ISP 205
Review Questions, Week 14

This is not required homework. It will not be graded. Answers will be supplied next week.

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1. What do we actually measure when we say that there is Cosmic Microwave Background (CMB) radiation? *We detect faint radio emission coming from all directions in space. It has a thermal energy distribution. The peak brightness is at a wavelength of about 1 millimeter which can only be observed from above the Earth's atmosphere using satellites, but the CMB was discovered using a radio telescope on the Earth's surface observing at a larger wavelength, where the CMB is much fainter. The spectrum of the CMB is that of a thermal emitter with a temperature of about 3 K (3 degrees above absolute zero)*

2. How was the CMB produced? *The whole universe used to be filled with thermal radiation corresponding to quite high temperatures. The radiation was formed by the universe basically glowing because it was hot. Any given photon associated with this radiation could not travel very far because the universe was also full of free electrons zipping around this way and that. The photons scattered off the electrons, as if they were in a fog bank. As the universe expanded, the electron gas cooled off and the temperature of the radiation field cooled with it. But when the universe was about 380,000 years old, it cooled down enough so that the electrons could be captured into orbits around atomic nuclei, forming (for the first time ever) neutral atoms. In that form, the electrons could no longer scatter the photons, so the photons just kept going straight and carried with them the energy distribution corresponding to their temperature at the time the atoms captured the electrons. The CMB is that radiation, but highly redshifted due to the subsequent expansion of the universe.*

3. What does it tell us about the overall history of the universe? *It demonstrates that the universe used to be much hotter than it is now, and hence has been evolving with time. This ruled out the "steady state" model of the universe.*

4. What do we mean by the term "Dark Matter? *This is a form of matter that does not interact through the electromagnetic force, so it neither absorbs or emits light. We think that it consists of particles called WIMPs (Weakly Interacting Massive Particles) left over from a time when the universe used to be way hotter.*

5. What are the three independent techniques, described in class, by which we detect the existence of Dark Matter? *(1) The orbital speed of stars and gas in the outer parts of spiral galaxies shows that there must be large amounts of unseen matter in the far outer regions of those galaxies, pulling on the normal matter (the stars, etc) through gravity. (2) The orbital speed of galaxies in giant galaxy clusters shows that the cluster must be pervaded by dark matter exerting a gravitational pull. (3) The gravitational field of the dark matter in giant galaxy clusters also bends the path of light that is passing through the cluster. When there is a large galaxy cluster in the foreground between us and very distant galaxies, this effect causes the images of the distant background galaxies to be distorted, often into the shape of large arcs. This is "gravitational lensing".*

6. What fraction of all matter is in the form of Dark Matter? *About 85%.*

7. On the largest observed scale, what is the general distribution of matter in space? Is it just a uniform distribution, or does it have some particular structure to it? If the latter, what type of structure? *Most galaxies are found on the surfaces of large bubbles that are empty inside.*

The bubbles intersect with each other, like soapsuds in a sink. The galaxies are really just tracing the structure of the dark matter. This distribution of matter is also sometimes described as being like a cobweb, and is called the "cosmic web".

8. What is meant by "top-down" structure formation, and what is meant by "bottom-up" structure formation? Which seems to be the prevalent case in the actual universe? *"Top-down" means that larger structure form first, and then break up into smaller structures. "Bottom-up" means the opposite… smaller things form first, and then gradually join together to form larger and larger structures. It seems that "bottom-up" is the usual order in the universe… small proto-galaxies with just a few hundred thousand stars worth of material formed first, and then these combined together to make larger galaxies, and then the large galaxies attracted each other to form giant clusters. But this all happened in a way so that we currently have the cosmic web structure.*

9. What is a quasar? *In terms of what we see, quasars are immensely luminous point-like objects. They have sizes similar to the size of our solar system, but emit 1000 times more light than our entire galaxy. This is all thought to be the result of matter falling into a black hole that contains up to 100 million times the mass of the sun. The light from the quasar is produced by infalling material crashing onto a disk of material that forms around the actual black hole. The disk is heated, and glows because it is so hot. So the light we see is generated outside the Schwarzschild radius of the black hole (as it must be).*

10. What do quasars have to do with galaxies? *The black holes were formed by material falling in to the centers of galaxies during the process of forming big galaxies through the mergers of smaller ones (the bottom-up" formation process). Now days, the rate of galaxy mergers has slowed way down, so there is not very much additional material falling into most of these black holes, with the result that we don't see many nearby quasars. But the black holes are still there, including one in the center of our own Milky Way galaxy.*

11. How do we know that the center of our own Milky Way galaxy contains a black hole with over a million solar masses of material inside it? *We can see that the stars in the very center of our Galaxy are orbiting around a point that has nothing visible in it. The stars' orbital motions show that the unseen central object has over 1 million solar masses in it. The stars' orbits take them to within about 60AU of that massive object, without them running into anything. So the massive object must be less than 60 AU in diameter (about the size of Pluto's orbit). That pretty well rules out anything except a black hole.*