December, 2006

Astronomy 102: SAMPLE REVIEW FINAL EXAM

1. Potassium-40 has a half-life of 1.26 billion years. It decays to Argon-40. Consider a rock that formed right at the beginning of the Solar System. When it first formed, it had a trace amount of Potassium-40, but absolutely no Argon-40; Argon, as a natural gas, doesn't easily combine with other elements.

We find this rock today, and measure the ratio of Potassium-40 to Argon-40. With extremely precise chemical measuring equipment, we figure out that the ratio of Argon-40 to Pottasium-40 is 4095-to-1. We're not sure what to do with that number, so we go to our computer geek friends. They immediately recognize that 4096 is two to the 12th power (2^{12}), or $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2$.

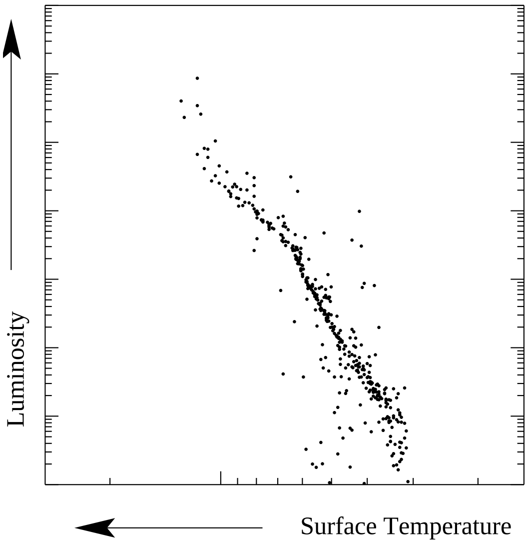
What would this ratio of Argon-40 to Potassium-40 tell us, if anything, about the age of the Universe? Explain. Be sure to consider also what we've learned about t_H and the age measured from the expansion history.

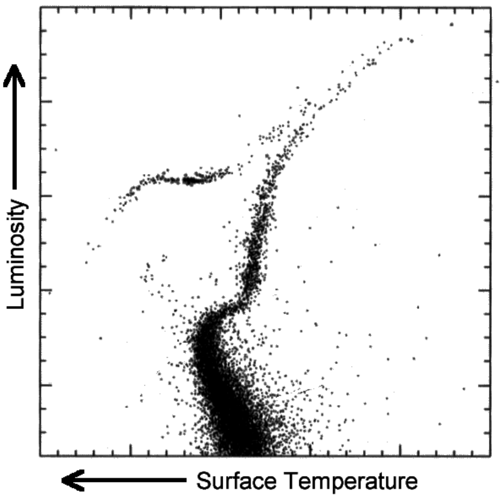
2. Part of the reason we know that fusion powers the Sun is that we have observed the neutrinos produced during fusion. In this problem, you will make a simplified calculation of the number of neutrinos produced by the sun, and figure out how many of them are going through your thumb every second.

Consider that the luminosity of the sun is $L_\odot = 3.8 \times 10^{26}$ W (where 1 W is 1 Joule per second). A fusion reaction uses up four Hydrogen nuclei (each one of which masses 1.67×10^{-27} kg), and produces two neutrinos. The efficiency of nuclear fusion is 0.007.

- **(a)** How much mass is converted to energy each second in the Sun?
- **(b)** Given the efficiency of the fusion reaction, how many Hydrogen nuclei must be used up in fusion reactions in order to produce the energy the Sun puts out?
- **(c)** How many fusion reactions per second must happen to account for the amount of Hydrogen used up in part (b)?
- **(d)** How many neutrinos are produced per second by the fusion reactions in (c)?
- **(e)** The neutrinos produced in (d) are emitted in all directions. Just as with light, by the time the neutrinos reach us (1 AU, or 1.496×10^{15} m away from the Sun), the neutrinos are spread out in a sphere whose radius is the same as our distance from the Sun. What is the surface area over which these neutrinos are all spread out, in m^2?
- **(f)** Hold up your thumb. It has an area of about 1 square cm. ($10{,}000\,\mathrm{cm}^2 = 1\,\mathrm{m}^2$.) What fraction is this area of the area you calculated in (e)?
- **(g)** How many neutrinos from the Sun are going through your thumb every second?

3. Consider the two H-R diagrams below:





- **(a)** One of these represents a population of stars that formed all at once, a long time ago (i.e., more than 10 billion years ago). The other represents a population of stars that formed fairly recently (i.e., within the last few hundred million years). Which is which?
- **(b)** What is the primary feature or features on the H-R diagrams that allowed you to answer (a)?
- **(c)** An astronomer is able to estimate the age of each star cluster. Other than the data plotted, what goes into finding that numerical estimate?
- **(d)** What can we conclude about the age of the Universe from H-R diagrams of star clusters like these?

4. **(a)** Explain, with pictures if that helps you explain, why the current expansion rate of the Universe is related to our estimate for the age of the Universe.

- **(b)** Suppose you don't know the current expansion rate of the Universe (and, thus, you don't know t_H). You measure the distance to a galaxy to be 120 Mpc. You measure the redshift of that galaxy to be 0.023. If you assume that the expansion rate of the Universe has been constant since the Big Bang, how old would you estimate the Universe to be?
- **(c)** If I told you that the Universe in (b) was 15 billion years old, and that its expansion had either always been accelerating, or always been decelerating, which would you conclude had been happening?

5. We observe two stars. Star A is dimmed because it's behind a dust cloud, whereas we have a clear field of view to Star B. Star A is observed to have 8 times the brightness that Star B does.

(a) We observe a parallax of $0.1''$ for Star A and $0.05''$ for Star B. What is the ratio d_A/d_B of the distances to the two stars?

(b) Suppose that we are able to determine that both stars have the same exact diameter, but that Star A has a surface temperature twice that of Star B. What is the ratio L_A/L_B of the two stars' luminosities?

(c) By what factor is the dust blocking Star A dimming its brightness? (I.e. what is the ratio of the brightness we *would* observe for Star A were the dust not there to the brightness we actually observe?)

6. Low mass stars are the most common sort of star, and low mass stars throw off a planetary nebula as they are ending their lives and becoming a white dwarf. Our galaxy has many billions of low mass stars, but only thousands of planetary nebula. What are the reasons for this disparity? (Give at least two.)

7. Our Universe is made up of normal matter, dark matter, and dark energy. Our best candidate for dark energy has the peculiar property that the density of dark energy is a *constant*, even as the Universe expands.

(a) What will happen to the ratio of normal matter to dark matter as time goes on and the Universe continues to expand?

(b) What will happen to the ratio of dark energy to dark matter as time goes on and the Universe continues to expand?

(c) When the Cosmic Microwave Background was emitted, the Universe was about 1,000 times smaller than it is right now, meaning that any given volume of the Universe was a billion times lower than it is right now. What was the ratio of *normal matter* to dark energy when the Cosmic Microwave Background was emitted?

(d) Why was the Comsic Microwave Background emitted when the Unvierse was so much smaller than it is right now? Why not, say, only a few hundred million years ago when the Universe was ∼98% of its current size?

(d) Consider the very early Universe (the CMB) and the distant future Universe. Is there anything about our time right now that is peculiar about the ratio of dark energy to matter (dark or normal)? What is it?