Astrophysics meets data science in studies of the Inter-Stellar Medium

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Inter-Stellar Medium studies are challenging. They need to model numerous physical and chemical processes on many decades of physical scales from the galactic environment to the formation of proto-planetary disks. Moreover, turbulence plays a key role, implying that the intrinsic prevalence of randomness in gas and dust observations. It is therefore important 1) to acquire self-consistent data sets that can be used as templates for theoretical work, 2) to accurately document the diagnostic capabilities of various observations (lines, dust, cosmic rays, etc), and 3) to develop powerful models and simulations that includes enough complexity to interpret the observations in coherent theory of the formation of stars and planets and of the development of the chemical complexity along the way.

I will describe some examples of the current efforts made by the French ISM community. Some of them will be taken from the ORION-B project (Outstanding Radio-Imaging of OrioN-B, co-PIs: J. Pety and M. Gerin), which is a Large Program of the IRAM 30m telescope that aims to improve the understanding of physical and chemical processes of the interstellar medium by mapping a large fraction of the Orion B molecular cloud (5 square degrees) with a typical resolution of 27'' (50 mpc at a distance of 400 pc) and 200 kHz (or 0.6 km s^{-1}) over the full 3 mm atmospheric band. In a first study [1], we showed how tracers of different optical depths like the CO isotopologues allow one to fully trace the molecular medium, from the diffuse envelope to the dense cores, while various chemical tracers can be used to reveal different environments. A clustering algorithm was then applied to the intensities of selected molecular lines, and revealed spatially continuous regions with similar molecular emission properties, corresponding to different regimes of volume density or far-UV illumination [4]. In addition, a global Principal Component Analysis of the line integrated brightnesses revealed that some combination of lines are sensitive to the column density, the density, and the UV field [2]. In a recent study, we go one step further by checking whether/ how it is possible to build a quantitative estimate of the H_2 column density, based on the molecular emissivity, and valid over a large range of conditions [6]. This is a prerequisite to accurately estimate the mass of the different (potentially velocity separated) components of a giant molecular cloud, in particular its filamentary nature [5]. To quantitatively interpret these results, we use the Cramer Rao Bound (CRB) technique to analyze and estimate the precision on the abundances, excitation temperatures, velocity field and velocity dispersions of the three main CO isotopologues [7].

References

[1] Pety et al., A&A, 599, 98 (2017)

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[4] Bron et al., A&A, 610, 12 (2018)

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[6] Gratier *et al*., A&A, 645, 27 (2021)

[7] Roueff *et al*., A&A, 645, 26 (2021)

[8] Bron. *et al*., A&A, 645, 28 (2021)