Big Bang, Black Holes, No Math
ASTR/PHYS 109
Dr. David Toback
Lectures 8 & 9
Prep For Today (is now due) – L9

- **Reading:**
  - BBBHNM Unit 2 (already due)
- **Pre-Lecture Reading Questions (PLRQ)**
  - Unit 2 – Revision (if desired), Stage 2: Was due today before class
- **End-of-Chapter Quizzes**
  - Chapter 5, parts a & b
- **Papers**
  - None assigned. 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
Overview of Gravity 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 with Dark Matter
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.
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.
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 that we're not used to can happen
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
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 Earth moves in a “straight line” around the Sun in the curved space-time created by the Sun

This is a VERY different way of thinking about things...
An analogy is to think of curved space-time as looking like one of those gravity wells you've seen downstairs.

1st floor of the Mitchell Physics building (MPHY)
Moving in Curved Space: Analogy

- Let's say my friend and I are at the equator and we both start working due North
  - Exactly parallel to each other
- We will notice that we "mysteriously" are getting closer to each other, and will eventually bump into each other
- Is there a Force drawing us together? No... moving in curved space time LOOKS like a force

The rules of geometry are different in curved space:
http://en.wikipedia.org/wiki/Parallel_(geometry)
Another Weird Thing: Mass Curves Space-Time

Think of each of the heavy things in the universe (stars, planets etc.) as being like a ball in the middle of a taut rubber sheet that represents space-time.

The weight of the ball will make it sink into the rubber sheet, creating a cone shaped dent around it.
Mass Curves Space

The heavier the ball, the bigger the dent in space-time!

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Physics We Need

Topic 2: Gravity
Mass in curved space-time

A mass moves in a “straight line” in curved space-time

In this example, this straight line in curved space-time makes the path of the small ball look like something is pushing it toward the big ball in 3-dimensions.
Back to Newton vs. Einstein: The Earth and the Sun

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

Einstein: There is no force, the Earth moves in a straight line in four dimensions, but the curved space-time around the Sun makes it go in an orbit in the three space dimensions.
The way the Planets go Around the Sun in General Relativity
Both Newton and Einstein correctly predict how the planets go around the Sun
- Actually mostly their predictions for the locations of the planets at any given time are almost identical

How do we decide if one is right and one is wrong?

Do an experiment where the predictions from the two competing theory's are very different!!!
When do General Relativity and Newton predict different things?

- Ok... One equation, but I'm guessing you've heard this one

\[ E=MC^2 \]

Ok... what is this equation saying?
Energy and mass may not be the same, but in Einstein's theory they are equivalent.
So what?

What about light?

It has energy, but no mass

• To Newton, there is no force on it
• To Einstein, its mass doesn’t matter, it is a particle that moves in curved space-time
What happens to light as it goes past the Sun?

- **Newton’s theory:** Only things with “real” mass “feel” the force of gravity.
- **General Relativity:** Objects move according to the curve of space-time, regardless of whether they have mass or not.
Do an Experiment

1st Experiment:
Can see the star directly

2nd Experiment:
Sun in the way

If Newton is right, we won’t see the star

Gross exaggeration of sizes

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Question: Where does the star appear when you actually do the experiment?

Looks like its over here!

If Einstein is right, the Sun curves the path of the starlight
The Great Experiment of 1919

Look at a star's position “behind” the sun as it “passes” in between us and the star during an eclipse to block the glare of the sunlight.
Another View

Photograph of stars when sun (eclipsed by moon) lies as indicated

Photograph of stars when sun swims elsewhere
Another view

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Physics We Need
Topic 2: Gravity
Evidence and More Evidence

- The results exactly agreed with Einstein's predictions
  - Contradict the predictions of Newton
- Over time, even more compelling evidence has come in in favor of General Relativity
  For example, observations of Dark Matter in galaxies
- Next give some of the evidence for dark matter and that the story hangs together
Evidence galaxies contain Dark Matter

- Described the Dark Matter in the Universe and in galaxies in Chapter 2
- In order to better understand dark matter in galaxies, it's useful to show some evidence that there IS Dark Matter in galaxies
- Start by considering the case that there IS no Dark Matter in galaxies and what we would observe
How stars move in galaxies

- Laws of gravity accurately predict the orbits of planets and stars as they move around the solar system and galaxy.
- The brightest region of both places is the center → lots of mass there.
- For the solar system, the data agree perfectly, but for the outer part of galaxies it should look like stars in orbit around a massive center.
- Problem: This isn’t what the data shows.
Topic 2: Gravity

The Data

- The diagram shows the solar system with planets labeled.
- The graph on the left plots speed versus distance, with data points for Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.
- The graph on the right compares expected values with actual measurements, showing a curve that represents gravitational effects.

