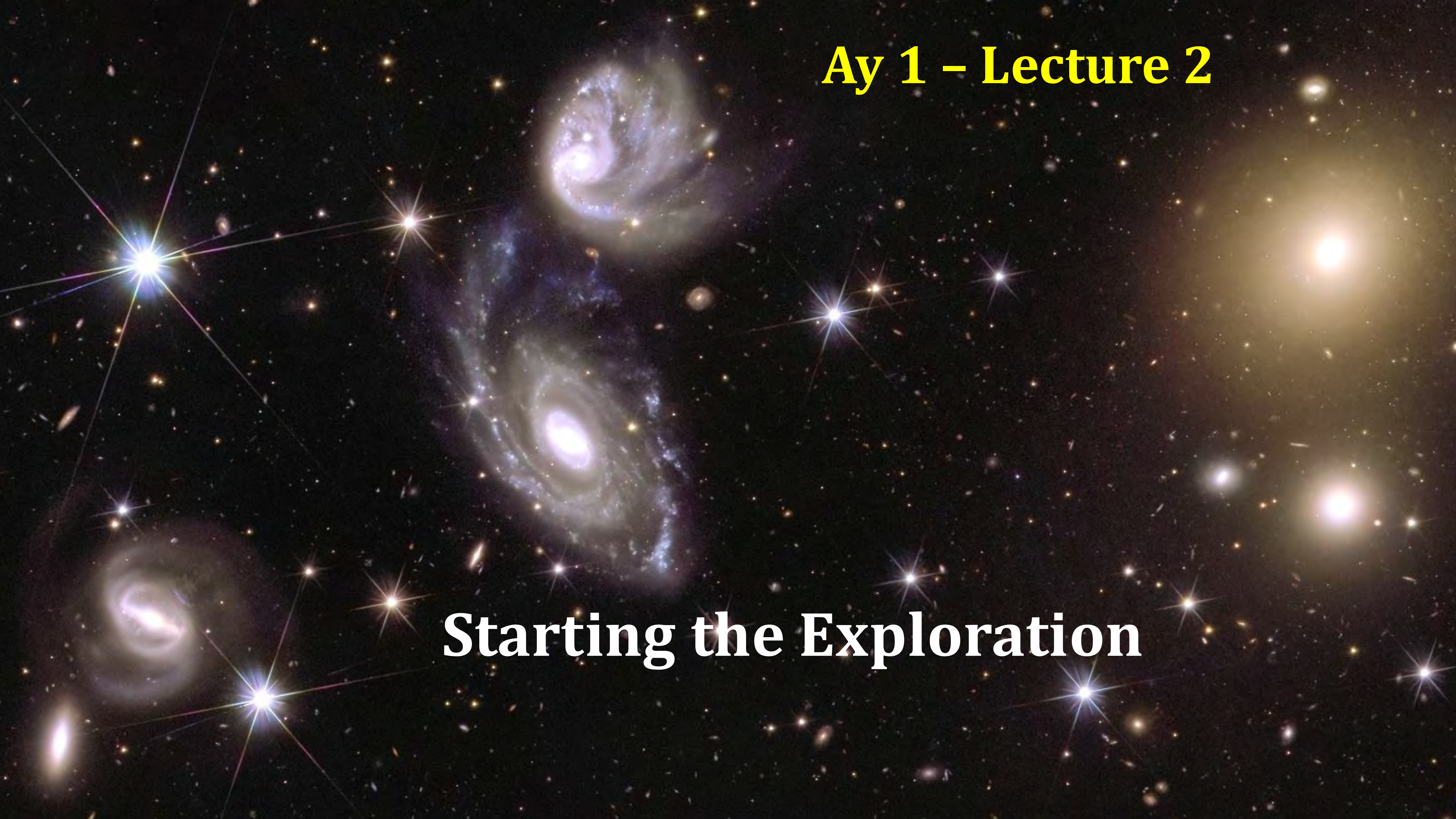


# Ay 1 – Lecture 2

# Starting the Exploration

# Some Commonly Used Units

- **Distance:**
  - ***Astronomical unit***: the distance from the Earth to the Sun, useful within the Solar system:

$$1\ \text{au} = 1.496 \times 10^{13}\ \text{cm} \sim 1.5 \times 10^{13}\ \text{cm} \sim 150\ \text{million km}$$

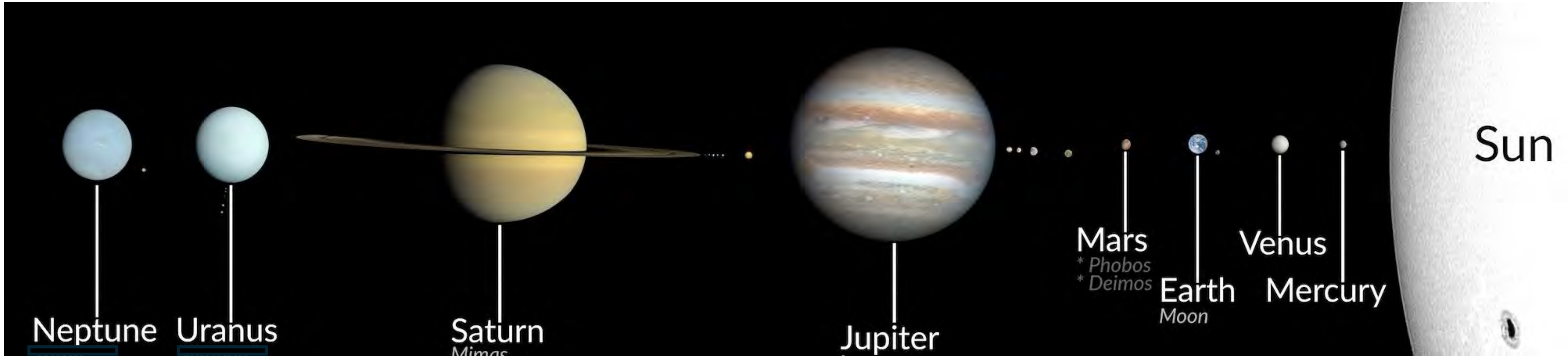
  - Light year: $c \times 1$ yr, $1\ \text{ly} = 9.463 \times 10^{17}\ \text{cm} \sim 10^{18}\ \text{cm}$
  - ***Parsec:*** the distance from which 1 au subtends an angle of 1 arcsec, useful for the distance in our Galaxy (pc or kpc) or extragalactic (Mpc to Gpc):

$1\ \text{pc} = 3.086 \times 10^{18}\ \text{cm} \sim 3 \times 10^{18}\ \text{cm}$ $\quad$ $1\ \text{pc} = 206{,}264.8\ \text{au} \sim 2 \times 10^{5}\ \text{au}$

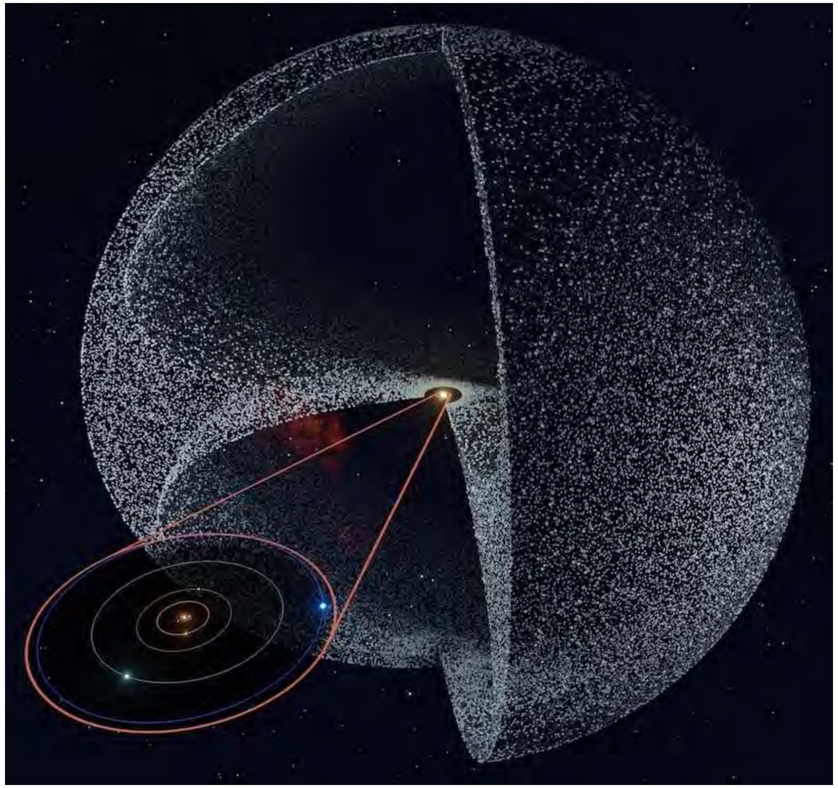
- **Mass and Luminosity:**
  - ***Solar mass***: $1\ M_\odot = 1.989 \times 10^{33}\ \text{g} \sim 2 \times 10^{33}\ \text{g}$
  - ***Solar luminosity***: $1\ L_\odot = 3.826 \times 10^{33}\ \text{erg/s} \sim 4 \times 10^{33}\ \text{erg/s}$

