

## **Concepts introduced in previous lectures:**

- Photon noise
- Astronomical units: magnitude brightness scale, parsec
- Lagrange invariant: large field = large optics
- Airy pattern, Nyquist sampling
- Atmosphere: emission, transmission, turbulence
- Angular resolution and sensitivity in background-limited observations
- Requirements for astronomical optical systems, measurements:
  - collecting area (telescope diameter)
  - angular resolution
  - field of view
  - spectroscopy, photometry
  - astrometry
- Pupil plane, focal plane, plate scale (conversion between angle and distance)
- Refracting vs. Reflecting telescopes
- Challenges of large telescopes: holding the primary mirror
  - telescope designs
  - aberrations in telescopes: wavefront aberrations, distortions, chromatism

# **Astronomical Optics**

## **2. Fundamentals of Telescope designs**

### **2.3. Space vs. ground, cryogenic telescopes, design choices, challenges**

#### **Outline, Key concepts:**

Space telescopes: how are they different from ground telescopes ?

Cryogenic telescopes

# Space Telescopes

## Advantages:

- no atmosphere: full access to spectra from radio to gamma ray
- no atmosphere: full angular resolution
- no atmosphere: no skyglow
- high stability measurements possible, well controlled environment (thermal management easier)
- possible to cool whole telescope
- no day/night cycle: can observe 24h / day

## Disadvantages:

- can't fix what is broken (or very expensive to fix) → somewhat risky
- very expensive
- use of low-risk older components
- limited communication bandwidth (costly to transfer large data)
- communication is not continuous

