

GOOD HOPE FOR EARTH SCIENCES

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Cape Town, South Africa



The South Atlantic magnetic Anomaly: A magnetic window from the Earth's core to space

Angelo De Santis

angelo.desantis@ingv.it

Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy

GIFT Meeting at IAPSO-IAMAS-IAGA 2017 Conference, Cape Town, S. Africa

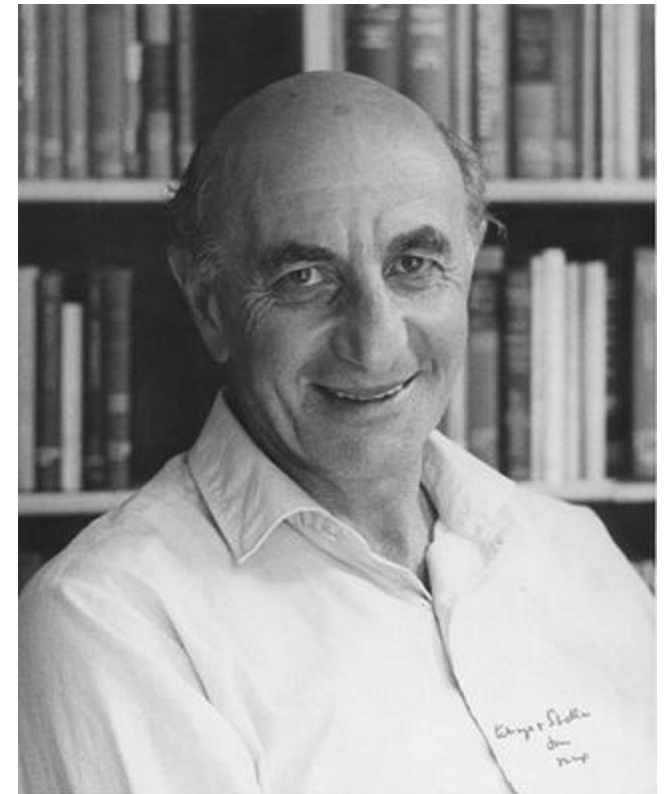
www.iapso-iamas-iaga2017.com



A science is any discipline in which the fool of this generation can go beyond the point reached by the genius of the last generation.

Max Gluckman

(South African Social Anthropologist 1911-1975)





What I will show you today

A trip from the beginning of space and time to now/here

Objectives:

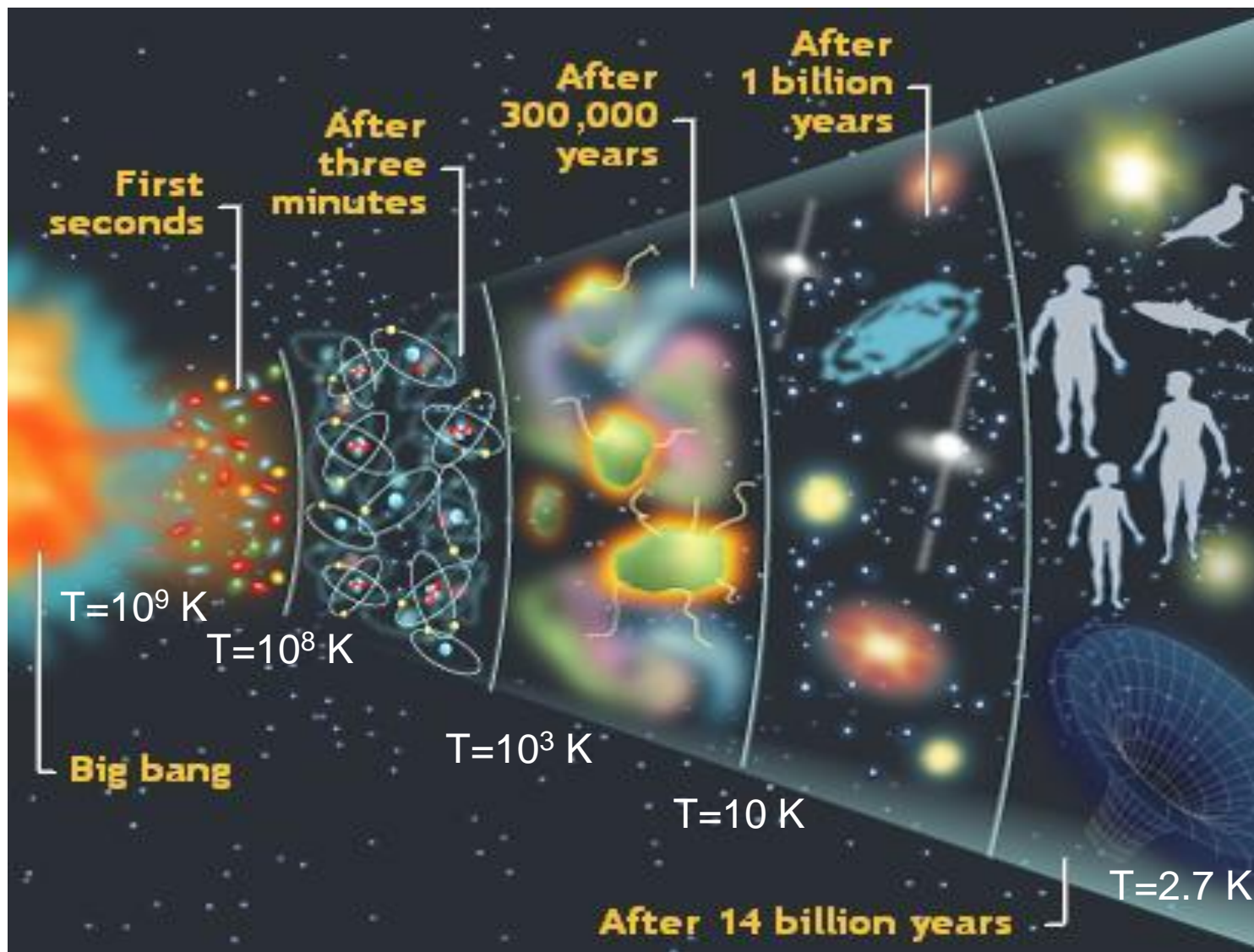
1. To assess the context (space and Earth) in which geomagnetic field and its South Atlantic Anomaly are and to introduce them to you.
2. To get an idea about what can happen to the geomagnetic field (& us) into the future



Index

- 1. From Big-Bang to now**
- 2. The Solar System**
- 3. Earth as a unique planet**
- 4. Earth's interior**
- 5. Sun, solar wind & geomagnetic field**
- 6. South Atlantic Anomaly and possible next reversal**
- 7. Conclusions**

1. From Big-Bang to now



H=Hubble constant
 $1/H$ = Universe age

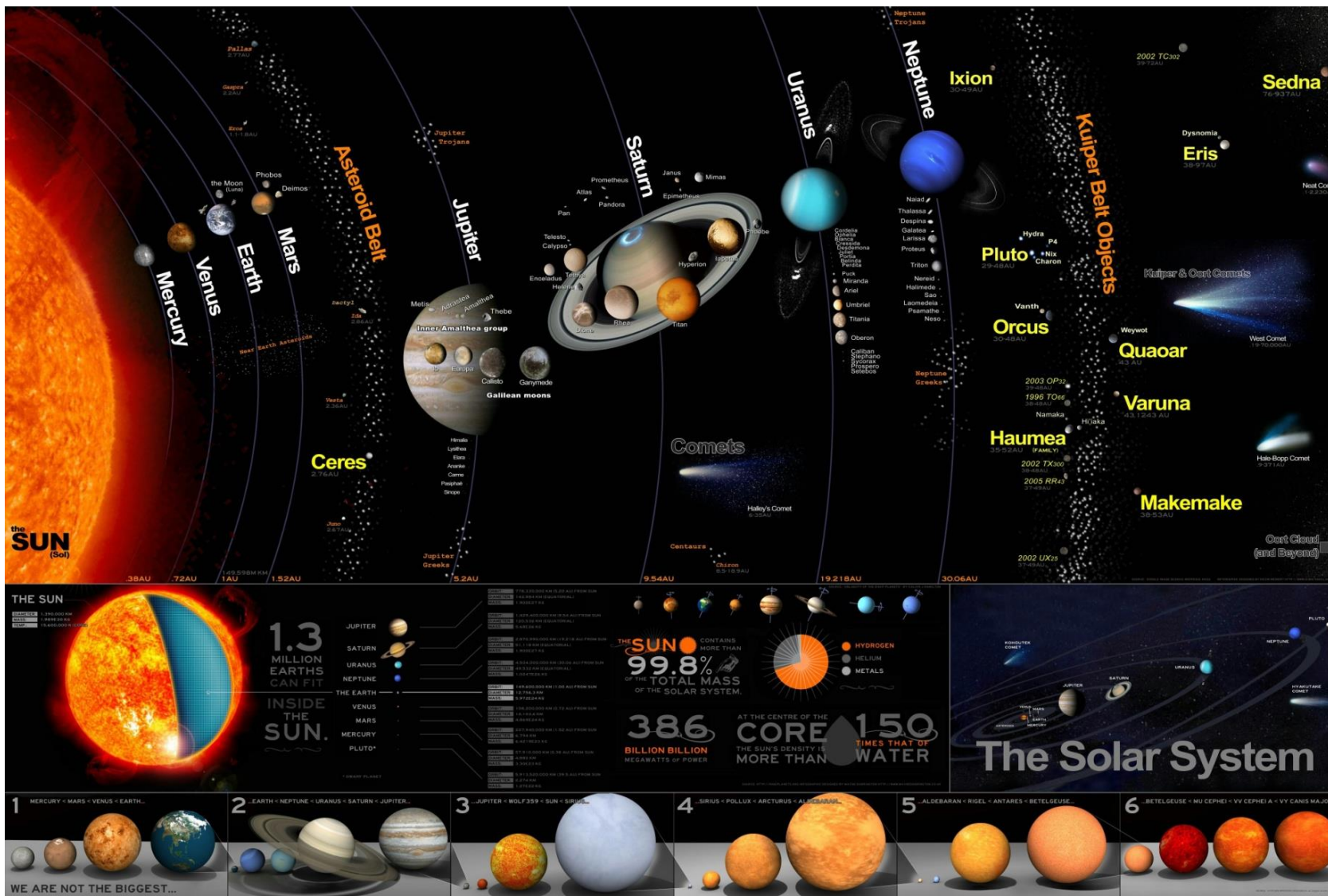
$< 10^{100}$ =googol
 (Kasner 1938) →

How many atoms in the universe?

Possible moves of chess 10^{123}

2. The solar system

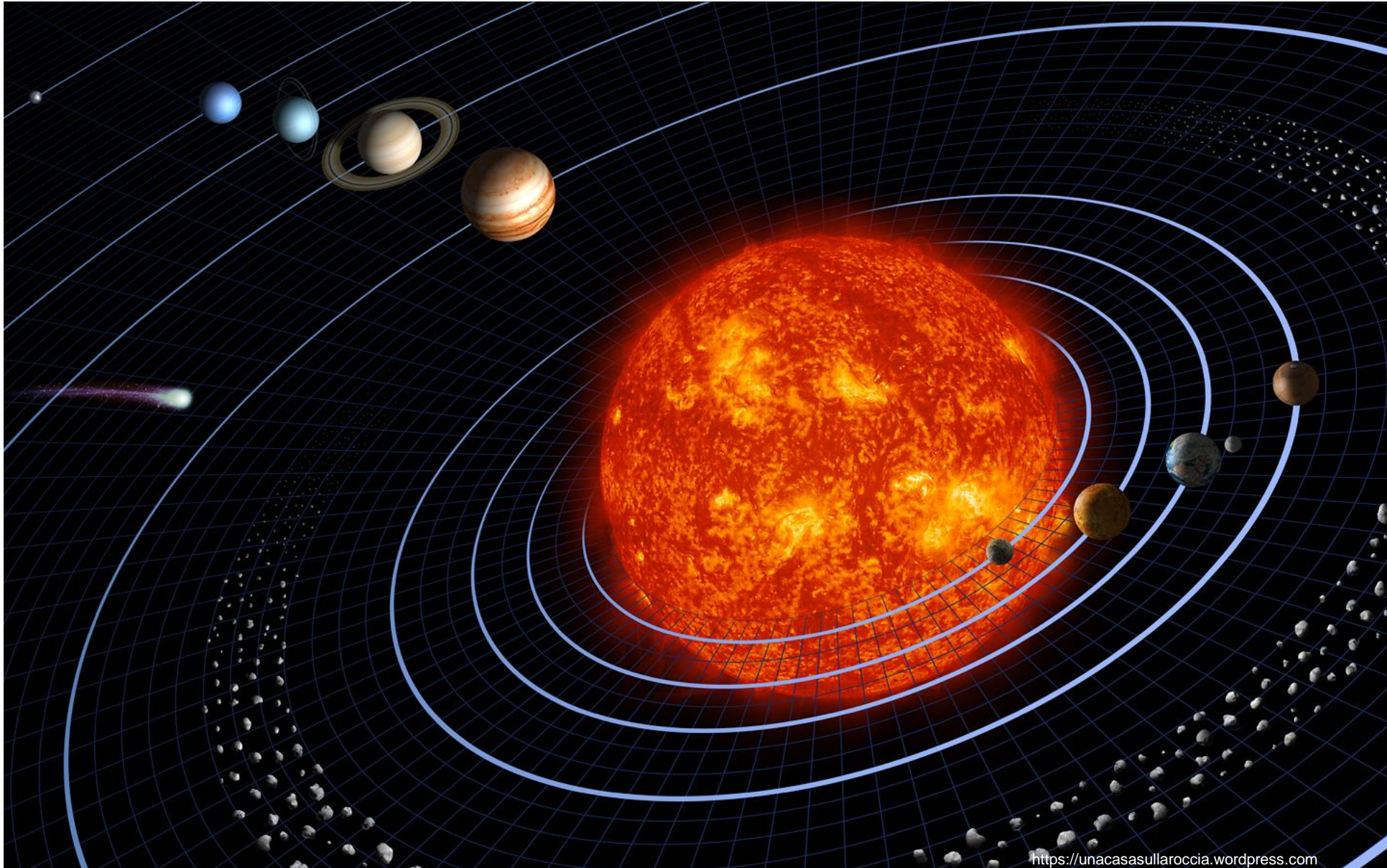
1 Astronomical Unit =
Sun-Earth distance=
150 Million Km



1 star
8 planets
>5 dwarf planets
(Pluto, Ceres,
Makemake, Eris,
Haumea, etc.)

