Article

Not peer-reviewed version

Optics Effect on the Observed Image about Sgr A* and Orbits of S-Stars

Yin Zhu *

Posted Date: 26 July 2024

doi: 10.20944/preprints202407.2142.v1

Keywords: dispersion of light in gravitational field; jet of Sgr A*; orbit of S-stars; jet of M87

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 July 2024 doi:10.20944/preprints202407.2142.v1

Article

Optics Effect on the Observed Image about Sgr A* and Orbits of S-Stars

Yin Zhu

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

Abstract: Light is dispersive in gravitational field. It results in that, under the condition of strong gravitational field, the observed numbers, size, distance and spectrogram of a celestial object is different from the real ones. Therefore, the observed jets of the Sgr A* and M87 need be understood further with the orbit of the stars around them. And, the observed orbits of the S-stars around the Sgr A* is different from the real ones. It implies that the observed optical images of the distant celestial body with strong gravitational field need be further understood with other observations and physics laws to accurately and precisely know the real physical configuration of it.

Keywords: dispersion of light in gravitational field; jet of Sgr A*; orbit of S-stars; jet of M87

---

1. Introduction

The center of the Milky Way is the most unusual place in all of the galaxy. Now, it was observed that there is a black hole, the Sgr A*, at the center of our Milky Way [1,2] and the M87 black hole at the center of the galaxy M87.[3,4] And, the images,[1–6] the jet,[5–13] the mass[1–3] and the size of the two black holes were observed.[4–6] And, some of the S-stars orbiting around the SgrA* in the radius of R ≤ 0.5 pc were observed.[14–21]

But, first, new observations, including the fastest stars,[14–21] the circular velocity curve of the Milky Way[22–27] and the fast galaxy bar,[28–31] could show that the traditional galaxy rotation curve, which was originally presented by Babcock, Oort and Rubin from 1939-1980,[32,33] is questioned. And, the traditional galaxy rotation curve was questioned in pure theory.[34,35] We know, the mass of the Sgr A* is related with the traditional galaxy rotation curve. Therefore, the mass of the Sgr A* need be reconsidered with the new observations.[36]

Second, it was well observed that there is a time lag between the light curves with different wavelengths.[37,38] It was presented that the distance of extragalactic system can be measured with "the time lag between variations in the short wavelength and long wavelength light from an active galactic nucleus".[39] And, it was presented that to have a right measurement of the numbers and spectrogram of the celestial objects and to have an accurate measurement of the size and distance of a celestial object, light dispersion in gravitational field need be considered.[40]

Therefore, in this work, it is presented that, the observation about the Sgr A* is a complex and complicated project. The new observations[14–31] are critical to understand Sgr A*. To well understand the Sgr A*, the observed orbits of the S-stars around the Sgr A* and the observed jet of the Sgr A* and M87 need be considered with that there is the time lag between the light curves with different wavelengths[37–39] and with that light is dispersive in gravitational field.[40]

2. The Optical Image and the Real Physical Configuration

It is well known that, for a celestial body with a very large distance from us, because a time is needed for a light ray running from the body to us, the body at its present position cannot be observed. We only can observe the body at the retarded time and retarded position. And,

$t' = t - L/c$ (1)

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 July 2024 doi:10.20944/preprints202407.2142.v1

where L is the distance between the body and the observer, c is the speed of light, t is the present time, t′ is the retarded time. For example, the Sun that we can observe is that at the time almost 8.5 min ago, while it at present time we cannot observe because a time almost 8.5 min is needed for the light running from the Sun to us.

From Eq.(1), the multi retarded time was formulated for the observation that there are time lags between the light curves with different wavelengths:[40]

$t_{\lambda i}$ = t – L/$c_{\lambda i}$, $c_{\lambda i}$ = $c/n_{\lambda i}$ (2)

where λi refers the ith wavelength of the light, $n_{\lambda i}$ is the refractive index of the light with the wavelength of λi.

It is noted that, correspondent to that there are i retarded times, i images can be produced for one single star. The i images can be connected with or separated from each other as discussed in [40]. Here, the multi retarded time with the multi-images is used to study the observation about the black holes and the orbits around the black holes at the center of a galaxy.

2.1. The Observed Jet of the Sgr A or M87*

The jet of the M87 and Sgr A* was observed.[4–13] It is important, the time lags between light curves of the Sgr A* was observed: the flux density of the jet is a function of the wavelength of the light.[13] In [40], it was demonstrated that two different kinds of images with different wavelengths can be produced from one single celestial body with super strong gravitational field. If there are several light curves with several wavelengths for a moving body, from Eq.(2), an image as shown in Figure 1 can be produced for the reason as that for the Figure 2B in [40].

