

# Ph 343 Lab 6 The Galactic Rotation Curve — Continued

Due: Thursday, December 5, 2002

**Purpose:** Measure the rotation curve of our Galaxy interior to the Sun's distance from the Galactic center. Also, place limits on the circular velocity at the Sun's distance from the Galactic center. The measured rotation curve will yield the amount and distribution of mass in our Galaxy from the center out to the Sun's location.

The first part of this lab gave the procedure for determining the galactic rotation curve,  $\Theta(R)$ , from the maximum positive radial velocities along different galactic longitudes,  $\ell$ . It also discussed finding the circular velocity at the distance of the Sun from the galactic center,  $\Theta_0 \equiv \Theta(R_0)$ , from observations of the most negative velocity of HI emission in the direction  $\ell = 90^\circ$ .

Because the HI gas in the galactic disk is on nearly circular orbits, the mass of the Galaxy interior to any radius  $R$  is given by the usual formula for circular motion:

$$M(R) = \frac{\Theta(R)^2 R}{G}. \quad (1)$$

Here  $G$  is the gravitational constant, equal to  $6.67 \times 10^{-8} \text{ cm}^3 \text{ g}^{-1} \text{ s}^{-2}$ . In units that are more useful for Galactic dynamics,  $G = 4.30 \times 10^{-6} \text{ kpc (km/s)}^2 (M_\odot)^{-1}$ .  $M_\odot$  is the solar mass ( $1.989 \times 10^{33} \text{ g}$ ). The above formula assumes that the mass of the Galaxy is spherically distributed. This is not very accurate for the region between the Galactic center and the Sun – the flat disk contains at least a significant fraction and perhaps most of this mass – but the correction for the flattened distribution of the mass is on the same order as the uncertainties in the rotation curve.

## Data:

The maximum radial velocities obtained by the class in the direction of the different longitudes are given in the table below. The first column is the galactic longitude, the second and third columns are the lowest observed frequency with HI emission and its estimated uncertainty, the fourth and fifth columns are the corresponding observed maximum radial velocity and its uncertainty, and the final column is the number which should be added to the observed radial velocity to correct for the motion of the Earth around the Sun.

The observed radial velocities also need to be corrected for the motion of the Sun with respect to the local standard of rest (LSR). Recent measurements (Dehnen, W. & Binney, J.J. 1998, Monthly Notices of the Royal Astronomical Observatory, Vol. 298, p. 387) suggest that the components of the motion of the Sun with respect to the LSR (the Sun's "peculiar velocity") are  $10.00 \pm 0.36 \text{ km/s}$  towards the Galactic center ( $\ell = 0^\circ$ ),  $5.25 \pm 0.62 \text{ km/s}$  in the direction of the Sun's rotation around the Galactic center ( $\ell = 90^\circ$ ), and  $7.17 \pm 0.38 \text{ km/s}$  towards the north Galactic pole ( $b = 90^\circ$ ). To correct a radial velocity to that which would be obtained by an observer moving with the LSR, calculate the component of the Sun's peculiar velocity along the line of sight and subtract it from the radial velocity corrected for the Earth's motion around the Sun.

The combined data from the class for  $\ell = 90^\circ$ ,  $b = 0^\circ$  and  $15^\circ$  are in the folder `\\Hubble\ph343\lab6`. I will also make them available on the class website. The uncertainties in the average temperatures are based on the agreement of the seven sets of measurements. The correction for the motion of the Earth is  $-14.4 \text{ km/s}$  for the  $b = 0^\circ$  spectrum and  $-8.1 \text{ km/s}$  for the  $b = 15^\circ$  spectrum.

Table 1: Measured Maximum Radial Velocities

longitude (deg)	$\nu_{min}$ (MHz)	unc $\nu_{min}$ (MHz)	$v_{r,max}$ (km/s)	unc $v_{r,max}$ (km/s)	$v_{helio}$ (km/s)
5	1420.08	0.04	68.9	8.5	-15.4
10	1419.96	0.04	94.2	8.5	-16.5
15	1419.64	0.04	161.8	8.5	-17.4
20	1419.72	0.04	144.9	8.5	-17.5
25	1419.76	0.04	136.4	8.5	-18.3
30	1419.76	0.02	136.4	4.2	-23.6
35	1419.80	0.02	128.0	4.2	-19.1
40	1419.84	0.04	119.5	8.5	-23.2
45	1419.92	0.02	102.7	4.2	-20.1
50	1419.92	0.02	102.7	4.2	-22.4
55	1419.96	0.04	94.2	8.5	-21.7
60	1420.08	0.02	68.9	4.2	-21.0
65	1420.16	0.02	52.0	4.2	-19.0
70	1420.16	0.04	52.0	8.5	-17.4
75	1420.20	0.04	43.5	8.5	-17.1
80	1420.16	0.02	52.0	4.2	-16.7
85	1420.20	0.04	43.5	8.5	-16.1

### Analysis:

The goals are to derive the Galactic rotation curve (which is the circular orbit velocity as a function of distance from the Galactic center) and an estimate of the circular velocity at the Sun's distance from the Galactic center,  $\Theta_0$ .

1. Calculate the radius of the tangent point,  $R_{min}$ , for each observed galactic longitude. Assume  $R_0 = 8.5$  kpc.
2. Calculate the correction to the LSR for each longitude and then correct the maximum radial velocity of the HI emission for the motion of the Earth and the Sun. This corrected radial velocity is the one that should be used in the expression for  $\Theta(R_{min})$ .
3. Calculate the circular velocity for each longitude,  $\Theta(R_{min})$ . Assume  $\Theta_0 = 220$  km/s. Use propagation of errors to derive a formula for the uncertainty in  $\Theta(R_{min})$  in terms of the uncertainty in  $v_{r,max}$ . Use this to estimate the uncertainty for every value of  $\Theta(R_{min})$ . Plot your rotation curve ( $\Theta(R_{min})$  vs  $R_{min}$ ), including your uncertainties, as well as listing your calculated values.
4. Use your calculated values for  $\Theta(R_{min})$  to calculate the mass of the Galaxy interior to each  $R_{min}$ ,  $M(R_{min})$ , in solar masses.
5. The radial velocities  $v_{r,max}$  in Table 1 are the greatest radial velocity with significant HI emission. This velocity probably slightly overestimates the radial velocity of the HI gas at the tangent point because turbulent velocities in the gas produce some emission at velocities larger than the average, bulk motion of the gas. Is there any evidence for such turbulent velocities in your rotation curve? (Hint: Consider the values of  $\Theta(R)$  for radii near  $R_0$ .)

6. Use the combined spectra for  $\ell = 90^\circ$ ,  $b = 0^\circ$  and  $15^\circ$  to determine the largest frequency with significant HI emission for both latitudes. Estimate the uncertainty in your frequencies. Do uncertainties in the level of the baseline play a significant role in the uncertainty in the largest frequency? Is there a significant difference in the maximum frequencies with emission for the  $b = 0^\circ$  and  $b = 15^\circ$  spectra? What could cause a difference?
  
7. Calculate the observed radial velocities implied by the maximum frequencies found in part 5. Correct these observed velocities for the motion of the Earth and the Sun and thus obtain a lower limit on  $\Theta_0$ . How do your values compare to the International Astronomical Union standard value of  $\Theta_0 = 220$  km/s. Can you give reasons for any difference from the standard value?