2024

Canonical treatment and quantization of fermionic systems

We extended a previously successful discussion of the constrained Schrödinger system through the Dirac–Bergmann algorithm to the case of the Dirac field [1]. Following the analogy, first we discussed the classical Dirac field as a spinorial variable, by introducing properly defined momenta and a suitably modified, factor ordered Poisson bracket. According to the Dirac–Bergmann algorithm two second class Hamiltonian constraints emerged, leading to a factor ordered Dirac bracket on the full phase space. This became the Poisson bracket on the reduced phase space in the canonical chart adapted to the shell. The Dirac equation was recovered both as consistency condition on the full phase space and as canonical equation on the reduced phase space. Alternatively, considering the Dirac field as odd Grassmann variable, we worked out the details of the Dirac–Bergmann algorithm (with either left and right derivatives acting on Grassmann valued superfunctions and involving a different type of generalized Poisson and Dirac brackets). We proposed a recipe for the canonical second quantization of all three versions of the generalized Dirac brackets, yielding the correct fundamental anticommutator. We also reviewed related aspects of the coupled gravity-Dirac field system.

Late time tails of components of electromagnetic waves on Kerr background

The behavior of solutions of the Fackerell–Ipser equation (the wave equation governing the evolution of the spin-zero component of the electromagnetic field) after very long times has been studied using numerical moduli on a physically relevant rotating black hole background. In our investigations, we have used an initial value problem based on a hyperboloidal initial surface connecting the event horizon of the black hole with null infinity, and a Penrose conformal compactification procedure. These allowed us to observe the behavior of the solutions both at the event horizon and in the future light-like infinity. We took as initial data pure multipolar configurations which are compactly supported and either stationary or non-stationary. We found that with such initial data, the solutions of the Fackerell–Ipser equation converge at late times either to an essentially known static solution or to zero. As the limit is approached, the solutions show a quasi-normal decay and finally a power-law decay. From the numerical data, we extracted the exponents characterizing the power-law decay of the spherical harmonic components of the field variable for different values of the initial data parameters, and we used the results to propose a Price law for the Fackerell–Ipser equation. To verify the numerical realization of the underlying mathematical model, we employed certain conserved energy and angular momentum fluxes. In studying these conservation laws, we also considered the discrete symmetry of the Fackerell–Ipser equation, which is the product of an equatorial reflection and a complex conjugation [2].

Magnetic fields in the vicinity of fast rotating black holes

The Event Horizon Telescope data for M87 as well for low power radio galaxies show consistency in the component of the magnetic field, which determines angular momentum and energy transport and is related to the radio jet characteristics. We interpreted this independence on the black hole (BH) mass as resulting from a wind emanating from the BH/accretion disk system and its surroundings. Near the BH collisions in the wind can produce a large fraction of anti-protons. The Cosmic Ray (CR) population from the wind/jet was conjectured to be visible as EeV protons and anti-protons in the CR data and is connected to a concept of inner and outer Penrose zones in the ergo-region [3].

Gravitational waveforms from spinning binaries

As part of the group's annual commitment to the Virgo Collaboration, we compared two eccentric waveform models based on post-Newtonian (CBWaves) and effective one-body

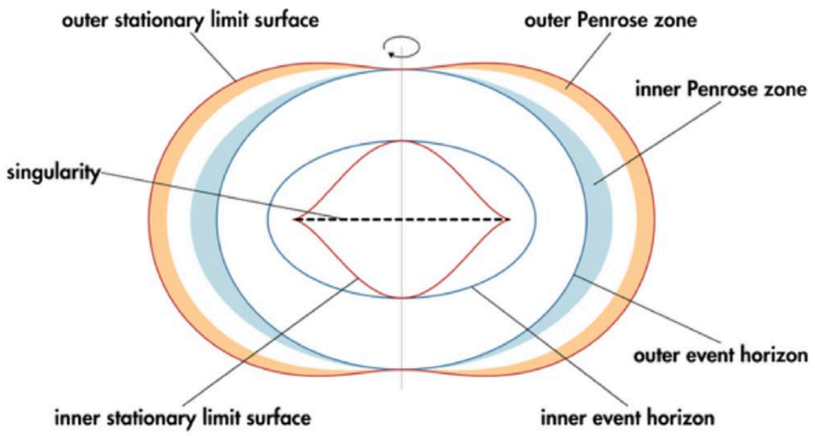

FIGURE 5
The key elements of the Kerr black hole with rotation parameter $a = 0.95$ are represented in a planar section containing the axis of rotation. The infinite curvature ring singularity appears from lateral side view as a segment. This is hidden inside a structure of two horizons, the outer horizon being the boundary of the Kerr black hole. Two stationary limit surfaces (where $g_{tt} = 0$) are positioned inside the inner horizon and outside the outer horizon, respectively. At the outer stationary limit surface the redshift is infinite and photons cannot counterrotate, while inside it they will always corotate, similarly to all the other particles, irrespective of their initial direction. The ergo-region, lying between the outer stationary limit surface and the outer event horizon, contains the outer and inner Penrose zones, attached to these limiting surfaces.

