Coupling Magnetosphere and Dynamo[A]:

Mercury's Feedback Dynamo

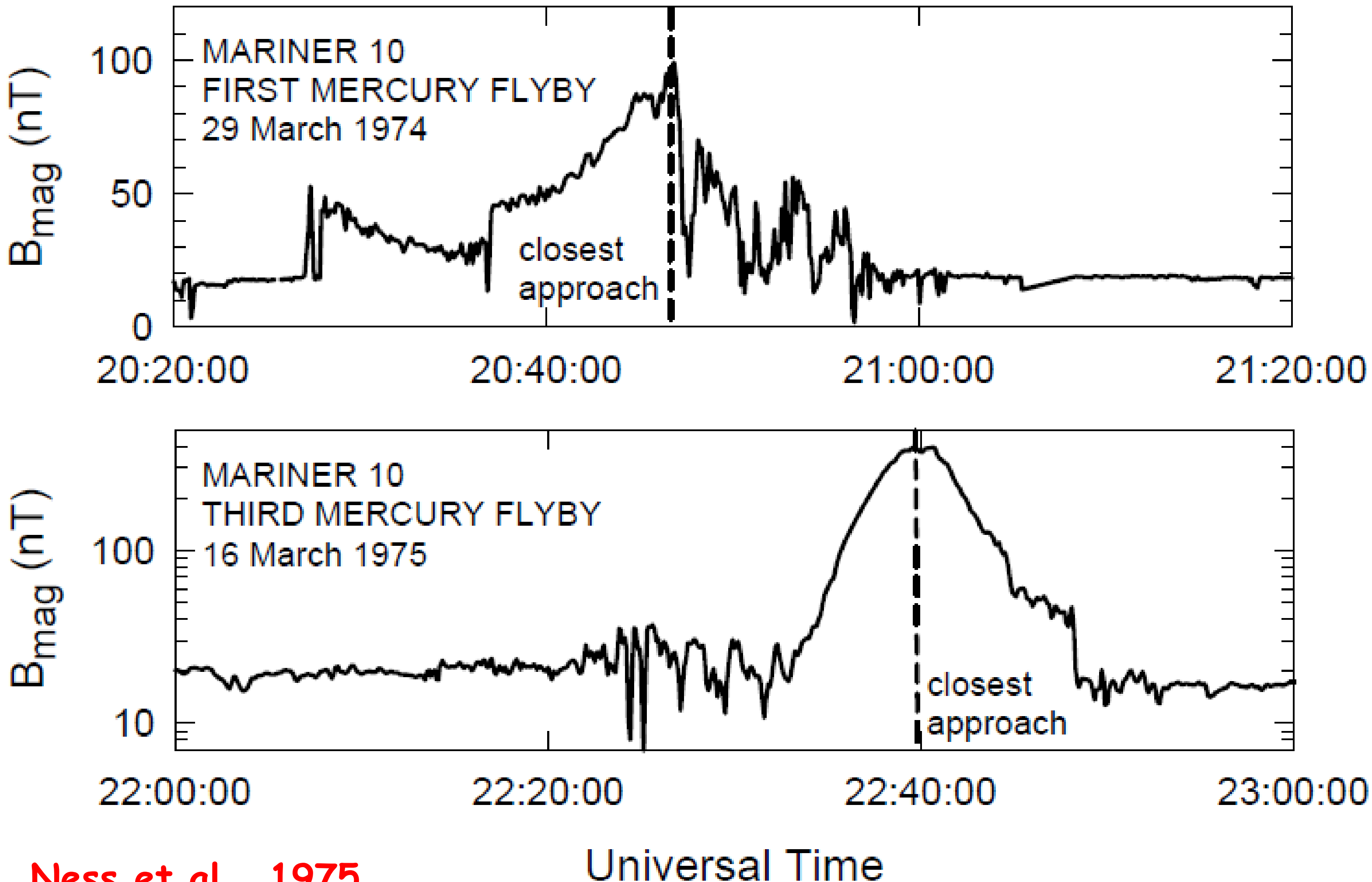
Daniel Heyner[1], Dieter Schmitt[2] and <u>Karl-Heinz Glassmeier</u>[1,2]

1: Technical University of Braunschweig
2: Max Planck Institute for Solar System Research

A: The Anti-Reconnection Process

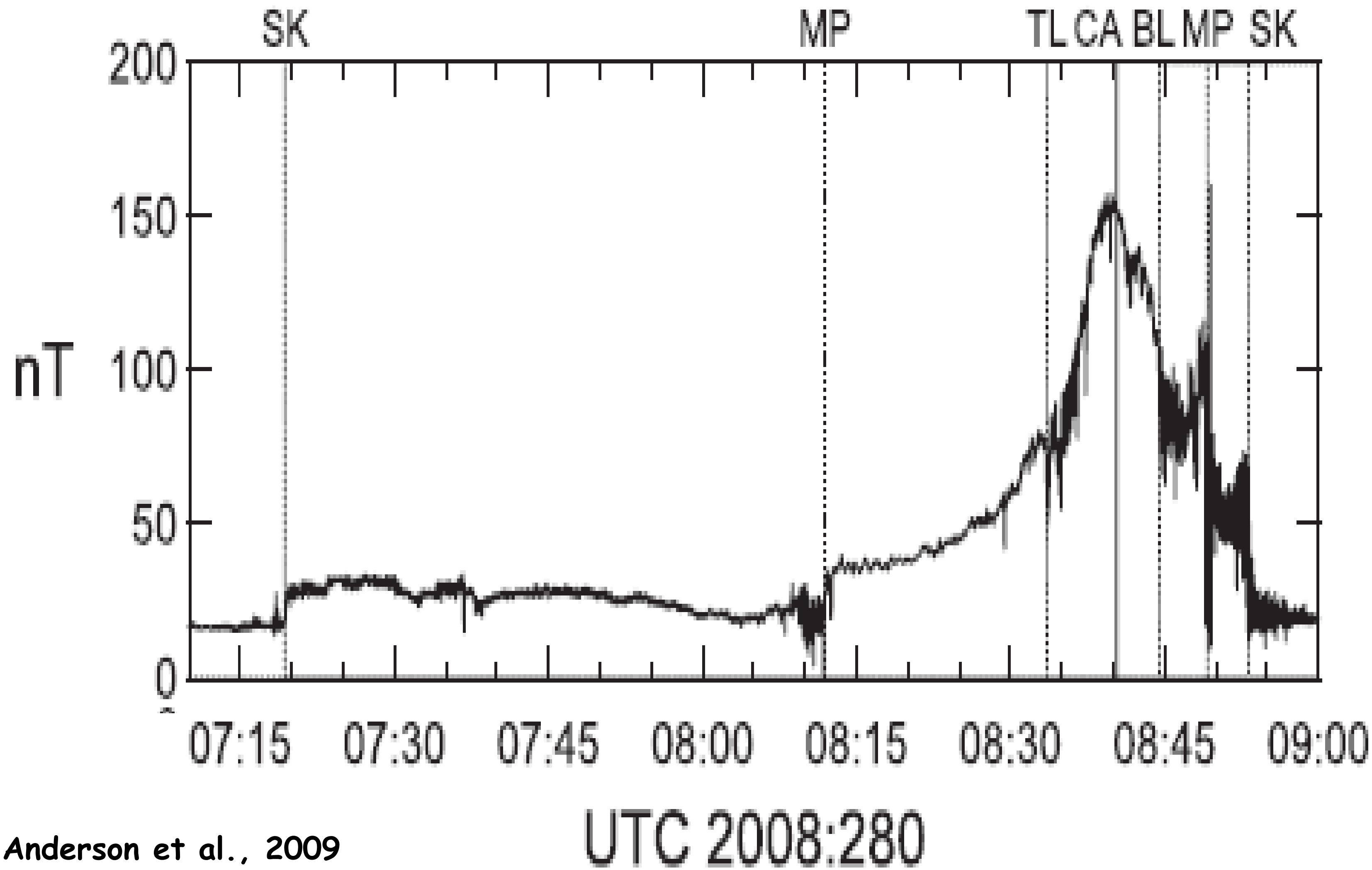
IGEP TU Braunschweig
Institut für Geophysik und extraterrestrische Physik

