the Stars

I. **Position and Motion**
   Parallax, Proper Motion, Redshift

II. Size
   Dwarfs, Giants, Stefan-Boltzman

III. Brightness
   Magnitude, flux,

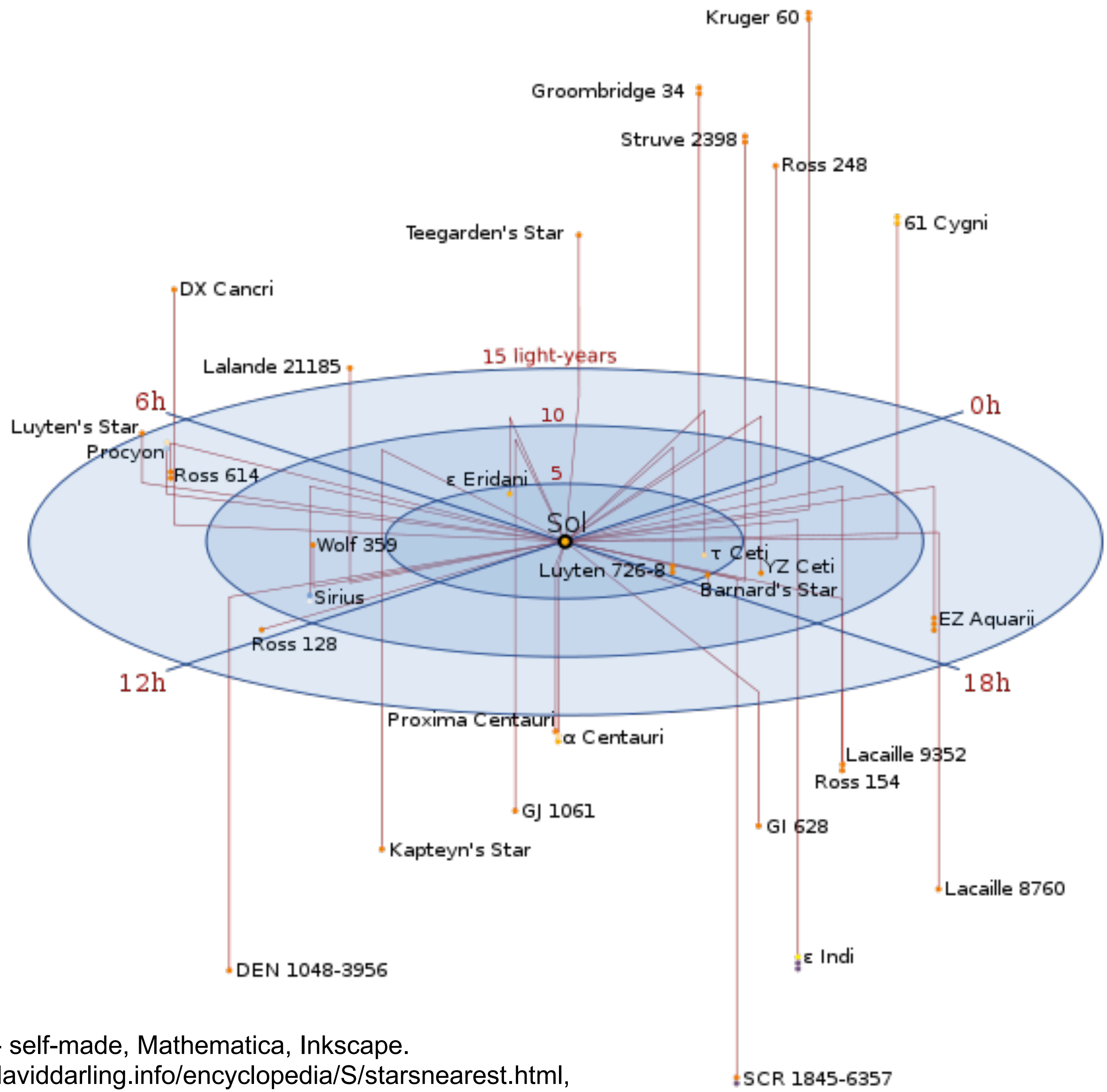
IV. Color
   B-*V* index

V. Spectral Type
   H-R diagrams

	The student will be able to:	HW:
1	Define and apply stellar parallax and the unit of the parsec.	1 – 3
2	Relate parallax and the parsec to skinny triangles and other units such as meters and light years.	
3	Define and describe proper motion.	4 – 6
4	Describe and apply methods by which the velocity of a star through space may be determined by including both radial and transverse velocity.	
5	Describe direct and indirect methods used to determine the size of a star and classify stars as giants, supergiants, or dwarfs.	7 – 8
6	State and apply the relation between luminosity, radius, and temperature.	
7	State and apply the relation between luminosity, distance, and energy flux.	9 – 16
8	Define and contrast the concepts: absolute magnitude, intrinsic brightness, luminosity, and apparent magnitude, apparent brightness, energy flux.	
9	Explain and apply the magnitude scale of brightness.	
10	Describe and apply the relation between a stars color and its temperature.	17
11	Define, describe, and apply color index and explain its application in photometry and its relationship to blackbody radiation and Wein's Law.	
12	State in order of temperature the stellar spectral classes and list characteristics and examples of each.	18
13	Describe and define the Hertzsprung-Russell diagram in terms of each axis.	19 – 23
14	Plot a star's coordinates on the H-R diagram.	
15	Explain and illustrate how the H-R diagram is used to help classify and understand different types of stars such as main sequence stars, red giants, blue giants, supergiants, red dwarfs, and white dwarfs.	
16	Define, describe, and give examples of the stellar luminosity classes.	24 – 25
17	Describe and apply the method of spectroscopic parallax and explain the importance of luminosity class to this method.	
18	Describe and explain methods for determining a star's mass and relate to the different types of binary-star systems: visual binary, spectroscopic binary, and eclipsing binary.	26
19	Describe and explain the significance of a star's mass in determining its location on the H-R diagram and in determining the lifetime of the star.	27
20	Describe properties and significance of open clusters and globular clusters.	

Parallax & Proper Motion

Where are the stars?
(and what are they *doing*?)

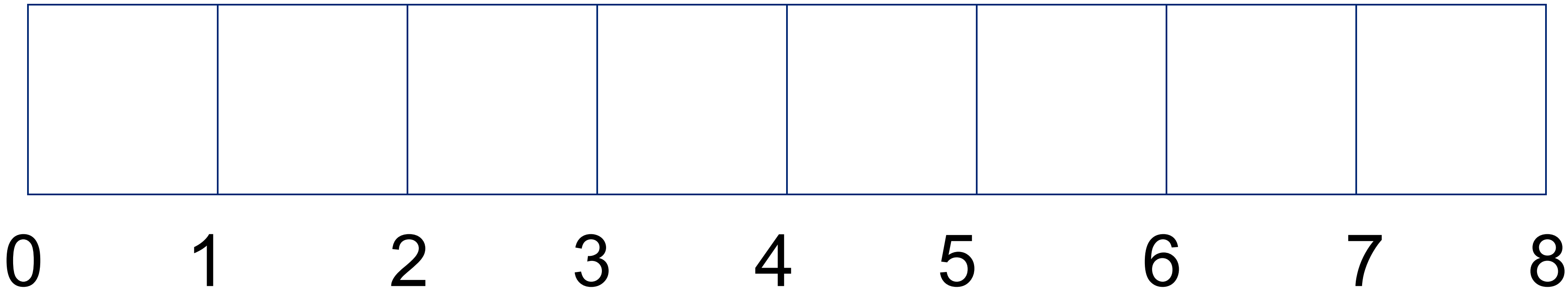


Kruger 60
Groombridge 34
Struve 2398
Ross 248
61 Cygni
Teegarden's Star
DX Cancri
15 light-years
Lalande 21185
6h
0h
10
Luyten's Star
Procyon
5
Ross 614
ε Eridani
Sol
Wolf 359
τ Ceti
YZ Ceti
Luyten 726-8
Barnard's Star
Sirius
EZ Aquarii
Ross 128
12h
18h
Proxima Centauri
α Centauri
Lacaille 9352
Ross 154
GJ 1061
Gl 628
Kapteyn's Star
Lacaille 8760
ε Indi
DEN 1048-3956
SCR 1845-6357

Parallax

- Parallax is a cyclical shift in a star's apparent position on the celestial sphere.
- A star that exhibits parallax appears to move and return to its starting point over the course of precisely one year.

