Viscosity in accretion discs: beyond the alpha model

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Introduction

Viscosity is the means by which angular momentum is transferred outwards in a disc, and mass inwards. It influences the structure and evolution of the disc, planet formation and migration. Shakura & Sunyaev (1973) proposed their famous and powerful α model for viscosity which

- Is independent of the physical mechanism of viscosity
- Reproduces observations quite accurately, especially in dwarf novae

Balbus & Hawley (1991) suggested that the magneto-rotational instability (MRI) drives viscosity. This model

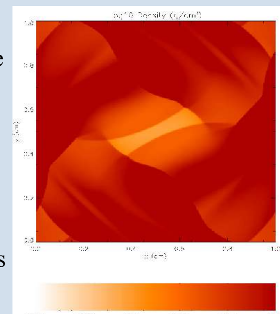
- Provides a feasible physical driver for MHD turbulence and hence for disc eddy viscosity
- Is extremely expensive to model in large-scale simulations

On this poster, I present some of our current efforts which, when combined, may permit large-scale modelling of the MRI, turblence and resulting disc evolution, including outburst behaviour.

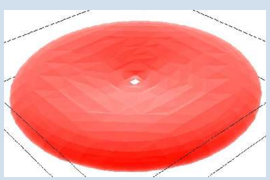
Sub-grid modelling of MHD turbulence

It is useful to be able to reproduce turbulent effects at lower, and computationally cheaper, resolutions. This can done using the large eddy simulation technique (LES), which has now been extended to MHD (e.g. Verma, 2001). The code used here

- Uses renormalised values for resistivity and viscosity
- Accounts for turbulent behaviour at unresolved scales
- Is based on the University of Chicago's grid-based FLASH code, which incorporates MHD and adaptive mesh refinement
- Renormalises using resolution and energy dissipation as inputs



The Orszag-Tang vortex test problem using the FLASH code, and incorporating renormalised resistivity and viscosity.



An accretion disc simulation performed in the FLASH code, plotted as a density isosurface.

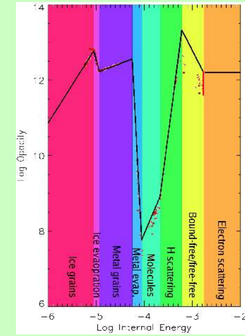
At present, pre-tabulated values for the viscosity and resistivity are used. We aim to move to a *dynamic* model. This will

- Use FLASH's AMR to evaluate MHD variables on two scales
- Tune model so that the effective viscosity and resistivity become independent of the grid resolution

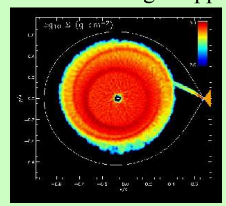
Realistic opacity driven outbursts

The thermal-viscous disc instability model (DIM) relies on the sudden change in opacity around the ionisation of hydrogen (e.g. Osaki 1989). This leads to a limit cycle between a high accretion state and a low accretion state. Previous 3D models (e.g. Truss 2002) have usually altered α by hand to mimic this effect. In our new model

- We use smoothed particle hydrodynamics (SPH)
- Internal energy is evolved using an ideal gas equation of state
- Opacity is set according to an analytic model (Bell & Lin, 1994)
- Cooling is applied using simple radiation transport



Opacity as a function of specific internal energy in arbitrary units. The functional relation at a given density is plotted in black, and SPH particles are plotted in red.

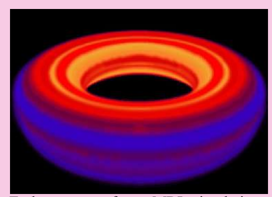


SPH simulation of a cataclysmic variable using variable opacity treatment.

The opacity function used stretches from the ice-crystal regime to electron scattering. Outbursts should arise naturally in this model and the effect of radiation from the accreting star or other sources can easily be accommodated.

This model is interesting in proto-planetary discs since the DIM may drive the FU Orionis type outbursts and influence planet formation.

The Magneto-rotational instability in SPH



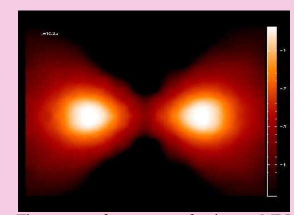
Early stages of an MRI simulation, plotted as a density isosurface.

The MRI is a probable driver of MHD turbulence in discs. It has never previously been reproduced in SPH. We apply the approach of Price & Monaghan (2006). The initial conditions consist of

- A pressure supported torus stably orbiting a central mass
- A toroidal magnetic field entirely within the torus
- A three-dimensional ensemble of equal-mass particles

First results are promising, showing mass accreting rapidly once the magnetic field is activated and the method will now be applied to disc geometries.

We hope to combine this work with the realistic opacity model to effectively eliminate the requirement for an α model in our codes. The addition of sub-grid modelling could then allow very large scale simulations to be performed.



The onset of mass transfer in an MRI simulation. Density is plotted in arbitrary units.

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