## How do space telescopes differ from ground telescopes:

Low mass, but must be mechanically strong to resist launch

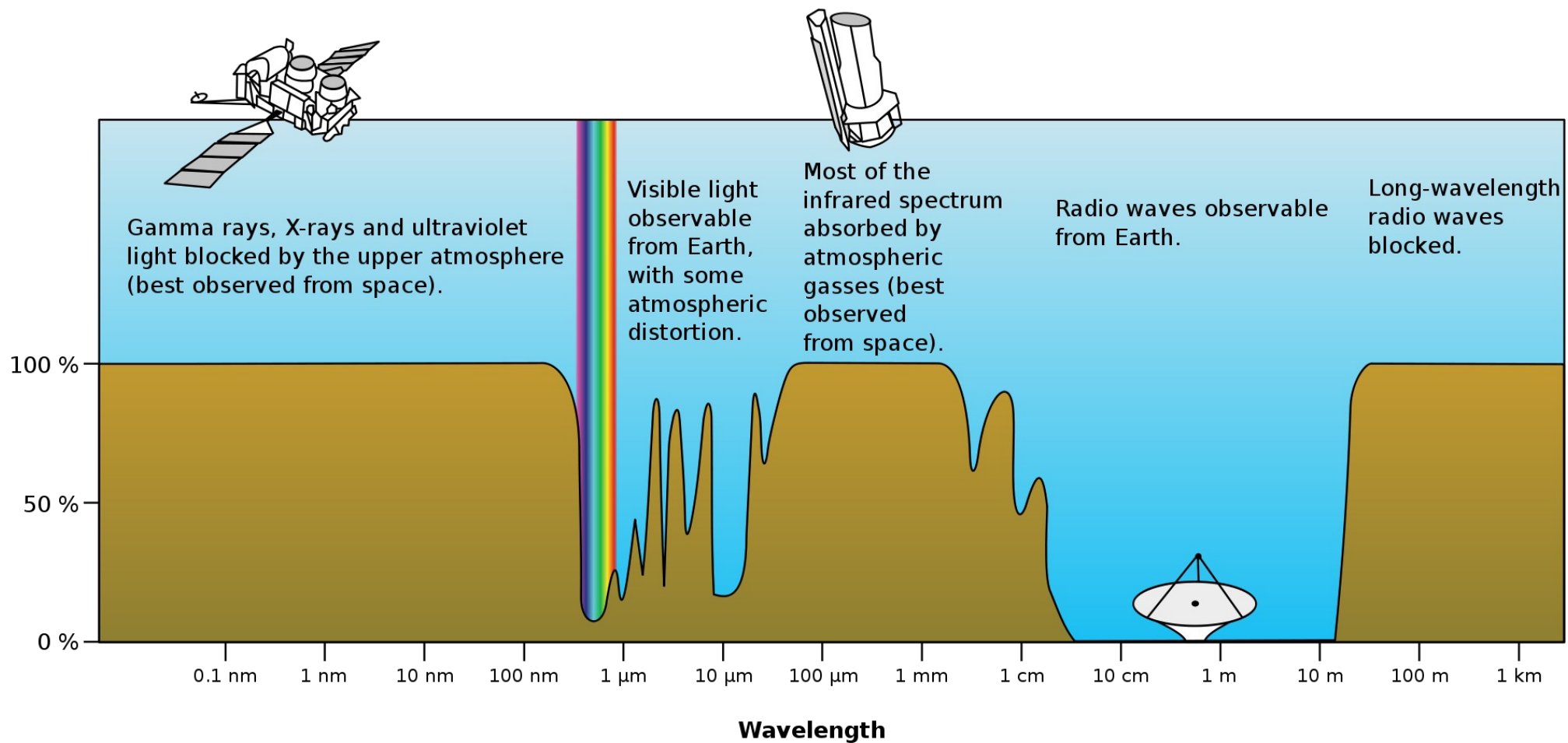
Low power consumption

Pointing using reaction wheels and thrusters

# The first optical element in every ground-based telescope: Earth's atmosphere

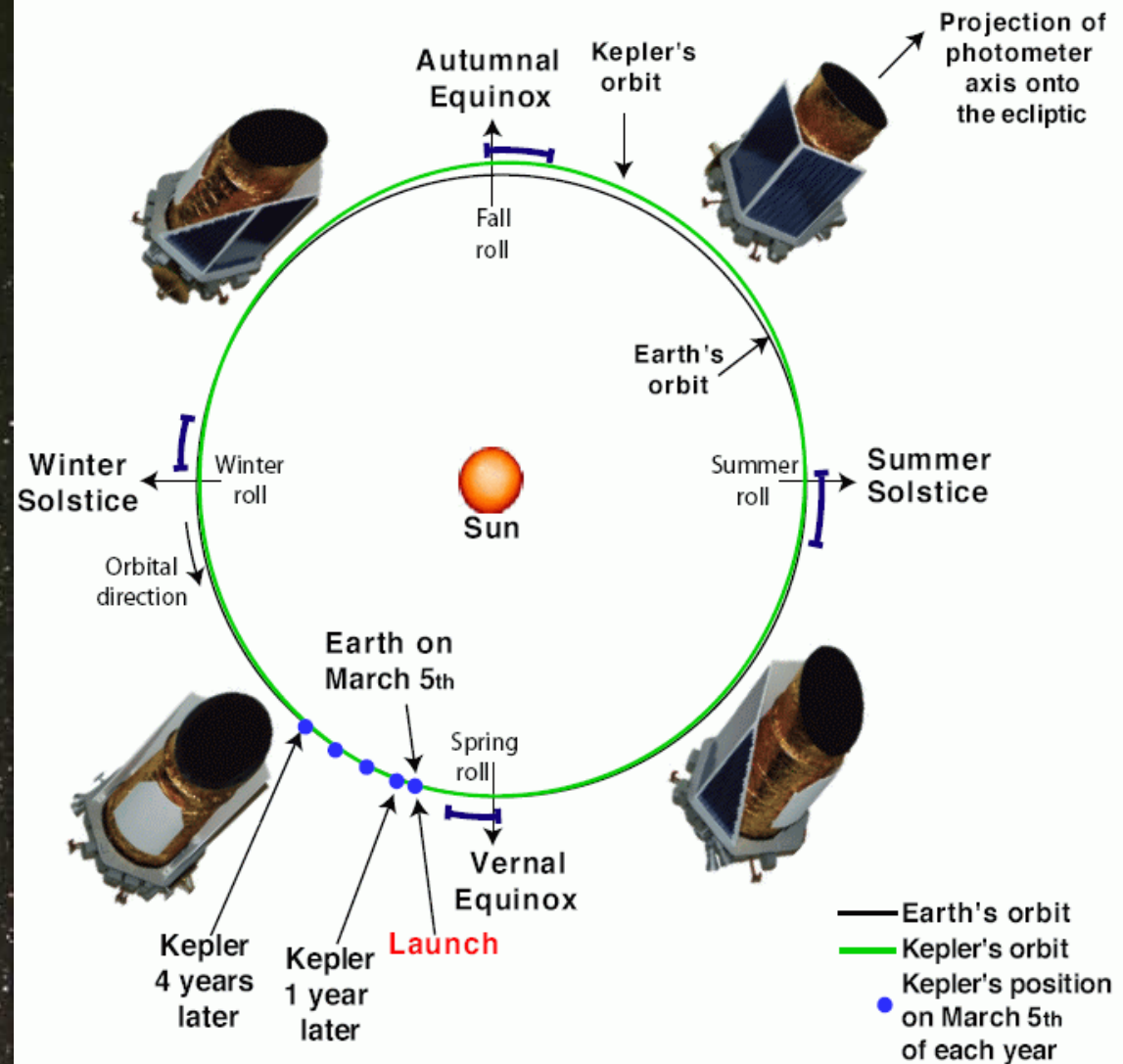
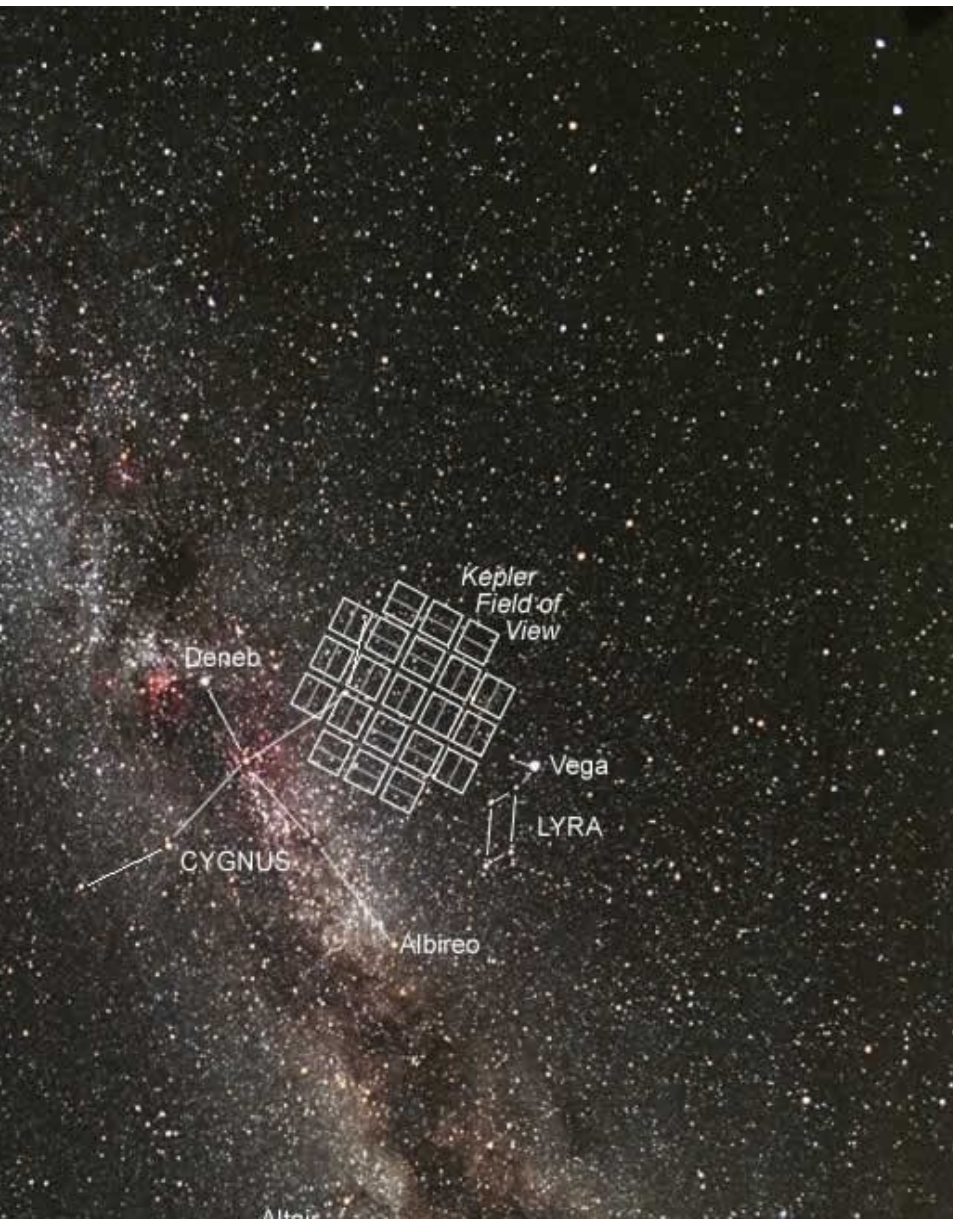
## Transmission

