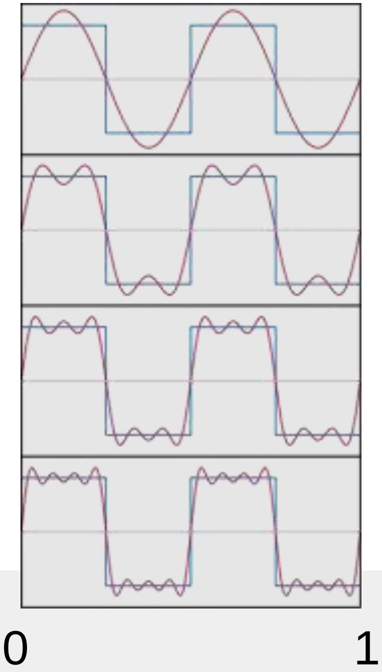
# Introduction to Geomagnetism

- The magnetic record of Earth's history that is frozen into crustal rocks has provided, perhaps, the most important geophysical evidence of past and on-going plate-tectonic processes.
- The nearly static magnetic field that is our strong dipolar geomagnetic field has been most interesting to geologists and geodynamicists.
- The generation of the field is now the most interesting scientific question for many mathematically oriented geophysicists.
- Why and how we have our field is informative about the processes at work deep within our Earth.

# Harmonic functions -- I

We can resolve any function over the line interval [0, 1] in terms of coefficients of a ***Fourier Series:***

$$\frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(nx) + b_n \sin(nx)]$$




All $a_n = 0$; $b_2 = 1$

Add $b_4 = 1/4$

Add $b_8 = 1/8$

Add $b_{16} = 1/16$

We can build up our square-wave function coefficient by coefficient. We can construct any function on the interval by adding up the Fourier components scaled by the appropriate coefficient.

# Harmonic functions -- II

We resolve the magnetostatic potential at any place over the nearly spherical Earth in terms of coefficients $g_l^m$ and $h_l^m$ of an expansion in ***Spherical Harmonics:.***

$$V(r,\phi,\theta) = a \sum_{\ell=1}^{L} \sum_{m=0}^{\ell} \left(\frac{a}{r}\right)^{\ell+1} (g_\ell^m \cos m\phi$$

$$P_0^0(\cos\theta) = 1$$

$$P_1^0(\cos\theta) = \cos\theta$$

$$P_1^1(\cos\theta) = -\sin\theta$$

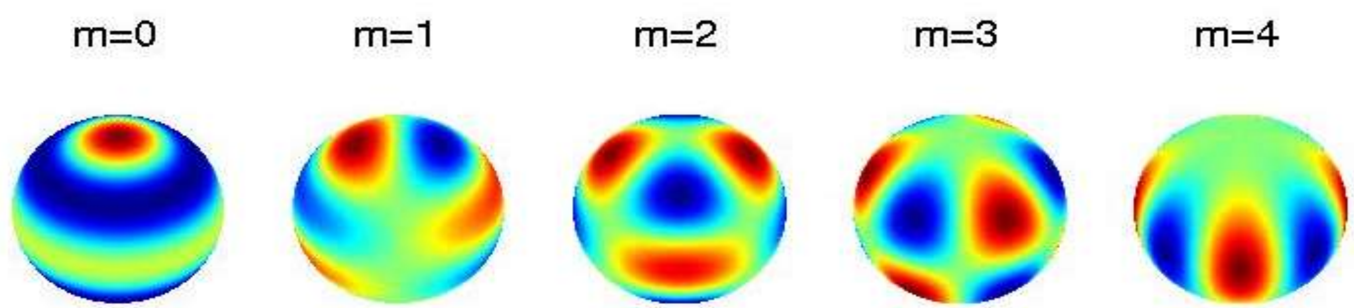
$$P_2^0(\cos\theta) = \tfrac{1}{2}(3\cos^2\theta - 1)$$

