SOAR
Lifelong Learning in the North Country

Potsdam
THE STATE UNIVERSITY OF NEW YORK

SOAR: The Sky in Motion

The Analemma, JWST & SgrA* Images

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ST. LAWRENCE UNIVERSITY

The Tilted Teacup Ride

- Coordinates and the Day: 9/6/22
  - Celestial Navigation
- The Year: 9/13/22
  - The Age of Aquarius
- The Month and Moon Phases: 9/20/22
  - The Harvest Moon
- The Day in All its Glory: 9/27/22
  - The Analemma

The Tilted Teacup Ride

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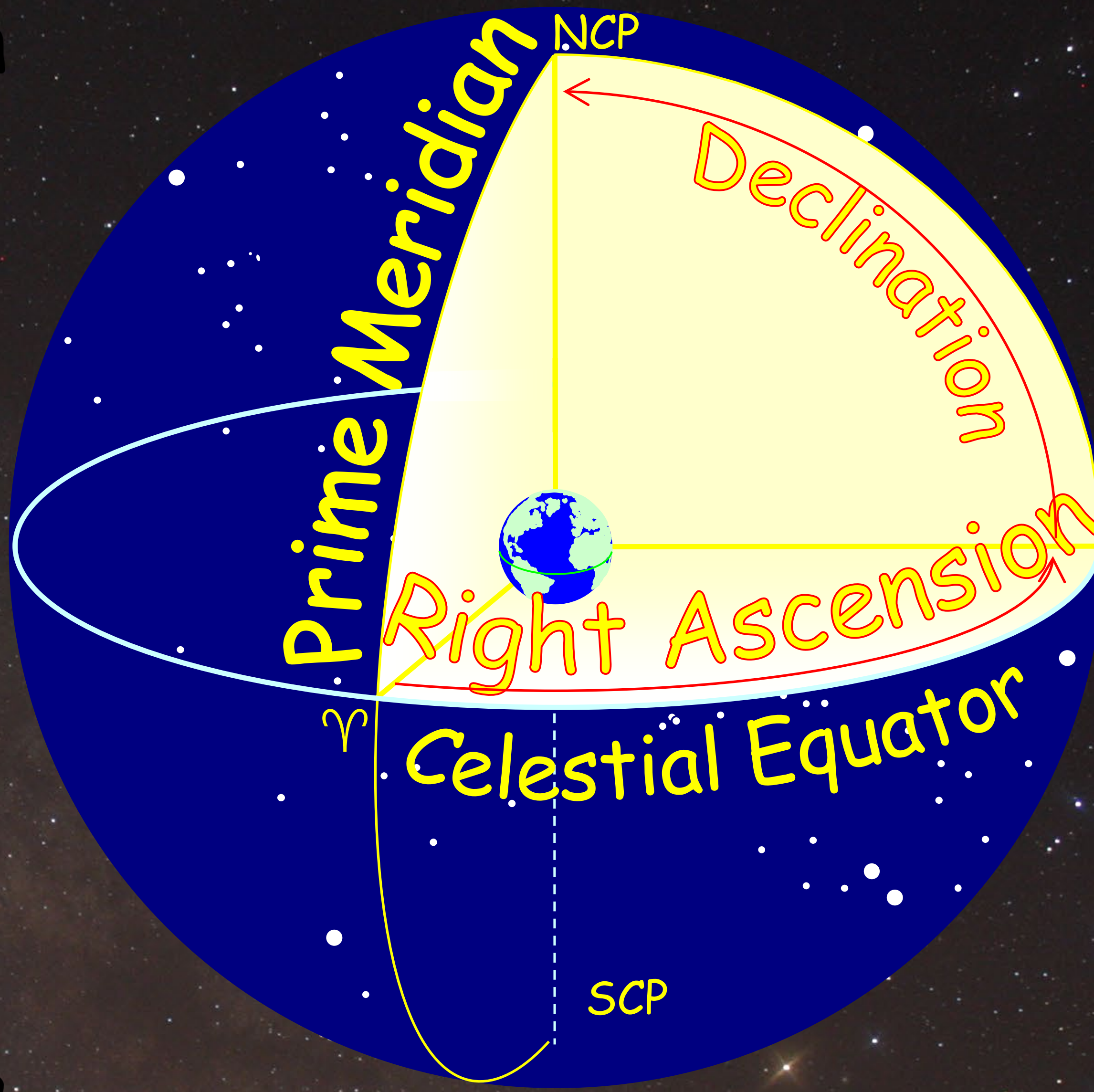
- The Analemma, JWST & SgrA* 9/27/22
  - The Analemma
  - JWST Images
  - SgrA* Image (Black Hole in the Milky Way)

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

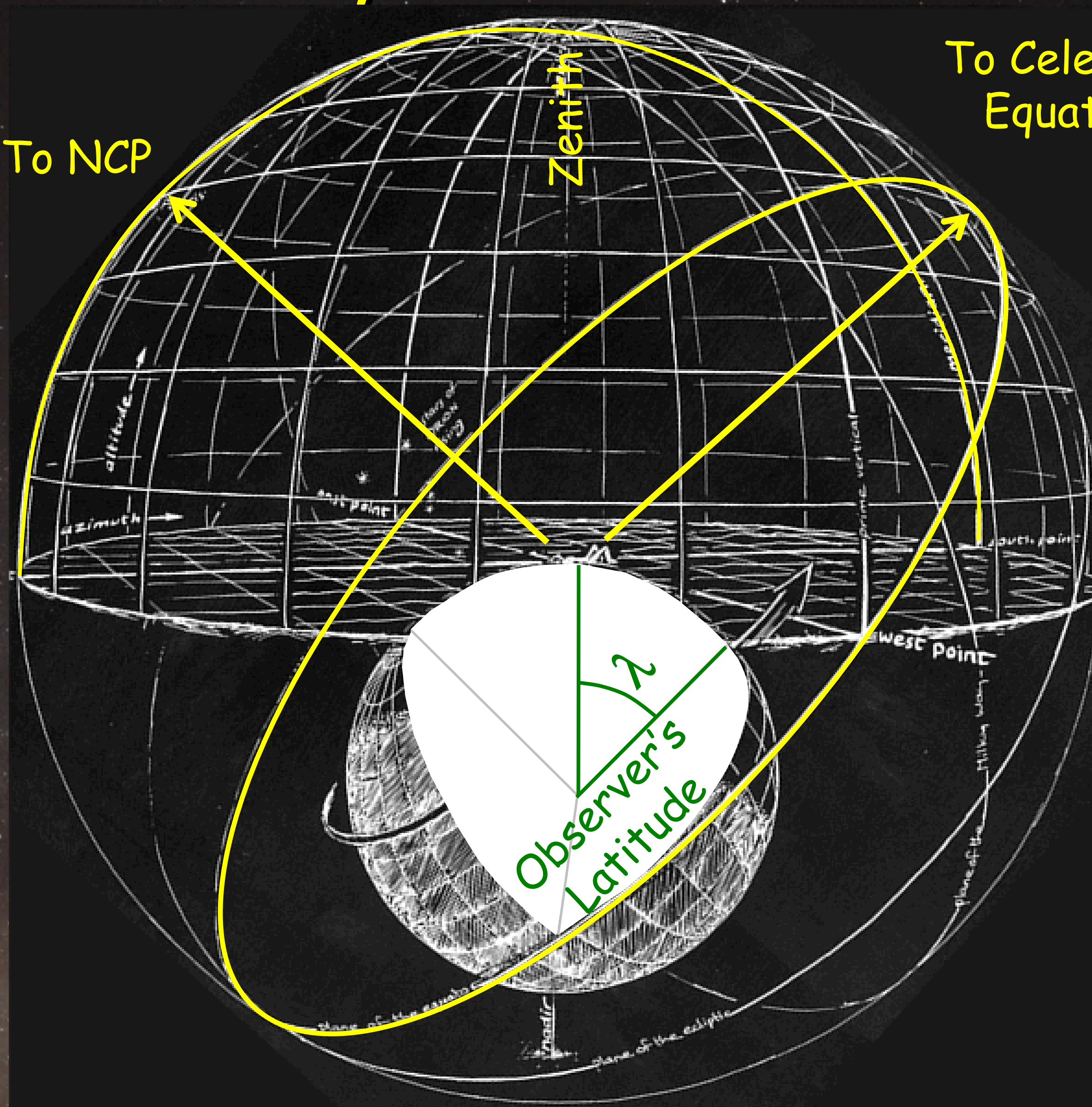


Photo by Marc Staves 2011

Standard Clock Time

- ☆ Every Longitude a… lifferent time

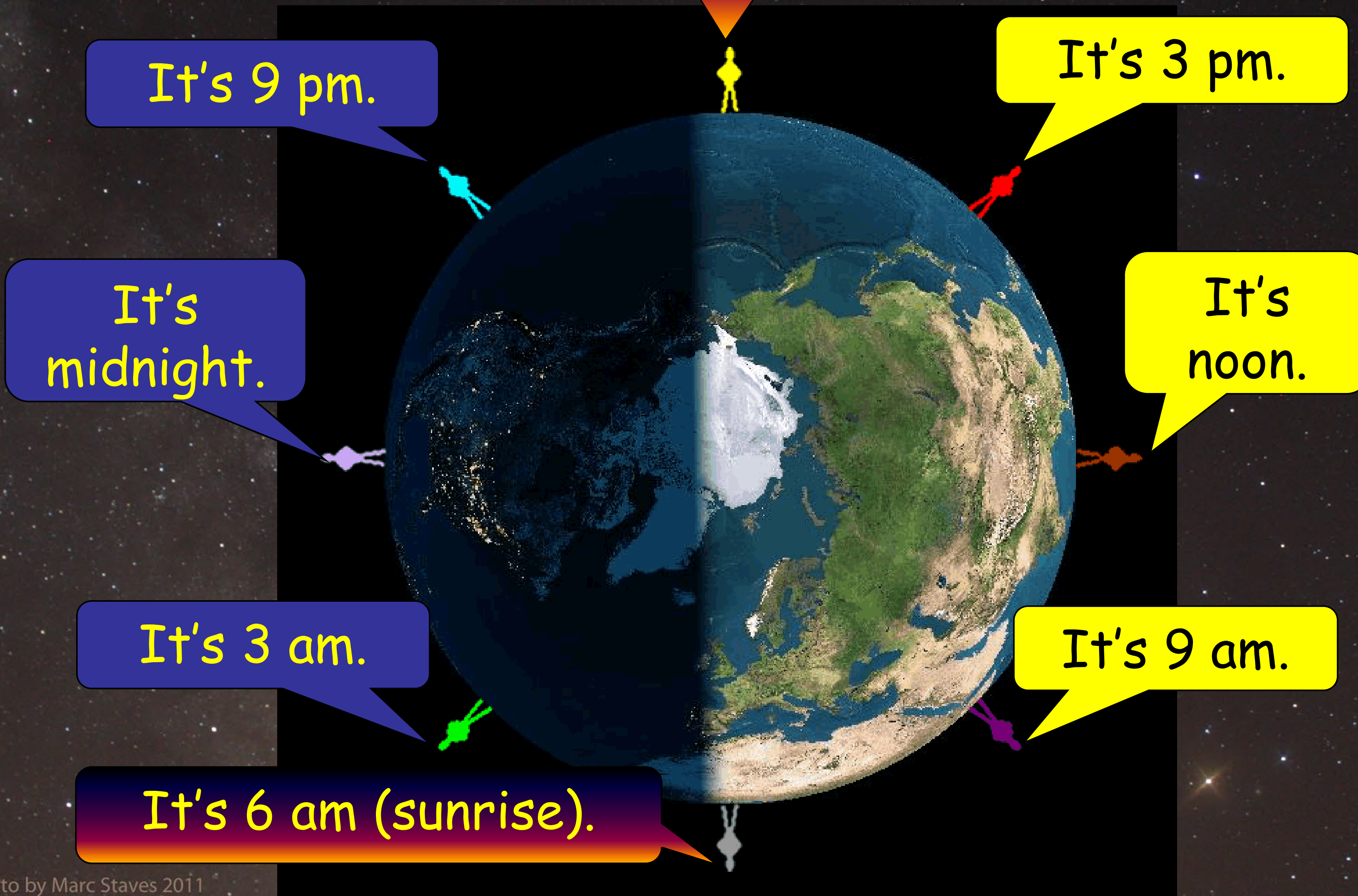
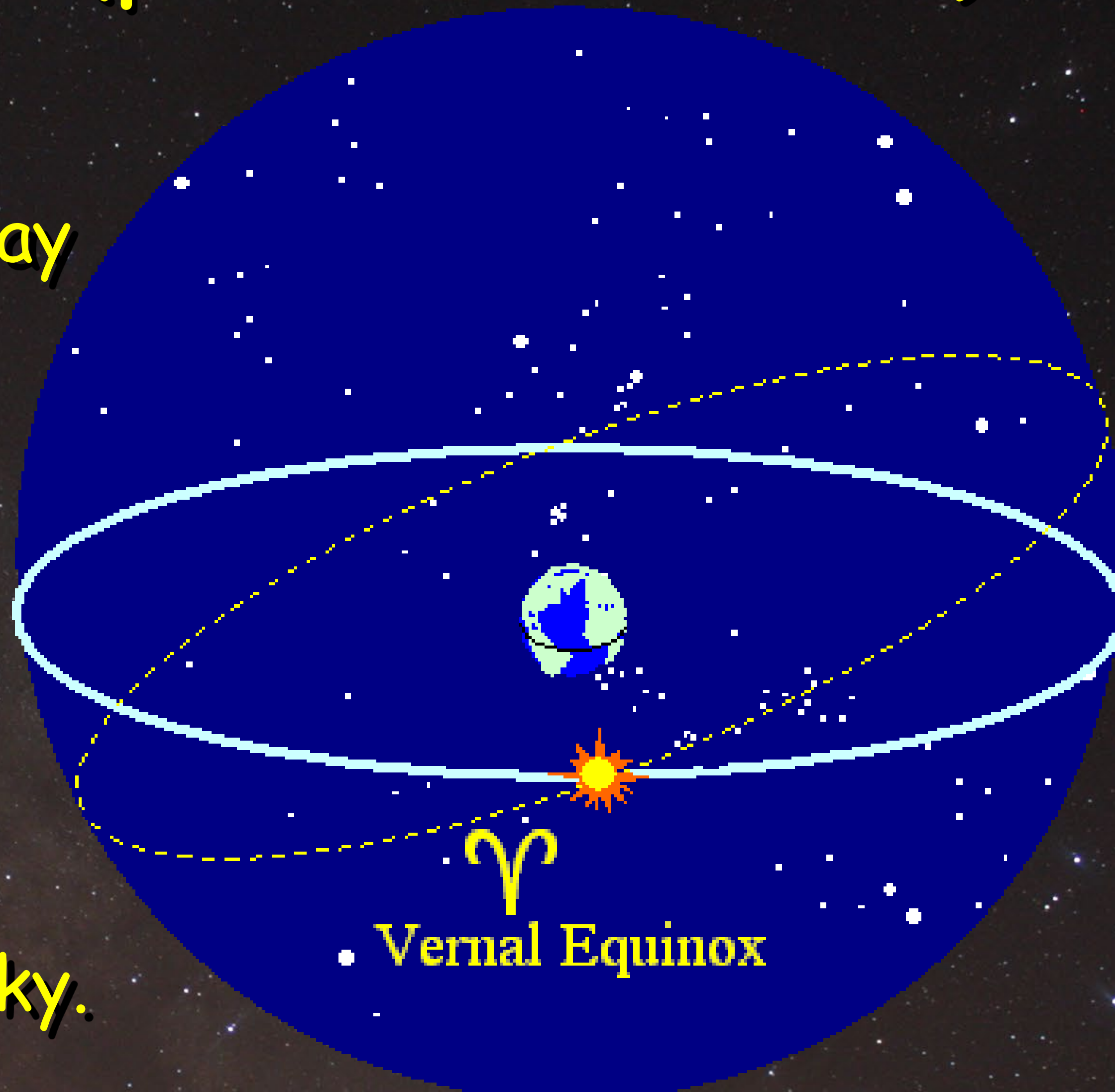


Photo by Marc Staves 2011

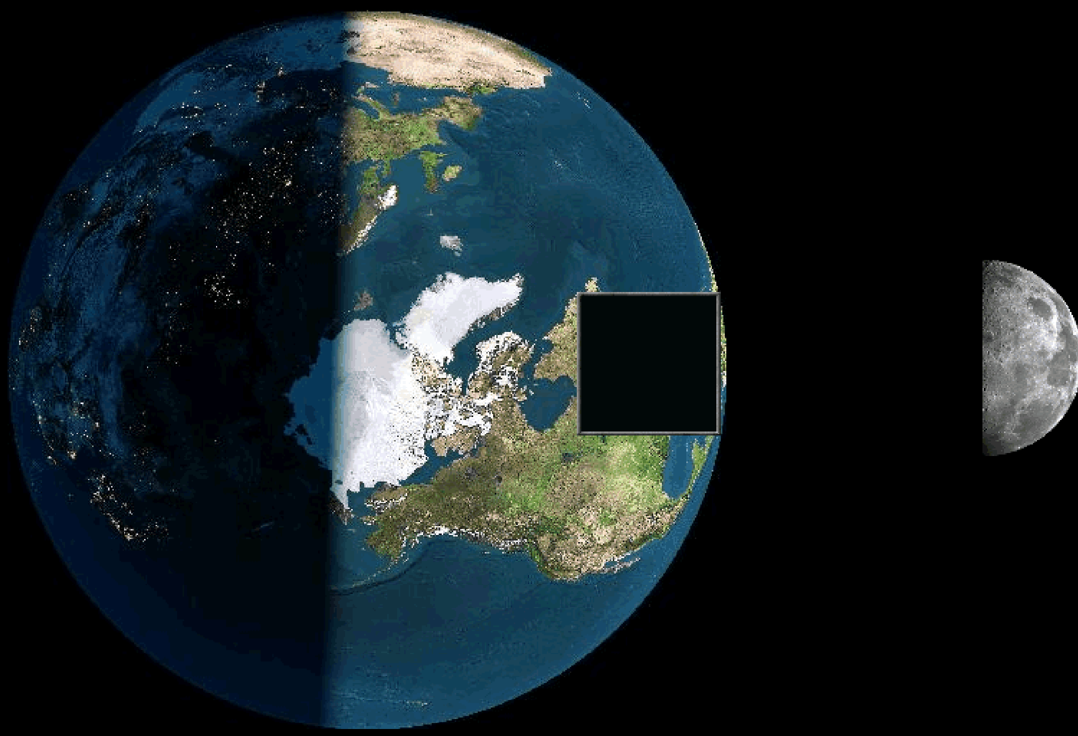
The Ecliptic (path of the sun)

- ☆ 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!

Photo by Marc Staves 2011



Moon Phase is lit moon visible

Insert is moon as see from Earth

Waxing Moon Phases

- ☆ Brown Lunation number 1234
  - ☽ Since first new moon of 1923 (1/16/23, 9:41 pm EST)
- New Moon: Sep. 25, 5:54 pm EDT
- 1st Quarter: Oct. 2, 8:14 pm EDT
- Full Moon: Oct. 9, 4:54 pm EDT
  - ☽ The Hunter's Moon!!

Waxing: Light on the right!

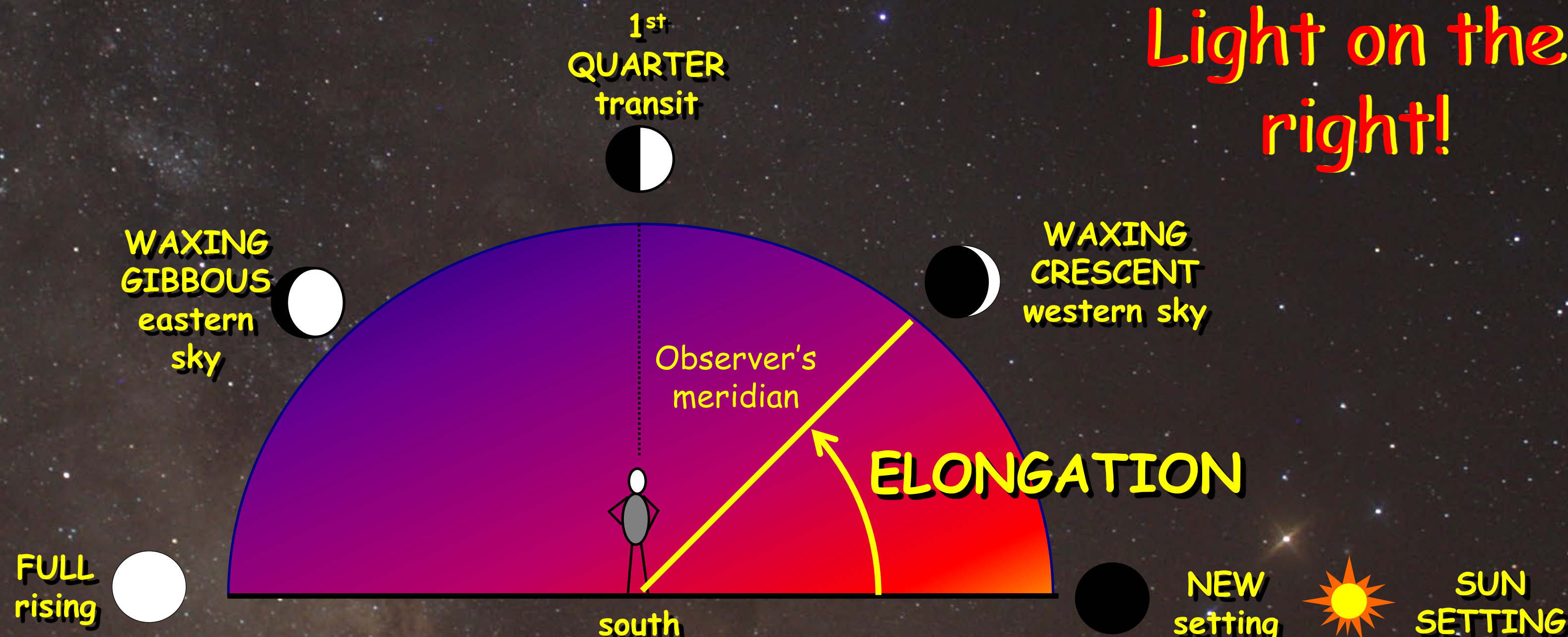


Photo by Marc Staves 2011

Waning Moon Phases

- ☆ Lunation Number 1234
  - ☆ Full Moon: Oct. 9, 4:54 pm EDT
  - ☆ 3rd Quarter: Oct. 17, 1:15 pm EDT
  - ☆ New Moon: Oct. 25, 6:48 am EDT

Waning: Light on the left!

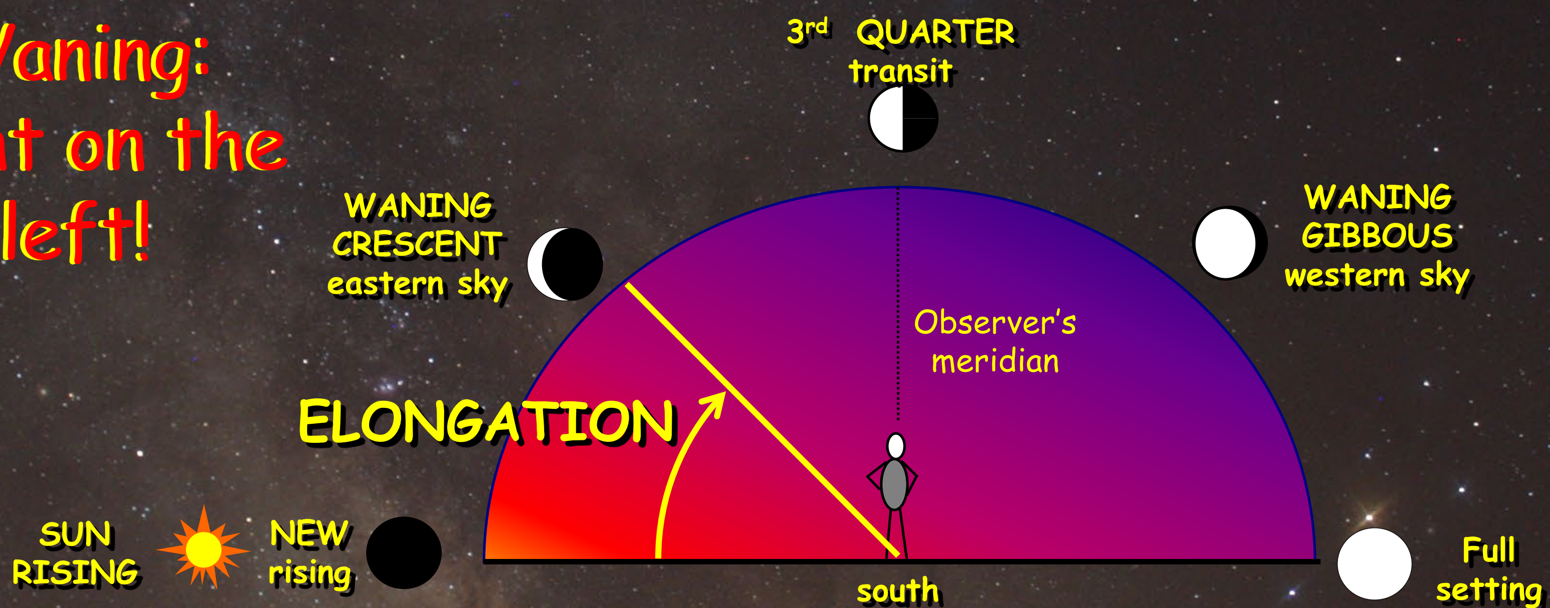
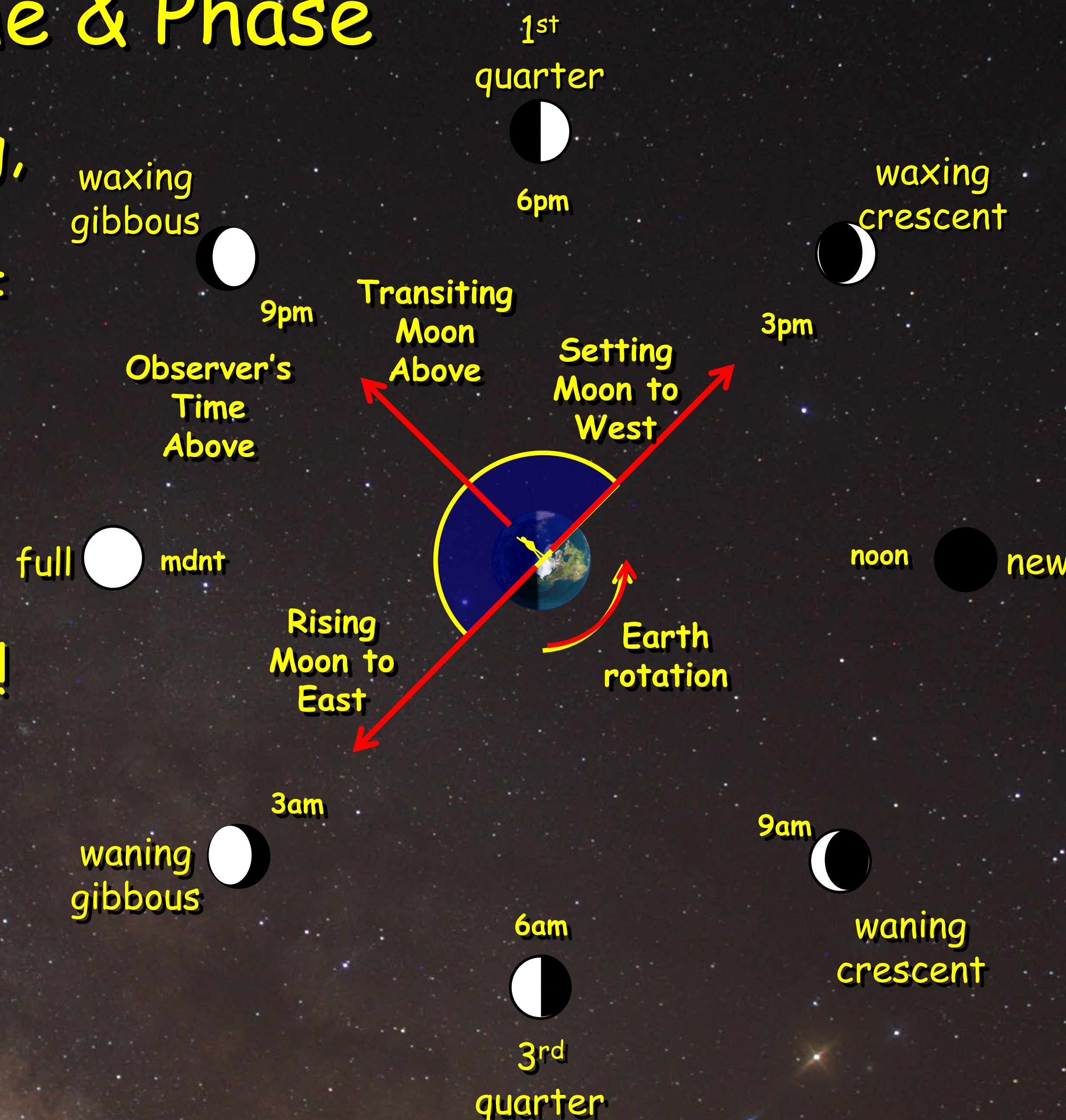


Photo by Marc Staves 2011

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 9 pm.
What phase is it?

a) Waxing Crescent
b) Waxing Gibbous
c) Waning Gibbous

Question

An observer sees the moon set at 3 am.
What phase is it?