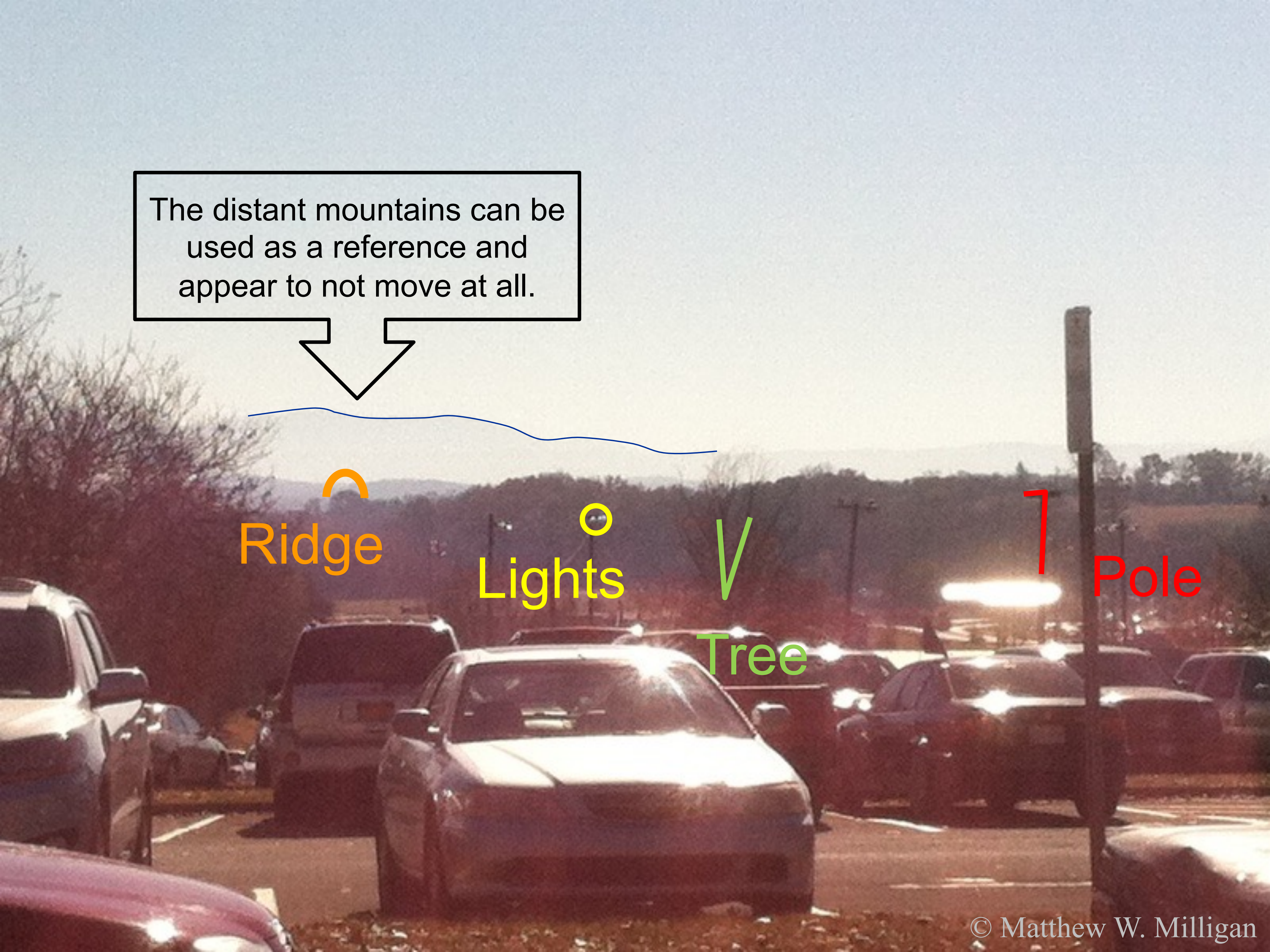
Parallax Demonstrated

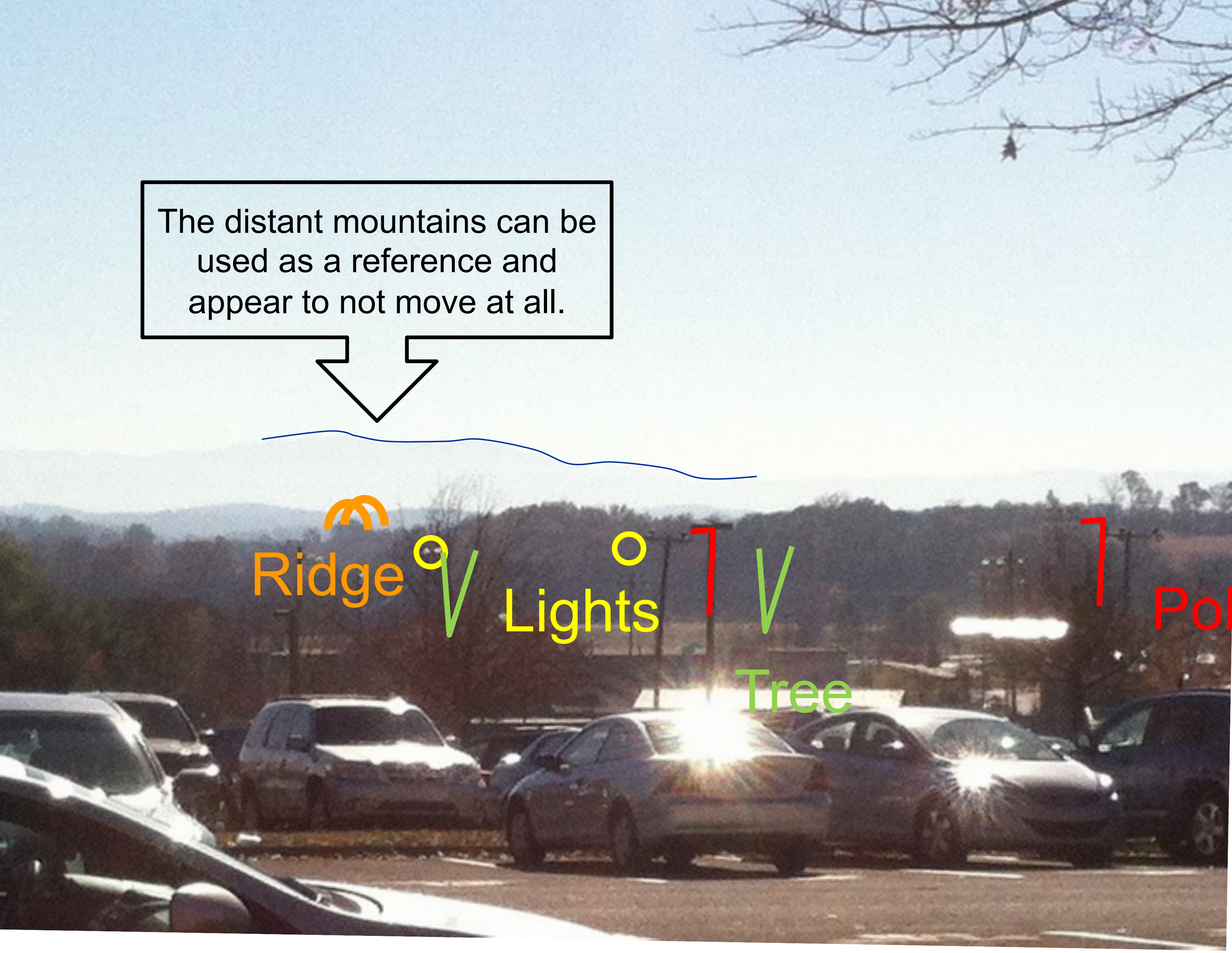


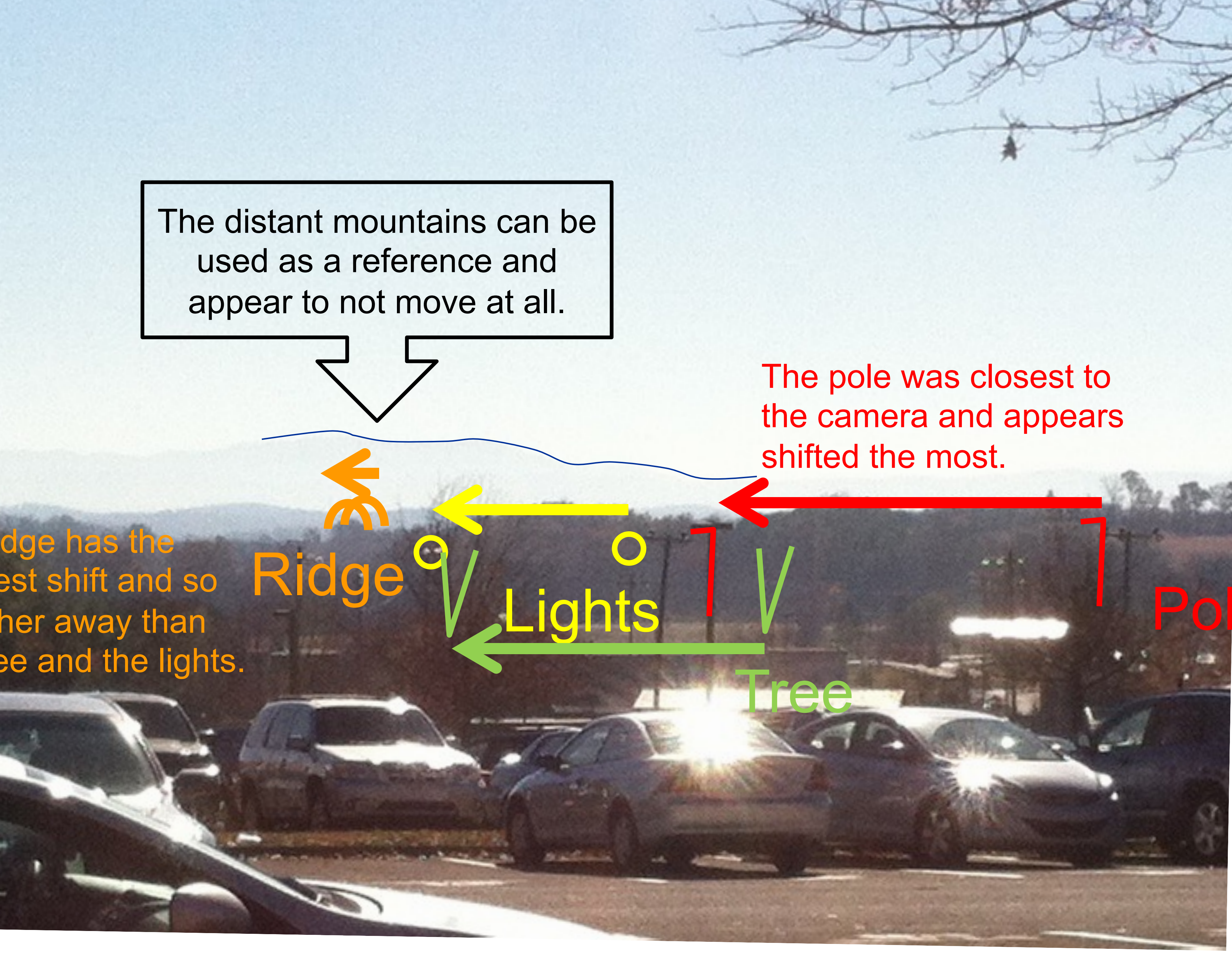
1. Close your left eye and use your right eye to line up your index finger with the zero.
2. Then, without moving your finger, close your right eye and open your left eye.
3. Repeat with your finger at a different distance in front of you – what happens to the amount of parallax?

Two pictures taken from different locations – which object was closer to the camera?

Two pictures taken from different locations – which object was closer to the camera?


The distant mountains can be used as a reference and appear to not move at all.
Ridge
Lights
Tree
Pole
© Matthew W. Milligan


The distant mountains can be used as a reference and appear to not move at all.
Ridge
Lights
Pole
Tree

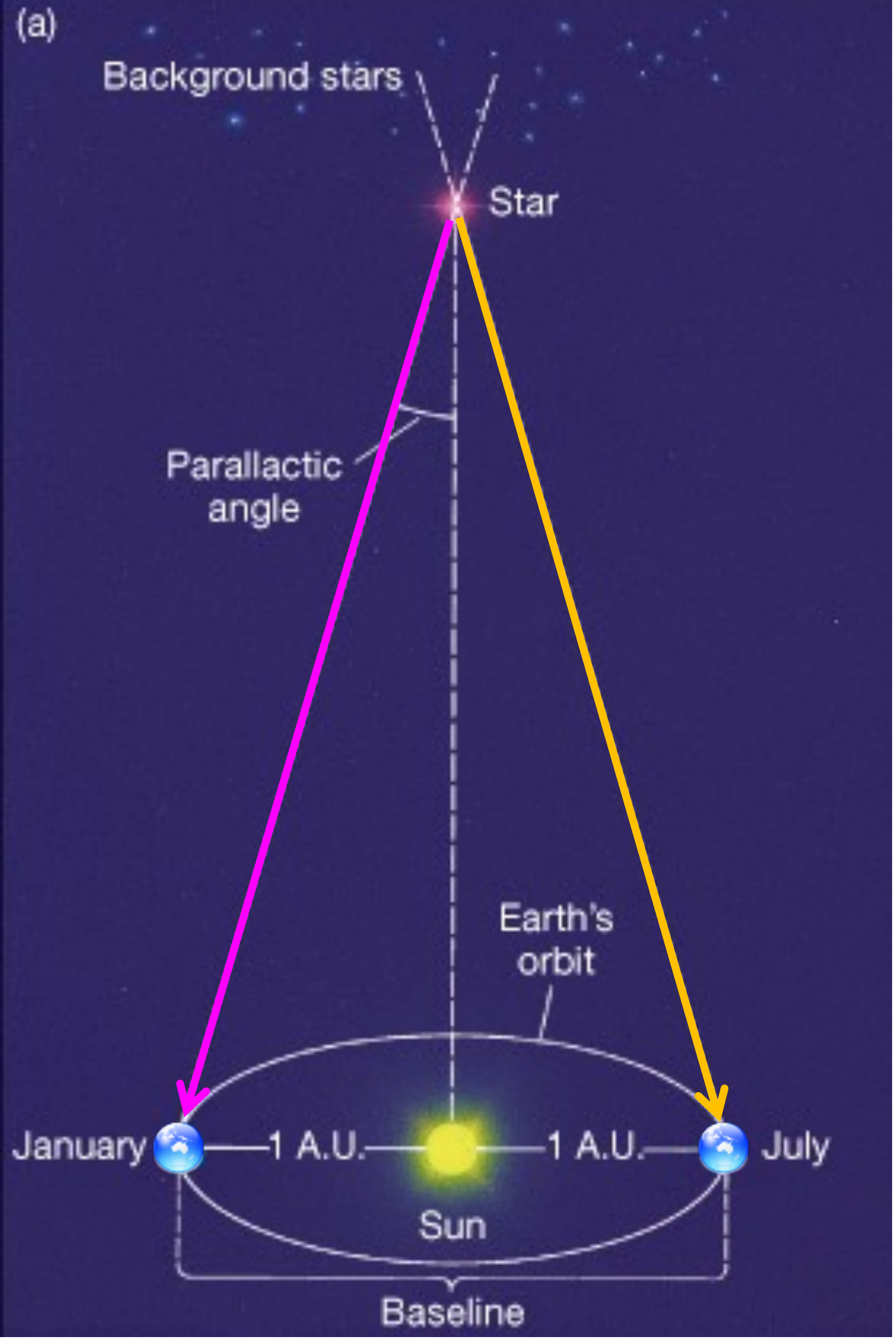


The distant mountains can be used as a reference and appear to not move at all.
The pole was closest to the camera and appears shifted the most.
dge has the
est shift and so
her away than
ee and the lights.
Ridge
Lights
Tree
Pole

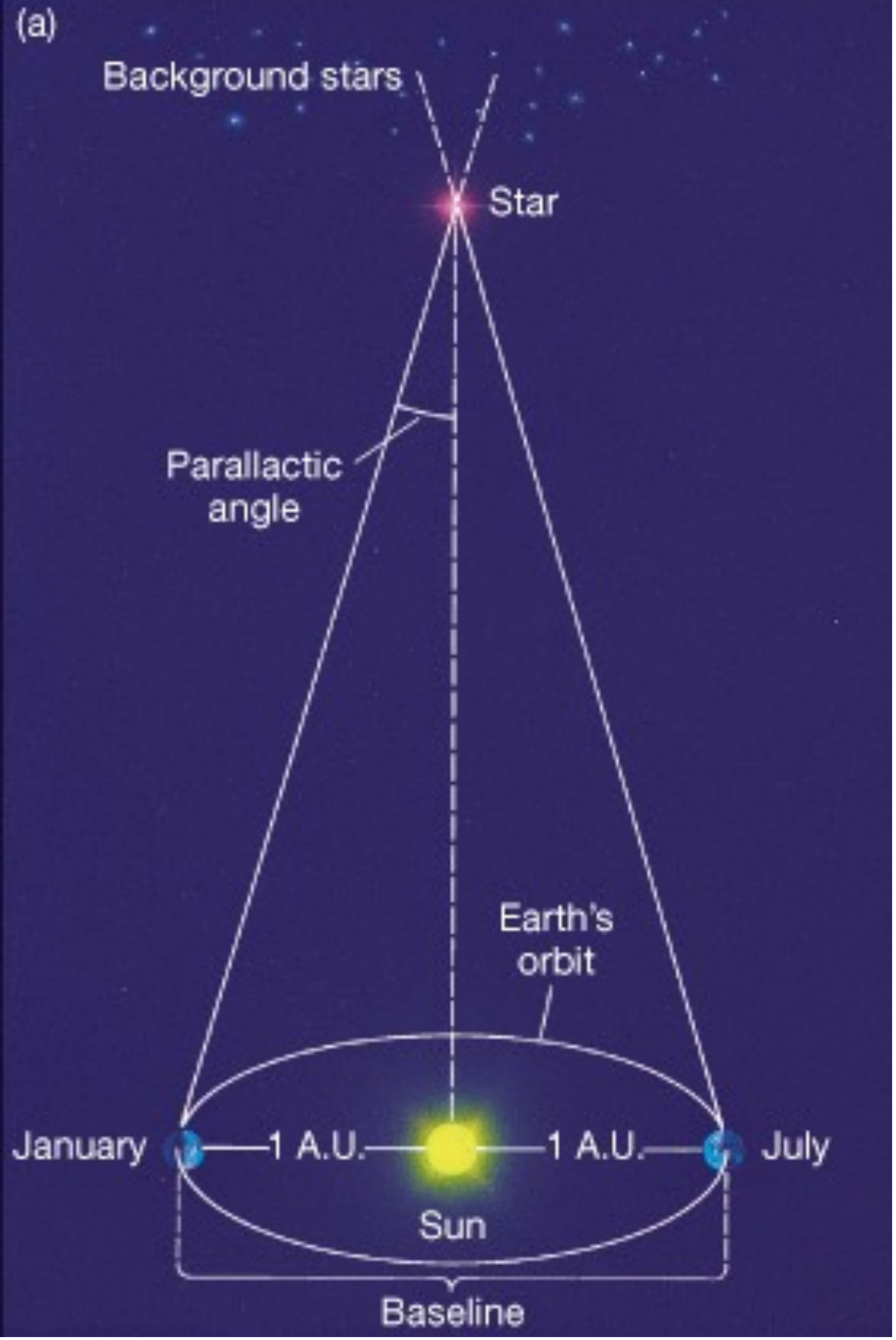
Parallax Explained

- Parallax is a shift in apparent position due to the motion of Earth in its orbit.
- The amount of parallax depends upon the distance to the star. The *greater* the distance, the *less* the parallax.
- Put another way: the distance is inversely proportional to the parallax.

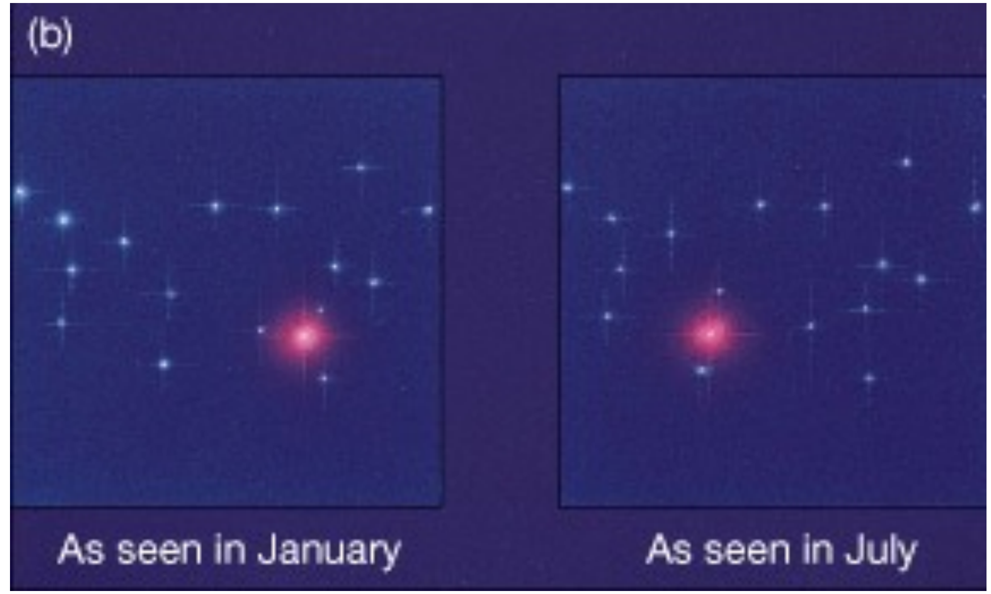
Parallax



Over the course of a year a relatively nearby star will *appear* to move because of Earth's motion.

