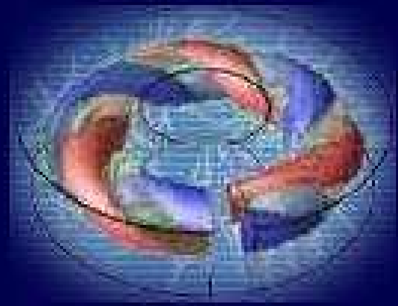
Perm Dynamo Days  7-11 February 2005

Influence of time-dependent flows on the onset of the dynamo action

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Outline

Analysis of time-dependent flows
(both spontaneous and forced)

- Why? $\rightarrow$ Motivation
- How and when? $\rightarrow$ Our approach
- ... and then? $\rightarrow$ Perspectives

Problem formulation

Governing Equations:

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times \left(\vec{v} \times \vec{B} \right) + \eta \nabla^2 \vec{B}$$

$$\frac{\partial \vec{v}}{\partial t} + \left(\vec{v} \cdot \vec{\nabla} \right) \vec{v} = -\frac{1}{\rho} \vec{\nabla} p + \nu \nabla^2 \vec{v} + \frac{1}{\rho \mu_0} \left(\vec{\nabla} \times \vec{B} \right) \times \vec{B} + F_{ext}$$

$$\vec{\nabla} \cdot \vec{v} = 0 \qquad \vec{\nabla} \cdot \vec{B} = 0$$

Problem formulation

How to solve it?

Different approaches:

- Analytical
- Numerical
- Experimental
- Experiments + Numerics

Problem formulation

How to solve it?

Different approaches:

- Analytical
- Numerical
- Experimental
- Experiments + Numerics $\rightarrow$ kinematic dynamo

Problem formulation

How to solve it?

Different approaches:

- Analytical
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$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times \left(\vec{v} \times \vec{B} \right) + \eta \nabla^2 \vec{B}$$

where $\vec{v}$ can be measured in experiments

Problem formulation

$$\frac{\partial \vec{v}}{\partial t} + \left(\vec{v}\cdot\vec{\nabla}\right)\vec{v} = -\frac{1}{\rho}\vec{\nabla}p + \nu\nabla^2\vec{v} + \frac{1}{\rho\mu_0}\left(\vec{\nabla}\times\vec{B}\right)\times\vec{B}$$

Below the threshold, $\vec{B} = 0 \Rightarrow \vec{v}$ is controlled by hydrodynamics

Widely used solution: to measure $\vec{v}$ in a material "much more friendly" than sodium: "water"

$$\nu_{water} \sim \nu_{sodium} \qquad \rho_{water} \sim \rho_{sodium}$$

(at working temperatures)

Experiments provide velocity field
Numerical simulations provide the magnetic field response

Problem formulation

$$\frac{\partial \vec{B}}{\partial t} = Rm\vec{\nabla} \times \left(\vec{v} \times \vec{B}\right) + \nabla^2 \vec{B}$$

In every real conducting fluid, $\eta \sim 10^5 \nu \Rightarrow Re \sim 10^5 Rm$

Then, each potentially dynamo-producing flow has to be turbulent!

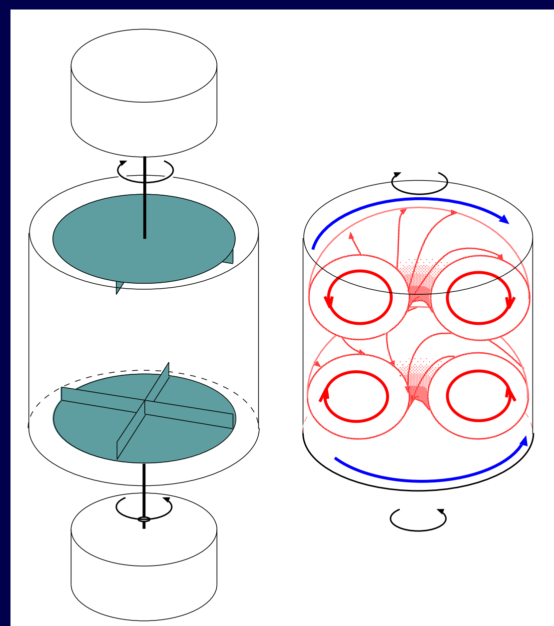
Hopefully, the mean velocity field in a lot of situations can be assumed as stationary and even axisymmetric!