The Discovery of the Magnet Field of Planet Mercury



Ness et al., 1975

Messenger at Mercury



Anderson et al., 2009

Comparing Earth and Mercury

Scaling a terrestrial standard dynamo model would predict a surface field of about 11,000 nT.

Observed are about 280 nT!

Why is the field so weak?

Planetary Dynamos

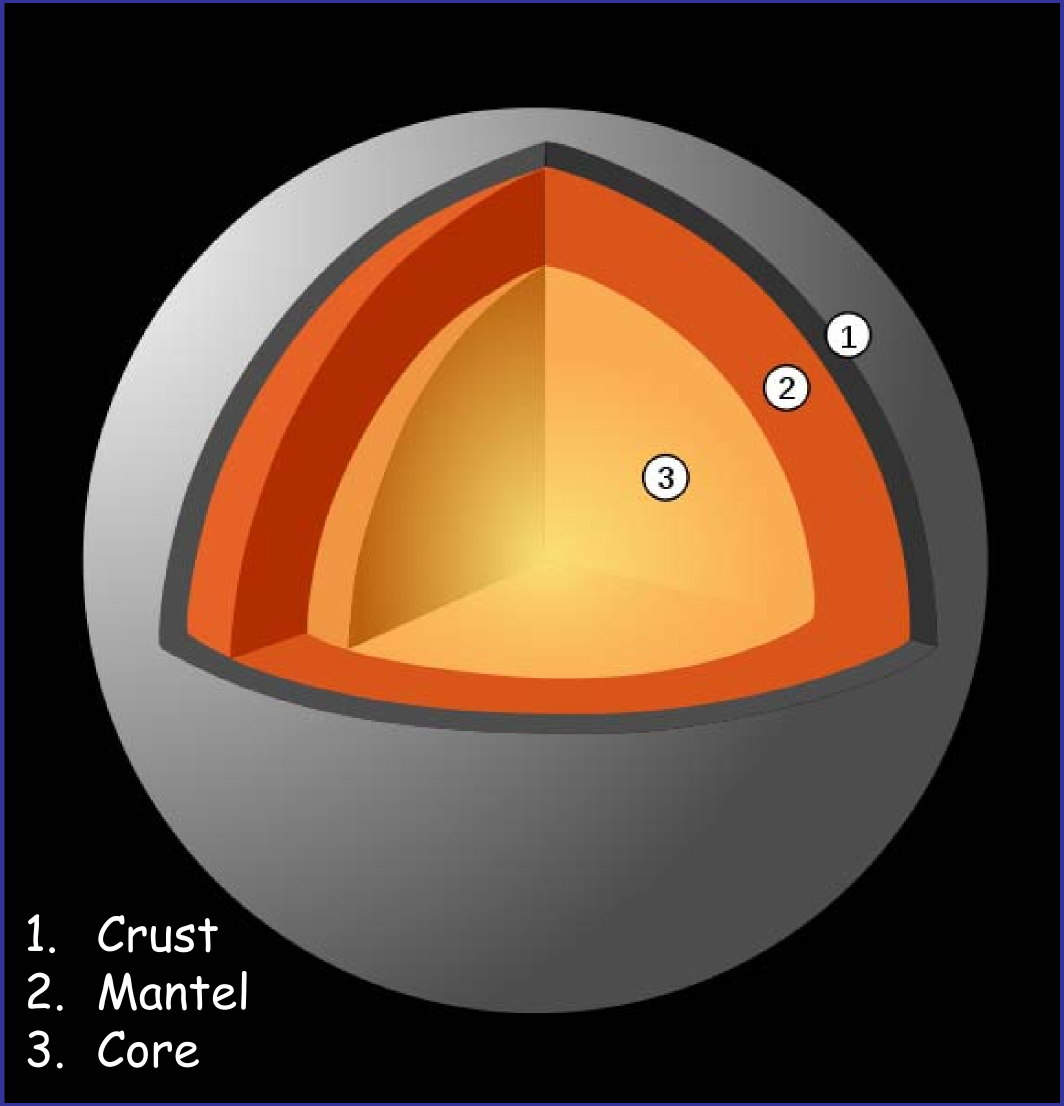
$$\frac{\partial \vec{B}}{\partial t} = \nabla \times \vec{U} \times \vec{B} + \frac{1}{\mu_0 \sigma} \Delta \vec{B}$$

