The Nature of Stars

- Measure properties of Stars

  Distance

  Mass

  Absolute Brightness

  Surface Temperature

  Radius

- Find that some are related

  Large Mass → Large Brightness

- Determine model of stellar formation and life cycle

Distances to Stars

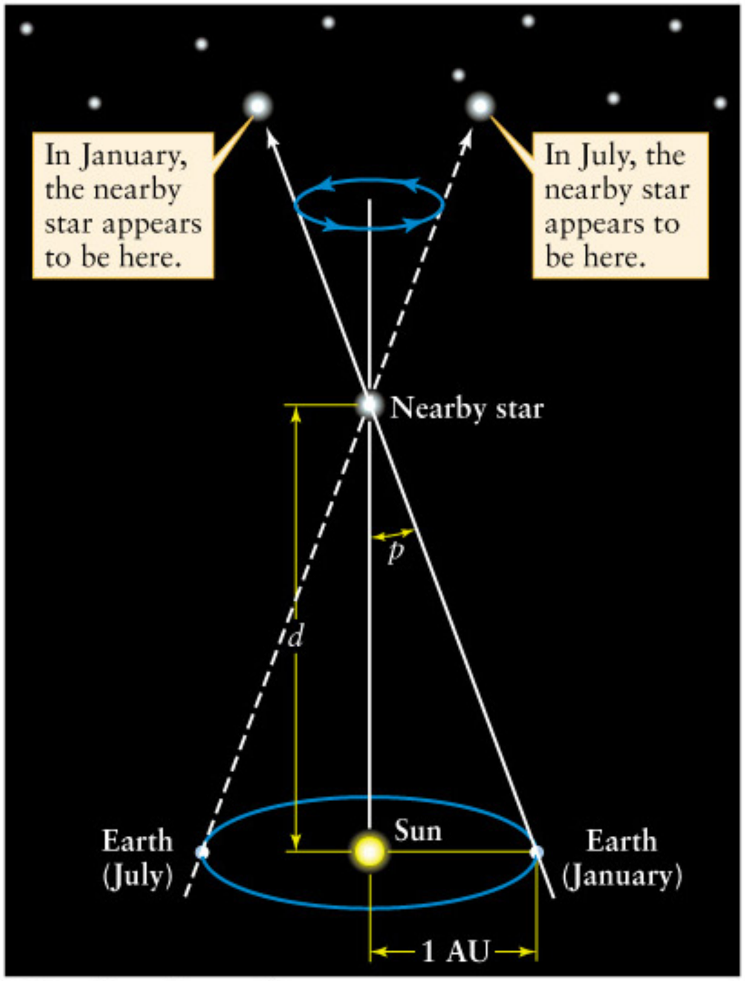
- Important as determines actual brightness but hard to measure as stars are so far away

  Closest Alpha Centauri

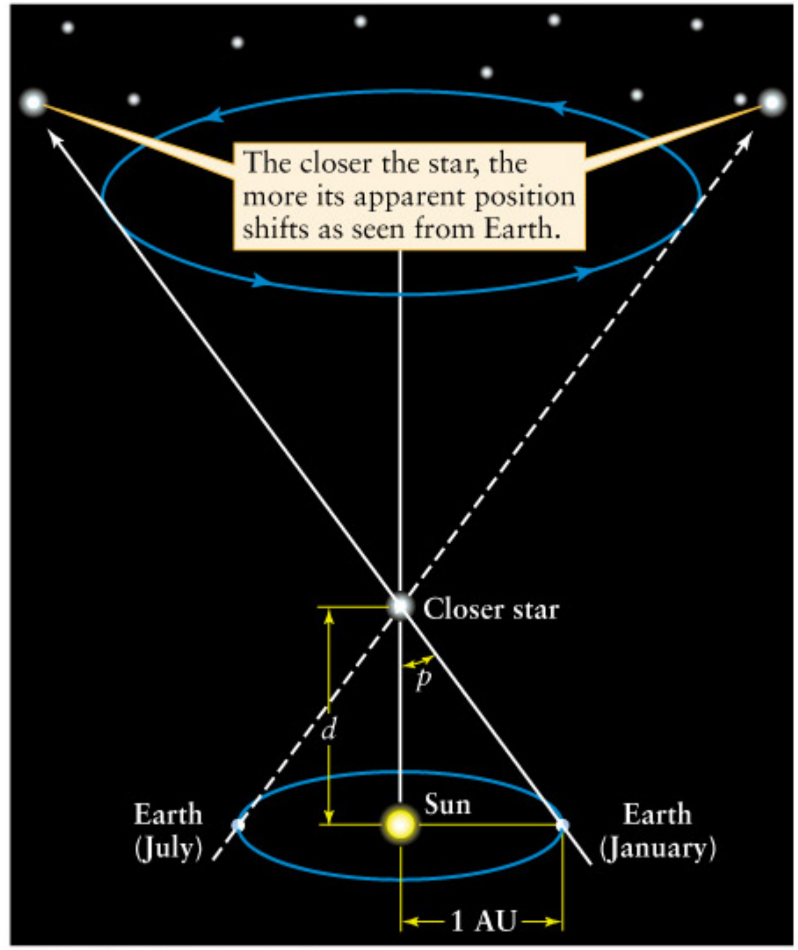
  4.3 light years = 4×10^{13} km

  (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 a few 100 LY. Need telescope: first observed in 1838. Study close stars in detail. Other techniques for distant stars

