Announcements

- **Mid-Term Exam #3 Next Tue, Nov 9th, in class**

- **Magazine Extra Credit, Due Today (in class or email).**

- **OBAFGKM 2 point extra credit available up through the date of the exam.**

- **Special Planetarium Showing next Monday evening for people with conflicts.**

Thursday, November 4, 2010
Exam 3 Buy-Back Change

- Up to 10 points credit on your exam.

- Same format, but now ONLINE.

- Look on MasteringAstronomy for the assignment “Exam #3 Buy-Back.”

- Fill out up to 5 buy-backs. Don’t forget to do all 5 parts for full extra-credit.

- Due 11/16.
Complete all 5 parts (A-E) for buy-back credit!

Part A - Question missed

Text of question you missed:

Submit my answers give up

Part B - What you chose

Text of the incorrect answer you chose:

Submit my answers give up

Part C - Why you missed

A description of why you missed this question (e.g. what misconception you had):

Submit my answers give up

Part D - Correct Answer

The text of the correct answer:

Submit my answers give up

Part E - Why it's correct

An explanation of why the new answer you chose is correct:

Submit my answers give up

Continue See Score and Provide Feedback
Special Planetarium Show

- For those whose schedules don’t permit Fri evening or Sat. afternoon visits.

- This coming Monday, November 8th at 6:30pm in Ritter Planetarium.

- Also possibility for evening observing afterwards (bring both tickets).

- First come first served (all 5 1010 sections are being informed).
OBAGFKM

- Obama's Building America For Good Kids, Man
- Oh Boy! A Farmer Got Kicked by Me
- Only Boys Are Favored, Girls “Kinda” Matter
- Only Bears Are Fishing, Generating Killer Meals
- Only Bald Apes Find Good Ketchup Meatloafs
- Our Big Awesome Fairy Got Kinda Mean Last Tuesday
Stellar Birth

- **Stars form in very large, cold interstellar clouds composed of molecular hydrogen and dust called, molecular clouds.**

- **These molecular clouds sit between the stars in the Galaxy.**

- **The are very cold (10 K) so we can only see them with infrared and radio telescopes.**
Stars will form where gravity can overcome the pressure of the gas.

A clump of gas will contract until it heats up enough to start nuclear fusion in its core. The star has been “born”.

The gravitational potential energy is converted to thermal energy during the contraction phase.

Star is “born” when fusion begins in the core, and contraction stops.
What if you could stop the contraction before fusion begins?

Stop!
Thermal Pressure
Depends on heat content.
The main form of pressure in most stars.

Degeneracy Pressure
Does not depend on heat content.
The electrons cannot be in the same state at the same place. They fight back by moving faster = Pressure!
Electron Degeneracy Pressure

- At the cores of young stars, the temperatures are so hot, the gas is ionized (electrons ripped away from the nuclei).

- The core of a brown dwarf is so dense that this “electron degeneracy” pressure halts the contraction before H fusion can begin.
Participation Question

- Take out a piece of paper, write your name and Rocket ID, and the answer(s) to this question:

- Brown Dwarfs never get hot enough at their cores for fusion to occur because

- Don’t forget to turn it in at the end of class in the back of the classroom on your way out for your participation credit!!!
How Stars Form

As the star contracts, it spins up due to angular momentum conservation and forms a disk of material around it (the “Solar” Nebula).
Stars Form in Groups
...AND MAKE JETS
JETS

100,000 A.U.
0.5 LY
Orion Star Formation Complex

Visible
Orion Star Formation Complex

Infrared
Orion Star Formation Complex

Radio
Orion Star Formation Complex

Radio
Orion Star Formation Complex (700 light-years away)
Orion Star Formation Complex (700 light-years)

Glowing gas is due to H and O.
Orion Star Formation Complex (700 light-years)
Flying through Orion

Thursday, November 4, 2010
Conditions for Star-Formation

- If massive enough, gravity of a collapsing cloud “wins” over the pressure preventing it’s collapse.

- Many stars are formed together in the same cloud: some are ejected from cloud, some stay together to form clusters.
Mathematical Simulation

- $T = 10 \text{ K}$
- Size = 80,000 A.U.
- Mass = 10 $M_{\text{Sun}}$
A star-forming pillar
And clouds
AND OTHER CLOUDS
An aside on color

Color in astronomical images is normally what’s called “false color”.