Atmosphere is fairly transparent in optical when not cloudy  
nearIR: windows of transparency exist, main absorber is water vapor



# Kepler Space Telescope: stability, and continuous viewing

Kepler stares at the same field for several years, and does precision photometry of a large number of stars to detect planetary transits



# Cryogenic telescope systems for IR observations

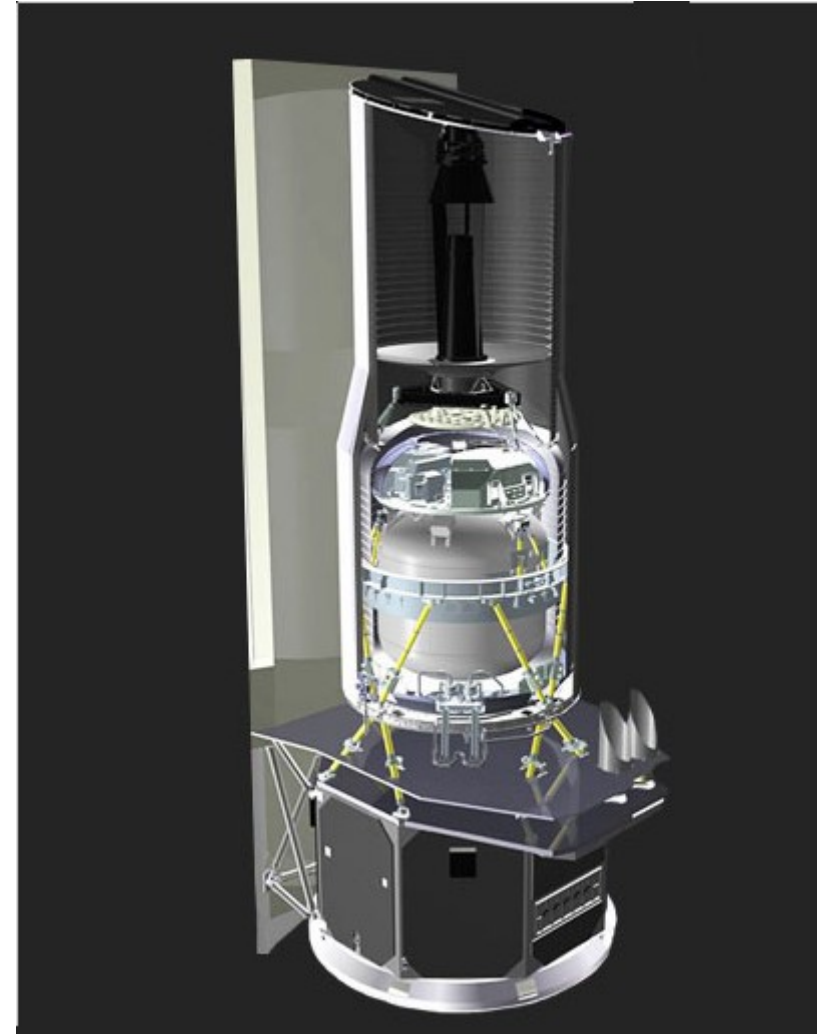
Blackbody radiation follows Planck's law:

$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}.$$

Total emission goes as emissivity  $\times T^4$

**Full cryogenic telescopes only possible in space**

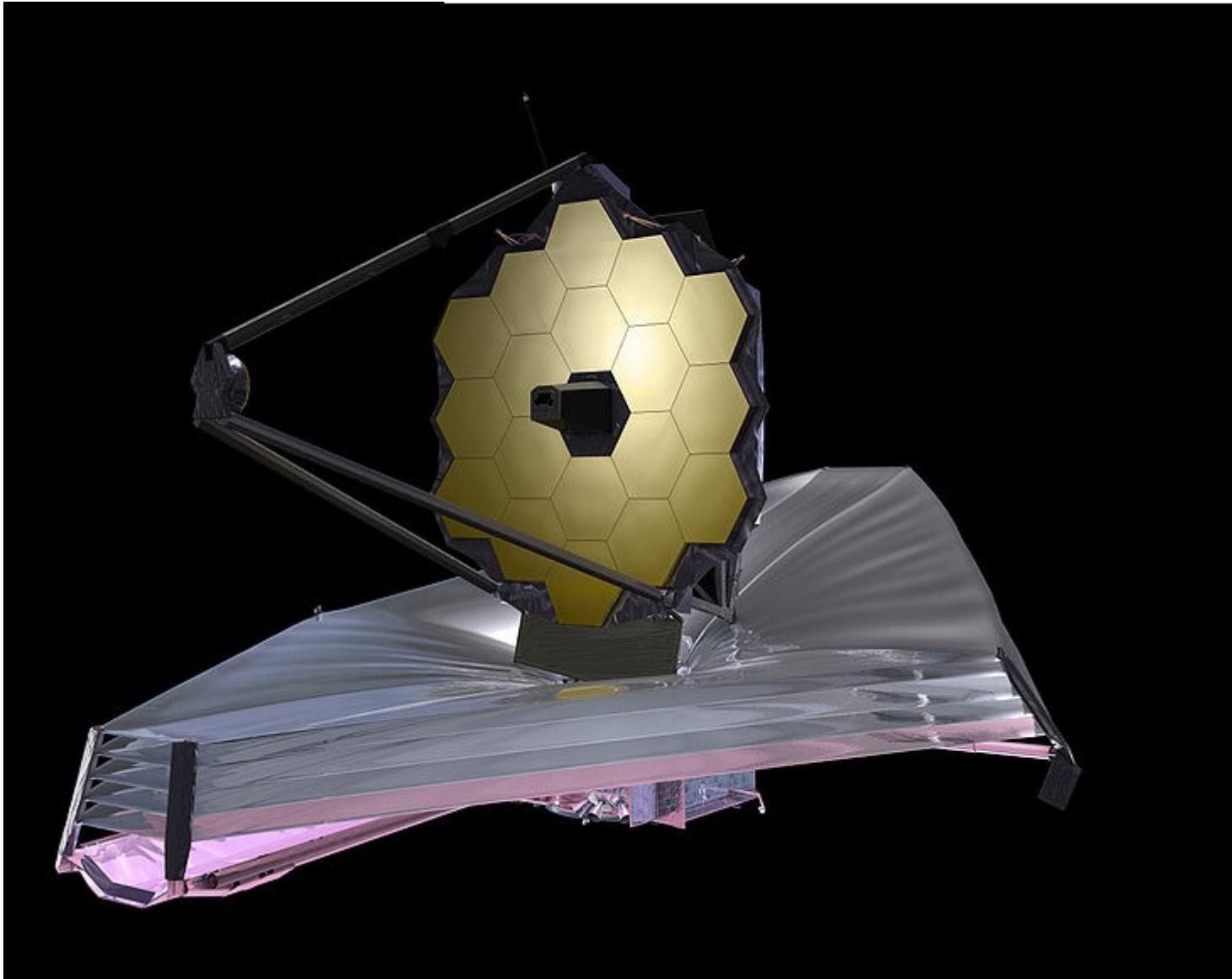
**Cold telescope + no IR-emitting atmosphere make space ideal environment for IR astronomy**



*Spitzer Telescope: the liquid helium tank is visible in the center of this figure. It holds 360 liters of liquid Helium to cool the telescope to 35K for ~5 yrs*

