ASTR20A:
Introduction to Astrophysics I

Dr. Devontae Baxter

Lecture 2

Tuesday, September 30, 2025

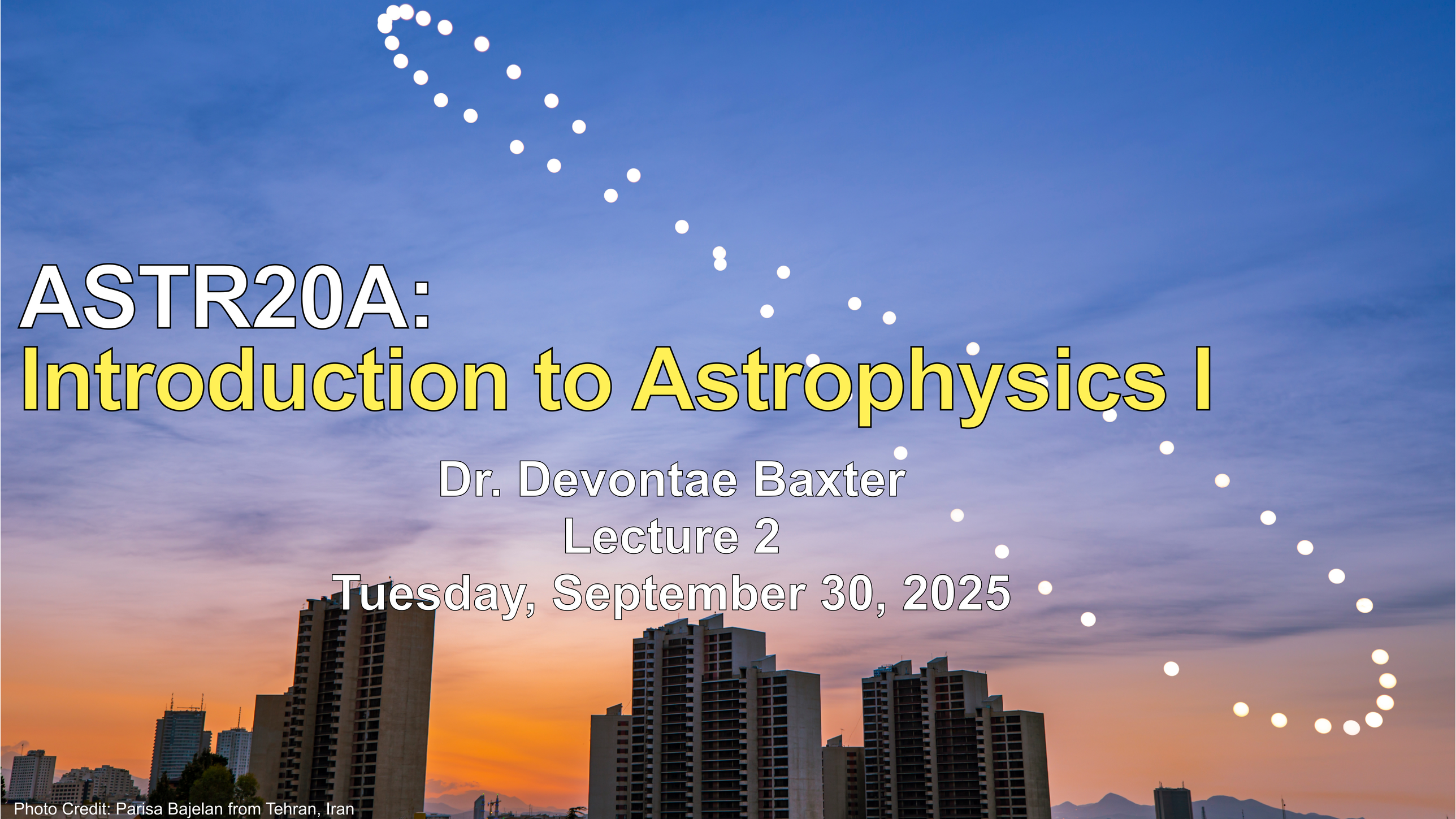
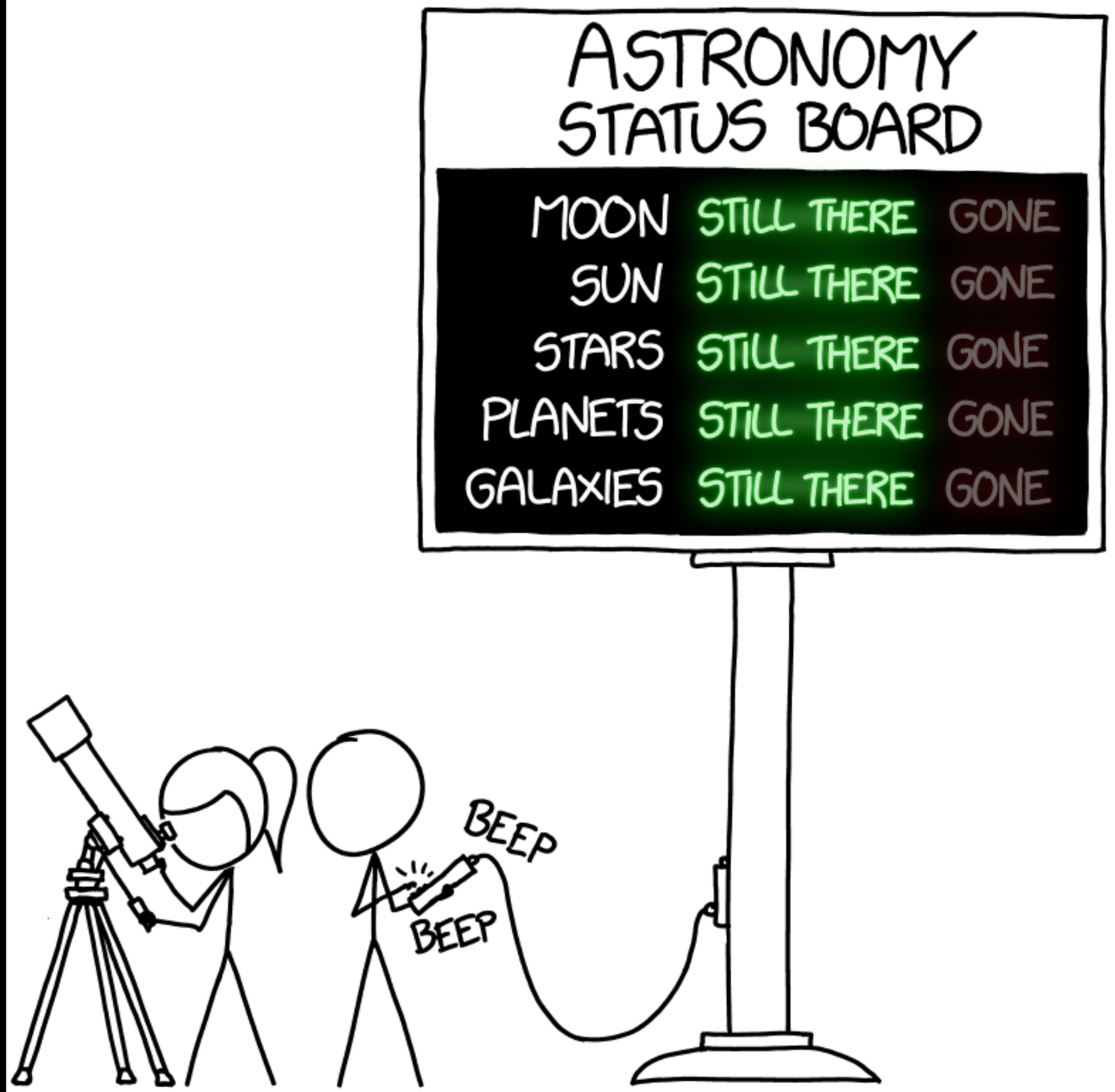


Photo Credit: Parisa Bajelan from Tehran, Iran

Announcements

- HW1 is a Canvas quiz. The other HW assignments will submitted via *GradeScope*.
- Coding assignment #1 is currently available on DataHub. To fetch the assignment:
    1. Log in to DataHub.
    2. Click the "Nbgrader" tab.
    3. Click "Assignment List".
    4. Click "Fetch" next to Coding Exercise 1.
    5. Once you complete the assignment, return to "Assignment List" and click "Submit".
- HW1 is due Sunday, 10/5 by 11:59 pm via Canvas
- Coding exercise #1 due 10/5 by 11:59 pm via DataHub.




Questions?

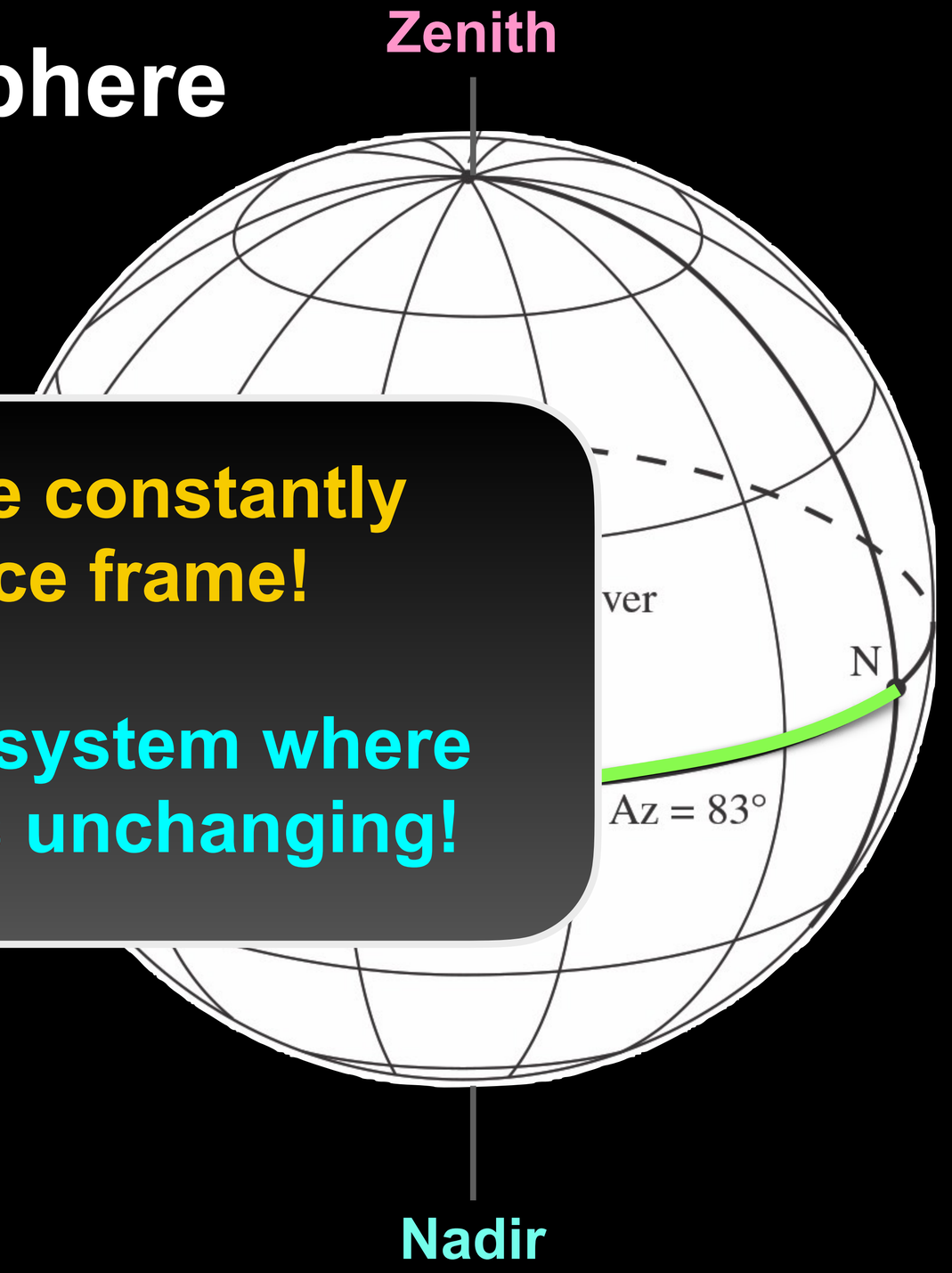
Review: Coordinates on a Sphere

(observer's frame – *horizontal coord system*)

- **Zenith** - the point directly *above* the observer.
- **Nadir** - the poi
observer.
- **Azimuth** - angl
Horizon Circle,
typically **taken**
- **Altitude** - angle **above** the *observer's horizon*.

Wonderful, but **stars are constantly moving in this reference frame!**

We need a **coordinate system where the position of stars is unchanging!**



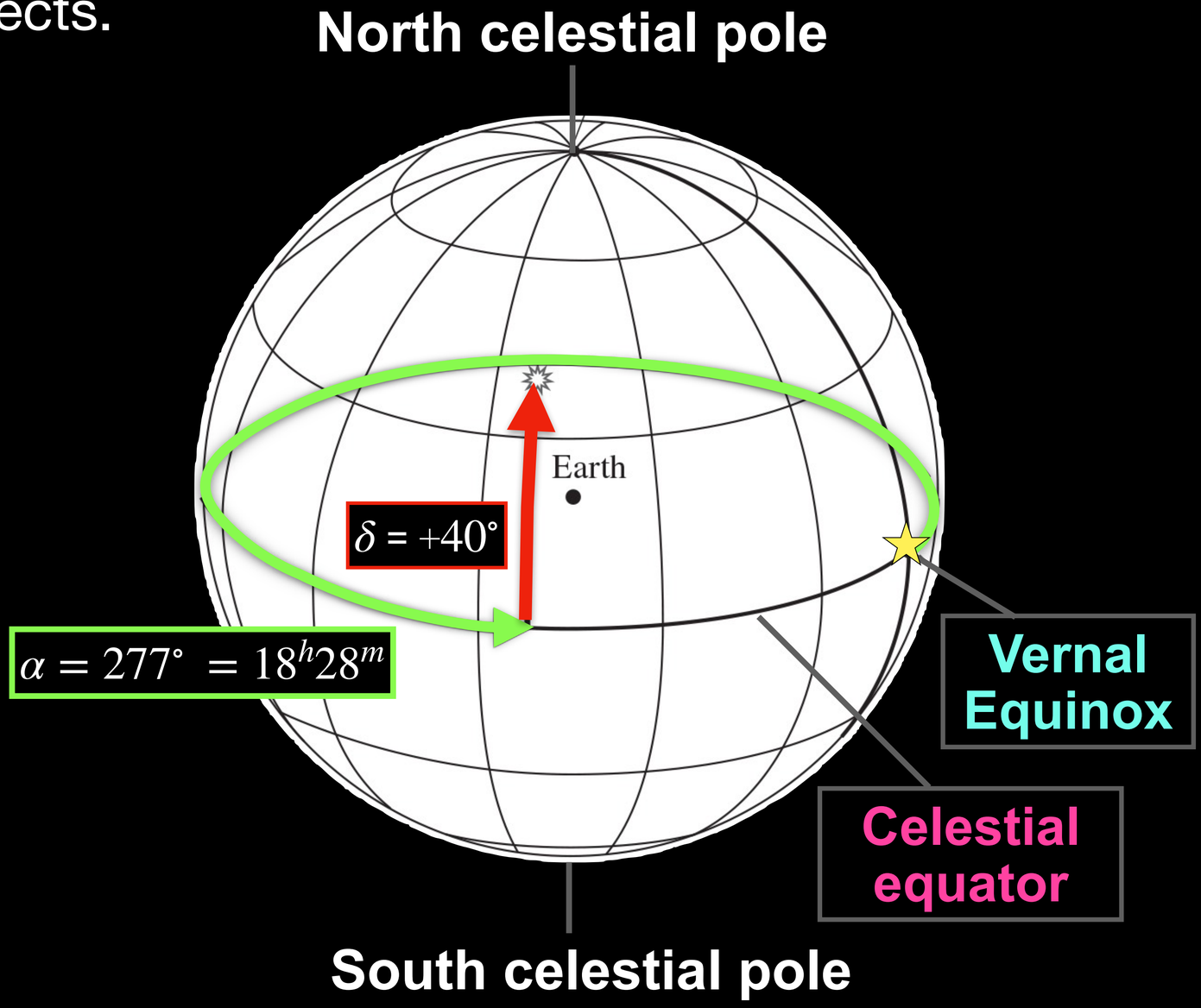
Equatorial Coordinate System

How astronomers describe celestial objects.

"Vernal Equinox" – the point where the Sun crosses the celestial equator *moving northward (around March 20th-21st)*, marking the start of spring in the northern hemisphere.

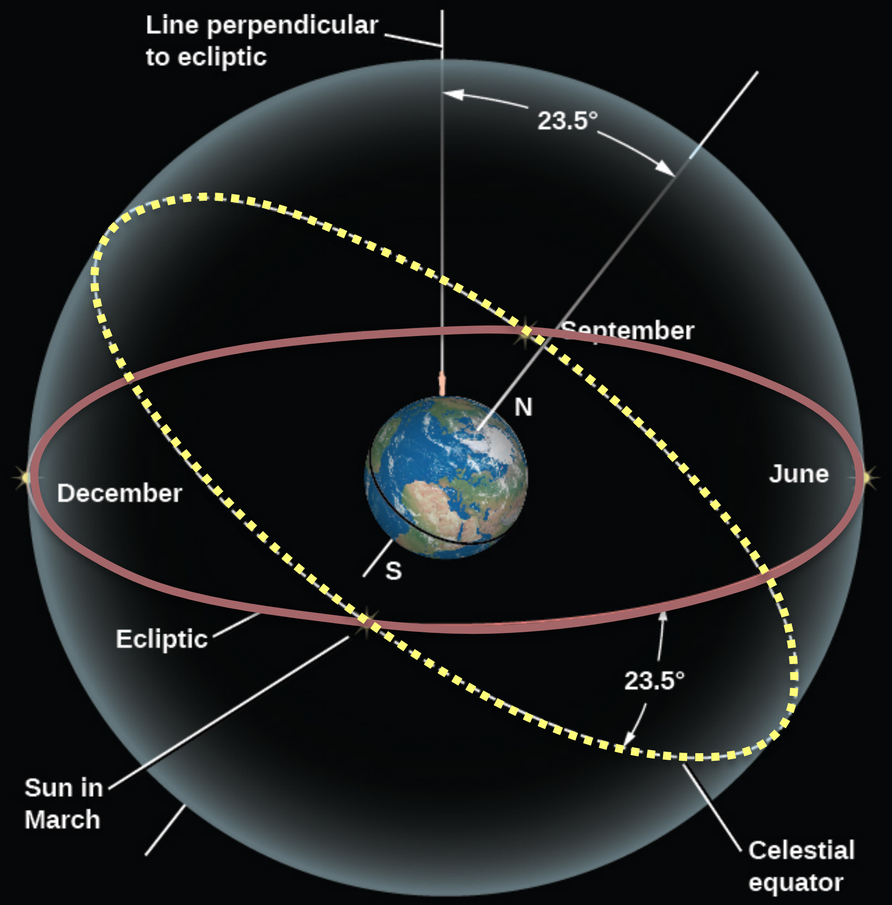
"Right Ascension" (α) – *longitude-like* coordinate that is measured *eastward* from the Vernal Equinox.

