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Teukolsky formalism for nonlinear Kerr perturbations

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We develop a formalism to treat higher order (nonlinear) metric perturbations of the Kerr spacetime in a Teukolsky framework. We first show that solutions to the linearized Einstein equation with nonvanishing stress tensor can be decomposed into a pure gauge part plus a zero mode (infinitesimal perturbation of the mass and spin) plus a perturbation arising from a certain scalar ("Debye-Hertz") potential, plus a so-called "corrector tensor." The scalar potential is a solution to the spin −2 Teukolsky equation with a source. This source, as well as the tetrad components of the corrector tensor, are obtained by solving certain decoupled ordinary differential equations involving the stress tensor. As we show, solving these ordinary differential equations reduces simply to integrations in the coordinate r in outgoing Kerr-Newman coordinates, so in this sense, the problem is reduced to the Teukolsky equation with source, which can be treated by a separation of variables ansatz. Since higher order perturbations are subject to a linearized Einstein equation with a stress tensor obtained from the lower order perturbations, our method also applies iteratively to the higher order metric perturbations, and could thus be used to analyze the nonlinear coupling of perturbations in the near-extremal Kerr spacetime, where weakly turbulent behavior has been conjectured to occur. Our method could also be applied to the study of perturbations generated by a pointlike body traveling on a timelike geodesic in Kerr, which is relevant to the extreme mass ratio inspiral problem.

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