

Rôle des petites échelles pour la dynamo dans le régime magnétostrophique

H-C. Nataf

Institut des Sciences de la Terre
Observatoire des Sciences de l'Univers de Grenoble
Université de Grenoble / CNRS
France

OSUG



CRS
Laboratoire Géodynamique
LGIT

ETARE n° 73c
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Quelles méthodes pour quelles instabilités ?

- L'instabilité dynamo à l'origine du champ magnétique des astres
- L'effet du champ magnétique sur l'écoulement
- Le rôle des petites échelles dans la dynamo
- Exploration expérimentale avec DTS

L'instabilité dynamo à l'origine du champ magnétique des astres

Equation d'induction:

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times (\vec{U} \times \vec{B}) + \eta \Delta \vec{B}$$

adimensionnée:

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times (\vec{U} \times \vec{B}) + \frac{1}{Rm} \Delta \vec{B}$$

le nombre de Reynolds magnétique:

$$Rm = \frac{UL}{\eta}$$

Dérivation de l'équation d'induction

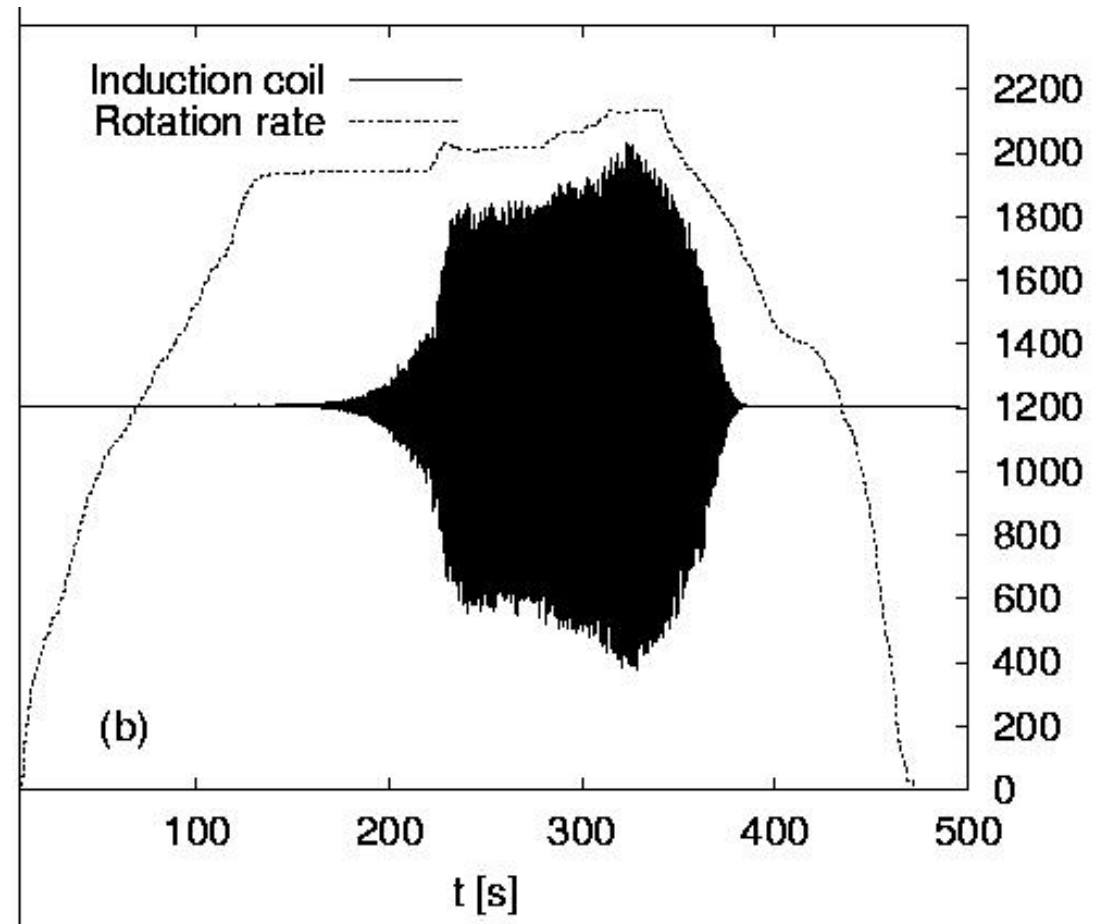
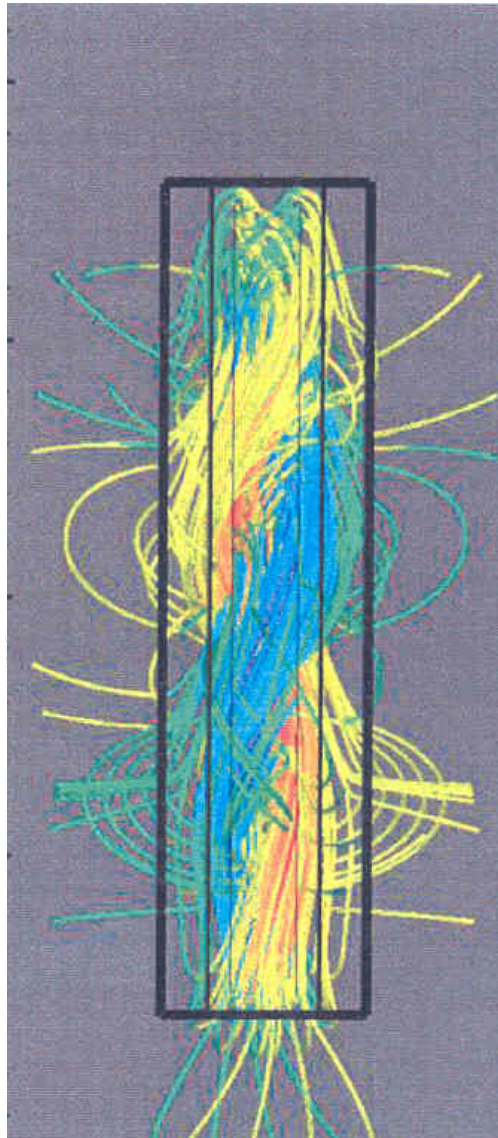
$$\frac{\partial \vec{B}}{\partial t} = -\vec{\nabla} \times \vec{E} \quad \text{Induction}$$

