Lesson 9: The Early Universe

Reading Assignment

- Chapter 26.7: The Cosmic Microwave Background
- Chapter 27.1: Back to the Big Bang
- Chapter 27.2: The Evolution of the Universe
    - More Precisely 27-1: More on Fundamental Forces
- Chapter 27.3: The Formation of Nuclei and Atoms
- Chapter 27.4: The Inflationary Universe
- Chapter 27.5: The Formation of Structure in the Universe
- Chapter 27.6: Cosmic Structure and the Microwave Background

Summary of Eras and Epochs

- Read Chapter 27.2, More Precisely 27-1, and Chapter 27.3
- **Radiation Era**
    - **Planck Epoch**
        - 0 seconds: Big Bang
            - Quantum gravity
    - **GUT Epoch**
        - 10^{-43} seconds: Gravity separates
            - Grand Unified Theory
    - **Quark Epoch**
        - 10^{-35} seconds: Strong force separates
            - Electroweak force
        - 10^{-12} seconds: Electromagnetic and weak forces separate
            - Hadron (p,n), lepton (e,ν), and photon (γ) gas
    - **Lepton Epoch**
        - 10^{-4} seconds: Hadrons freeze out
            - Lepton (e,ν) and photon (γ) gas (and CP-violation p, n)
        - 1 second: Neutrinos (ν) decouple
            - Cosmic Neutrino Background
            - Electron (e) and photon (γ) gas (and CP-violation p, n)
        - 10^{2} seconds: Electrons freeze out
            - Photon (γ) gas (and CP-violation p, n, e)
    - **Nuclear Epoch**
        - 3 minutes: Primordial nucleosynthesis begins
            - p, n $\rightarrow$ H (75% by mass), He (25% by mass), D (trace amounts)
        - 20 minutes: Primordial nucleosynthesis ends
- **Matter Era**
    - **Atomic Epoch**

        - 5×10^4 years: Matter dominates radiation
        - 4×10^5 years:
            - Recombination: Nuclei and electrons form atoms
            - Photons (γ) decouple: Cosmic Microwave Background
    - **Galactic and Stellar Epochs**
        - 4×10^8 years: First stars form
        - 10^9 years: First galaxies form
        - 2×10^9 years: Quasar-formation peaks
        - 3×10^9 years: Star-formation peaks
- **Dark-Energy Era**
    - 10^{10} years: Dark energy dominates matter
    - 1.4×10^{10} years: Now

Summary of Primordial Nucleosynthesis

- Read Chapter 27.3.
- proton: ^{1}H
- neutron: n
- deuterium (proton + neutron): ^{2}H
- tritium (proton + 2 neutrons): ^{3}H
- helium (2 protons + 2 neutrons): ^{4}He
- photon (energy): γ
- Major chain reaction:
    - **1. $^1\mathbf{H} + \mathbf{n} \rightarrow {}^2\mathbf{H} + \boldsymbol{\gamma}$**
    - **2. $^2\mathbf{H} + {}^1\mathbf{H} \rightarrow {}^3\mathbf{He} + \boldsymbol{\gamma}$**
    - **3. $^3\mathbf{He} + \mathbf{n} \rightarrow {}^4\mathbf{He} + \boldsymbol{\gamma}$**
- Primordial nucleosynthesis took place between ≈3 and ≈20 minutes after the Big Bang, creating the universe's initial abundances of hydrogen (≈75% by mass) and helium (≈25% by mass). Since then only a few percent of this hydrogen has been converted into helium and heavier elements in stars.

Summary of Mass and Energy in the Universe

Type of Mass/Energy	**Current Percentage of Total Mass/Energy**	**Evidence**
Dark Energy	≈73%	Type Ia supernova distances, Globular cluster ages, CMB fluctuation sizes
Matter:	≈27%	Galaxy cluster velocity dispersions and gravitational lensing measurements vs. Structure formation simulations
Dark Matter	≈23%	Galaxy rotation curves, Galaxy and galaxy cluster velocity dispersions and gravitational lensing measurements,

		CMB fluctuation measurements vs. Structure formation calculations
Normal Matter:	≈4%	Deuterium and lithium abundance measurements vs. Primordial nucleosynthesis calculations
H He	≈3% ≈1%	Helium abundance measurements, Primordial nucleosynthesis calculations
Radiation	≈0.006%	CMB

- Note: $E = mc^2$ is used to convert mass units into energy units or energy units into mass units so like quantities can be compared.

Homework 9

Download Homework 9 from WebAssign. Feel free to work on these questions together. Then submit your answers to WebAssign individually. Please do not wait until the last minute to submit your answers and please confirm that WebAssign actually received all of your answers before logging off.

Extra Credit Homework

Read a popular scientific article (e.g., Scientific American) on an aspect of relativity, black holes, cosmology, or the early universe. Write a 2-page essay summarizing it, including your own thoughts. I will grade this **optional** homework pass/fail. If you pass, I will drop your second worst homework when I average your homework grades at the end of the semester (I already drop your worst homework grade). The extra credit homework is due with the final exam.

To pass, follow these simple rules:

- The essay should be single spaced with 1.25-inch margins.
- Use 12-point Times New Roman font.
- The header should consist of a title, your name, and a single space before the beginning of the essay. Do not put spaces between paragraphs.
- The essay should run at least one line onto page three.
- Include a bibliography of your sources on page three.
- Stay on topic and don't make things up!