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The Mass of the Center of the Milky Way Revalued from the Fastest Orbits around the Center and the Circular Velocity Curve of the Milky Way

yin zhu *

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The Mass of the Center of the Milky Way Revalued from the Fastest Stars, Fast Galaxy Bar and the Circular Velocity Curve of the Milky Way

Yin Zhu

Agriculture and Rural Department of Hubei Province, Wuhan, China; waterzhu@163.com

Abstract: The new observations, including the fastest star, the circular velocity curve of the Milky Way and the fast galaxy bar, should imply that the mass of the center of the Milky Way is almost $10^{11} M_{\odot}$.

Keywords: fastest star; circular velocity curve of the Milky Way; fast galaxy bar; mass of the center of galaxy; Newtonian theory of orbit perturbation

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The galactic rotation curve, that was originally presented by Babcock, Oort and Rubin from 1939-1980, has been observed and studied for a long time. [1–3] Because of the advancement of the technology, now, the observation of the velocity of the orbit of the stars in our galaxy is more accurate and precision in a larger area. [4–19] First, the fastest star in the Milky Way was observed. [4–9] The S62 has the shortest known stable orbit around the supermassive black hole in the center of our Galaxy to date. It is with $t_{period} = 9.9\ yr$ and a periapse velocity of approximately 10% of the speed of light. [4] It is contradicted with the galactic rotation curve [1–3] in which the largest velocity is $V_{max} < 300\text{km/s}$ at the distance of $\text{R} \approx 6.5\text{kpc}$ from the center of the galaxy. Second, in recent, the circular velocity curve of the Milky Way from 4 to 30 kpc was measured. [10–15] It was observed that a significantly faster decline (Keplerian decline) in the circular velocity curve compared to the inner parts. It is contradicted with the previous observation for the galactic rotation curve in which the out parts could be larger or no decline. Third, in recent, it was observed that the fast galaxy bars continue to challenge standard cosmology [16–19] and the ultrafast bar cannot be ruled out. [19] From [4–19], we have Figure 1. It clearly showed that the traditional galactic rotation curve is questioned. Therefore, new understanding is needed for the new observations.

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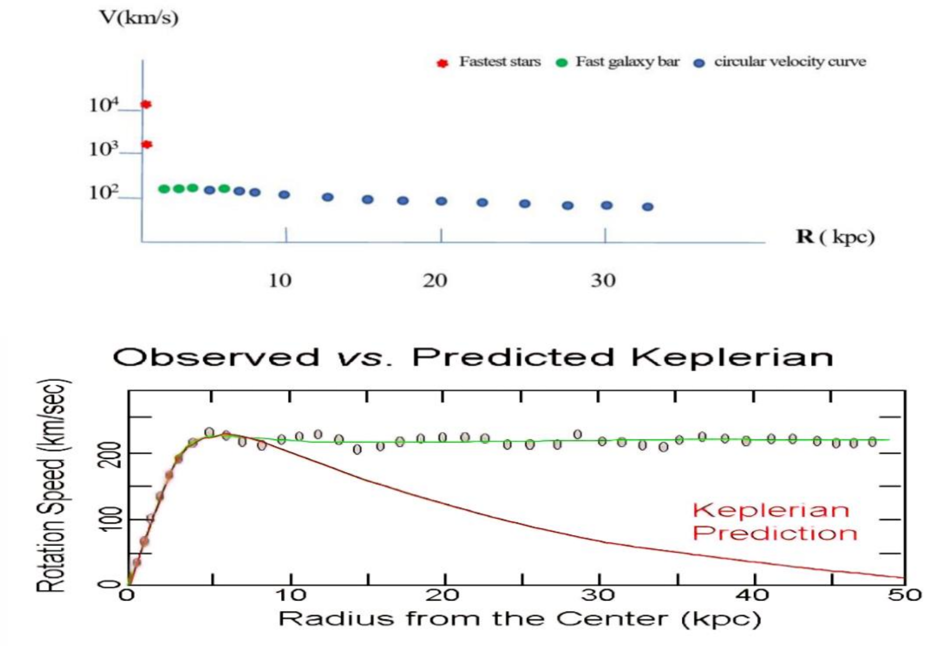

Figure 1. New observed circular velocity curve of the Milky Way *vs* **the traditional galactic rotation curve.** *Top*: The circular velocity curve of the Milky Way is organized from different observations in [4–19]. Including: the fastest stars (red) [4–9], fast galaxy bar in Figure 4 of [16] (green), the circular velocity curve of the Milky Way [10–15] (blue). *Bottom*: The traditional galactic rotation curve selected from internet. [20].

