Turbulence, Damping, and Hydrodynamic Transport in Ohmic Dead Zones

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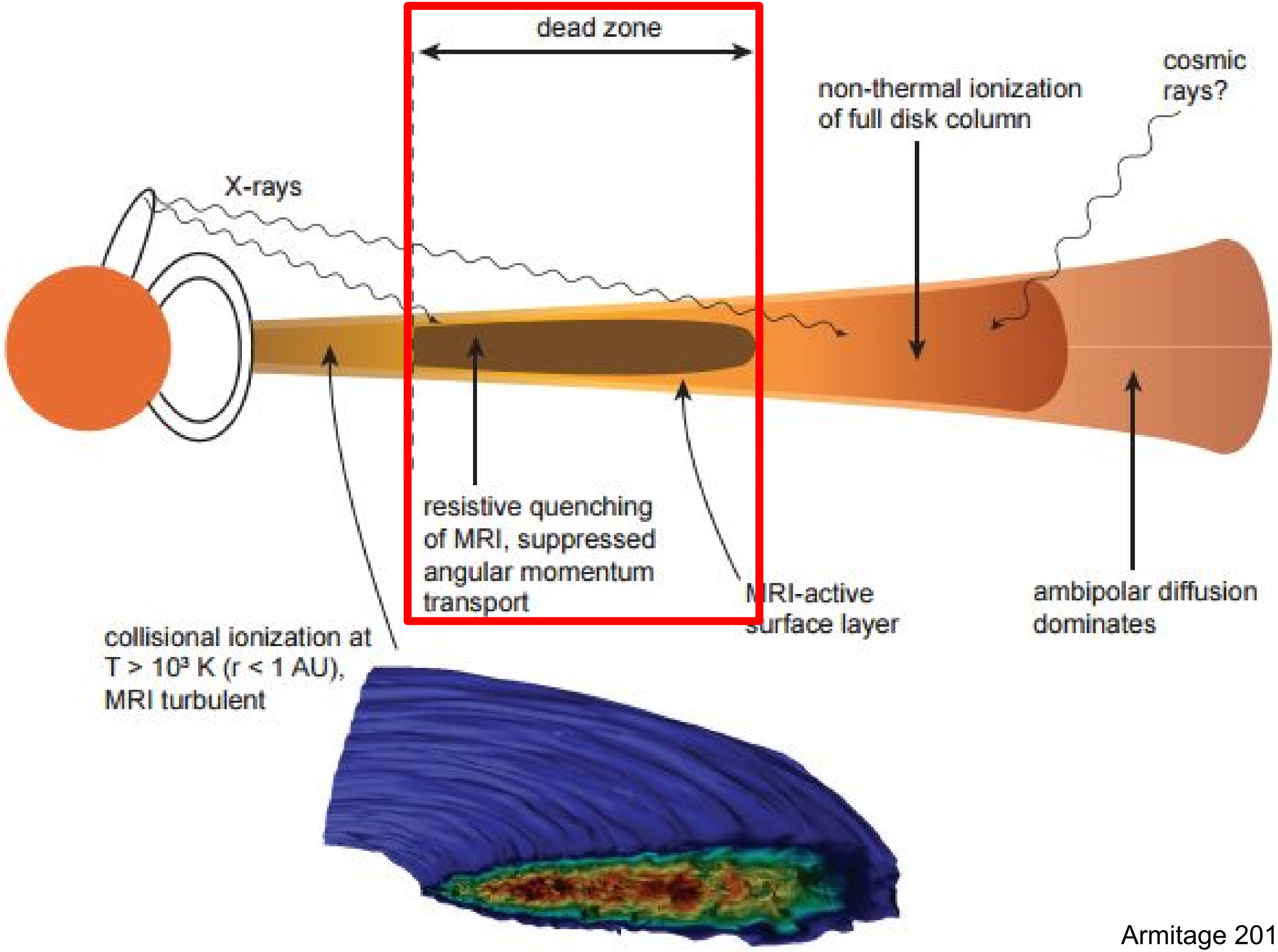
Outline

