Big Bang, Black Holes, No Math

ASTR/PHYS 109
Dr. David Toback
Lectures 19, 20 & 21

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

Topic 1: The Early Universe

Big Bang, Black Holes, No Math

Was due Today – L21

- Reading:
  - (Unit 4)
- Pre-Lecture Reading Questions (PLRQ)
  - For all PLRQ assignments: Let us know if you think you were misgraded
  - Unit 4: Grades posted soon
  - Unit 4 Revision (if desired): Due Tuesday before class
- End-of-Chapter Quizzes:
  - Do worksheet on class homepage to help prepare for EOC quizzes
    - Does not need to be turned in
  - Chapter 12 parts A&B
- Papers
  - Apologies for the grades flopping while we work with late activities
  - Send mail to 109help if:
    - If your score doesn’t look right (if you see a 0 for Writing Grade, assignment is probably open)
    - If your grade dropped because of back-evaluations
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  - Paper 3:
    - Draft for TA Feedback (if desired): Friday at 11:55PM
    - Text due *Thursday* Nov 8th

Bi Holes, No Main Topic on The Early Universe
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
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 (Bullies!)

• Later Days: They lose their ability to break things apart (no longer bullies!)
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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

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

Time
10^{-6}s 10^{-4}s 10^{-2}s 1s 1min 1h 1day 1y 10^2y 10^4y 10^6y 10^8y 10^{10}y

Temperature (K)
10^{12} 10^{11} 10^{10} 10^{9} 10^{8} 10^{7} 10^{6} 10^{5} 10^{4} 10^{3} 10^{2} 10^{1} 1

Notes, No Math Topic 1: The Early Universe
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

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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 anymore
A Millionth of a Second after the Big Bang

The quarks have combined to form Protons and Neutrons
The Evolving Universe

Early Universe

Later Times

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Topic 1: The Early Universe
Protons after a Millionth of a Second

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 energy 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
The 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

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Muons are an Important Part of the Early Universe

Muon pairs can always produce photon pairs. If the photons are energetic enough they can interact and create muon pairs (or vice versa).

μ, e, and γ 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

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The Evolution of the Universe
Topic 1: The Early Universe
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
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
Nuclei in the Early Universe

Proton + Proton $\rightarrow$ Deuterium

Deuterium + Photon $\rightarrow$ 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.
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 neutral atoms
  - Every one formed quickly gets 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.
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One hundredth of a second

Fancy particles gone by this time
Photons can break up nuclei and neutral atoms, but not protons
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Topic 1: The Early Universe

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 ($^4\text{He}$) even though it doesn’t happen too much...

• Complicated to produce $^4\text{He}$, 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 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 - L21

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  - (Unit 4)

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

- **Papers**
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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