American Journal of Modern Physics
2024, Vol. 13, No. 4, pp. 52-56
https://doi.org/10.11648/j.ajmp.20241304.11

Research Article

Keplerian Rotation Curve of the Milky Way

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Abstract

Use is made from the data from the Gaia satellite of 2013, which measured the rotation of our galactic system by parallax measurements. This implies that the rotation velocities were measured directly without applying the Doppler effect. The results from Gaia allow for a new understanding of flat rotation curves of galactic systems. The study uses earlier findings that the *G* measurements collected by CODATA show that the gravitational constant *G* is not a universal constant of nature, but depends on the distance to the center of a mass. At a place where *G* is larger, the inert mass of, for example, an electron will be larger. This leads to the concept of gravitational spectrum shift. It implies that the emitted spectrum of a star depends on its location within its galacticum. A different spectrum means a different redshift and that implies that the Doppler method for measuring the rotational velocities of stars generally provides wrong data. From available literature the Milky Way rotation curves for conditions with low as well as high accelerations are considered. The two different cases are the nearby solar region and a region far away from the galactic center. Within the solar region all spectra originate with the same *G* value as near the Sun, and therefore the Doppler method can safely be used. This is different for the case far away from the galactic center, where the impact of the center of mass of the Milky Way on *G* is small. The conclusions, which have been obtained by analyzing available data, lead to flat rotation curves with a Keplerian decline without introducing dark matter.

Keywords

Gravity, Galactic Rotation Curves, Doppler Effect, Gravitational Constant, Kepler

1. Introduction

Having examined the rotation of the Coma cluster, Zwicky calculated the gravitational mass of the galaxies within the cluster [14]. The calculated mass appeared to be 400 times larger than the mass expected from their luminosity. Zwicky then decided to introduce extra mass and named the unseen mass Dark Matter, after an idea of Oort [7]. In the seventies of the 20th century Rubin et al. measured rotation curves of galaxies and discovered a discrepancy between the expected angular motion of a galaxy based on their luminosity and the observed motion [11]. The galaxies are rotating too fast and the gravity of their constituent stars is too little to hold the stars together. Rubin concluded there must be a large amount of dark matter for holding it together. Also other researchers measured a too high rotation velocity and resolved the discrepancy as well by applying more mass in situ.

2. The Gravitational Constant

The gravitational constant *G* is commonly measured with

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Received: 5 August 2024; **Accepted:** 4 September 2024; **Published:** 23 September 2024

a torsion balance suspended by a wire as has been used by Cavendish. The plane of the rotating masses is positioned exactly horizontally and therefore the influence on the torsion balance by the variations of the local gravitational force is negligible. Analysing the measurements of *G* at several places on Earth a relationship of *G* with *g* has been found. See figure 2. (Colenbrander and Hulscher) [1].

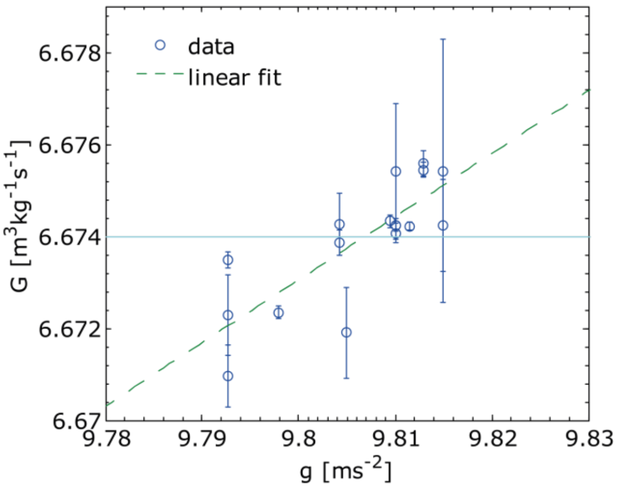

Figure 1. *The relation of the gravitational constant G with the gravitational acceleration g.*

Figure 1 shows the results at various latitudes, which are at different distances from the center of the Earth (Wuhan, Boulder, New Zeeland, Florence, Richland, Zurich, Seattle, Paris, Wuppertal).

The lower values of g represent locations more close to the equator, which are more distant from the center of the Earth than locations closer to the poles. Where g is lower the measured value of *G* appears to be lower than the value of *G* closer to the pole. In the Cavendish method of measuring the vertically directed gravitational force can have no influence on the horizontal movement of the rod with the two rotating masses of Cavendish. The cause for the measured differences in *G* can only be the distance of the masses to the center of the Earth.

A complication in the graph depicted in figure 1 could be the influence of the Earth rotation on *g*. However, the rotation of an object on Earth implies a centripetal acceleration and therefore *g* has to be corrected. Compare the measurement at g = 9.7927, which was taken in Wuhan, and the measurement at g = 9.81289, which was taken at Paris. In Wuhan the calculated centripetal acceleration $a_{centr.} = 0.0145$. So the real acceleration $g_r = g + a_{centr.} = 9.8072$ m/s^2. In Paris $a_{centr.} = 0.0111$ and $g_r = 9.8240$ m/s^2. Hence, plotting a graph of *G* and the real acceleration g_r will result in an slightly steeper line and so the relation between *G* and g_r holds even better.

