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

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Summary

Realistic models of Galactic emission are critical ingredients in the study of both the multi-phase interstellar medium (ISM) and precision cosmology. Models for the polarized synchrotron emission, absorption, and Faraday rotation are required in both cases. For ISM studies, these trace the physical conditions in the Galaxy and this emission is a significant foreground signal for cosmological surveys. The fundamental physical principles of the radiative transfer processes have been well understood for around half a century (Rybicki & Lightman, 1979), but simple analytic models are not sufficient to capture the local structure and non-linear phenomena revealed by the precision and range of modern measurements.

To meet the growing need for 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 up to the coding and numerical standards required for studies of the ISM and cosmic microwave background (CMB) foregrounds. Furthermore, the focus in the Galactic emission modelling has migrated recently from assuming simple regular field 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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