Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 14

Big Bang, Black Holes, No Math

Physics We Need

Topic 5: Temperature and Equilibrium
Was due Today - L14

- Reading:
  - BBBHNM Unit 3
- Pre-Lecture Reading Questions (PLRQ)
  - Unit 3, Stage 1: Was due today before class
- End-of-Chapter Quizzes:
  - Quizzes 8a and 8b
- Papers:
  - Paper 1:
    - Let us know if you think you were misgraded
  - Paper 1 Revision (if desired), Stage 1: Will be due Wednesday before class
    - Check on regrades to before submitting
    - Will need to turn in to both CPR and turnitin on eCampus even if the text is the same (that way we know that it's the same)

Bi

- Paper 2, Stage 1: Due Wednesday before class

Holes, No math, Topic 5. Temperature and Equilibrium
Where we are...

Topics

1. Light and Doppler Shifts \( \leftarrow \) Done
2. Gravity, General Relativity and Dark Matter \( \leftarrow \) Done
3. Atomic Physics and Quantum Mechanics \( \leftarrow \) Done
4. Nuclear Physics and Chemistry \( \leftarrow \) Done
5. Temperature and Thermal Equilibrium \( \leftarrow \) This Time
Bottom Line

I can tell that I am located in a gas in thermal equilibrium if:

1. The temperature is the same in all directions OR

2. The temperature looks as if either me or the gas is moving in a single direction

A gas in **Thermal Equilibrium** is well described by its **Temperature**
Overview of Today's Material

1. Temperature: Photons and Atoms
2. Thermal Equilibrium
3. Moving in a Gas
4. Different types of Equilibrium
5. What we can, and can't, learn from a system in Thermal Equilibrium
Other Types of Equilibrium?

- Different types of gas can mix
- When things stop changing (temperature and other mixing) we say it has come into thermal equilibrium
- Atoms (or particles) can interact and come into thermal equilibrium
Example 1: Two Gases Mixing

• Let’s say I have two different gases with different temperatures on opposite sides of a jar
  - High Mass atoms and Low Mass Atoms
• Before: Not in thermal equilibrium, doesn’t LOOK like equilibrium
  - Different temperatures on each side
  - If I weren’t at the center, it would look different than if I were at the center
• During: The atoms “mix” and come to thermal equilibrium
• After: We’re in thermal equilibrium \( \Rightarrow \) equal temperatures everywhere, looks the same in all directions
Two Gases Mixing

Low Mass Atoms  High Mass Atoms

http://bigbang.physics.tamu.edu/Figures/StolenAnimations/HeatTransferred.avi
Other Examples

- Can have many different types of “mixing” where things eventually come into thermal equilibrium with each other
- Hydrogen and oxygen can mix and turn into water in thermal equilibrium
- At high energies, I can get an electron/photon “soup” in thermal equilibrium
  - How?
Thermal Equilibrium at High Energies/Temperatures

- An electron and an anti-electron can collide and turn into two photons
- Two photons can collide and turn into an electron and an anti-electron
  - If they have enough energy
Photons and “Electrons”

2 Photons can turn into 2 “Electrons”

2 “Electrons” can turn into 2 Photons
Visualize: Electrons and Photons

Electrons, positrons, and photons in both production and annihilation
Electron and Photons

• If we have only lots of electrons and positrons, they will interact and create photons
  - Number of electrons/positrons falls, and number of photons rises

• If there are only lots of high energy photons, they will interact and create electrons/positrons
  - Number of photons falls, and number of electrons/positrons rises
What happens over time?

- If I start with slightly more high energy photons than electrons and positrons, then slightly more of the collisions produce electrons and positrons until things even out.
- Same is true if I start with slightly more electrons/positrons.
Always end up the same way

- Eventually, the number of electrons/positrons/photons stops changing
- The energy of the particles stops changing

$\Rightarrow$ I get an electron/photon “soup” in **Thermal Equilibrium**
I always end up with electron/photon “Soup”

- If I start with ONLY high energy electrons and positrons, eventually I’ll end up with electrons, positrons and photons in thermal equilibrium
- If I start with ONLY high energy photons, eventually I’ll end up with electrons, positrons and photons in thermal equilibrium
- Same with any combination to start!
Lots of **Types** of Thermal Equilibrium

- Given enough time (and things not changing) all places in the room will come to have the same temperature i.e., be in thermal equilibrium.

- Depending on what the particles are (electrons, photons, atoms etc.) they can turn into different types of particle bring the number of objects AND energy into Thermal Equilibrium also.
So what???

If we know how it all starts, we can figure out how it will look at the end!
Overview of Today’s Material

1. Temperature: Photons and Atoms
2. Thermal Equilibrium
3. Moving in a Gas
4. Different types of Equilibrium
5. What we can, and can’t, learn from a system in Thermal Equilibrium
What Thermal Equilibrium Can, and Can’t, Tell Us

• Lots of different ways of starting out will come to the same thermal equilibrium

• So what? Since this is true we can’t learn a lot about what happened BEFORE it went into equilibrium
  - Single cue ball hit a rack of balls?
  - Two balls hit the rack at the same time?

