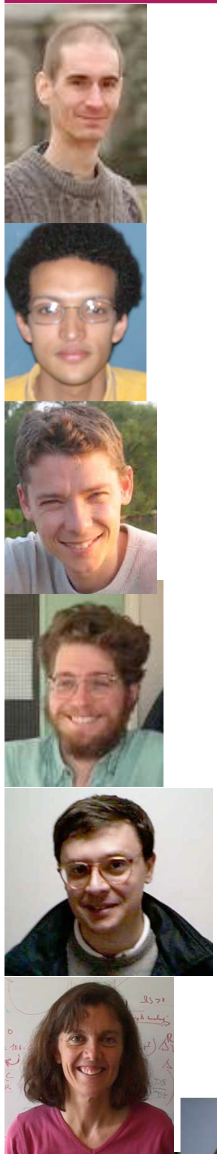


VKS experiment stationary dynamo

Groupe Instabilités et Turbulence, CEA-Saclay

A. Chiffaudel, F. Daviaud, B. Dubrulle,

L. Marié, R. Monchaux, F. Ravelet,

C. Gasquet, V. Padilla

Laboratoire de Physique Statistique ENS-Paris

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

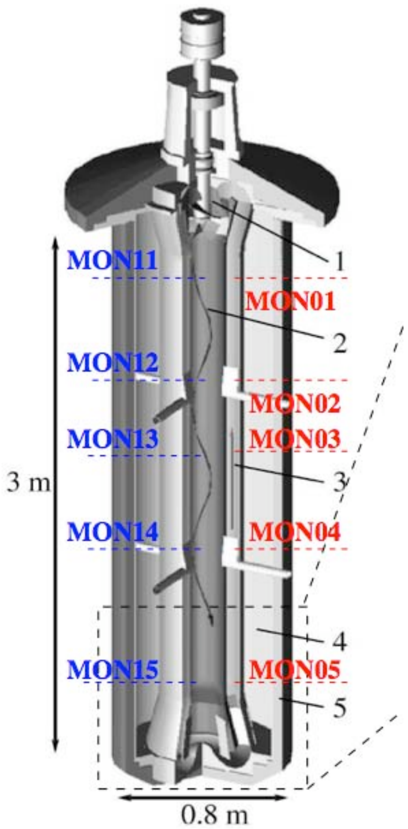
D. Courtiade, J.-F. Point

Laboratoire de Physique ENS-Lyon

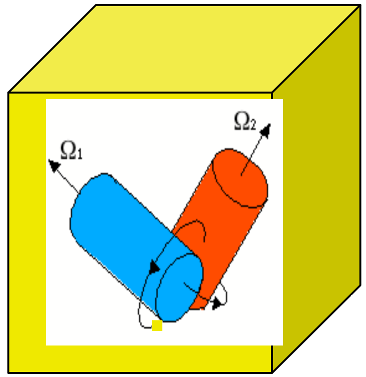
M. Bourgoin, R. Volk P. Odier, J.-F. Pinton, N. Plihon,

M. Moulin, P. Metz

Dynamo experiments



- Lowes & Wilkinson solid rotors (1963) (ω^2)
- Riga experiment (2000) (Ponomarenko flow)
- Karlsruhe experiment (2000) (Roberts flow)



sodium experiments

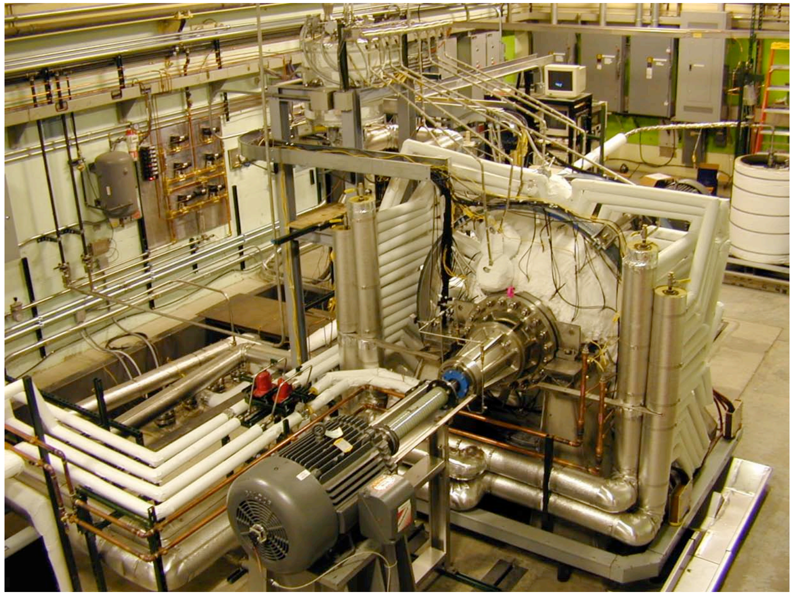
- U. Maryland
  (shear, spherical couette)

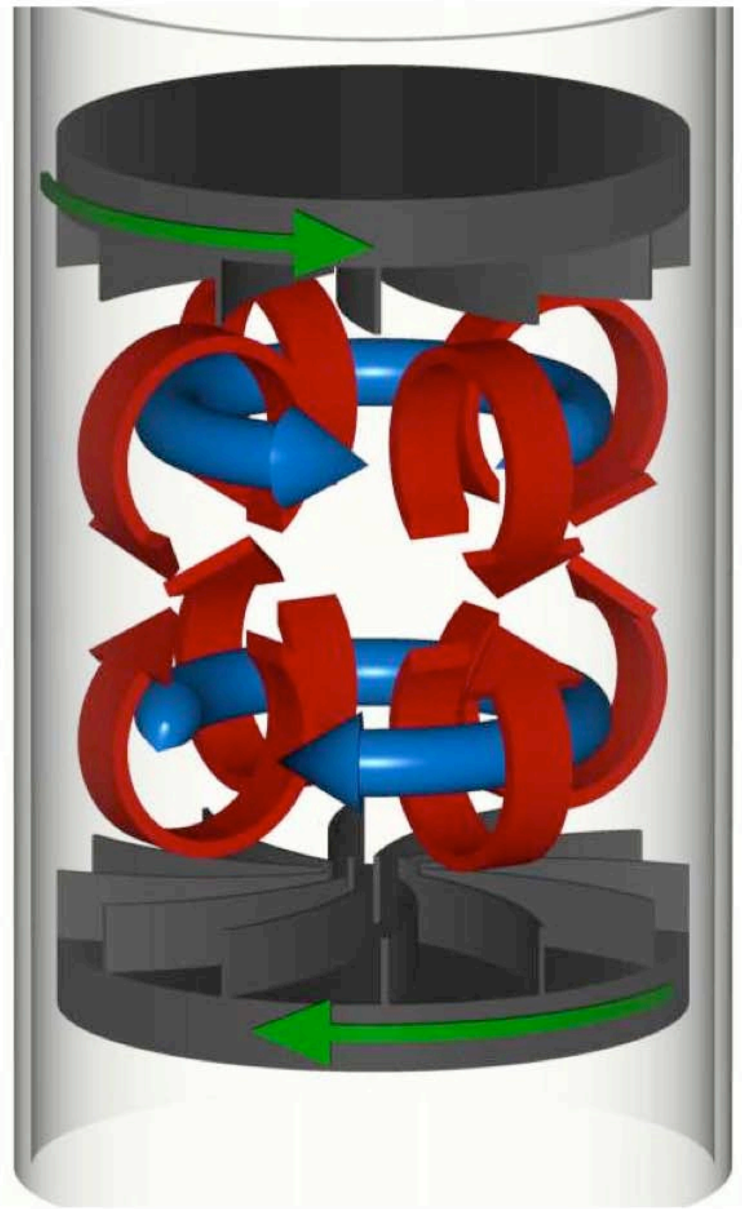
- U. Wisconsin
  (spherical 'VK' flow)

- Grenoble-DTS
  (spherical Couette)

- Dresden
  (cylindrical Couette)

- Perm
  (spin-down torus)





- Inductions ingredients:
  diff Rot, helicity
  Moffat, Cambridge UP, (1978)

- Kinematic dynamo simulation
  Duddley James, Proc. R. Soc. Lond. **A425** (1989)
  Marié et al., *Eur. Phys. J* **B33** (2003)

- DNS (P_m=1 down to 0.01)
  Nore et al., *Phys. Plasmas*, **4**, (1997)

- Induction equation

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

- Fluid equation

$$\partial_t \vec{u} + (\vec{u} \cdot \vec{\nabla})\vec{u} = -\vec{\nabla}\frac{p}{\rho} + \nu \Delta \vec{u} + \frac{(\vec{\nabla} \times \vec{B}) \times \vec{B}}{\mu_0 \rho} + \vec{F}$$

- Dimensionless parameters

$$P_m = \frac{\nu}{\eta} = \mu_0 \sigma \nu \sim \mathcal{O}(10^{-6})$$

$$R_m = \frac{\text{induction}}{\text{diffusion}} = \mu_0 \sigma U L \geq \mathcal{O}(1)$$

$$Re = \frac{\text{inertia}}{\text{viscosity}} = \frac{UL}{\nu} \sim \mathcal{O}(10^6)$$

Fluid dynamos : Rm > Rm^c

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

$\mu_0\sigma$: fluid

$L\,U$: 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

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

$Pm \approx 10^{-5}$ $Re > 10^{6}$: 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 : $g(Re) \rightarrow$ 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

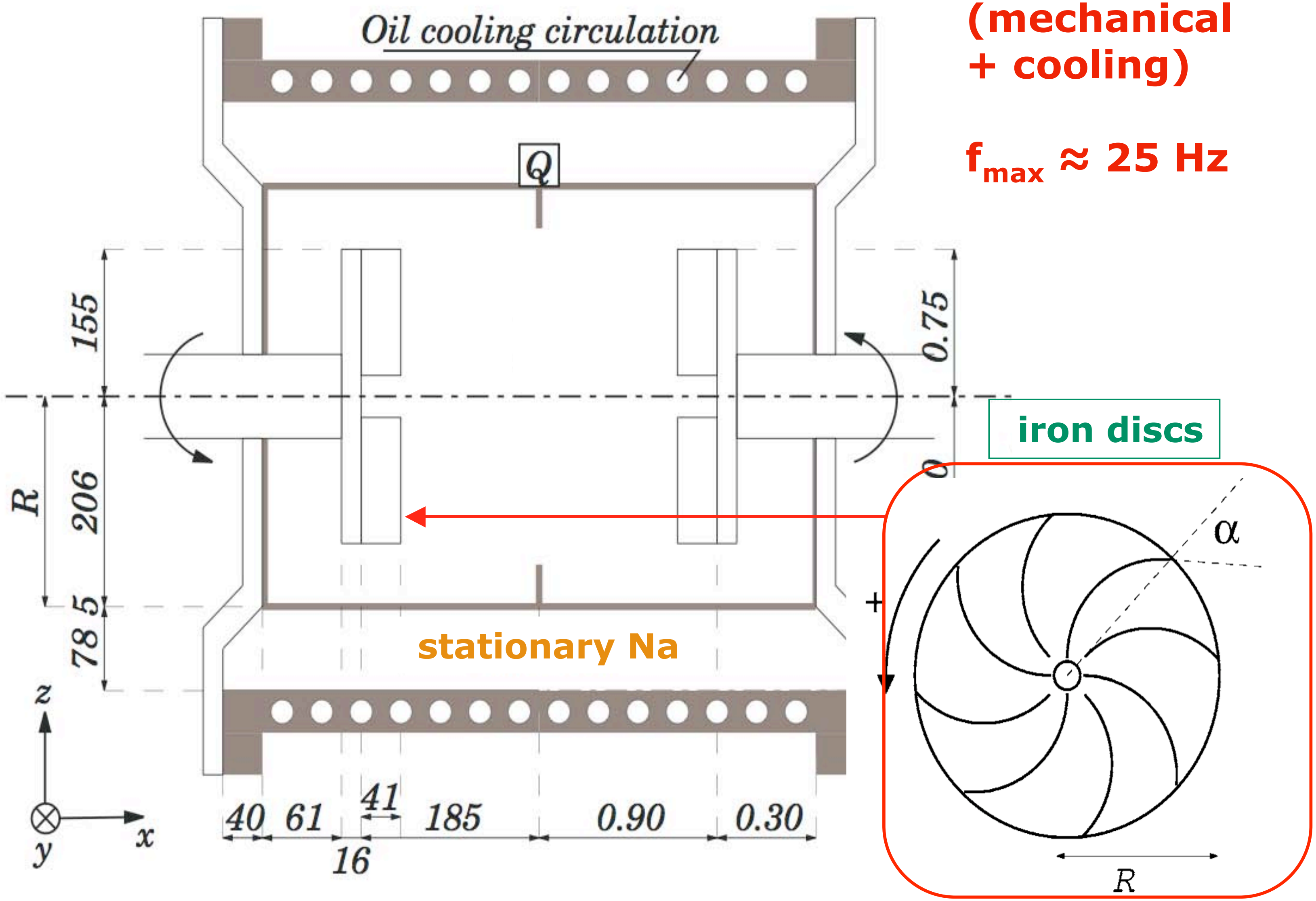
Fluid : Na
Power : x 100 kW
Size : 1 m
Low Rm^c

