The Earth's magnetic field

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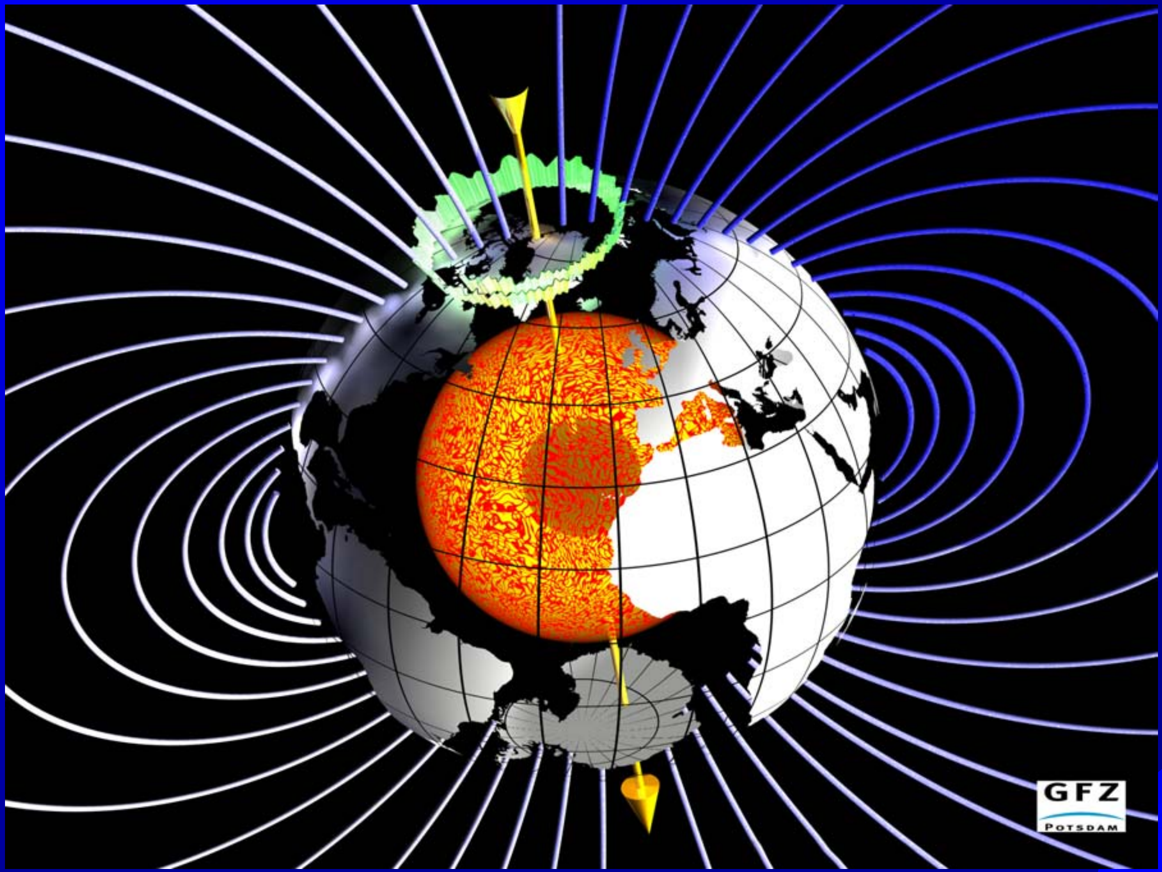
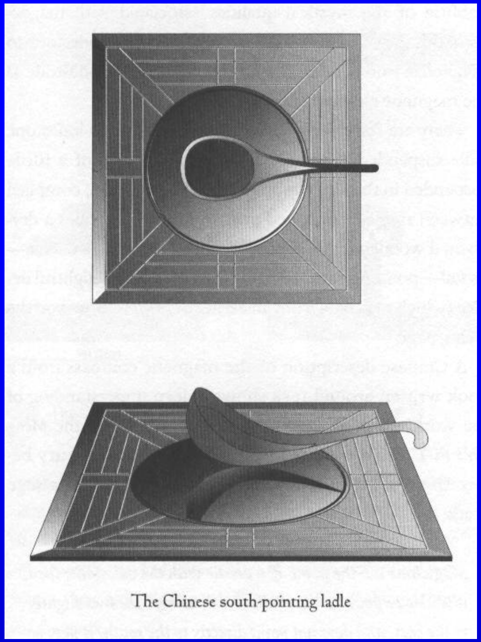
Our planet and its magnetic field

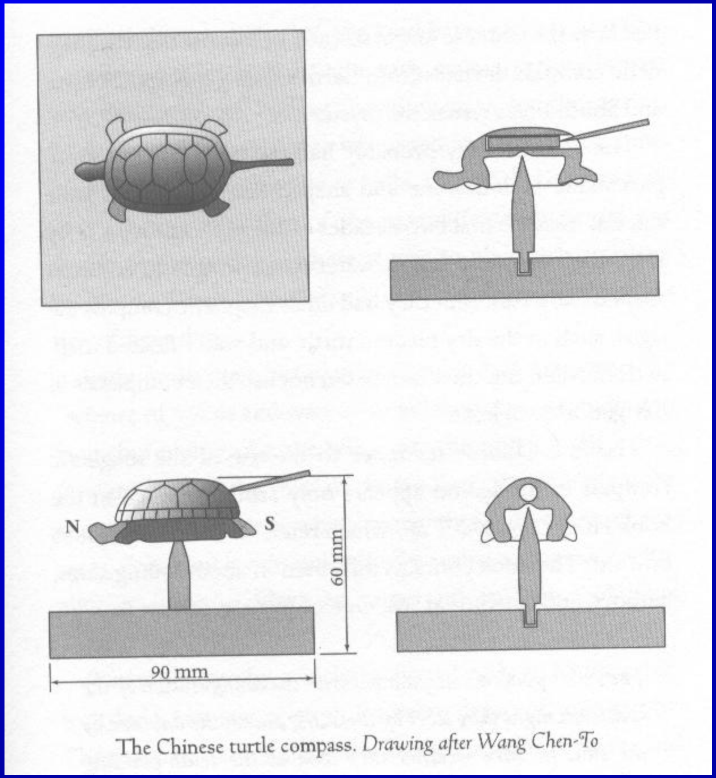


The magnetic field is self generated by the motions of the liquid iron in the Earth's core (dynamo effect).

Chinese compas



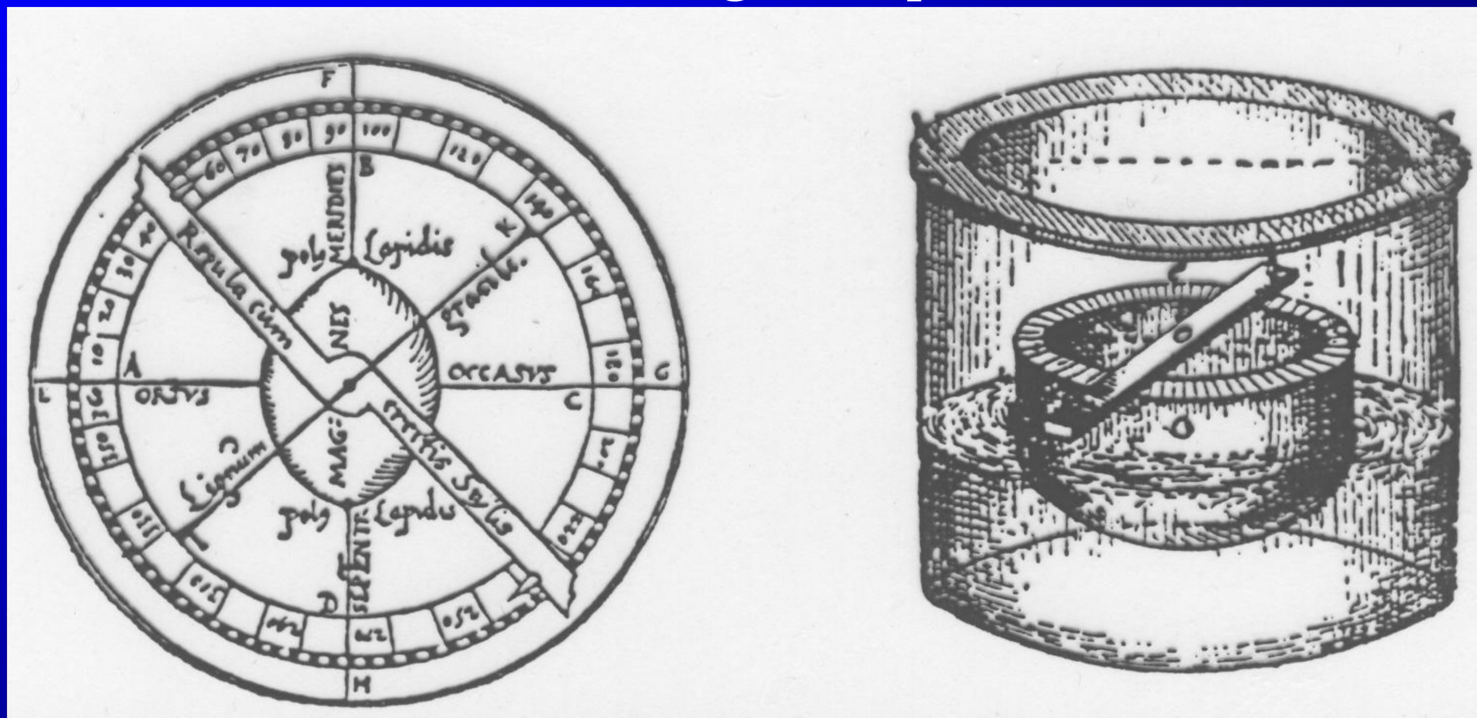
(Wang Mang, 23 a.C.)



(~1000 a.C.)

« Marinette »

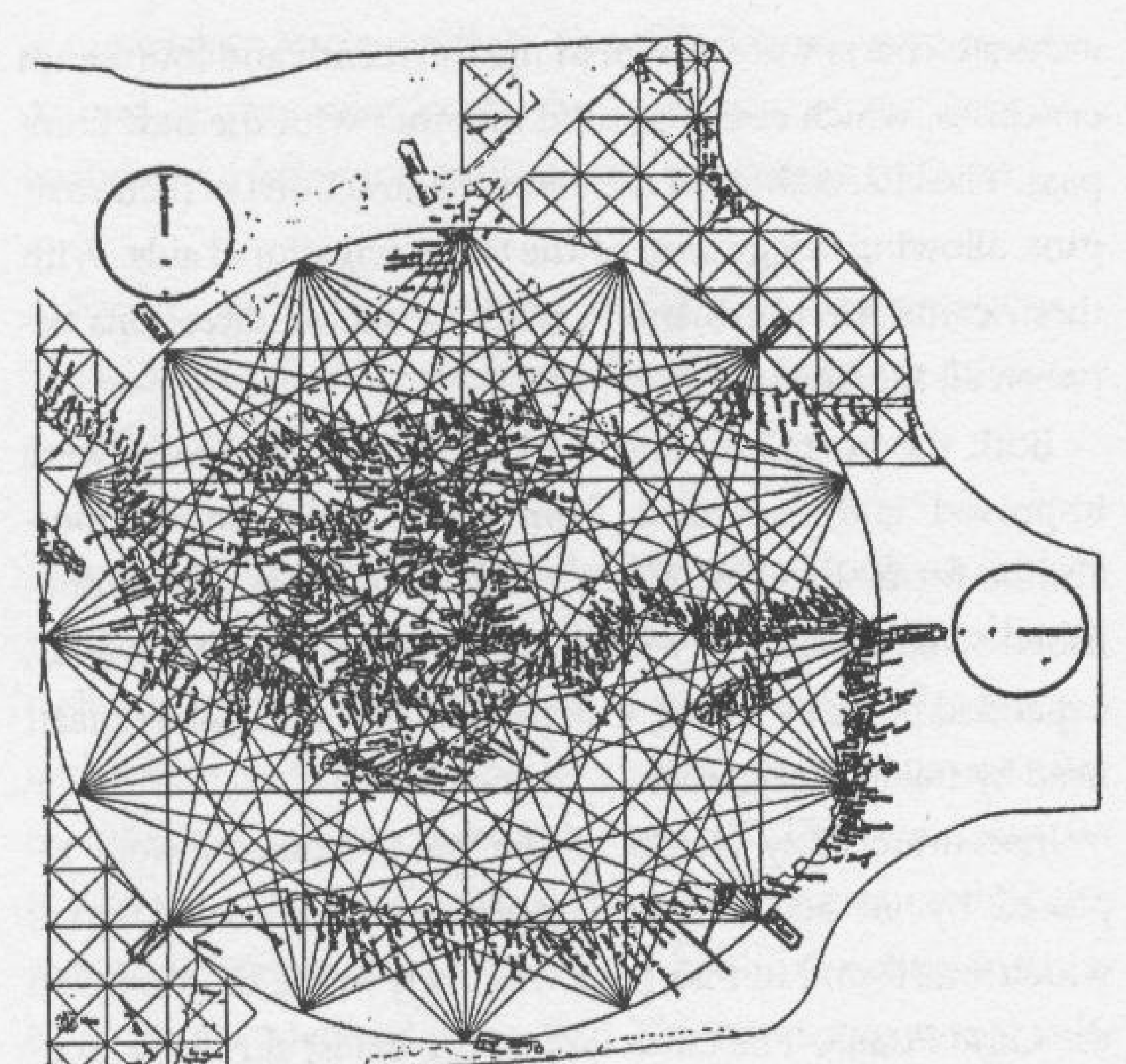
Middle age compas



Guyot de Provins, 1178 (Grande Encyclopédie, Diderot)

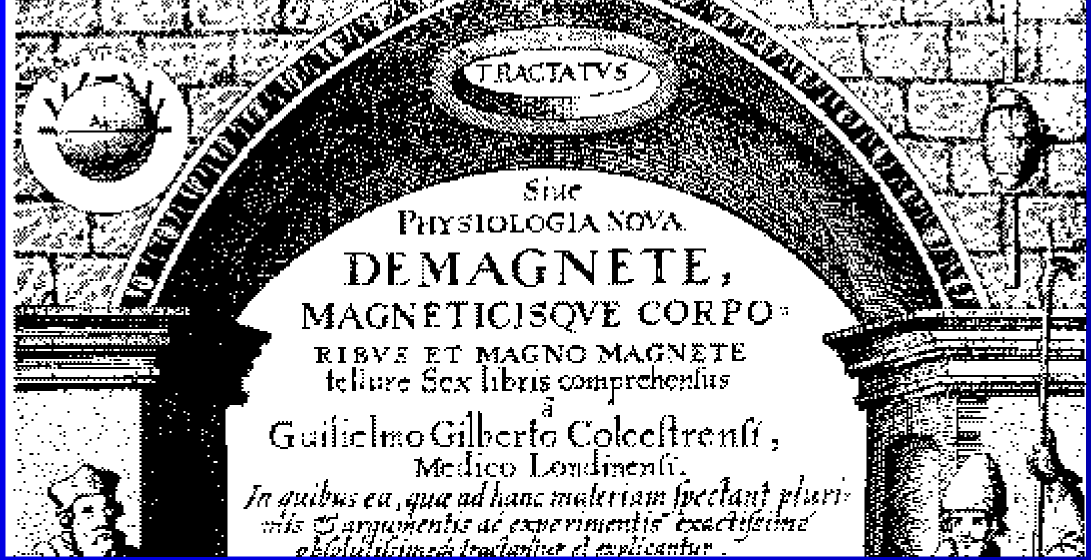
St Alban Monks, 1180, (Encyclopedia Britanica)

Carta pisana (1214)

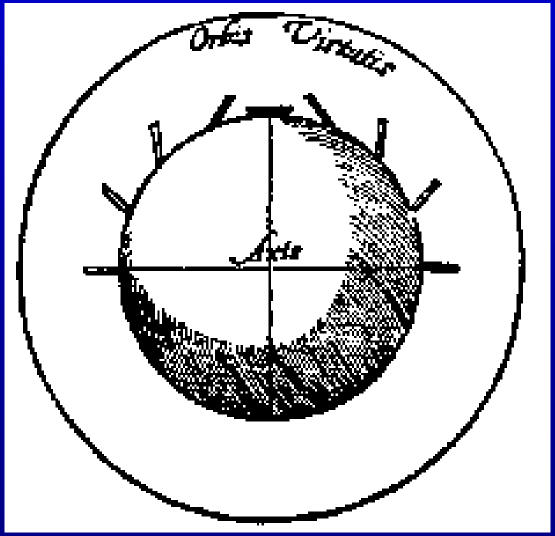


East mediterranean sea

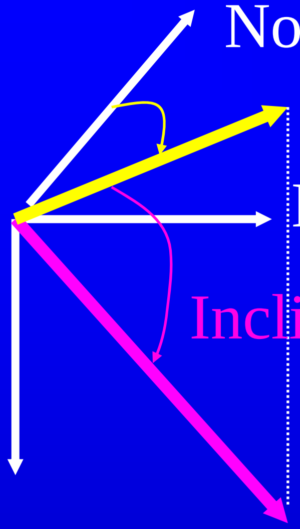
America

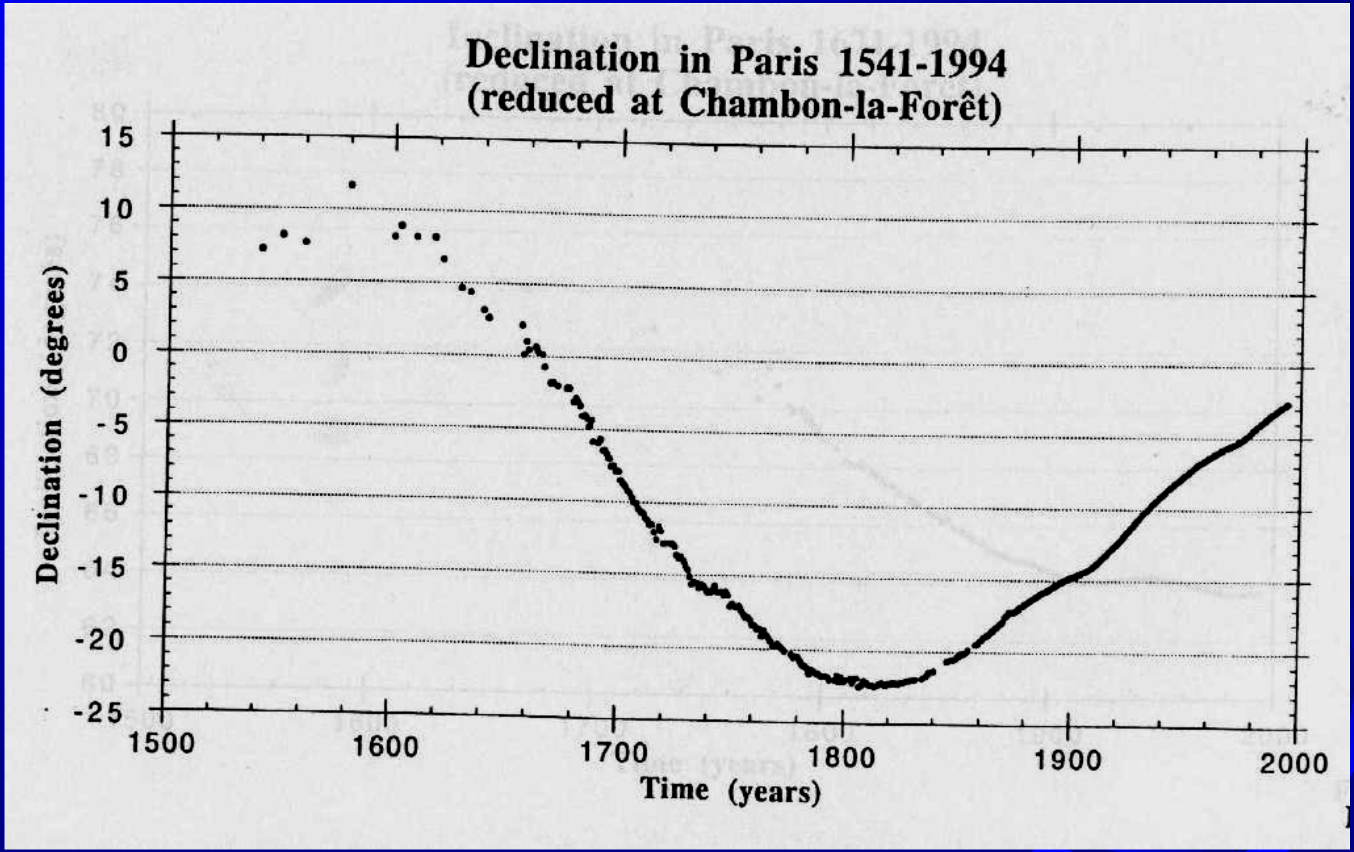


De Magnete, 1600



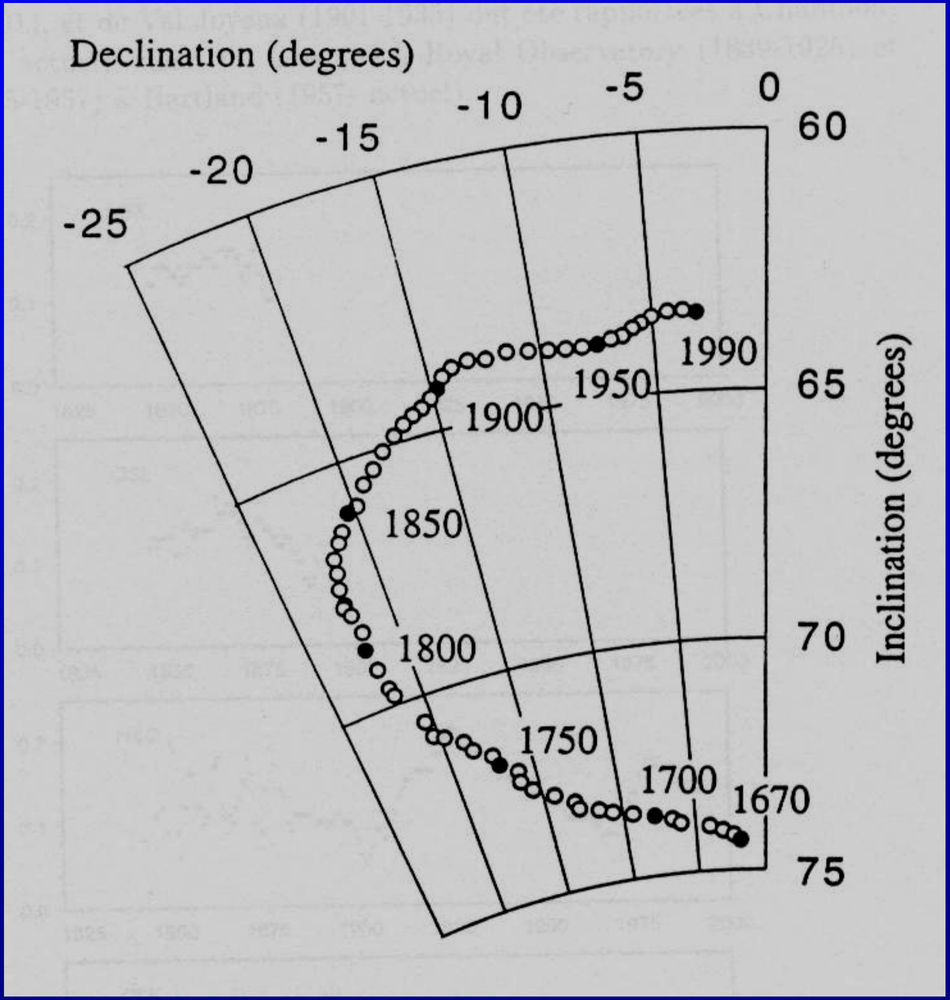
Secular variations of the magnetic field