$$\frac{\vec{j}}{\sigma} = \vec{E} + \vec{U} \times \vec{B} \quad \text{Loi d'Ohm}$$

$$\mu \vec{j} = \vec{\nabla} \times \vec{B} \quad \text{Loi d'Ampère}$$

Exemple : la dynamo de Riga

Gailitis et al, 2000, 2001, 2002



L'effet du champ magnétique sur l'écoulement

Equation de Navier-Stokes :

$$\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) + 2\rho \boldsymbol{\Omega} \times \mathbf{u} = -\nabla P + \mathbf{j} \times \mathbf{B} + \mu \Delta \mathbf{u} + \rho \mathbf{g}$$

- Effet sur les grandes échelles
- Effet sur les petites échelles

Equilibre magnétostrophique et état de Taylor

Equation de Navier-Stokes pour la Terre :

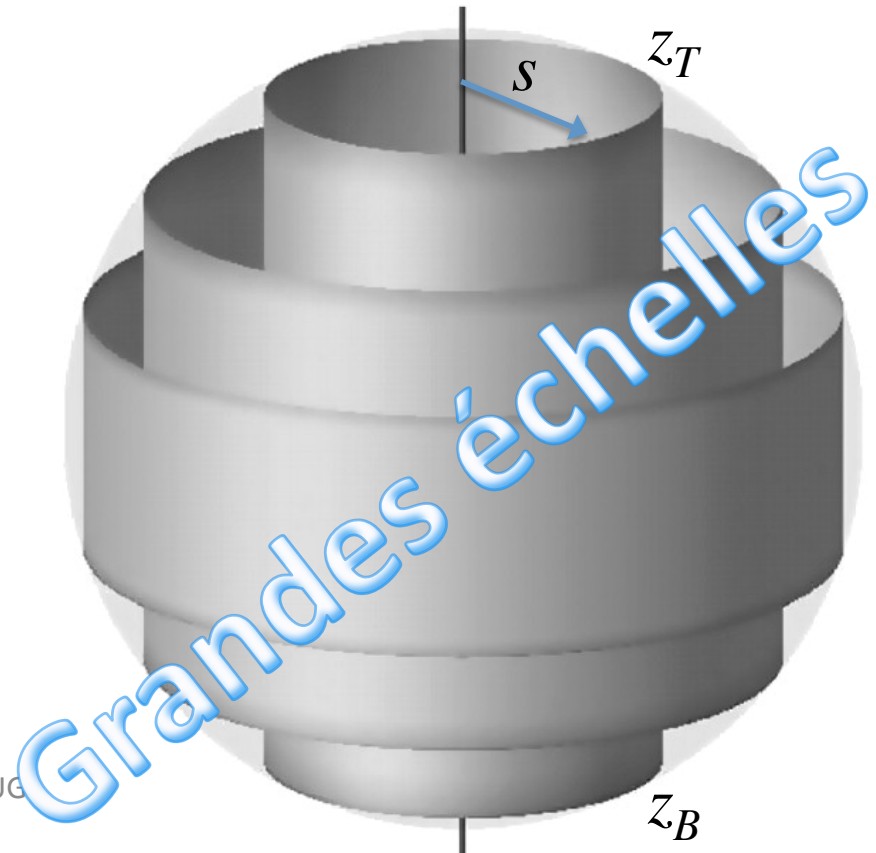
$$\rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) + 2\rho\Omega \times \mathbf{u} = -\nabla P + \mathbf{j} \times \mathbf{B} + \mu \Delta \mathbf{u} + \rho \mathbf{g}$$

