Bayesian inference and ISM studies: some statistical tools to make the most of your observations

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Wednesday, July 23, 2025, 14:00–15:45

Bayesian inference methods are now central to data analysis in astrophysics, providing a principled framework for incorporating prior knowledge, extracting insight from high-dimensional, complex data, including uncertainty quantifications. This lecture introduces the Bayesian paradigm, its key probability distributions, and three commonly used estimators: the Maximum Likelihood Estimator (MLE), the Maximum A Posteriori (MAP), and the Minimum Mean Squared Error (MMSE).

To build intuition, we will first examine these estimators in the simple case of conjugate priors, where closed-form solutions exist. We will then move to the general case, introducing Markov Chain Monte Carlo (MCMC) methods. Finally, we will explore applications of Bayesian methods to studies of the interstellar medium, such as physical parameter inference with astrophysical simulators.

The goal of this class is to provide the main theoretical concepts and some practical tools to help astrophysicists incorporate Bayesian reasoning into their research.

Bibliography

For a general overview of MCMC methods:

- Robert, C. P. & Casella, G. *Monte Carlo Statistical Methods* (Springer New York, New York, NY, 2004) doi:10.1007/978-1-4757-4145-2.
- Palud, P., PhD thesis, 2023, chapter 2 https://theses.hal.science/tel-04424965.

For a general overview of statistical inference applications to interstellar medium:

- Palud, P., PhD thesis, 2023, chapter 3 https://theses.hal.science/tel-04424965.