Reading: OpenStax, Chapter 19; Section 19.2
Chapter 5; Section 5.6
Chapter 17; Section 17.4

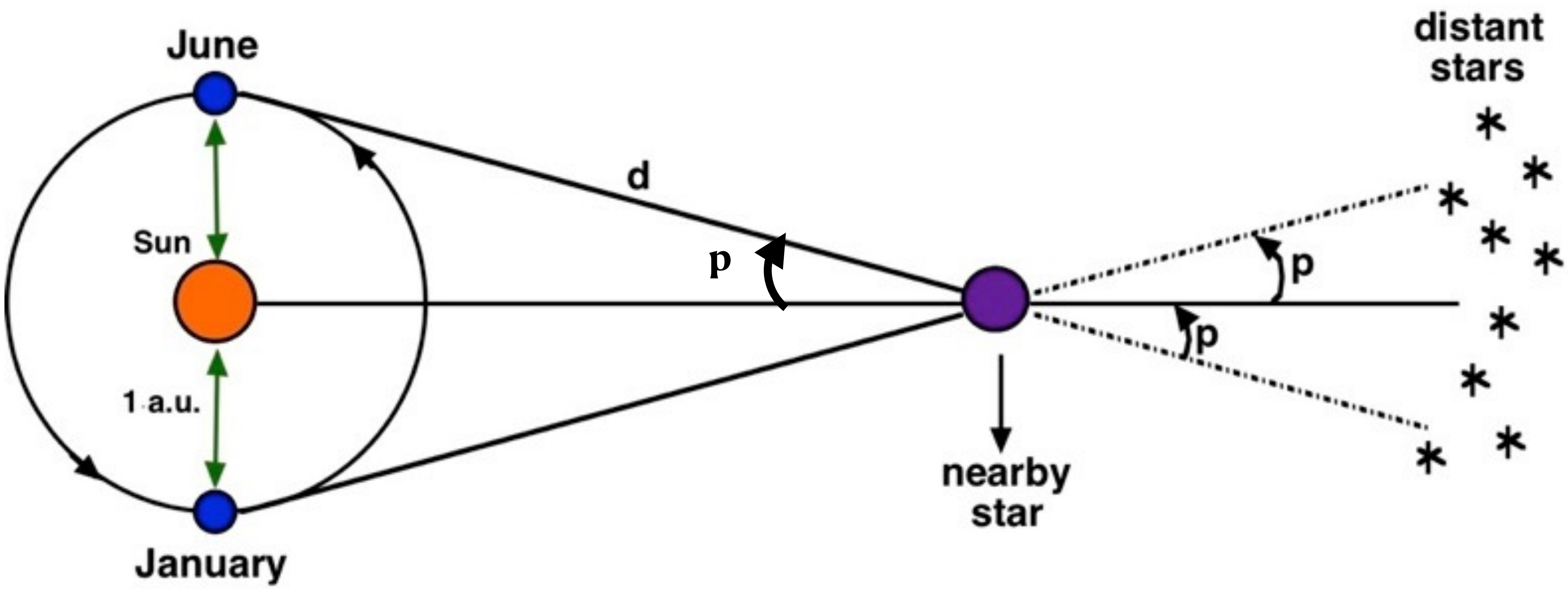
Brief review of last time: **Too small to see, too bright to ignore**

- The surfaces of the stars are too small to fully resolve
- Stellar spectra display a range of features that depend on temperature and composition; O B A F G K M

Today: **Stellar motions and the distances to the stars**

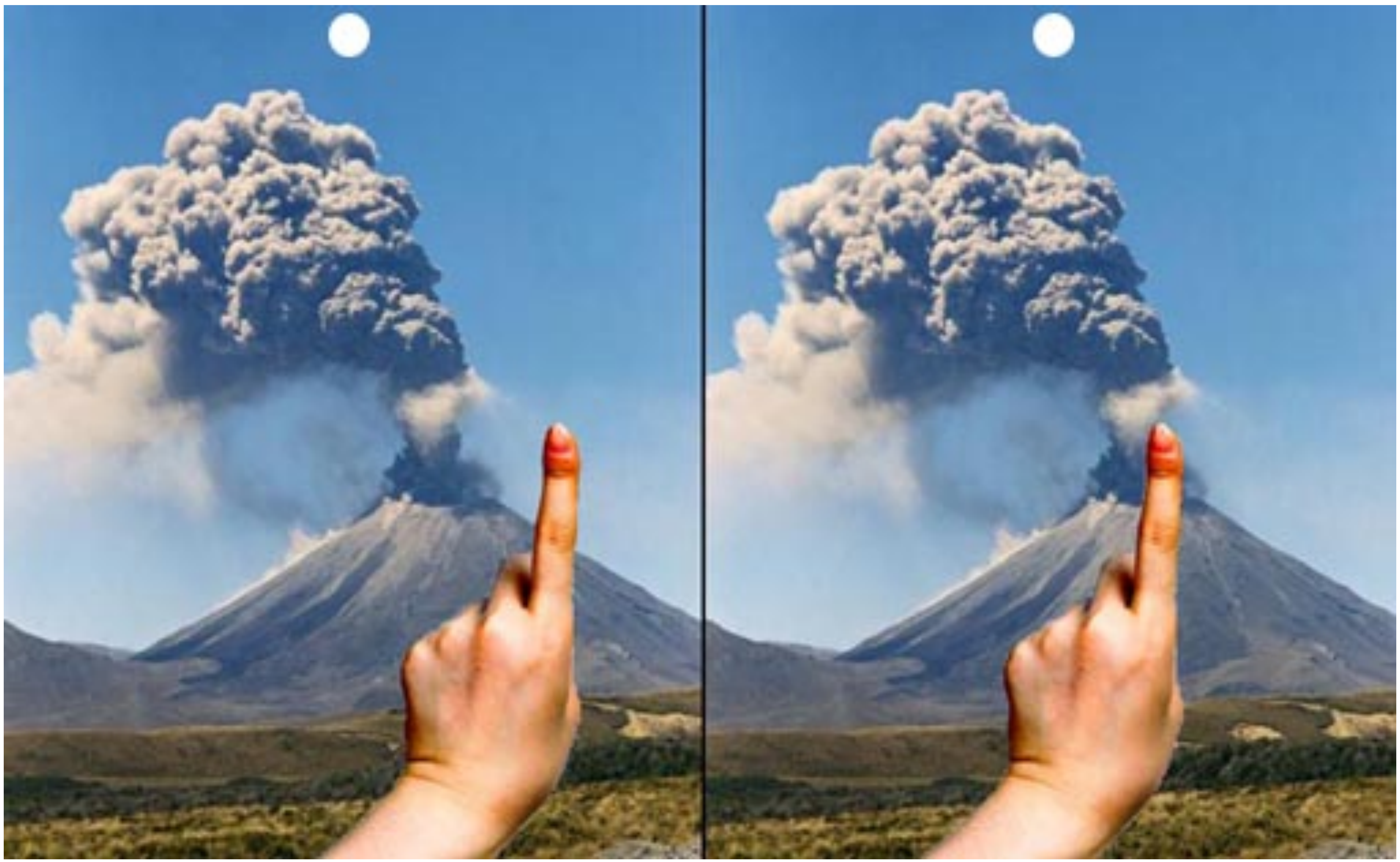
- Parallax — can measure distances to stars very accurately
- Proper motion — motion measured on the sky; stars are not fixed objects
- Radial motion and the Doppler effect — how to know if stars are moving toward or away from us

