

# Sizing Up The Universe

A Freshman Seminar

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Princeton Club of Rochester NY  
via Zoom

<http://vanderbei.princeton.edu>

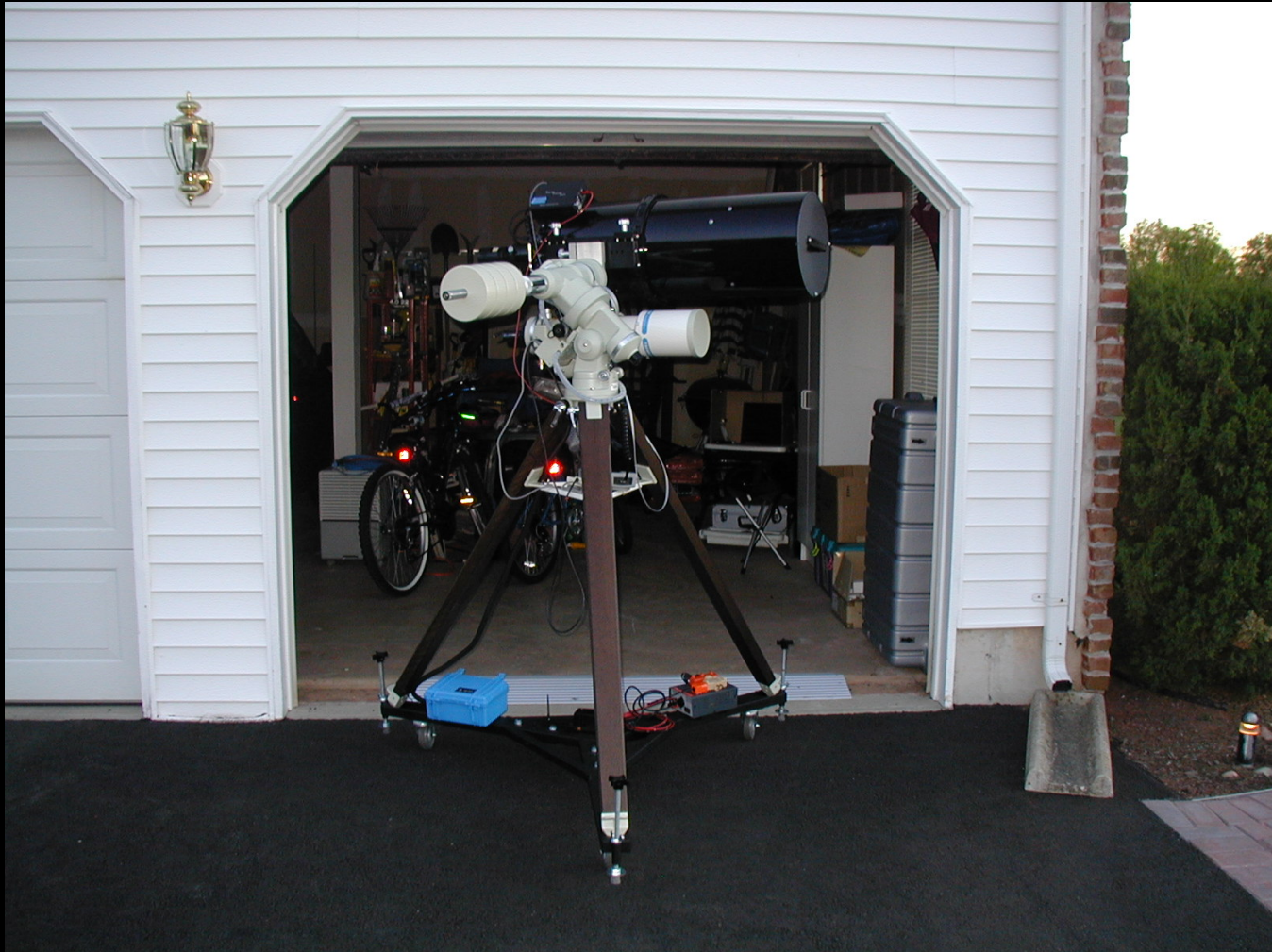
# A Little About Me

- Born/Raised: Grand Rapids, MI
- Undergrad: Chemistry, 1976, Rensselaer Polytechnic Institute (aka RPI not RIT)
- Grad: Applied Math, 1981, Cornell
- Postdocs:
  - NSF Fellow, Math, NYU
  - Visiting Lecturer, Math, Univ. of Illinois Urbana/Champaign
- Industry:
  - AT&T Bell Labs, Math Research Center
- Academia: Princeton, 1990-present
- Hobbies/Passions:
  - Soaring
  - Tennis
  - Astronomy
  - Photography
  - Math/Computation
  - Local Warming, Purple America, etc.

# 10" Reflector, 4" Refractor, Telephoto Lens



Move equipment outside.



