SECTION II: Nature of Stars

- Astronomers measure properties of Stars

  Distance

  Mass

  Apparent Brightness

  Surface Temperature

  Radius

- Find that some are related

  Large Mass → Large Absolute Brightness

- We will end up with a model of stellar formation and life cycle from “birth” to “death” and their final states: white dwarf, neutron star, black hole

Distances to Stars

- Important as determines actual brightness but hard to measure as stars are so far away

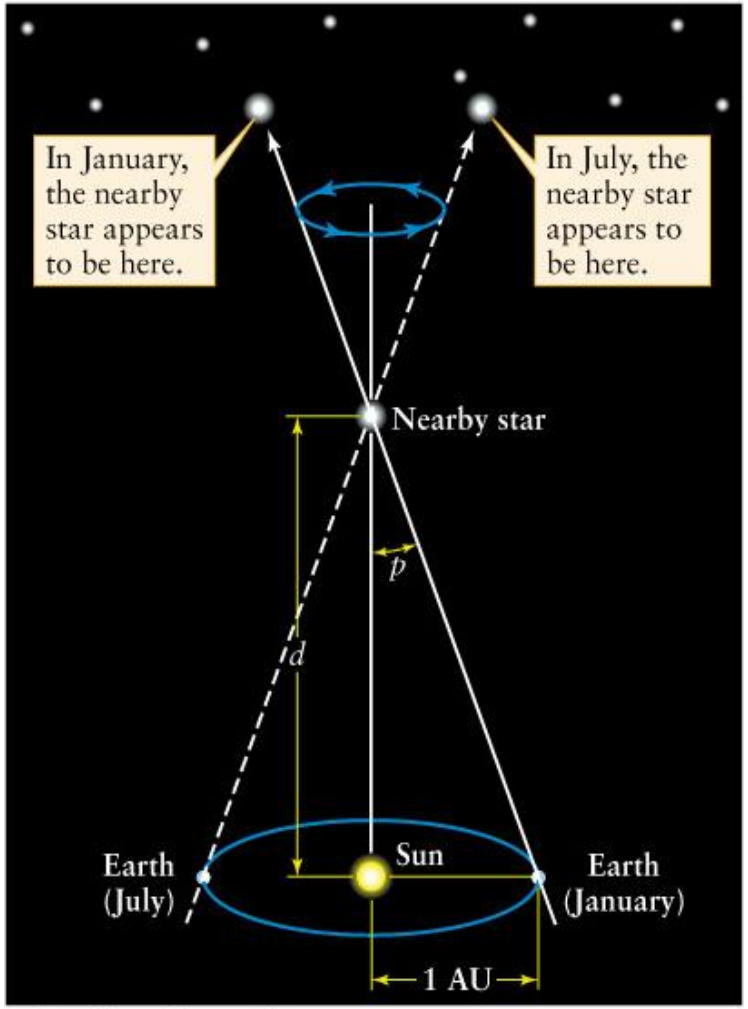
  Closest star system (3 stars) Alpha Centauri

  4.3 light years = 4×10^{13} km

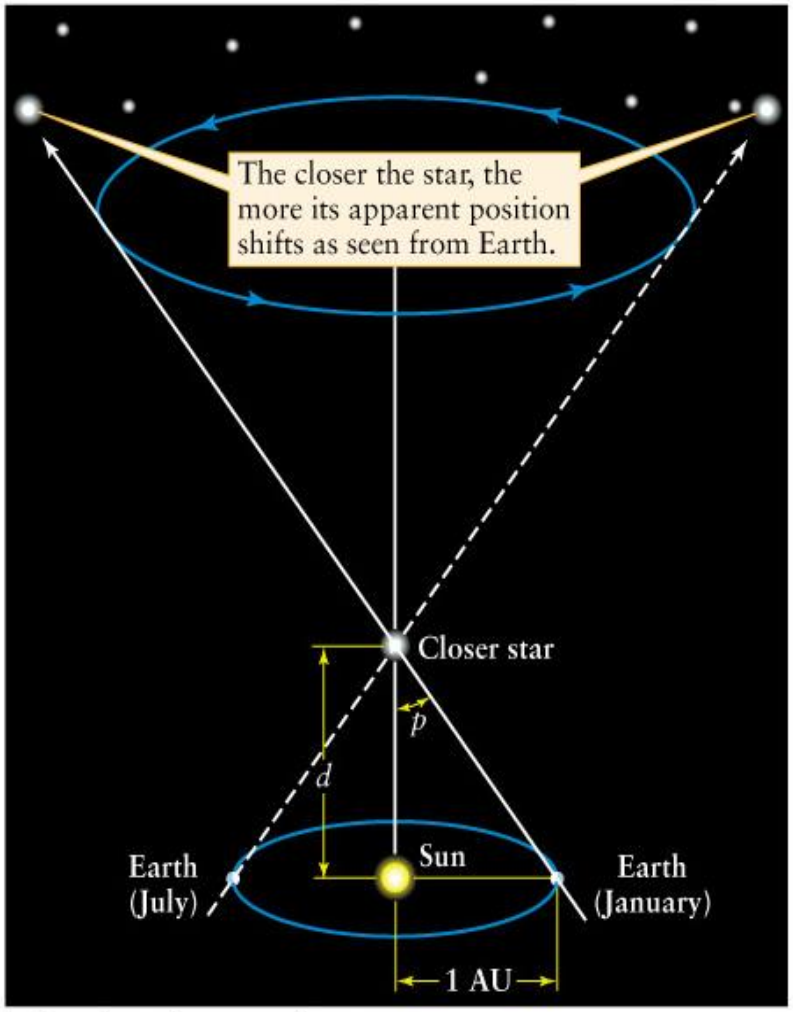
  (1 AU = distance Earth to Sun = 8 light minutes)

- Close stars use stellar parallax (heliocentric parallax or triangulation → same meaning)
- Can "easily" measure distance using parallax to about 500 LY. Need telescope: first observed in 1838. Study close stars in detail. Other techniques are used (later) for more distant stars

