Remarkable Features of Spiral Galaxies Revealed by a New Gravity Model

Yutaka Akiba
Astronomy researcher, member of the Physical Society of Japan
Email address: fujigarden@384.jp

Abstract

In order to solve the problem of flattening of the rotation curve $V(r)$, this research has proposed a "Spiral Gravity Model (SGM)" that focuses on the geometric shape of the Milky Way Galaxy and has verified its effectiveness.

By using the SGM, this paper solves the problems of increasing variation and characteristic velocity fluctuations seen in the observational data so far, while at the same time elucidate the actual state of the movement inside the spiral arms. Data analysis showed that problems such as variation arise from differences in centripetal force, which are the cause of significant differences, and that by distinguishing between these, it is possible to reduce measurement errors to a few percent of statistical accuracy. In relation to this, I propose a "Velocity Fluctuation Model (VFM)" that deals with local gravity, and for the first time provide theoretical support for the generation mechanism. In principle, this VFM is the same as the SGM, and a new centripetal force (gravity) is generated by the curved structure of the spiral arms (distortion of internal gravity) without an increase in mass. This is a discovery that would be completely unimaginable based on Kepler's law, and I believe that it once again shows a new generation principle for gravity. By applying this VFM to the solar system of the Milky Way, a theoretical basis was provided for proper motion treated with three-dimensional velocity parameters ($U0,\ V0,\ W0$). The results clarified the true nature of proper motion in the $V(r)$ characteristic, and predicted the existence of a new form of motion (multiple helical structures) inside the spiral arms. With the improvement of measurement accuracy, future verification is highly anticipated.

From the above, by adding the local model VFM to the basic model SGM, many important findings and predictions have been obtained. I believe that by utilizing these models as analytical tools in the future, the cosmology of spiral galaxies will be significantly reconsidered and our understanding will advance dramatically.

Keywords : spiral galaxy, rotation curve, Newtonian mechanics, Kepler's law, spiral arm, spiral force, geometric shape, centripetal force, proper motion, statistical accuracy, multiple helical structure, dark matter

1. Introduction

Nearly a century has passed since the discovery of flat rotation curves $V(r)$ that do not follow Kepler's law in spiral galaxies, including the Milky Way. [1),2)] At first, it was a great mystery, as it could not be explained well by Newtonian mechanics. Currently, models that assume the existence of dark matter (unknown invisible matter: elementary particles, etc.) that enhances gravity are mainstream. However, conclusive evidence for the existence of dark matter has not yet been found. [3)~6)] The basic idea of the conventional model is to match the $V(r)$ characteristics to the flattening characteristics of the observational data, as seen in modified Newtonian dynamics (MOND), etc., [7), 8), 9)] which of course meets the necessary condition, but is not sufficient. However, supported by indirect evidence such as the gravitational lensing effect [10)] and the cosmic microwave background radiation [11)], exploration and research of dark matter is being actively conducted worldwide.

On the other hand, there are also views that strongly doubt this current situation. [4)] Furthermore, many questions and problems remain unsolved regarding the basic observational data and measurement methods of spiral galaxies. One of these is the debate regarding the geometric shape data of spiral galaxies. The mystery of the rotation curve could not be directly solved by Newtonian mechanics, so the focus has been on fitting it to the observational data of $V(r)$, as seen in the dark matter model.

For this reason, theoretical support for the spiral shape (motion), which can be said to be the greatest characteristic of galaxies, has not progressed [12)] and is insufficient. There has been little progress in the essential discussion (proposition of sufficient conditions) of why galaxies form and maintain geometric and macroscopic spiral motion, or why they have no choice but to do so. This is thought to be because Kepler's law, based on the empirical rules of the solar system, have existed as absolute truth. When looking at galaxies from an objective and broad perspective, the scale of the universe is significantly different from that of the solar system in terms of space and time, so the principles and laws of gravity may differ from previous ideas. There is a necessity for the characteristic spiral shape and motion to exist, and as a result, it is thought that the $V(r)$ characteristic (flattening characteristic) exists. However, most models that use dark matter start from a rotation curve based on Kepler's law and are unable to fully explain it.

The flattening property is certainly caused by an increase of gravity (centripetal force) in the balance of forces. To explain this, it is said that there is a shortage of visible matter and that invisible matter (dark matter) exists to compensate for this. However, as mentioned above, this is based on necessary conditions and is not a correct judgment. There are two major problems with this. First, the centripetal force of gravity, if we consider its possibility, does not necessarily occur or increase only with mass. Second, invisible dark matter does not necessarily exist. Therefore, many of the features of spiral galaxies seen in the observational data described later (Chapter 3) are insufficiently interpreted or cannot be interpreted at all, and as a result, we are in a situation where we have to rely on indirect or empirical evidence. [13] I think that a unified and broad approach (theory) is needed to discuss what is meant by the phenomenon that a group of stars does not lose its shape even when it is caught in a spiral motion.

In this study, I have taken these points into consideration from the beginning and have proposed and verified a new "spiral gravity model (SGM)" for spiral galaxies. [14] As a result, I have succeeded in theoretically supporting the flattening properties of $V(r)$ for the first time based on Newtonian mechanics, which has been difficult to solve until now. In this model, I have discovered that even when there is a shortage of visible matter, a new force (spiral force) is generated instead by the macroscopic motion (structure) of the spiral arms. This is obtained from the force balance condition (gravity equation), which is a precursor to Kepler's law. The analytical solution $V(r)$ is an approach that is completely opposite to the conventional model that assumes necessary conditions from the beginning, and is derived from the sufficient conditions described above. For this reason, highly accurate observational data was required to rigorously verify the obtained analytical solution $V(r)$.

Another problem is the large measurement variability seen in the average value and deviation of the $V(r)$ characteristics, and we believe that the observational data necessary for verification is not necessarily available. Even now, there is unnatural and incomprehensible observational data[13] that cannot be explained by conventional models. This has been thought to be due to limitations (problems) in measurement accuracy. For example, in the case of the $V(r)$ characteristics of the Milky Way, when the average value and deviation are displayed, there are cases where the fluctuation in the average value at a nearby distance r is larger than the deviation. In particular, when the distance r is about 8 kpc or more, the fluctuation in the average value tends to become even larger. In addition, many phenomena have been pointed out, such as the change in the velocity fluctuation of the $V(r)$ characteristics depending on how the distance r in the measurement direction is taken. [13),15] These are also observed as proper motions (non-circular motions associated with the rotation curve $V(r)$), but even now, with the advances in measurement technology, there is no unified view on why they occur. [12), 16) - 18] Currently, it is empirically recognized that different results can be obtained depending on the method of obtaining observational data (for example, when the location or position is different even if the distance r from the center of the galaxy is the same). However, since the cause of this is unknown, it is treated as an issue that is difficult to measure.

Among them, a particularly different point was made in a paper by Vera Rubin et al.[15] published in 1978, about half a century ago. In this paper, it is argued that the fluctuation characteristics seen in the rotation curve are not statistical variations (errors), but velocity variations with significant differences. As the basis for this, a measurement method was used in which the distance r from the center of the galaxy was fixed in the radial direction, and the existence of positive velocity fluctuations was confirmed. However, the cause of this has not yet been clarified. For this reason, even though the velocity fluctuation is a type of proper motion, it is somehow treated as an average value in which statistical errors are less likely to appear. At the time, the flattening characteristic of $V(r)$ itself (characteristics that do not follow Kepler's law) has been a major unsolved problem, and I believe that this is the main reason why it has not been clarified even now, nearly a century later. However, when verifying the analytical solution of the $V(r)$ characteristics with observational data, as in the new model, it is necessary to overcome the limits of measurement accuracy (currently a deviation of about ±10%) in order to ensure the reliability of the data.

The purpose of this study is to solve the above questions and problems, focusing on the new model of SGM, and to obtain new knowledge about spiral galaxies that have not been clarified so far. Chapter 2 provides an overview of the SGM, focusing on its characteristics, and touches on its relationship to the variability problem of Chapter 3 and beyond. Chapter 3 takes up some actual observational data, analyzes the causes of the variability in the rotation curve $V(r)$, and succeeds in theoretically unifying the results. In conclusion, there are two causes of the measurement variability that have not been considered so far. Both are related to the centripetal force (existence of significant differences) that differs at the measurement position of the star, and it has been found that they need to be distinguished from the original statistical variability (deviation). On the other hand, the SGM model points out that the spiral arms have the characteristics of rigid body motion from the analytical solution of the $V(r)$ characteristics. Among these, the elucidation of the specific forms of movement inside the arm remained an issue. [14] In Chapter 4, in order to elucidate the velocity fluctuation phenomenon described in Chapter 3, a new "Velocity Fluctuation Model (VFM)" using local gravity is added. This model has been the first to provide theoretical support, predicting the existence of a surprising internal structure in the spiral arms. The spiral arms of galaxies not only form a spiral disk shape, but also form circular motion due to rigid body motion within the cross section of the arm. This analysis predicts the existence of a new multiple helical structure with two circular motions (orbits).

As described above, this research has obtained important insights and predictions about the problem of measurement variance and the actual movement of spiral arms through analysis and evaluation using the model, and further verification is anticipated.

2. Characteristics of New Model SGM and Problem of Variance

The new model, the "Spiral Gravity Model (SGM)", [14] captures from a macroscopic perspective the gravitational forces (interactions) that star groups exert on each other as they spiral. Based on spiral geometric data, it predicts the existence of a macroscopic force, the interstellar force T (and the spiral force derived from it), that occurs in the spiral structure of the arms. The success of this model lies in the fact that the predicted force $T(r)$ was analytically obtained for the first time based on Newtonian mechanics. Furthermore, the analytical solution $V(r)$ of the rotation curve derived from $T(r)$ has been verified to be in perfect agreement within about ±5% over the entire region when compared with observational data [19] from the bulge to the solar system. One of the purposes of this paper is to confirm the reliability of the observational data used in this verification.

A notable feature of this model is that it is the first to make a change to the conventional Kepler's law, which states that the centripetal force is only gravity. The mass of the clustered stars creates gravity (centripetal force) that points towards the center of the galaxy, but when spiral motion (distortion due to curved structures) is added to this, the newly discovered spiral force is formed as a centripetal force. Because the existence of spiral forces had not been considered until now, it was necessary to reconsider the balance conditions of forces (the gravitational equation) as a preliminary step to Kepler's law.