The von Kármán swirling flow

Starting point:
von Kármán swirling flow

Known to produce a strong vorticiy field

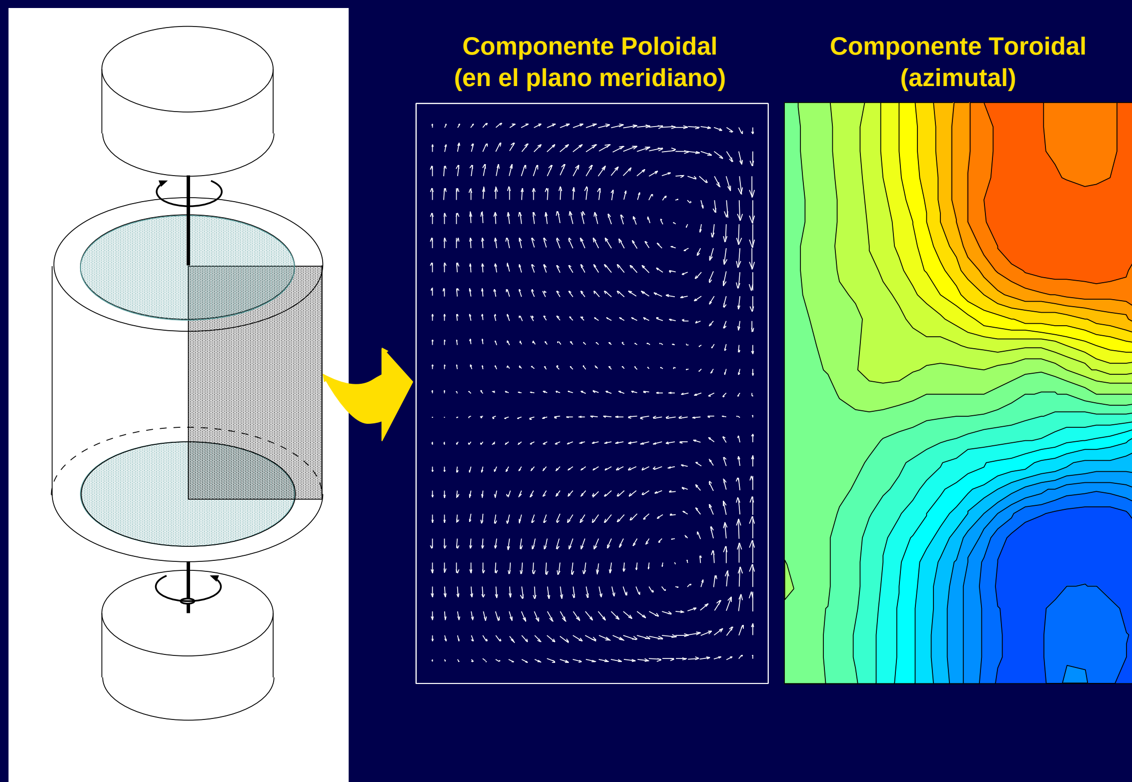
Experimental setup:



The von Kármán swirling flow

Velocity field:

Laser Doppler Anemometry→ only mean field (stationary)



L.Marié, J.Burguete, F.Daviaud, J.Léorat, EPJB **33** (2003) p 469.

The von Kármán swirling flow

Numerical simulations based in a mean velociy field predict dynamo action threshold in von Kármán flows.

But, using stationary mean velocity field :

- Deficient knowledge of $\vec{v}$, only:
  - Large scales
  - Stationary
  - Highly symmetric
- Turbulence effect?

The von Kármán swirling flow

Numerical simulations based in a mean velociy field predict dynamo action threshold in von Kármán flows.

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  - Large scales
  - Stationary
  - Highly symmetric
- Turbulence effect?

Time-dependent flows could produce unknown MHD effects!!

The von Kármán swirling flow

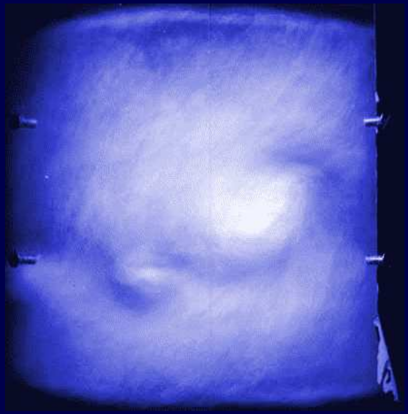
Our goal in this experimental work:

- To analyze the hydrodynamics of this problem for a wide range of Re
  - Behaviour at low frequencies
  - Using an external forcing
- To study the effect of $\vec{v}(t)$ on the threshold of the dynamo action:
  - Slow evolving fluctuations
  - Small scales effect.

Time dependent flows

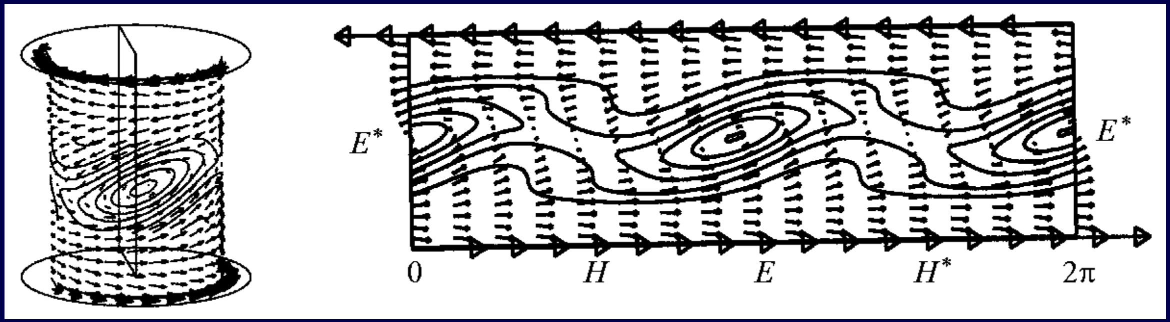
The mean flow destabilizes for large *Re*

- Experiments:



Louis Marié, Ph.D thesis, CEA / Université Paris 7, France (2003).

