

Astronomy...
Things Both Near and Far

Robert Vanderbei

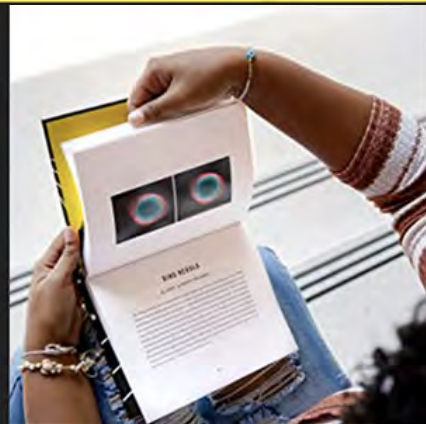
STEP Program @ Princeton University

<http://vanderbei.princeton.edu>

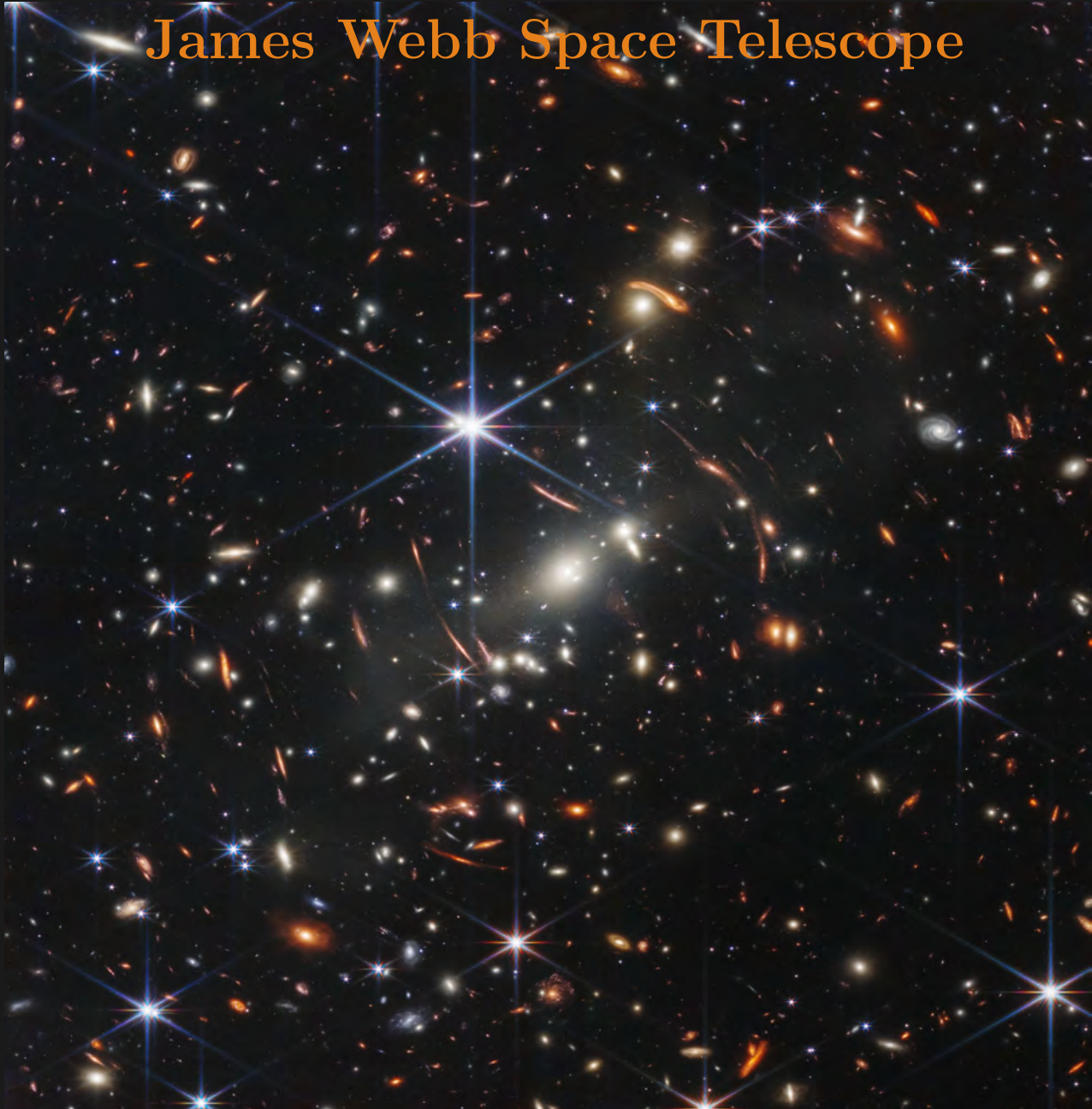


Welcome to the Universe in 3D *A Visual Tour*

Neil deGrasse Tyson, Michael A. Strauss,
J. Richard Gott, and Robert J. Vanderbei