Distances to Stars - Parallax



a Parallax of a nearby star



b Parallax of an even closer star

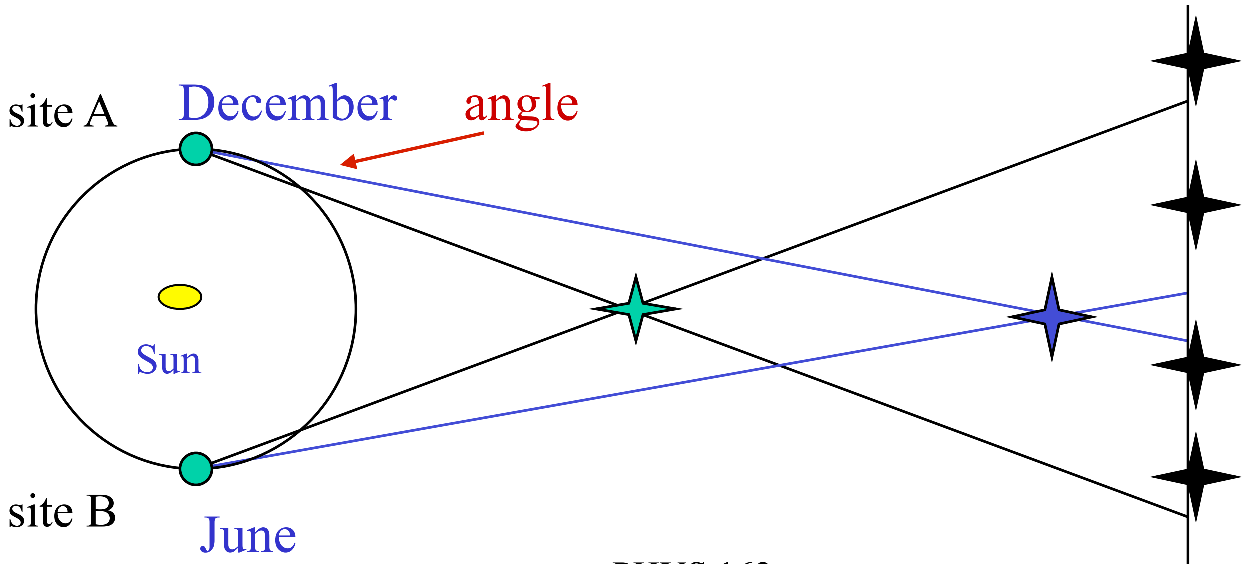
Shifting Star Positions

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

1 sec arc = 1 deg/3600

PARallax of one arc **SEC**ond

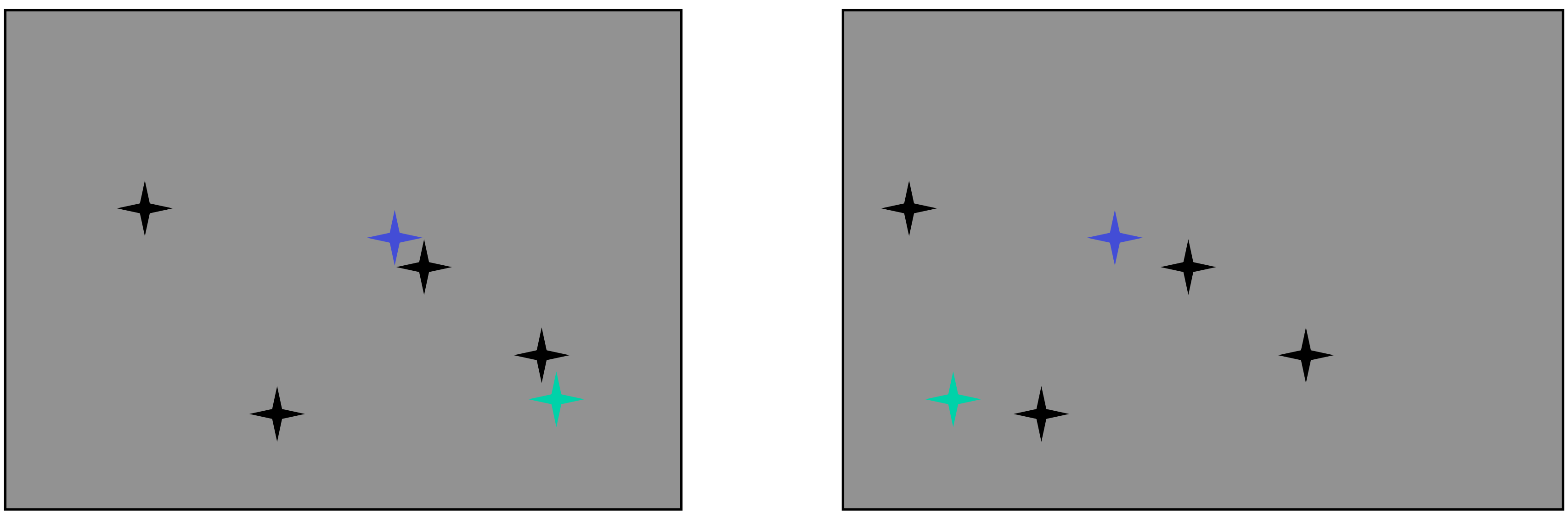
= 1 rad/206,265



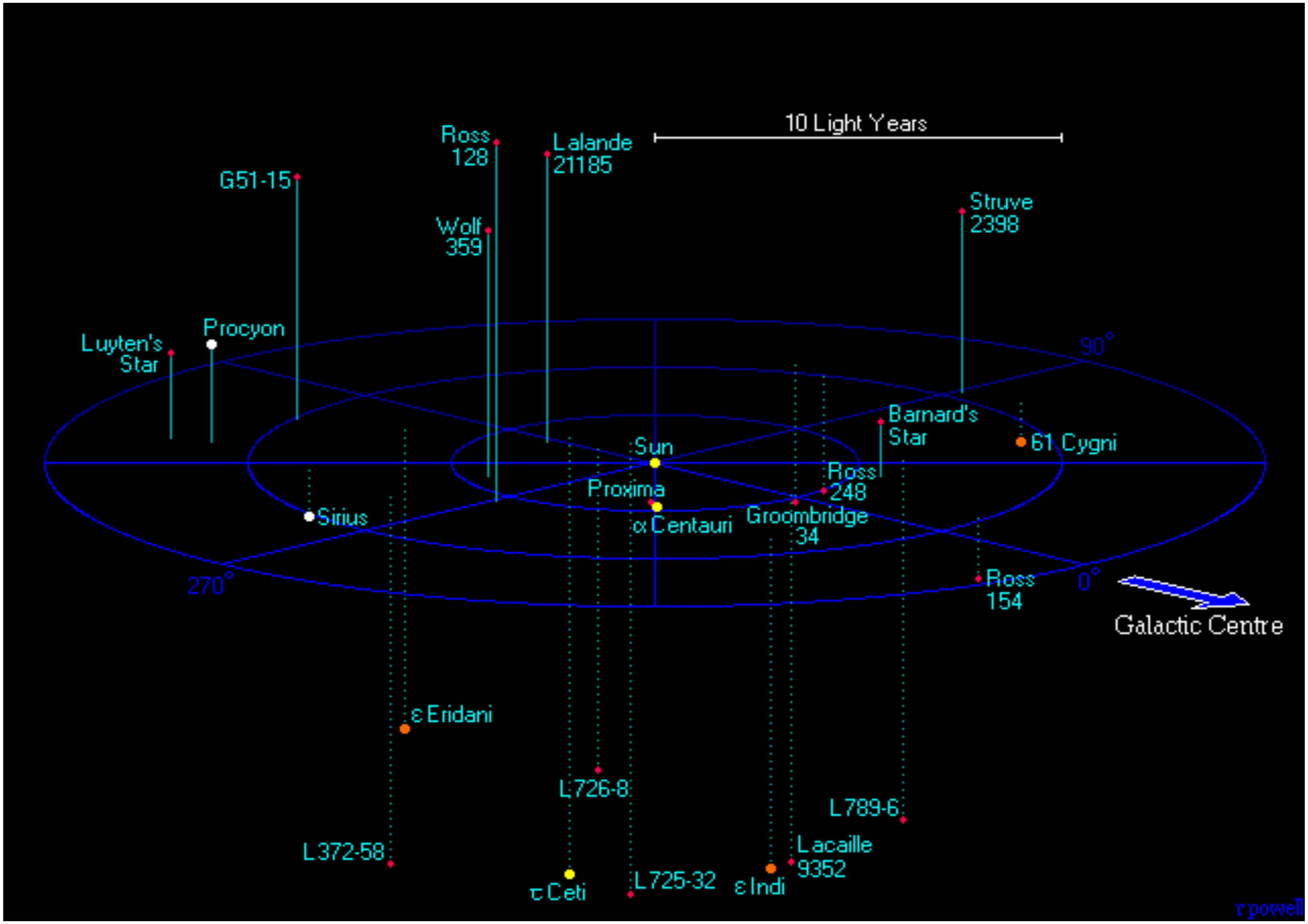
Stellar Parallax

- A photo of the stars will show the shift.

