Potsdam
THE STATE UNIVERSITY OF NEW YORK
1816

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

The Day in all its Glory:
The Analemma

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Kiva

December 1997 – October 27, 2009

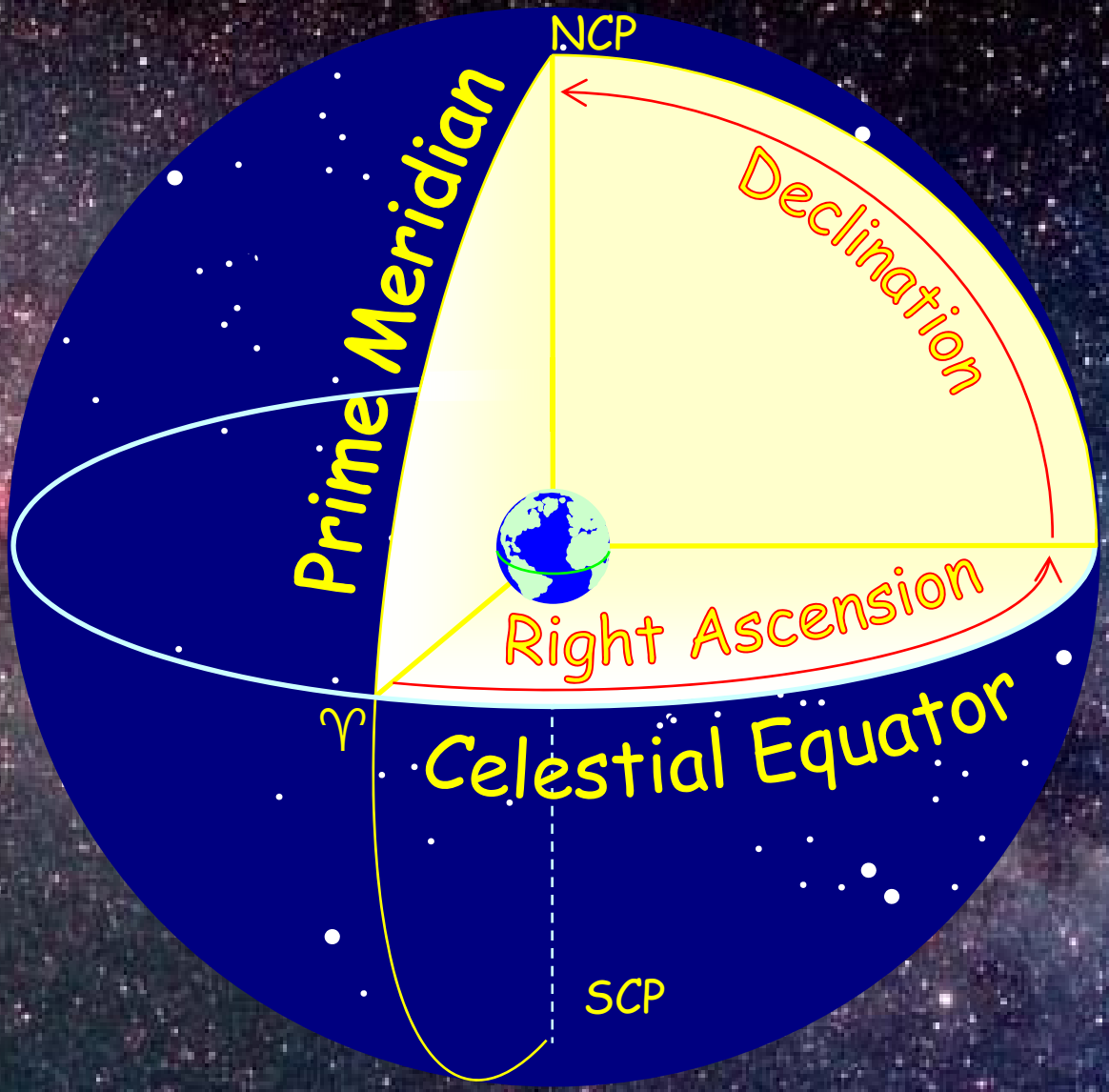
Celestial Coordinates

☆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°

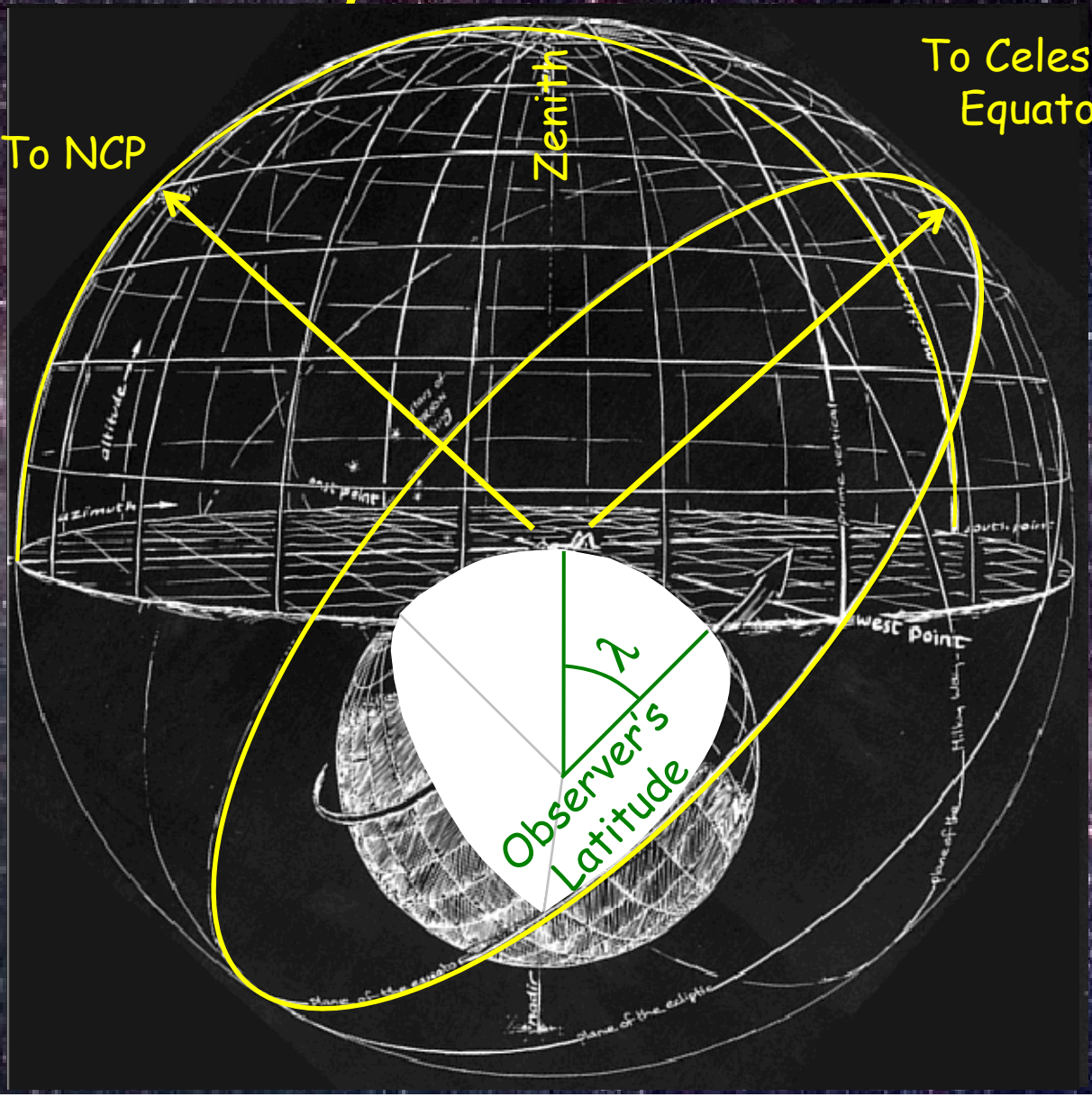


Tilted Sky

☆ Observers see sky "tilted" due to latitude

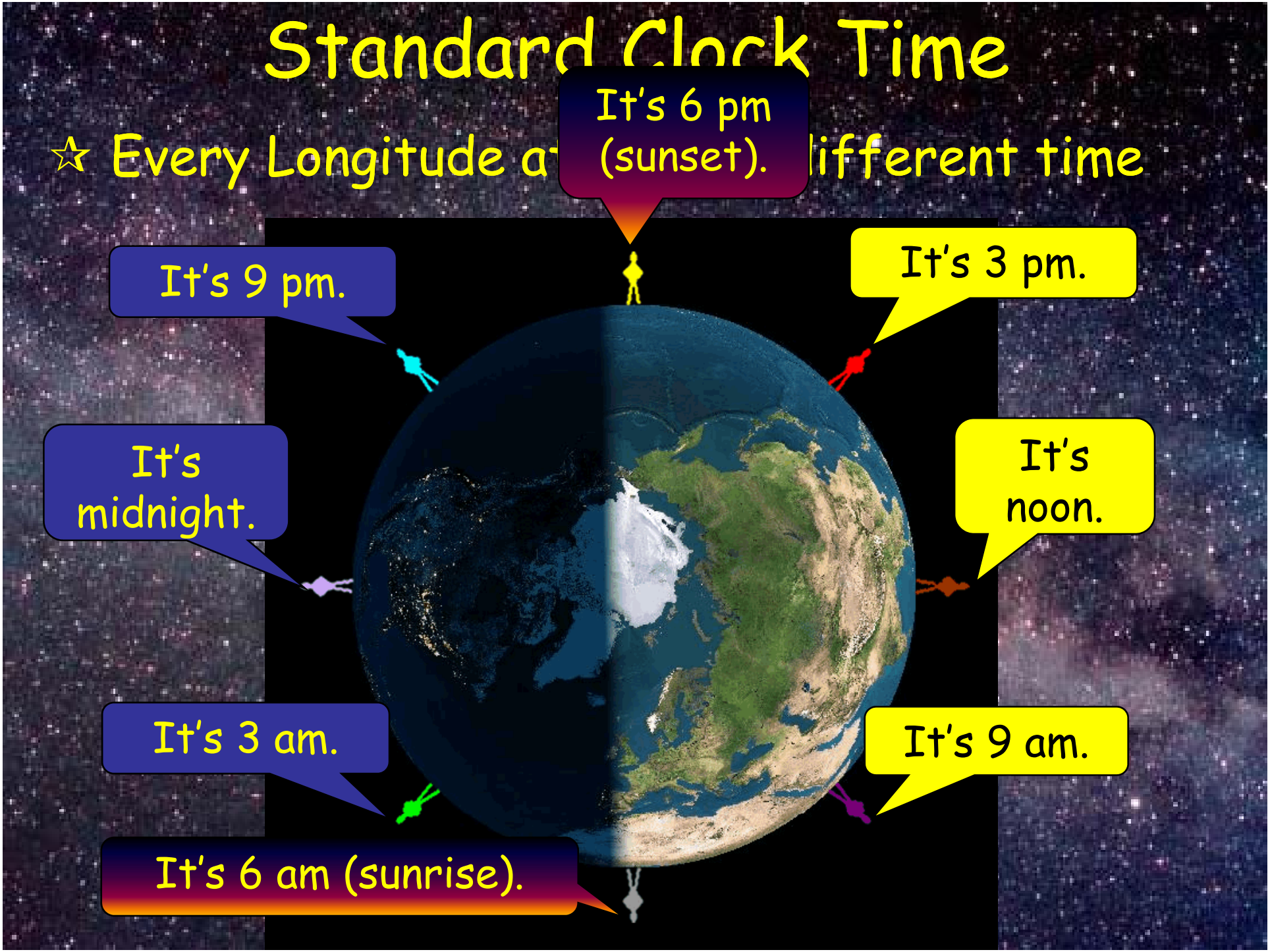
We see ourselves "on top" of the Earth, beneath the sky.

So we see sky motions tilted



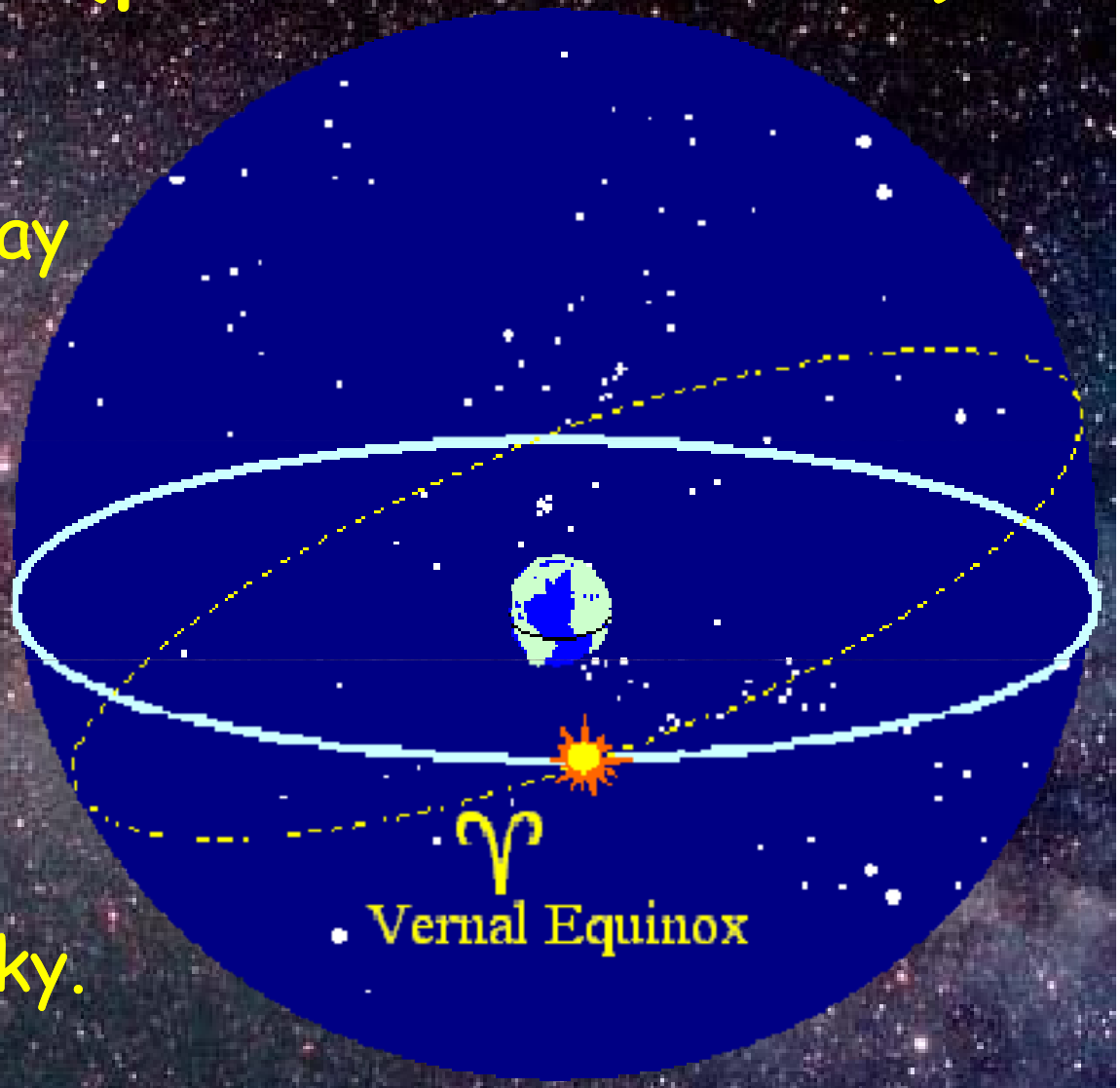
Standard Clock Time

☆ Every Longitude a[t] [a] different time

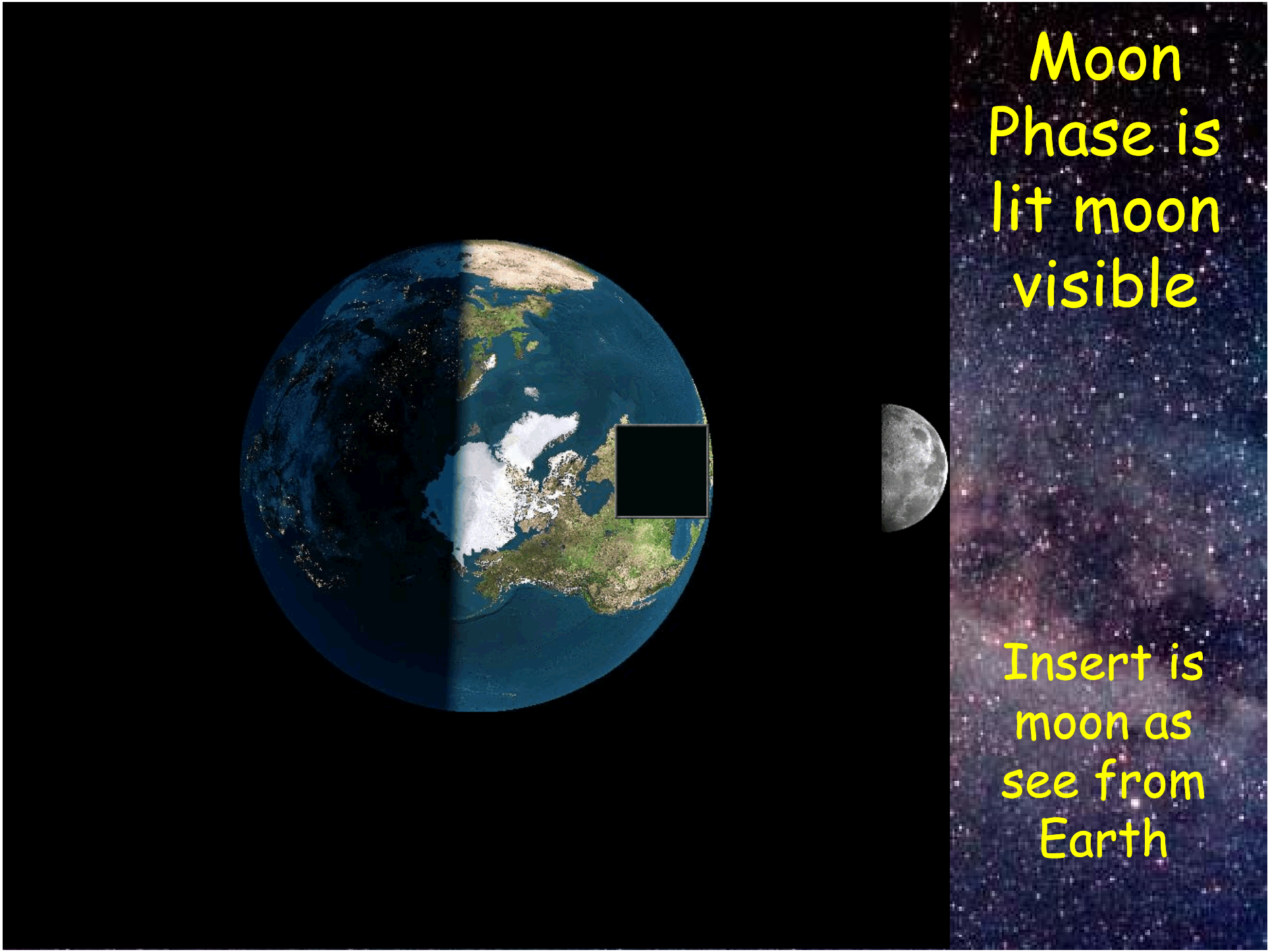


The Ecliptic (path of the sun)

- 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!

