MRI turbulence in accretion discs: angular momentum transport in the low Prandtl number limit

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The mechanisms and rate of angular momentum transport in astrophysical discs is a central problem in accretion theory. Currently the most widely studied mechanism for this transport is the turbulence induced by the magnetorotational instability (MRI). However previous studies have proven that this transport decreases with a decreasing ratio of fluid viscosity to fluid resistivity, also called Prandtl number $Pm=\nu/\eta$. This questions the role of MRI turbulence in discs with very low Prandtl number such as protoplanetary discs. In this context, we study the rate of angular momentum transport at low Prandtl number by the means of local simulations of MRI-driven turbulence at very high resolution. In this talk, I will present results showing a convergence of transport rate at low Pm for different magnetic field configurations and discuss the relevance of implicit Large Eddy Simulations (LES) for such a study.

Subject :	:	oral
Topics	:	Astrophysics

MRI TURBULENCE IN ACCRETION DISCS: Angular momentum transport in the low Pm limit

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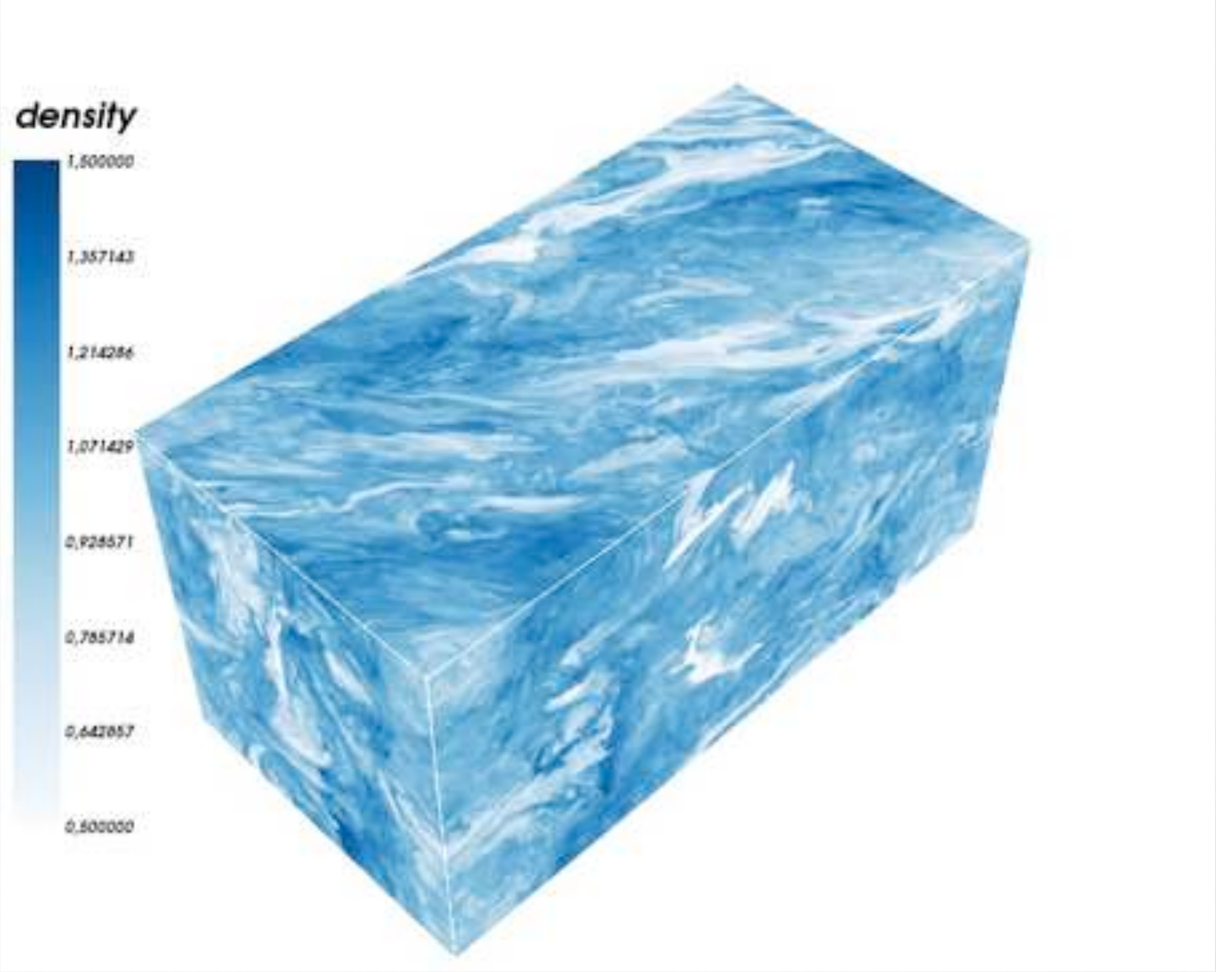
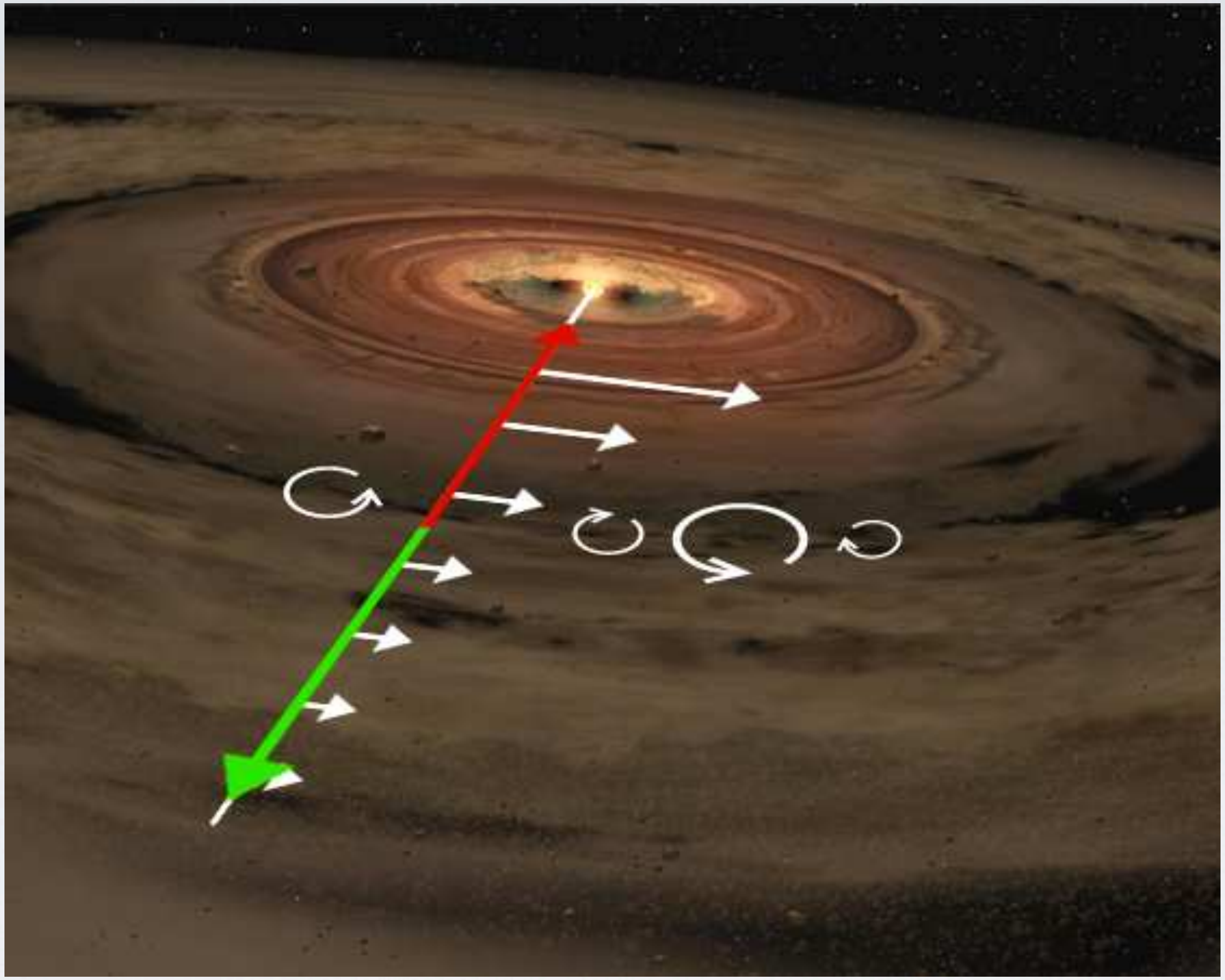