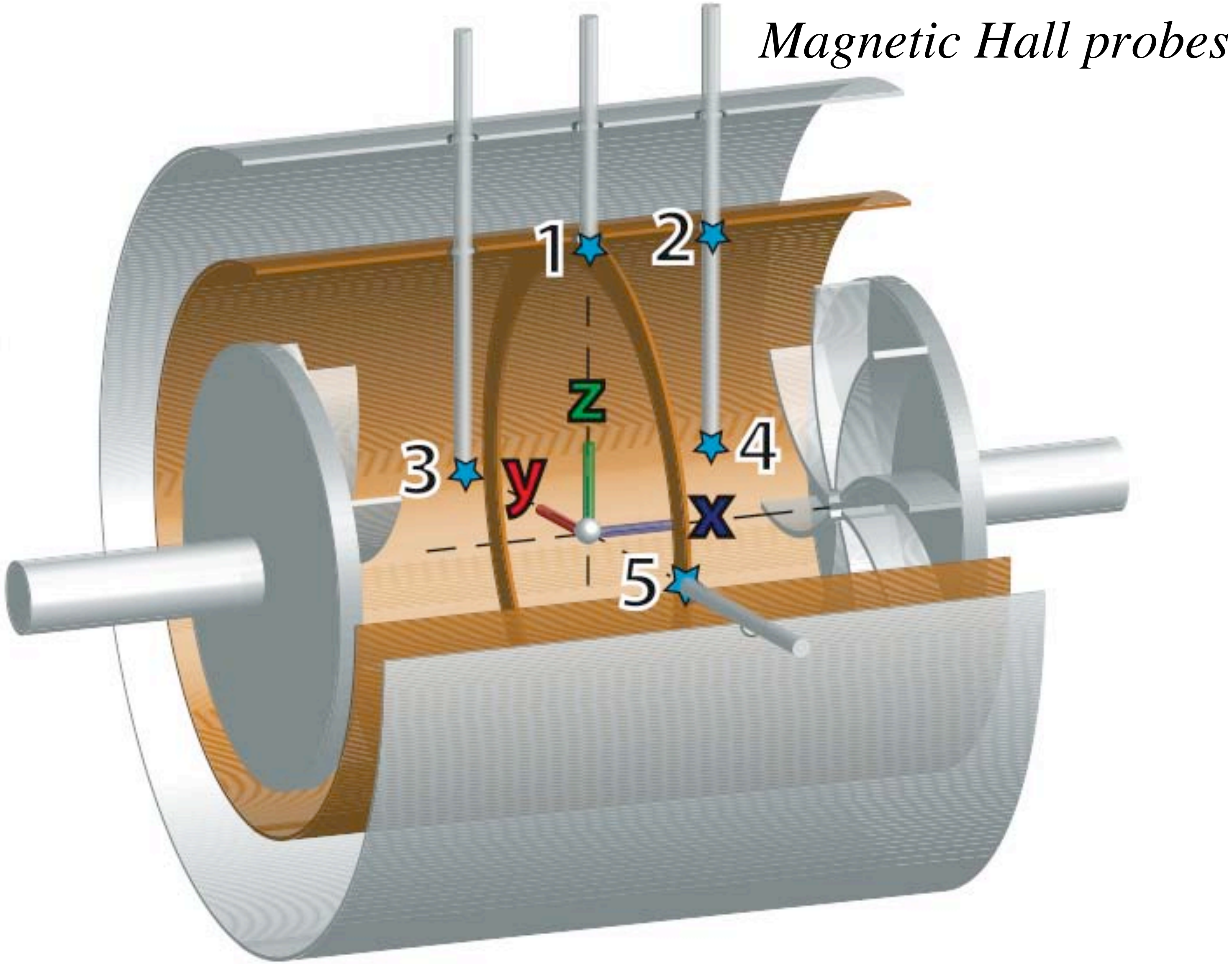
SELF-EXCITATION

VKS2

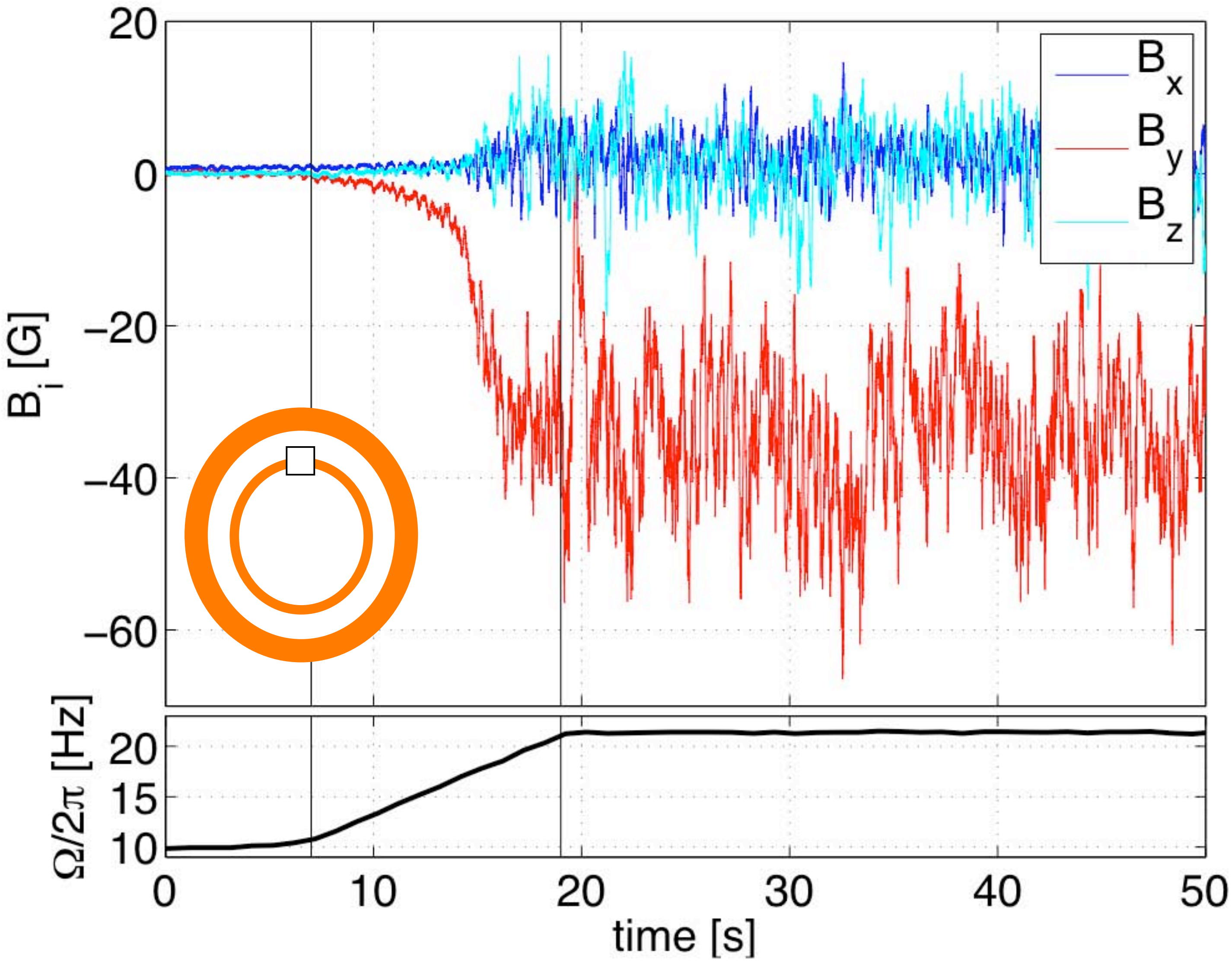
P = 300kW (mechanical + cooling)

$f_{max} \approx 25$ Hz



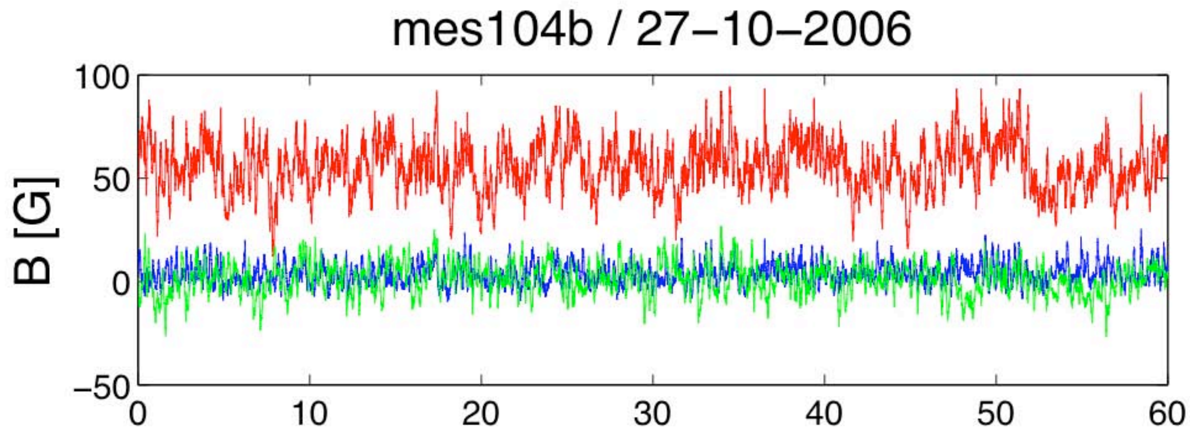

Magnetic Hall probes
1
2
z
3
y
4
x
5

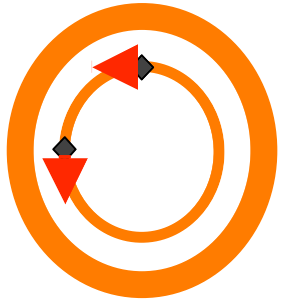
stationary dynamo $F_1 = F_2$

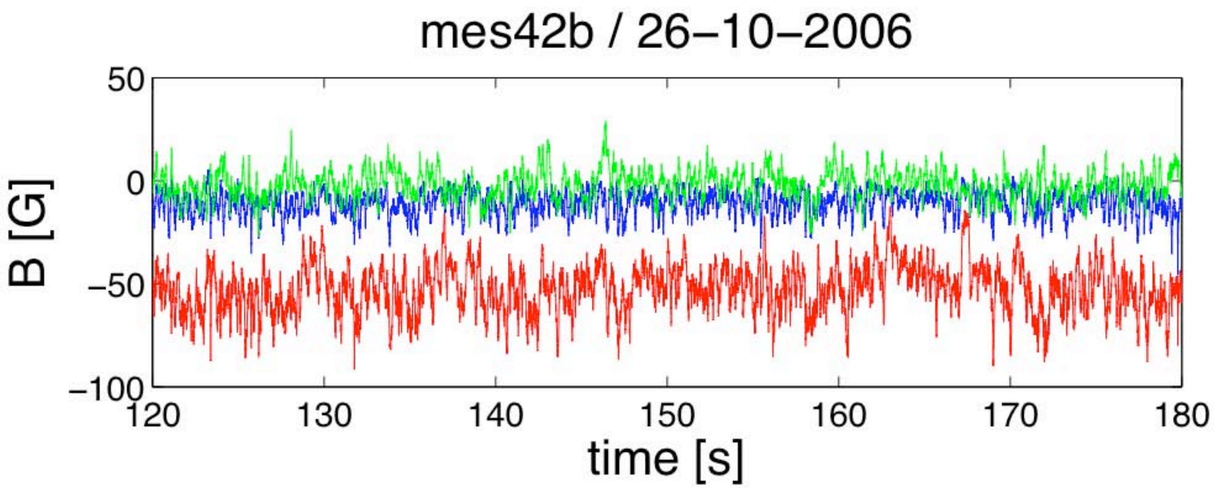


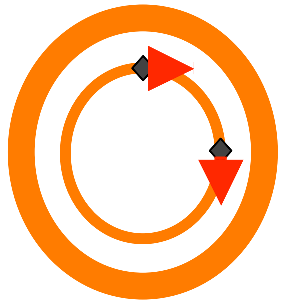
Monchaux et al., PRL, **98** (2007)