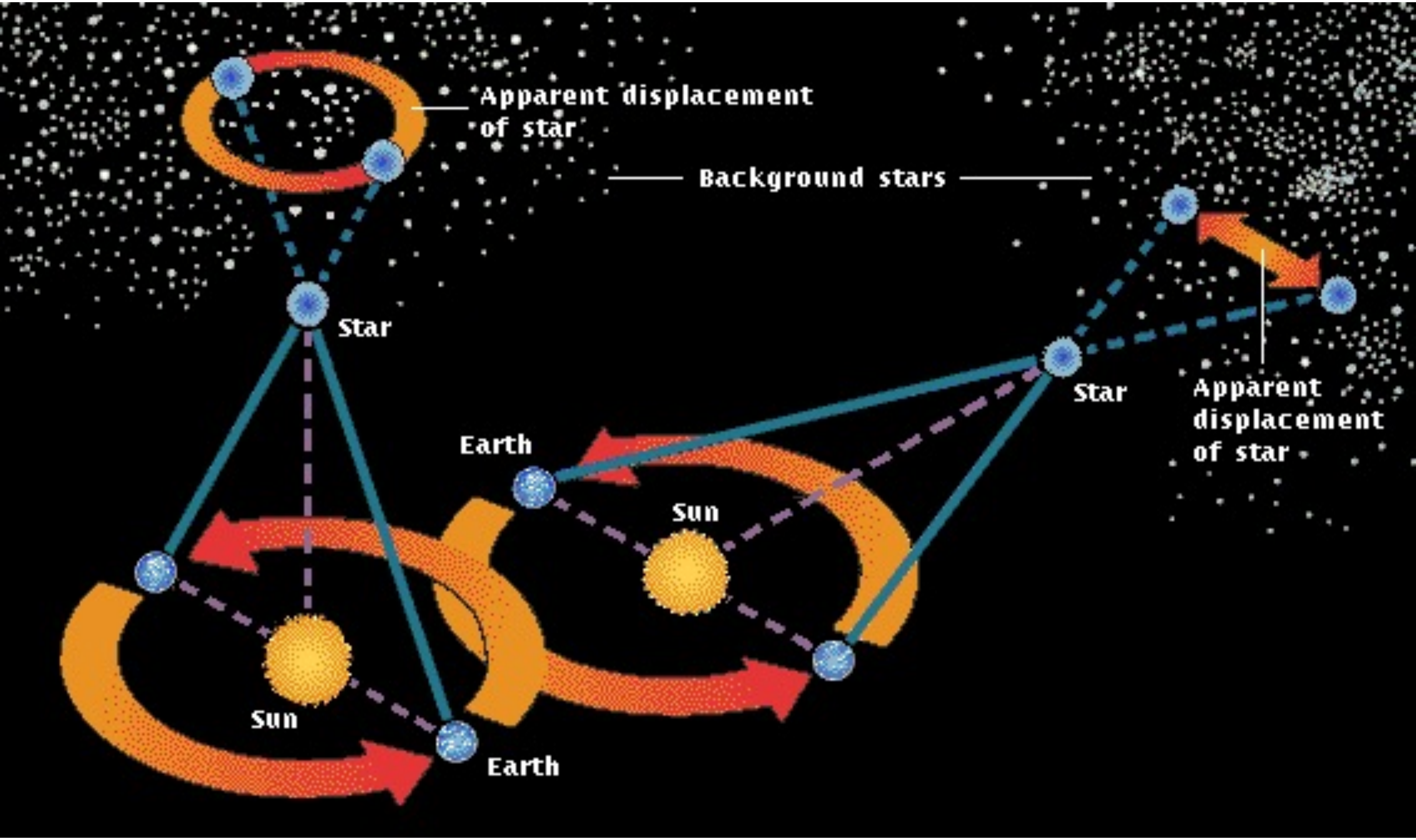


Parallax



The effect is tiny, and was not observed or measured with certainty until the 1830's.

Near Celestial Pole: Near Ecliptic:



Parallax Equation:

$$d = \frac{1}{p}$$

Where: d = distance in parsecs
p = parallactic angle in arc seconds

Parallax Practice

1. Star A has parallax 0.40″. How far away is it?
2. Star B's position shifts 0.20″ east from January to July and 0.20″ west from July to January. How far away is it?
3. Find the distance based on parallax: (a) Barnard's Star, (b) 61 Cygni, (c) Vega
4. Schedar and Caph (α and β Cass) are separated by 5.0° . But how far apart are they (really)? Parallaxes: 59.6 mas, 14.3 mas.
5. What should be the parallax of BI 253 given its distance is 50000 pc?

Measuring Parallactic Angles

- The greatest known parallax is 0.769″, that of the star Proxima Centauri.
- This is a tiny, tiny angle!
- Parallax was first measured in the 1830's by Bessel and Struve using telescopes designed and built by Fraunhofer.
- First stars for which parallax was measured: 61-Cygni, Vega, Alpha Centauri

Measuring Parallactic Angles

- Using ground-based optics the smallest parallax measurable is about 0.03″.
- Adaptive optics can push this to 0.01″.
- The ESA satellite Hipparcos measured down to 0.005″ and catalogued about one million stars. (1989 thru 1993) The greatest detectable distance was about 200 pc. Fairly accurate to about 50 pc.
- Update: ESA Gaia can measure down to 0.000 024″. Greatest detectable 40 kpc. Fairly accurate to about 10 kpc by 2020.

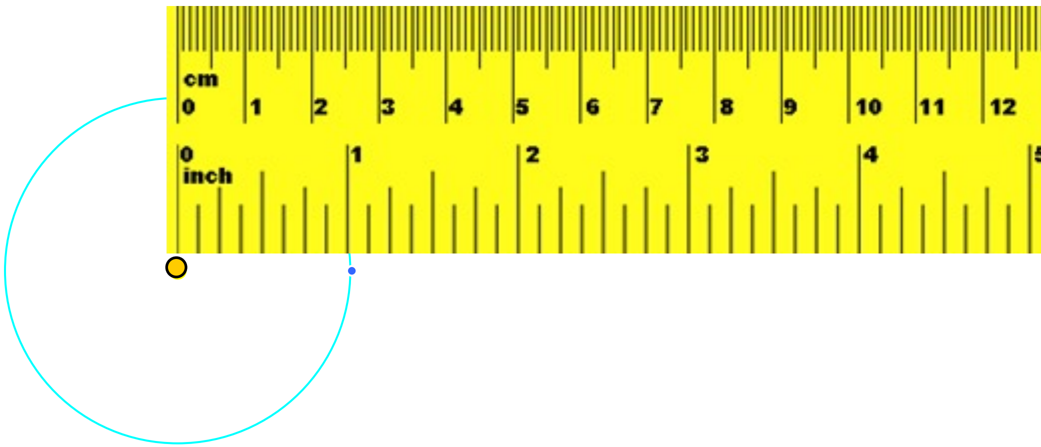
Parallactic Angles – how small?

- A parallax of 0.772″ is like a shift of 1 inch observed from 4.2 miles! (Largest known – "easiest" to observe!)
- A parallax of 0.03″ is like a shift of 1 inch observed from 100 miles! (Ground-based limit)
- A parallax of 0.005″ is like a shift of 1 inch observed from 600 miles! (Hipparcos space-based limit)
- A parallax of 0.000024″ is like a shift of 1 inch observed from 140000 miles! (Gaia space-based limit)

Comprehending Astronomical Distances

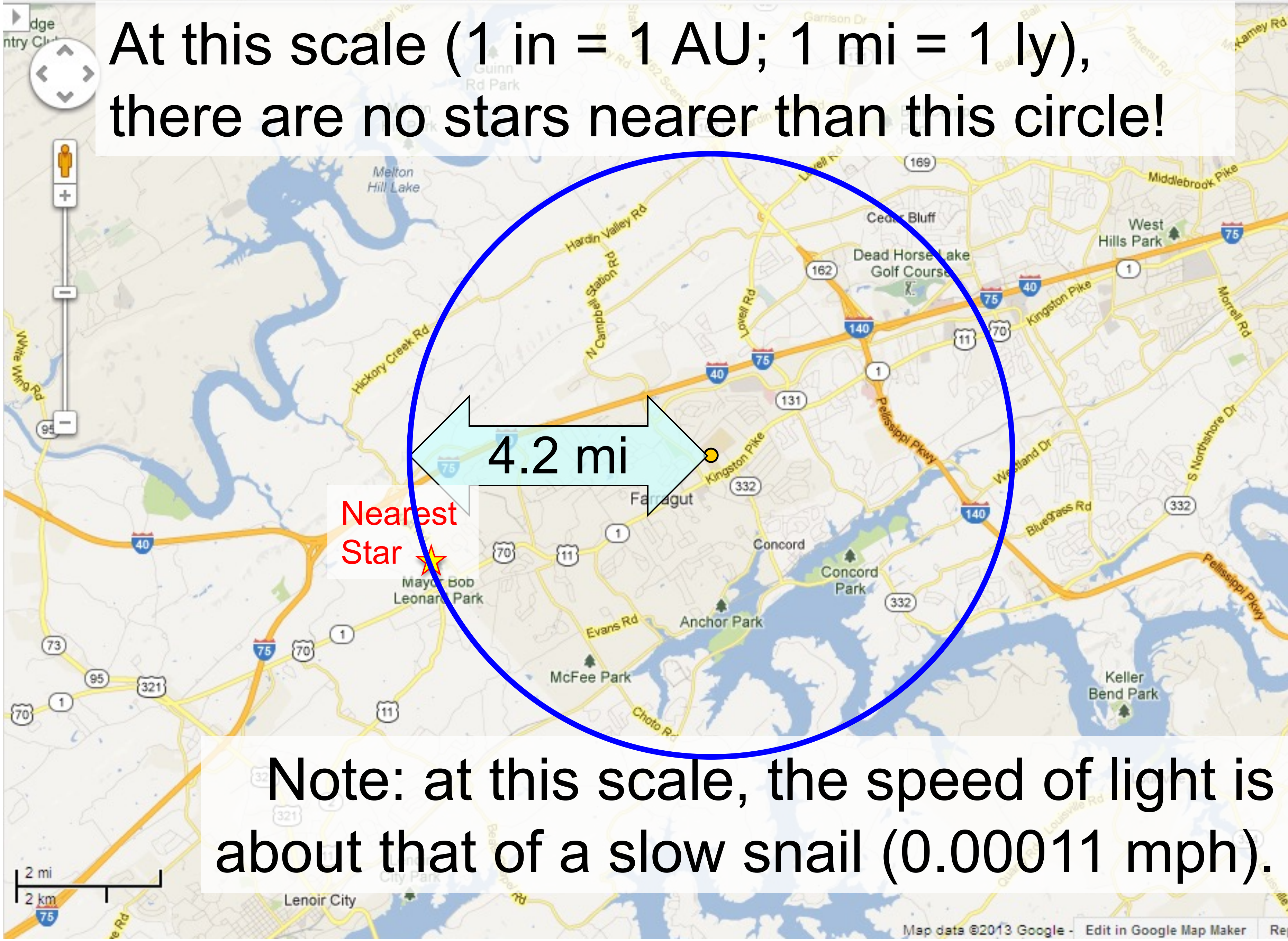
- To help you understand how far away the stars are, consider a scale where 1 inch represents the distance from the Earth to the Sun.
- On this scale: 1 inch = 1 AU.
- Coincidentally, using the same scale:
  1 mile = 1 light-year.
  (The number of inches in a mile happens to be *very nearly the same* as the number of astronomical units in a light-year!)

