PHYSICS 313 - Winter/Spring Semester 2017 - ODU

Astrophysics – FINAL EXAM - SOLUTION

GENERAL INSTRUCTIONS:
If possible, do all work ON these sheets and return them back to me. Try not to get stuck on the Y/N and multiple choice questions – pick the answer that looks best to you and move on. You have 3 hours total.

Problem 1

Mark each of the following statements with "Y" or "T" if they are correct, and with "F" or "N" if they are incorrect:

1a) Radiation created in nuclear reactions in the center of the sun reaches the surface of sun within about 2 seconds. **F**

1b) When observing the surface of sun, many dark absorption lines are visible within its light spectrum, which are a direct consequence of the laws of quantum mechanics. **T**

1c) The temperature of any star's surface can be inferred both from the wavelength with the maximum intensity in the continuous spectrum AND from the visible absorption lines. **T**

1d) The overall rotation of the Milky Way galaxy can be explained by the gravitational effects of all its visible stars. **F**

1e) All known galaxies have spiral arms like the Milky Way. **F**

1f) Quasars appear very bright because they are especially large, nearby galaxies. **F**

1g) For any bright object, there is a minimum mass it must have to remain stable, given its total energy output in the form of light (electromagnetic radiation). **T**

1h) Inflation in the context of cosmology refers to the normal Hubble expansion in a matter-dominated universe. **F**

1i) Time elapses uniformly and with the same rate everywhere in the Universe, including near the event horizon of black holes. **F**

1j) The expansion rate of a radiation-dominated universe slows more quickly as the scale parameter $a(t)$ increases than is the case for a matter-dominated universe. **T**

Problem 2

The following are NOT multiple choice questions! Instead, add a number from 1 to 10 in front of each of the listed items to indicate in which order they should appear, and (for extra credit) an age behind up to 5 of them.

2a) The following are several important (for us!) epochs or milestones in the history and the future of our universe. In which order did/will they occur? Indicate by numbers 1-10 to the left.

7 (or 8) a – Solar system born **Age: 9.2 Byr (4.6 Byr ago)**

4 b – (Mostly dark) matter begins to dominate the evolution of the universe (i.e., its size and expansion rate) **Age: 37,000-47,000 years**

1 c – Inflation begins **Age: 10^{-37} s**

8 (or 7) d – Dark energy overtakes matter as the most important contribution to the expansion rate of the universe **Age: 10 Byr (3.8 Byr ago)**

3 e – Quarks bind together to form protons and neutrons **Age: 1 μs**

9 f - Our sun becomes a white dwarf **Age 19 Byr, about 5 Byr from now**

5 g - The universe cools enough for protons, helium nuclei and electrons to form first atoms.

Age: 380,000 yrs

2 h - Radiation begins to dominate the evolution (expansion rate) of the universe. **Age: 10^{-35} s**

6 i - First galaxies and quasars are being formed (re-ionization epoch) **Age: few 100 Mio yrs**

10 j - The big rip - universe is cold, dark and all galaxies are isolated (invisible) from each other **Many Byr from now**

2b) XC: Add the rough age of the universe (since the Big Bang) to the right of up to 5 of these events. You get 1 XC point for each correct date, up to a total of 5.

Problem 3

Multiple choice questions - pick one and only one answer for each (circle or underline or add check mark).

3a) Which of the following is **not** a possible remnant at the end of the lifetime of ordinary stars (i.e. stars that spend some time of their lives on the main sequence line of the HR diagram)? **1**

1) Supermassive black holes at the center of galaxies

2) Pulsars

3) White Dwarfs

4) Planetary nebulae

3b) Which of the following elementary particle and nuclear reactions plays an important role in producing **most** of the energy in the center of the sun today? **1**

1) The weak interaction, turning a proton into a neutron, a positron and an electron neutrino.

2) Fission of heavy elements like uranium.

3) The fusion of nuclei like 28Si to 56Fe.

