Scan to know paper details and
author's profile

Rotation Curve of the Milky Way in 21cm

Zhongyuan Zhang

INTRODUCTION

The purpose of this paper is to examine evidence for the existence of dark matter in the Milky Way by analyzing the rotation curve of the Milky Way. The data was collected from 21cm radio wave and was processed from raw data to plot of rotation curve of the Milky Way. Data were compared to the Kepler model and the exponential disk model, which both predict the rotation velocity of galaxy; the data did not support either model. Instead, another model, the isotheral sphere model, was evaluated in order to incorporate the velocity of dark matter, a kind of invisible matter, which produced a better fit to the data.

Keywords: NA

Classification: FOR Code: 020199

Language: English

London
Journals Press

LJP Copyright ID: 925673
Print ISSN: 2631-8490
Online ISSN: 2631-8504

London Journal of Research in Science: Natural and Formal

Volume 19 | Issue 7 | Compilation 1.0

Rotation Curve of the Milky Way in 21cm

Zhongyuan Zhang

I. INTRODUCTION

The purpose of this paper is to examine evidence for the existence of dark matter in the Milky Way by analyzing the rotation curve of the Milky Way. The data was collected from 21cm radio wave and was processed from raw data to plot of rotation curve of the Milky Way. Data were compared to the Kepler model and the exponential disk model, which both predict the rotation velocity of galaxy; the data did not support either model. Instead, another model, the isotheral sphere model, was evaluated in order to incorporate the velocity of dark matter, a kind of invisible matter, which produced a better fit to the data.

II. BACKGROUND INFORMATION

21cm radio waves are a common and accessible method for probing the galaxy. 21cm radio waves originate from hydrogen atoms across the galaxy. A normal hydrogen atom has a proton in its nuclei and an electron moving around it. Both the proton and electron have a magnetic field, and if these magnetic fields are aligned, the hydrogen atom is at high-energy level, whereas if they are anti-aligned, the hydrogen atom is at low-energy level. When a hydrogen atom flips from a high-energy level to a low-energy level, a photon will be emitted, and the wavelength of the photon is 21cm. About 75 percent of mass in the universe is hydrogen, so despite hydrogen atoms flipping at a very low frequency, by virtue of the universe's immense number of hydrogen atoms, 21cm radiation is readily observable universe anywhere there is hydrogen { which is nearly everywhere in the universe.

The Doppler effect describes the change in frequency or wavelength of a wave in relation to an observer who is moving relative to the wave source. This phenomenon has important implications for measuring 21cm waves. The frequency of 21cm radio wave is about 1428 MHz, and using the Doppler effect, we understand that the object is moving toward us if the data shows a peak which is at the position larger than 1428 MHz. In contrast, if the peak is at a position less than 1428 MHz the object is moving away from us.

Dark matter is a theoretical invisible matter with mass. The data received from 21cm radio wave have shown that the visible matter located more than 10,000 light years from the center of galaxy are rotating much faster than would be expected. One possible explanation for this phenomenon is that there exists more mass in the galaxy than we have observed, and this kind of mass is termed \dark matter." Dark matter has not been observed, but it is added to Newton's gravity model because Newton's gravity theory fails to predict the rotation velocity of a galaxy when the distance to the center of a galaxy is extremely large.

III. THE APPARATUS

The experiment uses a TLM18 parabolic reflector antenna to collect data and uses python scripts to analyze and visualize the data. The incoming radio waves reflect upon the parabolic reflector of the dish and converge into the feed horn, which is a focus of the dish. The signal received by the disk then comes out from the feed horn.

Fiure 1: The disk used to get data

IV. ANALYSIS AND RESULTS

The collected data refer to the power of the signal from 21cm radio waves that corresponding to a particular time in Unix Timestamp. This paper aims to describe the rotational velocity curve of the Milky Way, which can be constructed from a plot of power vs. velocity. To clearly see the signal in the data, some correction was needed {specifically, dividing the power by the gain value to get the gain-corrected plot, which effects radio's volume setting, and then subtracting the background noise. When there is background noise in the data, the signal is not clear, which interferes with the analysis. For this reason, the background noises need to be removed from the data. The background noise can be calculated by

$$B = mv_D + b \tag{1}$$

Where

$$m = \frac{p_1 - p_2}{v_1 - v_2} \tag{2}$$

and

$$b = p_1 - mv_1. \tag{3}$$

The raw spectrum is presented in Figure 2. The gain-corrected spectrum is represented in Figure 3. The background subtracted spectrum is represented in Figure 4. As can be seen visually, the signal became clearer after each step of processing.