1. Brief description of motivation and simulation setup.

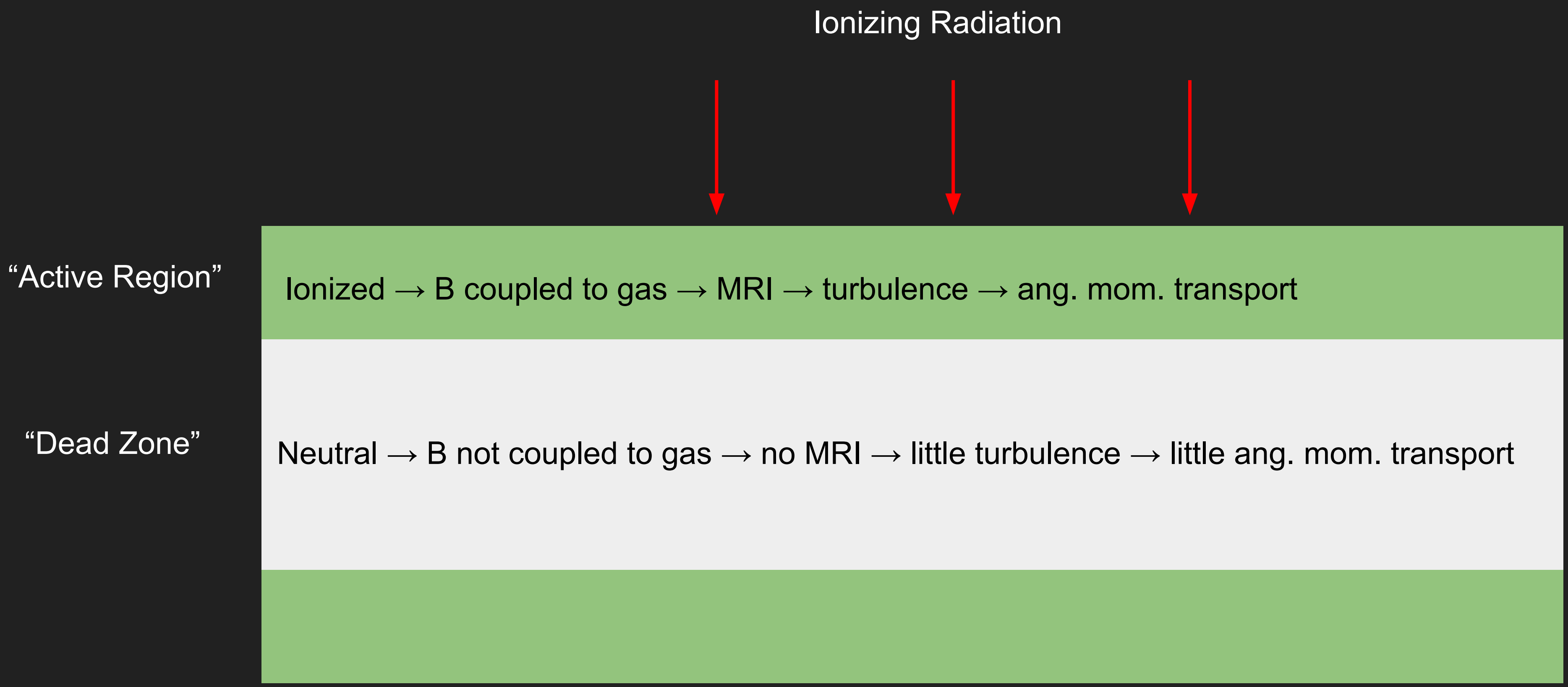
2. Turbulence and angular momentum transport (or lack-thereof) in dead zones

3. Large scale motions in dead zones

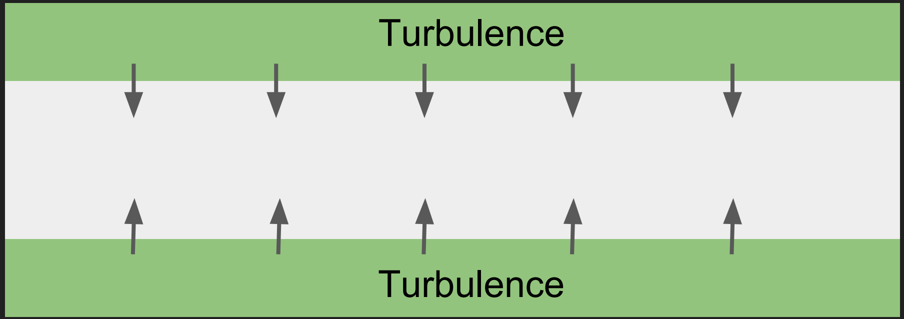


Armitage 2011

Layered Disk Model



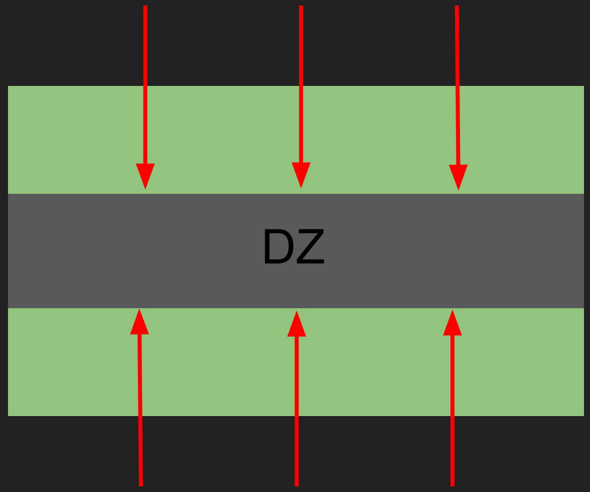
Main Questions



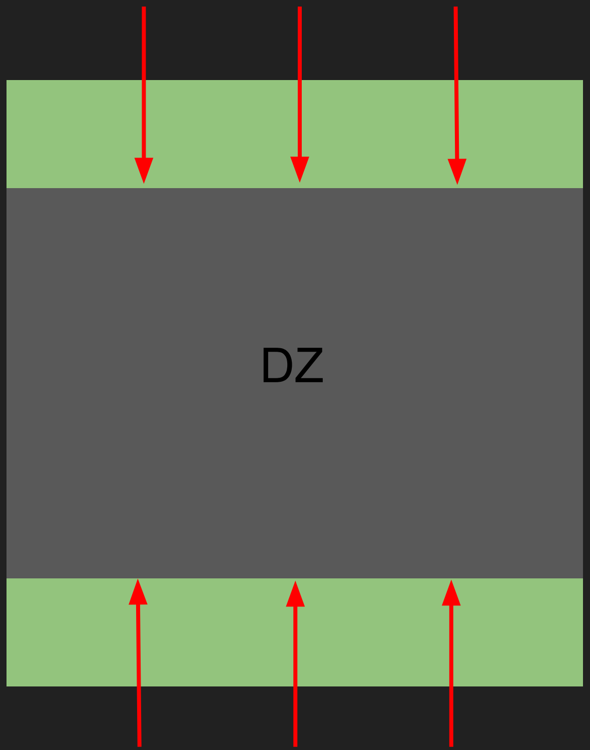
- To what extent can the active layer stir up motions in the dead zone?
- What is the nature of these motions?
  - turbulent properties
  - large scale motions
  - angular momentum transport
- How do these properties depend on the size of the dead zone relative to the active region?

What determines the size of the dead zone?

