The Evolution of the Universe

Topic 1: The Early Universe

Big Bang, Black Holes, No Math
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
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
### A Brief History of Time

<table>
<thead>
<tr>
<th>Event</th>
<th>Time Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well before a trillionth of a second</td>
<td></td>
<td></td>
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<tr>
<td>One millionth of one second</td>
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<tr>
<td>A few minutes</td>
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<tr>
<td>A few hundred thousand years</td>
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<tr>
<td>100 million to 1 billion years</td>
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<tr>
<td>9 billion years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>~13.5 billion years</td>
<td></td>
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</tbody>
</table>

- The Big Bang (?)
- All parts of the visible universe come to have the same temperature everywhere
- Quarks and gluons combine to form protons and neutrons
- Protons and Neutrons combine to form deuterium and helium nuclei
- Protons and electrons combine to form hydrogen atoms
- Stars and galaxies begin to form
- Our solar system forms
- You take ASTR/PHYS 109
Photons: The Bullies of the Universe

- In many ways, the history of the universe is the history of the energy of the photons
- Early Days: Energetic photons break apart anything formed (Bully!)
- Later Days: They lose their ability to break things apart (no longer bullies!)
The Evolution of the Universe

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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

More detail
Confidence in this Story?

• How do we know this is what happened back then?

• What is the evidence for it?

• Will walk through the reasons next... It’s all about the energy of the collisions...
The Evolution of the Universe

Overview

1. The Early Universe
2. The First Three Minutes
3. The next 300,000 years
4. The next billion years
5. The next ~13 billion years, until today

The particles have the same temperature everywhere

- Once the Universe has the same temperature everywhere, only the details really depend on what came before it
Not exactly sure how it all starts... Call it a Big Bang...
Well before a Trillionth of a Second

- Particles at VERY high energies
  - Small wavelengths

- What is now the visible universe was so small back then that it had the same temperature everywhere
  - Which is why we see it having the same temperature everywhere now
Before a Millionth of a Second

• All particles will be **FREE**
  - Composite particles would be broken apart
    • No protons, neutrons or heavy nuclei
    • No atoms

• Only **FUNDAMENTAL** particles
  - Quarks
  - Photons
  - Electrons
  - Muons
  - Other from Chapter 3, plus others
Before a millionth of a Second

Lots of free particles, same temperature everywhere
Quarks can combine in the Early Universe to make a proton, but are quickly broken apart by high-energy photons in the Universe.

\[ qqq \rightarrow Prc \]

\[ Photon + Proton \rightarrow qqq \]
Before a millionth of a second → very high energy collisions

- Lots of free quarks to make protons
- Not many protons in the Universe because they are quickly busted apart
Time passes

• The Universe Expands and Cools

• Easier to tell the story after a millionth of a second after the Big Bang

• Cool enough that when quarks combine to form a proton or neutron they stay together
  
  - Said differently, other particles aren’t energetic enough to bust them apart
A Millionth of a Second after the Big Bang

The quarks have combined to form Protons and Neutrons
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The Universe changes from this to this

Later Times
After a millionth of a second

- No more free quarks to make more protons
- Number of protons doesn’t decrease because they aren’t getting busted apart by high energy photons
  - High enough photons don’t exist anymore

All the free quarks have combined to form protons or neutrons

Lots of water in the tub = Lots of protons in the universe

Very few high energy photons: Can’t break apart protons
Very Early Universe is Still Very Complicated

• The other fundamental and composite particles also have a big impact

• One example is a Muon which is (for our purposes) just a heavier version of an electron

- Discuss them more in Chapter 19
Photons and Muons

At very high energies photons can also turn into Muon pairs

Muon pairs can turn into Photons
Muons are an Important Part of the Early Universe

- Electron
- Anti-Electron
- Photon
- Muon
- Anti-Muon

Muon pairs can always produce photon pairs. If the photons are energetic enough they can interact and create muon pairs (or vice versa). ➜ muons, electrons, and photons all have the same temperature.
Why Aren’t They Around anymore?

