Potsdam
THE STATE UNIVERSITY OF NEW YORK
1816

# SOAR: The Sky in Motion
## Life on the Tilted Teacup Ride

The Year


Aileen A. O'Donoghue
Priest Associate Professor of Physics
ST. LAWRENCE UNIVERSITY

# Kiva

December 1997 – October 27, 2009

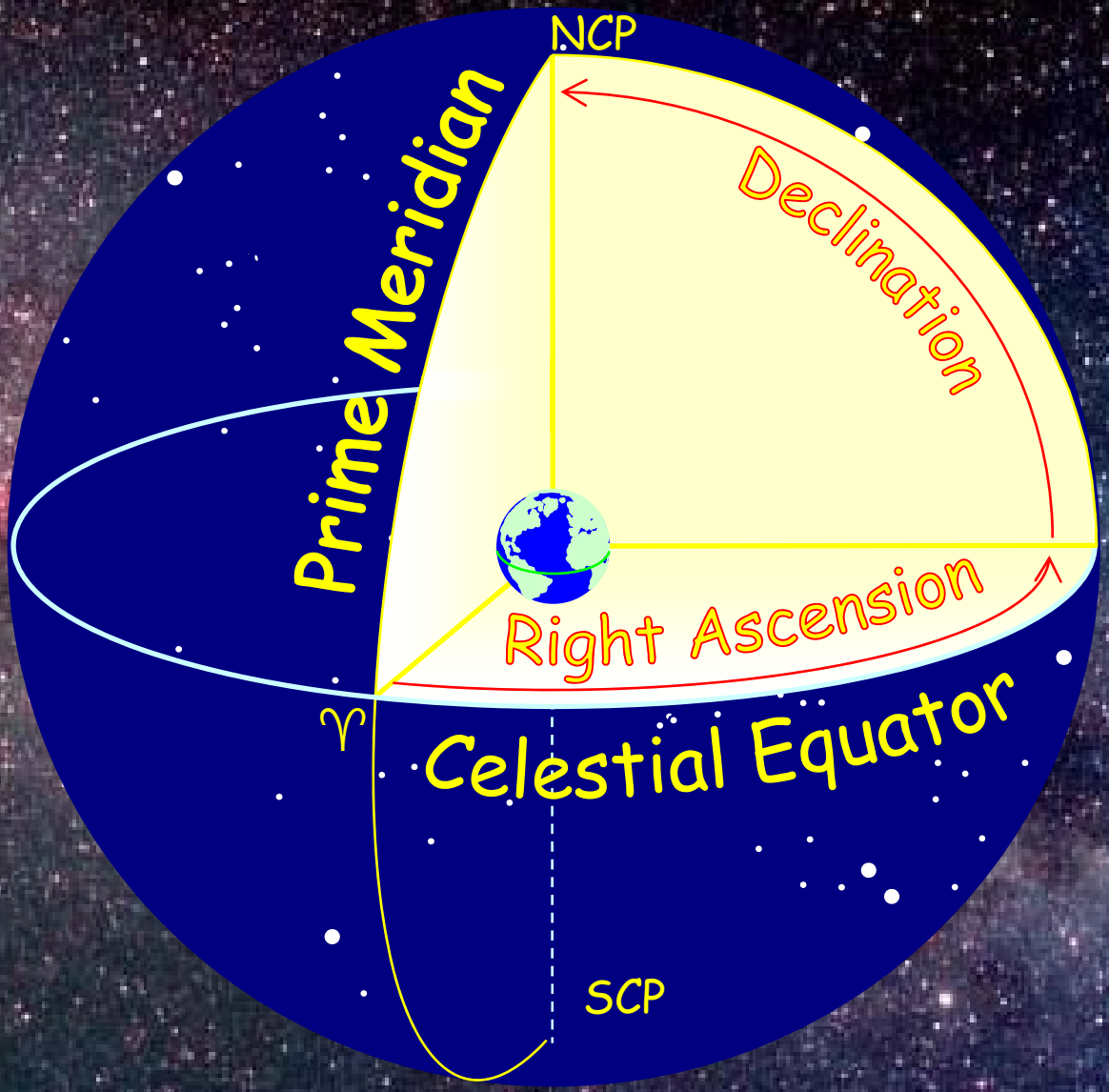
# Celestial Coordinates

## ☆Right Ascension

- RA or $\alpha$
- From prime meridian ($0^h$) to $23^h59^m59^s$ Eastward

## ☆Declination

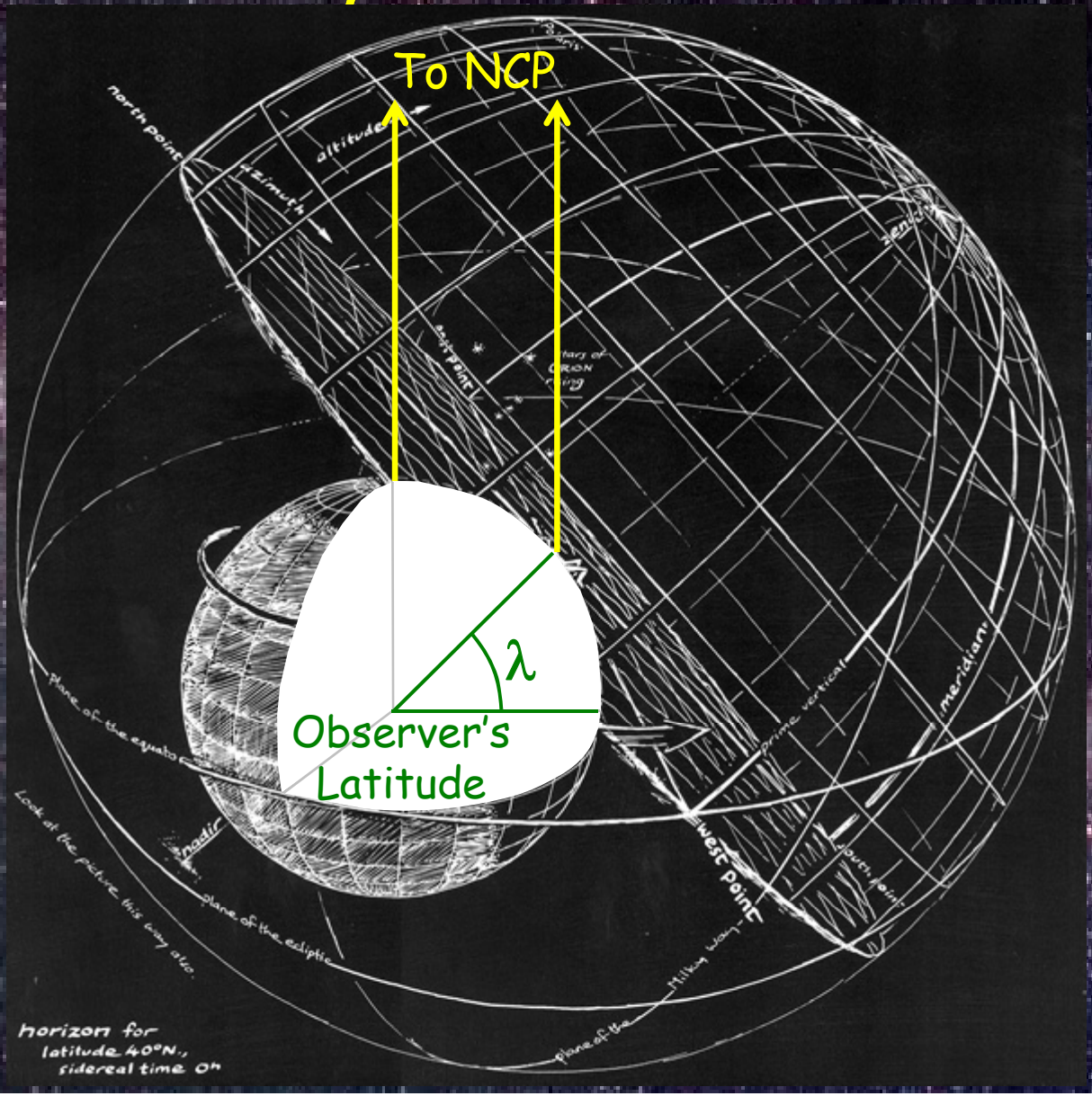
- Dec or $\delta$
- From celestial equator (0°) to poles N & S 90°



# Tilted Sky

☆ Observers see sky "tilted" due to latitude

Our view is tilted with respect to Earth's due to our latitude.

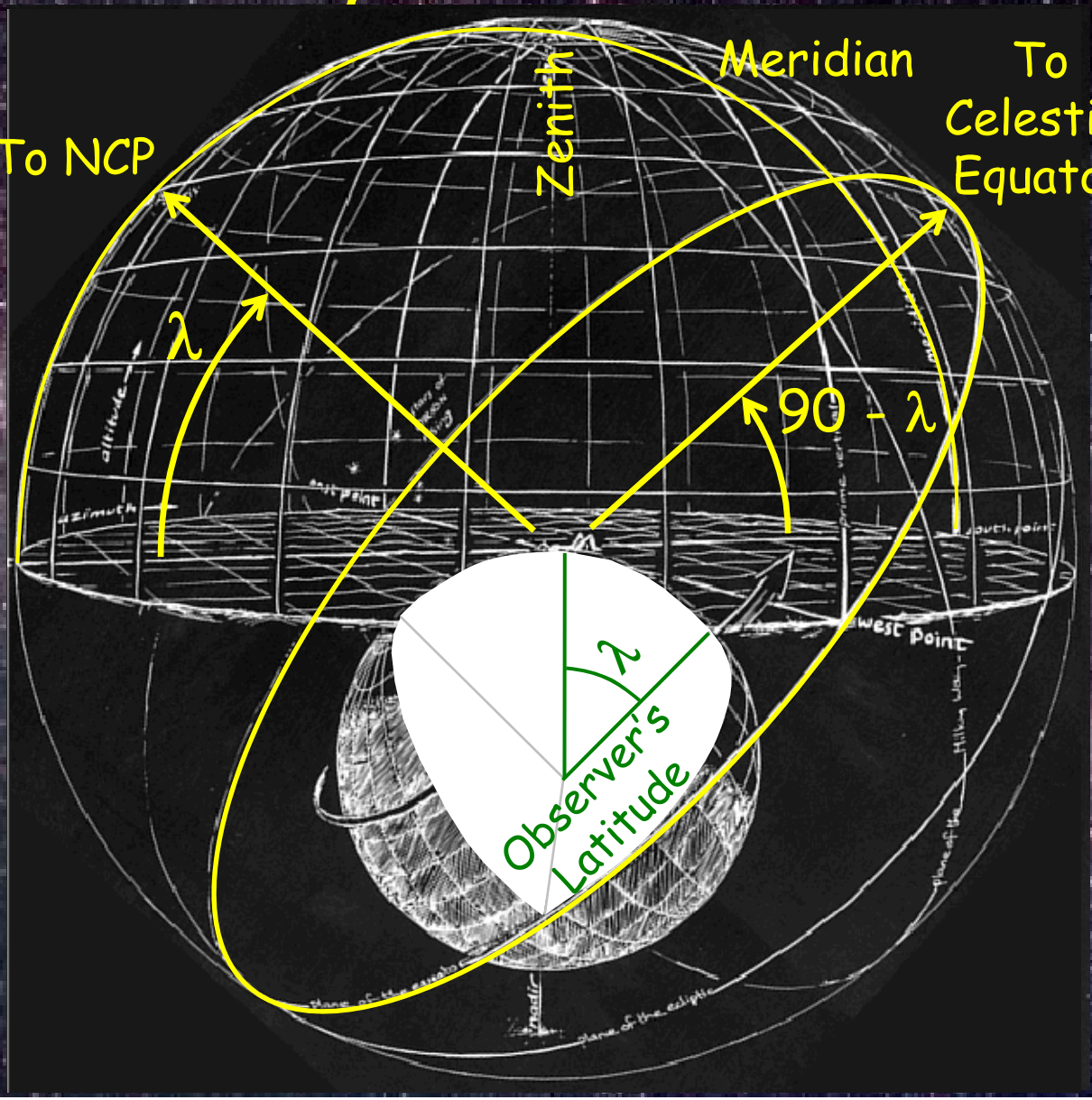


# Tilted Sky

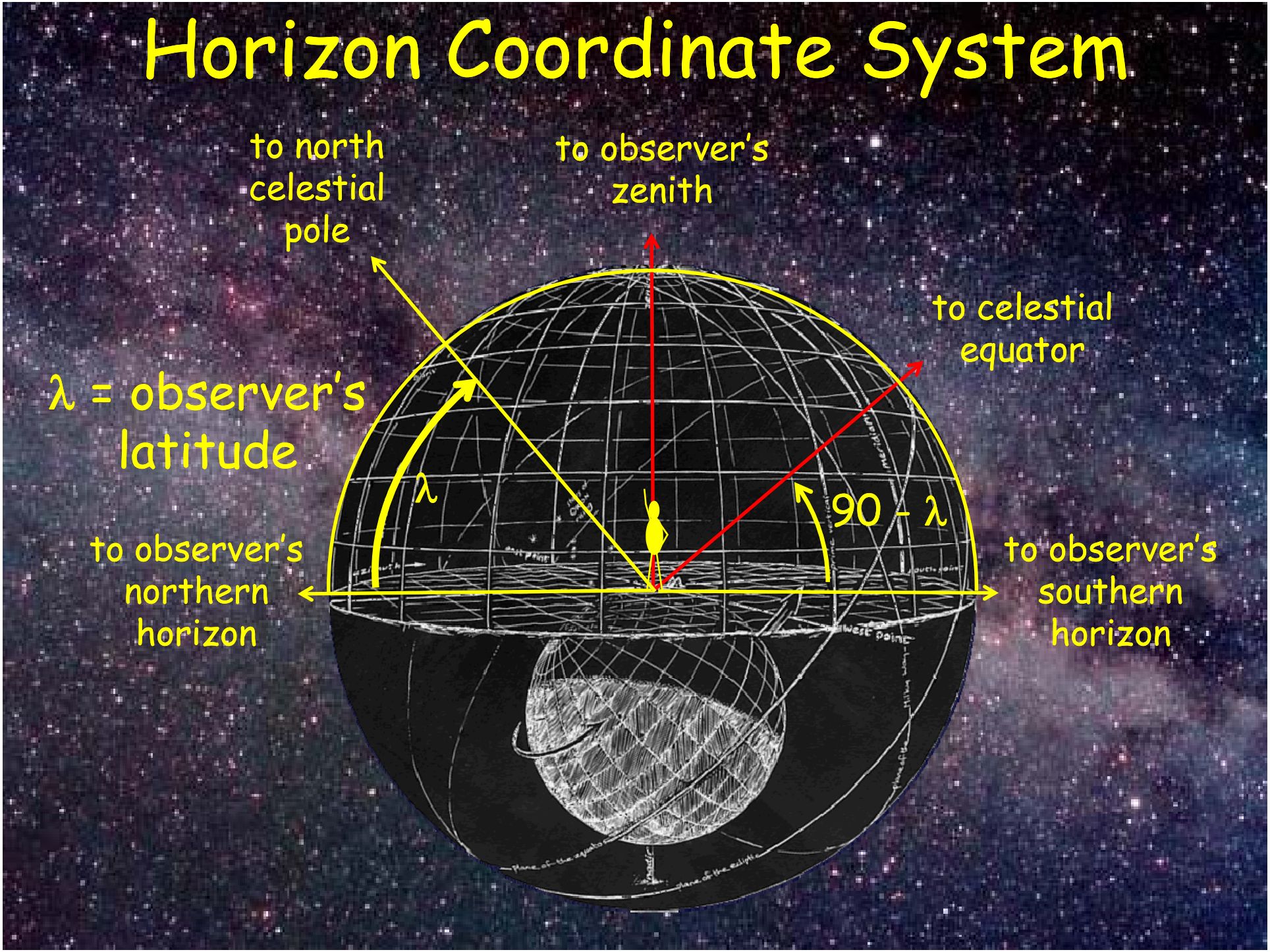
☆ Observers see sky "tilted" due to latitude

We see ourselves "on top" of the Earth, beneath the sky.

So we see sky motions tilted

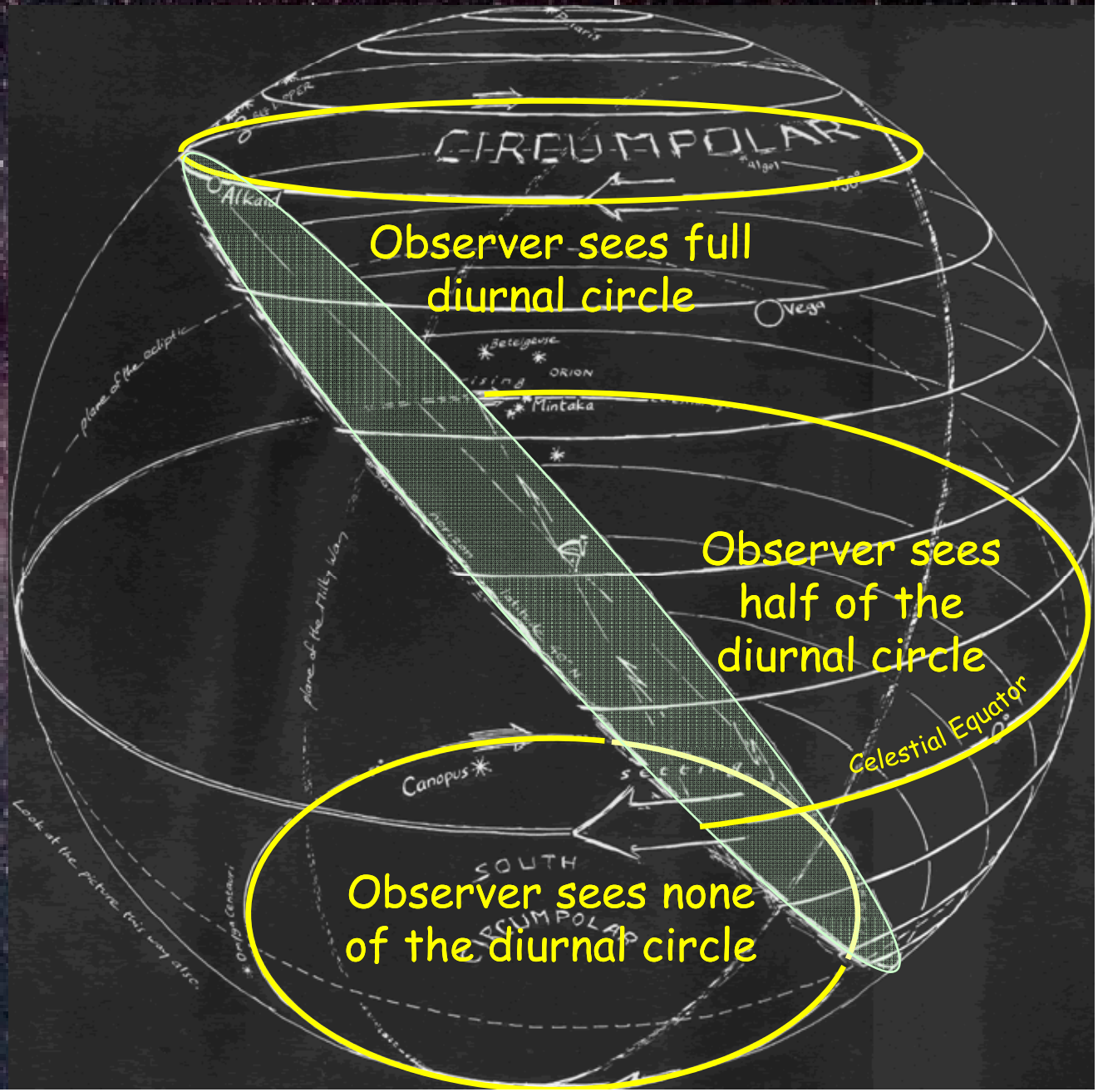


# Horizon Coordinate System



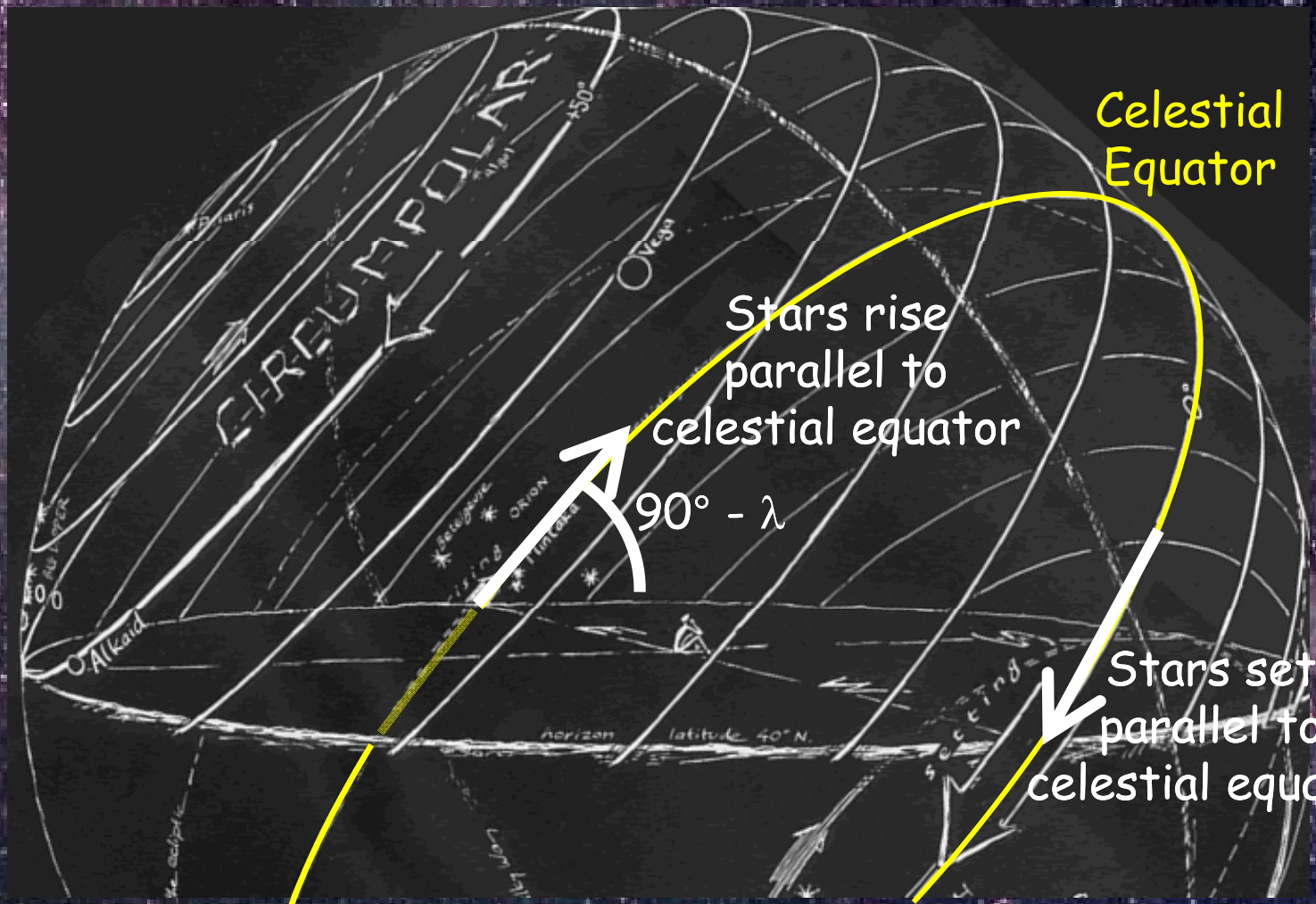
# Diurnal Circles

- ☆ Each celestial object circles the observer each day
- ☆ Observer sees part of each circle



