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A REVIEW ON MILGROM'S MODIFIED NEWTONIAN DYNAMICS IN 1983 AS AN ALTERNATIVE FOR THE DARK MATTER

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ABSTRACT

The spiral galaxies show a constant speed of rotation form their disk to the halo region, violating the Newtonian or the Keplerian motion. This feature is called the flat rotational curve, which seems to require some continuous dark matter distribution proportional to the distance. Some exotic elementary particles such as neutrinos are strong candidates for the dark matter. However, there is an alternative way to explain the flat rotational curve by modifying Newtonian law of gravitation, not introducing any form of dark matter.

KEYWORDS: history and philosophy of science, flat rotational curve, spiral galaxies, modified Newtonian dynamics, dark matter, Kepler motion, philosophy of physics, gravitation

INTRODUCTION

The spiral galaxies show a constant speed of rotation form their disk to the halo region, violating the Newtonian or the Keplerian motion. This feature is called the flat rotational curve, which seems to require some continuous dark matter distribution proportional to the distance. Some exotic elementary particles such as neutrinos are strong candidates for the dark matter. However, there is an alternative way to explain the flat rotational curve by modifying Newtonian law of gravitation, not introducing any form of dark matter.

The Kepler's third law

The flat rotational curve both in the galactic disk and in the halo, region is quite unexpected. For two objects such as the Sun and a planet, it is expected that the planet should follow some characteristics of the Newtonian motion known as the Keplerian motion. While the planet is making a circular motion around the Sun, the planet has an acceleration due to the circular motion, a_c, as follows.

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$$a_c = \frac{v^2}{r}$$

, where v is the speed of the planet around the Sun and r is the distance between them. Recall that the speed of the planet can be further expressed in terms of the circumference of the planet's circular orbit divided by the time of the planet's one circular motion around the Sun, the period of the planet, as follows.

$$v = \frac{2\pi r}{T}$$

, where T is the period of the planet.

According to the Newton's second law of motion, the centrifugal force F_c should be expressed by the acceleration times the mass of a moving object, in this case, the mass of the planet.

$$F_c = ma_c = m\frac{v^2}{r} = \frac{m}{r}(\frac{2\pi r}{T})^2 = \frac{m}{r}\left(\frac{4\pi^2 r^2}{T^2}\right) = \frac{4\pi^2 mr}{T^2}$$

On the other hand, the gravitational force F_G between the Sun and the planet is given by

$$F_G = G\frac{Mm}{r^2}$$

, where G is the gravitational constant, M is the mass of the Sun, m is the mass of the planet, and r is the distance between the Sun and the planet as before.
Now, the gravitation force between the Sun and the planet must be equal to the centrifugal force of the planet as follows.

$$G\frac{Mm}{r^2} = \frac{4\pi^2 mr}{T^2}$$

Rearranging the first and the last terms after cancelling the mass of the planet gives

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

This is the famous Kepler's Third Law, which states that the period of the planet squared is proportional to the distance between the Sun and the planet cubed. This law holds for all the planets around the Sun because the mass of the Sun M is constant for all the planets involved.

The Keplerian motion

One interesting result of the Kepler's Third Law is the Keplerian motion. If we equate the gravitational force with the centrifugal force again. Then,

$$G\frac{Mm}{r^2} = m\frac{v^2}{r}$$

From this we can express v in terms of the distance, $v = \sqrt{\frac{GM}{r}} \sim r^{-\frac{1}{2}}$

In other words, the rotational speed of the planet is inversely proportional to the square root of the distance. This feature is known as the Keplerian motion.

The flat rotational curve is, therefore, a clear violation of the Keplerian motion. However, the constant speed of the rotation in the galactic disk region can be understood in terms of the stellar and interstellar continuous (normal) mass distribution in the disk. In fact, a continuous mass distribution proportional to the distance from the galactic center can easily explain the flat rotational curve in the disk. Unfortunately, however, we cannot expect the stellar and interstellar (normal) mass distribution in the halo region where the stellar populations are clearly not visible in the halo region.

The flat rotational curve in the halo

Nonetheless, some neutral hydrogen atoms are sparsely present in the halo region. They are believed to be some left-over hydrogen atoms in the very early history during a galaxy formation. Given enough time, the hydrogen atoms emit the 21cm lines or the hyperfine structure lines in the radio frequency, which originate from changing the spin value of the orbital electrons around the nucleus. Since we know the original wavelength of the emission, we can determine their moving speed by measuring their Doppler shift of their observed wavelength.

