Astr 423, Spring 2019

Homework 1: the distance to the Pleiades

1 Introduction

Distance determination is a fundamental problem in Astrophysics. If we want to learn about the physics of any astrophysical object, one of the first things we need to know is how distant it is from us. Astronomical distances are so large that to measure them is a challenging task. Fortunately there are some nearby stars whose distances are easier to measure, and we can use their distances to learn about these nearby stars. Next, we try to use our acquired knowledge about them to devise astrophysical methods of distance determination, which can then be applied in turn to more distant objects. In this way we make progress, one step at a time, along a "distance ladder" which allows us in the end to reach the most distant objects in the Universe. Let us consider this method of the distance ladder in more detail.

2 Initial step: the distance to the Sun

The first step in the ladder is the Earth-Sun distance. We take this number (the Astronomical Unit, AU) as already known. In fact, we know all the distances within our Solar System to very high precision, because of radar measurements, Kepler's third law, and a variety of space probes.

3 Second step: trigonometric parallaxes

The most reliable method of distance determination is the geometric one, based on triangulation. We take advantage of the motion of the Earth around the Sun, and measure the apparent displacement of a nearby star projected against the more remote ones. To make these measurements we need at least one year. Working from ground-based observatories it was possible to measure distances up to about 30 pc. The HIPPARCOS astrometric satellite allowed to measure distances of 200 pc. The GAIA mission, currently (2019) in progress, promises to get reliable parallaxes for stars as distant as 2000 pc.

4 Cluster main sequences

Armed with the first trigonometric parallaxes we learned in the early 20th century that most stars fall along a well-defined band in the luminosity-temperature diagram. This band is called the "main sequence". Stars spend most of their lives as Hydrogen burners at some position along the main sequence.

Concerning the luminosity-temperature diagram, note that in practice we do not use temperatures, but colors that are a suitable function of the temperature. For example $(B-V)$, where B and V are magnitudes measured through Blue and Visual filters. The transmission curves of the 4 filters (U, B, V, I) as a function of wavelength have peaks of maximum transmission at (roughly) 3600, 4200, 5500 and 9000 Angstroms, respectively. The hotter the star, the smaller becomes the color $(B-V)$. It is zero for a star of spectral type A0 V (for example Vega, which is the brightest star of the constellation Lyra). The color $(B-V)$ is negative for even hotter stars. It is customary to refer to hot stars as "blue" and to cooler stars as "yellow" or "red". Note that a blue star has a negative $(B-V)$ color because astronomers have defined magnitudes in such a way that they become smaller for brighter objects.

It is fortunate that we can measure trigonometric parallaxes of the individual stars in groups called "clusters". You probably have seen or at least heard about the Pleiades; that is a nice example of a nearby cluster. Its distance is slightly more than 100 parsecs, or in other words the parallaxes of individual stars in the cluster are slightly smaller than 0.01 arc second.

Since the stars in a cluster are all at essentially the same distance, we find a main sequence even if we plot just the apparent magnitudes as a function of the $(B-V)$ color. This is very useful for our "ladder project". Unless the chemical compositions are very different, we expect the main sequences of different clusters to fall at the same absolute brightness for each intrinsic color $(B-V)$. Then any difference in the apparent magnitudes can be immediately translated into a difference in the distances. To know the trigonometric

parallax of one cluster is then enough to get the distances to all clusters with well-defined main sequences in the (apparent magnitude) vs. $(B-V)$ diagram. The use of the main sequence as a "standard candle" is a typical example of an astrophysical method of distance determination.
When we look in the direction of a star cluster, we may also see foreground and background stars projected upon the cluster. How can we decide if a given star is or not a physical member of the cluster? In the case of nearby clusters it is most efficient to consider the proper motions and radial velocities of the stars in the cluster. The members of the cluster move together in space (otherwise they would disperse very soon), and therefore all of them must have similar proper motions and radial velocities.

5 Description of data and homework activities

Visit the Catalog section of the Center of Stellar Data at Strasbourg:
http://cdsarc.u-strasbg.fr/cats/I.htx
Find the HIPPARCOS Catalog (new version) and search for the Pleiades cluster members, producing an output data file in ASCII format. The coordinates of the cluster are RA2000=3h 47m, Dec2000=+24° 03'. Bear in mind that the proper motions should be: μ_α around 20 mas/yr, and μ_δ around -45 mas/yr. The angular radius of the cluster is about 2 degrees.
Eliminate from your list those stars with wrong proper motions.
You should find some 40 members of the Pleiades. Make a file "pleiades.dat" with the information extracted from HIPPARCOS. Run the program "hipar.pro", which plots a histogram of the parallaxes. Discuss if some of the individual parallaxes should be rejected. Can we test if some of these objects do not belong to the cluster? Make a preliminary estimate of the cluster distance, derive from its angular size its physical size in pc, and consider if depth effects within the cluster can explain the different parallaxes determined by HIPPARCOS. After deciding which stars, if any, have to be rejected, calculate the average parallax and express the distance in parsecs and in magnitudes (distance modulus: the difference between the apparent and the absolute magnitude). Give an estimate of the uncertainty in the distance to the Pleiades from the HIPPARCOS data.