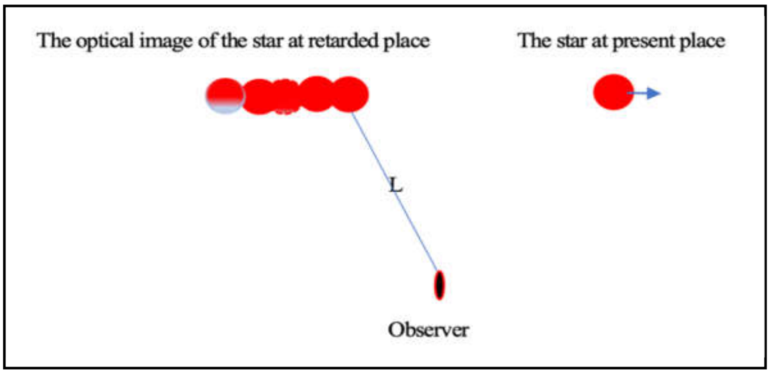

Figure 1. The image of a star observed at the retarded place. The star is moving along the arrow. As the star is arriving at its present place, it cannot be observed by the observer because a time $t - t_{\lambda i}$ = L/$c_{\lambda i}$ is needed for the light running from the star to the observer. Because of the dispersion of light in the gravitational field, the speed of light with different wavelengths is $c_{\lambda i}$ = $c/n_{\lambda i}$. Correspondent to one of $c_{\lambda i}$ = $c/n_{\lambda i}$, one retarded position is observed. This image is a combined one by i retarded positions.

The image of the jet of the M87 was observed. It is highly similar to the Figure 1.[4,9] Therefore, a question arise: how to know the observed image of the jet of M87 is a real jet? Or, it is only an optical effect as that shown in the Figure 1?

We know, the jet of the Sgr A* was observed.[5,10–13] While, the orbits of the S-stars around the Sgr A* was observed.[14–21]If there is a jet extending for 200au and with a big energy emitted from the SgrA*,the orbits of the S-stars should be affected by this jet for that, it is usually thought, the distance between the Sgr A* and many of the S-stars is less than 200au.[14–21] But, till now the effect of the jet of the Sgr A* on the orbits of the S-stars has not been observed. Therefore, there are two different possibilities: first, there should not be a jet of the Sgr A*. The observed image of the jet is only an optical effect. Second, the energy of the jet should be so little that cannot make the orbits varied. Therefore, further observation is needed to right understand the image of the jet.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 July 2024 doi:10.20944/preprints202407.2142.v1

For the same reason, the jet of the M87 also need be understood with further observation. It is thought that the energy of the jet of M87 is very large and is with a length of 5000 light year.[41] If it is so, then, first, the orbits of the stars around the M87 in the radius of r < 5000 lightyear shall be broken off. Second, as a big mass is limited in almost a cylinder with the radius of R ≈ 500au and the length of l ≈ 5000 lightyear, the orbits of the stars around the mass should be different from that around a sphere. However, no such a kind of orbit has been observed.

Therefore, from the orbits of the S-stars around the Sgr A* and the orbits around the M87, it could be concluded that, in a high probability, the jets of the M87 and Sgr A* is an optical effect, rather than a real one. If there are the real jets, these jets should be with a very little energy that cannot affect the orbits of the stars around the two black holes.

The Superluminal and Accelerating Jet

It was observed that the measured velocity profile of the jet of M87 is not described as a single streamline but rather explained by multiple ones. And, the jet can be accelerated.[41–46]. For example, the apparent jet speeds generally increase from ≈0.3c at ≈0.5mas from the core to ≈2.7c at ≈20 mas, and the jet moves at relativistic apparent speeds up to ≈5.8c at distances ≈200–410 mas. It appears that the jet is accelerated from subluminal to superluminal speeds.[43] Now, the observations is difficult to understood. But, as the Figure 1 in this work is considered, the observed jet should be only an image. From [40] we know, the images of one star at different distance from the star can be observed at a same time. It appears that the velocity of the observed image is instantaneous. And, the image of the black hole in the Figure 1 is formed by several analogous images connected with each other.

There is another question about the superluminal jet:[41–46] if the jet is with a large energy which is made up of the hadrons particles and is with a very large velocity, this jet could have a very large momentum on the M87. It should make the M87 moved along the converse direction of the jet. But, this effect has not been observed. Therefore, it also could be concluded that the observed jet may be an image, or the jet is with a very little energy.