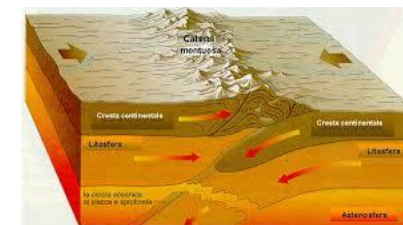
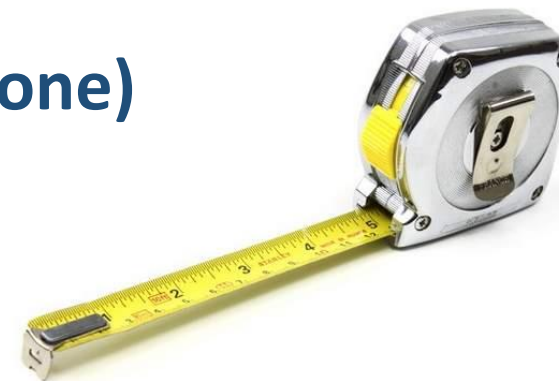
<https://solarsystem.nasa.gov>

Planets are in their own pre-ordered places (Titius-Bode Law)

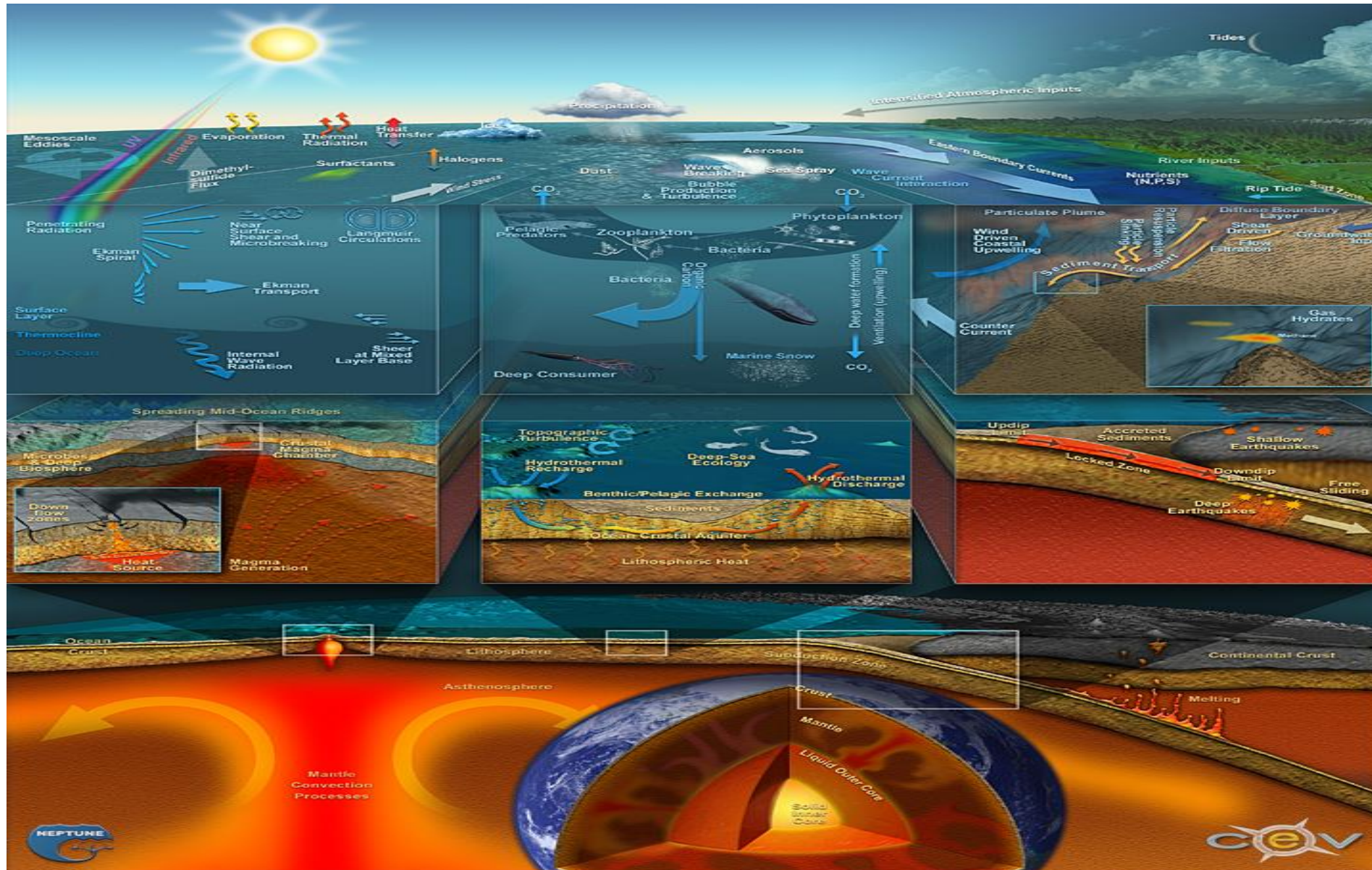


3. Earth as a unique planet

1. The right distance from the Sun (habitable zone)
2. The right dimension
3. Abundance of liquid water & atmosphere with oxigen
4. Inner and surface dynamics (Tectonics)
5. Earth & Moon form a "double system"
6. A planetary magnetic field



EARTH: a system of interconnected systems



Angelo De Santis, GIFT Meeting at IAPSO-IAMAS-IAGA 2017 Conference, Cape Town, S. Africa

A unique planet... but how long for?

1. Overpopulation



2. Pollution



3. Climate changes



4. Riduction of available resources



5. Decrease of biodiversity

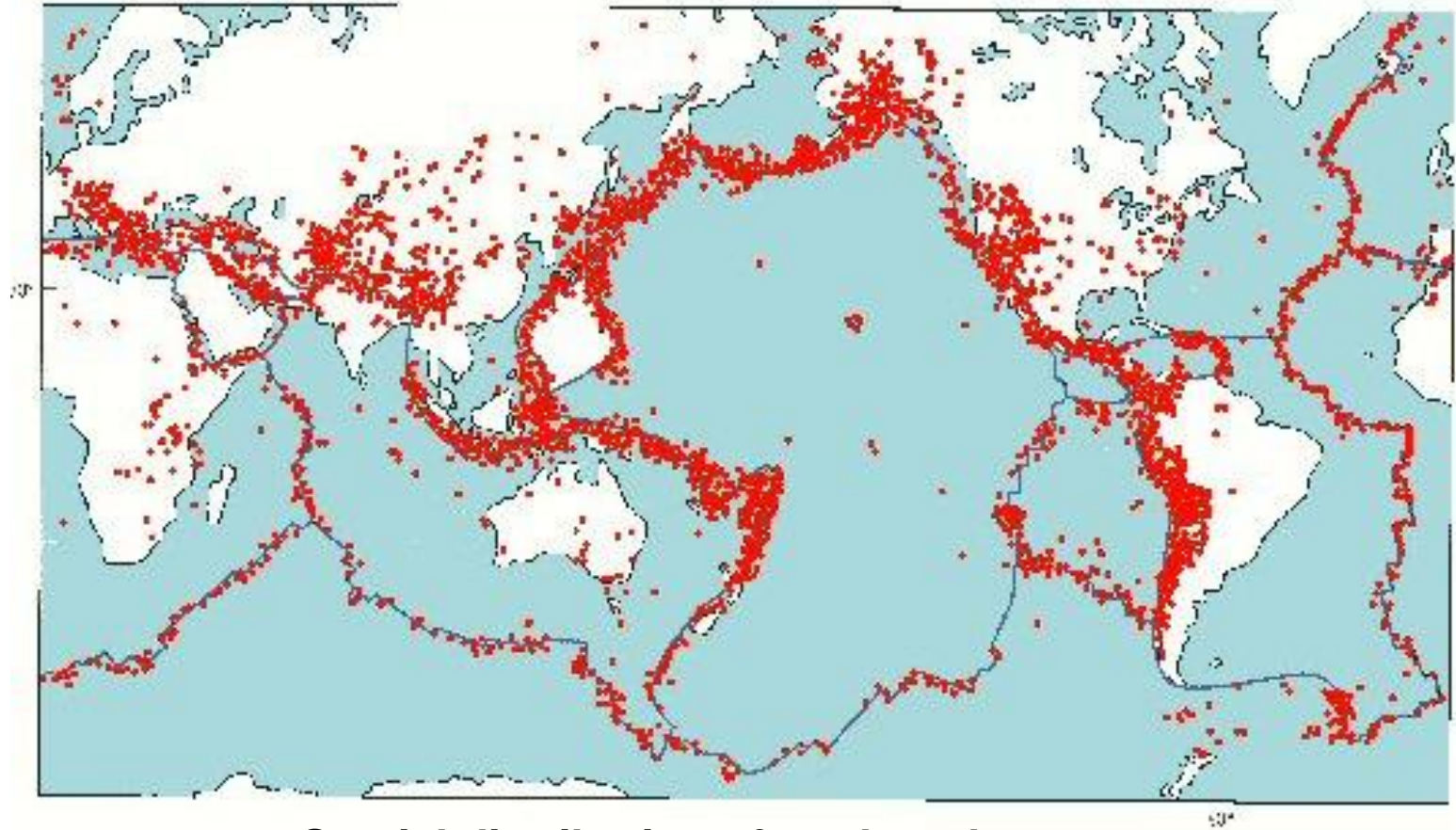


4. Earth's Interior

Tectonics & Earthquakes

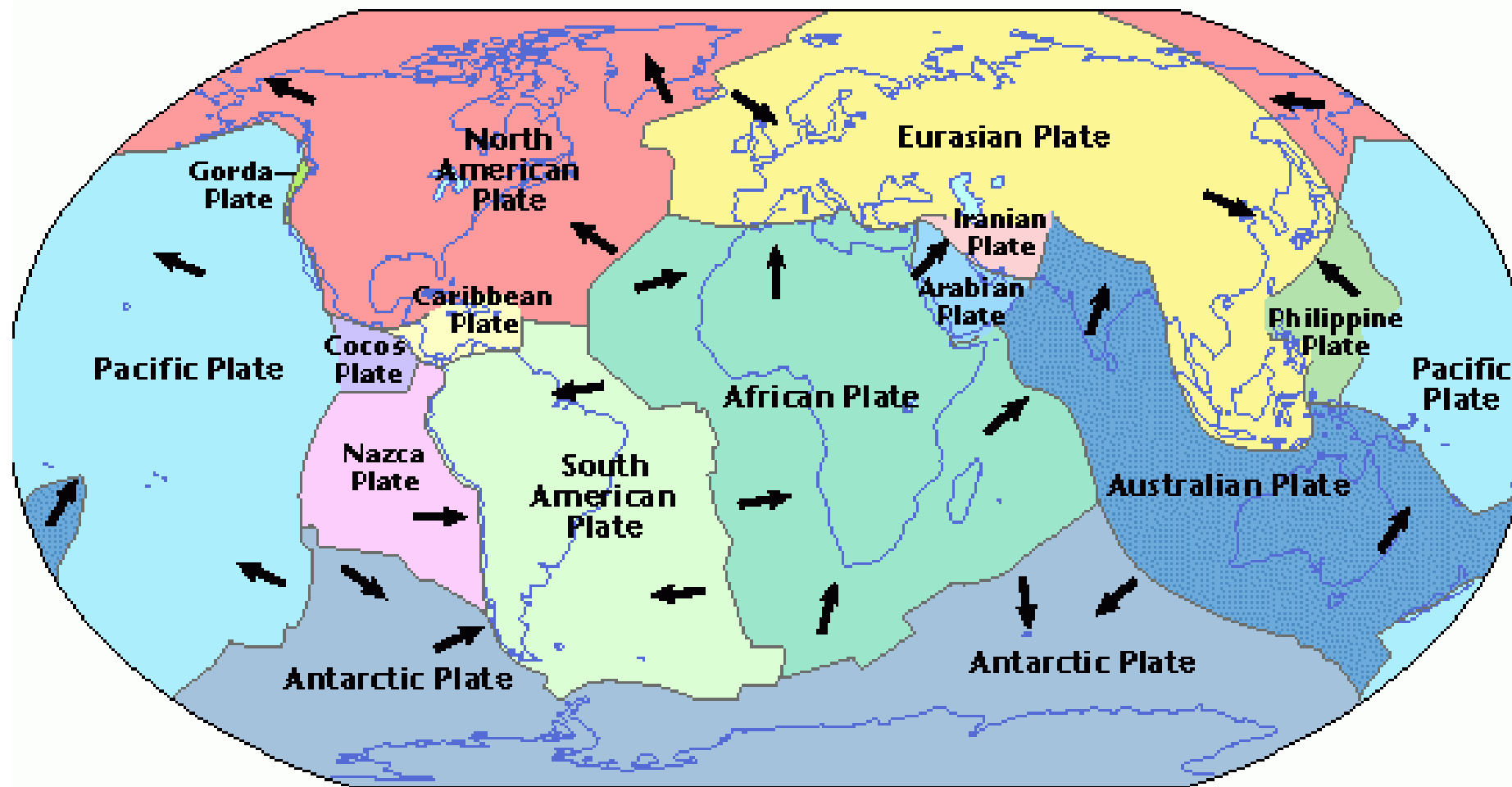


Tectonics:
deformations and dislocations of
the terrestrial crust

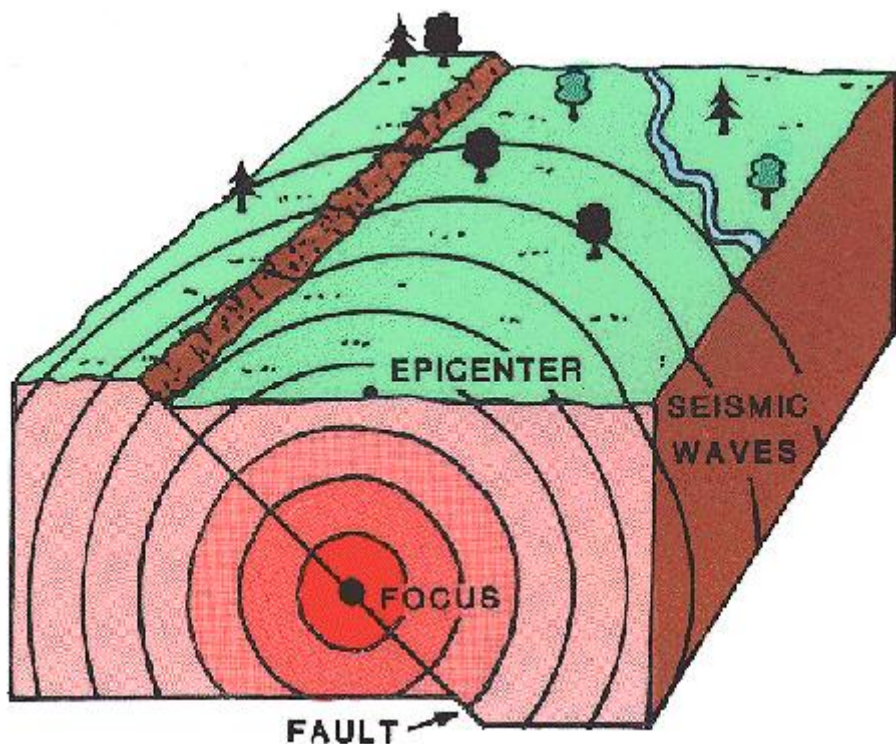


Spatial distribution of earthquakes

Plate Tectonics



An earthquake

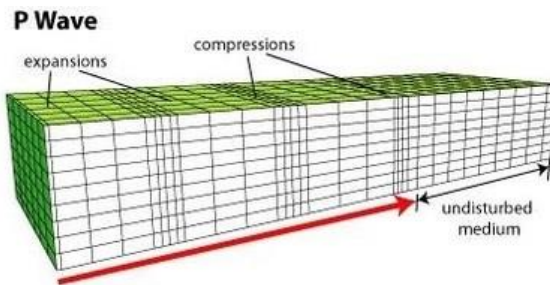


An earthquake is a shake of the ground due to an abrupt energy release previously accumulated by rocks.

