

VKS experiment :

turbulent dynamos in the laboratory

F. Daviaud

VKS collaboration: CEA – CNRS - ENS Paris - ENS Lyon



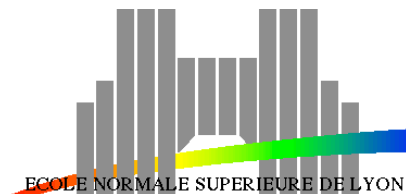
F. Daviaud, A. Chiffaudel, B. Dubrulle, S. Aumaitre,
C. Gasquet, V. Padilla, L. Marié, F. Ravelet, R. Monchaux

CEA, DSM/DRECAM/SPEC

in collaboration with DEN/DTN/STPA, CEA Cadarache



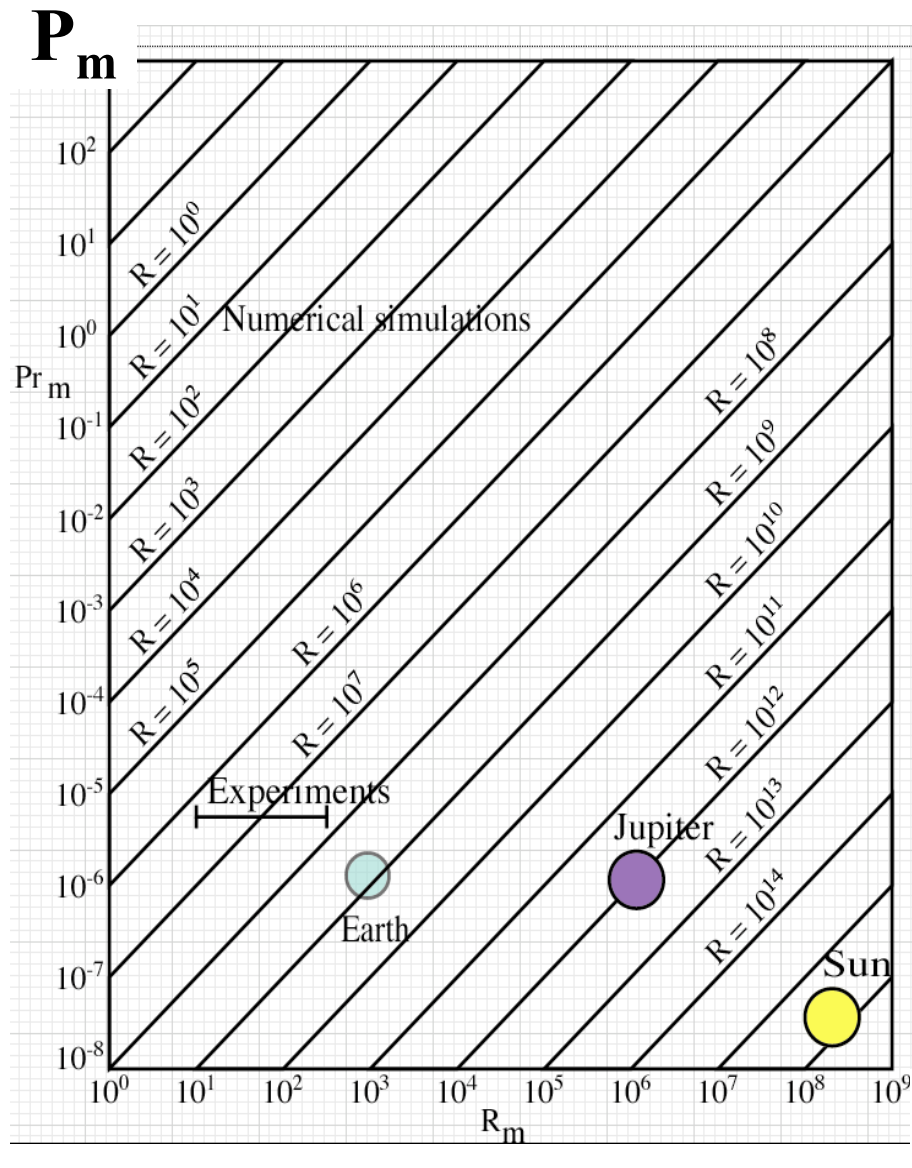
S. Fauve, F. Pétrélis, N. Mordant, M. Berhanu
ENS-Paris, Laboratoire de Physique Statistique



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

ENS-Lyon, Laboratoire de Physique

Simulations, Experiments and Nature



- *magnetic Reynolds number:*

$$R_m = \mu_0 \sigma U L$$

- *kinetic Reynolds number:*

$$R_e = U L / \nu$$

- *magnetic Prandtl number:*

$$P_m = \mu_0 \sigma \nu$$

($P_m = R_m / R_e < 10^{-5}$ liquid metals)

- *Rotation number:*

$$\Theta = L \Omega / U$$

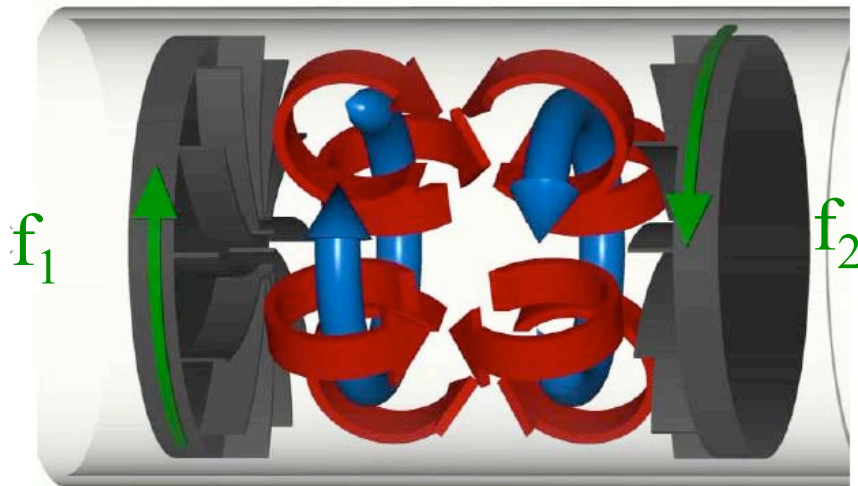
Dynamo experiments

The image is a composite of several elements related to dynamo experiments:

- Top Left:** A photograph of a complex experimental setup with various pipes, tanks, and machinery.
- Top Center:** A photograph of a vertical cylindrical apparatus mounted on a blue metal frame.
- Top Right:** A photograph showing the interior of a spherical container with a network of wires and components.
- Far Right:** A schematic diagram of a vertical probe labeled "sonde" with sections H1 through H6 and a height of 3 m. A diameter of 0.8 m is indicated at the bottom.
- Center:** A world map with red arrows pointing to various locations: Madison*, Maryland*, *Los Alamos, *Riga, *Karlsruhe, Cadarache*, *Grenoble, and Perm*.
- Bottom Left:** A photograph of a laboratory cart with various instruments and equipment.
- Bottom Center:** A photograph of a large, ribbed spherical container on a platform, with two people standing next to it for scale.
- Bottom Right:** A photograph of a circular cross-section of a spherical container, showing internal structures.
- Bottom Center-Right:** The text "VKs" in large red letters.

VKS2 experiment

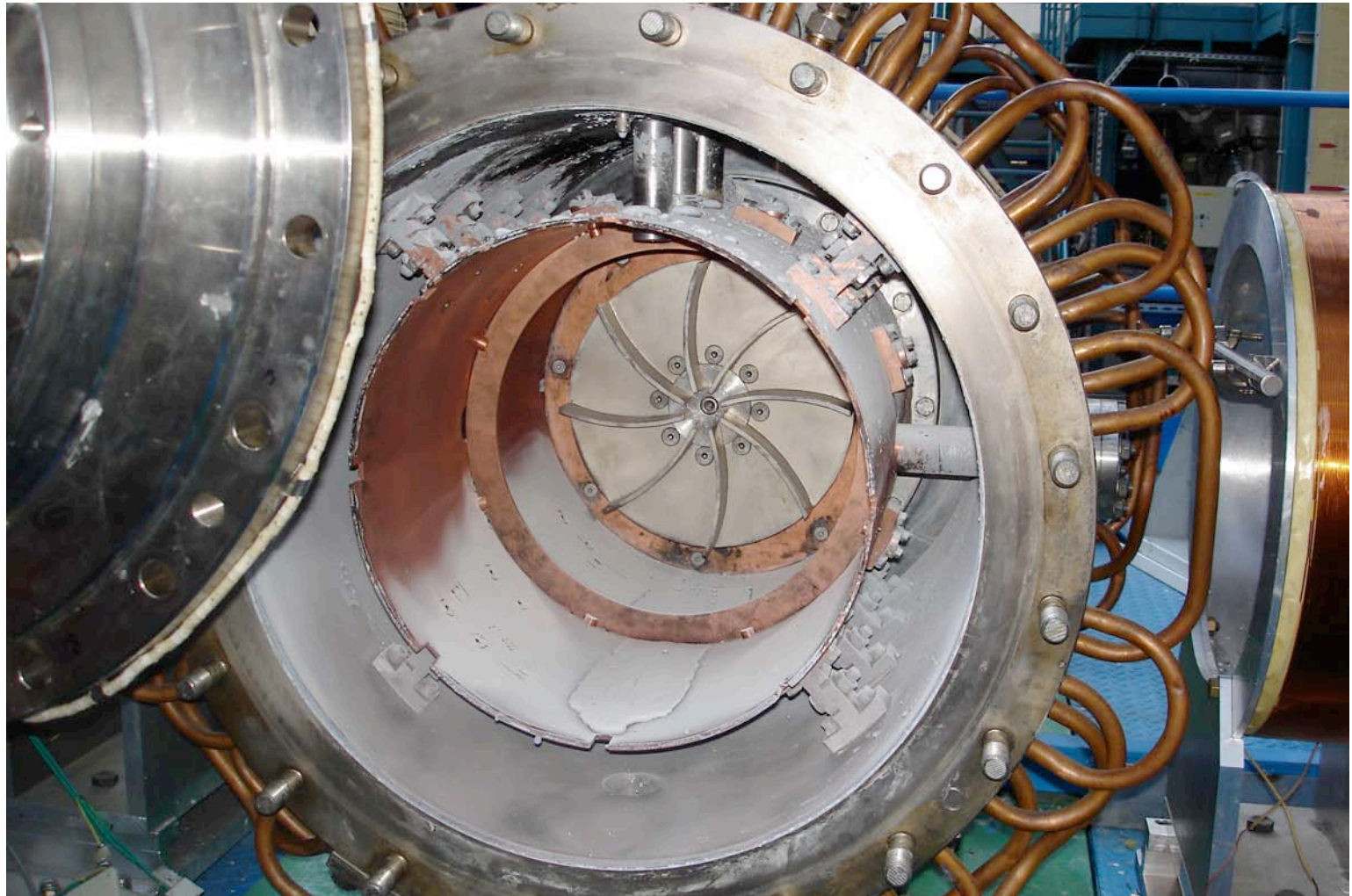
- von Karman flow in a cylinder filled with liquid sodium between 2 counter rotative propellers



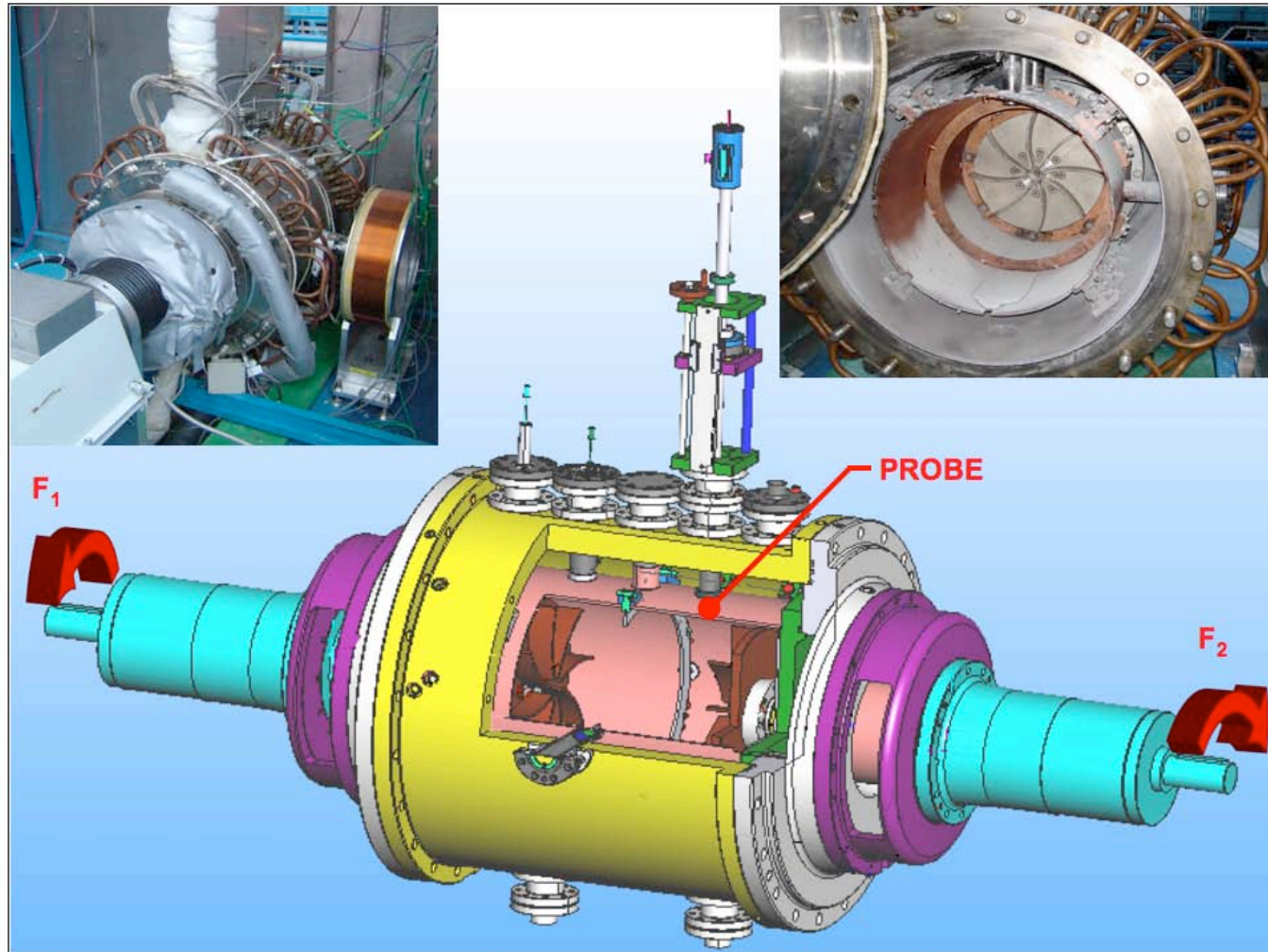
- cylinder $L = \varnothing = 0,6$ m
→ 160 l sodium
- power $P = 300$ kW
- 2 propellers f : 0 à 30 Hz
- cooling system 120° - 160° C
- mechanical seals special Na