At this scale (1 in = 1 AU; 1 mi = 1 ly)

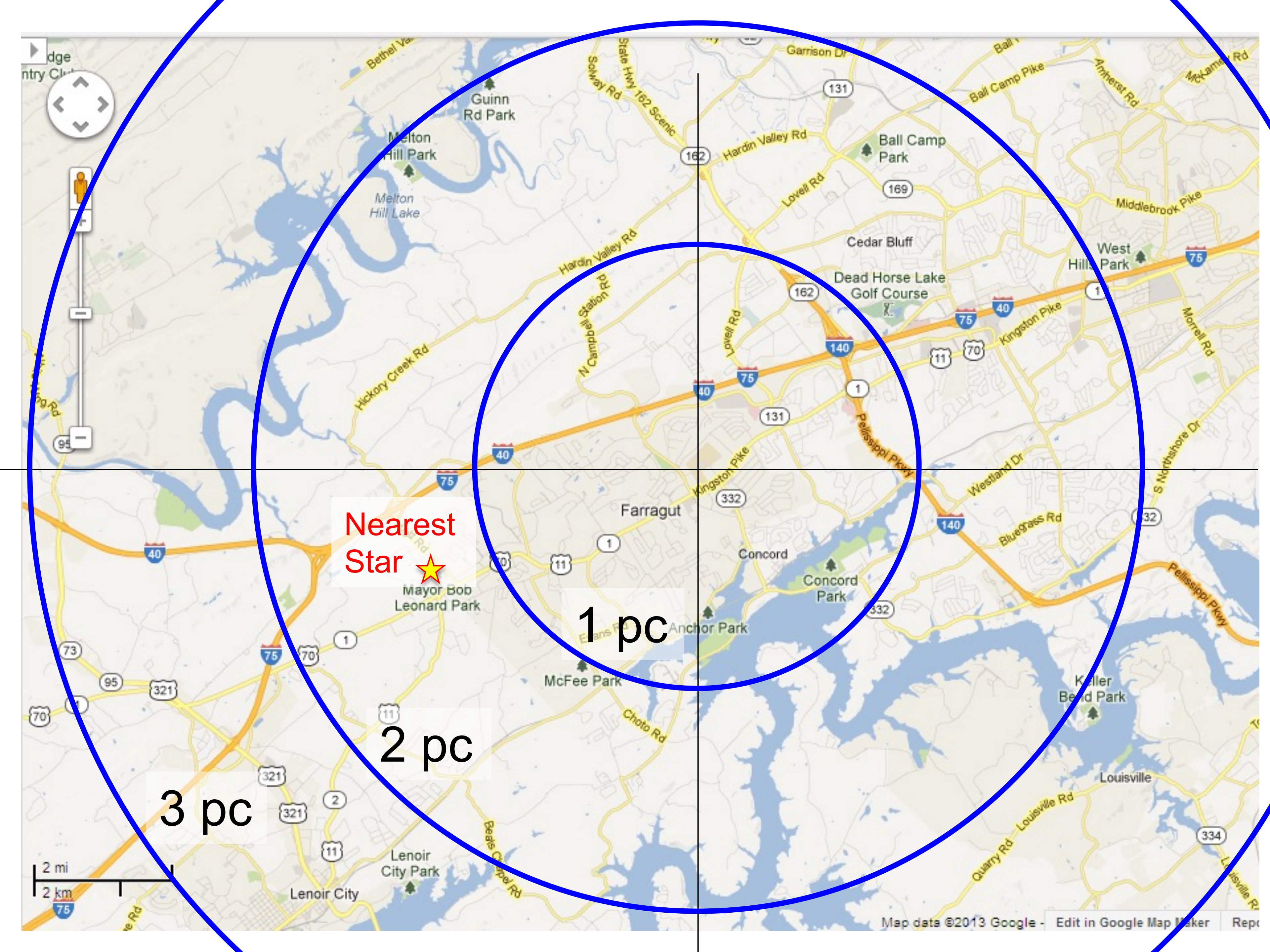


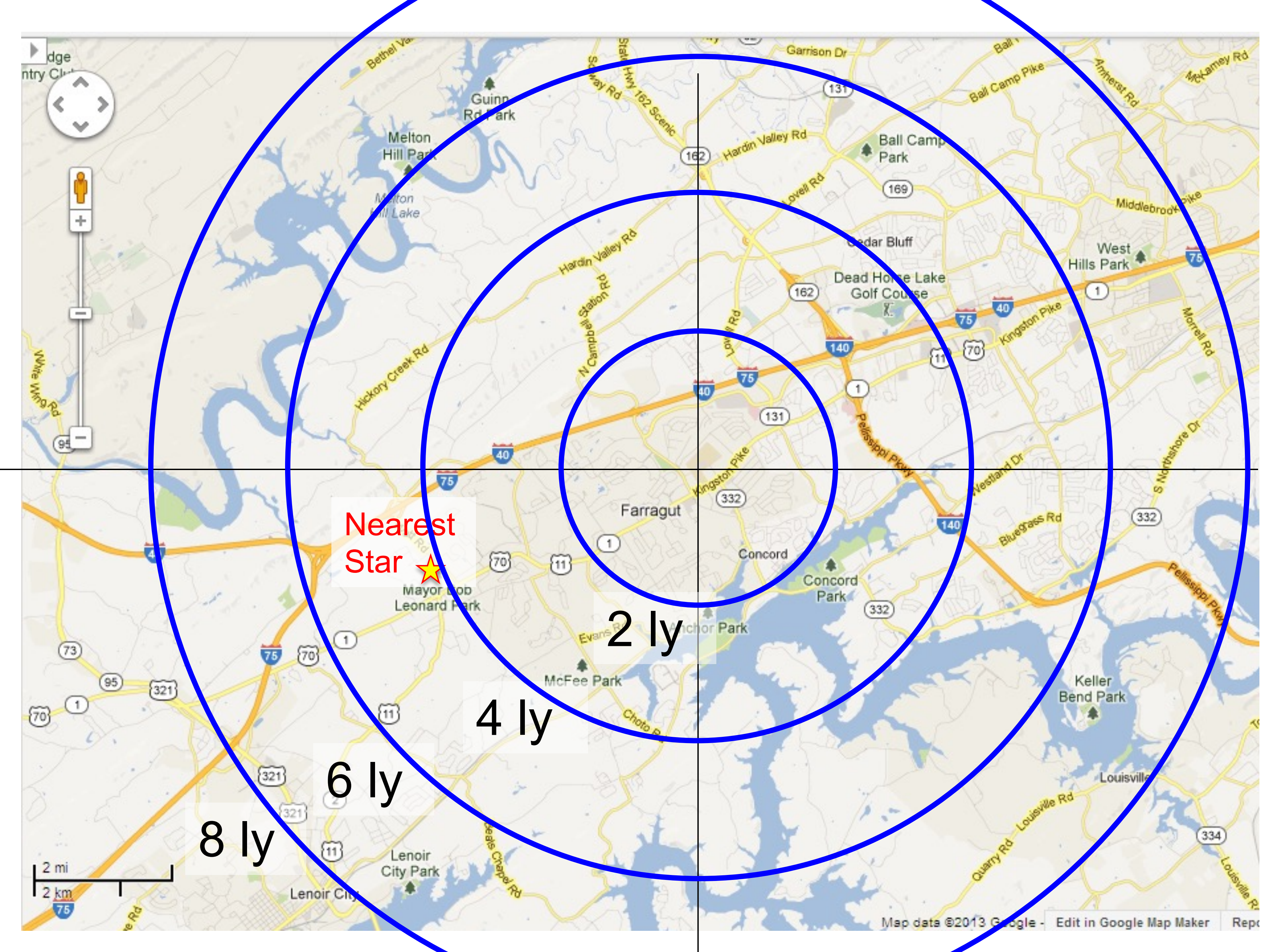
At this scale the Sun would be only 0.01 inch in diameter (much smaller than shown here). At the same avg speed as the Apollo missions, it would take about 3 years to travel 1 AU.

At this scale (1 in = 1 AU; 1 mi = 1 ly), there are no stars nearer than this circle!

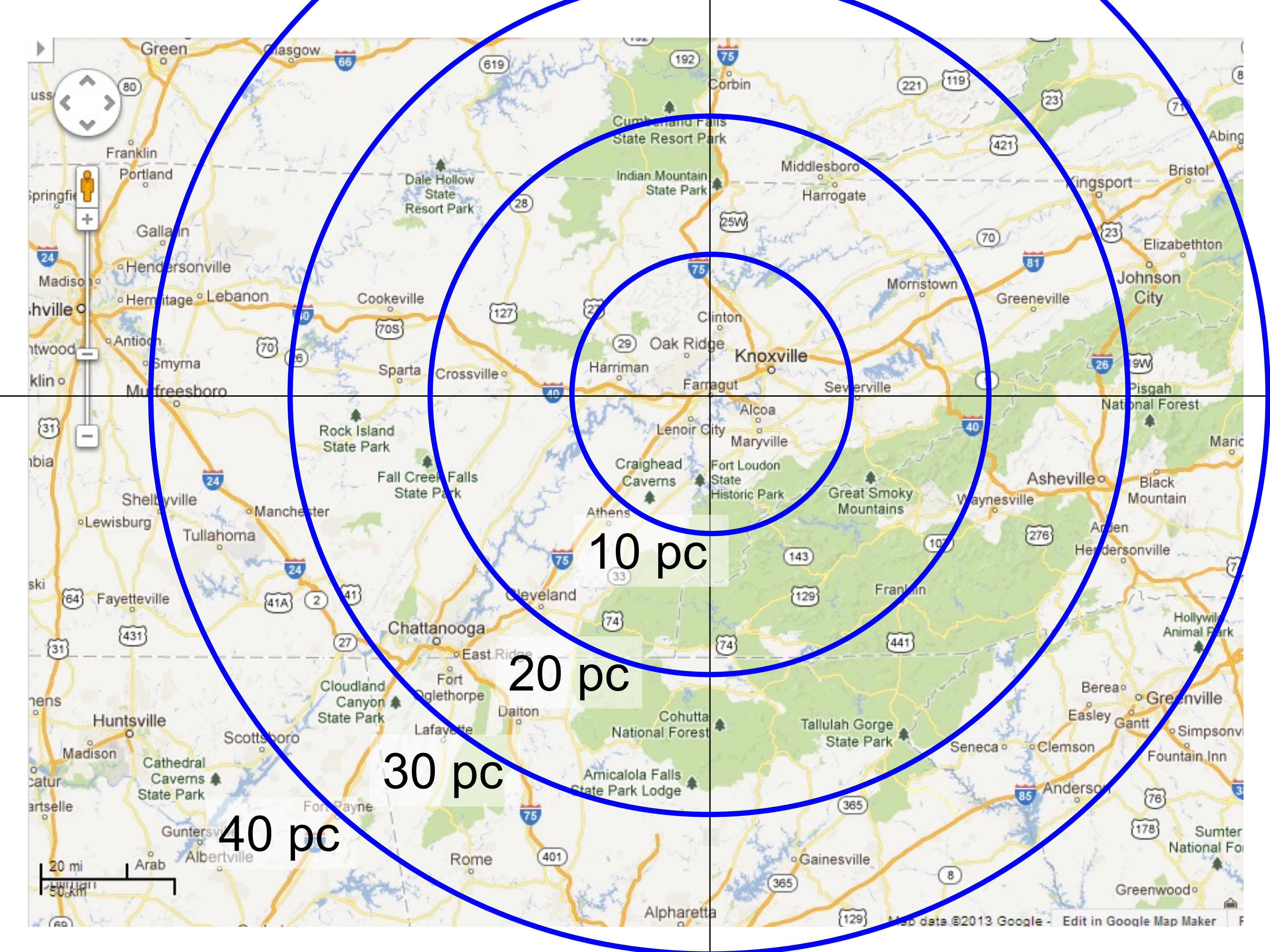


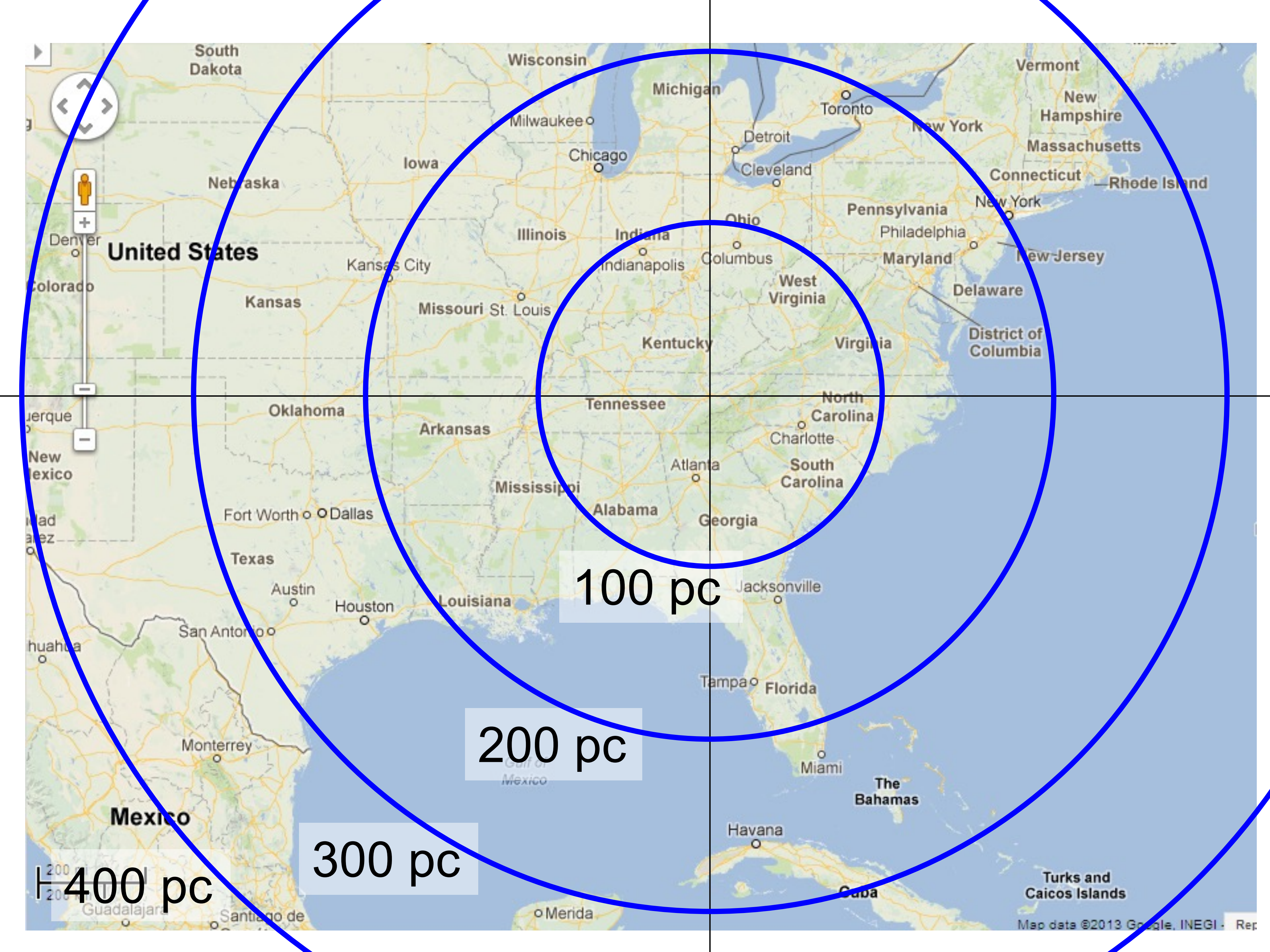
Note: at this scale, the speed of light is about that of a slow snail (0.00011 mph).


