Assignment #2

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1: Galactic Rotation Curve

The data from each galactic co-ordinate file was appended into lists for frequencies(online and offline), intensities(online and offline) and the calibration diode. The online raw data for co-ordinate l=6°, b=0° is shown in figure 1.

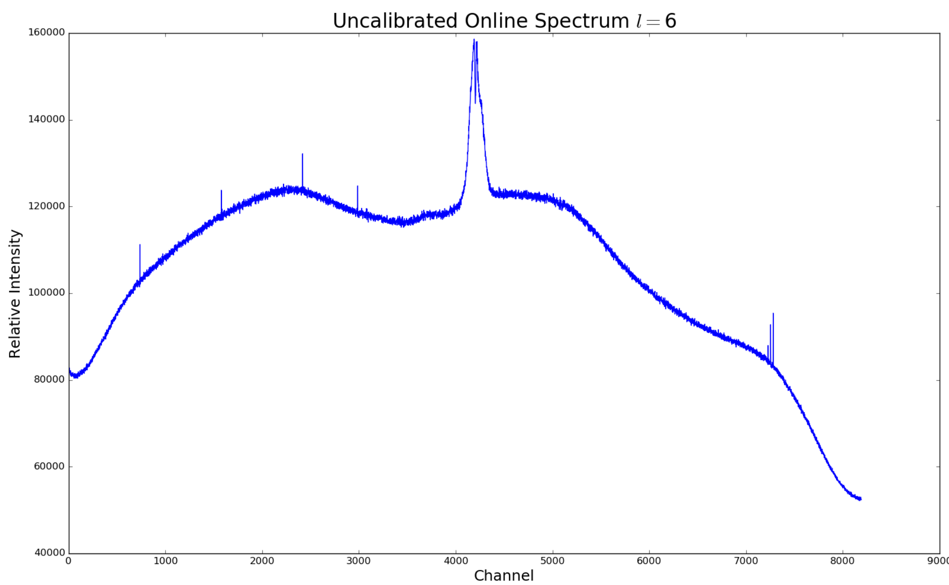

Figure 1: Uncalibrated online power spectrum

The narrow interference peaks were removed with the signal.medfilt() function from the Scipy library in Python. This filter algorithm replaces each signal value with the median value of its nearest neighbours, to adequately remove the noise peaks the closest 7 neighbours were chosen. The filter was applied to both intensities and the calibration diode data, shown in figure 2.

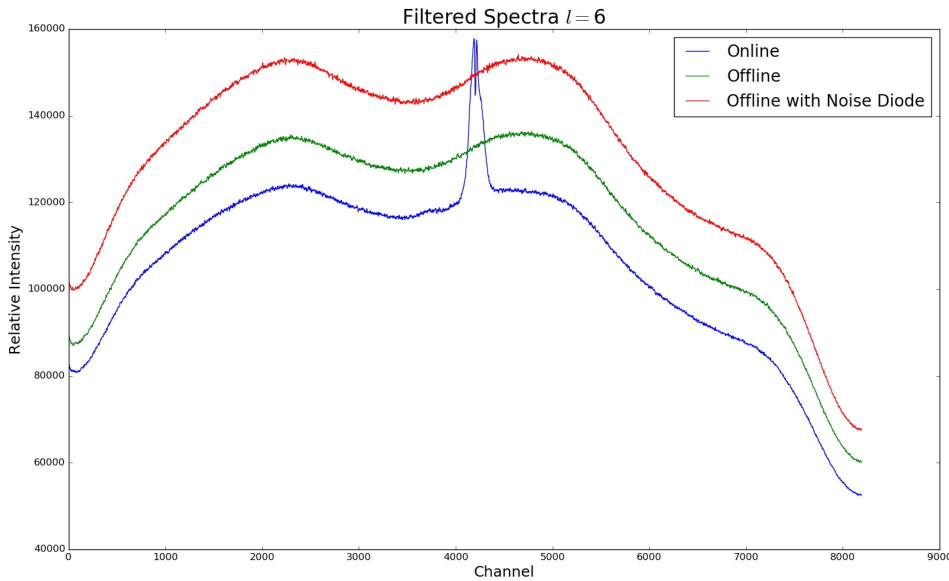

Figure 2: Filtered power spectra.

Using Eqs. (3) and (4) from lecture 7 in conjunction with the Doppler shift formula also given in lecture 7 the calibrated spectrum was obtained. The LSR uncorrected emission spectrum is also shown for reference.