Trigonometric Parallax

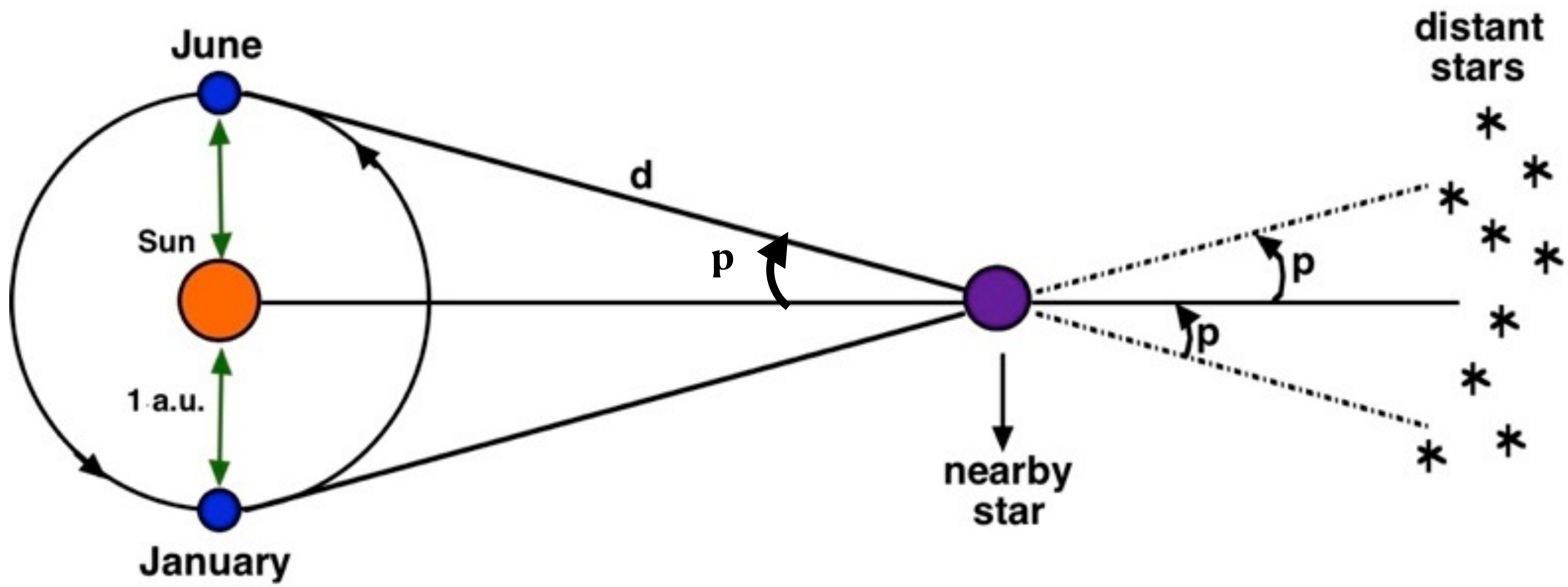


Trigonometric Parallax

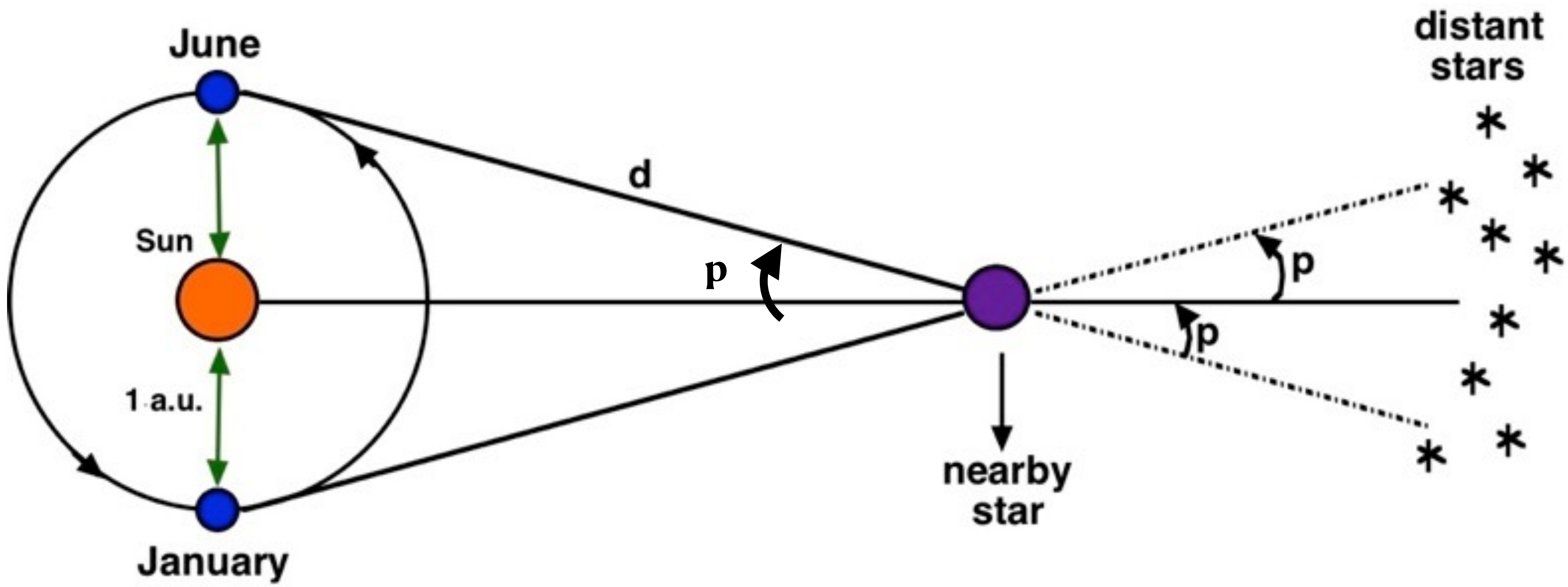
(do it yourself)

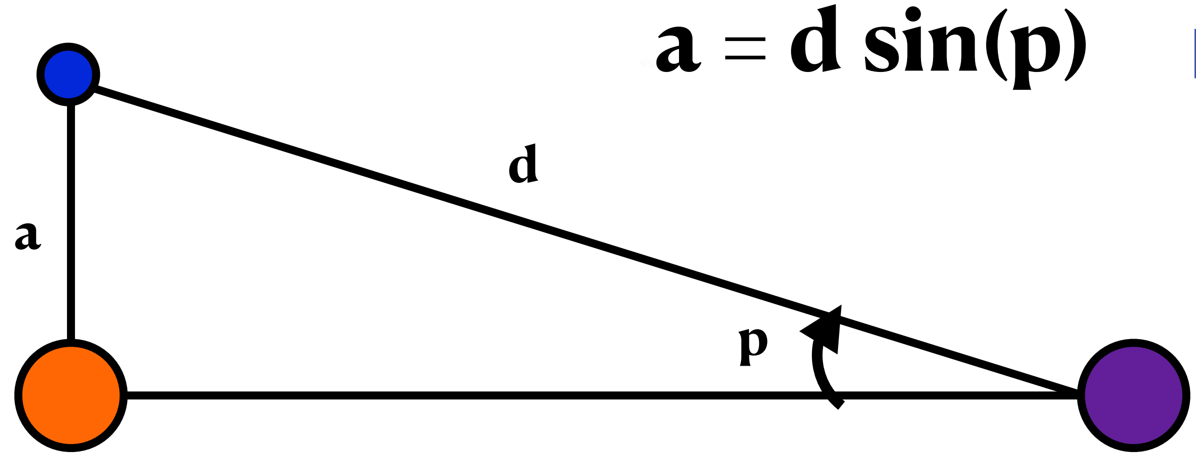


Trigonometric Parallax



Trigonometric Parallax





$$a = d \sin(p)$$

because a << d

$$a = d\,p$$

$$\boxed{d = a/p}$$

Trigonometric Parallax

$d = a/p$

If a is in AU (a = 1 AU) and p is in arc seconds (1/3600 of a degree), then d is in "parsec"

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

Trigonometric Parallax

distance (parsecs) = 1/parallax (arc seconds)

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

- a star with a parallax of 1 arc second lies at a distance of 1 parsec (=3.26 light years)

- example: α Centauri: parallax = 0.77 arc seconds
  - d [pc] = 1/0.77 arc sec
    = 1.3 pc

  - d [ly]= 1.3 pc x 3.26 ly/pc
    = 4.2 ly

Trigonometric Parallax

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Putting it in perspective…

- **1 arc second is about 0.5 mm as viewed over the length of one football field!**

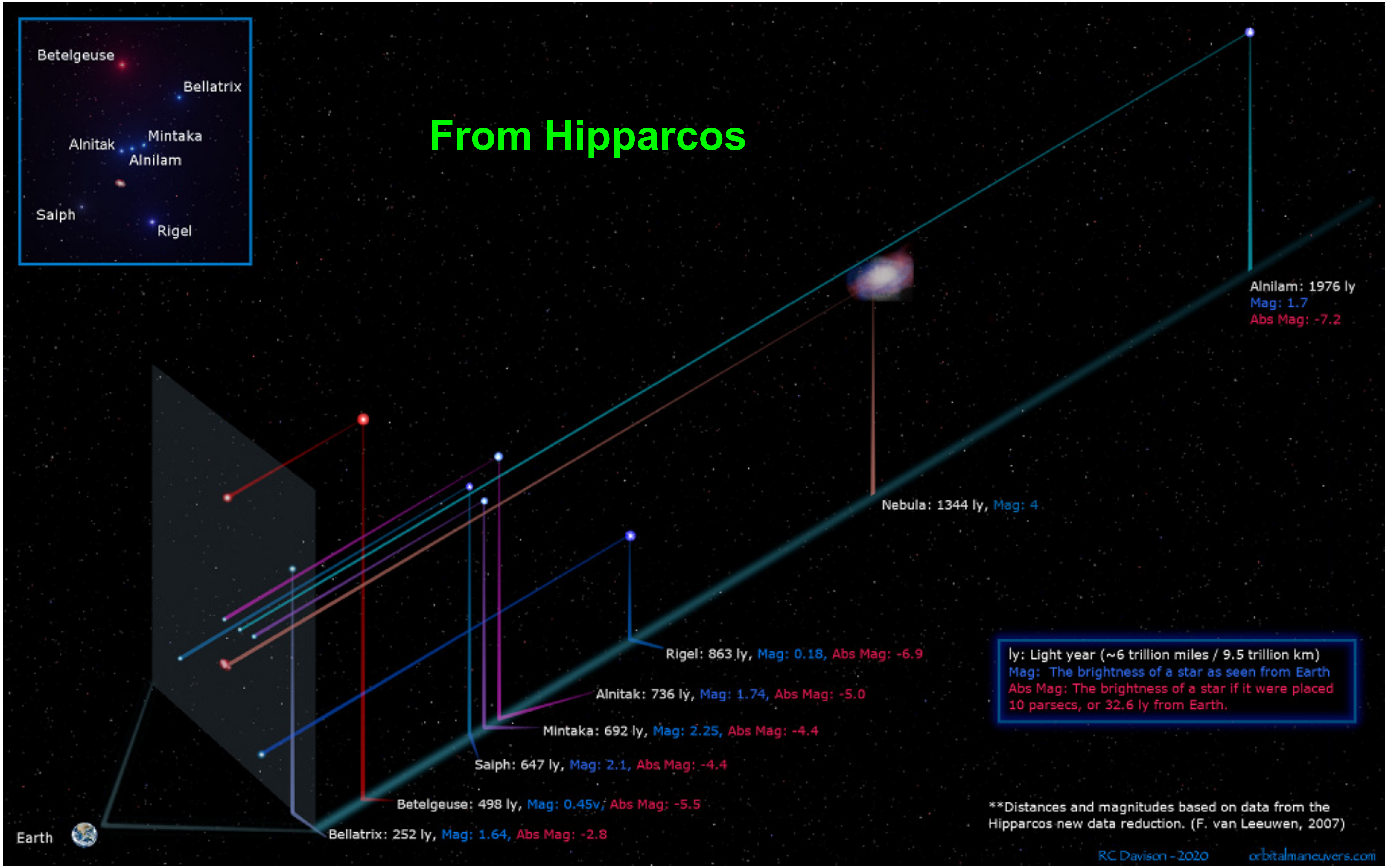
OR

- **1 arc second is about the size of the quarter viewed from 3 miles away (across the city of Ames)!!!**