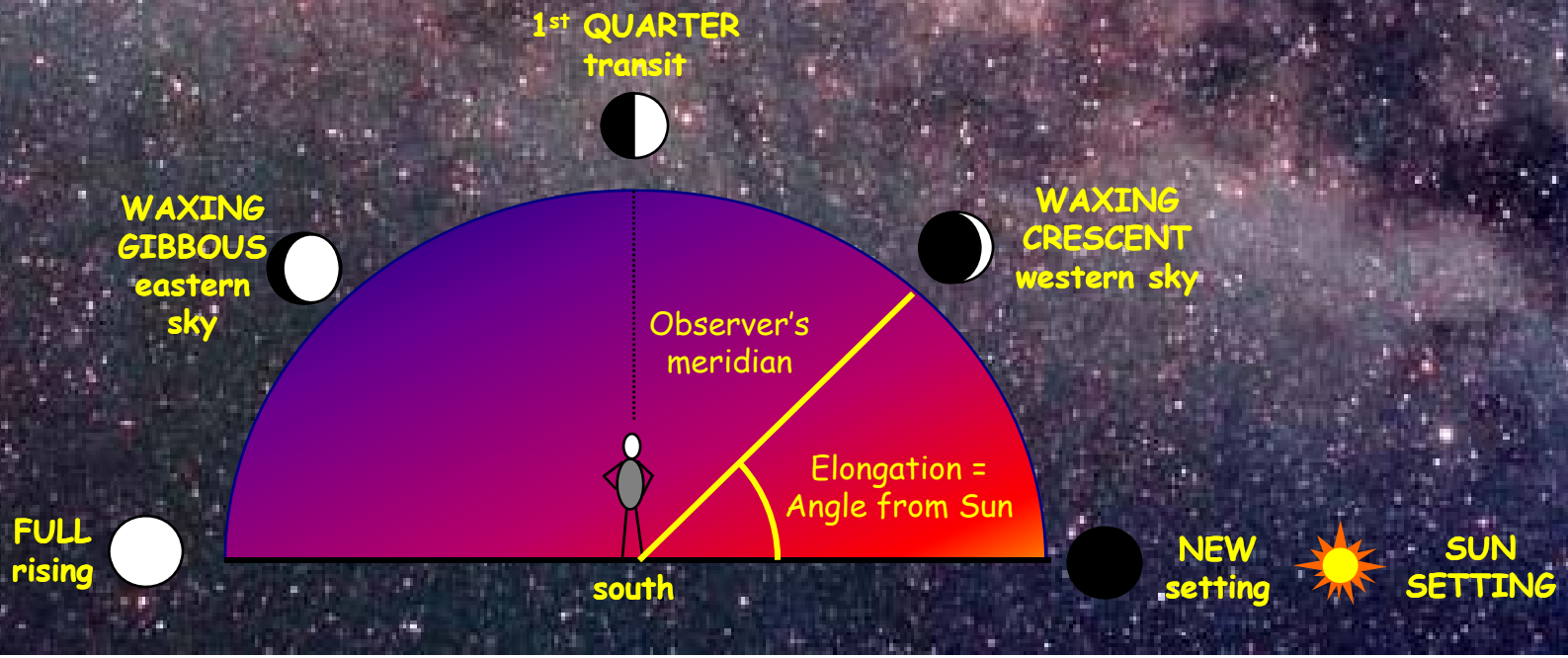

Moon Phase is lit moon visible
Insert is moon as see from Earth

Moon Phases

☆New Moon: Elongation = 0° (angle from sun to moon)

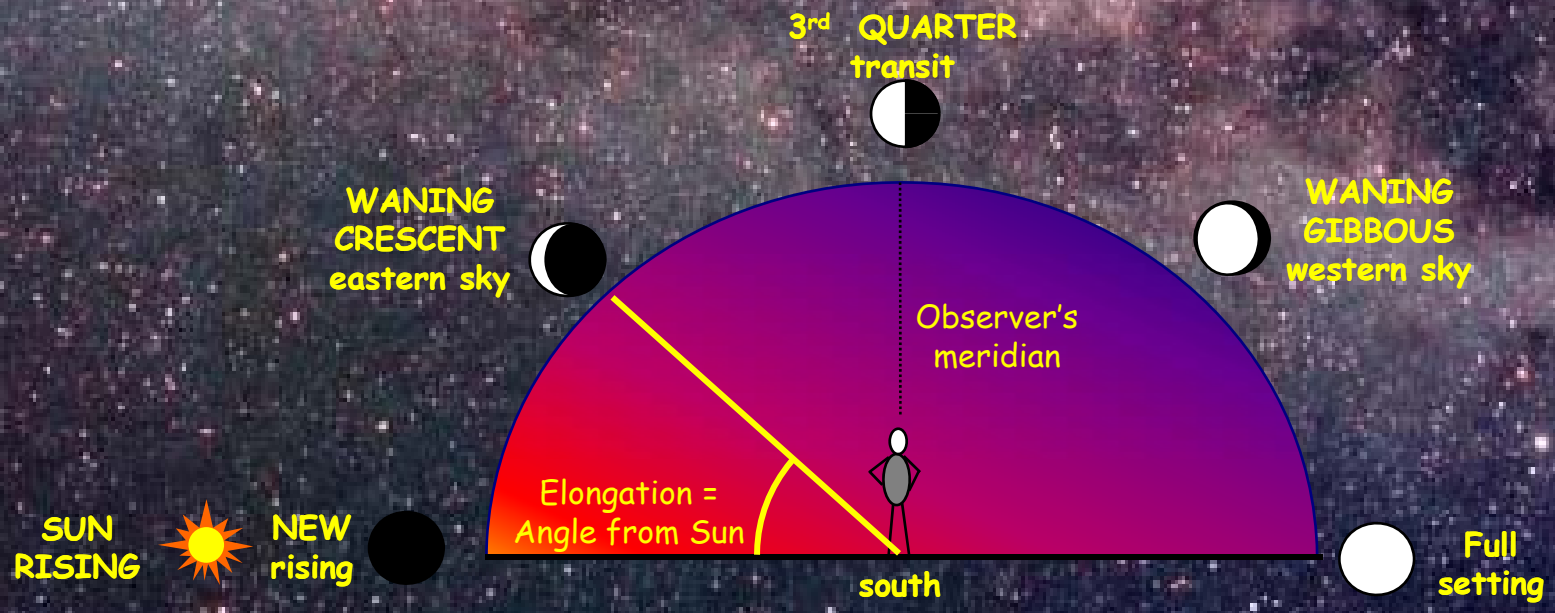
- Waxing Phases: visible after sunset
  - ☽ Waxing Crescent: 0° < Elongation < 90° E
  - ☽ First Quarter: Elongation = 90° E
  - ☽ Waxing Gibbous: 90° E < Elongation < 180°

☆ Full Moon: Elongation = 180°



Moon Phases

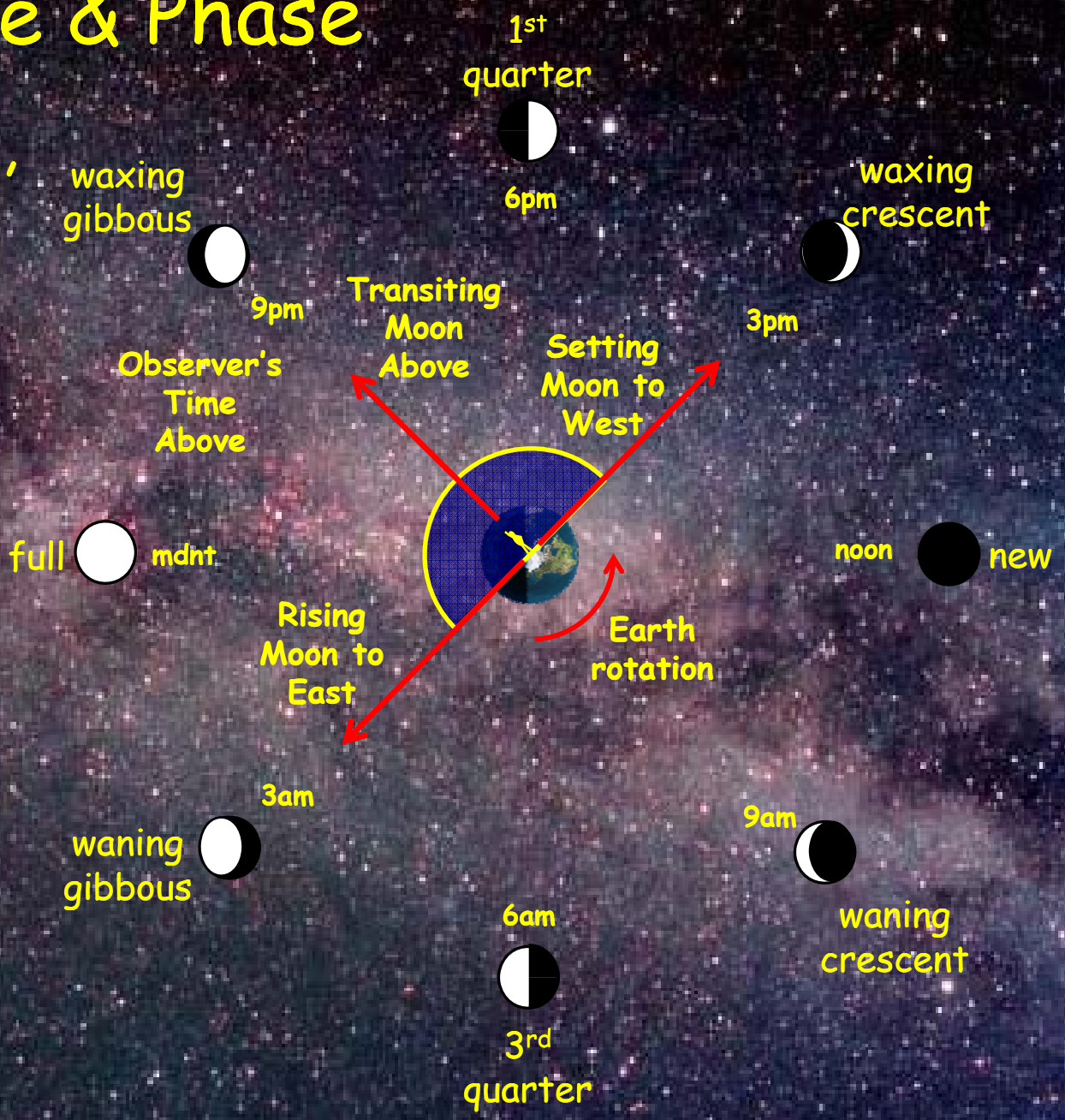
- ☆ Full Moon: Elongation = 180°
  - Waning Phases: visible before sunrise
    - ☽ Waning Gibbous: 90° W < Elongation < 180°
    - ☽ Third Quarter: Elongation = 90° W
    - ☽ Waning Crescent: 0° < Elongation < 90° W
- ☆ New Moon: Elongation = 0°



Fun with Time & Phase

Determine rising, transit and setting times of each phase

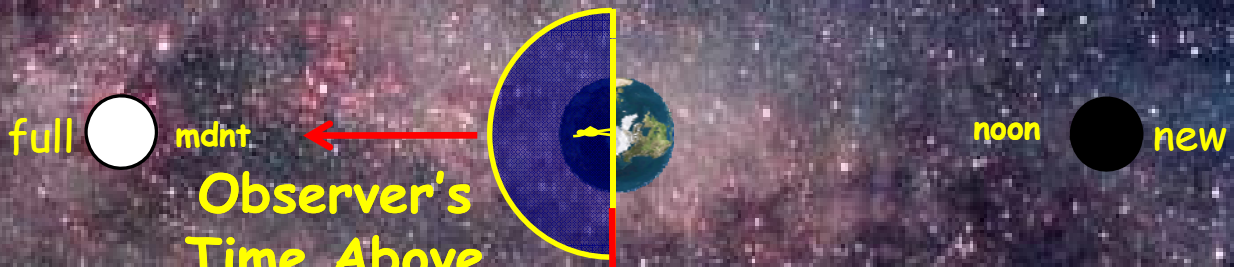
Time is the one above the observer's head!



Question

An observer sees the moon rise at midnight. What phase is it?

