DTS: a liquid sodium experiment in the magnetostrophic regime.

Équipe Géodynamo, Grenoble, France.

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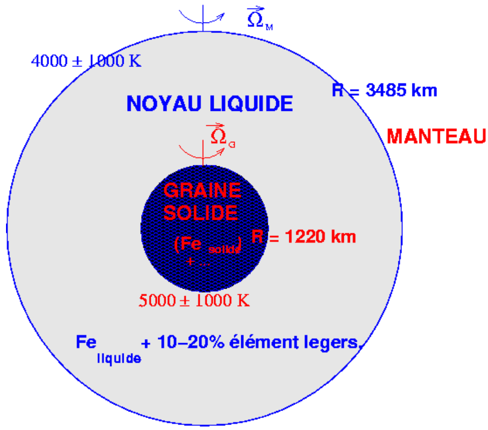
OUTLINE

1) The magnetohydrodynamics of the Earth's core.
2) Observation and numerical modeling.
3) Experimental approach with DTS.

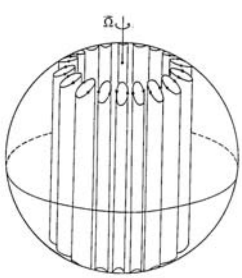
1) The Earth's core magnetohydrodynamics.

Fluid dynamics in rotation, in the presence of an electrically conducting fluid and a magnetic field.

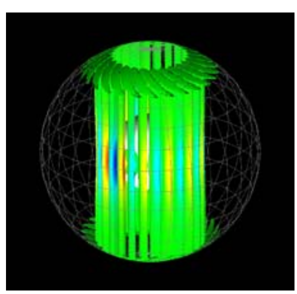


1) Convection in a rapidly rotating sphere

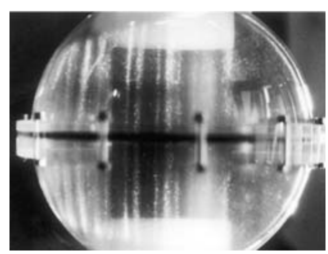
$(\vec{B} = \vec{0})$



Busse, 1970



Dormy et al., 1997



Aubert et al., 2001

Cardin et al., 1992.

Coriolis forces are dominant. (geostrophy)

1) The Earth's core magnetohydrodynamics.

$(\vec{B} \neq \vec{0})$

Coriolis forces are still dominant but the *Lorentz forces* come now into the balance.

Λ= Elsasser = Lorentz/Coriolis ~ 0.1-1

Magnetostrophic regime

How does such a system self-sustain the Earth's magnetic field (dynamo) throughout the Earth's history?

Induction equation

$$\frac{\partial \vec{B}}{\partial t} = \vec{Rot}\,(\vec{u} \wedge \vec{B}) + \frac{1}{Re_m} \Delta \vec{B}$$

Temporal evolution of the magnetic field

Induction : source of the magnetic field

Diffusion of the magnetic field

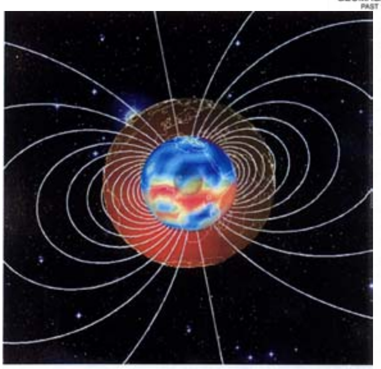
$$Re_m = \mu\, \sigma\, U\, L = \frac{U\, L}{\lambda}$$

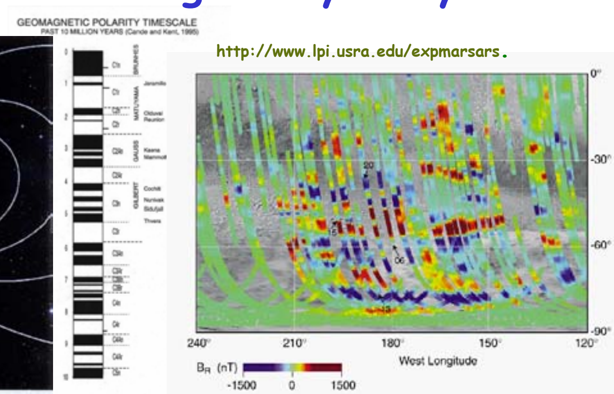
Magnetic Reynolds number

λ magnetic diffusivity

Dynamo if $Re_m >> 1$

1) The Earth's core magnetohydrodynamics.

