

When did Earth's magnetic field start and how has it contributed to the preservation of life?

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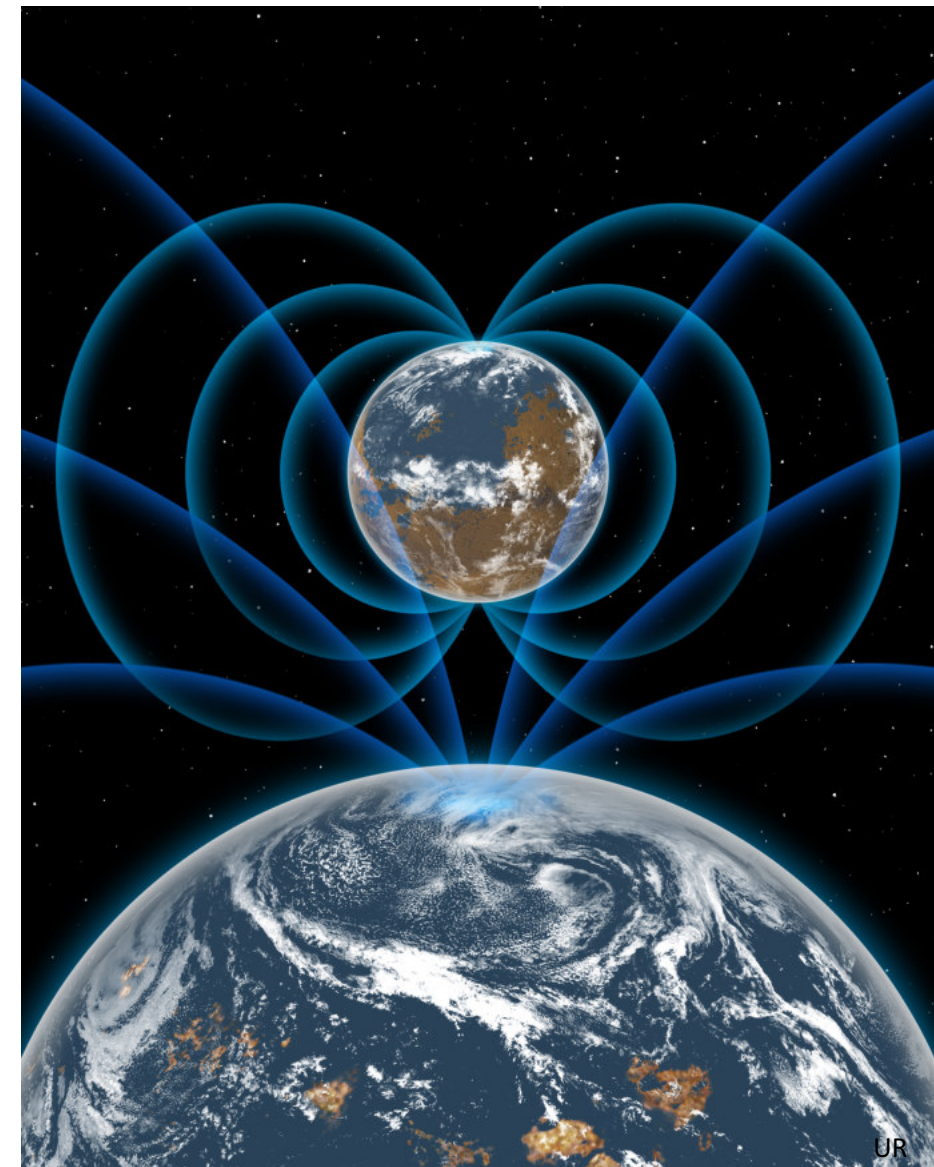
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EGU GIFT 2018

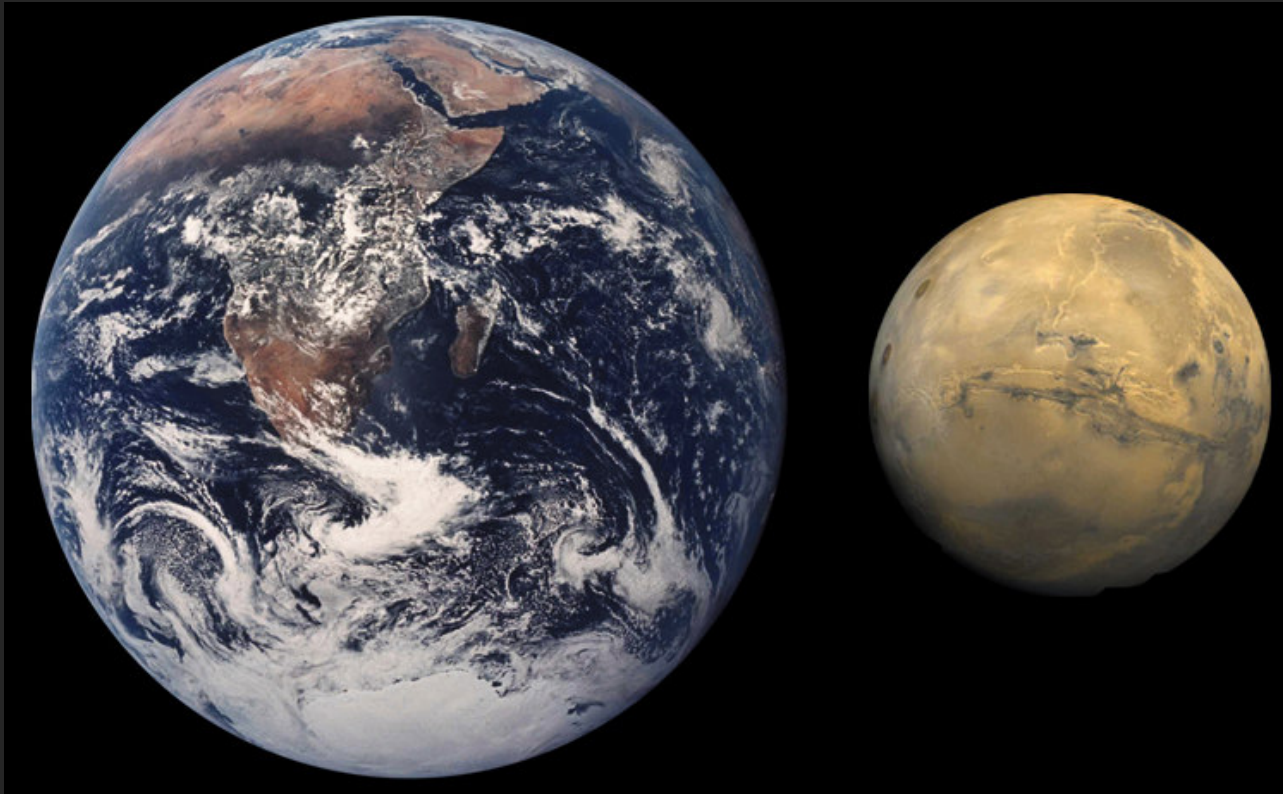
When did Earth's magnetic field start and how has it contributed to the preservation of life?

Are we in the early phases of a geomagnetic reversal and will this affect life?



Earth and Mars

4.2 billion years ago



Earth and Mars
today



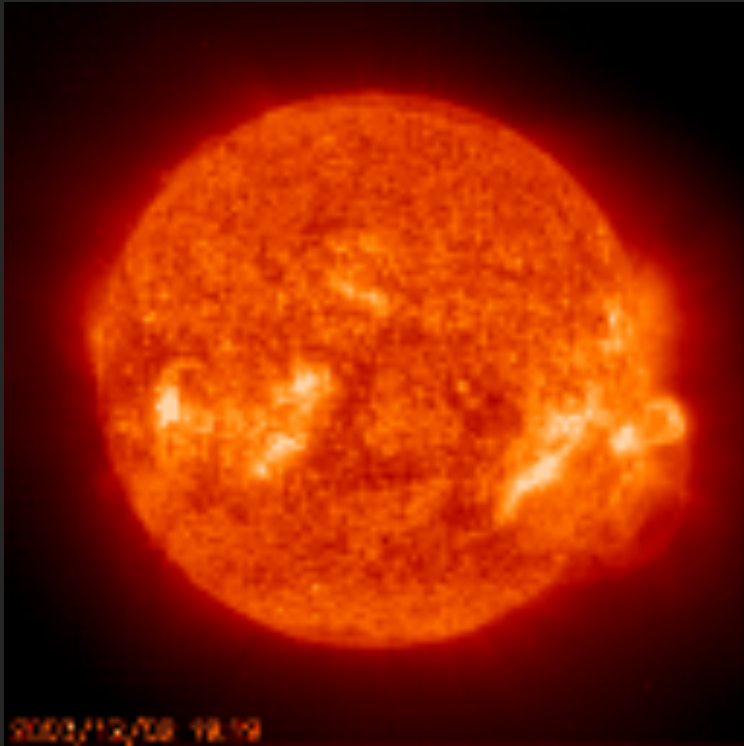
Why do comets have tails?