$$P_2^1(\cos\theta) = -3\cos\theta\sin\theta$$

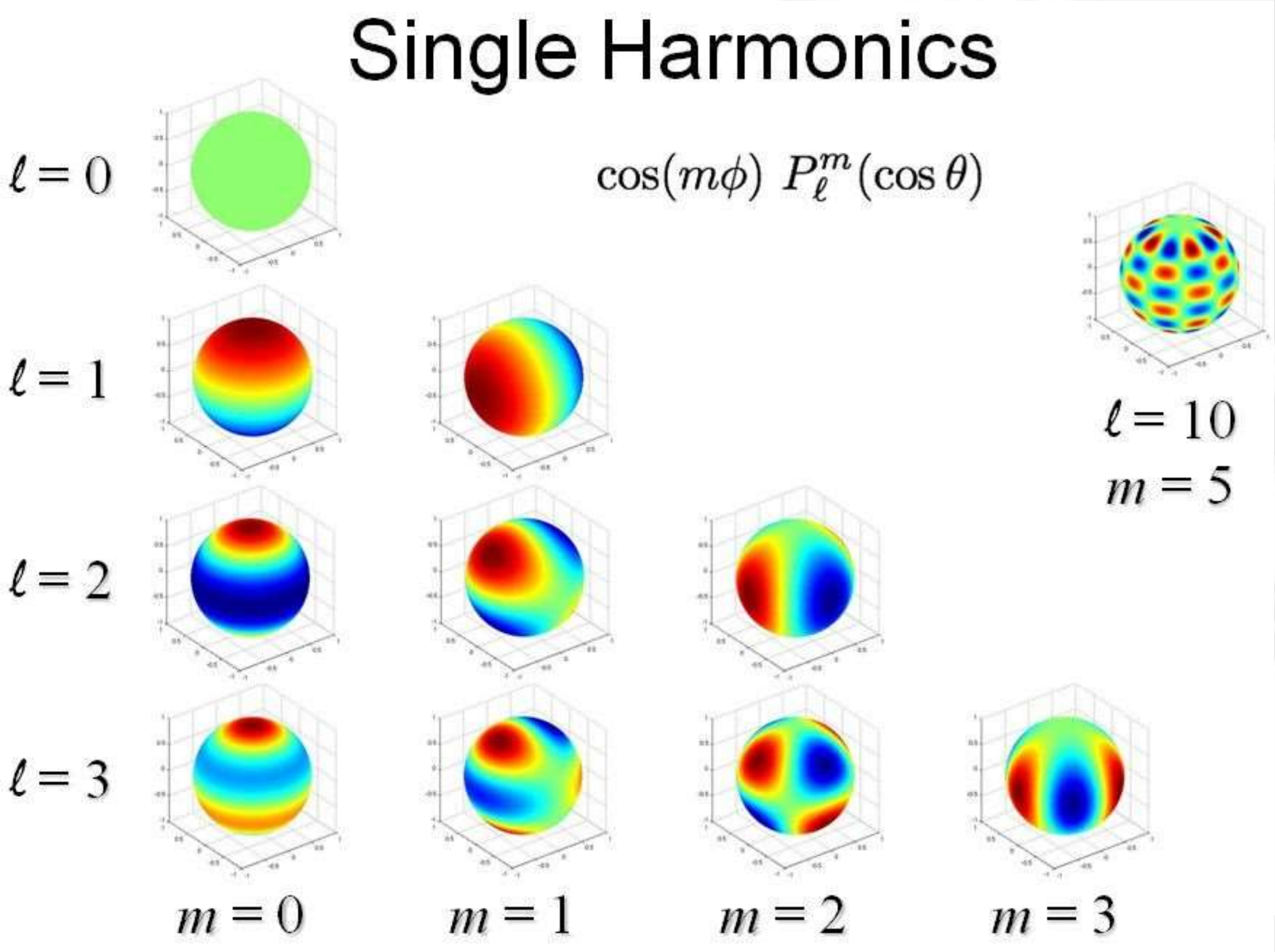
$$P_2^2(\cos\theta) = 3\sin^2\theta$$

$$P_3^0(\cos\theta) = \tfrac{1}{2}(5\cos^3\theta - 3\cos\theta)$$

Example of the forms of the harmonics:
***$g_l^m$=1, $h_l^m$*** =0, for l = 4, m = 0, 1,...4 at radiu