Distances to Stars - Parallax



a Parallax of a nearby star

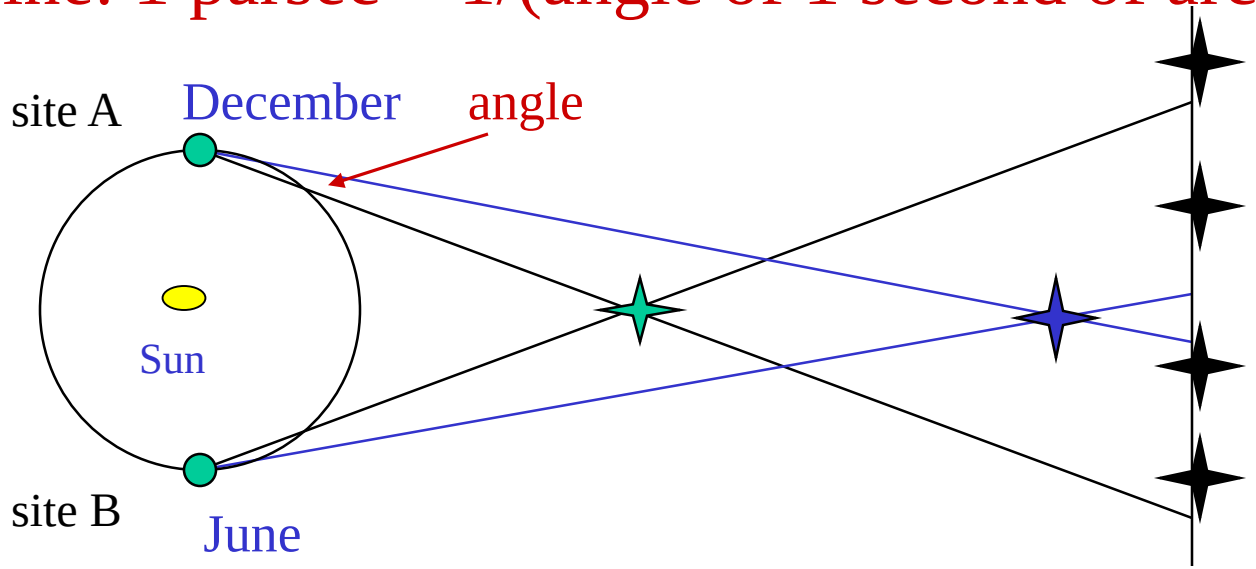


b Parallax of an even closer star

Compare position in sky of nearby star to those much further away

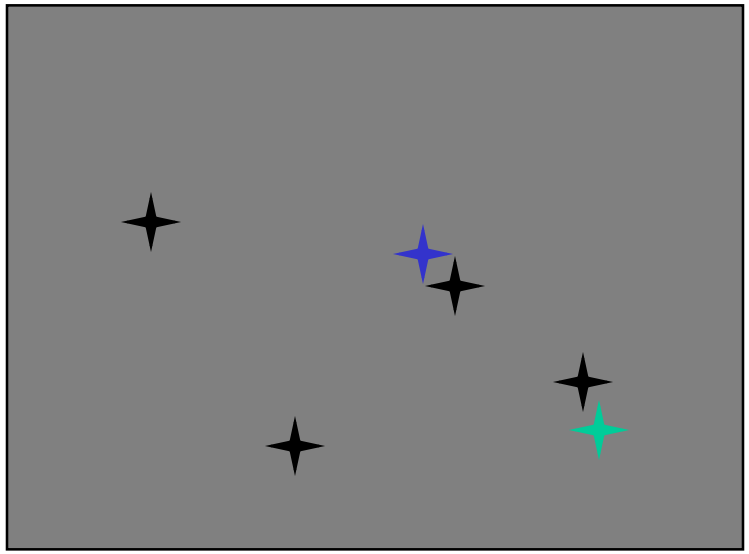
Shifting Star Positions

- The orbit of the earth is used as the base.
- Near stars appear to move more than far stars as Earth orbits Sun
- distance = (base length)/angle
- define: 1 parsec = 1/(angle of 1 second of arc) = 3.3 LY

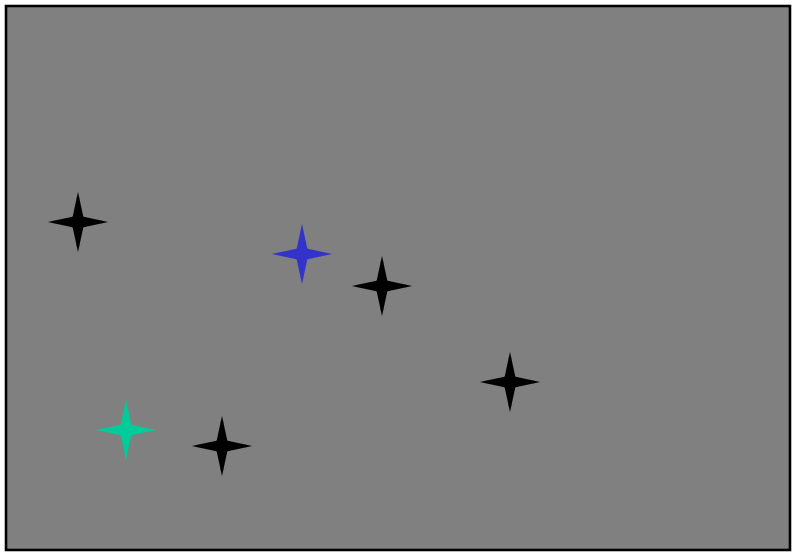


Stellar Parallax

- A photo of the stars will show the shift between January and June with green having bigger shift and so closer than blue and both green and blue closer than black stars. (in reality somewhat more complicated as stars also have a proper motion in a given direction and need to make measurements over many years to separate the two effects)