- Numerics:



C.Nore, L.S.Tuckerman, O.Daube, S.Xin. J. Fluid Mech **977** (2003) p.51

Time dependent flows

Effect on the MHD behavior

$$\frac{\partial \vec{B}}{\partial t} + \left(\vec{v} \cdot \vec{\nabla}\right) \vec{B} = \vec{\nabla} \times \left(\vec{v} \times \vec{B}\right) + \eta \nabla^2 \vec{B}$$

Kinematic approach in previous simulations:

- $\eta \sim 10^5 \nu \Rightarrow Re \sim 10^5 Rm$
- $L_B \sim 10^5 L_v$
- $\vec{B} \Rightarrow$ macroscopic evolution T and X
  (different scales for $\vec{B}$ and $\vec{v}$)

Questions:

- Effect of a slow evolution in the large scales T and X
- Validity of the "large scale" approximation (X).

Time dependent flows

Effect on the MHD behavior

F. Pétrélis and S. Fauve, COST-P6 meeting, Paris (2004).

- Temporal modulation of a Roberts flow:

$$\vec{v}(t) = \vec{v}_0 + \delta\vec{v} \begin{pmatrix} \cos(\omega t + \phi_v) \\ \cos(\omega t + \phi_u) \\ \cos(\omega t + \phi_u) \end{pmatrix}$$

where the phases $\phi_{u,v}$ can be different.

Time dependent flows

Effect on the MHD behavior

F. Pétrélis and S. Fauve, COST-P6 meeting, Paris (2004).

- Threshold increases or decreases, depending on the value of $\cos(\phi_u - \phi_v)$.
- The distance to the original threshold is proportional to

$$\frac{\omega_f^2}{\omega_u^2 + \omega_f^2}$$

where $\omega_f = \eta k^2$.

How and when?

Tasks Schedule

	Water experiments	Numerical simulations
Tools	PIV + LDA	Kinematic code
Temporal evolution	Natural behavior	Effect of different f
Spatial modulation	Analysis of localized structures	Effect on d.a. (meas. and analyt).
Forcing	Spatio-temporal evolution	Localized spatial modulation

How and when?

Tasks Schedule

	Water experiments	Numerical simulations
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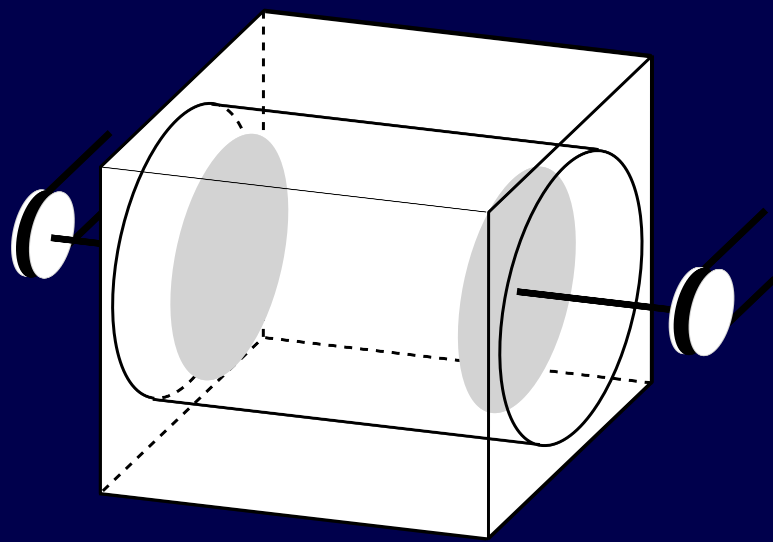
How and when?

Experimental setup:

- Cylindrical volume $D = 0.1$–0.4m, $H = 0.1$–0.5m
- Two counterotating propellers
- Re: propeller frequency and spatial dimensions



How and when?

Experimental setup:

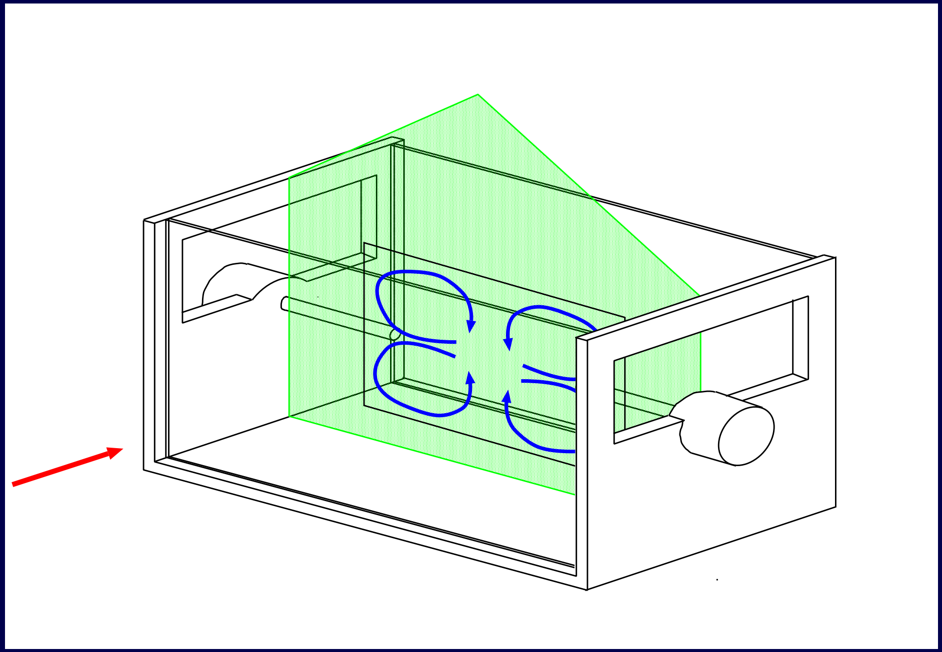
Velocity measurements:
PIV (spatial evolution) $\Leftrightarrow$ LDA (temporal evolution)

- Aliasing!