# Harmonic functions -- III



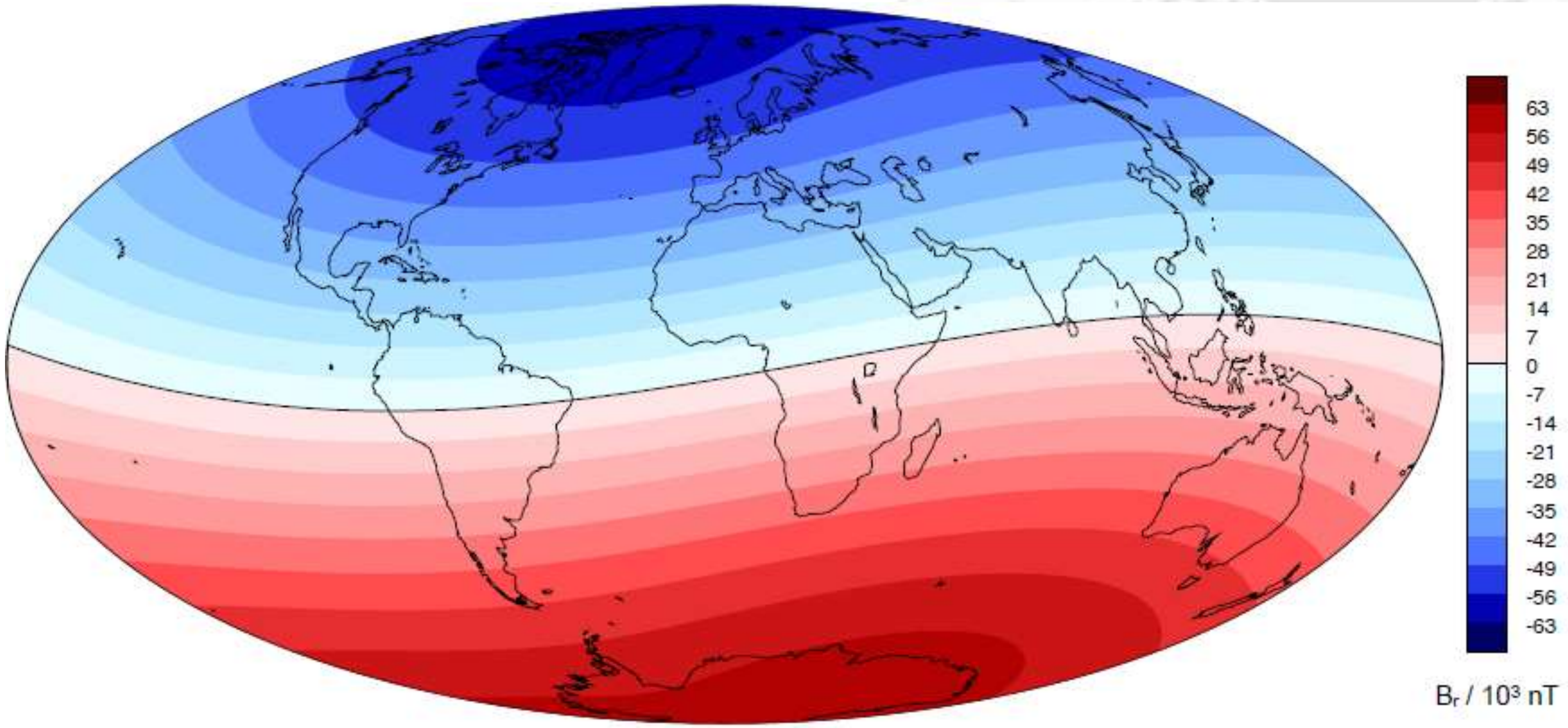
# Mapping the IGRF

Several satellite missions, most recently, the Øersted and Champ missions, have mapped the Earth's geomagnetic field from altitude and then downward continued the measurements to a sphere of average Earth radius.  The spherical harmonic coefficients obtained from these missions construct the IGRF (International Geomagnetic Reference Field) – that field that is taken as the datum field against which temporal and spatial anomalies are measured.

