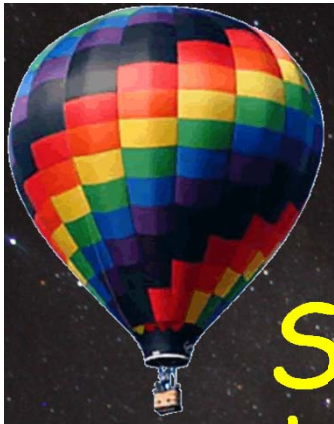


Potsdam
THE STATE UNIVERSITY OF NEW YORK
1816

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

dack Public Observatory

Celestial Coordinates

☆Right Ascension

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

☆Declination

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

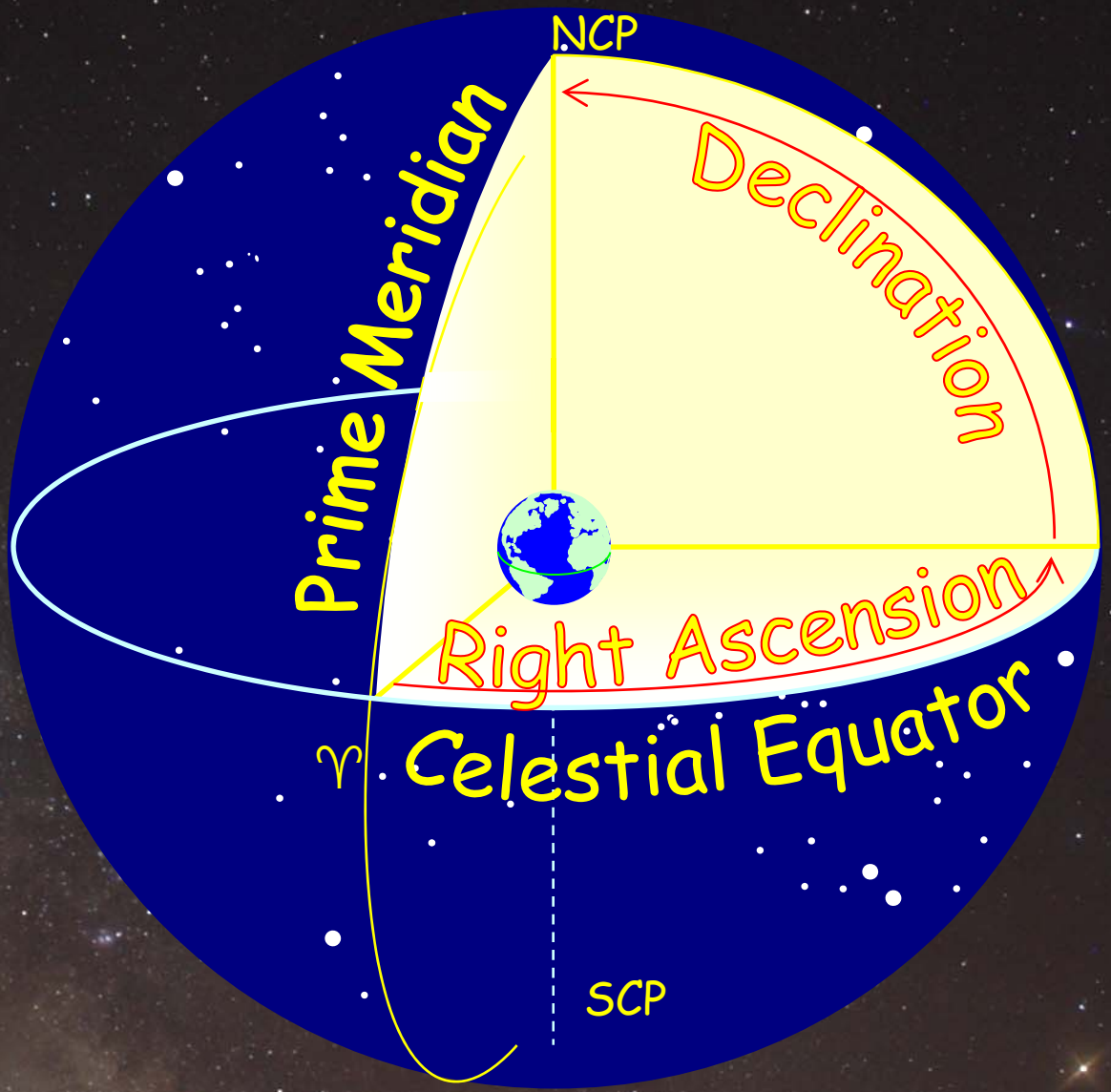
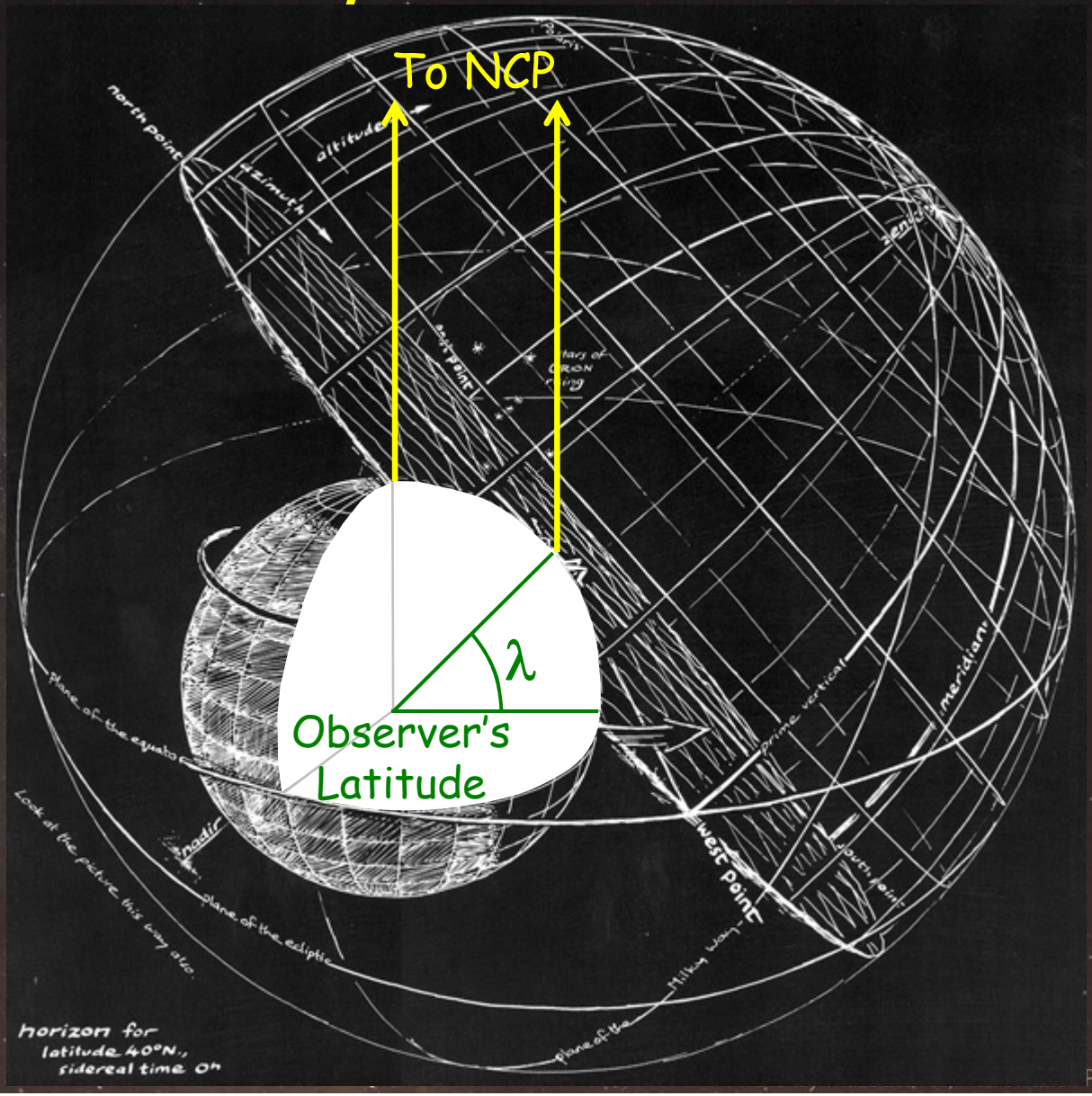


Photo by Marc Staves, Adirondack Public Observatory

Tilted Sky

☆ Observers see sky "tilted" due to latitude

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

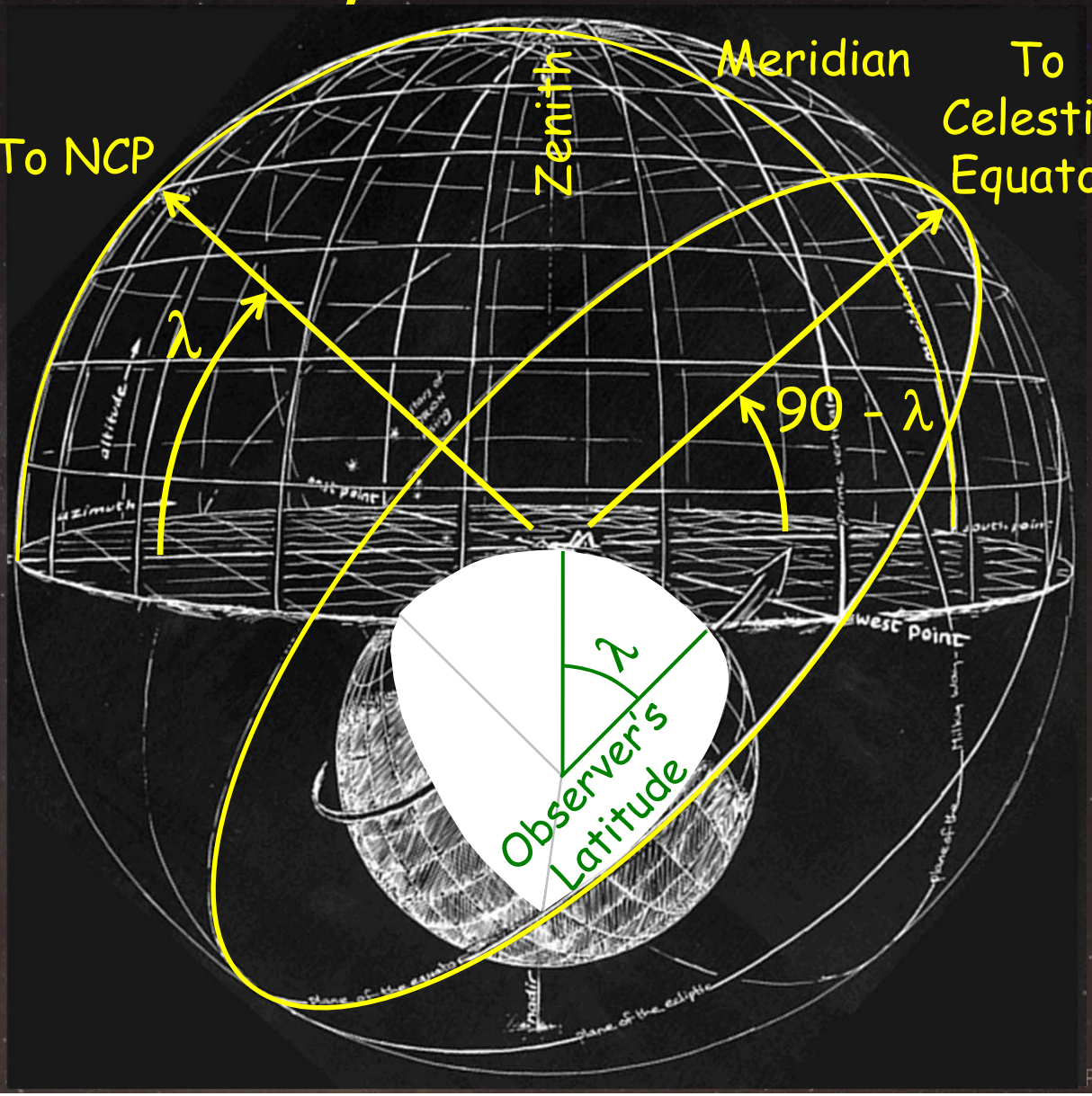


Tilted Sky

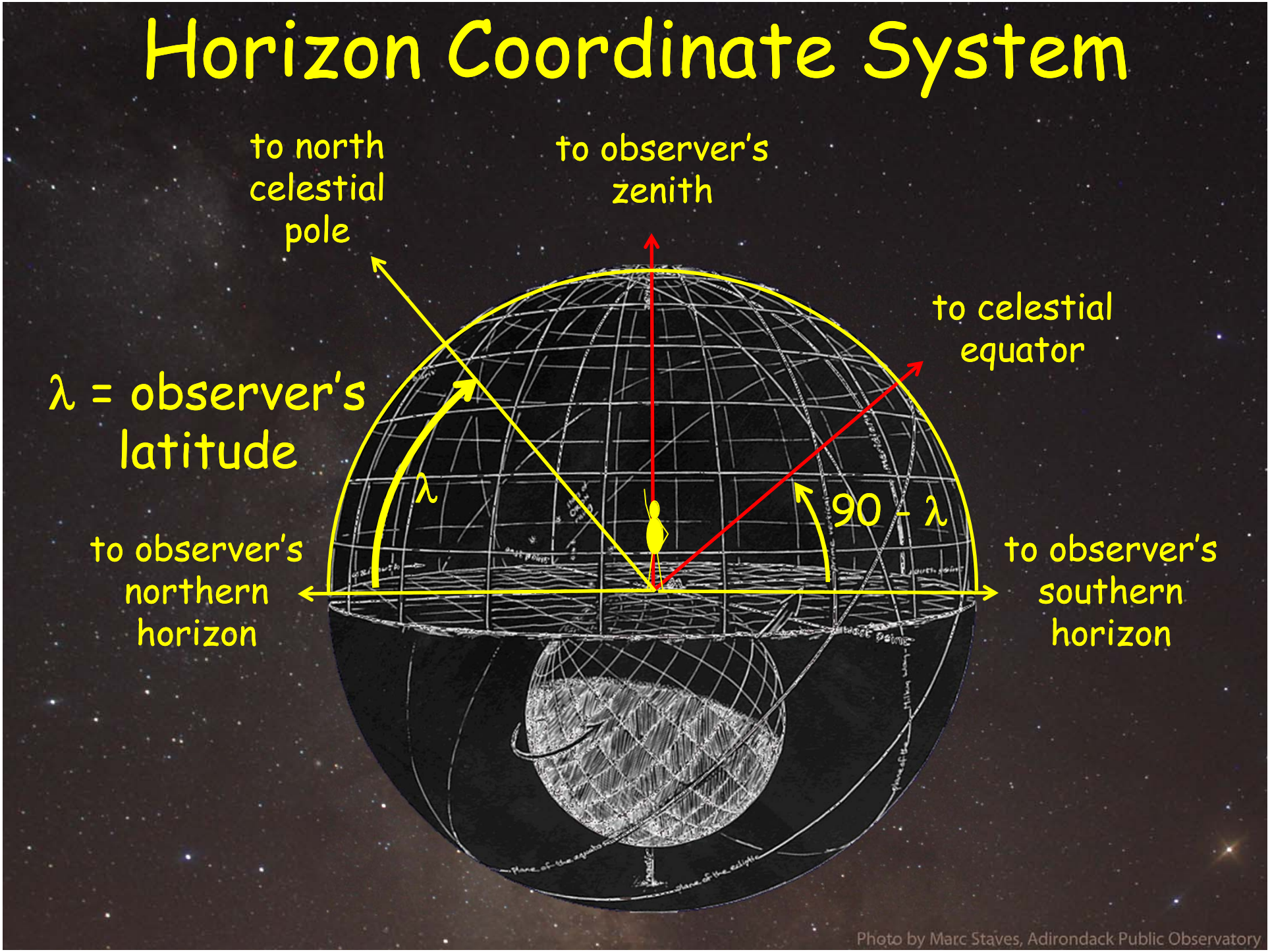
☆ Observers see sky "tilted" due to latitude

