

Astronomy 128: Galaxies

Week 1, Thursday, January 19

Topic: Review of basic stellar properties; history of our understanding of the Milky Way; basics of observational astronomy

Break: volunteers for snacks for our first break?

The basic building blocks of galaxies are stars and gas. For our first assignment, we're going to review and integrate some material from Astro 16 about basic stellar astrophysics and observational astronomy, in order to make sure that we're all on the same page in terms of having the basic tools well in hand to start to think about the bigger picture of galaxies.

Much of the material below draws on things you learned (or at least that were covered) in Astro 16, though much of it is covered briefly again in Chapter 1 of Sparke and Gallagher (which I'll refer to as "SG" from now on). There are also a few things here (coordinates, filter systems) that may be more familiar to those of you who have taken Astro 128, though again, the basics are covered in SG or in Binney and Merrifield (which I guess we should call "BM", despite other connotations for those initials).

Reading:

- Sparke & Gallagher, Chapter 1 through section 1.3. You can just skim sections 1.1.3 (on stellar evolution) and 1.1.4 (on binary stars).
- Binney & Merrifield, Chapter 1 (on reserve in Cornell library, honors reserve shelf).

Problems:

1. Come to class with at least one *written* question on the reading.
2. Keivan Stassun and his collaborators just announced at AAS last week the discovery of the first known eclipsing binary system composed of two brown dwarfs. The discovery will be published in *Nature* in a few months.

The great thing about an eclipsing binary system is that the eclipse light curves and measurements of the radial velocities together give you enough information to measure

the masses and radii of both objects; this is the first time that a brown dwarf’s radius has been measured, and one of only a handful of mass measurements. Both brown dwarfs (BDs) have spectral types of M6.5, and radii of about $0.6 R_{\odot}$.¹

- (a) What is the luminosity (in units of L_{\odot} , the solar luminosity) of these objects?
 - (b) If the K magnitude of one of these brown dwarfs is $K = 14.3$, and they are equal magnitude, what is the combined K magnitude of the total light of the system?
 - (c) Given the K magnitude above for one BD, what are that object’s V and I magnitudes? What is M_V , the absolute V magnitude, if the distance to the system is 400 pc?
 - (d) If there is extinction due to gas and dust between us and the system, how (qualitatively) would your answers to the previous two questions change?
 - (e) Compare the M_V you derived to that given for an M6.5 V star in Table 1.3 of SG; you should find that your M_V is smaller. Explain why. (Note: this is unrelated to the extinction question above.)
3. Use the information in Table 1.3 of SG, and the fact that the Sun’s bolometric absolute magnitude is $M_{\text{bol}} = 4.75$, to find the radius and luminosity of an M6 V star.
4. Fischer & Valenti (2005, ApJ 622:1102) have examined the relationship between the metallicity (heavy-element abundance) of stars and the likelihood that the star will be orbited by a planet that is detectable with current techniques. The abstract of their paper says,

From this subset of stars, we determine that fewer than 3% of stars with $-0.5 < [\text{Fe}/\text{H}] < 0.0$ have Doppler-detected planets. Above solar metallicity, there is a smooth and rapid rise in the fraction of stars with planets. At $[\text{Fe}/\text{H}] > +0.3$ dex, 25% of observed stars have detected gas giant planets.

- (a) Explain in words (without using the standard $[\text{Fe}/\text{H}]$ shortcut notation) what those metallicity numbers mean, i.e. by what factor does the number of Fe atoms (relative to H atoms) differ from that in the Sun for the ranges discussed above?
- (b) Fischer & Valenti find that the probability of detecting a planet is related to the target star’s metallicity by $P(\text{planet}) = 0.03 \times 10^{2.0[\text{Fe}/\text{H}]}$. Rewrite this equation in terms of the *number* of Fe and H atoms in the star relative to that in the Sun.

¹This radius might seem big for an object that is substellar, and indeed it is. These objects have only recently formed, and they are still collapsing and cooling, so their radii are much larger than they will be later in the objects’ lives.

5. If you were to observe the Milky Way from the Andromeda Galaxy, what would you measure the angular diameter of the Milky Way to be? What if you observed the Milky Way from a distance of 100 Mpc? Express each answer in the appropriate angular units (which typically means choosing a unit that makes the numerical value given of order ones or tens).
6. One of the tools that is essential to have in your toolbox for understanding astronomical data is the ability to take data and plot it. Often, we'll want to take a plain text file with numbers in various columns, and plot one column against another. Here's an exercise to help get you up to speed on doing that.²

Let's look at the distribution of globular clusters on the sky, so we can see that it shows that there is a preferred direction in the Galaxy, i.e. that we aren't at the center.

