Exact solutions of Einstein and Einstein-Maxwell equations

0.1 Topics

- Exact solutions in General Relativity and Supergravity
- Cosmology and Astrophysics
- Quantum Fields
- Fundamental Relativity

0.2 Participants

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0.3 Research activity

0.3.1 Exact solutions in General Relativity and Supergravity

• It was presented the proof of the existence of the stationary equilibrium state of the binary system containing Kerr-Newman black hole and Kerr-Newman naked singularity object. It was known that two Reissner-Nordstrom black holes or two over-extreme Reissner-Nordstrom sources cannot be in physical equilibrium. In the static case such equilibrium is possible only if one of the sources is a black hole and another one is a naked singularity. We define the notion of physical equilibrium in general (stationary) case when both components of a binary system are rotating and show that such system containing a Kerr-Newman black hole and a Kerr-Newman naked singularity also can stay in physical equilibrium. Reference (1).

0.3.2 Cosmology and Astrophysics

Cosmology

• It was investigated the question whether there are cosmological models in 2 + 1 space-time dimensions which exhibit dynamics similar to BKL oscillations, as the cosmological singularity is approached. Based on intuition, we conceive a toy model which displays such oscillatory dynamics. We show that in the phase space of this model, the cosmological singularity is represented by a separatrix curve and discuss the model's dynamics within the cosmological billiards picture. Finally, we proposed a physical interpretation for a family of similar cosmological models in terms of the topological degrees of freedom of gravity in 2 + 1 dimensions. Reference (2)).

• The existence of current-time universe's acceleration is usually modeled by means of two main strategies. The first makes use of a dark energy barotropic fluid entering by hand the energy-momentum tensor of Einstein's theory. The second lies on extending the Hilbert-Einstein action giving rise to the class of extended theories of gravity. In our work, we propose a third approach, derived as an intrinsic geometrical effect of space-time, which provides repulsive regions under certain circumstances. We demonstrate that the effects of repulsive gravity naturally emerge in the field of a homogeneous and isotropic universe. To this end, we use an invariant definition of repulsive gravity based upon the behavior of the curvature eigenvalues. Moreover, we show that repulsive gravity counterbalances the standard gravitational attraction influencing both late and early times of the universe evolution. This phenomenon leads to the present speed up and to the fast expansion due to the inflationary epoch. In so doing, we are able to unify both dark energy and inflation in a single scheme. Further, we argue that the spatial scalar curvature can be taken as vanishing because it does not affect at all the emergence of repulsive gravity. We check the goodness of our approach through two cosmological fits involving the most recent supernova compilation. Reference (4).

Astrophysics

• A year ago but published only in 2018 it was proposed a new alternative (with respect to the accelerated universe paradigm) explanation of the discrepancy between values of the distances to the far galaxies following from the observations and from the standard Friedmann model. Observations

show that these distances are a little bit larger in comparison with what is predicted by the usual Friedmann cosmology. However, this standard theory does not take into account traces the strong gravitational waves of cosmological origin leave in space. We show that such traces can be a cause for the aforementioned discrepancy. The sources of cosmological waves are inhomogeneities of a solitonic type of the gravitational field near the Big Bang. Due to expansion of the universe these inhomogeneities decay but each of them expels solitonic gravitational waves which also decay in course of propagation through the expanding space transfering, however, their energies to the Friedmann background making the distances different compared with those which would be observed without such waves. This effect has been described earlier (V. Belinski, 1979) by example of single-soliton cylindrical wave propagating on the Friedmann background. Now the same phenomenon has been confirmed for double-soliton waves both for cylindrical and planar symmetries. Reference (3).

• The equilibrium configurations of uniformly rotating white dwarfs at finite temperatures are investigated, exploiting the Chandrasekhar equation of state for different isothermal cores. The Hartle-Thorne formalism is applied to construct white dwarf configurations in the framework of Newtonian physics. The equations of structure are considered in the slow-rotation approximation and all basic parameters of rotating hot white dwarfs are computed to test the so-called moment of inertia, tidal Love number, and quadrupole moment (I-Love-Q relations). It is shown that even within the same equation of state the I-Love-Q relations are not universal for white dwarfs at finite temperatures. Reference (7).