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Physics
Does this work for Stars?

Watch how fast a star rotates around the center of the galaxy...

Simulation without Dark Matter

Simulation with lots of Dark Matter particles in the galaxy

Data looks like this

https://bigbang.physics.tamu.edu/figures/cravetanimations/gairot_anim.gif
Data well explained by lots of “Dark Matter” we can’t see

This is where it gets its name

In some sense, the name is a statement of almost all we know about it (it doesn’t interact with light, and it has mass)
Another Experiment

Maybe there isn’t dark matter and General Relativity is wrong?

Look at the gravitational impact on light that travels through the Universe, through a galaxy, and towards us.
Einstein Ring's?

Figure not to scale

Near galaxy filled with dark matter redirects light from far galaxy

Earth sees the near galaxy and a ring around it from light from the far galaxy

Apparent location of the far galaxy

Actual location of the far galaxy

Apparent location of the far galaxy
The “near” galaxy
The light from the “far” galaxy spread out into a ring
Amount of lensing explained by extra mass of dark matter

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Winner: General Relativity

• Many observations indicate that General Relativity correctly describes the motion of light, galaxies and stars in the Universe we live in → space and time are related

• Space can curve, stretch, change etc.

• Curved space-time will be very important in later chapters when we talk about the expansion of the Universe

• Dark matter is an important part of the evolution of our universe
Lecture on Chapter 6 now complete
Paper 1

• Abbreviated description: What is the evidence for Dark Matter?
  - More detail on CPR, you REALLY need to read ALL the instructions
• Explain it to someone who isn’t taking the class (no jargon)
• Follow the **required** Format:
  - Introduction paragraph
  - ~1 paragraph per piece of evidence
  - Conclusion paragraph that ties it together
• Help:
  - Example of good paper
    http://people.physics.tamu.edu/toback/109/WritingAssignments/samplepaper.shtml
  - The first 9 Rubric questions
Writing Prompt

All the writing assignments have components that are very similar, but there are parts that are particular for only this paper. We begin with the details of this paper.

Overview of Paper 1: Representative Bill Flores is meeting with a high school class in Waco to talk about science. He needs a short and sweet description of "The evidence for dark matter." He has asked his Chief of Staff to help him prepare for his presentation.

The Assignment: You are working in the Chief of Staff's office as a summer intern. The Representative is going to a hearing from a prominent cosmologist later and wants to know basic information about Dark Matter beforehand. Because you have taken a course that discusses this question you are tasked with this assignment. Your job is to create a "short and sweet" paper that summarizes and explains the reasons/evidence for dark matter in plain language so that both the Chief of Staff and the representative can understand them. Said differently, based on your report, both need to be able to answer this important question quickly and intelligently.

Some comments particular to this assignment:

- Clearly describe some of the aspects of gravity and how objects orbit around each other due to the attraction of gravity. This is NOT a paper about the difference between Newton and Einstein, or their theories. This is not about a proof of General Relativity. It is about Dark Matter and the evidence for it. You may assume that General Relativity is correct, but you cannot assume that your reader knows anything about it. You do not need to use the phrase General Relativity explicitly.

- Clearly describe how planets orbit the Sun as evidence for our understanding of gravity.

- Clearly describe how stars orbit in the outer reaches of galaxies and how this provides evidence.

- Clearly describe how the lensing of galaxies provides evidence.

- While you may choose your number of evidence paragraphs, the typical writer will choose one paragraph per piece of evidence.

- This is NOT a paper about Einstein's version of gravity vs. Newton's. Descriptions of the history are not needed, and can take away from the "short and sweet" nature of the paper.
Outline for Unit 2: Physics We Need

Topics
1. Light and Doppler Shifts ← Done
2. Gravity, General Relativity, and Dark Matter ← Done
3. Atomic Physics and Quantum Mechanics ← Next
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium
Prep For Next Time - L9

• Honor’s Paper:
  - Stage 1: Monday Oct 17th (Stage 0 must be explicitly approved)
• Reading:
  - BBBHNM Unit 2 (already due)
• Pre-Lecture Reading Questions (PLRQ)
  - Let us know if you were misgraded on any submissions
• End-of-Chapter Quizzes
  - If we finished Chapter 6 then End-of-Chapter Quiz 6 (else just Chapter 5a&b)
• Paper 1:
  - Stage 1 due 1 week from today, Wed Feb 22nd, before class
    • Due in CPR and turnitin on eCampus
  - Can submit a draft for feedback on eCampus if you like before Friday at 11:55PM
    • Will do our best for late submissions