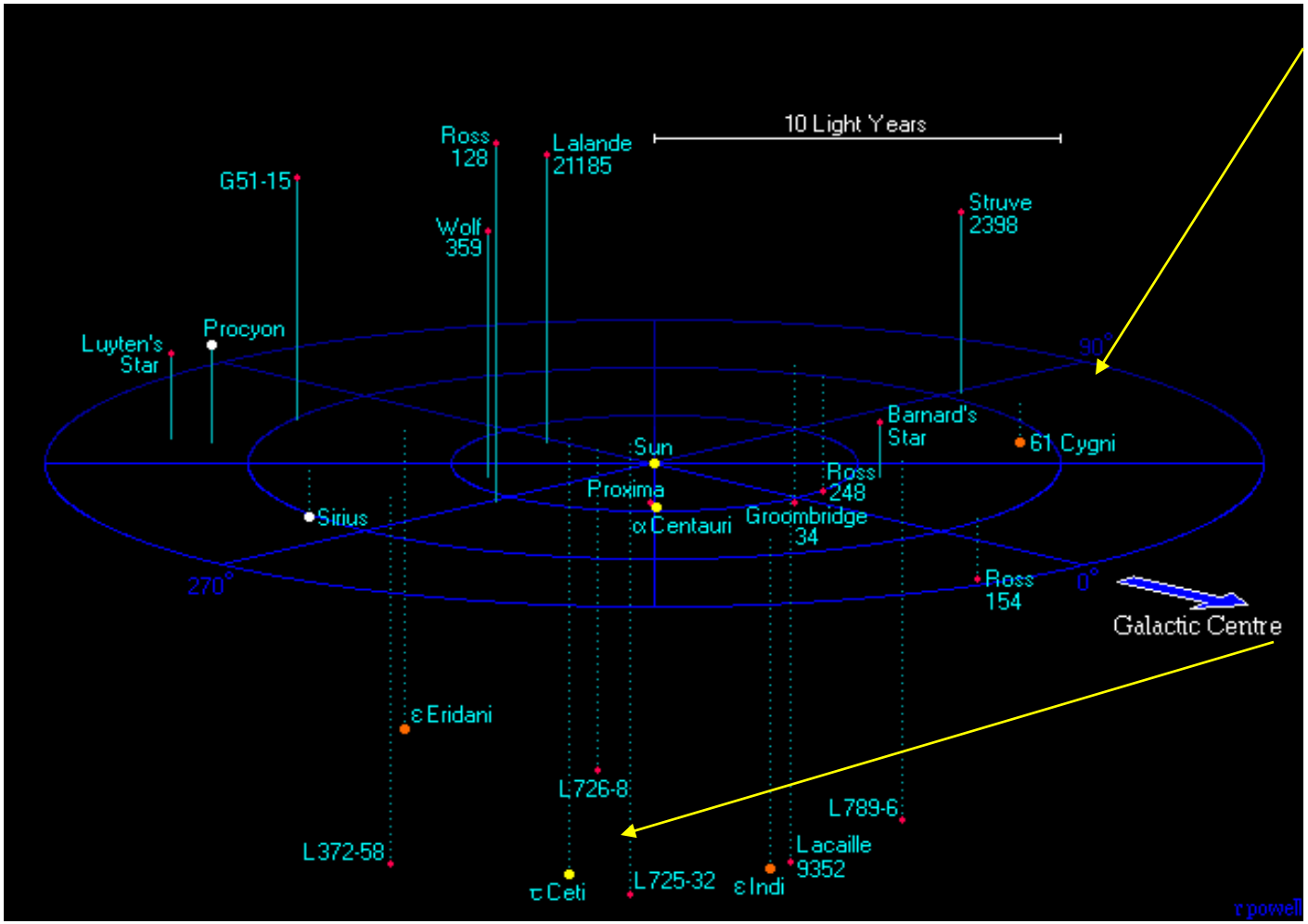


January



July

Nearest Stars



61 Cygni first observed parallax in 1838

Alpha Centauri
Sirius
Procyon
61 Cygni
Epsilon Indi
All binaries (2-3 stars)

Tau Ceti 12 LY closest single (not binary) "Sun-like" star

Epsilon Eridani single star- youngish

Color of stars indicates surface temp with white hottest, then yellow, orange, red. Most close by stars are small red stars.

Nearest Stars

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#	Name / Ident.	T.Par.	Dist.pc	Dist. ly
1	Proxima Centauri	0,770	1,30	4,24
2	Alpha Centauri A	0,750	1,33	4,35
3	Alpha Centauri B	0,750	1,33	4,35
4	Barnard's Star	0,546	1,83	5,98
5	Wolf 359	0,419	2,39	7,78
6	Lalande 21185	0,395	2,53	8,26
7	Sirius A	0,382	2,62	8,55
8	Sirius B	0,382	2,62	8,55
9	Luyten 726-8A	0,374	2,68	8,73
10	Luyten 726-8B (UV Ceti)	0,374	2,68	8,73
11	Ross 154	0,345	2,90	9,45

- The larger the angle (T.Par. = trigonometric parallax) the closer the star. pc=parsecs ly= light year with 3.3 factor between

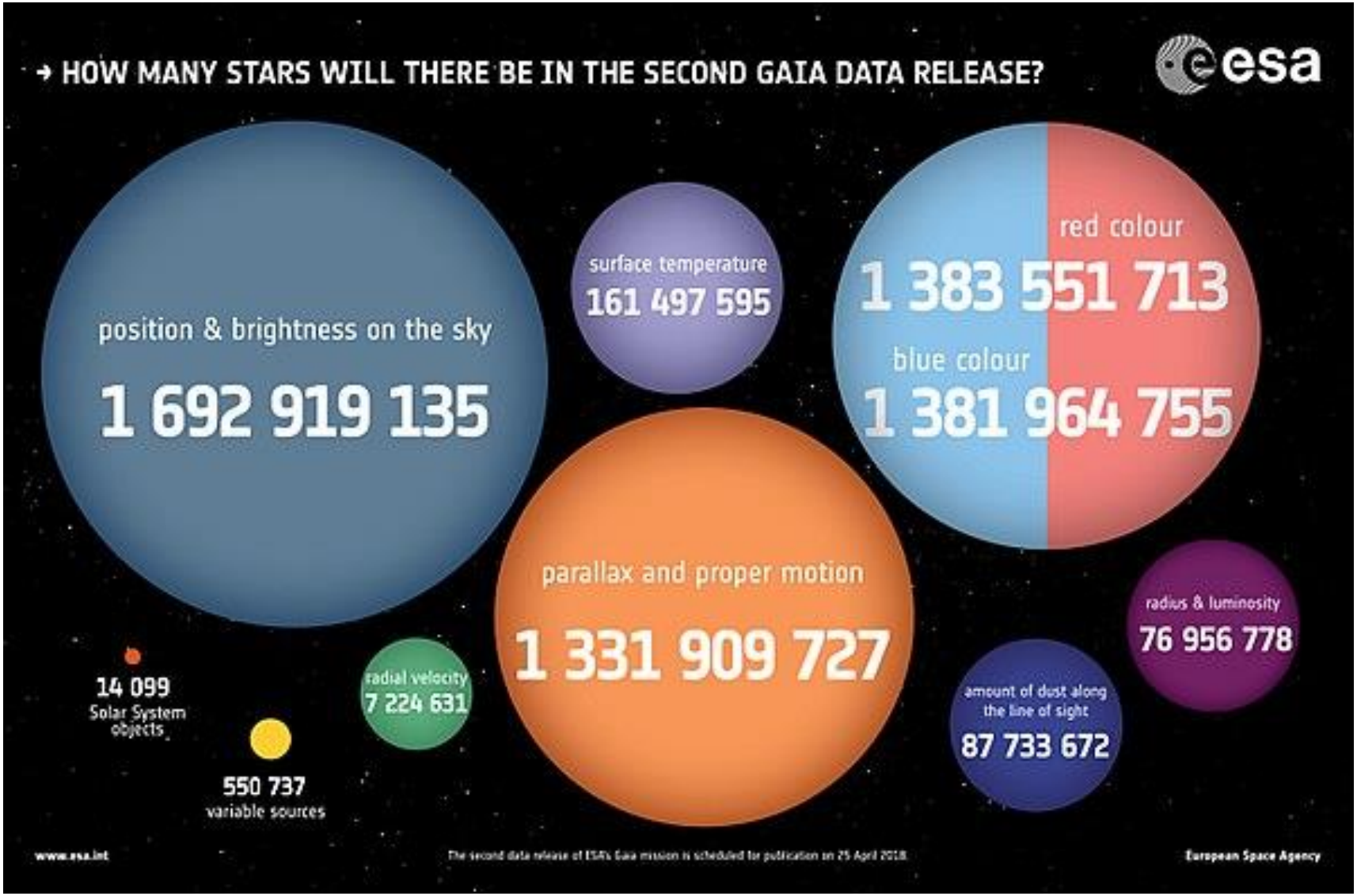
- many stars come in groups like the 2 stars A and B in the Sirius "binary cluster" → close together, within same "solar system" A is a little bit bigger then the Sun while B is a white dwarf