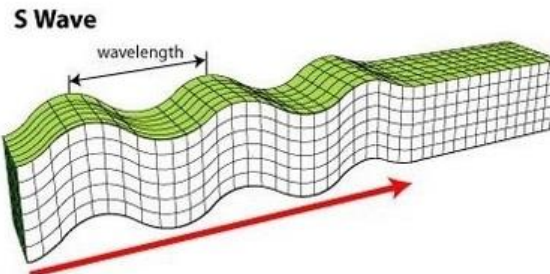
In a year around 100000 earthquakes occur in the world, most of them recorded only by instruments, but some tens of them can produce huge damages and death.

Seismic Waves

Primary Waves



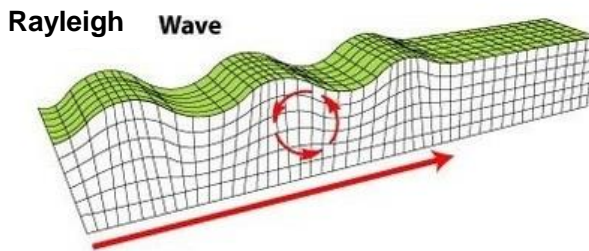
Secondary Waves



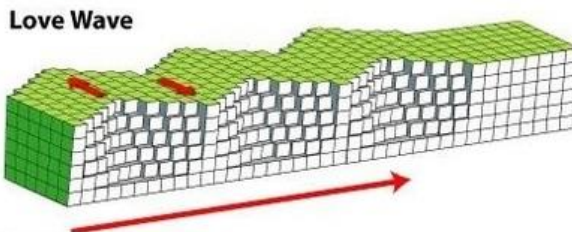
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Surface Waves

Rayleigh

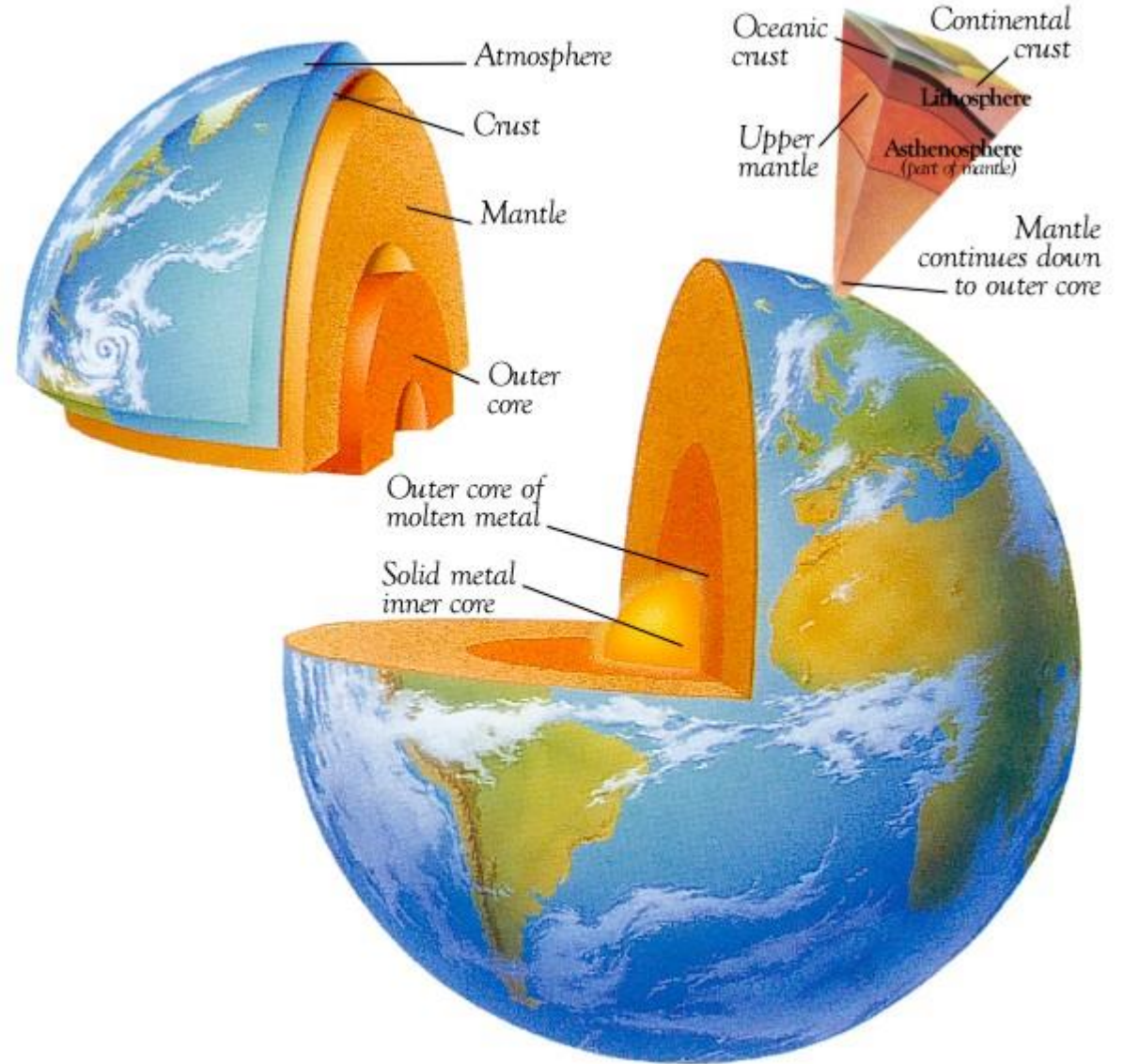
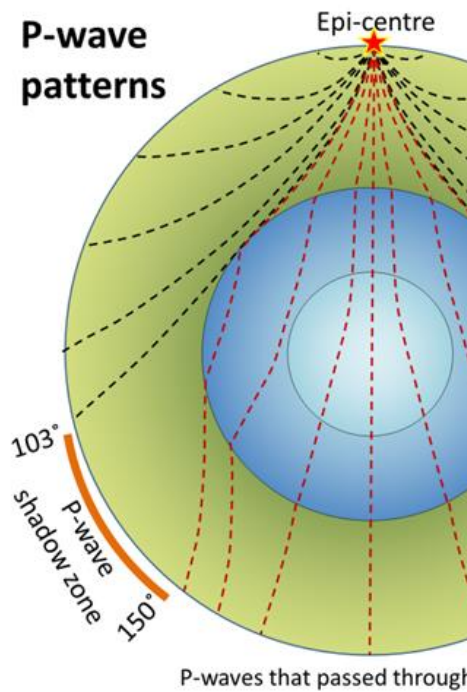
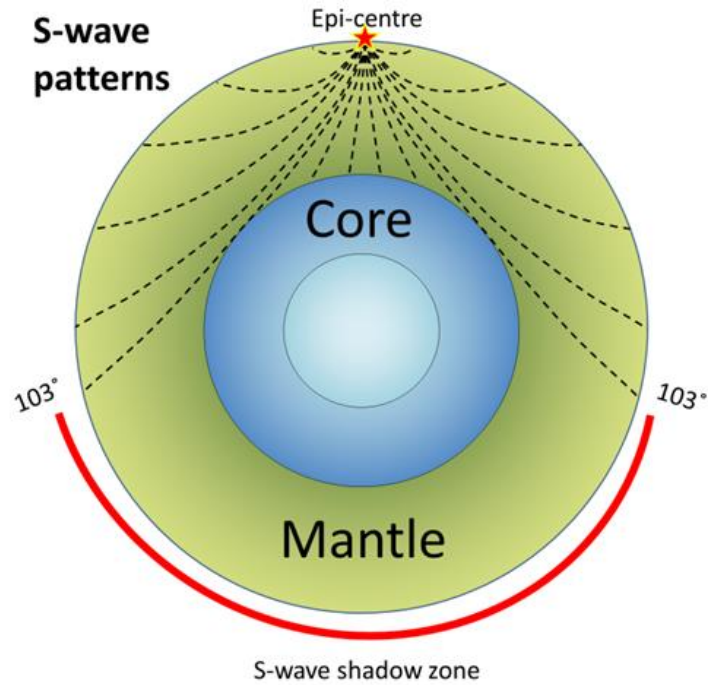


Love



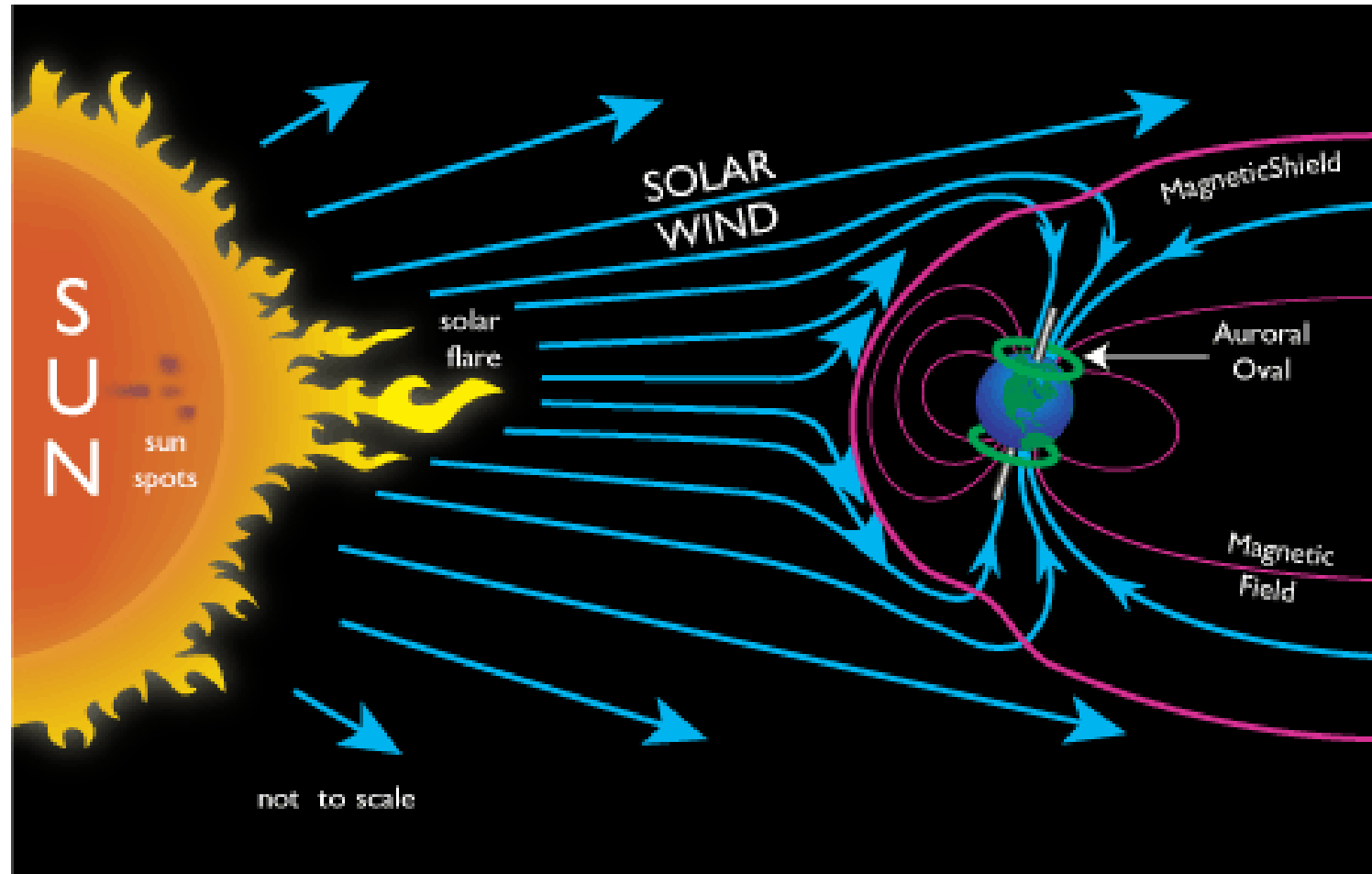
Surface Waves are the most destructive

The study of the seismic waves propagation allows us to know the Earth's interior