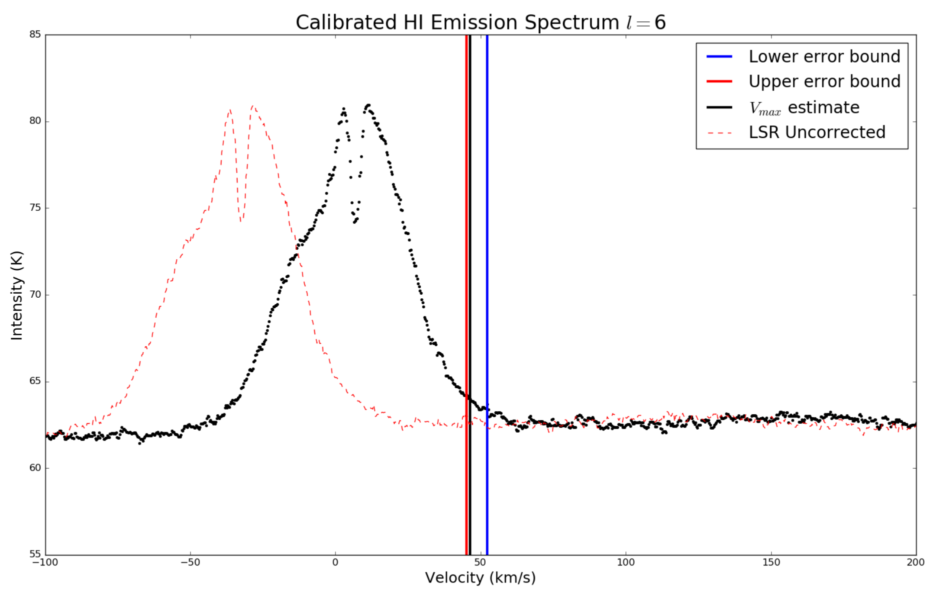

Figure 3: Calibrated HI emission spectra for galactic co-ordinates (l=6°,b=0°)

An estimate for V_{max} was achieved by first calculating the mean(μ) and standard deviation(σ) of the baseline signal. The point where the signal intensity reached a value $5\,\sigma$ above μ was chosen as the estimate for V_{max}. The lower and upper error bounds for V_{max} were taken to be $4\,\sigma$ and $6\,\sigma$ above μ respectively.

The rotation curve was obtained by determining V_{max} and the distance D for each galactic co-ordinate, and using

$$V_{rot} = V_{max} + V_0 \sin(l) \tag{1}$$

$$D = R_0 \sin(l) \tag{2}$$

with $V_0 = 220\,\text{km/s}$ and $R_0 = 8.5\,\text{kpc}$ being the rotational velocity and orbital radius of the earth around the galactic center respectively. A 9^{th} order polynomial was fitted to the data.

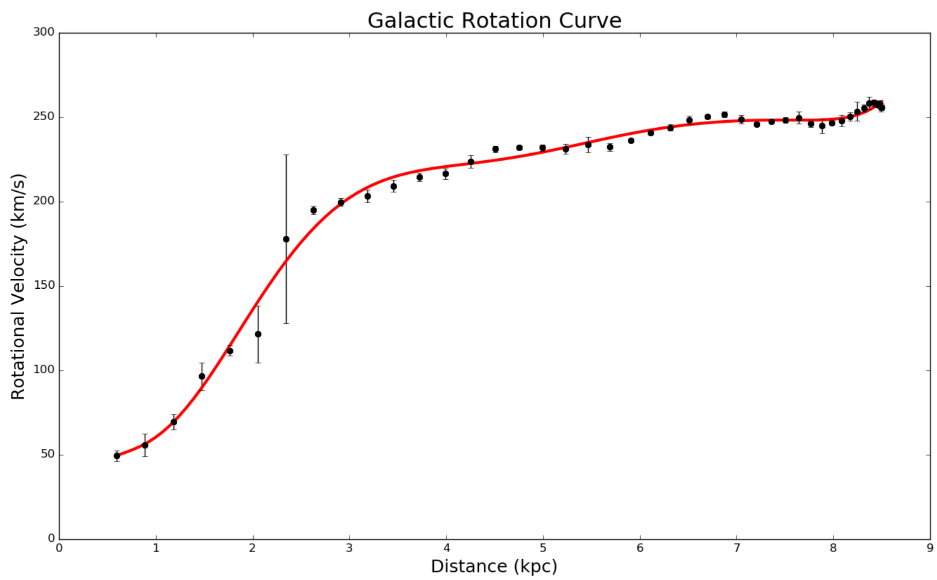

Figure 4: Orbital velocity as a function of distance for the Milky Way.