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

So we see sky motions tilted

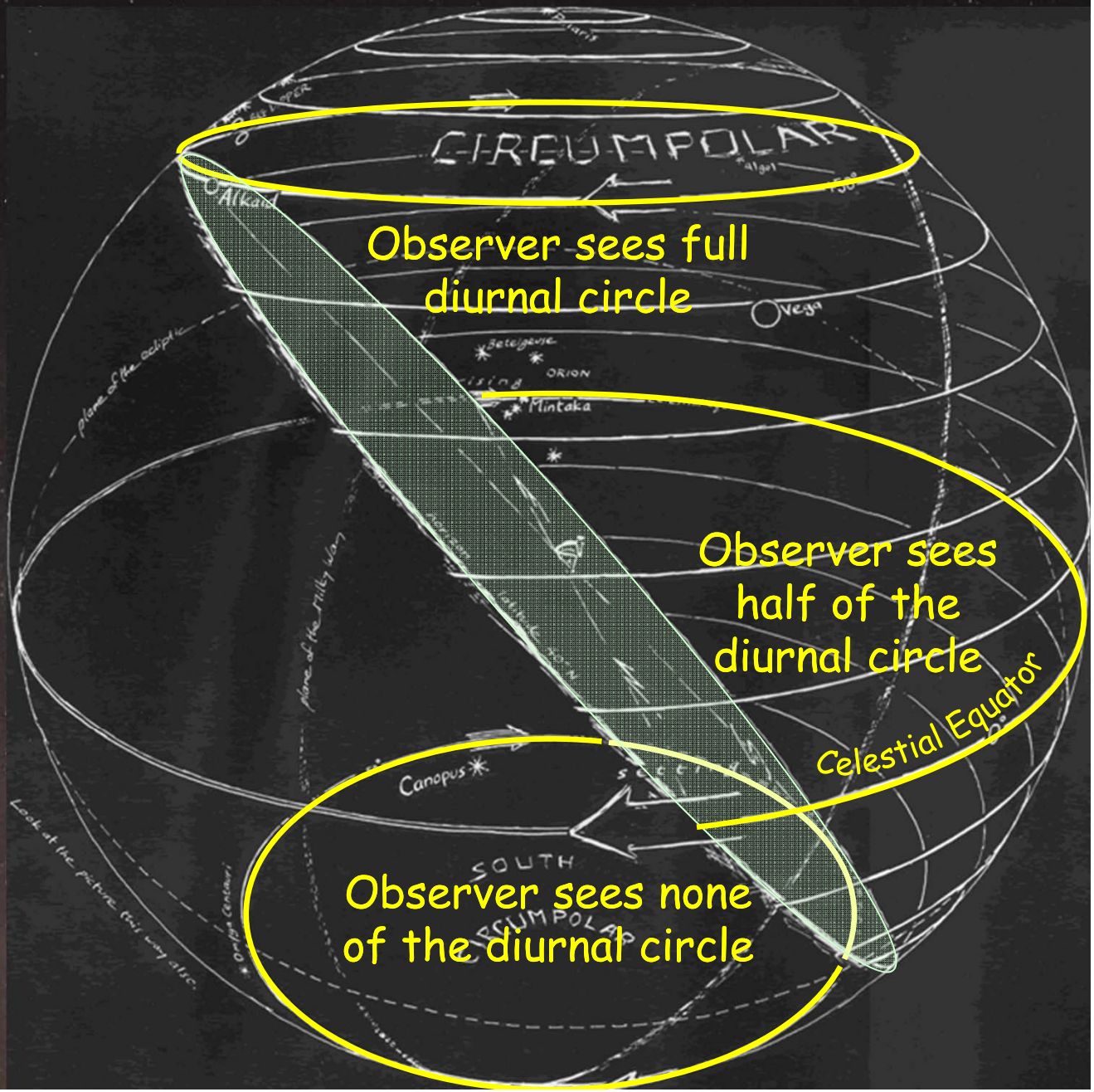


Horizon Coordinate System



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

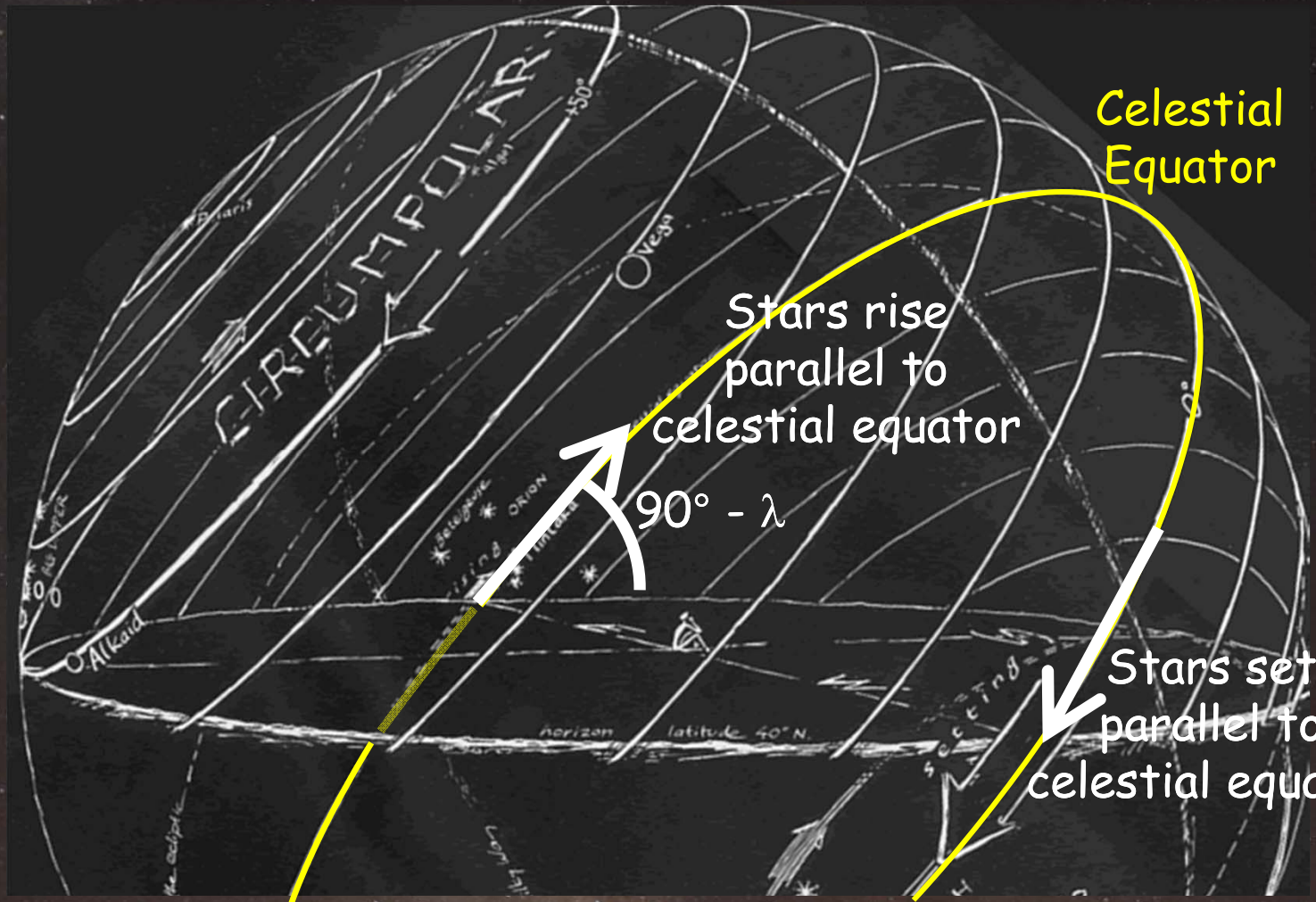
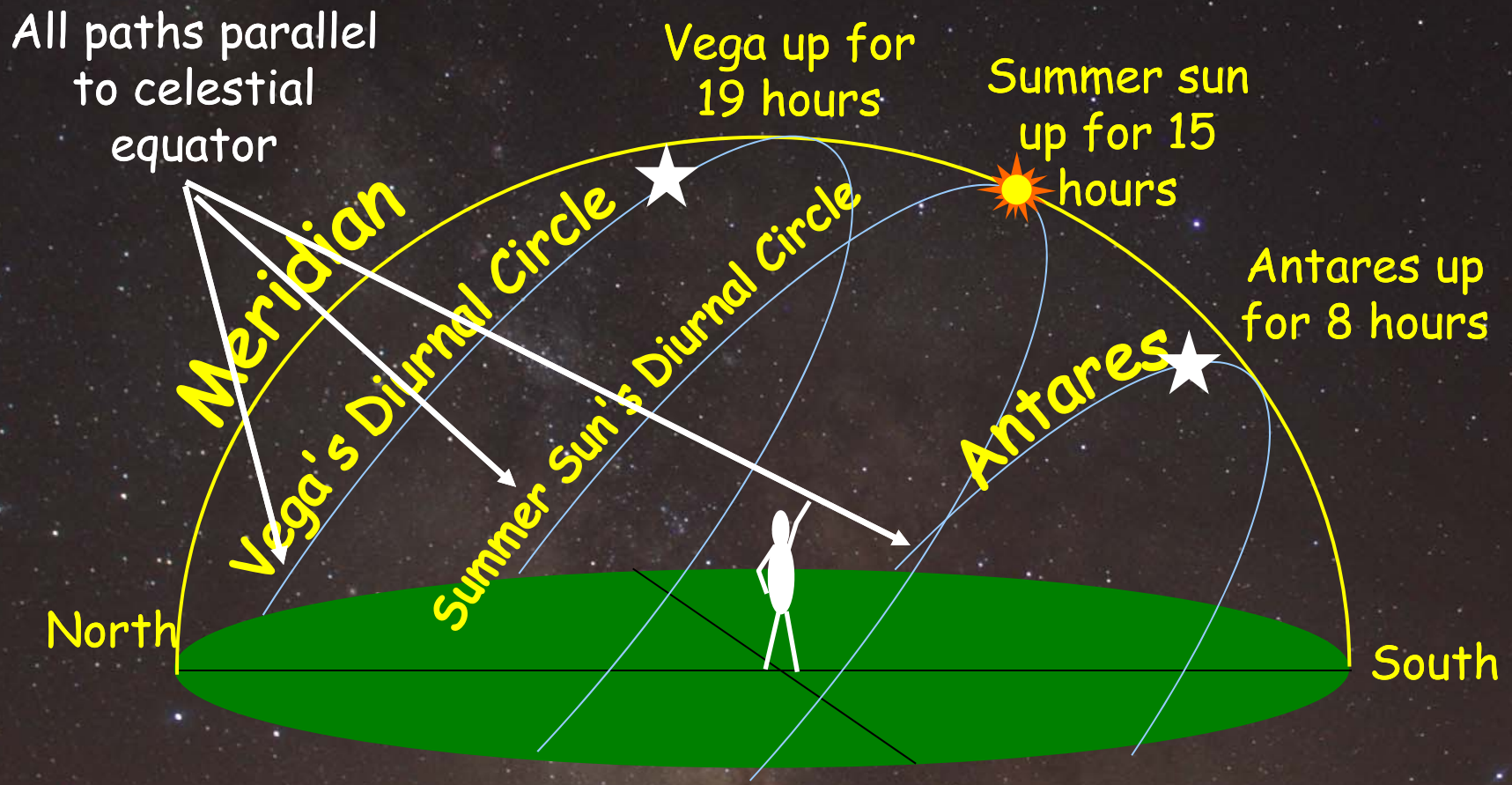


Photo by Marc Staves, Adirondack Public Observatory

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
- Sets in the west

each day

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

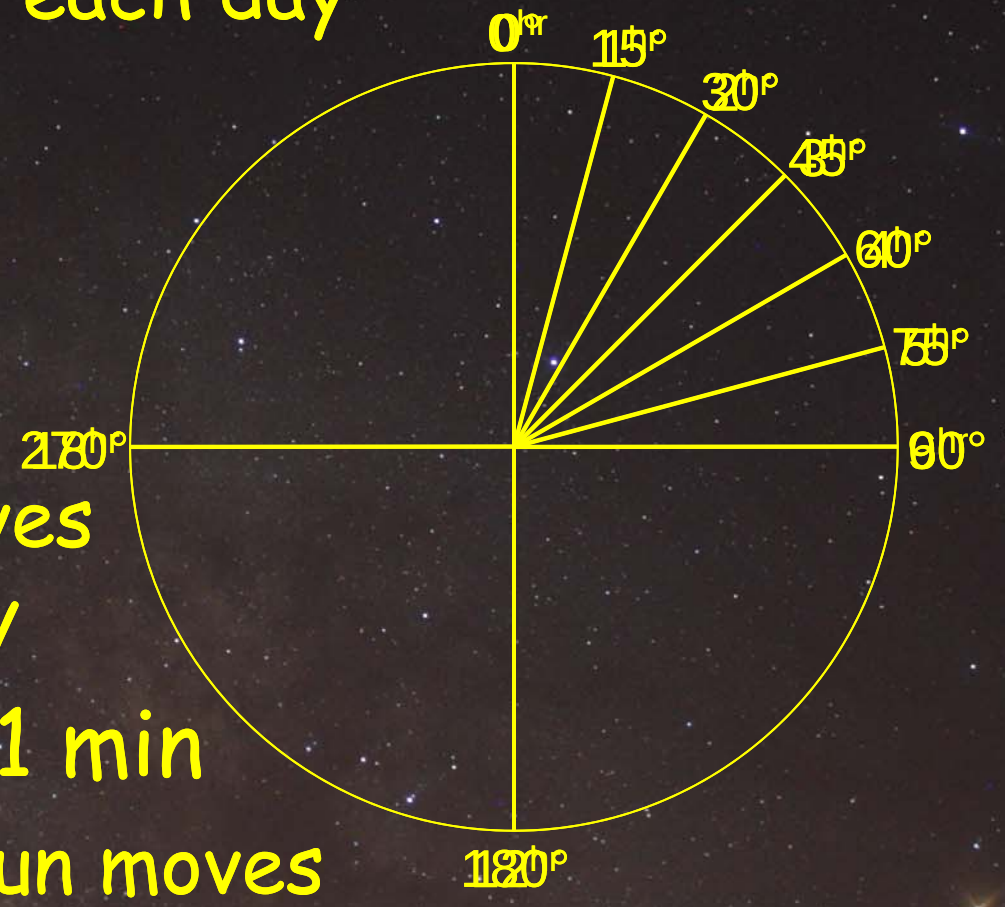
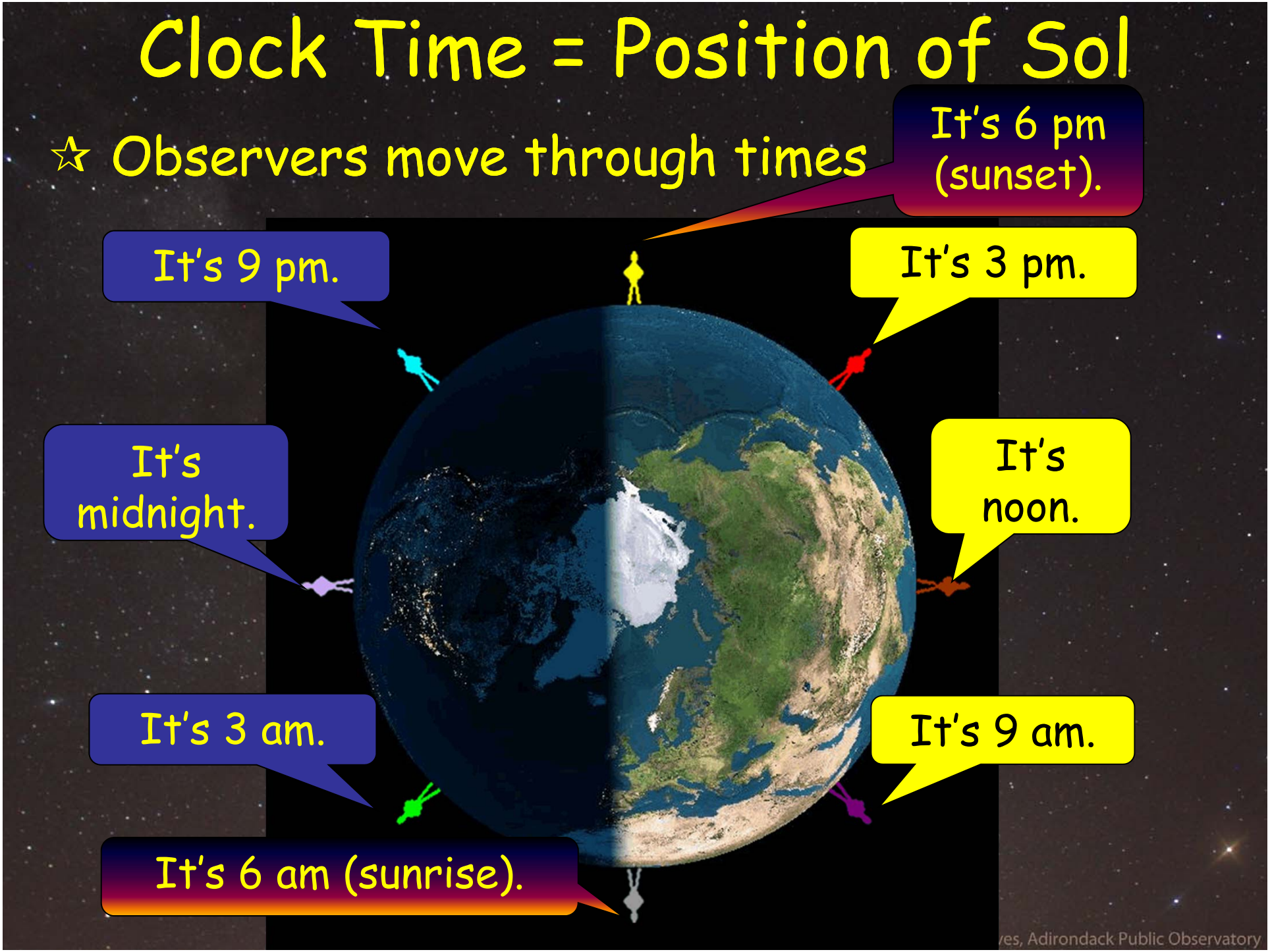


Photo by Marc Staves, Adirondack Public Observatory

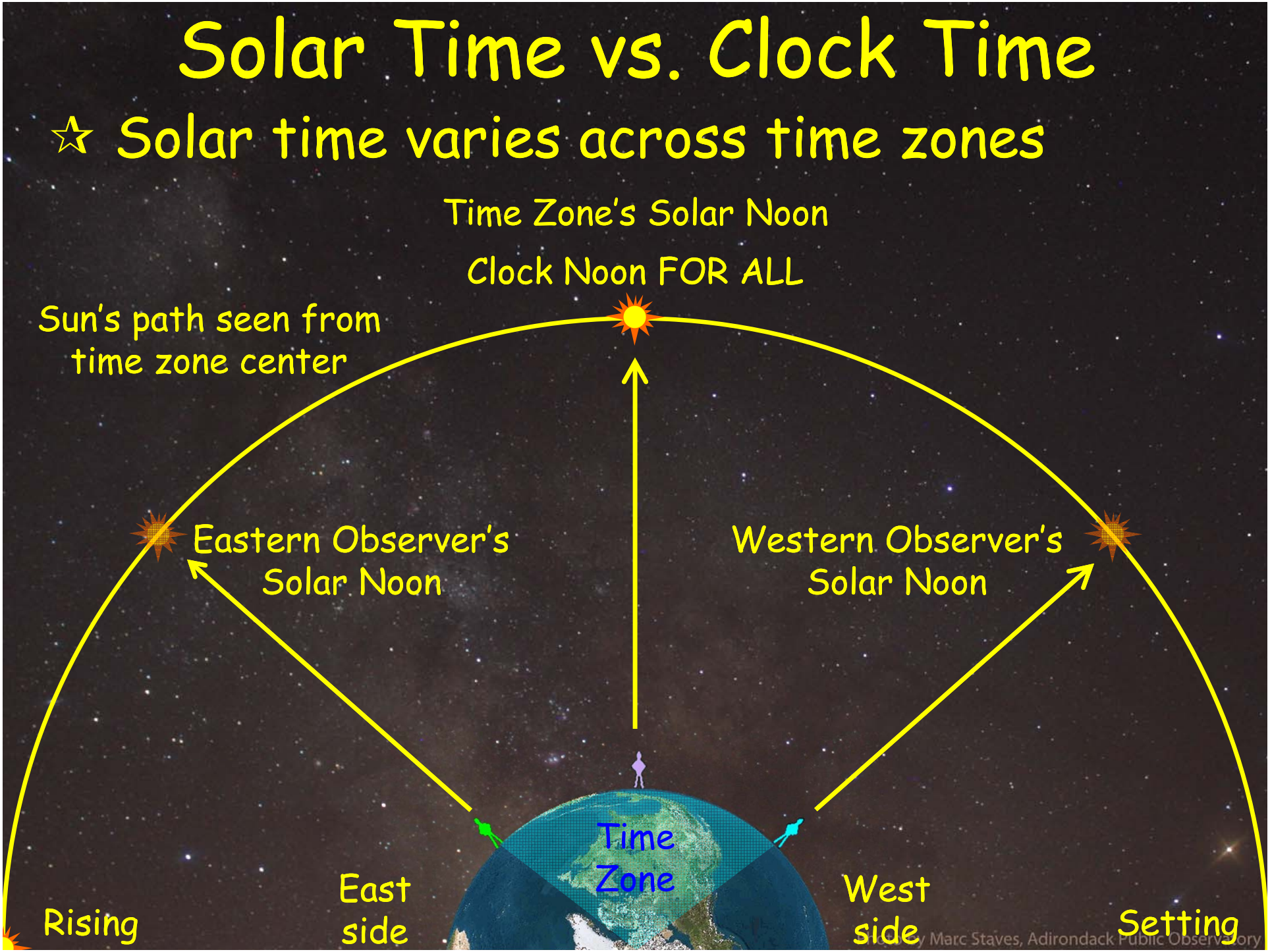
Clock Time = Position of Sol

☆ Observers move through times



Solar Time vs. Clock Time

☆ Solar time varies across time zones



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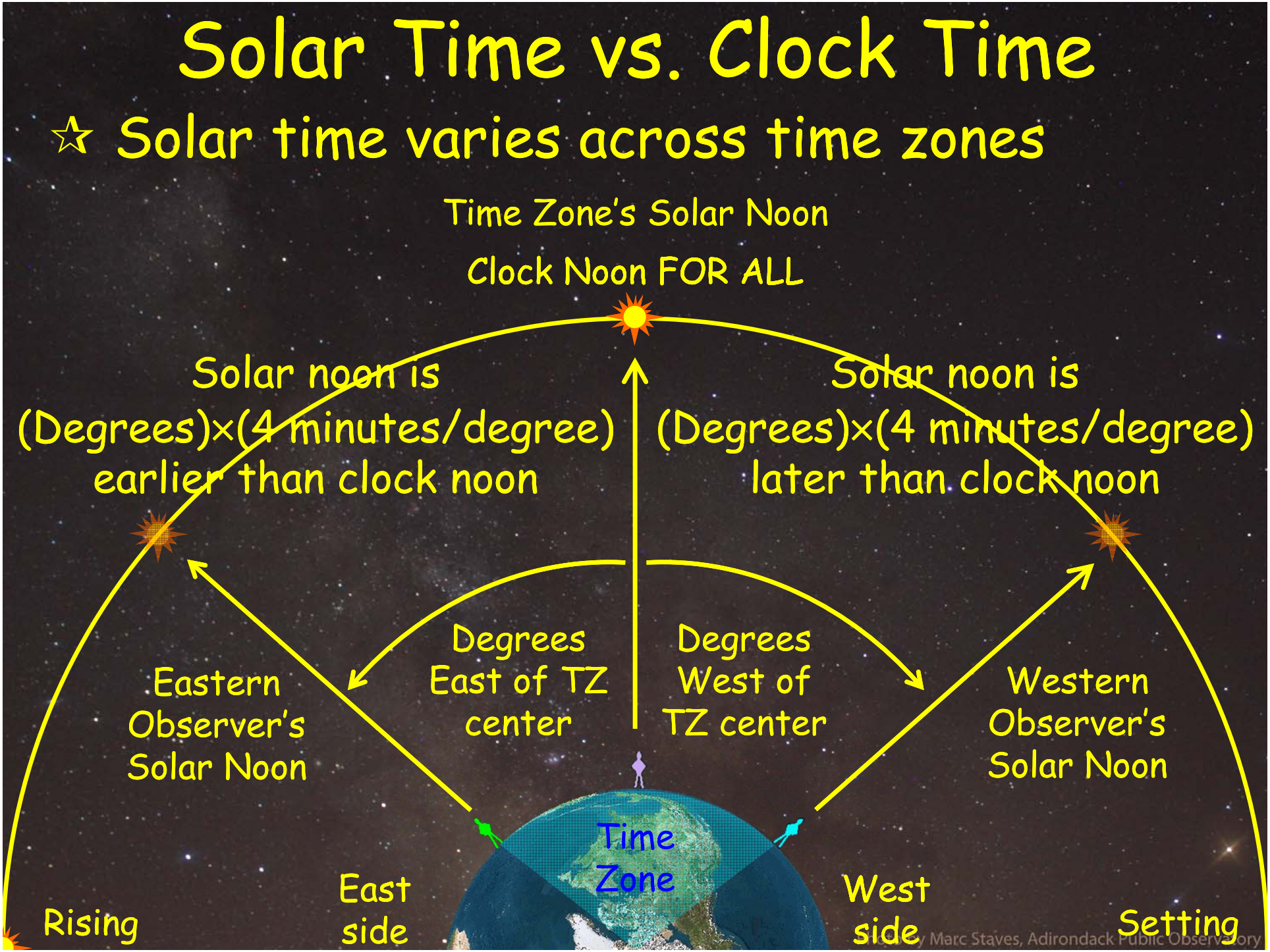
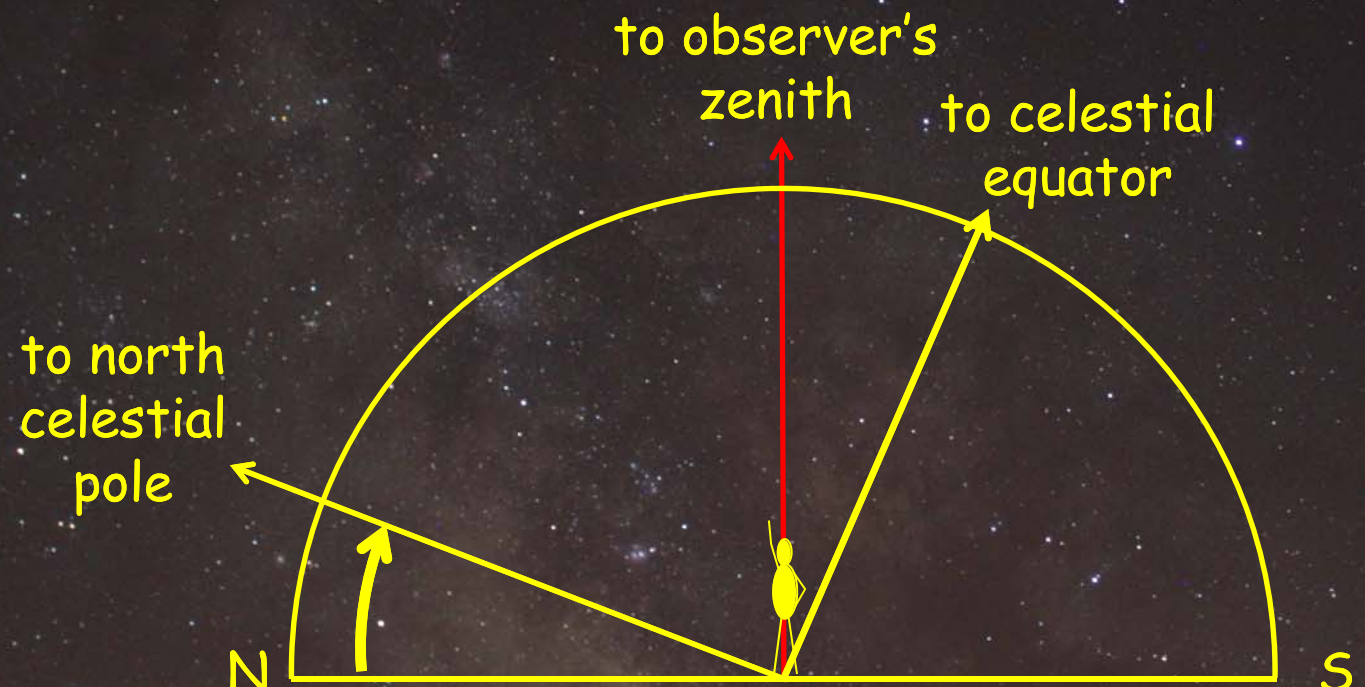


