LOCAL AND GLOBAL SIMULATIONS OF CONVECTIVE ACCRETION DISCS

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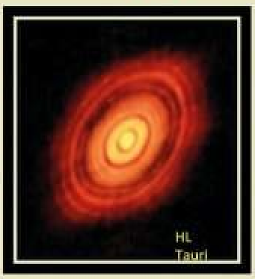
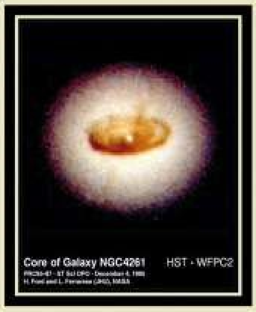
The astrophysical context





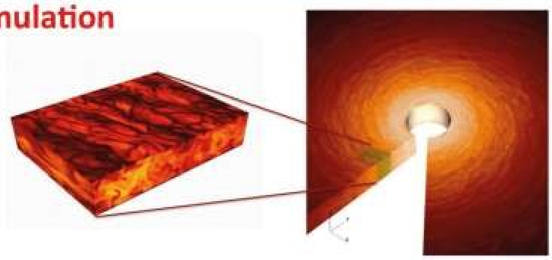
The process of accretion is of great importance in astrophysics. Many compact objects like planets, stars and massive black holes are formed by the infall of material into a central gravitational well. The release of gravitational energy by the accreting material can be extremely efficient and can power some of the most energetic phenomena in the universe. However many aspects of the accretion process are not yet completely understood.

The angular momentum problem

- The matter in the disc orbits around the central object like a planet around the Sun and it would continue forever if it there didn't exist a way to extract its angular momentum.
- An efficient transport of angular momentum can occur only if the disc is turbulent. There is a general consensus that the driver of turbulence is the magnetorotational instability (Balbus & Hawley 1992).
- In order to develop turbulence the disc has therefore to be magnetized, magnetic field can be external or can be regenerated by the turbulence through dynamo action.
- For determining the structure of an accretion disc one has therefore to answer to a series of complex physical questions: How turbulence develops and what are its properties? How the turbulence regenerates the magnetic field by dynamo action? How the energy dissipated by turbulence is transported to the surface layers of the disc to give origin to the observed radiation?

Local versus global simulation

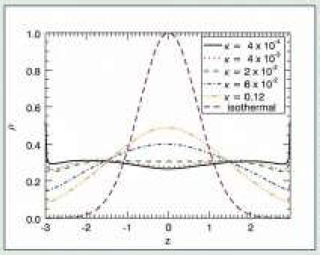
The disc dynamics can be studied by 3D MHD numerical simulations either by following the rotation of a small portion of the disc at very high resolution, in order to capture the turbulence at very small scale, or by studying at lower resolution the global disc.



Local simulations of convective discs

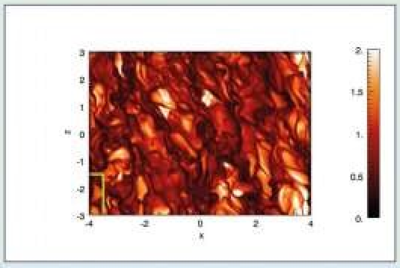
We performed local (shearing box) simulations, with a perfect gas equation of state (instead of isothermal as in most previous studies) and thermal conduction with constant diffusivity. We concentrate on the case in which there is a zero net magnetic flux threading the computational box, therefore the magnetic field has to be regenerated through dynamo action (Bodo et al. 2012, 2013, 2015a, 2015b)

The simulations have been performed (using FERMI at CINECA, Italy) with the PLUTO code (Mignone et al. 2007), and we used grid size up to 512x384x128. We considered boxes with different sizes in the radial direction. The initial state is isothermal. As the simulations progress and turbulence develops, the temperature and density stratifications depart from the initial state and reach a quasi steady state whose properties depend on the value of thermal diffusivity.

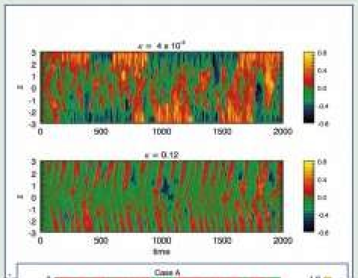


Depending on the value of thermal diffusivity we discovered two distinct regimes: at high thermal diffusivity heat is carried to the surface layers by conduction and the final steady state is similar to the isothermal one, at low thermal diffusivity the disc becomes unstable to convective motions, heat is then carried by convection , and steady state average temperature and density stratifications are dramatically different from the isothermal ones, as it is shown for density by the figure on the left. In the convective case the average density becomes uniform.

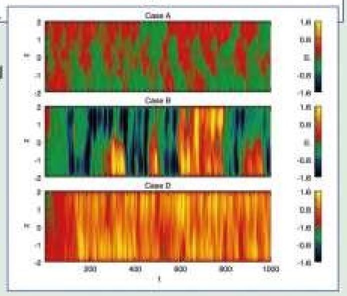
The figure on the right shows the temperature distribution close to the the top surface of the computational box, with a clear pattern of convective cells. Lighter regions are where the hotter material is flowing upwards, while the darker regions are where the cooler material is flowing down.

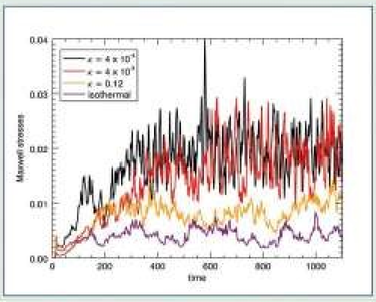


In the convective state also the properties of dynamo action are totally different. The figure on the right shows a spatio-temporal diagram of the azimuthal magnetic field component averaged on horizontal planes. The upper panel is for the convective case, while the lower panel is for the conductive case. In the convective case, we observe events in which coherent structures form that extend over the entire layer.



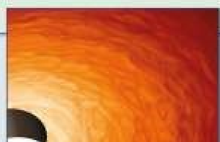
Cases A, B and D on the right are all convective, but for increasing extensions of the box in the radial direction. The resulting effect is that the episodes in which the entire layer becomes magnetized increase their temporal duration, up to about 160 disc revolutions (1000 time units) in case D.



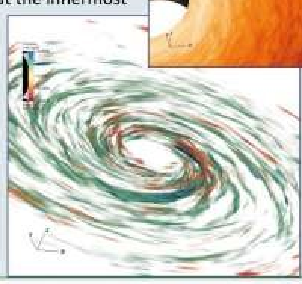


Also the efficiency of angular momentum transport is very different in the two regimes, with the convective case showing a much larger efficiency. The figure on the left shows the time history of the volume averaged Maxwell stresses, which give a measure of the angular momentum transport. The different curves are for different values of thermal diffusivity, we see that decreasing diffusivity, we have an increase of the stresses.

Global simulations of convective discs



The simulations have been performed with the PLUTO code (Mignone et al. 2007), and we used grid size up to 832x1024x128 points. After several hundreds rotations at the innermost radius, the disk seems to settle into a quasi steady state, where the accretion rate stays constant in time. Indeed, also in the global disk, we can observe the formation of a fully convective state, in particular in the inner part of the disk. This is shown in the upper figure, where we show the temperature distribution close to the surface of the disk and we can observe the pattern of convective cells similar to that seen in the shearing box. Similarly to the shearing box cases the dynamo process looks as a large scale dynamo with the generation of substantial amount of magnetic flux, mainly in the form of spiral structures (see bottom figure).



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