- Nombre d'Elsasser

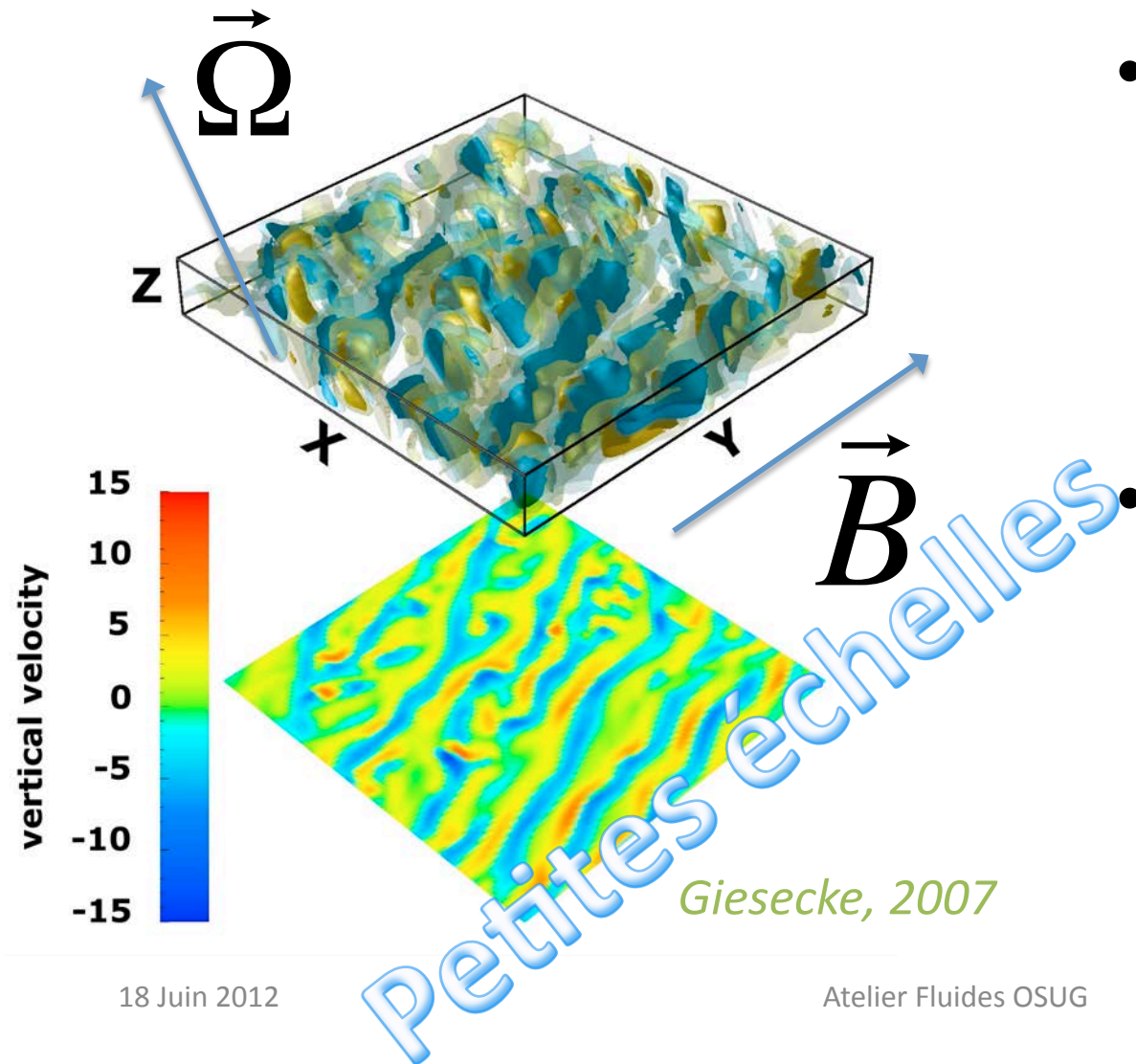
$$\Lambda = \frac{\sigma B^2}{\rho \Omega} \approx 1$$

- Couple magnétique nul sur les cylindres coaxiaux

$$\frac{d}{ds} \left[s^2 \int_{z_B}^{z_T} b_s b_\varphi dz \right] = 0$$



Turbulence magnétostrophique



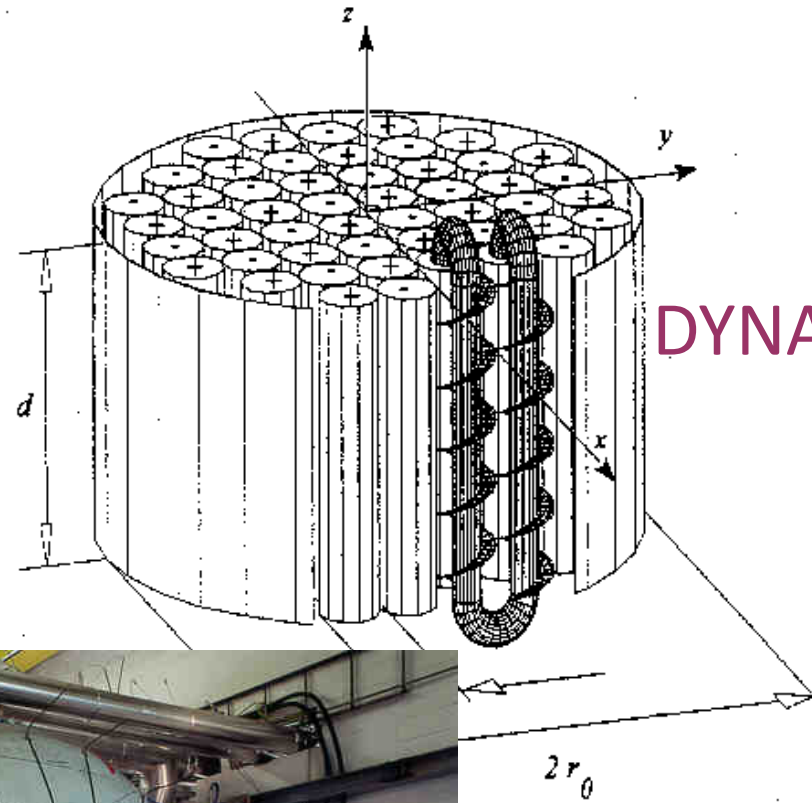
- Comment s'organise la convection sous l'action de B et Ω ?
- Nappes turbulentes (Braginsky & Meytlis, 1990) ?