geometry

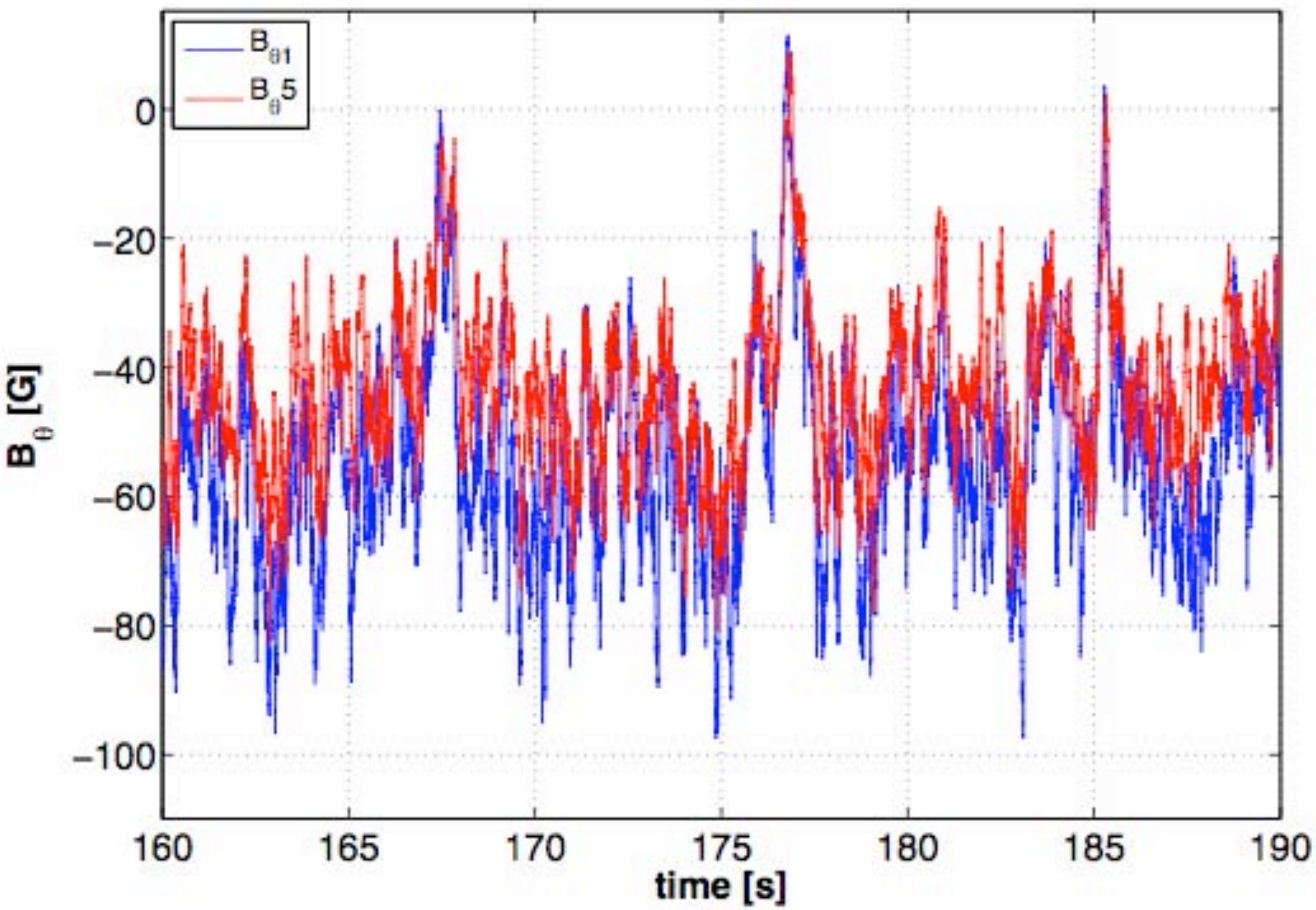

mes104b / 27–10–2006
B [G]
100
50
0
–50
0
10
20
30
40
50
60



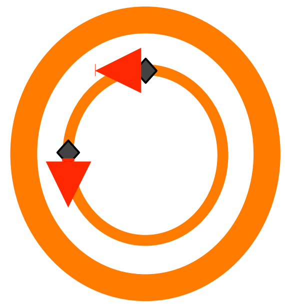

mes42b / 26–10–2006
B [G]
50
0
–50
–100
120
130
140
150
160
170
180
time [s]



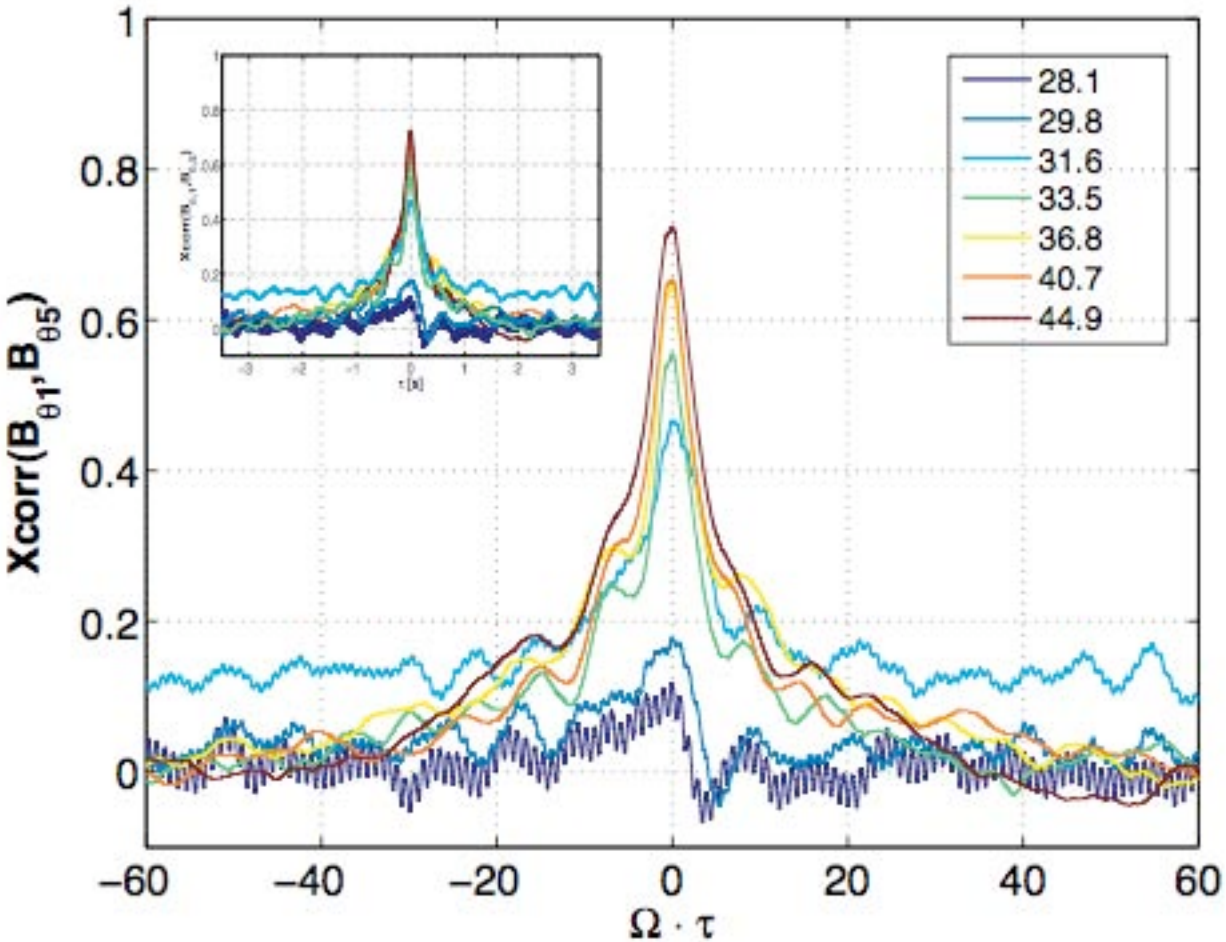
geometry

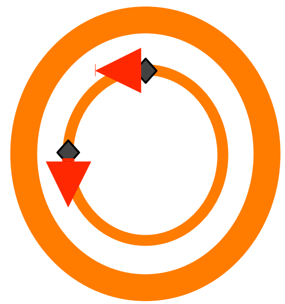


$B_{\theta 1}$
$B_{\theta}5$
0
−20
−40
−60
−80
−100
160
165
170
175
180
185
190
time [s]
B_θ [G]

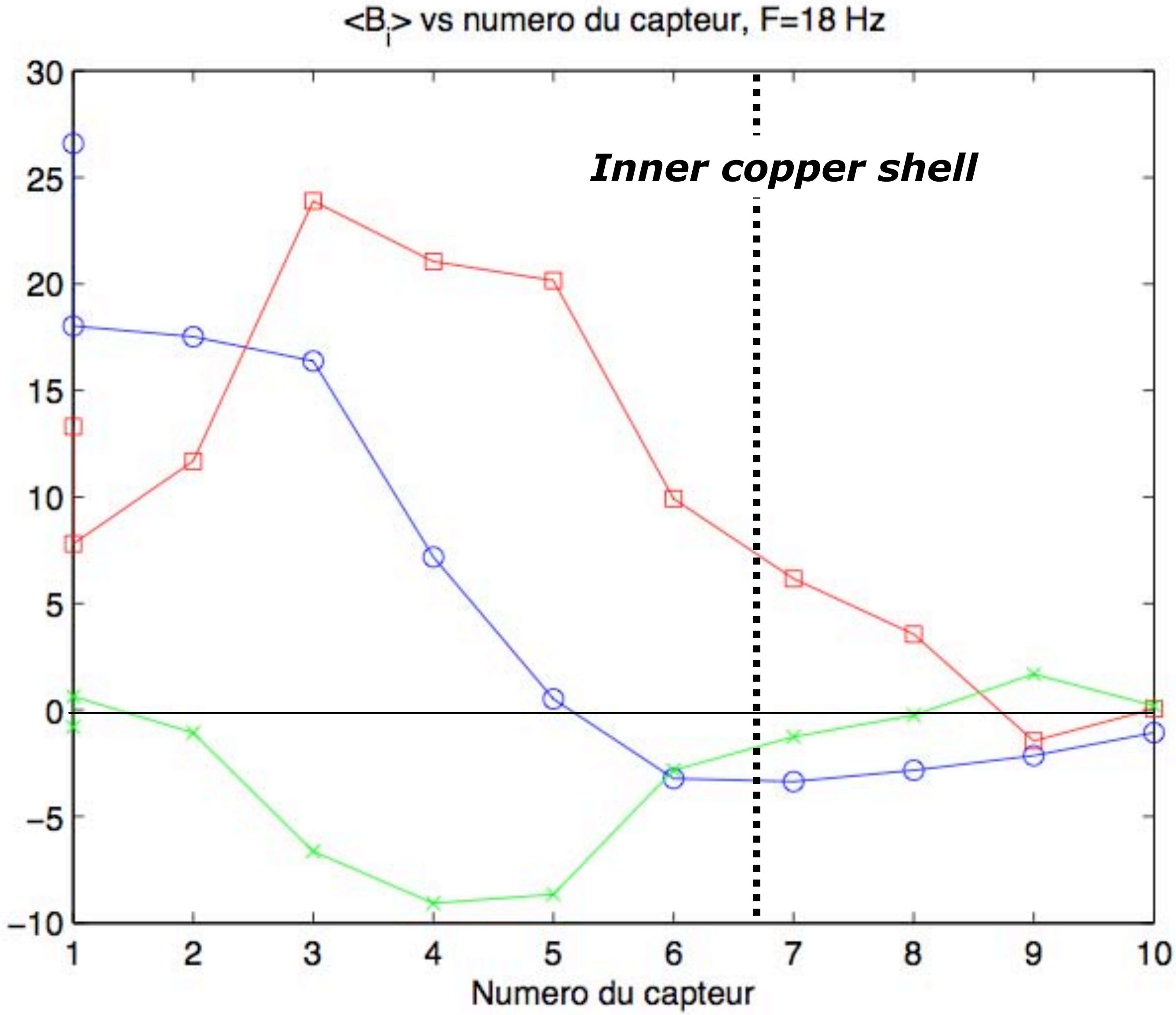


geometry


28.1
29.8
31.6
33.5
36.8
40.7
44.9
Xcorr(B$_{\theta1}$,B$_{\theta5}$)
Ω · τ
1
0.8
0.6
0.4
0.2
0
−60
−40
−20
0
20
40
60

