Announcements

- Webwork due on Friday
- Test 3 one week from Friday!
  - I'll aim to have study materials and old tests up by this weekend
  - Our Sun through stars
  - Probably finish content on Monday
- Polling: `rembold-class.ddns.net`

A bit of review. . .

A friend is telling you about main sequence stars they have been observing of different masses, a few of which include a $0.03M_\odot$, $0.5M_\odot$, $1M_\odot$,and a $120M_\odot$ star. Which would you be most skeptical about?

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B. $0.5M_\odot$

C. $1M_\odot$

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A Massive Undertaking

- A star's mass is likely its most influential property
- Determines:
  - Luminosity
  - Temperature
  - Lifetime
  - And its ultimate fate!
- Catagorize:
  - Low-mass: stars born with a mass $< 2M_\odot$
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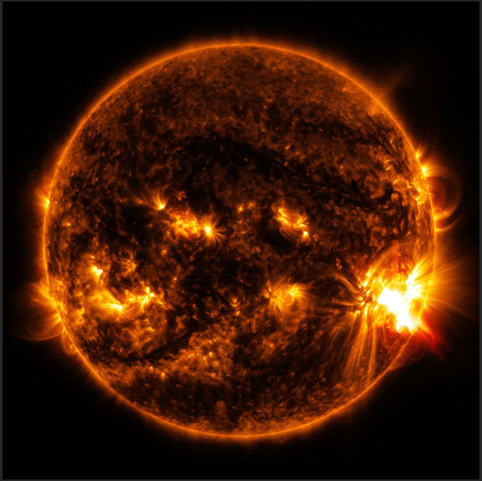
- We'll look at low mass star lifetimes first, then look at intermediate and high mass lifetimes together

The Main Sequence

- Happily creating energy by fusing hydrogen into helium
- Equilibrium between gravity and gas pressure
- Balanced between energy created and energy released
- Provides a steady source of energy
- Spends about 90% of its total lifetime on the main sequence
  - Billions of years



A Fateful Day

- We feel fairly decent at this point about the main sequence
- Our key question is what happens after that?
- Linked to running out of hydrogen to fuse, but what does that imply for our star?

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  - Gas pressure lessens $\Rightarrow$ gravity wins
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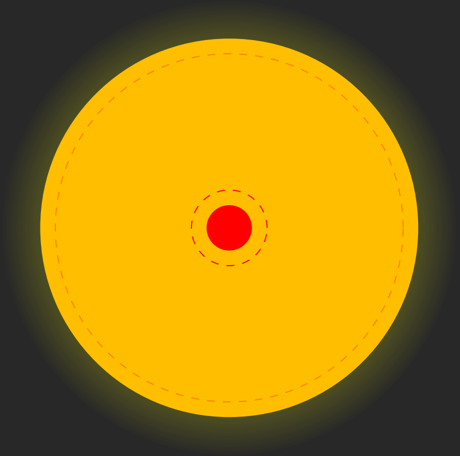
  - Gas pressure lessens $\Rightarrow$ gravity wins
  - Core compresses
- Outer layers still have hydrogen
- Core contraction brings the innermost of these layers into the "fusing zone"
- Hydrogen shell actually "burns hotter"!

A Broken Thermostat. . .

- Increase of fusion rate releases lots more energy
  - Increases gas pressure
  - Outer layers puff up
  - Solar winds start blowing away material



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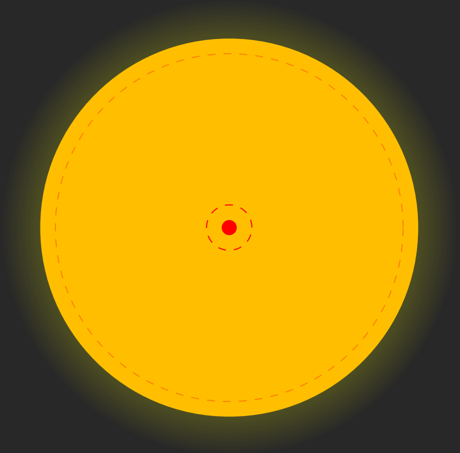

