Low Pm turbulence in Protoplanetary discs

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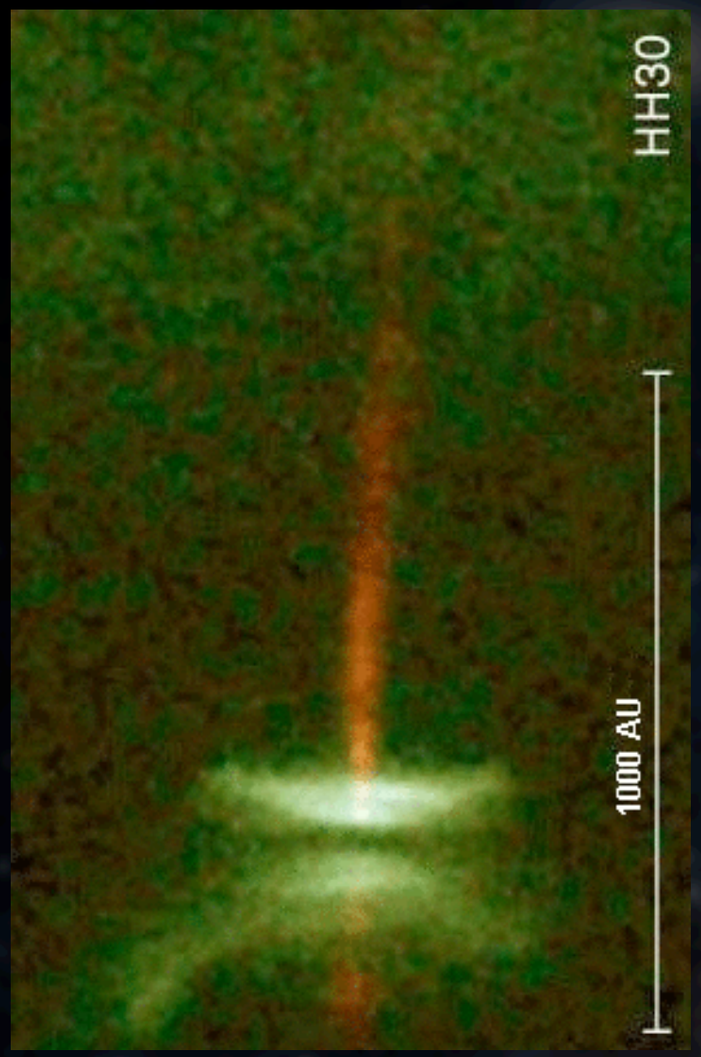
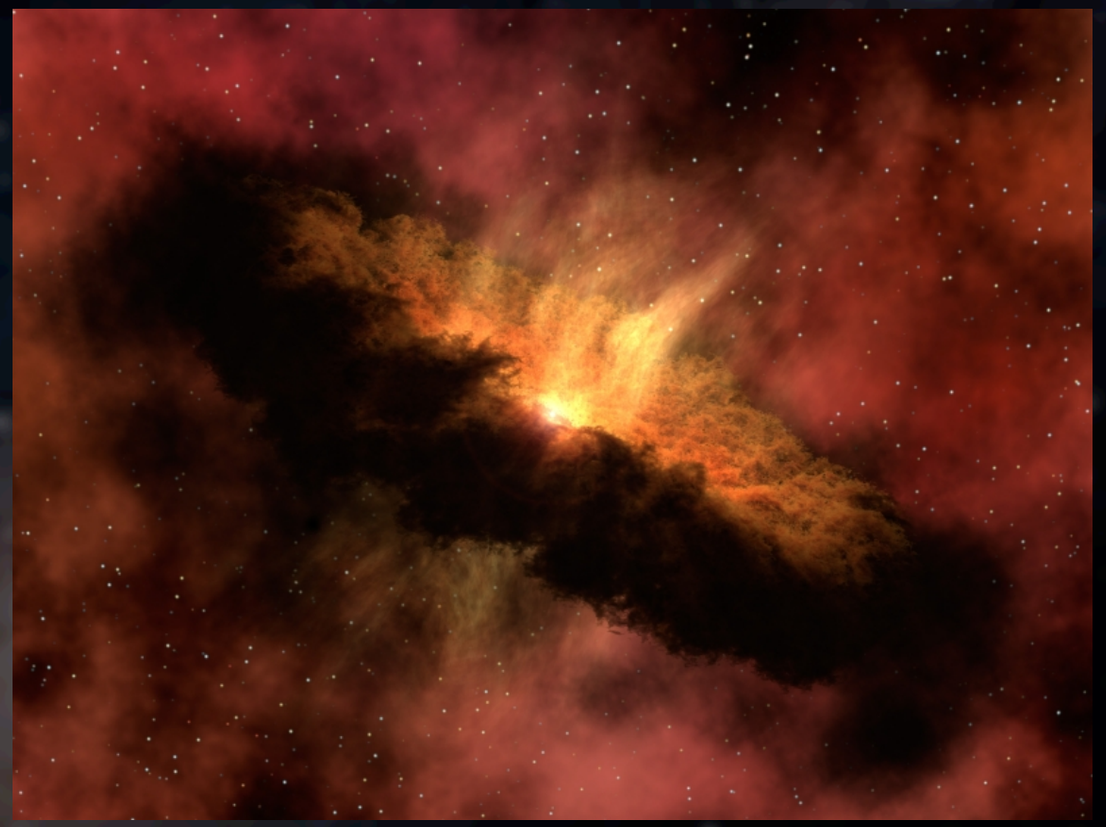
GTP Workshop on Large-Eddy Simulations of MHD Turbulence

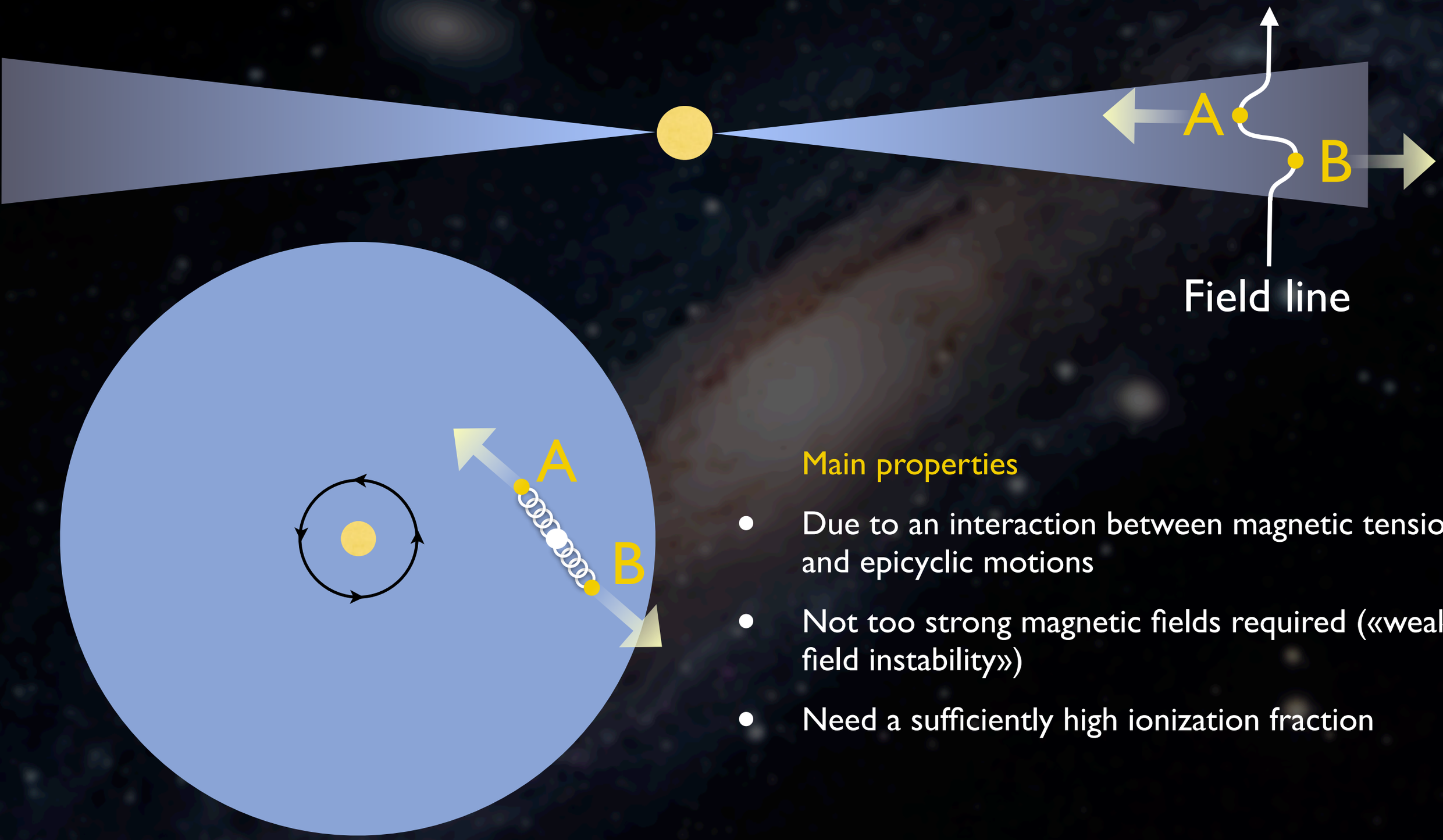
Protoplanetary disks





- Size: 10^{11}–10^{15} cm
- Temperature: 10^{3}–10^{1} K
- Number density: 10^{10}—10^{17} cm^{-3}
- Ionization fraction: $\sim 10^{-13}$

