Inferring physical conditions in star forming regions with new Bayesian approach and spatial regularization

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The role of the main feedback mechanisms that regulate star formation rates (radiative feedback, winds, jets, …) are still poorly understood. New facilities at IRAM, ALMA and the JWST might lead to breakthroughs in this regard in the coming years, thanks to the very rich hyper-spectral data they provide. For instance, the IRAM-30m Large Program “Orion B” observed the Orion B cloud at dense core resolution, resulting in a million-pixel map, with 240,000 spectral bands containing emissions of dozens of tracers [1].

We address the problem of estimating physical parameters maps (pressure, visual extinction, etc.) from those datasets. This task is challenging even for statisticians. When the observed lines constrain poorly the physical conditions or when the SNR is low, multiple solutions might reconstruct observations equivalently well. Currently most methods used in interstellar astrophysics (e.g., [2]) do not consider these degeneracies and only return one estimated map. Moreover, the non-linearity of astrochemistry models leads to non-convex and even multi-modal problems. Current methods get trapped in local minima and estimations have no optimality guarantees. Heuristics can overcome this issue for small datasets but would be unrealistically slow for larger ones. New methods are therefore needed to correctly and efficiently exploit these rich datasets.

In a collaboration between statisticians and astrophysicists, we developed a new inference method that tackles these difficulties in two ways. A spatial regularization enables pixels to exploit the information contained in their neighbours, which improves estimations. Second, instead of a standard optimization approach, we use a Bayesian one. Our Monte Carlo Markov Chain (MCMC) algorithm combines two samplers: one identifies local minima in the parameters space while the second efficiently explores them. This approach provides a complete description of the parameters space which enables to evaluate estimations uncertainties, for instance with credibility intervals on derived parameters.

After introducing the problem and method, we will show results on well-known PDRs like the Orion Bar from OMC-1 and the Horsehead from Orion B. We will then show how the method can be used with any set of lines from any instruments (ALMA, JWST) and environments that we can simulate (shocks, dark clouds).

Références

[1] Pety, J. *et al.* The anatomy of the Orion B Giant Molecular Cloud: A local template for studies of nearby galaxies. *Astronomy & Astrophysics* **599**, (2016).
[2] Wu, R. *et al.* Constraining physical conditions for the PDR of Trumpler 14 in the Carina Nebula. *A&A* **618**, A53 (2018).