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A New Gravitational Model of Spiral Galaxies Based on Newtonian Mechanics

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Abstract

In the spiral galaxies, including the Milky Way, a flat rotation curve V(r) that does not obey Kepler's law was discovered in the early 1930s and became a great mystery. Initially, this could not be explained correctly by Newtonian mechanics, and a hypothesis was proposed that there was a new, unidentified dark matter that increased the gravity. However, there is still no conclusive evidence, although the indirect studies of cosmic background radiation and gravitational lensing effect support this hypothesis. In this study, I focus on the characteristic spiral shape of galaxies and propose a new gravity model (basic equation) based on Newtonian mechanics. This model predicts the existence of a new centripetal force, the interstellar force T(r), which is different from the conventional gravity in the spiral motion. In the verification, an analytical solution V(r) was derived based on the new basic equation and compared with the observed data. As a result, the new model was successfully verified for the first time, agreeing for the entire region from the bulge edge to the solar system with a difference of about ±5%, including the fluctuation characteristics. It was found that the centripetal force of the disk part forms a new force, "spiral force" by the spiral motion in addition to the conventional gravity, and that these two forces are generated simultaneously in unison. The spiral force is generated by the macroscopic interaction of Universal gravitation between the stars and manifested by the expansion of the scale to the galactic system, and I believe that it represents a new principle for the generation of gravity that does not exist in the conventional concept. I hope that this new gravitational model (gravity theory) will be utilized as a useful tool for the deeper understanding of the spiral galaxies in the universe in the future..

Keywords: *Spiral Galaxies; Newtonian Mechanics; Bulge, Disk; Rotation Curve; Universal Gravitation; Gravitational Principle; Centripetal Force; Interstellar Force; Spiral Force; Dark Matter;*

Introduction

About a century has passed since the discovery of stellar rotation velocities (rotation curves) in the spiral galaxies, including the Milky Way, that do not obey Kepler's law. [1,2] However, from the viewpoint of the discussion on the rotation curve $V(r)$, I believe that the correct explanation and understanding of the discovery from a unified viewpoint have not been obtained. [3–6]

In this study, I proposed a "new gravitational model" focusing on the spiral shape based on Newtonian mechanics in order to solve the problem. In order to explain the complexity and difficulty of this problem, I will first review the history of conventional ideas and solutions, and explain how we have come to the present state of knowledge. Then, the contents of the proposed model will be outlined, and the position, importance, and innovativeness of the solution to this problem will be clarified.

The $V(r)$ characteristics of circular motion are derived from the kinematic force balance condition (basic equation), which is inversely proportional to the square root of the distance r from the galactic center (in accordance with Kepler's law). There was the theory of gravity (basic concept) that the centripetal force balanced with the centrifugal force is only gravity until now. This was also an empirical fact derived from the planetary motions of the solar system, and had become an absolute, common sense truth. However, in the early 1930s, with the improvement of measurement techniques, it was discovered that the stars of spiral galaxies do not follow the characteristics of $V(r)$ obtained from the basic equation, but show almost a flat characteristics. [1] This was a great kinematic mystery and problem. Moreover, the problem is still unsolved even now, more than 90 years later, and exists as "the mystery of the rotation curve" or "the problem of the mass defect". [2,6]

Since this problem could not be explained only by the observed mass data, it was considered to be caused by the lack of mass based on the basic equation.

Therefore, it has been assumed from the beginning that a new type of invisible matter called dark matter (= unknown elementary particles?) is involved. [9] The explanation (hypothesis) that dark matter increases the gravity (mass) seemed to solve the problem for a while. However, although many years have passed since this hypothesis was proposed, dark matter has not been discovered yet. Recently, it has been pointed out that there may be a fundamental problem with this idea of dark matter. [10,11]

In contrast, the new theories such as the modified Newtonian mechanics [12] have been proposed to address this problem. However, the contradictions have been reported in these theories. Furthermore, an attempt was made to determine the mass of the disk by an optical mean alone, regardless of the basic equation of $V(r)$. [13] This attempt is aimed at explaining the flat property of the disk with respect to its mass and at a new understanding. The mass is obtained statistically from the mass/luminance ratio (M/L), which converts the luminance L to the mass M. However, there were the problems with the accuracy of this method and its application to the invisible material. [7,14] There was also an attempt to obtain the analytical solution from a potential theory. Miyamoto and Nagai (MN) model was newly proposed based on the idea that the factor of gravity (mass) increase exists in the disk of the galactic plane. [15] However, the masses and the distributions of the bulge and the disk obtained from this model did not give the flat characteristics for the entire galactic region.