- Alpha Centauri A and B are a close binary systems. Proxima Centauri is a red dwarf which probably orbits Alpha Centauri every 500,000 years

Parallax Data – new digital camera on satellites vastly improve number of stars which are well-measured

- In 1900 only 60 stars had parallax measurements
- 1997-2000 a European satellite Hipparcos released parallax measurements for more than 2,300,000 stars up to 500 LY distance
- 118,000 stars measured with .001 arc-second resolution and 0.2% error on light intensity
- OLD(1990): 100 stars with distance known to 5%. “NEW” (2005): 7000 such stars. “NEWest” (2018) about 50,000,000 stars
- European Space Agency Gaia satellite: launched 2013 0.00001 arc-second. Goal: measure >1 billion objects ~70 times each over 5 years. Measure star distances to 30,000 LY, with over 20 million with 1% accuracy. Also measure exoplanets, asteroids, galaxies, etc. April 2018 releases position and brightness data on 1.7 billion stars (of which parallax on 1.3 billion), 500,000 quasars (active blackholes), and 14,000 asteroids

April 2018 Gaia Data Release (European Space Agency)



Luminosity of Stars

- Luminosity=Absolute Brightness=how much light/energy a star produces
- Scale relative to Sun. So

  $L_{sirius} = 23L_S$ means Sirius A radiates 23 times more energy than the Sun

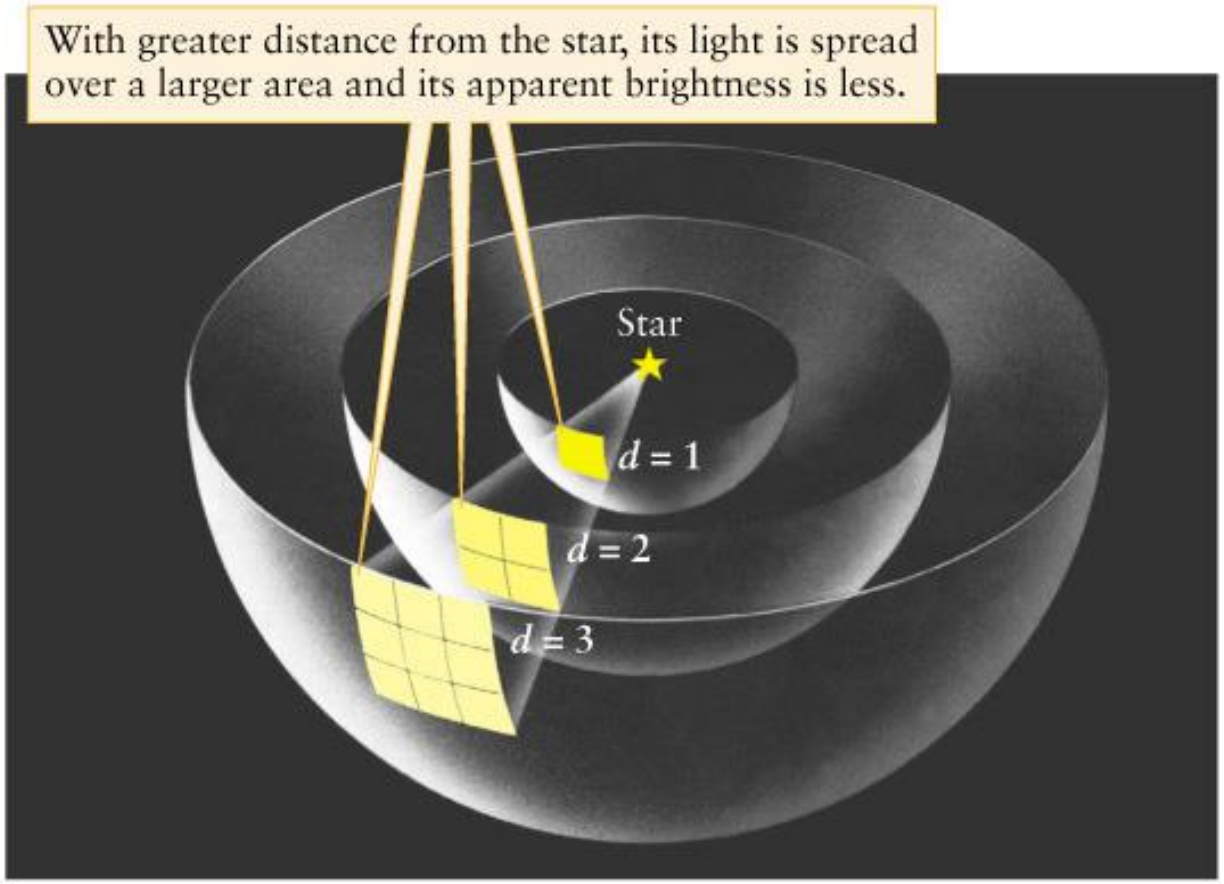
- Stars range from $.0001xL_S$ to $1{,}000{,}000xL_S$

Another scale: "magnitude" often used. A log scale to the power of ~2.5. **YOU DON'T NEED TO KNOW**. The lower the Mag the brighter the object.