L'effet des petites échelles sur les grandes...

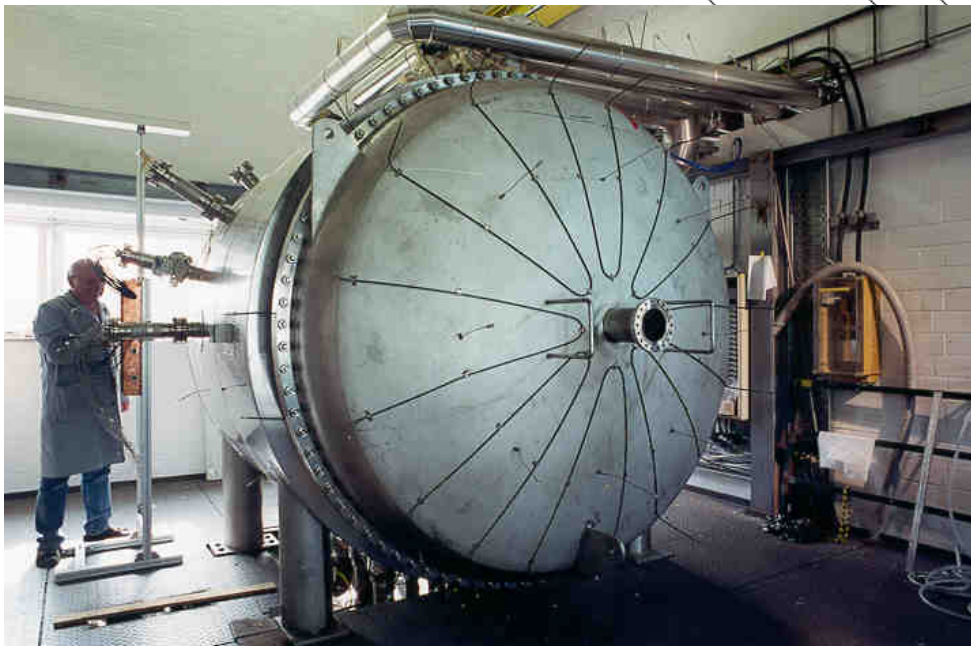
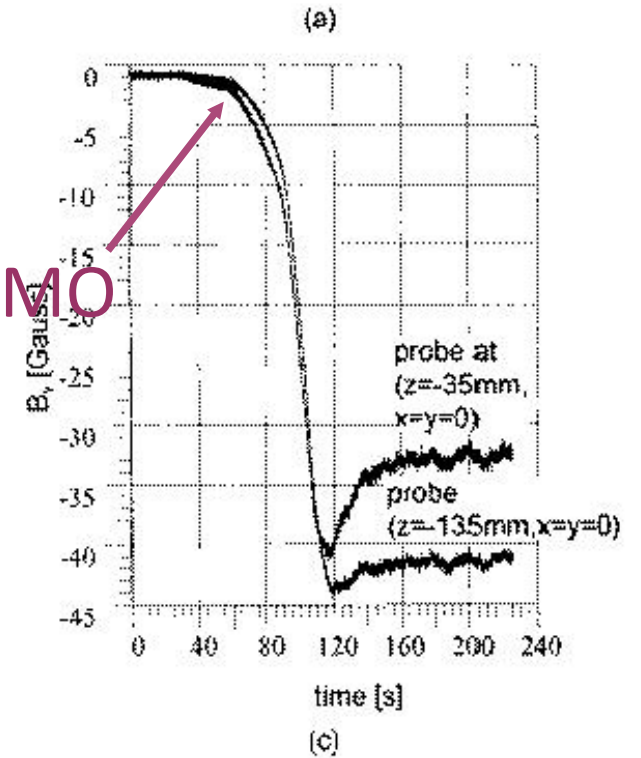
- Effet α , effet β ...

