Numerical Solar Dynamo and Dynamo experiments

(The low magnetic Prandtl number limit)

Yannick Ponty

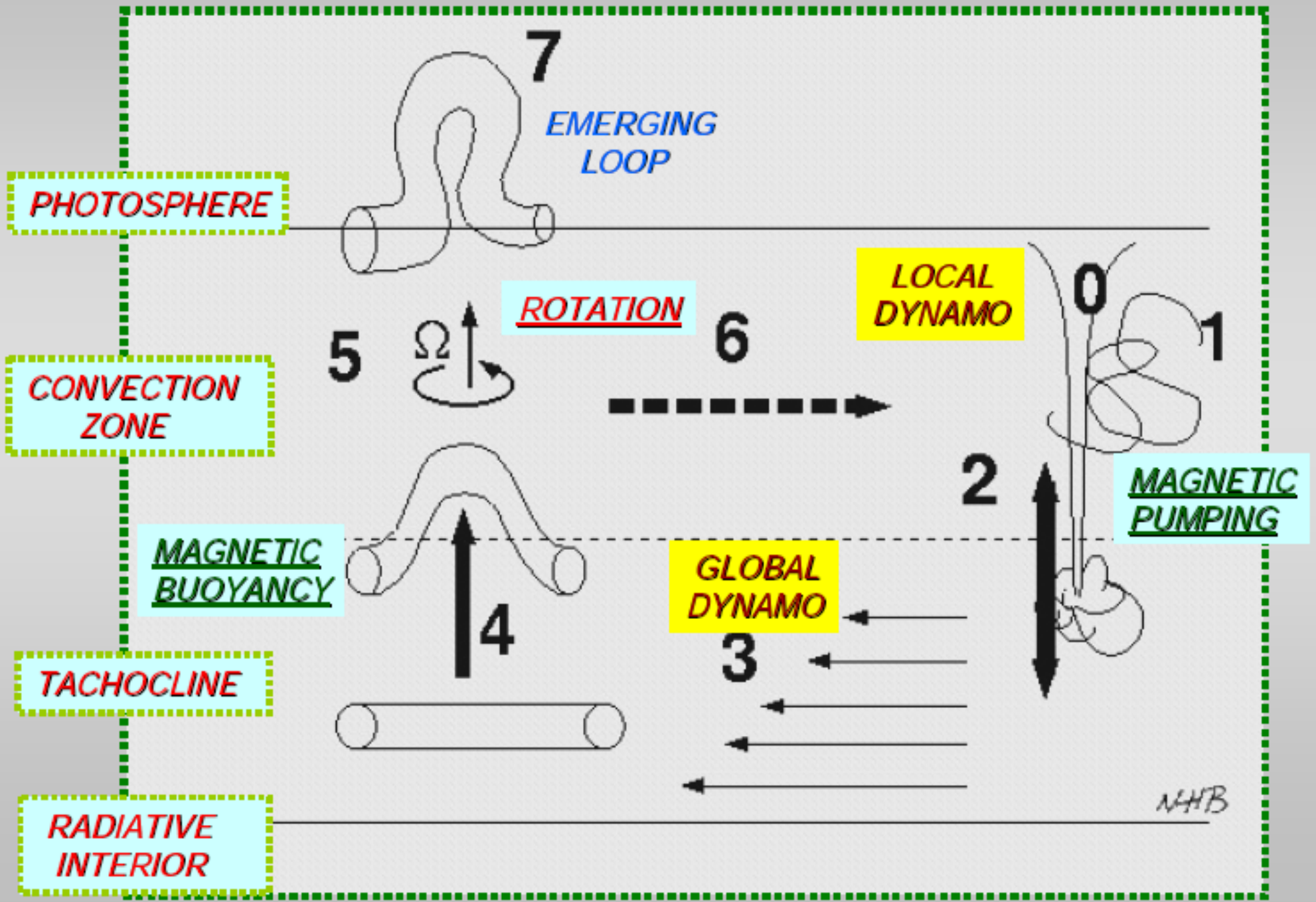
Laboratoire Cassiopée CNRS

Observatoire de la Côte d'Azur





Theoretical Solar Cycle (most likely)



Non dimensional Parameters

Reynolds number :

$$Rv = \frac{LU}{\nu}$$

eddy turn over time

Magnetic Reynolds number :

$$Rm = \frac{LU}{\eta} = \frac{L/U}{L^2/\eta}$$

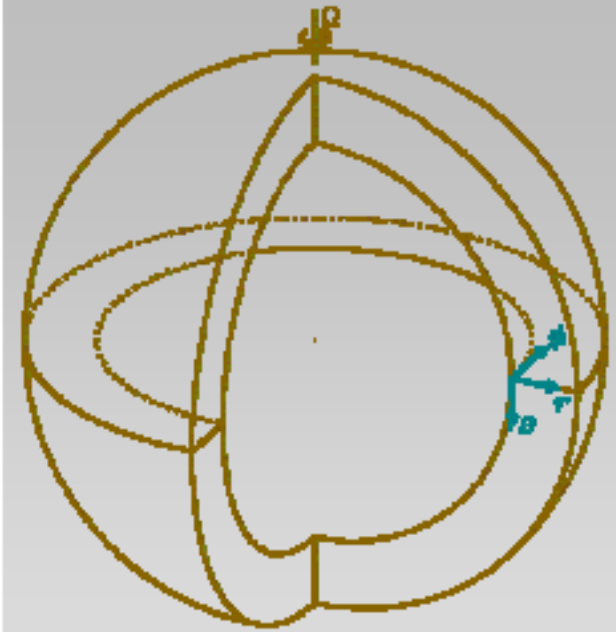
magnetic diffusion time

Magnetic Prandtl number:

$$Pm = \frac{\nu}{\eta} = \frac{Rm}{Rv} = \frac{\tau_\eta}{\tau_\nu}$$

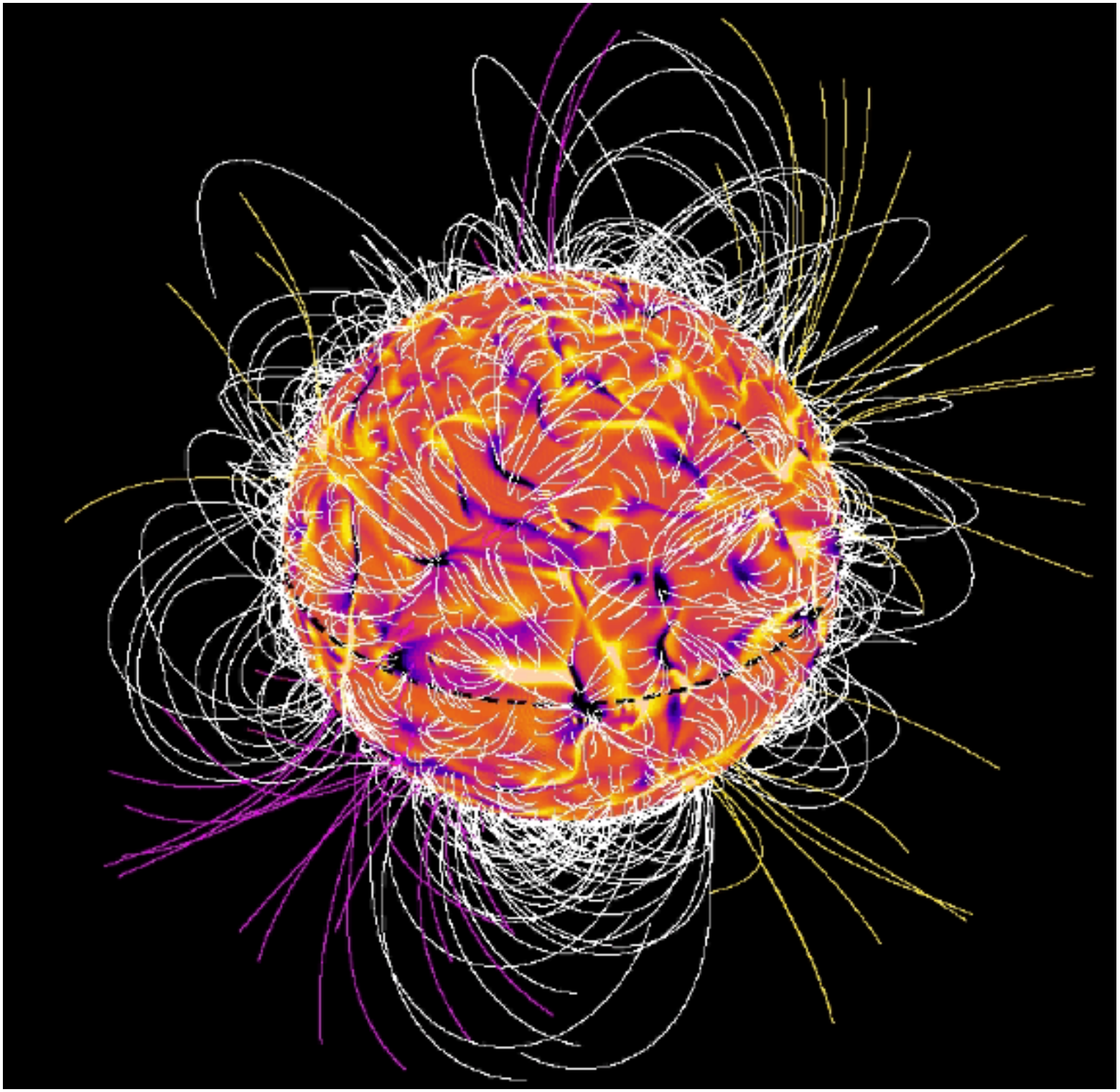
$\frac{\text{magnetic diffusion time}}{\text{viscous time scale}}$

	P_m	R_m	Re	Ro^{-1}
Earth	5×10^{-7}	500	10^9	10^6
Jupiter	10^{-6}	10^6	10^{12}	10^6
Sun	5×10^{-8}	10^8	2×10^{15}	1
Experiments	10^{-5}	50	$10^5 - 10^7$	$0 - 1$



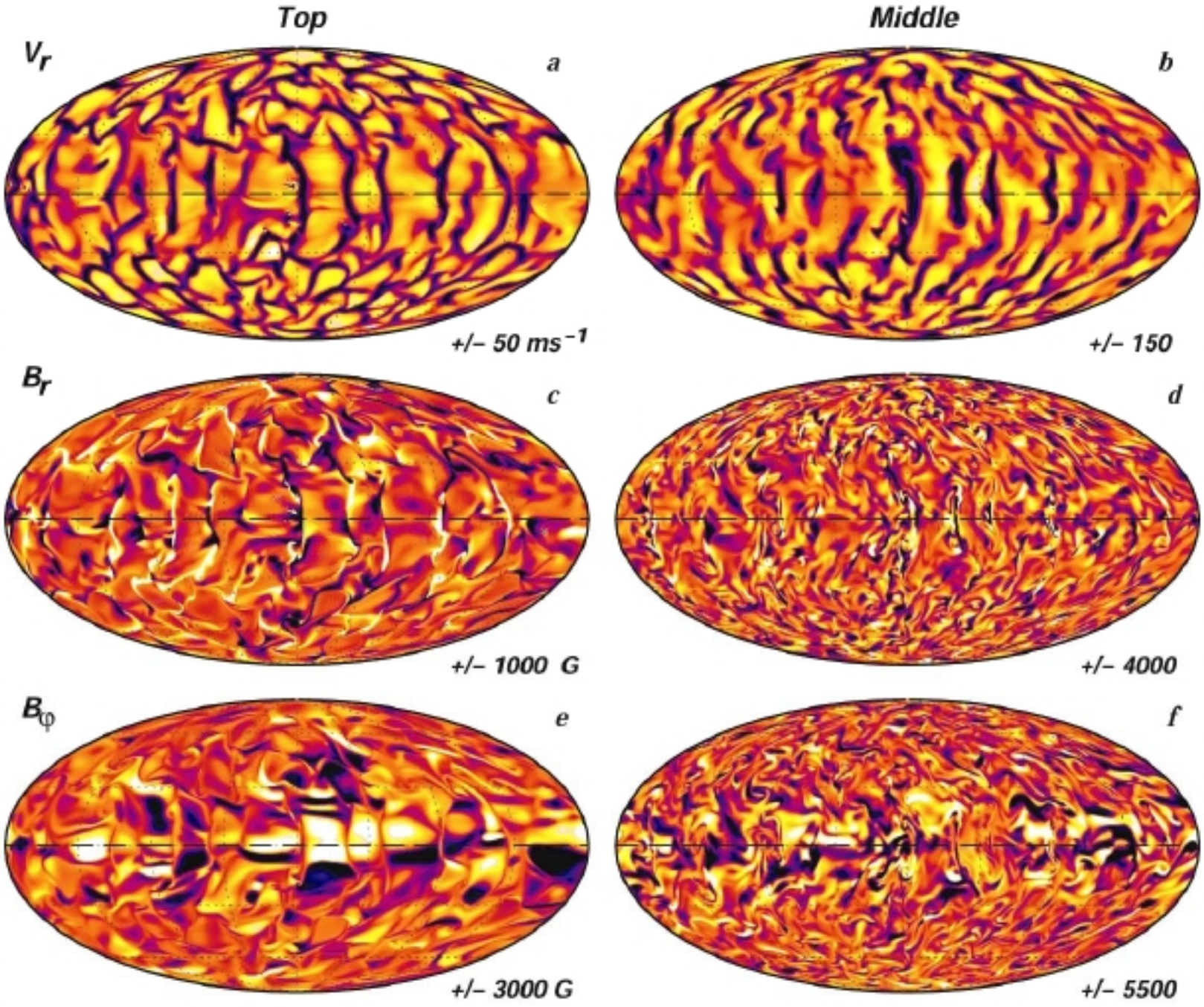
Anelastic Spherical Harmonic (ASH) Simulations

- Study turbulent convection interacting with rotation in bulk of solar CZ: 0.72 R - 0.97 R
- Realistic solar mean stratification
- Simplified physics: perfect gas, radiative diffusivity, compressible, subgrid transport
- Correct global spherical geometry



Brun, Miesch
& Toomre

Global Views of Flows and Fields



$R_m = 486$
$R_o = 0.11$
$E_{LS} = 20$
$P_m = 4$
$R_a = 8.\ 10^4$
$T_a = 1.2\ 10^6$

Dynamo action in a rotating convective layer

By FAUSTO CATTANEO[1] AND DAVID W. HUGHES[2]

J. Fluid Mech. (2006), *vol.* 553, *pp.* 401–418.

$$(\partial_t - \sigma\nabla^2)\boldsymbol{u} + \boldsymbol{u}\cdot\nabla\boldsymbol{u} + \sigma\, Ta^{1/2}\boldsymbol{e}_z \times \boldsymbol{u} = -\nabla p + \boldsymbol{J}\times\boldsymbol{B} + \sigma Ra\,\theta\boldsymbol{e}_z,$$

$$(\partial_t - \sigma/\sigma_m\nabla^2)\boldsymbol{B} + \boldsymbol{u}\cdot\nabla\boldsymbol{B} = \boldsymbol{B}\cdot\nabla\boldsymbol{u},$$

$$(\partial_t - \nabla^2)\,\theta + \boldsymbol{u}\cdot\nabla\theta = w,$$

$$\nabla\cdot\boldsymbol{B} = \nabla\cdot\boldsymbol{u} = 0,$$

$$\sigma = \frac{\nu}{\kappa}, \quad \sigma_m = \frac{\nu}{\eta}.$$

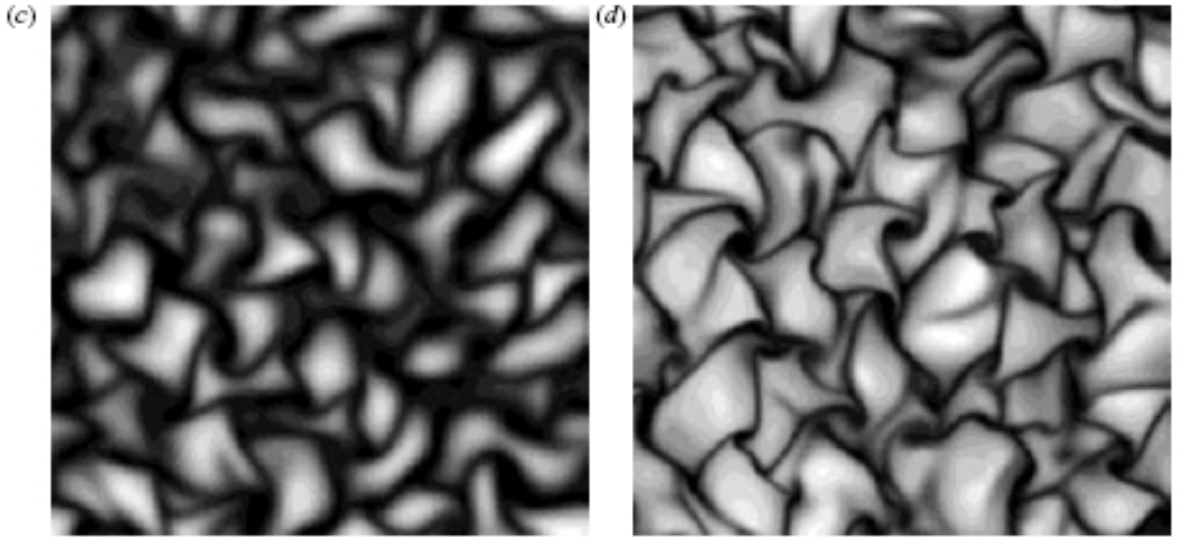


FIGURE 1. Density plots of temperature fluctuations near the upper surface ($z = 0.95$). Light (dark) tones correspond to hot (cold) fluid. All cases have $\lambda = 5$, $Ta = 5\times10^5$; (*a*) $Ra = 6.2\times10^4$, (*b*) $Ra = 7\times10^4$, (*c*) $Ra = 1.5\times10^5$ and (*d*) $Ra = 5\times10^5$. The transition from convective rolls to disordered cells is apparent.

F. Cattaneo, T. Emonet & N. Weiss

THE ASTROPHYSICAL JOURNAL, 588:1183–1198, 2003 May 10

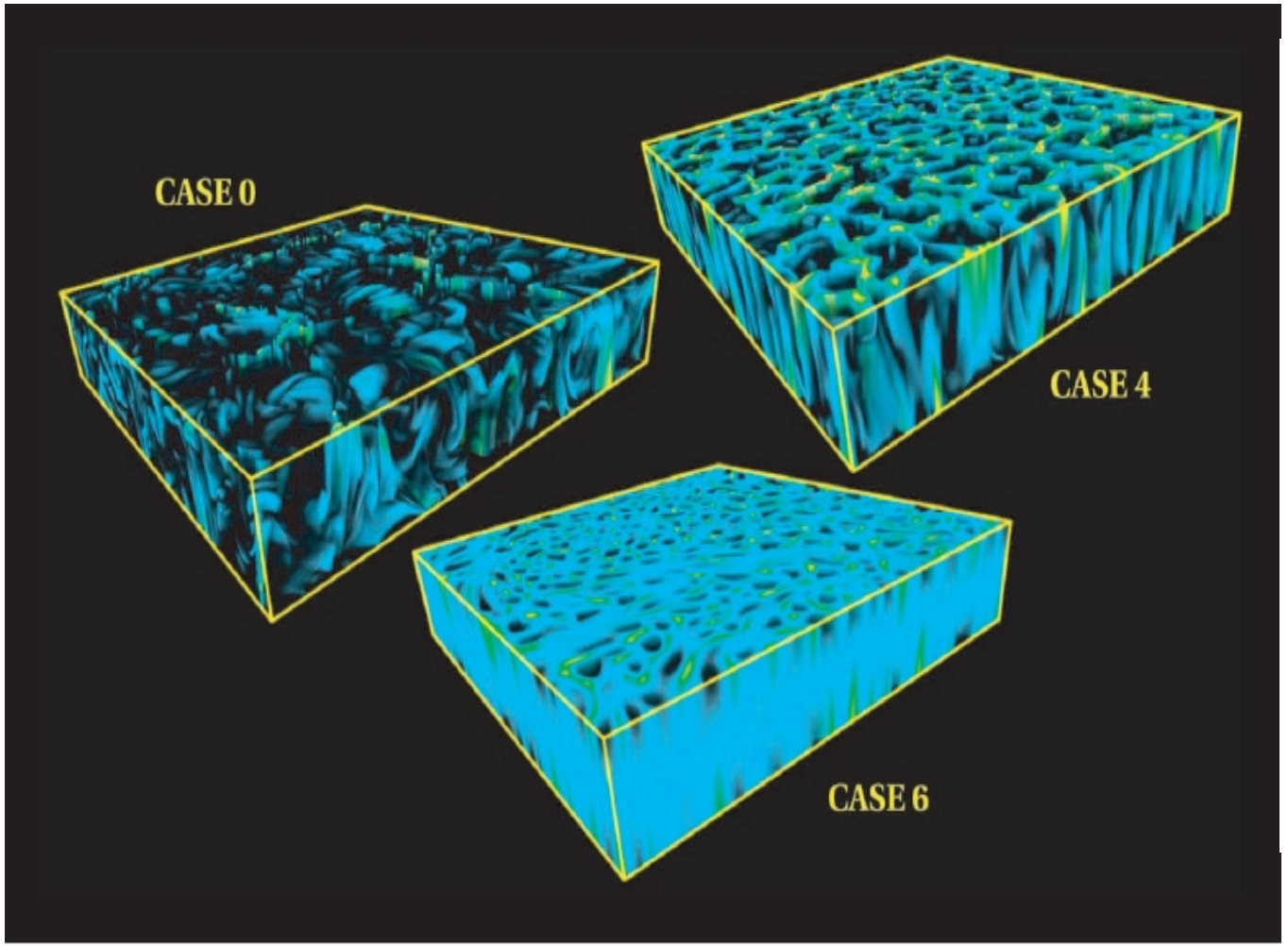


TABLE 1
PARAMETER SPACE

Case	B_0	Re	Rm	E_m/E_k
U	...	245	...	...
0[a]	Seed	201	1005	0.20
1.....	25	143	715	0.95
2.....	50	114	571	1.69
3.....	$50\sqrt{2}$	100	499	2.33
4.....	100	85	425	3.48
5.....	$100\sqrt{2}$	75	373	5.67
6.....	200	59	296	12.76
7.....	$200\sqrt{2}$	41	205	47.76

NOTE.—The following parameters are the same for all the cases: aspect ratio $10 \times 10 \times 1$, $\mathrm{Ra} = 500,000$, $\sigma = 1$, $\sigma_m = 5$, and a numerical resolution of $512 \times 512 \times 97$ Fourier collocation points. At time zero, $E_{k0} = 30,000$, and the rms velocity is $u_0 = 245$.

[a] From Cattaneo 1999.

J. Fluid Mech. (2006), *vol.* 553, *pp.* 401–418.

Ra	Ta	σ	σ_m	λ	B_0	$N_x \times N_y \times N_z$
5×10^5	0	1	5.0	10	0	$512 \times 512 \times 97$
10^6	5×10^5	1	5.0	10	0	$512 \times 512 \times 97$
10^6	5×10^5	1	5.0	5	10	$256 \times 256 \times 97$
6.2×10^4	5×10^5	1	5.0	5	0	$128 \times 128 \times 65$
7×10^4	5×10^5	1	5.0	5	0	$128 \times 128 \times 65$
1.5×10^5	5×10^5	1	5.0	5	0	$256 \times 256 \times 97$
5×10^5	5×10^5	1	5.0	5	0	$256 \times 256 \times 97$
5×10^5	5×10^5	1	5.0	5	1	$256 \times 256 \times 97$
5×10^5	5×10^5	1	5.0	5	10	$256 \times 256 \times 97$
5×10^5	5×10^5	1	5.0	5	100	$256 \times 256 \times 97$
1.5×10^5	5×10^5	1	5.0	5	1	$256 \times 256 \times 97$
1.5×10^5	5×10^5	1	2.5	5	1	$256 \times 256 \times 97$
1.5×10^5	5×10^5	1	1.0	5	1	$256 \times 256 \times 97$

TABLE 1. Summary of the numerical resolution and parameter values for the simulations.

A. Vögler, S. Shelyag, M. Schüssler, F. Cattaneo, T. Emonet and T. Linde

A&A 429, 335–351 (2005)

$$\frac{\partial \varrho \boldsymbol{u}}{\partial t} + \nabla \cdot \left[\varrho \boldsymbol{u}\boldsymbol{u} + \left(p + \frac{|\boldsymbol{B}|^2}{8\pi} \right) \underline{\mathbf{1}} - \frac{\boldsymbol{B}\boldsymbol{B}}{4\pi} \right] = \varrho \boldsymbol{g} + \nabla \cdot \underline{\tau},$$

$$\tau_{ij} = \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \delta_{ij} (\nabla \cdot \boldsymbol{u}) \right),$$

$$\frac{\partial e}{\partial t} + \nabla \cdot \left[\boldsymbol{u} \left(e + p + \frac{|\boldsymbol{B}|^2}{8\pi} \right) - \frac{1}{4\pi} \boldsymbol{B} (\boldsymbol{u} \cdot \boldsymbol{B}) \right] = \tag{3}$$

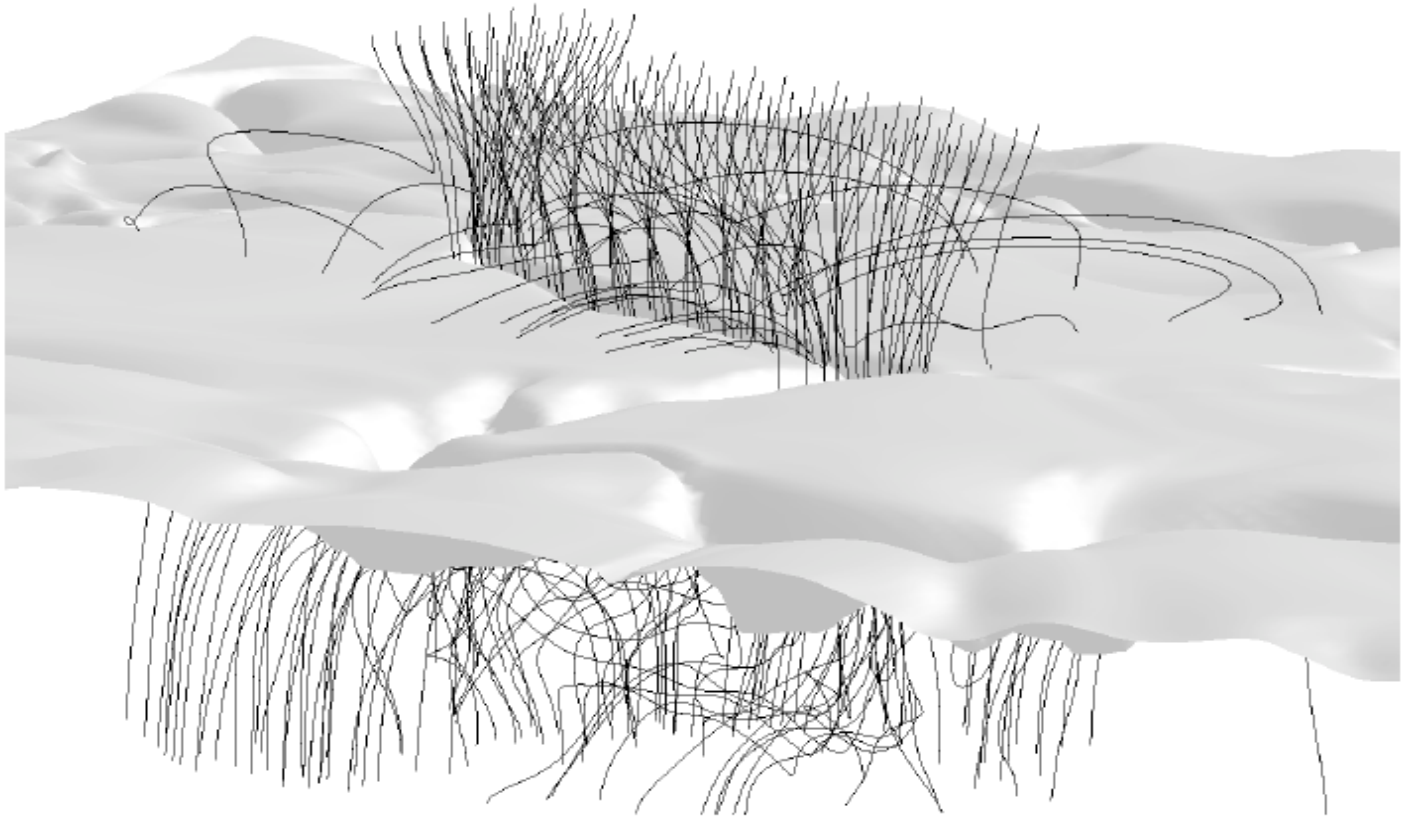
$$\frac{1}{4\pi} \nabla \cdot (\boldsymbol{B} \times \eta \nabla \times \boldsymbol{B}) + \nabla \cdot (\boldsymbol{u} \cdot \underline{\tau}) + \nabla \cdot (K \nabla T) + \varrho (\boldsymbol{g} \cdot u) + Q_{\mathrm{rad}},$$

