The Nature of Stars

- Measure properties of Stars

  Distance last class

  Mass last class

  Apparent Brightness last class

  Surface Temperature

  Radius last class
- Find that some are related

  Large Mass → Large Absolute Brightness
- Develop model of stellar formation and life cycle

Surface Temperature of Stars

- Continuous spectrum and the peak wavelength tells temperature

  lambda(max) = constant/Temp

where lambda=wavelength of light

- OR measure relative intensity at a few wavelengths like

  RED

  GREEN

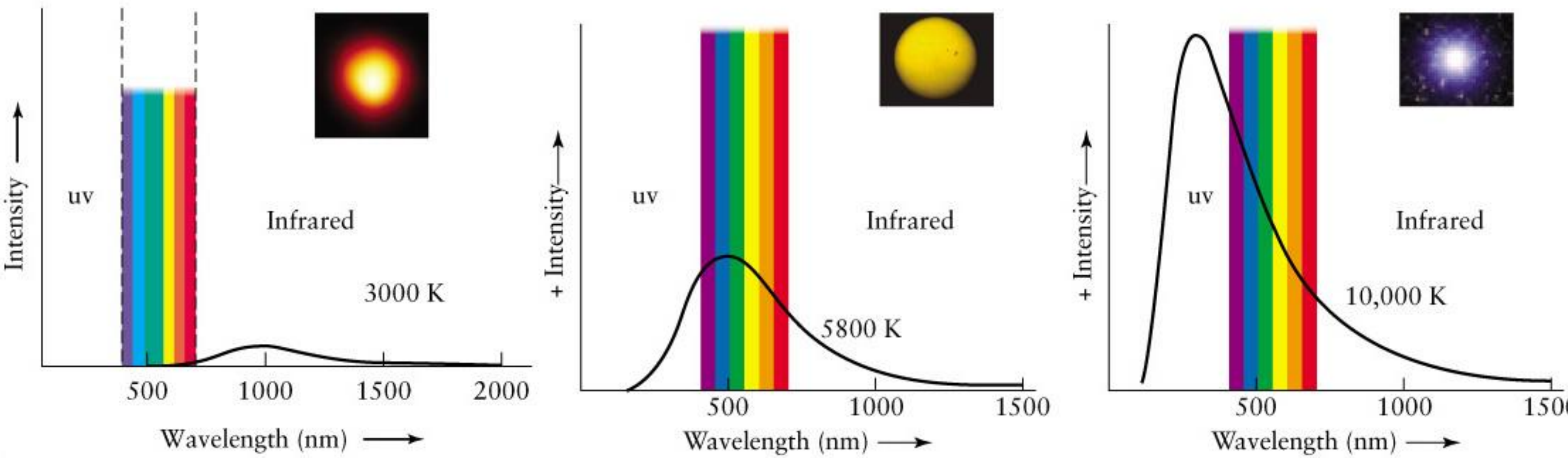
  BLUE

→ Easy to do

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

Examples: red, yellow, blue stars

3000, 5800, 10000 degrees



Peak in IR
More red than blue

peak in visible
more blue than red

peak in UV
more blue than red

Spectral Classes

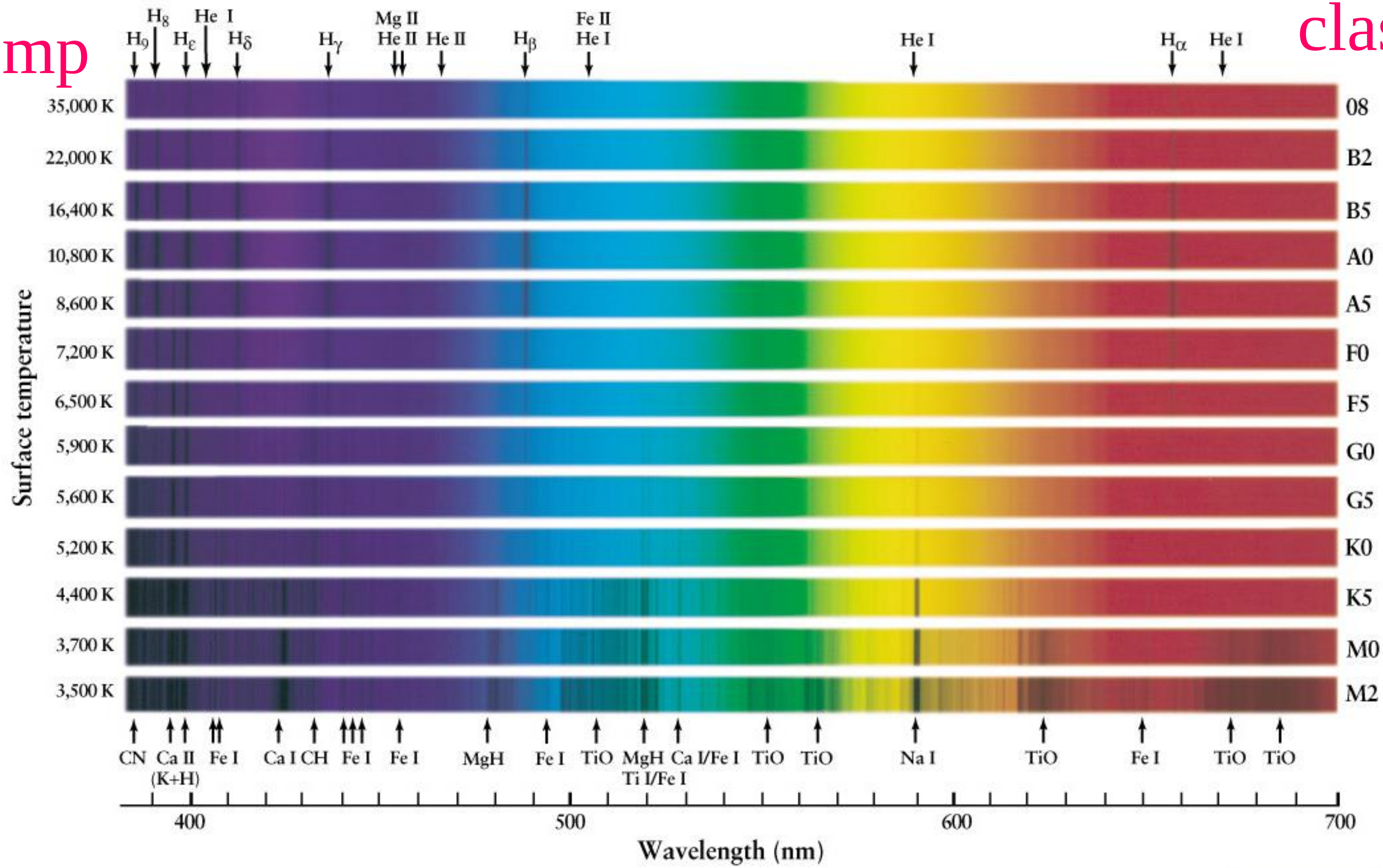
Light passing through a star's atmosphere gives dark line absorption spectrum. Tells:

- 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 – just note different lines for different surface temperatures

