Stars: Stellar Evol & “death”
Galaxies
“Ancient stars in their death throes spat out atoms like iron which this universe had never known. ... Now the iron of old nova coughings vivifies the redness of our blood.”

— Howard Bloom

“In the vast cosmical changes, the universal life comes and goes in unknown quantities ... sowing an animalcule here, crumbling a star there, oscillating and winding, ... entangling, from the highest to the lowest, all activities in the obscurity of a dizzying mechanism, hanging the flight of an insect upon the movement of the earth...”

— Victor Hugo
Announcements

- SS Homework posted, due 11/19
- 3rd midterm 12/3
- I will drop the lowest midterm grade
Last Class

- Midterm Debrief
- Stellar Classification (review)
- Intro to the HR Diagram
  - LT HR Diagram
- Stellar Evolution
  - Main Sequence
  - Red Giants and Supergiants
  - Endgame (time permitting)
    - Low mass stars—planetary nebulae, white dwarfs
    - High mass stars—supernovae, neutron stars, black holes
This Class

- Stellar Evolution ctd.
  - Red Giants and Supergiants
  - Endgame
    - Low mass stars— planetary nebulae, white dwarfs
    - High mass stars — supernovae, neutron stars, black holes
- Binaries & Clusters (time permitting)
- Galaxies
  - What’s a Galaxy?
  - Galaxy types
  - LT Galaxy classification
Life on Main Seq

recap
Rate of Mass-Energy Conversion

- p-p chain produces energy for low mass stars
  - $4H \rightarrow \text{He} + \text{energy}$
- for Sun $10^{38}$ reactions per second
- consumes $6 \times 10^{11}$ kg per second
  - 600,000,000 metric tons
  - Sun’s mass is very large! (2x$10^{30}$ kg)
  - 0.00001% per million year
Low Mass and High Mass Stars

- **Low mass:** less than about 4x Sun’s mass
  - Sun is good model
  - use the proton proton chain

- **High mass:**
  - use the CNO cycle rather than the p-p chain
    - same net result 4H->1He
    - different set of reactions
Let’s Practice
It takes extreme physical conditions to initiate nuclear fusion because _____.

A. nuclei have positive electrical charge and repel each other.
B. the nuclear forces that hold nuclei together are very short range
C. Both of these
D. Neither of these
If fusing H to He converts millions of tons of mass into energy every second, why aren’t we worried about using up the Sun?

A. The energy turns back into mass.

B. The proton-proton chain only operates for a few seconds.

C. A million tons of mass is a tiny fraction of the total mass of the Sun.

D. The Sun is constantly manufacturing new H to replace the fused H.
The condition that keeps a Main-Sequence star relatively stable in size and temperature is _____.

A. nuclear fusion

B. the Jeans Instability

C. hydrostatic equilibrium
The Sun’s Luminosity comes primarily from _____.

A. chemical burning
B. gravitational contraction
C. nuclear fusion
D. nuclear fission
Stellar Evolution and “Death”
The Main Sequence isn’t Forever!

- Stars on the MS are stable/stationary
- Stars leave main sequence to become red giants or supergiants
- Mass determines maximum core temperature & fate
Red Giants & Supergiants
The Main Sequence isn’t Forever!

- Low & Moderate Mass Stars become red giants
  - Up to about 4x Sun’s mass
  - Up to about type A
  - Max core temp supports fusion to He → C, O
Core H Runs Out

- No more fusion in core.
- What do you think happens when the power plant shuts down?
- Hint: think about pressure & gravity

Core H Runs Out

- pressure reduces
- star begins to collapse
- what happens when the star shrinks?
- It heats up!
- Area around core reaches 10,000 K
- H fusion starts again

A Red Giant Emerges

- H fusion starts again—Shell
- Causes outer layers to expand
- When they expand, they…..
- …cool
- Red Giant
- Core continues to heat
  - at 100,000,000K He begins fusing
  - C & O build up
A Red Giant Emerges

- H fusing shell expands
- He fusing shell forms
- Core stars to build up C,O “ash”
Life as a Red Giant (Low Mass Stars)

- Red Giant is
  - MUCH larger
  - cooler
  - more luminous
  - short-lived: about 1/10 Main Sequence life
  - Not as stable as a MS star

Image from: http://www.fromquarkstoquasars.com/the-day-with-no-tomorrow/
The Main Sequence isn’t Forever!