"Declination" (δ) – *latitude-like* coordinate that is measured *northward* from the Celestial Equator



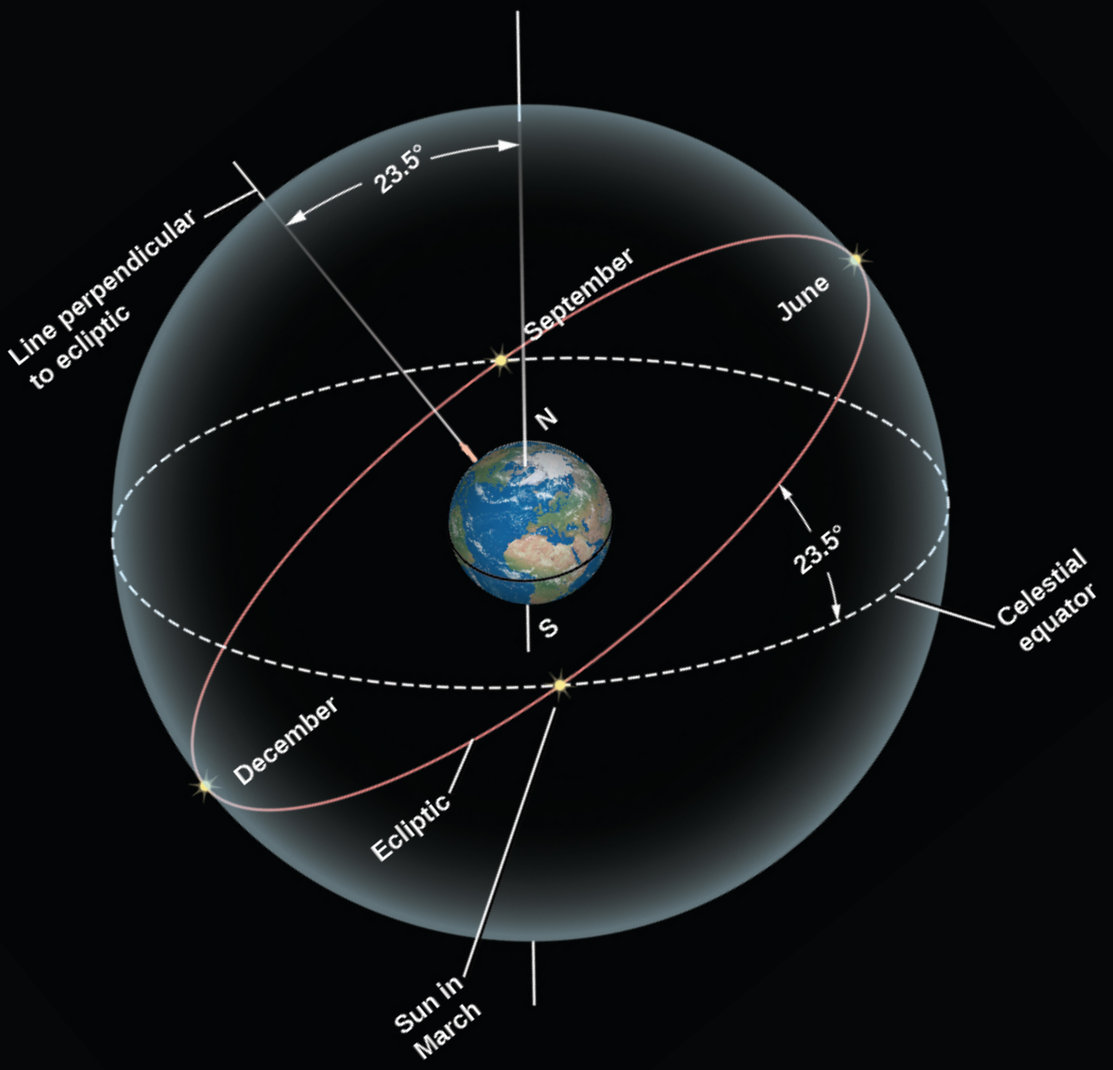
Comparing Horizontal vs. Equatorial Coordinates with **Stellarium (link here)**

Ecliptic and Celestial Equators



- The Celestial Equator is the **projection of the Earth's equator on the celestial sphere.**
- The "ecliptic" is the **great circle along which the Sun moves.**
  - Can be interpreted as **the plane on which the Earth orbits around the Sun.**
  - In fact, **most of the planets orbit close to the ecliptic!** More on this later…

Solstices and Equinoxes

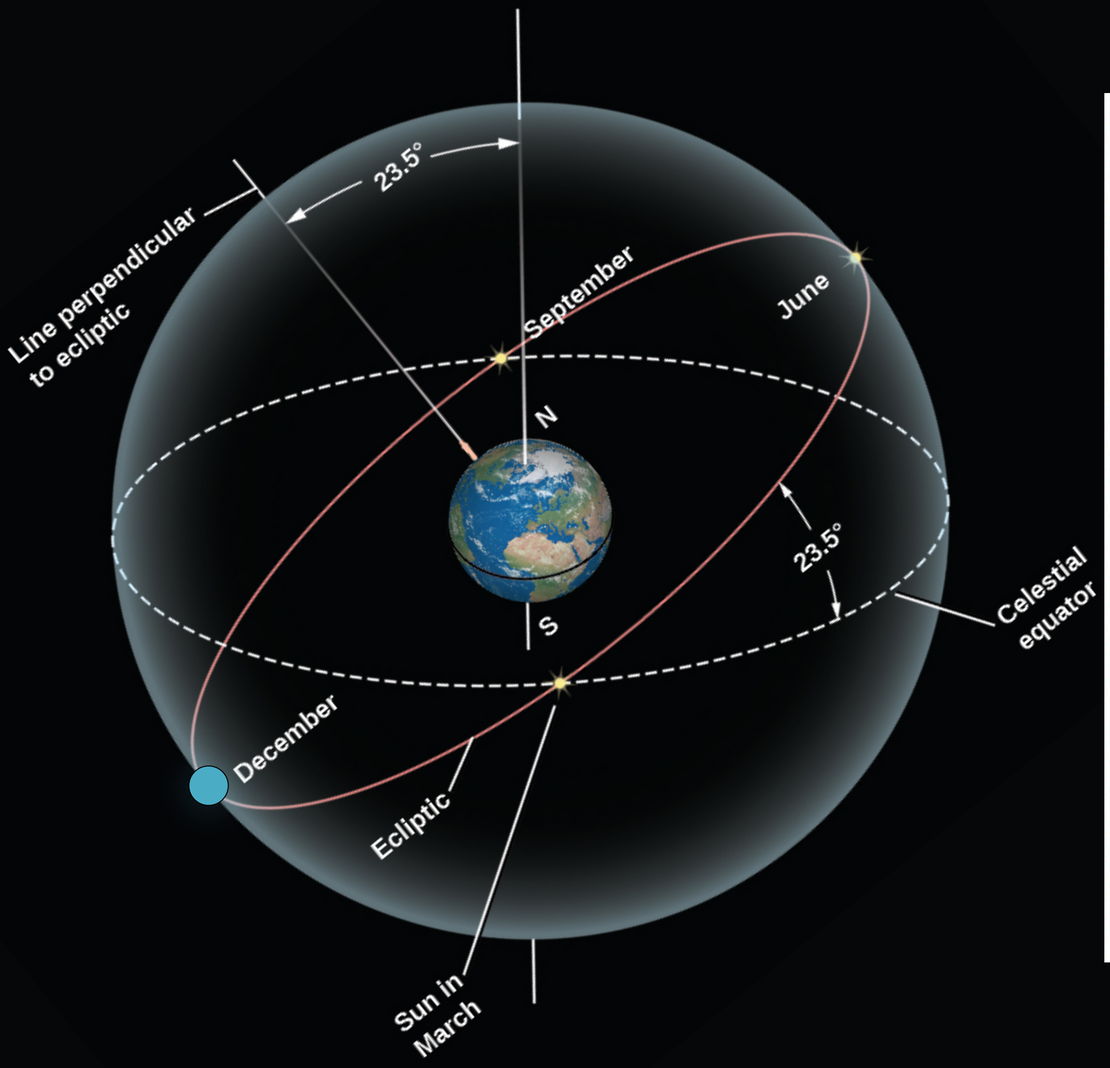


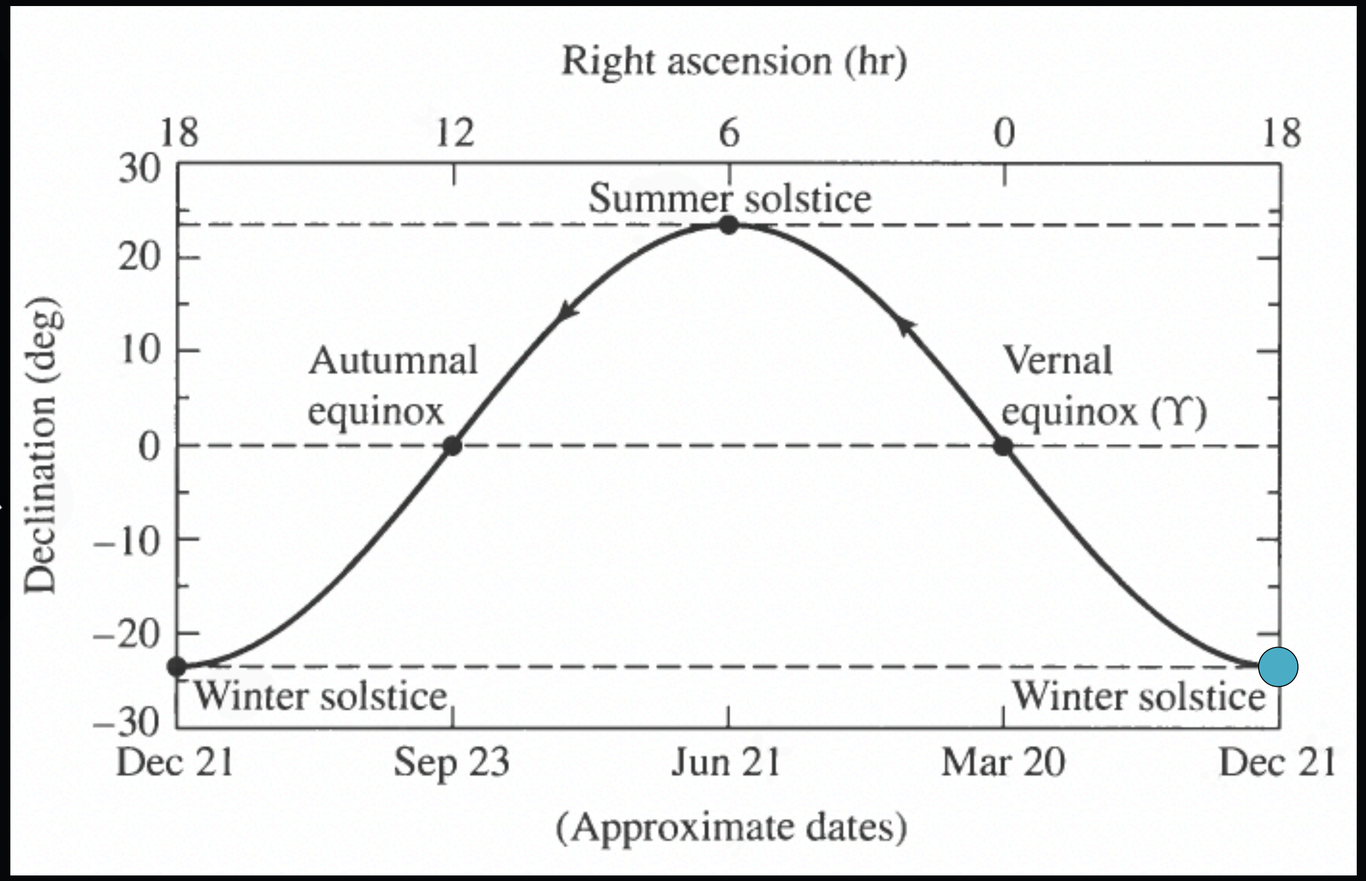
Definitions

“Solstice” – Date when the sun reaches its maximum/minimum declination

“Equinox” – Date with *nearly* equal amounts of night (and/or day)