Nearest Star
1 pc
2 pc
3 pc
Farragut
Concord
Concord Park
Anchor Park
McFee Park
Mayor Bob Leonard Park
Lenoir City Park
Lenoir City
Louisville
Keller Bend Park
Cedar Bluff
Dead Horse Lake Golf Course
West Hills Park
Ball Camp Park
Melton Hill Park
Melton Hill Lake
Guinn Rd Park
Hardin Valley Rd
Hickory Creek Rd
Kingston Pike
Pellissippi Pkwy
Westland Dr
Bluegrass Rd
Choto Rd
Beals Chapel Rd
Louisville Rd
Quarry Rd
S Northshore Dr
Middlebrook Pike
Ball Camp Pike
Garrison Dr
Lovell Rd
N Campbell Station Rd
State Hwy 162 Scenic
Solway Rd
Morrell Rd
Amherst Rd
2 mi
2 km
Map data ©2013 Google - Edit in Google Map Maker

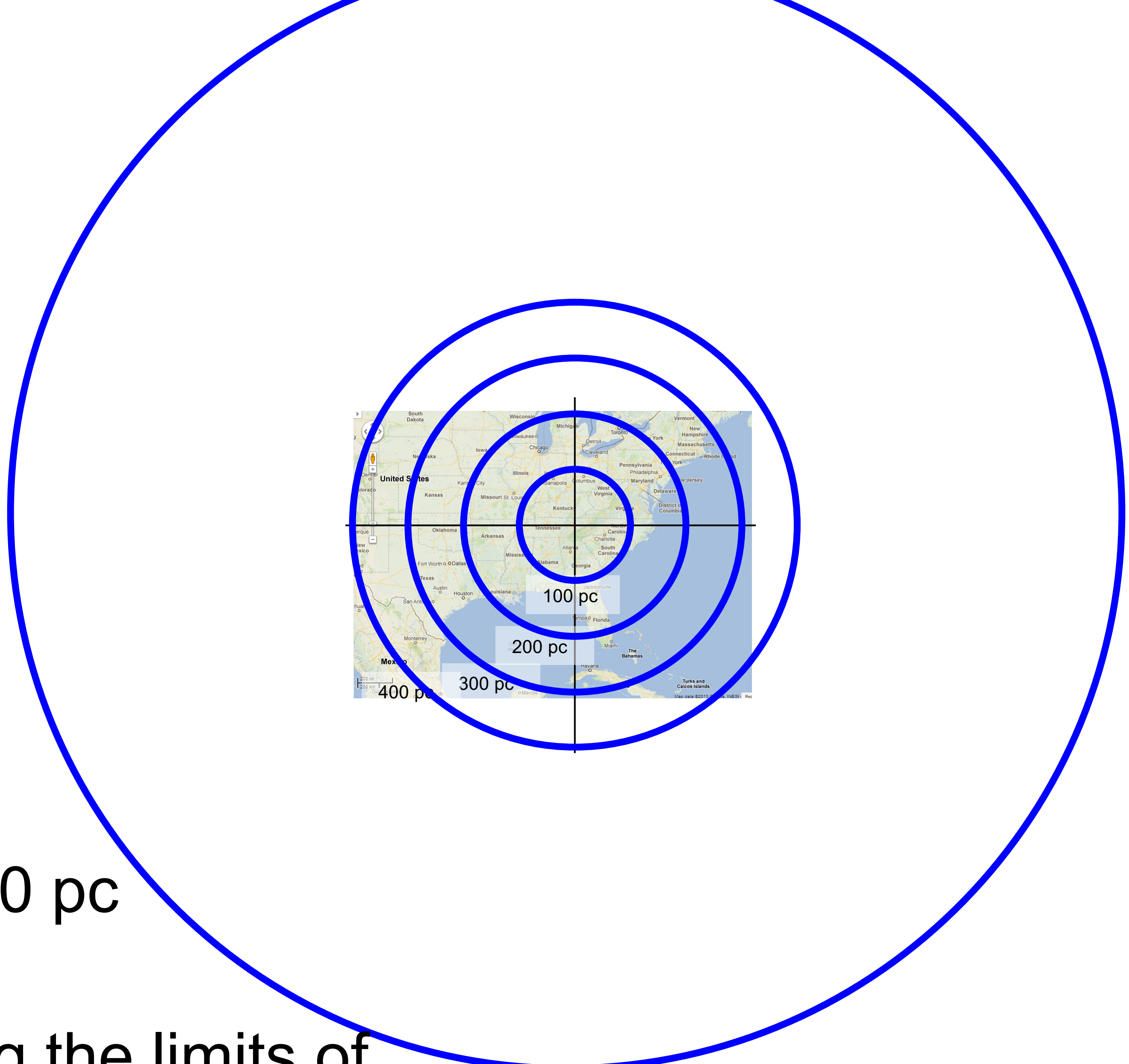


Nearest Star
2 ly
4 ly
6 ly
8 ly
Farragut
Concord
Concord Park
McFee Park
Mayor Bob Leonard Park
Lenoir City Park
Lenoir City
Keller Bend Park
West Hills Park
Ball Camp Park
Cedar Bluff
Dead Horse Lake Golf Course
Melton Hill Park
Melton Hill Lake
Louisville
Kingston Pike
Hardin Valley Rd
Hickory Creek Rd
Pellissippi Pkwy
2 mi
2 km
Map data ©2013 Google - Edit in Google Map Maker


10 pc
20 pc
30 pc
40 pc
Knoxville
Oak Ridge
Clinton
Harriman
Farragut
Alcoa
Maryville
Lenoir City
Sevierville
Craighead Caverns
Fort Loudon State Historic Park
Great Smoky Mountains
Athens
Cleveland
Chattanooga
East Ridge
Fort Oglethorpe
Dalton
Lafayette
Cloudland Canyon State Park
Cohutta National Forest
Amicalola Falls State Park Lodge
Tallulah Gorge State Park
Franklin
Asheville
Waynesville
Black Mountain
Arden
Hendersonville
Greeneville
Morristown
Johnson City
Elizabethton
Kingsport
Bristol
Middlesboro
Harrogate
Corbin
Cumberland Falls State Resort Park
Indian Mountain State Park
Dale Hollow State Resort Park
Cookeville
Crossville
Sparta
Rock Island State Park
Fall Creek Falls State Park
Manchester
Tullahoma
Shelbyville
Lewisburg
Fayetteville
Murfreesboro
Smyrna
Lebanon
Hermitage
Hendersonville
Gallatin
Portland
Franklin
Glasgow
Huntsville
Madison
Scottsboro
Cathedral Caverns State Park
Guntersville
Albertville
Arab
Fort Payne
Rome
Alpharetta
Gainesville
Seneca
Clemson
Anderson
Easley
Greenville
Berea
Gantt
Fountain Inn
Greenwood
Sumter National Forest
Hollywild Animal Park
Pisgah National Forest
20 mi
50 km
Map data ©2013 Google
Edit in Google Map Maker

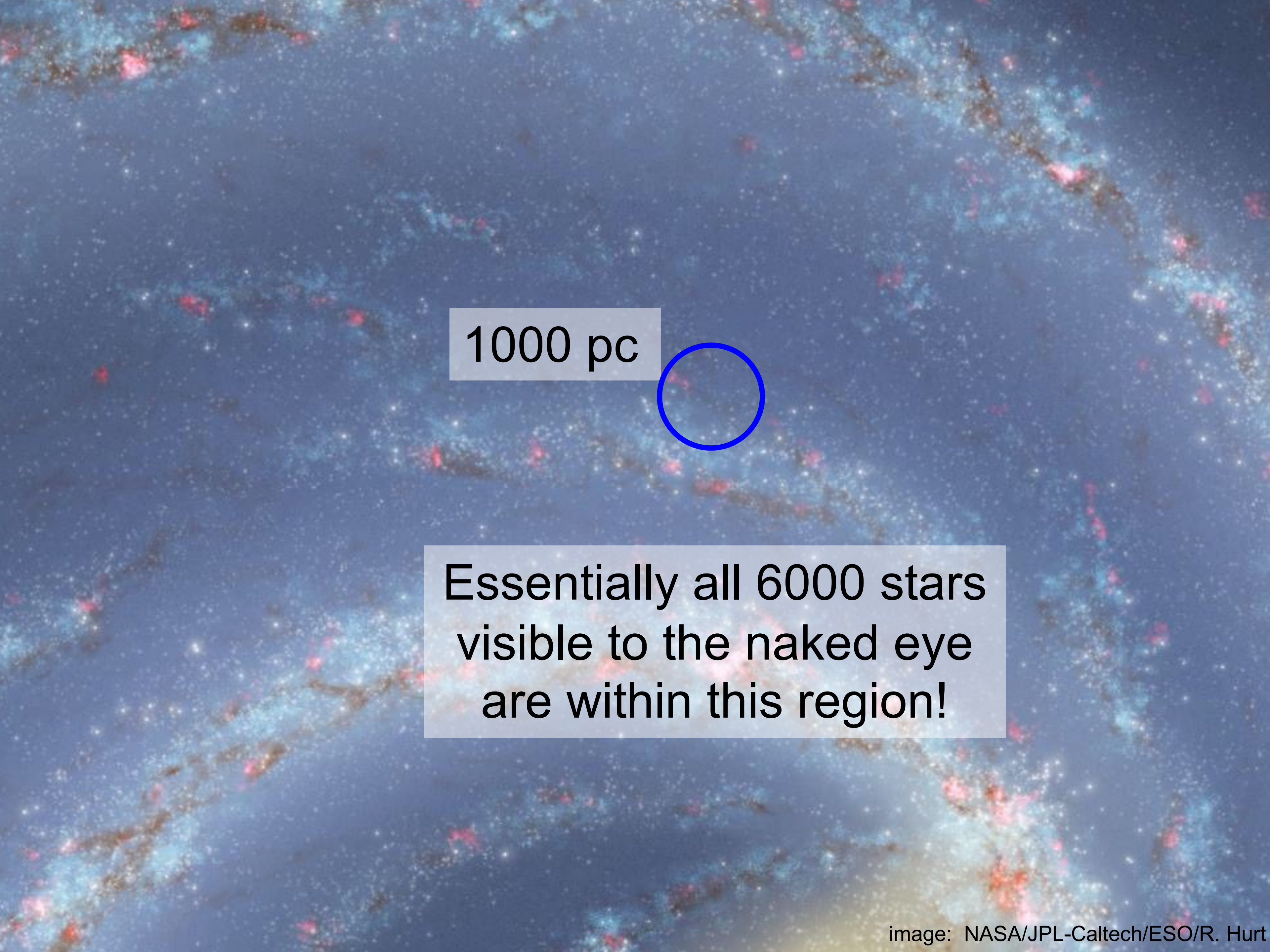


100 pc
200 pc
300 pc
400 pc



1000 pc

Straining the limits of detectable parallax


1000 pc
Essentially all 6000 stars visible to the naked eye are within this region!
image: NASA/JPL-Caltech/ESO/R. Hurt

The Milky Way Galaxy

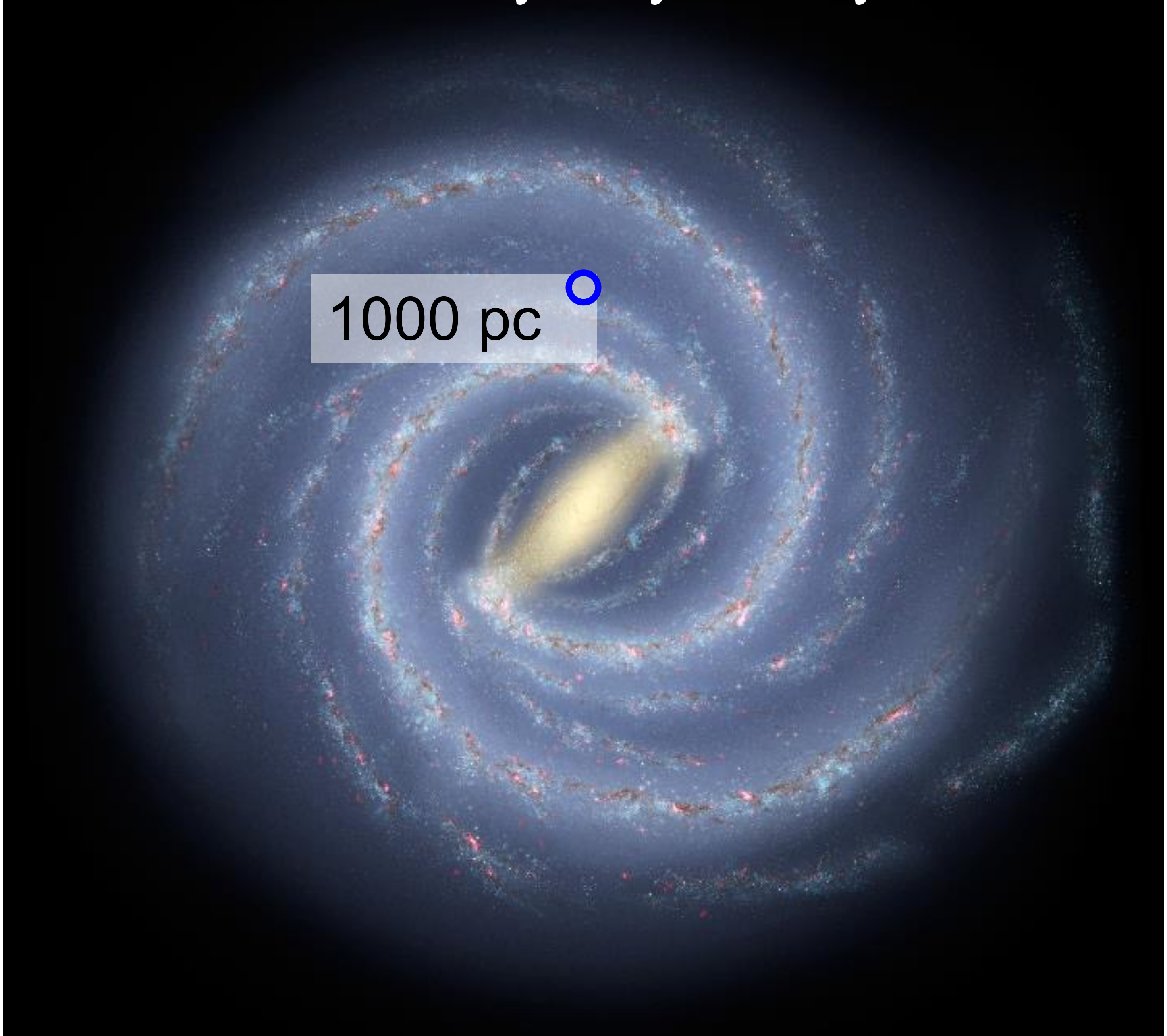
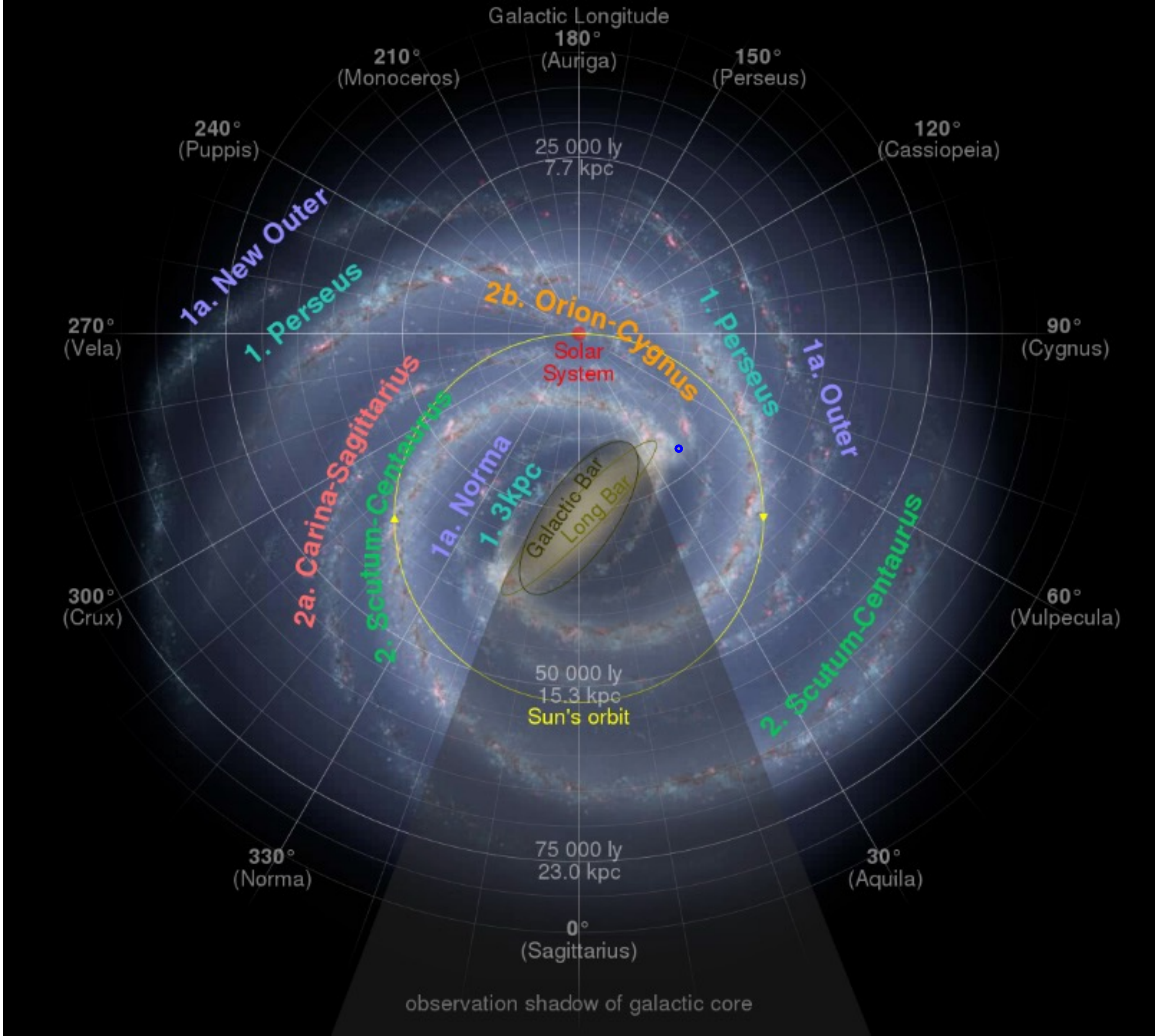