- High Mass Stars become red giants & Supergiants
  - Above 4x Sun’s mass: OB and most A stars
  - Much less stable & predictable
  - Max core temp supports fusion up to Fe
High Mass Stars

- Starts like low mass stars
  - Red Giant/Supergiant
- Core temps continue to increase
  - at ~1 billion K, C fusion stars
- Layers of fusion
  - up to Si (silicon) → Fe (iron)
- Once Fe fusion starts, death (supernova) is imminent
Let’s Practice
If the red giant phase lasts 10% of a star's life on the main sequence, we would expect to find there are

A. more main sequence stars than red giants.
B. more red giants than main sequence stars.
C. the same number of red giants as main sequence stars.
Why might we observe a larger fraction of red giants compared to main sequence stars than the ~10% you would expect from the previous question?

A. They live longer than main sequence stars.
B. They are larger and brighter than main sequence stars.
C. They are closer to us on average than main sequence stars.
ENDGAME OF LOW MASS/AVERAGE STARS STARS
From Red Giant to Planetary Nebula

- Low Mass Stars stop core fusion with He
- H, He fusion shells expand
- “Push off” outer layers
- planetary nebula
Planetary Nebulae

Final Remnant — White Dwarf

- Core exhausts He
- Contracts & interior heats
  - not hot enough to fuse C to O
- Contraction stopped by electron degeneracy pressure
  - resists putting 2 e in same place
- Core becomes white dwarf
  - a hot, dense naked core
  - ~25,000K at surface
  - up to 1.4 x Sun’s mass compressed to Earth size

Artist’s concept
Image ESA/NASA
White Dwarf

- White dwarfs last a long time
  - Held up by e- pressure
  - Cannot shrink, cannot heat up, cannot increase pressure “Stuck”
  - In isolation, very slowly cool and fade away

Artist’s concept Image ESA/NASA
A white dwarf is hot and tiny. This implies it will have a _____ color and a _____ luminosity than its main sequence progenitor.

A. redder, lower  
B. redder, higher  
C. bluer, lower  
D. bluer, higher
ENDGAME OF HIGH MASS STARS
Supernova Destroyer/Creater Space.com
The biggah boomah

- **Type II Supernova**
  - Huge cataclysmic explosion
  - about 10 billion times as luminous as the Sun
  - fade over months or years
  - everything heavier than iron fused by explosion

- Leaves behind a neutron star or black hole
Core-collapse

- "Onion layers" of heavier and heavier elements in their interiors.

- Fusion in stellar core won't go heavier than iron (Fe)
  - Fusing Fe uses up energy
  - Fe core reaches 1.4 $M_\odot$.
    - Chandrasekhar limit
    - electron degeneracy pressure can't hold it up
    - takes seconds!

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Time</th>
<th>Percentage of Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>7,000,000 years</td>
<td>93.3</td>
</tr>
<tr>
<td>He</td>
<td>500,000 years</td>
<td>6.7</td>
</tr>
<tr>
<td>C</td>
<td>600 years</td>
<td>0.008</td>
</tr>
<tr>
<td>O</td>
<td>0.5 years</td>
<td>0.000007</td>
</tr>
<tr>
<td>Si</td>
<td>1 day</td>
<td>0.00000004</td>
</tr>
</tbody>
</table>
Core-collapse

- **The core collapses.**
  - Protons and electrons are pushed together
  - form neutrons and neutrinos
  - exert a tremendous outward pressure.
    - observe neutrino outburst
  - stops when neutrons getting packed too tightly
    - neutron degeneracy
Core-collapse

- outer layers fall inward
  - outer layers crash into the core and rebound
  - shock waves move outward
- Star explodes — Type II Supernova
End result is either a Neutron Star or Black Hole

- Depending on the....?
End result is either a Neutron Star or Black Hole

• Depending on the.....?

• Remaining mass in the core!

• mass is (almost) everything if you are a star...
The Neutron Star Route

- Collapsed core <2 or 3 M☉
  - MS star about 8-20 M☉
  - made of degenerate neutrons
  - very intense magnetic fields

- VERY Dense
  - 1.4 to 3 M☉ compressed into a radius of about 10 km.

- As something spinning collapses, it spins faster.
- neutron stars spin very fast
Discovery of Neutron Stars/Pulsars

- Predicted in 1930s
- discovered 1967
  - A graduate student named Jocelyn Bell was monitoring radio emission from space
  - discovered a really regular signal.
  - Unlikely anything natural could produce such a regular, repeating signal.
  - The source of the radio signals was dubbed "LGM1". (Little Green Men)
- Several more were discovered.
Pulsars

- Astronomers finally deduced that they were observing very rapidly rotating neutron stars -- pulsars.

