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Amplification of magnetic fields in the ICM and IGM using a Kinetic MHD model

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Turbulent amplification of the MF in the ICM and IGM

- In the MHD framework, a weak field can be amplified by a conductive chaotic flow until saturation:

  Magnetic energy ~ Kinetic energy

  (Batchelor, 1950)

- Turbulence has a dynamo action
  (see poster by A. M. Beck, and Dolag's talk)

Does it apply directly to the ICM and IGM?

IGM & ICM - COLLISIONLESS

Low density of IGM & ICM:

➡ ion Larmor radius λ_L << mean free path λ_{mfp}

Ex.: Hydra cluster (Ensslin & Vogt 2006):

$\lambda_L \sim 10^5$ km << $\lambda_{mfp} \sim 10^{15}$ km

In absence of collisions: $p_{//} \neq p_\perp$

➡ ~~MHD~~: INADEQUATE

Kinetic-MHD description: $P_{ij} = p_\perp \delta_{ij} + (p_\parallel - p_\perp) b_i b_j$,

(previus talk by Falceta-Golcalves)

Goal

Test capability of this model on amplifying magnetic fields when turbulence is injected and compare with standard MHD turbulent dynamo.

Basic equations of the Kinetic-MHD model

- One fluid model (simplicity!)

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\rho \left(\frac{\partial}{\partial t} + \mathbf{u} \cdot \nabla \right) \mathbf{u} + \nabla \cdot P - \frac{1}{4\pi} (\nabla \times \mathbf{B}) \times \mathbf{B} = 0$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{u} \times \mathbf{B}) = 0$$

+ equations for the pressures

Linear waves + instabilities

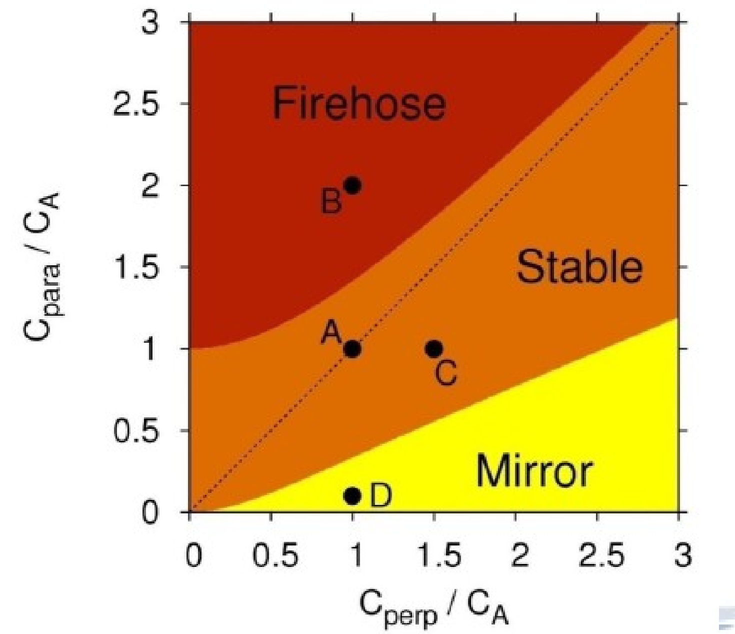
- Modified MHD waves:

		MHD	K-MHD
Max. speed of transverse wave:	$\left(\frac{\omega}{k}\right)_1^2 =$	C_A^2	$C_A^2 + C_\perp^2 - C_\parallel^2$

- Instability regimes:

