Understanding Galaxy Rotation Curves in terms of Interference of Gravitational Waves

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Abstract:

This paper proposes a new way of understanding the difference between observed and predicted velocities of the stars at the out skirts of spiral galaxies, as follows: The massive stars orbiting around the galactic center give rise to gravitational waves, which propagate towards the out skirts at the speed of light. Since the distances involved are so large that it becomes important to think in terms of superposition and interference of gravitational waves, rather than Newtonian gravity. The waves from different radial distances reach at different times at the out skirts giving rise to interference of gravitational waves. The slope of the resultant gravitational field can be different from the expected inverse square law followed by Newtonian gravity.

Key Words:

Galaxy rotation curves, Gravitational waves, Newtonian gravity

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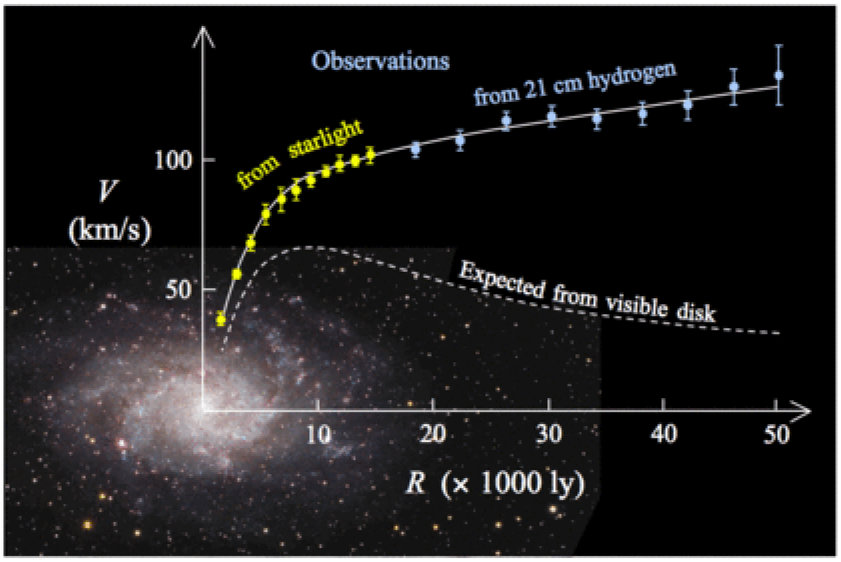
1.1 Introduction to Galaxy rotation curve

(From Wikipedia, the free encyclopedia)



Rotation curve of the typical spiral galaxy M 33 (yellow and blue points with errorbars) and the predicted one from distribution of the visible matter (white line). The discrepancy between the two curves is accounted for by adding a dark matter halo surrounding the galaxy.[1]

The **rotation curve** of a disc galaxy (also called a **velocity curve**) is a plot of the magnitude of the orbital velocities (i.e., the speeds) of visible stars or gas in that galaxy versus their radial distance from that galaxy's centre, typically rendered graphically as a plot.

A general feature of the galaxy rotation curves that have been obtained through measurement to date is that the orbital speed of stars and gas is rising or almost constant as far from the galactic centre as it can be measured: that is, stars are observed to revolve around the centre of the galaxy at increasing or the same speed over a large range of distances from the centre of the galaxy. If disc galaxies have mass distributions similar to the observed distributions of stars and gas then, the orbital speed would always decline at increasing distances in the same way as do other systems with most of their mass in the centre, such as the Solar System or the moons of Jupiter.

The rotation curves of spiral galaxies are also known to be asymmetric. The observational data from each side of a galaxy are generally averaged. Rotation curve asymmetry appears to be normal rather than exceptional.[2]

The **galaxy rotation problem** is the discrepancy between observed galaxy rotation curves and the theoretical prediction, assuming a centrally dominated mass associated with the observed luminous material. When mass profiles of galaxies are calculated from the luminosity profiles and mass-to-light ratios in the stellar disks, then they do not match with the masses derived from the observed rotation curves and the law of gravity. This discrepancy can be accounted for by postulating a large amount of dark matter that permeates the galaxy and extends into the galaxy's halo.

Though dark matter is by far the most accepted explanation for the resolution to the galaxy rotation problem, other proposals have been offered with varying degrees of success. Of the possible alternatives, the most notable is Modified Newtonian Dynamics (MOND), which involves modifying the laws of gravity.[3]

1.2 History and description of the galaxy rotation problem

Vera (Cooper) Rubin (born July 23, 1928) is an American astronomer who pioneered work on galaxy rotation curves. She uncovered what we call "Dark Matter".