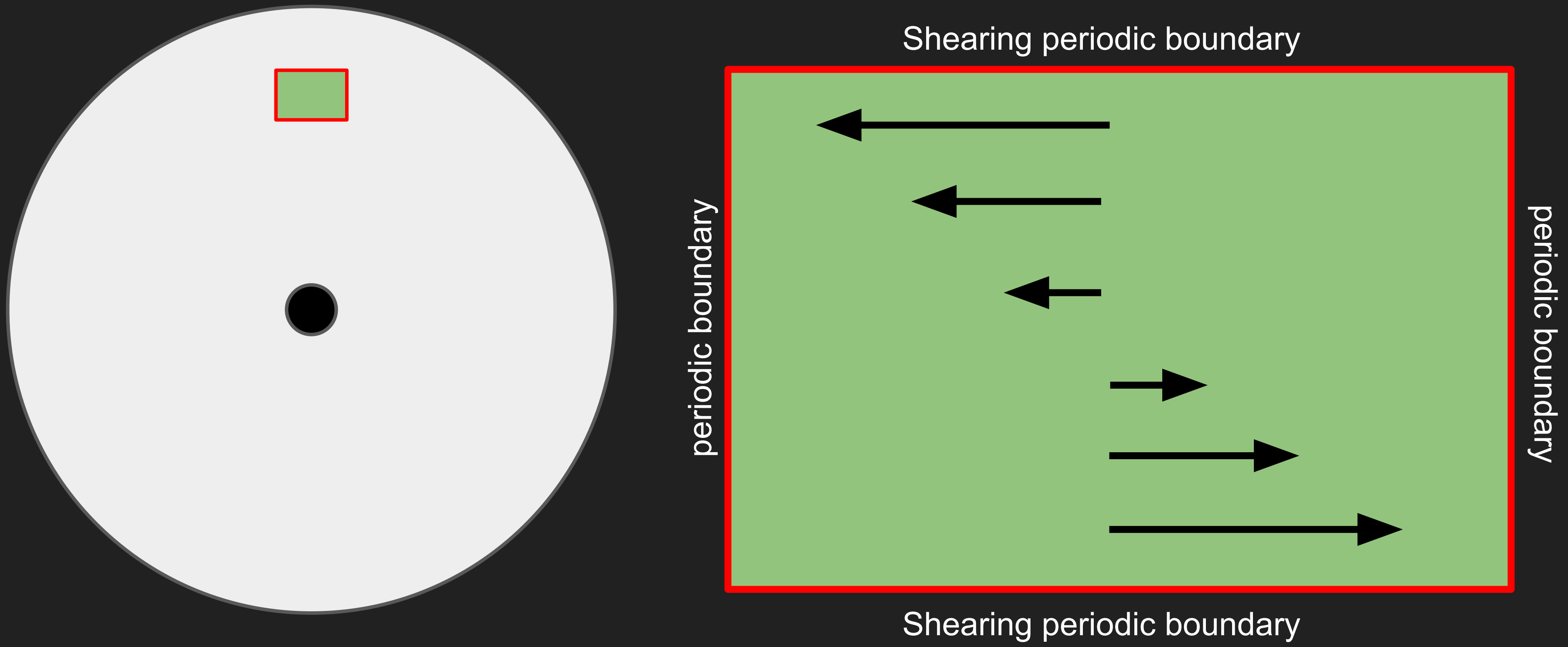
Small Disk



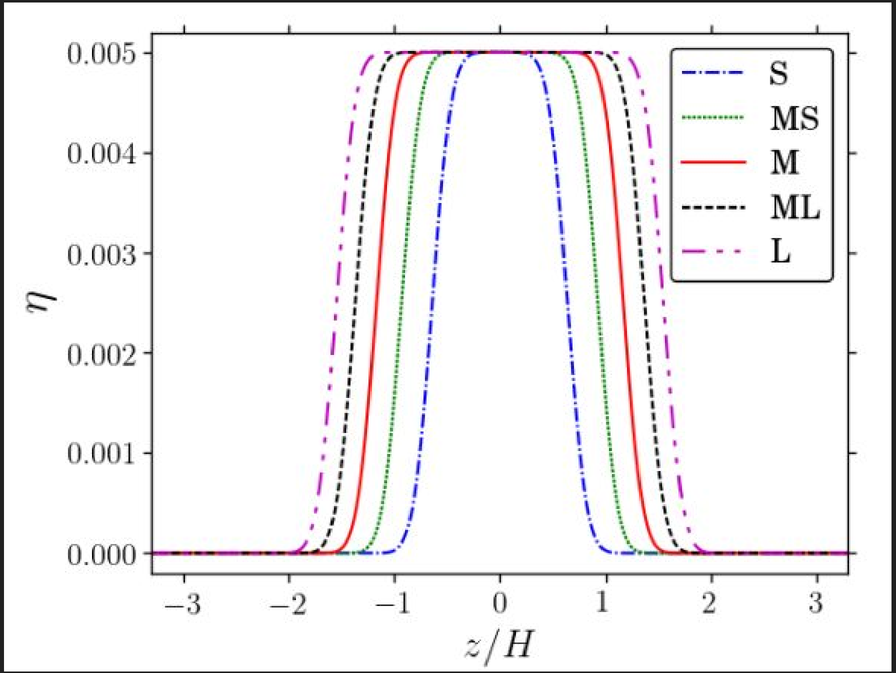
Larger Disk

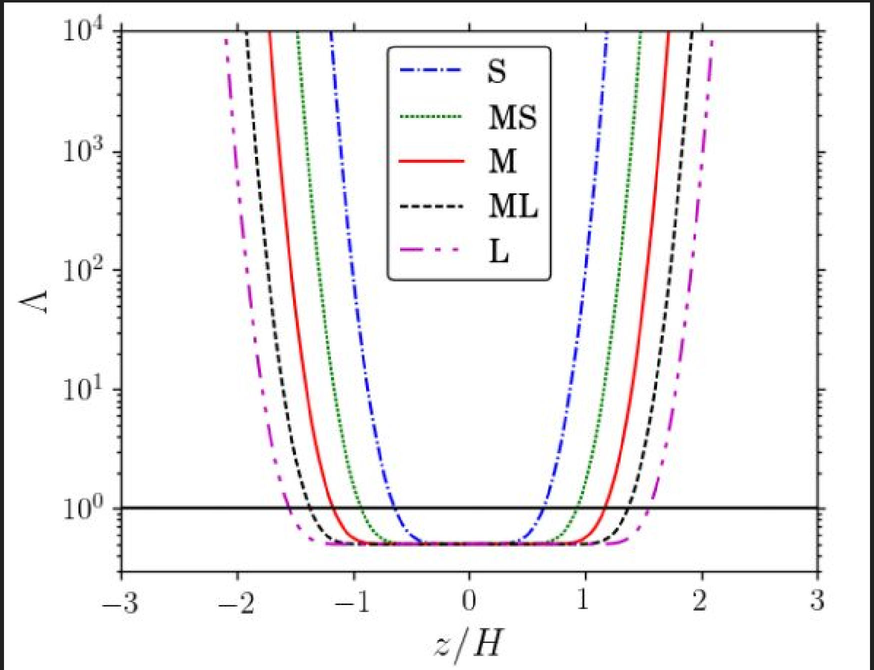


3D MHD in a Shearing Box