Mandea

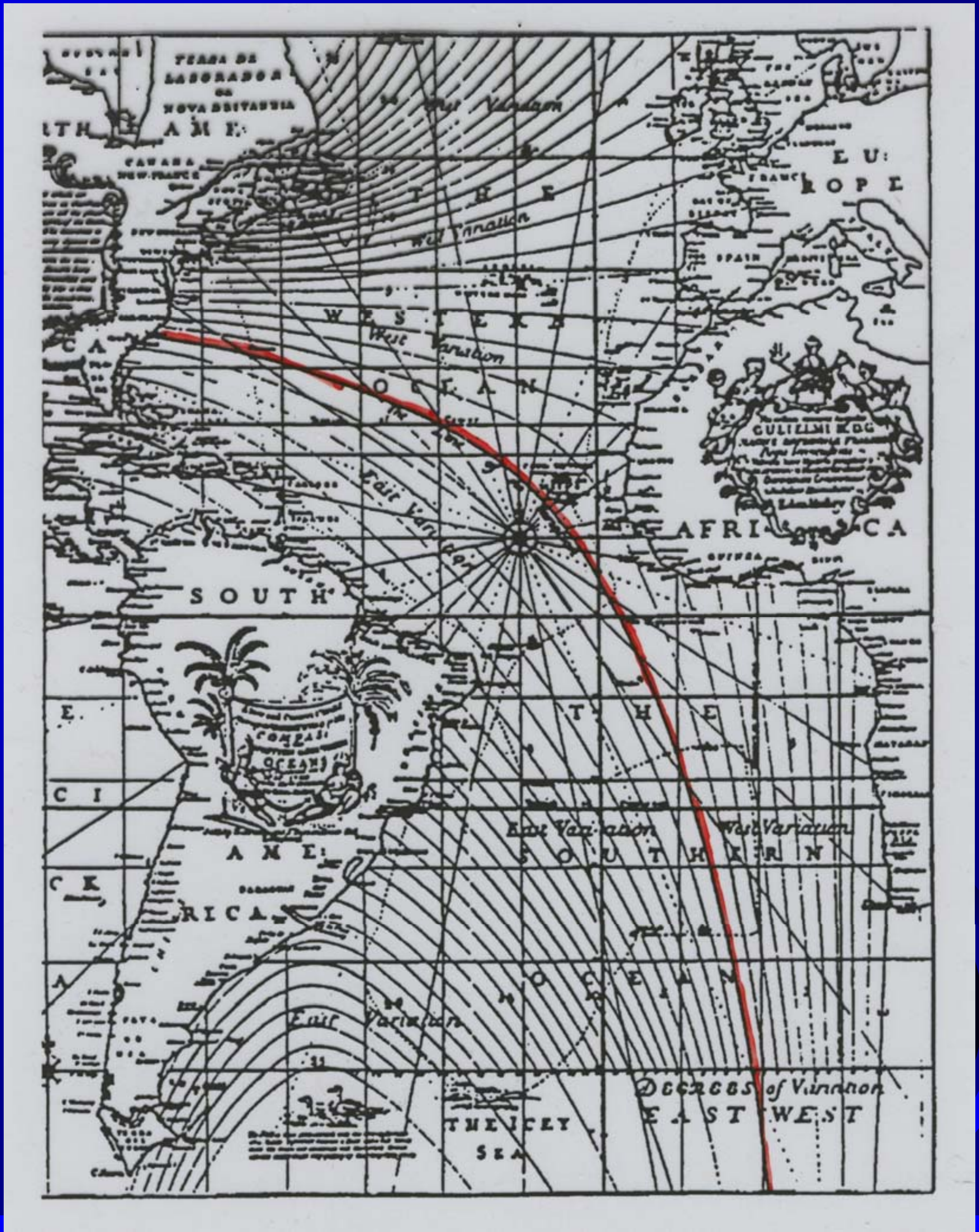
Inclination and declination



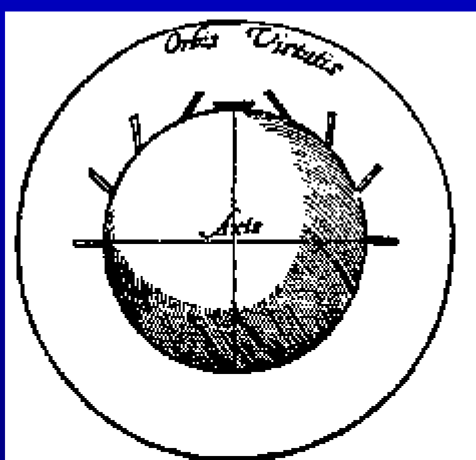
In Paris

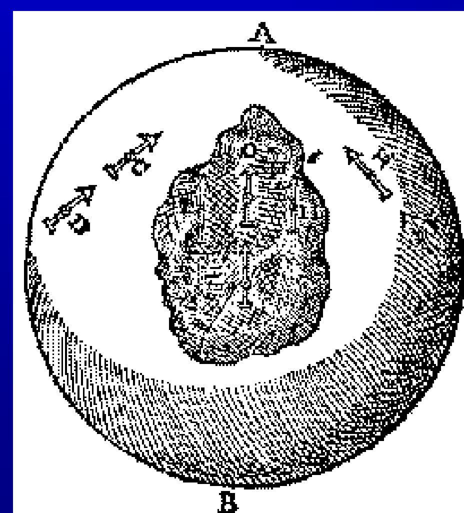
Halley, 1700

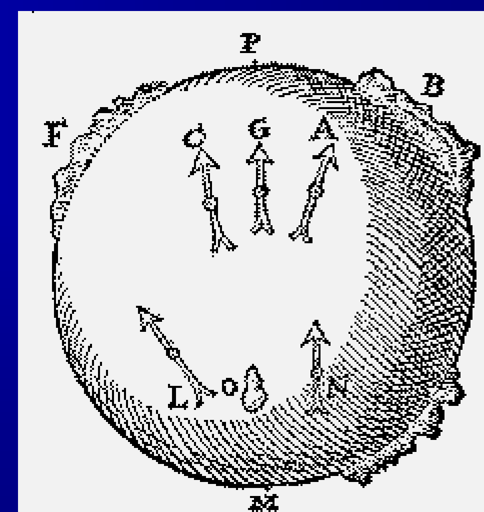
Isogonic map



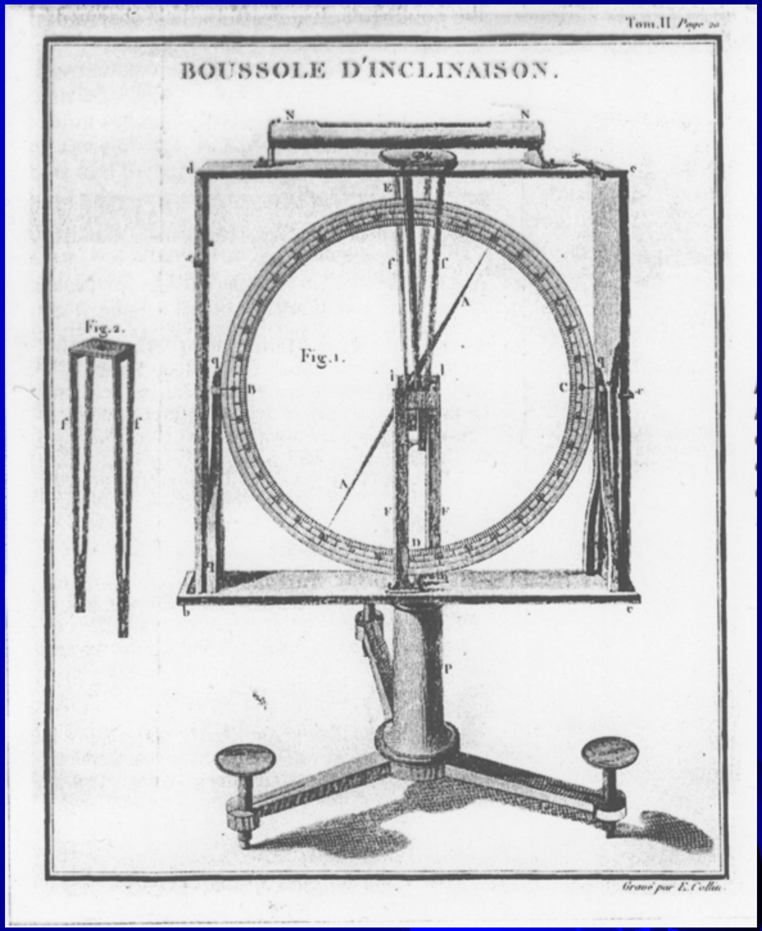
De Magnete, 1600



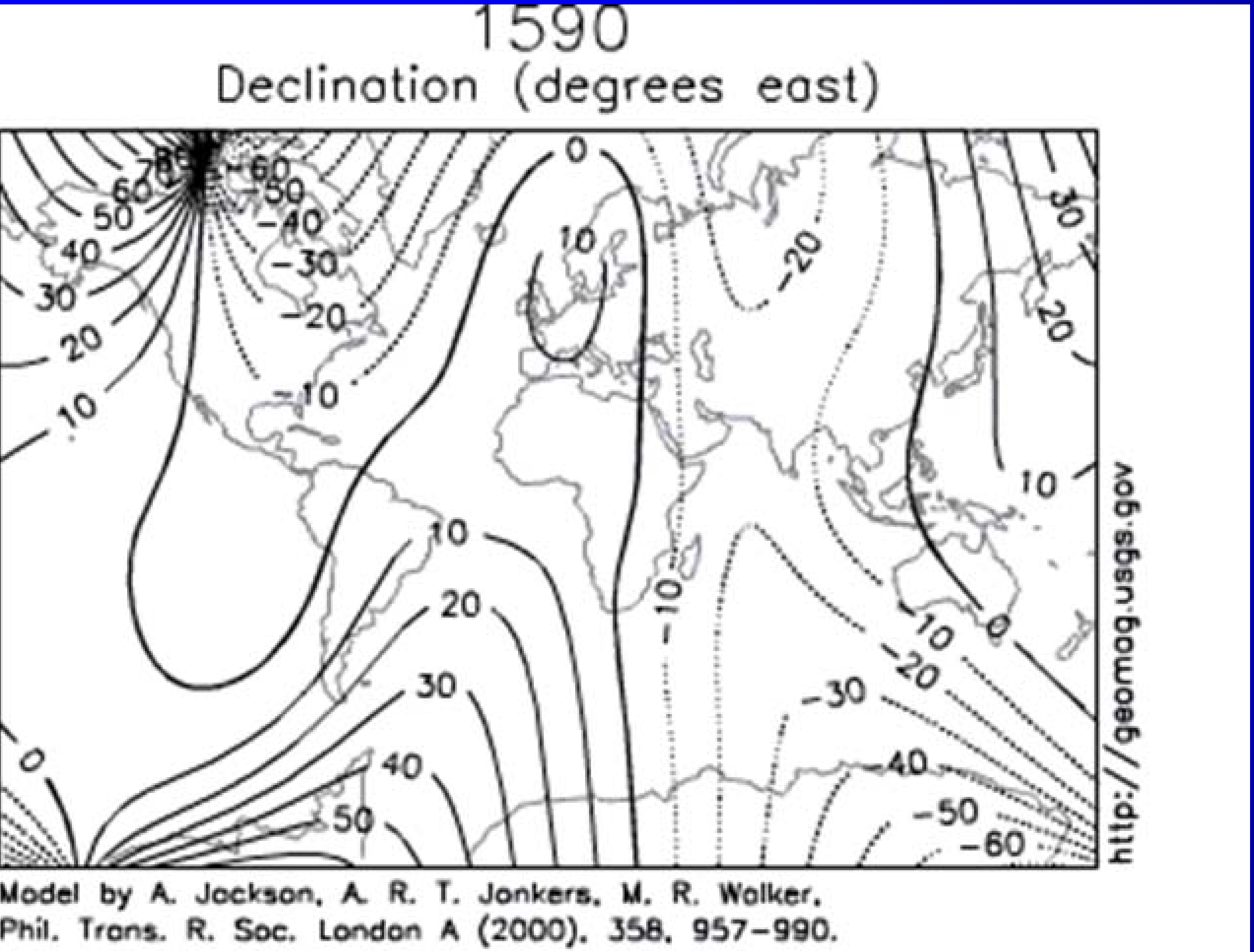




La Pérouse and d'Entrecasteaux expeditions

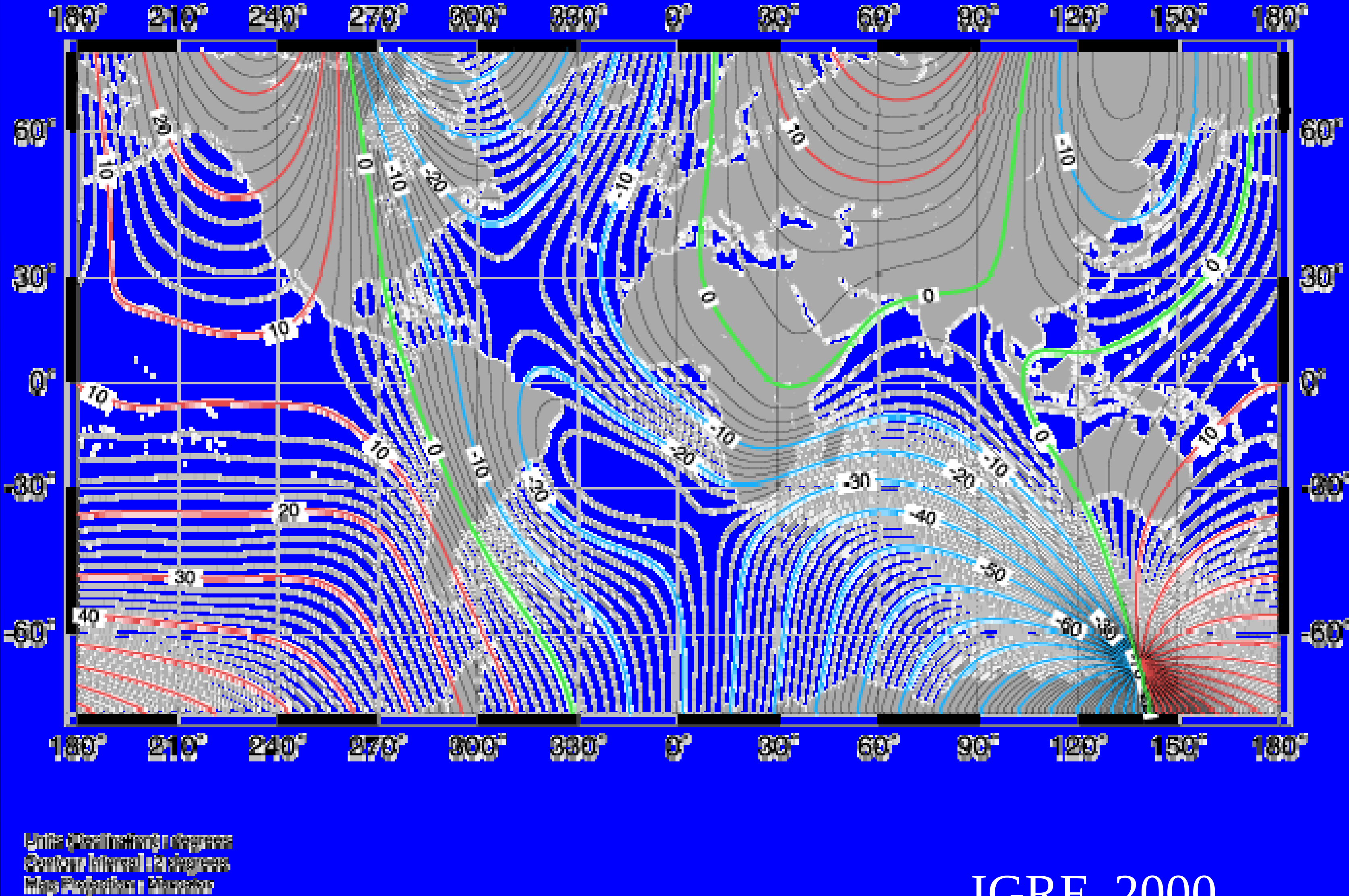


1788



Historical datas

US/UK World Magnetic Chart -- Epoch 2000
Declination - Main Field (D)

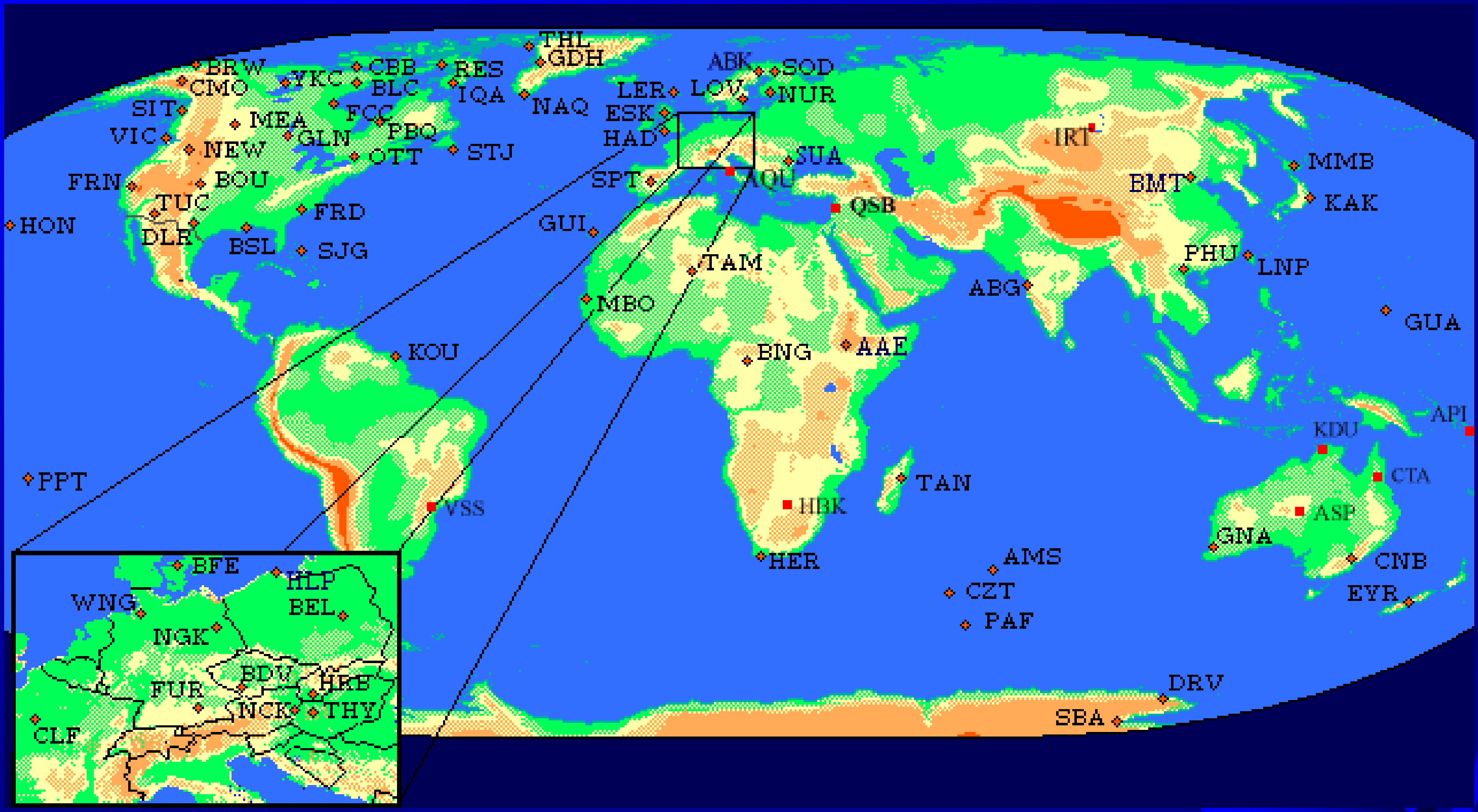


IGRF, 2000

Gauss, 1836

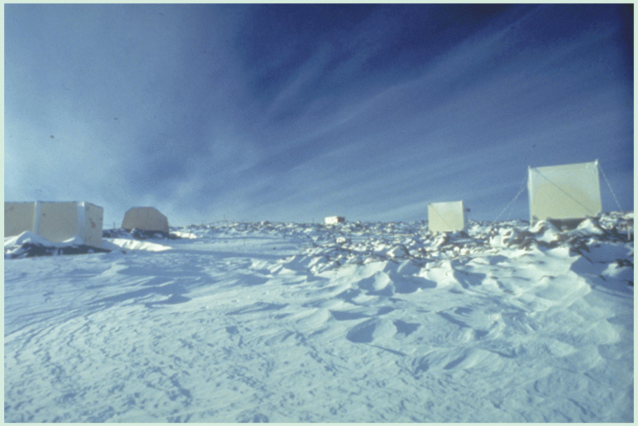
- Mathematical description of the Earth magnetic field (Spherical Harmonics).
- Internal origin of the field.
- Geophysical observatories.