The analytical solution of the spiral force is obtained from the gravity equation using the interstellar force $T(r)$, as in the analytical solution $V(r)$ of the rotation curve. The function form is inversely proportional to the square root of the distance r from the center of the galaxy, and shows a very gradual decay tendency compared to the previous gravity (inversely proportional to the distance r^2). Therefore, the centripetal force generated in the spiral arm is strengthened by the spiral motion, as the function form proves. This shows that the centripetal force (gravity) of the stellar group can be increased without increasing the mass due to the interaction of the spiral motion. This spiral force is a force that does not exist in the conventional concept of gravity, and is thought to show a new principle of gravity (centripetal force) generation [20].

The main characteristic of the spiral force is that it is generated only in the inner region of the spiral arm, and not in the outer region where only conventional gravity exists. Therefore, the centripetal force is different inside and outside the arm. This point is an important key to solving the problem of variation in the $V(r)$ characteristics.

From Chapter 3 onwards, I attempted to provide a theoretical basis by analyzing the causes of the variation, including confirmation of the measurement accuracy based on observational data. The cause of the large significant difference in the variation problem is not only the difference in centripetal forces (spiral force and gravity) found in the new model, but also another fluctuation characteristic (velocity fluctuation) pointed out by Vera Rubin et al.. [15] The latter significant difference is supported by a new local gravity model (Velocity Fluctuation Model: VFM) proposed in Chapter 4. In this VFM model, as in the SGM model, gravity causing velocity fluctuations is generated by the motion (structure) of the spiral arms. This phenomenon depends on the internal position of the arm cross section, which had not been taken into consideration before, and appears as one of the proper motions[12] at a radial distance r.

From these, I found that the causes of the variance are all caused by measurement locations (inside and outside the spiral arms, and internal positions of the arm cross section) that are different from the distance r from the galactic center, and that this problem should be distinguished from the original statistical fluctuation (error).

3. Analysis of Observational Data

In this chapter, I will take up the $V(r)$ characteristics seen in conventional observational data, and analyze and clarify questions and problems related to the measurement fluctuations (variances) of the mean and deviation.

The $V(r)$ characteristics of observational data have characteristic fluctuations (e.g., the fluctuations of the mean are larger than the deviation), and many measurement methods have been used to solve this problem. The cause of this fluctuation is still unknown and there is no particular tendency to improve it, and it is thought to be due to essential difficulties. [13]

However, when considering this problem based on the new model of SGM, it is found that the fluctuations are not statistical errors in the true sense of the word. In conclusion, as mentioned in Chapter 2, there are two causes of large fluctuations. These have never been considered at all until now, and both are related to the measurement location and position of the stars that the observational data targets (different from the distance r from the galactic center). For this reason, in conventional data acquisition and processing, it was necessary to distinguish and evaluate the measurement targets.

I believe that one of the major causes of the current situation is that Kepler's laws, which have been fundamentally regarded as absolute until now, no longer hold true. In the new model of SGM, it is argued that even if the measurement distance r is the same (on a concentric circle), the $V(r)$ characteristics differ greatly due to the location of the star, that is, the difference in centripetal force inside and outside the spiral arm. If the cause is due to the measurement location, it will be impossible to distinguish significant differences no matter how much measurement technology advances unless this is addressed.

The other cause is seen in the fluctuation characteristics (velocity fluctuations) of the

NGC2998 galaxy, which Vera Rubin et al. clearly pointed out. [15] This phenomenon has been discussed as one of the proper motions.[12),16),17)] However, although this velocity fluctuation has been distinguished by observational data, it has not yet been theoretically elucidated. This discussion will be analytically clarified by introducing a local model in Chapter 4 and later. In conclusion, the fluctuation characteristics are formed by local gravity generated inside the spiral arm, which adds to the flattening characteristic of $V(r)$.

These considerations show that the stellar measurements (variations) are influenced not only by the inner and outer regions of the spiral arms, but also by the location of the inner regions of the arms. In the following sections 3.1 and 3.2, I will carry out a detailed analysis of the observational data of the Milky Way and NGC 2998 galaxies, respectively, keeping in mind the above-mentioned causes of variations. The data used in the discussion here are all figures taken from the references, and consist of the average values and deviations of the $V(r)$ characteristics, as well as the measured values of individual data. In this paper, since it is not possible to directly include the figures that are the original observational data, new characteristic diagrams have been created based on the information the author has read from these diagrams, and the discussion is based on this. Therefore, for a detailed discussion of the state of variation, in addition to the characteristic diagram created by the author, it is necessary to reconfirm the original data described in the three references. [13), 15), 21)]

Based on these discussions, in section 3.3, I will describe how the $V(r)$ characteristics have reached their current state and the prospects for future improvements.

3.1 Rotation curve of the Milky Way

Using several papers that discuss observational data on the rotation curve, I will extract problems related to fluctuations and analyze them over time. Until now, various methods have been used for measurements, such as using the final velocities of the H_1 and CO lines. Among them, it has been said that there is a large variation between the data due to different methods of velocity conversion. [13)]

First, let us take a look at representative observational data on the $V(r)$ characteristics of the Milky Way in 1979 and 1985. Figure 1 is a characteristic diagram showing the characteristics of the variation range read from these, and is based on a part of the figure published in reference [21)] (Fig. 1 in Sofue 2016). The original data in Sofue (2016) is based on Blitz at al. (1979) [22)] and Clemens (1985) [23)].

In the characteristic diagram of Figure 1, there is a peculiar variation in the average value, sandwiched between two upper and lower dashed arrows, based on the analytical solution $V(r)$ shown by the solid line. However, since Figure 1 does not show the individual average values or deviations, it is necessary to check the original observational data in the reference

21) (Sofue 2016, Fig.1) . From this, two questions (problems) can be pointed out.

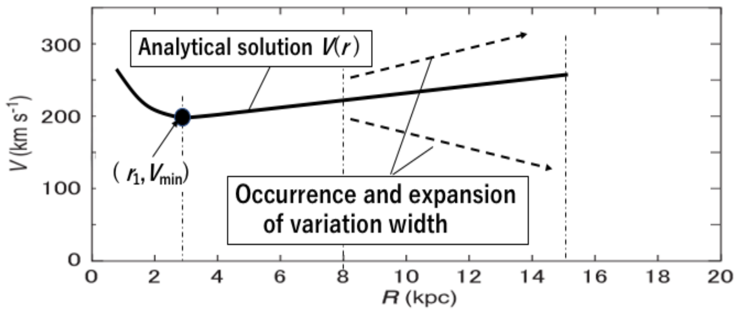

Figure 1. Characteristics of variation in $V(r)$ characteristics of the Milky Way (shown based on analytical solution)

This characteristic diagram is based on two sets of observed data [21), 22), 23)] and shows the characteristics of the occurrence and expansion of the range of variation relative to the average value, sandwiched between two dashed arrows. For comparison, the analytical solution $V(r)$ [14)], which indicates the central value of the characteristic, is shown as a reference value using a solid line. The minimum value shown by the black circle indicates the starting point [14)] where the spiral shape occurs and is the parameter that governs the $V(r)$ characteristics.

First, the variation in the average value is larger than the deviation of other average values in the vicinity for both sets of observational data. Secondly, the width of the variation in the average value suddenly expands and becomes larger when the distance r is approximately 8 kpc or more. From these, it is thought that there is a phenomenon in which the variation characteristics clearly show a significant difference. However, because the cause of this occurrence is unknown, even if it has been empirically known, it has not been possible to separate it, and it has been included in the statistical error.

At present, it is thought that the variation in stars outside the solar system are greater due to measurement problems and the existence of peculiar features (dips). [13)] However, as discussed in Chapter 2, the SGM analysis of the new model indicates that this variation problem arises from the difference in centripetal force between the inner and outer regions of the spiral arms.

Figure 2 shows the relationship between the contribution of the new spiral force and the contribution of the conventional gravity, based on the analytical solution $V(r)$ of the new model. It explains how the variation range $\Delta V(r)$ of the average value shown in Figure 1 expands due to differences in centripetal force. For the characteristics other than the analytical solution $V(r)$ shown by the solid line, the effects of bulge gravity are excluded for comparison. The contribution of gravity alone is the case where there is only the visible disk mass, without dark matter, in order to compare with the spiral force. The characteristics shown by the dashed line in this case are considered to follow Kepler's law from the conventional point of view, but since there is no observational data, they are predicted based on references, etc. [9), 11)]

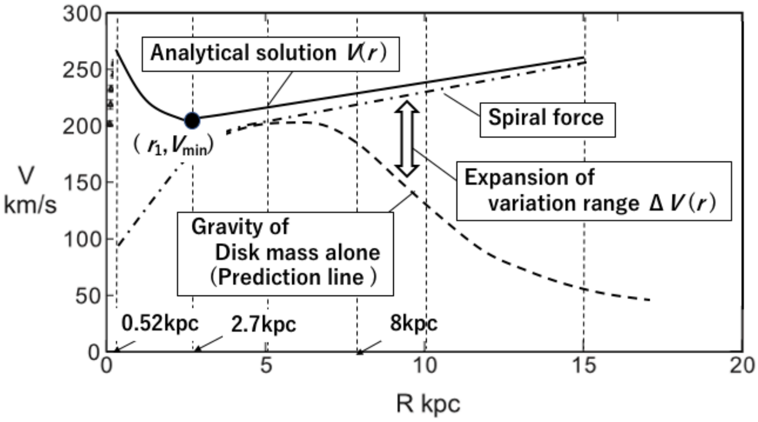

Figure 2. Variation width $\Delta V(r)$ caused by differences in centripetal forces (spiral force and gravity)

This figure shows the effect of the difference between spiral force and gravity on the variation width $\Delta V(r)$ for the average value data of the $V(r)$ characteristics. For comparison, the effects of bulge gravity have been removed from characteristics other than the analytical solution $V(r)$ [14)] used as the reference. Therefore, the difference between the analytical solution $V(r)$ and the spiral force indicates the effect of bulge gravity. At this time, the contribution of gravity alone, shown by the dashed line, shows the case of only the disk mass, which does not contain dark matter, in order to compare with the spiral force. However, since there is no observational data, predictions are made based on data from papers , etc. [9), 11)]

The $V(r)$ characteristic has been considered to absolutely follow Kepler's law, and it has been thought that the centripetal force is the same regardless of whether it is inside or outside the arm, if the distance r is the same on the concentric circle. Based on this, even if a unique variation range $\Delta V(r)$ occurs in the observational data, it is selected randomly without distinction. However, as shown in Figure 2, the difference in centripetal force becomes large depending on the selection method, especially when the distance r from the center of the galaxy is 8 kpc or more. For this reason, the variation range $\Delta V(r)$ increases, and even at nearby distances r, a problem (fault) occurs in which the average value varies more than the deviation. Therefore, this variation itself is different from the original measurement error (statistical error), but is due to the difference in centripetal force (significant difference), and is therefore considered to be a distinguishable characteristic.

