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Notes:
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- Shorter time period for Paper 4
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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
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 as usual

*** Note: The evidence in the newspapers is about Supermassive Black Holes***
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
Moving Towards Black Holes

• If a neutron star has a “critical mass” (about $3M_{\text{Sun}}$) it can continue to collapse.

• Nothing strong enough to oppose the crush of gravity! → Continues to collapse until it becomes a single point in space.

• Call this a Black Hole.
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
What it IS: A small, massive THING in Space

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

1.4 Million Kilometers across
Most people have seen the curved Space-Time figure, so let's understand those!

The size of the Sun...

Remember:
Diagram shows the CURVATURE of Space-time
Draw the dent to be deepest is where the force is largest → Where space is falling to the center “fastest”
Nothing to “See”
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

Remember: The black hole is just a point in space

Infinite curvature

Curvature is VERY different really close to where the mass is Nothing “curved” to SEE, deeper just means where space falling in fastest

Big Bang, Black Holes, No Math
What if our Sun were to (magically??) turn into a Black Hole?

The gravitational attraction far outside wouldn’t change, so the planets would continue to orbit.

Then again, without the light it would get really cold and we’d all die...
What does this have to do with light being able to escape?
Small speed objects can't leave the Earth

How fast does it need to move so that it can "escape" the pull of gravity? Call this the escape velocity

http://people.physics.tamu.edu/toback/119/lab/Lab3/PartI/Earth_P2.html
The Moon has a “small” escape velocity

Bullet can leave

The Moon

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

Photons can leave
The Escape Velocity for the 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

Big Bang, Black Holes, No Math

Big Objects and Black Holes

Topic 3: Properties of Black Holes
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, \( \sim 100,000 \text{ km/sec} \)
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
Event Horizon

- A rocket with a speed of 11km/sec can escape from the Earth
  - Needs a lower speed if it starts up high in the atmosphere
  - The higher it is, the smaller the escape velocity is
- We call that special distance from the center of a black hole where the escape velocity is equal to the speed of light the EVENT HORIZON
A Star with ~3 times the mass of the Sun is crushed into black hole → Event Horizon

Star gets crushed by gravity and becomes a single point in space/black hole (X marks the spot)

~5 km from black hole: Speed needed to escape from black hole this close is twice the speed of light (light can’t escape)

~10 km from black hole: Speed needed to escape is EXACTLY the speed of light. This distance from the black hole is known as the event horizon

~20 km from black hole: Speed needed to escape is less than the speed of light (can escape)

A Star with ~3 times the mass of the Sun is crushed into black hole
Event Horizon Cont...

- The bigger the mass of the black hole, the further out the event horizon is

http://people.physics.tamu.edu/toback/119/lab/Lab3/PartII/BHS1.html
Why do we call it a Black Hole?

A Black Hole is so dense that it’s escape velocity is GREATER than the speed of light → light can’t escape!

Looks at this from the perspective of Space-Time
Space-Time as an Escalator

Space falls towards the massive object, carrying objects along with it.

People can walk THROUGH space away from the massive object.

Man walks up at 1 m/s

Escalator moves down at 2 m/s
Falling into a Black Hole

If a person moves “up” slower than the “speed of the escalator” she will fall towards the object.

A person moving through space away from a black hole actually gets closer to the black hole over time.

If the escalator is moving down faster than the speed of light, even light can’t go “up”.

Man overall has moved down at 1 m/s
Space-Time Near a Black Hole

• If light can’t escape from a star, then we can’t “see” light coming from it and our star “appears” black

• Since light could fall in, and never come back out, we call it a “Black Hole”
Black Holes

Light falls in and never comes back

Light from inside can’t escape!

Path of light passing nearby gets bent
Gravitational Lensing of the light around a black hole

Light from stuff orbiting it, and light from stars behind it.

Big Bang, Black Holes, No Math
Different Types of Black Holes

- Two different types
  1. Stellar Black Holes (the types we have been discussing)
  2. Supermassive Black Holes
- Both have been observed and are now known to be common
  - Closest known stellar Black Hole is about 3,000 light years away
- Supermassive Black hole at the center of the Milky Way with a mass more than four million times that of our sun
  - At the center of many (all?) large galaxies
Some pictures from Chapter 2
Supermassive Black Holes

• Still learning about how they came to be. Some people think they started as a stellar Black Hole near the center of the galaxy when the galaxy was forming a half a billion years after the bang
  - “Ate” material that fell towards the center of the galaxy
  - Lots of light came from the atomic interactions as the material fell in
  - Called a Quasar

• Today: nothing falling in since everything either already fell in or is now rotating around the center of the galaxy
  - Quasars only observed in “distant” galaxies
Switch Topics

- Life near a black hole
- Evidence for black holes
Getting a Close-Up Look

What would a Black Hole look like to an observer who tries to get a closer look?
An Astronaut Near a Black Hole

Light falls in and never comes back

The same thing is true for our Astronaut
Spaghettification as he falls in...

- The gravitational pull on his feet would be much stronger than on his head
- He’d get stretched out and then ripped apart
Falling into a Black Hole

Spaghettification as he falls in

Can’t see him after he passes the event horizon...
not even light from his gun can escape

Holes, No Math    Topic 3: Properties of Black Holes
A Way to Observe Stellar Black Holes

- Let's say we have two stars orbiting each other (a binary pair), and one has already turned into a black hole.
- We can “see” light “from” a Black Hole by watching them “eat” their companion.
Black Holes Suck

- Can think of the stuff sucked in like crumbs on the surface of the water as it goes down the sink → swirl faster and faster until it reaches the drain and gets sucked down.
- As the matter moves more quickly the atoms collide.
- These collisions produce light that we can see → x-rays.
A way to observe Supermassive Black Holes

- Can observe supermassive black holes by looking at stars as they orbit "nothing" at the center of a galaxy
- Can even measure their mass like the way we measure the mass of the Sun
Measuring the Mass of a Stellar Black Hole

Can also measure the mass of a stellar black hole if its in a binary pair by watching the speed of its "partner" orbit.
Last Topic on Black Holes...

Why are Black Holes important in Cosmology?
In the 1970’s Hawking and Penrose realized that the creation of a Black Hole looks like a Big Bang in reverse.

Said differently, the Big Bang appears to be the creation of a Black Hole running backward in time...
Theory?

• Inside a Black Hole we get “infinite curvature” and “infinite density” of space
  - A singularity
• Here the particles would interact according to Quantum Mechanics
• Hard to calculate things… Quantum Mechanics and General Relativity predict different things and we don’t know which one is right…
In a way, this is Good...

- Since we now have observed Black Holes, we finally have a set of objects we can look at.
- Maybe by studying their properties we can tell which theory (if either) is correct.
- *Maybe neither? What is the final theory of “Quantum Gravity”? String Theory?* ... Stay tuned...
Lecture on Chapter 17 now complete
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
## Schedule - L25

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Big Bang, Black Holes, No Math

**Big Objects and Black Holes **

**Topic 3: Properties of Black Holes**
Full set of Readings So Far

• Required:
  - BBBHNM: Chaps. 1-18

• Recommended:
  • TFTM: Chaps. 1-5
  • BHOT: Chaps. 1-7, 8 (68-76), 9 and 11 (117-137), 12
  • SHU: Chaps. 1-3, 4(77-86), 5(95-114), 6-8 (up-to-page 164)
  • TOE: Chaps. 1-3
  • Seeds (Cosmology in the 21st Century)

Big Bang, Black 50  Big Objects and Black Holes
Holes, No Math  Topic 3: Properties of Black Holes