Magnetic observatories

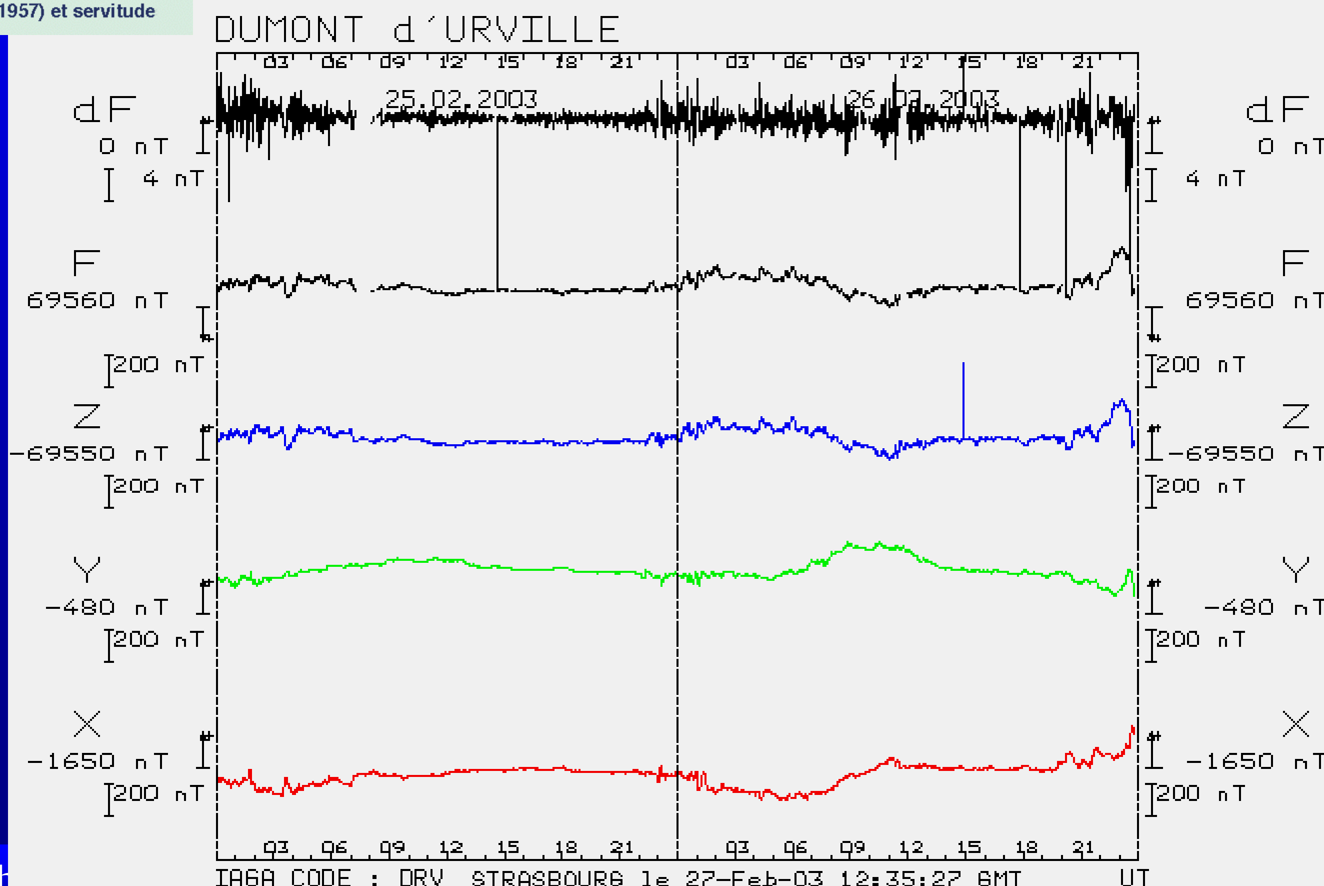


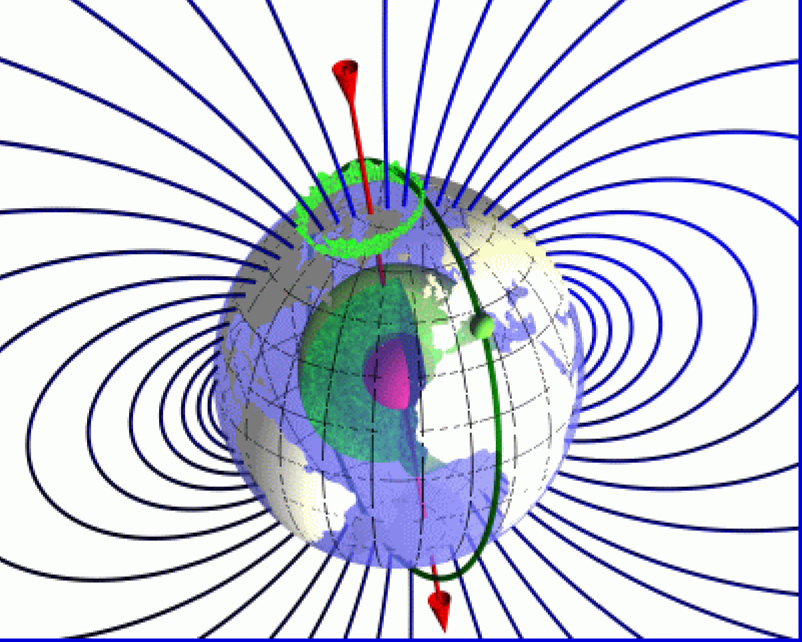
Magnetic measurements

OBSERVATOIRE MAGNETIQUE DE DUMONT d'URVILLE
66°40'S - 140°01'E



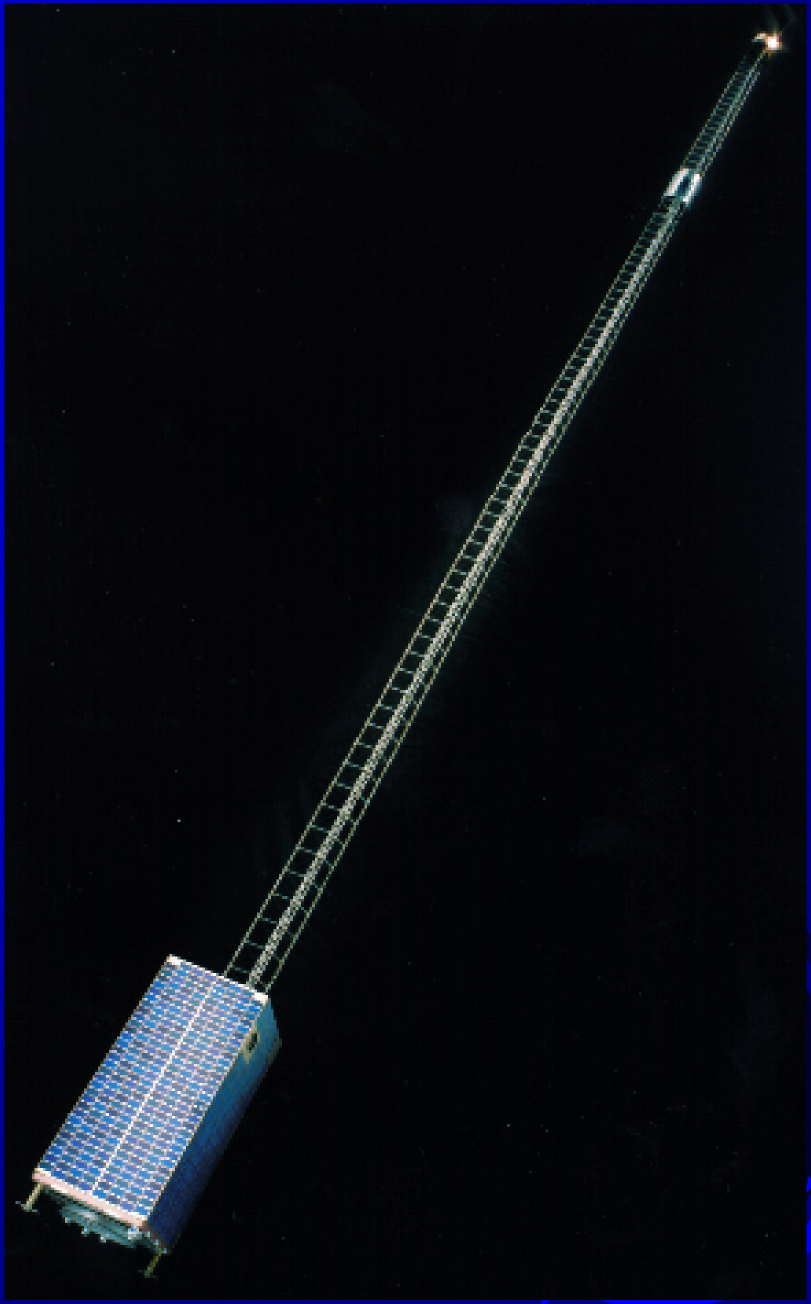
Abris mesures absolues, variomètres, magnétographe La Cour (1957) et servitude



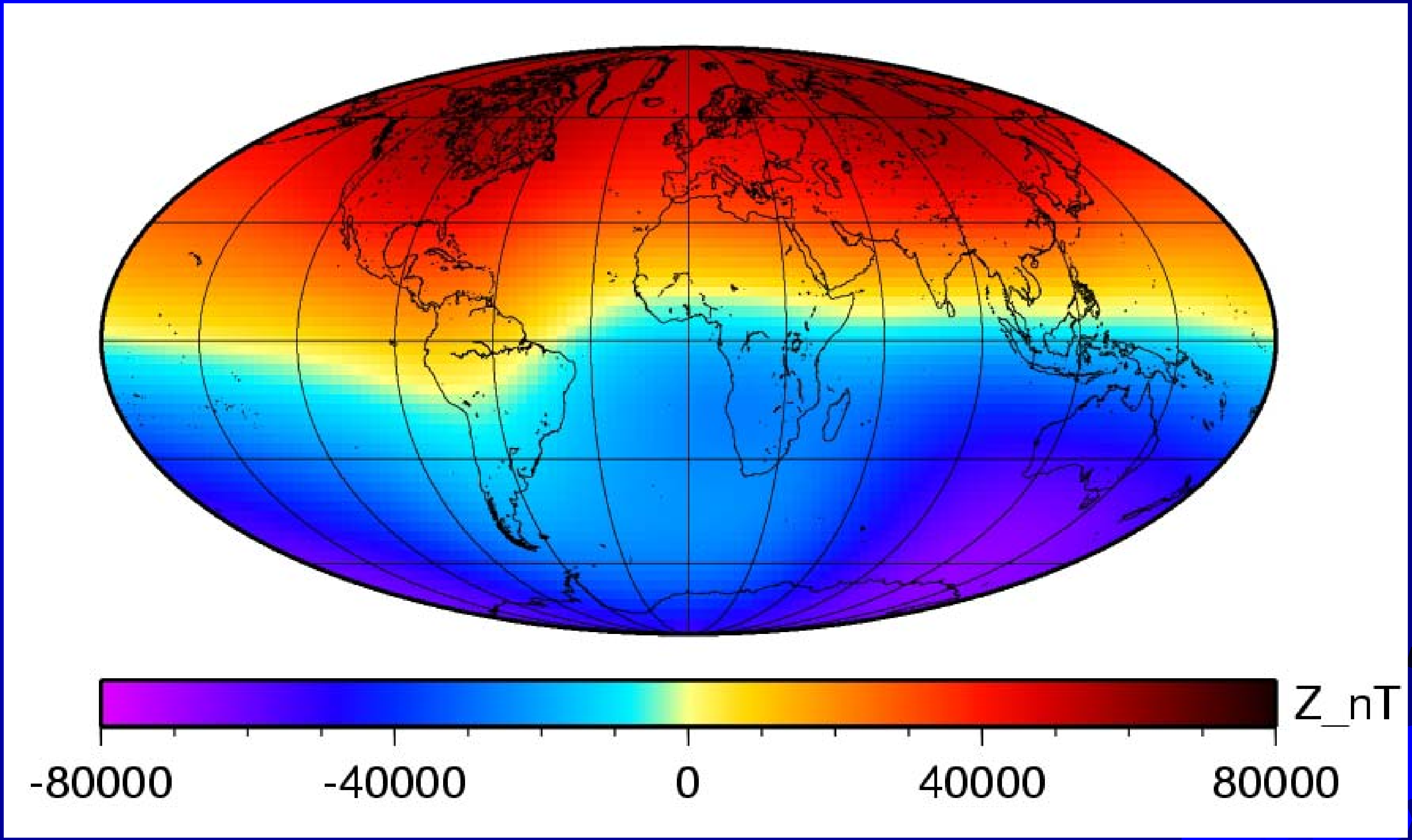


magnetic measurements from satellites

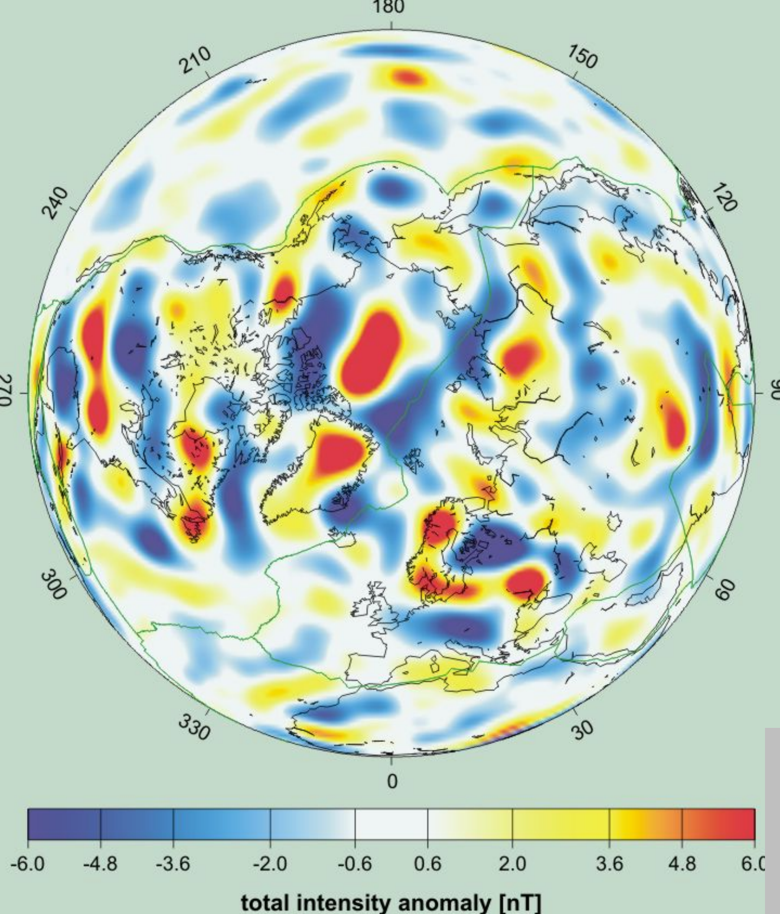
Oersted satellite, 2000



Magnetic field at the Earth surface



Ørsted data (2000-)

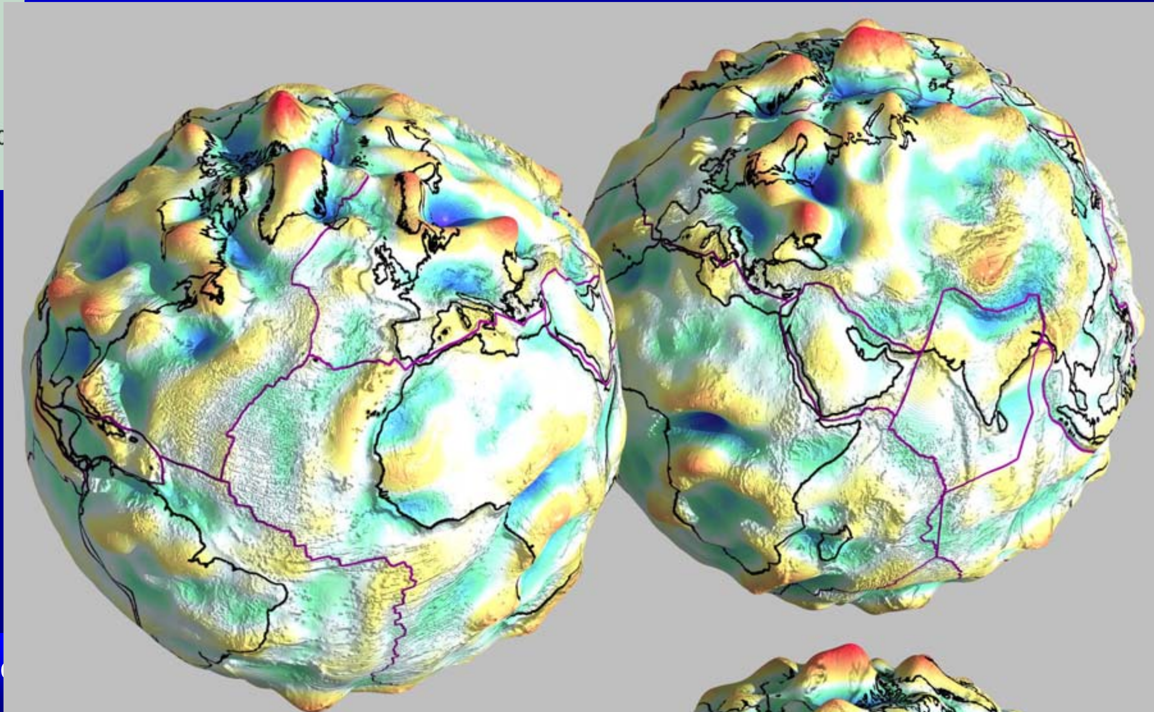


Magnetic field anomalies

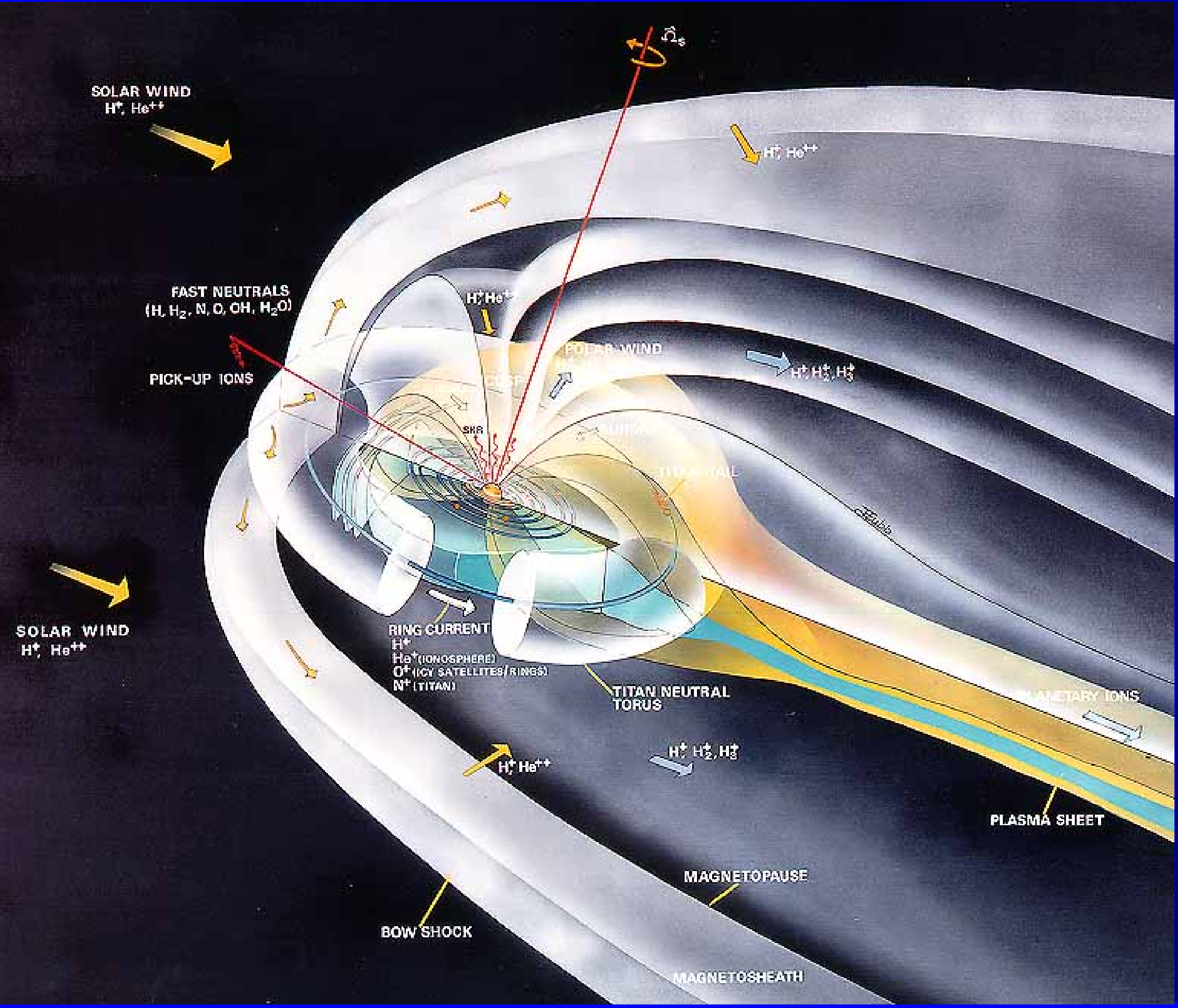
Crustal effets

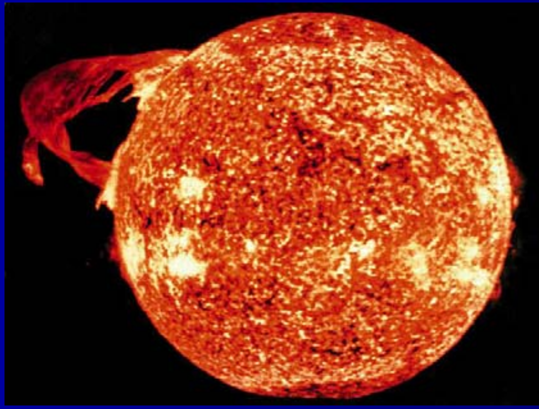
Champ data:

Filtered for SH<15

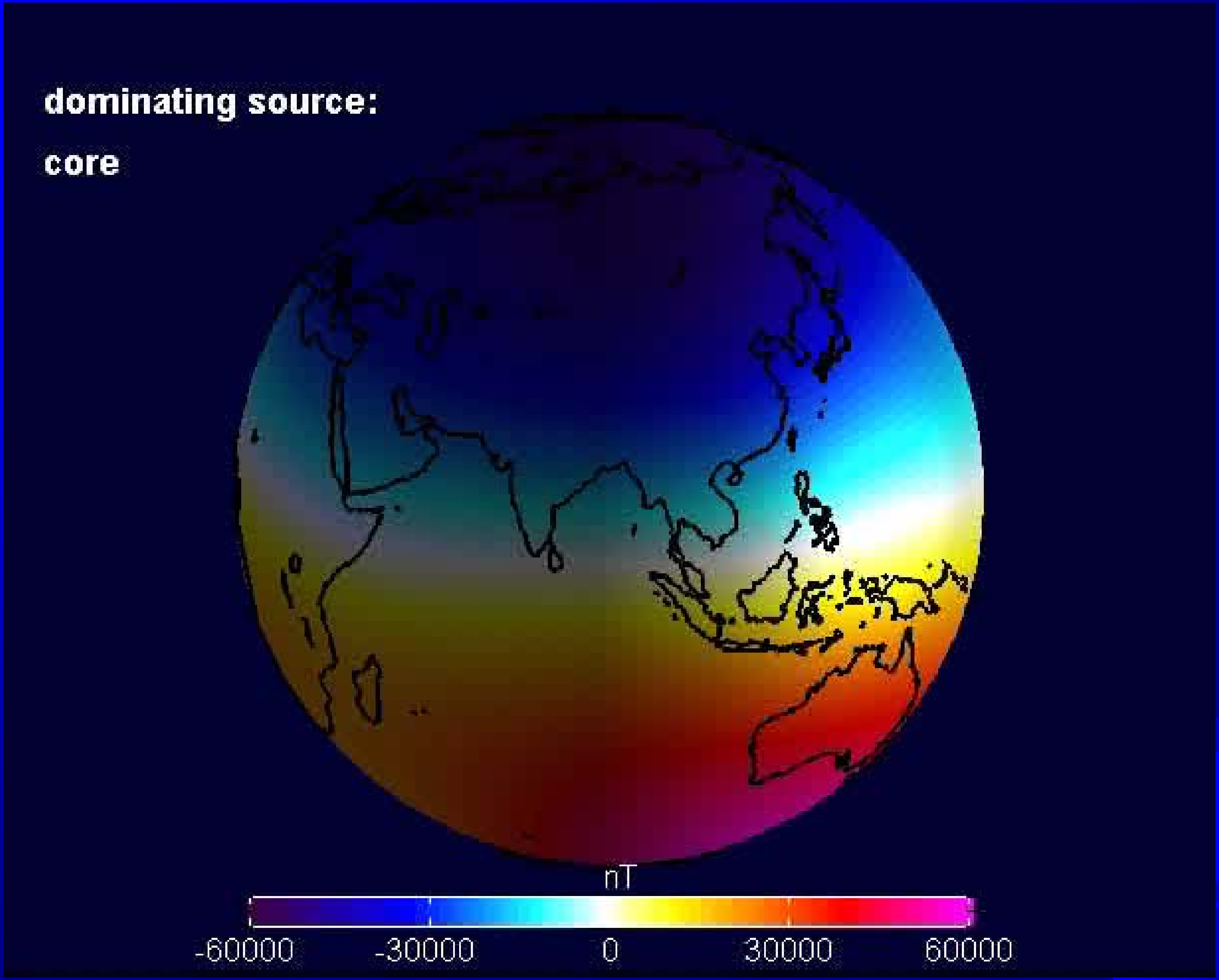


Magnetosphere



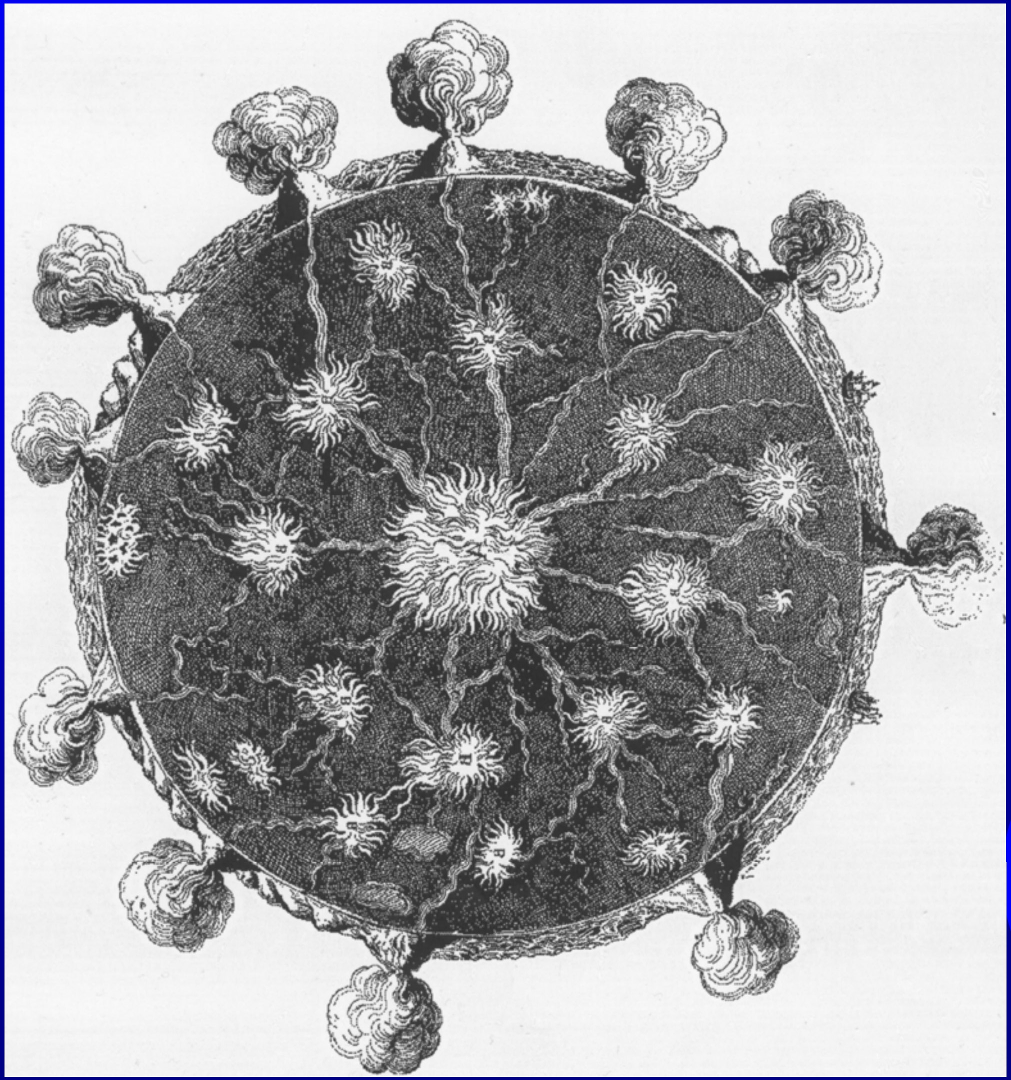


Catastrophe !



