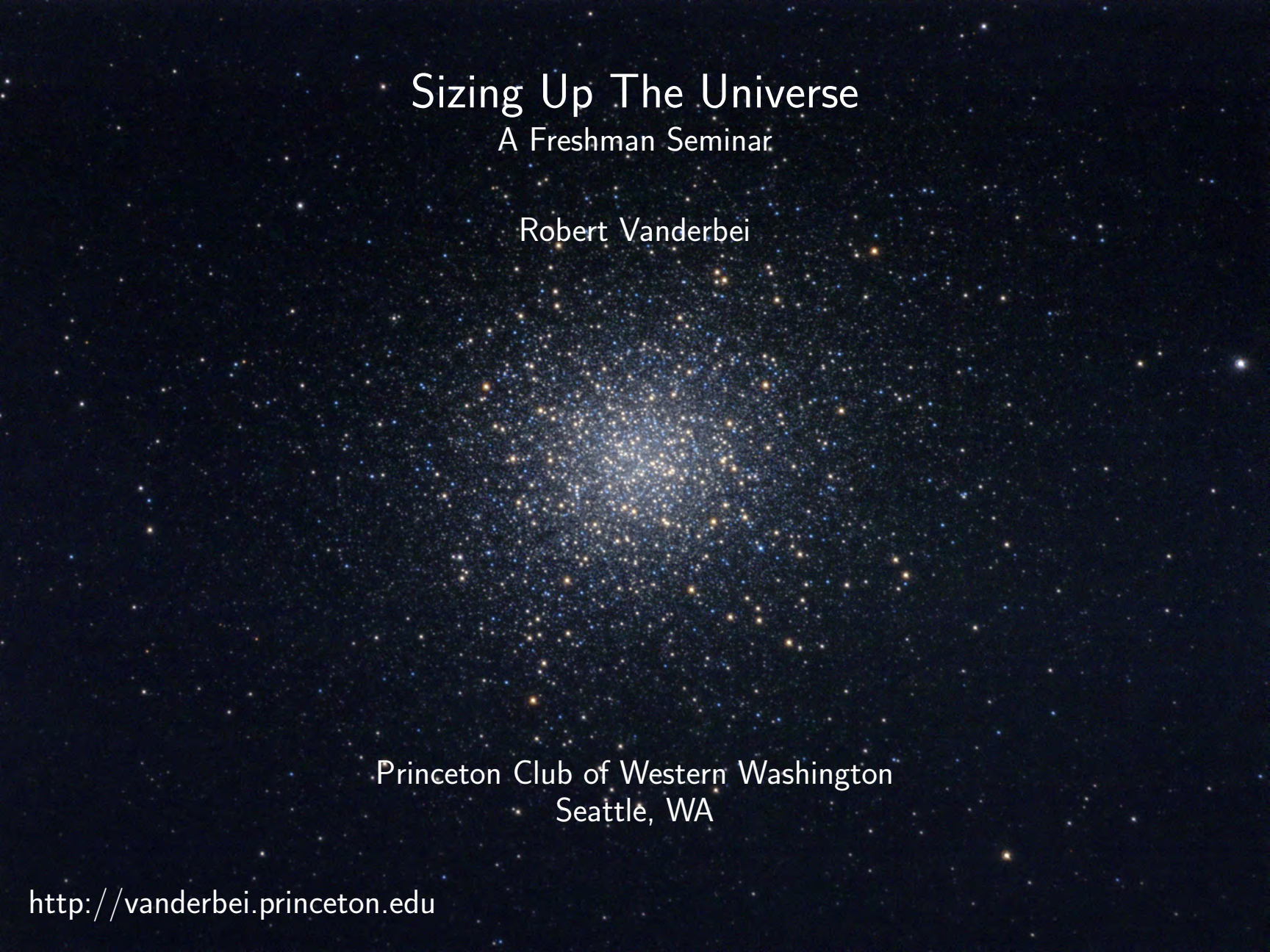

Sizing Up The Universe

A Freshman Seminar

Robert Vanderbei

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A Little About Me

- Born/Raised: Grand Rapids, MI
- Undergrad: Chemistry, 1976, Rensselaer Polytechnic Institute (RPI)
- 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.

Most Pics Were Taken From My Driveway

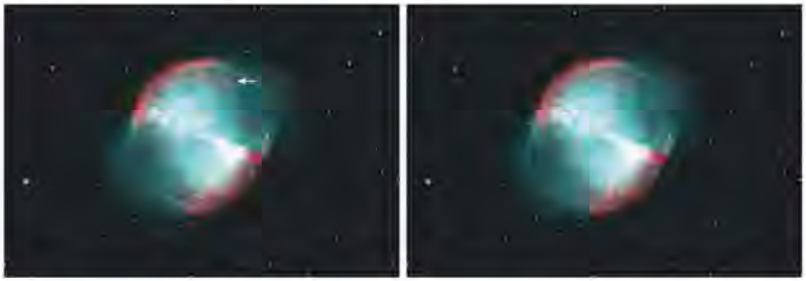
My Smaller Telescope is a Questar...

The Dumbbell Nebula (taken in Oct 2018)...