• It was computed the rotations, during a scattering encounter, of the spins of two gravitationally interacting particles at second-order in the gravitational constant (second post-Minkowskian order). Following a strategy introduced in Phys. Rev. D **96**, 104038 (2017), we transcribe our result into a correspondingly improved knowledge of the spin-orbit sector of the Effective One-Body (EOB) Hamiltonian description of the dynamics of spinning binary systems. We indicate ways of resumming our results for defining improved versions of spinning EOB codes which might help in providing a better analytical description of the dynamics of coalescing spinning binary black holes. Reference (8).

• The (first-order) gravitational self-force correction to the spin-orbit precession of a spinning compact body along a slightly eccentric orbit around a Schwarzschild black hole is computed through the ninth post-Newtonian

order, improving recent results by Kavanagh et al. [Phys. Rev. D **96**, 064012 (2017).] This information is then converted into its corresponding Effective-One-Body counterpart, thereby determining several new post-Newtonian terms in the gyrogravitomagnetic ratio . Reference (9).

• We study the metric perturbations induced by a classical spinning particle moving along a circular orbit on a Schwarzschild background, limiting the analysis to effects which are first order in spin. The particle is assumed to move on the equatorial plane and has its spin aligned with the z -axis. The metric perturbations are obtained by using two different approaches, i.e., by working in two different gauges: the Regge-Wheeler gauge (using the Regge-Wheeler-Zerilli formalism) and a radiation gauge (using the Teukolsky formalism). We then compute the linear-in-spin contribution to the first-order self-force contribution to Detweiler's redshift invariant up to the 8.5 post-Newtonian order. We check that our result is the same in both gauges, as appropriate for a gauge-invariant quantity, and agrees with the currently known 3.5 post-Newtonian results. Reference (10).

Gravitational self-force corrections to gyroscope precession along circular orbits in the Kerr spacetime

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• We generalize to Kerr spacetime previous gravitational self-force results on gyroscope precession along circular orbits in the Schwarzschild spacetime. In particular we present high order post- Newtonian expansions for the gauge invariant precession function along circular geodesics valid for arbitrary Kerr spin parameter and show agreement between these results and those derived from the full post-Newtonian conservative dynamics. Finally we present strong field numerical data for a range of the Kerr spin parameter, showing agreement with the GSF-PN results, and the expected lightring divergent behaviour. These results provide useful testing benchmarks for self-force calculations in Kerr spacetime, and provide an avenue for translating self-force data into the spin-spin coupling in effective-one-body models. Reference (11).

0.3.3 Fundamental Relativity

• We perform a detailed analysis of the properties of stationary observers located on the equatorial plane of the ergosphere in a Kerr spacetime, including light-surfaces. This study highlights crucial differences between black hole and the super-spinner sources. In the case of Kerr naked singularities, the results allow us to distinguish between "weak" and "strong" singularities, corresponding to spin values close to or distant from the limiting case of extreme black holes, respectively. We derive important limiting angular frequencies for naked singularities. We especially study very weak singularities as resulting from the spin variation of black holes. We also explore the main properties of zero angular momentum observers for different classes of black hole and naked singularity spacetimes. Reference (5).

• We investigated the properties of static and axisymmetric vacuum solutions of Einstein equations which generalize the Schwarzschild spherically symmetric solution to include a quadrupole parameter. We test all the solutions with respect to elemental, and asymptotic flatness and curvature regularity. Analysing their multipole structure, according to the relativistic invariant Geroch definition, we show that all of them are equivalent up to the level of the quadrupole. We conclude that the q-metric, a variant of the Zipoy Voorhees metric, is the simplest generalization of the Schwarzschild metric, containing a quadrupole parameter. Reference (6).

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