Celestial Navigation

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



Observer at 20° N

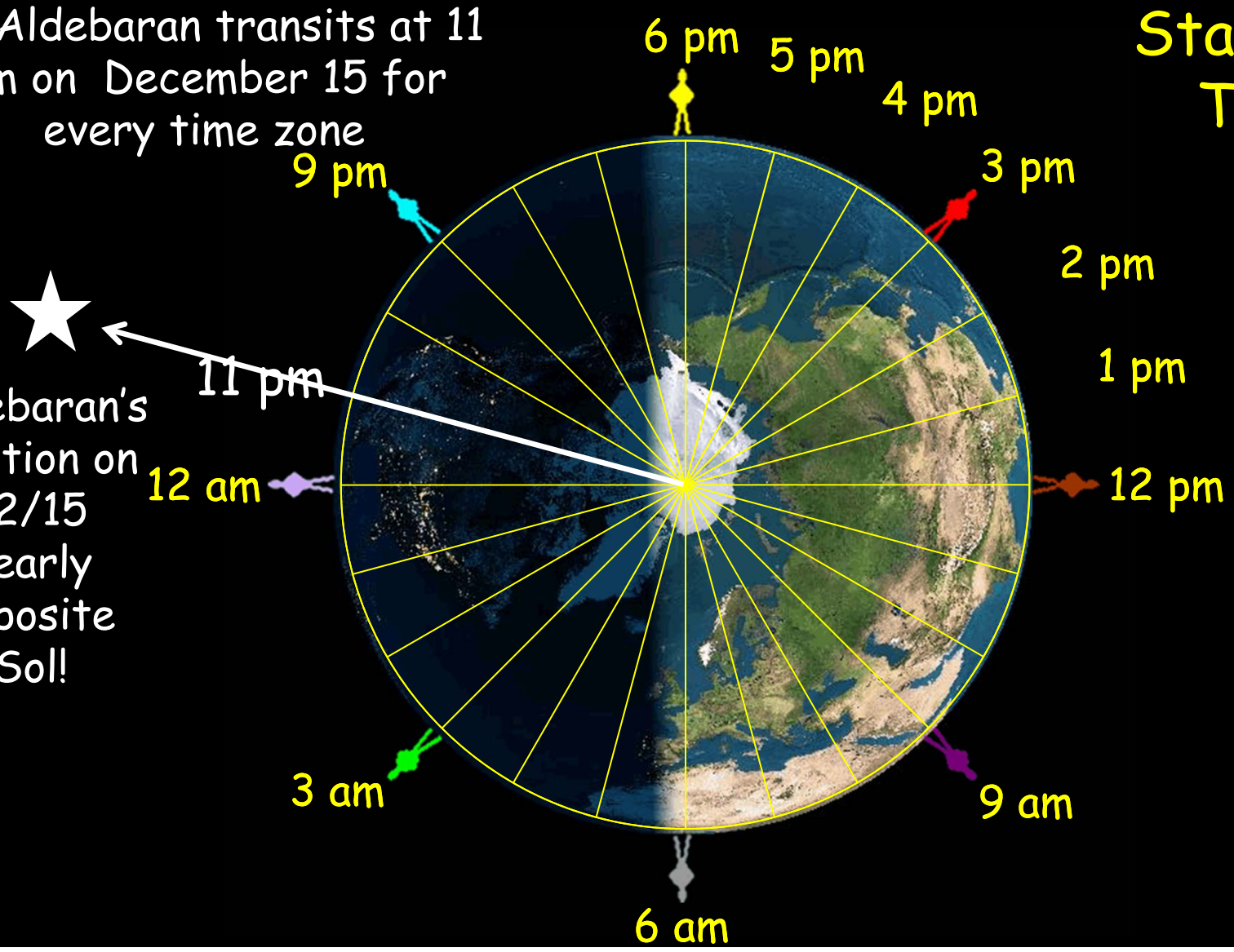
Photo by Marc Staves, Adirondack Public Observatory

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



Clicker Question

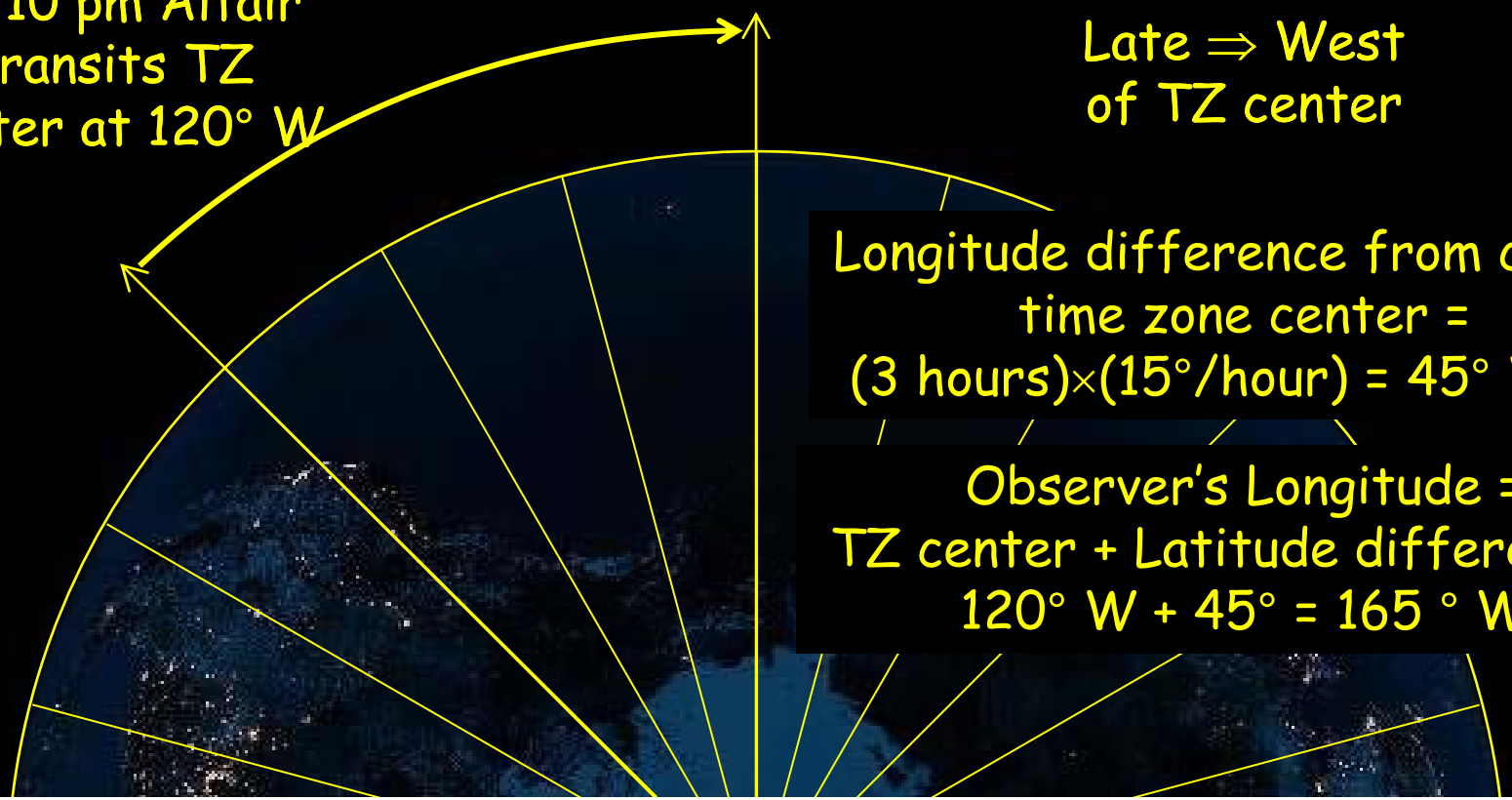
☆ What's your longitude if you see Altair transit at 1 am on September first and your watch is set for Pacific time?

On 9/1 Altair transits at 10 pm PDT

At 10 pm Altair transits TZ center at 120° W

Observer sees Altair transit at 1 am PDT

Late ⇒ West of TZ center



Longitude difference from clock's time zone center = (3 hours)×(15°/hour) = 45° West

Observer's Longitude = TZ center + Latitude difference = 120° W + 45° = 165 ° W

Models of Earth

Why are globes tilted?

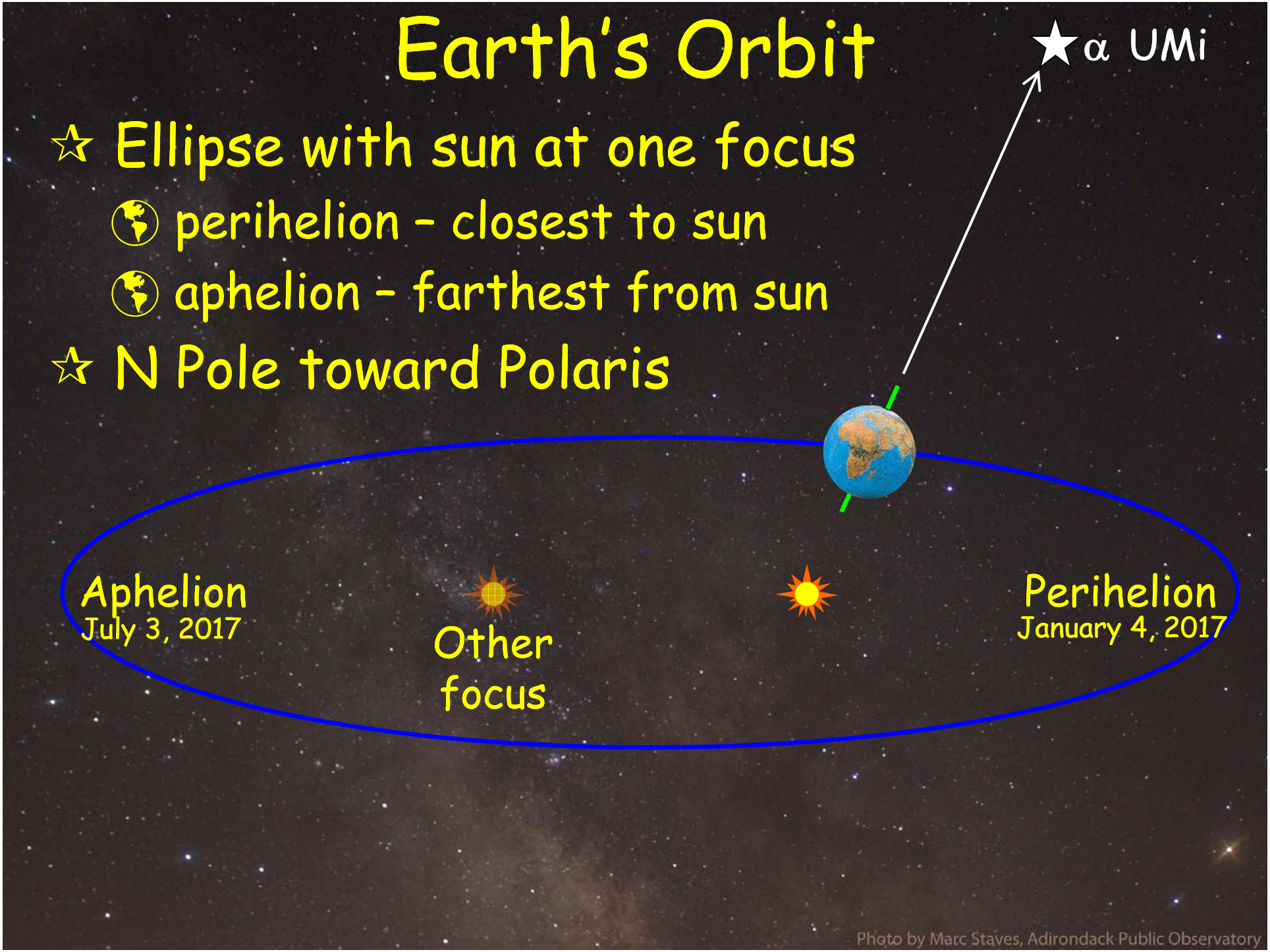
Photo by Marc Staves, Adirondack Public Observatory

Earth's Orbit

Photo by Marc Staves, Adirondack Public Observatory

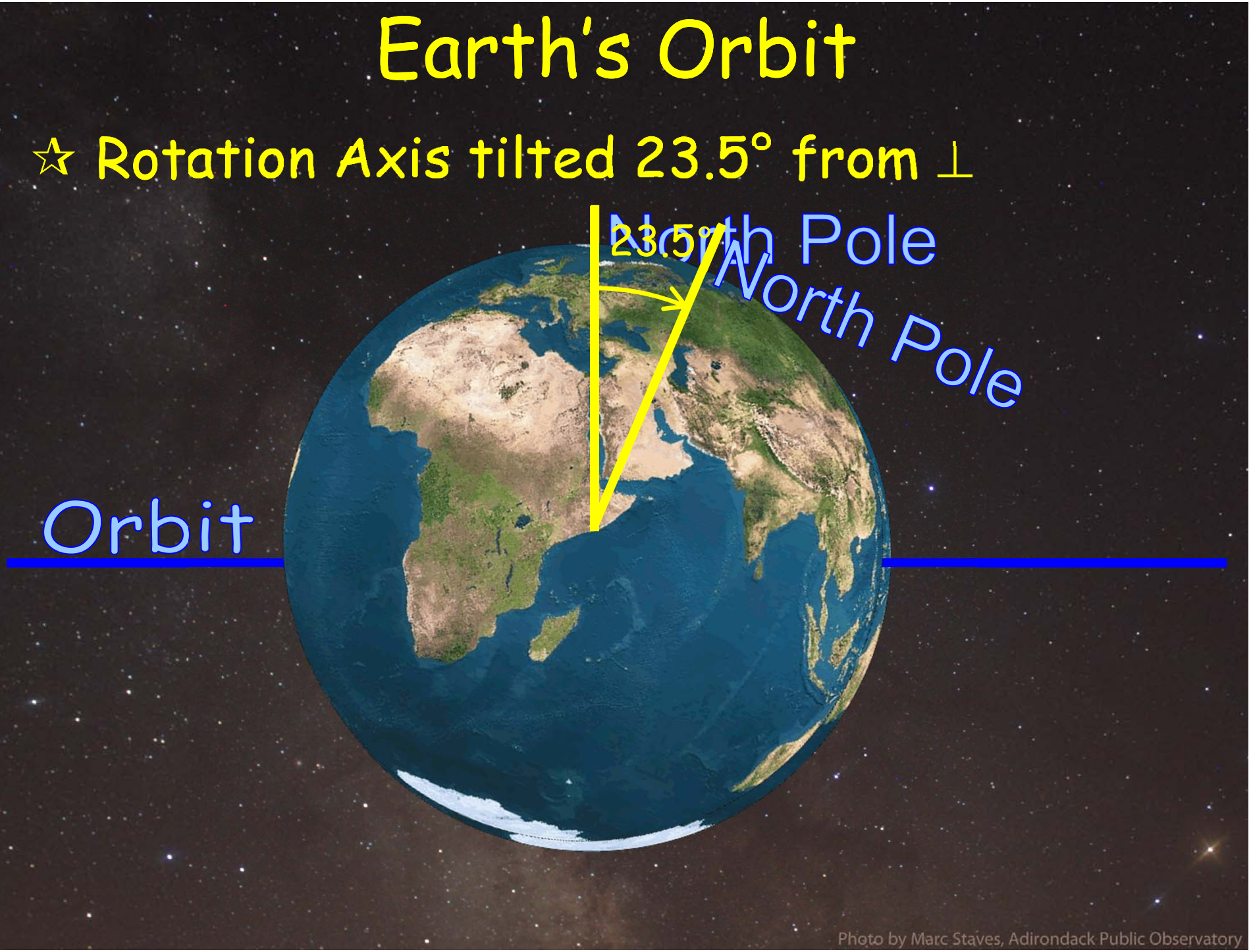
Earth's Orbit

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



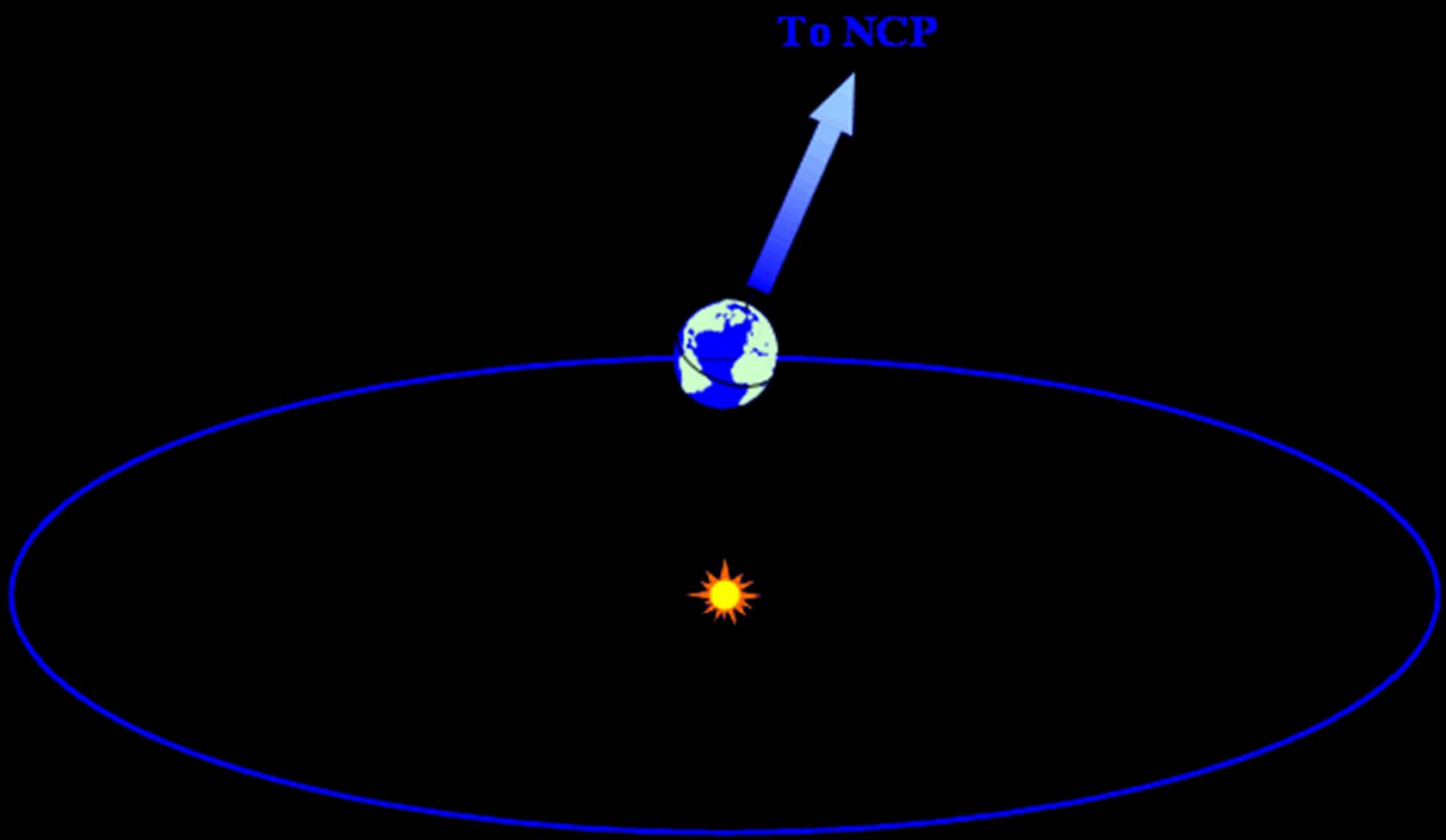
Earth's Orbit

☆ Rotation Axis tilted 23.5° from ⊥



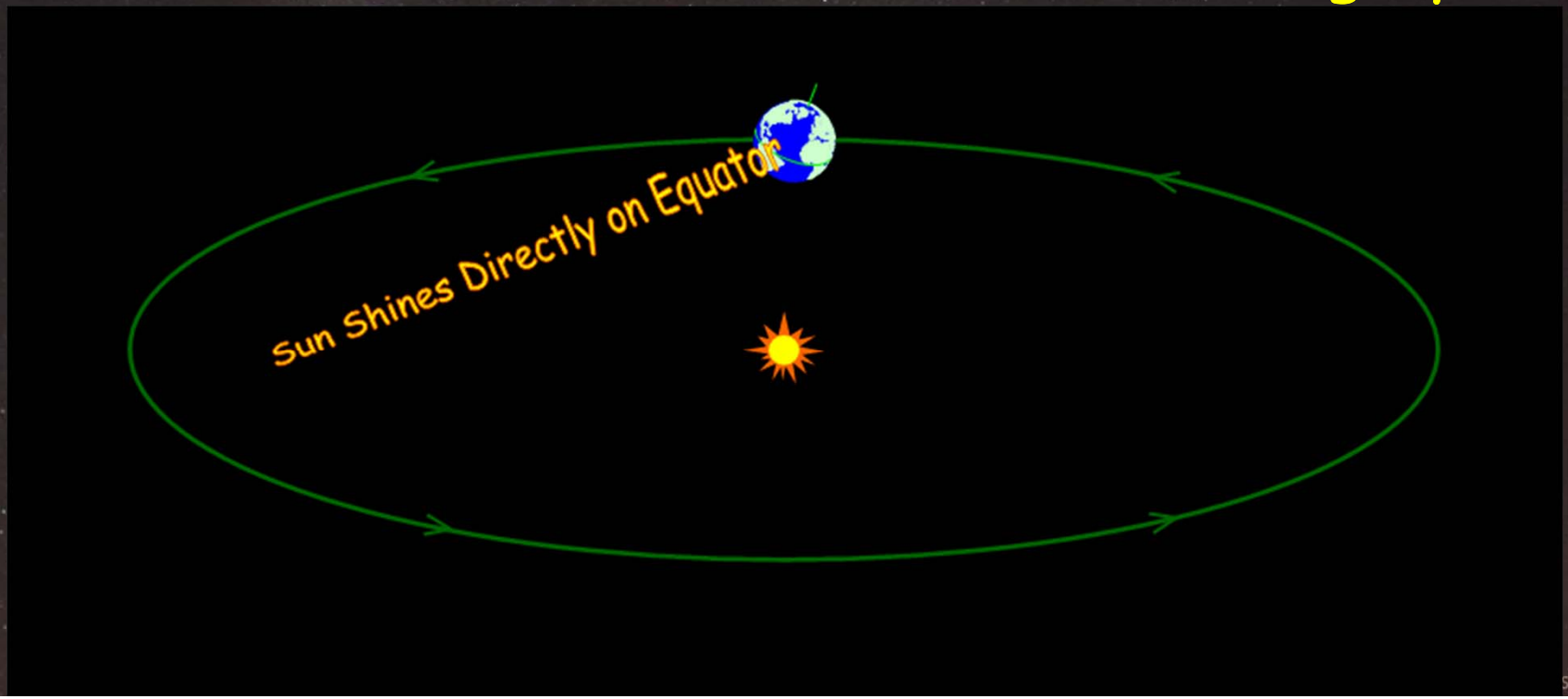
Earth's Orbit

- ☆ 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 (δ) 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 (α) 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