January July



Nearest Stars



61 Cygni first parallax in 1838

Nearest Stars

#	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
- many stars come in groups like the 2 stars in the Sirius "binary cluster" → close together, within same "solar system"
- Alpha Centauri and Procyon are close binary systems

Parallax Data

- 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
- ESA Gaia satellite: 2013 0.00001 arc-second. Goal: measure 1 billion objects ~70 times each over 5 years

Luminosity of Stars

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

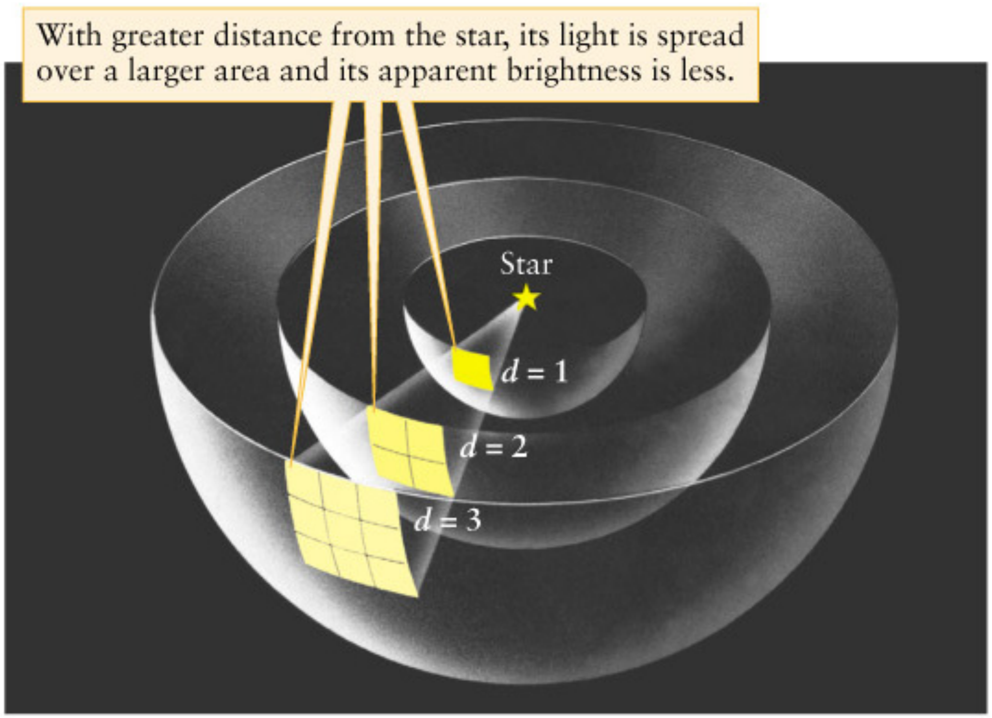
  $L_{sirius} = 23L_S$ means Sirius radiates 23 times more energy than the Sun
- Stars range from $.0001xL_S$ to $1{,}000{,}000xL_S$

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

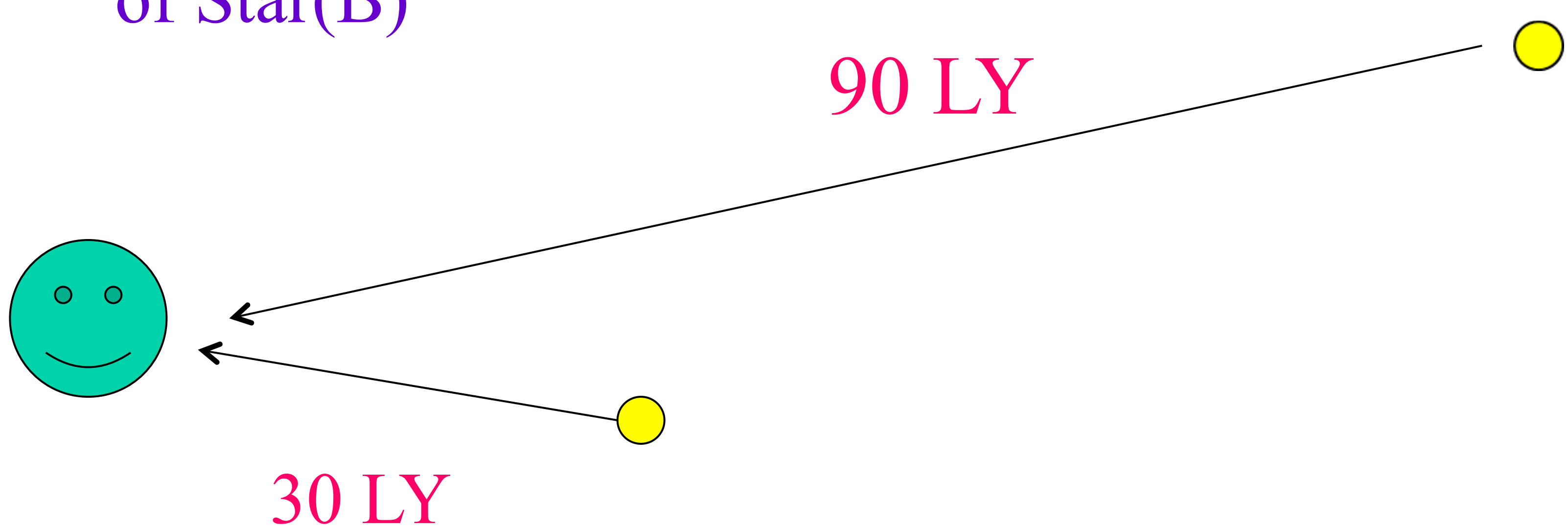
Apparent Brightness is what is seen by eye or in a telescope and so depends on distance (1/Distance^2)



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

THE BRIGHTEST STARS

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

close to us

far away

but very large Absolute brightness

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? Has the larger apparent luminosity? → Sirius

