Space Telescopes

Lecture 7

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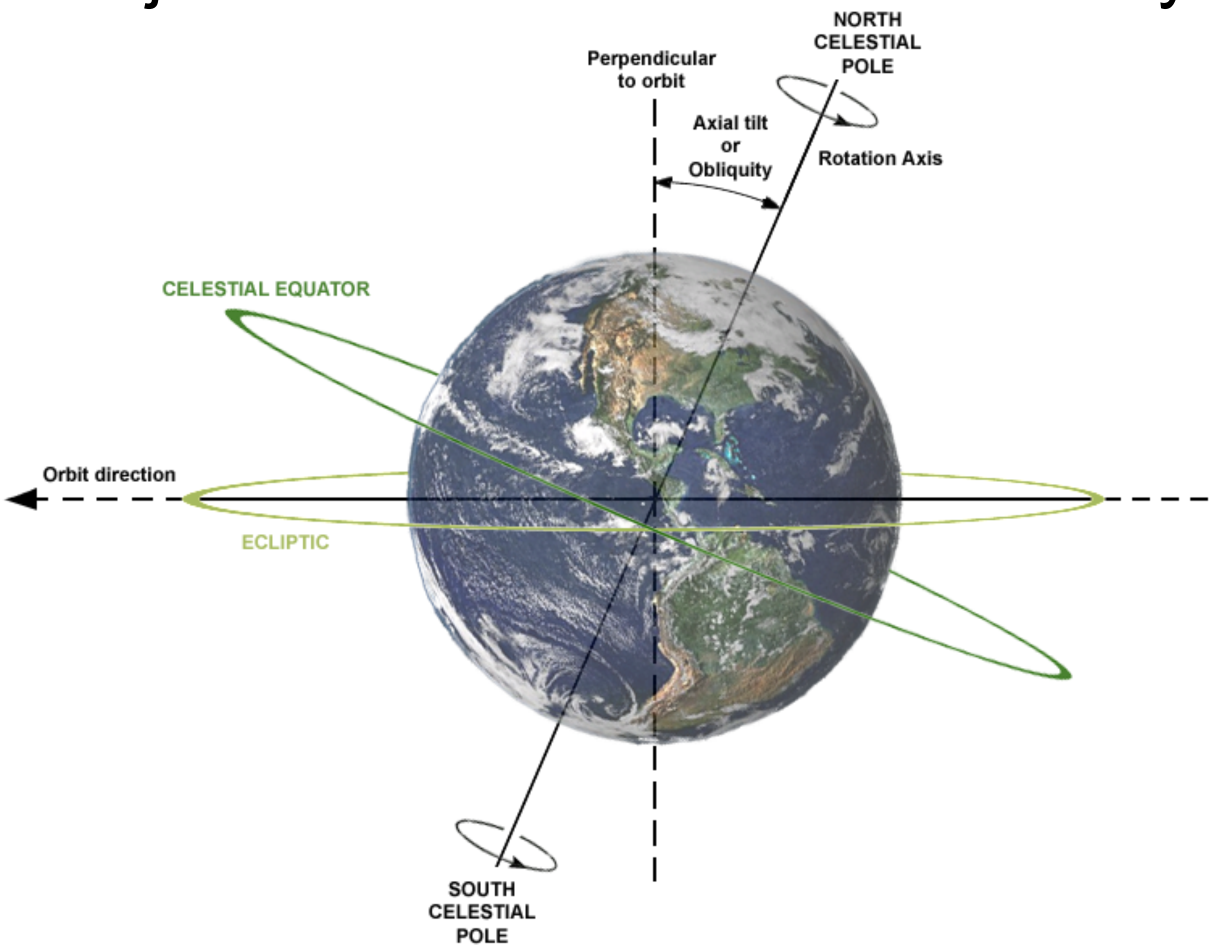
Limitations of ground-based observatories

- Night-time observations
- Atmospheric turbulence
- Atmospheric absorption
- Astroclimate
- Diffuse background and light pollution