ACCRETION PROCESS

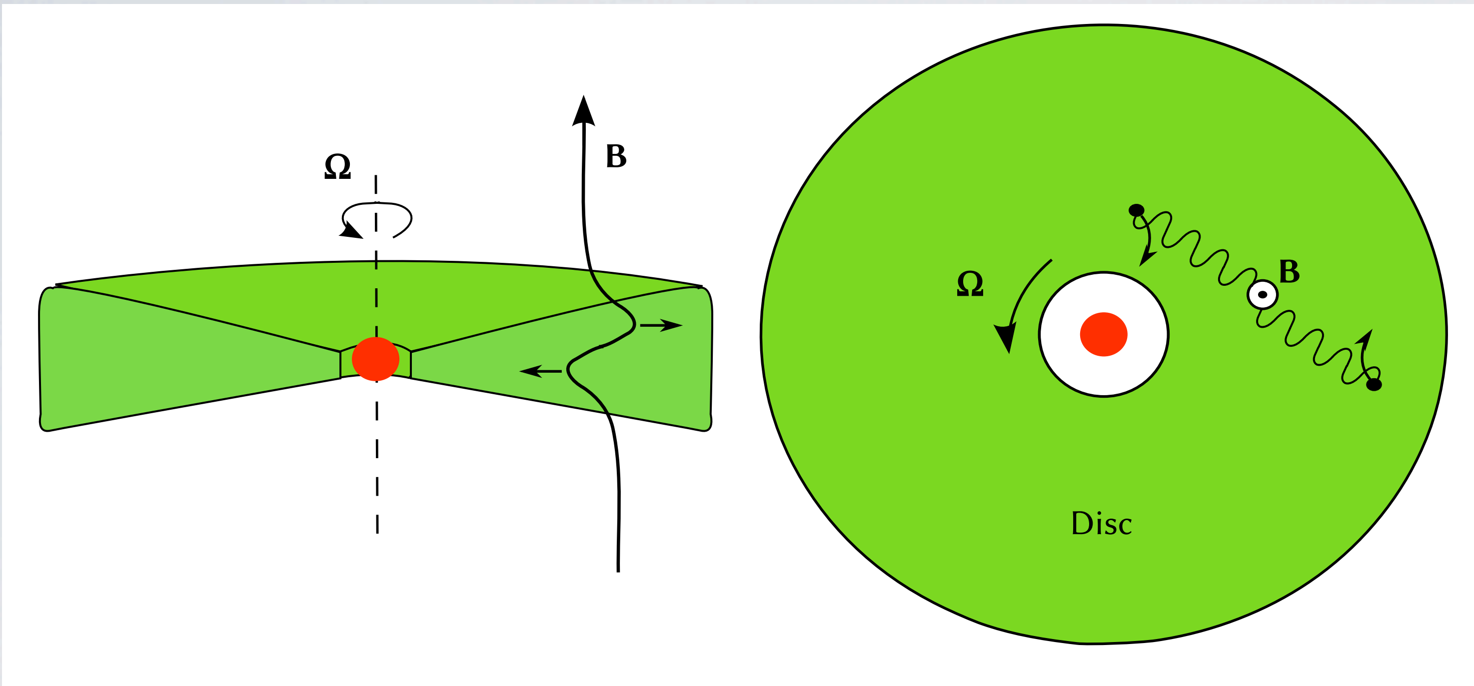


Julien Faure

$$\nu = \alpha c_s H$$

$$\alpha \sim 10^{-3} - 10^{-1}$$

MAGNETO-ROTATIONAL INSTABILITY



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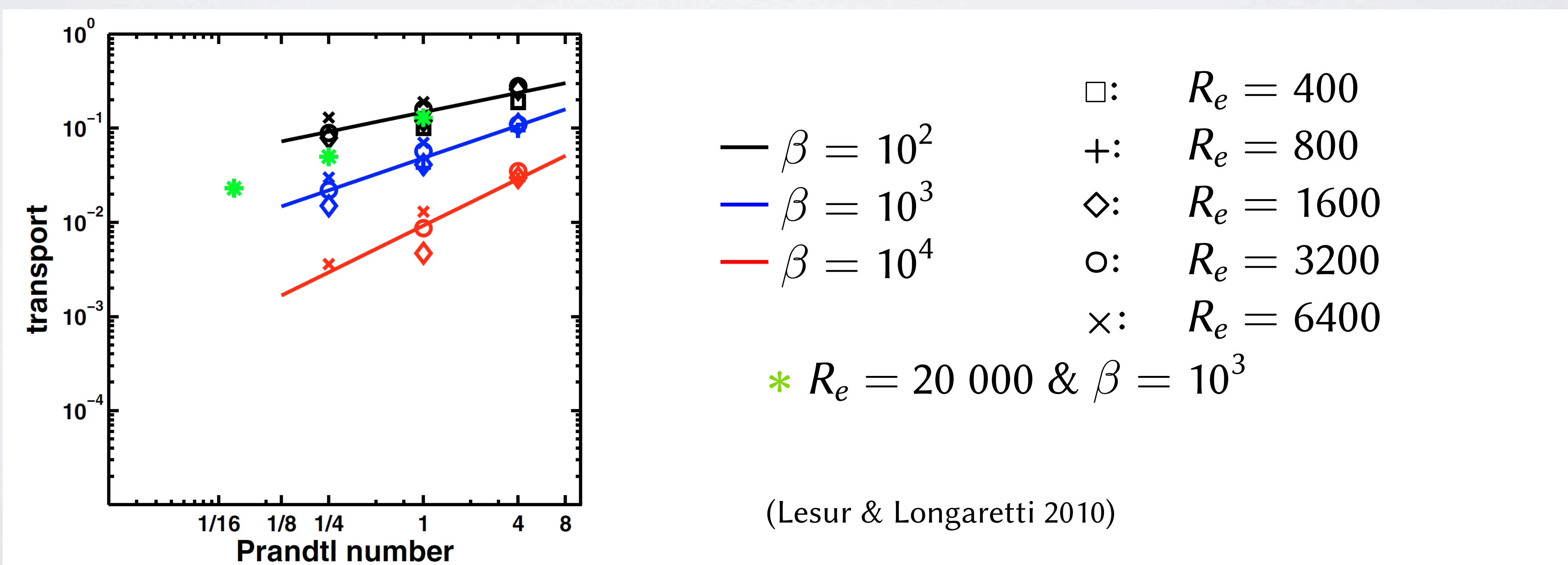
- Linear mechanism
- Turbulence
- Low Pm limit: no transport?



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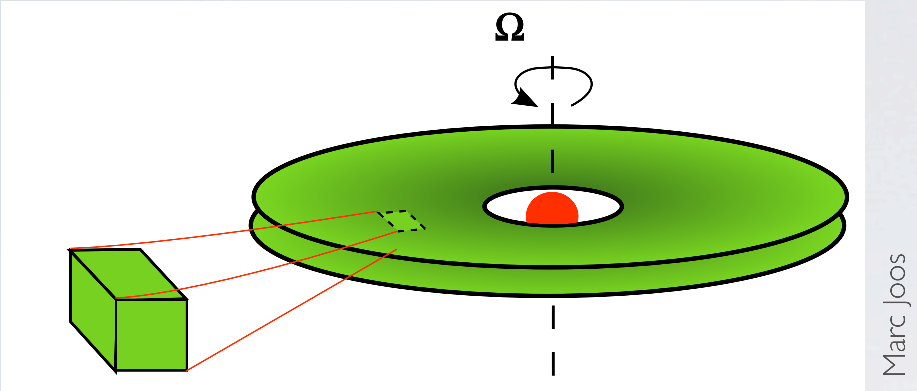
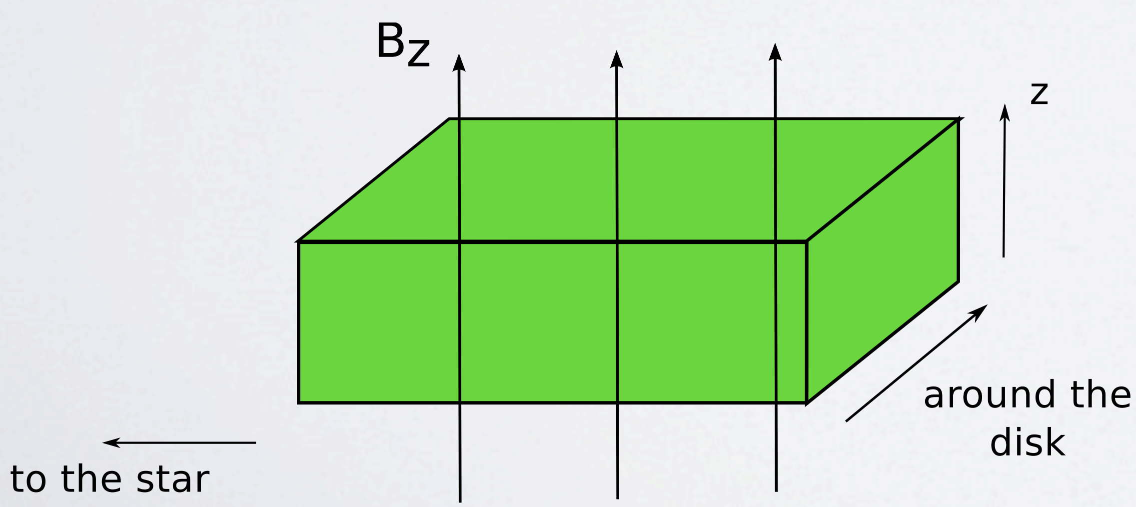
SHEARING BOX SIMULATIONS

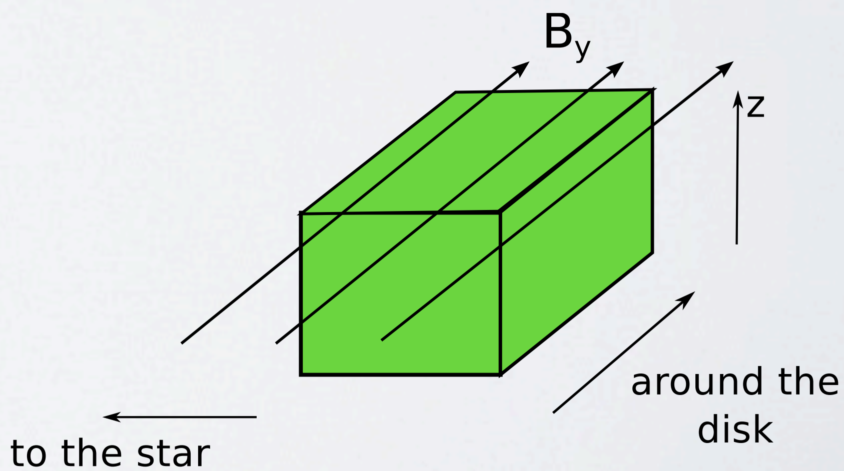


- Shearing box boundary conditions
- Ramses code
- Isothermal disc $\quad P = c_0^2\rho$
- Unstratified disc

$$
\begin{aligned}
\partial_t\rho + \nabla\cdot(\rho\boldsymbol{v}) &= 0 \\
\partial_t(\rho\boldsymbol{v}) + \nabla\cdot(\rho\boldsymbol{v}\boldsymbol{v} - \boldsymbol{B}\boldsymbol{B}) &= 2\rho\Omega_0 x\boldsymbol{i} - 2\rho\boldsymbol{\Omega}_0\times\boldsymbol{v} + \nabla\cdot\boldsymbol{T} - \nabla P_{tot} \\
\partial_t\boldsymbol{B} &= \nabla\times(\boldsymbol{v}\times\boldsymbol{B} - \eta\nabla\times\boldsymbol{B})
\end{aligned}
$$

$$T_{ij} = \nu\rho(\partial_j v_i + \partial_i v_j - \frac{2}{3}\delta_{ij}\nabla\cdot\boldsymbol{v})$$