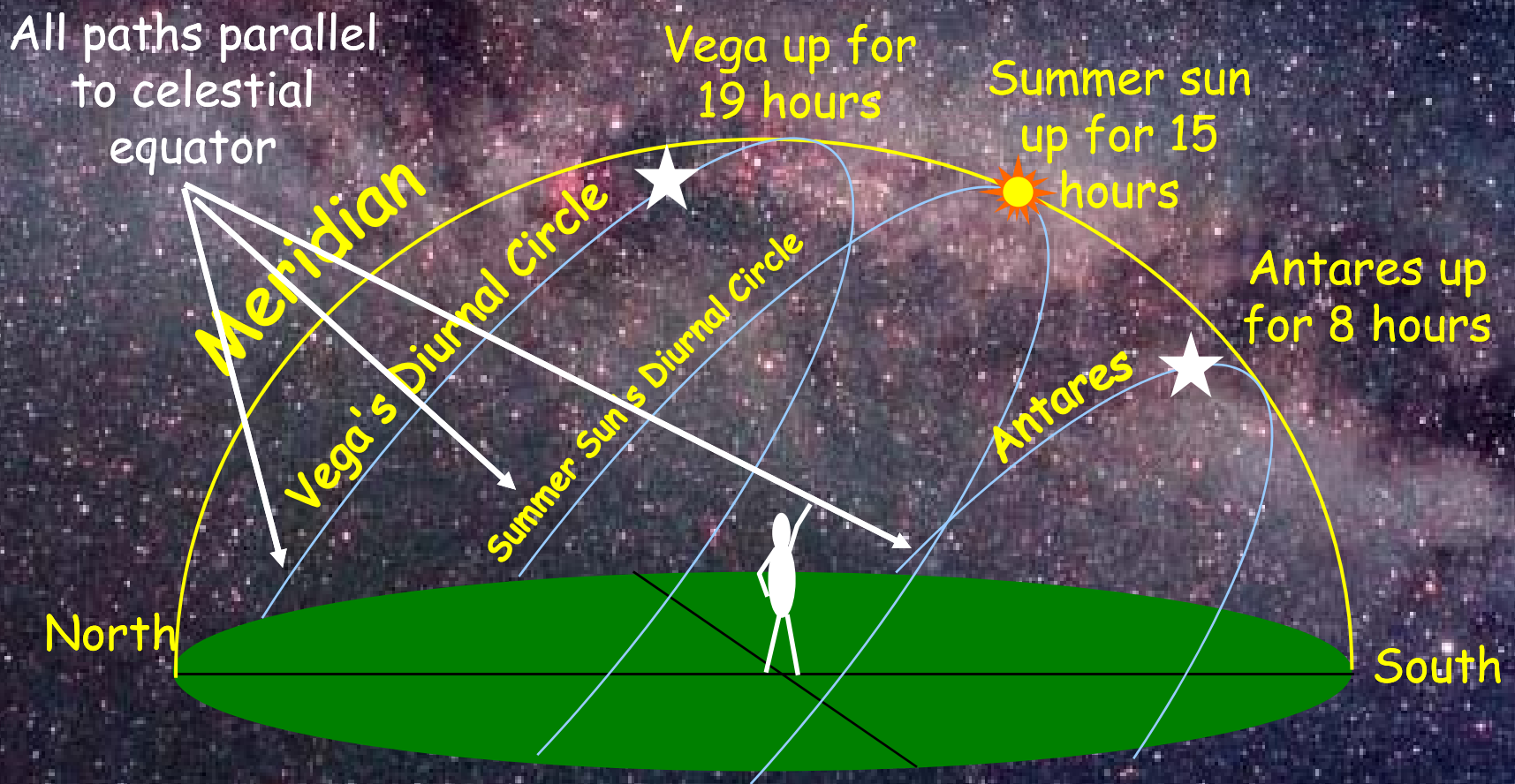
# View of Observers

- Diurnal circles are parallel to CE
  - Stars rise and set at CE's angle from horizon



# Star Paths

- Each travels a diurnal circle
  - Portion of diurnal circle above horizon determines time object is "up"



# Sunrise, Sunset …

☆ Everything in the sky (sun, moon, stars, etc.)