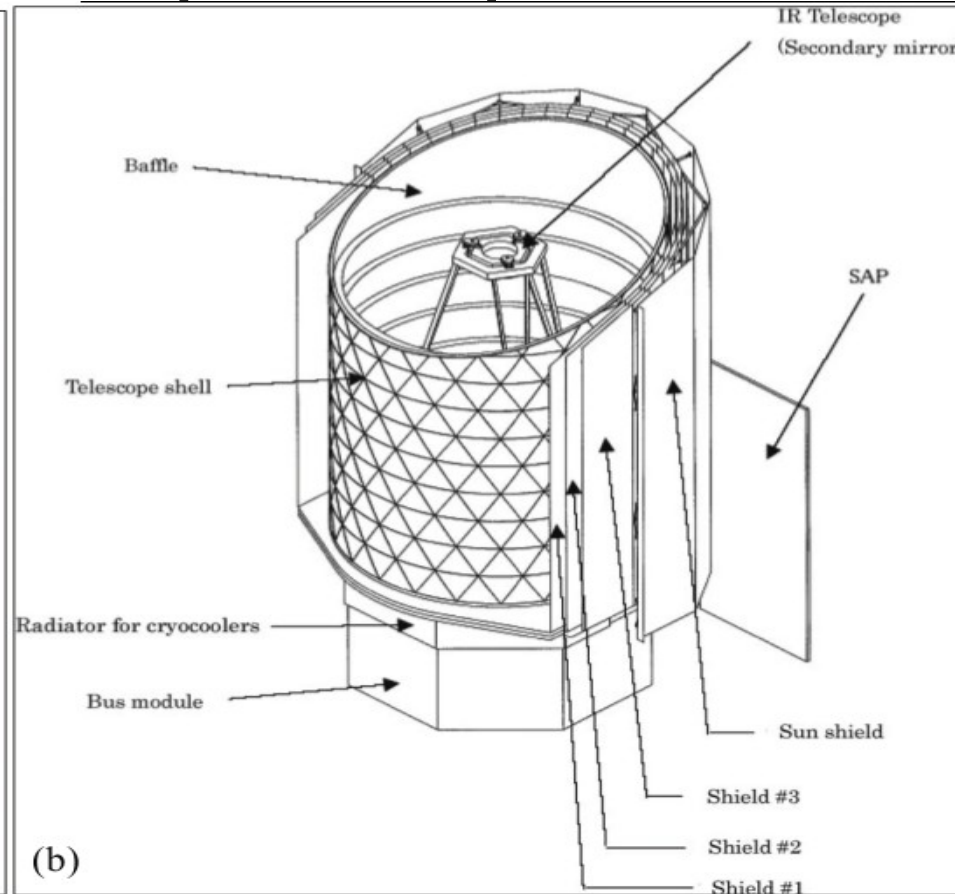
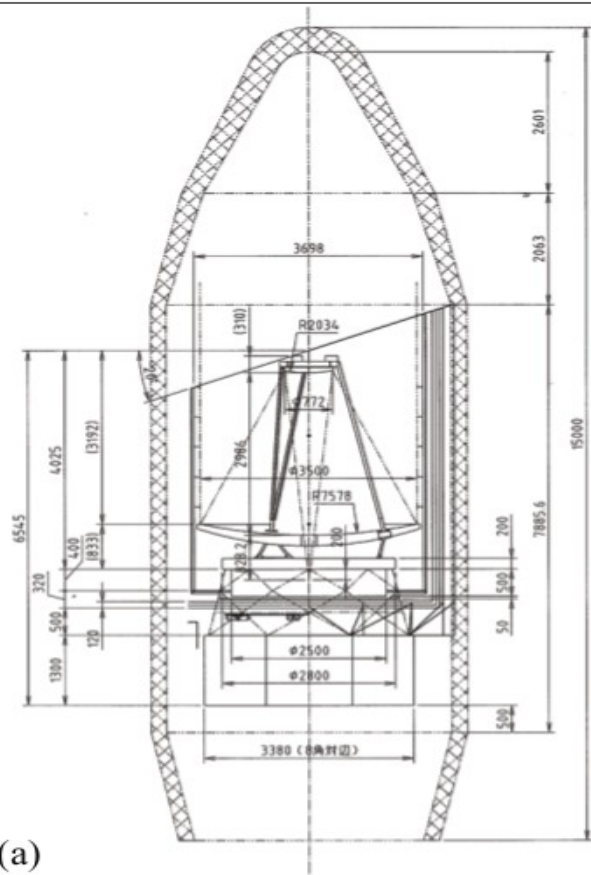


## Passive Cooling can get to ~40K



*JWST's sunshield keeps radiation due to Sun, Earth and Moon from heating the telescope → telescope should cool to ~40K passively*

## Active cooling of telescope to $\sim 5\text{K}$ possible with liquid He



Source: SPICA mission (Japan)  
3m IR telescope

		Mechanical Support	Wire	Radiation	Radiation to Space
Outer Shell	150.0 K				
Bus Module	150.0 K				
Shield 1	76.0 K	465.4	3.3	13170	4707
Shield 2	54.6 K		1.4	1162.3	
Shield 3	37.9 K		0.9	298.5	
Tel. Support	20.2 K	113.9	0.5	98.3	
Tel. Baffle	10.5 K		0.82	9.22	
Telescope	4.5 K	3.61		0.47	
FPI	4.5 K	0.72	0.12	1.24	
		15.0	21.0		
		FPI Heat Load	JT Cooler		



# Cryogenic telescope systems for IR observations

Blackbody radiation follows Planck's law:

$$I(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Total emission goes as emissivity  $\times T^4$

To optimize sensitivity:

- reduce T
- reduce emissivity (gold coating is good for IR telescopes)

Note: Cryogenic telescopes do not use glass for their mirrors

JWST, Spitzer:	Beryllium (Be)
Herschel :	Silicon Carbide (SiC)