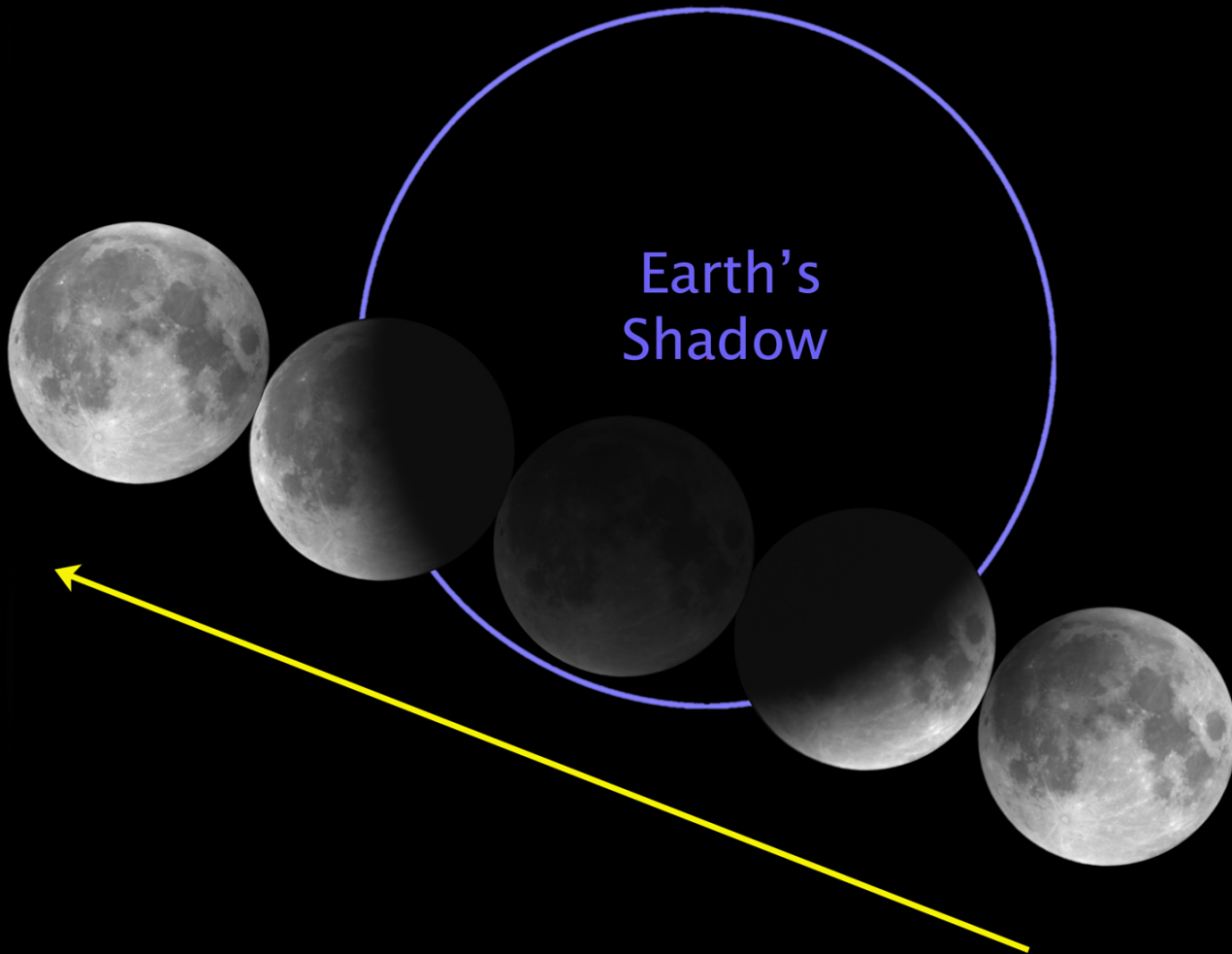
Ready To Go...



# Is The Earth Flat?

A Picture's Worth a Thousand Words...





How Aristarchus measured the size of the Moon.

