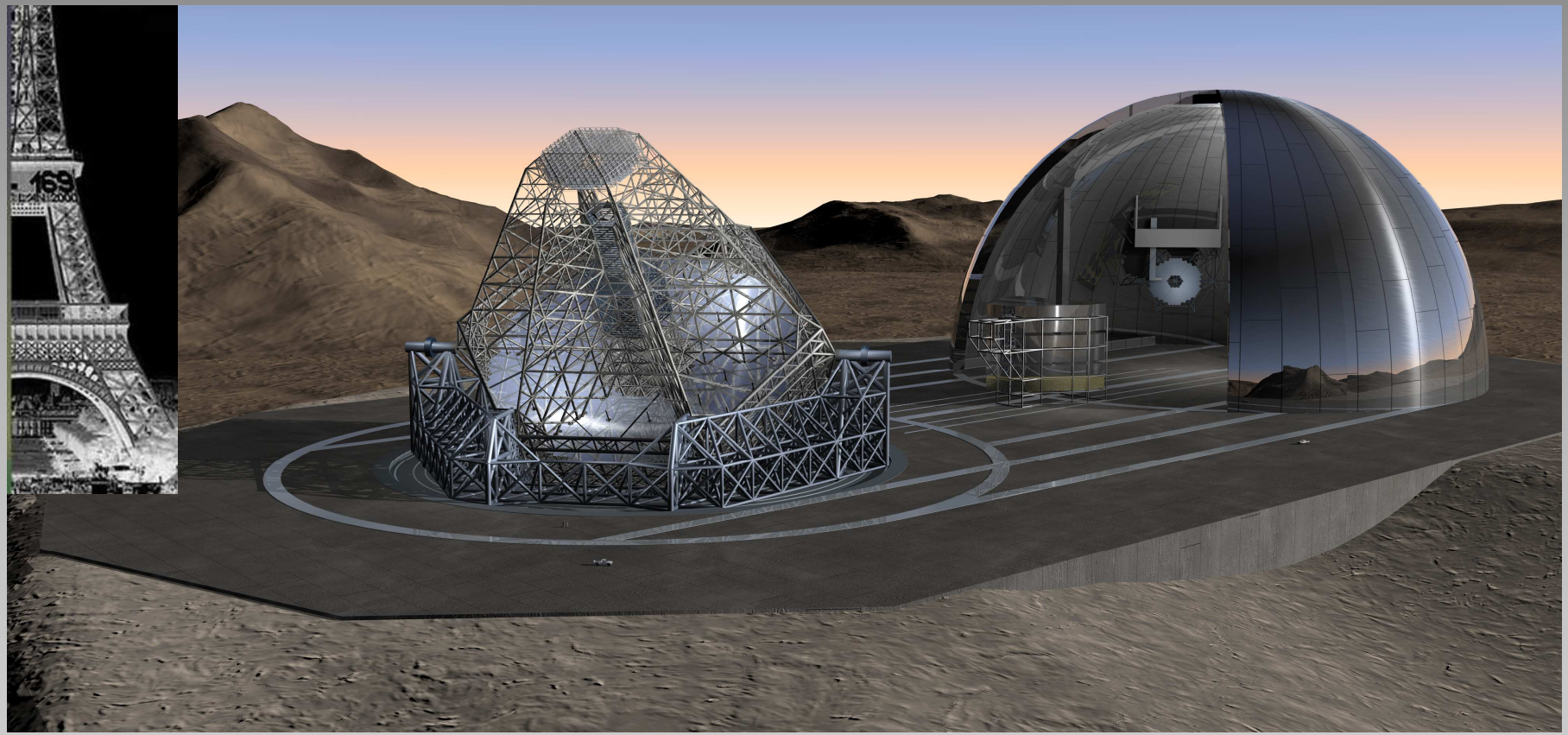
TMT: Thirty Meter Telescope (US-Canada-India) 30-m

Extremely Large Telescopes



The Original European 100-m OWL concept

(Overwhelmingly Large Telescope)



(Also sometime disparagingly called the ULT: Unnecessarily Large Telescope!)