Limits for Trigonometric Parallax

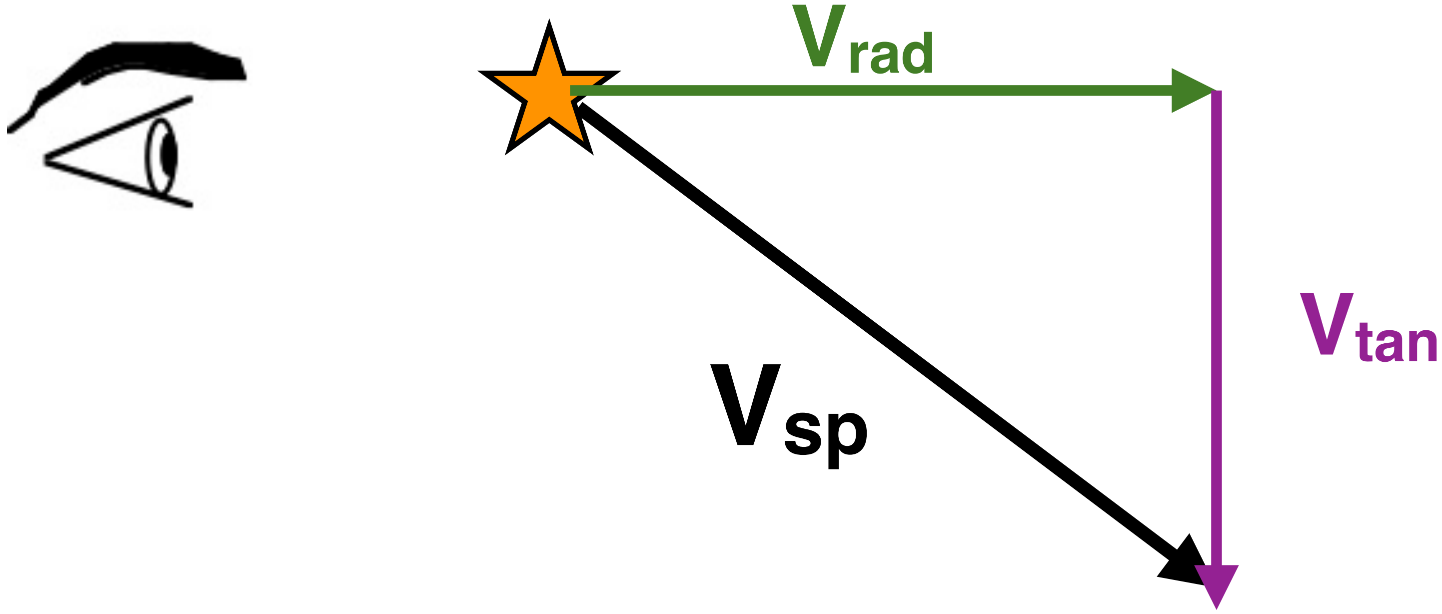
- **From Earth**:
  - smallest measurable parallax: **~0.01 arc sec**
  - farthest measurable distance: **~100 pc**
  - nearest **20,000 stars**
- **From space**: the **Hipparcos** Mission (1989-1993)
  - smallest measurable parallax: **0.0014 arc sec**
  - farthest distances: **700 pc**
  - **120,000 stars** out to 700 pc
  - **400,000 fainter stars** out to 350 pc
- **In progress: Gaia (2013-2022)**
  - smallest measurable parallax: **0.000024 arc sec**
  - **farthest distance: 40,000 pc**
  - brightness, position, distance to **1,700,000,000 stars**