# How Big Is Earth?

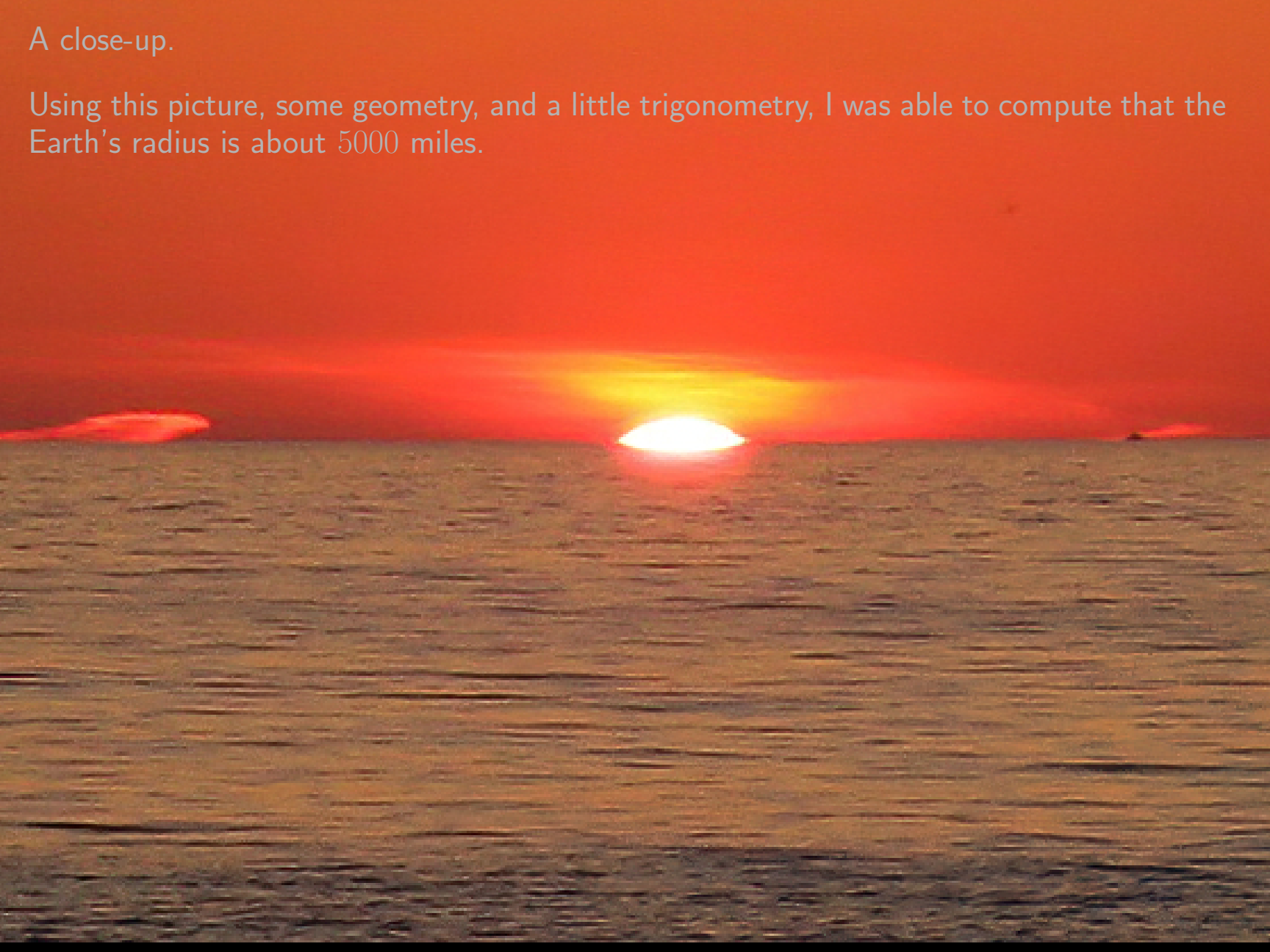
A picture I took of a sunset over Lake Michigan.



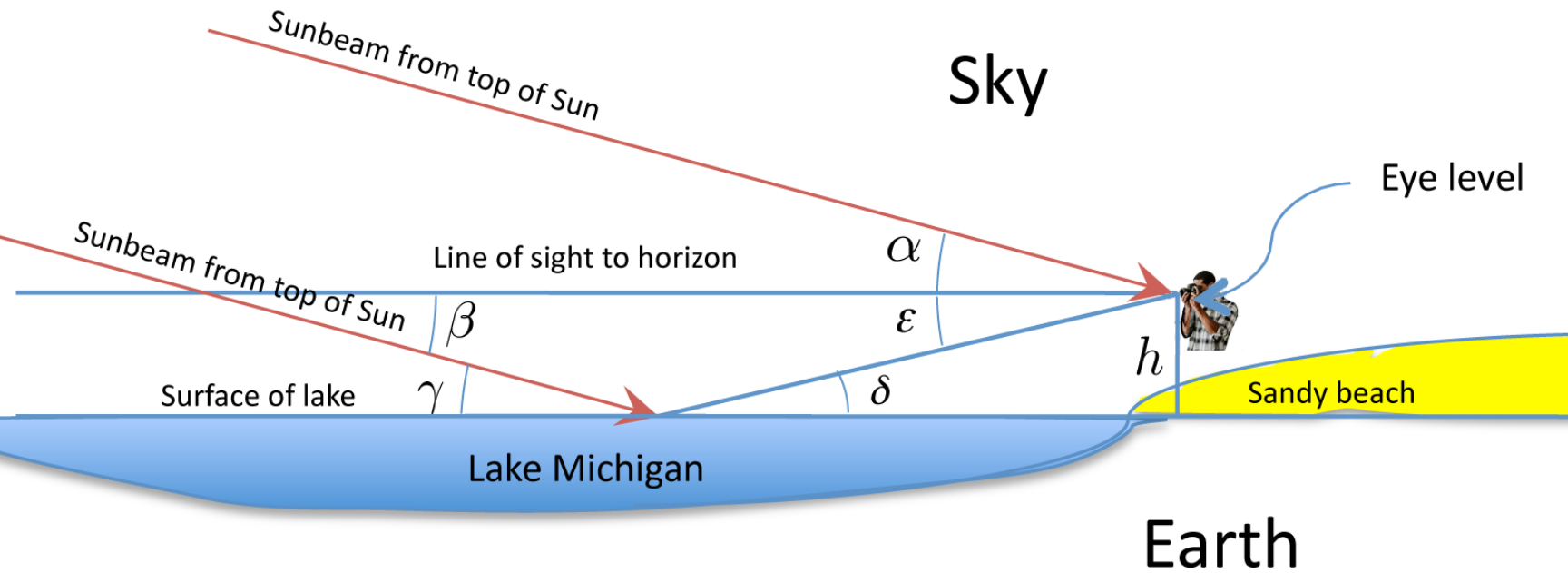


A close-up.

Using this picture, some geometry, and a little trigonometry, I was able to compute that the Earth's radius is about 5000 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.