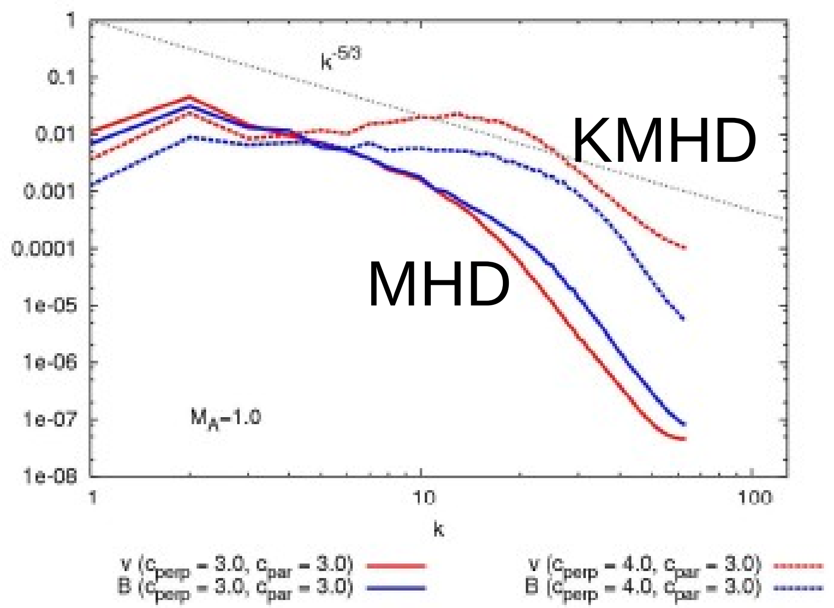
$$C_A^2 + C_\perp^2 - C_\parallel^2 < 0$$

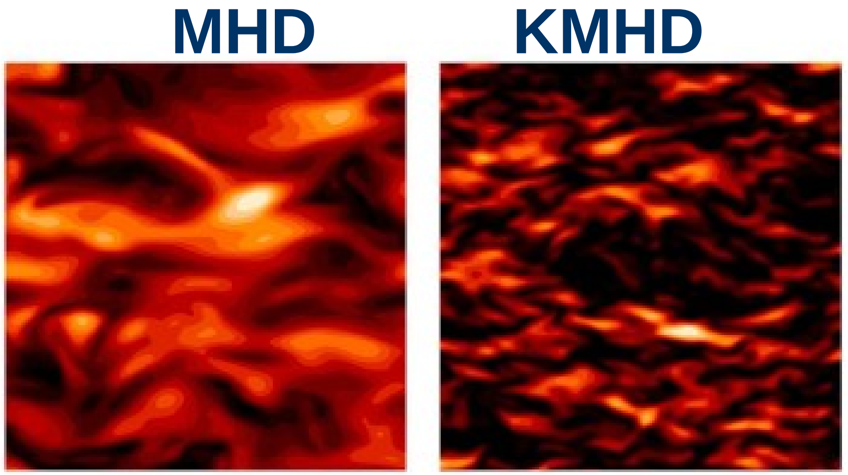
$$3C_\parallel^2 - \frac{C_\perp^2}{2 + C_A^2/C_\perp^2} < 0$$



Isothermal K-MHD

- Assumes constant sound speeds (Falceta-Goncalves' talk)
- Simplest → helps to understand the role of the anisotropy on turbulence statistics (Kowal et al. 2011)