temp

class



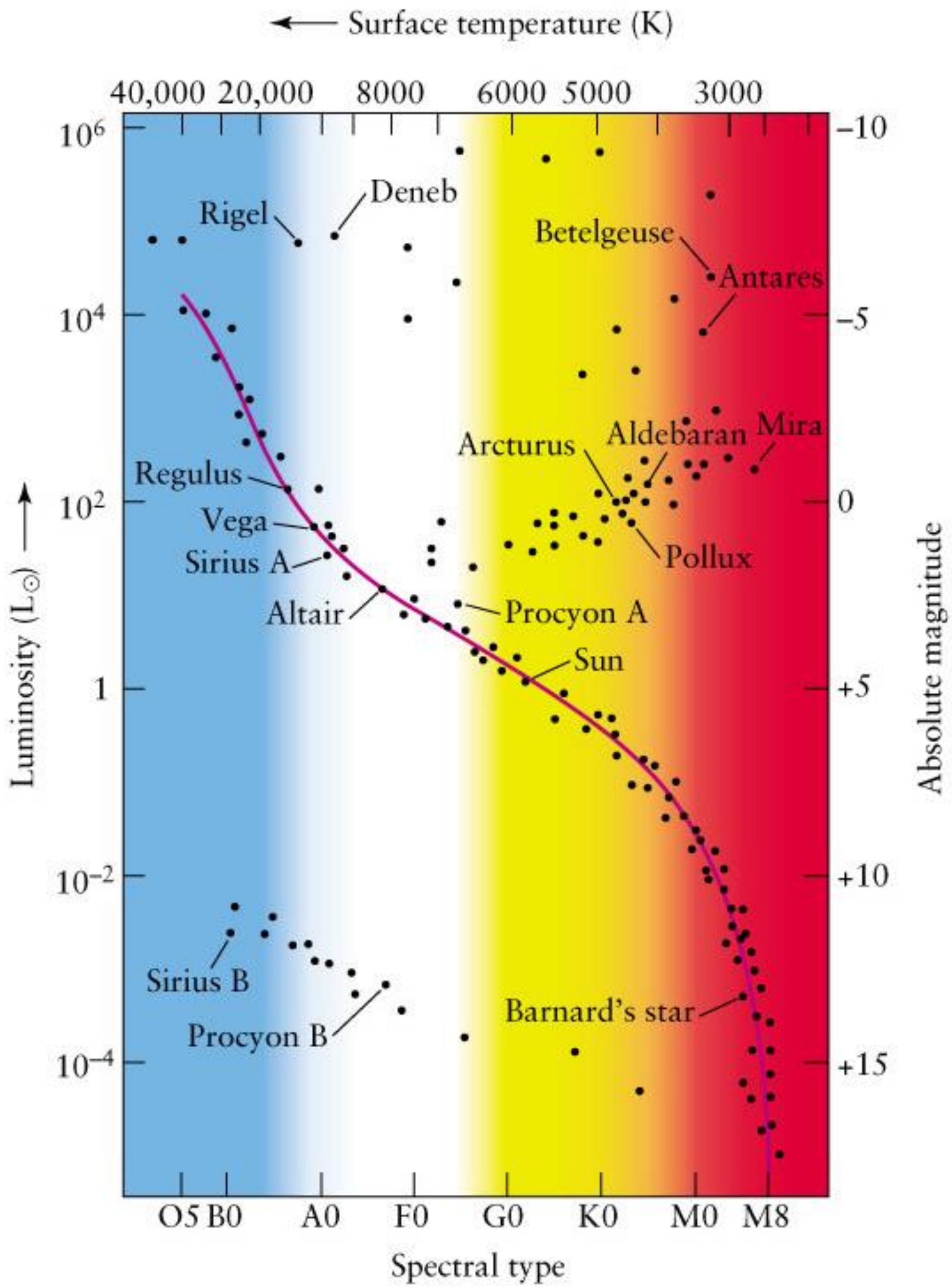
Spectral classes originally ordered in 19th century A,B,C,D… based on the amount of hydrogen absorption in the visible:

- Now order by surface temperature

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

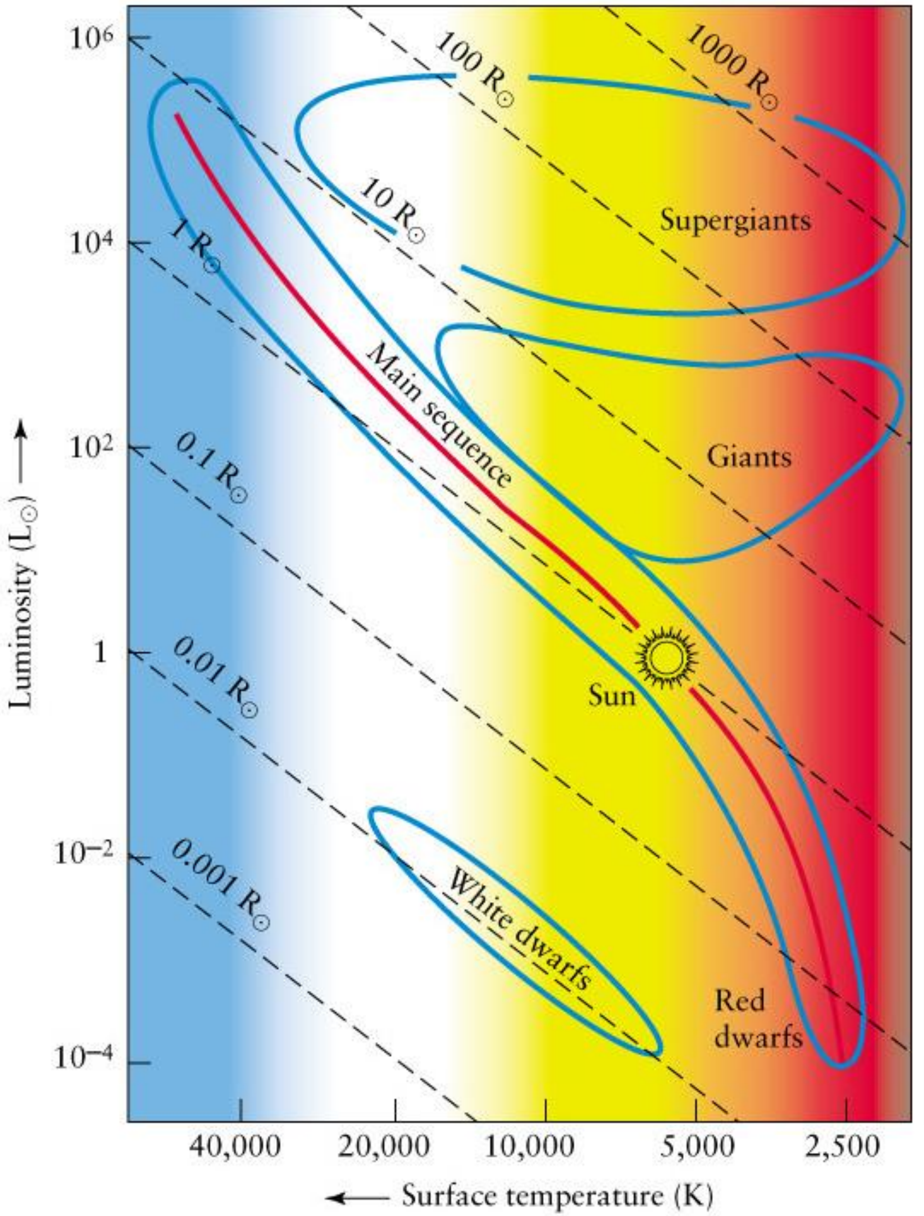
Don’t need to know

There is then a suborder 0-9, and so G0 or G3 or G7



Hertzprung-Russell Diagram

- Plot Absolute Luminosity (relative to Sun) with range from .0001 to 1,000,000 versus surface temperature. Both are log scales
- Luminosity and absolute magnitude both on vertical scale while surface temp and spectral class both on horizontal scale



Hertzprung-Russell Diagram

The radius of a star are diagonal lines on a HR diagram. The largest stars are at the upper right and the smallest stars at the lower left.

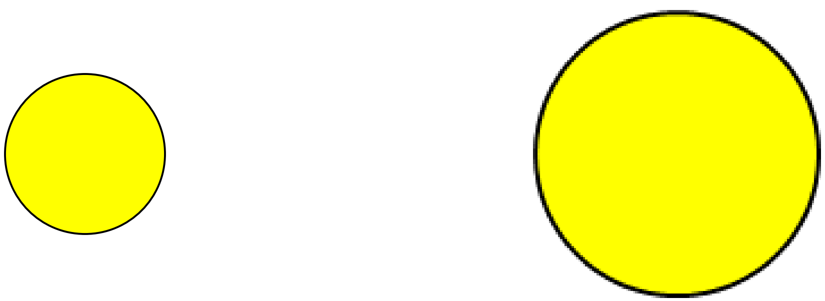
Stars with larger sizes are brighter than a smaller star with the same surface temperature