- Charged particles move around the magnetic fields
  - most intense around the magnetic poles.

- As the pulsar rotates, acts like a "light house."

- When the radio emission is pointed at us, we see a "pulse."
The Black hole Route

- Collapsed core >2 or 3 $M\odot$
  - Progenitor star > about 20 $M\odot$
- for objects more massive than a neutron star, there is nothing that can stop the inward collapse due to gravity
- The final result is a black hole, a very small, very dense “singularity” that warps spacetime sufficiently that not even light can escape.

Artist’s Concept of a Black Hole
Credit: NASA
So what is a black hole?
What is a black hole?
Journey into a Black Hole
Another Scenario (involving more than 1 star)
Type Ia Supernovae

- Ingredients: a white dwarf with a post-main-sequence companion
  - Or 2 white dwarfs
- Companion dumps material onto the white dwarf
- When the mass > 1.4 Msun, the degenerate gas cannot support the pressure
- Resulting supernova completely obliterates the white dwarf
Importance of Type Ia SN

- **Standard Candle**
- SNIa explosions happen under very consistent conditions
- The light output of a Type Ia SN is therefore very predictable
- Can assume the same peak brightness is always produced
Let's Practice
What is the fate of a 10-solar mass star?

A. Type Ia supernova
B. Type II supernova
C. white dwarf
What is the fate of a 5 solar mass remnant core after a Type II supernova has occurred?

A. neutron star  
B. black hole  
C. white dwarf  
D. planetary nebula
If your black hole research spaceship approached the site of very massive star that had gone supernova, what would happen?

A. It would inevitably get sucked into the black hole with no possibility of escape.

B. It would detect the gravitational pull of the black hole and be able to go into orbit around it.

C. It would be unable to locate the black hole because it’s, well, black.

D. It would be repelled by the black hole.
Stars in Groups
Binaries & Clusters

- Single stars are not common!
- 1/2-2/3 stars are in pairs (binaries) or larger multiple star systems
Binary Stars & Multiple Star Systems
Binary Stars

- 2 stars orbiting around their common center of mass
  - not generally resolved
- Important
  - masses of component stars can be determined from orbit
  - other properties can be indirectly estimated
    - e.g. radius and density
Mass Transfer

- If stars are close, gravity tidally distorts outermost layers
- can exchange mass
- can lead to novae & type Ia supernovae
Let’s Practice
Suppose you discover two stars that appear to be very close to each other in terms of angular separation. You measure the stellar parallax for each and find one to be at 4 pc and the other at 10 pc. Have you discovered a binary star system?

A. Yes
B. No
C. Maybe
HDE 226868, a very high mass star, orbits Cygnus X-1, the first widely accepted black hole. The fact that Cygnus X-1 was in a binary system was key in making the initial argument that it was a black hole. This was because _____.

(use your knowledge of binaries and black holes to reason this out)

A. HDE 226868 was observed falling into Cygnus X-1

B. the light from HDE226868 illuminates Cygnus X-1 allowing it to be seen

C. the orbit of HDE226868 allows the mass of Cygnus X-1 to be determined
Clusters
Stars in Groups: Clusters

- Stars come in singles & binaries but also in larger groups. **Clusters of stars are groups of stars that formed at the same time, from the same molecular cloud.**
  - similar age
  - similar metallicity
- Cluster HR diagrams change as the cluster ages
Stars in Groups: Clusters

- Open Clusters
  - Sparse & small
    - Loosely grouped & move through space together but can be disrupted
    - Usually only a few hundred to a few thousand stars
  - "Young" subsequent generation metal-rich stars
    - Appear bluer (Population I)
Open Clusters

M36

M45 Pleiades

NGC 602 -- a very young cluster
Stars in Groups: Clusters

- **Globular Clusters**
  - **Spherical** collection of stars gravitationally bound together
  - dense
    - hundreds of thousands to millions of stars, packed most densely in the center.
  - Orbit the galactic core in the halo (not in the plane of the galaxy)
  - “Old” first generation metal-poor stars
    - Appear redder (Population II)
Globular Clusters

M55

M15

M2
Let’s Practice
In a stellar cluster, all the members have ______.

