Aspect Ratio Dependence in Magnetorotational Instability Shearing Box Simulations

Andrea Mignone, Attilio Ferrari, Gianluigi Bodo, Paola Rossi, and Fausto Cattaneo

Abstract Three-dimensional numerical simulations of the magnetorotational instability in the shearing box approximation with a nonzero net flux are presented. By changing the size of the computational domain in the radial direction relative to the vertical box height, we find, in agreement with previous studies, that transport of angular momentum (associated with the so-called “channel solution”) is strongly intermittent and maximized for boxes of unit aspect ratio. On the other hand, in boxes with larger aspect ratio the intermittent behavior disappears and angular momentum transport is inhibited.
1 Motivations

It is commonly accepted that the magnetorotational instability (MRI, [2]) may provide a viable driving mechanism for turbulence in accretion disks and that it may account for the required rate of angular momentum transport [13].

Much of what is presently known about MRI driven turbulence relies on a local model of a differentially rotating system, the so-called “shearing-box”, where a small periodic patch of the disk is considered (see, e.g., [5, 11, 12, 1, 14, 7]). The advantage of a local approach (as opposed to a global disk simulation) is the possibility of reaching higher resolutions at the same computational cost. The model is based on a local expansion of the equations in a reference frame corotating with the disk at some fiducial radius \( R_0 \) [6]. The validity of the model should be verified \textit{a posteriori}, by checking, for example, that the properties of the solutions do not depend on the size and geometrical properties of the computational domain. A critical discussion of the validity of the shearing box approximation can be found in [10].

With the present study we investigate one aspect of the self consistency of the shearing box results, namely, the dependence on the box aspect ratio. In the MRI, the characteristic length scale is set by the vertical wavelength of the mode with maximum growth rate which in turn depends on the magnetic field strength. Typically, the vertical size of the computational domain is chosen to contain some multiple of that length whereas there is no general guidance in choosing the width in the radial and azimuthal directions. Practitioners in the field commonly adopt boxes with aspect ratio of unity, although this issue has not received careful consideration and there has been no systematic study of the dependence of the solutions on the aspect ratio.

Here and in [3], we present a systematic study of shearing box results as a function of the aspect ratio by performing a series of 3D, compressible, isothermal numerical simulations in the shearing box approximation. In particular, we want to see if the results observed in boxes of unit aspect ratio are representative of more extended systems, or if they display peculiarities induced by an overly constrained geometry.

2 Results

Simulations with unit aspect ratio show that the transport of angular momentum has an intermittent behavior with episodes of enhanced transport. During these states

During these states, loosely referred to as “channel” solutions, velocity and magnetic perturbations are highly spatially correlated. It is now believed that the formation of near channel solutions and their subsequent disruption by the parasitic instabilities of [4] are the basis for the observed intermittent behavior [11]. Note that, although the channel solutions are, strictly speaking, exponentially growing exact solutions of the incompressible shearing box equations [4], the same terminology