The outer regions of the galactic plane could not be explained, and the existence of dark matter was inferred to be necessary. [9]

Let us now focus on dark matter as the current mainstream model. The purpose of this model is to discover the unknown matter (e.g., elementary particles) with a new mass distribution that increases the gravity based on Kepler's law. From a different point of view, instead of trying to understand the flat characteristics of the observational data itself, it shifts the challenge to the discovery of unidentified dark matter, which is one of the hypotheses. This is mainly owing to the fact that for a long time the observed characteristics have not been well explained in kinetic terms. As explained in Section 2 below, dark matter is basically configured to fit the observational data. There is a degree of freedom in its properties and mass distribution, and no problem arises at the introduction stage. Dark matter has now been narrowed down to its properties and location, and its coverage has been extended to the halo region surrounding the spiral galaxies. This is called the dark halo.

The dark halo is supported as one of the factors that increase the gravity, as shown in the paper on the gravitational lensing effect [16]. Furthermore, the observations suggest that about 95% of the universe is composed of dark energy and dark matter, which forms the background for understanding the universe as a whole. Based on these circumstances, the Milky Way is considered to be composed of three major components: a bulge containing the black holes and the central core, a spiral disk surrounding the bulge, and a huge dark halo (dark matter) enveloping the entire galaxy. [8,17]

As mentioned earlier, the switch in the target of the problem (issue) has led to the misunderstanding that the mystery of the $V(r)$ characteristics has been solved. Nowadays, as can be seen in research publications, the direction of the issue has almost shifted to the search for dark matter worldwide, and observations, measurements, and theoretical developments toward its discovery are being actively carried out. [10,18]

In this way, it can be said that the research flow has been basically narrowed down to the search for and discovery of dark matter, owing to the absolute existence of Kepler's law (gravity theory) based on experience and the observation results that are considered to be caused by the increase in gravity.

However, if we face the fact that Kepler's law does not hold, there is a possibility that a "new theory of gravity" may exist, and there is a risk that dark matter will not be discovered. [11)]

The aim of this study is quite different from the previous attempts to discover dark matter. I focus on the observational data of $V(r)$, which is the origin of the mystery, and aim to derive the new basic equation (the balancing condition) that can be explained in terms of the kinetic theory. This will simultaneously lead to the search for a new theory of gravity in Newtonian mechanics. Unlike the solar system, the spiral galaxies have a characteristic spiral shape and motion. This feature is considered to be a necessary condition for the stable rotational motion of stars in the spiral galaxies. By clarifying this point kinematically, I believe that the new physical phenomena (generation of force by the spiral motion) will be found, which have not been predicted so far.

In Section 2, the new basic equation is predicted kinematically and geometrically from this point of view, and the new gravity model for the spiral motion is proposed. In Section 3, the analytical solution $V(r)$ of the rotation curve is derived from this basic equation, and is compared and verified with the observed data. As a result, the validity of the model is confirmed, and at the same time, a new force, which does not exist in the conventional concept of gravity, is found. I believe that this force is caused by a "new principle (theory) of the generation of gravity" in Newtonian mechanics. [11)]

In this study, while verifying the new gravity model as described above, $V(r)$ characteristics are analyzed and evaluated to physically support the model. And many important findings are obtained as well as solving the mystery of the spiral galaxies.

2. NEW GRAVITY MODEL

In this Section 2, I propose a new gravity model based on Newtonian mechanics, focusing on the spiral motion (shape) by the observational data of the Milky Way.

2.1 Approach of model

According to the observational data of the Milky Way, the stars including our solar system are in the stable circular motion while maintaining the spiral shape as a whole. When analyzing this motion, there are two types in the features. One is the circular motion of stars around the galactic center, and the other is the spiral motion of stars (group of stars) that is simultaneous with the circular motion. The main feature of the new model is that these two types of motions are considered separately. Therefore, the motion region of the new model basically covers only the interior of the two-dimensional spiral arms that form a stellar population in the spiral galaxy. In contrast, the conventional model covers the three-dimensional space of the entire spiral galaxy (in particular, it does not distinguish between the interior and the exterior of the spiral arms), which is significantly different from the new model.

2.1.1 Conventional model

Figure 1 shows the conventional model of circular motion. It is also the circular motion shown by the planets in our solar system.