In order to remove this significant difference, it is necessary to confirm that the distance r of the star to be measured is inside the arm where the spiral force acts, even if it is on the concentric circle. As a result, the variation range $\Delta V(r)$ of the observational data is basically only a statistical error, and is therefore expected to approach the analytical solution $V(r)$. In addition, near the lower limit of $\Delta V(r)$ shown by the dashed line in Figure 2, stars outside the arm are selected, and the effect of the spiral force is reduced, so that it approaches the rotation velocity $V(r)$ due to gravity alone. These phenomena will be clarified by analyzing the state of variation in observation data, which will be described later in Figures 3 and 4.

On the other hand, another tendency (characteristic) can be seen in Figure 1. Conversely, when the distance r is below 8 kpc, the variance in the average value and its deviation become smaller, as shown by the characteristics in Reference, [21] In this region, the contribution of the spiral force becomes almost the same as that of gravity, as shown in Figure 2. For this reason, the difference in centripetal force between the inside and outside of the arm is almost eliminated. At first glance, this seems to be approaching Kepler's law. As a result, the measurement accuracy (statistical error) within the solar system can be estimated to be around a few percent from the observational data on which Figure 1 is based. By eliminating the variance due to significant differences, it is believed that the measurement accuracy was quite high even back then.

Next, I will look at another observational data showing a significant variation distribution that is quite different from the previous examples. It is the unified rotation curve $V(r)$ shown in Fig. 1 of Reference [13] in 2009. The rotation curve shown here was reconstructed by unifying many existing data (samples) into one by recalculating distances and velocities for a set of galactic constants R0 = 8 kpc and V0 = 200 km s^{-1}. The reason for taking this up is to reconfirm the variation width $\Delta V(r)$ explained in Fig. 2 with many observational data.

Figure 3 shows the characteristics of the variation range of the unified rotation curve $V(r)$. The variation range $\Delta V(r)$ is interpreted based on reference [13] , and as one way of looking at it, it is shown with two arrows, one above and one below, based on the analytical solution $V(r)$ [14] .

First, comparing Figures 1 and 3, a difference can be seen in the lower part of the variation range (distribution) of the average values. I believe that the large change in the lower part shown in Figure 3 is the result of the tendency of the variation range shown in Figure 2 appearing because many stars were randomly selected for measurement, regardless of whether they were inside or outside the arms. In other words, the decrease due to gravity only outside the arms is large, so this appears as the number of samples increased. On the other hand, the distance r where the variation increases rapidly occurs at the same distance r of around 8 kpc. This is because the tendency of the variation to increase is less affected by an increase in the number of samples in particular.

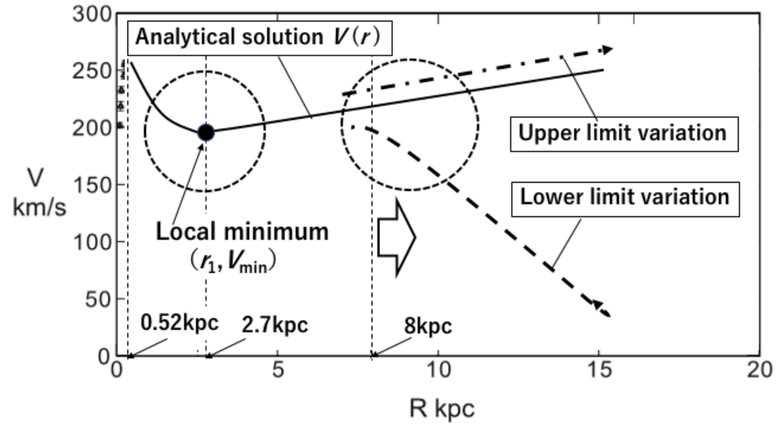

Figure 3. Characteristics of variability range $\Delta V(r)$ of the unified rotation curve $V(r)$

This figure shows the characteristics of the variability range of the unified rotation curve $V(r)$. The variability range $\Delta V(r)$ is shown with two arrows, one above the other from the original data in Reference [13]. The analytical solution $V(r)$ [14] shown as a solid line indicating the central value exists between the upper variability shown as a one-dashed line and the lower variability shown as a dashed line. If the analytical solution $V(r)$ is used as a base line, the upper line of the observed data maintains a constant width, but the lower line shows a significant decrease. In this figure, the black dot dip shown in the circle on the left represents the minimum value (r_1, V_{min}) in the SGM analysis, and is an important parameter that governs the overall characteristics of the analytical solution $V(r)$. There is no dip in the analysis near the circle shown by the dashed line on the right.

In Figure 3, the upward swing shown by the dashed-dotted line is about +10% compared to the straight line (solid line) of the analytical solution that serves as the reference. Since the measurement target is inside the arm, the variation range remains constant as the distance r increases. Conversely, the downward deflection shown by the dashed line shows asymmetry, unlike the upper side, and decreases rapidly compared to the analytical solution. I believe that the reason for the larger swing on the lower side is that, as explained in Figure 2, the increase in the number of samples selected results in an increase in the observation data in the outer region (gravity only).

On the other hand, the dip within the circular dashed line seen in Figure 3 have been theoretically solved by the new SGM model. [14] This dip around 3 kpc gives an important minimum value in principle, and occurs due to the balance condition where the bulge gravity and the spiral force are equal. Furthermore, it has been found that the parameters of the minimum value (r_1, V_{min}) govern the entire characteristics of the analytical solution $V(r)$.

Next, Figure 4 shows a characteristic diagram created based on the $V(r)$ characteristics [21),24)] of individual data around 2015, for comparison with the variation range in Figure 3.

The original observational data in Figure 4 is based on data from Honma et al. (2015) [24].

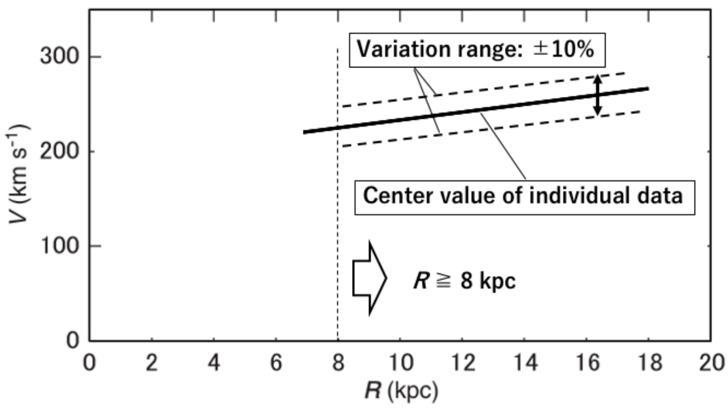

Figure 4. Center value and variation of $V(r)$ characteristics based on individual data (distance $r \geqq 8$ kpc)

This figure was created based on the figure published in reference [21] (Fig. 1 in Sofue 2016) and is based on data from Honma et al. (2015) [24]. Looking at the variation range of the dashed line from the center value shown by the solid line, it shows about ±10% both above and below at distances of 8 kpc or more, and is symmetrical and constant.

Figure 4 shows the central value (solid line) and the variation range (dashed line) based on the observational data. In this case, the variation range of the individual data is symmetric and constant at about ±10% both above and below in the region where the distance r is 8 kpc or more. Here, the sharp decrease seen in the lower part of Figure 3 is not observed, which is quite different. For the reasons explained in Figure 2, the researchers limited their measurement target to the inside of the arm, and it is thought that they were aware of the possibility of obtaining such results empirically. Although the cause was unknown from the time, it is believed that they had confirmed that the variation range $\Delta V(r)$ was basically eliminated. This estimated result shows very important point for isolating the subsequent fluctuation variability.

What is noteworthy about the individual data (Figure 4) is that, although the comparison target is different from the average data (Figure 3), the upper variation range is the same at about +10%, and remains constant with respect to the distance r. Another feature of the individual data is that the asymmetry of the variation range shown in Figure 3 has been removed. These points can be thought of as follows. Because the centripetal force is dominated by spiral force alone, the variation within the arm is thought to occur not only above but also below the central value, as shown in Figure 4 (±10% of the analytical solution).

However, in the case of Figure 3, a large variation in the outer region (a large decrease in centripetal force) is simultaneously added due to the random measurement object, and this is thought to hide the variation in the lower part of Figure 4, resulting in an asymmetric distribution. Therefore, the $V(r)$ characteristics shown in Figure 4 are thought to represent the first observational data using the inside of the arm as a measurement object. This is also important in another sense, which will be explained next.

The analytical solution $V(r)$ of the new model gives the central value inside the arm in principle, so it is expected to match the central value of the individual data shown in Figure 4. This means that the analytical solution $V(r)$ obtained with the new model will be unintentionally confirmed as new verification data in addition to the verification data [19] used up to now. Figure 5 compares the central value of the individual data shown in Figure 4 with the analytical solution $V(r)$ on the same scale.

In Figure 5, the analytical solution $V(r)$ and the central value data shown in Figure 4 are partially superimposed with the scales of both axes aligned. As shown in Figure 5, the analytical solution shown by the solid line agrees well with the central value of the dashed line, including the slope of the line.