Absolute vs Apparent Brightness

Absolute Brightness/Luminosity means total energy output

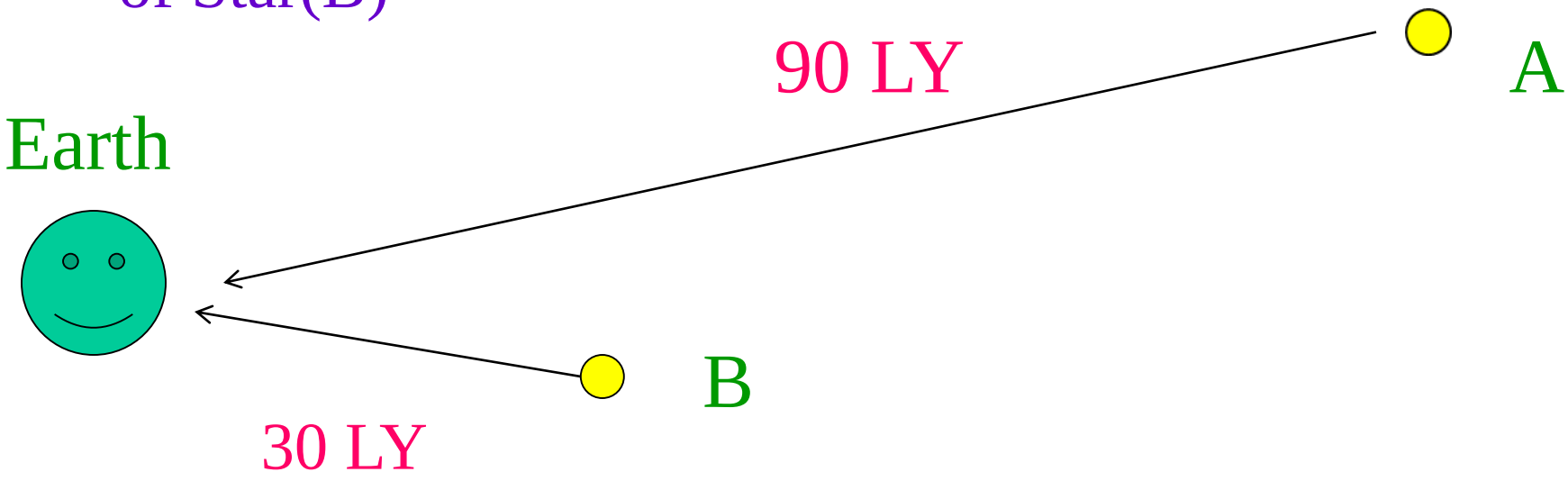
Apparent Brightness is what is seen by eye or in a telescope and so depends on distance (1/Distance^2)



Absolute vs Apparent Brightness

Example: 2 stars with the same absolute brightness

Star(A) is 3 times further away from us then Star(B) therefore the apparent brightness of Star(A) is 1/9 that of Star(B)



Magnitude Scale

- **YOU DON'T NEED TO KNOW**
- Historically, first magnitude stars are the brightest as seen by the eye and sixth magnitude stars are just barely visible to the eye. The lower the magnitude the brighter the star
- About a factor of 2.5, so a second magnitude star is about 2.5 times brighter than a third magnitude star
- Need to convert magnitude (which is really apparent magnitude) to absolute magnitude and astronomers do by asking what magnitude each star would have if it was at a distance of 10 parsecs. This is compared to the Sun's absolute magnitude to give the absolute luminosity relative to the Sun.
- Astronomers like to use and it is the scale given in Stellarium.

Absolute vs Apparent Brightness

A star's apparent brightness is a combination of its absolute brightness and its distance from us

Some stars have a very large apparent brightness as they are close to us – Table on next slide

Some stars have a very large apparent brightness as they have a very large absolute brightness – Table on next slide

Order of apparent brightest stars

magnitude scale

Apparent absolute

Luminosity

THE BRIGHTEST STARS

Stars close to us

apparent brightness = what we see

No.	Name	Star	Mag.	Abs. Mag.	Lumin. Sun = 1	Spec Type	Distance Lt Yr
0.	Sun		-26.8	+4.8	1.0	G0	(1AU)
1.	Sirius	α CMa	-1.46	+1.4	23	A0	8.6 ly
2.	Canopus	α Car	-0.72	-3.1	1400	F0	120 ly
3.	Rigel Kent	α1 + α2 Cen	-0.27	+4.5	1.3	G0	4.3 ly
4.	Arcturus	α Boo	-0.04	-0.3	91	K0	36 ly
5.	Vega	α Lyr	+0.03	+0.5	52	A0	26 ly
6.	Capella	α Aur	+0.08	+0.1	76	G0	32 ly
7.	Rigel	β Ori	+0.12	-6.4	30200	B8	680 ly
8.	Procyon	α CMi	+0.38	+2.7	6.9	F5	11.4 ly
9.	Achernar	α Eri	+0.46	-2.6	910	B5	140 ly
10.	Betelgeuse	α Ori	+0.57 var	-5.1	9400	M0	427 ly
11.	Hadar	β Cen	+0.61	-3.1	1450	B1	180 ly
12.	Acrux	α1 + α2 Cru	+0.75	-4.2	3960	B1	321 ly
13.	Altair	α Aql	+0.93	+2.2	10.9	A5	16.8 ly
14.	Aldebaran	α Tau	+0.99	-0.63	149	K5	65 ly
15.	Spica	α Vir	+1.06	-3.55	2180	B2	262 ly
16.	Antares	α Sco	+1.06	-5.28	10700	M0	600 ly
17.	Pollux	β Gem	+1.22	+1.09	30.5	K0	33.7 ly
18.	Fomalhaut	α PsA	+1.23	+1.74	16.7	A3	25.1 ly
19.	Mimosa	β Cru	+1.31	-3.92	3070	B1	353 ly
20.	Deneb	α Cyg	+1.33	-8.7	250000	A2	3200 ly

Stars far away but very large Absolute brightness. Rigel is 30,000 times the Sun's

Sun is brightest (0), Sirius is next (1)

Brightness: Sirius vs Rigel

- Sirius is 23 times as bright as our Sun
  Rigel is 30,000 times as bright as our Sun
- Sirius is 8.6 light years from us
  Rigel is 680 light years from us
- Which star looks brighter in the sky? Which has the larger apparent luminosity? Need to use distance squared → Sirius is about 4 times brighter than Rigel when we look at it in the sky

