AY2 Homework for Quiz 4: Spring 2019

1. **In the spectrum of a distant galaxy the absorption line of hydrogen that in the lab is at a wavelength of 656.3 nm is measured at 690.3 nm.**
   a. What is the redshift, z, of this galaxy? $z=(\lambda-\lambda_0)/\lambda_o=(690.3 - 656.3)/656.3= 0.05$

   b. What is the recession velocity, v, of the galaxy? $v=cz=(3 \times 10^8$ m/s$) \times 0.05 = 1.5 \times 10^7$ m/sec $= 1.5 \times 10^4$ km/sec

   c. By what factor has the size of the Universe changed since the light left the galaxy?

Scale factor = 1+ z = 1.05 (Universe is larger by this factor since the light was emitted by the galaxy)

2. **For many years, the value of the Hubble Constant was the subject of many studies and some controversy. The values from different studies clustered around two values: 50 km·s^{-1}·Mpc^{-1} and 100 km·s^{-1}·Mpc^{-1}. For each of these values calculate the expansion age of the Universe assuming no acceleration or deceleration.**

Expansion age =

$$\frac{1}{Ho} = \frac{1}{50}\frac{s \cdot Mpc}{km} \times (3 \times 10^{19})\frac{km}{Mpc} = 6 \times 10^{17}\ s$$

$$\frac{1}{Ho} = \frac{1}{100}\frac{s \cdot Mpc}{km} \times (3 \times 10^{19})\frac{km}{Mpc} = 3 \times 10^{17}\ s$$

3. **Dark matter has been invoked to explain three observations on very different spatial scales. What are these observations?**
   1) Flat rotation curve of the Galactic disk and that in other spiral galaxies
   2) Galaxy clusters do not have sufficient mass in luminous stars and gas to hold the clusters together gravitationally. Need to have a dark matter component.
   3) Large scale structure such as seen in surveys of galaxies does not form in models of the Universe without having dark matter in the models

4. **A period of rapid inflation in the size of the Universe at very early times can be used to resolve four problems associated with non-inflation cosmologies. What are these four problems?**
   1) Flatness of the Universe. If the Universe at early times deviated even a tiny amount from flat ($\Omega = 1$) would have resulted in a Universe with a very short lifetime before recollapse or on in which no structure formed. Inflation drove the universe to be spatially flat.
   2) Rareness of magnetic monopoles in the Universe. The period of inflation diluted the density of monopoles by a factor of 10^{78}
   3) Origin of the density perturbations that eventually led to galaxy formation. Quantum fluctuations in the pre-inflation universe were amplified to macroscopic scales
   4) Horizon problem. The uniformity of the cosmic microwave background is very high despite the fact that parts of the sky separated by large angles would not have been in causal contact ever. With inflation, these regions were in equilibrium in the pre-inflation time after the Big Bang

5. **What is the evidence for an acceleration of the expansion of the Universe?**

Observations of SN1 at large distances and lookback times show that the Universe was expanding more slowly in the past and the expansion has been speeding up.

6. **Based on our current data and models, what is the most likely long-term fate of the Universe?**

____ Eventual slowing of the expansion and a recollapse and "Big Crunch"

_X__ Ever-increasing expansion rate and cold, dark Universe

____ Radioactive decay of matter will light up the Universe for as long as we can predict

____ Star formation in galaxies will keep the Universe heated and light for at least the next 10^{20} years

7. **Which of the following best describes the large-scale distribution of galaxies in the Universe?**

____ Uniform in all directions

__X__ Clusters of galaxies, filaments and voids

____ Uniform except for small density variations at the level of ~1 in 100,000

____ completely random

8. Which of the following are thought to be properties of or true of Dark Matter?

__X__ it is "cold" (i.e. moves slowly compared to the speed of light)

__X__ it does not readily interact directly with photons or other matter (i.e. it has a small cross-section for interations)

__X__ it does not emit or absorb electromagnetic radiation

__X__ it is primarily inferred by its gravitational effect on other matter

9. Which of the following are true (T), which false (F)?

__F__ the total star formation rate in the Universe has been relatively steady since about 1 billion years after the Big Bang

__T__ Quasars were much more common in the period between 1 and 3 billion years after the Big Bang than they were before or after that time

__F__ the merger rate of galaxies has been steadily increasing over time as the Universe expands

__T__ Dark Matter is much more common than the type of matter that makes up stars, planets and humans

10. Which of the following are fundamental particles?

___ Proton
_X__ Electron
___ Hydrogen atom
___ Neutron
__X_ Up quark
_X__ positron (anti-electron)
_X__ electron neutrino

11. What was the temperature of the Universe in kelvins and the average energy of a particle in eV at 10^{-4} seconds after the Big Bang?

$T(K)=10^{10}/\text{sqrt}(10^{-4})= 10^{12}K$

12. When was the last instant after the Big Bang when it was possible to form Top quark/anti Top quark pairs in interactions in the expanding Universe?

Top quark mass: 172.5 GeV = 172.5×10^{9}eV

$t=(8.6 \times 10^{5})^{2}/(2 \times 172.5 \times 10^{9})^{2}=(8.6^{2} \times 10^{10})/(345^{2} \times 10^{18})=6.21 \times 10^{-12}$ seconds

13. Where is the formation site for each of the following elements? equilibrium fusion in stars (A), SNII explosions (B), Hot Big Bang (C)

________C_____ Hydrogen

________B_____ Thorium

________A_____ Iron

_______A,C_____ Helium

14. Use the diagram below (next page) to answer the following questions:

a) At what times is the neutron abundance at its largest?