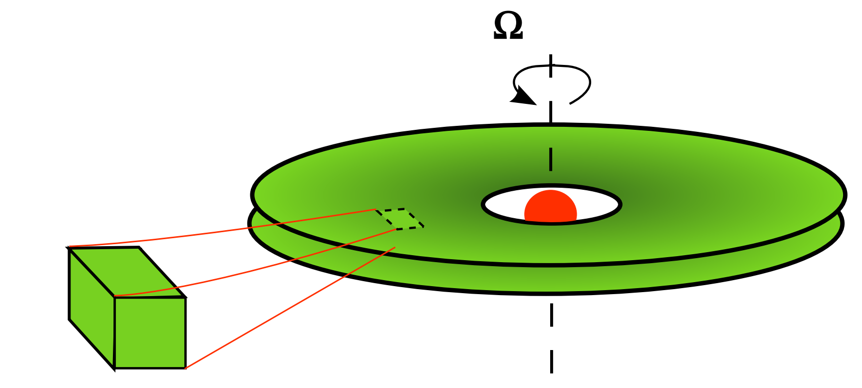
NON IDEAL SIMULATIONS

- Viscosity and resistivity coefficient
- High resolution is needed ! (Fromang et al. 2007)

$$Re = \Omega L_z^2/\nu$$

$$Rm = \Omega L_z^2/\eta$$

$$Pm = Rm/Re$$



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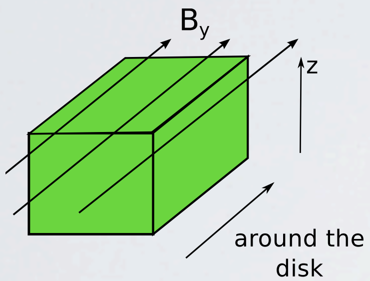
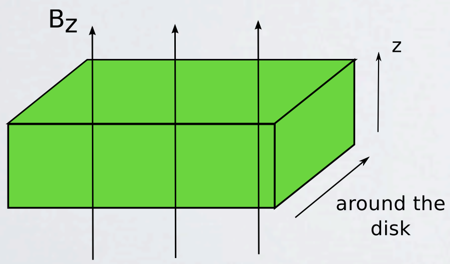


Model	Resolution	Re	Rm	Pm
Y-C-Re650	(64, 128, 64)	650	2600	4
Y-C-Re2600	(64, 128, 64)	2600	2600	1
Y-C-Re13000	(128, 256, 128)	13000	2600	0.2
Y-C-Re26000	(256, 512, 256)	26000	2600	0.1
Y-C-Re85000	(800, 1600, 800)	85000	2600	0.03



Model	Resolution	Re	Rm	Pm
Z-C-Re400	(128, 64, 32)	400	400	1
Z-C-Re800	(256, 128, 64)	800	400	0.5
Z-C-Re3000	(512, 256, 128)	3000	400	0.13
Z-C-Re8000	(1024, 512, 256)	8000	400	0.05

THE 'GRAND CHALLENGE' SIMULATION

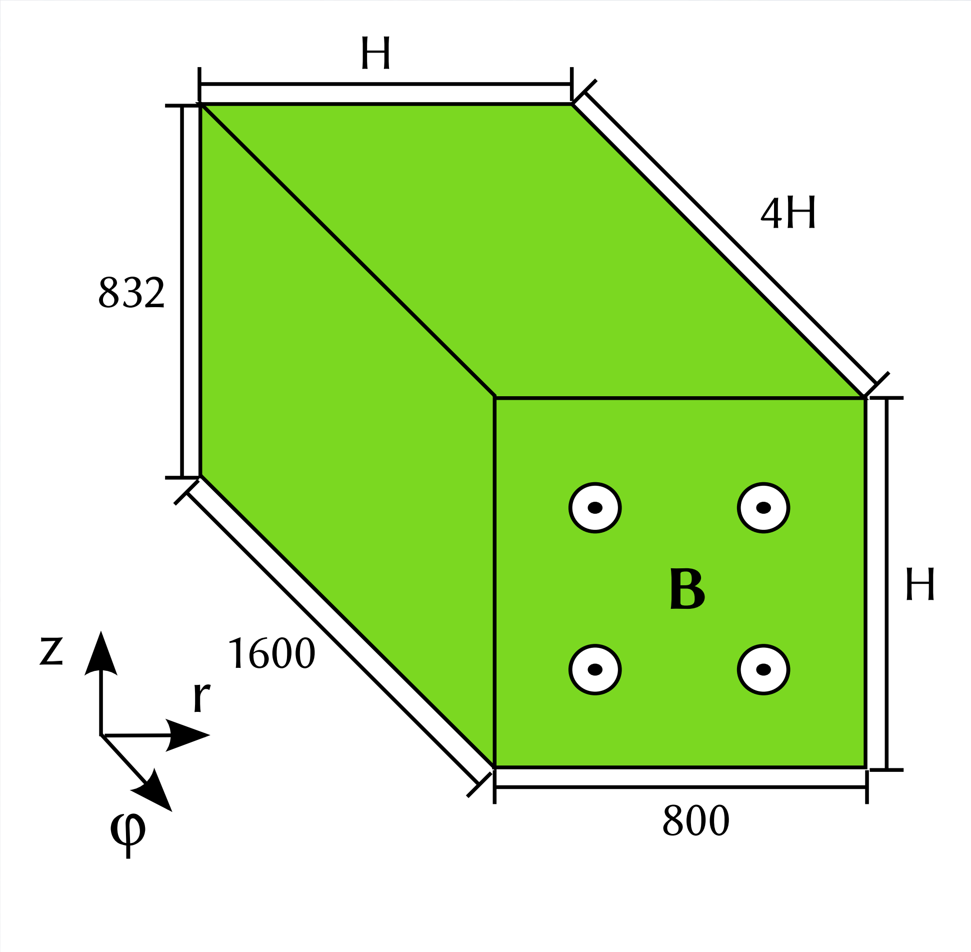
- Toroidal magnetic field $\beta \sim 100$
- Two steps:

1. Ideal step:

$$Re = \infty \quad Rm = \infty$$

2. Visous and resistive step:

$$Pm = 0.03 \quad Re = 85000 \quad Rm = 2600$$



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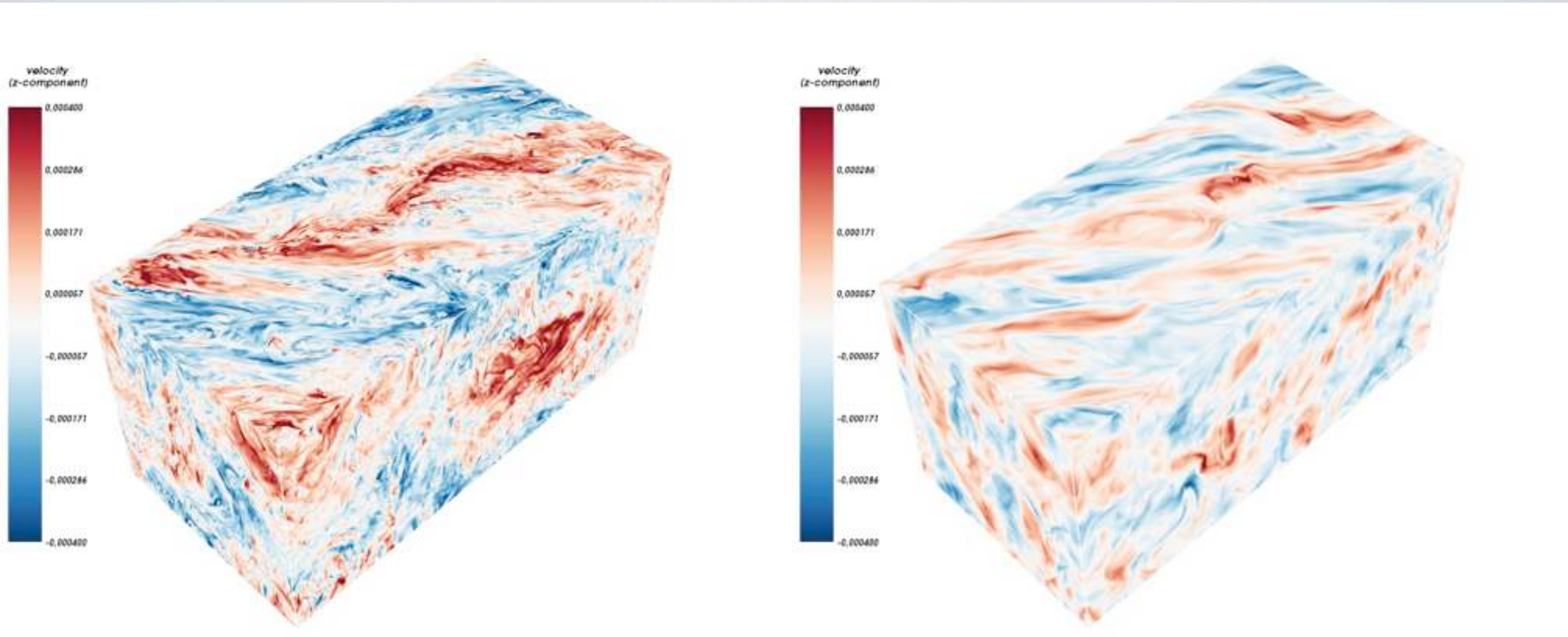
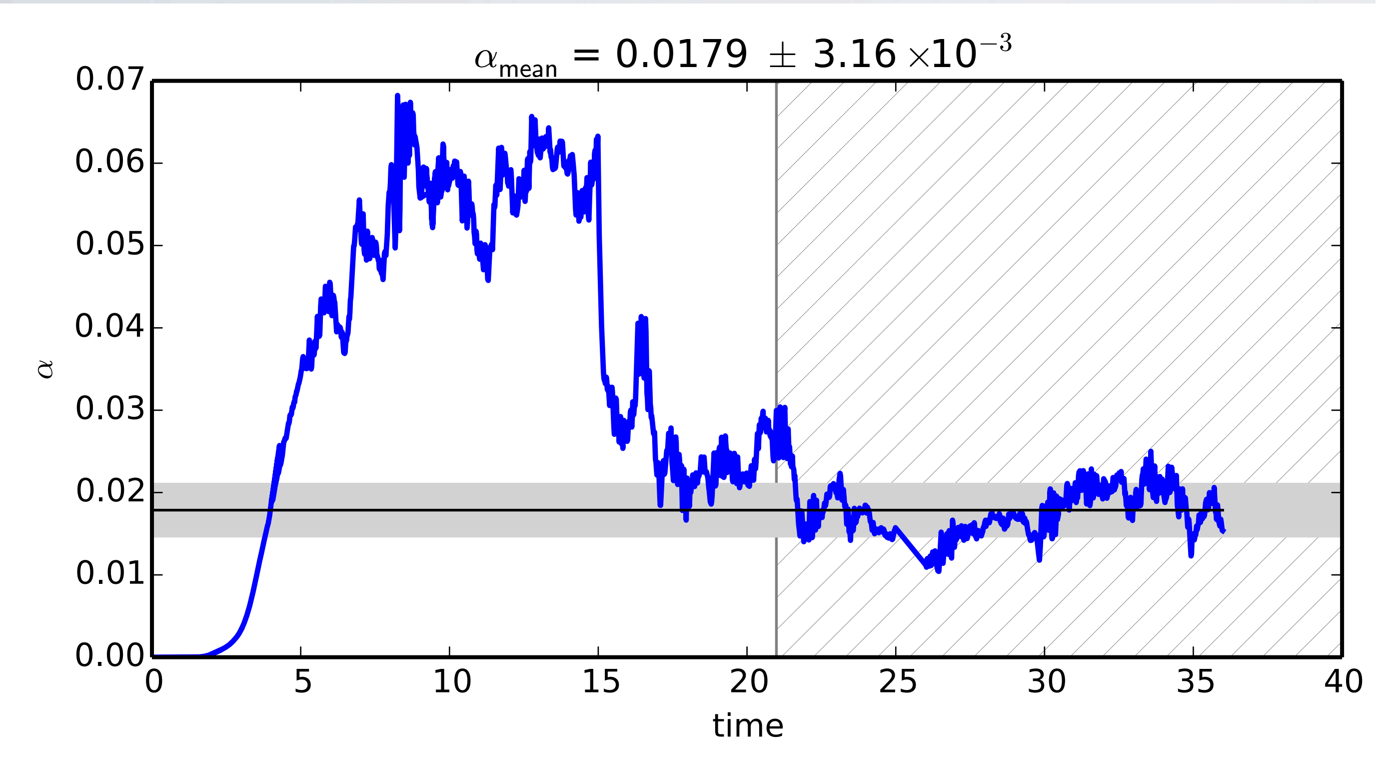
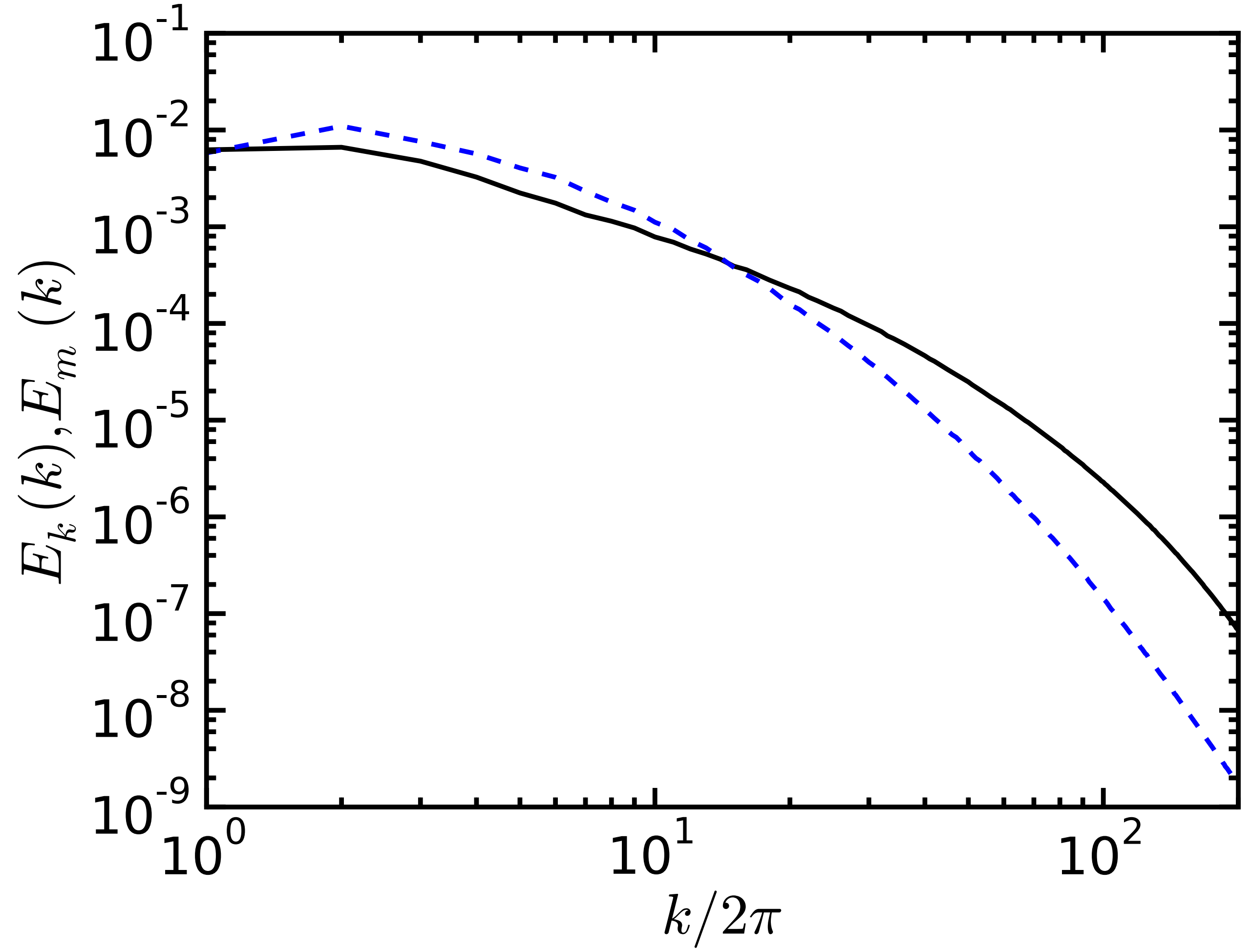
10^6 time-steps
10^7 CPU hours (Blue Gene)
2^{15} cores
131 072 threads

