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Planetesimal dynamics in hydromagnetic turbulence

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Abstract. Planet formation theory is founded on the concept of dust coagulation and subsequent growth into planetesimals. This process is by no means an isolated one, but possibly happens in a turbulent nebula. It is therefore crucial to understand how particles of different sizes are affected by their gaseous environment via stochastic forcing and aerodynamic damping. We here report on the effects of magneto-rotational (MRI) turbulence in the presence of non-uniform ionisation leading to the formation of a magnetically inactive dead-zone. While we find that collisional growth is impeded by fully-active MRI, it may be possible within a dead-zone.

Keywords. accretion disks, MHD, methods: numerical, planetary systems: formation, planetary systems: protoplanetary disks

1. Introduction

Planetesimals are the building-blocks of protoplanets. New approaches to their rapid formation via streaming and gravitational instabilities (e.g. Johansen & Youdin 2007) require a thorough understanding of particle stirring by the gas and the level of sedimentation in stratified disks. When particles grow from metre to kilometre sizes, they aerodynamically decouple from the gas flow. Independent of their mass, they feel a gravitational force from fluctuations in the potential near density waves, and the acquired velocity dispersion governs whether collisional growth eventually becomes disruptive.

2. Results

The global cylindrical disc simulations of Nelson (2005) have demonstrated that density fluctuations from developed MRI turbulence pose a severe limitation to the growth of planetesimals. We have now confirmed this original finding in the framework of local simulations with large enough box sizes (Nelson & Gressel 2010).

2.1. *Stratified discs with dead-zone*

In the following, we give a first report on the extension of this work to stratified discs harbouring a dead-zone due to insufficient ionisation (Gammie 1996). Our stratified dead-zone simulations cover $\pm 5\,{}^1/_2$ pressure scale heights, and apply a zero-net-flux magnetic configuration with $\beta_{\rm p} = 50$, and an additional weak B_z net field. Since recombination occurs mostly on small grains, we adopt a simplified treatment of the gas-phase reactions. We update the diffusivity, $\eta = \eta(\mathbf{x}, t)$, according to a lookup table derived from the reaction network in model 4 of Ilgner & Nelson (2006), and assuming a dust-to-gas mass ratio of 10^{-3}, and ionisation due to X-rays and cosmic rays (cf. Turner & Drake 2009).

In Figure 1, we show the evolution of the toroidal field $\bar{B}_\phi$ in the presence of a dead-zone. The field exhibits the typical dynamo cycles (cf. references in Gressel 2010) in the MRI active layers. As already seen by Turner & Sano (2008), the toroidal field leaks

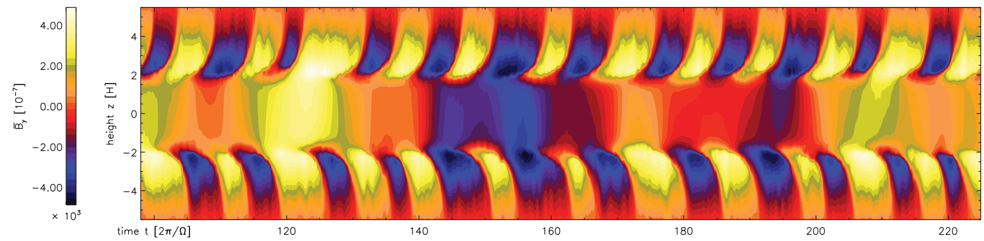

Figure 1. Space-time diagram of the horizontally-averaged toroidal magnetic field $\bar{B}_\phi$.

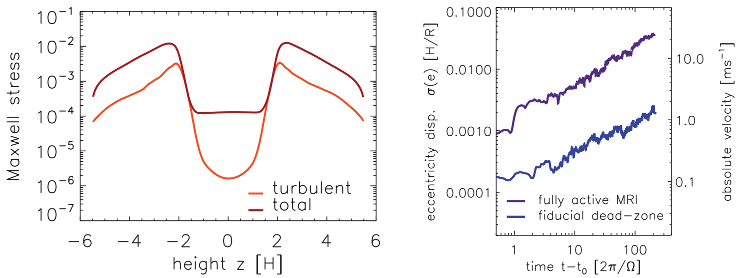

Figure 2. Time-averaged profiles of the total/turbulent Maxwell stress (*left*), and random-walk eccentricity growth (*right*).

into the diffusively dominated midplane region, contributing to the overall stress (see Fig. 2, left panel). Despite the absence of strong turbulence, density fluctuations reach a level of 10-20 percent within the dead-zone. Surprisingly, these fluctuations result in very moderate stochastic torques on the particles. Accordingly, the eccentricity growth is substantially reduced in the case of a dead-zone (Fig. 2, right panel).

2.2. *Conclusions*

Simulations of planetesimals embedded in fully turbulent, non-stratified disc models show that the velocity dispersion of km-sized bodies grows quickly and exceeds the threshold for catastrophic disruption. This raises important questions about the viability of planetesimal accretion in such turbulent discs.

Our simulation of a fully turbulent, vertically stratified disc confirms this basic picture. We find, however, that planetesimals which are embedded in a disc with a dead-zone whose vertical size is approximately two density scale-heights experience a substantially reduced stochastic forcing, being decreased by a factor of 10-20. It thus appears that dead-zones may provide an environment which is conducive to planet formation via planetesimal accretion.

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