Rotation Curves of Spiral Galaxies May Not Reflect Orbiting Bodies

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Abstract

The rotation curves of spiral galaxies usually display near-constant velocities in their outer regions. This is contrary to an expected continuing decline in the velocities moving away from the galaxies' centers. The behavior prompted astrophysicists to declare that dark matter must exist and enclose these galaxies to hold the velocities constant. The centrifugal accelerations that the velocities would produce if the bodies were in orbit are small. They imply that the gravitational accelerations toward the centers of the galaxies on the bodies are also small relative to other orbital systems (e.g., the solar system). The accelerations may not be strong enough to hold the bodies in orbits about the galactic center. Consequently, the bodies may not be in orbit around the galactic centers, but moving away from them. That would allow explanations of flat rotation curves without introducing dark matter or altering gravity. However, due to the radii of the orbits (kilo-parsecs) and the assumed orbital velocities of the bodies (hundreds of km/s), the bodies would move only an infinitesimal distance of the length of their presumed orbital paths over many human generations. This makes verification that the bodies are actually in orbit virtually impossible.

Rotation curves are measurements of the orbital velocities of bodies (many times planets or stars) in orbital systems plotted as a function of the bodies' distances from the centers of the systems [1]. The orbital velocity of a body combined with the body's orbital radius generates a radial acceleration that counters the acceleration due to gravity pulling the body toward the center of the system, keeping the body in its orbit. The expression of this so-called centrifugal acceleration is

$$a_c = \frac{v^2}{r}, \quad (1)$$

where a_c is the acceleration, v is the orbital velocity, and r is the orbital radius. Since the gravitational acceleration a body experiences is given by

$$a_g = \frac{GM}{r^2}, \quad (2)$$

with a_g being the gravitational acceleration, G, the universal gravitational constant, M, the mass contained inside the body's orbit, and r, again, the orbital radius; if M is essentially constant for a system, the gravitational acceleration declines inversely with the square of the orbital radius. For bodies in orbit, the magnitude of the gravitational acceleration is equal to that of the centrifugal acceleration, so the orbital velocity is

$$v = \sqrt{\frac{GM}{r}}. \quad (3)$$

The variables in this equation determine the shape of the rotation curve. When M is near constant, the velocity in equation (3) becomes a function of the inverse of the square root of its orbital radius. The velocity gets smaller as the body lies farther away from the system's center, as seen in the rotation curve of the Solar System in Figure 1.

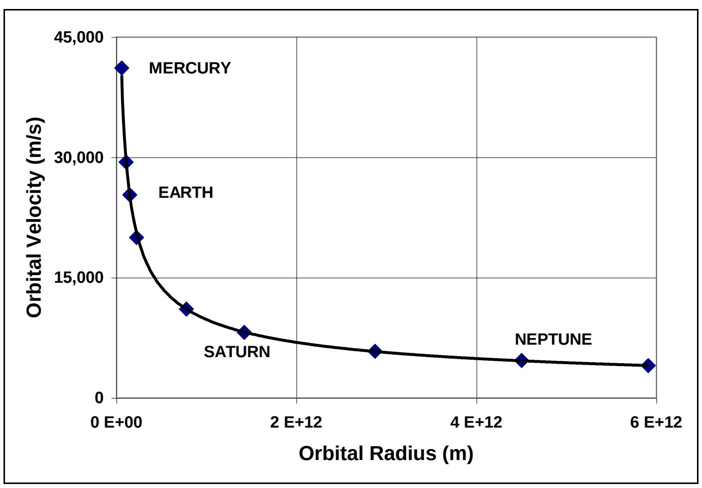

Figure 1: Solar System Rotation curve

The gravitational accelerations represented by this rotation curve range from 4 x 10^{-2} m/s^2 for Mercury, to 4 x 10^{-6} m/s^2 for Pluto. Compared to the 9.8 m/s^2 gravitational acceleration at the surface of the Earth, these accelerations are small, but they are apparently adequate to hold the Solar System together.

Astronomers became aware of the rotation of spiral galaxy in the early twentieth century. They were generating rotation curves for these galaxies by the 1920s [2]. Initially, astronomers believed that the orbital velocities of the rotating bodies in these galaxies behaved in accordance with Newton's laws and asymptotically declined with distance from the center of the galaxy, similar to Figure 1. However, in the 1960s astronomers began to discover that the rotation curves of the spiral galaxies did not behave in a Newtonian way at all [2]. Contrary to the expected exponential decline in velocity as the orbital radius increases, orbital velocities in rotation curves of spiral galaxies increased linearly as the orbital radius increased, and eventually flattened out similar to the rotation curve of the NGC 3198 galaxy shown in Figure 2 [3, 4, 5].