THE 'GRAND CHALLENGE' SIMULATION



THE 'GRAND CHALLENGE' SIMULATION

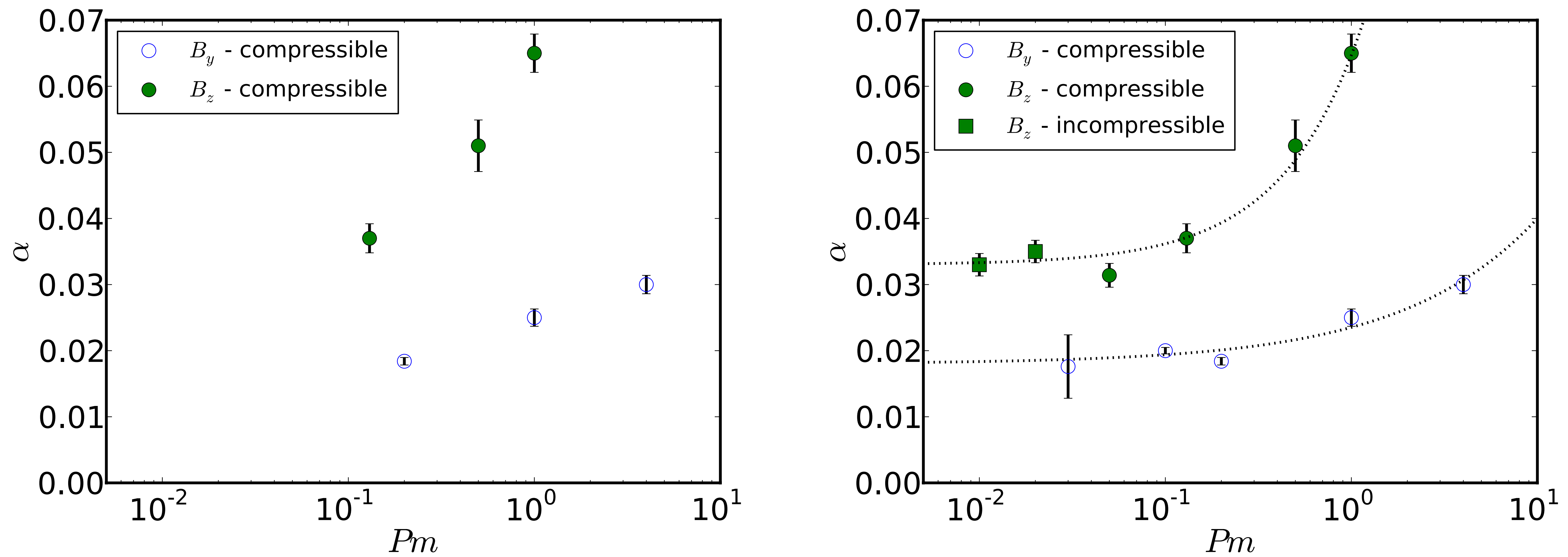




$$\alpha_{Rey} = < \rho \delta v_r \delta u_\phi >$$
$$\alpha_{Max} = - < B_r B_\phi >$$