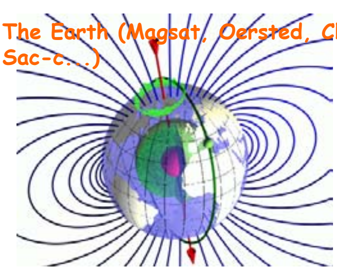




Earth's core composed of iron in motion, self-sustaining the magnetic field, for more than 3 billion years and with aperiodic reversals (4 in average by million years).

2) Observation and numerical modeling.

The Earth (Magsat, Oersted, Champ, Sac-c...)



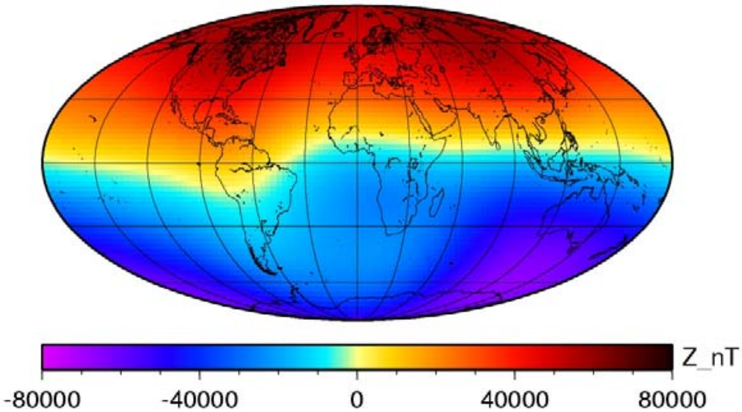
Mars (Mars Global Surveyor)

Sun (Soho)

Jupiter and satellites (Galileo)

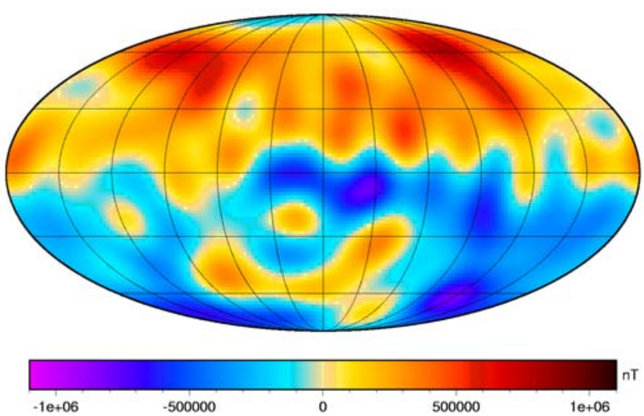
Satellite time..

Earth's magnetic field at the surface.



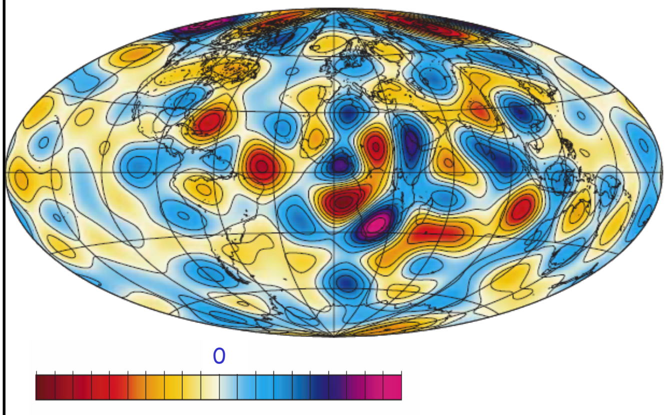
Satellite data Ørsted, 2000.

Earth's magnetic field at the core-mantle boundary.



Satellite data Ørsted, 2000.