In 1932, Jan Hendrik Oort became the first to report measurements that the stars in the Solar neighborhood moved faster than expected when a mass distribution based upon visible matter was assumed, but this measurement was later determined to be essentially erroneous.[4] In 1939, Horace Babcock reported in his PhD thesis measurements of the rotation curve for Andromeda which suggested that the mass-to-luminosity ratio increases radially.[5] He attributed it to either absorption of light within the galaxy or modified dynamics in the outer portions of the spiral and not to any form of missing matter. In 1959, Louise Volders demonstrated that spiral galaxy M33 does not spin as expected according to Keplerian dynamics.[6] In the late 1960s and early 1970s, Vera Rubin, an astronomer at the Department of Terrestrial Magnetism at the Carnegie Institution of Washington worked with a new sensitive spectrograph that could measure the velocity curve of edge-on spiral galaxies to a greater degree of accuracy than had ever before been achieved.[7] Together with fellow staff-member Kent Ford, Rubin announced at a 1975 meeting of the American Astronomical Society the discovery that most stars in spiral galaxies orbit at roughly the same speed,[8] and that this implied that galaxy masses grow approximately linearly with radius well beyond the location of most of the stars (the galactic bulge). Rubin presented her results in an influential paper in 1980.[9] These were the first robust results to suggest that either Newtonian gravity does not apply universally or that, conservatively, upwards of 50% of the mass of galaxies was contained in the relatively dark galactic halo. Although initially met with skepticism, Rubin's results have been confirmed over the subsequent decades.[10]

Based on Newtonian mechanics and assuming, as was originally thought, that most of the mass of the galaxy had to be in the galactic bulge near the center, matter (such as stars and gas) in the disk portion of a spiral should orbit the center of the galaxy similar to the way in which planets in the solar system orbit the Sun, i.e. where the average orbital speed of an object at a specified distance away from the majority of the mass distribution would decrease inversely with the square root of the radius of the orbit (the dashed line in Fig. 1).

Observations of the rotation curve of spirals, however, do not bear this out. Rather, the curves do not decrease in the expected inverse square root relationship but are "flat", i.e. outside of the central bulge the speed is nearly a constant (the solid line in Fig. 1). It is also observed that galaxies with a uniform distribution of luminous matter have a rotation curve that slopes up from the center to the edge, and most low-surface-brightness galaxies (LSB galaxies) rotate with a rotation curve that slopes up from the center, indicating little core bulge.

The rotation curves can be explained if there is a substantial amount of matter permeating the galaxy that is not emitting light in the mass-to-light ratio of the central bulge. The material responsible for the extra mass was dubbed, "dark matter", the existence of which was first posited in the 1930s by Jan Oort in his measurements of the Oort constants and Fritz Zwicky in his studies of the masses of galaxy clusters, though these proposals were left unexplored until after Rubin's work was accepted as correct. The existence of non-baryonic cold dark matter (CDM) is today a major feature of the Lambda-CDM model that describes the cosmology of the universe.

1.3 Further investigations

The rotational dynamics of galaxies are, in fact, extremely well characterized by their position on the Tully–Fisher relation, which shows that for spiral galaxies the rotational velocity is uniquely related to its total luminosity with essentially no scatter. A consistent way to predict the rotational velocity of a spiral galaxy is to measure its bolometric luminosity and then extrapolate its rotation curve from its location on the Tully–Fisher diagram. Likewise, knowing the rotational velocity of a spiral galaxy is an excellent indication of its luminosity. Thus the amplitude of the galaxy rotation curve is related to the galaxy's visible mass.[14]

While precise fitting bulge, disk, and halo density profiles is a rather complicated process, it is straightforward to model the observables of rotating galaxies through this relationship.[15] So, while state-of-the-art cosmological and galaxy formation simulations of dark matter with normal baryonic matter included can be matched to galaxy observations, there is not yet any straightforward explanation as to why the scaling relationship exists as observed.[16][17] Additionally, detailed investigations of the rotation curves of low-surface-brightness galaxies (LSB galaxies) in the 1990s[18] and of their position on the Tully–Fisher relation[19] showed that LSB galaxies had to have dark matter haloes that are more extended and less dense than those of HSB galaxies and thus surface brightness is related to the halo properties.