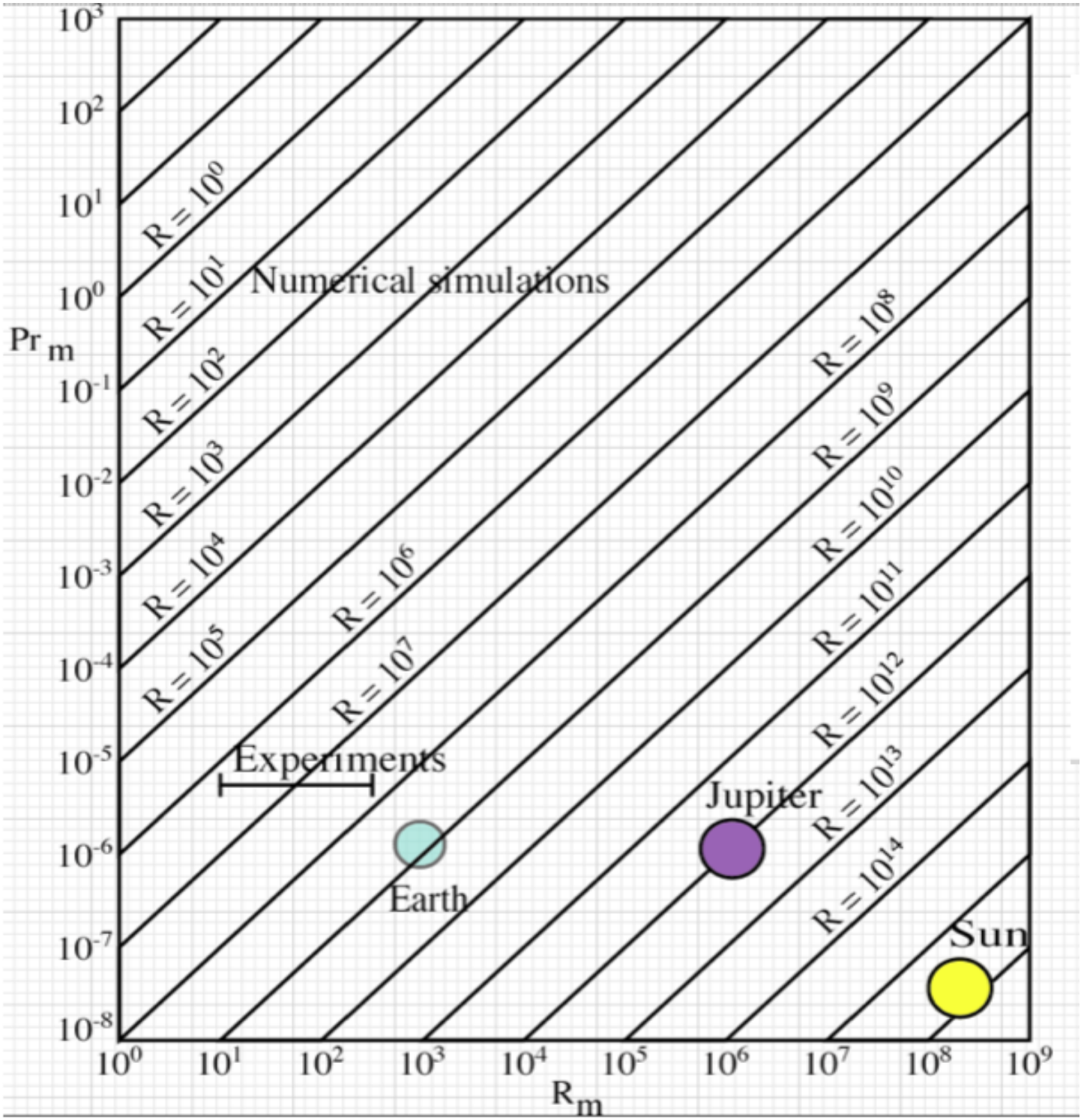
$$\frac{\partial \boldsymbol{B}}{\partial t} + \nabla \cdot (\boldsymbol{u}\boldsymbol{B} - \boldsymbol{B}\boldsymbol{u}) = -\nabla \times (\eta \nabla \times \boldsymbol{B}).$$

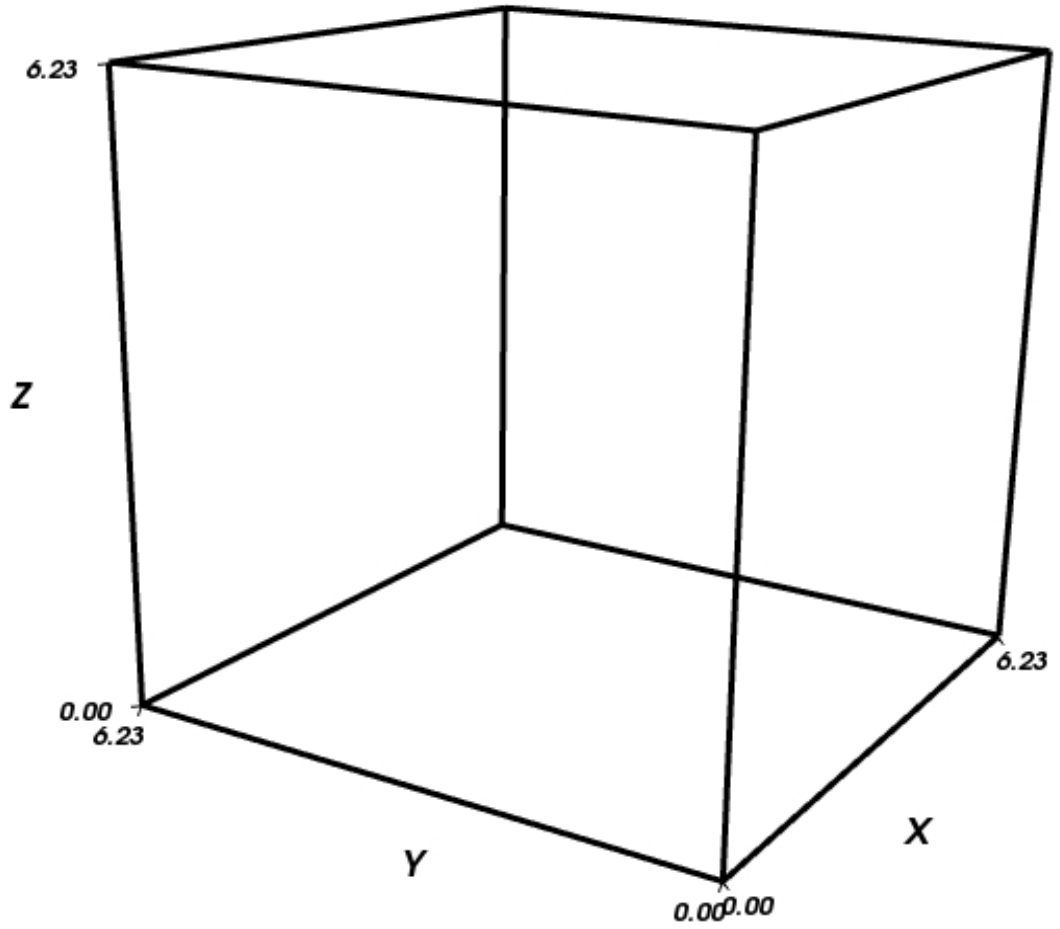
$$\frac{\partial \varrho}{\partial t} + \nabla \cdot (\varrho \boldsymbol{u}) = 0$$

For each physical quantity subject to diffusion and for each coordinate direction, a separate diffusion coefficient, consisting of a shock-resolving and a hyperdiffusive part, is defined:

$$\nu_l(u) = \nu_l^{\mathrm{shk}} + \nu_l^{\mathrm{hyp}}(u). \tag{24}$$




10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
Pr_m
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
R_m
$R = 10^0$
$R = 10^1$
$R = 10^2$
$R = 10^3$
$R = 10^4$
$R = 10^5$
$R = 10^6$
$R = 10^7$
$R = 10^8$
$R = 10^9$
$R = 10^{10}$
$R = 10^{11}$
$R = 10^{12}$
$R = 10^{13}$
$R = 10^{14}$
Numerical simulations
Experiments
Earth
Jupiter
Sun



$(2\pi)^3$ ***periodic box***

incompressible MHD equations in a periodic box

$$\partial_t \vec{u} + \vec{u} \nabla \vec{u} = -\nabla P + \nu \Delta \vec{u} + \vec{j} \times \vec{b} + \vec{F}$$

$$\partial_t \vec{b} = \nabla \times (\vec{u} \times \vec{b}) + \eta \Delta \vec{b}$$

$$\nabla \vec{u} = 0 \quad \nabla \vec{b} = 0$$

$$\vec{u}(x, y, z, t) = \vec{u}(x + 2\pi i, y + 2\pi j, z + 2\pi k, t)$$

$$\vec{b}(x, y, z, t) = \vec{b}(x + 2\pi i, y + 2\pi j, z + 2\pi k, t)$$

$$i, j, k = 0, 1, 2, \ldots \infty$$

Turbulence and mesh point :

$$R_\nu = \frac{L_i U_{rms}}{\nu}$$

64^3 TG1 R ~ 200
128^3 TG1 R ~ 460
256^3 TG1 R ~ 900
512^3 ABC1 R ~ 3500

Y. Ponty et al 2007

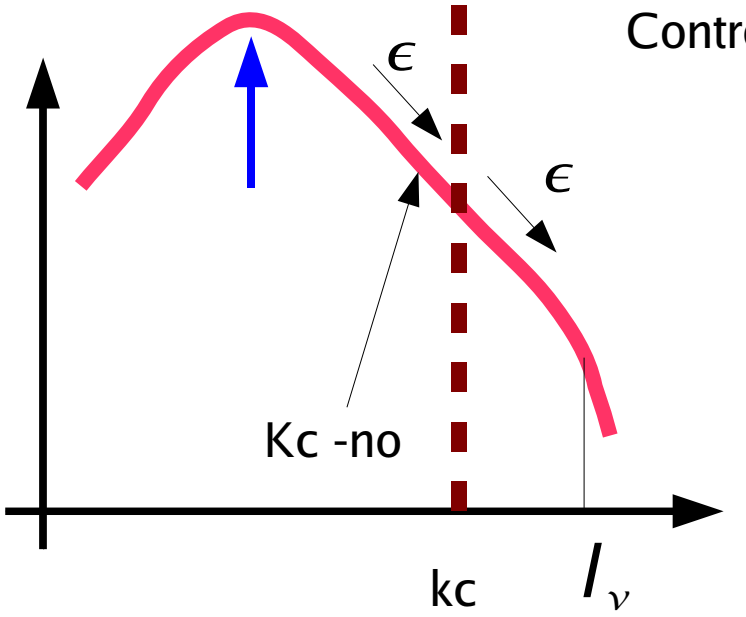
Run	N	f	k_F	ν	R_e
I	256	TG	2	2×10^{-3}	675
II	512	TG	2	1.5×10^{-3}	875
III	1024	TG	2	3×10^{-4}	3950
IV	256	ABC	10	2.5×10^{-3}	275
V	256	ABC	3	2×10^{-3}	820
VI	512	ABC	3	6.2×10^{-4}	2520
VII	1024	ABC	3	2.5×10^{-4}	6200
VIII	256	RND	1	1.5×10^{-3}	2030

Mininni et al 2006

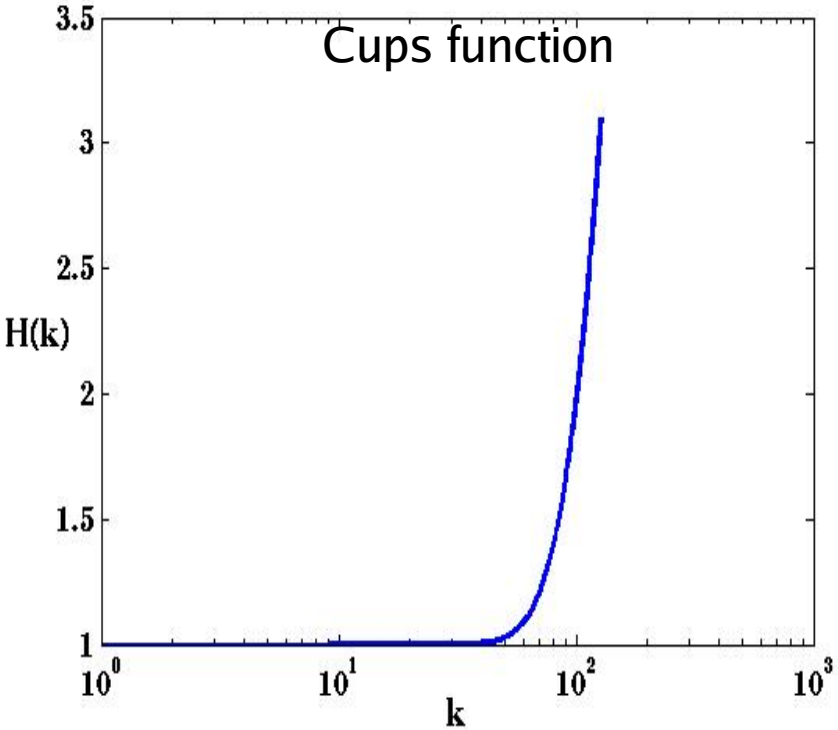
256^3 R ~ 1600
512^3 R ~ 4000
1024^3 R ~ 10 000
2048^3 R ~ 25 000
4096^3 R ~ 65 000

Kaneda et al *PoF* 15 2003
(Earth Simulator, japan)

Large eddy simulation (LES) : J.P Chollet & M. Lesieur J. Admos. Sci **38** (1981)



Control the transfer into the subgrid scale



$$\nu(k,t) = 0.441\, C_k^{\frac{3}{2}} \sqrt{\frac{E(K_c - n_o, t)}{K_c - n_o}}\, H(k)$$

Ref: **"Turbulence in Fluids"** M. Lesieur *Kluwer*

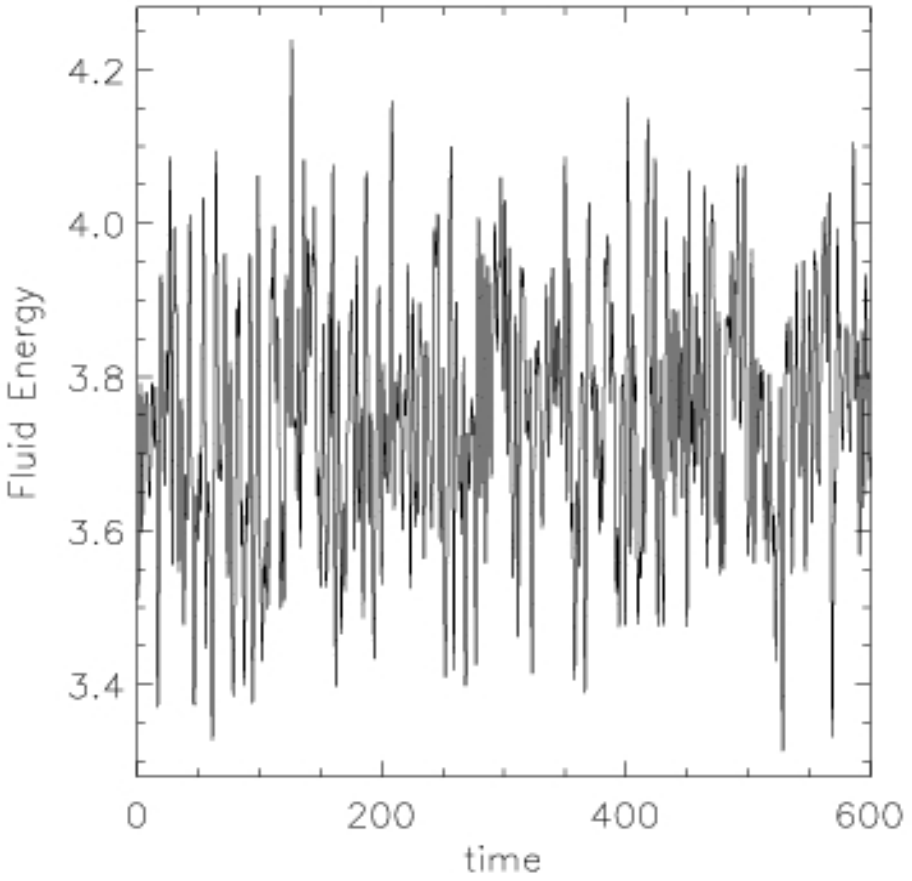
"Large Eddy Simulation for incompressible flow" P. Sagaut *Springer*

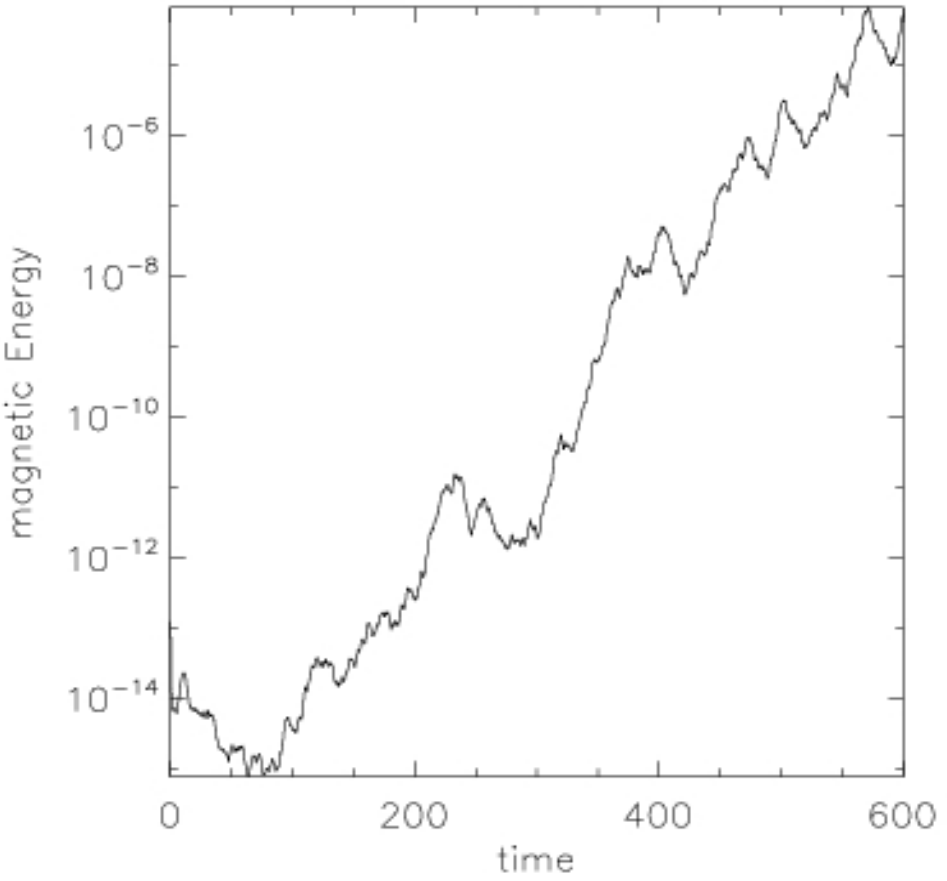
Turbulent kinematic dynamo

$$\partial_t \vec{u} + \vec{u}\nabla\vec{u} = -\nabla P + \nu\,\Delta\vec{u} + \vec{j}\times\vec{b} + \vec{F}$$

$$\partial_t \vec{b} = \nabla\times(\vec{u}\times\vec{b}) + \eta\,\Delta\vec{b}$$

$$\nabla\vec{u} = 0 \quad \nabla\vec{b} = 0$$





Taylor-Green forcing

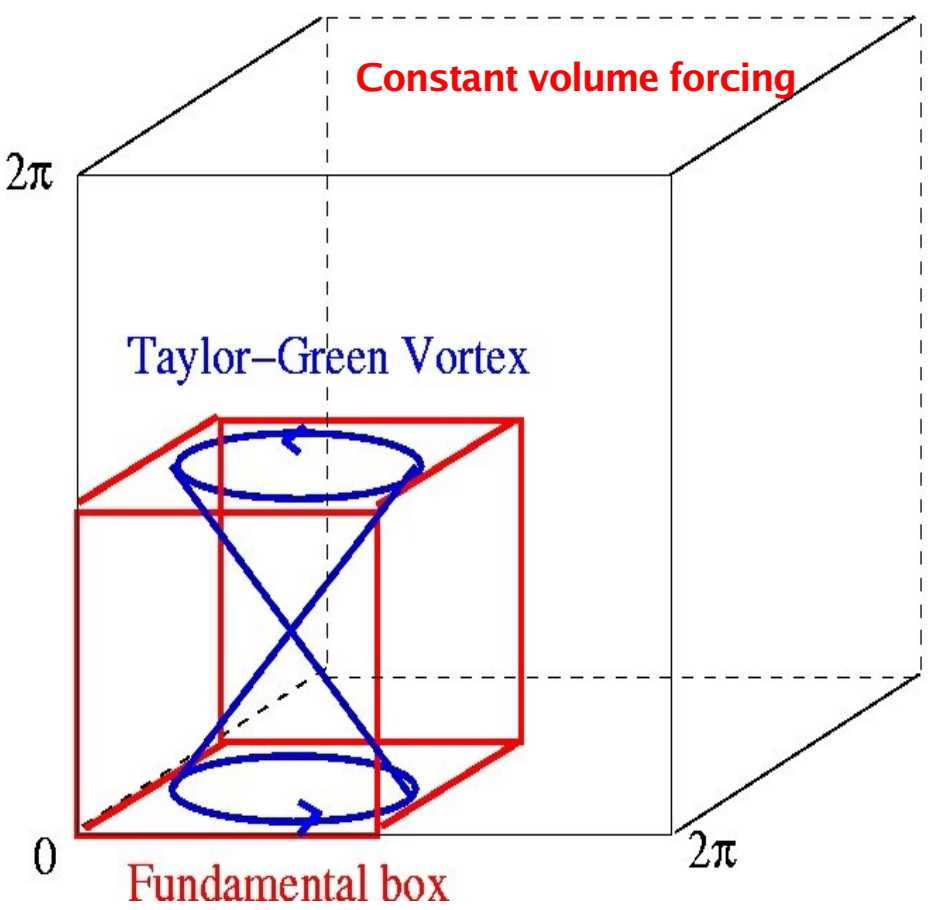
$$\partial_t \vec{u} + \vec{u}\nabla\vec{u} = -\nabla P + \nu\,\Delta\vec{u} + \vec{j}\times\vec{b} + \vec{F}$$

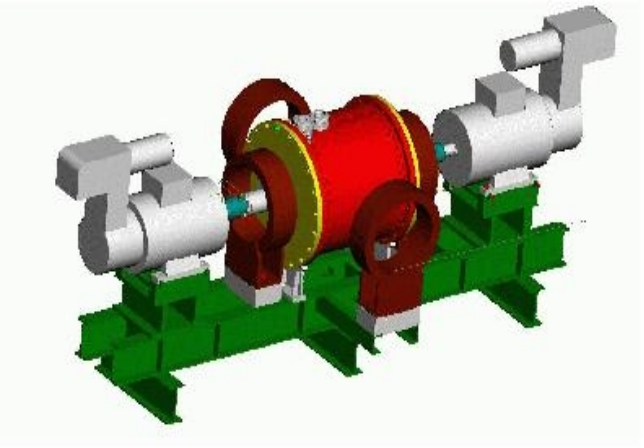
$$\partial_t \vec{b} = \nabla\times(\vec{u}\times\vec{b}) + \eta\,\Delta\vec{b}$$

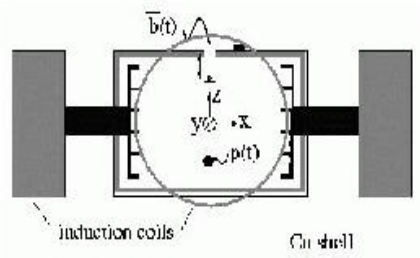
$$\nabla\vec{u} = 0 \quad \nabla\vec{b} = 0$$

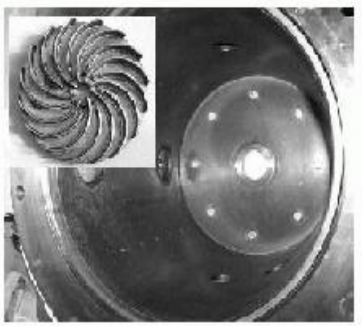
$$F_{k0} = \begin{bmatrix} \sin(k0\,x)\cos(ko\,z)\cos(k0\,z) \\ -\cos(k0\,x)\sin(ko\,y)\cos(k0\,z) \\ 0 \end{bmatrix}$$

Non helical forcing: $H = u_{tg}.\omega_{tg} = 0$





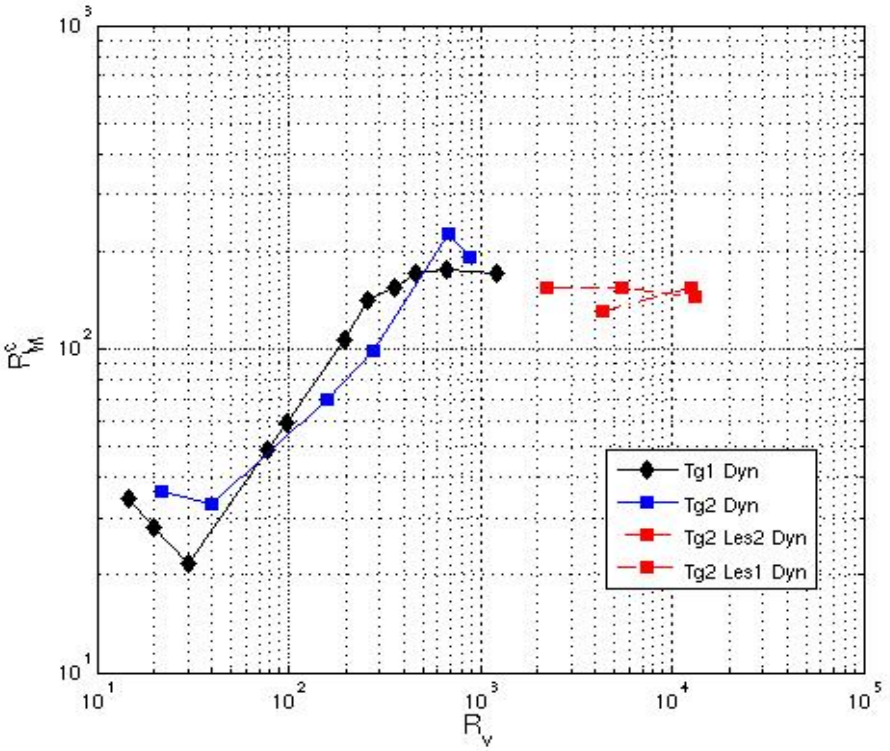




Von Kármán Sodium (VKS)

R. Monchaux, M. Berhanu, M. Bourgoin, M. Moulin, Ph. Odier, J.-F. Pinton, R. Volk, S. Fauve, N. Mordant, F. Petrelis, A. Chiffaudel, F. Daviaud, B. Dubrulle, C. Gasquet, L. Marie, F. Ravelet **Phys. Rev. Lett., 98 044502 (2007)**

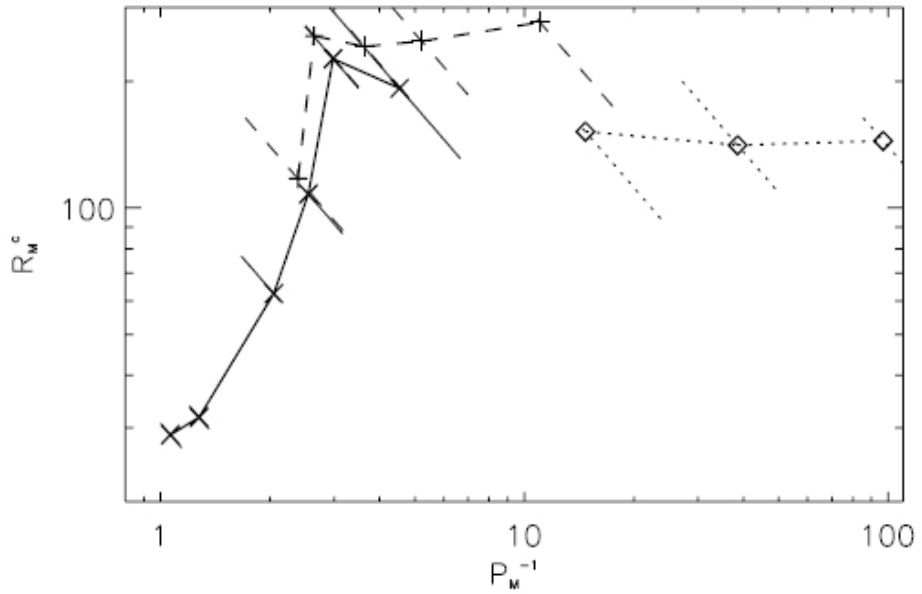
Linear Dynamo regime :



Kinetic spectra $E_u(k)$

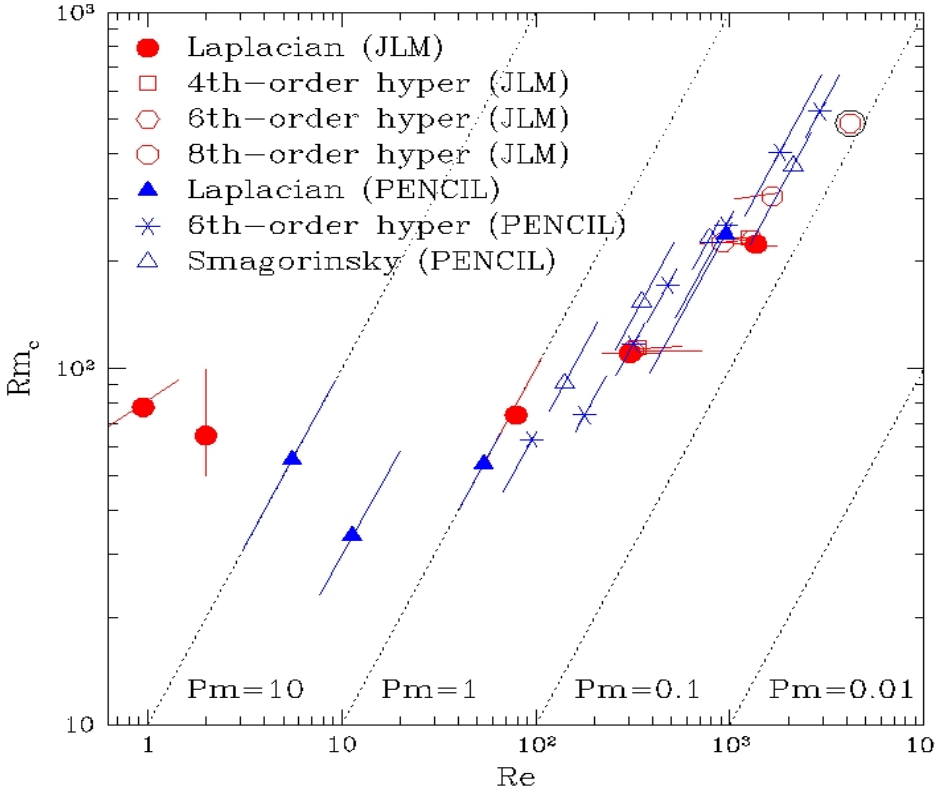
$$L = 2\Pi \frac{\sum E_u(k)/k}{\sum E_v(k)} \qquad u_{rms} = \sqrt{2E_u}$$

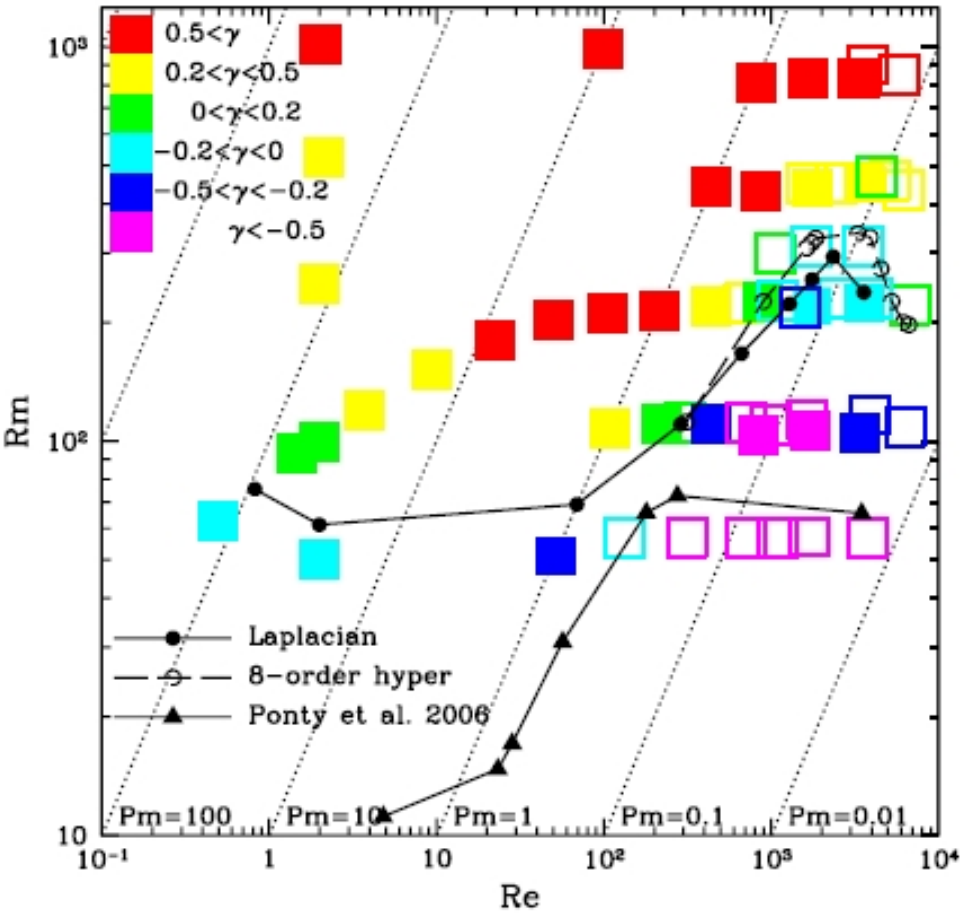
$$R_e = \frac{LU_{rms}}{\nu} \qquad R_m = \frac{LU_{rms}}{\eta}$$