The Dumbbell Nebula (taken in Aug 2016)...

Blink and You'll See It

The author's serendipitous rediscovery of a Mira variable recalls the decidedly singular way the star was originally found.



▲ Messier 27, aka the Dumbbell Nebula, with the Goldilocks Variable visible in 2016 (left, see arrow) and invisible in 2018 (right)

THE DUMBBELL NEBULA, also known as Messier 27 and NGC 6853, is one of my favorite nebulae, and over the years I've taken many pictures of it. I like to joke to my friends that it's named after me — the dumbbell.

Last October, I invited my freshman seminar astronomy class to my home to show them how to do some astrophotography. Eight students came. We snapped images of stars and other objects before I suggested we take a sequence of pictures of M27. They agreed, and over the next few hours my telescope and camera did just that while my students and I enjoyed tea and brownies inside and talked astronomy.

The resulting photo came out pretty nicely — almost as nicely as one I'd taken two years earlier with the same telescope and camera. Seeing the similarity between the two, I thought it'd be fun to combine the pair, thereby achieving a better picture. So I loaded both photos into a stacking program and set about aligning the images.

As I flipped back and forth between the two photos, I noticed that a fairly prominent star in the 2016 image was entirely missing from the 2018 one. This caught me completely by surprise. I'd never before seen a star totally disappear like that.

I uploaded the earlier photo showing the star to **astrometry.net** to get an astrometrically annotated version of the picture in FITS, the widely used digital file format. I loaded that into my planetarium program and determined the mysterious star's right ascension and declination. Finally, I entered these coordinates into the SIMBAD website. The database revealed that the star is a known Mira-type variable star.

Although a thrill for me, my accidental rediscovery pales in interest next to the unusual manner of the original identification, which occurred as recently as 1990. While creating a map of M27, Czech amateur astronomer Leos Ondra consulted the covers of that year's May issue of *Astronomy* and Autumn issue of *Deep Sky*, both of which, by chance, featured photos of the Dumbbell Nebula. To his astonishment, Ondra noticed a red star on the *Astronomy* cover that was altogether missing from the *Deep Sky* image. After the star was confirmed as a newly identified Mira star, he dubbed it the Goldilocks Variable.

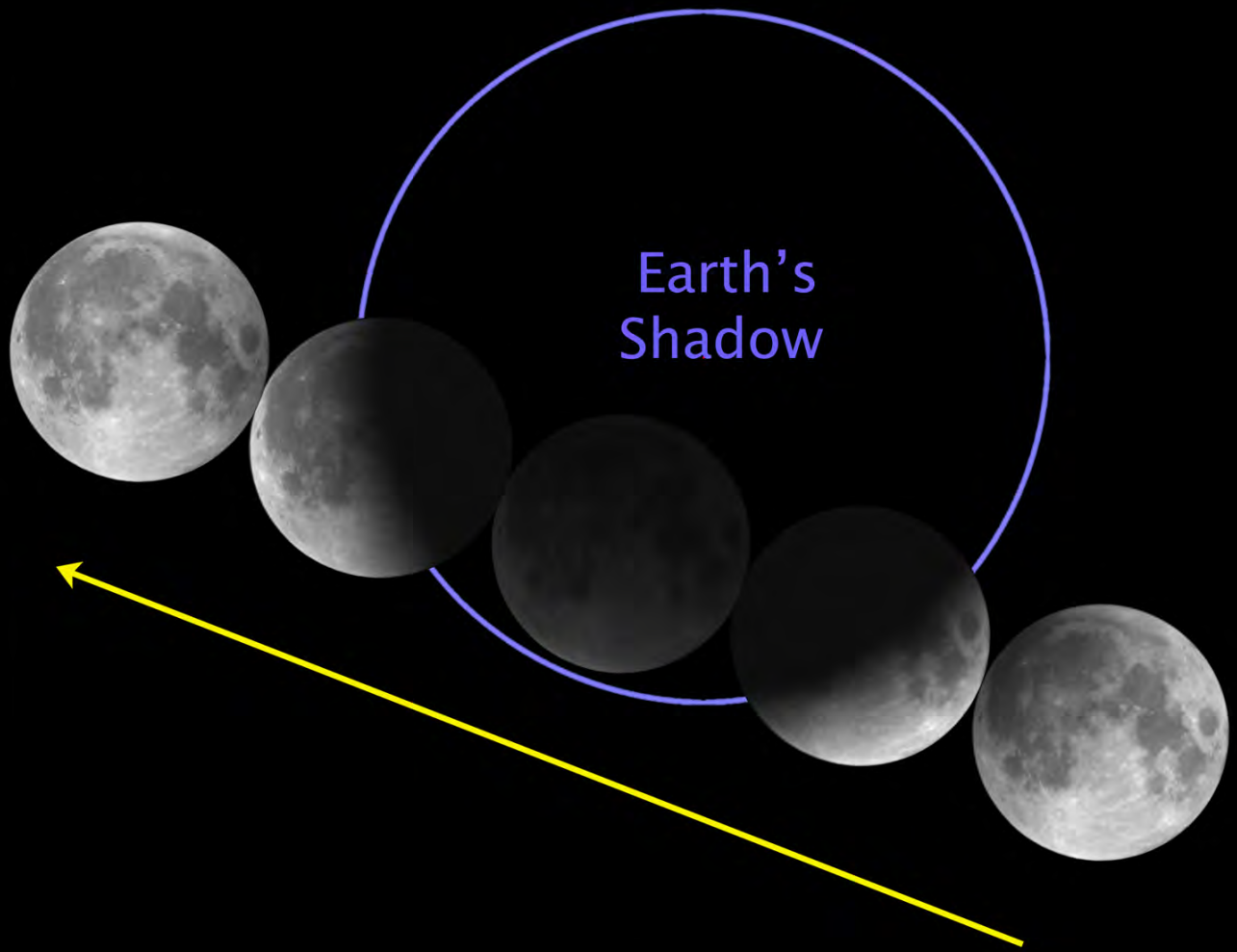
Prior to my own "discovery," I was unfamiliar with Mira stars, though I've long had an interest in RR Lyrae variables and the globular clusters in which they lie. Noticeably blue, RR Lyrae stars have a period that's typically shorter than a day, and they vary in brightness by only a modest amount. Mira variables, on the other hand, are red giants with long periods — on the order of a year — and dramatic dips in brightness.