Trigonometric Parallax and Orion

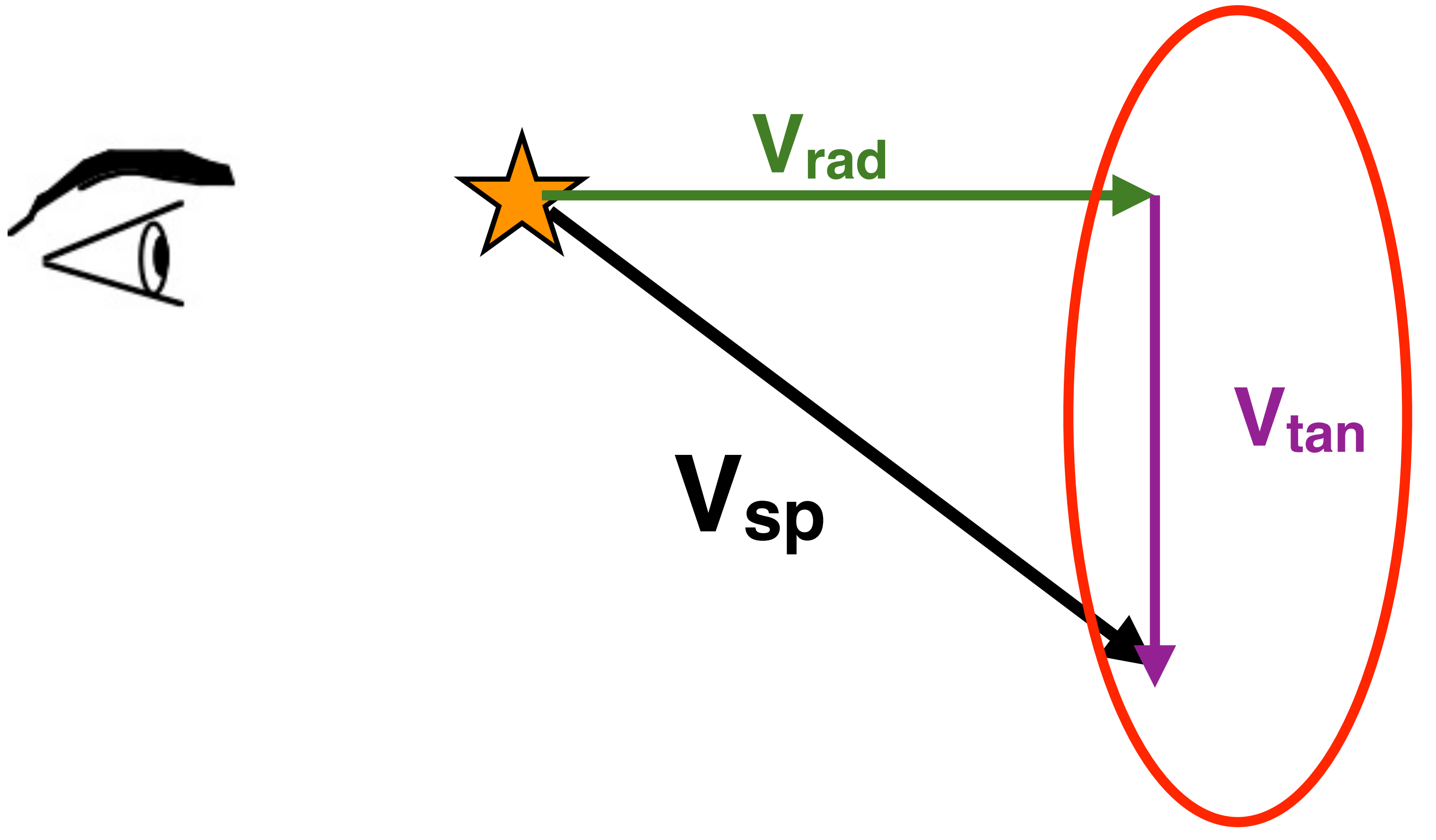


https://apod.nasa.gov/apod/ap200919.html

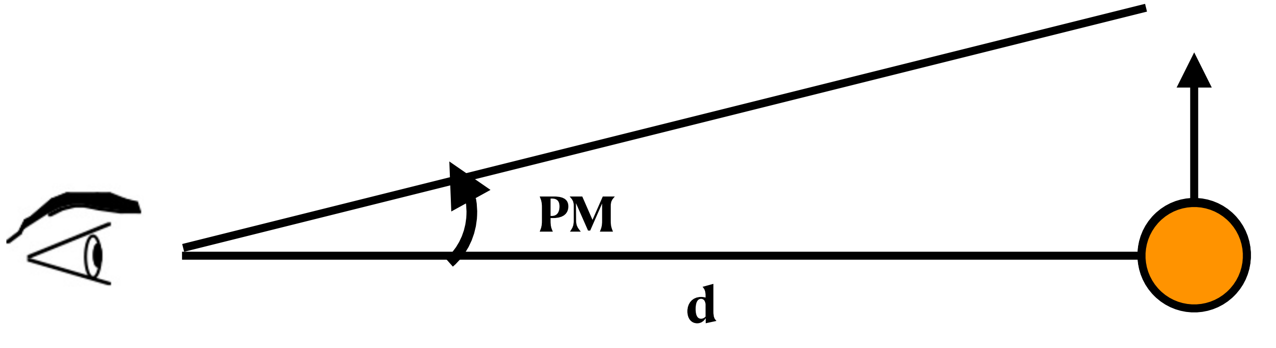
Stellar Motions



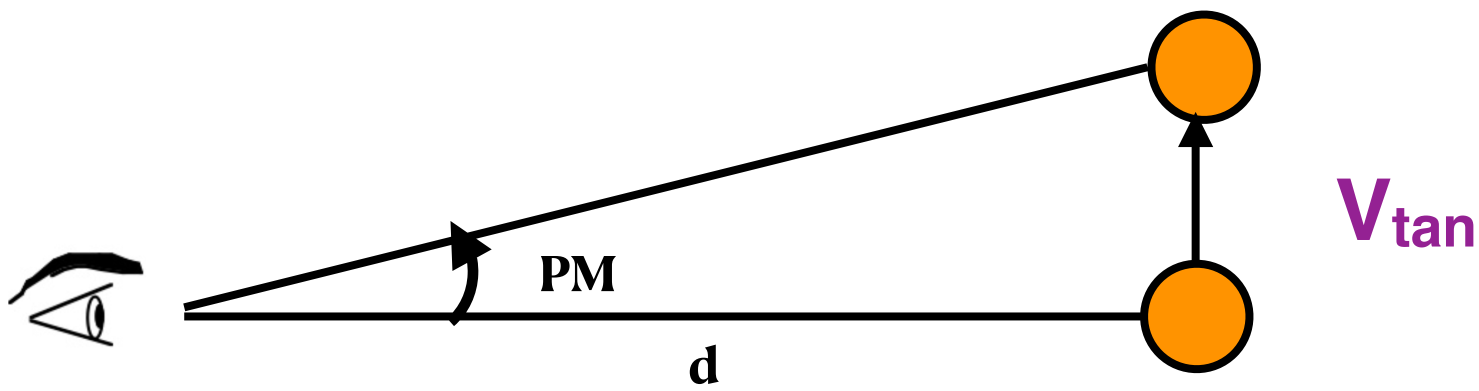
Stellar Motions



Tangential velocity can be written in terms of "proper motion"



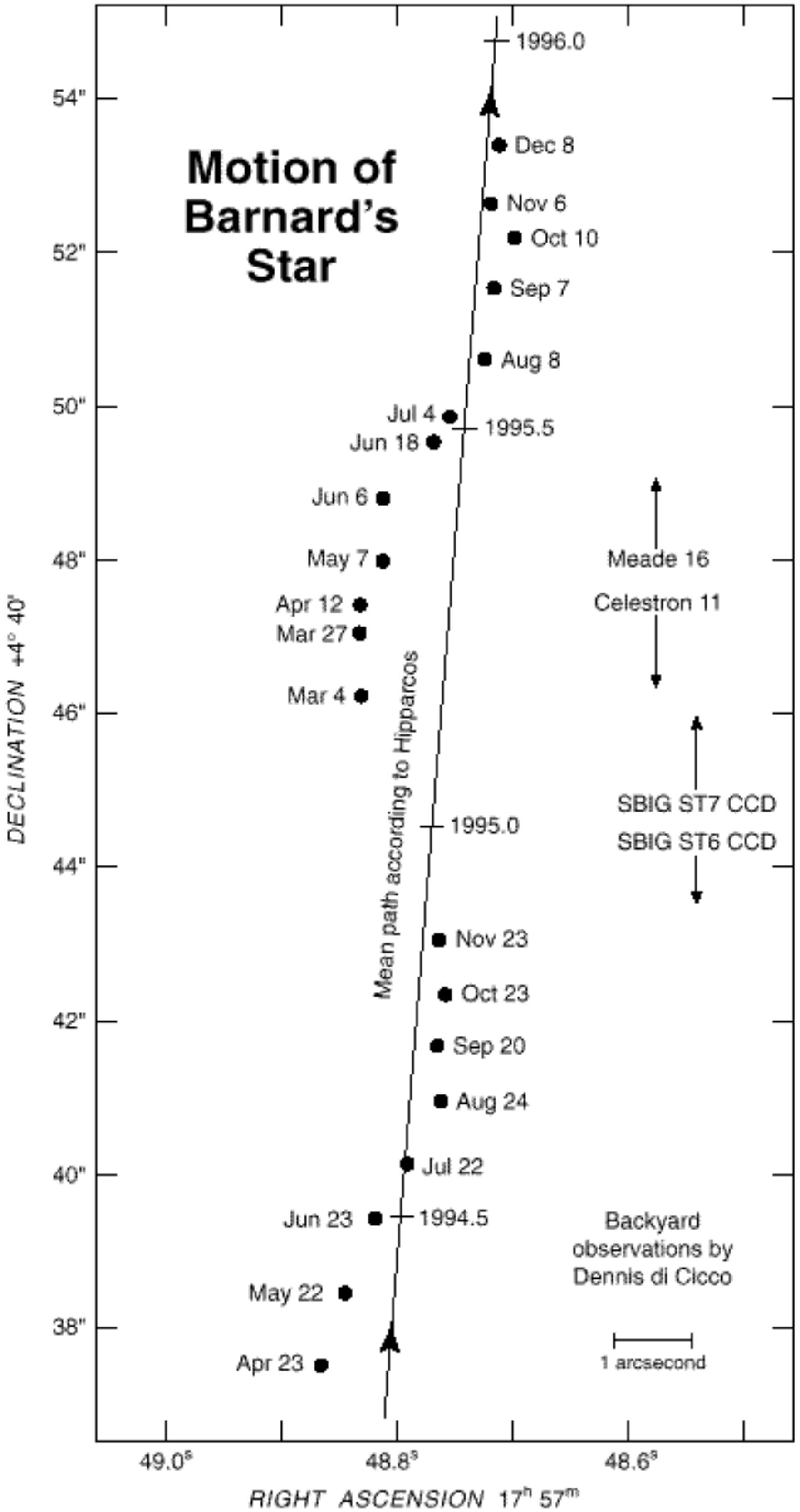
Proper Motion



$$V_{\rm tan} \propto {\rm PM} \times d$$

Can think about cars on a highway!