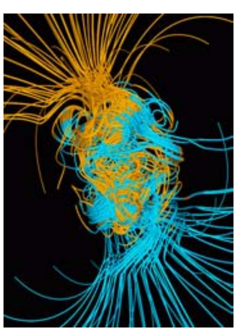
Small scale secular variation of the Earth's magnetic field



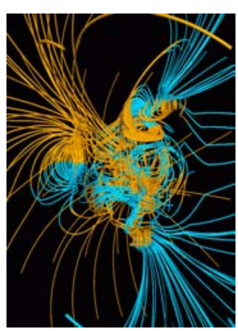
Magsat (1980)
to Oersted (2000)
main-field changes

(Hulot et al., 2002)

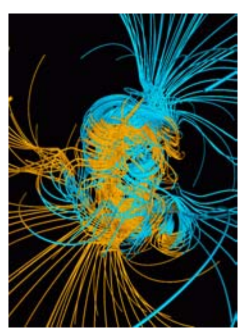
2) Numerical modeling.



t-500 years



t

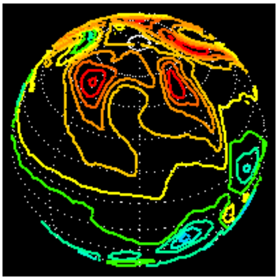


t+500 years

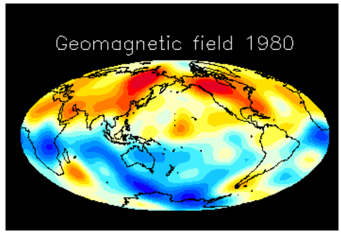
(Glatzmaier and Roberts, 1995).

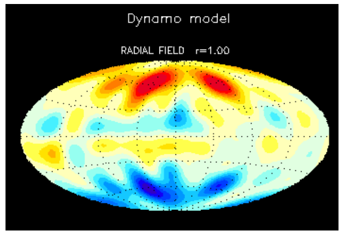
First NUMERICAL DYNAMO with a conducting fluid in thermal convection
… with a reversal of the magnetic field.

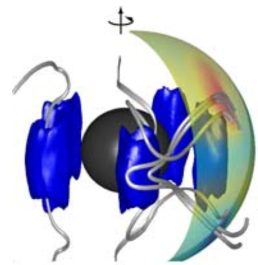
2) Numerical modeling.



(Christensen, Olson and Glatzmaier, 2000).







(Aubert and Wicht, 2004)

DIPOLAR with strong similarities with the Earth's magnetic field.

Where are we regarding numerical geodynamo modeling?

Paradox: Very CLOSE, with results reproducing the ESSENTIAL features of the Earth's magnetic field …very FAR because the numerical physical parameters of the models are far from being Earth's like.

The difficulty in solving planetary dynamo fields:
Prandtl $P=\nu/\kappa \sim 10^{-3}$.
Magnetic Prandtl : $P_m = \nu/\lambda \sim 10^{-6} \rightarrow \nu \sim 10^{-3}\,\kappa \sim 10^{-6}\,\lambda$
Temperature, velocities, magnetic time-scales different.

In numerical modeling $P=P_m \sim 1$.

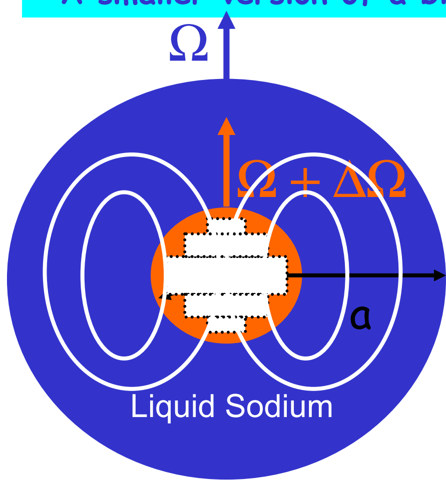
One serious difficulty: When P_m is lowered, no more spherical dynamos…

3) Experimental approach of a planetary-like rotating dynamo.

After the successes in Riga and Karlsruhe, can we go further and produce a planetary like dynamo in an homogeneous volume of sodium?

DTS (Derviche Tourneur Sodium)

A smaller version of a bigger rotating sphere ?