Y. Ponty, P.D. Mininni , D.C. Montgomery ,
J.-F. Pinton , H. Politano and A. Pouquet
Phys. Rev. Lett. 92 144503 (2004)

- The forcing is δ correlated in time





"0nset of small-scale turbulent dynamo at low magnetic Prandtl numbers"
A. A. Schekochihin, N. E. L. Haugen, A. Brandenburg, S. C. Cowley,
J. L. Maron, and J. C. Mcwilliams 2005

A. Schekochihihin, S.C Cowley, J.L. Marton & J.C McWilliams , *Phys. Rev. Lett.* (2004)

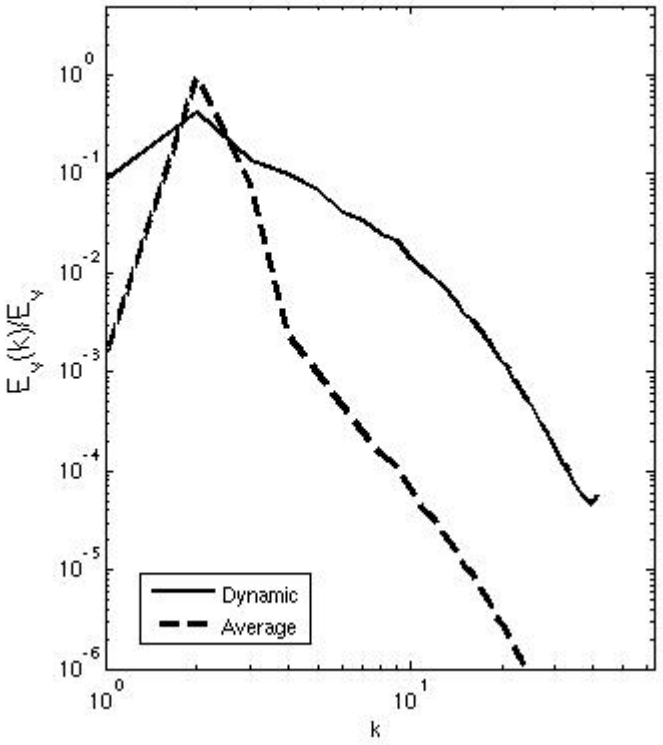
N.E Haugen, A. Brandenburg & W. Dobler , *Phys. Rev. E.* 70 (2004)

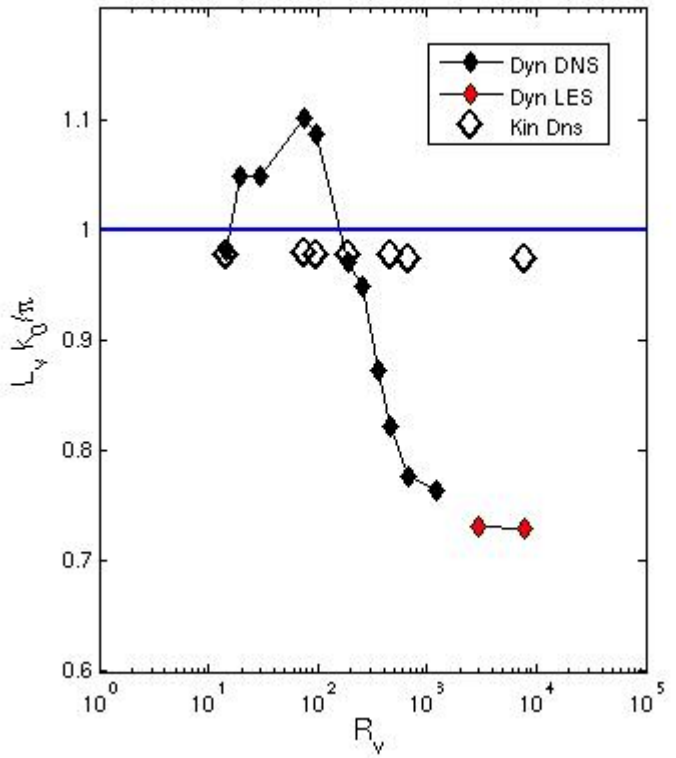
- Compressible MHD
- September 2004 MSI : The Smagorinsky method

Average in time velocity

$$\left\langle \vec{u}(\vec{r}) \right\rangle_{time} = \int_0^T \vec{u}(\vec{r},\tau)\, d\tau$$

$$\left\langle \vec{u} \right\rangle_{time} = \vec{u}_{tg} + recirculation$$





$$d\tau \ll U/L \ll T$$

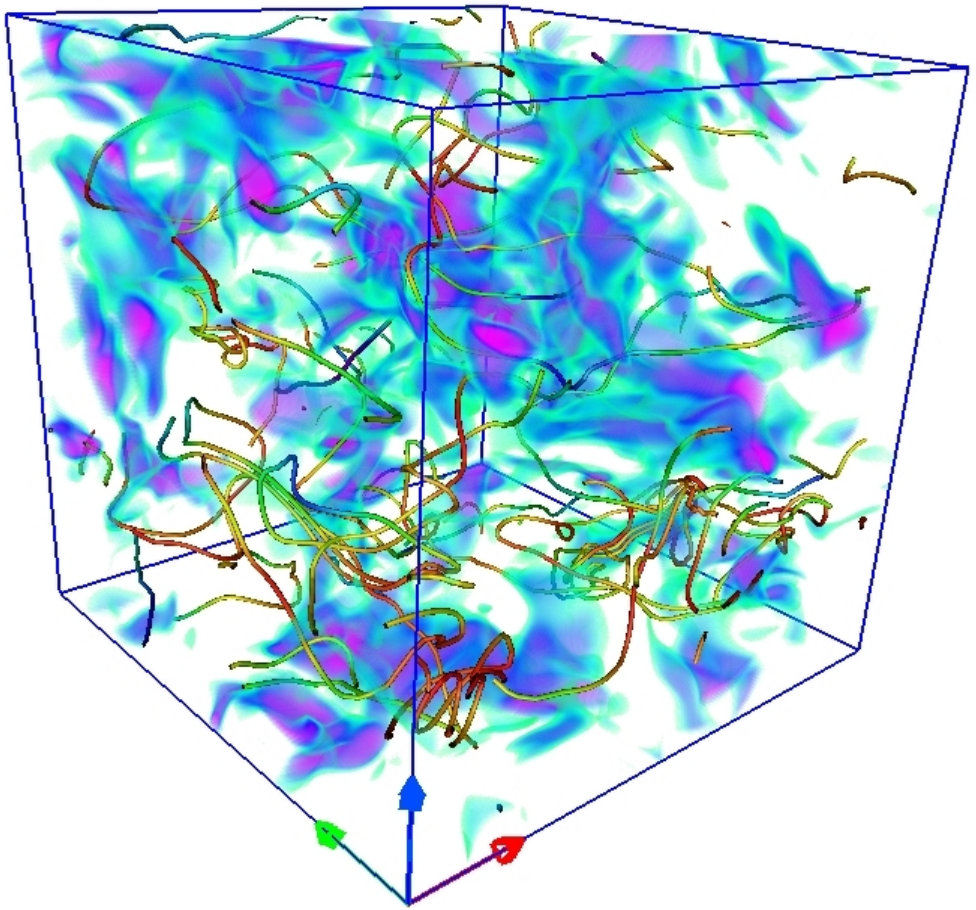
100 200 - 1000

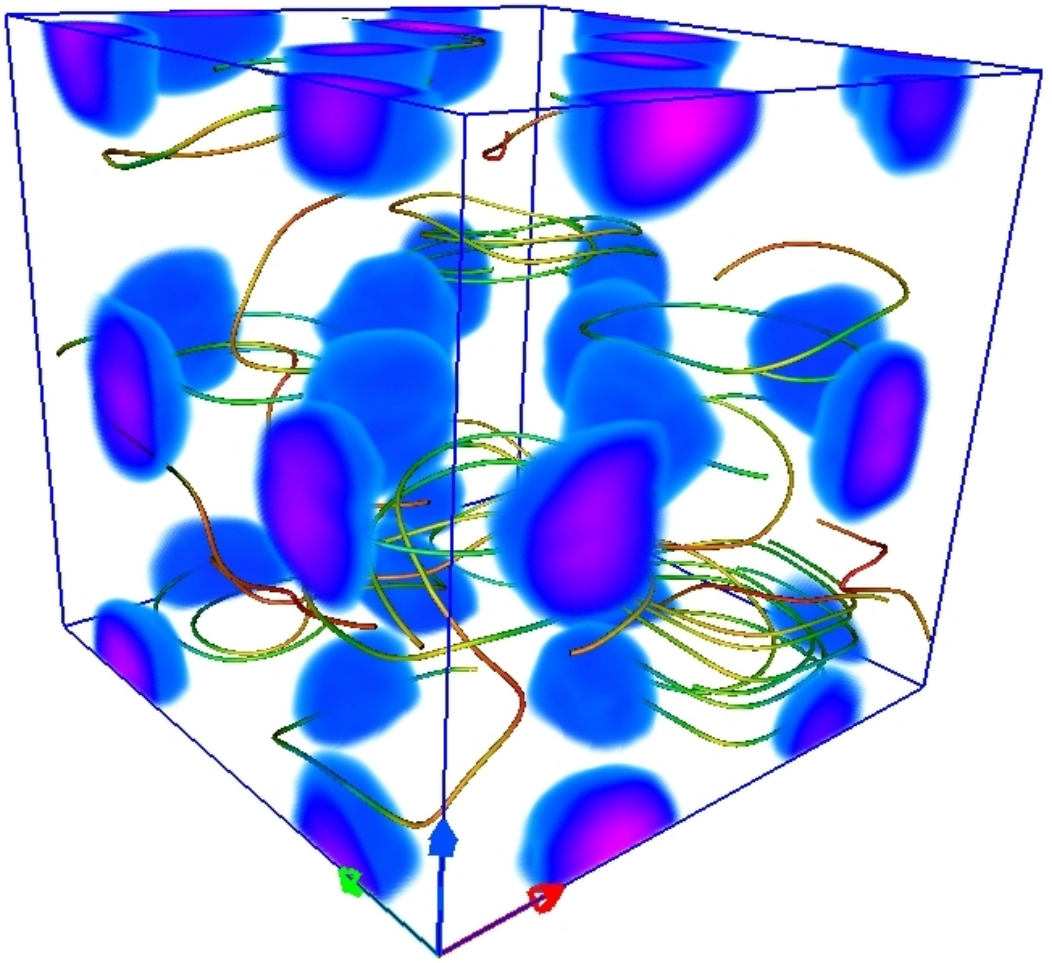
20 000 – 100 000 Fields averaged

Y.Ponty et al

$\vec{u}(\vec{x},t)$

$\left\langle \vec{u}(\vec{x}) \right\rangle_{time}$

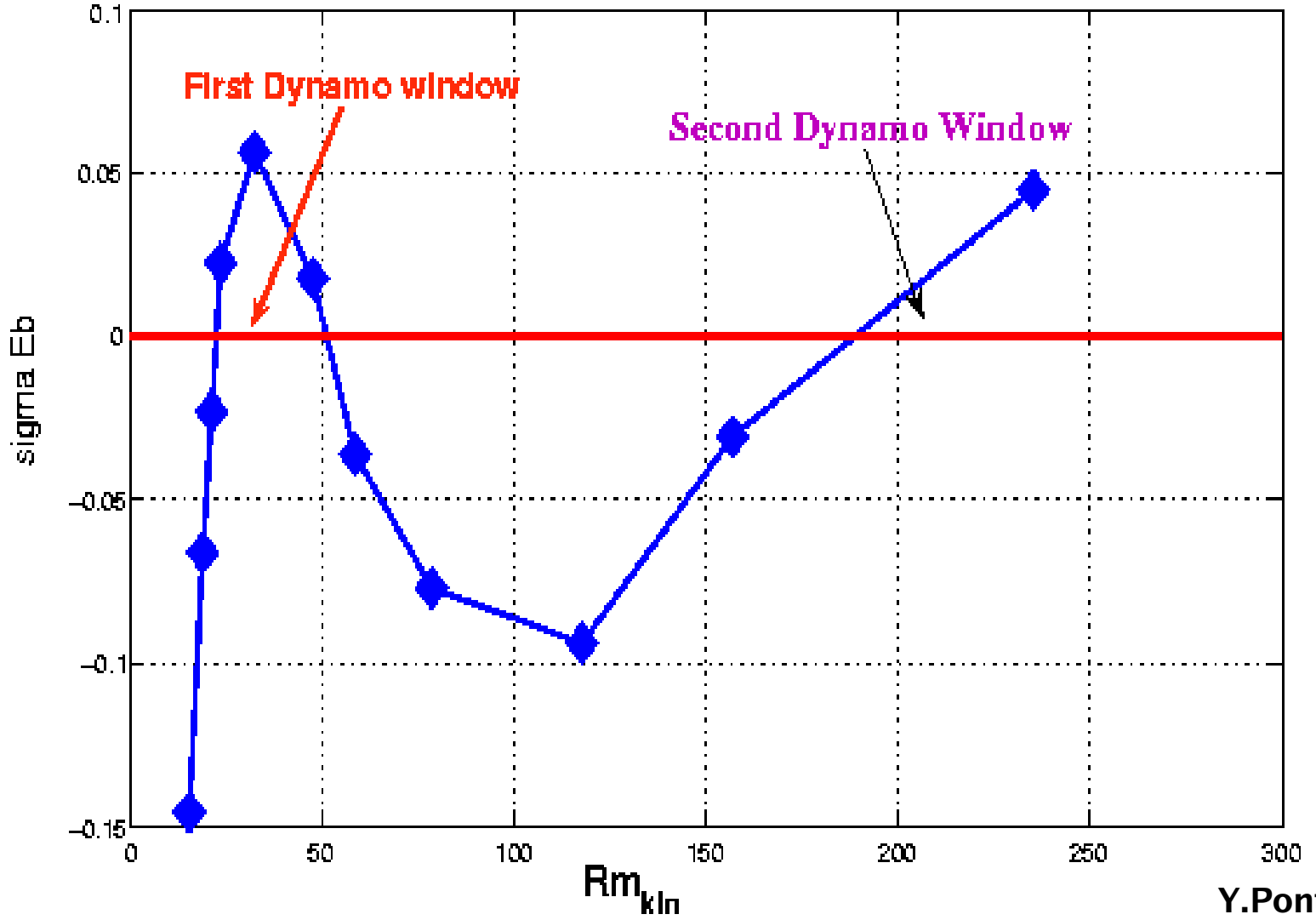




Made with Vapor

Kinematic Dynamo modes in the time average velocity

$$\partial_t \vec{b} = \nabla \times (\langle \vec{u} \rangle_{time} \times \vec{b}) + \eta \Delta \vec{b}$$

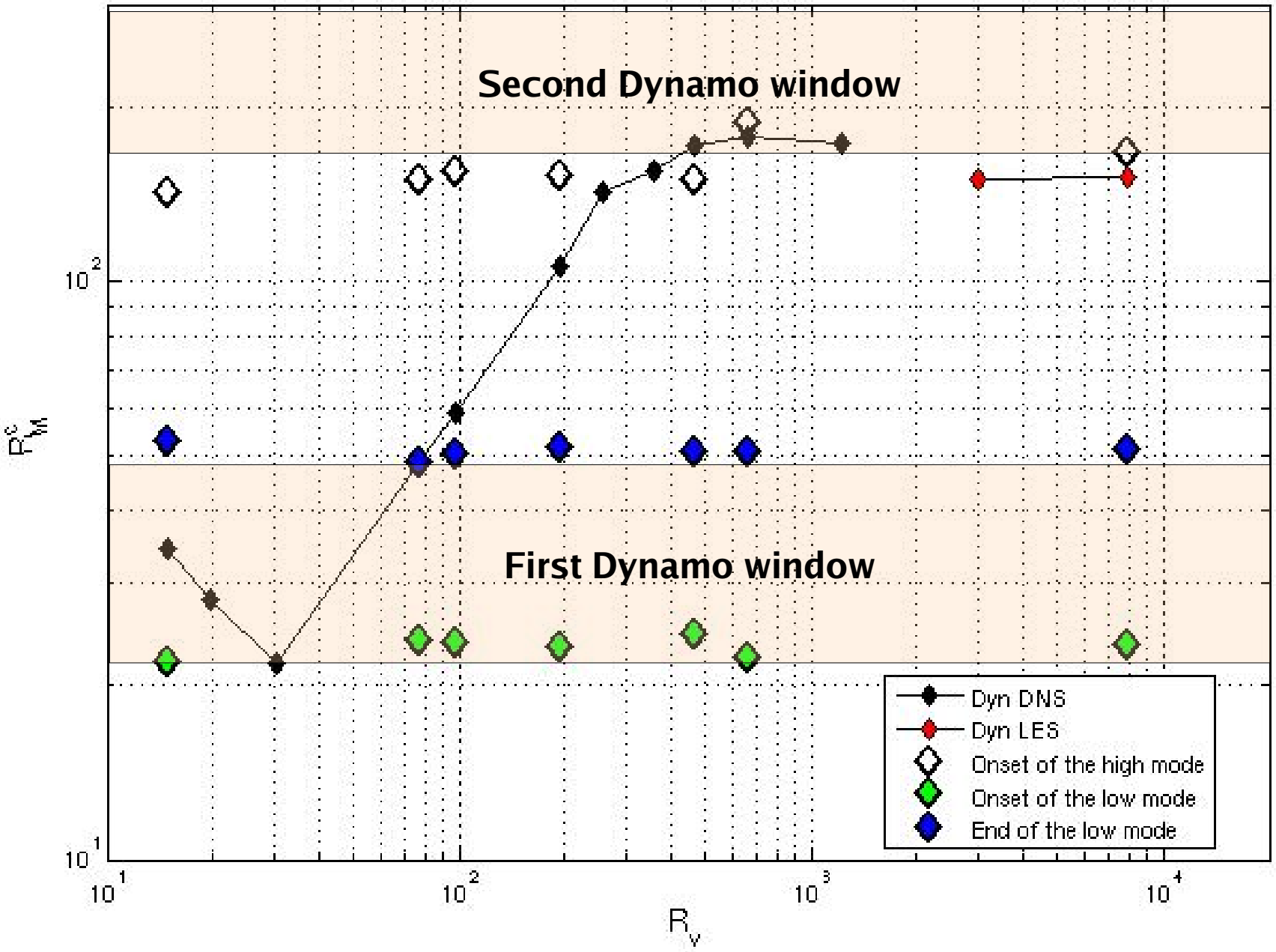


Y.Ponty et al NJP 2007

Onset of the Dynamo

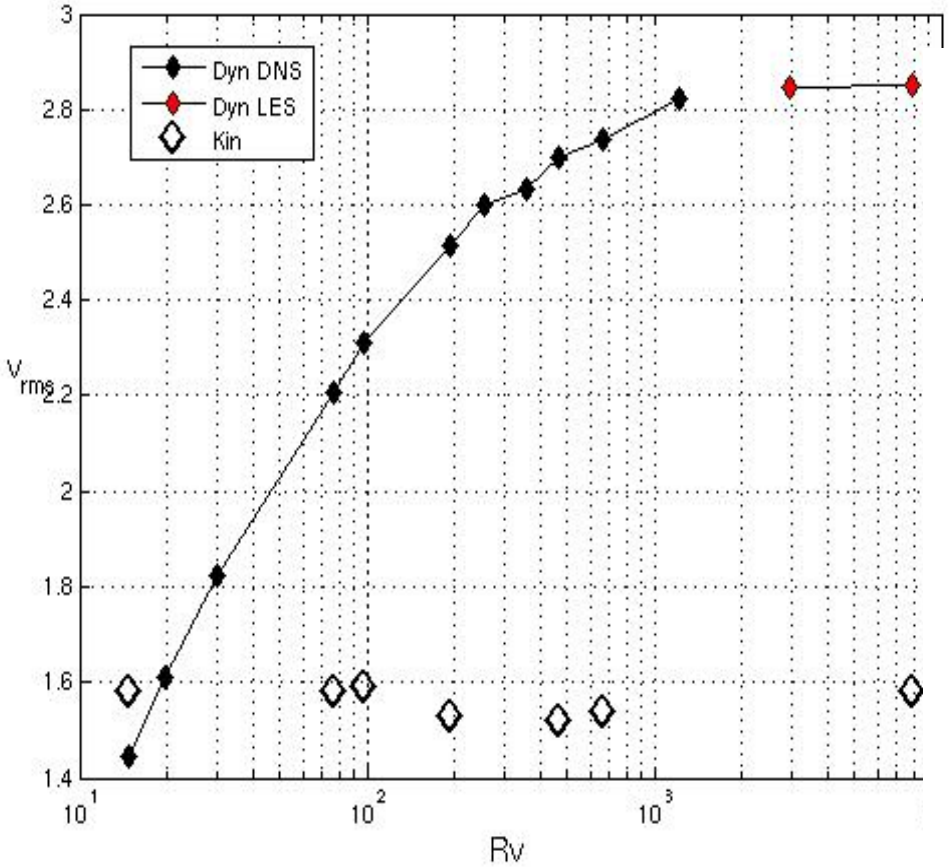
Dynamo action at low magnetic Prandtl numbers: mean flow versus fully turbulent motions

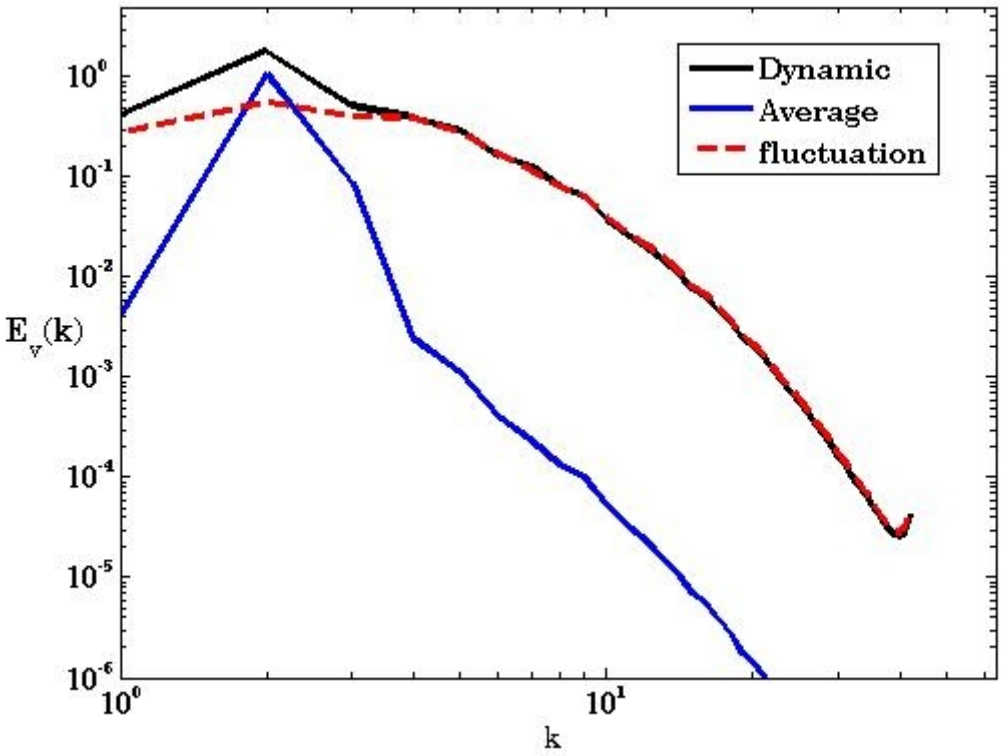
Y. ponty, P Minnini, H. Politano. A. Pouquet & J-F Pinton *New Journal of Physics 2007*



Fluctuation of the velocity

$$\tilde{u} = U - \langle U \rangle$$



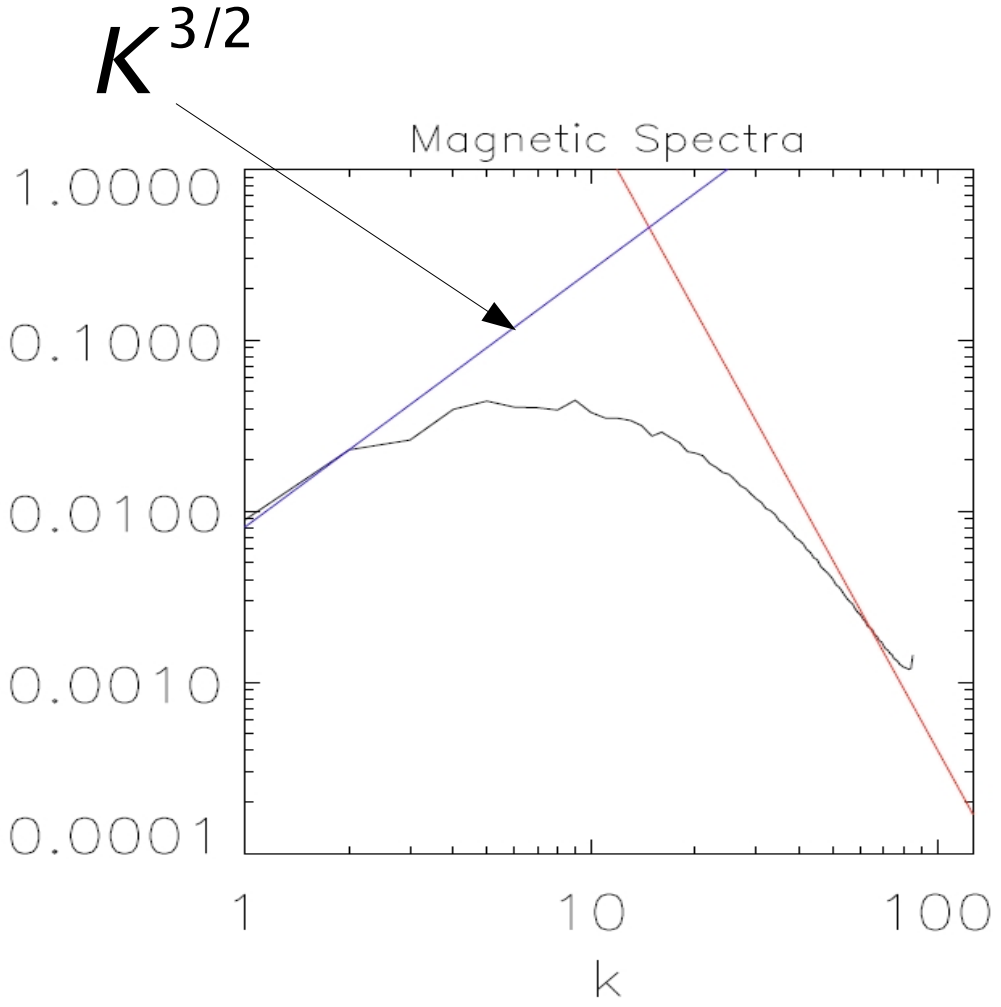


$$\delta = \frac{E_U}{E_{\langle U \rangle}} = 3 \rightarrow \quad \frac{\tilde{u}}{\langle U \rangle} = 0.73$$

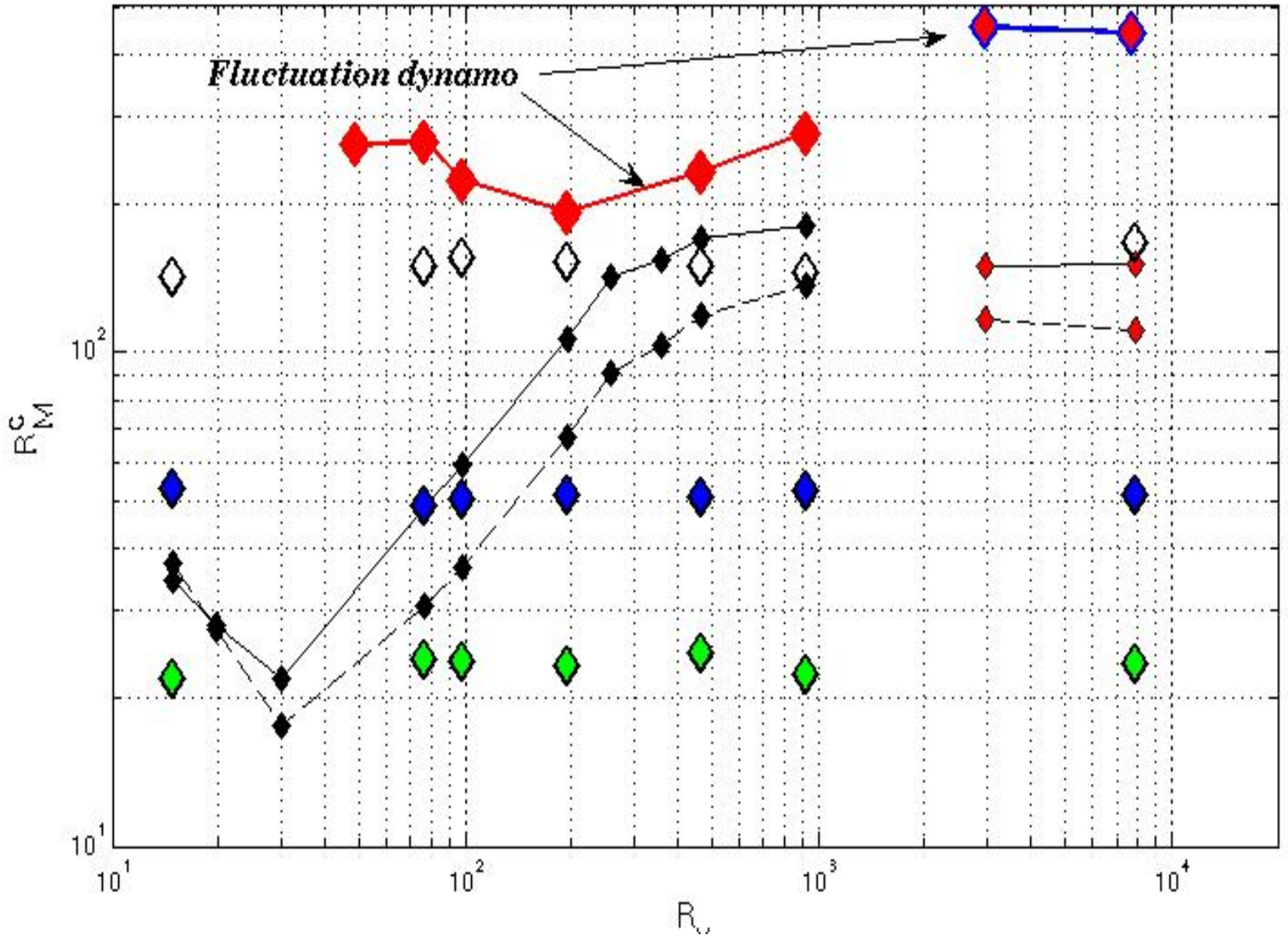
Y.Ponty et al

Fluctuation Dynamo :

$$\partial_t \vec{b} = \nabla \times ((\vec{u} - \langle \vec{u} \rangle_{time}) \times \vec{b}) + \eta \Delta \vec{b}$$



$$\partial_t \vec{b} = \nabla \times ((\vec{u} - \langle \vec{u} \rangle_{time}) \times \vec{b}) + \eta \Delta \vec{b}$$