a) Waxing Crescent
b) Waxing Gibbous
c) Waning Crescent

Photo by Marc Staves 2011

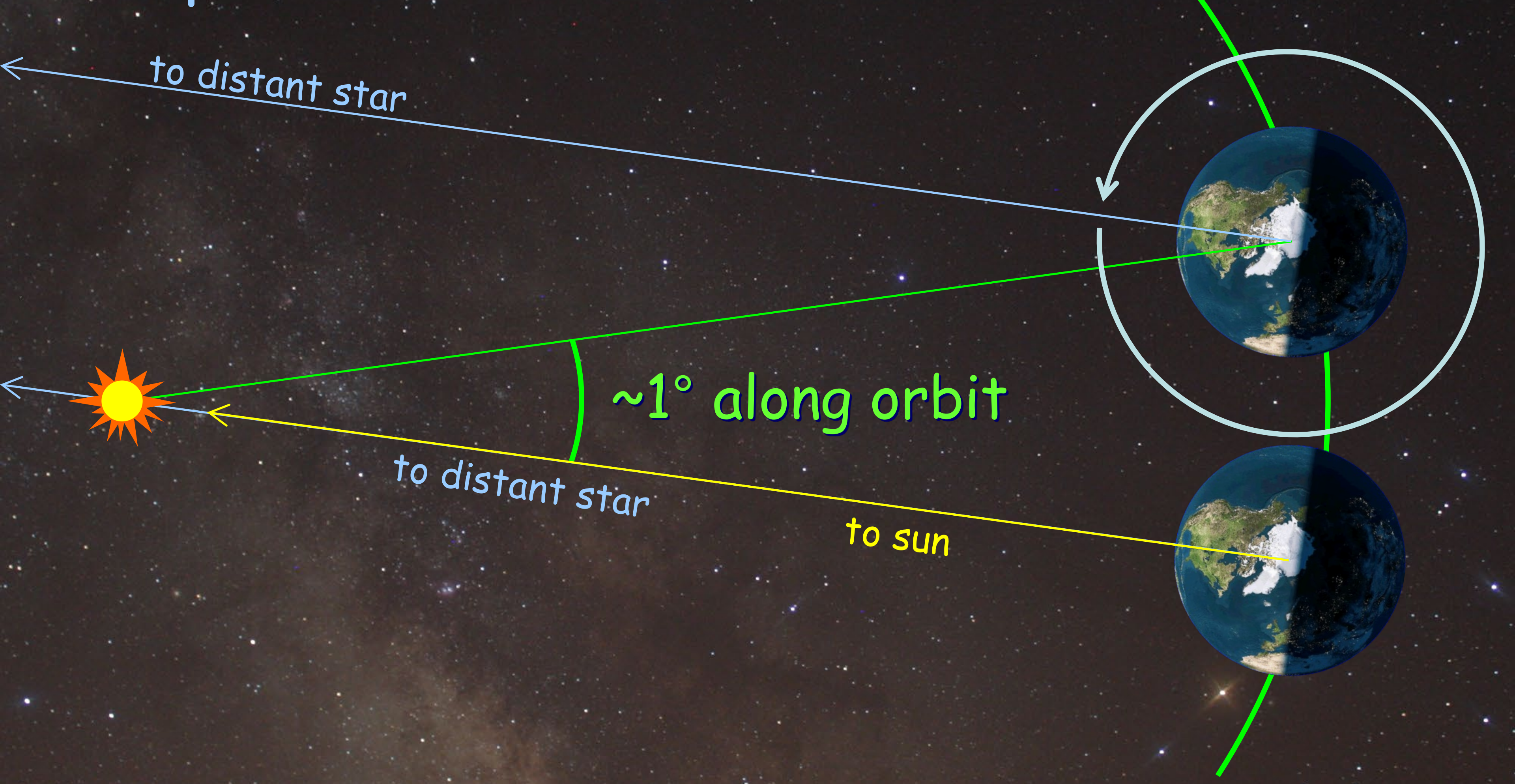
Time

- Clock Time
  - the position of the mean sun at TZ center
    - e.g. 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 with respect to the observer
    e.g. Noon = sun transits
  - Solar Day varies as shown by analemma
- Sidereal Time
  - the position of ♈ with respect to the observer
    - e.g. 0^h Local Sidereal Time (LST) = ♈ transits in Pisces
    - Sidereal time = R.A. on the meridian
  - Sidereal Day = 23:56:00

Photo by Marc Staves 2011

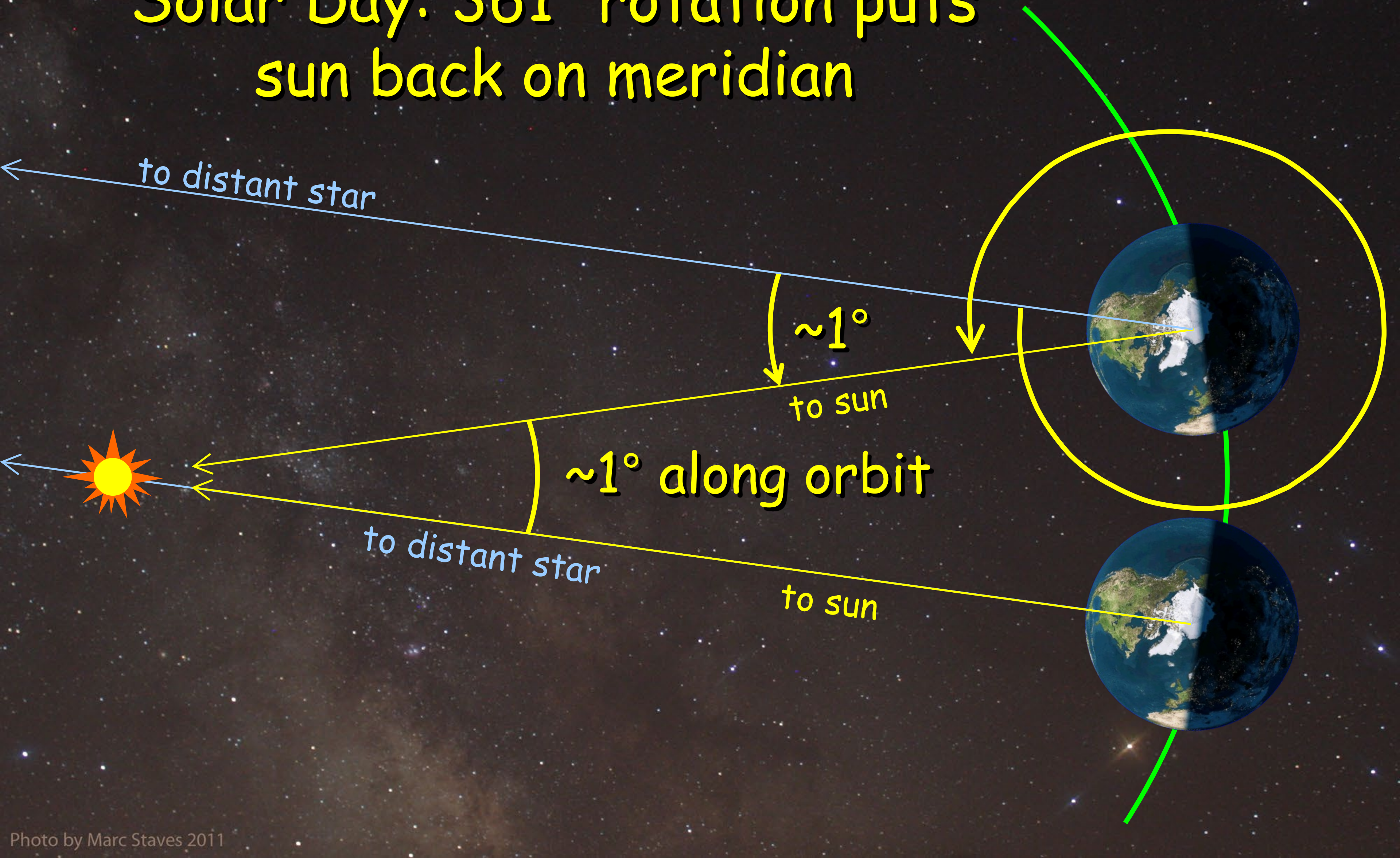
The Sidereal Day

Sidereal Day: 360° rotation puts star back on meridian



The Solar Day

Solar Day: 361° rotation puts sun back on meridian



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

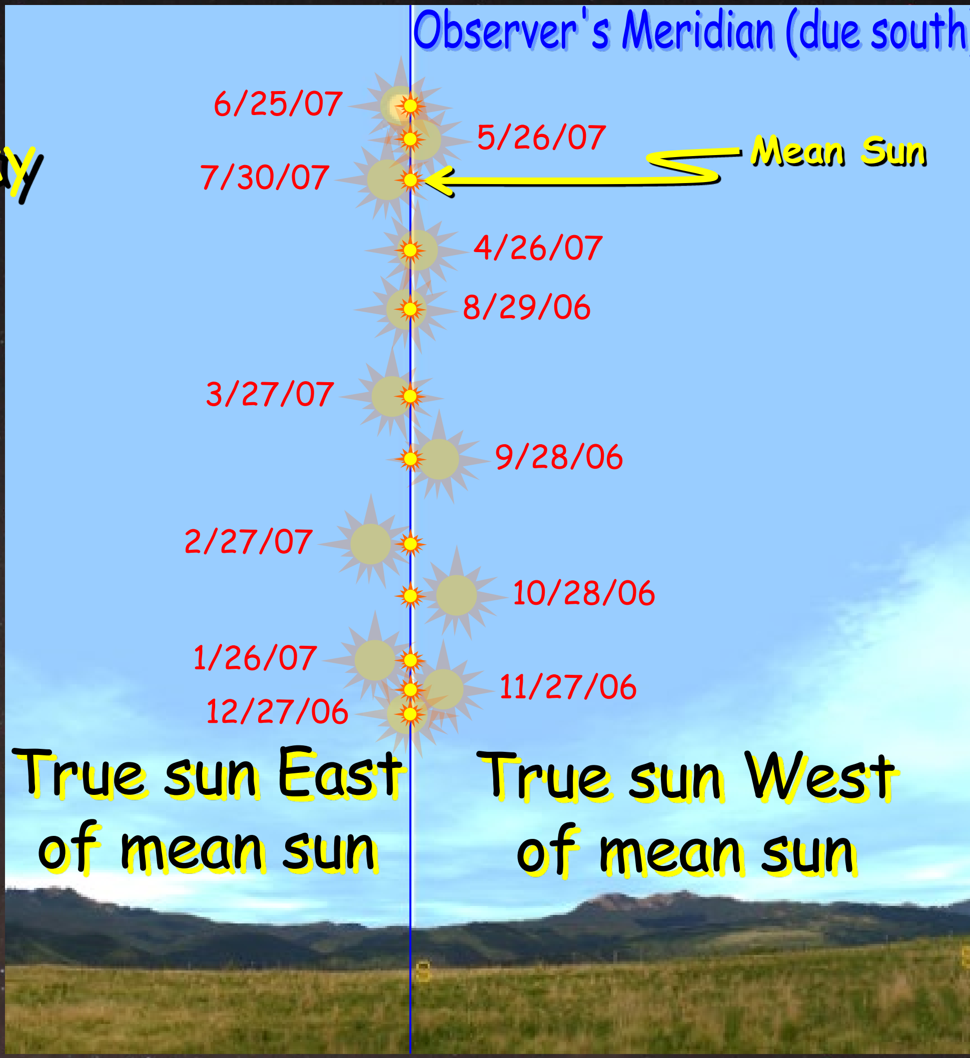
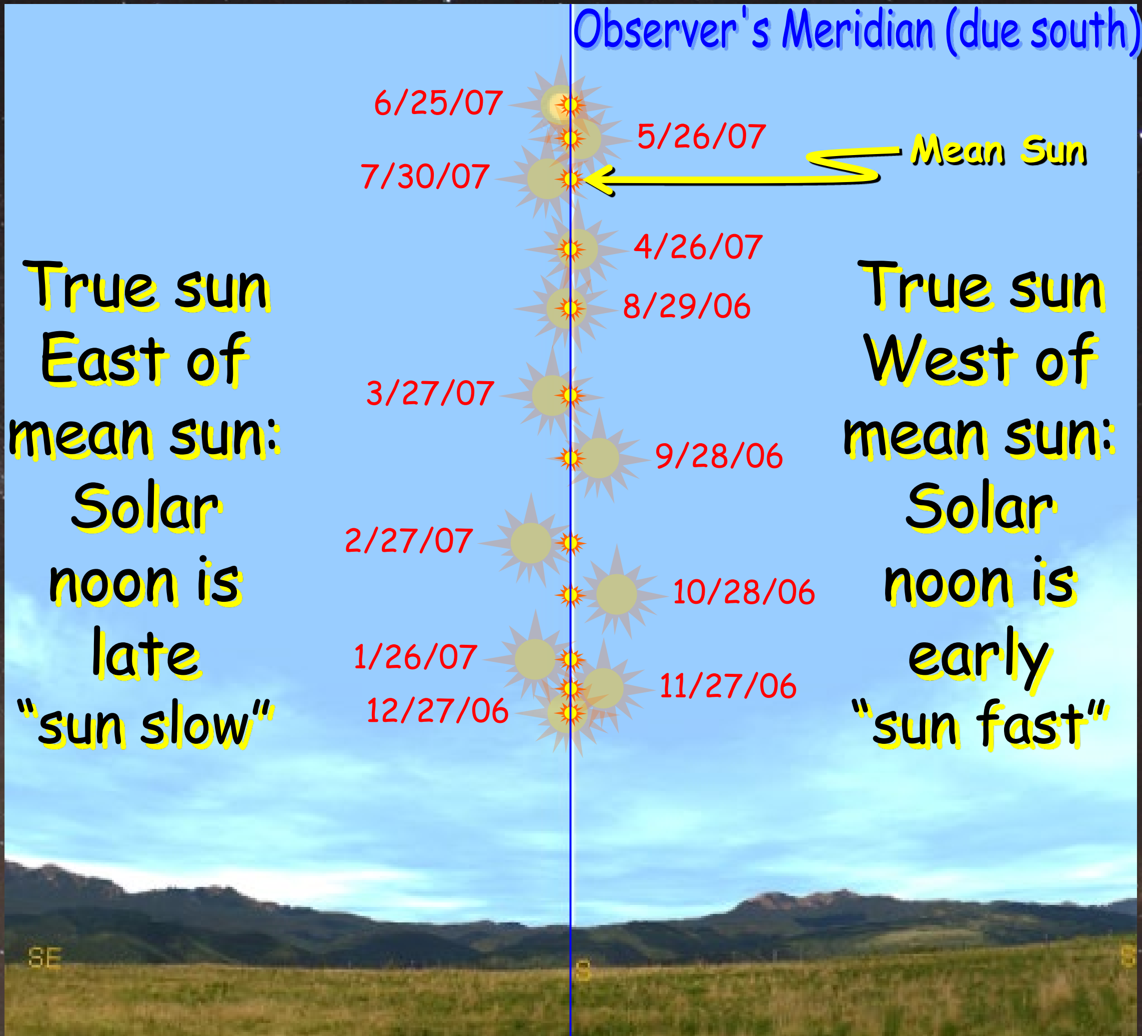


Photo by Marc Staves 2011

Mean Sun & True Sun

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

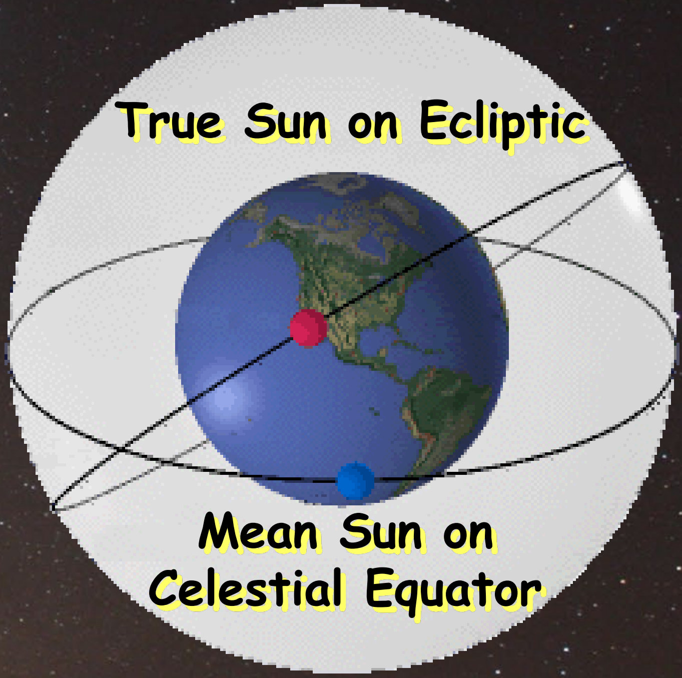


Doing the Math

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

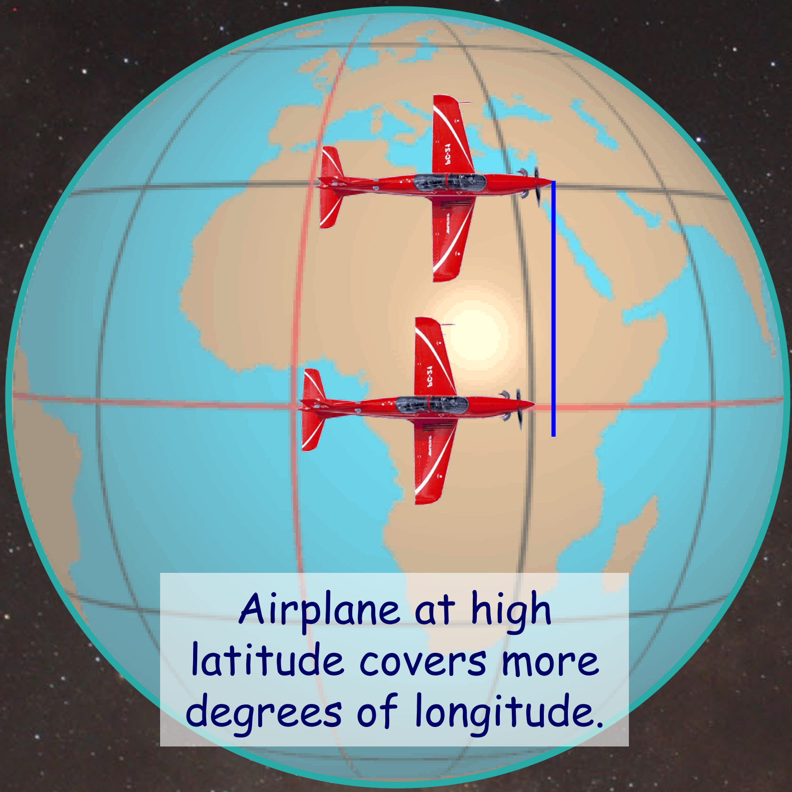
$$v_{\text{Mean Sun}} = \frac{360^\circ}{365.242191\,\text{days}} = 0.985647356\ ^\circ/\text{day}$$

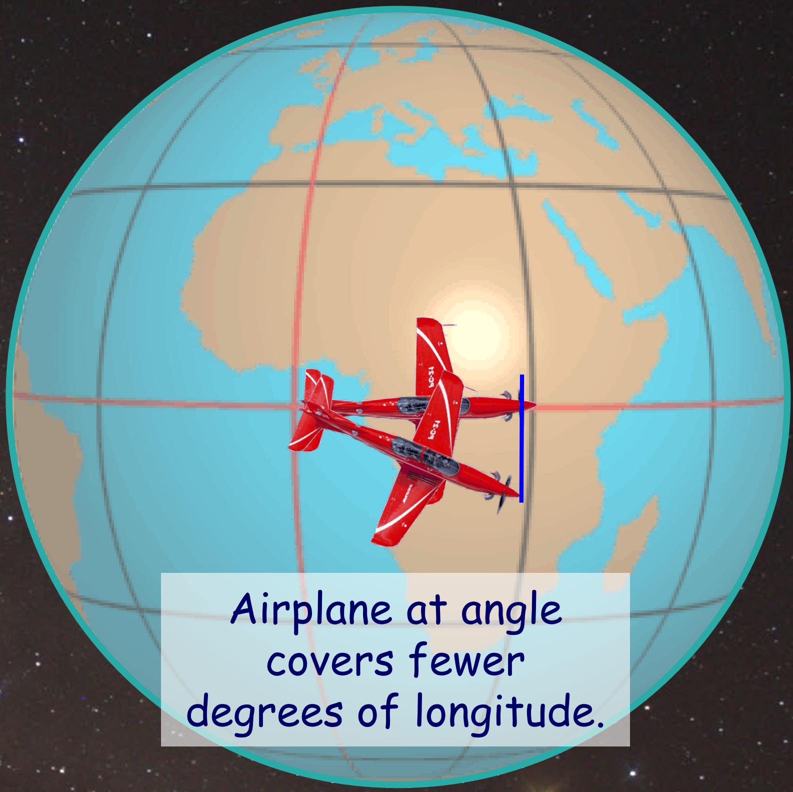
- ☆ True Sun
  - speed varies due to
    - Sun's changing Declination
    - Elliptical orbit



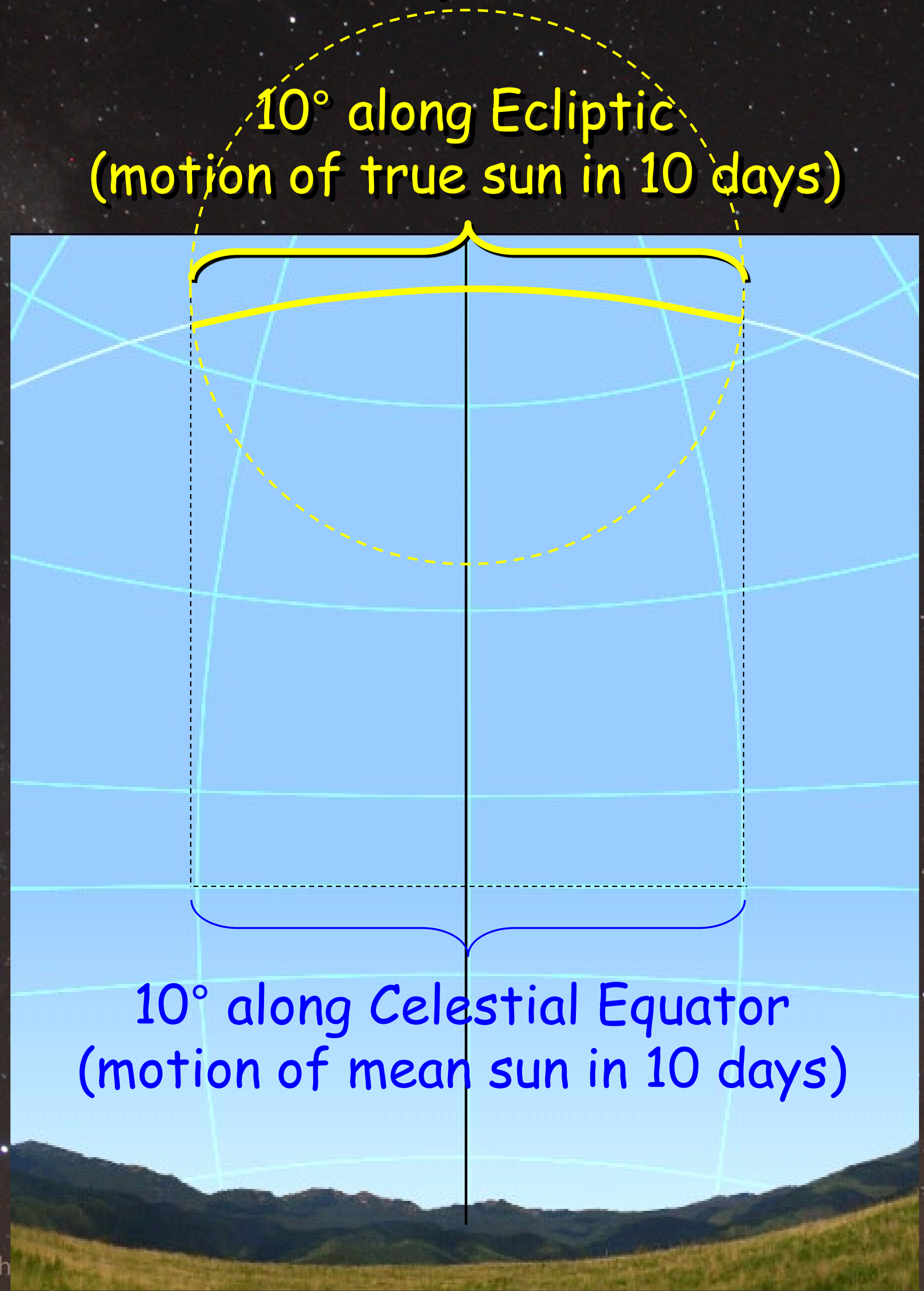
Speed Variation Due to Tilt

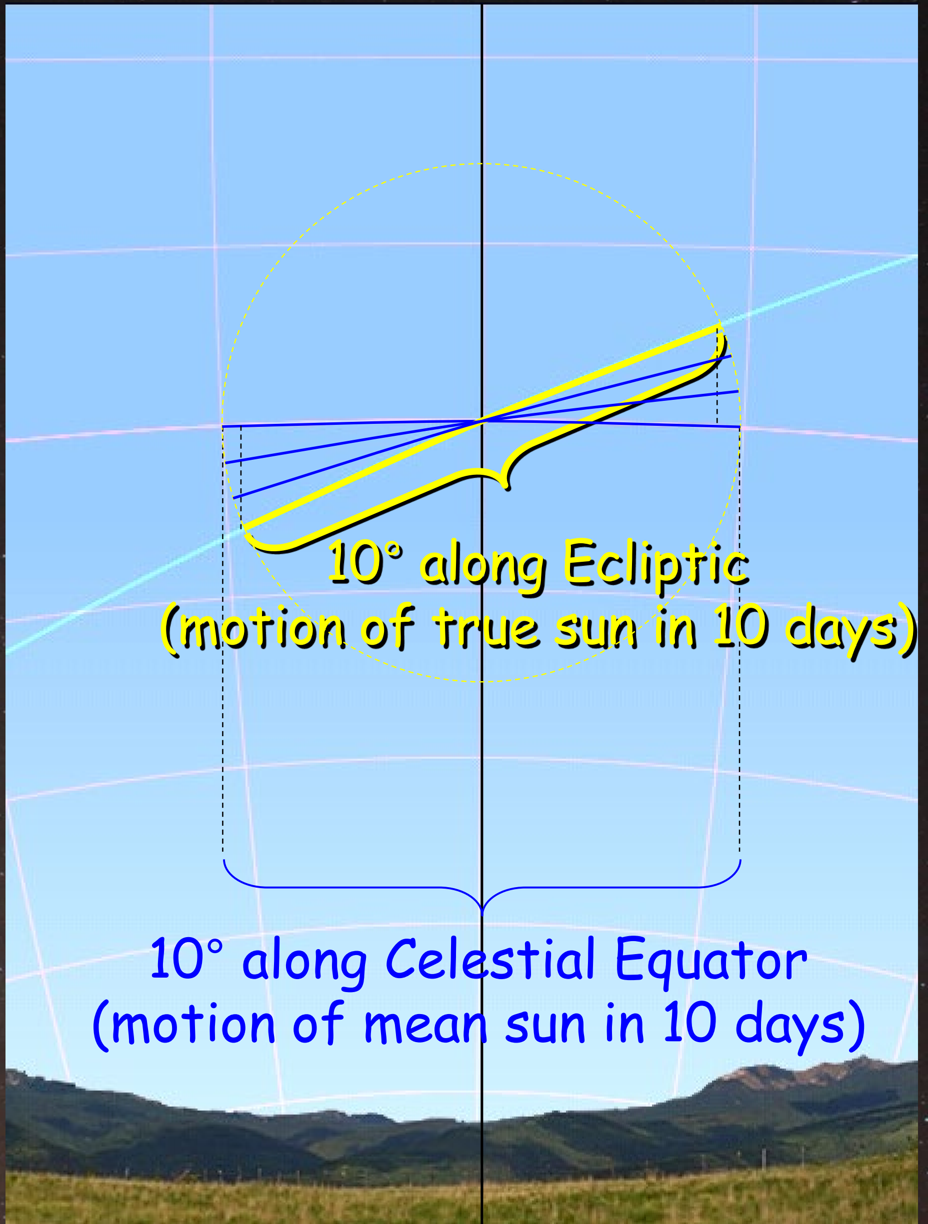
- Analogy: Airplanes on Earth
  - Both fly at same speed (mph)