*Gold-coated segment of JWST (6.5m diameter, to be launched in a few yrs)*

# Orbits for space telescopes

**Low Earth Orbit** (<2000 km from surface)

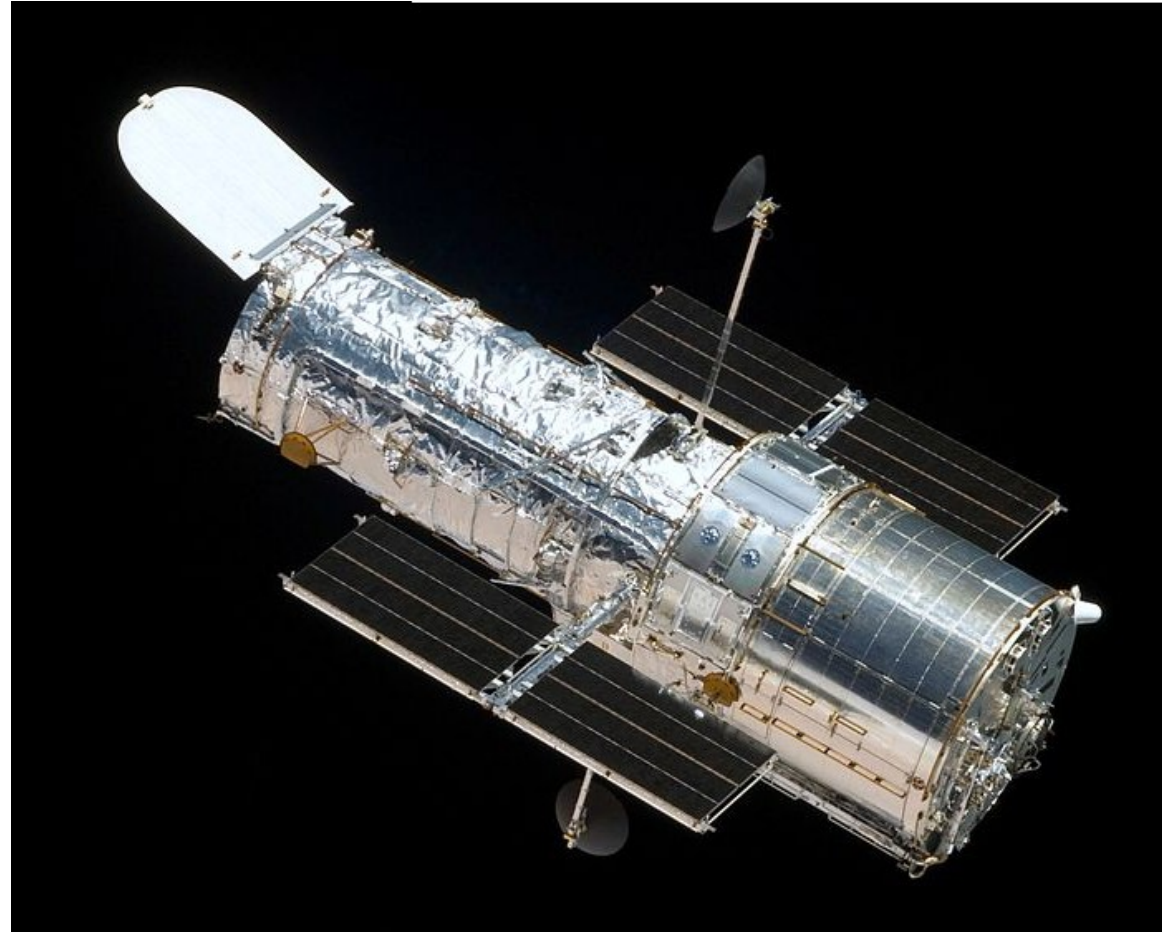
**Easy access**

**Frequent day/night cycles**

→ difficult to keep telescope very stable

→ solar panels not always illuminated

**Not stable over long timescales:  
altitude loss due to upper  
atmosphere**



*The Hubble Space Telescope (HST) is in LEO,  $h=559$  km*

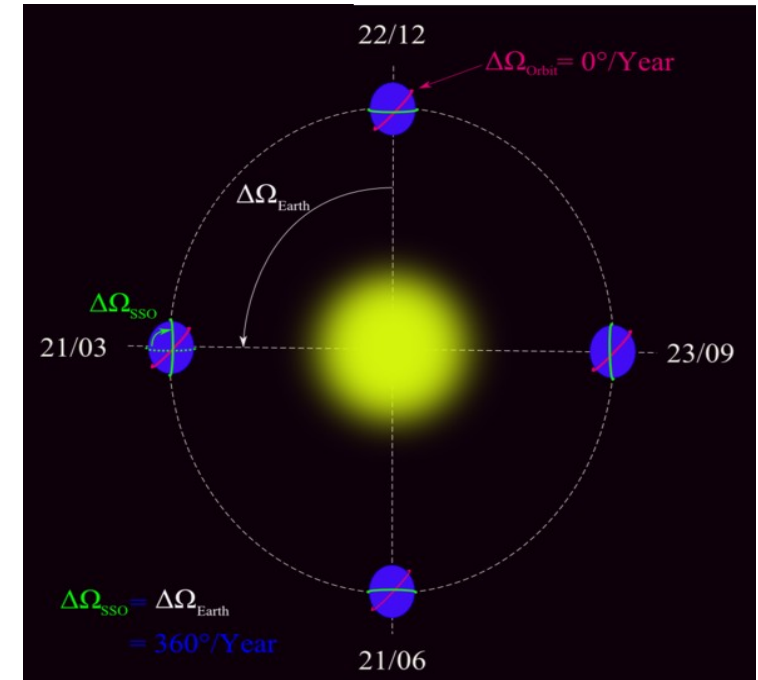
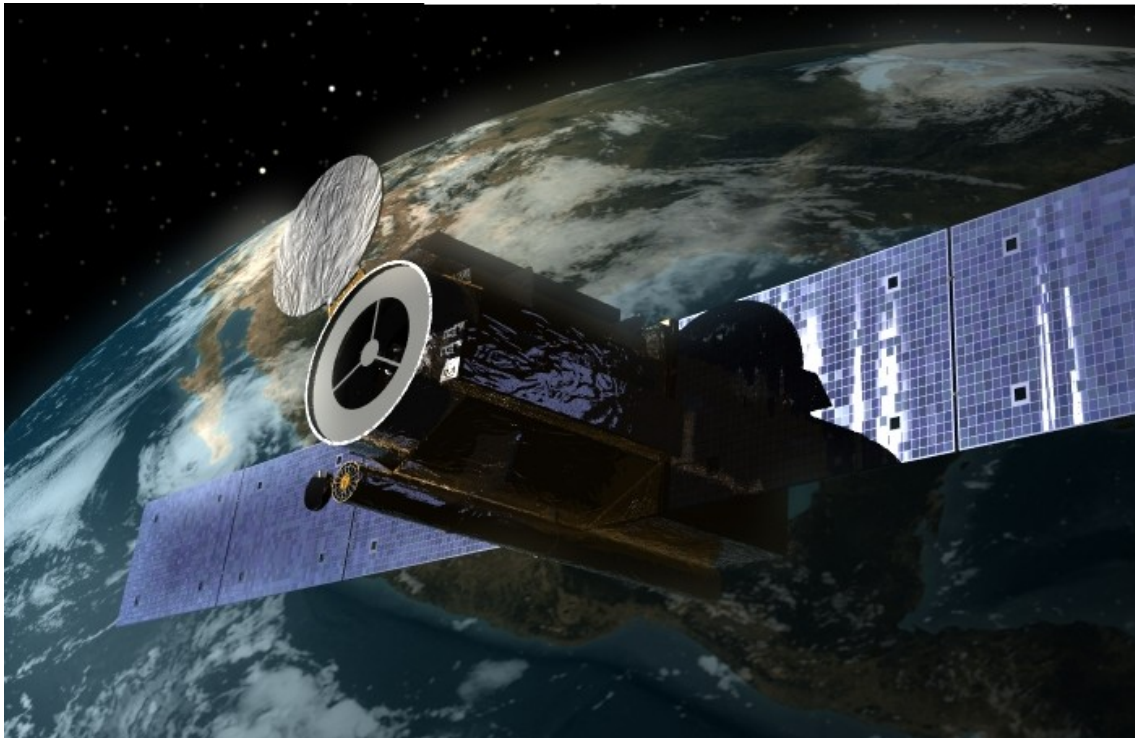
# Orbits for space telescopes

