Big Bang, Black Holes, No Math
ASTR/PHYS 109
Dr. David Toback
Lectures 14 & 15
Was due Today - L15

• Reading:
  - BBBHNM Unit 3: Was due before class
• Pre-Lecture Reading Questions (PLRQ)
  - Unit 3: Was due before class
• End-of-Chapter Quizzes:
  - (Quizzes 8a and 8b)
• Papers:
  - Paper 1:
    • Let us know if you think you were misgraded
    • You may submit a revised text to TurnItIn. Due Thurs Oct 18th, before 11:59PM
  - Paper 2:
    • Text: due Tonight (Tues Oct 16th)
      - Both Peerceptiv and TurnItIn
    • Reviews: Due Thursday Oct 18th
    • Back-evaluations: Due Tuesday Oct 23
Where we are...

Topics
1. Light and Doppler Shifts ← Done
2. Gravity, General Relativity and Dark Matter ← Done
3. Atomic Physics and Quantum Mechanics ← Done
4. Nuclear Physics and Chemistry ← Done
5. Temperature and Thermal Equilibrium ← This Time
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 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?
Electron and Photons

• If we have only lots of electrons and positrons, and no photons, 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
Always end up the same way

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

\[
\Rightarrow \text{I get an electron/photon “soup” in Thermal Equilibrium}
\]
What happens over time?

• It doesn’t matter HOW it starts
• 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
• Can always predict how it will end up
Lots of *Types* of Thermal Equilibrium

- It isn't just electrons and photons
- Given enough time (and things not changing) all places in any 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 particles and bring the number of objects AND energy into Thermal Equilibrium also
So what???

• Often the details of how it starts don’t matter

• If I know the particles and the energies I can figure out how it will come out in the end

• Things come to be in thermal equilibrium... they stop changing
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
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 Chapter 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

Not Moving away from us
Put it all together

Measure **distance** from how much light reaches us

Measure **speed and direction** from Doppler shift of Spectral lines
Distances

- **Near:** Andromeda (the closest galaxy to our own) is ~2 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
Prep for Next Time - L15

- Reading:
  - (BBBHN M Unit 3)
- Pre-Lecture Reading Questions (PLRQ)
  - (Unit 3)
- End-of-Chapter Quizzes:
  - If we finished Chapter 10 then end-of-chapter quiz 10 (else just through Chapter 9)
- Papers:
  - Paper 1:
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