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Galactic Rotation Curve Need Be Improved for the Discovery of Sgr A*

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Abstract: Galactic rotation curve was formulated before the Sgr A* had been confirmed. The action of the Sgr A* on the rotation curve has not been considered. Now, it was observed that the fastest stars in the Milky Way is in the distance less than 0.5pc from the Sgr A*. It is contradicted with the current galactic rotation curve in which the orbital velocity near the center of the galaxy is the smallest. And, because of the advance of technology, it was observed that the circular velocity curve of the Milky Way from 5 to 30 kpc is with a significantly faster decline (Keplerian decline) compared to the inner parts. It is contradicted with the current curve in which the out parts could be larger or no decline. And, it was observed that the fast galaxy bar continue challenge the standard cosmology. For the reasons, we present an improved galactic rotation curve.

Keywords: Sgr A*; galactic rotation curve; galaxy bar; orbit of S-stars

1. Introduction

Milky Way rotation curve was originally found by Babcock [1] in 1939 and Oort [2] in 1957. It is an important discovery to understand the structure and motion of our Milky Way. Current galactic rotation curve was formulated before 1980 [3] while the Sgr A* was confirmed after 2000 [4,5]. Therefore, in the rotation curve, the Sgr A* cannot be considered. But, the action of the Sgr A* on the orbits in the whole galaxy is very important: 1) most importantly, all of the celestial bodies, including both the baryonic and gaseous matters, are rotating directly or indirectly around the Sgr A*; 2) the fastest stars is near the Sgr A* [6–11]. Therefore, an improved galactic rotation curve is needed to understand the observations after the Sgr A* was confirmed. Although the Sgr A* was considered in the rotation curve early in 2001 [12], it still has not been noted theoretically and observationally that, in the curve, the largest orbital velocity is the S-stars around the Sgr A*. The current rotation curve is still within the frame presented in 1980 [3]. It is clearly contradicted with new observations.

It was tried to revise the galactic rotation curve from theory and observations. In theory, different revised curve was presented [12–16]. In observations, first, it was observed that the circular velocity curve of the Milky Way from 5 to 30 kpc is with a significantly faster decline (Keplerian decline) compared to the inner parts [17–23]; second, the fast galaxy bar continue challenge the standard cosmology [24–27]; third, the fastest stars is near the Sgr A* [6–11].

In this work, we present an improved rotation curve by only combining the new observations [4–11,17–27]. Therefore, only the orbits of star and black hole is considered while the rotation of gaseous and other objects is omitted. We think, the orbit in a galaxy is determined with the structure. The action of the bar and the stellar cluster on the rotation curve are focused on. It is presented that some of the stars in the bar or in a stellar cluster cannot have the orbit directly around the Sgr A*.

2. New Observations and Improved Galactic Rotation Curve

From the new observations: the Sgr A* [4,5] and the fastest stars [6–11], the circular velocity curve [17–23] and the fast galaxy bar [24–27], the improved galactic rotation curve is expressed in Figure 1.

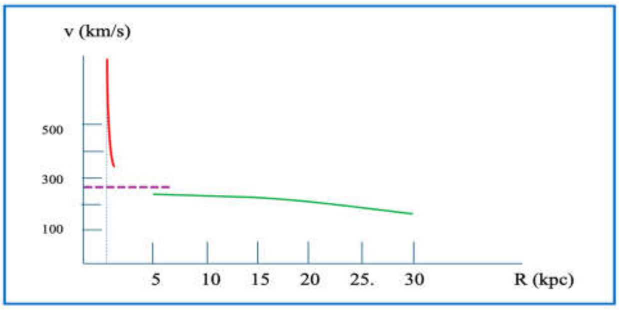

Figure 1. The improved galactic rotation curve. The dotted blue line is the smallest radius of the star orbiting around the Sgr A*. The green curve is the recent observed Milky Way circular velocity curve. The red curve is the orbital velocity of the stars near the Sgr A*, the largest velocity of them is 8% of the light speed. The purple dotted straight line is the rotation velocity of the bar which is obtained from the observed bar pattern speed. The red curve is not connected with the green one for that the rotation curve in the bar cannot be observed.