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times (\vec{U} \times \vec{B}) + \alpha \vec{\nabla} \times \vec{B} + (\eta + \beta) \Delta \vec{B}$$

Exemple : la dynamo de Karlsruhe



DYNAMO

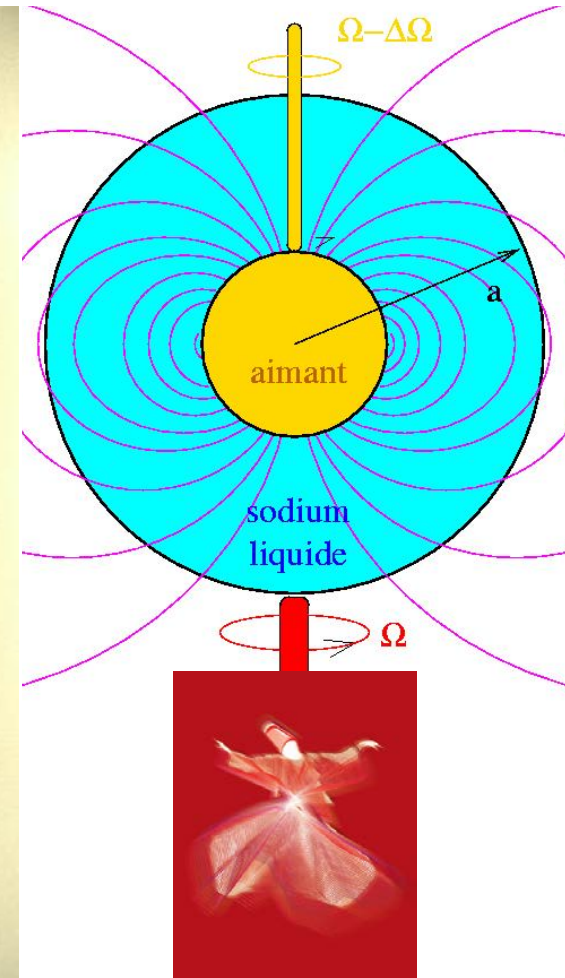
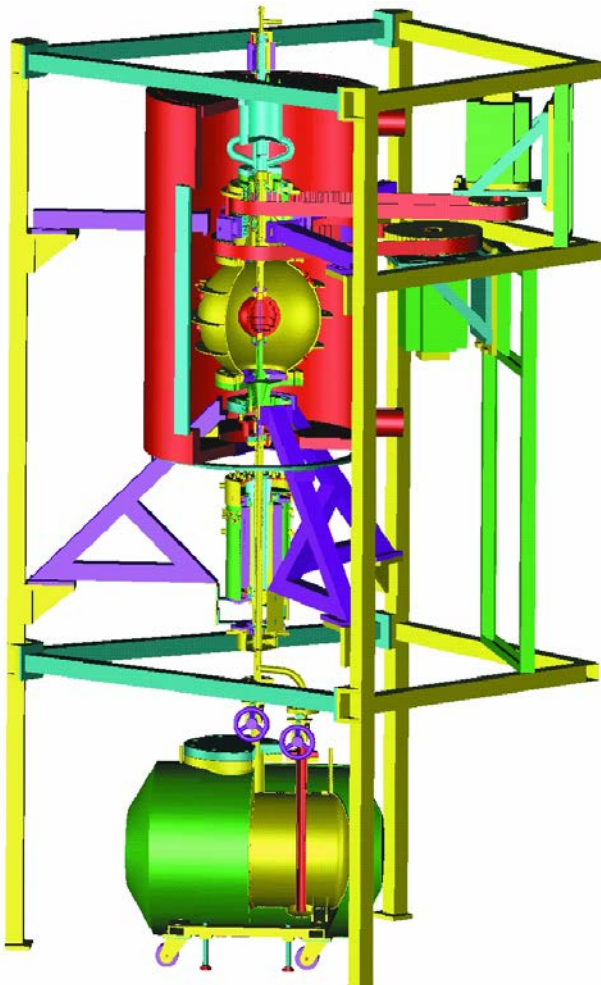


