The main sequence and the HR diagram

- **X-axis**: the stars' visible color (also pictorially) and surface characteristic (blackbody temperature in reverse order)

- **Y-axis**: brightness relative to the sun, or in absolute units

- Contours and/or included as visual: size (spherical radius)

1/9
Notice mass is not included on giant branches (density considerations)

Colors sometimes too faint for eye to discern. Divided by spectral class
An animated version

http://abyss.uoregon.edu/~js/ast122/lectures/lec15.html
A medium mass protostar escapes becoming a long-lived red dwarf, or a dead brown one
  • Around same mass as Sun, or up to order of magnitude larger (numbers on the previous slide)
  • These are known as T Tauri protostars

As a protostar becomes a star, entering the main sequence, the core heats up to millions of degrees (while the surface remains at a few thousand) and hydrogen is converted into helium
  • This is related to greater pressure with greater depth: think diving underwater. All about gravity, and fusion.

Photons and neutrinos radiate away the energy from near center, latter quite easily
  • In external layers, convection takes over, like in your (classic) ovens: layers of gas turn over and mix, roiling
After O(10) billion years (our Sun is thus about half-way spent) there is now lots of helium around.

Helium is heavier than hydrogen, and it is inert, so the core collapses under own mass.

Heat from collapse ignites leftover hydrogen, which becomes a rapidly expanding shell, bloating the star to O(100) times its original radius.

Newly compressed core becomes hot enough to fuse helium to carbon (3-α process) at 100+ million degrees.

In few thousand years, this spreads into a helium flash.

- Before helium ignition and flash, all nuclear fusion ceases for O(10) million years, so pressure eases up, and gravity leads to an extra squeeze at the center.
- Resulting heat reduces density of outer hydrogen dregs => expansion.
- Hydrogen still converted into helium in outer shell. Surface cools, reddens.
Red (super)giant countdown

- 1 million years to go: a carbon/oxygen core appears inside helium core that is even denser and hotter. Star re-stabilizes (but intense stellar winds are constantly tearing the cold, mostly inactive, hydrogen away from the outermost layers)
- 1 thousand years: neon/magnesium core (other elements persist as nested interior shells). In general, cycle is: fuel expended -> fusion pauses -> contraction occurs again -> at higher pressure and temperature and density, then new and different, higher-energy, reactions become possible that were not before. Progress gets faster & faster toward doom
- ~7 years: Oxygen/magnesium central nucleus. Starting to look like complex onion with concentric ‘skins’ of distinctive elements. Unique reactions happening across regions.
- ~1 year: Silicon/Sulfur. Temperature reaches the billions!!
- ~Days: Iron heart develops that is ~150% mass of our sun. End of the line because iron can not undergo nuclear fusion
~0.1 seconds to go: Fusion finally stops for good. The central sphere of elemental iron collapses in upon itself at ~0.25c (~50,000 mps). At 100+ BILLION degrees iron nuclei melt together (not technically fusion) and melt into fragments too.

**Maximum scrunch** occurs when the electromagnetic force, which is stronger than gravity, halts the contraction for good: the many, all positively-charged, protons floating around can’t stand closeness any longer. Collapse “springs” back. Neutrinos from iron nucleus overlap phase jiggling around.

**Milliseconds into explosion**: the iron recoil causes a massive shockwave to form. As it rips through the many skins of the star, it re-heats parts and generates nickel, and other, heavier elements, both radioactive and stable, sometimes even an entire periodic table worth. Explosion spreads them.

**Seconds into explosion**: Supernova neutrino burst takes away ~99.5% of energy. Beats main shock wave, traveling at near-c. Ironically, is the first sign of trouble externally. White dwarf, neutron star, or black hole is the result of the scrunch.
A diversity of fates

By: Idrees Kahloon and Kevin Waterman

**Life Cycle of a Star**

1. **Average Star**
   - After achieving equilibrium, the star begins burning up its supply of hydrogen and helium through nuclear fusion.

2. **Red Giant**
   - Loss of fuel in the core results in expansion by up to 1000 times.

3. **Planetary Nebula**
   - The star has no energy left and begins losing layers and forms a complex structure.

4. **White Dwarf**
   - Very dense star that is the end stage of average star life.

5. **Neutron Star**
   - Remnant of supernova that ejects particles.

6. **Black Hole**
   - Infinite gravity, and no mass.

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**Stellar Nebula**

This is the protostar composed of dust clouds. In this stage the star is trying to achieve equilibrium between gravity, the pressure on the core, and the temperature.

**Massive Star**

These fundamental stars produce heavy metals that help regulate the accretion rates of normal stars, their formation is still a great mystery.

**Red Supergiant**

Biggest stars in universe, with short life cycle. Forms at the end of star life.

**Supernova**

A stellar explosion that is triggered by the loss of any remaining fuel, enriches interstellar medium.

Sources: [http://www.aseasky.org/cosmic/assets/images/starlife.jpg](http://www.aseasky.org/cosmic/assets/images/starlife.jpg)
Read [http://abyss.uoregon.edu/~js/ast122/lectures/lec15.html](http://abyss.uoregon.edu/~js/ast122/lectures/lec15.html) starting with “Cluster HR Diagrams,” and then continuing to read on straight through to the end, paying special attention to the section entitled “Variable Stars,” which will be our next topic.

- The Discovery of Pulsars (an American Physical Society look back at physics history) [http://www.aps.org/publications/apsnews/200602/history.cfm](http://www.aps.org/publications/apsnews/200602/history.cfm)

**HW #10**