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ORION2: A magnetohydrodynamics code for star formation

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Software

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Summary

The formation of stars and stellar clusters remains a grand challenge problem in astrophysics that has important implications for the evolution of the interstellar medium as well as shaping the evolution of galaxies. The computational challenges are formidable and involve a coupling of highly non-linear physical processes such as hydrodynamics, self-gravity, magnetic fields, radiation transfer, supersonic turbulence, ionization, protostellar outflows, stellar winds and chemistry that have both disparate timescales as well as operate over many decades of physical length scale. These processes can regulate the feedback from nascent protostars onto the surrounding turbulent gas clouds that are the embryos of new star formation, and as a result, the feedback itself can influence the gaseous reservoir feeding newly formed protostars which in turn influence the star formation process.

Statement of need

To address the myriad of problems associated with star and cluster formation we have advanced the development of ORION2 over the past several years. ORION2 is a radiation-magneto-hydrodynamic (MHD) 3-D code that operates in the block structured Adaptive Mesh Refinement (AMR) framework of CHOMBO for parallel computation. The code is written in C++, C and Fortran. We developed a new magneto-hydrodynamic (MHD) module using a Constrainted Transport scheme for adaptive mesh refinement (Li et al., 2012) based on the framework of the publicly released PLUTO code version 3.0 (Mignone et al., 2012, 2007). We also implemented a variety of additional functionality needed for modeling our target problems, which focus on the dynamics of the interstellar medium and star formation. Our first code release includes MHD, self-gravity, sink and star particles, protostellar outflows and main sequence stellar winds. ORION2 is state of the art and compares well with other commonly used packages. It has an extremely robust MHD for adaptive grids with multiple options for Godunov solvers and a robust and efficient gravity solver (Li et al., 2012). The code includes several packages that enable feedback effects from star particles, which are not included in some of the other commonly used packages in the community. Future releases of ORION2 will include a hybrid ray trace moment radiative transfer method enabling the computation of radiative forces associated with massive star formation. Data from ORION2 simulations can be analyzed straightforwardly using yt and VISIT. Example Python analysis scripts are included in the release.

The ORION2 methodology in this release has been described in a variety of prior publications:

- MHD: (Li et al., 2012)
- Gravity: (Martin et al., 2008; Miniati & Colella, 2007)
- Sink particles: (Krumholz et al., 2004)
- Star particles: (Offner, Klein, et al., 2009)
- Protostellar Outflows: (Cunningham et al., 2011)
- Stellar Winds: (Offner & Arce, 2015; Rosen et al., 2021)

Research with ORION2

ORION2 has been used to explore a variety of problems in the field of star formation. Notable papers that utilize the release functionality have been written on:

- The Jeans condition and resolving gravitational fragmentation: (Truelove et al., 1997)
- Bondi accretion under turbulent conditions with and without magnetic fields: (Krumholz et al., 2005; Lee et al., 2014)
- Properties of stars and dense cores under driven and decaying turbulence conditions: (Offner, Krumholz, et al., 2008; Offner, Klein, et al., 2008; Offner & Krumholz, 2009)
- Stellar kinematics and clustering of young star clusters: (Kirk et al., 2014; Offner, Hansen, et al., 2009)
- Impact of protostellar outflows on low-mass star formation: (Hansen et al., 2012)
- Chemical mixing in star-forming clouds and metallicity homogeneity in open clusters: (Feng & Krumholz, 2014)
- Momentum- and energy-driven feedback from stellar winds in star-forming environments: (Offner & Liu, 2018; Rosen et al., 2021)
- Magnetized turbulence excited by stellar winds: (Offner & Liu, 2018)
- Binary and multiple star formation in magnetized clouds: (Lee et al., 2019)
- Magnetic properties of cloud clumps: (Li et al., 2015)
- Cluster formation in filamentary dark clouds: (Li et al., 2018)
- Infrared dark clouds formation simulation: (Li & Klein, 2019)

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