a) First Quarter
b) Full Moon
c) 3rd Quarter



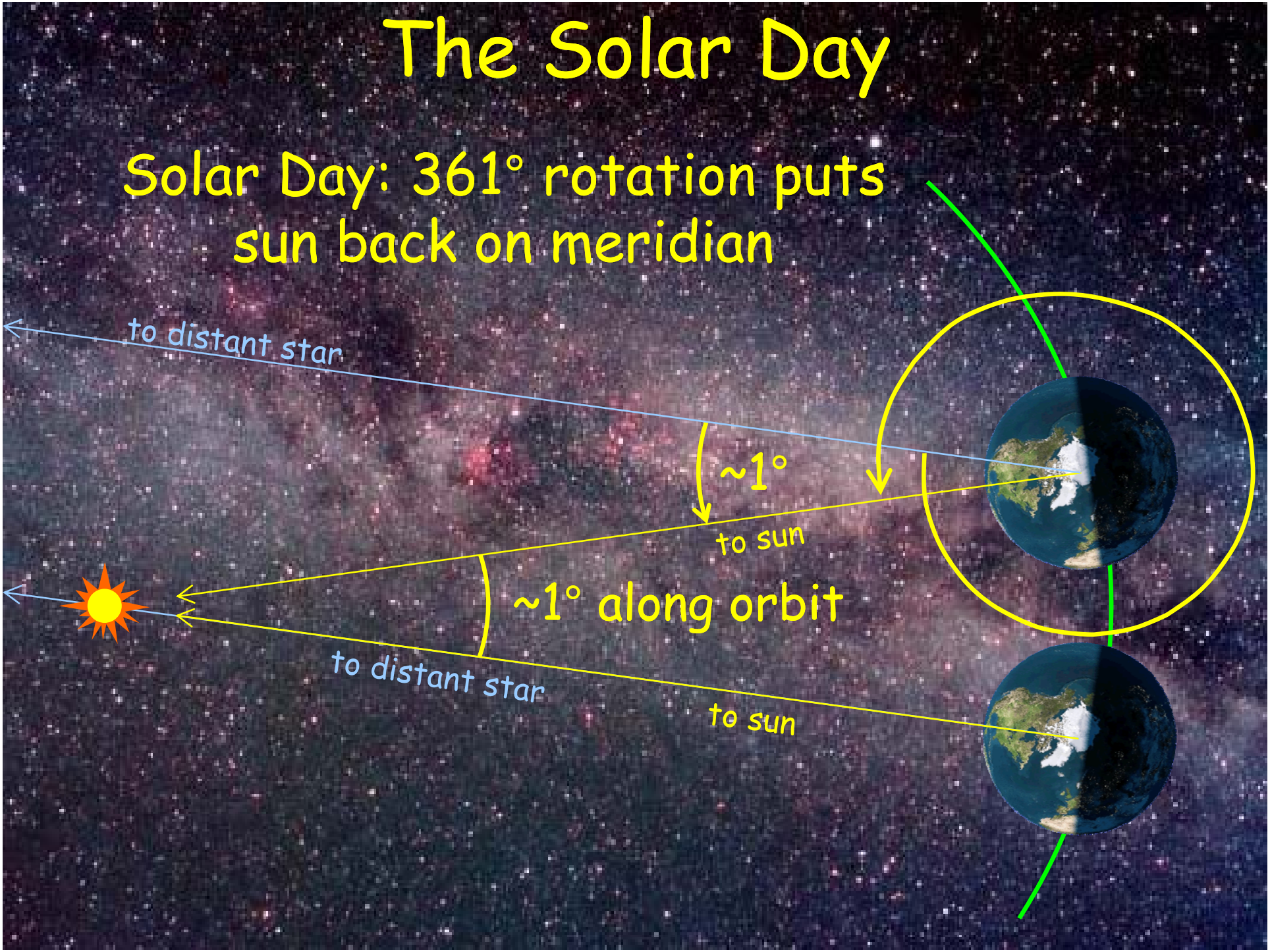
Time

- ☆ 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 Sidereal Day

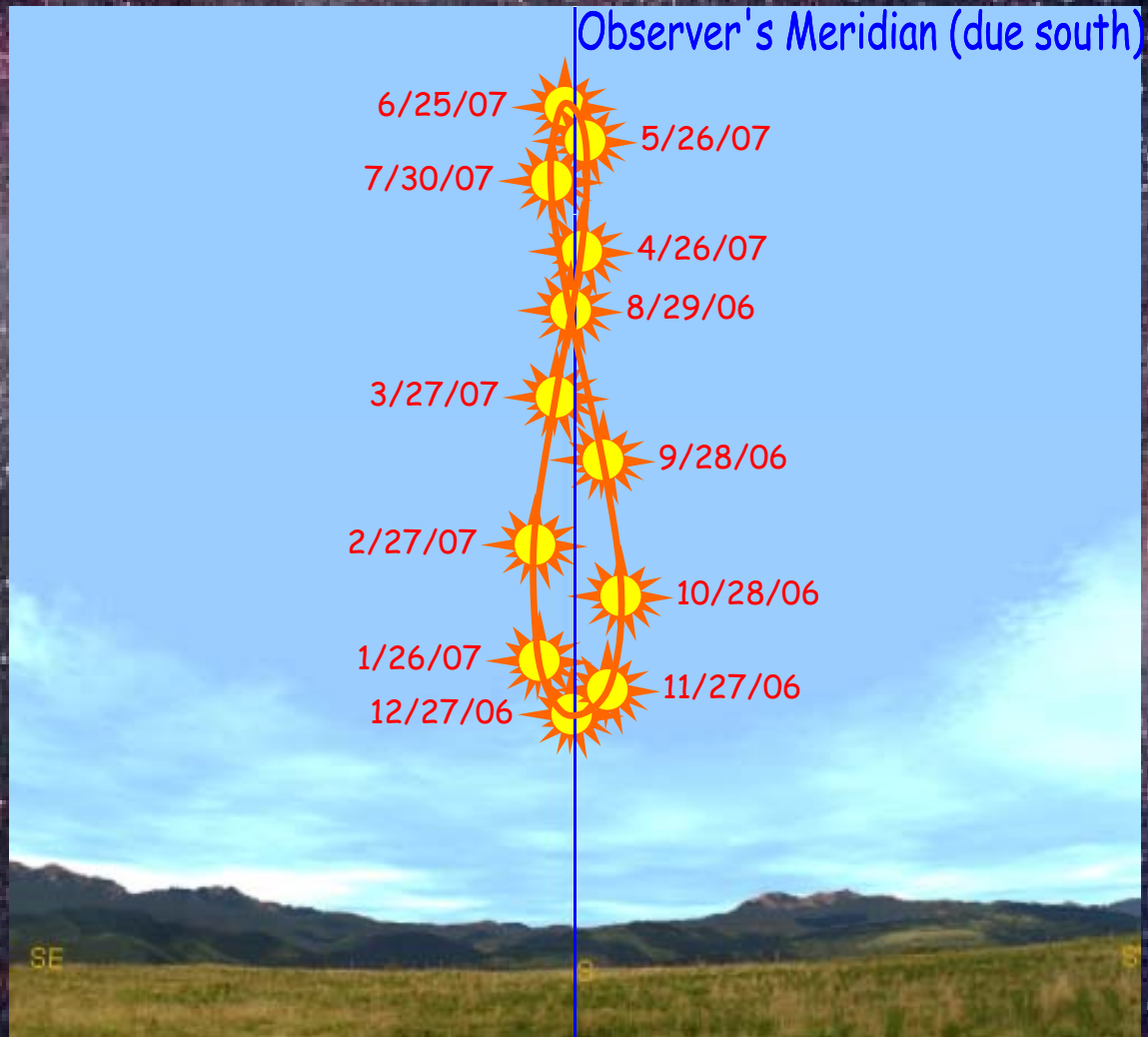
Sidereal Day: 360° rotation puts star back on meridian

The Solar Day



The Sun at Noon

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



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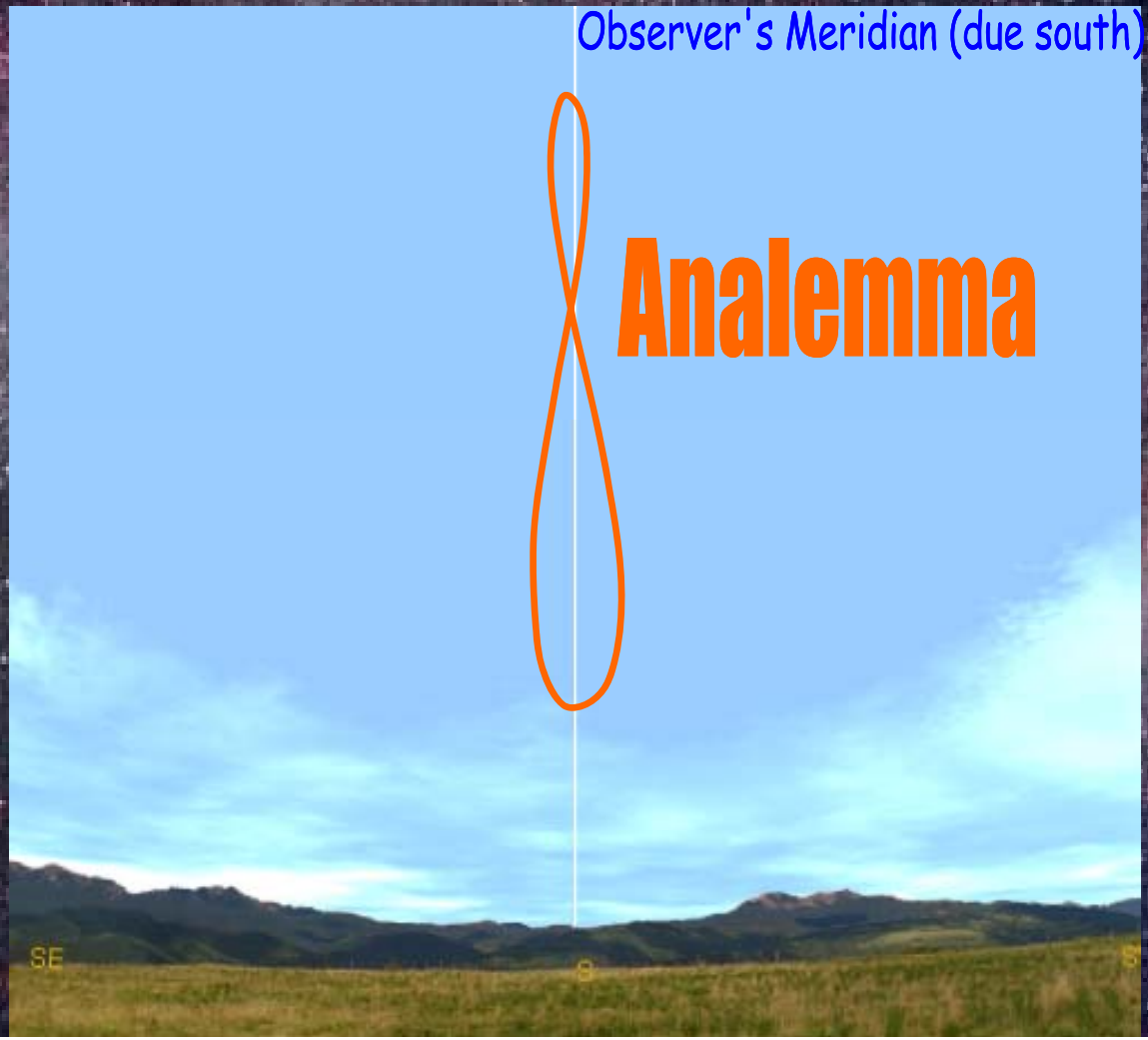
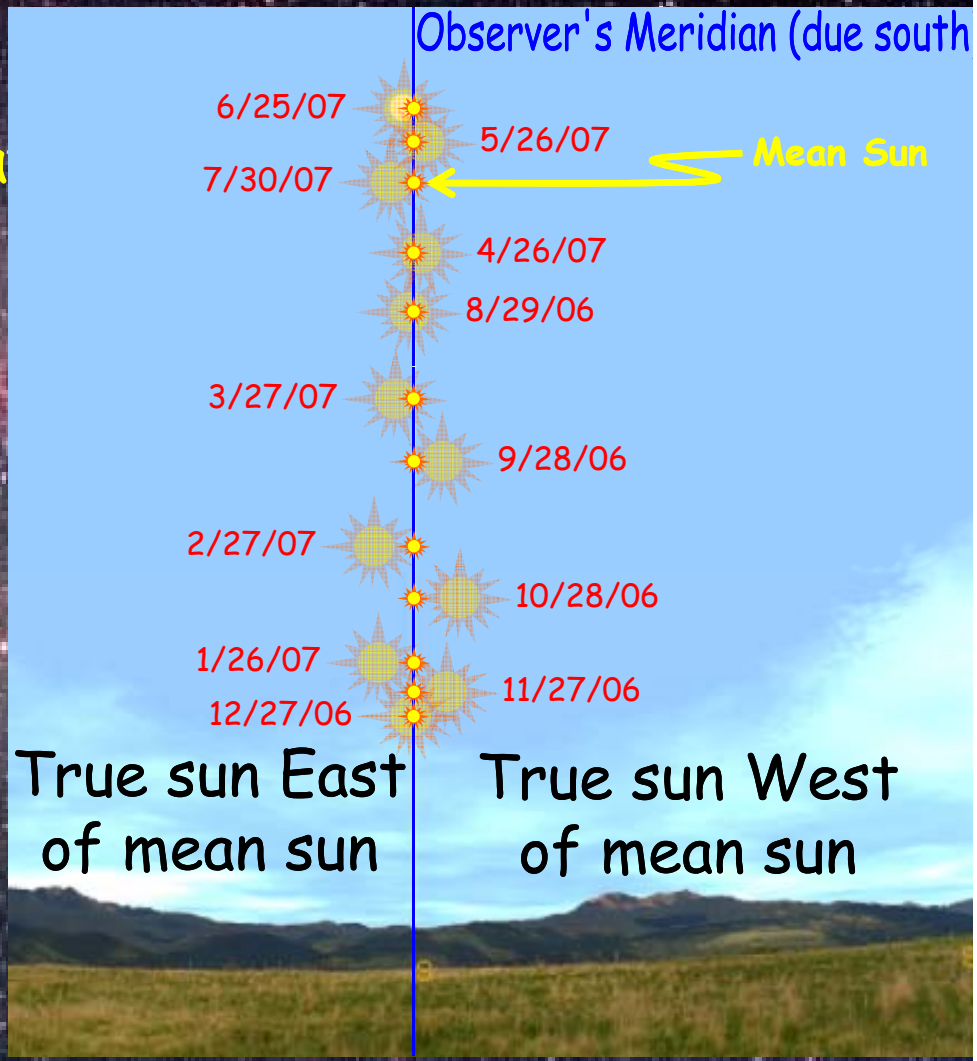


The Analemma

☆ Position of true sun at clock noon

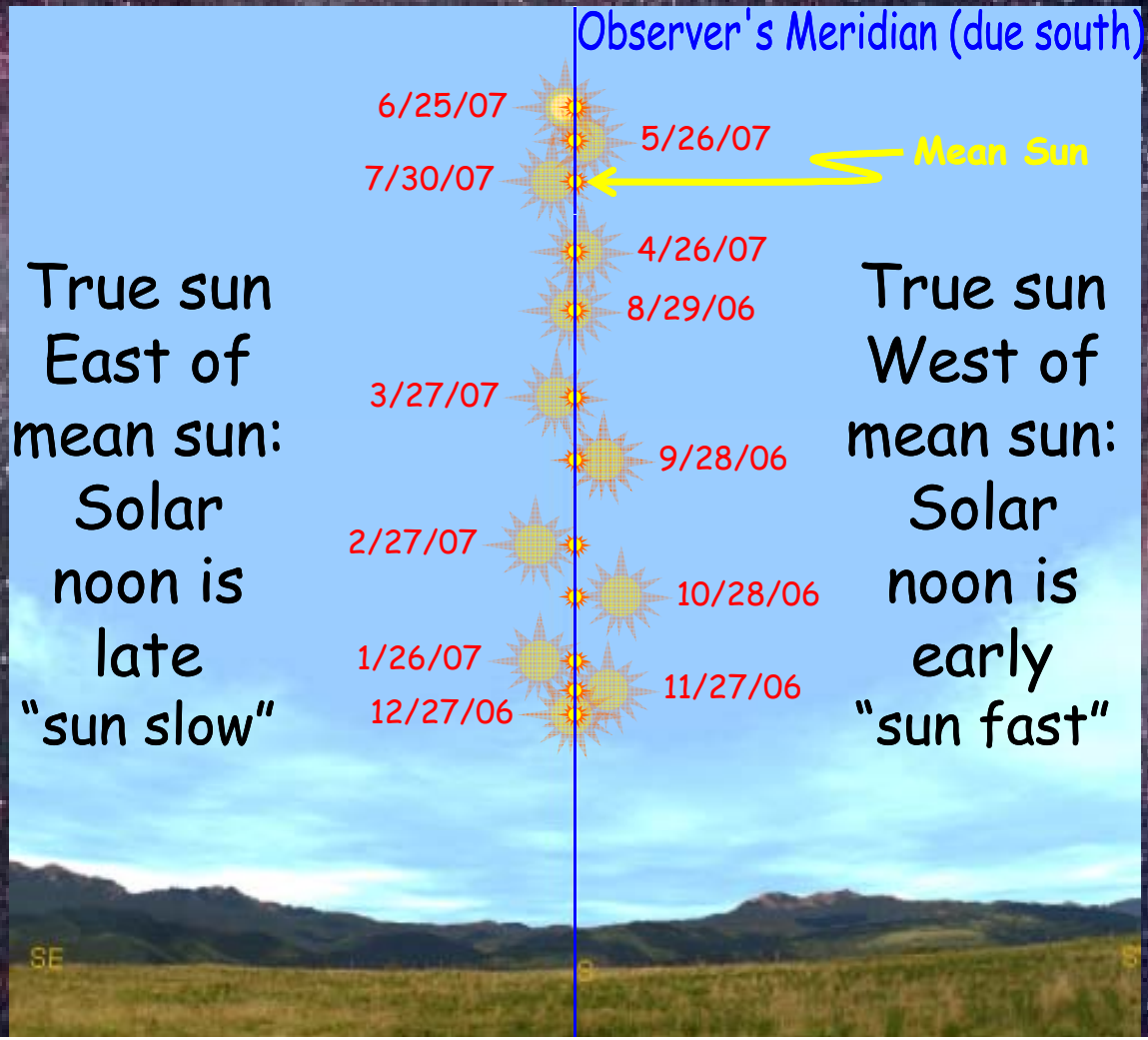
- Clock Noon
  - 12:00 pm in a 24:00:00 da
  - Position of Mean Sun at noon
- True Sun's Position
  - varies due to Sun's speed along path
    - ♈ varies due to elliptical path
    - ♈ varies due to tilted path



Mean Sun & True Sun

☆ Mean sun on meridian defines clock noon

☆ True sun on meridian defines solar noon



The Calendar

☆ The Year

- Tropical (equinox to equinox) = 365.242190 d
- Sidereal (star to star) = 365.256363 d
- Anomalistic (perigee to perigee) = 365.259635 d
- Lunar (node to node) = 346.620076 d

☆ Julian Calendar (45 BCE) = 365.25 d

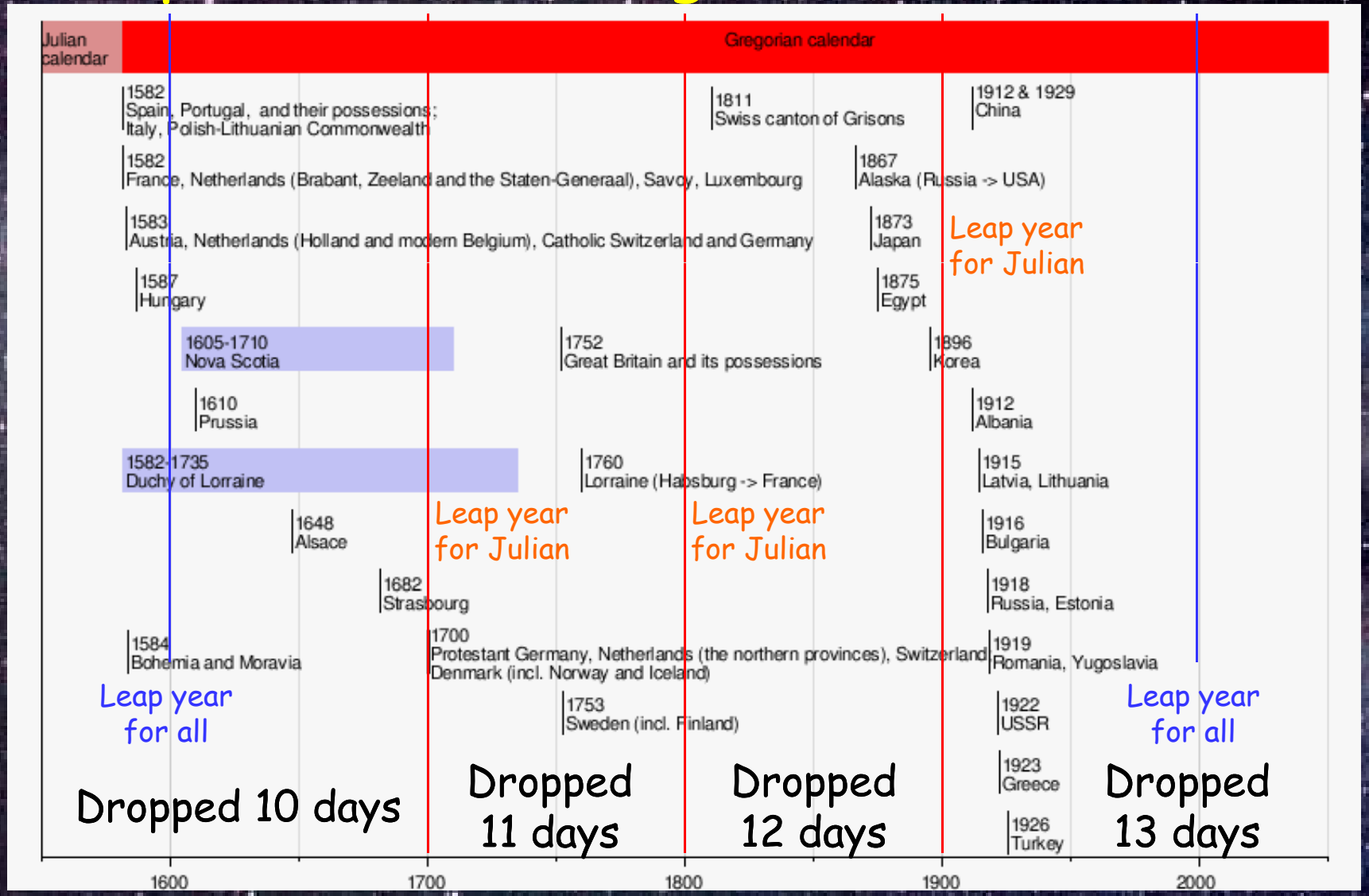
- Add 1 day every four years
  - 365.25 - 365.24219 = 0.00781 days/year too many
    - ⇒ Extra day every 128 years