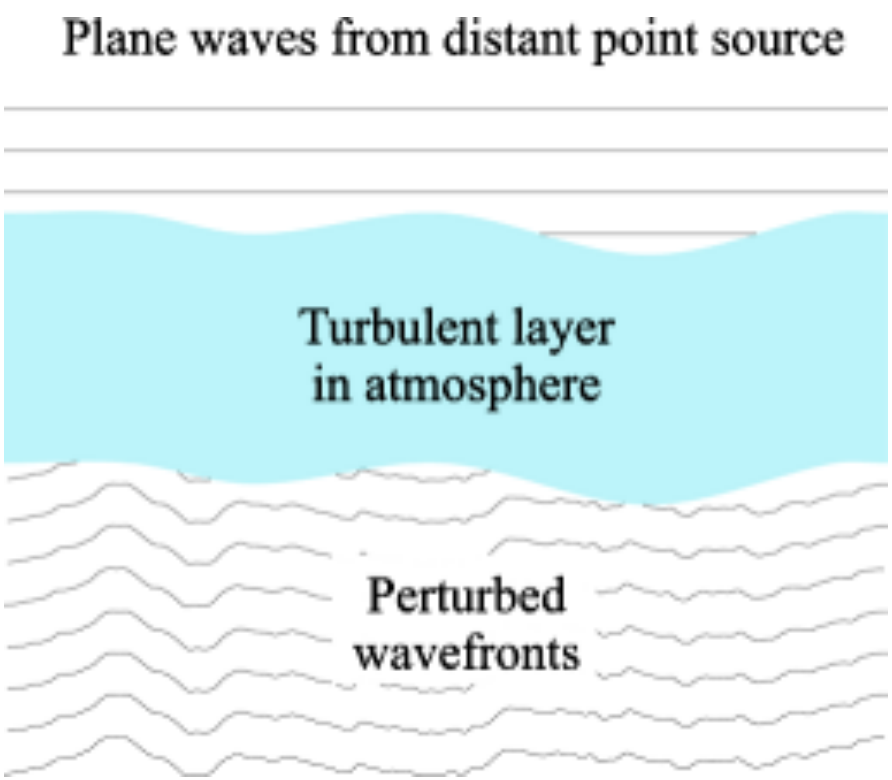
Night-time observations

- Low duty cycle
- Most objects are visible for a fraction of year

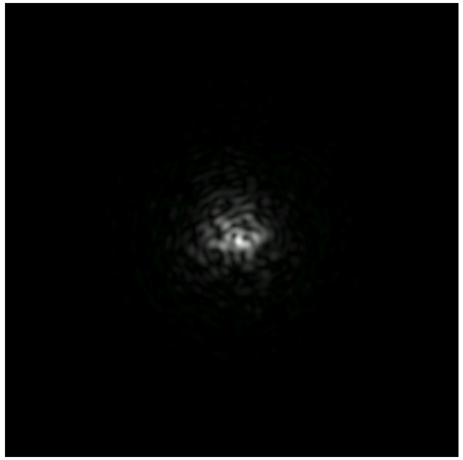


Atmospheric turbulence

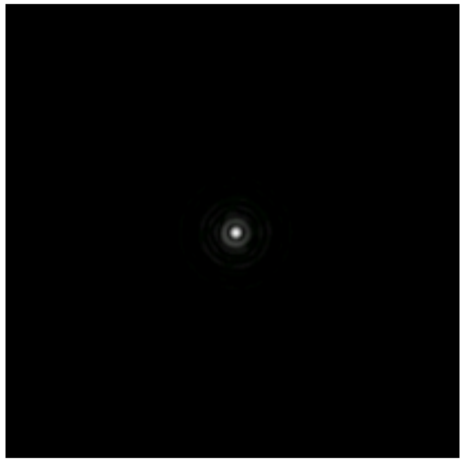
- Seeing



poor



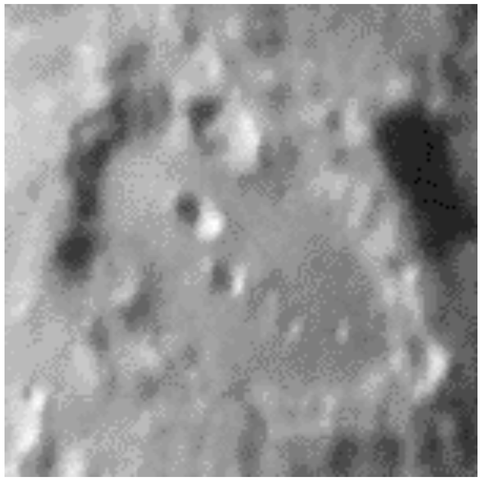
excellent



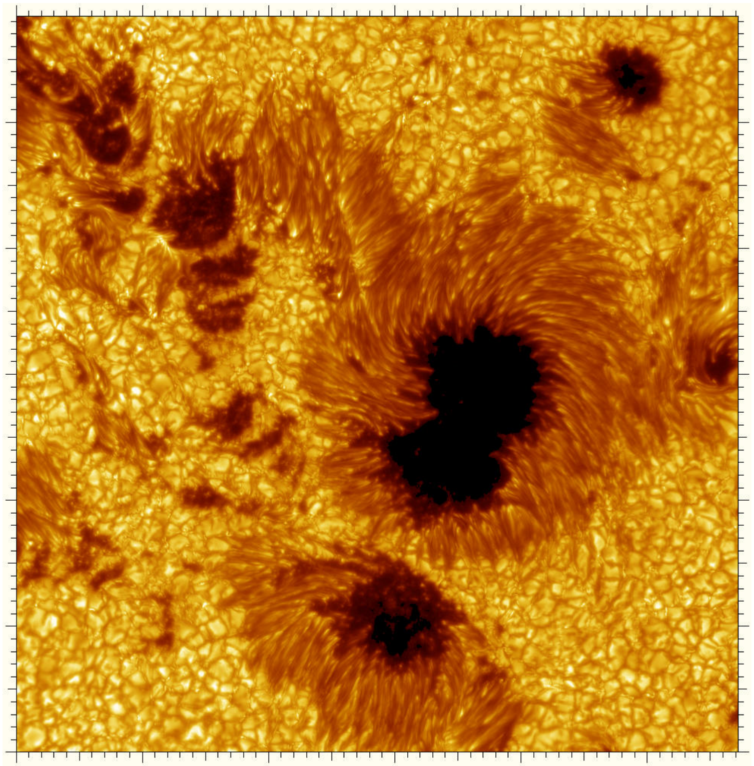
Seeing compensation

- High-speed imaging and post-processing

Moon surface through the Earth atmosphere

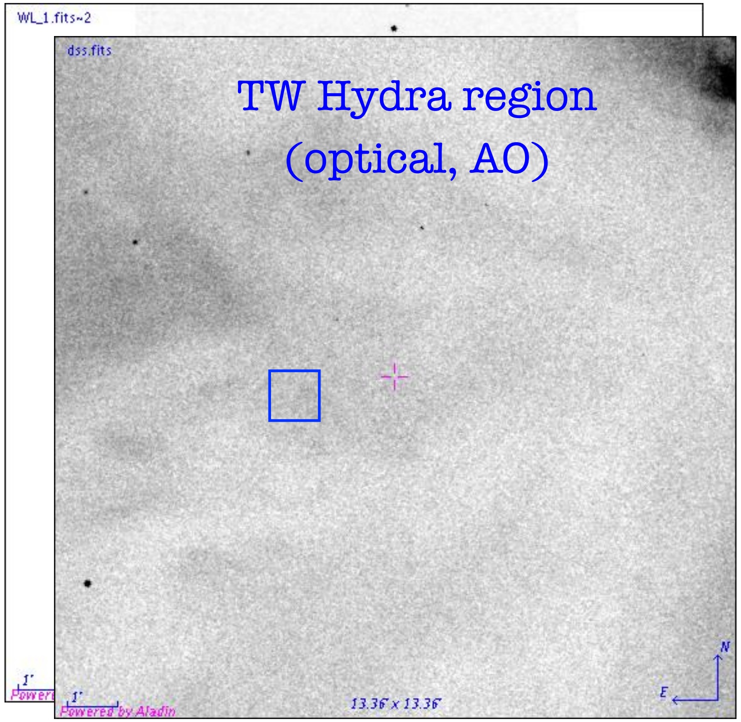


Processed image of the solar surface (SVST)

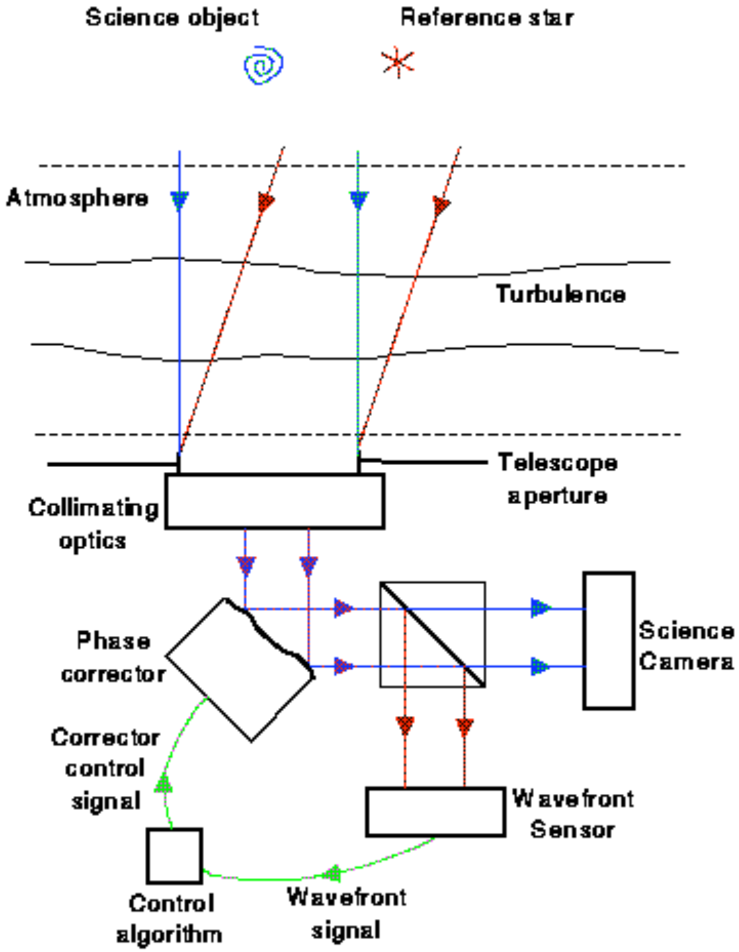


Seeing compensation

- High-speed imaging and post-processing
- Adaptive Optics
  - complex and expensive
  - needs bright guide stars