- Rises in the east each day
- Sets in the west

## Measuring Circles:

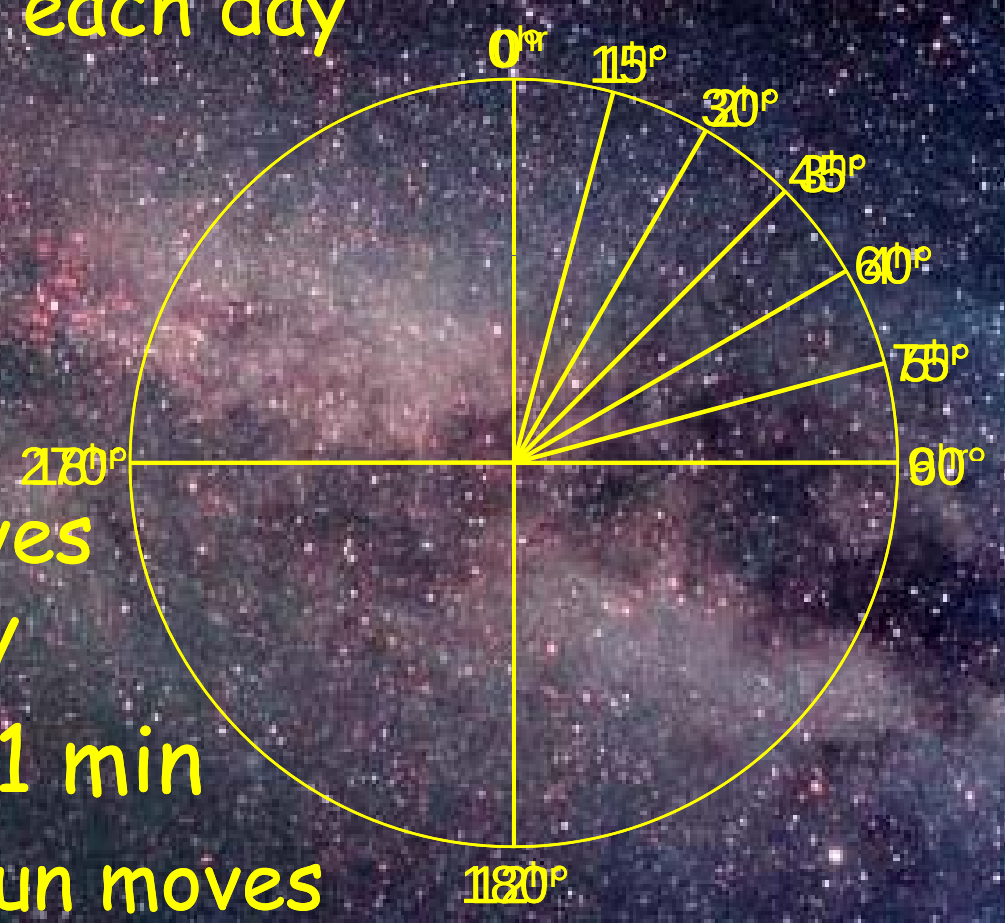
360° = 24 hr

15° = 1 hr

Each hour, the sun moves 15 degrees in the sky

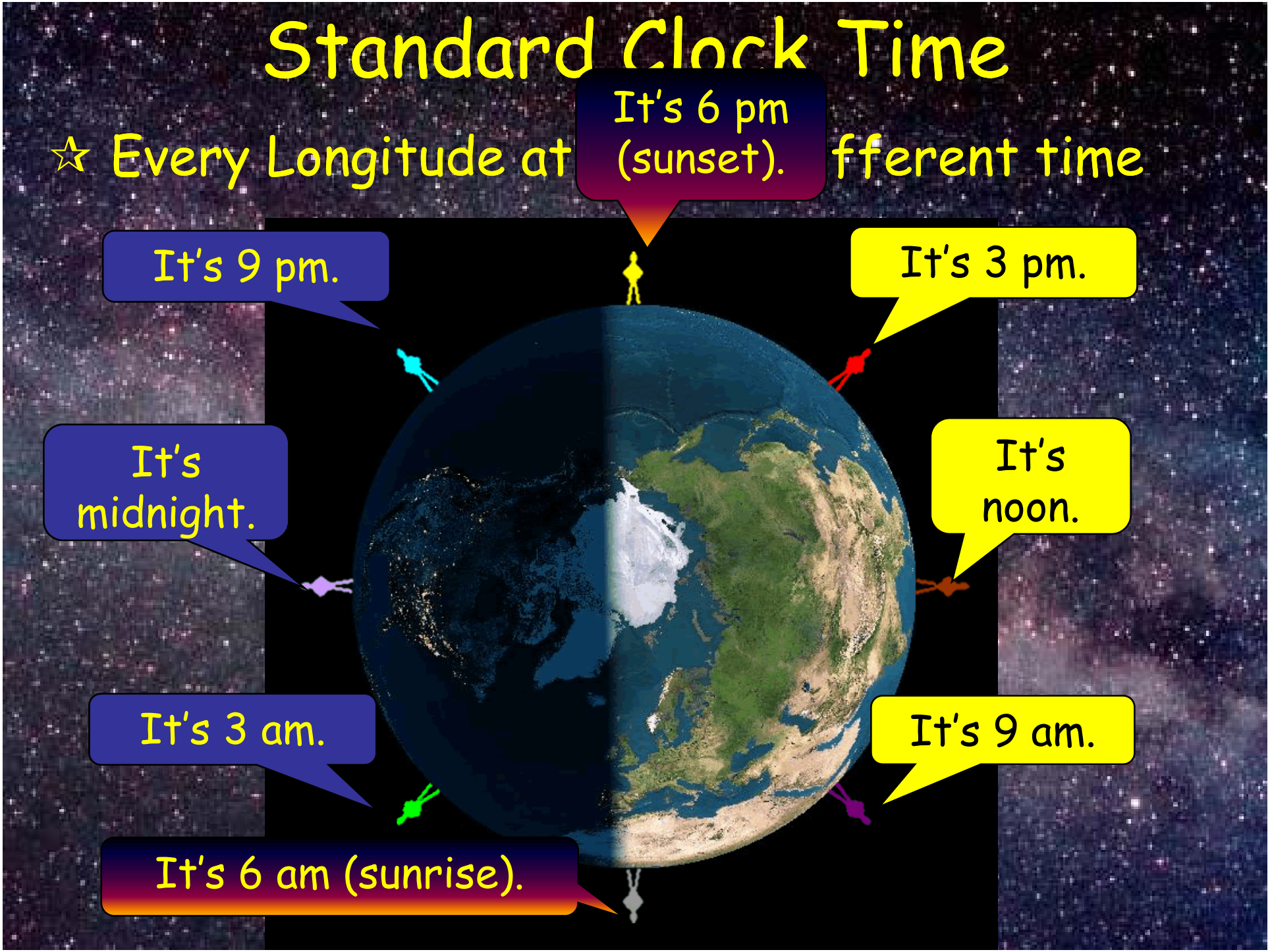
1° = 4 min or 15′ = 1 min

Every 4 minutes, the sun moves 1 degree = 60′ in the sky



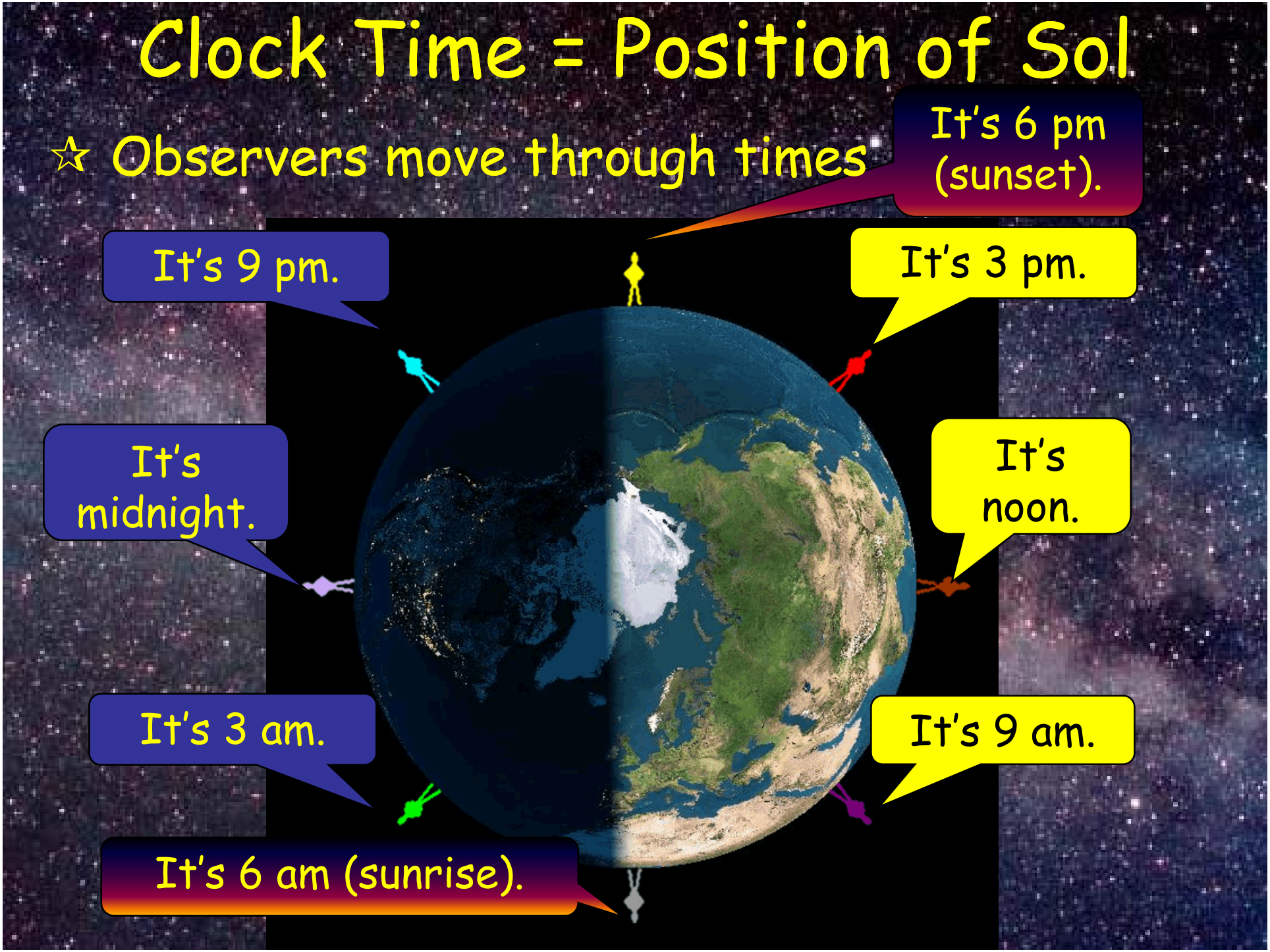
# Standard Clock Time

☆ Every Longitude at fferent time



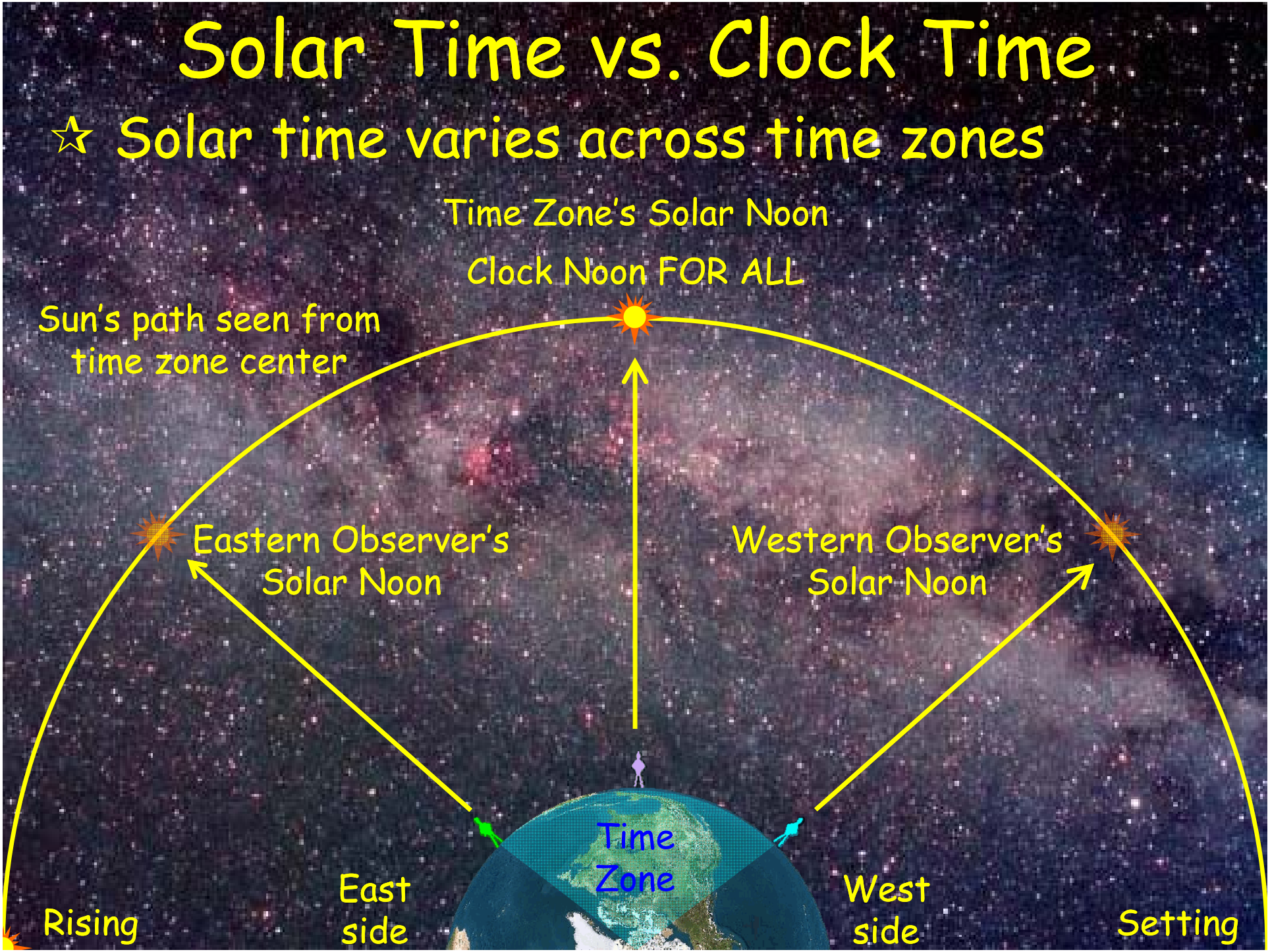
# Clock Time = Position of Sol

☆ Observers move through times



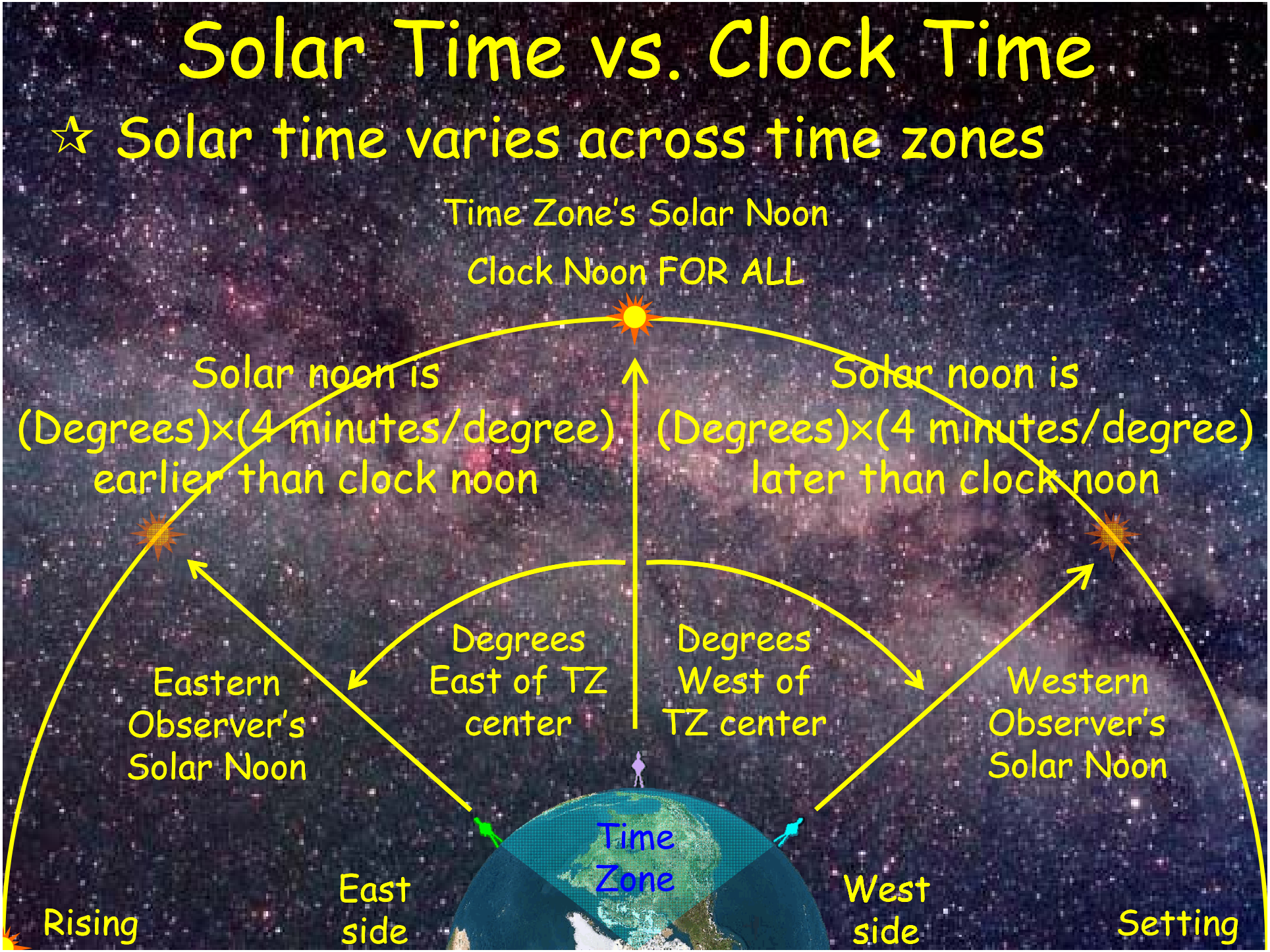
# Solar Time vs. Clock Time

☆ Solar time varies across time zones



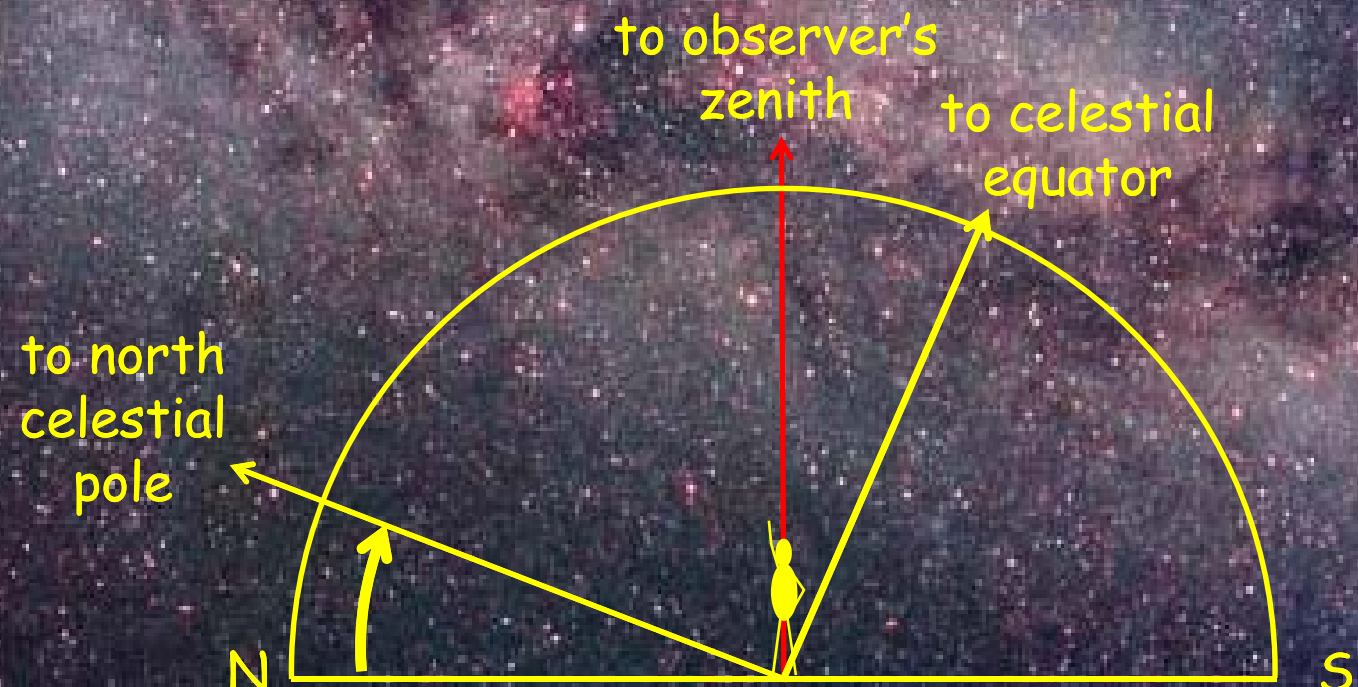
# Solar Time vs. Clock Time

☆ Solar time varies across time zones



# Celestial Navigation

- ☆ Finding Latitude & Longitude from
  - Altitude of Polaris (NCP)
  - Transit time of star
    - ☽ Looked up in an ephemeris (eg. Field Guide)



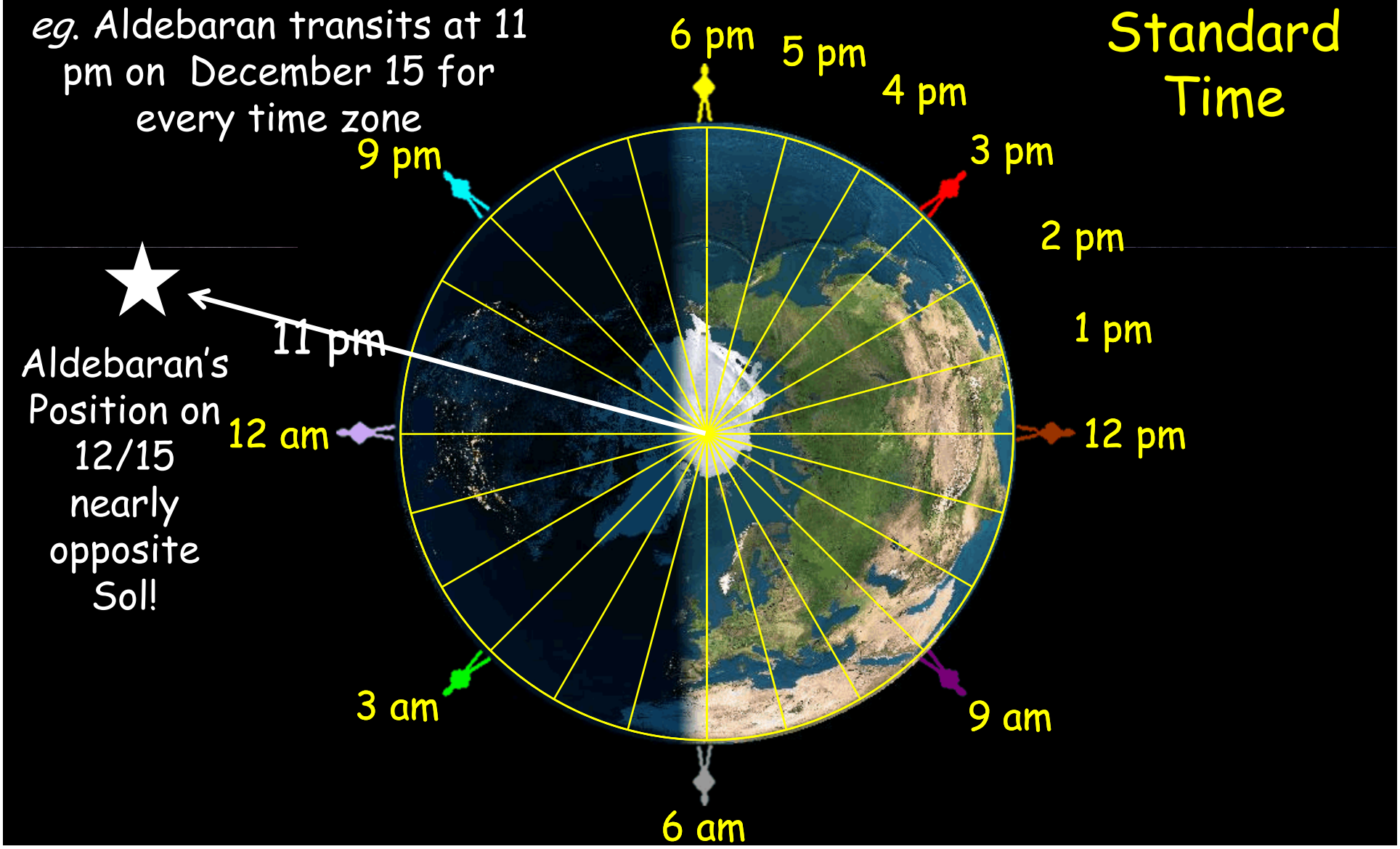

Observer at 20° N

# Star Transit Time

## Gives position of star with respect to the sun

*eg.* Aldebaran transits at 11 pm on December 15 for every time zone

Standard Time



# Celestial Navigation

## ☆ Difference between observed and expected transit times gives longitude

Observer watches star transit.

Clock is set to some time zone.

Observed transit time disagrees with ephemeris.


Star's Transit

Clock's Time Zone Longitude

Degrees East of TZ center

Longitude difference from clock's time zone center = (Time difference)×(15°/hour)

# Celestial Navigation

## ☆ Example: Transit of Deneb on August 1

Colorado Day!

Observer sees Deneb transit at 11 pm EDT

At 1 am Deneb will transit TZ center at 75° W

Looks up transit time in FG

On 8/1 Deneb transits at 1 am

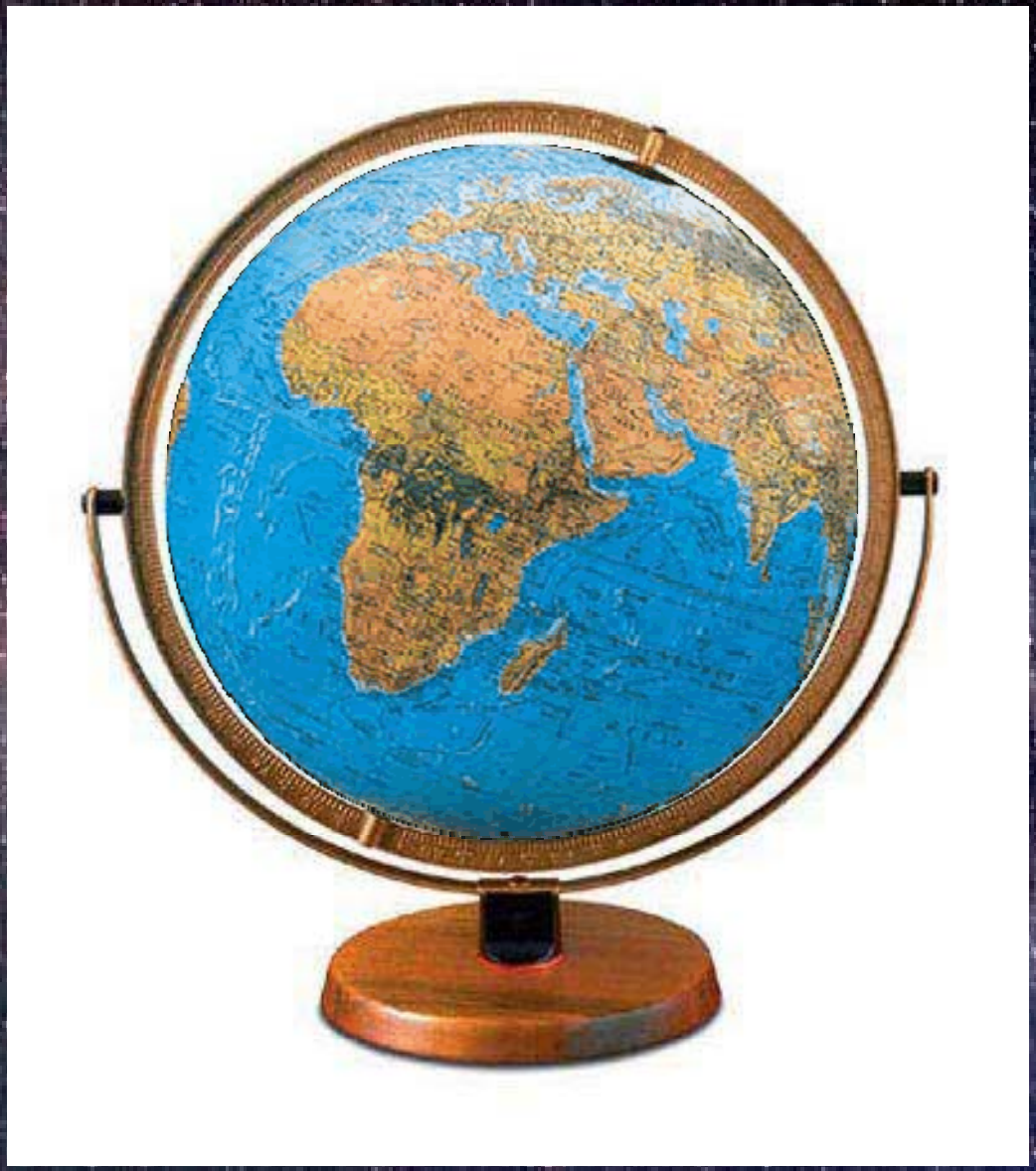

Early ⇒ East of TZ center

Longitude difference from clock's time zone center = (2 hours)×(15°/hour) = 30° East

Observer's Longitude = TZ center – Latitude difference = 75° W - 30° = 45 ° W

# Models of Earth

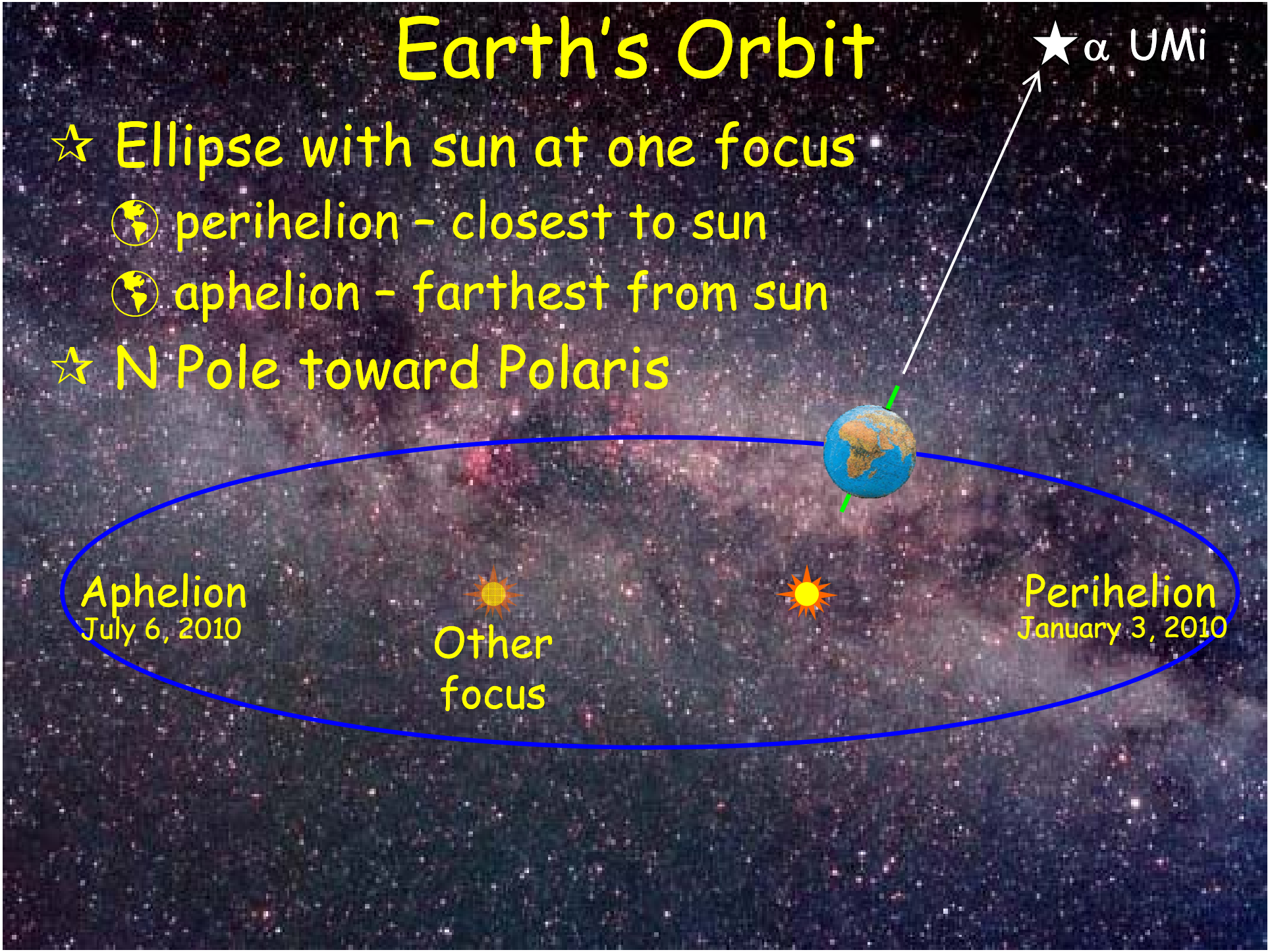
Why are globes tilted?



# Earth's Orbit

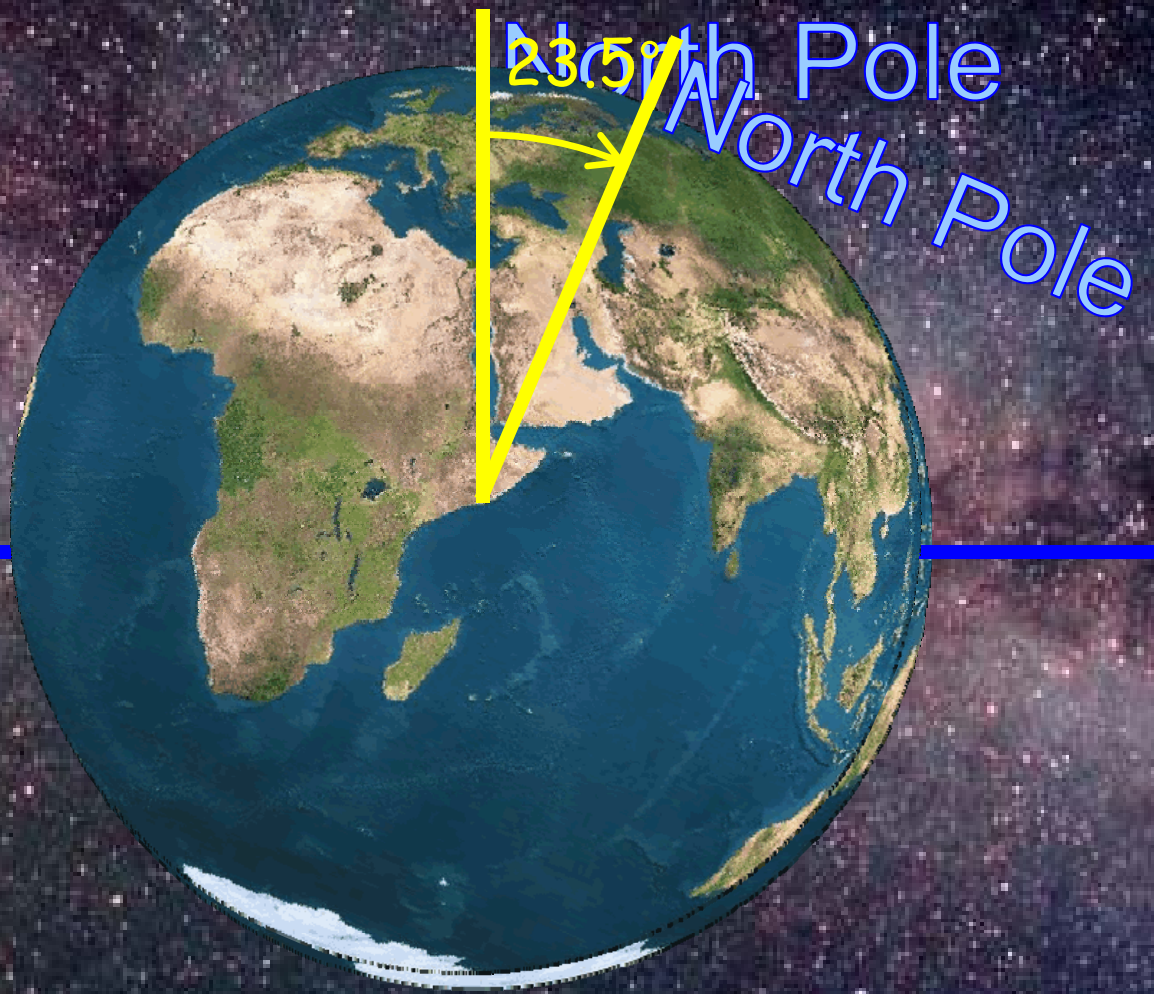
# Earth's Orbit

- ☆ Ellipse with sun at one focus
  - perihelion – closest to sun
  - aphelion – farthest from sun
- ☆ N Pole toward Polaris