<https://opentextbc.ca>

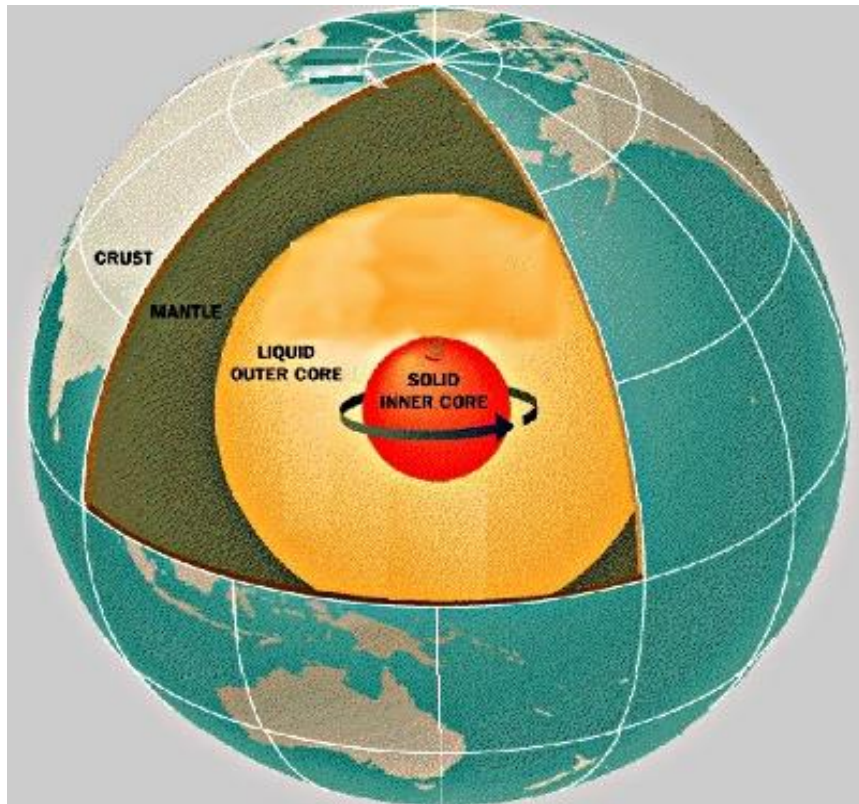
5. Sun, solar wind & geomagnetic field



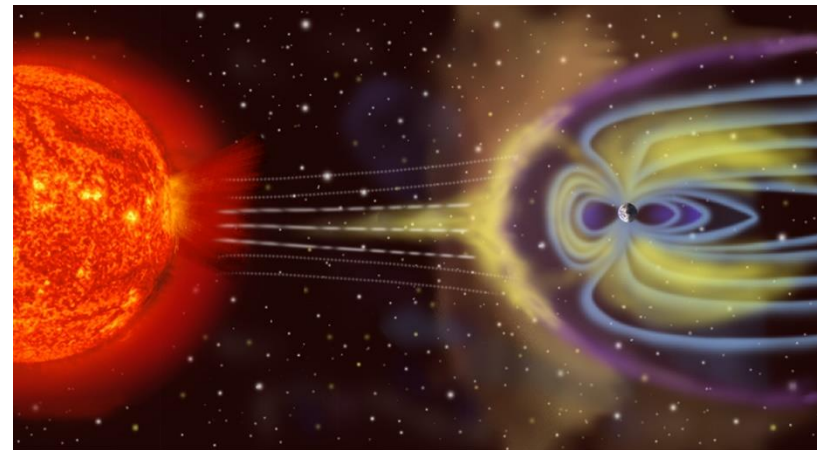
<http://www.madoc.mobi>

Geomagnetic field: main properties

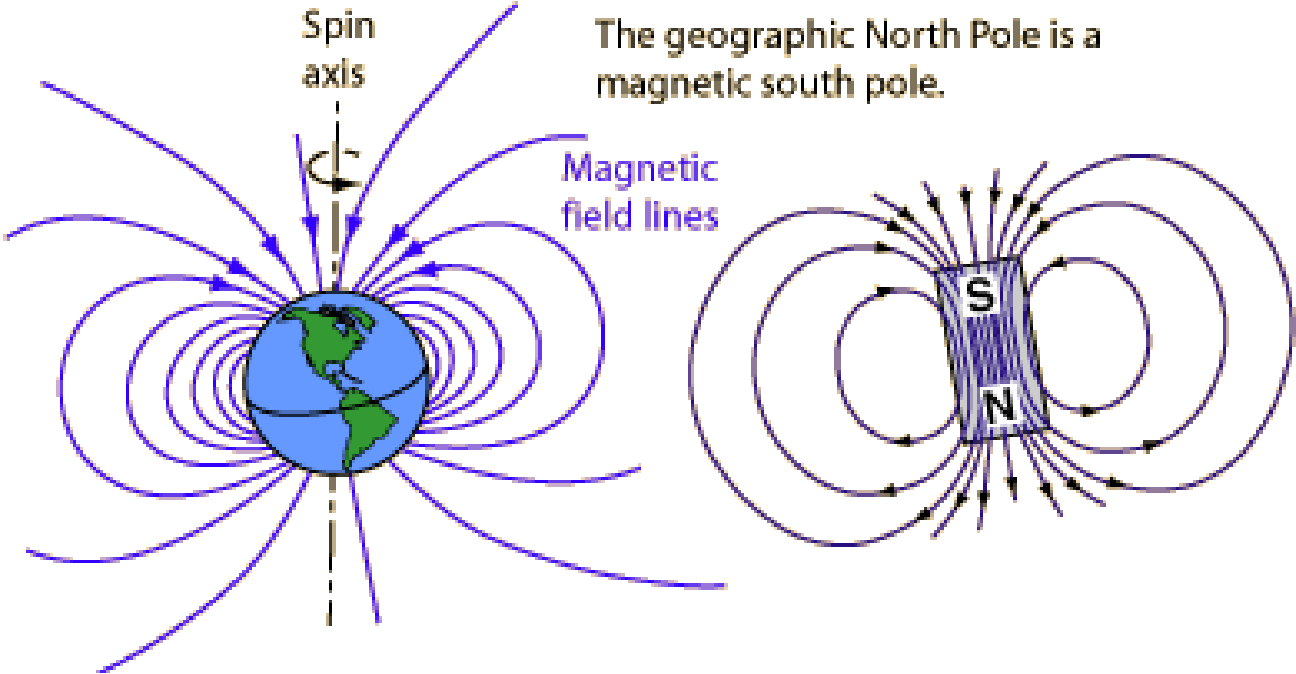
The importance of the geomagnetic field:



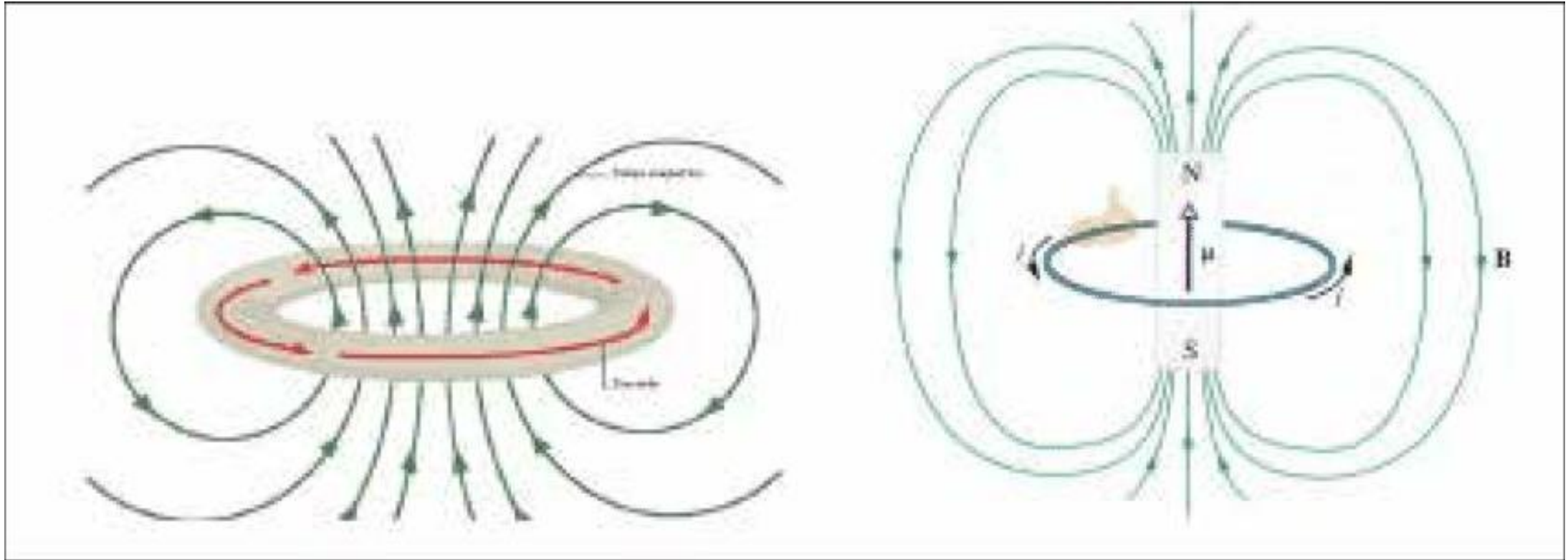
- Scientific
- Practical
- Vital



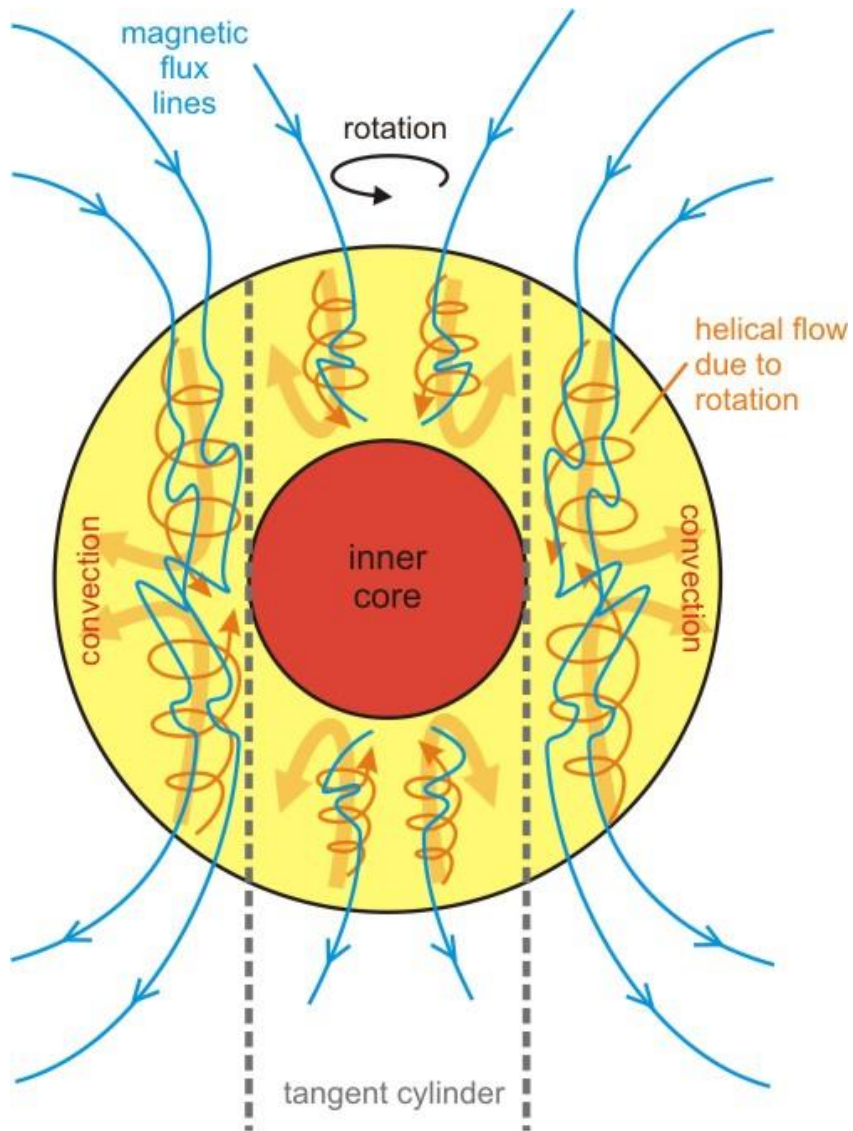
6. Geomagnetic field, South Atlantic Anomaly & reversals



Analogy between magnetic dipole and current loop

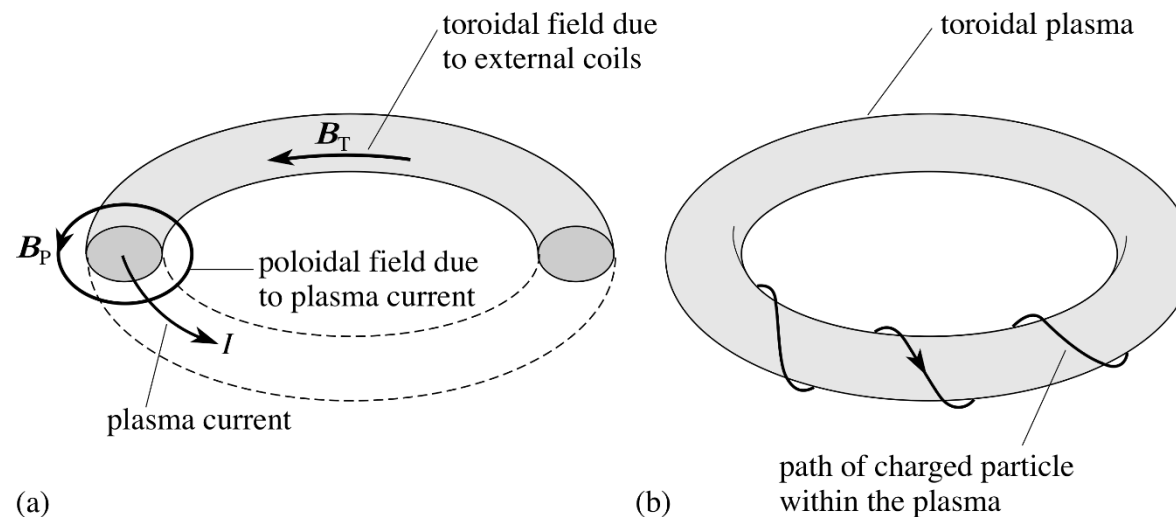


Electric Currents in the fluid outer core



What is observed at the Earth surface is produced by the poloidal field.

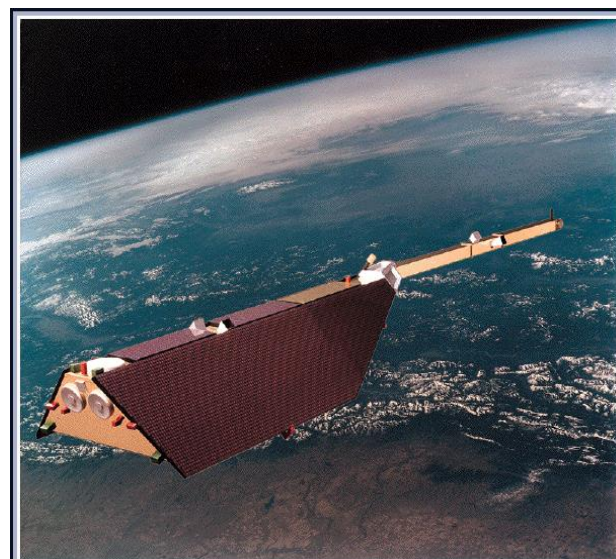
A part of the geomagnetic field is anyway mysterious: the toroidal field.