Stieglitz & Müller, 2000

3 m³ de sodium, 500 kW

The DTS experiment: spherical Couette flow in a dipolar magnetic field

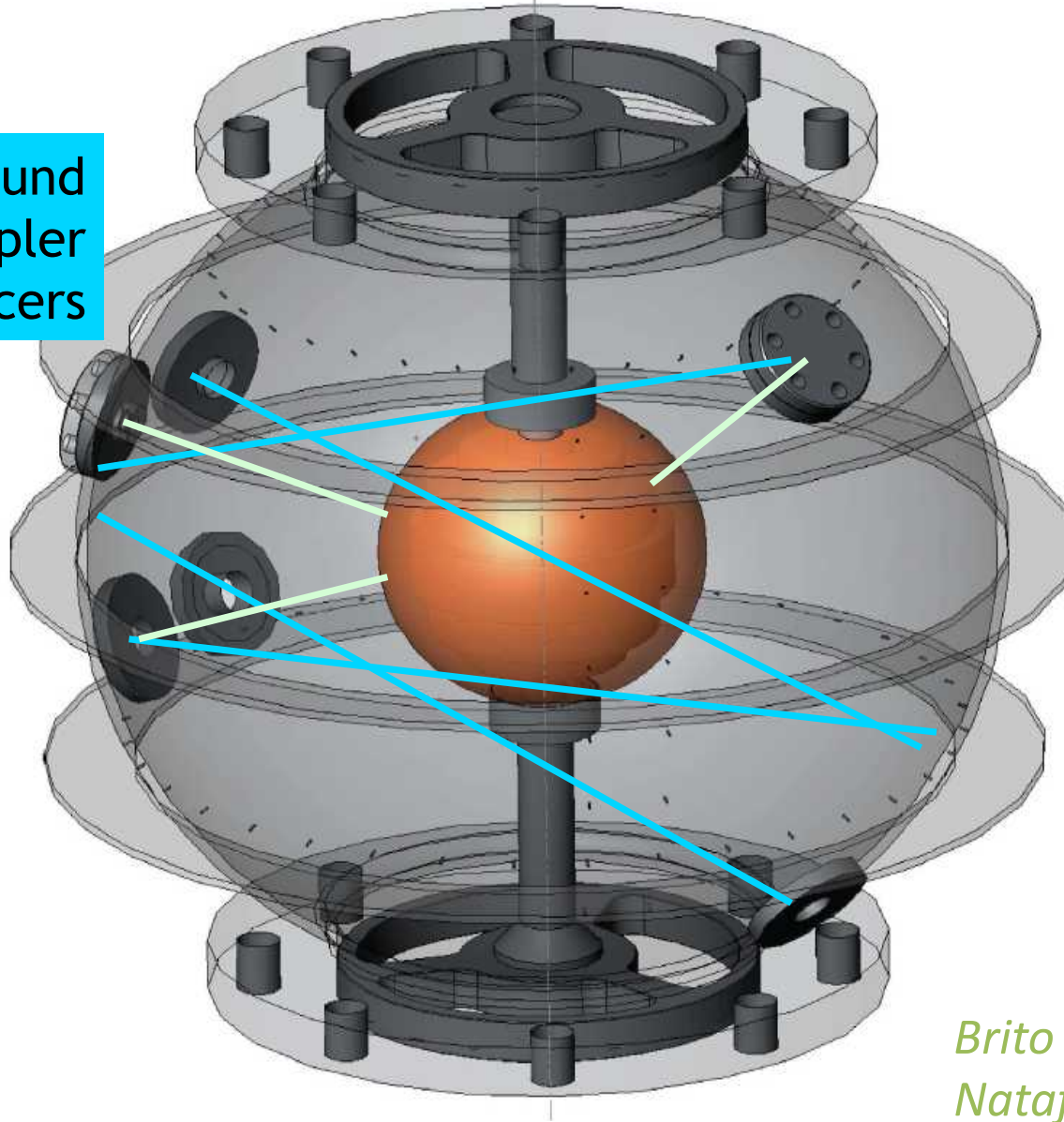
$$\Lambda = \frac{\sigma B^2}{\rho \Omega}$$