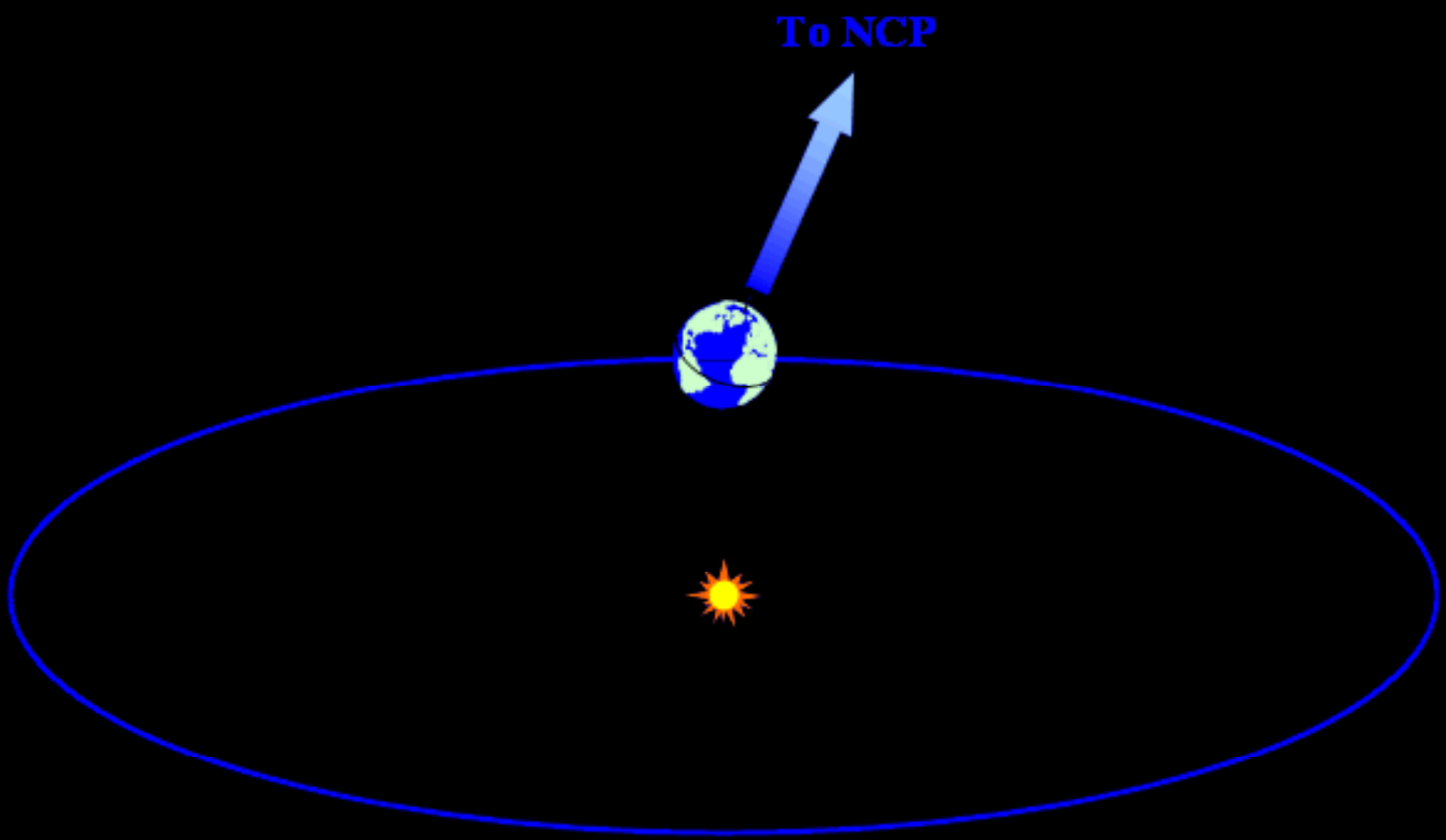
# Earth's Orbit

☆ Rotation Axis tilted 23.5° from ⊥



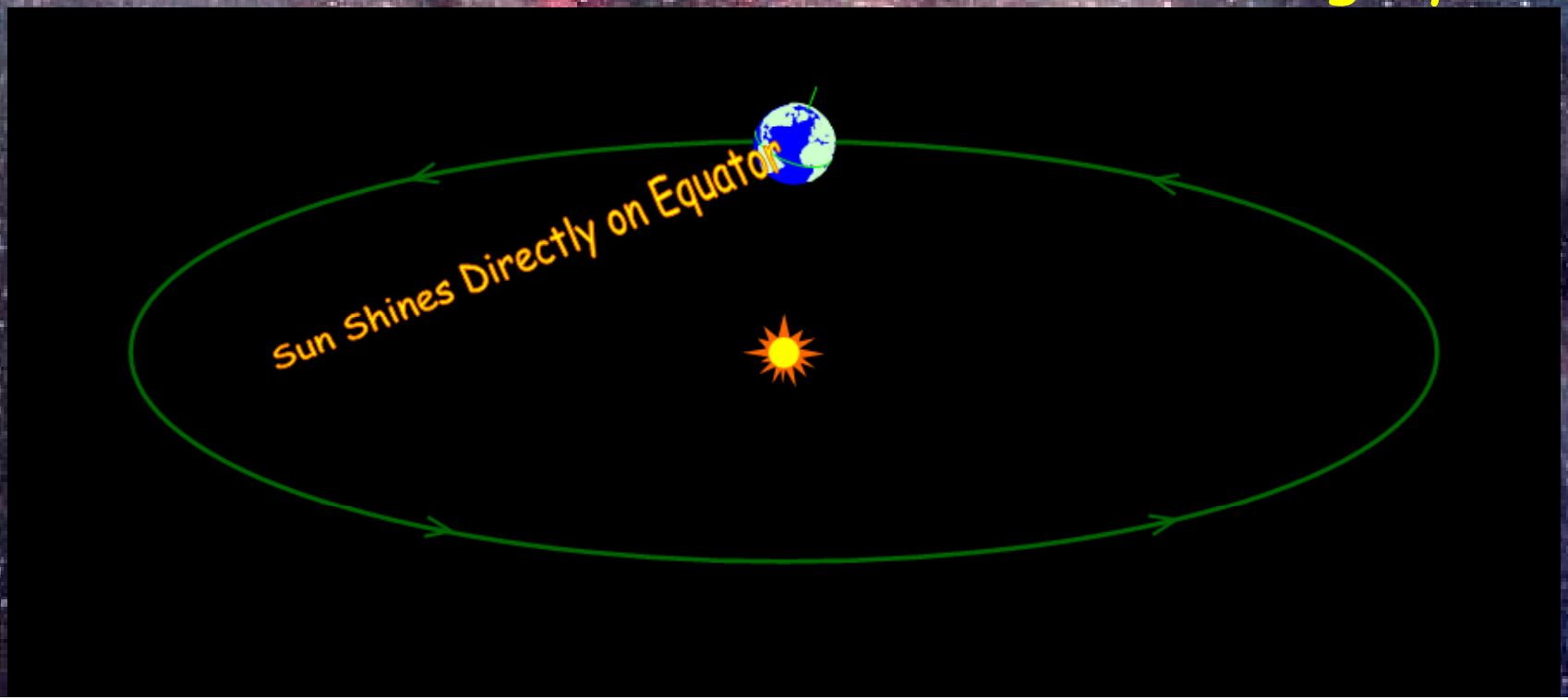
# Earth's Orbit

☆ Axis always points at Polaris



# The Home World

- ☆ The Earth in space
  - 360° in 365 days ⇒ ~1°/day
  - Rotation axis tilted 23.5° from orbit axis
    - ⇒ Declination of sun varies through year
    - ⇒ subsolar latitude varies through year

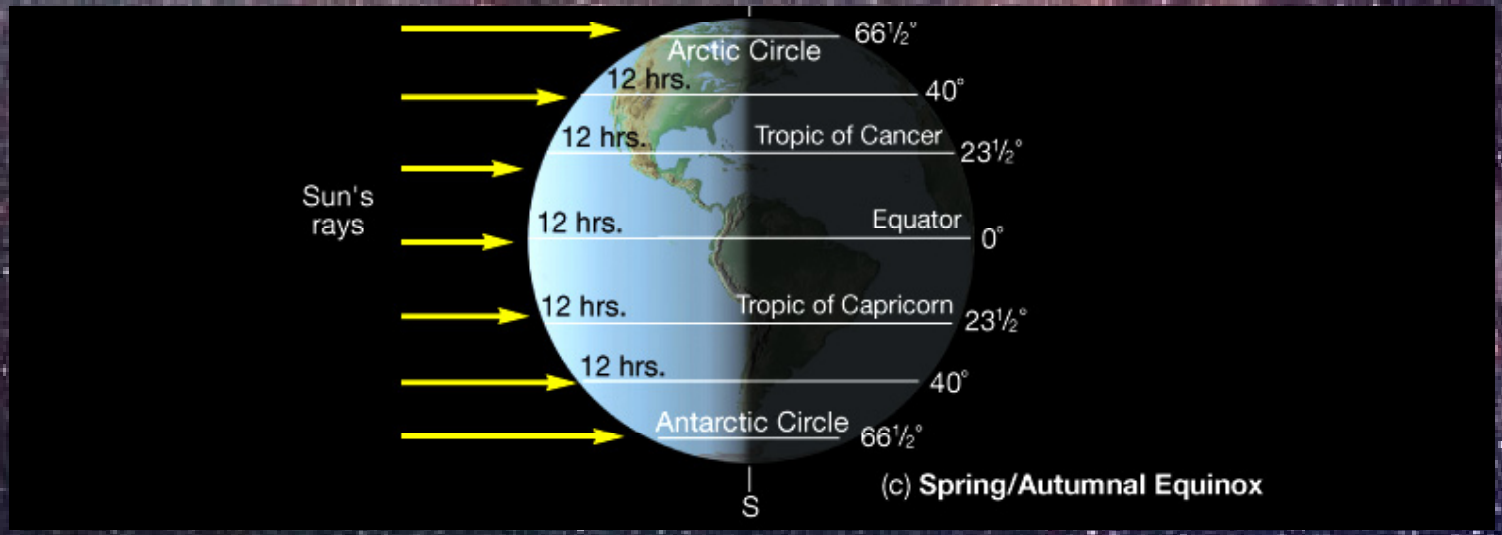


# Solstices & Equinoxes

- ☆ Declination ($\delta$) of the sun
  - 🌎 Equinox: Sun crossing celestial equator $\delta_{Sol} = 0°$
    - ☽ Vernal Equinox: sun moving north
    - ☽ Autumnal Equinox: sun moving south
  - 🌎 Solstice: Sun at N/S extreme $\delta_{Sol} = \pm 23.5°$
    - ☽ (N) Summer solstice: sun at northernmost point
    - ☽ (N) Winter solstice: sun at southernmost point
- ☆ Right Ascension ($\alpha$) of the sun
  - 🌎 $0^h$ = Vernal Equinox (♈)
  - 🌎 $6^h$ = Summer Solstice (♊)
  - 🌎 $12^h$ = Autumnal Equinox (♍)
  - 🌎 $18^h$ = Winter Solstice (♐)

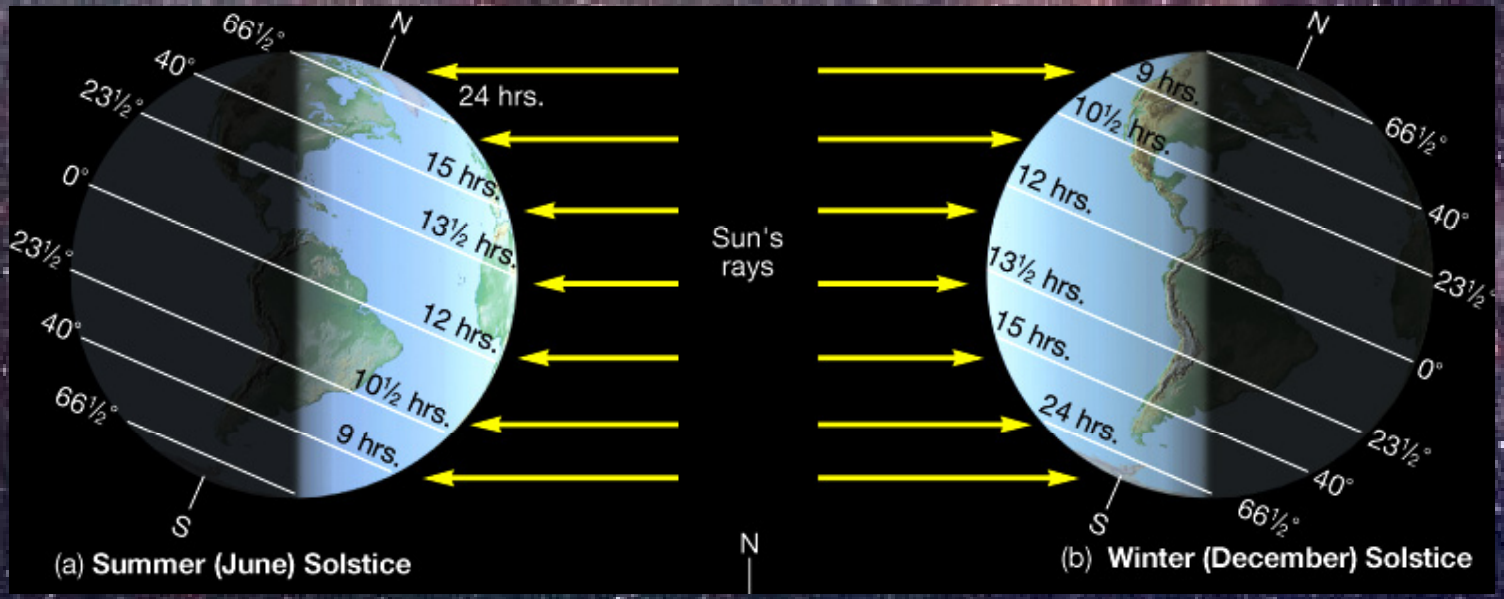
# Seasons

- ☆ Equinox – sun on Celestial Equator
  - 🌎 Vernal (spring): $\delta = 0°$, $\alpha = 0^h$
    - ☽ Sun crossing equator moving north
  - 🌎 Autumnal (fall): $\delta = 0°$, $\alpha = 12^h$
    - ☽ Sun crossing equator moving south



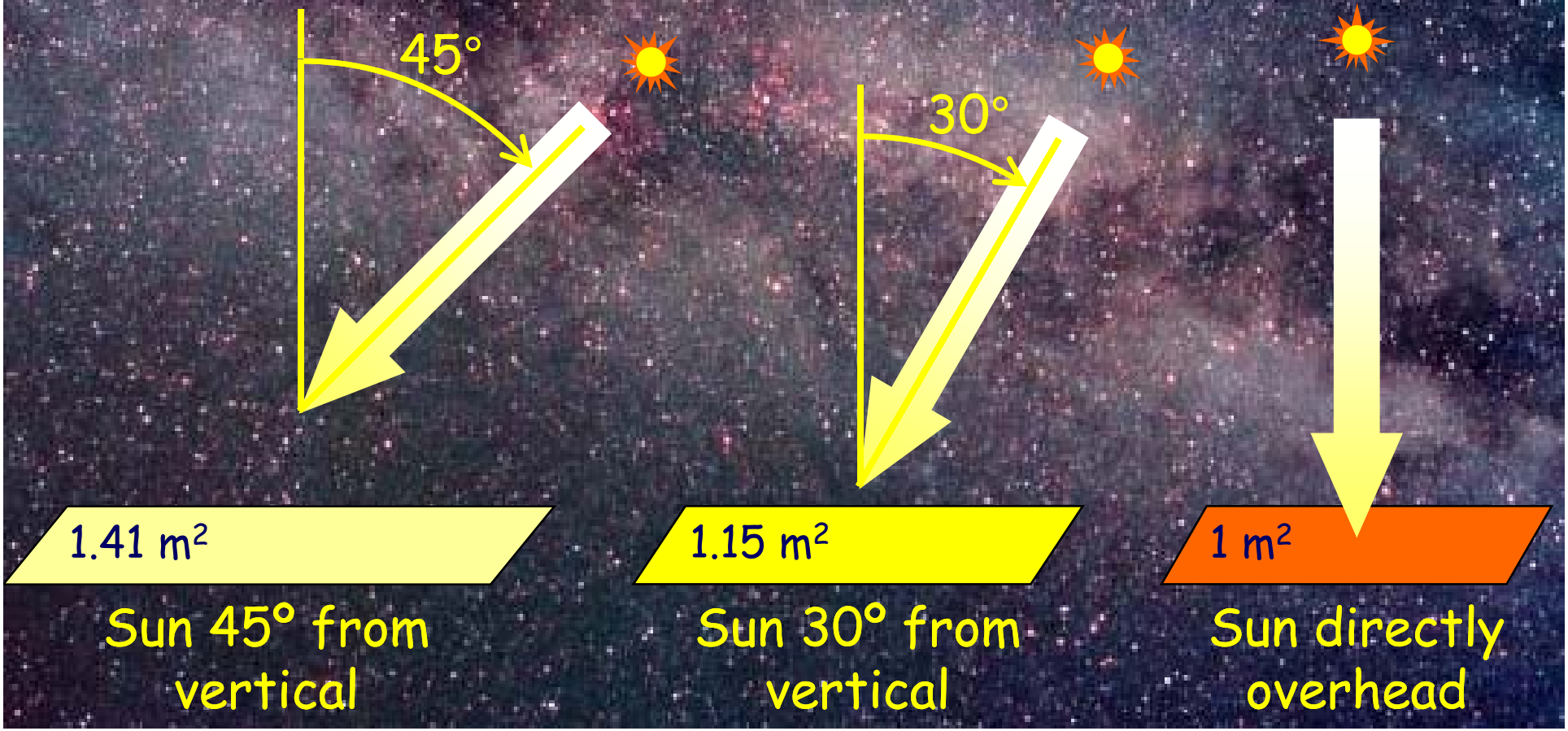
# Seasons

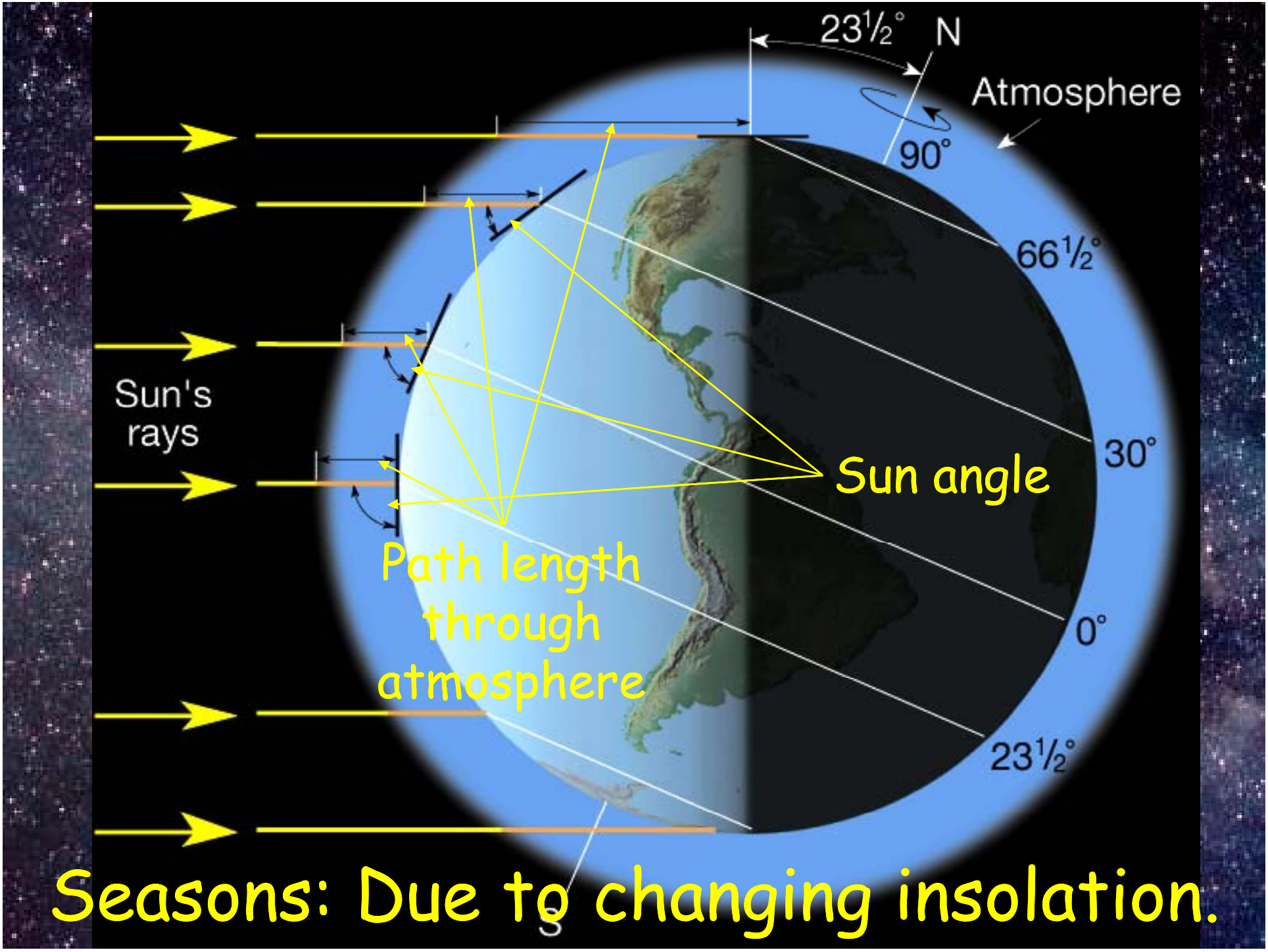
- ☆Solstice – sun farthest north or south
  - Northern Summer $\delta = +23.5°$, $\alpha = 6^h$
    - Sun over Tropic of Cancer (23.5°N)
  - Northern Winter $\delta = -23.5°$, $\alpha = 18^h$
    - Sun over Tropic of Capricorn (23.5°S)



# Seasons

- Due to changing angle of sunlight
  - At low angles, sunlight spreads out
    - less energy falls on any piece of ground