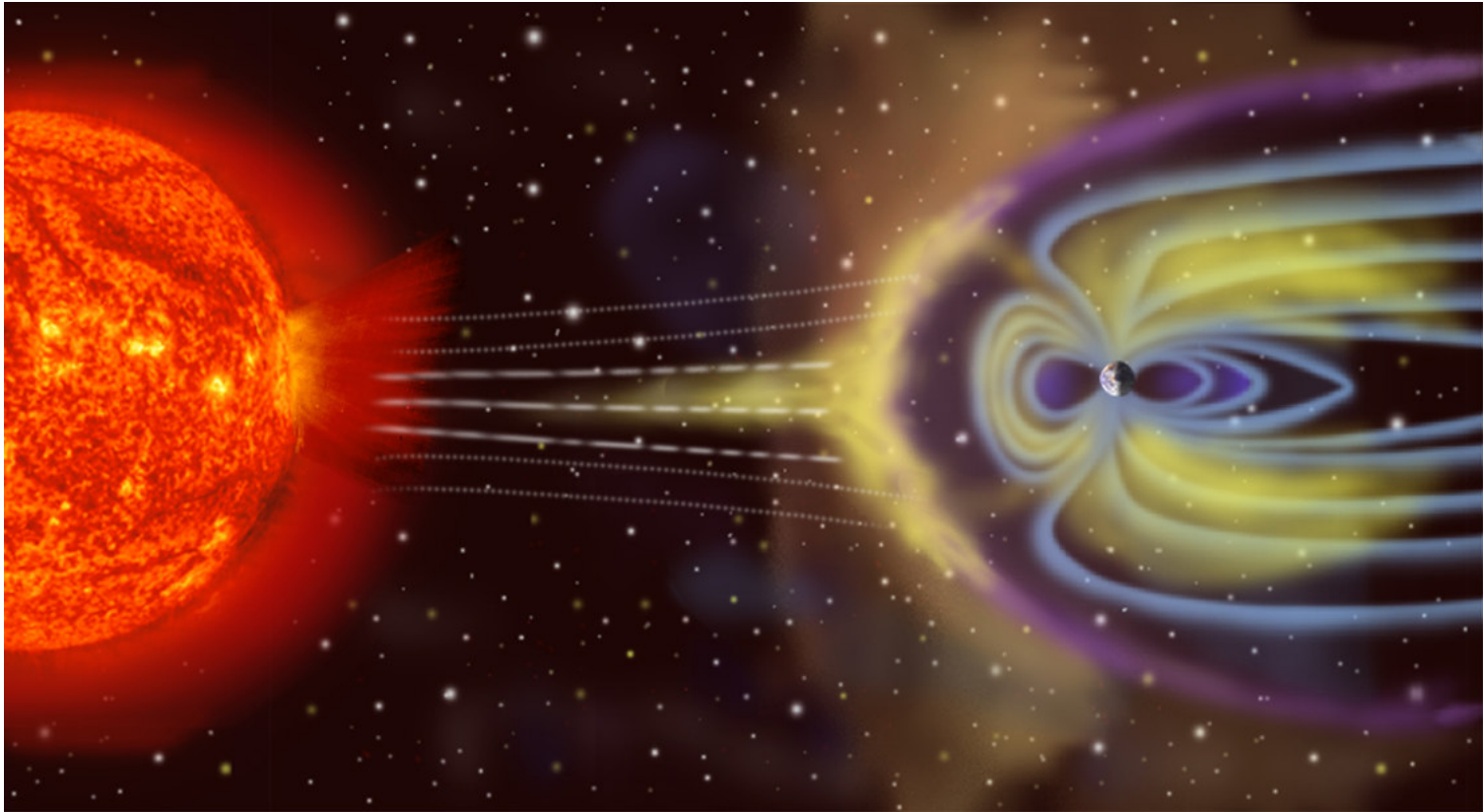
Why do comets have tails?

Visible manifestation of the invisible:

“Solar Wind”

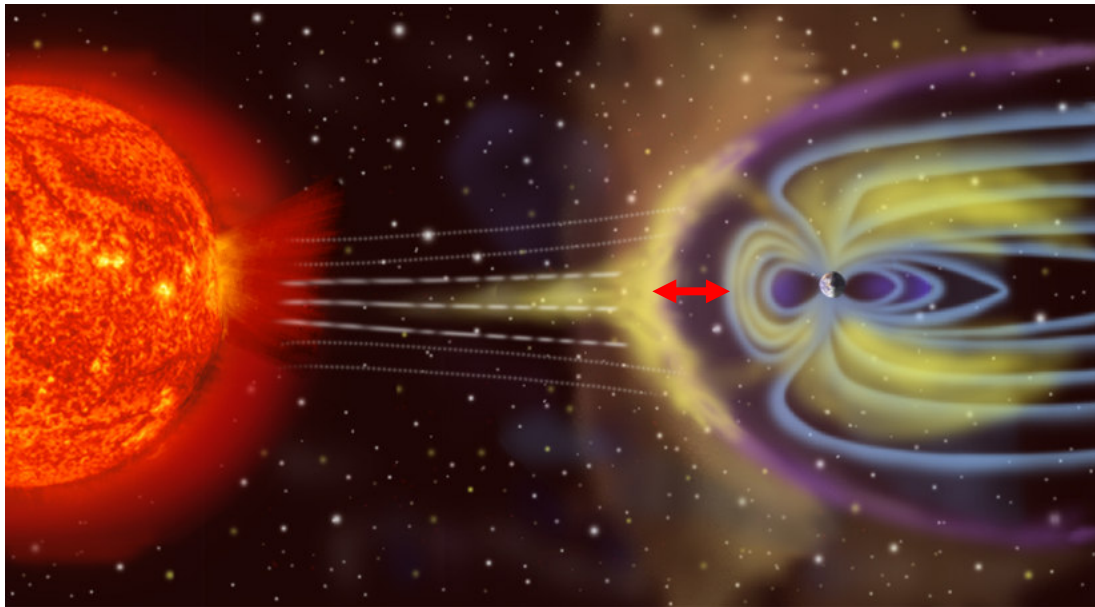


Constant stream of *charged* particles
from the Sun



Earth's magnetic shield

Pressure balance between the solar wind and the geomagnetic field



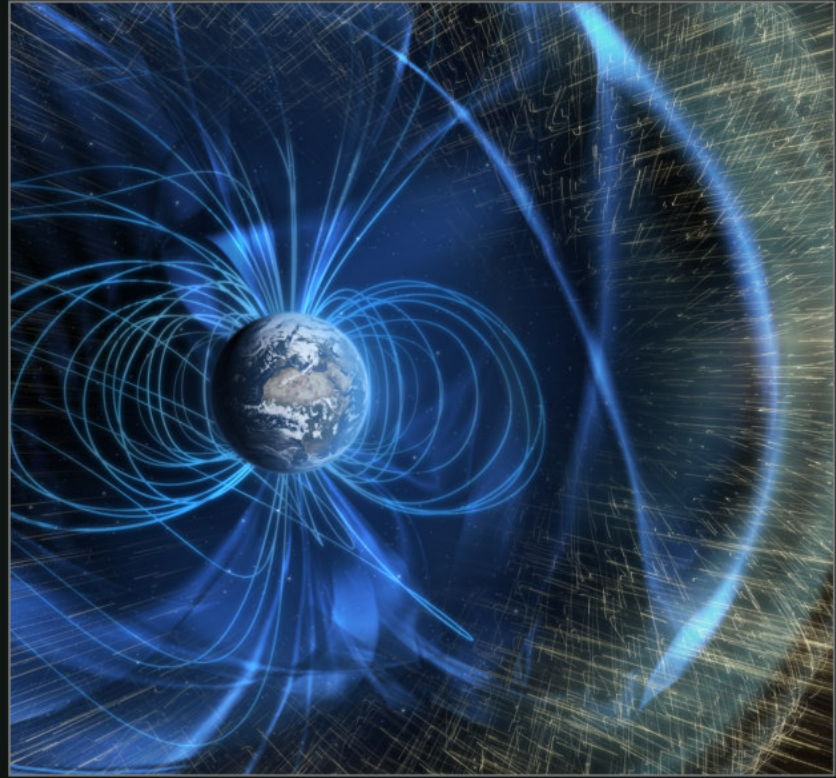
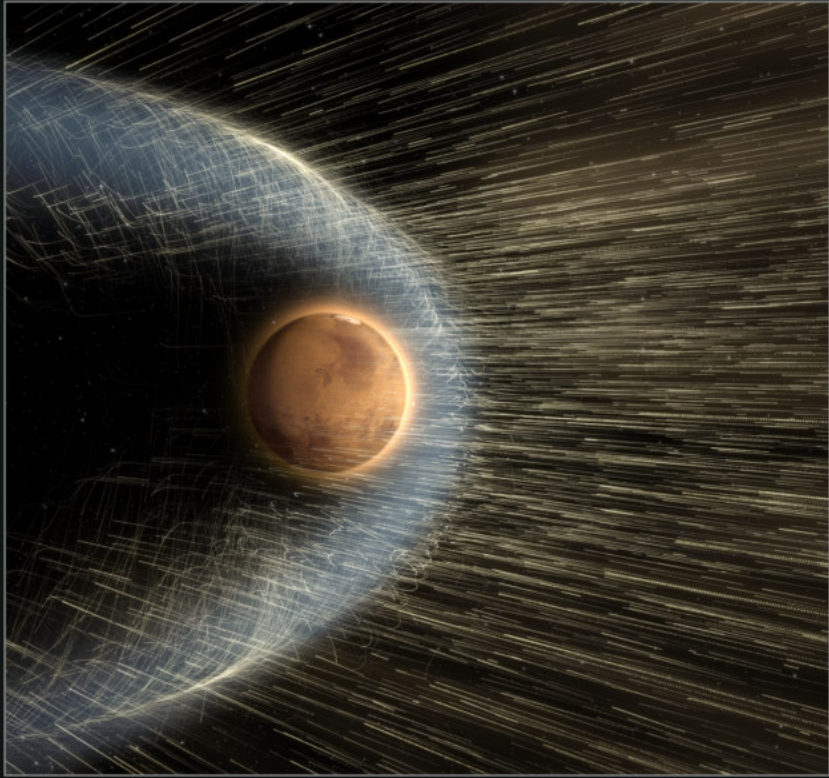
Standoff distance