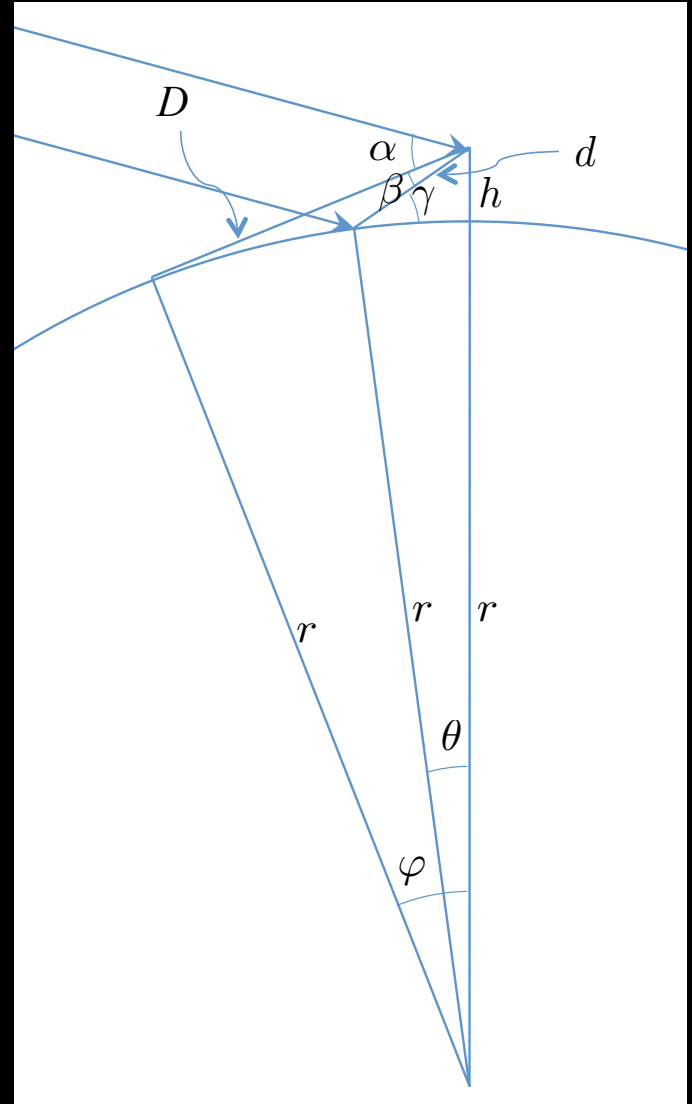
Label everything of possible relevance.

Identify what we know:

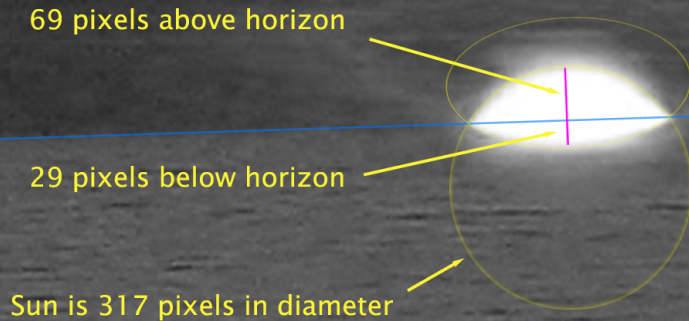
$\alpha$  Angle between horizon and top of Sun (measured from photo)

$\beta$  Angle between horizon and “top” of Sun in reflection (measured)

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



# What We Know (Measure!)



The Sun is  $1/2^\circ$  in diameter. Therefore,  $1^\circ$  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

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

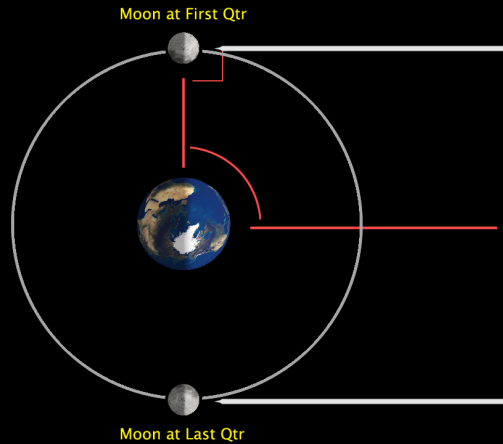
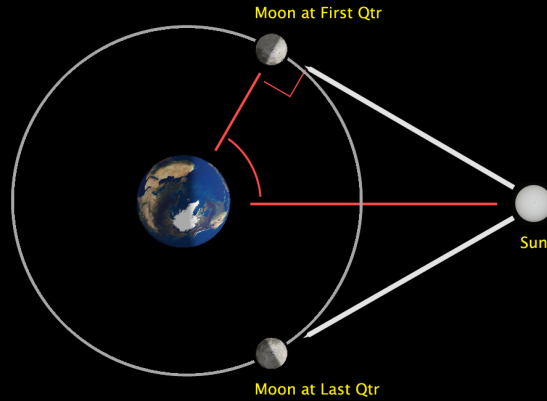
And, we assume that eye level is

$$h = 7 \text{ feet}$$

Hence... Earth's radius is about 5,000 miles.