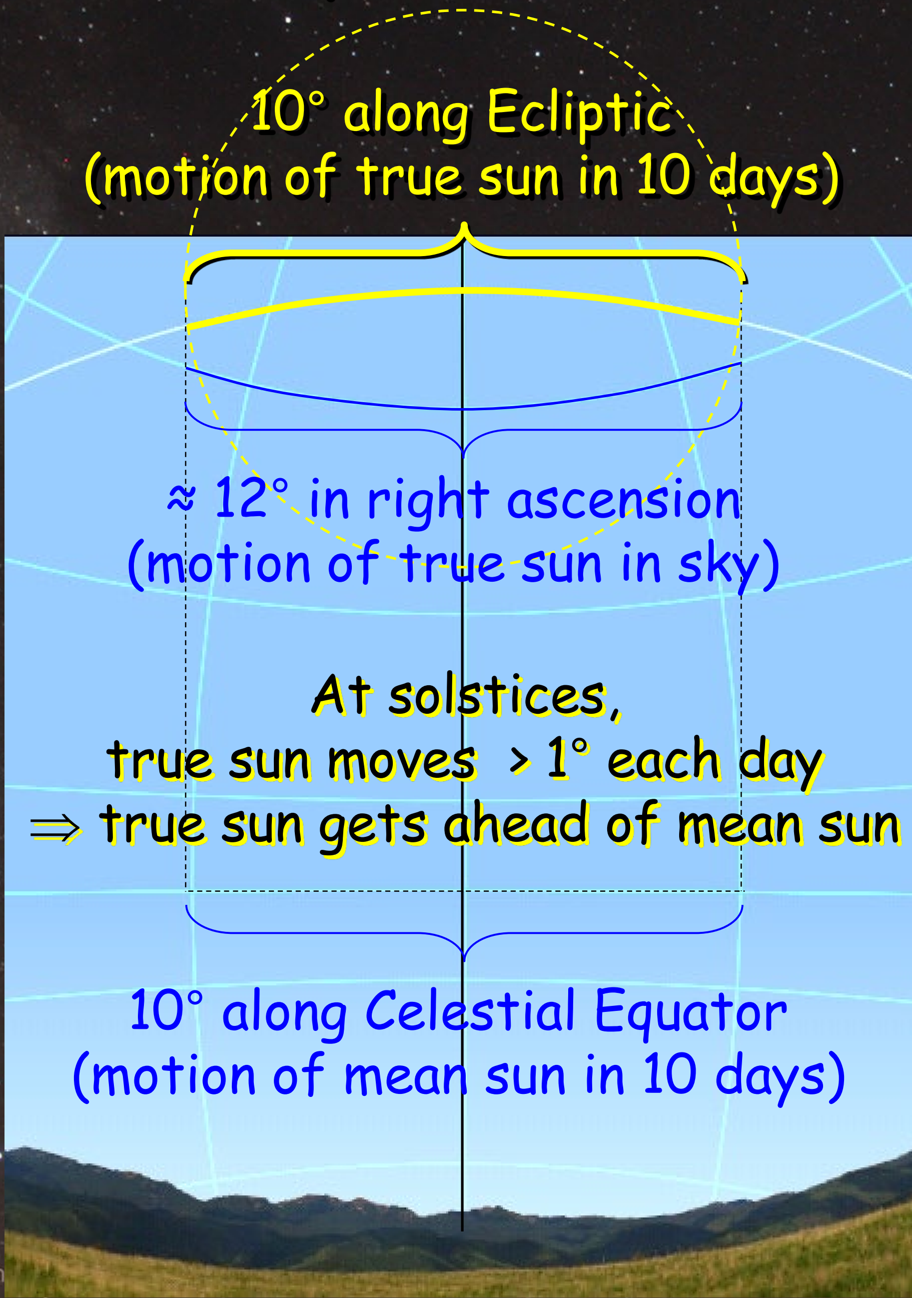


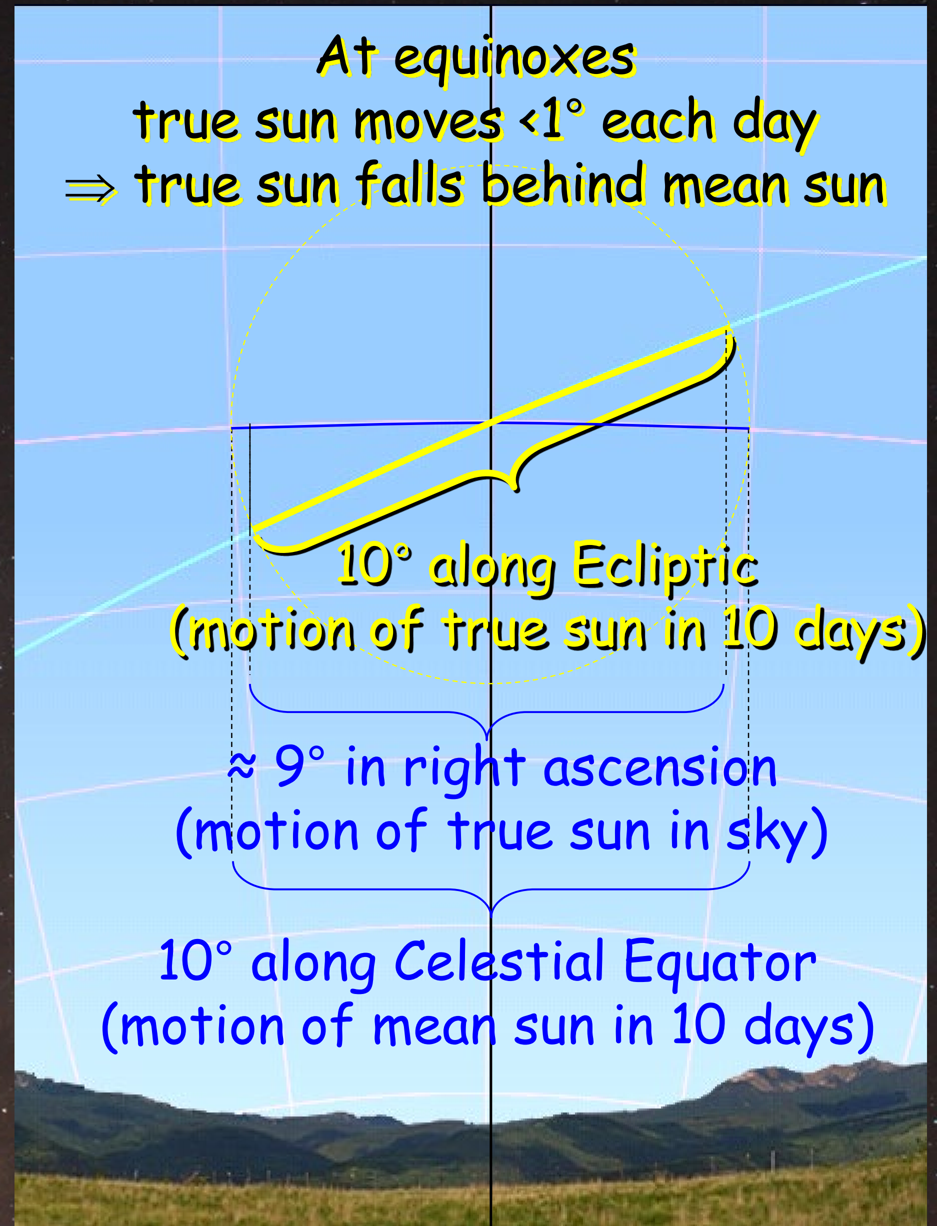
Sun Speed Variation Due to Tilt



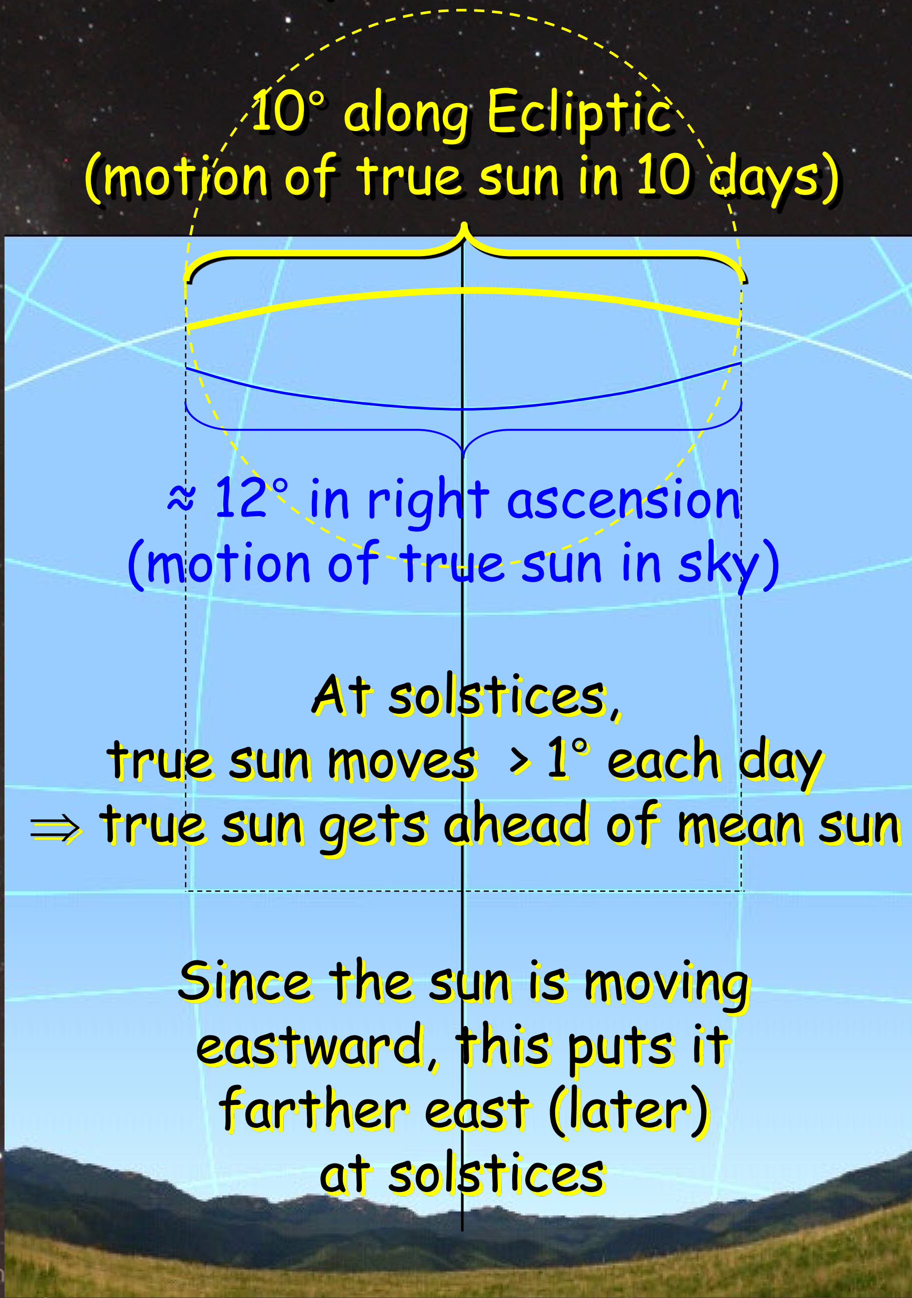


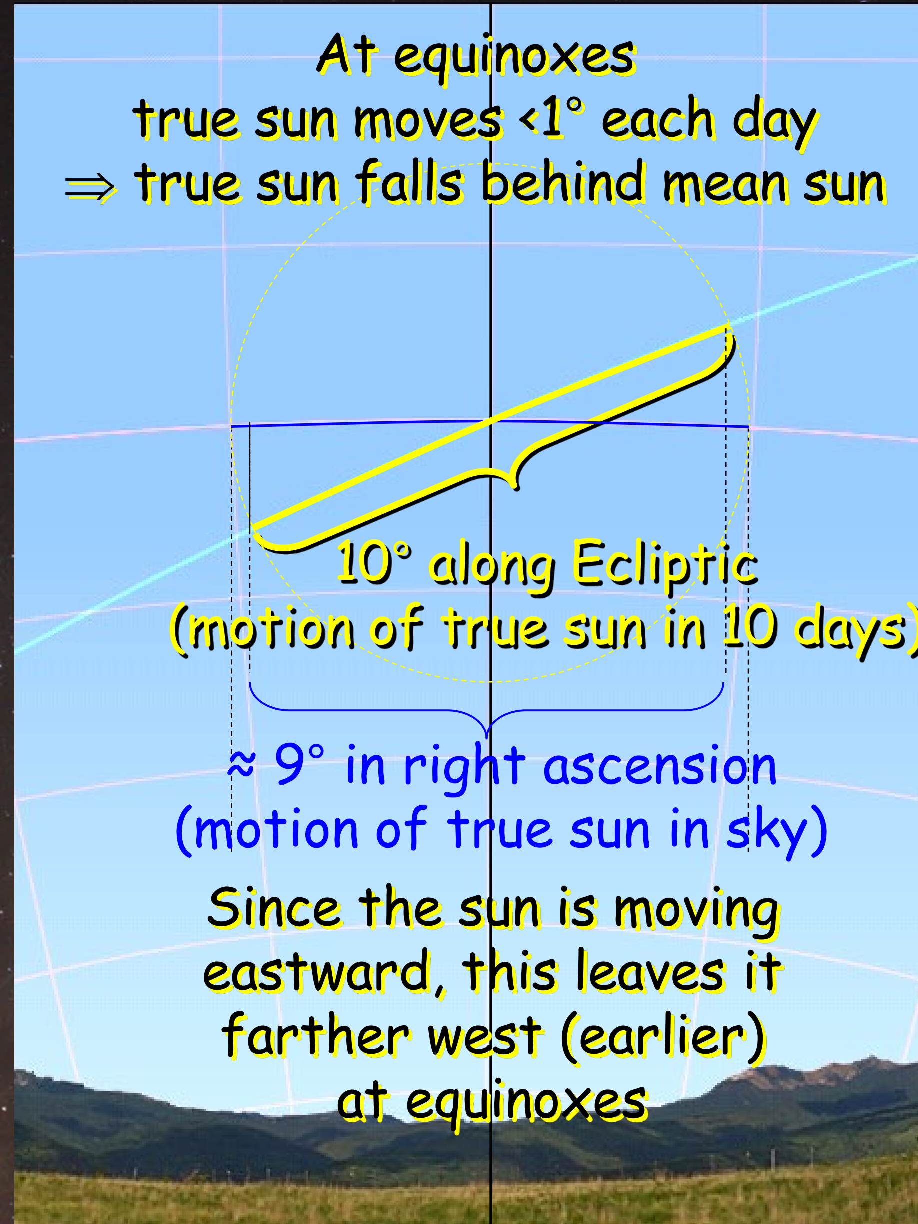
Speed Variation Due to Tilt





Speed Variation Due to Tilt



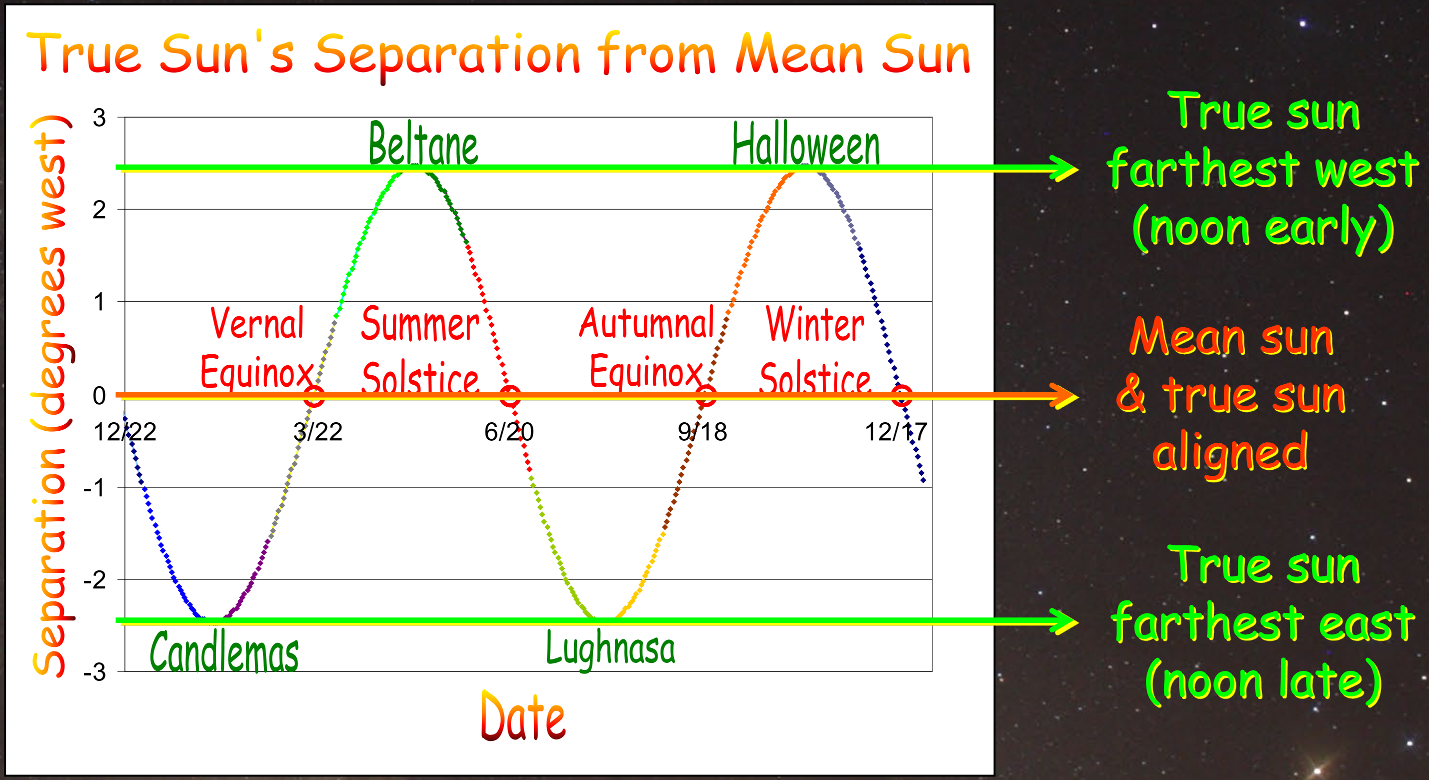


True Sun Speed Variation

- 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

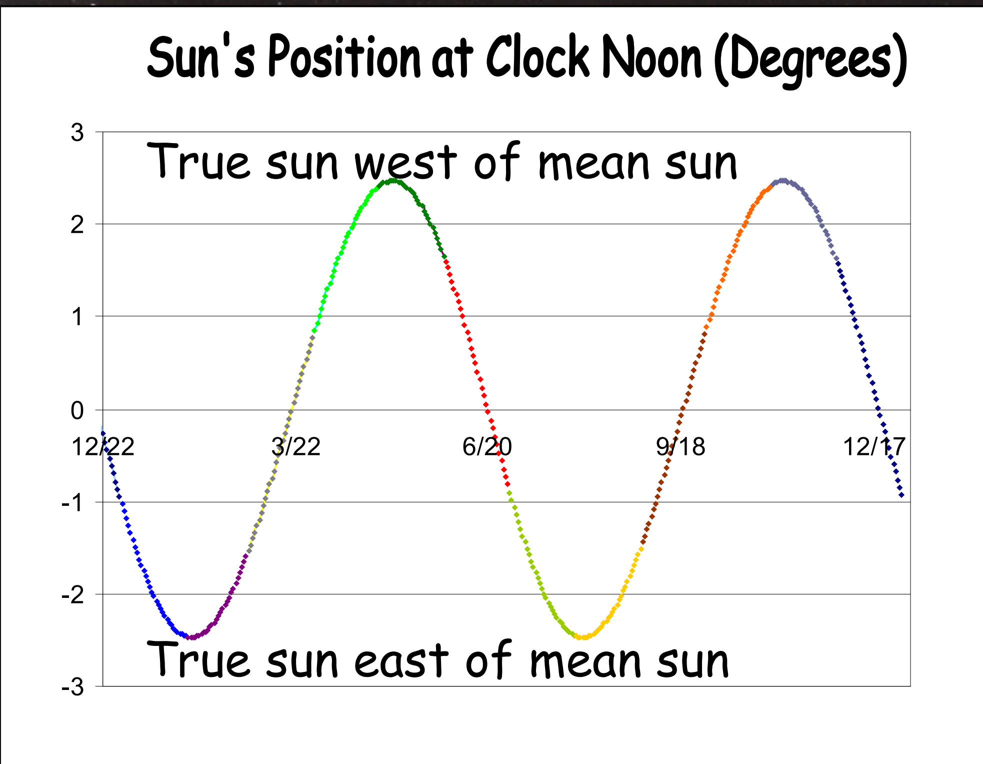
Speed Variation Due to Tilt

- Solstices & Equinoxes (June & December)
  - mean and true sun align, fastest rate of change
  - Solstices: moving east, Equinoxes: moving west



Tilt Analemma

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



But there's more to it …

Tilt Analemma: Potsdam, NY

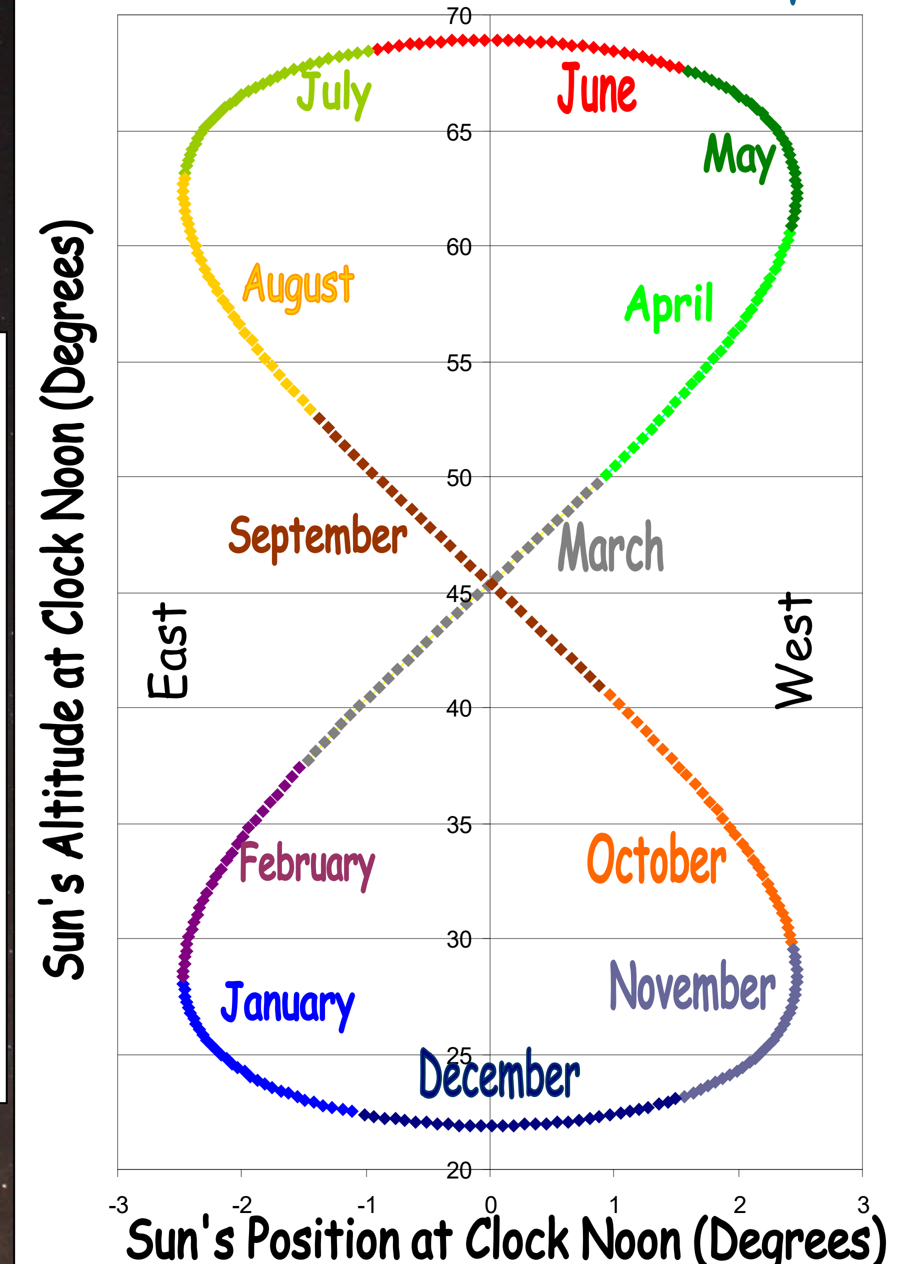
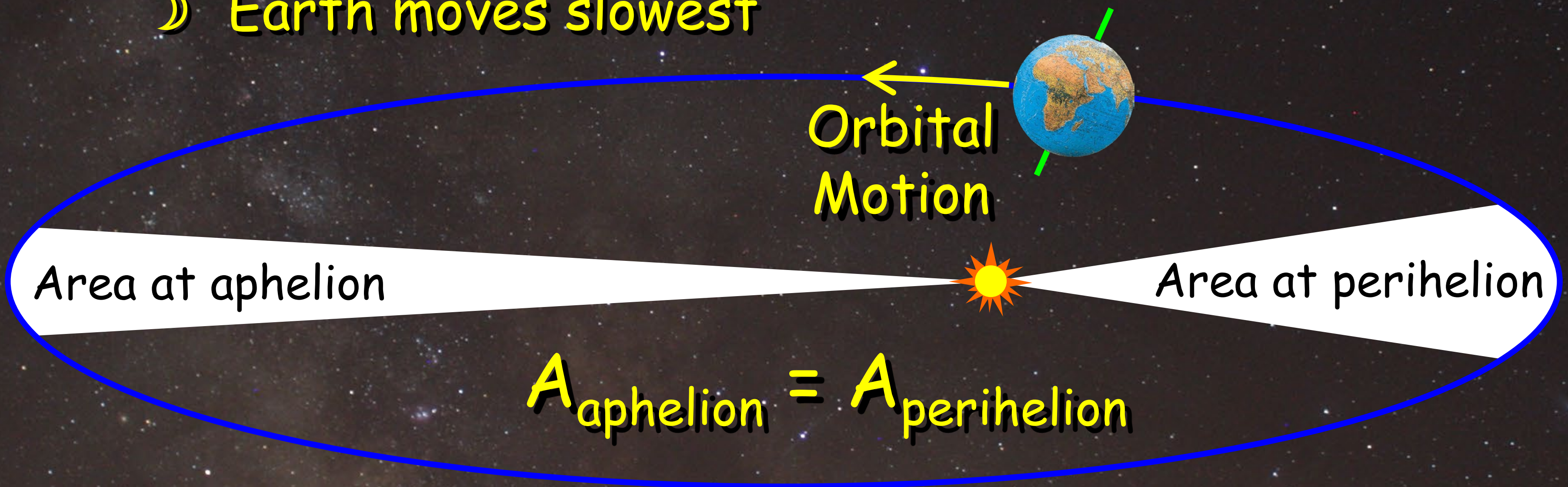


Photo by Marc Staves 2011

Earth's Orbit

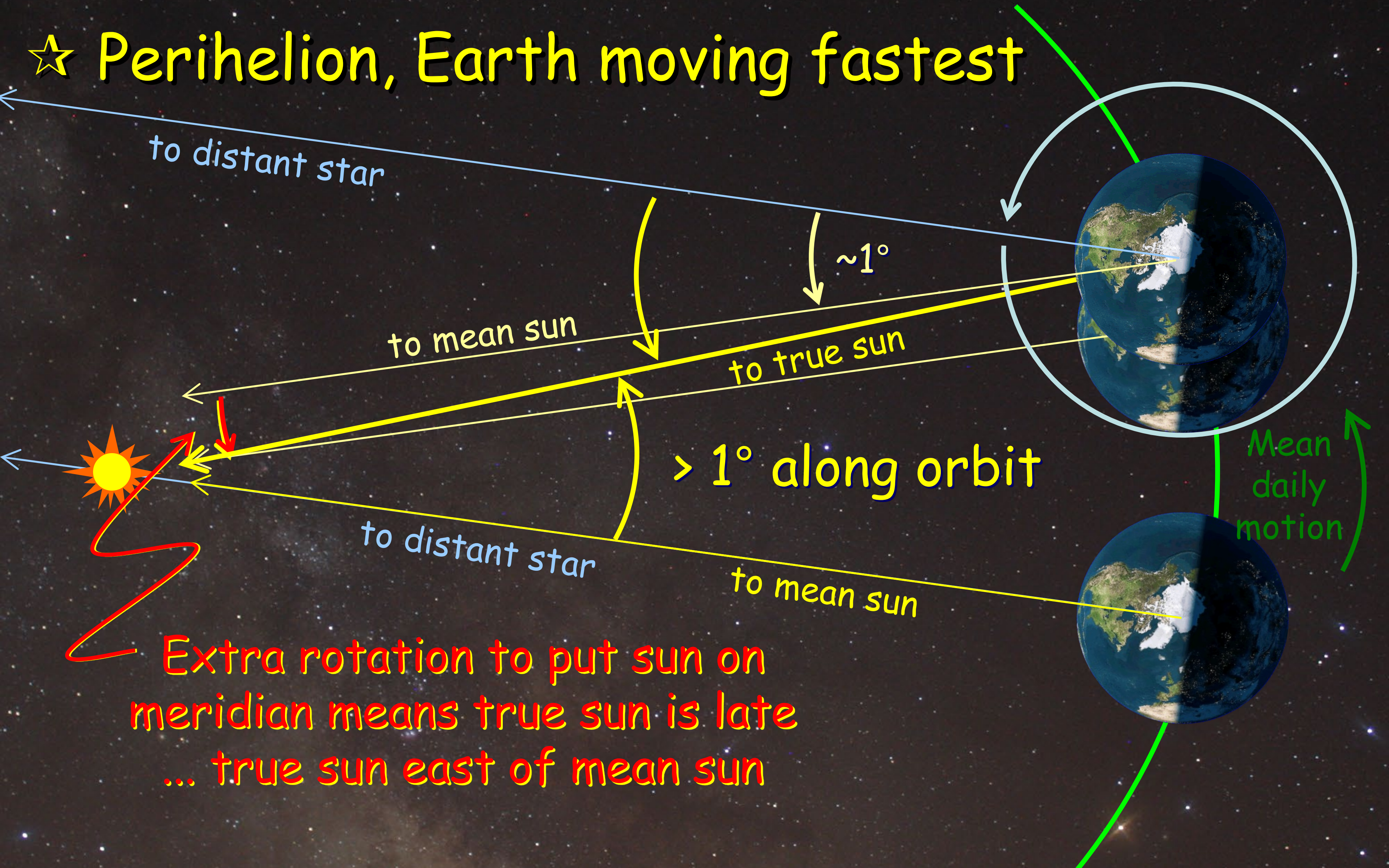
- ☆ Earth's speed varies in orbit
  - area swept out in a given time stays equal
  - perihelion (~ January 4)
    - ☽ Earth moves fastest (February is shortest month!)
  - aphelion (~ July 4)
    - ☽ Earth moves slowest



Orbital speed changes to keep swept areas equal

The Analemma

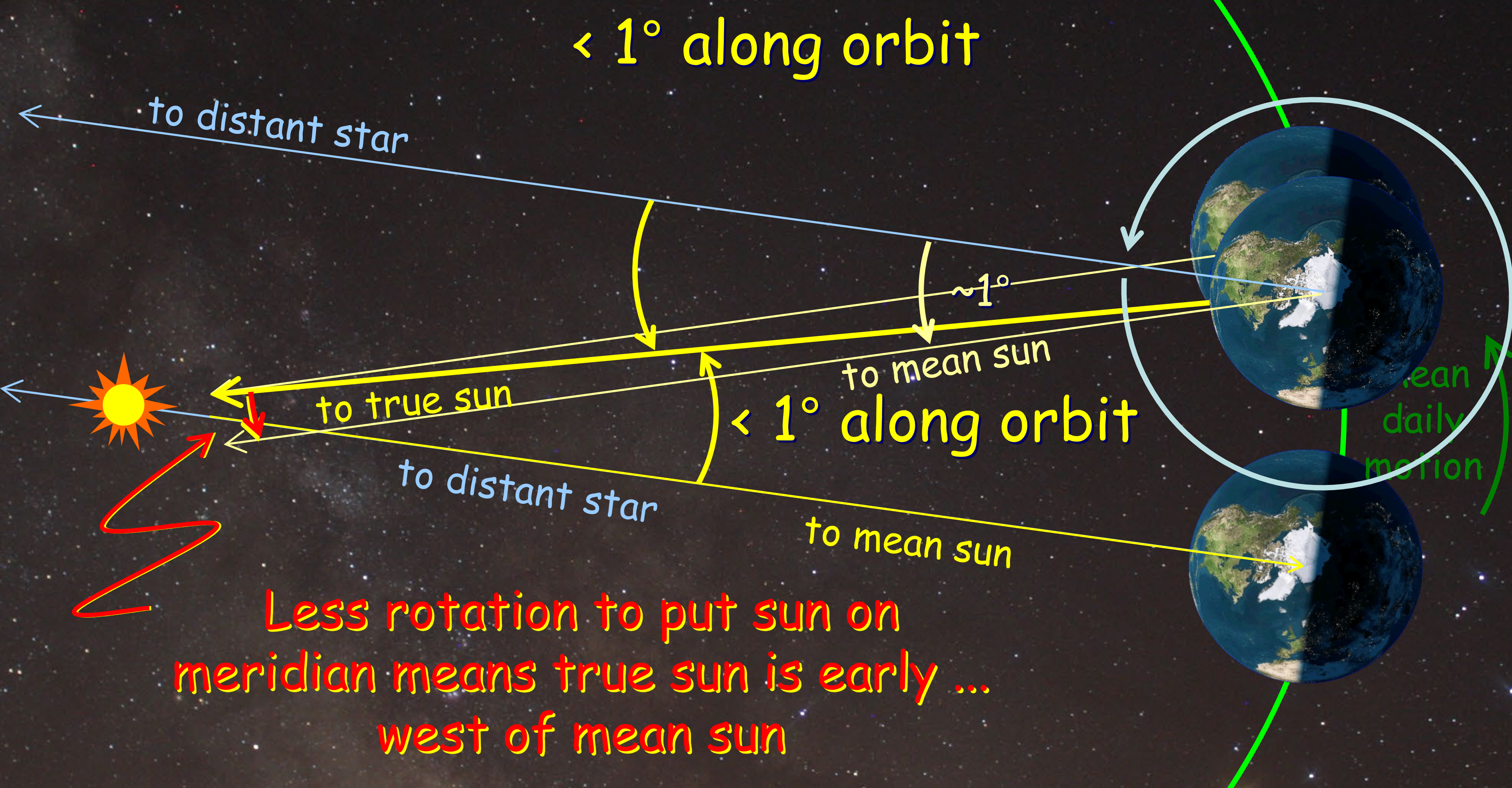
☆ Perihelion, Earth moving fastest



$r_{perihelion}$ = 91.4 million miles, $v_{perihelion}$ = 67,754 mph

The Analemma

☆ Aphelion, Earth moving slowest



Less rotation to put sun on meridian means true sun is early ... west 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

