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General relativistic particle-in-cell simulations of compact neutron star magnetospheres

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Magnetospheres of compact objects such as neutron stars and black holes are complex systems where quantum electrodynamic (QED) processes, kinetic-scale pair plasma physics and general relativity (GR) play all an important role. To study such intricate and exotic systems, advanced simulation techniques are required. In this work, we present a GR module recently developed for the particle-in-cell (PIC) code OSIRIS [1]. PIC simulations treat the plasma as particles and capture the self-consistent coupling between particles and fields down to the plasma kinetic scales. All algorithms in this GR-PIC module of OSIRIS (field solver, particle pusher and current deposit) support Minkowski, Schwarzschild or the slow-rotation limit of the Kerr metric. The prescribed stellar boundary conditions grant a steady convergence to the GR dipolar magnetic field solution of a neutron star in vacuum [2]. We present two-dimensional simulations of isolated neutron star magnetospheres, where QED processes are mimicked by injecting plasma at the stellar surface [3, 4]. We discuss the differences in the plasma current distribution in the vicinity of the star for different ratios between the Schwarzschild and the stellar radii, identifying possible locations of unscreened electric field and potential emission of coherent radiation. Finally, we compare analytical estimates of the polar cap geometry with simulations in the force-free regime [5, 6].

References

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