Swarm mission, ESA

The Earth's interior

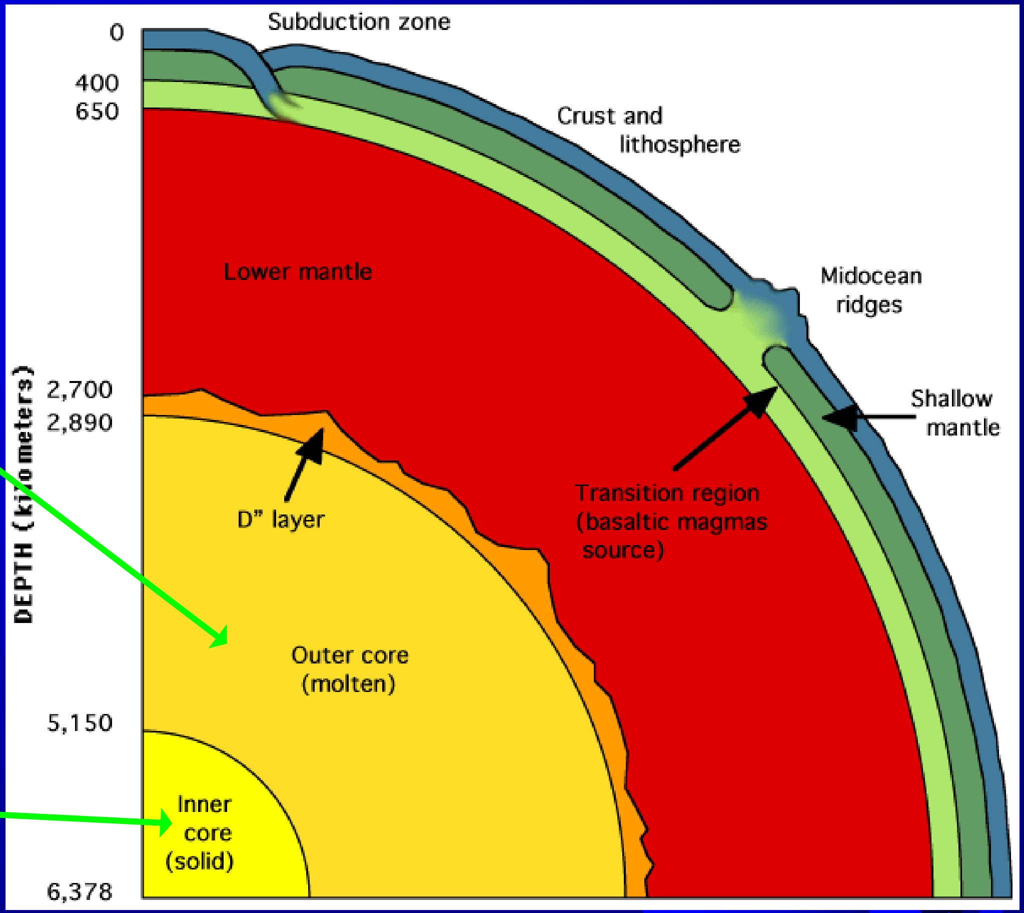


XV^{ème}

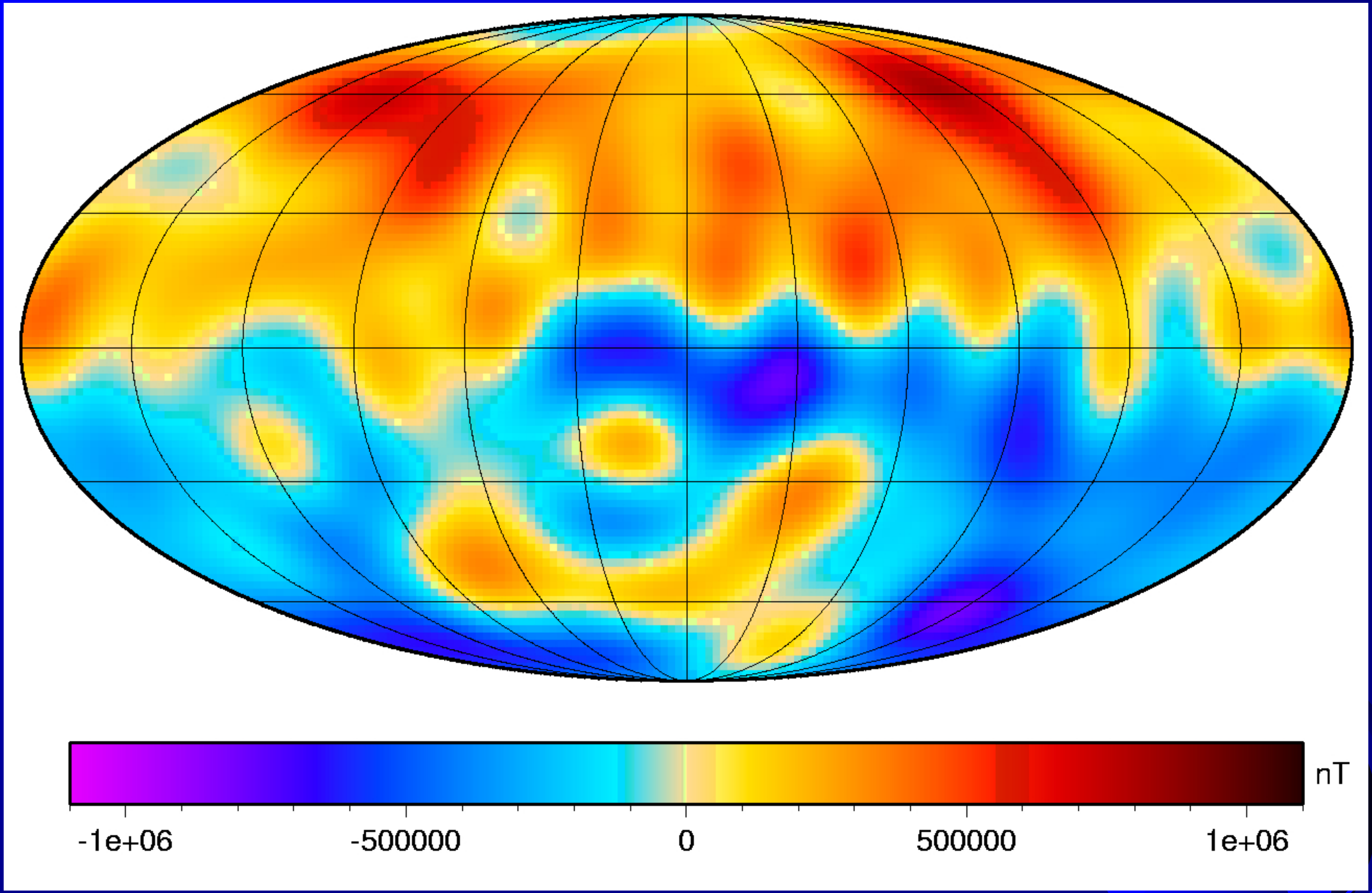
The Earth's interior

Liquid iron

Solid iron



Magnetic field at the core mantle boundary

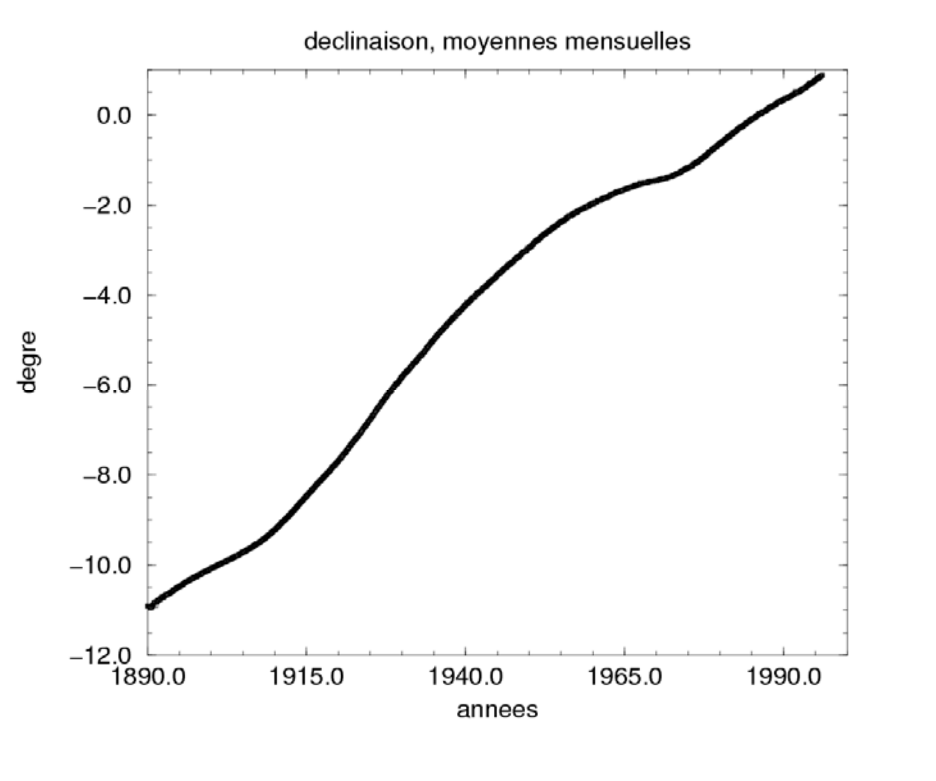


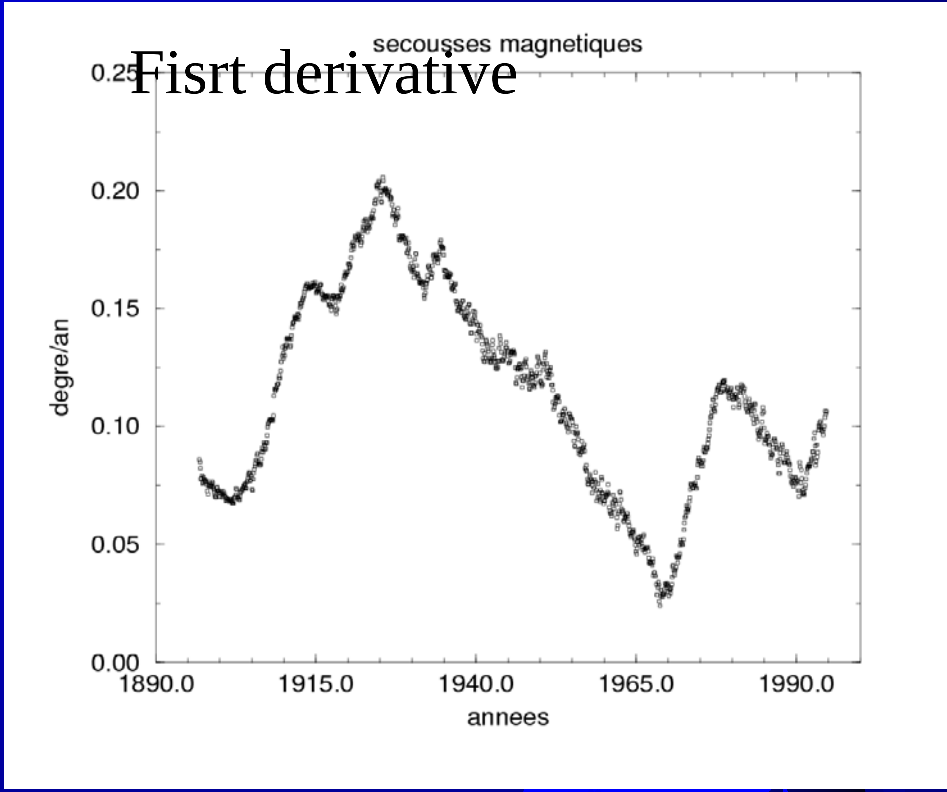
Ørsted satellite data (2000-)

Summary

1. The Earth magnetic field is mainly a dipole.
2. Global and crustal anomalies.
3. Rapid external time variations (< 10 years).
4. Secular internal variations (>10 years).
5. Of internal origin.

Magnetic jerks

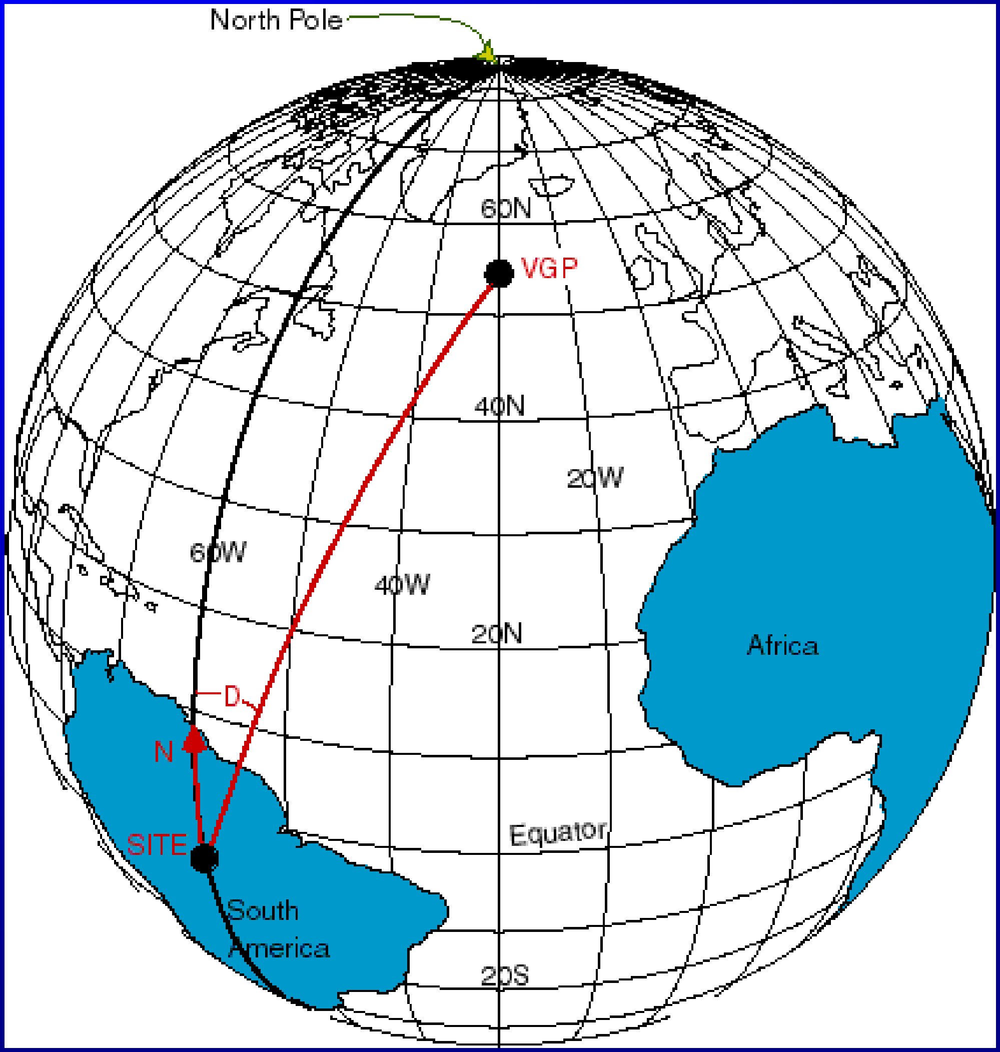




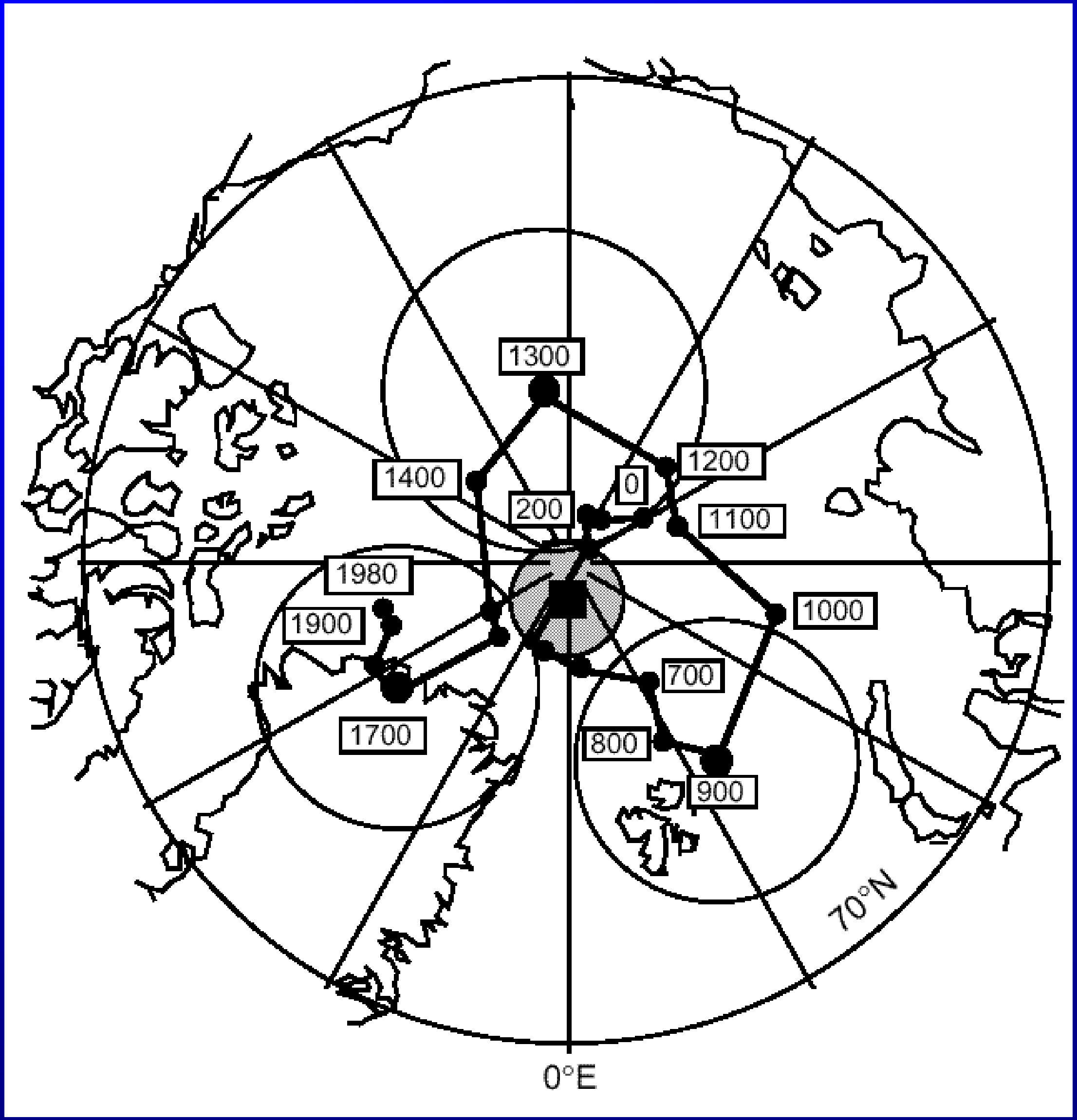
Discontinuity of the second time derivative of the East component of the magnetic field

Magnetization of rocks

Virtual Geomagnetic Pole (VGP)



