Name	
PID	
1	/4
2	/6
3	/5
4	/11
5	/10
6	/6
7	/3
8	/6
9	/6
Total	/57

You may use one sheet of notes during this test. You may not have any books or other notes. Some of the information in the table below is not used on this test.

Write brief answers. Your time is limited, and the graders like to read answers that address the point. Graders do not like to read answers that address off-topic ideas.

You may pick up the exam next year in room 1219. If you want your grade by e-mail, send me an e-mail at Loh@msu.edu.

Good luck.

Planet	Period (yr)	Semi-major axis (AU)	Eccentricity
Mercury	0.241	0.387	0.206
Venus	0.615	0.723	0.007
Earth	1.000	1.000	0.017
Mars	1.881	1.523	0.093
Jupiter	11.86	5.202	0.049
Saturn	29.46	9.539	0.056

Kepler's 3rd Law	$P^2 = R^3/M$ (in AU, year, & M_{sun})	Hubble's Law	$v = H D$
	$M = 233 v^2 R$ (in parsec, km/s, & M_{sun})	Wien's Law	$\lambda_{peak} T$ = constant
Redshift	$z = 1/a - 1$; $a = 1/(1+z)$	Hubble's Constant	70 km/s/Mpc
	$v = c z$; $v = c (\lambda_{rec}/\lambda_{emit} - 1)$	Speed of Light	300,000 km/s
Number density	$ND(a) = ND(now)\, a^{-3}$.	Parsec	3.09×10^{13} km
Mass density	Matter: $MD(a) = MD(now)\, a^{-3}$	AU	1.50×10^{8} km
	Radiation: $MD(a) = MD(now)\, a^{-4}$	Year	3.16×10^{7} s
Sun	Apparent mag = –26.7		
	Absolute mag = 4.8		

1. In my 1992 Chevy are hydrogen and carbon in the gasoline, iron in the frame, and silicon in the windshield. For each question, name one element that fits the description, or if there is no such element, write "none." There may be more than one correct element. If so, write the one that you are most certain of.
    a. (1 pt.) The nucleus in my car was present when the universe was a day old.

       H

    b. (1 pt.) The nucleus in my car was made on earth.

       None

    c. (1 pt.) The nucleus in my car was present when the universe was a million years old.

       H

    d. (1 pt.) The nucleus in my car was made in the sun.

       None

2. Tycho Brahe and Kepler made important contributions that led to Newton's discovery of the law of gravity. How did (3 pts.) Kepler and (3 pts.) Brahe contribute to the discovery of the law of gravity? Be brief. Do not write about discoveries that did not lead to the law of gravity.

   Kepler's 3rd Law implies that the force of gravity falls as distance^2. Kepler used Brahe's observations to discover his 3 laws.

3. The earth is farthest from the sun in July.
    a. (3 pts.) Find the distance between the earth and sun in July, when the distance is the greatest. Express your answer in AU.

       Greatest distance = (1+eccentricity)(semimajor axis) = (1+0.017) 1AU.

    b. (2 pts.) Draw a picture of the path of a hypothetical comet that has a 1 year period. (A comet's orbit has a high eccentricity.) On the same picture, show the sun and the earth's orbit. For clarity, draw the picture as viewed from far above the plane of the earth's orbit, and draw the earth's path as a circle.

       Because the period is 1 year, the SMA is 1 AU. The sun must be at a focus.

4. (3 pts.) Sketch a Hertzsprung-Russell diagram that shows the sun, the main sequence, giants, and white dwarfs.

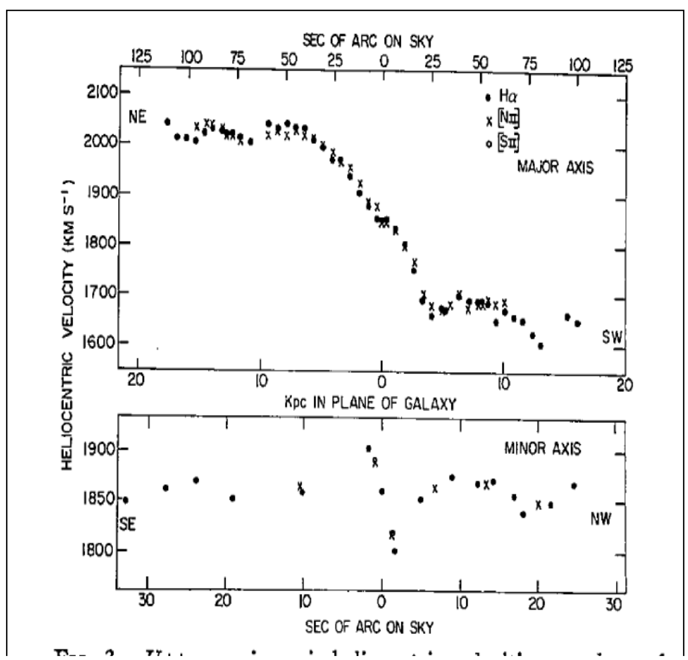

Figure 1 Velocity along the major axis (top panel) and along the minor axis (bottom panel) of NGC 3762. The axis labeled "kpc in plane of galaxy" is the distance from the center of the galaxy. Figure is from Rubin, Thonnard, & Ford, 1977.

a. (1 pt.) Place a star on the H-R diagram that will live longer than the sun. (2 pts.) Explain why you placed it there.

b. (1 pt.) Place a star on the H-R diagram that is brighter and less massive than the sun. (2 pts.) Explain why you placed it there.