Measuring the Field Today: Magnetic Satellites

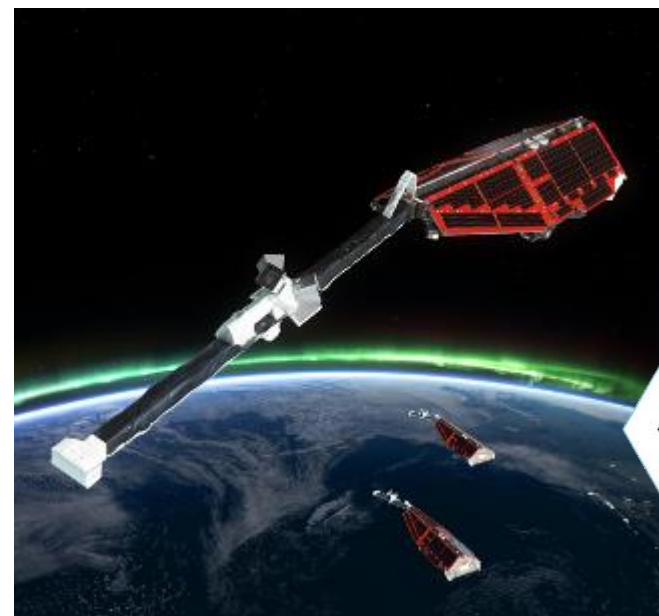


Ørsted: 1999-



<http://www.ggos-portal.org>

CHAMP:
2000-2010



Swarm 3-satellite
[A,B & C]
constellation:
launched 2013-

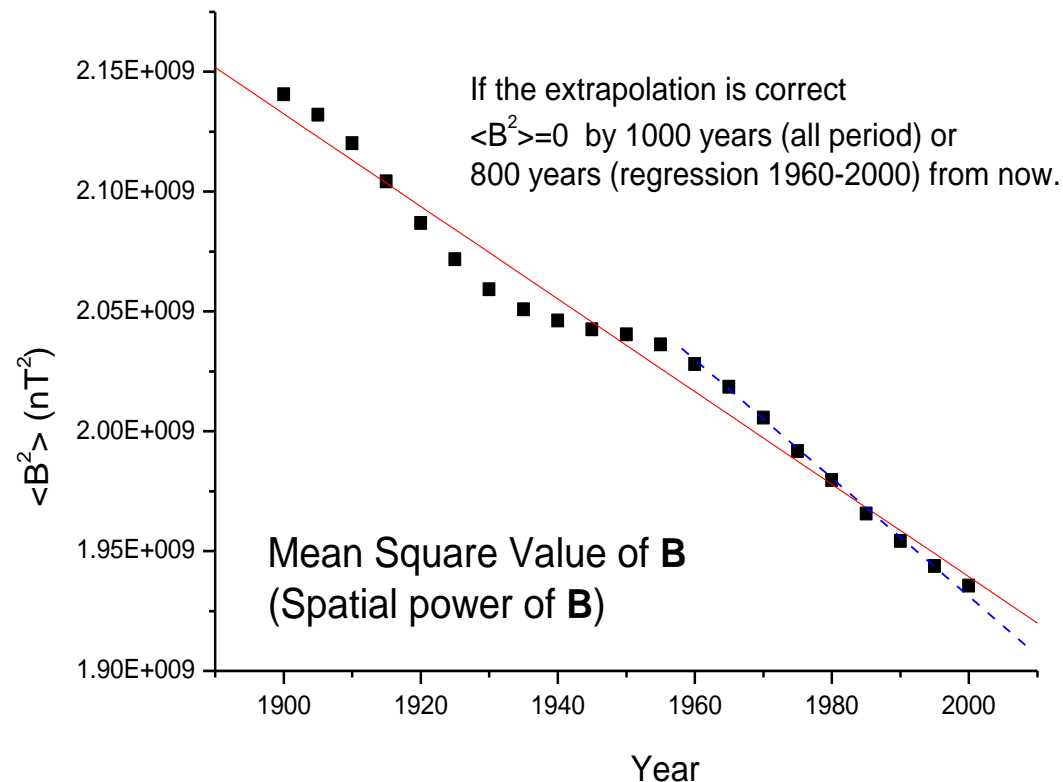


E-pop satellite
[Swarm-E]
launched 2013-



Simple facts

From global energy density

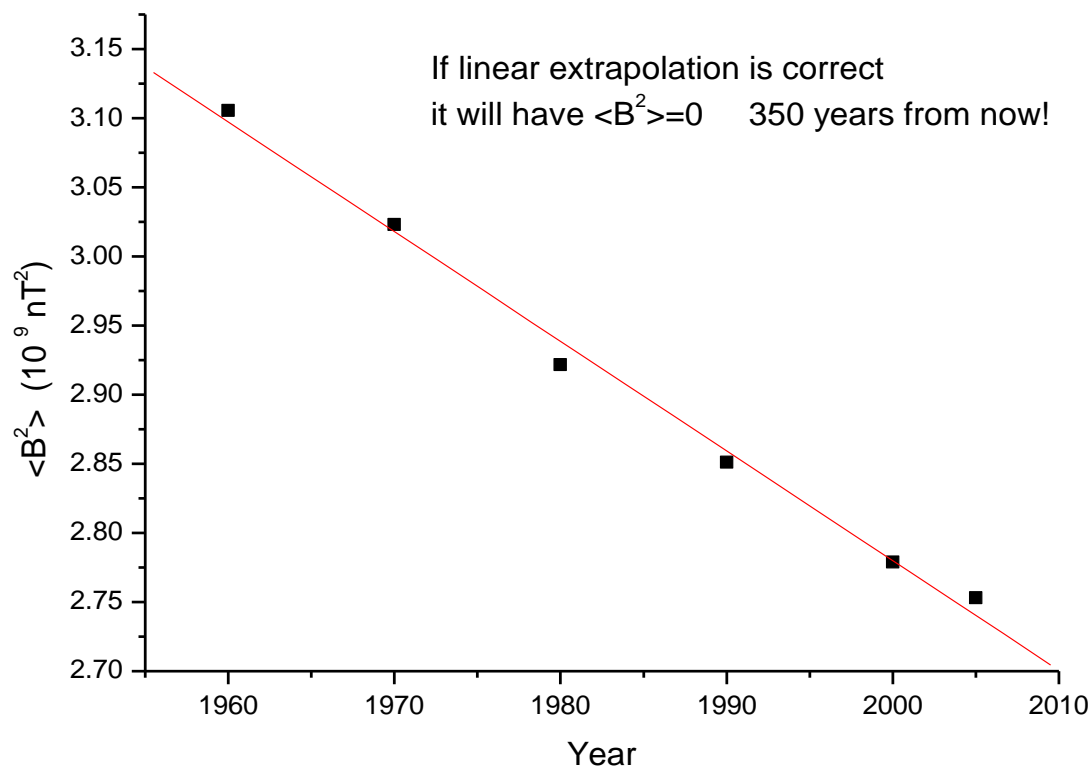


... If extrapolation is right.... Reversal by 800-1000 years!



Simple facts

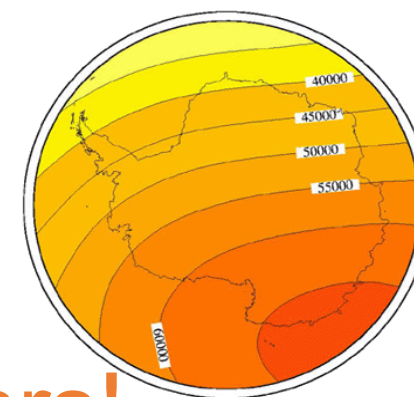
From Energy density in Antarctica (South Lat > 60 degree)



From a Spherical Cap
Harmonics Model (ARM)
Time: 1960-2005
Space: 1600-13000 km

Data:
Ground/balloon/satellites

(De Santis et al., GRL, 2002)

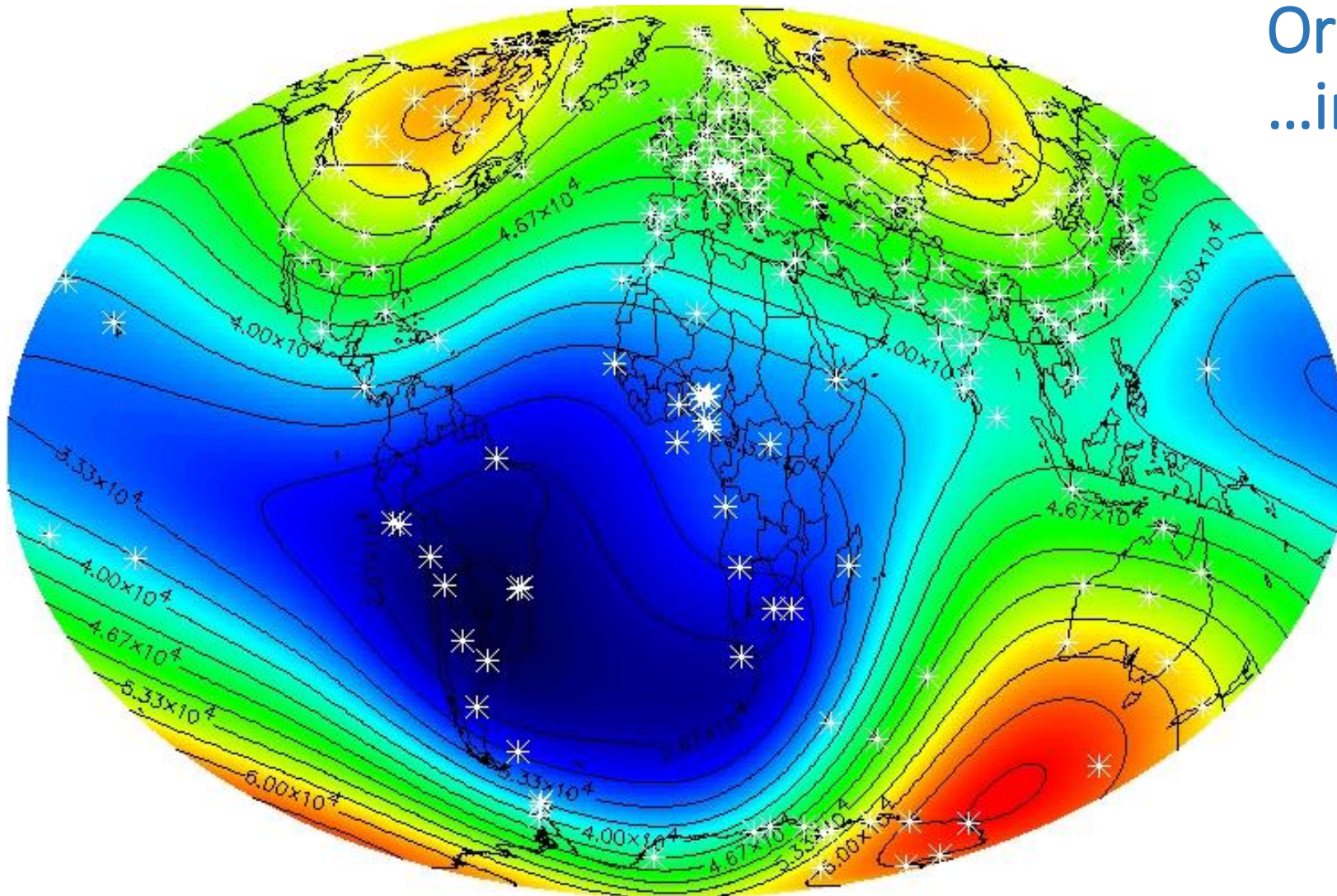


... zero energy density by 350 years!

South Atlantic magnetic Anomaly (SAA)

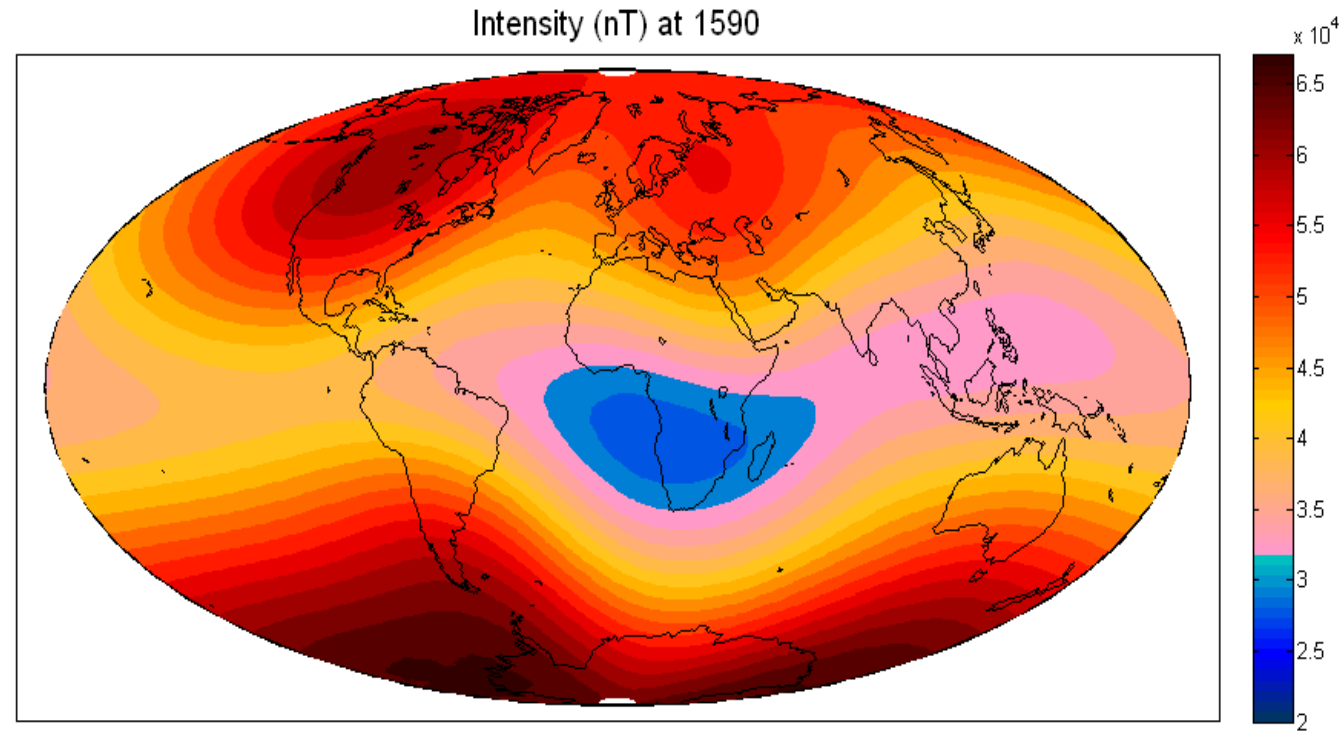


Origin in the deep Earth
...in the outer core as an
emerging reverse
magnetic flux