The Calendar

- ☆ Gregorian Calendar (1582) = 365.2425 d
  - 🌎 Council of Trent: want ♈ on March 21
    - ☽ as it was during Council of Nicaea in 325 CE
    - ☽ Easter is 1st Sunday after 15th day of moon after ♈
      - ♈ Moon phases tabulated, not observed!
  - 🌎 325 to 1582 (1257 years), 9.8 days ahead
    - ☽ Drop 10 days: 10/15/1582 followed 10/4/1582
      - ♈ American Colonies 9/14/1752 followed 9/2/1752
        - ♍ George Washington born 2/22/1732, 2/11/1732 OS
        - http://en.wikipedia.org/wiki/Old_Style_and_New_Style_dates
  - 🌎 Century years divisible by 400 have leap days
    - ☽ 1600, 2000 had leap days, 1700, 1800, 1900 did not

Doing the Math

☆Adoption of the Gregorian Calendar



Doing the Math

☆Old Style & New Style dates

Marriage certificate from Warsaw (then in Russia)


ГОРОДЪ ВАРШАВА. № 160 / 1907

Рим.-Кат. ПРИХОДЪ СВЯТАГО ІОАННА

Въ употребленіе рекрутскаго набора или книгъ народонаселенія

СВИДѢТЕЛЬСТВО О БРАКОСОЧЕТАНІИ

ВЫДАННОЕ НА ОСНОВАНІИ МЕТРИЧЕСКИХЪ КНИГЪ

Объявляетъ, что ______ лѣтъ отъ роду

съ ______ урожденною ______ 19 лѣтъ отъ роду

заключилъ брачный союзъ

Дня 3/16

мѣсяца Октября

Тысяча ______ года

Достовѣрность чего симъ свидѣтельствую.

Г. Варшава ______ мѣсяца 23/6 дня 1907 года

Чиновникъ Гражданскаго Состоянія

Приставъ Исполнительной Полиціи 4 Участка

Собственноручную подпись Ксендза ______ симъ свидѣтельствуетъ.

Г. Варшава ______ 24 мѣсяца ______ 1907 года

Marriage
Dated 3/16/1907

Certificate
Dated Nov/Dec 23/6

Doing the Math

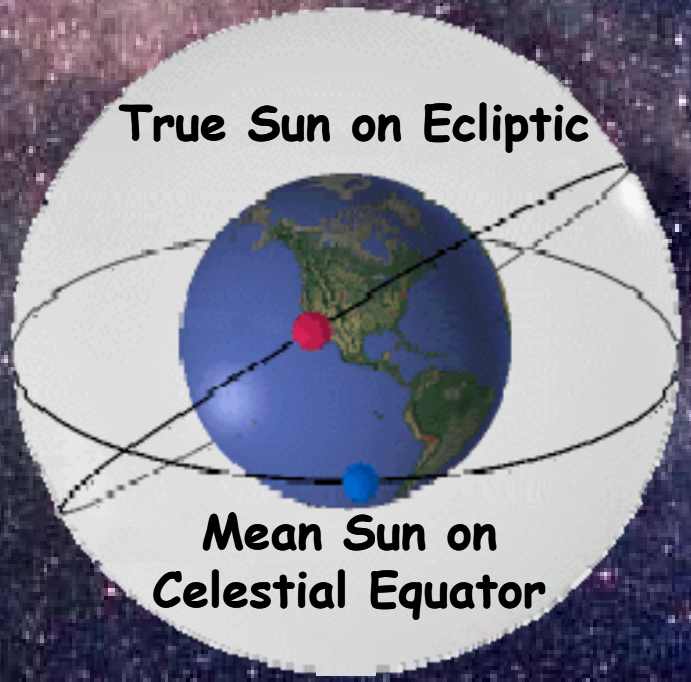
☆ Mean Sun

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

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

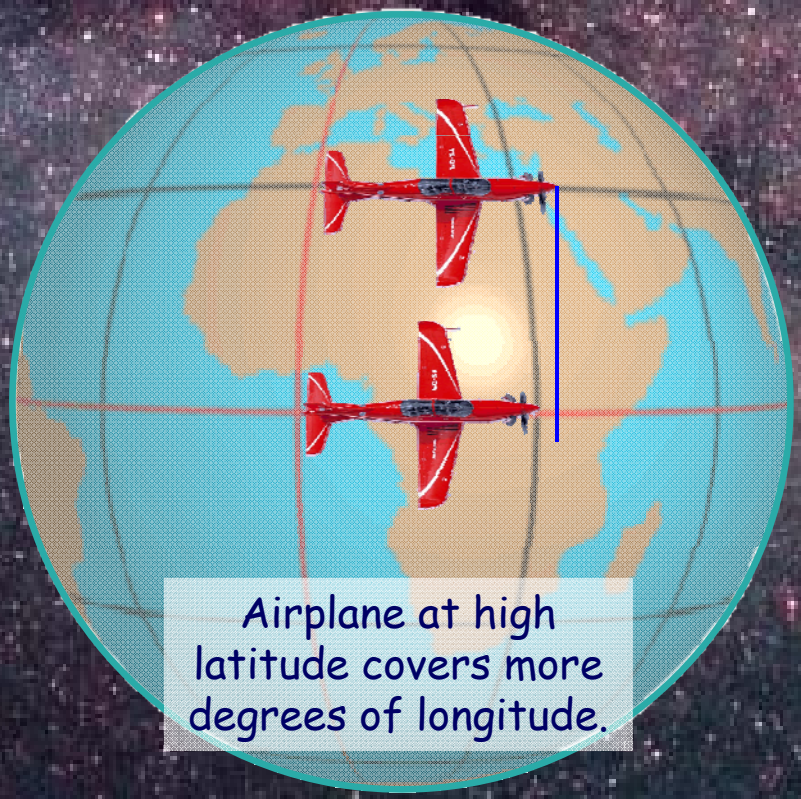
☆ True Sun

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

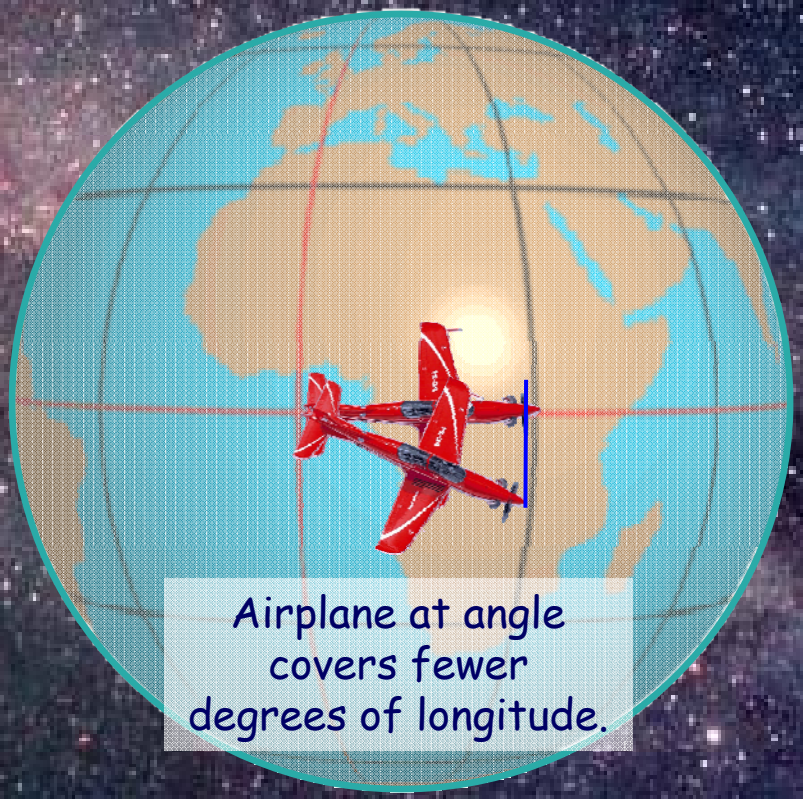


Speed Variation Due to Tilt

- ☆ Analogy: Airplanes on Earth
  - Both fly at same speed (mph)

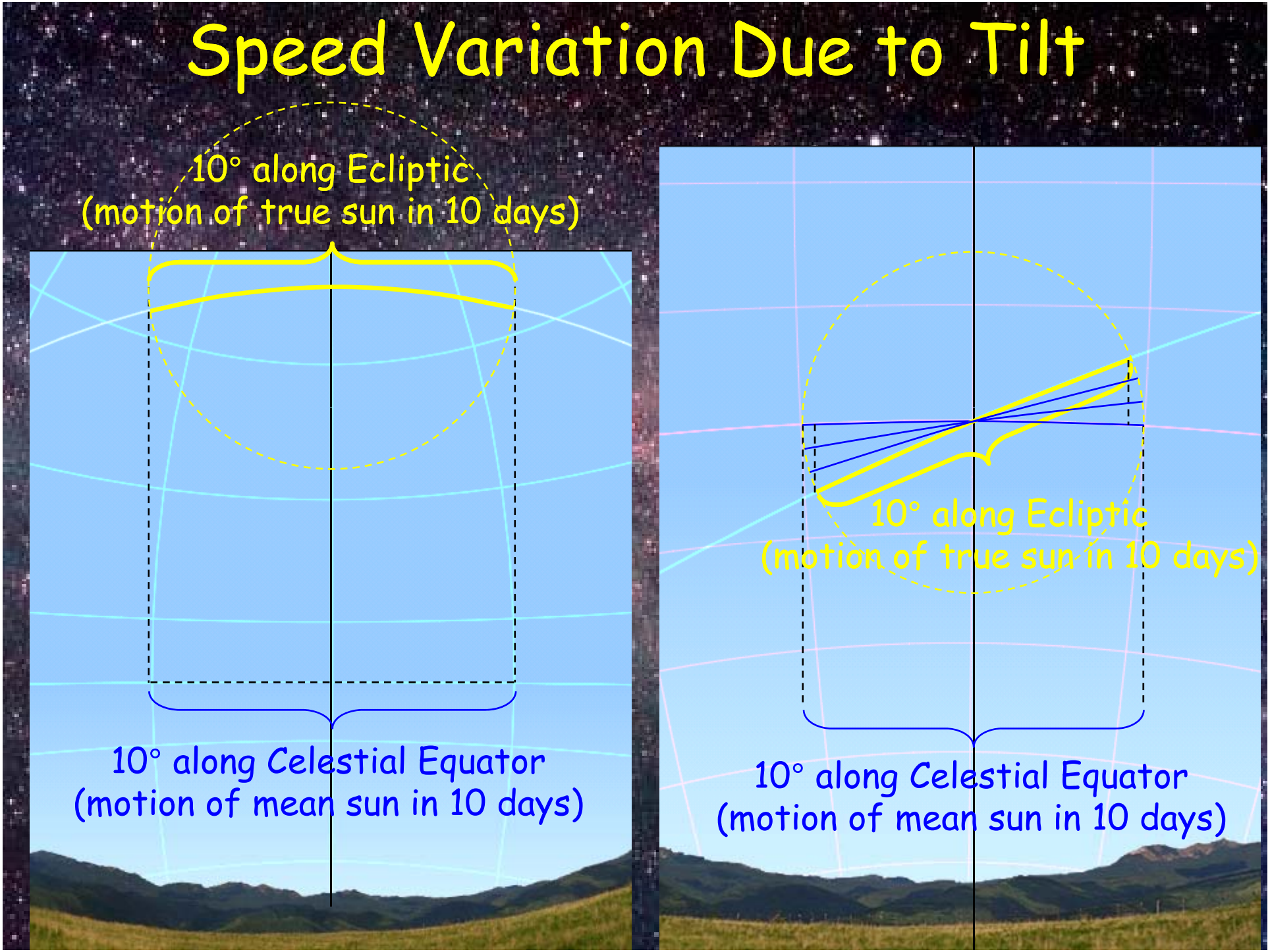


Airplane at high latitude covers more degrees of longitude.

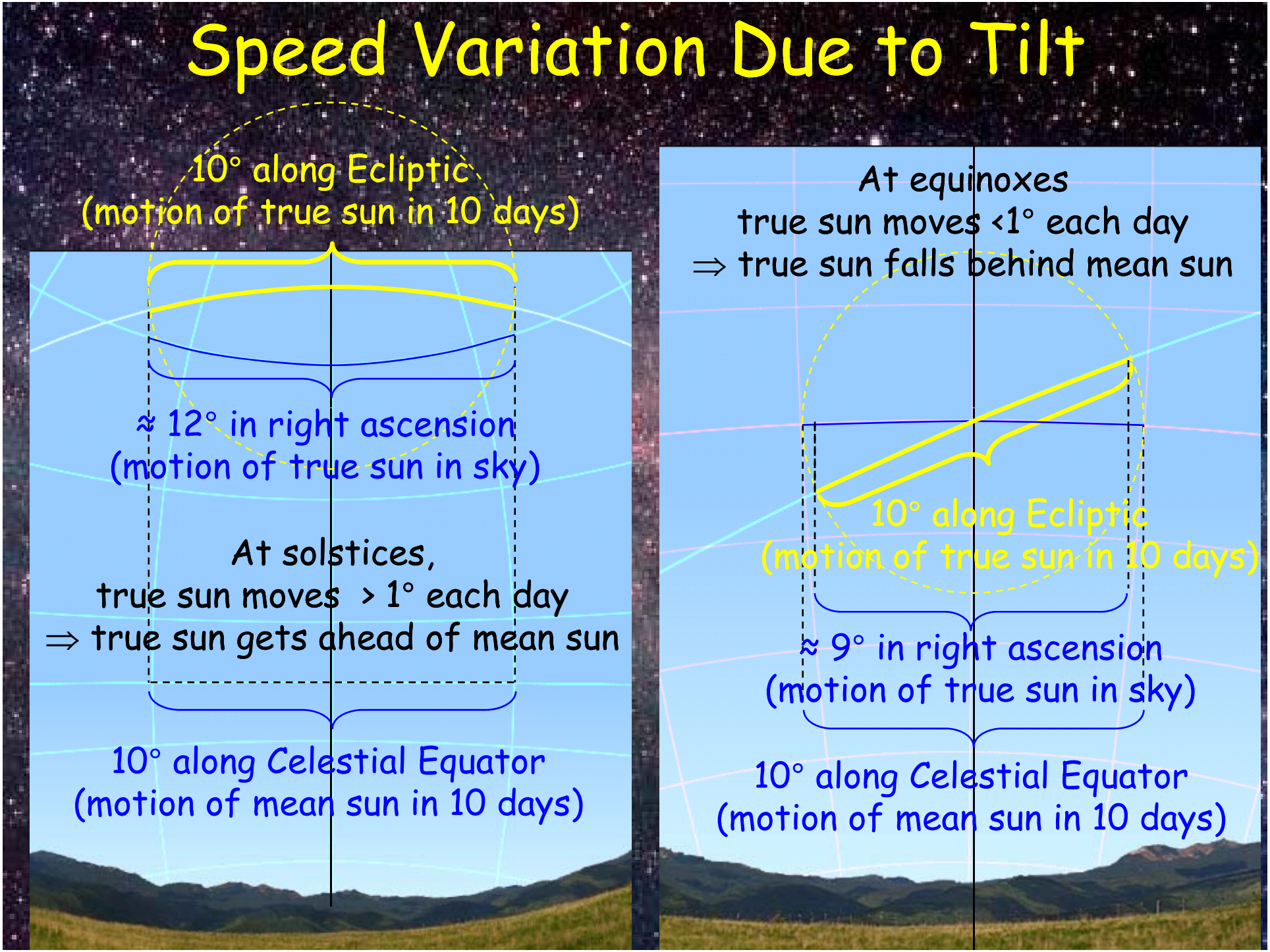


Airplane at angle covers fewer degrees of longitude.