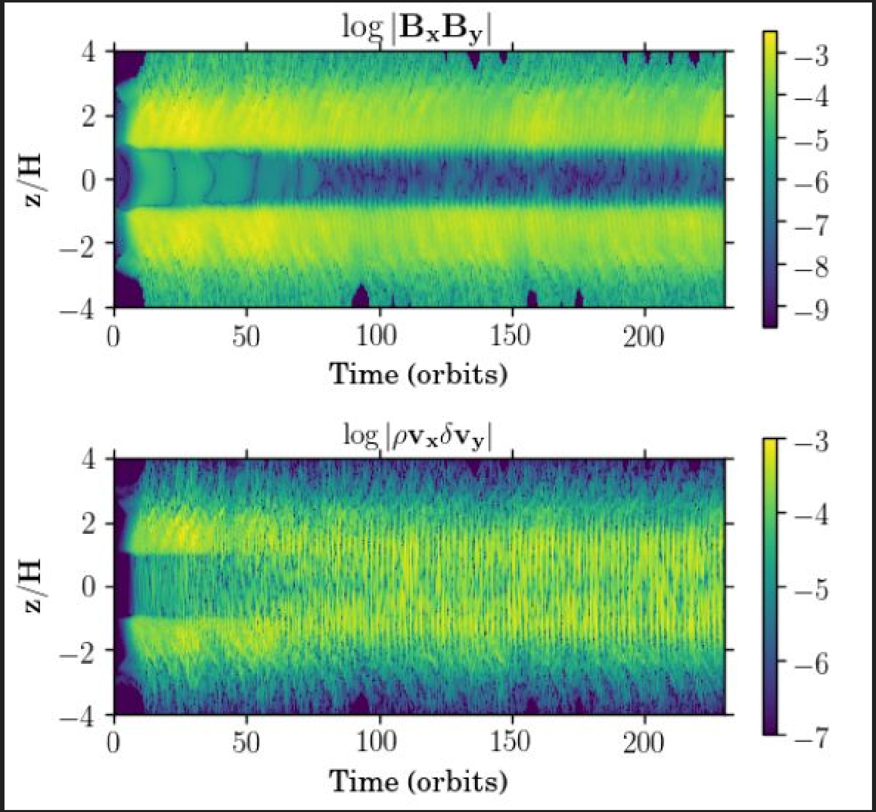
Static Resistivity Profiles



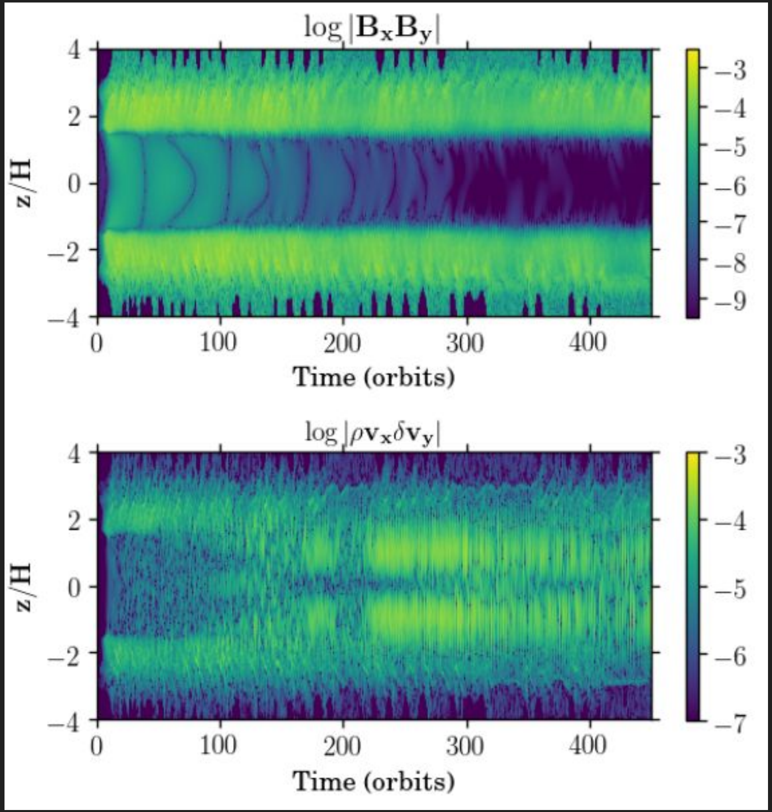


$$\Lambda = \frac{v_{az}^2}{\eta\Omega} = \frac{2c_s^2}{\beta\eta\Omega}$$