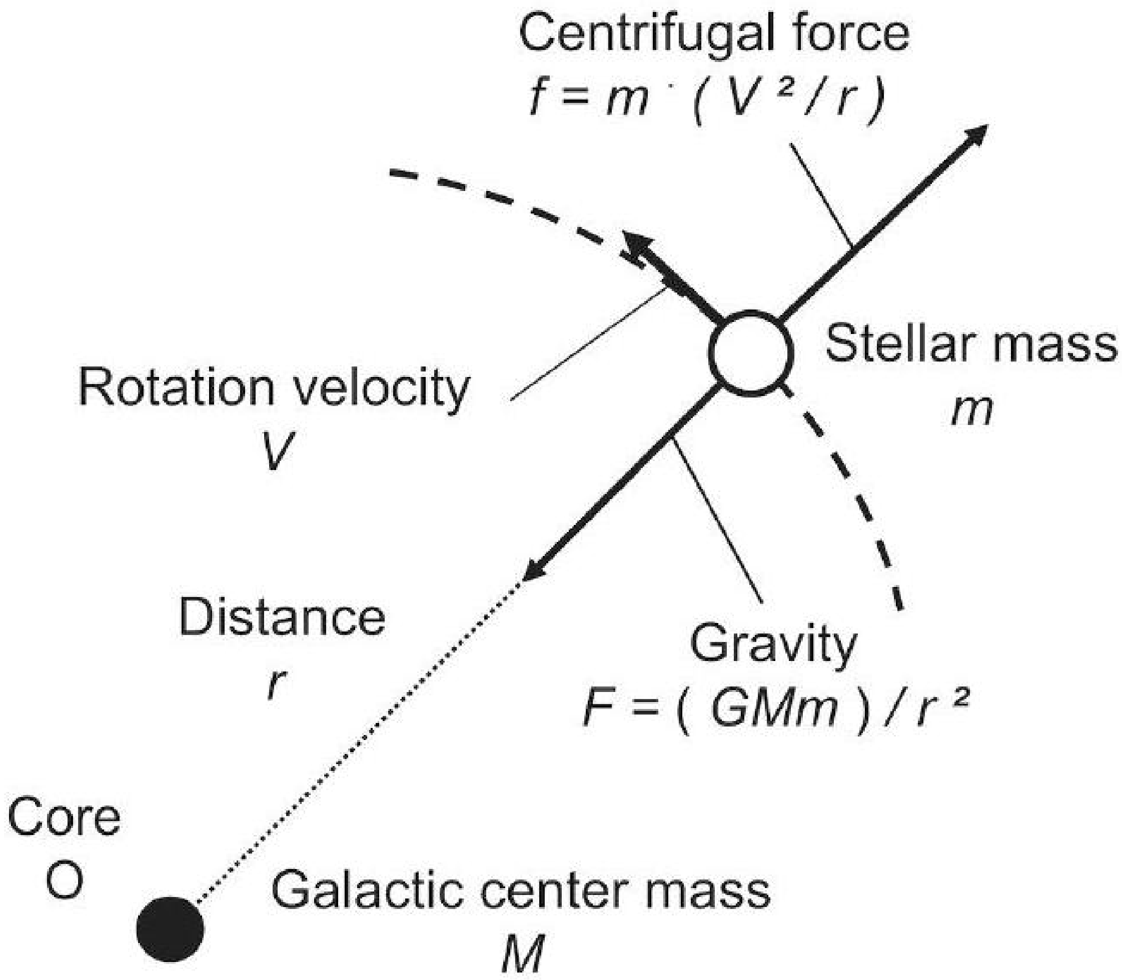

Figure 1. Conventional model of circular motion

This is a vector diagram showing the equilibrium condition between the gravitational force F by the central mass M and the centrifugal force f with respect to the stellar mass m. The basic equation is given by the equation (1),
which is conventionally considered absolute. [8]

$$(GMm)/r^2 = m \cdot (V^2/r) \qquad (1)$$

Similar to the planetary motions in the solar system, the region of motion covers the three-dimensional space where the gravity F acts. In contrast, the right-hand side of equation (1) is the centrifugal force f, which indicates the two-dimensional balancing condition with respect to the star.

In this basic equation, the existence and necessity of another spiral shape (motion) exhibited by the stellar population has not been specifically considered.

This is because it was thought that even if one circular motion exhibits the characteristics of two motions, they are kinematically identical.