This is how we could obtain the flat rotational curve in the halo region. Almost all spiral galaxies have a constant rotational speed in the halo, extending over the region at least several times larger

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than the size of the galactic disk. According to the Newtonian laws of motion, however, we expect the Keplerian motion in the halo such that the rotational speed is inversely proportional to the square root of the distance from the galactic center. In other words, given enough distance from the center in the outer halo of the galaxy, the rotational speed should rapidly approach zero, practically stopping the movement of the entire hydrogen atoms in the outer halo. Those hydrogen atoms should not be influenced by the galaxies' gravitational force.

The dark matter

One natural way of explaining the flat rotational curve in the galactic disk is to introduce a continuous distribution of stellar and interstellar (normal) matter. Recall that, in the Newtonian dynamics, the rotational speed v in terms of the distance from the galactic center is given by

$$v = \sqrt{\frac{GM}{r}}$$

In the Newtonian dynamics, M is the total mass of the galaxy. But assuming that M has a linear functional dependency on r such that $M = M(r) \sim r$.

Then, v becomes "flat" or independent of r as follows $v = \sqrt{\frac{GM(r)}{r}}$ = constant

Now, in the halo region, one famous way to understand the flat rotational curve is to further introduce some continuous distribution of matter, already practiced in the disk region. But, this time the matter in the halo is invisible or unobservable matter. This is the so-called dark matter which interacts with normal matter only through the gravitational force. Thus, if we include all the dark matter summed over all the region of the flat rotation curve, the total mass of the spiral galaxies is at least several times the visible mass in the galactic disk. At the same time, sine the spiral galaxies are one of the most common types of galaxies in the Universe, the dark matter in the halo can increase the total mass of the entire Universe, thus determining the fate of the universe in the future. Ever since the first suggestion about the dark matter in the sixties, however, almost all major attempts to find the dark matter turned out to be utterly empty handed.

For example, astrophysical compact objects cannot account for the huge amount of the dark matter in the halo. Astrophysical compact objects such as black holes, neutron stars and dark dwarfs etc. are all final products of the stellar evolutions through star burst activities. In other words, they must once have been some visible stellar population before. But all the spiral galaxies show absolutely no signs of such stellar activities in the halo region.

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The only remaining candidates for the dark matter include some exotic elementary particles. One of those elementary particles is neutrino. Although the exact individual masses and the total numbers of the neutrinos are still uncertain, they are practically the only dark matter candidate possibly responsible for the flat rotational curve in the galactic halo. Nonetheless, this kind of the neutrino dark matter hypothesis has some serious problems. Neutrino particles are moving almost at the speed of light and it is not easy to understand why they exist only in the halo but not in the galactic disk where stellar and interstellar normal matter can easily explain the flat rotation curve. For some reason, even if they are confined to exist only in the halo region at the beginning, within an order of a hundred thousand years or so, they can quickly travel and start to reside in the galactic disk region due to their relativistic speed. Currently, there is no obvious reason why those neutrinos are allowed to exist only in the halo region. Nonetheless, they are the strongest dark matter candidate.

The modified Newtonian dynamics

Milgrom (1983) try to modify the Newtonian dynamics to account for the flat rotation curve without assuming any dark matter whatsoever. Recalling that the gravitational force and the centrifugal force again are equal, we have

$$G\frac{Mm}{r^2} = m\frac{v^2}{r}$$

In the above equation, the distance dependency of the Newtonian gravitational force can be modified to make the speed v constant. The Newtonian gravitation states that the force of gravity is inversely proportional to the distance squared. But, in the modified Newtonian dynamics, the force of gravity is inversely proportional to the distance as follows.

$$G\frac{Mm}{r} = m\frac{v^2}{r}$$

Then, r dependency on both sides disappears, and v becomes constant or independent of r, showing the flat rotational curve. But this particular modified gravitation gives diverging potential energy. On top of it, the Newtonian gravitation shows an excellent agreement on the planetary motions in our solar system. On the solar system scale, the Newtonian gravitation of $\frac{1}{r^2}$ dependency may be good enough. Instead, on the galactic scale, the modified gravitation of $\frac{1}{r}$ dependency should be employed. From the scale of the solar system to that of galaxies, a smooth transition of r dependency is required. The Milgrom's modified Newtonian dynamics can achieve this smooth transition without introducing any dark matter.

CONCLUSION

The flat rotational curve of the spiral galaxies seems to require some continuous dark matter distribution proportional to the distance. Many astronomers believe that some exotic elementary particles such as neutrinos are strong candidates for the dark matter. However, there is an alternative way to explain the flat rotational curve by modifying Newtonian law of gravitation, not introducing any form of dark matter.

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