$$r_s = \left[\frac{\mu_0^2 f_0^2 (M_E^2)}{4\pi^2 (2\mu_0 P_{sw} + B_{IMF}^2)} \right]^{1/6}$$

Magnetopause standoff distance

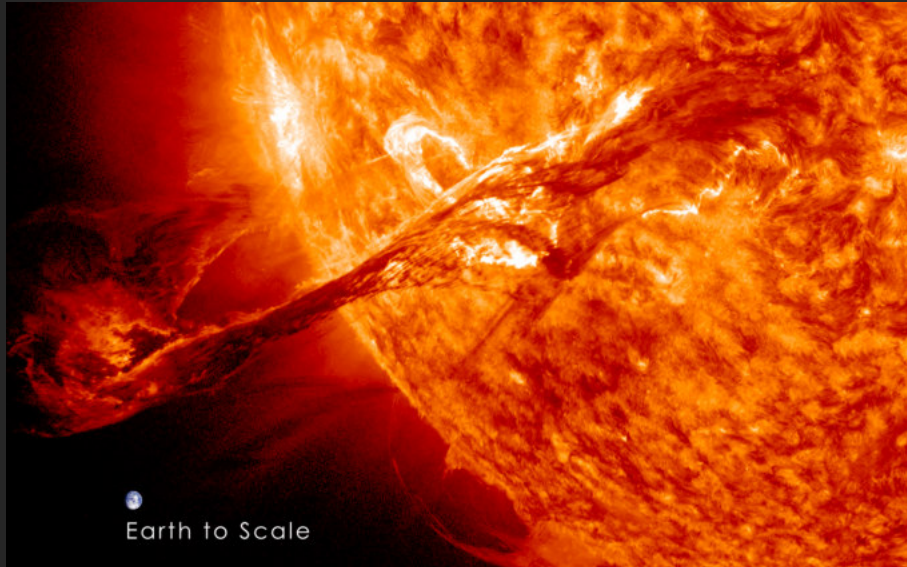
Solar wind pressure

Dipole Moment (Geomagnetic field strength)



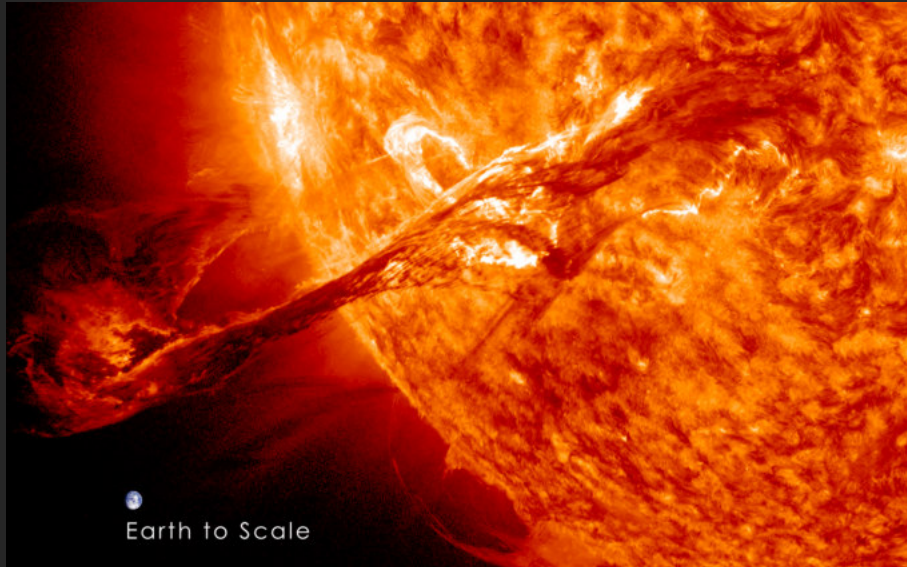
When did Earth's magnetic field start and how has it contributed to the preservation of life?

- When was Earth's magnetic shield in place?



Sometimes the Sun gets angry

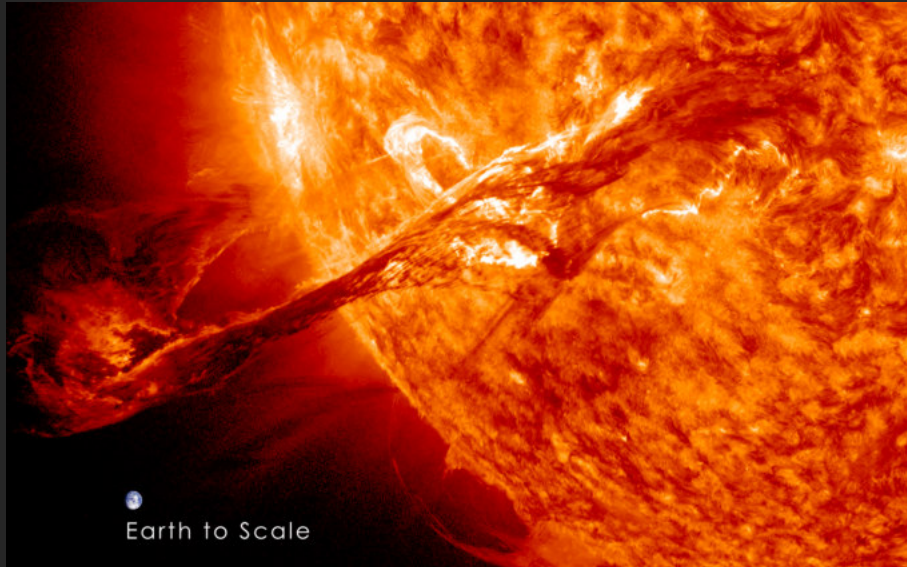
Coronal Mass Ejections (CMEs)



Sometimes the Sun gets angry

Coronal Mass Ejections (CMEs)

And it was much angrier when it was young



Sometimes the Sun gets angry

Coronal Mass Ejections (CMEs)

And it was much angrier when it was young

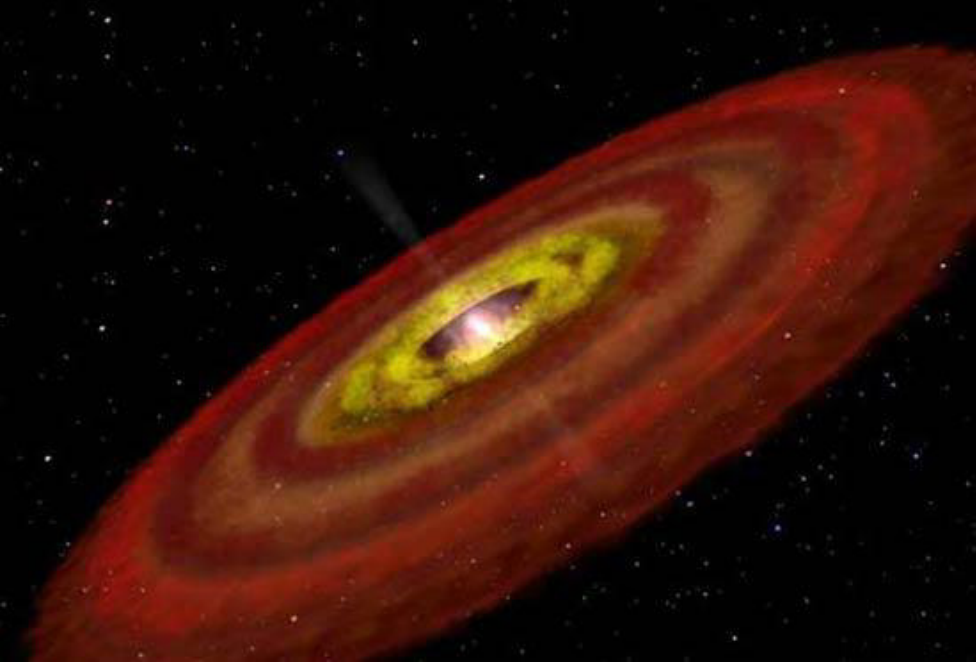
How do we know this?