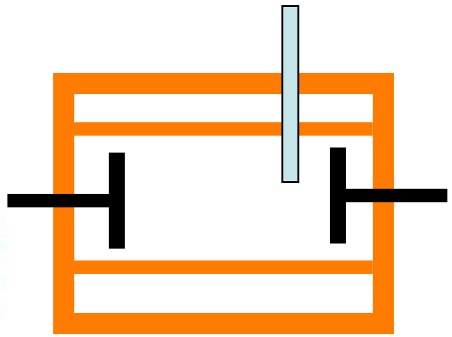


geometry

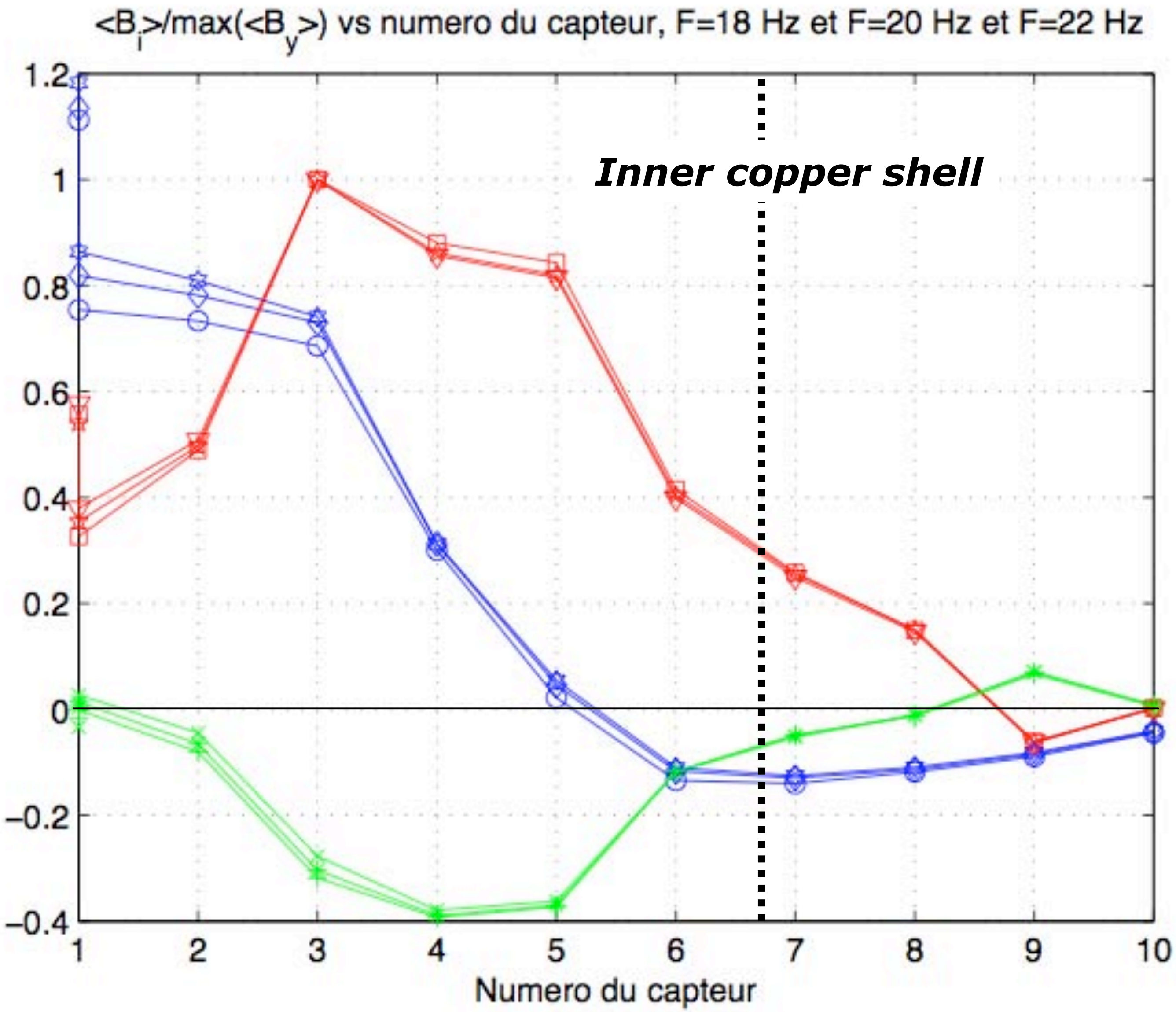


10 probe array

#1 at 4.7cm from axis

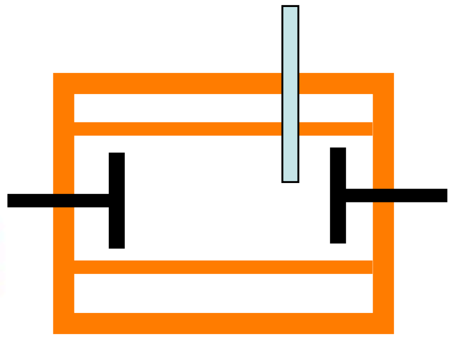


geometry

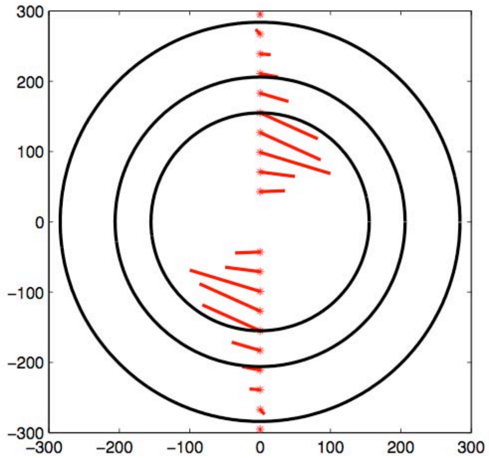


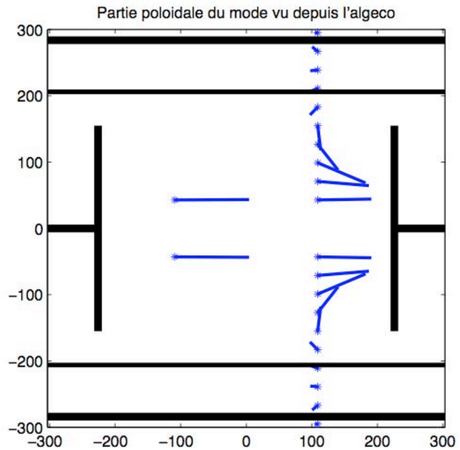
10 probe array

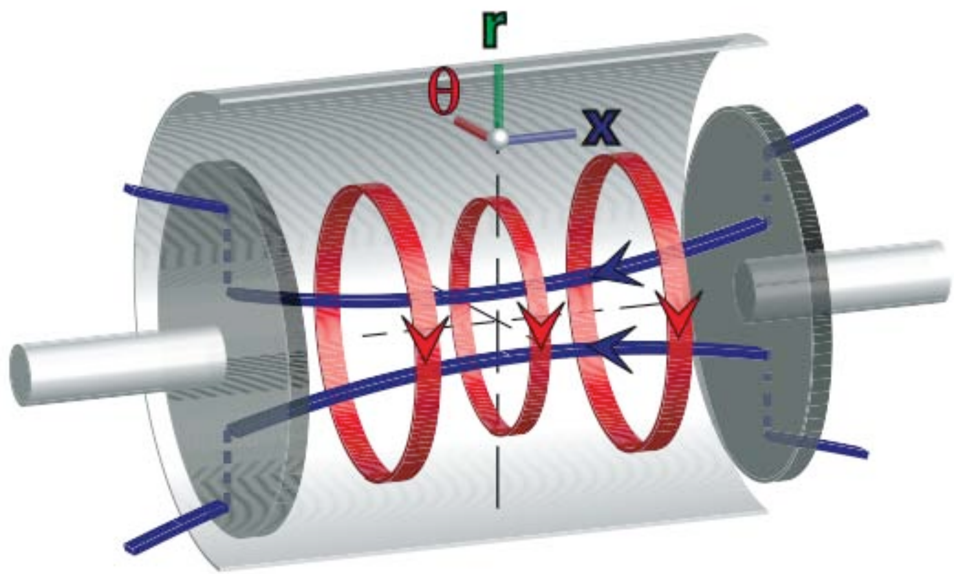
#1 at 4.7cm from axis



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


r
θ
x

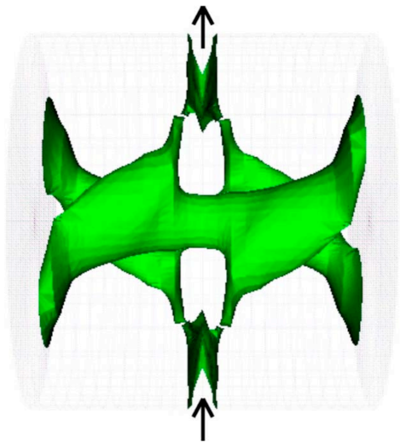
a turbulent dynamo

(m=0) / dipole dynamo

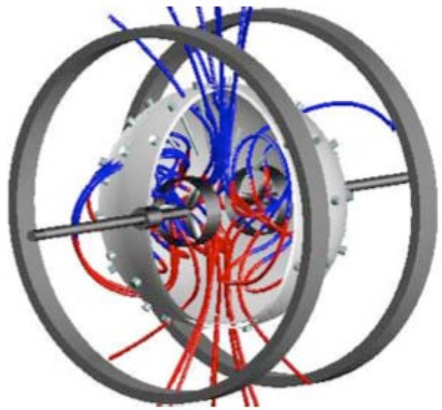
⟶ not generated by the mean flow (Cowling theorem)

New, compared to Riga & Karlsruhe exp.

kinematic modes for s2t2



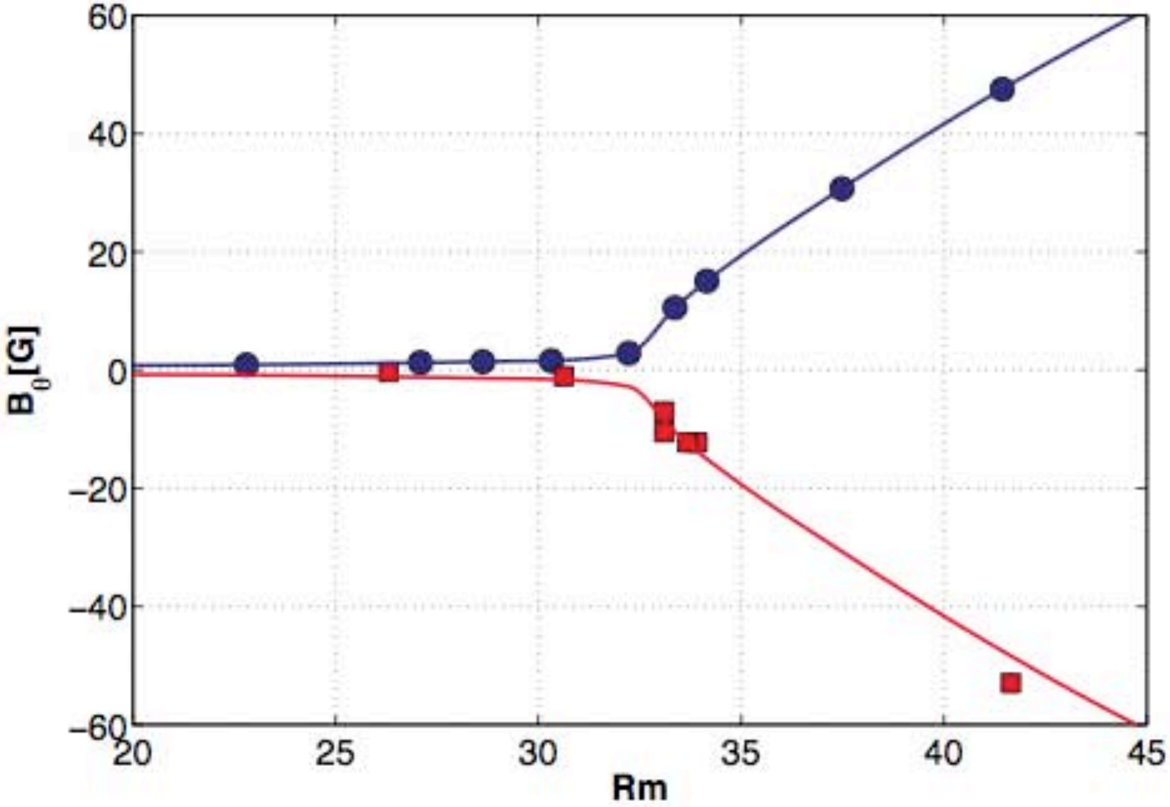
Ravelet et al., *Phys. Fludis* **17**, 117104 (2005)
M. Bourgoin et al., *Phys. Fluids* **16** (2004)