VKS2 experiment

- iron propellers
- annulus in shear layer
- copper shell with Na at rest



VKS2 experiment



Measurements: B , pressure, temperature, torque

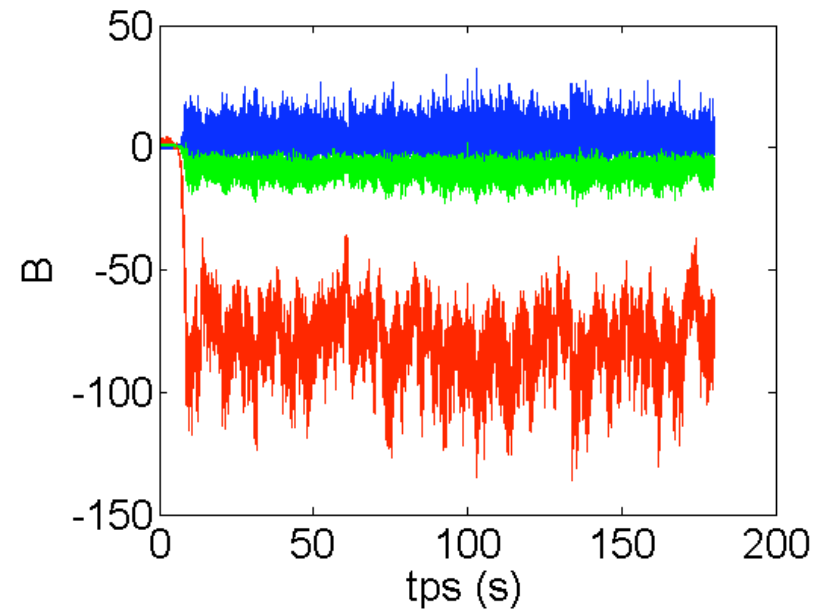
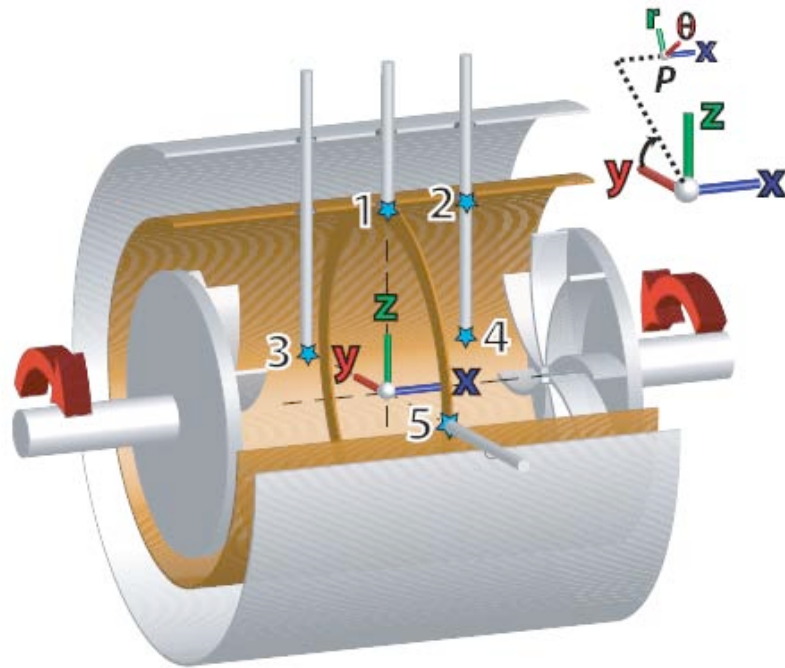
VKS2 experiment



Experimental platform CEA Cadarache (DEN/DTN/STPA)

VKS2 experiment

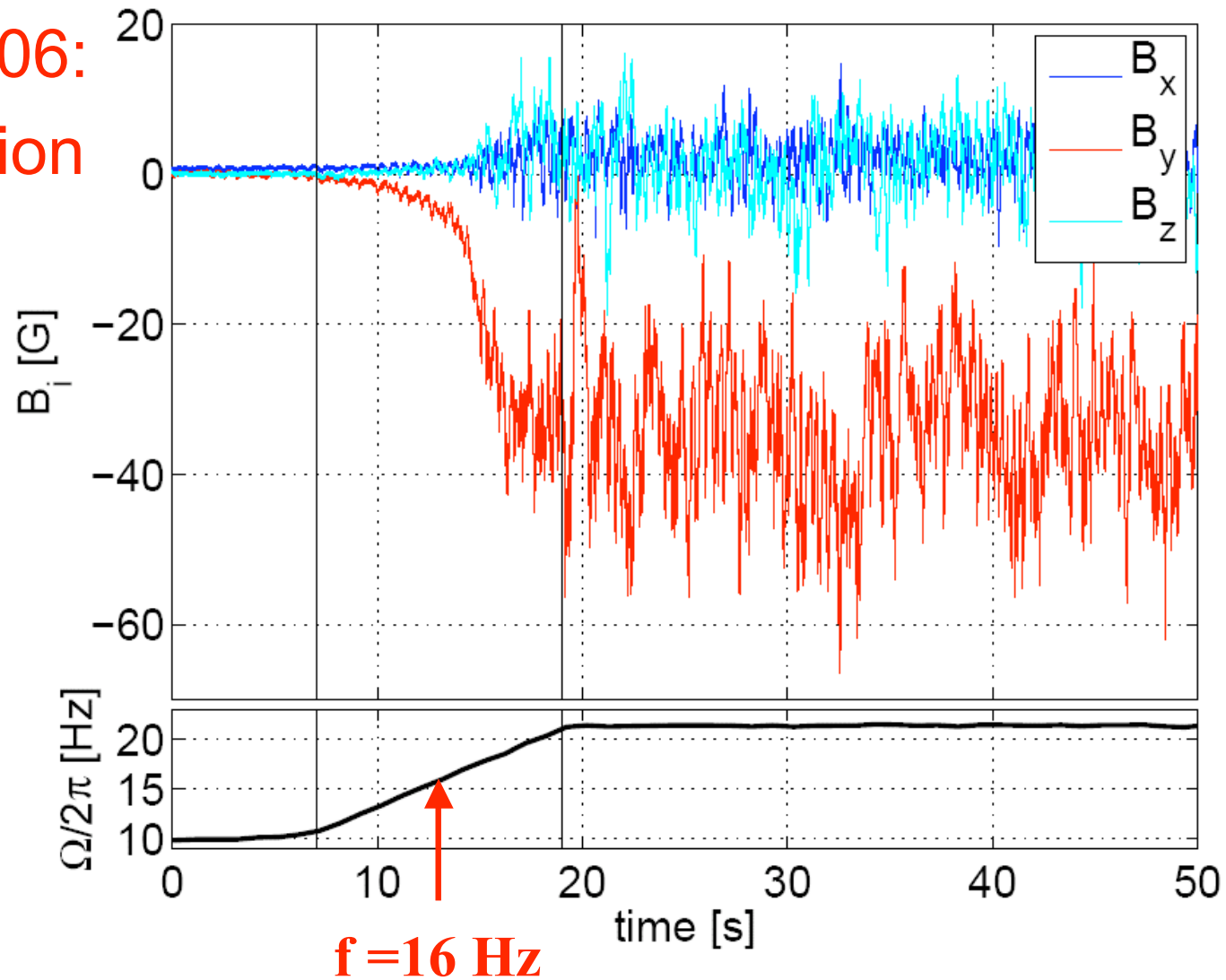
Stationary dynamo with symmetric driving $f_1=f_2$



Observation of a turbulent dynamo

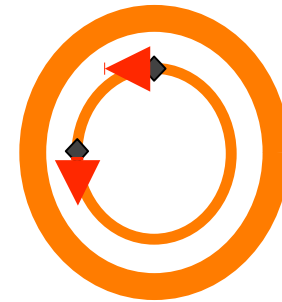
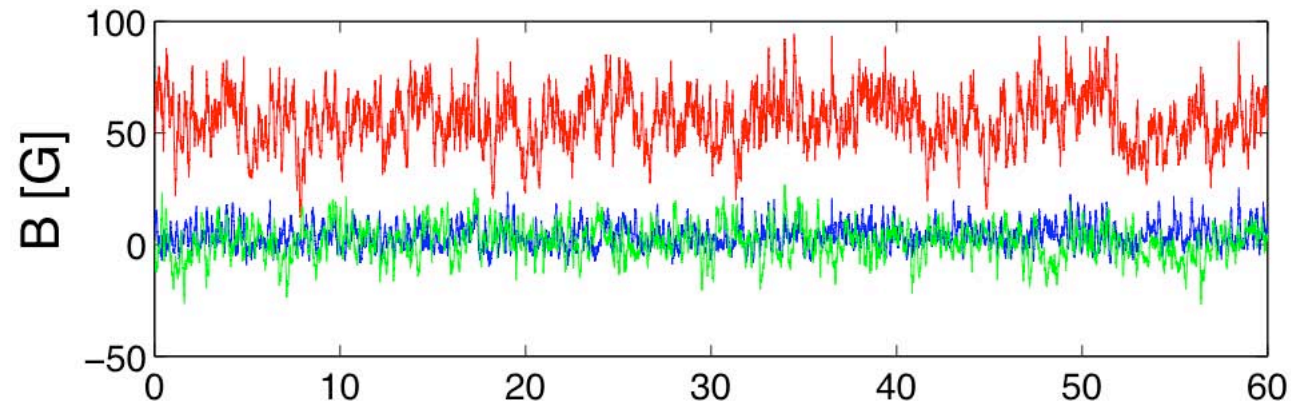
September 06:
dynamo action
for $f > 16$ Hz

$$f_1 = f_2$$

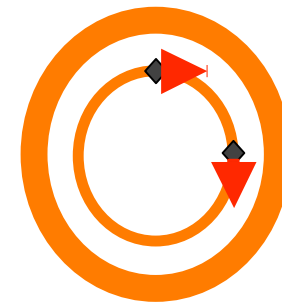
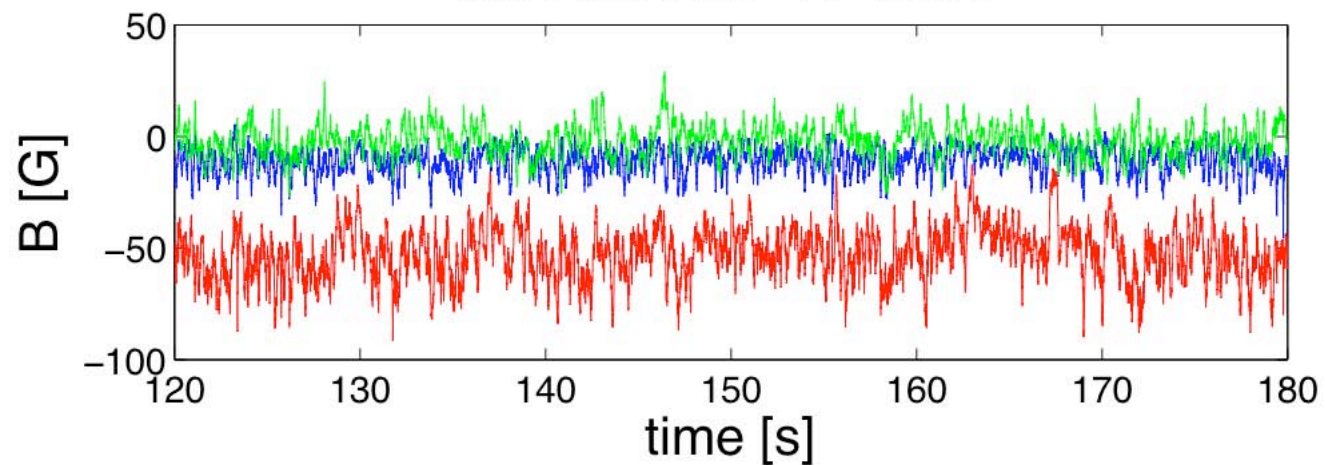


Dynamo field orientation

mes104b / 27-10-2006



mes42b / 26-10-2006

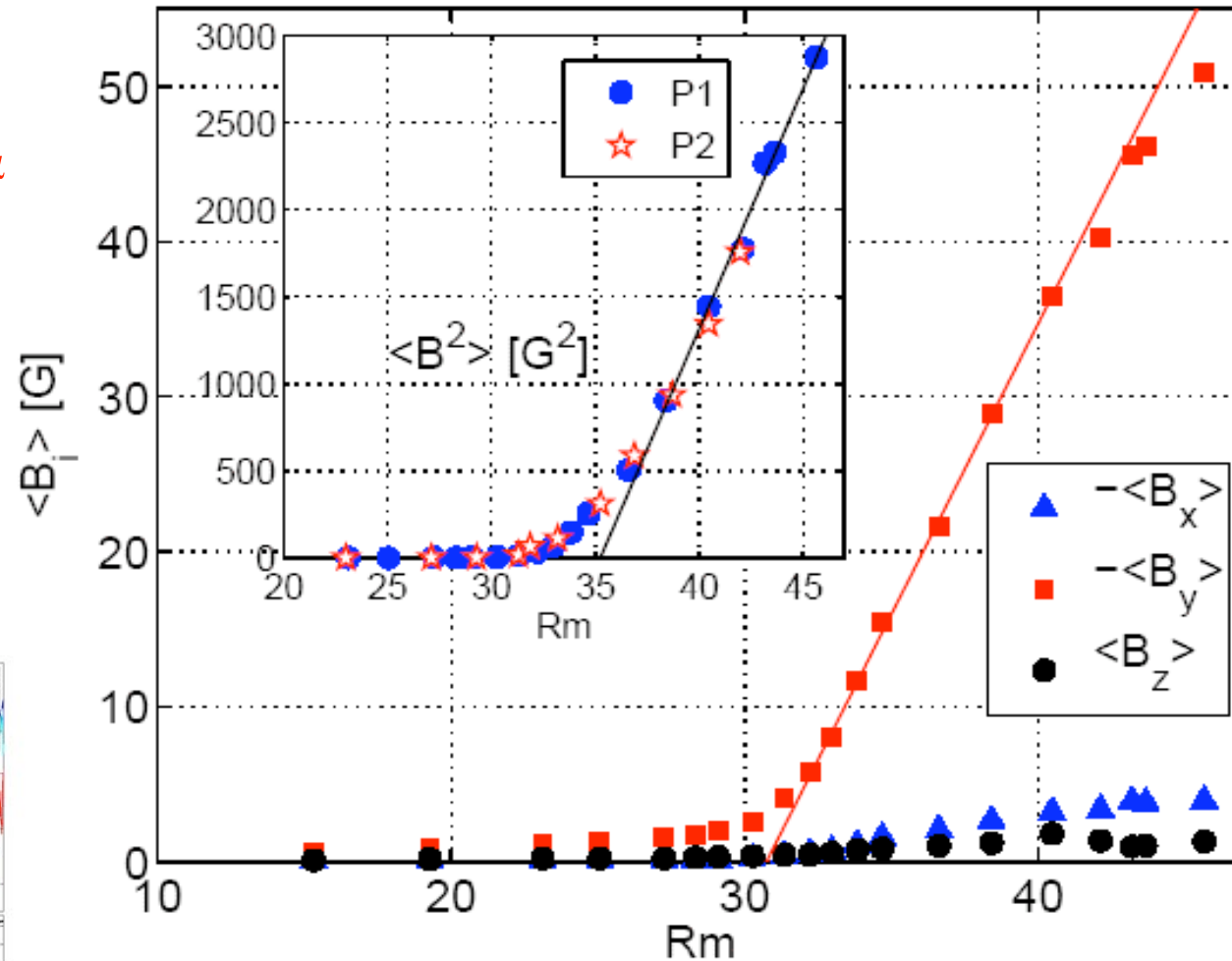
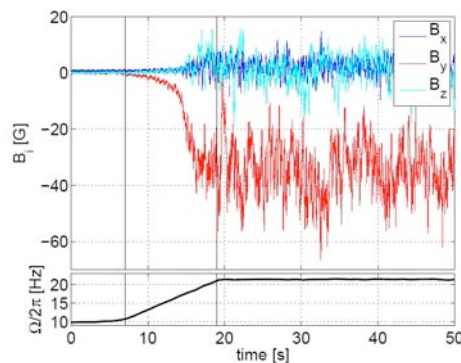