Magnetorotational instability

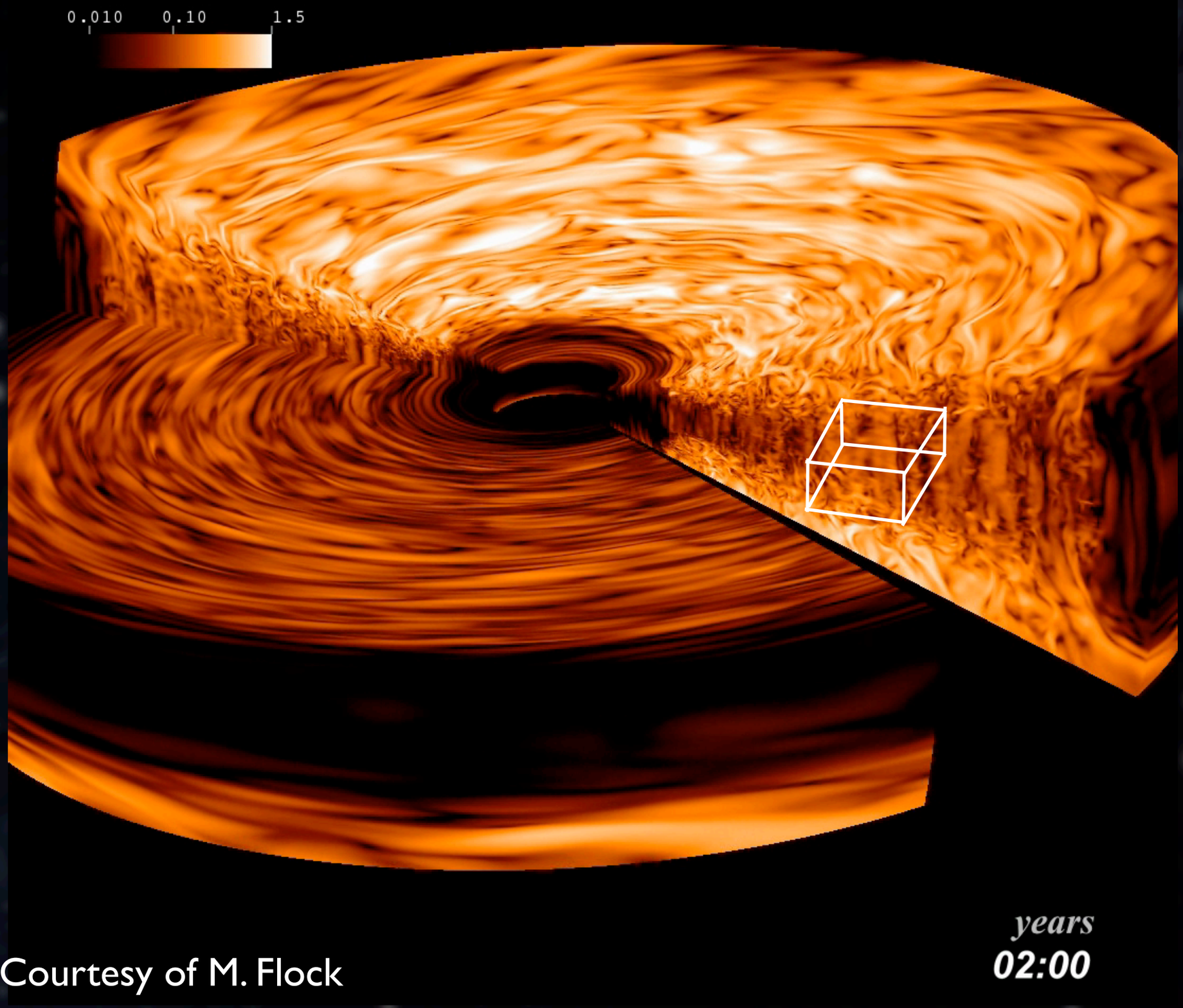


Main properties

- Due to an interaction between magnetic tension and epicyclic motions
- Not too strong magnetic fields required («weak field instability»)
- Need a sufficiently high ionization fraction

Balbus & Hawley 1991, Balbus 2003

Protoplanetary disks

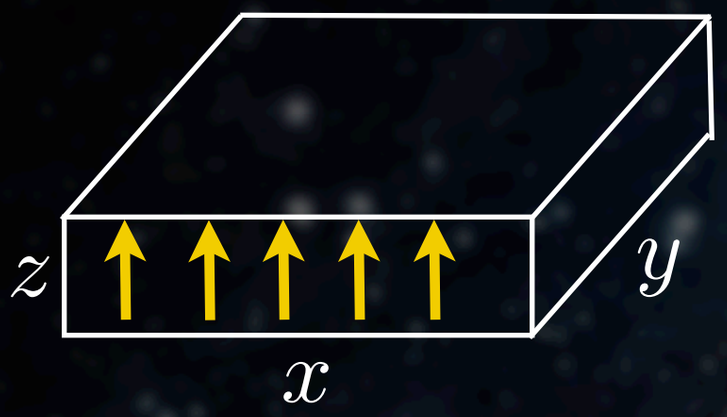


Courtesy of M. Flock

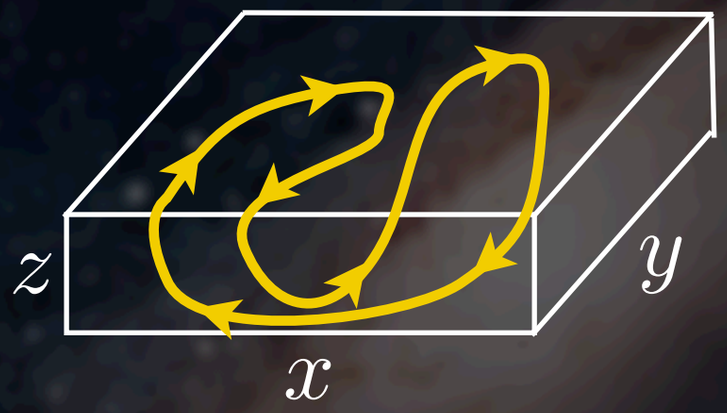
The incompressible shearing box model

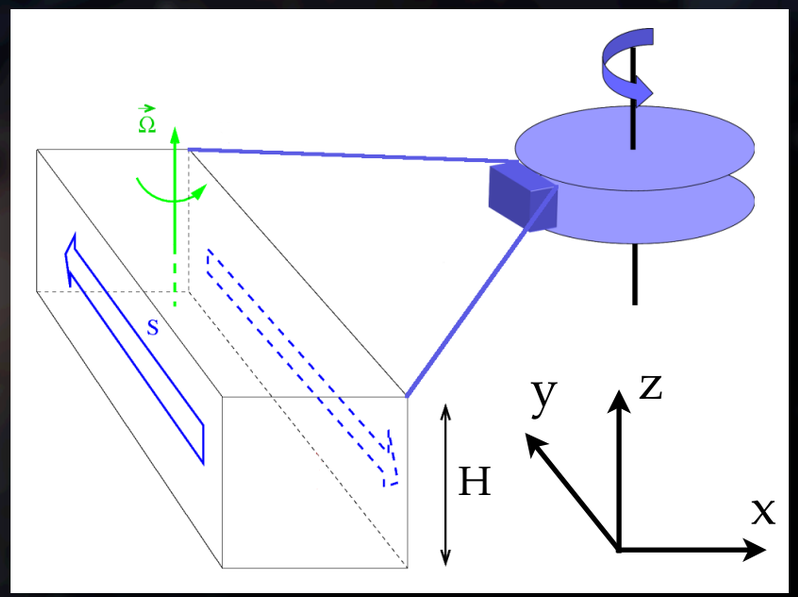
Vertical and toroidal total magnetic flux conserved

mean vertical field («guide field»)