Growth Excitation Diffusion

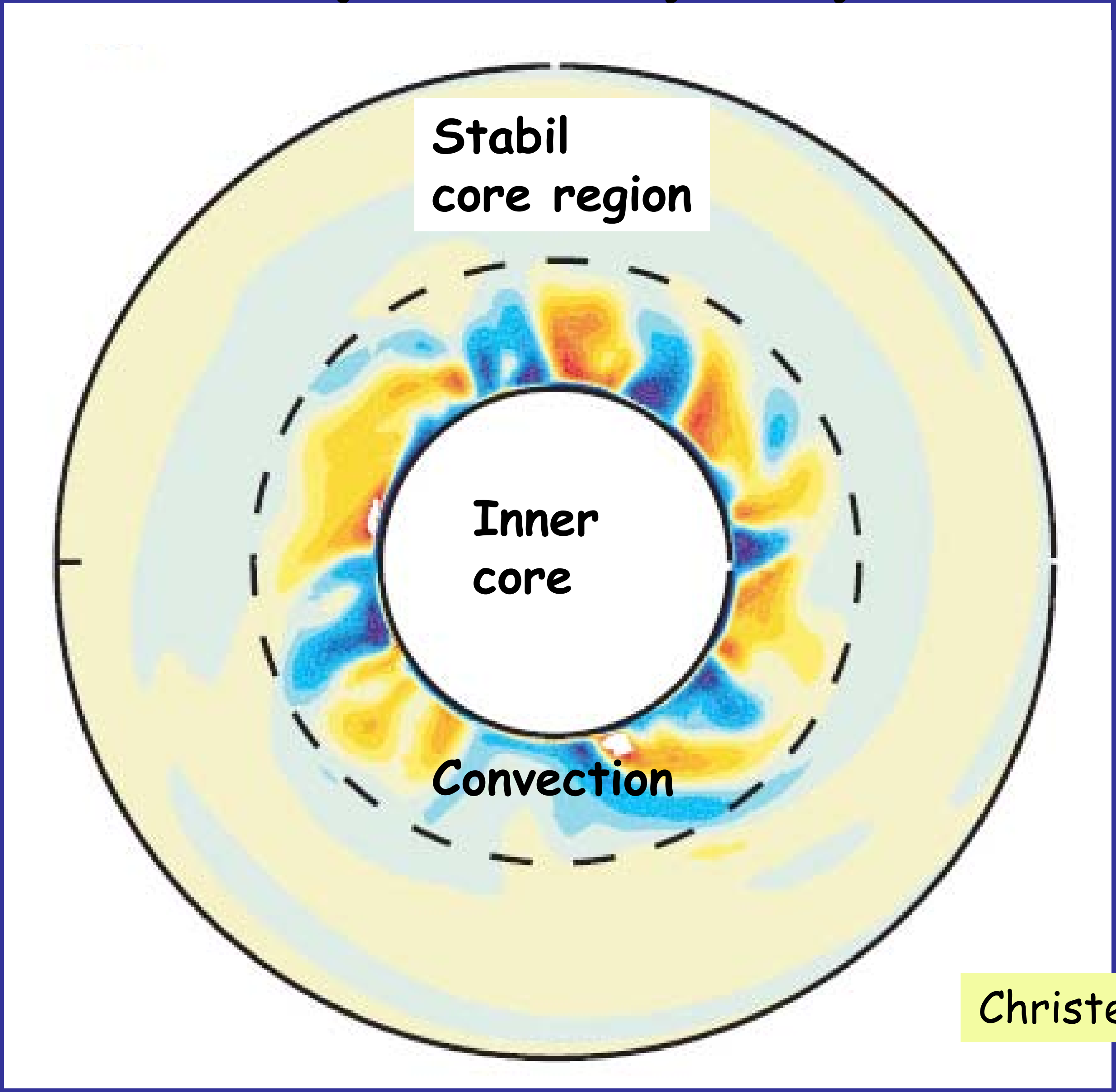
For the dynamo process we need an electrically conducting, heavily convecting planetary core