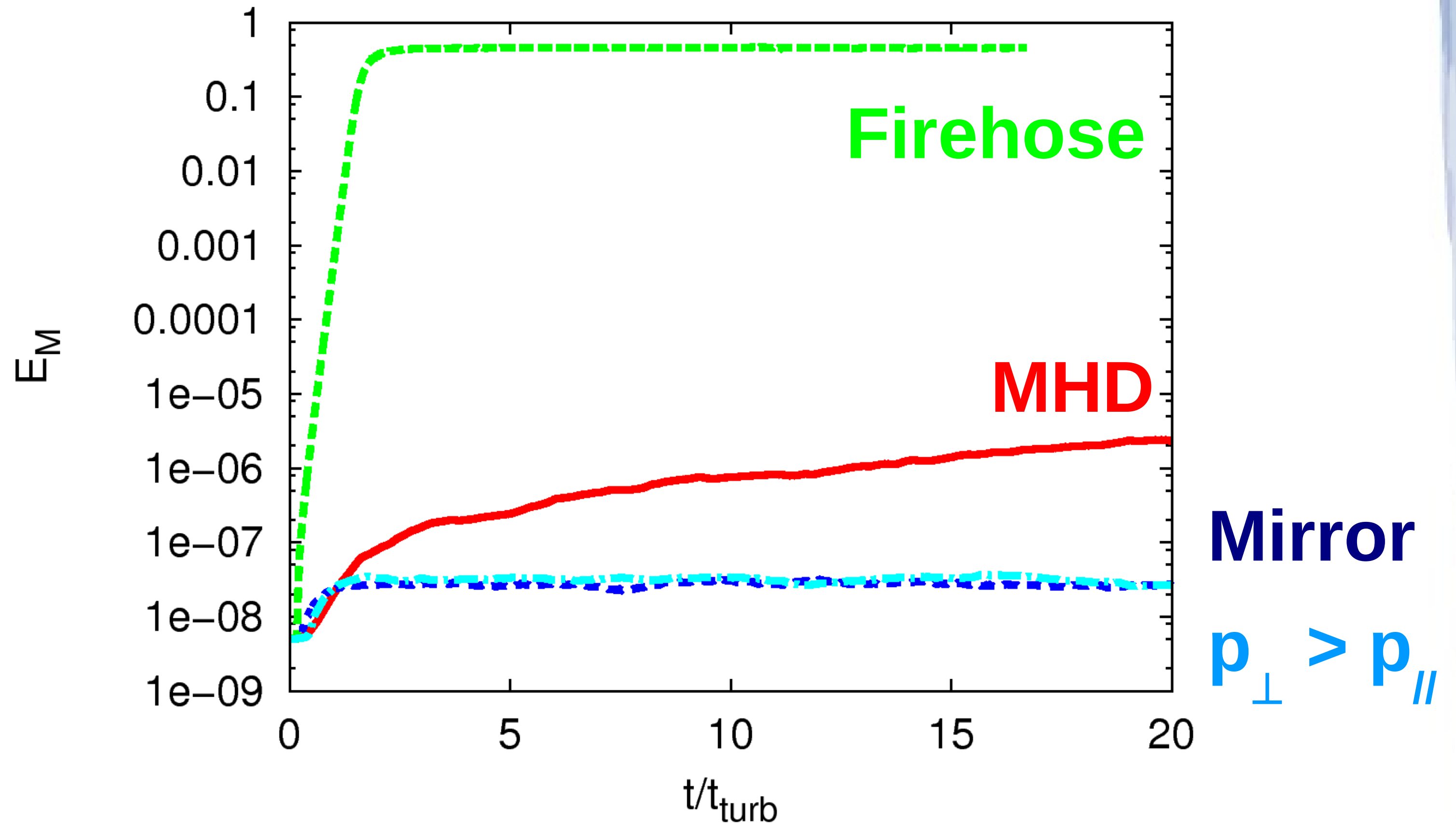


Instabilities due to anisotropic pressure accumulate energy in the smallest scales

Turbulent Dynamo in Isothermal KMHD

Resolution: 128^3

Numerical code writen by G. Kowal (Kowal et al. 2011)



Highly dependent on the anisotropy regime!

Adiabatic KMHD

- Adiabatic conditions (Chew et al. 1956)

$$\frac{d}{dt}\left(\frac{p_\perp}{\rho B}\right) = 0$$

$$\frac{d}{dt}\left(\frac{p_\parallel B^2}{\rho^3}\right) = 0$$

- In the presence of turbulence ➔ reconnection ➔ irreversible processes

Non-adiabatic K-MHD

- More consistent with the fact that the system suffers dissipation due to turbulence:

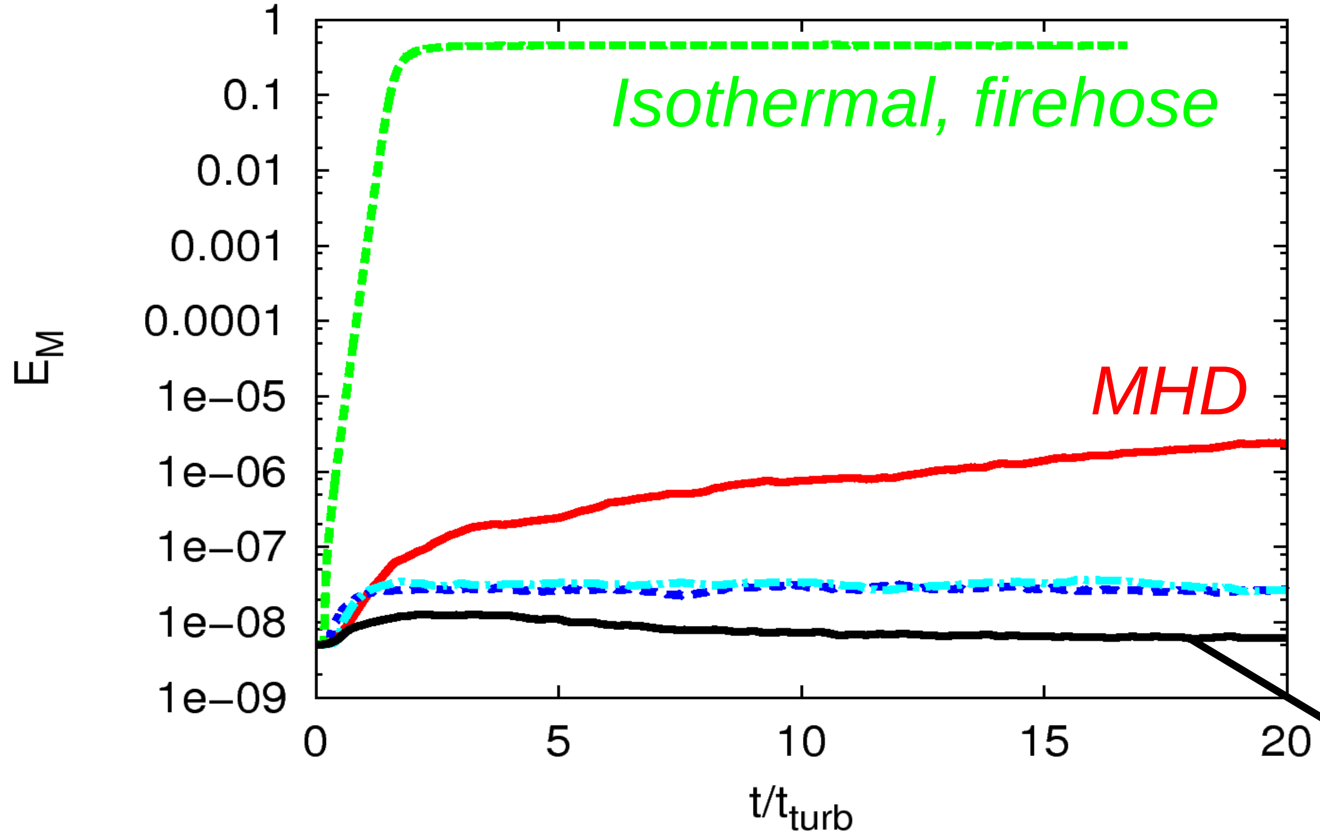
$$\frac{\partial p_{||}}{\partial t} + \nabla \cdot (p_{||}\mathbf{U}) + 2p_{||}\mathbf{b} \cdot \nabla \mathbf{U} \cdot \mathbf{b} = 0$$

$$\frac{\partial p_{\perp}}{\partial t} + \nabla \cdot (p_{\perp}\mathbf{U}) + p_{\perp}\nabla \cdot \mathbf{U} - p_{\perp}\mathbf{b} \cdot \nabla \mathbf{U} \cdot \mathbf{b} = 0$$

(Kulsrud 1983)

