Announcements

- Webwork due on Friday
- I'm looking to get new grade reports issued
- I'll hand Test 2 back on Friday
- Test 3 will be 2 weeks from Friday (the Friday before Thanksgiving)
- Polling: `rembold-class.ddns.net`

End of an Era

- The Kepler Space Telescope has run out of fuel
  - Can no longer reorient itself to point at certain objects
- Orbits the Sun, not Earth
- History
  - Launched in 2009
  - Originally stared at a single patch of sky
  - In 2013 a reaction wheel failed, but was able to compensate using sunlight pressure
  - Switched to K2 mode just looking at interesting things
- Found 2,327 confirmed exoplanets with about 2,900 still to confirm
- Work is taken over largely by TESS, the Transiting Exoplanet Survey Satellite

Understanding Check!

Jupiter is 12 times brighter than Vega while Venus is approximately 60 times brighter than Vega. What is the difference between the apparent magnitudes of Jupiter and Venus ($m_V - m_J$)

A. -1.7
B. -0.7
C. 0.2
D. 5

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Refresher

We wanted to be able to find:

- Surface Temperature
- Motion
- Distance (sometimes)
- Size (in a way)
- Power output (Luminosity)
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Star Sizes

- We've mentioned that we can *not* resolve most stars
- We can get the size in a sneaky way though!
  - Stefan-Boltzmann law and Luminosity:

$$\begin{aligned} L &= 4\pi R^2 \times I \\ &= 4\pi R^2 \times \sigma T^4 \end{aligned}$$

- A cooler star can have a high luminosity if it is large
- A hot star can have a low luminosity if it is small

Stellar Distances

- Back to parallax!
- Still the only real method we have to determine distances to stars
- Recall parallax effects are larger for closer objects
  - We need as large a baseline as we can get: observe during 6 month intervals
  - The parallax effects from stars are still tiny!
  - Generally less than an arcsecond
- A Parsec is the distance that corresponds to a parallax angle of 1 arcsecond
  - Equivalent to 3.26 light years
- Measuring the parallax angle (p) in arcseconds yields

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

where d is in parsecs.

Driving to Vega(s)

Example

You measure the parallax angle of the star Vega to be $0.130\,14''$. If you were to drive at the speed of light, how long would it take you to get to Vega?

Stellar Masses

- Almost all information on mass comes from Kepler's 3rd law
- Need another massive object to be rotating around $\Rightarrow$ Binary Systems

Binaries and Kepler

- Recall that binary stars orbit about the center of mass
- Both stars have the same period
- By fancy application of Kepler's 3rd:

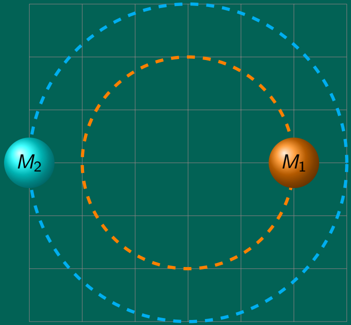
$$\frac{a_{AU}^3}{P_{yr}^2} = (M_1 + M_2)_\odot$$

  - a is the average separation of the stars in AU
  - P is the orbital period in years
  - $\odot$ indicates the masses are in "Solar Mass" units. (eg. $5M_\odot$ is 5 times the mass of the Sun)
- Careful observations of both stars can result in finding the center of mass point, and thus finding the mass of both stars

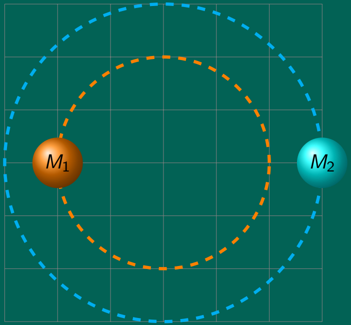
Round and Round

Example

What is the combined mass of the below binary system? Each grid line is 1 AU.