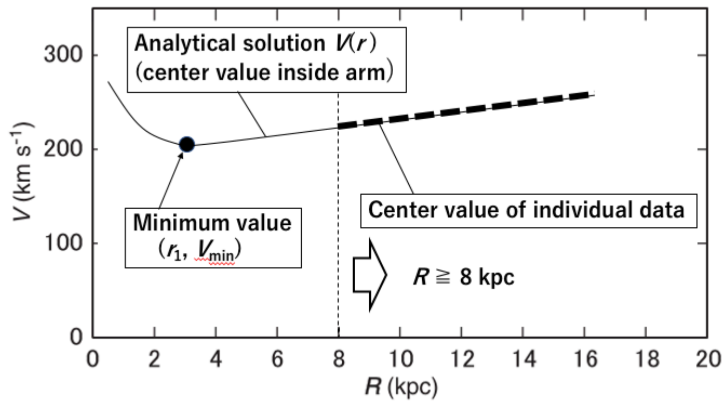

Figure 5. Relationship between central value of individual data and analytical solution $V(r)$ (overlapped diagram)

This diagram shows that when the distance r is 8 kpc or more, the central value of the individual data (dashed line) shown in Figure 4 matches well with the analytical solution $V(r)$. In principle, the analytical solution represents the central value inside the arm, and the agreement between the solid line and the dashed line reaffirms the validity and reliability of the SGM model with new observational data.

This means the following two things. First, although it is only in the limited region where the distance r is 8 kpc or more, both the analytical solution $V(r)$ and the central value of the individual data are extremely accurate, once again confirming the validity and reliability of the new model for SGM. Second, the $V(r)$ characteristics inside the arm agree with the analytical solution, which is a straight line with a gentle slope, reaffirming the state of rigid body motion in the disk shape. The rigid body motion of the spiral arms will also be discussed in Chapter 4.

From the above analysis, it became clear that by measuring the internal area of the arm rather than the external area, the variation in the average data could be suppressed to within the deviation (approximately ±10%, or ±20km·s^{-1}). At this stage, due to its symmetry (approximately ±10%), the variation (deviation) appears at first glance to be a statistical error without significant differences. However, it was later discovered that there was another fluctuation component (significant difference) within the above deviation. This will be discussed in the analysis of the fluctuation characteristics (velocity fluctuation) in the next section.

3.2 Rotation curve of the NGC2998 galaxy

Here, I take up the fluctuation characteristics (velocity fluctuations) present in the flattening characteristics of the rotation curve and analyze the actual state of the fluctuations from a different perspective than that in Section 3.1.

The first figure I will look at here is the rotation rate of individual data for NGC 2998, published in reference (Fig. 2) by Vera Rubin et al. [15]

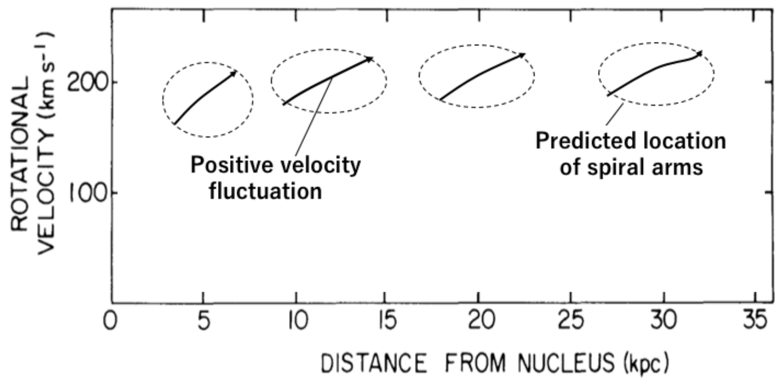

Figure 6. Velocity distribution of individual data $V(r)$ for the NGC2998 galaxy

This figure shows the velocity gradient (distribution) within the arm with a solid line, based on the $V(r)$ characteristics of the individual data shown in reference (Fig.2) [15]. It is noteworthy that the distance r is taken in the radial direction, and data is acquired in a direction perpendicular to the central axis of each spiral arm, and the measurement targets are separated into the inner/outer regions of the spiral arm. This allows positive velocity fluctuations to be seen in the arm cross section, and the size and position of the arm width to be estimated.

Figure 6 is a newly created characteristic diagram based on the rotation curve $V(r)$ from reference [15]. The characteristic velocity gradients (distributions) within the arms are connected with solid lines, and in addition to the positive velocity fluctuations in the cross section of the arms, the size and position of the arm width can be estimated. The distance r of the star to be measured is fixed in two radial directions from the center of the galaxy (the same direction as the centripetal force toward the center of the galaxy), northeast and southwest. In this measurement, data is acquired in a direction perpendicular to the spiral arms, so the inside and outside of the arms are clearly separated as described in Section 3.1. Therefore, the difference in centripetal force is also distinguished. In the figure, the velocity distribution of the strongest radiation region is connected with a solid line, and this difference in strength is thought to correspond to the number of stars, and it is thought to indicate the boundary between the inner and outer regions of the arms.

Although not shown in Figure 6, in the original individual data, when looking at the velocity distribution for radii of 10 kpc or more, it can be seen that there are almost no stars or no stars at all in the outer regions of the spiral arms. In SGM theory, this is because the difference in centripetal force becomes large, and stars cannot exist in a steady state outside the spiral arms. In other words, even if they exist transiently, they will be caught up (fall) into the spiral arms located inside. [14] Also, when the radius r is around 8 kpc or less, stars exist in a V-shaped distribution between the spiral arms. This phenomenon is thought to occur because the difference in centripetal force with the outer regions becomes small, as described in Figure 2. In this way, by taking the measurement direction in the radial direction, characteristic fluctuation characteristics can be seen in each region inside the arms, and the velocity fluctuations (significant differences) pointed out by Vera Rubin et al. can be confirmed.

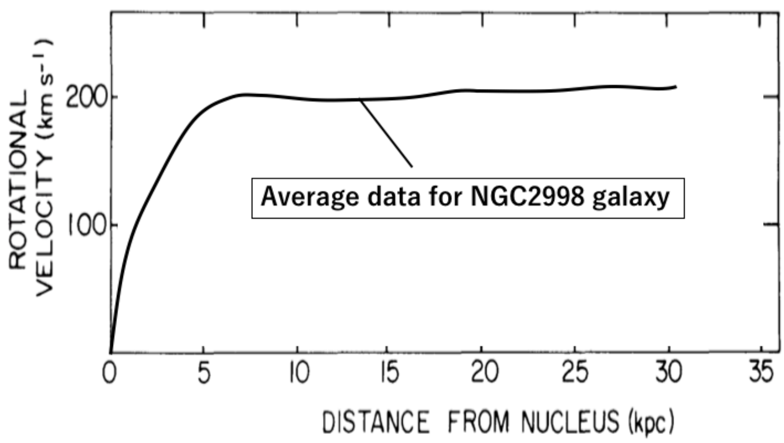

Figure 7. Velocity distribution of average data $V(r)$ for NGC galaxies

This figure, like Figure 6, is a rotation curve created based on the figure published in Reference (Fig.4)[15] by Vera Rubin et al. In addition to the NGC2998 galaxy, the characteristics of several other galaxies are also listed, but they have flat characteristics with no particular velocity fluctuations. Unlike the case of individual data, no particular arm fluctuation characteristics (velocity fluctuations) are observed.

On the other hand, Figure 7 shows the velocity distribution of the average data for the galaxy NGC 2998. This distribution is clearly different from that of the individual data. As with other characteristics, it is shown in a form that does not show any significant fluctuation characteristics (flattened characteristics). This is thought to be because the changes in the individual data are averaged and hidden in the average data, and this will become clear in the analysis that follows. At this time, the distance r in the average is thought to be taken in the radial direction, just as in the case of the individual data.

What is noteworthy here is that, even though new fluctuation characteristics showing significant differences had been recognized as early as around 1978, the average data has been used without any particular separation. Therefore, next I will analyze the basis for this treatment.

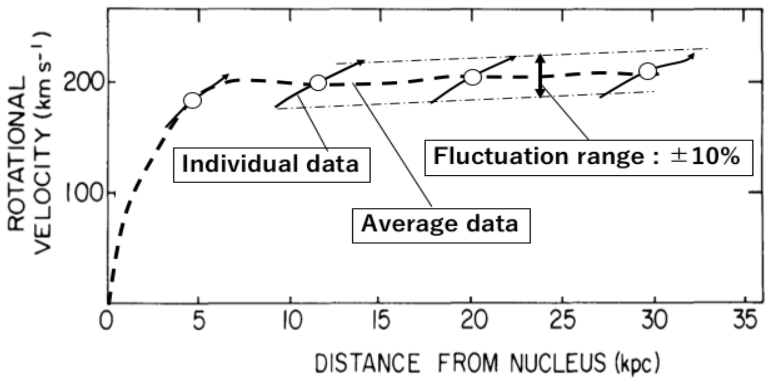

Figure 8. Overlay of individual data and average data for NGC2998

This figure shows the individual data (Figure 6) and average data (Figure 7) overlaid on each other. From this, it can be seen that the average data (dashed line) almost coincides with the central value of the individual data (solid line) marked with a circle.

Figure 8 overlays the two characteristics of Figures 6 and 7, and shows that the central value of the velocity fluctuation shown by the individual data is almost the same as the average data shown by the dashed line. This shows that the velocity fluctuation, which is a significant difference, appears depending on the measurement method of the individual data (measurement in a radial direction, not on a concentric circle), but the average data is equal regardless of the measurement direction (method). However, in the case of random measurements, it is thought that the phenomenon of velocity fluctuation appears in the deviation rather than the average value. The velocity fluctuation shown by the individual data in Figure 8 shows a linearity that is almost symmetrical around the average value, and the fluctuation range is about ±10%. When estimating this variation from linearity, almost all of it is significant, and I believe that by removing this significant difference, the statistical deviation (error) will be within a few percent. Therefore, when measurements are taken randomly, the linearity indicating the significant difference will be hidden, but the velocity fluctuations will be added to the statistical deviation, and I believe that the apparent deviation will increase to about ±10%. This apparent deviation can also be seen in the characteristics of the Milky Way analyzed in Figures 3 and 4 in Section 3.1, and it can be confirmed that it contains a deviation of about ±10%.

Considering the measurement method and characteristics of the variability analyzed in Section 3.2, it is believed that this variability is a local phenomenon within the arm cross section. For this reason, the velocity fluctuation itself is a phenomenon that is added independently of the flattening characteristics obtained from the average data. The theoretical support for the velocity fluctuation will be discussed separately in Chapter 4 and onwards, but it has been successful in analysis using a local model.

By analyzing the cause of the variability characteristics (velocity fluctuation) in this way, it became clear why average data had been selected and displayed up until now. The reason is thought to be because it was recognized that the deviation differs empirically depending on how the distance r is taken, but the average does not change. In the end, velocity fluctuation has not been considered a problem because it can be replaced by a deviation problem without the need to isolate significant differences. In this analysis, it was shown that the $V(r)$ characteristics of the rotation curve can obtain two types of observation data (points with the same average value but different deviations) depending on the measurement method.