Speed Variation Due to Tilt



Speed Variation Due to Tilt



True Sun Speed Variation

- ☆ Solstices
  - True sun and mean sun aligned, but …
  - True sun getting ahead of mean at maximum rate
- ☆ Equinoxes
  - True sun and mean sun aligned, but
  - True sun getting behind mean at maximum rate
- ☆ Cross-Quarter Days
  - Between solstices & equinoxes
  - True sun farthest from mean
  - Switching between getting ahead & behind

Cross Quarter Days

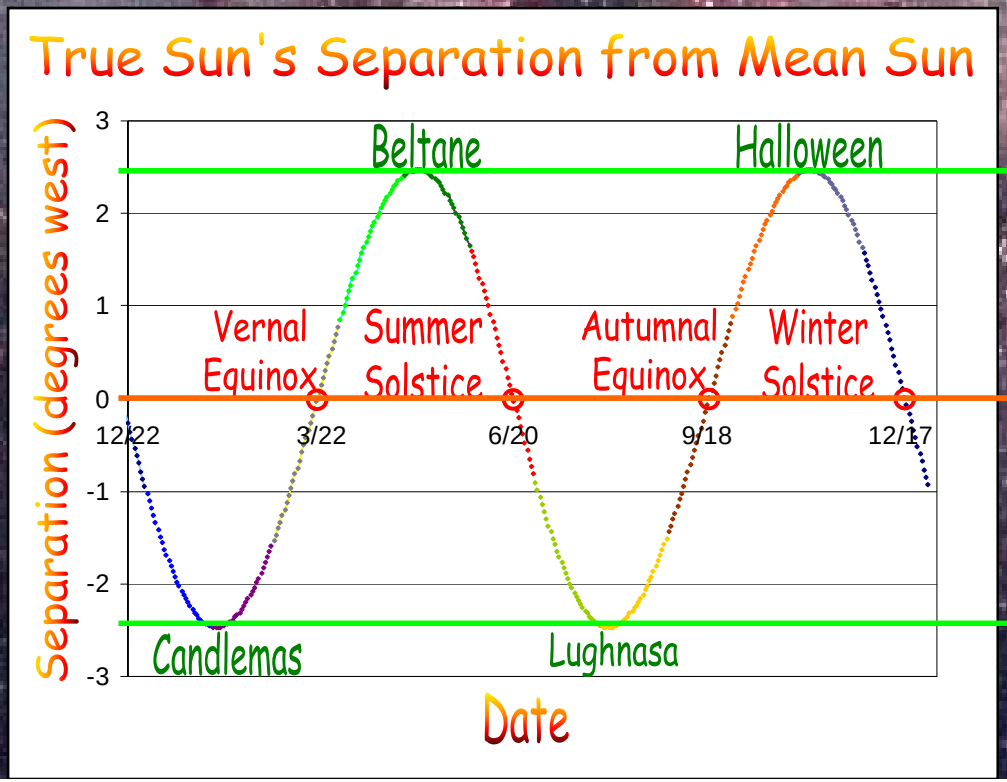
- ☆ Days ½ way between solstices & equinoxes
  - 🌎 Beltane ~May 1
    - ☽ ½ way from Vernal Equinox to Summer Solstice
  - 🌎 Lughnasa ~ August 2
    - ☽ ½ way from Summer Solstice to Autumnal Equinox
  - 🌎 All Hallows (Samhain) ~November 1
    - ☽ ½ way from Autumnal Equinox to Winter Solstice
  - 🌎 Candlemas (Imbolc) ~ February 2
    - ☽ ½ way from Winter Solstice to Vernal Equinox

If Candlemas Day be fair and bright,
Winter will have another flight

If Candlemas Day be damp & black, It
will carry cold winter away on its back.

Speed Variation Due to Tilt

- ☆ Solstices & Equinoxes (June & December)
  - mean and true sun align, fastest rate of change
- ☆ Cross-Quarter Days
  - maximum separation of mean and true sun
  - switching direction of change

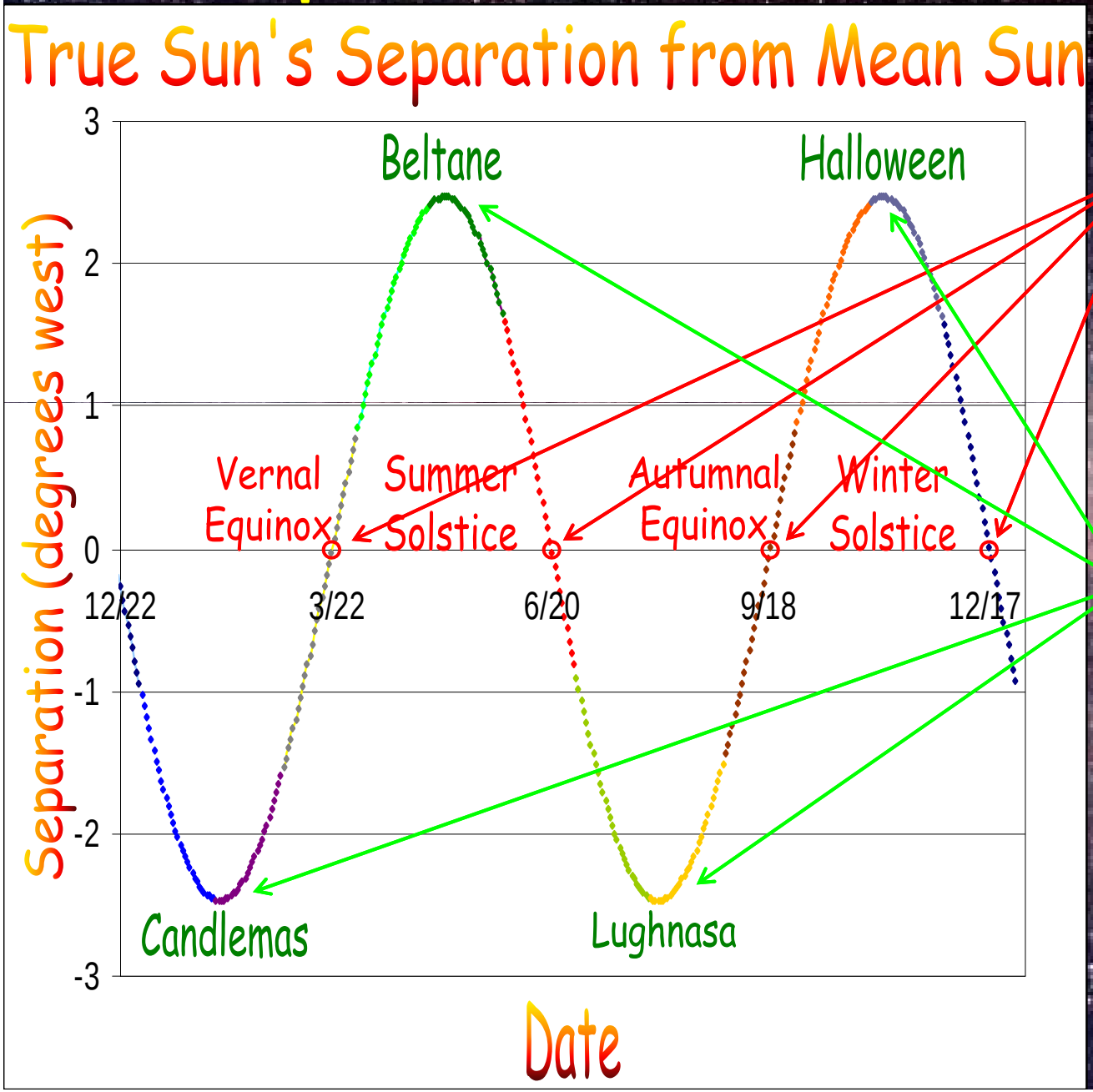


True sun farthest west (early, fast)

Mean sun & true sun aligned

True sun farthest east (late, slow)

Speed Variation Due to Tilt

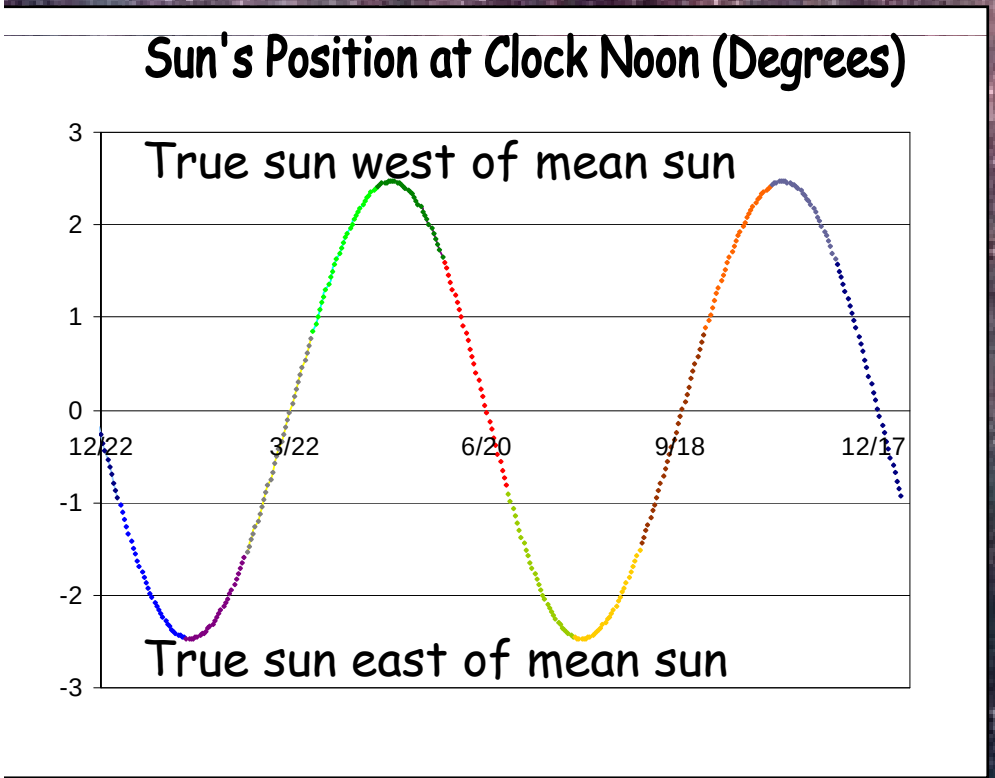


Maximum rate of change at solstices & equinoxes

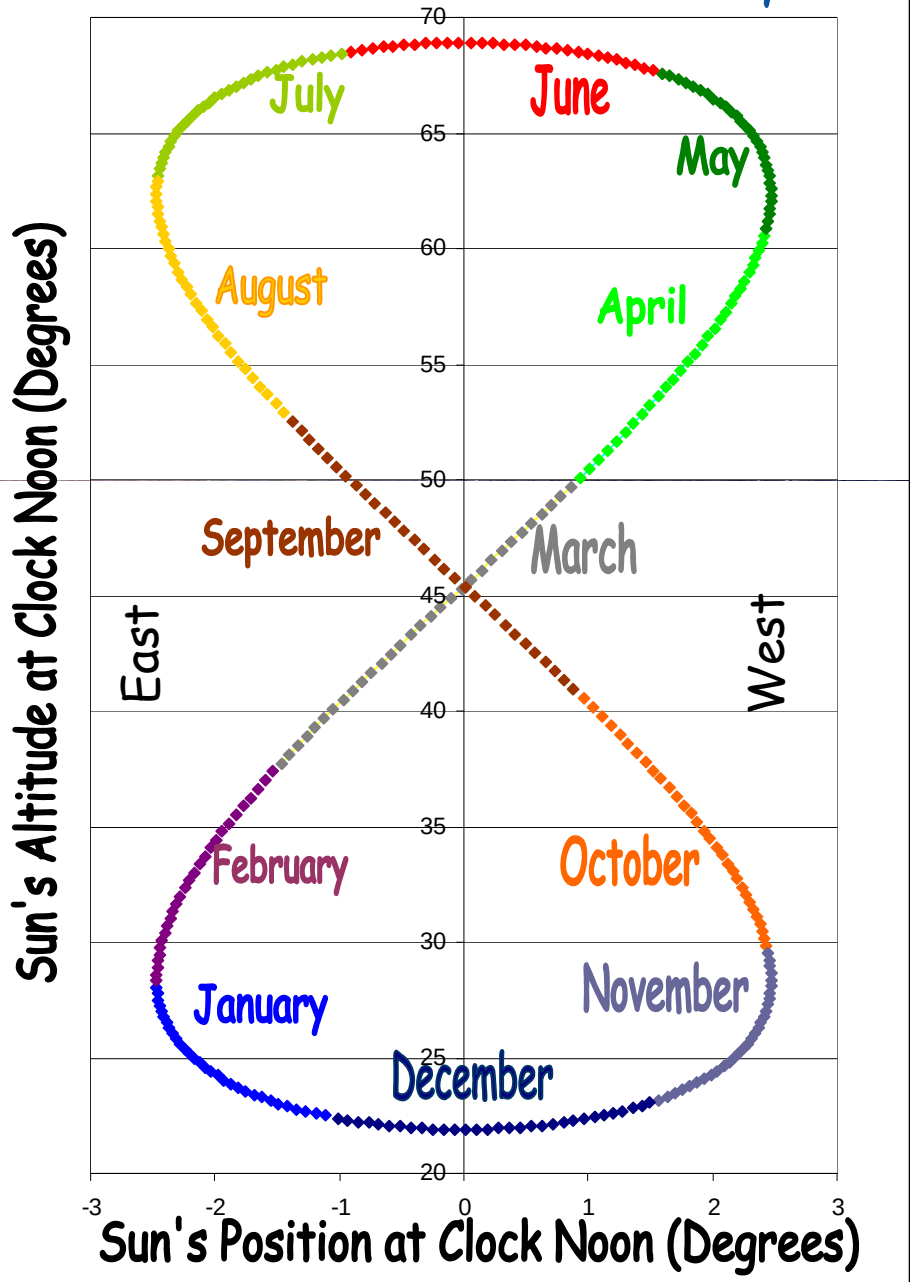
Maximum difference at cross-quarter days (direction of change switches)

Tilt Analemma

- Position of true sun through the year for Earth in a circular orbit.



Tilt Analemma: Potsdam, NY

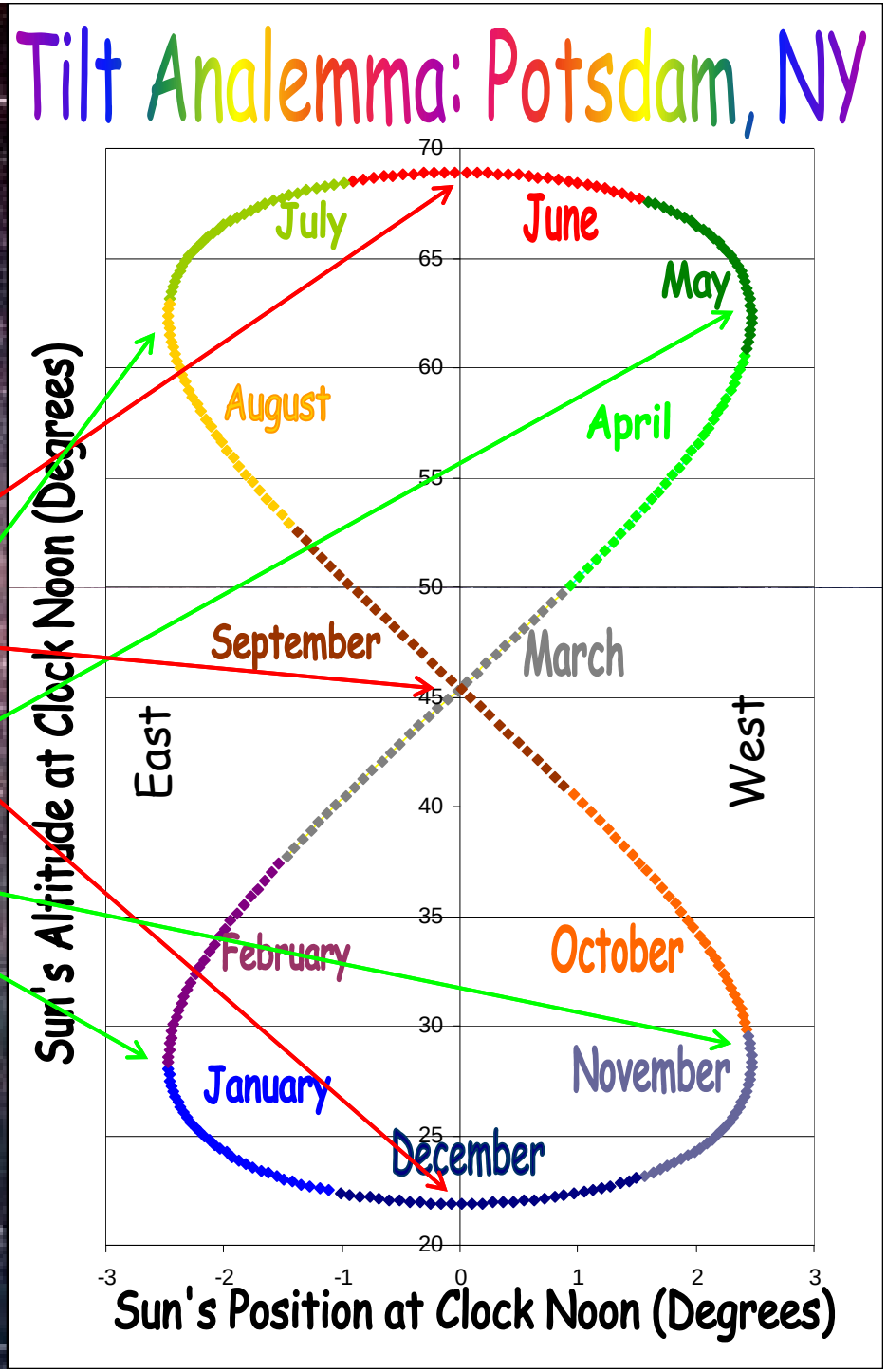


Tilt Analemma

- Position of true sun through the year for Earth in a circular orbit.