$$E_M(k) = < \boldsymbol{B}_k^2(k)/2 >$$
$$E_K(k) = < \rho v_k^2(k)/2 >$$

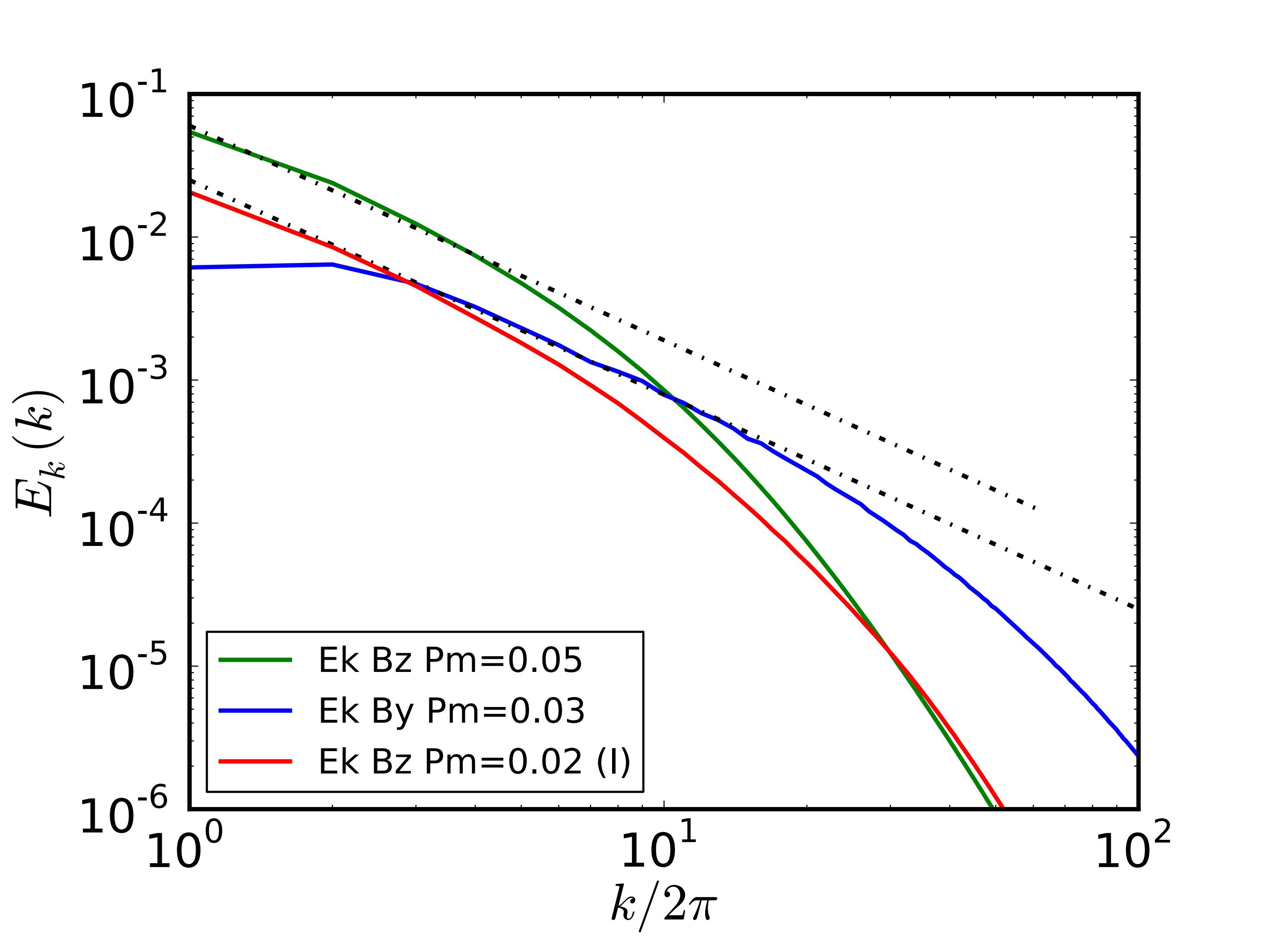
CONVERGENCE AT LOW PM



TURBULENT SPECTRA

$$E_M(k) =< \boldsymbol{B}_k^2(k)/2 >$$

$$E_K(k) =< \rho v_k^2(k)/2 >$$