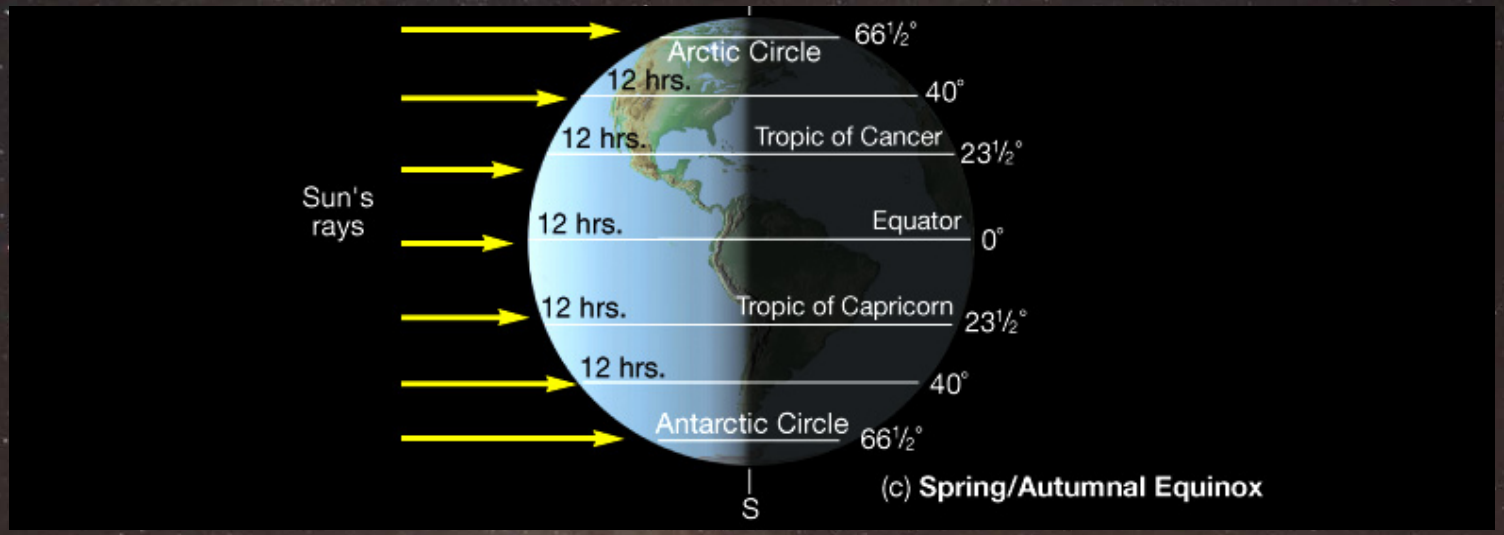


Photo by Marc Staves, Adirondack Public Observatory

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)

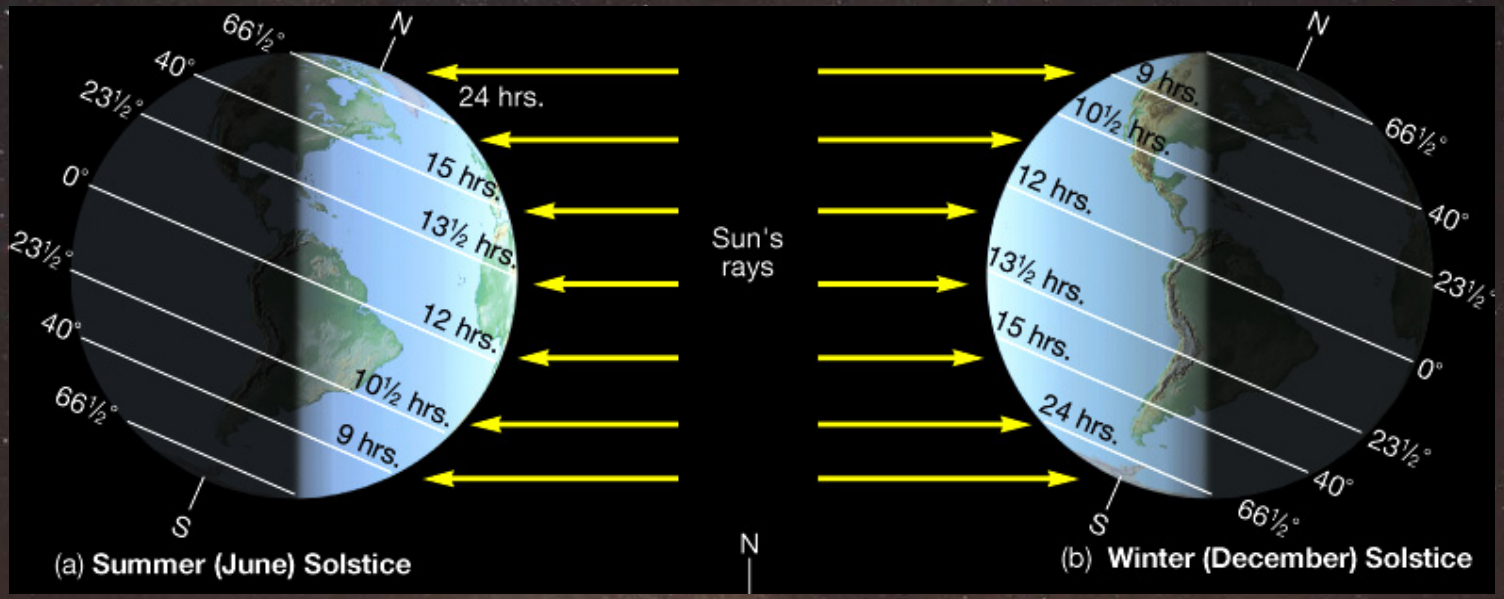
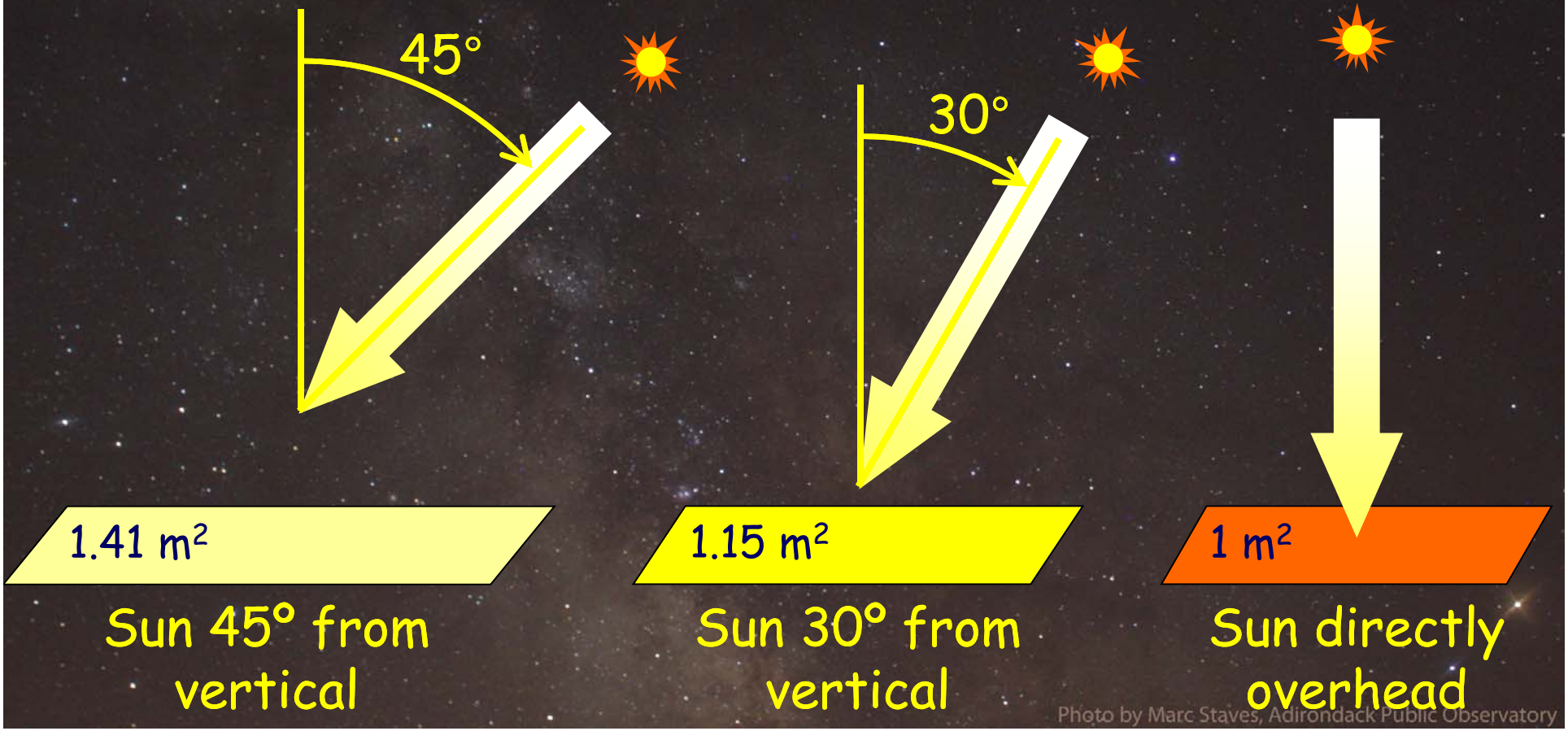
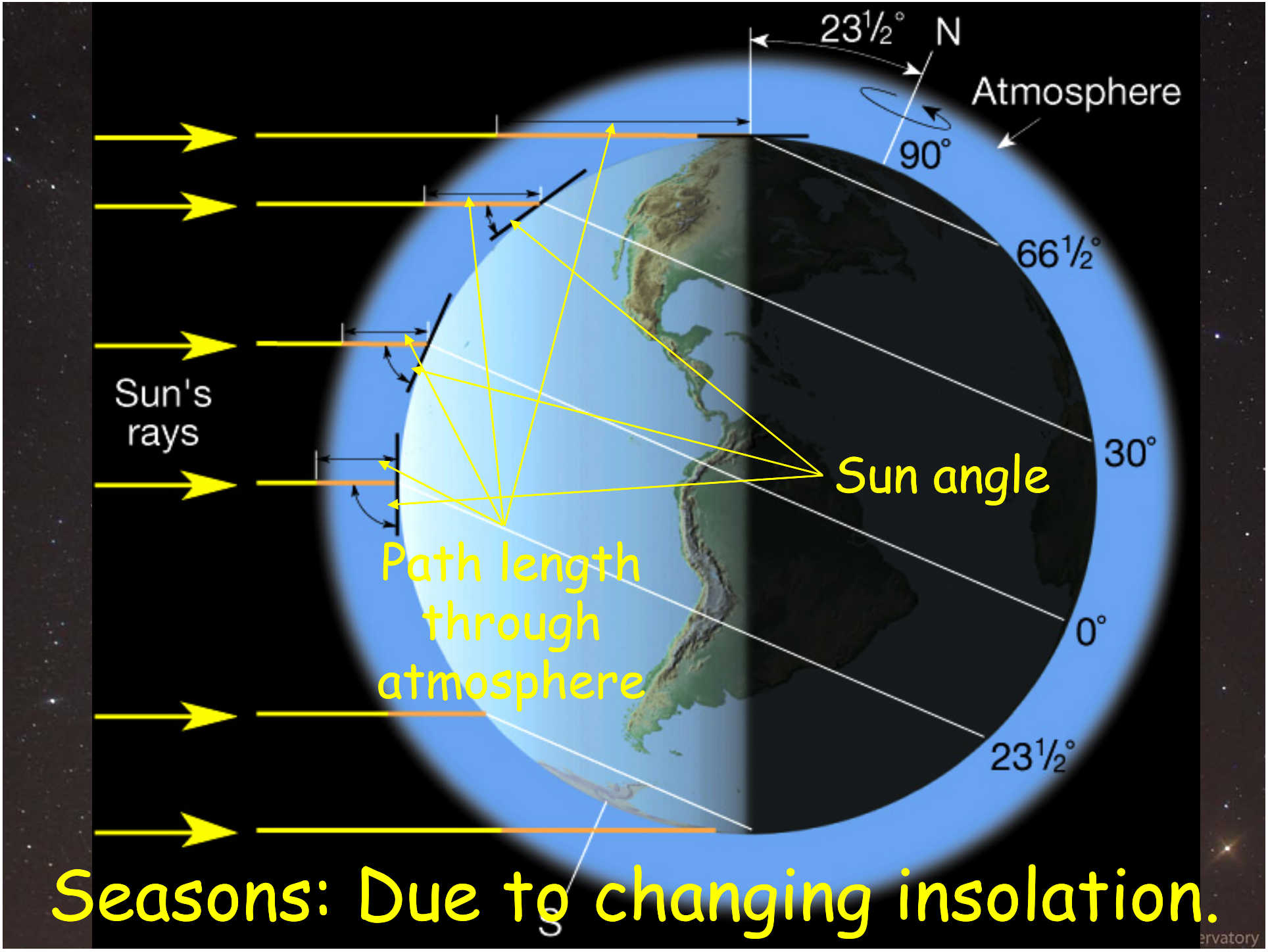


Photo by Marc Staves, Adirondack Public Observatory

Seasons

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

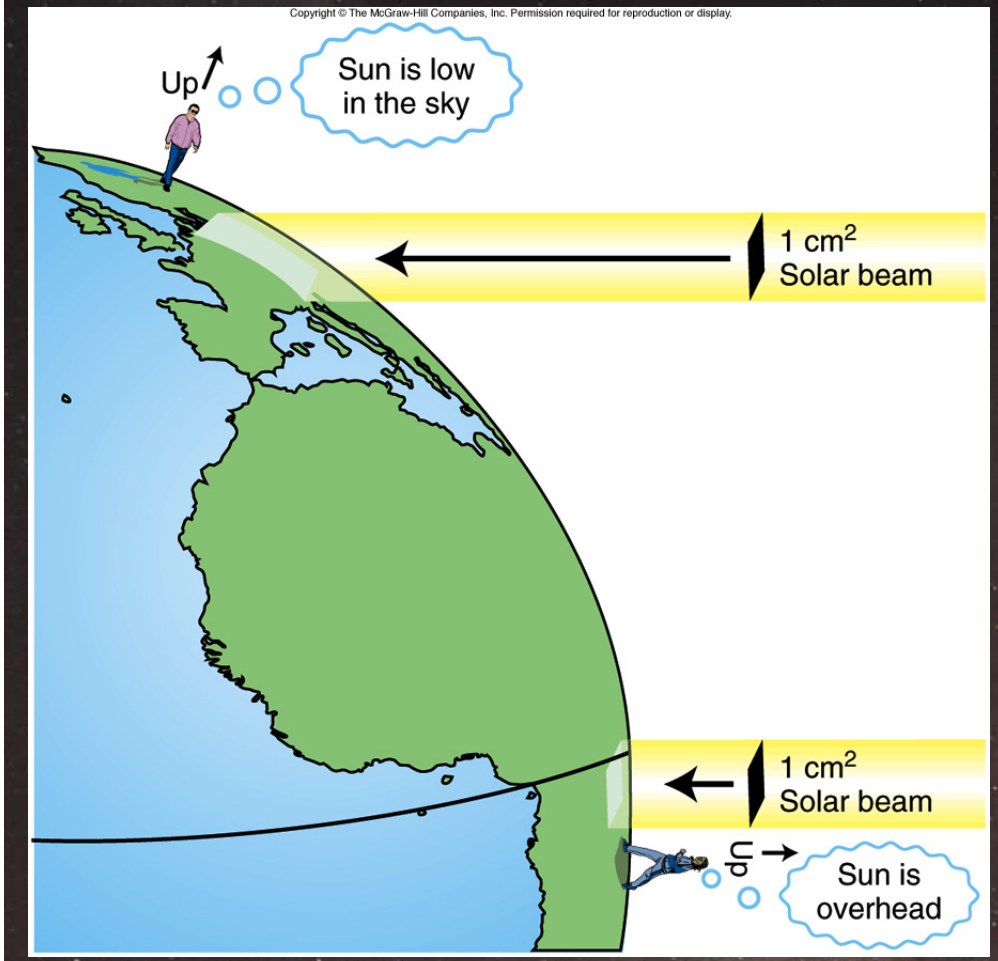


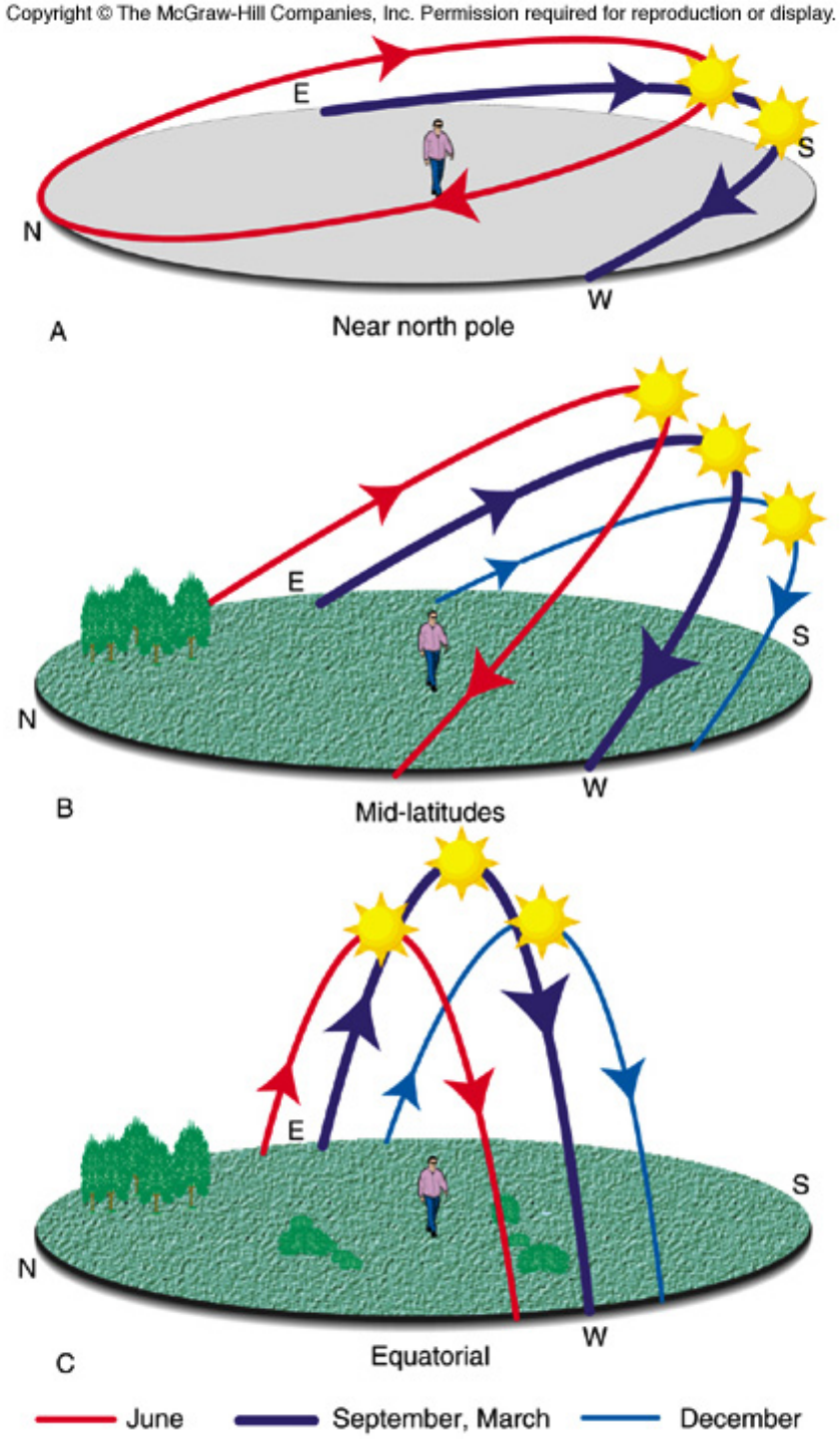


Seasons: Due to changing insolation.