The file at http://astro.swarthmore.edu/astro128/globular_clusters.dat is a text file with columns as follows: cluster name, cluster number, RA1, RA2, Dec1, Dec2, l, b. RA and Dec are standard equatorial coordinates for the cluster (with the two separate numbers given hours and minutes of RA, and degrees and arcminutes of Dec), while l and b are Galactic latitude and longitude of the cluster.

First, plot the globular cluster positions in RA and Dec. You'll want to combine the two RA columns into one number, and likewise for the Dec. IDL's *ten* and *six* functions are handy for this sort of thing. You should be able to see that the globular clusters are preferentially concentrated in one part of the sky. What is located in this direction?

Second, plot the globular cluster positions using Galactic coordinates (the existence of which were of course only possible once we realized where we are in the Galaxy). You may find the plot more illustrative if you convert Galactic longitudes greater than 180° to negative numbers, i.e. if the range of longitudes is -180° to $+180^\circ$ rather than

²For this and other plotting/computational exercises we'll be doing in class, I recommend using IDL. If you don't have access to a machine with a current IDL installation, I'd be happy to give you an account on the Linux machines in the astronomy lab. If you use a different machine, you will find it very useful to install some additional routines. The IDL Astronomy User's Library (<http://idlastro.gsfc.nasa.gov/>) has a large number of astronomy-specific routines that are very useful. Installing them is as simple as downloading a zipped file and unpacking it in some directory that's in your IDL path. Also, I recommend routines written by Craig Markwardt (<http://cow.physics.wisc.edu/craigm/idl/idl.html>), particularly the excellent *transread* program for reading data from a text file. Unfortunately, IDL (which is powerful in many other ways) makes it harder than it should be to get columns of data from a text file into IDL arrays for plotting; this routine helps a lot. If you'd like to use something else for your computation and plotting, that's fine with me as long as you know how to use it and it can make decent plot. Mathematica is fine for analytic work, but not so great for plotting data, I think. Feel free to talk with me if you have any questions about using other routines, or getting up to speed with IDL.

0° – 360° . Optional but recommended: take a look at the IDL Astrolib routines *aitoff* and *aitoff_grid* to create a more accurate projection of the coordinates onto the sky (since we’re dealing with spherical coordinates projected onto a plane).

For both of these plots, and for other plots during the semester, you should clearly label both axes and provide an informative title.

7. It is common to describe the distribution of stars in a galaxy using an exponential density distribution, as SG do on p. 25. Let’s consider the *scale height* of such a distribution. At a given Galactocentric radius, what fraction of stars lie within one scale height of the Galactic plane? (We’re not considering variations of density with distance from the Galactic center, just perpendicular to the plane.) How many scale heights do we have to go above or below the plane to encompass 95% of the stars? Don’t worry about thick or thin disk here; assume that there is just a single vertical exponential density distribution, and that it extends all the way to infinity; if z is the distance from the plane, then $n(z) \propto e^{-z/h_z}$.
8. Here’s a little practice using Galactic coordinates. If you took Astro 121 last semester, you’ve already done a similar problem. Do it again anyway, being as specific and quantitative as possible about the various possibilities for each scenario.
 - (a) An optically observed G dwarf has Galactic coordinates $l = 283^\circ$, $b = -2^\circ$. What can you conclude about whether it is located in the disk or the halo of the Galaxy?
 - (b) As part of my research, I discovered a young star with Galactic coordinates $l = 149^\circ$, $b = -82^\circ$, probably the highest-latitude T Tauri star known. As above, what can you conclude about whether it is located in the disk or the halo of the Galaxy?
 - (c) A radio source has Galactic coordinates $l = 202^\circ$, $b = 3^\circ$. What can you conclude about its distance from the Galactic center compared to the Sun’s distance from the Galactic center?
 - (d) Same as part (c), but for $l = 15^\circ$, $b = -2^\circ$.
9. To get a sense of scale in the Galaxy, compute the following:
 - (a) Find the distance to the nearest star in units of solar radii.
 - (b) Find the distance to the Andromeda Galaxy in units of Milky Way radii.