Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 21
Was due Today - L21

- Reading:
  - Unit 4: Was due before class
- Pre-Lecture Reading Questions Quiz:
  - Unit 4 Quiz: Was due before class
- End-of-Chapter Quizzes:
  - Chapter 12, parts a&b
- Papers (All items due at 11:55PM in Peerceptiv)
  - Paper 2:
    - Text: Was due Wednesday Oct 23rd (Grace period with late penalties)
    - Reviews: Was due Monday Oct 28th (Grace period with late penalties)
    - Back Evaluations: Was due Monday Nov 4th
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  - Paper 3: (Best guesses)
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Big Bang, Black Holes, No Math

The Evolution of the Universe

Topic 1: 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
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 has 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 Evolution of the Universe

Topic 1: The Early Universe

- Big Bang
- Black Holes
- No Math

The History of the Universe

- Universe expands as time passes
- Universe cools down as time passes

Temperature (K) vs. Time (y)

- 10 billion degrees
- 1 degree
- 1 second
- 10 billion years

Bigger wavelengths → Smaller energies → Smaller Temperature

Holes, No Math

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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

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The Evolution of the Universe
Topic 1: The Early Universe
What Happening?

What happens to the particles at each of these times?*

Collisions!

* Much of this is stuff you have already learned... we're just telling the story with more detail now
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
A Brief History of Time

- Zero
- Well before a trillionth of a second
- One millionth of one second
- A few minutes
- A few hundred thousand years
- 100 million to 1 billion years
- 9 billion years
- ~13.5 billion years

- 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 (Bullies!)
- Later Days: They lose their ability to break things apart (no longer bullies!)
The Evolution of the Universe

Topic 1: The Early 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

Temperature (K)

Time

10^{-6} Seconds
Protons and Neutrons form

A Few Minutes
Nuclei form

\(10^5\) Years
Hydrogen atoms form

\(10^8\) Years
Stars and Galaxies form

\(10^9\) Years
Our Solar System forms

\(10^{10}\) Years
You Read This Book
Confidence in this Story?

- Why do we think it happened this way?
- 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

Artists conception...
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.

\[ qqq \rightarrow P + \text{Proton} + \text{Photon} \]

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The Evolution of the Universe

Topic 1: The Early Universe

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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

Particles in the Universe: The Bathtub Analogy

Protons-in-The-Early-Universe Bathtub

Lots of free quarks: Can combine to form protons

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

Lots of high energy photons: quickly break apart any protons created
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

- Up Quark
- Down Quark
- Photon
- Electron

Later Times

- Electron
- Neutron
- Proton
- Photon

The Universe changes from this to this

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The Evolution of the Universe

Topic 1: The Early Universe
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
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

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

µons, 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

- Muon
- Neutrino
- Electron
- Neutrino
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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The Evolution of the Universe

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
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 is the Universe like at about a millionth of a second after the Bang?

- Lots of protons
  - Photons can’t break them apart any more
- Not many nuclei heavier than hydrogen
  - 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.
One hundredth of a second

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

**A Few Minutes**
- Nuclei form

**~10^5 Years**
- Hydrogen atoms form

**~10^8 Years**
- Stars and Galaxies form

**~10^9 Years**
- Our Solar System forms

**~10^{10} Years**
- You Read This Book

*Fancy particles gone by this time*
*Photons can break up nuclei and neutral atoms, but not protons*
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 the various stages in its history (and why)
- Since many people struggle with this 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
  - We understand you can cheat/game the system to complete the spreadsheet, but if you do you will REALLY struggle with the quizzes (and there are lots of them)
For Next Time - L21

- Reading:
  - (Unit 4)
- Pre-Lecture Reading Questions Quiz:
  - (Unit 4 Quiz)
- 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)
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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