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

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

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

Binary Stars → Stellar Masses

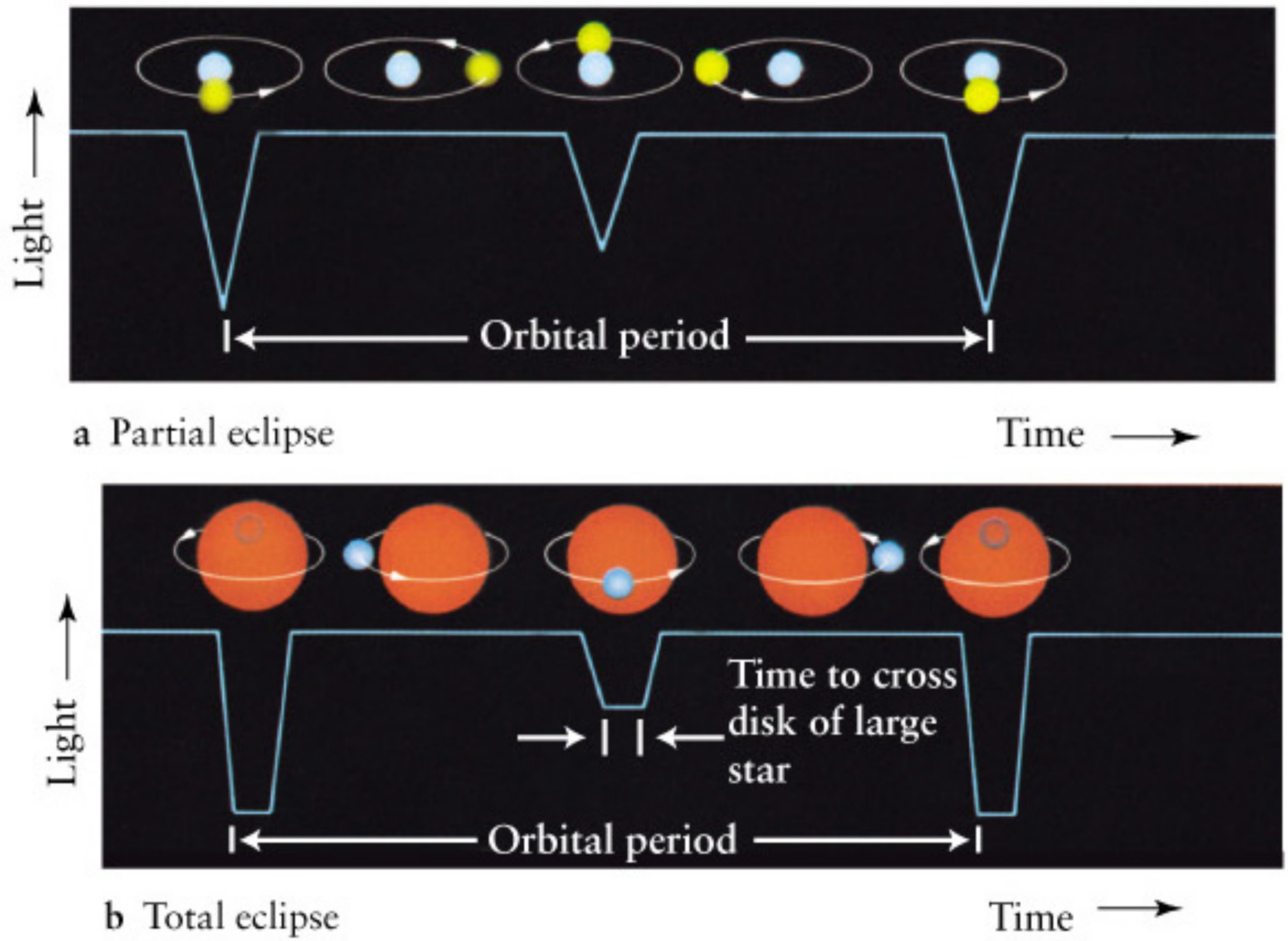
→Visual Binary. Can see two distinct starts

→Spectroscopic Binary

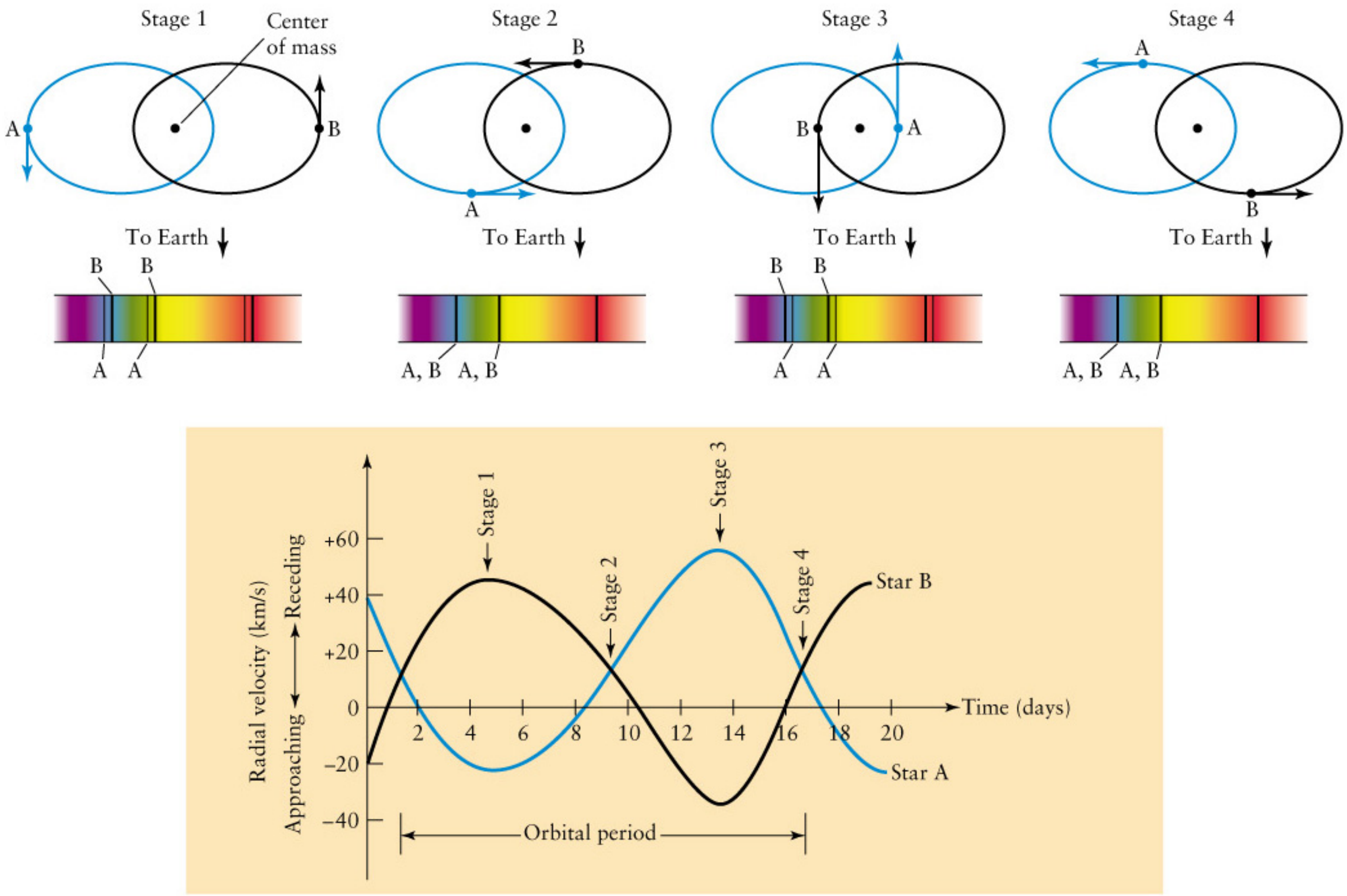
Can only separate into 2 stars by looking at the spectrum
(eclipse each other plus have different Doppler shifts)