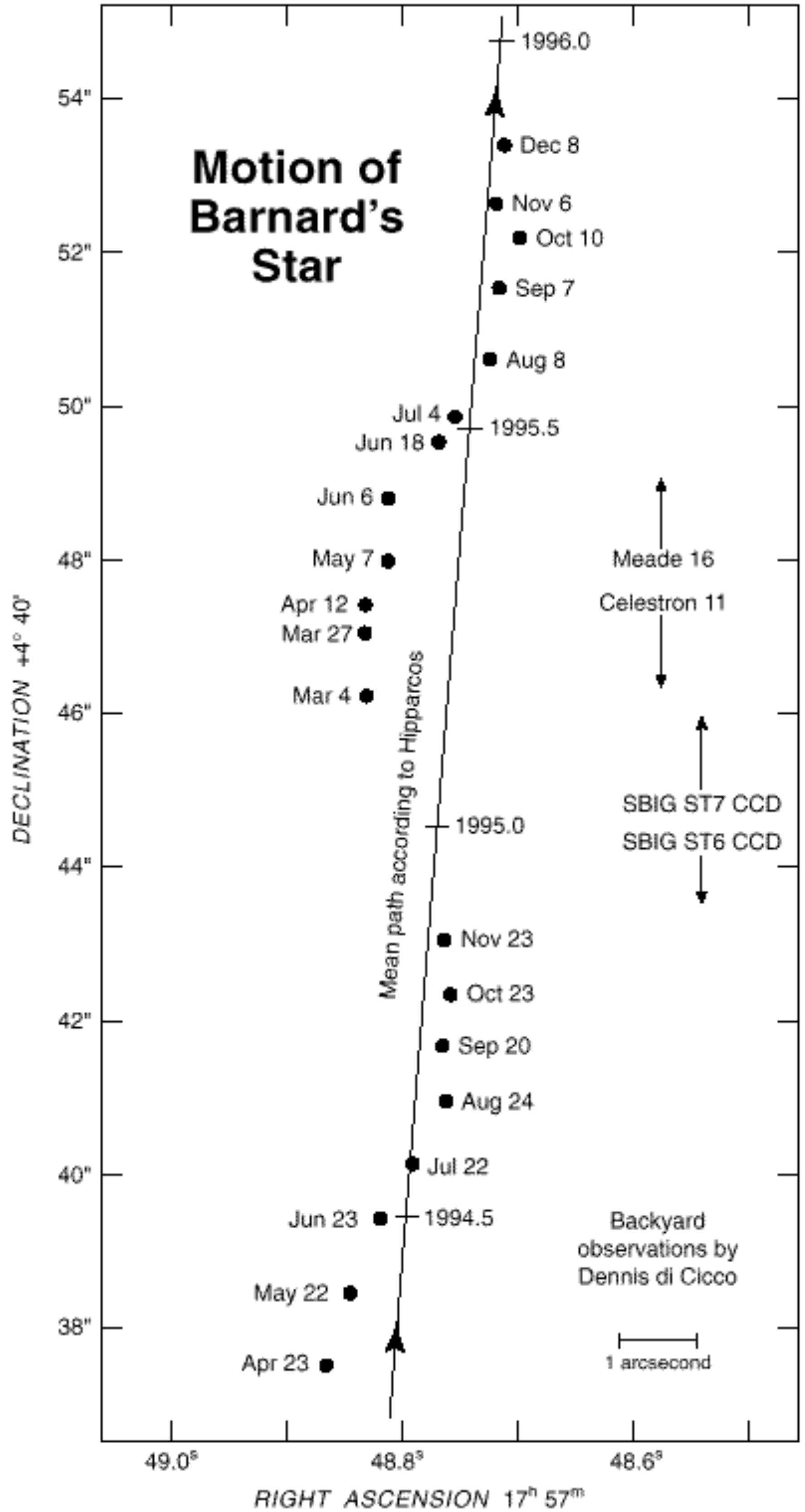
Example: Barnard's Star



http://www.perseus.gr/Astro-Star-Dwarf-Barnard-2010.htm

d = 1.8 pc
PM = 10.3''/yr → **V_{tan} = 90 km/s (~200,000 mph)**

Example: Barnard's Star



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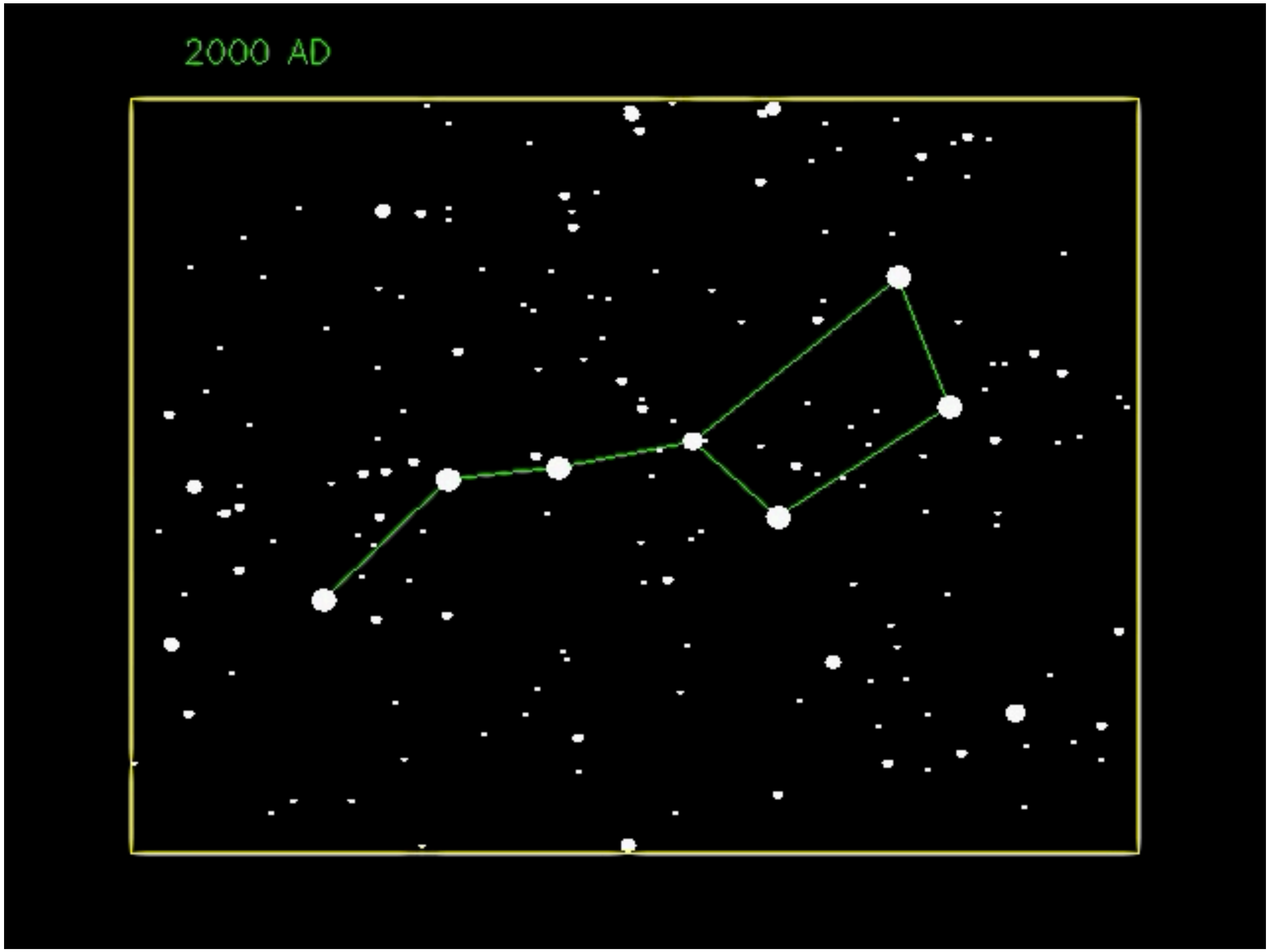
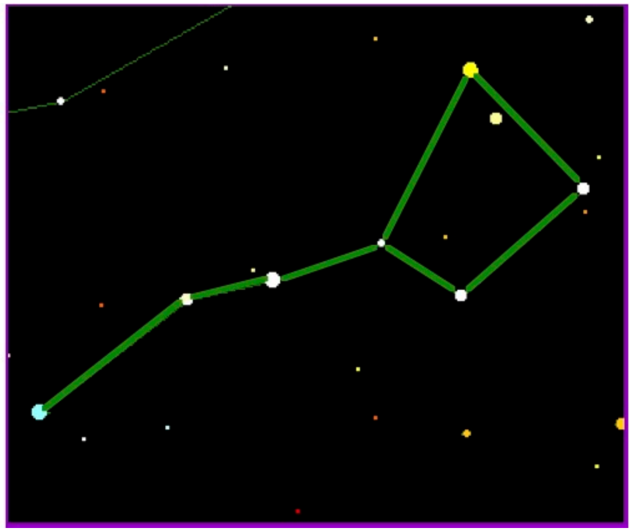
Proper Motions in the Big Dipper