image: NASA/JPL-Calt



Galactic Longitude
180° (Auriga)
210° (Monoceros)
150° (Perseus)
240° (Puppis)
120° (Cassiopeia)
270° (Vela)
90° (Cygnus)
300° (Crux)
60° (Vulpecula)
330° (Norma)
30° (Aquila)
0° (Sagittarius)
25 000 ly
7.7 kpc
50 000 ly
15.3 kpc
75 000 ly
23.0 kpc
1a. New Outer
1. Perseus
2b. Orion-Cygnus
1. Perseus
1a. Outer
Solar System
2a. Carina-Sagittarius
2. Scutum-Centaurus
1a. Norma
1. 3kpc
Galactic Bar
Long Bar
2. Scutum-Centaurus
Sun's orbit
observation shadow of galactic core

Astronomical Distances

- The astronomical unit (radius of Earth's orbit):

  1 A.U. = 1.496×10^{11} m

- The light-year (distance light travels in 1 year):

  1 ly = 63240 A.U. = 9.46×10^{15} m

- The parsec (distance to star with parallax of 1″):

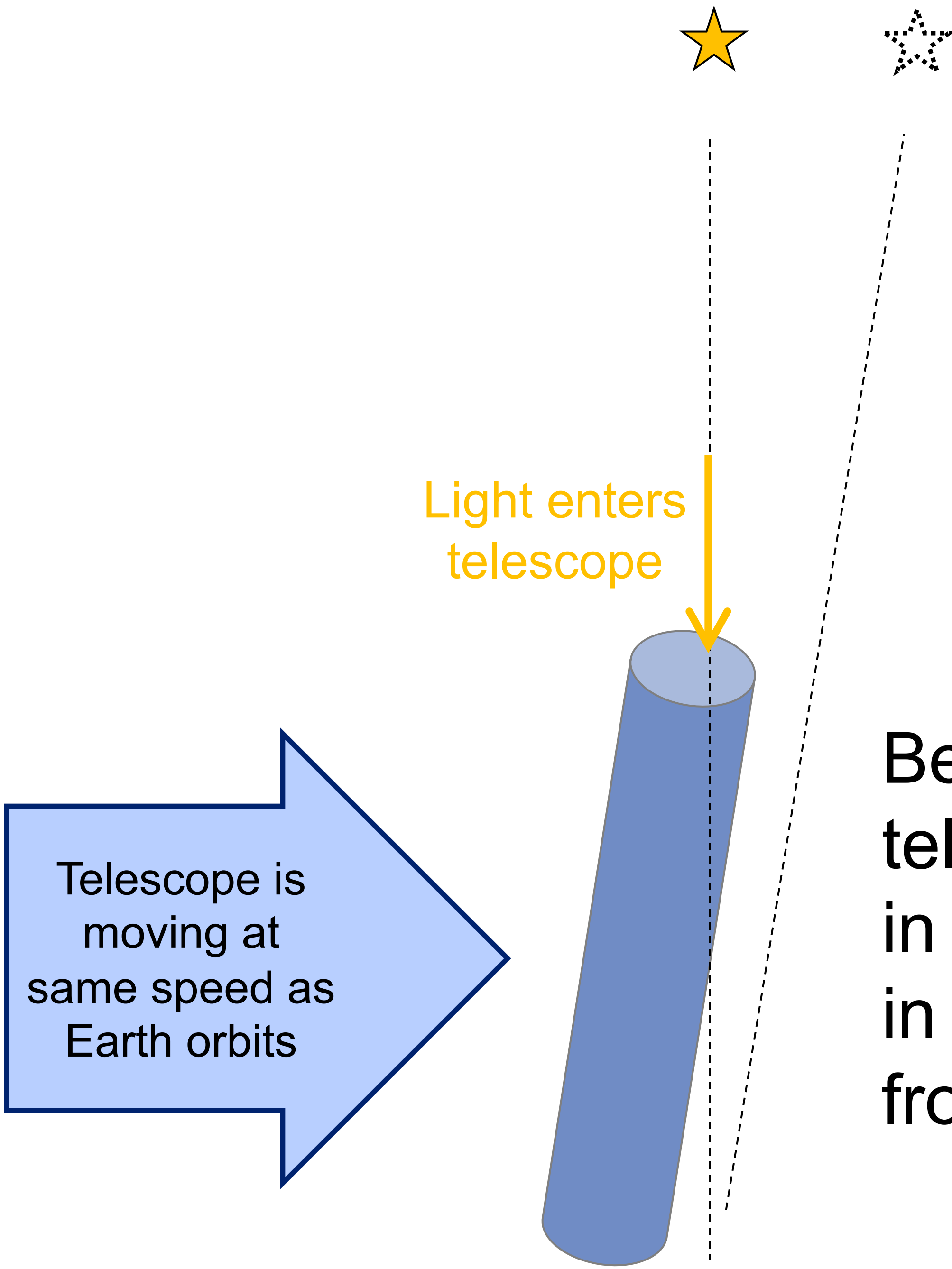
  1 pc = 3.26 ly = 206265 A.U. = 3.09×10^{16} m

Name of star	Parallax (arc sec)	Distance (pc)	Distance (ly)	Distance (m)
Barnard's Star	0.545			
Vega	0.13			
Sirius		2.7		
Alpha Centauri		1.33		
Proxima Centauri			4.24	
Rigel			815	
Deneb				1.33×10^{19}
Capella				4.32×10^{17}

Name of star	Parallax (arc sec)	Distance (pc)	Distance (ly)	Distance (m)
Barnard's Star	0.545	1.83	5.98	5.66×10^{16}
Vega	0.13	7.7	25	2.4×10^{17}
Sirius	0.37	2.7	8.8	8.3×10^{16}
Alpha Centauri	0.752	1.33	4.34	4.10×10^{16}
Proxima Centauri	0.769	1.30	4.24	4.01×10^{16}
Rigel	0.0040	250	815	7.7×10^{18}
Deneb	0.0023	431	1410	1.33×10^{19}
Capella	0.0714	14.0	45.7	4.32×10^{17}

Stellar Aberration

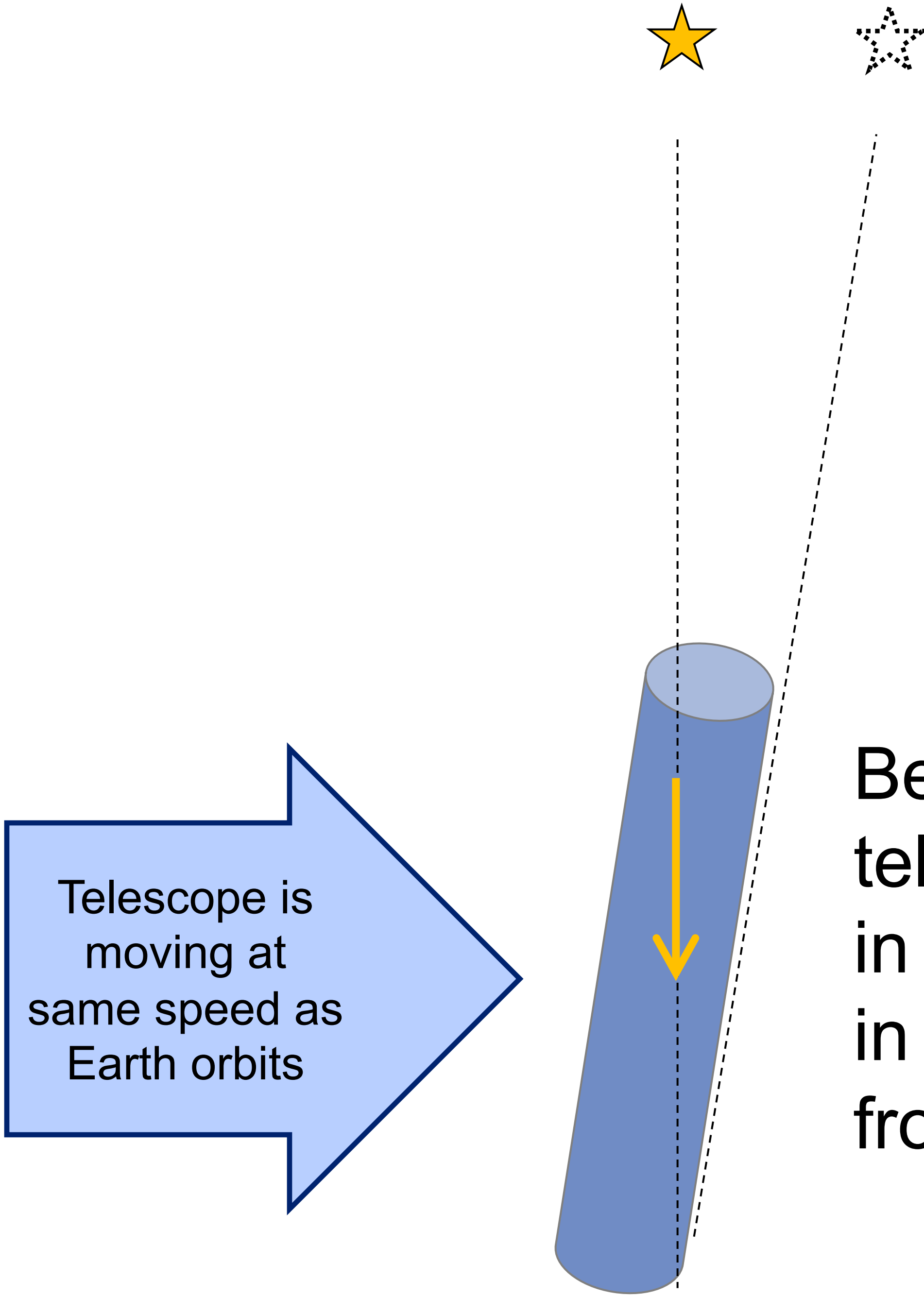
- Aberration is also a cyclical apparent change in the position of stars.
- However, <u>ALL</u> stars in a particular region of the sky undergo the same shift over the course of one year.
- Aberration does not tell us anything about the star (but rather relates to Earth's velocity in its orbit).