Luminosity proportional to (area of star surface) X (Temp)^4

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)= 4xLuminosity(A)

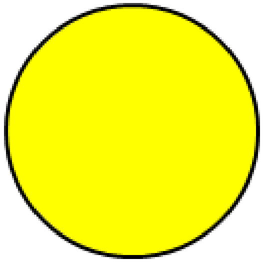


Radius = 1 radius = 2

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 and so same surface area. Temperature(B) = 2xTemperature(A). (Energy/Area)B = 2^4(Energy/Area)A or (Energy/Area)B = 16x(Energy/Area)A → Luminosity(B) = 16xLum(A)



Temp = 6000

Temp = 12,000

Hertzprung-Russell Diagram

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

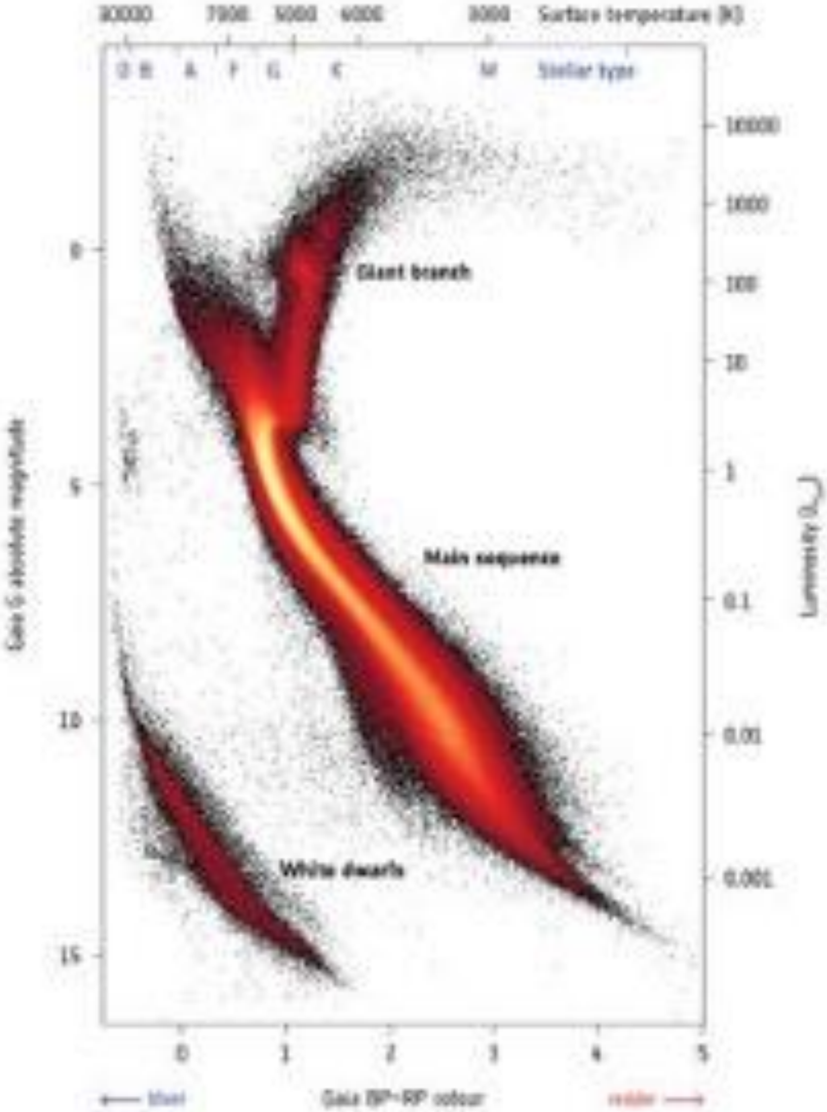
  hot surface temp → large radius

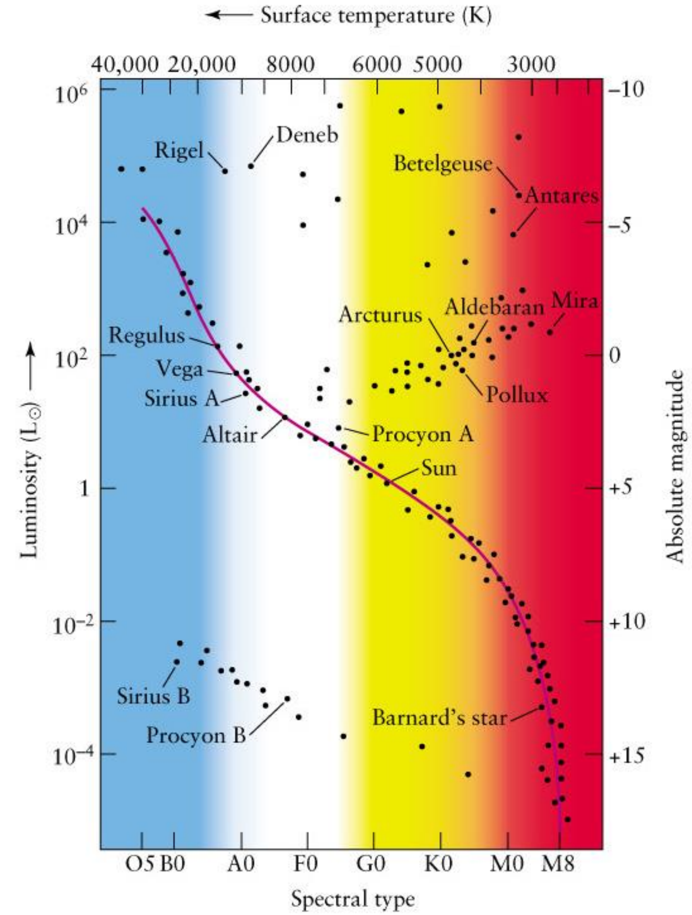
  medium surface temp → medium radius

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

4 million stars from Gaia data, 2018 (ESA)

→ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM





Spectroscopic Parallax

- Geometric parallax using the Earth's orbit about the Sun can measure distances to about 30,000 LY with new satellite data like Gaia. Very, very good for < 500 LY. Need other techniques for stars further away.
- If we use well-understood close stars to determine the overall brightness scale of a specific class of star, then measuring the spectrum of a star can be used to give its distance for stars further away. This is called "spectroscopic parallax" even though it really has nothing to do with parallax.
- The technique is simply to infer that a faraway star whose spectrum is, as an example, identical to the Sun's has the same absolute luminosity as the Sun

Spectroscopic Parallax

- Steps:

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

works best if many close-by stars like in a star cluster

not very accurate and not used much now as new telescopes have extended the distance for heliocentric parallax