James Webb Space Telescope



Neil deGrasse Tyson with Stephen Colbert



Parallax



Parallax

Left Eye View

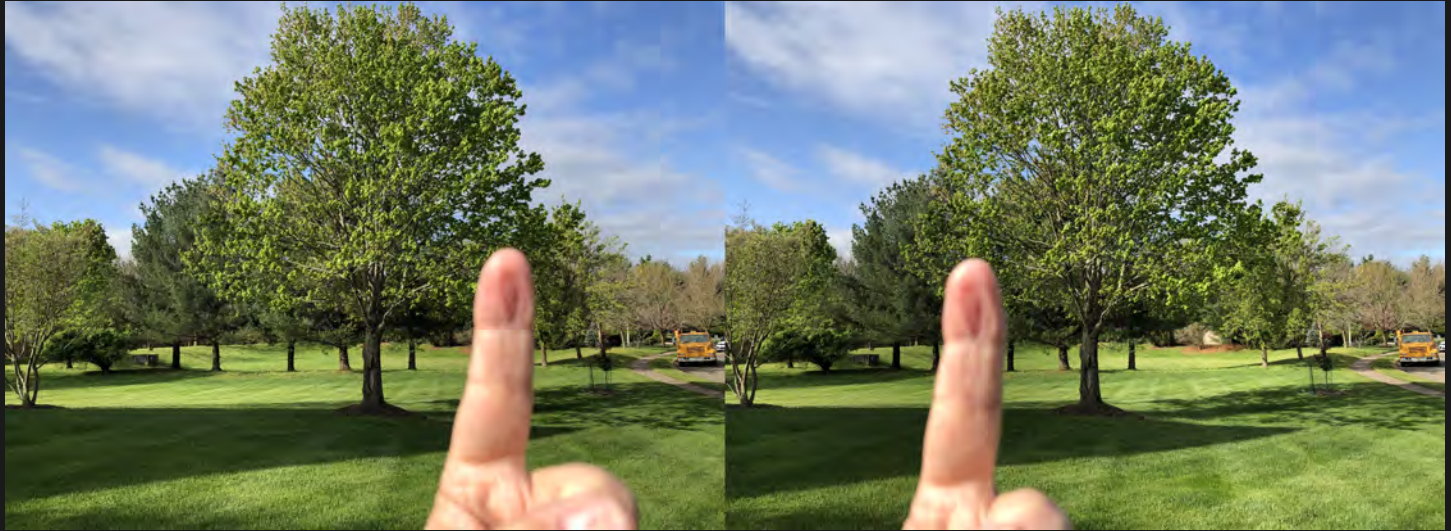


Parallax

Right Eye View



My Finger – Parallax



My Finger – Left Eye



My Finger – Right Eye



My Finger – Both Eyes



Let's Go Astro

10" Reflector, 4" Refractor, Telephoto Lens



Move equipment outside.



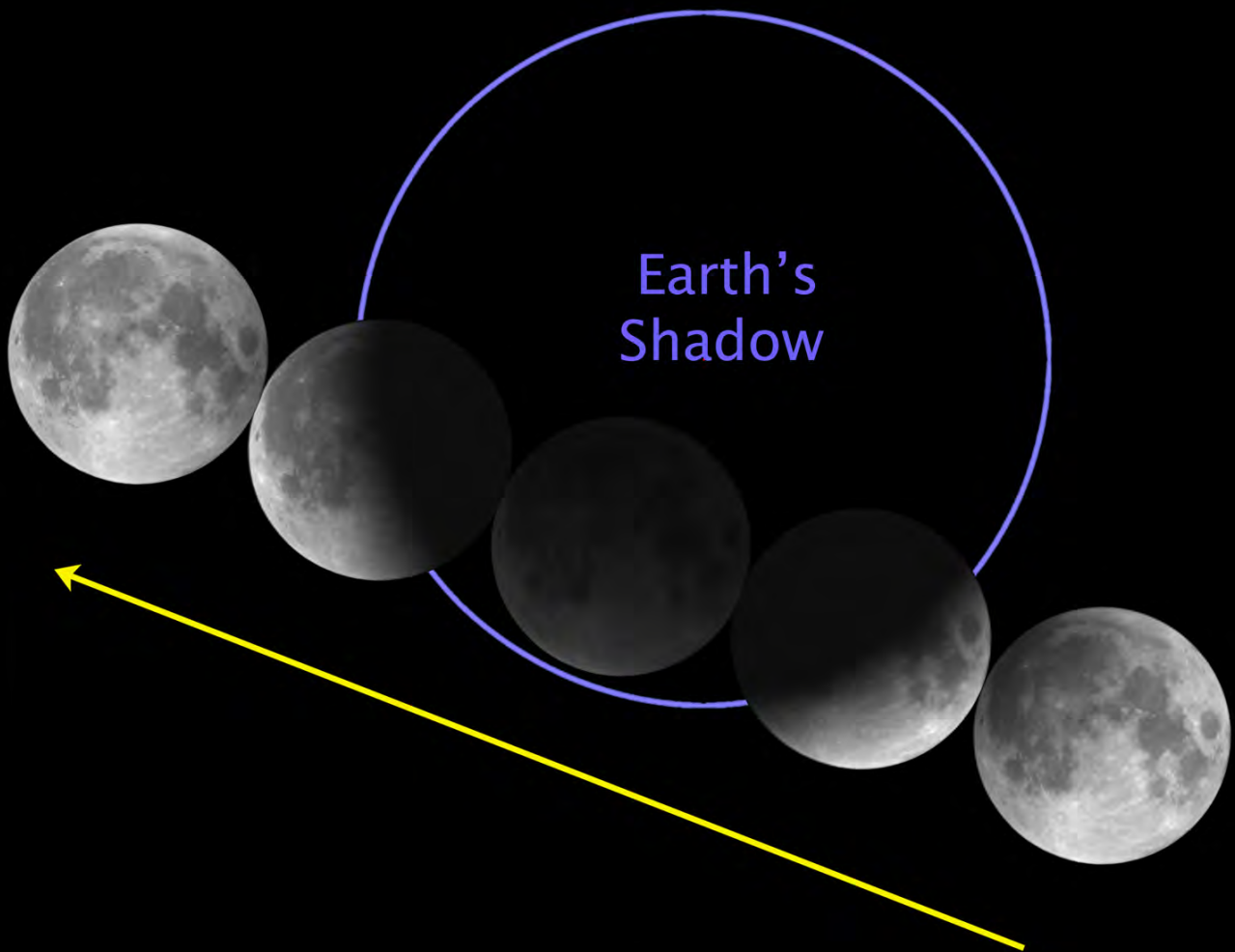
Ready To Go...