Here, we emphasize, the current theory for the orbit of the star/stellar around the center of the galaxy was misled by the Poincaré's equation for Three-body problem. For the convenience of the readers, we copy our previous sentence here: [21]

Newton established the theory of orbit in 1660s. But, Newton's theory has not been completely understood till now. As soon as comparing Poincaré's equation of Three-body problem with Newtonian orbital perturbation theory, we shall know what is the problem in current understanding about Newtonian theory of gravity. The Sun-Earth-Moon system is the oldest Three-Body problem. It is clear, the orbits about it was well resolved by Newton. But, there is a famous old problems: calculating with $F = G\frac{Mm}{R^2}$*, the attractive force of the Sun on the Moon is almost 2.2 times that of the Earth, but the orbit of the Moon around the Earth cannot be broken off by the Sun. It is clear, as Poincaré's equation for Three-body problem is applied on the solar system, the orbits in it should be broken off in a short time. We think, this is the crucial evidence to show that the Poincaré's equation for Three-body problem is wrong. And, the triple star system and multiple star systems, including Six-star system, [22,23] were observed. The orbit in these systems are stable and certain.*

The Poincaré's equation for Three-body problem is very strange. First, no orbit of the celestial body is chaotic. A broken orbit also is predictable. So, Poincaré's equation cannot be related with any real orbit. Second, the orbits of the typical Three-body system, such as the Sun-Earth-Moon system and Sun-Pluto-Charon system, are stable. Poincaré's equation is invalid to understand these orbits. Third, Poincaré's equation is invalid to design an artificial orbit. It is very clear, the Poincaré's equation is nonsense in understanding any real orbit. Additionally, the relationship between the Poincaré's equation and other theory is very weak. If there was not Poincaré's equation, the celestial dynamics could not be affected. But, very unfortunately, Poincaré's equation is the mainstream understanding about Newtonian theory of gravity. It results in that, the current theory of orbit about the galaxy is questioned.

Applying the Poincaré's equation to the N-body problem, there is the Poisson equation: $\nabla^2\varphi = 4\pi G\rho$, $\mathrm{M} = \iiint \rho dV$, $\varphi = -\mathrm{G}\frac{M}{r}$. Therefore, the Poisson equation is also wrong in studying celestial

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orbit. Consequently, the formula, $g = G\frac{M(R)}{R^2}$, where M(R) is the sum of all the mass in the radius of R, is wrong. In another word, the Poisson equation is the same as the Poincaré's equation for the Three-body problem in misunderstanding the Newtonian theory of gravity. As the Three-body problem is described with the Poisson equation, the described orbits of them also are chaotic.

In the Newtonian theory of gravity, [21] the radius and velocity of the orbit of all the stars/stellar in a galaxy is only determined with

$$g = G\frac{M_{center}}{R^2} \quad (1)$$

where, M_{center} is only the mass of the center of the galaxy. Therefore, the circular velocity curve of the Milky Way could be predicted only with the mass of the center of the galaxy.

In the Newtonian orbit theory of perturbation, from the velocity of the orbit of the Sun around the center of the Milky Way, it could be concluded that the mass of the center of the Milky Way should be $M_{center}{\sim}10^{11}M_{\odot}$. This conclusion could be approximately accordant with that from the circular velocity curve of the Milky Way [10–15]. Therefore, if the Newtonian orbit theory of perturbation is right to the orbit of the galaxy, the mass of the center of the Milky Way should be $M_{center}{\sim}10^{11}M_{\odot}$.

We noted that, $M_{center}{\sim}10^{11}M_{\odot}$ is a very big mass. The total mass of the Milky Way is ${\sim}5.8\times10^{11}M_{\odot}$. [24] And, it is currently thought that the mass of the center of the Milky Way is ${\sim}4\times10^{6}M_{\odot}$. [25,26] Here, it is emphasized that the current thought were misled by the wrong Poisson equation (or the Poincaré's equation). It is clear, the galactic rotation curve only is a conclusion of the Poisson equation. Although that the mass of the center of the Milky Way is $4\times10^{6}M_{\odot}$ was obtained from different observations, [25,26] it is only such a conclusion that is mainly misled by the Poisson equation and the traditional galactic rotation curve. First, it is contradicted with the new observations in [10–19] while highly accordant with the Poisson equation and the traditional galactic rotation curve. Second, it is much more important, the orbit about the star S4714 [6] is clearly questioned by the Roche limit. The periapse distance of S4714 only is $r_p = (12.6 \pm 9.3)au$ while the Roche limit can be $d > 200au$ for the S-star under the condition that the mass of the center of the Milky Way is $4\times10^{6}M_{\odot}$. Third, It seems that that the precision of the distance between center of the Milky Way and our Sun is $R_0 = 8.32 \pm 0.07|_{stat} \pm 0.14|_{sys}kpc$ [27] is too large to have an accurate orbit in the radius of $R \le 0.5pc$. The orbits of the S-stars is taken as a critical factor to have the conclusion that the mass of the center of the Milky Way is $4\times10^{6}M_{\odot}$. [25–27] Therefore, new understanding is needed to have a more accurate mass for the center of the Milky Way.