Magnetic and Hydrodynamic Stresses

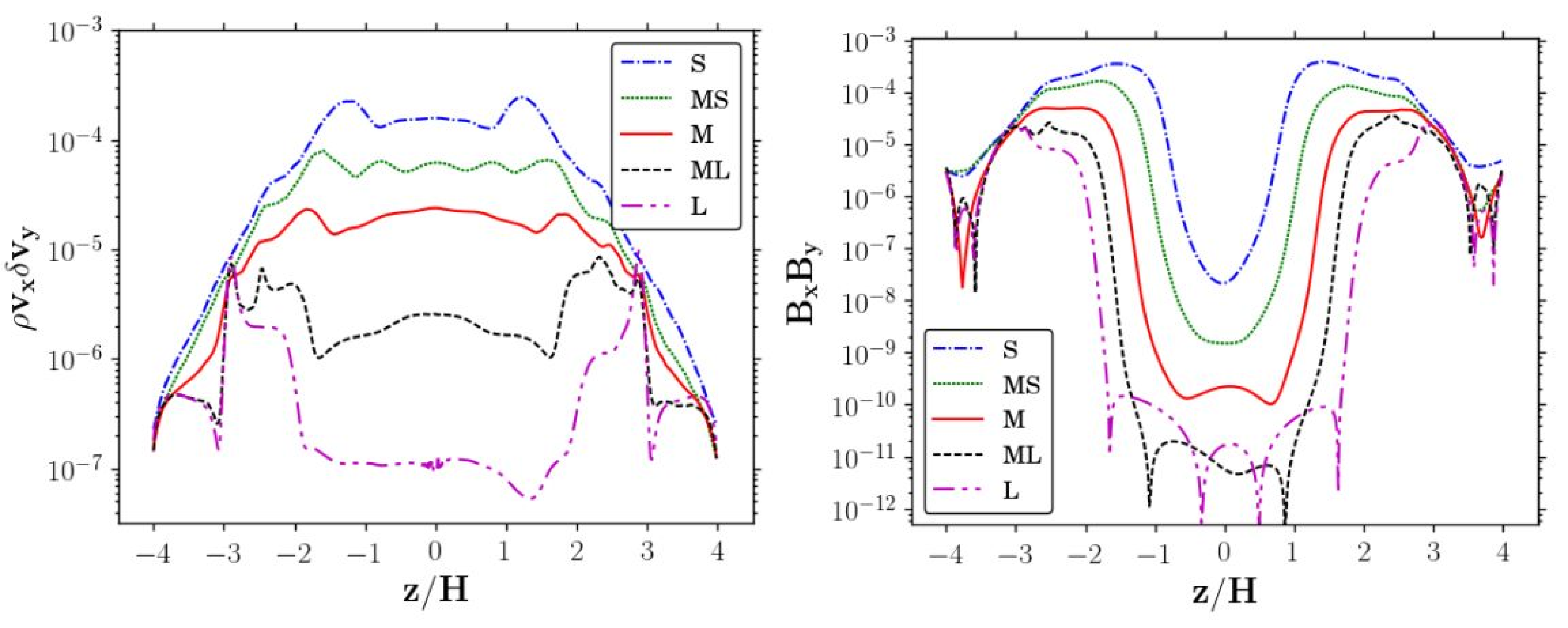


Small DZ

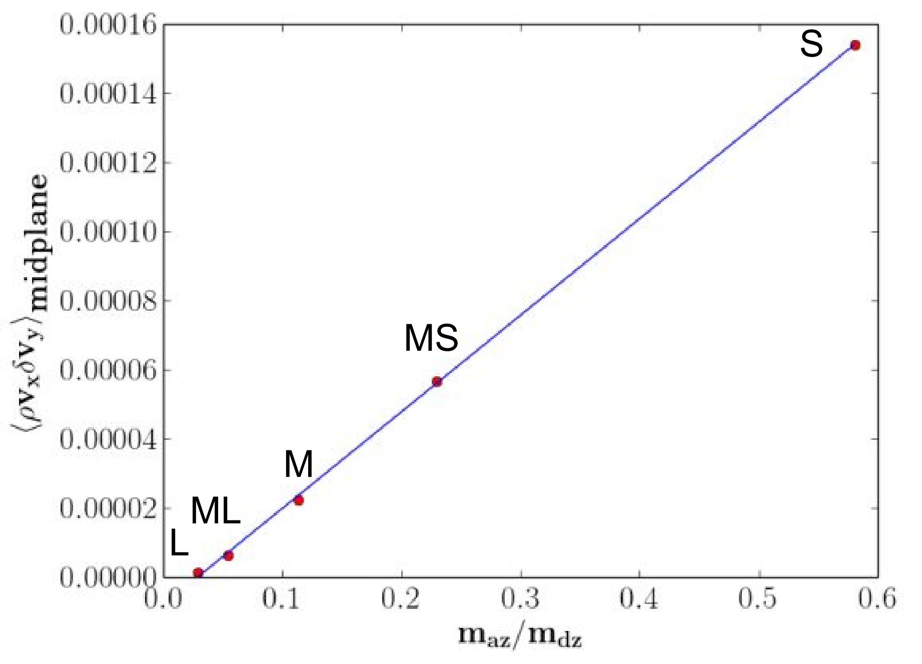


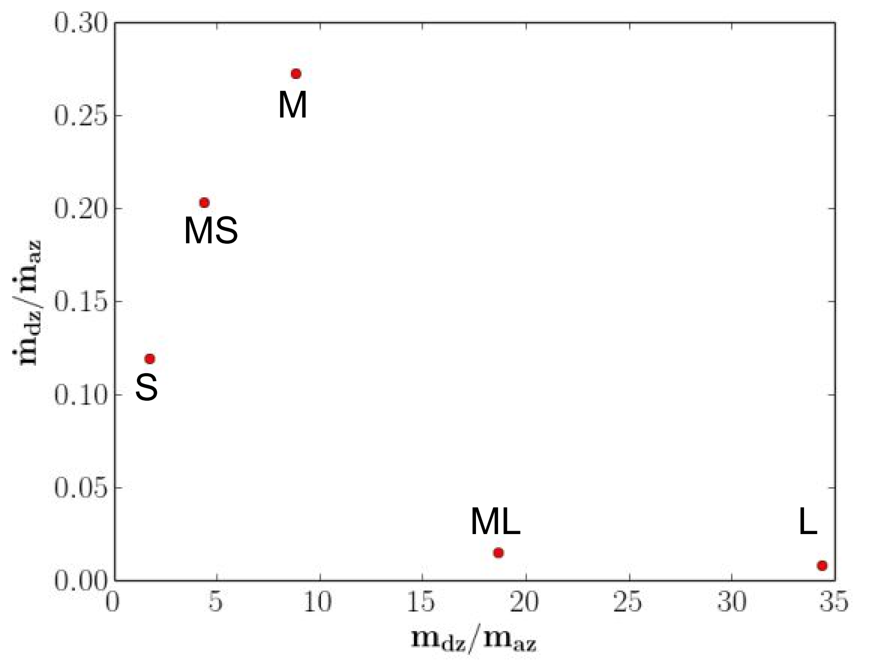
Medium-Large DZ

