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Editorial

Post-Editorial of the Special Issue "Wormholes in Space-Time: Theory and Facts"

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Wormholes made their first appearance in gravitational physics as soon as in 1916 but, as with their black hole cousins, it took a long time and effort for their true nature to be properly understood. They are now known to actually arise as exact solutions to Einstein's general relativity (GR) and are typically interpreted as structures connecting two far away regions of space-time within the same or different universes. The region at which two such regions meet is called the throat, which must fulfil several conditions in order not to spontaneously collapse. By construction, wormholes manage to restore geodesic completeness, that is, the fact that in these space-times, all paths of free-falling physical observers as well as the trajectories of light rays are well defined at all times. However, wormholes also face severe theoretical challenges. The first challenge is related to the fact that, since the singularity theorems (guaranteeing the incompleteness of some geodesics under a set of reasonable conditions) still apply, the restoration of geodesics completeness comes at the cost of the unavoidable violation of the energy conditions of the matter fields required to sustain the wormhole throat. Among the many proposals to ameliorate this problem, the one of thin-shell wormholes has had quite some success. In this approach, one resorts to a cut-and-past procedure, in which two different patches of space-time are merged at some hypersurface (a shell) in such a way that the violations of the energy conditions can be restricted to that region of space-time, which can be constructed to be as small as required. The second main challenge of wormhole physics is to construct a well-defined mechanism of gravitational collapse by which a wormhole could be generated in physically realistic astrophysical scenarios. Indeed, while the theory of formation of black holes from fuel-exhausted main sequence stars is extremely well developed and its compatibility with astronomical observations is secured, the same cannot be said for wormholes. It can be conjectured that in the last stages of gravitational collapse, the formation of a throat can be developed in such a way that a traversable wormhole is formed rather than a black hole (if the throat lies beyond the would-be event horizon), or that a black hole is formed, but in such a way that a wormhole structure is hidden in its interior behind the event horizon. These questions have very relevant ramifications for the black hole evaporation and the information loss problem, or for the causality under the existence of closed time-like curves.

Research in the XXI century has brought forward a number of relevant developments for wormhole physics. From a theoretical point of view, a large number of new solutions have been found in the literature, dealing with the most subtle aspects of the restoration of geodesic completeness and its relation with the tremendous tidal forces that should appear at the (tiny) wormhole throat. The consideration of extensions of GR via several approaches in what is nowadays known as modified theories of gravity has shed some light on the possibility of building wormhole solutions without violation of the energy conditions, and on the relation between geodesics completeness and the divergences of curvature scalars, and its consequences for the many attempts to quantize gravity. From an observational point of view, the absence of an event horizon within traversable wormholes has raised suggestions of qualitatively new phenomena in these solutions, such as echoes (periodic secondary releases of gravitational radiation of decaying amplitude) and double shadows (in asymmetric wormholes, thanks to the existence of different photon spheres on both sides of the wormhole). These are signals that could be used to observationally discriminate these objects with respect to canonical GR black holes within the newly born field of multimessenger astronomy. The implications of wormhole solutions for cosmological observations, and for analogue and condensed matter models, are also under deep scrutiny in the literature.

Four papers were submitted to this issue. Bahamonde, Benisty and Guendelman [1] considered asymmetric wormhole geometries having a linear gravitational potential that can be used to explain galaxies rotation curves by assuming the central supermassive object to be a wormhole of this kind rather than a black hole. Kirilov and Savelova [2] studied the scattering of radiation by wormholes from cosmic rays, yielding a specific damping in addition to that caused by ordinary matter. Since wormholes can capture particles on one side and re-emit them on the other side, this yields a wider spectrum for the re-emitted particles, which form a diffuse background of very low intensity around a discrete source, which might have relevant implications for the cosmic microwave background. Sanchidrián-Vaca and Sabín [3] propose to estimate the parameters of massless (Ellis-type) wormholes by using the quantum metrology techniques. In this approach, a distant wormhole on a flat space-time induces a tiny perturbation that can be tested using interferometers and compared to the theoretical estimations. Finally, Sabin [4] considered the propagation of light in a three-dimensional nanophotonic structure simulating the shape of a traversable wormhole, finding that, in this simulated space-time, the corresponding waves would suffer a significant change of phase and group velocity, that can be tested with current technology.

The field of wormhole physics is more alive than ever thanks to the powerful theoretical new developments and the new opportunities available for testing their properties in both astrophysical/cosmological environments, as well as in laboratory simulated-systems. We encourage the community to keep pursing this line of research and to close the gap between the theory and observation of wormholes.

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