ASTRONOMY 460 PROJECT INTRO: GALACTIC $l - V_r$ Diagram

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1. Introduction

The main goal of our project is to measure the Milky Way $l - V_r$ diagram over the the longitude range that is visible from Madison. None of the previous SRT projects have attempted to do this. The $l - V_r$ diagram shows the overall rotation pattern of the Milky Way, as well as coherent large-scale structures like spiral arams. It will be great to see whether our SRTs can detect spiral arms.

For a reference, Astronomy 330 and 320 cover (or will cover) details of various derivations (but do not go into details of how you obtain measurements). We will focus on the practical aspects and doing the measurements in this class. If you would like more background information please see "An introduction to modern astrophysics", Carroll & Ostlie Chapter 24, and "Galaxies in the Universe", Sparke & Gallagher, Chapter 2.3.

New features this year relative to previous years: (1) we are mapping the $l - V_r$ diagram for the first time!!! (2) we want to sample well our observations by observing every 3 degrees in longitude (Nyquist sampling); (3) we will use the baseline calibration method developed by Astronomy 460 2014 class - this should make our data reduction more robust; (4) we will be working with a *larger* number of spectra so data processing scripts should be well organized and streamlined to handle different data files easily.

2. Basic Equation and Applications

Under a simple assumption that stars and neutral hydrogen (HI) clouds in the disk of the Milky Way (MW) move along circular orbits around the Galactic Center (GC), we can easily express the radial velocity component of the stellar/interstellar orbital motion (V_r):

$$V_r = R_\odot \sin l \left(\frac{V}{R} - \frac{V_\odot}{R_\odot} \right) \quad (1)$$

where l is the Galactic longitude of the observed star/cloud, V and $V_\odot$ are the orbital velocities of the star/cloud and the Sun, respectively, and R and $R_\odot$ are the distances from GC to the star/cloud and the Sun, respectively.

This main equation is extremely useful and can be used in many ways.

If we know the Galactic rotation curve, $V(R)$, we can use this equation to estimate the radial velocity we expect to measure in different regions of the MW. If we plot V_r as a function of Galactic longitude l we get the $l - V_r$ diagram (Fig. 24.10 in Carroll & Ostlie). Hydrogen clouds co-rotating with the MW disk will have a special, well-defined appearance in this digram so it is very easy to see objects that have velocities inconsistent with the Galactic rotation model (e.g. high velocity clouds that are likely being accreted from nearby galaxies, etc.). Please see class slides for examples.

If we know the Galactic rotation curve, $V(R)$, and we measure V_r, we can estimate the Galactocentric distance R to the particular star/cloud; this is directly related to the distance between the Sun and the star/cloud, so essentially we can get an estimate of the object's distance this way. Of course this distance estimate depends on our initial assumption of simple circular motions etc., but for many stars/clouds is the only distance estimate we can ever make so it is very important. Such distances are called "kinematic distances" as they depend on the assumed rotation curve.

If we know the Galactic rotation curve, $V(R)$, we can estimate the total mass of the MW M_R inclosed within a particular Galactocentric radius R:

$$M_R = \frac{V^2 R}{G} \tag{2}$$

where G is the gravitational constant.

The shape of the rotation curve is telling us about the distribution of mass in the MW. The MW rotation curve stays flat to about $R = 10$ kpc, with some indication that it increases beyond this radius. According to Newtonian mechanics, if most of the mass is distributed within particular radius (as we observe that stellar disk goes up to a certain radius), than beyond this radius we would expect orbital velocity $\propto R^{-1/2}$. As observational data do not support this in the case of the MW and most other spiral galaxies, this suggests the existence of dark matter that extends beyond visible galaxy disks.

3. Project Observations

For our project we are measuring the $l - V_r$ diagram of the Milky Way. We can observe from Madison the longitude range from 0 to 250 degrees, and we want to space our measurements every 3 degrees. This means we will have about 83 positions, and 11 class students. Each of you will observe seven Galactic positions (I will help if additional verifications are needed). We will process and analyze individually data files, following the same data reduction strategy, and then combine all results to produce the final plot of the rotation curve.