*2.2. The Observed Image of the Orbits of the S-Stars around the Sgr A**

We know, the image of Sgr A*[5,6] with its jet[10–13] was directly observed. Therefore, the orbits of the S-stars around the Sgr A* can be directly observed. As the Sgr A* is moving along the blue arrow and the S-star is orbiting around the Sgr A*, if the speed of the light emitted from Sgr A* and S-star are $c_{sgrA} = c/n_{sgrA}$ and $c_{star} = c/n_{star}$, respectively, the observed image is that as shown in Figure 2. The time for the light running from the Sgr A* to the observer is $t - t_{sgrA} = L/c_{sgrA}$ while for that from S-star to the same observer is $t - t_{star} = L/c_{star}$. From the Shapiro time delay we know, the gravitational field is stronger, the speed of light should be slower. Thus, there is $c_{sgrA} < c_{star}$ and $t_{sgrA} > t_{star}$. It should result in that, under the condition that the Sgr A* is at the center of the circular orbit for the real orbit, while the observed orbit is an ellipse and the Sgr A is not at the center. And, the observe speed of the orbit is larger than the real one.

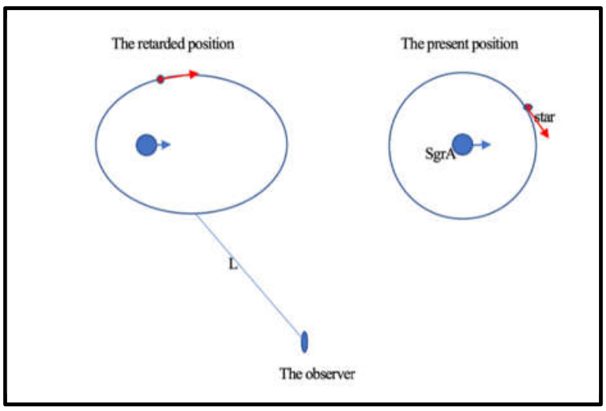

Figure 2. The observed optical orbit vs real orbit of the S-star around Sgr A*. The Sgr A* is moving along the blue arrow, the star is along the red one. Under the condition that the real orbit is a circle and the Sgr A* is at the center of the circle, the observed orbit is an ellipse and the Sgr A* is no at the center of the orbit. And, the observed speed of the orbit is larger than the real one.

The speed of light in a gravitational field is determined mainly with two factors: 1) The strength of the gravitational field. From the Shapiro time delay we know, the field is stronger, the speed of light is slower. 2) The wavelength of the light. It was well observed that there is time lag between the light curves with different wavelengths.[37–40] The two factors result in that the observed image is radically different from the real physical configuration of the orbit of a star around a center mass. Besides the cases in the Figures 1 and 2, there are these cases: 1) As the velocity of the orbit of the S-star is vertical to the velocity of Sgr A*, the observed Sgr A* is not in the plane of the observed orbit. 2) As the light of one S-star is with several wavelengths, several optical orbits with different speeds of one single S-star can be observed. 3) As the orbits of two stars in one same plane, if the wavelengths of the light of them are different, the observed orbits are not in one plane. The combinations of these cases can make the observed optical image of these orbits very complicated and radically different from the real physical configuration. Therefore, to accurately and precisely know the real physical configuration of the orbits of the S-stars is a very complicated project.

3. Conclusion

The mass of the Sgr A* can be accurately and precisely measured through the orbits of the S-stars around it. But, the multi-image gravitational lensing and the time lag between the light curves with different wavelengths was well observed.[37–39] It was known that, to well understand the numbers of the image and the spectrum and to right know the size and the distance of a celestial body, the time lag and the light dispersion in gravitational need be considered.[40] The Sgr A* is with the strongest gravitational field in all of our Milky Way. The speed of light emitted from it or near it is strongly affected by the gravitational field of it. Therefore, to accurately and precisely know the orbits of the S-stars around the Sgr A*, the dispersion of the light in gravitational need be considered.

And, it is important to clarify the effect of the observed image of the jet of the Sgr A* on the orbits of the S-stars. Comparing Figure 1 to the observed image of the jet of M87,[4,9] it is easy to find that, if the light dispersion in gravitational field had not been considered, the observed optical image should not can be completely understood. The optical image of the orbits of the S-stars around the Sgr A* also is affected by light dispersion in gravitational field, and the optical images of the orbits is much more complicated than the real one. Therefore, the observed optical image of the jets of them need be further understood with the orbits of the stars around them. And, the optical image of the orbits of the S-stars around the Sgr A* need be further formulated with Newtonian theory of gravity to know the orbits accurately and precisely.