It is this last property that astonished me the most after my find. It means that, as my two pictures above show, a Mira star can seemingly disappear and then return, phoenix-like, from the sidereal ashes. A few days after my revelation, I blinked the two pictures for my class, and they were as dumbfounded as I'd been.

■ ROBERT VANDERBEI is a professor at Princeton University affiliated with several departments, including Astrophysics. He coauthored, with J. Richard Gott, *Sizing Up the Universe: The Cosmos in Perspective* (National Geographic). A mathematician by training, he's interested in variables of all sorts.

Is The Earth Flat?

A Picture's Worth a Thousand Words...



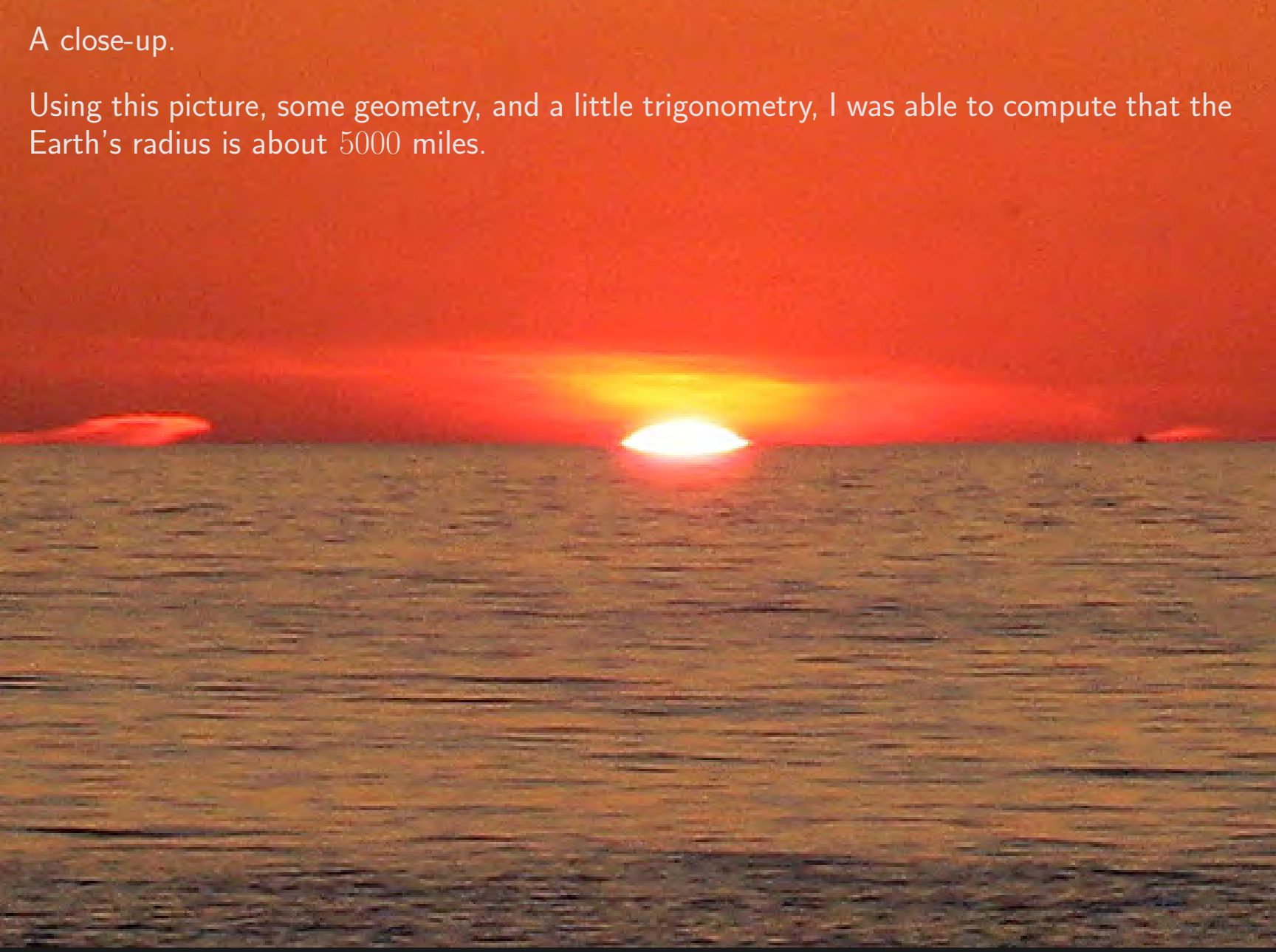
How Aristarchus measured the size of the Moon.