Stars!

Solar analogs: stars that are similar to the Sun but of different age

We can use astronomical observations to obtain estimates of solar winds from these stars



A sun-like star's rotation decreases with time

Young, more rapidly rotating Sun generated winds orders of magnitude greater than today

Young Sun is less bright but emits X-rays to far Ultraviolet radiation orders of magnitude greater than today

Young Earth would have been vulnerable to atmospheric erosion!

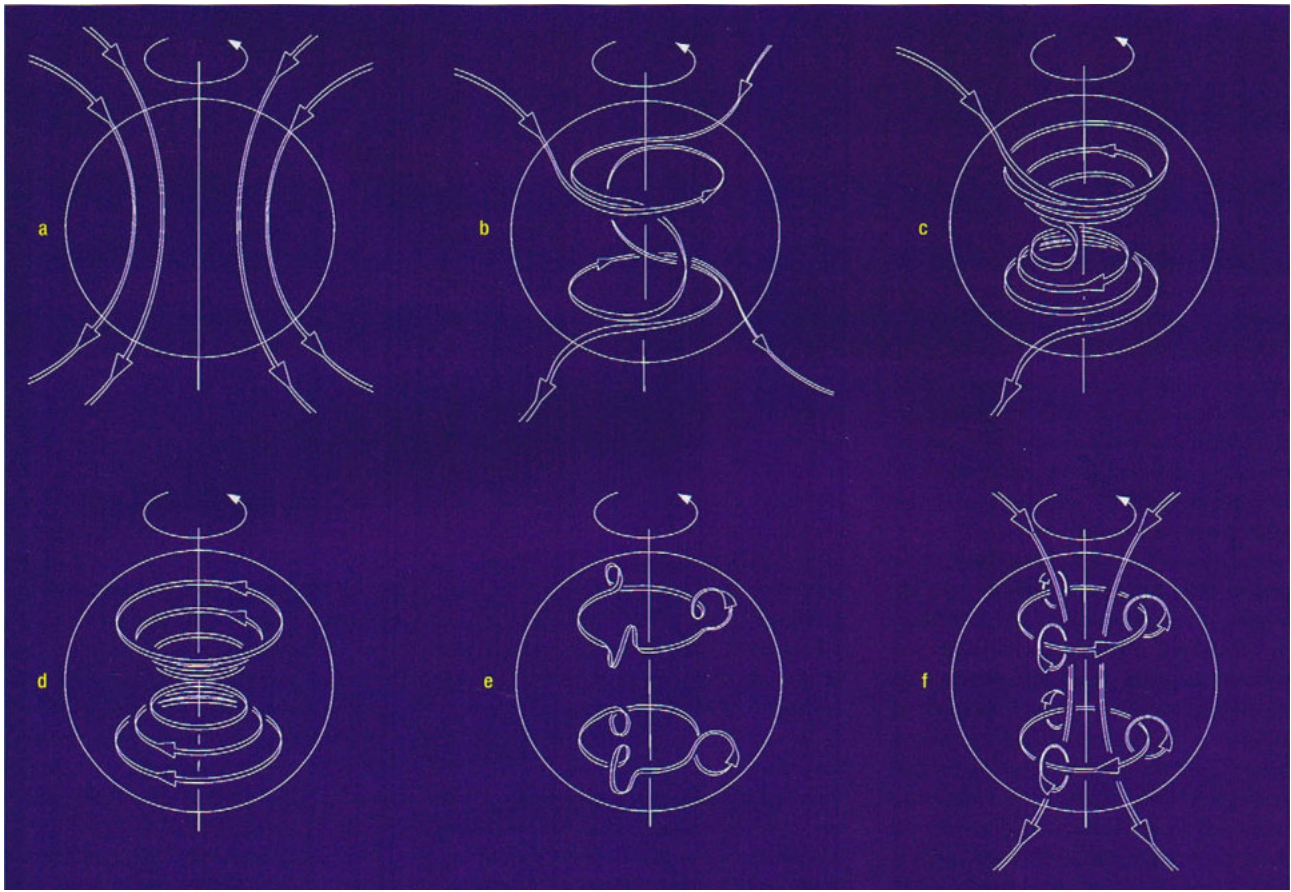
Hence, the importance of a geomagnetic shield for the early Earth



When was the magnetic shield in place?

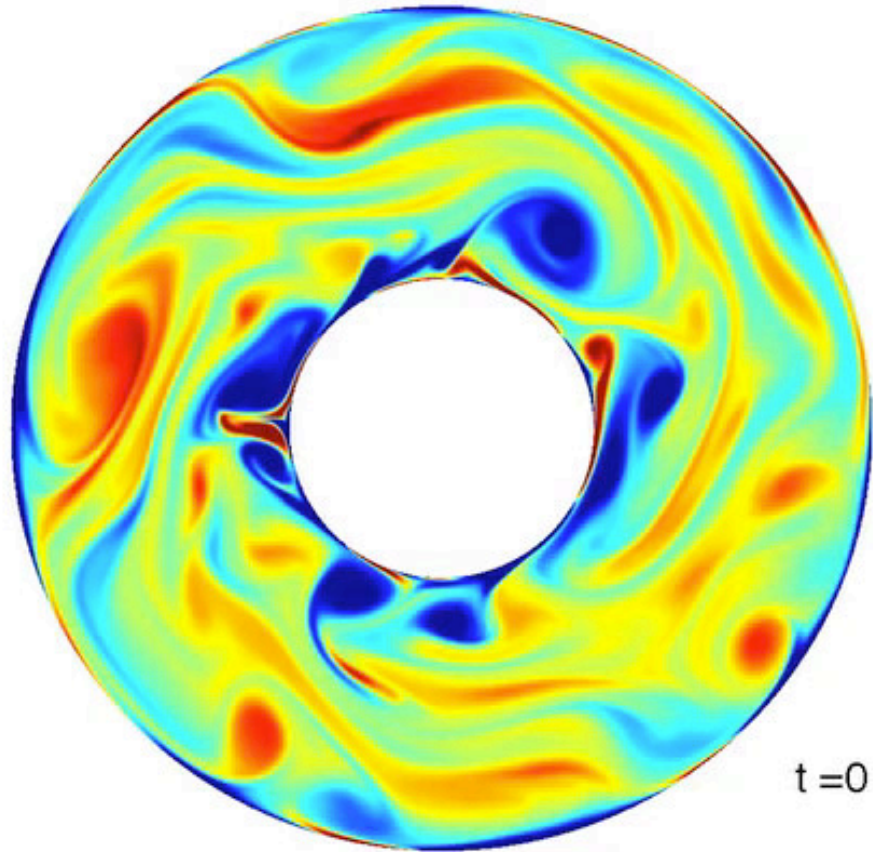
Ultimately the start of the geodynamo may be related to the Lunar forming impact

Why?