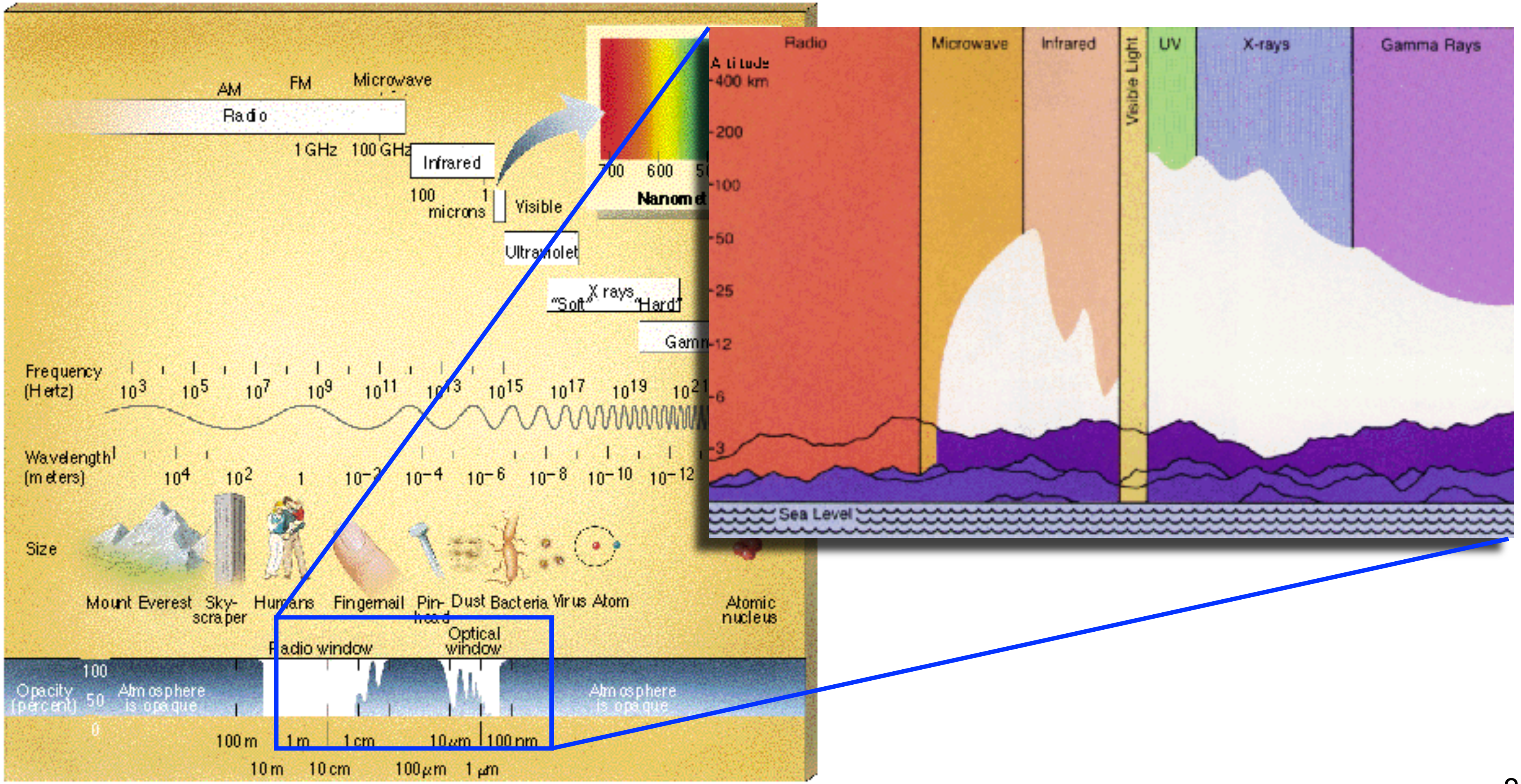


CRIRES@VLT AO-enhanced observations of IR targets impossible



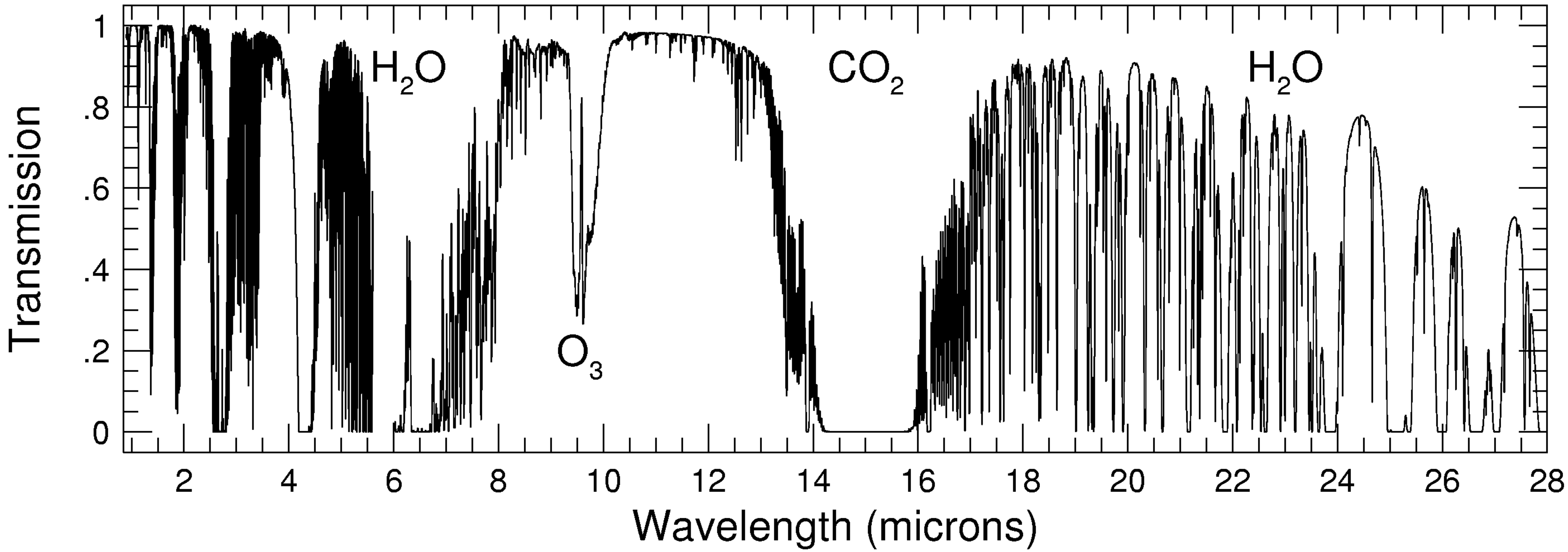
Atmospheric transmission

- Earth atmosphere is mostly opaque



Absorption in Earth atmosphere

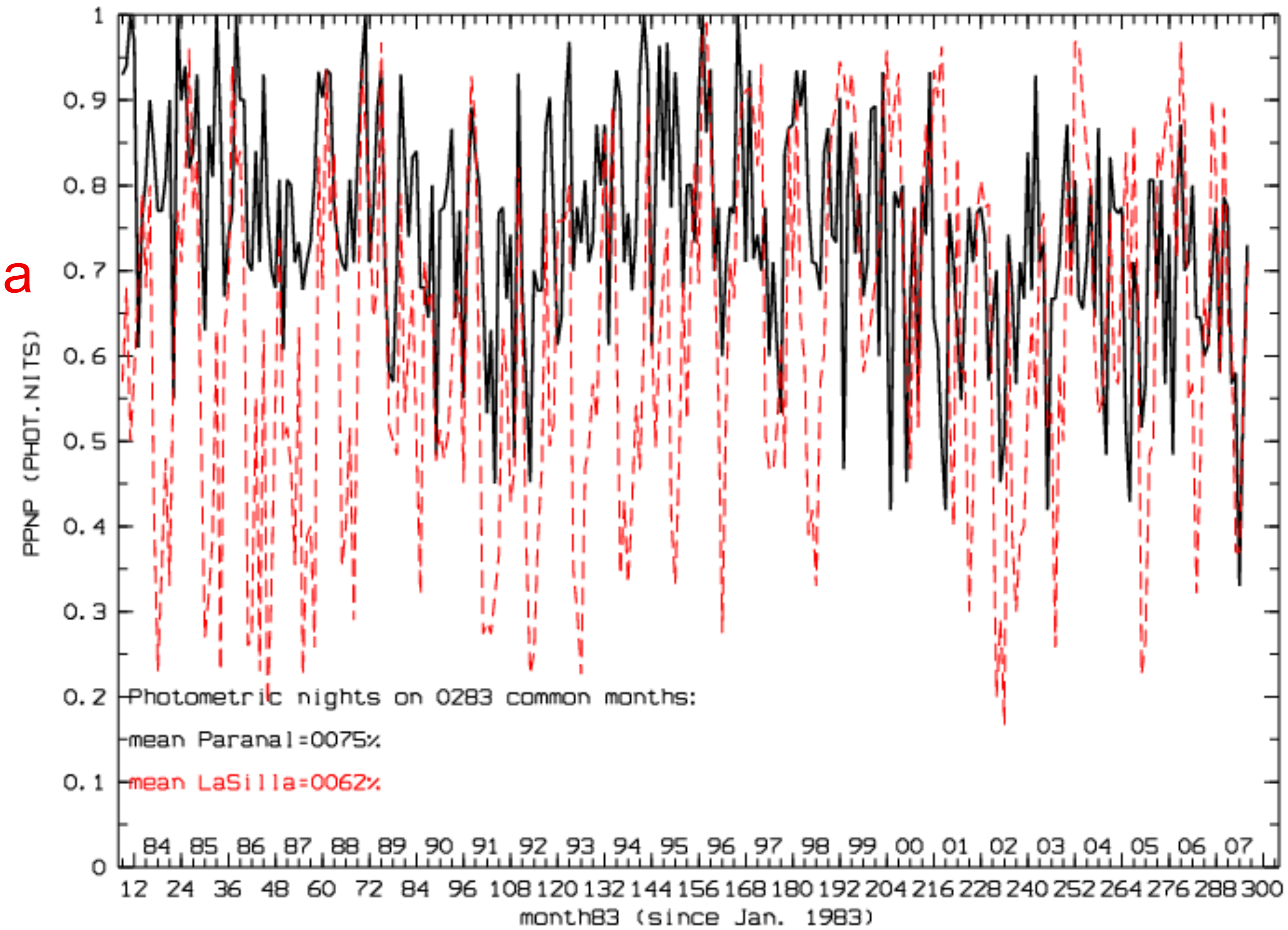
- UV: O_3 (ozone) at 15-40 km
- Infra-red: CO_2, H_2O
- Radio: H_2O, O_2



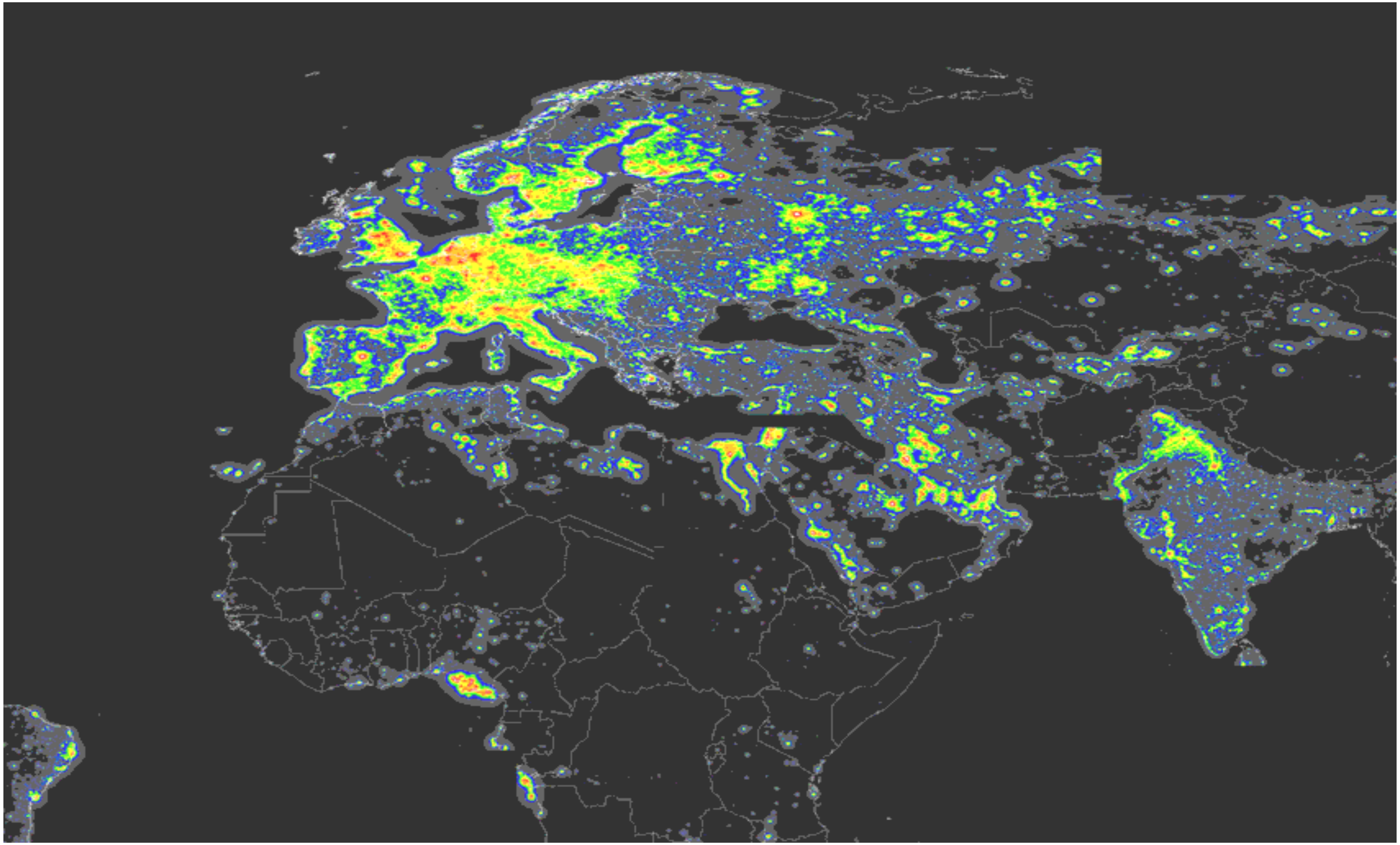
Astroclimate

- Cloudiness, transparency, seeing, wind, humidity

Fraction of clear nights for ESO Paranal and La Silla observatories



Light pollution



Many reasons to go to space but ...