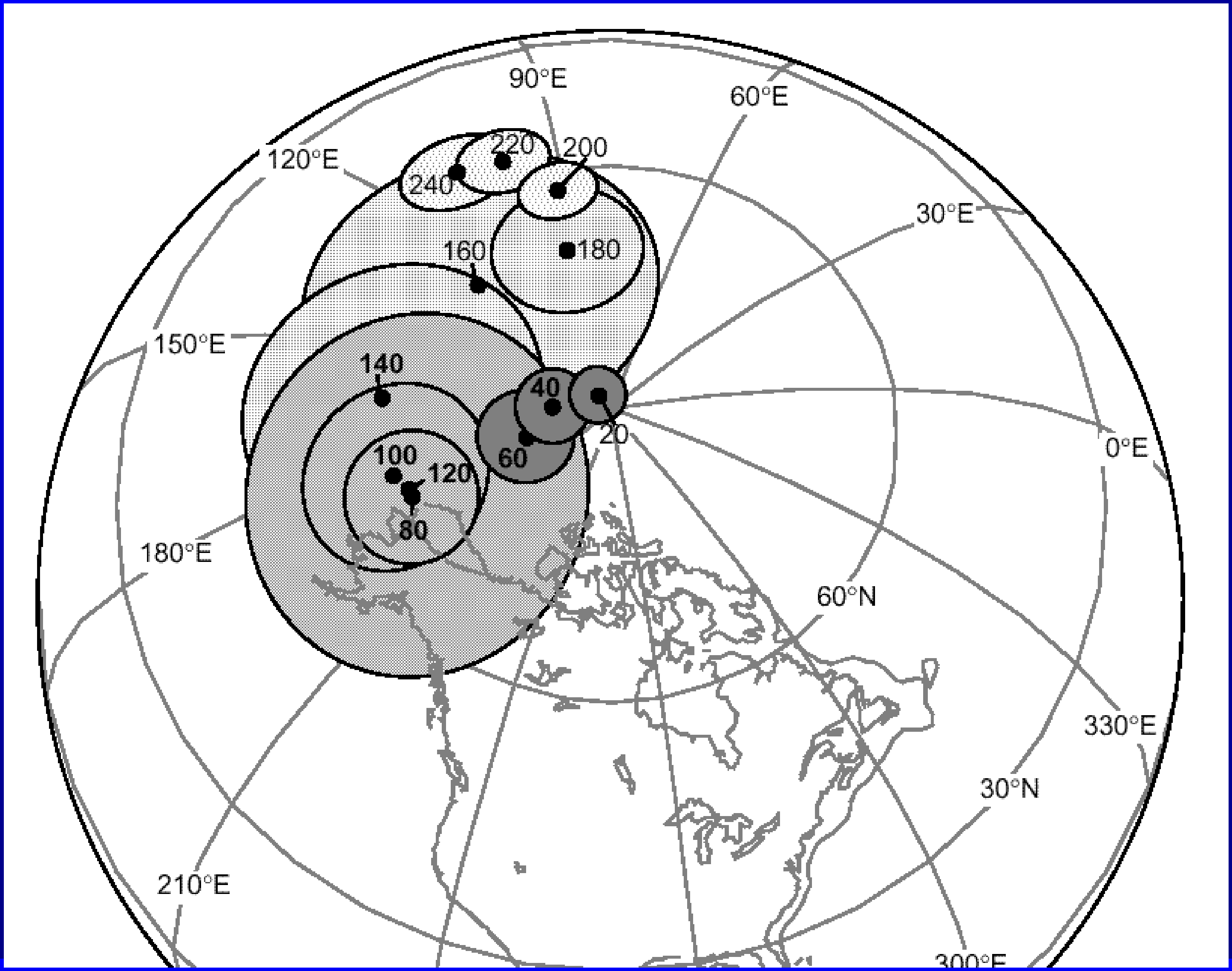
Archeomagnetism



Magnetic pole position for the last 2000 years

Butler

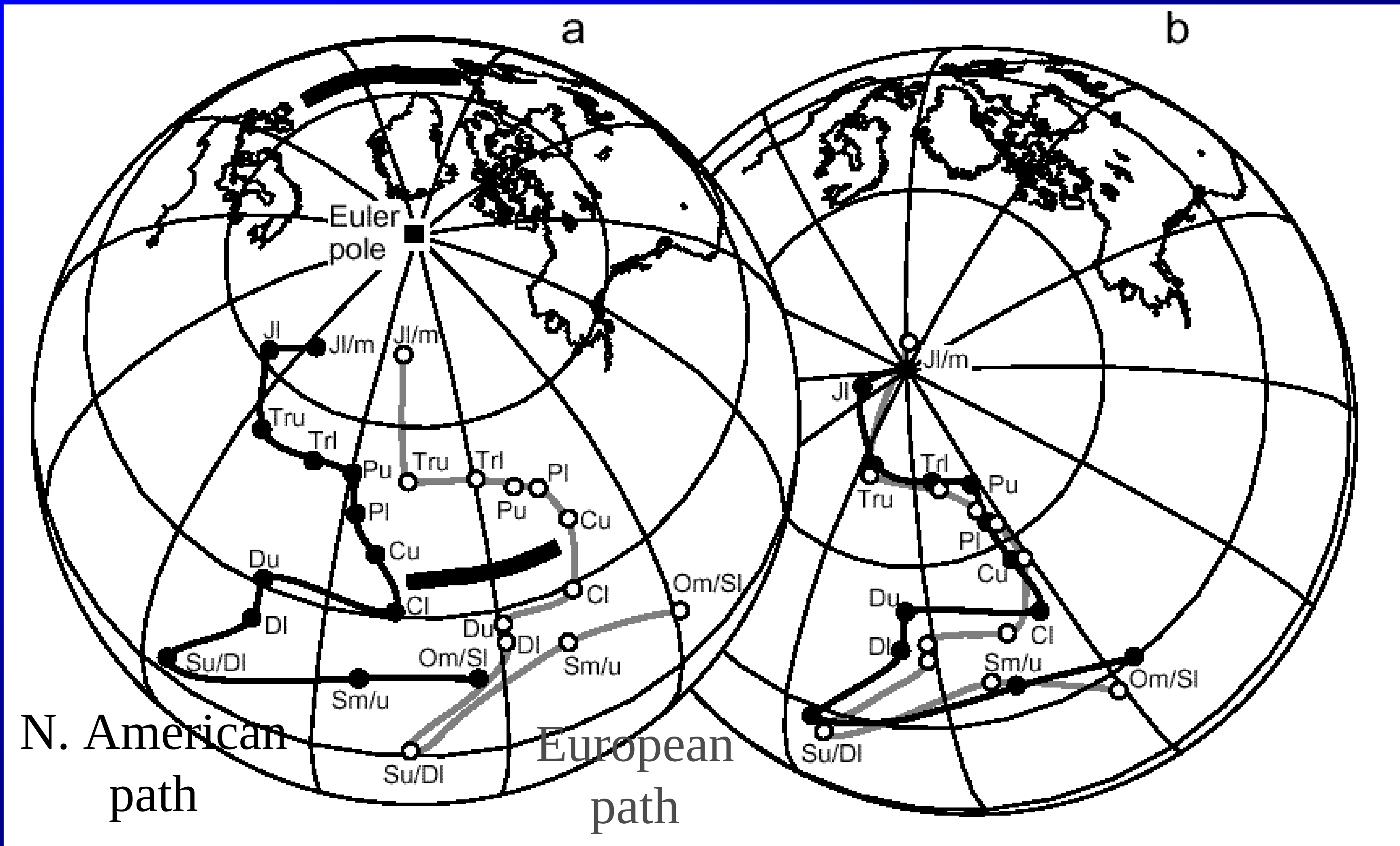
Migration of the VGP

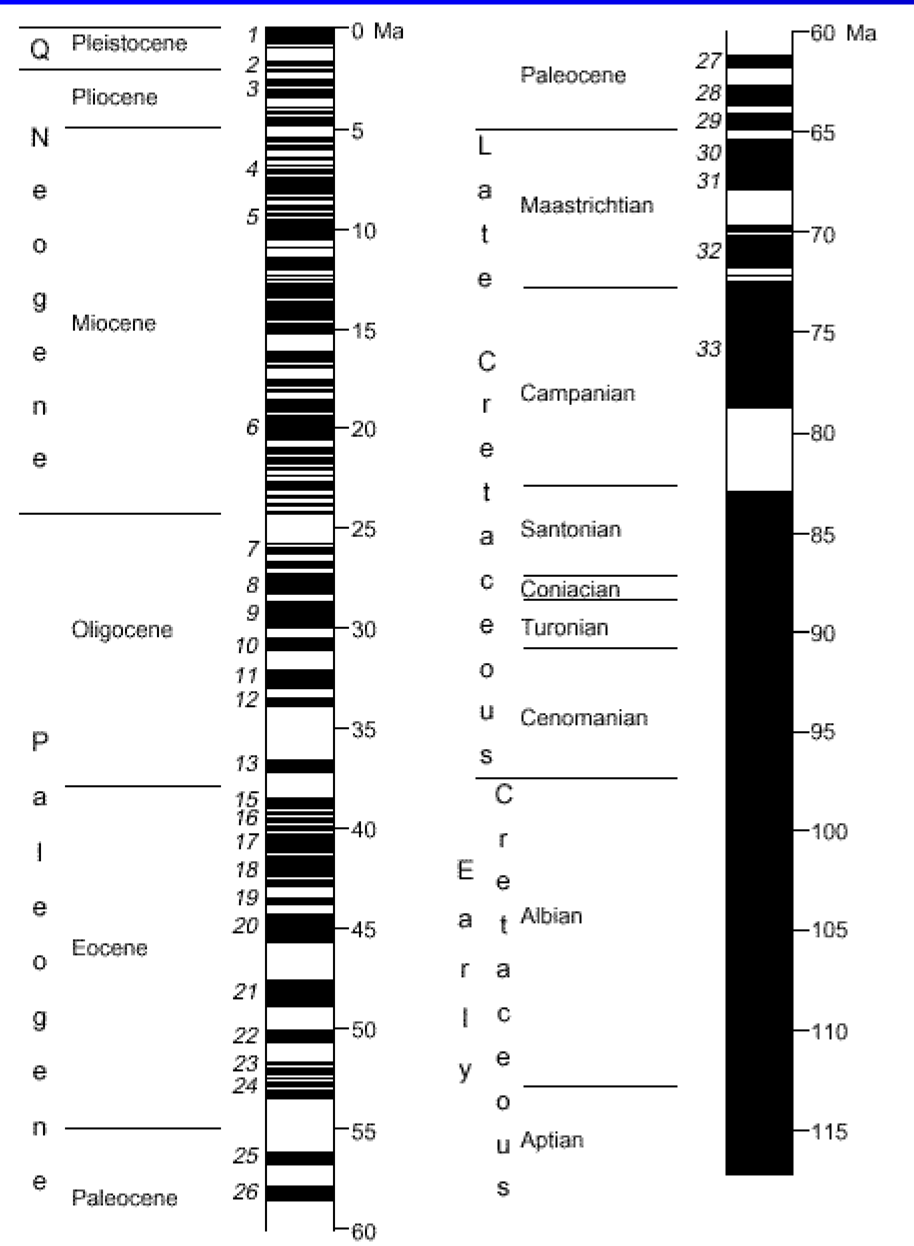


Paleomagnetic data from north America

Butler

Plate tectonic proof



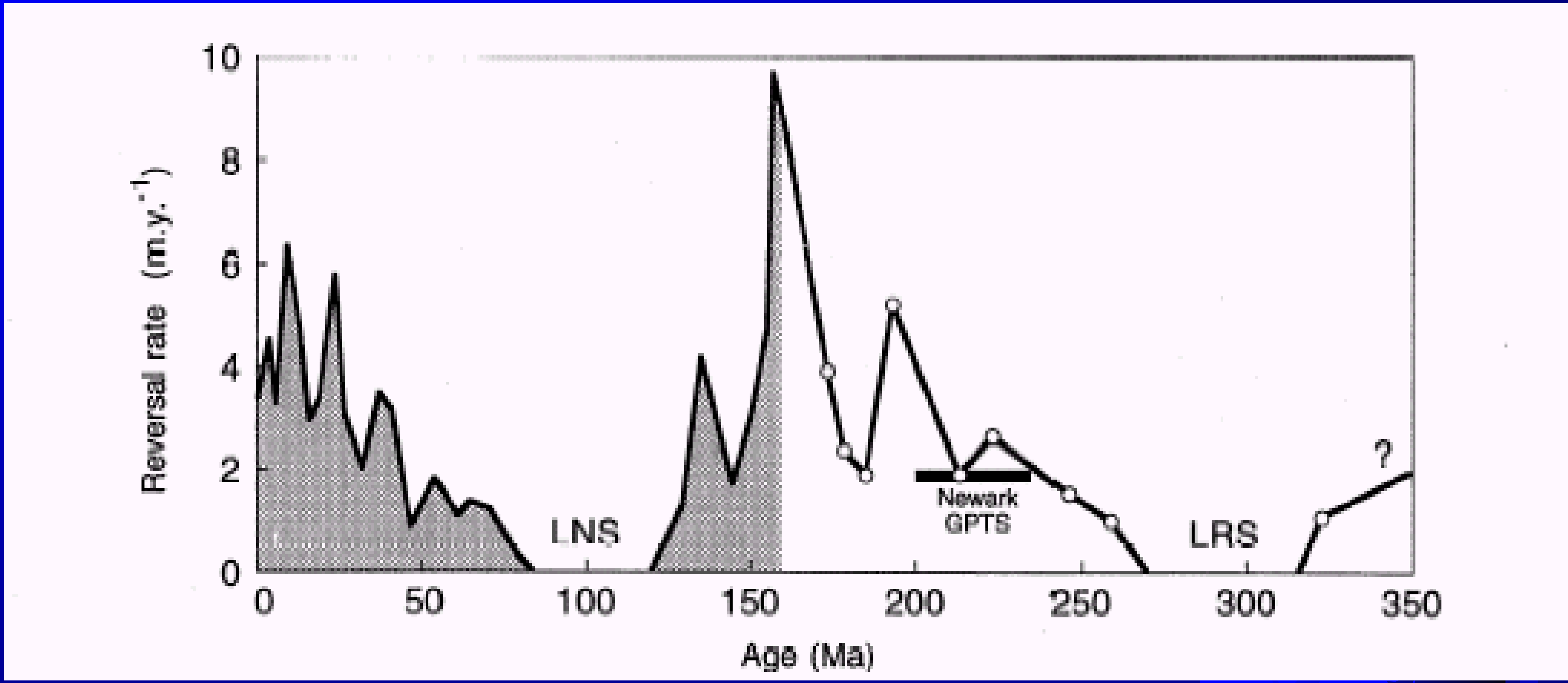


Magneto-stratigraphic chart

Pierre Brunhes
1905

Butler

Reversals frequency

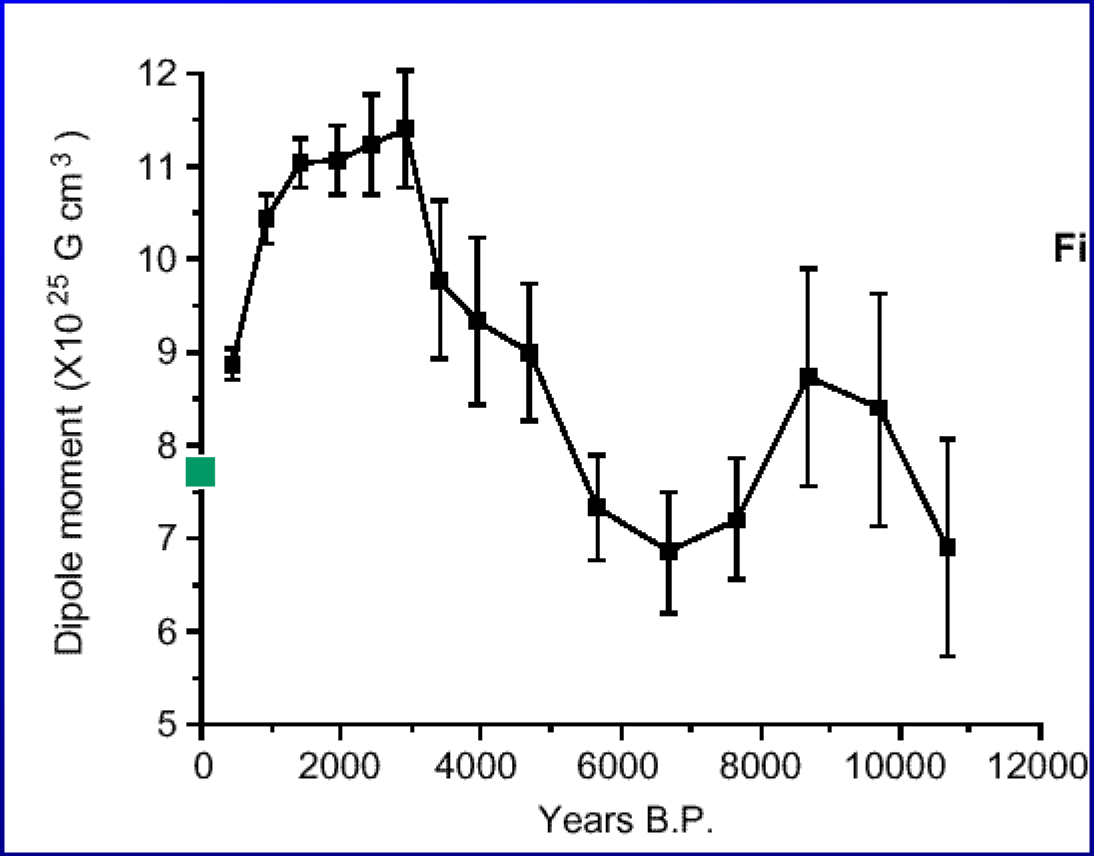


Kent et Olsen, 1999; Gallet et al., 1992

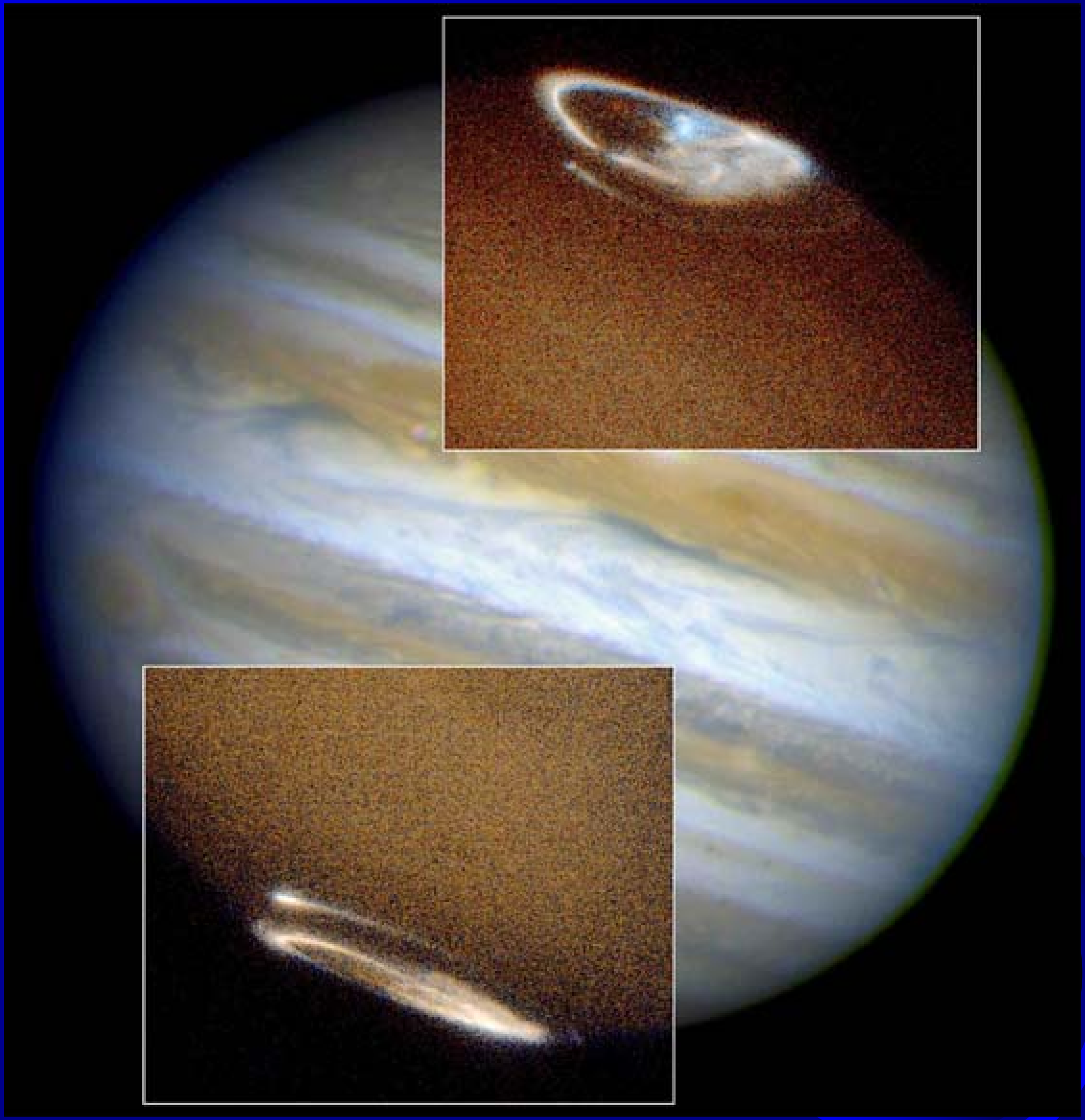
Summary

1. Dipolar magnetic field aligned with the axis of rotation
2. Reversals
3. Very old (at least 2.8 By)
4. Same intensity ?

The Earth magnetic field is failing?



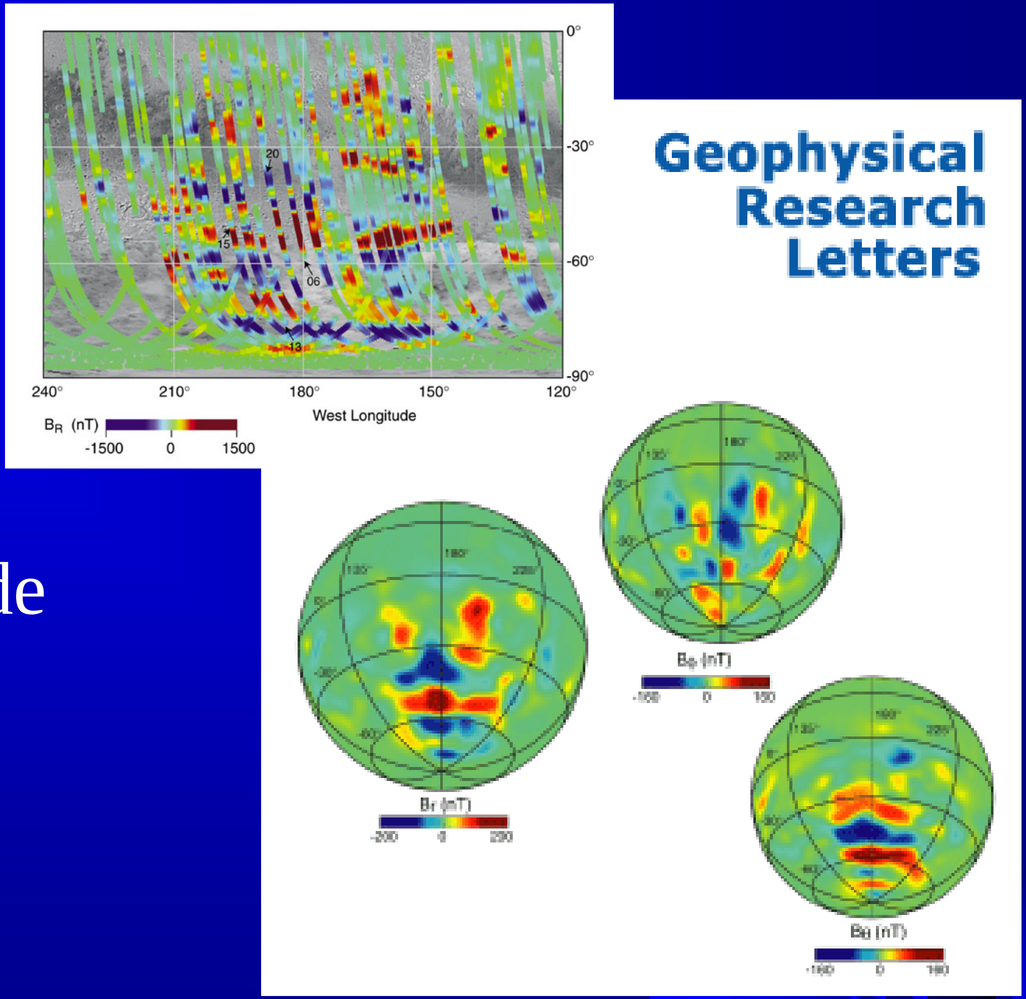
Magnetic field on Jupiter



Terrestrial planets

Io

Ganimède

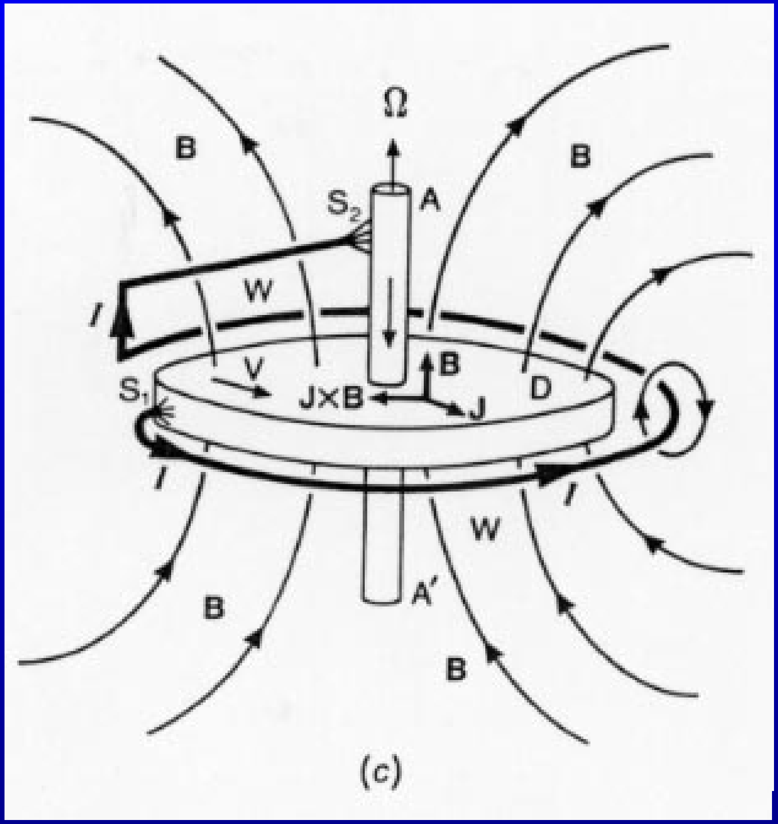


Venus?

