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A-MAZE: A code package to compute 3D magnetic flows, 3D NLTE radiative transfer, and synthetic spectra

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Abstract. We have developed A-MAZE, a code package to compute astrophysical flows and to derive synthetic spectra from the computed density- and velocity-structure. AMRCART is a 3D adaptive mesh MHD-code. D3NEBEL is an optically thin NLTE-radiative transfer code to compute ionization structures and line profiles for 3D moving media. TR3D computes optically thick 3D NLTE-radiative transfer in moving media using modified Sobolev-theory. Unix shell scripts allow for automatic handling of most job-control and data-management issues. Modules on the basis of common graphics packages allow for visualization, including fast hierarchical multi-block data-visualization and creation of movies. This code package is freely available for use in research.

1. Introduction

Our numerical simulation package A-MAZE comprises Fortran codes to compute 3D magnetic, compressible, and reactive flows, 3D NLTE radiative transfer under optically thick and optically thin conditions, and scripts for data-management and visualization. Due to the limited space, we can here only briefly sketch the numerical techniques applied in the codes. The interested reader may take details from the referred papers. We also give references to papers with astrophysical results in different fields already obtained by these codes[2]. A more extended description of this package is in preparation.

2. AMRCART: an adaptive 3D MHD-code

AMRCART is a highly flexible code to compute magnetic and radiative flows from one up to three space dimensions. It makes use of high-resolution finite volume integrators (either Riemann-solver based, following Colella 1990 or LeVeque

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[2] Papers by the authors, brief code-descriptions, computational examples, and video animations can be found on our web-pages, http://www.astro.phys.ethz.ch/staff/walder/walder.html or http://www.astro.phys.ethz.ch/staff/folini/folini.html. The codes can be ordered there as well.

1997, or the modified Lax-Friedrichs method proposed by Barmin, Kulikovskij, & Pogorelov 1996). MHD-fluxes are treated according to Powell (1994), ensuring the magnetic field to be divergence-free up to numerical truncation errors. We have implemented the adaptive mesh refinement algorithm of Berger, which automatically adjusts the spatial and temporal discretization where a higher resolution is needed (e.g. Berger & Colella 1989). The code was developed by Walder (1993) on the basis of a 2D adaptive hydro-code provided by Berger & LeVeque (1990). It is user friendly in the sense that a new problem requires adapting three subroutines only.

A number of astrophysical results have already been obtained with this code, ranging from simulations of colliding winds (Nussbaumer & Walder 1993; Mürset, Jordan, & Walder 1995) and accretion flows in symbiotics (Dumm et al. 2000), to general wind-accretion models (Walder 1997), colliding wind models in hot star systems (Walder 1995; Walder, Folini & Motamen 1999), the investigation of the stability of radiative shocks and their contribution to structure formation in space (Walder & Folini 1996; Walder & Folini 1998a; Walder & Folini 1998b), and to the interaction of magnetic, molecular jets with protostellar clouds (with J. Heyvaerts, in preparation).

3. D3NEBEL: ionization structures and line profiles under nebular conditions

D3NEBEL computes optically thin NLTE radiative transfer in 3D moving media under nebular conditions. The input data consist of a 3D density and velocity structure, a central radiation source, and atomic data. Matter temperatures are either computed consistently or given as input data. The code then computes the ionization structures and Doppler broadened line profiles as seen by different observers. The 3D structure is captured by a series of independent 1D rays, all emerging from the central radiation source. Along each ray, automatic adaptation of the spatial step size guarantees the capturing of ionization fronts. A variety of atomic processes are taken into account.

Many people of the group of Harry Nussbaumer (Nussbaumer & Schild 1981; Vogel 1990; Folini 1998) have contributed to the development of this code. Its 1D- and 2D versions have produced many results in the field of symbiotics, e.g. an investigation of the evolution of the symbiotic nova HM Seg (Nussbaumer & Vogel 1990), the determination of the temperature and luminosity of a variety of hot components (Mürset et al. 1991), or the influence of the wind-wind interaction zone on the symbiotic spectra (Nussbaumer & Walder 1993). Applications of the recently developed 3D version can be found in Folini (1998) and in Walder & Folini (review on wind dynamics in symbiotics, this volume).

4. TR3D: 3D NLTE optically thick radiative transfer

TR3D solves the optically thick NLTE radiative transfer problem in 3D for moving media. A generalized mean intensity approach, as suggested by Turek (1993), is used for the continuum transport. The code uses some sort of short characteristic formulation, discrete ordinates, a modern iterative solver, and Sobolev theory adapted to 3D for the treatment of lines. For a given 3D density, velocity, and temperature structure, and given radiation sources, atomic level populations are computed. A full description can be found in Folini (1998), a shortened version in Folini & Walder (1999a).

First applications – among them a preliminary investigation on the ionization stage of the cold part of the wind-wind interaction zone of the hot star system γ-Velorum – can be found in Folini (1998) and Folini & Walder (1999b). Even though this code is potentially a powerful tool to attack a variety of astrophysical problems, it is still under development and therefore needs a deeper insight in numerical issues for its usage than the other two codes presented.

5. Graphics and scripts

Visualization of the computed results is a big issue, in particular for 3D data. We have built a variety of interfaces to commercial graphics packages (IDL, PV-wave, NCAR, AVS 5, AVS/express). In particular, for the visualization of time-dependent simulations based on adaptive meshes with several hundred of gigabytes of data, we apply hierarchical high-speed multi-block data-visualization with AVS/express which was newly developed by Jean Favre of the Swiss Supercomputing Center (CSCS), Manno, in collaboration with our institute (Favre 1997; Favre, Walder, & Folini 1998; Favre 1999).

A variety of Unix scripts (perl, csh) have been developed to facilitate the administration of the numerical simulations. Among others, this includes scripts for the adaptation of input files, the annotation and storage of output files, or various issues related to graphics. Small Fortran programs provide the intersection between the different codes with their different input and output data.

6. Conclusions

The codes of the A-MAZE package have already been used to achieve relevant scientific results. They have been employed by users other than the developers. In this sense, the codes have proven their reliability. Although the authors tried to code carefully and some code-documentation exists, the codes are not on the level of commercial software. Also, the package deals with problems for which the 'best solution' is not yet known. Many questions around the numerical solution of non-linear partial differential equations are settled neither theoretically nor in a practical sense. Using these codes needs some numerical and computer science skills. Nevertheless, A-MAZE provides powerful tools for scientific research. We would be happy if many of our colleagues could benefit from them.

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