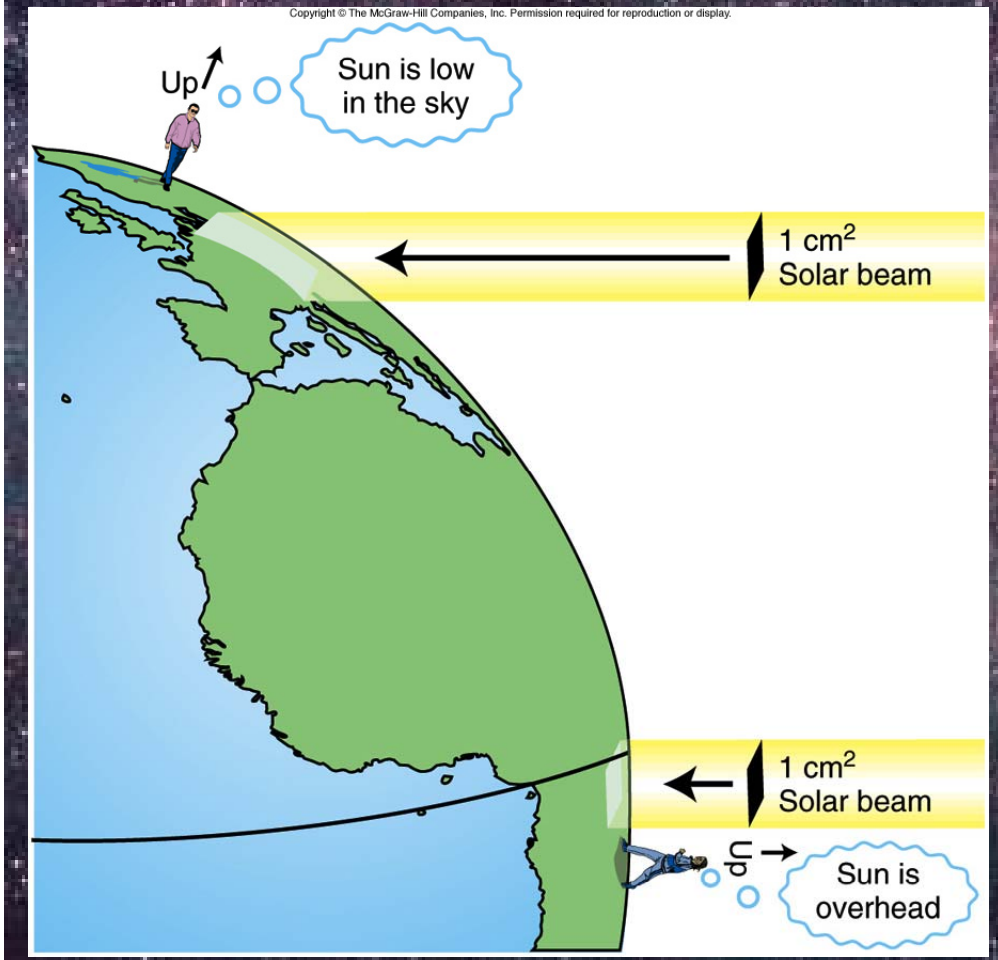



# Seasons: Due to changing insolation.

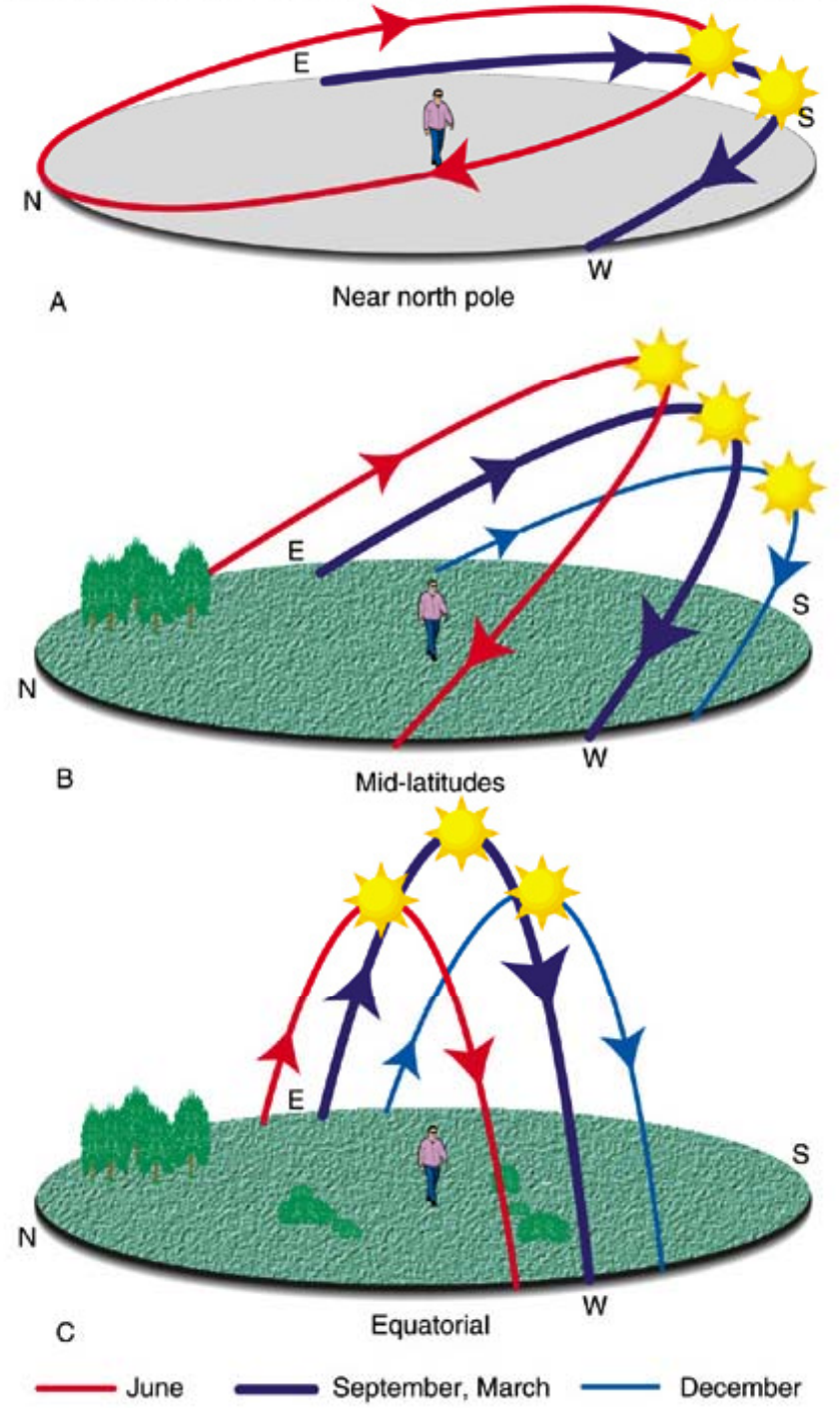
# Seasons

☆ Vary with latitude



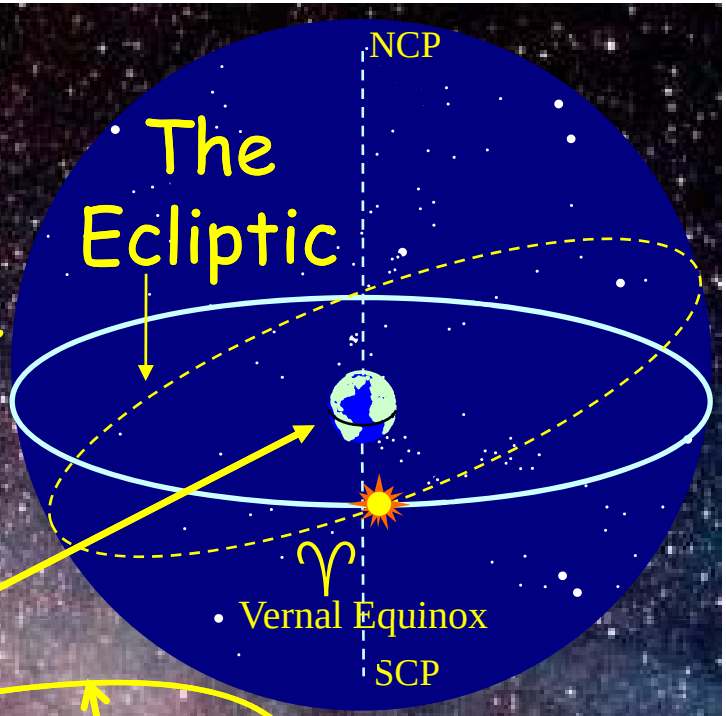




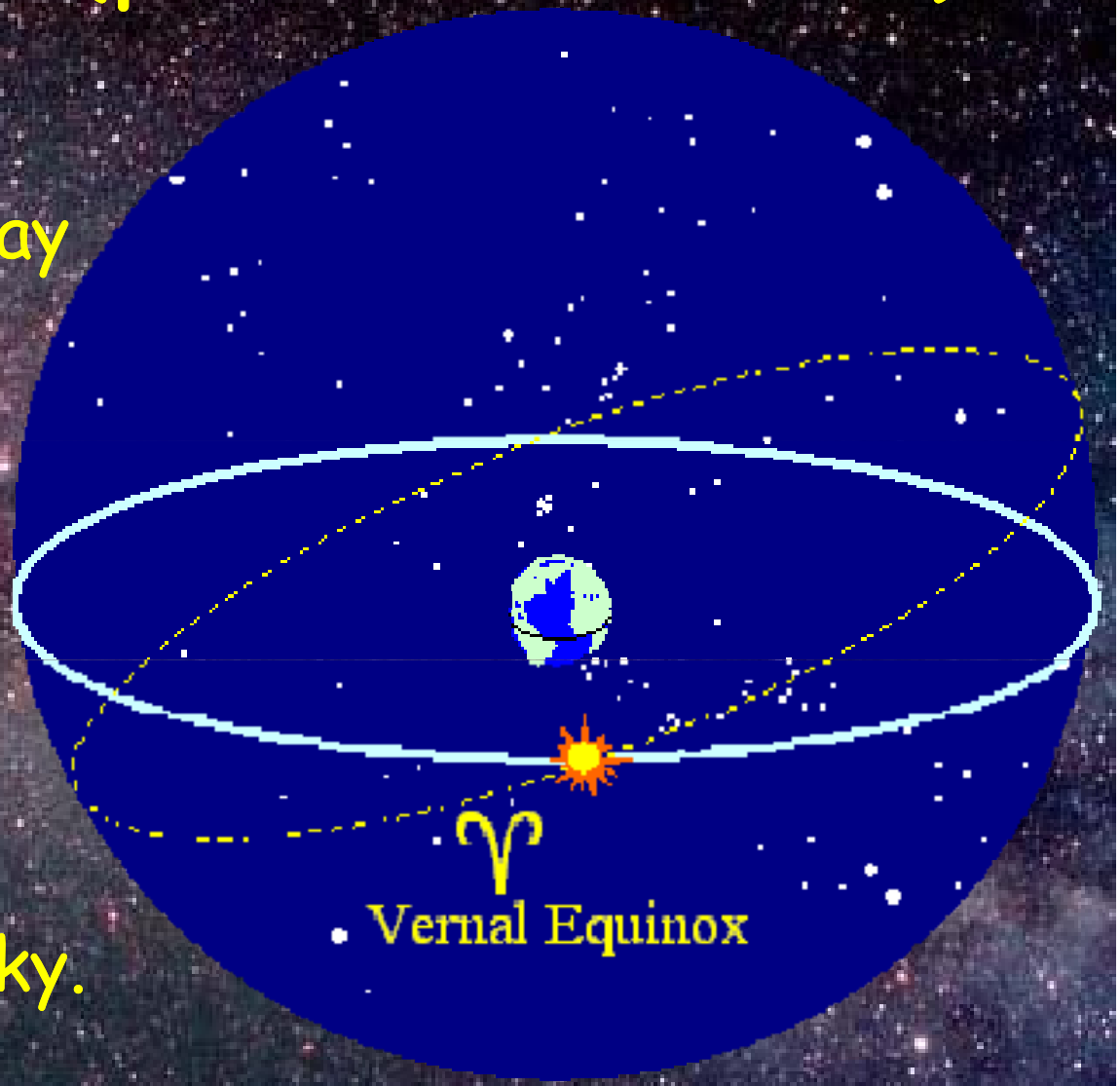
# Sun in the sky

- View from Earth
  - Rotate to Earth's equatorial plane
  - Center on Earth
  - Project sun onto sky



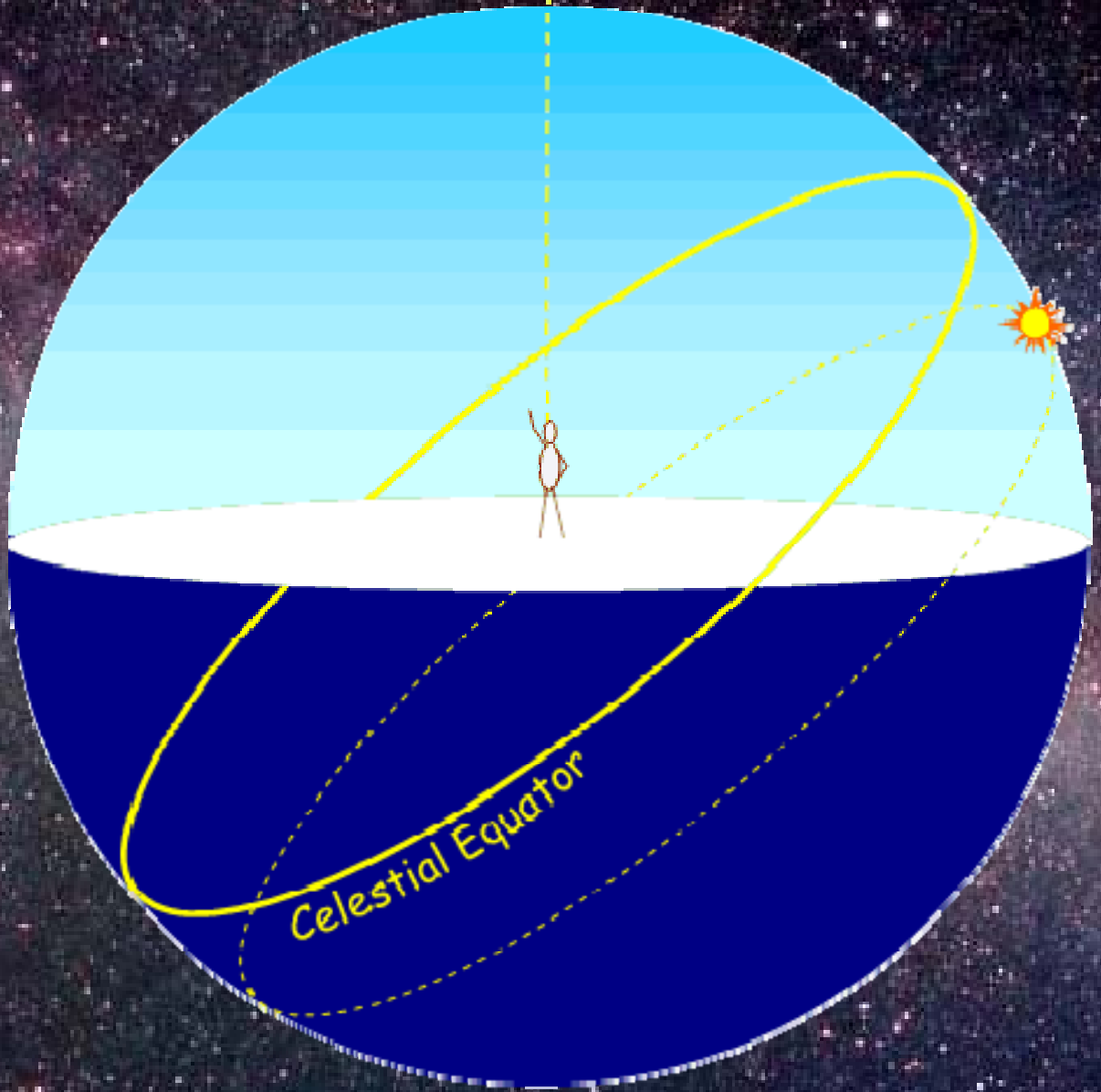
# The Ecliptic (path of the sun)

- View from Earth
  - Sun moves ~1°/day eastward across stars
  - Sun moves north and south in declination
  - Solstices & Equinoxes are positions in the sky.

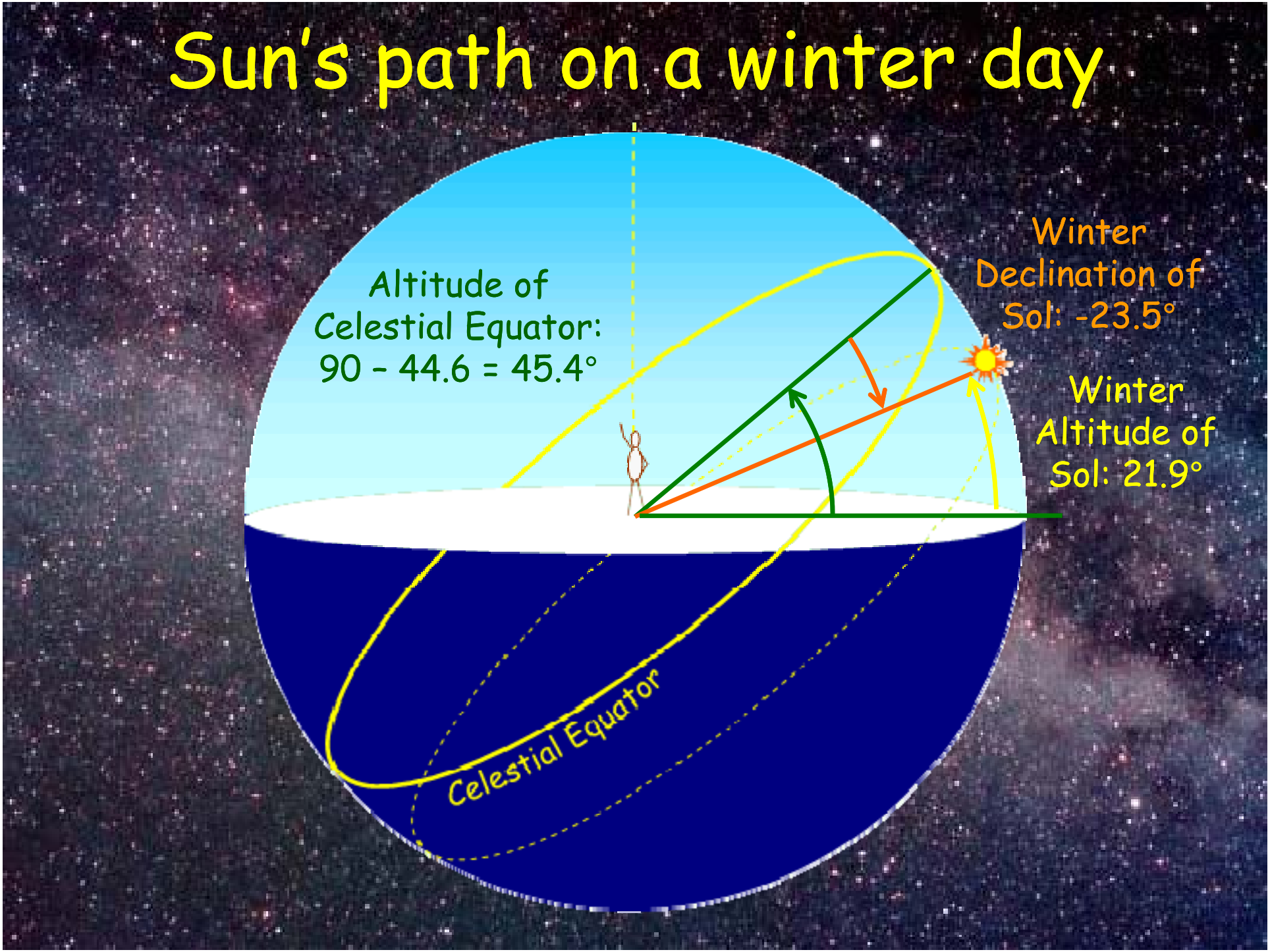



This motion is through the YEAR!