The Hermean Planetary Interior

Mercury probably has a very large core with a radius of about 1800 km

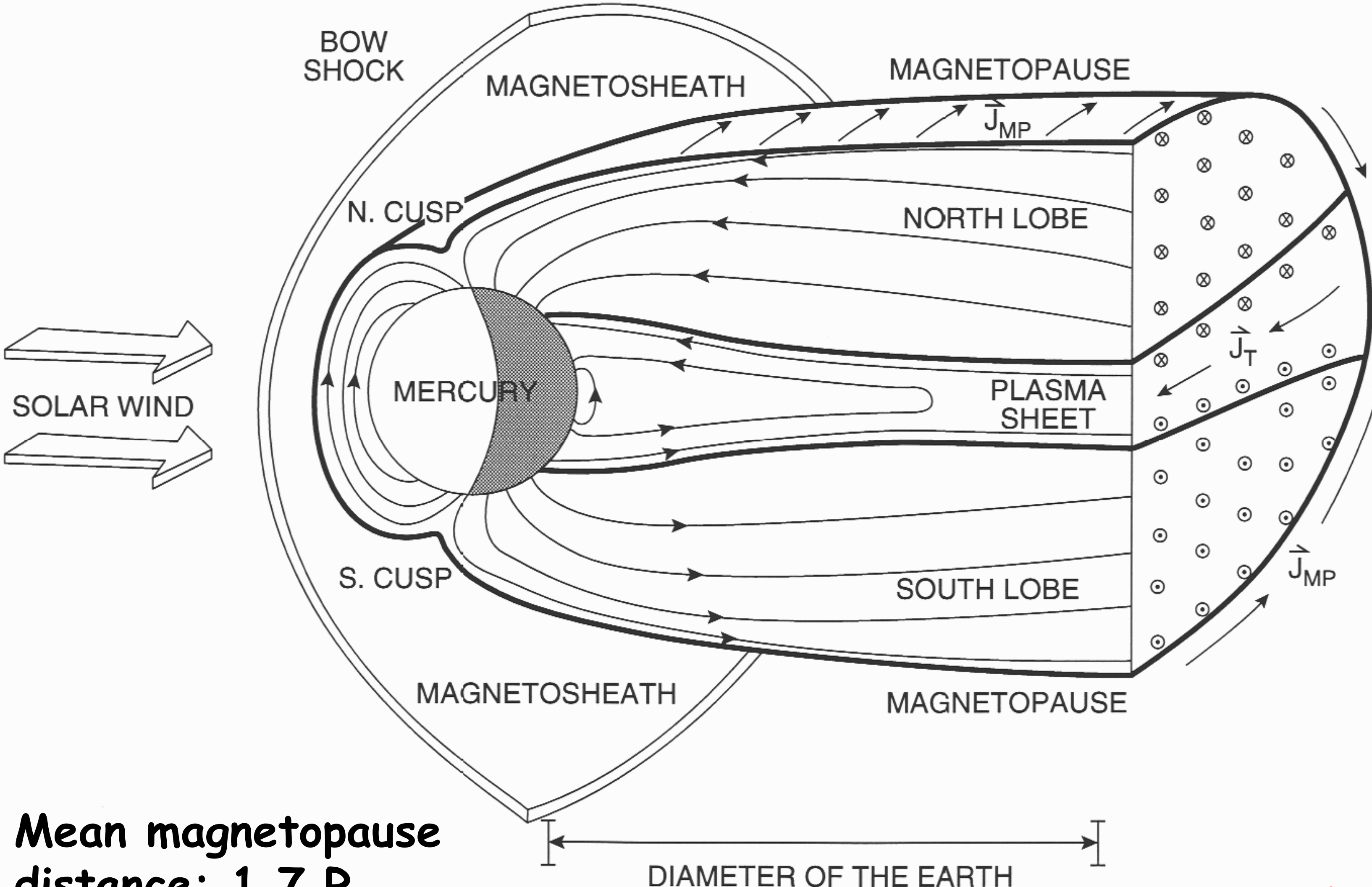


Mercury's *Deep Dynamo*



Christensen, 2006

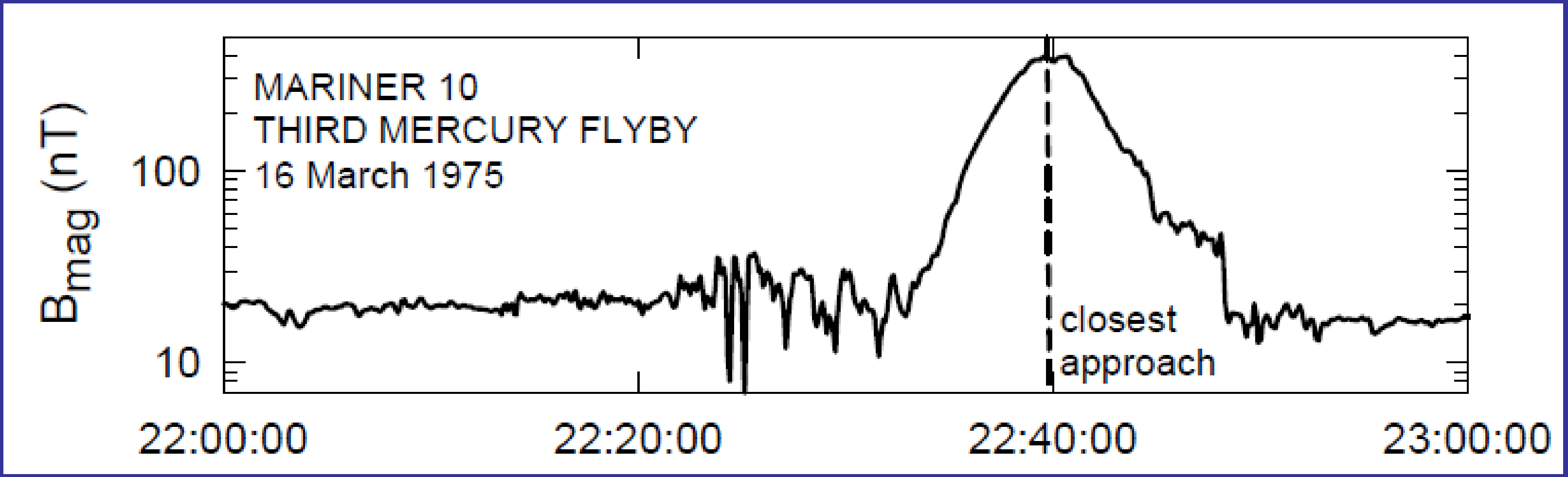
Mercury's Magnetosphere



Mean magnetopause distance: 1.7 R_M

Courtesy J. Slavin

Magnetopause Curents



$$\nabla \times \vec{B} = \mu_0 \vec{j}$$

$$j \approx \frac{\delta B}{\mu_0 L}$$

$$\delta B \approx 30\, nT$$

$$L \approx 500\, km$$

$$j = 5 \cdot 10^{-8}\ Am^{-2}$$

$$I = 100{,}000\ A$$

The Magnetic Field of Magnetopause Currents

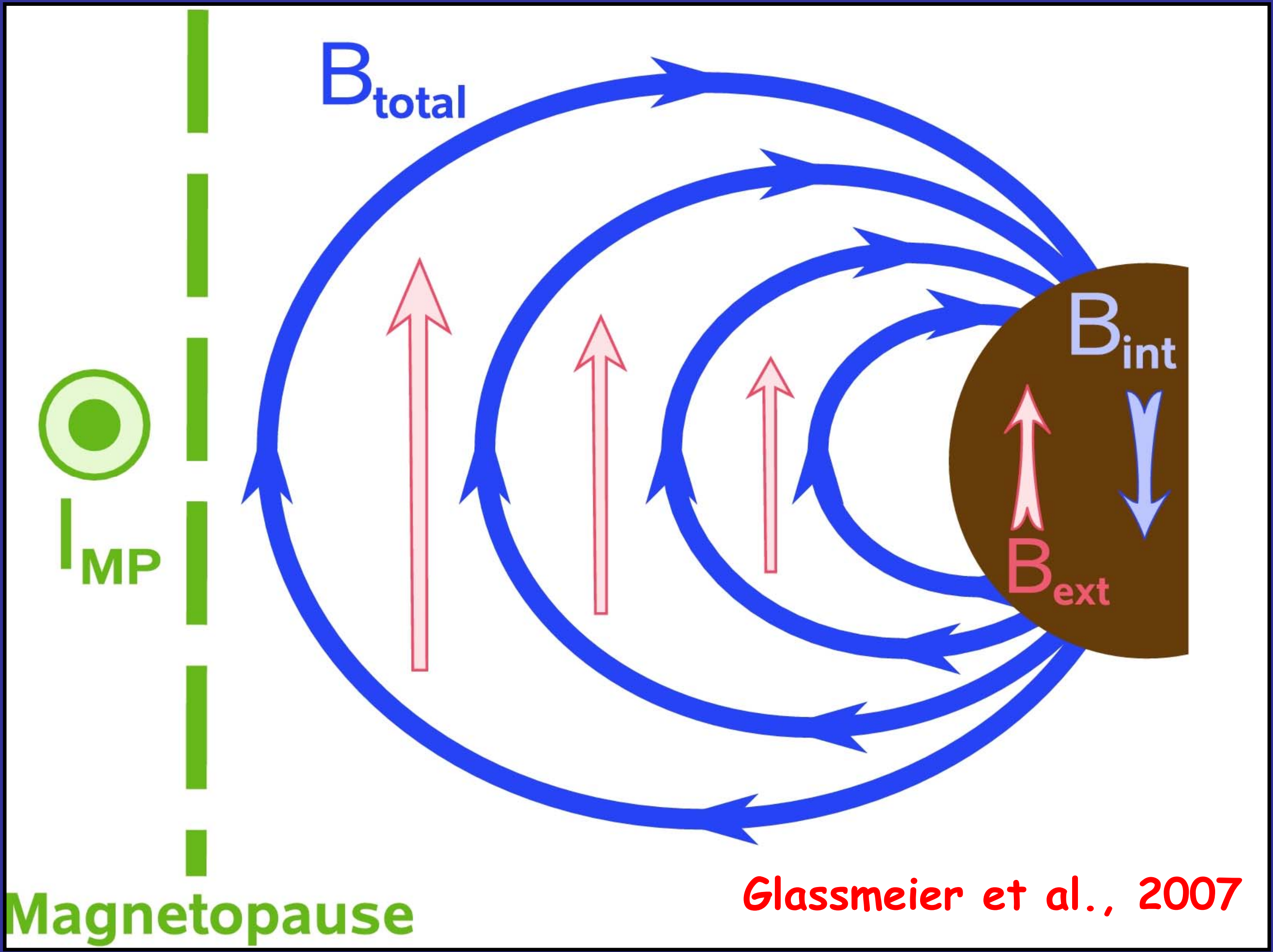
Terrestrial surface:

10 nT vs. 31,000 nT

Hermean surface:

70 nT vs. 280 nT

A Dynamo, Embedded in a Self-Excited, Ambient Magnetic Field



Dynamo Action and Ambient Magnetic Field

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

