Splinter Meeting E

Numerical Astrophysics

9 contributions

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3D Simulations of Weakly Magnetized Accretion Disks

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The global evolution of weakly magnetized accretion disks is studied within two physically distinct models, which utilize different kind of radial boundary conditions. Each model is furthermore evolved using two different numerical schemes with different grid structures. We focus on cylindrical disk models with no vertical gravity, which allows for a simplified treatment of the vertical boundaries. For the magnetic field we assume that the disk is (on average) unmagnetized and apply zero-net-flux boundary conditions.

In all cases the magneto-rotational instability (MRI) induced flow structure settles to quasi-stationary states which are very similar to each other. The magnitude of the α-parameter depends clearly on the chosen radial boundary condition. The global density distribution displays particular features and time dependencies which appear to be characteristic for the MRI.

The MRI in stratified accretion discs

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Since the introduction of the notion of a magneto rotational instability (MRI) to drive accretion in circumstellar discs some 15 years ago there has been a huge development in corresponding simulations. Although, global simulations become available due to the advancement of computational resources, there are still unresolved problems even with regards to local models incorporating the MRI.

Here we will present new results for the MRI in a stratified accretion disk obtained by using different numerical

approaches. For stratified disks in particular the boundary conditions vertical to the disk have to be handled with care, since they might influence the outcome of the numerical experiment. For these simulations we explicitly included physical dissipation. Even though it is not – and will not be for the near future – possible to include dissipation at the very high Reynolds numbers as they are realised in nature, its inclusion is nonetheless important for studies of the MRI. This is due to the fact that the strength of the MRI depends on the numerical dissipation, in case no physical dissipation is present. The former, however, changes in strength and form for different codes, or even for different spatial resolutions. Therefore, we applied different numerical schemes to the problem simultaneously in order to be able to distinguish between physical effects and numerical influences of such schemes.

Comparison between observed and simulated globular clusters

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At variance to galaxies, in these dense stellar systems the stellar population and hence the integrated spectrum depends strongly on the dynamical evolution of the cluster. The main difference is the typical collision timescale in comparison to the cluster lifetime. As a comparison, in galaxies the typical collision timecales of stars would exceed the lifetime of the galaxy or even the age of the universe.

Hence, in dense stellar systems such as globular clusters the effects of stellar dynamics *and* stellar evolution are important and interact with each other. For example, stellar evolution in close binaries takes place different than in single stars due to their mutual interaction, which may cause mass transfer. On the other handside, the stellar evolution changes the stellar mass, and therefore influences the dynamical evolution of the system. The dynamical effects on the stellar population and therefore on their integrated colors or spectra is certainly important for clusters orbiting in the field of their host galaxy. In these objects the effect of mass segregation leads to a preferentially escape of red, low mass stars. At variance to isolated clusters these objects therefore become bluer.

Such a color change due to the dynamical evolution of the cluster cannot be simulated by an ordinary stellar population synthesis code. Insead of that we use the N-body code NBODY6++ and its stellar evolution routine implemented by J. Hurley in combination with the BaSeL 2.0 library (Lejeune et al. 1997) for simulating integrated spectra and colors of globular clusters. The simulations are executed at the Hydra Beowulf cluster at ARI, and at the Titan cluster at ARI as well.

We will present our simulation results of globular clusters in a tidal field with single stellar evolution and without initial binaries. The influence of different parameters, such as the metallicity and the strength of the tidal field, is investigated. The results of our simulations are compared to the integrated spectra and colors of galactic globular clusters. For extragalactic clusters in M81 and M31 we looked at medium band spectral energy distributions of Ma et al. (2006) and found for some clusters a good agreement.

Presentation of simulation results of our 3D PIC Code

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Particle-in-Cell (PIC) plasma simulation codes model the interaction of charged particles with surrounding electromagnetic fields. We will present simulation results of our newly developed object-oriented relativistic 3D Particle-in-Cell code.

The electromagnetic fields are solved self-consistently due to the superposition of internal (and external) fields from the charge distribution. This is done by determining the charge density at each grid position by a second order weighting scheme and the potentials are calculated using Maxwell's equations. The Particles are moved via Lorentz's equation, using a second order leap-frog finite differencing method.

In particular, we studied the evolution of the Weibel instability in a 3D relativistic simulation of two initially counterstreaming electron distributions in order to understand the typical electromagnetic structures (and the characteristic time and lengthscales) to be expected as a consequence of the development of the Weibel instability.