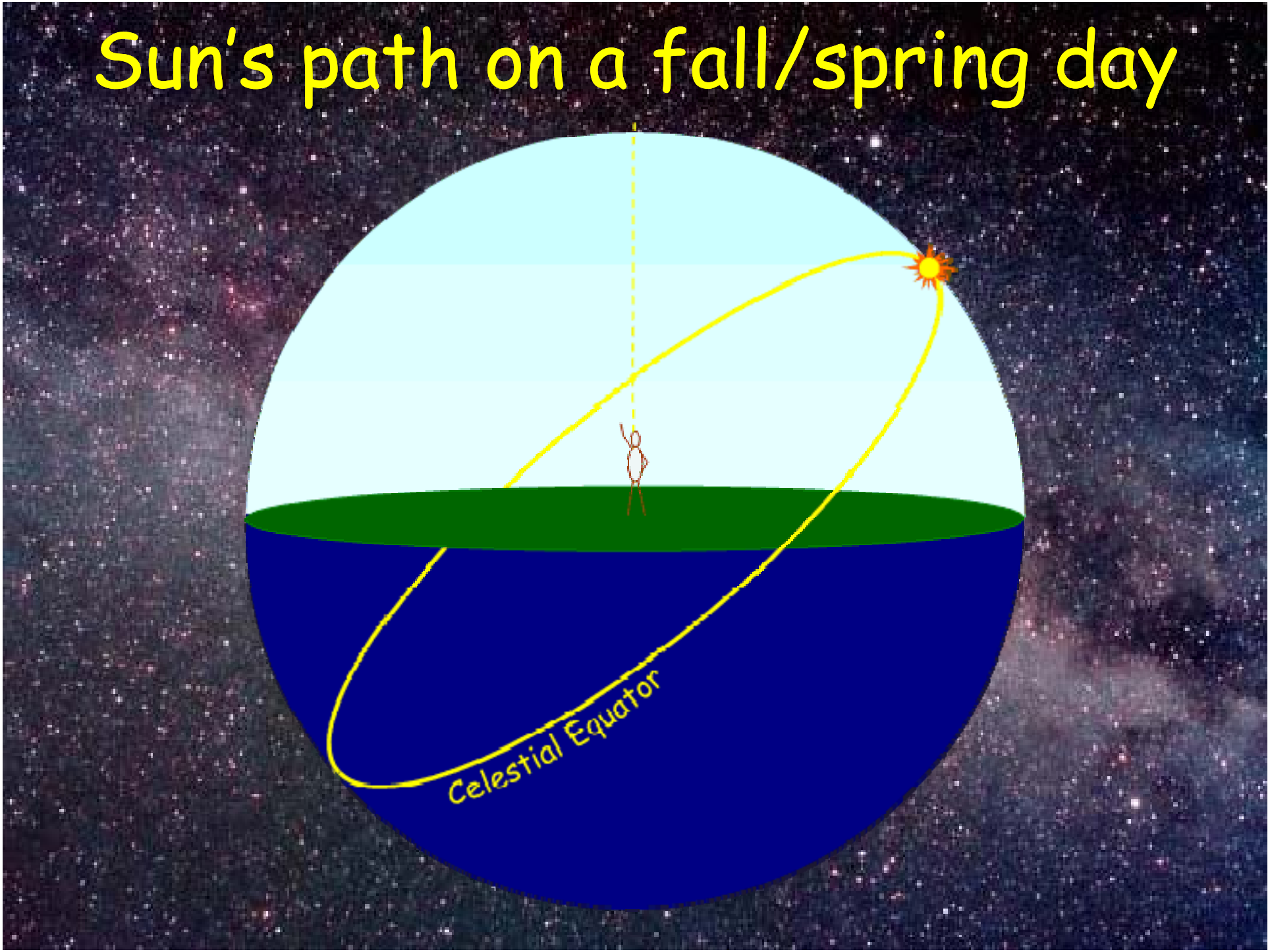
# Sun's path on a winter day



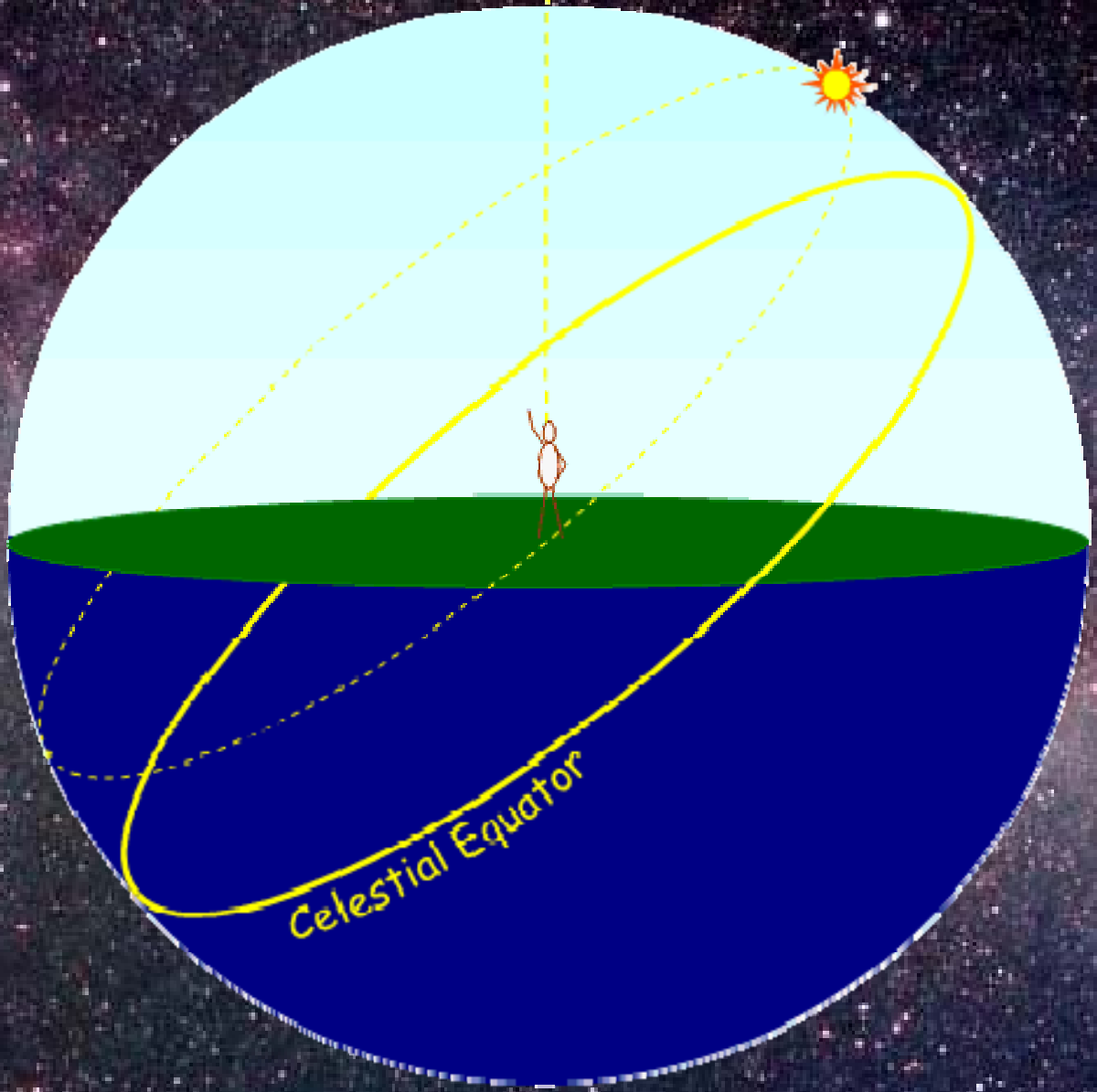
# Sun's path on a winter day



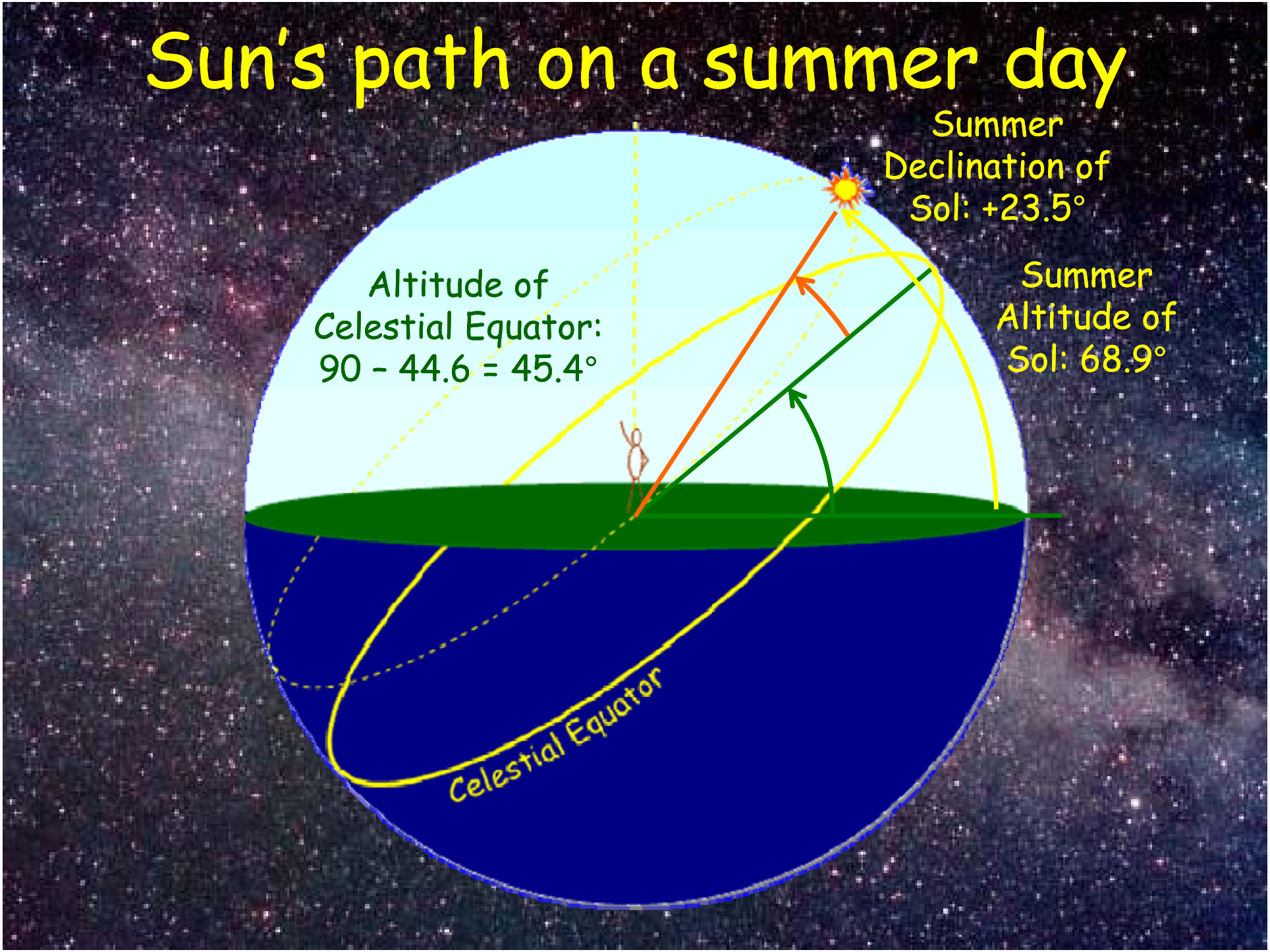
# Sun's path on a fall/spring day



# Sun's path on a summer day

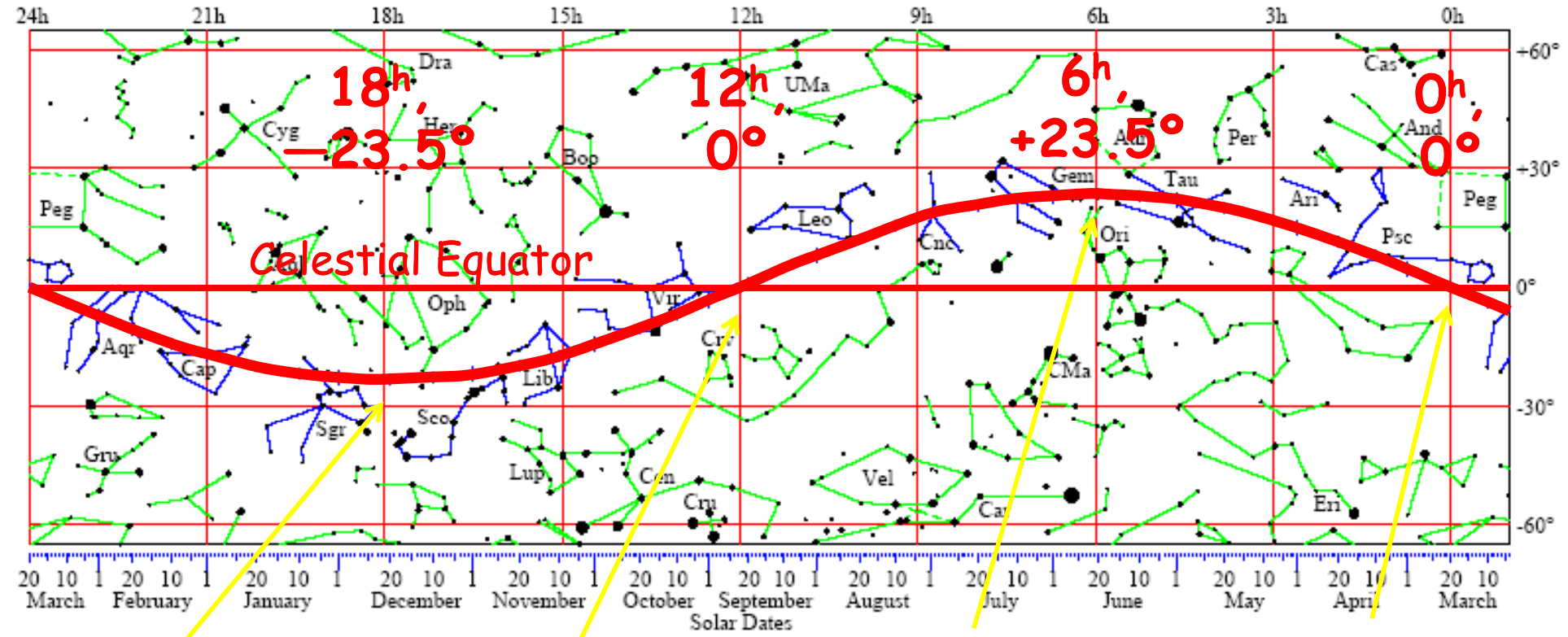


# Sun's path on a summer day



# Sun in the sky

- View from Earth
  - Sun moves ~1°/day eastward across stars
  - Sun moves north and south in declination




Winter Solstice in Sagittarius

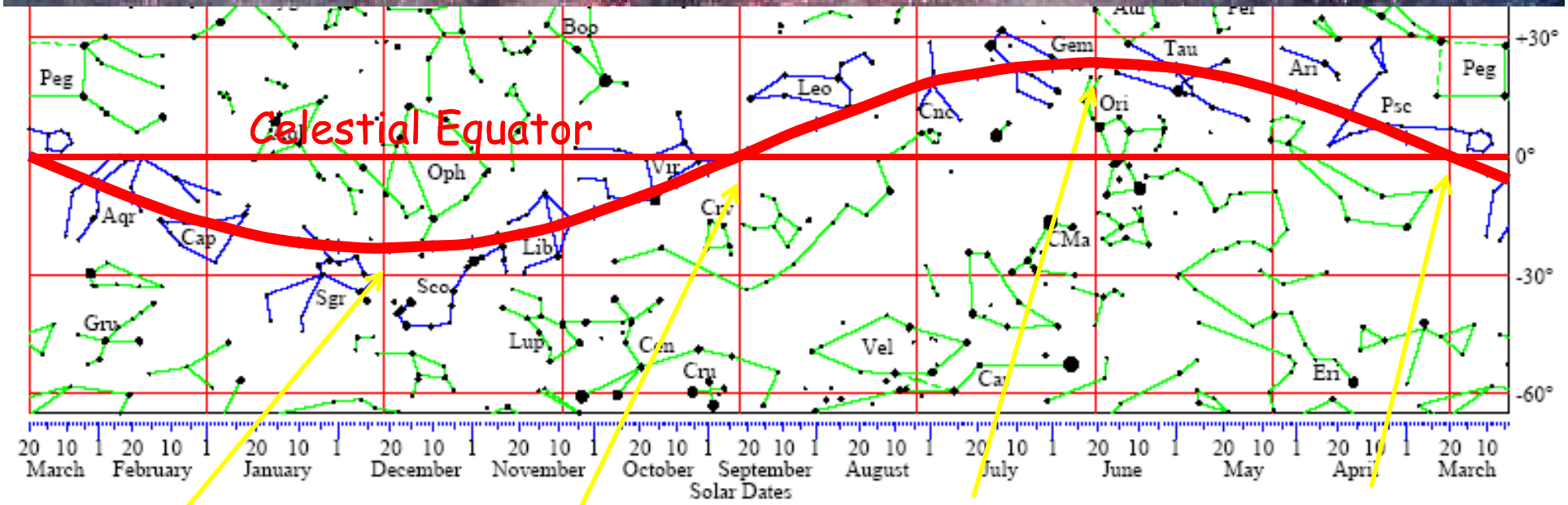
Autumnal Equinox in Virgo

Summer Solstice in Taurus

Vernal Equinox in Pisces

# Stars in the sky

- ☆ Midnight view from Earth
  - 🌎 Stars opposite sun's position
    - ☽ see opposite season's constellations;
      - ♈ eg. Gemini is a winter sky constellation, Scorpius summer
  - 🌎 Midnight "window" shifts 1° eastward/day




Winter Solstice in Sagittarius

Autumnal Equinox in Virgo

Summer Solstice in Taurus

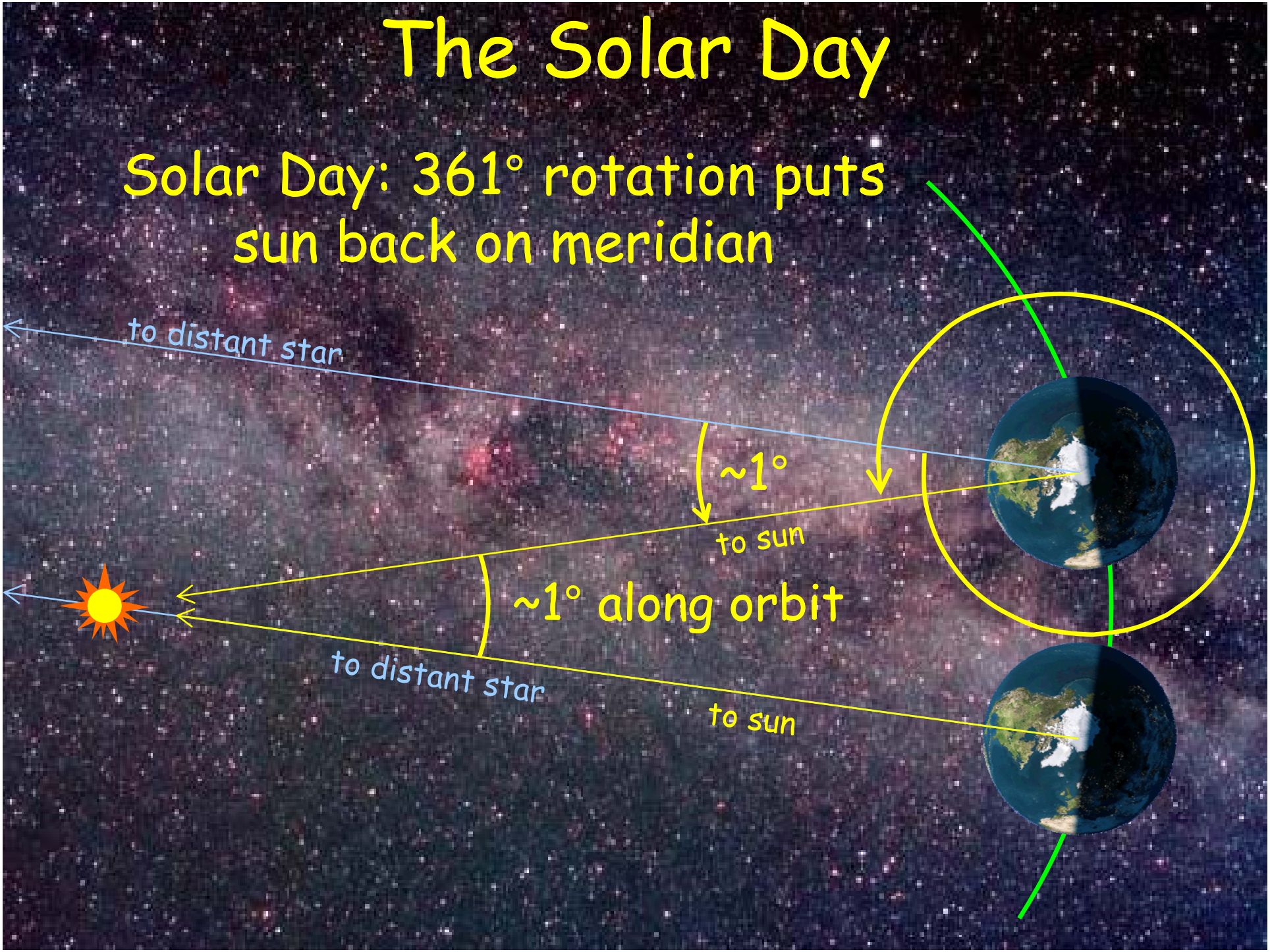
Vernal Equinox in Pisces

# Time

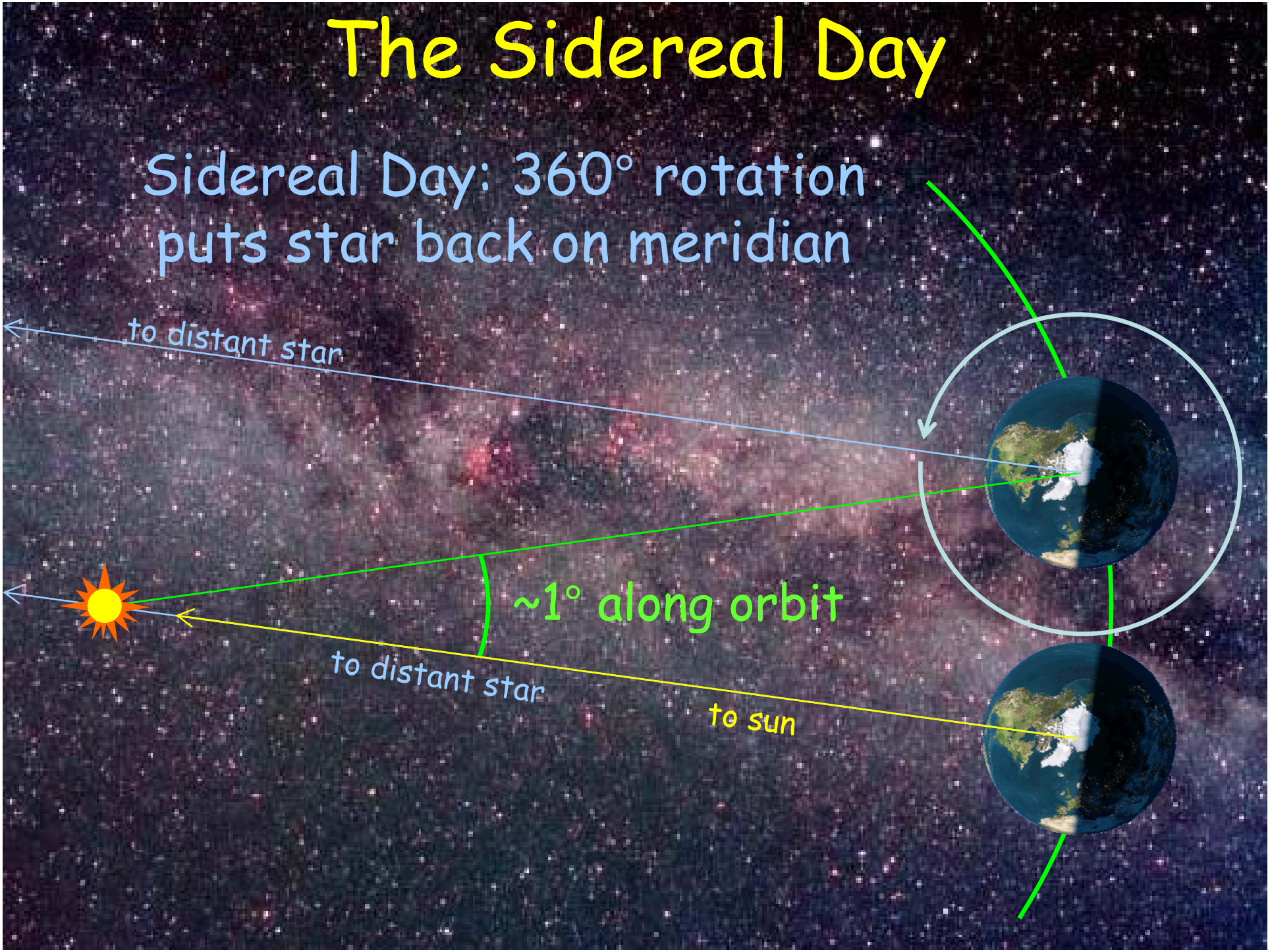
- ☆ Clock Time
  - 🌎 the position of the mean sun at TZ center
    - ☽ eg. 12 pm = transit of mean sun (avg. of analemma)
  - 🌎 Mean Solar Day = 24:00:00 (hours:min:sec of time)
- ☆ Solar Time
  - 🌎 the position of the sun wrt the observer
    - eg. Noon = sun transits
  - 🌎 Solar Day varies as shown by analemma
- ☆ Sidereal Time
  - 🌎 the position of ♈ wrt the observer
    - ☽ eg. $0^h$ Local Sidereal Time (LST) = ♈ transits
    - ☽ Sidereal time = R.A. on the meridian
  - 🌎 Sidereal Day = 23:56:00