This additional terms helps to work against diffusion

$$\vec{B} = \vec{B}_{CF} + \vec{B}_{dyn}$$

$$\frac{\partial \vec{B}_{dyn}}{\partial t} = \nabla \times (\vec{u} \times \vec{B}_{CF}) + \nabla \times (\vec{u} \times \vec{B}_{dyn}) + \eta \, \Delta \vec{B}_{dyn}$$

A Feedback Dynamo Model

$$\frac{\partial \vec{B}_{dyn}}{\partial t} = \nabla \times (\vec{u} \times \vec{B}_{CF}) + \nabla \times (\vec{u} \times \vec{B}_{dyn}) + \eta \, \Delta \vec{B}_{dyn}$$

Spherical $\alpha - \Omega$ *dynamo region and axial symmetry*

$$\frac{\partial B_\phi}{\partial t} - \eta \left(\Delta - \frac{1}{r^2 \sin^2 \Theta} \right) B_\phi = \Omega(r,t) \cdot (B_r + B_{CF} \cos \Theta)$$

$$\frac{\partial A_\phi}{\partial t} - \eta \left(\Delta - \frac{1}{r^2 \sin^2 \Theta} \right) A_\phi = \alpha(r,t) \cdot B_\phi$$

$$B_r = \frac{1}{r \sin \Theta} \frac{\partial}{\partial \Theta} (A_\phi \sin \Theta)$$