MAGMA: A 3D Lagrangian hydrodynamics code

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Historically, numerical MHD schemes have first been developed for grid-based methods. Several implementations of magnetic fields into smoothed particle hydrodynamics exist, but their success has somewhat been hampered by quite some numerical difficulties, not least of which is the difficulty in fulfilling the $\vec{\nabla} \cdot \vec{B} = 0$-constraint. Here I present a new approach that combines a Smoothed Particle Magnetohydrodynamics method with so-called Euler potentials. The hydrodynamic and gravitational parts of the equations are derived from a Lagrangian taking changes of the smoothing lengths self-consistently into account. The $\vec{\nabla} \cdot \vec{B} = 0$-constraint is fulfilled by construction. The method and various tests are presented.

FEARLESS - A new modelling approach for turbulent astrophysical flows

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Turbulence has significant influence on several astrophysical processes, for instance, the formation of stars in molecular clouds or the dynamics of hot gas in galaxy clusters. Tackling the complexity of supersonic turbulence in self-gravitating gas including diverse chemical processes as well as radiative cooling poses a grand challenge. As there is no general theory yet that would allow for substantial predictions, we have to resort to three-dimensional numerical simulations in order to gain understanding of phenomena involving turbulence. We present a novel method that combines adaptive mesh refinement for resolving small-scale structure and the notion of large eddy simulation which aims at the explicit computation of the large-scale flow only. This ansatz is called Fluid mEchanics with Adaptively Refined Large Eddy SimulationS (FEARLESS). Using FEARLESS, shock fronts and collapsing gas regions can be traced over a wide range of length scale without computing nearly homogeneous turbulence in the surrounding medium which would become computationally intractable. This is possible by means of a subgrid scale model that records the numerically unresolved kinetic energy and pressure. Therefore, FEARLESS offers the versatility of smoothed particle hydrodynamics and, at the same time, permits the reliable computation of turbulent flow.

Cosmic ray transport in MHD turbulence: Numerical calculation of $D_{\mu\mu}(\mu)$ and $D_{\mu\mu}(p)$

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The Fokker-Planck coefficients are important parameters to understand the transport of cosmic rays in the interstellar Medium. There have been several different analytical theories in the past, but it is a challenging task to describe nonlinear effects of diffusion.

We developed a 3D relativistic test particle code to calculate the Fokker-Planck Coefficients. To model the interstellar Medium we used a MHD-Code, which solves the MHD-equations on a three-dimensional cartesian grid. In this code we implemented test particles. As the mean free path for coulomb scattering of relativistic nucleons

is much too large to play an important role in the dilute interstellar medium we considered wave-particle interactions only. The force acting on the particles is given by the electromagnetic fields which are interpolated by a three-dimensional cubic spline from their positions in the grid. The Fokker-Planck Coefficients result directly from the trajectories of the test particles.

FEARLESS modeling of turbulent flows applied to numerical simulations of galaxy clusters

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The FEARLESS (Fluid mEchanics with Adaptively Refined Large Eddy SimulationS) numerical technique is based on the combination of the adaptive mesh refinement and the Large Eddy Simulations (LES) approach for the modeling of turbulent flows. In this contribution, applications to the physics of galaxy clusters are presented. In a simplified setup, the interaction of a merging subcluster with the intra-cluster medium of a more massive galaxy cluster is studied with 3D numerical simulations. We show that the choice of AMR criteria, specially designed to refine on the vorticity production, is necessary for properly resolving the turbulent flow. Further implications for full cosmological simulations are discussed.

FEARLESS* - Subgrid Scale Turbulence modeling and Applications to Star Formation

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Combining the capabilities of adaptive mesh refinement (AMR) and large-eddy simulations (LES) to capture localized features and to represent unresolved turbulence, respectively, we are developing a new scheme called *Fluid mEchanics with Adaptively Refined Large-Eddy SimulationS (FEARLESS). A subgrid scale (SGS) model based on local similarity arguments for turbulent transport is currently being implemented into the hydrocode ENZO. With the unique capability to compute the local SGS turbulent energy of unresolved turbulence we plan to utilize a recently proposed star formation algorithm (Krumholz & McKee 2005) to simulate star formation in disk galaxies and also primordial star formation (Abel et al. 2002).

References:
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