Øersted

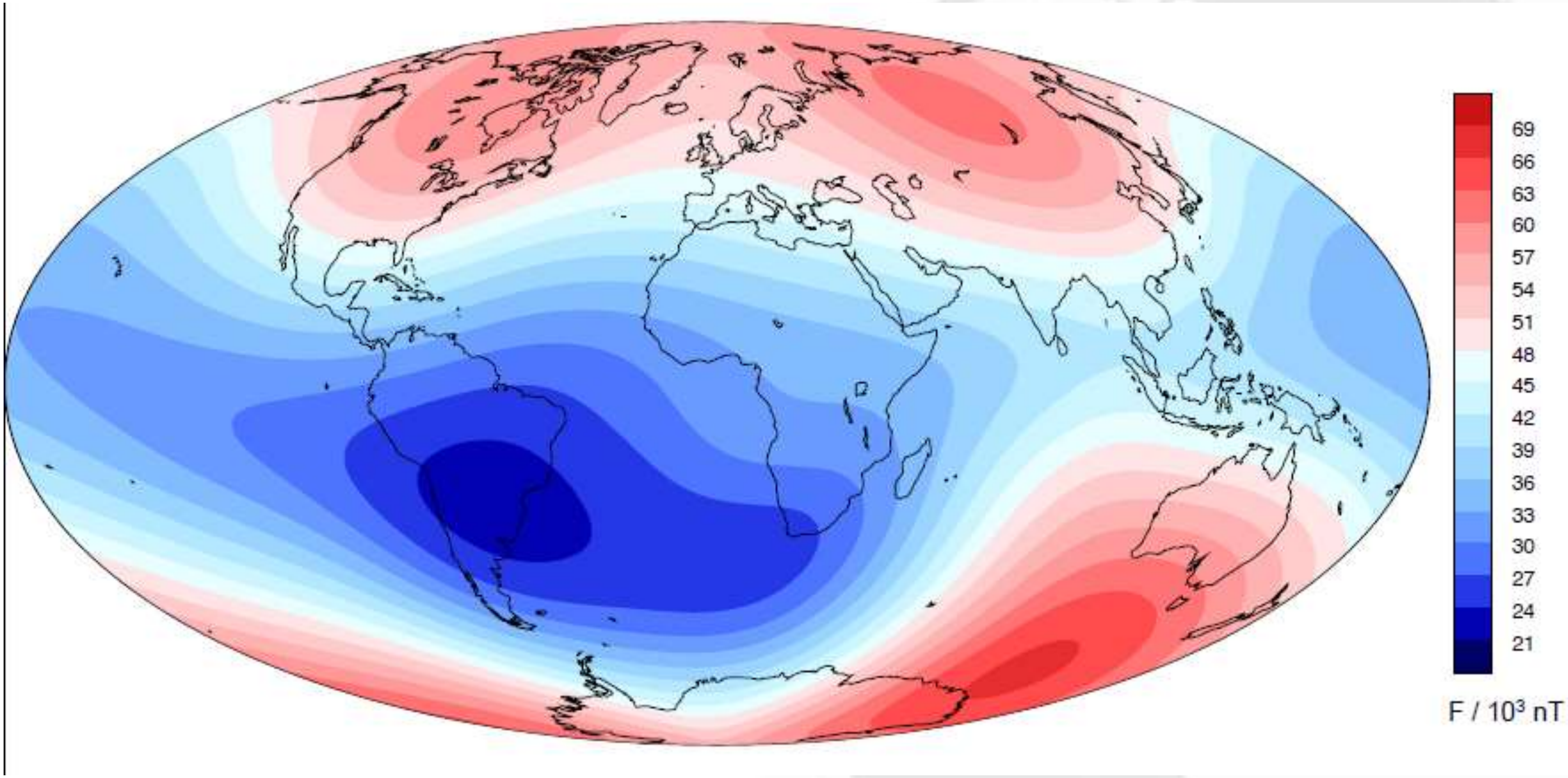
Champ

# The IGRF - I




The radial (local vertical) component $B_z$ – dipole components only

# The IGRF - II




The total field |B| – degree 13 (i.e. all l = 0 to 13 coefficients)