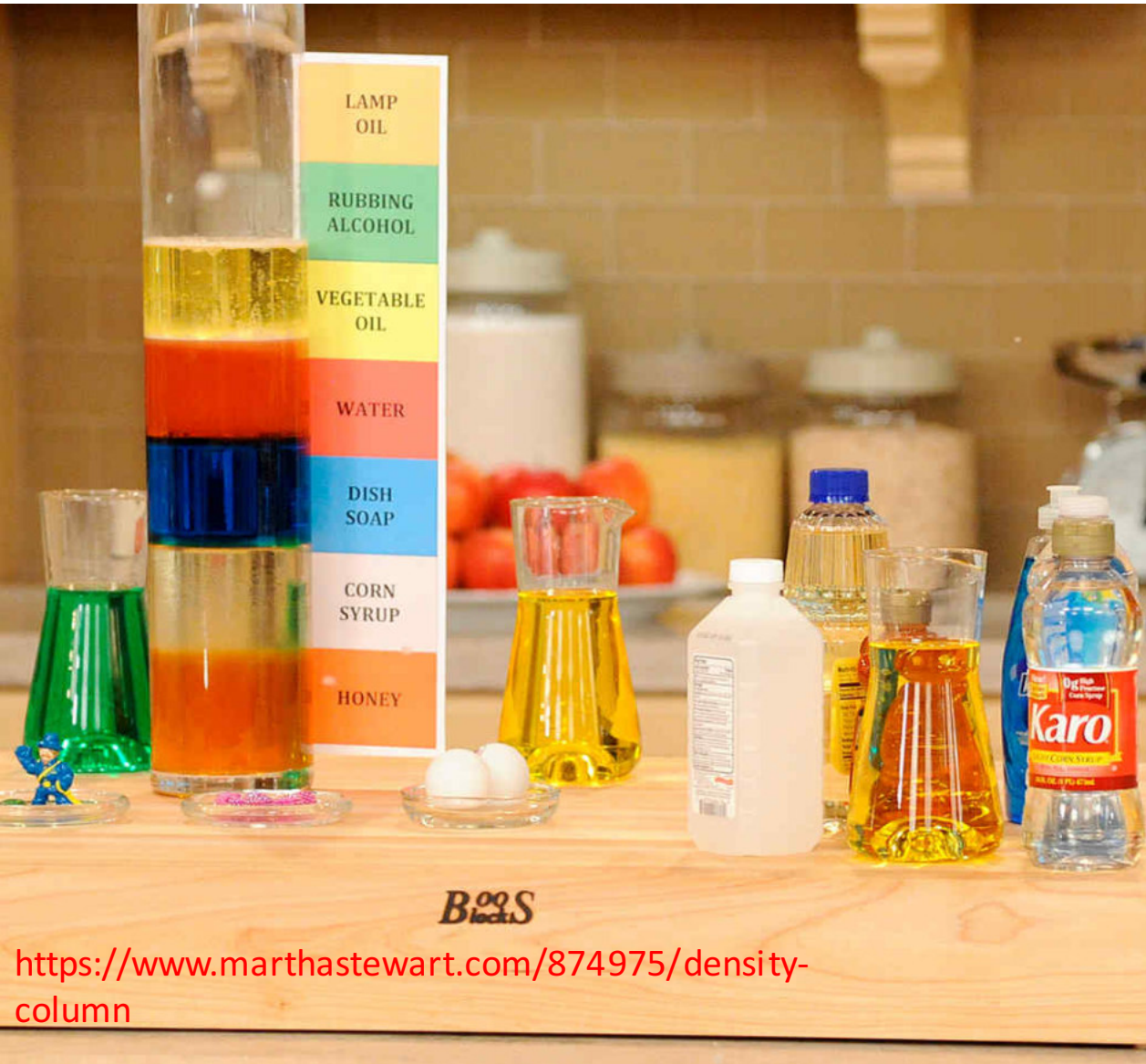
Self-sustaining
geodynamo requires
convection in the liquid
Iron core

Reversals and excursions of the geodynamo *Astronomy and Geophysics*. 1999



t=0

Calkins et al., The effects of boundary topography on convection in Earth's core *Geophys. J. Int.* (2012)



Tendency for Proto-Earth to develop Stratified layers in its core preventing convection and magnetic field generation

The lunar forming impact would have destroyed this layering

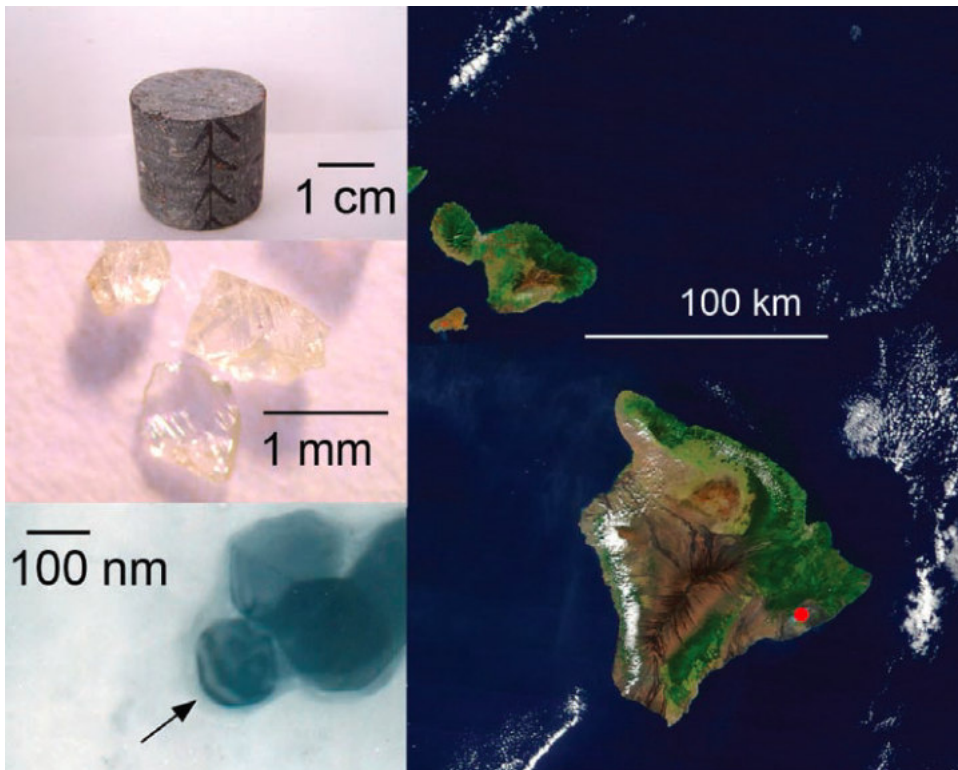
<https://www.marthastewart.com/874975/density-column>

Data on Earth's ancient magnetic field: Paleomagnetism



Single Silicate Crystal Paleointensity

Small is awesome: Minute magnetic mineral inclusions (50 nm-450 nm) in silicate crystals (e.g. feldspar) can preserve records of magnetic fields for *billions* of years