Mean Stress Profiles



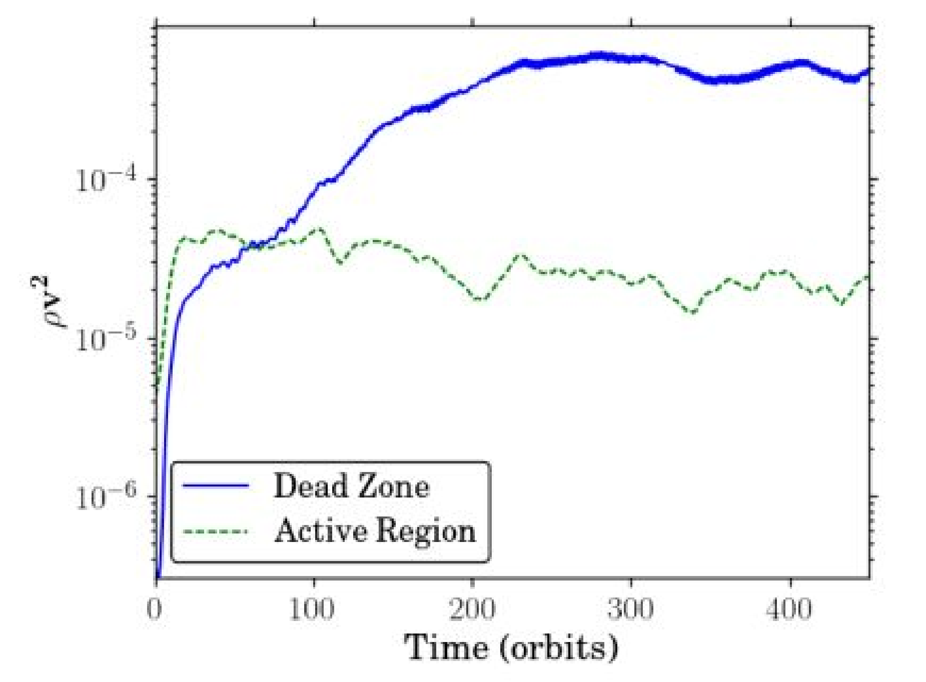
Midplane Stress and Accretion Rates





Ohmic dead zones may exhibit episodic accretion events (Martin & Lubow 2011)