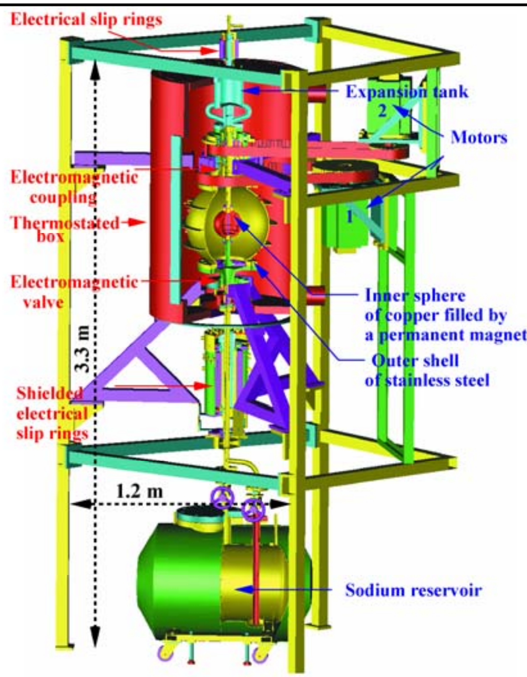


$a = 0.21$ m
$b = 0.074$ m
$\Omega = 2000$ rpm
$\Delta\Omega = \pm 2000$ rpm
$P = 22$ KW (11kW per motor)

$B < 0.1$ T

H.-C. Nataf's communication, Session 9, Wedensday.

Cardin, Brito, Jault, Nataf and Masson, 2002



DTS

DIMENSIONLESS NUMBERS:

$a = 0.21$ m, $b = 0.074$ m

$L = b+(a-b)/2 = 0.142$ m

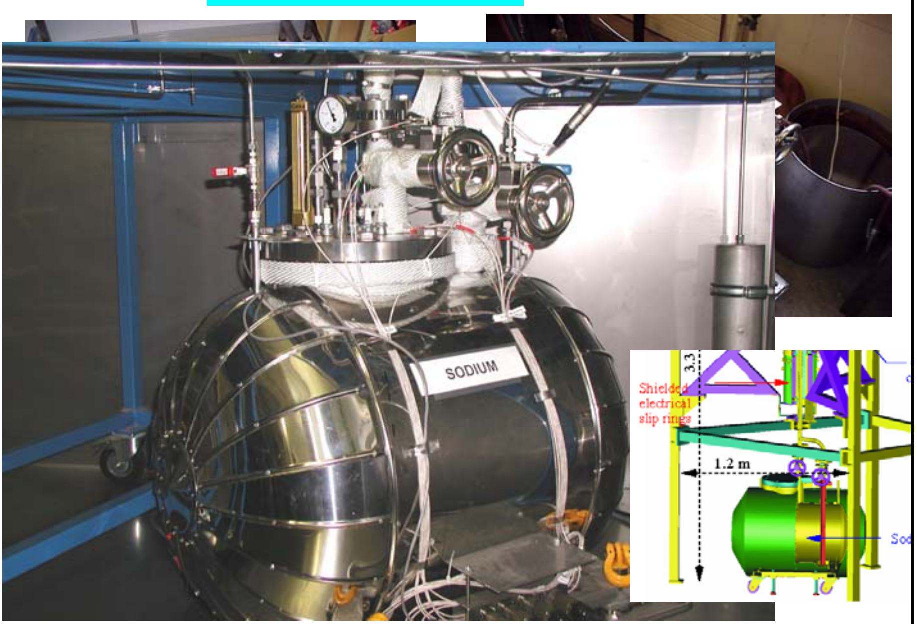
Elsasser $= \sigma B^2 / \rho\Omega = 2\ 10^{-2}$

Ekman $= \nu / \Omega L^2 \approx 10^{-8}$

$Re_{max} = (\Delta\Omega)_{max} * b * L/\nu \approx 10^7$

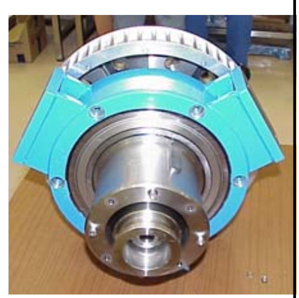
$Re_{m\ max} = \mu_0 \sigma ((\Delta\Omega)_{max} b^2) \approx 40$

The sodium tank

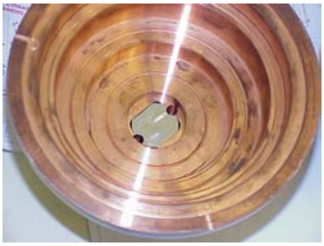


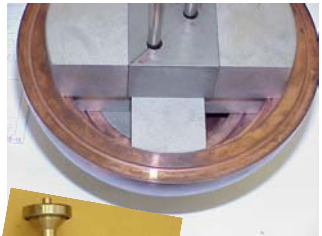
The external sphere, rotating slip-rings