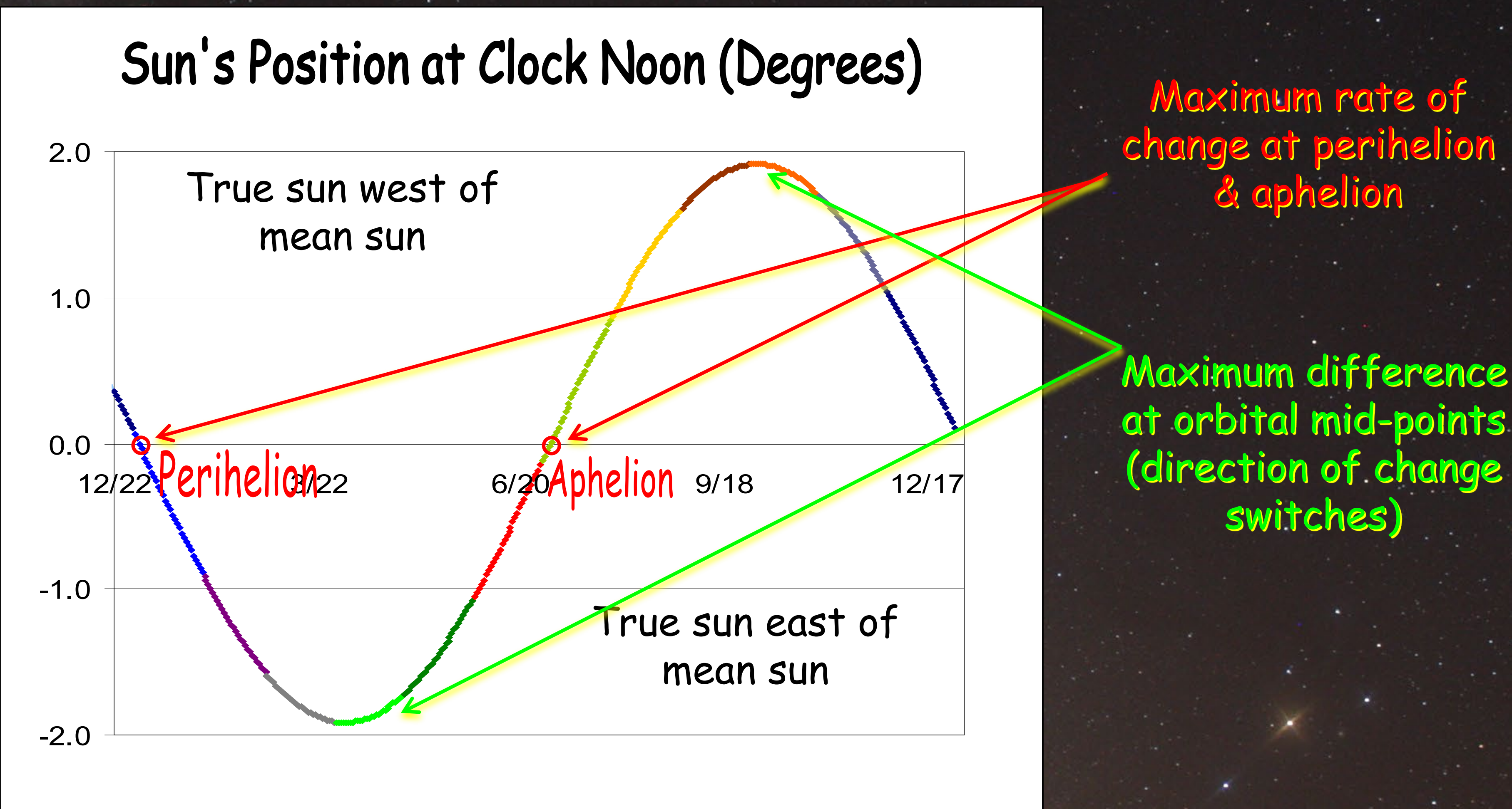


Photo by Marc Staves 2011

Orbit Analemma

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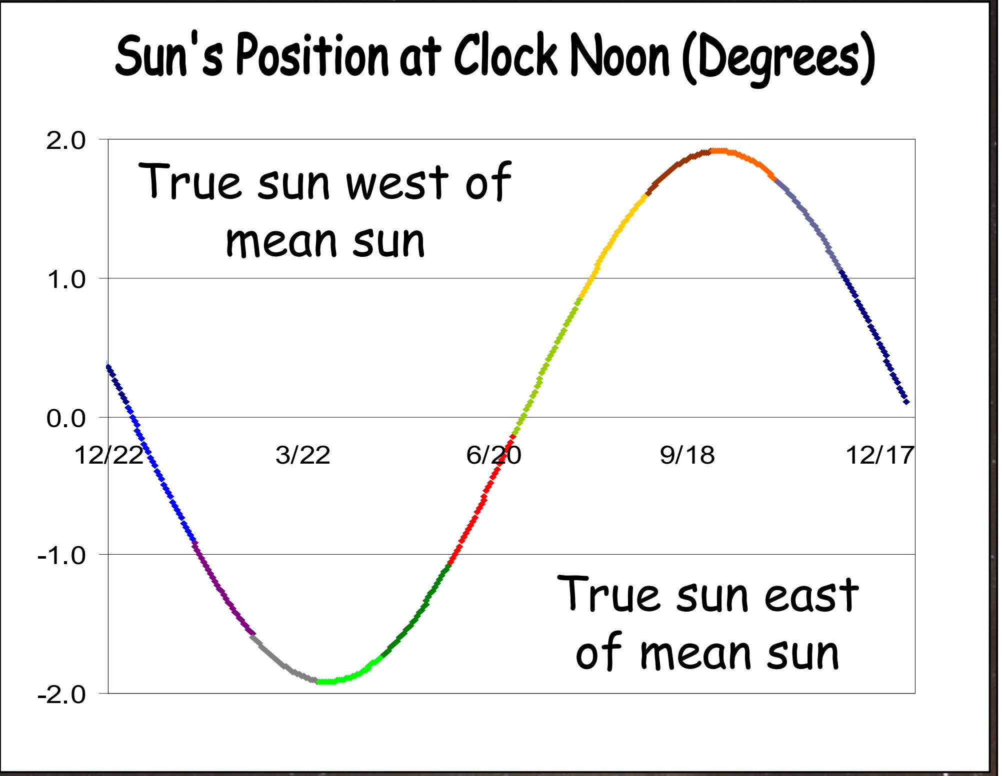
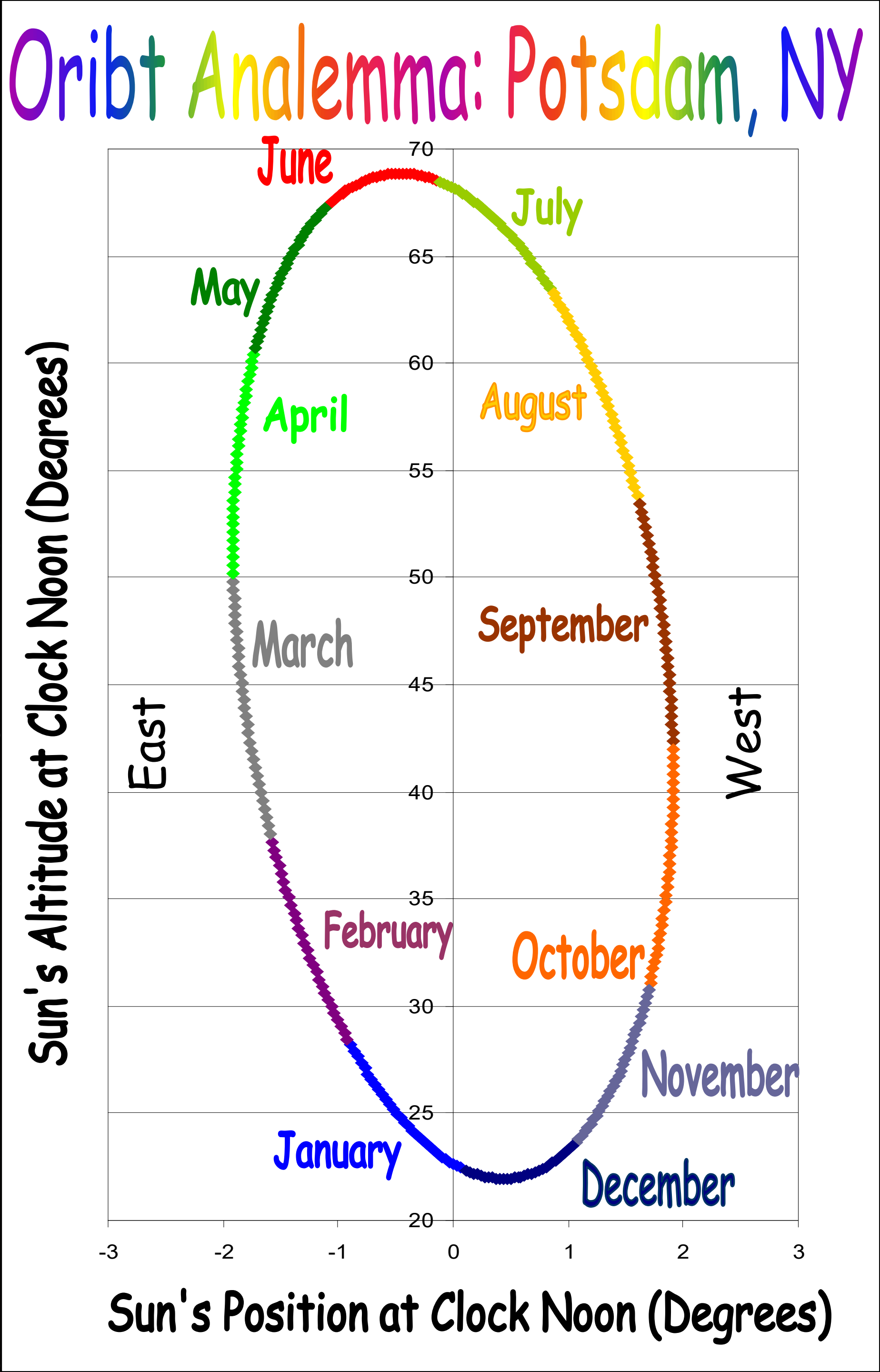
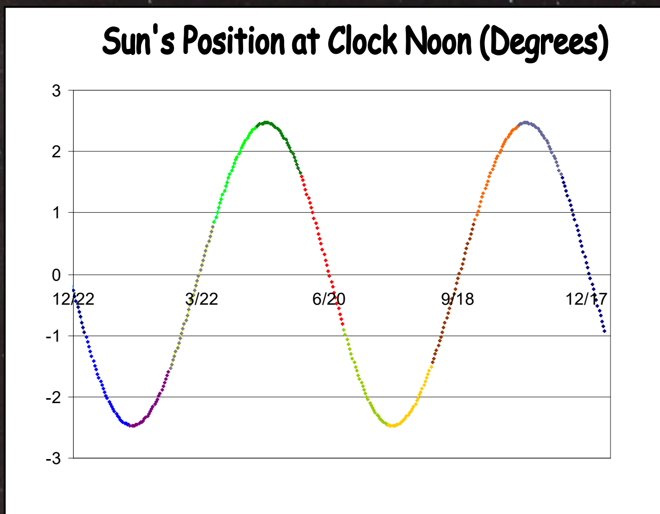
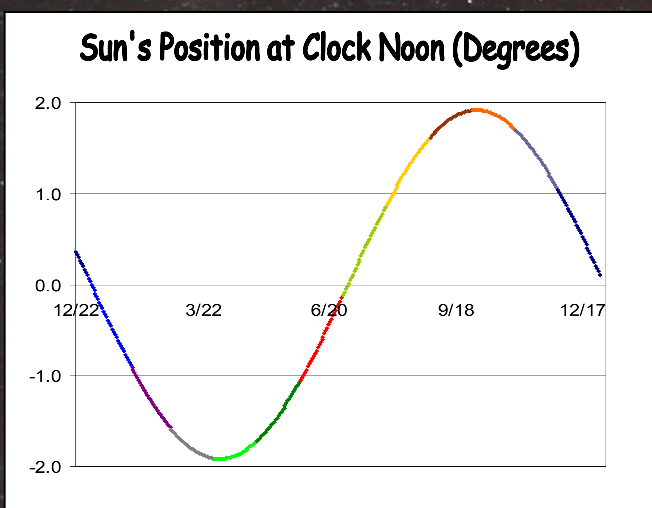




Total Analemma

☆ Tilt and Orbit effects add





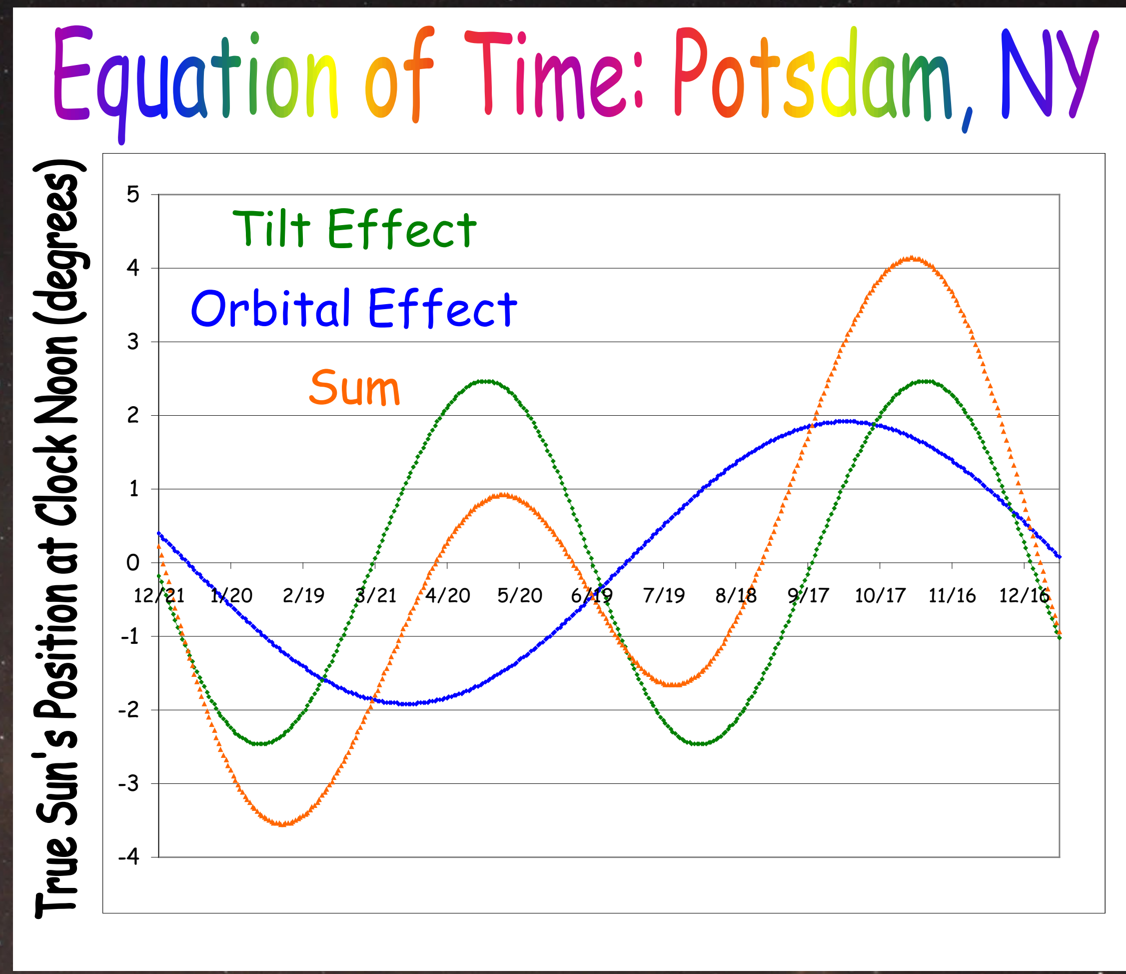


Photo by Marc Staves 2011

Total Analemma

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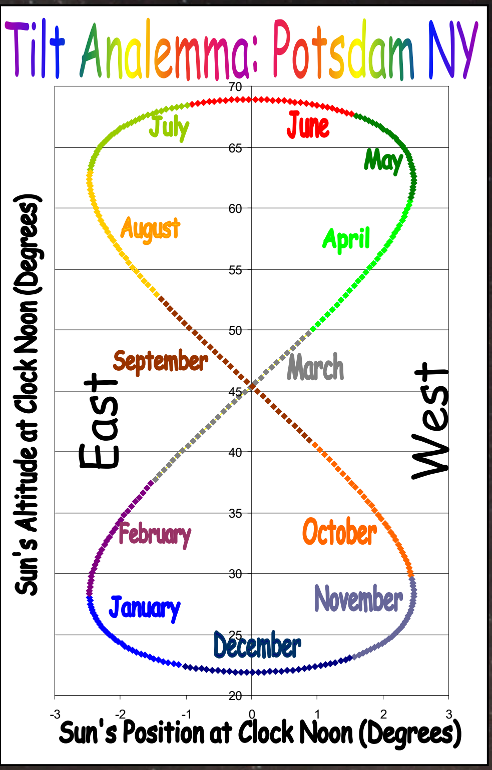
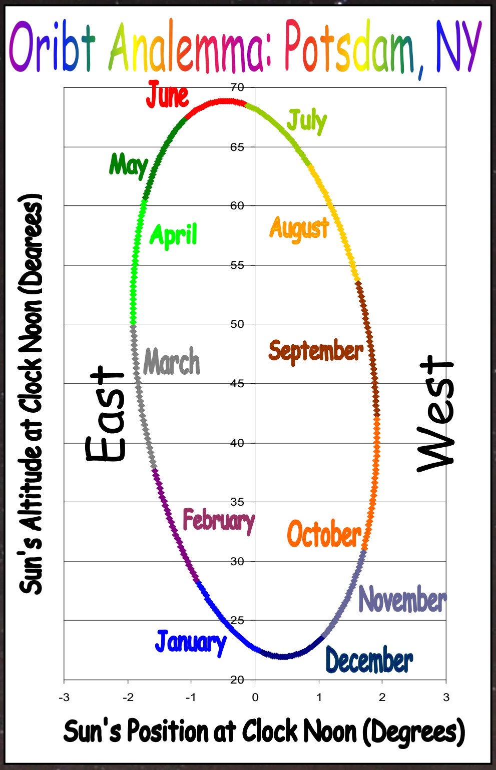




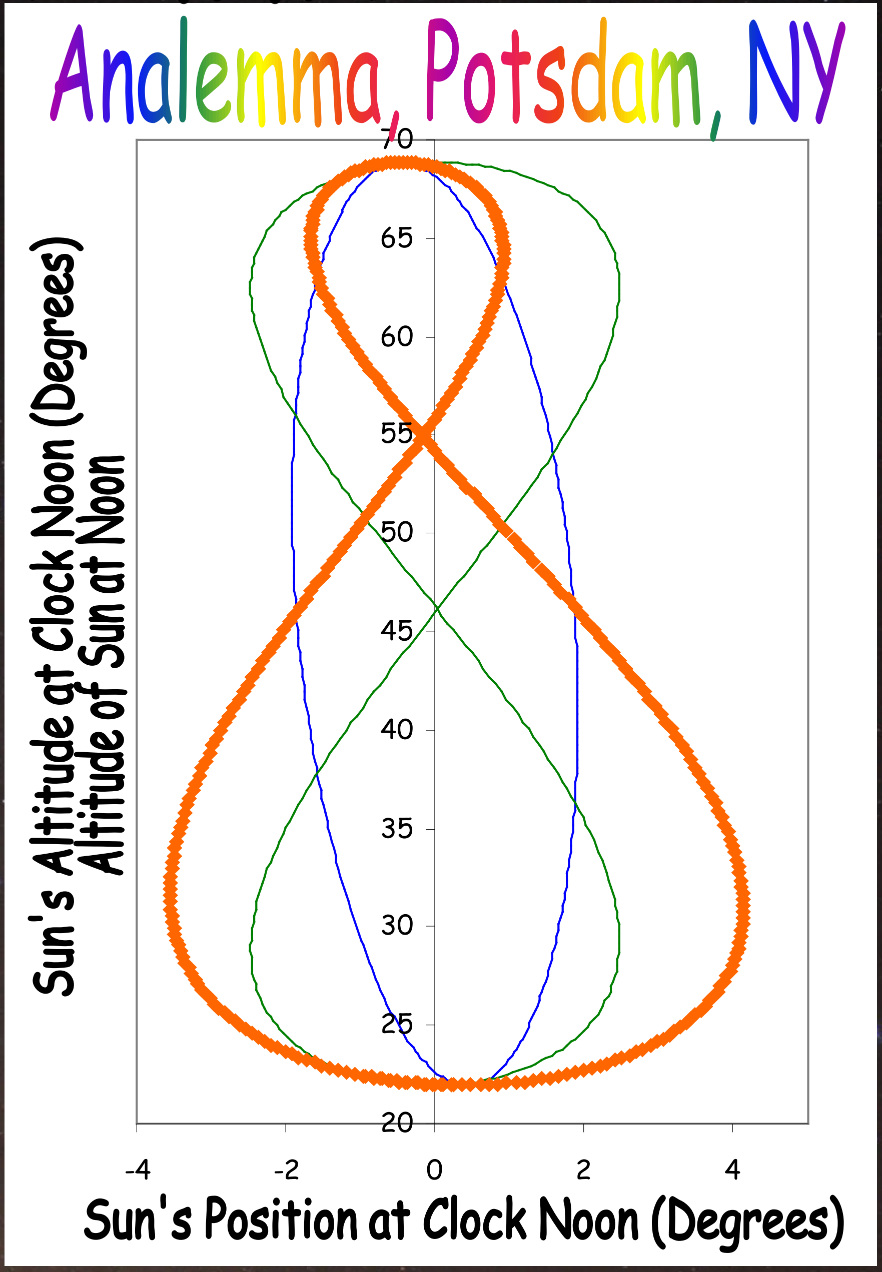


Photo by Marc Staves 2011

Potsdam's Analemma

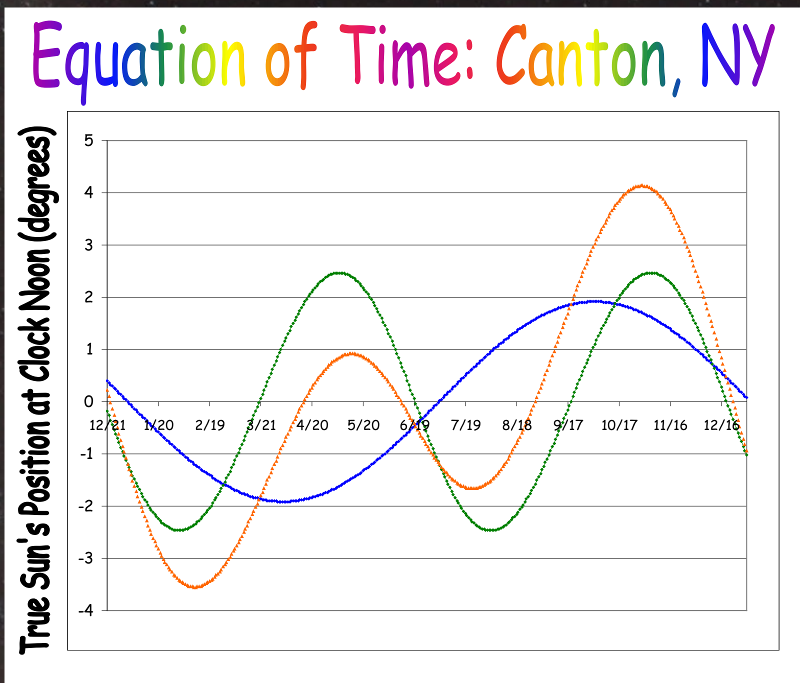
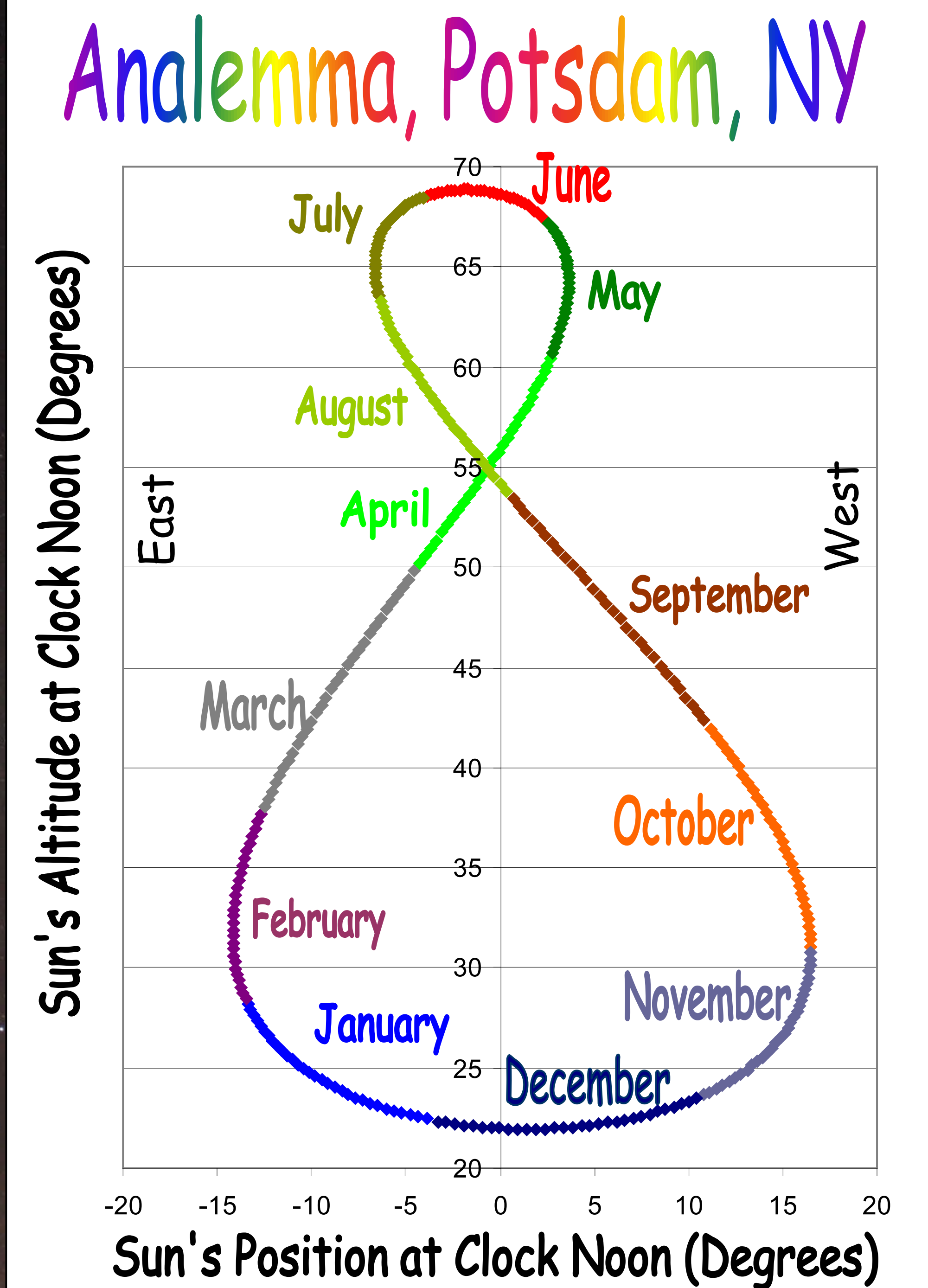
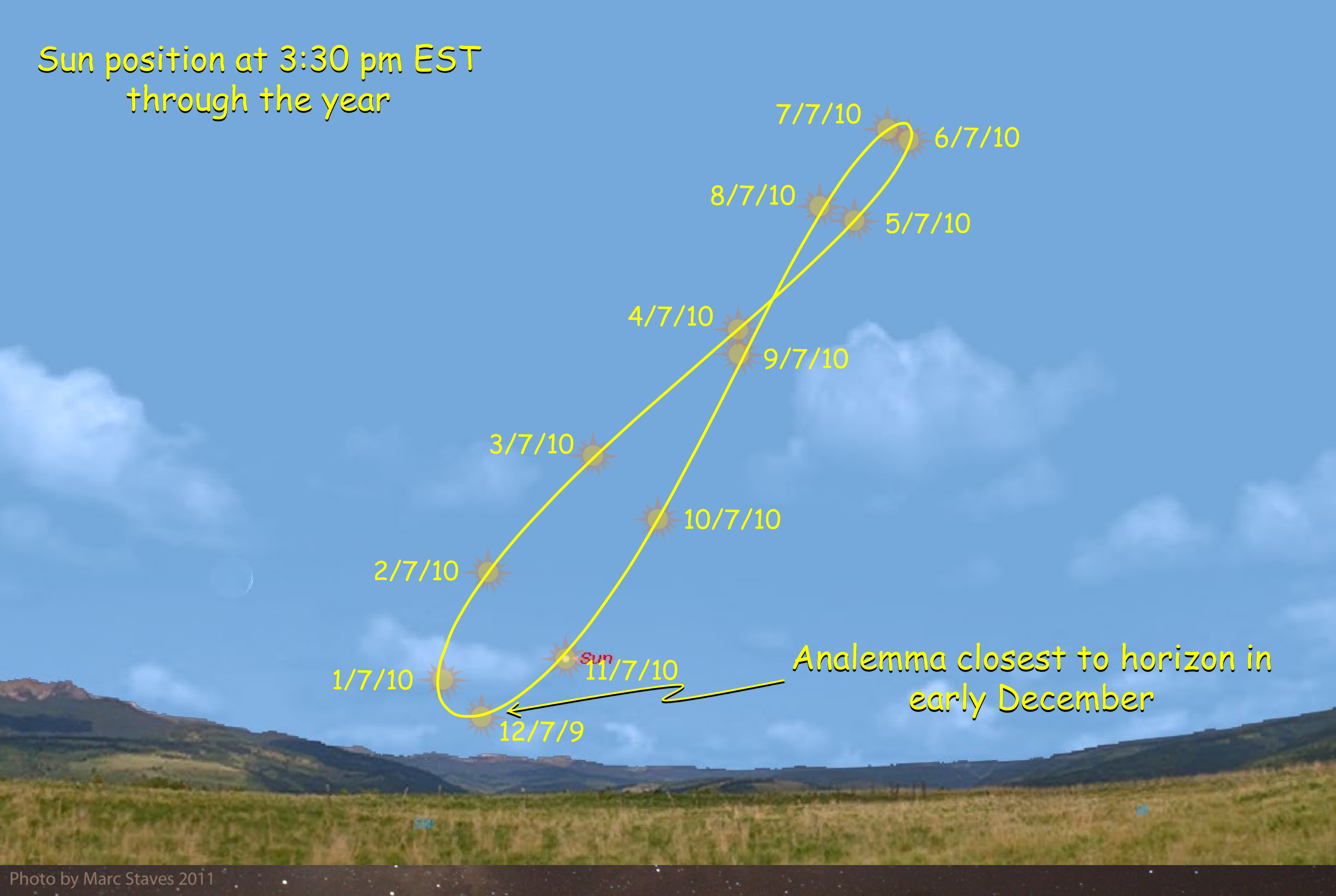


Photo by Marc Staves 2011



Why was the earliest sunset on December 7?