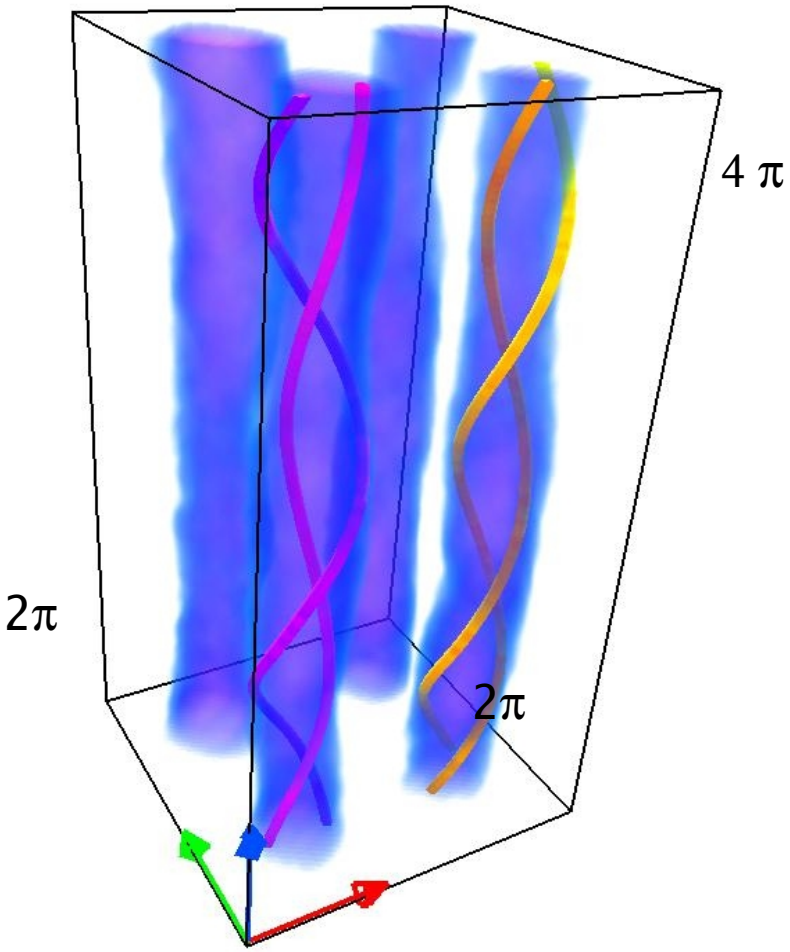


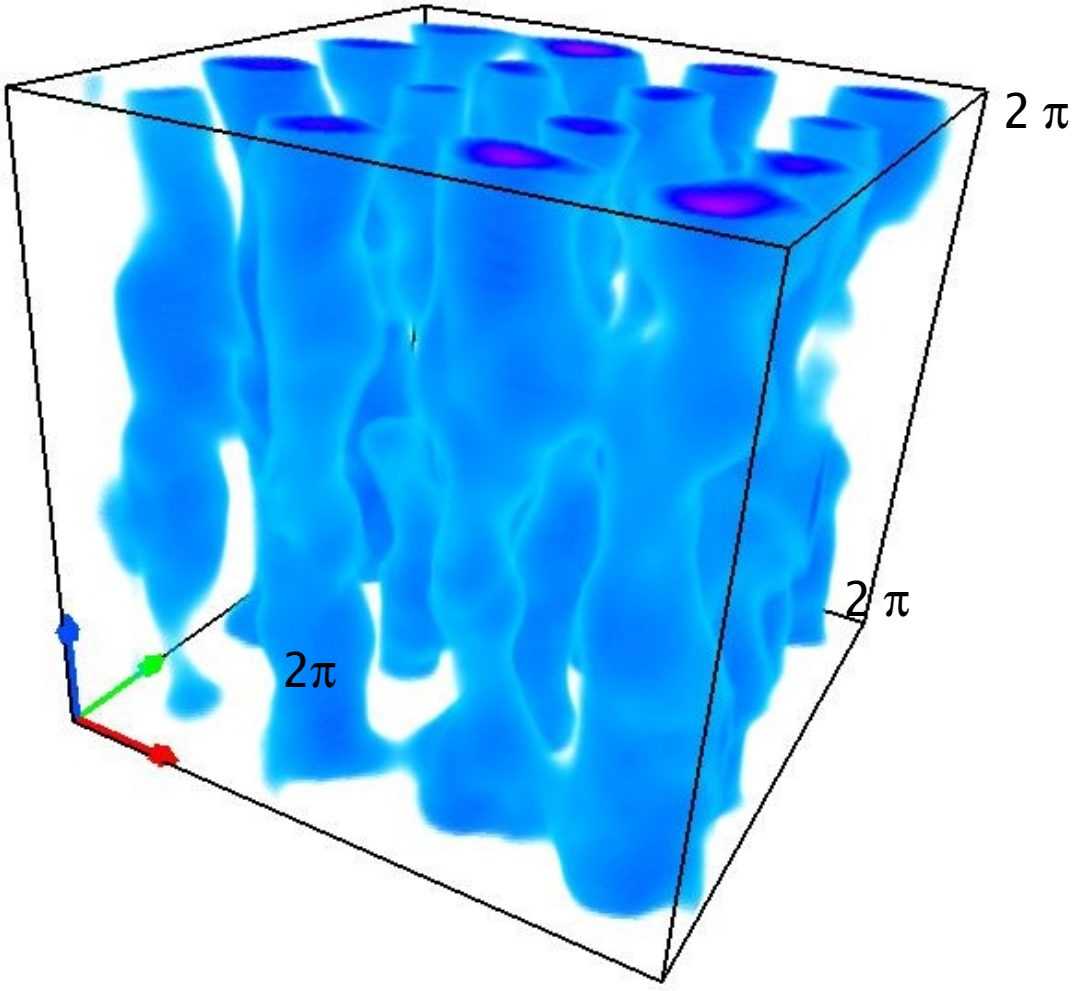
G.O Robert Forcing : Helical forcing, Dynamo α

$$F=\begin{bmatrix} \sin(ko\ \ x)\ \ \cos(ko\ \ y) \\ -\cos(ko\ \ x)\ \ \sin(ko\ \ y) \\ \sqrt{2}\ \ \xi\ \ \sin(ko\ \ x)\ \ \sin(ko\ \ y) \end{bmatrix}$$

Y.Ponty & F. Plunian (on going research)

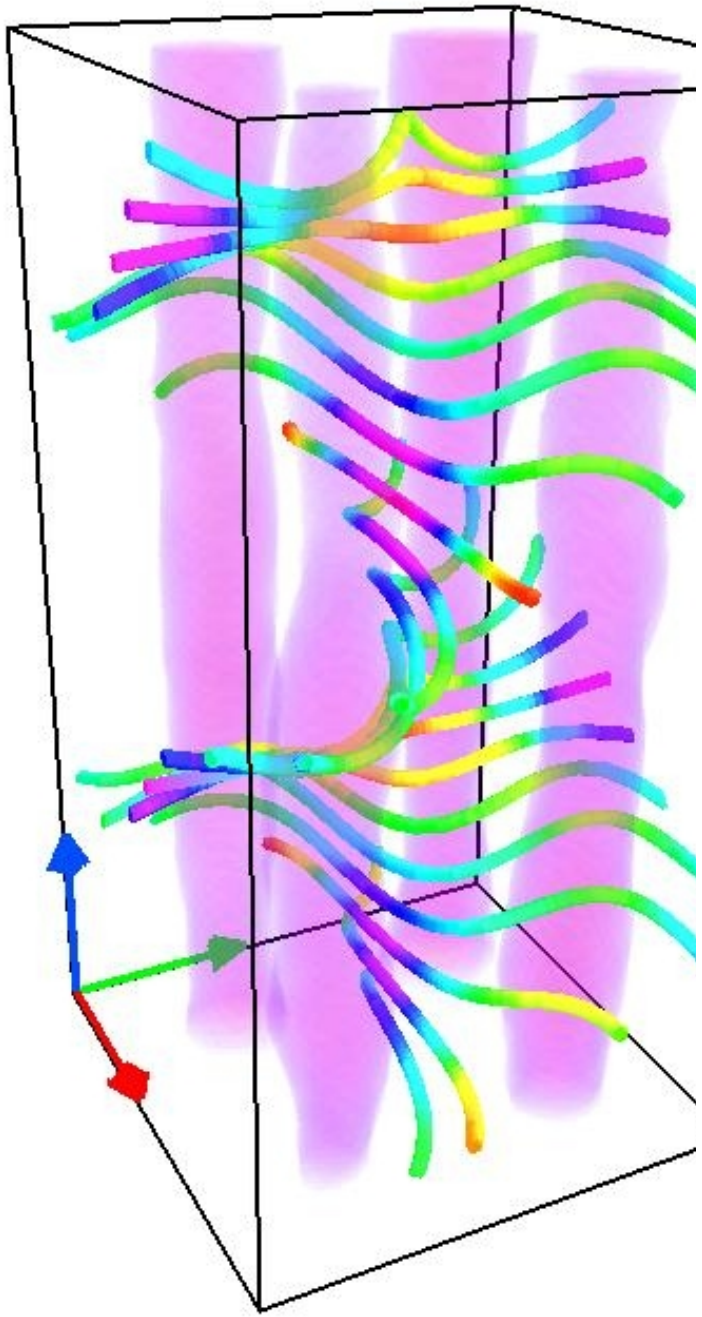
$\xi=1 \qquad ko=1,2$

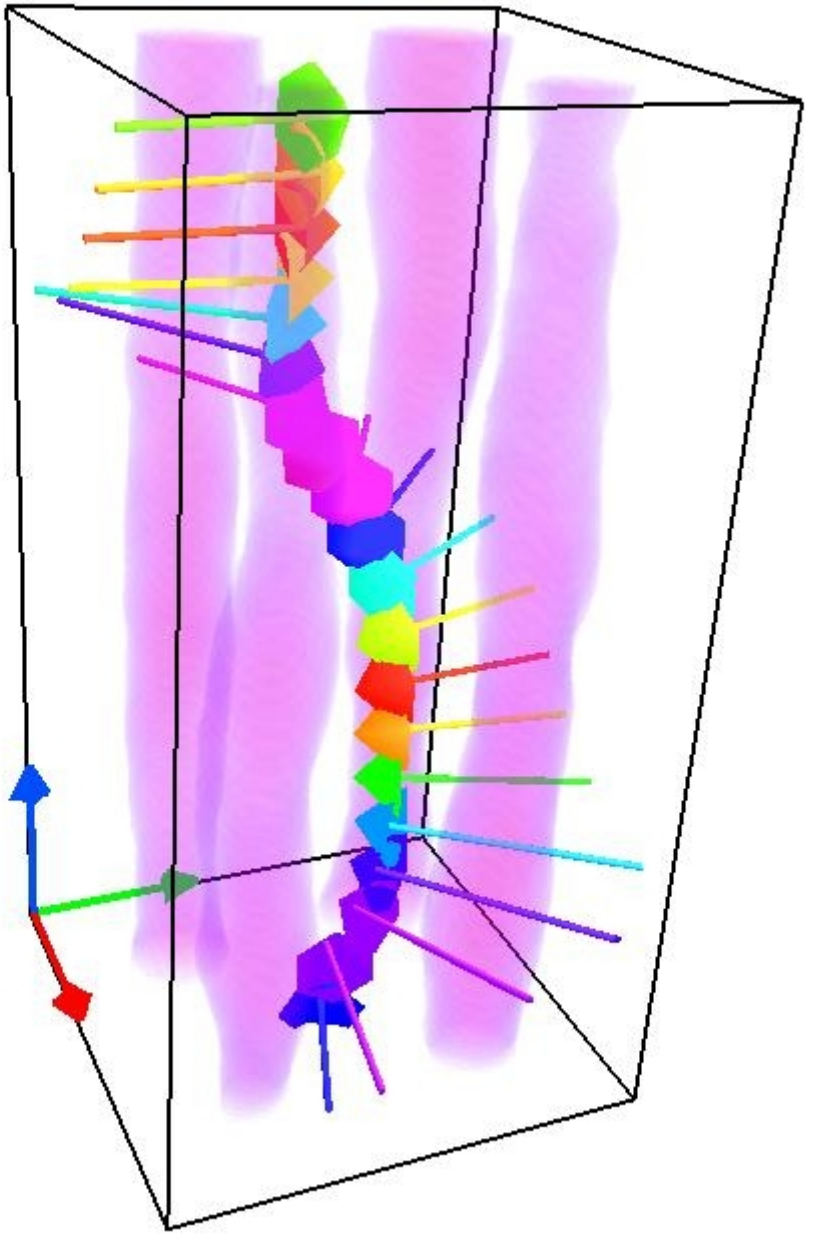




$b \sim (\cos(k_z x), \sin(k_z y), 0)$

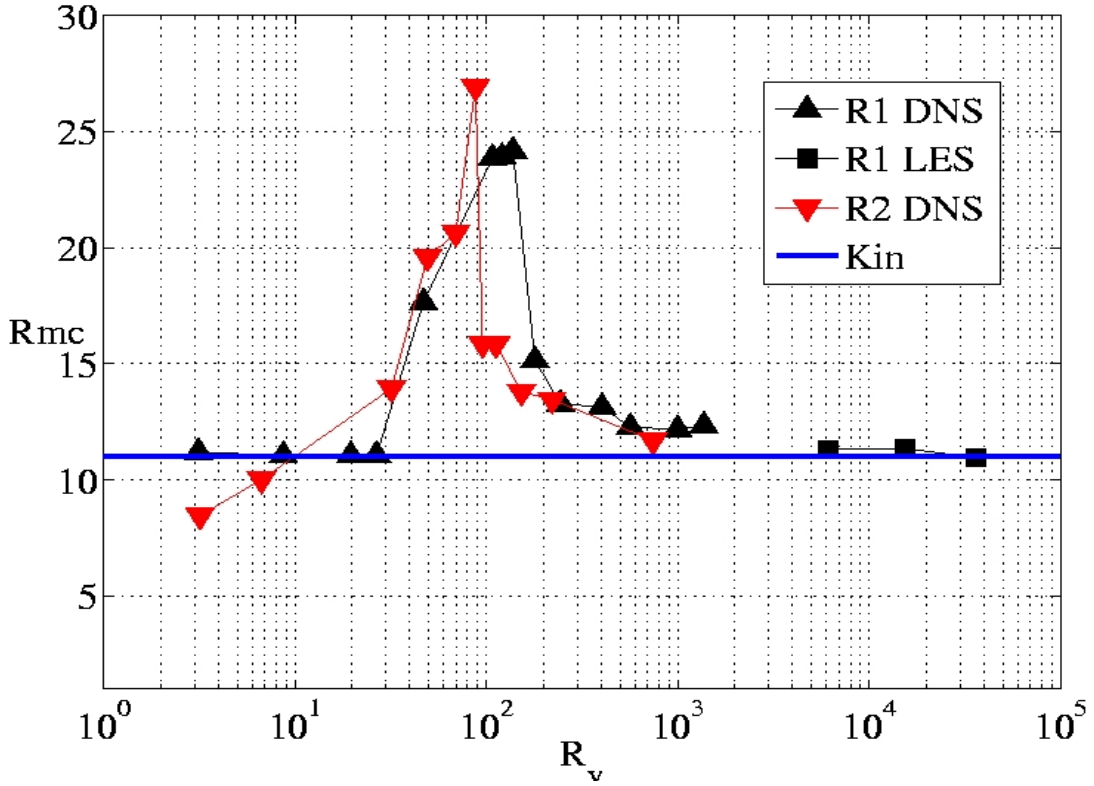
$\hat{b} \sim (0, 0, k_z)$

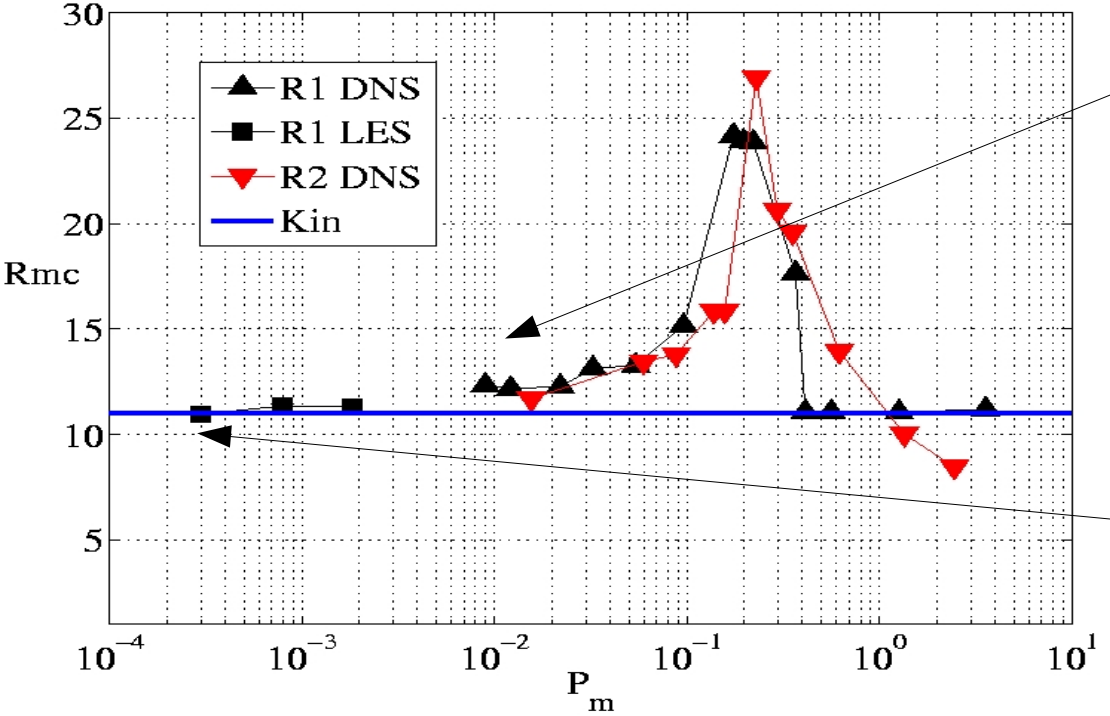




Powered by Vapor!

Y.Ponty & F. Plunian





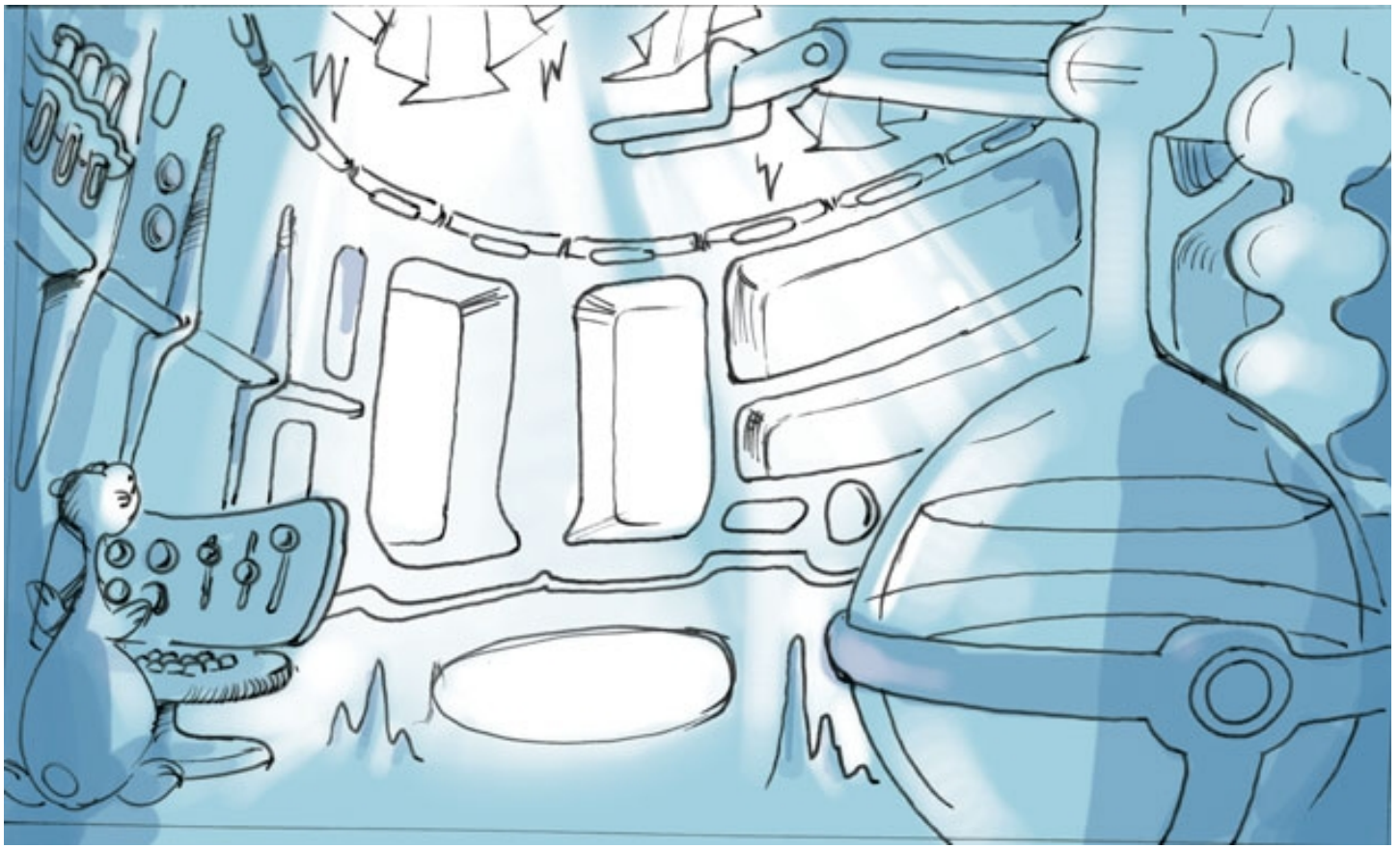
$Pm = 5.10^{-3}$ (DNS)

(256 x 256 x 512)

$Pm = 2.10^{-4}$ (LES)

Y.Ponty & F. Plunian

Experimental Dynamo



Fluid dynamos : Rm > Rm^c

$$Rm = \frac{\text{induction}}{\text{dissipation}} = \mu_0 \sigma \; L \; U = 10 \times 1$$

fluid engineering

Fluid	conductivity		temperature	density
Iron	1	10^5	x 1,000	12
Mercury	3	10^4	ambiant	13.6
Gallium	3.7	10^6	> 40°C	6.1
Sodium	1	10^7	> 100°C	0.93
Silver	6	10^7	> 950°C	10.5

Fluid dynamos : Power

fluid

engineering

$Rm = \mu_0 \sigma L U = \mu_0 \sigma \nu \ (L U/\nu) =$ Pm x Re

$Pm \approx 10^{-5}$ $Re > 10^{6}$: turbulence

Assuming no global rotation $P = f(\rho, \nu, L, U)$

$P = [E_K]/[t] = (\rho L^3).U^2/(L/U)\ g(Re)$

Fully developped turbulence : g(Re) $\overrightarrow{\text{Const.}}$

$P \approx \rho L^2 U^3$

Fluid dynamos : Power

$Rm = \mu_0 \sigma L U$

$P \approx \rho L^2 U^3$

$\Rightarrow Rm \approx \mu_0 \sigma (PL/\rho)^{1/3}$

$(PL/\rho)=1$: $P \approx$ kW

$(PL/\rho)=10$: $P \approx$ MW

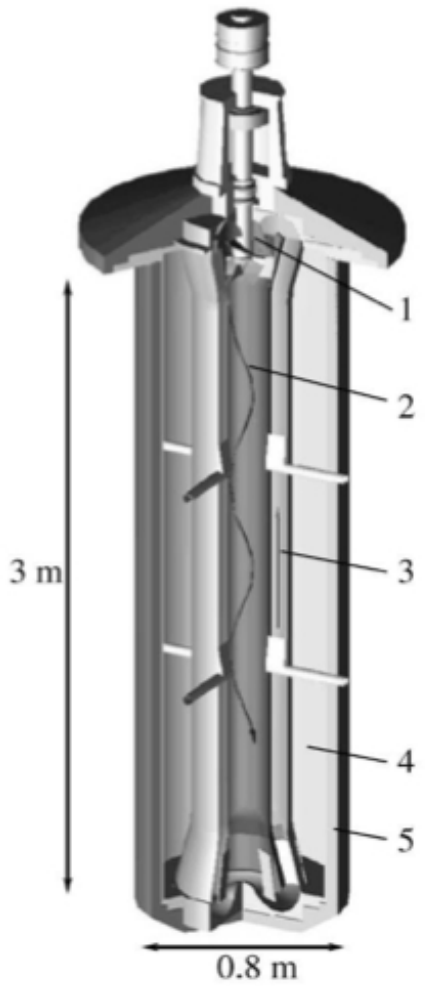
Fluid : Na

Power : x 100 kW

Size : 1 m

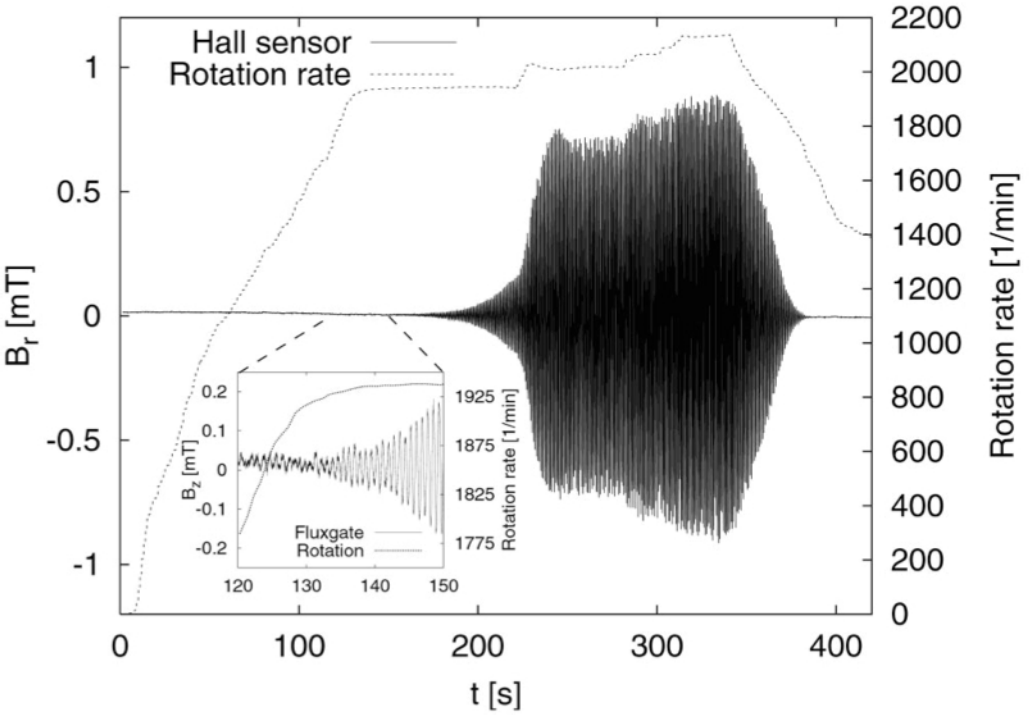
Low Rm^c

Riga / Ponomarenko dynamo



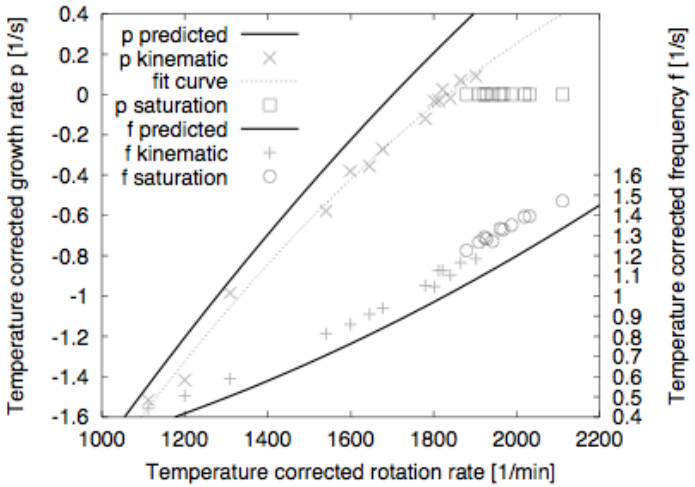
P ≈ 120 kW
Na at 150°C

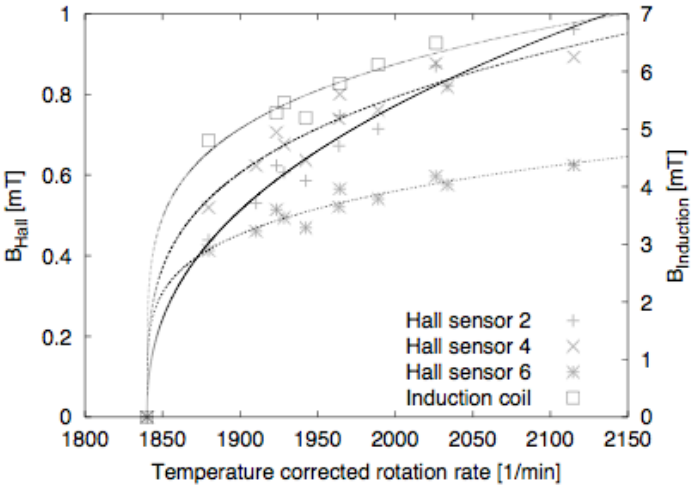




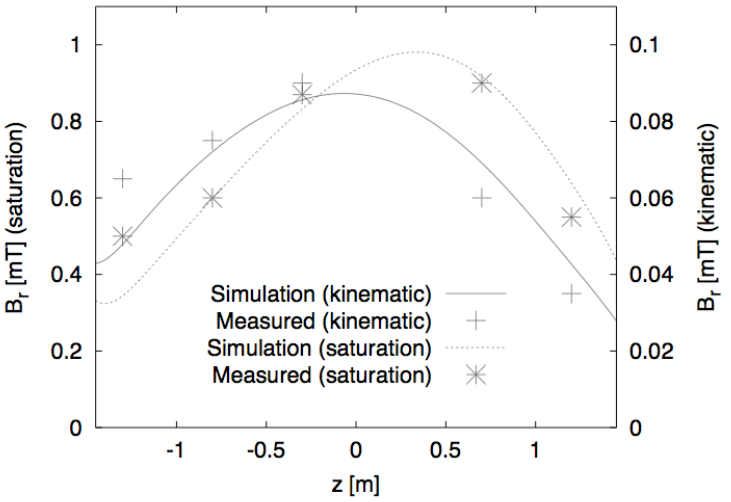
Gailitis & Freiberg, *Magnetohydrodynamics*, **16** (1980)
Gailitis et al, *PRL*, **84**, (2000)