  PIV velocity field sampling at $f = f_0$
  is different from low filtering $\vec{v}$ with $f = f_0$.

How and when?

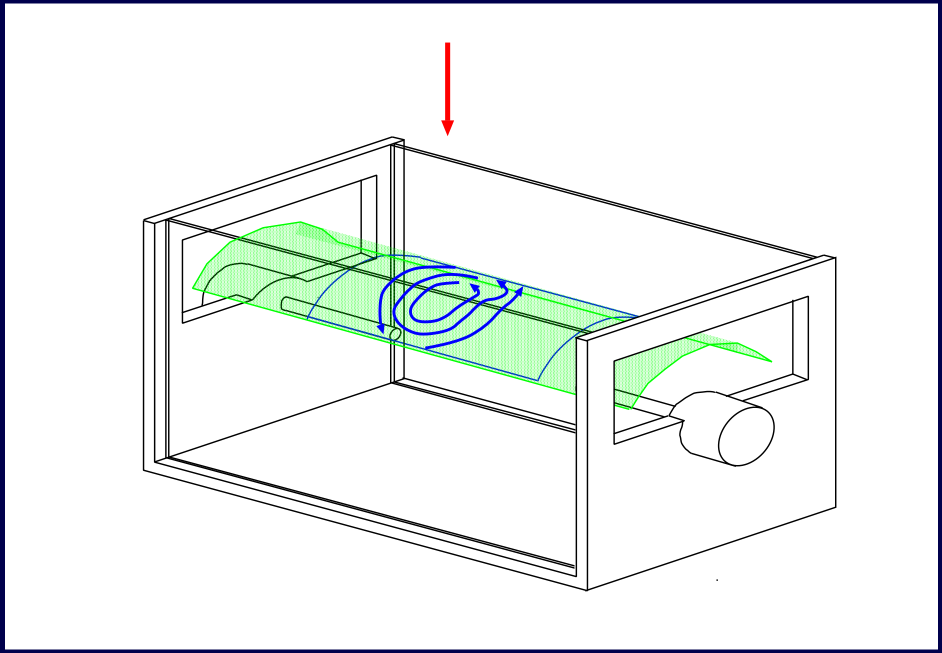
Experimental setup:



Simultaneous $v_r + v_z$

How and when?

Experimental setup:



Two lateral windows + transparent propeller "floors"

$\Downarrow$

Simultaneous $v_\theta + v_z$

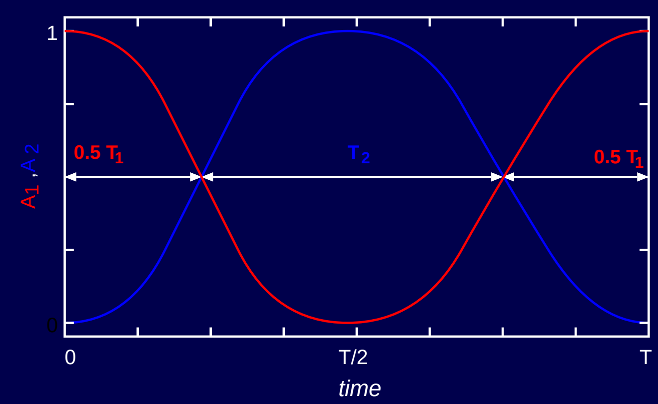
How and when?

Numerical Simulations:

- Different frequencies ($\vec{v}$ analytical and measured)
  $f \gg 1/T_B$ where T_B is the diffusion time of $\vec{B}$:

$$\vec{v} = \vec{v}_1 \cos^2(\pi f t) + \vec{v}_2 \sin^2(\pi f t)$$

where the "activity-time" for both velocity fields are the same:

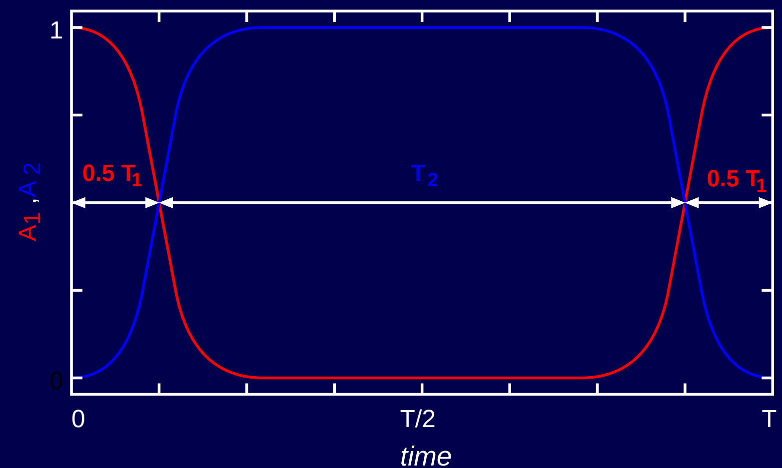


$$T_1 = T_2 = 1/2f$$

How and when?

