You may use 4 sheets 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 do not like to read answers that address off-topic ideas.

You may pick up the exam next year in room 3260. If you want your grade by e-mail, send me an e-mail at Loh@msu.edu.

Good luck.

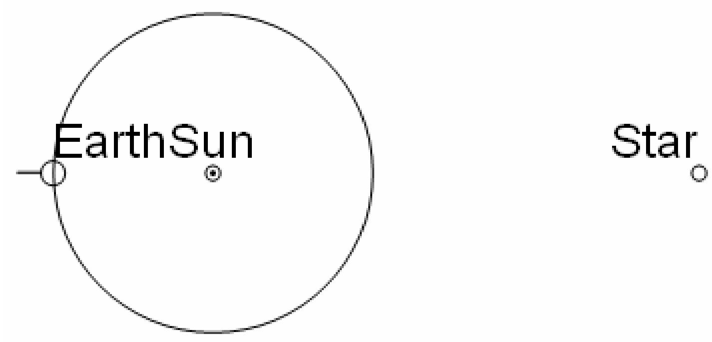
Name	
PID	
Signature	
1	/8
2	/6
3	/6
4	/18
5	/8
6	/6
7	/6
8	/15
Total	/73

Star	App mag	Abs mag	Spectral type	Distance (pc)
Sun	–26.74	4.83	G2	1/200,000
Mimosa	1.26	–4.7	B0	150
Canopus	–0.73	–4.7	F0	60

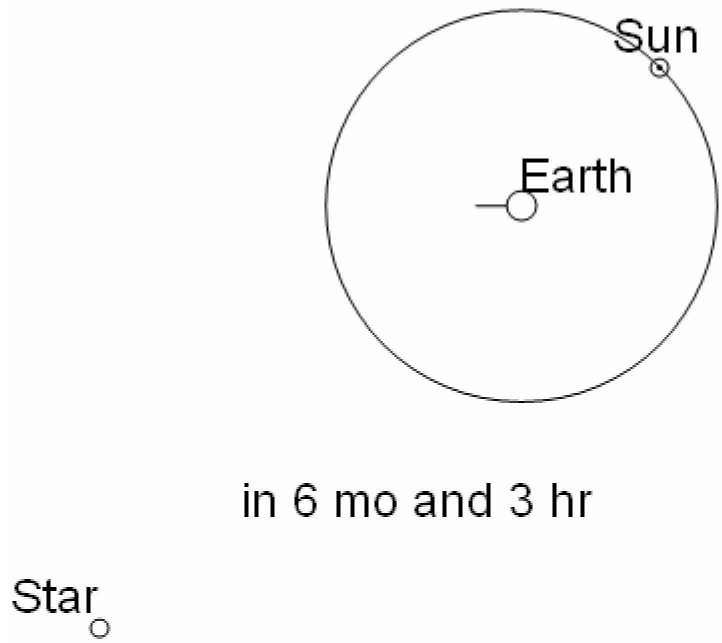
Kepler's 3rd Law	$P^2 = R^3/M$ (in AU, year, & M_{sun})	Hubble's Law	$v = H D$
	$M = 233 v^2 R$ (in parsec, km/s, & M_{sun})	Wien's Law	$\lambda_{peak} T$ = constant
Redshift	$z = 1/a – 1; a = 1/(1+z)$	Hubble's Constant	70 km/s/Mpc
	$v = c z; v = c (\lambda_{rec}/\lambda_{emit} – 1)$	Speed of Light	300,000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

1. The figure shows the Sun, Earth, and a star. It is midnight.

    a. (4 pts.) Draw the Sun, Earth, and star 6 months and 3 hours later according to Ptolemy.

    In 3 hours, the sun moves one eighth (3/24) of the way around the earth. In 6 months, the star moves from being in the direction of the sun to being in the opposite direction.

    b. (2 pts.) What was the principle observation that Copernicus explained more naturally than Ptolemy?

    Motion of the planets with respect to the stars. The motion is both east-to-west and west-to-east. Copernicus explained it as due to earth's motion.

    c. (2 pts.) What 17th century observation refuted Ptolemy's model?

    Galileo observed the full phase of Venus. In Ptolemy's model, this cannot occur.

2. A star is found in orbit around object X. Its period is 1 year, and its orbit is a circle with a radius of 100 astronomical units.

    a. (4 pts.) Find the mass of object X. Express your answer in units of the mass of the sun.

    $M=P^3/R^2=100^3=10^6 M_{sun}$.

    b. (2 pt.) Could object X be a neutron star? (Your answer must include a reason.)

    No. The maximum mass of a neutron star is a few solar masses.

3. Consider the stars Canopus and Mimosa. (See front sheet.)

   a. (2 pt.) Which is the hotter star? Explain your reasoning.

      Mimosa is hotter, since the spectral types run OBAFGKM in order of decreasing temperature.

   b. (4 pt.) Which star is larger? Explain your reasoning.

      Canopus is larger. Since both stars have the same absolute magnitude, their luminosities are the same. $L=R^2T^4$. Since Canopus is cooler, it must be larger to match Mimosa in luminosity.

4. In a few years many of you will be teaching, and your students will have hundreds of questions. Imagine that a student in your class asked each of these questions, and write a few sentences to answer your student. Be brief. Your answer must include an explanation. (3 pts. for each question.)

   a. “Galaxies are moving away from us in all directions. Why did we happen to be at this special place in the universe?”