Levy, 1979

A Simple Feedback Function

$$B_{dyn} \Rightarrow R_{MP} \Rightarrow I_{CF} \Rightarrow B_{CF}$$

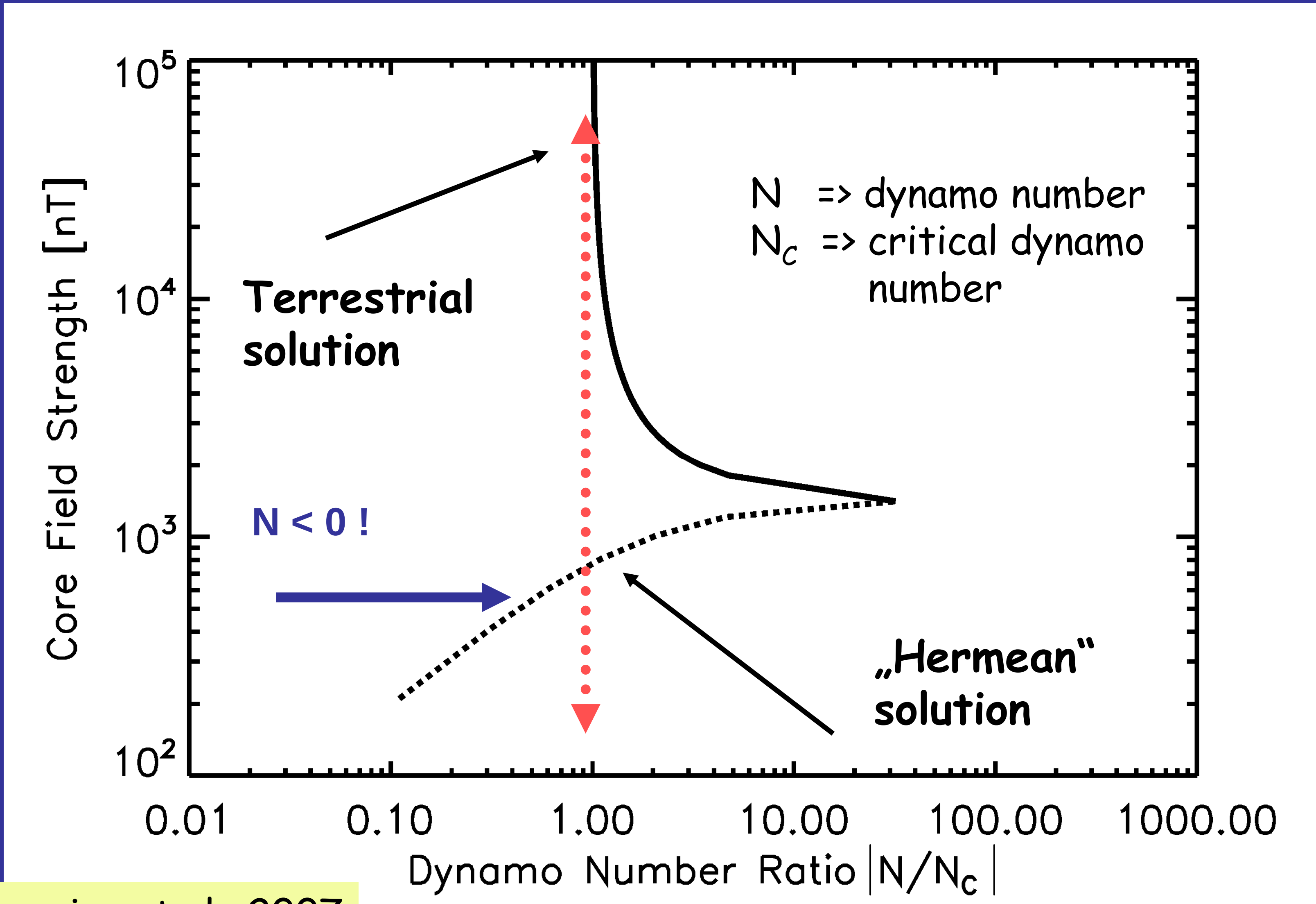
Chapman - Ferraro Current =>

Ring current in the equatorial plane

$$B_{CF} = f(B_{dyn}) = \ldots\ldots\ldots\ldots$$

Glassmeier et al., 2007

A Stationary Feedback Dynamo Solution



Glassmeier et al., 2007

Further Aspects to be Studied

Stability of the stationary solutions

Improved feedback function

Temporal evolution into stationary solution

