You may use one sheet of notes. You may not use books or additional notes.

Do the easy questions first. Then go back to the harder ones.

If you need the result of part (a) to do part (b) but cannot do part (a), explain how you would do part (b) if you had the answer to part (a).

Name	
PID	
1	/ 10
2	/ 6
3	/6
4	/6
Total	/ 37

Hubble's constant is 60(km/s)/Mpc.

The speed of light is 300,000km/s.

The present temperature of the radiation from the Big Bang is 2.7K.

Table 1. Spectral lines of hydrogen and oxygen and their laboratory wavelengths. OII means oxygen with one electron removed, and OIII is oxygen with two electrons removed.

Line	*Wavelength Å*	*Line*	*Wavelength Å*
Hα	6562	OII	3727
Hβ	4861	OIII	5007
Hγ	4340		
Hδ	4101		
Hε	3970		

1. Astronomers measured the spectrum of galaxy X. They found the OIII line to be spread over a range of wavelengths. The peak is at 7000 Å, and the light is spread between 6995 Å and 7005 Å.

    a. (2 pts.) Compute the redshift z of galaxy X.

    z=(observed wavelength)/(rest wavelength)-1=7000/5007-1=0.40

    b. (2 pts.) What does the spread in the wavelength of the OIII line tell us about galaxy X?

    Parts of the galaxy are moving at different speeds. The part that emitted light that we see at 6995 Å was moving toward us relative to the whole galaxy.

    c. (2 pts.) What is the distance D to galaxy X?

    v=cz=300,000km/s 0.4=119,000km/s

    D=v/H=119000km/s/(60Mpc/(km/s))=1990Mpc.

    d. (2 pts.) At the time the light was emitted from galaxy X, what was the distance D_1 to galaxy X?

    The universe expands by the same factor as the wavelength of light. The expansion parameter a=(emitted wavelength)/(observed wavelength)=5007/7000=1/1.4

    D_l=D1990Mpc /1.4=1420Mpc

    e. At the time the light was emitted from galaxy X, was the temperature T_1 of the radiation from the Big Bang cool enough that water freezes (273K)? (2 pts.) Explain.

    T1=2.7/(expansion parameter)=2.7×1.4=3.8K. Temperature was cool enough that water freezes.

2. Simplicio says.

    a. (3 pts.) Simplicio says, “Almost all other galaxies move away from us. We in the Milky Way are lucky to be at the center of the universe.” Are we lucky to be at the center of the universe? Explain.

    It is not luck. With Hubble’s Law, every galaxy in the universe is at the center in the sense that galaxies move away from it in exactly the same manner.

    b. (3 pts.) Simplicio says, “Everything in the universe obeys Hubble’s Law.” In this case, Simplicio is wrong. What is an example of something that does not obey Hubble’s Law? Explain how it was able to violate Hubble’s Law.

    The solar system does not obey Hubble’s Law. The distance between Earth and the sun does not increase. Early in the history of the universe, two hydrogen nuclei that eventually became part of Earth and the sun did obey Hubble’s Law. The gravity of the blob that became the Milky Way (and the sun and earth) overcame the motion of the Big Bang long before the solar system formed.

3. (6 pts.) A small fraction of the nuclei in the solar system, which includes the sun, was made in other stars, but most was made when the universe was 3 minutes old. Where could you collect sample A of material primarily made in stars and where could you collect sample B of material primarily existing when the universe was 4 minutes old? What in your two samples is material made in stars and what existed when the universe was 4 minutes old? You must write an explanation to get any credit.

Sample A, that was mostly existing when U was 4 min old.: Collect some of the outer part of the sun. The hydrogen and the vast majority of the helium were present when the U was 4min old. The other elements were made in stars.

Sample B: Collect a teaspoon of the ocean. The hydrogen was present when the U was 4min old. The other elements like oxygen were made in stars.

4. Nucleosynthesis in the Big Bang.

    a. (4 pts.) Why does the ratio of neutrons to protons, #n/#p, fall slowly from 1:1 to 1:7 as the universe ages from 0.001s to 3min, and then flat-line at 1:7.

    "The ratio of neutrons to protons falls from 1:1 to 1:7 due to the temperature drop as the universe expanded. As the temperature dropped, the available energy for protons to change to neutrons decreased. The ratio fell to 1:7 as this progressed until 3 min. At 3 min., [deuterium became stable and] neutrons became captured in He nuclei, where proton-neutron changes do not occur…"—J Poth.

    b. (2 pts.) If helium could form at 0.001s, how much helium and how much hydrogen would form from 16 nucleons? (A nucleon is a proton or a neutron.)

    At 0.001s, the temperature is so hot that #n/#p=1. Helium has equal numbers of n and p. There is no hydrogen.