Riga / Ponomarenko dynamo





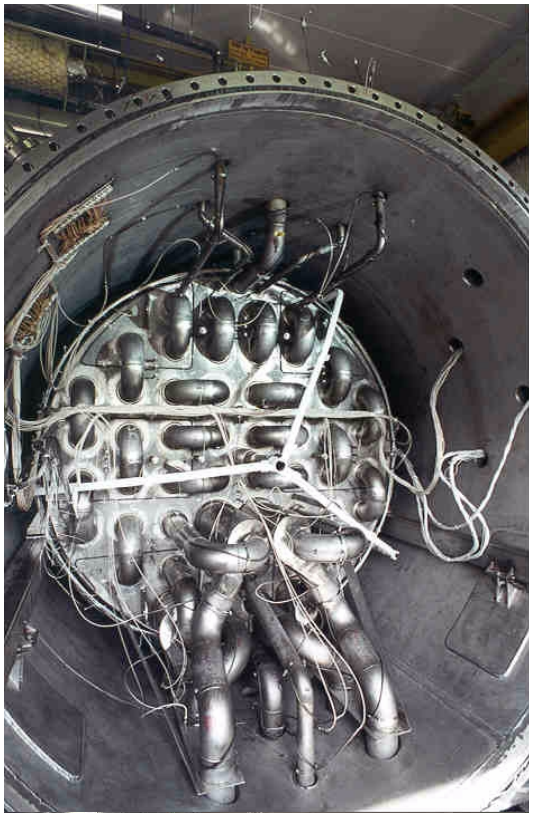
$$\overline{B} = \text{dynamo}\,(\overline{U})$$



Gailitis et al, *Magnetohydrodynamics*, **38**, (2002)

Gailitis et al., *Rev. Mod. Phys.*, **74** (2002)

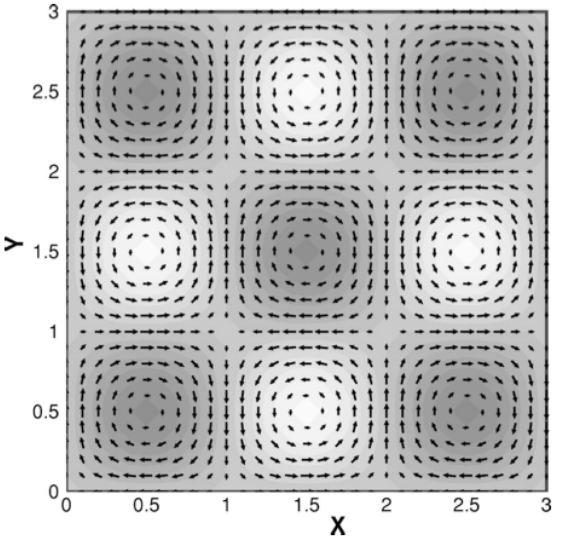
Karlsruhe / Roberts-Busse dynamo

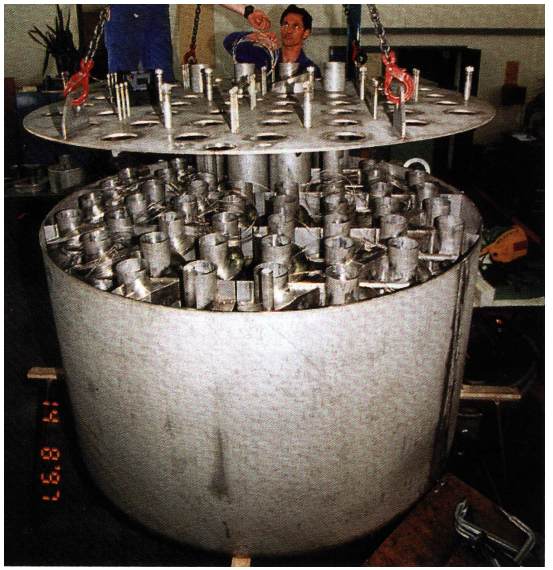


Q ≈ 110 m^3/h

P ≈ 210 kW

Na 120°C





G.O. Robert, *Phil. Trans. Roc. Soc. L,* 421 (1972)

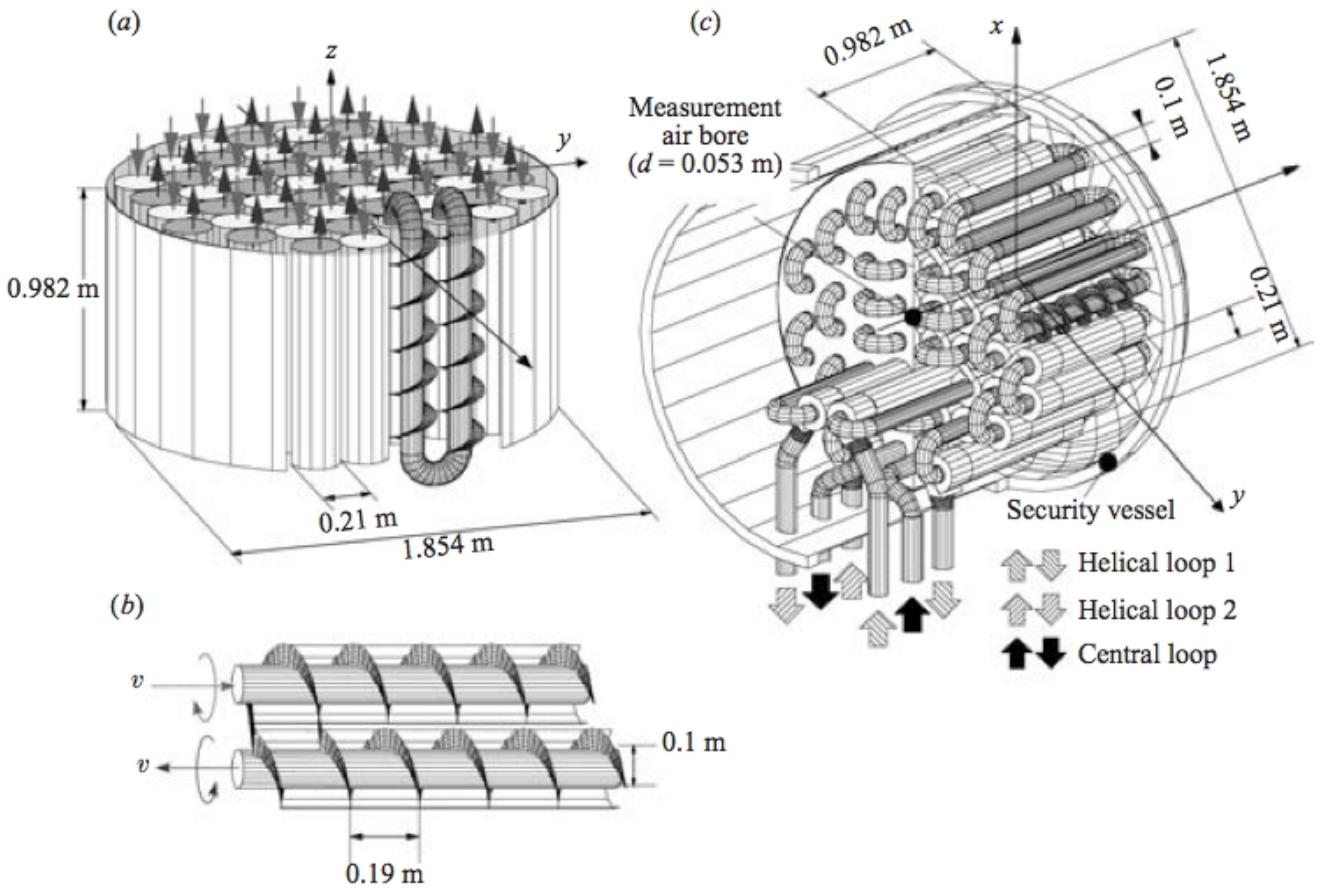
Busse, *Geophys. JRAS*, **42**, (1975)

Tilgner, *Phys. Lett. A,* **226** (1997)

Rädler et al., *Study Geoph. Geod.*, **42** (1998)

Müller & Stieglitz, *Naturwissenschaften*, **87** (2000)

Karlsruhe / Roberts-Busse dynamo



G.O. Robert, *Phil. Trans. Roc. Soc. L,* 421 (1972)

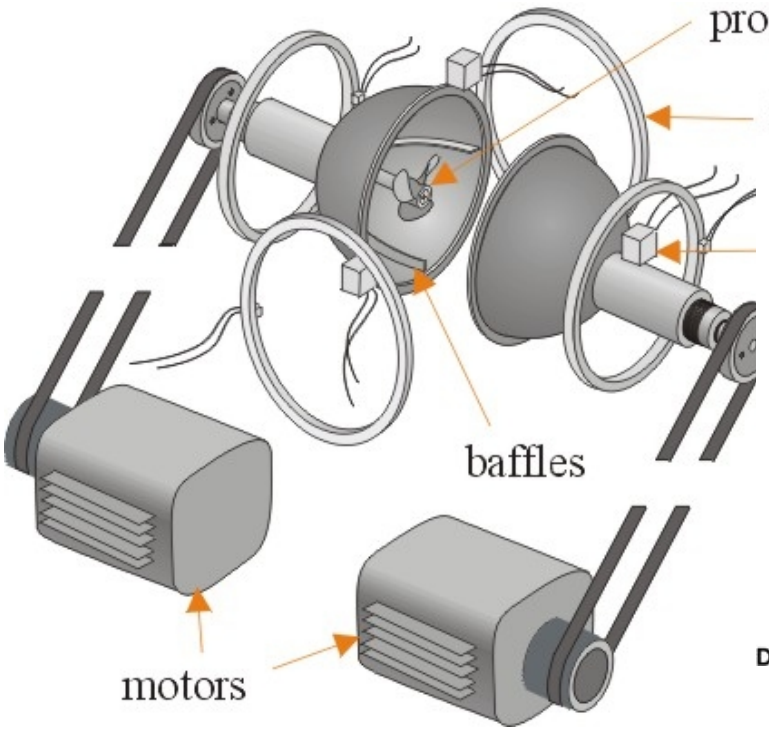
Busse, *Geophys. JRAS*, **42**, (1975)

Tilgner, *Phys. Lett. A,* **226** (1997)

Rädler et al., *Study Geoph. Geod.*, **42** (1998)

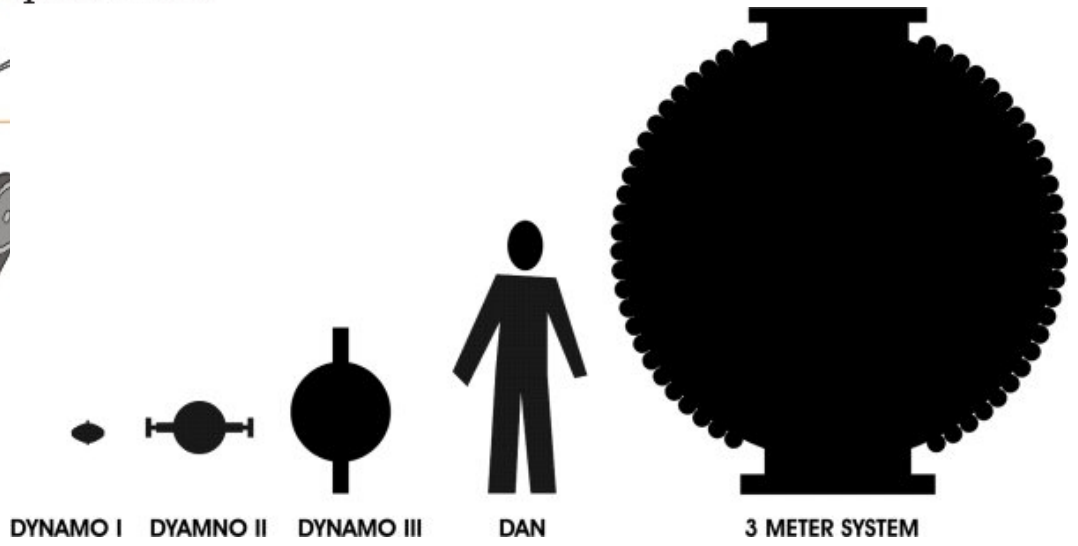
Müller & Stieglitz, *Naturwissenschaften*, **87** (2000)

Maryland Experiment





Dan Lathrop
complex.umd.edu



Maryland Experiment

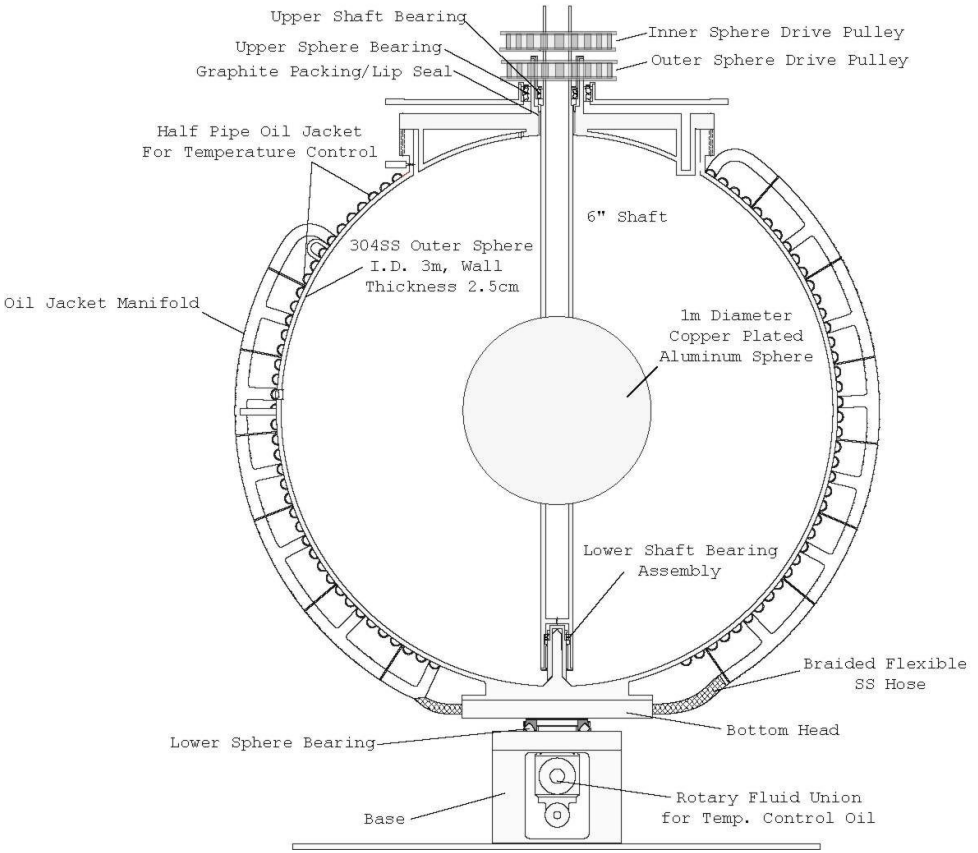
$R_1 = 0.5$ m

$R_2 = 1.5$ m

Ω_{max}=12 Hz

Rm_{max}= 680



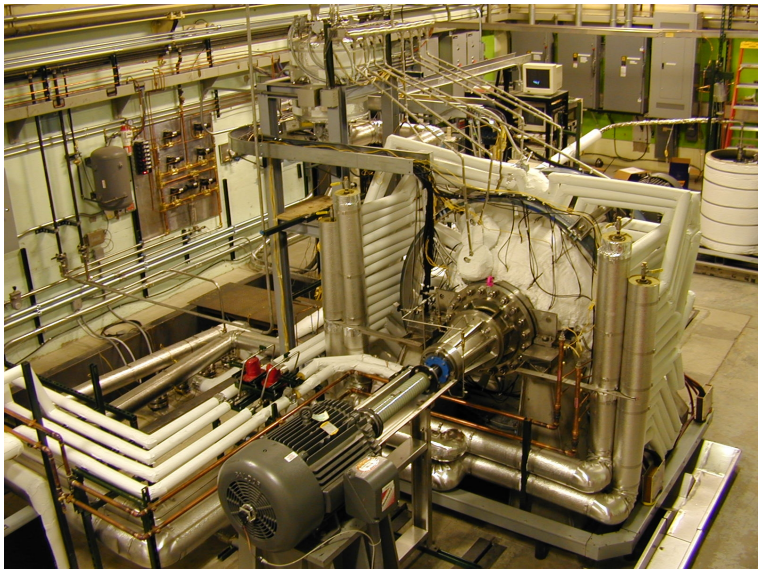


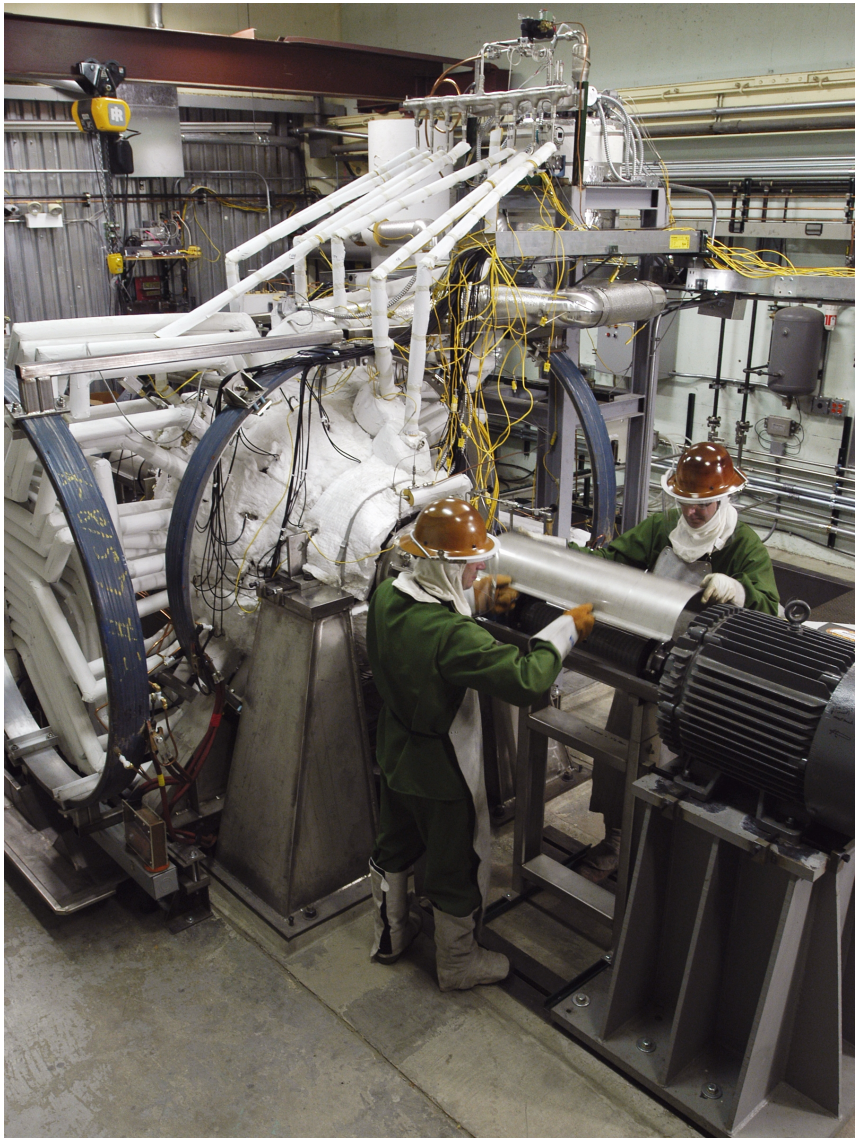
Madison Experiment

Cary Forest

home.physics.wisc.edu/~cbforest/







DTS (Derviche Tourneur Sodium)

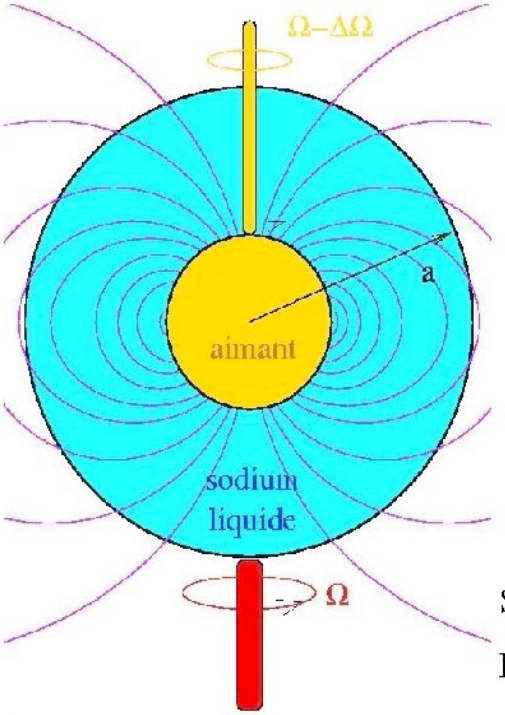




Université Joseph-Fourier, Grenoble, FRANCE

Y.Ponty





Maquette (éch. 1/5):

Derviche Tourneur Sodium

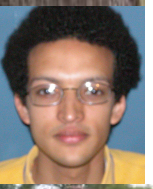
Système Terre (MENRT)

Intérieur de la Terre (INSU)

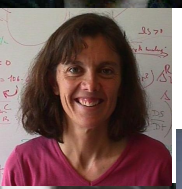
Equipe Géodynamo 2003

LGIT

Y.Ponty

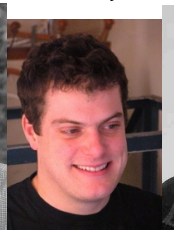



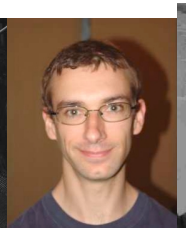









(experimental dynamos) & VKS induction

Laboratoire de Physique ENS-Lyon

M. Bourgoin, P. Odier, J.-F. Pinton, N. Plihon R. Volk

M. Moulin, P. Metz

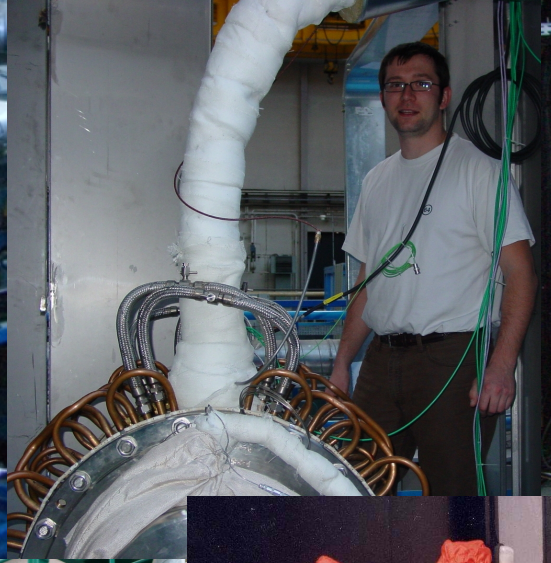
Laboratoire de Physique Statistique ENS-Paris

M. Berhanu, S. Fauve, N. Mordant, F. Pétrélis

D. Courtiade, J.-F. Point

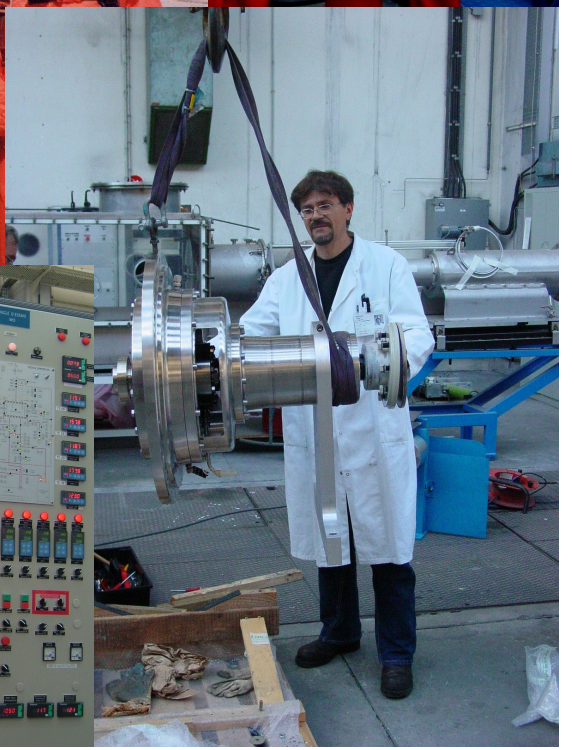
Groupe Instabilités et Turbulence, CEA-Saclay

- Chiffaudel, F. Daviaud, B. Dubrulle, L. Marié,

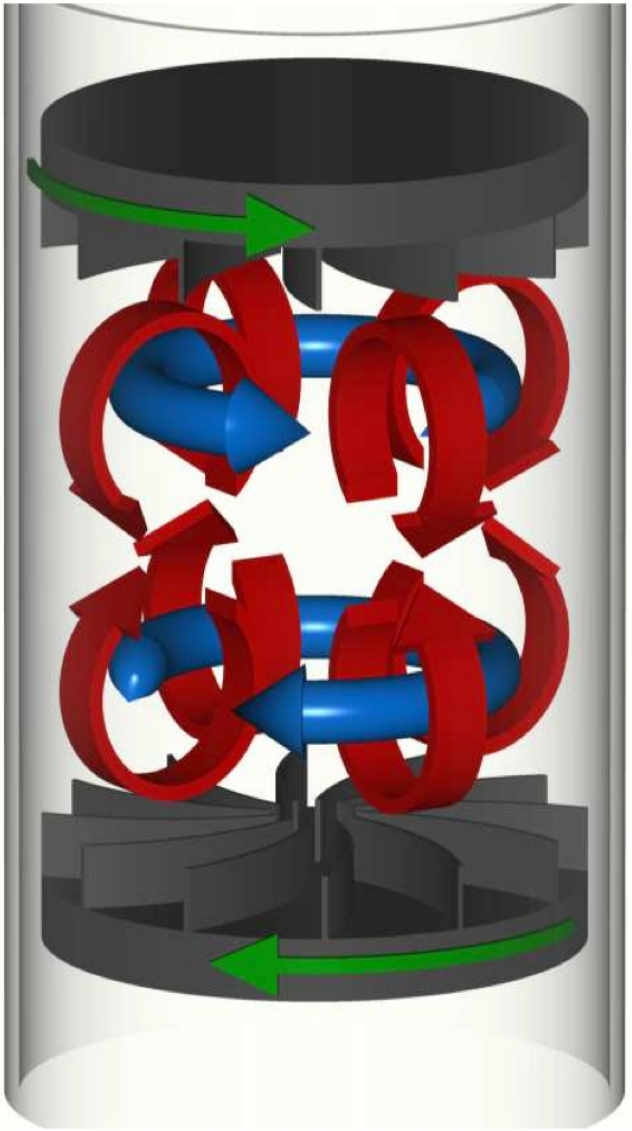


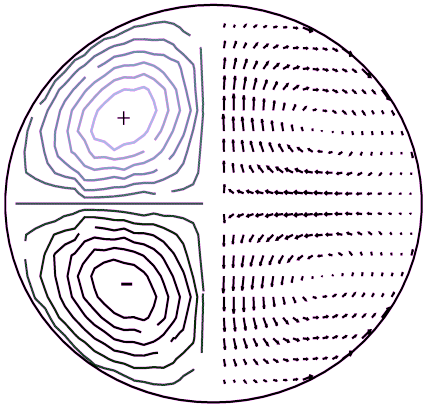




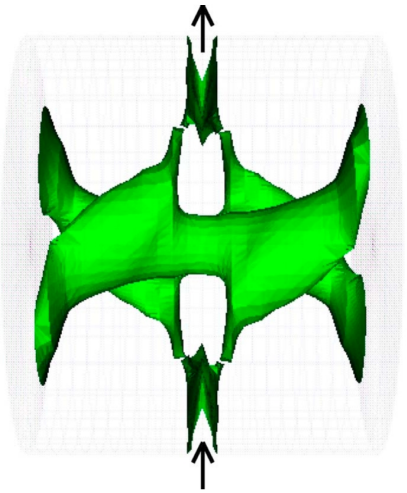



Dudley & James (1989)