Is The Earth Flat?

A Picture's Worth a Thousand Words...





Earth's
Shadow

How Aristarchus measured the size of the Moon.

How Big Is Earth?

A picture I took of a sunset over Lake Michigan.

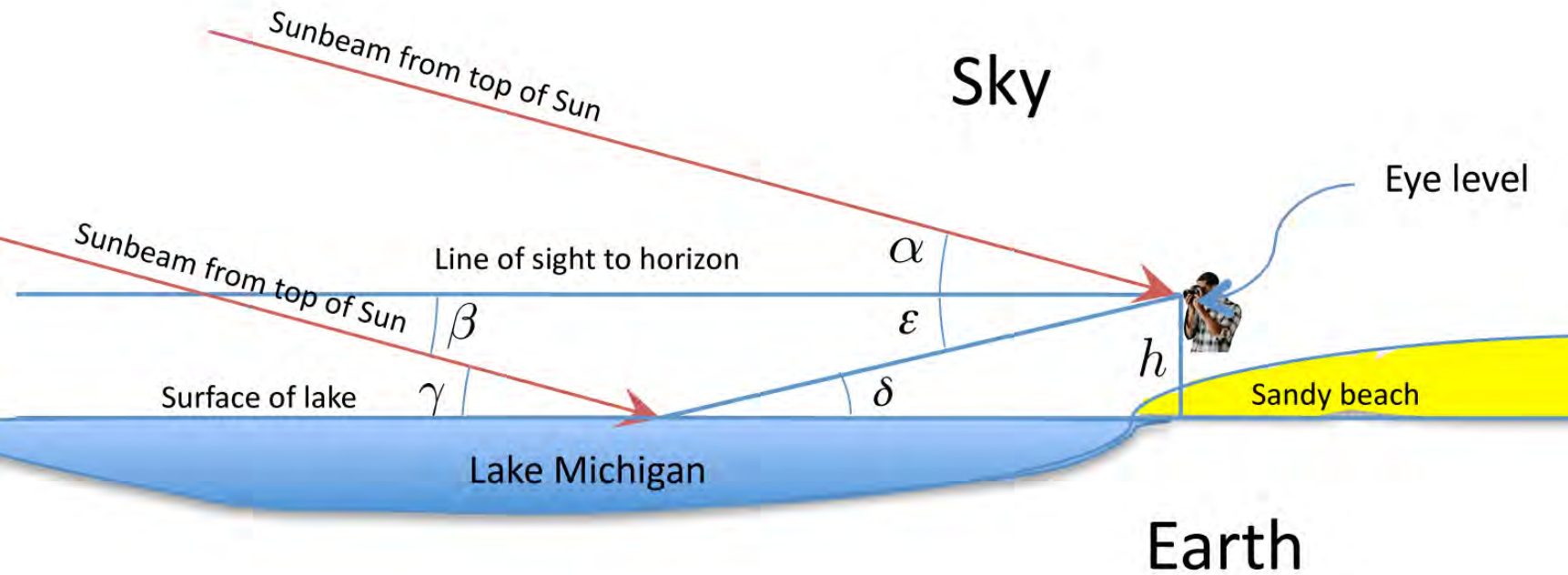


A close-up.

Using this picture, some geometry, and a little trigonometry, I was able to compute that the Earth's radius is about 4350 miles.



Geometry — If the Earth Were Flat!



- $\alpha = \beta$ alternate interior angles are equal
- $\beta = \gamma$ alternate interior angles are equal
- $\gamma = \delta$ angle of incidence equals angle of reflection (from Physics!)
- $\delta = \epsilon$ alternate interior angles are equal

Therefore,

$$\alpha = \epsilon.$$

The reflection dips just as far below the horizon as the Sun stands above the horizon.

Geometry — The Earth Is Not Flat

Draw a picture.

Label everything of possible relevance.

Identify what we know:

α Angle between horizon and top of Sun (measured from photo)

β Angle between horizon and “top” of Sun in reflection (measured)

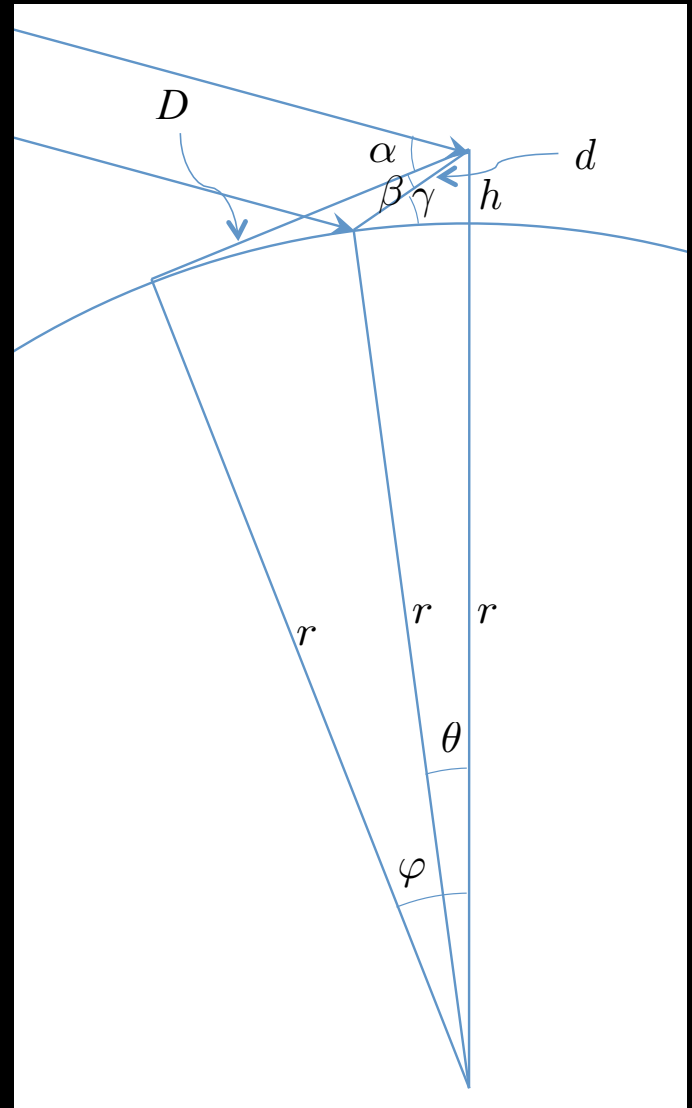
h Height of “eye-level” above “water-level”.

