Prep For Today (is now due) - L10

- Reading:
  - BBBHNM Unit 2 (already due)
- Pre-Lecture Reading Questions:
  - Unit 2 Original: Grades posted
    - If you were misgraded, need help or an extension let me know
  - Unit 2 Revision (if desired): Due Monday before class
    - Make sure you get a Receipt from TurnItIn
- End-of-Chapter Quizzes
  - Chapter 5, parts a & b
- Papers
  - Paper 0 (Reviewer Training):
    - Nothing to write!
    - Reviews: Extended to Wednesday (tonight) at 11:59PM
    - Back-Evaluations: Extended to 11:59PM Friday
    - You are required to do all the parts of this assignment
  - Paper 1 will be assigned when we finish Chapter 6
Heads Up: Paper 1

- What is the evidence for Dark Matter?
- This will be the topic of Paper 1

- In order to understand the evidence, we next talk about gravity and Dark Matter
- Will be due 1 week after we finish Chapter 6
Outline for Unit 2: Physics We Need

Topics
1. Light and Doppler Shifts ← Done
2. Gravity, General Relativity and Dark Matter ← Today
3. Atomic Physics and Quantum Mechanics ← After that
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium
Why Gravity Next?

- By looking at photons/light we can learn about things here on Earth as well as about inner/outer space
- What else do we need to describe/understand the Universe? → Quantum Mechanics and Gravity
- To understand the answer to these questions we need to learn more
The Two Great Theories

- **General Relativity:** (Gravity) Predictions about the very large, from sizes of a few meters to the size of the universe ($10^{24}$ miles across)

- **Quantum Mechanics:** Predictions about the very small (atoms, particles, $<10^{-10}$ m)

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Big Bang, Black Holes, No Math

Physics We Need

Topic 2: Gravity
Overview of Gravity and Dark Matter for the Course

1. What's so important about Gravity?
2. Newton's Theory of Gravity
3. Einstein's more-correct version
   • Curved Space-Time, and evidence for it
4. Dark Matter and Evidence for it
Gravity: Why do we care?

- **Gravity:** The great attraction in the Universe
- Gravity is the theory that predicts the attraction and the motion of BIG things over large distances:
  - Planets
  - Suns
  - Galaxies
  - How Galaxies form etc.
Newton and Gravity

1. Everything moves in a straight line unless acted upon by a force

2. Gravity is a force
   - Every object in the universe attracts every other object in the universe
   - The further the distance between the objects, the smaller the attraction
   - The bigger the mass, the bigger the attraction
     • Light is massless → not affected by gravity
Large Number of Scales

Kinda amazing!

Gravity covers the attraction between

- An apple near the Earth
- The Earth and the Moon
- The Earth and the Sun
- The Sun and our galaxy
- Our galaxy and the universe
- Every particle in the universe and an apple
- The Earth and you
- Bevo and Reveille
Gravity continued...

The force of Gravity makes the Moon “fall” towards the Earth

→ Call this an orbit

→ Does a great job of explaining how the planets move around the Sun

Without gravity, the Moon would fly off into space and ignore the Earth completely
What’s next?

Tell you the different, and surprising, way that Einstein describes space, time and gravity

Then tell why his description of why the Earth goes around the Sun is better than Newton's
Einstein in the 1910’s

- In the early 1910’s Einstein was thinking about some recent experimental results that didn’t make any sense to him using Newton’s theories.
- Decided we need new ways of thinking about space, time and Gravity.
- Einstein says that Newton’s Laws aren’t really quite right…
- Einstein’s theory is known as the “General Theory of Relativity”.

2nd year Grad School Course
Observational Fact

Light *ALWAYS* moves at the speed of light to all observers

So what?
What happens if I’m driving a car moving at half the speed of light and I turn the headlights on?
Two observers get different answers

From the perspective of the person on the side of the road, the car moves at half the speed of light and the photon moves at the speed of light. After 2 nanoseconds, the photon is 1 foot ahead of the car.

From the perspective of the driver, the car is stationary and the photon moves at the speed of light. After 2 nanoseconds, the photon is 2 feet ahead of the car.

The light is one foot ahead of that car!

The light is two feet ahead of me!
Einstein’s Answer

From the perspective of the person on the side of the road, the car moves at half the speed of light and the photon moves at the speed of light. After 2 nanoseconds, the photon is 1 foot ahead of the car.

From the perspective of the driver, the car is stationary and the photon moves at the speed of light. After 2 nanoseconds, the photon is 2 feet ahead of the car.

Einstein says both observers are correct.

Space and Time are more related than we thought.
Start with Space-Time

Can’t think of Space and Time as separate
- Space (measured with a ruler)
- Time (measured with a clock)

➤ Single combined entity which we call four dimensional space-time
- If the four dimensions are related, unexpected things can happen that we’re not used
Other Weirdness

• Space and time are not only more related than we thought, Space can Curve

• Need to talk about what we mean by *Curved Space-Time*

• Explain what this has to do with gravity
What are we trying to explain?

Two things:

1. Why do things fall to the surface of the Earth?
2. Why do things further out in space fall in more slowly than things close to the surface?
We’ll start by using the strange “new” words of General Relativity in an example about why we care, and THEN explain them a bit more.

*Space-Time and Gravity*
Example: Newton vs. Einstein

Newton: The Earth moves around the Sun because of “the force of gravity” is pulling it

Einstein: There is no “force” of Gravity, the Sun curves the space-time around it and the Earth moves in a “straight line” through that curved space-time

This is a VERY different way of thinking about things... What is Curved Space-Time?
Curved Space?

An analogy is to think of curved space-time as looking like one of those gravity wells you've seen downstairs.
Prep For Next Time - L10

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• End-of-Chapter Quizzes
  - If we finished Chapter 6 then End-of-Chapter Quiz 6 (else just Chapter 5a&b)

• Papers
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