It’s not what your eyes would see.

In many cases, your eyes couldn’t see it at all (e.g. an infrared image).
Stellar Youth

Once stars are formed, they begin fusing hydrogen in the cores on the zero age main sequence.

They spend most of their lives on it burning H to He.

Move only slowly on the H-R diagram (up and to the right), broadening it.
**Stellar Lifetime**

<table>
<thead>
<tr>
<th>Spectral Type</th>
<th>Mass (Sun=1)</th>
<th>Lifetime on MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>O5</td>
<td>40</td>
<td>1 million years</td>
</tr>
<tr>
<td>B0</td>
<td>16</td>
<td>11 million years</td>
</tr>
<tr>
<td>A0</td>
<td>3.3</td>
<td>440 million years</td>
</tr>
<tr>
<td>F0</td>
<td>1.7</td>
<td>3 billion years</td>
</tr>
<tr>
<td>G0</td>
<td>1.1</td>
<td>8 billion years</td>
</tr>
<tr>
<td>K0</td>
<td>0.8</td>
<td>17 billion years</td>
</tr>
<tr>
<td>M0</td>
<td>0.4</td>
<td>56 billion years</td>
</tr>
</tbody>
</table>

*(Current age of universe: 13.7 billion years)*
Stellar Old Age

As a star ages, it begins to deplete the store of hydrogen it gathered in its core when it formed.

As the fuel supply drops, something must change.

At some point, either gravity or pressure “wins out”

Eventually, stars become white dwarfs, black holes, or neutron stars.
Main Sequence to Red Giant

- H in core used up
- He “ash” in core
- No more fuel for energy
- Gravity begins to win
- Core contracts, gets hotter, starts H fusion in shell surrounding core
- Thermostat is broken: outer layers expand
- Star becomes Red Giant
Losing the Battle

At some point, the Core contracts so far, the temperature becomes very hot.

Now hot enough to fuse Helium into Carbon.

 Stops collapse: star is stable again.
Helium Fusing

- Like hydrogen fusion, if the temperature is high enough (10^8 K), helium can be fused into carbon.

- Helium fusing can then become a source of outward pressure to counteract gravity (but not for long!)
The degenerate He core becomes hot enough to fuse He and the He flash occurs.

The temperature of the core skyrockets and thermal pressure again dominates, expanding the core.

He is fused to C for roughly 100 million years.

Eventually the He runs out and $g > p$, so the core shrinks, heating up, causing the star to expand to an even bigger red giant.
Beginning of the End

- Helium runs out, and core collapse resumes.

- Helium begins burning in a shell, and the outer layers expand.

- Star becomes a Red Supergiant

- Strong mass loss occurs via stellar winds
**Life and Death as a Low-Mass Star (<8x the Sun)**

- **Sun is an example. It will shine for 10 billion years.**

- **Runs out of Hydrogen in the core. Burns it in “shells”, but the core keep collapsing, heating.**

- **Expands to 100x it’s current size, 1000x the luminosity.**

- **Lose it’s outer layers to become a “planetary nebula”**.
Life and Death as a Low-Mass Star (<8x the Sun)

- Low mass star is never hot enough to fuse carbon. Electron degeneracy stops core collapse.
- Eventually will become a white dwarf: a hot “decaying Corpse” remnant of the star’s core. Cools and vanishes.
Planetary Nebula

- The carbon core becomes degenerate but never gets hot enough to use carbon as a fuel. But shells of He and H are still fusing.

- The outer layers of the star are blown off and create a Planetary Nebula with the degenerate carbon core at its center.

- The leftover carbon core is called a white dwarf.
Planetary Nebula

Eskimo Nebula
Planetary Nebula

Helix Nebula
Planetary Nebula

Cat's Eye Nebula
Planetary Nebula

Retina Nebula
Planetary Nebulae
Summary of Low-Mass Star’s Life

- **A low-mass star is usually in 1 of 2 states:**

  - **$g = p$:** The core is fusing and possible shells around the core are fusing.

  - **$g > p$:** Shells around the core are fusing and dumping material onto the inert core. The star is very large because of the broken thermostat.

- **Electron degeneracy can stop the core from collapsing enough to start fusion again.**
What about the Earth?

A.D. 5,000,000,000: Sun’s luminosity will go up by 1000x! Earth temperature 1000K.