Dynamo bifurcation: evolution of $\langle B \rangle$

$$B \sim (R_m - R_m^c)^\alpha$$

scaling

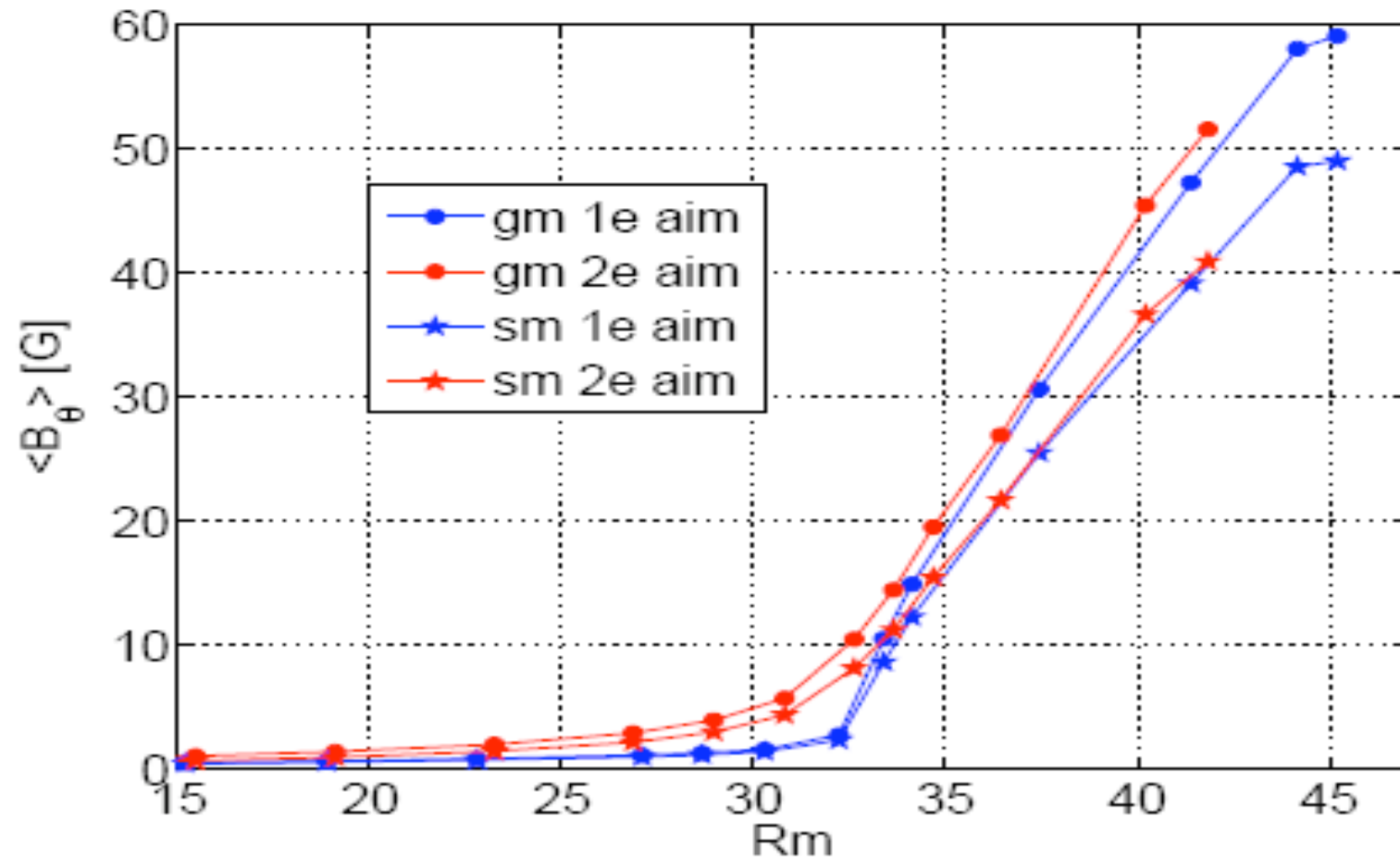
$$\frac{1}{2} < \alpha < 1?$$



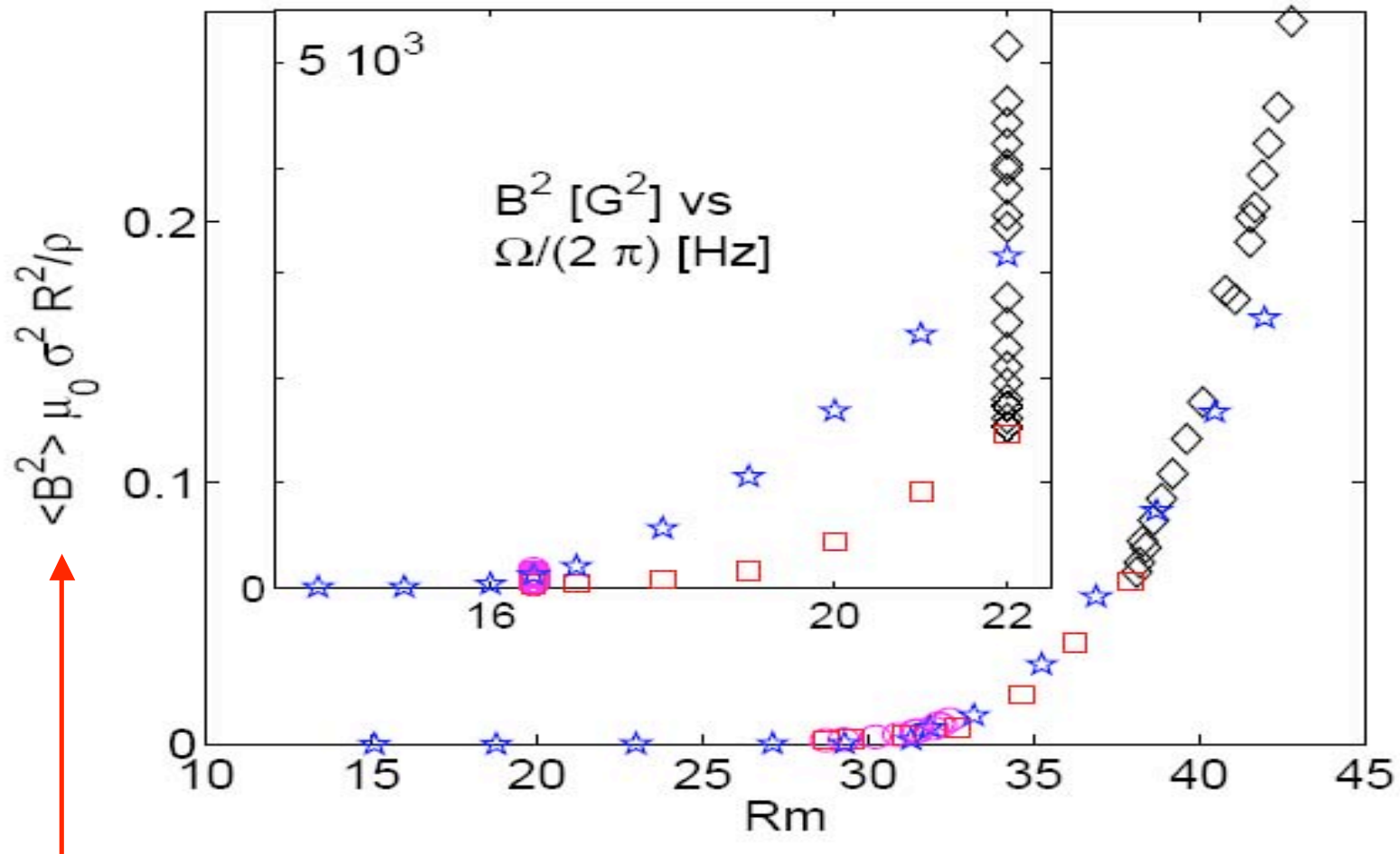
Monchaux et al. Phys.Rev.Lett. 2007

Bifurcation: evolution of $\langle B \rangle$

Imperfect
bifurcation



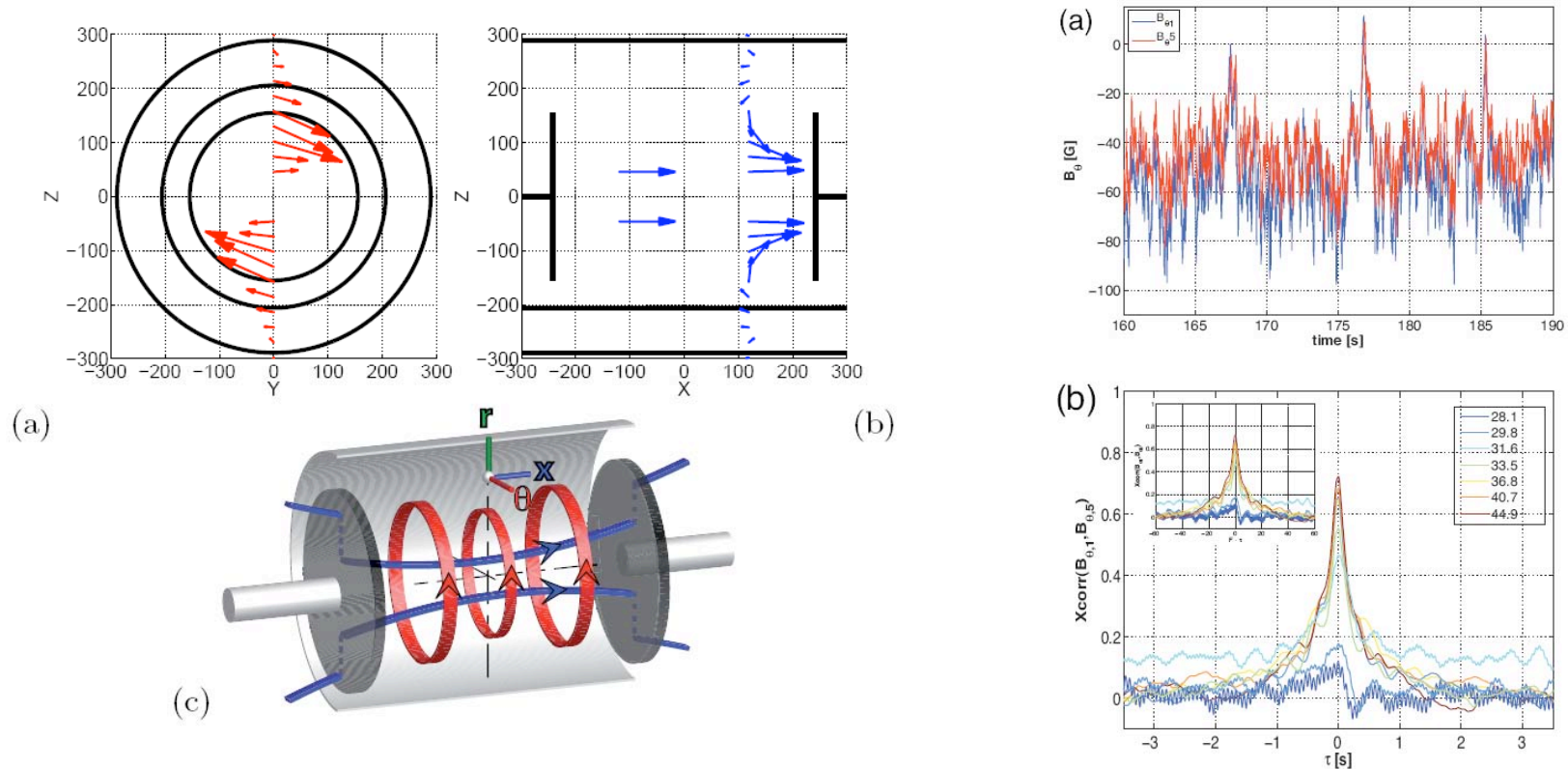
Bifurcation: scaling law of saturated $\langle B \rangle$



Turbulent scaling

Prediction Petrelis et Fauve EPJB 22 (2001)

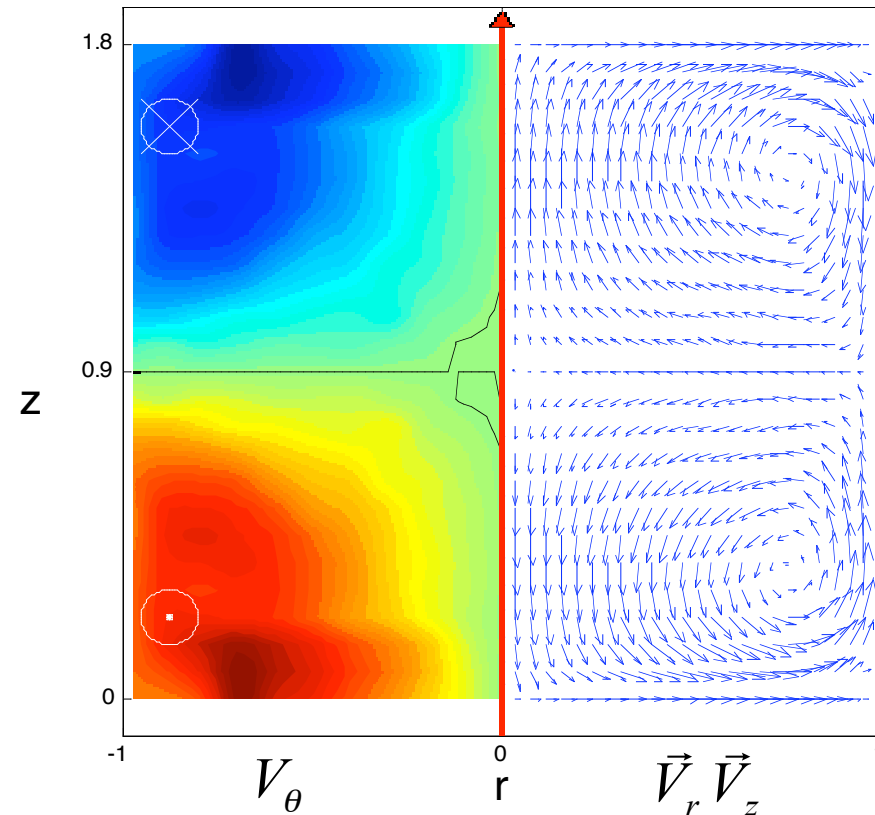
Geometry of the dynamo field



Dipolar magnetic field ~ **axisymmetric ($m=0$ B mode)**

- \neq kinematic mode predicted with $\langle V \rangle$ ($m=1$ B mode)
- forbidden by Cowling theorem for $\langle V \rangle$ axisymmetric
 → created by turbulent fluctuations?