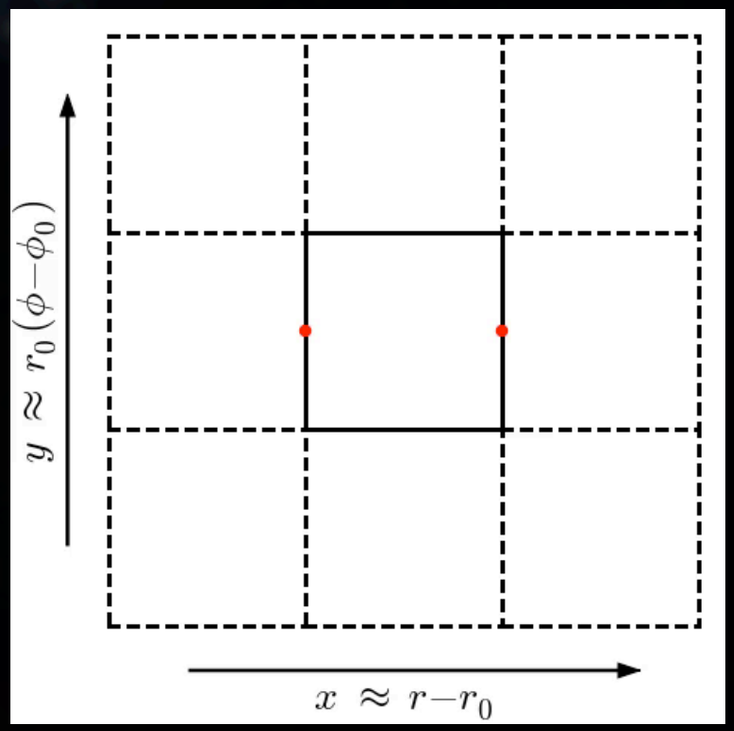
zero mean field





Boundary conditions

- Use shear-periodic boundary conditions= «shearing-sheet»
- periodic in y and z (non stratified box)

