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Does no-hair theorem fail in the modified theories of gravity?

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The no-hair conjecture asserts that all black holes in general relativity (GR) coupled to any matter must be Kerr–Newman type. The three independent externally observable classical parameters— mass, electric charge, and angular momentum — uniquely determine all the information about the matter that formed into a black hole. However, the conjecture fails in some cases where the matter sources are described by non-linear field equations.

This raises a few questions: Is the no-hair theorem a feature of gravity or GR? Are there other types of rotating black hole solutions besides Kerr's, which are specific to GR? If yes, which category of modified gravity theories support and how do they differ from the Kerr solution in GR? This talk addresses the no-hair conjecture in the $f(R)$ gravity. We show this by explicitly constructing multiple slow-rotating black hole solutions, up to second order in rotational parameter, for a class of $f(R)$ models. We analytically show that multiple vacuum solutions satisfy the field equations up to the second order in the rotational parameter. In other words, we show that the multiple vacuum solutions depend on arbitrary constants, which depend on the coupling parameters of the model. Hence, our suggests that the no-hair theorem for modified gravity theories merits extending to include the coupling constants. We discuss the kinematical properties of these black hole solutions and compare them with slow-rotating Kerr solutions, which are the rotating black hole solutions in GR. Specifically, we show that the circular orbits for the black holes in $f(R)$ are smaller than that of Kerr. This implies that the inner-most stable circular orbit for black holes in $f(R)$ is smaller than Kerr's; hence, the shadow radius might also be smaller, which will have implications for observations of black holes

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