Mean flow: water experiments



Turbulent: $Re \sim 5 \cdot 10^5$
 $\delta v/v = 0.4$

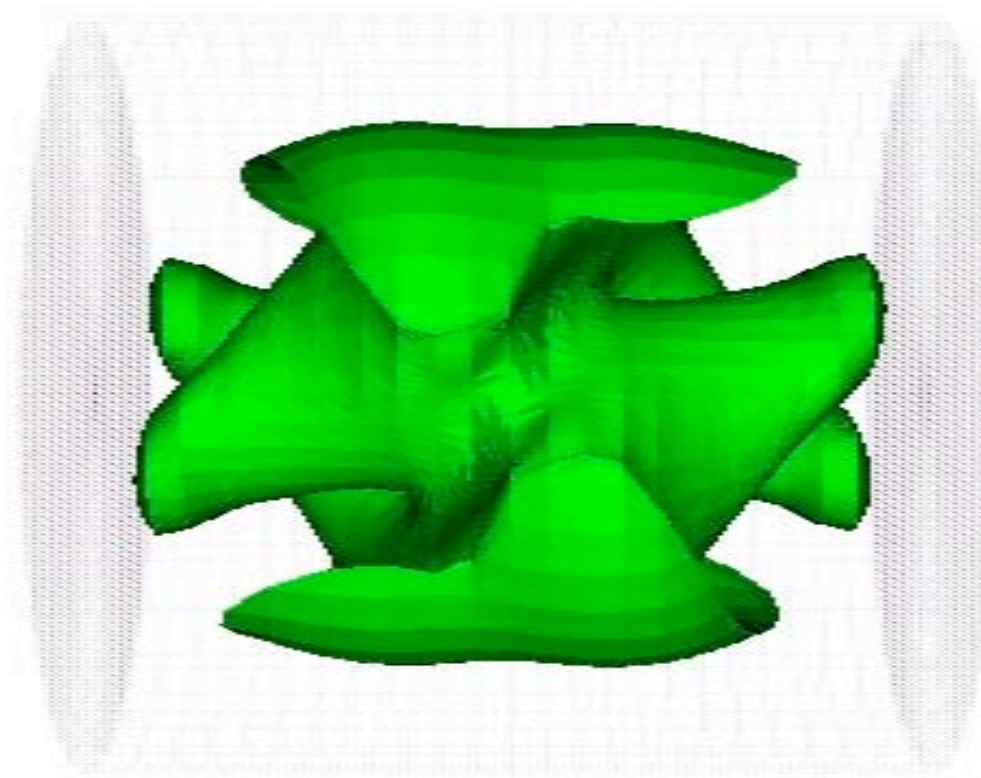
Mean velocimetry measurements
(LDV-PIV)

Kinematic neutral mode

$$\frac{\partial \vec{B}}{\partial t} + R_m (\vec{v} \cdot \overrightarrow{\text{grad}}) \vec{B} = R_m (\vec{B} \cdot \overrightarrow{\text{grad}}) \vec{v} + \Delta \vec{B}$$

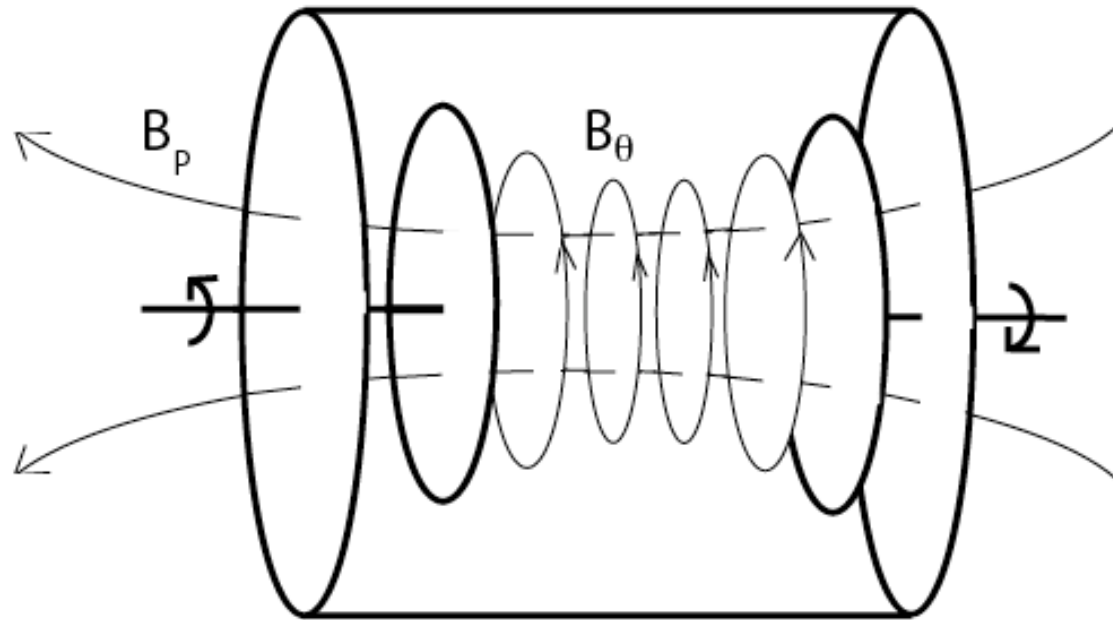
Ravelet et al.
POF 2005

Stationary
equatorial
dipole ($m=1$)



- equatorial dipole killed by turbulent fluctuations?
- equatorial dipole bifurcates towards axial dipole?

Turbulent α - Ω dynamo



B_θ generated from B_p because of the differential rotation (Ω effect)

B_p generated from B_θ because of helicity of the radial divergent flow between blades (α effect)

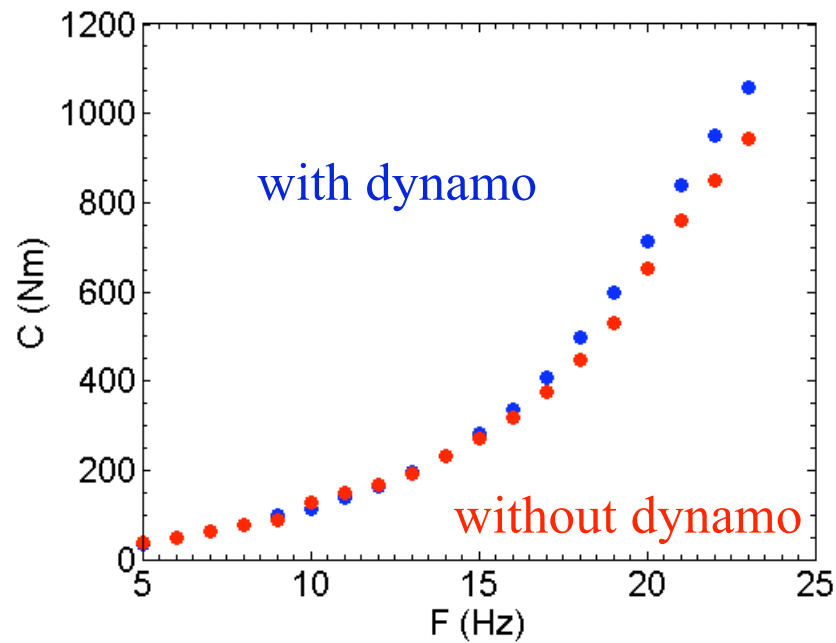
B created by turbulent non axisymmetric fluctuations?

Petrelis et al. GAFD 2007

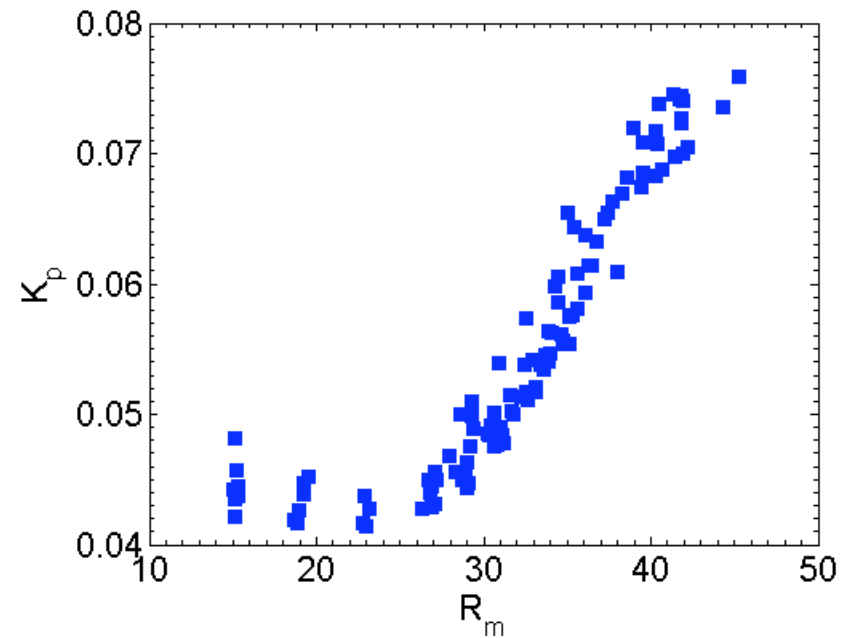
Power budget in VKS

Dynamo power: $P_T = P_{cin} + P_{mag}$

Torque



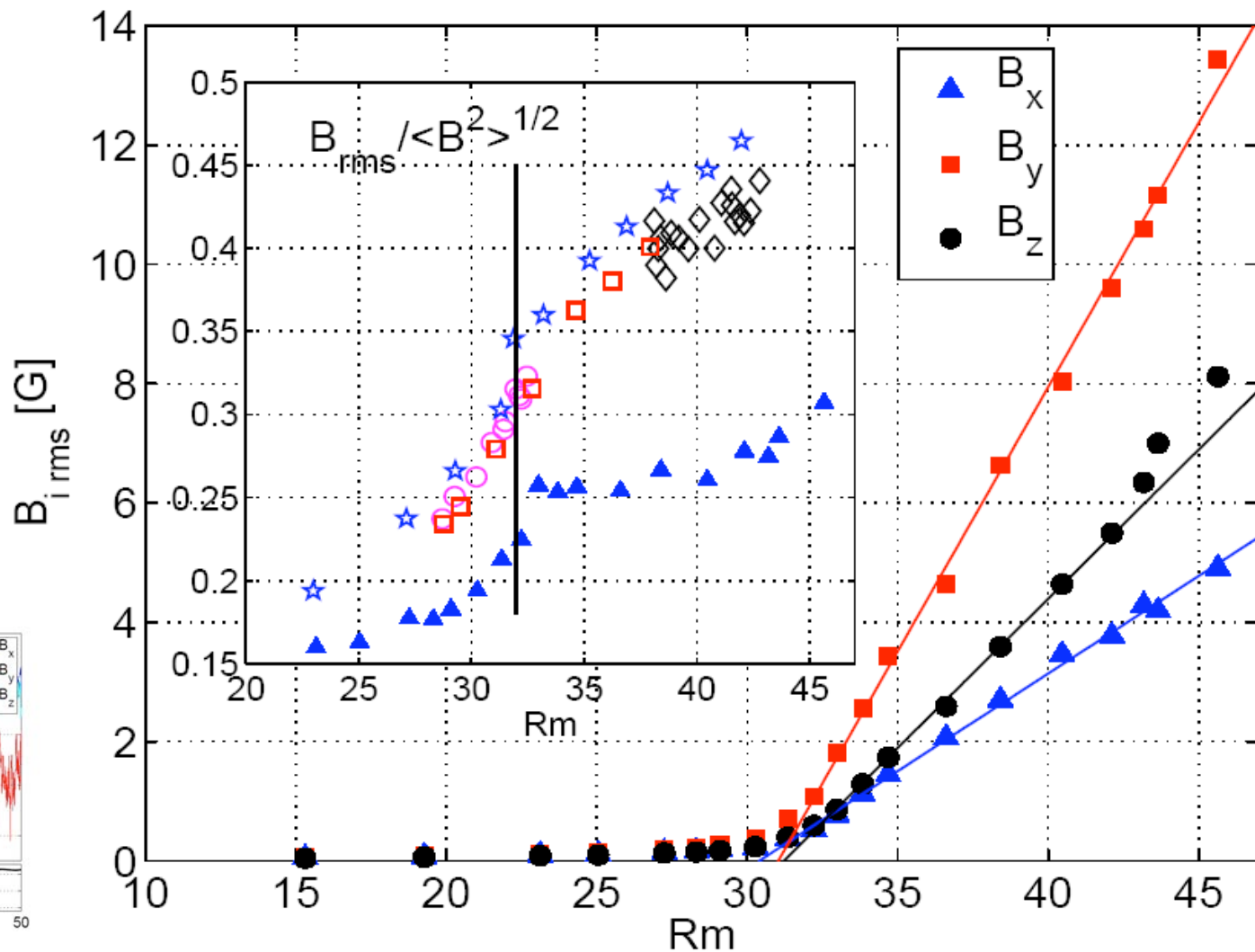
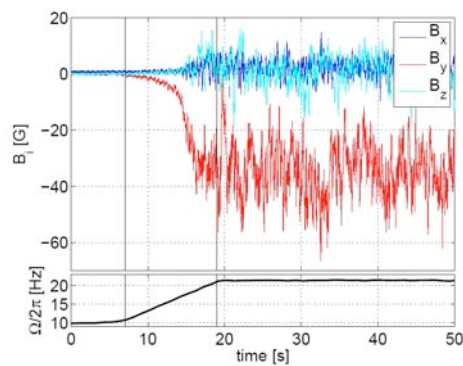
Non dimensional torque