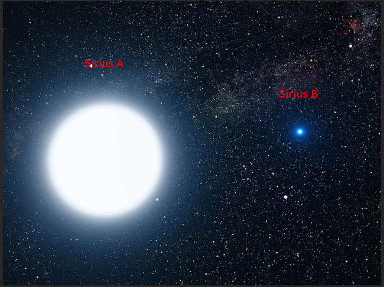
As seen
October 31, 2013

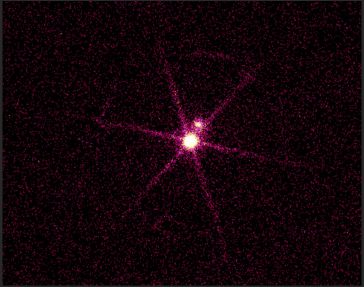


As seen
October 31, 2016

Example: Sirius A and B

- An interesting visual binary system:
  - A is 10000 times brighter than B
  - B is twice as hot





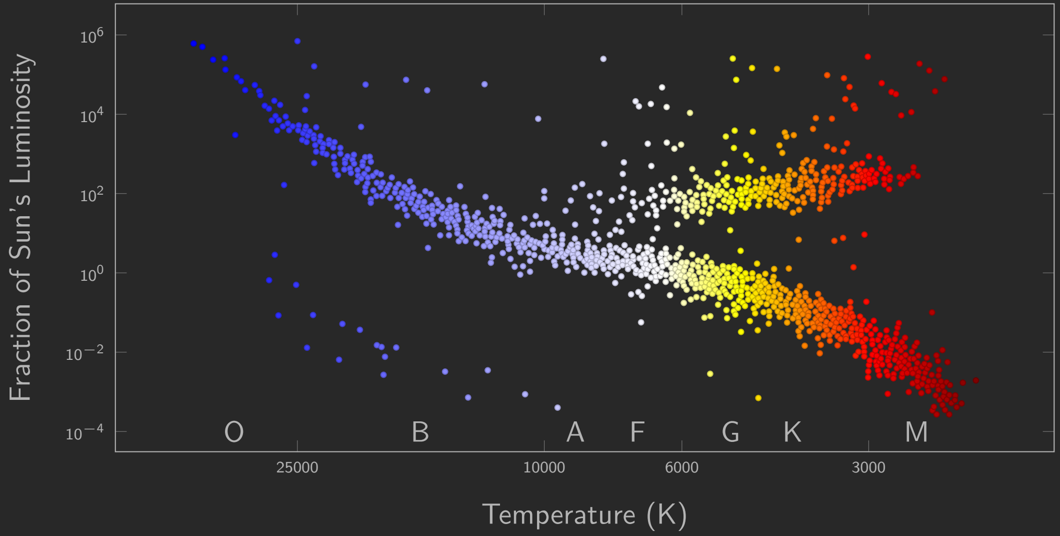
- We observe: spectra, parallax, angular separation, period
- We can infer: temperature, distance, physical separatiaon, mass, luminosity, and SIZE

Sirius. . . Black?

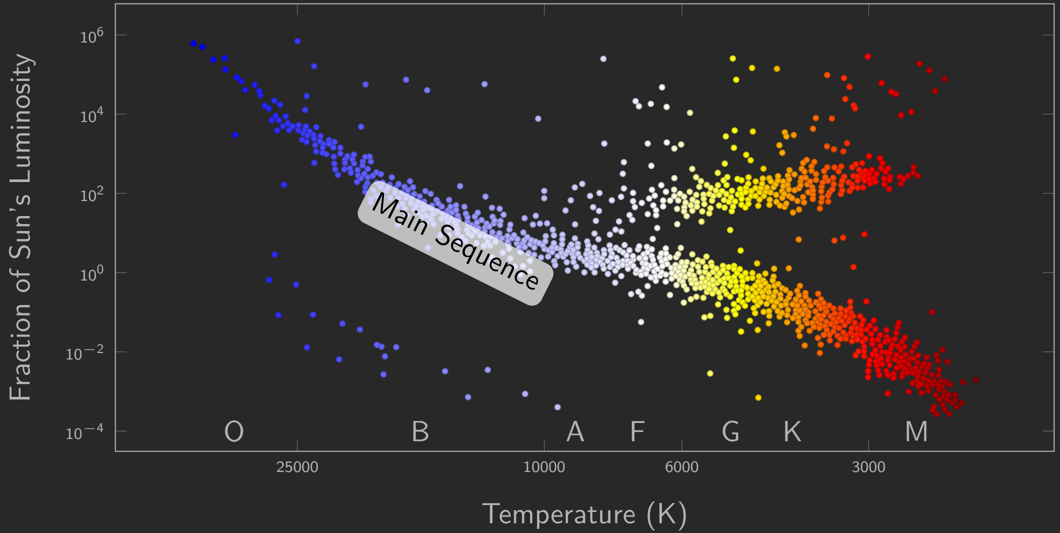
- Found that Sirius B is really small
  - Smaller than the Earth
  - As massive as the Sun
- Really confused early astronomers!
- Arthur Eddington:

> *The message of the Companion of Sirius when it was decoded ran: "I am composed of material 3,000 times denser than anything you have come across; a ton of my material would be a little nugget that you would put in a matchbox." What reply can one make to such a message? The reply that most of us made in 1914 was: "Shut up. Don't talk nonsense."*

Hertzsprung-Russel Diagrams



Hertzsprung-Russel Diagrams



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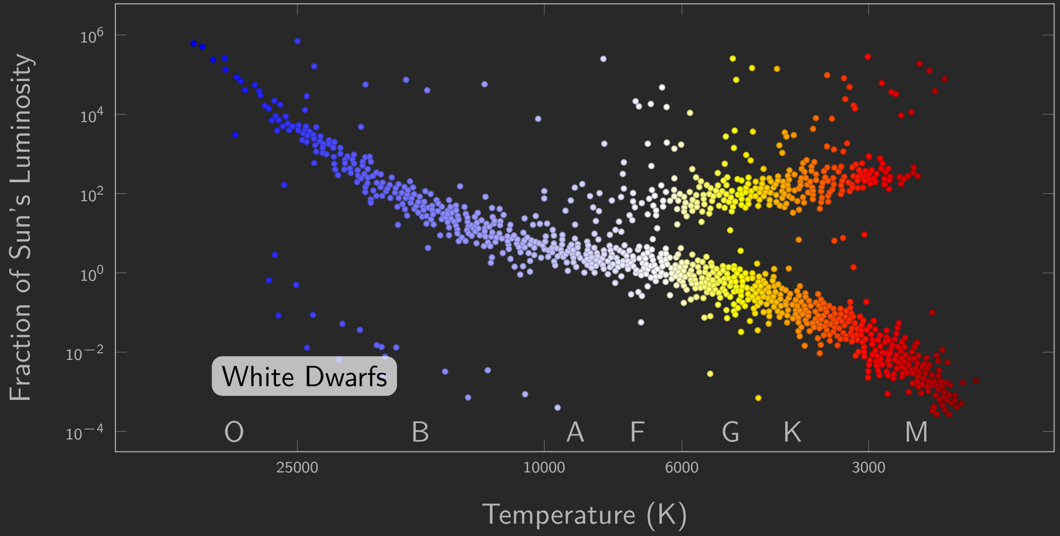

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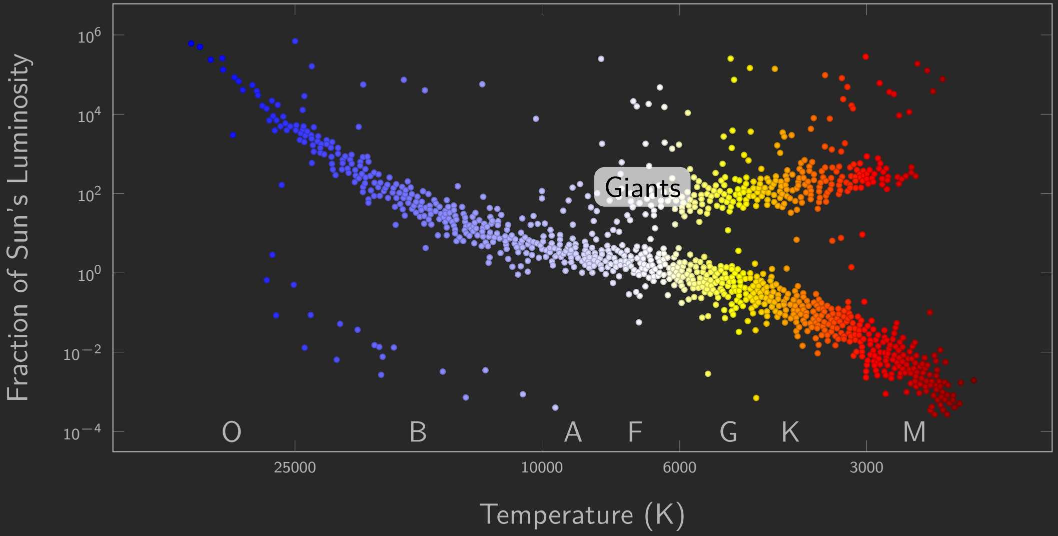