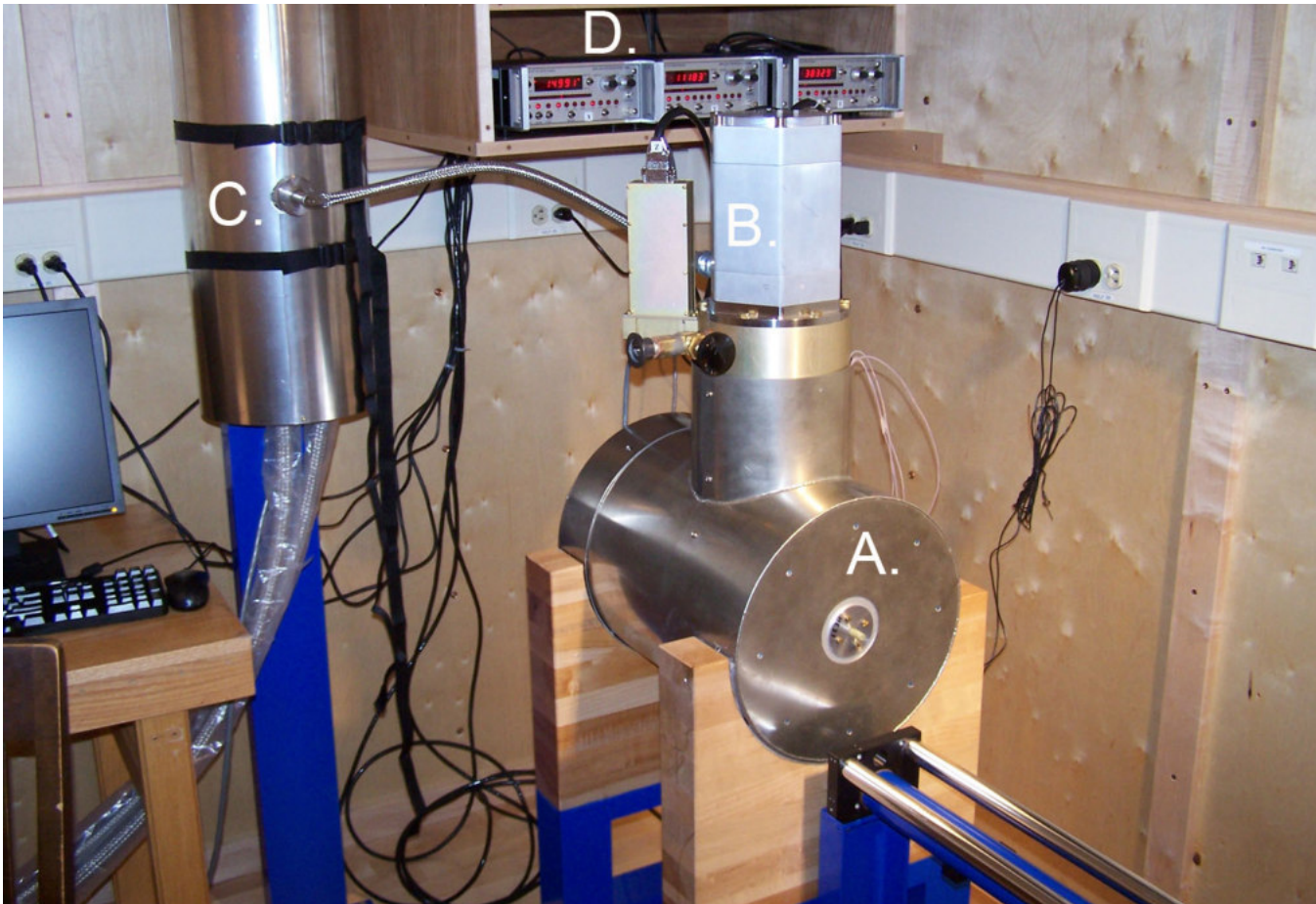




SQUID

Superconducting
quantum interference
device magnetometer

Supported by
NSF EAR-IF



One order of
magnitude greater
Sensitivity

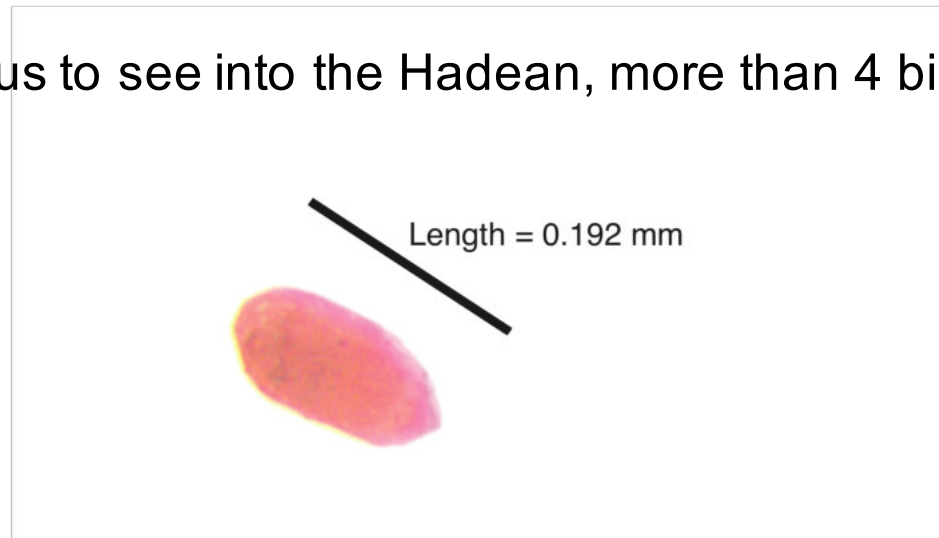
Approaching the
physical limits of
recording (Maxwell-
Boltzmann Limits)

Supported by
NSF EAR-IF/MRI

Ultra-high resolution DC SQUID magnetometer

Zircons: The oldest terrestrial materials

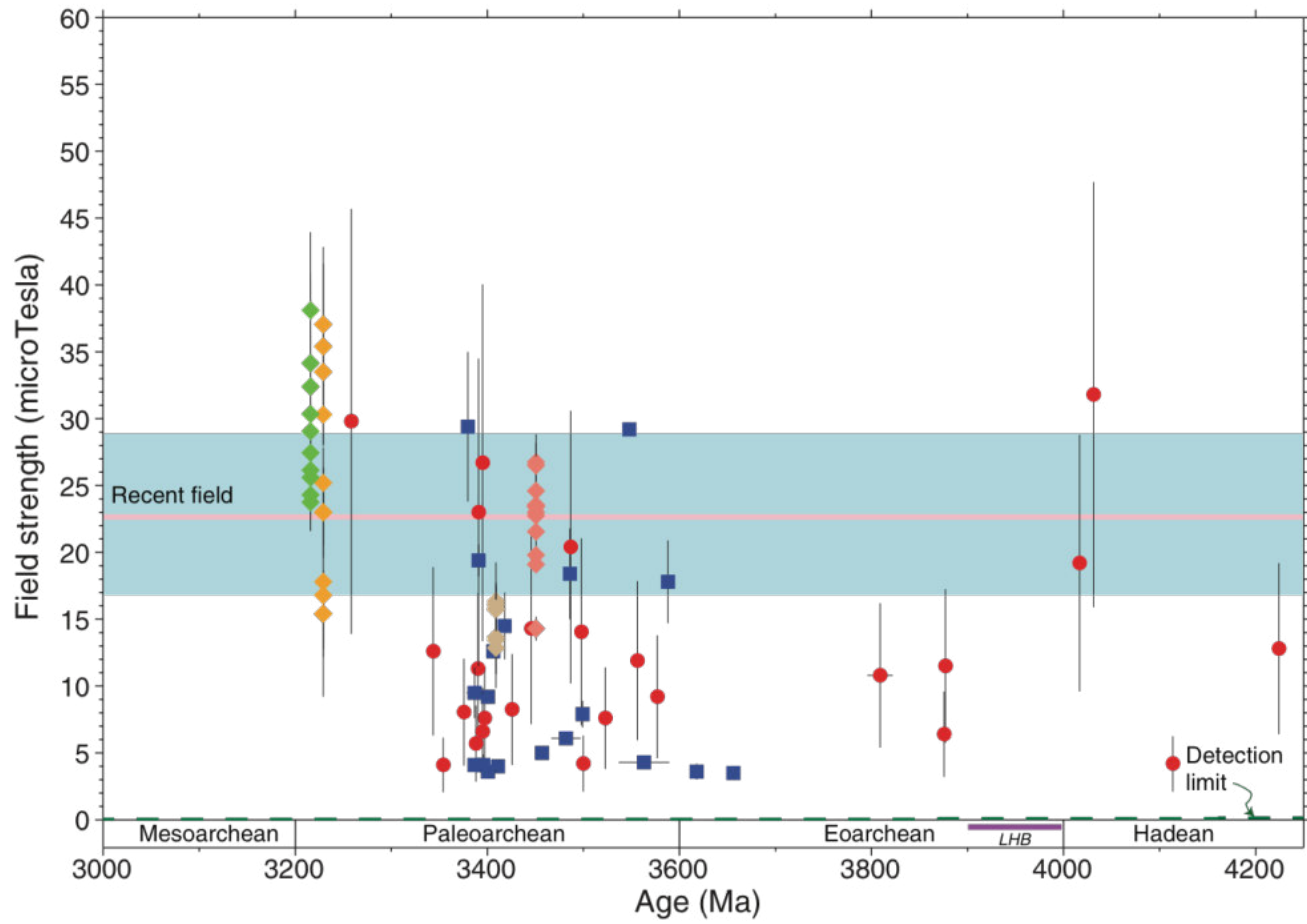
Allow us to see into the Hadean, more than 4 billion years ago