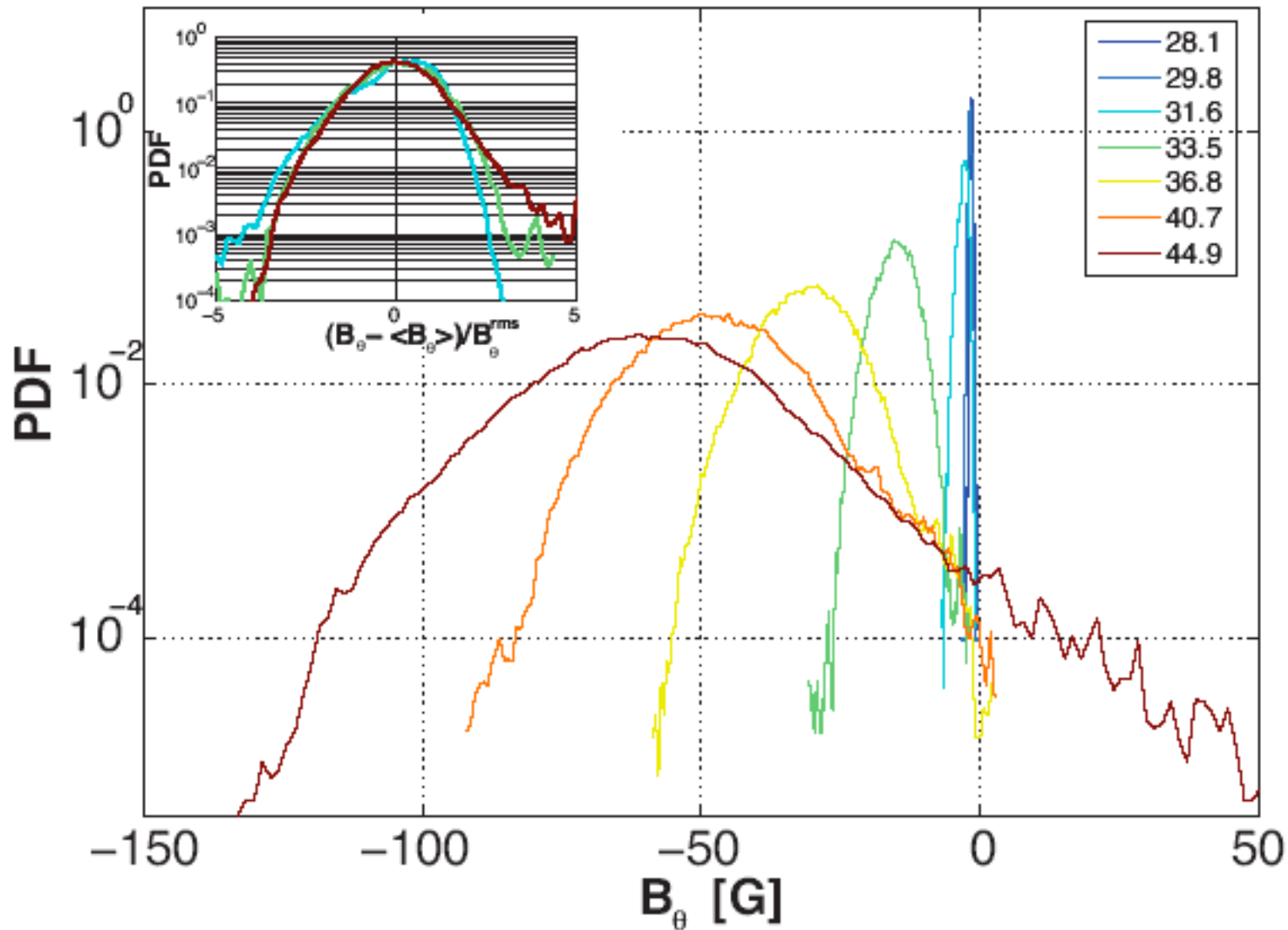
dynamo = increase of power 15%

Fluctuations: evolution of B_{rms}

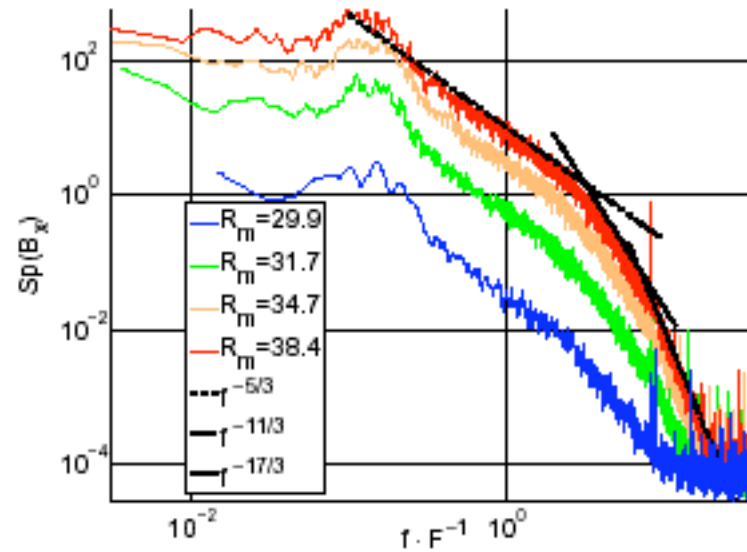
Bifurcation
in presence
of noise



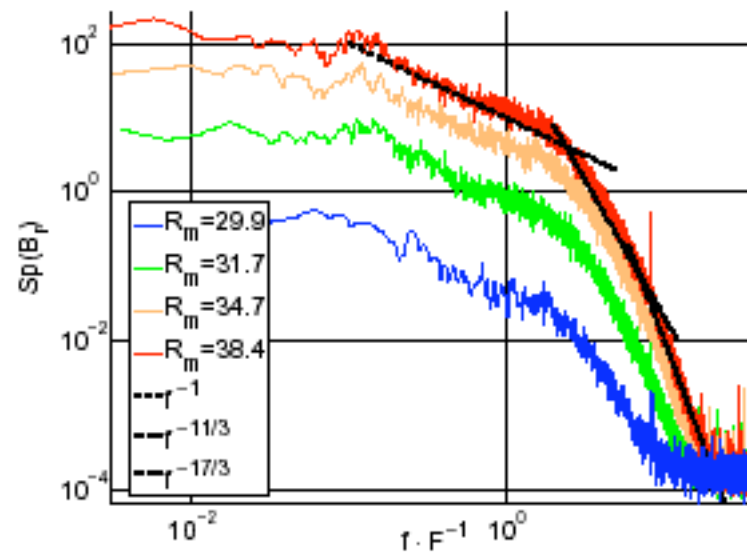
Fluctuations: PDFs



Fluctuations: time spectra



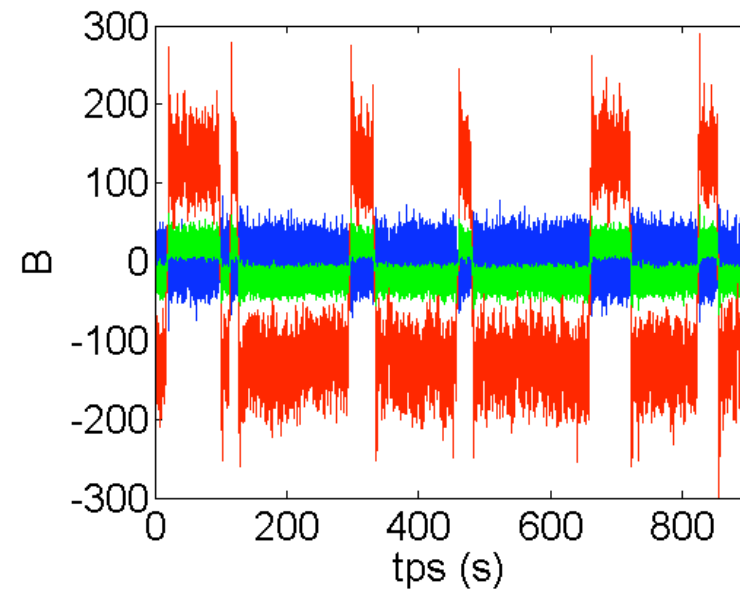
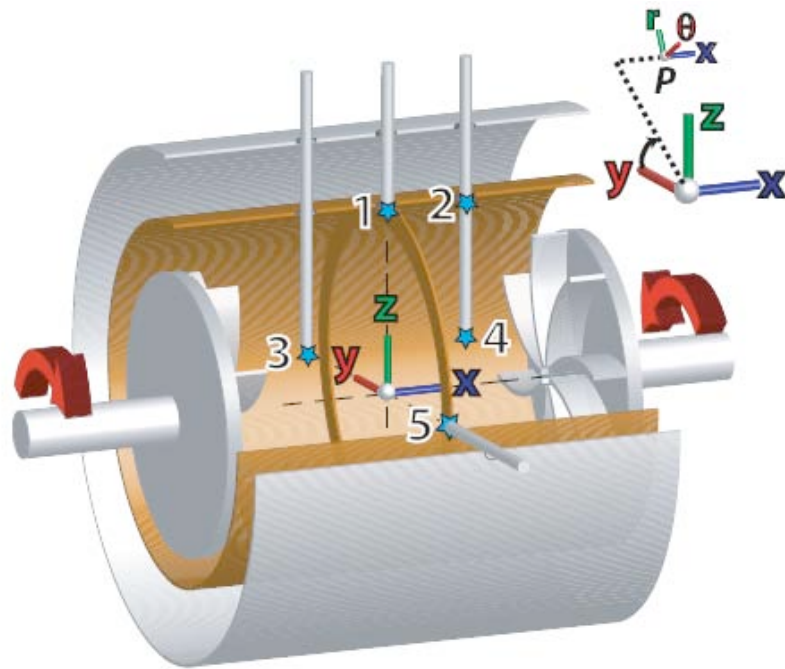
axial component



