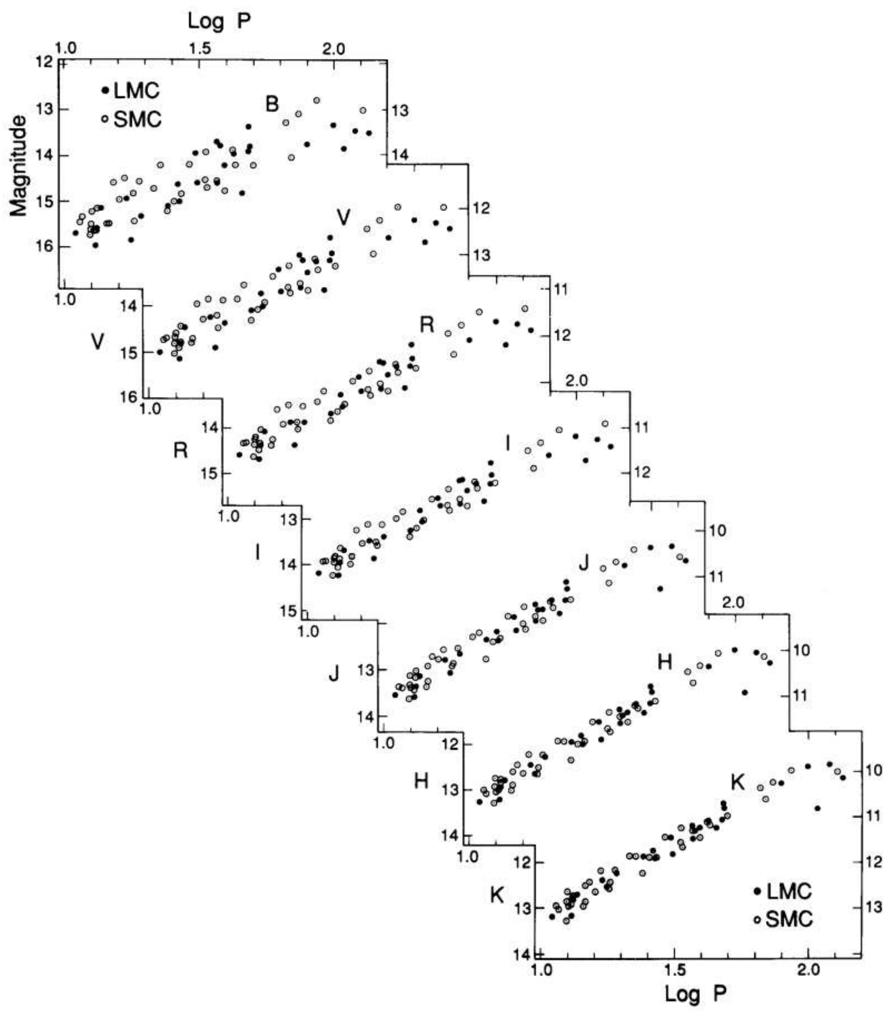
A311 Problem Set 2

Due Wednesday, October 6, 2005

1. High-mass stars go through a post-main sequence stage where they pulsate regularly; these are Cepheid Variable stars. Empirically, there is a simple relationship between the period and luminosity of these stars. This is convenient; measure the period, and you know the star's luminosity. Measure it's flux, and you can figure out the distance. These stars are bright enough that they can be individually identified in nearby galaxies (e.g. Freedman *et al.*, 2001, ApJ, 47). Thus, they form a very important rung on the "Cosmic Distance Ladder," as they can be used to calibrate distance measurement techniques that are then applied to more distant galaxies.

The plot below (Madore & Freedman, 1991, PASP, 103, 993) shows the period-luminosity relationship for Cepheid Variables measured in the Large and Small Magellanic Clouds (satellites to our galaxy) in various different filters. The period P is in days. Assume that the distance modulus to the LMC is 18.6.



(a) You observe a Cepheid Variable in another galaxy. It has a period of 40 days. You measure a V magnitude of 26.4 and an R magnitude of 25.8. Assuming that any dust in the host galaxy of the Cepheid is just like standard Milky-Way interstellar dust, how far away is the galaxy?

(b) What is the average optical depth in the R-band?

(c) What is the average optical depth in the V-band?

2. [***Solo Problem***] Fire up Firefox (Mozilla, Opera, Safari, Konqueror, Galeon, and other browsers are also acceptable, but use IE only if you are willing to risk failing the class) and look at this picture:

`http://heritage.stsci.edu/2001/10/big.html`

The Sun is 8kpc from the center of the Galaxy. It has an orbital velocity about the center of the galaxy of 220 km/s. To first approximation, *all* of the stars (and gas clouds and so forth) have this orbital velocity, regardless of their distance from the center of the Galaxy.

Assume that M51's dynamics are just like the Milky way.

Just from looking at the picture in its full-color glory above (and perhaps doing things like putting rulers or protractors on it), answer the following questions:

(a) Recall everything we've talked about in class regarding scenarios for star formation and evolution. (What do stars form from, what do different sorts of stars do when they're young and old, how long do different sorts of stars live, what is most of the stellar mass and most of the light of a galaxy coming from, etc.) Where is the star formation in M51 happening? Explain.

(b) Spiral arms aren't made up of stars that are "in" the arm, and stay in the arm as the galaxy spins. If you think about the rotation curve of the galaxy, that would mean that they should wind up pretty quickly. For a demonstration of this, see:

`http://brahms.phy.vanderbilt.edu/~rknop/classes/a102/fall2004/handouts/spiral.shtml`

Rather, they are *density waves*, much like the car density enhancement you get near a bottleneck on the freeway. Assume that the spiral pattern is orbiting so that the arms trail, and that the stars orbit in the same direction.

Consider stars and gas which are about halfway out from the center in the picture. Is the pattern speed *faster* or *slower* than the star orbital speed? Explain.

(c) Estimate the spiral pattern speed in km/s. How long does it take the pattern to complete one rotation? (For comparison, how long does the Sun take to compete one orbit around the center of the Galaxy?)

3. Consider the [OIII] $\lambda 5007$Å line discussed in class. This is a collisionally excited line, where collisions excite the ion into the upper state of the transition. Because this line comes from doubly-ionized Oxygen, and the second ionization potential of Oxygen is substantially higher than the first ionization potential of Hydrogen, it is frequently seen from fully ionized plasmas. In fully ionized interstellar plasmas, to first order the electron density is the same as the Hydrogen density (since interstellar gas is 90% Hydrogen by number).

One of the many jolly places where one observers astrophysical plasmas is in active galactic nuclei (AGN). The line profiles in some AGN show emission from two different regions: high-velocity "broad line" gas (where lines have widths of several 10^3 km/s) and lower-velocity "narrow line" gas (where line widths are typically several 10^2 km/s). The [OIII] $\lambda 5007$Å line is observed in narrow line gas, but *not* in broad line gas.

(a) In a plasma at thermal equilibrium, most of the collisions an O^{++} ion will experience will be with electrons. Explain why.

(b) Consider the lifetime of the transition as discussed in class, and the mean time between collisions for a plasma at $T = 10^4\,\mathrm{K}$. For an O^{++} on in the upper state of the $\lambda 5007$Å transition, the cross-section for collision with a typical electron at this temperature is about $3 \times 10^{-15}\,\mathrm{cm}^2$. (Unless I made a mistake, but assume I'm right for now.)

What limits can you set on the number densities (in cm^{-3}) of the broad-line gas and the narrow-line gas based on this information?

(c) A more sophisticated analysis of these considerations provides the concept of "critical density" for a given line. It is usually relevant only for forbidden lines; why?