- Turbulent power included in energy equation

Turbulent Dynamo under non-adiabatic K-MHD



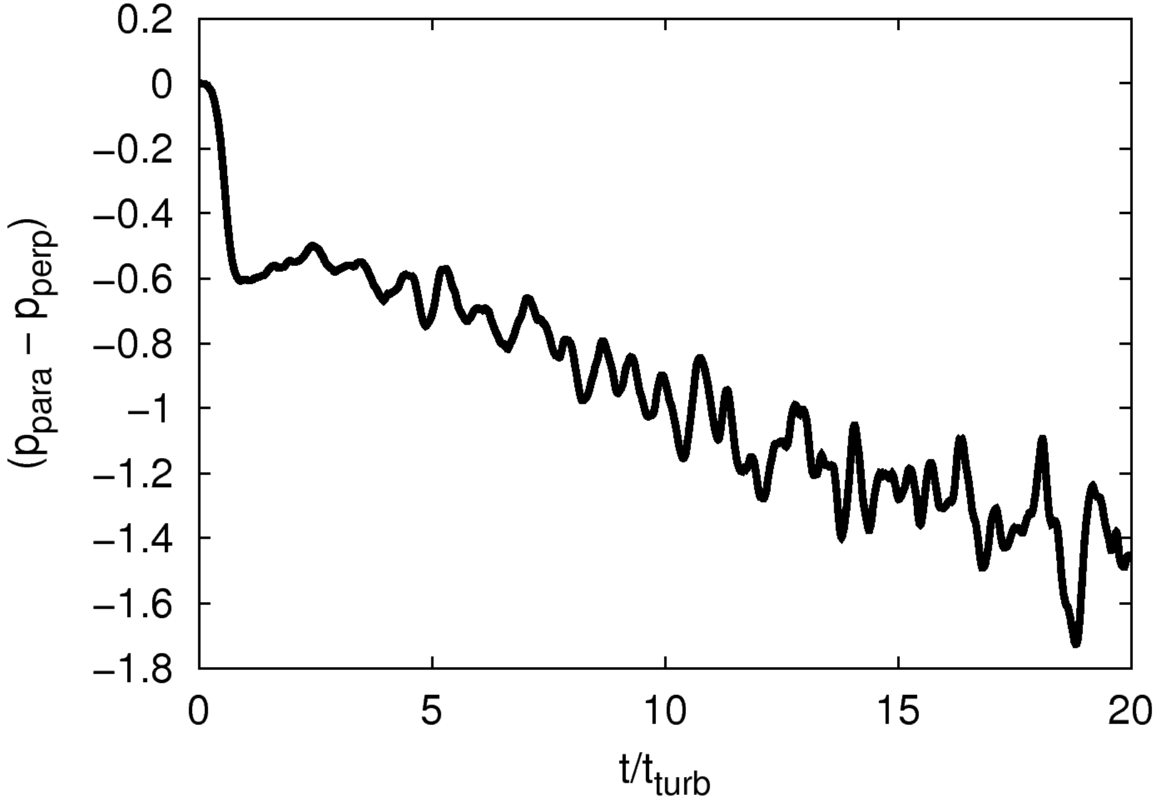
Isothermal, mirror

Isothermal, $p_\perp > p_{//}$

Dynamo fails.

Setup initially with isotropic pressure.

Turbulent Dynamo under non-adiabatic K-MHD



Preponderancy of $p_{\perp} > p_{//}$ anysotropy

How to prevent pressure anisotropy catastrophe ?

Possible mechanisms reducing anisotropy involve pitch-angle scattering imposing:

- Isotropization rate ~ growth rate of instability

$$\left(\frac{\partial \Delta p}{\partial t}\right)_{scatt} = -A\gamma\Delta p$$

growth rate of the kinetic instability

free parameter

- sharp limits on anisotropy (Sharma 2006):