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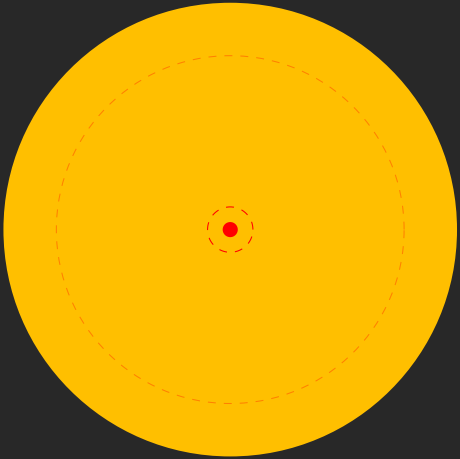
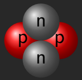
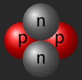


Helium Fusion!

- At temperatures of about 100 million K, helium starts fusing to Carbon
  - Uses a two step process
  - Need such high temperatures because $^{8}\mathrm{Be}$ is very unstable
  - Need it to combine with another Helium before it decays
- Helium fusion actually causes the star to shrink some in size!
- Some Oxygen also created (adding another Helium to Carbon)





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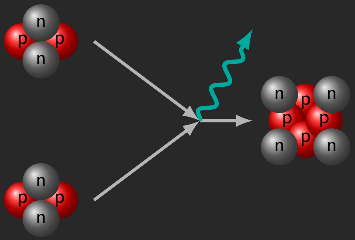

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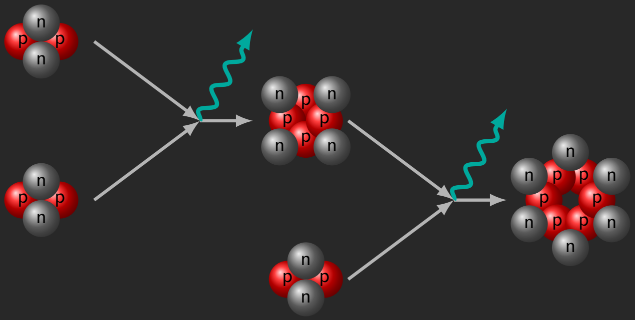
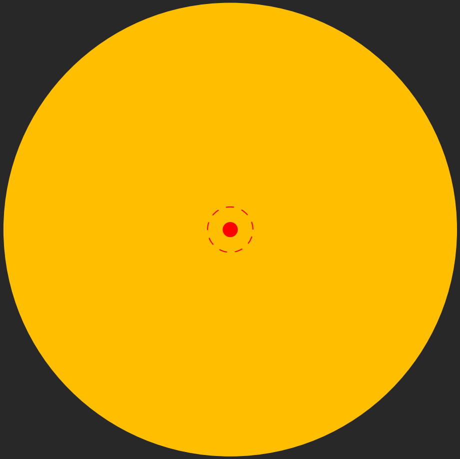


A Flash in the Pan

- Energy from initial helium fusion rapidly expands core (Helium Flash)
  - Pushes out hydrogen burning shell



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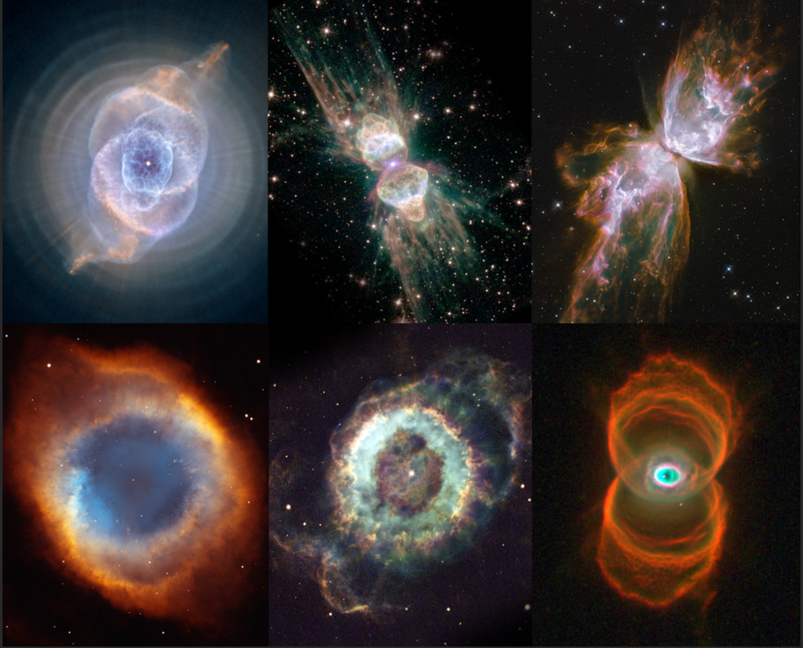
  - Lasts maybe 10-20% as long as hydrogen fusion
- When run out of helium, a repeat occurs, but even worse