• Can’t tell the difference looking at much later times…
Different Initial Conditions

Much later in time (after we’re in thermal equilibrium) can’t tell if the system started in

Funny Way

Usual Way
A Universe in Thermal Equilibrium

- We will see evidence that the Universe appears to have the same temperature everywhere
  - Was it in Thermal Equilibrium at some point in its history?
- Tells us a lot about the Universe and how it evolved (and will evolve)
- Can’t tell us about what happened BEFORE it came into Thermal Equilibrium
  - For example: Was there actually a Big Bang? Something else?
Lecture on Chapter 9
now complete
The Plan...

Finished:
1. Light and Doppler Shifts
2. Gravity, General Relativity and Dark Matter
3. Atomic Physics and Quantum Mechanics
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium

Next time:
• Starting Unit 3
• Using the “Physics We Need” to teach us about the EVIDENCE for the Big Bang
Starting Unit 3

Finished Unit 2: Physics We Need
1. Light and Doppler Shifts
2. Gravity, General Relativity and Dark Matter
3. Atomic Physics and Quantum Mechanics
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium

Starting Unit 3: Evidence for Big Bang
1. The Exploding Universe
2. Expanding Space-Time
3. Photons and Hydrogen in the Universe
Where we are going…

• First give three pieces of evidence for the Big Bang
  - Don’t worry… you don’t need to memorize them now
  - Will keep coming back to them over and over again
  - Will be in the lecture notes
• Then tell the story about how they all fit together
• Will be the topic of Paper 3
Overview: Evidence for the Big Bang

1. We observe all distant galaxies to be moving away from us
   - The further away the galaxy is the faster it is moving away from us
   - True no matter which direction we look

2. We observe low energy photons (microwaves) uniformly distributed in all directions which are consistent with a temperature of about 2.7 degrees above absolute zero (Kelvin)

3. The atoms in the Universe are basically Hydrogen and Helium and not much else
3 Lecture Outline

1. The Exploding Universe
   • Today

2. Expanding Space-Time
   • Next Lecture

3. Photons and Hydrogen in the Universe
   • The Lecture After That
Today’s Outline

• Looking at Galaxies
• Light from distant galaxies is Red Shifted and appears the same in all directions
• The Exploding Universe
• A problem...
Our understanding of “The Universe” before the 1920’s

• Before the 20’s, when the telescopes became powerful enough, there was no convincing evidence that there was anything outside the Milky Way

• When Einstein first wrote about the Universe, he meant “The Milky Way”
Edwin Hubble

- In the 1920's Hubble established that there are distant galaxies made of individual stars
  - VERY far away
- Now know that in the same way that the Sun is just one star of many, the Milky Way is just one of about a 100 billion galaxies
What can we Learn from Galaxies?

Measure some important things:

- How far away are they?
- How fast are they moving?
- What directions are they moving?
How do you measure the distance to a galaxy?

Use a special Star called a “Cepheid Variable”

• We know how much light they emit
  - Like a 100 Watt Light bulb

• If we measure how much light we see, we can figure out how far away it is

• If we can find a Cepheid in a galaxy, then we can figure out how far away that galaxy is
What is Their Velocity?

- How fast are they moving?
- What direction are they moving?

Use the Doppler shift and measure their spectral lines!
Observing a Galaxy

Galaxy Emitting Light

Moving away from us
Put it all together

Measure distance from how much light reaches us

Measure speed from Doppler shift of Spectral lines

Evidence for the Big Bang
Topic 1: The Exploding Universe
Distances

- **Near**: Andromeda (the closest galaxy to our own) is \(~2\text{ million light years away!}\)
  - While we don’t consider this to be a “distant” galaxy, it is more than 10 times farther away than the furthest thing in our own galaxy

- **Far**: We see galaxies over 10 billion light years away
Speeds

A fast star can travel a few hundred kilometers per second!

Put this in perspective

- **Big**: Can travel 10 billion kilometers in a year
- **Small**: That’s less than a 1000th of the distance to the star nearest us
Prep for Next Time - L14

- Reading:
  - (BBBHNEM Unit 3)
- Pre-Lecture Reading Questions (PLRQ)
  - Unit 3, Stage 2: Due before class Wednesday
- End-of-Chapter Quizzes:
  - If we finished Chapter 10 then end-of-chapter quiz 10 (else just through Chapter 9)
- Papers:
  - Paper 1:
    - Let us know if you think you were misgraded
  - Paper 1 Revision (if desired), Stage 1: Due before class Wednesday
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  - Paper 2, Stage 1: Due before class Wednesday
    - Make sure you have submitted to both CPR and turnitin on eCampus

Holes, no math

Topic 1: The Exploding Universe
Full set of Readings So Far

• Required:
  - BBBHNM: Chaps. 1-12

• Recommended:
  - TFTM: Chaps. 1-3
  - BHOT: Chaps. 1-7, 9 and 11 (117-122)
  - SHU: Chaps. 1-3, 4(77-86), 5(95-104), 6, 7 (up-to-page 153)
  - TOE: Chaps. 1 & 2