**Sun-synchronous orbit** (600-800 km, always sunlit)  
Solar observation telescopes (Hinode, Yohkoh, TRACE)

Precession due to Earth's oblateness is adjusted to match orbital period of Earth around the Sun

**Requires more energy**

**No occultations**



*Hinode (optical / UV / Xray  
solar observatory)*



# Orbits for space telescopes

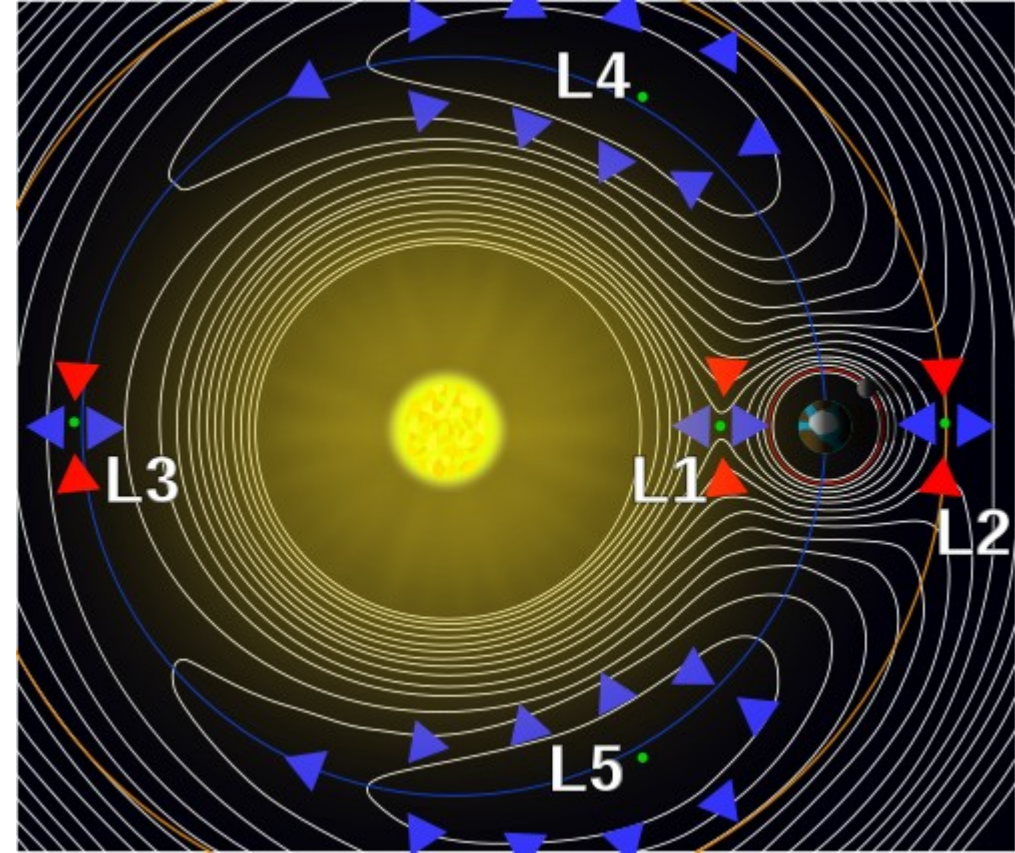
## Lagrange points (Sun-Earth)

points where combined gravitational force of Earth and Sun allows co-rotation with Earth around Sun.