$$1 - \frac{p_\perp}{p_\parallel} - \frac{2}{\beta_\parallel} \lesssim \zeta$$

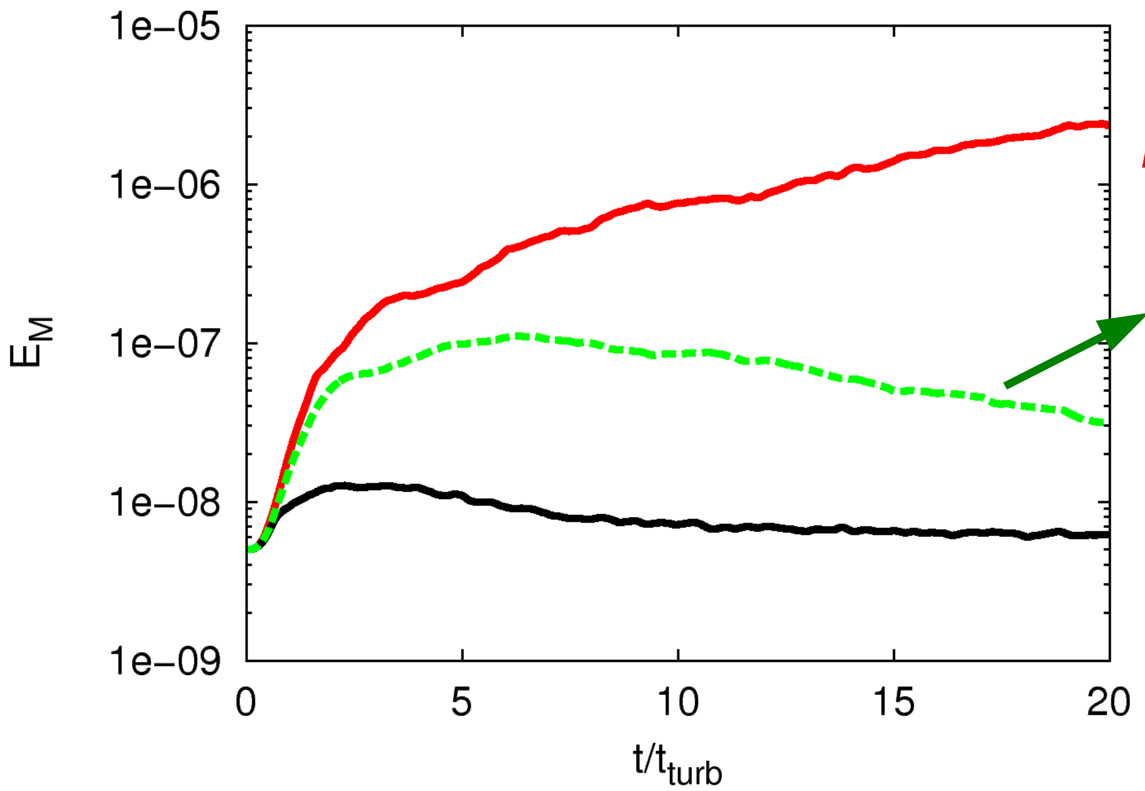
$$\frac{p_\perp}{p_\parallel} - 1 \lesssim \frac{2\xi}{\beta_\perp}$$

Dynamo solutions in the non-adiabatic K-MHD with pitch-angle isotropization

$$\left(\frac{\partial \Delta p}{\partial t}\right)_{scatt} = -A\gamma\Delta p$$

γ → growth rate of the local instability

A → = 1



MHD

Dynamo still fails, even for larger values of A.