IGRF calculator for any place on the Earth's surface: IGRFWMM-NOAA-NGDC

# Global Magnetic Anomaly – $B_z$

## Residual to the IGRF

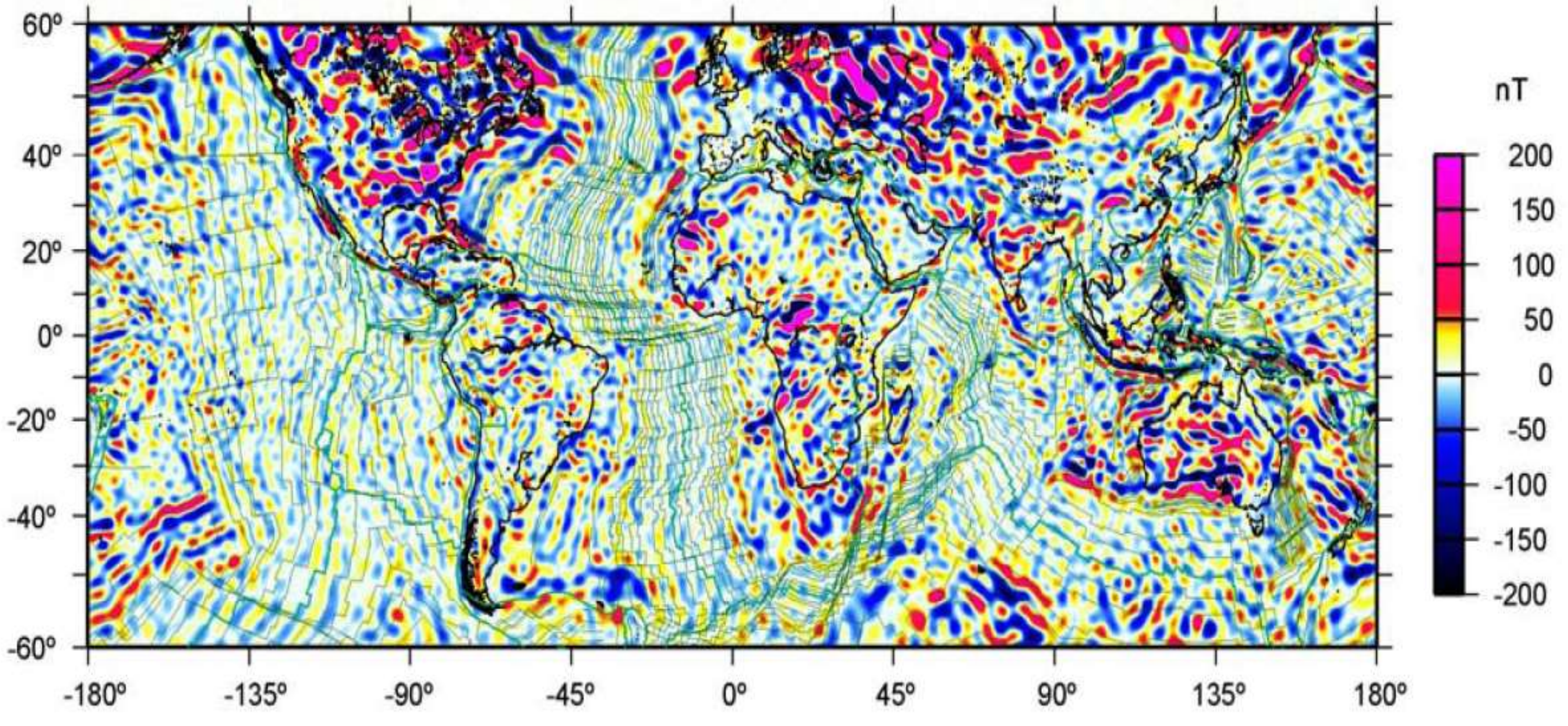



Figure 1: Vertical component of the CHAMP-satellite-derived MF6 crustal magnetic field at the Earth surface, overlain with the isochrons of an ocean-age model inferred from independent marine and aeromagnetic data by Muller et al. (2008).