# Distances Within the Solar System

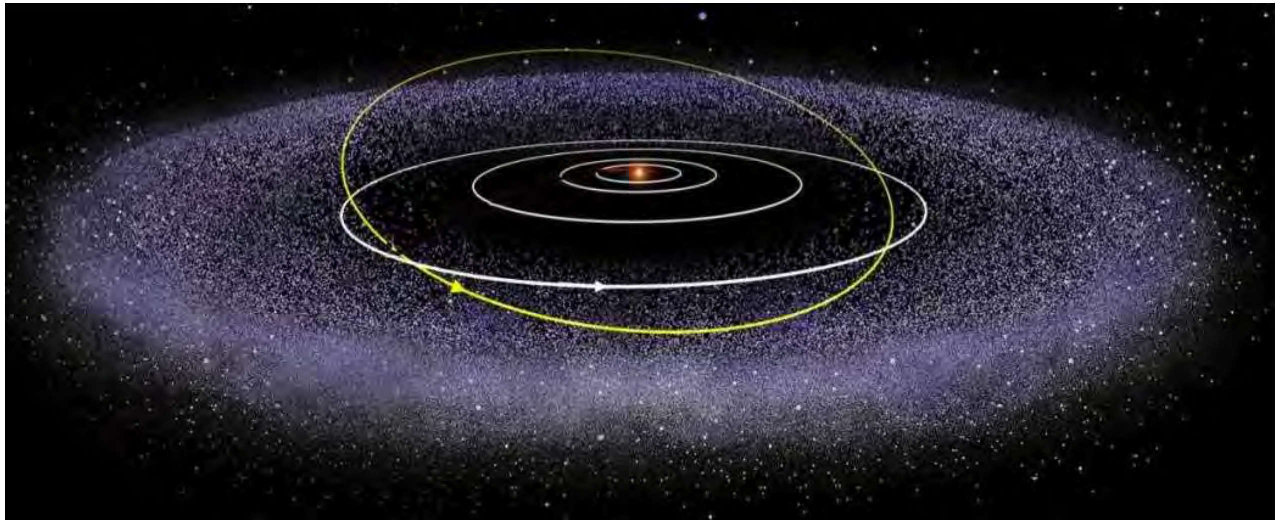
Inner Solar system: up to ~40 au




Oort Cloud: ~2000 to ~100,000 au →



Kuiper Belt: ~30 to ~55 au



Leftover planetesimals from the formation of the Solar system

# Interstellar Distances





# Distances in the Galaxy

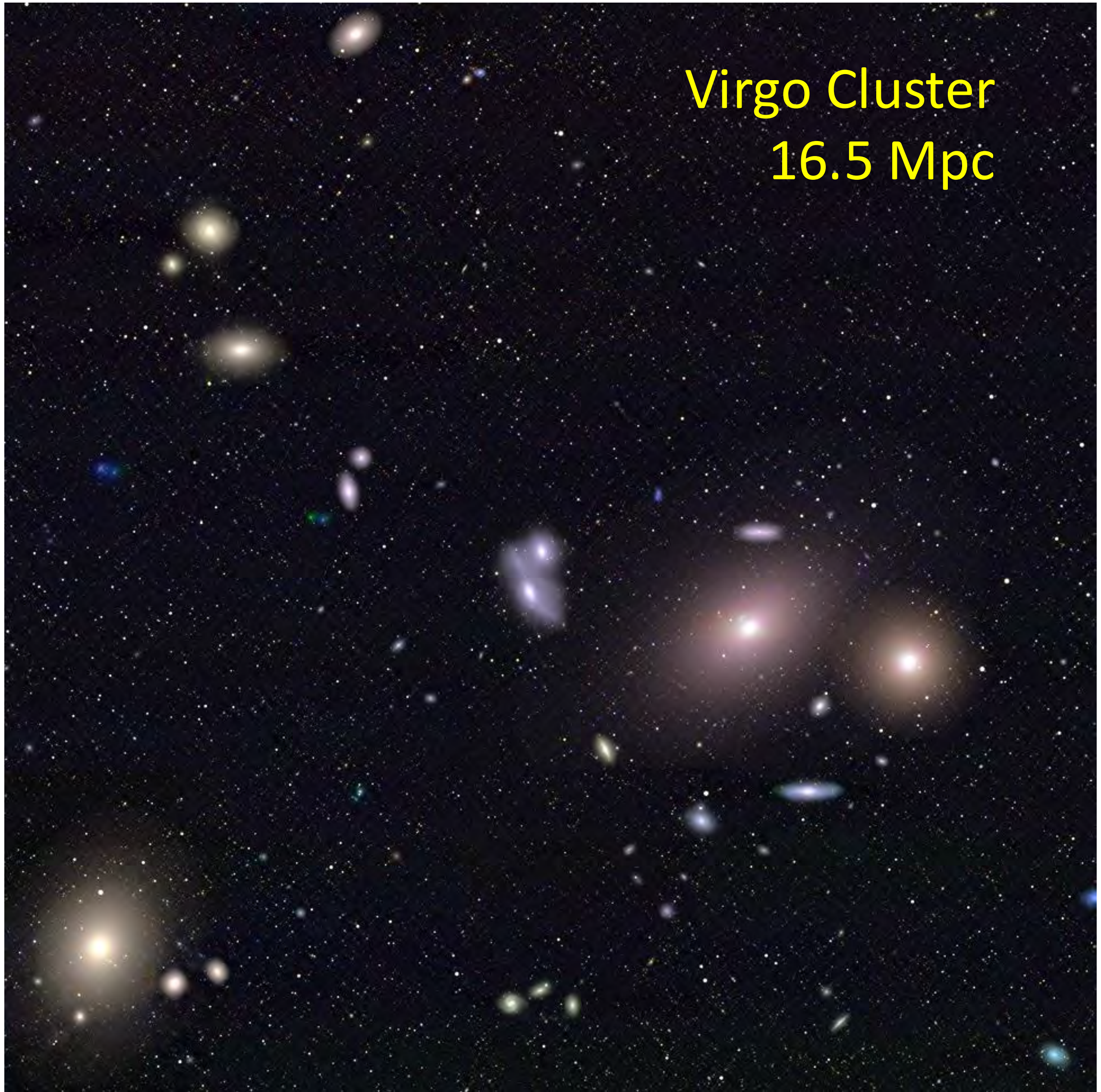

Milky Way diameter
~ 50 - 100 kpc

Distance to the Galactic center
~8 kpc

Galaxy rendering by Robert Hurt

# Our Extragalactic Neighborhood





# The Deep Universe

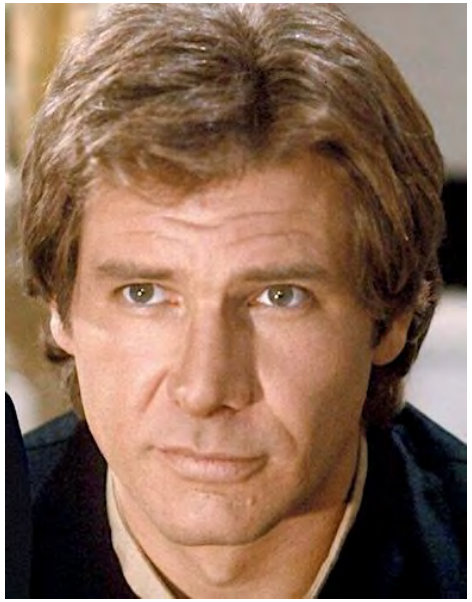
~1 – 10 Gpc

JWST JADES deep field

# A parsec is…

A. Radius of the Earth's orbit
B. About $10^{27}$ cm
C. Angle corresponding to the size of the Earth's orbit from 1 light year away
D. About $3 \times 10^{18}$ cm
E. About 200,000 astronomical units
F. About 3 Alderaan days

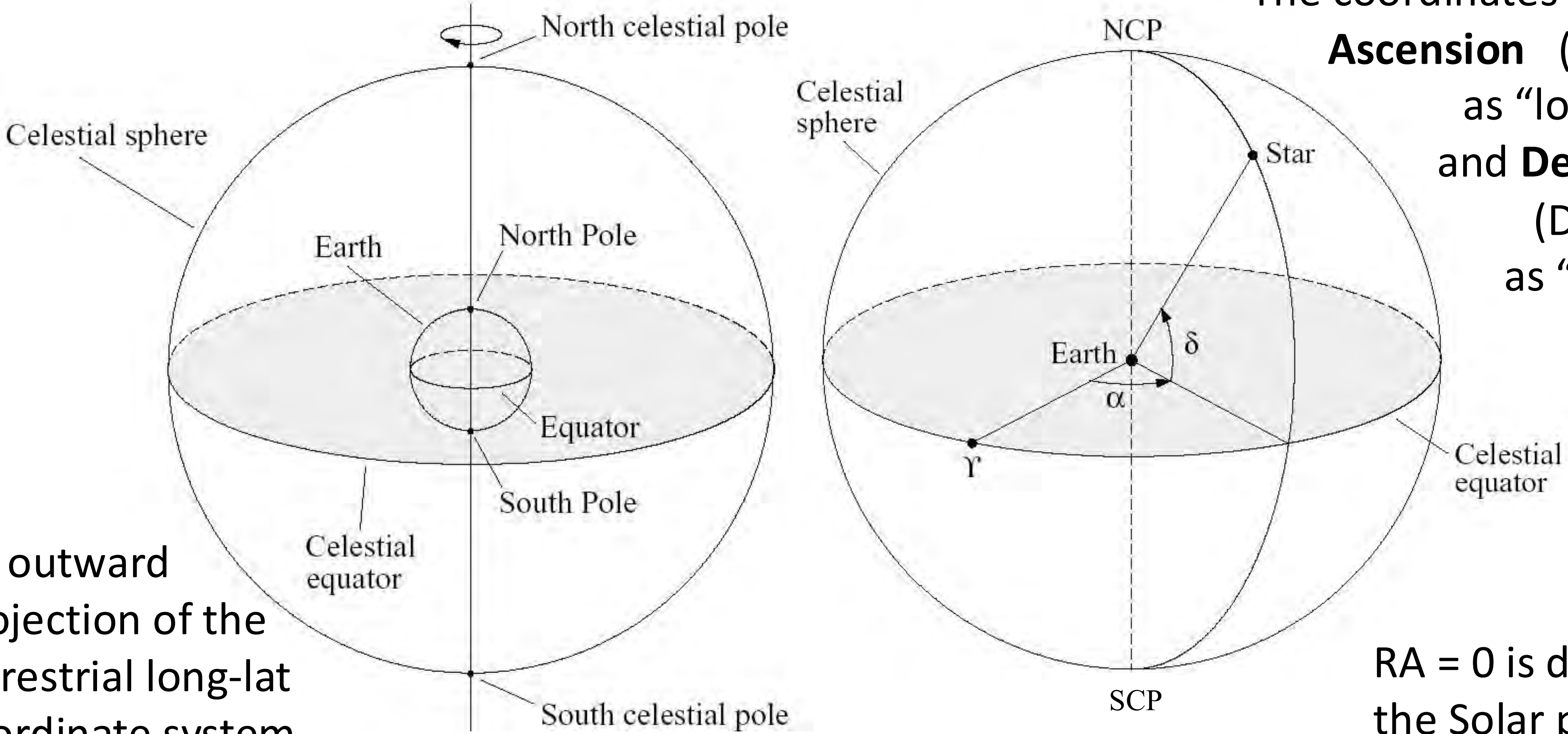
I completed the Kessel Run in just under 12 parsecs!