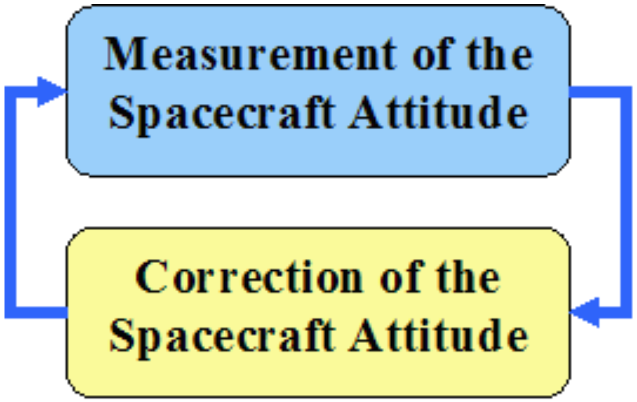
- **Cost** (HST ~6×10^9 \$ vs. ~8×10^8 \$ for 42-m ELT)
- Long-term development and planning
- Multi-institutional and international effort
- Short mission duration*
- No possibility to upgrade or fix faulty equipment*
- Equipment must operate in extreme and unusual conditions

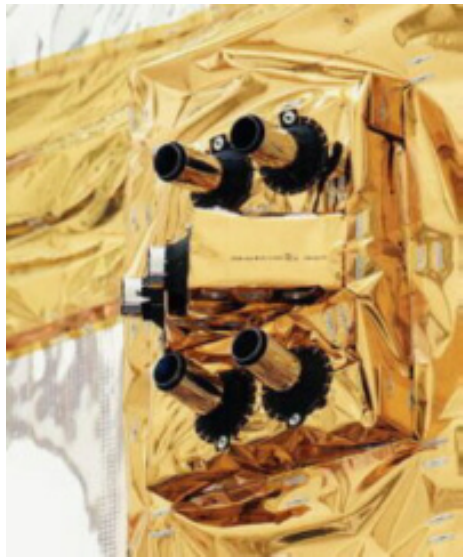
* except very few missions (IUE, HST)

* except HST

Operation of a space telescope

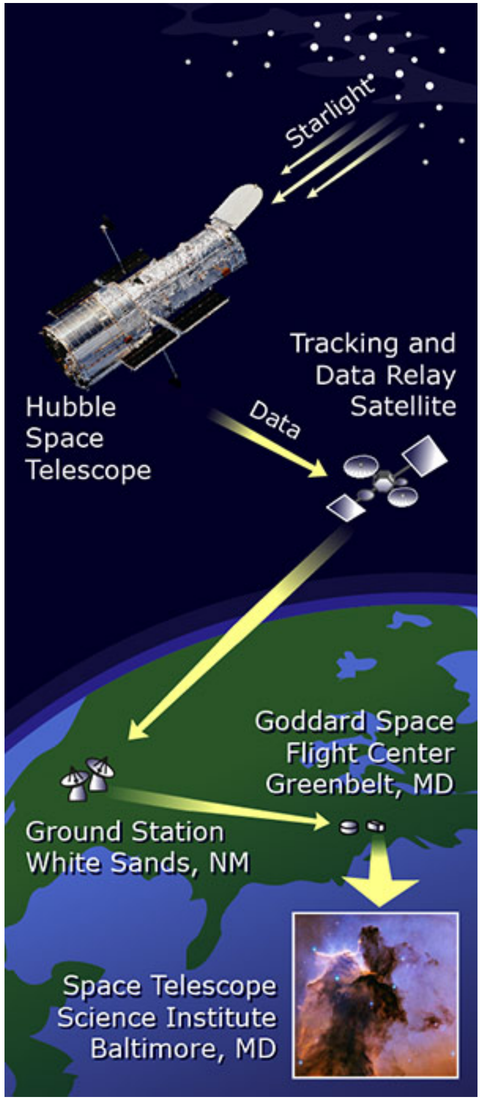
- Weight constraints (3000-5000 $/kg)
- Power constraints
- Coolant for infra-red instruments
- Thermal insulation
- Attitude control
  - *Sensors*: gyroscopes, star/Sun sensor
  - *Actuators*: thrusters, reaction wheels





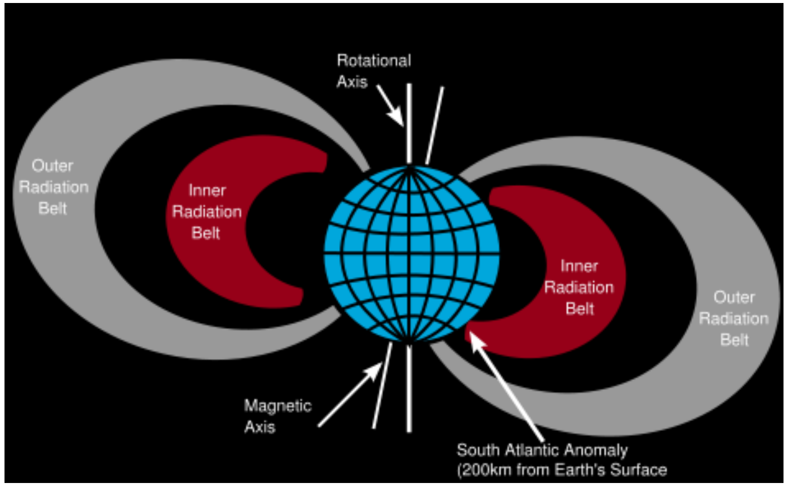
Operation of a space telescope

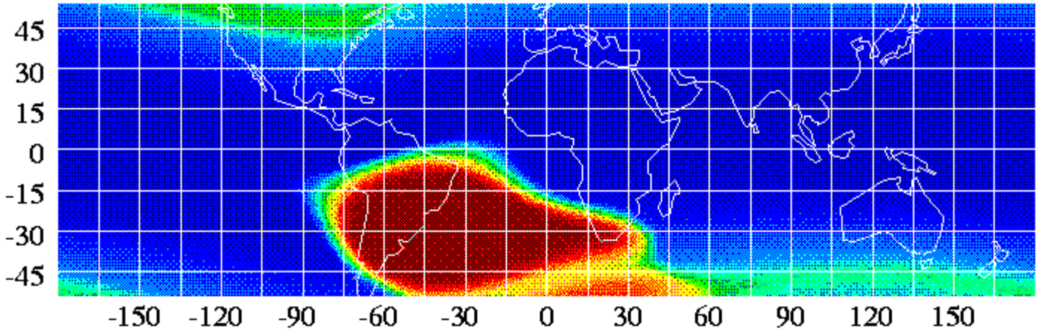
- Weight constraints
- Power constraints
- Coolant for infra-red instruments
- Thermal insulation
- Attitude control
- Communication bandwidth
- Ground stations
- Radiation damage
- Choice of satellite orbit