Moon?

Mars ?

Dynamo principle; dynamo disk



$$F = q(u \wedge B)$$

$$j = \sigma(E + u \wedge B)$$

$$Rot\,B = \mu_0 j$$

$$Rot\,E = -\frac{\partial B}{\partial t}$$

Induction equation

Time evolution of magnetic field $= Rm$ Induction : source of magnetic field $+$ Joule effect: Destruction of magnetic field

Elsasser, 1946

Magnetic Reynolds number

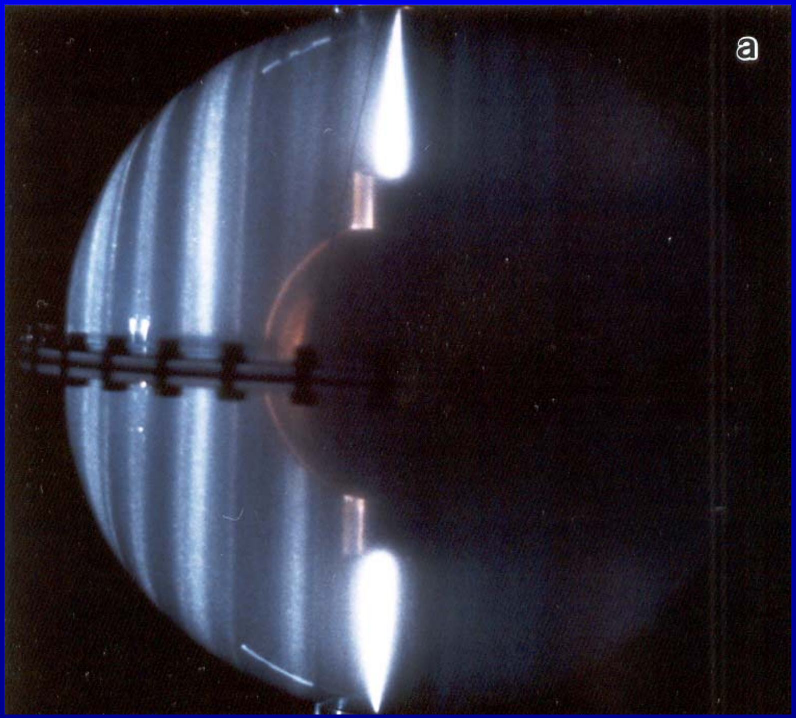
$$Rm = \frac{UL}{\eta}$$

Magnetic diffusivity

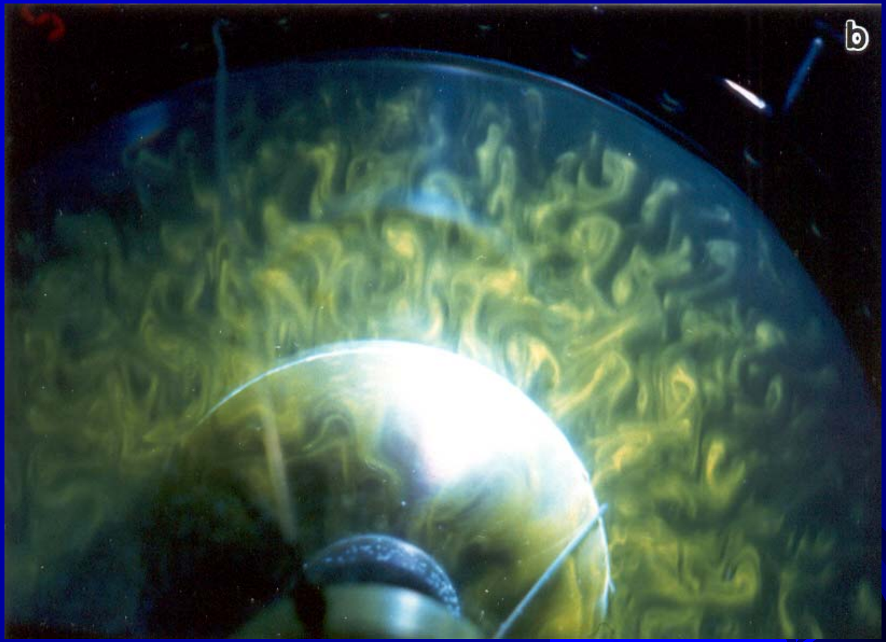
Dynamo effect if Rm is greater than ≈ 50

Cooling of a rotating planetary cores

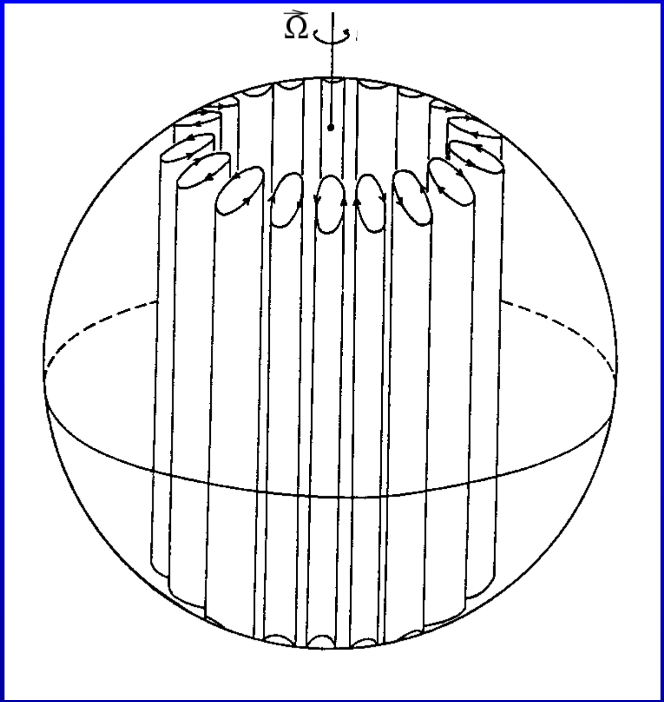
Side view



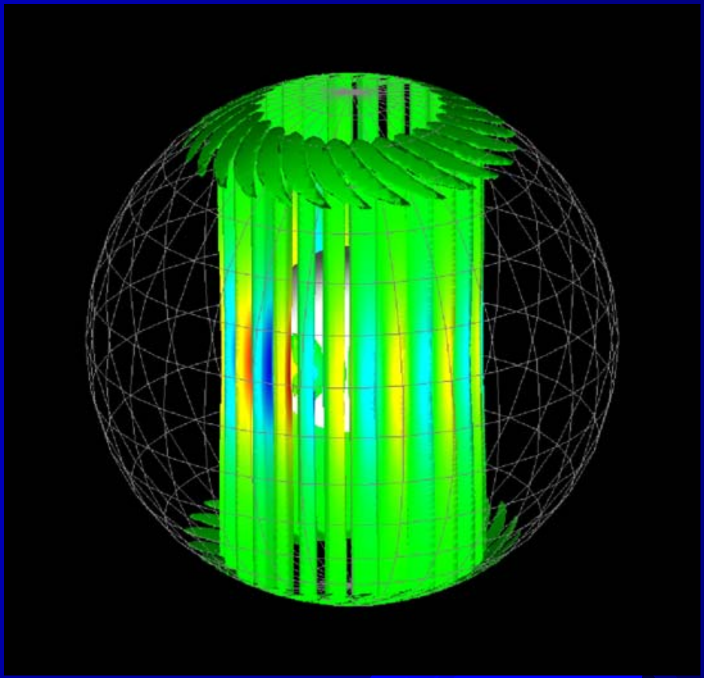
Equatorial view



Thermal convection in planetary cores



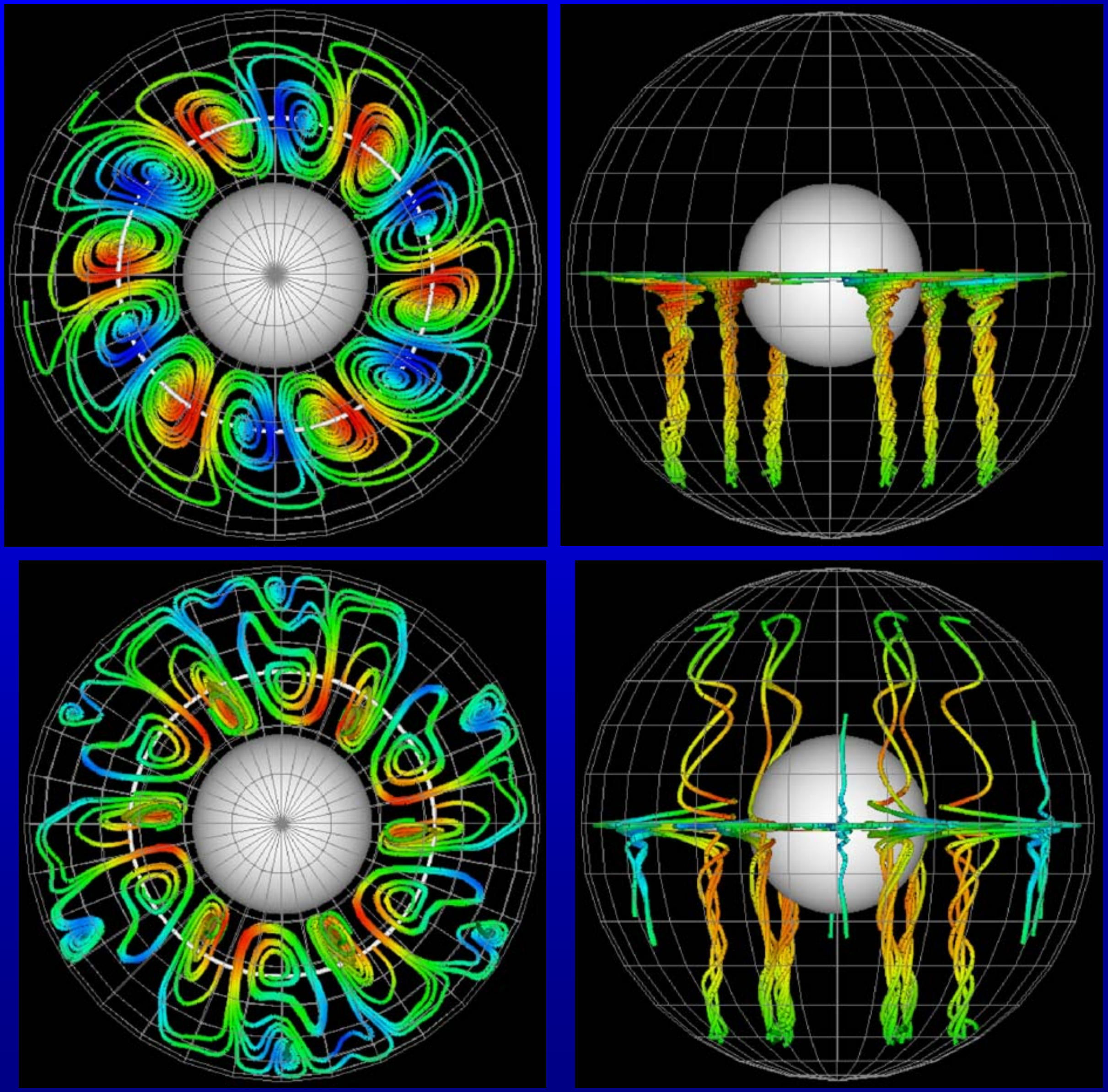
Theoritical , Busse 1970



Numerical, Dormy et al, 1997

ROTATION

Numerical simulation

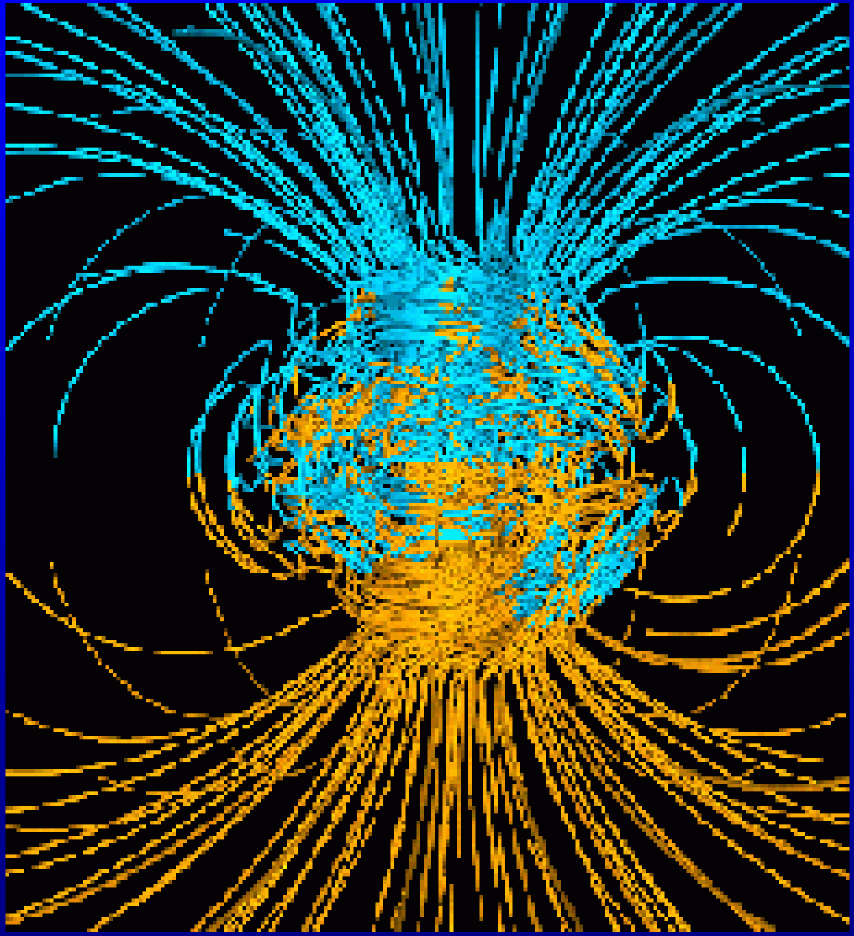


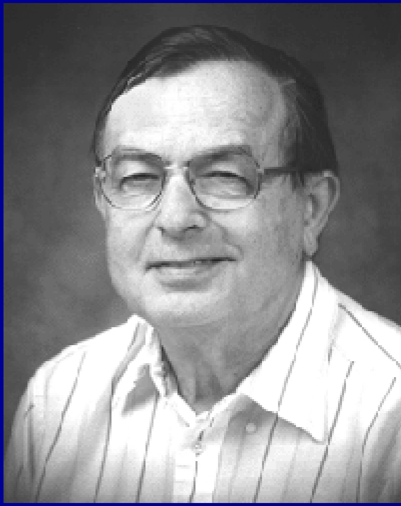
Onset of convection

Two times critical

Dormy et al.,1998

The first numerical dynamo

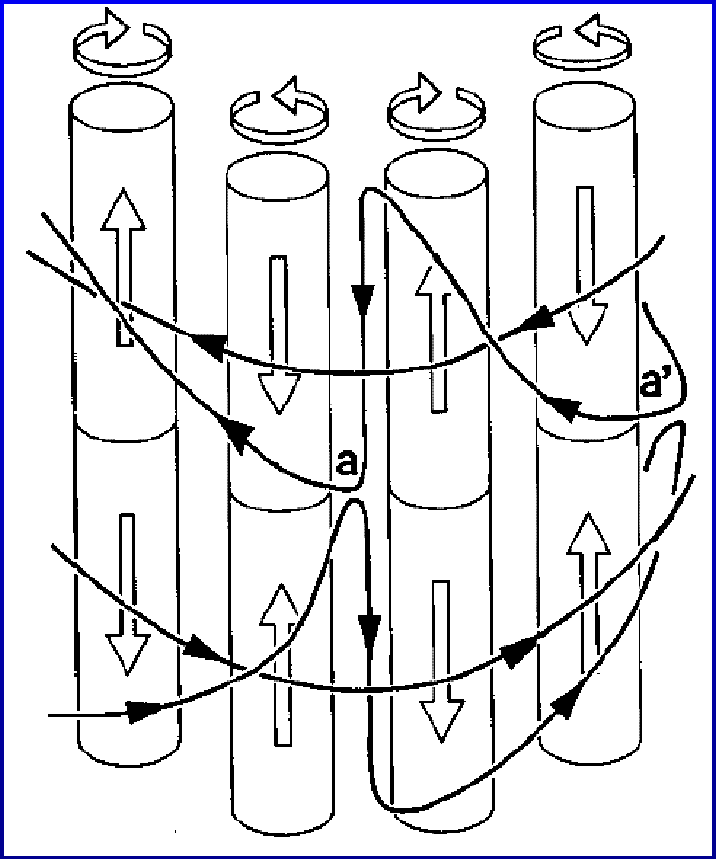




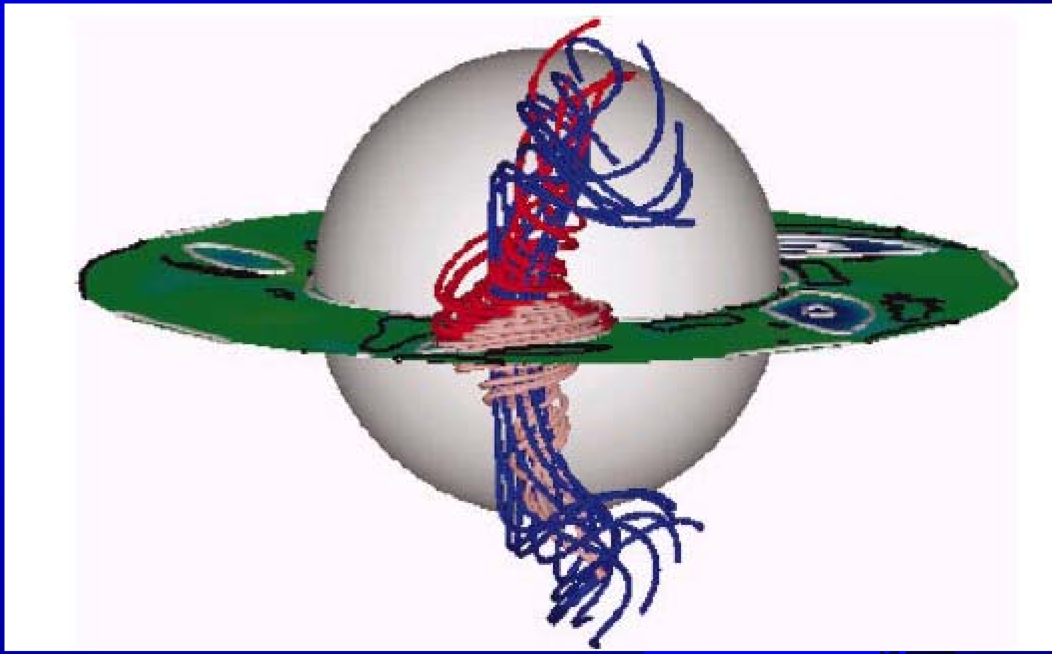
Roberts

Glatzmaier et Roberts 1995

Pumping in the vortices

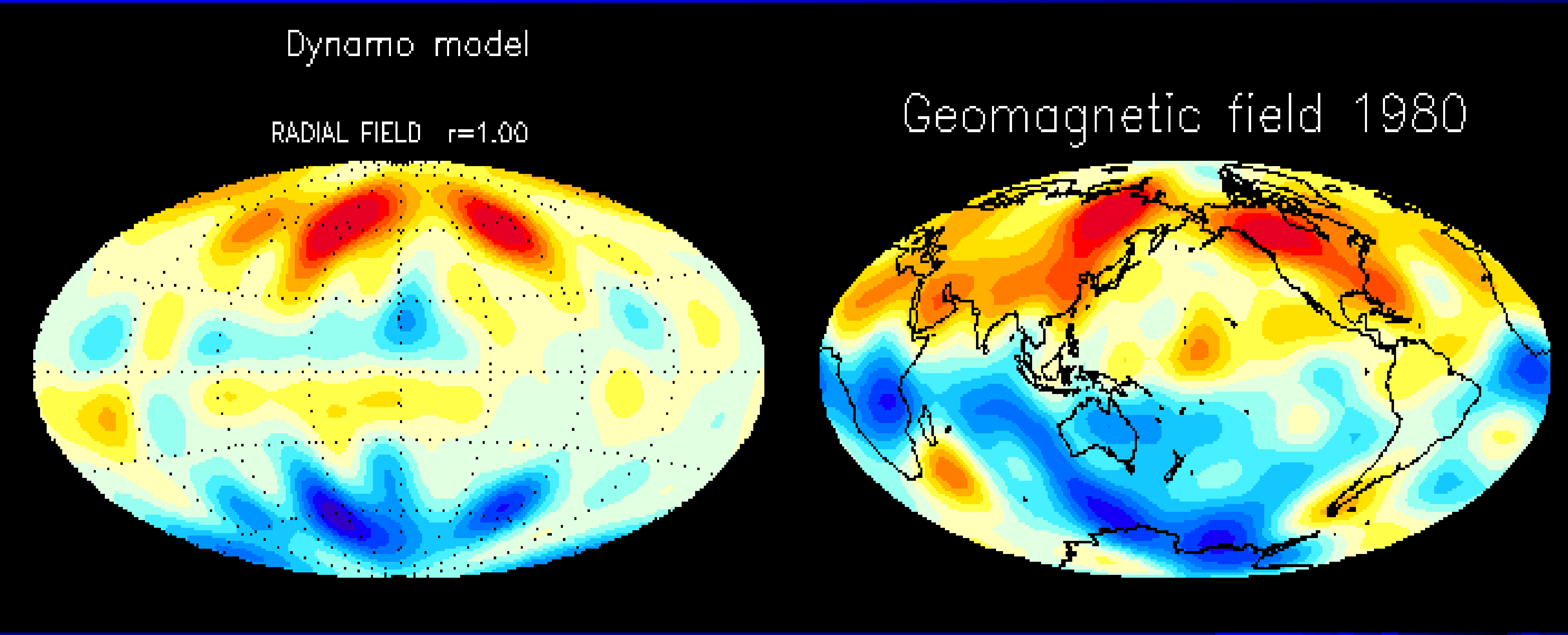


Kageyama et al 1996



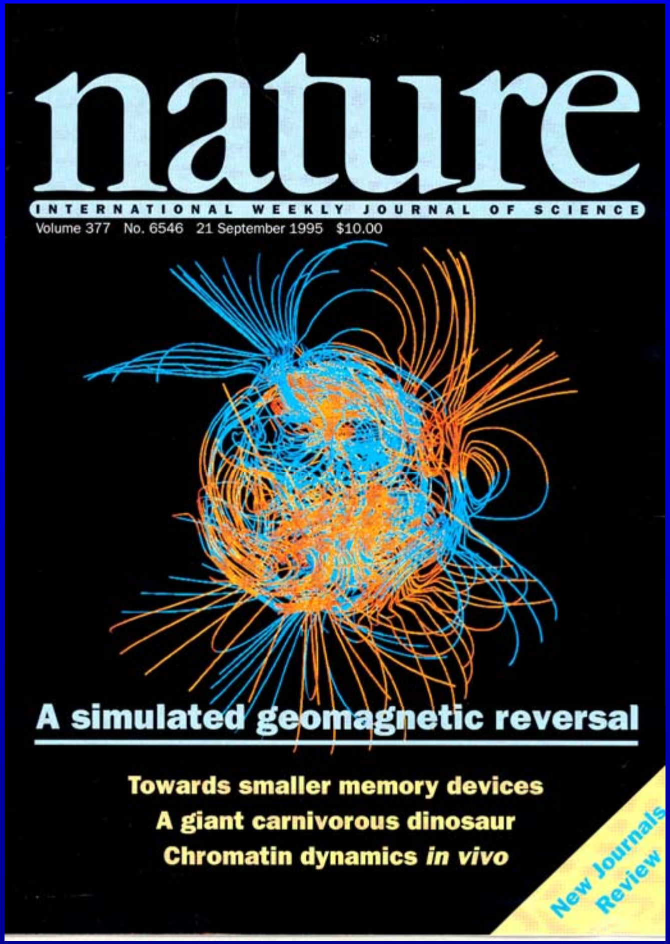
Ishihara et Kida, 2002

Which one is the Earth?