radial component

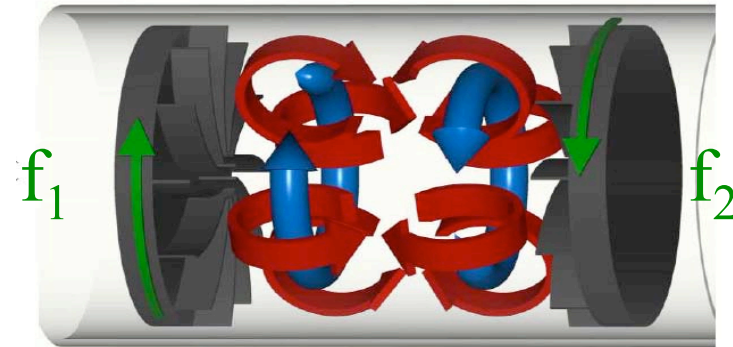
VKS2 experiment

Dynamical dynamos with asymmetric forcing $f_1 \neq f_2$

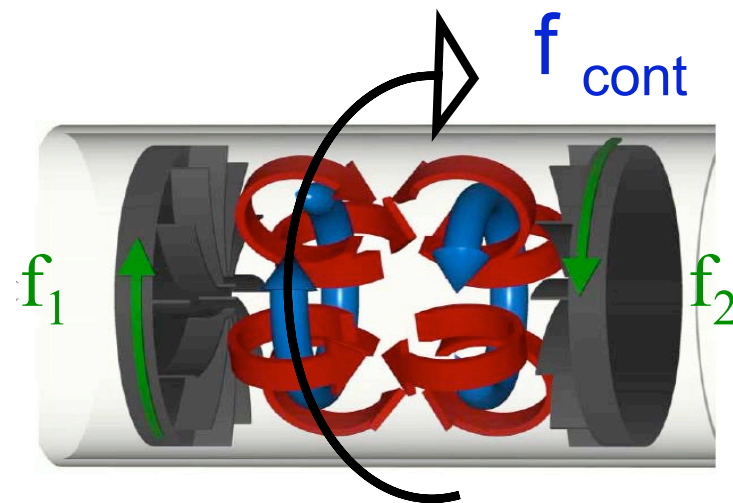


Global rotation : propellers with $f_1 \neq f_2$

$$f_1 \neq f_2 \text{ and } f_{\text{cont}} = 0$$

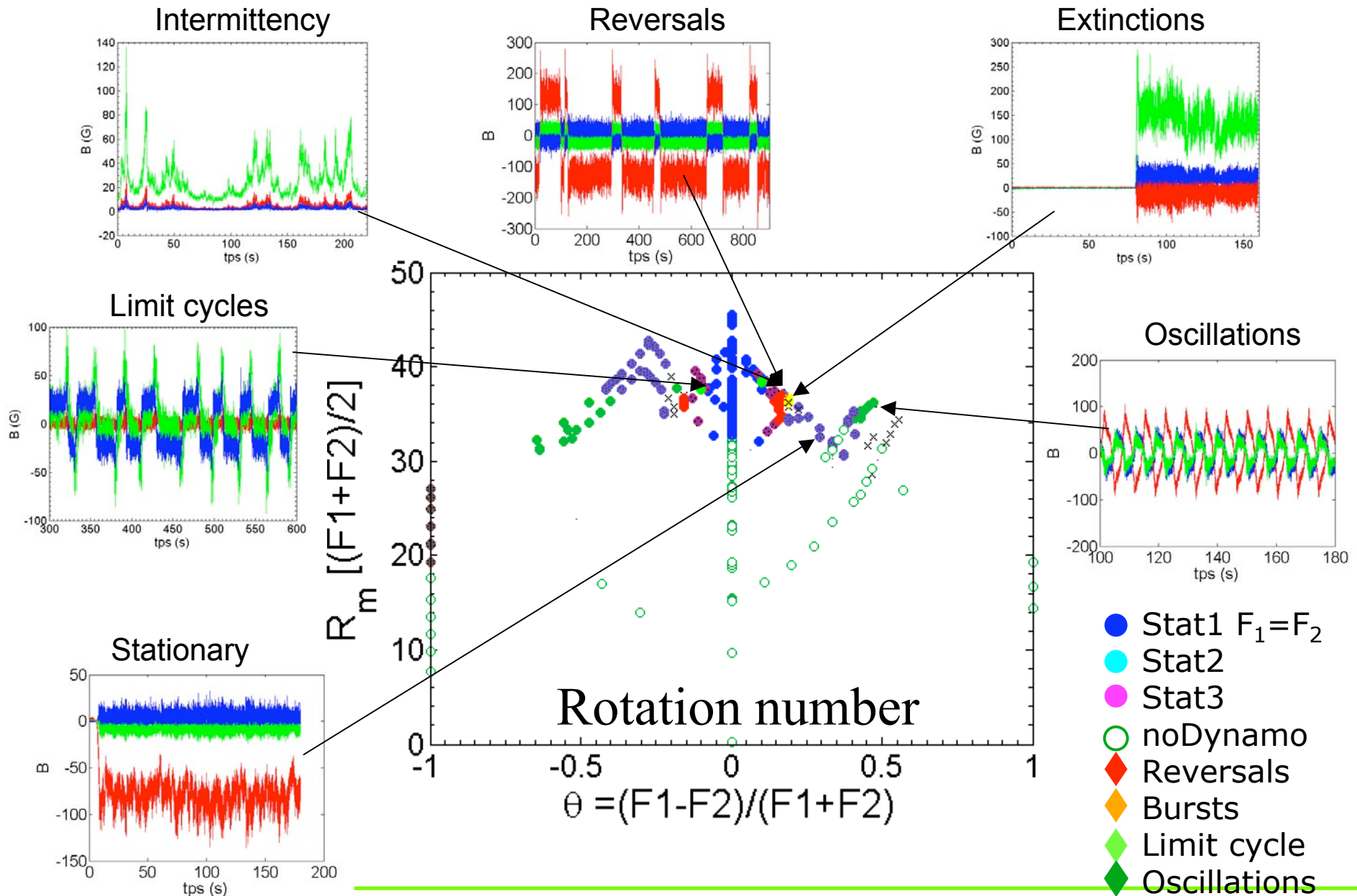


$$f_1 = f_2 \text{ and } f_{\text{cont}} = \frac{1}{2} (f_1 - f_2)$$



L.Marié PhD

Global rotation: observed dynamics



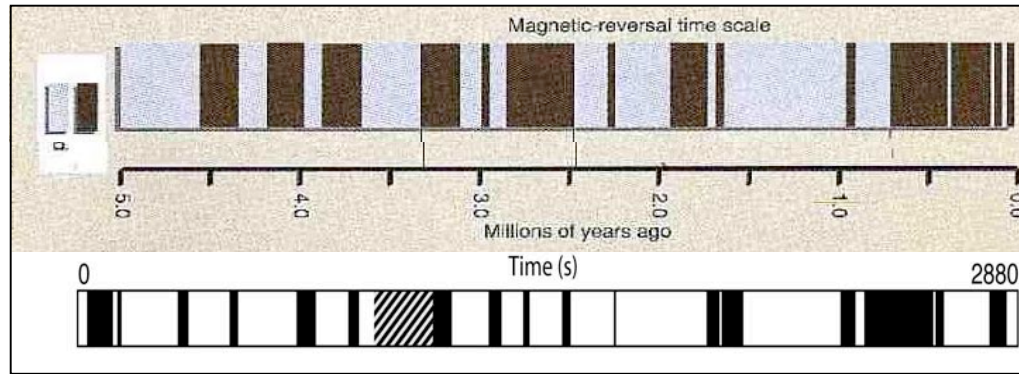
Erratic reversals of B

Berhanu et al. EPL 2007

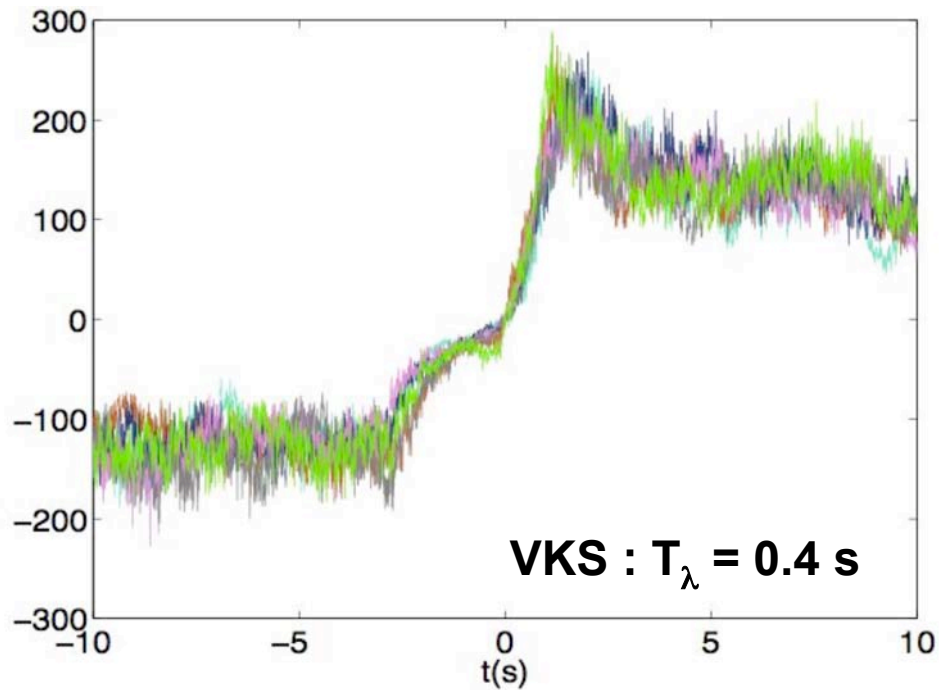
July 16, 2008

KITP UCSB

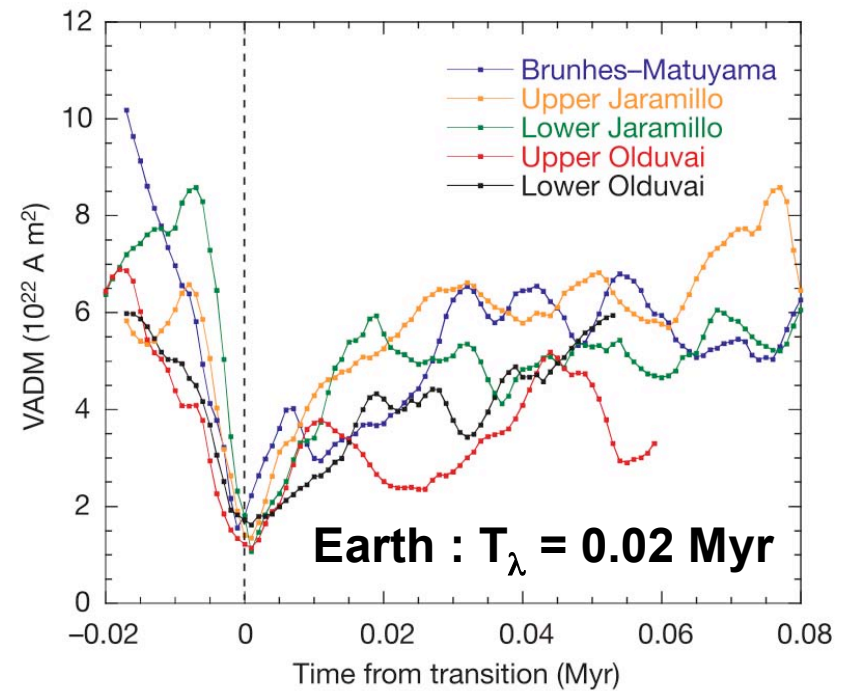
Erratic reversals of B: VKS / Earth



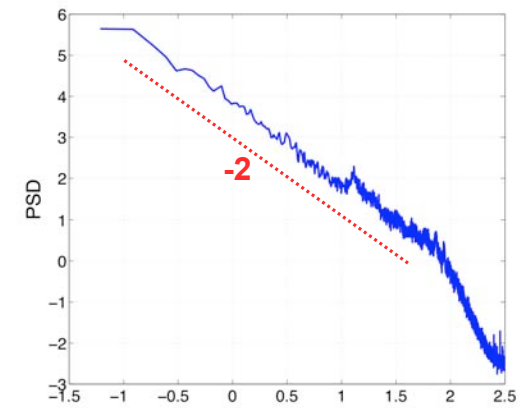
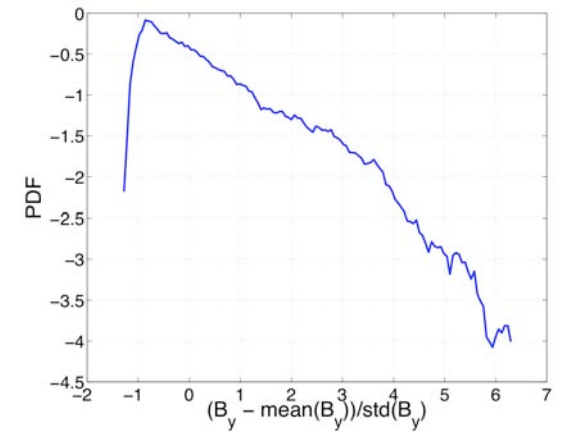
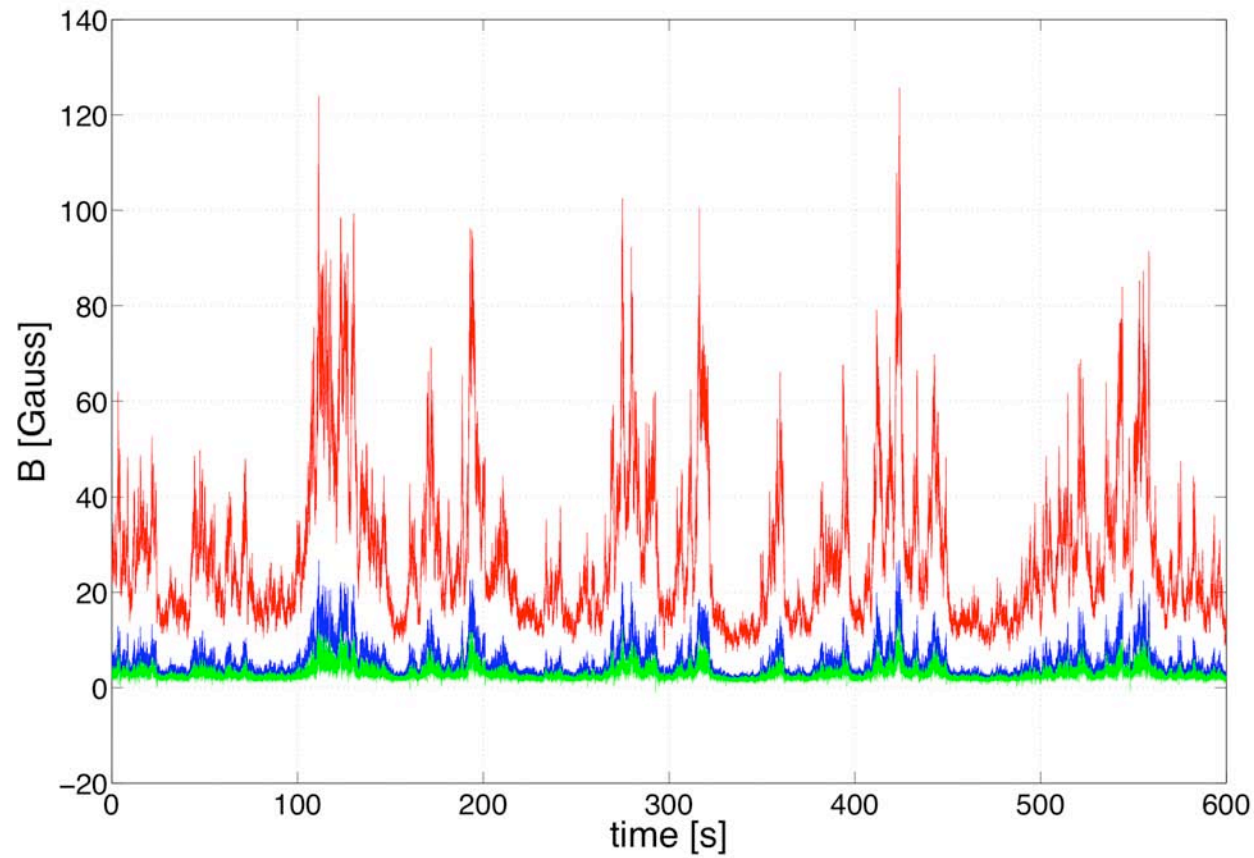
Berhanu et al. EPL 2007