# The Celestial Sphere and Coordinate Systems

## The Equatorial System

The coordinates are **Right Ascension** (RA, or $\alpha$) as "longitude", and **Declination** (Dec, or $\delta$), as "latitude"

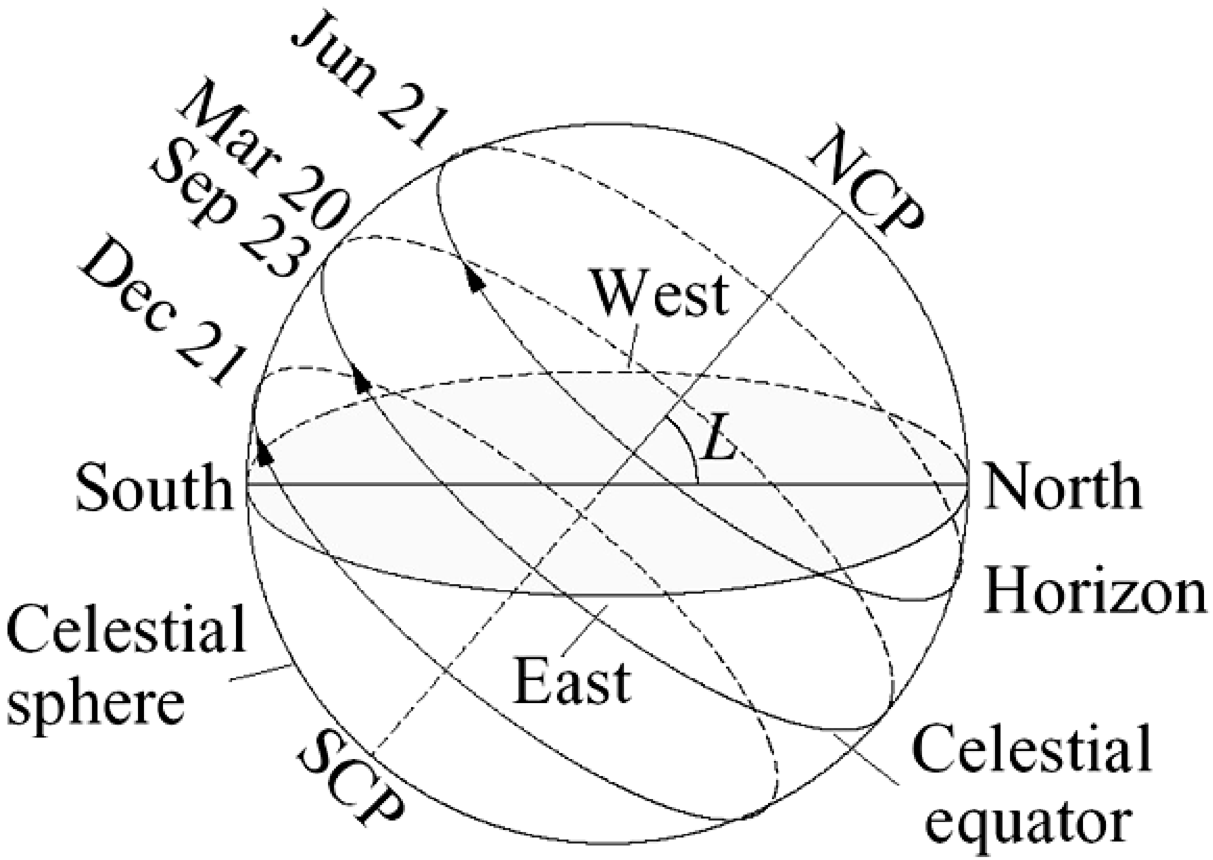


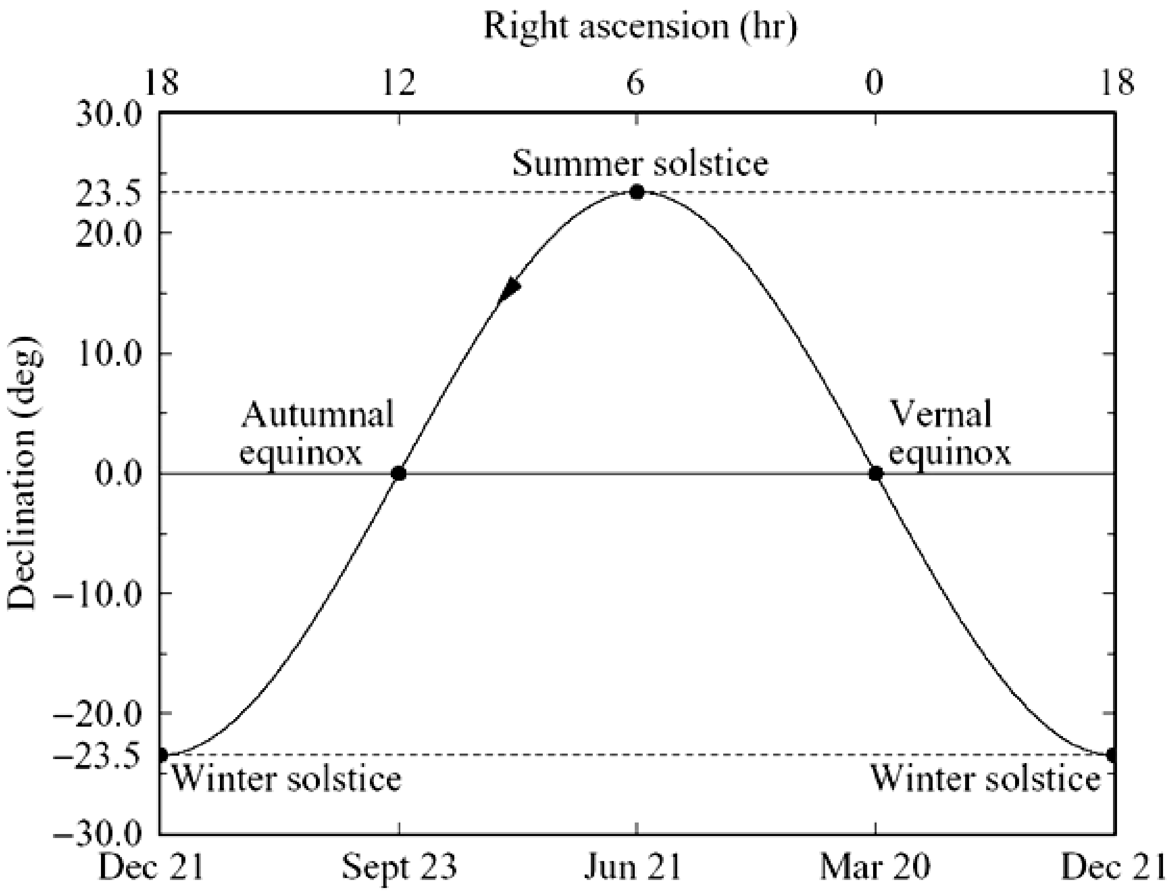

An outward projection of the terrestrial long-lat coordinate system onto the sky

RA = 0 is defined by the Solar position at the Vernal Equinox

# The Seasonal Change of the Solar Declination

Earth's rotation axis is tilted by 23.5° relative to its orbital plane (the ecliptic). This is the cause of Earth's seasons because it causes different hemispheres to receive varying amounts of sunlight throughout the year