Seasons

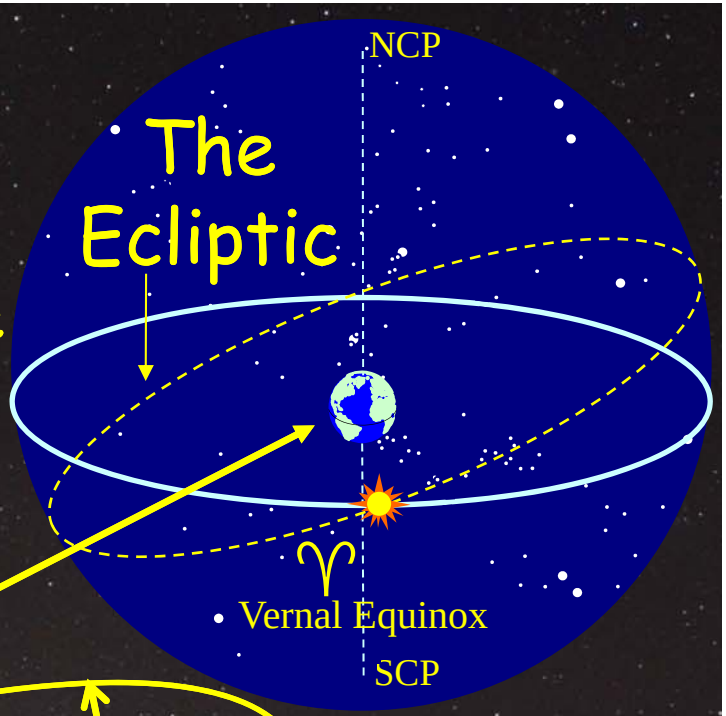
☆ Vary with latitude





Sun in the sky

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



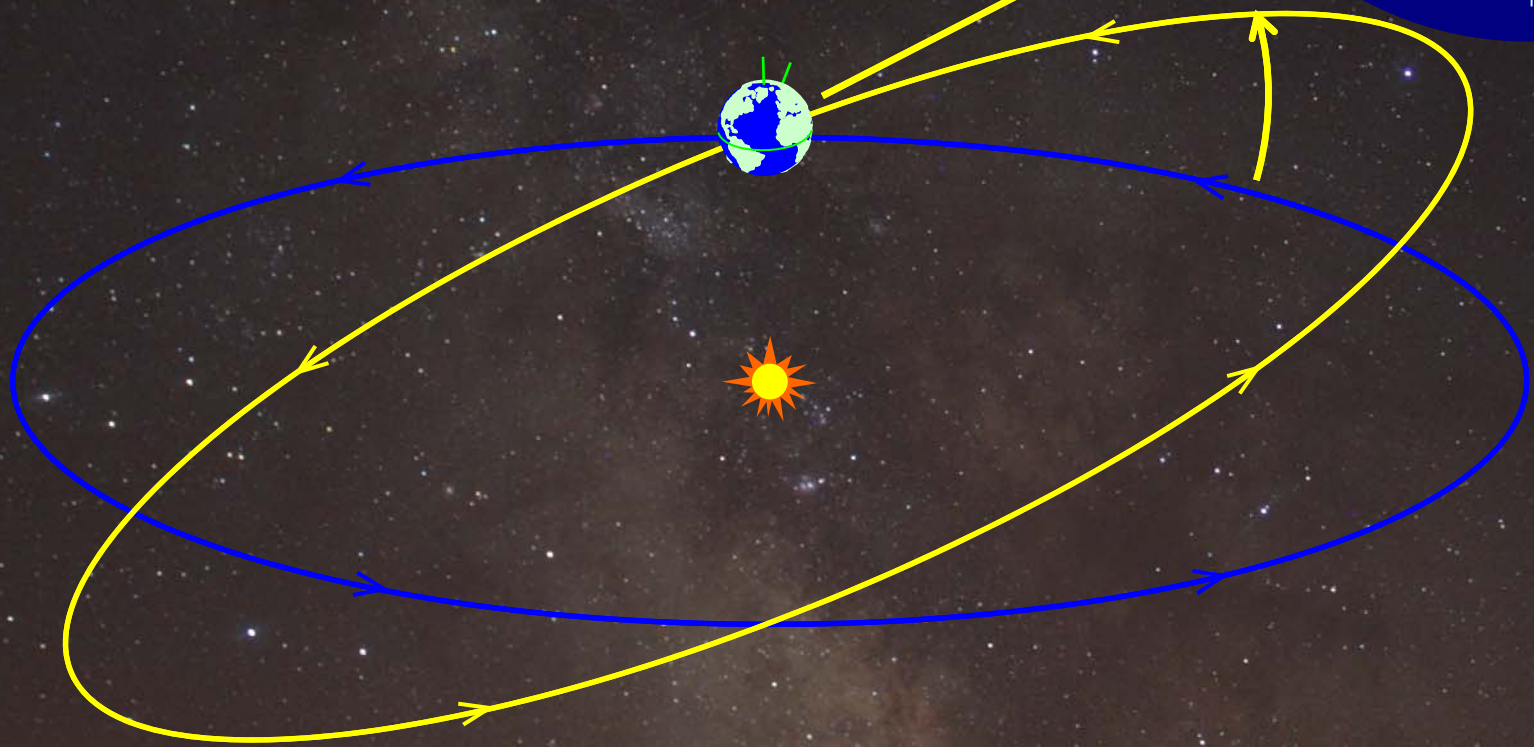
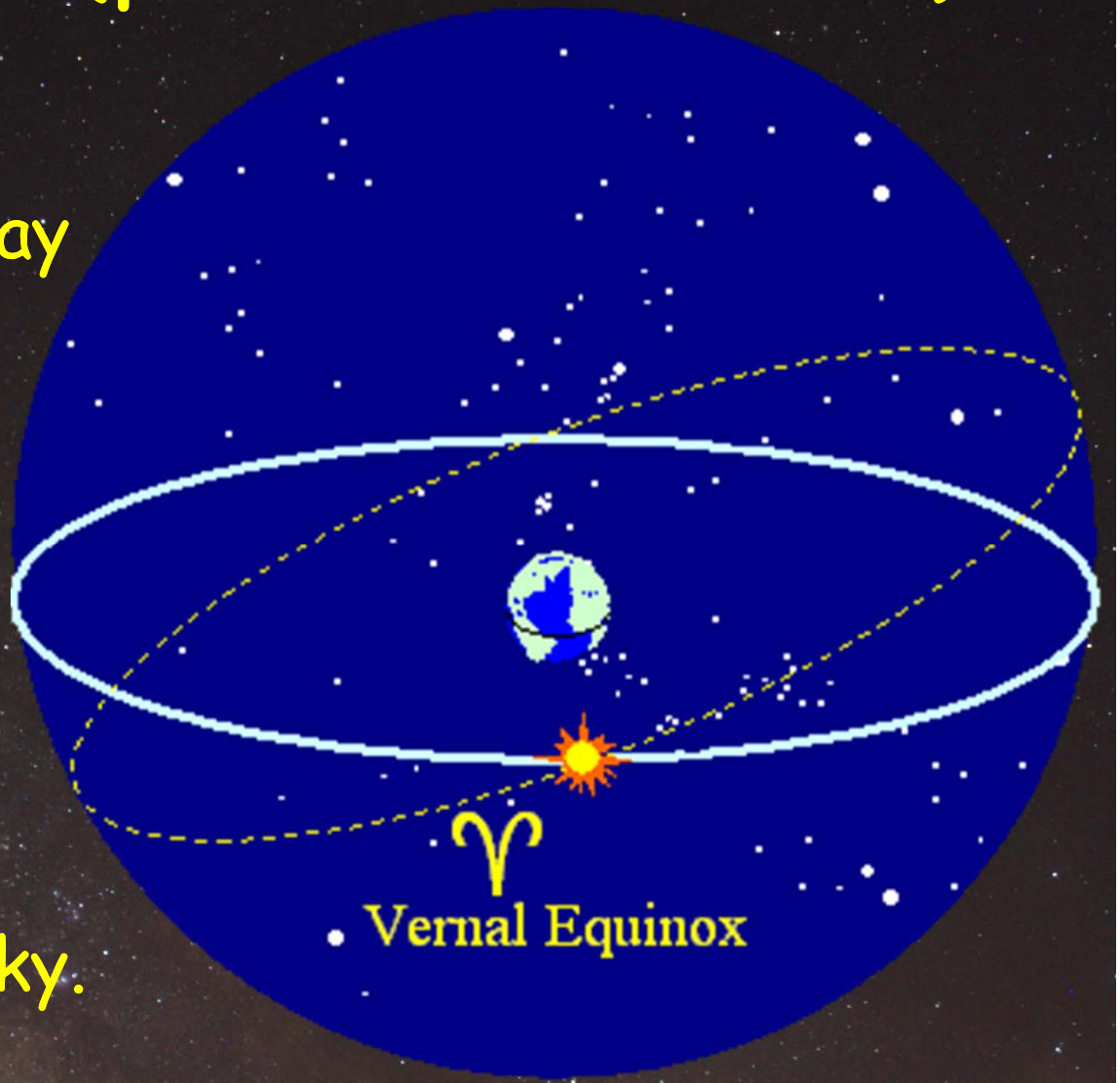