Valet et al. Nature 2005

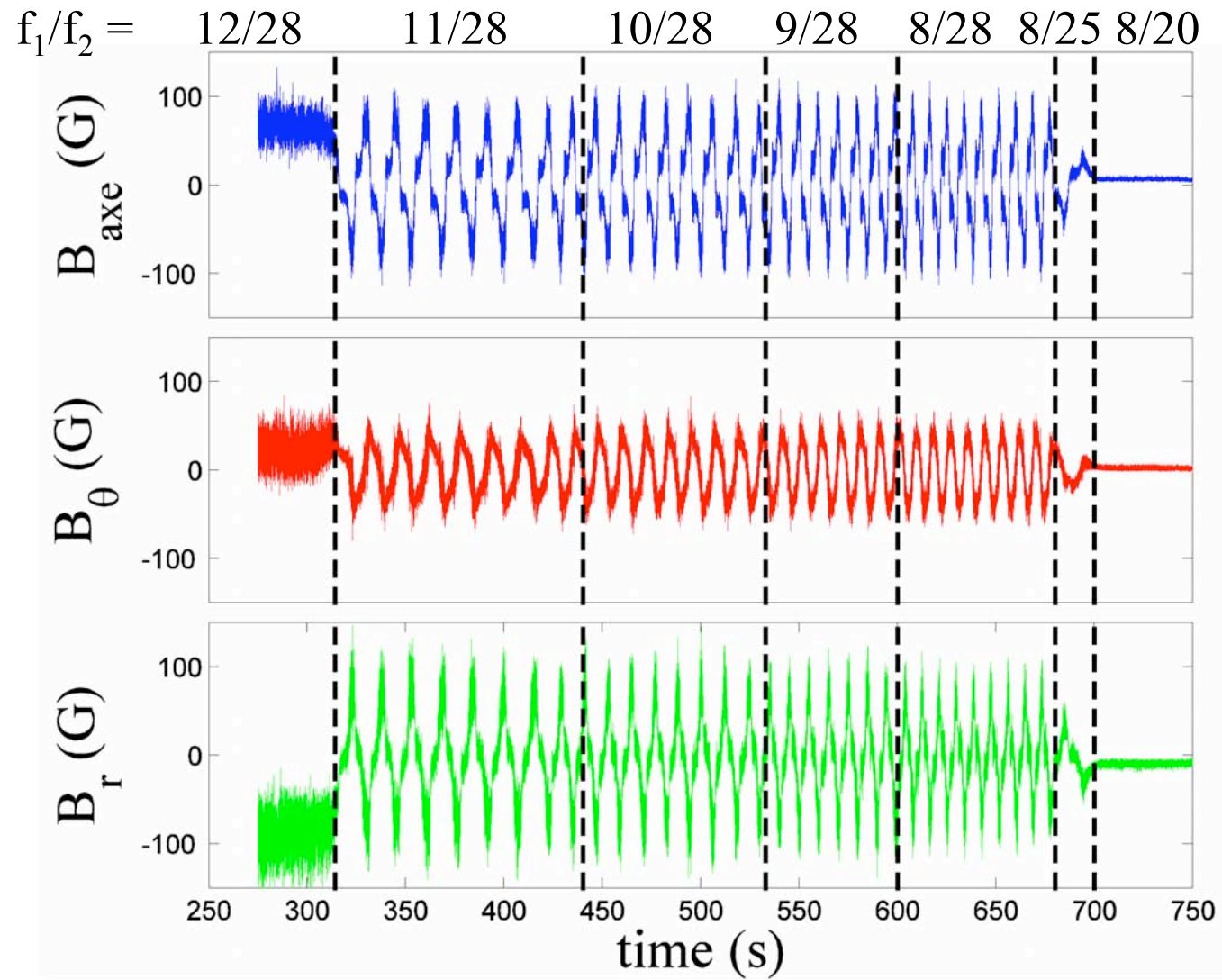


Dynamo bursts

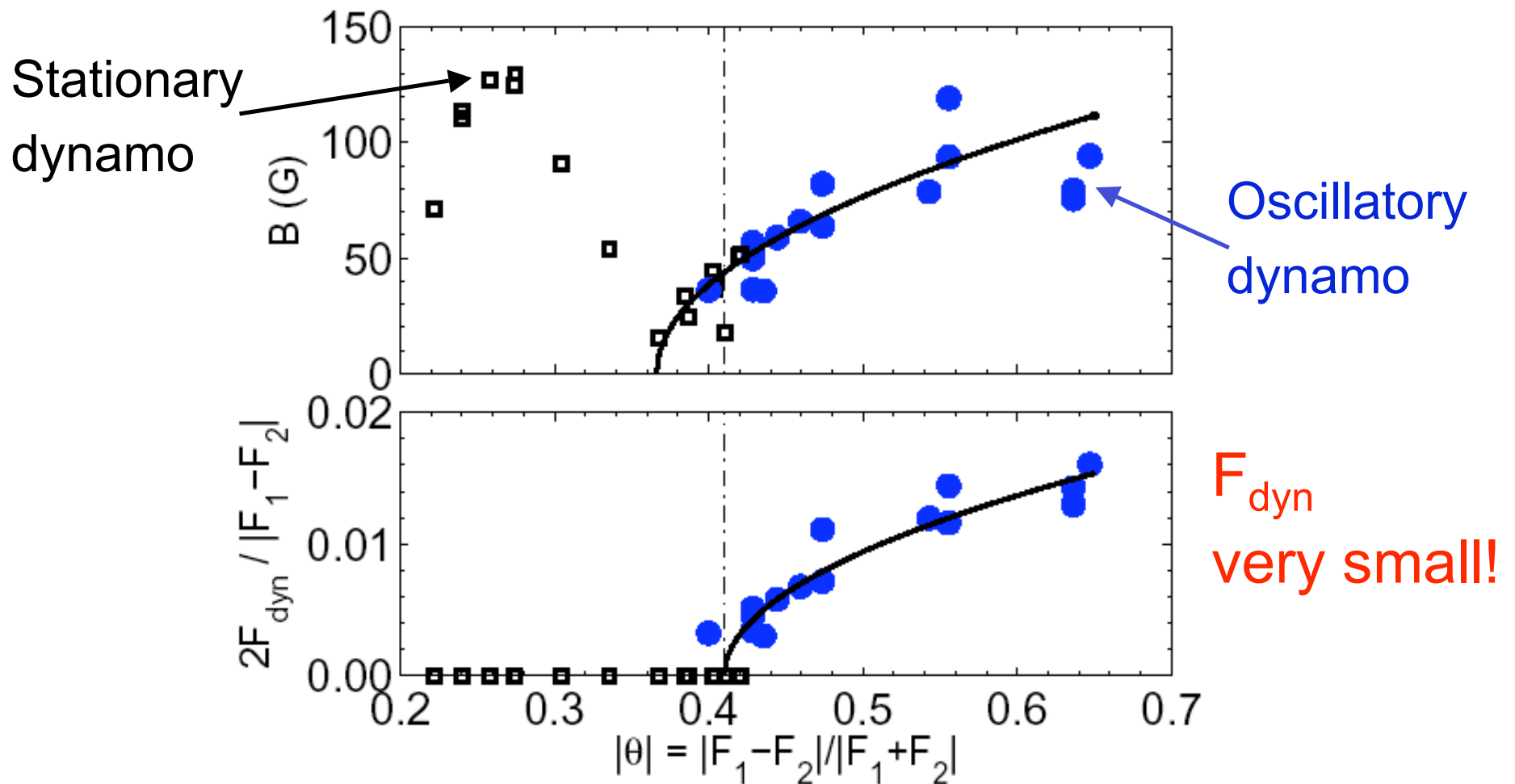


15/22, $\theta = 0.19$

Oscillatory dynamos

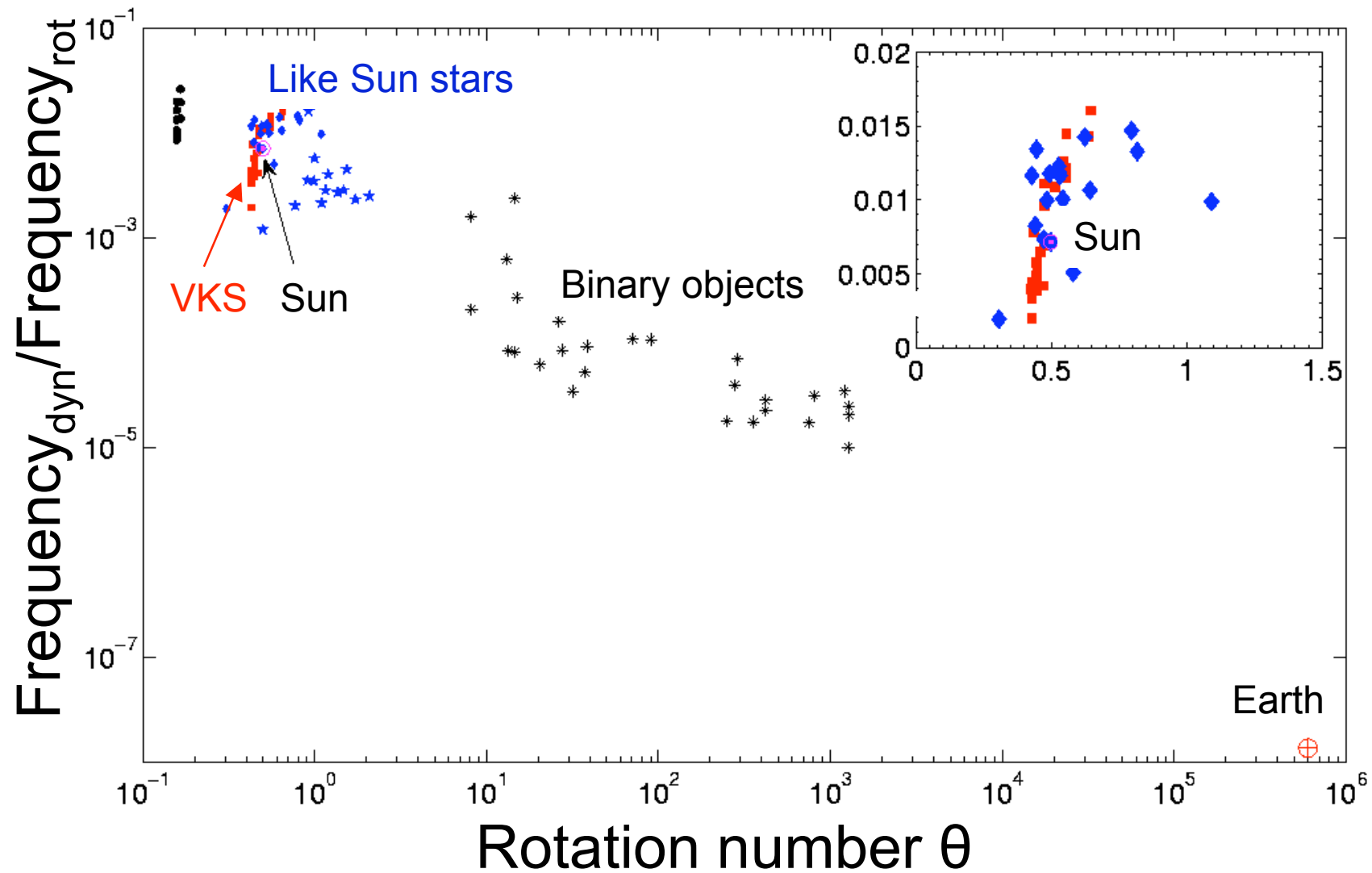


Transition to oscillatory dynamos



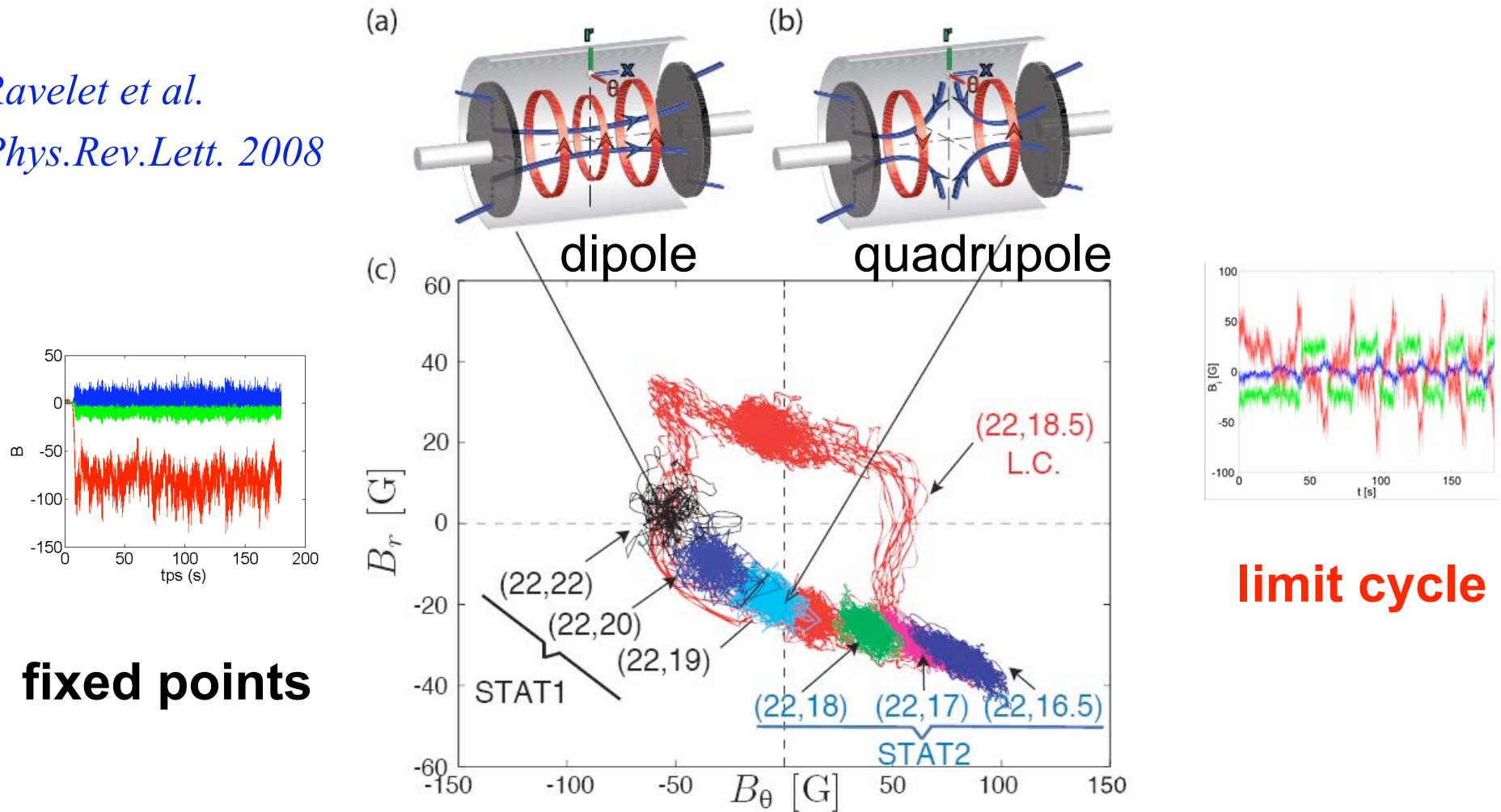
Finite amplitude and zero frequency secondary bifurcation as in low dim. systems: B and $F_{\text{dyn}} \sim (\theta - \theta_c)^{1/2}$

