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# CSC-RUB PhD Project Proposal

**Title:** Magnetic reconnection in solar wind plasma: particle heating and heat flux regulation

**Sector of research:** Dr. rer. nat.

**Degree awarded**: Theoretical Physics

**Keywords**: solar wind, plasma, magnetic reconnection, kinetic, heat flux, Parker Solar Probe, Solar Orbiter, PIC, data analysis

**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. Examples of this interaction are magnetic reconnection, a process triggered at the electron (==small) scales that reconfigures the magnetic field topology at planetary (== global) scales, and heat flux regulation in the solar wind, where kinetic (== small) scale processes contribute to determine the spatial extension of the entire heliosphere, the bubble produced by solar wind in interplanetary space. 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 wind and magnetospheric plasmas.

**Publications:**


1. Micera, A., Zhukov, A. N., López, R. A., Boella, E., Tenerani, A., Velli, M., ... & Innocenti, M. E. (2021). arXiv preprint arXiv:2106.15975, accepted for publication on The Astrophysical Journal
2. 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.
3. Innocenti, M. E., Boella, E., Tenerani, A., & Velli, M. (2020). The Astrophysical Journal Letters, 898(2), L41.
4. Innocenti, M. E., Tenerani, A., Boella, E., & Velli, M. (2019). The Astrophysical Journal, 883(2), 146.
5. Innocenti, M. E., Tenerani, A., & Velli, M. (2019). The Astrophysical Journal, 870(2), 66.


**Summary of research plan**

**Background:** Recent observations by the Parker Solar Probe and Solar Orbiter missions, launched in 2018 and 2020 respectively, have confirmed the fundamental role of kinetic processes in solar wind dynamics. In particular, kinetic processes appear to be the main regulatory mechanism of the heat flux, that measures energy transport in the heliosphere and hence, in a sense, how far away from the Sun the heliosphere will extend. The study of kinetic processes in the solar wind is however complicated by two factors. First, the extreme separation between kinetic scales and system scales in the solar wind. Second, the specificities of the environment. A solar wind plasma parcel, in facts, expands while moving away from the Sun, causing a variation of plasma parameters with distance from the Sun that tend to make the wind unstable to specific kinetic instabilities, which have to be factored in in the simulations. In the group, we have developed targeted simulation methods that address these specific simulation challenges.

**Study objective:** The primary objective is to study the impact of magnetic reconnection in solar wind dynamics. Magnetic reconnection is a reconfiguration of the magnetic field topology associated with particle heating and acceleration. As part of the dissertation, we will simulate magnetic reconnection events starting from initial conditions compatible with Parker Solar Probe and Solar Orbiter observations. We will incorporate in the simulations the specificities of the solar wind environment which have not been previously addressed in reconnection studies: the presence of multiple electron (core, halo and strahl) and ion (core and beam) populations and the underlying presence of plasma expansion, which triggers instabilities that interact with reconnection. Heat flux regulation depends on the modification of the electron velocity distribution function (VDF), and in particular on the reduction of its suprathermal components. We will study how the multi-population VDF observed in the solar wind is modified by magnetic reconnection.

**Expected Results:** We expect a better understanding of the role of magnetic reconnection in the solar wind in 1) the formation of energetic power-law tails in electron distribution and in 2) heat flux regulation. 1) It is known that magnetic reconnection accelerates electrons to non-thermal speeds, but it is not yet clear if it can produce power-law distributions with spectral indexes consistent with values observed in the solar wind (other candidate processes are turbulence, shock acceleration, magnetic pumping). 2) The role of magnetic reconnection in regulating heat flux in the solar wind has been poorly studied. A study of how the non-thermal, non-equilibrium electron VDF in the solar wind is modified by reconnection events is especially needed, given the potential impacts of these modifications in heat flux regulation.

**Methods:** The study will include numerical simulations and comparison of simulation results with observations from Parker Solar Probe and Solar Orbiter. The numerical codes have been developed within the group. The candidate will have the possibility to participate in further model development, if interested. Support in the analysis of observations will come from international collaborators directly involved in the missions

**Candidate Requirements:** MSc degree in Physics, Applied Mathematics or similar field, 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 on one of the most challenging open questions in heliospheric physics with state-of-the-art numerical codes and access to the most recent observations from the Parker Solar Probe and Solar Orbiter missions. You will develop leading expertise in kinetic modelling of plasmas and data analysis, and you will have the possibility to interact with some of the best scientists in the field, with whom we are collaborating. 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 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, of which RUB is part. The RUB International Office will welcome you with information and targeted assistance to facilitate your move to Bochum.