**Stable environment (no eclipses, far from Earth and Moon)**

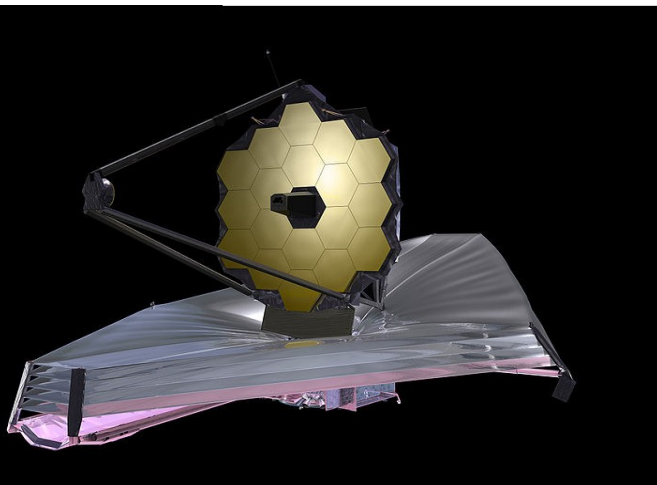
**Difficult access**

**Requires station-keeping (not stable)**



*Herschel  
3.5m IR/submm  
telescope in halo orbit  
around L2*

*JWST  
halo orbit around L2*



# Orbits for space telescopes

## Heliocentric: Earth trailing

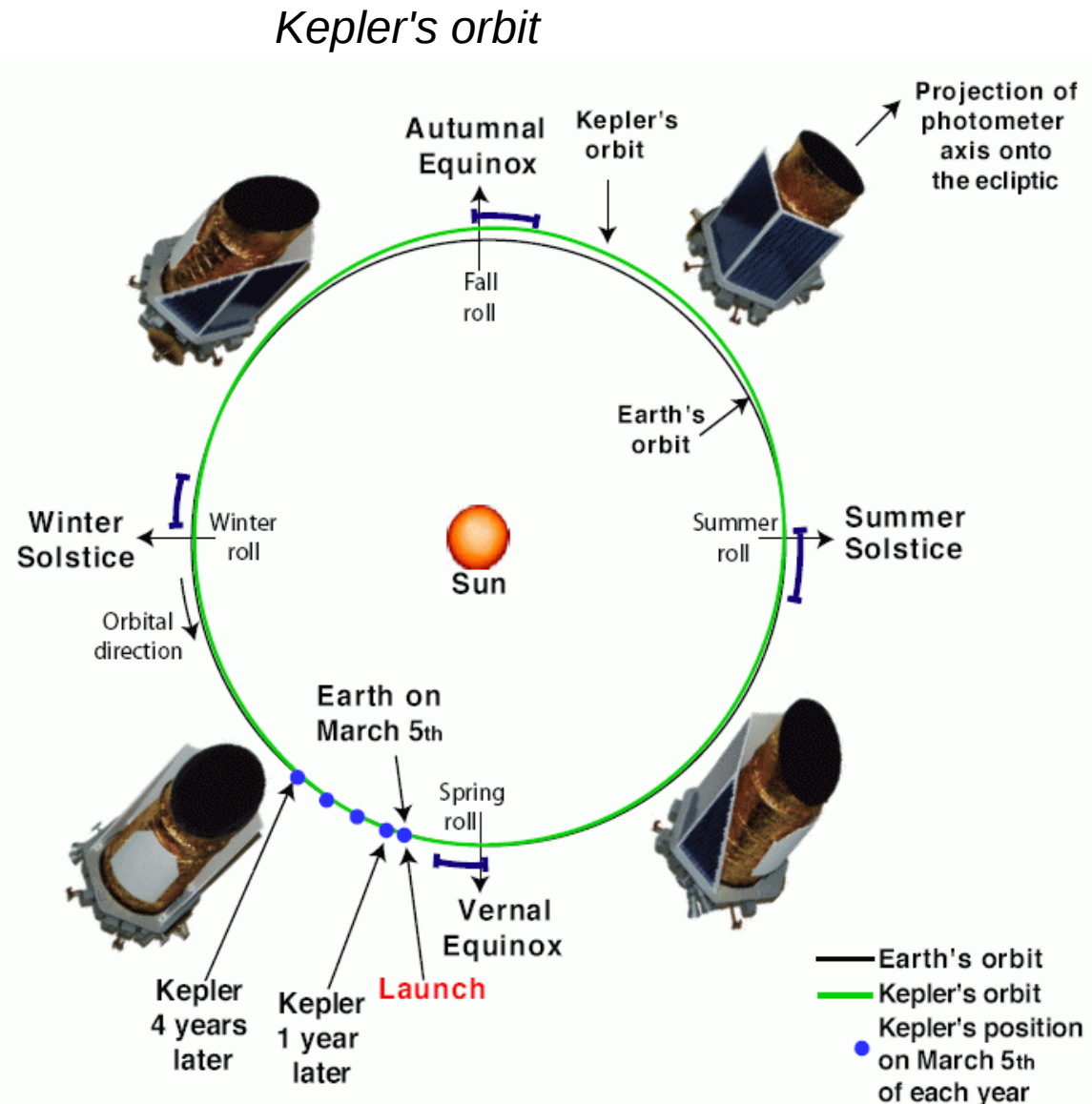
Orbit close to Earth's orbit  
Spacecraft slowly drifts away from Earth  
(~0.1 AU per year)

Stable environment (no eclipses, far from Earth and Moon)

No access

Reduced communication after a few years

No station-keeping



# Pointing space telescopes

**Reaction wheels** allow fine pointing and steering of the spacecraft without fuel (requires electric power provided by solar panels)

Change in speed of reaction wheel = smaller change in rotation speed for whole spacecraft

**Control momentum gyroscope (CMG)** = reaction wheel where the axis of rotation can be changed (as opposed to wheel rotation speed)

Reaction wheels and CMGs rely on conservation of angular momentum

Reaction wheels rotation speed can buildup with time, and needs to be offloaded using:

**magnetic torquer** (use Earth's magnetic field): only works if close to Earth

**thruster**: requires fuel

Solar wind

Pointing to few milli-arcsecond is achieved in space : Hubble Space Telescope pointing is better than 10 milli-arcsecond