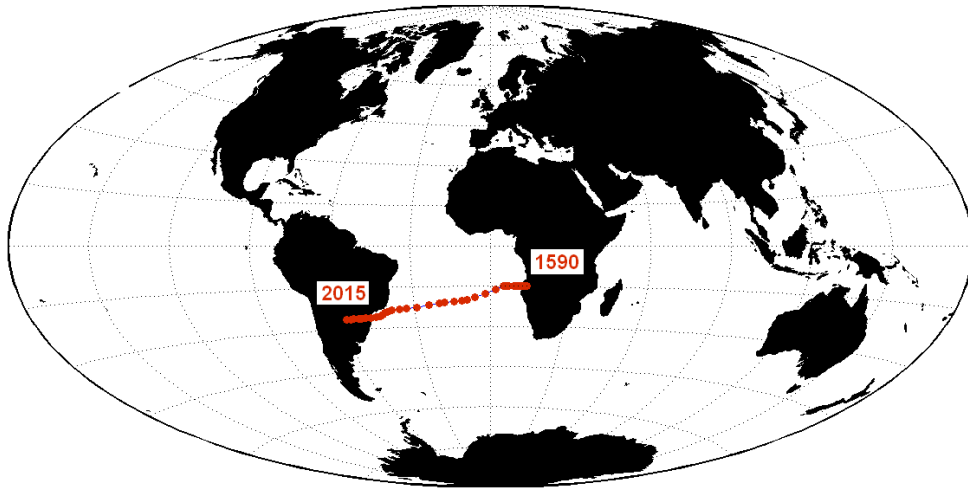
<http://www.ngdc.noaa.gov>

Time evolution of the South Atlantic Anomaly (SAA)

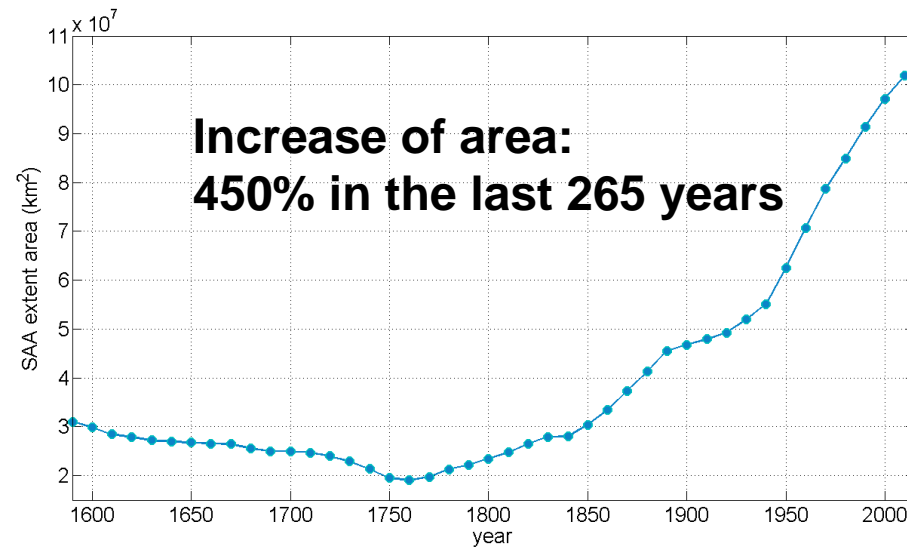
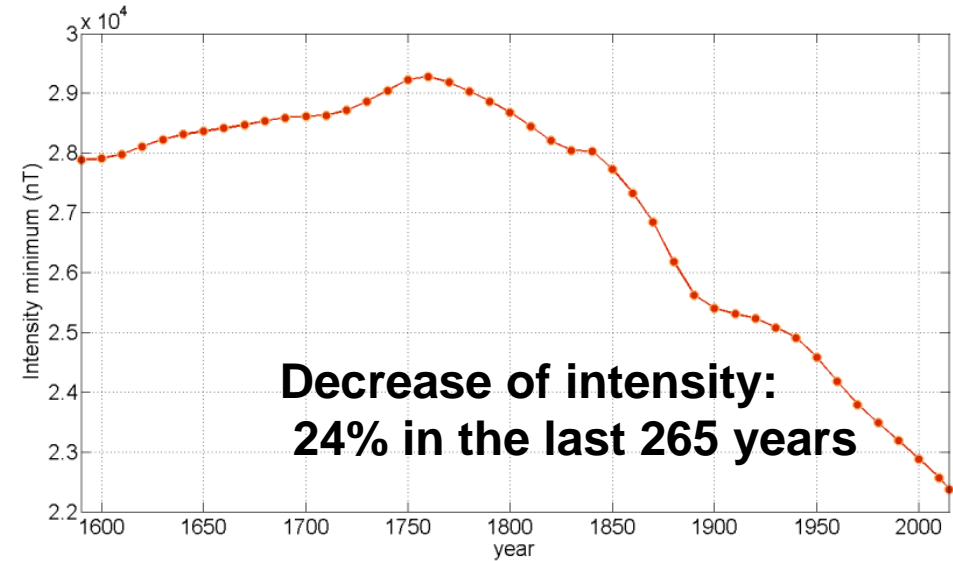


Time evolution maps of the geomagnetic field intensity from 1590 to 2015. The SAA extent area is given by the isoline of 32000 nT.

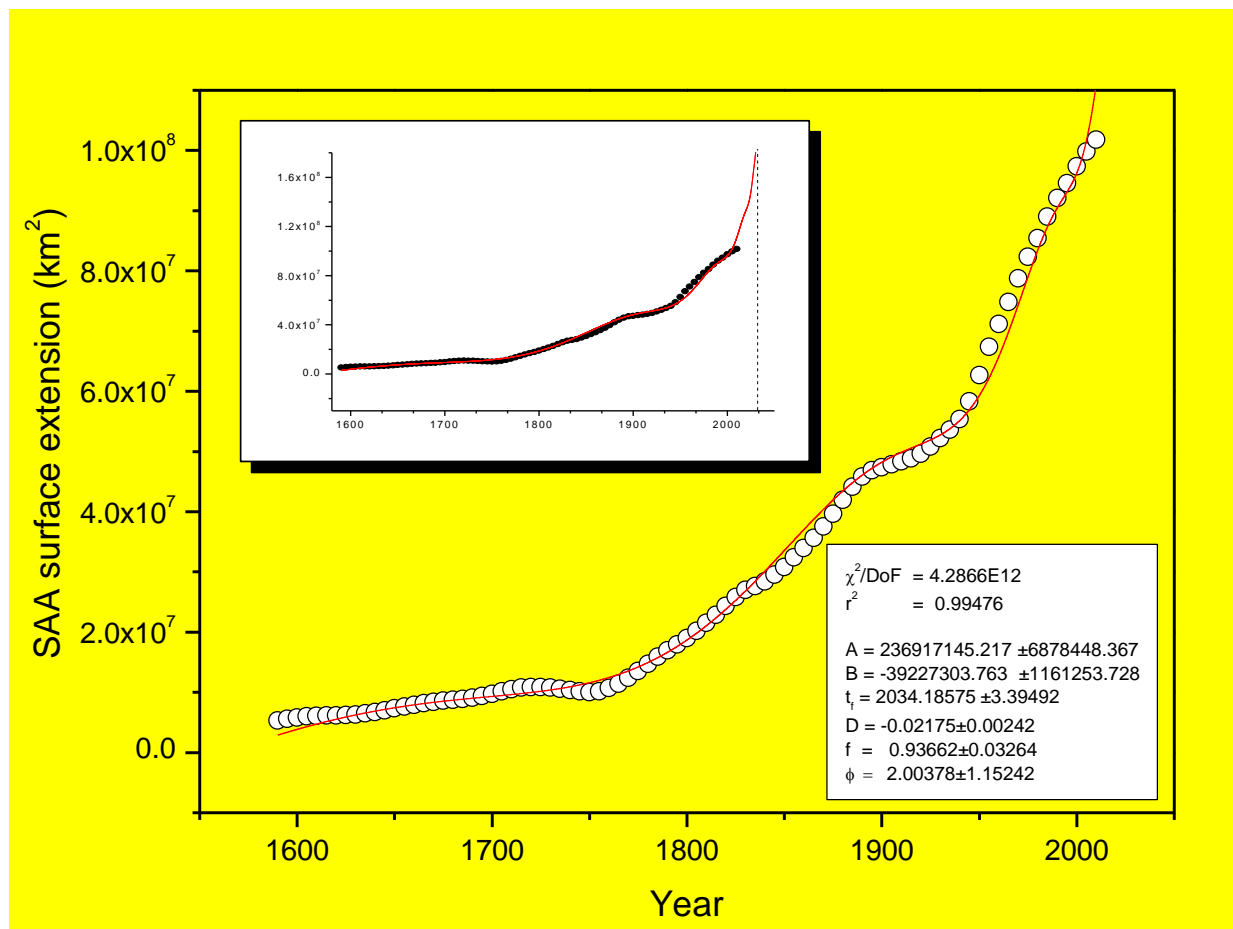
Spatial and temporal characteristics of the SAA at the Earth's surface (1840 - 2015):



Western Drift
around 0.1-0.2°/year



The geomagnetic field as a critical system: An imminent geomagnetic transition?



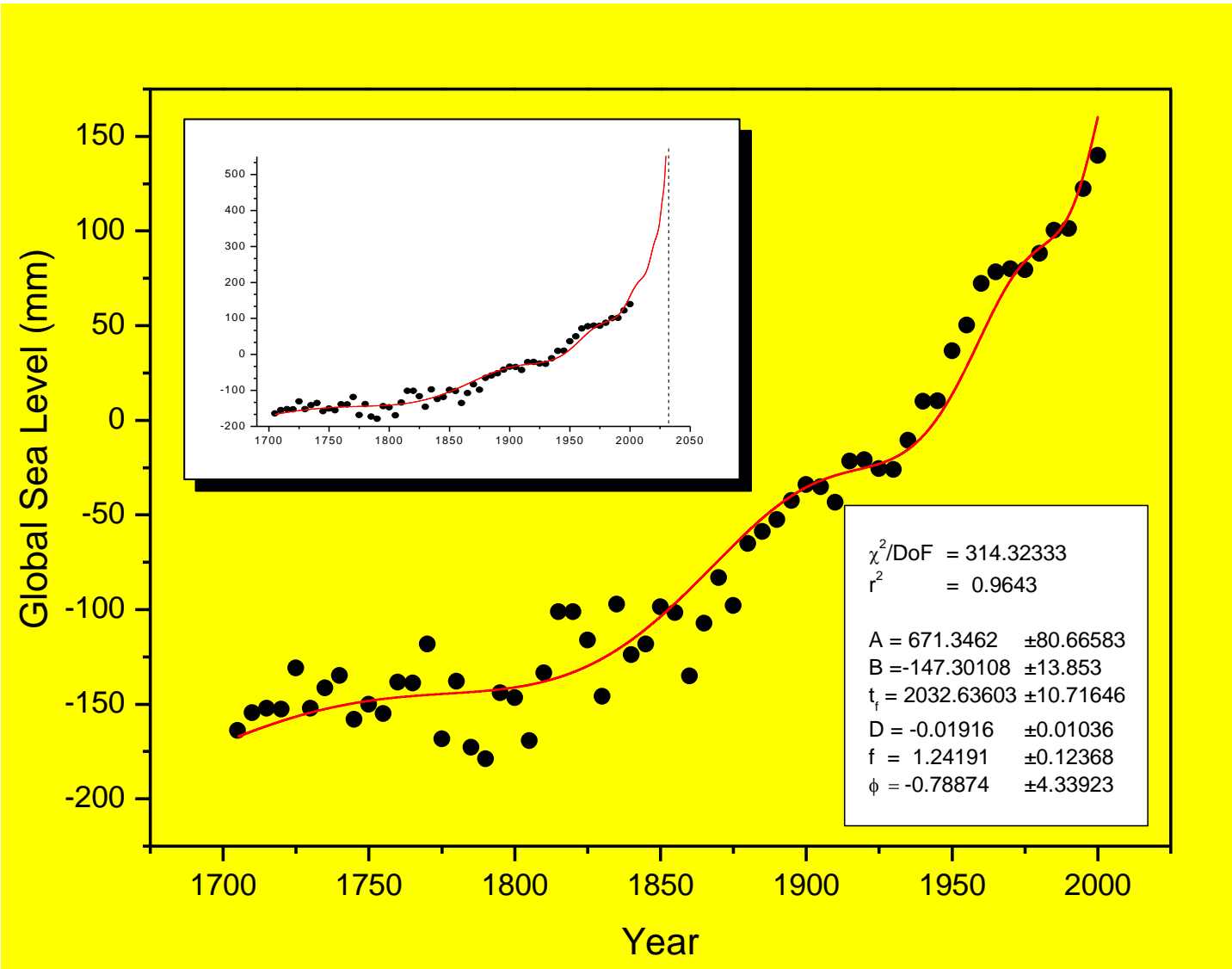
A log-periodic singular function satisfies the behaviour in time of SAA with critical time:

$$t_c = 2034 \pm 3 \text{ years}$$

when a possible critical transition might occur.