Full dynamo solution

Early solar system conditions

Stability of the Solutions

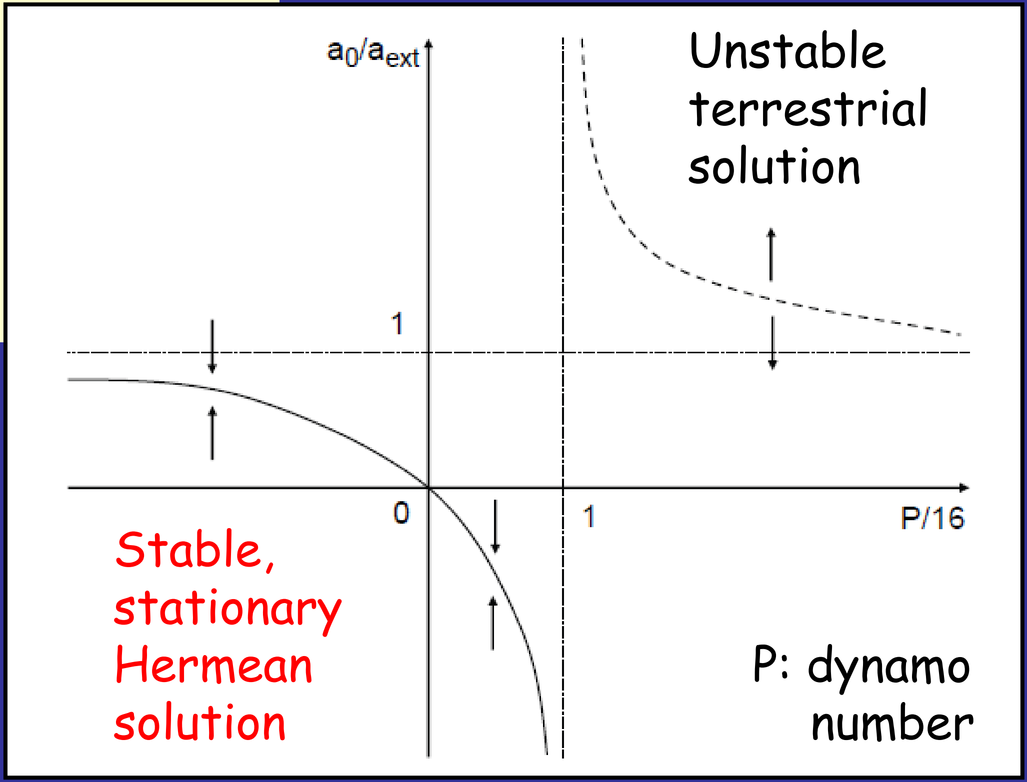
A simplied Cartesian Model

$$\dot{A} = A'' + \cos x \, B$$

$$\dot{B} = B'' + P \sin x \,(A' - a_{ext} \cos x)$$

$$A(x,t) \approx a(t) \sin x$$

$$B(x,t) \approx b(t) \sin 2x$$



Heyner et al., 2010b
Schmitt & Schüssler, 1989

Improved Feedback Function

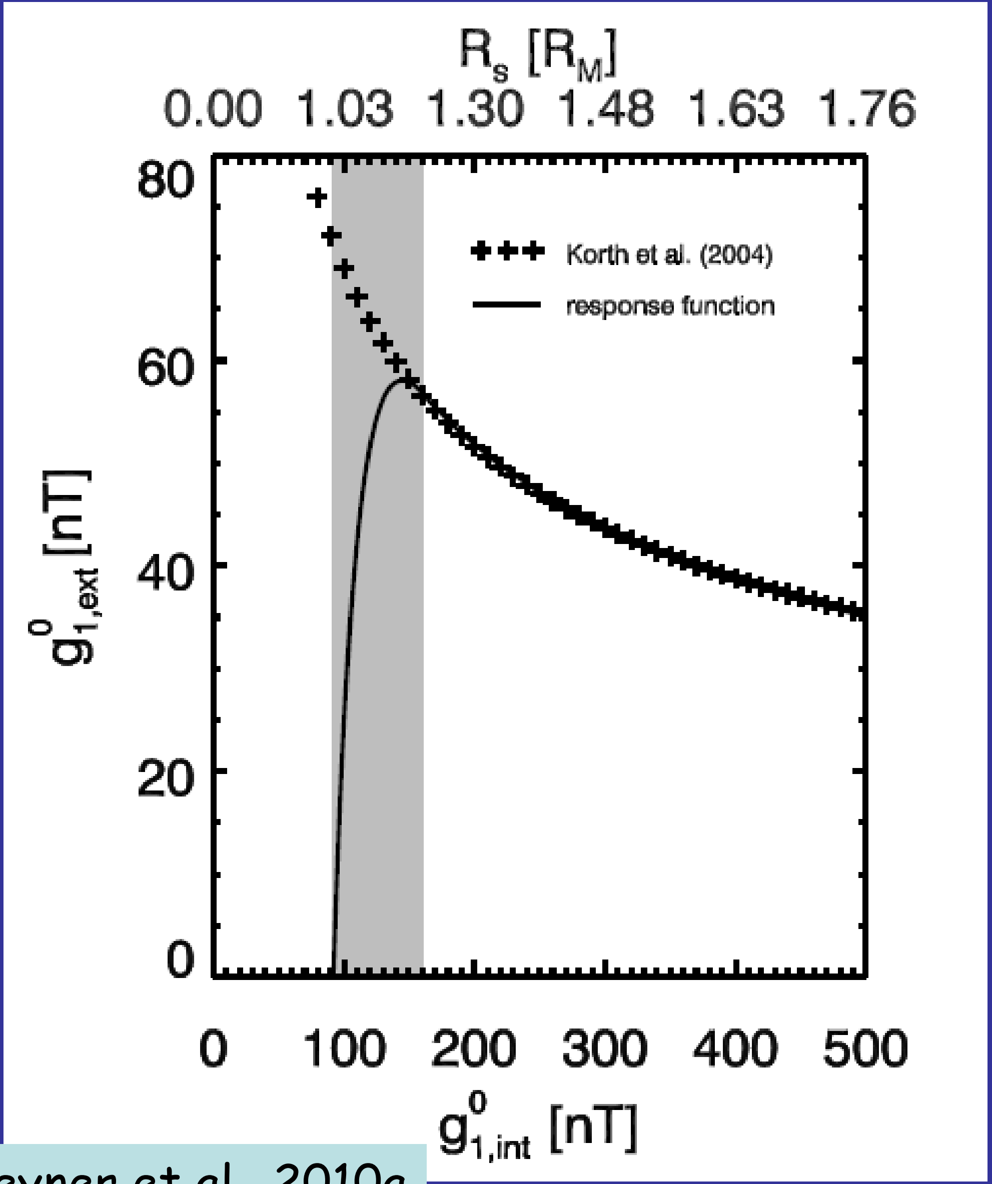
$$\Psi_{ext}(r,\theta,\varphi) = \sum_{n=1}^{\infty} G_n \cdot f(\theta,\varphi) \cdot r^n$$

