The Mystery of Dark Matter: the Galactic Rotation Curve for the Milky Way

Kyle McGinty and David Brotman

Duke TIP Field Study in Astronomy, Physics, and Astrobiology at

Pisgah Astronomical Research Institute

June 28, 2006

Abstract

Dark matter is one of the most mysterious presences known to science. Its existence can only be deduced from other data. One of those forms of data is the galactic rotation curve. In order to ascertain the presence of dark matter in our own galaxy, velocities and distances to the galactic center for selected points will be made. Once observations and calculations are complete, the results indicate the existence of dark matter in the Milky Way Galaxy.

Introduction

What is dark matter? Essentially, it can be defined as matter that exerts a gravitational effect upon other matter but is not currently detectable. Dark matter is theorized to have at least two forms: hot and cold. Hot dark matter has an extremely low mass, but moves at extremely high speeds. Hot dark matter could potentially consist of particles like neutrinos. Conversely, cold dark matter has a high mass, but moves at very low speeds. It might be made up of particles like WIMPs, or Weakly Interacting Massive Particles. In addition, dark matter can possibly be either baryonic matter or non-baryonic matter. Baryonic candidates, those objects that are made up of atoms, include brown dwarfs, dim nebulae and stars, or black holes. Non-baryonic candidates, those previously mentioned as hot or cold dark matter, might even include an unknown form of matter.

Regardless, dark matter is a poorly known substance, still in theoretical status, that could be several objects.

The presence of dark matter can be inferred from other data, such as rotation speeds of stars that are higher than predicted, gravitational lensing, and the formation of universal structures (with the amount of gravity provided by luminous matter, the universal structures would not form). This inference leads to the purpose of the project, which is to calculate the rotation curve of the Milky Way Galaxy and thus ascertain the presence of dark matter in the galaxy.

Method

A certain procedure was used in collecting data and calculating results. First, points to observe were chosen. All chosen points had a galactic latitude equivalent to 0°; galactic longitudes started at 0° and varied by 10° up to 350°. Second, these points were converted to the equatorial system to meet the parameters of the 4.6 meter radio telescope used to obtain data. The telescope is nicknamed Smiley and is located at the Pisgah Astronomical Research Institute near Rosman, North Carolina. The conversion of the points was accomplished via the following equations:

$\mathbf{\sin(?)=\cos(b^{II})\sin(l^{ii}-33)\sin(62.6) + \sin(b^{II})\cos(62.6)}$ and

$\mathbf{\cos(?)\sin(a-282.25)=\cos(b^{II})\sin(lii-33)\cos(62.6) - \sin(b^{II})\sin(62.6)}$

where **?** represents declination, **a** represents right ascension, $\mathbf{b^{II}}$ represents galactic latitude, and $\mathbf{l^{ii}}$ represents galactic longitude. The original points in the galactic system (measured in degrees) and the converted points in the equatorial system (right ascension in hours, minutes, and seconds, and declination in degrees, arcminutes, and arcseconds) are in Table 1 as follows:

Table 1- Points and Converted Points

Galactic Latitude	Galactic longitude	Right ascension	Declination.
0	0	17 42 26.6	-285500.1
0	10	18 04 47.2	-201751.3
0	20	18 24 44.5	-113113.1
0	30	18 43 28.4	-23947.5
0	40	19 13 59.6	6 12 41
0	50	19 21 02.1	15 02 40.9
0	60	20 33 31.3	23 45 57.6
0	70	20 05 30.2	32 17 47.4
0	80	22 43 29.5	40 29 21.5
0	90	21 10 17.5	48 07 24.2
0	100	21 55	54 48 33.4
0	110	22 59	59 53 22.7
0	120	00 24	62 26 56
0	130	01 42	61 47 13.9
0	140	03 07	58 06 19.7
0	150	03 59	52 17 01.2
0	160	04 39	45 09 24.9
0	170	05 26	37 15 50.4
0	180	05 49	28 55 00.4
0	190	06 08	20 17 51.5
0	200	06 27	11 31 13.1
0	210	06 44	02 39 47.5
0	220	07 01	-61241
0	230	07 24	-150240.9
0	240	07 43	-234557.6
0	250	08 04	-321747.4
0	260	08 37	-402921.5
0	270	09 12	-480724.2
0	280	10 01	-544833.4
0	290	11 06	-595322.7
0	300	12 08	-622656
0	310	13 51	-614713.9
0	320	15 03	-580619.7
0	330	15 59	-521701.2
0	340	16 02	-450924.9
0	350	17 11	-371550.4

