Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lectures 8, 9 & 10
Prep For Today (is now due) - L10

- Reading:
  - (Unit 2)
- Pre-Lecture Reading Questions Quiz:
  - Unit 2 Text Submission
    - If you still didn’t pass the Revision, send mail to 109help
  - Unit 2 Quiz: Was due before class
    - Doesn’t open until you are done with the other stuff that is due
    - Extensions granted for those struggling to pass the text submission
- Extra Credit opportunity:
  - Submit Unit 1 or Unit 2 questions (TurnItIn Folder)
- End-of-Chapter Quizzes
  - (Chapter 5, parts a & b)
- Papers (All items due at 11:55PM in Peerceptiv)
  - Paper 0 (Reviewer Training):
    - (Reviews & Back-evaluations)
    - You must do ALL the required parts of this assignment to pass it. Will put results in the Gradebook (1=Pass,0=Contact Instructor)
    - If you didn’t/couldn’t get something in on time send email to 109help ASAP
  - Paper 1:
    - Draft for Feedback (Optional)
      - Due on eCampus/TurnItIn before Friday Sept 27\textsuperscript{th}
      - Will do our best for late submissions
    - Text: Due Wednesday Oct 2\textsuperscript{nd} (Grace period with late penalties)
      - Submit to Peerceptiv AND TurnItIn
    - Reviews: Open Friday Oct 5\textsuperscript{th}, Due Monday Oct 7\textsuperscript{th} (Grace period with late penalties)
    - Back Evaluations: Open Thursday Oct 10\textsuperscript{th}, Closes Monday Oct 14\textsuperscript{th}

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Physics We Need

Topic 2: Gravity
• 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
Ok...

- 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 through 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

Looks like its over here!
If Einstein is right, the Sun curves the path of the starlight

Question: Where does the star appear when you actually do the experiment?
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 out the glare of the Sun.
Another View
Yet another way of looking at it
Evidence and More Evidence

- The results exactly agreed with Einstein's predictions
  - Contradict the predictions of Newton
- Since then 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
The Data

Distance [Multiples of Earth-Sun Distance]

Speed [km/s]

Distance [Thousands of Light-Years]

Expected Values

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Physics

Topic 2: Gravity
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

http://bigbang.physics.tamu.edu/Figures/gravynimations/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 or atoms very much (if at all), 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?

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

Figure not to scale
Fact: We observe Einstein Rings

The “near” galaxy

The light from the “far” galaxy spread out into a ring

Amount of lensing explained by extra mass of dark matter

Have observed LOTS of Einstein ring (most just not this pretty)

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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 Peerceptiv, 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
    • Lawyers opening arguments at a Trial
  - ~1 paragraph per piece of evidence/talking point
    • The case at a Trial
  - Conclusion paragraph that ties it together
    • Lawyers closing arguments at a Trial
• Help:
  - Example of good paper

http://people.physics.tamu.edu/toback/109/WritingAssignments/samplepaper.shtml
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Physics We Need
Topic 2: Gravity
Reminders about Papers

Re-read pages 48-52 of the Course Organization Document


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Physics We Need

Topic 2: Gravity
Outline for Unit 2: Physics We Need

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3. Atomic Physics and Quantum Mechanics ← Next
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Physics we Need

Topic 2: Gravity
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- End-of-Chapter Quizzes
  - If we finished Chapter 6 then End-of-Chapter Quiz 6 (else just Chapter 5a&b)
  - Won’t open until Paper 0 is passed
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