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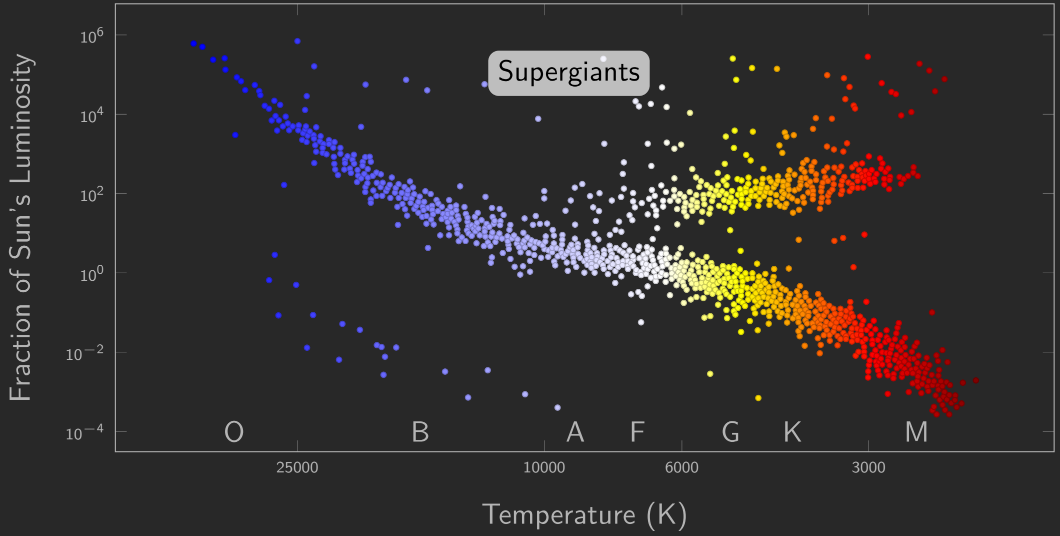


Patterns in HR Diagrams

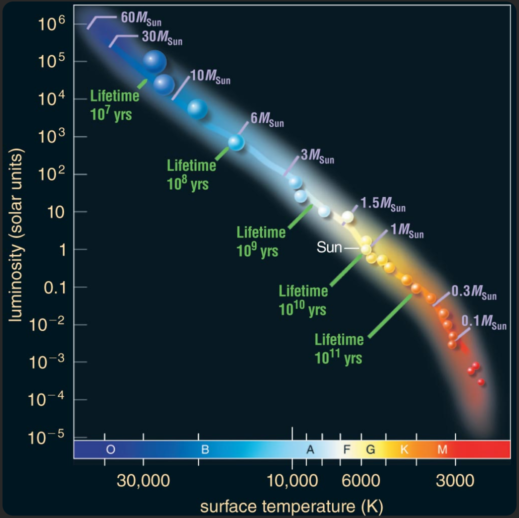
- Hot, Bright stars in upper left
- Cool, dim stars in lower right
- Luminosity depends on both temperature and size
    - Size increases toward the upper right
- Most stars lie along the Main Sequence
- How does mass come into it?

Mass and HR Diagrams

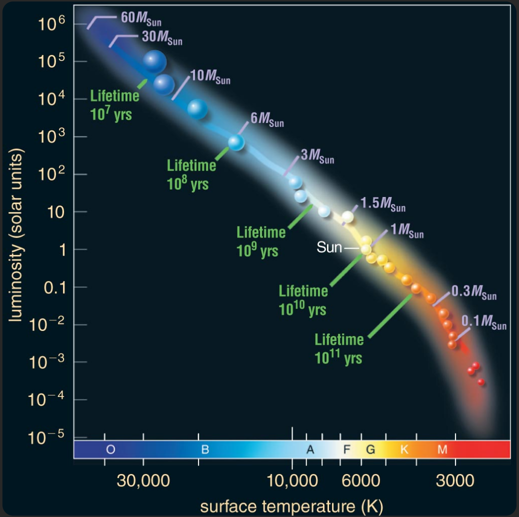
- Globally, there is not an obvious trend
- Trends are clear though for subgroups:
  - Main sequences stars decrease in mass from upper left to lower right
  - White dwarfs are all generally low mass
  - Giants and Supergiants can be any mass
- Mass determines where the balance point between energy in and energy out lies
  - More mass implies hotter and denser fusion and thus more energy
  - Also influences how large the star is
  - Lots of interacting systems striving for balance

Not much for Vacations

- Stars tend to live most their lives in one place on the main sequence
- Stars do not (significantly) change mass over their lifetimes



Shine Bright (like a diamond)



- A star's mass and luminosity do not increase at the same rate:
  - O star
    - $60 M_\odot$
    - $100000 L_\odot$
  - G star
    - $1 M_\odot$
    - $1 L_\odot$
  - M star
    - $0.2 M_\odot$
    - $0.01 L_\odot$
- Brighter stars have shorter lifetimes than dimmer stars!