•Measure orbital information → period and separation distance. Get Mass though Kepler/Newtonian-like methods

Binary Star Orbits - Eclipses



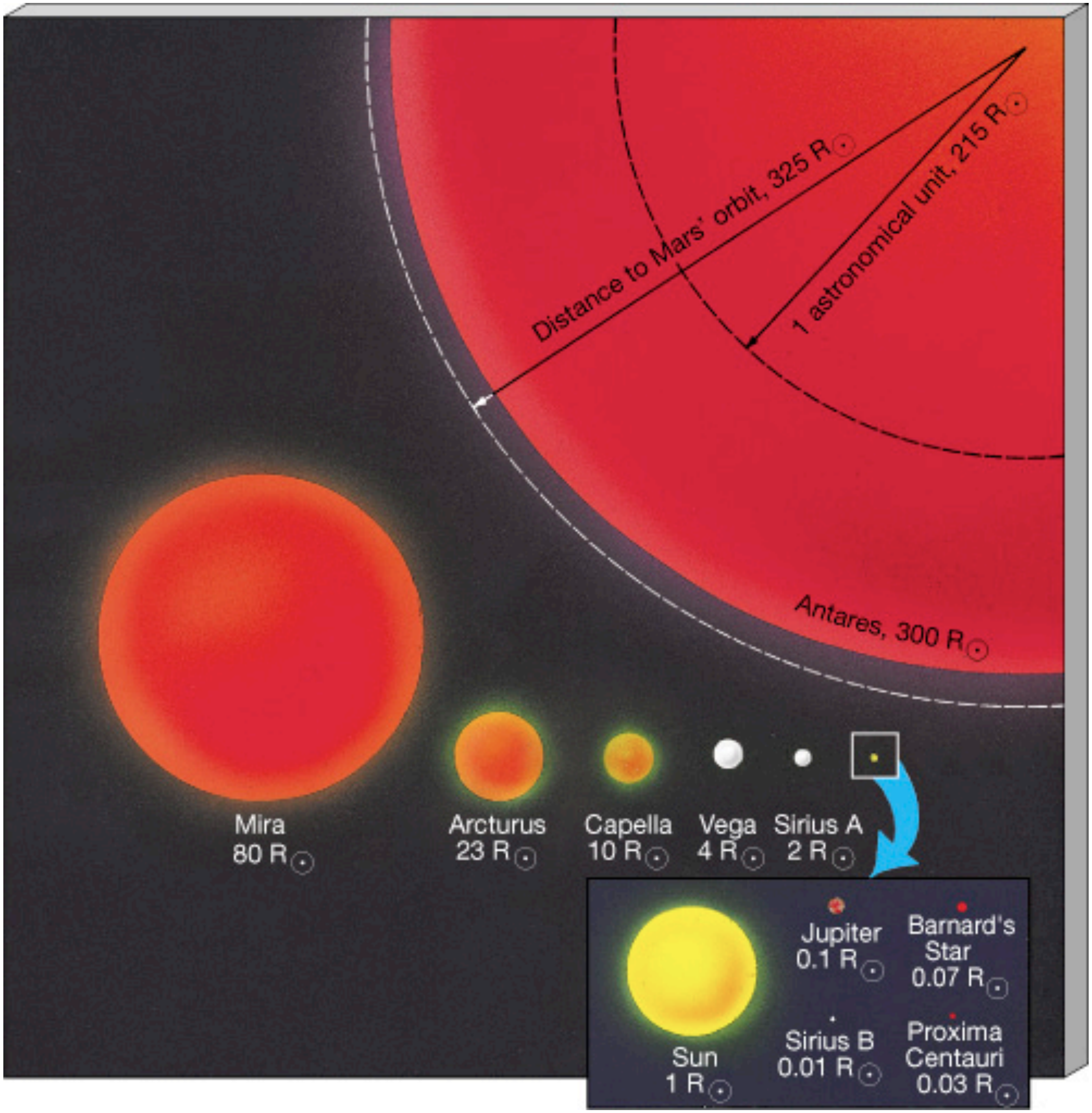
Binary Star Orbits – Doppler Shifts



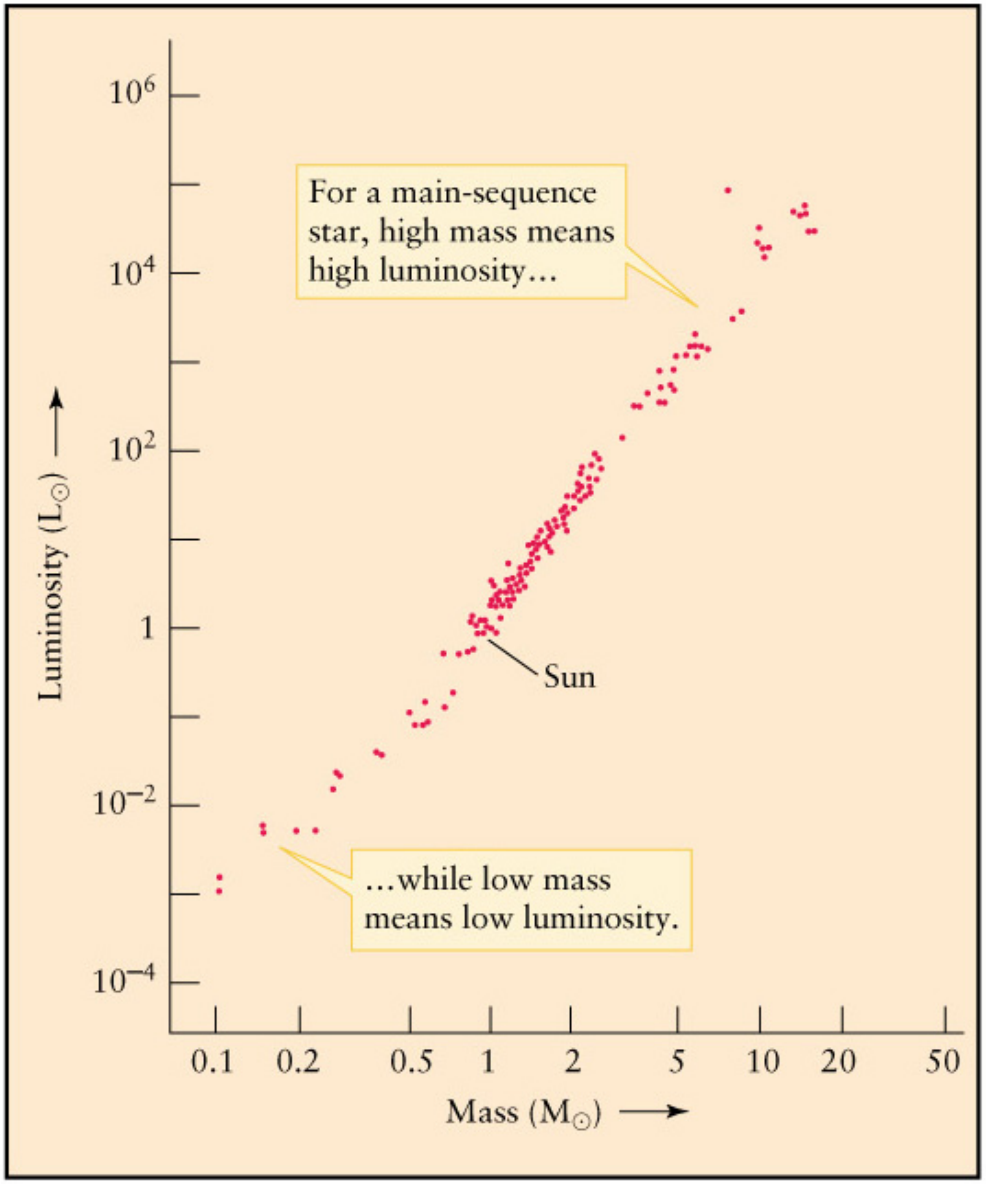
Stellar Sizes

- 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



Mass vs Luminosity

always on these plots it is the Absolute Luminosity of the star

High mass →
High brightness

Surface Temperature of Stars

- Continuous spectrum and the peak wavelength tells temperature

  lambda(max) = A/Temp

where lambda=wavelength

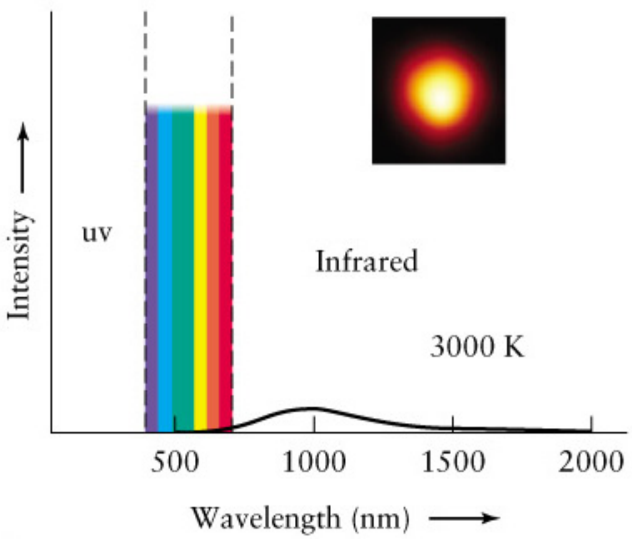
- OR measure relative intensity at a few wavelengths like