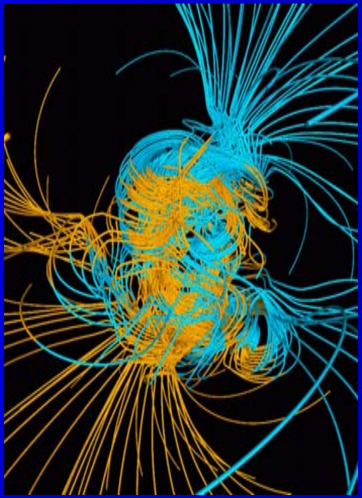


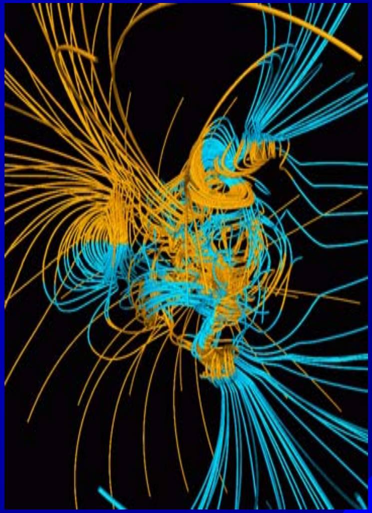
Olson et al., 1999

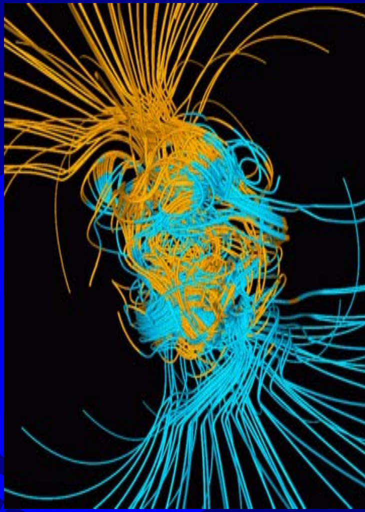
Reversal of magnetic field



Glatzmaier et Roberts 97







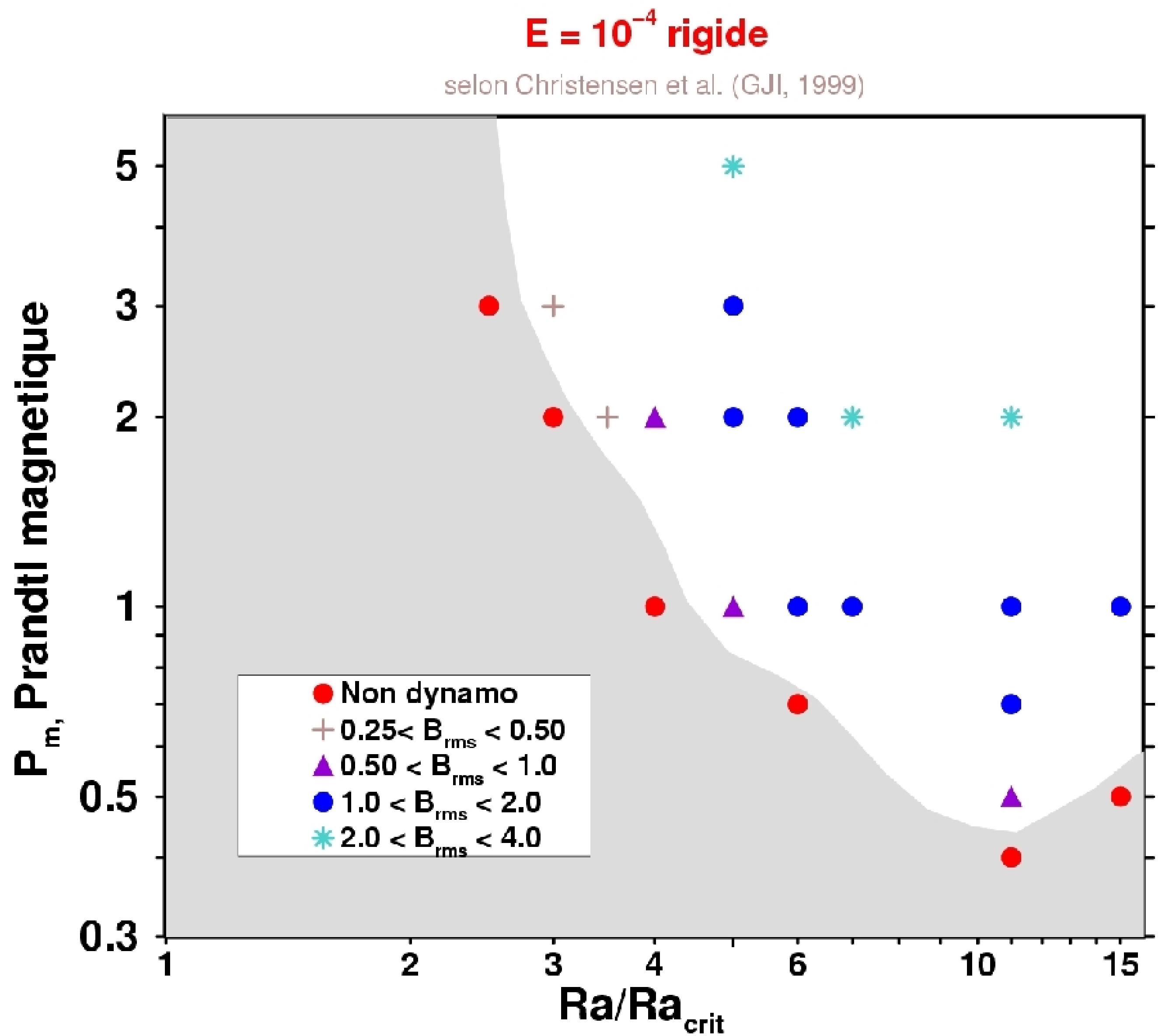
Numerical limits

1. Viscosity = magnetic diffusivity
2. Salt water
3. Metallic glass
4. 1 day = 100 millions of year
5. No motion less than 100 km.

Viscosity/

conductivity

10^{-6}



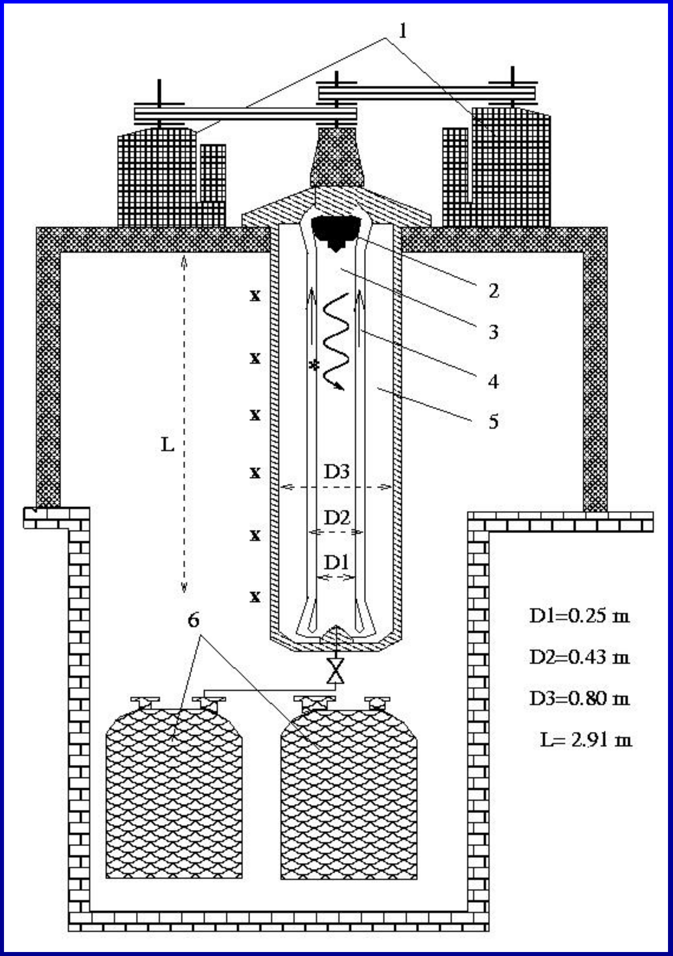
Vigor of thermal convection

Experimental approach

$$Rm = \frac{UL}{\eta} > 100$$

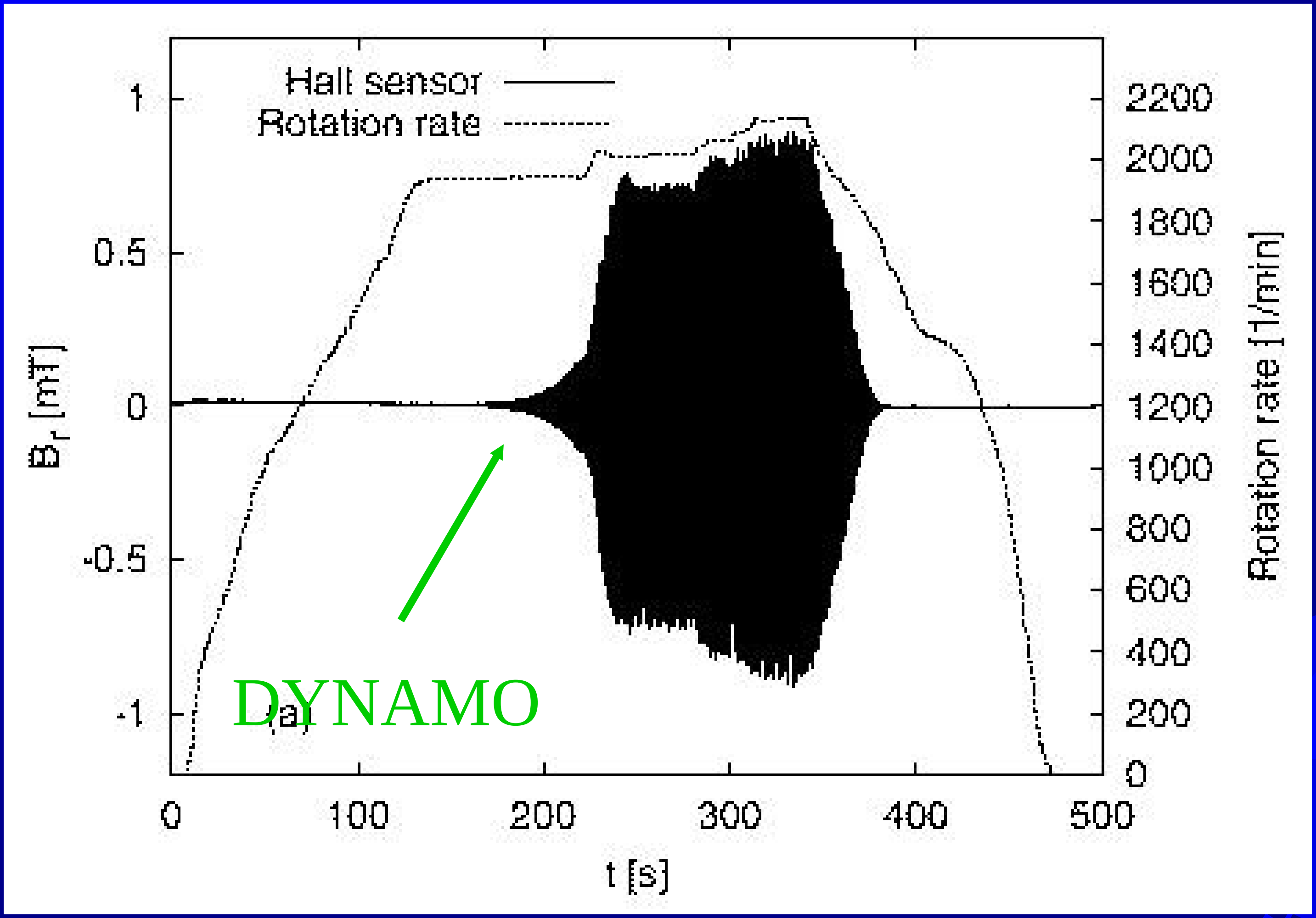
- liquid sodium : $\eta = 0.1\ m^2/s$
- size : L > 1 m
- velocity U > 10 m/s
- density 980 kg/m^3