True & mean sun aligned at solstices & equinoxes (rate of change maximum)

Maximum difference at cross-quarter days (direction of change switches)



Tilt Analemma

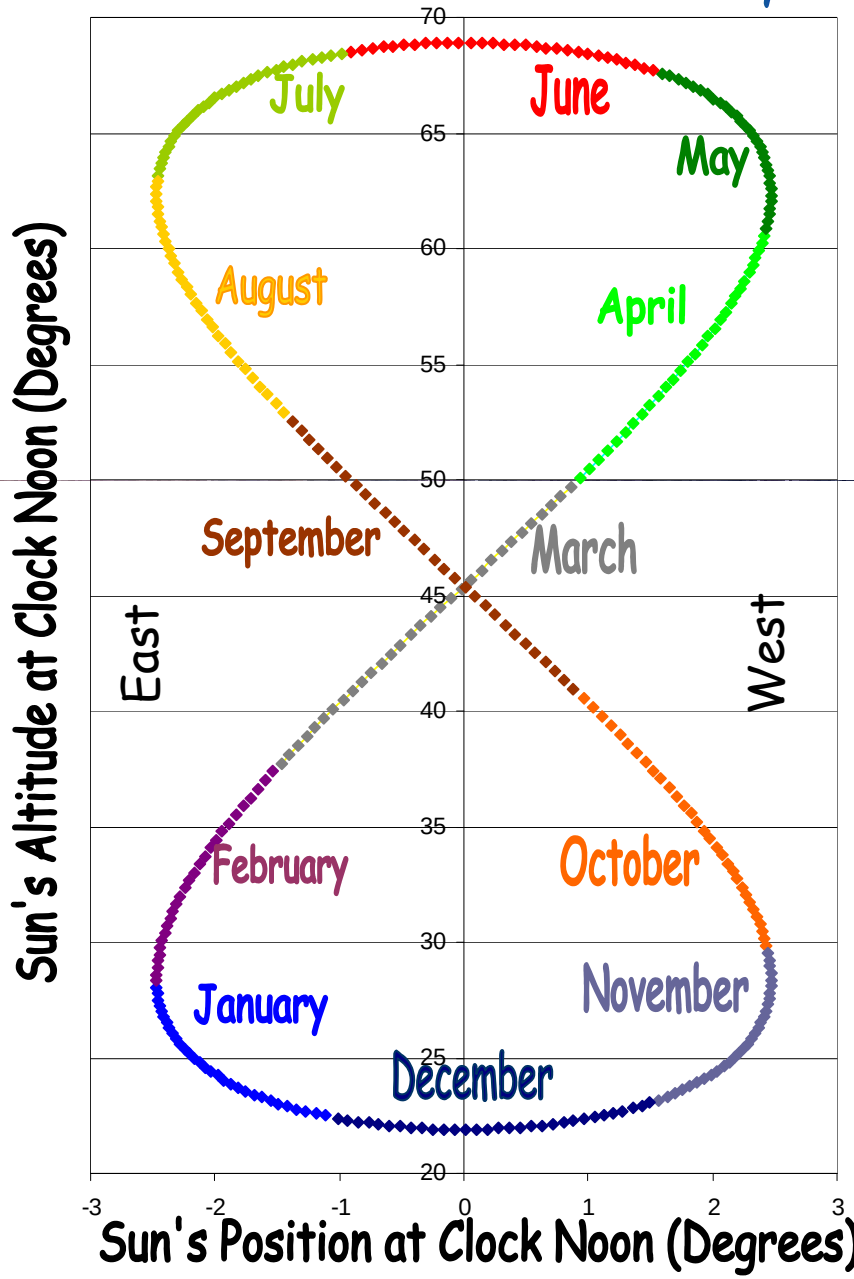
- Position of true sun through the year for Earth in a circular orbit.

True & mean sun aligned
at solstices & equinoxes
(rate of change maximum)

Maximum difference
at cross-quarter days
(direction of change switches)

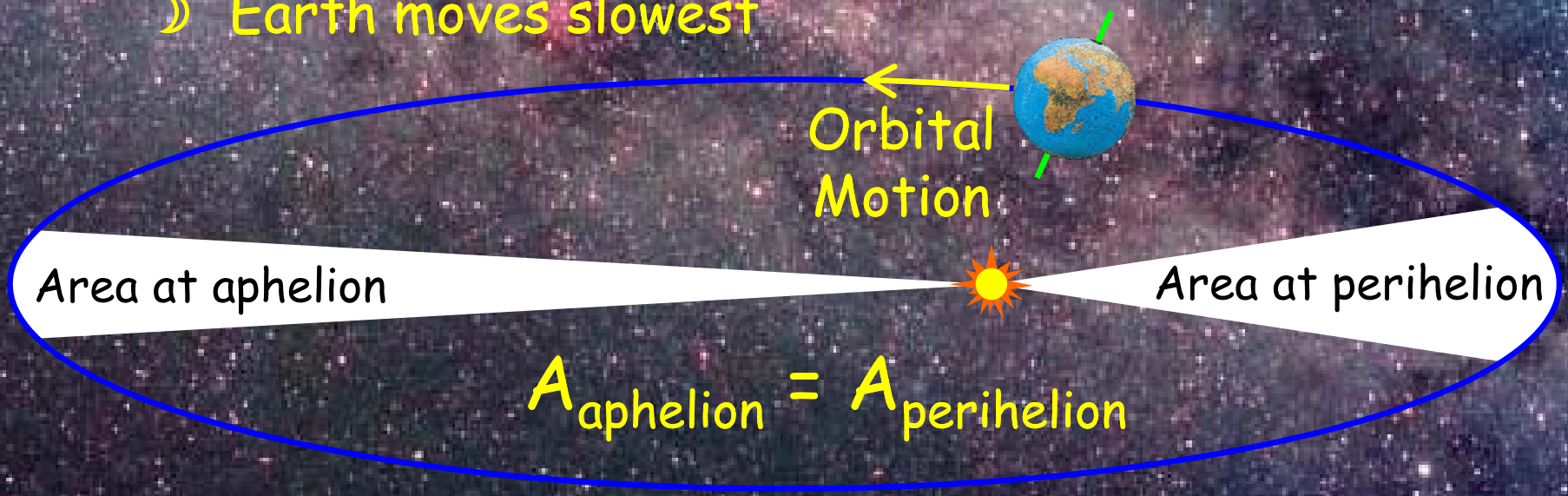
But it's not this simple …

Tilt Analemma: Potsdam, NY

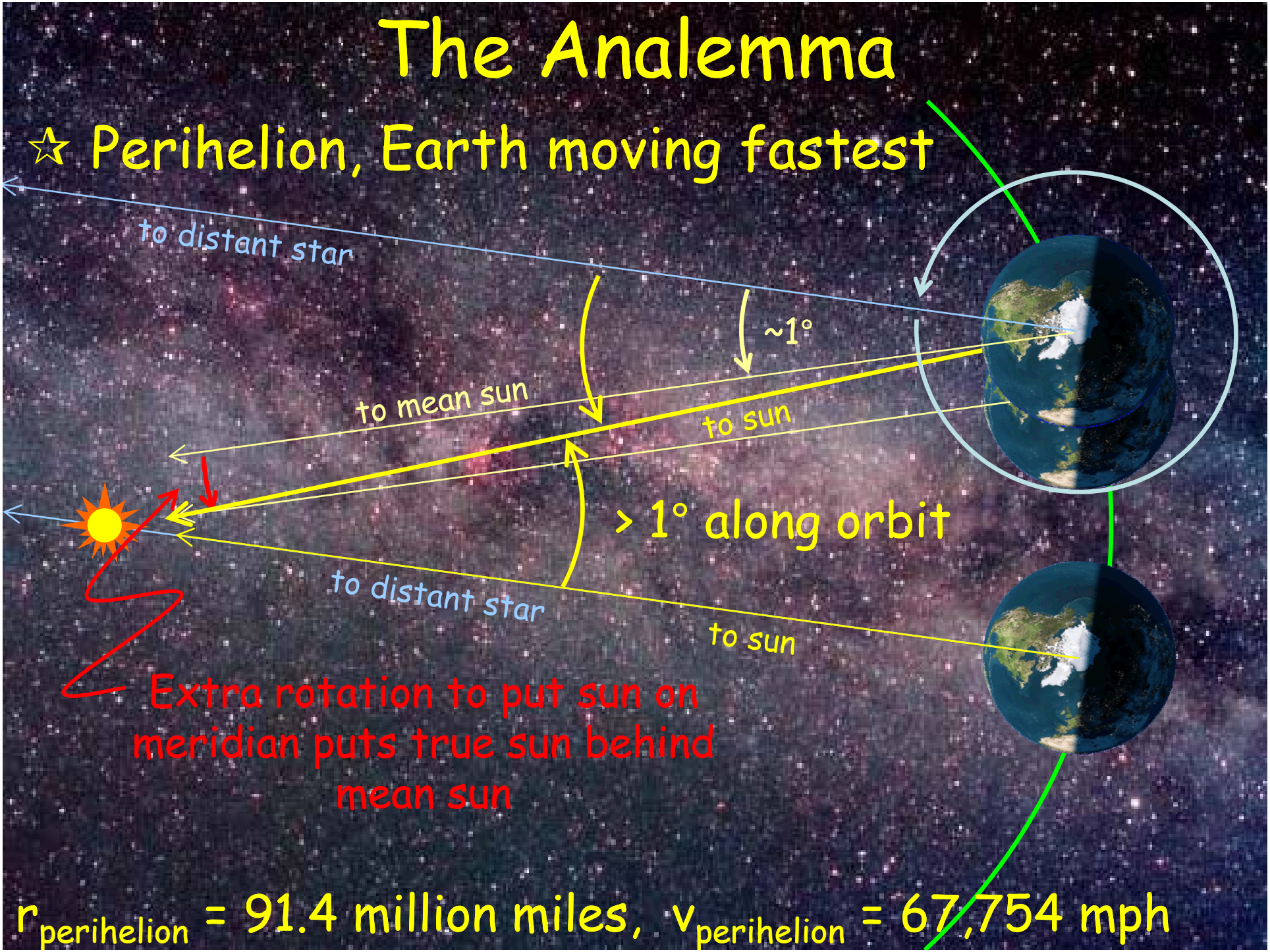


Earth's Orbit

- ☆ Earth's speed varies in orbit
  - area swept out in a given time stays equal
  - perihelion (~ January 4)
    - ☽ Earth moves fastest (February is shortest month!)
  - aphelion (~ July 4)
    - ☽ Earth moves slowest



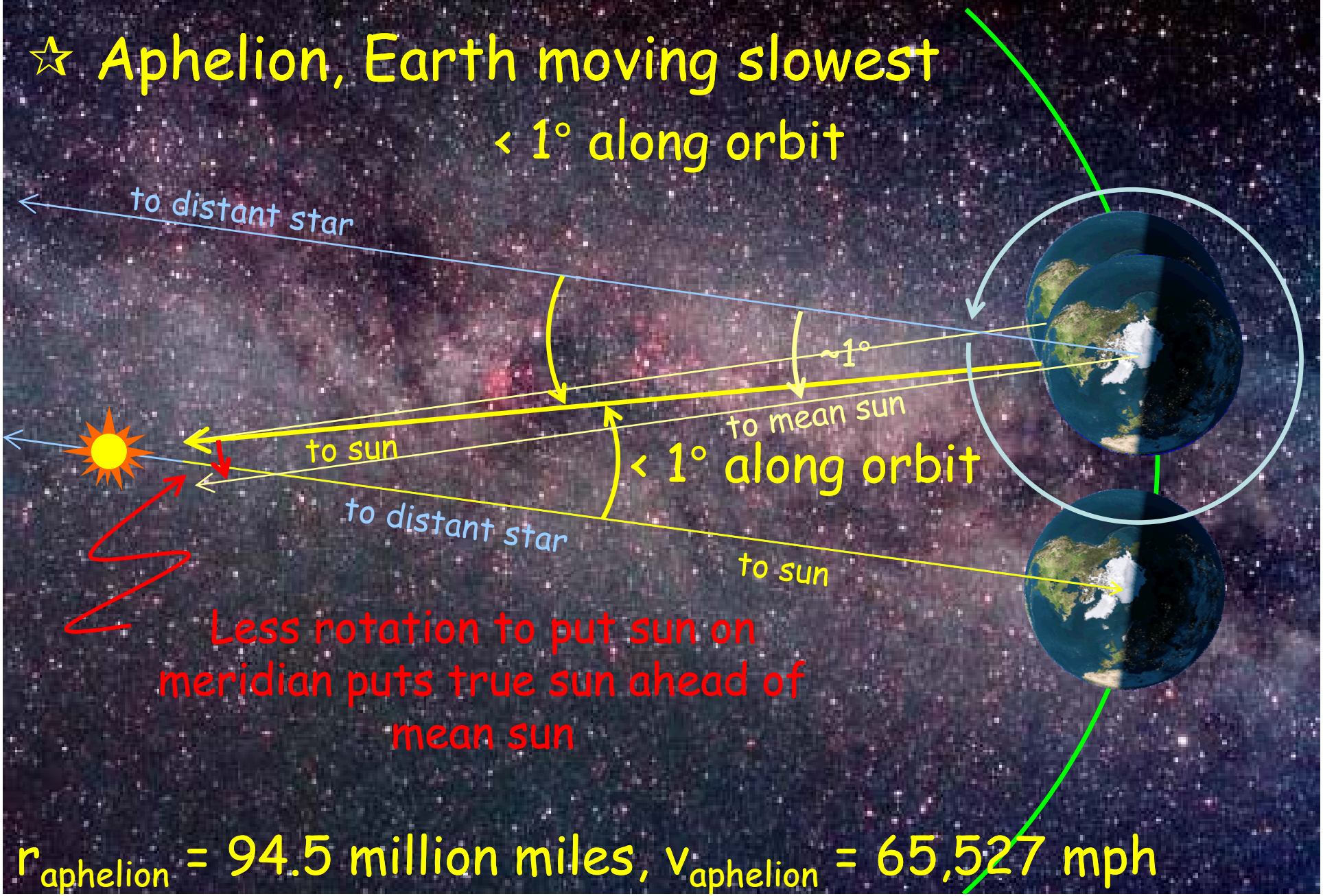
Orbital speed changes to keep swept areas equal


The Analemma
☆ Perihelion, Earth moving fastest
to distant star
~1°
to mean sun
to sun
> 1° along orbit
to distant star
to sun
Extra rotation to put sun on meridian puts true sun behind mean sun
$r_{perihelion}$ = 91.4 million miles, $v_{perihelion}$ = 67,754 mph

The Analemma

☆ Aphelion, Earth moving slowest

< 1° along orbit

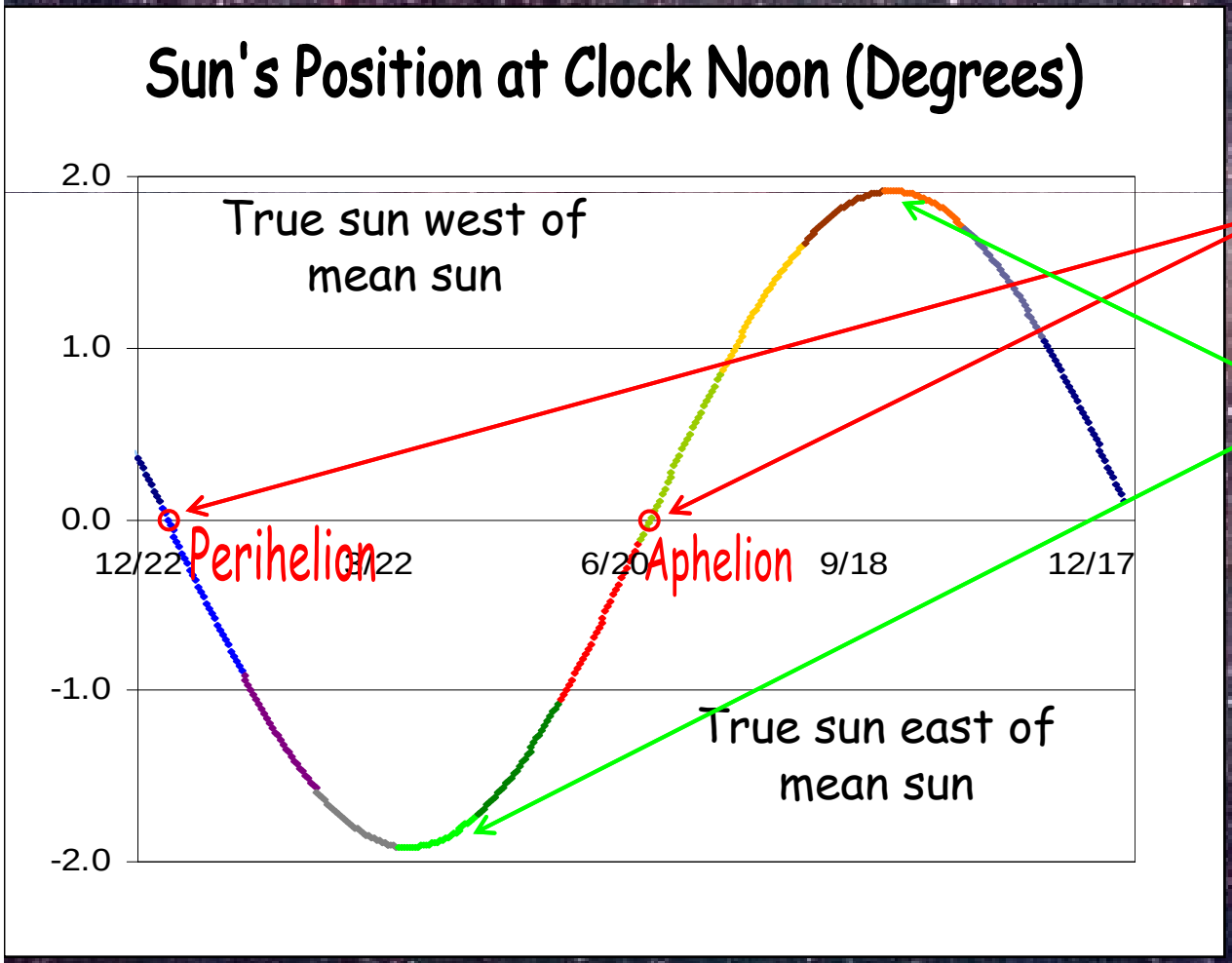


Less rotation to put sun on meridian puts true sun ahead of mean sun

$r_{aphelion}$ = 94.5 million miles, $v_{aphelion}$ = 65,527 mph

Orbit Analemma

☆ Position of true sun through the year for Earth in an elliptical orbit just due to orbital speed variation