A fundamental conclusion about the astronomical observation could be presented: For the celestial body with super strong gravitational field, the observed image about the body could be radically different from the real physical configuration produced from the body. Therefore, an observed astronomical image need be further formulated or corrected with other observations and physics laws.

References

1. R. Genzel, F. Eisenhauer and S. Gillessen, The Galactic Center Massive Black Hole and Nuclear Star Cluster, Reviews of Modern Physics, 82.4, 3121-3195 (2010)
2. S. Issaoun, M. D. Johnson, L. Blackburn, C. D. Brinkerink, et al., The Size, Shape, and Scattering of Sagittarius A* at 86 GHz: First VLBI with ALMA, Astrophysical Journal, 871, 1 (2019)
3. K. Akiyama, et al. [Event Horizon Telescope Collaboration]. First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole, Astrophys. J. Lett., 875, L1 (2019)
4. F. Tazaki, Y. Cui, K. Hada, M. Kino, et al. Super-Resolved Image of M87 Observed with East Asian VLBI Network. Galaxies, 11, 39 (2023)

5. X. Cheng, I. Cho, T. Kawashima, M. KinO, et al. Monitoring the Size and Flux Density of SgrA during the Active State in 2019 with East Asian VLBI Network, Galaxies, 11, 46 (2023)
6. The Event Horizon Telescope Collaboration, First Sagittarius A* Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole in the Center of the Milky Way, APJL, 930, L12 (2022)
7. K. Hada, et al. An origin of the radio jet in M87 at the location of the central black hole. Nature 477, 185–187 (2011)
8. R. C. Walker, P. E. Hardee, F. B. Davies, C. Ly, & W. Junor, The structure and dynamics of the subparsec jet in M87 based on 50 VLBA observations over 17 years at 43 GHz. Astrophys. J. 855, 128 (2018)
9. Y. Cui, K. Hada, T. Kawashima, et al., Precessing jet nozzle connecting to a spinning black hole in M87, Nature 621, 711–715 (2023)
10. T. Do, G. Witzel, A. K. Gautam, Z. Chen, et al. Unprecedented Near-infrared Brightness and Variability of SgrA . Astrophys. J. Lett. 2019, 882, L27.
11. G. Witzel, G. Martinez, J. Hora, S. P. Willner, et al. Variability Timescale and Spectral Index of Sgr A* in the Near Infrared: Approximate Bayesian Computation Analysis of the Variability of the Closest Supermassive Black Hole. Astrophys. J. 2018, 863, 15
12. A. Eckart, K. Mužiˊc, S. Yazici, N. Sabha, et al., Near-infrared proper motions and spectroscopy of infrared excess sources at the Galactic center, Astron. Astrophys., 551, A18 (2013)
13. S. Issaoun et al., Persistent Non-Gaussian Structure in the Image of Sagittarius A* at 86 GHz, ApJ 915, 99 (2021)
14. S. Gillessen, P. M. Plewa, F. Eisenhauer, R. Sari, et al., An Update on Monitoring Stellar Orbits in the Galactic Center, ApJ, 837, 30 (2017)
15. F. Peißker, A. Eckart and M. Parsa, S62 on a 9.9 yr Orbit around SgrA*, ApJ, 889, 61 (2020)
16. F. Peißker, A. Eckart, M. Zajaček and S. Britzen, Observation of S4716- A star with a 4 year orbit around Sgr A*, ApJ, 933, 49 (2022)
17. F. Peißker, A. Eckart, M. Zajaček, S. Britzen, B. Ali and M. Parsa, S62 and S4711: Indications of a Population of Faint Fast-moving Stars inside the S2 Orbit—S4711 on a 7.6yr Orbit around Sgr A*, ApJ, 899, 50 (2020)
18. F. Peißker1, A. Eckart and B. Ali, Observation of the Apoapsis of S62 in 2019 with NIRC2 and SINFONI, APJ, 918, 25 (2021)
19. GRAVITY Collaboration, et al., Deep images of the Galactic center with GRAVITY, A&A 657, A82 (2022)
20. GRAVITY Collaboration, et al., Mass distribution in the Galactic Center based on interferometric astrometry of multiple stellar orbits, A&A 657, L12 (2022)
21. Shogo NISHIYAMA,Tomohiro KARA, Brian THORSBRO, Hiromi SAIDA, et al., Origin of an orbiting star around the galactic supermassive black hole, Proc. Jpn. Acad., Ser. B 100 (2024)
22. M. Roshan, N. Ghafourian, T. Kashfi, I. Banik, M. Haslbauer, et al., Fast galaxy bars continue to challenge standard cosmology, Monthly Notices of the Royal Astronomical Society, 508(1) 926–939 (2021)
23. F. Fragkoudi1, R. J. J. Grand, R. Pakmor, V. Springel, et al., Revisiting the tension between fast bars and the CDM paradigm, A&A650, L16 (2021)
24. E. M. Corsini, J. A. L. Aguerri, Victor P. Debattista, A. Pizzella, F. D. Barazza, and H. Jerjen, The Bar Pattern Speed of Dwarf Galaxy NGC 4431, ApJ, 659, L121 (2007)
25. J. A. L. Aguerri, J. Méndez-Abreu, J. Falcón-Barroso, A. Amorin, et al., Bar pattern speeds in CALIFA galaxies I. Fast bars across the Hubble sequence, A&A,576, A102(2015)
26. A. Eilers, D. W. Hogg, H. Rixand M. K. Ness, The Circular Velocity Curve of the Milky Way from 5 to 25 kpc, ApJ, 871 120 (2019)
27. P. Mróz, A. Udalski, D. M. Skowron, J. Skowron, et al., Rotation Curve of the Milky Way from Classical Cepheids, ApJL 870, L10 (2019)
28. H. Wang, Ž. Chrobáková, M. López-Corredoira and F. S.Labini, Mapping the Milky Way Disk with Gaia DR3: 3D Extended Kinematic Maps and Rotation Curve to ≈30 kpc, ApJ, 942, 12 (2023)
29. Y. Zhou, et al., The Circular Velocity Curve of the Milky Way from 5–25 kpc Using Luminous Red Giant Branch Stars, ApJ, 946, 73 (2023)
30. Y. Jiao, F. Hammer, H. Wang, J. Wang, et al., Detection of the Keplerian decline in the Milky Way rotation curve, A&A678, A208 (2023)
31. X. Ou, A. Eilers , L. Necib and A. Frebel, The dark matter profile of the Milky Way inferred from its circular velocity curve, MNRAS 528, 693–710 (2024)
32. Y. Yoon, C. Park, H. Chung and K., Zhang, Rotation Curves of Galaxies and Their Dependence on Morphology and Stellar Mass, ApJ, 922, 249 (2021)
33. S. S. McGaugh, F. Lelli and J. M. Schombert, Radial Acceleration Relation in Rotationally Supported Galaxies, Physical Review Letters, 117, 201101 (2016)
34. Q. Feng James and C. F. Gallo, Modeling the Newtonian dynamics for rotation curve analysis of thin-disk galaxies, *Res. Astron. Astrophys.* **11** 1429 (2011)
35. A. M. Hofmeister and R. E. Criss, Debated Models for Galactic Rotation Curves: A Revieand Mathematical Assessment, Galaxies, 8, 47 (2020)

