ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT ET PHYSIQUE DE L'UNIVERS, PARIS

Subject title: **THE INTERPLAY BETWEEN COSMIC RAYS AND THE INTERSTELLAR MEDIUM**

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Host lab/Team :

Laboratoire AIM – UMR 7158 –
Astrophysics Department CEA Saclay

Financing: Doctoral contract with or without teaching assignment

Presentation of the subject:

Summary

Are cosmic rays actors or passengers in galaxy evolution? In the current models of galaxy evolution stars form too efficiently and too early in the history of the Universe. High-energy processes such as jets from supermassive black holes and supernova explosions can modify how the gas and magnetic fields cycle in and out of a galaxy, but their impact fails to explain key observations such as galactic outflows. Cosmic rays can play a particular role in galaxy evolution as they mediate energy transfers from supernovae to the interstellar medium over thousands of parsecs and tens of millions of years around their source. They also increase the gas buoyancy and add anisotropic pressures along magnetic field lines and off galactic discs. To evaluate their impact, it is central to understand how cosmic rays propagate through a galaxy and how their transport properties vary with the ambient interstellar conditions. To gain insight into this problem, we propose to compare for the first time the distribution of cosmic rays obtained in numerical simulations of interstellar clouds with measurements obtained from multi-wavelength observations in comparable regions of the Milky Way. A team of well-known experts in the Astrophysics Department will advise the PhD student on high-performance computing simulations and on multi-tracer observations of the interstellar medium, magnetic topology, and cosmic rays. He or she will also work within the broad international collaboration for the Fermi Gamma-ray Space Telescope.

Work plan

The interstellar medium is filled with gas, magnetic fields, dust, light, and relativistic particles (cosmic rays). It is very dynamic and its ever-changing structure controls the evolution of galaxies. Cosmic rays are an integral part of this evolution as they directly influence the thermodynamical and chemical states of the dense clouds that lead to star formation [Grenier et al. 2015]. They also provide anisotropic pressure support to the gas circulation and play an important role in shaping the different gas phases and in regulating the gas inflows and outflows perpendicular to the galactic disc [e.g. Girichidis et al. 2018]. The project concerns cosmic rays with energies ranging from a few GeV to a few tens of GeV as they contribute most to the interstellar pressure and they constitute the bulk of the cosmic-ray population observable in gamma rays and in the radio across the Milky Way.

We poorly know how cosmic rays propagate through the different types of interstellar environments found in a galaxy [Ivlev et al. 2018, Amato & Blasi 2018]. Current models only assume ad-hoc, often uniform prescriptions for the transport properties even though we expect considerable changes according to the ambient conditions: propagation can transition from slow diffusion on self-excited Alfven waves to rapid diffusion on interstellar MHD turbulence, or even to ballistic motion at the speed of light in dense clouds. In the simpler diffusion case, the effective diffusion coefficients are uncertain by one or two orders of magnitude.
The project aims to study and compare the different modes of cosmic-ray transport by measuring the cosmic-ray flux in a selection of nearby Galactic regions chosen for their cloud content and for their magnetic-field configuration. We have indeed just found observational evidence that the magnetic topology affects the cosmic-ray flux threading a cloud [PhD of T. Joubaud 2019]. In parallel, the student will participate to state-of-the-art simulations of cloud complexes similar to the observed ones for different cosmic-ray transport schemes. He/she will then produce synthetic radio and gamma-ray maps to compare with the observations.
For the simulations, the student will use the adaptive mesh refinement code RAMSES for the gas MHD distribution [e.g. Hennebelle 2018], solving cosmic-ray diffusion and/or self-streaming with modules recently added to RAMSES [Commerçon et al. 2019, Dubois et al. 2019].
For the observational part of the thesis, the student will exploit maps from different interstellar gas tracers in order to quantify the gas distribution (gas lines in the radio, dust emission in the sub-mm and infrared bands, gamma rays). He/she will use multi-frequency radio and gamma-ray surveys to measure the synchrotron and pion emissions from cosmic rays, as well as magnetic-field information from radio and dust polarization data. Examples of similar analyses can be found in Remy et al. 2017, Joubaud et al. 2019, Clark et al. 2014, Clark 2019. Joining the radio, gamma-ray, and magnetic-field diagnostics has never been attempted before and will provide key constraints to allow quantitative comparisons between simulations and observations.

Working environment and collaborations

The work will take place in the Astrophysics Department of CEA. It will be formally advised by Pr. Isabelle Grenier in close collaboration with astrophysicists from different teams of the department: Drs. Patrick Hennebelle and Frédéric Bournaud for the simulations, Drs. Marc-Antoine Miville-Deschênes, Jean-Marc Casandjian, and Julien Girard for the interstellar observations.
The student will benefit from numerous exchanges with colleagues working on cosmic rays, the interstellar gas and dust, and the interstellar magnetism across the international Fermi, Planck, and SKA-GASKAP Collaborations, and the Interstellar Institute.

Required skills

A master's degree in astroparticle physics or in astrophysics, a strong interest in data analysis, a good knowledge of the Python language, a sufficient command of English to present the work progress in the international collaborations.

Acquired skills

- Data analysis skills: line emission, non-thermal continuum radiations, high-energy particle interactions, and polarization data at various wavelengths; critical analysis of the reliability of results for complex data (confusion, low signal-to-noise ratios).
- Methodological skills: different statistical methods; topological detectors.
- Personal skills: autonomy, synthesis of problems and results, writing articles and reports, presentations in international meetings, teamwork.

Teaching missions are possible.

Doctoral contract financing

Contrat de Formation par la Recherche du CEA ou Contrat Doctoral de l'Université de Paris (half of the contract already funded by a research grant from the Labex UnivEarthS initiative)

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Bibliography

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