Pleiades star cluster →

What to measure about a star

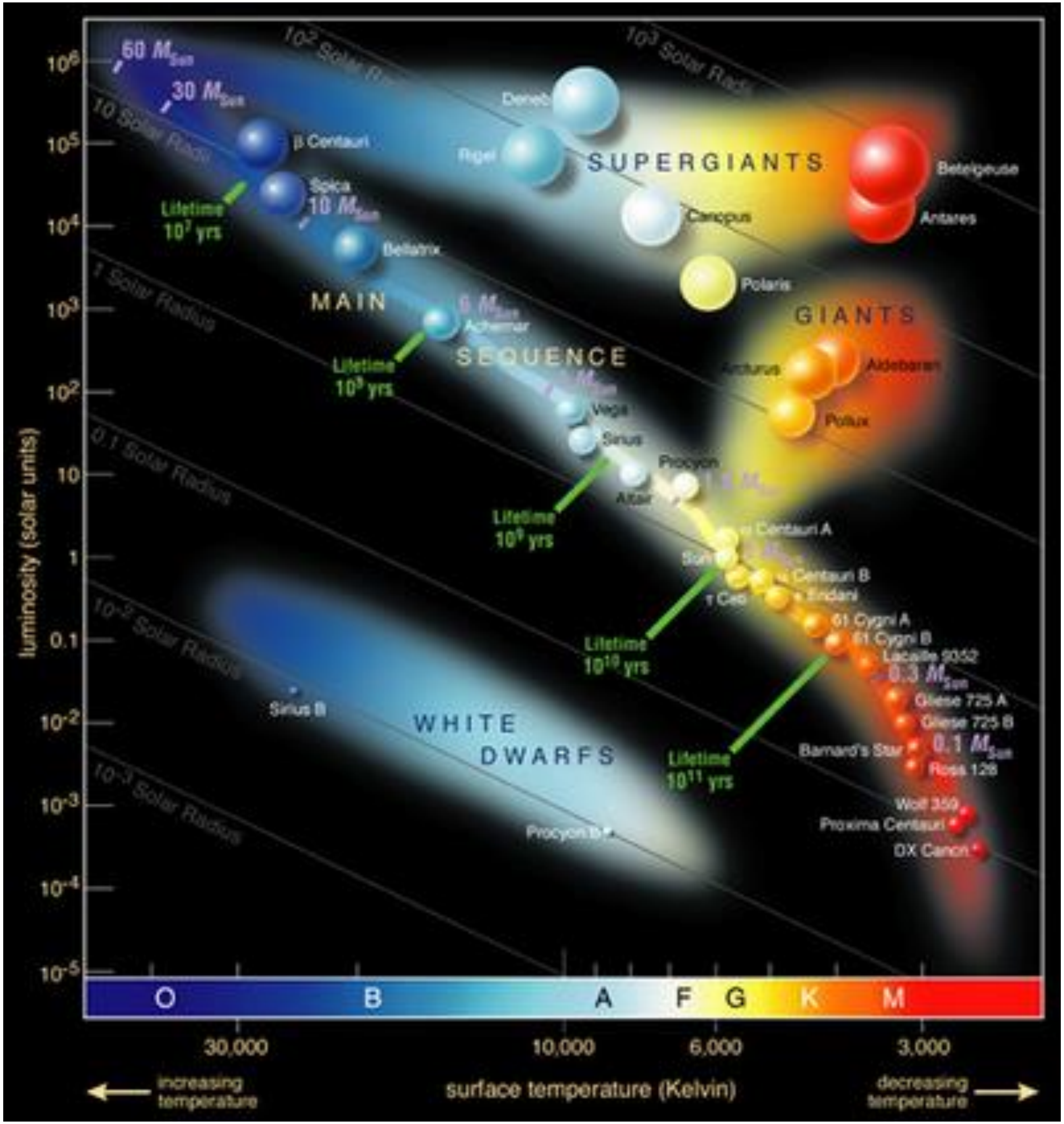
- Pick a star, make many measurements over many years
- Apparent brightness. If this is seen to vary, make additional measurements to try and understand why. Repetitive (binary star or variable star or exoplanet as examples) or non-repetitive (gravitational lensing or nova or supernova)
- Measure position. If varies with Earth’s orbit then close-by and can get distance by heliocentric parallax. If not, then further away
- Measure spectrum. Gives surface temperature, spectral class, Doppler shift. If any of these vary, then maybe “interesting” and make more detailed measurements

Luminosity, surface temp, and radius all increase when star mass increases.

Lifespan decreases when star mass increases

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}



From Wikipedia. Note lifetime of stars along Main Sequence

Star Lifespan vs Star Mass

- Hydrogen is the fuel for a star → higher mass = more fuel
- The Luminosity is how fast is the fuel burning (how many fusion reactions happen each second)
- High mass stars have higher core temperature and so burn fuel (have more fusion reactions) much faster than just the increase in mass → they have shorter lifespans

Sun Mass=1 Luminosity=1 lifespan = 10,000,000,000 years

Star with Mass=10 has Luminosity=10,000 → has 10x more mass but burning 10,000x faster than Sun and so lifespan is about 10000/10=1000x shorter than Sun. From table lifespan for star with 10x mass is 20,000,000 years and so almost correct

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 shorter lifecycles” in your mini-report but do not use that as your “one topic”.