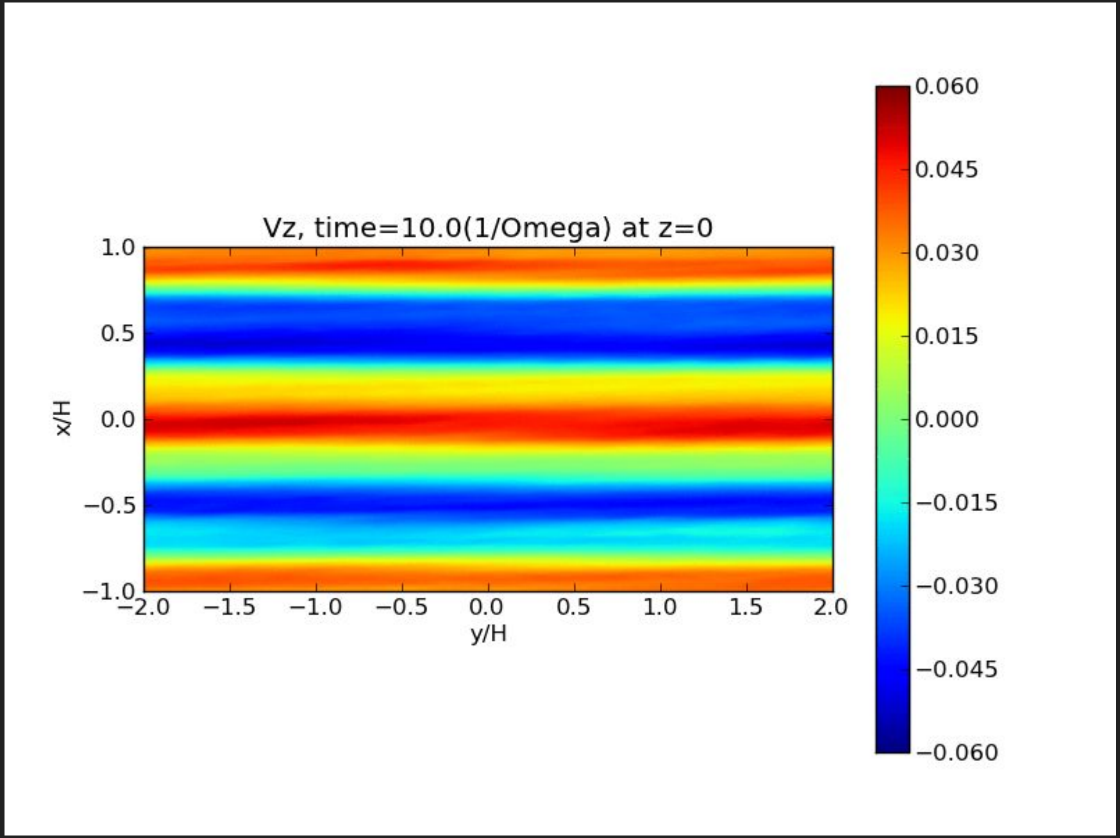
Large Scale motions in the DZ

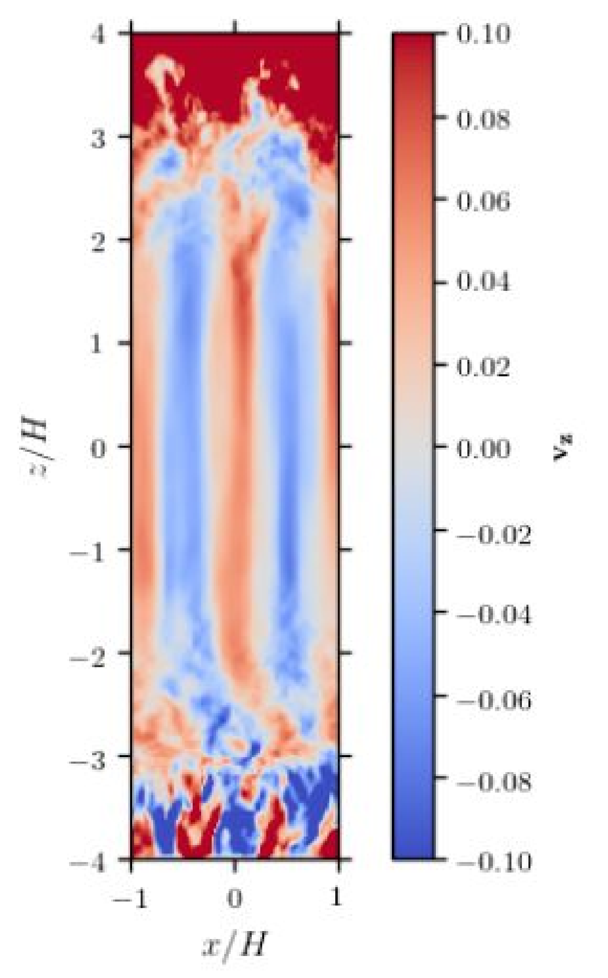


$$\frac{\langle \text{reynolds stress} \rangle}{\langle \text{KE} \rangle} = \frac{\langle \rho v_r v_\phi \rangle}{\langle \rho v^2/2 \rangle}$$

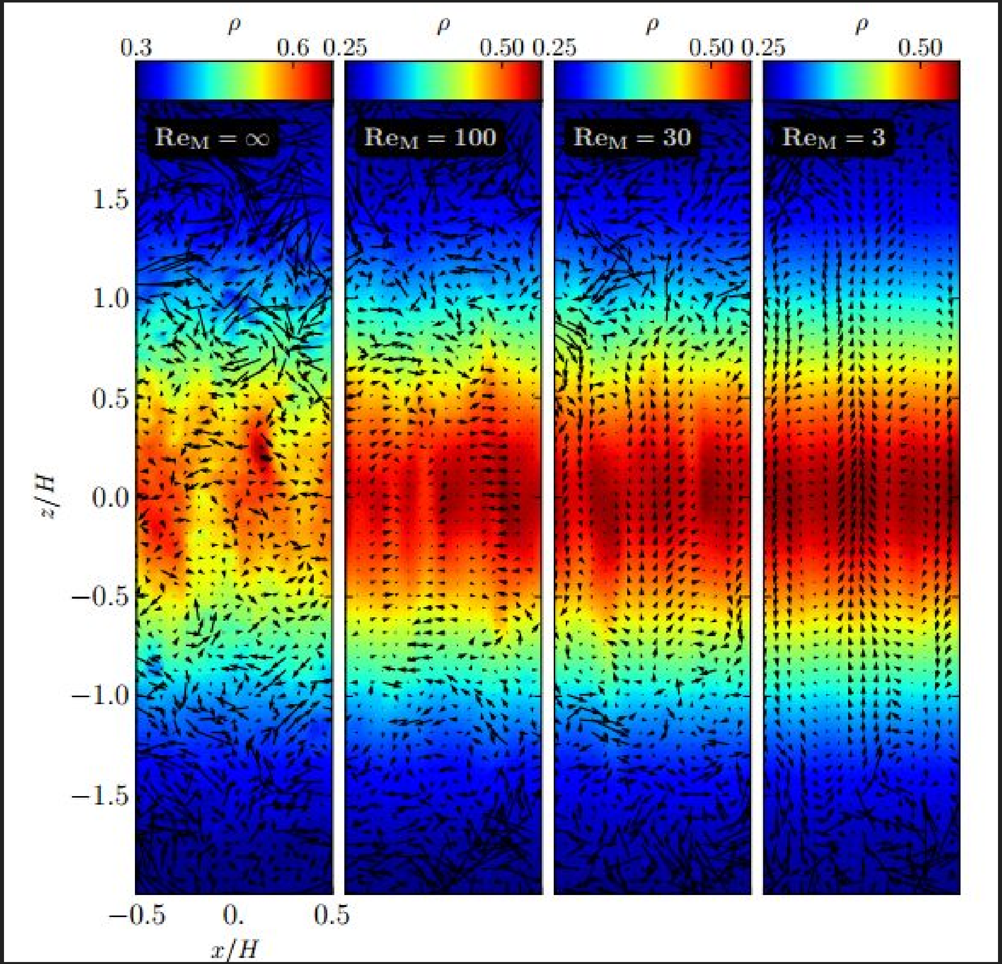
DZ Size	Trans. Eff. Dead	Trans. Eff. Active
S	0.048	0.17
MS	0.023	0.15
M	0.02	0.16
ML	0.0098	0.18
L	0.0041	0.18

Large Scale motions in the DZ





$$\omega \simeq 0.22\Omega$$



$$\varpi_{max} \simeq 0.23\Omega_0$$

Oishi & Mac Low (2009)

What are these modes?

