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Black hole shadows as a source for testing extended theories

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The first images of black holes have opened up new possibilities for testing extended theories of gravity. In this paper, we propose and develop a method for constructing the background of the shadow of spherically symmetrical non-rotating black holes for the case of $g_{11} \neq -g_{00}^{-1}$. The results of the analysis for the extended theories of gravity are compared with the predictions of the general theory of relativity (GRT) when taking into account the data of the Event Horizon Telescope (the global network of radio telescopes on which the first direct image of the BH was obtained).

After the publication of the article by Alexeyev, Prokopov, and Zenin in J. Exp. Theor. Phys. (2022), the Event Horizon Telescope (EHT) project obtained the first direct image of a black hole in the center of our galaxy, Sagittarius A*[The Astrophysical Journal Letters, 930, L17, 2022]. The results obtained in [Alexeyev, Prokopov, and Zenin in J. Exp. Theor. Phys. (2022)] are in full agreement with the results of observations of Sagittarius A* and M87*for the following models: the Horndeski model with the Gauss-Bonnet invariant, loop quantum gravity, Bambelby scalar model, Gauss-Bonnet model. In conformal gravity, large values of m_2 and Q_s should be excluded. In $f(Q)$ gravity, observations of Sgr A* additionally limit the values of the parameter α: $-0.025 < \alpha < 0.005$. For an alternative generalization of the bumblebee metric with the Schwarzschild approximation, the constraint becomes as follows: $-0.05 < l < 0.45$.

The idea to extend the existing classical gravity theories with their black hole solutions is extensively developing now. In this way, some theories that were "closed" by GW170817 test obtained new possibilities. For example, the well-known Fab Four model was saved in such a manner not so long ago. The same method was also used to extend the black hole solution in $R + R^2$ gravity model [Phys. Rev. D 100, 086010 –Published 14 October 2019]. So, a new solution was obtained. Based on the ideas of black hole's shadows modeling and the latest Event Horizon Telescope results, it seems interesting to test the accuracy of experimental predictions for the "improved" models based on such a solution in $R + R^2$ gravity.

Here, it is important to note that both black holes whose images were taken by the Event Horizon Telescope are spinning, so the first step is to obtain the spinning version of the solution [Xavier Calmet, Roberto Casadio, Folkert, "Quantum gravitational corrections to a star metric and the black hole limit," Phys. Rev. D 100, 086010, published on 14 October 2019].

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