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Binary pulsars and GW170817 set limits on fourth-order extensions of Einstein's gravity

A 2026 study computes gravitational-wave emission in fourth-order gravity. The ghostful version needs extra modes above about 10^-11 eV, and the ghost-free version's couplings are capped.

15 November 2026 · based on a paper in Physical Review Letters



Photo: Matthew Stephenson

Physicists treat general relativity as an effective field theory, an approximation that works within a limited regime. Here that regime is the 'infrared' of long distances and low energies, and the theory is expected to need changes in the 'ultraviolet' of very short distances. A common way to explore such changes is to add terms built from the square of spacetime curvature, giving what are called fourth-order gravity theories. The catch, as the authors of a 2026 paper in Physical Review Letters note, is that these theories generically carry a 'ghost'. This is a massive particle with spin 2 that makes the theory non-unitary, meaning its predicted probabilities do not add up consistently.

One proposed cure is to enlarge the geometry of spacetime by allowing torsion, a kind of twisting, and non-metricity, in which lengths can change as they are carried from place to place. The study asks a practical question: how do the ghostful and ghost-free versions fare against observation? The authors calculate the gravitational waves each theory predicts for orbiting pairs of compact

objects. They compare these with observations that include the shrinking orbits of the binary pulsars PSR B1913+16 and PSR J1738+0333, and the evolution of the chirp mass in the signal GW170817. The chirp mass is a combination of the two bodies' masses that governs how fast the signal's frequency sweeps upward.

The ghostful theory runs into trouble beyond its known theoretical flaw, the authors report. In the limit where the extra particles become massless, the ordinary gravitational-wave flux is cancelled by the combined flux from the massive spin-2 ghost and a massive spin-0 scalar. The theory therefore fails to recover, at leading order, the quadrupole formula, general relativity's prediction of how much energy a binary radiates. To match the observations, the extra modes must have a mass of at least about 10^-11 eV.

The ghost-free theory behaves differently. According to the study, it smoothly returns the Newtonian potential and the quadrupole formula when two coupling constants, α1 and α2, go to zero, whatever the mass of the extra modes. Observations then cap the size of the couplings, with a cap that depends on the mass. Assuming for simplicity that the two couplings are equal, the authors obtain upper limits of 4.2×10^83 for a mass near 3×10^-16 eV and 1.3×10^75 for a mass near 10^-11 eV. To their knowledge, these are the first astrophysical-scale bounds on either kind of fourth-order gravity.

The study sets limits; it does not report any departure from general relativity. The coupling bounds quoted are for one simplifying assumption, equal couplings, so they illustrate a single slice of the theory's possible parameters rather than the full picture.

The paper joins earlier braintankAI coverage of how far gravitational-wave signals can be pushed as tests of gravity. That story found that a prompt 'direct wave' in black hole ringdowns is of limited use as a probe of the event horizon (earlier story).

PAPER	*Exorcising ghosts with gravitational waves*
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VENUE	Physical Review Letters · 4 November 2026
LINK	doi:10.1103/2shh-sstq
INDEX	stacks.braintank.ai