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.



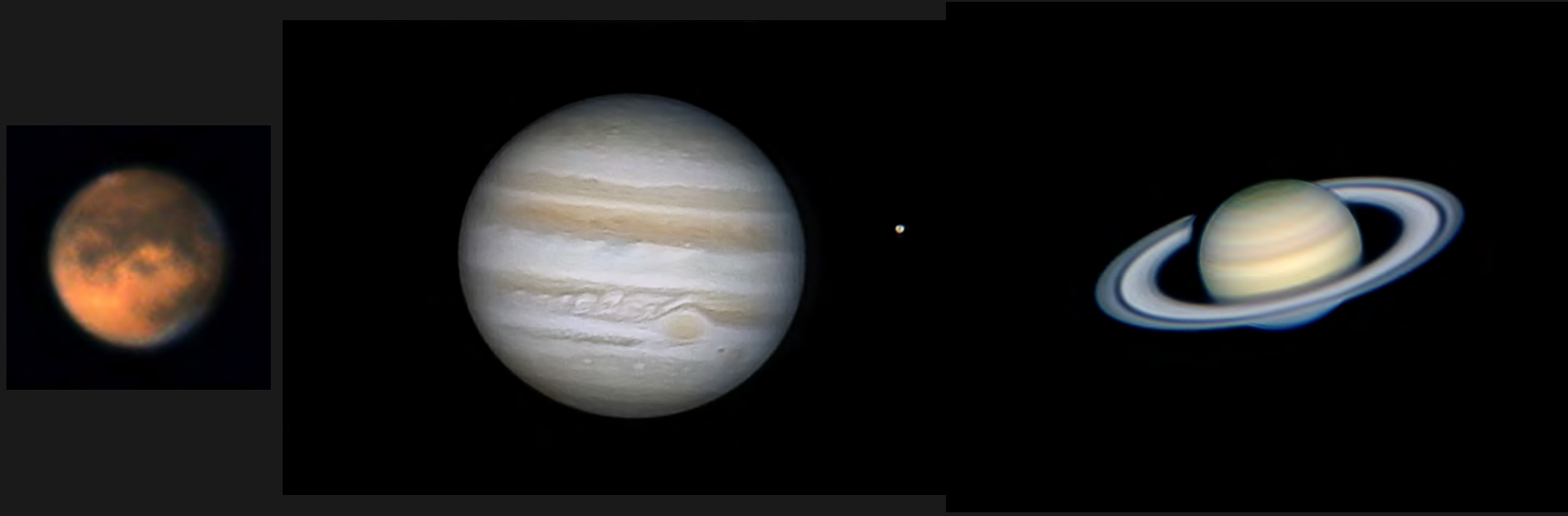
Angular Size

Let's start by looking at the angular size of things.