It is concluded that the value of *G* increases closer to the center of a mass. At this point reference is made to the overall lack of consensus amongst specialised institutes about the measured values of *G* [6, 9]. All measurements ignored the effect of the vicinity of mass, though apparently a mass influences the value of *G*. The mechanism of this is as yet unknown. In this study the variability of *G* is accepted, even though it may not be in line with common thinking in physics.

3. Gravitational Spectral Shift

Because of their larger distance to the center of a galaxy we would expect the outer stars to have a lower rotational velocity than the velocity of stars near the center. But this is not what has been measured. The reason is an incorrect measurement of the rotational velocity. This is explained in the following [2].

The spectral lines of an hydrogen atom depend on the reduced mass $\mu = \frac{m_e m_p}{m_e + m_p}$, and due to the large mass ratio m_p/m_e the spectral lines depend on the electron mass. Than the following formula applies for the frequencies of the spectrum of a hydrogen atom:

$$f = \frac{me^4}{8\varepsilon_0^2 h^3}\left(\frac{1}{j^2} - \frac{1}{k^2}\right)$$

m is the mass and e is the electric charge of the electron. ε_0 *is the permittivity of free space and h is Planck's constant. j and k are integers describing the lower and the upper stationary states of the atom.*

The stronger the gravitational field is, the higher is the gravitational mass and because of the Equivalence principle the higher the inert mass of the electron is, which is moving with a virtually relativistic speed around the nucleus. And therefore the frequencies emitted by an atom are higher than the frequencies emitted in a weaker gravitational field. This phenomenon can be called *gravitational spectral shift,* which is in line with the Equivalence principle. So the spectra of hydrogen and other atoms near the center of the Milky Way are blue shifted relative to their spectra as measured in the laboratories on Earth. At the outskirt of our galaxy (i.e. the galaxy which encompasses the Earth) the gravitational field is weaker than that field at the Earth, so the inert mass of an electron is lower and so the spectra emitted are redshifted relative to the spectrum measured on Earth.

Note that this type of spectral shift has nothing to do with the *gravitational redshift*, an effect that occurs when a photon travels from a gravitational source and loses energy. The energy of this escaping photon decreases and so its wavelength increases.

4. Rotation Curve Correction

At the outskirts of our galaxy the gravitational field, and so *G*, is weaker than at the Earth, which is within our galaxy, and therefore the spectra measured have to be corrected. The real redshift z must be calculated with $z = \frac{\lambda_m - \lambda_s}{\lambda_s}$, were λ_m is the wavelength measured and λ_s is the value of the source and not the laboratory value. This results in a lower redshift z because the wavelengths of the source in situ are longer than the laboratory value on Earth. A lower redshift z at the outskirts means a lower velocity of the stars further away from the galactic center. Hence, the right hand side of the rotation curve will become more Keplerian in the sense that it will represent a better match with Newton's law, which requires that the velocity is inversely proportional to the distance square.

Moreover, close to the center G will increase, so the wavelengths of the source become lower than the value at the Earth. And therefore the real redshift increases in the direction of the center and so does the velocity of the stars, which will also make the rotation curve more Keplerian.

Here it should also be noted that the common presentation of the left hand side of the rotation curve is largely fictitious because of the notorious difficulty of measuring a rotation speed close to the galactic center. Rather than starting at zero the curve is likely to start at a high value, which would be conform a Keplerian curve.

In the following the implications of the correction for interpreting galactic rotation curves are analysed, acknowledging that G will have different values at the center and at the outskirts of the galactic center.

Two different cases are analysed, namely the solar region and a region far away from our galactic center where the impact of the center of mass on G is small. It will be seen that in both cases accepting the variability of G substitutes for any adhoc explanations of the observations. This analyses can only be qualitative, because for a quantitative analysis the relation between G and an emitted spectrum must be known.

5. No Dark Matter at the Solar Position

In 1932 J. Oort published an analysis of the vertical kinematics of stars in the solar neighborhood [7]. He found that the dark matter density is 0.054 M_{Sun} /pc^3.

80 years later C. Moni Bidin et al. estimated the dynamical surface mass density at the solar position between Z = 1.5 and 4 kpc from the Galactic plane and found about the same low dark matter density as Oort in the solar neighborhood of 0.001 M_{Sun} /pc^3 [5]. C. Moni Bidin et al. obtained their results by studying the kinematics of about 400 red giant stars of the thick disk towards the south Galactic pole, vertically distributed with respect to the Galactic plane. The authors found an excellent agreement between the measured mass and the visible mass. So, the observations of both J. Oort and C. Moni Bidin et all. point to an absence of dark matter at the solar position, contrary to the expectations of current models of Galactic mass distributions.

All models of the Milky Way require a dark spheroidal component to sustain the Galactic rotation curve, which are observationally confirmed to be flat for R ≥5 kpc, Sofue et al. [12]. In both studies of Oort and Moni Bidin the absence of dark matter is caused by the fact that the observed stars are at the solar position of 8 kpc to the galactic center. At that position the gravitational constant G will be not much different from the G value at the Sun, so the emitted spectra of these stars don't need a correction and their velocities calculated with the Doppler effect are reliable.