Doing a bunch of trigonometry and algebra we get

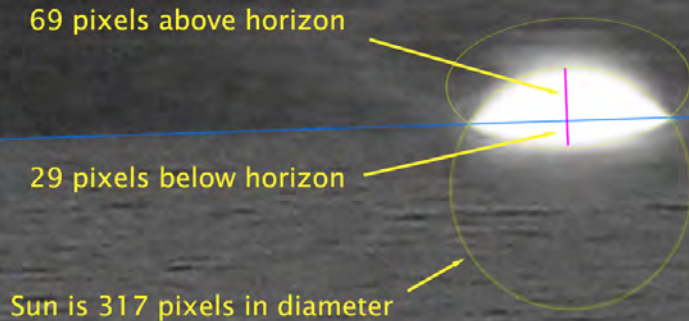
$$r = \frac{h}{\frac{\sqrt{1 - 2 \cos \beta \cos \gamma + \cos^2 \gamma}}{\sin \beta} - 1}$$

where

$$\gamma = (\alpha + \beta)/2$$



What We Know (Measure!)



The Sun is $1/2^\circ$ in diameter. Therefore, 1° equals $2 \times 317 = 634$ pixels.
And so,

$$\alpha = 69 \text{ pixels} \times \frac{1 \text{ degree}}{634 \text{ pixels}} = 0.1088 \text{ degrees}$$

and

$$\beta = 29 \text{ pixels} \times \frac{1 \text{ degree}}{634 \text{ pixels}} = 0.0457 \text{ degrees.}$$

And, we assume that eye level is

$$h = 6 \text{ feet}$$

Hence... Earth's radius is about 4,350 miles. Diameter is twice a radius: 8,700 miles.

BETTER ANSWER: Earth's Diameter \approx 8,000 miles

How Far to the Moon?

Angular Size of the Moon.

Using my iPhoneX, I took 16 pics to make a 360° panorama from the middle of the road in front of my house. I used Photoshop to assemble the pics:



Here's a closeup of my neighbor's car as seen at the left edge and the right edge:



The horizontal pixel distance of the car's rear view mirror as seen on the left and on the right is $38108 - 83 = 38025$ pixels.



Using the same camera I took a picture of the crescent Moon:



Here's a closeup showing that the Moon's diameter is 59 pixels:



Using these pixel measurements, we can compute the angular size of the Moon:

$$\begin{aligned} \text{Moon Size} &= \frac{59}{38025} \times 360^\circ = 0.56^\circ \\ &\approx 1/2 \text{ deg} \end{aligned}$$

From a lunar eclipse, we can determine that the Earth is about 4 times larger than the Moon. Earth's diameter is about 8,000 miles. Hence, Moon's diameter is about 2,000 miles.



Next total lunar eclipse visible from the "east coast" is on November 8 at 6am.

ANSWER: Distance to the Moon \approx 240,000 miles

Moon's diameter = 2,000 miles

Moon's orbital circumference = 2,000 miles $\times \frac{360 \text{ deg/circumference}}{1/2 \text{ deg/Moon diameter}}$

Moon's distance = $\frac{\text{Moon's orbital circumference}}{2\pi} \approx \frac{\text{Moon's orbital circumference}}{6} = \frac{2,000 \times 720}{6} = 240,000 \text{ mi}$

ANSWER: Distance to the Moon \approx 240,000 miles

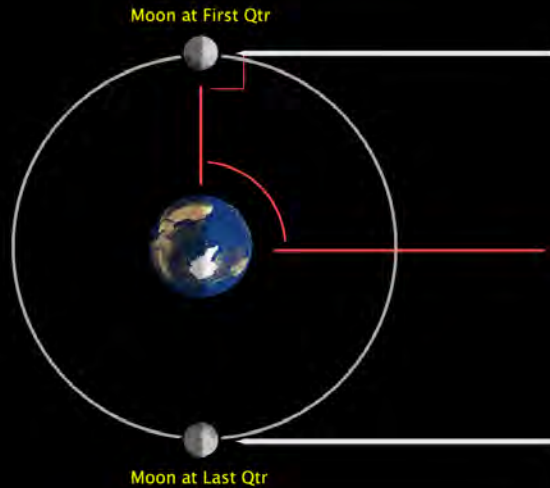
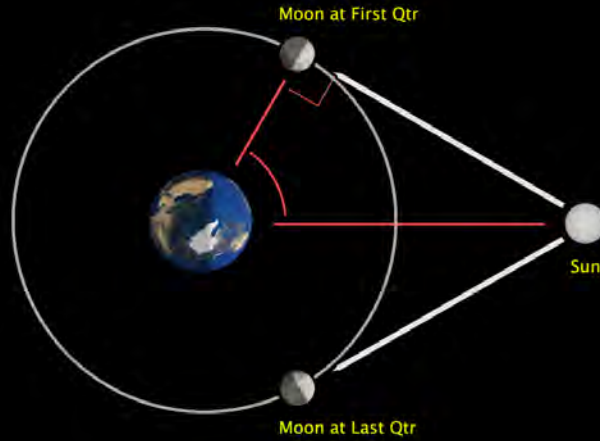
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Which Is Further Away... Sun or Moon?