2: Discussion & Enclosed mass

From figure 4 it is clear that the orbital velocity of stars around the galactic center does not decrease with increased distance, such as in solar/planetary systems. In these systems the orbital velocities result from the centrally concentrated mass distribution. The flattening of the rotation curve can be attributed to the presence of a uniform dark matter halo surrounding the galaxy.

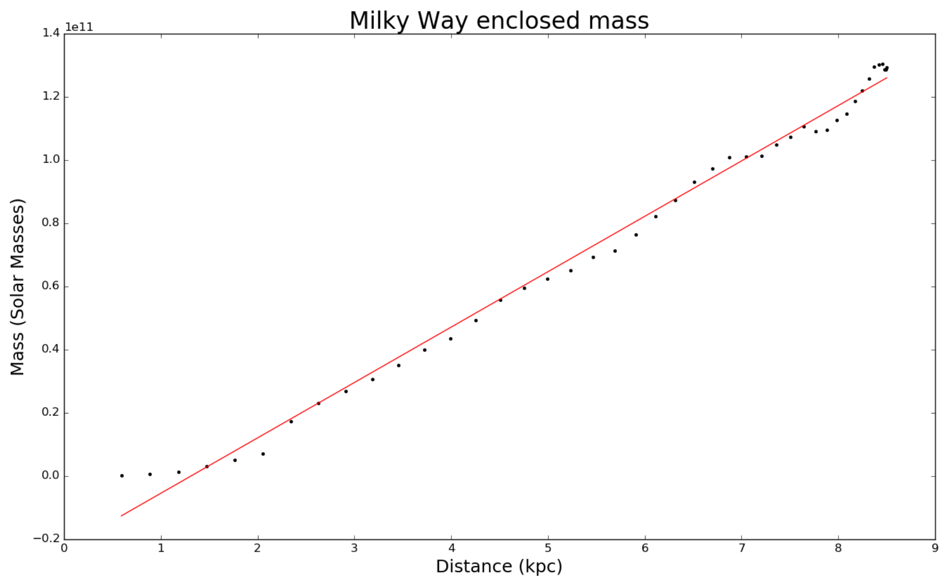

Figure 5: Enclosed mass of the Milky Way out to 8.5 kpc

The above plot shows the enclosed mass of the Milky Way as calculated using Kepler's 3$^{\text{rd}}$ Law

$$M \propto \frac{a^3}{P^2}$$

here a is the orbital radius and P the orbital period. The resulting enclosed mass for the Milky Way is seen to increase linearly with distance from the galactic center and at 8.5 kpc was calculated to be $1.29 \times 10^{11}\ M_{\odot}$, which is in close agreement with the value of 100 billion solar masses given in literature.

3: Rotation curve data for distances $> R_0$

The APOGEE experiment collected infra-red spectra from over 100,000 red giant stars on various lines of sight over a 2.5 year period. By observing in the infra-red the effects of stellar extinction is reduced, allowing for the ability to observe spectra at distances greater than R_0.

> Additional benefits of using the intermediate-age to old stellar population to trace the dynamics of the disk are that these populations are much less sensitive to non-axisymmetric streaming motions than cold gas, and that the large asymmetric drift can be used to constrain the component of Galactic rotation that possesses a uniform angular speed.[1]

4: Rotation curves for other galaxies

The rotation curves for other galaxies can be determined from a number of different sources, the transition lines of carbon monoxide in the millimeter wave range are used to study the central regions of spiral galaxies as extinction in these areas are negligible at CO's transition wavelengths. Limitations arise from the fact that only high inclination or edge-on galaxies are useful for analysis, this minimizes the uncertainty that arises from inclination corrections[2].

References

[1] J. Bovy, C. A. Prieto, T. C. Beers, D. Bizyaev, L. N. Da Costa, K. Cunha, G. L. Ebelke, D. J. Eisenstein, P. M. Frinchaboy, A. E. G. Pérez, et al., "The milky way's circular-velocity curve between 4 and 14 kpc from apogee data", The Astrophysical Journal **759**, 131 (2012).

[2] Y. Sofue and V. Rubin, "Rotation curves of spiral galaxies", Annual Review of Astronomy and Astrophysics **39**, 137–174 (2001).