Maximum rate of change at perihelion & aphelion

Maximum difference at orbital mid-points (direction of change switches)

Orbit Analemma

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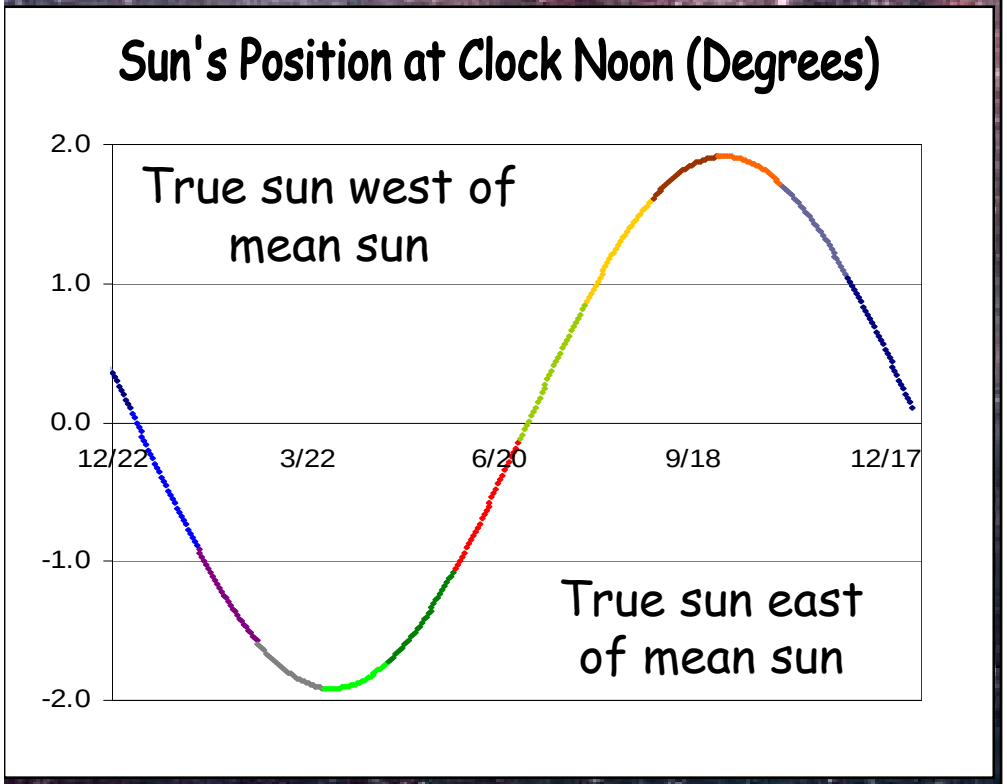
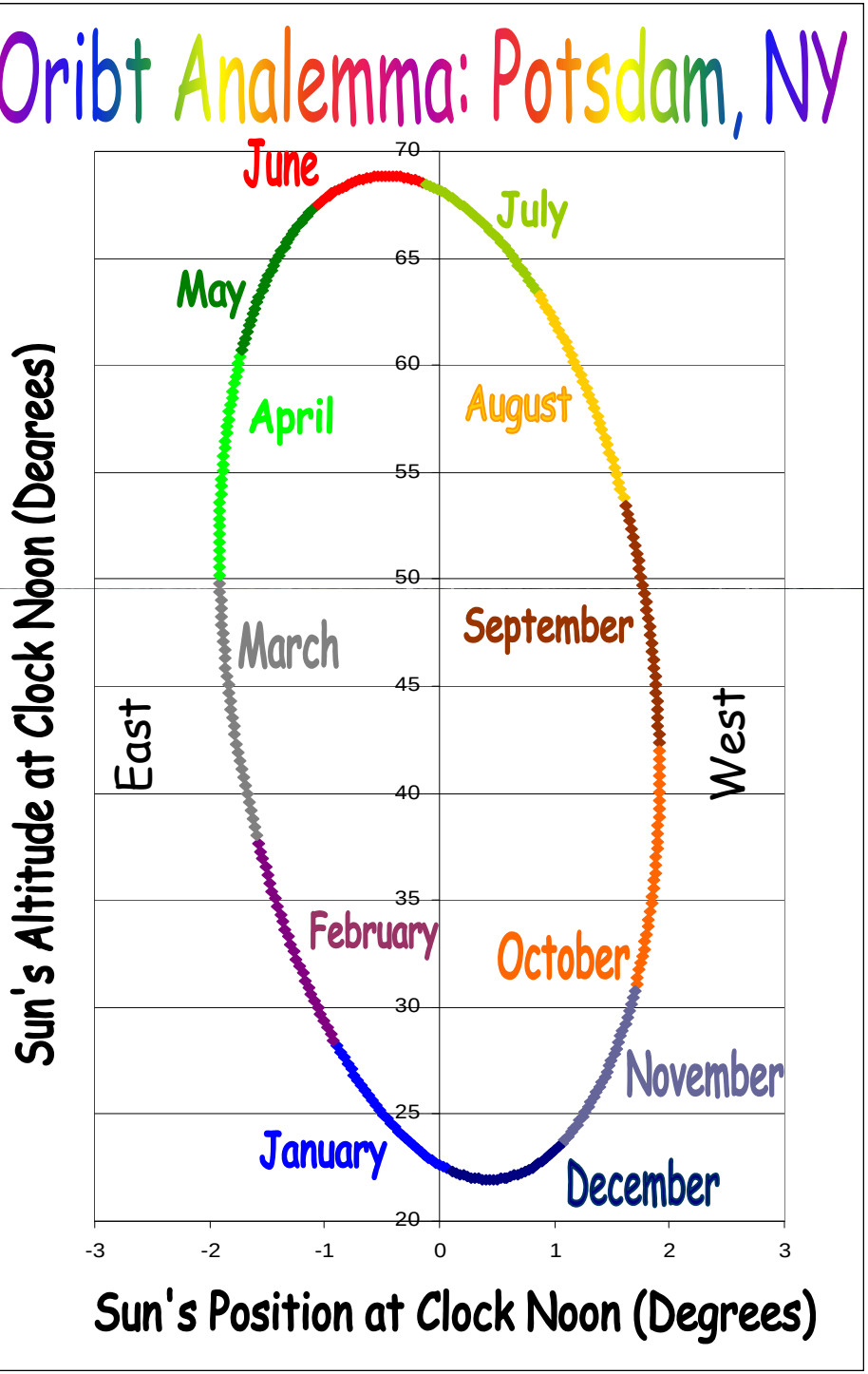
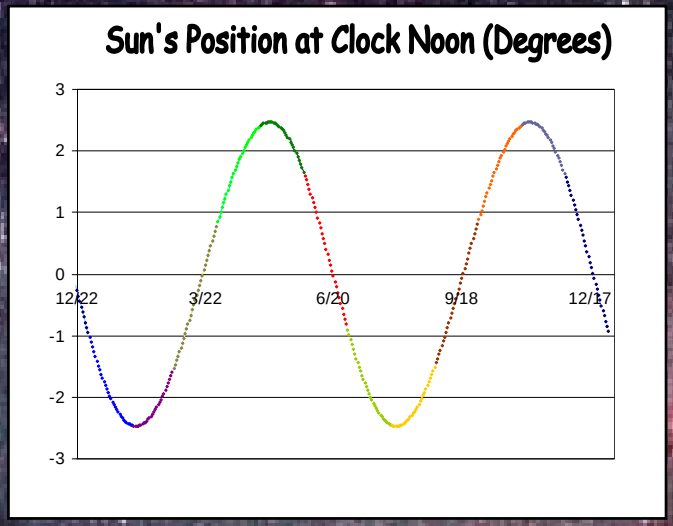
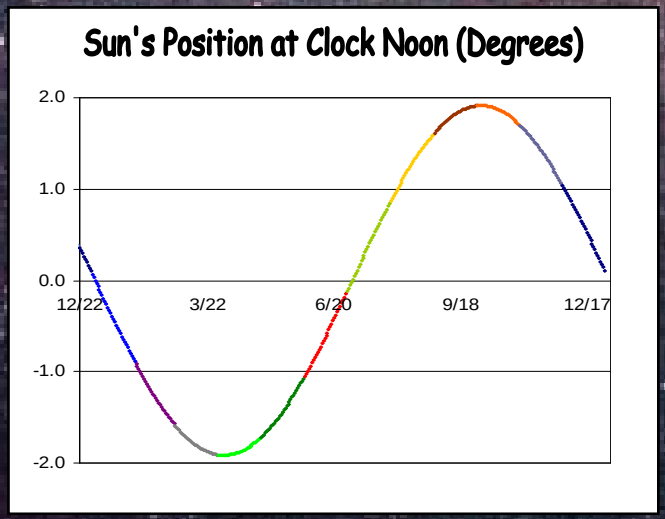


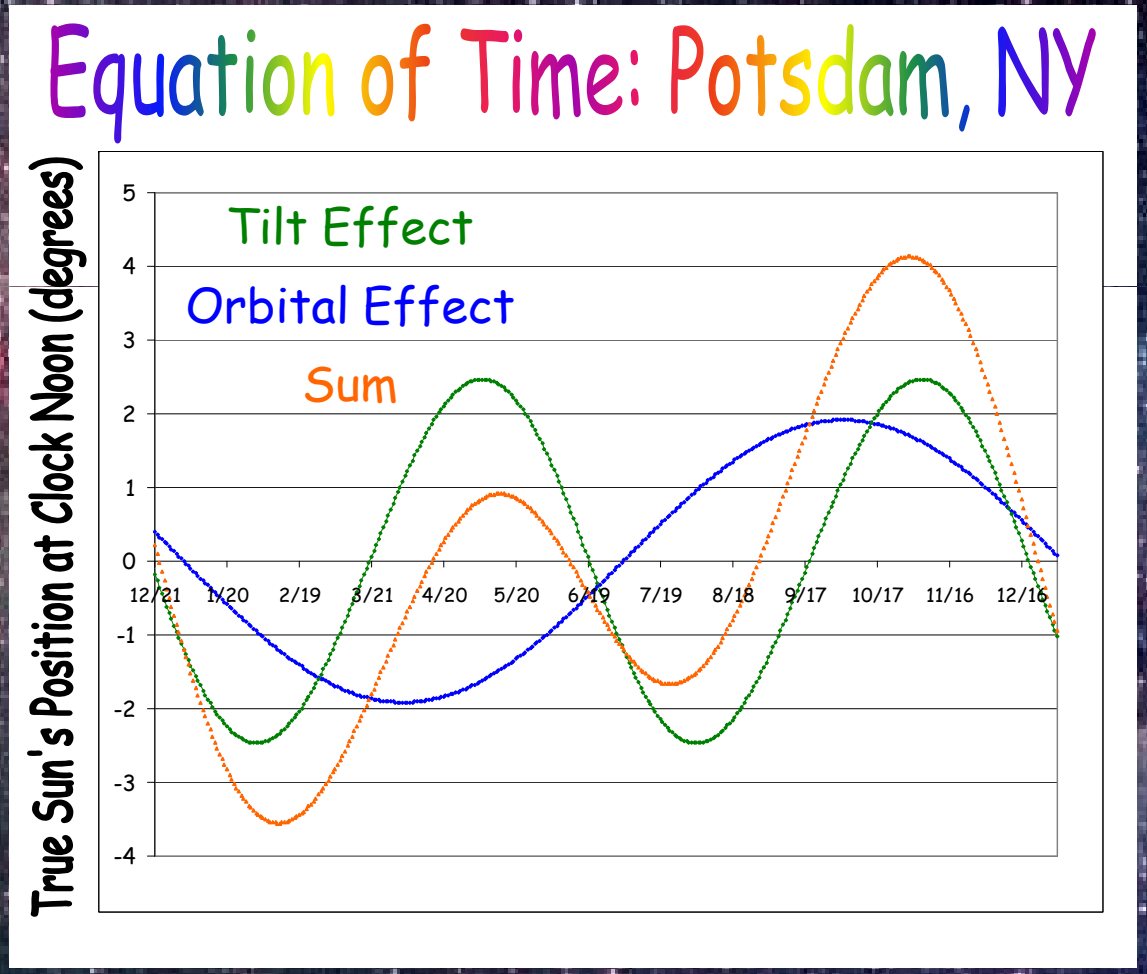


Total Analemma

☆ Tilt and Orbit effects add







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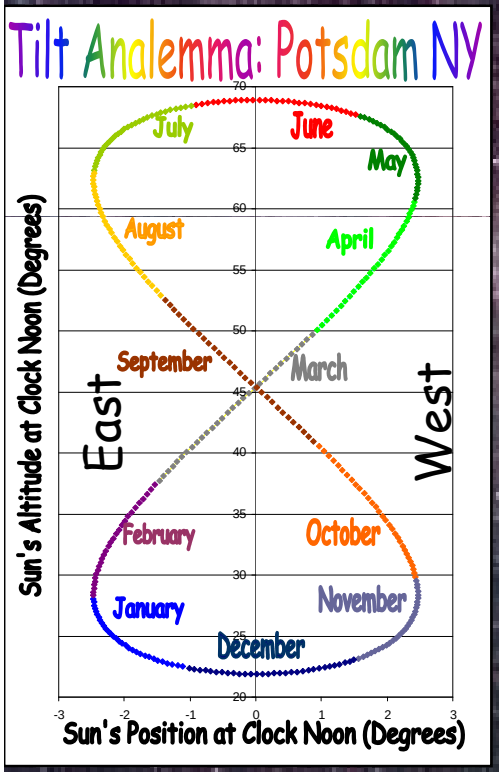
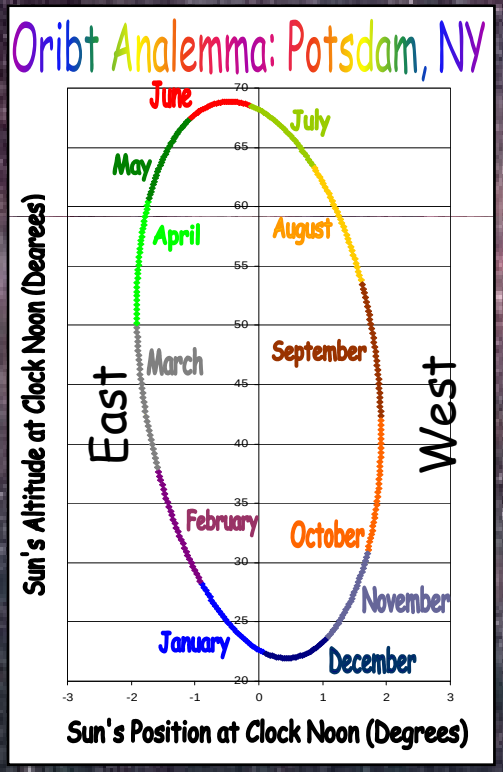
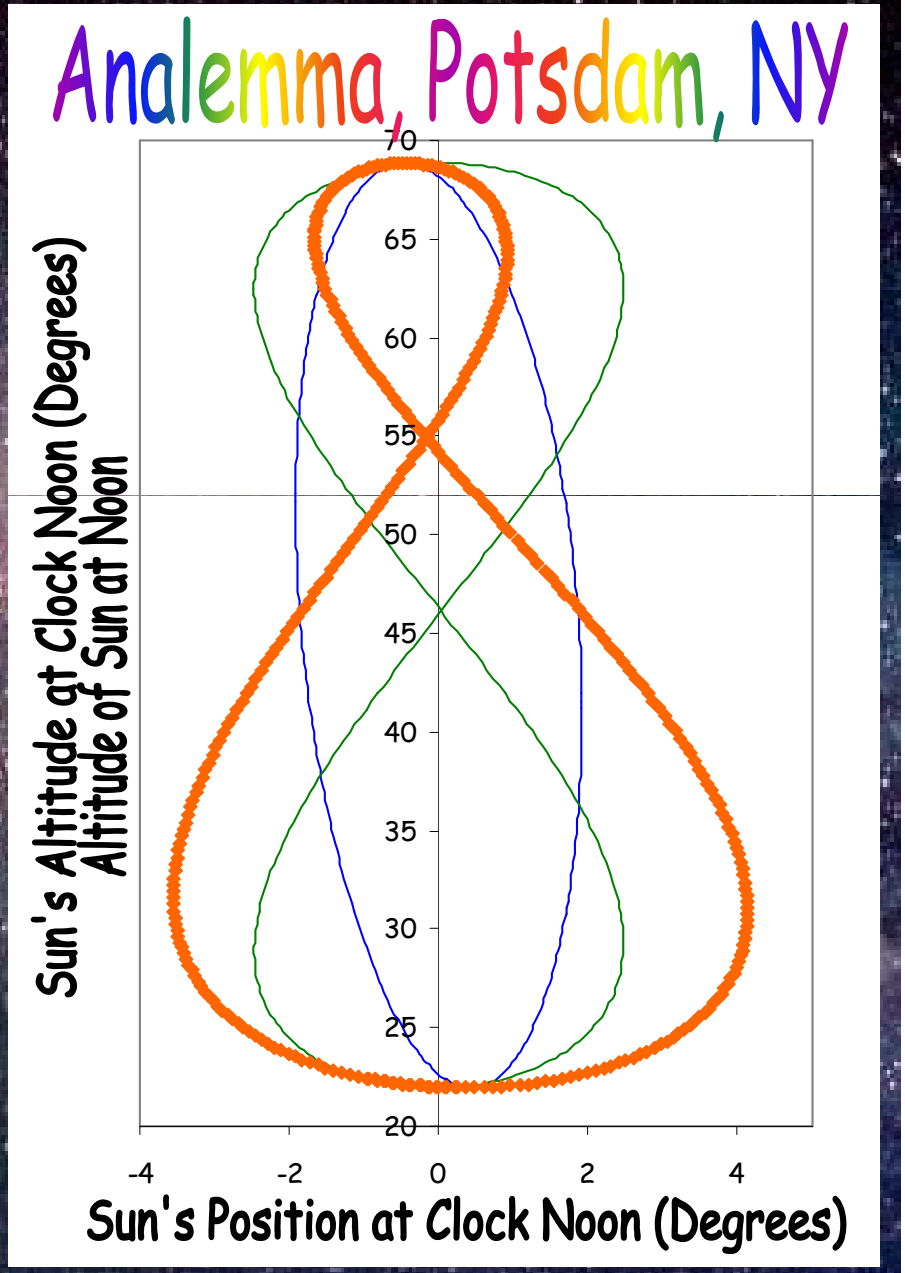
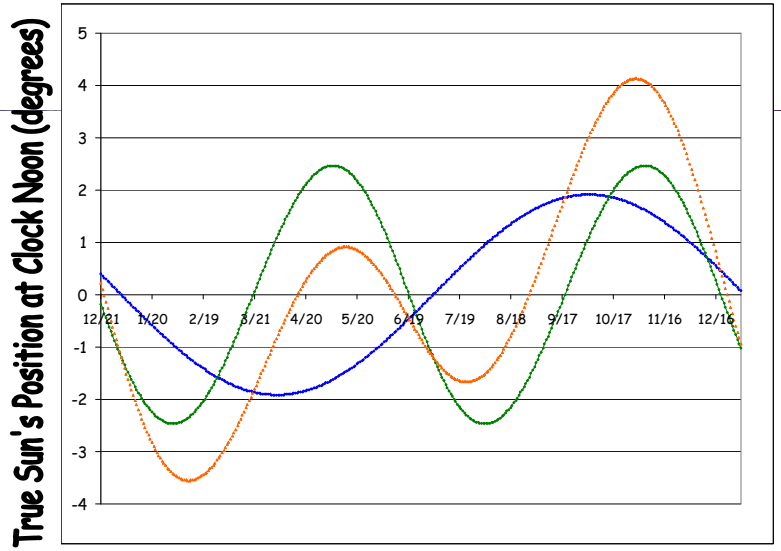