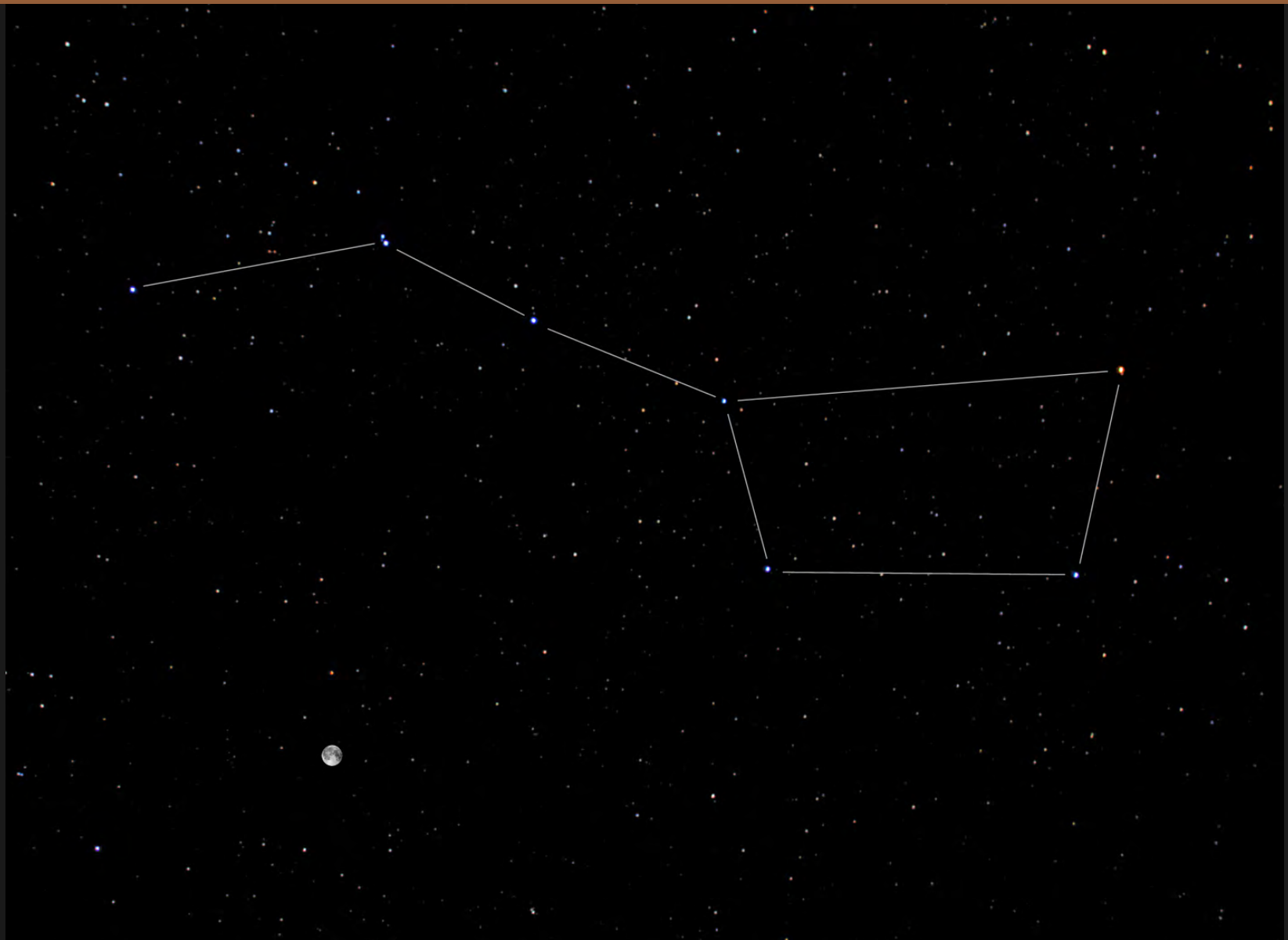
That's just a first step toward learning the actual size.