$$Sirius: \quad \frac{23}{8.6^2} = \frac{23}{74} = 0.3$$

$$Rigel: \quad \frac{30000}{680^2} = \frac{30000}{460000} = 0.07$$

Arbitrary unit for ratios

Measuring Apparent Brightness

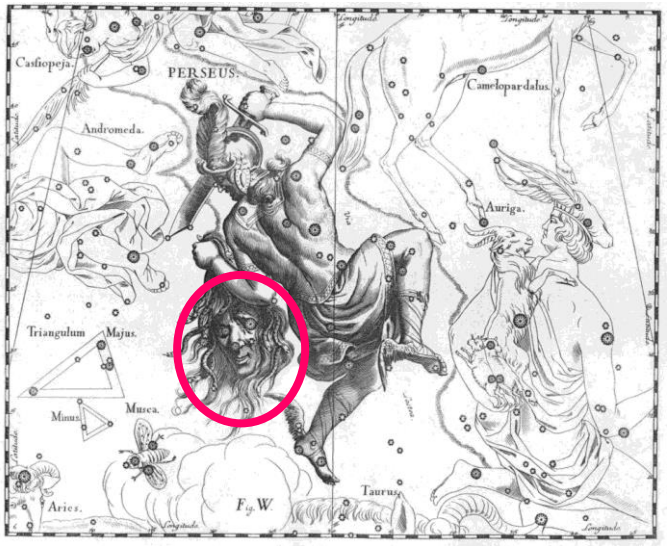
- With today's digital cameras, with millions of pixels, and the ability to store the data for later computer analysis it is very important to see if the brightness of a star varies with time. Very hard with photographic film, "easy" today
- Need to calibrate to get very good accuracy.
- Stars whose brightness varies in time are called "variable stars" and can be due to many reasons including
  - binary star system where the stars eclipse each other
  - exoplanet eclipsing its parent star
  - Cepheid variables which are stars in the giant phase (will be used to measure distances)
  - novas
  - supernovas
  - neutron-neutron star collisions gives kilonovas

Binary Star Systems

- Many stars come in groups of 2 or 3 that are close (few AU) to each other: BINARY Star Systems
- Gravitationally bound and probably formed at the same time
- SiriusA is 23 times as bright as our Sun
  SiriusB is 0.005 times as bright as the Sun
  Their separation varies from 8 to 31 AU. Can see both stars using telescope

Binary Star Systems

See link on web page to Algol, the star system that forms one eye of Medusa in the constellation Perseus. Due to the two stars eclipsing each other, the brightness varies and can be seen by unaided eye. Called “demon” or “ghoul” star and its period was probably measured by the Egyptians and used to determine Lucky and Unlucky days



Flipped images

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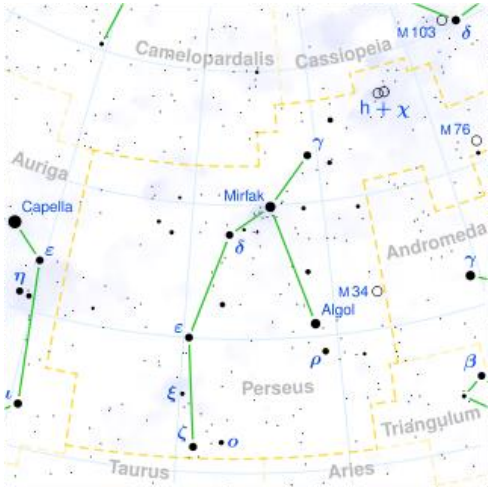
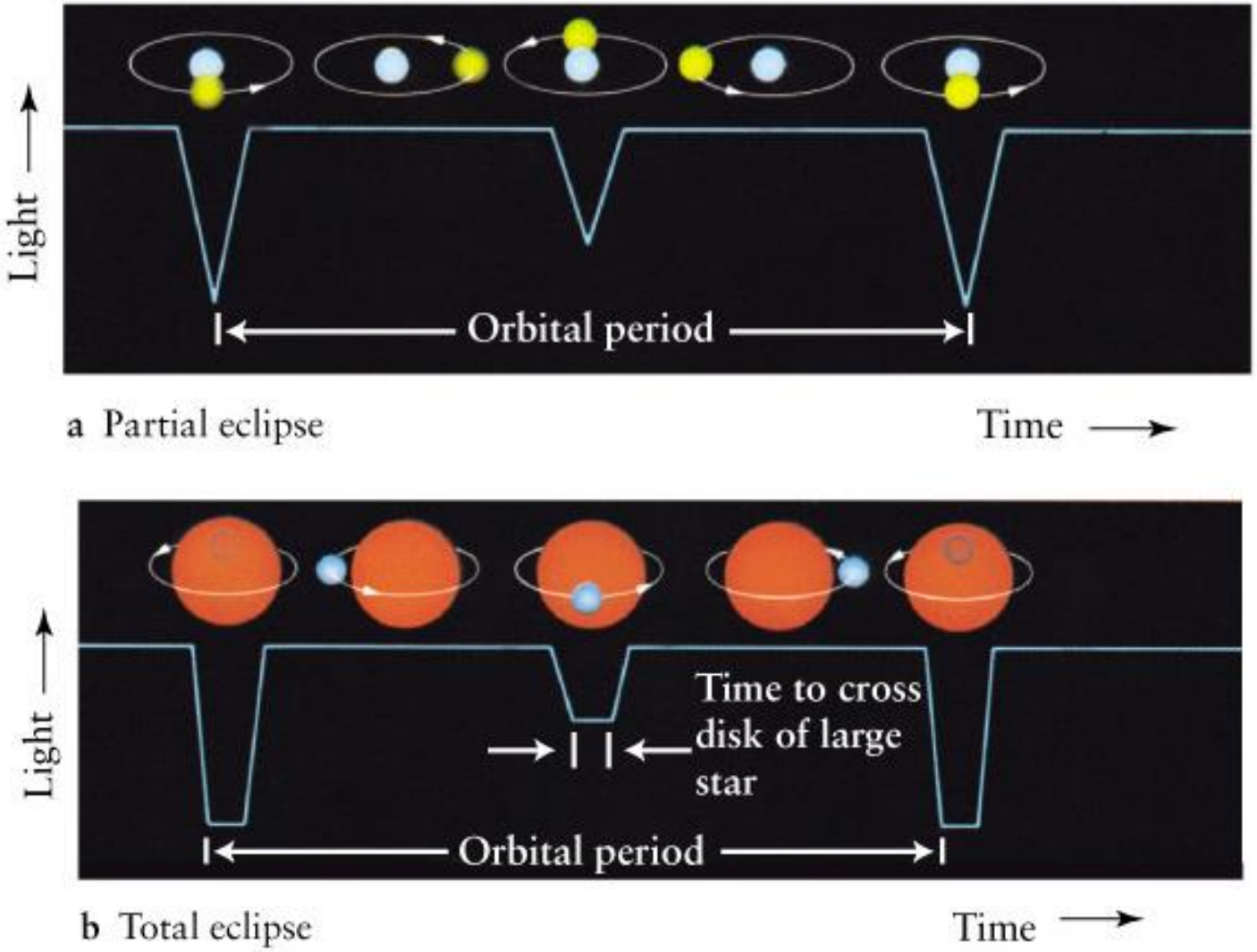