The observation data of spiral shapes have been discussed using various parameters based on the logarithmic spiral shape, including the measurement method. However, there is no particular attempt to reconsider kinematically the features of the spiral shape in relation to the $V(r)$ characteristics. [19] Equation (1) has been used as the kinematic balance condition for the stars as well as the planets in the solar system. From this equation, the $V(r)$ characteristics of star moving in a circle are given by the following equation (2). In most cases, the conventional models consider this equation (2) as a starting point (precondition).

$$V(r) = (GM/r)^{1/2} \quad (2)$$

However, the $V(r)$ data observed in the spiral galaxies did not decrease with increasing the distance r, but showed almost the flat characteristics. The disk mass M_d at this time means the real measurable mass. However, the flat characteristics could not be obtained even when the M_d was taken into account to increase with the distance r. To explain this discrepancy, the balancing condition in equation (1) itself was not questioned, and the mass M in equation (2) was considered to increase. The kinematic acceptance of this idea is a major difference from the new model, which will be discussed later in Section 2.1.2.

The mass M is given as the center-of-mass, which is the total mass M_t ($= M_b + M_d$) of the bulge mass $M_0 (= M_b)$ at the center of the spiral galaxy and the disk mass M_d surrounding it. The two masses were predicted as the real masses by the conventional methods, but they did not show any increase in the missing mass. Therefore, the mainstream model assumes the existence of unidentified "dark matter" to explain the cause of the mass increase. [6] This model explains the $V(r)$ characteristics by adding the dark matter mass $M_m(r)$ to the conventional total mass $M_t (= M)$ in order to increase the gravity. However, the distribution of $M_m(r)$ can satisfy the necessary conditions for fitting the observed data, but not sufficient if the balancing condition in equation (1) is problematic. Therefore, in order to verify this model, the existence of dark matter must first be discovered by the observation, and then the mass distribution $M_m(r)$ must be confirmed. However, no evidence of the existence of dark matter has been found for a long period of time up to the present day.

2.1.2 Construction of new model

In contrast, the new model focuses on the spiral shapes (motions) of the galaxies, which have not been specifically treated in the conventional model.

Considering the necessity of the characteristic spiral shape and structure, the balance model presented in equation (1) was reconsidered from the kinematic point of view. The following is the idea, in which the physical phenomena (a new gravity model) are considered on the basis of Newtonian mechanics from the present situation of the spiral galaxies.

Apart from the gravity generated by the center-of-mass of the disk, the stars interact with each other by Universal gravitation between the neighboring stars.

Usually, the collisions are likely to occur when the stars are grouped together, but the spiral galaxies maintain their spiral shape as a whole (rigid body motion) and have the stable rotational motion. In other words, the stars have acquired the motion that maintains a constant spacing between the stars in spiral motion, and have stabilized. It is inferred that a new force (macroscopic force caused by the interaction between the stars) is generated inside the grouped spiral arms to maintain the stable motion, in addition to the gravity (centripetal force) that maintains the circular motion.

The new force in the spiral motion is considered to be the driving force that stabilizes the circular motion of the stars and generates the force along the shape of the spiral (tangential force). This macroscopic force is hereafter referred to as the " interstellar force T ". The force T generated on the disk forms the new circular orbit and rotational velocity because the circular motion simultaneously behaves as the spiral motion. Therefore, the interstellar force T is inferred to have the characteristics of both the gravity F of the disk and the new force.

Furthermore, the characteristic of this force T is that, although it includes the gravity F of the disk, the other new force depends basically on the interstellar distances inside the spiral arms and is not directly affected to the decay with respect to the distance r (scale expansion) from the center of the galaxy.

Therefore, among the interstellar forces T, the new force is expected to affect the flattening of the $V(r)$ characteristics.

Figure 2 is the diagram of the "new gravity model of the spiral motion" proposed based on the above ideas. The average spiral arm shape, which is called the logarithmic spiral shape, is represented by a single dashed line (the center line), and the balancing condition of the interstellar force T is shown by the vector diagram.

The interstellar force T is generated in the tangential direction of the spiral shape shown by the dashed line in Figure 2, and acts as a macroscopic force on the stars in the spiral arms.