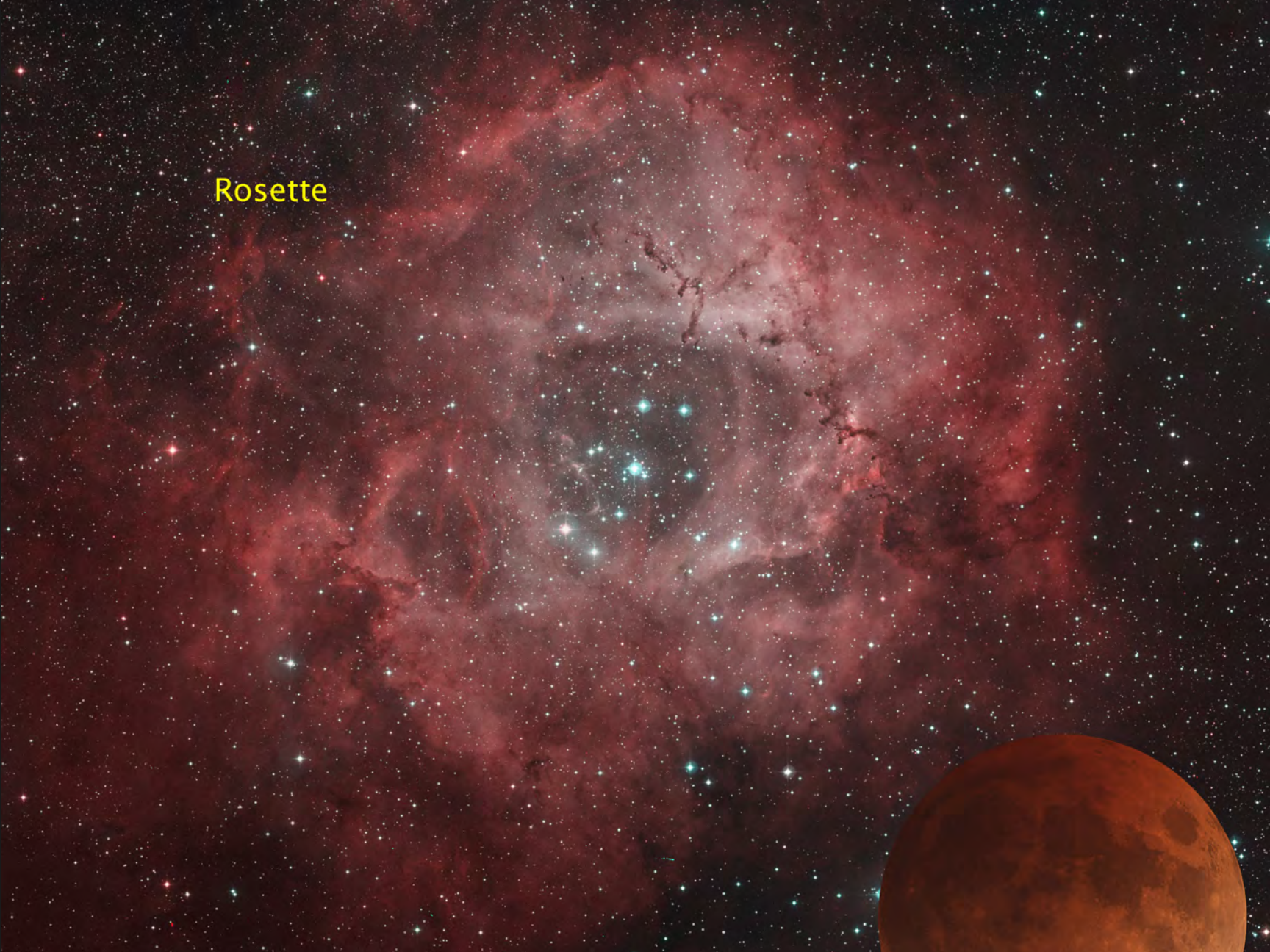
For that, we also need to know the distance.