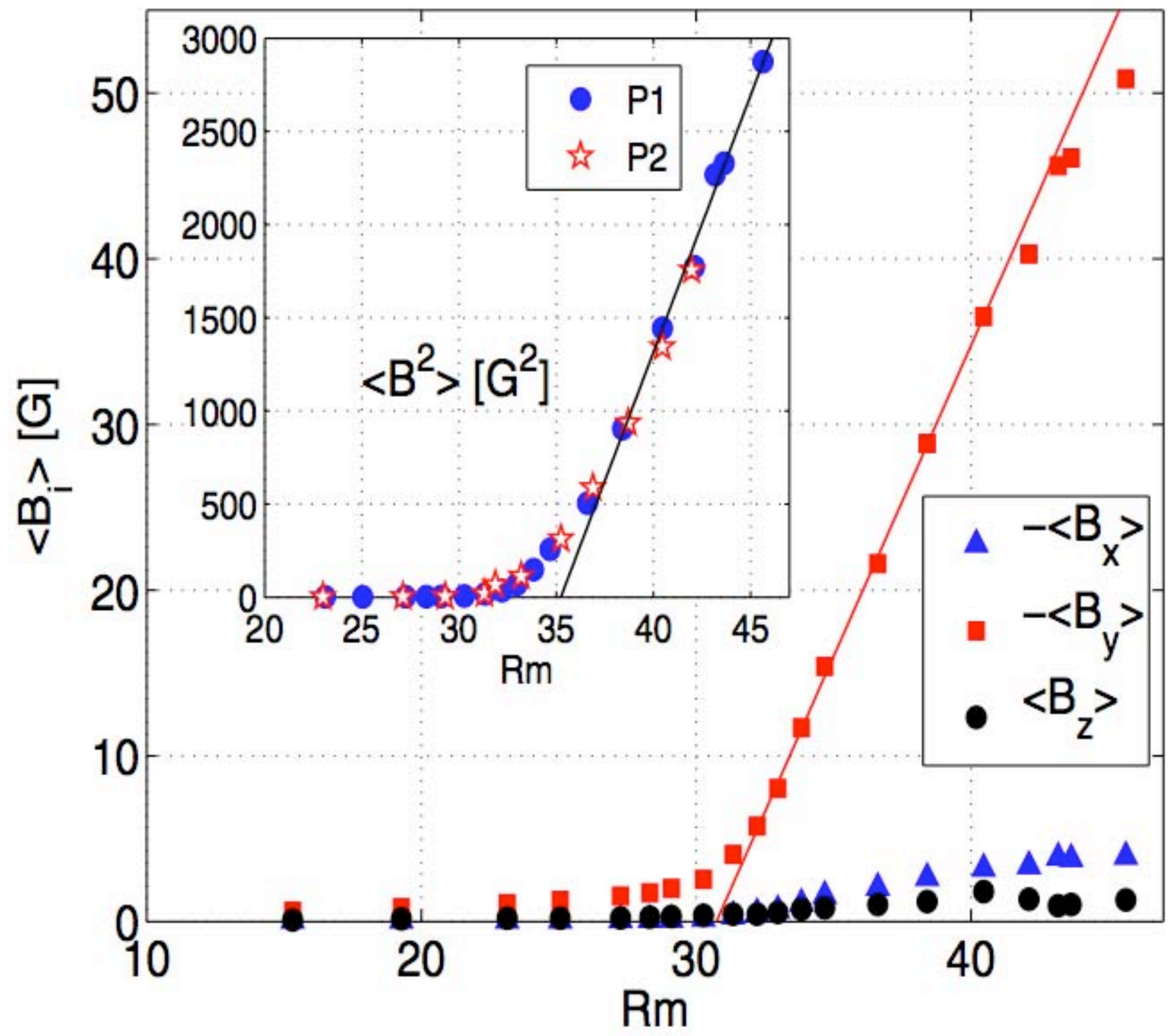
Transverse intermittent dipole
Phys. Rev. Lett. **97**, 044503 (2006).