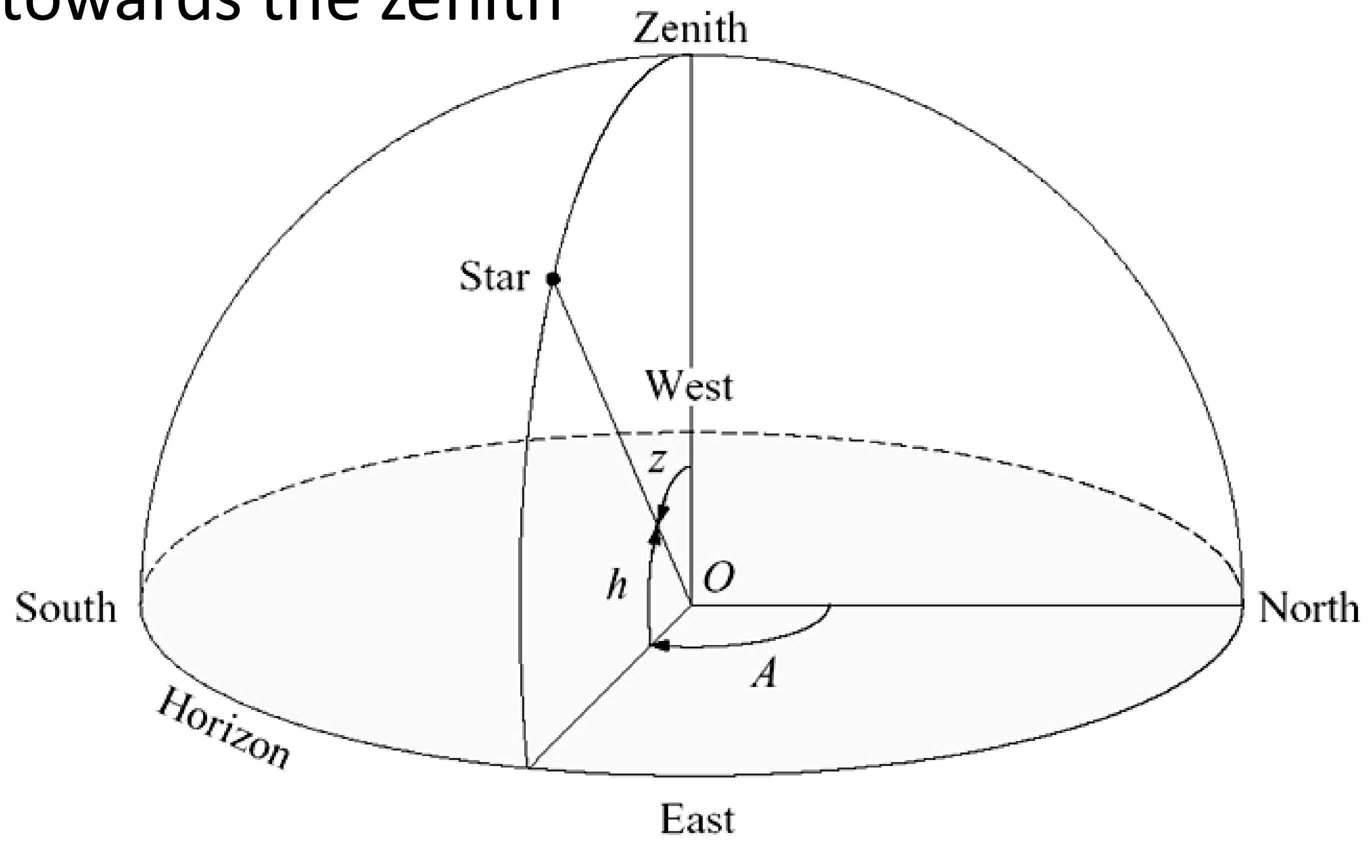


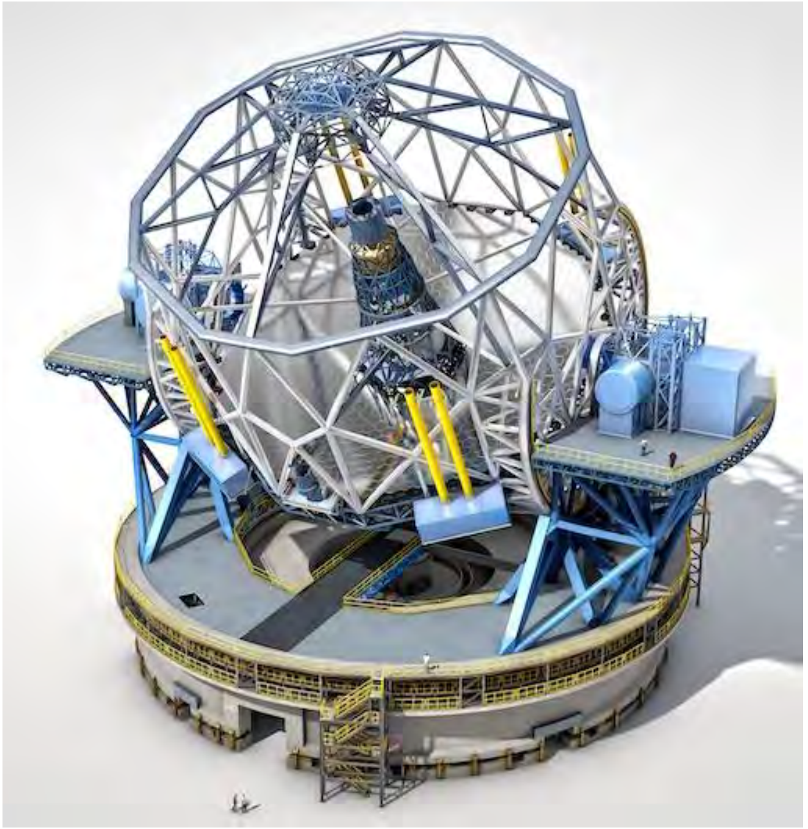
# The Altitude-Azimuth Coordinate System

It is obviously *location-dependent*

The coordinates are **azimuth**, measured clockwise from the direction to the North, and **elevation**, measured from the horizon towards the zenith



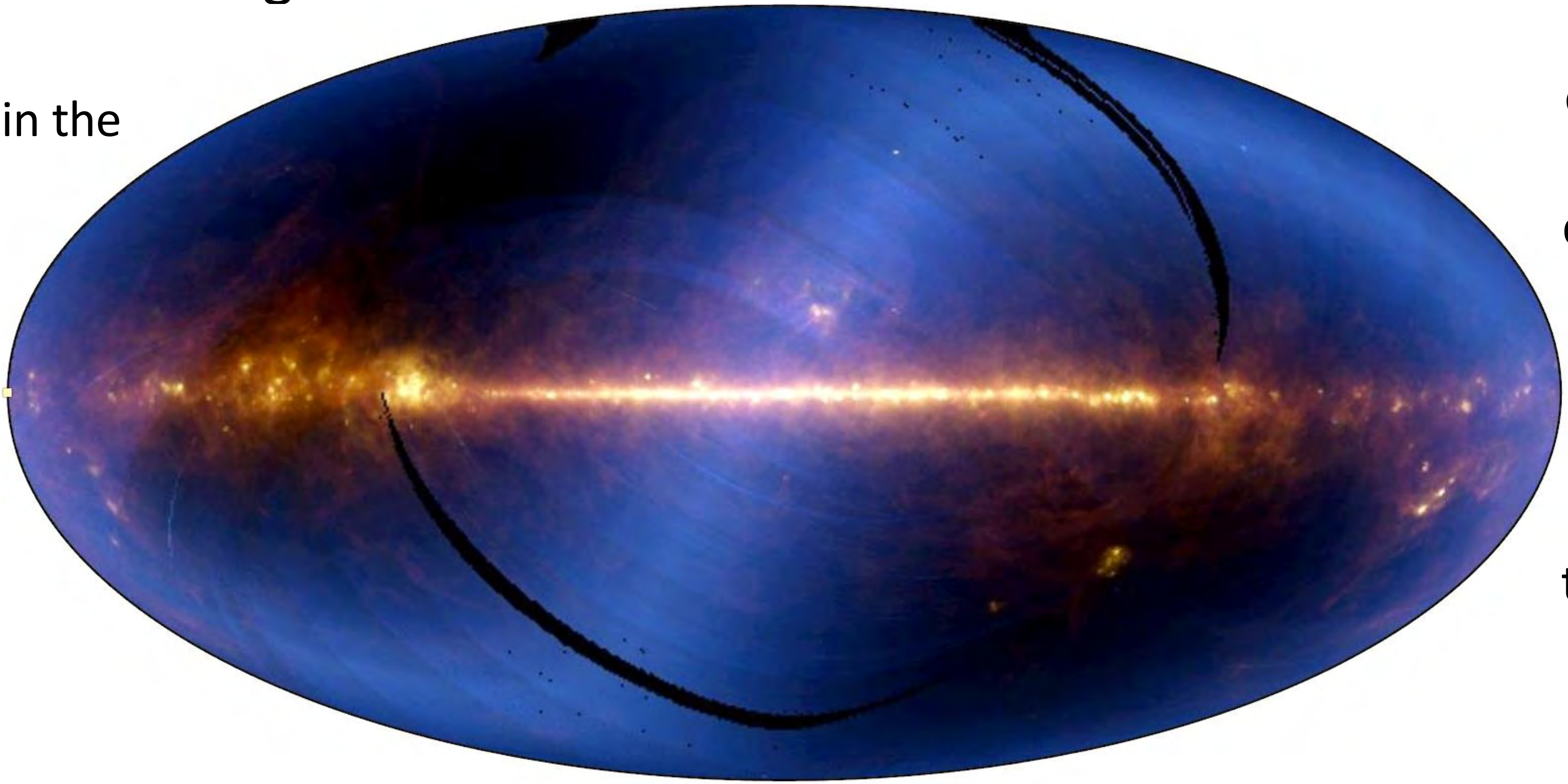

Most telescopes nowadays are built with Alt-Az mounts, so instruments need ti be rotated to match the sky



