Dynamics of magnetospheres of rotating compact objects with General Relativity
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Motivation
Understanding some of the most extreme events in the Universe

Compact objects have been known to play a role in the most violent space events, such as active galactic nuclei (AGN) jets and gamma-ray bursts [1]. Due to their complex and extreme nature, they combine sub-fields as:

- General Relativity (GR);
- Quantum Mechanics;
- Plasma Astrophysics.

Ongoing campaigns such as the Event Horizon Telescope and GRAVITY, aim at resolving horizon-scale structures of the supermassive black hole at the centre of our galaxy and M87.

Global models of compact objects (pulsars [2,3] and rotating black holes [4]) and their active magnetospheres are required to fully understand how microscopic physical processes (QED) and space-time curvature (GR) affect self-consistently the macroscopic magnetosphere dynamics.

State-of-the-art
From neutron star to black hole magnetospheres

1967-68: Observation of rapidly pulsating radio sources.
1969: First global studies of pulsar magnetospheres (Goldreich and Julian):
- Star rotation induces an electric field capable of pulling charged particles from its surface;
- Magnetosphere filled with plasma;
- Rotational energy and angular momentum extracted due to electromagnetically driven wind.
1974: Vacuum solution for Maxwell’s equations in Kerr space-time coordinates (Wald).
1977: Blandford-Znajek mechanism explains black hole jet launching and rotational energy extraction due to plasma-filled magnetosphere.

Figure 1: (a) Illustration of a neutron star with a schematic of the magnetic field lines. (b) Observational appearance of an accretion disk from a rotating black hole. Credit: Reed, C. Penn State University (2000) and Hotaka Shiomakawa.

Figure 2: Magnetic field lines of an accreting black hole. Credit: Alexander Tchekhovskoy, Lawrence Berkeley National Laboratory (2014).

Figure 3: (a) Current density of an axisymmetric global pulsar simulation for a low and high plasma injection from the star surface. Credit: Fabio Cruz @ GoLP, IST. (b) Modifications to be implemented in the OSIRIS framework.

Scientific goal
- Shed light on the gravitational frame dragging effects in macroscopic plasma dynamics in the vicinity of compact objects.
- Develop a novel GR-PIC module within OSIRIS framework to self-consistently study the evolution of the magnetospheric plasma in extreme environments, showing the interplay between the microscopic and macroscopic processes.
- Identify key particle accelerating and rotational energy extraction mechanisms.

References and Acknowledgments

Work supported by the European Research Council (InPairs ERC-2015-AdG 695088) and Fundação para a Ciência e Tecnologia (grant PD/BD/142971/2018).

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