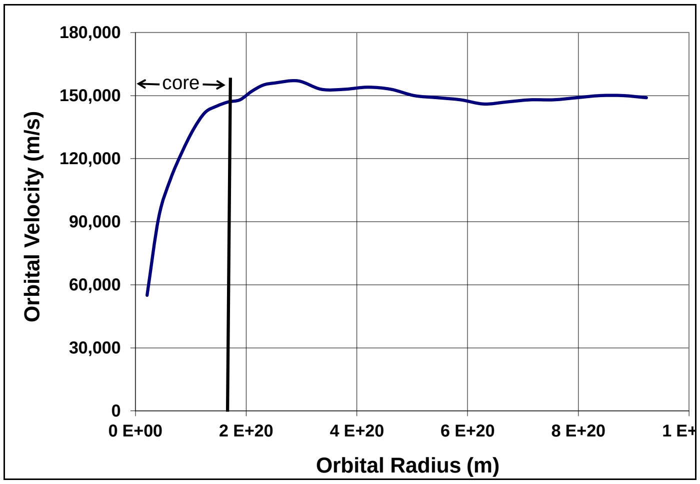

Figure 2: Rotation curve of Galaxy NGC 3198

The initial climb in velocity seen in Figure 2 is the result of measuring the rotational velocity along the radius of a massive core at the center of the galaxy [1]. The core behaves as a contiguous mass, so that the rotational velocity at any point along its radius is the radial distance of the point from the center of the core, multiplied by the rotational frequency of the core. This behavior of the rotation curve is understood and expected. Beyond the central core, the free bodies (stars, gas clouds, etc.) that appear to be rotating around the core seem to defy gravity. Their rotational velocities are about the same regardless of how far away from the core they reside.

Assuming that the stars in spiral galaxies are in orbit around their cores, scientists began to wonder whether the flat rotation curves represented an example of the law of gravity breaking down [6]. Refusing to believe that gravity works differently in large galaxies than in other physical systems; many astronomers postulated and eventually declared that a substance called dark matter, in addition to the visible matter seen in the galaxies, drove the velocities of the bodies rotating within spiral galaxies [7].

Dark matter supposedly is matter that gives off no light, therefore it is invisible [8]. Astronomers incorporated dark matter into the spiral galaxy model to produce more gravity in galaxies. This provides a mechanism for bodies in the outer regions of the galaxies to achieve higher orbital velocities than if they were driven by the mass of the galaxy's central core, alone [9]. To get the flat curves, astronomers postulate that significantly more dark matter exists in the universe than matter we can actually see. They estimate about five times as more dark matter than visible matter [10].

Proposing dark matter is a convenient way to solve the rotation curve problem. However, to date, we have not found any in the universe [11]. Scientists arguing for its existence claim that dark matter is different from anything we have ever encountered. They believe that we have not detected it yet because we do not really know what we are looking for or how to look for it [12].

It just seems suspicious that something so vital to the workings of the universe on a relatively large scale is so hard to find. Perhaps there is another explanation for the flat rotation curves. One that is consistent with what we see in galaxies and works without creating elusive exotic new stuff or changing universal physical laws. The key to understanding and explaining the flat rotation curves of spiral galaxies may lie in acknowledging and appreciating the scale of these entities.

Most galactic rotation curves display orbital radius in units of kilo-parsecs (kpc). A parsec is an astronomical unit that is roughly 3×10^{16} meters, so a kilo-parsec is 3×10^{19} meters. The flat portions of the rotation curves usually extend from about 10 kpc out to as many as 50 kpc [4]. Velocities for these curves tend to range from 100 km/s up to around 300 km/s. Assuming the bodies are in orbit, using 10 kpc to 50 kpc as the range of orbital radii of the rotating bodies in the galaxies, the centrifugal accelerations experienced by these bodies at the observed velocities are on the order of 10^{-11} m/s^2.

Compared to the acceleration the Sun exerts on Pluto of about 4×10^{-6} m/s^2, the gravity the spiral galaxies apparently exert on their rotating bodies is 100,000 times smaller. The object orbiting the sun whose orbit takes it farther from the sun than any other object observed, travels about 2,000 AU or 3×10^{14} meters away from the sun before turning back [13]. The strength of the Sun's gravitational acceleration on this object at its most distant point is on the order of 10^{-8} m/s^2, still 1,000 times stronger than the spiral galaxy rotation curve accelerations. This revelation raises an interesting question. Can a gravitational acceleration of 10^{-11} m/s^2 hold these bodies in orbit? Is the gravity of the spiral galaxies actually holding the bodies moving in them in orbit?

The assumption was made that, because the bodies appear to be moving, they must be in orbit around the center of the galaxy. What seems an equally plausible assumption, given the information about the rotation curves, is that because the rotation curves for spiral galaxies tend to be flat out beyond a few kilo-parsecs, the bodies (stars, gases, etc.) contained within a galaxy are not in orbit around its center. In fact, because the bodies beyond the core of a galaxy seem to all have about the same velocity; it appears these bodies are all emanating from the core of the galaxy.

The rotating core flings the bodies out of it with radial velocities that are about equal and all greater than the escape velocity for the core mass. Since the core is rotating, the bodies also come out with a velocity component normal to their radial velocity. It is about equal to the angular velocity of the outer edge of the core (see Figure 2). This combination would give all of the bodies the same apparent "orbital" velocity, but none of the bodies would actually be in orbit. They are all moving toward the outer regions of the galaxy and tangent to the core, creating a spiral configuration over time.

There appears to be no way to confirm physically that the bodies moving in spiral galaxies are actually in orbit within the galaxies. A body with a velocity of 300 km/s travels about 10^{16} meters in 1,000 years. Since an orbit of radius 10 kpc (a small galaxy orbit) has a circumference of about 2 x 10^{21} meters, if the body is in orbit, it travels one-thousandth of one percent of the circumference of the orbit or 0.0036 degrees (13 seconds) along the path of the orbit in 1,000 years, which is roughly 30 human generations. That seems too slow to detect with the technology currently available.

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