# Other Common Cellestial Coordinate Systems

**Ecliptic:** projection of the Earth's orbit plane defines the Ecliptic Equator. The Sun defines the longitude = 0

Infrared sky in the Galactic coordinates projection

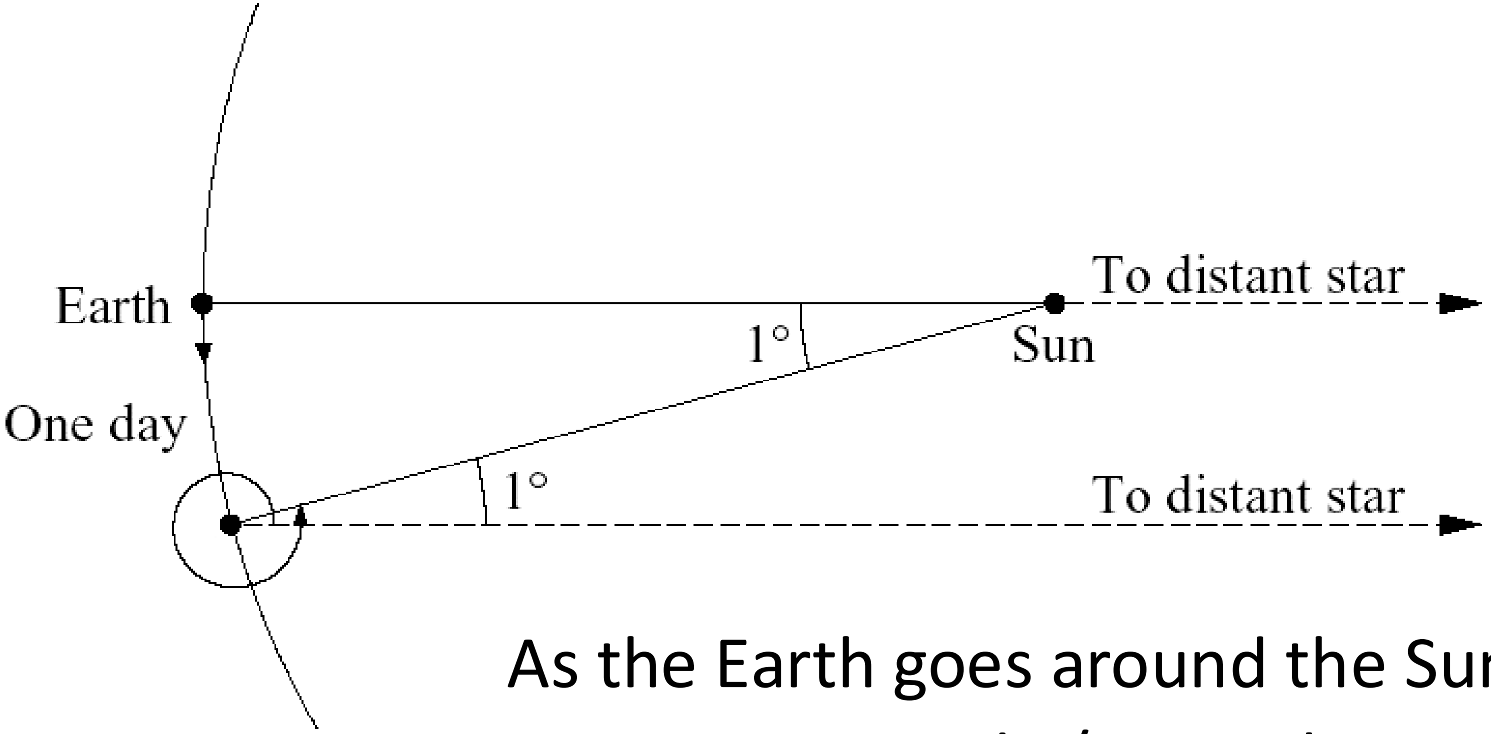


**Blue:** thermal emission from the Zodiacal dust along the Ecliptic

**Red:** thermal emission from the interstellar dust along the Galactic plane

**Galactic:** projection of the mean Galactic plane is close to the Galactic Equator; Galactic longitude = 0 is close, but not quite at the Galactic center

# Synodic and Sidereal Times




**Synodic** = relative to the Sun

**Sidereal** = relative to the stars

As the Earth goes around the Sun, it makes an extra turn. Thus:

Synodic/tropical year = 36**5**.25 (solar) days

Sidereal year = 36**6**.25 sidereal days = 365.25 solar days

**Universal time**, UT = relative to the Sun, at Grenwich

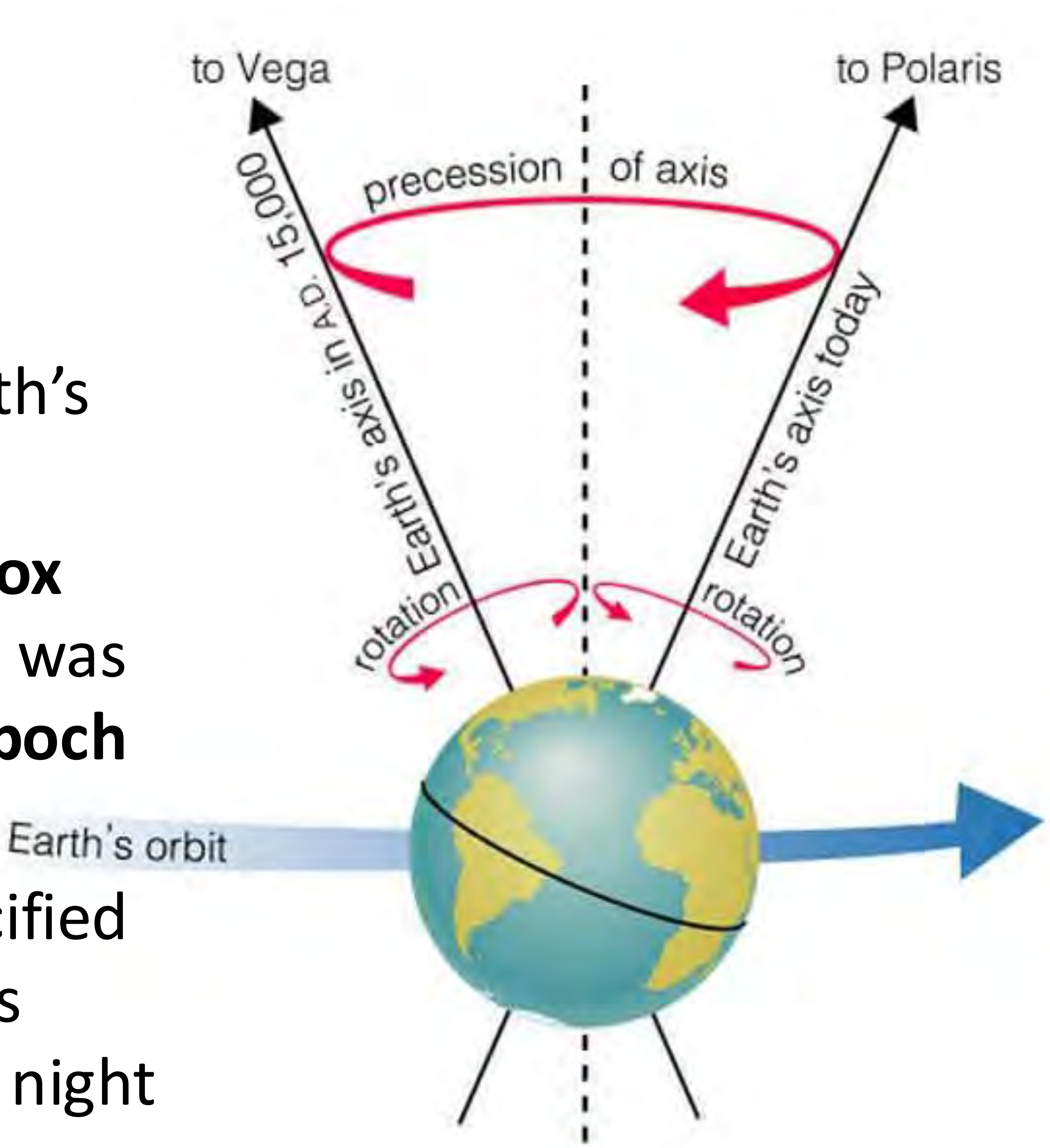
**Local Sidereal Time** (LST) = relative to the celestial sphere

= RA now crossing the local meridian (to the South)

They differ by about 4 minutes per day

# The Precession of the Equinoxes

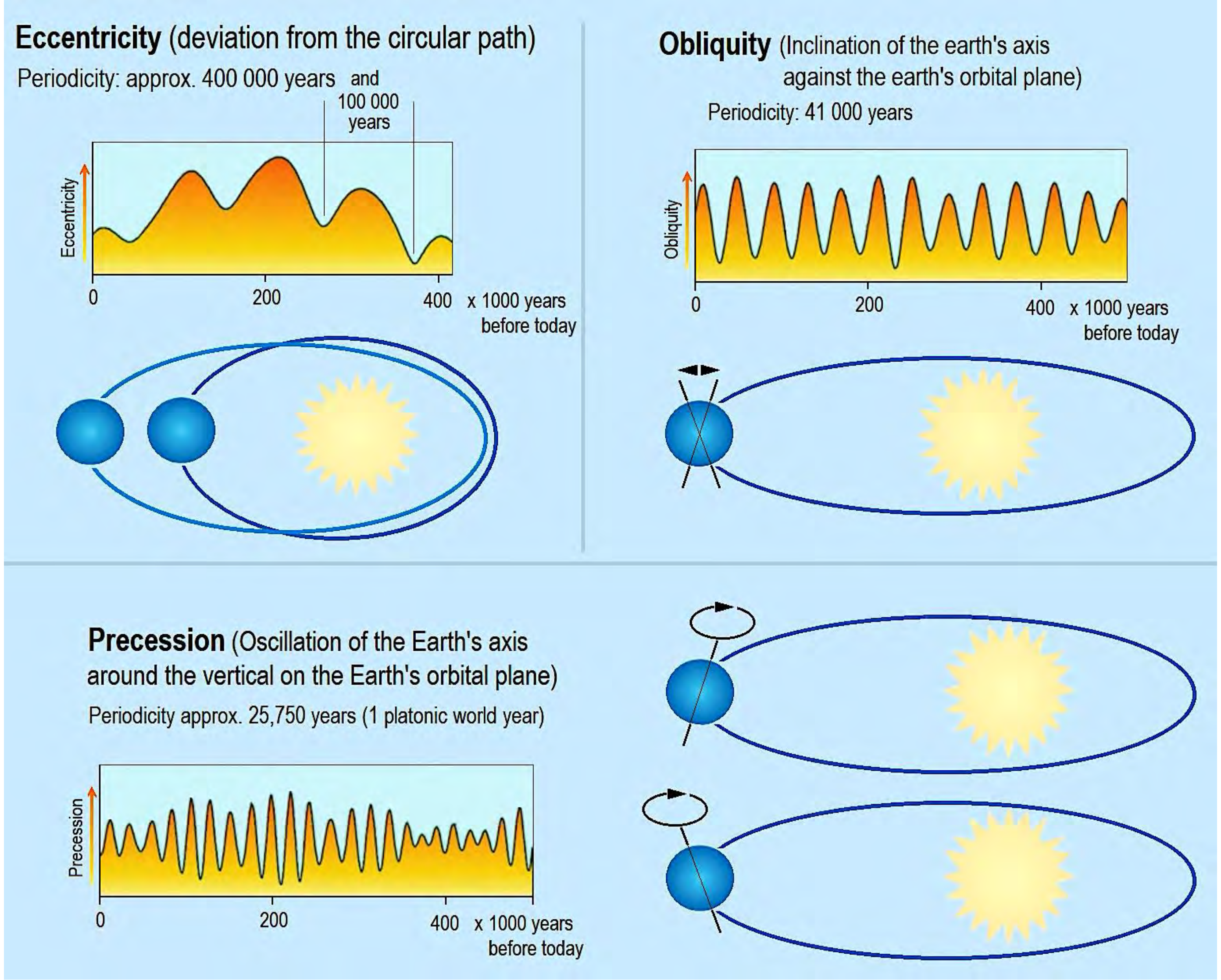
- The Earth's rotation axis **precesses** with a period of ~ 26,000 yrs, caused by the tidal attraction of the Moon and Sun on the the Earth's equatorial bulge
- There is also **nutation** (wobbling of the Earth's rotation axis), with a period of ~19 yrs
- Coordinates are specified for a given **equinox** (e.g., B1950, J2000, coordinate system as it was on Jan. 1, 1950, or 2000) and sometimes **epoch** (e.g., 2026.2)
- Astronomical catalogs are always for a specified epoch, but for observations the coordinates need to be precessed to the epoch for that night