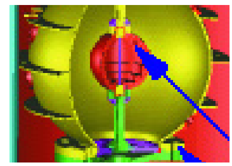
The magnetic coupling (avoid rotating seals)

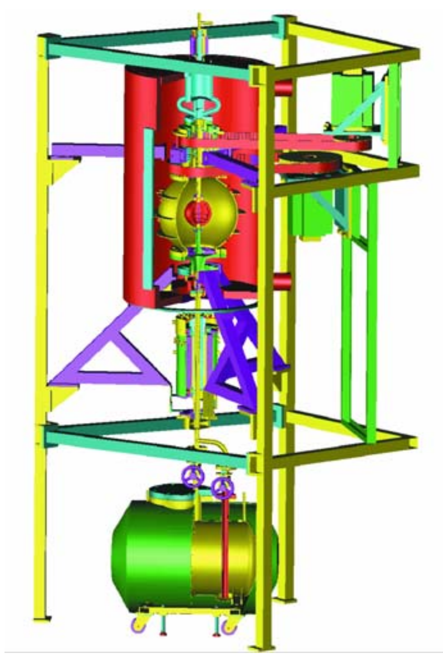


The magnetised inner sphere









DTS

1) What do we want to study and see ?

2) How?

3) So far ?

DTS

1) What do we want to study and see ?

.Characterize turbulence in the magnetostrophic regime.

.Torsional oscillations

.Super rotation of the fluid ? (Dormy et al., 1998)

.Deduce scaling of a planetary-like, larger, dynamo experiment from the DTS smaller version.

DTS

1) How do we want to study and see ?

.Ultrasonic velocity measurements.

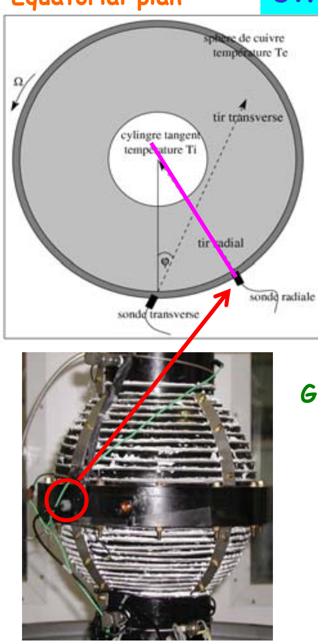
.Velocity and torque power delivered by the motors.

.Induced magnetic field measurements.

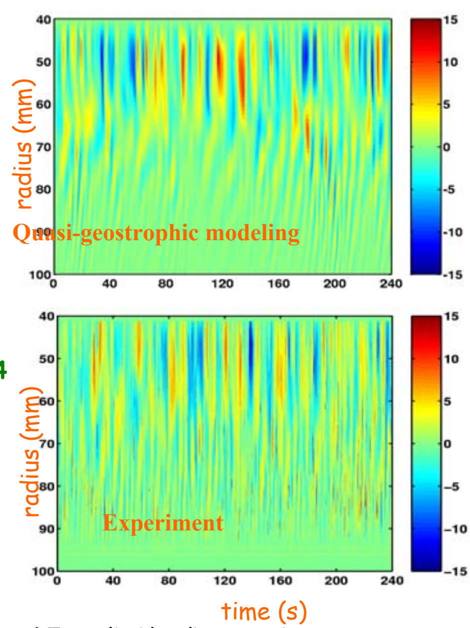
.Dynamic pressure measurements.

Ultrasonic Doppler Velocimetry (USV)

