Homework 2, due Thursday, October 10 at 1:00pm

Instructions: Please write your answers clearly on a separate sheet of paper. You should turn in the assignment by the beginning of class, preferably at the website below. If that is not possible, you may also turn in the assignment on paper (stapled together) or by email (gjh1@pku.edu.cn) as a **single pdf document**. Show all work. **Late homework will not be accepted**.

https://disk.pku.edu.cn/link/AAE3C4E0DC3A6F44B6AB2545E3E62DBEB2
Folder: Homework 2

Write your own name in Chinese and in pinyin and your ID number, all at the top of the page. You can use any *reliable* source of information to answer the questions, but copying from others is not allowed and will result in a 0 on the assignment. Parts of these questions are meant to be challenging, with answers that cannot easily be found in lectures. For all questions, include the information source that you used. The online textbook may be helpful:
https://openstax.org/details/books/astronomy

There are three pages in this homework! Do not miss the last page.

1. "Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist's, but that's just peanuts to space." Douglas Adams, The Hitchhiker's Guide to the Galaxy. (15 points)

(a) If the sun were the same volume as a soccer ball and placed at the front of this room, how far away would Earth be? How far would Pluto be?

(b) With the same scaling, how far away would the next nearest star be? What about Andromeda Galaxy? When converted to question (a), what locations correspond to those two distances?

(c) The movie *The Martian* portrays a crewed mission to Mars. When someone on Mars sends a message to Earth, how long would it be until they hear back? Do the same for alpha Centauri, the home planet of the alien species in *The Three-body Problem.*

(d) Estimate the fractional volume of space that is "empty", in other words, not solid objects or star/planetary atmospheres. Make the same estimate for the solar system. What is between the stars?

2. Star clusters (25 points): An observational astronomer studies the contents of two star clusters using a small telescope. The astronomer measures the brightness and the colour of as many stars as possible. From these measurements the astronomer then calculates the temperatures and luminosities of all the stars that that were detectable in the two clusters. The results of these measurements are shown in the Figure on page 3, for star cluster A and for star cluster B.

(a) How is the astronomer able to derive the temperature of each star?

(b) Which of the two star clusters is the oldest? How do you know?

(c) Which of the two star clusters is the most distant from the Sun? How do you know?

(d) Star 1 is actually a binary system, with two stars. However, the two stars were not resolved and appear like a single star. If the stars were resolved into the two different components, where would these two stars be in the diagram, with respect to Star 1? To the left, top-left, top, top-right, right, bottom-right, bottom, or bottom-left of the current location of Star 1 in the diagram?

(e) In the distant future, will Star 2 become a white dwarf, a neutron star, or a black hole? What about Star 3?

(f) Imagine that Star 2 has a planet at a distance of 0.7 AU, and Star 3 also has a planet at a distance of 0.7 AU. Which of the two planet is a more pleasant place to live, and why?

(g) If Star A has an absolute magnitude of 12 and star B has an absolute magnitude of 9, which star is brighter and by what factor (or ratio)?

3. How do we measure distances (35 points)? The *Gaia* observatory has measured the positions, space motions, and parallax to over one billion stars! I believe this to be the most perfect dataset that mankind has ever produced. This question asks you to analyze real *Gaia* data of the Pleiades (Mǎo in pinyin), a famous nearby star cluster that you can see without a telescope, if you are away from city lights. I have sent by wechat an excel file with real *Gaia* data of the region around the Pleiades, located at 130-140 pc.

(a) Describe the Gaia Satellite. Why is Gaia in space? Why is that different from the reason that JWST and Chandra Telescopes are in space? Why are some telescopes built on the ground? What affects the decision to build a telescope on the ground or in space?

(b) How does *Gaia* measure distances?

(c) What are three other ways to measure distances to objects that are outside our solar system? In that context, why is *Gaia* important?

(d) How were the distances to the moon and sun first reliably measured?

(e) Star positions are measured in "right ascension" and "declination", equivalent to longitude and latitude on the Earth. The "proper motion" describes how quickly the star is moving on the sky in both of those directions. Use excel or some other plotting software to plot the positions (right ascension and declination) and separately the proper motions of the stars in the spreadsheet.

(f) List the ID number of 5 stars that you think are not members of the Pleiades and 5 stars that you think are members. What did you use to distinguish between members and non-members? List at least two ways.

(g) List the stars that you think are the "seven sisters", by number in the spreadsheet. How did you select them?

(h) Plot the color-magnitude diagram for the Pleiades, with $Bp - Rp$ on the x-axis and G on the y-axis. Where are the more massive stars on this diagram? Compare this color-magnitude diagram to the color-magnitude diagram with non-members. Explain the comparison.

4. Kepler's Laws (25 points): The remarkable HR 8799 system has four known, directly imaged planets. Direct images of planets are rare, so HR 8799 is unique and a fantastic laboratory to understand extra-solar planets. A youtube video at https://www.youtube.com/watch?v=x9EG3gbQ5P0, made by Prof. Jason Wang shows the planets orbiting the central star (in the video, the central star is blocked out by a coronagraph). I will circulate the video, for those who cannot access it. For the purposes of this question, label the innermost-to-outermost planet as a, b, c, and d.

(a) Which do you think is the most massive planet? The least massive planet? How is this system different than our own solar system?

(b) What do Kepler's Laws state (all three)?

(c) Measure the positions of the four planets at different times. Which is orbiting fastest?

(d) Are the orbits circular or elliptical? Provide evidence for your answer.

(e) Calculate the mass of the star from the Keplerian orbits. Show your calculation