Was due Today – L25

- Reading:
  - Unit 4: Was due before class

- Pre-Lecture Reading Questions (PLRQ)
  - Unit 4: Was due before class

- End-of-Chapter Quizzes:
  - (Chapter 11)

- Papers
  - Paper 2:
    - Text: Was due already in both TurnItIn and Peerceptiv
    - Reviews: Was due Monday night.
    - Back-evaluations: Due tonight
  - Paper 3:
    - Draft for TA (if desired): Friday at 11:55PM.
    - Text: Due Wed March 28th
Evidence Today: Hydrogen

• We can see how to build up heavier nuclei... Should have lots of each. No?

• Observed facts:
  - 91% of all the atoms in the universe are hydrogen
  - Most of the rest are helium
  - In comparison, almost nothing of heavier types

• Why is this?
**Why so few atoms Heavier than Helium?**

**Nuclear Physics**

Can build up Hydrogen and Helium one at a time

⇒ Next possibility, $^5\text{He}$ or $^5\text{Li}$, isn't stable

**So What?** Since $^5\text{He}$ and $^5\text{Li}$ decay quickly they don't have enough time to find another proton to become $^6\text{Li}$ and be stable

⇒ Almost no elements heavier than helium are produced in the early Universe

• Will happen much later, and in stars
The Helium Story

• Able to predict the fraction of the atoms in the Universe that are Helium
  - 75% of atomic mass in hydrogen
  - 25% of observed mass in helium
    • Same as saying about 91% of the atoms are hydrogen
• Helium is the same in every direction because it was created everywhere
  - Entire Universe had the same temperature everywhere
  - If it was created mostly in stellar cooking we’d see it coming from the directions where there are more stars
    • I.e., the direction of galaxies
• More on this in Chapter 16
The same Temperature in all directions?

Look at the full sky in a single map Temperature Map
(i.e., different colors correspond to different temperatures)

Stretch out a sphere onto a flat page Incredibly Uniform!

2.78 Kelvin

Big Bang, Black Holes, No Math Topic 3: Photons and Hydrogen in the Universe
Conclusion from the data?

- Data is exactly consistent with a Universe that was small and hot a long time ago... what we would expect with a Big Bang!

- No other reasonable explanation for where lots of photons with a specific temperature would come from, and be the same in all directions.
Summary

1. We observe galaxies moving away from us in a manner that is consistent with an expansion of space-time.

2. Most of the atoms in the universe are hydrogen and helium and not much else.

3. We observe photons (the cosmic background radiation) uniformly distributed in all directions that have a temperature consistent with cooling for ~13.7 billion years.
Fun Way to think about things

- Look at things “far away” in space ➔ Backward in time
- Can see stars from millions of years ago
  - Look like stars today
- Look at galaxies from billions of years ago
  - Look like galaxies today
- Look at galaxies from about 13 billion years ago
  - Look like baby galaxies forming
- Look even “farther back”
  - No galaxies! Why? Because they haven’t even formed!
- Look further still... See the “white noise” of the cosmic background radiation and no evidence of any galaxies
  - Looking back at the earliest times we can “see” without the photons going through the “fog” of the early universe... Can’t see through the fog to earlier times... Then again, there isn’t much time before that anyway
How far can we look back in time?

All we can see is back a certain distance in TIME
We can’t see anything “past” the background radiation

Big Bang, I
Holes, No
Lecture on Chapter 12 now complete
What’s Next?

Unit 4: Evolution of the Universe

• The Early Universe
• After the First Three Minutes
Paper 3: The Assignment

• **Abbreviated Description:** What is the evidence for the Big Bang?
  - Explain it to someone who isn’t taking the class (no jargon)

• Make sure you read ALL the instructions
Unit 4: Evolution of the Universe

- Big Picture of the Evolution of the Universe:
  - Temperature and Time
- Collisions and how they explain what we see
- Photons as “Bullies of the Universe” and “Bathtubs” of particles
- The First Three Minutes
- After the First Three Minutes
Getting Started

We now have a basic understanding of the evidence for the Big Bang.

Let's look at the Evolution of the Universe after the Big Bang in more detail.
The Big Bang

• Ideally we’d start telling the story at the Big Bang itself and then move forward

• Maybe even talk about what came BEFORE the Big Bang

• Unfortunately, we don’t REALLY understand the Bang part or if there even was a bang
Best We Can Do

• The best we can do with confidence is start describing the Universe a short time AFTER its beginning.

• Start there, then work our way forward and backward in time.

What happened RIGHT AFTER the Big Bang?

Then what happened after that?
Then what? Etc.
The Big Bang Theory

- A Big Bang occurs and the early Universe has the same temperature everywhere and with lots of high energy particles
- Then the Universe gets
  - Bigger
  - Older and
  - Colder
- As time goes by it changes over time
  - Often we use the word evolves
The History of the Universe

Universe expands as time passes

Universe cools down as time passes

Bigger wavelengths → Smaller energies → Smaller Temperature

1 second

10 billion degrees

1 degree

10 billion years

Now
What happens at Different Times?

Particles, nuclei and atoms interact in different ways at early times and later times

- Early Times
  - High Temperature
  - High-energy collisions

- Later Times
  - Low Temperature
  - Low-energy collisions
Various Times

Explain what happens during each of a number of different periods in time

- The VERY early universe
- The first three Minutes
- The next 300,000 years
- The next billion years
- ~13 billion years later (now)
- The ultimate fate of the universe?

* The first four will take a couple of lectures

Big Bang, Black Holes, No Math  The Evolution of the Universe  Topic 1: The Early Universe
What Happening?

What happens to the particles at each of these times?

Collisions!
Collisions

In each collision a number of things can happen

- Can create new particles
  » Only in high-energy collisions
- Particles can combine to form composite objects
  » Protons, neutrons, atoms etc.
- Composite particles can get broken up
- Collisions can transfer energy

Thus, the energy of the particles and what particles CAN exist in nature has a HUGE impact on the evolution of the early universe.

Should also say that particles can decay
Chapter 13 and 14 worksheet

• One of the most important things to understand is How much of each type of “stuff” is found in the universe during its History (and why)

• Since many people struggle with this (especially for the EOC quizzes) we have made a handout and an Excel worksheet to help you
  - On the main 109 page
  - Make sure you enter in “Negligible” or “Abundant” in all boxes
  - There is feedback for you if you didn’t enter in things correctly
For Next Time - L25

- Reading:
  - (Unit 4)

- Pre-Lecture Reading Questions (PLRQ)
  - Unit 4: Was due before class

- End-of-Chapter Quizzes:
  - Chapter 13 parts A,B,C and D (if we finished Chapter 13, else just Chapter 12 parts A&B)

- Papers
  - Paper 2:
    - Text: Was due already in both TurnItIn and Peerceptiv
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Full set of Readings So Far

- **Required:**
  - BBBHNM: Chaps. 1–14

- **Recommended:**
  - TFTM: Chaps. 1–5
  - BHOT: Chaps. 1–7, 8 (68–76), 9 and 11 (117–122)
  - SHU: Chaps. 1–3, 4 (77–86), 5 (95–114), 6, 7 (up-to-page 159)
  - TOE: Chaps. 1 & 2