Photo by Marc Staves, Adirondack Public Observatory

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

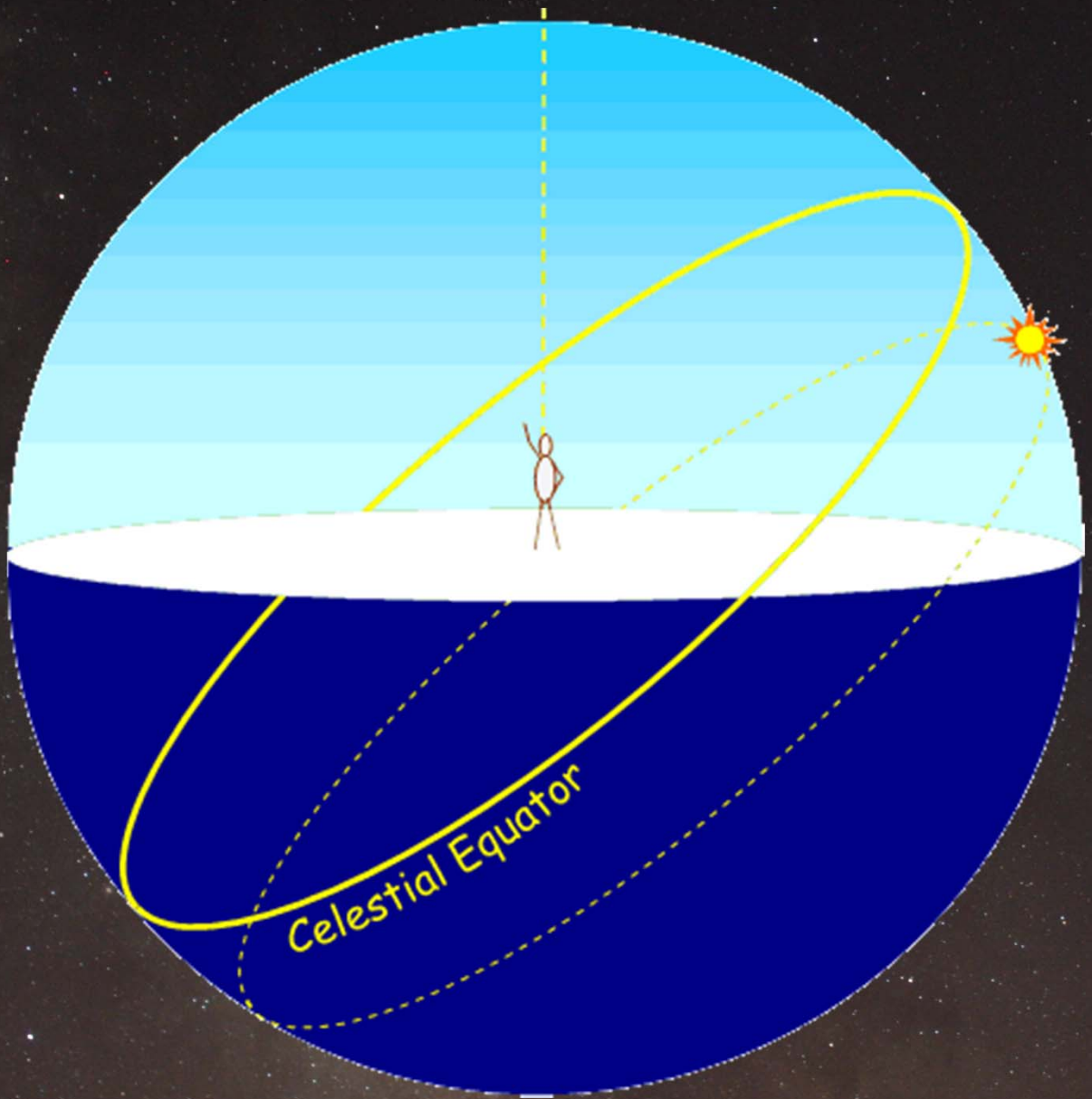


Photo by Marc Staves, Adirondack Public Observatory

Sun's path on a winter day

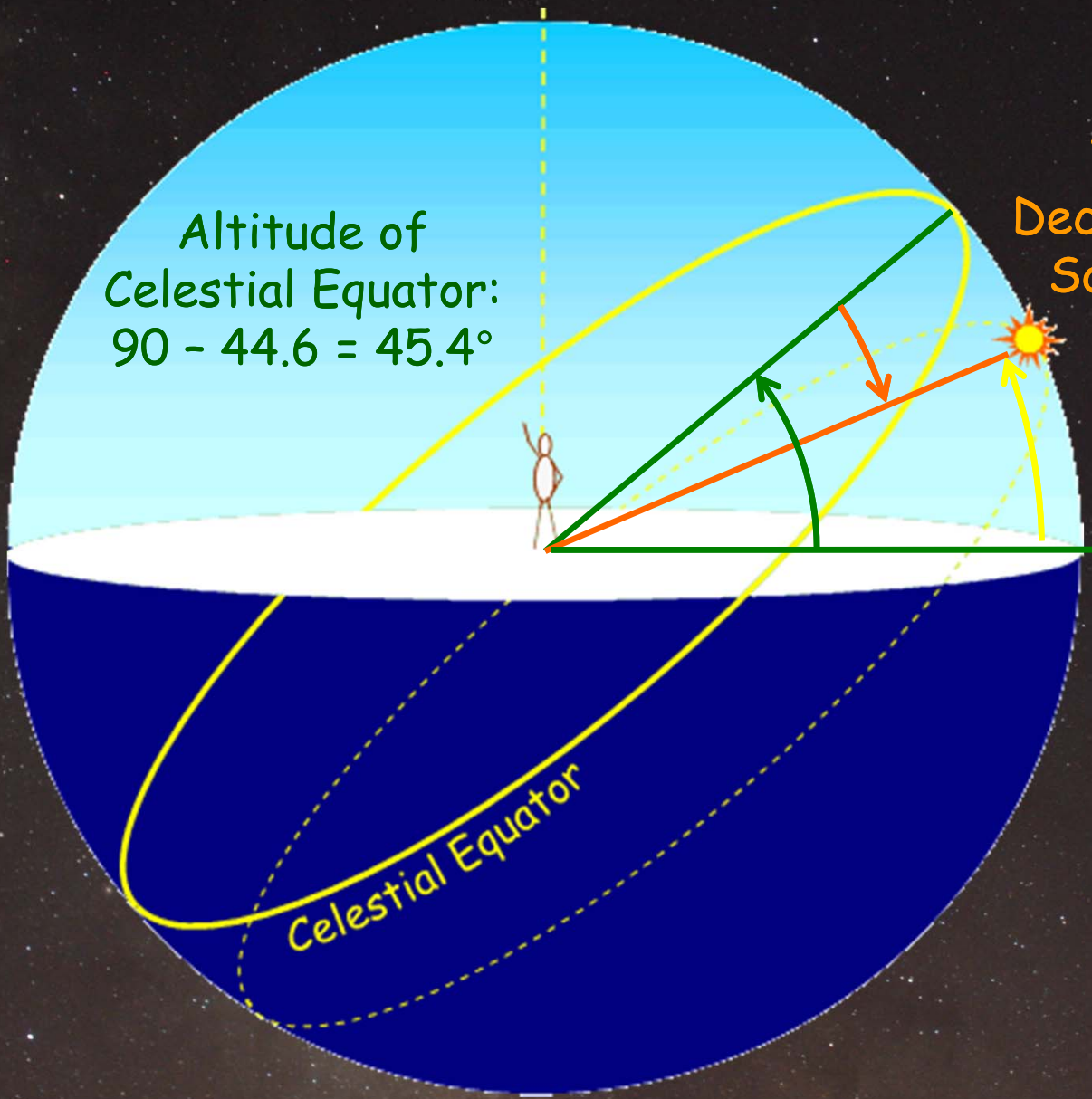


Photo by Marc Staves, Adirondack Public Observatory

Sun's path on a fall/spring day

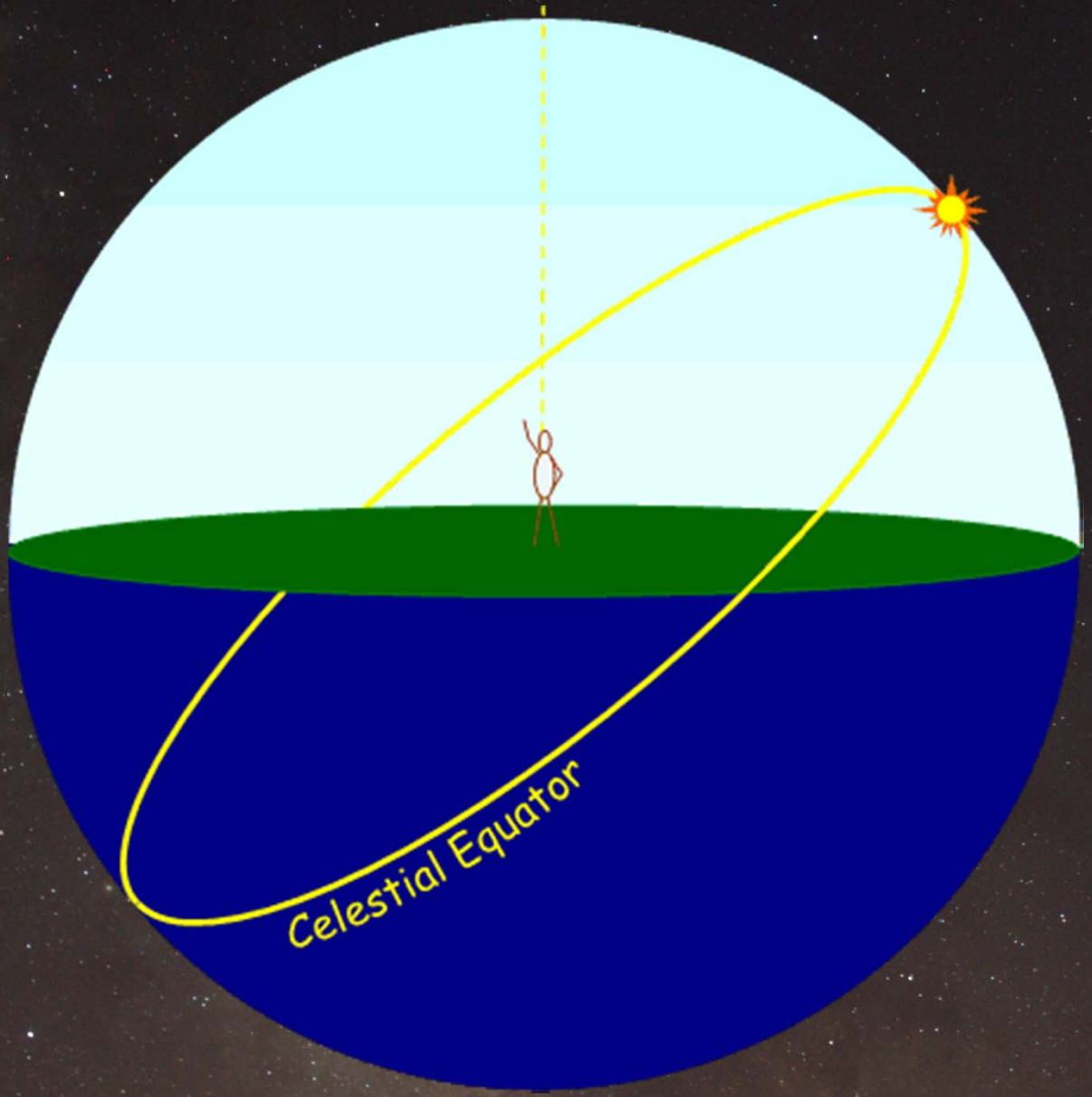


Photo by Marc Staves, Adirondack Public Observatory

Sun's path on a summer day

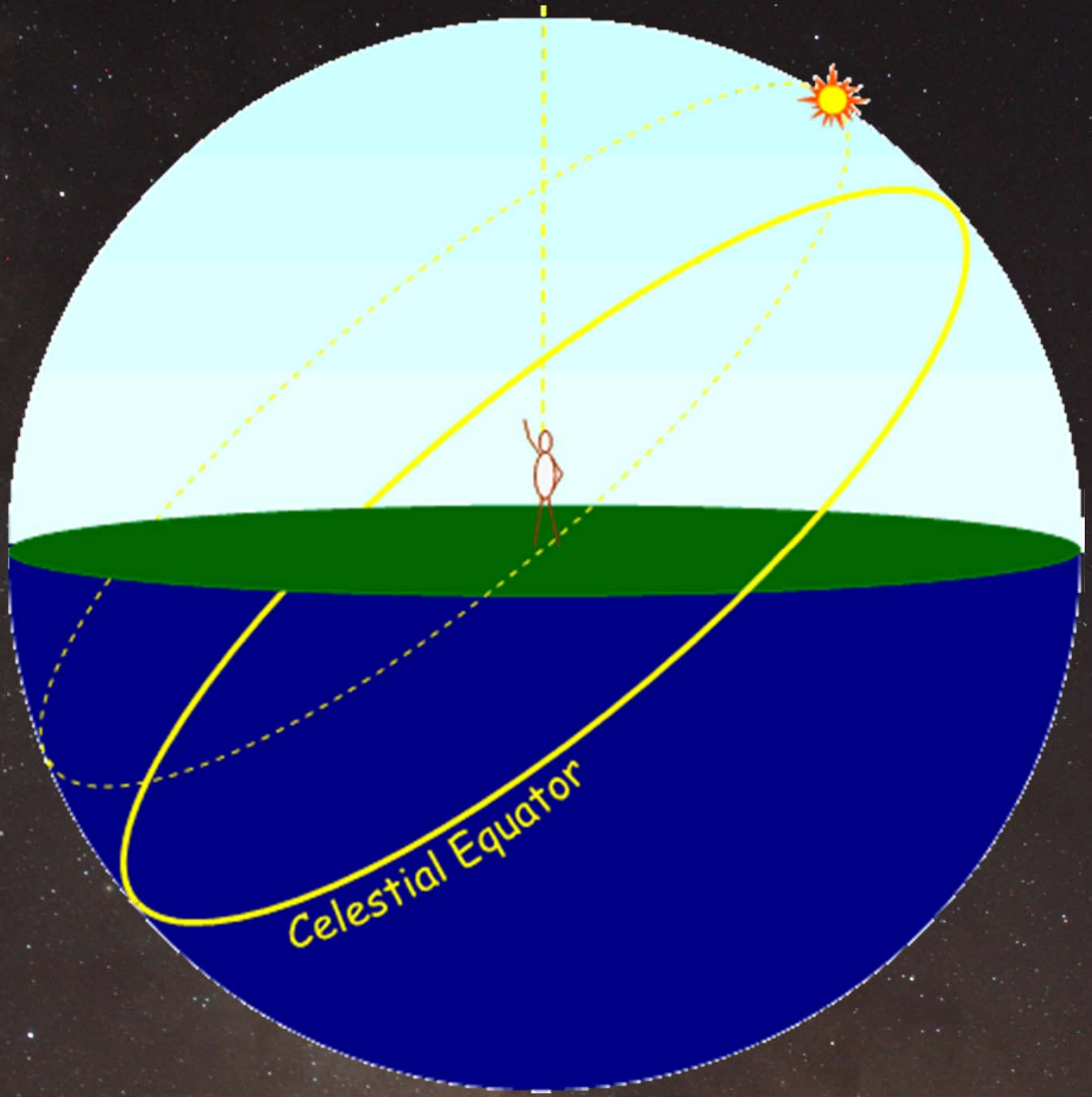
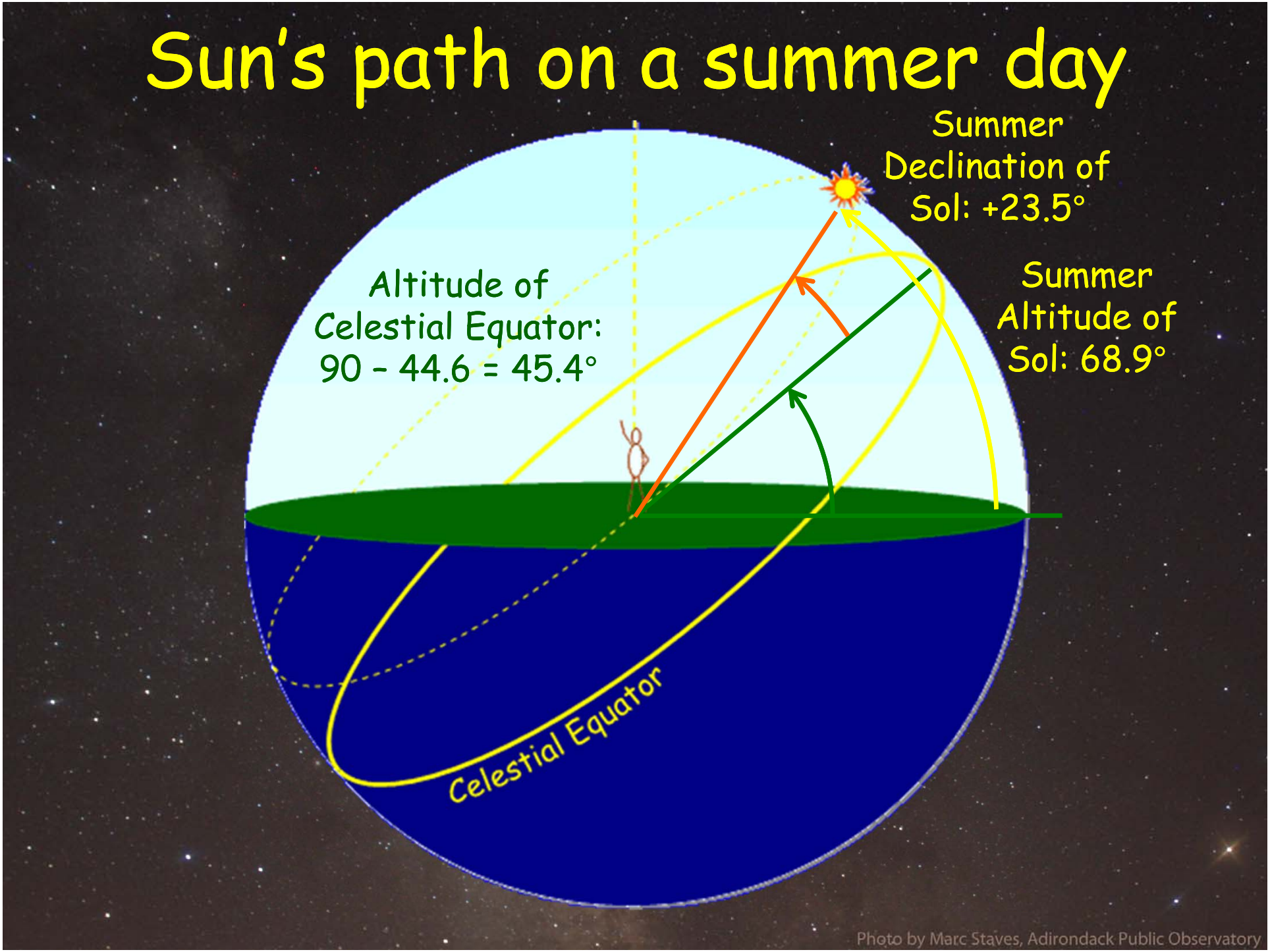


Photo by Marc Staves, Adirondack Public Observatory

Sun's path on a summer day



Clicker Question

At noon on the summer solstice, the sun's maximum altitude in Key West (24.6°N) is

A. 41.9°

B. 65.4°

C. 88.9°

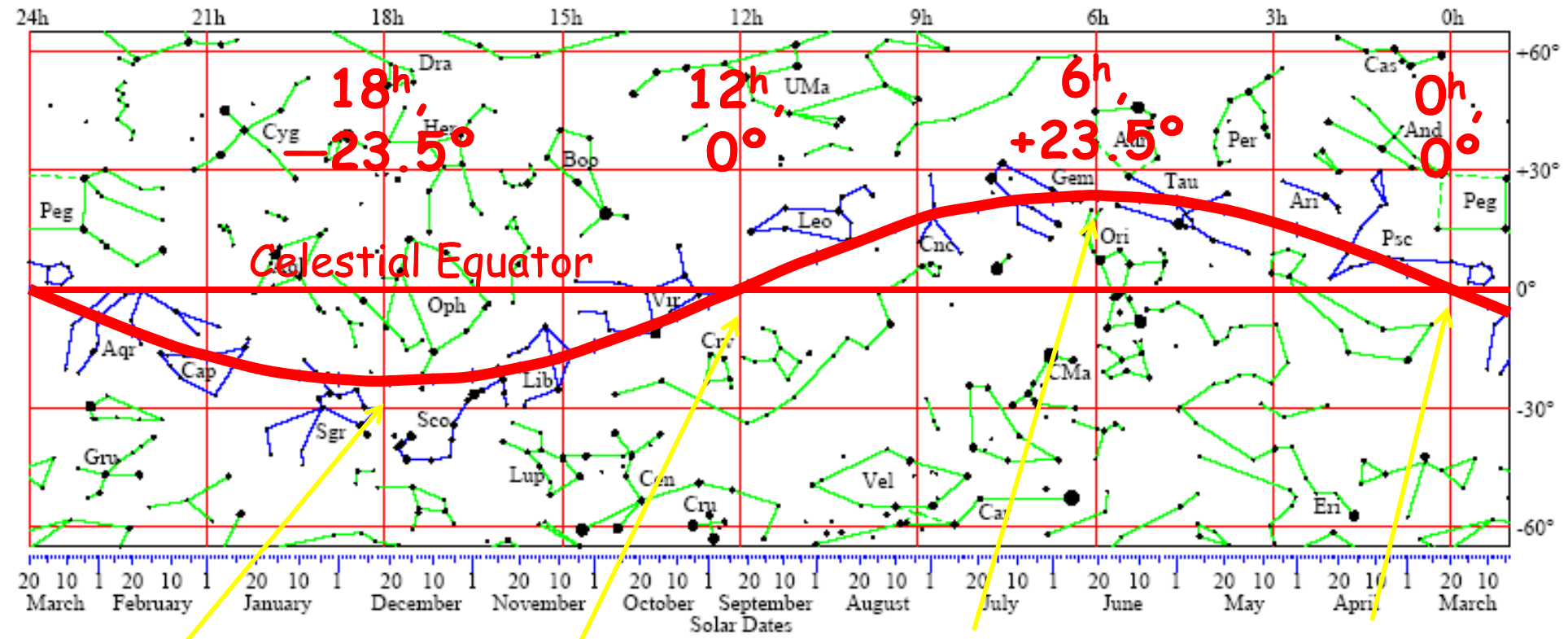
Hint:
90° – 24.6° = 65.4°

Hint: What is 65.4° + 23.5?

Photo by Marc Staves, Adirondack Public Observatory

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

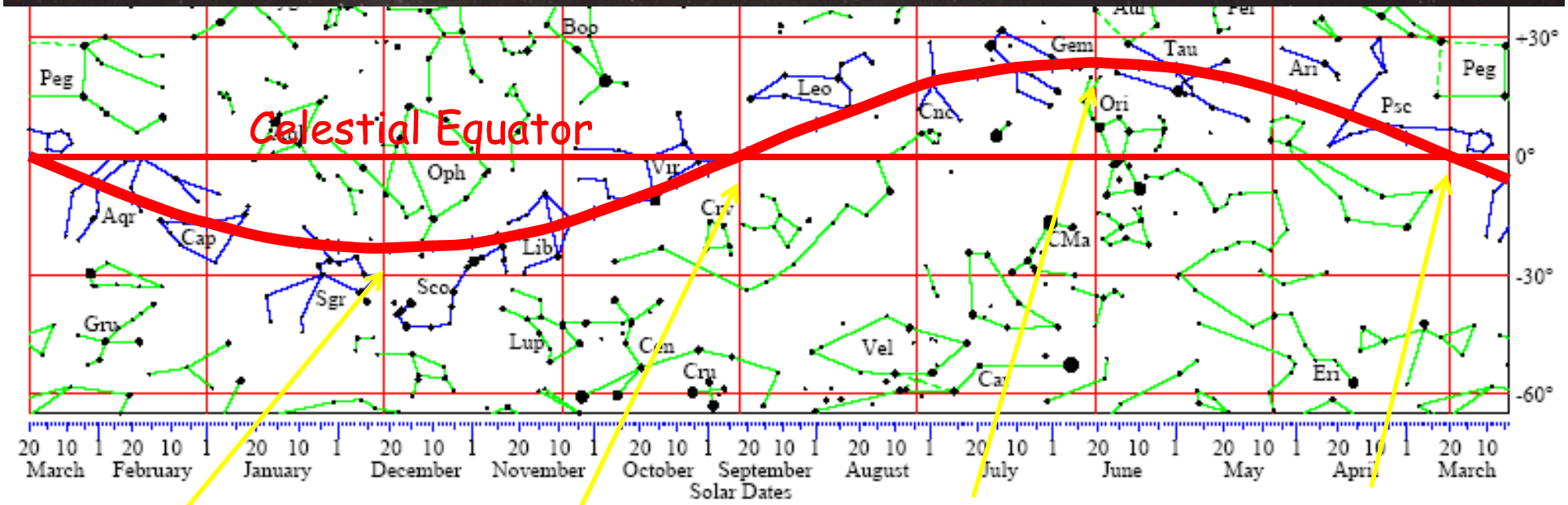
Summer Solstice in Taurus

Vernal Equinox in Pisces

Photo by Marc Staves, Adirondack Public Observatory

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

Photo by Marc Staves, Adirondack Public Observatory

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

Photo by Marc Staves, Adirondack Public Observatory

The Sidereal Day

- Earth turns 360° with respect to stars
  - eg. Vega transit to Vega Transit
- 23:56:00

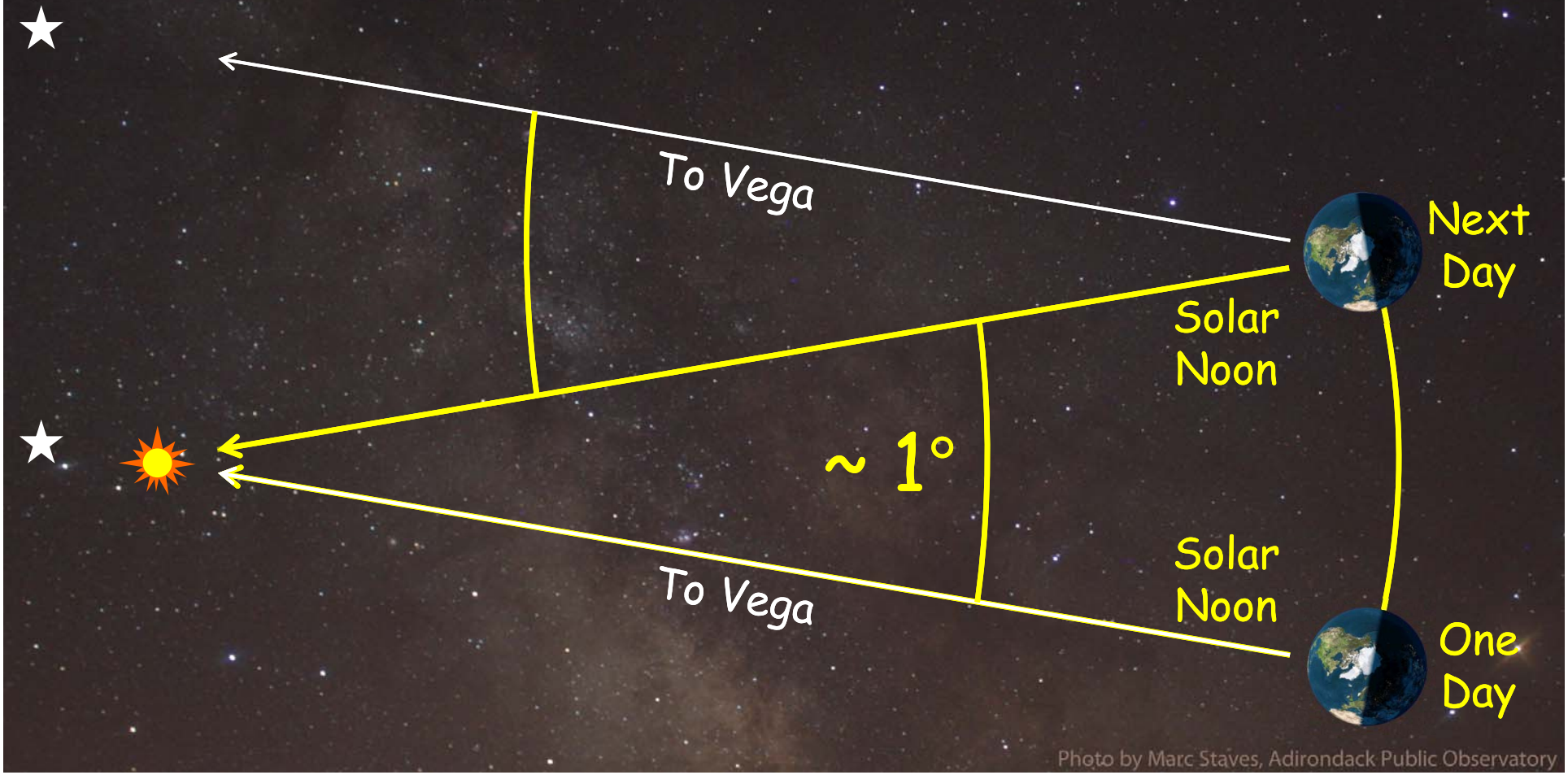


Photo by Marc Staves, Adirondack Public Observatory

The Sidereal Day

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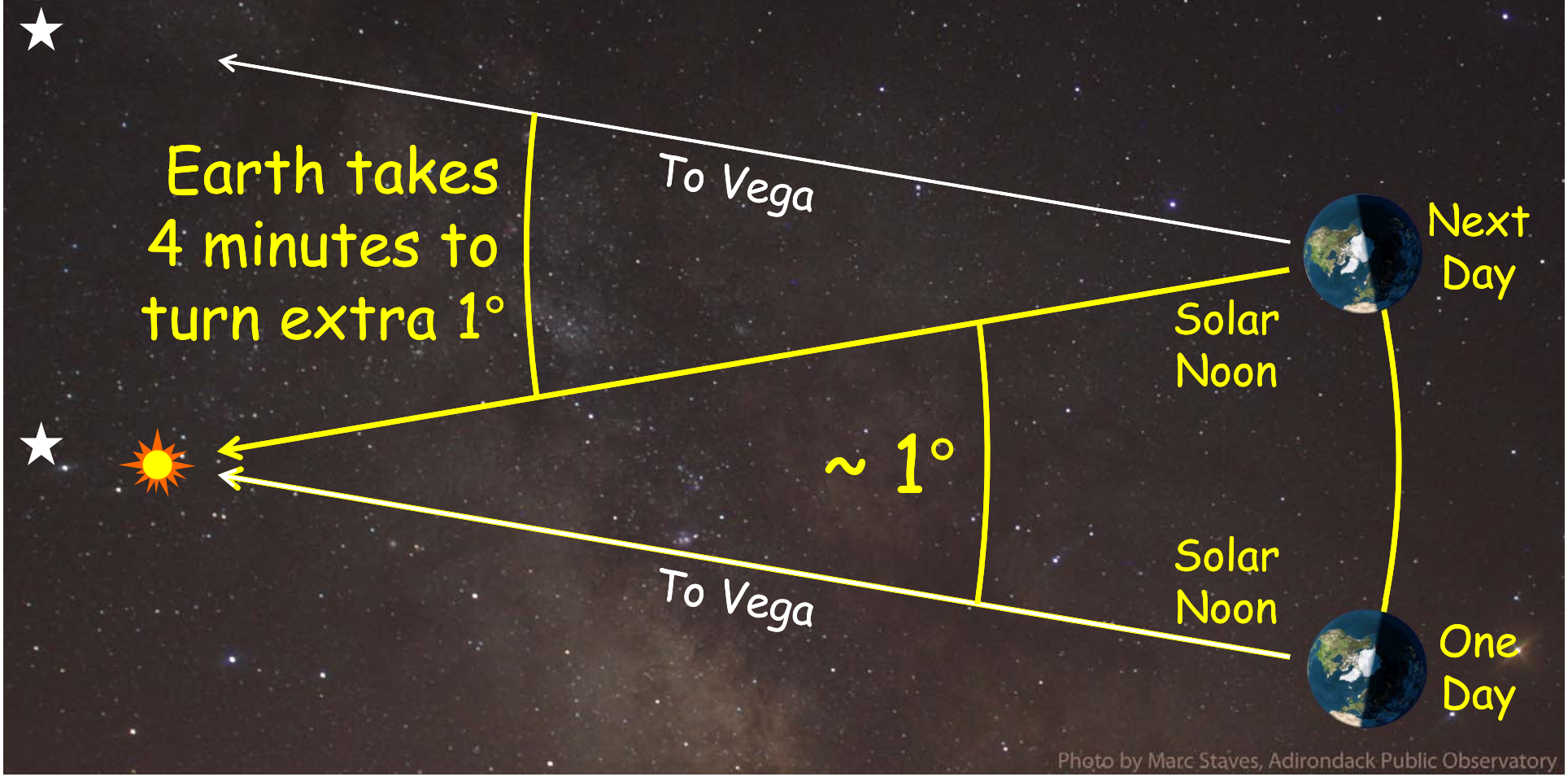
  - eg. Vega transit to Vega Transit
- 23:56:00



The Sidereal Day

- Earth turns 360° with respect to stars
  - eg. Capella transit to Capella Transit
- 23:56:00

Next Night

midnight

To Capella

Transit of Capella occurs 4 minutes earlier

One Night

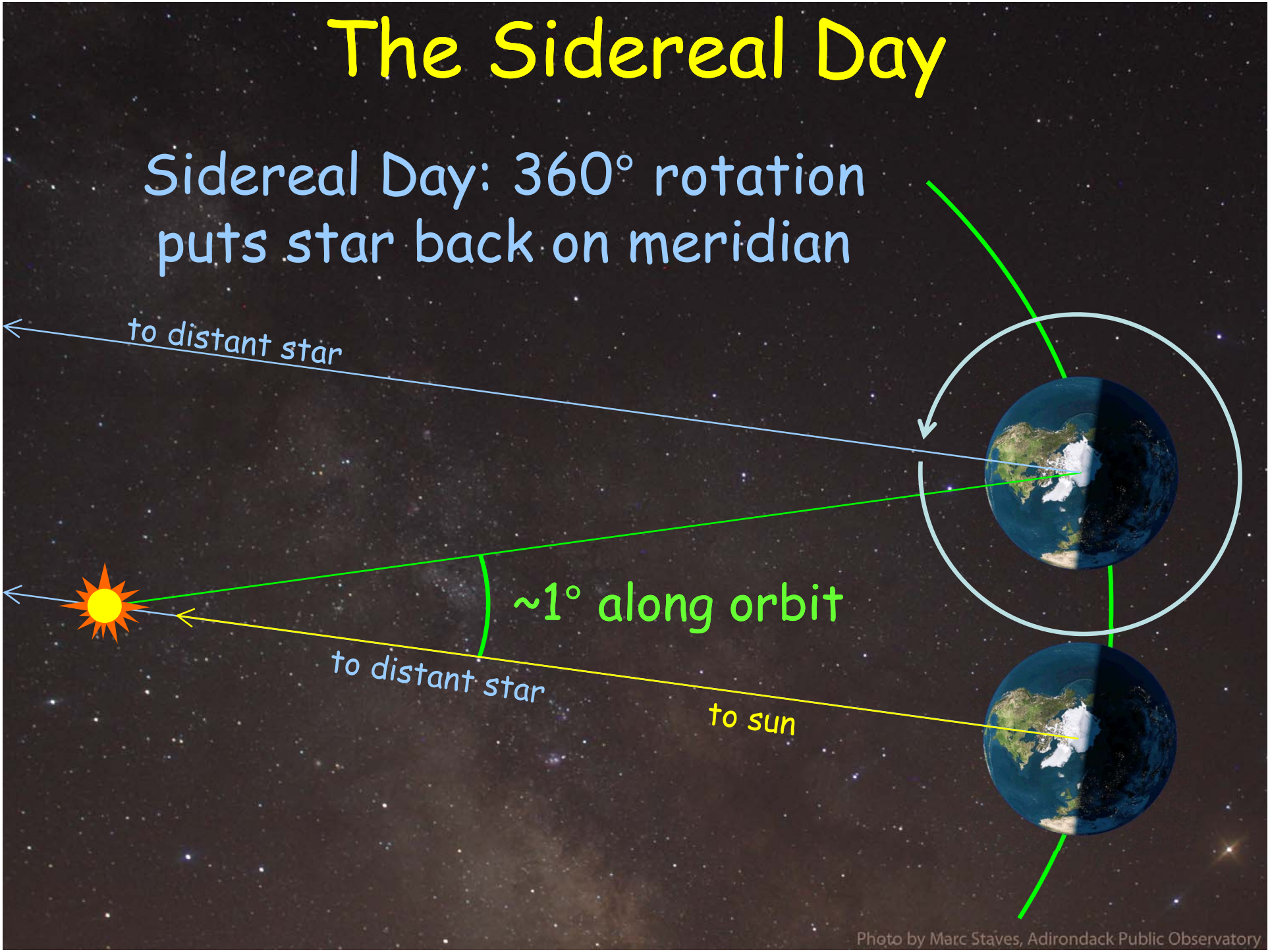
To Capella at midnight

Transit

Stars rise, transit & set four minutes earlier each day!