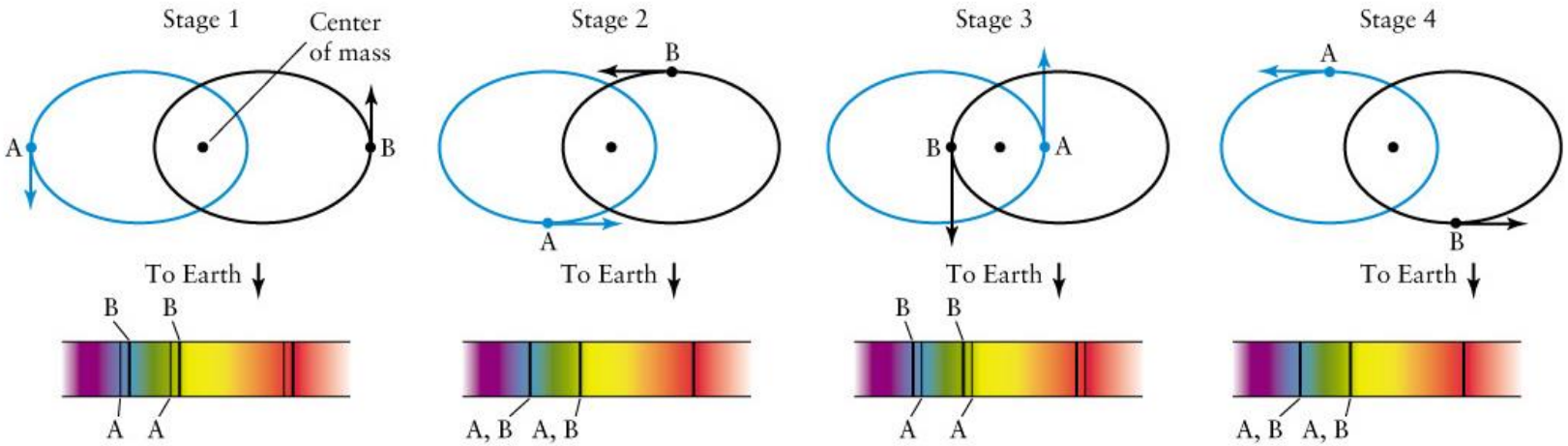
Binary Stars → Stellar Masses

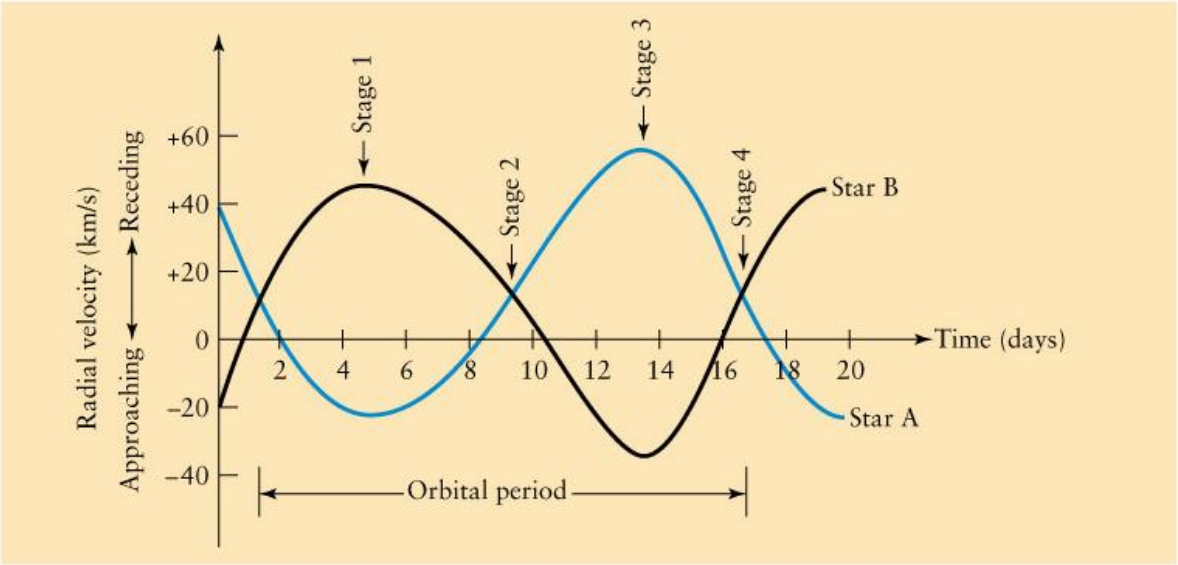
- visually observe both stars → Visual Binary. If only separate into 2 stars by looking at the spectrum → Spectroscopic Binary (eclipse each other plus have different Doppler shifts)
- Measure orbital information → period and separation distance. Get Mass though Kepler/Newtonian-like methods. See link on web page to "Center of mass examples"

Binary Star Orbits – In eclipses sum of light from 2 stars decreases as one passes in front of the other. Also used to measure relative sizes of stars