**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

1.1 sec



# Moon and Mars



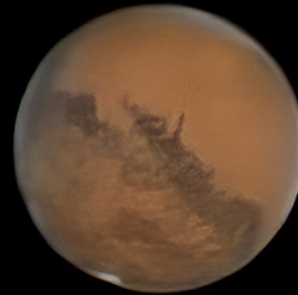
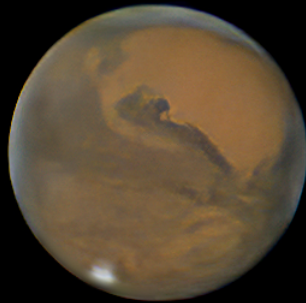
# Moon and Mars

1.1 sec and 3.3 min



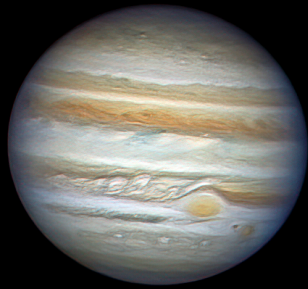
# Mars

Oct. 6 and 18, 2020

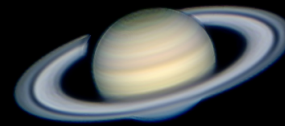


# Jupiter and Saturn

32 and 67 min



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# 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.

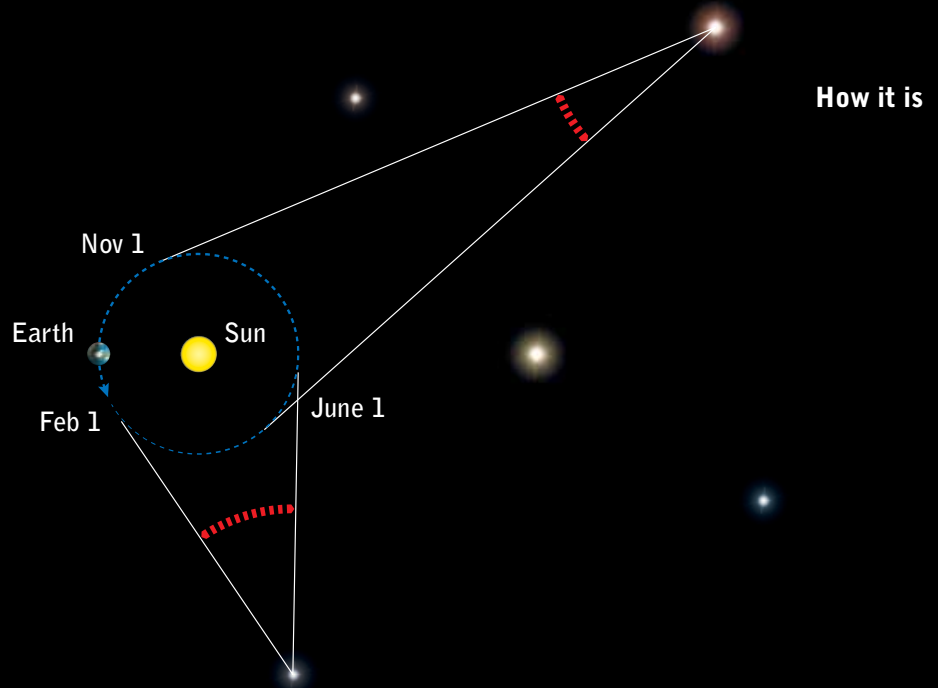
The simplest is called *parallax*.