K- MHD with out isotropization

Dynamo solutions in the non-adiabatic K-MHD with pitch-angle isotropization

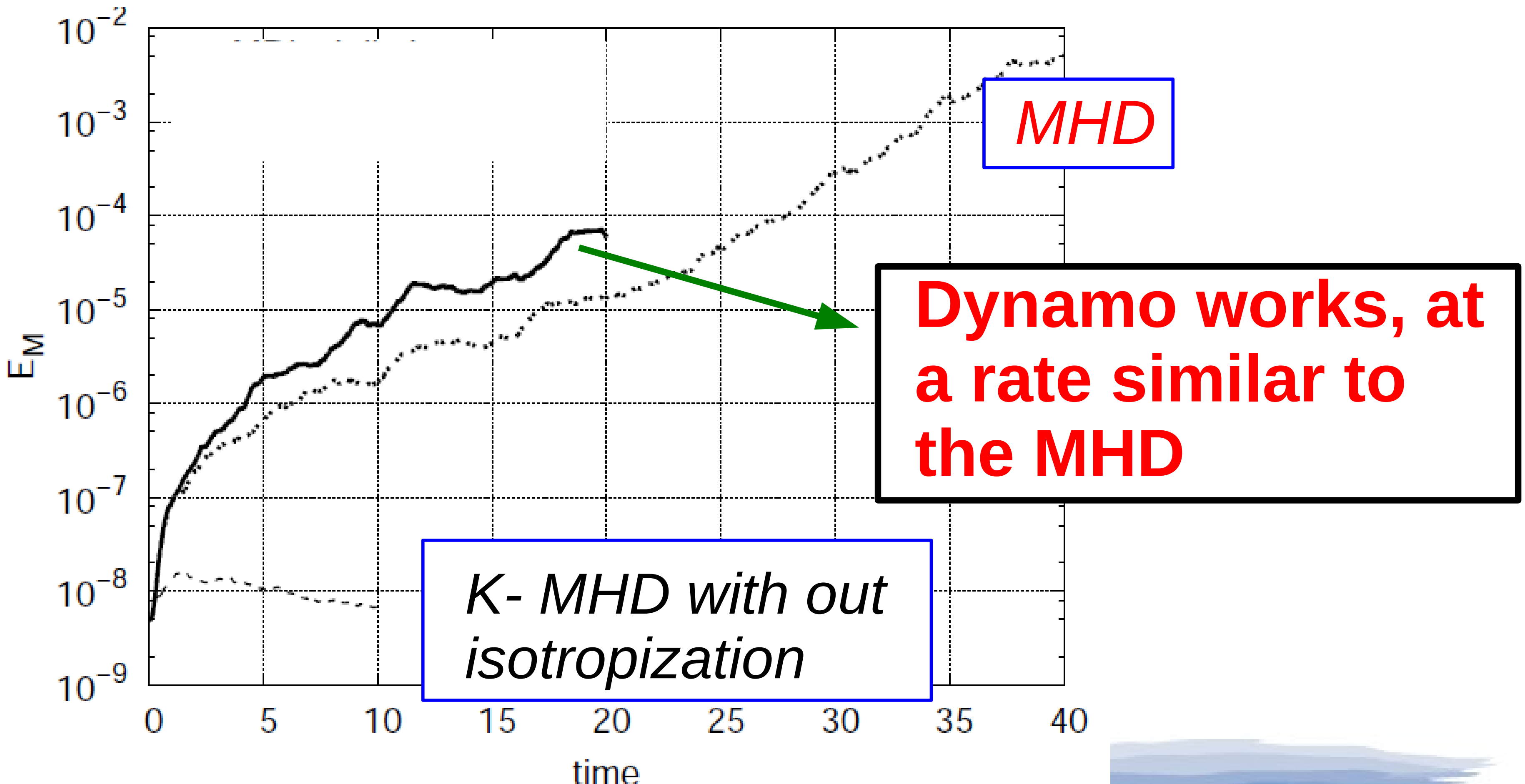
Sharp limits:

$$1 - \frac{p_\perp}{p_\parallel} - \frac{2}{\beta_\parallel} \lesssim \zeta$$

→ **0.5**

$$\frac{p_\perp}{p_\parallel} - 1 \lesssim \frac{2\xi}{\beta_\perp}$$

→ **3.5**



Conclusions

- Pressure anisotropy arises naturally in a collisionless plasma;
- When turbulence is present: non-adiabatic K-MHD required;
- Success of turbulent dynamo: highly dependent on anisotropy regime of K-MHD;
- Isothermal K-MHD dynamo: POSSIBLE if $\mathbf{p}_{//} > \mathbf{p}_{\perp}$
- Non-isothermal K-MHD dynamo: POSSIBLE with sharp limits on pressure anisotropy;

Conclusions

- Relevant radiative losses (e.g. cosmic rays, Synchrotron, Bremsstrahlung) must be introduced in order to provide appropriate release of the heating due to turbulence;
- Micro-instabilities leading to pitch angle scattering: have to be better understood to produce a more consistent K-MHD.