Equatorial plan

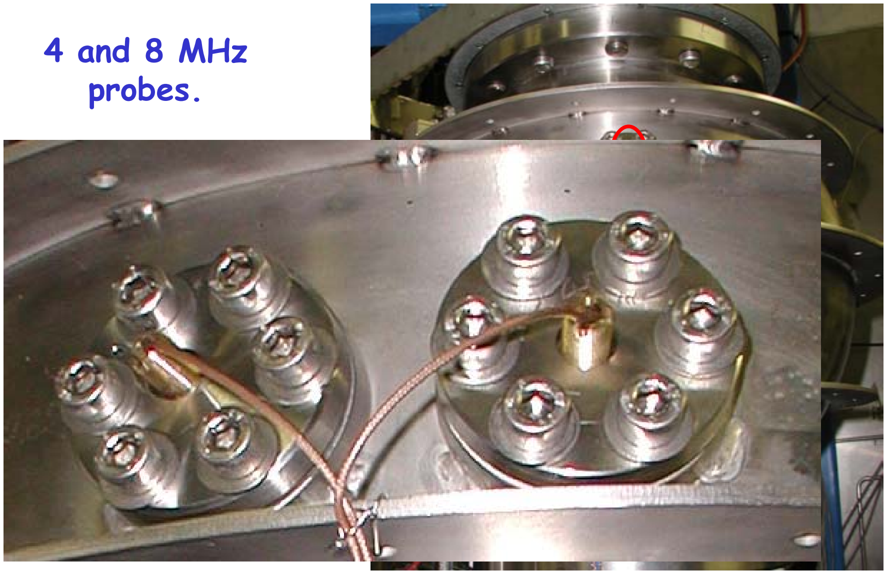


Gillet,04

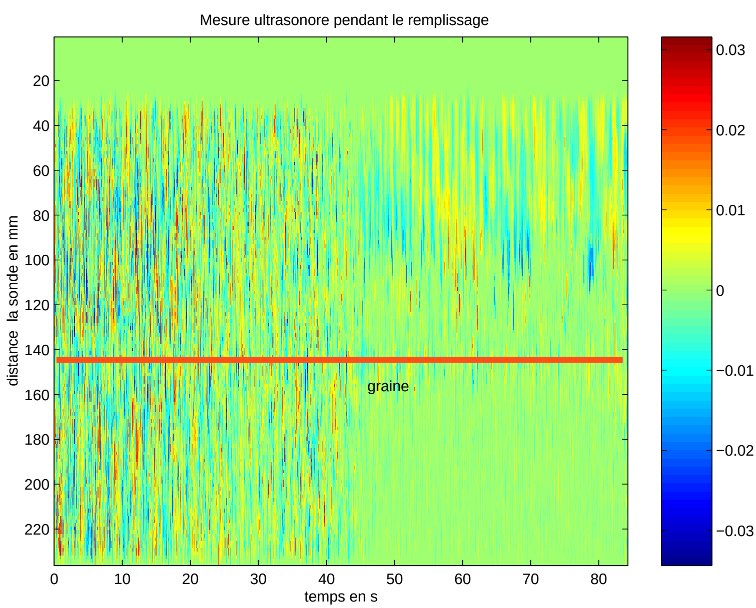


Ultrasonic Doppler Velocimetry (USV)

4 and 8 MHz probes.



USV during the filling of the sphere.

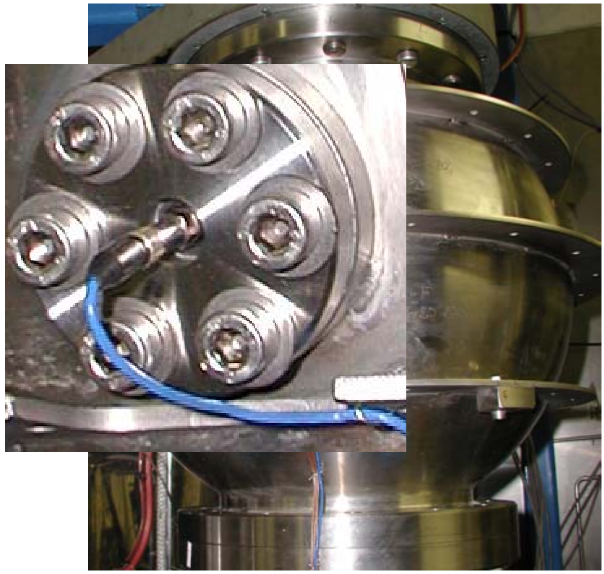


Dynamic pressure measurements

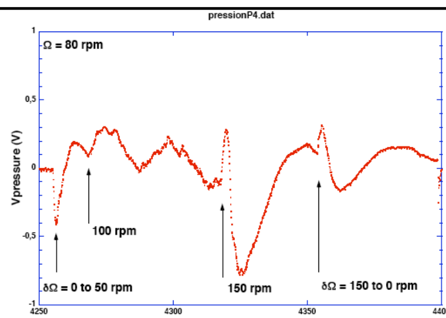
PCB Piezotronics, model SM 112A22

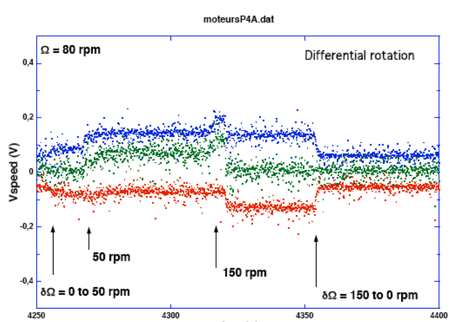
- Sensitivity : 14.5 mV/kPa

-Filtering : Krohn-Hite, 15 Hz low-pass, 20 dB gain



Dynamic pressure measurements





Magnetic field measurements.