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



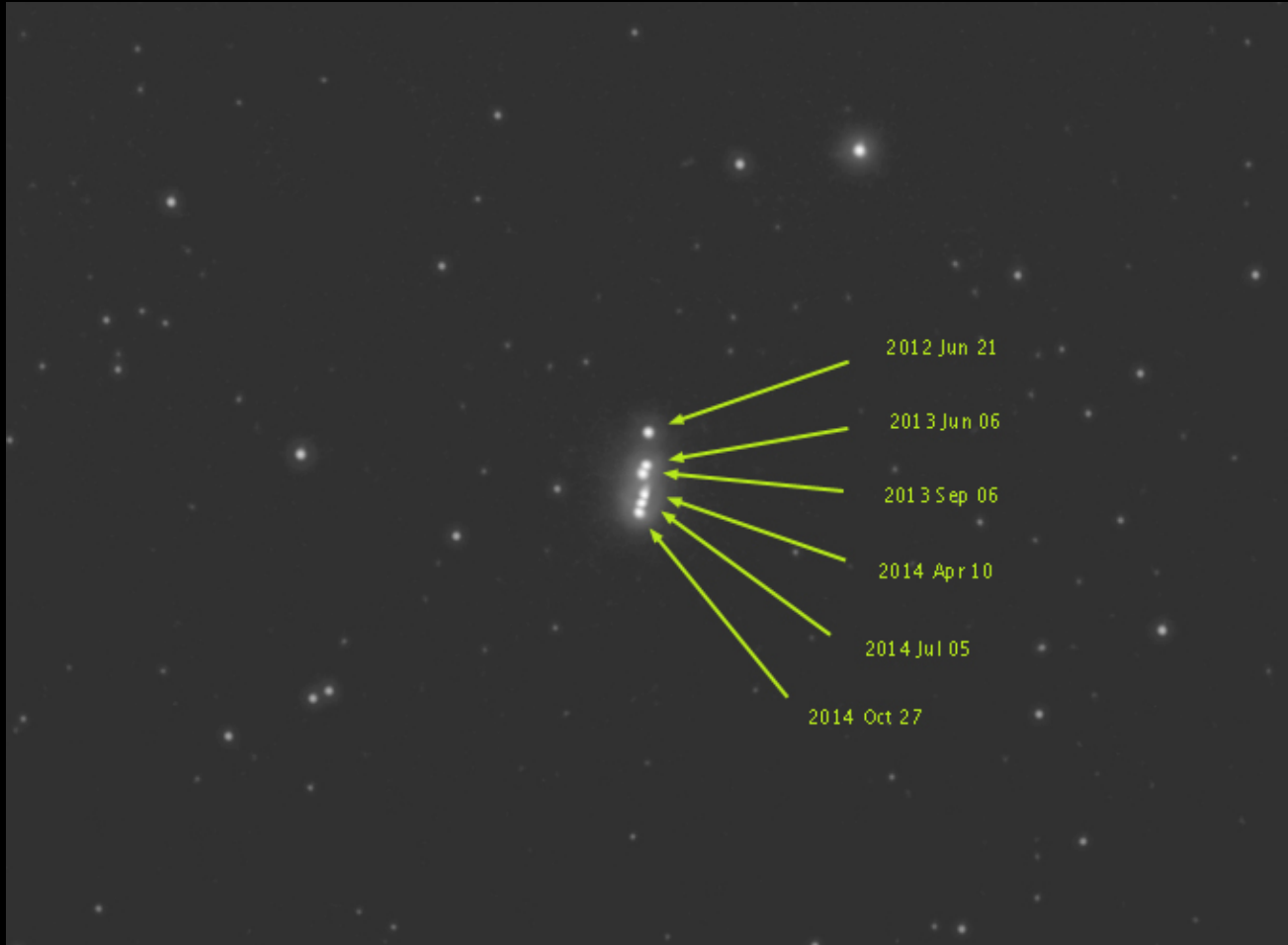
# Barnard's Star



# Barnard's Star

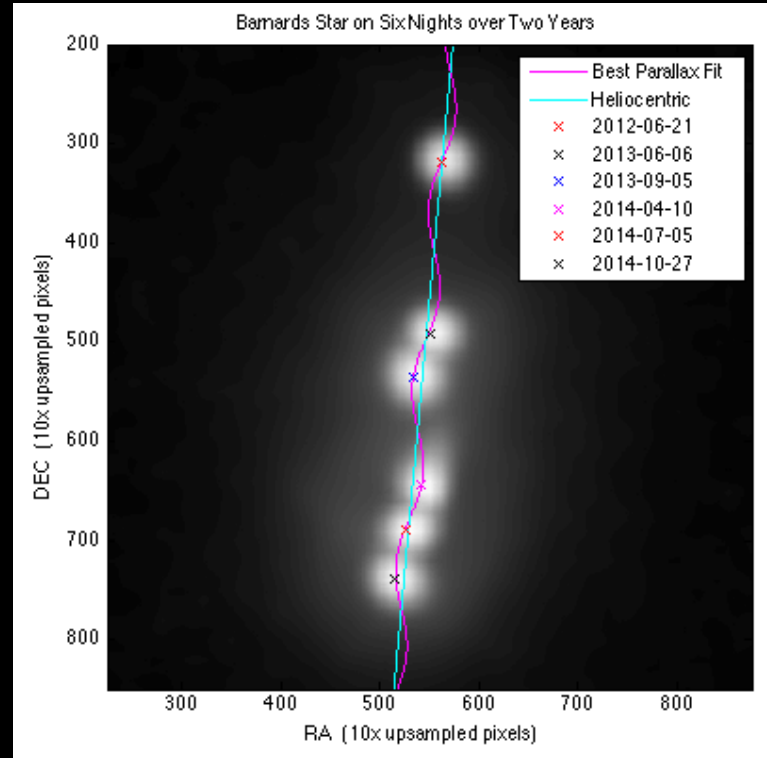


# Barnard's Star Overlay





# Barnard's Star Closeup



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

# Is The Universe Infinitely Big? – Olbers' Paradox



# Orion Nebula: M42

1,344 yrs



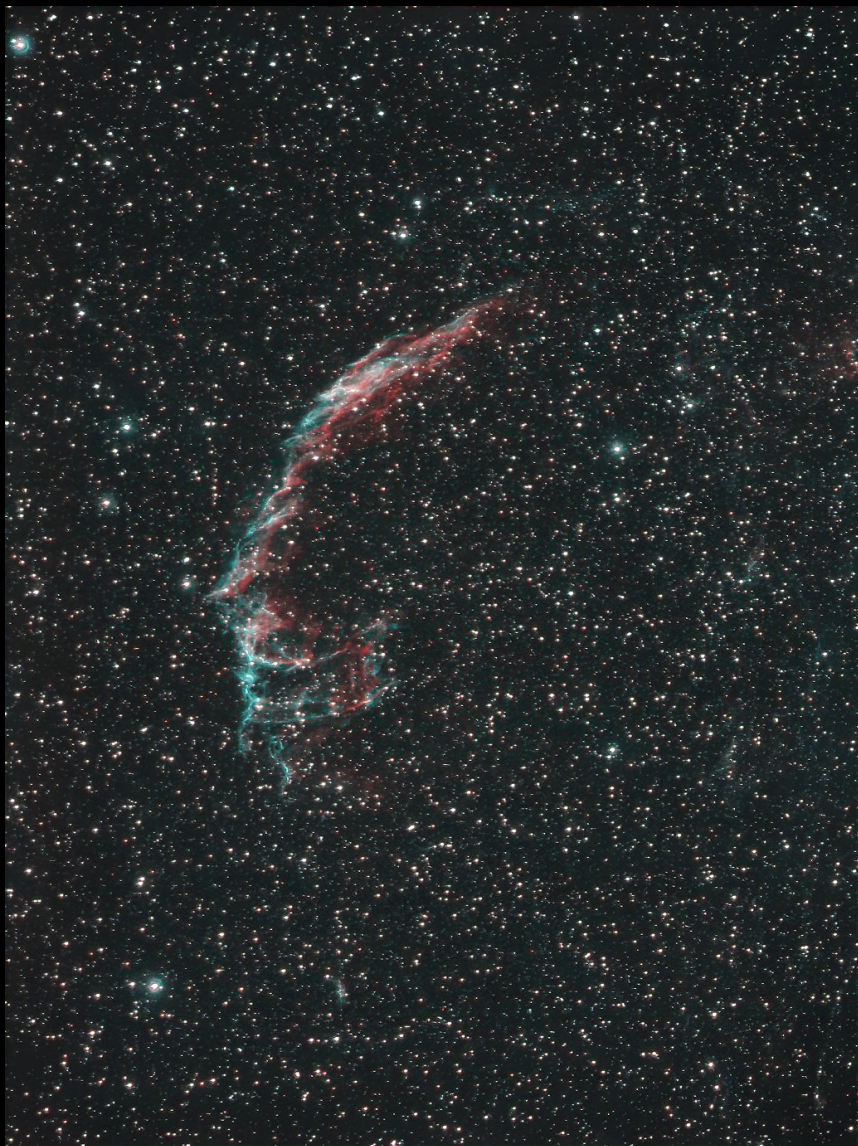