Such dark-matter-dominated dwarf galaxies may hold the key to solving the dwarf galaxy problem of structure formation.

Very importantly, the analysis of the inner parts of low and high surface brightness galaxies showed that the shape of the rotation curves in the centre of dark-matter dominated systems, indicated a profile that differed from the NFW spatial mass distribution profile.[20] This so-called cuspy halo problem is a persistent problem for the standard cold dark matter theory. Simulations involving the feedback of stellar energy into the interstellar medium in order to alter the predicted dark matter distribution in the innermost regions of galaxies are frequently invoked in this context.[21]

1.4 Alternatives to dark matter

There have been a number of attempts to solve the problem of galaxy rotation curves by modifying gravity without invoking dark matter. One of the most discussed is Modified Newtonian Dynamics (MOND), originally proposed by Mordehai Milgrom in 1983, which modifies the Newtonian force law at low accelerations to enhance the effective gravitational attraction. MOND has had a considerable amount of success in predicting the rotation curves of low-surface-brightness galaxies,[22] the so-called baryonic Tully–Fisher relation,[23] and the velocity dispersions of the small satellite galaxies of the Local Group.[24] These results are surprising in the context of dark matter, which does not predict the same things as MOND without considerable fine-tuning.

MOND is not a relativistic theory, although relativistic theories which reduce to MOND have been proposed, such as tensor–vector–scalar gravity,[3][25] and scalar–

tensor–vector gravity (STVG), of John Moffat and the f(R) theory of Capozziello and De Laurentis.[26]

2. Proposed new way of understanding the galaxy rotation problem:

In this paper we propose a new way of understanding the difference between observed and predicted velocities of the stars at the out skirts of spiral galaxies, as follows: The massive stars orbiting around the galactic center give rise to gravitational waves, which propagate towards the out skirts at the speed of light. Since the distances involved are so large that it becomes important to think in terms of superposition and interference of gravitational waves, rather than Newtonian gravity. The waves from different radial distances reach at different times at the out skirts giving rise to interference of gravitational waves. The slope of the resultant gravitational field can be different from the expected inverse square law followed by Newtonian gravity, as shown in the following figure:

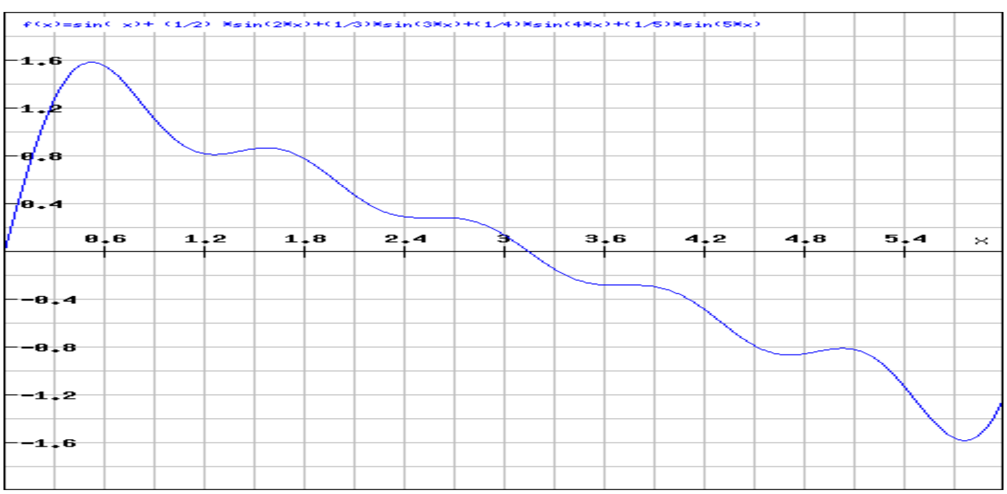


Fig. 2.1: An example of superposition of many gravitational-waves: X-axis showing radial-distance from the center, and Y-axis showing sum of amplitudes of the waves: sin (x) + (1/2) sin (2*x) + (1/3) sin (3*x) +(1/4) sin (4*x) + (1/5) sin (5*x), giving rise to a slope different from the slope $G M / r^2$.

Conclusion:

This paper qualitatively proposed a new way of understanding the observed galaxy rotation curves; in terms of superposition of many gravitational waves emitted by different stars orbiting around the galactic center. Scientists equipped with telescopes, computers, knowledge and motivation can do the further work .

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