A. the same spectral type
B. similar age
C. Both
D. Neither
You observe two similar star clusters, which you call Wally and Eddie. You collect enough data on each cluster to plot its H-R diagram. The brightest main sequence star in Wally is almost 10 times brighter than the brightest main sequence star in Eddie. What do you conclude?

A. Wally is larger than Eddie
B. Eddie is larger than Wally
C. Eddie is younger than Wally
D. Wally is younger than Eddie
Galaxies: Classification, Spiral Structure, Oddballs
What is a galaxy?

- Large-scale collections of stars, gas, and dust
- Together with intergalactic medium, make up the universe
- Held together by the gravitational attraction
- Organized around a galactic nucleus
- Elliptical or spiral in shape
- Small percentage irregular

A Distant Cluster of Galaxies
Image Credit: FORS1, 8.2-meter VLT, ESO
Galaxies come in many shapes & sizes

Hubble eXtreme Deep Field (XDF) showing 5500 galaxies
DISCOVERY OF GALAXIES
IN WHICH OUR WORLD BECAME SMALLER ANOTHER TIME
Galaxies

- Until early 20th century these were thought to be “spiral nebulae”
- By 1920 some scientists began to argue they might be “island universes” outside our own system

M51 -- the Whirlpool galaxy
In 1920 the so-called Great Debate took place

- Shapley & Curtis

The final "proof" came with the use of the new 100-inch telescope on Mount Wilson by Edwin Hubble (in 1923-26).
Edwin Hubble

- accumulated deep exposures on large fields to resolve stars in M31 (the Andromeda Galaxy)
- identified Cepheid variable stars which gave a distance to M31 well outside the Milky Way, demonstrating that it is an “island universe”
- also developed the currently used system of galaxy classification & discovered Hubble’s Law
GALAXY CLASSIFICATION
Three main types

• Spirals

• Ellipticals

• Irregulars
Morphological Classification Scheme

Edwin Hubble's Classification Scheme

Ellipticals

E0  E3  E5  E7  S0

Spirals

Sa  Sb  Sc

SBa  SBb  SBc

NASA/ESA
Elliptical Galaxies

- Ellipsoidal shape & smooth brightness profile
- ~20% of observed galaxies
- 10s of millions to > 1 trillion stars
- Older, red, low-mass stars
- Sparse interstellar medium
- Minimal star formation activity
Spirals

- Round bulge, flat disk, spiral arms and spherical halo
- Divided into “normal” (S) and “barred” (SB)
Spirals

• together make 77% of observed galaxies
• Younger blue stars in arms
• Older red stars in bulge and halo
Spiral Galaxy M81

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC07-19a
Whirlpool Galaxy • M51

Sb

NASA, ESA, S. Beckwith (STScI), and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-12a
Barred Spiral Galaxy NGC 1300

NASA, ESA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-01
SN2012fr discovered 10/27/12 type Ia supernova -- explosion of a white dwarf star.
Irregular Galaxies

- Denoted Irr
- Lack symmetry
- about 3% of observed galaxies
- Mostly young, blue stars

Active Galaxy M82

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS/WFC • STScI-PRC06-14a
WARM-UP QUESTION
A galaxy that appears to be populated by mostly red stars, likely _____.

A. never had blue stars in the galaxy.
B. had blue stars that are not present anymore but were at one time long ago.
C. has been around long enough for blue stars to all evolve into the red main sequence stars we see.
D. never contained enough gas to have blue stars develop.
E. as blue stars that are being blocked by dust.
LT Galaxy Classification
A galaxy that appears to be populated by mostly red stars, likely _____.

A. never had blue stars in the galaxy.
B. had blue stars that are not present anymore but were at one time long ago.
C. has been around long enough for blue stars to all evolve into the red main sequence stars we see.
D. never contained enough gas to have blue stars develop.
E. as blue stars that are being blocked by dust.
Let's Practice
How would you classify the Milky Way?

A. SBbc
B. Sb
C. S0
The centers of most spiral galaxies appear redder than the arms. The most likely explanation for this is _____.

A. young blue stars are primarily in the arms and old red stars in the bulge

B. nuclear reactions in the center are creating heat

C. the black hole in the center is glowing red
Elliptical galaxies contain mostly red stars. What can you conclude about the rate of star formation in elliptical galaxies?

A. Few to no new stars are forming.
B. Many new stars are forming.
C. There is not enough information to conclude anything.
WRAP-UP
Topic for Next Class

- Galaxies & Our galaxy
Reading Assignment

- Astro:10&11
- Astropedia:15&16
Homework

- HW SS Posted, Due 11/19