Massively-parallel simulations of pulsar and black hole magnetospheres

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The surroundings of pulsars and black holes are some of the most extreme and exotic environments in the Universe. A global model of these high energy density systems involves self-consistently describing the collective dynamics of the electron-positron plasma and the evolution of the strong fields that permeate them. Moreover, only by accounting for the *ab initio* generation and acceleration of plasma particles, as well as the associated radiation processes, will we be able to make a connection with astronomical observations. This is a challenging endeavor, since it requires including, from first principles, the Quantum Electrodynamics (QED) effects responsible for the production of electron-positron pairs and the General Relativity (GR) spacetime metrics that strongly influence and warp the electromagnetic fields in these scenarios. In this presentation, we will describe the recent implementation of specialized modules to account for the relevant QED and GR effects in OSIRIS [1], a fully relativistic, massively parallel particle-in-cell (PIC) code that self-consistently resolves the dynamics of plasmas down to their kinetic scales from first principles. We will present simulations that capture the global structure of pulsar magnetospheres, and describe how the interplay between micro and macroscopic scales can be critical to determine the global distribution of charges and currents in the magnetospheres, ultimately determining the radiative signatures of these objects [2, 3, 4]. We will also describe recent steps taken towards simulating black hole magnetospheres. The bridge between the relevant microscopic physical processes of electron-positron plasma generation and the macroscopic plasma dynamics of the magnetospheres of compact objects that this research establishes is an important step towards understanding recent observations from first principles. The simulations performed in this work would not be feasible without the access to HPC facilities, secured for this project through multiple PRACE calls. The complexity of the algorithms and the large scale disparity of the problem required simulations to be massively parallel, and in particular different parallelization schemes.

References:

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[3] A. Y. Chen *et al.*, The Astrophysical Journal 889 1 (**2020**)
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