The Analemma

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

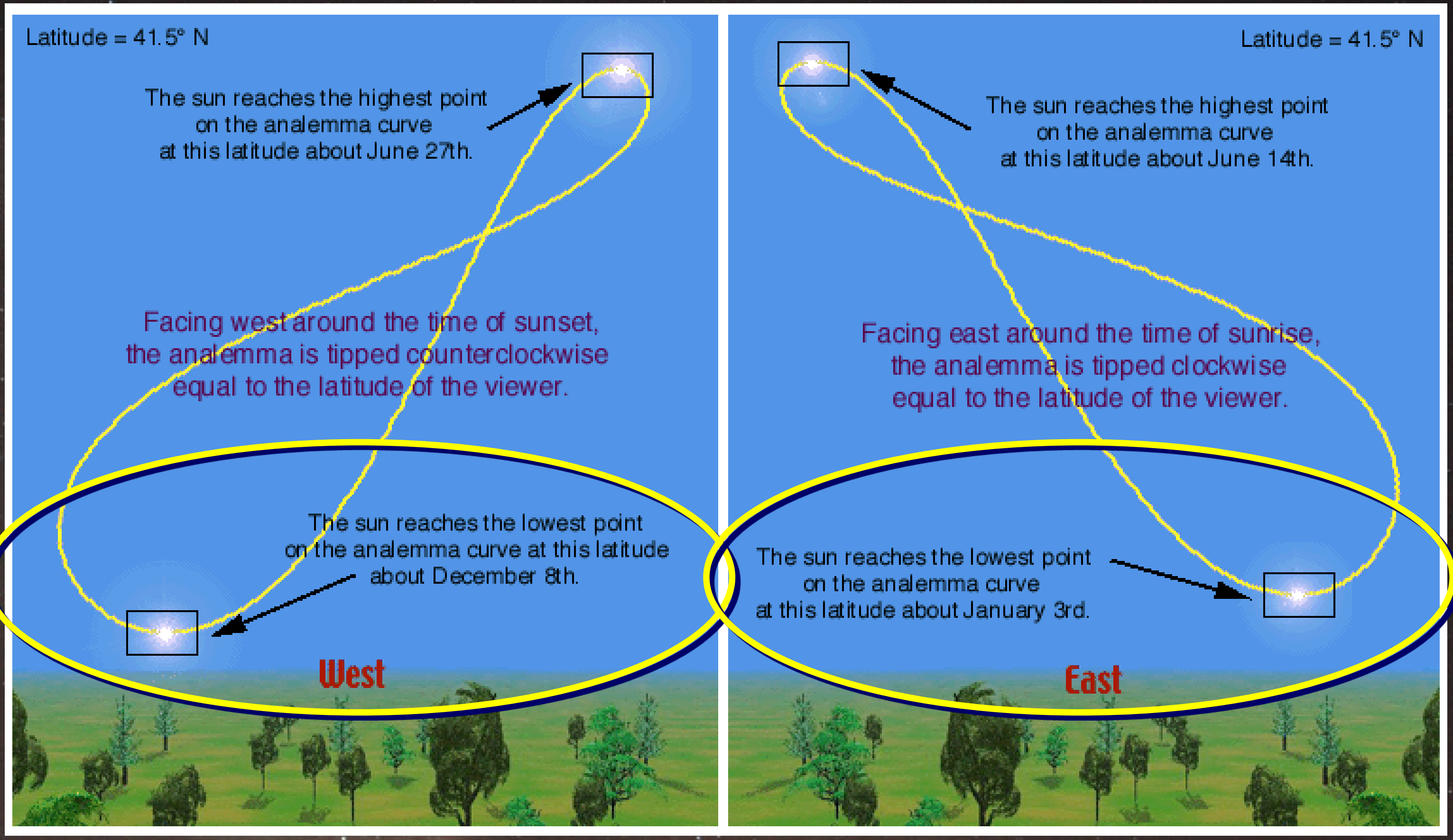


Photo by Marc Staves 2011

Cornelius Vanderbilt Whitney
LONG LAKE PUBLIC LIBRARY

Exploring the Deep Universe with the James Webb Space Telescope

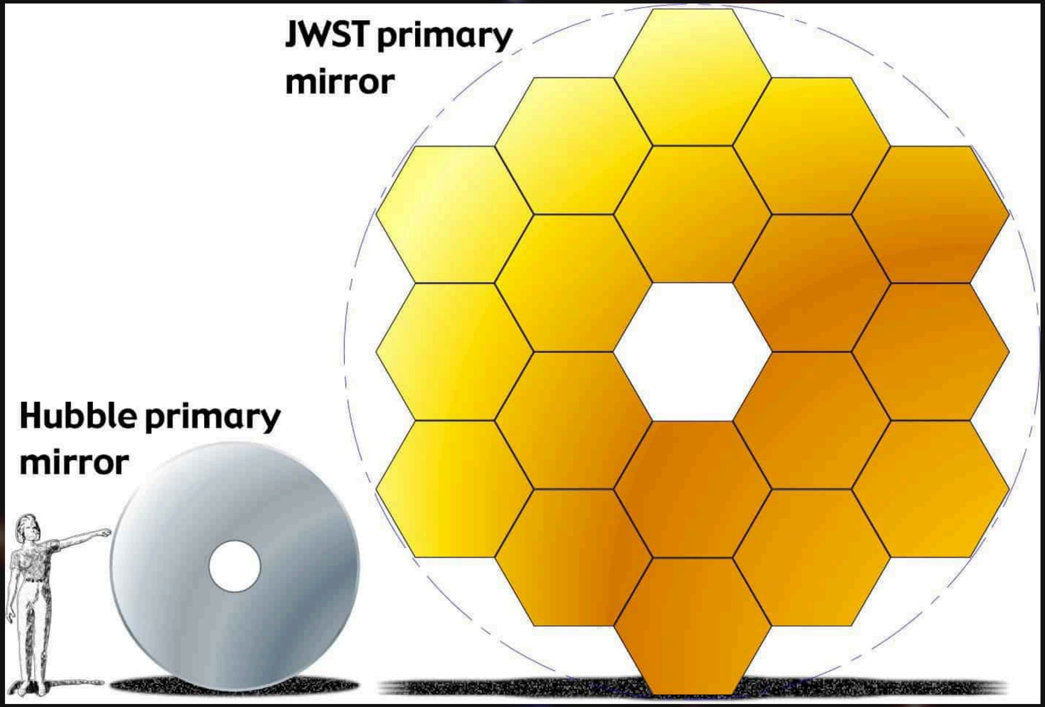
Aileen O'Donoghue
St. Lawrence University
Adirondack Sky Center & Observatory

ST. LAWRENCE UNIVERSITY

JWST vs. Hubble

- Larger Telescope
  - Telescopes = light buckets
    - Light from mirror focused on smaller area
    - More mirror area ⇒ more light at focus

      ⇒ less observing time needed



$A_{JWST} = 25.37\ m^2$
$= 273\ ft^2$

$A_{HST} = 4\ m^2$
$= 43\ ft^2$

$A_{JWST} = 6.3\ A_{HST}$

JWST vs. Hubble

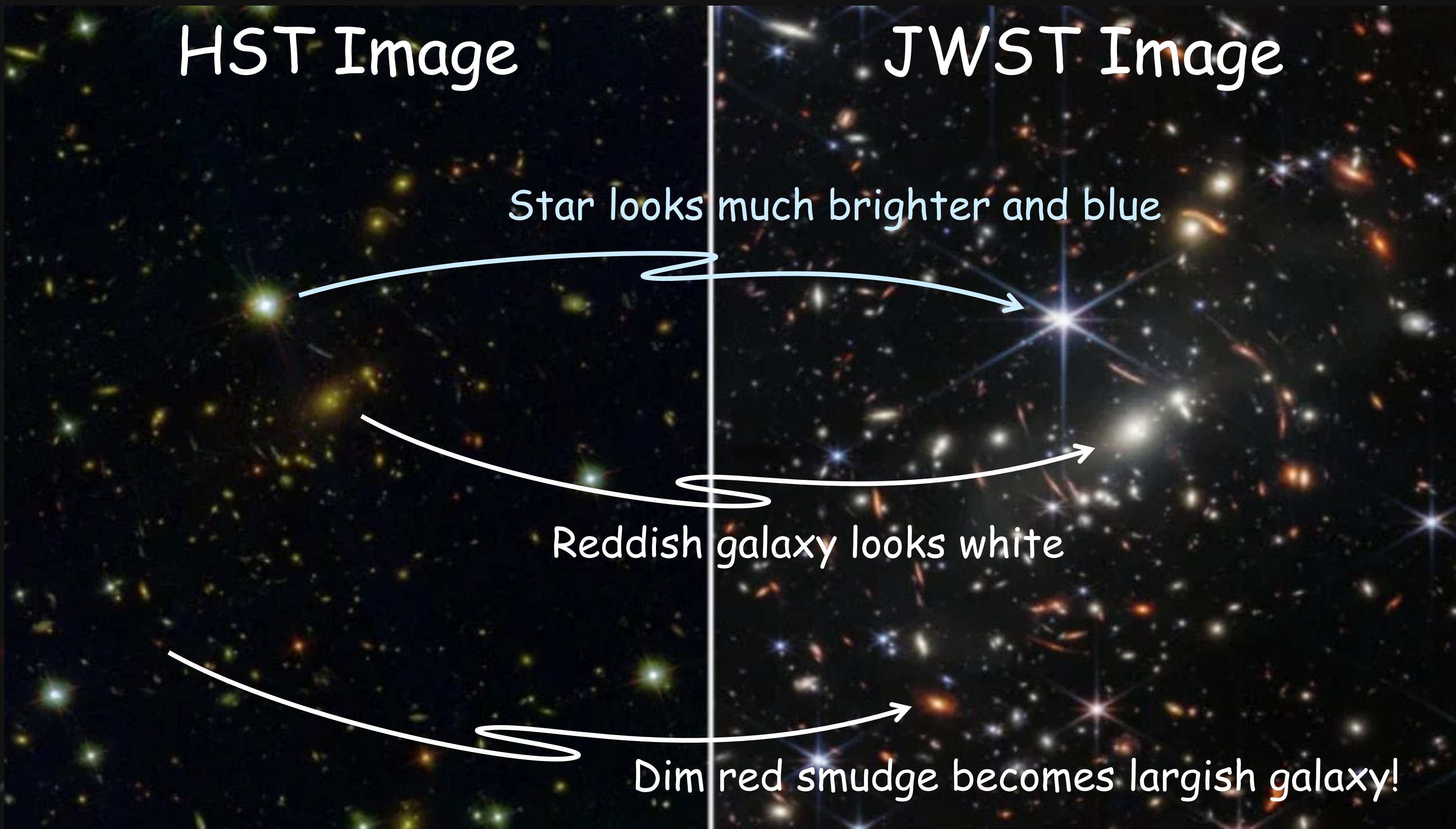
- Detects Redder Light
  - Hubble Wavelengths: UV → visible → IR
    - 0.1 microns – 2.5 microns (1 micron = 10^{-6} m)
      - Span = 2.4 microns
  - JWST Wavelengths: visible → IR
    - 0.6 microns (red) – 28 microns
      - Span = 22 microns!
  - Visible Spectrum 0.380 – 0.700 microns
    - 300 - 700 nm (1 nanometer = 10^{-9} m)

JWST vs. Hubble

- Visible Light
  - Stars & gas glow in visible
  - Dust blocks visible light
    - Smoke = dust + water vapor = opaque to light
- Infrared (IR) Light
  - Stars, gas, and dust glow in IR
    - Humans & animals also glow in IR!
  - Dust transparent to some IR wavelengths
    - Smoke transparent to some IR
  - More distant objects are redder
    - Due to expansion of the universe

Expansion of the Universe

- More distant objects are redder
  - Hubble viewed galaxies in visible light, near IR
  - JWST views galaxies in near IR to far IR



JWST *and* Hubble

- Are the colors real? ... no!
  - Human's can't see UV, IR, Radio, X-ray
    - Images must be in "false colors"
    - Artists work to make images show most details
- Color schemes for images
  - Shorter (IR) wavelengths colored bluer
  - Longer (IR) wavelengths colored redder
  - Color schemes for images explained
    - Depend on information going into image
      - Different telescopes
      - Different emitting objects

JWST Galaxy Images

- Stephan's Quintet
  - Five galaxies that look close together
    - Two seem to be colliding and merging
    - All but one seem "disturbed"

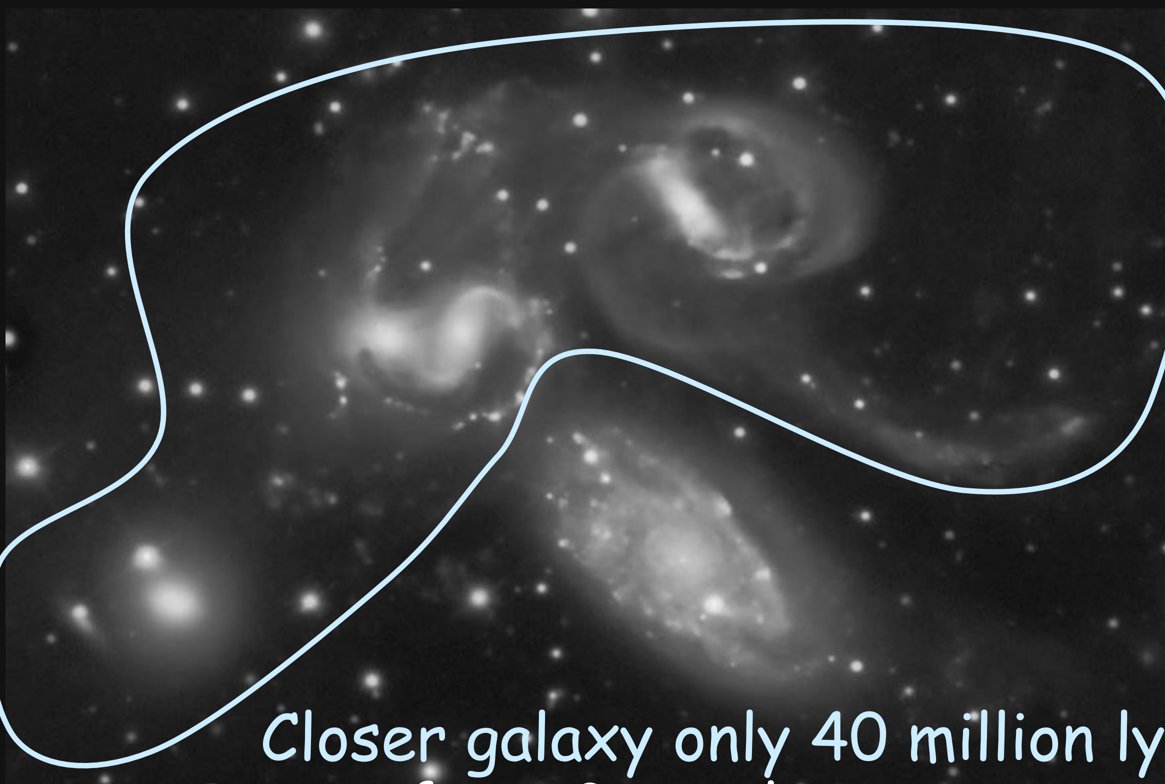


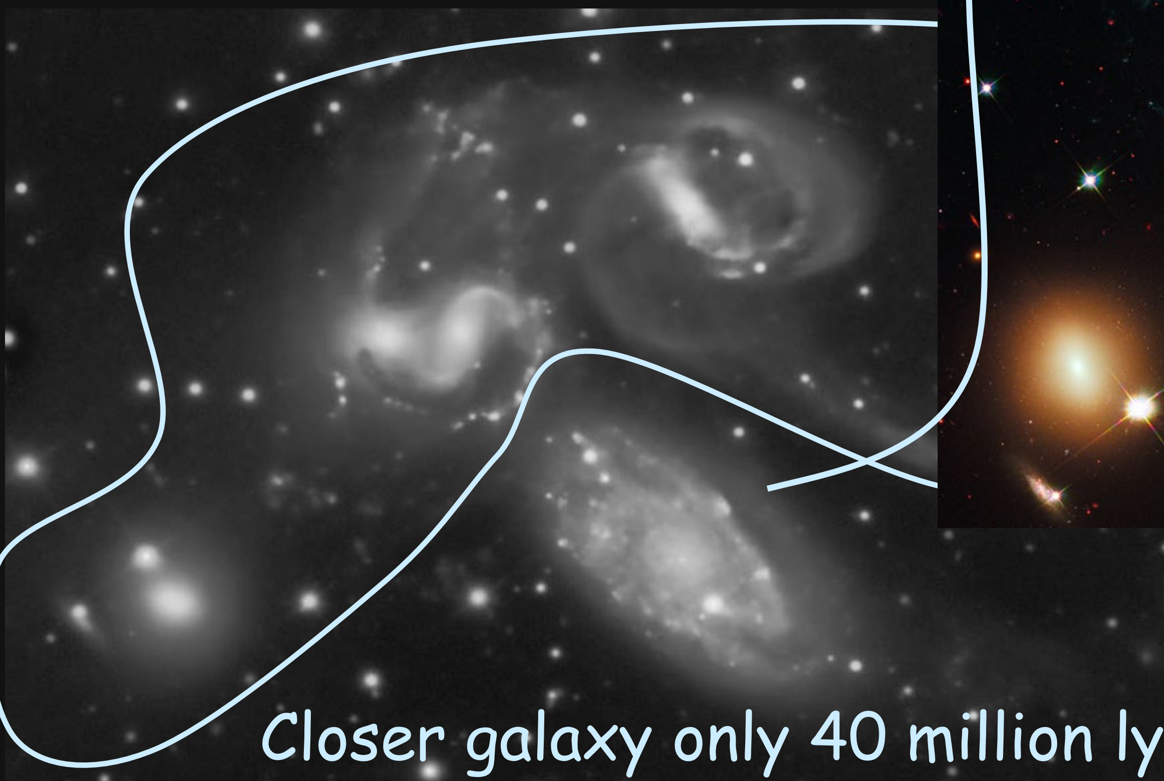
Image from 2 m telescope

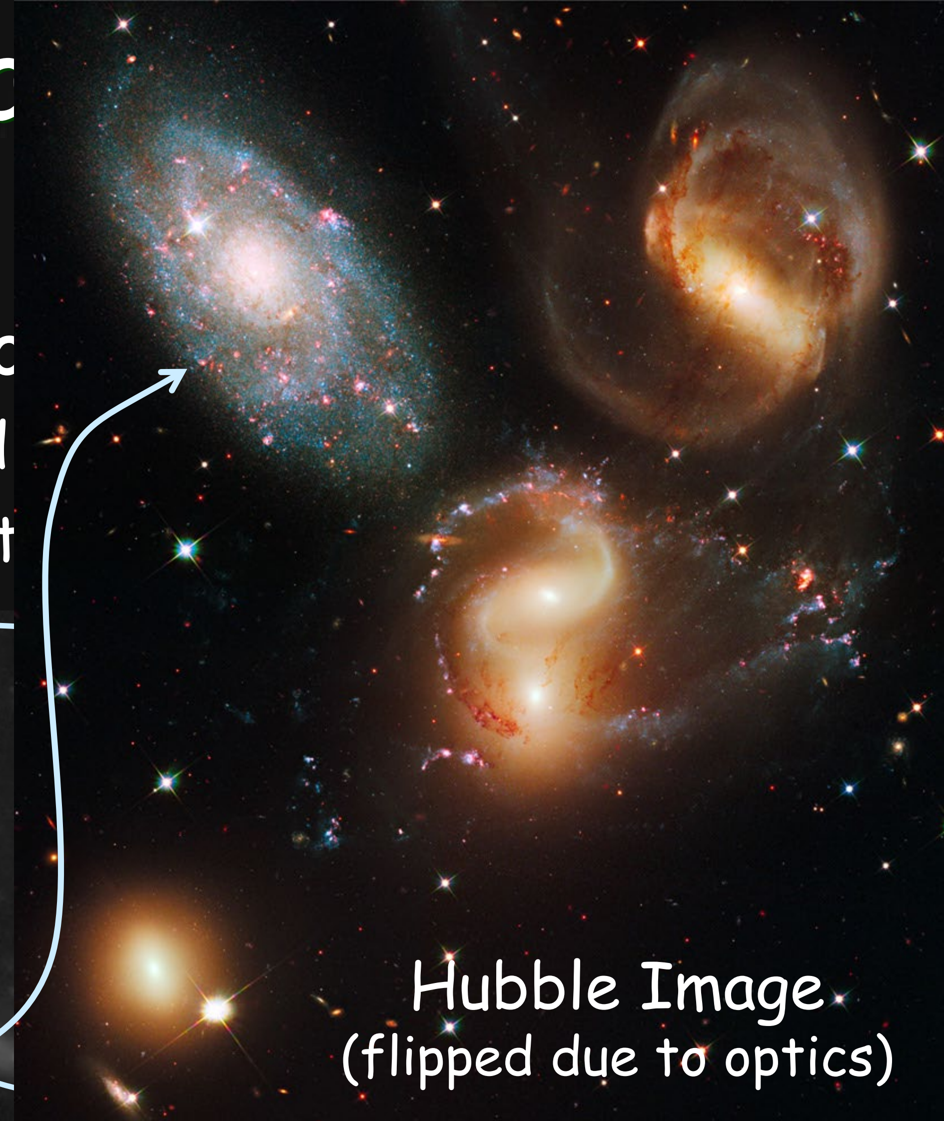
Galaxy distances
270 million ly
to
315 million ly

Images now show them as they were when the first reptiles were appearing on Earth!

JWST Gal

- Stephan's Quintet
  - Five galaxies that loo
    - Two seem to be collid
    - All but one seem "dist





Hubble Image
(flipped due to optics)

when the first
reptiles were
appearing on Earth!

Hubble Image

Close galaxy much bluer!! Not redshifted as much!

Blue is due to hot young stars. Old stars glow red.

Brightly glowing red regions are where stars are forming due to galaxies colliding.

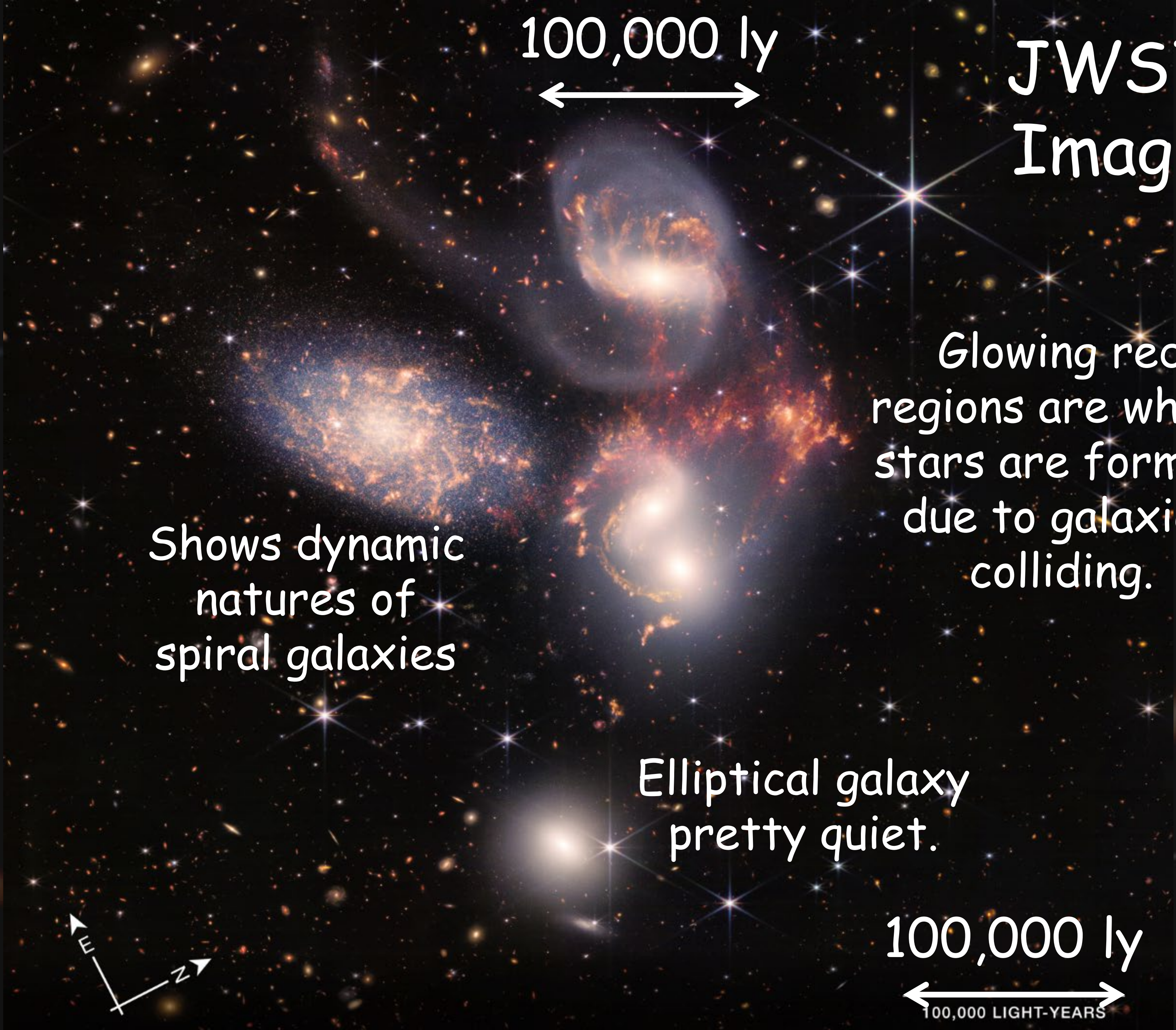
Elliptical galaxy seems less disturbed

JWST Image

Looks like a galaxy X-ray!

Glowing red regions are where stars are forming due to galaxies colliding.

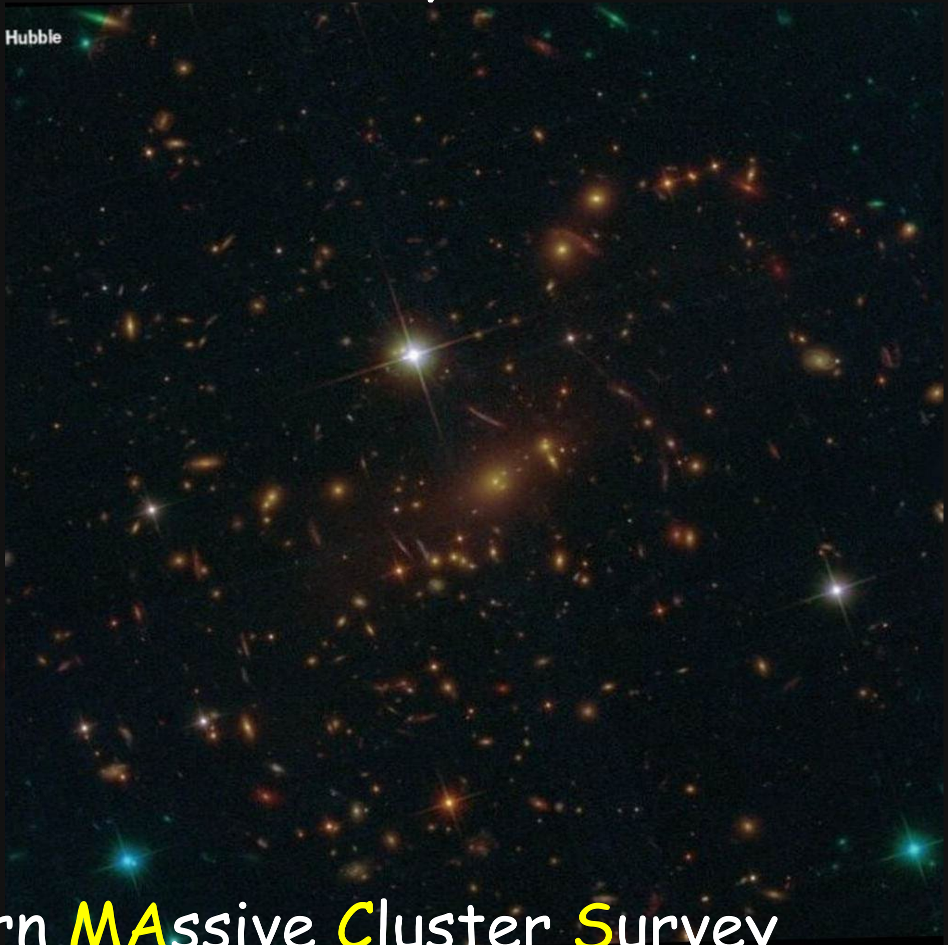
Elliptical galaxy still less disturbed


100,000 ly
JWST Image
Glowing red regions are where stars are forming due to galaxies colliding.
Shows dynamic natures of spiral galaxies
Elliptical galaxy pretty quiet.
E
N
100,000 ly
100,000 LIGHT-YEARS

JWST Galaxy Images

- Galaxy Cluster SMACS* 0723
  - ~ 4 billion ly from Earth
    - Earth barely cool from formation!