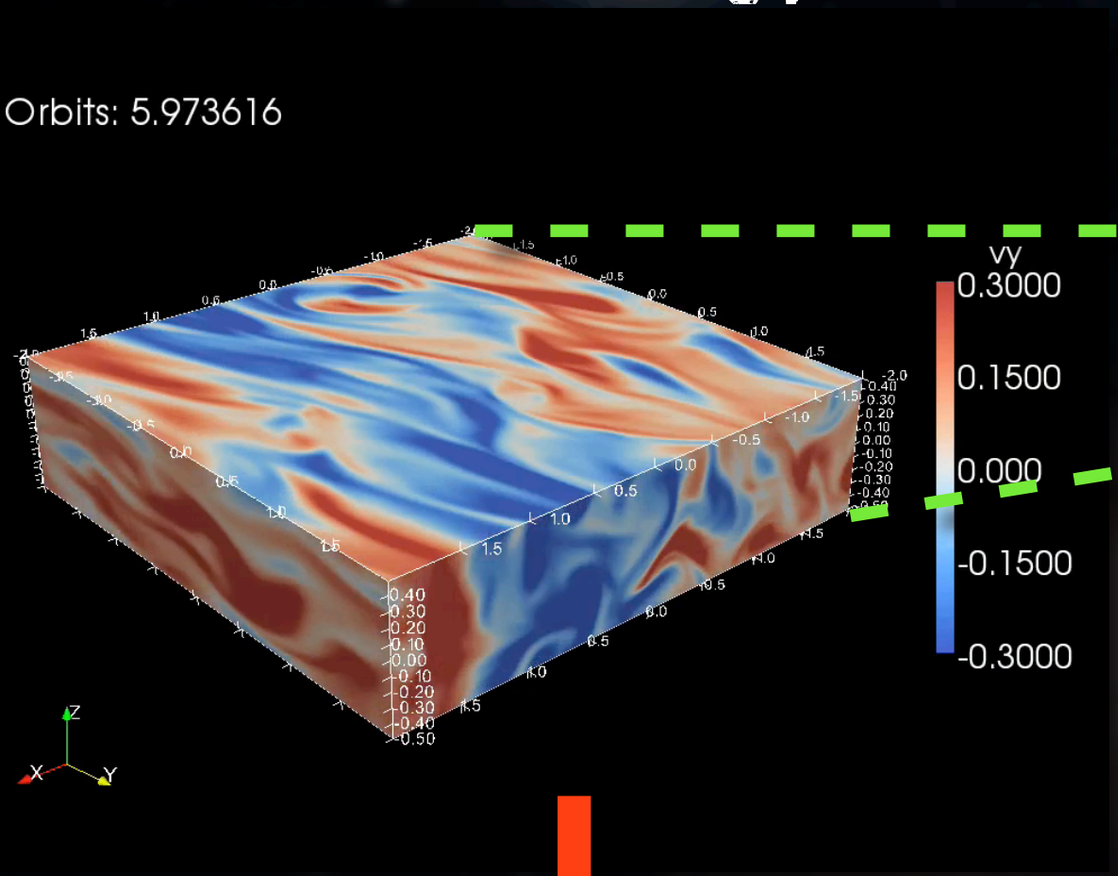


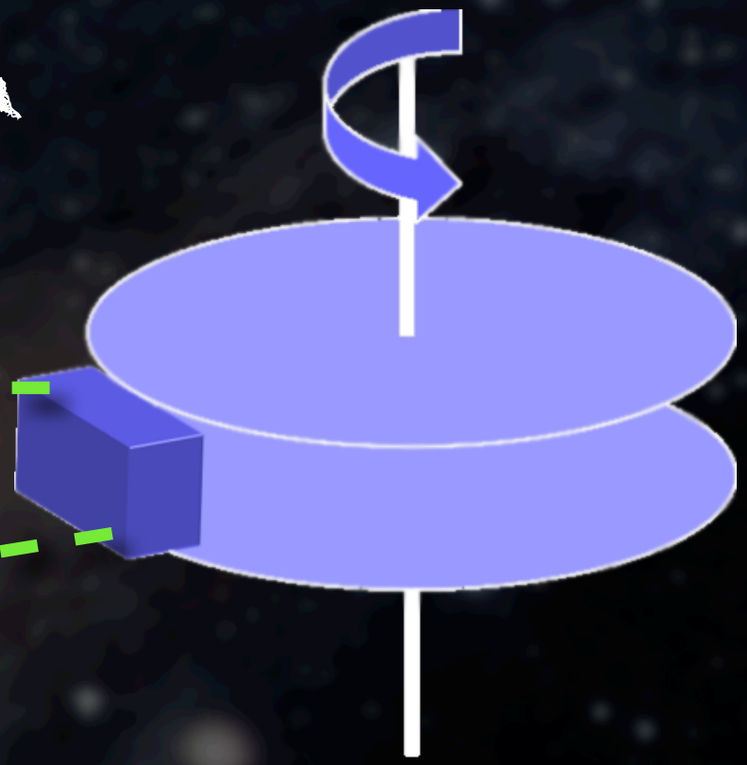
Radial turbulent transport

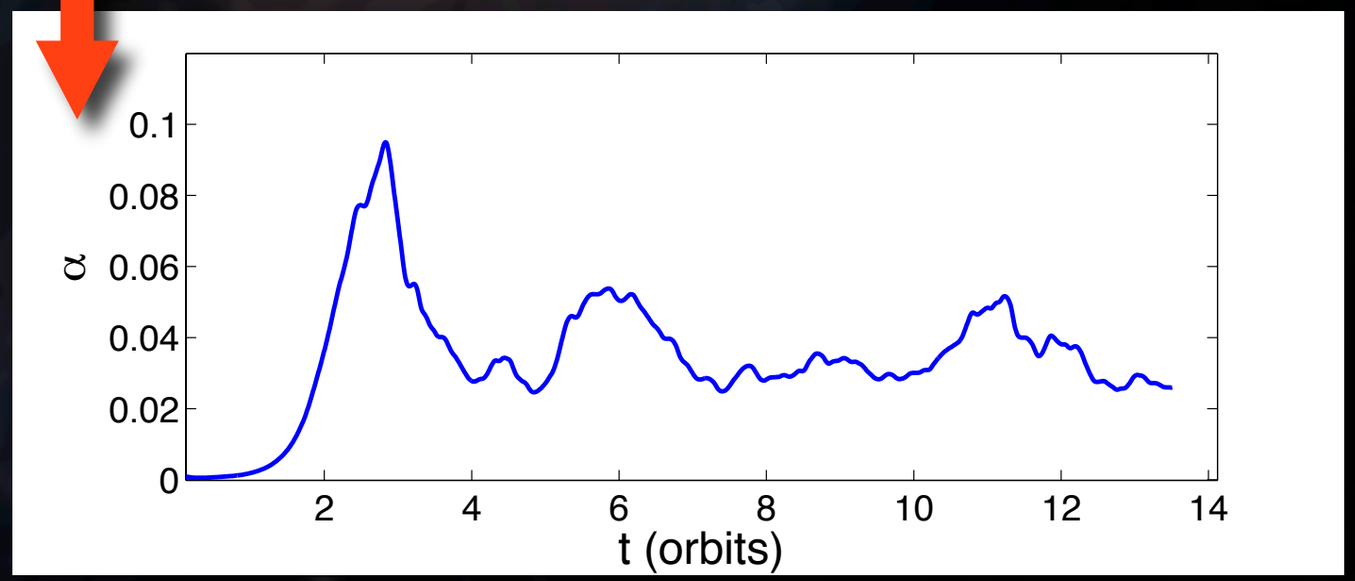
$$\alpha = \frac{\langle \delta v_x \delta v_y - \delta B_x \delta B_y \rangle}{\Omega^2 H^2}$$

MRI simulations

Typical simulation

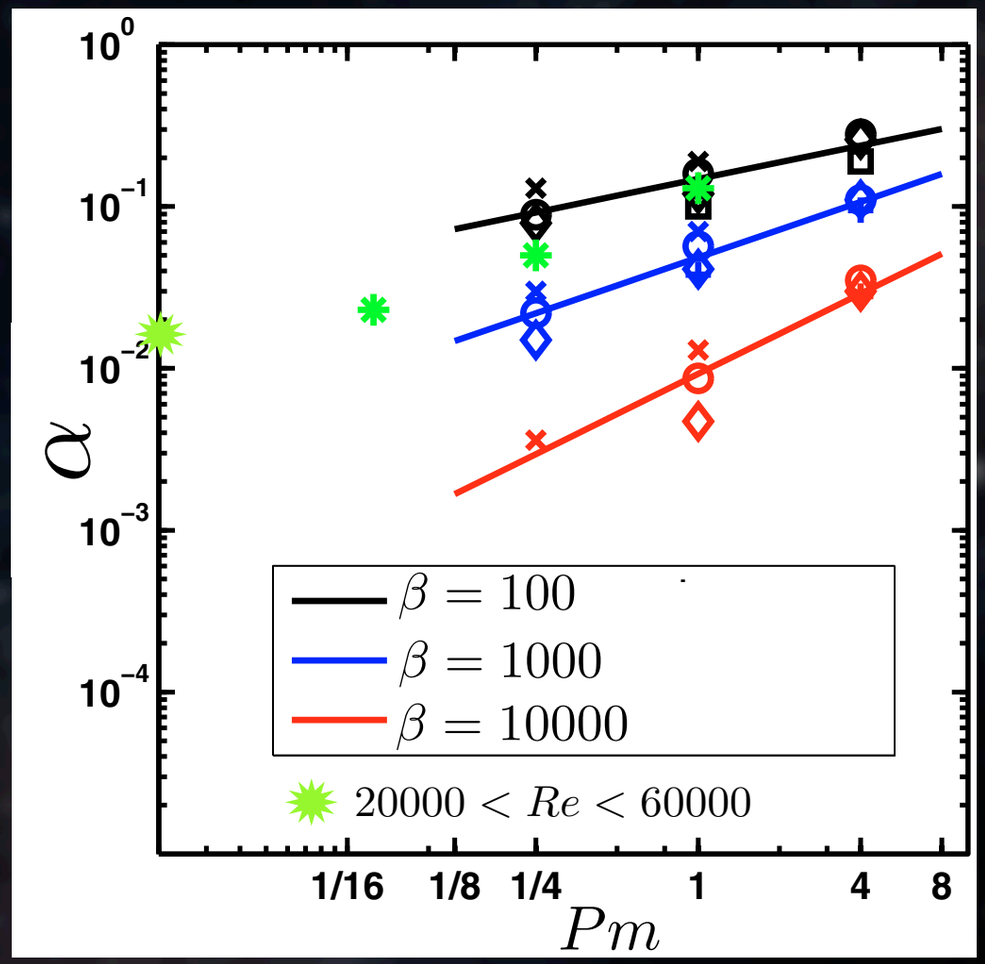






Pm vs large scale transport with a guide field

Protoplanetary discs Pm~10^{-5}

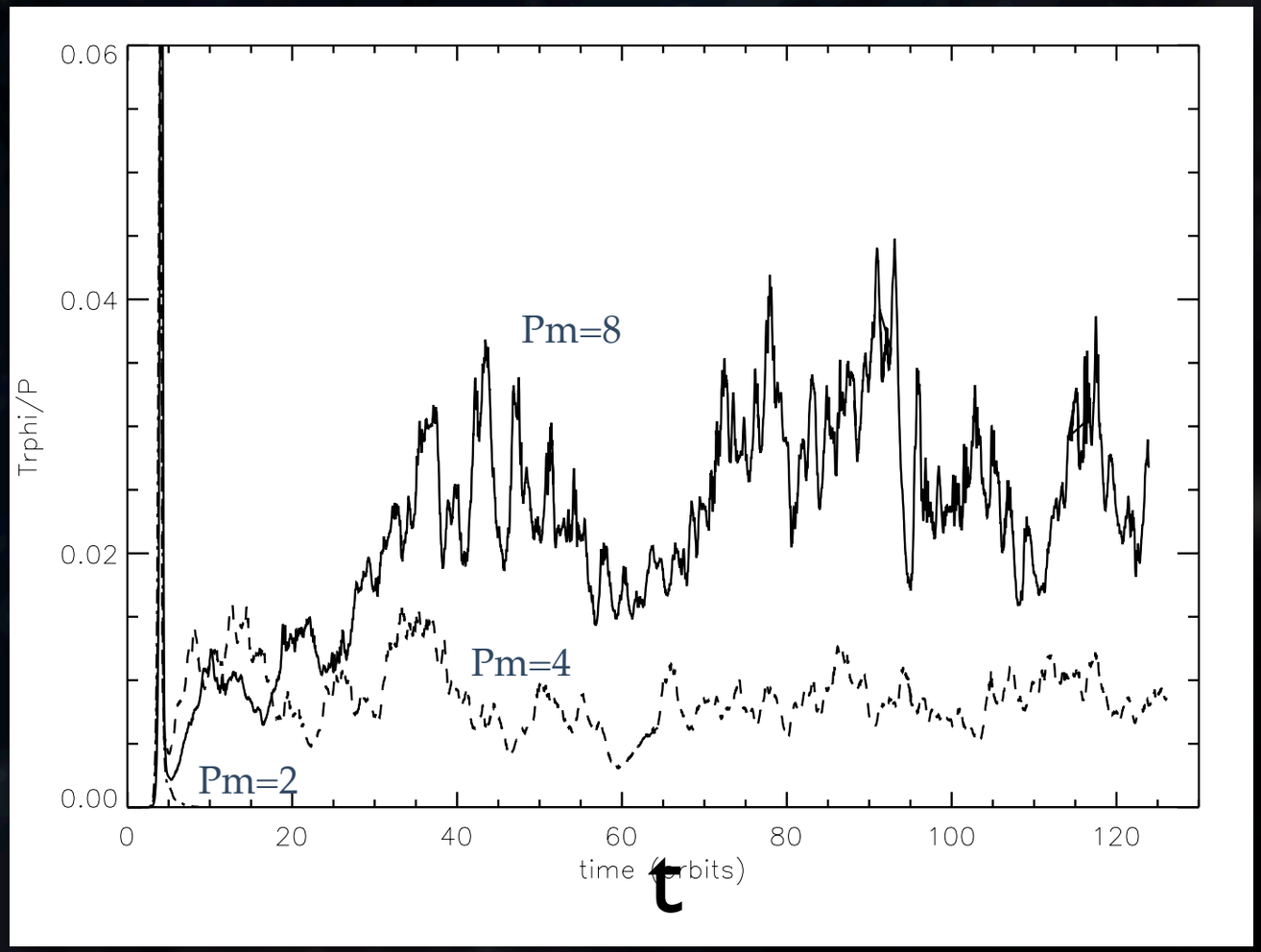


Longaretti & Lesur 2010

→ Reaction of small scales (Pm) on large scales (α)

→ MHD subgrid model should be a function of Pm?