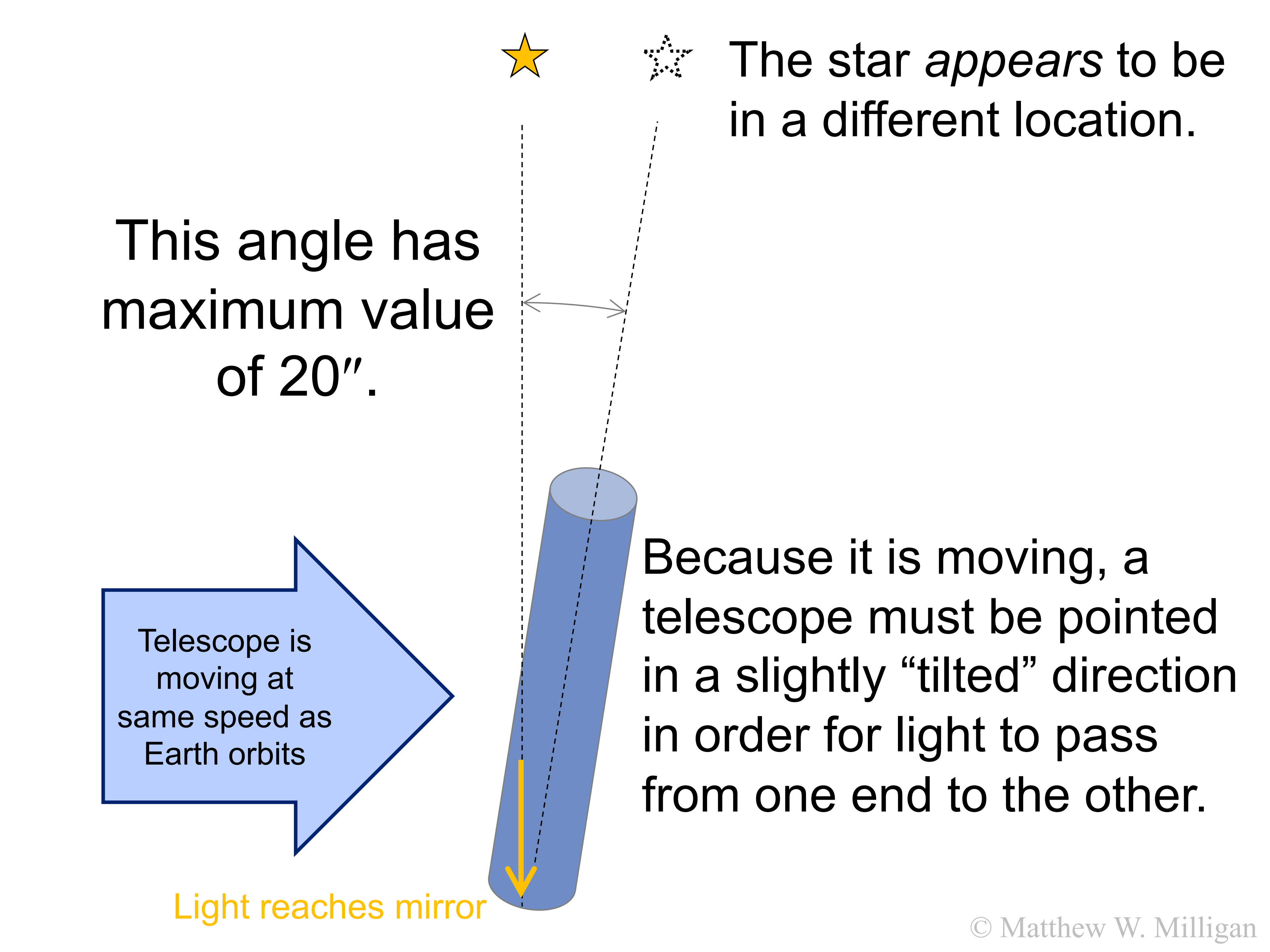
The star *appears* to be in a different location.

Because it is moving, a telescope must be pointed in a slightly “tilted” direction in order for light to pass from one end to the other.

The star *appears* to be in a different location.



Because it is moving, a telescope must be pointed in a slightly “tilted” direction in order for light to pass from one end to the other.


The star *appears* to be in a different location.
This angle has maximum value of 20″.
Because it is moving, a telescope must be pointed in a slightly "tilted" direction in order for light to pass from one end to the other.
Telescope is moving at same speed as Earth orbits
Light reaches mirror
© Matthew W. Milligan

Parallax vs. Aberration

- Stellar aberration is a much larger shift of around 20″ and was discovered by Bradley in the 1720's.
- Unlike parallax, aberration is unrelated to distance – near stars and far stars exhibit the *same* aberration.
- Unlike parallax, the shift is in the *same* direction as Earth's motion, instead of the *opposite*!

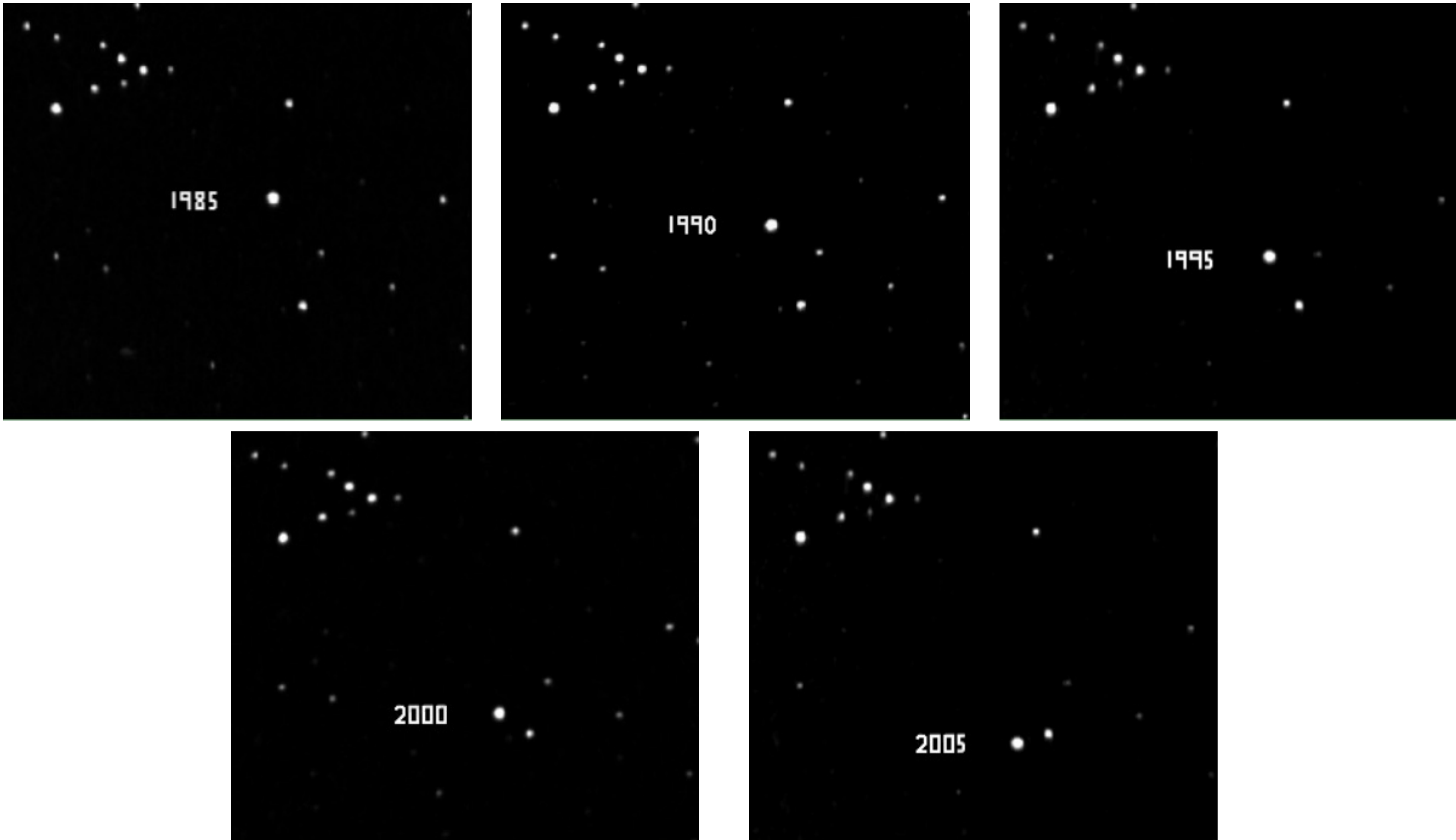
	The student will be able to:	HW:
1	Define and apply stellar parallax and the unit of the parsec.	1 – 3
2	Relate parallax and the parsec to skinny triangles and other units such as meters and light years.	
3	Define and describe proper motion.	4 – 6
4	Describe and apply methods by which the velocity of a star through space may be determined by including both radial and transverse velocity.	
5	Describe direct and indirect methods used to determine the size of a star and classify stars as giants, supergiants, or dwarfs.	7 – 8
6	State and apply the relation between luminosity, radius, and temperature.	
7	State and apply the relation between luminosity, distance, and energy flux.	9 – 16
8	Define and contrast the concepts: absolute magnitude, intrinsic brightness, luminosity, and apparent magnitude, apparent brightness, energy flux.	
9	Explain and apply the magnitude scale of brightness.	
10	Describe and apply the relation between a stars color and its temperature.	17
11	Define, describe, and apply color index and explain its application in photometry and its relationship to blackbody radiation and Wein's Law.	
12	State in order of temperature the stellar spectral classes and list characteristics and examples of each.	18
13	Describe and define the Hertzsprung-Russell diagram in terms of each axis.	19 – 23
14	Plot a star's coordinates on the H-R diagram.	
15	Explain and illustrate how the H-R diagram is used to help classify and understand different types of stars such as main sequence stars, red giants, blue giants, supergiants, red dwarfs, and white dwarfs.	
16	Define, describe, and give examples of the stellar luminosity classes.	24 – 25
17	Describe and apply the method of spectroscopic parallax and explain the importance of luminosity class to this method.	
18	Describe and explain methods for determining a star's mass and relate to the different types of binary-star systems: visual binary, spectroscopic binary, and eclipsing binary.	26
19	Describe and explain the significance of a star's mass in determining its location on the H-R diagram and in determining the lifetime of the star.	27
20	Describe properties and significance of open clusters and globular clusters.	

Proper Motion

- Proper Motion is a steady shift in a star's apparent position on the celestial sphere.
- The star moves steadily in a particular direction and does not return to its starting point.

Barnard's Star

20 years of Proper Motion:



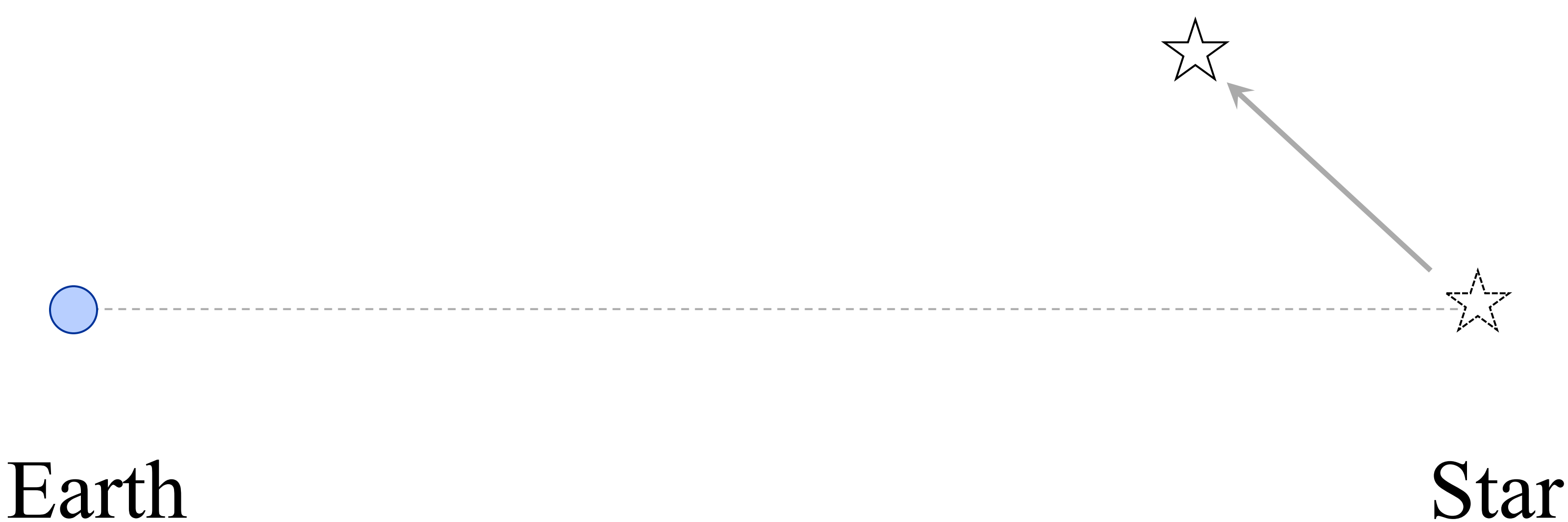
By Steve Quirk [Public domain], via Wikimedia Commons

Proper Motion Explained

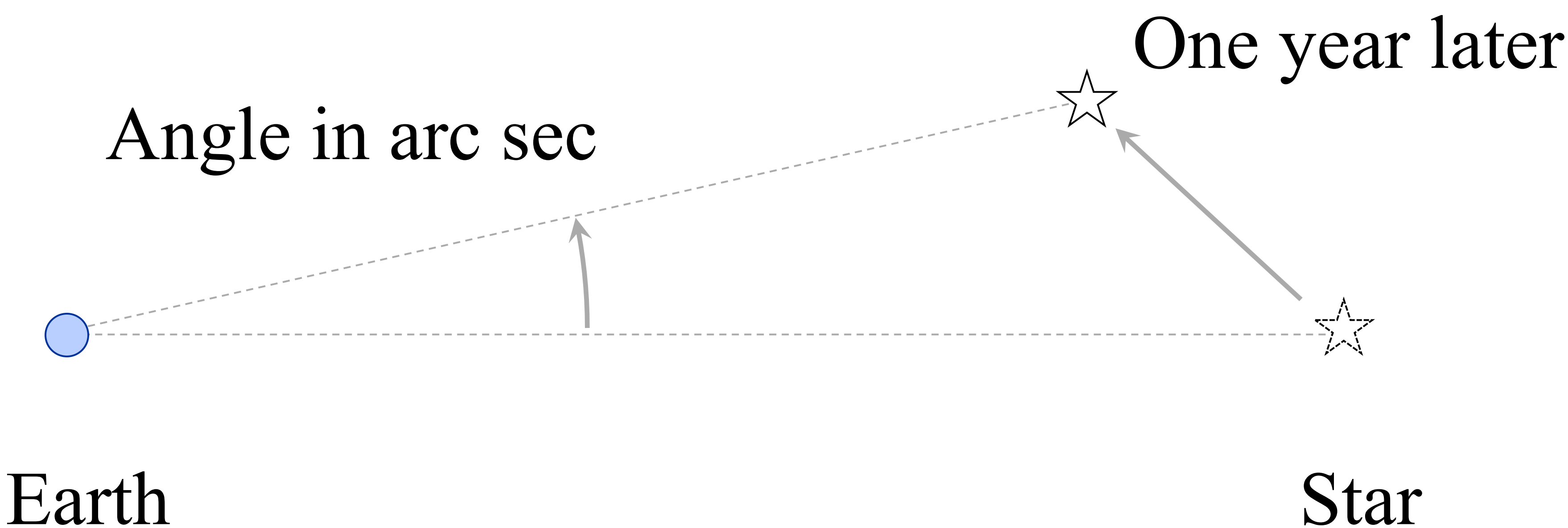
- Proper Motion is a change due to <u>actual</u> motion of a star through space.
- The amount depends on how fast the star is moving, the direction the star is moving, and the distance to the star.
- 61-Cygni is known as the "Flying Star" exhibits a large proper motion of about 6 arcseconds per year.

Suppose a star is moving through space . . .