From the above, it was found that the variation in deviation that occurs within the arm cross-section occurs with a significant difference, similar to the variation in the average value described in Section 3.1, and can be separated from the original statistical error. By clarifying the causes of variation that occurs with two types of significant difference in this way, measures to eliminate these can be obtained. Essentially, it is necessary to appropriately set and select the areas inside and outside the arm, and the positions inside the arm cross-section, depending on the purpose of acquisition. In the next Section 3.3, I will comprehensively evaluate the existence of variation, including statistical error, based on the results of these analyses.

3.3 Comprehensive evaluation of variation in rotation curve

I believe that the causes of the variation in the observational data have been basically isolated by using the new model of SGM as an analysis tool. As a result, I have pointed out that the variation in the average value can be eliminated, and the deviation, which was previously considered to be about ±10%, can be reduced to a few percent.

Here, I divide the characteristics of the significant differences that caused the variation into two types, Type A and Type B, as shown below, and evaluate their relationship with statistical error. In addition, based on the results of the analysis so far, I will also touch on the observational data used to verify the new model and the newly discovered verification data in this analysis.

(1) Variation in average value (Type A)

The actual nature of this variation is reflected in the large downward variation in the average value shown in Figure 3, which is caused by the difference in centripetal forces (spiral force and gravity) in the inner and outer regions of the spiral arm. As shown in Figure 2, according to the principles of the new model, the gravity in the outer region, which acts as a centripetal force, is smaller than the spiral force in the inner region, and is particularly greatly reduced when the distance r is about 8 kpc or more. In contrast, below about 8 kpc, where the Solar System exists, the difference with the spiral force almost disappears, and the variation in the average value is eliminated. As a result, the variation in the deviation due to Type B that follows remains, but by eliminating this, I believe that the original statistical error can be reduced to about a few percent.

(2) Variation in deviation (Type B)

The reality of this variation has been recognized empirically since around 1978, and appears in observational data in which the distance r is fixed in the radial (centripetal) direction within the arm cross section. At this time, as shown in Figure 8, the central value of the individual data showing a symmetric distribution due to significant differences coincides with the average data. As a result, the variation in deviation increases to about ±10% in appearance due to the random addition of the significant difference fluctuation (the linear part in Figure 6) in addition to the statistical deviation. This apparent fluctuation is also seen in the observed data in Figures 4, which remove Type A variation.

In the following Chapter 4, I will take up the cause of the significant difference of Type B, which has remained unexplained for many years, and provide theoretical support for it. As a result, it is found to be due to local gravity generated inside the arm.

(3) Statistical error

As mentioned above, the accuracy of the measurement technology has been high since around 1978, at a few percent, if the significant differences in (1) and (2) are removed. However, because the cause of the variation has not been clarified, the measurement accuracy is still limited to a variation (deviation) of about ±10% due to the following circumstances.

As can be seen from the changes in the acquired data of Figures 3 and 4, the existence of Type A (differences between the inside and outside of the arm) seems to have been empirically understood for a long time. Therefore, it is presumed that the individual data shown in Figure 4 was deliberately measured only in the area inside the arm. From this, it is shown that the variation in the average value in Type A has been eliminated, and the variation range (deviation) is about ±10%. However, at this point, it is believed that the existence of the deviation due to Type B described in (2) above was not properly recognized. For this reason, if the acquisition method shown in Figure 4 is not used (if Type A fluctuations are not taken into consideration), the variation range will be even larger because it will include the variation of the average value in addition to Type B, as shown in Figures 1 and 3.

The above analysis shows that by simultaneously removing the newly clarified Type A and Type B fluctuations, the current variation range (estimated deviation: ±10%) can be reduced to the original statistical error (a few percent).

(4) Verification data for new model (SGM)

In the case of the new model, as described below, the present analysis has removed type A and type B fluctuations from the observational data used to verify the analytical solution $V(r)$, and the statistical error is on the order of a few percent. [14), 19)]

What is particularly important in the verification is that the overall characteristics of the analytical solution $V(r)$ (the region from the edge of the bulge to the outermost edge of the galaxy) are determined only by the minimum values (r_1, $V_{\min}$) used in one-point fitting due to the fundamental characteristics of the model. As shown in the analysis, the distance r_1 of the minimum value that is important in the observational data is located at 2.7 kpc, so Type A variations are removed. Furthermore, the observational data for the minimum value $V_{\min}$: 200 km· s^{-1} uses the central value of the $V(r)$ characteristics, so Type B variations are also removed at the same time. From these points, I believe that the observational data (measurement accuracy) used to verify the SGM has both significant differences removed and is guaranteed to be within the statistical error of about a few percent at the time.

On the other hand, this analysis has revealed a new discovery about the observational data. That is, the $V(r)$ characteristics of the individual data measured inside the spiral arm shown in Figure 4. The central value of this individual data will in principle match the characteristics of the analytical solution $V(r)$, which also shows the central value. As shown in Figure 5, although it is a comparison over a partial range of more than 8 kpc, it was confirmed that there is an extremely good match, including the slope of the straight line. Although the two observational data were measured nearly 40 years apart, both of the central value data show that they are equal to the analytical solution. From this, including the accuracy of the analytical solution $V(r)$, I believe that the validity and reliability of the new model SGM have been proven once again.

In the next 4 chapters, I will discuss the theoretical basis for the velocity fluctuations mentioned in Section 3.2, which have not been elucidated for a long time. The results of this analysis will lead to the discovery of further surprising movements of spiral galaxies.

4. Velocity fluctuations of rotation curve

Here, I consider a new approach to clarify the mechanism of the characteristic velocity fluctuations shown by the fluctuations of the $V(r)$ characteristics. First, based on the observational data shown in Figure 6 , I summarize the characteristics of the fluctuation characteristics used in the analysis as follows.

(1) The $V(r)$ characteristics show linear velocity fluctuations with a positive slope with respect to the width of the spiral arm.

(2) The velocity fluctuations increase and decrease in proportion to the arm cross-sectional radius rs around the average value (center value), resulting in a point-symmetric distribution. The cross-sectional shape of the arm at this time is considered to be approximately circular.

(3) The maximum positive and negative fluctuation widths of the velocity fluctuations ΔV_{max} appear at almost the same level for each spiral arm, and are approximately ±20 km·s^{-1} (±10%) from the center value (average value).

(4) The maximum radius r_a of the arm cross-section is approximately 3 kpc from the fluctuation width.

Based on these observational data, I propose and analyze a new model that generates the velocity fluctuations. In order to elucidate the mechanism of velocity fluctuation, this model will be distinguished from the basic model (SGM) mentioned first, and will be called the "velocity fluctuation model (VFM)" as a local model inside the arm.

4.1 Construction of velocity fluctuation model

This model focuses on the fundamental questions of why characteristic velocity fluctuations appear only in limited cases of the centripetal force direction and why they need to occur.

The velocity fluctuation discussed here is one of the proper motions (corresponding to the velocity component $V0$) exhibited by the stellar group in terms of its $V(r)$ characteristics [16),17)], and observational data shows that rigid body motion is maintained for each cross section of the arm. Furthermore, the disk shape (structure) of the spiral arms also shows a tendency toward rigid body motion from the analytical solution $V(r)$ of the basic model (SGM). [14)] For these reasons, the model is based on a structure that takes rigid body motion into consideration.

The driving force of the velocity fluctuation model (VFM) is considered to be the local gravity generated inside the arm. As shown in the upper part of Figure 9, in order to form the cylindrical structure of the spiral arm, I consider that the mass of the spherical structure changes along the central axis of the arm, and there are two components as the internal gravity F_2. The gravity component along the central axis inside the arm (Z-axis direction) and the gravity component toward the central axis in the cross section perpendicular to this (XY plane). The former balances in a way that is invisible from the outside in the cross section of the arm, and becomes the force that connects the arm (bonding force). The latter is the force that restrains the cross section of the arm, and balances with the centrifugal force f_2 due to the rotation velocity V_2. These components are called the internal gravity F_2, and are distinguished from the centripetal force F_1 that gives the flattening characteristic of $V(r)$.

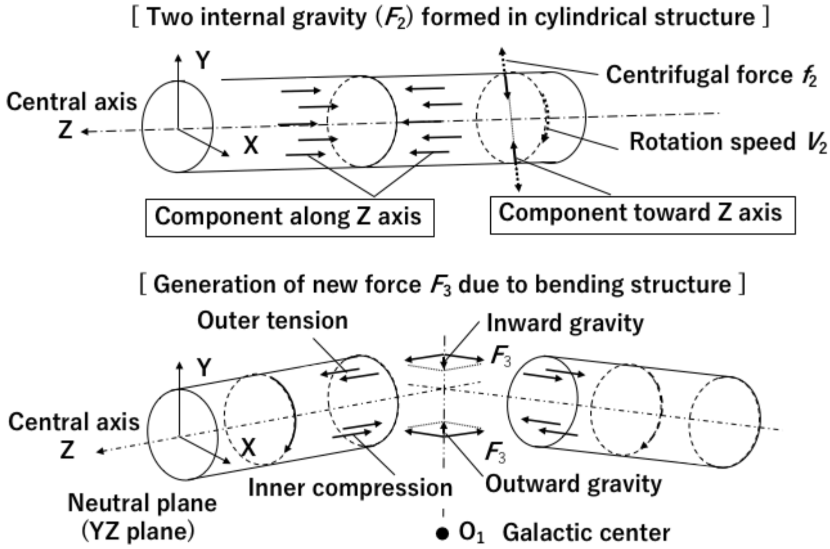

Figure 9. Modeling the internal gravity and bending structure of a cylindrical arm structure

In this model, to form the cylindrical structure of the spiral arm shown at the top, the mass of the spherical structure changes along the central axis of the arm, forming two gravity components that become the internal gravity F_2: the component along the central axis of the arm (Z axis) and the component perpendicular to it toward the central axis of the arm cross section (XY plane). It is noteworthy that the spiral arm generates distortion due to the "bending structure", and this distortion formation causes the internal gravity F_2 to generate a "new force F_3". As shown in the divided bending structure on the drawing at the bottom, the force F_3 equivalent to the bending stress consisting of tension and compression is generated on the outside and inside of the neutral plane (YZ plane) passing through the central axis, which becomes the inward gravity and outward gravity, respectively.

