Homework 4, due Thursday, November 28 at 1:00pm

Instructions: Please write your answers clearly on a separate sheet of paper. Submit the assignment as a **single pdf document** at:
https://disk.pku.edu.cn/link/AAA46AD9DBF0E345C498A160A74F722D35
Show all work. No late homework will be accepted.

Write your own name in Chinese and in pinyin and include your PKU student ID number. Some questions may not be covered in class. The online textbook may be helpful: https://openstax.org/details/books/astronomy

1. Seasons, Lunar Phases, and the Earth (20 pts): This is basic astronomy that everyone should know.

(a) What causes the seasons? Draw a picture.

(b) What causes the lunar phases? Draw a picture.

(c) Why are some solar eclipses total eclipses and others not total? What are lunar eclipses? Are solar eclipses or lunar eclipses more common?

(d) Compare four photos of sunsets (or sunrises) from the same location at different times of the year (ideally you have taken these photos; if not, do the best you can for a minor point deduction). What time do they occur? How does the location of the sunet change? Draw a picture to explain these differences.

2. Searching for Life in the Universe (25 pts)

(a) If you could know everything about a planet and its atmosphere, what do you think would be the most important properties to understand whether the planet is habitable? How would you define whether a planet is habitable?

(b) What observations would you want to do to determine habitability? What about life?

(c) Why is that search for life not currently feasible?

(d) The equilibrium temperature, $T_{\rm eq}$, of the Earth depends on how much energy is absorbed, as

$$T_{\rm eq}^4 = \frac{L_\odot(1-a)}{16\pi d^2\sigma} \quad (1)$$

where the Solar Luminosity $L = 3.83 \times 10^{26}$ W m^2, the distance d from the Sun to the Earth is 1 AU, a is albedo (how much energy is reflected), and Stefan-Boltzmann constant is σ is 5.67×10^{-8} W m^2 K^4. Assuming $a = 0.3$, what is the equilibrium temperature of the Earth?

(e) As discussed previously, the luminosity of a star on the main sequence is roughly proportional to the mass to the fourth, $L \propto M^4$. If a planet around a 5 $M_\odot$ star has the same equilibrium temperature of the Earth, how far from its host star would it be located? What would the distance be if the planet were around a 0.2 $M_\odot$ star?

(f) Is there anywhere in our solar system where it might make sense to look for life (other than Earth)? Explain.

3. Climate change and the Earth (30 pts): The International Panel on Climate Change describes every ~ 6 years the scientific consensus regarding climate change to inform policy-makers so that politicians may make better decisions. While many details are very technical, this problem should help you to familiarize yourself with some of the supporting data. Some files for this problem are available at:
https://gherczeg.github.io/modernastronomy/

(a) Describe the greenhouse effect in both broad terms and the atmospheric physics.

(b) What is the "anthropogenic global warming" hypothesis?

(c) How long does CO_2 stay in the atmosphere? What about methane? and water?

(d) Plot the global temperature for at least the past 100 years. Also plot the CO_2 abundance in the atmosphere.

(e) A competing hypothesis has been that solar activity may affect the Earth's climate. Sunspots are a measure of solar activity. Plot the number of sunspots since the early 17th century.

(f) Correlate the CO_2 abundance and the sunspot number with the global temperature. What do you find?

(g) What are the predictions from the IPCC for the future? What do these predictions assume about greenhouse emissions?

(h) What steps is humanity taking to reduce greenhouse emissions? What are some policy challenges for China? What about for South Africa? Nigeria?

4. How many stars that have been born are still here? (25 pts): In this question, we will calculate how many stars that have been born in the Milky Way are still here. We can only answer this question with simplifying (and incorrect) assumptions, but the answers should lead us to a reasonable answer. For the purposes of this question, assume that stars have masses between $0.1 - -100$ M$_\odot$.

This is a difficult question that requires some math and could be done with excel, a programming language, or analytically. I do not expect many people to be able to complete this question.

(a) The history of star formation has been measured by averaging the rate of star formation in galaxies across cosmic time. The generally accepted star formation rate SFR from Madau & Dickinson (2014) is:

$$SFR = 0.015\frac{(1+z)^{2.7}}{1+[(1+z)/2.9]^{5.6}}, \quad (2)$$

where SFR is the star formation rate in units of $M_\odot$ yr^{-1} Mpc^{-3} and z is redshift. Plot the star formation rate versus redshift, from $z = 0 - 10$, and separately the star formation rate versus lookback time, from now through 13 billion years ago. Estimate the lookback time $t(z)$ as

$$t(z) = \frac{2}{3H_0}(1 - \frac{1}{(1+z)^{3/2}}, \quad (3)$$

where the Hubble constant is $H_0 = 70$.

(b) The *initial mass function* describes the distribution of stars that form versus stellar mass. A commonly used IMF from Salpeter et al. (1955) is:

$$\xi(m)\Delta(m) = \xi_0 (m/M_\odot)^{-2.35} (\delta m/M_\odot) \tag{4}$$

In other words, this means that the distribution of stars has a power-law slope of -2.35, so there are more low-mass stars than high-mass stars. Plot the IMF from $0.1 - 100$ $M_\odot$ and use this mass range for the rest of Question 4. For every one star from 90–100 $M_\odot$, how many stars are there from $0.9 - 1.0$ $M_\odot$? What fraction of stars are > 8 $M_\odot$, the approximate cutoff for supernova?

(c) The luminosity of a star can be estimated as

$$L/L_\odot \approx (M/M_\odot)^{3.9}. \tag{5}$$

Assume that the lifetime of the sun is 10 billion years (10^{10} yr), after which H burning in the core will cease. Plot the stellar lifetime versus mass. This question is similar to a question in homework 3.

(d) Combine your answers to (b) and (c) to estimate the fraction of stars that formed 8 billion years ago have burned out. Do the same for 2 billion years ago.

(e) Now expand your answer to (d) by plotting the fraction of stars that formed at any age have burned out. This can be done through brute force, by calculating answers at a range of ages and summing them up, or analytically. Brute force is best done either with a programming language or advanced use of excel, though it can be done more simply with excel.

(f) Combine the plot from (e) with the star formation history from (a) to estimate the fraction of stars that have ever been born in the Milky way are still with us today.

(g) Assuming that the star formation rate versus cosmic time from (a) continues into the future, what fraction of all stars that will ever formed have already formed?