Big Bang, Black Holes, No Math
ASTR/PHYS 109
Dr. David Toback
Lecture 8
Prep For Today (is now due) – L8

- Reading:
  - (Unit 2)
- Pre-Lecture Reading Questions Quiz:
  - Unit 2 Text Submission
    - Grades have been posted
  - Pass/Revise assignment:
    - If you didn’t pass (10/10): Revision submission was due before class
    - We are still grading revisions
    - If you still didn’t pass the Revision, send your 2nd Revision to 109help
  - Unit 2 Quiz:
    - Doesn’t open until you are done with the other stuff that is due
    - Will be assigned today, due Monday before class
- Extra Credit opportunity:
  - Submit Unit 1 or Unit 2 questions (TurnItIn Folder) for use in future quizzes (and to get you answers).
    - If we use them we will give you extra credit
  - Grading them soon
- End-of-Chapter Quizzes
  - Chapter 5, parts a & b: Was due before class
- Papers
  - Paper 0 (Reviewer Training):
    - Reviews: Were due already. Grace period with late penalties.
    - You must do ALL the required parts of this assignment to pass it
    - If you didn’t/couldn’t get something in on time send email to 109help ASAP
  - Paper 1 will be assigned when we finish Chapter 6
- Honors Section:
  - Start working on Stage 0: Email due Sunday
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
What’s Next?

• Now that we have some understanding of photons/light we can use the knowledge to learn more 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
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)

**Chapter 6**

**Chapter 7**
Why Gravity Next?

• Gravity tells us about the big stuff in the universe and how the big stuff is held together (plus a whole lot more)

• Also, with an understanding of gravity and light we can provide the evidence for Dark Matter
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 \( \rightarrow \) 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

If Gravity were to suddenly turn off 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.

This unexpected way of describing things changes how we understand how/why the Earth goes around the Sun is better than Newton’s.

Will take some understanding before we get to the prediction.
In the early 1910’s Einstein was thinking about some recent experimental results that didn’t make any sense 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?

This simple observational fact throws a monkey wrench in Newton’s theories Why?

Let’s give an example of why...
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

Space and Time are not truly 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 to
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Physics We Need

Topic 2: Gravity