Jérome Pety

Astrophysics meet data science for the study of Giant Molecular Clouds (PCMI)

DAOISM (Deep Analysis Of the Inter-Stellar Medium) is a collaborative project between observational astronomers, theoretical astrophysicists and data scientists. We aim at bridging Galactic and extragalactic studies of Star formation in relation with the molecular interstellar medium by developing advanced statistical methods and data mining techniques and performing deep observations of the cold interstellar medium. These new approaches are urgently needed as the latest generation of astronomical data and models for the ISM now regularly attains volumes that defy human capacity for visual inspection and a complexity level that is intractable to the simple correlation analysis methods employed in the field.

In this talk, I will review the progress made in characterizing the physical and chemical properties of Giant Molecular Clouds using emission maps of multiple molecular lines. These include the determination of the H2 column density and thus the cloud mass, the evaluation of the far UV illumination, the thermal pressure, the ionization fraction in different regions of the clouds, and the characterization of the filamentary structures and of the turbulent velocity field. These results required the development of a robust method to denoise spectral line cubes, an accurate emulation of a sophisticated modeling code (e.g., the Meudon PDR code) with a fast neural network, and a new fast Bayesian framework that takes into account additive and multiplicative noise, censored information, and a spatial regularization to retrieve the spatial distribution of the gas fundamental parameters (pressure, total extinction, and FUV illumination) from emission line maps.

I will complete the talk with perspectives from the next generation of instrumentation in the (sub-)millimeter domain.

Bron et al. 2021, A&A, 645, 28B, "Tracers of the ionization fraction in dense and translucent gas. I. Automated exploitation of massive astrochemical model grids"
Gratier et al. 2021, A&A, 645, 27G, "Quantitative inference of the H2 column densities from 3 mm molecular emission: case study towards Orion B"
Roueff et al. 2021, A&A, 645, 26R, "C18O, 13CO, and 12CO abundances and excitation temperatures in the Orion B molecular cloud. Analysis of the achievable precision in modeling spectral lines within the approximation of the local thermodynamic equilibrium"
Pety et al. 2022, EPJ Web of Conferences, 265, "Revealing which combinations of molecular lines are sensitive to the gas physical parameters of molecular clouds"
Gerin et al. 2022, Proceedings of the 7th Chile-Cologne-Bonn Symposium, 230, "Multi-dimension analysis of molecular clouds: The exemple of Orion B"
Gaudel et al. 2023, A&A, 670, 59A, "Gas kinematics around filamentary structures in the Orion B cloud"
Einig et al., 2023, A&A, 677, A158, "Deep learning denoising by dimension reduction: Application to the ORION-B line cubes"
Palud et al., 2023, A&A, 678, A198, "Neural network based emulation of astrophysical models"
Palud et al., accepted by IEEE Transactions on Signal Processing, "Efficient Sampling of Non Log-Concave Posterior Distributions With Mixture of Noises"
Santa-Maria et al., 2023, A&A, 679, A4, "HCN emission from translucent gas and UV-illuminated cloud edges revealed by wide-field IRAM 30m maps of Orion B GMC”

Titre: A la rencontre la science des données pour caractériser les nuages moléculaires géants

DAOISM (Deep Analysis Of the Inter-Stellar Medium) est un projet collaboratif entre observateurs, théoriciens et spécialistes des données. Nous cherchons à rapprocher les études galactiques et extragalactiques sur la formation des étoiles dans le milieu interstellaire moléculaire en combinant des méthodes statistiques avancées et de nouvelles techniques d'exploration des observations profondes du milieu interstellaire froid. Ces approches sont critiques car les données et les modèles actuels du milieu moléculaire atteignent des volumes qui défient les capacités manuelles d'inspection et une complexité irréductible par les méthodes d'analyse de corrélation simples employées jusqu'aujourd'hui dans le domaine.

Dans cet exposé, je passerai en revue les progrès réalisés dans la caractérisation des propriétés physiques et chimiques des nuages moléculaires géants à l'aide de cartes d'émission de plusieurs raies moléculaires. Il s'agit notamment de la détermination de la densité de colonne de H2 et donc de la masse du nuage, de l'évaluation du champ d'illumination UV lointain, de la pression thermique, de la fraction d'ionisation dans différentes régions des nuages, et de la caractérisation des structures filamentaires et du champ de vitesse turbulente. Ces résultats ont nécessité le développement d'une méthode robuste de débruitage des cubes de raies spectrales, une émulation rapide et précise de codes sophistiqués de modélisation (par exemple, le code PDR de Meudon) avec un réseau neuronal, ainsi qu'un nouveau cadre bayésien rapide qui prend en compte le bruit additif et multiplicatif, l'information censurée, et une régularisation spatiale pour récupérer la distribution spatiale des paramètres fondamentaux du gaz (pression, extinction totale, et illumination FUV).

Je terminerai mon exposé en évoquant les perspectives de la prochaine génération d'instruments dans le domaine (sub)millimétrique.

Bron et al. 2021, A&A, 645, 28B, "Tracers of the ionization fraction in dense and translucent gas. I. Automated exploitation of massive astrochemical model grids"
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