Lubow & Pringle (1993): “g modes”

Ogilvie (1998): “r modes”

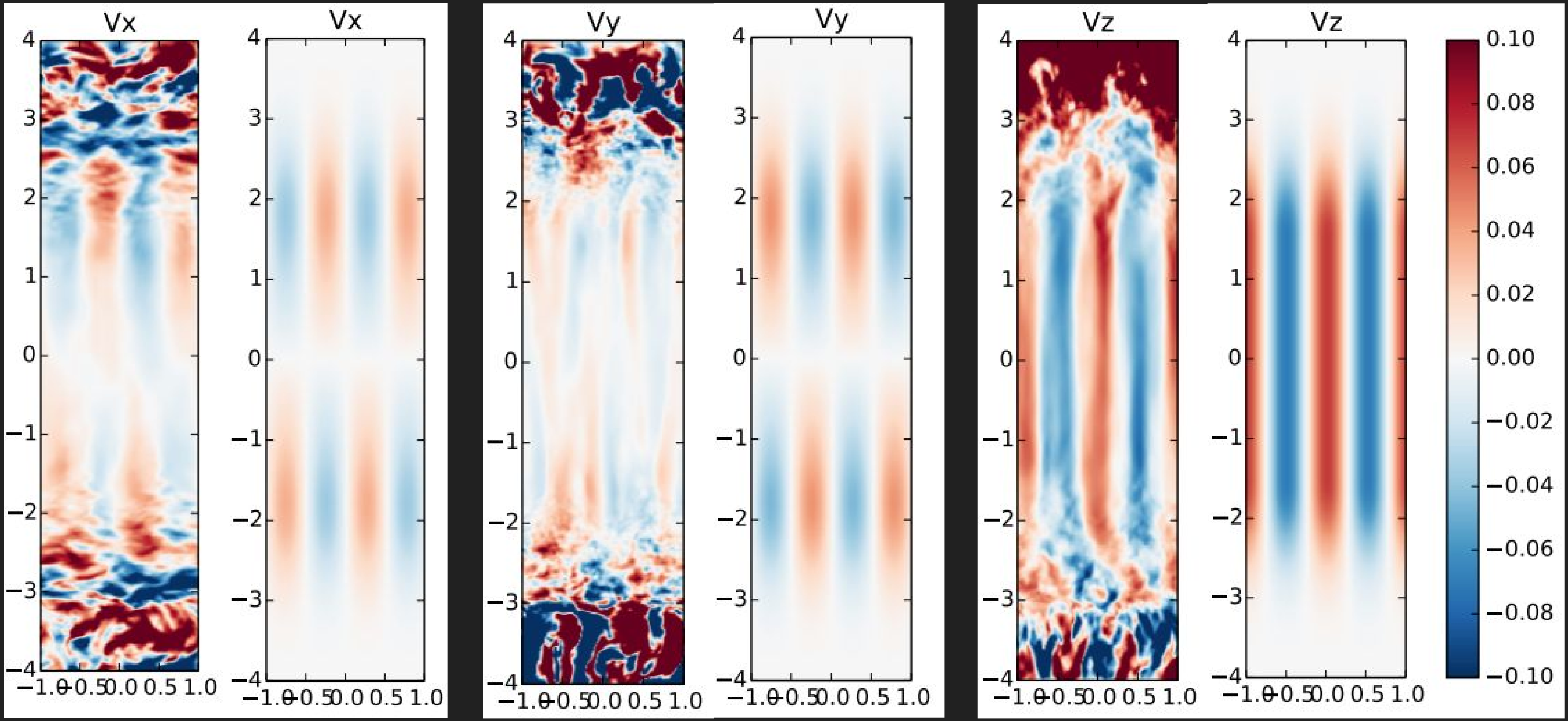
Dispersion (for n=0 and isothermal): $$\omega = \frac{\sqrt{2}\,\Omega}{2}\sqrt{2 + K^2 - |K|\sqrt{4 + K^2}},$$

Calculated from dispersion relation: $\omega = 0.2147\Omega$

Calculated from fourier analysis of simulation data: $\omega \simeq 0.22\Omega$

Velocity Structure:

$$v_{\mathrm{x}}(x, z, t) = \sqrt{2}W\left(\frac{\omega z}{\Omega H}\right)\sin\left(k_{\mathrm{x}}x\right)\cos\left(\omega t\right),$$
$$v_{\mathrm{y}}(x, z, t) = -\frac{\sqrt{2}}{2}W\frac{z}{H}\sin\left(k_{\mathrm{x}}x\right)\sin\left(\omega t\right),$$
$$v_{\mathrm{z}}(x, z, t) = W\cos\left(k_{\mathrm{x}}x\right)\cos\left(\omega t\right),$$



Simulation Theory Simulation Theory Simulation Theory

Conclusions

1. Midplane hydrodynamic stress scales strongly with the size of the dead zone.

2. Smaller dead zones can accrete at up to 30% of the rate of accretion in the active zone, while for large dead zones it’s more like 1%.

3. We find slowly oscillating, large scale circulation patterns in the dead zone and identify them as r modes.