Pm vs large scale transport without a guide field

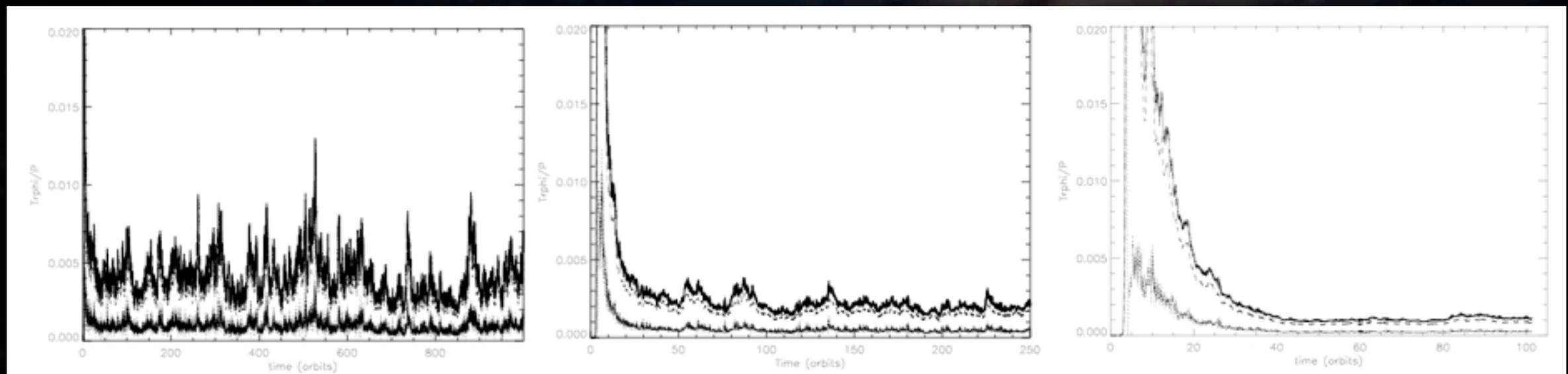


Fromang et al. 2007

No turbulence for Pm<2?

ILES and no guide field MRI: a worst case scenario?

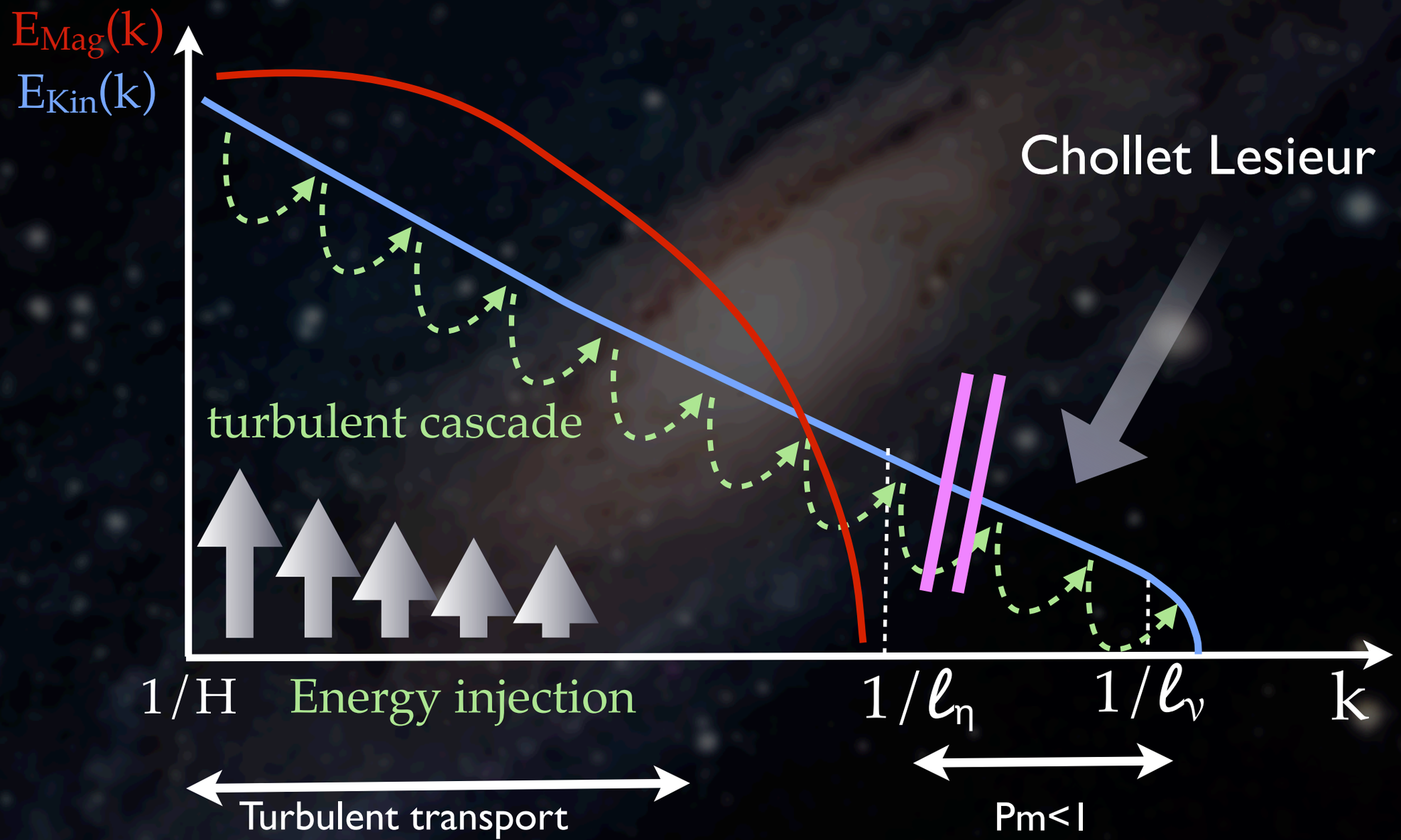
64x100x64 128x200x128 256x400x256



Fromang & Papaloizou 2007

- ILES fails to converge to a solution
- Not true anymore for stratified boxes (Davis et al.2010)

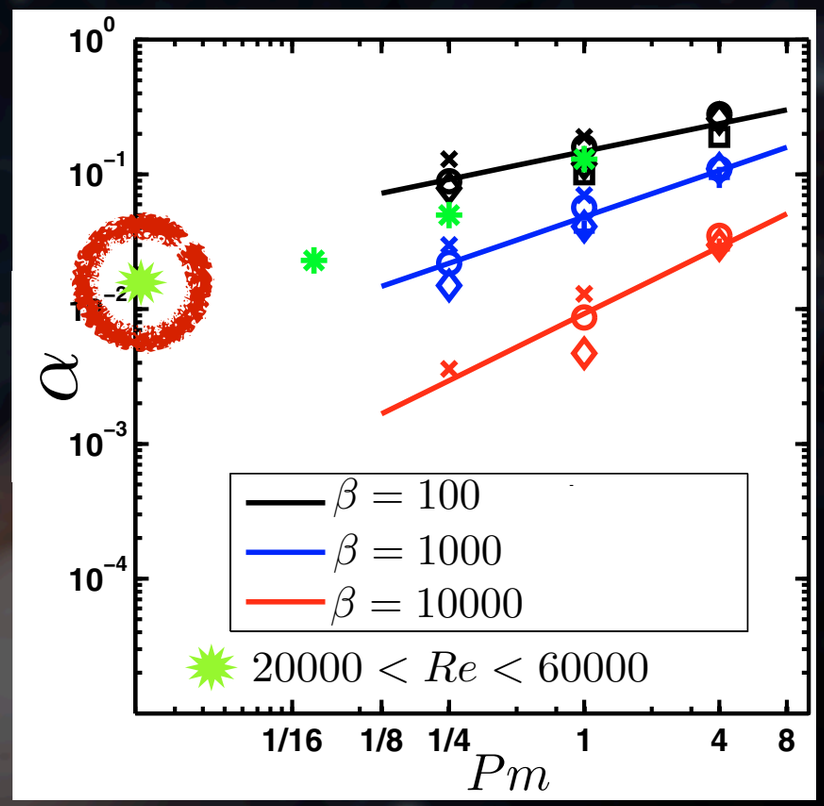
Introducing LES for the sub-resistive cascade (à la Ponty et al. 2004)