4) The triple-alpha reaction

3c) Which of the following types of cosmic rays is **not** considered a fundamental (non-composite) elementary particle? **3**

1) gamma-rays

2) neutrinos

3) protons

4) positrons

3d) Which of the following objects in today's universe has the smallest **mass**? **5**

1) Neutron star

2) Black hole

3) Brown dwarf

4) White dwarf

5) Planet Earth

3e) Which of the following objects has the smallest **size (diameter)**? **1**

1) Neutron star

2) Brown dwarf

3) White dwarf

4) Planet Earth

3f) Which of the following objects can emit periodic radio wave pulses at extremely constant repetition rate? **1**

1) Neutron star

2) Black hole

3) Brown dwarf

4) White dwarf

Problem 4

For the following questions, you only **have** to supply a numerical answer. However, you should add a short derivation (below or attach on a separate sheet at the end of this exam) for partial credit.

4a) Calculate the radius of a neutron star with total mass $3 \cdot 10^{30}$ kg (1.5 times solar mass).

$$R = \frac{\hbar^2 N_{tot}^{5/3}}{m_p G M^2}\left(\frac{9\pi}{4}\right)^{2/3} = \frac{\hbar^2 \left(M N_A / 0.001009 \text{ kg}\right)^{5/3}}{m_p G M^2}\left(\frac{9\pi}{4}\right)^{2/3}$$

Pluggin in yields 10.8 km

4b) Calculate the Schwarzschild radius of this neutron star

$$R_s = \frac{2GM}{c^2} = 4460 \text{ m}$$

4c) Calculate how much time elapses on the surface of this neutron star while a far-away observer (in empty space) observes an elapsed time of 10 seconds.

$$\Delta t_{local} = \sqrt{1 - \frac{R_s}{r}}\Delta t_\infty = 7.65 \text{ s}$$

4d) By what factor would you have to "squeeze" down the volume of this neutron star to make it collapse into a black hole?

$$\left(\frac{R}{R_s}\right)^3 = 14 \text{ times}$$

Problem 5 XC

Mini-Essay: In your own words, describe the present-day structure of the universe - what does it contain, and how is matter organized hierarchically from small (planetary) objects to the largest observable structures? One XC point (up to 5) for each layer of this hierarchy that you describe appropriately (2-3 sentences each). Provide some details, e.g., what is the structure made of? what is its approximate size scale? How did it come into being?

1) The smallest "layer of matter" are individual heavenly bodies - stars, planets, moons, asteroids etc. forming solar systems, as well as protostellar clouds and the interstellar medium on the one hand and burned-out relics like black holes, neutron stars, white dwarfs and "planetary nebulae" on the other hand. These objects range in size from a few km (neutron stars, black hole event horizons) to many A.U. for solar systems and even many pc for large dust and gas clouds. As an example, our solar system came into existence about 4.6 Byrs ago.

2) The next layer up are the various structures within a galaxy like the Milky Way: the central bulge with its supermassive black hole, the disk with its spiral arms (and perhaps bars), the halo with its globular clusters and other massive objects (including dark matter), and finally its dwarf satellites (e.g., the large and small Magellanic clouds). Depending on what you include, the size of the Milky Way is about 30 kpc across (main disk), and galaxies in general have sizes of order 100s of kpc. Most galaxies began to exist a few hundred million years after the big bang.

3) Next up is the local group of galaxies, which in our case includes all dwarf satellites and the Andromeda nebula. The latter is 780 kpc away from us, meaning that the local group has a size of order several Mpc. It is likely that the whole local group developed together from initial "seeds" (clumps of dark matter), but it's also possible that Andromeda is younger than the Milky way and the two only came into a gravitationally bound state more recently. We know that they will eventually collide (perhaps multiple times) and perhaps merge.

4) Galaxies are futher grouped into clusters and superclusters, which can span 100 Mpc or more. These superclusters are at sites where dark matter started clumping within a few 100 Million years after the big bang.

5) Superclusters are not distributed uniformly (randomly) throughout the observable universe, but tend to be arranged in even larger structures, including filaments and walls surrounding large "voids". The biggest observable structure appears to be a "supervoid" of order 1Gpc across.

BUT: The universe is still **roughly** homogeneous over even larger scales.