Numerical Simulations:

- Same frequency, different "activity-time" ($T_1 \neq T_2$):



$$T_1 + T_2 = 1/f; \qquad 0 < T_1/T_2 < 0.5T$$

How and when?

Numerical Simulations:

- Tried different configurations with two velocity fields producing dynamo and two others without threshold:

Velocity Field v_1	Velocity Field v_2
Dynamo	Dynamo
Dynamo	No Dynamo
No Dynamo	No Dynamo

These velocity fields:

- have the same topology, with very small differencies.
- are experimental (Time averaged).

How and when?

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These velocity fields:

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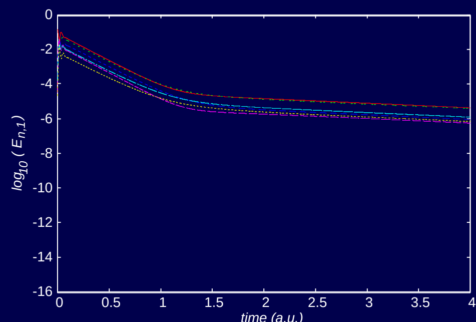
Some preliminary results

Magnetic energy growthrates:

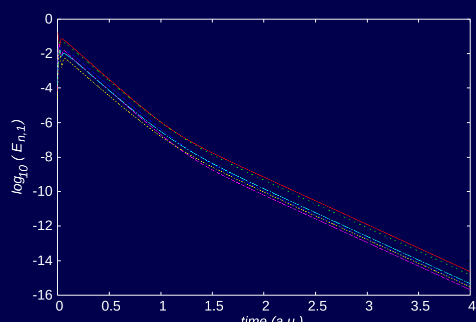
$$E_{m,n} = e^{\sigma_{n,m} t}$$

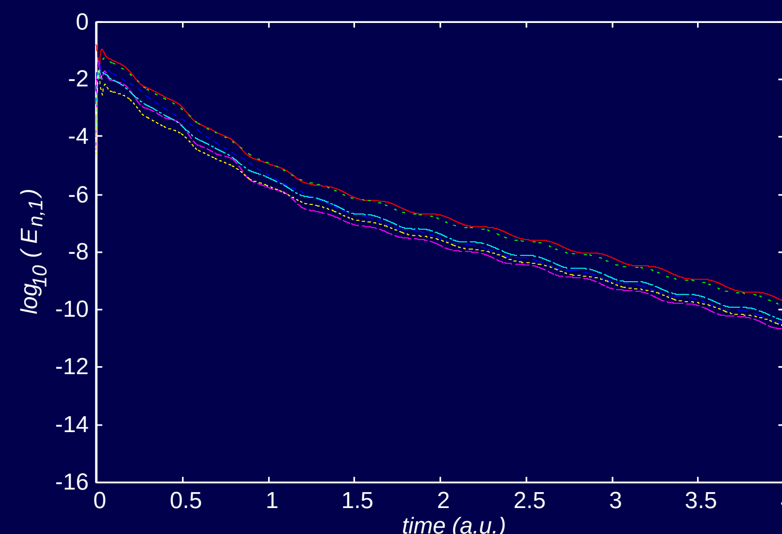
Case $Rm = 120$

Velocity Field v_1 (has dynamo threshold)



Velocity Field v_2 (no dynamo action)





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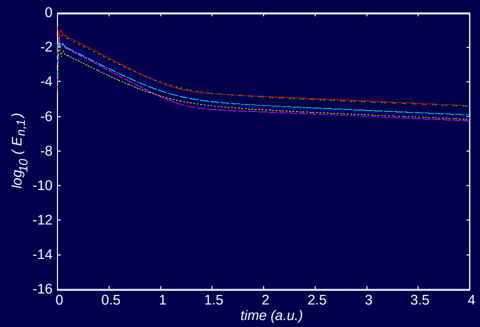
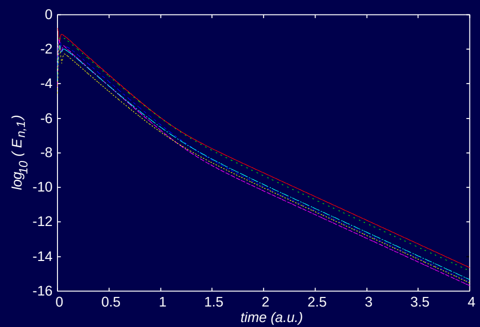
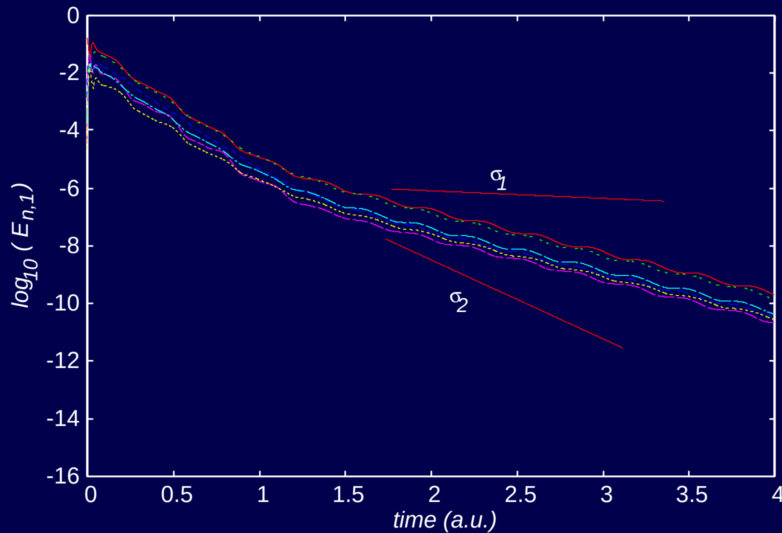