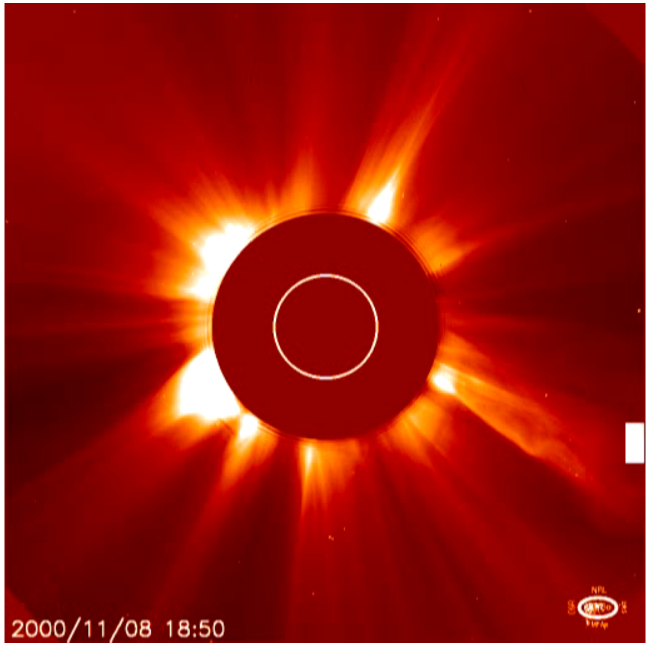
Radiation damage

- South Atlantic Anomaly





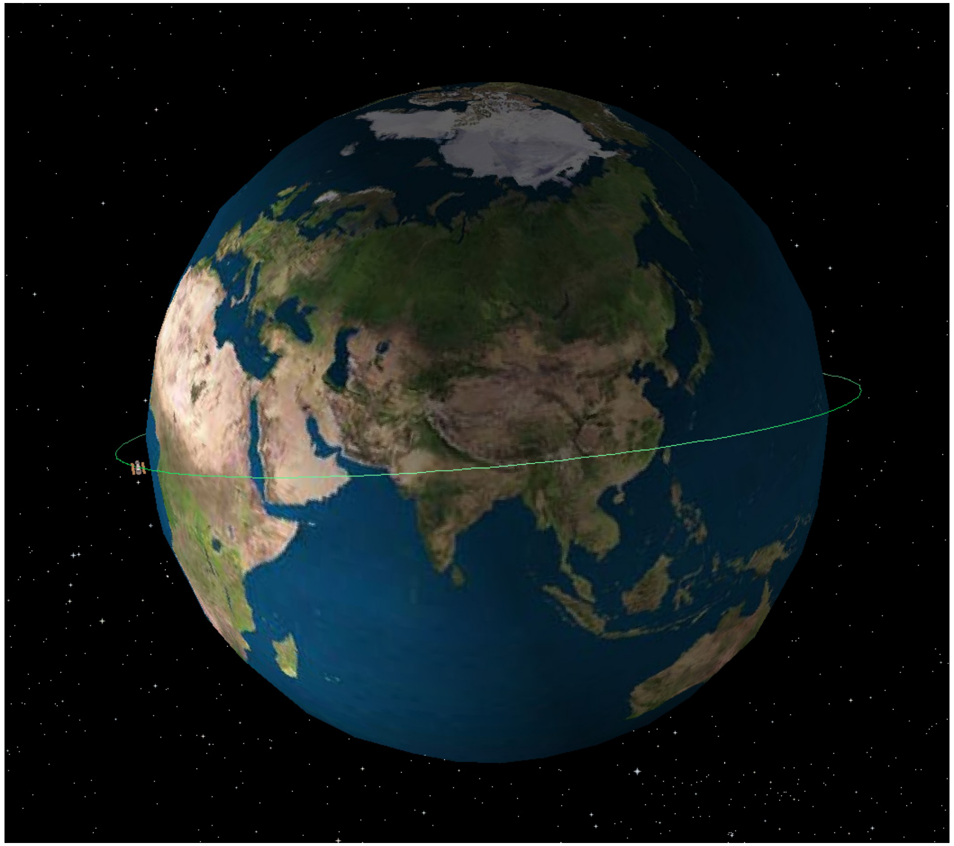
- Solar flares



Satellite orbits: low earth

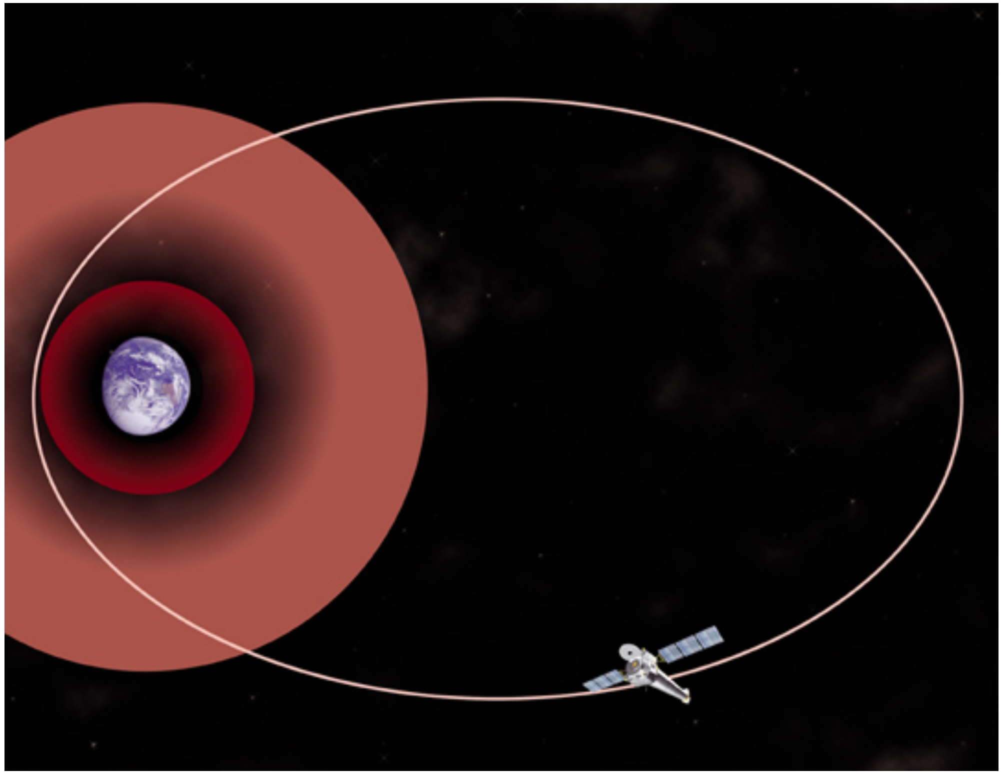
- Low earth orbits (96-min, 600 km for HST)
  - impact of the upper atmosphere
  - earthshine
  - limited CVZ
  - multiple ground stations and/or relay satellites

HST orbit to scale



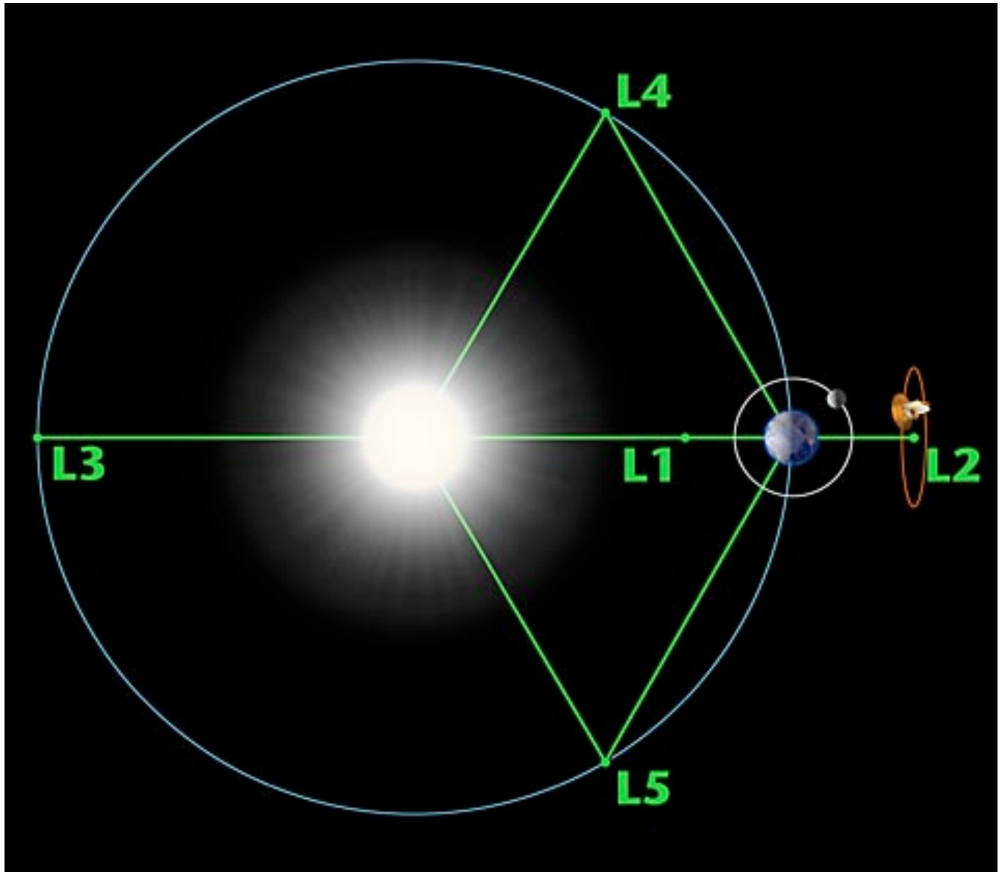
Satellite orbits: elliptical

- Increased CVZ
- Example: Chandra X-ray Observatory:
  - perigee: 10000 km
  - apogee: 140000 km
  - 64-hour period
  - In Earth shadow for <2-h at each orbit
  - 85% of the orbit lies outside radiation belts



Satellite orbits: Lagrangian points

- Stationary positions of small objects in massive 2-body systems

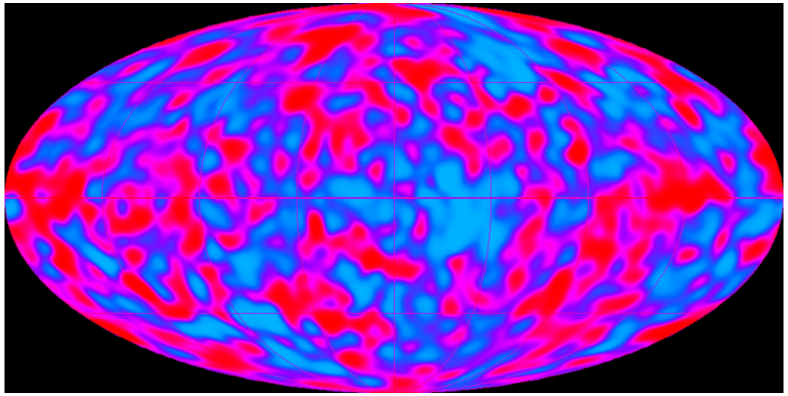


- L1: solar observatories
- L2: deep space observatories
- L4,L5: dust clouds
- L3: ??

