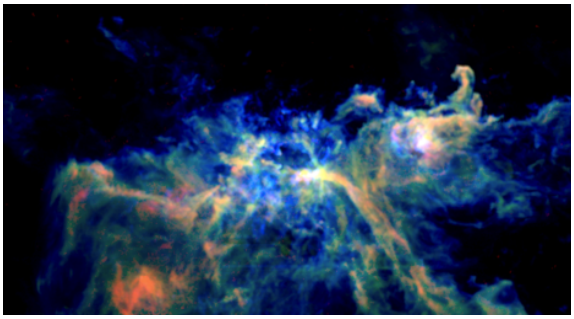
Data science meets astrophysics in the Orion B Giant Molecular Cloud

Context: Star formation, near and far



Millimetre view of Orion B

Giant Molecular Clouds (GMCs) are the sites of star formation. They exhibit complex structures shaped by a highly non-linear interplay of physical and chemical processes, including supersonic turbulence, gravity, and magnetic fields. From the most diffuse envelope to the densest prestellar cores and protostellar objects, GMCs harbor large gas density variations, strong temperature gradients and dramatically different chemical environments. To better understand the transition from one environment to another, all the way to star formation, these different environments must be precisely identified and characterized.

The ORION-B project (Outstanding Radio-Imaging of OrioN B)[1] has been using the IRAM 30m radio telescope equipped with the EMIR 3mm receiver to image a large field (5 square degrees) in the southern half of the Orion B molecular cloud, over a wide bandwidth (40 GHz), at high angular (27”) and spectral (195 kHz) resolutions. The primary product of this program is a position-position-frequency cube of 1000 x 750 x 240000 pixels (enough to make a 2h45 movie!) in which the emission from several molecular lines stand out from the noise (CO isotopologues, HCO^+, HCN, HNC, CN, CCH, C_3H_2, CS, SO, N_2H^+, SiO, H_2CO, CH_3OH, DCO^+ and many other weaker species). This detailed study of one of the closest high-mass star-forming regions in our Galaxy does not only shed light on various aspects of the star formation process. It also provides benchmarks for understanding them in external galaxies, where GMCs are barely resolved.

Questions: Characterization of the physics and chemistry of a Giant Molecular Cloud

Our international team of 20 researchers (France, USA, UK, Spain, Chile, Sweden) has been analyzing this data to answer several questions related to the characterization of the physics and chemistry of this archetypal GMC: How do various species trace environments that differ in terms of extinction, volumetric density, UV illumination, ionization fraction, …)? How can we use tracers of different optical depths (such as CO isotopologues) to fully trace the molecular medium, from the diffuse envelope to the dense cores? Do similar environments necessarily exhibit similar line integrated intensities? If so, how can we quantitatively deduce key physical parameters (column density, density, UV field, ionization fraction…) directly from these line integrated intensities? What are the kinematic properties of the gas and can we relate them to the star-formation efficiency in different regions of the cloud? What are the properties of the observed molecular filaments and their role in the formation of dense cores and subsequently stars?

M2 work: Texture analysis of the molecular emission

The complex morphologies of the various molecular emission maps stem from the non-linear interplay of physical processes at work. The resulting structures are highly non-Gaussian, and cannot be fully characterized by usual tools such as distribution functions, correlation functions, or power spectra. To properly and finely characterize the structure of these maps, the student will use a framework developed in the field of applied mathematics to characterize non-Gaussian structures. The Wavelet Scattering Transform (WST, Mallat 2012, and RWST, Allys et al. 2019) is able to capture the interactions across scales that are central to non-linear physical processes, with a small number of coefficients.

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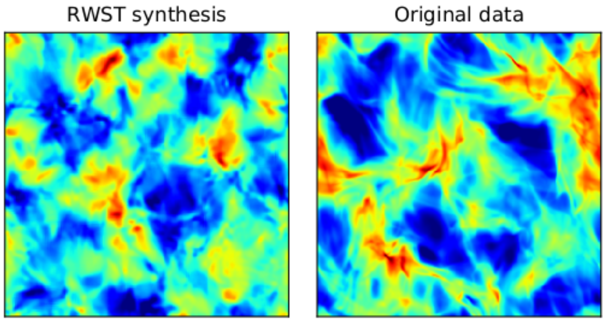
1 *http://www.iram.fr/~pety/ORION-B/*



An example of RWST synthesis

As a first step, the student will apply the RWST to the emission maps associated with different chemical tracers, and to maps of thermal dust emission that trace most of the mass, in order to study how turbulent properties of the molecular gas vary as a function of density. Since the RWST fully describes the spatial statistical properties of the chemical tracers emission maps, they may also be used to quantitatively compare observations to 3D MHD simulations of GMCs, and therefore guide the development of physically accurate simulations. In a second part of the internship, the student will use a set of such simulations available to us (Valdivia et al. 2017), to infer the relative importance of physical parameters (e.g. turbulence, magnetic field, self-gravity) on the dynamics of the Orion B cloud.

Practical information The student will be co-supervised by François Levrier (LPENS, Paris) and Jérôme Pety (IRAM, Grenoble). He will have access to HPC resources at ENS and IRAM.

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