The Sun is about 400 times further away...



Halloween's Blue Moon

Oct. 31, 2020



Crescent Moon

4:07pm Nov. 5, 2021



Moon

1.2 sec



Moon and Mars



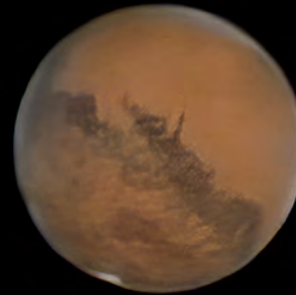
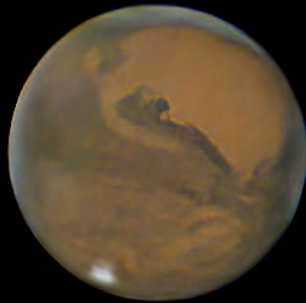
Moon and Mars

1.2 sec and 3.3 min



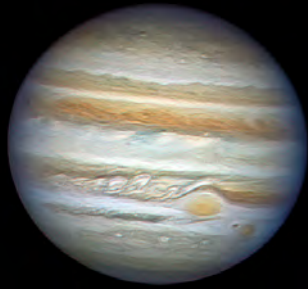
Mars

Oct. 6 and 18, 2020



Jupiter and Saturn

32 and 67 min



.



Comet 103P / Double Cluster

1.2 min / 7,460 and 7,640 yrs



Looking Out Beyond Our Solar System

Distance Measurements

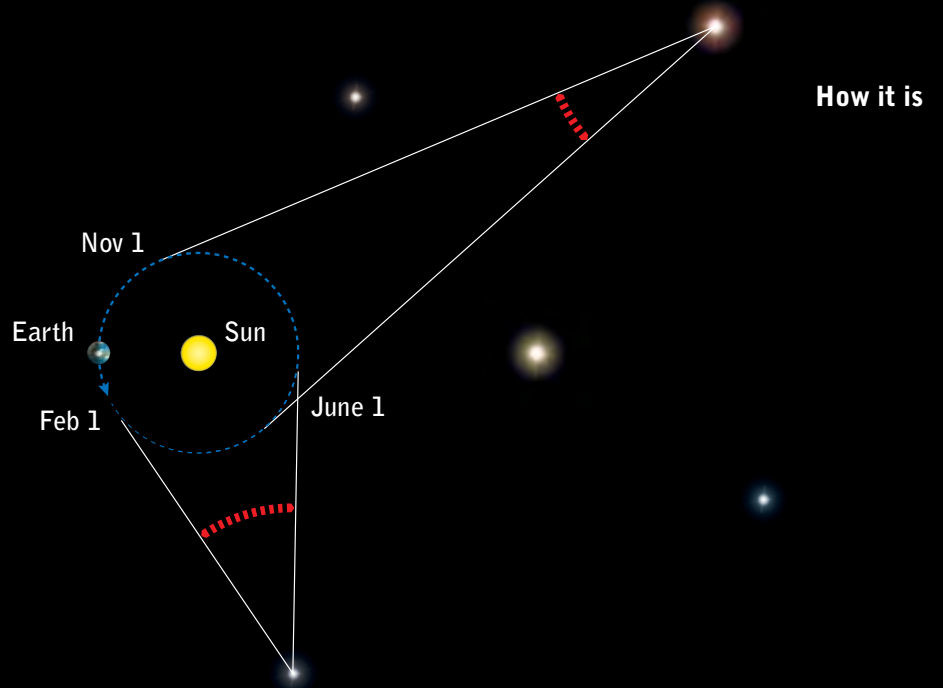
There are various ideas/methods for measuring distances.

The simplest is called *parallax*.

Using parallax, we can measure the distance to nearby stars.

For things further away, we need more clever/subtle methods.

