Class #12 (April 4) Reading Questions - Cosmic Onion, Chapt. 14

Summary: The present day universe contains a very inhomogeneous distribution of matter and photons, with the matter clumped into widely separated galaxies and clusters of galaxies. The seeds for this non-uniform distribution can be seen in the small temperature fluctuations in the cosmic background radiation. Detailed study of this radiation over the past 20 years has provided critical tests of the standard model of cosmology know as Lambda-CDM. In this model, the universe (space and time) began with a big bang 13.7 billion years ago and is comprised of 74% dark energy (represented by "Lambda" in Einstein's field equations), 22% cold dark matter (CDM), and 4% "normal" matter (the stuff of the standard model of particle physics) with the total amount of matter/energy giving a globally flat space-time geometry. From the perspective of particle physics, the very early universe would have consisted of a homogeneous mixture of all possible elementary particles. However, as the universe rapidly expanded it would have "cooled" (decreased in energy density) and undergone a series of symmetry breaking phase transitions leading to the appearance of the strong, weak, and electromagnetic interactions as distinct forces of nature. Although we can not directly "see" farther back than when the universe was 10^6 years old (when electrons and protons combined to form atoms and the background radiation was released), observation of the relative abundance of hydrogen vs helium (these being produced 0.01s and 100s after the big bang, respectively), are in good agreement with predictions from the standard model of particle physics. Large accelerators, such as the LHC, are able to reach collision energies that would have been present when the universe was only 10^-9s old allowing us to probe the physics of the very early universe.

Questions:

1. What is the evidence for the existence of dark matter? How does dark matter fit into the standard model of particle physics?

2. What is the evidence for the existence of dark energy? How does dark energy fit into the standard model of particle physics?

3. The energy density in the very early universe was large enough for all the particles of the standard model to be produced in roughly equal abundances. Considering that photons are only one out of many different particle types, why are there so many more photons than "matter" particles (see ratio on pg. 195) in today's universe?

4. Does the standard model provide an explanation for the matter/antimatter asymmetry in the present day universe?

5. About three minutes after the big bang the universe consisted of roughly 75% protons (note typo on pg 199) and 24% helium nuclei. Where did the helium come from? Where do the heavier elements that make up you and the earth come from?

Your Question: Please give a well-formulated question that you have regarding the material covered in this reading assignment.