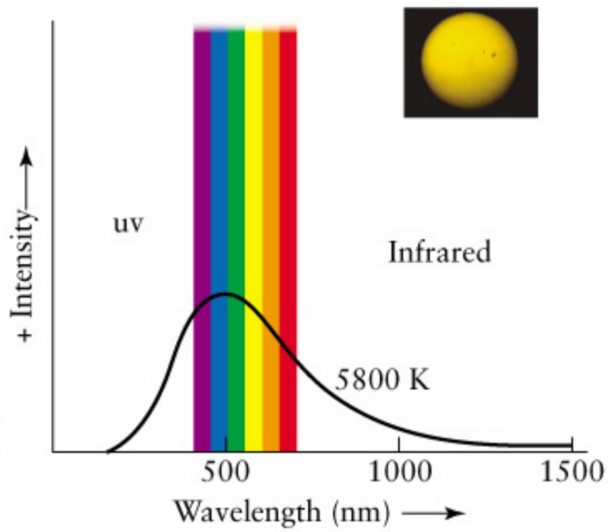
  RED

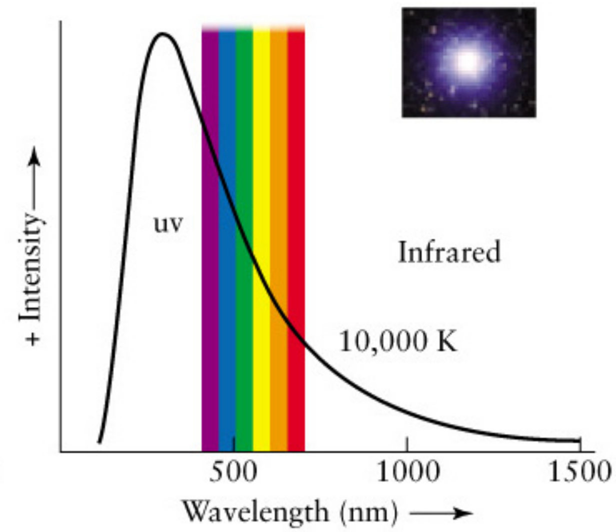
  GREEN

  BLUE → Easy to do

HST image. “add” together images taken with different color filters





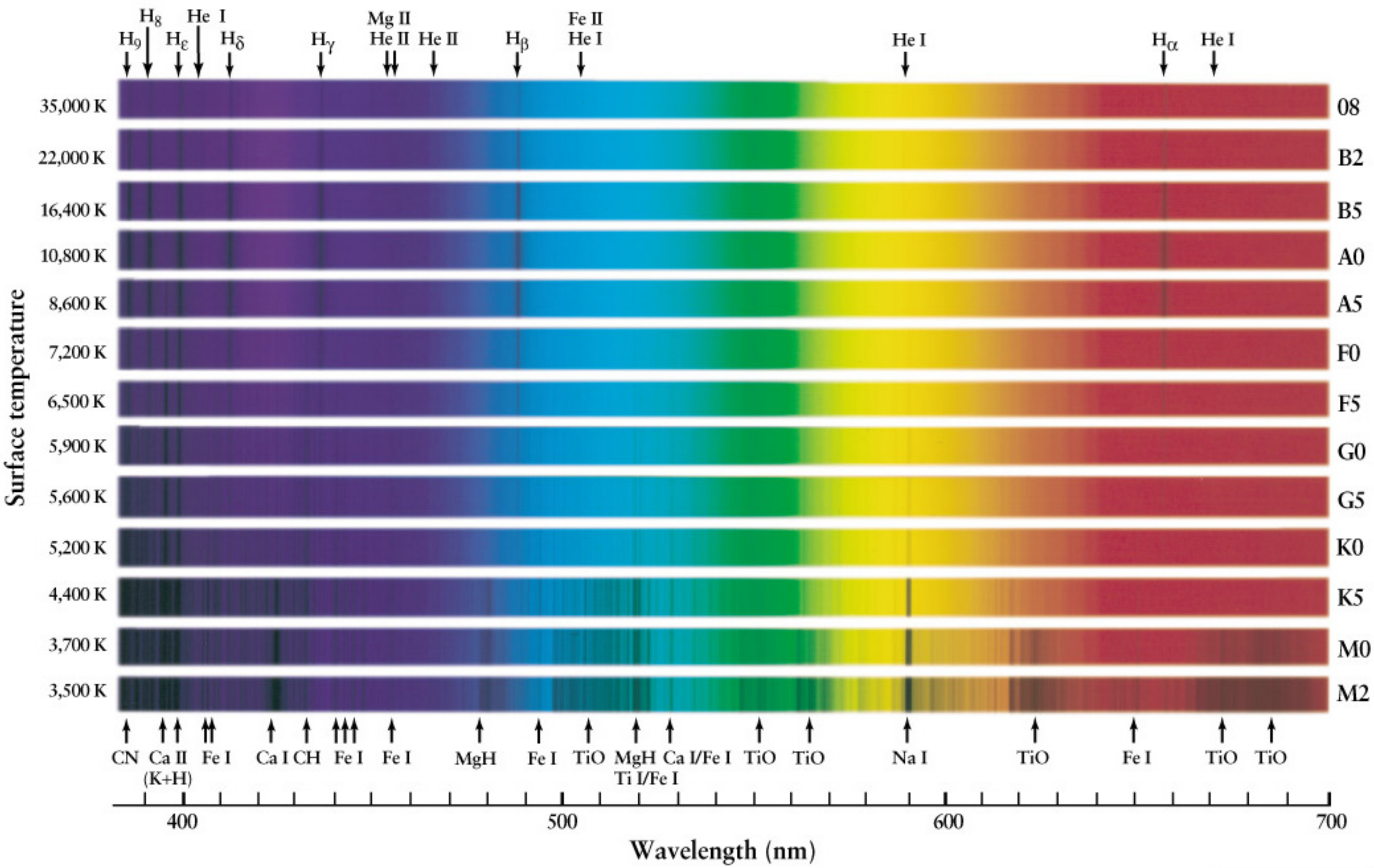


Spectral Classes

Light passing through a star's atmosphere gives dark line absorption spectrum. Tells:

- What atoms are present