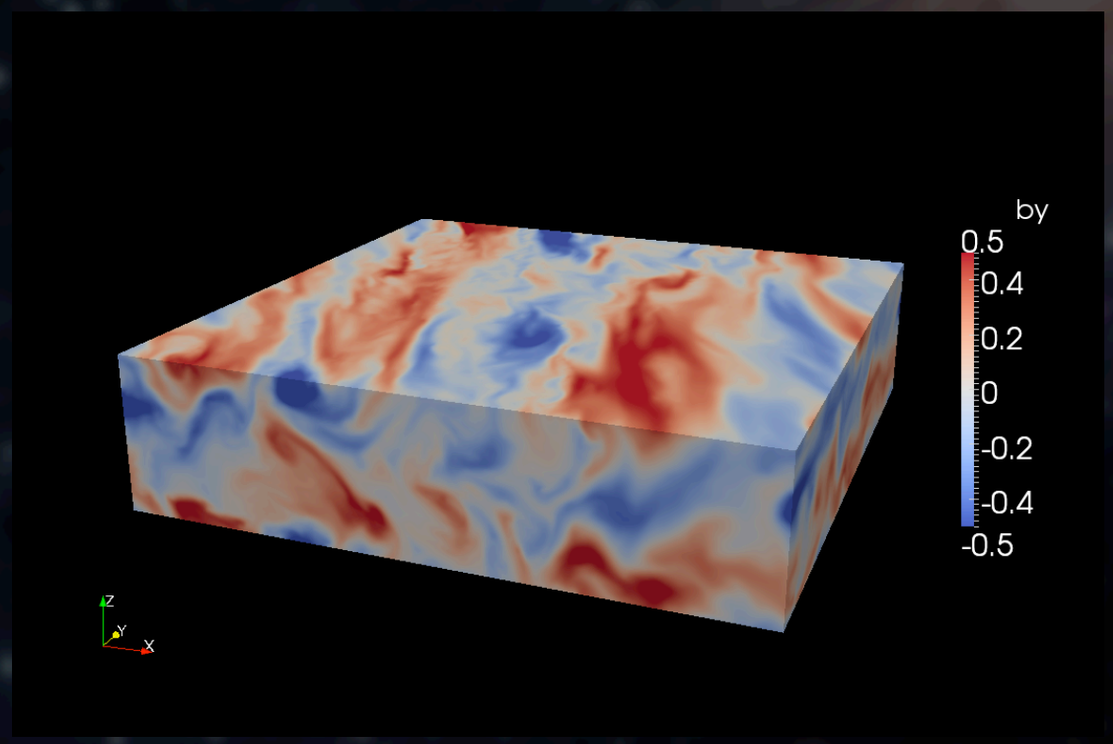


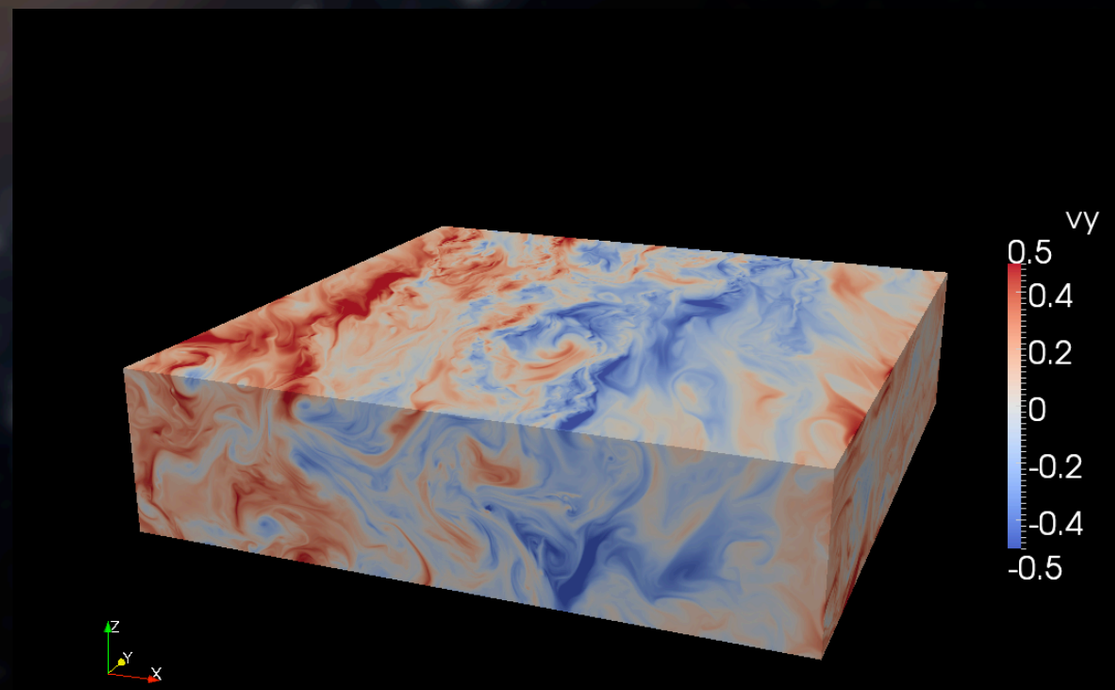
Chollet Lesieur 1981

Reference DNS

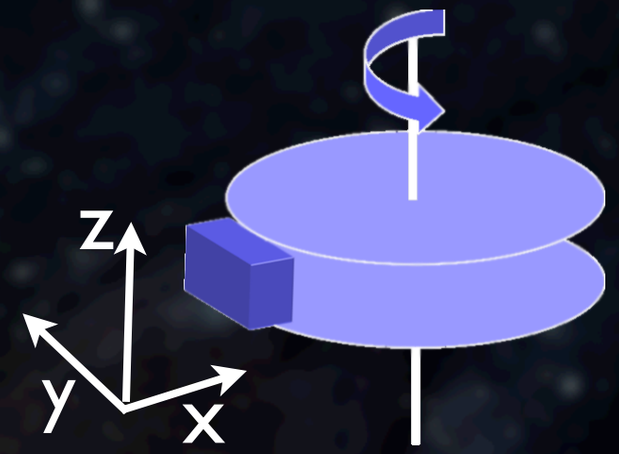
Re=60000
Rm=600
Pm=0.01
384 pts/H

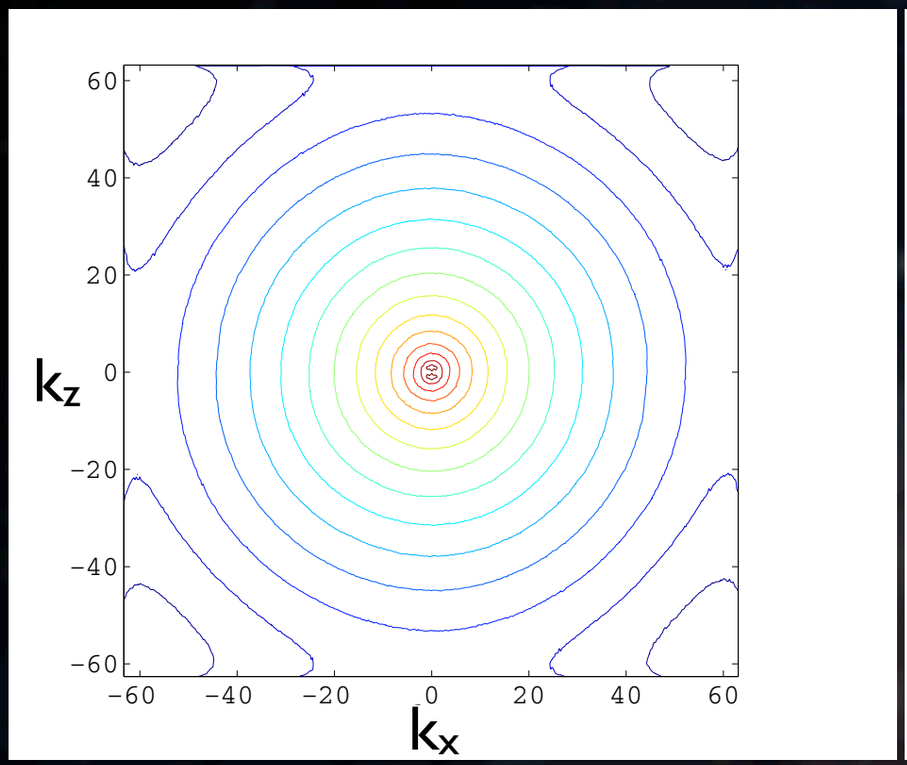


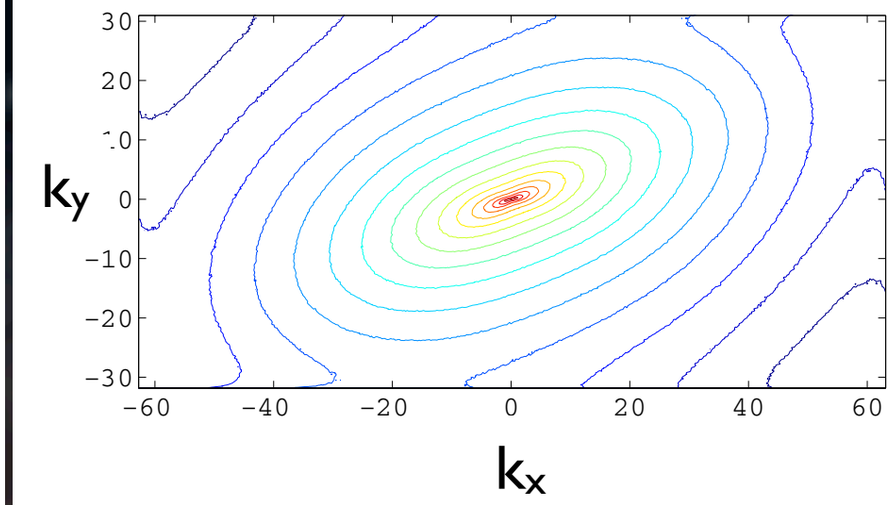


