ON DESCRIPTION OF SHADOW OF PARAMETRIZED ROTATING BLACK HOLES

A.L. Abduvokhidov[1], A.A. Abdujabbarov[2]

[1]Andijan State University, Andijan, Uzbekistan

[2]Ulugh Beg Astronomical Institute, Tashkent, Uzbekistan

Abstract: The analysis of the dependence of the average radius of the shadow and asymmetry (distortion) parameter from the spin parameter and KRZ parameters have been performed. Among the effects of other parameters the effect of the first parameter is dominant in changing the average radius of the shadow

Keywords: Black hole, Shadow, parameterized spacetime.

One of the main problems of gravity theories is to test the theory in strong field regime with high accuracy. However, the LIGO-Virgo experiments on gravitational wave observation [1–2] and observation of black hole shadow image at the center of M87 elliptic galaxy [3] give us the opportunity to develop new tests of general relativity and modified/alternative theories of gravity in the strong field regime. In this note we plan to study shadow of the black holes described by the parametric spacetime metric proposed in [4].

The lowest-order metric expression of the KRZ parametrization has the following form [4]:

$$ds^2 = -\frac{N^2(\tilde{r},\theta) - W^2(\tilde{r},\theta)\sin^2\theta}{K^2(\tilde{r},\theta)}dt^2 - 2W(\tilde{r},\theta)\tilde{r}\sin^2\theta dt d\phi + K^2(\tilde{r},\theta)\tilde{r}^2\sin^2\theta d\phi^2 + \Sigma(\tilde{r},\theta)\left(\frac{B^2(\tilde{r},\theta)}{N^2(\tilde{r},\theta)}d\tilde{r}^2 + \tilde{r}^2 d\theta^2\right), \quad (1)$$

where $\tilde{r} = r/M,\ \tilde{a} = a/M$ and $\Sigma = 1 + a^2\cos^2\theta/\tilde{r}^2,$

$$N^2 = (1 - r_0/\tilde{r}) \left[1 - \epsilon_0 r_0/\tilde{r} + (k_{00} - \epsilon_0)\, r_0^2/\tilde{r}^2 + \delta_1 r_0^3/\tilde{r}^3\right]$$
$$+[a_{20} r_0^3/\tilde{r}^3 + a_{21} r_0^4/\tilde{r}^4 + k_{21} r_0^3/\tilde{r}^3 L]\cos^2\theta,$$
$$B = 1 + \delta_4 r_0^2/\tilde{r}^2 + \delta_5 r_0^2 \cos^2\theta/\tilde{r}^2,$$
$$W = \left[w_{00} r_0^2/\tilde{r}^2 + \delta_2 r_0^3/\tilde{r}^3 + \delta_3 r_0^3/\tilde{r}^3 \cos^2\theta\right]/\Sigma,$$
$$K^2 = 1 + aW/r + \left\{k_{00} r_0^2/\tilde{r}^2 + k_{21} r_0^3/\tilde{r}^3 L \cos^2\theta\right\}/\Sigma,$$
$$L = \left[1 + \frac{k_{22}\,(1 - r_0/\tilde{r})}{1 + k_{23}\,(1 - r_0/\tilde{r})}\right]^{-1}.$$

We have studied the shadow of the black hole described by the parametrized KRZ spacetime. It has been shown that the parameters δ_1 and δ_4 can change the size of the shadow but with opposite effect. The parameter δ_2 makes the shadow deviate from the center, the parameter δ_5 also can change the size of the shadow but effect is relatively weak. The parameters δ_3 and δ_6 can change the contour shape. The shape of the shadow has different sensitivity to different parameters: the shadow is more sensitive to parameters δ_1, δ_2, δ_4 and less sensitive to parameters δ_3, δ_5, δ_6. The effects of the parameters δ_7 and δ_8 to the shape of shadow is very weak and almost negligible (compare with [5] where authors have neglected the effects of δ7 and δ8 on the iron line in the X-ray spectrum of black holes).