- Most particles, except protons, electrons and photons decay REALLY quickly
  - Some at $10^{-24}$ sec, some $10^{-10}$ sec
  - Muons can live for $10^{-6}$ sec
- Can study lots of different types of particles here in experiments on Earth
- Need an accelerator to produce most new ones if you want to study them
- The photons in Today’s Universe aren’t energetic enough to produce new ones
Muon decay

Electron

Neutrino

Neutrino

Muon

Muon decay
Muons in the Universe

Early Universe

Lots of high energy collisions:
Can create lots of muons

Some water in the tub = Muons in the Universe

Muons are decaying and interacting to produce other particles

Later Times

Very few high energy collisions:
Very few muons being produced

Very little water in the tub = Very few muons in the universe

Muons decay away very quickly

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Topic 1: The Early Universe
Very Early Universe is Very Complicated

What particles CAN exist determine what’s going on in the Very Early Universe

Problem:

We don’t know if we have discovered all the fundamental particles yet!

- Good reasons to believe there are new ones out that we just haven’t found yet
  - Need bigger accelerators and/or Other tools
  - More on this later also

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The Evolution of the Universe

Topic 1: The Early Universe
Nuclei in the Early Universe

Proton + Proton → Deuterium

Deuterium + Photon → Proton + Neutron

A high energy photon can break apart a nucleus before it can find an electron to create an atom or find another nucleon to form a bigger nucleus.

High Energy Photon

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Topic 1: The Early Universe
What’s happening at about a millionth of a second after the Bang?

- Lots of protons
  - Photons can’t break them apart any more
- Not many heavy nuclei
  - Every one formed gets quickly busted apart
- Not many atoms
  - Every one formed gets quickly busted apart
- Very few other fundamental particles
  - Old ones would have decayed already, new ones not being produced
Moving towards later times...

- Universe gets bigger, older and colder
- By one hundredth of a second after the Big Bang there are basically no unstable fundamental particles left and the story is simpler to tell
- Protons, Neutrons, Electrons, Photons etc.
One hundredth of a second

- **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.

**Fancy particles gone by this time**

Photons can break up nuclei, but not protons.

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**Big Holes, No Math**

**Topic 1: The Early Universe**
The Evolution of the Universe

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Topic 1: The Early Universe

Photons and Electrons at Later Times

Electron pairs interact and annihilate but photon pairs no longer turn into particle pairs.

No easy way to produce more positrons.
Approaching the Three Minute Mark

• By three minutes after the bang the Universe is cool enough for Helium nuclei to form ($^4$He) even though it doesn’t happen too much...

• Complicated to produce $^4$He, lots of intermediate steps that are easier to break apart
At these lower energies the photon can't often break apart the nucleus

→ Amount of Deuterium in the Universe rises
Lecture on Chapter 13 now complete
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 an Excel worksheet to help you
  - On the main 109 page or directly at http://people.physics.tamu.edu/toback/109/Chap13-14Worksheet_Calc3.xlsx
- 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- L18

- Reading:
  - (Unit 4)
- Pre-Lecture Reading Questions (PLRQ)
  - Unit 3 (Original or Revision):
    - Let us know if you think you were misgraded
  - Unit 4: Was due today before class
- End-of-Chapter Quizzes:
  - Chapter 13 Parts A&B (if we finished Chapter 13, else just 12 Parts A&B)
- Papers:
  - Paper 1 Original or Revision:
    - Let us know if you think you were misgraded
  - Paper 2:
    - Let us know if you think you were misgraded
    - Revisions: Due Monday in TurnItIn at 11:55PM
  - Paper 3:
    - Text: Due Wednesday in Peerceptive and TurnItIn at 11:55PM
    - Reviews: Due next Monday at 11:55PM
    - Back-Evaluations: Due next Wednesday at 11:55PM

Big Bang, Black Holes, No Math, Topic 1: The Early Universe
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

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