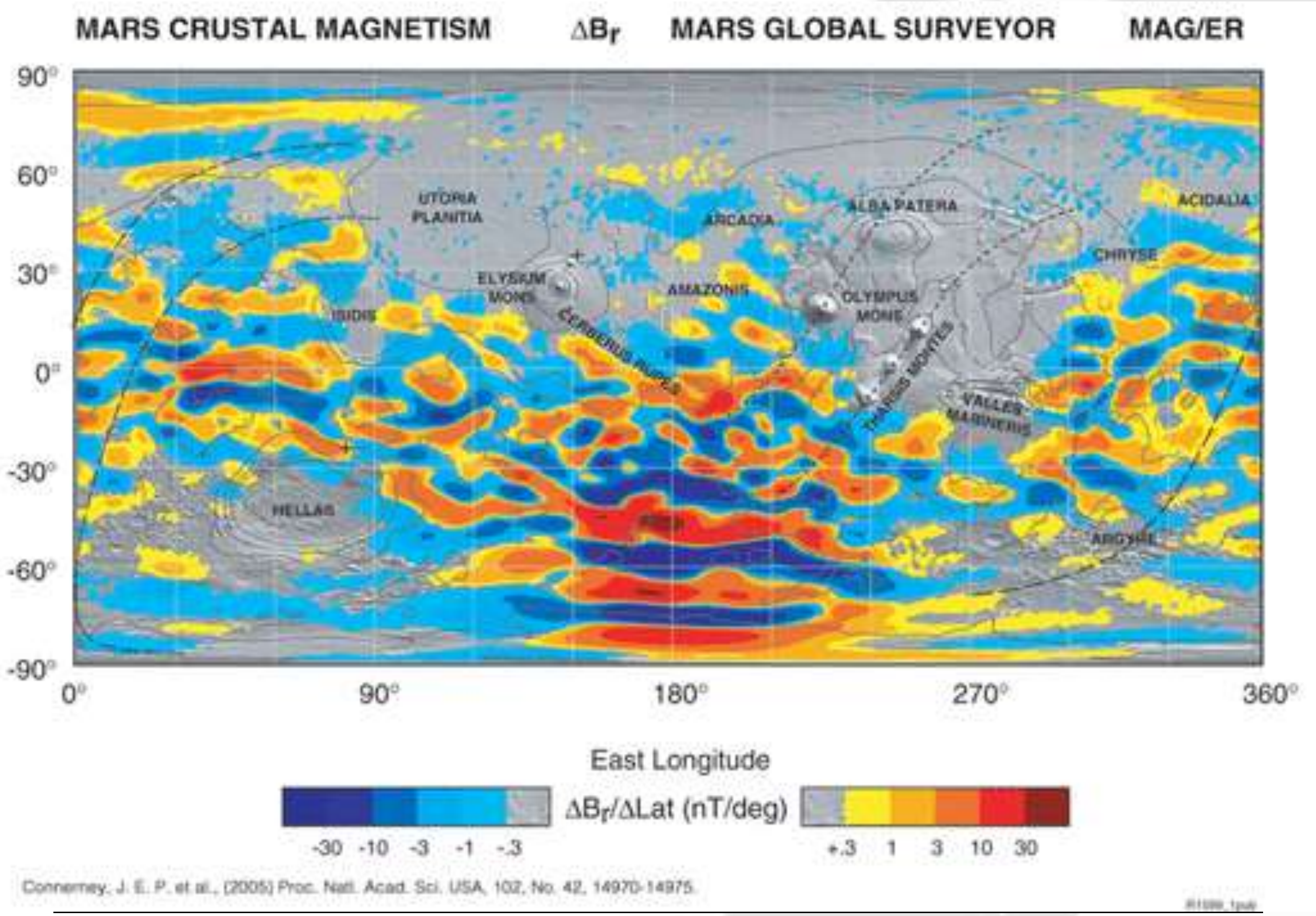
# Elsewhere in the Solar System

## Can we detect a tectonic history written into the crust?

- Most space missions are launched with probes carrying magnetometers.
- The first interest is in the character of the global magnetic fields surrounding planets and moons that might suggest an internal magneto-dynamic dynamo.
- Where among the rocky bodies: Mercury, Earth, Io, Ganymede have dynamos.
- Perhaps Mars and Earth's Moon once had dynamos that have imprinted a paleomagnetic record into crustal rocks.

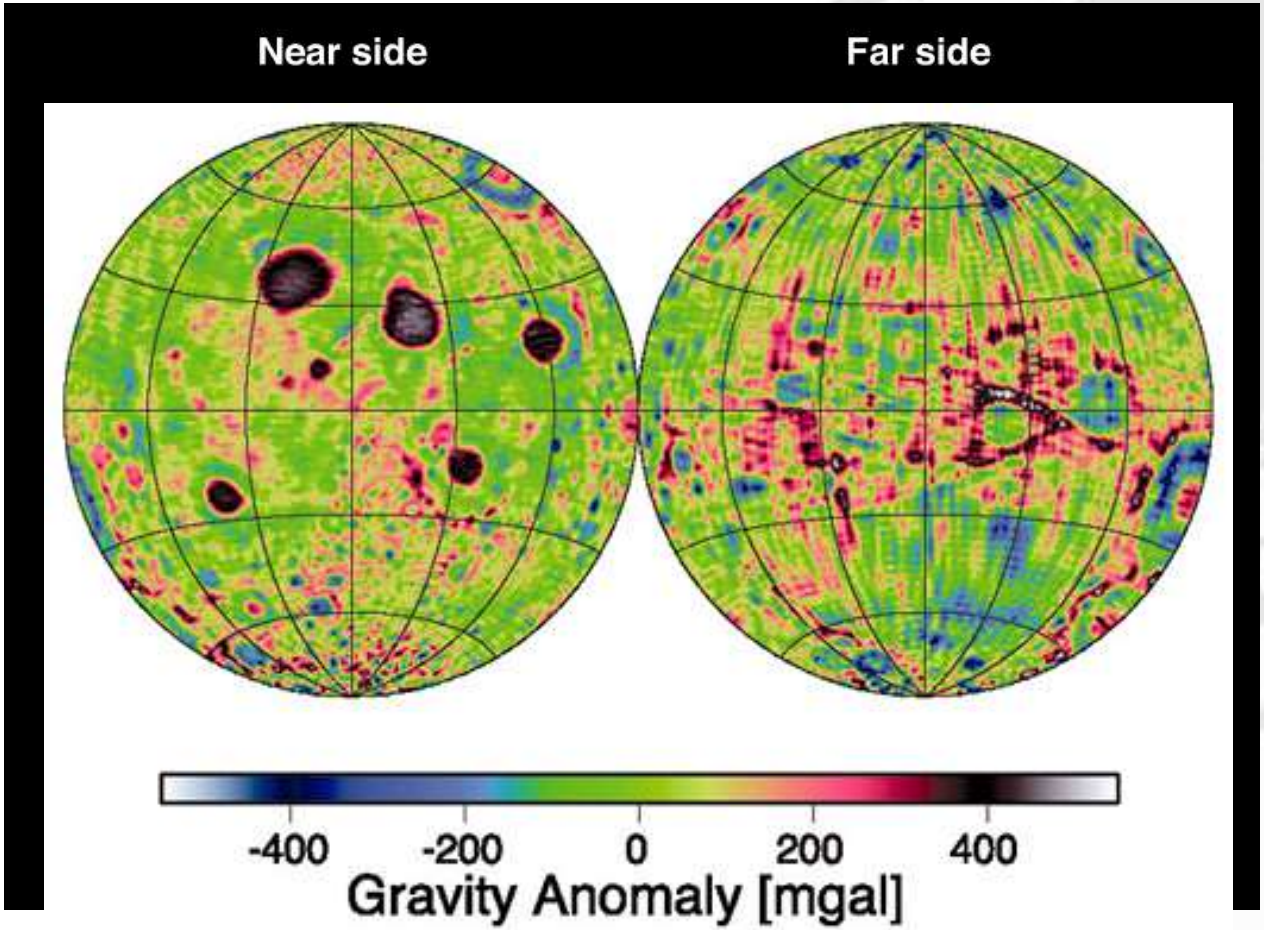
# Mars' Magnetic Anomaly

## Reveals tectonic history?




Mars *Global Surveyor* Mission

# Lunar Magnetic Anomaly -- |B|




The Apollo astronauts returned rocks from the Moon which showed very high remnant magnetism – *Lunar Prospector* mapped the field.