5. The galaxy NGC3672. Use the graphs in Figure 1.

a. (3 pts.) What is the distance between us and that galaxy?

Use Hubble's Law. D=v/H=(1850km/s)/(70 km/s/Mpc)=26Mpc.

b. (1 pt.) If NGC3672 had no dark matter, would the lower panel change? Would the upper panel change? (3 pts.) Explain why.

Lower panel does not change, because its velocities are due primarily because of the expansion of the universe. The upper panel does change, because part of its velocities is due to motion of matter around the galaxy.

c. (3 pts.) Draw the panel that would change for the case with <u>no</u> dark matter. Label your axes.

In the upper panel, the velocity would fall in the outer parts rather than stay constant.

6. Discovery of dark energy.

a. (3 pts.) Figure 2 shows evidence of dark energy. Instead, assume the hypothesis that there is no dark energy. Draw several supernovae on the bottom panel of Figure 2 consistent with that hypothesis. (The points show scatter vertically because of measurement errors and variations in the supernovae.) Explain how you placed the points.

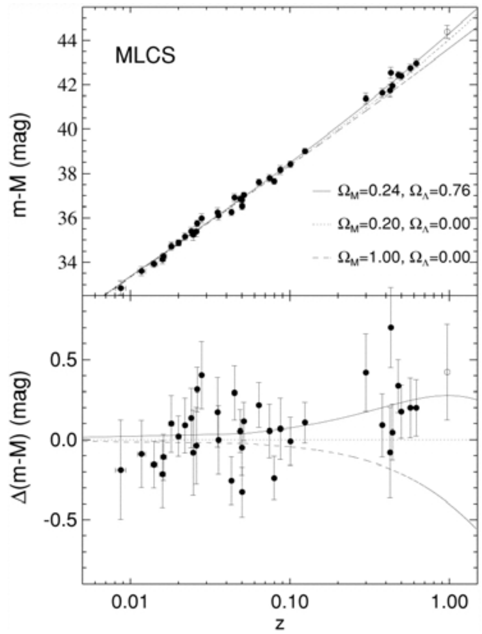

Figure 2 Redshift & magnitude of supernovae from Riess et al, 1998, ApJ.

The distant supernovae would be brighter. For example, they could be on the horizontal line at Δ(m-M)=0.

b. (3 pts.) Simplicio reasons, "If distant supernovae produce less light than nearby ones, the evidence for dark energy would disappear." Is Simplicio right? Explain.

He is right. If the luminosity of the distant supernovae are less than that of nearby ones, then their faintness would not be due to the acceleration of the universe.

7. Production of the light elements. Deuterium is

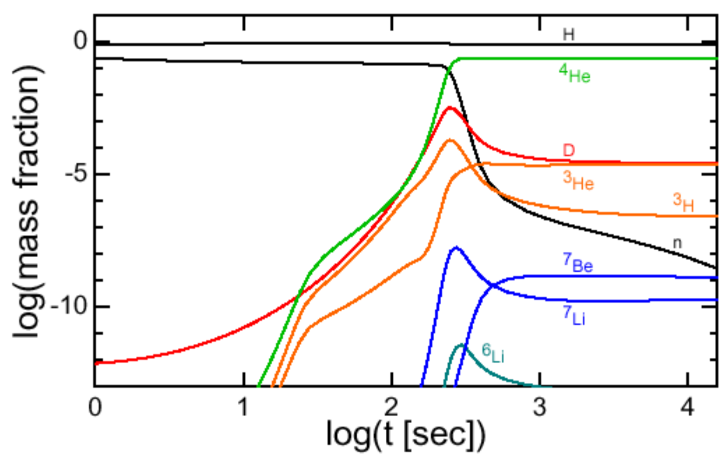

Figure 3 Fraction by mass of the elements *vs*. time after the beginning of the universe. Both axes are logarithmic: For log(t) = 2, the time t=10^2=100 s, and for log(abundance)=–10, the abundance is 10^{-10}. The graph is from Ned Wright's notes on cosmology.

destroyed by photons having more than 2 MeV (million electron volts) of energy. For this problem assume that deuterium is more stable: it takes a photon with more than 4 MeV to destroy it.

a. (3 pts.) If deuterium were more stable, how would Figure 3 change? On Figure 3, draw the changes for ^{1}H, ^{4}He, and n.

   ^{1}H would change little. ^{4}He would appear sooner. Neutrons would disappear sooner.

b. (3 pts.) Would more, less, or the same amount of helium be produced? Explain.

   More helium would be produced, since at earlier times there were more neutrons.

8. Simplicio reasons, “Penzias and Wilson’s observation that the cosmic radiation was isotropic was used to argue that the radiation was from the Big Bang. Therefore the observation that it is slightly hotter in the direction of Crater and slightly cooler in the opposite direction shows that it is not from the Big Bang.” (3 pts.) Rewrite Simplicio’s statement so that it is correct. (3 pts.) Explain Simplicio’s error in reasoning.

   “The observation that it is slightly hotter in the direction of Crater and slightly cooler in the opposite direction indicates we are moving in the direction of Crater.” This is a natural way to explain the small anisotropy.

9. (6 pts.) What are the three major contributors to the mass of the universe? What is the density parameter for each component?

   The density parameter of ordinary matter is 4%. The density parameter of dark matter is 23%. The density parameter of dark energy is 73%.