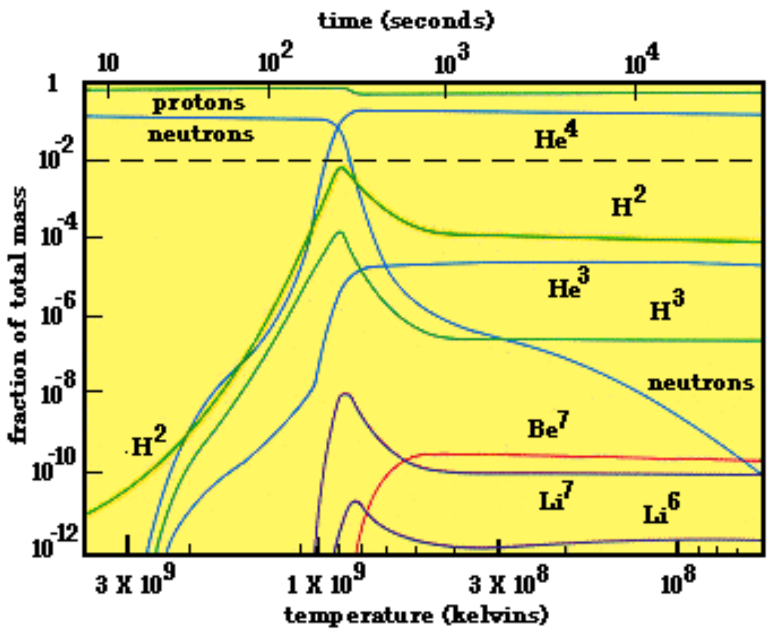
10s – few hundred seconds

b) What is the ratio of He^4 to He^3 after nucleosynthesis has ended?

$10^{-1}/10^{-5}$=10,000

c) At what temperature does nucleosynthesis in the early Universe end?

8×10^{8} K



15. What was the nature of the transition in the Universe that occurred around 380,000 years after the Big Bang?

____ the end of the era of nucleosynthesis

__X__ electrons recombined with hydrogen nuclei and the Universe became transparent to electromagnetic radiation

____ the first stars were formed

____ quarks combined to make protons and neutrons

16. Which of the following provide supporting evidence for the Hot Big Bang model?

__X__ The abundances of elements heavier than He are lower than the solar values in older stars

__X__ The predicted abundances for He^4, He^3, H^2, and Li^7 at the time of "element freezeout" around 300 seconds after the Big Bang match observations

__X__ The presence of a ubiquitous background radiation characteristic of that from a 3K solid

__X__ fluctuations of around 1 part in 100,000 in the temperature of the cosmic microwave background

17. The temperature of the gas in the Universe at the time it became neutral was ~3000K. Why does the cosmic microwave background appear to arise from a 3K source?

Because of the 1100 x expansion of the Universe since decoupling

18. Which of the following describe the "horizon problem" in cosmology?

__X__ the cosmic microwave background is at a uniform temperature over the entire sky yet regions separated by large angles would not have been in causal contact in a Universe that had expanded uniformly since the Big Bang

____ we see the same galaxies looking directly forward and directly back because light is curved around the universe which confuses investigations of large-scale structure

____ if the Universe was not spatially flat it would have collapsed back on itself

____ because of the curvature of the Universe we can not see a large part of the observable Universe

19. The theory of cosmic inflation was originally motivated to understand why magnetic monopoles were so rare in the Universe. What other cosmological puzzles does inflation resolve?

_X__ That we appear to live in a spatially "flat" universe with Ω_{total} =1.0

___ The energy released during the inflationary period that resulted in the formation of the light elements H, He and Li

_X__ The growth of quantum fluctuations during inflation provided the small fluctuations in the cosmic microwave background that were the seeds of galaxy and structure formation

___ Inflation allows us to understand what existed before the Big Bang

20. Which of the following are true (T), which false (F)?

__F_ the merger rate of galaxies has been steadily increasing over time as the Universe expands

__T_ Dark Matter is much more common in the Universe than the type of matter that makes up stars, planets and humans (baryonic matter)

21. Which of the following techniques are used to detect planets orbiting stars other than the Sun?

__X__ measuring small periodic radial velocity variations in the exoplanet host stars

__X__ measuring small changes in the total light from a host star when the exoplanet passes in front of the star

__X__ directly imaging exoplanets orbiting their host stars

__X__ using the boost in brightness of a background star when an exoplanet passes directly between the back star and the Earth and gravitationally lenses the star

22. Which of the following are true (T) which false (F) regarding what we know about exoplanets as of 2019?

__F__ Although we have now discovered many exoplanets, to date we have not found another system with more than one planet

__F__ The most common type of exoplanet discovered to date is approximately ½ the mass of the Earth

__F__ Most exoplanets discovered to date are very close to or in the "habitable zone" of their host stars

__T__ the majority of exoplanets discovered to date have been detected via the light curve/transit technique

23. Which of the following statements are true (T), which false (F) regarding the "habitable" zone for exoplanets?

__T__ It is the region in possible orbits for exoplanets where the temperatures allow for liquid water

__T__ For smaller-mass, cooler stars than the Sun, the habitable zone is closer to the star

__T__ For a given mass exoplanet, it is easier to detect the planet in the habitable zone of a low-mass star than to detect it in a higher-mass star

__F__ The only planet known to existing in the habitable zone of a star is the Earth