The improved rotation curve is made up of three parts:

First, the Milky Way circular velocity curve. It was observed that the circular velocity curve of the Milky Way from 5 to 30 kpc is with a significantly faster decline (Keplerian decline) compared to the inner parts. The curve in green from 5 to 30 kpc is directly obtained from the observations in Refs [17–23].

Second, the rotation curve of the stars near the Sgr A*. It was observed that the fastest star is with almost 8% of the light speed. Therefore, in the whole Milky Way, this is the observed fastest star. And, the orbital velocity of the S-stars in the radius of $R \leq 0.5pc$ was observed [6–11]. The red curve is based on the observations. But, the orbital velocity of the stars with the radius of $0.5\,pc \leq R \leq 5kpc$ has not been observed. The other part of the red curve is only a calculated result according to $v = \sqrt{M_{SgrA*}/R}$.

Third, the rotation curve about the bar. The orbits in the bar are very complicated. Now, the complete orbital velocity in the bar has not been observed. Because the structure of the bar is very complicated and is unclear, the orbital velocity in it cannot be calculated theoretically.

In recent, several teams observed the fast bar pattern speed. The rotation curve of the bar which is expressed in the purple dotted straight line in Figure 1 is obtained from the observed bar pattern speed [24–27].

3. Discussions

In this work, it is emphasized that the galactic rotation curve is determined with the structure of a galaxy. Before the structure has not been known, the orbits in it cannot be clear. For example, before the Sgr A* had been discovered, we cannot know that the fastest stars are in the center of the Milky Way. Now, the structure of the Milky Way has been generally known. 1) at the center of the Milky Way, there is the Sgr A* which the whole galaxy is rotating around; 2) around the Sgr A*, there is a bar; and 3) out of the bar, there is the galactic disc which is formed by that a lot of celestial bodies, including stars, planets, other black holes, nebula, gas and so on, are orbiting or rotating around the Sgr A*. Here, we shall discuss the improved rotation curve as shown in Figure 1 by considering the structure of our galaxy.

3.1. The Rotation Curve in the Galactic Disc

It is noted that there are stellar clusters in the disc which is with 10 to more than 10^5 stars. From Newtonian theory of gravity we know a center mass is needed to form a star cluster [28], such as the possible intermediate-mass black hole in ω Centauri with the stars [29]. (here, it is called the black hole—stars cluster). It results in that the speed of the stars in the black hole—stars cluster is

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complicated, such as that there are the fast-moving stars around an intermediate-mass black hole in ω Centauri.

In a stellar cluster, the speeds of the stars relative to the Sgr A* could be expressed in Figure 2:

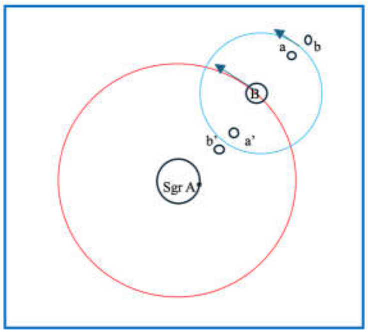

Figure 2. The difference between the speeds of the stars in and out a stellar cluster. The green circle is a black hole-stars cluster. B is a black hole at the center of the cluster. a and a′ are the stars in the cluster while b and b′ are the stars out of the cluster. The distances between a and b and between a′ and b′ are very small. The red circle is the orbit of the black hole B around the Sgr A*. The black hole and the stars are orbiting along the arrows.

In Figure 2, the black hole B orbits around the Sgr A* in the red orbit while a lot of stars orbit around the B to form a stellar cluster in the green circle. The stars a, a′ and b, b′ are on the edge of the cluster and a and a′ is in the cluster while b and b′ is out. The distances between a and b and between a′ and b′ are very small. It is easy to know that, around the Sgr A*, the speed of the stars a and b are $v_a = \sqrt{M_{SgrA*}/R} + \sqrt{M_B/r}$ while $v_b = \sqrt{M_{SgrA*}/(R+r)}$; and that of the stars a′ and b′ are $v_{a'} = \sqrt{M_{SgrA*}/R} - \sqrt{M_B/r}$ while $v_{b'} = \sqrt{M_{SgrA*}/(R-r)}$, where M_{SgrA*} and M_B are the mass of the Sgr A* and B, R and r are the orbital radius of the B around the Sgr A* and the star a around the B. (It is noted that the fast-moving stars around an intermediate-mass black hole in ω Centauri showed that the Poisson equation is invalid to understand why these stars are fast and why there is a difference of velocities between the star a and b and between a′ and b′. So, here, the Poisson equation is not considered.) Therefore, the speed of the stars in a stellar cluster around the Sgr A* is variant. These stars cannot have an orbit around the Sgr A*. The motion of these stars cannot form the galactic rotation curve while only the orbit of the black hole B can form the curve analogous to the solar system orbiting around the Sgr A* which was studied in detailed in [28].