# The Solar Day

Solar Day: 361° rotation puts sun back on meridian

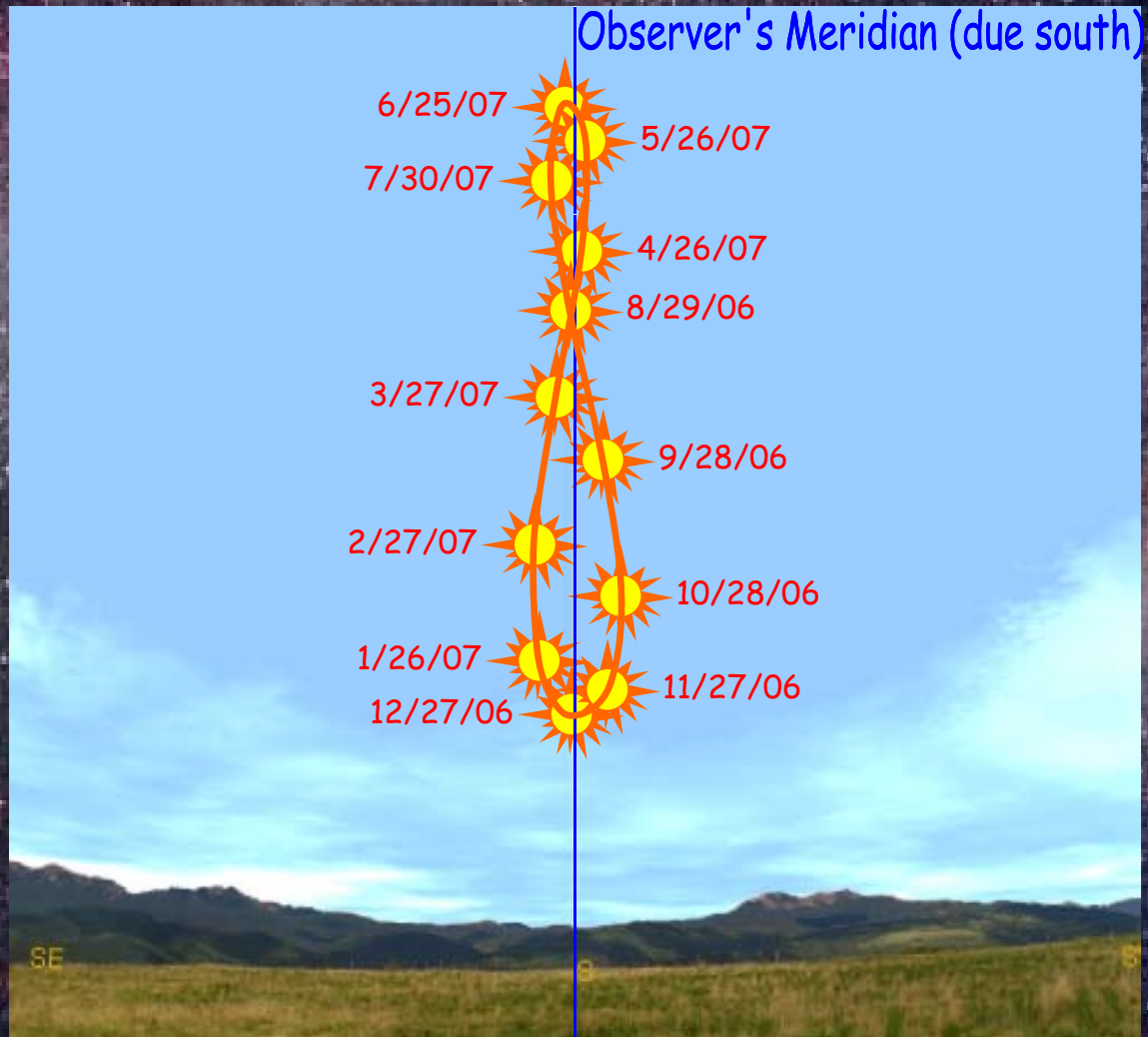


# The Sidereal Day



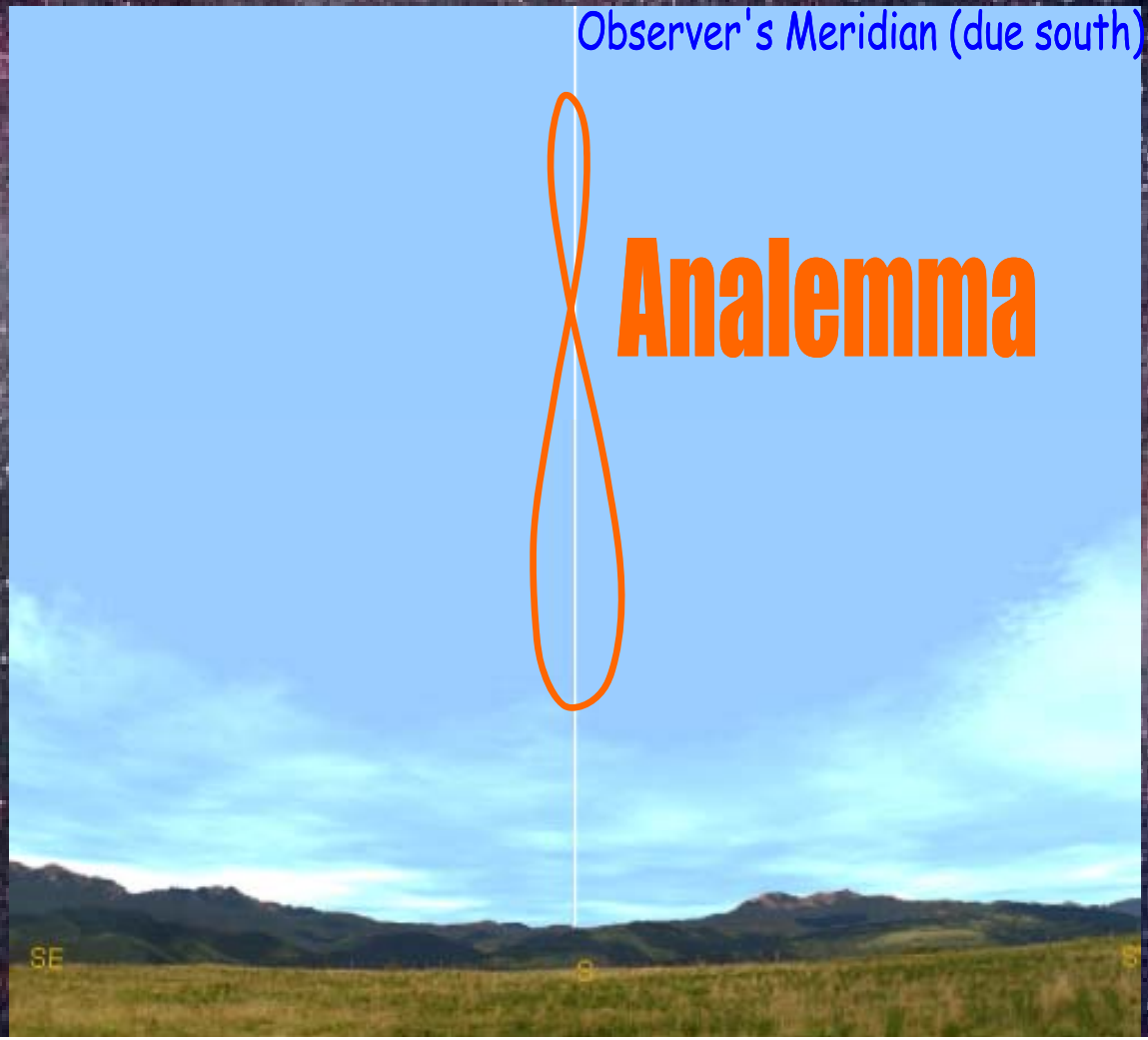
# The Sun at Noon

- ☆ Noon ⇒ Sun on meridian
- ☆ Sun's position varies: the Analemma



# The Sun at Noon

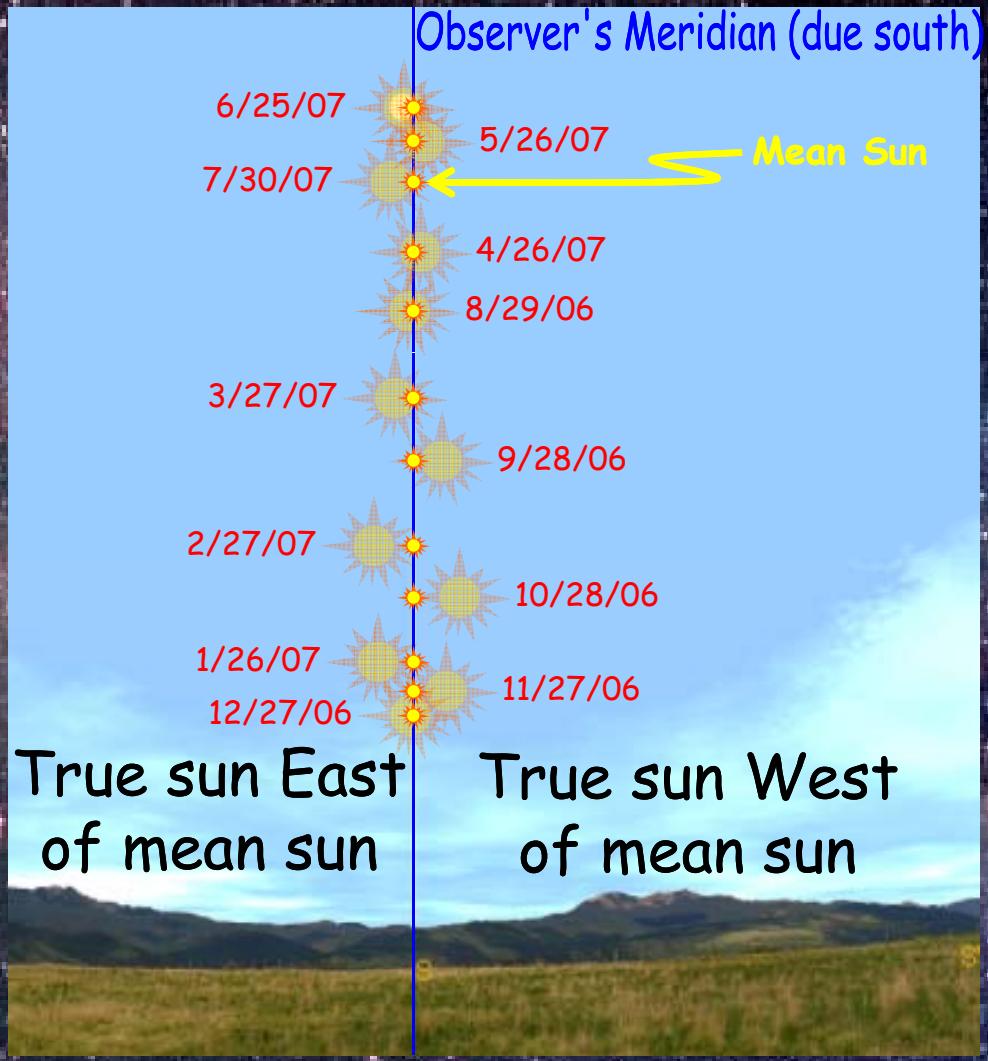
- ☆ Noon ⇒ Sun on meridian
- ☆ Sun's position varies: the Analemma



# The Analemma

## ☆ Position of true sun at clock noon

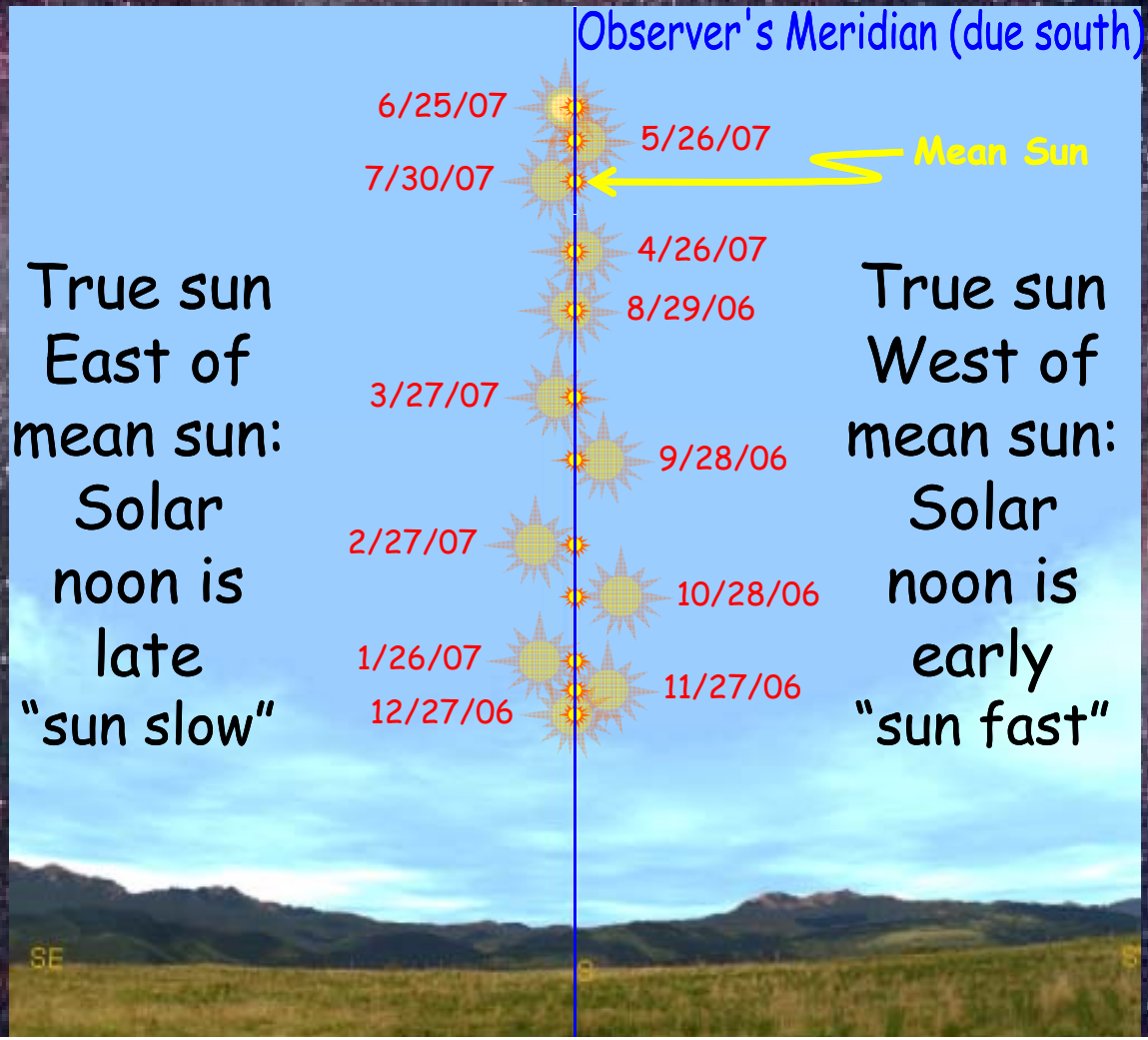
- Clock Noon
  - 12:00 pm in a 24:00:00 day
  - Position of Mean Sun at noon
- True Sun's Position
  - varies due to Sun's speed along path
    - ♈ varies due to elliptical path
    - ♈ varies due to tilted path



# Mean Sun & True Sun

☆ Mean sun on meridian defines clock noon

☆ True sun on meridian defines solar noon



# Doing the Math

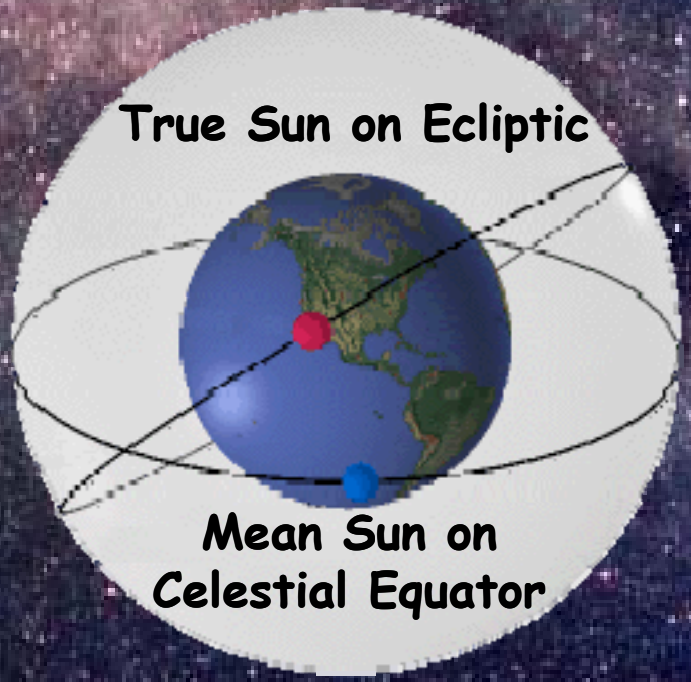
## ☆ Mean Sun

- Projection of sun onto Celestial Equator
  - moves 360° in one year (365.242191 days)

$$v_{\text{Mean Sun}} = \frac{360^\circ}{365.242191\ \text{days}} = 0.985647356\ ^\circ/\text{day}$$

## ☆ True Sun

- speed varies due to
  - Sun's changing Declination
  - Elliptical orbit



# Position of Sunrise & Sunset

☆ Azimuth of rising depends on $\delta$

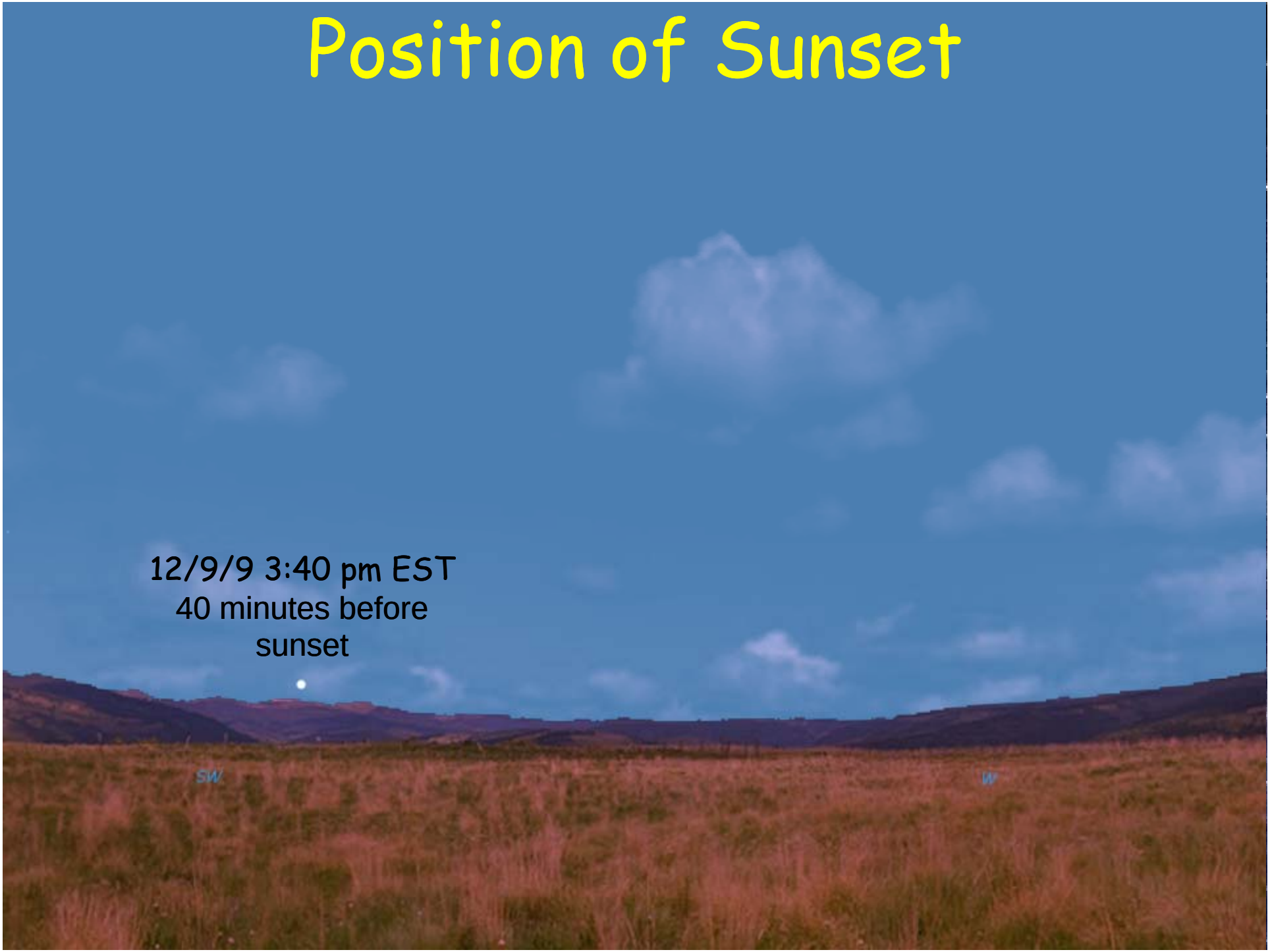
$$A_{rise} = \cos^{-1}\left(\frac{\sin\delta}{\cos\lambda}\right) \text{ degrees}$$

☆ Sunrise appears to move along horizon

🌎 original calendar!