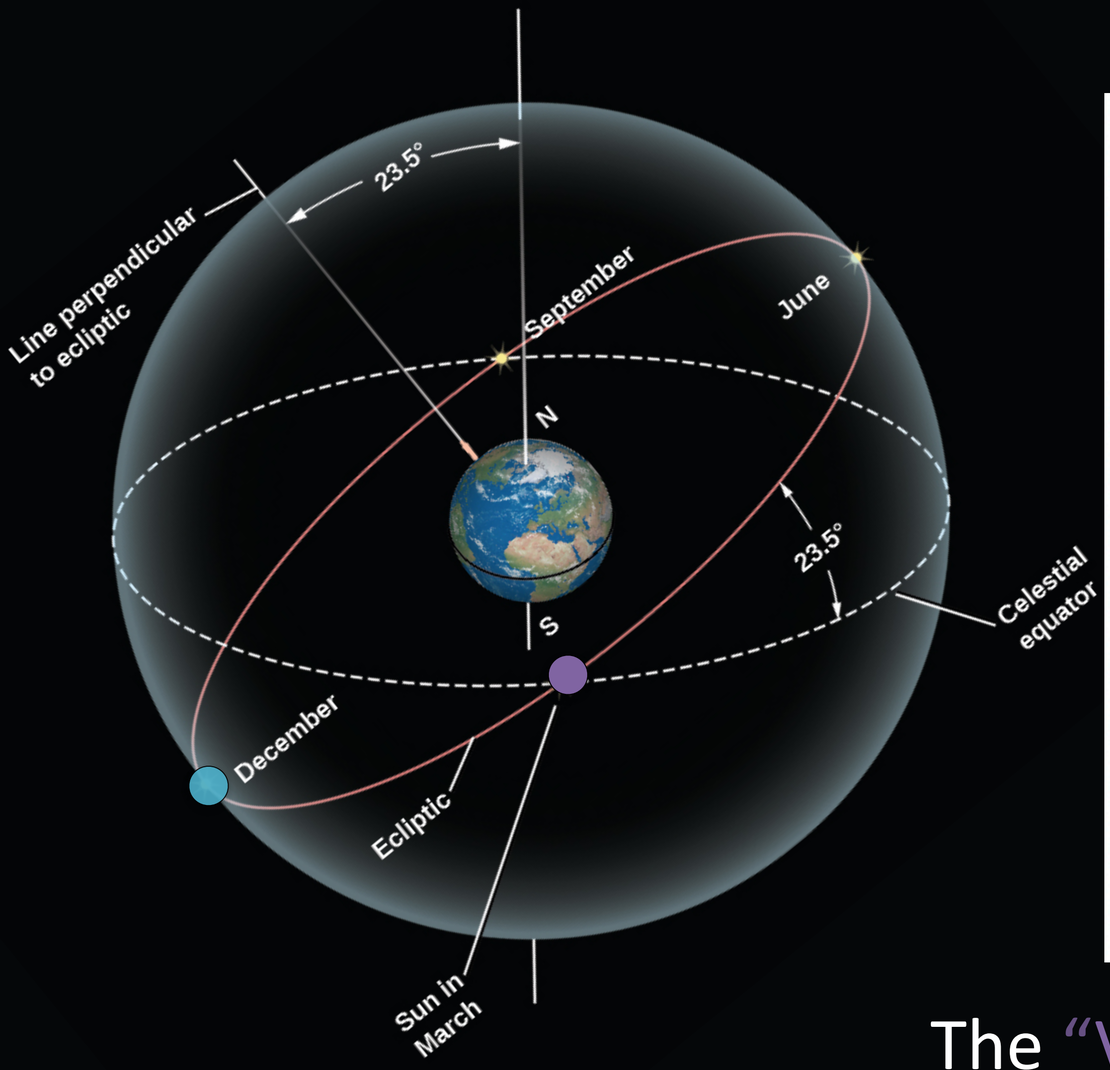
Solstices and Equinoxes

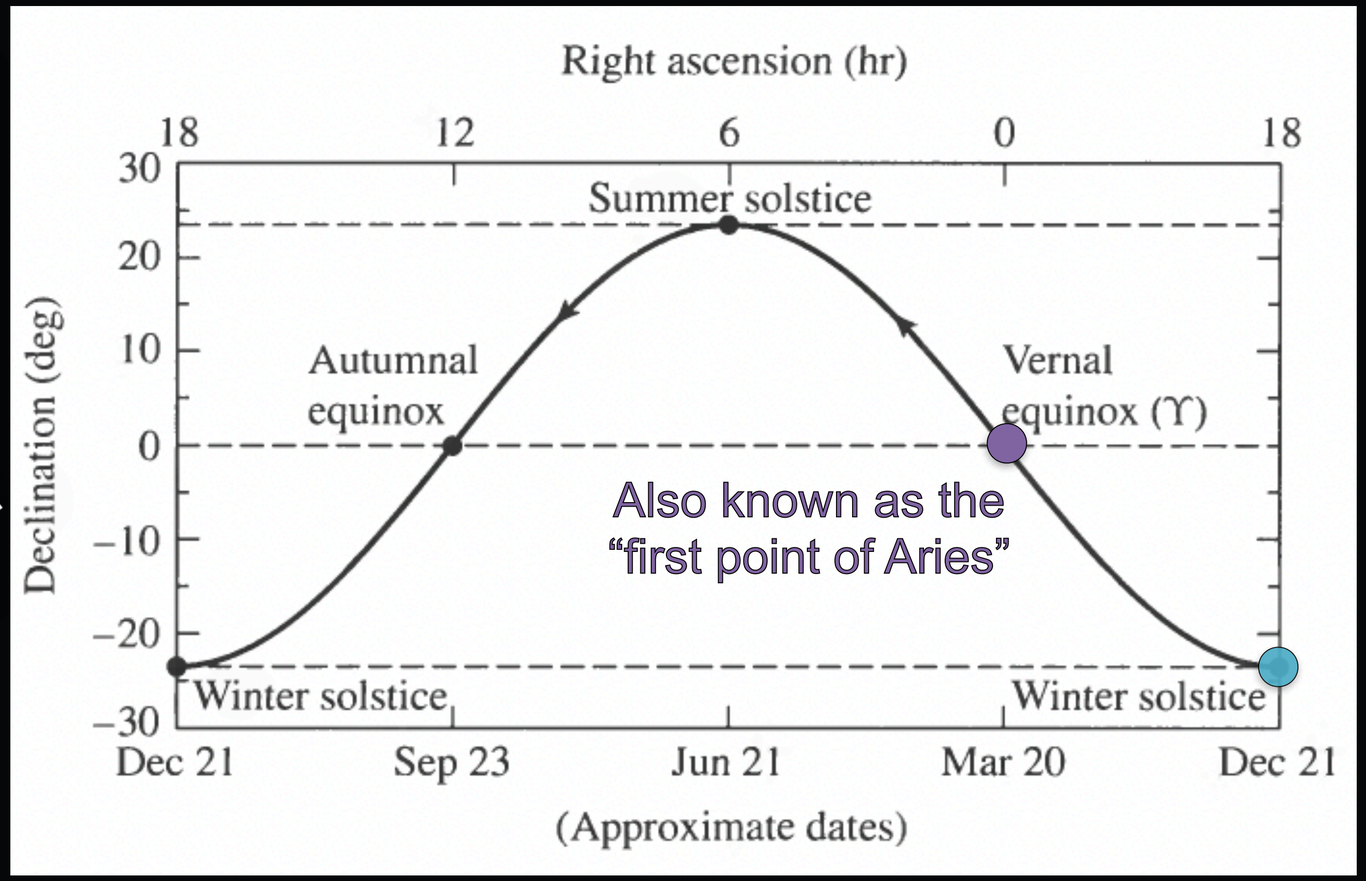




"Winter Solstice" – Longest night of the year in the Northern Hemisphere

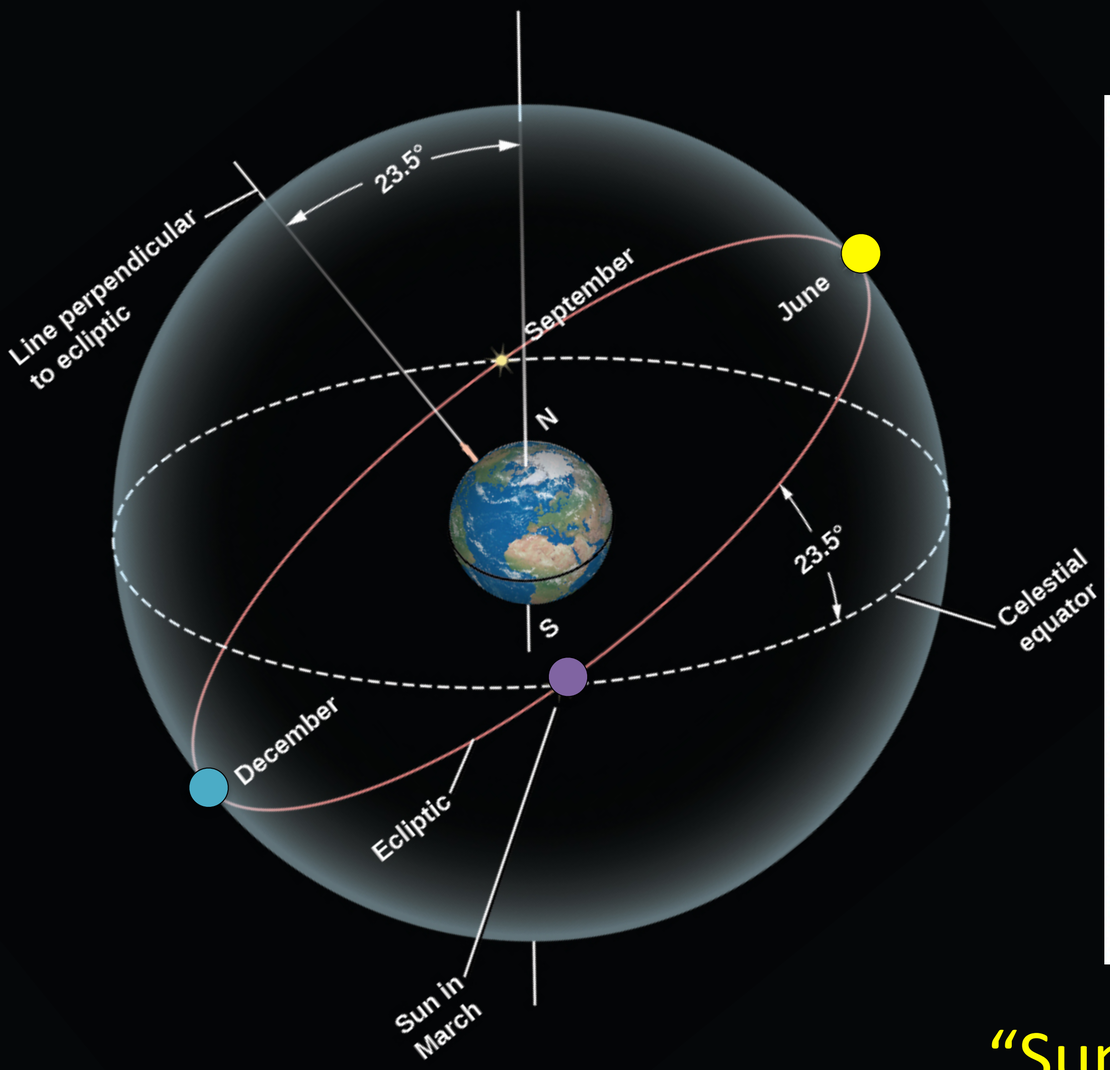
Solstices and Equinoxes

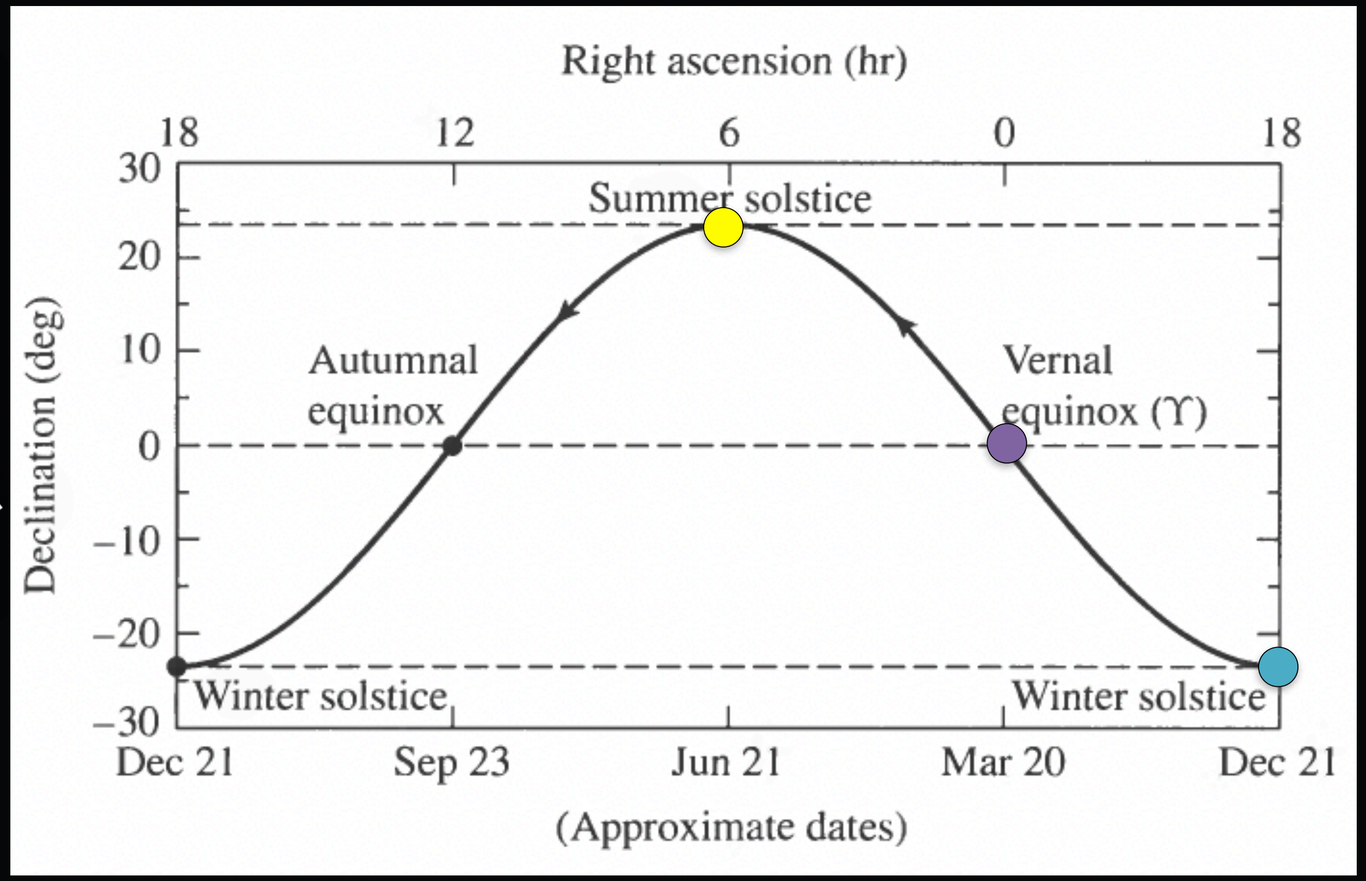




The "Vernal Equinox" is when the Sun moves from the Southern Celestial Hemisphere to the Northern.

