Was Due Today - L24

• Reading:
  - Will assign Unit 6 at the end of class
• Pre-Lecture Reading Questions (PLRQ)
  - Will assign Unit 6 at the end of class
• End-of-Chapter Quizzes:
  - Chapter 16
• Papers:
  - Paper 1 and 2 Regrades and Revisions: Working on these, but will be slow as we figure out how to integrate revised grades into Peerceptiv
  - Paper 3 Revision (if desired): Due tonight in TurnItIn
  - Paper 4: Due date extended to Monday Dec 4th
• General:
  - Mis-graded on any Assignment? Let us know
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 as usual
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 Object 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

~25 Kilometers

Single point in space
(often called a Singularity)
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

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?
Small speed objects can’t leave the Earth

A person throwing a ball in the air on the surface of the Earth

People can’t throw balls with high enough speed to 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

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

Photons can leave

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

Bullet can’t leave

The escape velocity for the Neutron star is about a third of the speed of light, ~100,000 km/sec

Photons can leave
A Black Hole

Bullet can’t leave

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

Photons can’t leave
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
Even later times.

If a man moves “up” slower than the “speed of the escalator” he 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”.

Big Objects and Black Holes, No Math
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”
Event Horizon

- A rocket with a speed of 11 km/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**
Rest of the Semester

Week 13:
- **Wed, Nov 22:** Reading day, no class

Week 14:
- **Mon, Nov 27:**
  - Unit 6 Reading due, PLRQ Unit 6 due
  - Class: Finish Chapter 17, first part of Chapter 18
- **Wed, Nov 29:**
  - EOC 17 due
  - Class: Finish Chapter 18, first part of 19

Week 15:
- **Mon, Dec 4:**
  - No class: redefined day (Friday)
  - Paper 4 text due
- **Wed, Dec 6:**
  - Last day of class: Finish chapters 19 and 20
  - EOC 18 due, Paper 4 Reviews due
- **Friday December 8:** No Final

Week 16:
- **Mon, Dec 11:**
  - No class
  - EOC 19 and 20 due, Paper 4 back-evaluations due
For Next Time - L24

- No Class Wednesday (Reading Day)
- Reading:
  - Unit 6 (due Monday before class)
- Pre-Lecture Reading Questions (PLRQ)
  - Unit 6 (due Monday before class)
- End-of-Chapter Quizzes:
  - Chapter 17 if we finished Chapter 17 (else just Chapter 16)
- Papers:
  - Paper 1 and 2 Regrades and Revisions: Working on these, but will be slow as we figure out how to integrate revised grades into Peerceptiv
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