==>

$$B_{ext} \approx G_1 + G_2 \cdot r + G_3 \cdot r^2 +$$

with $G_1 \propto \sqrt{\mu_0 \, p_{SW}}$

A Hermean Feedback Function



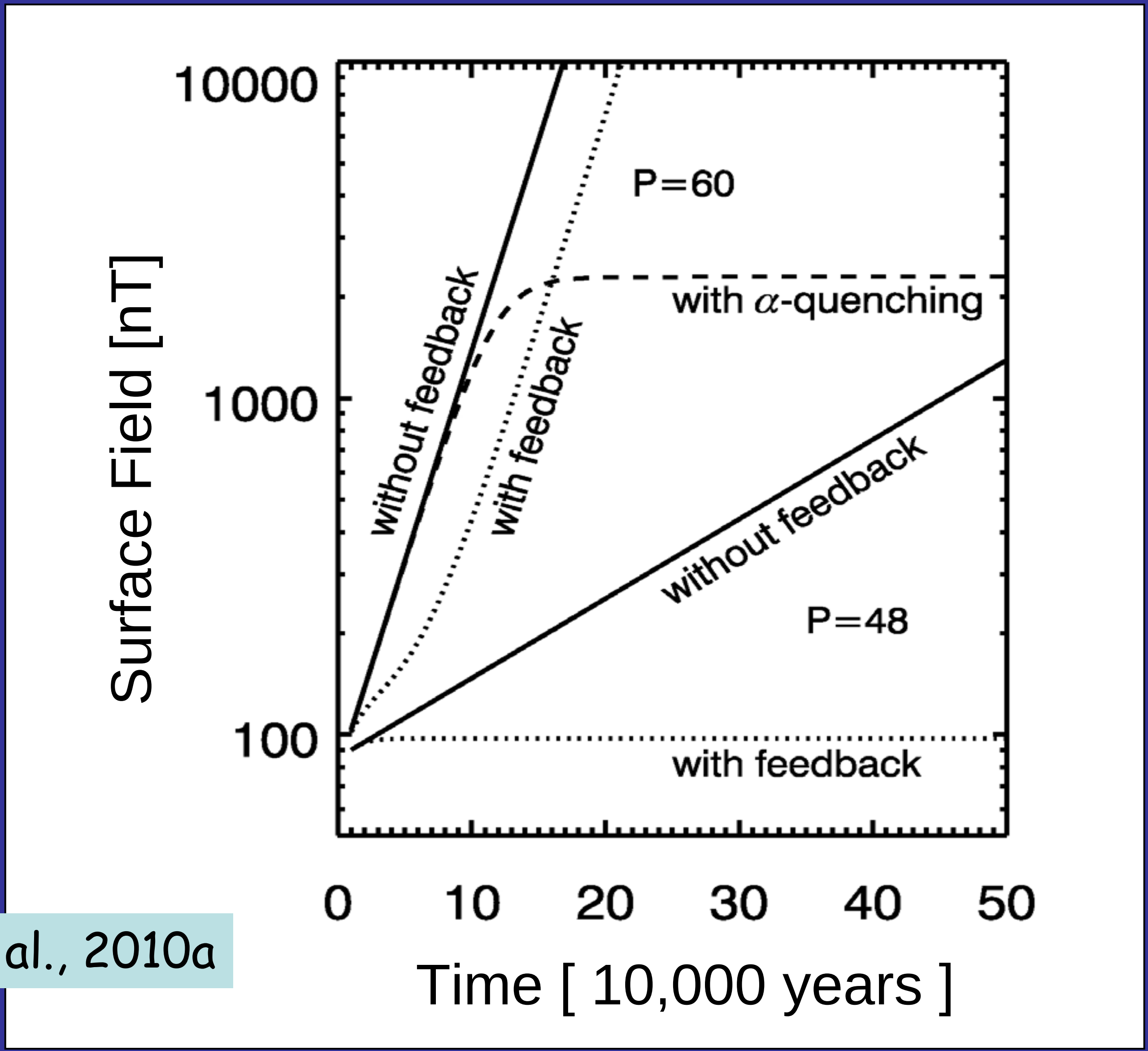
Heyner et al., 2010a

Modified Tsyganenko model for Hermean conditions provides a suitable model for the feedback function:

$$g^0_{1,ext} \approx 0.2 \cdot (\mu_0 p_{sw})^{1/2} + 0.2 \cdot (\mu_0 p_{sw})^{2/3} \cdot (g^0_{1,\mathrm{int}})^{-1/3}$$

at the surface of Mercury

Temporal Evolution of Feedback Dynamo



Heyner et al., 2010a

A Noteworthy Result

There exists a range of dynamo numbers, where the feedback causes the dynamo field to be locked at a value comparable to

$$\sqrt{\mu_0 \, p_{SW}}$$

Full Dynamo Simulations

We started to work on this…

Early Solar System Considerations

$$\text{Wood et al. (2002):}$$

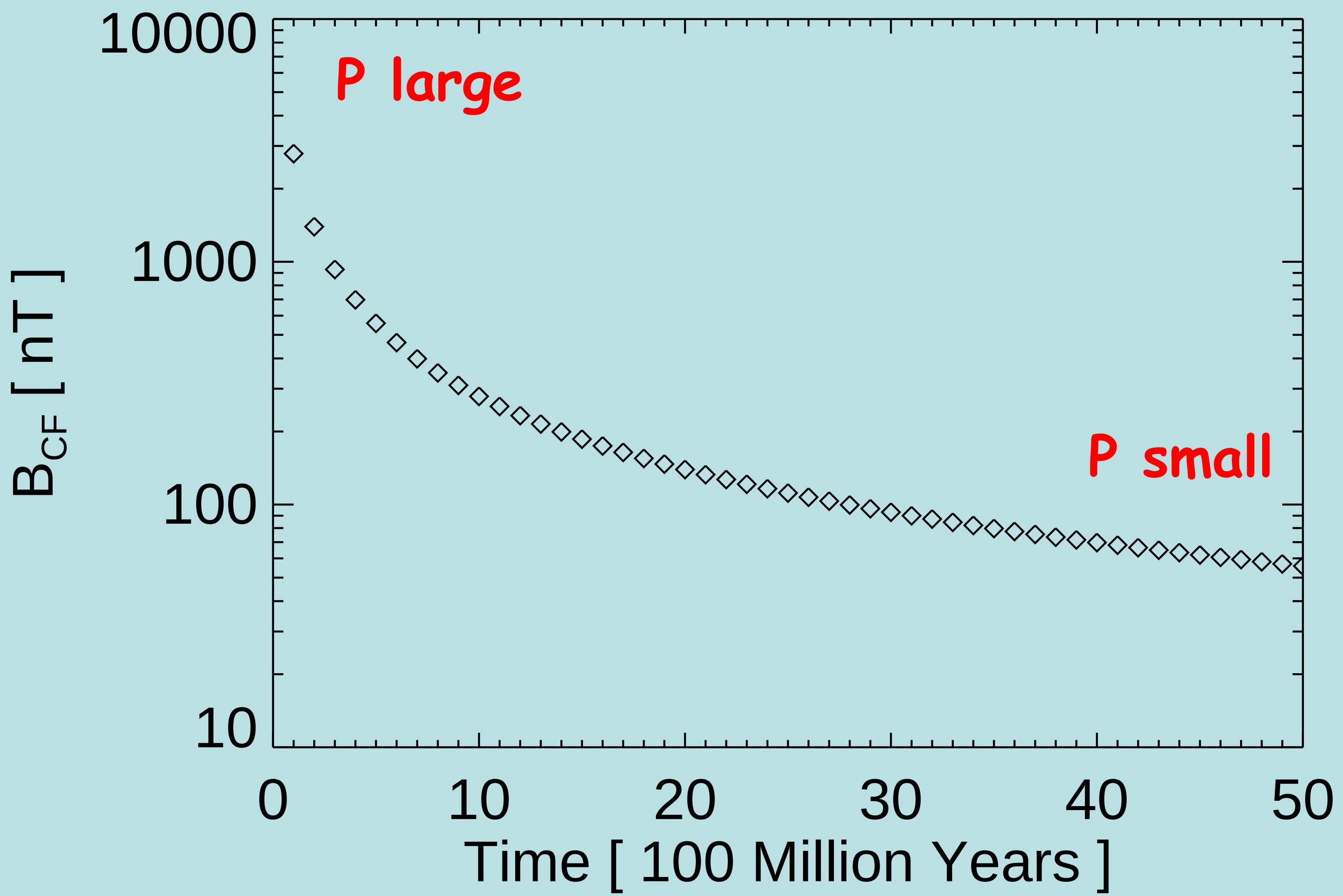
$$\dot{M} = 2.5 \cdot 10^{43} \cdot t^{-2}$$

$$n = \frac{\dot{M}}{m_P \cdot v \cdot 4\pi \cdot r^2}$$

$$p_{SW} = \frac{M \cdot v}{4\pi \cdot r^2} \quad \Rightarrow \quad B_{CF} \approx 2 \cdot 10^{10} \cdot t^{-1}$$

Field, in which a Hermean dynamo is/was embedded

External Field Evolution



Summary

Mercury: Could be a planet with a dynamo embedded in a self-excited ambient field

During the initial temporal evolution dynamo can be locked-in for small dynamo numbers at field values determined by solar wind dynamic pressure

Early solar system: embedding field much larger and lock-in possible also at large dynamo numbers !!!!