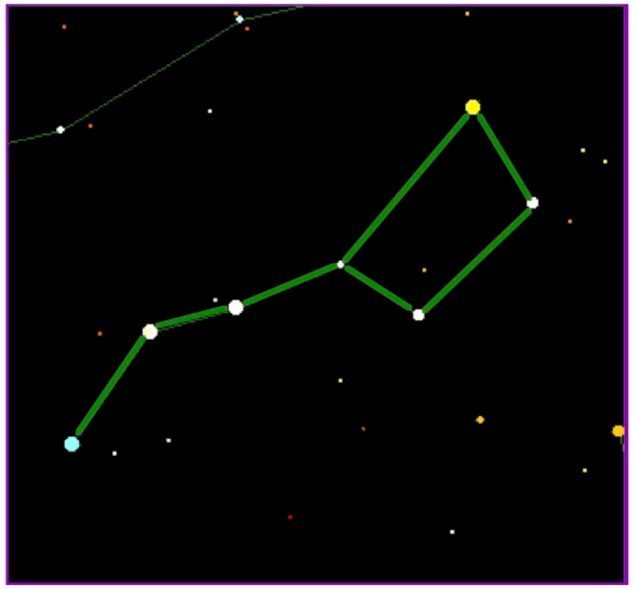


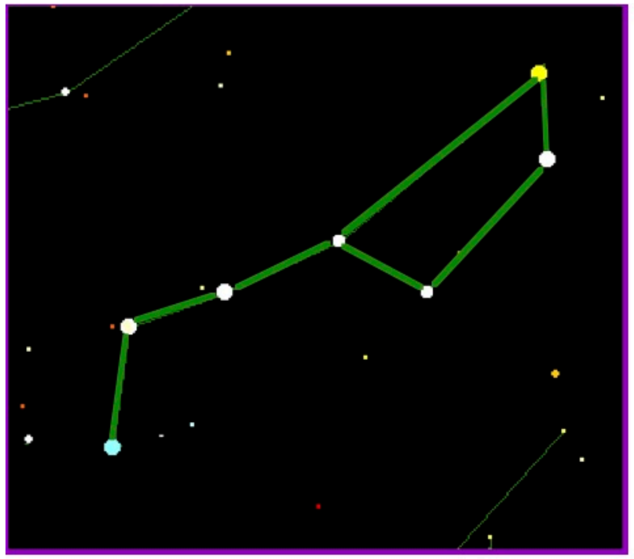
Proper Motions in the Big Dipper

70,000 years ago



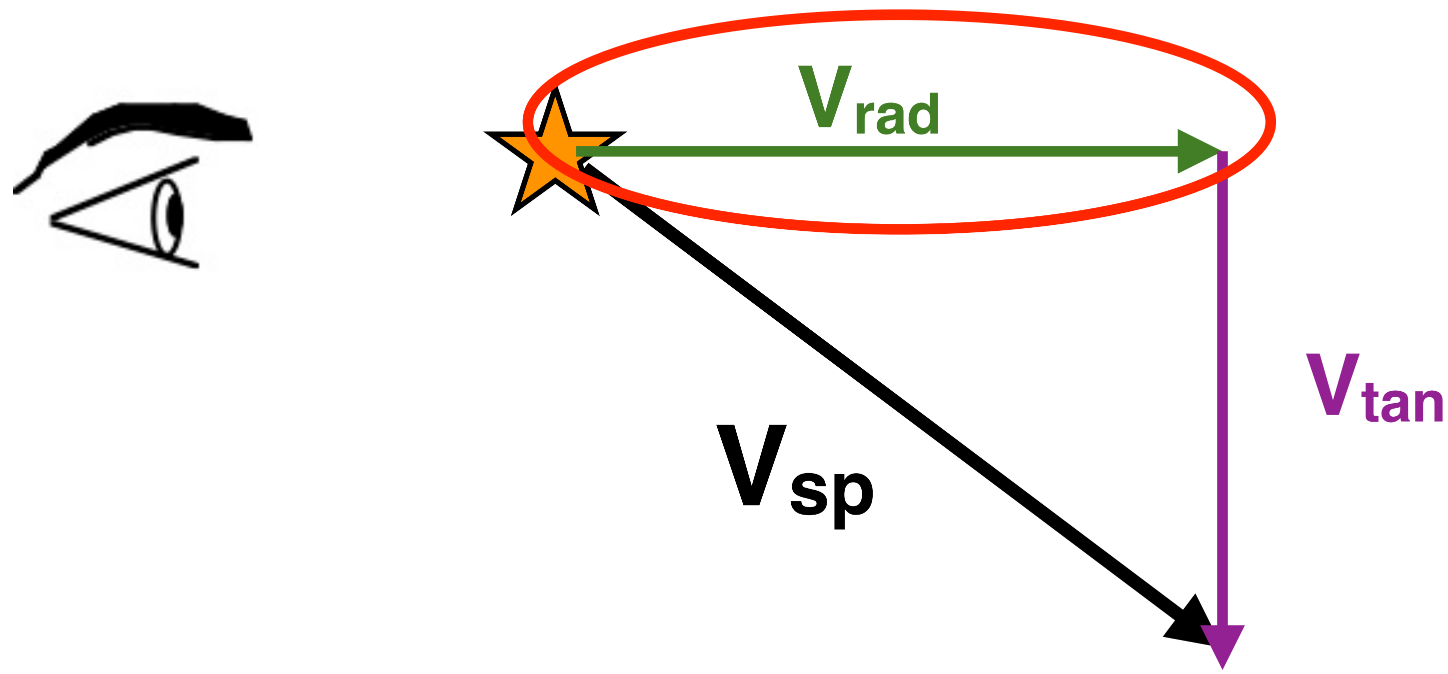
Today



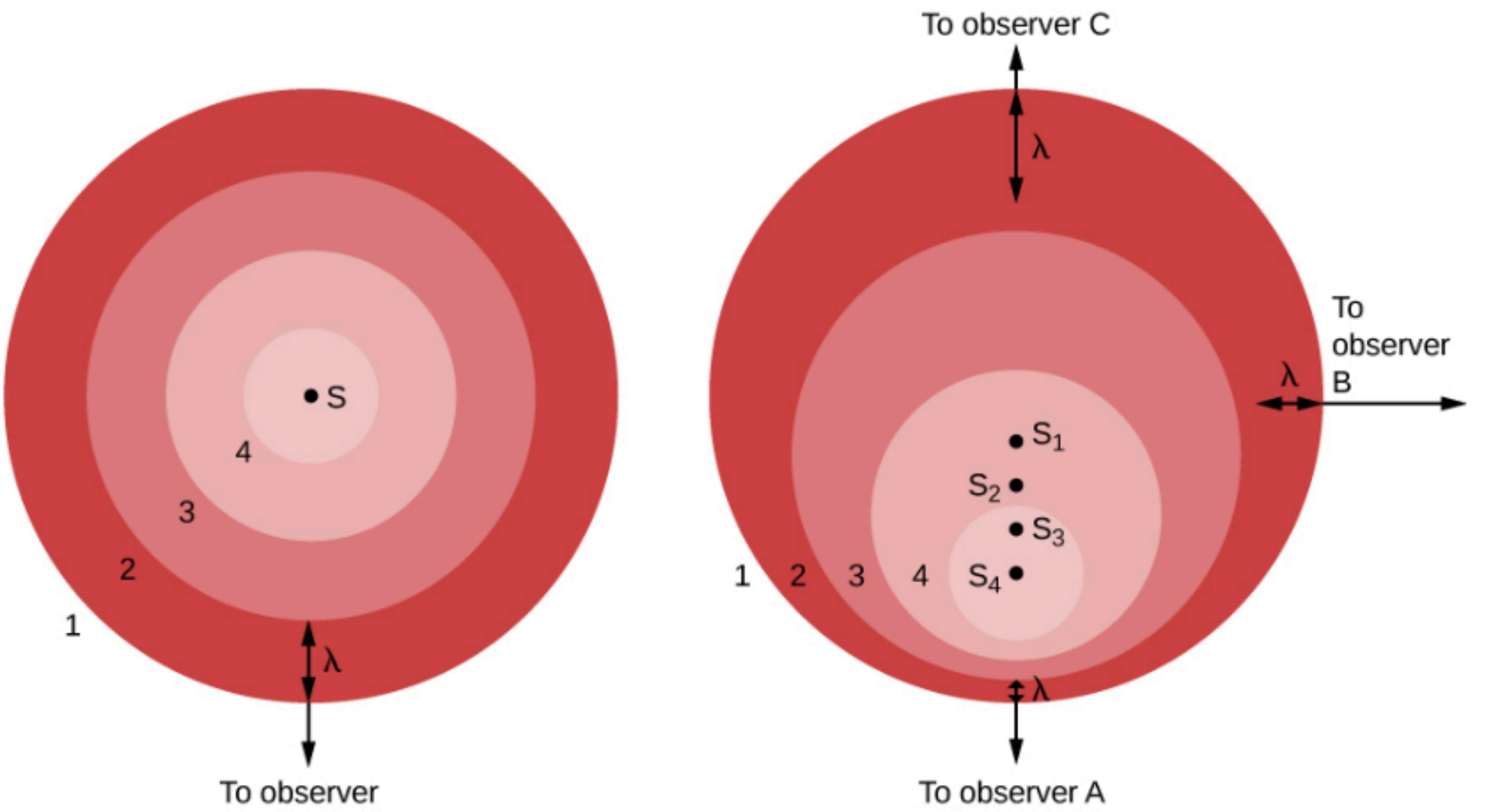


70,000 years from now

What about radial motion?



Doppler Effect



Doppler Effect (Virtual) Demo

https://astro.unl.edu/classaction/animations/light/dopplershift.html

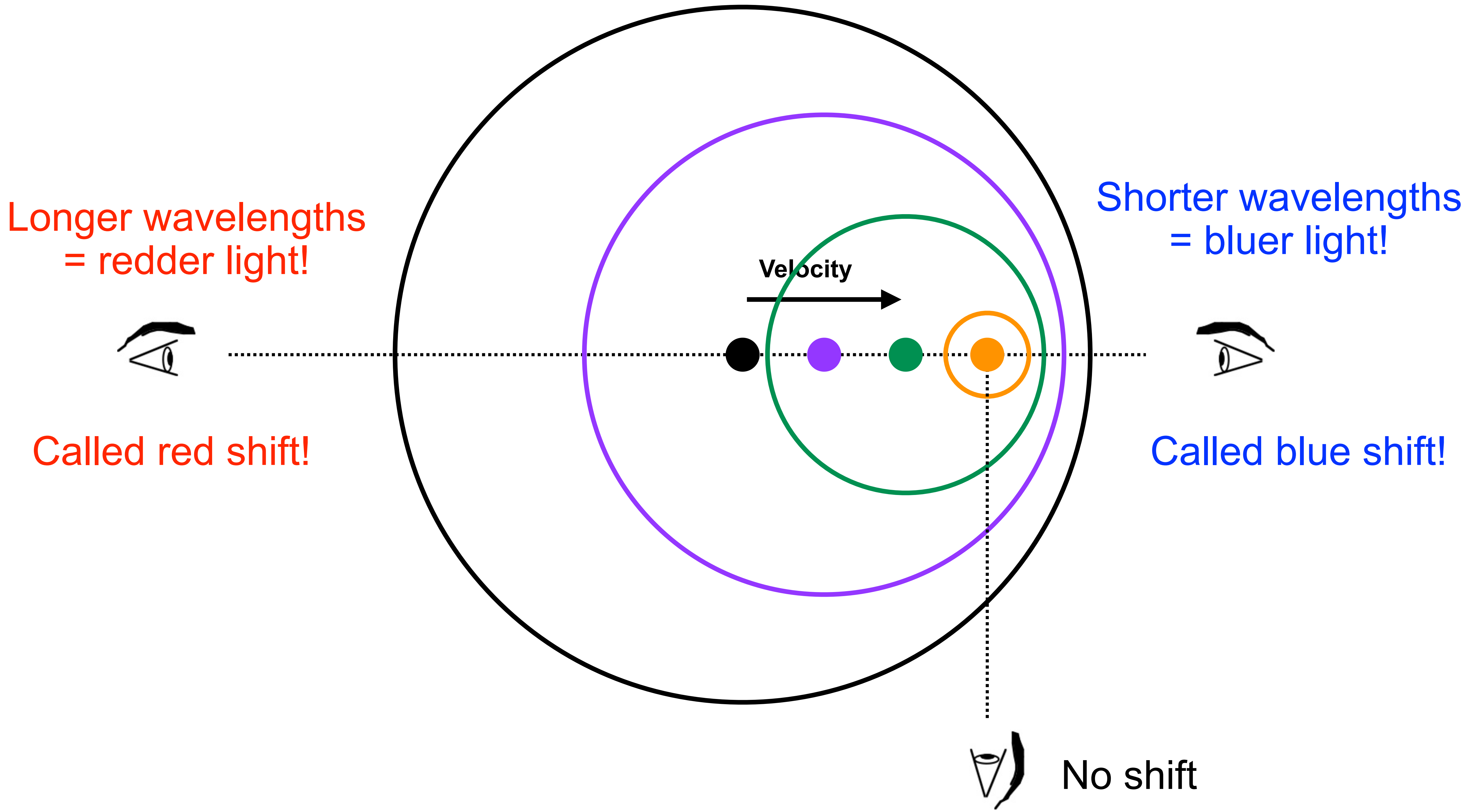
Warning: need to enable Flash (ugh!)