The method for determining the local dark matter density by extrapolation of the Milky Way rotation curve is incorrect, because it does not correct for the position-dependent G value. For example, measurements beyond 8 kpc yield a rotation velocity that is much too high, which then leads to a large dark matter density. In a review J. Read shows that the dark matter densities obtained by extrapolation are generally too high [10]. In fact, both Oort and Moni Bidin, who only use the vertical kinematics of stars close to the Sun, find a very low dark matter density.

6. Keplerian Decline in the Milky Way Rotation Curve

Recently Jiao et al. found a sharply decreasing rotation curve for the Milky Way based on the third Gaia data release (Gaia DR3) [3]. This is remarkable because it is widely believed that the rotation curve remains flat beyond the distance of 8 kpc to the galactic center. In fact, here it is found that the Milky Way rotation curve is declining in a Keplerian way. It appeared that the value of the enclosed mass is $2x\, 10^{11}\, M_{\text{Sun}}$, about ten times less than the previously known value. This result could be obtained because Gaia DR3 provided improved parallaxes and proper motions measurements. More groups working with these data found about the same results as mentioned by Jiao et al. See figure 2.

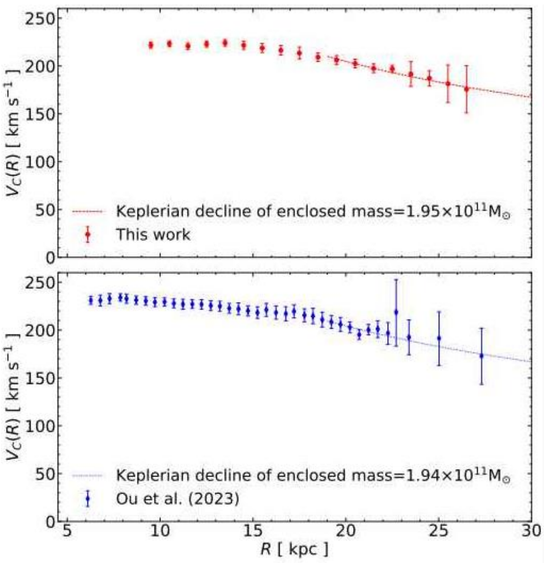

Figure 2. *Rotation curve with the best fit of the Keplerian decline for the rotation curve measurement of Jiao et al. (top panel) and that from Ou et al. (bottom panel) [8].*

It is concluded that the rotation curve based on Gaia data deviates so much from the previously known flat curve, because of incorrect previous measurements of the rotational velocity Vc. Till now rotational velocities were always measured using the Doppler method, but since the Gaia data, the velocity can also be determined from parallax measurements. In section 4 it is shown that the Doppler method is incorrect due to uncertainty in the frequencies of the emitted spectra of the stars in question. The spectrum of the Sun is used as the calibration frequency, which is incorrect when the star in question is far away from the Sun.

Accepting the variability of *G*, its value at the outskirts of the Milky Way becomes smaller than at the Earth and therefore the rotational velocity there must also be smaller than the rotation velocity of the Sun at 8 kpc. However, determining the velocity using the parallax method has no calibration problems and is therefore more reliable than the Doppler method.

7. Conclusion

Acceptance of the variability of *G* makes the introduction of dark matter for understanding galactic rotation curves unnecessary. The conundrum of missing mass can well be understood when the measurements are corrected for gravitational spectral shift. This applies to conditions with low as well as high accelerations.

The results of the studies by Oort, Moni Bidin and Y. Jiao support the conclusion that a Keplerian rotation curve will result, based on only baryonic mass and thus without dark matter. The direct measurement of galactic rotation velocities by the Gaia satellite of 2013 has opened a way for rethinking the basics of the common model of gravity.

Author Contributions

Bernard Colenbrander: Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing

Willem Hulscher: Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

In section 3 it is stated that the mechanism which influences the value of *G* is unknown. However, a modified theory of particle based gravity, as suggested by the scientist Le Sage in the 18th century, may offer a possibility. It is assumed that throughout the universe small particles are randomly traveling in all directions. These particles may not interact with each other and many of them pass without interactions through cosmic bodies, but some collide with these *elastically* (unlike Le Sage) and so exert a pushing force. The random movement of the particles implies that in free space a body is hit radially symmetric by the particles, which results in no net force. However, two neighboring masses partly shield each other from the particles, and as a result they are pushed towards each other by the net flux of incoming particles. This implies a force according to Newton's law, in which *G* is determined by the effectiveness of the shielding (which depends on the density of the particles and the fraction that collides with the mass of the cosmic body). The nearer the location is to a mass, the larger is the fraction which is shielded, and so the larger is G. This explains why nearby the Earth - or any other mass - *G* is larger than in free space.

Obviously it remains to study what could be these particles and whether their existence could eventually link gravity to quantum theory. Some authors have suggested that the particles could be gravitons, i.e., Mc Dowell, A. C. [4] and Trippe, S. [13].

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