# Earth's Orbit, Rotation, and the Ice Ages

**Milankovich Theory:** cyclical variations in Earth-Sun geometry (orbit eccentricity, rotation axis tilt, precession) combine to produce variations in the amount of solar energy that reaches Earth, in particular the ice-forming regions

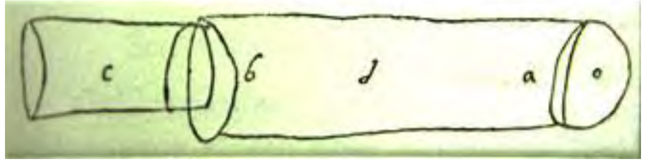
These variations can be computed for the past, and they correlate well with the ice ages



# The change of seasons is due to…

A. The tilt of the Earth's rotation axis relative to the celestial equator
B. The tilt of the Earth's rotation axis relative to the plane of the ecliptic
C. Eccentricity of the Earth's orbit
D. Precession of the equinoxes
E. Human sacrifices to the gods

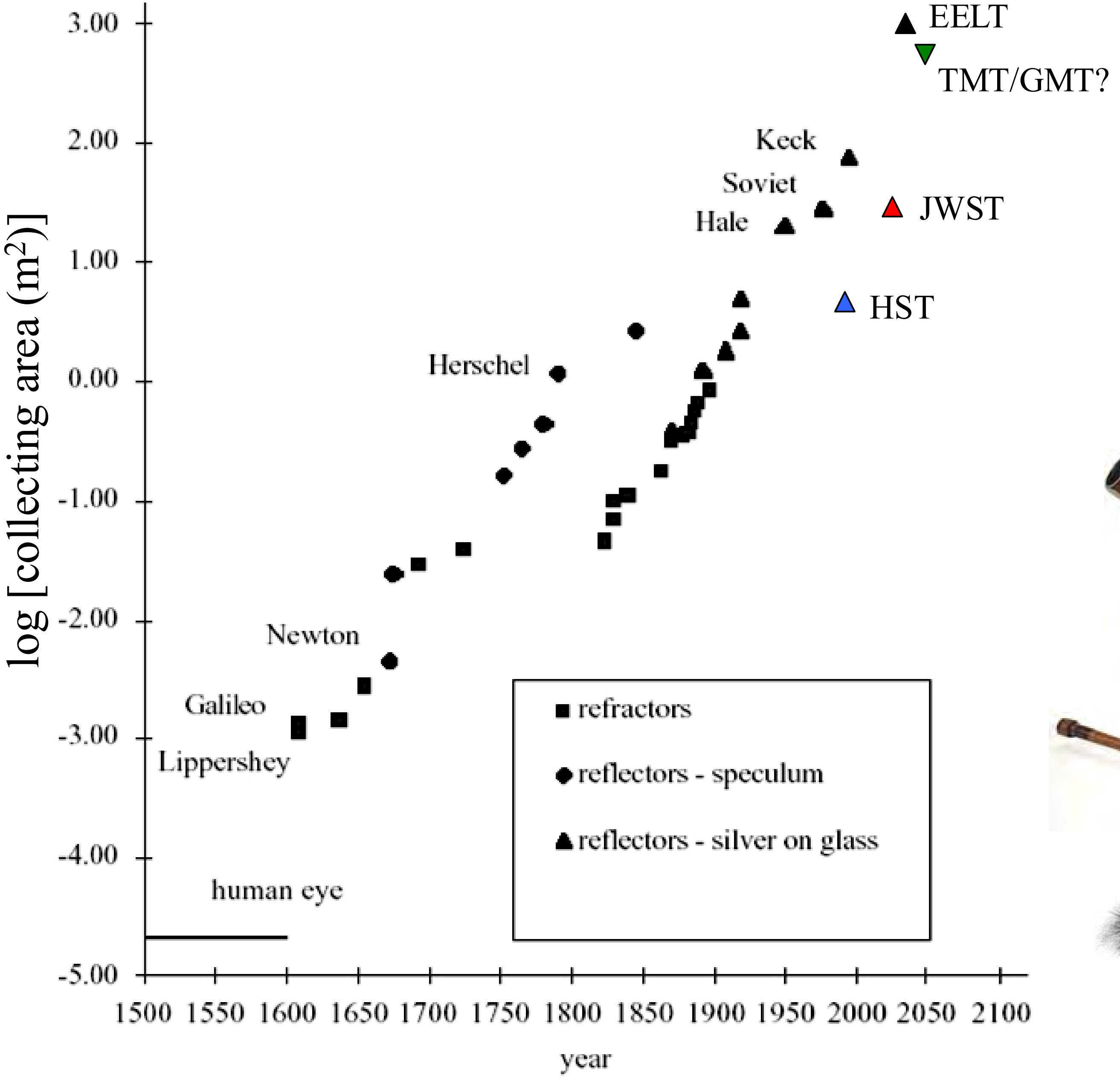
# History of Visible Light (±)Telescopes

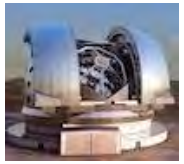


Giovanibattista della Porta, in a letter written in August 1609

Galileo's refractor (1609)

Newton's reflector (1671)



# Modern Telescope Mirror Designs

- Lightweight honeycomb structures
- Thin meniscus (+ active optics)
- Segmented (all segments parts of the same conic surface); e.g., the Kecks, JWST/TMT/EELT
- Multiple (each mirror/segment a separate telescope, sharing the focus); e.g., HET, SALT
- Liquid, spinning (not really used or practical)

**The critical issues:**

- Surface errors (should be < $\lambda/10$)
- Active figure support (weight, thermal)
- Thermal equilibrium (figure, seeing)

