Dynamics and chemistry in the interstellar medium : a stepping stone on the pathway to star formation

PhD thesis subject proposed by F. Levrier and M. Gerin (LERMA-LRA-ENS Paris)

The interstellar medium (ISM) is a paradigm of complex systems, for it is the meeting ground of many physical processes of similar magnitude, interacting on a wide range of spatial and temporal scales. At Galactic scales (a few kpc), kinetic energy is injected into the medium via differential rotation, and cascades through turbulent motions down to dissipation scales (some mpc). The ISM is a partly ionized mixture of gas and dust, with densities varying from 0.001 to 10,000 particles per cc, illuminated by stellar radiation and threaded by a pervasive magnetic field. Stars themselves are born out of the collapse of dense gas regions under their own gravity, and they in turn release energy and new elements into the ISM, sometimes during catastrophic events (supernovae).

Observations of the interstellar medium (ISM) have seen much progress in recent years. First results from Herschel have underpinned the molecular diversity of the diffuse ISM, and revealed the complexity of its spatial and kinematic structures. At the same time, Planck has been mapping the thermal emission of Galactic dust at high resolution, including its polarized component, which gives access to the interstellar magnetic field. Finally, high resolution interferometric observations of molecular gas have uncovered large velocity gradients at very small scales, with signatures indicative of intermittent turbulent dissipation. To understand the formation of molecules, in the gas phase and on dust grain surfaces, remains a challenge, as it is established that both dynamical and radiative processes contribute to the chemical state and evolution of the ISM.

Numerical simulations of astrophysical fluids, on the other hand, have made significant progress through high-performance parallel computing codes, and they now consistently treat self-gravity, thermodynamics and magnetohydrodynamics. Their challenge is to incorporate an adequate treatment of chemistry and grain physics, to reliably compare with observations of atomic and molecular lines.

The aim of the proposed PhD is to bridge the gap between observations and simulations, in order to understand the interplay between chemistry and dynamics of the ISM. This is recognized as a main science objective for LERMA, and a first paper on the subject has been submitted. Specific tasks that the PhD student will undertake are the following :

- Treatment of chemistry as a post-processing to existing numerical fluid simulations : chemical networks are solved on a static background. This step should in particular include the effcts of UV radiation, dissipation of turbulence in regions exhibiting large shears, and different prescriptions for the propagation of cosmic rays in the ISM.
- Simulated observations : once chemical structures are determined, radiative transfer is solved along lines of sight through the simulated medium, and instrumental simulators yield expected observational signatures. This is the key step in the proposed work, that will make use of radiative transfer codes such as RADEX and RADMC-3D, as well as of the ALMA simulator in the GILDAS package.
- Interpretation of existing observations : the team at LRA has access to Herschel, Planck and IRAM data, which may be interpreted in novel and precise ways with the help of simulated observations obtained in the previous step.
- Predictions for future instruments : Results from the simulated observations will make it possible to propose new observational strategies with instruments that are in operation (IRAM, VLT), in construction (ALMA) or even in development (SPICA/SAFARI)

LRA comprises experts in state-of-the-art numerical simulations (Hennebelle, Lesaffre), observations of the ISM (Gerin, Falgarone), and fosters interactions between the two (Levrier). Depending on the ability and wishes of the student, the work may lean more on the observational or on the numerical side. However, a reasonable balance should be held between both aspects, to preserve the originality of the proposed work, which should lead to the publication of several papers.

F. Levrier is part of the Planck/HFI Core Team, of COSMIS (PI Hennebelle), an ANR project to study the influence of cosmic rays on ISM physics, and STARFORMAT (PI Hennebelle), an ASTRONET project to develop a platform of numerical simulations for the ISM. He is involved in the preparation of the SPICA/SAFARI mission. M. Gerin is PI for the PRISMAS Key Project with Herschel/HIFI and is part of COSMIS.