      For expansion according to Hubble’s Law, galaxies move away from every location.

   b. “Why do galaxies move apart?”

      The Big Bang set material in motion. When galaxies formed from that material, they keep the motion.

   c. “There is iron in my blood. Did iron always exist?”

      Iron did not always exist. It was made in massive stars and in a certain type of supernovae.

   d. “You cannot see dark matter and dark energy. Are they two names for the same thing?”

      Dark matter and dark energy are different. Dark matter can be pulled by gravity to form galaxies. The gravity of dark energy repels mater and radiation.

   e. “Will the sun last forever?”

      The sun will last another 5 billion years when it runs out of the hydrogen fuel in its center. Then it becomes very different looking.

   f. “How do you measure the distance to a star, even though you cannot go to it?”

      You measure the distance to a star in the same way a surveyor measures the width of a river by setting up two stations on one side of the river and measuring the angle of something on the other side. You can determine a triangle by measuring one side and two angles.

5. (8 pts.) Compare the discovery of dark energy and the measurement of the mass of the sun.

   To measure the mass of the sun, you measure the period of a planet. If the period is short, the mass is greater.

   To measure the mass density of the universe, you time the expansion of the universe. Astronomers measured the expansion parameter and flux of Type I supernovae, which are “standard candles.” From the flux, astronomers could deduce the distance and therefore the time for the universe to expand by a factor of 1/(expansion parameter). (Time and distance are related, since the distance is that traveled by light.) If flux is brighter, then the time is shorter, and the mass density of the universe is greater.

6. (6 pts.) Production of the light elements. The figure shows the fraction by mass of the elements vs. time after the beginning of the universe. Explain why the abundance of free neutrons (labeled "n") drops slowly at first, then suddenly, and finally slowly. Be certain to address what is happening to the neutrons.

   Initially, the abundance of free neutrons drops because the temperature of the universe cools, and the 2-MeV energy cost of a neutron rather than a proton becomes more appreciable. The neutrons combine with a positrons to change into protons. The abundance of free neutrons drops suddenly when deuterium becomes stable. The free neutrons are incorporated in deuterium, and then into heavier nuclei. The heavier nuclei require deuterium as a starting point. Finally, the few free neutrons decay into protons.

7. In 1965, Penzias and Wilson found that the radiation that they observed was isotropic and free of seasonal variations.

   a. (3 pts.) What source of the radiation, plausible at the time, was ruled out by the observation that the radiation was isotropic? Explain.

      The Milky Way Galaxy, nearby galaxies, and nearby galaxy clusters would produce radiation that is brighter in their directions.

   b. (3 pts.) What source of the radiation, plausible at the time, was ruled out by the observation that the radiation was free of seasonal variations? Explain.

      Sources near the antenna would produce radiation that varies with the seasons.

8. You are transported back in time to when the universe was 13 million years old and the expansion parameter was 1/100.

   a. (3 pts.) What was the temperature of the radiation from the Big Bang? (You must show your work.) What has a comparable temperature?

      $T=T_{now}/a=2.7/0.01=270K$. This is a comfortable temperature with a light coat.

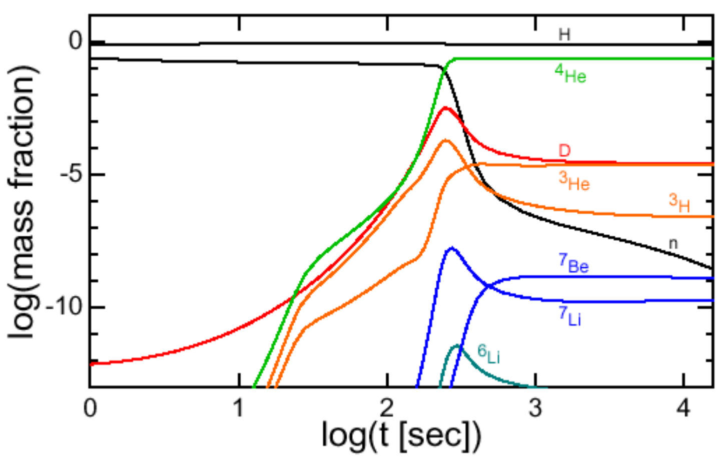


Figure 1 Fraction by mass of the elements *vs*. time after the beginning of the universe. Both axes are logarithmic: For log(t) = 2, the time $t=10^2=100$ s, and for log(abundance)=–10, the abundance is 10^{-10}. The graph is from Ned Wright's notes on cosmology.

   b. (3 pts.) What were three very rare elements? Explain.

      Since this epoch is before the first stars formed, the only elements were those made at 3min. The rare ones are ^{7}Li, deuterium, and ^{3}He.

   c. (3 pts.) What was the ratio of neutrons to protons? Explain.

Since this epoch is after the light elements formed in the big bang, the ratio of neutrons to protons is 1/7.

d. (3 pts.) What did you see around you? Explain.

This epoch is after recombination and before the first stars formed. The universe is transparent, but there were no stars and galaxies. You would see nothing. You would feel comfortable because you would be bathed in 270K radiation.

e. (3 pts.) How much dark matter was in a box with 1 kg of ordinary matter?

A primary achievement of astronomy was to find that the universe is 4% ordinary matter, 23% dark matter, and 73% dark energy. Thus there is 6 times as much dark matter as ordinary matter. There was 6 kg of dark matter in the box.