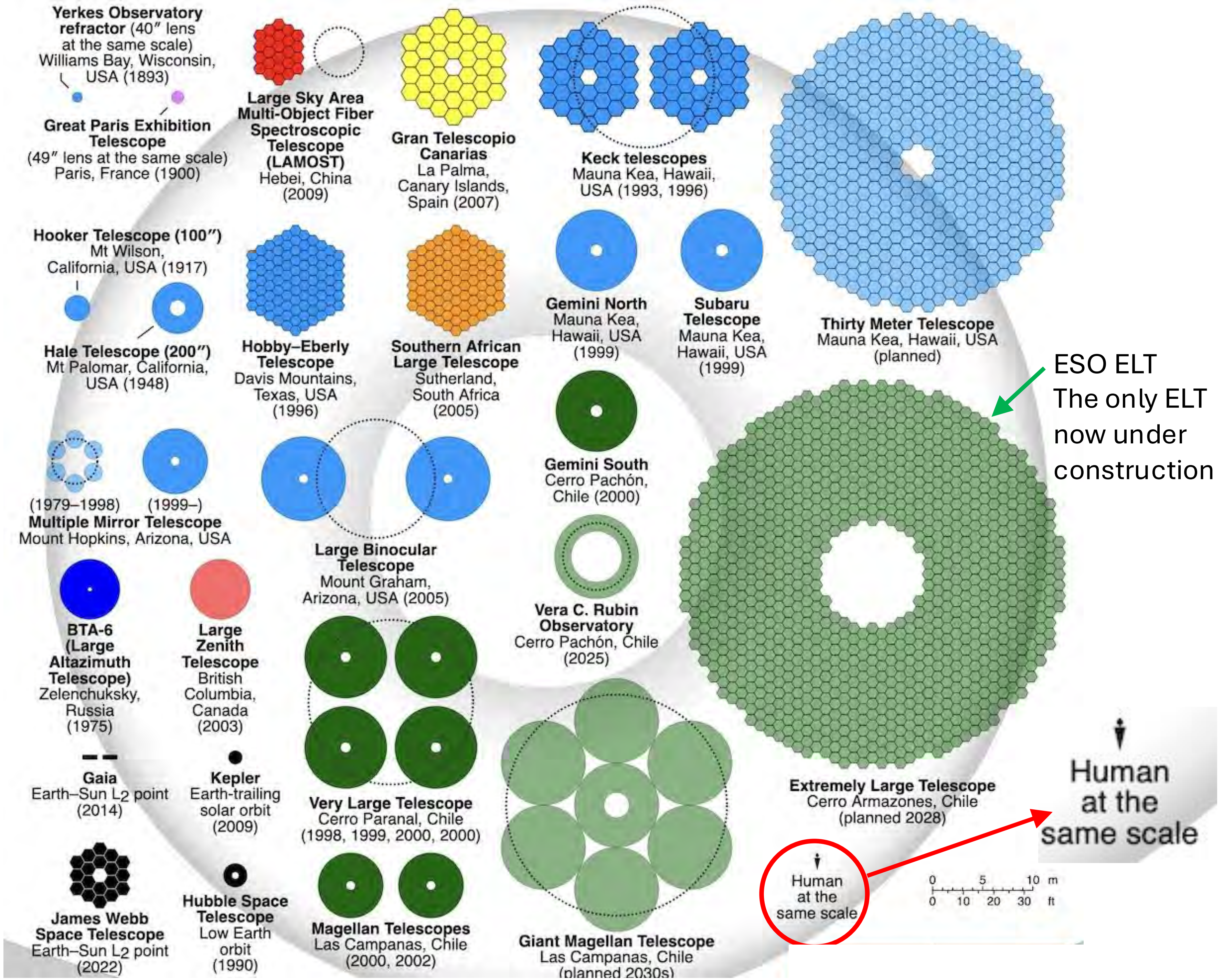
Palomar 200” mirror

ESO VLT 8m mirror cell

Keck 10m segmented primary

Hobby-Eberly multiple-mirror primary

# Past, Present, and Future Large Telescopes



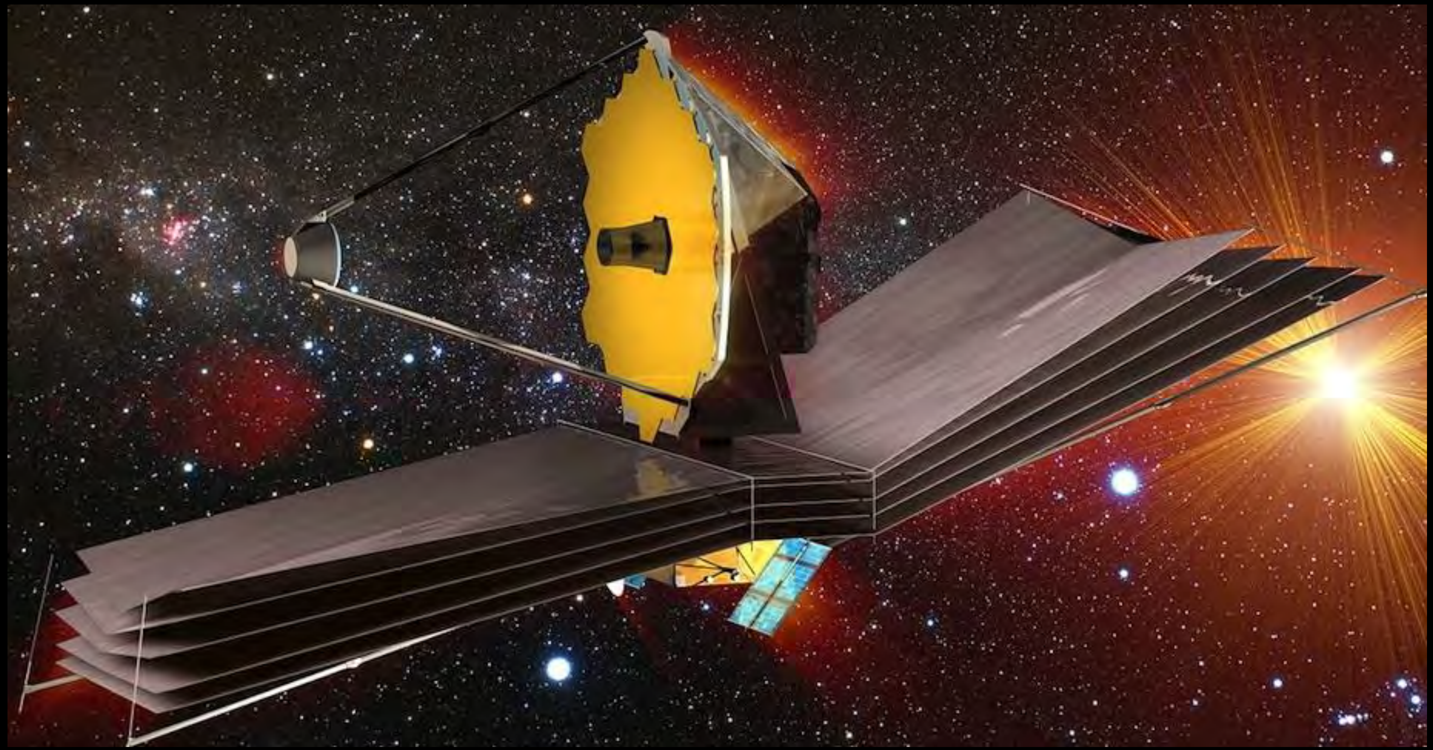
# Night in America:

# Light Pollution

This is why modern observatories are built at dark sites, like the Northern Chile

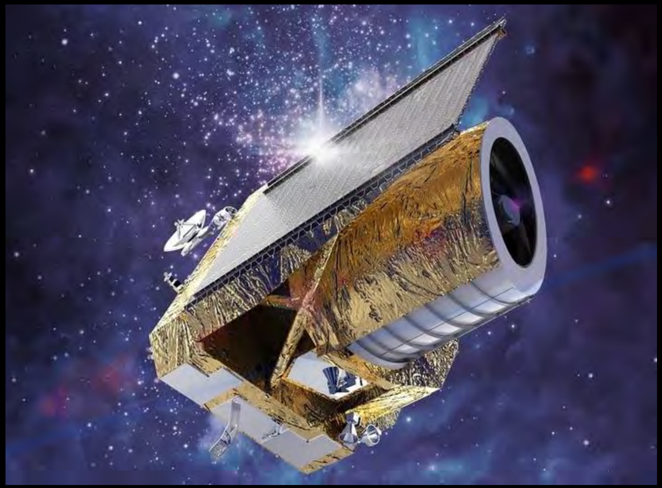
# Telescopes in Space

James Webb (JWST), 6.5 m, 2021-?

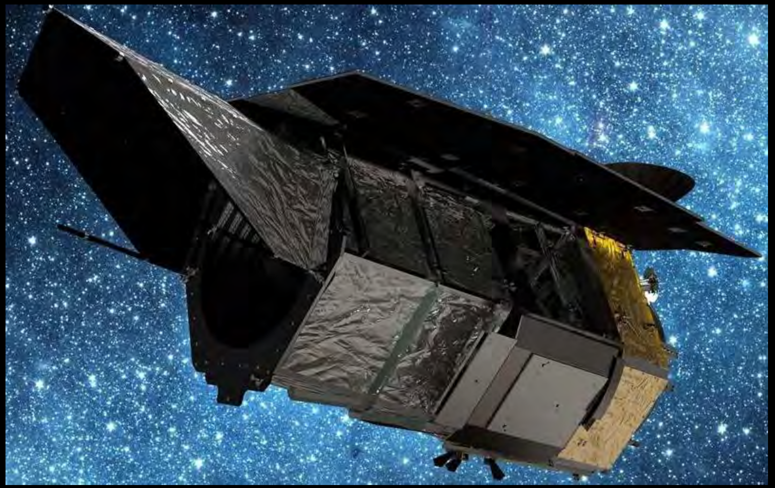


Hubble (HST), 2.4 m, 1990-?

Euclid, 1.2 m, 2023-?



Roman, 2.4 m, 2027?-?



# Space Observatories From IR to UV


# Distances and Parallaxes

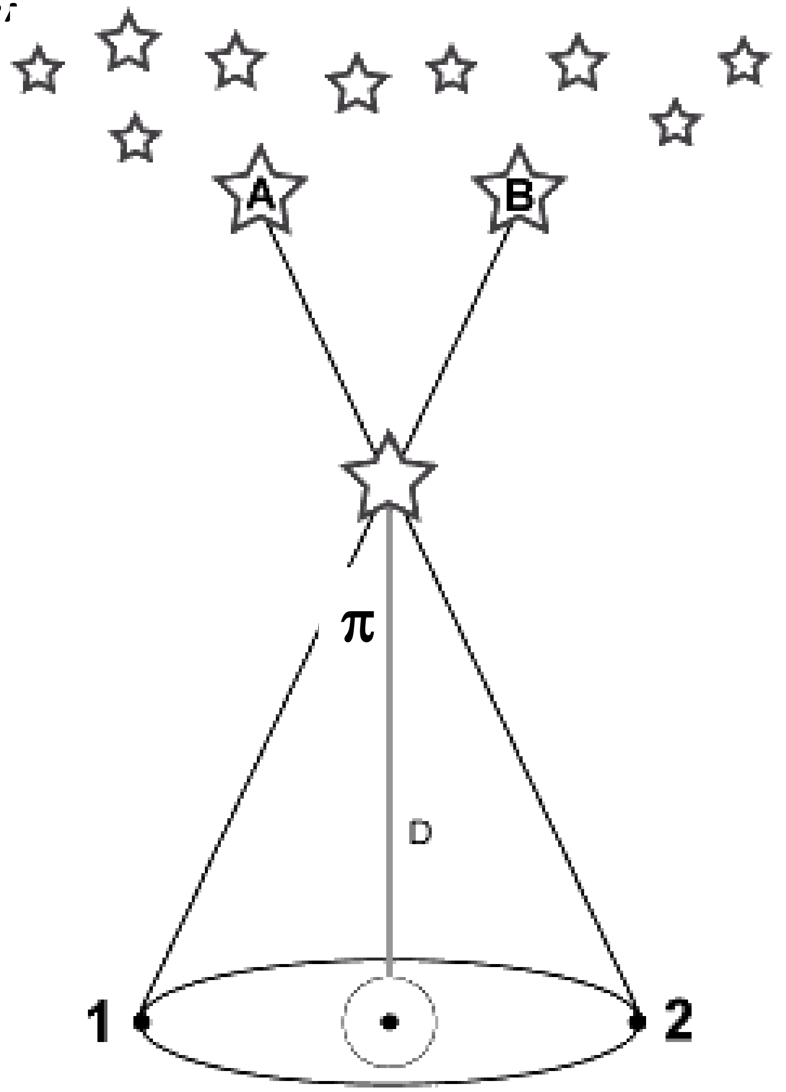
Distances are necessary in order to convert apparent, measured quantities into absolute, physical ones (e.g., luminosity, size, mass…)