S2t2 flows :
helicity + Diff-Rot

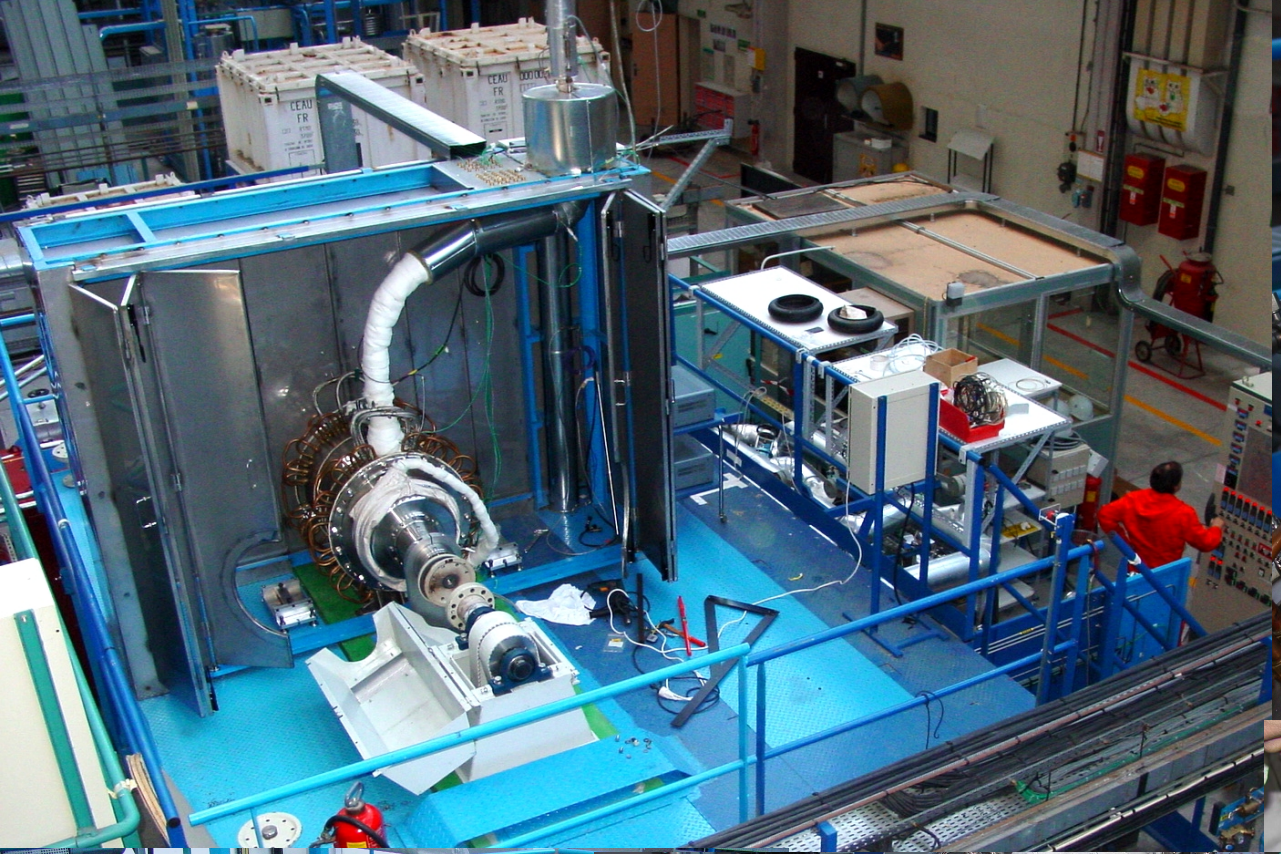
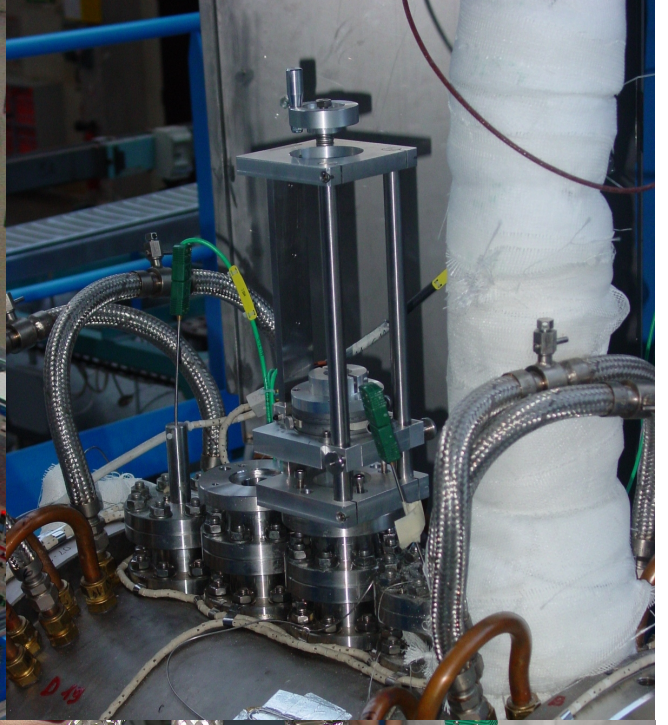
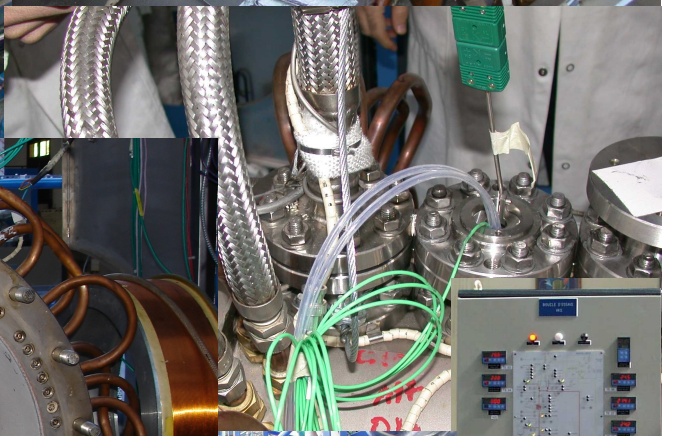
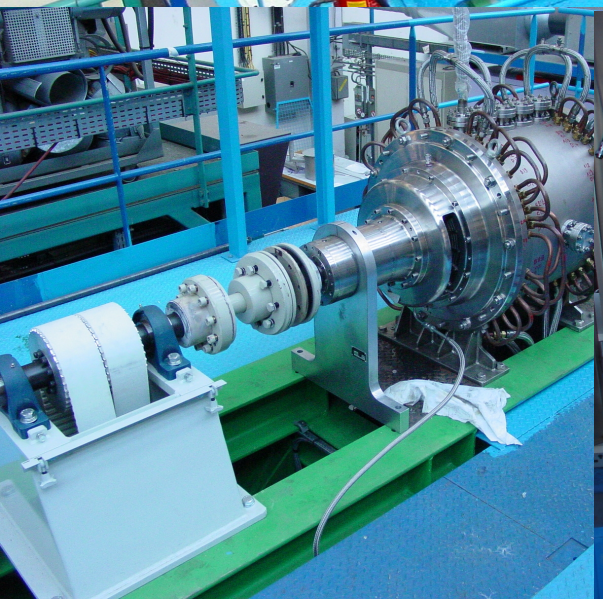
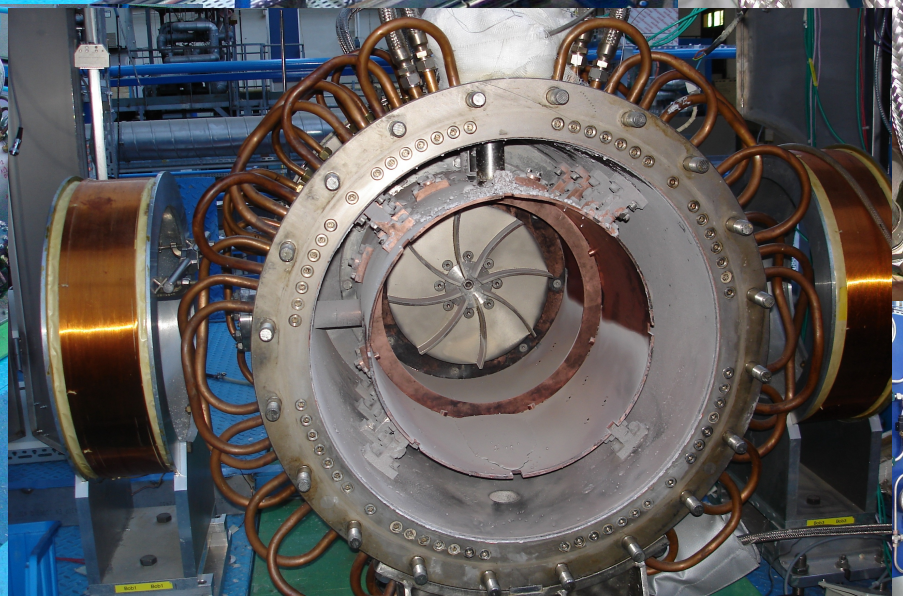


Kinematic dynamo (Ravelet et al. PoF, Vol.17, 2005)

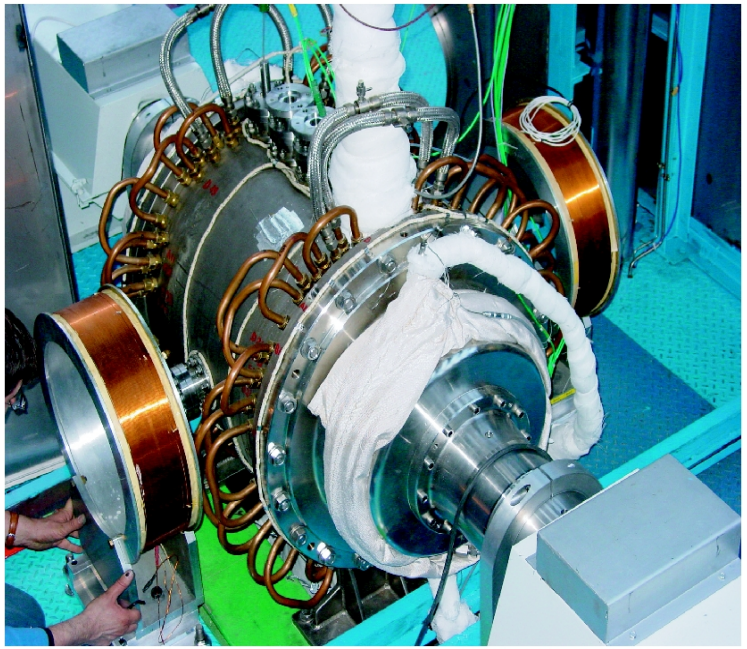
FIG. 14. Isodensity surface of magnetic energy (50% of the maximum) for the neutral mode without conducting layer (w=0). Cylinder axis is horizontal. Arrows stand for the external dipolar field source regions.



Y.Ponty

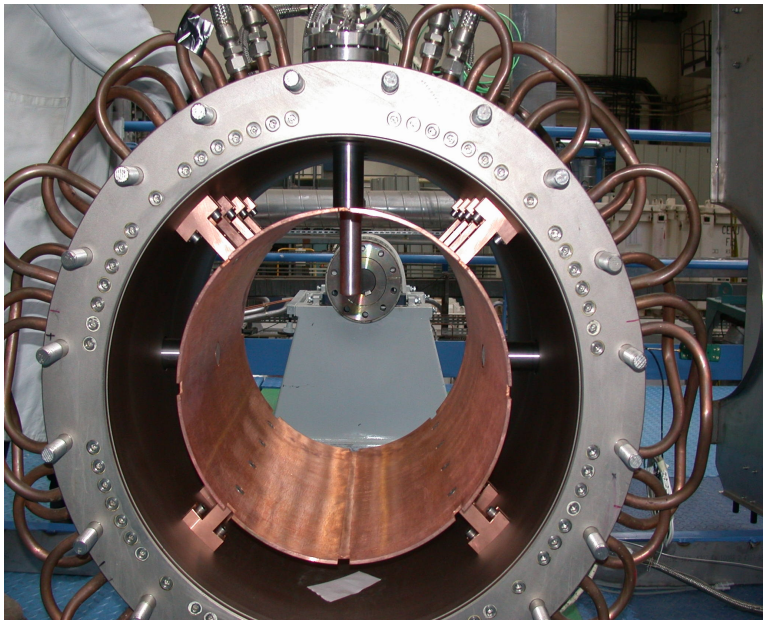

VKS experiments



Fluide : sodium
Taille : R=0.3 m
Puissance : 300 kW

$$R_m = \mu\sigma \left(\frac{PR}{\rho K_P}\right)^{1/3} \sim 10 - 50$$

VKS1 : 2000-2003
VKS2 : 1st run April '05

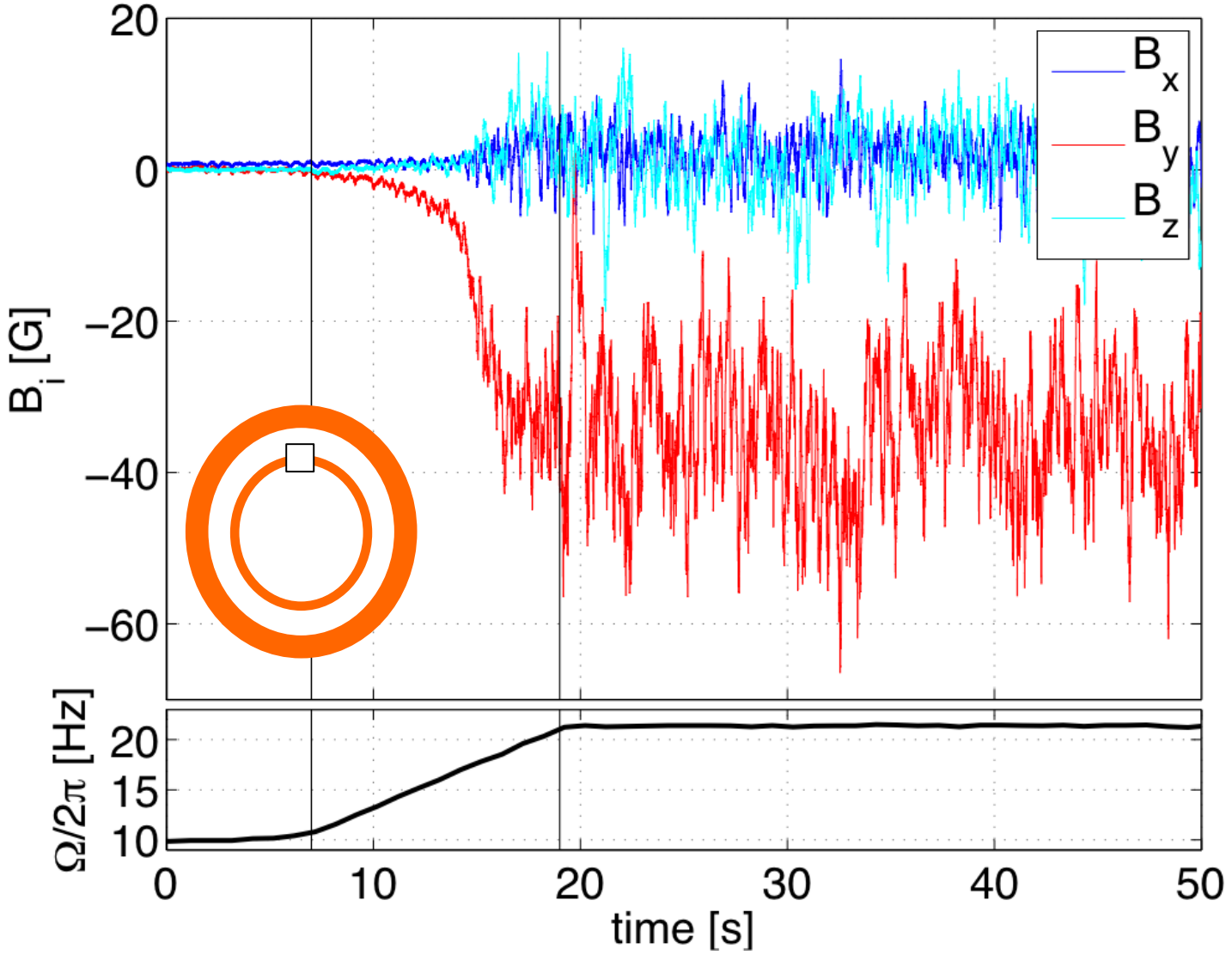


BALANCED REGIMES

$$F_1 = F_2$$

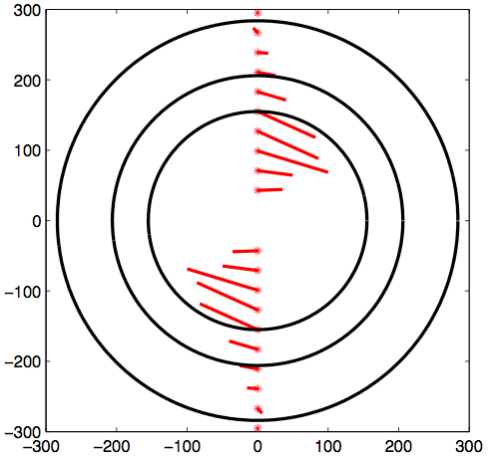
$$R_M > 32$$

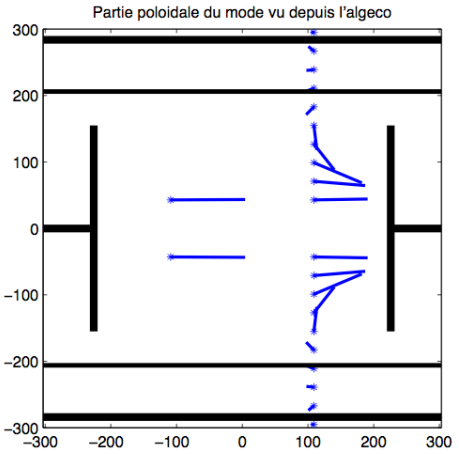
stationary dynamo $F_1 = F_2$

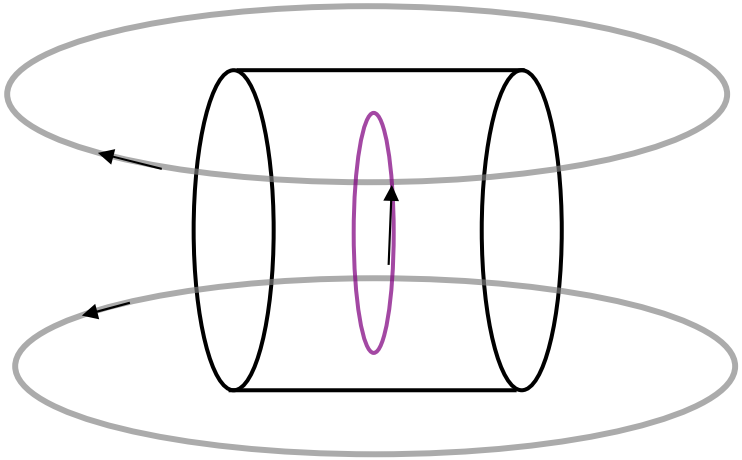


Monchaux et al., PRL, **98** (2007)

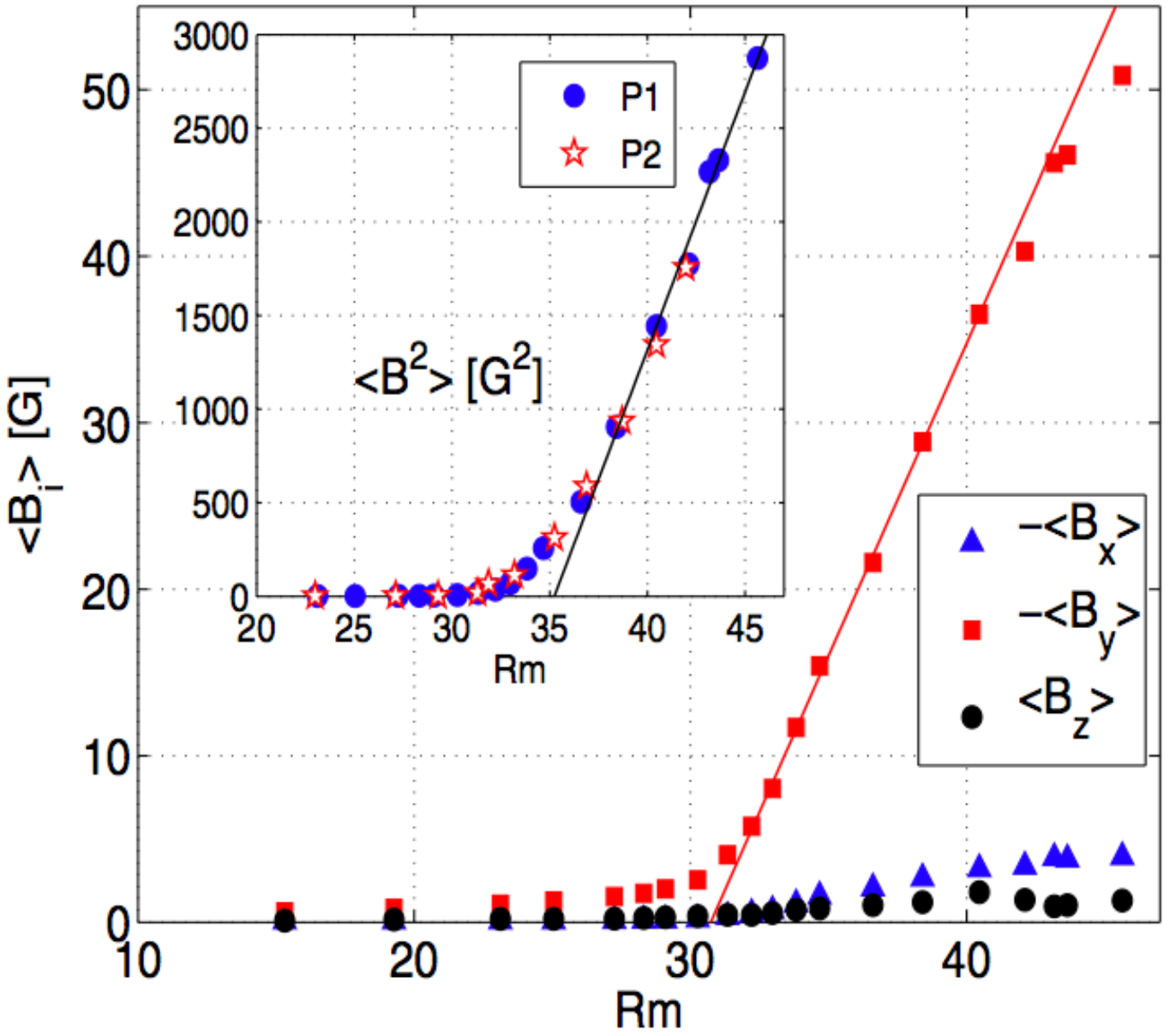
geometry


300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300

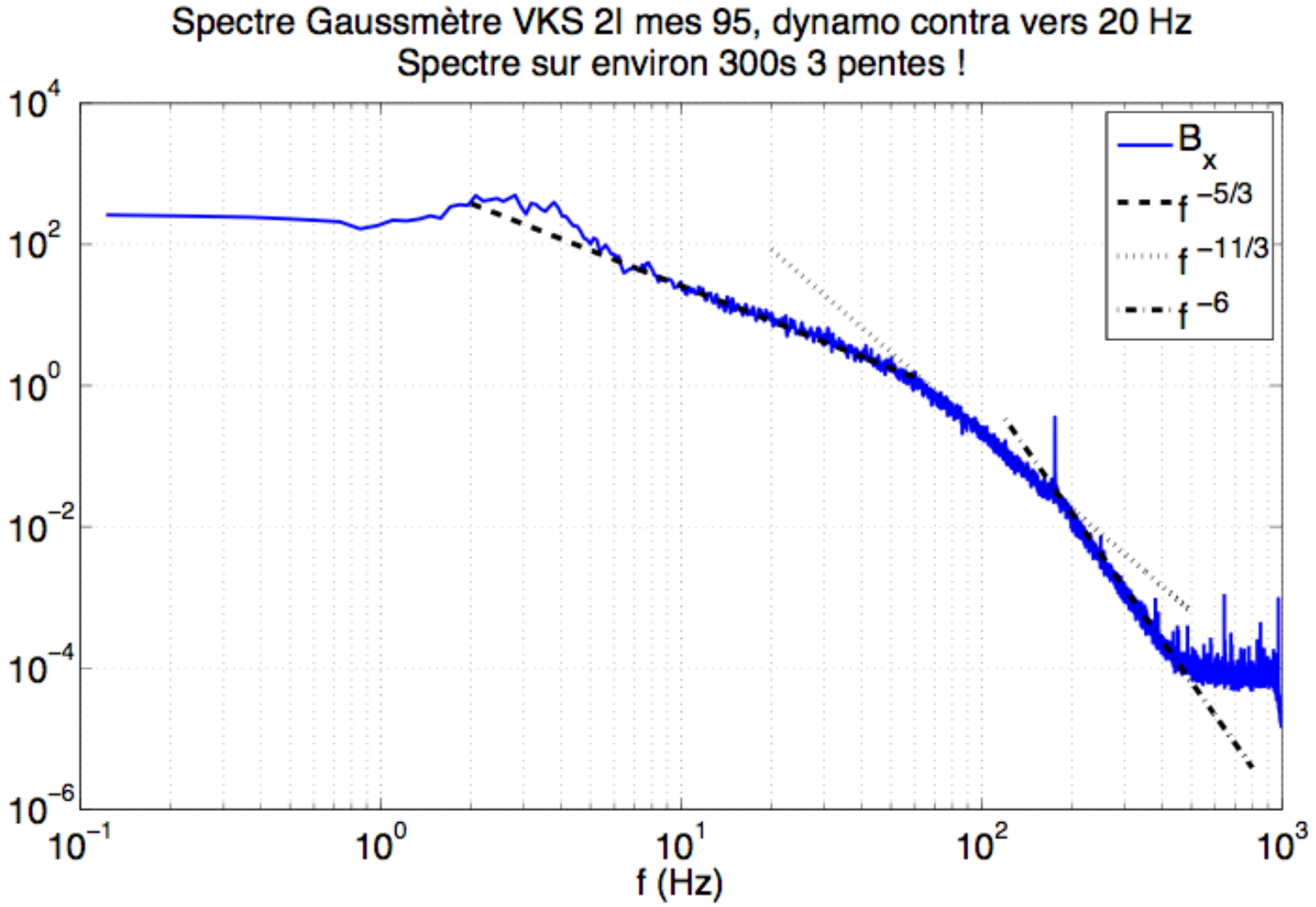

Partie poloidale du mode vu depuis l'algeco
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
300