Sun will swell to the Earth’s orbit, before turning into a white dwarf.
Life and Death as a High-Mass Star (>8x the Sun)

- At first, evolution similar to low mass star:
  - Core of hydrogen, fusing to helium
  - Red giant phase with H fusing in a shell.
  - Core of helium fusing into Carbon.
The CNO Cycle

- The CNO cycle is just another way to fuse H into He, using C, N, O as a catalysis.

- The CNO cycle is the main mechanism for H fusion in high-mass stars because their core temperatures are higher.
Life as a High-Mass Star ($M > 8 \, M_{\text{Sun}}$)

- **High-mass stars become supergiants when the core runs out of H.**

- Begins the process of expansion and contraction as the core goes through several phases of fusing heavier elements.
How do stars make the elements?

The Big Bang makes H (75%) and He (24%), and Li, Be, B (1%).
Helium fusion makes carbon in low-mass stars.
The CNO cycle makes N and O.
How do stars make the elements?

Helium capture adds two protons at a time.
Helium capture builds C into, N, O, Ne, Mg.
How do stars make the elements?
Helium capture converts Si into S, Ar, Ca, Ti, Cr, & Fe.
How do stars make the elements?

- **All of these various fusion reactions occur as the star evolves.**
- **Like a low-mass star, a high-mass star goes through stages where the core is and is not fusing.**
- **The star ends up with numerous fusing shells.**
How do stars make the elements?

Other reactions create the other elements up to Fe.
Can this go on forever?

- The Helium has less mass than 4 hydrogen atoms.
- The difference is converted to energy ($E=mc^2$).
- The mass per nucleon decreases.
Can this go on forever?

The mass per nucleon goes down until iron.

Iron cannot be fused into anything and therefore the star has no energy source.
How does a high-mass star die?

We are left with a core of degenerate iron (Fe).

Eventually the iron core cannot support itself under the crushing weight of the star.
And then....SuperNova!!!
How does a high-mass star die?

- Electrons and protons combine to form neutrons and neutrinos.
- The core collapses to form a degenerate neutron core.
- The star explodes in a **supernova**, and we are left with a **neutron star**.
The energy from the supernova creates all the other elements.
**Exam Review**

- **Nov 9th, in class. Closed book/notes.**

- **Bring a Pencil!**

- **Use the M.A. Study Guide (e.g. “concept quizzes”).**

- **Concepts stressed: don’t try to memorize everything, just focus on understanding physical concepts.**

- **Chapters 5.3 (telescopes), 6-11, Planets and Stars**
Telescopes

- Bigger is better: resolution, light gathering power.
- Refracting vs. reflecting
- Reason for space telescopes (atmosphere blocks most light, atmospheric turbulence)
- Adaptive optics and interferometry
Solar System Overview

- Basic structure and arrangement (mostly in flat, mostly circular orbits, everything orbiting/rotating in the same sense).

- Components (sun, planet, moons, asteroids, comets, kuiper belt, oort cloud).

- Mass in various parts (mostly in Sun).

- Two different planet flavors: terrestrial and jovian.
**Terrestrial Planets**

- **Rocky, dense, small.**

- **Surface Activity:** cratering, volcanism, tectonics, erosion

- **Cratering as a means of age-dating a body's surface**

- **Mars/Mercury/Moon:** “Dead” planets... why? (small! so interior cooled fast, lost magnetic field, etc.)

- **Magnetic fields and its role protecting from solar storms + aurora**

- **Greenhouse effect:** trapping heat by atmosphere. Keeps earth warmer than it would be (good in moderation!) runaway Greenhouse effect on hot Venus.
**Jovian Planets**

- **Giant, gas-rich, low-density (Saturn would float in water!)**

- **Formed beyond the "Frost Line" where ice could accumulate and build up planets fast and large. Small rocky/metallic cores.**

- **See cloud tops, not surface: ammonia, methane, etc. Determines colors.**

- **Major storms/rings of small particles**
Moons

- Terrestrial planets few and small (except Earth’s... impact origin!). Jovian moons are diverse and many.

- Volcanism and other activity due to tidal heating (e.g. squeezed by Jupiter’s tidal forces in forced elliptical orbits).

- Water oceans, fresh icy surfaces, atmosphere, as big as Mercury
Small Bodies

- **Asteroids**: A failed planet between Mars and Jupiter, largest is hundreds of KM.