PLAN: All observations are for $b = 0$ degrees.

Eggen ($l = 0, 3, 6, 9, 12, 15, 18$ deg)

Andersen ($l = 21, 24, 27, 30, 33, 36, 39$ deg)

Nestingen-Palm ($l = 42, 45, 48, 51, 54, 57, 60$ deg)

Brewer ($l = 63, 66, 69, 72, 75, 78, 81$ deg)

Beeler ($l = 84, 87, 90, 93, 96, 99, 102$ deg)

Hillard ($l = 105, 108, 111, 114, 117, 120, 123$ deg)

Yang ($l = 126, 129, 132, 135, 138, 141, 144$ deg)

Keith ($l = 147, 150, 153, 156, 159, 162, 165$ deg)

Noughani ($l = 168, 171, 174, 177, 180, 183, 186$) deg

Thornton ($l = 189, 192, 195, 198, 201, 204, 207$) deg

Kelley ($l = 210, 213, 216, 219, 222, 225, 228$) deg

Based on my Az/El vs LST plots, looks like the best window for our observations is around LST = 15-24 hrs, which corresponds to late afternoons/evenings.

YOUR OBSERVING SCRIPT – THIS IS HOMEWORK 5: To make observing and file labeling as easy as possible, you should write seven observing scripts, one for each position. These scripts will be essentially identical, the only difference will be the file name and the position coordinates. Each script should: open a data file, set a central frequency and use observing mode 4, go to a selected Galactic position, fire a noise diode, then integrate for 300 sec, and close the observing file. Then in the same script and in exactly the same way execute additional positions.

NOTE - Most of you should be able to center observations at a frequency of 1420.405 MHz. However, at $l = 0 - 50$ deg the HI spectrum is all at positive velocities. At $l = 60 - 130$ deg, the HI spectrum is all at negative velocities. This means that if you center your observations at 1420.405 MHz, the observed line will be covered in one half of the observing band. By shifting your central frequency slightly you can use the observing bandwidth more efficiently. Please consider this and let me know if you need some suggestions. Also, the Simulator can be handy for deciding how exactly to center your observations.

FILE NAMING:
Example command file: snez_l50.cmd;
example data file: snez_l50_6sep14.rad (it's nice to know when were observations obtained in case we have to repeat them).

Please keep your files/scripts in your class directory and I will copy them from there to OBSERVER.

3.1. Observing sessions

We will start observing from Oct 11 and continue throughout the semester.

4. Data processing

To look at our data files, and produce final HI spectra that we will plot together as a $l - V_r$ diagram, we will use a commercial package called IDL. We will learn and practice basics of IDL, and will then together learn how to read SRT data files within IDL.

Here is a summary of the data processing steps we will need to do for each position:

1. Read a data file in IDL and place data in a 2-dimensional array representing a stack of spectra (each row of the array will be a single HI spectrum).
2. To convert from artificial telescope units to brightness temperature, and for baseline calibration, we will use our noise diode observations. Will talk about this in class.
3. Average all HI spectra to produce a single HI spectrum. Your y-axis is now Brightness Temperature in units of Kelvin. Your x-axis is Frequency. Use the Doppler equation to convert from Frequency to Topocentric Radial Velocity. Topocentric means the spectrum is measured relative to our telescope. To convert from Topocentric to LSR Velocity add a velocity factor I will provide.
4. Using the noise diode scans calculate the spectral shape or gain function.
5. Produce the HI spectrum corrected for the spectral gain and plot this spectrum as a function of the LSR velocity. Make a nice plot of the resultant HI spectrum.
6. At the end we will map/grid all spectra into a data cube to examine the $l - V_r$ structure.

We will discuss all these details in class step by step!

5. Galactic Standards: $V_\odot$ and $R_\odot$

For our calculations we will use the Galactic constants: $R_\odot = 8.5\,\mathrm{kpc}$ and $V(R_\odot) = 220\,\mathrm{km\,s^{-1}}$ for Sun's distance from the Galactic center and its circular velocity (IAU recommended standard in 1985).