Magnetic sensors: GMR

(Giant MagnetoResistance)

Sensitivity:

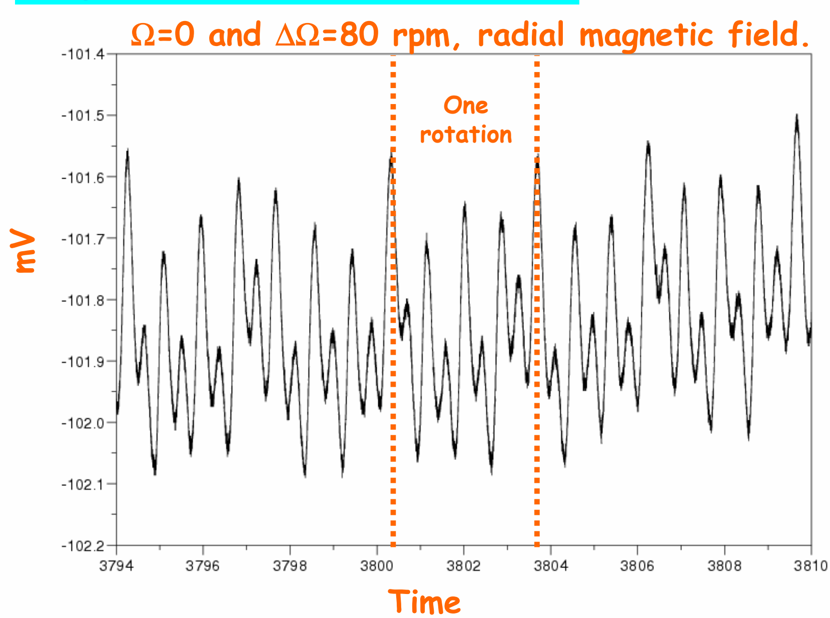
radial field 7.5 mV/Gauss

latitudinal field 15 mV/Gauss

Acquisition: NI-PXI acquisition system

2000 samples per second

Magnetic field measurements.



3) What have we seen so far (January 2005) ?

- 3 days of run so far…
- Handling of sodium OK.
- No mechanical problems.
- Heating underestimated.
- Magnetic coupling OK but must be hotter.
- Pressure and magnetic measurements promising.
- USV should work.

- Run scheduled very soon.

3) Experimental approach of a planetary like rotating dynamo.

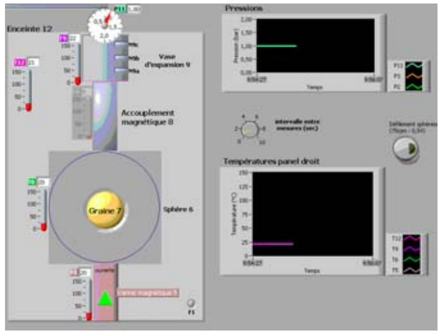
NECESSARY ingredients for an experimental dynamo.

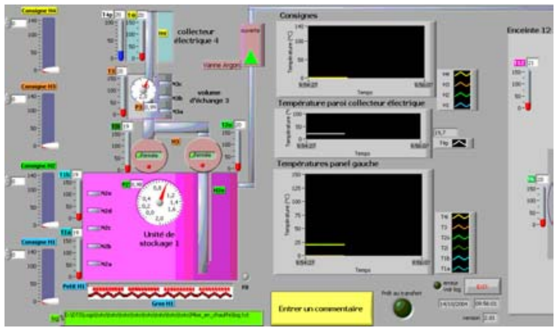
$$Re_m = \frac{UL}{\lambda} = \mu_0 \sigma UL \geq 50$$

$$Re_m = \frac{\nu}{\lambda}\frac{UL}{\nu} = P_m \; Re \quad \Rightarrow Re > 10^6$$

$P_m \sim 10^{-6}$

..Turbulence.





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