1. PHD PROJECT DESCRIPTION (4000 characters max., including the aims and work plan)

Project title: Cosmic Rays as a diagnostic tool of galactic magnetic fields.

1.1 Project goals

- To understand the impact of cosmic rays on the evolution of structure of galactic magnetic fields in a sample of external galaxies.
- To understand the spectrally-resolved propagation of galactic cosmic ray electrons (CRs) in dynamically evolving magnetized interstellar medium (ISM) through the confrontation of numerical models against observational data of galactic radioemission.
- To understand the fine galactic magnetic field structure shaped by the dynamics of cosmic rays.

1.2 Outline

Radiofrequency continuum observations of distant galaxies often show halos and other structures extending far beyond features visible in the optical range, with emission extending farther out of the source at lower frequencies. This nonthermal radiation comes mainly from synchrotron emission of cosmic ray (CR) electrons [see, e.g. 1]. Radio observations of polarized radiation from edge-on galaxies show X-shaped structures in the polarised synchrotron emission [2, 3]. Phenomenological models [4] and MHD simulations [5, 6] indicate that these features may reflect the globally helical structure of large-scale magnetic fields in galactic halos [7]. The main questions related to this phenomenon concern: the formation mechanism and the global geometry and fine-scale structure of the magnetic field observed in edge-on and face-on galaxies. Since radio observations only give a picture of polarised emission, the underlying magnetic field structure can only be deduced by comparison to plausible models, however, an ultimate verification of the models is inaccessible without a direct comparison of the observed emission of real galaxies against the polarized emission resulting from simulation models. Verification of MHD galaxy models is possible only if we have proper tools to simulate galactic propagation of CR electrons in a spectrally resolved manner. To reach this goal we have developed the Cosmic Ray Energy SPectrum (CRESP) algorithm [8], being a part of Piernik MHD code, to simulate the spectrally resolved population of CR electrons and nucleons in MHD simulation models of prominent cases of real galaxies such as M51, NGC6946, M81 and M82.

1.3 Work plan

1. Construction of initial states, based on the available observational data (rotation curves, stellar masses, gas content) for the sample of selected galaxies.
2. Numerical simulations of the dynamics of galactic interstellar medium with cosmic ray electrons and protons.
3. Analysis of simulation results and tuning CR propagation parameters to match observational properties of galactic radio-emission.
4. Determination of CR propagation parameters through the comparison of synchrotron radiomaps of modelled galaxies to their real counterparts.

5. Deduction of magnetic field small-scale and large-scale structures for the galaxy sample.

1.4 Literature

[1] E. Orlando and A. Strong, *Galactic synchrotron emission with cosmic ray propagation models*, *MNRAS* **436** (2013) 2127 [1309.2947].

[2] M. Krause, *Magnetic Fields and Star Formation in Spiral Galaxies*, in *Revista Mexicana de Astronomia y Astrofisica Conference Series*, vol. 36 of *Revista Mexicana de Astronomia y Astrofisica, vol. 27*, pp. 25–29, Aug., 2009 [0806.2060].

[3] M. Soida, M. Krause, R.-J. Dettmar and M. Urbanik, *The large scale magnetic field structure of the spiral galaxy NGC 5775*, *A&A* **531** (2011) A127 [1105.5259].

[4] M. Hanasz, D. Wóltański and K. Kowalik, *Global Galactic Dynamo Driven by Cosmic Rays and Exploding Magnetized Stars*, *APJL* **706** (2009) L155 [0907.4891].

[5] M.A. Ogrodnik, M. Hanasz and D. Wóltański, *Implementation of Cosmic Ray Energy Spectrum (CRESP) Algorithm in PIERNIK MHD Code. I. Spectrally Resolved Propagation of Cosmic Ray Electrons on Eulerian Grids*, *ApJSupp* **253** (2021) 18 [2009.06941].

[6] M. Hanasz, A.W. Strong and P. Girichidis, *Simulations of cosmic ray propagation*, *Living Reviews in Computational Astrophysics* **7** (2021) 2 [2106.08426].

1.5 Required initial knowledge and skills of the PhD candidate

- ➔ Analytical thinking and curiosity.
- ➔ Basic knowledge about high energy astrophysics, fluid dynamics, numerical methods for fluid dynamics.
- ➔ Theoretical inclinations
- ➔ Some experience in numerical simulations
- ➔ Strong programming skills

1.6 Expected development of the PhD candidate's knowledge and skills

Cosmic rays and their impact on the formation and evolution of galaxies are currently a hot topic of theoretical astrophysics investigated in leading astronomical institutes in the world. The PhD candidate will learn very interesting aspects of rapidly developing understanding of galaxies, including the physics of interstellar medium, galactic magnetism, galactic evolution, cosmic ray astrophysics, magnetohydrodynamical simulations with modern numerical codes, advanced programming techniques and high performance computing. The candidate will develop his/her scientific personality in the international collaboration with excellent scientists.