BIFURCATION

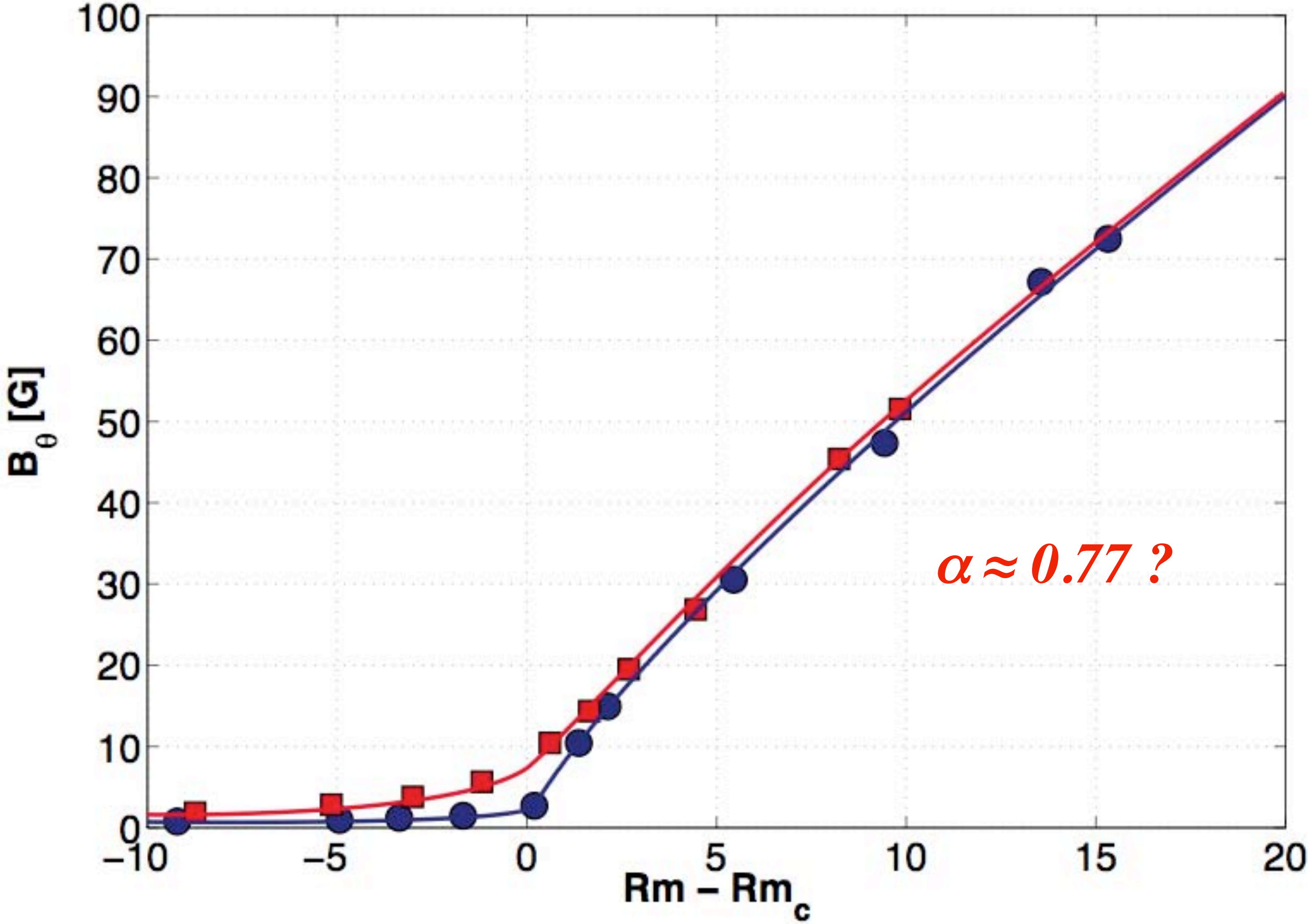
bifurcation onset



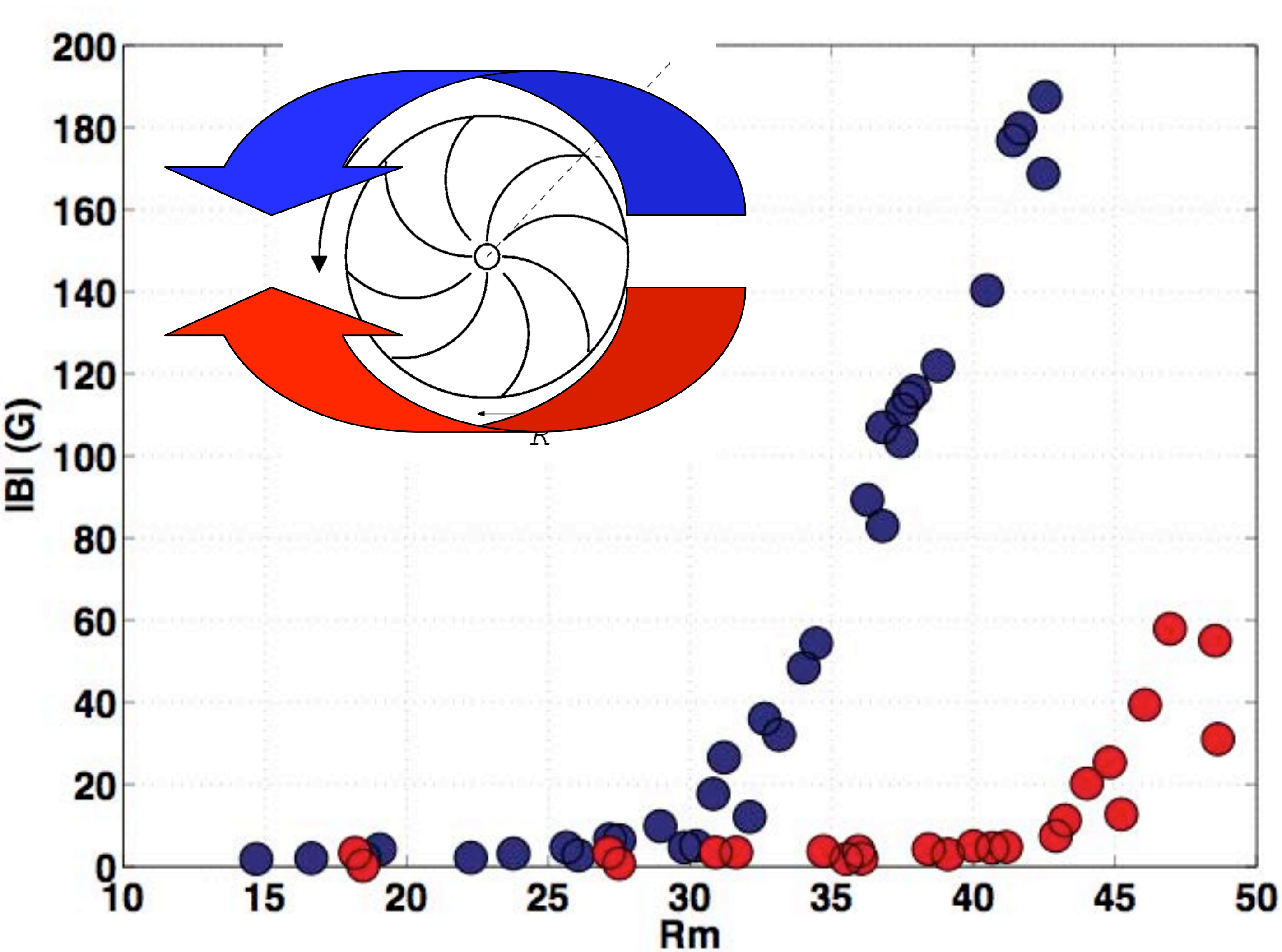
bifurcation onset



bifurcation onset

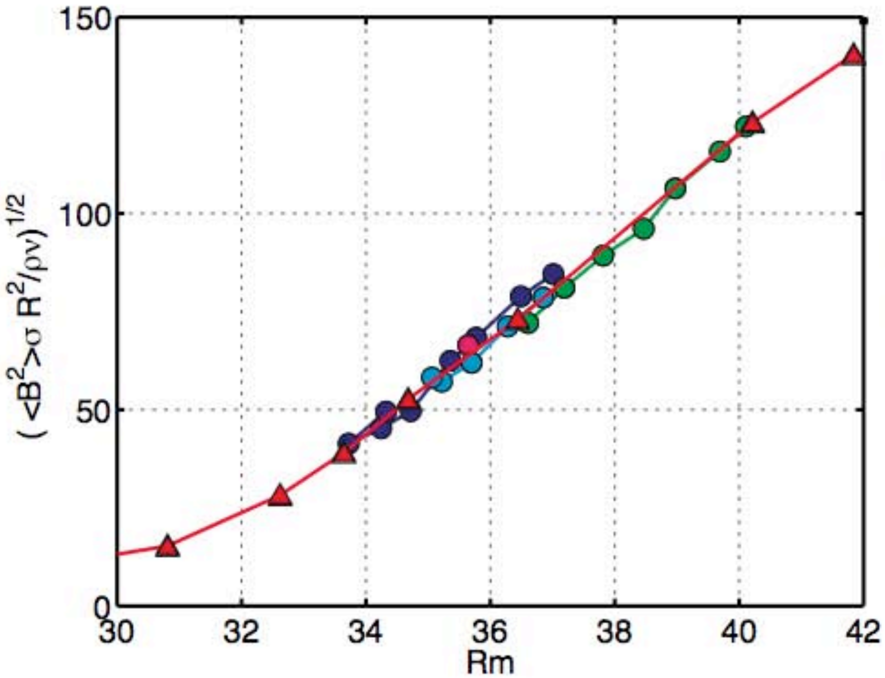


bifurcation onset



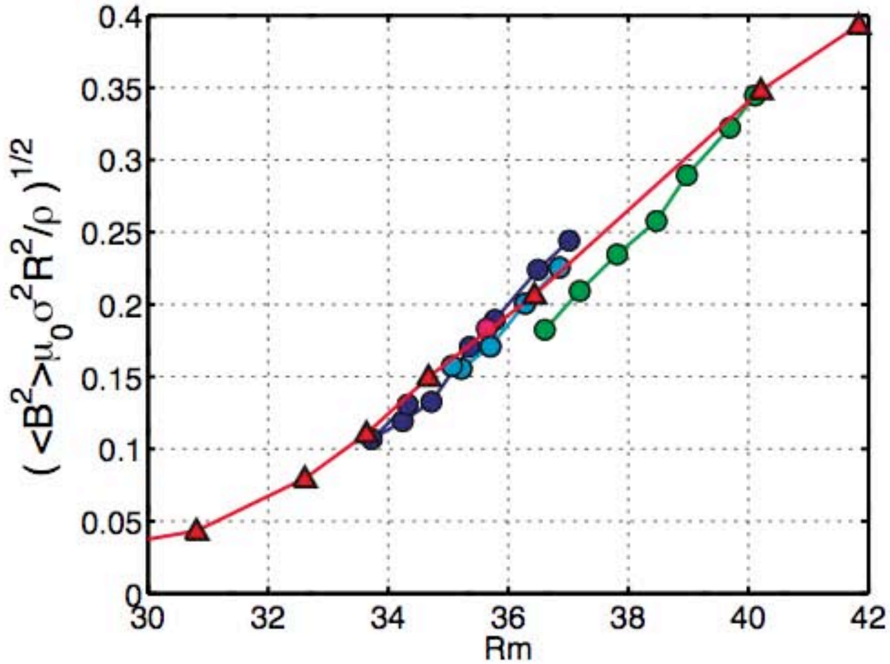
Scaling at saturation

$F_{lorentz} \approx$ viscous forces



Low - Reynolds scaling

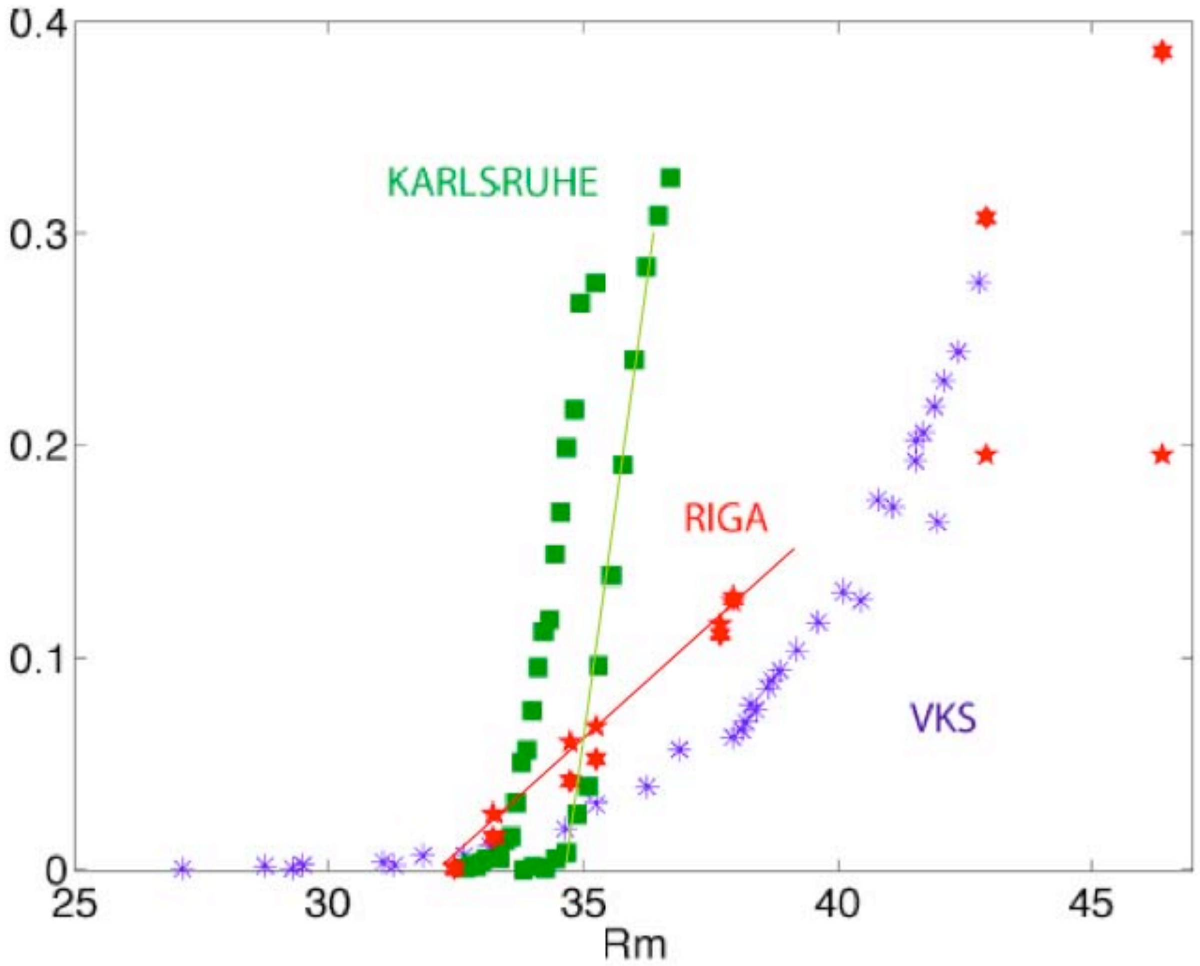
$F_{lorentz} \approx$ inertial forces



High - Reynolds scaling

Comparison with Riga / Karlsruhe

Lundquist number: $\langle B^2 \rangle \mu_0 (\sigma R)^2 / \rho \quad \propto \quad (R_m - R_{mc})^\alpha$



power

Turbulent scaling

$P \approx \rho R^5 \Omega^3$ $\quad\quad$ $Kp = P / \rho R^5 \Omega^3$

Dynamo

$P = P(mag) + P(hydro)$

$Rm < Rm^c$: $\quad P = P(v_1)$

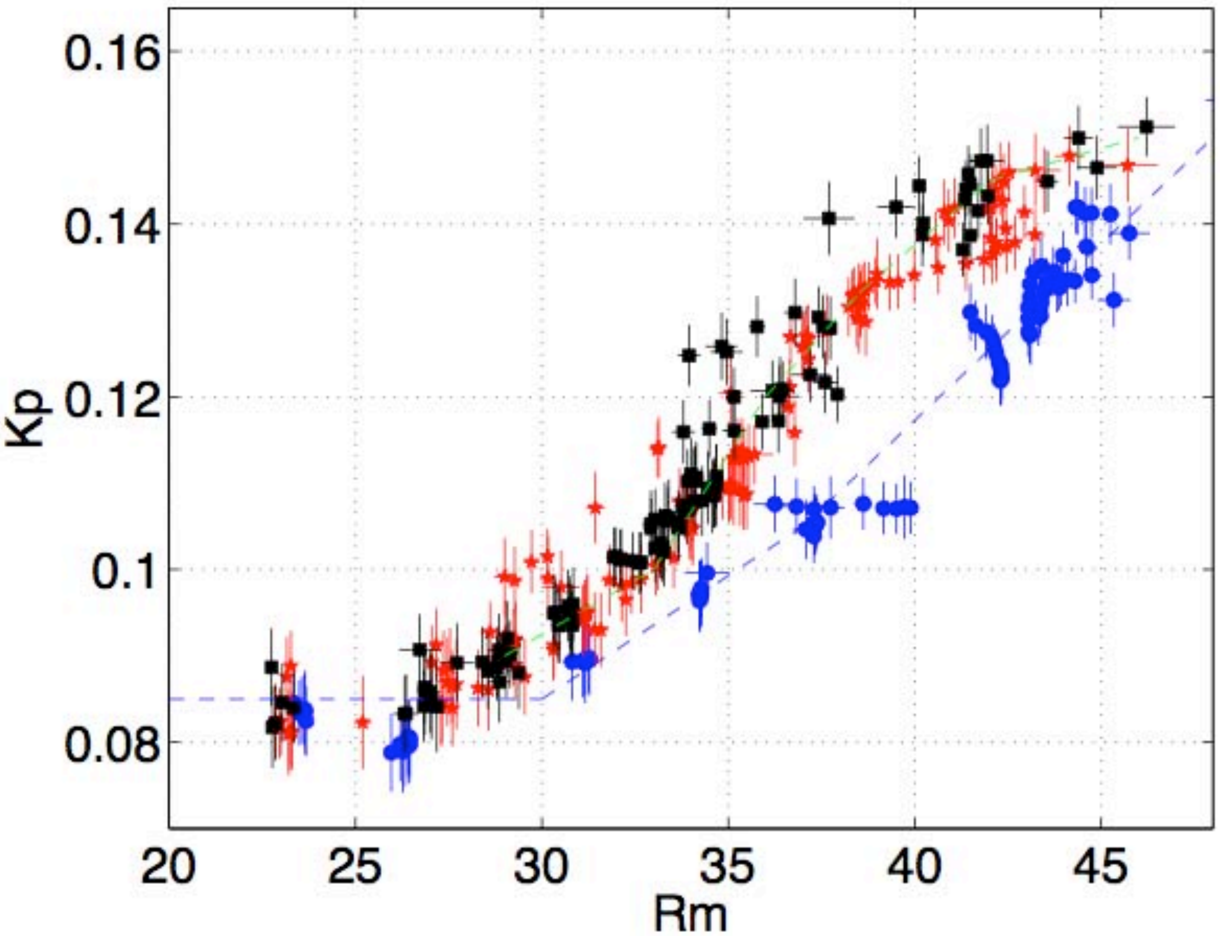
$Rm > Rm^c$: $\quad P = P(v_2) + P(B)$

with $\quad \langle v_2 \rangle \neq \langle v_1 \rangle$?

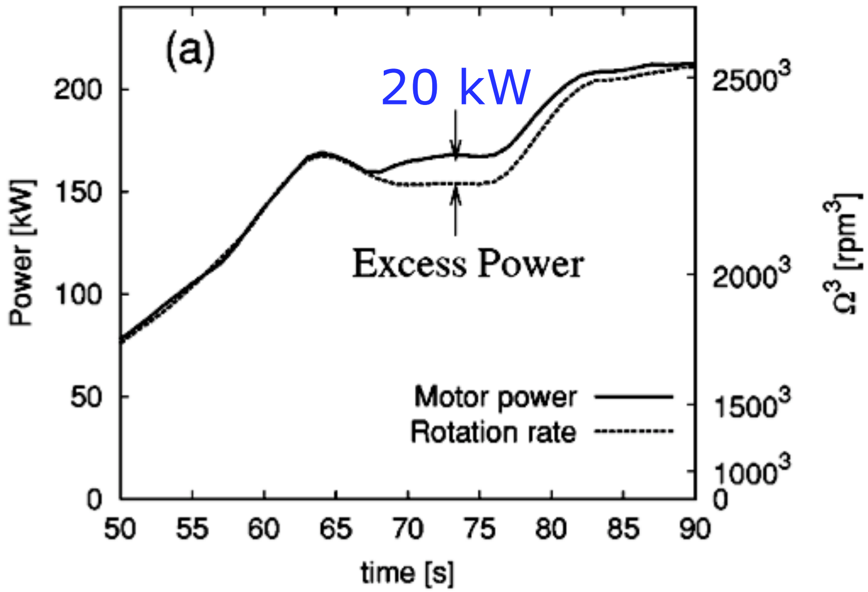
and $\quad v_2' \neq v_1'$?