Doppler Effect in Real Life

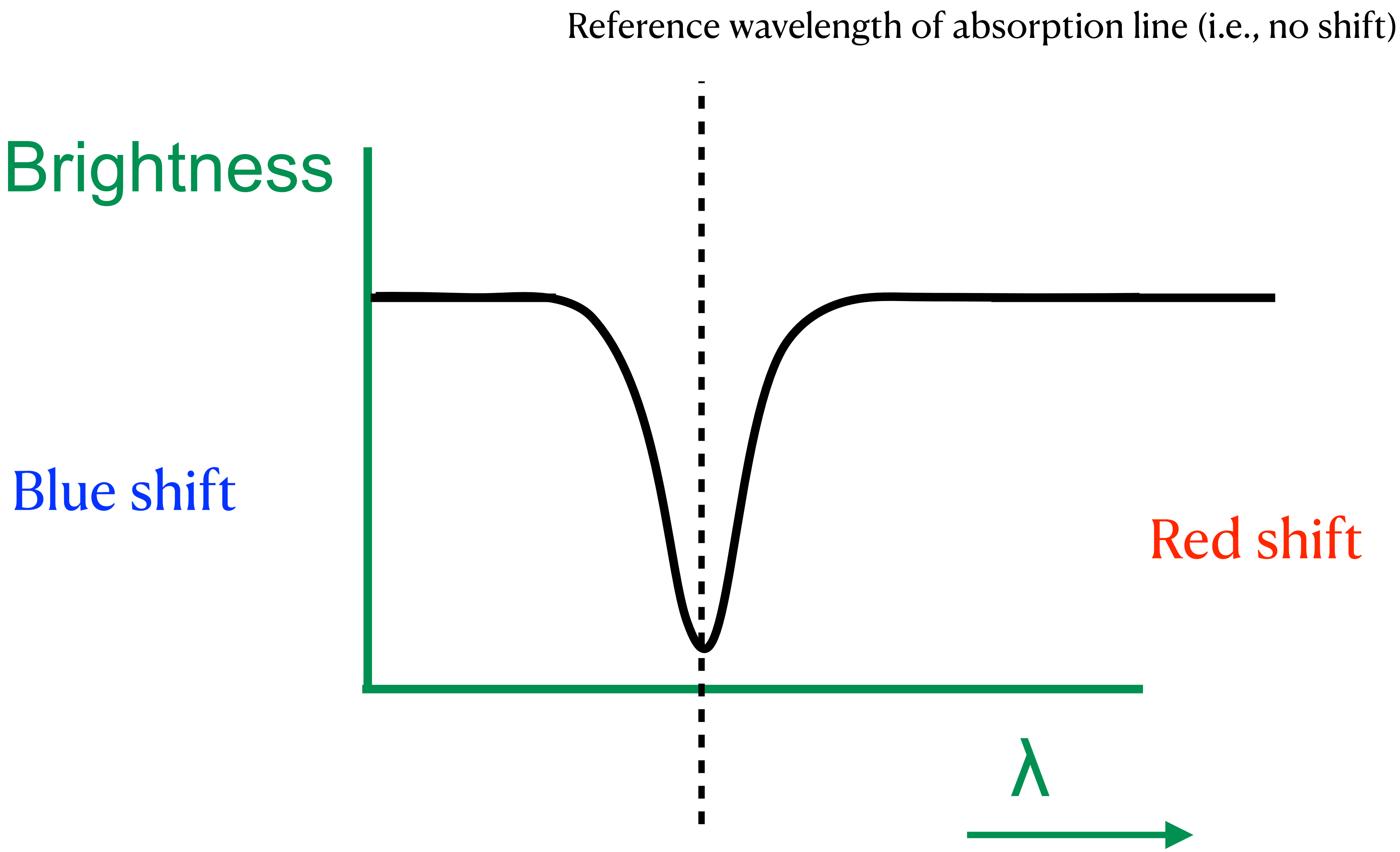
Sound waves from a passing car

https://www.youtube.com/watch?v=a3RfULw7aAY

The Doppler Effect is present with light waves too!



Emission/absorption lines shift too



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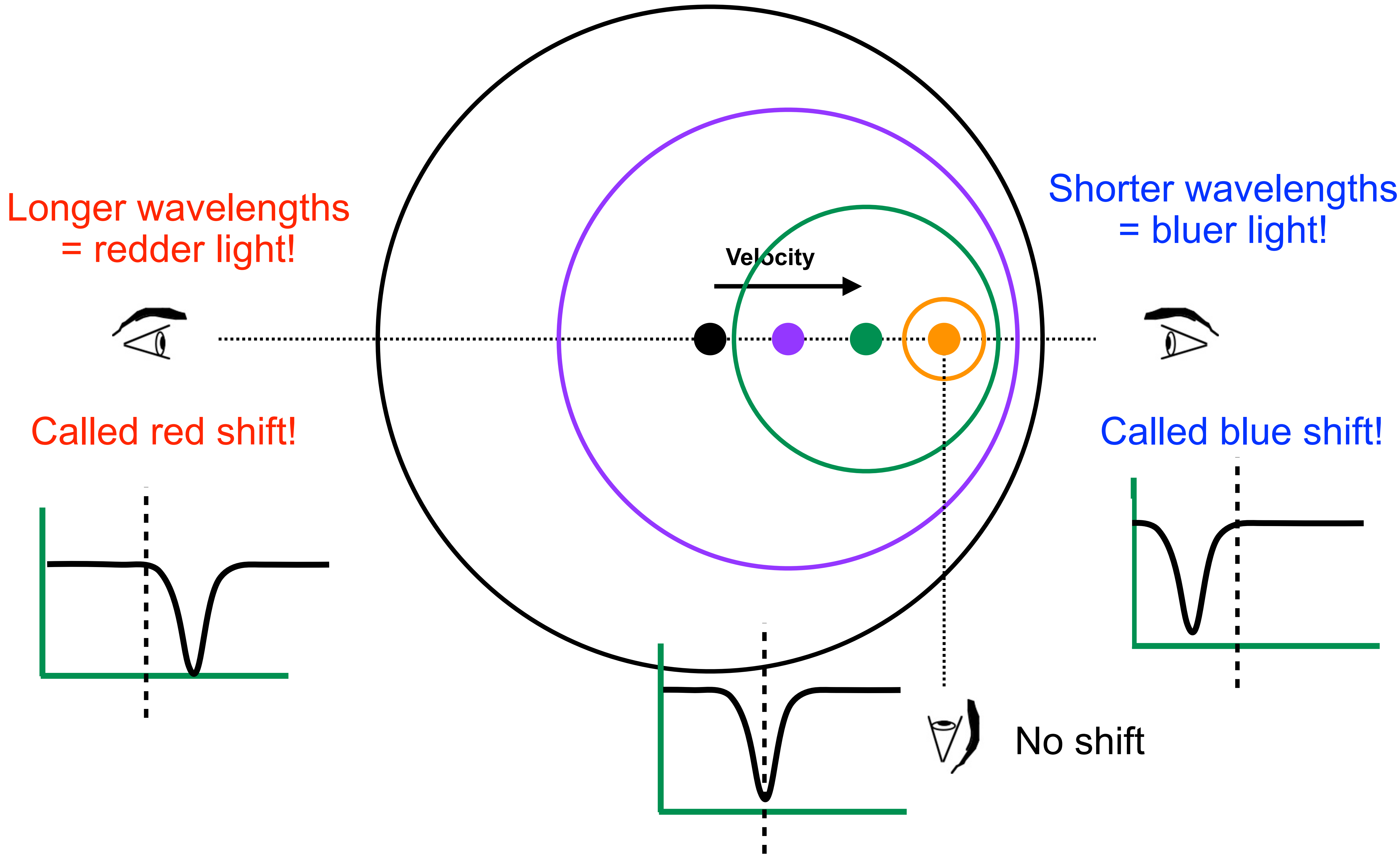
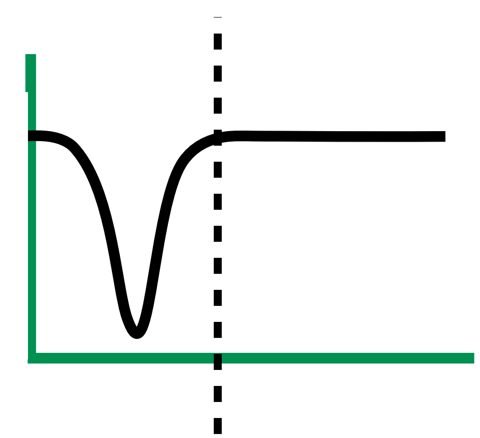


Can calculate radial velocity from the red/blue shift of lines

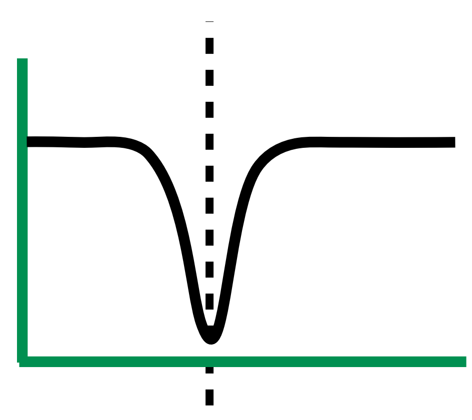
Wavelength of line observed in the star

$$v_r = c\,\frac{\lambda_{\text{rest}} - \lambda_{\text{observed}}}{\lambda_{\text{rest}}}$$