bifurcation onset



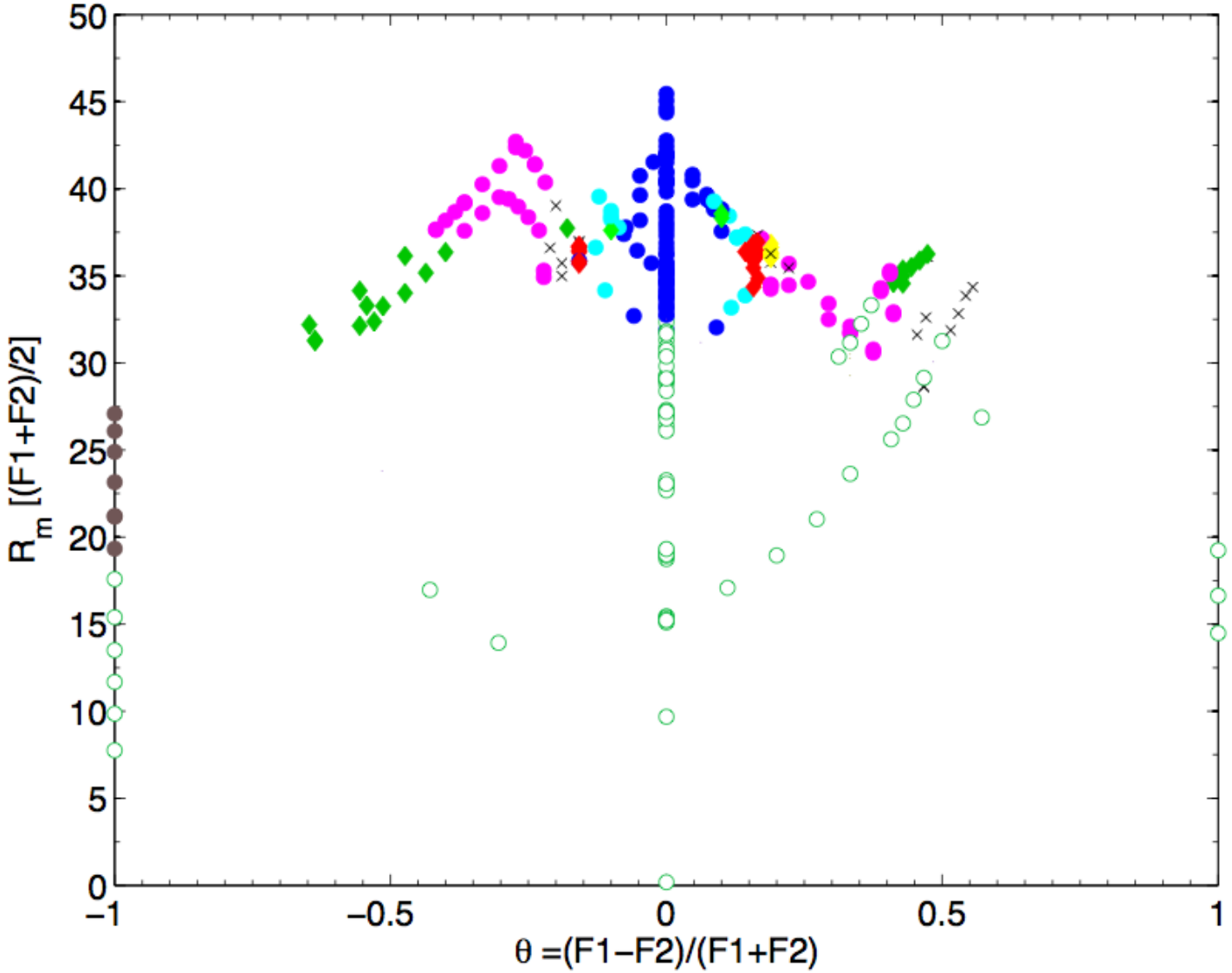
B fluctuations - VKS2i



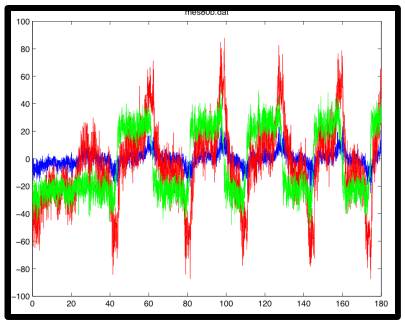
UNBALANCED REGIMES

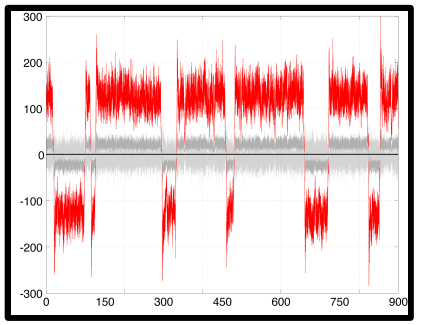
$$F_1 \neq F_2$$

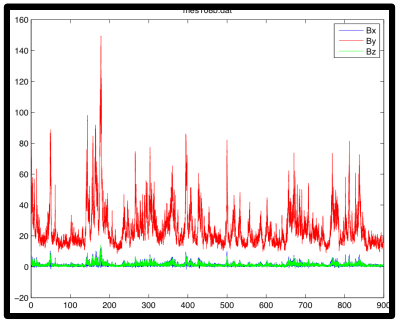
a phase space

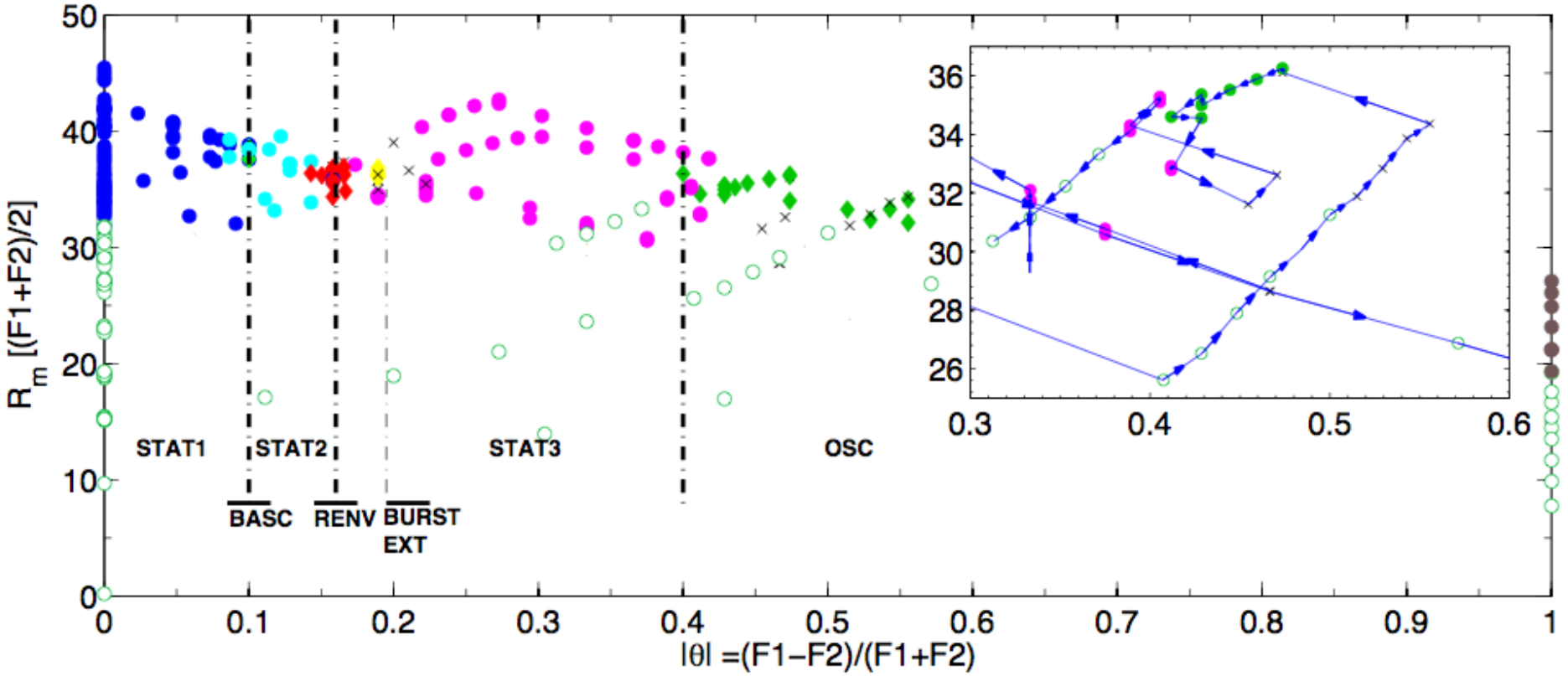


a variety of regimes

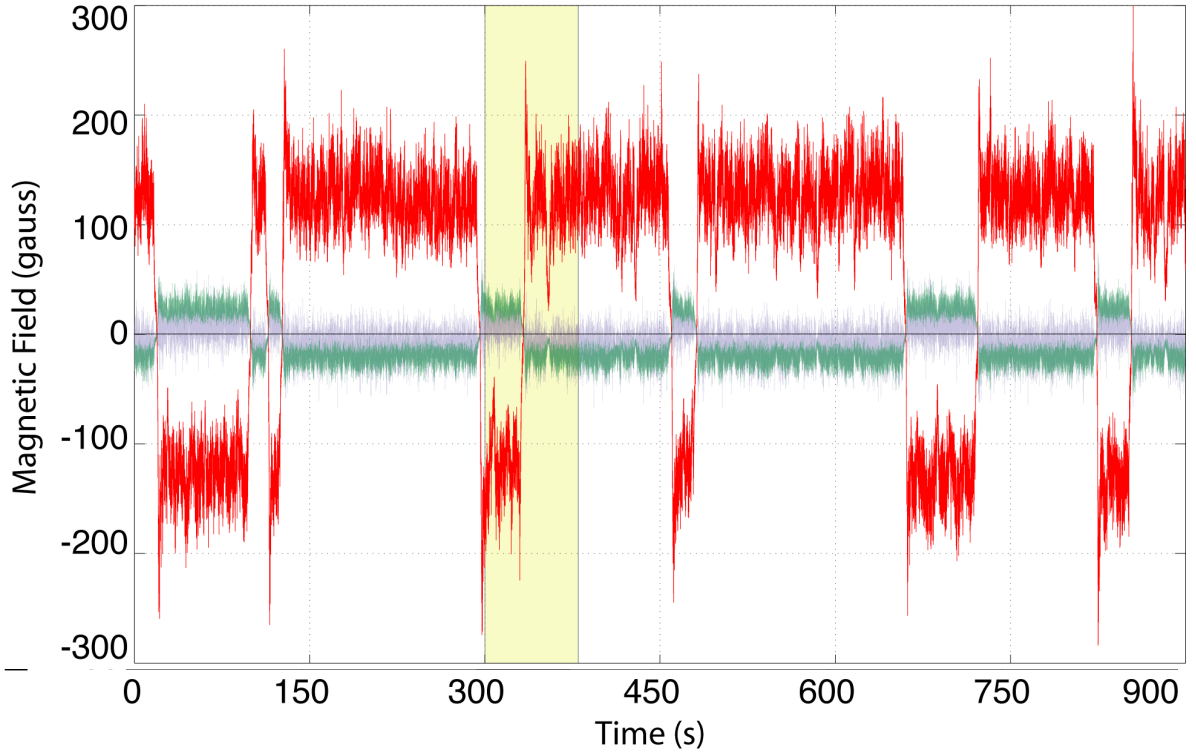






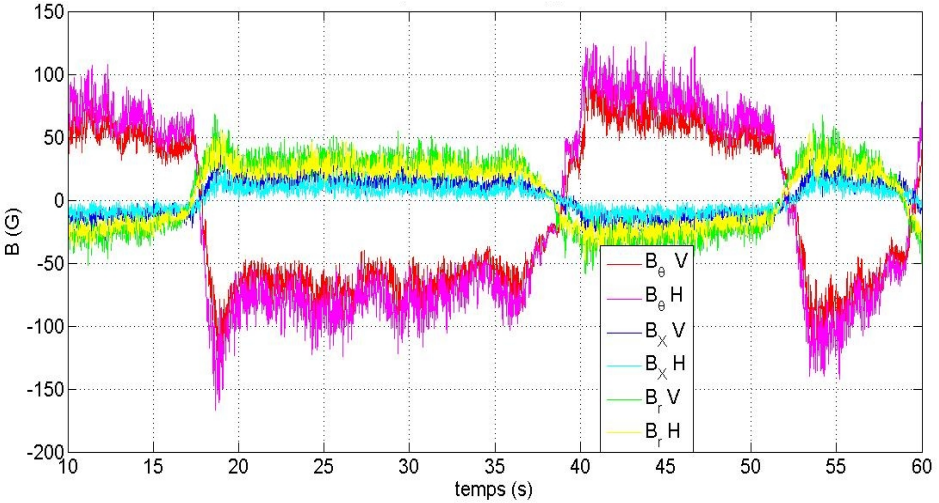


reversals



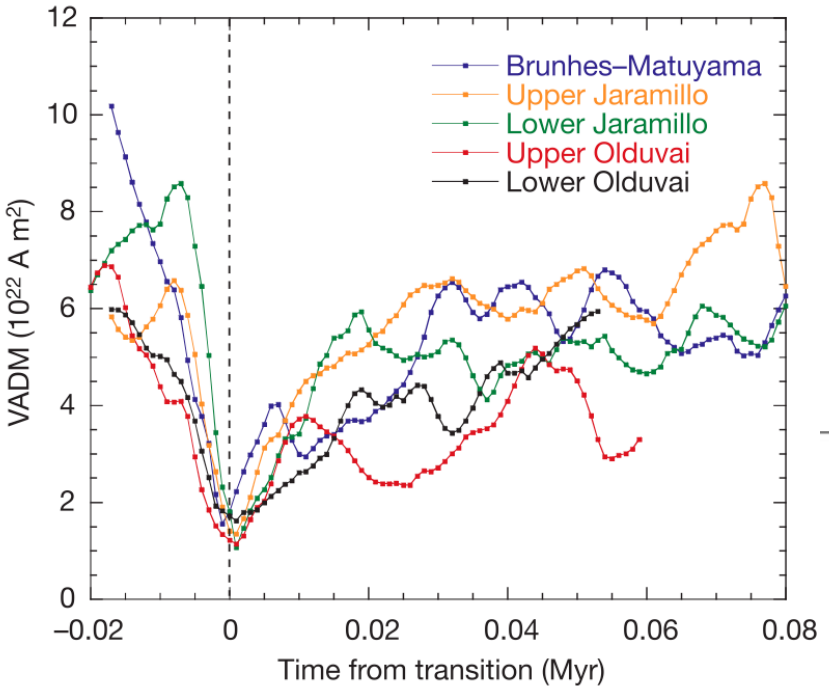
$\partial_t \mathbf{B} = \mathrm{rot}(\mathbf{u} \times \mathbf{B}) + \lambda \Delta \mathbf{B}$