power, from motor drives

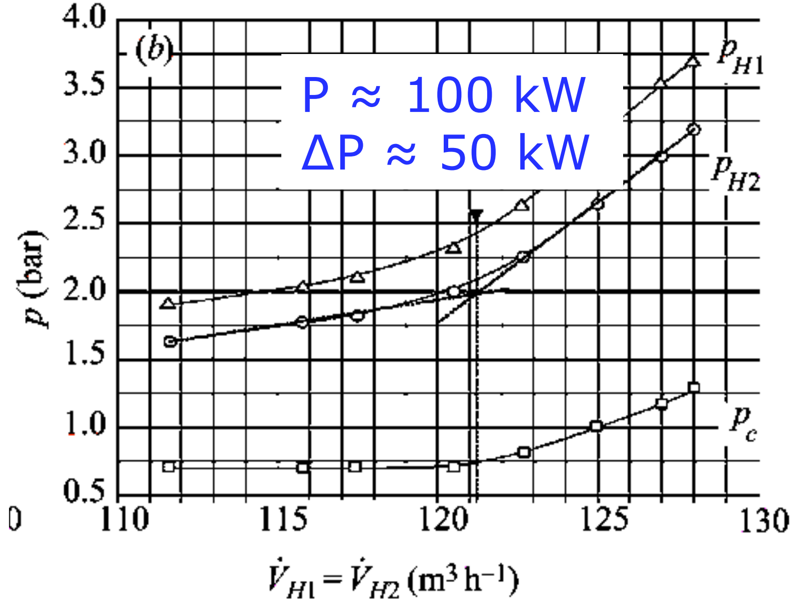
$$Kp = P \,/\, (\rho\, R^5\, (2\pi F)^3)$$



Comparison Karlsruhe & Riga



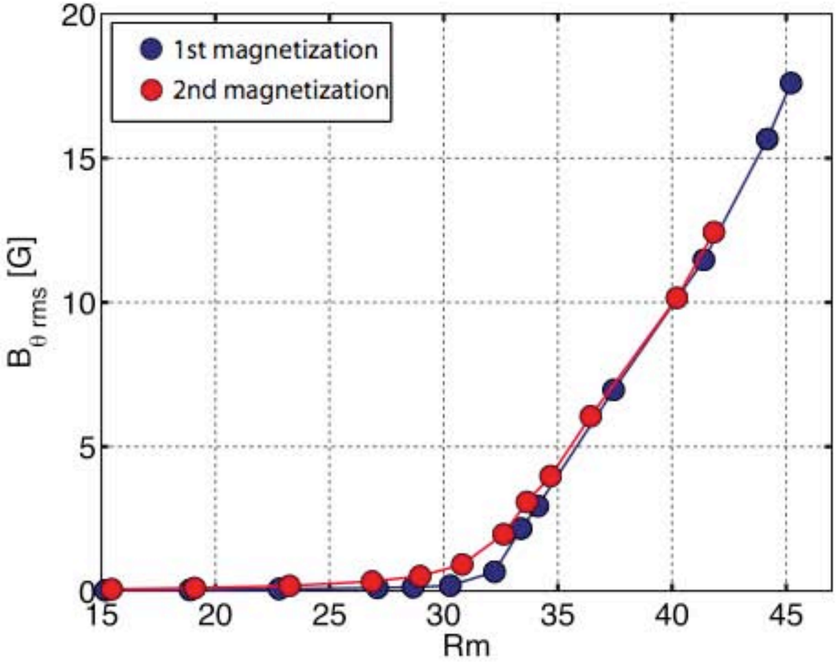
Stieglitz & Müller, *PoF*, **13** (2001)
Müller, Stieglitz, Horanyi, *JFM*, **498** (2004)

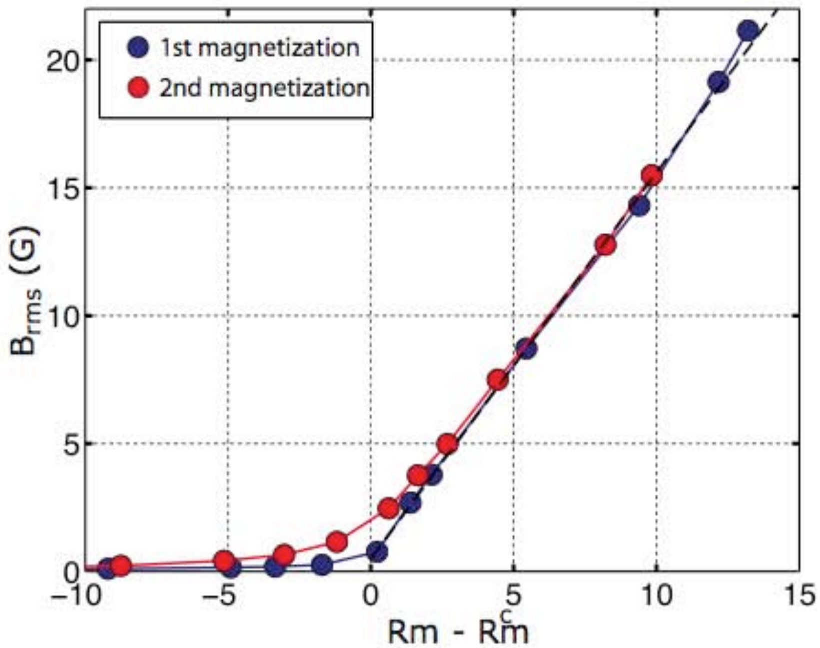


Gailitis et al. *Phys. Plasmas* **11** (2004)

