RUHR UNIVERSITÄT BOCHUM RUB

CSC-RUB PhD Project Proposal

Title: Study of magnetic reconnection in partially ionized plasmas

Sector of research: Dr. rer. nat.

Degree awarded: Theoretical Physics

Keywords: plasma, magnetic reconnection, partially ionized, Coulomb collisions, PIC, chromosphere, laboratory, neutrals, code development

Supervisors of PhD project:

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Research focus of supervisor: The main research interest of the group is the understanding of the non-trivial interaction between small- and large-scale processes in plasmas, an environment which is intrinsically multiscale. An example of this interaction is magnetic reconnection, a process triggered at the electron (==small) scales that reconfigures the magnetic field topology at global scales. In partially ionized plasmas, the collisional frequencies associated with ions/ neutrals, electrons/ neutrals collisions may introduce additional characteristic scales in the system. The study of small/ large scale interaction requires the development of novel simulation approaches, a field where we excel. These methods are used to tackle open questions in selected plasma environments, such as solar and laboratory plasmas.

Publications:

1. Micera, A., Zhukov, A. N., López, R. A., Innocenti, M. E., Lazar, M., Boella, E., & Lapenta, G. (2020). The Astrophysical Journal Letters, 903(1), L23.
2. Innocenti, M. E., Tenerani, A., & Velli, M. (2019a). The Astrophysical Journal, 870(2), 66.
3. Innocenti, M. E., Johnson, A., Markidis, S., Amaya, J., Deca, J., Olshevsky, V., and Lapenta, G. (2017). Advances in Engineering Software, 111:3–17.
4. Innocenti, M. E., Goldman, M., Newman, D., Markidis, S., & Lapenta, G. (2015). The Astrophysical Journal Letters, 810(2), L19.
5. Innocenti, M. E., Lapenta, G., Markidis, S., Beck, A., & Vapirev, A. (2013). Journal of Computational Physics, 238, 115-140.

Summary of research plan

Background: Magnetic reconnection explosively converts stored magnetic energy into particle acceleration and heat. It occurs in environments as diverse as the Sun and the other stars, planetary magnetospheres, accretion disks and astrophysical jets. Magnetic reconnection occurs in collisionless and collisional plasmas, in fully or partially ionized plasmas, and can be associated with one or multiple X-points. The measure of reconnection efficiency is called reconnection rate, and it changes in all cases mentioned above. While reconnection in collisional and collisionless plasmas has been extensively studied, reconnection in partially ionized plasmas is, by comparison, still relatively poorly studied, notwithstanding the fact that partially ionized plasmas are extremely common in heliospheric (solar photosphere and chromosphere, planetary ionospheres) and astrophysical (protostellar and planetary disks, interstellar clouds, warm interstellar medium) environments. Also the plasma in laboratory experiments is only partially ionized.

Study objective: The objective is to study the evolution of the reconnection rate and of characteristic signature of Hall, collisionless reconnection (e.g. the Hall quadrupolar field pattern) as a function of the levels of ionization of the gas, and hence of plasma/ neutral coupling. Partial ionization introduces three main effects: increased resistivity due to collisions between charged particles and neutrals, plasma-neutral drift and effective increase of the ion mass. This results in a decrease of the Alfvén speed, which limits outflow speed in single X point reconnection, and in the increase of the ion skin depth, the collisionless scale that control the thickness of the diffusion region. Quite surprisingly, this expected increase of the thickness of the diffusion region is not observed in laboratory studies. The numerical methods we will develop will be in principle applicable to a number of heliospheric and astrophysical environments, but we will target specifically the solar chromosphere (for the expected importance of chromospheric reconnection in solar dynamics) and laboratory plasmas.

Expected Results: We expect to characterize the evolution of the reconnection rate and of the characteristic kinetic features of reconnection as a function of the ionization percentage. We will be able to compare our simulation results with laboratory study of reconnection in partially ionized plasmas (e.g., MRX experiments). In laboratory experiments boundary effects may have a significant impact on reconnection evolution, since the system is of the order of the ion skin depth, but we do not have similar limitations in simulations. Our final aim is to predict the evolution of magnetic reconnection in the upper parts of the chromosphere, where the ionization level changes significantly with the solar radius and kinetic scales are expected to be comparable with collisional scales.

Methods: A great part of the PhD work will be code development. An existing Particle-In-Cell code will be augmented with a Coulomb collisional module and with a Monte Carlo module for ion/neutral and electron/ neutral collisions. While the study of collisions of neutrals with charged particles is the main aim of this study, Coulomb collisions have to be introduced in the code as well because their characteristic collisional frequencies may be comparable with ion/neutral, electron/ neutral collisional frequencies in many environments of interest.

Candidate Requirements: MSc degree in Physics, Applied Mathematics or equivalent; basic knowledge of plasma physics including kinetic theory; experience with programming languages and coding; sound knowledge of English.

Motivation for CSC application: You will work at the development of state-of-the-art numerical codes, with the aim of using them to investigate some of the most challenging open problems in plasma physics and astrophysics. You will develop leading expertise in plasma modeling and data analysis, and the code you will develop will be applicable to laboratory and astrophysical settings. You will work in a growing group in an international environment, where pursue of personal research interests, collaboration and constant exchange of ideas with peers and supervisors alike are appreciated and encouraged. You will have the opportunity to co-supervise (in English) bachelor and master students working on short projects similar, in topic, to your PhD work. You will present your work in international conferences and have the possibility to visit foreign groups for research visits. You will have access to the Ruhr Research School, that supports the students in the development of interdisciplinary skills, and to the career-building resources of the University

Alliance Ruhr. The RUB International Office will welcome you with information and targeted assistance to facilitate your move to Bochum.