4.1.1 New forces generated by binding forces

The gravitational component that acts as the binding force (bonding force) forms the flow of stars along the central axis and exists as one of the internal gravitational forces that maintain the cylindrical shape. It is important to note that the actual spiral arms have a curved structure (with a constant pitch angle Φ [14]) within the cylindrical shape. This curved structure is formed by the centripetal force, which is an external force, but this structure causes a bias (distortion) in the internal gravity F_2, generating a new force F_3.

Specifically, the bending structure shown in the lower part of Figure 9 generates gravity F_3, which is equivalent to bending stress (strain) consisting of tension and compression, on the outside and inside of the neutral plane (YZ plane) passing through the central axis in the arm cross section.

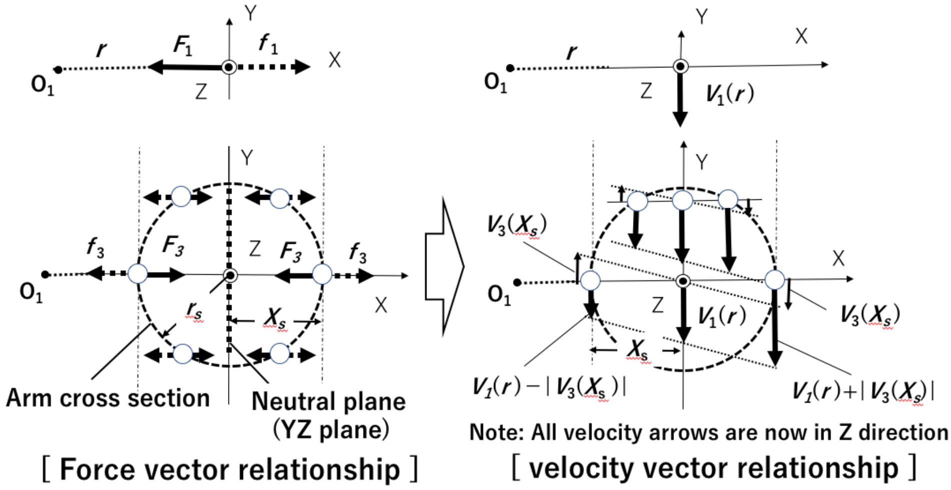

Figure 10. Relationship between force vector and velocity vector depending on the position of the arm cross section (XY plane)

The force vector on the left side of this figure shows a new force F_3 that occurs due to distortion caused by the "bent structure". This F_3 occurs within the arm cross section (XY plane) and changes due to the bending stress of tension and compression according to the position X_s from the neutral plane shown by the dashed line. On the other hand, the centrifugal force f_3 that balances this force F_3 occurs on the same disk surface (XZ plane) as the centripetal force F_1 and like the new force F_3, it changes according to the distance (position) X_s from the neutral plane on the arm cross section, not the radius r_s of the rotation orbit. For this reason, the centrifugal force f_3 occurs by a new mechanism different from the past. The rotation velocity at this time acts to eliminate the difference between the inside and outside of the orbit inside the arm. As shown on the right side, it forms a positive and negative velocity vector V_3 (X_s) that depends on the position X_s of the arm cross section, and has a maximum value at the outer end and the inner end. However, since the position coordinate of the arm cross section (XY plane) is selected in the figure, when looking at the arrows of the velocity distribution, it is necessary to replace all the Y-axis direction with the Z-axis direction.

In other words, it is a force generated when the interaction between stars causes a deviation due to spiral motion. In the figure, the central axis is drawn to intersect with a dashed line for drawing purposes, but in reality it is continuously connected by a logarithmic spiral curve. This new force F_3 is an inward gravity toward the neutral plane of the arm on the outside, and an outward gravity in the opposite direction on the inside.

Here, Figure 10 shows the relationship between the force vector and the velocity vector, which depends on the position of the arm cross section (XY plane). As shown on the left side of this figure, an new internal gravity F_3 that changes based on the neutral plane of the arm cross section (XY plane) is generated on the same disk surface (XZ plane) as the centripetal force F_1. The corresponding centrifugal force f_3 depends on the position in the arm cross section along with gravity F_3. This centrifugal force f_3 has different characteristics from the centrifugal force f_2 shown in Figure 9. It occurs on the radius r_s of the rotation orbit, but increases or decreases depending on the distance (position) X_s from the neutral plane. This f_3 occurs in balance with F_3 due to the spiral structure, and is considered to be a new type of gravitational effect not seen before. [20] As a result, the rotation velocity that generates the centrifugal force f_3 appears as a phenomenon called velocity fluctuation $V_3(X_s)$ seen in the observation data $V(r)$ in Figure 6.

The velocity distribution at this time forms a positive and negative velocity vector $V_3(X_s)$ that depends on the position X_s of the arm cross section, as shown on the right side of Figure 10. It should be noted that in this figure, the position coordinates of the arm cross section (XY plane) are selected, so all the arrows of the velocity distribution must be relocated from the Y axis to the Z axis. The positive velocity fluctuation $V_3(X_s)$ seen in the observational data has a maximum value in the opposite direction on the outside and inside as shown in Figure 10, and maintains rigid body motion on the disk surface (XZ plane) due to the nature of gravity F_3. In this case, the function of $V_3(X_s)$ is to adjust the difference (distortion) between the inside and outside of the orbit distance that occurs in the curved structure, and does not exist on the neutral surface where gravity F_3 does not occur. This can also be confirmed from the fact that the average value of the velocity fluctuation matches the center value of the individual data, as shown in Figure 8.

Furthermore, Figure 11 shows the velocity fluctuation characteristics seen in each arm of the galaxy NGC 2998. In this case, the velocity fluctuation distribution, as shown by the dashed and dotted straight line, does not depend on the distance r from the center of the galaxy, but shows a linear distribution with almost the same slope for each spiral arm. This indicates that the newly generated force F_3 depends (is proportional to) the distance X_s from the central axis, because the bending structure of the arm has a constant pitch angle Φ. Therefore, when the pitch angle of the arm changes, the slope of $V_3(X_s)$ also changes. In particular, in the case of the outermost edge of the disk, as shown by the double-dashed line, the slope of the line is the same for both the distance r from the center of the galaxy and the distance X_s of the arm, and stable rigid body motion is formed not only for the arms but also for the disk shape. This consistency of slope is an interesting point, as it may govern the external shape of the disk in a spiral galaxy.

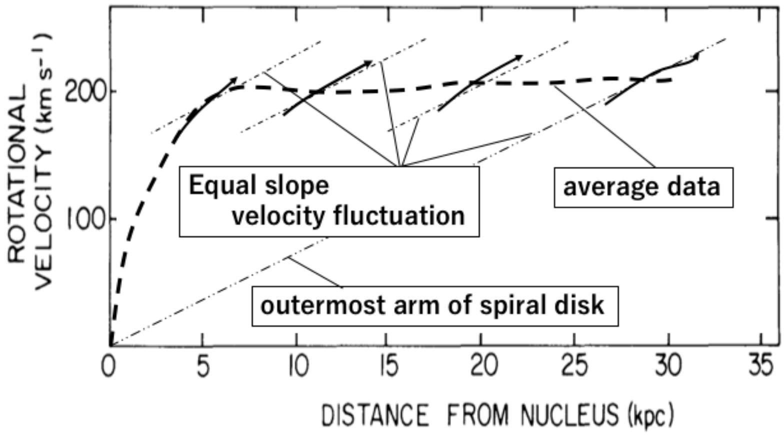

Figure 11. Velocity fluctuation characteristics seen in each arm of the NGC2998 galaxy.

In this figure, based on the velocity fluctuation characteristics shown in Figure 8, a dashed-dotted line and a dashed-double straight line are drawn for the slope of the solid arrow of each arm. As shown by the dashed-dotted line, the velocity fluctuations do not depend on the distance r from the galactic center and show a linear distribution with almost the same slope for each spiral arm. Stars inside the arms adjust the difference (distortion) between the inner and outer orbital distances using this distribution. Therefore, velocity fluctuation on the neutral plane does not occur, as shown by the average data of the dashed line. On the other hand, in the case of the outermost arm of the disk shown by the dashed-double straight line, the slope of the line is equal not only to the arm distance X_s but also to the distance r from the center of the galaxy.

4.1.2 Rotational motion due to internal gravity

On the other hand, within the cross section of the cylindrical arm, a gravitational component accompanied by rotational motion is formed as internal gravity to keep the motion of the stellar group stable. As shown in Figure 9, this gravity cannot exist alone, and is balanced by the centrifugal force f_2 due to a new rotational motion (velocity V_2) around the central axis. The existence of this rotational motion is predicted by the model (VFM), and it shows the reason why the cross section of the spiral arm is circular. This phenomenon has not been directly observed, but it is one of the proper motions in the rotation curve $V(r)$, like the velocity fluctuation mentioned above. The proper motion of the spiral arms has been observed and discussed in terms of three-dimensional velocity components (*U0, V0, W0*) for the Milky Way Galaxy, but the mechanism by which it occurs has not been elucidated due to the difficulty of measurement, etc. [16),17)] Therefore, the analysis results of the velocity fluctuation and rotational motion shown here are expected to provide new insights into the proper motion of spiral galaxies.

In the following discussion, in order to make the model (VFM) correspond to the proper motion, it is necessary to pay attention to the way the coordinate axes (X, Y, Z) in Figure 9 are taken. In proper motion, the velocity components (*U0, V0, W0*) are discussed in correspondence with three-dimensional space (X, Y, Z). In the case of the VFM this time, the direction of rotation of the Galactic disk is taken to be the Z-axis direction, so the plane that crosses this perpendicularly corresponds to the XY plane. Therefore, the *U0* component coincides with the X-axis direction, but the *V0* and *W0* components correspond to the opposite Z-axis and Y-axis directions, respectively.

The rotation velocity V_2 shown in Figure 9 corresponds to the vector sum of the two velocity components *U0* and *W0*, taking into account the proper motion so far. In addition, by adding the centrifugal force f_2 due to the rotation motion (rotation velocity V_2), three types of centrifugal forces (f_1, f_2, f_3) exist in the spiral arms in the analysis.

In the next section, 4.2, the motion of the spiral arm (the second circular orbit) that generates the centrifugal force f_2 will be discussed in relation to proper motion.

