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ENZO: An Adaptive Mesh Refinement Code for Astrophysics (Version 2.6)

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Software

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Summary

Enzo (Enzo Developers, 2019a) is a block-structured adaptive mesh refinement code that is widely used to simulate astrophysical fluid flows (primarily, but not exclusively, cosmological structure formation, star formation, and turbulence). The code is a community project with dozens of users, and has contributed to hundreds of peer-reviewed publications in astrophysics, physics, and computer science. The code utilizes a Cartesian mesh can be run in one, two, or

three dimensions. It supports a wide variety of physics including (magneto)hydrodynamics, the self-gravity of fluids and particles, cosmological expansion, primordial gas chemistry, optically thin radiative plasma cooling, radiation transport, conduction, and models for star formation, stellar feedback, and the feedback from supermassive black holes.

Enzo's original method paper (Bryan et al., 2014) was published in 2014, and documented Version 2.3. This paper describes Enzo's most recent public release, Version 2.6 (released on August 2, 2019; see (Enzo Developers, 2019b)). Since Version 2.3, there have been several new features added to the code:

- Support for the Grackle chemistry and cooling library (Smith et al., 2017)
- Several new types of adaptive mesh refinement algorithms (Peeples et al., 2019)
- Cosmic ray pressure, diffusion, and injection (Salem & Bryan, 2014)
- A stochastic forcing module (for driven turbulence calculations) (Schmidt, Federrath, Hupp, Kern, & Niemeyer, 2009)
- A subgrid-scale turbulence modeling framework (Grete, Vlaykov, Schmidt, & Schleicher, 2017)
- Kinetic supernova feedback (Simpson, Bryan, Hummels, & Ostriker, 2015)
- Magnetic supernova feedback (Butsky, Zrake, Kim, Yang, & Abel, 2017)
- An "active particle" framework for complex particle types (Meece, Voit, & O'Shea, 2017; Regan & Downes, 2018)
- Fuzzy dark matter evolution (Li, Hui, & Bryan, 2019)
- Many new code test problems
- Automated regression testing on GitHub with CircleCI

In addition, there are a much larger number of code enhancements and bug fixes. A complete listing of new features, enhancements, and bug fixes for all code releases can be found at (Enzo Developers, 2019b).

Research with Enzo

Enzo is used extensively in the astrophysics research community. A few recent notable research areas that have benefited from the use of Enzo include:

- Exploration of galaxy formation in the early universe (O'Shea, Wise, Xu, & Norman, 2015; Smith, Wise, O'Shea, Norman, & Khochfar, 2015; Wise et al., 2019)
- Reionization of the universe (Norman, Chen, Wise, & Xu, 2018)
- High resolution examination of the circumgalactic medium around Milky Way-like galaxies (Peeples et al., 2019; Salem, Bryan, & Corlies, 2016)
- The impact of supermassive black holes on the regulation of galaxy cluster cores (Li et al., 2017; Meece et al., 2017)
- Astrophysical turbulence (Grete et al., 2017; Kritsuk, Flauger, & Ustyugov, 2018)
- Star formation, both in a primordial context and in a Milky Way-type environment (Burkhart, Stalpes, & Collins, 2017; Chiaki & Wise, 2019)
- The interstellar medium and its effect on galaxy behavior (Fujimoto, Bryan, Tasker, Habe, & Simpson, 2016; Goldbaum, Krumholz, & Forbes, 2016; M. Li et al., 2017)
- Supernova deflagration (Hristov, Collins, Hoeflich, Weatherford, & Diamond, 2018)

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