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3D global simulations of proto-planetary disk with dynamically evolving outer edge of dead zone

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Abstract. 3D global MHD simulations of magneto-driven turbulence are performed for the disk of 100 AU with reduced amount of 10μm fluffy dust grains. We use X-ray and cosmic ray ionization, as well as simplified treatment of recombination on dust grains. The ionization of gas and charging of dust grains are dynamically evolving during the simulation, making the zone of high magnetic dissipation ('dead' zone) variable. In our simulations, the jump in MRI-driven turbulent viscosity inside and outside of dead zone is insignificant. We find no hard edge, but rather a smooth transition between active and dead zone. Subsequently, there is no visible pressure bump at outer edge of the dead zone.

Keywords. accretion disks, turbulence, MHD

1. Introduction

Magneto-rotational instability (MRI) is necessary to sustain the observed mass accretion rates in the proto-planetary disks and could govern viscous disk evolution. Due to presence of dust, large part of disk is poorly ionized, leading to a 'dead' zone where MRI turbulence is suppressed. 'Dead' or laminar zone can help making planets in many ways. At the radial transition from active to dead zone we could expect a jump in turbulent stresses, what will lead over time to a density bump and therefore to a trapping of the planetesimals (Johansen *et al.* (2009) and references therein). Usual assumption is that the transition from active to dead zone is one pressure scale height broad. Typically the inverse Elsässer number $\Lambda = 1$ separates dead from active zone, assuming that the fastest growing mode of MRI is dissipated within one orbit. It is known that ideal MRI turbulence is reached only for lower dissipation then $\Lambda > 10$. For dissipations of $0.1 < \Lambda < 10$ the gas is in 'transitional' state, showing still a weak turbulence. If the jump in turbulent viscosity is sharp enough or space separation for $0.1 < \Lambda < 10$ is narrow then trapping of planetesimals is possible. Viscous instability of dead zone may appear when ionization of the gas is treated dynamically. Here, the dead zone may get unstable and broken into rings, each of those could serve as a trap for planets.

2. Model

3D global MHD simulations of magneto-driven turbulence are performed for dynamically ionized disk with reduced amount ($f_{\rm dg} = 0.001$) of fluffy dust grains of 10μm. MHD equations are same as in Dzyurkevich *et al.* (2010). We solve the equations of non-ideal MHD using 3D ZeusMP code. The disk domain is from 5 to 95 AU and includes 8.4 pressure scale heights. Resolution on spherical grid is [256:128:128] for $[r, \Theta, \phi]$. Gas is

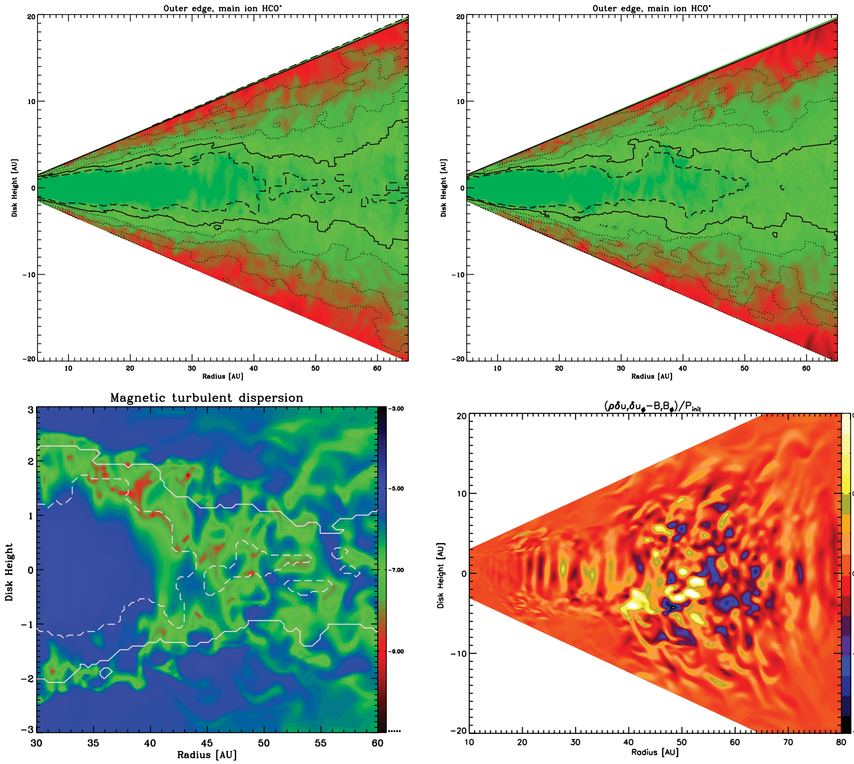

Figure 1. Top: Colors show inverse Elsässer number, decades are notated as solid line for 1, dotted for 10 to 10^3, dashed for 0.1. Location of 'dead' zone edge fluctuates between 40 and 55 AU for time 390 and 450 orbits. Bottom left: Logarithmic turbulent magnetic fields, with white line repeating decades in inverse Elsässer Number. Bottom right: Snap-shop of turbulent stress.

locally isothermal with T(R) constant on cylinders. Gas density is $\rho \propto (r, \Theta)$. Dead zone appears naturally, as we calculate magnetic diffusivity after Okuzumi (2009) and Wardle (2007) for fluffy dust, where $\eta(r, \Theta)$ is space and time dependent and is updated every time-step. Initial magnetic field is a purely azimuthal field, leading to azimuthal MRI.

3. Implications

MRI-free zone is defined within $\Lambda = 0.1$ (not unity) and its edge location can fluctuate over several AU within an orbital time. We find no evidence for viscous instability of dead zone. 'Dead' region with $\Lambda < 0.1$ has significant Reynolds stress, the pillar structures in r, Θ snap-shot of stress are spiral density waves. At midplane, contrast in total stress between 'dead' $\Lambda < 0.1$ and 'MRI-active' $\Lambda > 0.1$ locations is insignificant. - We observe no density bump at $\Lambda = 0.1$ at the length of simulation.

Space separation between dead zone ($\Lambda = 0.1$) and ideal MRI turbulence ($\Lambda = 10$) is stretched over several AU, for given weak magnetic field. Therefore we conclude, that even a longterm formation of a pressure bump would be too shallow to trap dust grains and planetesimals.

References

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