The history of space telescopes

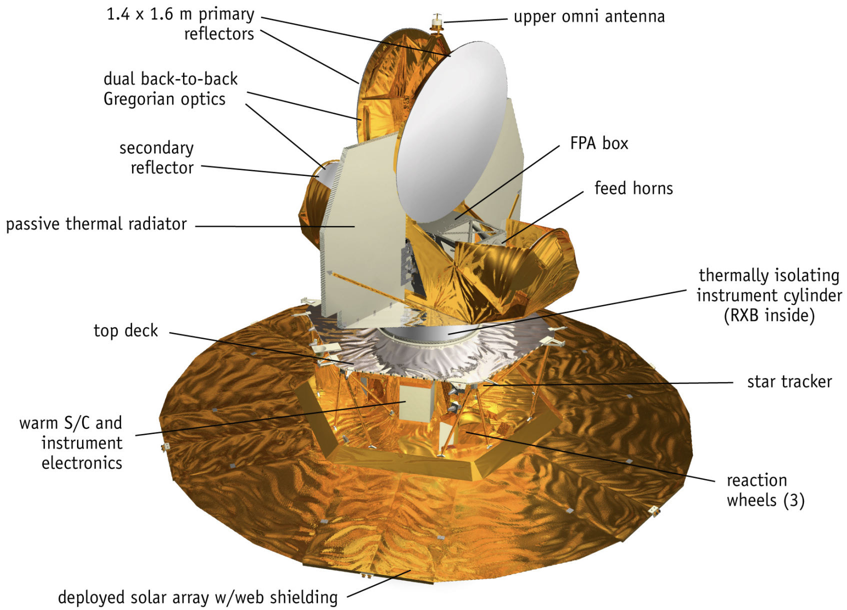
- First astronomical satellite: UK, Ariel 1, 1968
- >50 experiments, >10 operating now
- Notable space telescopes
  - IUE, 45-cm UV telescope (1978-96)
    UV spectroscopy, massive stars
  - Hipparcos, astrometry (1989-93)
    positions and distances to 10^6 stars
  - COBE, microwave background radiation (1989-93)

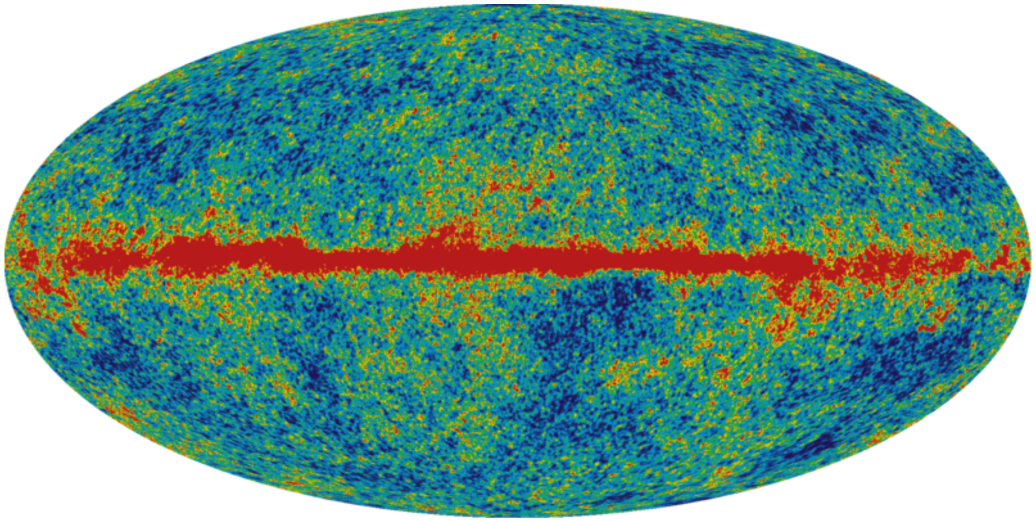
2006 Nobel prize in Physics



The history of space telescopes

- Notable space telescopes
  - WMAP (2001), high resolution imaging of microwave background $\Rightarrow$ age, size, expansion of the Universe





The history of space telescopes

- Notable space telescopes
  - WMAP (2001), high resolution imaging of microwave background $\Rightarrow$ age, size, expansion of the Universe
  - Compton γ-ray observatory (1990-2000)
  - Rosat (1990-99), 84-cm X-ray telescope
  - Infrared Space Observatory, 60-cm IR telescope (1995-98)
- Major space telescopes in operation
  - Hubble Space Telescope (1990)
  - Solar and Heliospheric Observatory (1995)
  - Chandra and XMM Newton X-ray observatories (1999, X-ray)
  - Spitzer Space Telescope (2003, IR)

Hubble Space Telescope

Hubble Space Telescope

launch: 1990, mission: >20 yr

mass: 11 t, mirror: 2.4 m

λ range: UV, optical, near-IR

location: low earth orbit

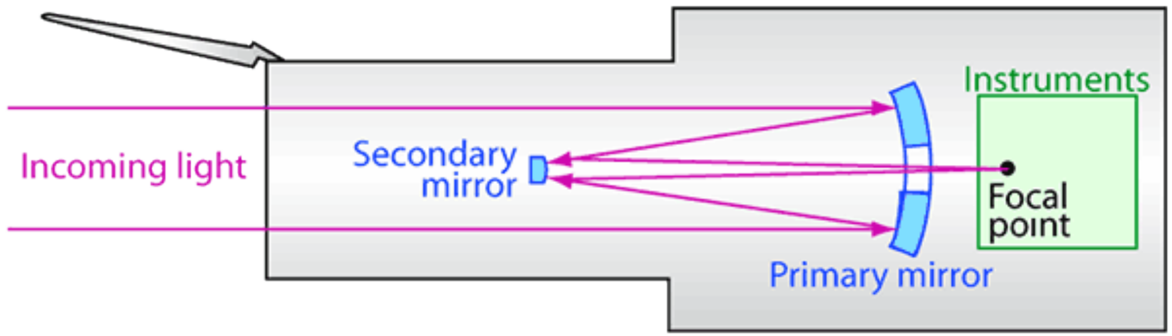
cost: 6 billion $

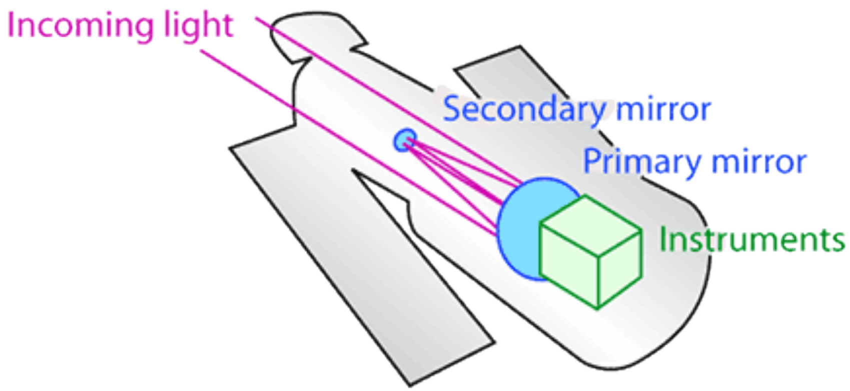
- The only serviceable space telescope

Wide Field Planetary Camera 1 Wide Field Planetary Camera 2

Hubble Space Telescope

- Ritchey-Chrétien optics, modular design
- 2008: 5 instruments
- 2009: last servicing mission