- **Smallish (few km), not round**

- **Meteorites**: Small bits of asteroid/moons/planets that fall to earth. Meteor is the tail of debris left behind as it plummets through Earth’s atmosphere (“shooting star!”).

- **Comets**: Icy visitors from outer reaches of solar system, some come near Sun producing tails.
**Outer Solar System**

- "Kuiper" belt, a flat extension of the solar system to 100AU: contains Kuiper Belt Objects (like Pluto!).

- Pluto “demoted” when other more like it found in the K.B. (eris, Sedna, etc.).

- Oort Cloud: large random orbits, very cold, to 50,000AU
EXTRASOLAR PLANETS

Many hundreds now known! Very difficult to detect (star much much brighter)... indirect “wobble” methods used based on velocity (Doppler shift) or position (Astrometry) of the star, “transits” (planet blocks starlight).

Which detection method can be used depends on orientation of orbit “face-on” or “edge-on”

Many “hot Jupiters” found: heavier than Jupiter, closer to their sun than Mercury! Revise the nebular theory (inward migration?).

Earth-like planets still hard to find, but likely there.
The Sun

An average star, made of gas, 6000K surface, 10 million K core. Mostly H and He.

Nuclear Fusion only possible power source... others (gravitation collapse, chemical energy like a bonfire) not nearly enough to fuel the prodigious power output ("Luminosity").

Hydrogen is turned into Helium in the core: mass of 4H < 1 He, rest turned into energy (E=mc²!)

Equilibrium between Gravity (wants to contract), and pressure (wants to expand, powered by core fusion).
The Sun

Core, Radiation zone, convection zone, photosphere, atmosphere (chromosphere, corona, solar wind).

Sheds energy from core by random walk of photons as they bounce their way out (hundreds of thousands of years!) and convection, like boiling oatmeal.

Sunspots: at the base of giant magnetic loops which twist and are thrust out from the sun. Cooler than surroundings (so darker), frequency governed by 11 year cycle. Used to gauge rotation (25 days at equator, slower at poles).

Prominences, flares and coronal mass ejection: solar storms of energetic particles.
Stars

All powered by nuclear fusion, like sun.

Many billions in the galaxy, differing primarily by Mass, from 10% to 150x suns.

Magnitudes based on Hipparchus by-eye: Apparent vs. Absolute: you have to know the distance to know intrinsic brightness. Apparent brightness drops like $1/D^2$. Measuring apparent magnitude: "Photometry". Brighter = lower magnitude!

Stars move in the Galaxy, but slowly: constellations change over thousands of years.
Distances to Stars

- Needed to gauge true luminosity (or, equivalently, “absolute” magnitude).

- Use parallax for close stars.

- Find intrinsic luminosities from .0001 to 1,000,000x the sun’s!

- Spectra and colors give surface temperatures: from 50,000K down to 700K: very different color stars.
HR Diagram

- Stars fall into neat classes: stellar classification letter OBAFGKM(LT), a sequence of temperatures, from hot to cool.

- Plot Temperature vs. Luminosity (the “HR diagram”): find a “main sequence” where stars spend most of their lives burning hydrogen.

- Mass is the controlling factor along main sequence: High mass=High Luminosity=Hot Temperature=Blue Color=Large Radius=Short Lifetime. Smallest stars live for trillions of years!
**Off the main sequence**

- Some stars hot but faint, or cool but very bright: **Stars not on the main sequence:** giants and super-giants, white dwarfs (all late phases in a star’s lifetime).

- "Luminosity class" used to distinguish a red main sequence (e.g. M5V) from a red super-giant (M5I).

- Sizes of stars vary tremendously: **White Dwarfs tiny (size of Earth), Supergiants larger than the entire solar system!**
Stars

- Clusters of stars: open (young, <1000 stars) and globular (oldest things we know of in the universe, up to a million stars!).

- Useful for stellar “census” since all stars born at the same time.

- Main sequence “turn-off” in clusters: most massive star which hasn’t yet died.

- As in the local Solar neighborhood, find many more low-mass than high-mass stars. Most stars are small!
Reminders

- Exam on Tuesday, bring a pencil!

- OBAFKM: Still time (before Tue) to submit

- Special evening planetarium show Mon @6:30pm.

- HW #7 due this Sunday.

- No HW next week, and no class next Thursday (Veteran’s Day).