Third, 21 chosen points were observed. Because of equipment and location limitations, it was not possible to observe certain points. The points actually observed are in Table 2 as follows:

Table 2- Observed Points (in degrees)

gal. lat.	gal. long.
0	10
0	20
0	30
0	40
0	50
0	60
0	70
0	80
0	90
0	100
0	110
0	120
0	130
0	140
0	150
0	160
0	170
0	210
0	220
0	230
0	240

The above points were, in equatorial form, entered into the controls of the 4.6 meter radio telescope. Scans of neutral hydrogen in the 2.7 degree range of the telescope for each point were conducted. The value where the neutral hydrogen intensity peaked (in Megahertz) was used in the following formula to obtain a raw radial velocity:

f/1420.406 MHz (c) where **f** is frequency in Megahertz and **c** is the speed of light (300,000 km/s). These velocities are in Table 3 below.

Table 3- Raw Radial Velocities

Galactic Longitude	Radial Velocity (in km/s)

(degrees)	
10	4.224
20	16.897
30	21.103
40	23.233
50	25.345
60	29.569
70	27.457
80	35.905
90	31.681
100	32.737
110	33.793
120	31.681
130	25.345
140	16.897
150	19.009
160	21.121
170	8.448
210	-33.793
220	-38.017
230	-52.802
240	-46.466

The above raw velocities were corrected for the motion of the Local Standard of Rest (LSR) and for heliocentric velocity. To correct for the LSR motion, a website program[1] was used; to correct for the heliocentric velocity, an IRAF program put out by the NOAO was used. Velocities after 1) being corrected for LSR motion and 2) after being corrected for both the LSR motion and heliocentric velocity are displayed in (respectively) Tables 4 and 5 below.

Table 4- Velocities Corrected for LSR motion

Galactic Longitude (degrees)	LSR-corrected Velocities (km/s)
10	-8.746
20	-.703
30	-.657
40	-3.177
50	-2.595
60	-3.471

[1] fuse.pha.jhu.edu/support/tools/vlsr.html

70	-3.293
80	3.765
90	1.811
100	4.637
110	8.393
120	10.011
130	7.375
140	4.327
150	10.569
160	17.551
170	11.988
210	-11.783
220	-12.727
230	-24.522
240	-16.586

Table 5- Final Velocities Corrected for LSR Motion and Heliocentric Velocity

Galactic Longitude (degrees)	Velocity(km/s)
10	3.9
20	19.2
30	25.3
40	31.9
50	34.6
60	46.0
70	40.1
80	57.3
90	46.2
100	47.4
110	48.0
120	45.2
130	37.9
140	27.7
150	28.8
160	29.2
170	12.9
210	39.2
220	45.5
230	62.8
240	58.0

The final velocities were plotted in a velocity curve (absolute value was taken of all to eliminate negatives). **All velocities have an uncertainty of + or – 1.1**. Next, the observed points' distance from the galactic center (Rmin) was calculated using the following equation:

Rmin=Ro(sin l) where **Rmin** is the distance from the galactic center, **Ro** is equivalent to 8 kiloparsecs, and **l** is the galactic longitude. Table 6 charts the obtained distances in kiloparsecs as follows:

Table 6- Distance from the Galactic Center

Galactic Longitude (degrees)	Distance (kpc)
10	1.389
20	2.736
30	4.000
40	5.142
50	6.128
60	6.928
70	7.518
80	7.878
90	8.000
100	7.878
110	7.518
120	6.928
130	6.128
140	5.142
150	4.000
160	2.736
170	1.389
210	4.000
220	5.142
230	6.128
240	6.928

Absolute value was taken of all distances to eliminate negative values. A rotation curve for the Milky Way Galaxy, with velocity as a function of distance from the galactic center, was then plotted. To demonstrate the presence of dark matter, a Keplerian rotation curve was plotted on top of the Milky Way rotation curve. The equation for calculating the Keplerian rotation curve is as follows:

v(GM)/vR where **G** is the gravitational constant, **M** is 10^{10} solar masses, and **R** is the distance from the galactic center in meters. (Answers should be converted to km/s because meter was used to cancel units.) Table 7 below contains the values obtained for the Keplerian Rotation Curve.