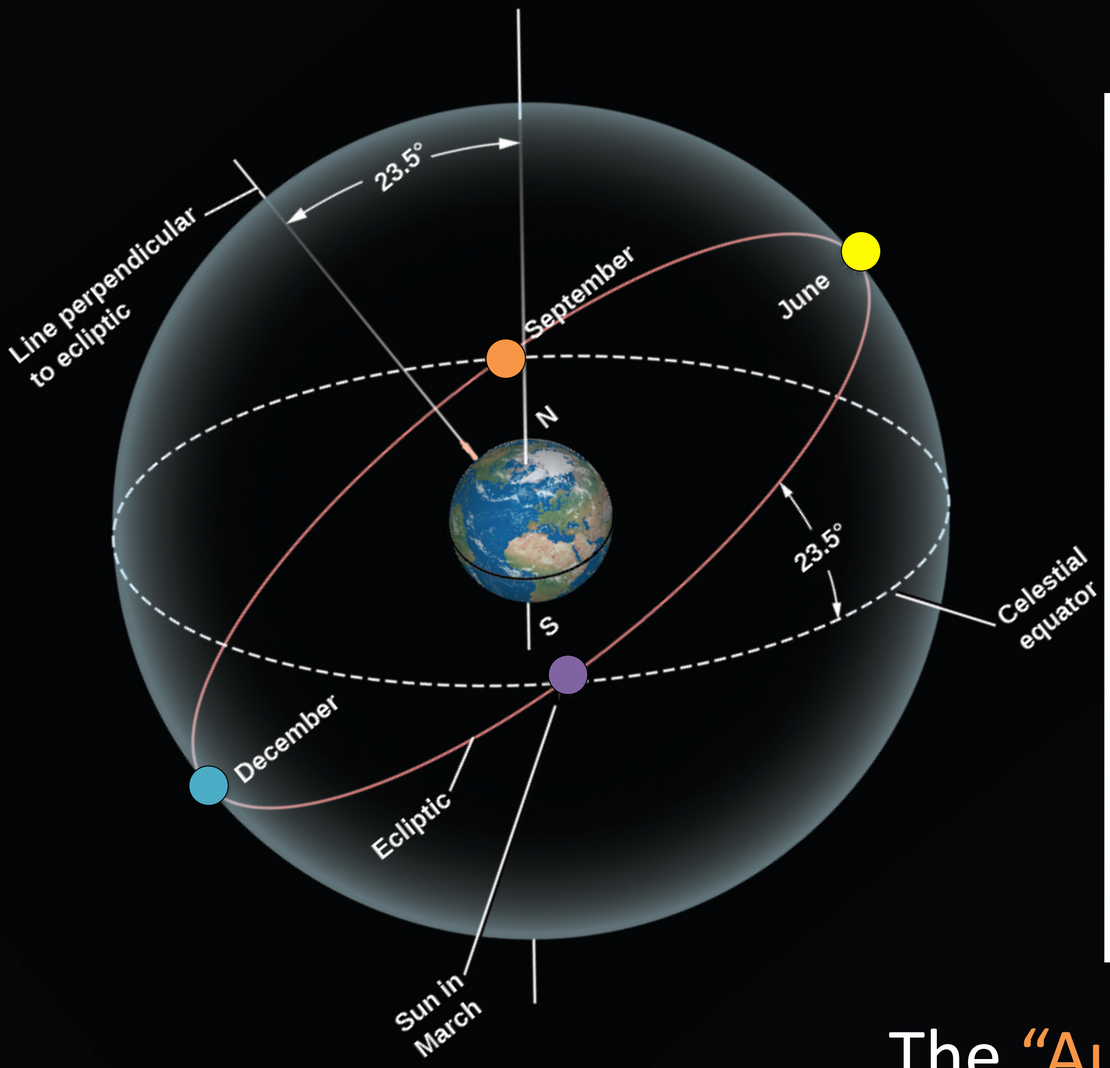
Solstices and Equinoxes

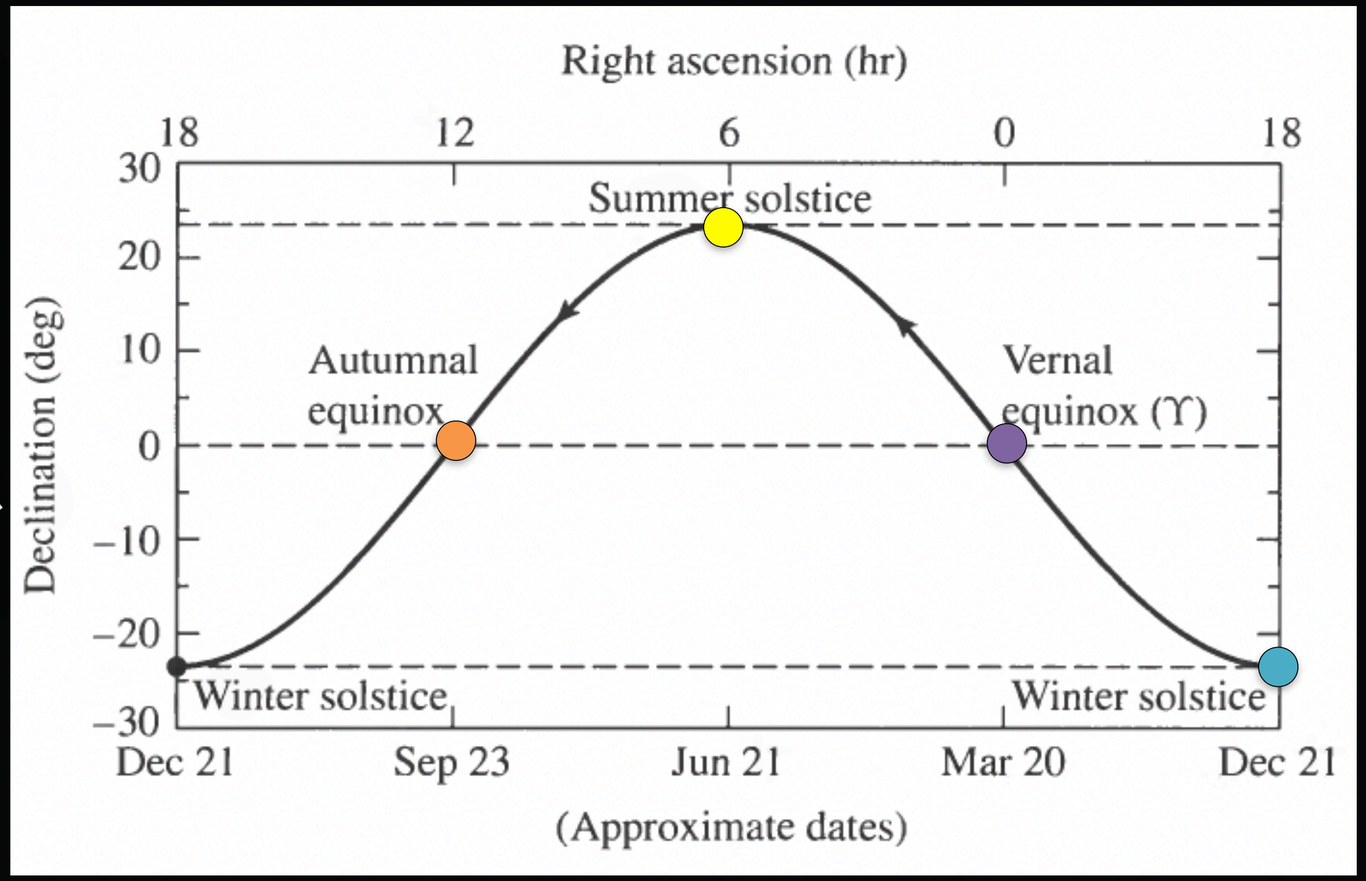




"Summer Solstice" – Longest day of the year in the Northen Hemisphere

Solstices and Equinoxes

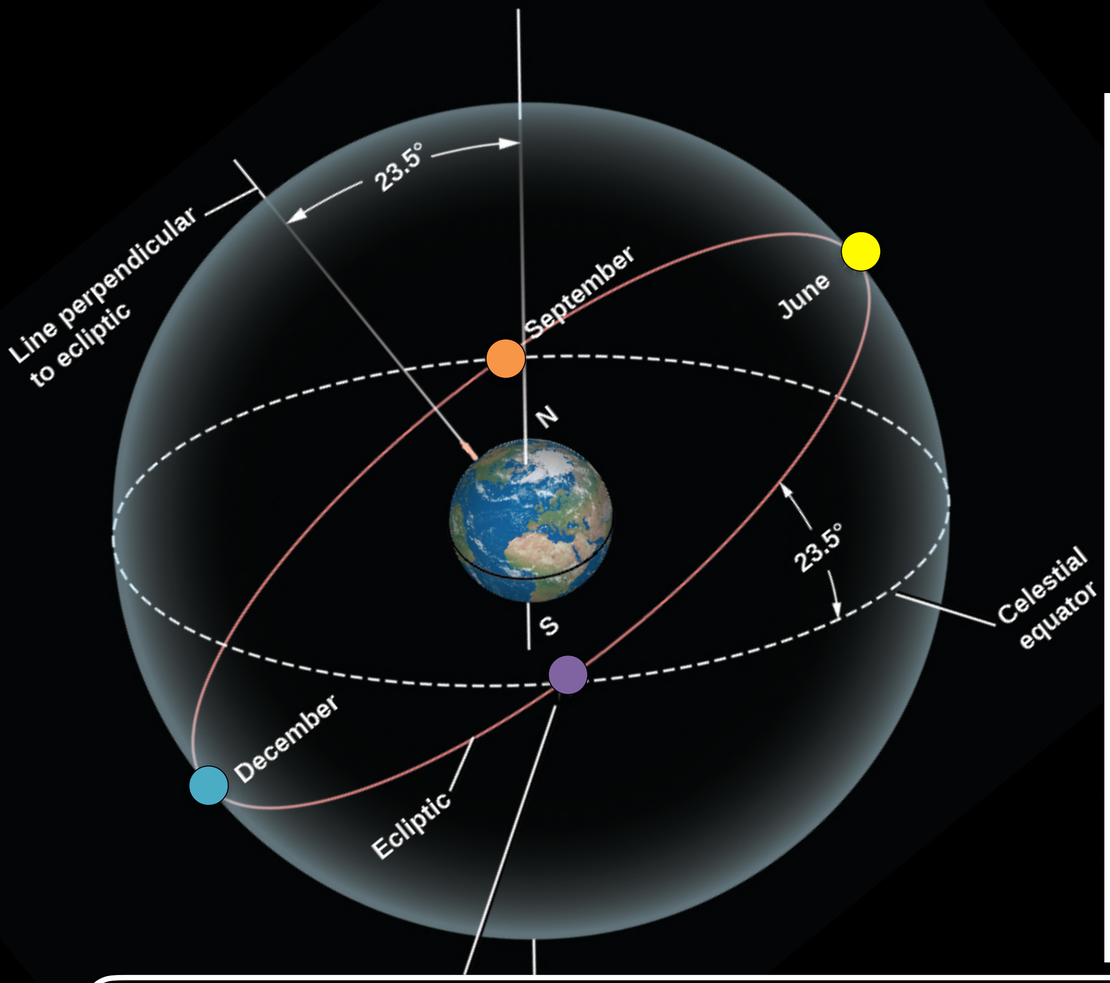


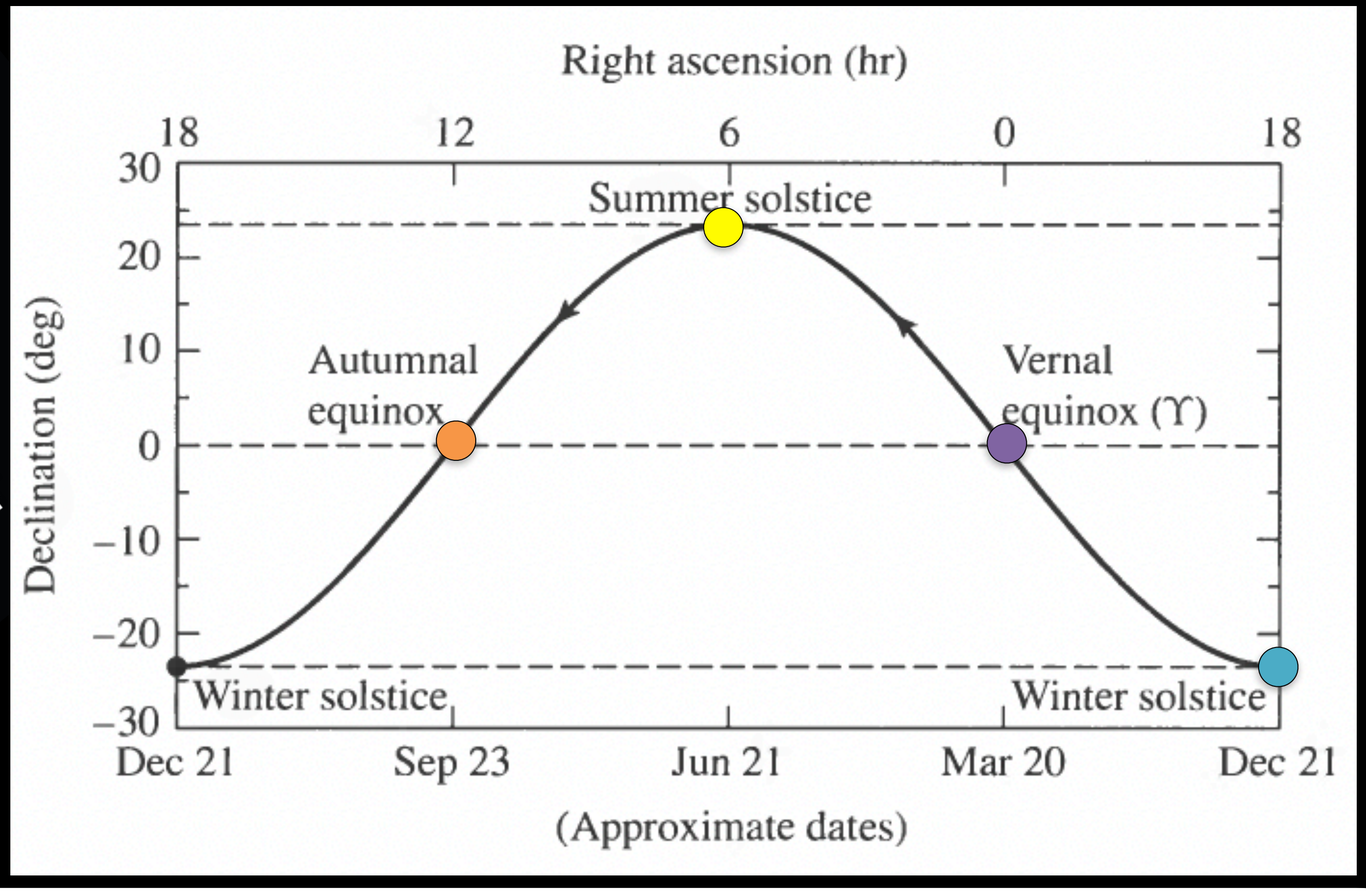


The “Autumnal Equinox” is when the Sun moves from the Northen Celestial Hemisphere to the Southern.


Questions?

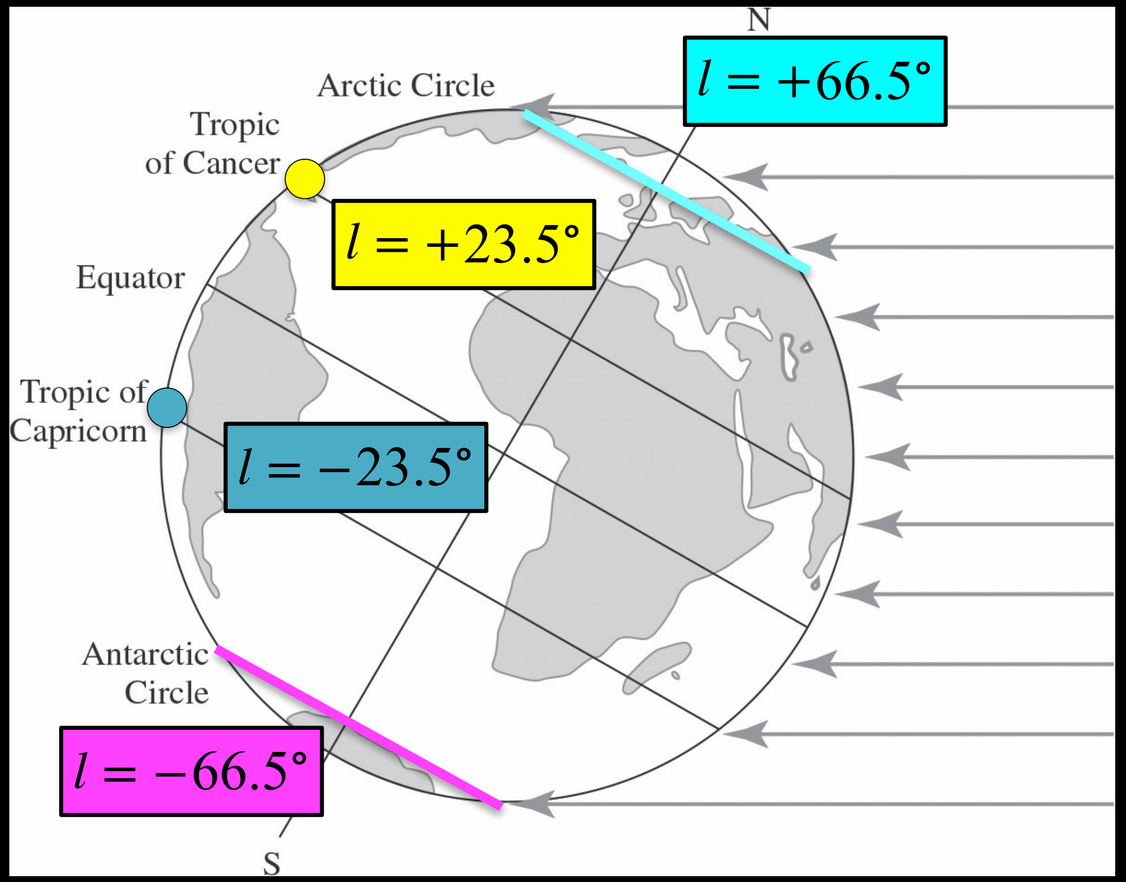
Brain Break – Think-pair-share





If I want to observe a star with right ascension of 6 hours, would June 21st be a good night to observe it with a telescope? **Why or why not?**

Taking a trip to the Arctic and the Tropics

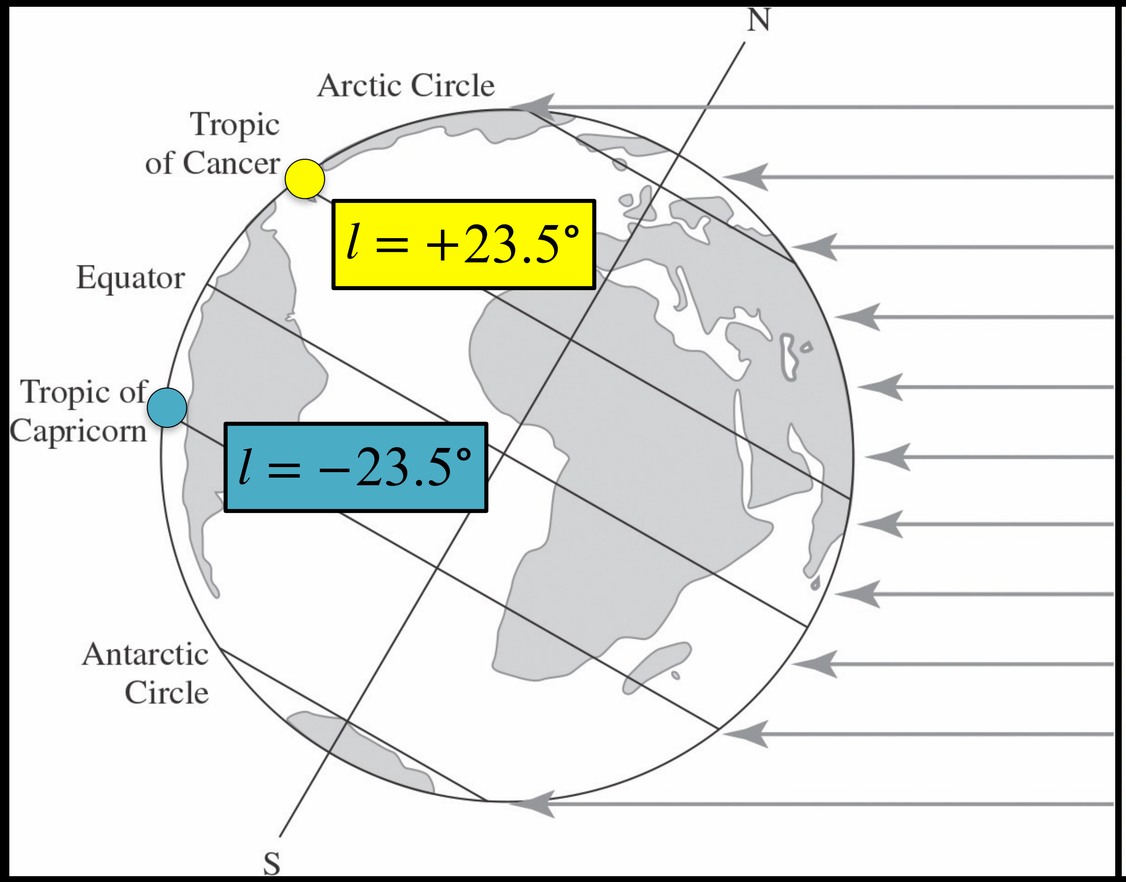


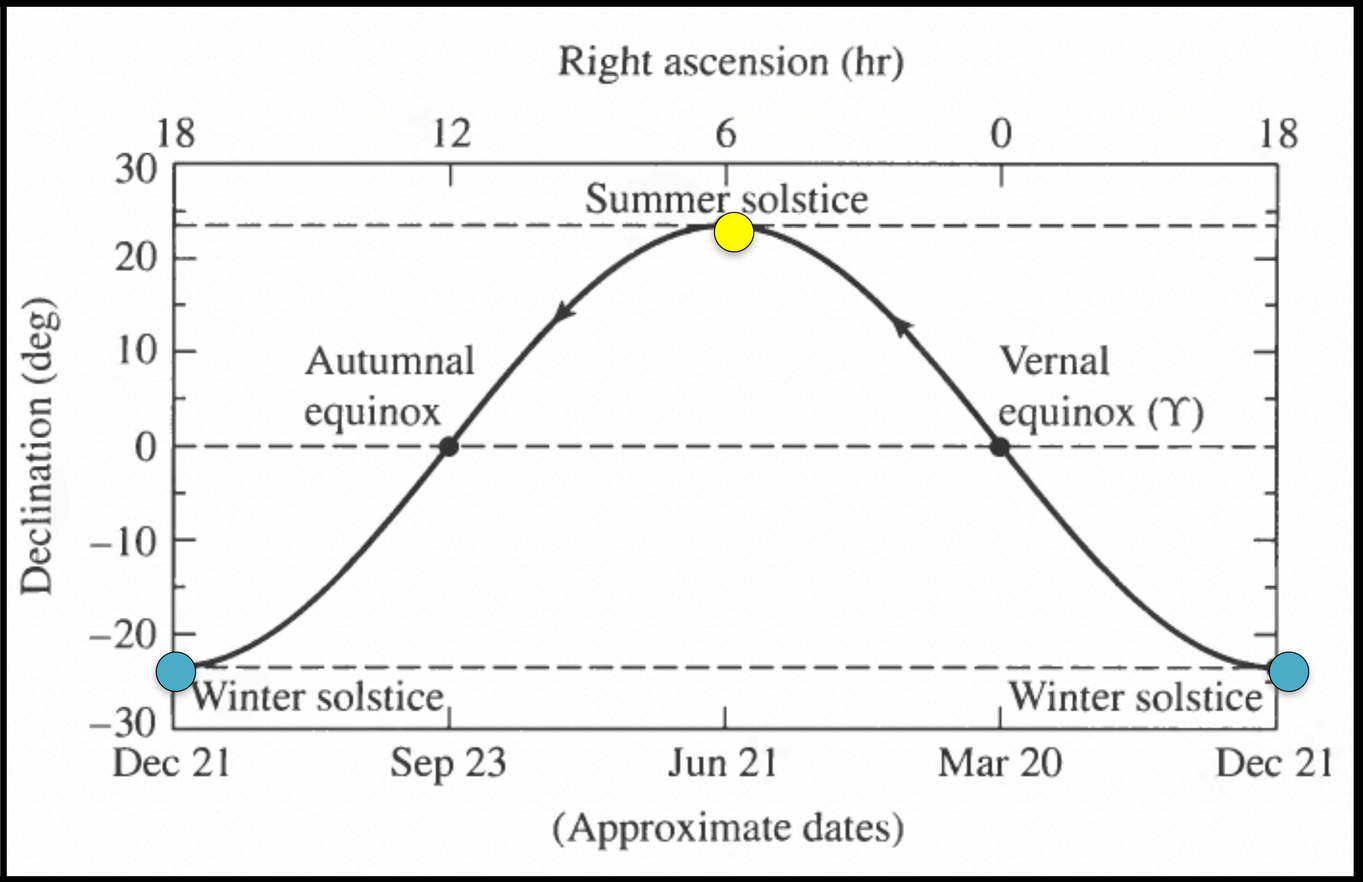
Sun's rays striking the Earth, around the time of the summer solstice. The Arctic and Antarctic Circles, as well as the Tropics of Capricorn and Cancer are indicated.

The Arctic and Antarctic Circles are locations **where there are times the Sun will never set** ("*midnight Sun*") **and never rise.**

The **Tropic of Cancer** (**Tropic of Capricorn**) is the location where the Sun will pass directly overhead during the **summer** (**winter**) solstice

Taking a trip to the Arctic and the Tropics



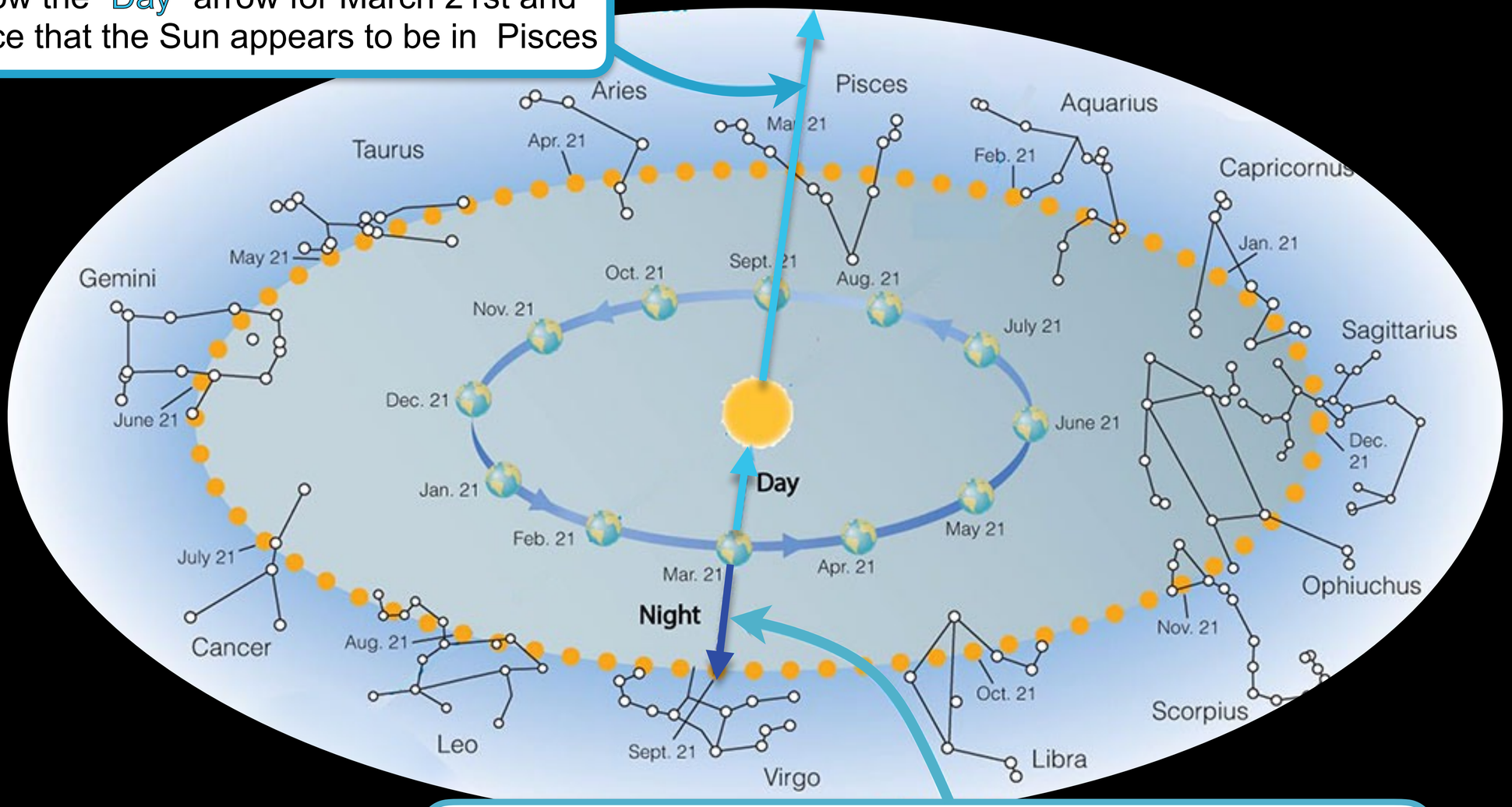


Sun's rays striking the Earth, around the time of the summer solstice. The Arctic and Antarctic Circles, as well as the Tropics of Capricorn and Cancer are indicated.