From $V = \sqrt{GM/R}$, as $M_{center}{\sim}10^{11}M_{\odot}$, the complete figure for the circular velocity curve of the Milky Way for $R = 0{\sim}30kpc$ could be shown with the Figure 2.

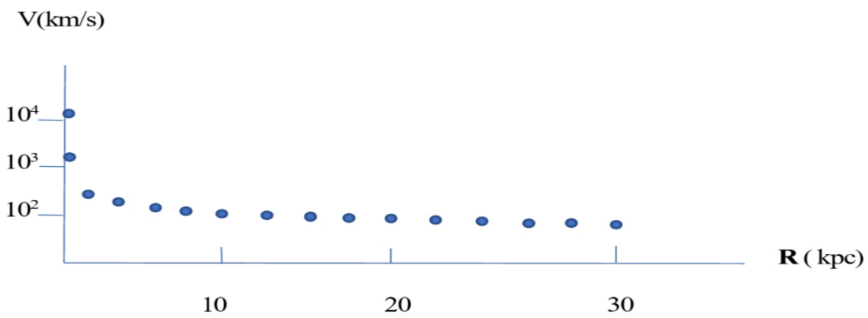

Figure 2. The calculated circular velocity curve of the Milky Way for $M_{center} = 1\times10^{11}M_{\odot}$. The observed largest V is approximately 10% of the speed of light. At $R = 8.3kpc$, the velocity of the Sun is ${\sim}220km/s$. In a rough standard, this Figure is approximately accordant with the observations of the fastest orbits [4–9] and the circular velocity curve of the Milky Way [10–15]. And, for the ultrafast galaxy bar, [16–19] the Figure 4 in [16] is practically accordant with this Figure in $2kpc \le R \le 6.5kpc$.

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In addition, the measurements in [10] for $5\text{kpc} \leq \text{R} \leq 6.5\text{kpc}$ and in [11] for $4\text{kpc} \leq \text{R} \leq 6.5\text{kpc}$ are practically accordant with this Figure.

Astonishingly, the circular velocity curve of the Milky Way predicted from the Newtonian orbit theory of perturbation in the Figure 2 is completely accordant with the new observed circular velocity curve of the Milky Way in the Figure 1. Especially, the conclusions in [10–19] is obtained under the condition that the Newtonian orbit theory of perturbation has not been considered.

It is noted that, in the Newtonian theory of gravity, besides the center of the galaxy, other stars also have actions on the orbit. Because all stars are orbiting around the center of the galaxy, [21,28] just as the planets are orbiting around the Sun, and, only the Newtonian theory of orbit perturbation is valid to understand the celestial orbit, [21,29] the orbit of a star around the center in a galaxy only can be described with the Newtonian theory of orbit perturbation:

$$g_{total} = G\frac{M_{center}}{R_{cs}^2} + \sum g_i \quad (2)$$

where c and s denote the center of the galaxy and the stars, $\sum g_i$ is the perturbation of other stars on this star, $g_i = G\frac{M_{si}}{R_{ssi}^3}\boldsymbol{dr}$, where $\boldsymbol{dr}$ is a vector which determines that $\sum g_i$ can be very little. From Eq.(2) we know, (for convenience, assuming that the orbit is a circle,) the radius and velocity of an orbit is determined with Eq.(1) while it is perturbed by other stars/stellar with $\sum g_i$. But, the perturbations are so little that the radius and velocity of the orbit can be approximately determined with Eq.(1). And, as the perturbation is large, the orbit shall be broken of. So, to know the velocity of the orbit for our purpose, the perturbation need not be considered. Therefore, although the Figure 2 is only an approximation to the real orbit, it is useful to know the velocity and radius of an orbit.

It is important that the S-star cluster was observed. [25–27,30] First, the S-star is confined to a region of 0.04 pc from Sgr A* and the fastest stars are observed from them. [4–9] Second, nearly 200 massive stars have been detected in the Sgr A* proximity. The disk stars have semimajor axis in the range of $0.04\text{ pc} \leq \text{R} \leq 0.5\text{pc}$. [30] As pointed out in the above, that the mass of the center of the Milky Way is $4 \times 10^6 M_\odot$ related with the Poisson equation and the traditional galactic rotation curve need be reconsidered.