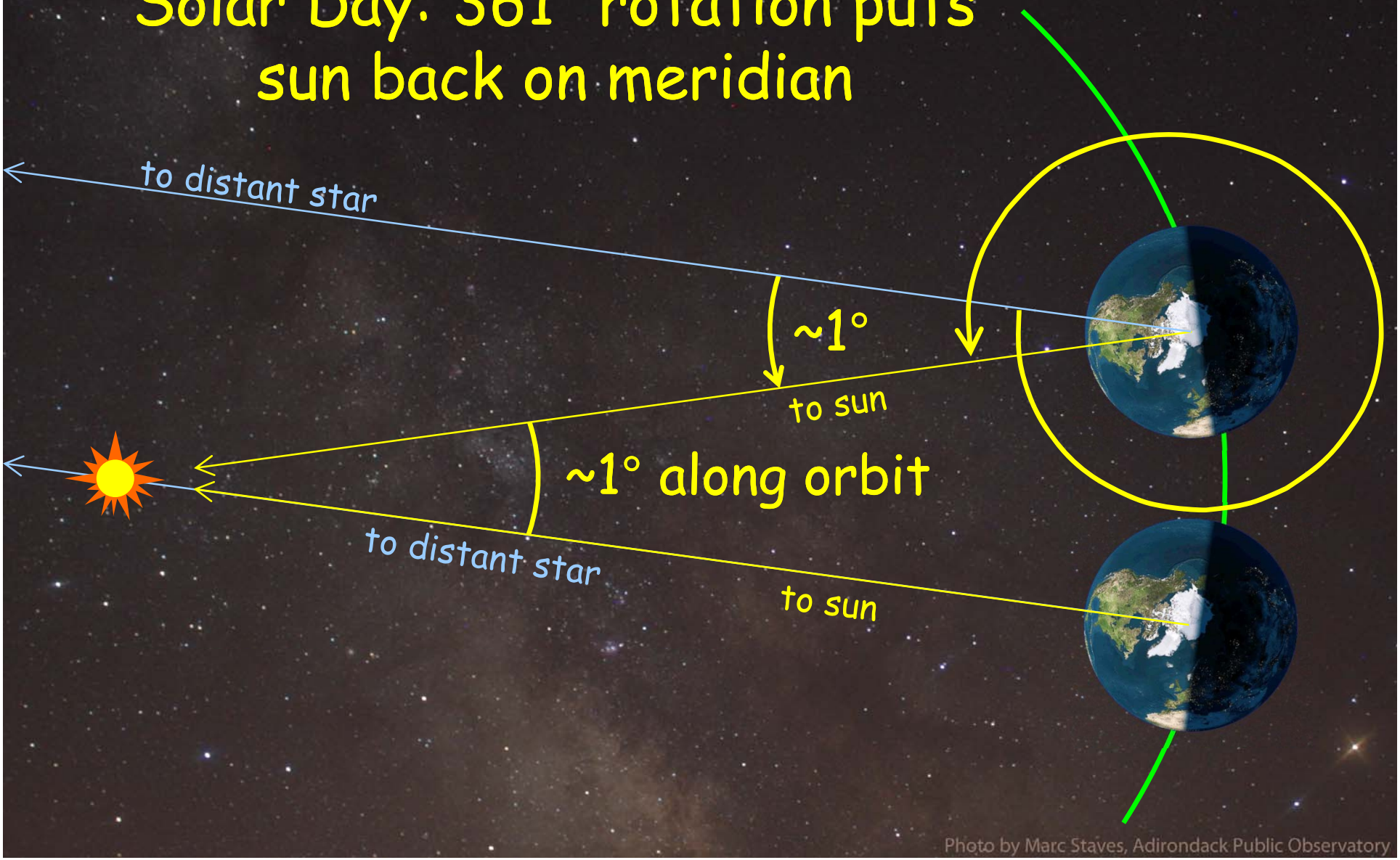
Photo by Marc Staves, Adirondack Public Observatory

The Sidereal Day



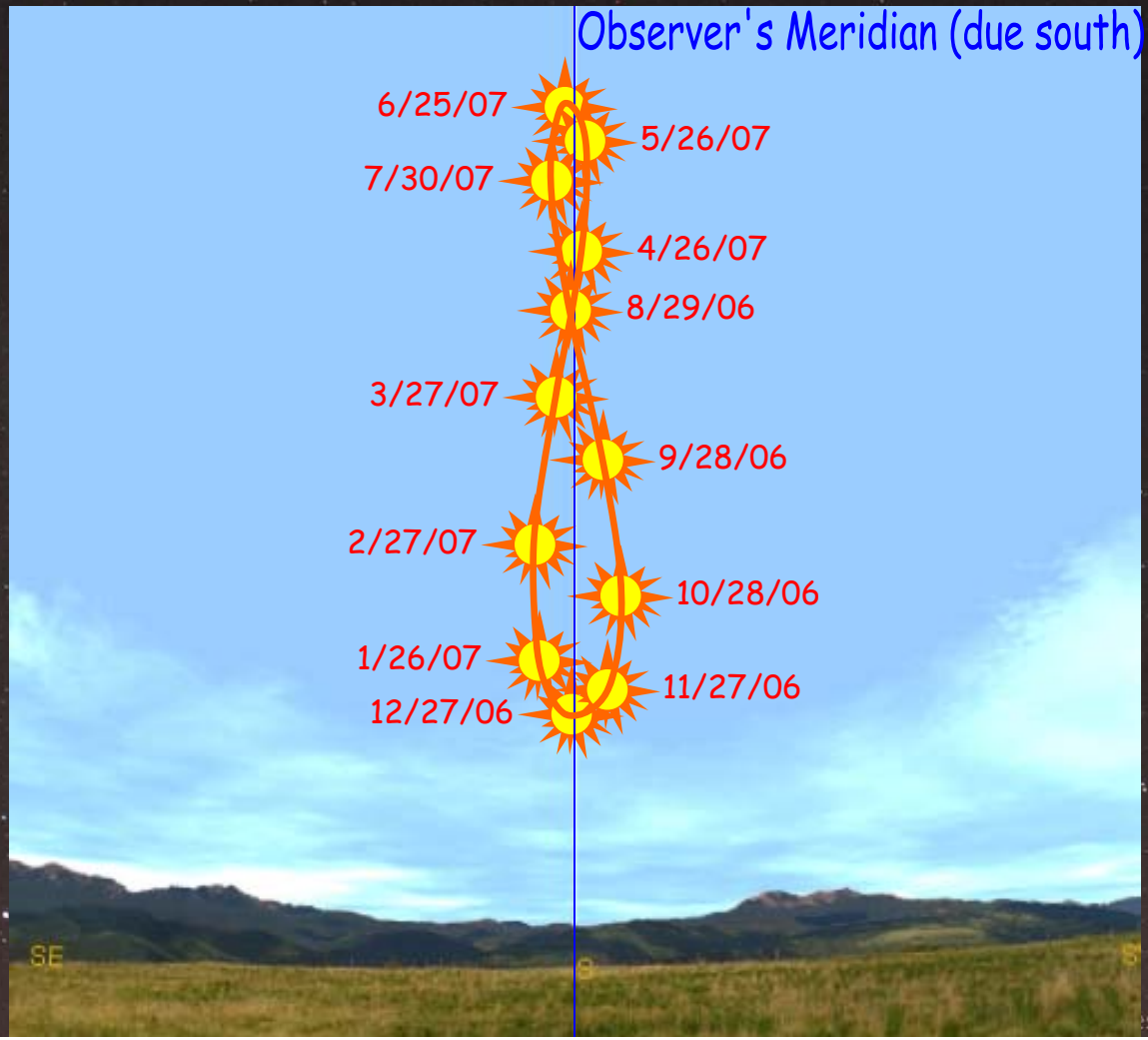
The Solar Day

Solar Day: 361° rotation puts sun back on meridian



The Sun at Noon

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



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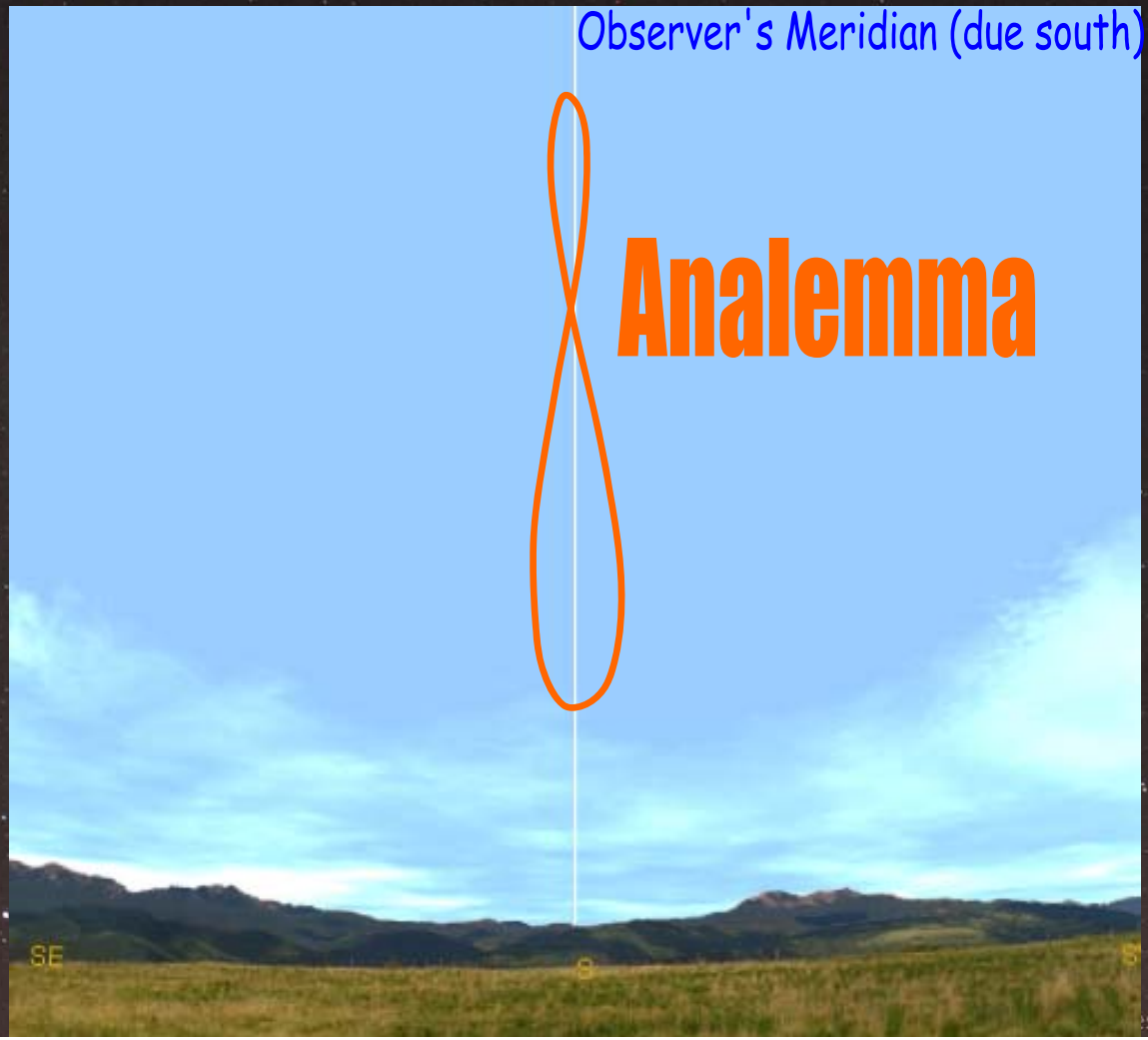


The Analemma

☆ 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

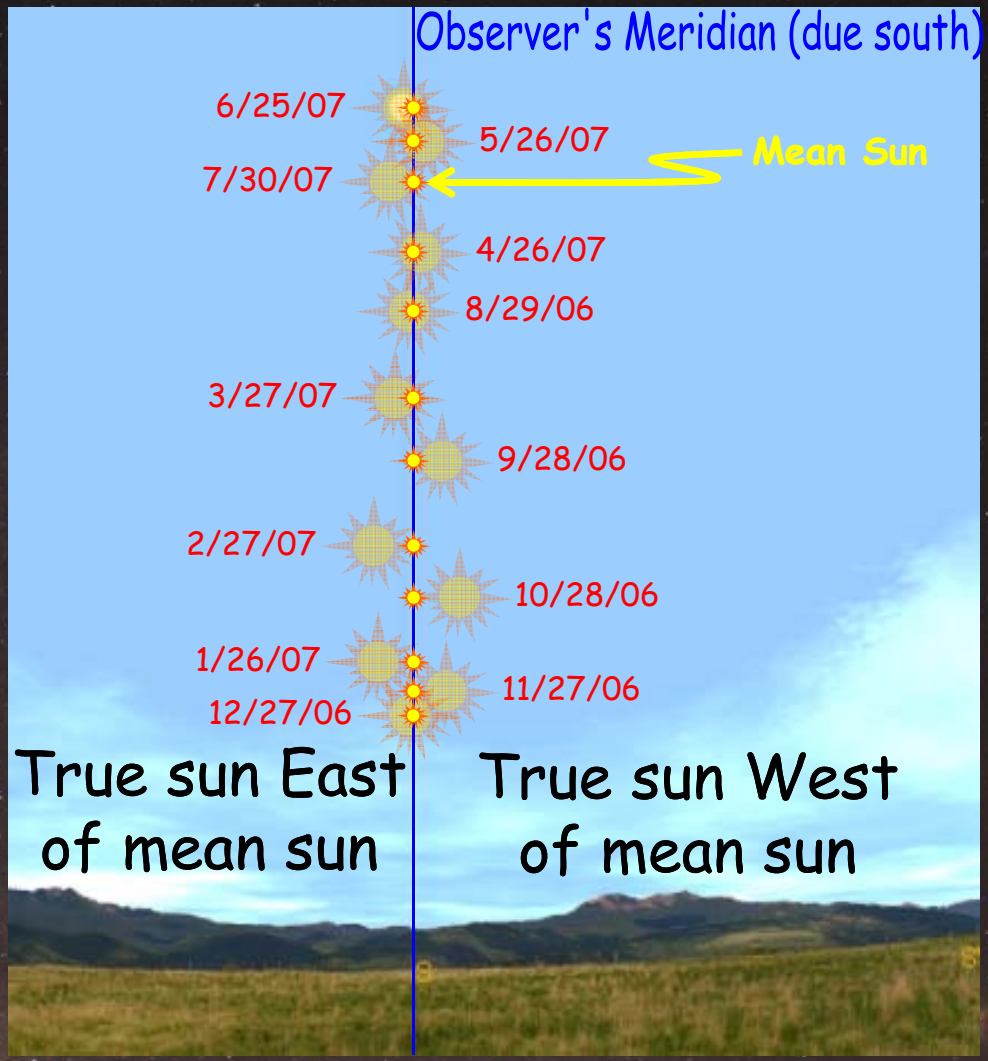
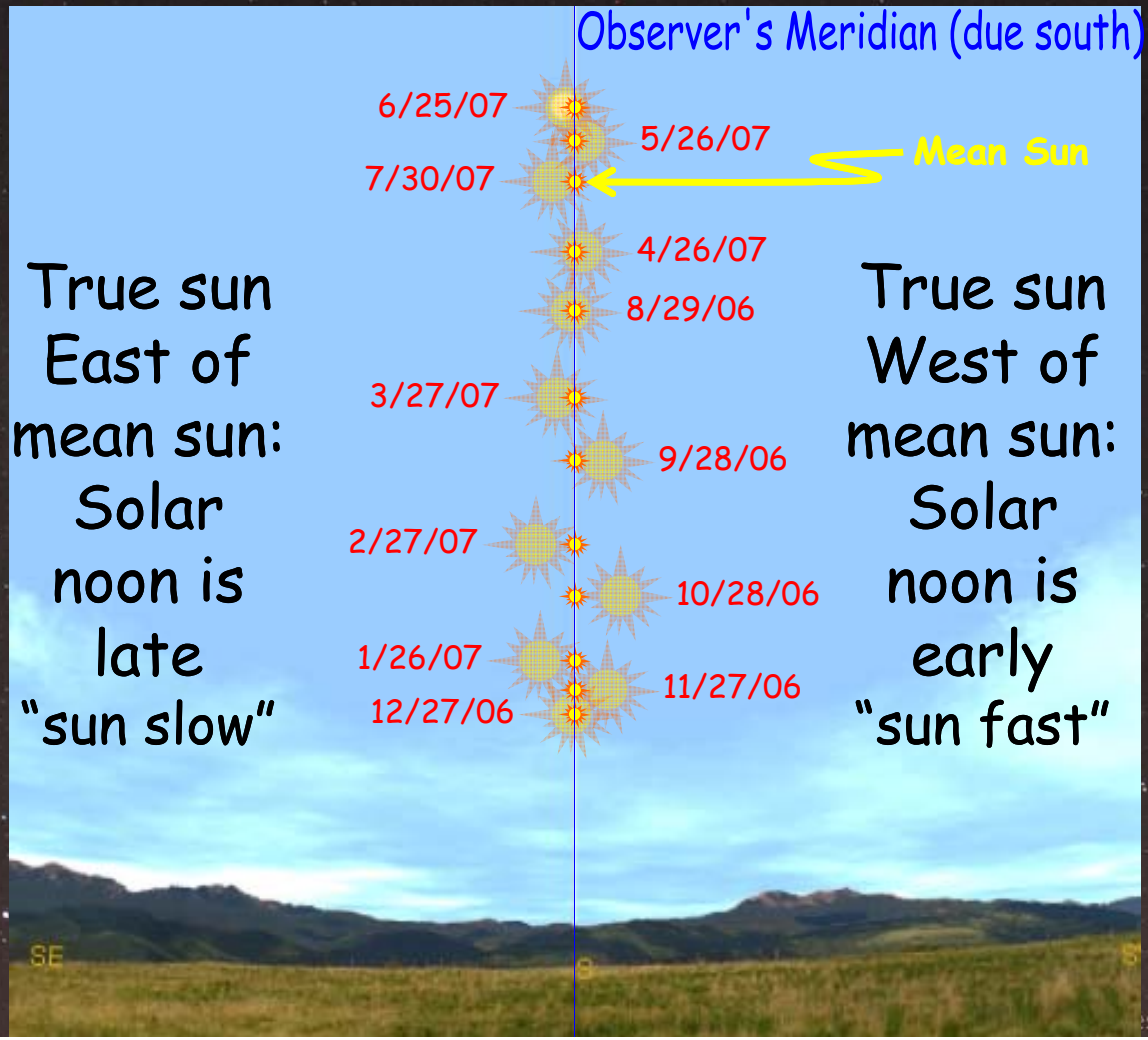


Photo by Marc Staves, Adirondack Public Observatory

Mean Sun & True Sun

- ☆ Mean sun on meridian defines clock noon
- ☆ True sun on meridian defines solar noon



Solar Noon Today (9/12/17)

- ☆ Potsdam (44° 40′ N, 75° 00 W)
  - Standard time of solar noon = 11:56:13 am
  - Daylight time of solar noon = 12:56:13
- ☆ Canton (44° 36′ N, 75° 10 W)
  - Standard time of solar noon = 11:56:53 am
  - Daylight time of solar noon = 12:56:53
  - 40 seconds later than Potsdam
    - ☽ Earth turns 1° in 4 minutes
      - ⇒ Earth turns 15′ in 1 minute
      - ⇒ Earth turns 10′ in 40 seconds!!
      - ⇒ Celestial events in Canton 40 seconds later than in Potsdam!!