Our Solar System – Pictures from my Driveway

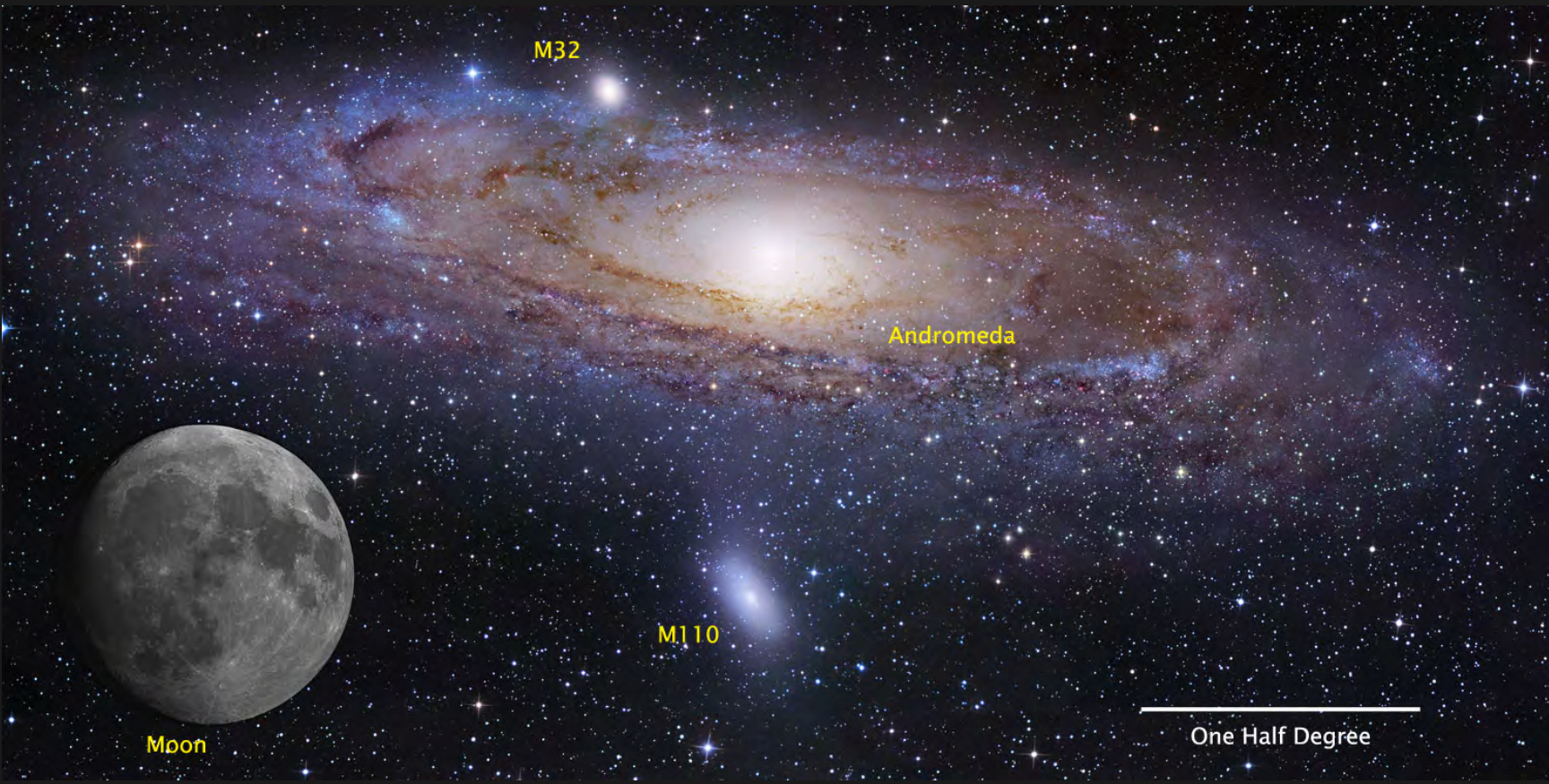


The Moon and the Big Dipper




Rosette

The Andromeda Galaxy and the Moon



Distance Measurements

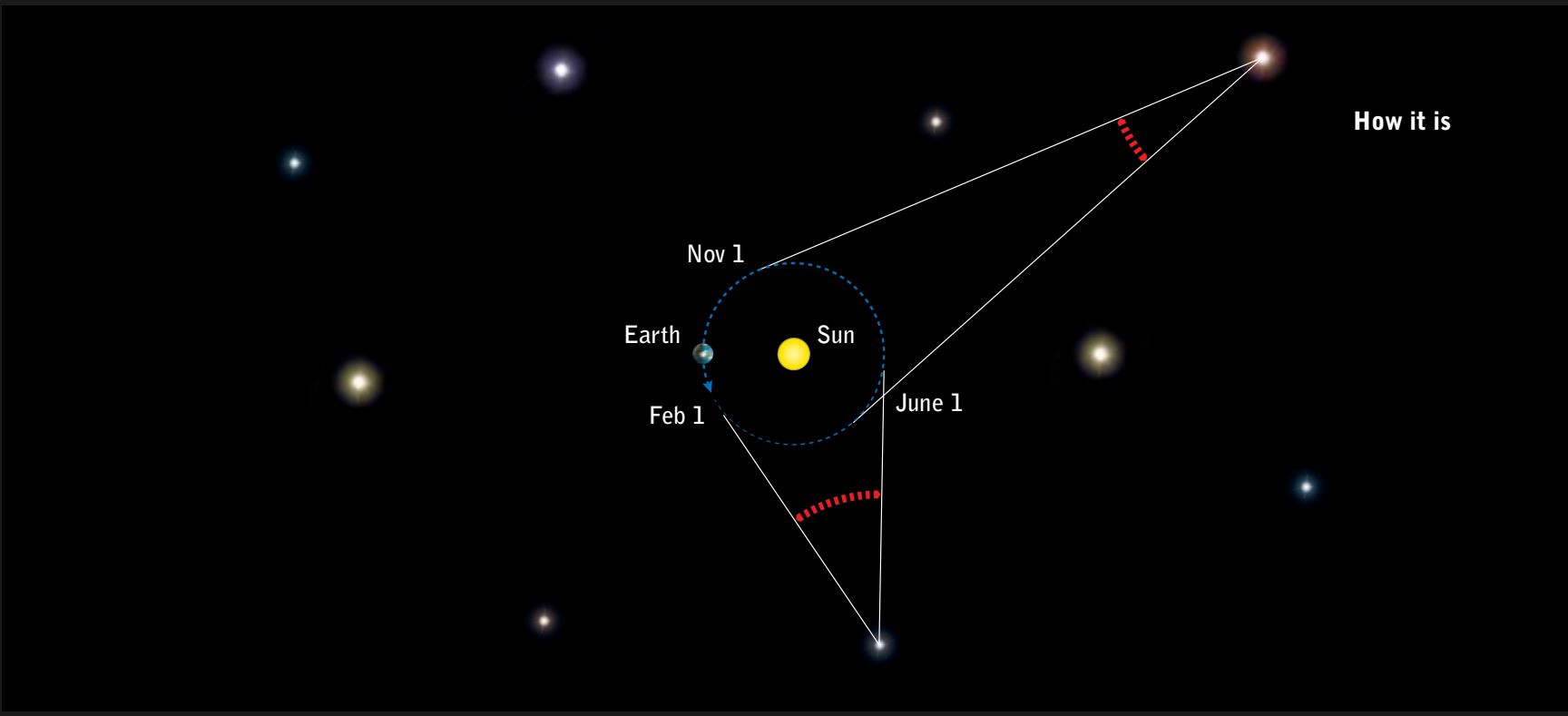
There are various ideas/methods for measuring distances.