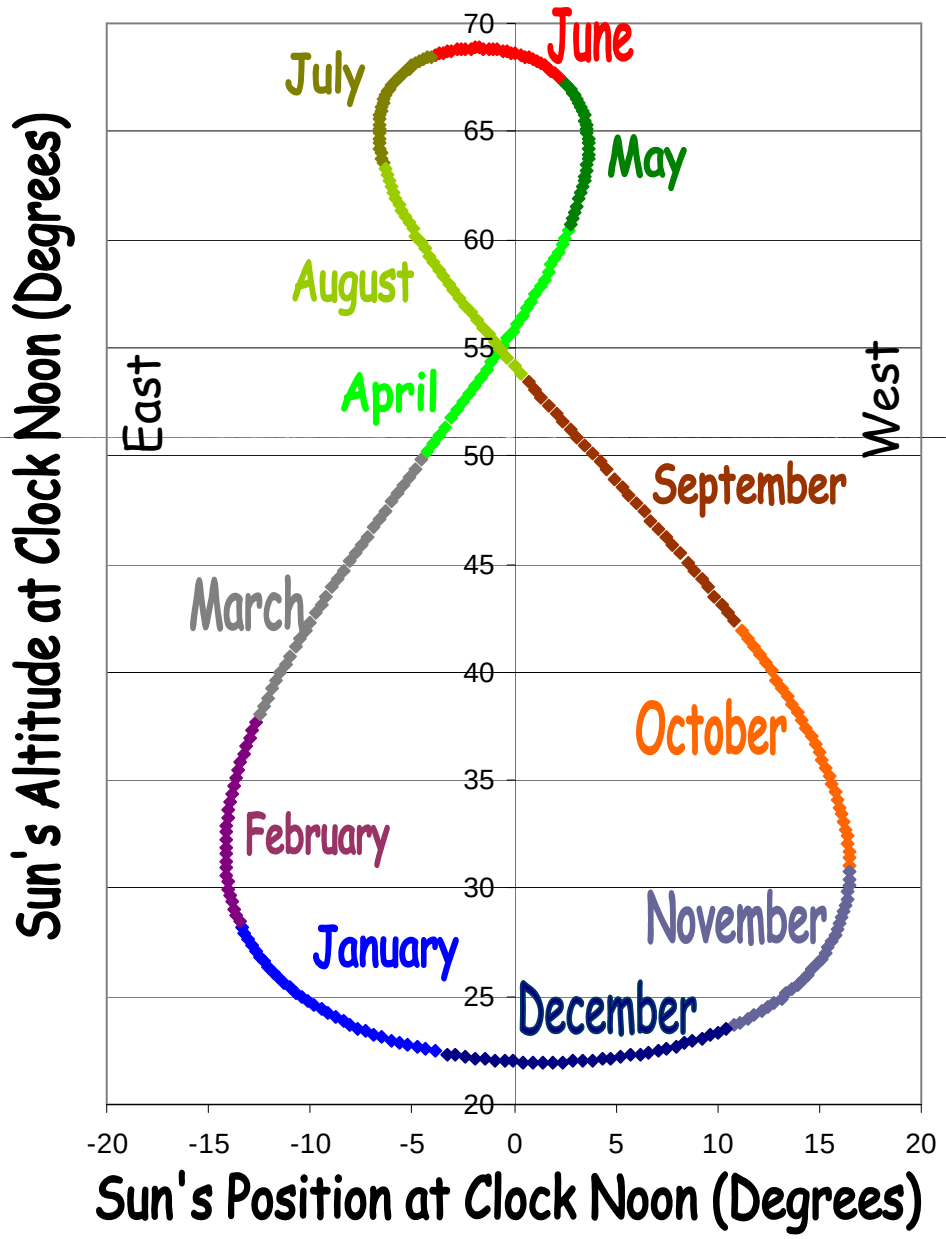


Potsdam's Analemma

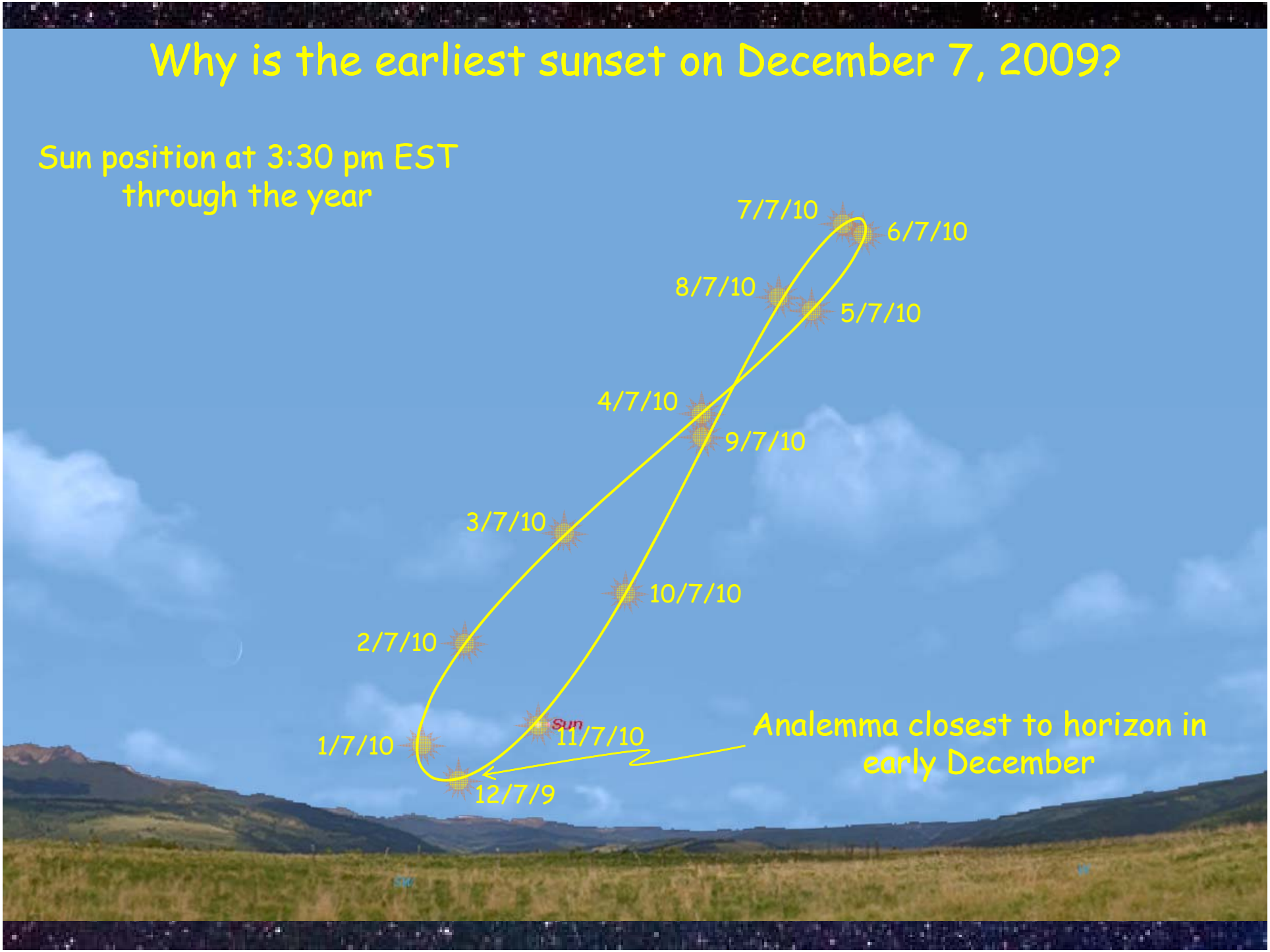
Equation of Time: Canton, NY



Analemma, Potsdam, NY

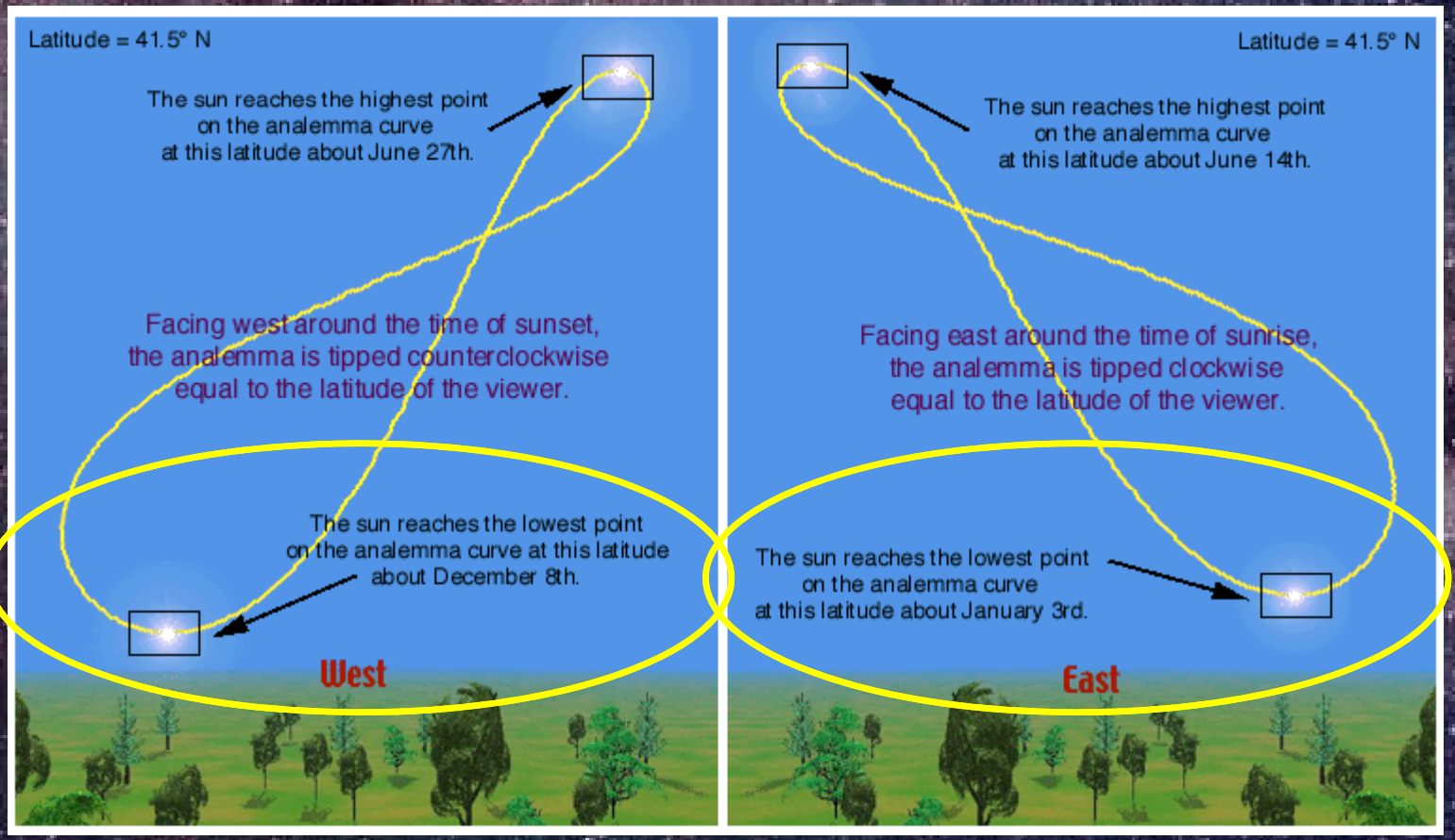


Why is the earliest sunset on December 7, 2009?



The Analemma

- ☆ Varies time of sunrise & sunset
  - Earliest sunset on about December 8
  - Latest sunrise on about January 3



The Analemma

☆ Posi
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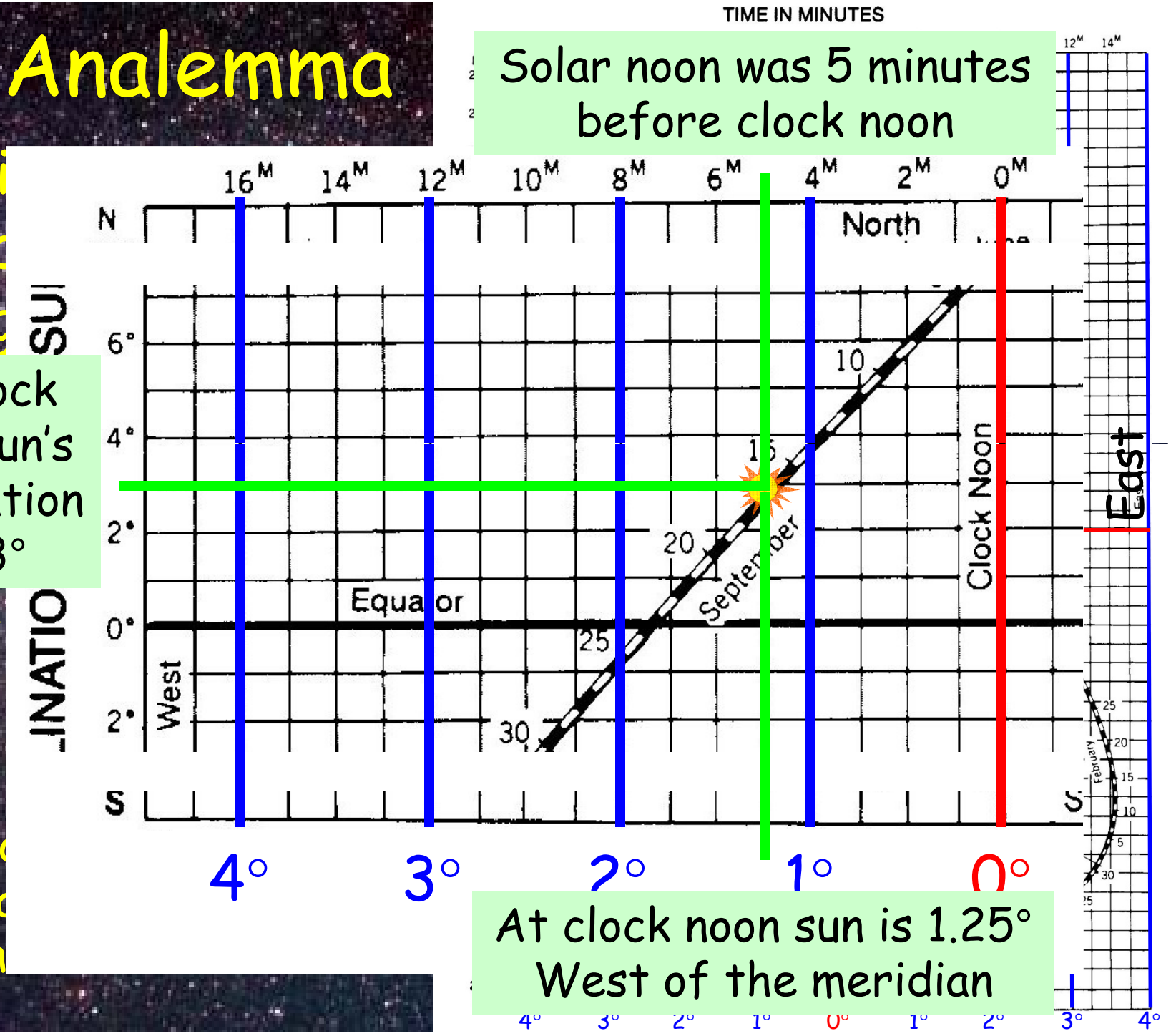
At clock noon sun's declination is +3°

clocks

Solar n
to solc
noon



Solar noon was 5 minutes before clock noon

At clock noon sun is 1.25° West of the meridian