Under the condition of $M_{center} = 1 \times 10^{11} M_\odot$, the calculated velocities of the orbits of the S-stars in the radius of $0.04\text{ pc} \leq \text{R} \leq 0.5\text{pc}$ can be shown in Figure 3.

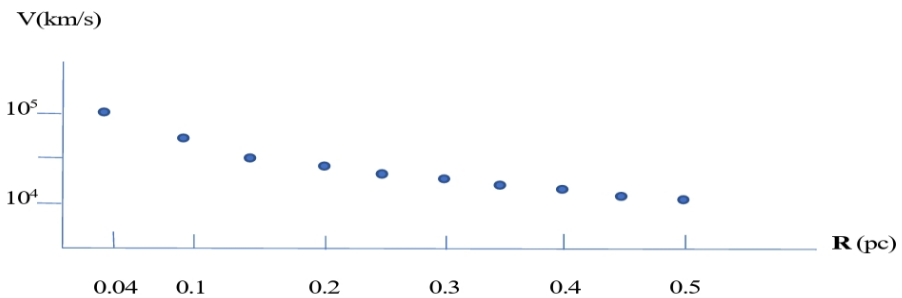

Figure 3. The circular velocity curve of the Milky Way as $M_{center} = 1 \times 10^{11} M_\odot$ for the S-stars in the radius of $\text{R} \leq 0.5\text{pc}$. As $\text{R} = 0.04\text{pc}$, $\text{V} \approx 1 \times 10^5 km/s$. As $\text{R} = 0.5\text{pc}$, $\text{V} \approx 2.9 \times 10^4 km/s$.

However, in the Figure 3, the velocities in the radius of $\text{R} \leq 0.5\text{pc}$ seems too large for current perception. But, the observed and predicted circular velocity curve of the Milky Way in the Figure 1 and Figure 2 are so accordant with each other, we intend to believe that the velocities in the Figure 3 is possible. And, it should be easy to have a right observed orbits of the S-stars cluster for these reasons: 1) the technology for the measurement is being fast advanced; 2) we clearly know that the orbits of the S-star cluster in [4–9] related with the traditional galactic rotation curve and the Poisson equation need be reconsidered; and 3) the light is dispersive in the gravitational field, [31] the velocity of celestial body larger than that in the Figure 3 is not impossible.

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Conclusions: 1) Figure 1 clearly contradicted the traditional galactic rotation curve with the Poisson equation. It showed that the mass of the center of the Milky Way need be reconsidered. 2) Figure 2 is a new predicted galactic circular velocity curve by returning to the Newtonian theory of gravity. The observations in [4–19] could be complete evidence for it. It is astonishingly accordant with the new observed circular velocity curve of the Milky Way in the Figure 1. It could imply that, from the circular velocity curve of the Milky Way, [10–15] the mass of the center of the Milky Way should be $\sim 10^{11} M_{\odot}$. 3) We emphasize, the mass of the center of the Milky Way can and need be certainly known from the orbits of the S-star cluster. But, new measurement is needed to accurately and precisely know the orbits.

The mass of the center of the Milky Way is one of the critical factors about the structure and origin of the galaxy. Therefore, new understanding is needed for the new predicted mass of the center. But, factually, new understanding is needed in more general area. As I know, first, the Poincaré's equation with the Poisson equation need be excluded from the theory of the orbit of the galaxy. We have had no evidence to show that the Poincaré's equation with the Poisson equation is valid to the orbit in the galaxy or to any other orbit. [21] Therefore, we need return to the Newtonian theory of gravity, especially, the Newtonian orbit theory of perturbation is the necessary theory for right understanding the celestial orbit. Second, the gravitational field is with a very tremendous energy and energy density. It is omitted in current theory of gravity while it should be very important to judge the dark energy. [32,33] Third, a galaxy is always moving. Then, how is this galaxy moving? Is it with an orbit around a larger object? These problems showed that our knowledge about the galaxy is poor. We need new knowledge about it from new observation.

The center of the Milky Way is the most unusual place in all of our galaxy. It is a pity if no unusual things shall be discovered from where. I was excited and astonished as I had the Figure 3 in it the velocities of the orbits in the radius of $\mathrm{R} \leq 0.5\mathrm{pc}$ can be $\sim 10^5 km/s$ or larger. However, it need be confirmed observationally.

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