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hammurabi X: a C++ package for simulating Galactic emissions

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Summary

Understanding the Galactic emission is critical for studying not only the multi-phase interstellar medium (ISM), but also for detailed investigations of the cosmic microwave background (CMB) radiation or the 21cm cosmology. Both areas recognize the importance of physical modellings of the Galactic polarized synchrotron emission, absorption, and Faraday rotation. For ISM studies, these trace the physical conditions in the Galaxy, while for CMB studies, these provide the most important CMB foreground.

The fundamental physical principles of the radiative transfer processes have been well understood for around half a century (Rybicki & Lightman, 1979), however, with the growing precision and range of observations we are overwhelmed by various local structures and non-linear phenomena within the Galaxy. This is slowing down conceptual and theoretical advancements in the mentioned research areas since the observables are no longer analytically calculable in a high-resolution and non-perturbative regime.

To meet the growing need of numerical simulation of the Galactic emission, `hammurabi` (Waelkens, Jaffe, Reinecke, Kitaura, & Enßlin, 2009) was developed to simulate Galactic observables based on a 3D modelling of the physical components of the Galaxy. The original code design was, however, not matching modern coding and numerical standards required by the current scientific developments in ISM and CMB foreground modelling. Furthermore, the focus in the Galactic emission modelling has migrated recently from assuming simple regular fields structure to more complicated fields with turbulence, enhancing the need for an accurate state-of-the-art simulation package for Galactic emission.

To extract information on the Galactic magnetic fields, Boulanger et al. (2018) proposed a Bayesian method for parametric and non-parametric Galactic magnetic field inference. As Bayesian inference is computationally expensive, it has to rest on a high-performance simulation package. To meet these requirements, the hammurabi code has been upgraded to `hammurabi X`, with a complete package redesign including modern coding standards and support for multi-threading.

Technically, `hammurabi X` performs an efficient line-of-sight radiative transfer integral through the simulated Galaxy model using a HEALPix-based nested grid to produce observables such as Faraday rotation measure and diffuse synchrotron emission in full Stokes I, Q and U, while taking into account beam and depth depolarization as well as Faraday effects.

The scientific aim of `hammurabi X` is to provide the ISM and CMB communities with a versatile numerical package to simulate Galactic emission. The numerical framework can also be

applied to other settings, for example, recently `hammurabi X` provided extra-galactic Faraday rotation maps resulting from (reconstructed) primordial magnetic fields (Hutschenreuter et al., 2018).

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