4.2 Analytical solution of rotational velocity V_2

Here, the rotational velocity V_2 occurring within the cross section of the arm is derived using a balance condition with local forces to see its function. The internal gravity F_2 and centrifugal force f_2 occurring within the cross section of the arm are given by equations (1) and (2), respectively, from the spherical structure (mass) inscribed in the cylindrical structure.

$$F_2 = G \cdot m \cdot M_2(r, r_s) / r_s^{\,2} \qquad (1)$$

$$f_2 = m \cdot V_2(r, r_s)^2 / r_s \qquad (2)$$

Here, r_s is the radius within the cross section of the arm, indicating the distance from the central axis. $M_2(r, r_s)$ depends on the distance r from the center of the galaxy, and is a spherical mass that exists within the distance r_s.

Next, by determining the spherical mass $M_2(r, r_s)$, an analytical solution of $V_2(r, r_s)$ can be obtained. The density distribution required in this case is a uniform distribution $\rho_0(r)$ that does not depend on the distance r_s, taking into account the stable rotational motion of the spiral arms. From this, the mass $M_2(r, r_s)$ that generates the internal gravity F_2 is given by equation (3).

$$M_2(r, r_s) = \int \rho_0(r)\mathrm{d}v$$

$$= (4\pi/3) \cdot r_s^3 \rho_0(r) \quad (3)$$

Using equations (1) to (3), the rotational velocity $V_2(r, r_s)$ in the arm cross section is given by equation (4).

$$V_2(r, r_s) = [(4\pi/3)G\rho_0(r)]^{1/2} \cdot r_s \quad (4)$$

This analytical solution $V_2(r, r_s)$ shows a rotational velocity proportional to the radius r_s from the center of the arm cross section, while having a close relationship with the radius r_s and uniform density $\rho_0(r)$.

From this, the rigid body motion of the spiral arm is formed not only on the disk surface (XZ plane) shown by the rotation curve $V(r)$ and velocity fluctuation, but also in the arm cross section (XY plane) perpendicular to this, and exists three-dimensionally. From another perspective, spiral galaxies have a more stable overall structure due to the rigid motions that form inside and outside the arms. In the next section 4.3, the nature of rigid motion due to such three-dimensional structures will be discussed in relation to proper motion.

4.3 Actual motion and proper motion of spiral arms

4.3.1 Prediction of actual movement state

First, I consider the actual motion (rigid body motion) occurring inside the arm based on the velocity fluctuation model (VFM). In the model, I have analyzed the velocity fluctuation V_3 (proper motion *V0* in the direction of galactic rotation) that appears in the rotation curve $V(r)$. However, because it also includes the rotational velocity V_2 (vector sum of proper motions *U0* and *W0*) with respect to the cross section of the spiral arms (XY plane), this has led to a unified elucidation of proper motion.

Looking at the movement of a spiral galaxy from a macroscopic perspective, as shown in the upper part of Figure 12, there is a three-dimensional rotation structure, consisting of a first circular orbit (horizontal rotation plane) that forms a disk around the galactic center O_1, and a second circular orbit (vertical rotation plane) that forms a new arm cross section perpendicular to this. At this time, the orbit of the rotation curve $V(r)$ forms a helical structure by adding two proper motions, rotation velocity V_2 and velocity fluctuation V_3, to the first circular orbit $V_1(r)$, as shown in the lower part of Figure 12.

Of particular note is the relationship between the velocities V_2 and V_3 shown in the orbit of the star. The star rotates once around the cross section orbit at the velocity of V_2, but at the same time, V_3 velocity reverses direction in a structurally timed manner inside and outside the neutral plane. This shows that the two proper motions of V_2 and V_3 are structurally closely related, and form an equal-periodic helical structure while integrating as a rigid body structure in the arm. This suggests that the stellar group may form a new, stable, multiple-helical structure with a common axis at the center of the spiral arms, something that was previously unthinkable.

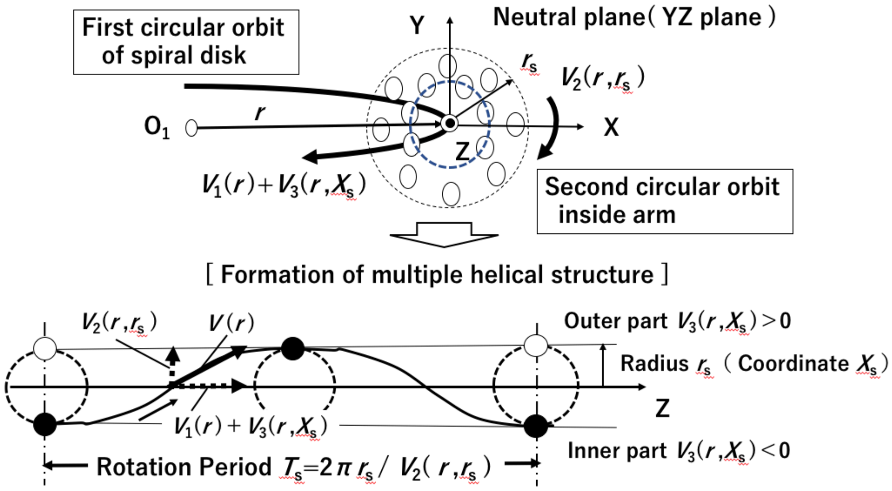

Figure 12. Existence of a multiple helical structure predicted from a new second circular orbit

The upper part of this figure shows a three-dimensional circular motion by a unified analysis based on the velocity fluctuation model (VFM). The first circular orbit (horizontal rotation plane) forms a disk around the center of the galaxy, and the second circular orbit (vertical rotation plane) is further formed in an arm cross section perpendicular to the first circular orbit. At this time, the orbit of the rotation curve $V(r)$ forms a helical structure as shown in the lower figure, due to the proper motion of the rotation velocity V_2 (vector sum of $U0$ and $W0$) and the velocity fluctuation V_3 ($V0$). From this, it is predicted that spiral galaxies form a new, unprecedented multiple helical structure with a common axis at the center of the arms.

Meanwhile, in the macro world, it has recently been pointed out that such spiral structures may also exist in the large-scale structure of the universe. [25] The shift caused by the Doppler effect predicts that the cosmic filaments of galaxies (groups of galaxies connected like strings) themselves rotate (in helical motion). The existence of this new helical structure in the spiral galaxy is thought to indicate a common hierarchical structure (formation of rigid body motion due to gravity) even on an expanded cosmic scale. This is the result of an analysis of the NGC2998 galaxy, but it is thought that a similar structure exists in the Milky Way galaxy.

Next, the true nature of the proper motion associated with the spiral arms will be examined based on current observational data.

4.3.2 Actual state of proper motion

The VFM analysis described in Sections 4.1 and 4.2 revealed that the proper motion of the arms forms velocity fluctuations due to two generation mechanisms. Among these, velocity fluctuations V_2 and V_3 have characteristics such as the same motion period, and form a stable rigid body motion within the arms.

Although many proper motions have been reported so far, there have been no concrete examples that specifically point out the existence of the helical structure predicted in this study from the current observational data. [12),16)-18)] This is thought to be due to the existence of the problem of variation in measurement accuracy described in Chapter 3 and the need for precise position observation (information) of the helical orbit. In the case of the Milky Way galaxy, the existence of a velocity distribution ($U0, V0, W0$) as a three-dimensional proper motion has been discussed from observations such as annual parallax measurements. It has been pointed out that there are characteristic differences in the proper motions, but theoretical support has not been established. Among them, observational data has been presented for the solar system, one of the fixed stars, with values of $U0$ (inward radial direction): 11.1±1 km·s^{-1}, $V0$ (galactic rotation direction): 12.24±2 km·s^{-1}, and $W0$ (vertically upward): 7.25±0.5 km·s^{-1}. [17)] However, there is no unified view on the proper motion indicated by these data.

This analysis has been successfully backed up theoretically by VFM, and has clarified the true nature of proper motion in a unified manner. The vector sum of the velocity components $U0$ and $W0$ in two directions gives the rotational velocity $V_2(r, r_s)$ that generates centrifugal force within the cross section of the arm. Therefore, $U0$ and $W0$ form a pair, and the following relationship is considered to hold between them and the rotational velocity $V_2(r, r_s)$.

$$V_2(r, r_s) = [\ U0(r, r_s)^2 + W0(r, r_s)^2\ ]^{1/2} \tag{5}$$

The remaining velocity component $V0$ forms $V_3(r, X_s)$ to maintain the curved structure of the spiral arms, as analyzed by VFM. $V_3(r, X_s)$ occurs in the direction with the same velocity vector as the rotation curve $V_1(r)$, as shown in Figure 12. For this reason, as mentioned in Chapter 3, it has been difficult to distinguish this phenomenon in terms of theoretical support and measurement accuracy.

Next, I will take the solar system as a concrete example and predict the helical period T_s shown in Figure 12 using the observational data of proper motion. The velocity $V_2(r, r_s)$ of the observed data is set to 13.26 km· s^{-1} using the average value [17)] of $U0$ and $W0$ mentioned above. Furthermore, if the orbital radius r_s is 400 pc [18], the period T_s is derived to be about 200 million years. This shows that the star group maintains rigid motion while switching between the outer and inner regions of the arm cross section every 100 million years. Additionally, the 200 million year period is intriguing, as it is equal to the solar system rotating once around the center of the galaxy. At this time, the velocity component $V0$ in the direction of galactic rotation increases or decreases so that the periods of the outer and inner orbital regions match, as mentioned above, mitigating the orbital difference. From this, it can be said that the phenomenon of velocity fluctuations (proper motion) that occur within the arms forms a helical structure (rigid body structure) in order for the stars to maintain a stable rotational motion $V(r)$.

In light of the above, I believe that the local model (VFM) used in this analysis is an effective tool for gaining new knowledge and predictions about spiral arms.

5. Conclusion

In order to solve the problem of the flattening of the rotation curve $V(r)$, this study has proposed and verified the "spiral gravity model (SGM)" that focuses on the geometric shape of the Milky Way Galaxy.

In this paper, I use this SGM as an analysis tool to solve the problem of unnatural measurement variations and characteristic velocity fluctuations that have been seen in observational data for a long time, and succeeded in elucidating the actual state of the spiral arms that occur within it. It was found that all of the variation problems occurs due to differences in centripetal force, and it was pointed out that by removing this cause, the measurement accuracy can be reduced to a few percent of the statistical deviation.

