Big Bang, Black Holes, No Math
ASTR/PHYS 109
Dr. David Toback
Lectures 23, 24 & 25
Was due Today - L25

- **Reading:**
  - (Unit 5)

- **Pre-Lecture Reading Questions (PLRQ):**
  - Unit 5 Revision (if desired), Stage 2: Was due today before class

- **End-of-Chapter Quizzes:**
  - Chapter 15

- **Papers:**
  - Paper 3 Revision (if desired), Stage 1: Was due today before class
    - Turn in to both CPR and turnitin on eCampus even if the text is the same (that way we know that it's the same)

- **General:**
  - Still behind the Syllabus Schedule, due dates will be extended
  - CPR: Mis-graded on any Assignment? Let us know
Unit 5: Big Objects

1. Galaxies
2. Star Birth and Death
3. More on Black Holes

It turns out that the way Galaxies and Stars form is very similar... start there

The way stars “die” depends on the star itself... sometimes they die to form a Black Hole
Today's Lecture

- A star is born
- Nuclear reactions and gravity keep stars alive and make them shine
- The life of stars: shining and converting hydrogen into heavier elements
- Life and death of stars like our Sun
- Life and death of massive stars
The Fuel of a Star

The Hydrogen and Helium provide the “fuel” that both:

1. Creates the light we see
2. Keeps the star stable

Converting light atoms into heavy atoms
What happens when the Hydrogen Runs out?

- Without hydrogen fuel to make things “expand,” gravity crushes atoms closer and closer together.
  - It takes a temperature of 100 million Kelvin to fuse Helium, this may never happen for many stars.
- From there what happens next depends on the “mass” of the star.
The Life and Death of our Sun

- Sun is using its hydrogen to create light
- Helium produced falls to the center (the core)
  - Today: Core is only about 15 million Kelvin → not hot enough to convert helium into Carbon

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White Dwarf → Black Dwarf

• Eventually a white dwarf star runs out of the rest of its fuel (nothing left but iron) and it stops emitting light.

• Call this a “Black Dwarf”

• However, predictions are that it takes so long for this to happen that none should exist yet... none observed.

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Next move to heavier stars...
The Life of a Heavy Star

• For heavy stars the first part of their life is the same as for lighter stars: fuse hydrogen, and after the hydrogen runs out, gravity crushes the core.

• What is different is that for heavy stars there is so much mass that gravity can continue to crush the core, and the temperature can rise significantly.

• For stars with more than 8 times the mass of the Sun, the core can reach a temperature of 100 million Kelvin, and helium fusion can start.

• Helium can fuse to make heavier elements.
Stages in a Massive Star's Life

1. Hydrogen fusion in the core
2. Helium fusion in the core
3. Hydrogen fusion in the shell

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Massive Things: Galaxies, Stars and Black Holes 45

Topic 2: Stars
Converting Helium to Beryllium

\[ ^{4}\text{He}_4 + ^{4}\text{He}_4 \rightarrow ^{8}\text{Beryllium} \]

This happens a lot in the early universe, but Beryllium quickly decays.
Converting Beryllium to Carbon

\[ ^8\text{Beryllium} + ^4\text{He} \rightarrow ^{12}\text{Carbon} + \text{Photon} \]

Even though Beryllium doesn't last long, the core is so dense that the Be nucleus quickly finds another helium nucleus and we get Carbon (and more energy).
The Most Massive Stars

- For the heaviest stars, after the helium is used up the carbon can start to fuse.
- Then Neon.
- Keep going... Get "shells" of various types of atoms.
- This is where the atoms of the Earth get created.

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Topic 2: Stars
How Long do Stars Live?

Weird: stars with huge mass die faster than lighter stars. Why?

• The more massive the star, the more it crushes atoms in the center and raises their temperature

• The hotter/denser the star, the faster the nuclear reactions occur → The sooner it uses up its fuel
Death of Very Massive Stars

• If the star is much more massive than our Sun it runs out of fuel quickly
  - 1x Sun $\rightarrow$ ~10 billion years
  - 10x Sun $\rightarrow$ ~30 million years
  - 100x Sun $\rightarrow$ ~100,000 years

• Different things happen as it runs out of fuel $\rightarrow$ gravity is so strong it can REALLY crush the star
More Crushing → Neutron Star

• After the fuel runs out, if the mass of the star is large enough, things change quickly!
• Gravity quickly crushes the atoms into each other
• The electrons are pushed so close to the protons that they start to interact
  - Turn into Neutrons (more on the physics of this interaction in Chapter 19)
• The star crushes itself into a ball of neutrons about the size of Manhattan
Creating Neutron Stars

Proton + Electron → Neutron + Neutrino

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Neutron Stars

- Neutrons don’t like to be “too close” to each other because of Quantum Mechanics $\rightarrow$ core can stabilize

- In this process the core has collapsed from the size of the Earth into a ball of neutrons just a few kilometers across

- Incredibly dense!
  - Billions of tons per cubic inch
  - A marble made from neutron star material would weigh the same as the Earth
What about the outer part?