- Stellar parallax is ***the only*** direct way of measuring distances in astronomy! Nearly everything else provides relative distances and requires a basic calibration

- Small-angle formula applies:

$$\mathbf{D}\ [\mathrm{pc}] = \mathbf{1} / \pi\ [\mathrm{arcsec}]$$

- Limited by the available astrometric accuracy (now ~ 0.1 milliarcsec, i.e., D < 10 kpc or so)

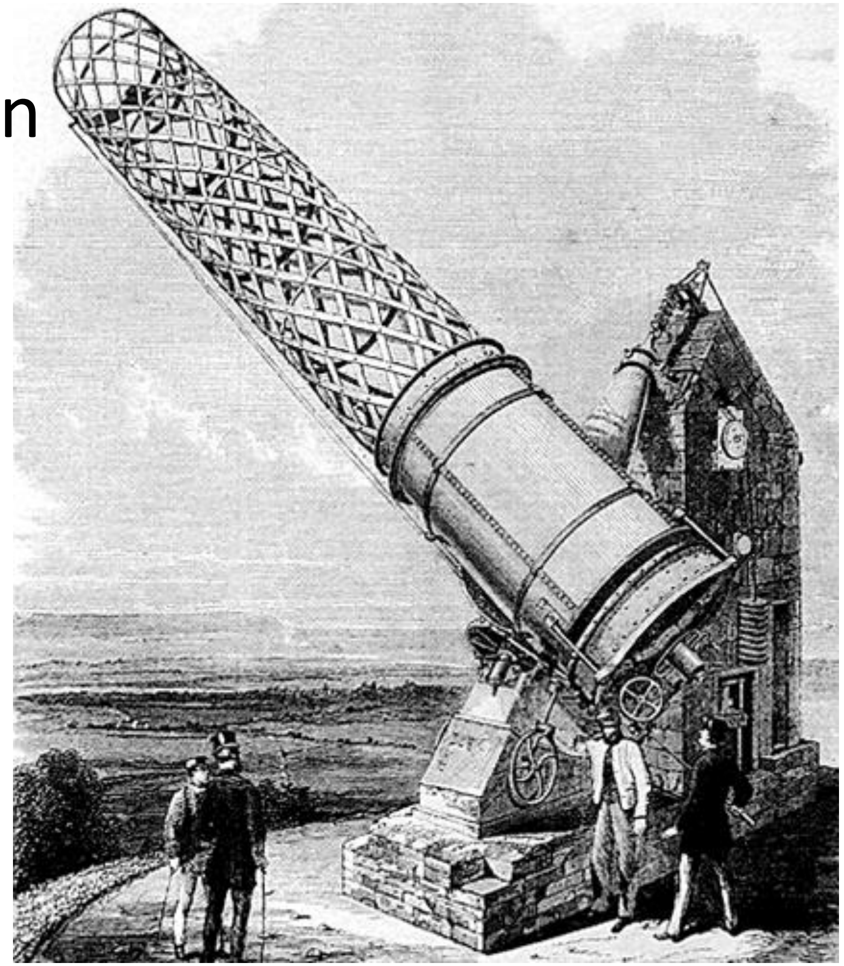


Parallax

# How Far Can We Measure Parallaxes?

Since nearest stars are > 1 pc away, and ground-based telescopes have a seeing-limited resolution of ~1 arcsec, measuring parallaxes is hard

**1838**: Friedrich Bessel measured $\pi$ = 0.316 arcsec for star 61 Cyg (modern value $\pi$ = 0.29 arcsec)



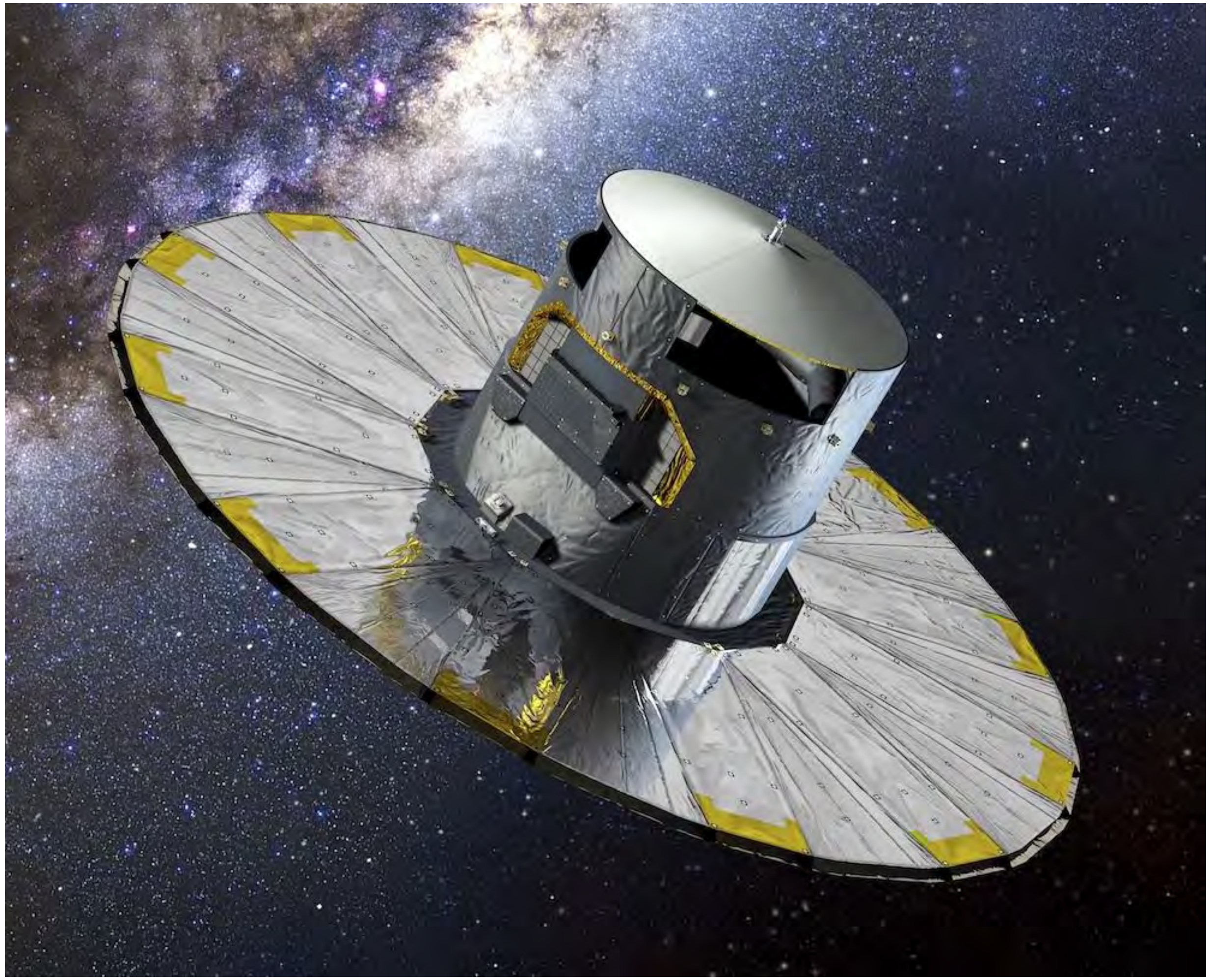
**Current ground-based**: best errors of ~ 0.001 arcsec

**Space-based** (*Gaia* mission) ~ 0.0001 arcsec

# How Far Can We Measure Parallaxes?

***Hipparcos* satellite** (1989 – 1993, last data release 2000) measured ~$10^5$ bright stars with errors ~0.001 arcsec (1 kpc distance).

***Gaia* satellite** (launched 2013) measured positions of ~ $2 \times 10^9$ stars with an accuracy < 0.1 milliarcsec (distances ~ 10 kpc, i.e., most of the Milky Way!) + a lot of other data. Data Release 4 expected in Dec. 2026



This had a ***major impact*** on the stellar and Galactic astronomy

# Key Concepts in This Lecture

- Some commonly used **units**:
  - **Astronomical unit**: the Earth-Sun distance, 1 au = $1.496 \times 10^{13}$ cm ~ 150 million km
  - **Light year**: c × 1 yr, 1 ly = $9.463 \times 10^{17}$ cm ~ $10^{18}$ cm
  - **Parsec**: the distance from which 1 au subtends an angle of 1 arcsec, 1 pc = $3.086 \times 10^{18}$ cm ~ $3 \times 10^{18}$ cm, 1 pc = 206,264.8 au ~ $2 \times 10^{5}$ au
  - **Solar mass**: 1 $M_\odot$ = $1.989 \times 10^{33}$ g ~ $2 \times 10^{33}$ g
  - **Solar luminosity**: 1 $L_\odot$ = $3.826 \times 10^{33}$ erg/s ~ $4 \times 10^{33}$ erg/s
- Common **coordinate systems** are **Equatorial** (RA ~ longitude, Dec ~ latitude), **Alt-Az** (altitude and azimuth), **Ecliptic,** and **Galactic**
- Common **time** systems are **synodic** (based on the solar noon) and **siderial** (based on the stars, has an extra day in a year, due to the Earth's orbit around the Sun)
- Earth's rotation **axis is tilted by 23.4$^o$**, and its **precession** has a period ~ 26,000 yrs
- **Parallaxes** are the only real, geometric measure of distance in astronomy

?