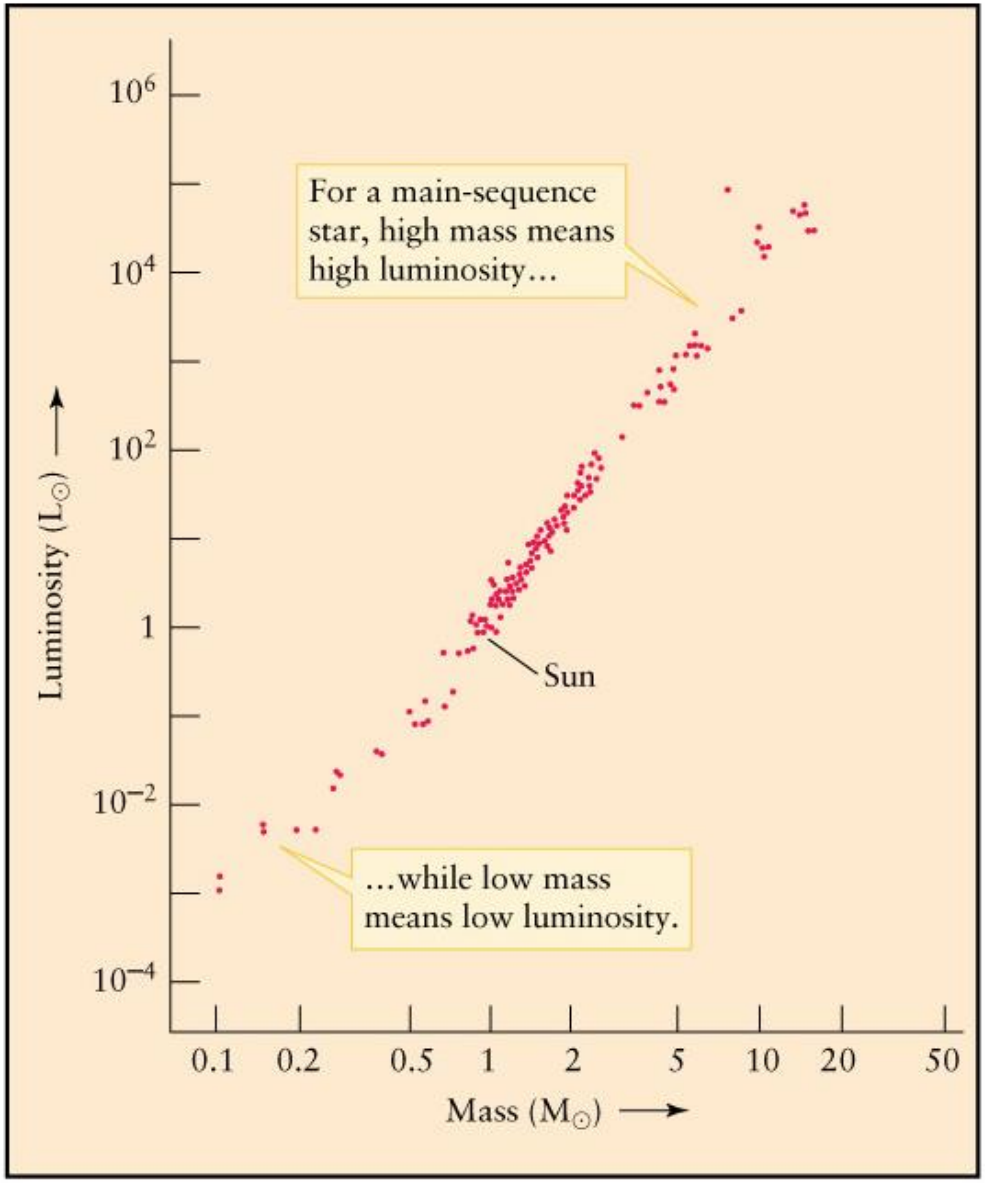


Binary Star Orbits – Doppler Shifts – can observe red/blue shifts as stars move to/from us





Mass vs Luminosity



always on these plots it is the Absolute Luminosity of the star relative to our Sun

High mass → High brightness

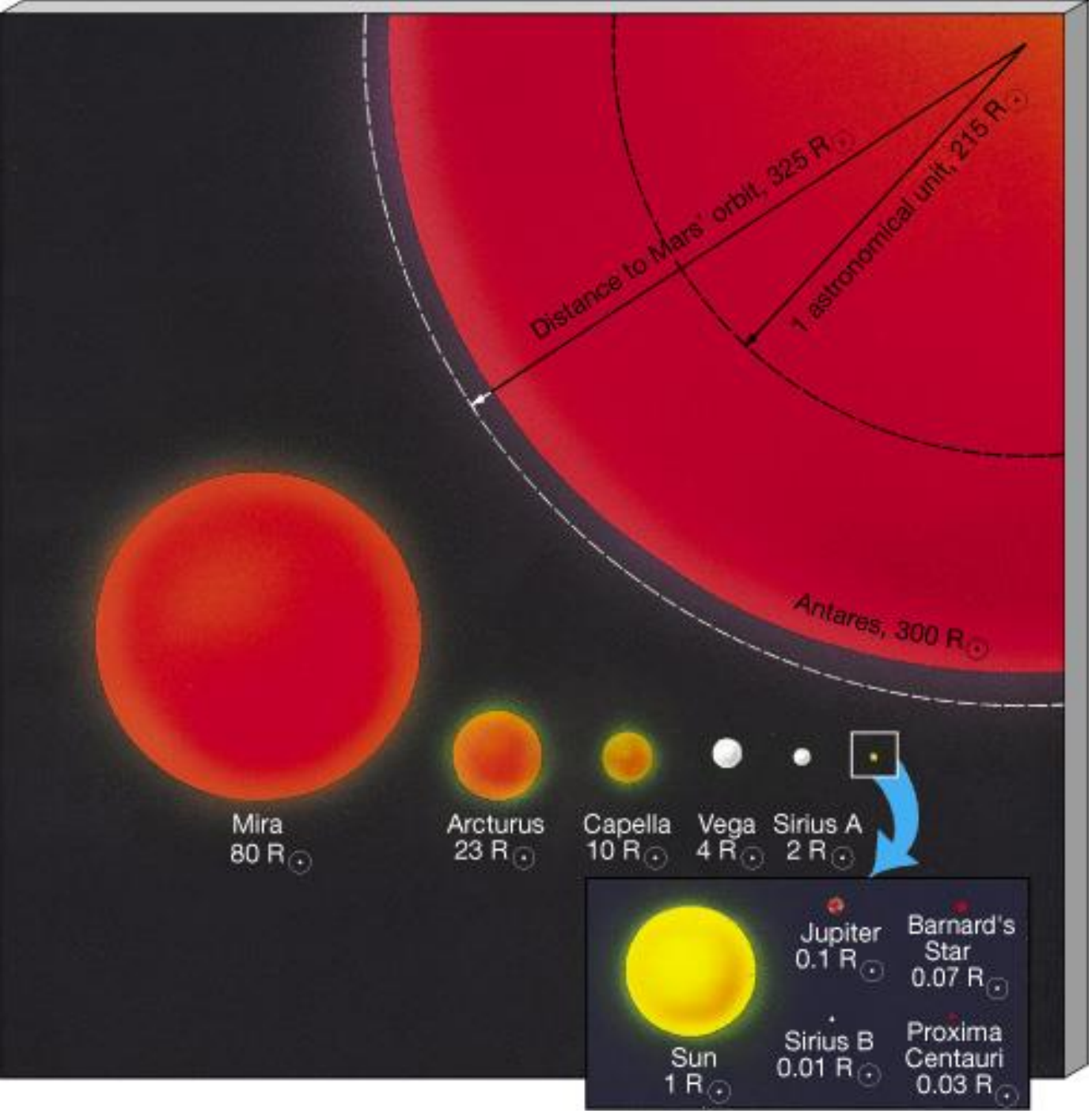
Log-log plot. Slope give $L = M^4$

don't need to know

Stellar Sizes

- For a few close, big stars, they can be seen in a telescope as non-point objects
- Measure angular size; if know distance then get size of star

  Example: Betelgeuse 300 times larger radius than the Sun
- If further away but a binary star, get size of stars when they eclipse each other → length of time one star passes in front or behind each other



Stellar Sizes

compared to size of our Sun.

So 60R_sun means 60 times larger radius than our Sun.

Largest stars extend beyond Earth's distance to Sun

Lecture Feedback

E-mail me a few sentences describing one topic you learned from this set of presentations. Please include the phrase “Stars with larger masses have larger absolute luminosities” in your mini-report but do not use that as your “one topic”.