Parallax: Distance to the Stars



Barnard's Star



Barnard's Star



Barnard's Star



Barnard's Star



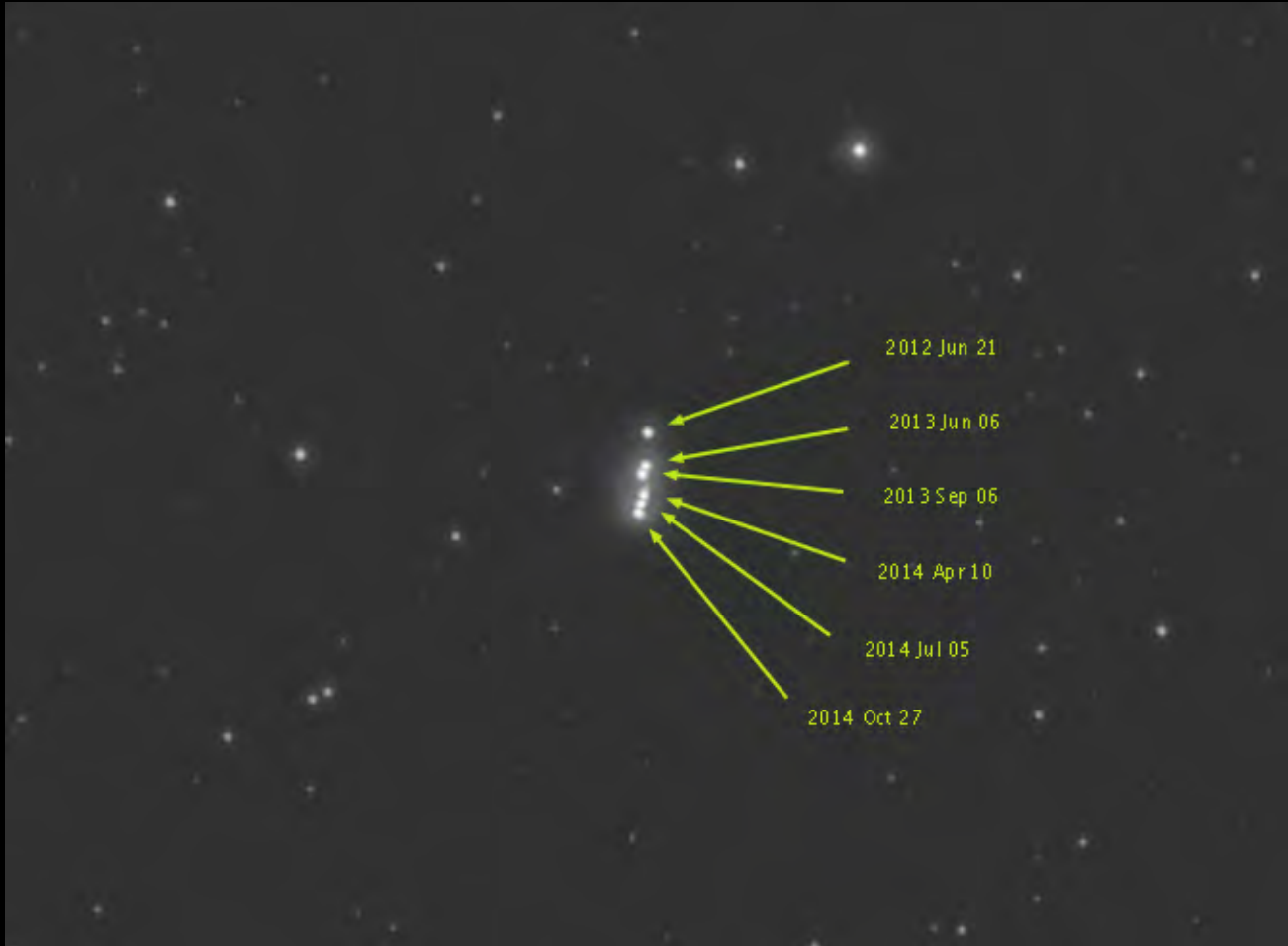
Barnard's Star



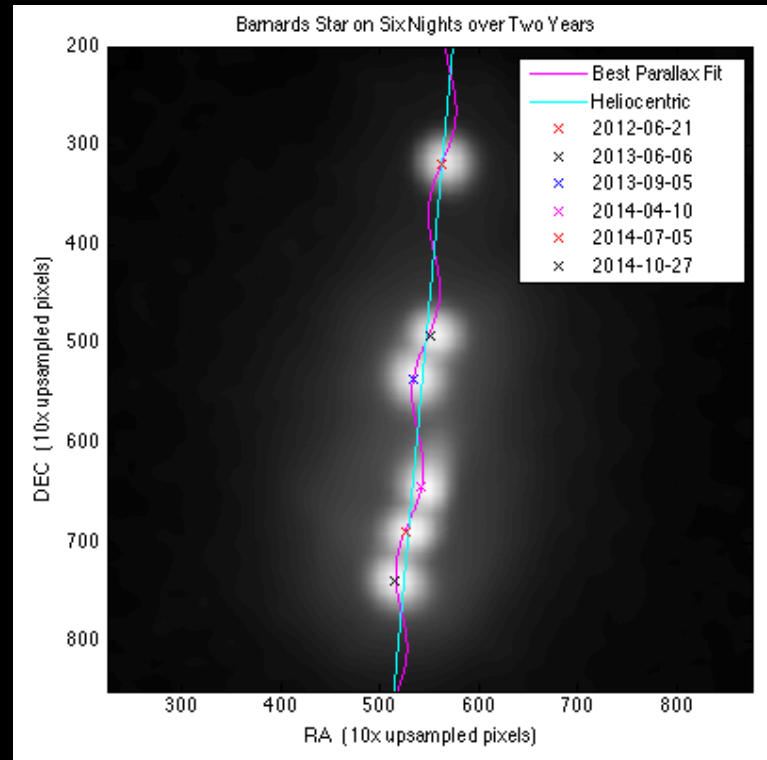
Barnard's Star



Barnard's Star Overlay



Barnard's Star Closeup



The measured parallax is 0.5478 arcsecs. Corresponds to a distance of 5.97 lightyears.