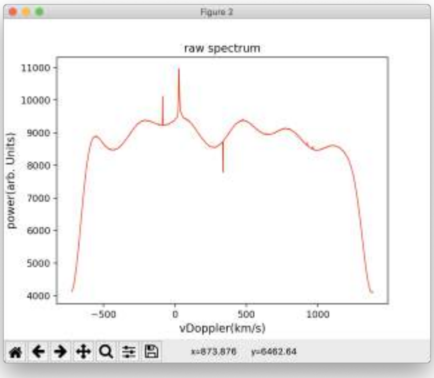

Figure 2: Raw Spectrum

This paper mainly focuses on objects that moves less than 300km/s toward or away from us, so the x axis in plots after correction is only from -300km/s to 300km/s. Negative velocity indicates an opposite direction of velocity.

After the background noise was subtracted, the peak was identified. In Lab05, spectra from each file of data were first transformed into gain-corrected ones. Then, the background noises were subtracted from each spectra. Lastly, the results were plotted on a longitude vs. velocity heat map. The heat map is shown in Figure 5.

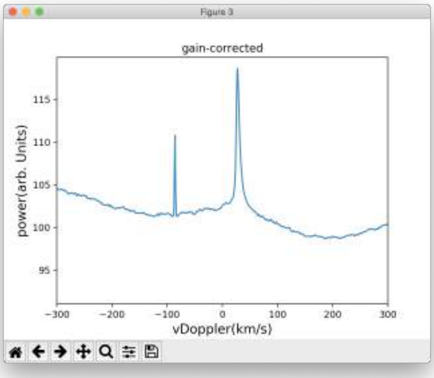

Figure 3: Gain Corrected Spectrum

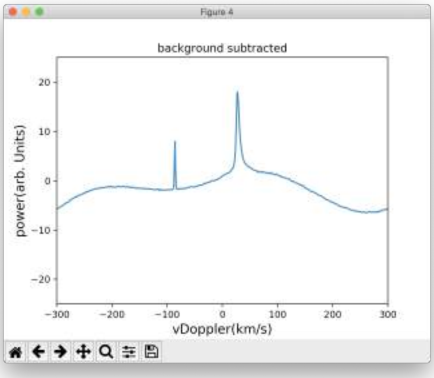

Figure 4: Background Subtracted Spectrum

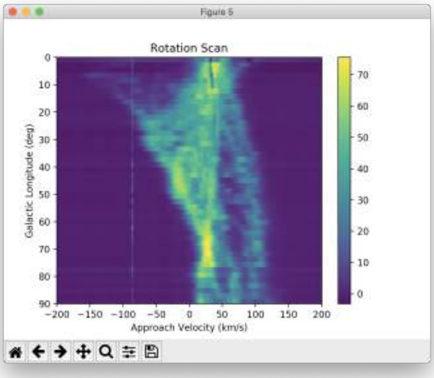

Figure 5: Heat map

Because the rotation curves are created by connecting certain points from each spectra, and a heat map is capable of showing multiple lines and rows of value at the same time, a heat map can effectively visualize the rotation curves. The x-axis is labeled as approach velocity and y-axis is labeled as galactic longitude in degree. The value for each point on the heat map is the power of the signal in the data received from a 21cm radio wave.

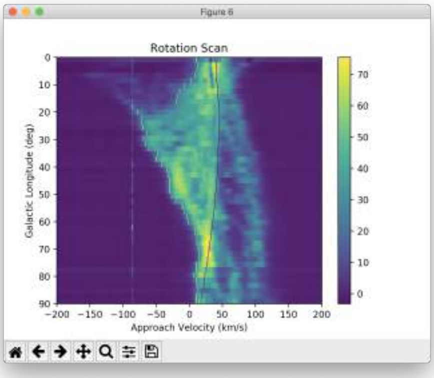

Figure 6: Curves

Next, the heat map in Figure 5 was used to identify two curves: the curve on the right is the velocity of gas corresponding to Earth and the curve on the left represents the maximum velocity that the cloud of gas is moving from the Earth. The difference between these two curves is the orbital speed of the gas under observation. The left curve can be calculated by finding the first channel from the left that is above 20K for each file of data. The right one is calculated by the velocity Projection function with time and the longitude and latitude of the galaxy. These two curves are shown in Figure 6.

The next step to determine the rotation curve of Milky Way was to calculate the difference in velocity of the two curves, minus the value of the right curve to get velocity of the objects in galaxy, $v_{(r)}$. Conceptually, this is equivalent to how when a person and a car are moving in the same direction and when the speed of the car corresponding to the ground v_{cg} is known and the speed of the person corresponding to the car v_{pc} is also known, the person can calculate his or her speed corresponding to the ground v_{pg} by $v_{cg} - v_{pc}$. Next the velocity of the earth multiplied by the sine value of the longitude was added to $v_{(r)}$ to get the final velocity of rotation of the Milky Way. A plot of velocity vs. radius was then created, which shows the relationship between rotational velocity of mass in the galaxy and the distance of the mass to the center of galaxy (i.e., the radius of the galaxy). The final step was to make a plot of velocity vs. radius. The result is shown in Figure 7.