- Motion of the star by the Doppler shift of the absorption lines
- temperature of the photosphere by relative intensity of different absorption lines and by amounts of different molecules and ions

Spectral Classes

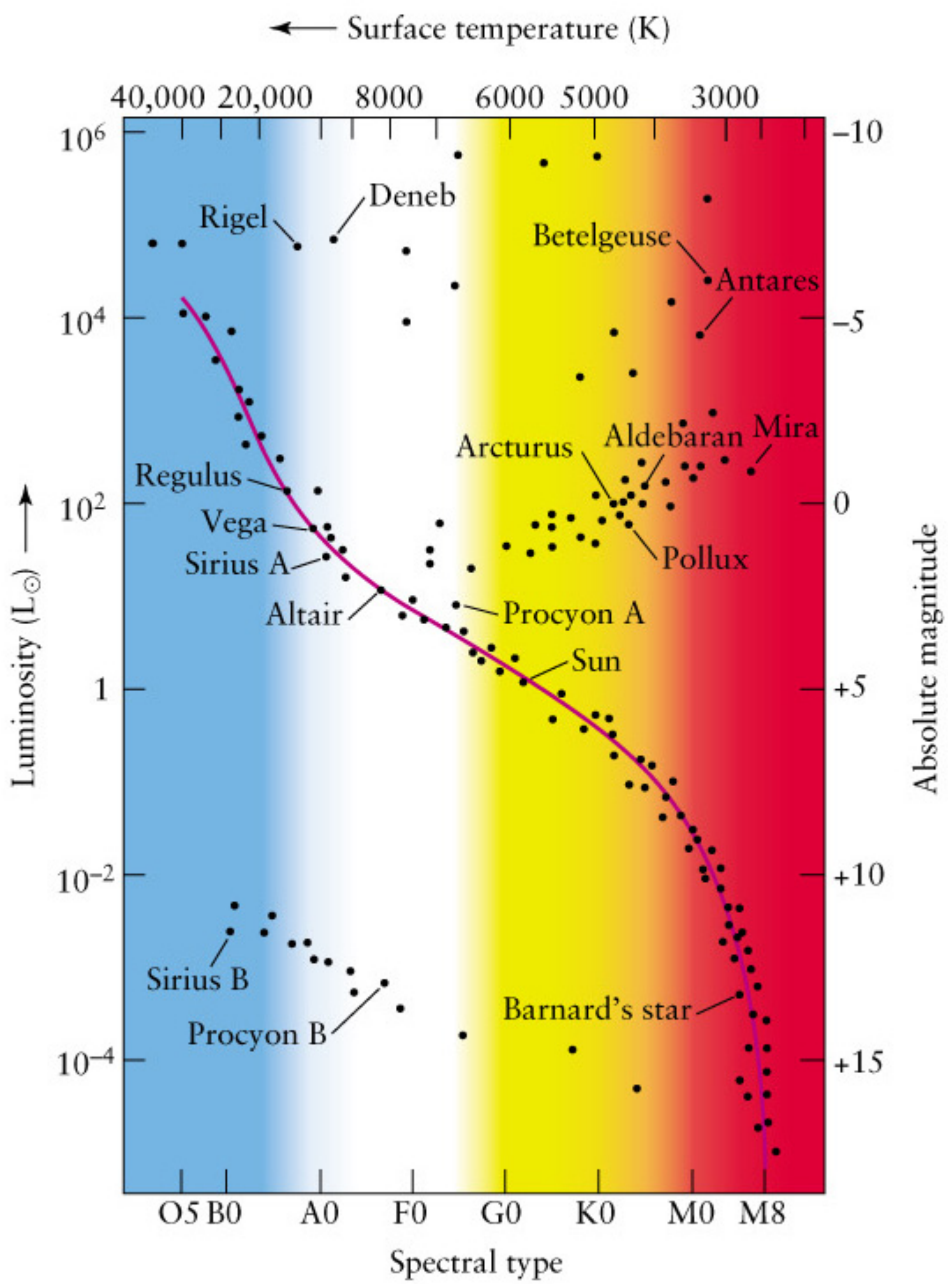


Spectral classes originally ordered A,B,C,D… based on the amount of hydrogen absorption in the visible:

- Now order by surface temperature

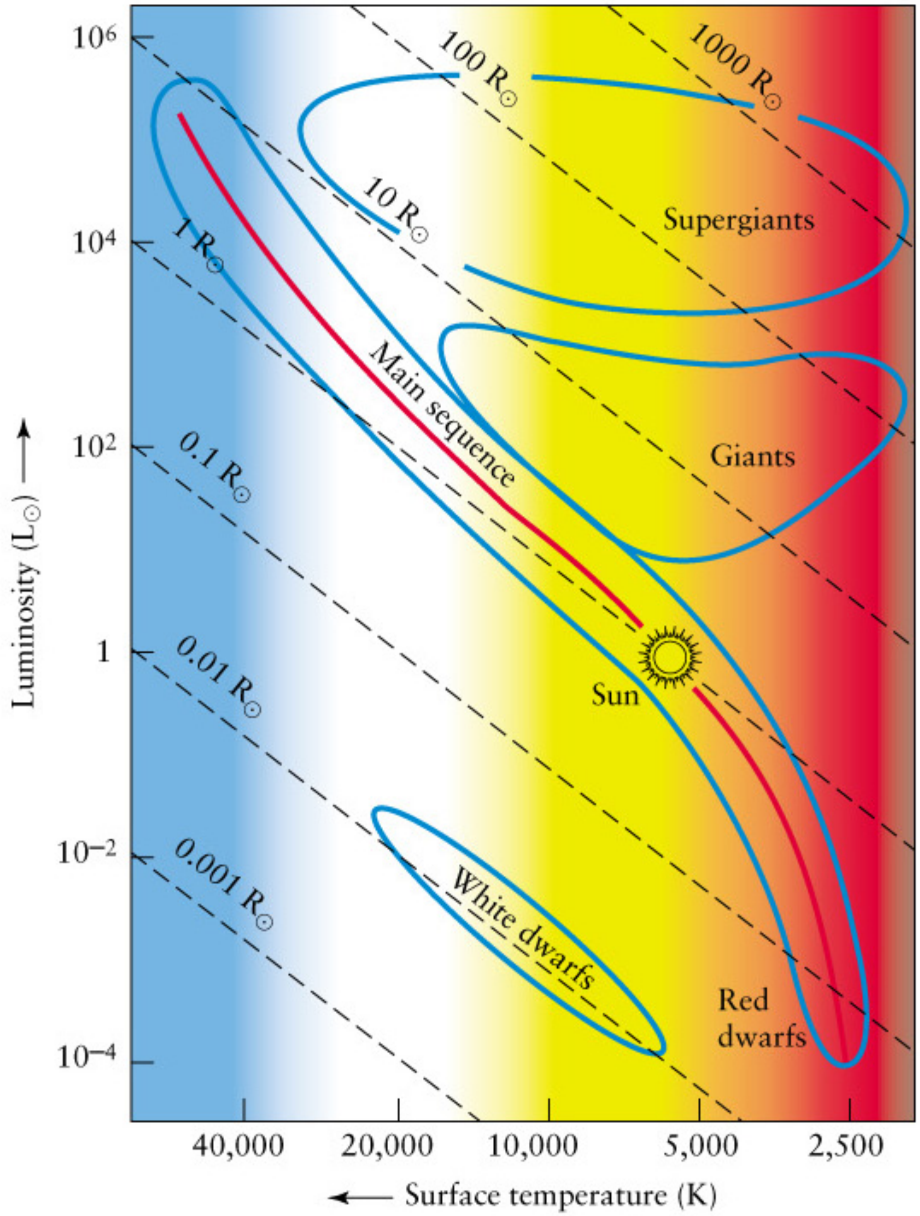
Spectral Class		Temperature
O	oh	hottest
B	be	
A	a	
F	fine	
G	girl/guy	
K	kiss	
M	me	coolest

Don’t need to know



Hertzprung-Russell Diagram

Plot Luminosity versus surface temperature



Hertzprung-Russell Diagram

Stars with larger sizes are brighter then a smaller star with the same surface temperature

Temperature vs Luminosity vs Radius of Stars

Energy emitted by surface of star due to EM radiation is Energy/area = σT^4. Examples

- Two stars. Same temperature and radius → same Luminosity
- Two stars. Same temperature. Radius(B) = 2xRadius(A). So surface area(B)= 4xsurface area(A) → Luminosity(B)= 4xLum(A)

Radius = 1 radius = 2

Temperature vs Luminosity vs Radius of Stars

Energy emitted by surface of star due to EM radiation is Energy/area = σT^4. Examples

- Two stars. Same radius. Temperature(B) = 2xTemp(A). (Energy/Area)B = 2^4(Energy/Area)A or (Energy/Area)B = 16x(Energy/Area)B → Luminosity(B) = 16xLum(A)

Temp = 6000 Temp = 12,000

Hertzprung-Russell Diagram

- Most stars are on a “line” called the MAIN SEQUENCE with

  hot surface temp → large radius

  medium temp → medium radius

  cool surface temp → small radius

- There are also stars with cool surface temperature but very large radius: RED GIANTS
- Stars with hot surface temperature but very small radius: WHITE DWARVES

Key Properties of Main Sequence Stars

Mass/M_{Sun}	Luminosity/L_{Sun}	Effective Temperature (K)	Radius/R_{Sun}	Main sequence lifespan (yrs)
0.10	3×10^{-3}	2,900	0.16	2×10^{12}
0.50	0.03	3,800	0.6	2×10^{11}
0.75	0.3	5,000	0.8	3×10^{10}
1.0	1	6,000	1.0	1×10^{10}
1.5	5	7,000	1.4	2×10^{9}
3	60	11,000	2.5	2×10^{8}
5	600	17,000	3.8	7×10^{7}
10	10,000	22,000	5.6	2×10^{7}
15	17,000	28,000	6.8	1×10^{7}
25	80,000	35,000	8.7	7×10^{6}
60	790,000	44,500	15	3.4×10^{6}

Spectroscopic Parallax

- If we use well-understood close stars to determine the overall brightness scale of a specific class of star, then measuring the spectrum can be used to give the distance for stars > 500 LY away

1. Determine Surface Temperature + spectral class of star
2. Determine where on HR diagram should go
3. Read off absolute luminosity from HR diagram
4. Measure apparent luminosity and calculate distance

- works best if many close-by stars