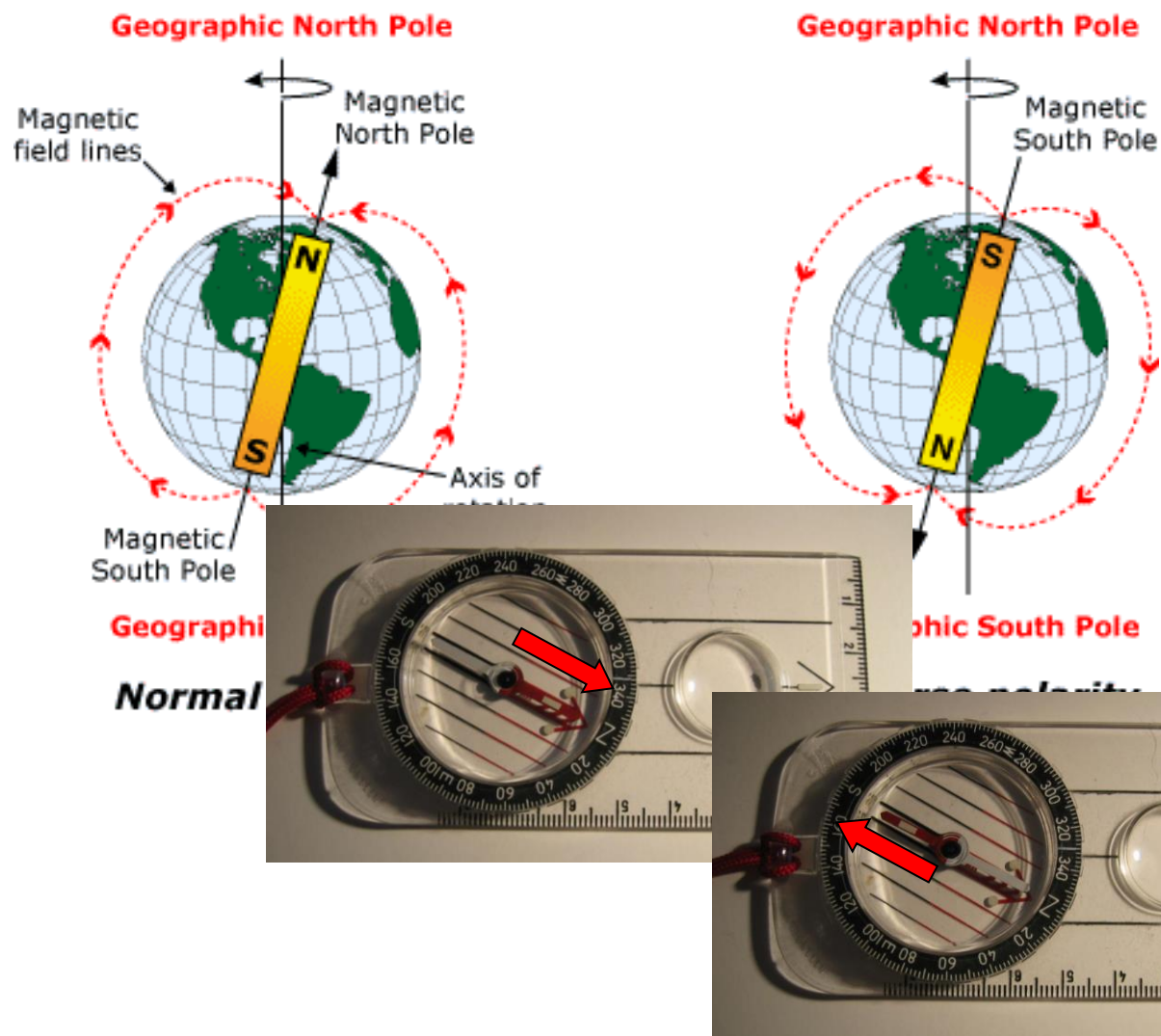
Would this be the point of no-return for a transition?

Also for the mean Global Sea Level?

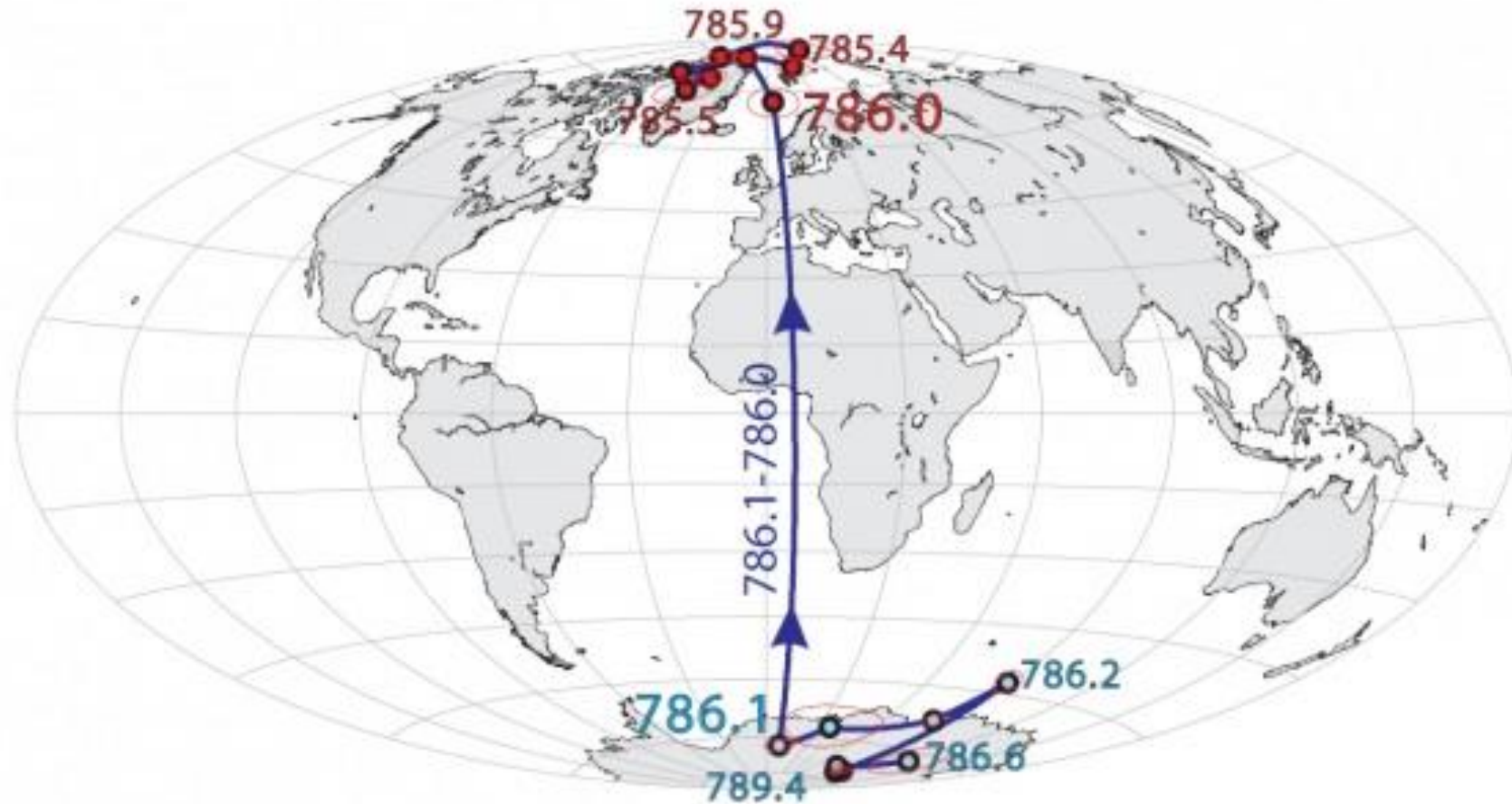


$t_c = 2033 \pm 10$ years

Reversals of the geomagnetic field



A reversal or excursion can be very rapid (in less than a century!)

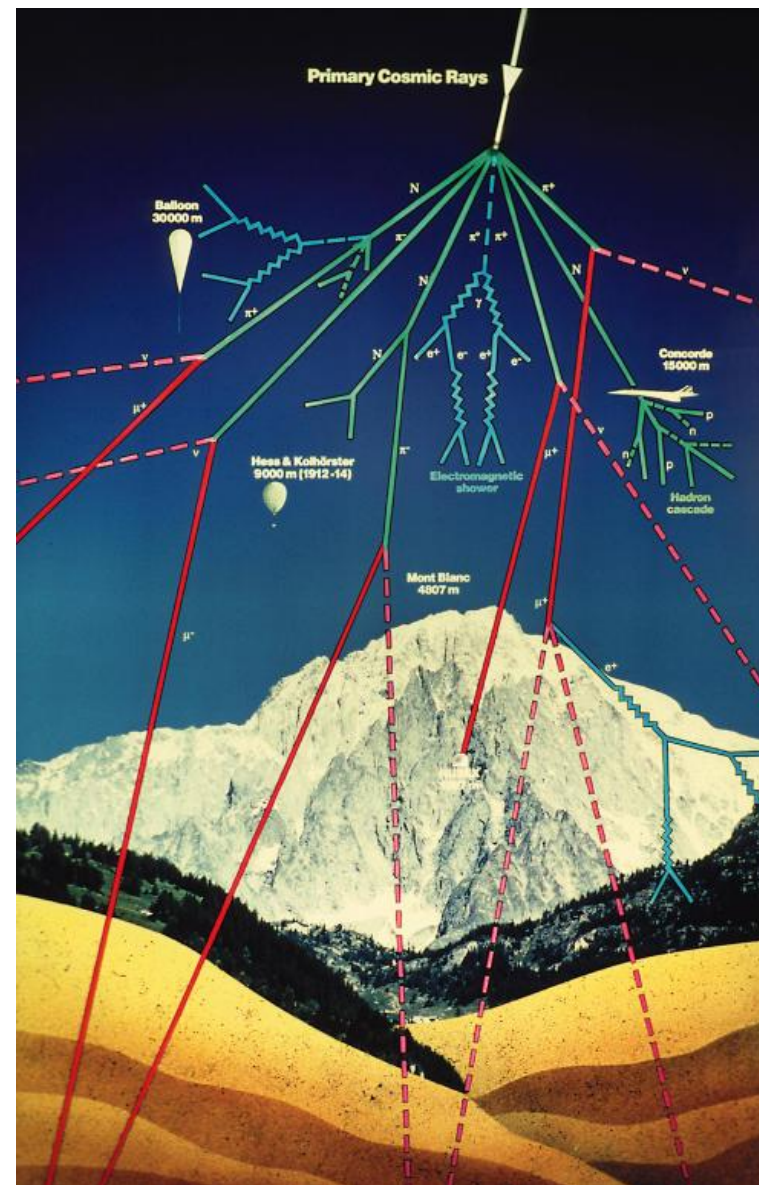


Path of the geomagnetic pole during the last reversal 800 thousand years ago. Reversal in less than a century.

Why worry?

Cosmic Rays

- The Earth's magnetic field deflects charged particles
 - During a reversal we will have as high dosages as at high latitudes (by a factor of 2-3 w.r.t. mean latitudes)
- The Earth's atmosphere absorbs radiation
 - Higher dosages when in an aircraft



Original Photo CERN



Magnetic field and Plants

The absence of a magnetic field reduces the capability of plants for photosynthesis

Forum

From Trends in Plant Science, Jan. 2014

Cell
PRESS

Magnetoreception: an unavoidable step for plant evolution?

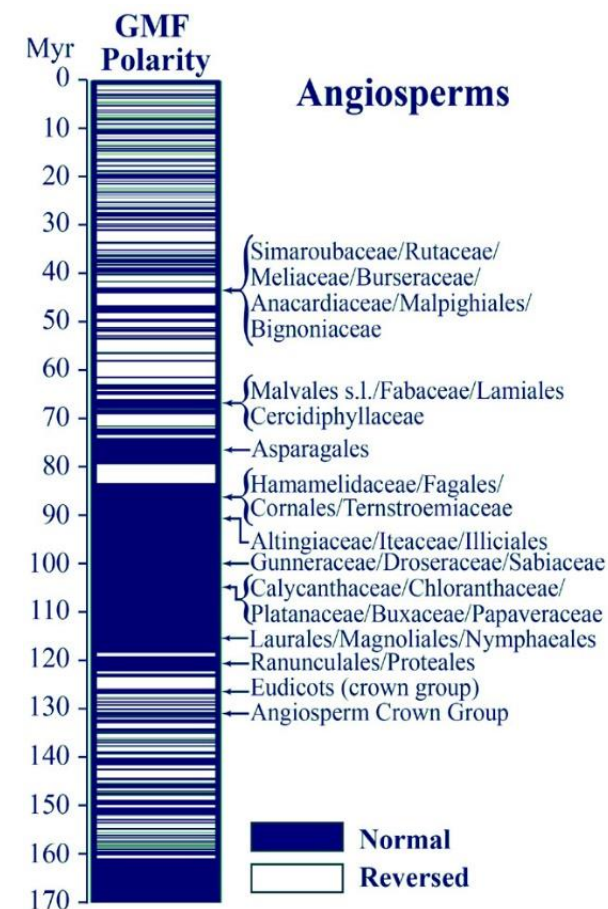
Andrea Occhipinti¹, Angelo De Santis², and Massimo E. Maffei¹

¹ Department of Life Sciences and Systems Biology, Innovation Centre, Via Quarellino 15/A, University of Turin, 10135 Turin, Italy

² Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata, 605 00143 Rome, Italy

The geomagnetic field (GMF) is steadily acting on living systems, and influences many biological processes. In animals, the mechanistic origin of the GMF effect has been clarified and cryptochrome has been suggested as a chemical magnetoreceptor. Here we propose a possible role for the GMF variations in plant evolution.

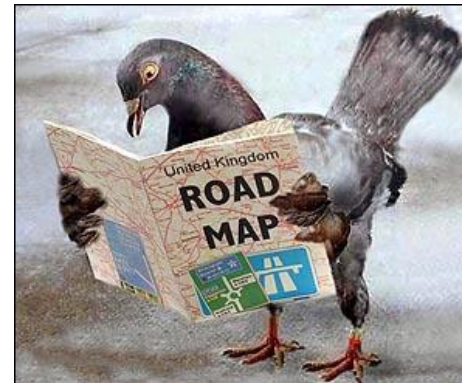
mean time between one reversal and the next has been estimated to be around 300 000 years. Because the present normal polarity started around 780 000 years ago, and significant field decay has been taking place during the past 1000 years, an imminent geomagnetic reversal would not be unexpected. The South Atlantic anomaly, a surface mani-



Triaxial Helmholtz coils systems (A) and power controls (B)
 At University of Turin (Italy)

Other Possible Effects

- Loss of Earth's atmosphere – “blown away” by the solar wind?
- This is thought to have happened on Mars - but over period of a billion years
- Atmospheric changes
- Ozone depletion
- Climate change?
- Difficult to answer – cloud nucleation by cosmic rays?
- Animal navigation?
- Pace of adaption





7. Conclusions

- 1. Earth is a unique planet**
- 2. Its position in the solar system has permitted life**
- 3. Tectonics & Earthquakes are expression of planetary vitality**
- 4. Earth's magnetic field protects us**
- 5. South Atlantic Anomaly is a window from which solar wind and radiation can penetrate into the atmosphere**
- 6. SAA could be a precursor of a reversal or excursion?**

Thanks !!!