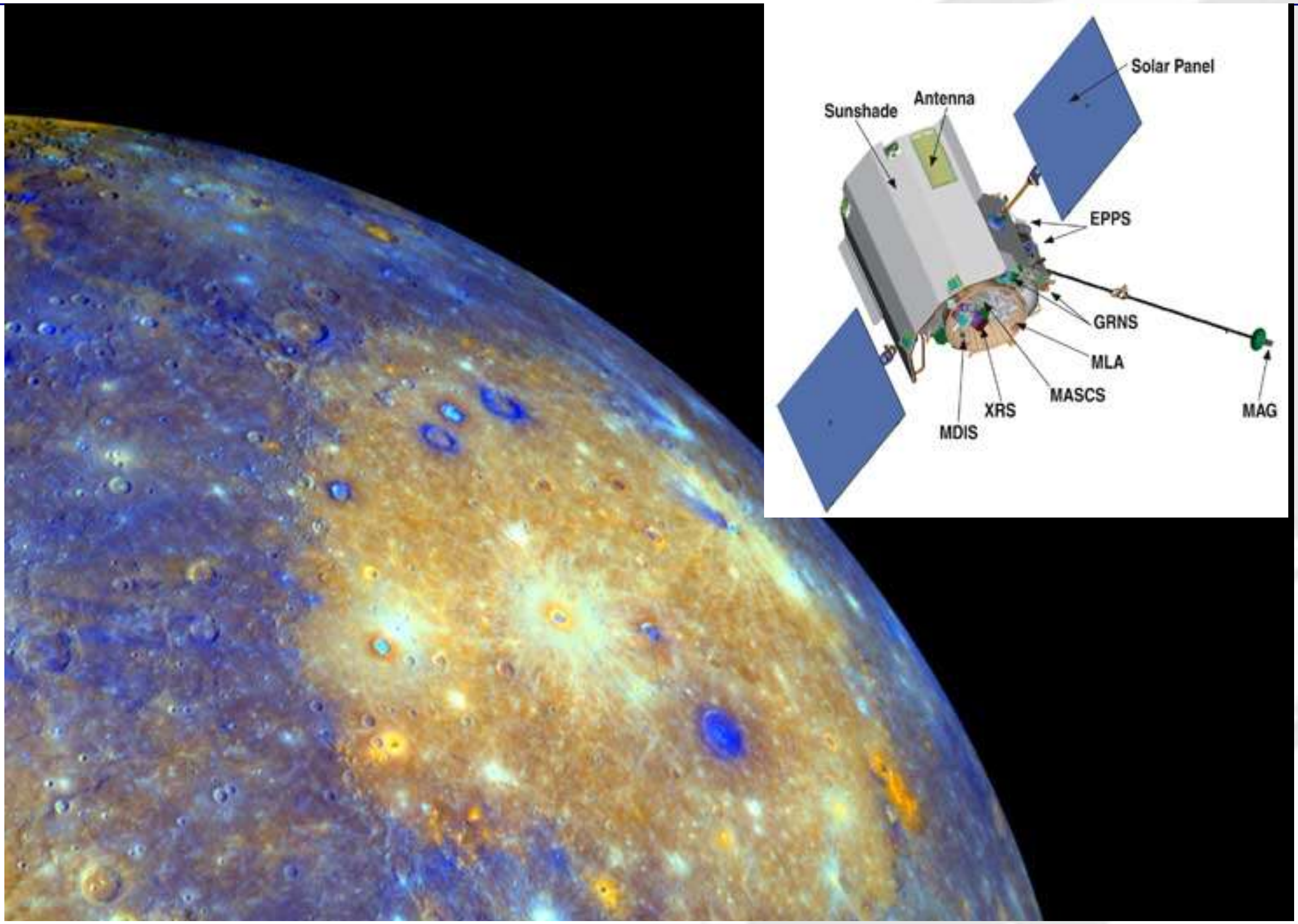
# Venus' Magnetic Anomaly?

## A tectonic history written into the crust?

- *No geomagnetic field* has been detected on Venus – probably no convecting core.
- The surface temperature is 740K; most minerals are well above their Curie temperature at 740K – no field imprinted in crustal rocks.
- What we can say about the surface is that it is very “young” -- completely resurfaced within the past 400-700 million years.
- We must infer tectonic history based on surface topography and gravity.