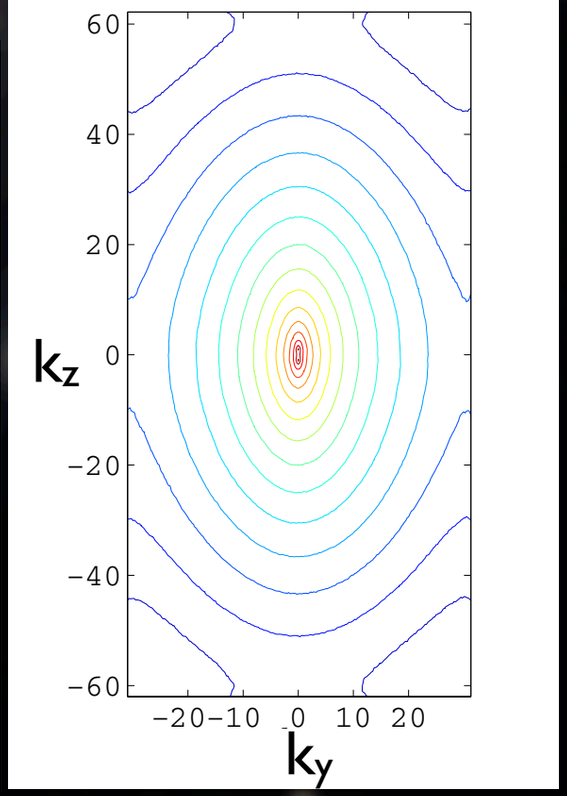


Anisotropy





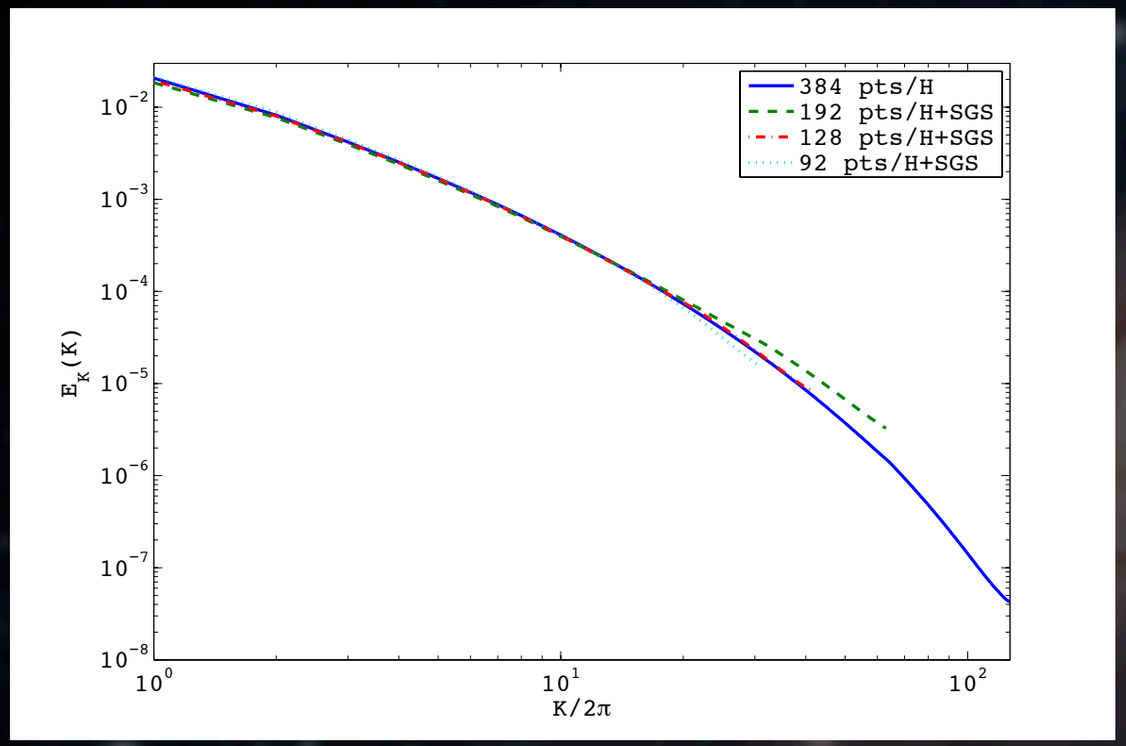




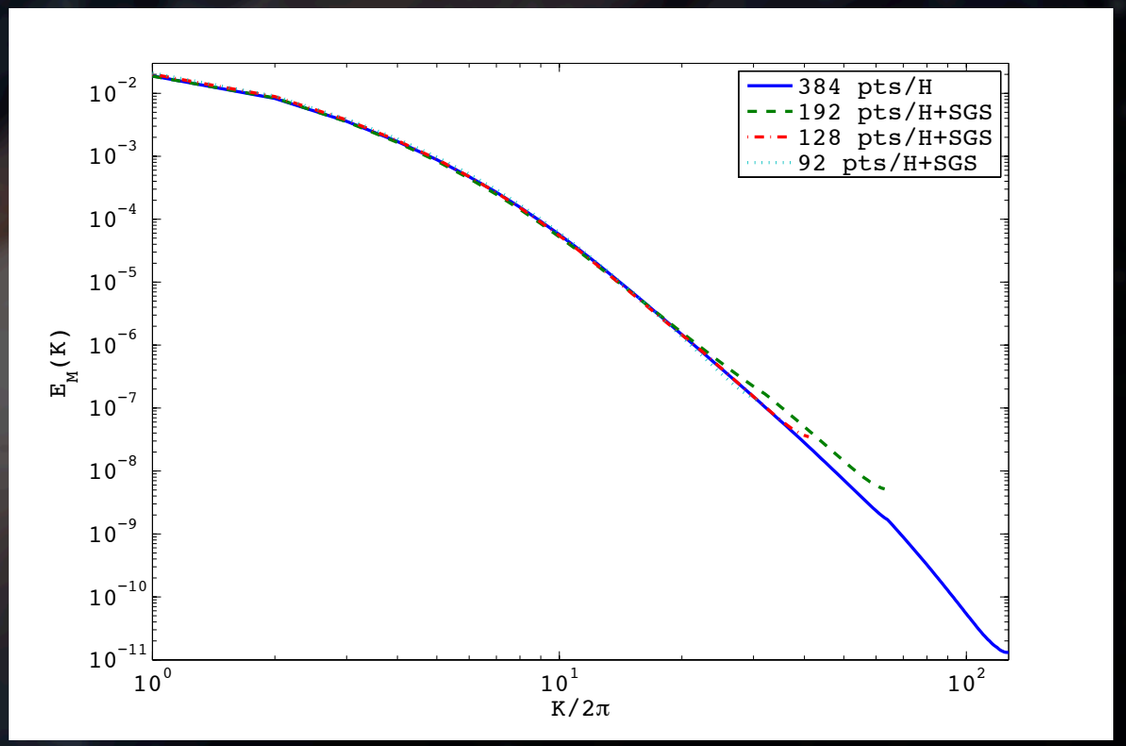
- No anisotropy associated to the guide field ($\frac{\delta B}{B_Z^0} \gg 1$)
- Strong *x-y* anisotropy due to the shear
- Chollet-Lesieur not adapted in this case...