Questions?

The Zodiac

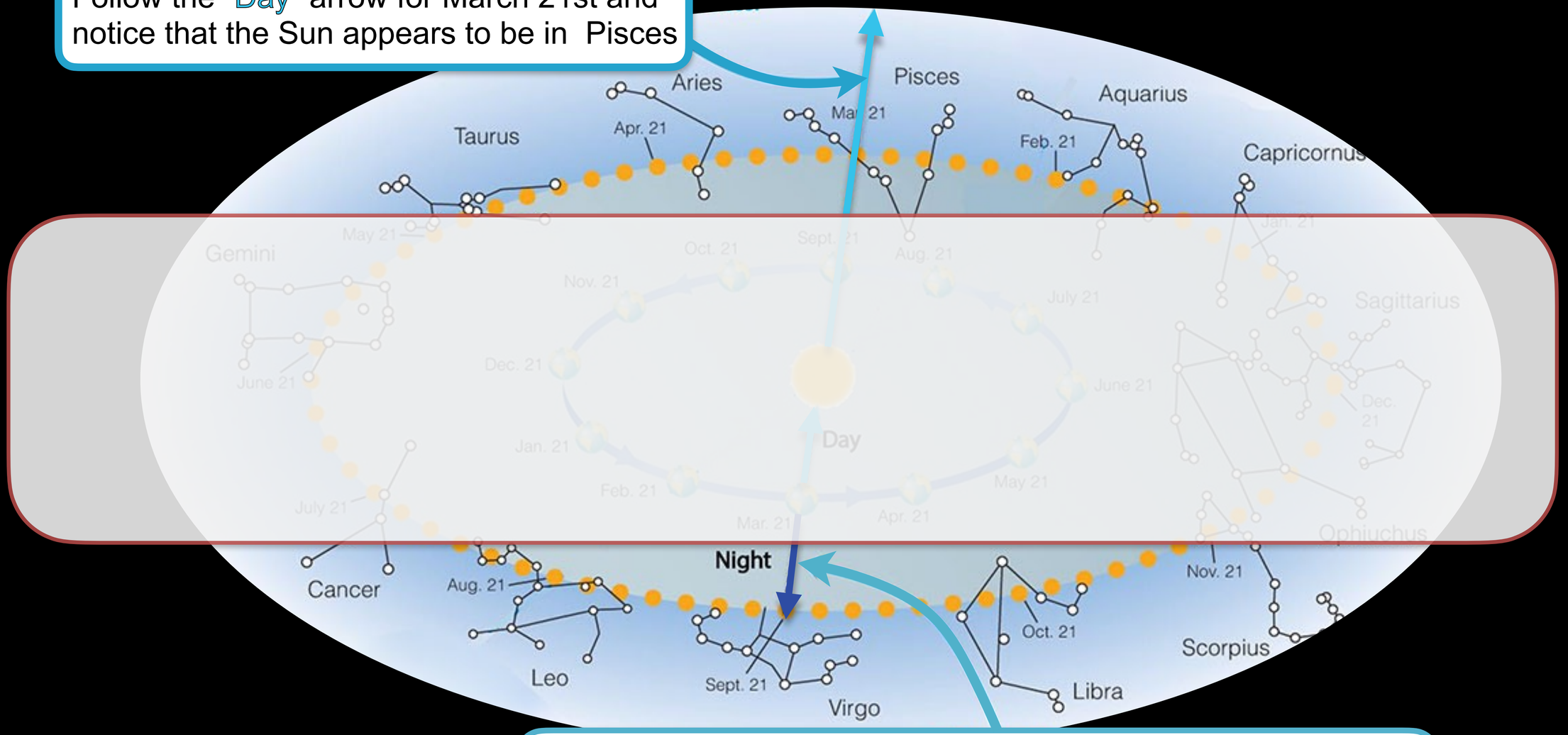
Follow the "Day" arrow for March 21st and notice that the Sun appears to be in Pisces



Follow the **"Night"** arrow for March 21st and notice that Virgo is *opposite* of the Sun in the sky, and hence visible all night long!

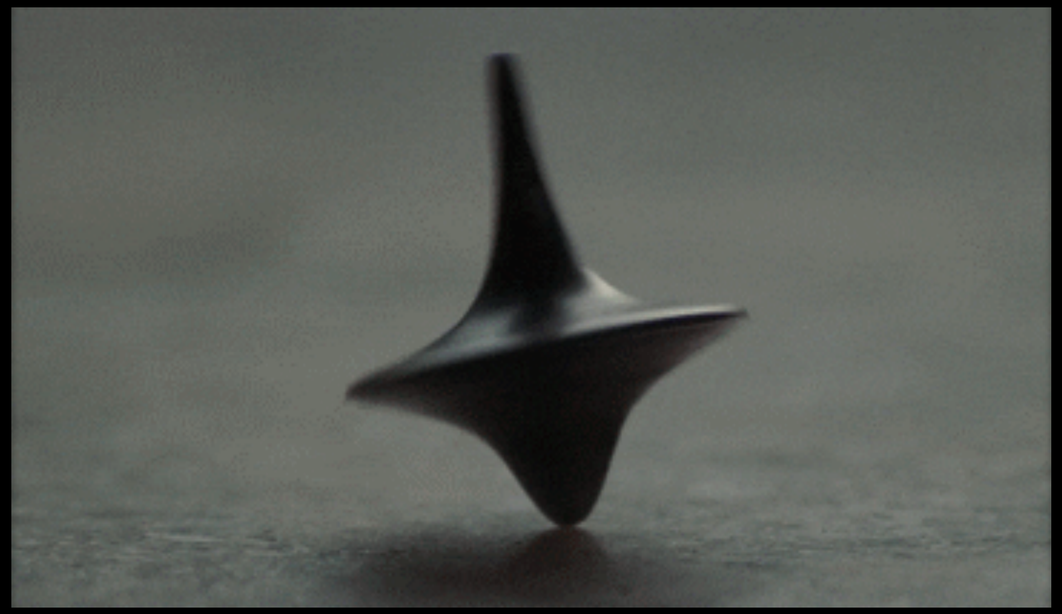
The Zodiac

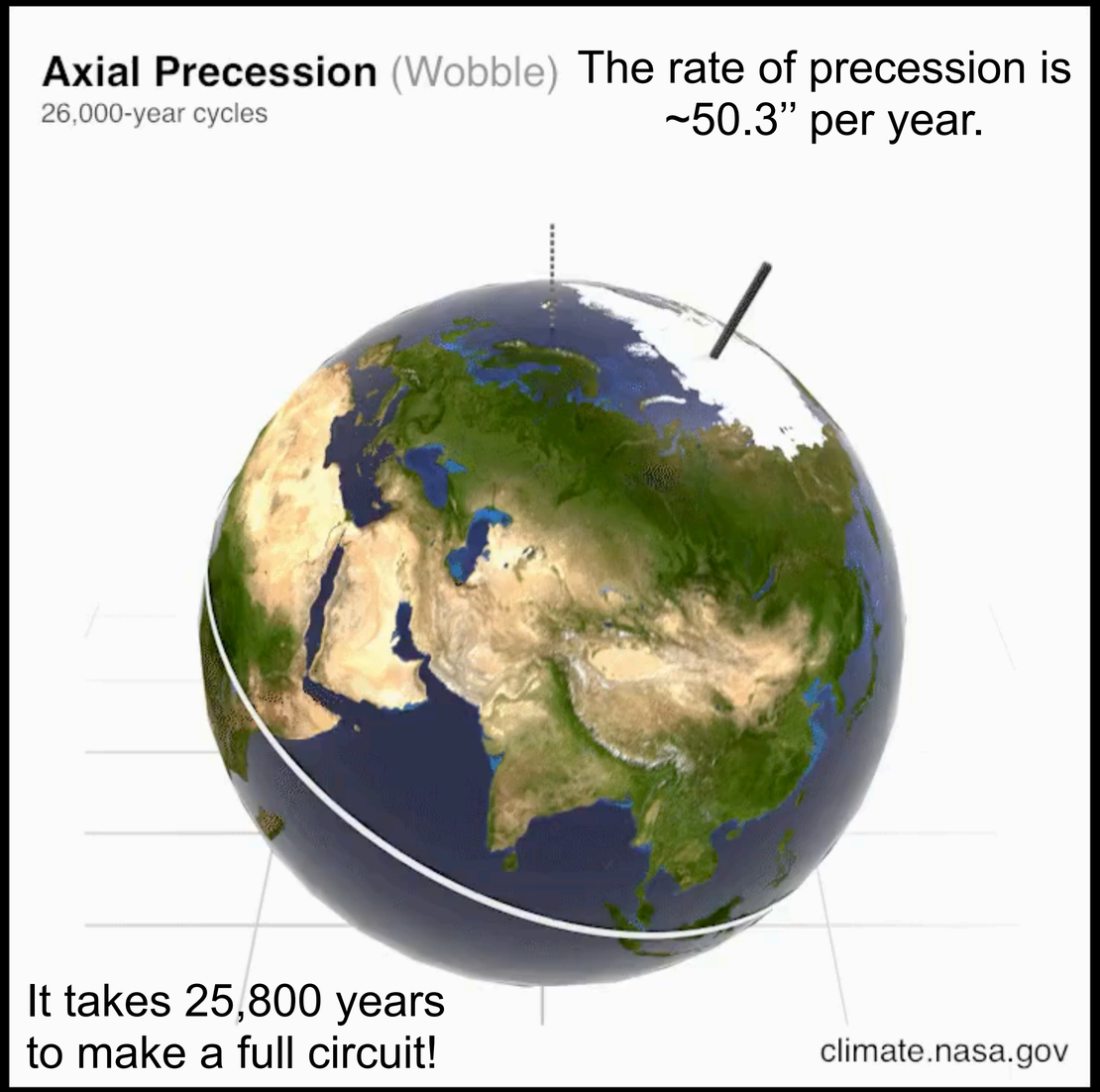
Follow the "Day" arrow for March 21st and notice that the Sun appears to be in Pisces



Follow the **"Night"** arrow for March 21st and notice that Virgo is *opposite* of the Sun in the sky, and hence visible all night long!

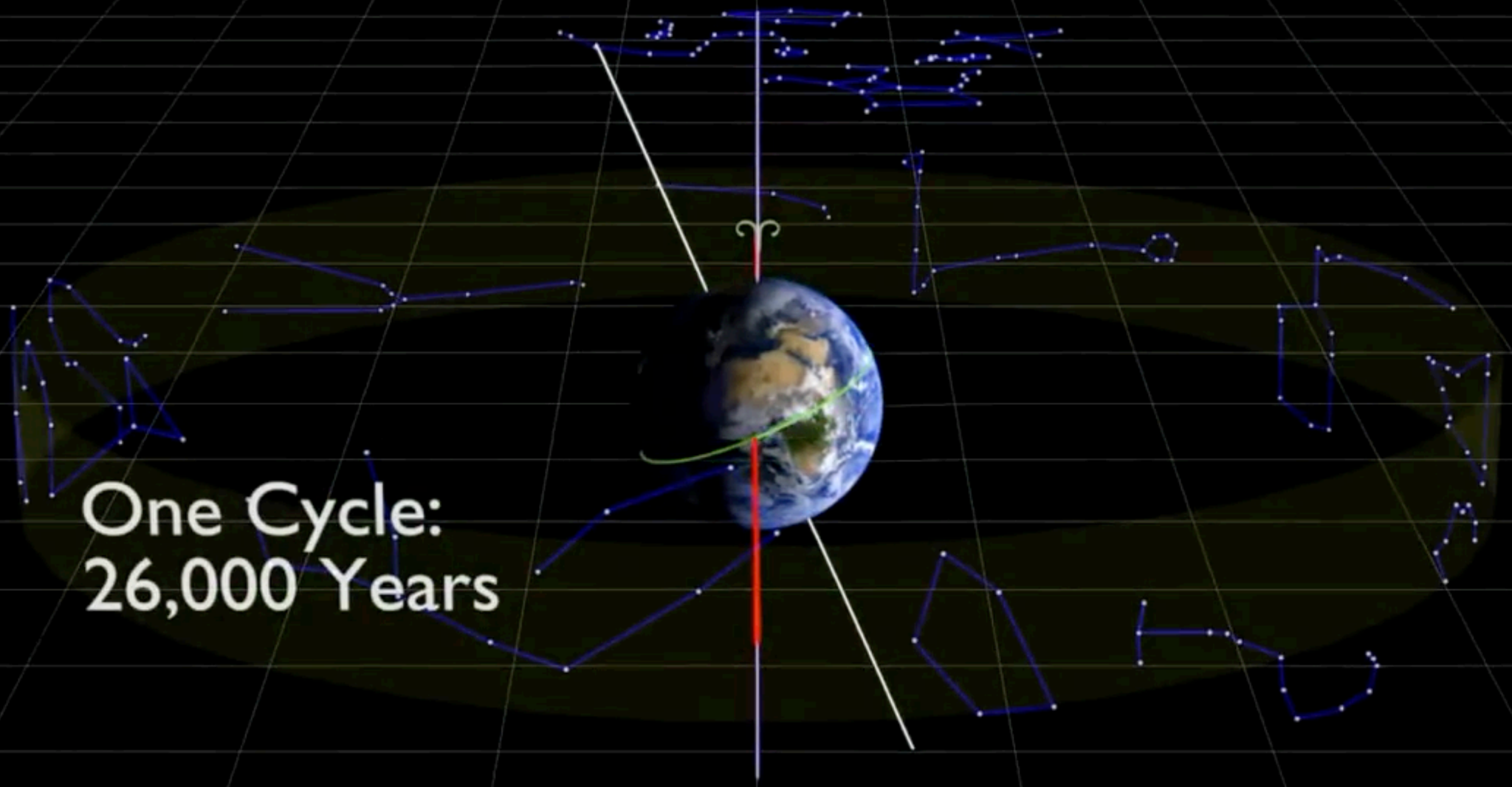
Precession of the Equinoxes





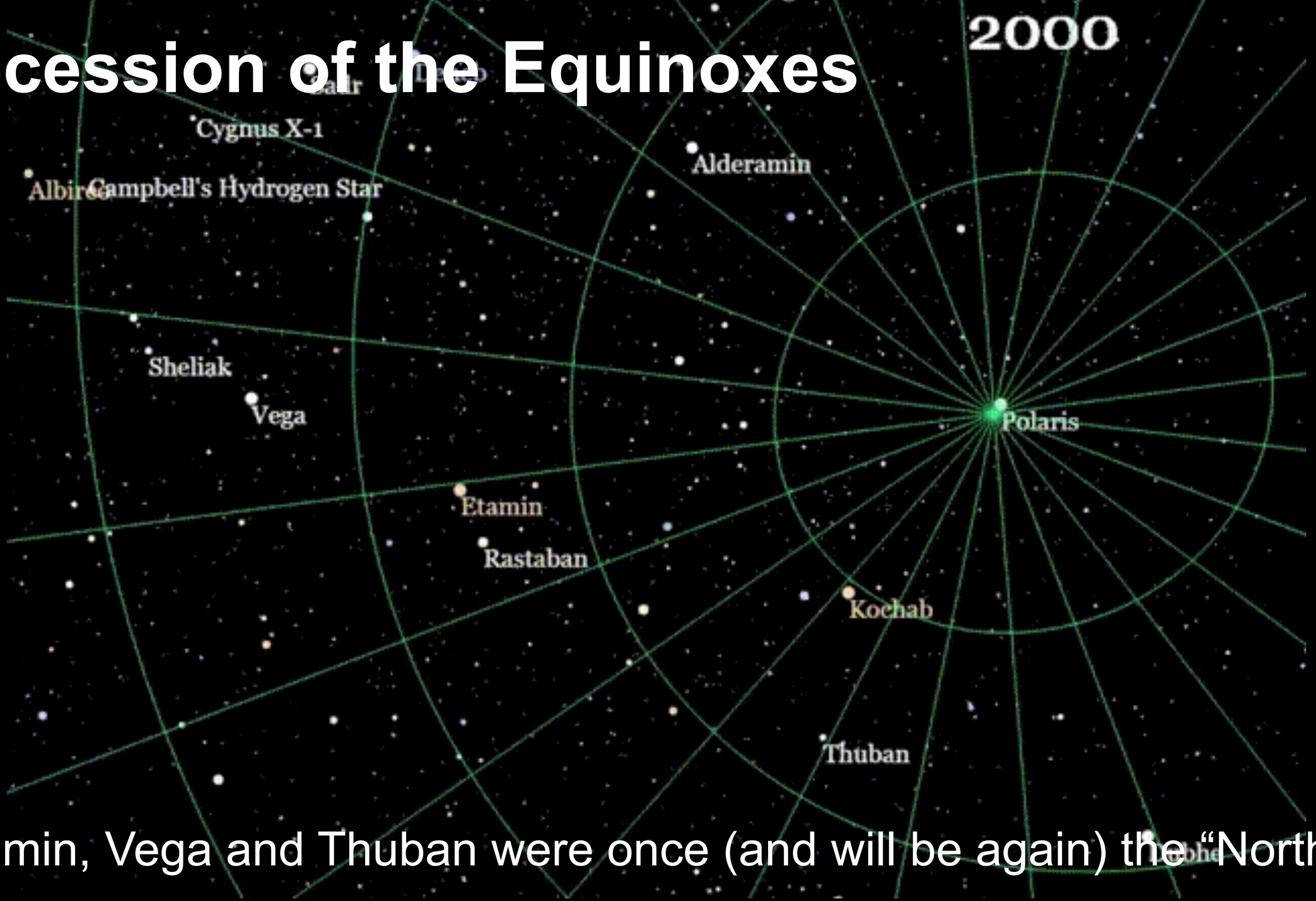
Similar to a dying top, the Earth’s axis of rotation precesses!

