ASTR 340 - Origin of the Universe – Fall 2005 December 15, 2005
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FINAL EXAM

Answer all questions in your exam booklet. There are 150 points total, with each questions as marked.

1. Scientists – Matching

For each of the scientific contributions below, write the name of the scientist who made it. Use names from the following list (*note: some names may be used more than once!*). [**2 points each**]

Albert Einstein
Alexander Friedmann
George Gamow
Alan Guth
Edwin Hubble
Sir James Jeans
Henrietta Leavitt
Arno Penzias
Willem de Sitter
Vesto Slipher

(a) Discovered the period-luminosity relation for Cepheid variable stars.

(b) First observed large recession velocities for spiral nebulae.

(c) Measured the distance to the Andromeda galaxy using Cepheids.

(d) Showed that the distances to "spiral nebulae" are proportional to the redshifts of their spectral lines.

(e) Worked out the minimum possible mass for gravitational collapse at a given density and temperature.

(f) Obtained a solution for the expanding universe with zero curvature (flat space), zero matter, and a nonzero cosmological constant.

(g) Obtained a static (neither expanding nor contracting), closed (positive curvature) solution for the space-time of the universe, by including a cosmological constant.

(h) Was the first to propose that the Universe started off in a very hot state with matter and radiation mixed together.

(i) Was the first to predict that "relic radiation" with temperature of 5K should be present in the present universe.

(j) Was the first to detect the presence of cosmic background radiation, using a microwave antenna.

(k) Developed theory that a period of "cosmic inflation" ocurred very early in the history of the universe.

(l) Developed equation, based on Einstein's theory of general relativity, to relate the expansion rate of the universe to its matter content and spatial curvature.

2. Cosmological events – matching & definition

For each of the cosmological events (a)-(g) below, match with the approximate point in time or interval when it occured (from the list following), and briefly state what happened physically. [**4 points each**]

$t = 0 - 10^{-43}$s
$t = 10^{-37} - 10^{-32}$s
$t = 10^{-6}$s
$t = 3$minutes
$t = 400,000$yrs
$t = 10^{9} - 10^{10}$yrs

(a) Recombination

(b) Quark-hadron phase transition

(c) Planck epoch

(d) Galaxy formation

(e) Nucleosynthesis

(f) Inflation

3. Short answers

Answer the following questions, being as concise as possible. Full sentences are not required as long as your answer is clear. [**8 points each**]

(a) What are *peculiar velocities*, and how do they affect redshift surveys?

(b) Why is the fact that neutrons decay useful for estimating the baryon density of the universe?

(c) How are type 1a supernovae used as a "tool" in observational cosmology?

(d) What is the main observational evidence that there is eight times as much nonbaryonic dark matter as ordinary matter?

(e) What is the main observational evidence that space, on the scale of the universe, is flat (zero curvature)?

(f) What causes the "dipole" pattern in the CBR as observed by the COBE and WMAP satellites?

4. Cosmic expansion and redshifts

The highest reported redshift to date is for the galaxy Abell 1835, for which scientists estimated a redshift of $z = 10$. Consider a light ray emitted by Abell 1835 with wavelength 122 nanometers at the time of emission.

(a) What is the wavelength for the light ray as measured on Earth at the present day? [**4 points**]

(b) By what factor has the distance between the Milky Way and Abell 1835 increased between the time of emission and reception of the light? [**4 points**]

5. Generalized Friedmann equation

The generalized Friedmann equation can be written as

$$H^2 R^2 = H_0^2 R_0^2 \left[\Omega_M \frac{R_0}{R} + \Omega_\Lambda \left(\frac{R}{R_0} \right)^2 + \Omega_k \right]$$

(a) What do the terms Ω_M, Ω_Λ, and Ω_k represent, and what are their "cosmic concordance" measured values? **[9 points]**

(b) In what sense is the universe expected to be dominated by "dark energy" in the future, and what does this imply for the future expansion rate? **[9 points]**

6. Cosmic evolution diagrams

(a) Diagram $R(t)$ vs. t for the three standard (non-inflationary, no cosmological constant) cases of models of the universe, labeling which is open ($k = -1$), closed ($k = +1$), and flat ($k = 0$). **[9 points]**

(b) State how the three cases in (a) correspond to positive, zero, and negative total energy in a Newtonian interpretation, and how this would relate to the ultimate fate of the universe in each model. **[9 points]**

(c) Marking the present on an R–t diagram by a point with coordinates (t_0, R_0), indicate the interval on the t axis corresponding the "Hubble time," and compare to the actual age of the universe. **[10 points]**