Velocity Field v_2 (no dynamo action)





Some preliminary results

Magnetic energy growthrates:

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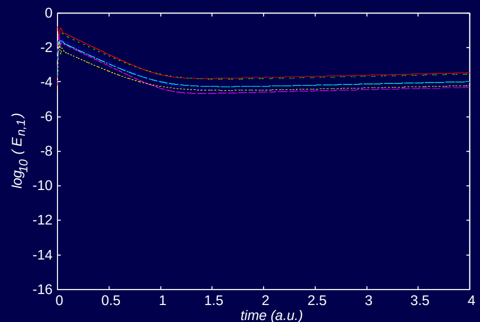
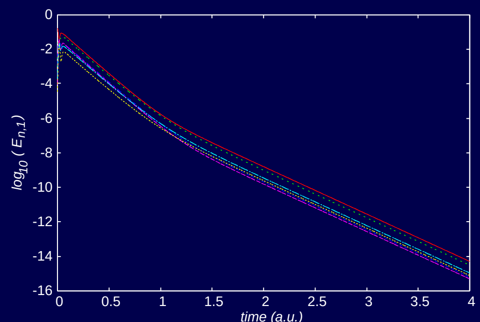
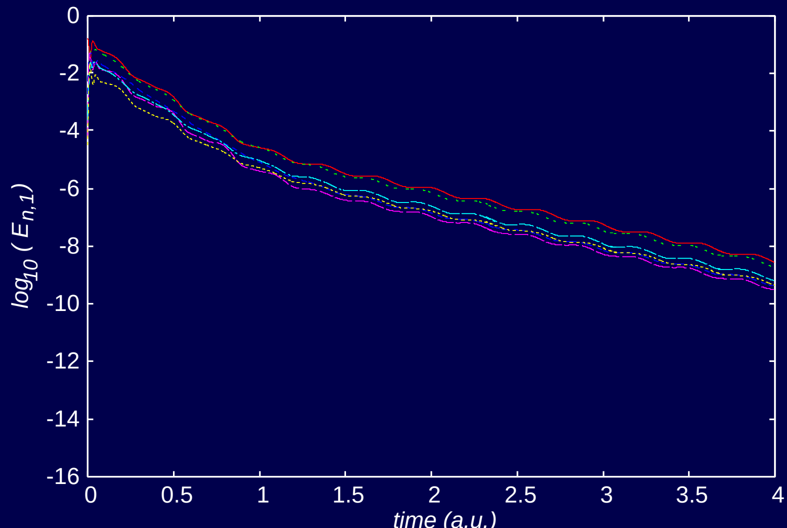
Case $Rm = 140$

Velocity Field v_1 (has dynamo threshold)



Velocity Field v_2 (no dynamo action)





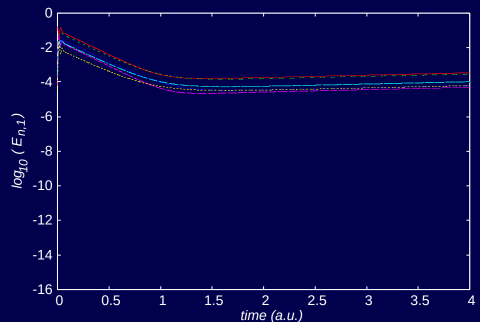
Some preliminary results

Magnetic energy growthrates:

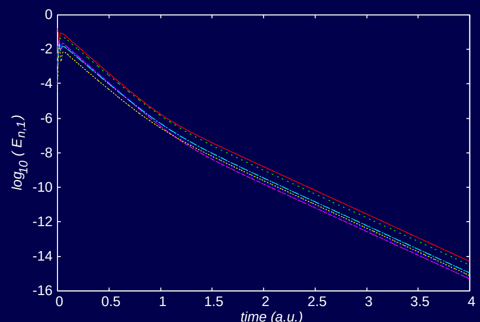
$$E_{m,n} = e^{\sigma_{n,m} t}$$

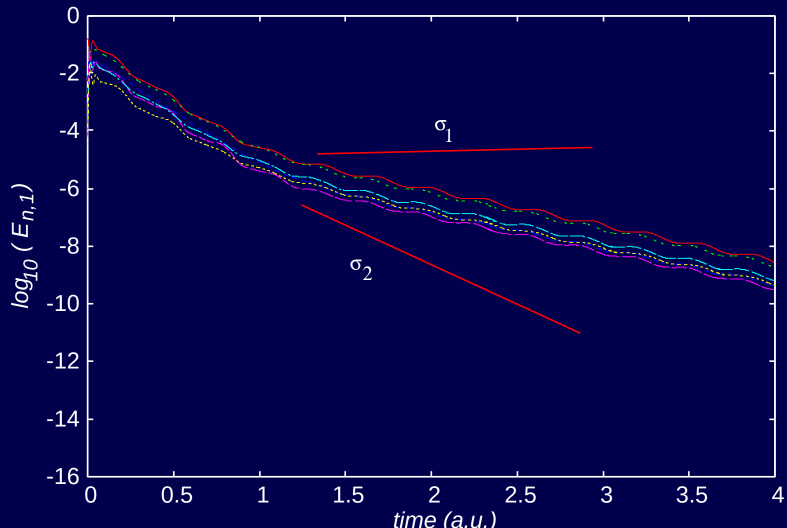
Case $Rm = 140$

Velocity Field v_1 (has dynamo threshold)



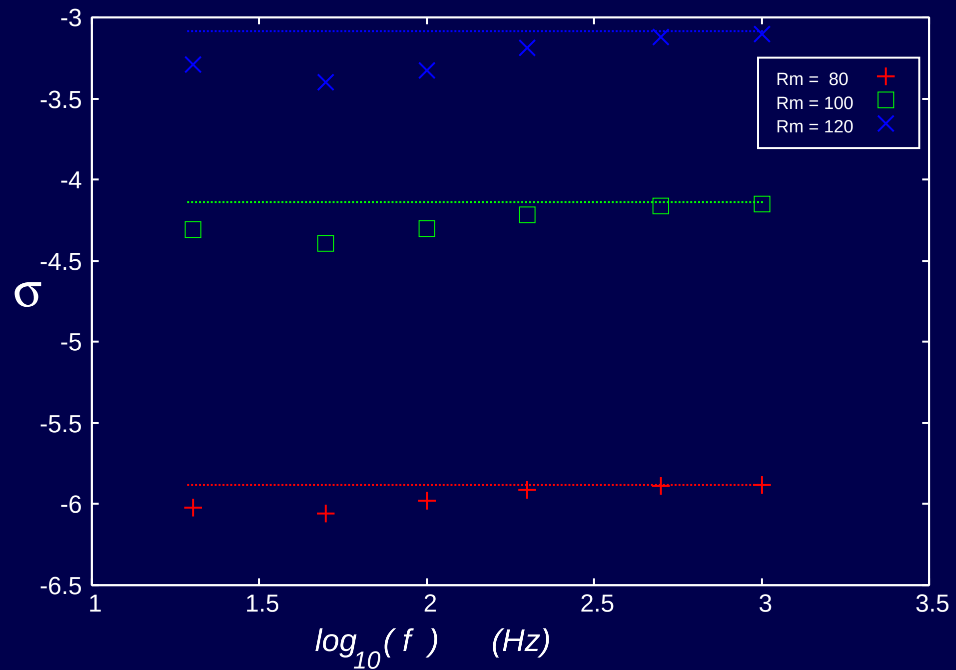
Velocity Field v_2 (no dynamo action)





Some preliminary results

Evolution of the growthrates *vs*. the frequency:



Some preliminary results

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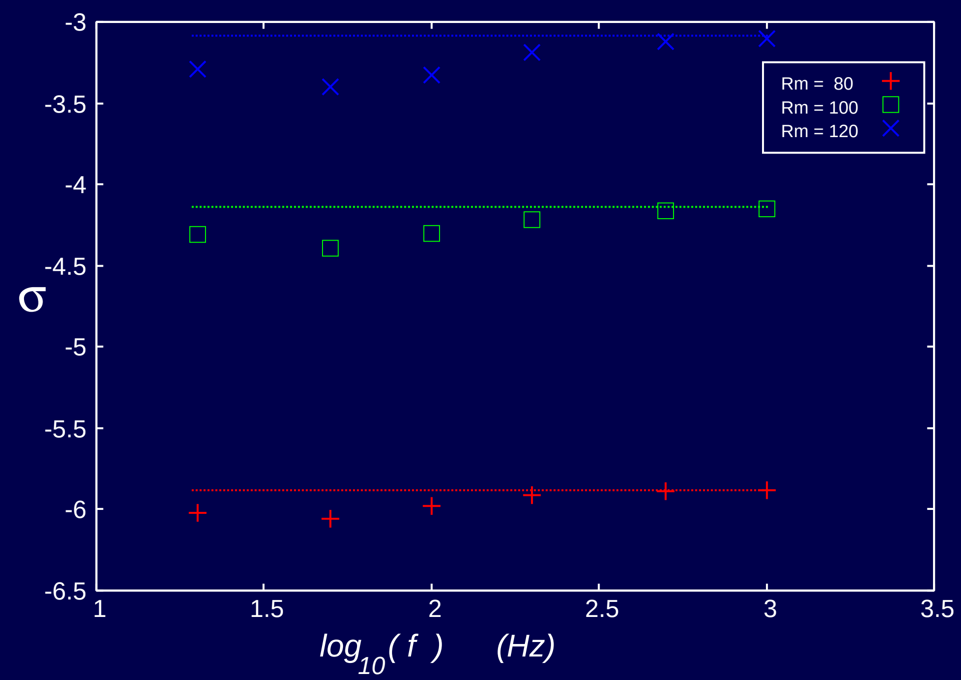
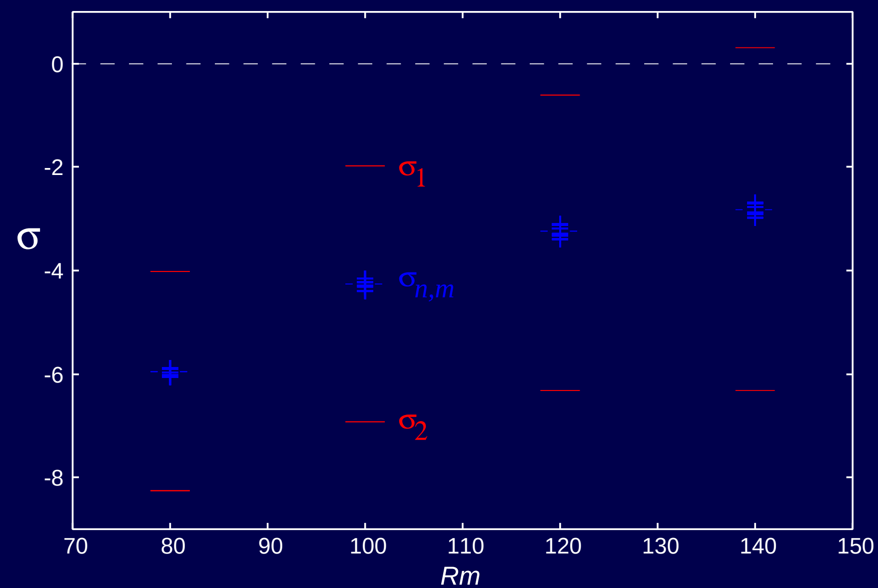