Precession of the Equinoxes



The constellation in which the vernal equinox (♈) occurs varies with time due to the precession of Earth's axis of rotation!

Precession of the Equinoxes

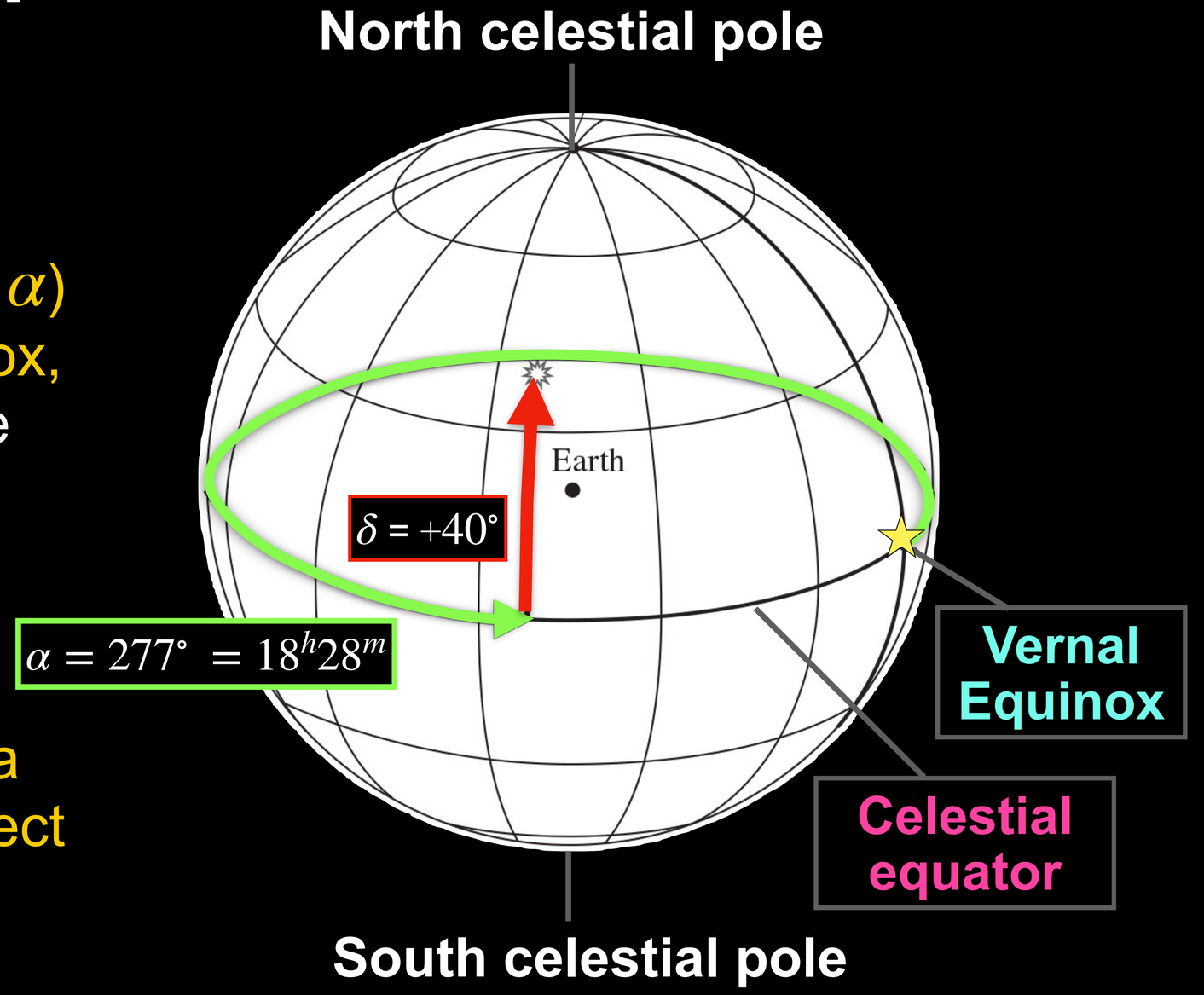


Alderamin, Vega and Thuban were once (and will be again) the “North Star”

Precession of the Equinoxes

Since the Right Ascension (R.A. or α) of a star is tied to the Vernal Equinox, which is also changing location, the RA is continuously changing!

As a result, coordinates also need a date (epoch) to tie them to the correct celestial reference frame!



The current epoch commonly used is **“equinox 2000.0”**


Questions?

Brain Break – Think-pair-share

Composite photo capturing the apparent motion of Mars relative to background stars.

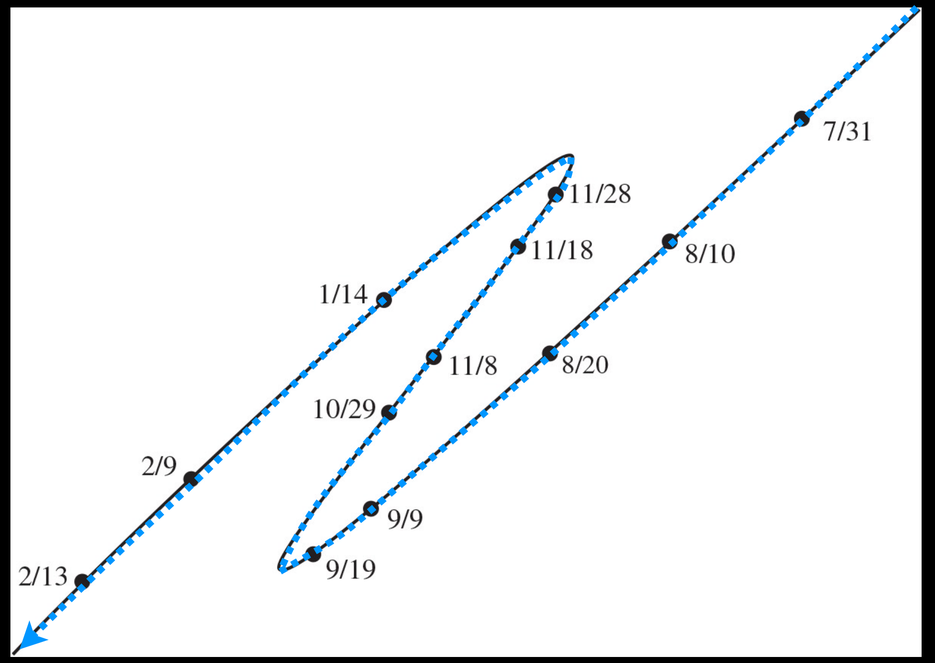
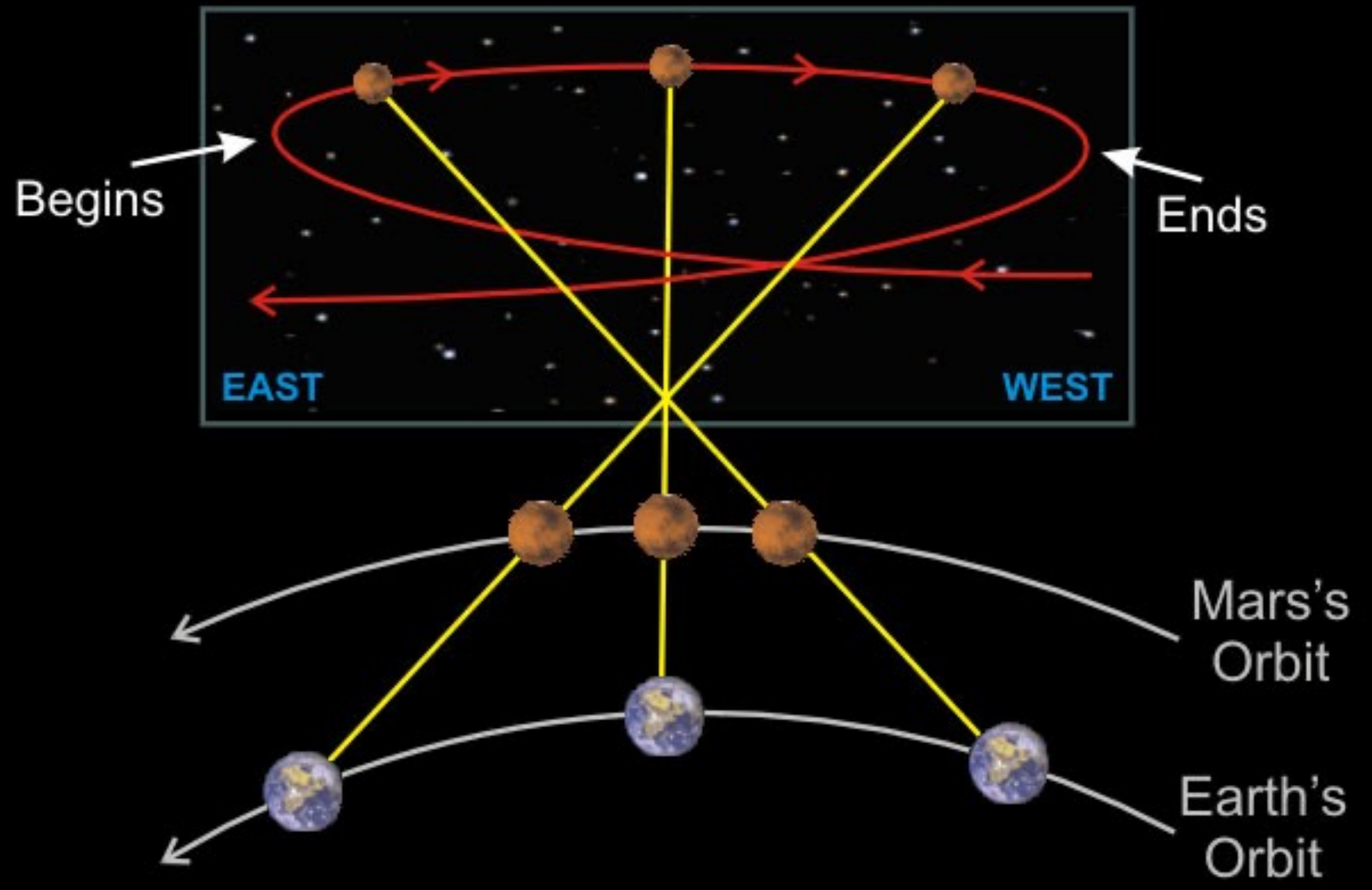


Diagram showing the apparent motion **(starts at the top right)**

Question: Why do you think Mars moves backwards and forwards? What other planets might exhibit this behavior?

Retrograde Motion



Inner planets move more quickly than outer planets in their orbits. Retrograde motion happens **due to the difference in orbital periods.**

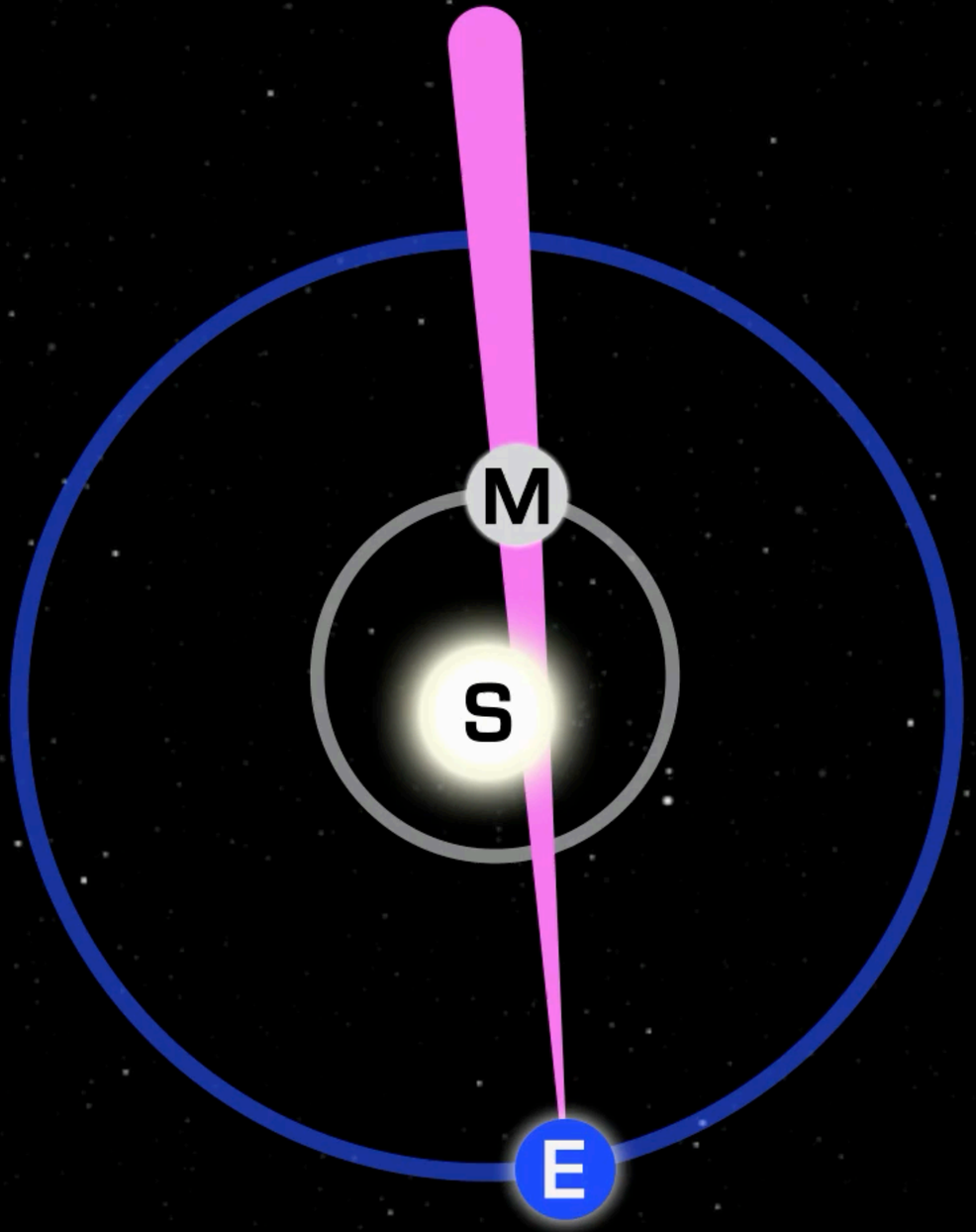
Mercury in "retrograde"

S Sun

M Mercury

E Earth

Path of Mercury in Earth's sky



Retrograde occurs when a planet appears to move 'backwards' in the sky (relative to stars)

2020 Mercury Retrograde
Feb 16 — Mar 9
June 18 — July 12
Oct 14 — Nov 3

CURRENT DATE
2020-JAN-01

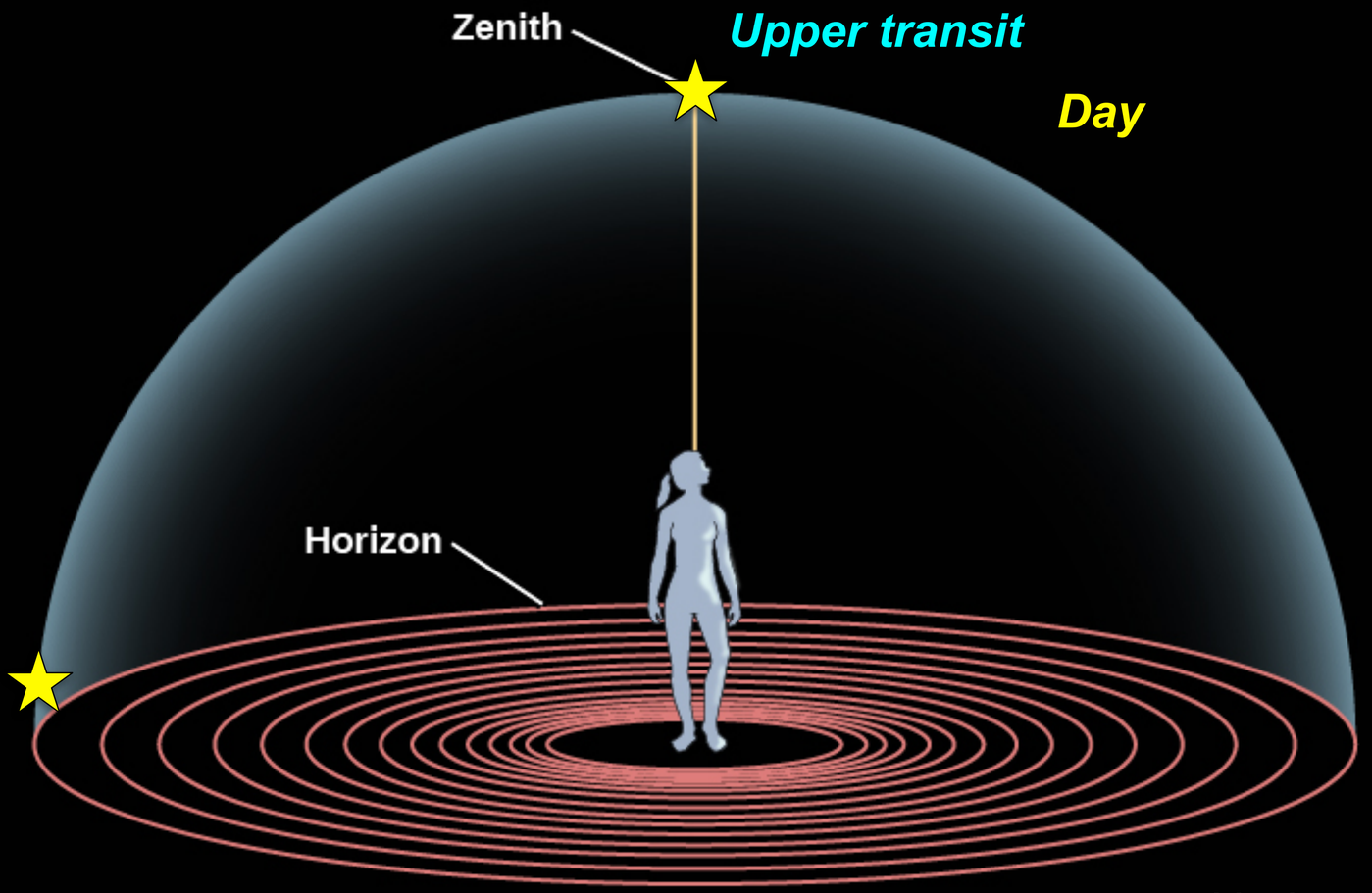
A retrograde cannot affect human affairs

James O'Donoghue @PhysicsJ
with NASA JPL data


Questions?