Cardin et al, 2002

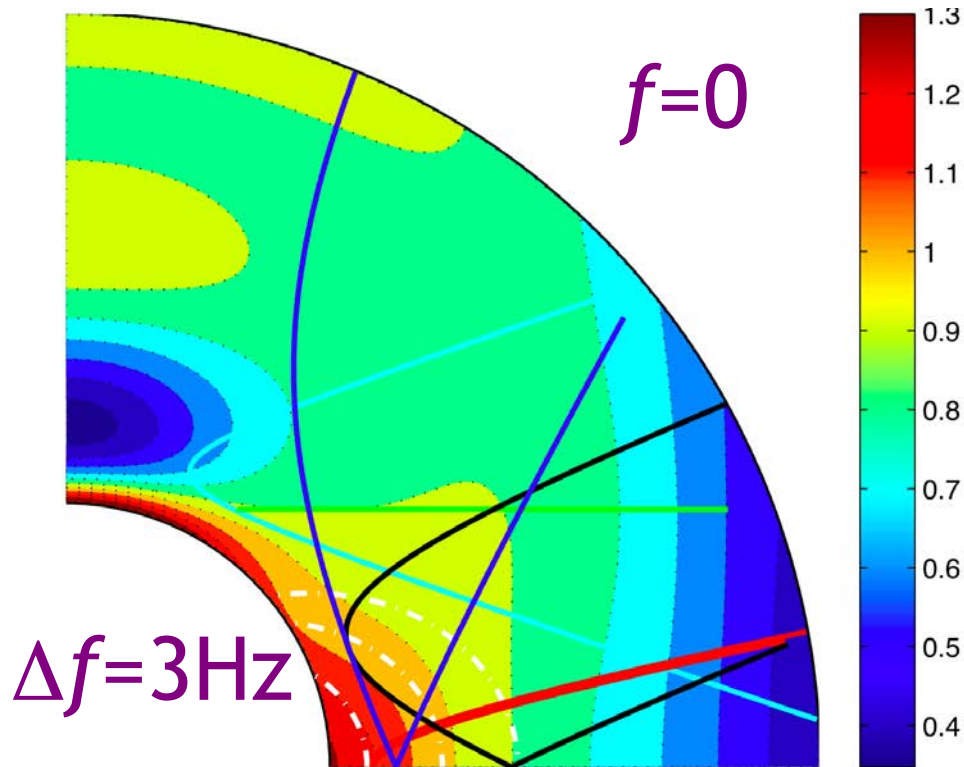
Ultrasound Doppler velocimetry

ultrasound
Doppler
transducers



Brito et al, 2001
Nataf et al, 2006, 2008

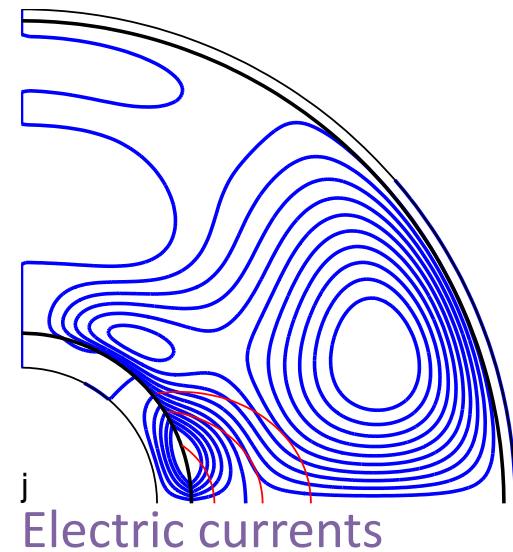
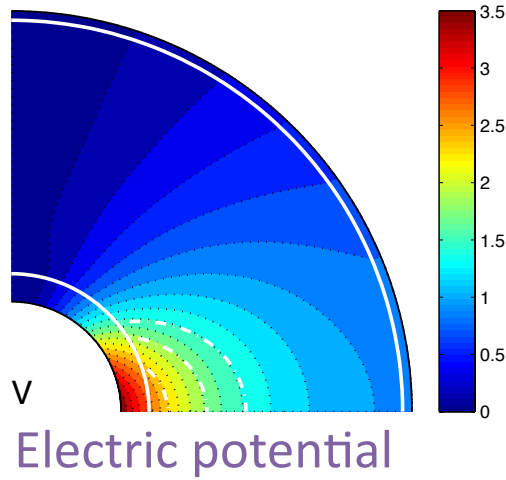
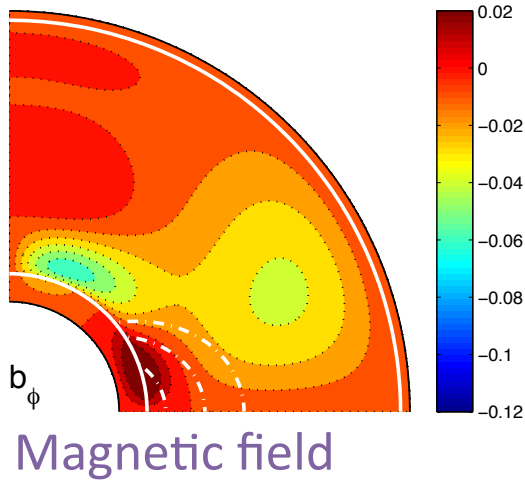
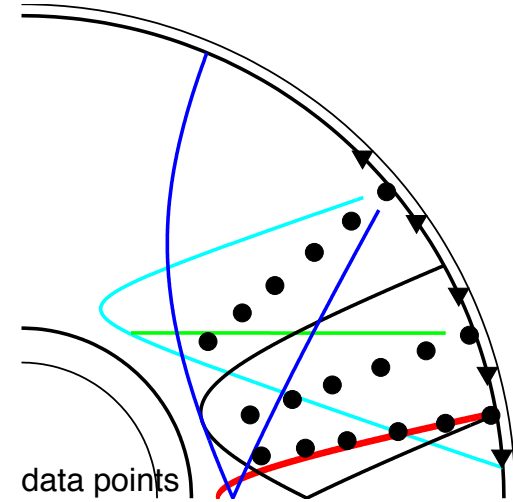
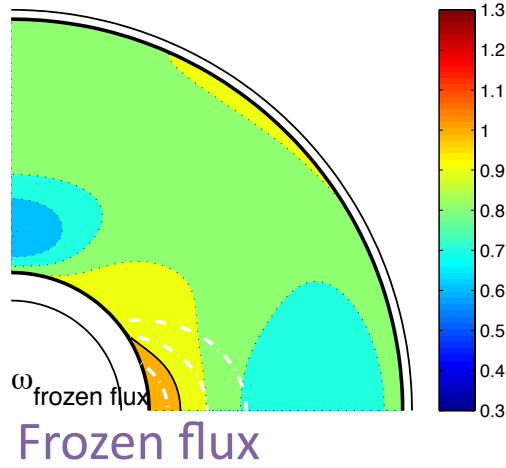
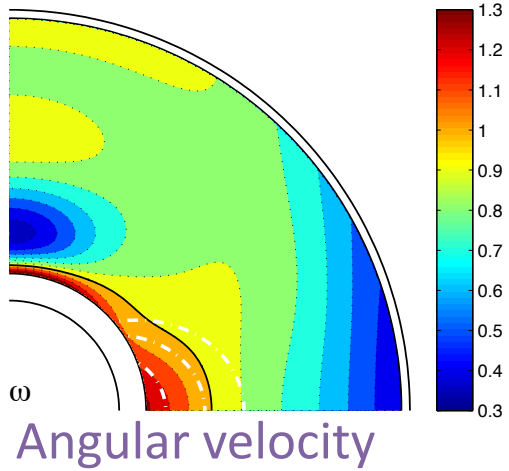
Mean flow



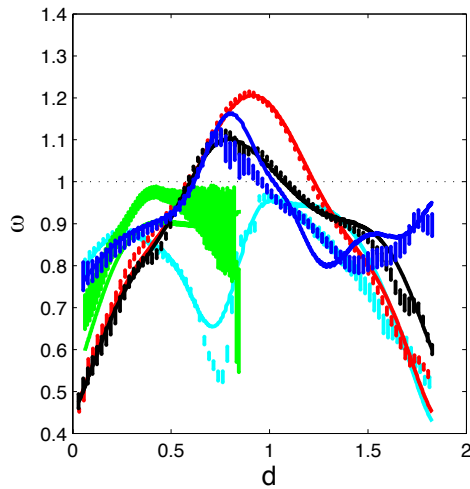
Isovalues of the mean fluid angular velocity in a meridional half-plane, reconstructed from acoustic Doppler velocity profiles

- The rotation of the fluid imposes geostrophy in the outer region.
- The fluid obeys Ferraro law close to the inner core in the equatorial region.