One of the main results of this paper is the analysis of the dependence of the average radius of the shadow and asymmetry (distortion) parameter from the spin parameter and KRZ parameters. Among the effects of other parameters the effect of parameter δ_1 is dominant in changing the average radius of the shadow. On the other hand the main contribution to the change of the asymmetry parameters comes due to the presence of the parameter δ_2. Fig. 1 shows the dependence of R and A as a function of the spin parameter (Kerr metric) and δ_i (KRZ metric) for the fixed values of inclination angle $\theta_0 = \pi/4$ and the spin parameter a = 0.5. From Fig. 10b one can easily see that the δ_1 and δ_4 have a greater impact on R, but with different trend: when δ_1 increases the value of R decreases and when δ_4 increases the value of R increases.

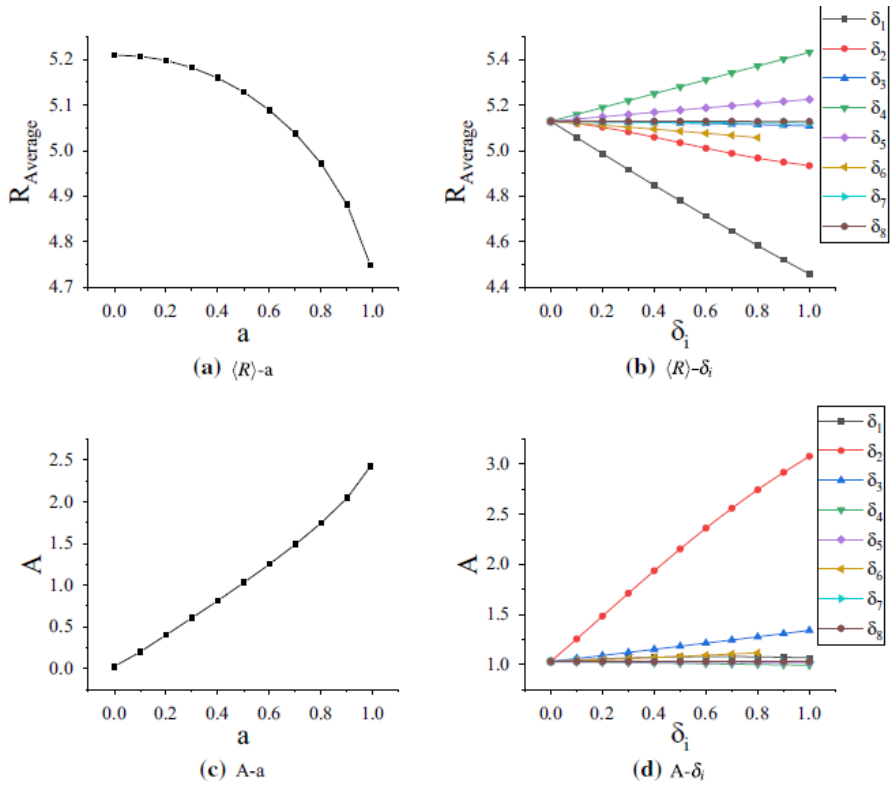

Fig. 1 Average radius R (top row) and asymmetry parameter A (bottom row). The

first column corresponds to the Kerr metric with the values of spin $0 \leq a \leq 1$, the second column corresponds to the KRZ metric with different values of δ_i and the spin $a = 0.5$

References

1. T. Damour, G. Esposito-Farèse, Phys. Rev. D 58, 042001 (1998). https://doi.org/10.1103/PhysRevD.58.042001

2. A. Cárdenas-Avendaño, S. Nampalliwar, N. Yunes, Class. Quantum Gravity 37, 135008 (2020). https://doi.org/10.1088/1361-6382/ab8f64

3. K. Akiyama et al., Event horizon telescope. Astrophys. J. 875, L1 (2019). https://doi.org/10.3847/2041-8213/ab0ec7

4. R. Konoplya, L. Rezzolla, A. Zhidenko, Phys. Rev. D 93, 064015 (2016). https://doi.org/10.1103/PhysRevD.93.064015

5. Y. Ni, J. Jiang, C. Bambi, J. Cosmol. Astropart. Phys. 2016, 014 (2016). https://doi.org/10.1088/1475-7516/2016/09/014