Evidence for the Big Bang

Topic 1: The Exploding Universe
Was due Today - L23

- Reading:
  - (BBBHNM Unit 3)
- Pre-Lecture Reading Questions Quiz:
  - Unit 3 Quiz: Due today before class
- End-of-Chapter Quizzes:
  - Chapter 9: Due today before class
- Papers
  - Paper 1:
    - Grades now posted
    - Let us know if you think you were misgraded
    - Text Revisions: Due tonight, Friday March 8th, at 11:55PM to TurnItIn
  - Paper 2:
    - Text: Was due Wednesday (TurnItIn and Peerceptiv)
    - Reviews: Due Tonight, Friday March 8th, at 11:55PM
    - Back-Evaluations: Due Wednesday March 20th (after spring break)

Holes, no math  Topic 1: The Exploding Universe
Overview: Evidence for the Big Bang

1. We observe all distant galaxies to be moving away from us
   - The further away the galaxy is the faster it is moving away from us
   - True no matter which direction we look

2. We observe low energy photons (microwaves) uniformly distributed in all directions which are consistent with a temperature of about 2.7 degrees above absolute zero (Kelvin)

3. The atoms in the Universe are basically Hydrogen and Helium and not much else
Is there a trend?

- Most of the galaxies are red shifted
  - Moving away from us
- More importantly:
  - More distant = More red-shifted
  - The further away they are the faster they are rushing away from us!
- Perhaps even more important: Looks the same in all directions!
Put this in Perspective

- They are traveling away from us really quickly
  - From New York to California in ~1 second
- Can't see this effect in our galaxy
  - Furthest stars in our galaxy are $\sim 10^5$ light years away
  - Thousand times smaller size
So What?

- We live in a Universe where things are clearly moving!
- Galaxies are moving away from us very quickly
- Is something pushing them?
Why are Things Flying Apart?

• The answer turns out to be complicated
• We’ll start with a hypothesis that turns out to be wrong but helps us understand
• Then we’ll go back and explain it more correctly
An Explosion?

- Georges Lemaitre (1927): The galaxies are not flying apart because something is “forcing” them apart, they are moving apart because they were part of an “explosion” a long time ago.

- It all started with a big bang...
Simple Example First: A Race

- Start a race with a bang...
- Soon the **fastest** runners will be **further** from the start
Is the data consistent with the simplest picture of an exploding Universe?
A Simple Explosion
A Snapshot in Time

Fast Stuff is far from the explosion

Slow Stuff is close to the explosion

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A (wrong) Hypothesis...

Fast Stuff is far from the location of the explosion

Slow Stuff is close to the location of the explosion

Consistent with this data
A Beginning?

If galaxies are rushing apart from us then at some point in the past they must have all have been closer together.
Running Backward in Time
The data about the velocities of the galaxies provides evidence that we live in a Universe that exploded into existence a long time ago.

We now know it was about 14 billion years ago.
The Story is Always more Complicated

Let's think about our data a little more carefully

Say it again: Galaxies are moving away from us AND moving the same way in EVERY direction

Simple explanation? We're located at the center of the explosion and we're not moving!
We're at the CENTER and NOT MOVING: Red Shifted Light

Consistent with what we observe!
If We’re at the Center

Equal amounts of stuff on each side

Fast Stuff  Slow Stuff  Medium Speed

Consistent with what we observe!

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Another possibility:
We’re at the center and MOVING

Not what we observe!
If We're Not At The Center

Medium Speed

Slow Stuff

Lots of stuff on this side
Not much stuff on this side

Fast Stuff

Not what we observe!

Big Bang, Black Holes, No Math
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• Do we REALLY believe we’re the center of the Universe AND that we’re not moving?

• Is there a better explanation?
Lecture on Chapter 10 now complete
Full set of Readings So Far

- **Required:**
  - BBBHNM: Chaps. 1-12

- **Recommended:**
  - TFTM: Chaps. 1-3
  - BHOT: Chaps. 1-7, 9 and 11 (117-122)
  - SHU: Chaps. 1-3, 4(77-86), 5(95-104), 6, 7 (up-to-page 153)
  - TOE: Chaps. 1 & 2
Overview

• Finished: The Exploding Universe
• This Time: Expansion of Space-Time and General Relativity
• After That: Photons and Hydrogen in the Universe
Outline

• General Relativity and Expanding Space-Time

• Expanding Space and Red-Shifts
Recapping the Data

Galaxies are moving away from us, faster if they are further away AND we see this to be true in ALL DIRECTIONS.

Simple-but-wrong explanation: We are the center of an explosion!
Is this right?

Only consistent with this data if we're at the center of the Universe and not moving.

Not consistent with other data.

Need a better explanation!
General Relativity to the Rescue

• Space-time can change
  - E.g. Mass causes it to curve and stretch

• What if space-time is expanding?
Balloon Analogy

- Our Universe doesn't have any overall curvature, but thinking of Space-Time like the SURFACE of a balloon is something you can try at home
  - Surface of a balloon is a two dimensional example/analogy
  - There is no inside, space IS just the surface

- As space-time expands, the distance between any two spots increases, but there is no spot ON THE SURFACE that is the center of the expansion
Prep for Next Time - L23

- Reading:
  - (BBBHNEM Unit 3)

- Pre-Lecture Reading Questions Quiz:
  - (Unit 3 Quiz)

- End-of-Chapter Quizzes:
  - If we finished Chapter 11 then end-of-chapter quiz 11 (else just through Chapter 10)

- Papers
  - Paper 1:
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Topic 2: Expanding Space-Time