Chandra X-ray observatory

Chandra X-ray Observatory

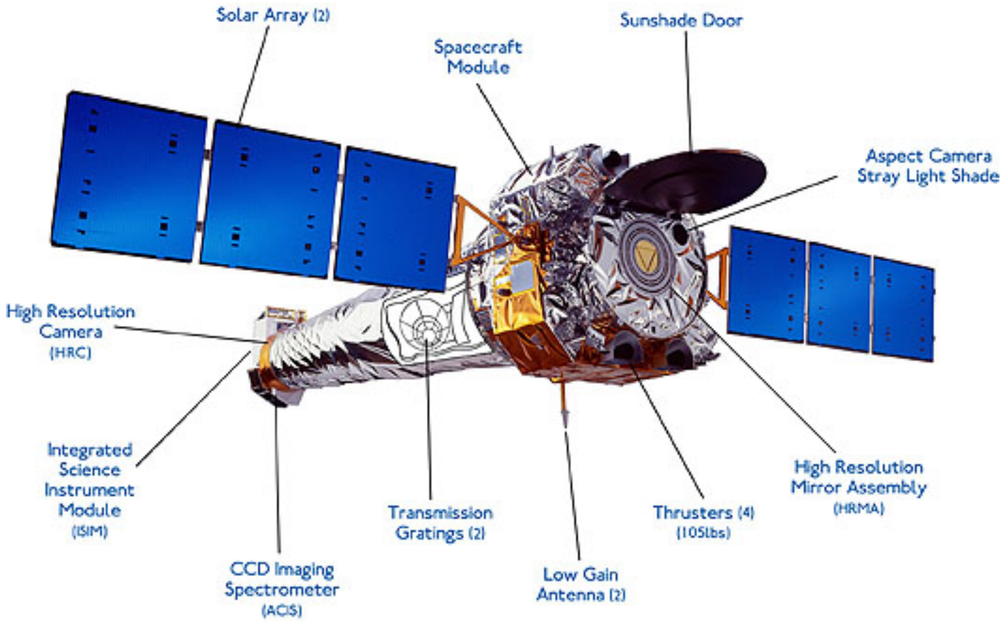
launch: 1999, mission: >5 yr

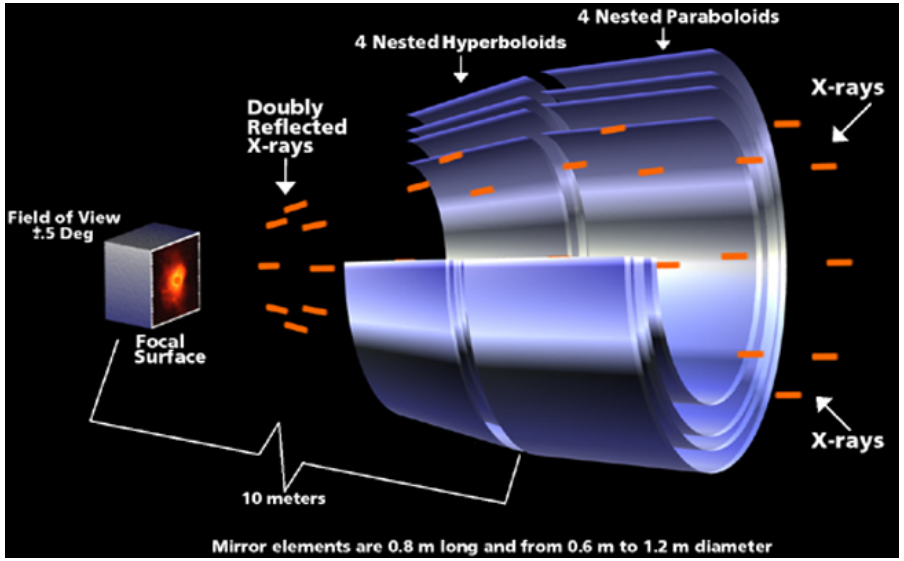
mass: 4.8 t, λ range: X-ray

location: high elliptical orbit

cost: 3.7 billion $

- Special grazing mirrors needed to reflect X-ray photons





SOHO

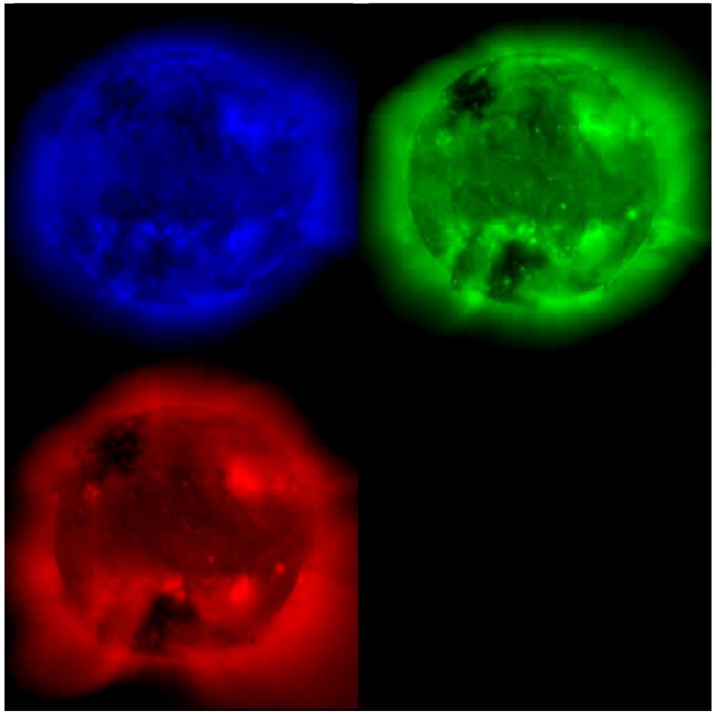
Solar and Heliospheric Observatory

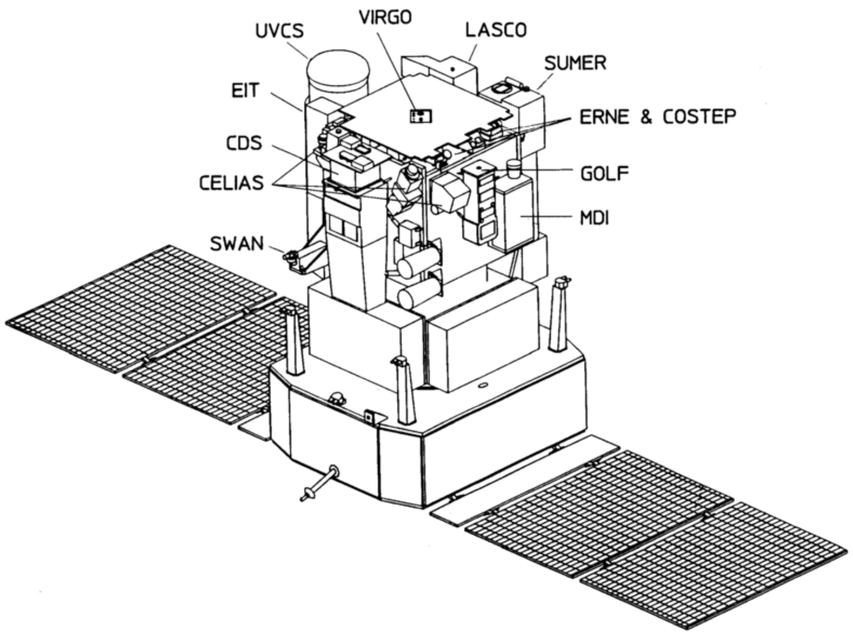
launch: 1995, mission: >15 yr

mass: 0.6 t, λ range: UV, optical

location: L1

- Space platform concept
- 12 diverse instruments





Small-scale space telescope: MOST

Micro variability and

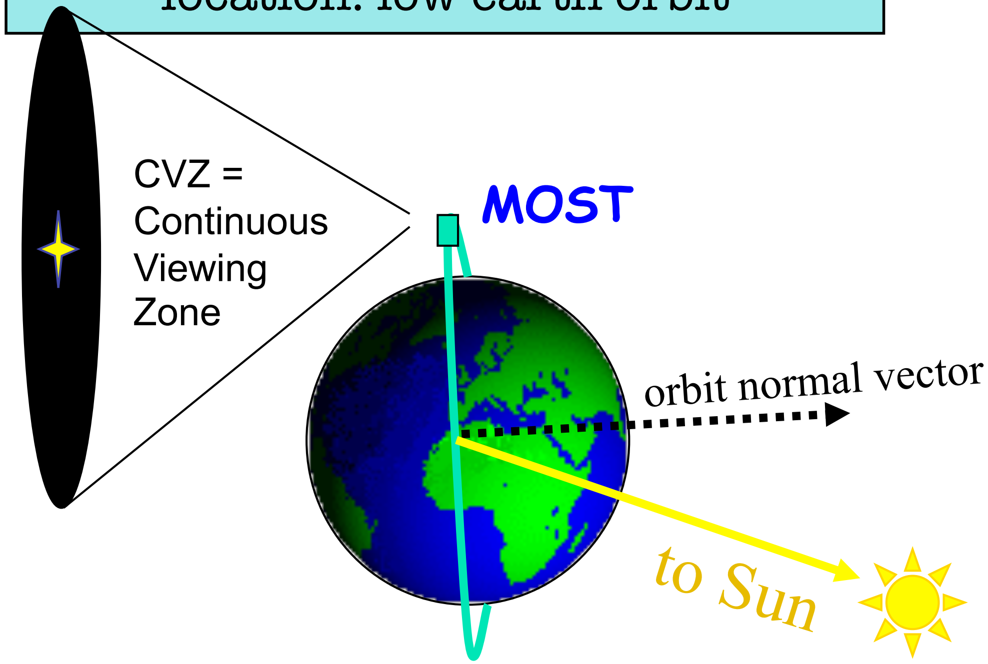
Oscillations of STars

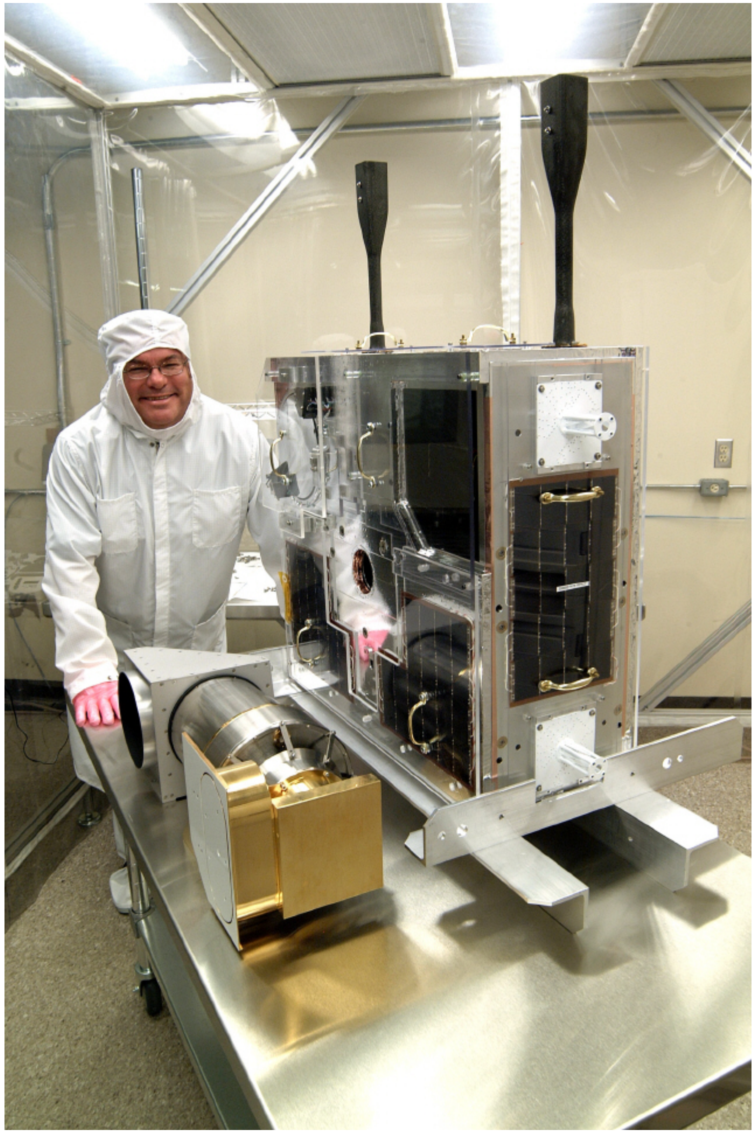
launch: 2003, mission: >7 yr

mirror: 15 cm, mass: 60 kg

λ range: optical, cost: 10 million $

location: low earth orbit





Small-scale space telescope: MOST

