In-situ cosmic ray injection in protostars: Insights from 3D non-ideal MHD simulations

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Abstract

The role of cosmic rays (CRs) in shaping the physical and chemical environment of young protostars remains an open question. While the interstellar CR flux is attenuated in dense collapsing regions, local CR acceleration — for instance at accretion shocks — can significantly enhance the ionization rate in the immediate protostellar environment, with important consequences for magnetic field coupling and disk formation. We present 3D numerical simulations of protostellar collapse performed with the RAMSES code, combining a non-ideal MHD solver, sink particles, and the newly implemented two-moment CR physics module (Rosdahl et al. 2025). To model in-situ CR production, we assume that a fraction (0.1%) of the sink accretion luminosity is converted into CR energy. We explore two initial configurations: an isolated 1 $M_\odot$ dense core collapse and a setup representative of the B335 protostar, both initialized with a Boss & Bodenheimer density profile. Our results show that locally accelerated CRs produce enhanced ionization rates in the MHD-driven outflow region and in the vicinity of the young protostar, in good agreement with observational constraints. These findings support a scenario in which in-situ CR acceleration is a significant source of ionization in protostellar environments, and highlight the importance of self-consistent CR transport for modeling early disk formation.