Astronomical Timekeeping

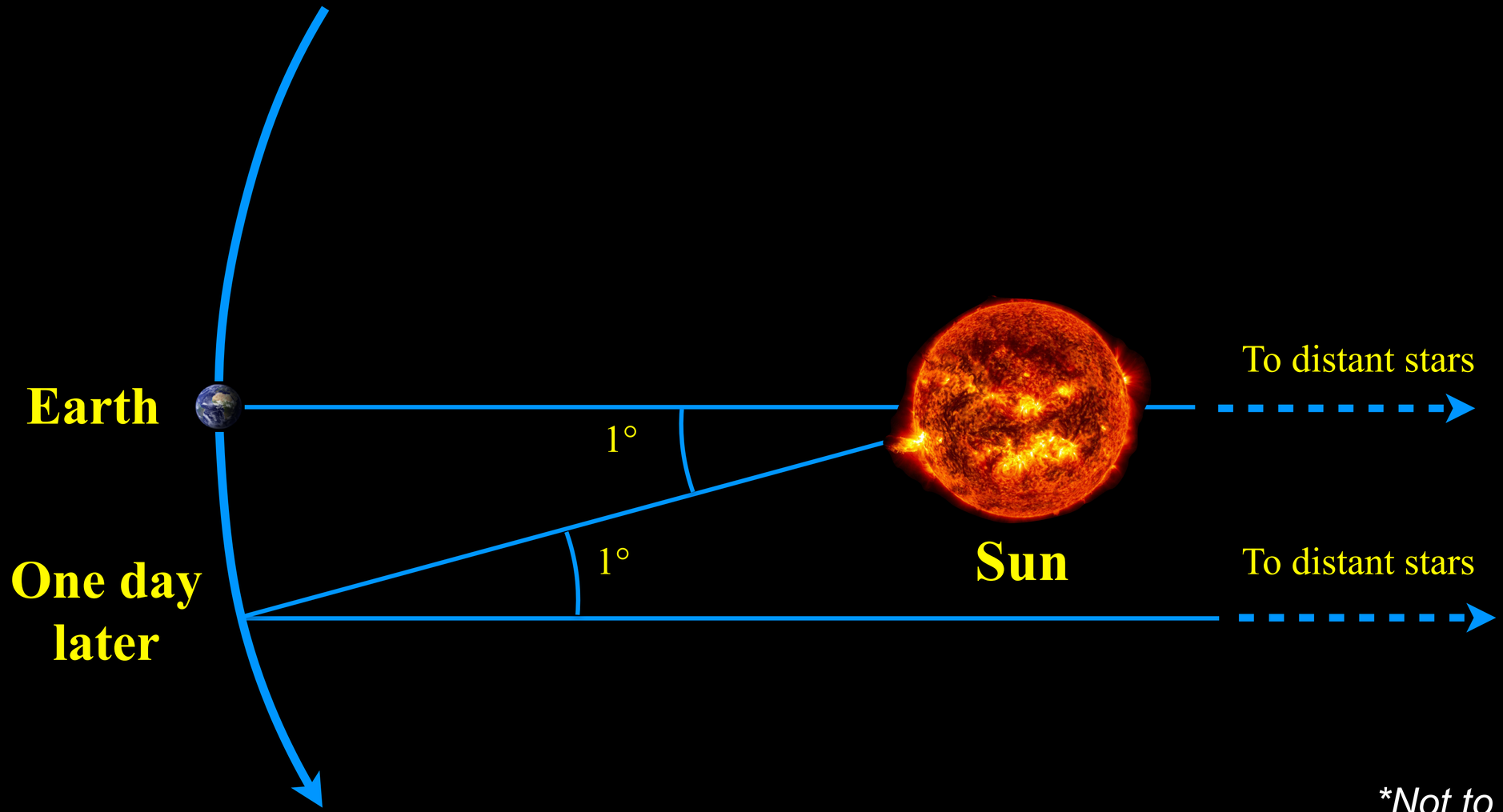
The length of a ***day*** is close to the rotation period of the Earth, but is defined as the interval of time between successive ***upper transits*** of a celestial object.



Horizontal (observer reference frame)

Astronomical Timekeeping

The length of a ***day*** is close to the rotation period of the Earth, but is defined as the interval of time between successive ***upper transits*** of a celestial object.



**Not to scale whatsoever!*

The time between successive upper transits of a *distant star* is called a "**sidereal day**"
The time between successive upper transits of the *Sun* is called a "**solar day**"

Earth Rotation
0°

0hrs 0min

0hrs 0min

SUN

Sidereal Day = 23hr 56min 4sec

Solar Day = 24hrs

James O'Donoghue (@physicsJ)

Angular velocity

$\omega =$ angle per unit time (typically radians / s)

Angular velocity of Earth's rotation

Difference between Earth and Sun' rotational velocity

Angular velocity of Earth's orbital motion

$$\vec{\omega}_{\text{sid}}(t) = \vec{\omega}_{\text{sol}}(t) + \vec{\omega}_{\text{E}}(t). \tag{1.1}$$

We can simplify things if we assume that
the Earth & Sun *rotate in a parallel plane* (they do not!)

If the angular velocity vectors are parallel, this can be rewritten as a scalar equation,

$$\omega_{\text{sid}}(t) = \omega_{\text{sol}}(t) + \omega_{\text{E}}(t). \tag{1.2}$$

Angular velocity

$\omega =$ angle per unit time (typically radians / s)

If we assume that the rotation periods are constant (they're not!)
we can rewrite ω in terms of the orbital periods P

$$|\omega| = 2\pi / P$$

$$\frac{2\pi}{P_{\text{sid}}} = \frac{2\pi}{P_{\text{sol}}} + \frac{2\pi}{P_{\text{E}}}$$

$$\frac{1}{P_{\text{sid}}} = \frac{1}{P_{\text{sol}}} + \frac{1}{P_{\text{E}}}$$

$P_{sid} =$ length of sidereal day

$P_{sol} =$ length of solar day

$P_E =$ Earth's orbital period around the Sun

Difference Between Solar and Sidereal Day

$$P_{\text{sol}} - P_{\text{sid}} \approx P_{\text{sol}} \left(\frac{P_{\text{sol}}}{P_{\text{E}}} \right)$$

$$\approx 1 \text{ day} \left(\frac{1}{365} \right) \left(\frac{24 \text{ hr}}{1 \text{ day}} \right) \left(\frac{60 \text{ min}}{1 \text{ hr}} \right)$$

$$\approx 4 \text{ min}$$

This implies that, relative to the Sun, **the stars rise 4 minutes earlier each day** as the Sun moves eastward along the Ecliptic.


Questions?

The Sun *is not* an accurate time-keeping device

Reason: The length of the **"solar day" is *not* constant!**

Astronomers thus define two types of time:

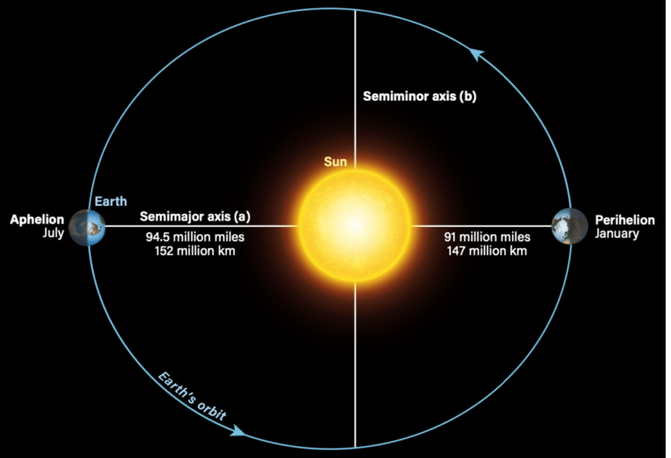
1. **Apparent solar time** - Measured by the Sun's position **relative to the observer's local meridian —** essentially, what a sundial measures.
2. **Mean solar time** – Measured by an imaginary "mean Sun" moving uniformly along the celestial equator, averaging the real Sun's motion over the year — i.e., the basis for "Civil Time".

Mean solar day = average length of all apparent solar day in one year

The Sun *is not* an accurate time-keeping device

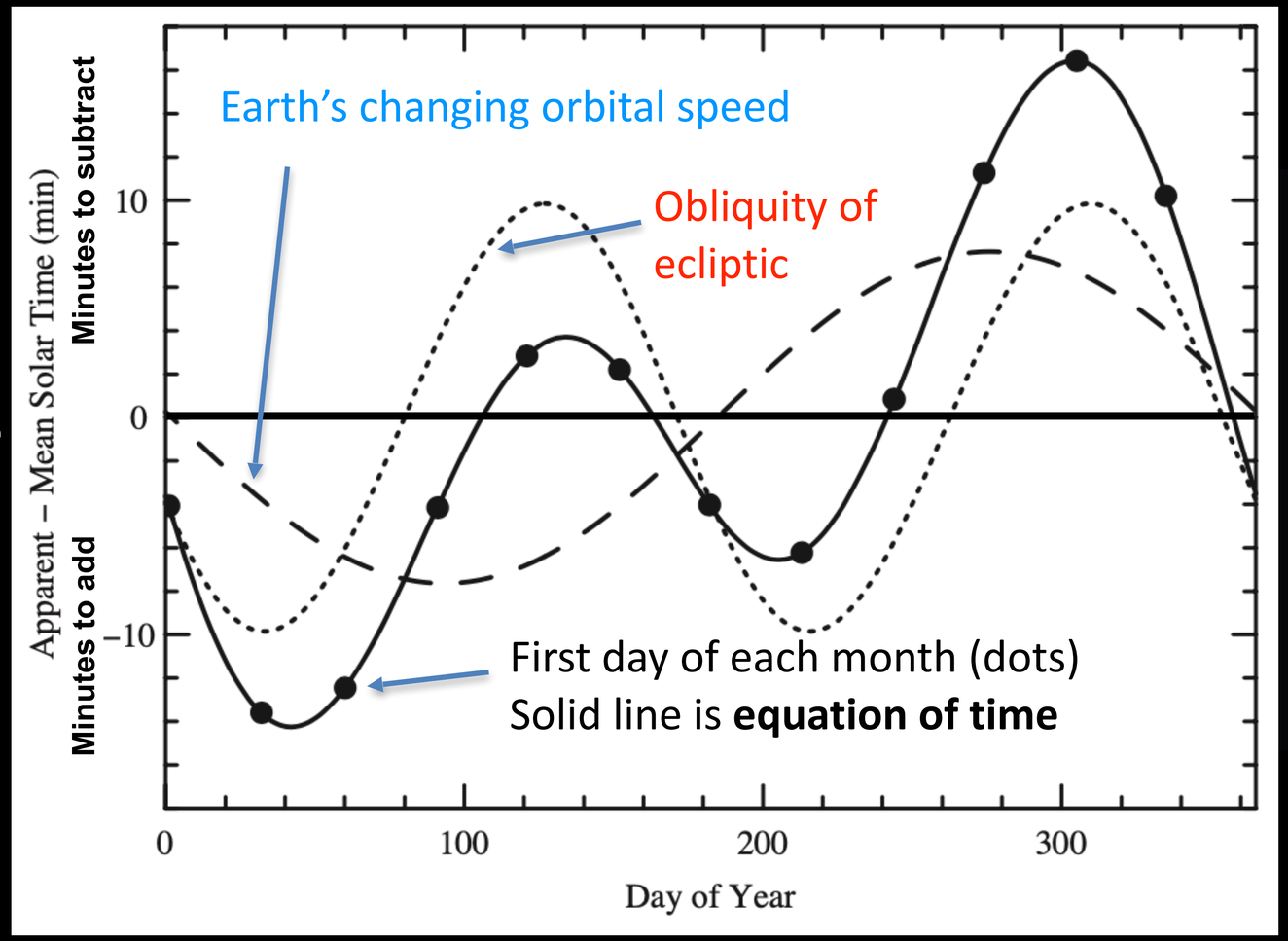
Now we can define an "Equation of Time"

Earth's non-circular orbit

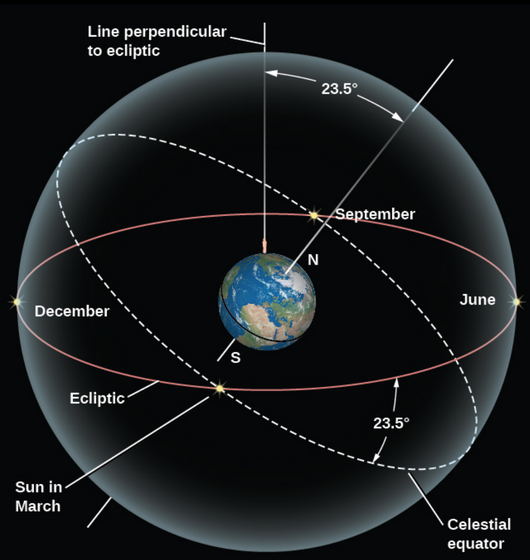


Earth orbits fastest at Perihelion (closest to the Sun)

Earth orbits slowest at Aphelion (farthest from the Sun)



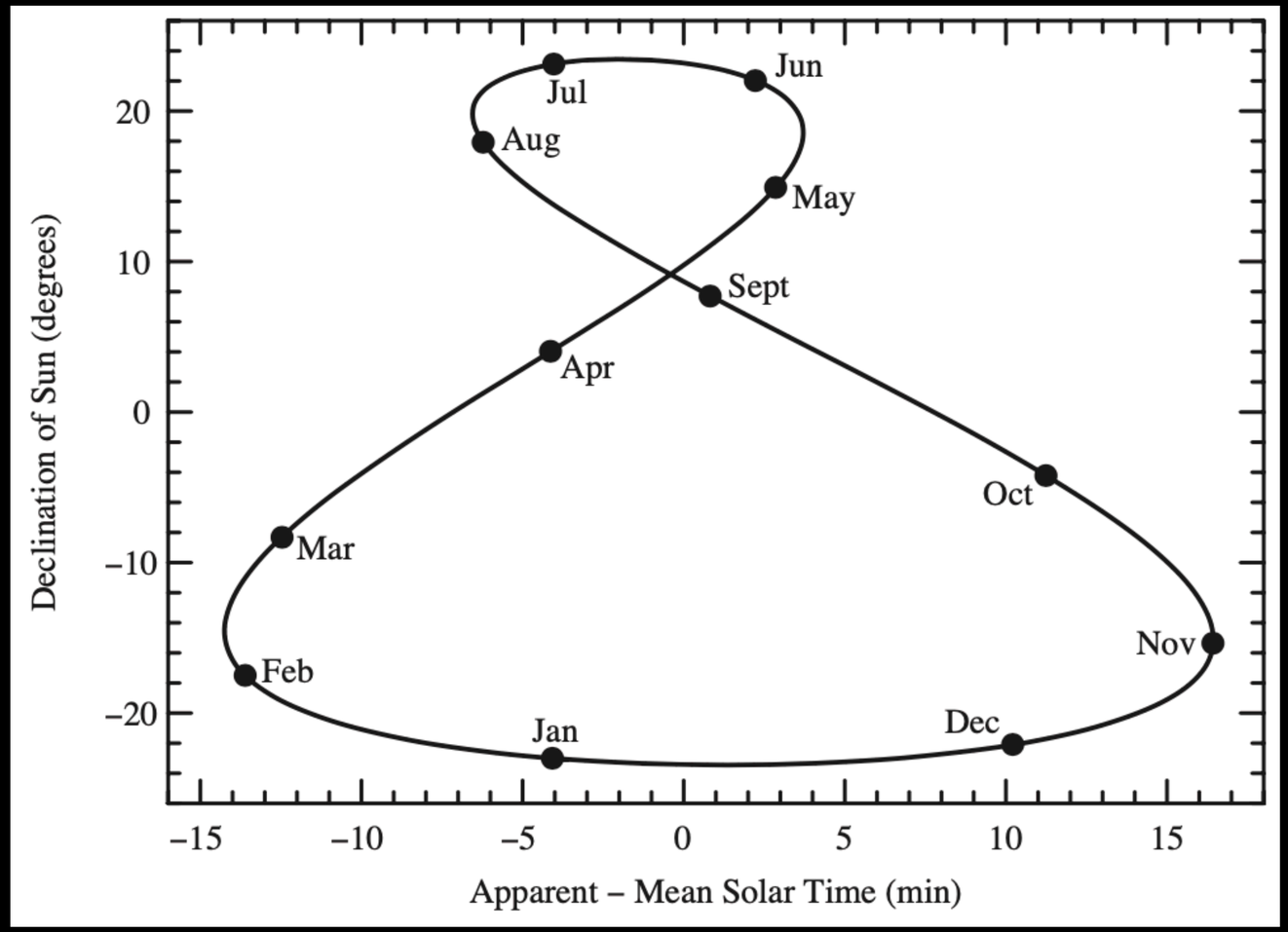
Obliquity of ecliptic



EoT = Apparent Solar Time – Mean Solar Time

The Sun *is not* an accurate time-keeping device

If we plot the EoT against the Sun's declination we get the "**analemma**"



Analemma - "support" in Greek and refers to the pedestal that *supports* a sundial.

The analemma has two components:

- A vertical component, caused by the **Earth's axial tilt.**
- A horizontal component, primarily caused by the **Earth's orbital eccentricity** (i.e., it's non-circular orbit), with a smaller contribution from Earth's axial tilt.

What would the analemma look like if the Earth had an axial tilt of 0°?