LES vs DNS spectra

Kinetic energy



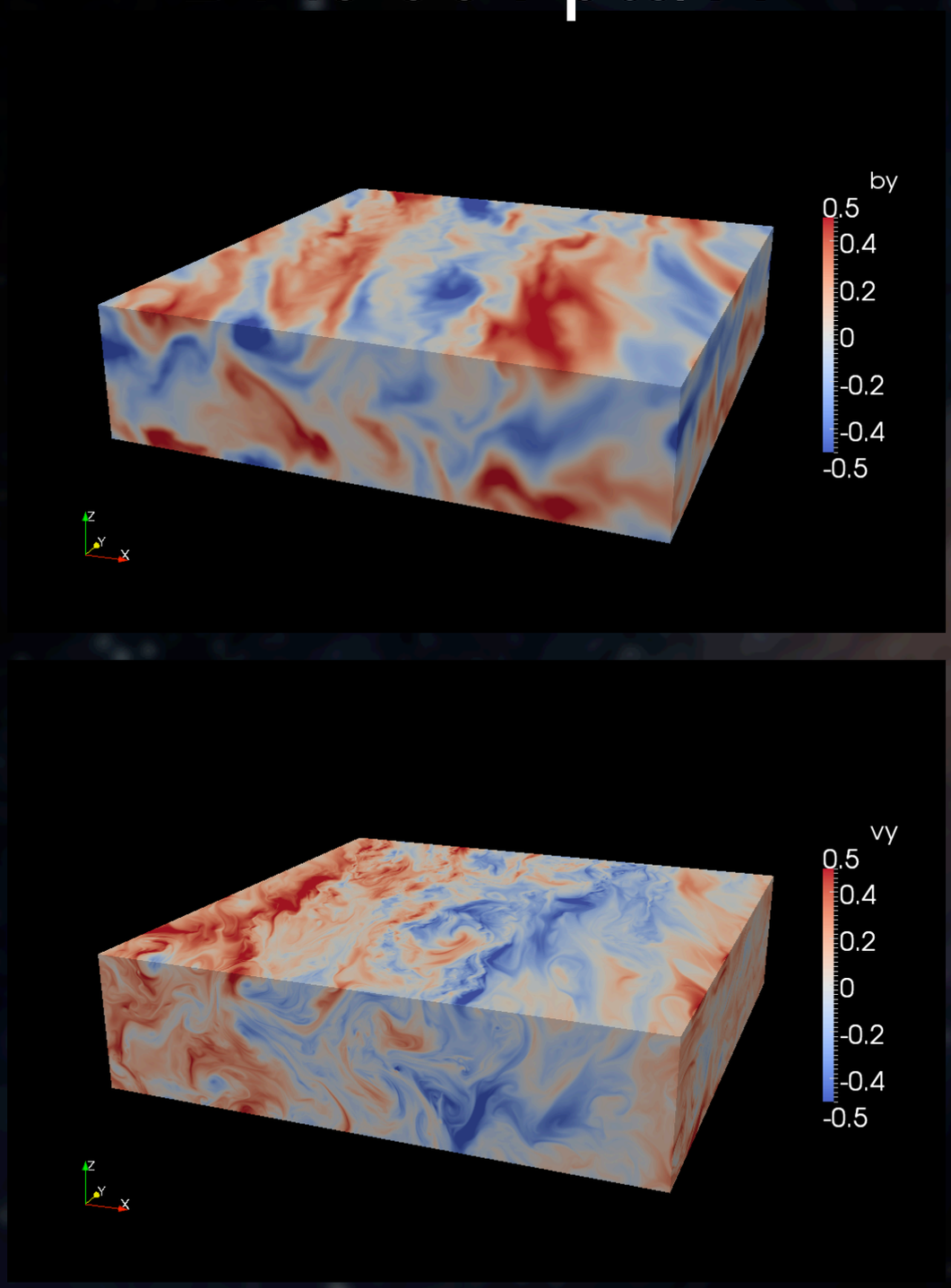
Magnetic energy



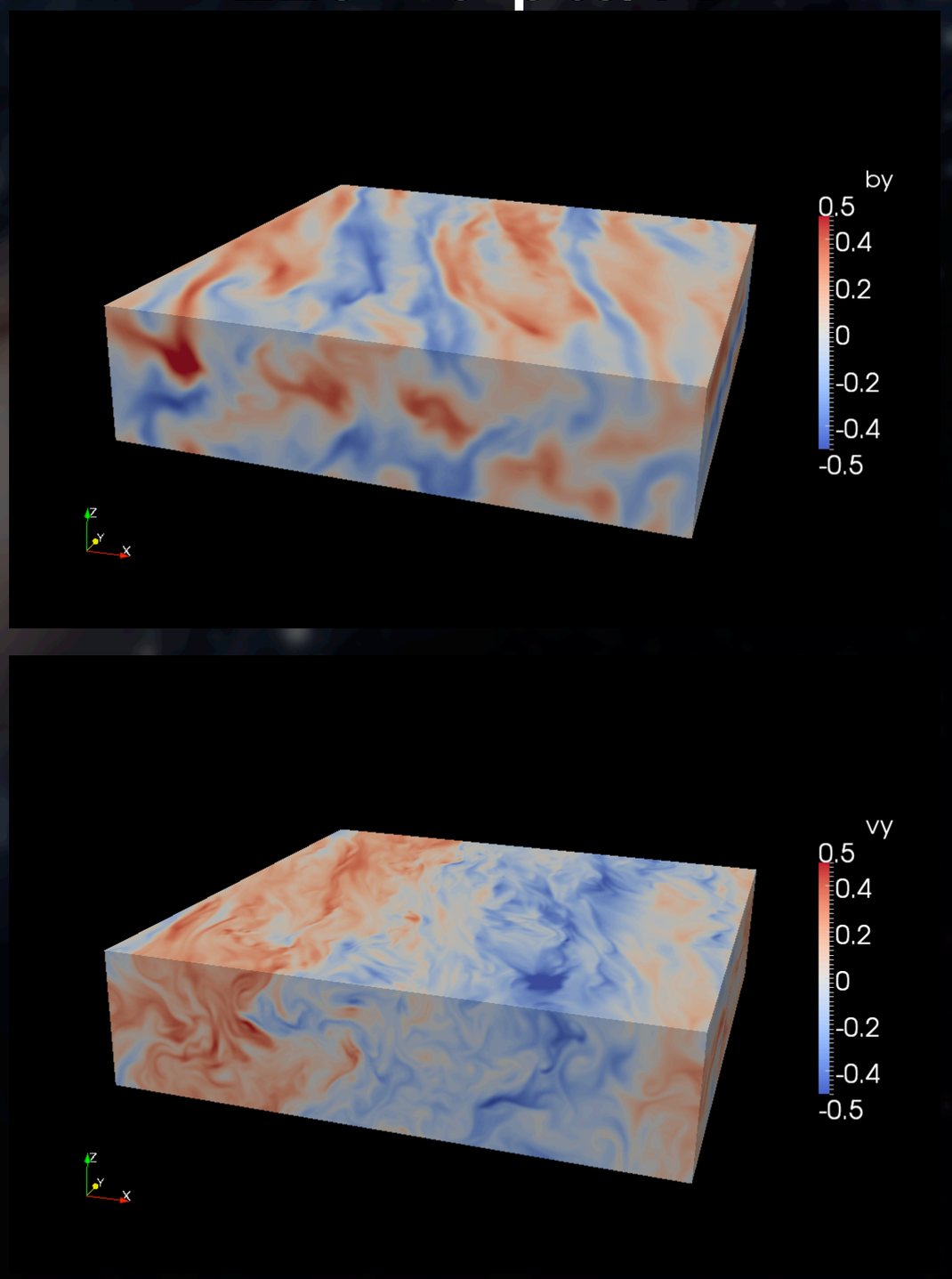
- Computation time gain~100
- Have we reached an asymptotic regime for Pm<<1 ?

LES vs DNS flows

DNS 384 pts/H



LES 96 pts/H



Conclusions

- MRI-driven turbulence is sensitive to small scale processes.
- Should MHD LES models depend on small scale physics? (locality ?)
- ILES sometimes fail to converge. In general, it automatically implies Pm~2-3.
- In the Pm<<1 limit, Chollet-Lesieur works well for the hydro cascade, despite the strong anisotropy (ILES for hydro seems to work as well)

LES challenges in the MRI context:

- MRI without a guide field in the Pm<1 regime.
- Asymptotic regime in the Pm>>1 limit (full LES-MHD model)