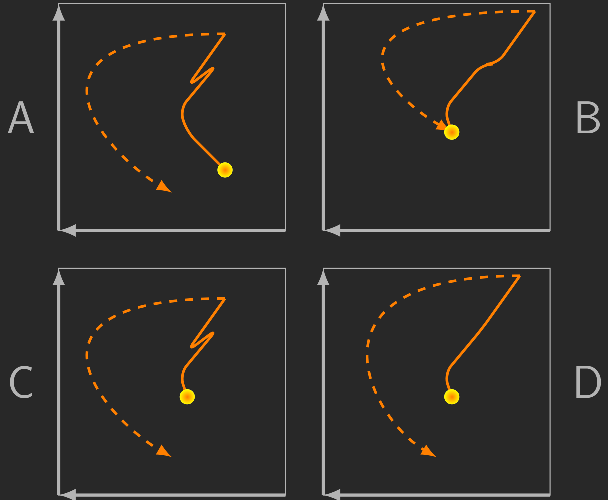
Game Over

- What happens when the star runs out of helium?
- Another growth surge:
  - Core cools, and constricts
  - Now there are two fusing shells, one of helium and one of hydrogen
  - Heats outer layers and causes star to puff up even bigger!
- Core collapses inward until supported by degeneracy pressure
- Not massive enough to squeeze carbon atoms close enough together to start carbon fusion
- Internal energy source turns off
- Most gas outside the core has been blown away
- Becomes a white dwarf
- Outgoing radiation excites expelled gases, creating planetary nebula!



Understanding Check

Which of the following HR Diagrams would show the path of our Sun's lifetime?



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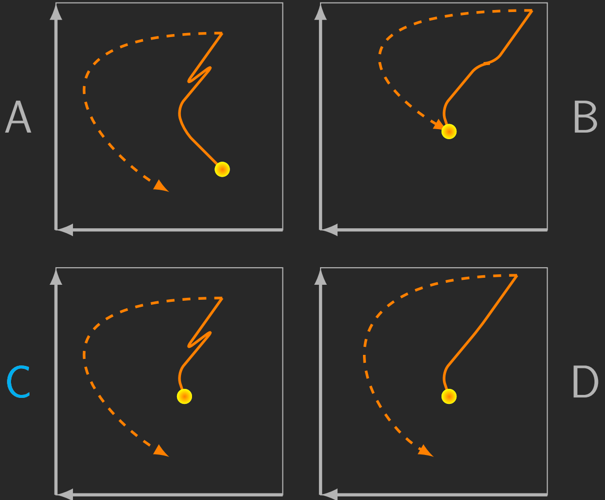
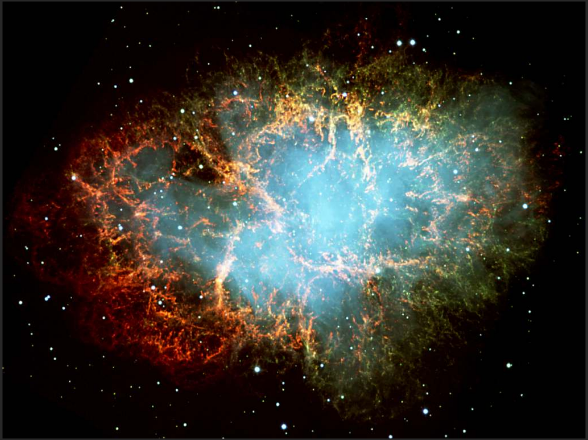