Riga Dynamo

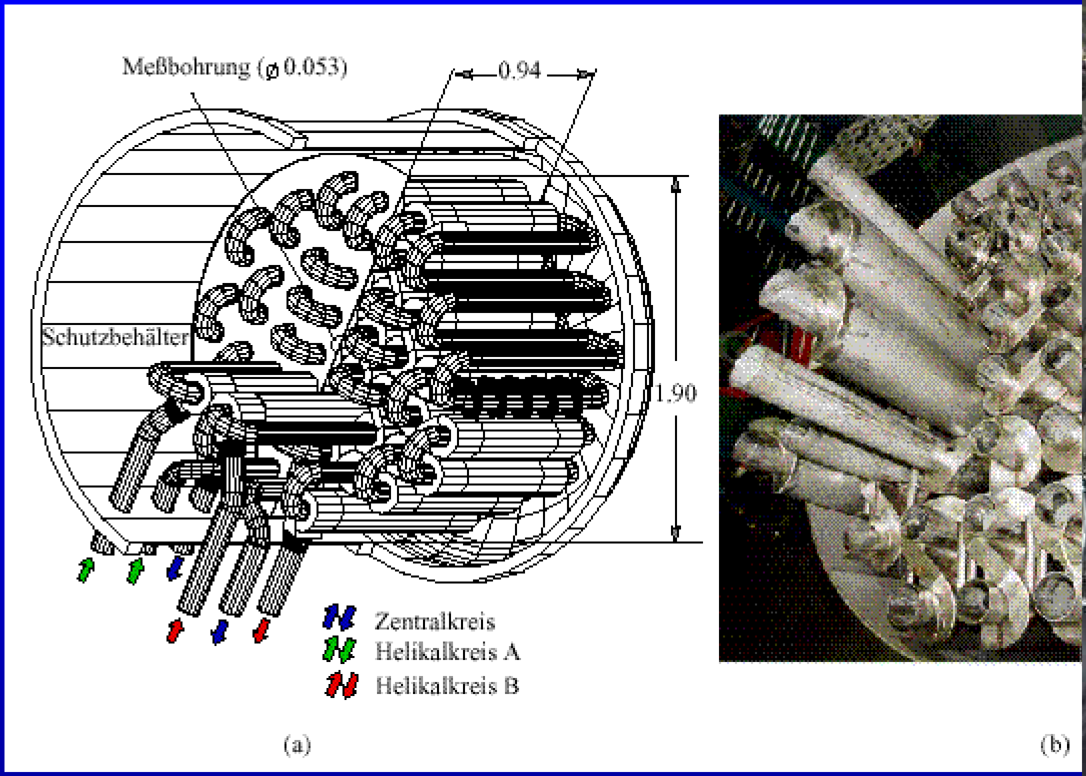


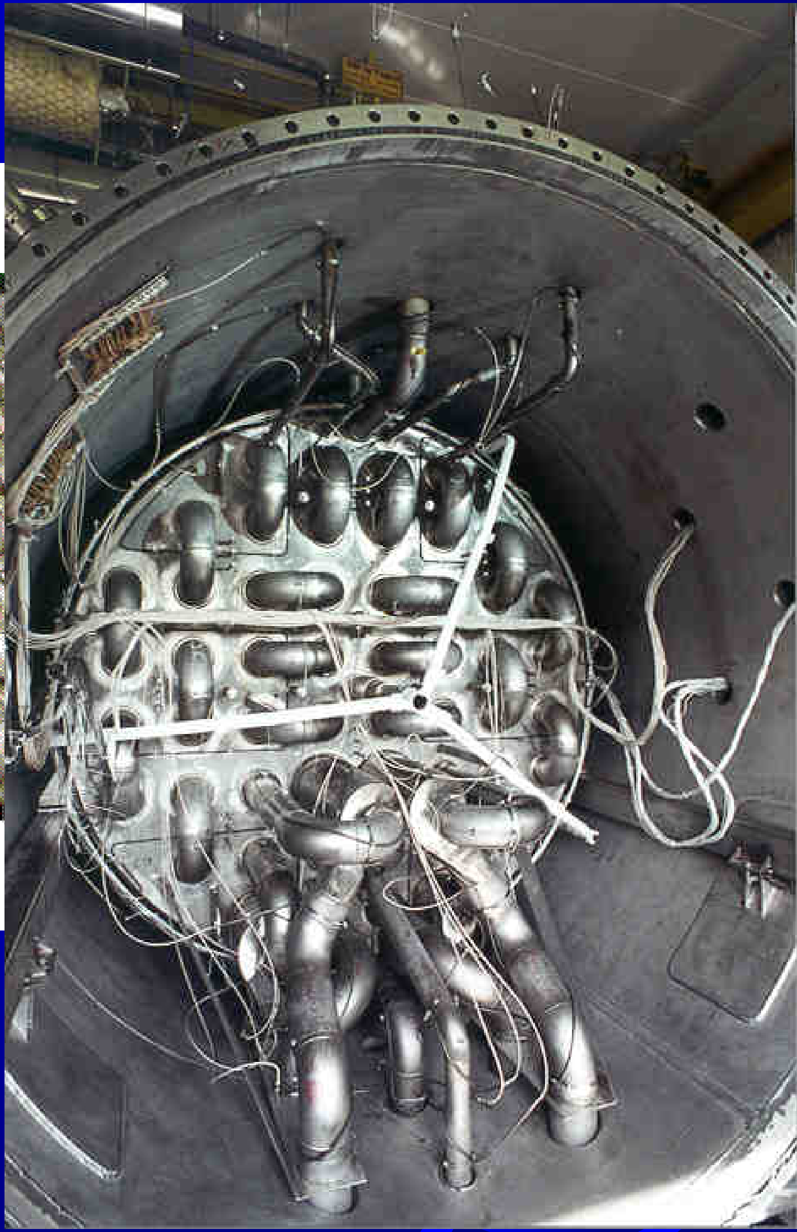
2 m3 of Na, 200kW

Self exitation in Riga



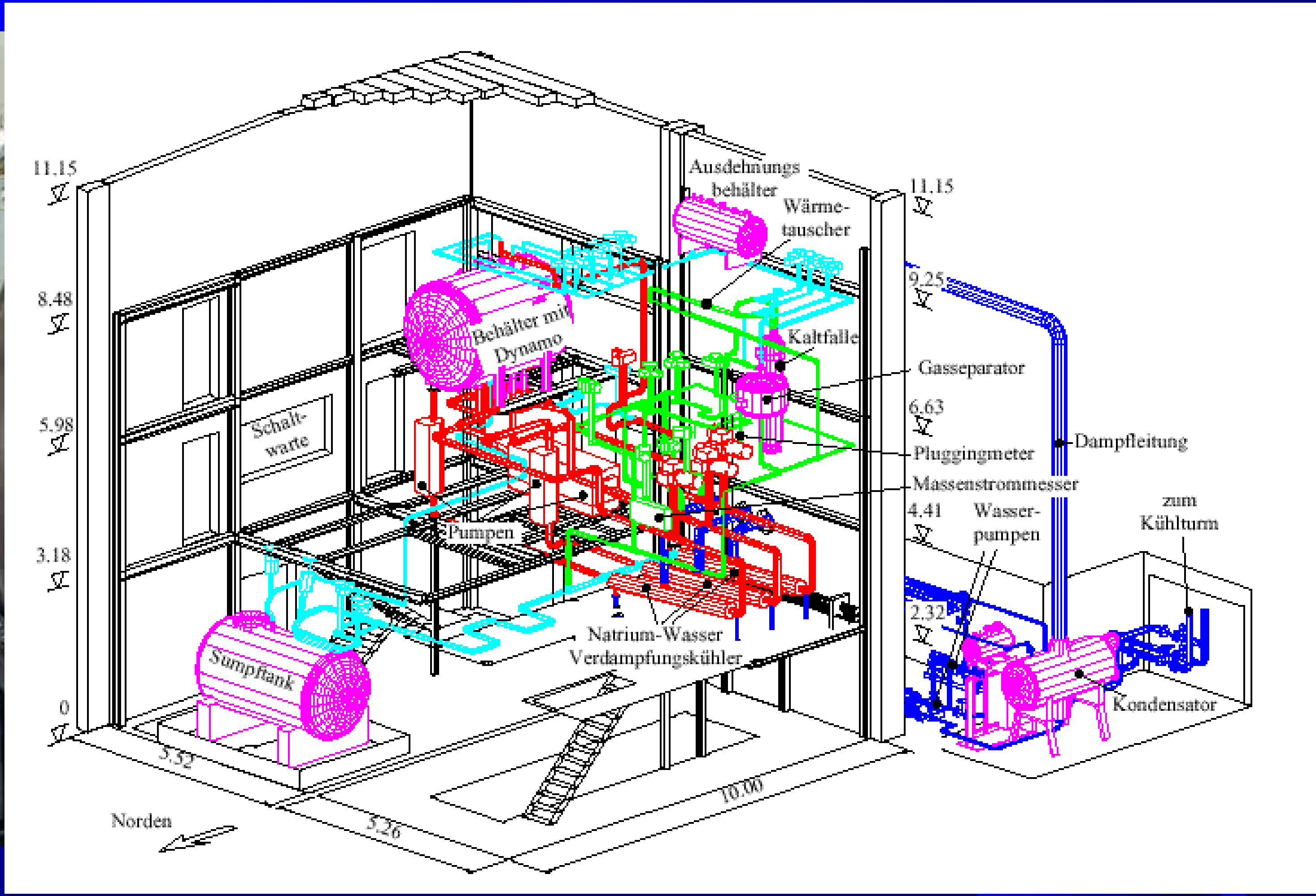
Karlsruhe experiment



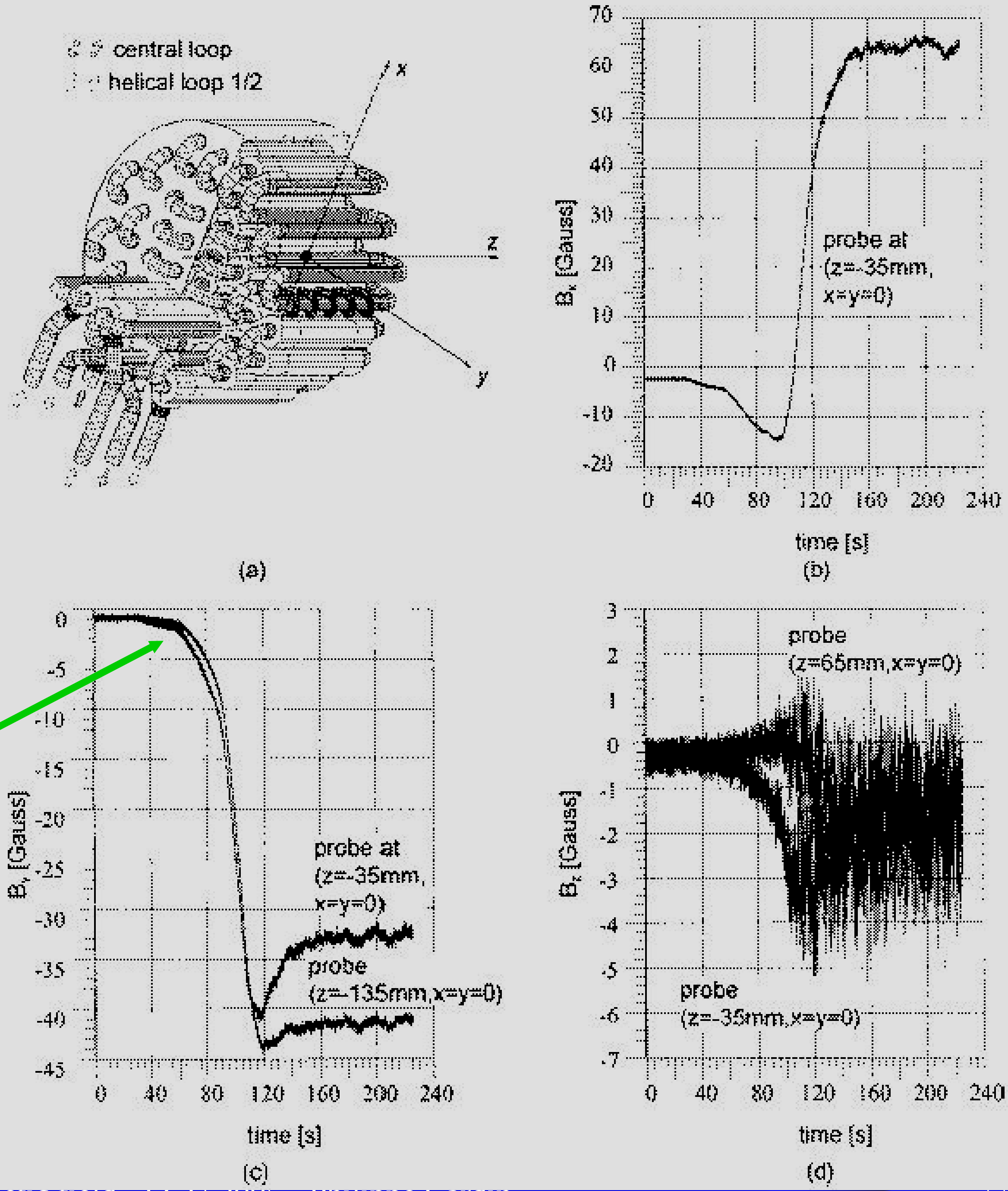


3 m3 of Na, 500 kW

Photos Karlsruhe

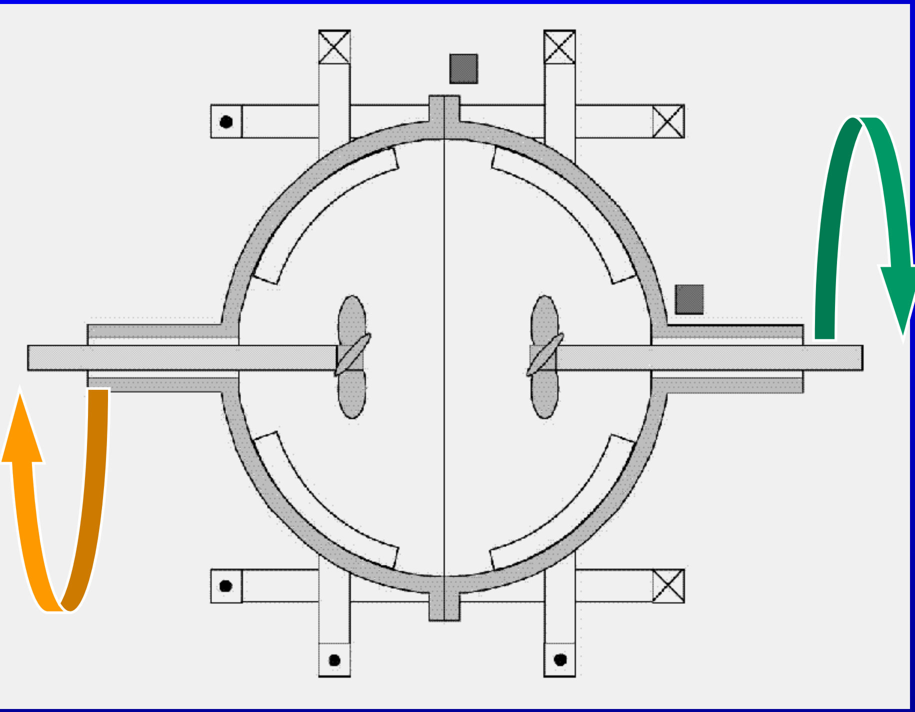


Karlsruhe results

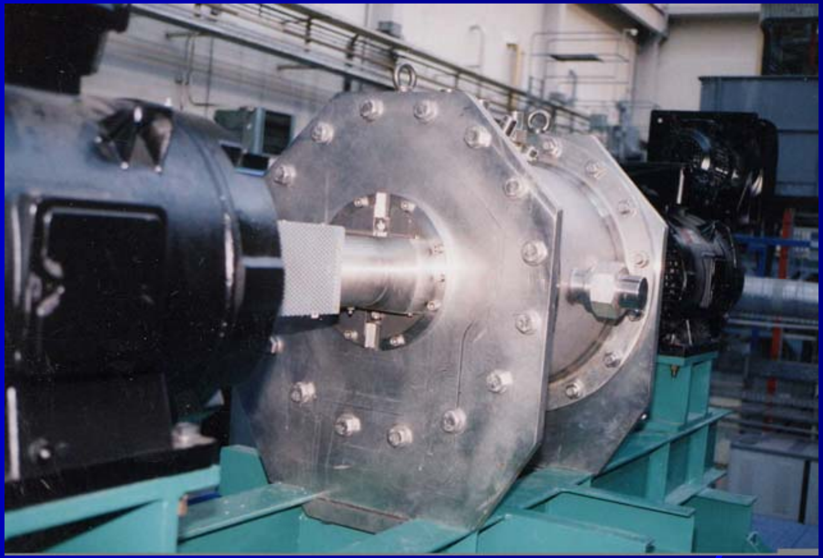


DYNAMO

Second generation dynamos



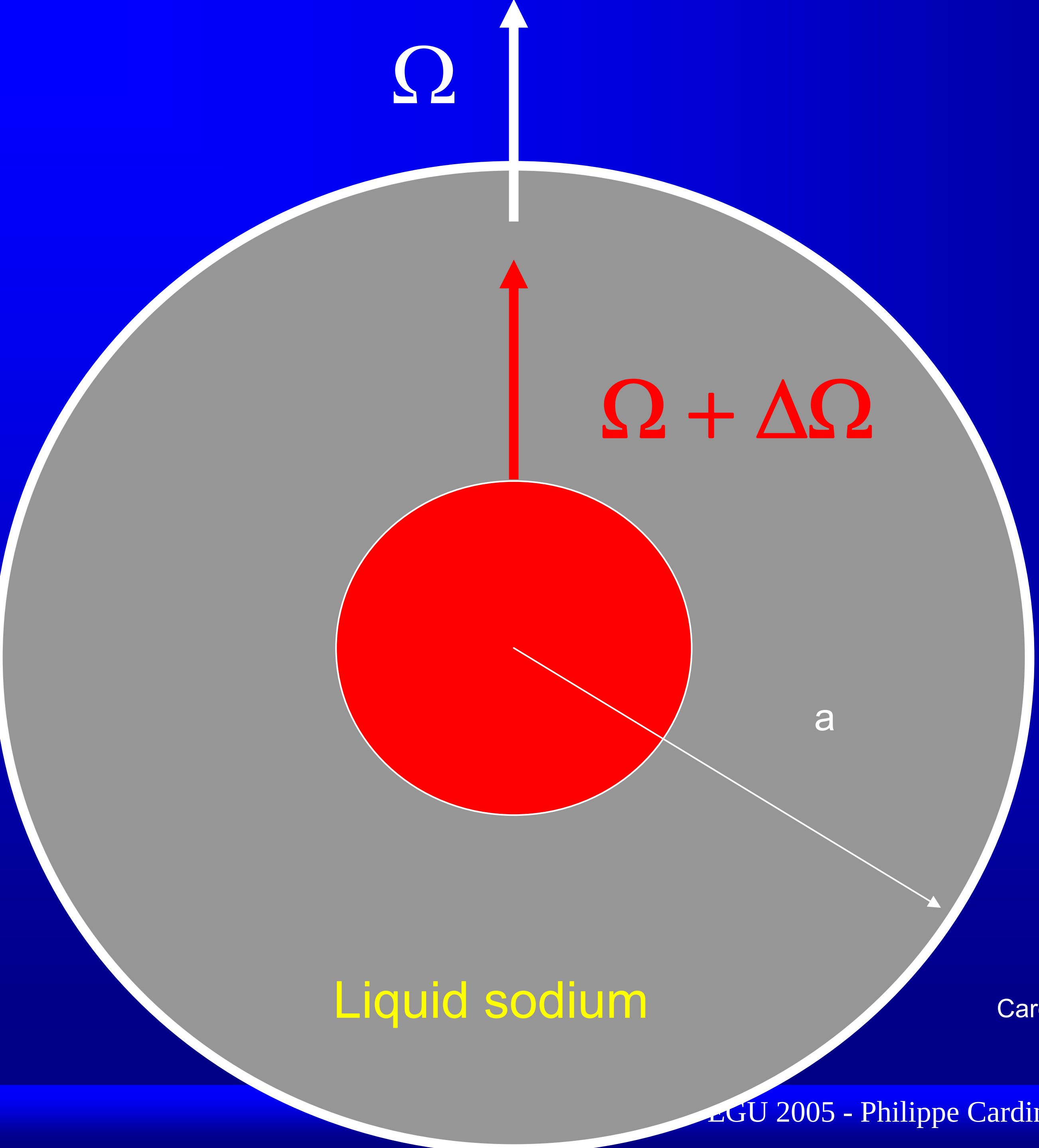
Maryland University, (1998-)



VKS, Cadarache, (2000-)

No dynamo

A planetary dynamo ?

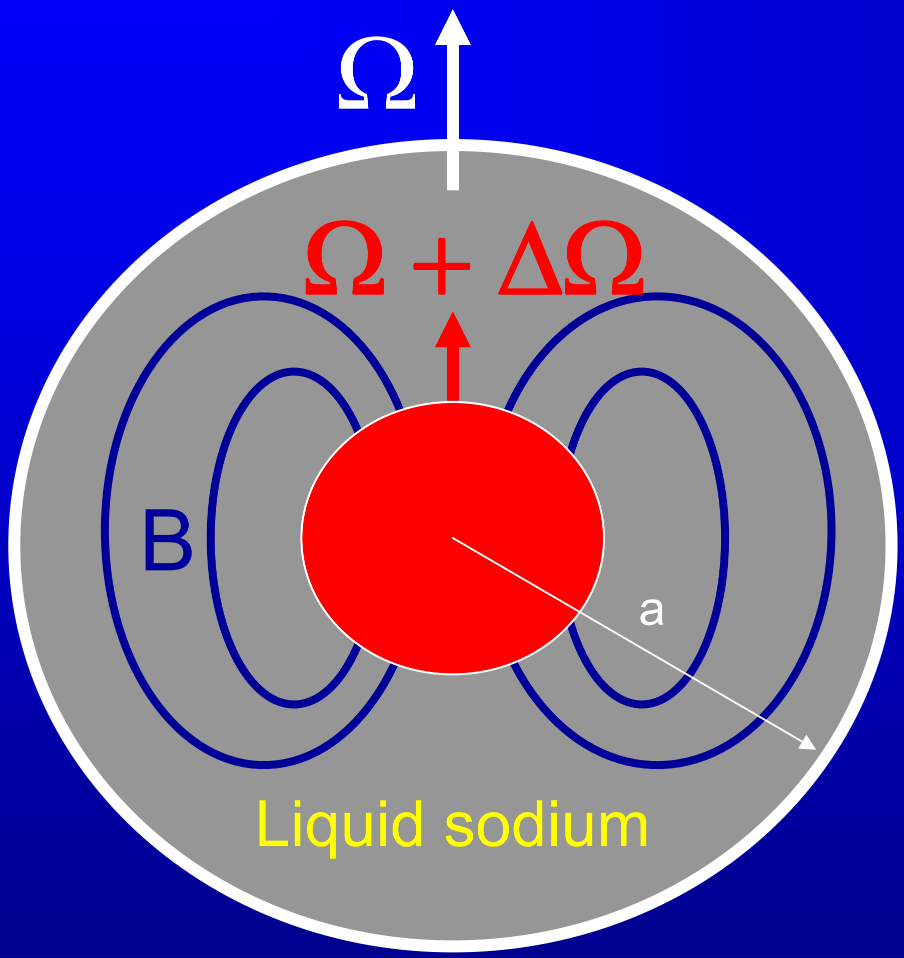


a = 1 m ?
Ω = 450 rpm ?
ΔΩ = 150 rpm ?
P = 600 KW ?

Dynamo ?
B= 0.3 T

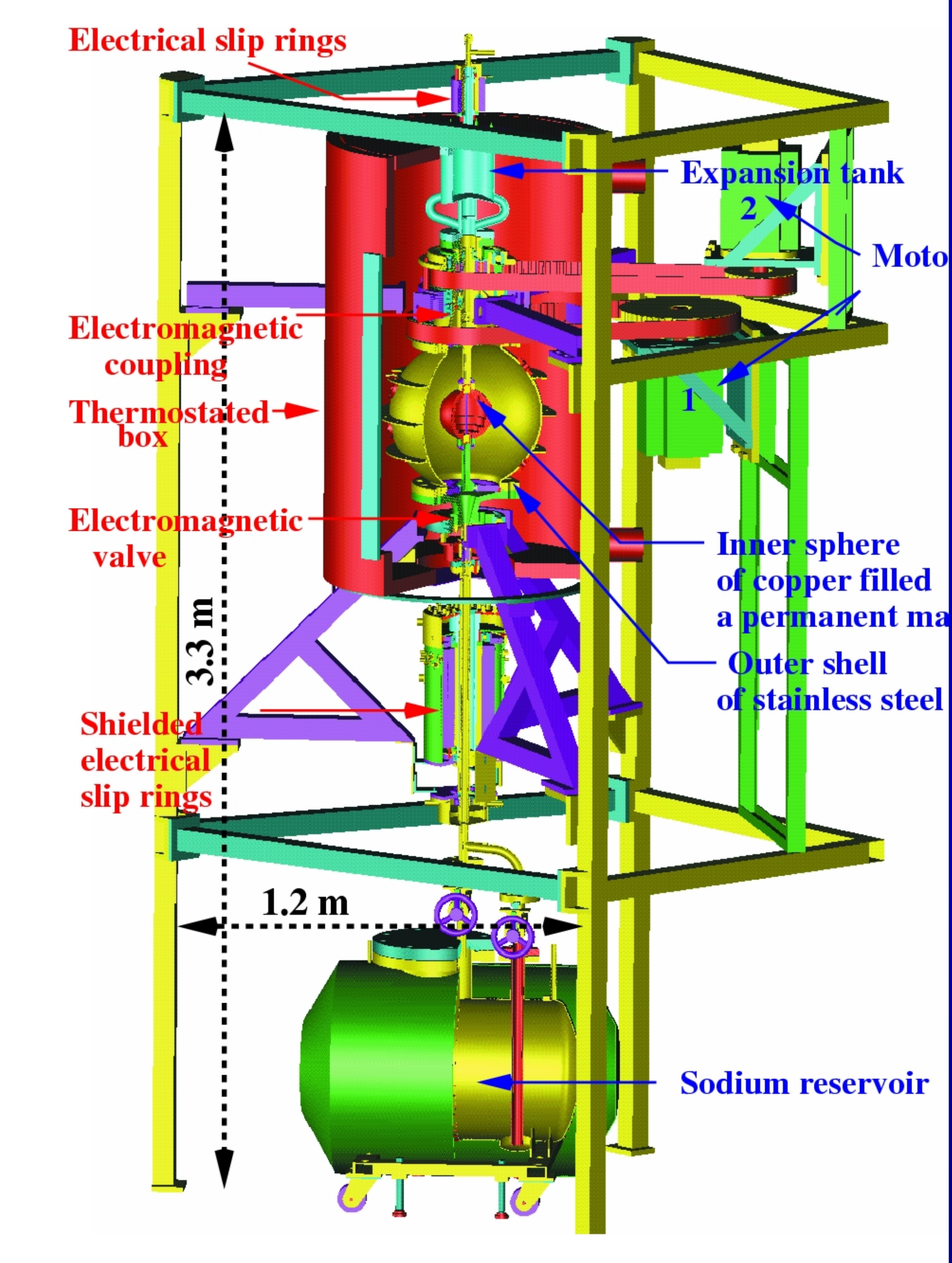
Cardin, Brito, Jault, Nataf et Masson, 2002

DTS : a 1/5 prototype ?



a = 0.21 m
Ω = 2000 rpm
ΔΩ = ±2000 rpm
P = 22 KW

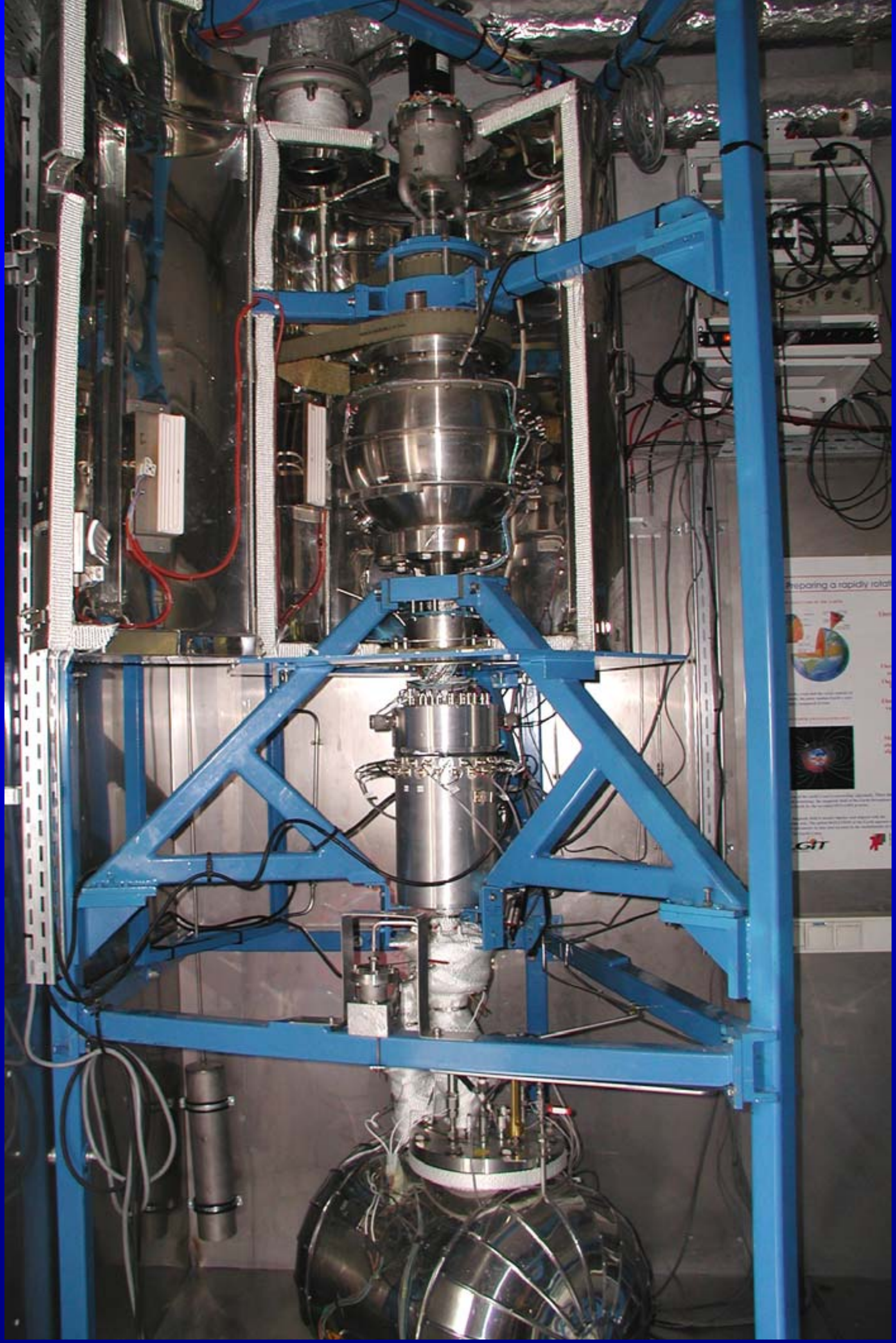
B= 0.1 T



DTS : the experiment

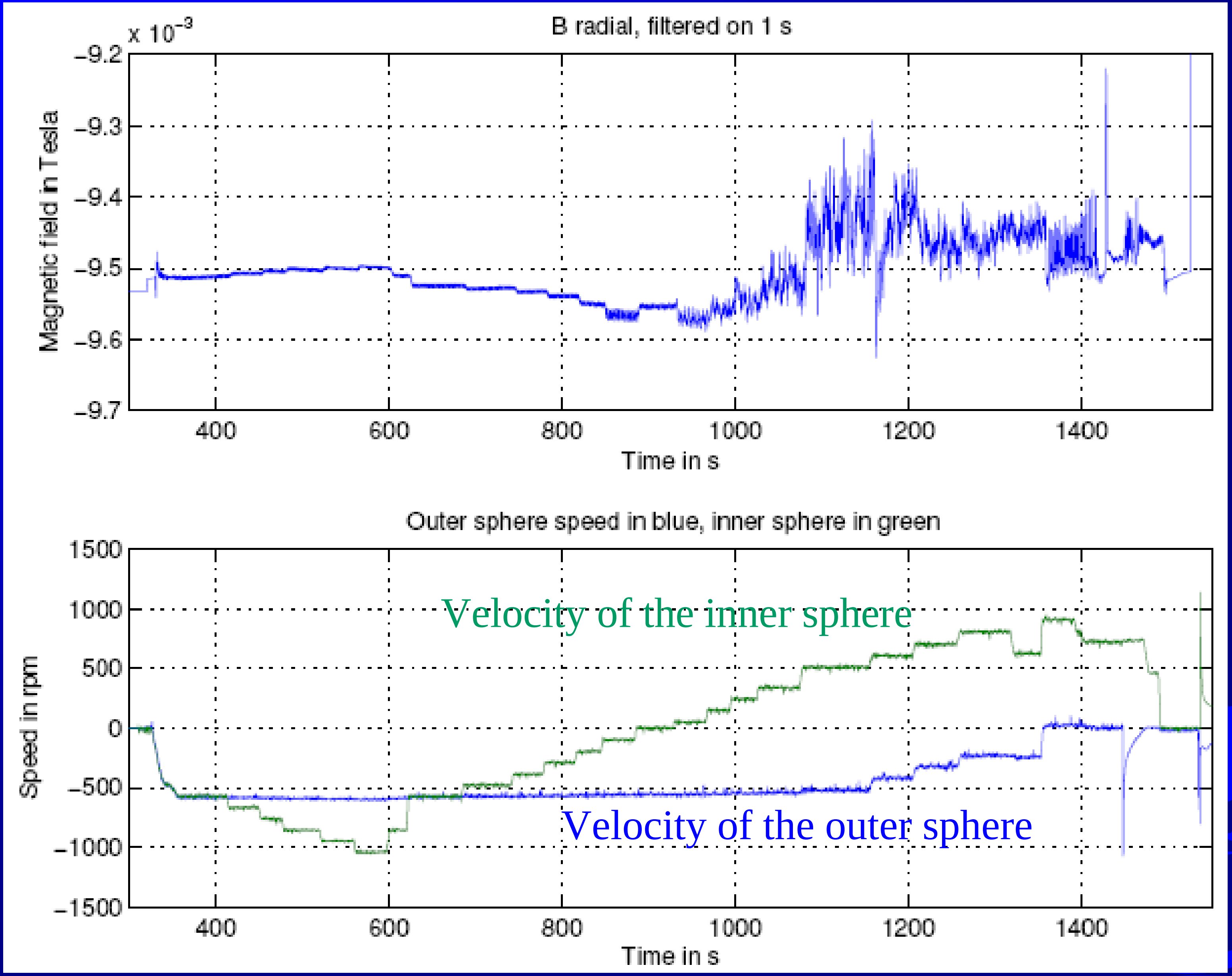
The sodium lab

24 m^2



DTS

Induced magnetic field in DTS (run of 17/03/05)



Magnetic field of the Earth:

The end of a mystery?