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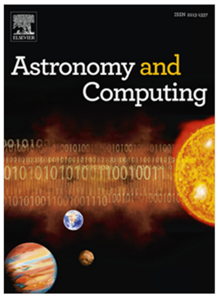

Two-fluid dusty gas in smoothed particle hydrodynamics: Fast and implicit algorithm for stiff linear drag

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Two-Fluid Dusty Gas in Smoothed Particle Hydrodynamics: Fast and Implicit Algorithm for Stiff Linear Drag

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Abstract

Simulation of the dynamics of dust-gas circumstellar discs is crucial in understanding the mechanisms of planet formation. The dynamics of small grains in the disc is stiffly coupled to the gas, while the dynamics of grown solids is decoupled. Moreover, in some parts of the disc the concentration of the dust is low (dust to gas mass ratio is about 0.01), while in other parts it can be much higher. These factors place high requirements on the numerical methods for disc simulations. In particular, when gas and dust are simulated with two different fluids, explicit methods require very small timestep (must be less than dust stopping time t_{stop} during which the velocity of a solid particle is equalized with respect to the gas velocity) to obtain solution, while some implicit methods requires high temporal resolution to obtain acceptable accuracy. Moreover, recent studies underlined that for Smoothed particle hydrodynamics (SPH) when the gas and the dust are simulated with different sets of particles only high spatial resolution $h < c_{\mathrm{s}} t_{\mathrm{stop}}$ guaranties suppression of numerical overdissipation due to gas and dust interaction.

To address these problems, we developed a fast algorithm based on the ideas of (1) implicit integration of linear (Epstein) drag and (2) exact conservation of local linear momentum. We derived formulas for monodisperse dust-gas in two-fluid SPH and tested the new method on problems with known analytical solutions. We found that our method is a promising alternative for the previously developed two-fluid SPH scheme in case of stiff linear drag thanks to the fact that spatial resolution condition $h < c_{\mathrm{s}} t_{\mathrm{stop}}$ is not required anymore for accurate results.

Keywords: protoplanetary discs — hydrodynamics — Epstain drag simulation

1. Introduction

Simulation of the dynamics of circumstellar discs is crucial in understanding the mechanisms of planet formation. The state-of-the-art models of formation and evolution of circumstellar discs include a variety of physical processes: dynamics of a two-phase medium (gas and solid particles) in the field of the star and in their own gravitational field, radiation transfer, chemical processes, effects of magnetic hydrodynamics and other phenomena. The review by Haworth et al. (2016) describes applied approaches and newest computational challenges for this field. For the simulation of disc dynamics such software solutions as GANDALF (Hubber et al., 2018), PHANTOM (Price et al., 2017), GADGET (Springel, 2005), ZEUS (Stone and Norman, 1992), FEoSaD (Vorobyov and Basu, 2006), Sombrero (Snytnikov and Stoyanovskaya, 2013; Stoyanovskaya et al., 2017a) and many others are developed. They are run on supercomputers with shared and distributed memory.

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