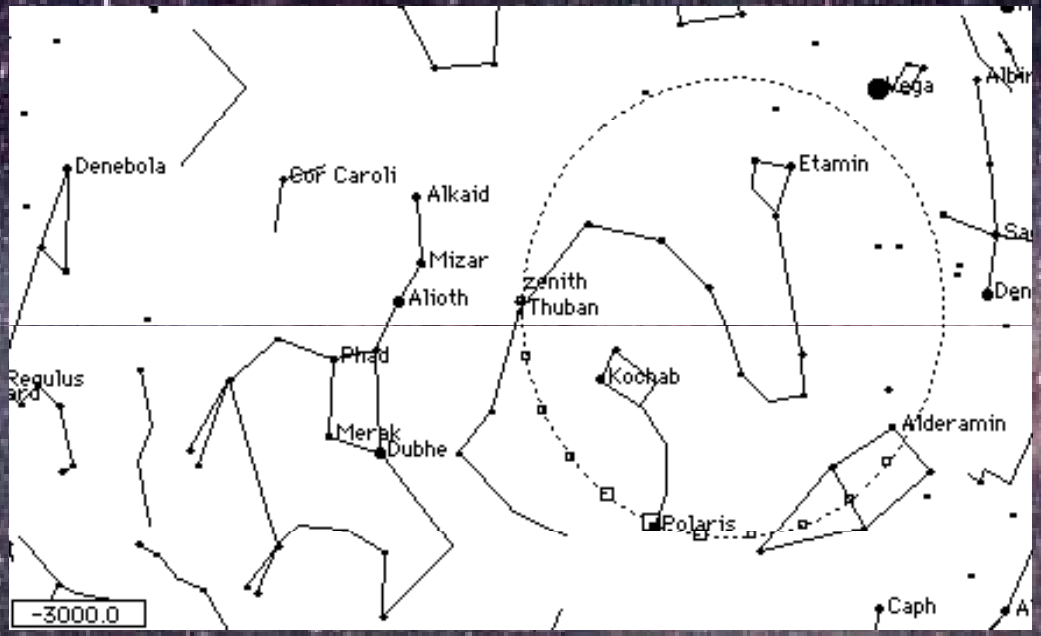
eg. Stonehenge, Machu Pichu, Woodhenge (Illinois)

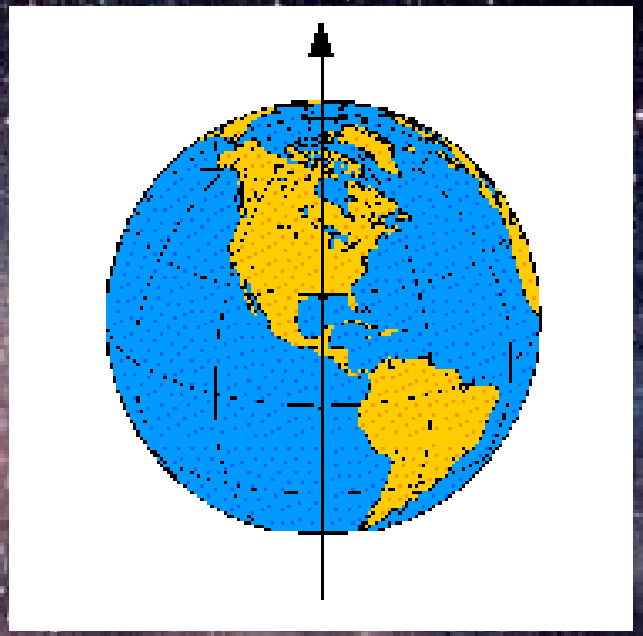
# Position of Sunset



# Precession

☆ Earth's axis wobbles over 26,000 years



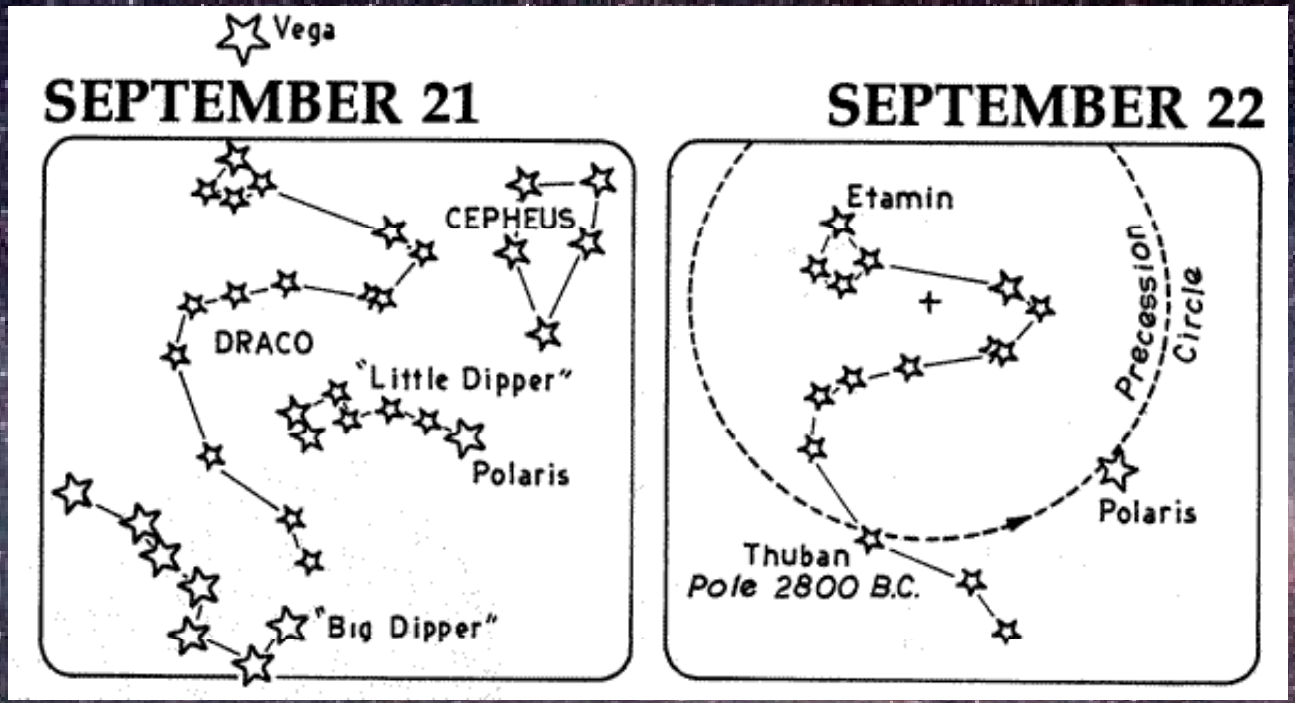



RA and Dec grid wobbles with pole, ecliptic does not wobble so solstices & equinoxes change position

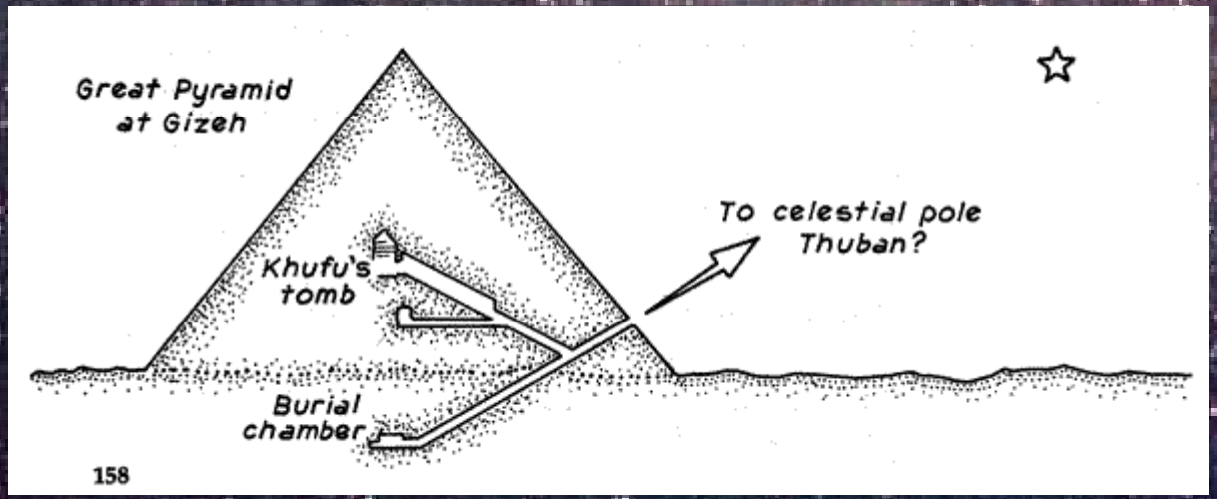


http://www.opencourse.info/astronomy/introduction/03.motion_earth/

# Raymo's 365 Starry Nights



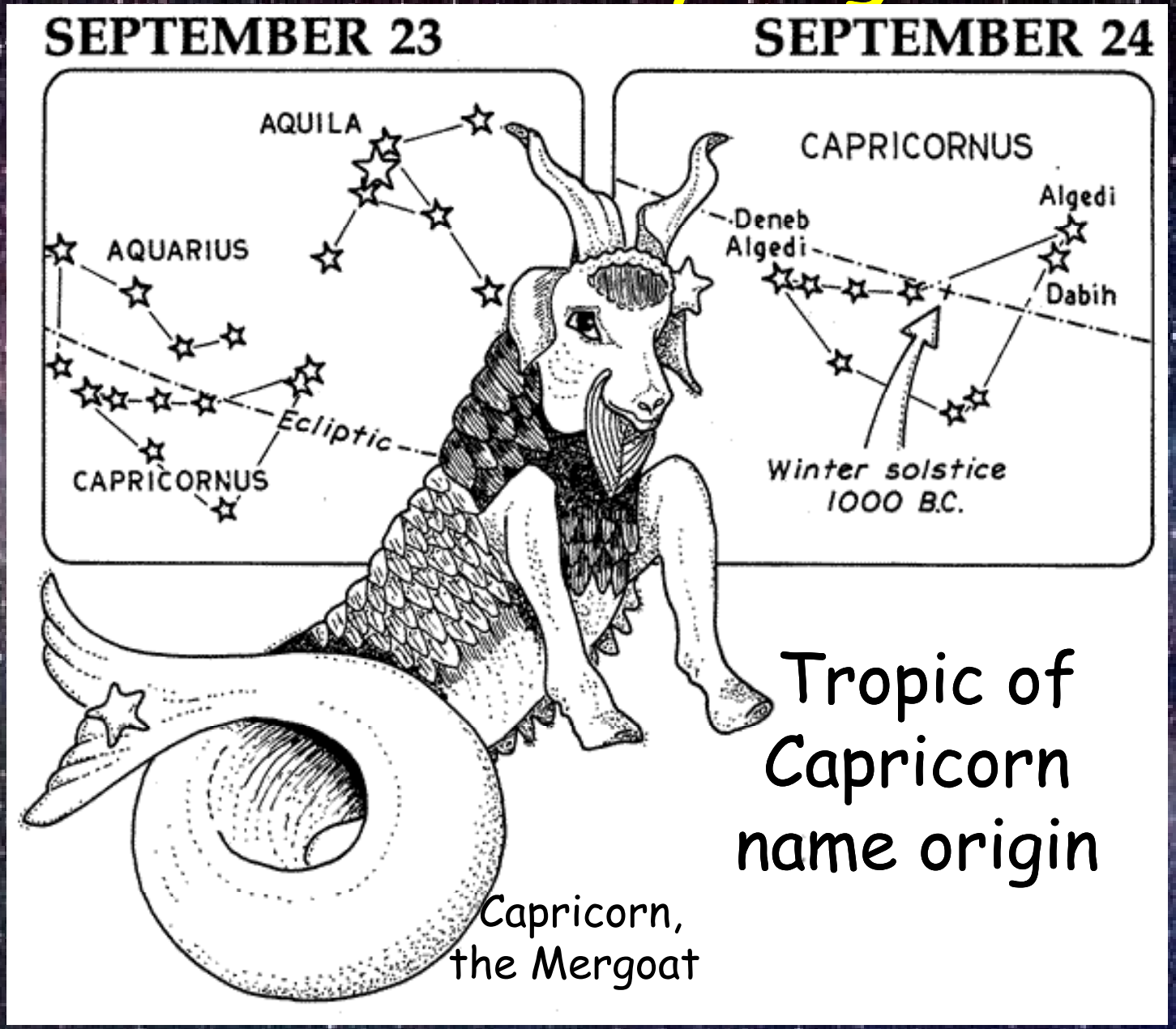

Precession Circle




View from the Pyramids

# Raymo's 365 Starry Nights

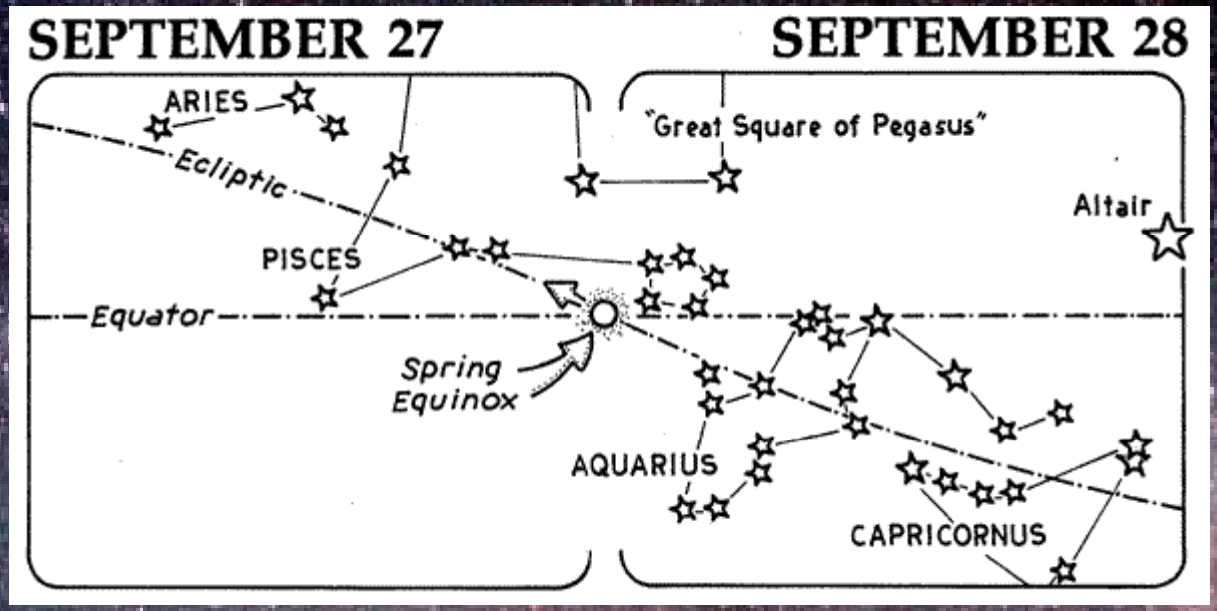
Position of the winter solstice in 1000 BCE




Capricorn, the Mergoat

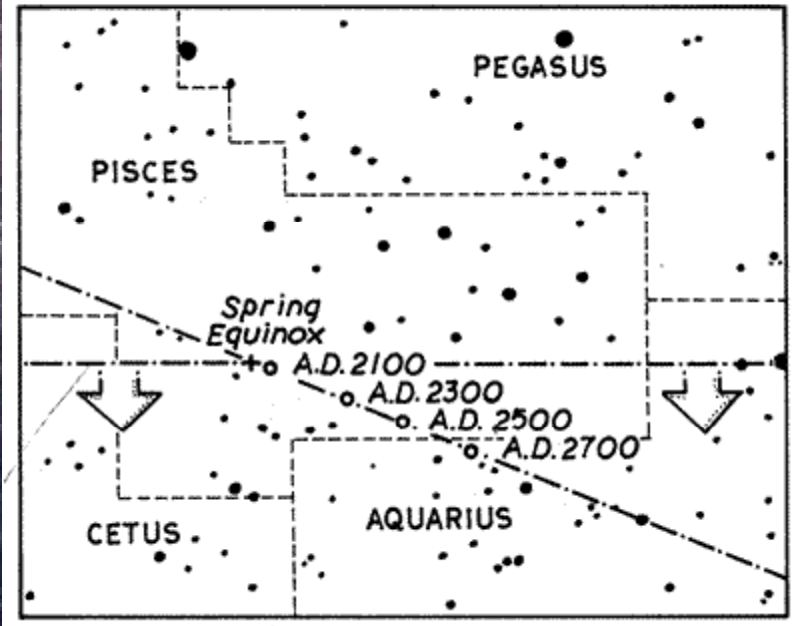
Tropic of Capricorn name origin

# Raymo's 365 Starry Nights

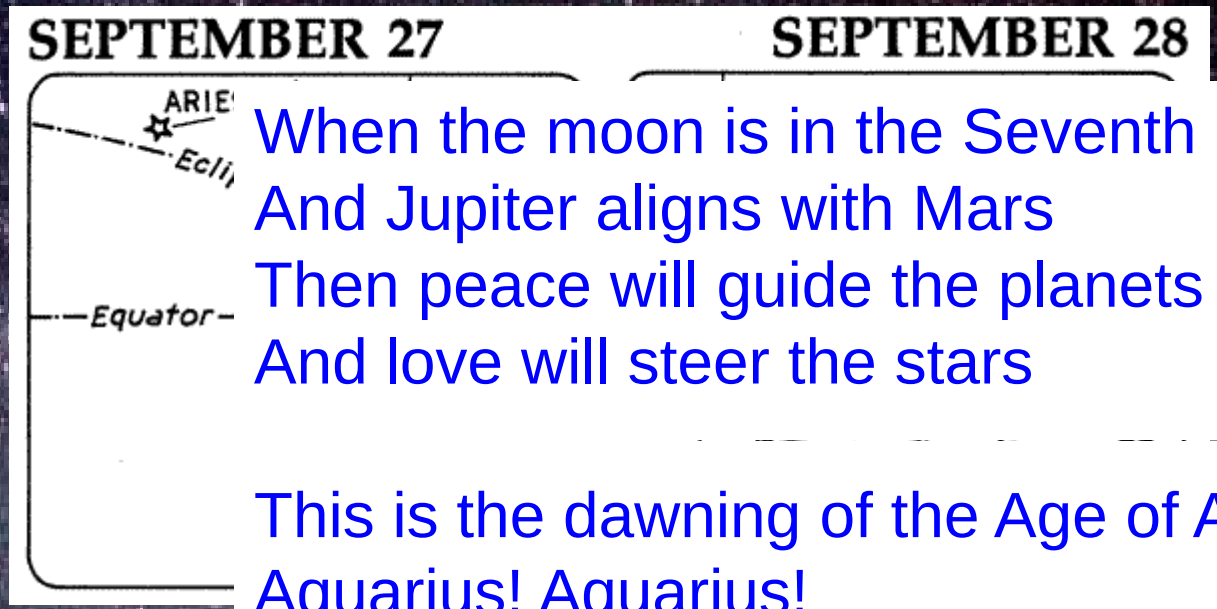



Position of the Vernal Equinox now

Motion of the Vernal Equinox to the "Age of Aquarius"



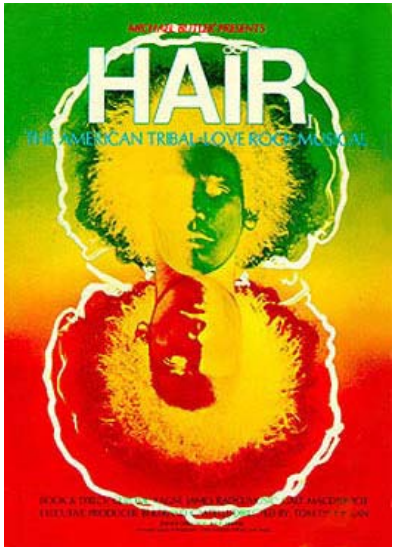
# Raymo's 365 Starry Nights

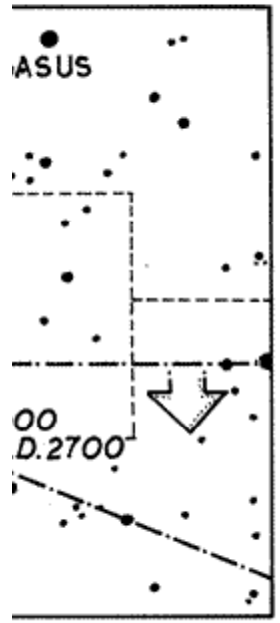



When the moon is in the Seventh House
And Jupiter aligns with Mars
Then peace will guide the planets
And love will steer the stars

This is the dawning of the Age of Aquarius
Aquarius! Aquarius!

Harmony and understanding
Sympathy and trust abounding
No more falsehoods or derisions
Golden living dreams of visions
Mystic crystal revelation
And the mind's true liberation
Aquarius! Aquarius!



# Kiva

December 1997 – October 27, 2009