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 July 2024 doi:10.20944/preprints202407.2142.v1

36. 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[v3] | Preprints.org
37. M. M. Fausnaugh, et al., Space Telescope and Optical Reverberation Mapping Project. III. Optical Continuum Emission and Broadband Time Delays in NGC 5548, ApJ 821, 56 (2016)
38. J. H. H. Chan, K. Rojas, M. Millon, F. Courbin, V. Bonvin and G. Jauffret, Measuring accretion disk sizes of lensed quasars with microlensing time delay in multi-band light curves, A&A, 647, A115 (2021)
39. Y. Yoshii, Y. Kobayashi, T. Minezaki, S. Koshida and B. A. Peterson, A New Method for Measuring Extragalactic Distances, ApJL 784 L11(2014)
40. Y. Zhu, Light Dispersion in Gravitational Field[v3] | Preprints
41. E. T. Meyer, *et al.*, Optical Proper Motion Measurements of the M87 Jet: New Results from the Hubble Space Telescope, *ApJL* 774 L21 (2013)
42. M. Kino *et al.*, Implications from the Velocity Profile of the M87 Jet: A Possibility of a Slowly Rotating Black Hole Magnetosphere, *ApJ* **939** 83 (2022)
43. J. Park *et al.*, Kinematics of the M87 Jet in the Collimation Zone: Gradual Acceleration and Velocity Stratification, *ApJ* **887** 147 (2019)
44. M. Nakamura *et al.*, Parabolic Jets from the Spinning Black Hole in M87, *ApJ* 868 146 (2018)
45. K Chatterjee, M Liska, A Tchekhovskoy, S B Markoff, Accelerating AGN jets to parsec scales using general relativistic MHD simulations, *Monthly Notices of the Royal Astronomical Society*, 490, 2200 (2019)
46. B. Snios, *et al.*, Detection of Superluminal Motion in the X-Ray Jet of M87, *ApJ* **879** 8 (2019)