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.

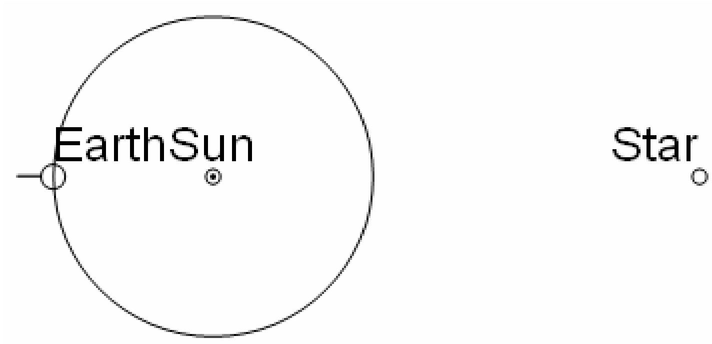
Name	
PID	
Signature	
1	/8
2	/6
3	/6
4	/18
5	/8
6	/6
7	/6
8	/15
Total	/73

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.



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

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

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.

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

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

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

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

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?"

    b. "Why do galaxies move apart?"

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

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

    e. "Will the sun last forever?"

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

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

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.

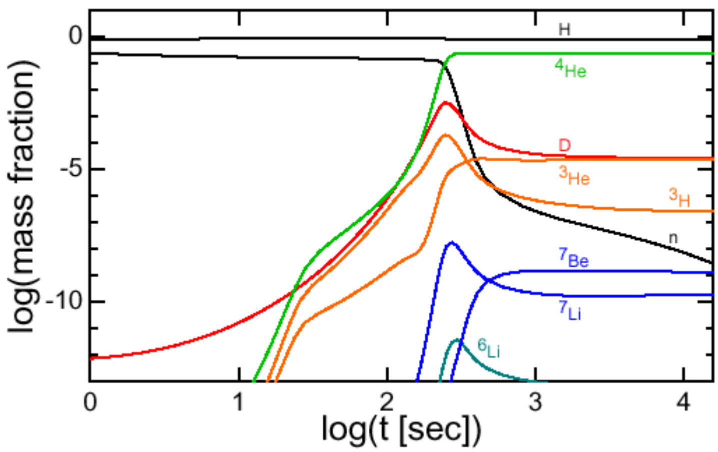


Figure 1 Fraction by mass of the elements *vs*. time after the beginning of the universe. Both axes are logarithmic: For log(t) = 2, the time $t=10^2=100$ s, and for log(abundance)=–10, the abundance is 10^{-10}. The graph is from Ned Wright’s notes on cosmology.

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.
   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.

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?
   b. (3 pts.) What were three very rare elements? Explain.
   c. (3 pts.) What was the ratio of neutrons to protons? Explain.
   d. (3 pts.) What did you see around you? Explain.
   e. (3 pts.) How much dark matter was in a box with 1 kg of ordinary matter?