Oscillatory dynamos : VKS / stars



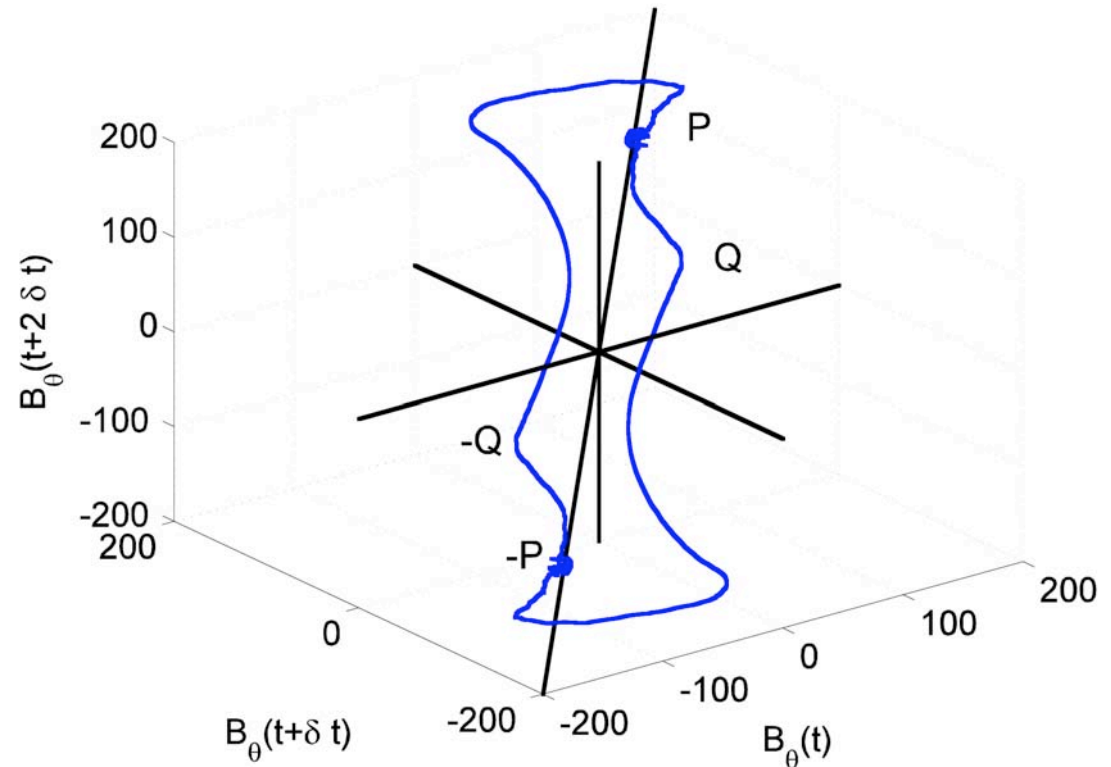
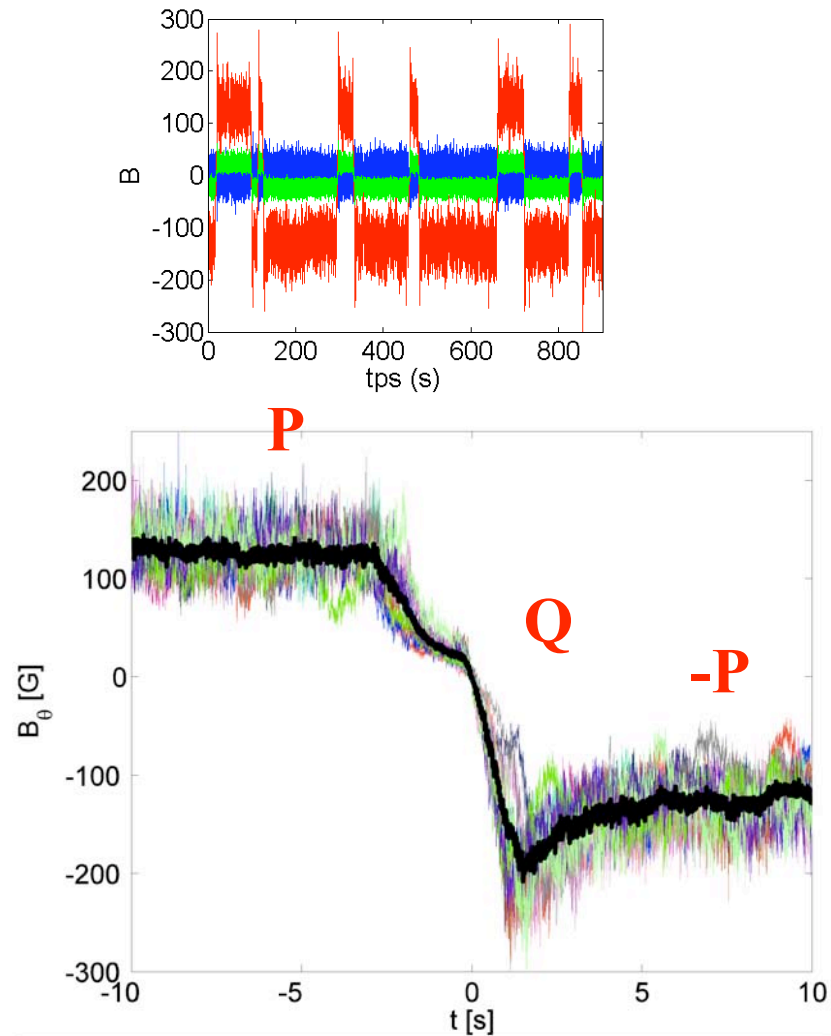
Transition stationary-limit cycle dynamos

Ravelet et al.
Phys.Rev.Lett. 2008



Saddle node-bifurcation fixed point \rightarrow limit cycle
 \sim transition in low dimensional excitable system

Dynamo reversals

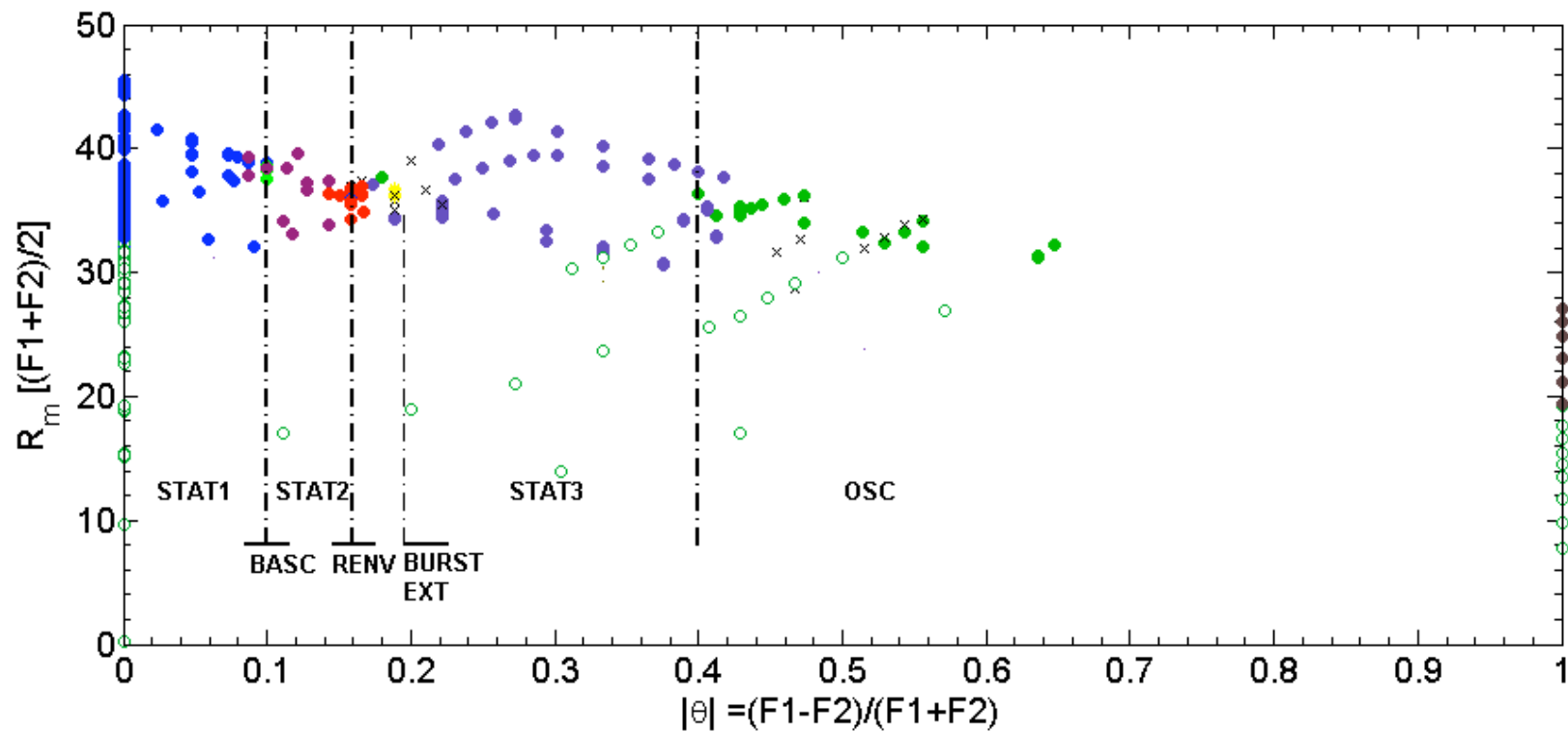


Heteroclinic orbits connecting unstable fixed points

Global rotation: states diagram

- $\theta = (f_1 - f_2) / (f_2 + f_1)$
- $R_m = 2\pi K\mu_0\sigma R^2 (f_1 + f_2)/2$

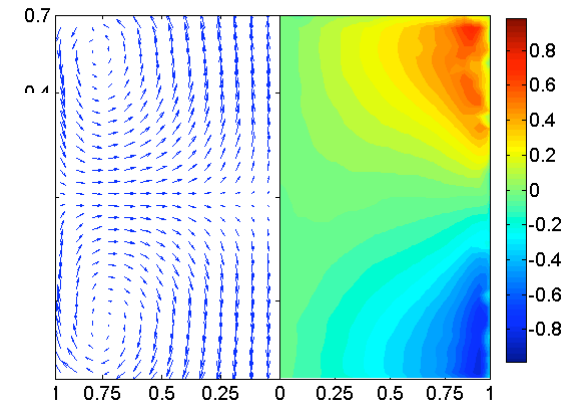
- Stat1 $F_1 = F_2$
- Stat2
- Stat3
- noDynamo
- Reversals
- Bursts
- Basc: Limit cycle
- Oscillations



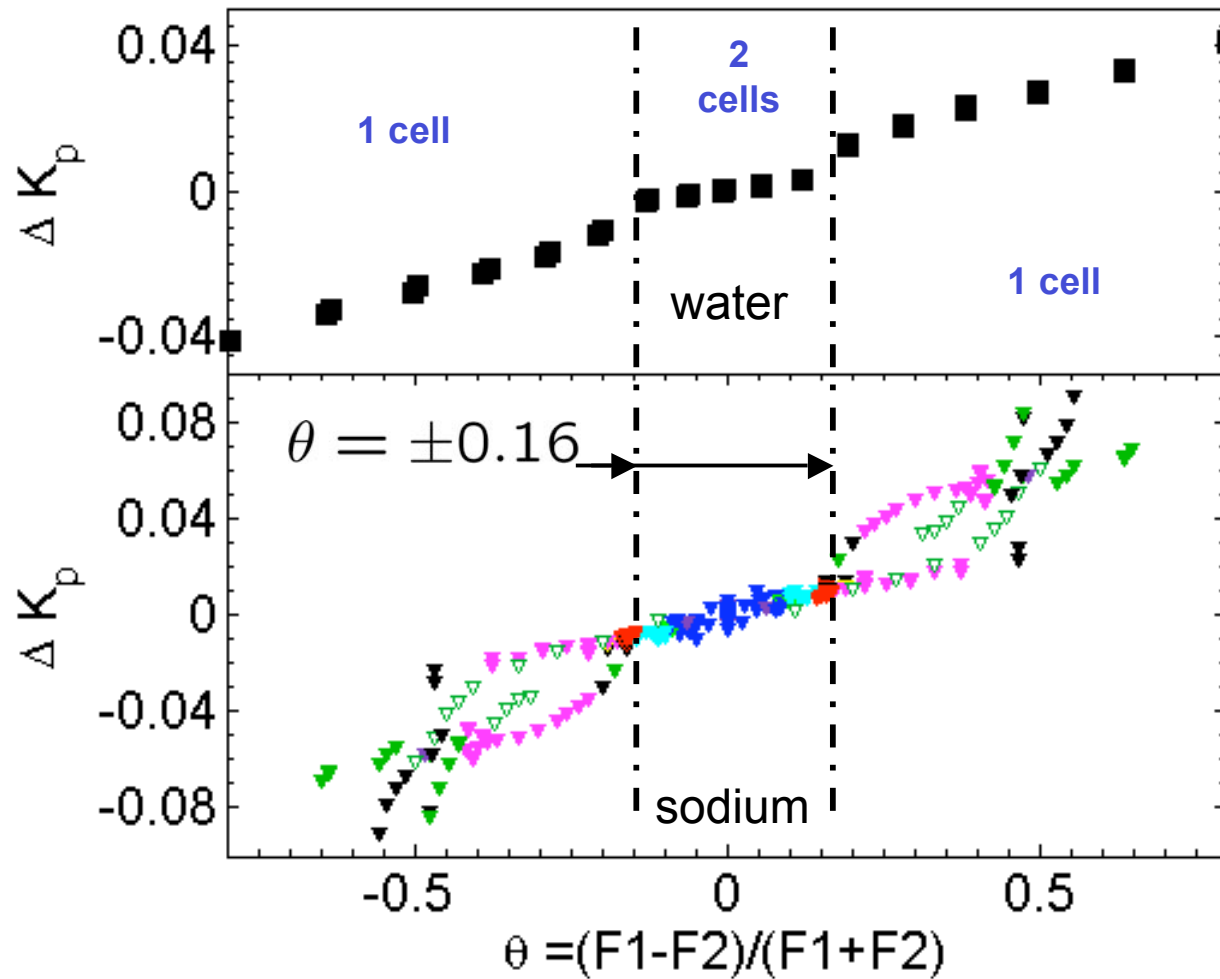
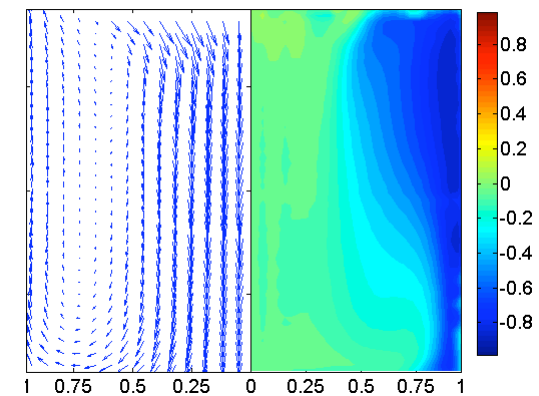
Couplings MHD - hydrodynamics

$$K_p = \text{Torque} / \rho R_c^5 (2\pi f)^2$$

$|\theta| < 0.16 \rightarrow 2 \text{ cells}$



$|\theta| > 0.16 \rightarrow 1 \text{ cell}$



Conclusion

- $f_1=f_2$: stationary turbulent dynamo
axisymmetric neutral mode not generated by
mean flow alone
- $f_1 \neq f_2$: dynamical dynamos
large scale dynamics of B
 - characteristic of low – dimensional systems
 - not qualitatively modified by turbulent
fluctuations