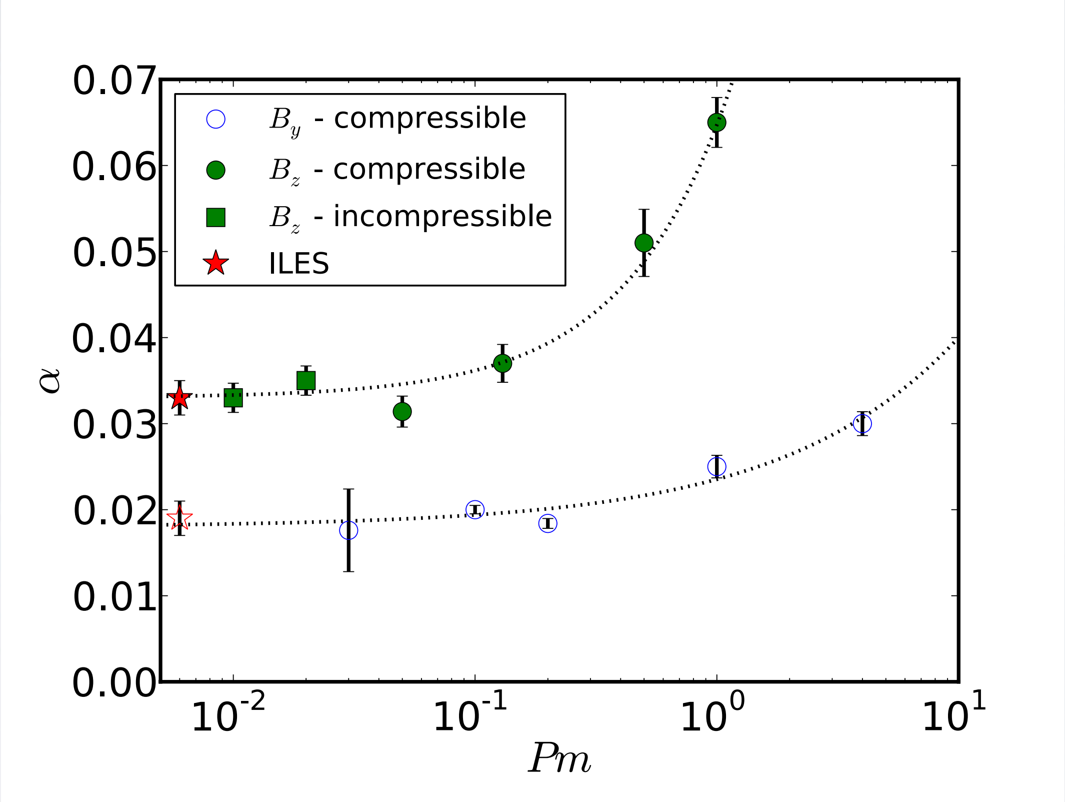


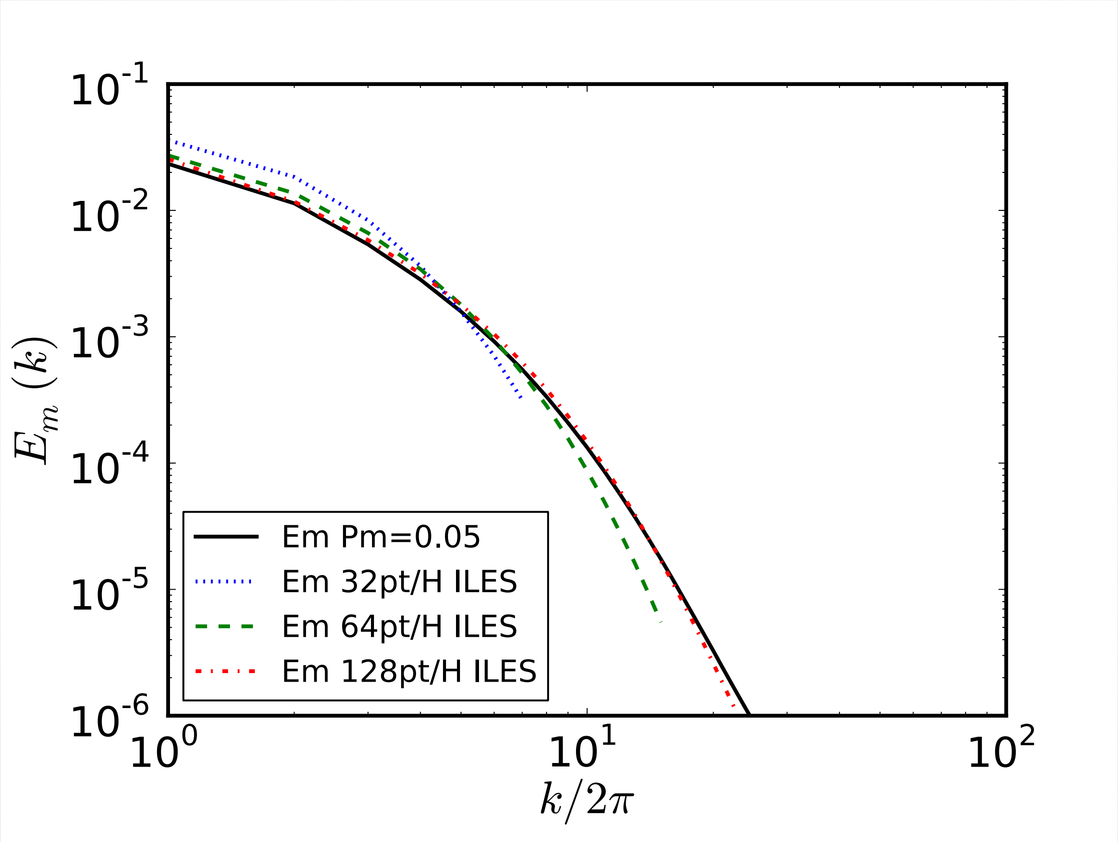
$$E_k \propto k^{-3/2}$$

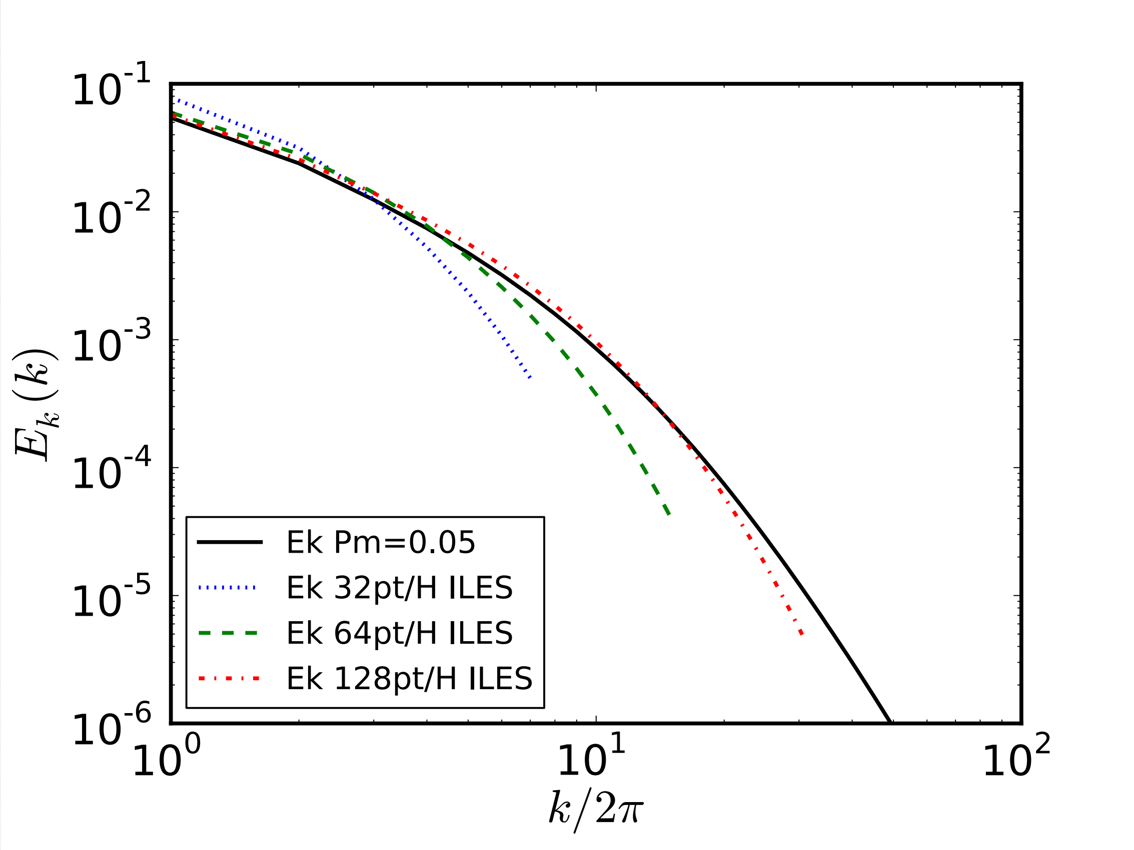
LARGE EDDY SIMULATIONS (?)

$$Rm = 2600 - 400$$

$$Re = \infty$$







SUMMARY & DISCUSSION