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Peer Review

Review of: "Inverting No-Hair Theorems: How Requiring General Relativity Solutions Restricts Scalar-Tensor Theories"

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The manuscript with the title "Inverting No-Hair Theorems: How Requiring General Relativity Solutions Restricts Scalar-Tensor Theories" analyzes the space of scalar-tensor theories that admit several types of "stealth" GR solutions: GR metric solutions that still solve the scalar-tensor equations of motion in the presence of a time-dependent scalar field with a constant kinetic term. They classify all operators allowed in four different types of stealth solutions. In the case of static and spherically symmetric black hole solutions, they analyze the odd (axial) parity sector of perturbations, discuss potential deviations from GR, and derive the stability conditions. Also, a discussion on the modification of the propagation speed of the dynamical mode in the odd sector is included.

While the methods used in the manuscript seem sound, I would have a few questions and would recommend a few changes:

The first paragraph of the introduction is misleading, as one could deduce that the paper is focusing on DHOST theories, which is not the case.

In this context, it could be useful to elaborate on the distinction between "exact" theories (theories that are well-defined when taken at face value) and "perturbative" theories, which are theories with an exact principal part, but on top of which perturbative operators are added. In the former case, the absence of Ostrogradsky instabilities is a must; otherwise, the theory is just unstable. Only in the latter case is it possible to tame ghost degrees of freedom, based on the fundamental perturbative nature of the theory. I believe the work is focusing on the second class of theories.

The acronyms "HOST" and "SdS" are never written out.

I did not fully understand the argument on the existence of a foliation with X=const: being a local argument, how useful is it when considering full solutions of the equations of motion?

The rationale behind imposing the existence of stealth solutions on the theory space is still not entirely clear to me: why is it interesting to restrict the theory space to admit such solutions? Is it because it is an easy way to evade existing constraints on the (black-hole) spacetime solutions? What is the connection to the cosmological use of such theories? It would be nice to elaborate on this crucial motivational point.

Since a minimal coupling to matter is assumed (such that a stealth solution indeed implies that at the background level, to matter, the geometry is indistinguishable from GR), it would be nice to add the term "metric theories" of gravity, which are precisely defined as the theories of gravity that satisfy the principle of minimal and universal coupling to a spacetime metric.

It would be nice to get some more insight into Fig. 1: for instance, why is the general expectation that a weakening of the assumptions on the background geometry will allow for more freedom in the validity of the theory not valid for all the functionals? For instance, the function F_2 seems to be admissible for the SdS solutions, while this is apparently not the case anymore for the Schwarzschild solution, which can be viewed as a subclass of the former?

Otherwise, the paper is nicely structured, and the conclusion section helps a lot.

Declarations

Potential competing interests: No potential competing interests to declare.

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