Hubble Image

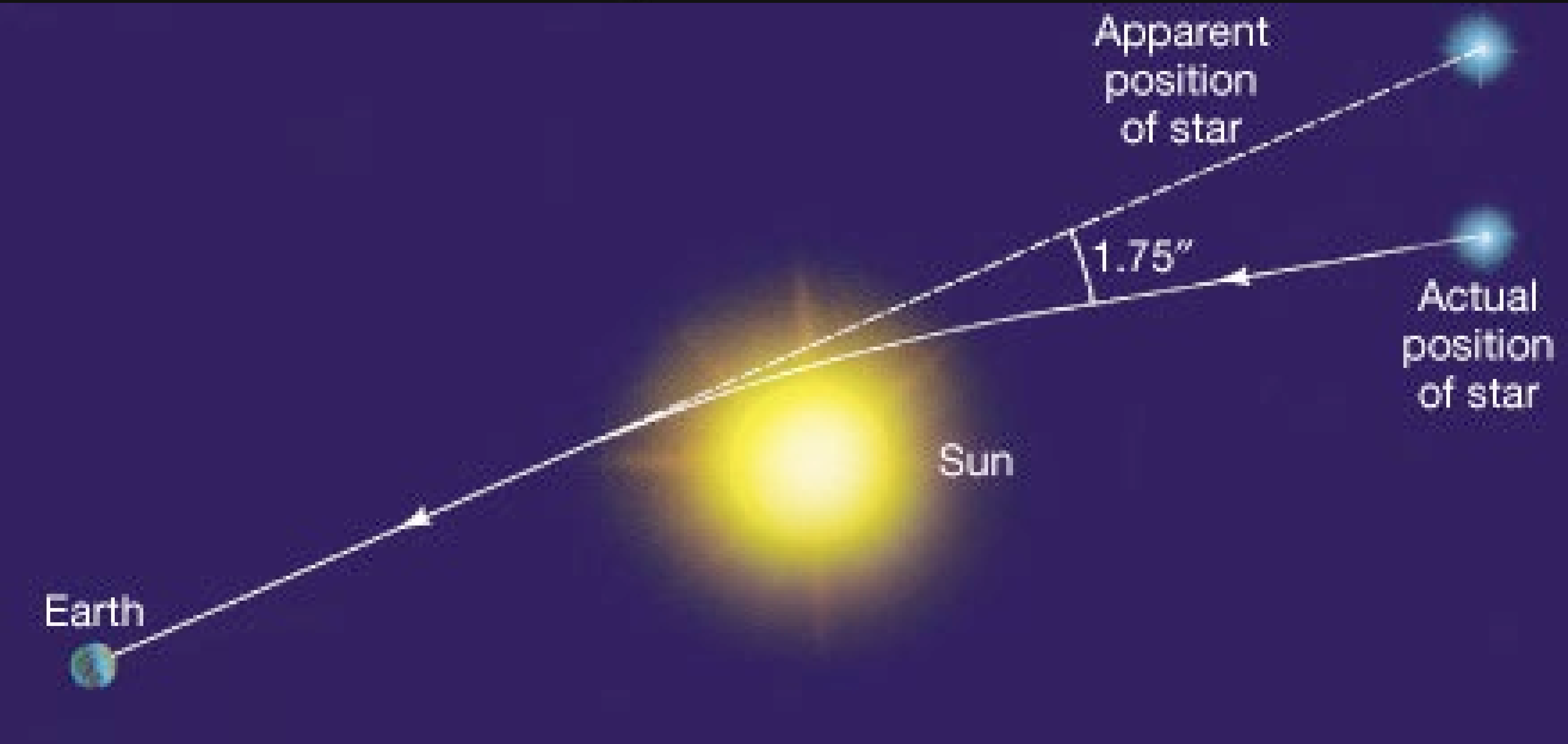


Arcs are warped images of galaxies farther away lensed by gravity of 0723

Southern MAssive Cluster Survey

Gravitational Lensing

- Star positions change when near sun!
  - Seen during total eclipse
  - A confirmation of General Relativity

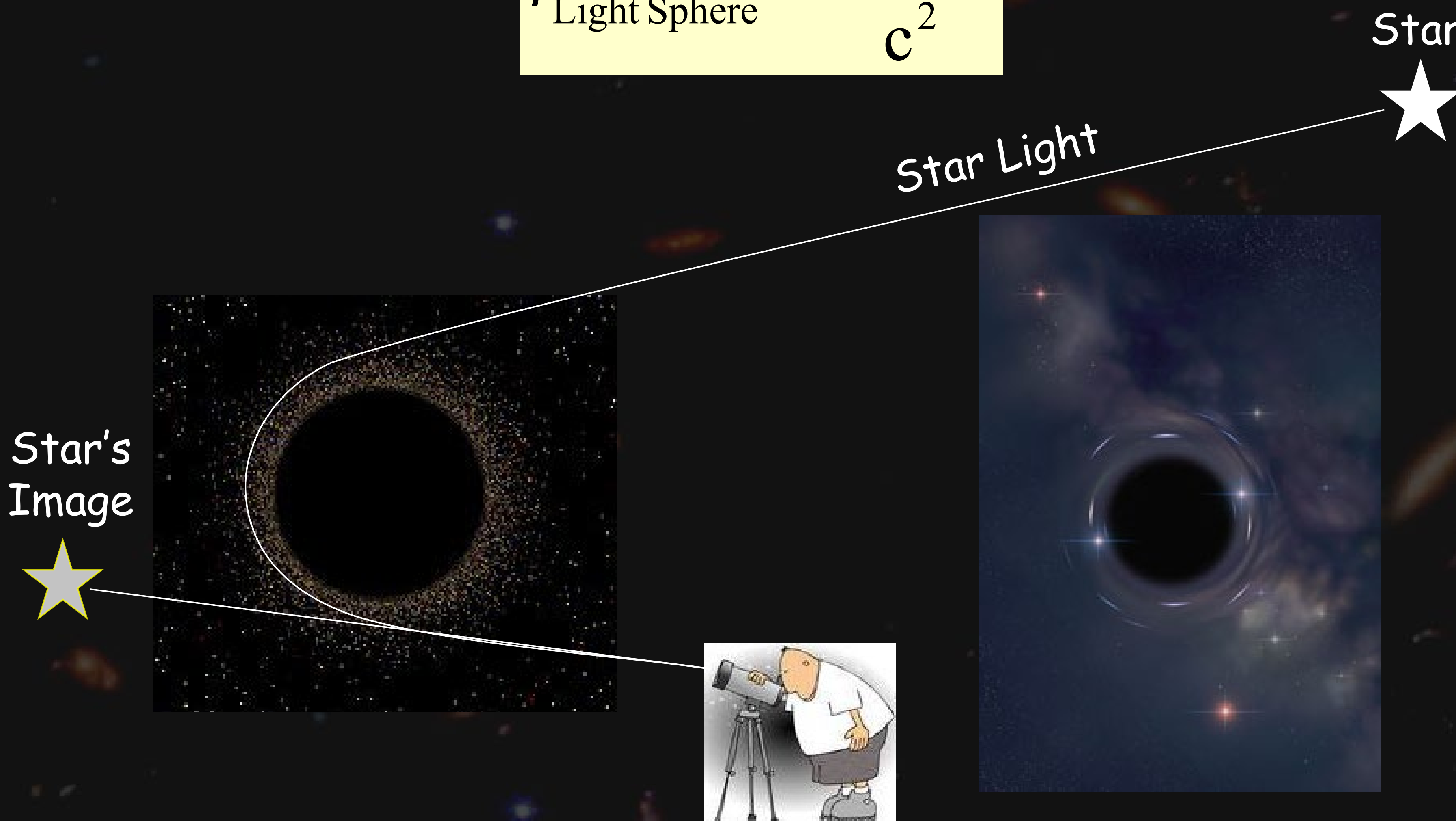



Star
sun!
Se
A
Stars with positions deflected by the presence of the sun.
First observed by Arthur Eddington in 1919!
Earth
Actual position of star

Gravitational Lensing

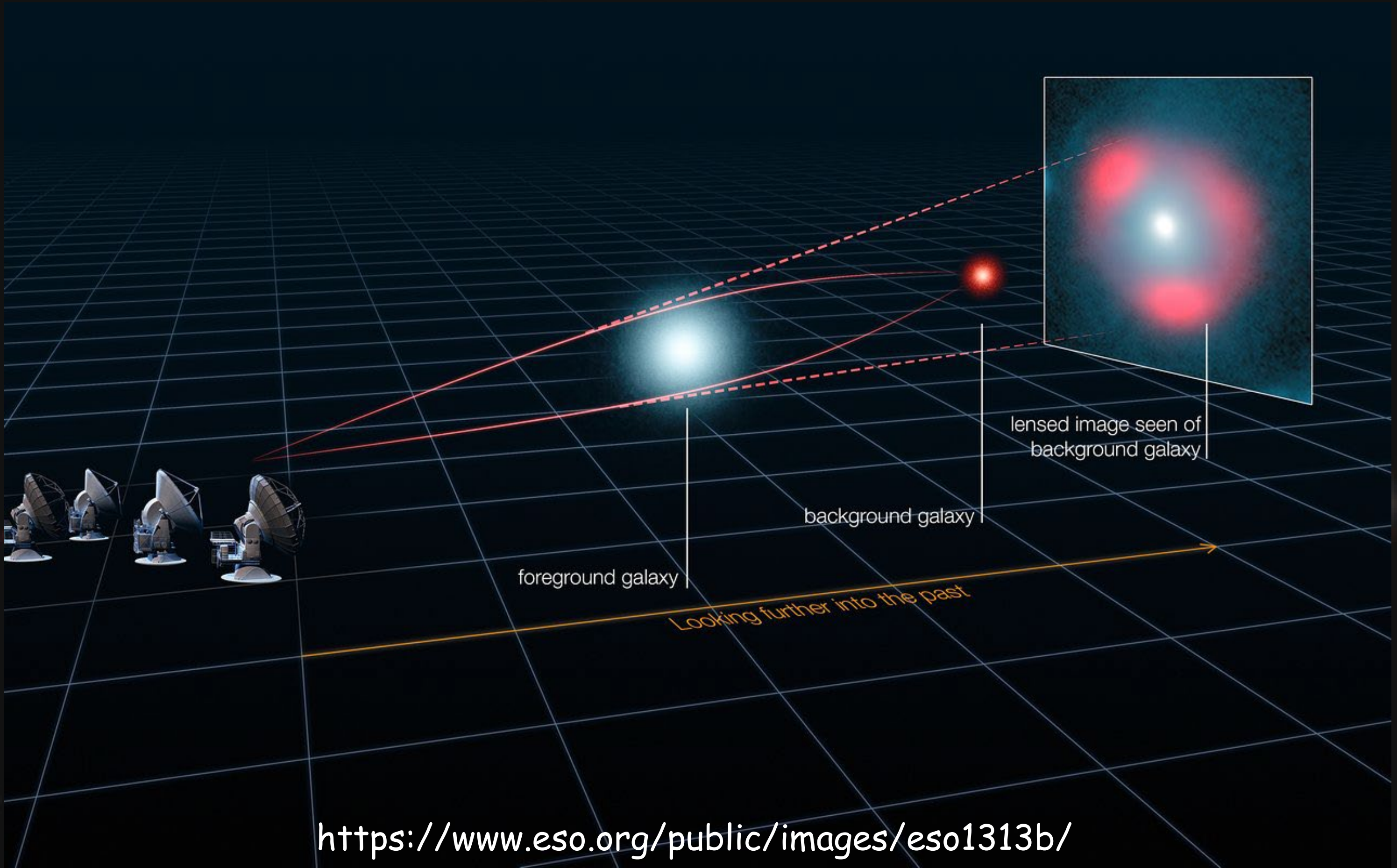
- Light can orbit black holes

$$r_{\text{Light Sphere}} = \frac{3GM}{c^2}$$



Gravitational Lensing

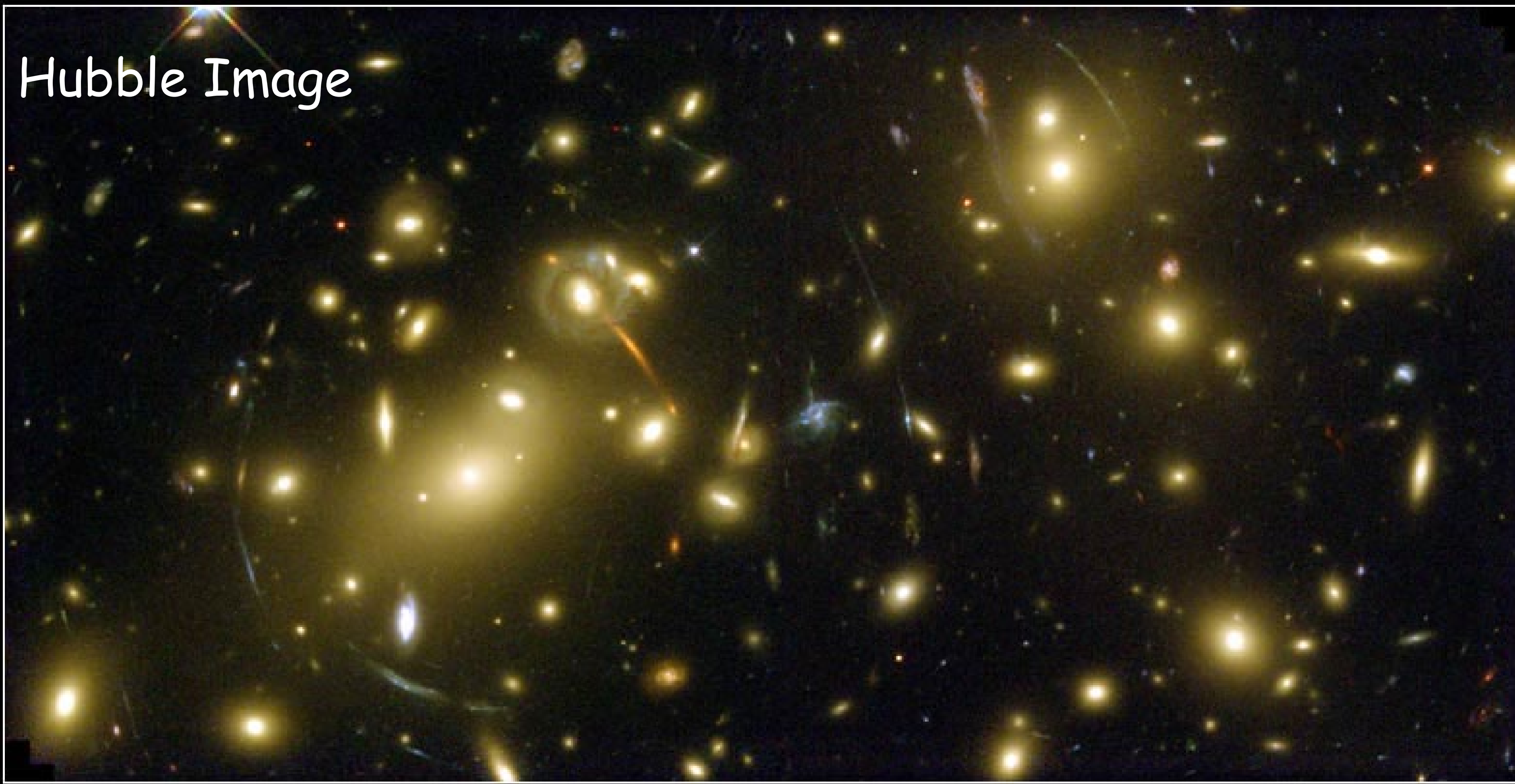
- Galaxy Lensing
  - Light rays bend around nearby galaxy focus to create image of distant galaxy



https://www.eso.org/public/images/eso1313b/

Gravitational Lensing

- Galaxy Clusters Lens Distant Clusters

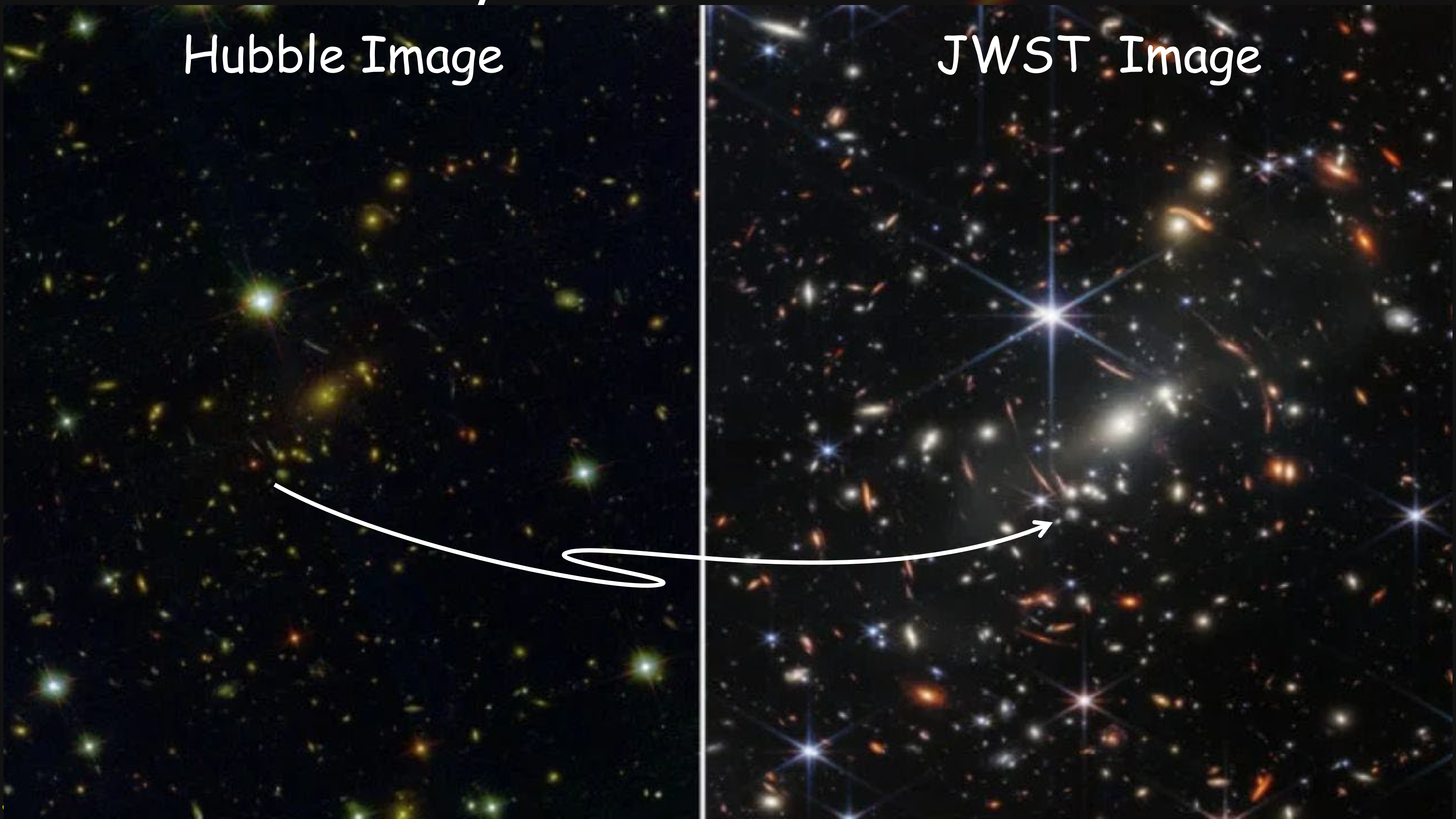


Galaxy Cluster Abell 2218 **HST • WFPC2**

NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

JWST Galaxy Images

- Galaxy Cluster SMACS* 0723
  - ~ 4 billion ly from Earth



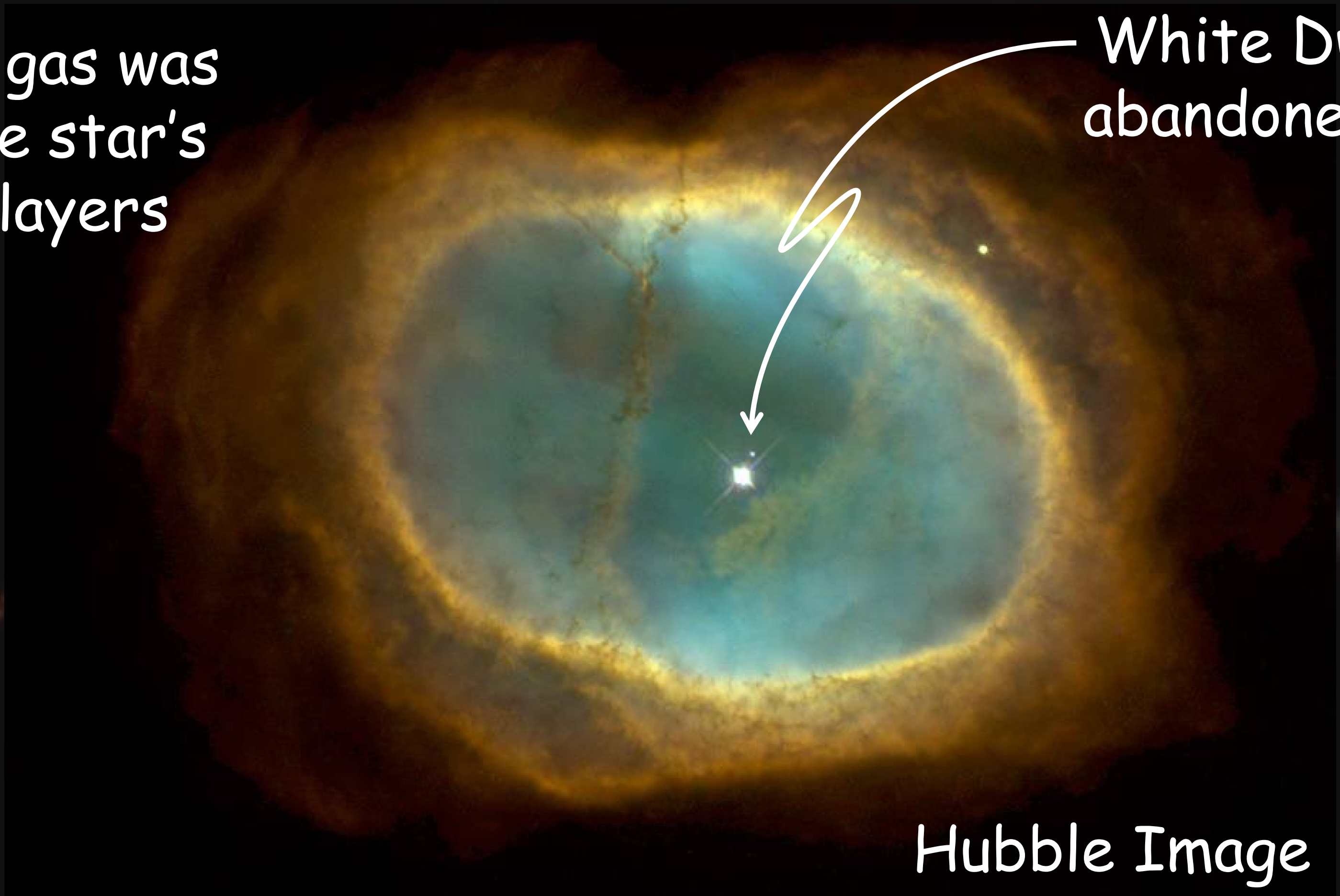
Every spike-less smudge is a galaxy!

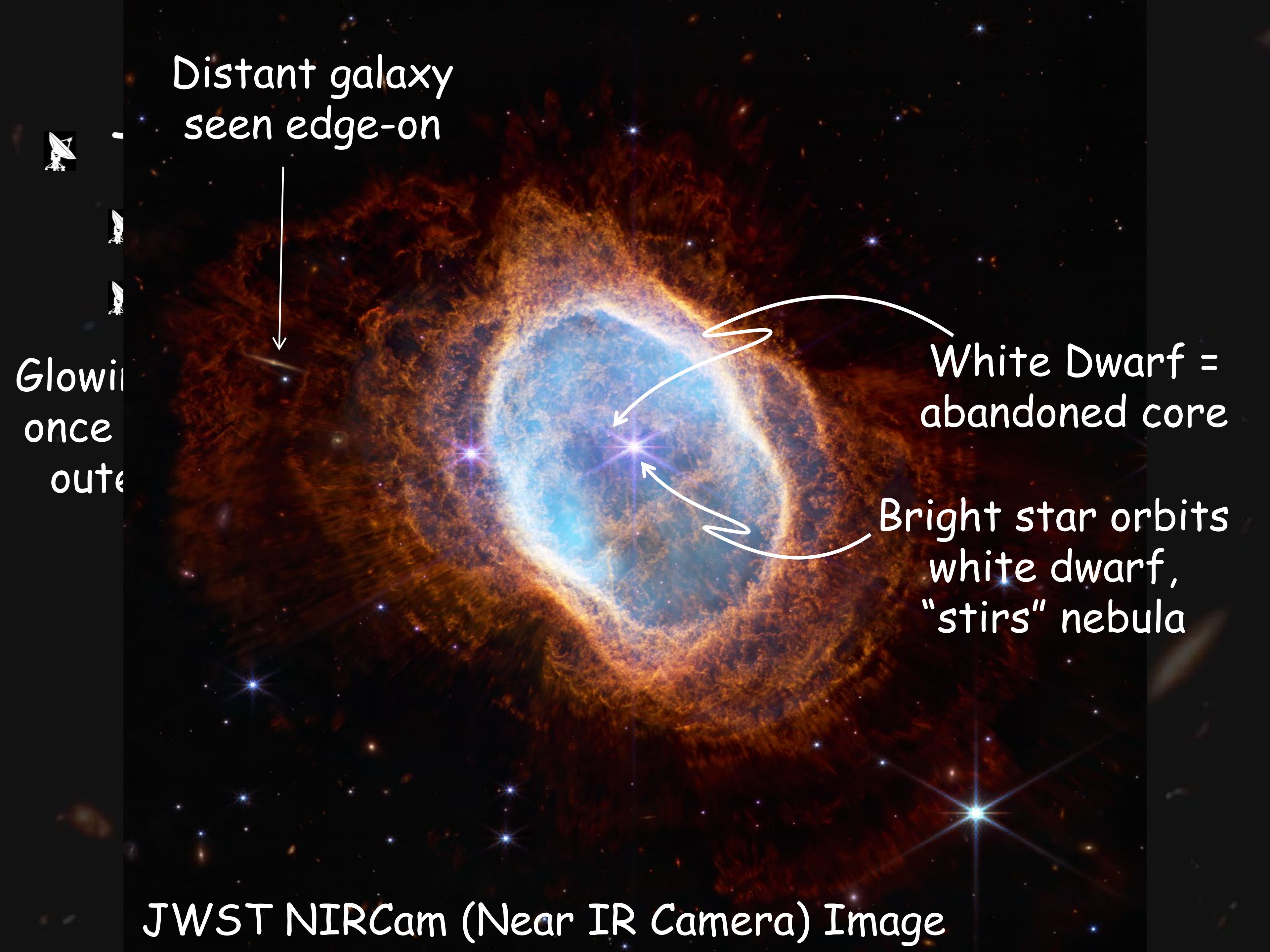
Stars have spikes due to telescope structure


Individual star clusters
can be studied in lensed
galaxies!