Micro variability and Oscillations of STars

launch: 2003, mission: >7 yr

mirror: 15 cm, mass: 60 kg

λ range: optical, cost: 10 million $

location: low earth orbit

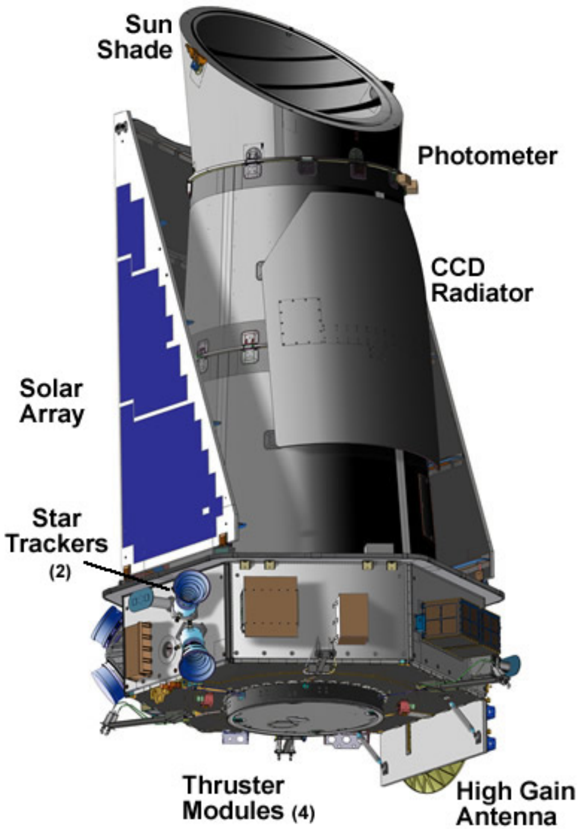
Operated by ~10 astronomers from Canada, US, Austria

Vienna ground station

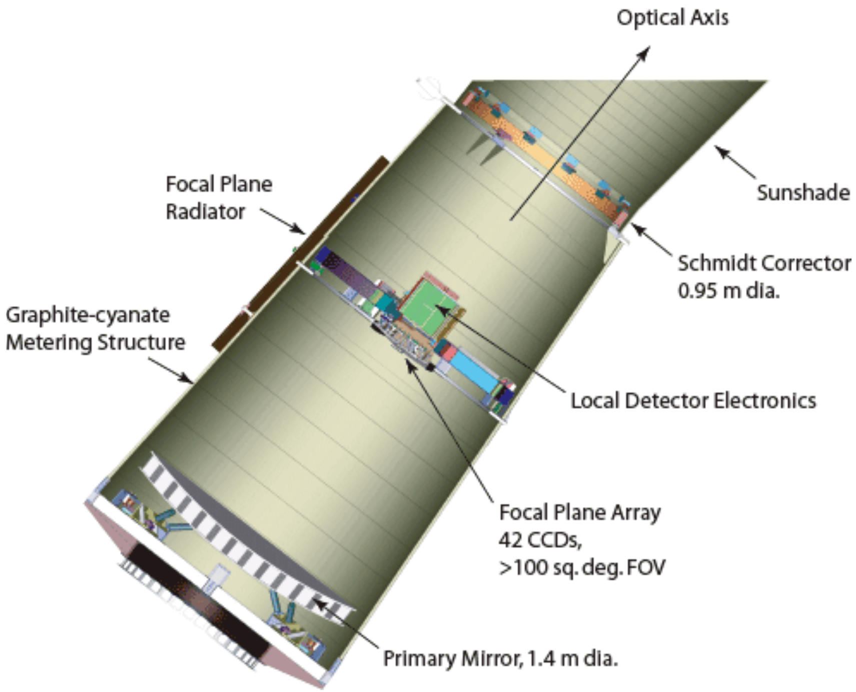
launch from Plesetsk

Currently: high-precision photometry from space

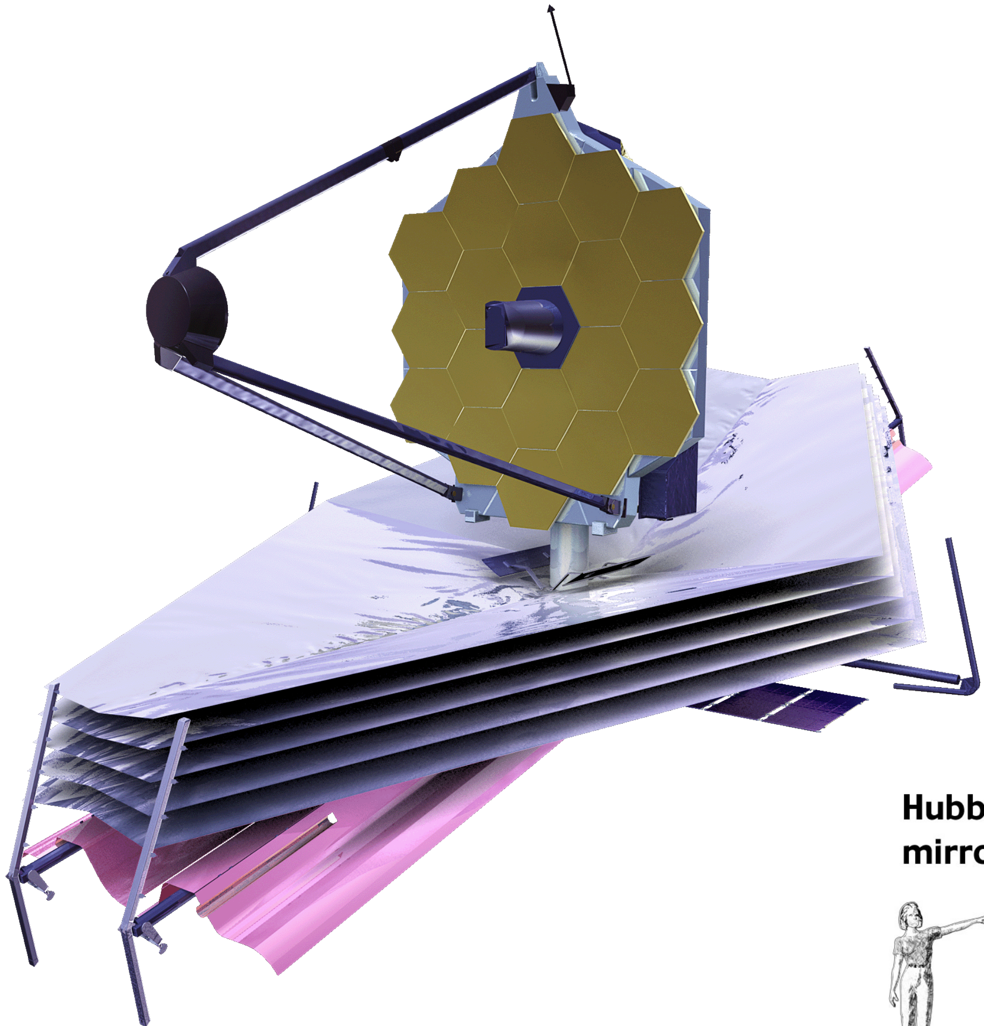
- Brightness of stars with 1 ppm=0.0001% precision
  - CoRoT (2006): 30 cm, 4 2K×2K CCDs, 8 sq.d. FOV
  - Kepler (2009): 95 cm, 42 2K×1K CCDs, 105 sq.d. FOV



Kepler's structure and detectors



Near (?) future: JWST



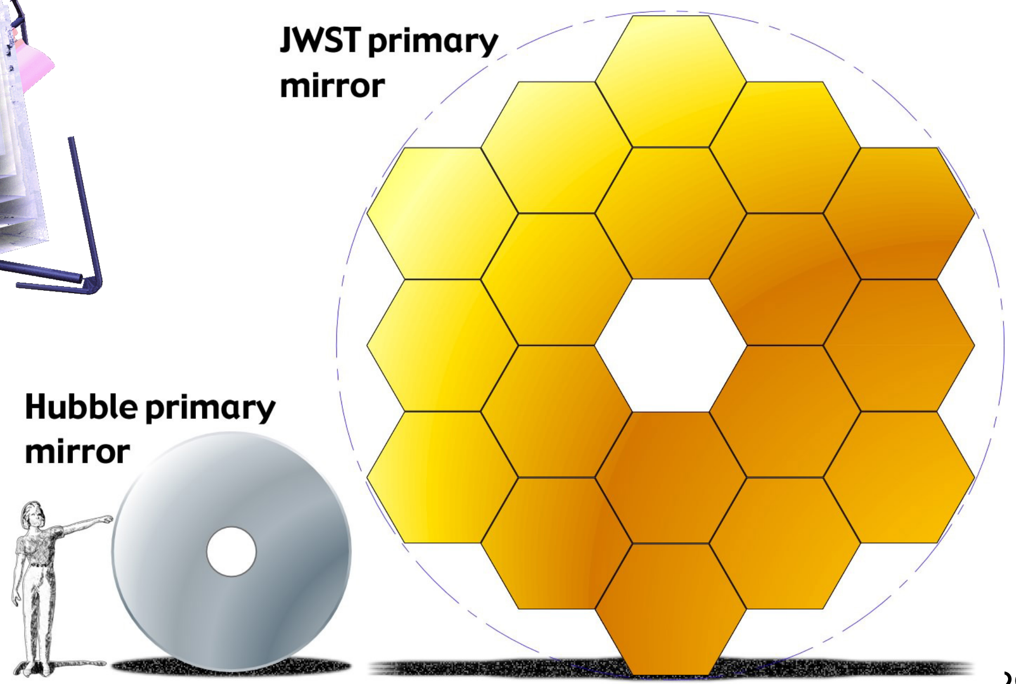
James Webb Space Telescope

launch: 2018, mission: 5-10 yr

mass: 6.2 t, mirror: 6.5 m

λ range: IR, location: L2

cost: 1-> 8.7 billion $



Far future: telescopes on the Moon?