• The inner part of the star is quickly crushed into what becomes the neutron star

• What happens to the outer part? Atoms fall towards the center!

• Hits the dense neutron core and bounces back into space as a giant explosion
Huge Explosion = Supernova

• The explosion can be so violent that it can shine as bright as 10 billion suns for a couple of weeks.
• The temperatures in the explosion are so high and the atoms are so densely packed that really heavy atoms can be created and then blown into space.
  - This is how we get stuff like uranium on the Earth.
• We call the “remnants” of supernovas “nebulae.”
Moving Towards Black Holes

- If the remaining neutron star (what was the core of the star) has a "critical mass" (about $3M_{\text{Sun}}$) it can continue to collapse under its own weight.

- Nothing left to oppose the crush of gravity! → Continues to collapse until it becomes a Black Hole.
Lecture on Chapter 16 now complete
Unit 5: Big Objects

1. Galaxies

2. Star Birth and Death

3. More on Black Holes

Today
Where are we now in the history?

Half a billion years after the bang,
Black holes start forming.
Paper 4: The Assignment

- **Abbreviated Description:** What is the evidence for Stellar Black Holes? Note there is an emphasis on what is a black hole and how it forms.
  - Explain it to someone who isn't taking the class (no jargon)
- **Make sure you read ALL the instructions**
- **Same format and due dates as usual**
  - Text due 1 week after we finish Chapter 17
  - Calibration, reviews and self-assessment due a week after that
Outline

• What makes Black Holes black
• What a black hole would look like to a nearby observer
• Evidence for Black Holes
• Different types of Black Holes
• A few words on why black holes are so important in cosmology and our understanding of the Big Bang
Why do we call it a **black hole**?

Call it a Black Hole because light can’t “escape”

Say more about what this means
What they are... and aren't

- Black holes aren't demonic, sucking power holes
- A black hole is just another thing a star can turn into when it runs out of fuel
- It is basically a really massive, non-shining, ex-star
- Then again, something with that much mass but a size smaller than a proton does have some unusual properties
No dent in space... Just a small Object

- What if the Sun compressed into a Neutron Star?
  - Shrink Sun to 10% of its size
  - Now 1%
  - Neutron star is 0.004% of its size
- What if it were crushed into a black hole?

1.4 Million Kilometers across

~25 Kilometers across
Space looks the same, but let's look at the Curvature of Space-Time near the Sun

The size of the Sun...

Remember:
Diagram is the CURVATURE of Space-time
The curvature can be thought of as the force...bigger curvature → more force
How the Curvature Changes as we Compress the Sun

What if we compressed the Sun into a Neutron Star?

Far outside the Sun you can't really tell the difference

- Force is the same

You can tell the difference if you are very close to the Sun itself

- Force is bigger

The sun is now a few kilometers across
Compress the Sun into a Black Hole

Black hole is just a point in space

Curvature is VERY different really close to where the mass is

Infinite curvature
What does this have to do with light being able to escape?
How fast does it need to move so that it can "escape" the pull of gravity? Call this the escape velocity.
The Moon has a “small” escape velocity

The escape velocity for the Moon is about 2.4 km/sec

Bullet can leave

Photons can leave
The Escape Velocity for the Earth

Earth

Bullet can’t leave

Photons can leave

The escape velocity for the Earth is about 11.2 km/sec
The Sun

Bullet can’t leave

The escape velocity for the Sun is about 620 km/sec

Photons can leave
A Neutron Star

Bullet can’t leave

Photons can leave

The escape velocity for the Neutron star is about a third of the speed of light, \( \sim 100,000 \text{ km/sec} \)

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A Black Hole

A Black Hole, by definition, has an escape velocity greater than the speed of light, 300,000 km/sec

Bullet can’t leave

Photons can’t leave
For Next Time – L25

• Reading:
  - Unit 6

• Pre-Lecture Reading Questions (PLRQ)
  - Unit 6, Stage 1: Due before class Wednesday
  - Unit 6, Stage 2: Due before class Monday

• End-of-Chapter Quizzes:
  - Chapter 17 if we finished Chapter 17 (else just Chapter 16)

• Papers:
  - Paper 3 Revision (if desired), Stage 2: Due next Monday before class
    • Turn in to both CPR and turnitin on eCampus even if the text is the same (that way we know that it’s the same)
  - Paper 4, Stage 1: Due Monday if we finished Chapter 17
  - Paper 4, Stage 2: Due Monday May 8th by 11:55PM

• General:
  - Still behind the Syllabus Schedule, due dates will be extended
  - CPR: Mis-graded on any Assignment? Let us know