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Structure and evolution of the Milky Way: the interstellar medium perspective

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Abstract. The Herschel and Planck satellites have started imaging the sky at far-IR to mm wavelengths with an unprecedented combination of sky and spectral coverage, angular resolution, and sensitivity, thus opening the last window of the electromagnetic spectrum on the Galaxy. Dedicated observing programs on Herschel and the Planck all-sky survey will provide the first complete view at cold dust across the Galaxy, opening new perspectives on the structure and dynamical evolution of the Milky Way relevant to Gaia. The analysis and modelling of these observations will contribute to our understanding of two key questions: how do stars form from interstellar matter? how are the interstellar medium and the magnetic field dynamically coupled? The comparison with Gaia observations will contribute to build a 3D model of the Galactic extinction taking into account dust evolution between ISM components

Keywords. Interstellar medium, Star formation, Magnetic field, Interstellar dust

1. Introduction

The Gaia mission will produce an extraordinary stellar database and we have to consider how the data may be used to build a dynamical model of the Milky Way that will unravel its past history. To understand the evolution of the Galaxy, we need a model that describes physically how star formation proceeds from the chemical and thermodynamical evolution of interstellar matter. This is a vast field of research. At the meeting I highlighted the prospect of imminent advances made possible by the successful launch of the Herschel and Planck satellites. Here I focus on two main topics related to star formation: the inventory of the cold interstellar medium across the galaxy, and the structure of the Galactic magnetic field and its coupling to interstellar matter.

2. Cold interstellar matter across the Galaxy

Herschel and Planck surveys will provide the small-scale (down to the detection of individual pre-stellar cores) and global views of the distribution of cold interstellar matter in the Galaxy. Both missions will image the far-IR emission from large ($> 10\,$nm) grains that account for the bulk of the dust mass. The spectral coverage will allow us to determine the dust temperature and thereby infer dust column densities and masses. With an empirical determination of the dust-to-gas mass ratio, the infrared brightness becomes a tracer of interstellar gas. It complements usual interstellar matter tracers, like the H I and CO line emission, in a unique way because the dust emission is independent of the chemical composition and physical conditions of the gas. For the first time we will have access to a complete inventory of cold interstellar matter in the Galaxy. This step forward opens several key perspectives.

The dust temperature may be used to identify the cold infrared emission from dense condensations within molecular clouds. In doing this, we will quantify the mass and

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distribution of matter that is presently susceptible to collapse into stars. The data will be sensitive enough to look for dust emission from High Velocity Clouds, the Magellanic Stream and the outer disk. This will help us to quantify the mass-inflow rate available to sustain star formation over the past history of the Galaxy. The dust seen in emission by Herschel and Planck is the dust that makes the extinction at optical and near-IR wavelengths. The data analysis will involve the characterisation of dust evolutionary processes that may account for the observed variations in the optical and near-IR dust extinction curve. The outcome of these dust studies will need to be taken into account to build the 3D model of extinction for Gaia.

3. The Galactic magnetic field

The Galactic magnetic field and cosmic-rays are tied to the interstellar gas. Their dynamical coupling is a prime facet of interstellar-medium physics, and many questions remain quantitatively open due to the paucity of data on the small-scale structure of the magnetic field. Planck will map the polarisation of the dust and of the synchrotron emission. The two emissions provide complementary perspectives on the structure of the Galactic magnetic field. Dust grains, unlike relativistic electrons, are coupled to the interstellar gas. Thus, the dust polarisation traces the magnetic field within the thin Galactic disk where matter is concentrated and within interstellar clouds, while the synchrotron polarisation probes the field over the whole volume of the Galaxy up to its halo. The novelty of upcoming observations ensures major progress in our understanding of the magnetised Galactic interstellar medium.

Polarisation of the dust emission results from the presence in the ISM of elongated grains with a preferred orientation. Several alignment mechanisms have been proposed. They are expected to work through interstellar clouds even if their efficiency may depend on the gas density and radiation field. It is thought to be generally true that the magnetic field acts on elongated grains so they spin with their long axes perpendicular to the field. In this case, the direction of polarisation in emission is perpendicular to $B_\perp$ the magnetic field component in the plane of sky. The degree of polarisation depends on dust properties (e.g. which grains are aligned), the efficiency of the alignment mechanism and the structure of the magnetic field within the beam.

Measurement by Planck of the polarisation of the thermal emission from aligned grains provide an unprecedented means to map continuously the orientation of the magnetic field within the ISM, from diffuse clouds to dense molecular gas. The Galactic magnetic field is commonly described as a vector sum of a regular and a random component. A first goal will be to complement existing models of the regular component. To fully describe the ordered field, we will face two open questions: (i) what is the impact of nearby bubbles powered by massive star associations on the field structure? (ii) how is the field within the thin Galactic disk, where gas and star formation is concentrated, connected to the thicker disk and the Galactic halo? The turbulent component results from the dynamical interaction between the field and interstellar turbulence. The data will also allow us to study the geometry of the magnetic field in relation to the density structure and kinematics of interstellar clouds derived from dust and gas maps. The degree of randomness in the magnetic field orientation may be combined with Doppler measurements of the turbulent gas velocity to measure the magnetic field intensity and quantify the dependence on gas density. These investigations will test theoretical and numerical studies, stressing the importance of the magnetic field in the dynamical evolution of the interstellar medium and the regulation of the star-formation efficiency.

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