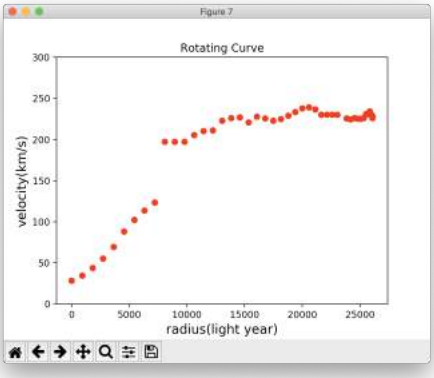

Figure 7: Rotating Curve of Milky Way

V. THEORY AND DISCUSSION

There are three models that predict the relationship between rotational velocity and radius: the Kepler model, the exponential disk, and the isothermal sphere. The Kepler model assumes that all mass of the Galaxy is concentrated at the center. Equation 4 gives the relationship between the velocity(v) of mass in the galaxy and radius(r) of the galaxy according to the Kepler model. The radius is the distance to the center of galaxy.

$$v(r) = \sqrt{\frac{GM}{r}} \tag{4}$$

As shown in Figure 8, the curve in blue representing the Kepler model fits the data poorly.

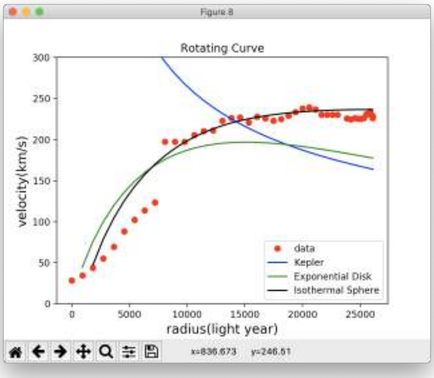

Figure 8: Different Models

The exponential disk model fits the data when r = 10,000 light year, but it predicts that the rotation velocity will decrease as r increases, On The Disks of Spiral and S0 Galaxies[1]. However, the velocity observed in the data is still increasing when r = 10,000 light year. The exponential disk assumes that not all mass are concentrated at the center of the galaxy, and the amount of mass is proportional to the amount of light of the objects. Even though Kepler model and exponential disk model differ greatly when the radius is small, they tend to overlap with each other as the radius increases. The data shows that when the radius is 10,000 light years, the corresponding velocity is about 200km/s. In both models, as the radius increases velocity begins to decrease, however the velocity in data never decreases. This trend indicates that both of the models are smaller than the data observed. As shown in Figure 8, the Kepler model in blue and exponential disk in green are both lower than data in red. Equation 5 gives the relationship between v and r of exponential disk model.

$$v^2(r) = \frac{GMr^2}{2R_d^3}[I_0(u)K_0(u) - I_1(u)K_1(u \tag{5}$$

Because the exponential disk model fails fit the data adequately, the isother-mal sphere model was considered to produce a better fit; this model assumes that there is a kind of invisible matter called dark matter. This matter is as- sumed to have mass even though it cannot be observed.

Equation 6 gives the relationship between v and r of isothermal sphere, the structure of dark matter haloes in hierarchical clustering models [2].

$$v^2(r) = 4\pi\rho_0 G(R_0^2 + a^2)[1 - \frac{\alpha}{r} tan^{-1}\frac{r}{\alpha} \tag{6}$$

The result of isothermal sphere is the model for dark matter, while the one of exponential disk is for visible matter. So the total velocity is the sum of these two velocity by:

$$v_{total} = \sqrt{v_{iso}^2 + v_{exp}^2} \tag{7}$$

In Figure 8, the black curve is one for isothermal sphere. The model fits the data well when r is larger than 10,000 light years, which provides evidence that there is dark matter in Milky Way even though it has not been observed yet.

VI. SUMMARY AND CONCLUSION

The data collected from 21cm radio wave challenges Newton's gravity theory because neither the Kepler model nor the exponential disk fit the data well.

The predictions from these models are smaller than observed when r = 10,000 light year. It is important to know that these two models fail because Newton's theory is less applicable when the distance to the center of galaxy is extremely large, and the theory and model of a kind of invisible matter is carried out, and that is dark matter.

REFERENCES

1. K.C. Freeman, The Astronomy Journal, Vol. 160, June 1970.
2. Cole, S., & Lacey, C. MNRAS, 281, 716(1996).
3. Frank Shu, The Physical Universe.

This page is intentionally left blank