Why?

- The effect becomes more important when $1/f \to T_B$.
- We are performing simulations for $1/f \geq T_B$

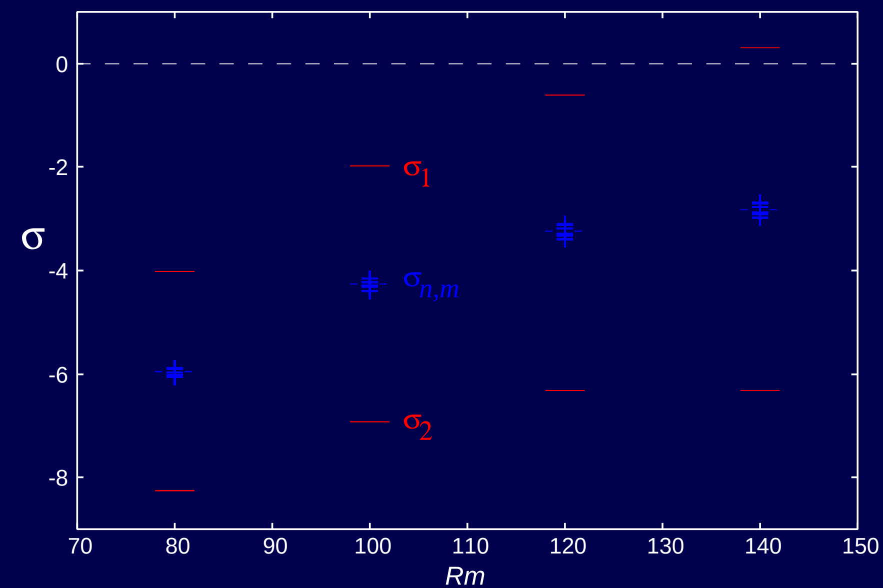
Some preliminary results

Evolution of the growthrates *vs*. the *Rm*:



Some preliminary results

Evolution of the growthrates *vs*. the *Rm*:



Why?

- $v = v_m + \delta v \cos(2\pi f t)$
  where $v_m = (v_1 + v_2)/2$ and $\delta v = (v_1 - v_2)/2$.

- We cannot change the relative phase or δv!!
  $\rightarrow$ realistic velocity fields.

Conclusions and perspectives

(Preliminary)

Hydrodynamics:

- Experimental cell is being constructed (almost finished)
- Our goal is to obtain a detailed description of the
  - Large scales (temporal)
  - Small scales (spatial)
  - Response to an external forcing ($f_{ext}(t)$)

Conclusions and perspectives

(Preliminary)

MHD:

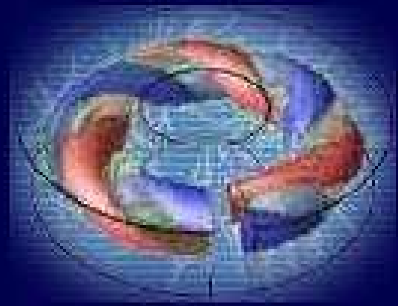
- Numerical study: kinematic dynamo code where $\vec{v}(t)$.
- Effect of slow temporal scales:
  - For very large frequencies

$$Rm^c_{v(t)} = Rm^c_{v_m}$$

  - For smaller frequencies, but $f \gtrsim 1/T_B$

$$\sigma_{v(t)} \lesssim \sigma_{v_m}$$

  - For very small frequencies???
- Effect of a better knowledge of the small spatial scales.

Perm Dynamo Days  7-11 February 2005

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