Section 11: Cosmology and Relativity

1. Cosmic Chronology

Place the following events of the early universe in chronological order: Recombination (formation of neutral atoms), Big Bang Nucleosynthesis, Inflation, Formation of first galaxies, Quark-gluon plasma era.

2. Hubble's Law

According to Hubble's Law ($v = H_0 d$), and using $H_0 \approx 70$ (km/s)/Mpc, at what distance would a galaxy be receding from us at the speed of light? This defines the approximate size of the observable universe.

3. Galactic Year

Our Solar System orbits the center of the Milky Way (a distance of about 27,000 light-years) at a speed of about 220 km/s. How long does it take to complete one orbit (a "galactic year")?

4. Time Dilation

A muon has an average lifetime of $2.20\,\mu$s in its own rest frame. If it travels at $0.990c$, what will its average lifetime be as measured by an observer on Earth?

5. Length Contraction

What speed must a 1-meter-long ruler have for its length to be observed as 0.5 meters due to length contraction?

6. Mass-Energy

The "Little Boy" atomic bomb converted about 0.7 grams of mass into energy. Using $E = mc^2$, calculate the energy released in Joules. (1 kiloton of TNT is approx. 4.184×10^{12} J).

7. Twin Paradox

An astronaut spends one year on the ISS, which travels at about 7.66 km/s. How much younger would the astronaut be than their twin on Earth due to kinetic time dilation?

8. Velocity Transformation

A rocket traveling at $0.8c$ away from Earth shoots a probe forward at $0.5c$ relative to the rocket. What is the probe's speed as measured by an observer on Earth?

9. High Energy Physics

How much energy (in GeV) is required to accelerate a proton from rest to a speed of $0.99c$? The rest mass of a proton is about 938 MeV/c^2.

10. Relativistic Mass

What is the relativistic mass of a 1000 kg car traveling at 99.9% of the speed of light?