(SEOBNRE) approaches of eccentric and spinning binary systems. Their mismatch was investigated by conducting 260,000 simulations on a common grid of parameter values over the parameter space, defined by the mass ratio $q \equiv m_1/m_2 \in [0.1, 1]$, gravitational masses $m_i \in [10M_\odot, 100M_\odot]$, spin magnitudes $S_i \in [0, 0.6]$ and initial orbital eccentricity e_0. We identified the parameter ranges with the largest mismatch [4].

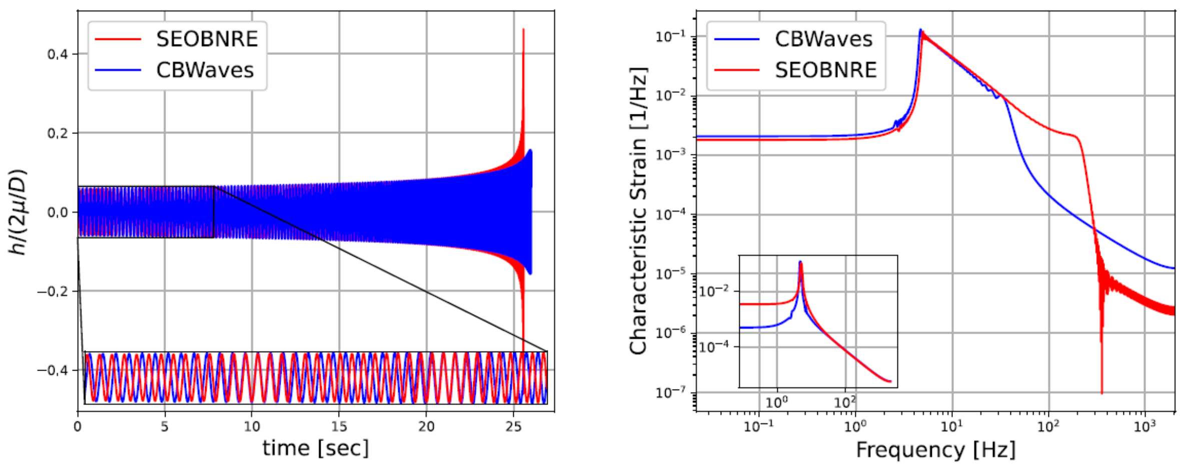

Figure 1. The right panel of the figure shows the time series of the gravitational wave strain, while the left panel is the characteristic strain, derived from the strain, of the $q \simeq 0.8775$ and $M \simeq 83.6364$ outlier point. On both panels, the time window is magnified where the mismatch was calculated.

Heat propagation in cryogenic systems

The Einstein Telescope gravitational wave detector, among other cutting-edge techniques will employ cryogenic methods to minimise noises. Cryogenic applications often require the use of an advanced heat equation, particularly for a transient situation. The simplest extension of the Fourier heat equation, the Maxwell–Cattaneo–Vernotte heat equation considers the inertia of heat propagation. This model can take into account the wavelike propagation of heat, important for materials at low temperatures, such as the mirrors of the Einstein Telescope. Additionally, nonlinear material behaviour stands as a modelling challenge in such a low-temperature environment. In an international collaboration we developed a possible heat conduction model assuming temperature-dependent transport properties. Furthermore, we proposed a reliable numerical method to solve this system of nonlinear partial differential equations, allowing the transient simulation for investigating further questions and benchmarking [5].

Virgo, Einstein Telescope, CosmoVerse and BridgeQG activities

In the framework of the Rapid Response Team of the Virgo Collaboration, we have participated in the semi-automated data quality assessment, during the O4b observational run. As members of the Einstein Telescope (ET) Collaboration, we contributed to the writing and editing of the Waveform and Nuclear Physics chapters of the "Blue Book", intended to summarize the scientific objectives and potential of the ET detector, due to be published in 2025 in Living Reviews in Relativity. We participated in the activities of the COST Collaborations CA21136 - Addressing observational tensions in cosmology with systematics and fundamental physics (CosmoVerse) and CA23130 - Bridging high and low energies in search of quantum gravity (BridgeQG).

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