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Numerical Simulations of High-Mach Number Astrophysical Radiative Flows with HADES

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The understanding of astrophysical phenomena requires to deal with robust numerical tools in order to handle realistic scales in terms of energy, characteristic lengths and Mach number that cannot be easily reproduced by means of laboratory experiments. We will show simulations of realistic astrophysical phenomena in various contexts, taking into account radiative losses. We will present the 2D numerical code HADES in both optically thin and thick media. Validation of HADES is performed using several benchmark tests and some realistic applications are discussed. The goal of our simulations is to compute a full radiation transfer coupled to hydrodynamics using the same HADES code. In this latter case, the computational time is really expensive therefore we need faster and simpler numerical simulations in order to constrain efficiency complete simulations.

Optically thin radiative loss is modeled by a cooling function in the conservation law of energy. Optically thick is computed in the diffusion approximation. These approaches are respectively two asymptotic models of the radiation hydrodynamics. Numerical methods involve the MUSCL-Hancock finite volume scheme as well as HLLC and HLLE Riemann solvers, coupled with a second-order ODE solver by means of Strang splitting algorithm that handles source terms arising from geometrical or radiative contributions, for cartesian or axisymmetric configurations.

A good agreement has been observed for all benchmark tests, either in hydrodynamic cases or in radiative cases. Furthermore, an overview of the main astrophysical studies driven with this code is proposed. First, simulations of radiative shocks in accretion columns [1] and supernova remnant dynamics at large timescales (see Fig.~1) including Vishniac instability [2, 3] have improved the understanding of these phenomena. Then astrophysical jets are investigated and the influence of the cooling effect on the jet morphology is numerically demonstrated. It is also found that periodic source enables to recover pulsating jets that mimic the structure of Herbig-Haro objects. These results can be compared to other young stellar jet simulations given in [4] and using the full radiative transfer version of the code. HADES code has revealed its robustness [5], especially for the wall-shock test and for the so-called implosion test which turns out to be a severe one since the hydrodynamic variables are self-similar and become infinite at finite time. The simulations have proved the efficiency of HADES code and the usefulness of this tool for astrophysical applications.

References

[1] C. Busschaert, É. Falize, C. Michaut, J.-M. Bonnet-Bidaud and M. Mouchet, Astron. & Astrophys. 579, A25 (2015)
[2] C. Michaut, C. Cavet, S. Bouquet, F. Roy, H.C. Nguyen, Astrophys. J. 759, 78 (2012)
[3] J. Miniere, S.E. Bouquet, C. Michaut, J. Sanz, M. Mancini, Astron. & Astrophys. 617, A133 (2018)
[4] C. Michaut, H.C. Nguyen, L. Di Menza, Astrophys. Space Sci. 336, 175 (2011)
[5] Michaut, C. and Di Menza, L. and Nguyen, H.C. and Bouquet, S.E. and Mancini M., High Ener. Dens. Phys., 2017, 22, 77-89

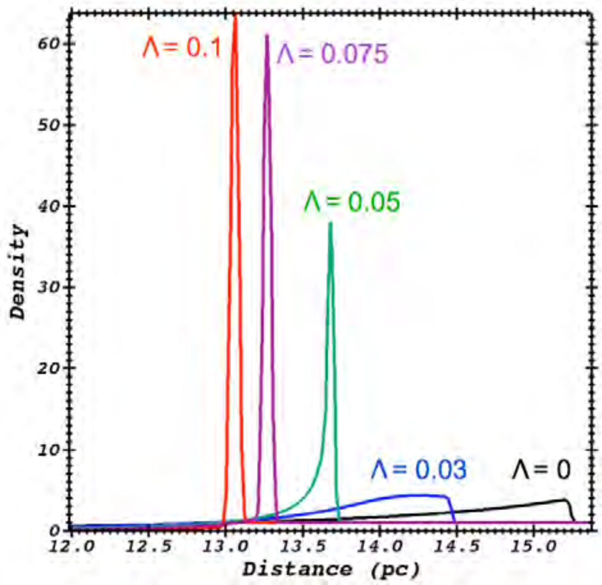

Figure 1: Different density evolutions at 33 kyrs of the thin shell of a supernova remnant depending of the type of considered cooling Λ in the numerical model.

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