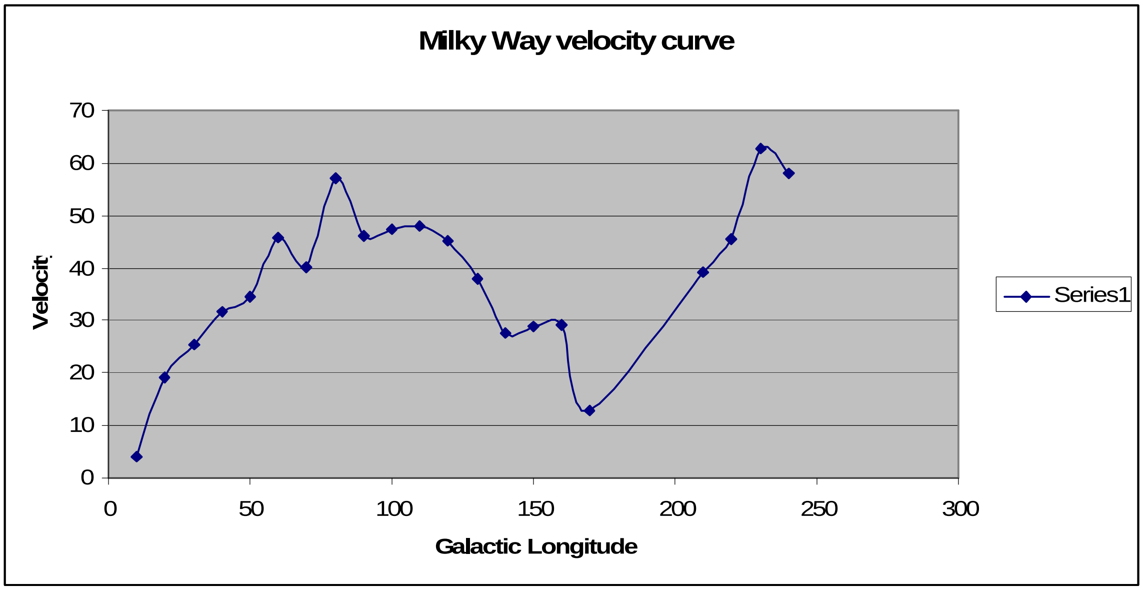
Table 7- Keplerian Rotation Curve Values

Distance from the Galactic Center (kpc)	Velocity(km/s)
8	73.39
9	69.19
12	59.92
15	53.60
18	48.93

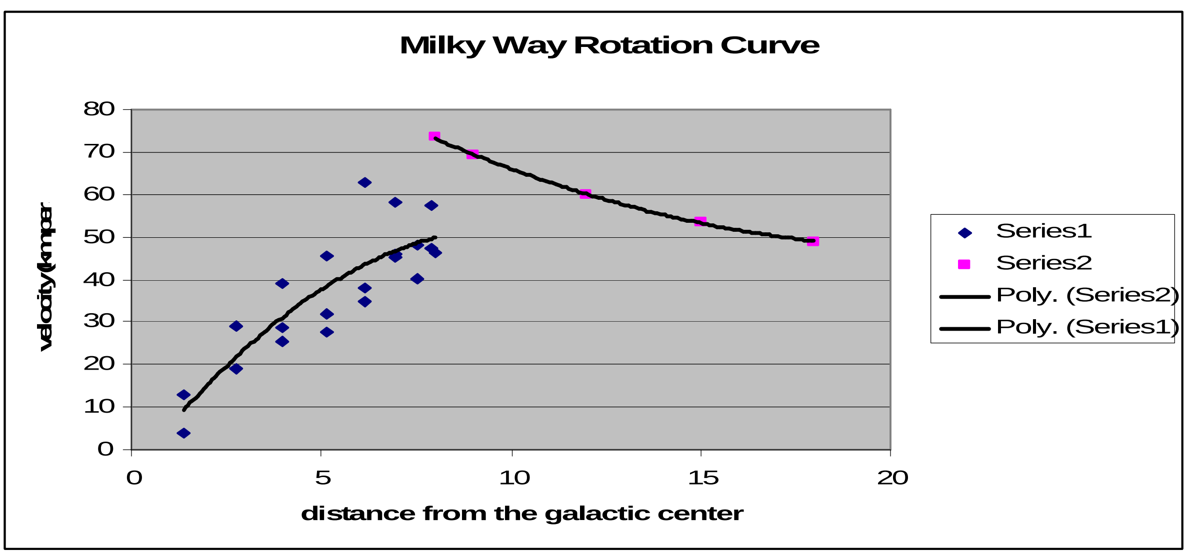
The two different rotation curves for the Milky Way Galaxy were compared to ascertain the presence of dark matter.