# Mercury's Magnetic Anomaly?

## The *Messenger* mission should reveal tectonic history




The story is just now being told!

*Mercury's magnetic field*

# Plate tectonics

- Morley and Larochelle (1964) And, then, following, Vine and Matthews (1963) recognize paleomagnetic banding across ocean ridges was due to sea-floor spreading.
- During the late 1950s, Edward (Ted) Irving had been mapping paleomagnetic pole paths to show the history of continental drift.
- The age of the sea-floor basins has been established by magnetic surveying since the original recognition of spreading.

# Sea-floor spreading revealed by paleomagnetic anomalies

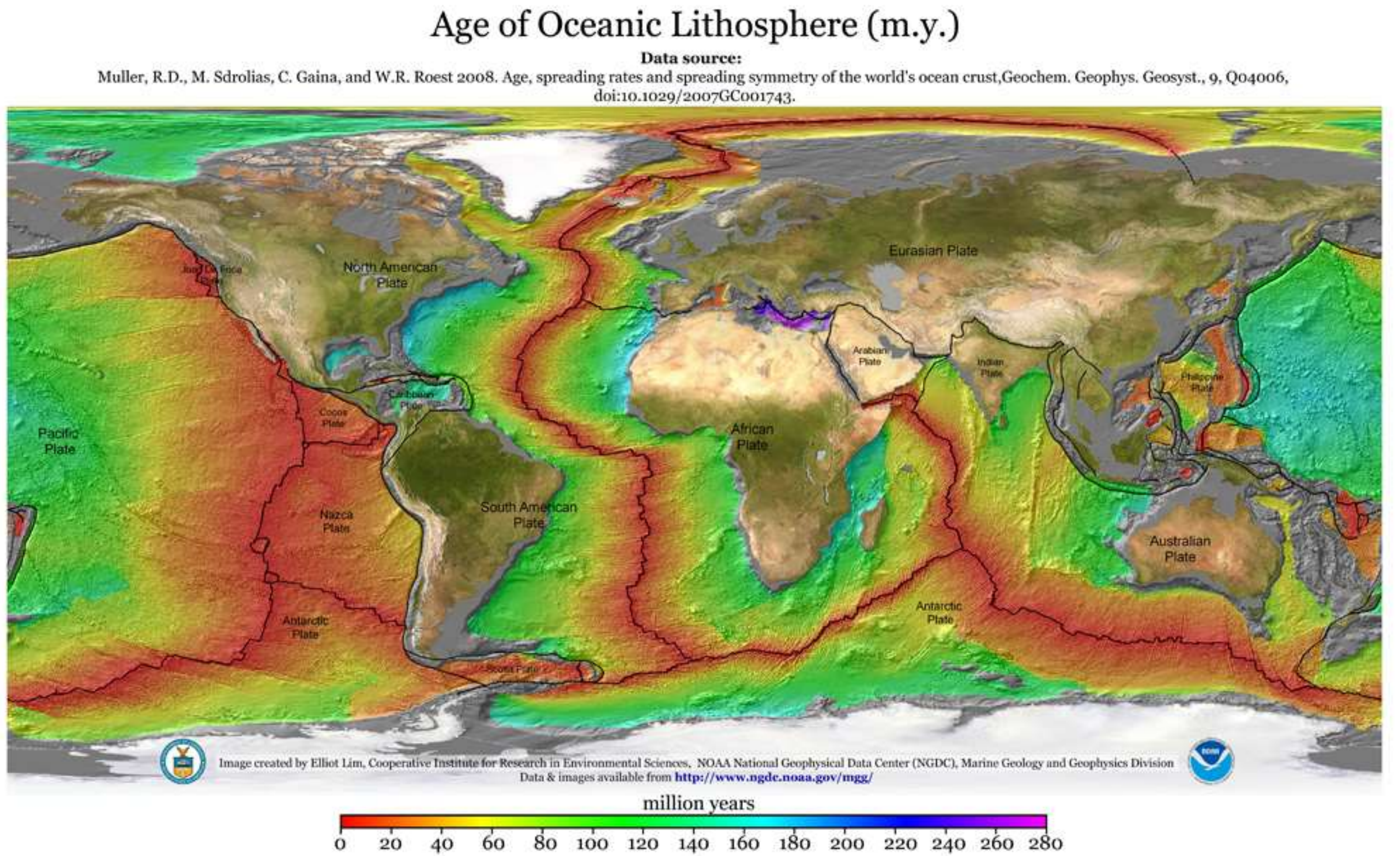



Plate tectonics – The theory is demonstrated by paleomagnetic evidence for sea-floor spreading