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

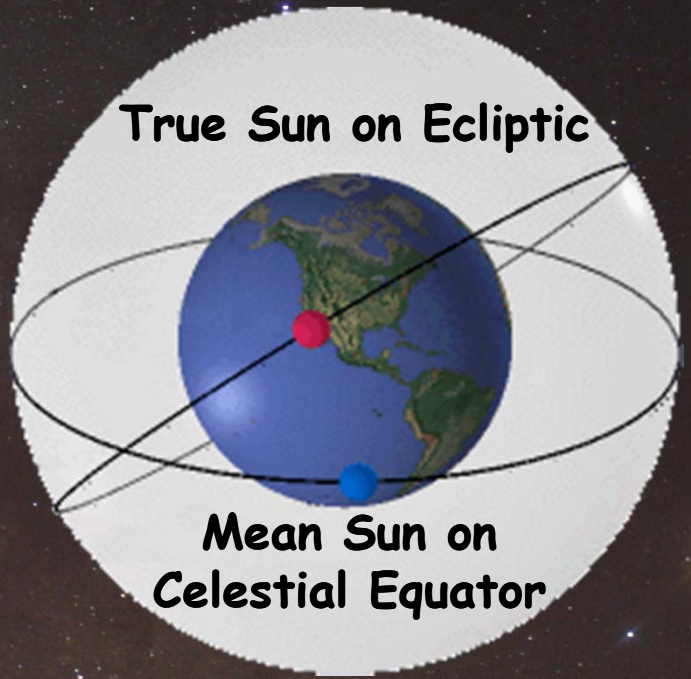


Photo by Marc Staves, Adirondack Public Observatory

Position of Sunrise & Sunset

- ☆ Azimuth of rising depends on δ

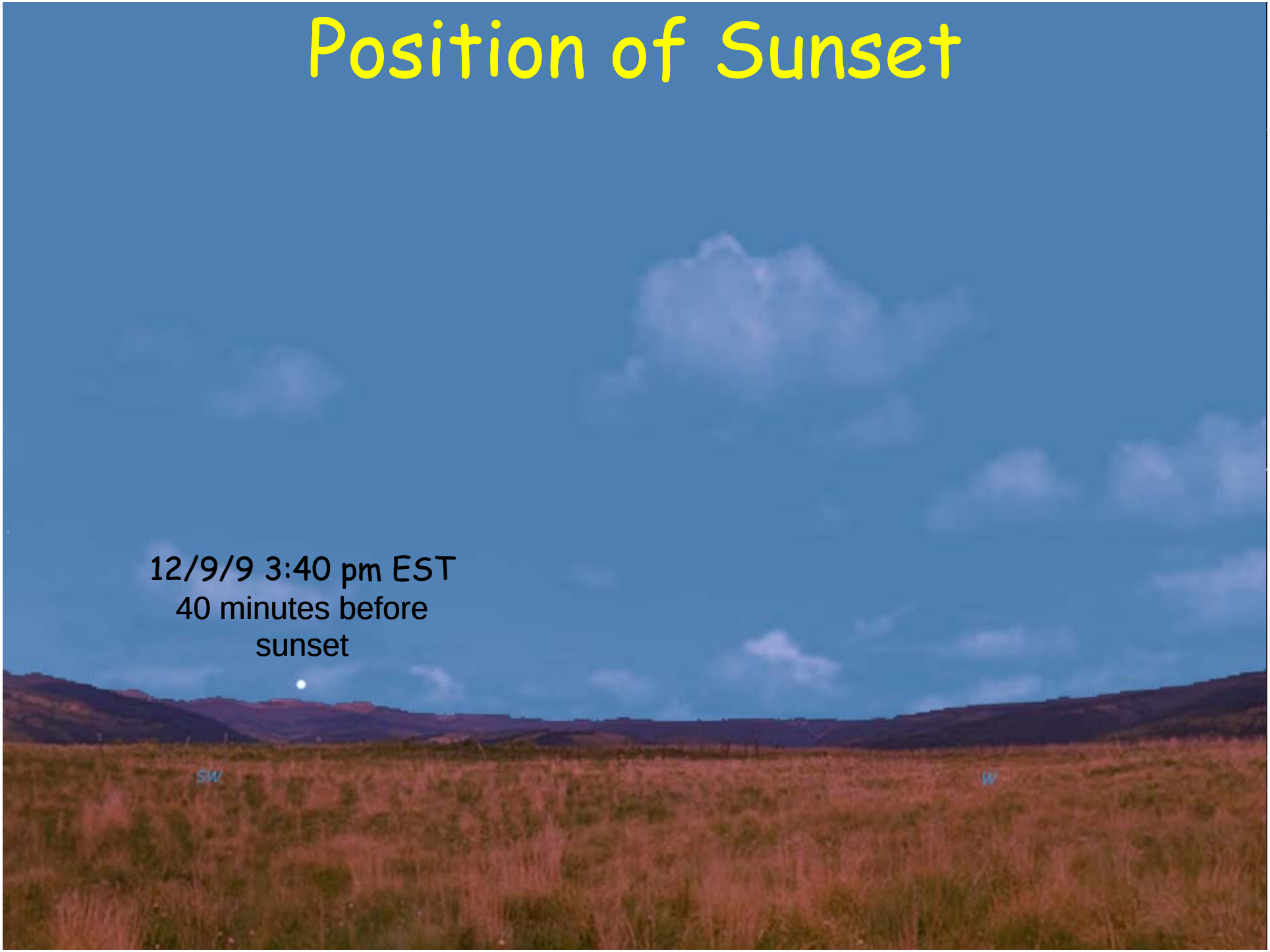
$$A_{rise} = \cos^{-1}\left(\frac{\sin\delta}{\cos\lambda}\right) \quad \text{degrees}$$

- ☆ Sunrise appears to move along horizon
  - 🌎 original calendar!

    eg. Stonehenge, Machu Pichu, Woodhenge (Illinois)

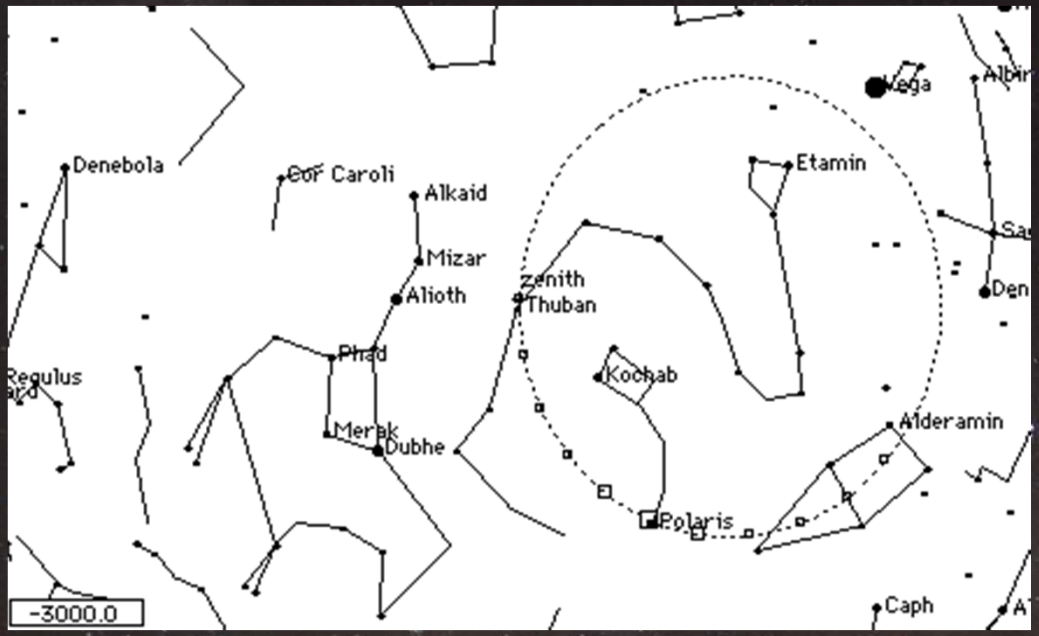
Photo by Marc Staves, Adirondack Public Observatory

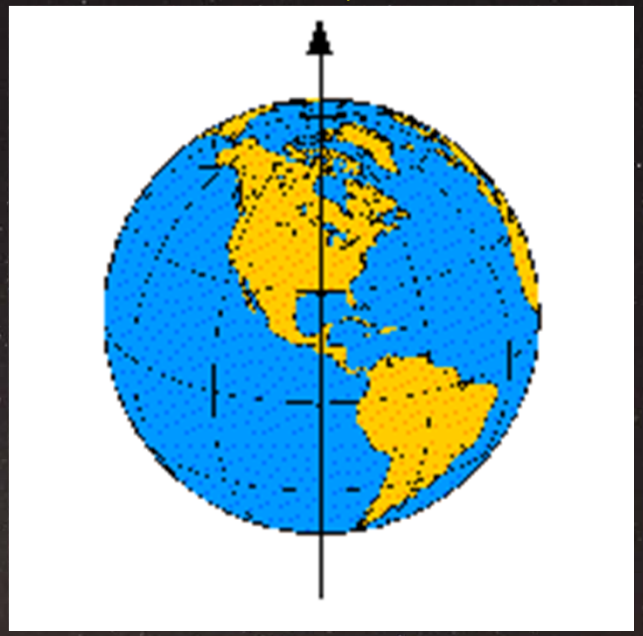
Position of Sunset



Precession

☆ Earth's axis wobbles over 26,000 years

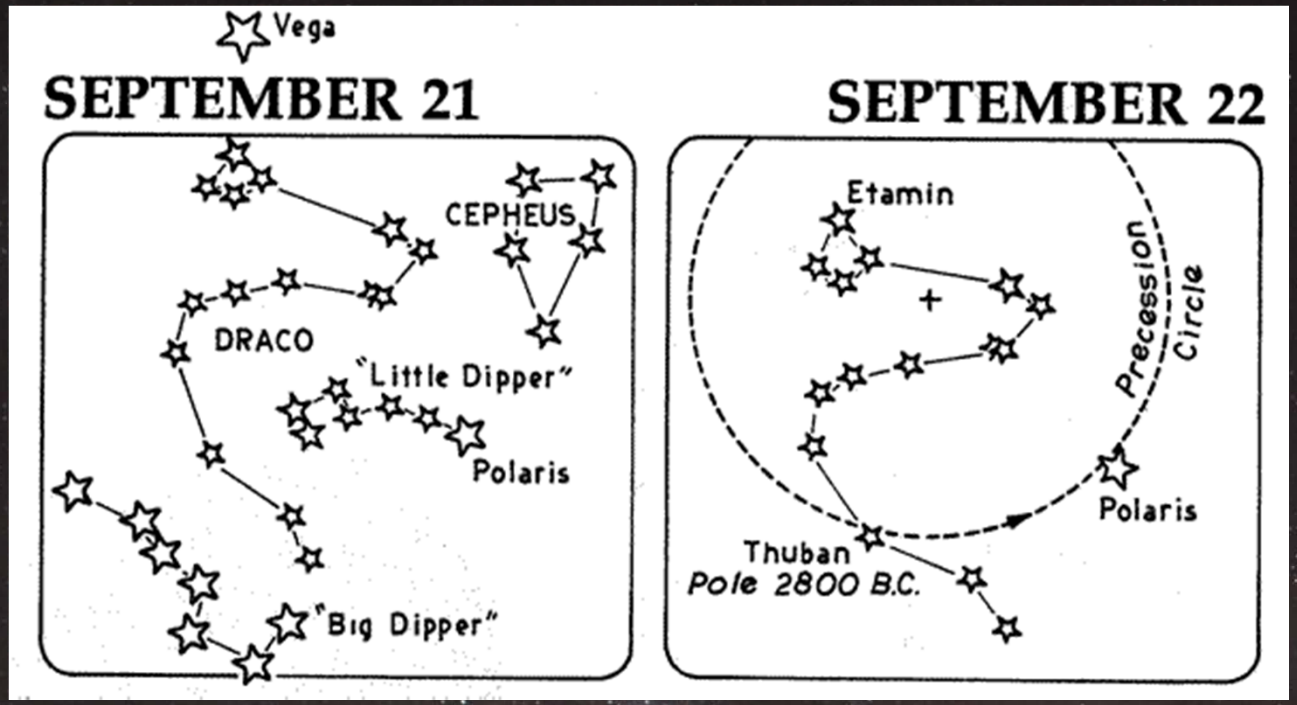




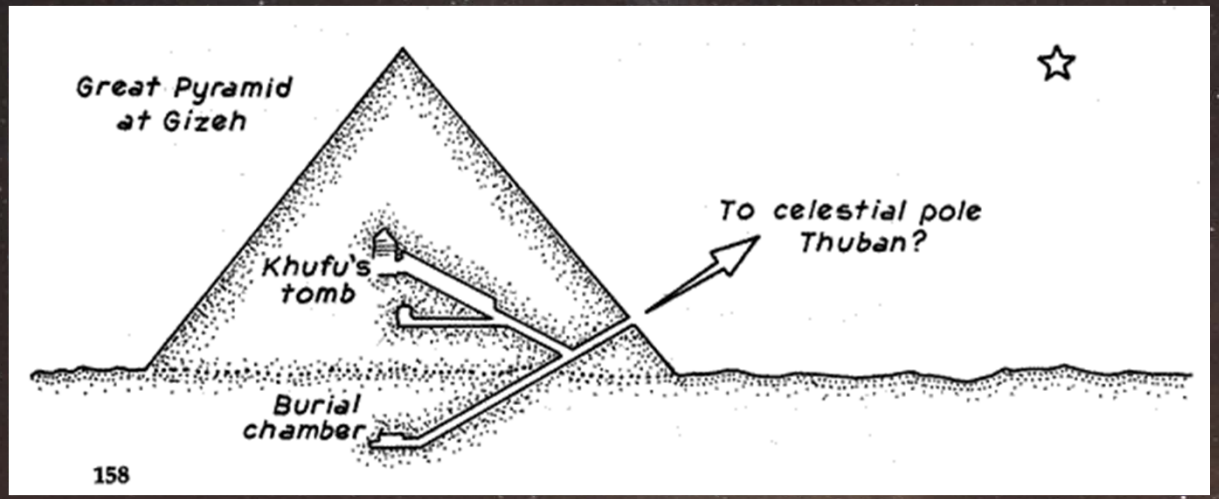
RA and Dec grid wobbles with pole, ecliptic does not wobble so solstices & equinoxes change position

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

Raymo's 365 Starry Nights



Precession Circle

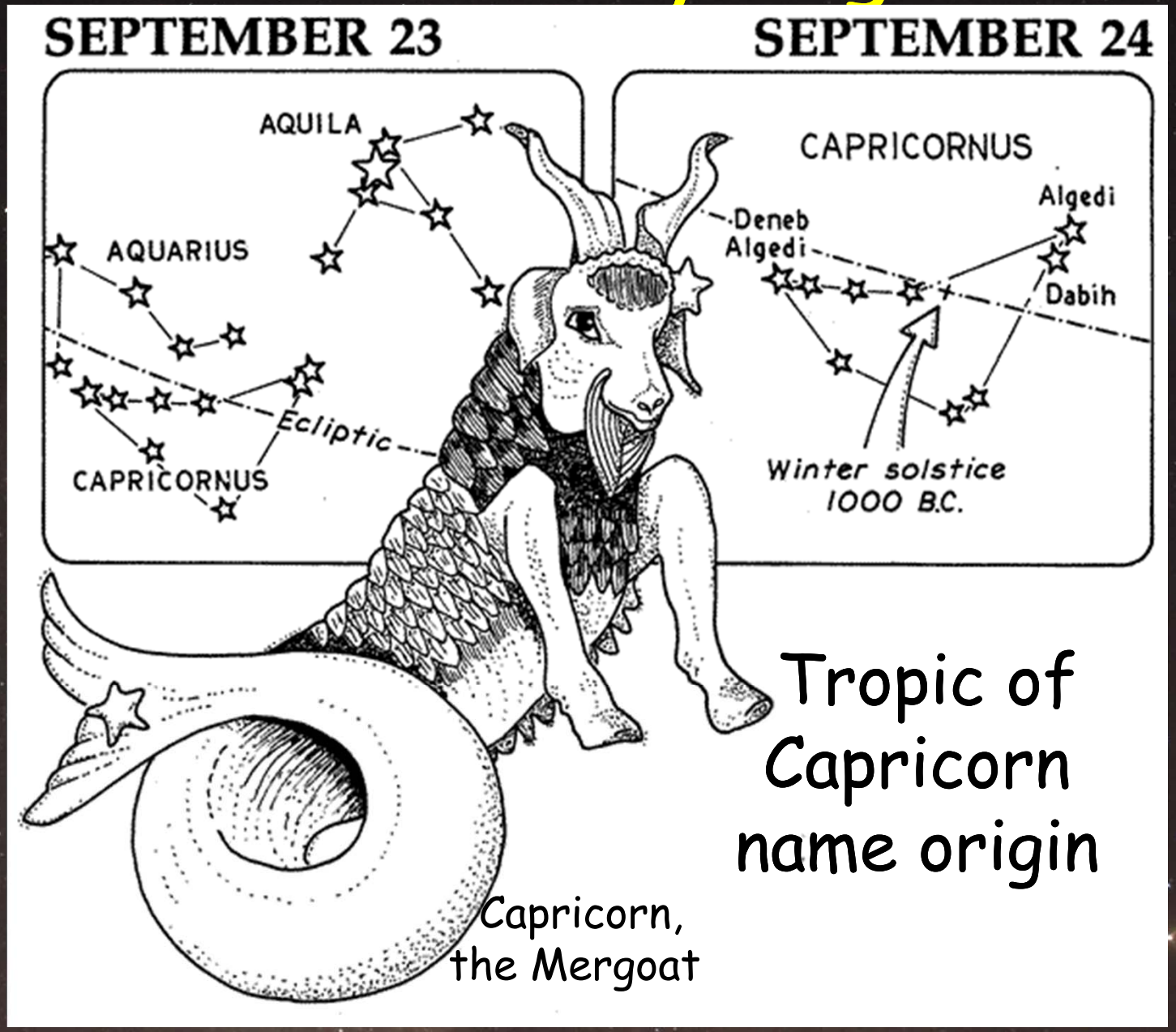


View from the Pyramids

Photo by Marc Staves, Adirondack Public Observatory

Raymo's 365 Starry Nights

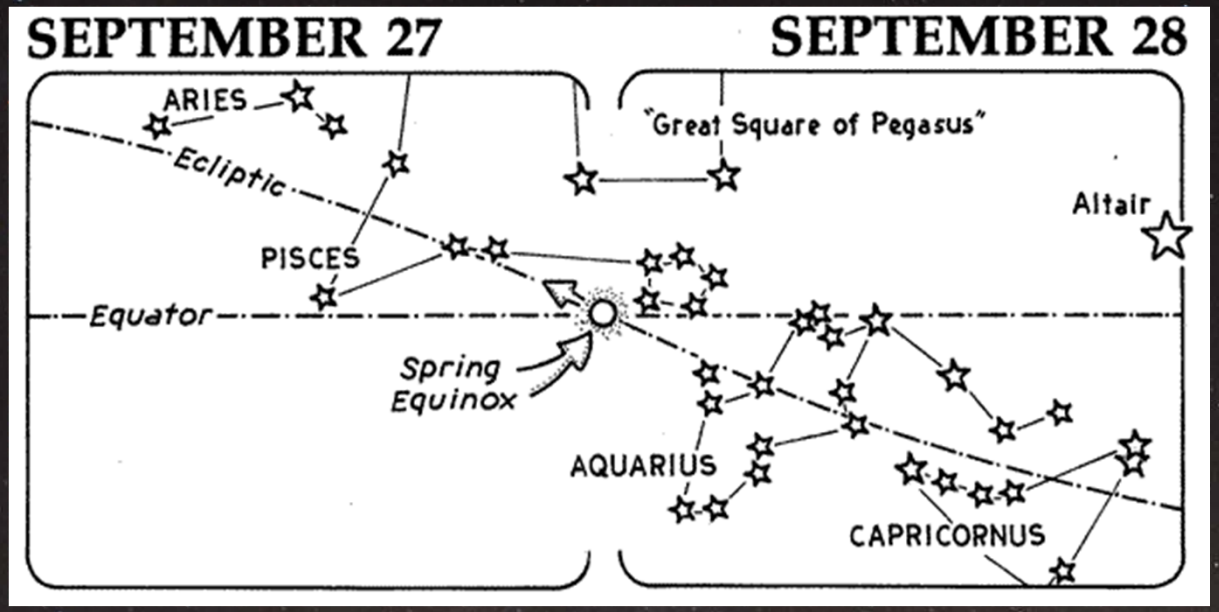
Position of the winter solstice in 1000 BCE



Tropic of Capricorn name origin

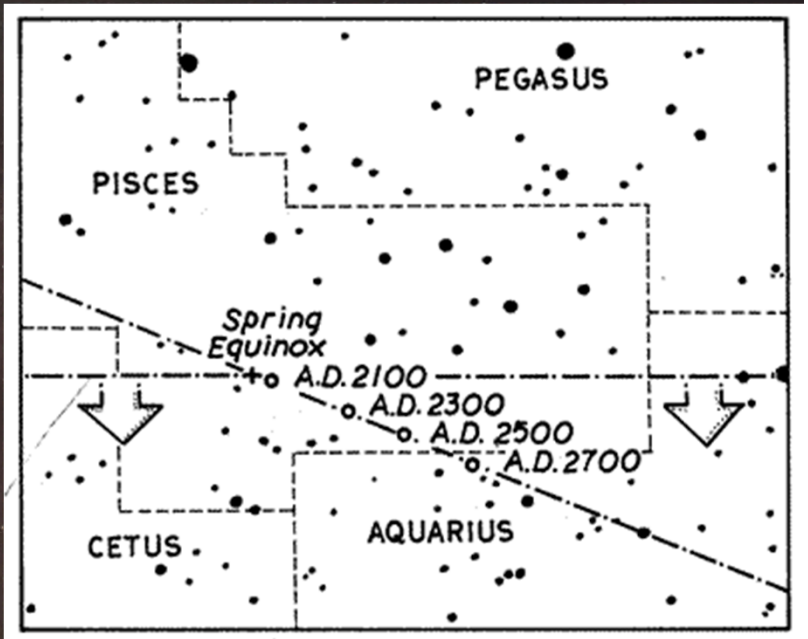
Photo by Marc Staves, Adirondack Public Observatory

Raymo's 365 Starry Nights

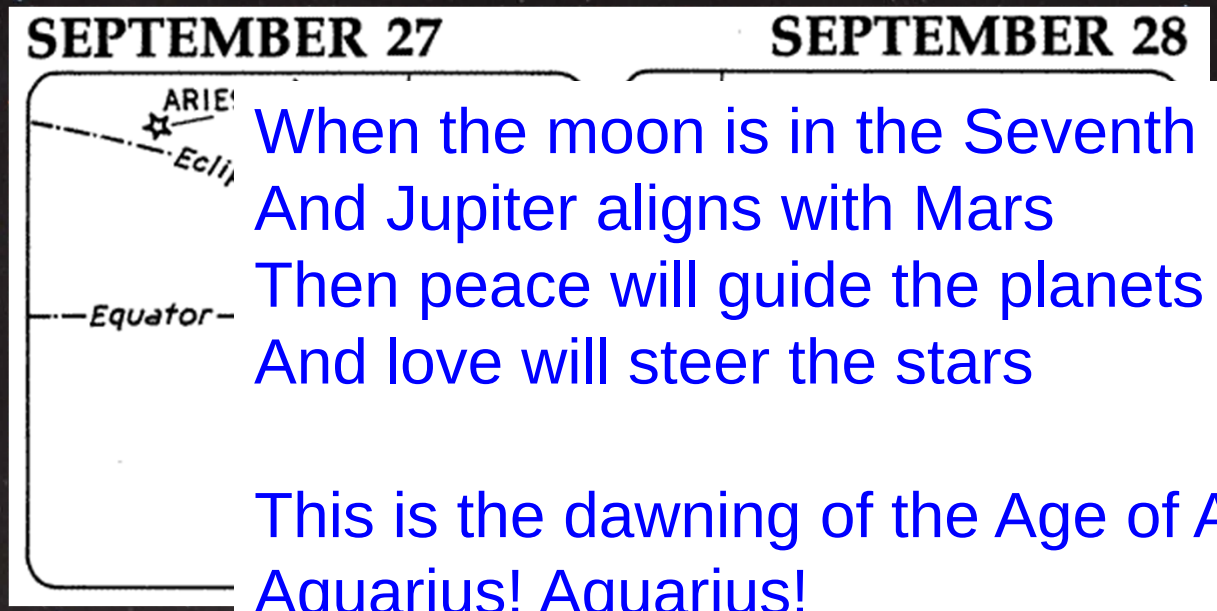


Position of the Vernal Equinox now

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!