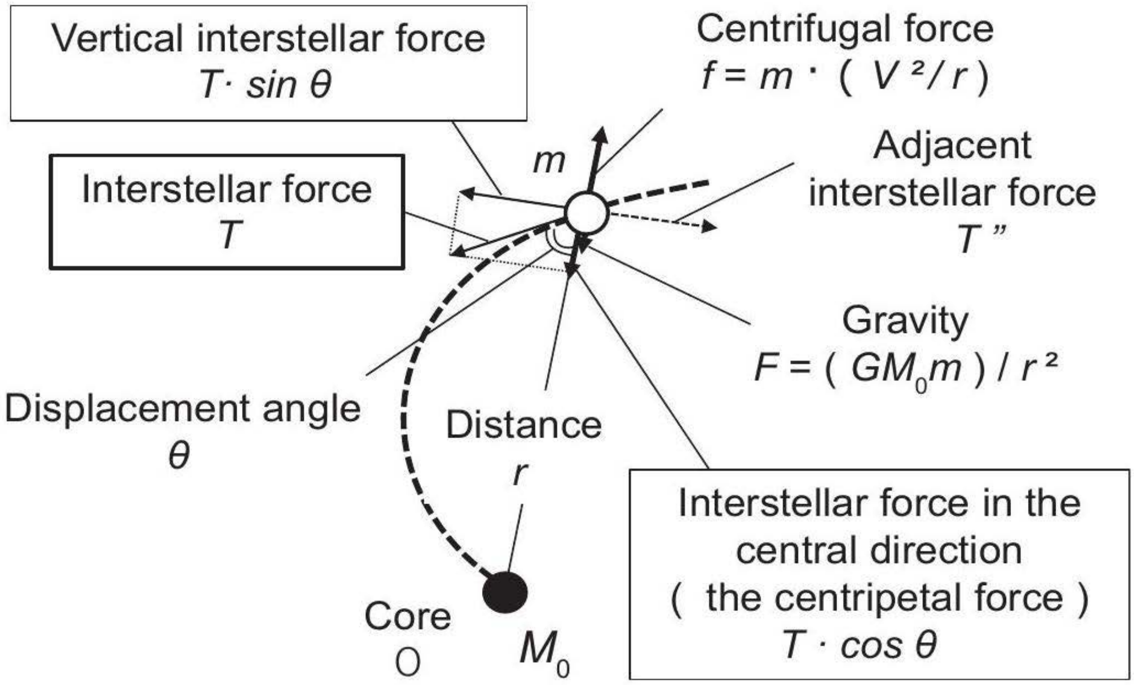

Figure 2. New gravity model of spiral motion

The displacement angle θ represents the angle of shift from the vector of the interstellar force T to the center direction, and is related to the pitch $\Delta\Phi$, which indicates the logarithmic spiral shape parameter, by $\theta + \Delta\Phi = 90°$. The relation of the logarithmic spiral is discussed in equation (7) of Section 2.2.

This force T can be geometrically divided into two vector components based on its function, as shown in Figure 2. One is the centripetal force, which is necessary for the stable circular motion of the grouped stars and is added to the gravity of the disk as a new force. This force is the component toward the center of the spiral galaxy and is given by $T \cdot \cos\theta$. The other force, which is necessary to maintain the macroscopic spiral motion (shape) as a whole, is the binding force that forms a new orbit and connects the neighboring stellar population. This force is the component orthogonal to the generating direction of gravity, and is given by $T \cdot \sin\theta$.

Now let consider the external case of the spiral arms, in which the interstellar force T does not act. Since there is no interaction between the stars, the conventional gravity model is basically valid as in the case of single motion.

However, since the stars are not affected by the interstellar force T and thus cannot acquire the new orbits or the rotational velocities, the motion is considered to be irregular (i.e., they are entangled in the neighboring spiral arms). As a result, it is inferred that the star is in a transient state of motion outside the spiral arms.

Consequently, the stars cannot or will not exist in the outer regions, so they will move to the more stable inner regions of the spiral arms or the bulge. From this point of view, the region of stellar motion in the new model is basically limited to the interior of the spiral arms in two-dimensional space (the galactic plane), as described in the first discussion. It can be inferred that most of the previous observational data obtained in the past have targeted (selected) the interior of the spiral arms, where there are many stars. The reasons for this are that the stellar data observed by the conventional model is considered to be unaffected by the positional relationship with the spiral arms, and that there were few stars to be measured outside of the spiral arms. The observational data showing this can be found in the paper by Rubin et al. [14)]

From the above, the new gravity model for the spiral galaxies has three main features. (1) The two-dimensional macroscopic interstellar force component $(T \cdot \cos\theta)$, which is a new concept, exists as the centripetal force balanced with the centrifugal force f. (2) There exists the interstellar force component $(T \cdot \sin\theta)$ that binds the adjacent stellar populations together to form the spiral motion (rigid body motion). (3) The stellar motion region is interior of the spiral arms in the galactic plane, which is different from the conventional model.

From the first feature (1), the new gravity model (basic equation) of equation (3) can be obtained kinematically, in which the centrifugal force f is balanced with the two forces, namely, the conventional gravity F of the bulge plus the centripetal force $T \cdot \cos\theta$ of the disk part.

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