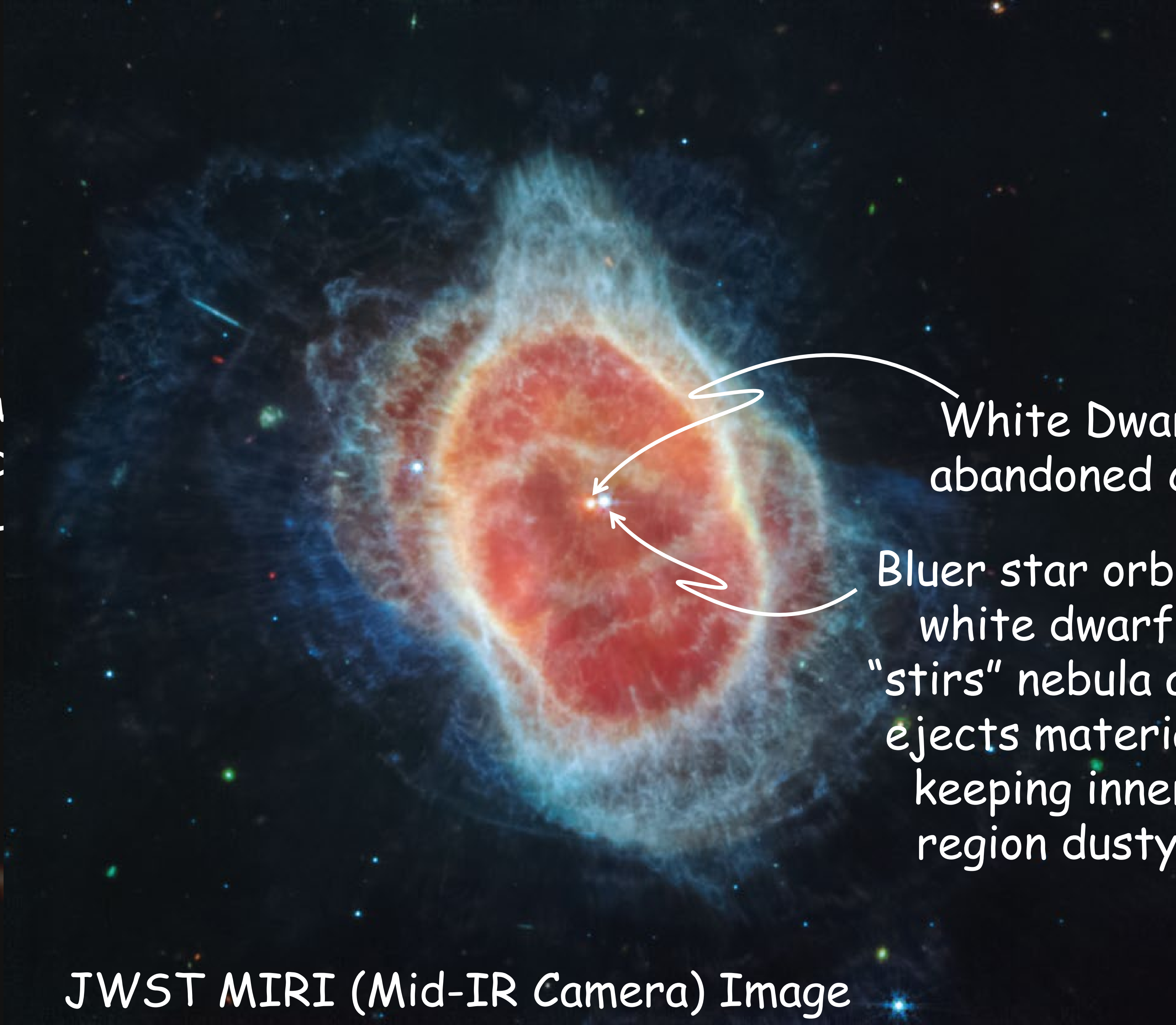
JWST Nebula Images

- The Southern Ring
  - Dying stars blow off outer layers
  - Core left as white dwarf star




Distant galaxy
seen edge-on
Glowi
once
oute
White Dwarf =
abandoned core
Bright star orbits
white dwarf,
“stirs” nebula
JWST NIRCam (Near IR Camera) Image

Glo
onc
ou


White Dwarf = abandoned core
Bluer star orbits white dwarf, "stirs" nebula and ejects material, keeping inner region dusty.
JWST MIRI (Mid-IR Camera) Image

JWST Nebula Images

- The Carina Nebula
  - Gas & dust gravitationally collapsing into stars
  - Near young stars emit X-rays to evaporate it

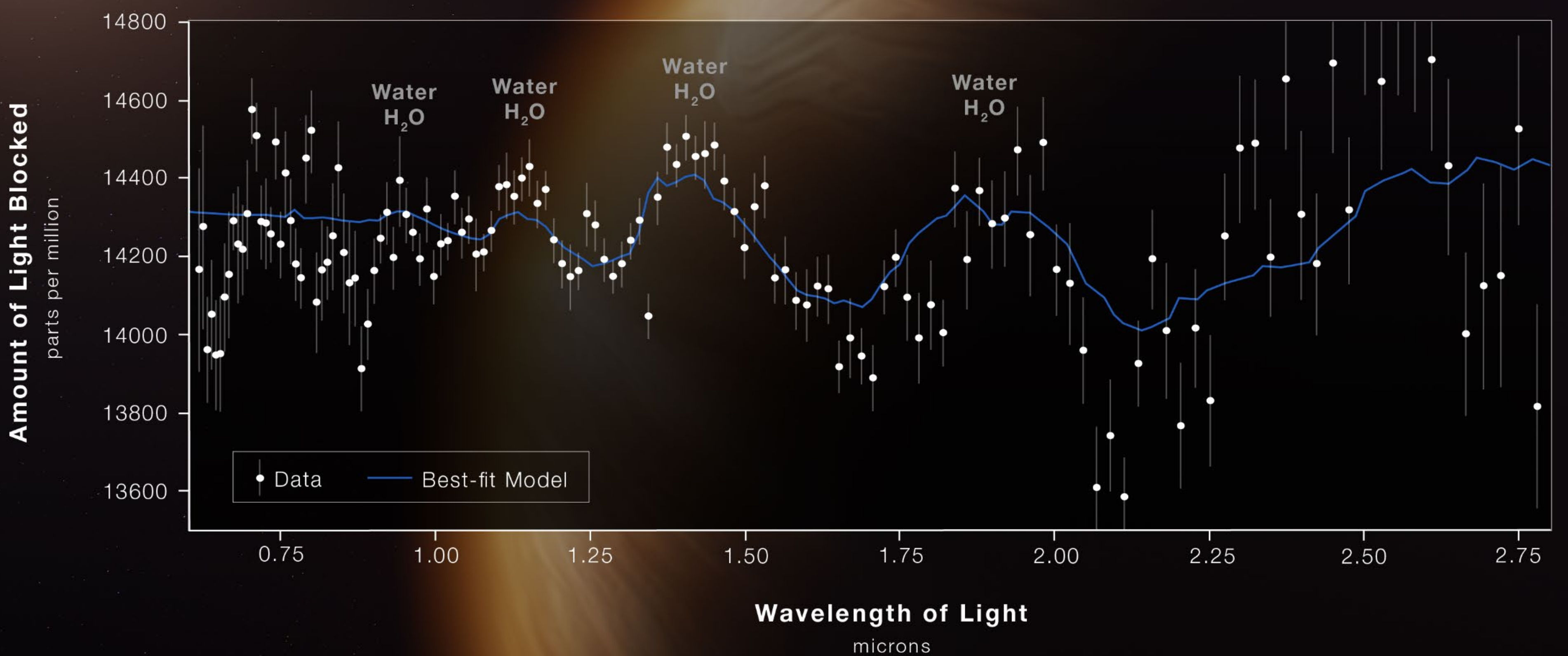
Hubble Image


JWST Image
Evaporation more obvious
Forming stars clearly
seen within cloud


Gas and dust hides forming stars within cloud.

JWST Exoplanet Spectrum

- WASP-96b in Phoenix
  - Starlight passed through planet's atmosphere
  - Showed molecules present ... no free oxygen!



JWST Image

What JWST will help us Learn

- More about distant galaxies
  - Formation & Development ... OUR origins!
- More about nebulae
  - How stars form
  - Processes of stellar death
- Molecules in atmospheres of planets
  - Any with free oxygen ... life?
- Much, much more we don't expect!!

Galaxies

- Systems of billions to trillions of stars
  - Milky Way Galaxy
    - Our home galaxy
    - ~300 billion stars
    - Barred Spiral

King of Wings & Milky Way, NW New Mexico

https://apod.nasa.gov/apod/ap170328.html

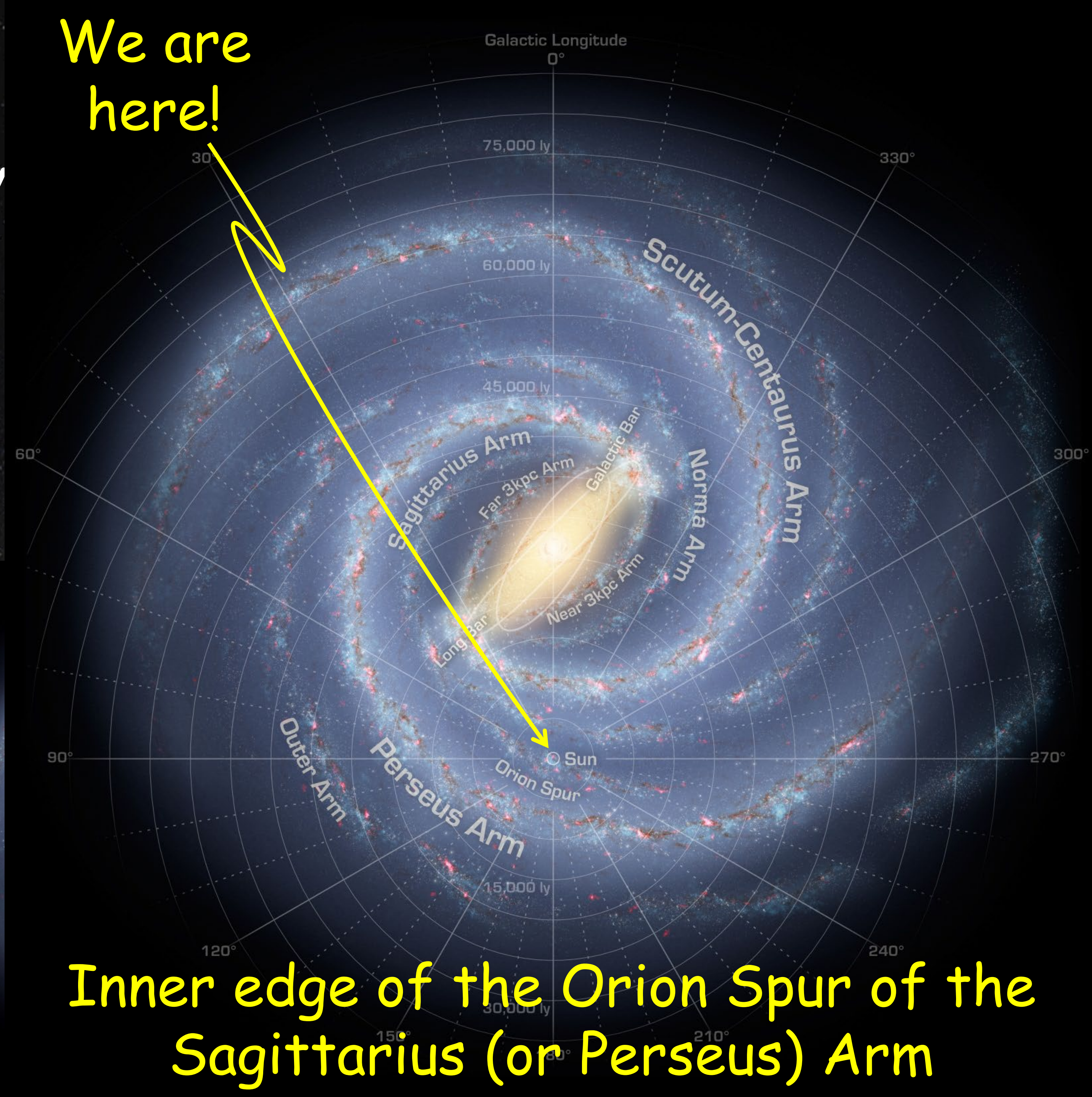
NASA Science
SOLAR SYSTEM EXPLORATION

https://solarsystem.nasa.gov/resources/285/the-milky-way-galaxy/

Sy

s

We are here!



Inner edge of the Orion Spur of the Sagittarius (or Perseus) Arm

w Mexico

l/ap170328.html

ay-galaxy/

/Jose Franci

Inner edge of the Orion Spur of the Sagittarius Arm

0/Jose Franci ay-galaxy/

Center of the Milky Way

- Sagittarius A
  - Brightest radio spot in Sagittarius
  - ~27,000 ly from Earth
    - 1 ly = distance light travels in 1 yr at 186,000 mph
    - 1 ly ≈ 6 trillion miles
  - Behind Scutum-Centaurus and Norma Arms
    - Blocked from visible view by dust
    - Visible in radio (cell signals come through fog!)
- Sagittarius A* (Sgr A*)
  - Brightest radio spot in Sgr A

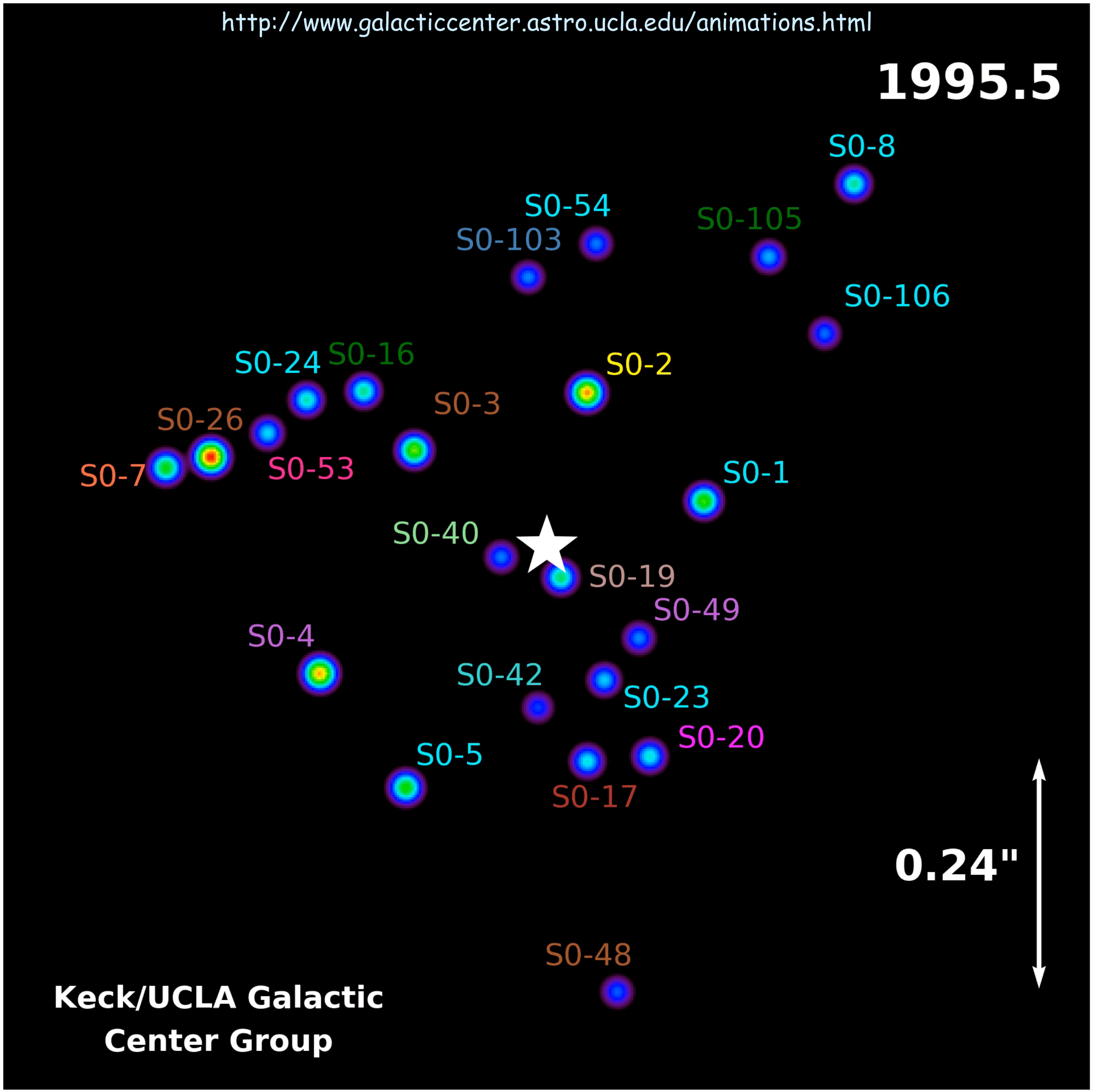
Center of the Milky Way

- Sagittarius A*
  - Stars orbit center at high speeds!
    - Observed from 1995 until present

- Sa
  - S

Image in Near Infrared

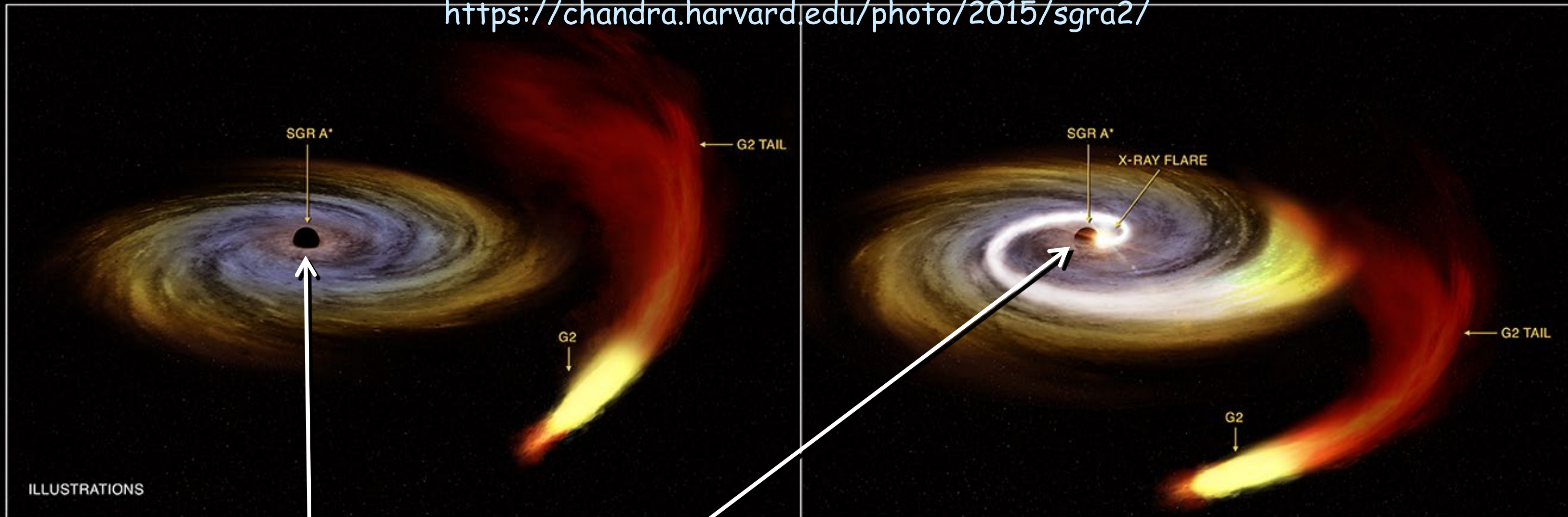
O/Jose Francisco Salgad


http://www.galacticcenter.astro.ucla.edu/animations.html
1995.5
S0-8
S0-54
S0-103
S0-105
S0-106
S0-24
S0-16
S0-2
S0-26
S0-3
S0-7
S0-53
S0-1
S0-40
S0-19
S0-49
S0-4
S0-42
S0-23
S0-20
S0-5
S0-17
0.24"
S0-48
Keck/UCLA Galactic
Center Group

Center of the Milky Way

- Sagittarius A*
  - Stars orbit center at high speeds!
    - Observed from 1995 until present
  - Increased X-ray flares detected since 2014
    - X-ray satellites observing Sgr A* since 1995
    - First flare after passage of object G2
      - G2 thought to be cloud of gas
      - Close passage to BH didn't disrupt G2
        - Astronomers working on what G2 is!
    - Flares continued ...
      - Material from G2 falling in slowly due to interactions?

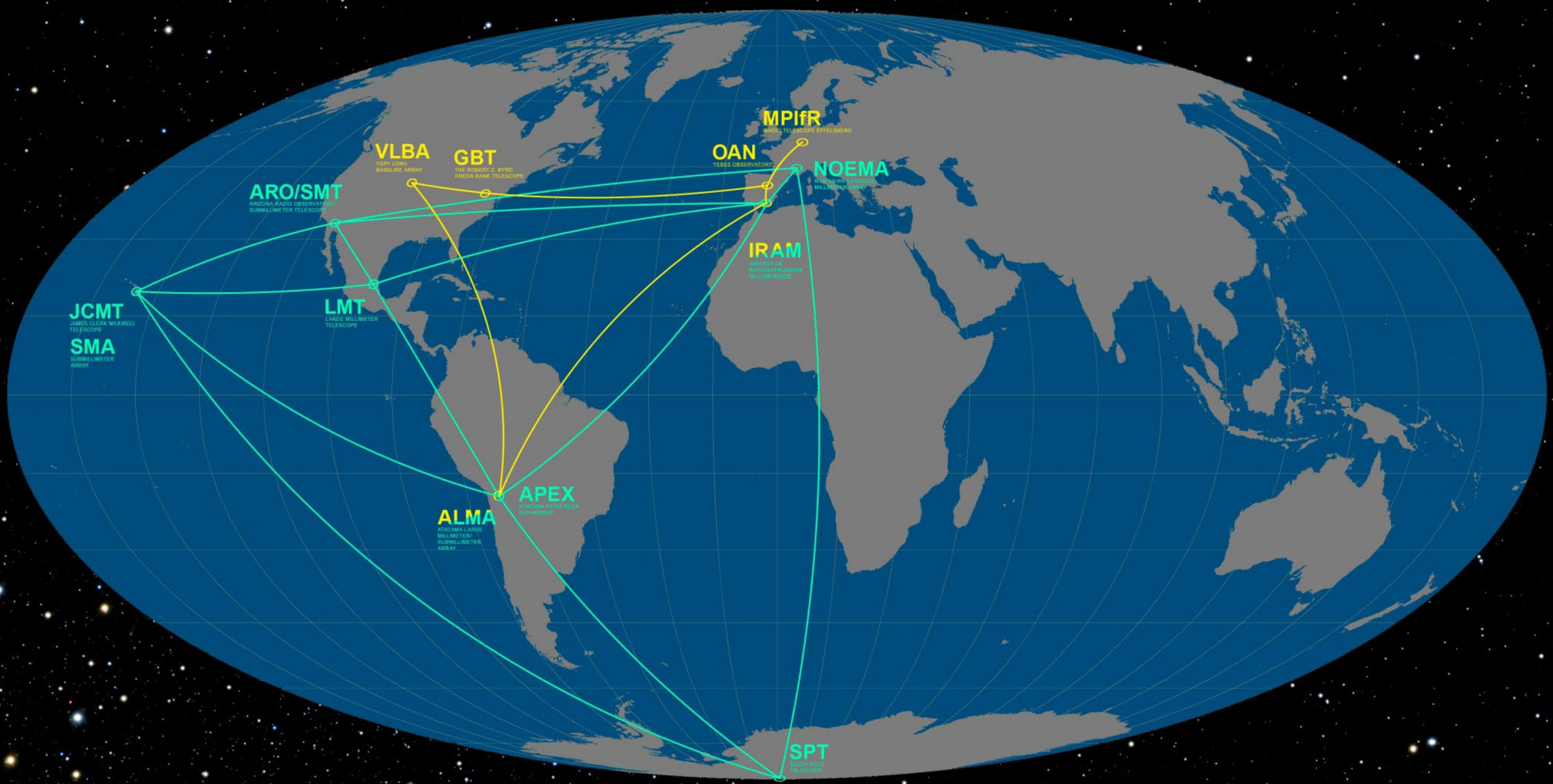
https://chandra.harvard.edu/photo/2015/sgra2/



https://www.nasa.gov/mission_pages/chandra/milky-way-s-black-hole-shows-signs-of-increased-chatter.html

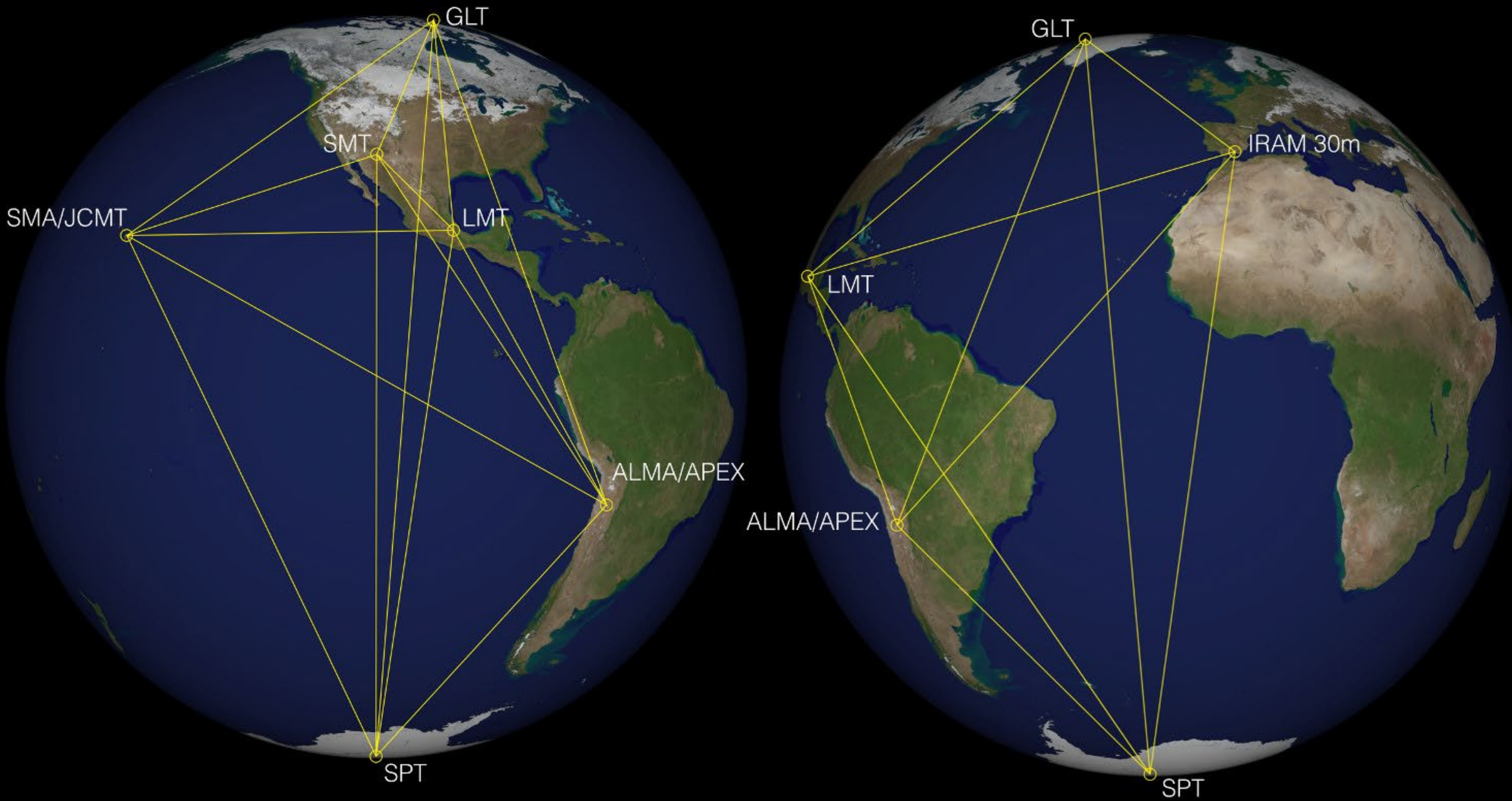
Event Horizon Telescope

- A telescope the size of Earth
  - Radio observations synchronized & combined!



https://eventhorizontelescope.org/

Event Horizon Telescope



Credit: D. Marrone, U. Arizona, https://askbygeeks.com/science/134625/

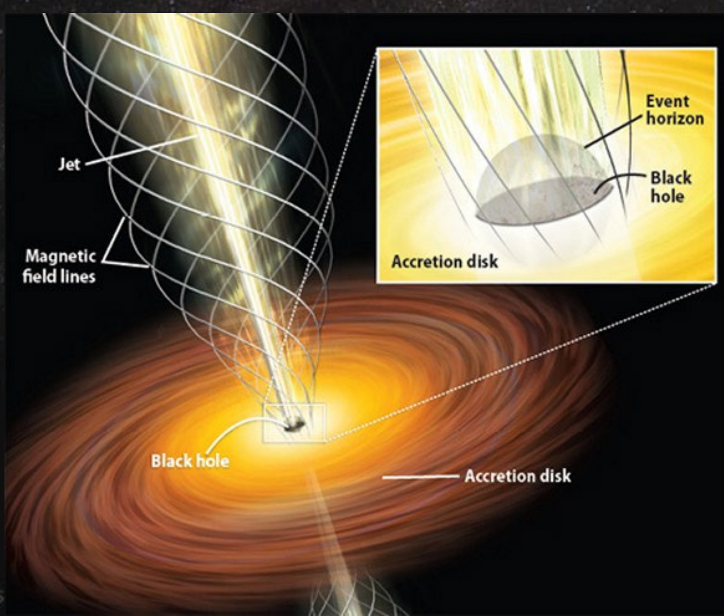

SMA: Submillimeter Array
JCMT: James Clerk Maxwell Telescope
Event Horizon Telescope
GLT: Greenland Telescope
IRAM: Institute de Radioastronomie Millimétrique
GLT
SMT
SMA/JCMT
LMT
LMT: Large Millimeter Telescope
GLT
IRAM 30m
LMT
ALMA/APEX
ALMA: Atacama Large Millimeter/Submillimeter Array
APEX: Atacama Pathfinder Experiment
ALMA/APEX
SPT
SPT: South Pole Telescope
SPT
Credit: D. Marrone, U. Arizona, https://askbygeeks.com/science/134625/
SMA/JCMT
SMT
LMT
GLT
ALMA
APEX
SPT
IRAM 30m

Black Hole Images

- Black hole cannot be seen
  - No light gets out of black hole
  - Black hole absorbs light from around it
- What do we see?
  - Shadow of BH absorbing light from beyond
  - Disk of material falling into black hole
    - Black hole warps image of disk into ring
      - Requires hours of observation time (long exposures)
      - Requires intense computing
        - Create an image from 8 telescopes!
        - Calculate how BH will bend light!