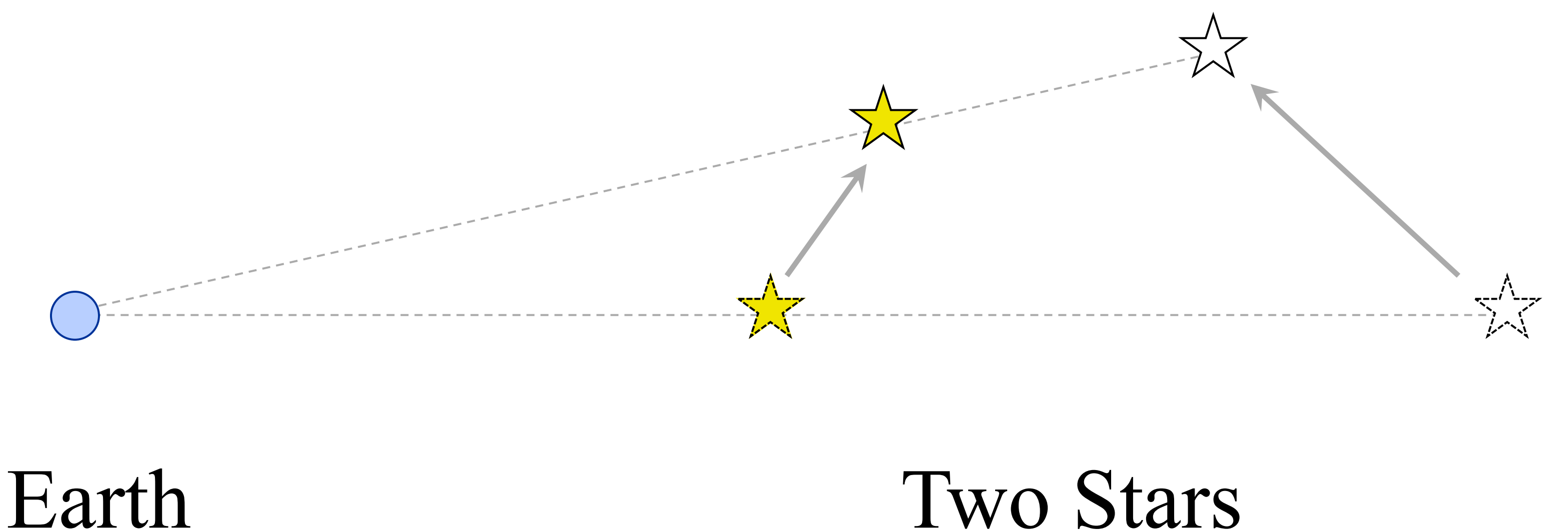
From our perspective on Earth it will change position by a certain angle. This angle is the "proper motion" and is usually given in arc seconds per year.



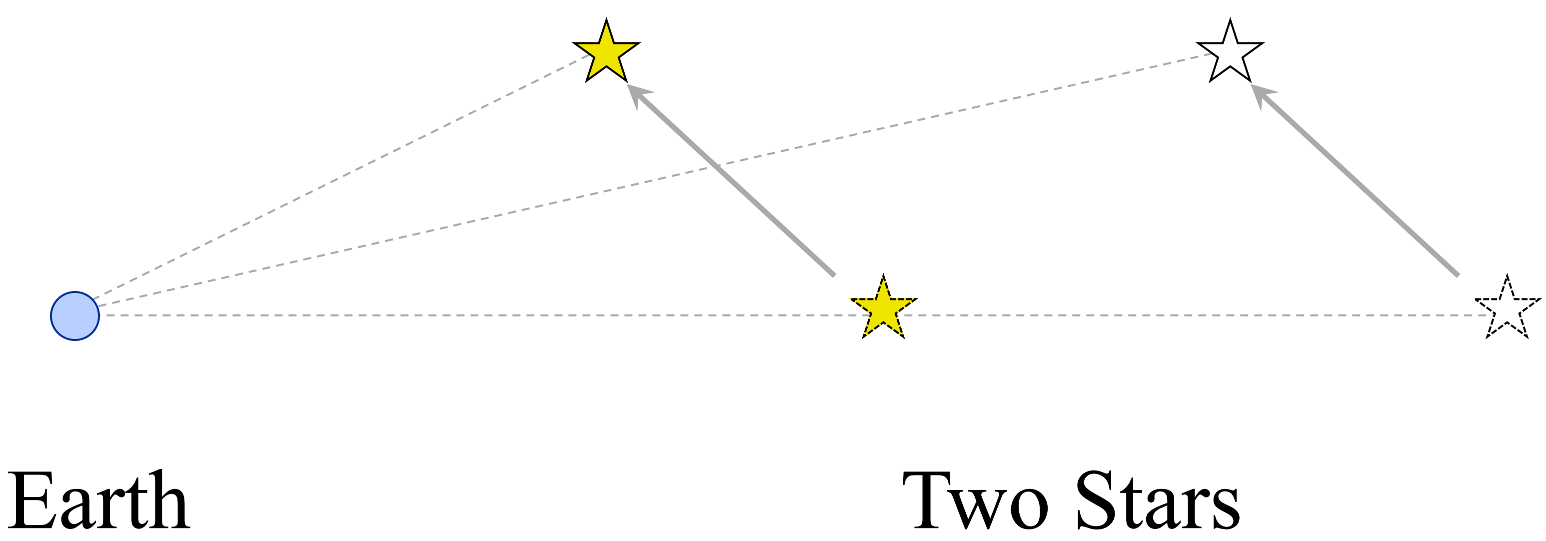
From our perspective on Earth it will change position by a certain angle. This angle is the "proper motion" and is usually given in arc seconds per year.



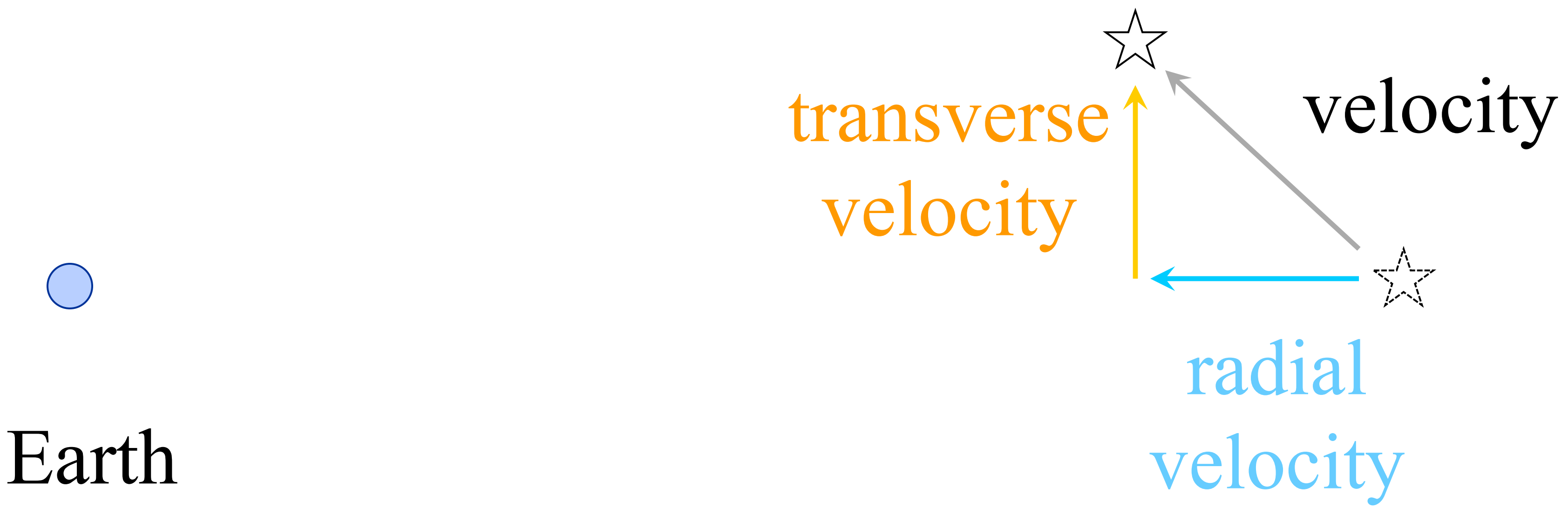
Note that two different stars could have the *same* proper motion in spite of very different *actual* motion in space ...



Also two different stars could have the same *actual* motion in space and very different *proper* motion from Earth ...

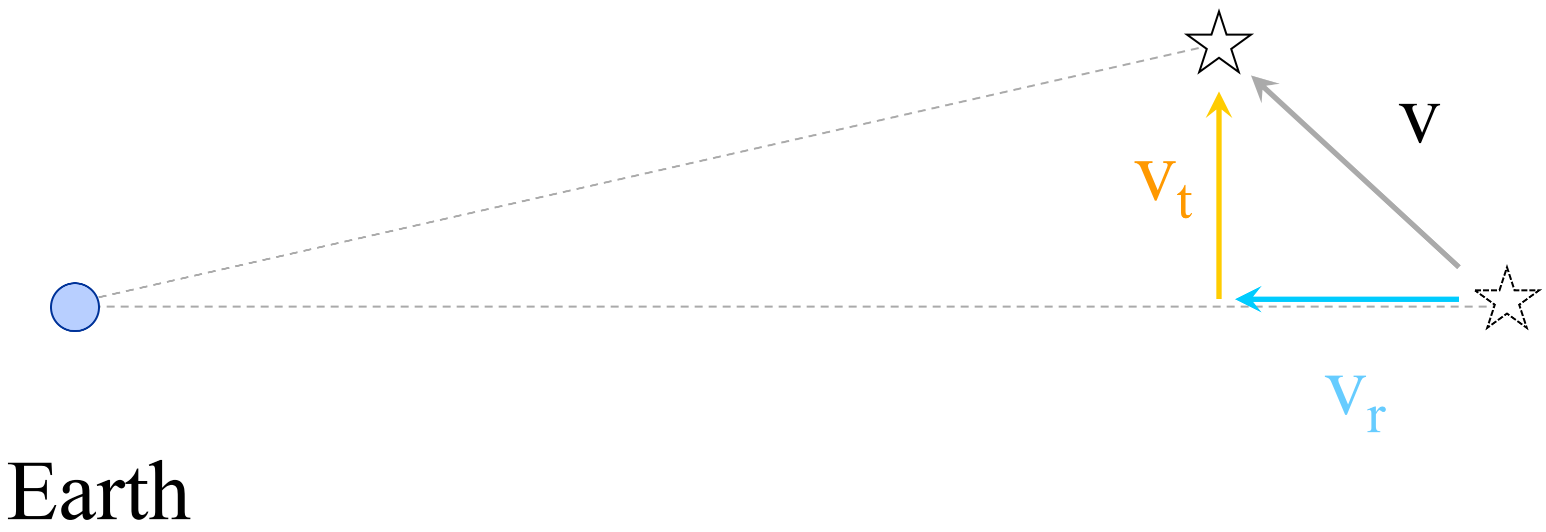


The overall velocity through space is a combination of "radial velocity" and "transverse velocity".



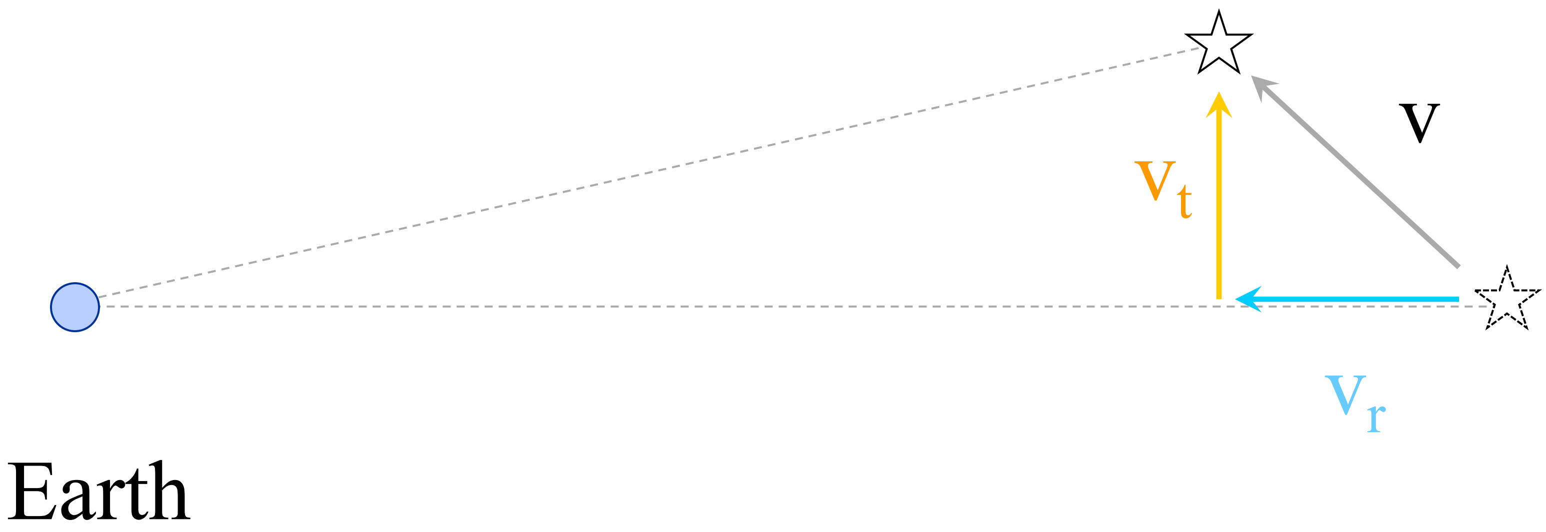
Radial velocity can be determined by the doppler shift.

Transverse velocity can be determined by proper motion.



The overall velocity can then be found by the Pythagorean Theorem:

$$v^2 = v_r^2 + v_t^2$$



Stellar Motion Practice

5. Proxima Centauri has transverse velocity 23.8 km/s and radial velocity −22.2 km/s. Find its true velocity through space. Will it get even closer to us?
6. Canopus: v_t = 2.9 km/s and v_r = +20.3 km/s. Find its true velocity through space. Where is it going?
7. Scholz's star has parallax 0.147″ and proper motion 0.12″/yr. The wavelengths of its light are shifted: $\Delta\lambda/\lambda = +2.75 \times 10^{-4}$. Find its velocity. Where has it been?

Gliese 710 – the "Death Star"?

- parallax = 0.05252″
- proper motion = 0.461 mas/yr
- $\Delta\lambda/\lambda = -4.84 \times 10^{-5}$
- $m = 9.69$
- Based on this information it is predicted that this star will …?

Gliese 710 – the "Death Star"?

- parallax = 0.05252″
- proper motion = 0.461 mas/yr
- $\Delta\lambda/\lambda = -4.84 \times 10^{-5}$
- m = 9.69
- Based on this information it is predicted that this star will pass within 0.06 pc of the Sun in about one million years. It will appear as bright as Betelgeuse!
- Compare and contrast with Scholz's star…