# Dumbbell Nebula

1,360 yrs



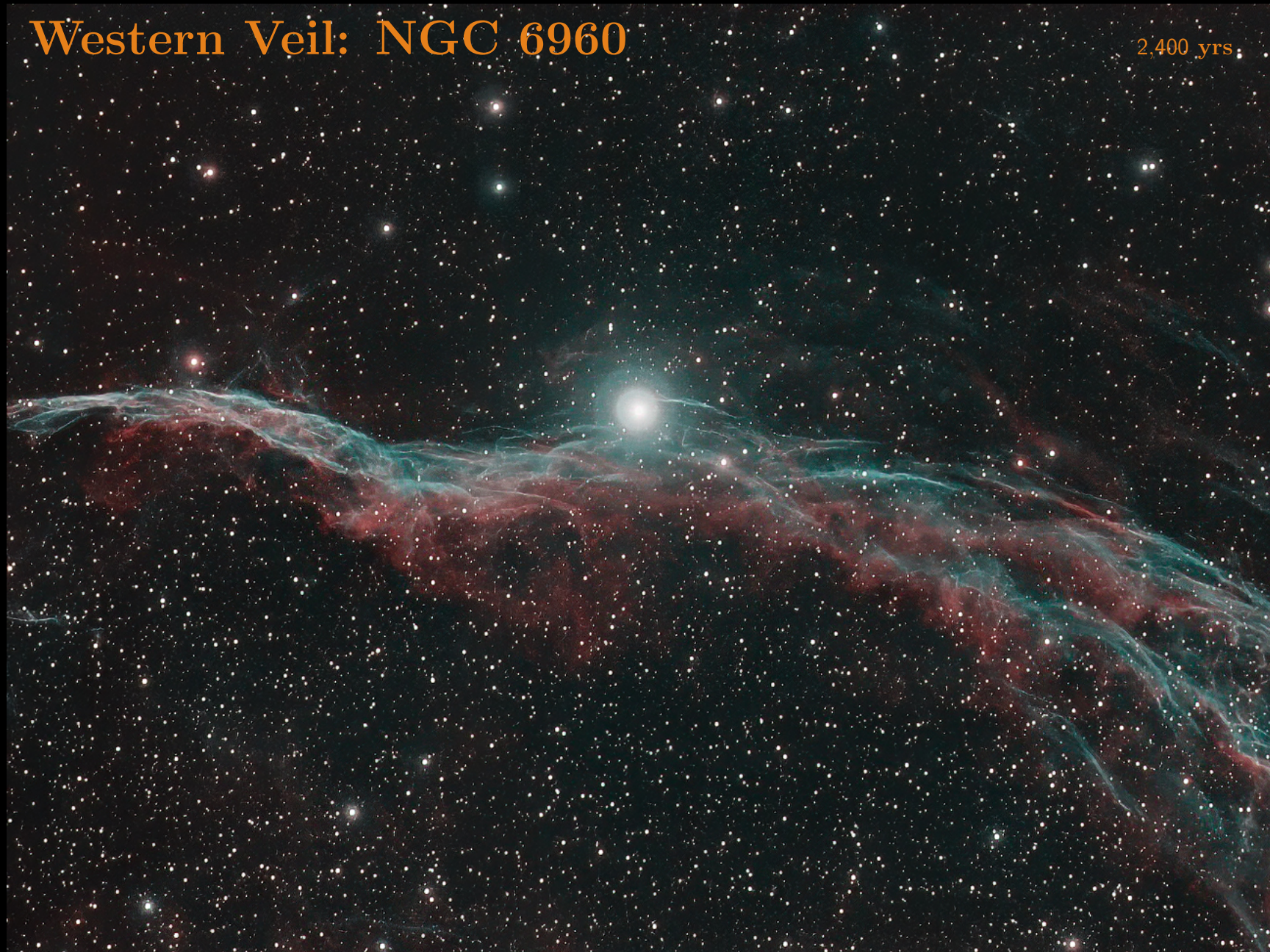
# Veil Nebula: NGC 6960 and 6992

2,400 yrs



# Western Veil: NGC 6960

2,400 yrs



# Eastern Veil: NGC 6992

2,400 yrs



# 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

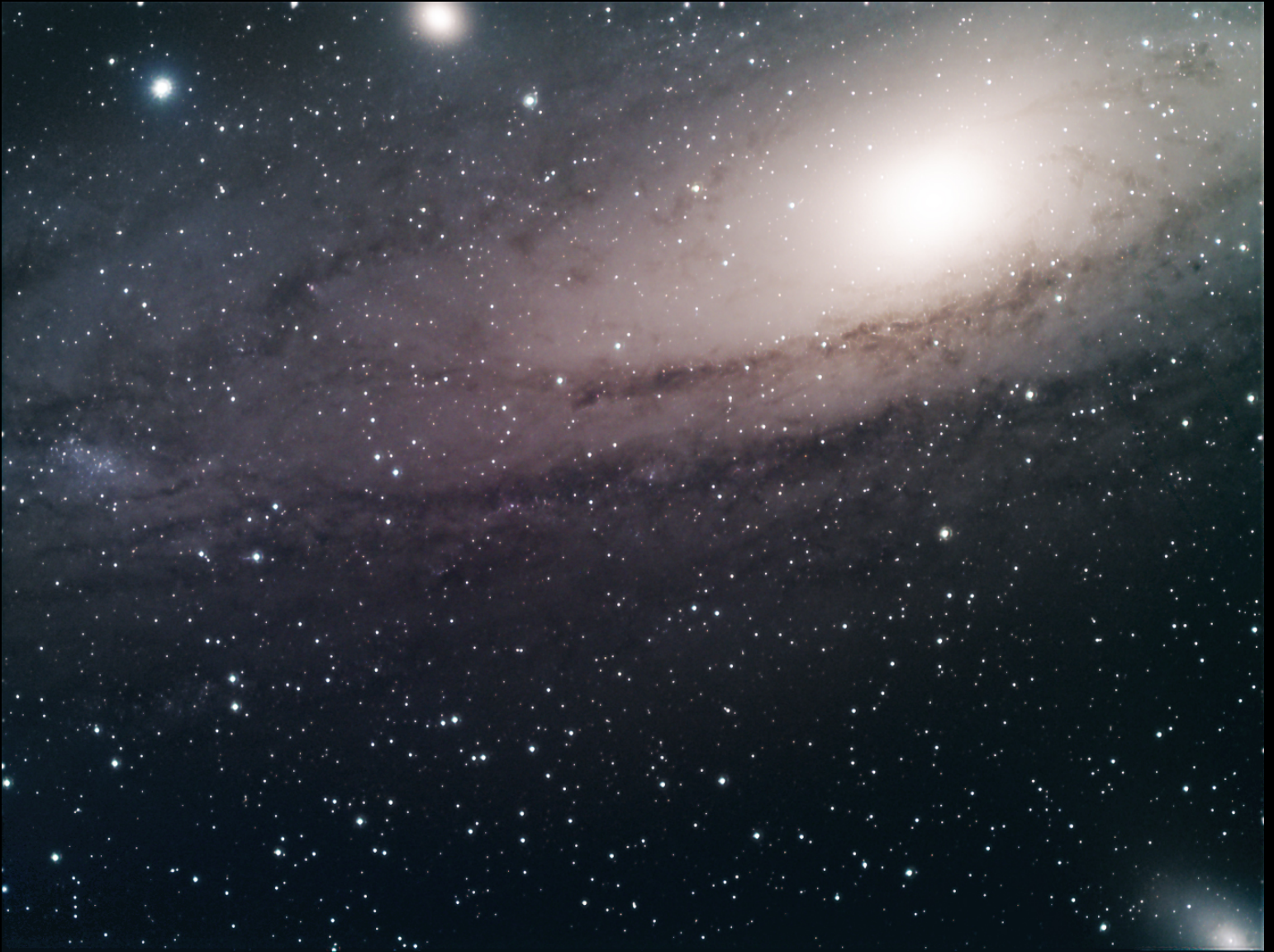




# Looking Out Beyond Our Milky Way

# 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



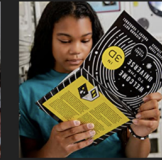
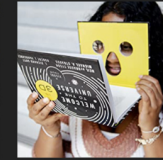
# The Needle Galaxy (NGC 4565)

42,700,000 yrs





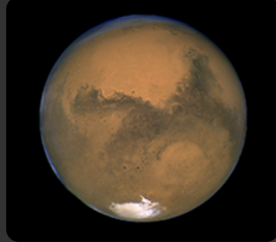
# Welcome to the Universe in 3D



## 3D Pictures from the Book



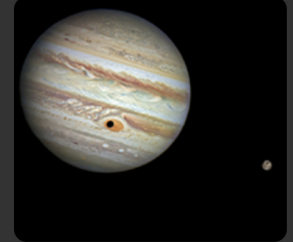
Moon



Mars



Comet Lovejoy



Jupiter and Ganymede



Mimas



Crab Nebula



Andromeda



Hubble Ultra Deep Field

Questions?