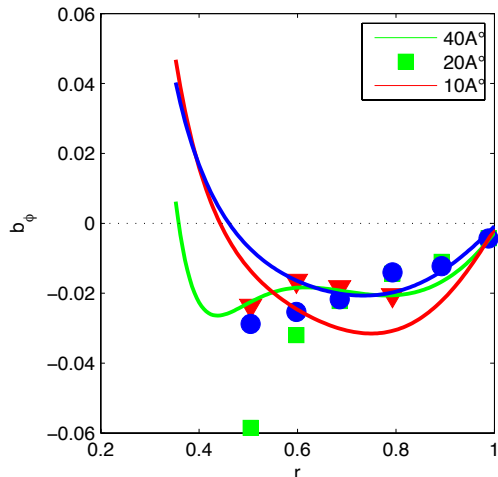
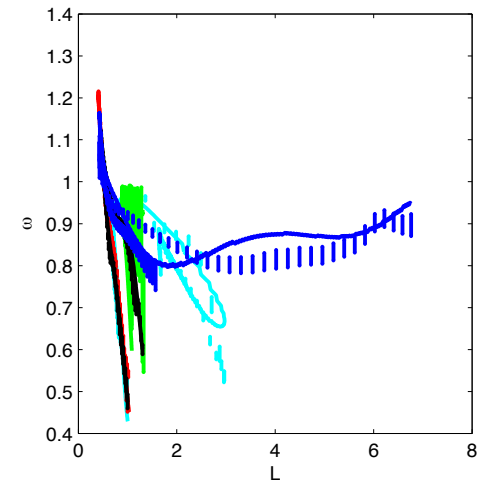
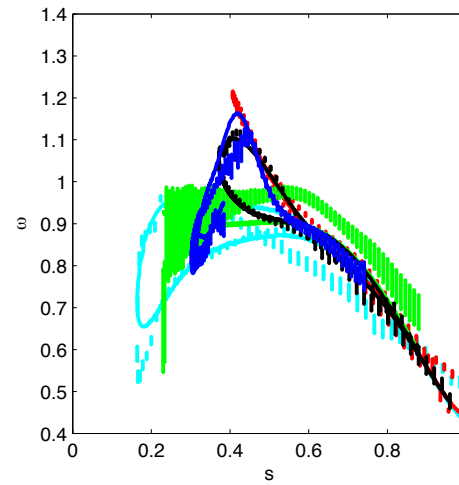
Mean flow predictions



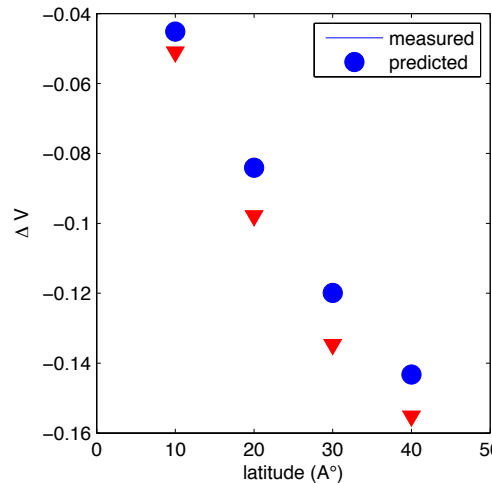
Mean flow predictions *versus* mean magnetic field measurements



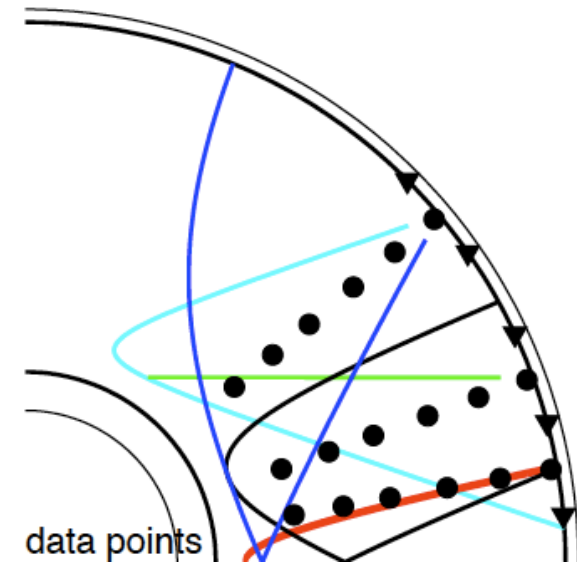
Velocity profiles



Magnetic field



Electric potential differences



The next experimental dynamo ?

The Maryland « BigSister »
experiment of Dan Lathrop's
team with 12 000 litres of
liquid sodium!