In the process, in order to clarify the mechanism of the generation of velocity fluctuations, a new local gravity model, the "velocity fluctuation model (VFM)", was proposed and theoretically supported. In this VFM analysis, it was found that in principle, new gravity is generated by the spiral structure rather than by an increase in mass. At the same time, the actual state of the proper motion ($U0$, $V0$, $W0$) that moves like a rigid body was also analytically confirmed. As a result, the existence of an unexpected motion (a second rotation orbit) inside the arms was revealed, and the existence of a new three-dimensional multiple helical structure was predicted.

As described above, by using the two models (SGM and VFM) as analytical tools, I have obtained many important findings and predictions about spiral galaxies. It is expected that verification of these findings in the future will lead to a major reexamination of the cosmology of spiral galaxies and a dramatic advance in our understanding.

5.1 Problems with measurement variation

Currently, the observed data of rotation curves show unnatural phenomena, such as the fluctuation range of the average value being larger than the deviation, which has caused problems in terms of measurement accuracy. However, these phenomena have long been considered problems with measurement technology because the causes could not be theoretically elucidated.

This time, from the results of an analysis of this problem using mainly SGM, it was found that there are two significant causes of occurrence. These causes have long been recognized empirically, but they were completely incomprehensible because they are based on Kepler's law (theory). In principle, both causes are related to differences in centripetal force (gravity) at the point of measurement. By theoretically backing this up, it becomes a problem that can be distinguished, rather than a statistical variation or an error in data acquisition and processing technology.

It was pointed out that this problem can be solved by appropriately selecting the measurement location and measurement method, and the cause of the significant difference can be removed, improving the current deviation of about 10% to a few percent, which is the original statistical deviation.

5.2 Mechanism of velocity fluctuation phenomenon

The velocity fluctuations[15)] pointed out by Vera Rubin et al. are fluctuation characteristics in the galactic rotation direction of the $V(r)$ characteristic, and are also one of the proper motions. In order to clarify the mechanism of their generation, I have proposed a velocity fluctuation model (VFM) for the cylindrical structure of the spiral arms.

In this model, local internal gravity occurs inside the spiral arms, and there are two types of components that change from the gravity of the spherical structure (mass) to form and maintain the cylindrical structure. The gravity component along the central axis, which becomes the binding force of the arms, and the gravity component toward the central axis of the arm cross section perpendicular to this component. Using this model, it was found that the velocity fluctuations are generated by the binding force generating a "new force (internal force)" due to the "bending structure" (distortion) of the spiral arms. Inside the arms, the interaction of the stellar groups generates gravity equivalent to bending stress (new force) consisting of compressive and tensile forces at the neutral plane passing through the central axis. This gravity is outward and inward with respect to the center of the galaxy, and as the observational data shows, it increases and decreases in proportion to the position (distance) X_s from the neutral plane.

The characteristic that emerges from this is that gravity is generated by spiral motion (structure) even without an increase in mass, and I believe that this indicates a new principle of gravity generation, as in the case of SGM. The velocity fluctuation is a phenomenon that cannot be considered at all based on Kepler's law. Furthermore, the centrifugal force that balances this gravity occurs in the same disk plane as the centripetal force that causes the rotational motion of the galaxy, but acts independently. The centrifugal force in this case changes depending on the distance X_s from the neutral plane, just like the new force, and unlike the case where it changes with the radius r in the rotation curve, it shows a new type of action.

In this way, the successful analysis of the mechanism has revealed new facts about spiral motion.

5.3 Theoretical support for proper motion

Through velocity fluctuation analysis using VFM, I clarified the reality of three-dimensional proper motion based on theoretical support. The velocity component $V0$ of proper motion corresponds to the velocity fluctuation $V_3(r, X_s)$, and adjusts the orbital difference by rigid body motion, stably maintaining the curved structure of the spiral arm. The velocity vector of $V_3(r, X_s)$ occurs in the same vector direction as the rotation curve $V(r)$, so it is a phenomenon that was difficult to separate in measurement. On the other hand, the velocity components $U0$ and $W0$ correspond to the rotation velocity $V_2(r, r_s)$ of the centrifugal force generated on the arm cross section by the vector sum of the two directions. Therefore, $U0$ and $W0$ form a pair, and I believe that the relationship equation (5) holds between the three, including the rotation velocity $V_2(r, r_s)$. From the analysis results, $V_2(r, r_s)$ is proportional to the radius r_s of the arm, and the proper motion in this case also forms a stable rigid body motion. From this, the proper motion forms a three-dimensional rigid body motion through two generation mechanisms. In particular, V_2 and V_3 form a stable second circular orbit (spiral motion) within the arm, with the added feature that their motion periods are structurally identical.

However, in the case of the Milky Way, although the existence of proper motions ($U0, V0, W0$) has been observed to date, the spiral structure behind them has not been predicted. I believe that the main reason for this is that it was not possible to distinguish them due to the measurement variability of the observational data discussed in this study and the difficulty of measuring their positions.

This analysis provides unified support for the proper motion seen in the rotation curve, and I believe it has clarified the true function of the velocity fluctuations.

5.4 Prediction of a new nature of spiral arms

This VFM analysis revealed the existence of an unexpected motion (second rotational orbit) inside the spiral arms. In addition to the first circular orbit (horizontal rotational plane) of the spiral disk, the galaxy's star group forms a second circular orbit (vertical rotational plane) due to proper motion, and the existence of a new three-dimensional multiple helical structure is predicted. Of particular interest, as mentioned in Section 5.3, is the relationship between the velocity fluctuations V_2 and V_3, which are proper motions. The star rotates periodically within the orbit of the arm cross section at the velocity of V_2, but at this time the velocity of V_3 changes direction in a way that matches the timing of the structure. From this, the two orthogonal velocity fluctuations (V_2, V_3) are closely related, and form a helical structure with a periodicity inside the arm while moving rigidly. From another perspective, the proper motions (*U0, V0, W0*) form a helical structure (rigid structure) in order for the star group of the spiral galaxy to maintain a stable rotation curve $V(r)$. From this, I believe that the stellar group forms a stable multiple helical structure with a common axis at the center of the spiral arms, which has never been seen before. Stars switch positions inside and outside the arms due to their spiral motion (period T_s), which may affect the movement and environment of the solar system and the earth. What is noteworthy here is that the helical period T_s inside the arms is almost the same as the period in which the solar system rotates around the center of the galaxy. Furthermore, in relation to this, the existence of a helical structure has been predicted due to the shift caused by the Doppler effect in galactic filaments (galaxy groups), which are large-scale structures in the universe.

From this, it is thought that even in galaxy groups expanded to a cosmic scale, the rotational motion caused by gravitational action may change shape to form a common stable hierarchical structure (formation of rigid body motion).

Acknowledgements

In this study, I take the position that Kepler's law do not hold based on past observational data. This problem was analyzed with the idea that the cause could be eliminated by appropriately distinguishing the measurement objects based on the principle of SGM. In the process, observational data that seemed to have been separated was found, and for the first time, the reduction in variation could be directly confirmed. The existence of this data gave me great confidence in solving the problem and also provided support for the SGM theory. Furthermore, by analyzing the problem of velocity fluctuations, which is proper motion, I also discovered a new form of motion for the spiral arms.

In this way, thanks to the fact that I were able to cite a large amount of observational data, the purpose of this study was almost achieved. I would like to express our deep gratitude to all the authors.

References

1) F. Zwicky, Helv. Phys. Acta., 6, 110-127 (1933).
2) G. Bertone, and D. Hooper, FERMILAB-PUB-16-157-A, III(11-15) (2016).
3) Y. Sofue, PASJ, 1-34 (2014).
4) James Q. Feng, Galaxies, *8*(1), 9 (2020); Rotating Disk Galaxies without Dark Matter Based on Scientific Reasoning, doi.org/10.3390/galaxies8010009.
5) M. J. Reid, and T. Dame, ApJ, 832, 159 (2016).
6) Y. Sofue, Galaxies, 8, 37 (2020).
7) G. Mohan, U. D. Goswami, 2023.11: Galactic rotation curves of spiral galaxies and dark matter in f (R, T) gravity theory, arXiv:2211.02948v2 [gr-qc].
8) M. Rybicki, Journal of Modern Physics, 14, 72-87 (2023).
9) D. Babusci, F. Bossi, The problem of dark matter - INFN-LNF (2018).
10) Reyes, R., Mandelbaum, R., Gunn, J.E., et al, Mon. Not. R. Astron. Soc., 425, 2610-2640 (2012).
11) C. Shuohui, 2024: Dark matter: The mysterious entity in the universe, DOI:10.54254/2753-8818/38/20240567.
12) W. Dehnen, J. Binney, Mon. Not. R. Astron. Soc. 298, 387–394 (1998).
13) Y. Sofue, M. Honma, and T. Omodaka, PASJ, 61, 227–236 (2009).
14) Y. Akiba, 2023.2: A New Gravitational Model of Spiral Galaxies Based on Newtonian Mechanics, DOI: https://doi.org/10.51094/jxiv.268.
15) V. C. Rubin, W. K. Ford, Jr., and N. Thonnard, ApJ, 225, L107-L109 (1978).
16) N. Sakai, M. Honma, H. Nakanishi, et al., PASJ 64, 108 (2012).
17) R. Schonrich, J. Binney, W. Dehnen, Mon. Not. R. Astron. Soc. 403, 1829–1833 (2010).
18) M. J. Reid, K. M. Menten, A. Brunthaler, et al., 2019: Trigonometric Parallaxes of High-mass Star-forming Regions: Our View of the Milky Way, arXiv:1910.03357v1 [astro-ph.GA] 8 Oct 2019.
19) J. E. Gunn, G. R. Knapp, and S. D. Tremaine, AJ, 84, 1181 (1979).
20) N. Sugiyama, JPSJ, 70, 2 (2015).
21) Y. Sofue, PASJ, 69, R1 (2016).
22) L. Blitz, C. J. Lada, ApJ, 227, 152 (1979).
23) D. P. Clemens, The Astrophysical Journal, 295, 422-436 (1985).
24) M. Honma, T. Nagayama, N. Sakai, PASJ, 67, 70 (2015).
25) Peng Wang, Noam I. Libeskind, Elmo Tempel, et al., Nature Astronomy, vol.5, 839–845 (2021).