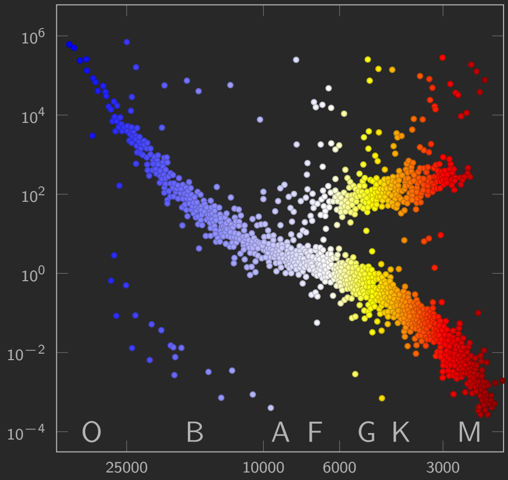
Time to get Massive

- Now we'll shift our attention to the more massive stars
- Talking stars with masses greater that $2M_\odot$



The Boring Part

- Like their low mass bretheren, high mass stars start out on the main sequence
- Burning hydrogen
- Larger mass means:
  - Blue (Hotter)
  - Brighter (Greater Luminosity)
- Fuses through a CNO cycle instead of Proton-Proton chains



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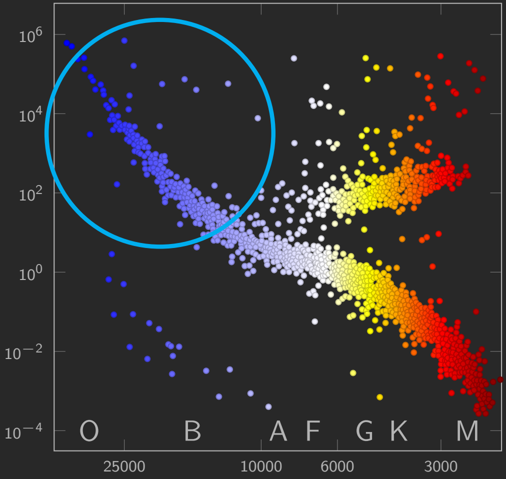
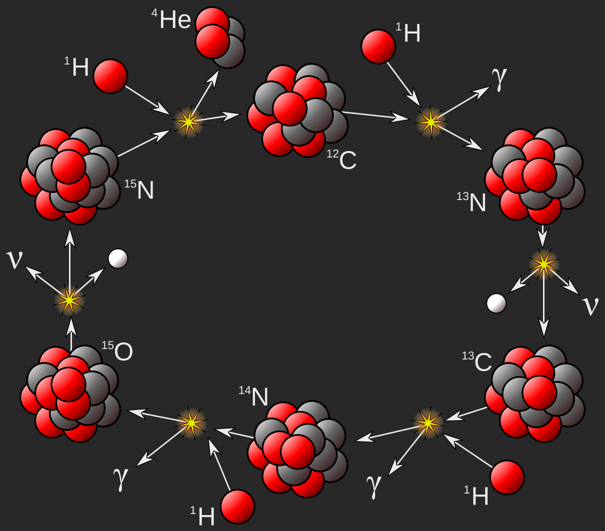


The CNO Cycle



When the H runs out. . .

- The hotter temperatures and CNO cycle fuse the hydrogen much quicker than in low mass stars
- The effects of running out of hydrogen in the core is similar to low mass stars:
    - The core begins to cool and contract
    - Hydrogen shell burning begins and puffs out the outer layers
    - The core contracts and heats until hot enough for helium fusion
- Becomes a Supergiant!
- When Helium fusion activates, there is no helium flash
    - Core still hot enough to support with gas pressure
- Outer layers slower to react means the luminosity stays about the same

When the (Insert Element Here) runs out...

- Things get exciting!
- Core contracts again
  - This time there is enough mass and heat to start carbon fusion
  - Repeats the same cycle as with helium fusion
  - But even shorter timescales this time
  - Carbon fuses into Neon, Sodium, and Magnesium
- Then the carbon runs out!
  - Core contracts again until hot enough for Oxygen or Neon fusion to begin
- Cycle keeps repeating each time the core runs out of fuel
  - Each cycle results in larger elements being produced
  - Each cycle is shorter, as there is less of the heavier element
  - At some point we reach Iron

Our Onion Star

At this point we have multiple layers of shell fusion happening throughout the star