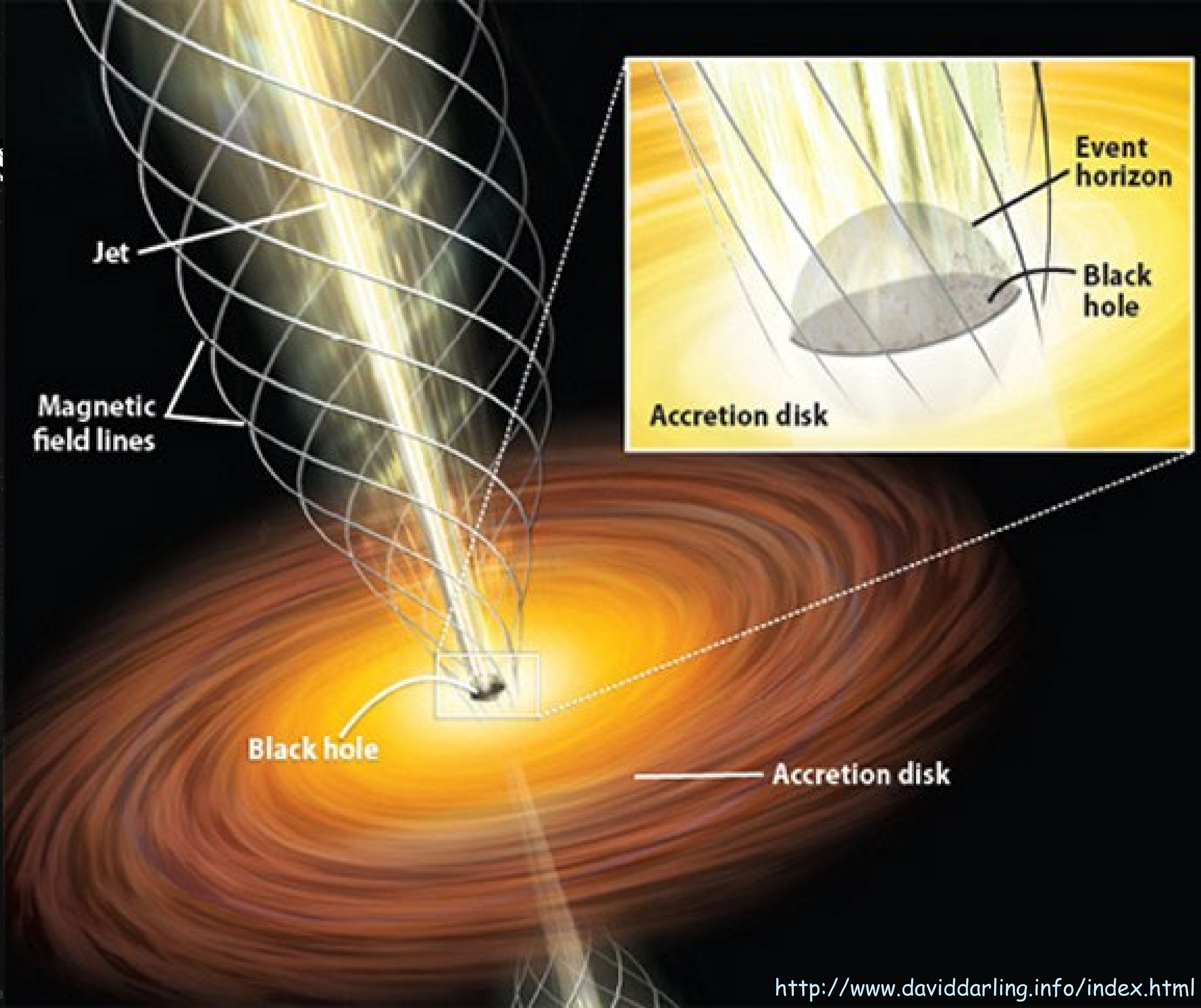
Accretion Disks

- Material spirals into black hole
  - accelerates as it gets closer
    - Particles fly off in all directions
  - charged particles create magnetic field
    - Very strong, spiraling out from black hole
    - Constrains particles to create jets



DAVID DARLING

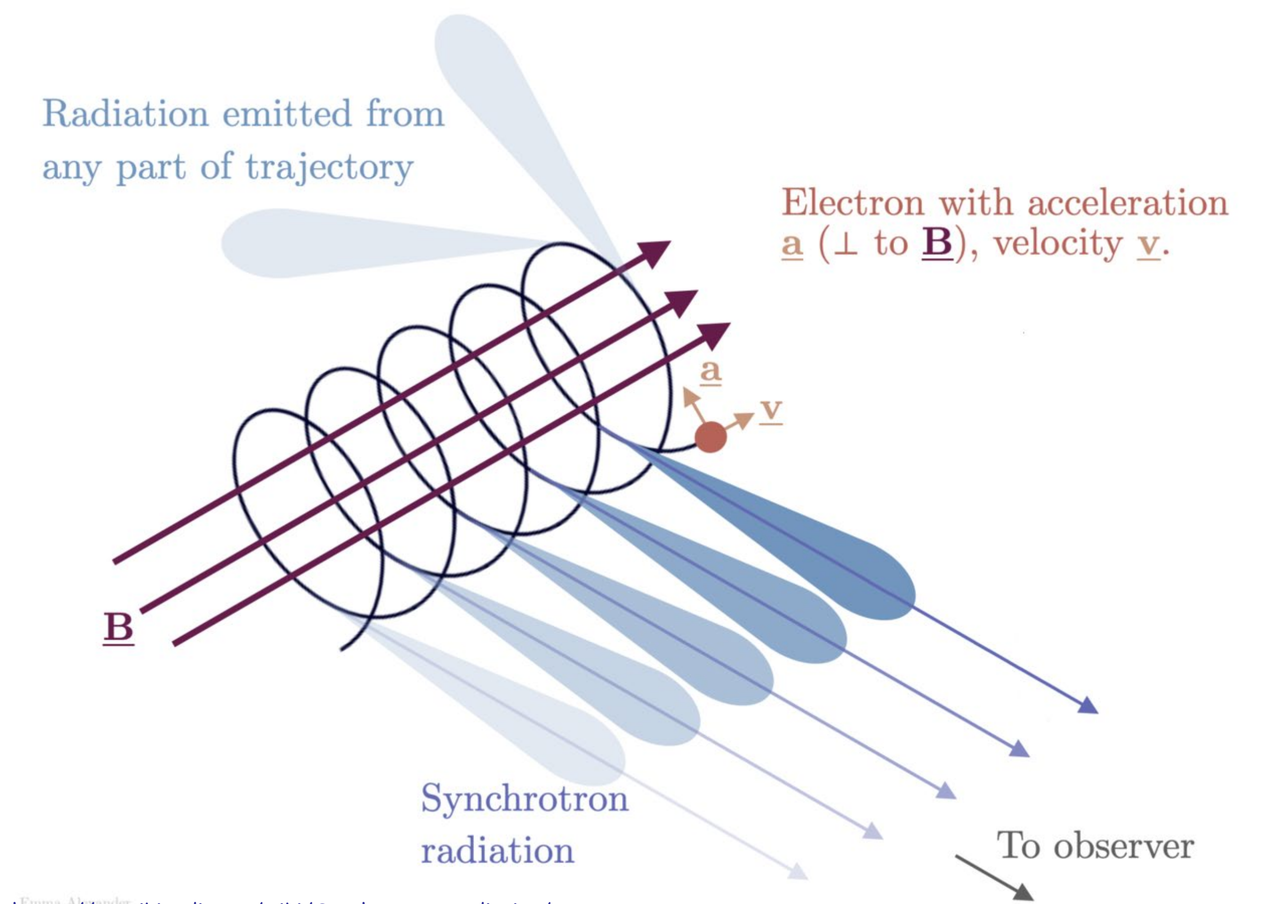
http://www.daviddarling.info/index.html



http://www.daviddarling.info/index.html

Synchrotron Radiation

- Particles spiral around magnetic field lines
  - Emit radiation in direction of travel
    - Brightest where particles coming at us



https://en.wikipedia.org/wiki/Synchrotron_radiation/

Synchrotron Radiation

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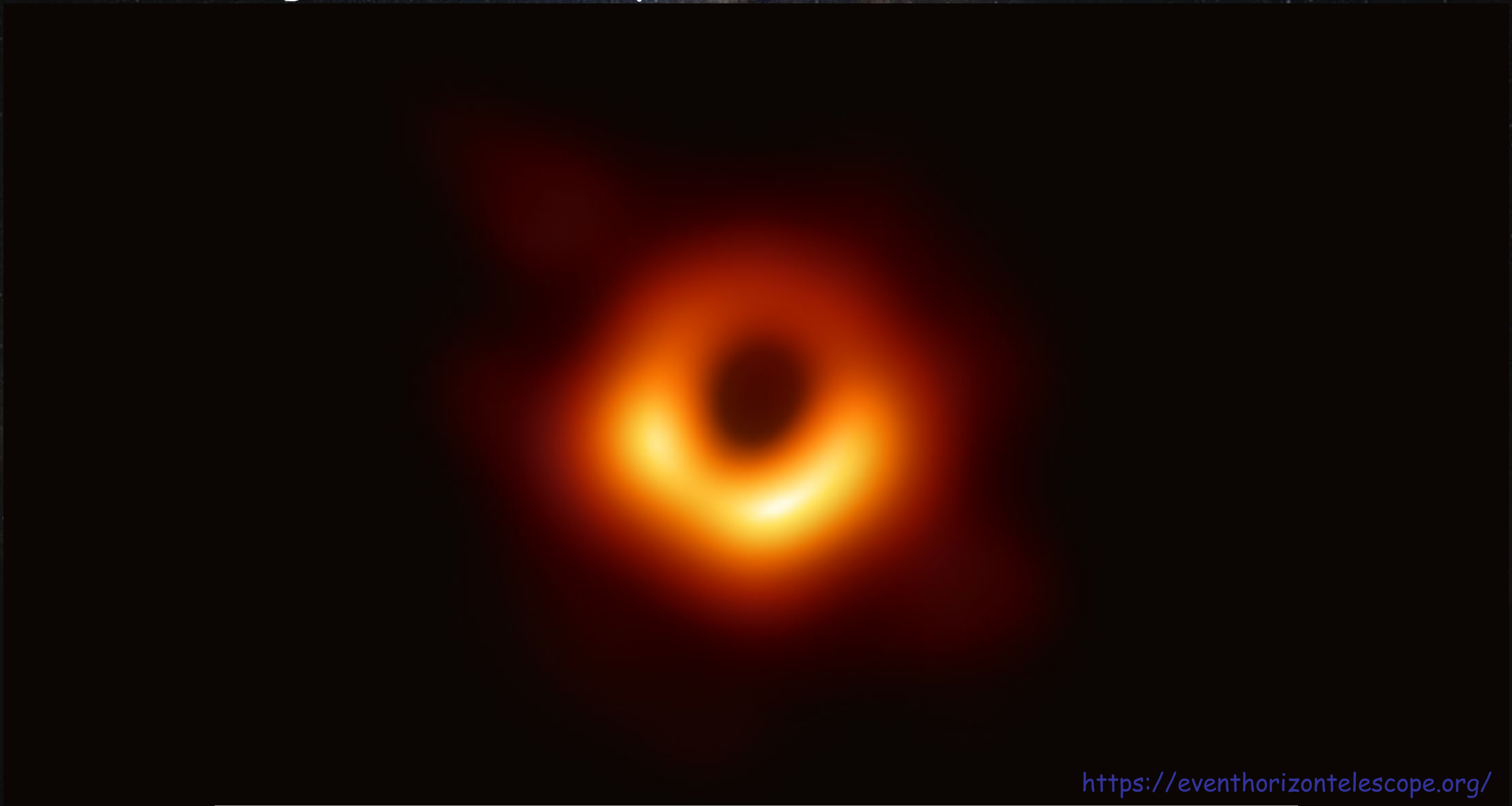
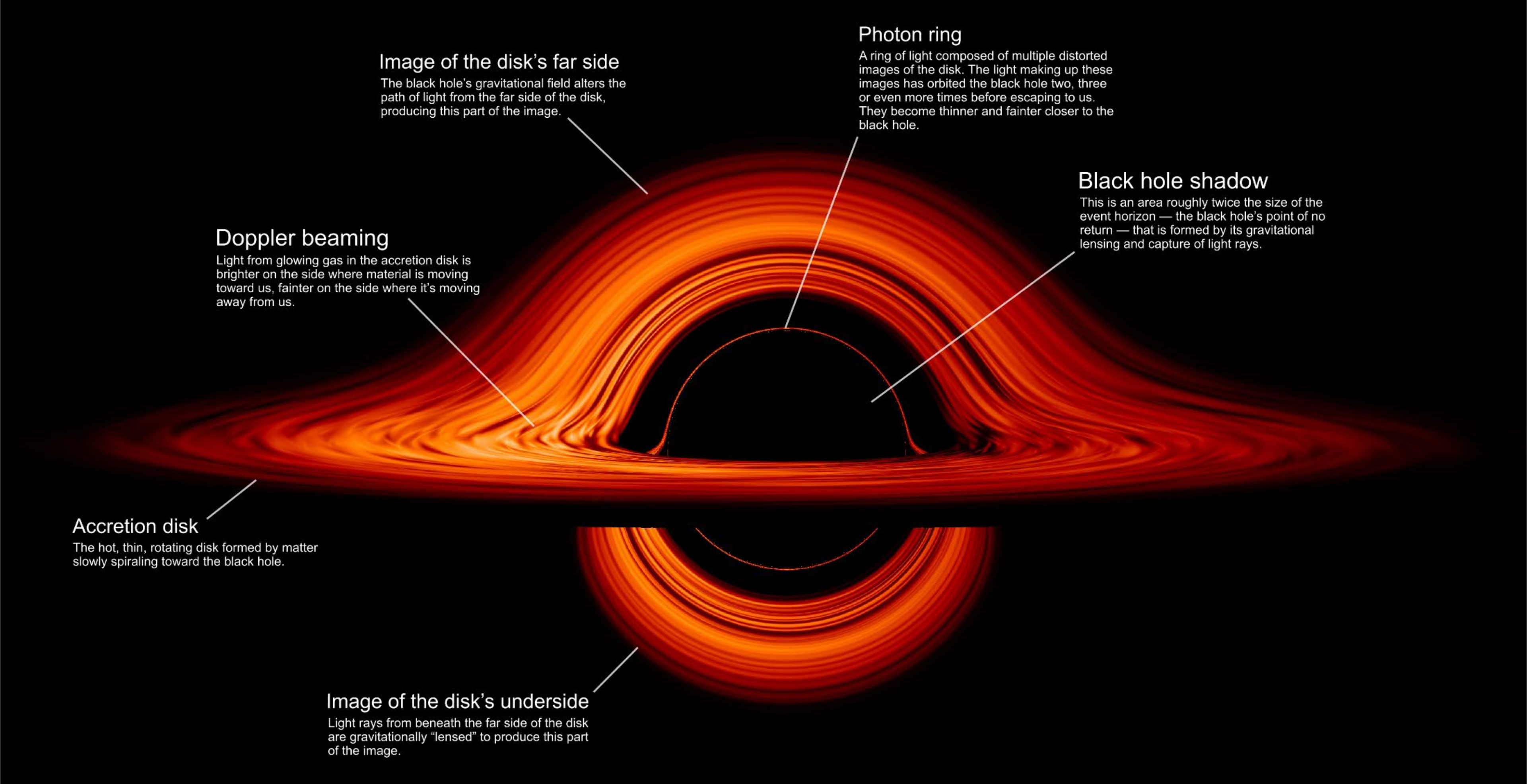


Black Hole Images

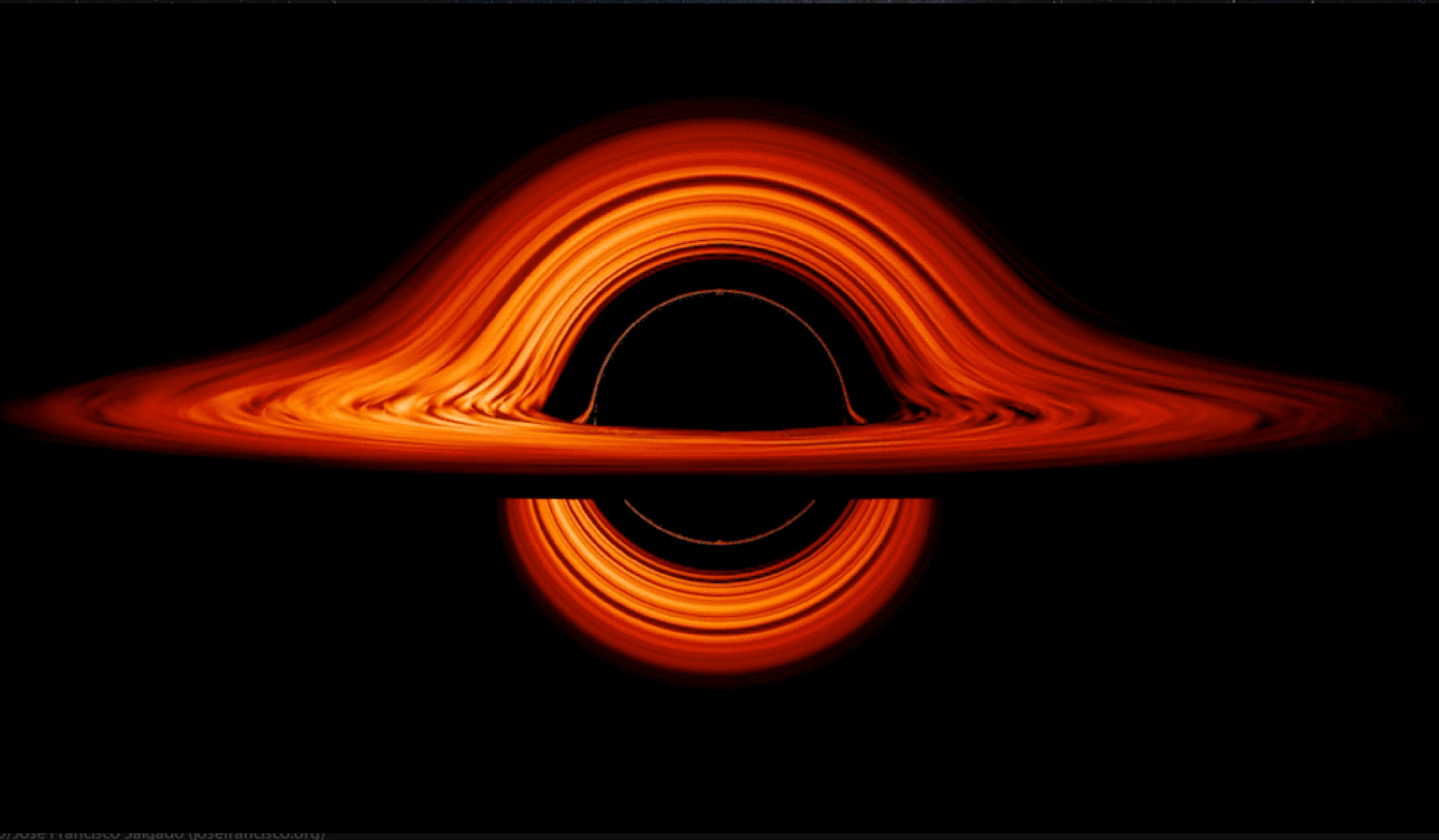
NASA: Black Hole's Warped World



https://www.nasa.gov/feature/goddard/2019/nasa-visualization-shows-a-black-hole-s-warped-world

Black Hole Images

- NASA: Black Hole's Warped World



Center of the Milky Way

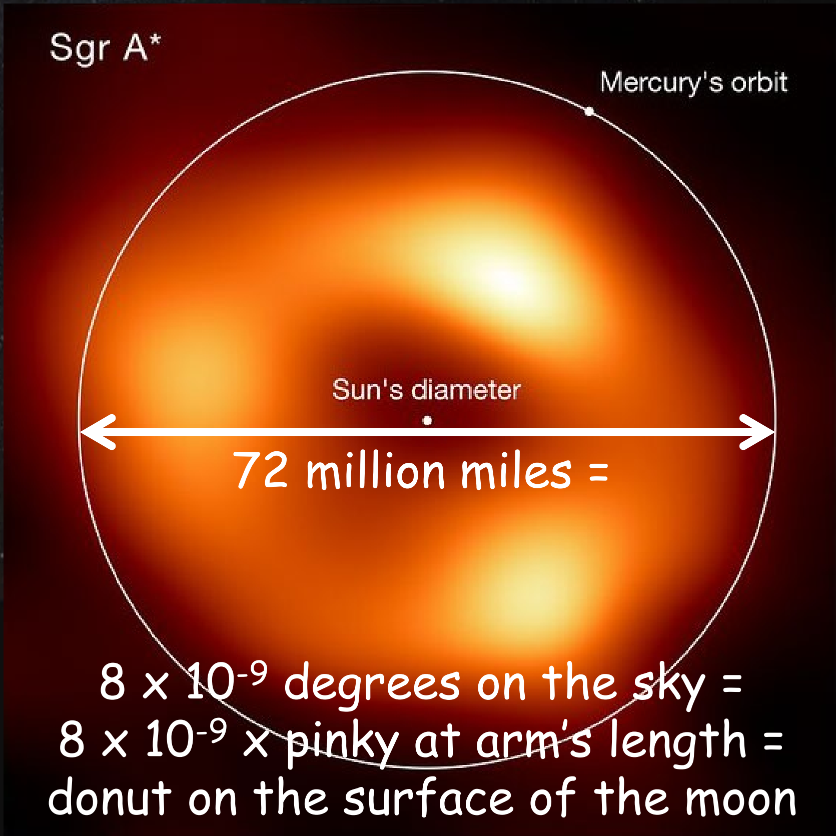
- Sagittarius A*
  - Stars orbit center at high speeds!
    - Observed from 1995 until present
    - Orbital speeds give mass of object in center

$M_{\text{MW Black Hole}}$ = 4.3 million M_{Sun}

$D_{\text{MW BH Event Horizon}}$ = 16 million mi

$r_{\text{Earth to Sun}}$ = 93 million mi

Milky Way's black hole is 4.3 million times the Sun's mass in a volume much smaller than the Sun ... r_{BH} = 0



72 million miles =

8 x 10^{-9} degrees on the sky =
8 x 10^{-9} x pinky at arm's length =
donut on the surface of the moon

Center of the Milky Way

European Southern Observatory

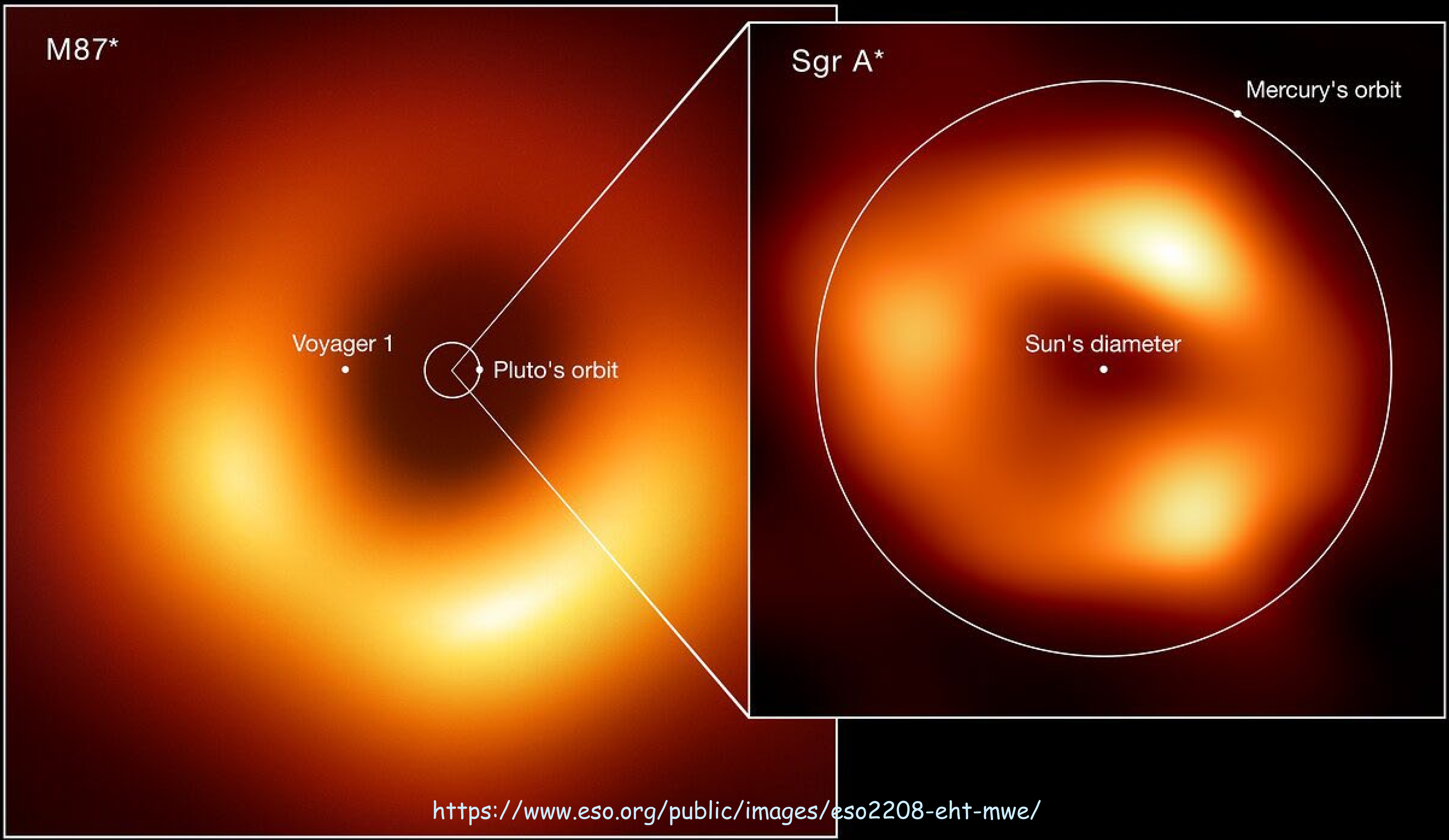
Four ALMA antennas on the Chajnantor plain *

https://www.eso.org/public/images/alma-jfs-2010-10/

O/Jose Francisco Salgado (josefrancisco.org)

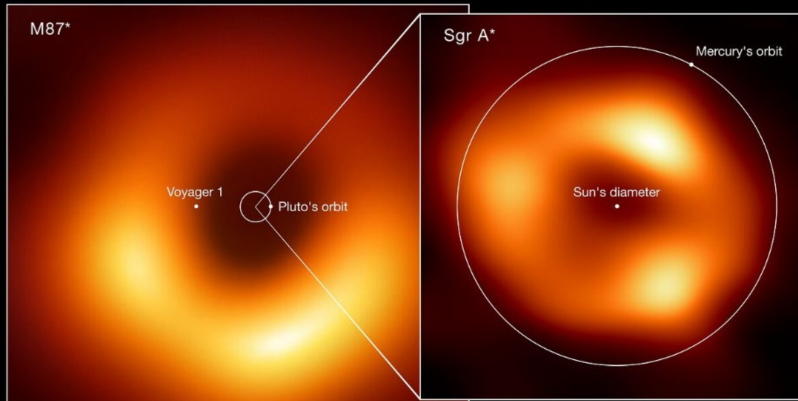
Black Hole Images

- M 87 vs. Sgr A*: Pluto orbit ~100 x Mercury's



https://www.eso.org/public/images/eso2208-eht-mwe/

Black Hole Images

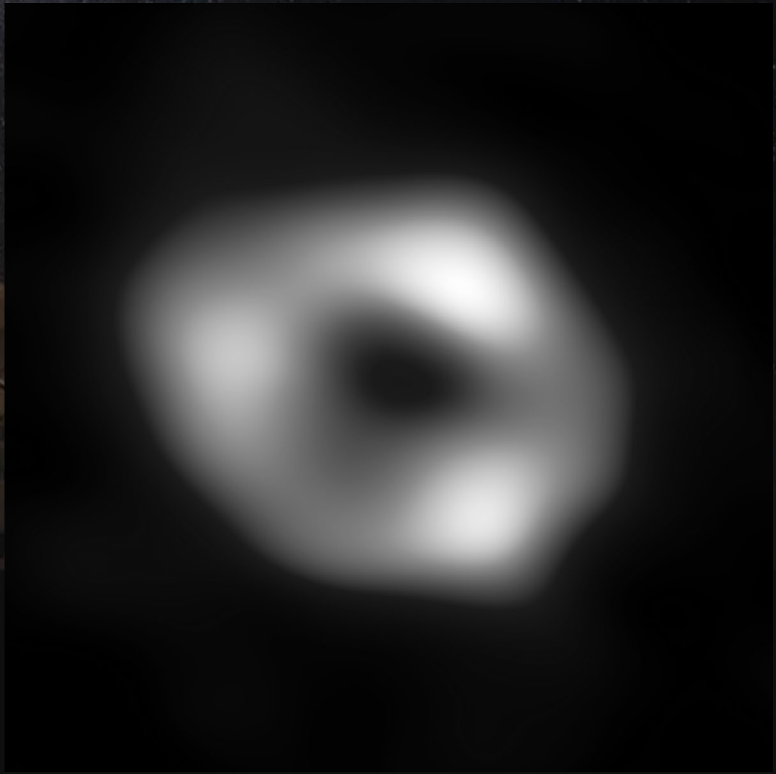


https://www.eso.org/public/images/eso2208-eht-mwe/

- M 87 vs. Sgr A*
  - $M_{M\ 87} = 1000\ M_{Sgr\ A^*}$
  - $Dist_{M\ 87} = 1000\ Dist_{Sgr\ A^*}$
  - Orbit Times (at nearly speed of light)
    - Observations take hours (faint objects)
      - M 87: Disk material orbits in a few days
      - Sgr A*: Disk material orbits in a couple minutes
    - Image of Sgr A* blurrier than M 87 due to motions
    - Image of Sgr A* harder to create due to motions
  - Sgr A* and Earth in dusty plane of galaxy
    - We look in from out of M 87's galaxy plane

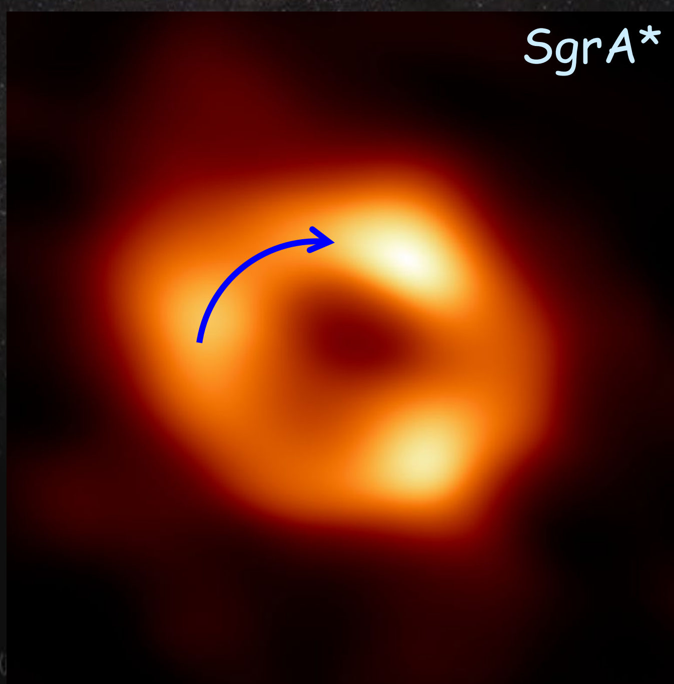
Black Hole Images

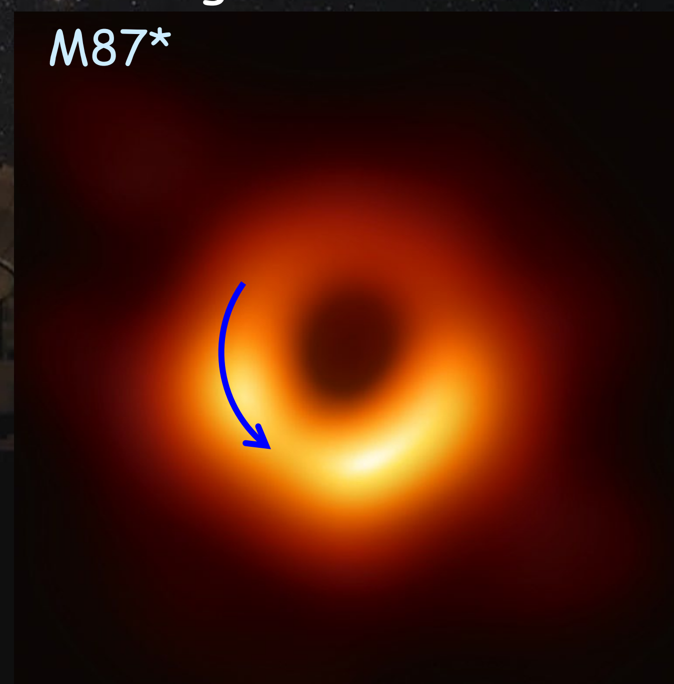
- Why orange?
  - Human eye can see more levels
    - Black → orange → yellow → white
    - Standard for images in low frequencies (JWST)



Black Hole Images

- Why blobs?
  - Accretion disk not uniform
    - Blobs of material glow brighter
  - Doppler Beaming
    - Material coming toward us looks brighter
      - Shows direction disk is rotating






The adventure continues ...
ADIRONDACK
SKYCENTER
& OBSERVATORY
Please support the ASCO
/Jose Francisco Salgado (josefrancisco.org)