Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 28
Was due Today - L28

• Reading:
  - (Unit 4)
  - Unit 5: Assigned today

• Pre-Lecture Reading Questions (PLRQ)
  - Unit 4: Grades posted. Let us know if you think you were misgraded
  - Unit 4 Revision (if desired): Due Friday before class time (no class)
  - Unit 5: Assigned today

• End-of-Chapter Quizzes:
  - Do worksheet on class homepage to help prepare for EOC quizzes
    • Does not need to be turned in
  - Chapter 13 Parts A-D

• Papers
  - Paper 2: Grades posted/fixed. Let us know if you believe you were misgraded
  - Paper 2 Revision (if desired): Due Friday March 30 in TurnItIn
  - Paper 3:
    • Text: Due Wed March 28th in Peerceptive and TurnItIn at 11:55PM
    • Reviews: Due Monday April 2nd at 11:55PM
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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
Where are we now in the history?

3 Minutes:
Photons can no longer break up nuclei

Big 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
  - ~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 $\rightarrow$ Deuterium + Electron + Neutrino

Nuclear Reaction

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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

Nuclear Reaction

Proton

Deuterium

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

\( ^3\text{He} \)

\( ^4\text{He} \)

\( ^3\text{He} \)

\( ^4\text{He} \)

\( ^3\text{He} \)

\( ^4\text{He} \)

Proton

Proton

Proton

Nuclear Reaction
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

\(^{4}\text{Li}\) 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

- Neutron
- Proton
- Electron
- Neutrino

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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

Electromagnetic Reaction

Hydrogen Atom

Proton

Electron

Photon

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Evolution of the Universe

Topic 2: After The First Three Minutes
Where are we now in the history?

200,000-700,000 years

Photons can no longer break apart atoms
The Transition From a Hot Universe to a Cool Universe

Proton

$^{4}\text{He}$ Nucleus

Deuterium Nucleus

Photon

Electron

Some Time Passes

The Transition From a Hot Universe to a Cool Universe
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-

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Topic 2: After The First Three Minutes
Atoms in the Universe

Early Universe

A couple hundred Thousand Years Later

These days

Big Bang, Black Holes, No Math
Before and After the Creation of Atoms

Before:
Lots of free electrons and protons in the Universe
$\rightarrow$ Photons scatter from charged particles

After:
Protons and electrons combine to form atoms
$\rightarrow$ Universe becomes transparent for photons
The Universe now **LOOKS** different!

- The light (photons) have no free electrons to interact with
- Since all the electrons are in atoms, because of Quantum Mechanics, they largely ignore the photons
- Photons just travel in a straight line → Like traveling through glass
Evolution of the Universe

Topic 2: After The First Three Minutes

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Atoms in the Universe

Early Universe
Photons bust apart atoms

A couple hundred Thousand Years Later
Photons can only excite atoms

These days
Universe is transparent to photons

Hydrogen

High energy photon

Proton

Electron

Aha!

Ahh.

Oops.

No thanks. Wrong energy.
A Cartoon...

Before

Recombination:

Photons interact with charged particles

After Recombination:

Photons travel in straight lines

No Math
Cosmic Background Radiation

- The photons we see in the cosmic background radiation are essentially the photons AFTER they interacted with their last charged particle.

- Well... they've been traveling for awhile so they've changed a bit.
After recombination, photons can travel freely through space.
Their wavelength is only stretched (red shifted) by cosmic expansion.
→ Observe most photons as the cosmic background radiation!
→ Also can observe photons emitted from Galaxies a billion years ago (just reaching us now) as being red-shifted.

The expansion of space-time stretches the photon to longer wavelength as it travels.

The farther the photon has to travel, the more it is stretched.

When the photon arrives at our galaxy, we see it with a longer wavelength — a red shift that is proportional to distance.
For Next Time - L28

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  - Chapter 14 Parts A-D (if we finished Chapter 14, else just 13 Parts A-D)

- **Papers:**
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Big Bang, Black Holes, No Math Topic 2: After The First Three Minutes
Full set of Readings So Far

• Required:
  - **BBBHNM**: Chaps. 1-15

• Recommended:
  - **TFTM**: Chaps. 1-5
  - **BHOT**: Chaps. 1-7, 8 (68-85), 9 and 11 (117-122)
  - **SHU**: Chaps. 1-3, 4(77-93), 5(95-114), 6, 7 (up-to-page 159)
  - **TOE**: Chaps. 1-3