Usually, the scale of a stellar cluster is very large, such as with a radius larger than 100 light years. If the stars in a stellar cluster are selected to measure the rotation curve, the difference of the measured results for different stars is very large.

3.2. The Rotation Curve and the Bar

The shape of the bar is stable. Therefore, the bar can be treated as a single rigid body. Although the Sgr A* is in the bar, the bar rotating around the Sgr A* is analogous to a stellar cluster rotating around the Sgr A*: the bar with the stars in it is rotating as a single body. From Figure 2, it is easy to know that the velocity of some of the stars in the bar is also a sum of two parts: the velocity of the bar rotating around the Sgr A* and the orbital velocity of the stars. Just as the velocity of the stars in a cluster, the stars cannot have an orbit around the Sgr A*.

But, the structure of the bar is more complicated than that of a stellar cluster. In the bar, it was observed: 1) the pure cylindrical rotation [30,31], 2) the orbits in different components in the bar correspondent to different distinct orbital families [32,33], and, 3) two red clumps [34] or an inner bar [35] which may be with different orbits.

It is noted that, the bar pattern speed cannot describe the orbital speeds of the stars in the bar. It only is a description of the motion of the bar as a single rigid body rotating around the Sgr A*.

For these reasons, we cannot have a Figure to directly describe the motion of the stars in the bar by analogous to that in a stellar cluster as shown in Figure 2. Therefore, the purple dotted straight line is only the rotation speed of the bar obtained from the observed bar pattern speed.

It is generally thought that the stars around the Sgr A* can form the Milky Way rotation curve which is continuous without any structure. But, the Milky Way is with complicated structure which results in that the motion of the stars in it are correspondently complicated. The complicated structure and tremendous scale of the bar and some stellar clusters make the continuous rotation curve impossible.

It was conjectured that there may be another supermassive black hole in the bar [36]. Under the conjecture, the orbits of the stars in the bar should be better understood.

*3.3. The Rotation Curve Near the Sgr A**

The orbits of the stars near the Sgr A* is much simpler than that in the all bar and in the disc. It is clear, these orbits are directly orbiting around the Sgr A*. The velocity of the orbits is simply determined with $v = \sqrt{M_{SgrA*}/R}$. Therefore, the orbits near the Sgr A* can form the rotation curve.

It is noted, although the S-stars are in the bar, the orbits of them cannot be affected by the motion of the bar. The reason is that the Sgr A* is the only center for both of them orbiting or rotating around.

In current observation, the shortest radius of the orbit of the S-star around the Sgr A* is almost 3 AU and the largest orbital velocity is almost 8% of the speed of light [6–11]. While it has not been observed, in the bar, what is the largest radius of the orbit that a star is directly around the Sgr A*. So, now, we have not observed the smallest orbital velocity with the orbital radius of the stars in the bar directly around the Sgr A*.

It was observed that the orbits of the S-stars are in a sphere, rather than in a plane [6–11]. But, it is certain, there are the orbits of the S-stars in the plane of the rotation curve. And, the other orbits can be transferred to the plane.

4. Conclusion

1) In the current galactic rotation curve, the orbital velocity in the center of the Milky Way is the smallest; while, in the improved one that is the largest. It is clear, after the Sgr A* was discovered, it is easy to know that the orbital velocity near the Sgr A* is the largest.
2) The improved rotation curve is not continuous. The bar is rotating around the Sgr A* with a stable shape and there are two red clumps [34] or an inner bar [35]. The orbits in the bar is very complicated [30–35].
3) The recent observations [17–23], which are based on the advanced technology, directly showed that the improved rotation curve from 5 to 25 kpc is with the Keplerian decline.

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