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

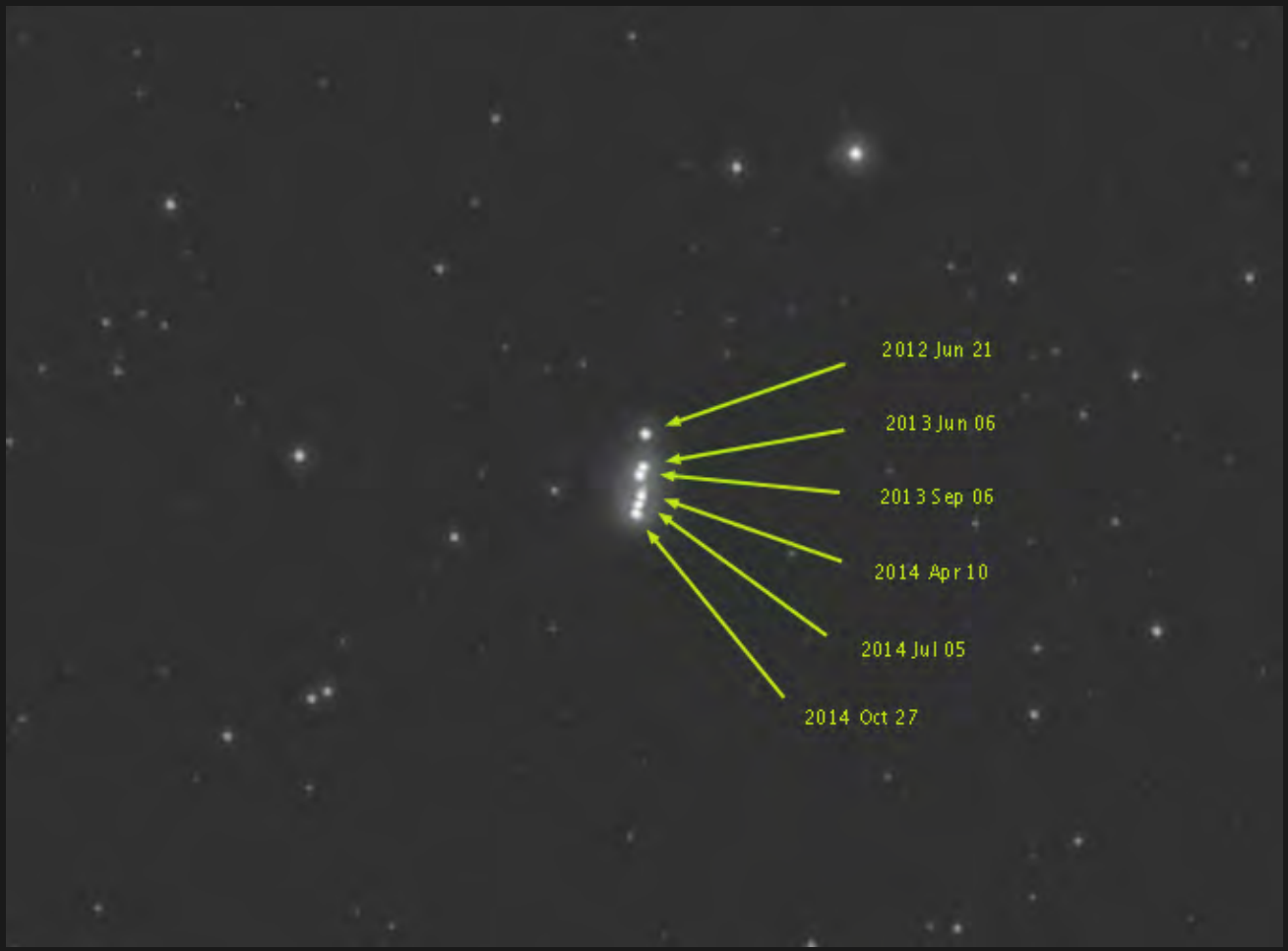
Barnard's Star

Barnard's Star

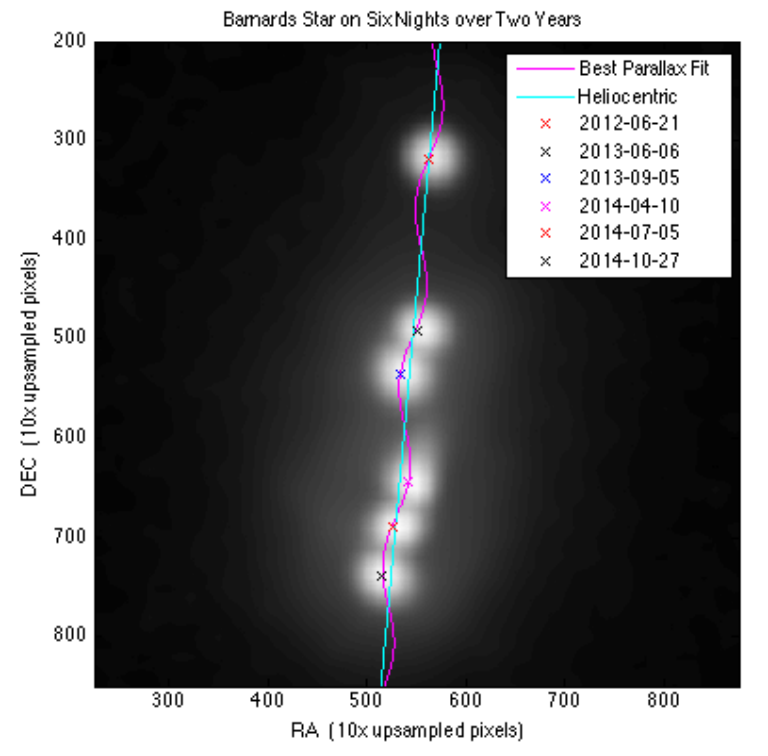
Barnard's Star

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

Here are some more pictures of my favorite things

M13 – The Great Globular Cluster in Hercules

M16 – The Eagle Nebula

M27 – The Dumbbell Nebula

M31 – The Andromeda Galaxy

M42 – The Great Orion Nebula

M51 – The Whirlpool Galaxy

M57 – The Ring Nebula

NGC7635 – The Bubble Nebula

IC434 – The Horsehead Nebula

IC1396 – The Elephant Trunk Nebula

Thank You

Thank You

Questions?