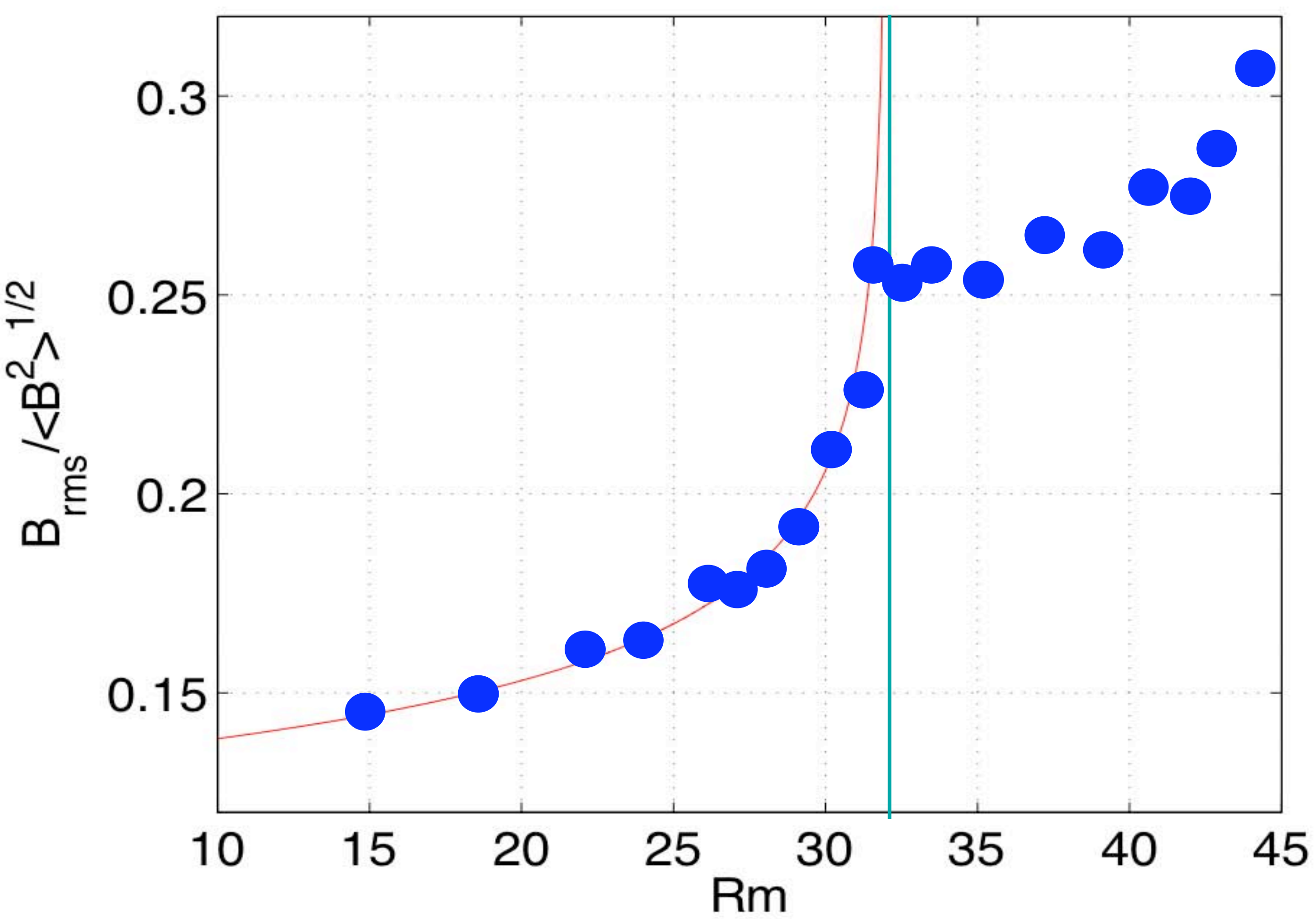
FLUCTUATIONS

bifurcation onset

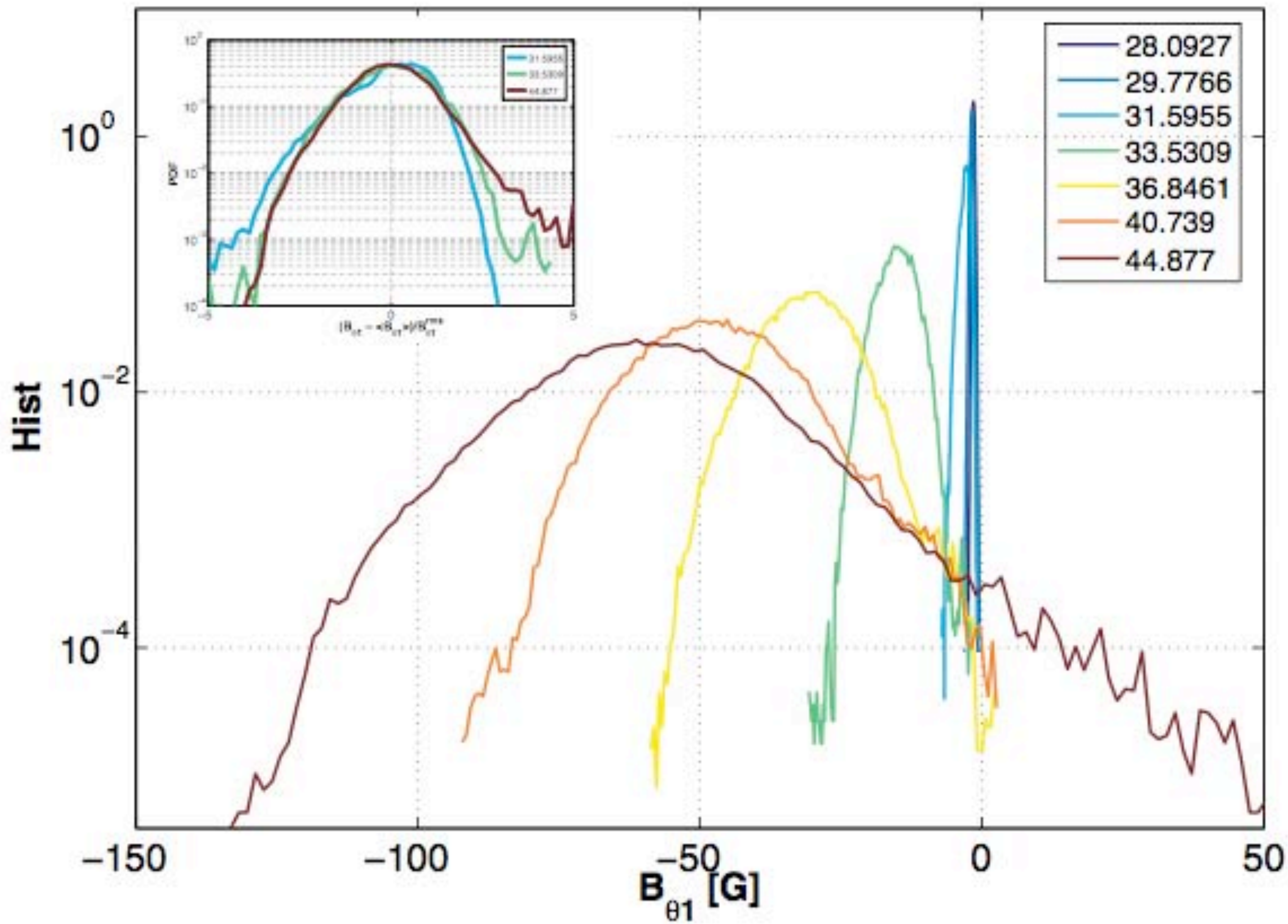




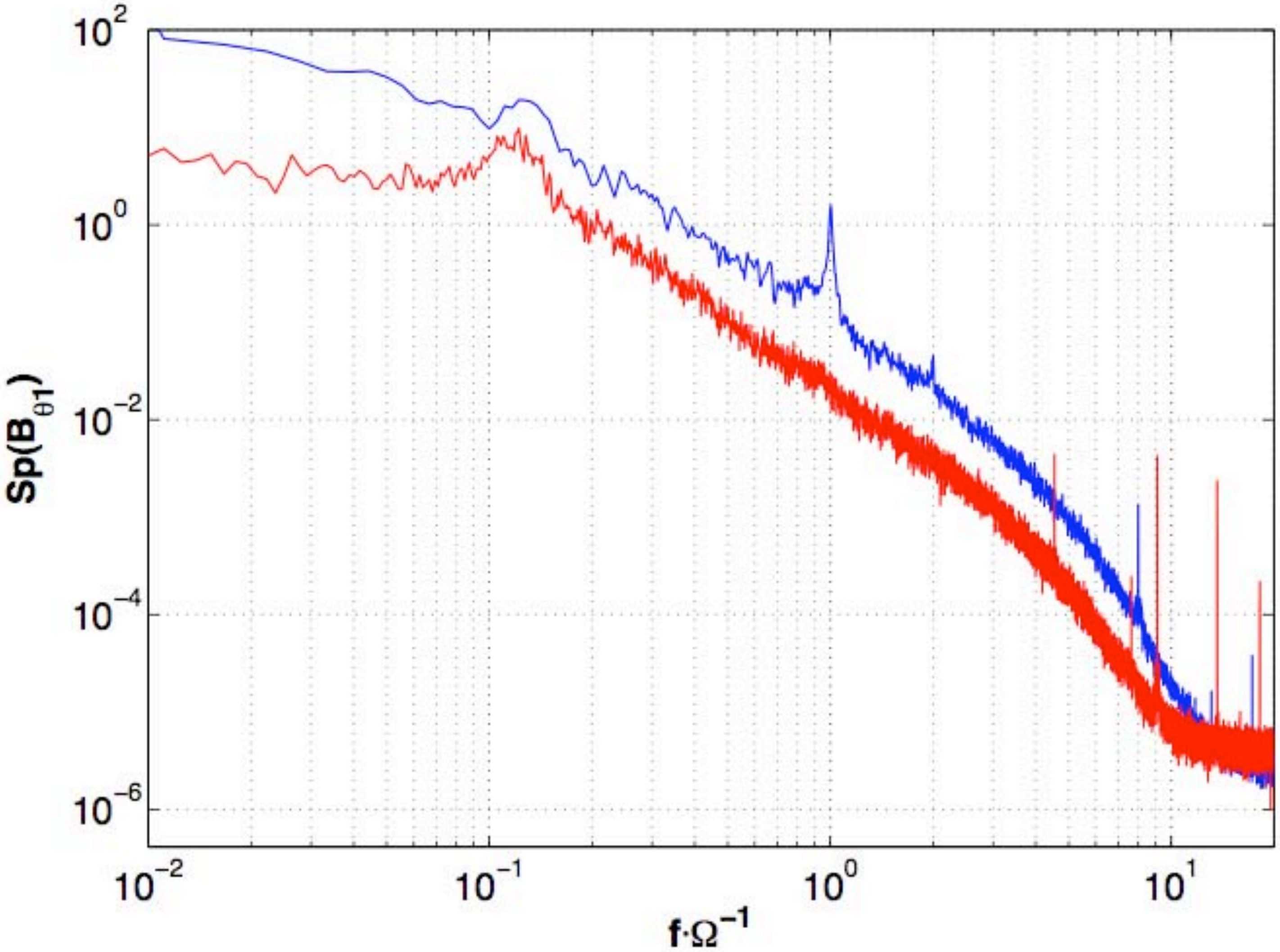
a susceptibility ?



Local fluctuations



Local fluctuations



PSD scaling

PSD of local magnetic fluctuations

- K41 scaling, strong Joule dissipation, passive vector : $E_M(k) \approx k^{-5/3}$

- Equipartition, Alfven waves Iroshnikov-Krainchan : $E_M(k) \approx k^{-3/2}$

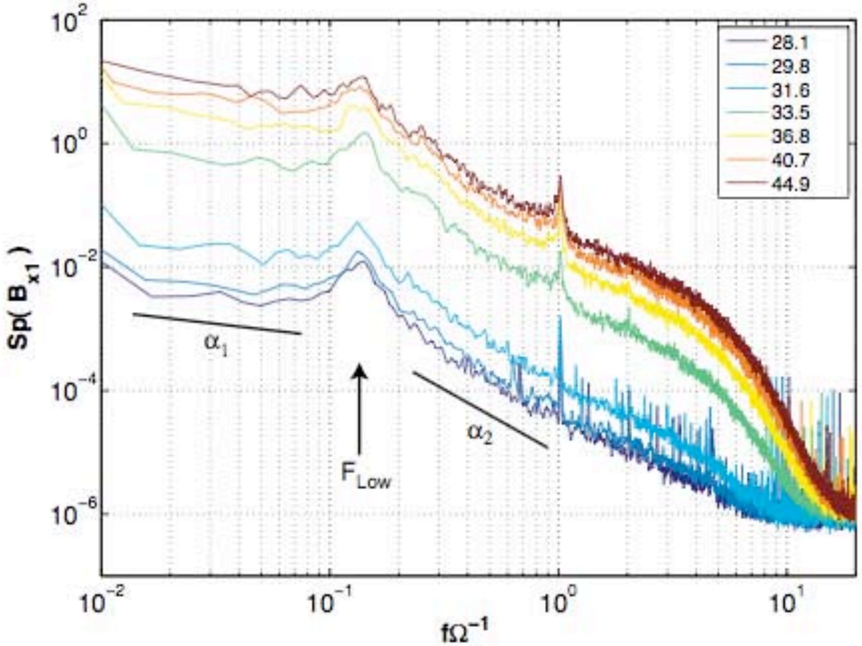
- Strong correlation V-B, scale separation, Pouquet et al. : $E_M(k) \approx k^{-3}$

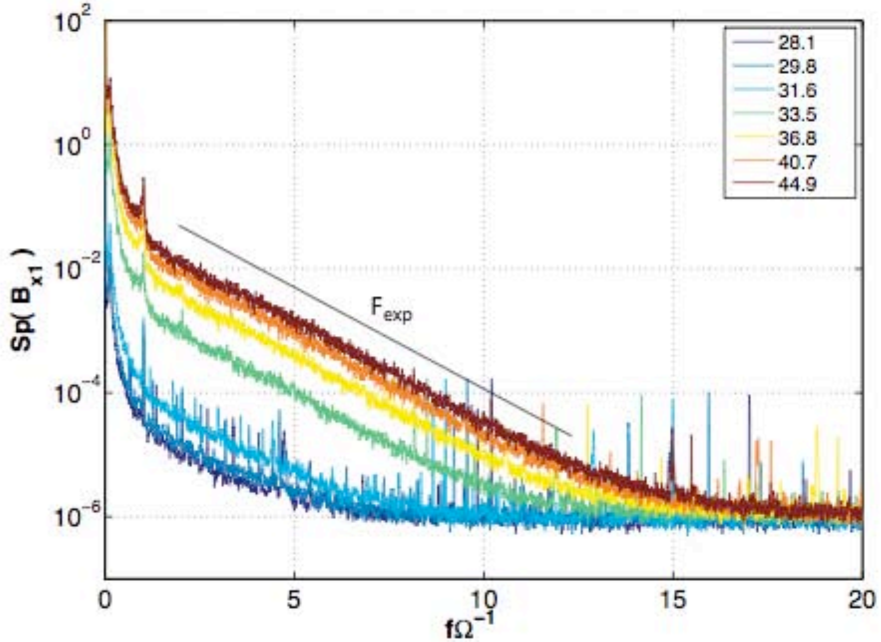
- Significant Joule diss., low Pm, Moffat : $E_M(k) \approx k^{-2} E_V(k)$

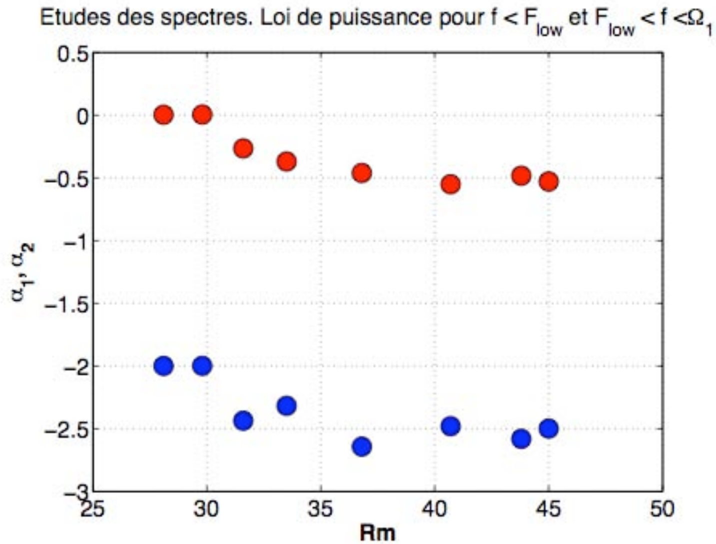
  if K41 velocity : $E_M(k) \approx k^{-11/3}$

  if IK field : $E_M(k) \approx k^{-5}$

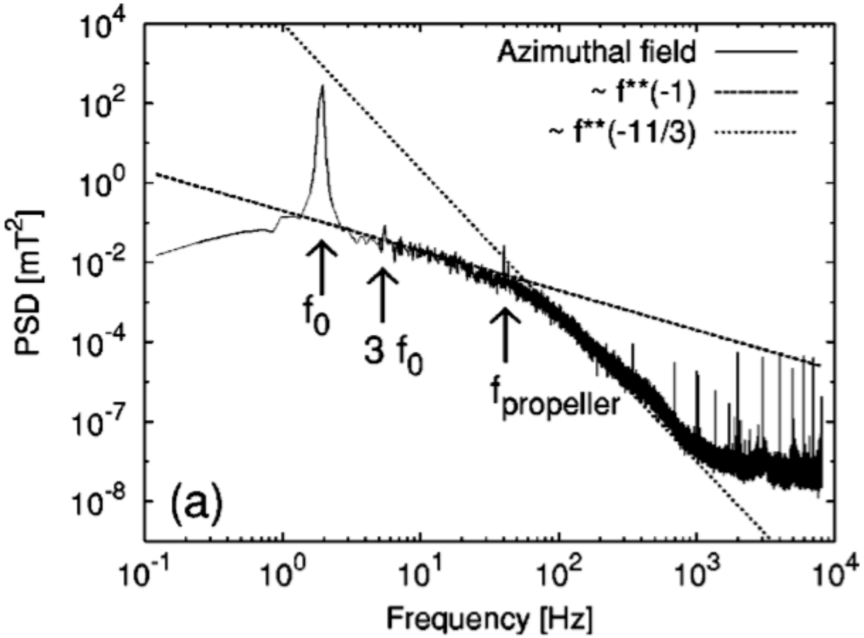
Local fluctuations



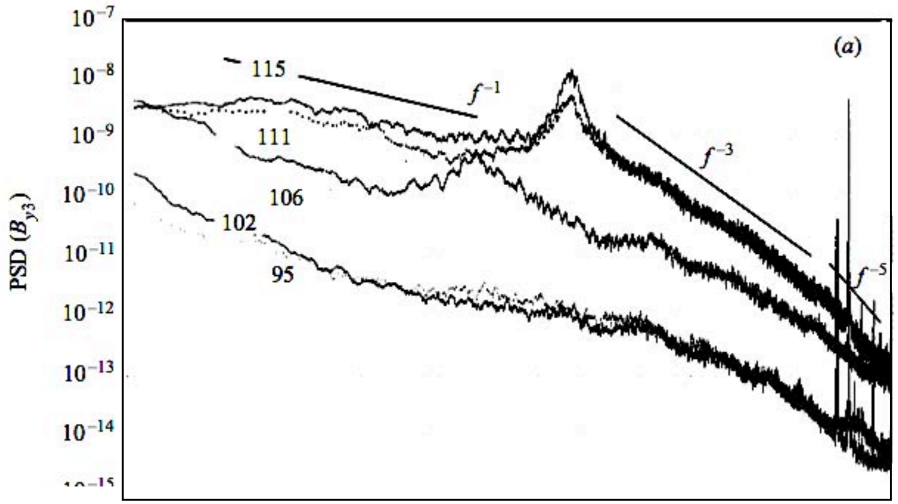




Comparison Karlsruhe & Riga



Stieglitz & Müller, *PoF*, **13** (2001)
Müller, Stieglitz, Horanyi, *JFM*, **498** (2004)



Gailitis et al. *Phys. Plasmas* **11** (2004)


NEXT