Results

Because of the nature of the Smiley telescope scans, it is not possible to include them. However, the link to them is as follows: http://smiley.pari.edu:8080/smiley/analyze/mainpanel.html (scroll on the drop-down menu to tip2006; the data are labeled as [coordinates] DK scan). The velocity curve obtained is below, with velocity in km/s and galactic longitude in degrees.



This curve indicates that different points in the galaxy have varying velocities, spanning from about 4 to 64 Km/sec. This fact stems from the various natures of the galactic objects. The rotation curves obtained are below. Blue is the observed rotation curve, and pink is the Keplerian rotation curve. Velocity is in km/s; distance from the galactic center is in kpc.



The observed curve had an overall upward trend, leveling off toward the end of observed data. The Keplerian curve had a gradual downward trend, also leveling off toward the end of calculated data. If the trends continue, the observed rotation curve should cross the Keplerian curve somewhere between 10 and 15 kiloparsecs. This occurrence would indicate the presence of some unknown type of matter-dark matter.

Discussion

As with most projects, some assumptions, approximations, and limitations were present. First, more data points of velocity would be useful; because of latitudinal and telescope limitations, some points could not be observed. These extra points of data would confirm the hypothesis that the trend lines of the two rotation curves would cross, with the observed rotation curve becoming higher than the Keplerian curve. Second, most data points were rounded to two or three significant places. Third, the distance from the galactic center and the measured velocity were assumed to be perpendicular and thus at the tangent point of an object's orbit. Fourth, all formulae used were assumed to be correct; the telescope was assumed to be functioning correctly.

In addition, the results obtained are comparable to other available data. However, this project could be improved through more collection of data from a different location, as well as a longer time to collect data. The short time inhibited the project. Nevertheless, meaningful data were still able to be obtained.

Conclusion

In order to determine the presence of dark matter in the Milky Way Galaxy, velocities and distances from the galactic center for selected points were measured and calculated. Next, an observational rotation curve and a calculated Keplerian rotation curve were made. The comparison of the two corroborates the presence of extra or dark matter in the universe. This dark matter could be any number of objects in our galaxy, or something completely unknown; nevertheless, it encompasses one of the mysteries of the universe.

References

Binney, James, and Scott Tremaine. *Galactic Dynamics*. Princeton, NJ: Princeton University Press, 1987.

Blake, Mel. Assorted Lectures. TIP astronomy program at PARI. Multimedia Room, Pisgah Astronomical Research Institute, Rosman, NC. June 2006.

Britt, Robert Roy. “Understanding Dark Matter and Light Energy.” 5 Jan. 2001. 25 June 2006 <http://www.space.com/scienceastronomy/astronomy/dark_matter_sidebar_010105.html>

Castelaz, Michael. Assorted Lectures. TIP astronomy program at PARI. Multimedia Room, Pisgah Astronomical Research Institute, Rosman, NC. June 2006.

Chaikin, Andrew. “Dark Matter: Hidden Mass Confounds Science, Inspires Revolutionary Theories.” 8 Jan. 2002. 25 June 2006 <http://www.space.com/scienceastronomy/astronomy/cosmic_darkmatt_020108-1.html>

Cooper, W. Alan, et al. *Observing the Universe*. Ed. Andrew J. Norton. The Open University. Cambridge, UK: Cambridge University Press, 2004.

“Dark Matter.” 25 June 2006 <http://csep10.phys.utk.edu/astr162/lect/cosmology/darkmatter.html>

“Dark Matter.” Wikipedia. 26 June 2006. 27 June 2006 <http://en.wikipedia.org/wiki/Dark_matter>

Genuth, Iddo. “Dark Matter-One Mystery Solved.” 7 Oct. 2005. 25 June 2006 <http://www.physorg.com/news7058.html>

Jacobs, Kenneth C., and Elske v.P. Smith. *Introductory Astronomy and Astrophysics*. Philadelphia: W.B. Saunders Company, 1973.

White, Martin. “Dark Matter.” University of California at Berkeley. 25 June 2006 < http://astro.berkeley.edu/ ~mwhite/darkmatter/dm.html>