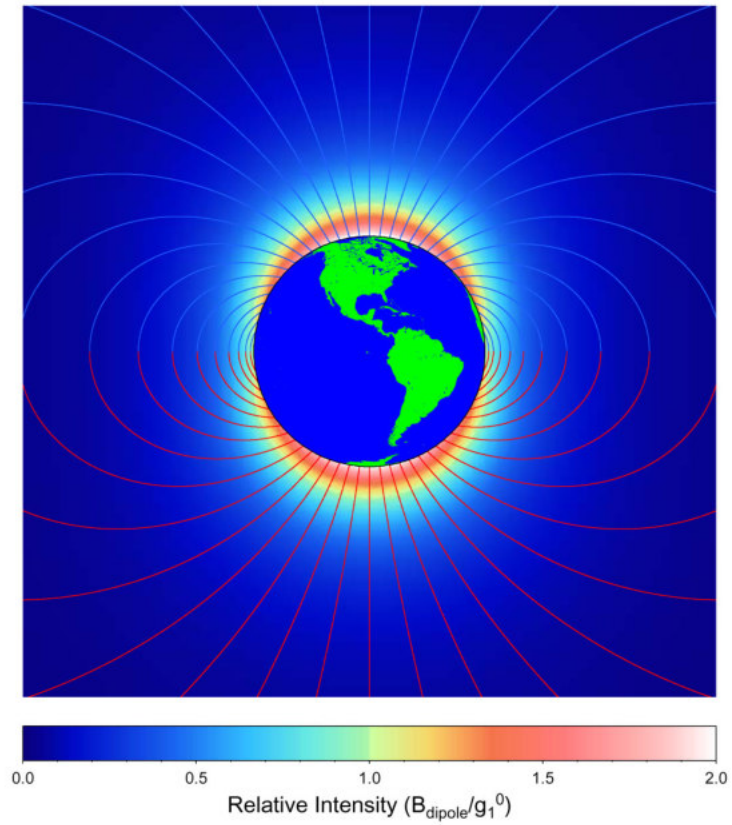


The First Billion Years of the Geodynamo

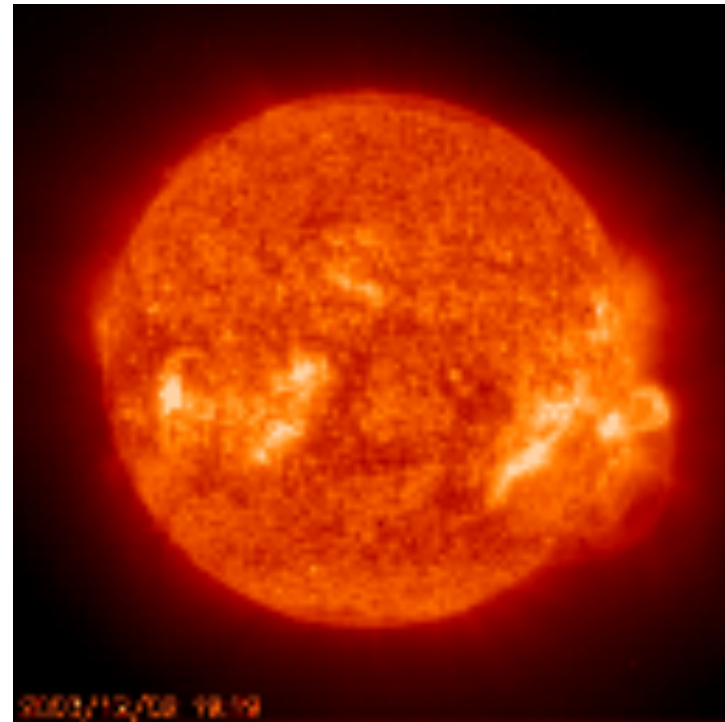


Tarduno et al., *Science*, 2015

Review



vs.



Review

Sun constantly ejects charged particles = Solar wind

Solar wind was intense for the early (Hadean) Earth (astronomy/astrophysics)

Magnetic fields can deflect the solar wind

The proto-Earth's core was probably stratified, inhibiting convection needed for generation of magnetic fields

Paleomagnetic data available so far suggest that there has been a seemingly uninterrupted magnetic field since the Hadean

When did Earth's magnetic field start and how has it contributed to the preservation of life?

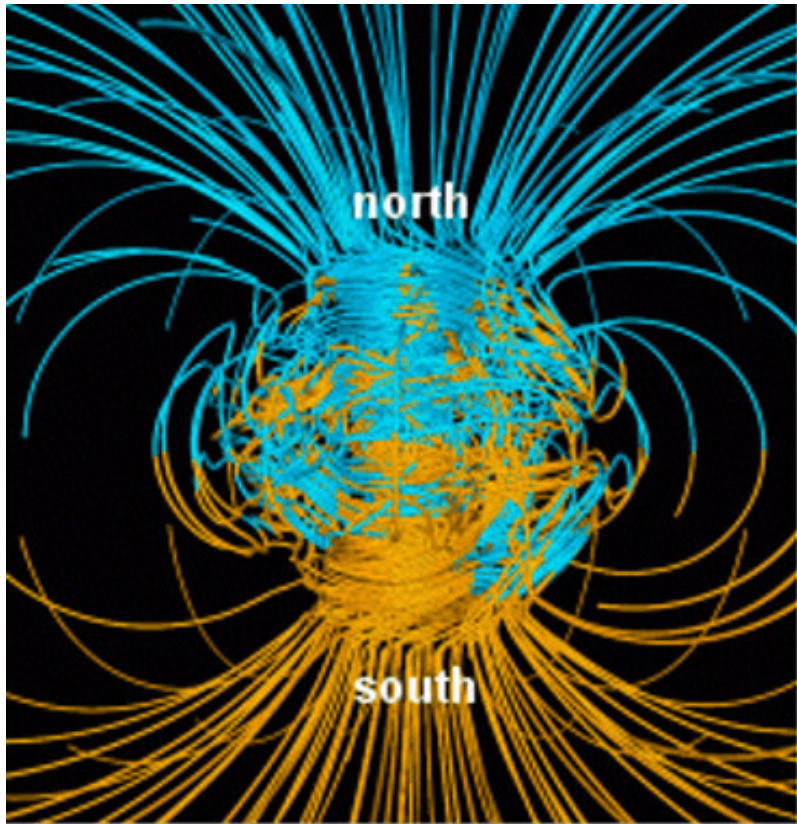
Probably shortly after the Lunar forming impact ~60 m.y. after the formation of the solar system

The magnetic shield is likely responsible for preventing early massive atmospheric erosion when the young Sun was pelting Earth with intensive charged particles

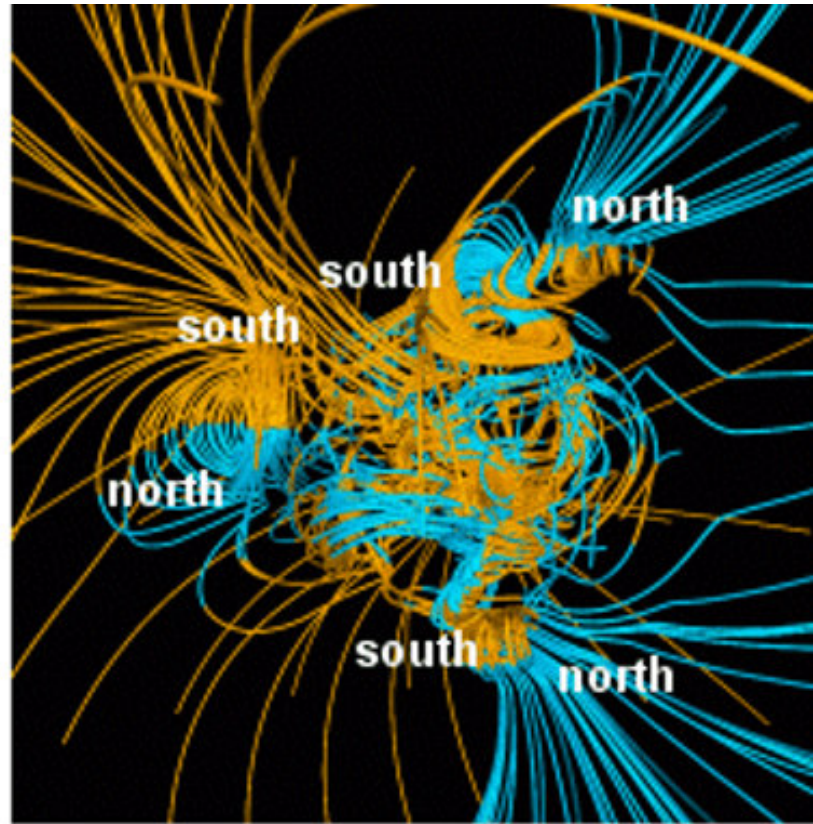
The magnetic shield was likely important for preventing the slow loss of the atmosphere and water throughout history

When did Earth's magnetic field start and how has it contributed to the preservation of life?

Are we in the early phases of a geomagnetic reversal and will this affect life?



