Was due Today - L22

- Reading:
  - Unit 5: Will assign today
- Pre-Lecture Reading Questions Quiz:
  - Unit 5 Quiz: Will assign today
- End-of-Chapter Quizzes:
  - Chapter 13:
    - Do worksheet on class homepage to help prepare for EOC quizzes
      - Does not need to be turned in
    - Chapter 13 parts A-D (Yes... lots more parts this time, but each quiz is smaller and designed to help you get to the later quizzes)
- Papers (All items due at 11:55PM in Peerceptiv)
  - Paper 2:
    - Grades posted. Let us know if you think you were misgraded
    - If you want to do a Revision, due Monday Nov 18th by 11:55 in TurnItIn
  - Paper 3: (Best guesses)
    - Rough Draft (if desired): Was due Friday Nov 8th, will do our best for late submissions
    - Text: Due Wednesday Nov 13th (Grace period with late penalties)
    - Reviews: Open Saturday Nov 16th, due Monday Nov 18th (Grace period with late penalties)
    - Back Evaluations: Open Thursday Nov 21st, Closes Monday Nov 25th

Big Bang, Black Holes, No Math  Topic 2: After The First Three Minutes
A Big Bang Occurs... Then What?

Universe goes through a phase of being hot and small

As the universe evolves it gets bigger, older and colder
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  Evolution of the Universe  Topic 2: After The First Three Minutes
Evolution of the Universe

Topic 2: After The First Three Minutes

Big Bang, Black Holes, No Math

More detail

Photons no longer energetic enough to bust apart protons

Photons no longer energetic enough to bust apart nuclei

Photons no longer energetic enough to bust apart atoms

Temperature (K)

Time

- $10^{-6}$ Seconds
  - Protons and Neutrons form

- A Few Minutes
  - Nuclei form

- $\sim 10^5$ Years
  - Hydrogen atoms form

- $\sim 10^8$ Years
  - Stars and Galaxies form

- $\sim 10^9$ Years
  - Our Solar System forms

- $\sim 10^{10}$ Years
  - You Read This Book

Holes, No Math  Topic 2: After The First Three Minutes
Where are we now in the history?

3 Minutes:
Photons can no longer break up nuclei

Big Bang, Black Holes, No Math

Topic 2: After The First Three Minutes
After the First Three Minutes

- At about the 3 minute mark the temperature of the Universe is about 1 billion degrees

- Electrons and positrons have *mostly* annihilated each other
  - No particles energetic enough to produce new ones
  - \( \sim 1 \) electron for every proton
What else?

- The temperature drops so much that the photons, on average, can’t even break up deuterium
  - Easier to start building up the heavier nuclei
Forming Heavy Nuclei in the Early Universe

Proton + Proton → Deuterium + Electron + Neutrino

Electron

Nuclear Reaction

Deuterium

Big Bang, Black Holes, No Math

Evolution of the Universe

Topic 2: After The First Three Minutes
Nuclei and Low Energy Photons

At the 3 minute mark, low energy photons only "bump" nuclei

Deuterium
Can Now Build Heavier Nuclei

Proton + Deuterium $\rightarrow$ $^3$He + Photon

Deuterium

Proton

Nuclear Reaction

Photon

$^3$He

Evolution of the Universe
Topic 2: After The First Three Minutes
Creating Stable Helium

\[ ^3\text{He} + ^3\text{He} \rightarrow ^4\text{He} + 2 \text{ Protons} \]

Replenishes the hydrogen in the Universe

Big Bang, Black Holes, No Math

Evolution of the Universe
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

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$^4\text{Li}$ lifetime = $9 \times 10^{-23}$ sec
$^5\text{Li}$ lifetime = $4 \times 10^{-22}$ sec
$^5\text{He}$ lifetime = $7 \times 10^{-22}$ sec
Time marches on...

- Universe continues to expand and cool
- Number of protons goes up and number of neutrons goes down

- Why? Any neutron not in a nucleus will decay into a proton (about 15 minutes)
Neutron Decay

Neutron $\rightarrow$ Proton + Electron + Neutrino
The End of an Era

- For the next couple hundred thousand years things don’t change much.
- Nuclear processes eventually stop making helium since the Universe gets too big.
- Still MUCH too hot for atoms to form.
  - Any formed quickly get busted apart.
The beginning of a new Era

• From 200,000–700,000 years the universe expands and cools

• All the nuclei and electrons combine to form atoms
  - Said differently: Universe cools until the photons in the universe can’t knock all the electrons out of the atoms any more
Atoms in a Lower Temperature Universe

At these lower temperatures photons can’t easily break up atoms

Proton

Electron

Electromagnetic Reaction → Hydrogen Atom

Big Bang, Black Holes, No Math

Evolution of the Universe

Topic 2: After The First Three Minutes

Photon

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Where are we now in the history?

200,000-700,000 years
Photons can no longer break apart atoms

Big Holes, No Math  Topic 2: After the First Three Minutes
The Transition From a Hot Universe to a Cool Universe

Proton

$^4$He Nucleus

Deuterium Nucleus

Photon

Electron

Big Bang, Black Holes, No Math
The Universe at ~700,000 Years Old

• At a temperature of about 3000K photons, on average, can’t knock apart atoms
• Stable atoms can form and most electrons become part of atoms
• The atoms are now free to form into stars and galaxies
Give this special time in history a name

Call this time "Recombination" Crappy Word!
Atoms are combining for the first time, not recombining!
Evolution of the Universe

Big Bang, Black Holes, No Math

Topic 2: After The First Three Minutes
Before and After the Creation of Atoms

**Before:**
Lots of free electrons and protons in the Universe
→ Photons scatter from charged particles

**After:**
Protons and electrons combine to form atoms
→ Universe becomes transparent for photons

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**Big Bang, Black Holes, No Math**
Topic 2: After The First Three Minutes
For Next Time - L22

- **Reading:**
  - Unit 5: Due before next class
- **Pre-Lecture Reading Questions Quiz:**
  - Unit 5 Quiz: Due before next class
- **End-of-Chapter Quizzes:**
  - Chapter 13:
    - (Do worksheet on class homepage to help prepare for EOC quizzes, Does not need to be turned in)
    - (Chapter 13 parts A-D)
    - Chapter 13 Parts D-F: Due before class
  - Chapter 14
    - Chapter 14 Parts A-D: Will assign next time
    - Chapter 14 Parts E-G: Will assign after that
- **Papers (All items due at 11:55PM in Peerceptiv)**
  - Paper 2:
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**Big Bang, Black Holes, No Math**

**Evolution of the Universe**

**Topic 2: After The First Three Minutes**

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