Orion Nebula: M42

1,344 yrs



Dumbbell Nebula

1,360 yrs



Veil Nebula: NGC 6960 and 6992

2,400 yrs



Western Veil: NGC 6960

2,400 yrs



Eastern Veil: NGC 6992



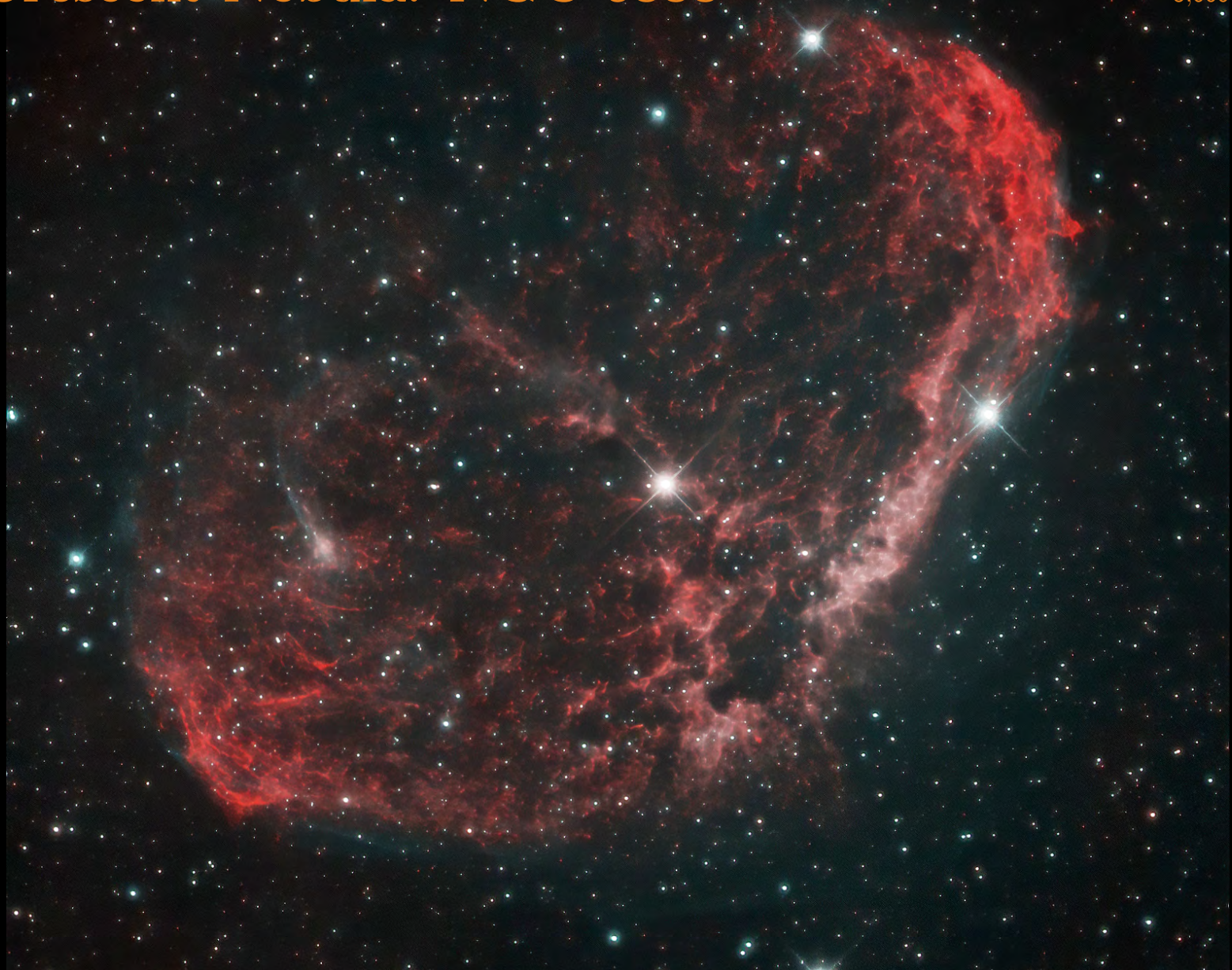
Ring Nebula: M57

2,567 yrs



Crescent Nebula: NGC 6888

5,000 yrs



Jellyfish Nebula: IC 443

5,000 yrs



Rosette Nebula: NGC 2237

5,200 yrs



Eagle Nebula: M16

5,700 yrs



Crab Nebula

Mar. 26, 2019

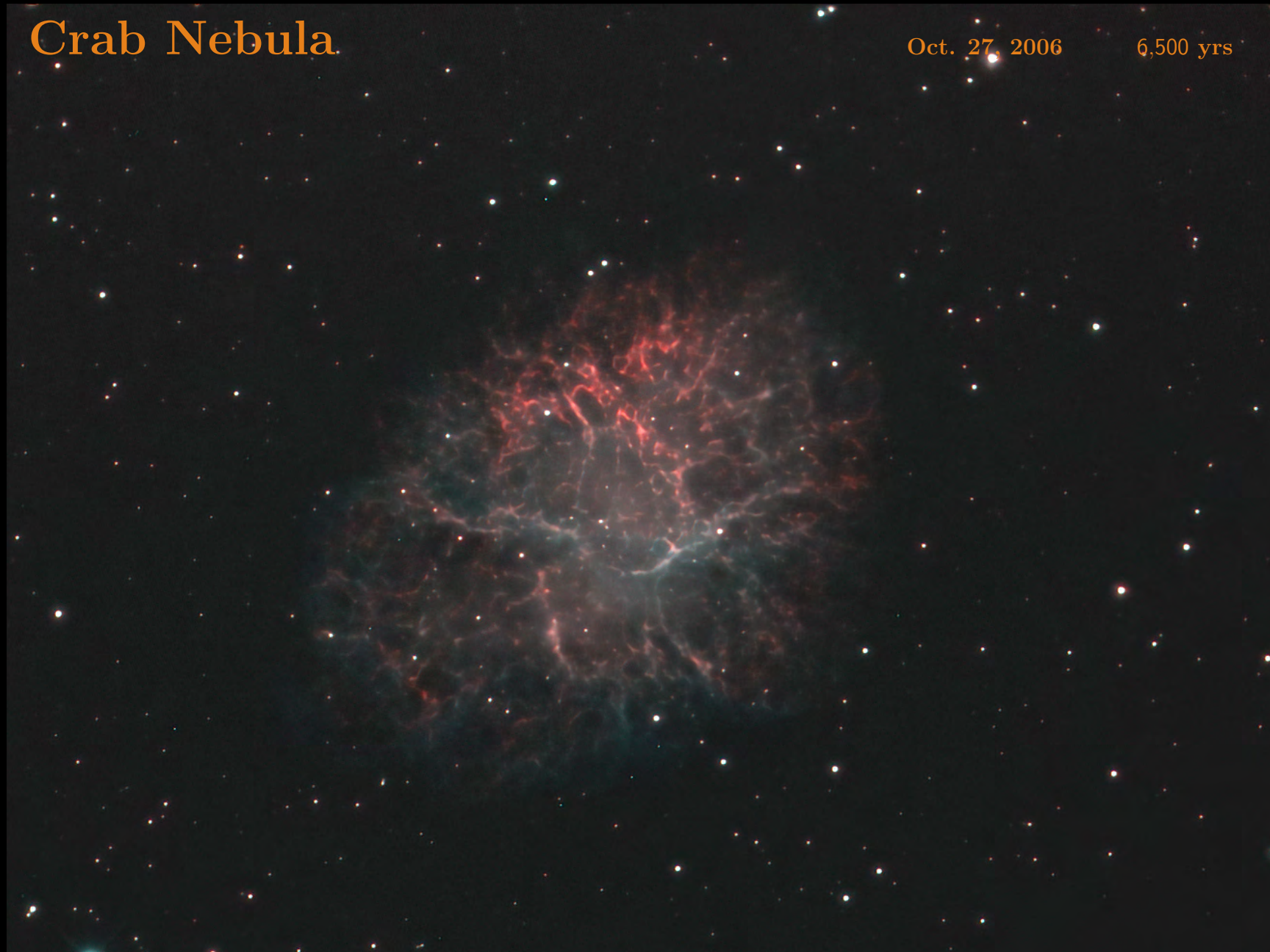
6,500 yrs



Crab Nebula

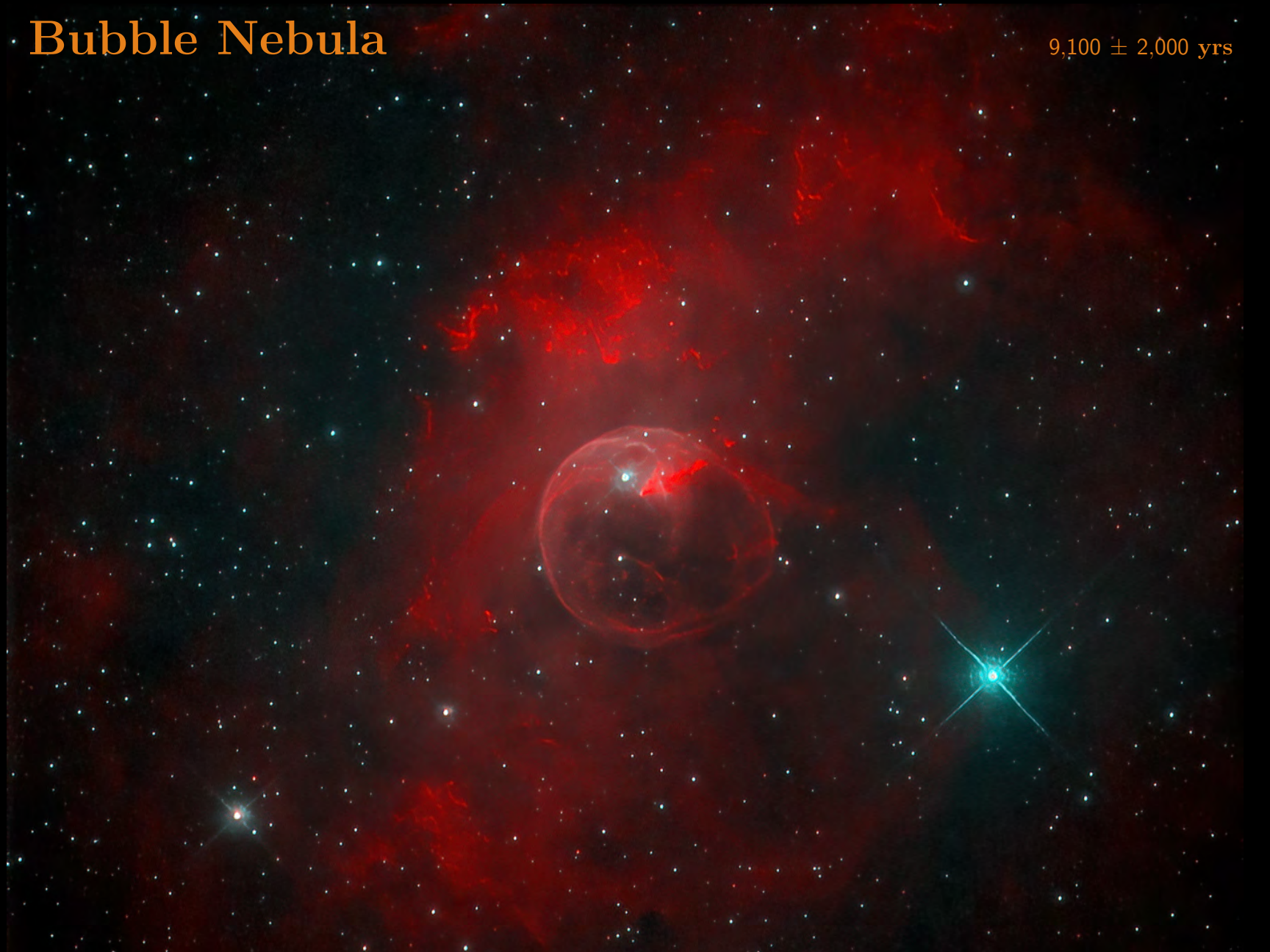
Oct. 27, 2006

6,500 yrs



Bubble Nebula

9,100 \pm 2,000 yrs



Globular Cluster M13

22,200 yrs



Looking Out Beyond Our Milky Way

The Andromeda Galaxy

2,450,000 yrs



M81 and M82

12,000,000 yrs



The Whirlpool Galaxy

31,000,000 yrs



The Whirlpool Galaxy

31,000,000 yrs



The Whirlpool Galaxy

31,000,000 yrs



The Leo Trio

32,000,000 yrs



The Needle Galaxy (NGC 4565)

42,700,000 yrs



Welcome to the Universe in 3D



3D Pictures from the Book



Moon



Mars



Comet Lovejoy



Jupiter and Ganymede



Mimas



Crab Nebula



Andromeda



Hubble Ultra Deep Field

Questions?