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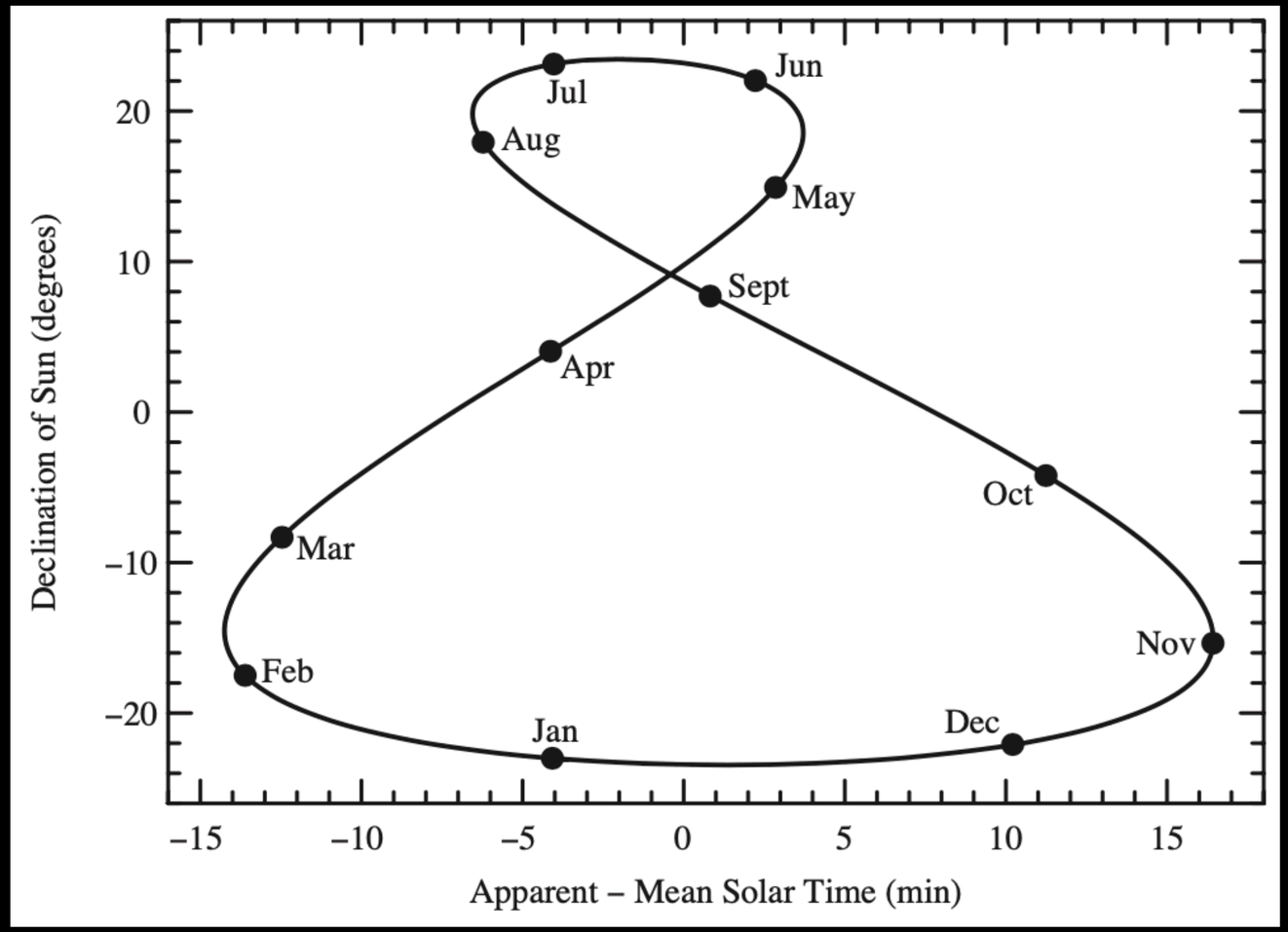

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What would the analemma look like if the Earth had an axial tilt of 0°?

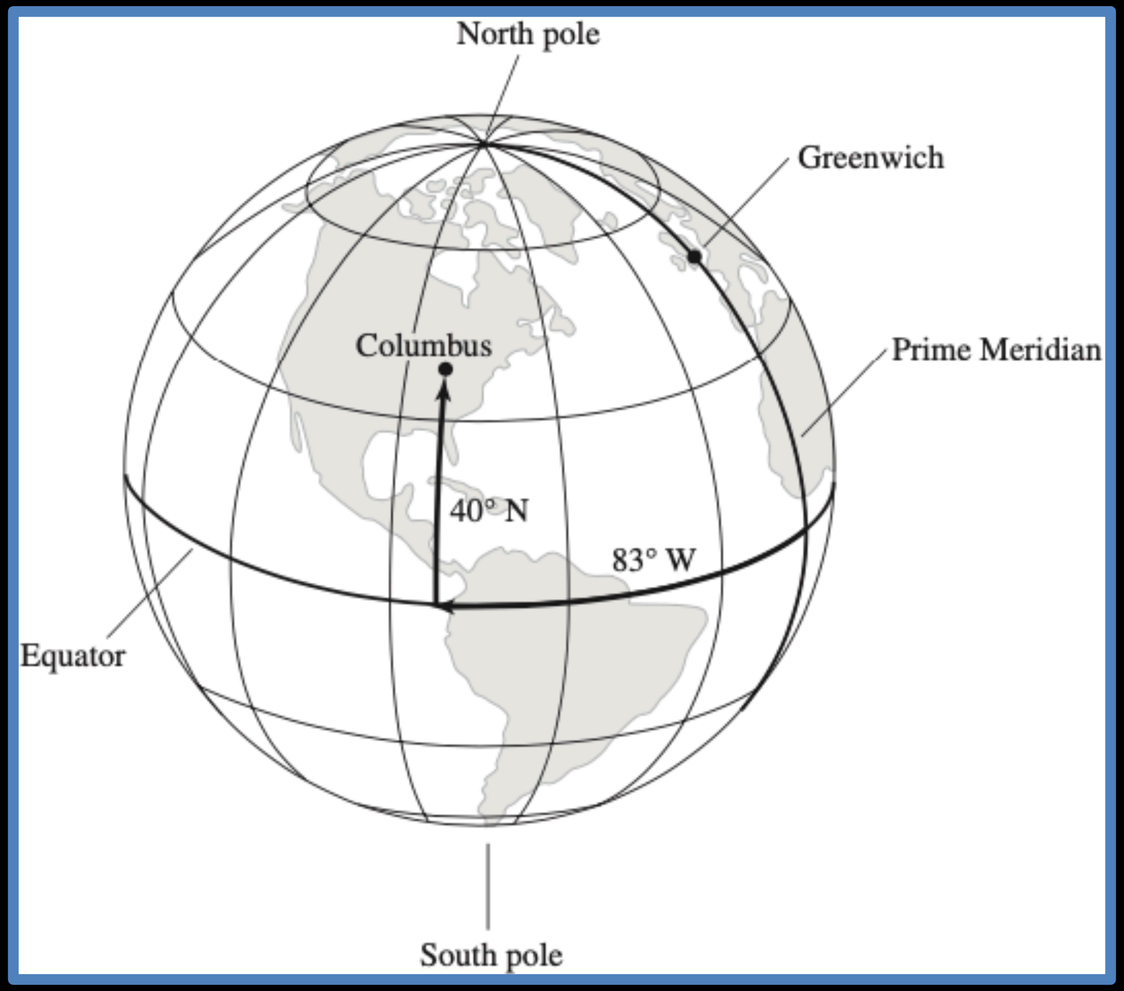
Link to Analemma Calculator!

Useful Astronomical Time

Time is relative to where you are (i.e., time zones).

The International Date Line (which separates between days) is on the meridian, opposite the Prime Meridian

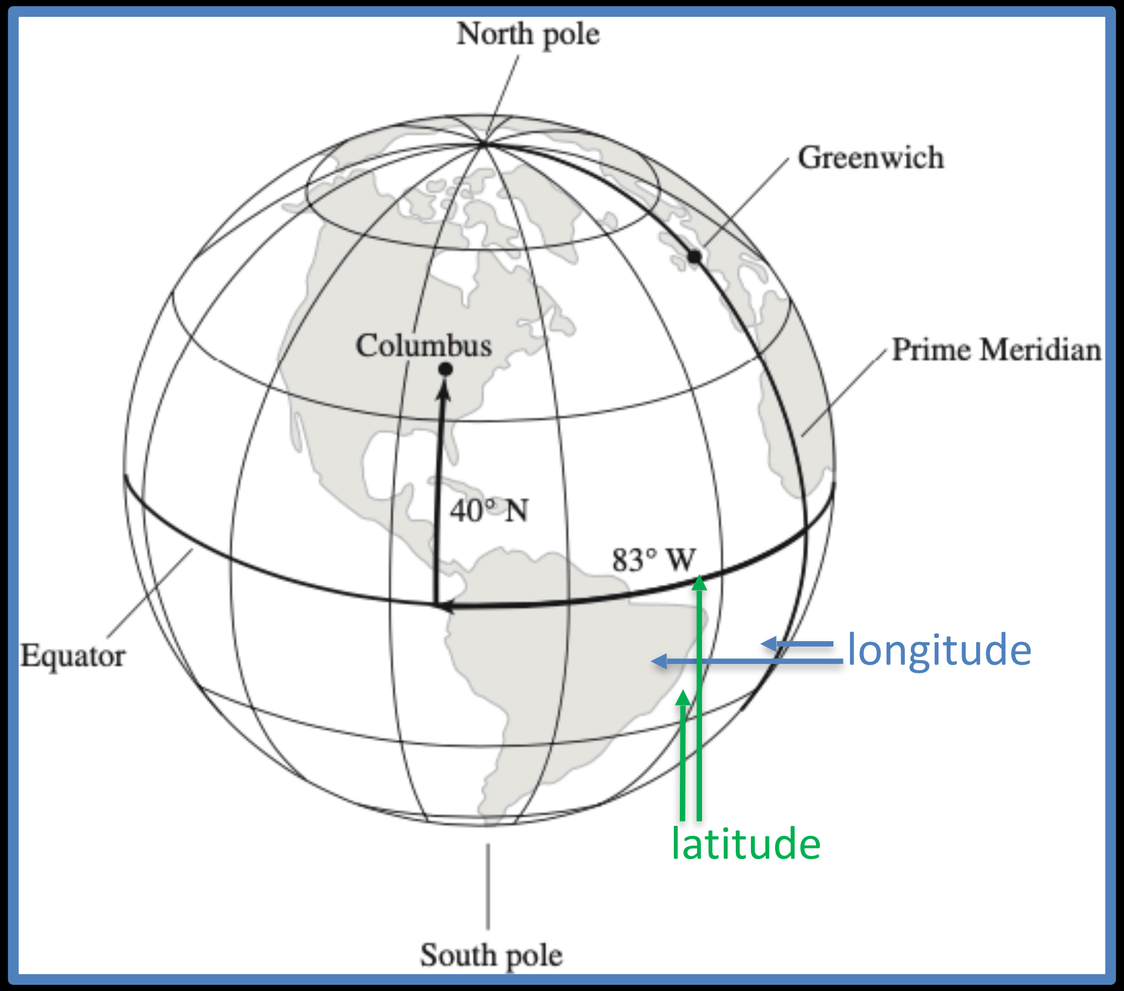
However, astronomer's want a **measure of time, independent of location on Earth.**



Useful Astronomical Time

Enter **Greenwich Mean Time (GMT)**
The universal standard!

Mean Solar Time = GMT + l_{east},
where l_{east} is the **east longitude of the observer.**



Definition of a second

However, the Earth's rotation rate isn't constant — e.g., the Moon's tidal effects slows the Earth's rotation by ~1.6 milliseconds per century!

Today, we use **atomic clocks** to keep precise track of time.

The *second* is defined as 9,192,631,770 times the period of radiation emitted by the hyperfine transition of cesium-133 atom at absolute zero temperature.

This definition was *chosen* so the second was equal in length to 1/60 of 1/60 of 1/24 of a mean solar day measured around 1900 AD.

Cesium Atomic Clock: Measures the oscillation of electrons between two energy states in Cesium atoms.

Definition of a second

So, **we are using something that has nothing to do with Earth's rotation or the orbit around the Sun to define a unit of time…**

There couldn't possibly be any issues with that…

Luckily, we have invented yet another time to deal with this disagreement, the Coordinated Universal Time (UTC*).

Basically we keep the SI definition, but then we add in a **leap second** to ensure UTC stays consistent within 0.9 seconds of mean Sun time.

*UTC was a compromise between Temps Universel Coordiné (TUC) and Coordinate Universal Time (CUT)

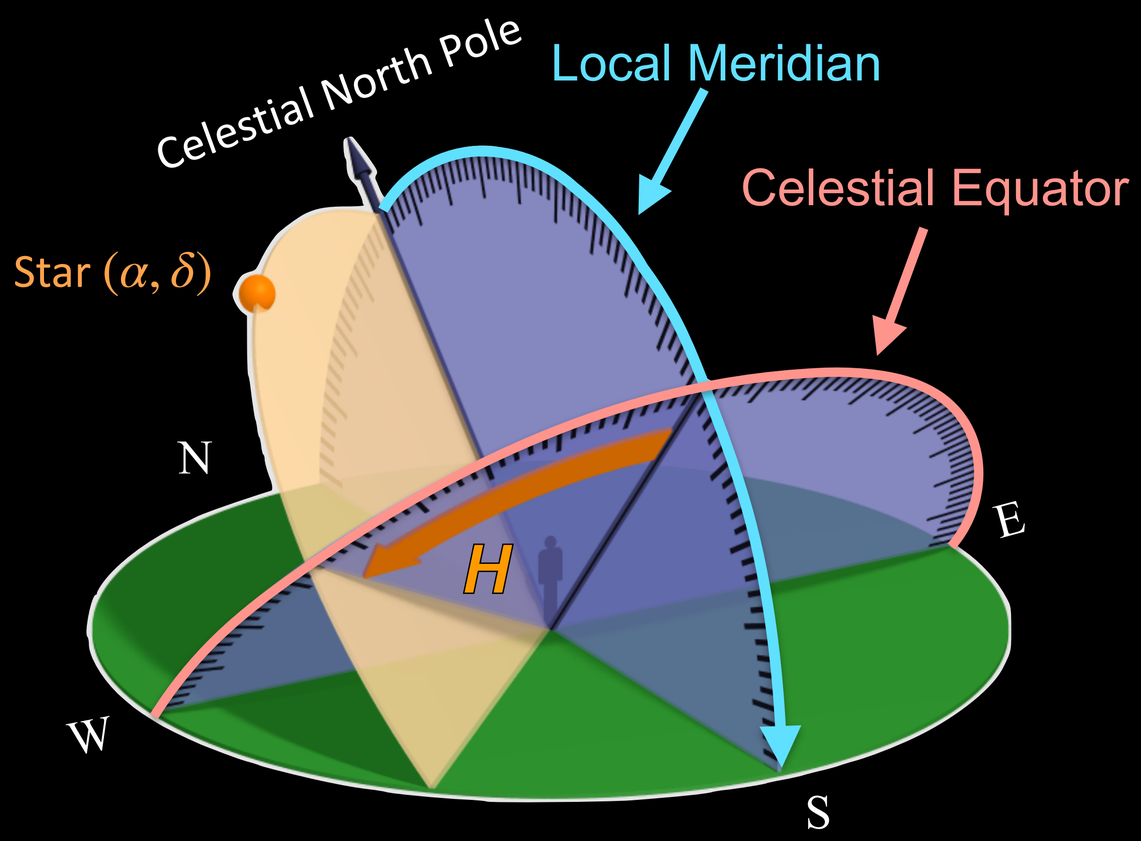
But Astronomers care about stars

The sidereal time tracks the **upper transits of distant stars** (or any distant object). This makes it more useful for tracking stars at night when we observe them.

We define ANOTHER time called the **“local sidereal time”.**

This is defined as the **“*hour angle*”** (*H*) of the *vernal equinox*, which is measured *westward* along the **celestial equator** from the **local meridian.**

A little bit about the Hour Angle

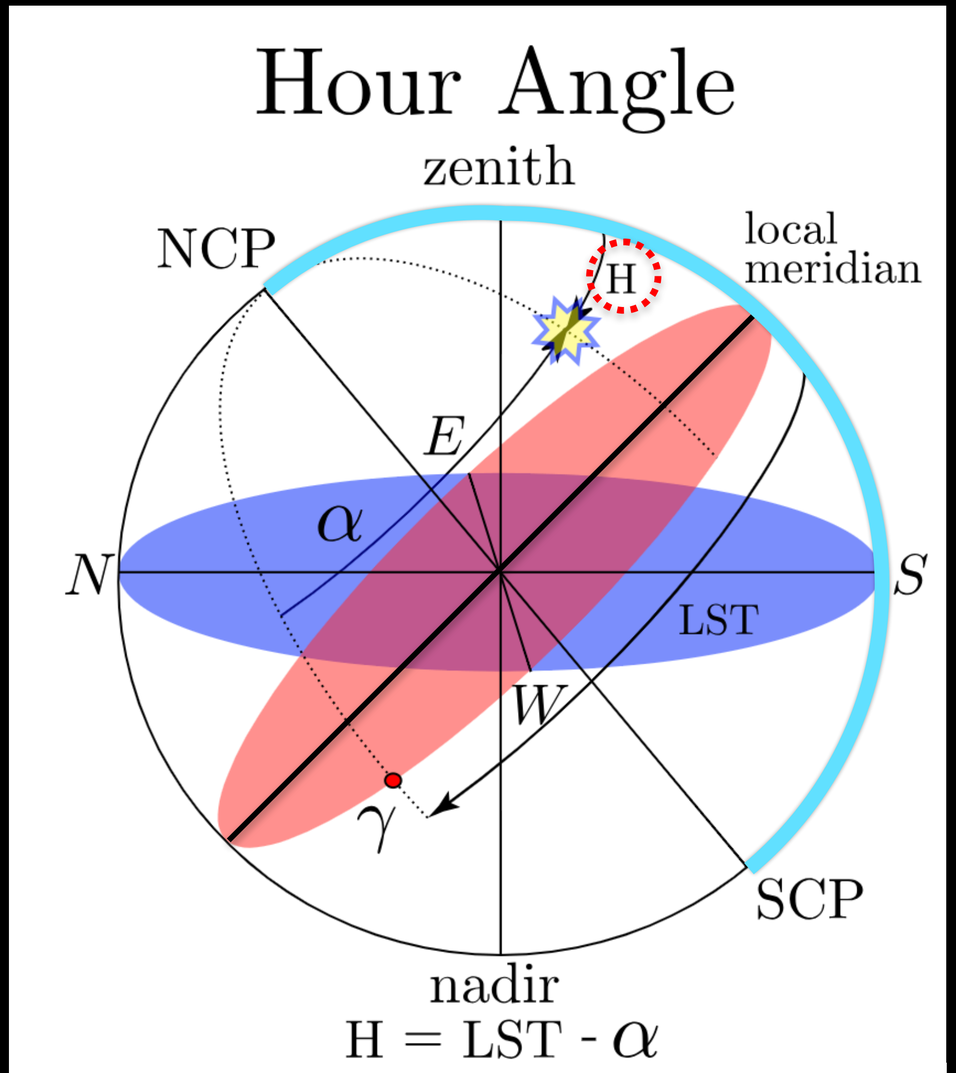


The *hour angle* (*H*) is measured d *westward* along the **celestial equator** from the **local meridian** to the object's **hour circle.**

The hour angle is an *extremely important measurement* because it lets us know **when an object will be observable** in the night sky at any given place on any given night.

Hour Circle — a great circle on the celestial sphere passing through the celestial poles and a celestial object.

Back to the local sidereal time (LST)



Local sideral time is defined as

$$\mathrm{LST} = H + \alpha,$$

Where H and α are the hour angle and right ascension of a star, respectively.

We (astronomer's) use this **to compute the hour angle of a star with a known right ascension at a specific LST.**

What does the Hour Angle Tell Us?

$H = 0$ means that the object is on the *local meridian* — i.e., the *highest point* in the sky.

$H < 0$ means that the object is to the *East* — tells you how long until the object reaches the local meridian.

$H > 0$ means that the object is to the *West* — tells you how *long ago* the object transited your local meridian.


Questions?

Reminders

- The first coding exercise is due Sunday at 11:59pm.
- The first homework assignment is due Sunday at 11:59pm
- Log into canvas and submit your answer to the discussion question by the end of the day to receive participation credit.