sym **B** / -**B**

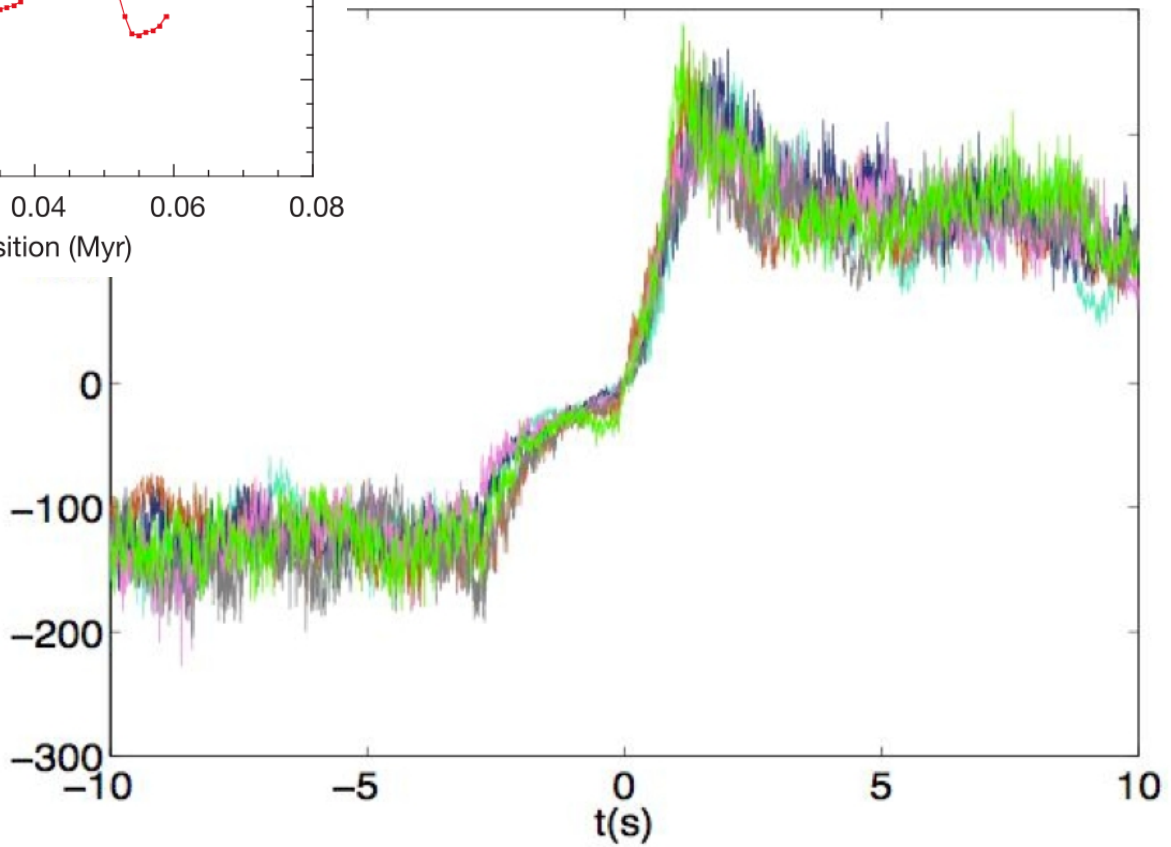


- $T_{dyn} \approx 100$ s
- $T_{rev} \approx 5$ s
- synchronous : **B** = 0

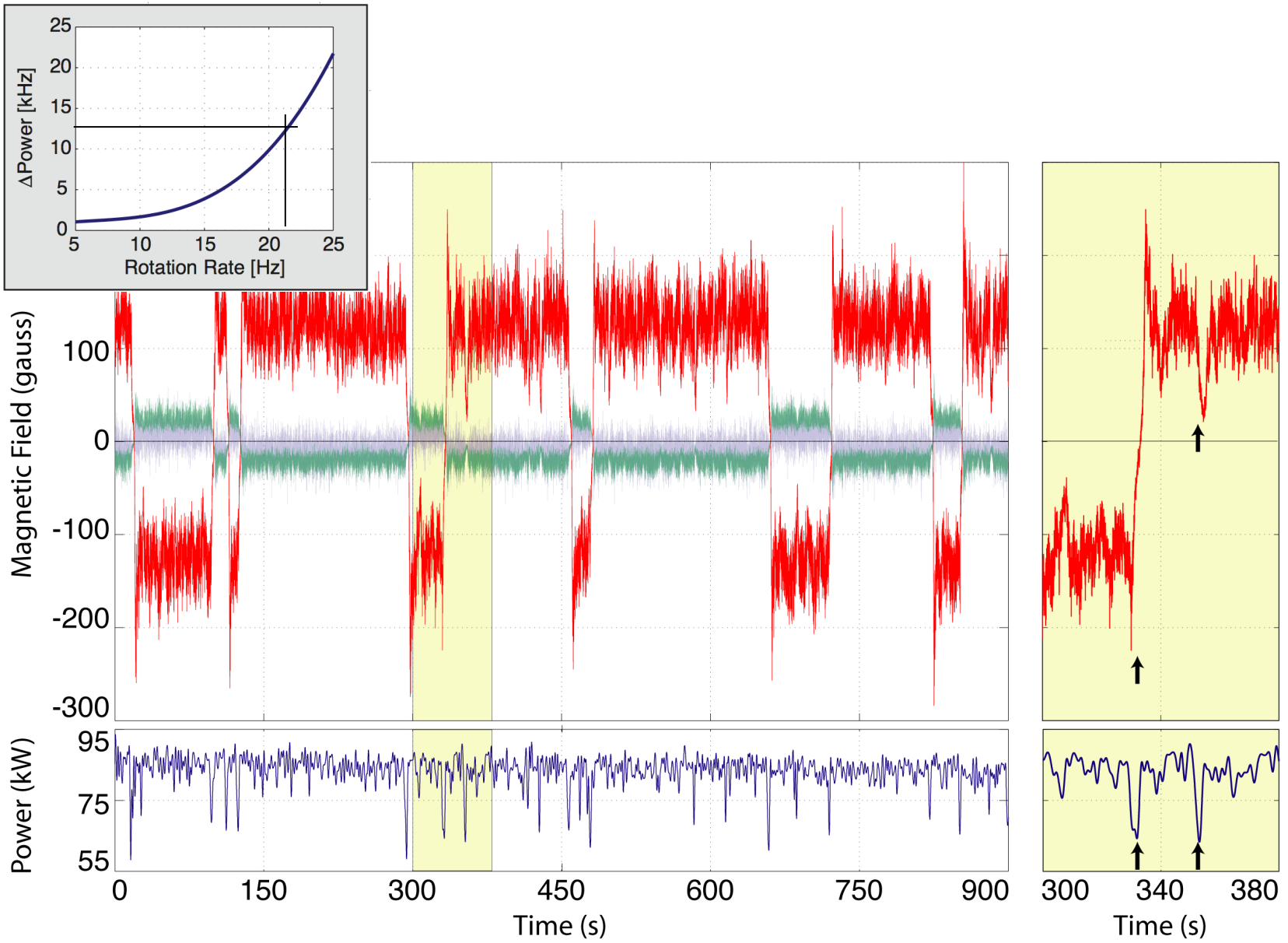
reversals



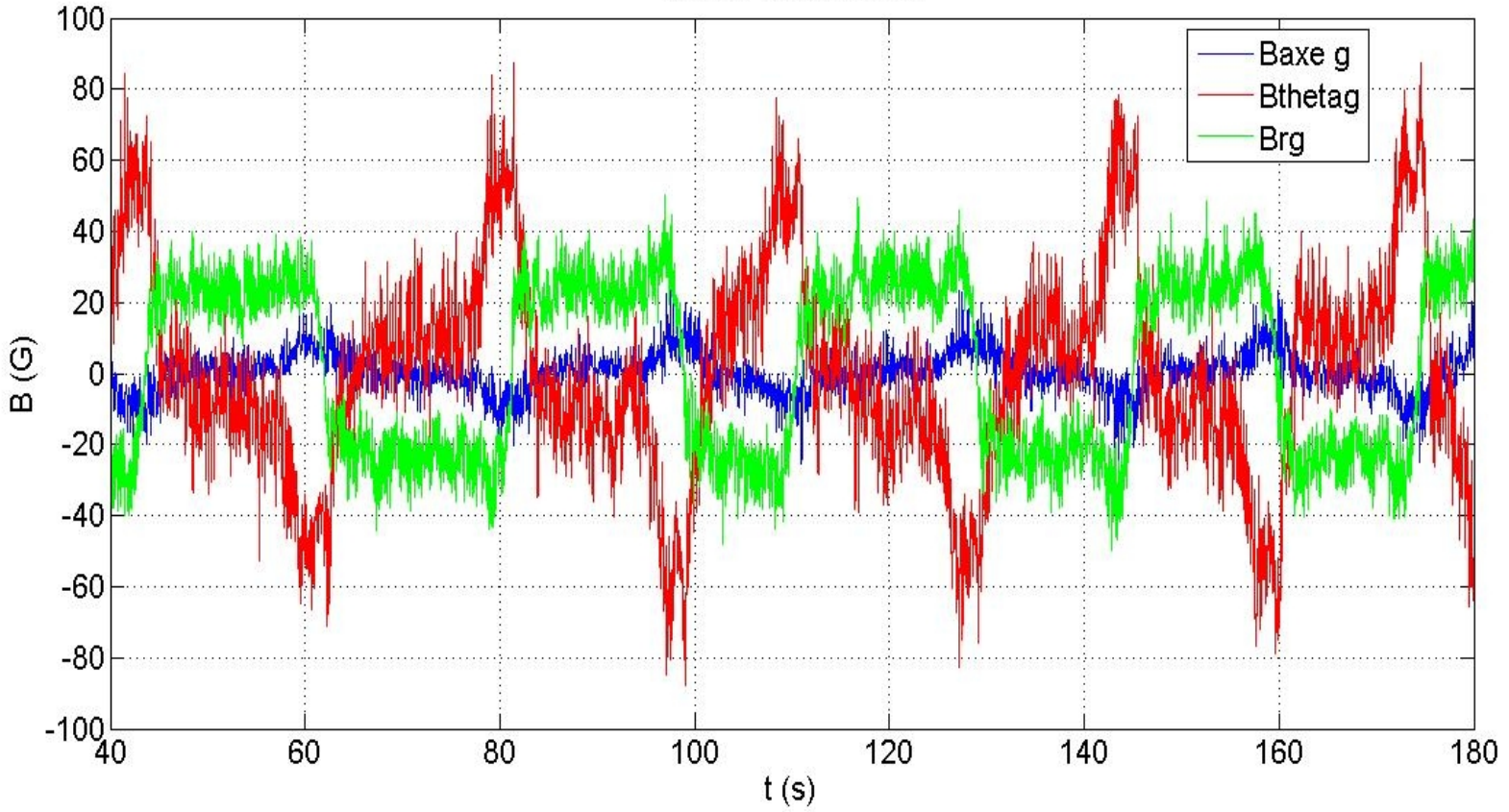
*Valet, Nature **435** (2005)*



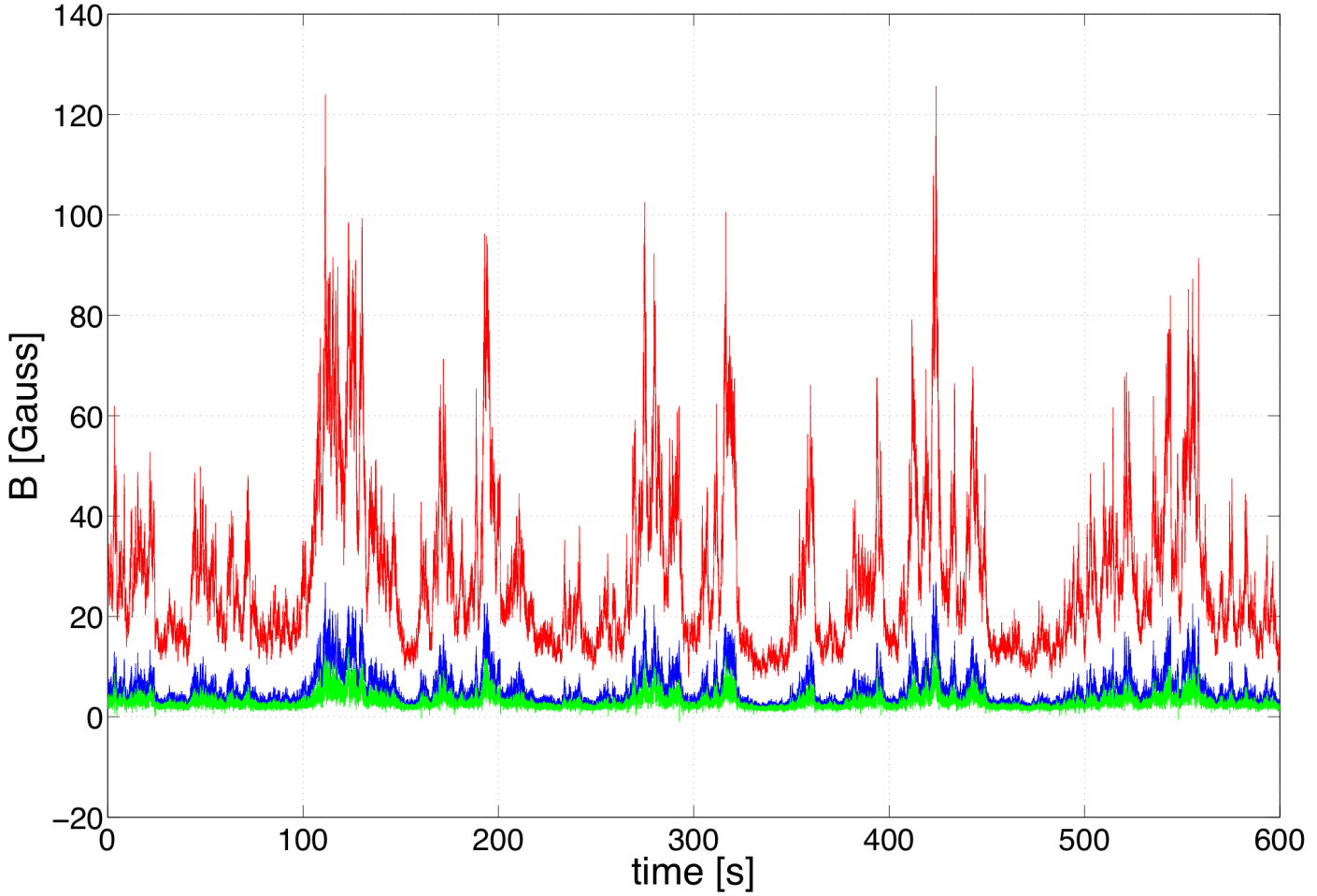
reversals and power



oscillating dynamos



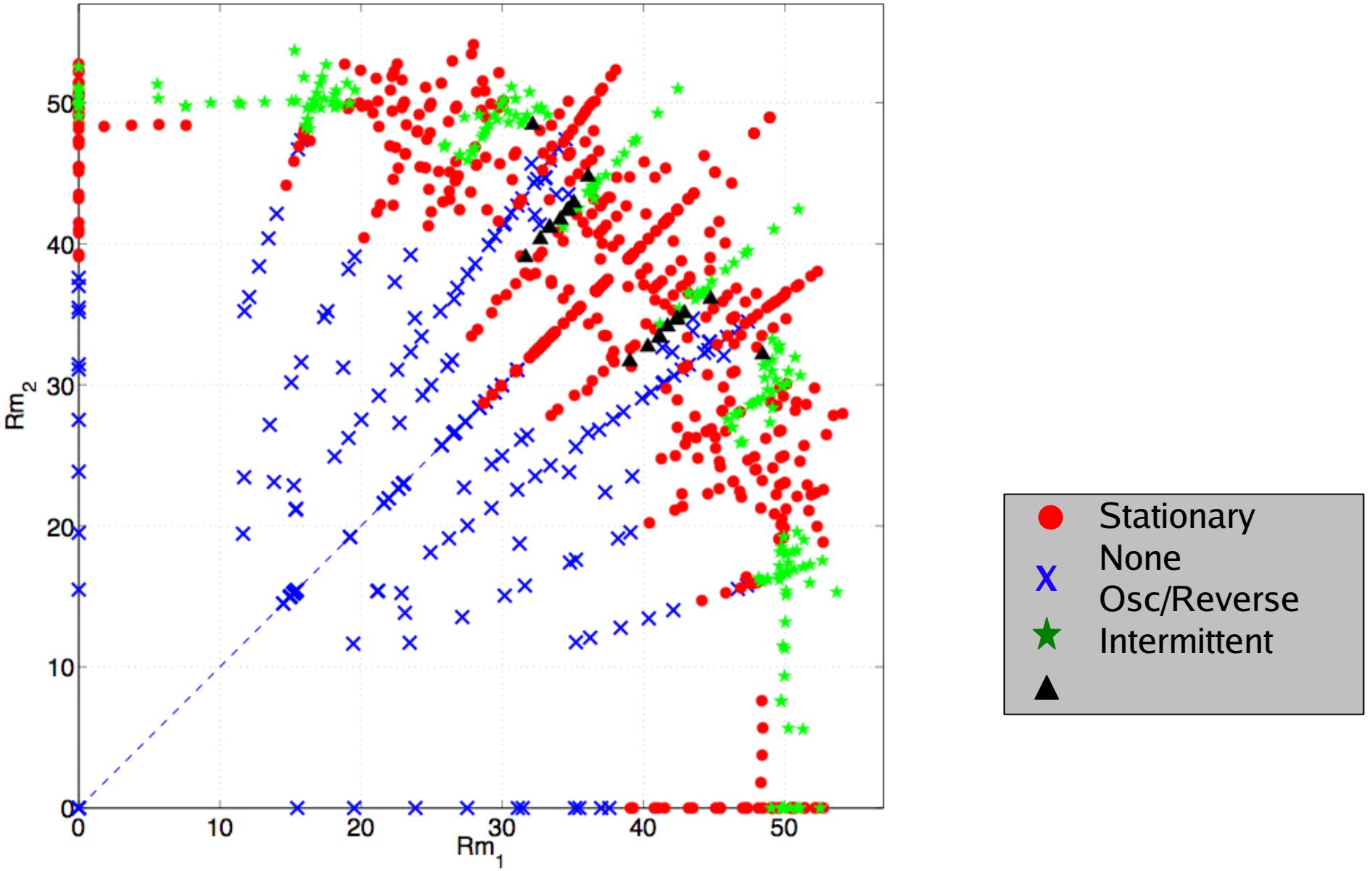
dynamo bursts



Flow without annulus in mid-plane

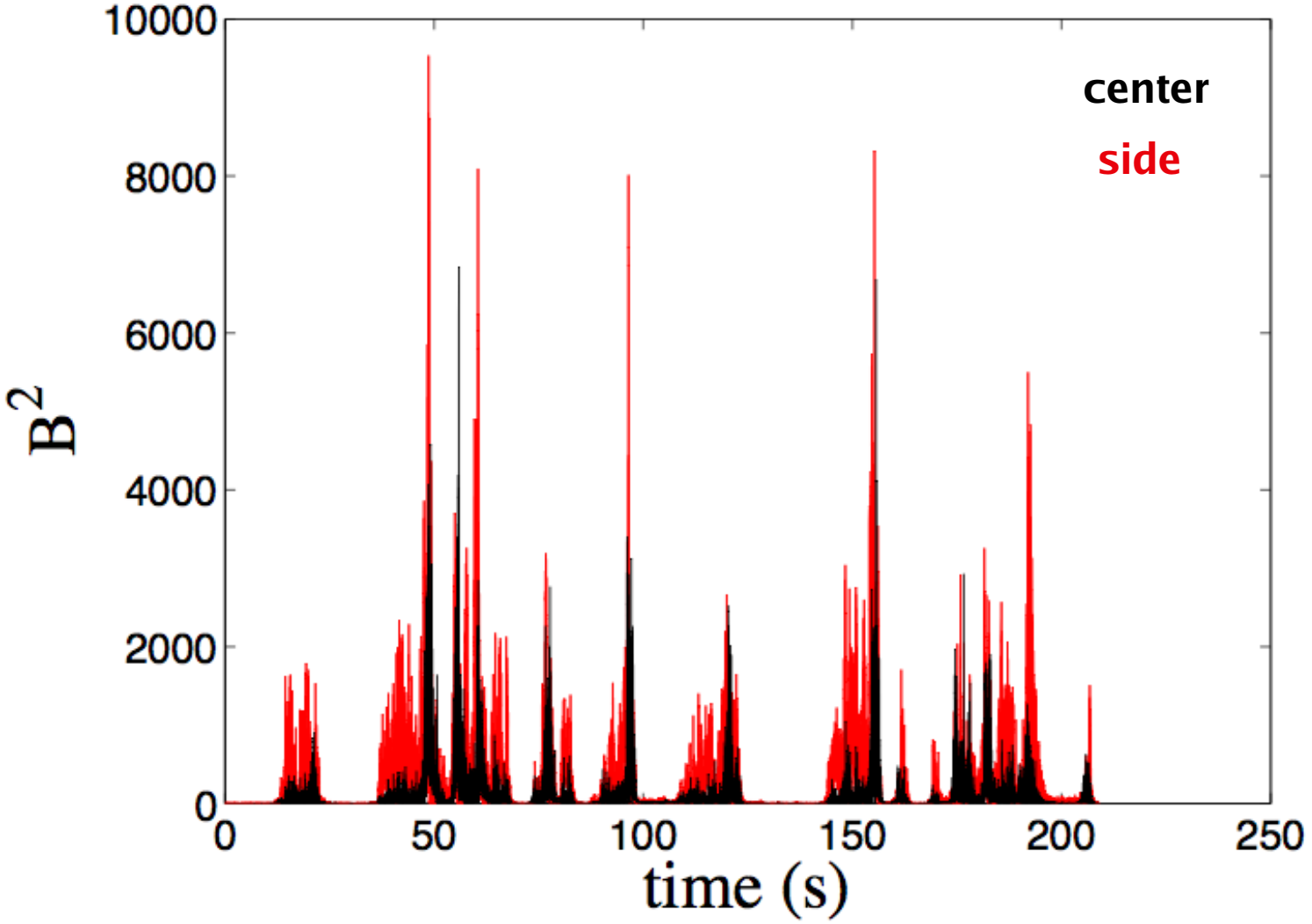
$$F_1 \neq F_2$$

a phase space



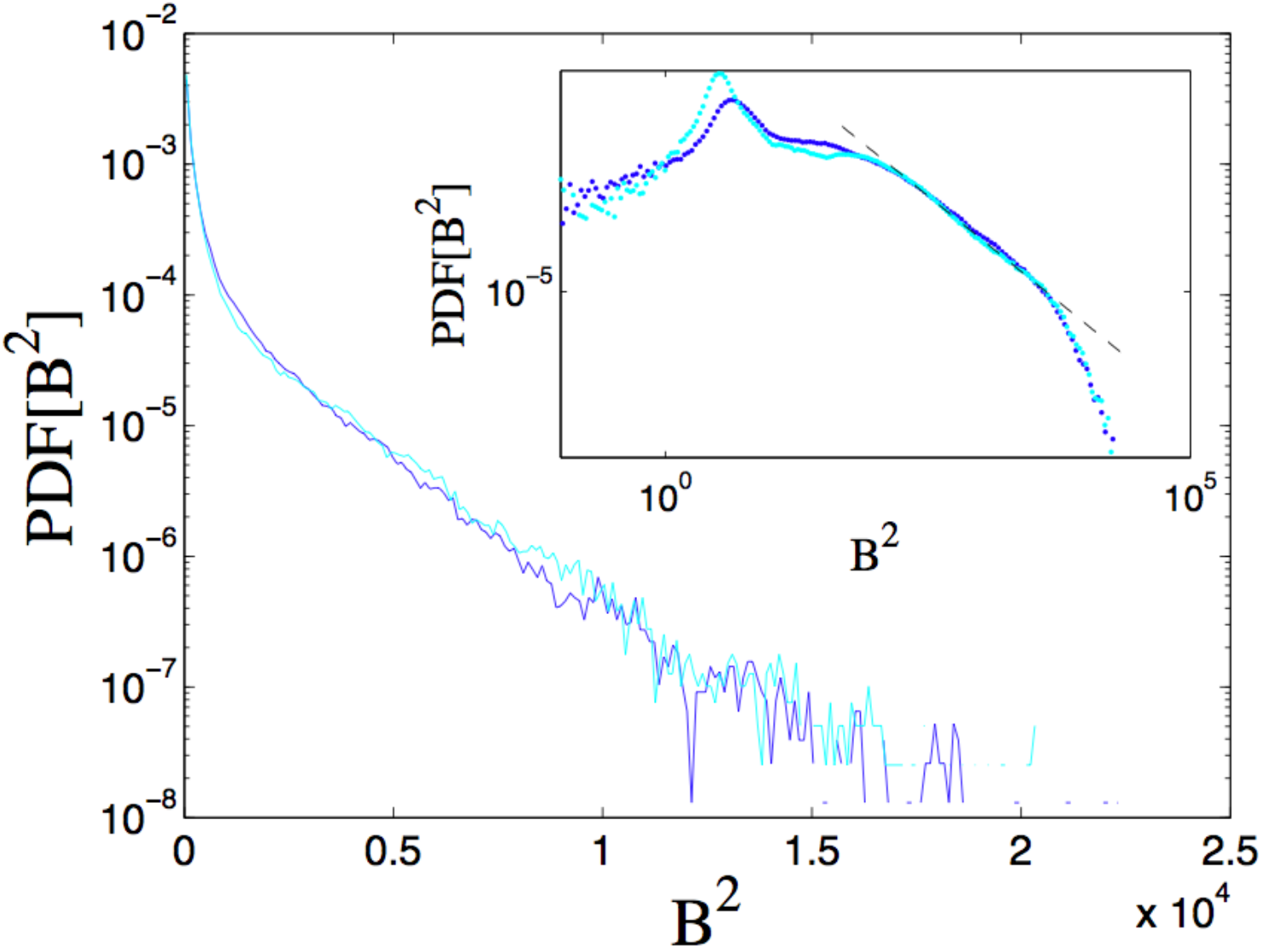
example of time signals

intermittent 18/22

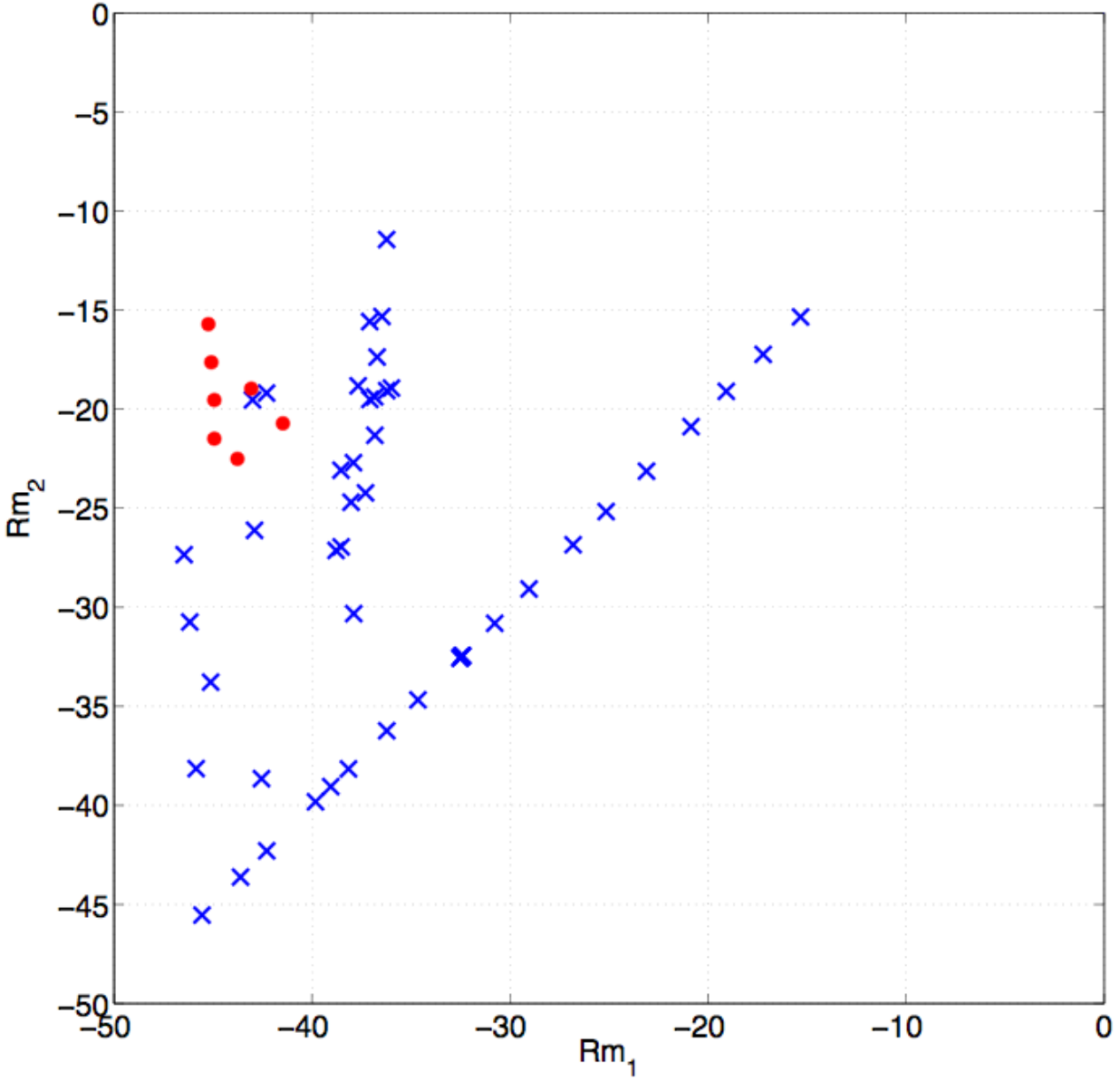


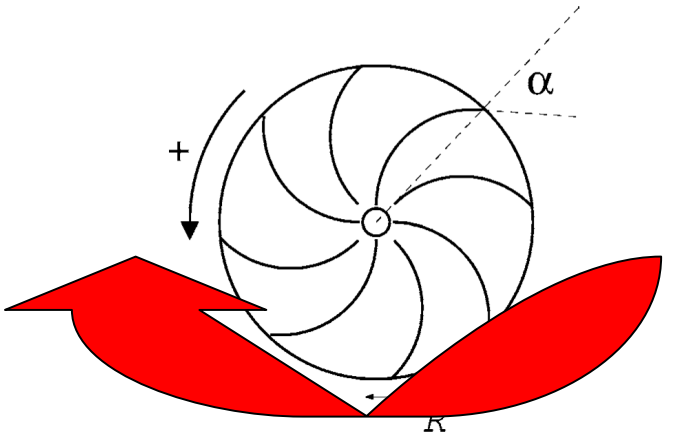
example of time signals

intermittent 18/22



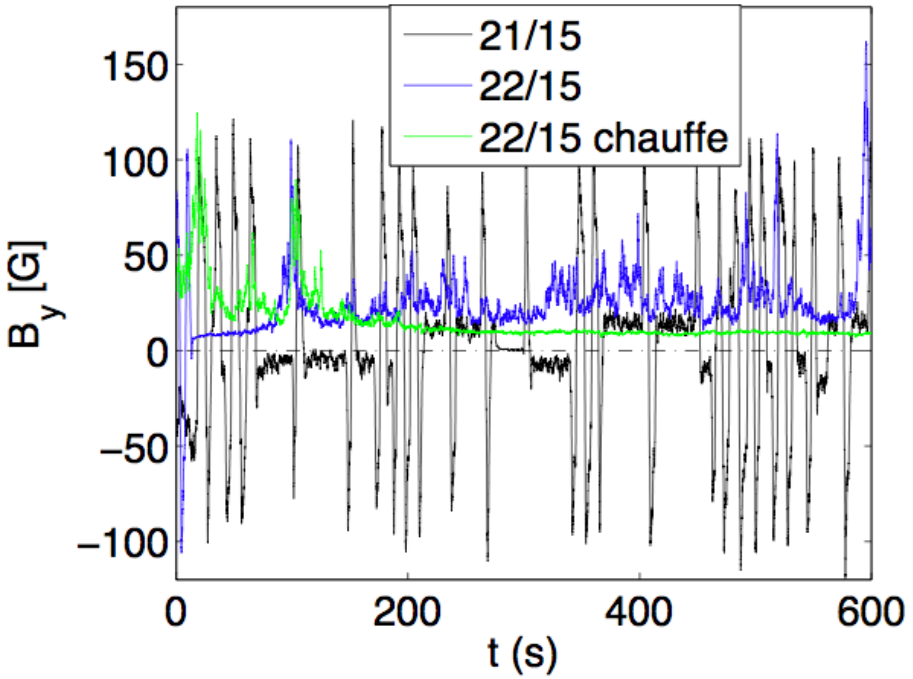
a phase space
“anti - contra”

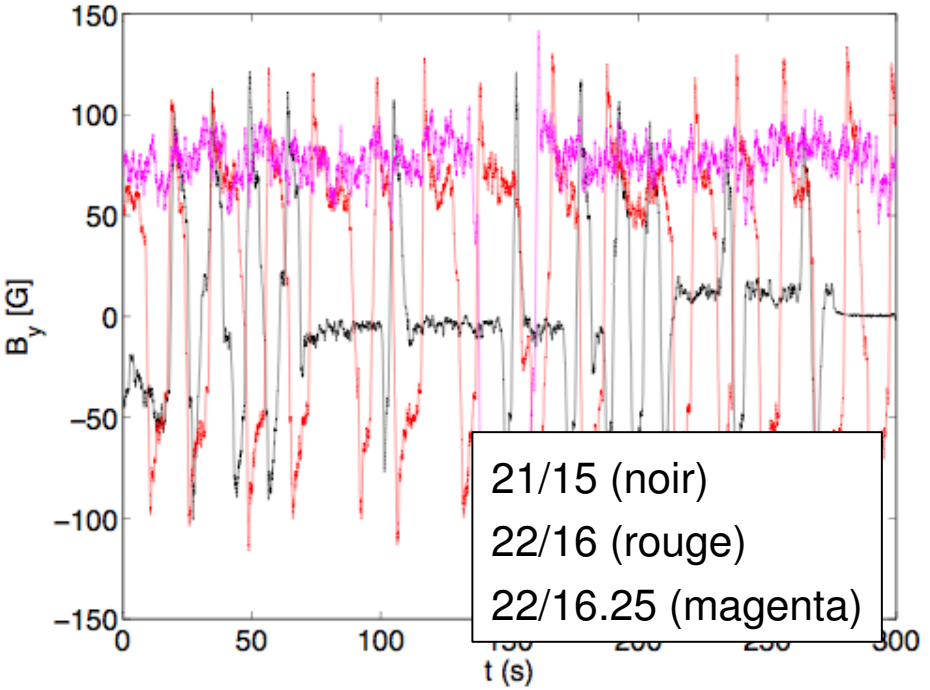




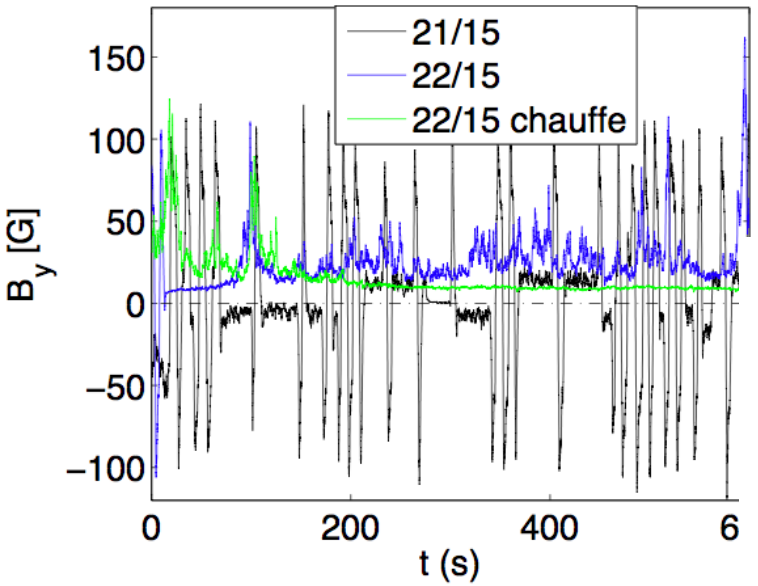
low dimensional chaos ?

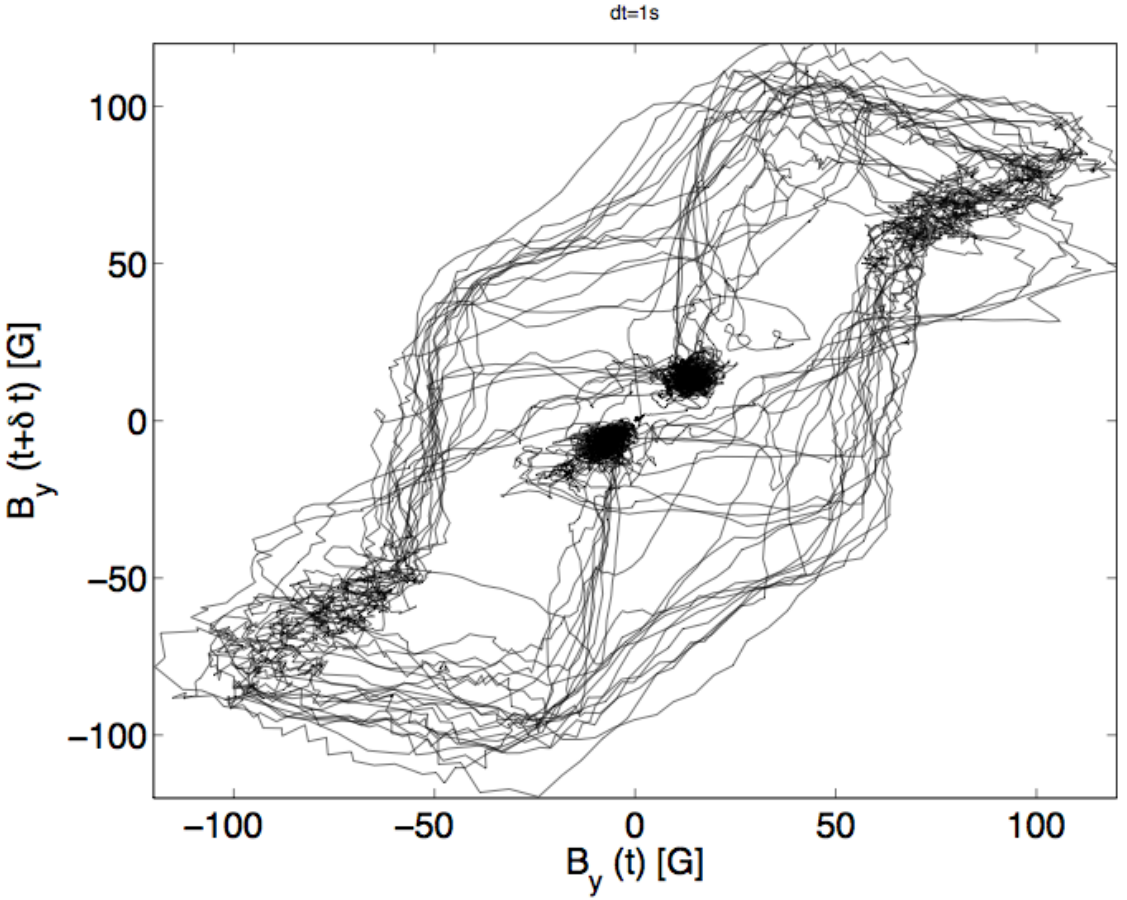
Neighbouring dynamical regimes



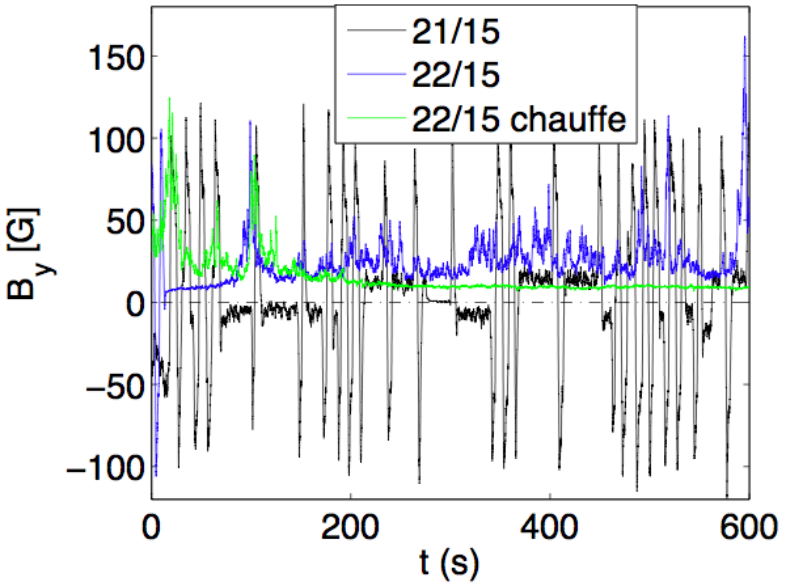


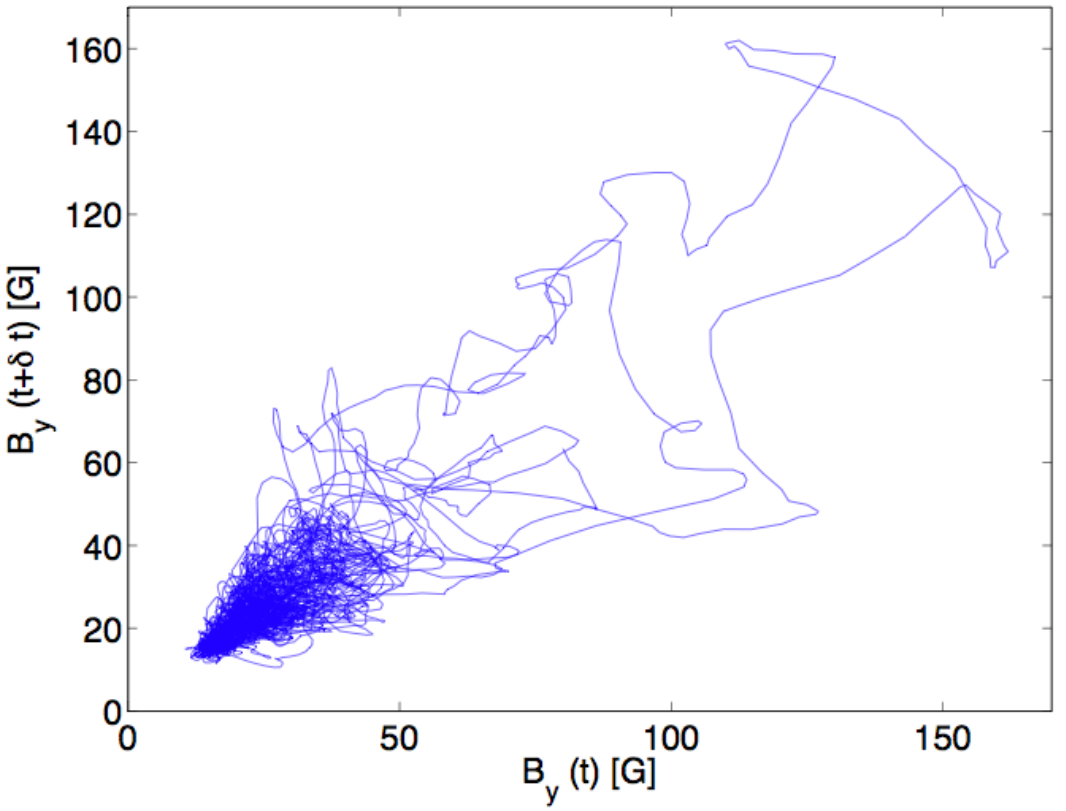
21/15: (-b,+b,-B,+B) paths



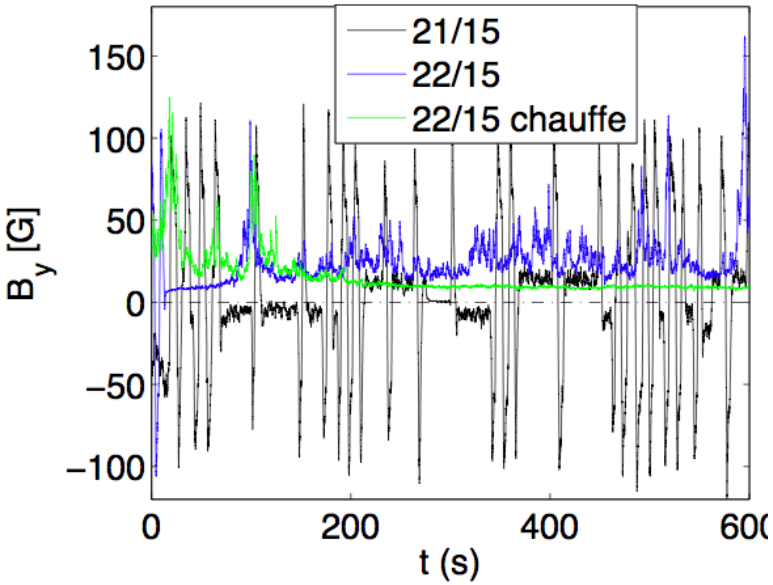


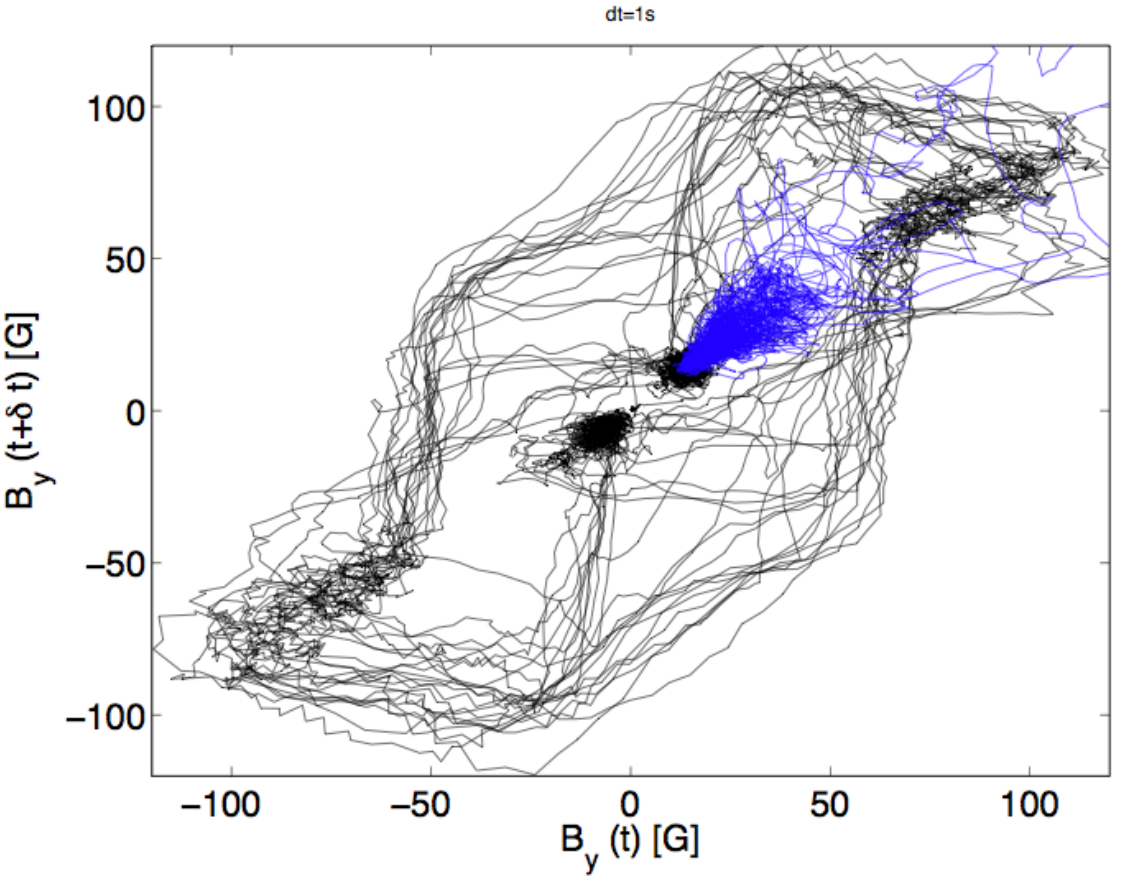
22/15: (b,B) bursts



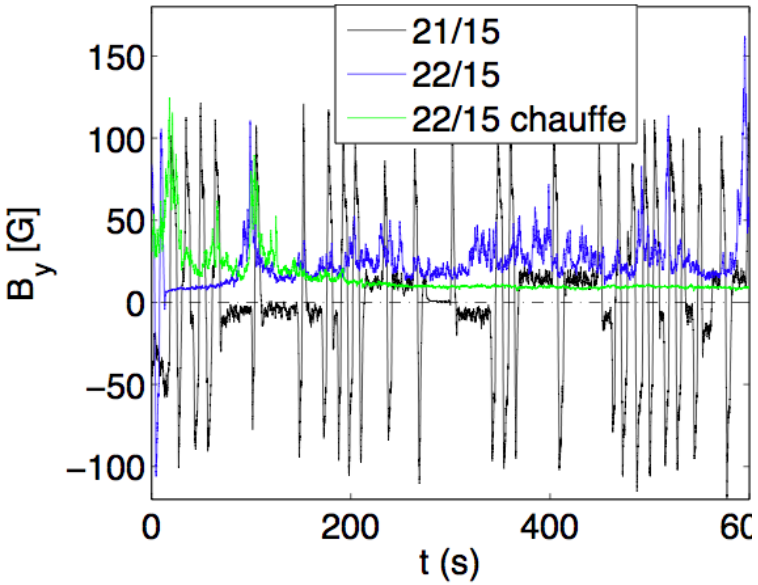


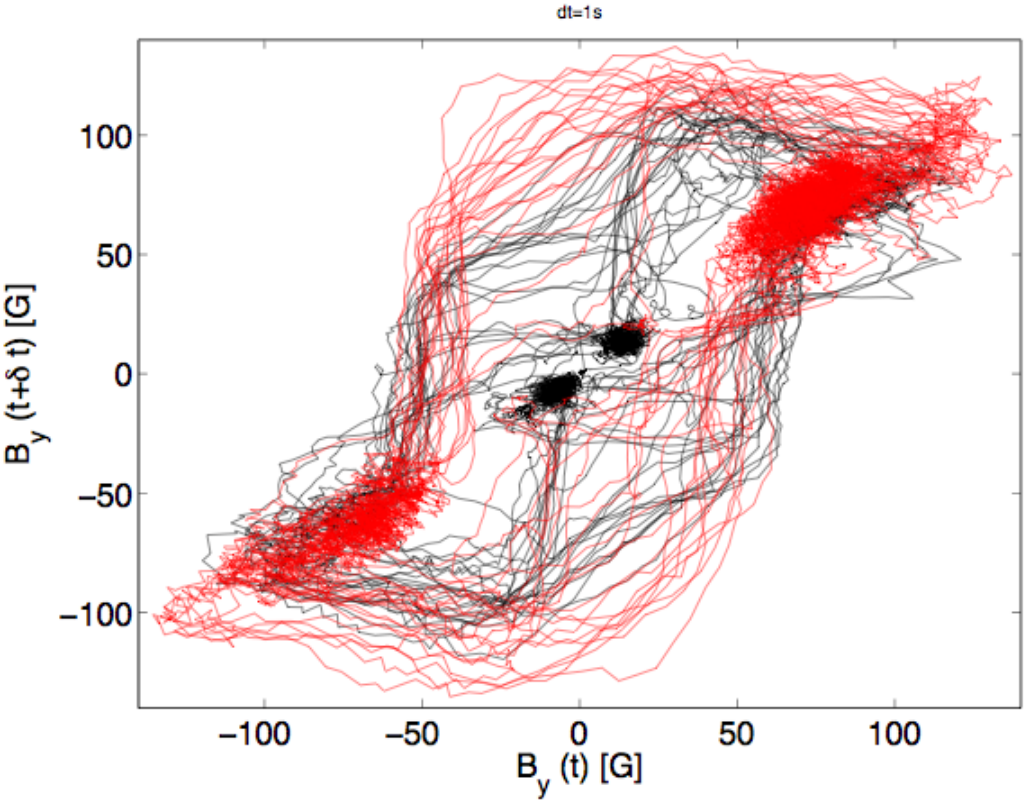
21/15 (b,B) and 22/15 (bursts)





22/15 (bursts) and 22/16 (reversals)





Conclusion :

Low magnetic Prandtl number : A difficult limit for numeric but an important physical regime. Re = 10^5 Rm

Mean flow dynamo versus the fluctuation dynamo

Experimental Dynamo and MHD in metal liquid:

A gate for the astrophysical objects understanding

* rich dynamical system
  - periodic dynamo solution (solar cycle)
  - reversal, excursion behavior (earth, telluric planet)
  - bust dynamo, on-off intermittency