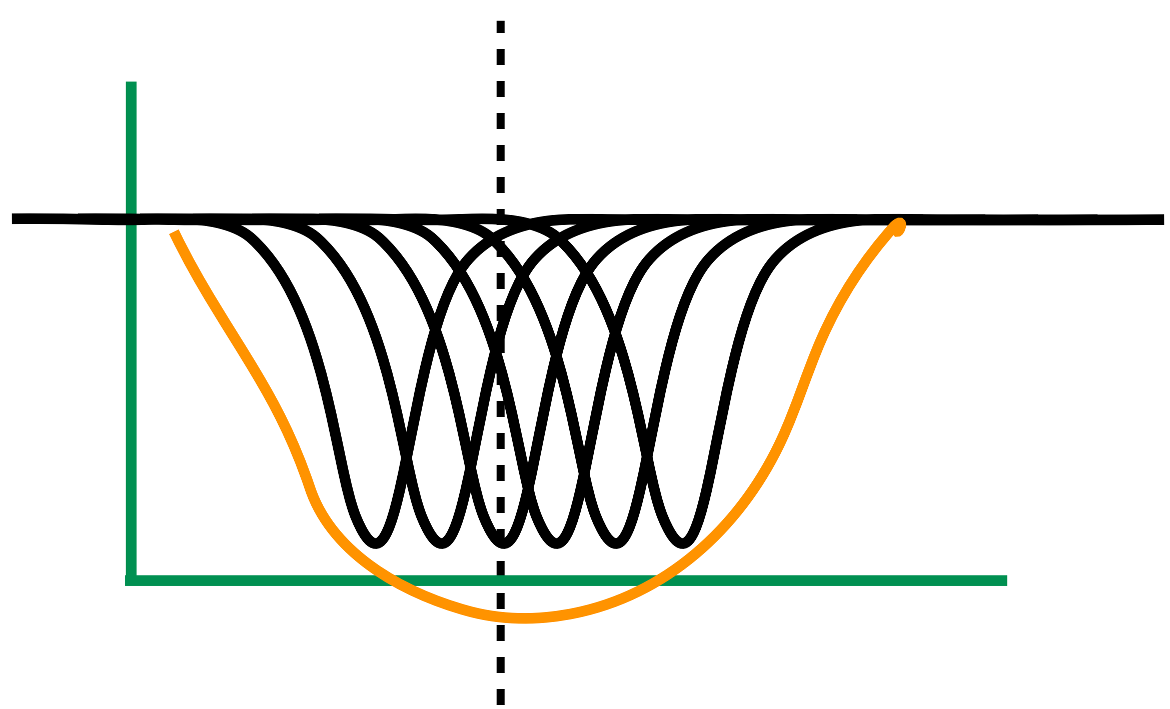
Radial velocity

Wavelength of line at rest
(i.e., observed in a lab)

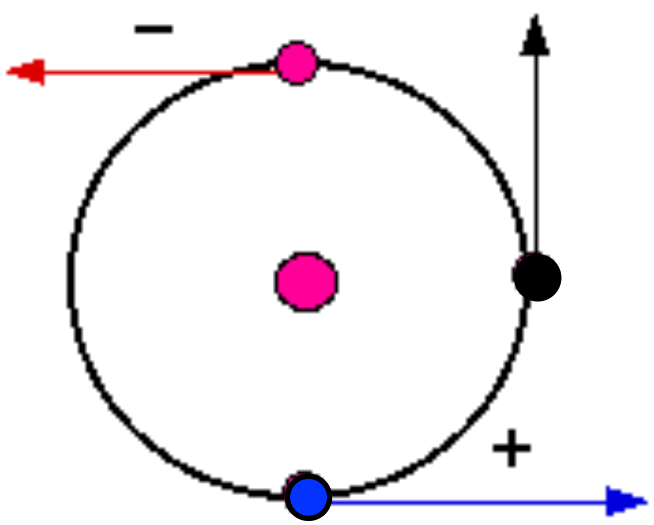


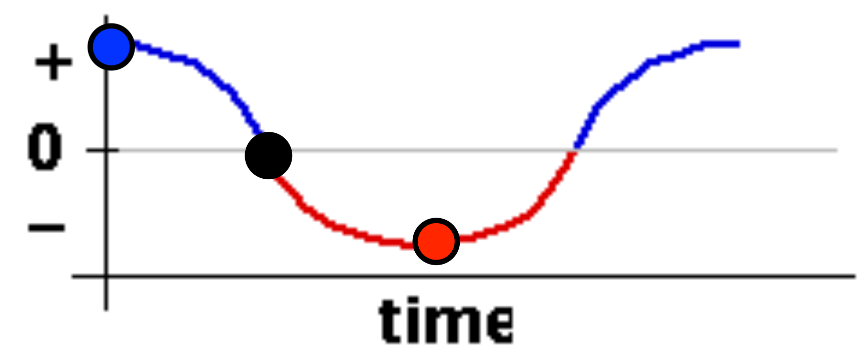
Other uses for the Doppler Effect: Stellar rotation

Broader lines!



Other uses for the Doppler Effect: Orbital motion





Summary of stellar positions and motions

- Use parallax to get distances to (closest) stars
- Can measure the proper motion (velocity “angle” on the sky)
- Can use both distance and angle velocity to calculate an actual velocity
- Can use the shift of spectral lines to determine radial velocity

Another advantage to knowing distance

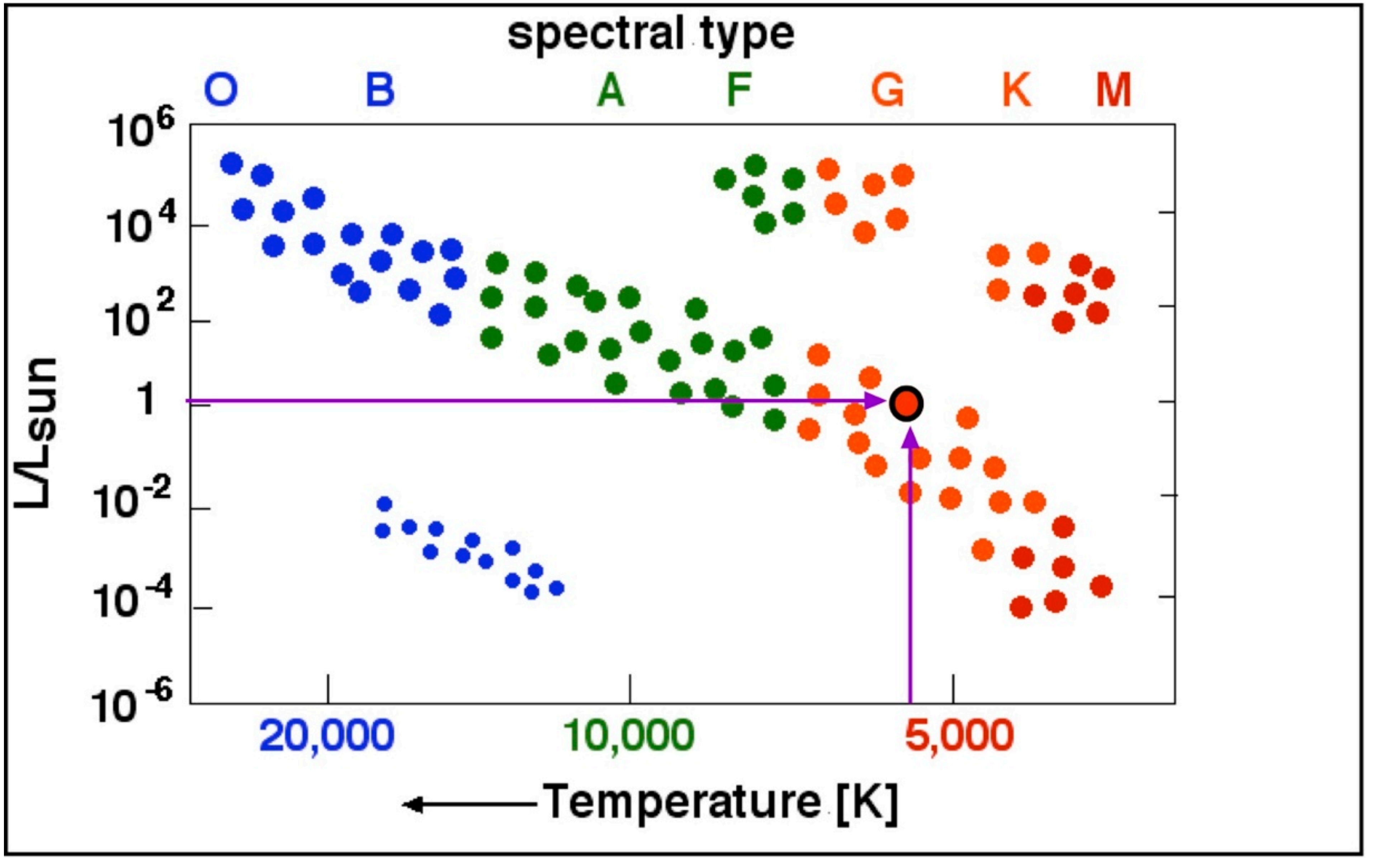
Can calculate the actual luminosity!

$$\text{Brightness} = \frac{\text{Luminosity}}{d^2} \quad \Rightarrow \quad \text{Luminosity} = \text{Brightness} \times d^2$$

Since we can figure out the distance (parallax), we can calculate luminosity

The spectral lines can also give us the *type* of star (OBAFGKM)

Putting all of this together: Hertzsprung-Russell Diagram



More on this next time!