Thanks!!

Acknowledgements

- Carlo Laj for Organizing GIFT-EGU seminars

And to whom funds my research:

- INGV (LAIC-U project)
- ESA (SAFE project) →
- ASI (Limadou Project)

Credits: images from web





Ma perché i pianeti sono a quelle distanze dal Sole?



Una vecchia storia: la “legge” di Titius-Bode:

$$D_n = 0.4 + 0.3 \cdot 2^n \quad n = -\infty, 0, 1, 2, 3, \dots$$

$$D_{-\infty} = 0.4 \quad a \text{ (Mercurio)} = 0.39 \text{ UA}$$

$$D_0 = 0.7 \quad a \text{ (Venere)} = 0.72 \text{ UA}$$

$$D_1 = 1.0 \quad a \text{ (Terra)} = 1.00 \text{ UA}$$

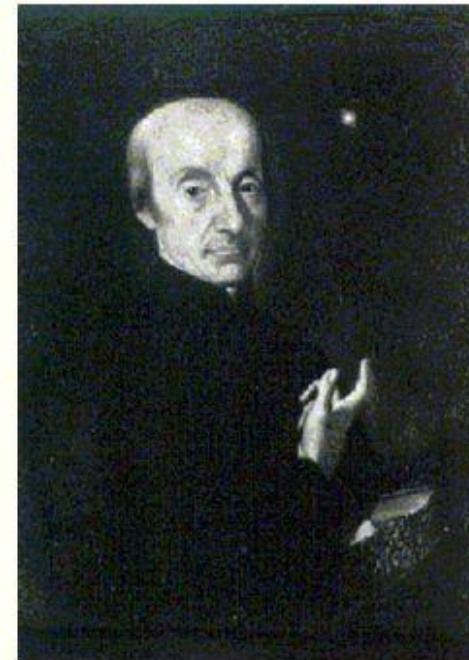
$$D_2 = 1.6 \quad a \text{ (Marte)} = 1.52 \text{ UA}$$

$$D_3 = 2.8 \quad a \text{ (??)} = 2.8 \text{ UA}$$

$$D_4 = 5.2 \quad a \text{ (Giove)} = 5.20 \text{ UA}$$

$$D_5 = 10.0 \quad a \text{ (Saturno)} = 9.54 \text{ UA}$$

$$D_6 = 19.6 \quad a \text{ (Urano)} = 19.18 \text{ UA}$$

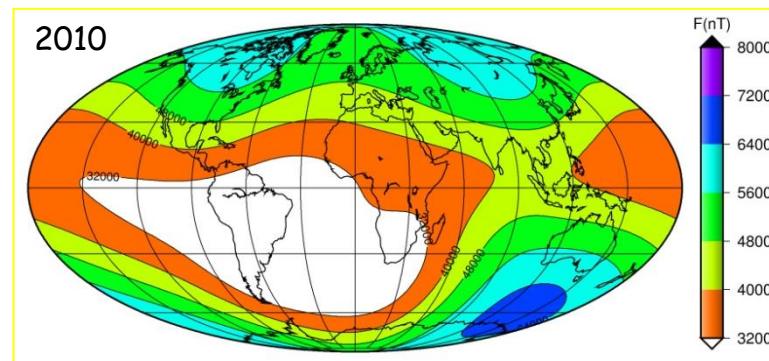
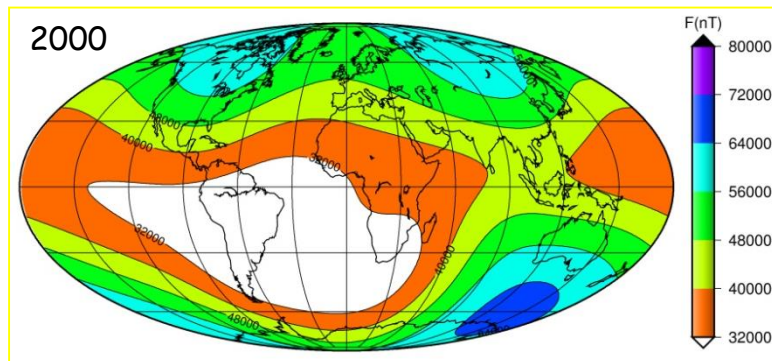
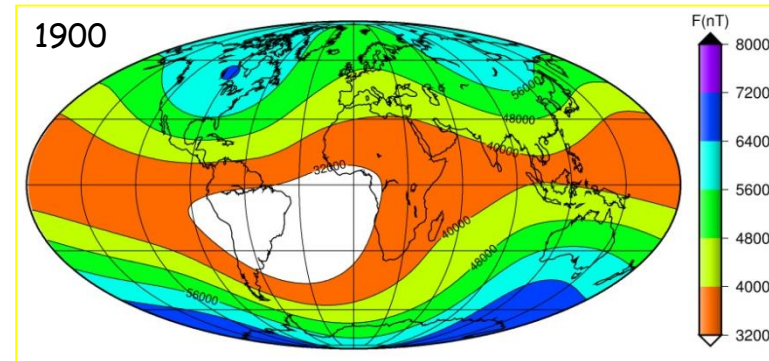
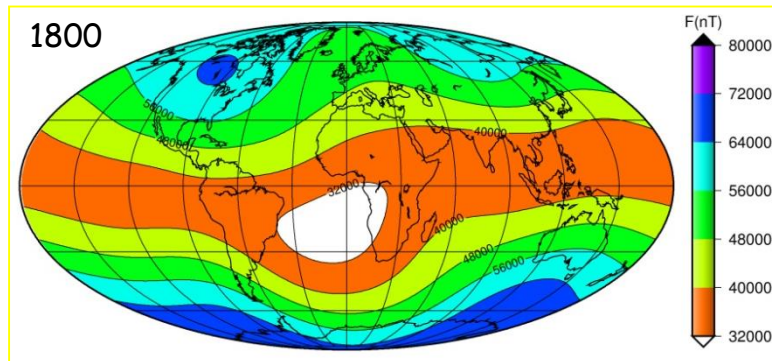
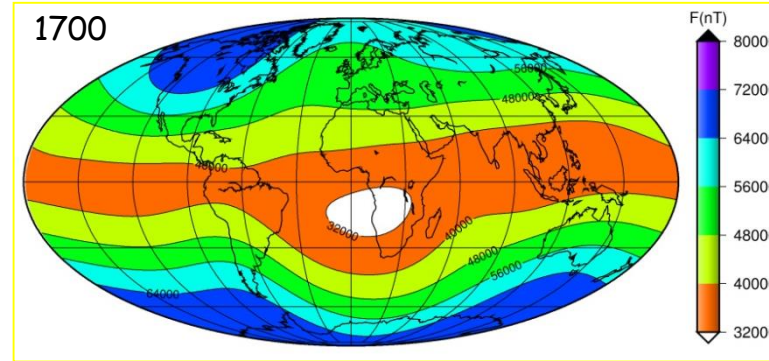
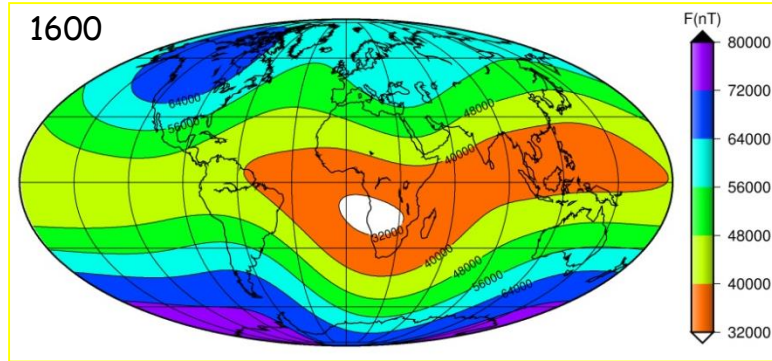


Johann Elert Bode 1747-1826

SAA Space-time evolution



INGV



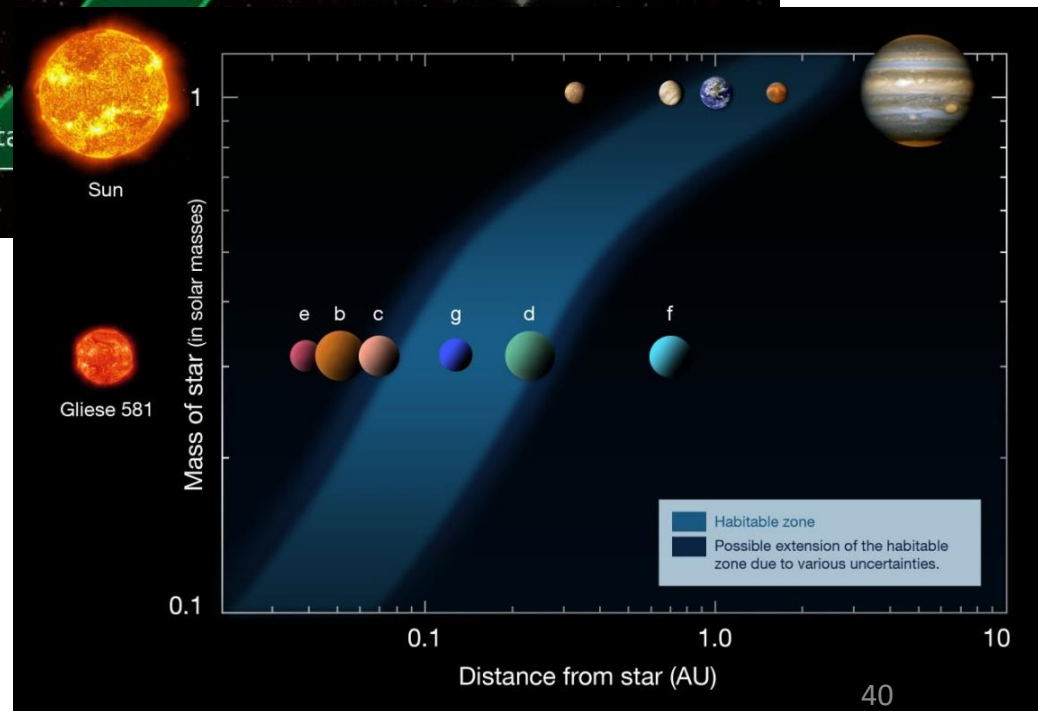
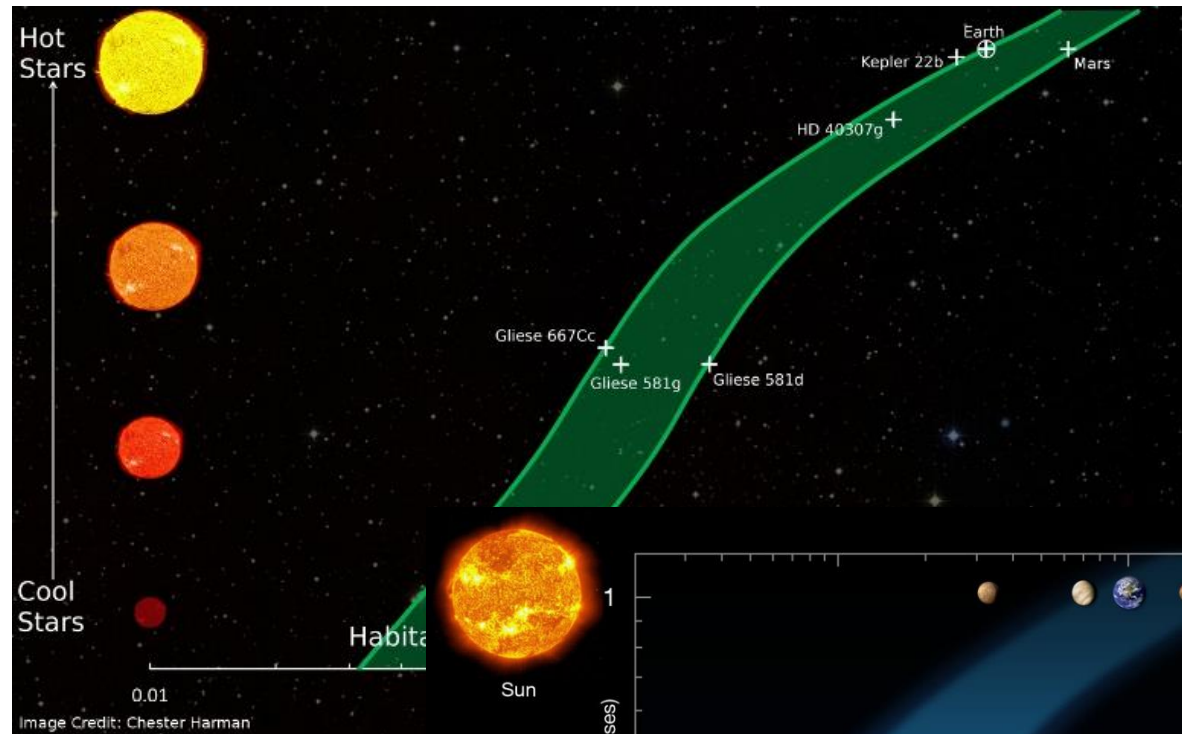
Habitable zone around a star

Una **zona abitabile** è quella regione intorno ad una stella ove è teoricamente possibile per un pianeta mantenere acqua liquida sulla sua superficie e quindi sostenere la vita

Dipende dalla temperatura e dalla luminosità (e dimensione) della stella stessa.

Scoperte recenti: Super Terre

Esempio della stella nana rossa Gliese 581 con 2 forse 3 pianeti abitabili (a 20 anni luce da noi)





Physical mechanisms behind the observed correlation

- A first external mechanism: an increase of the SAA area facilitates the inflow of charged particles from space, which implies a warming of the atmosphere and a consequent melting of major ice caps (Antarctica and Greenland) that finally causes a global increase of sea level.
- A second external mechanism: a possible depletion of the ozone layer in the upper stratosphere over the South Atlantic region can modify the radiative flux at the top of the atmosphere and hence cause changes in the weather and climate patterns, including cloud coverage.
- The third internal mechanism: a convective vigour in the outer core causes a variation of the magnetic field and an elastic deformation at the Earth's surface (Greff-Lefftz et al., 2004). Fang et al. (1996) shows that geostrophic pressure fields, derived from "frozen-flux" core surface flow estimates, produce a relative radial velocity field in the range of 0.3 mm/yr; although this value is lower than the typical changes of GSL, larger pressure effects cannot be excluded.