between reversals



during a reversal

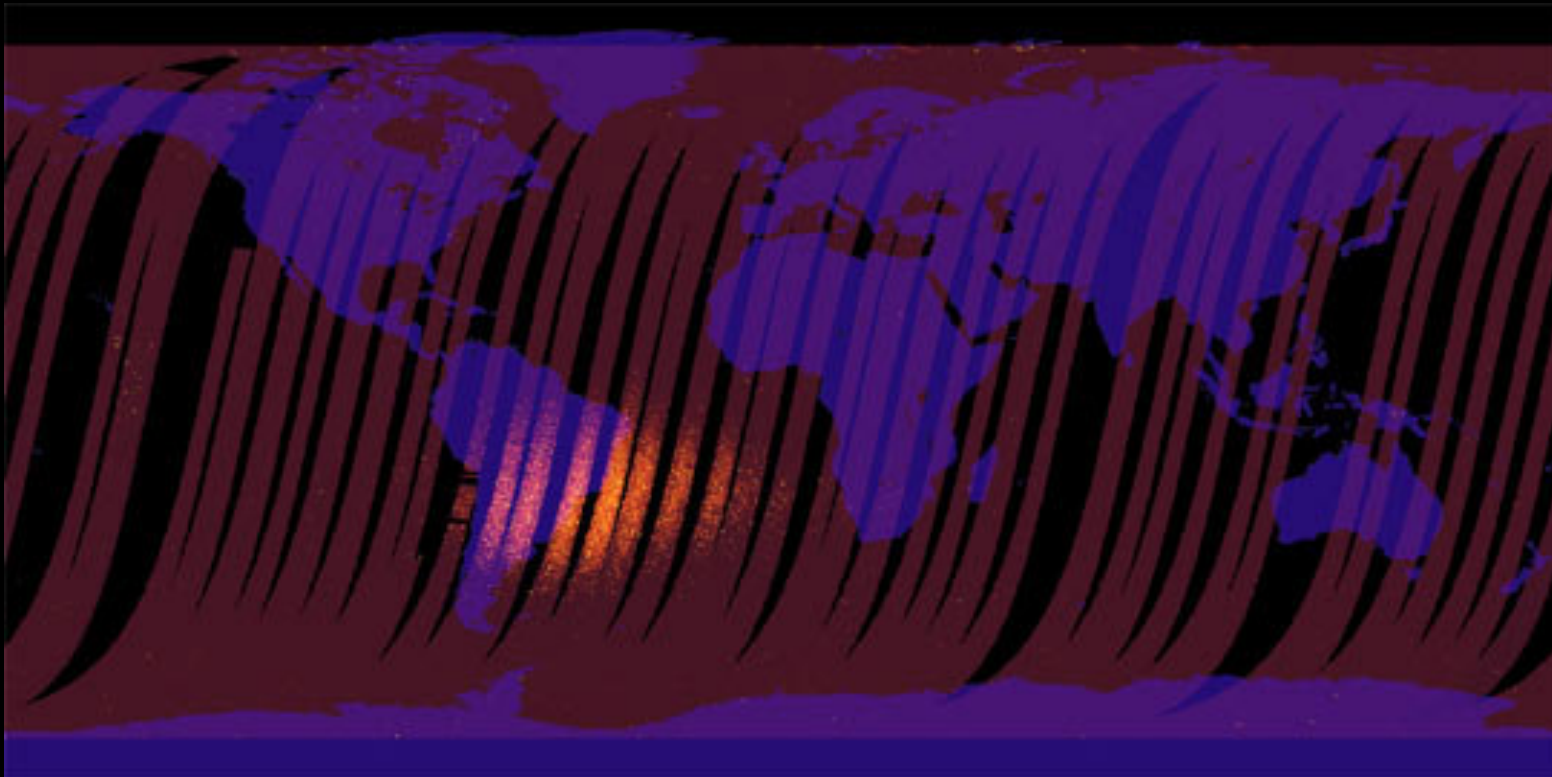
THE FOLLOWING **PREVIEW** HAS BEEN APPROVED FOR

ALL AUDIENCES

BY THE MOTION PICTURE ASSOCIATION OF AMERICA

THE FILM ADVERTISED HAS BEEN RATED

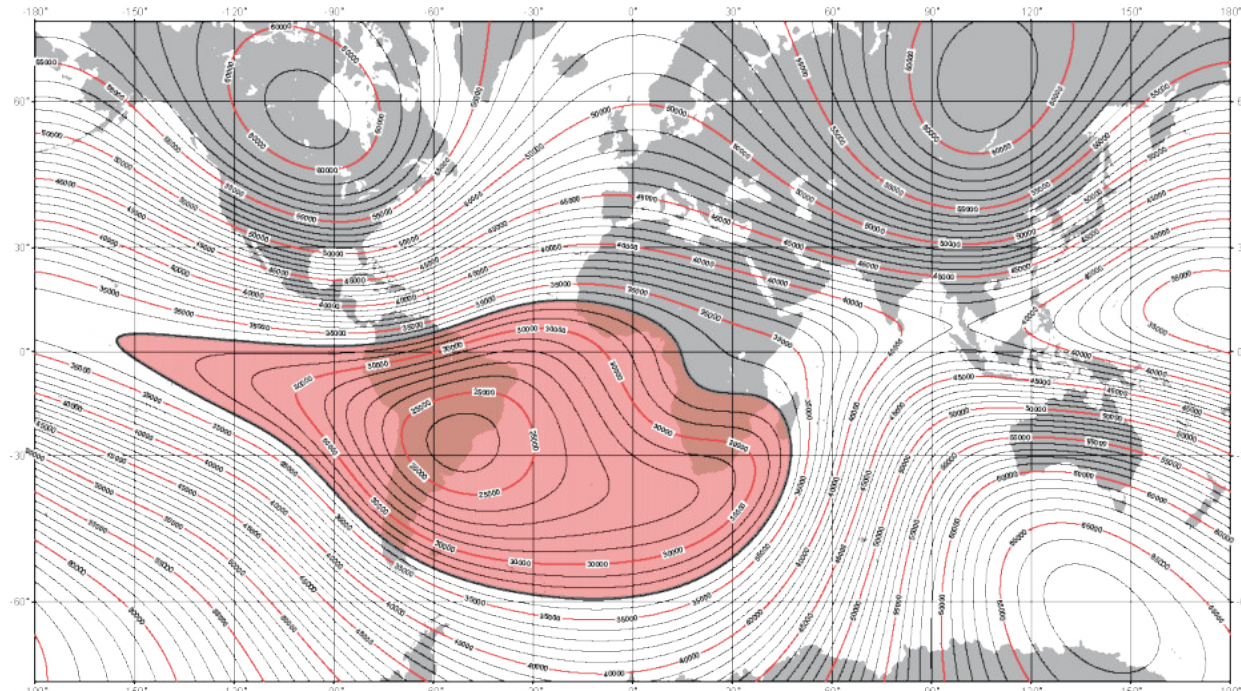




Multi-angle Imaging SpectroRadiometer/NASA's Terra spacecraft 3 -16 Feb, 2000

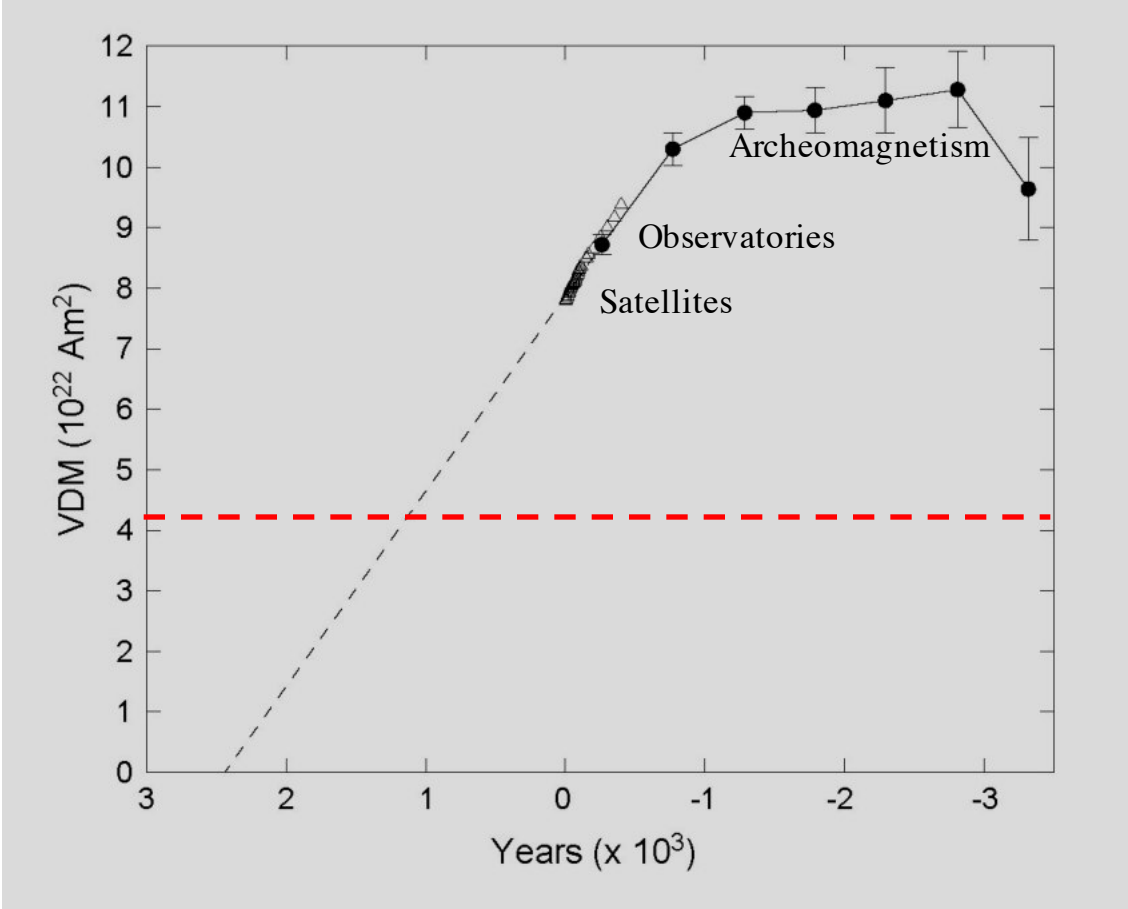
a

Main Surface Field Total Intensity (nT)

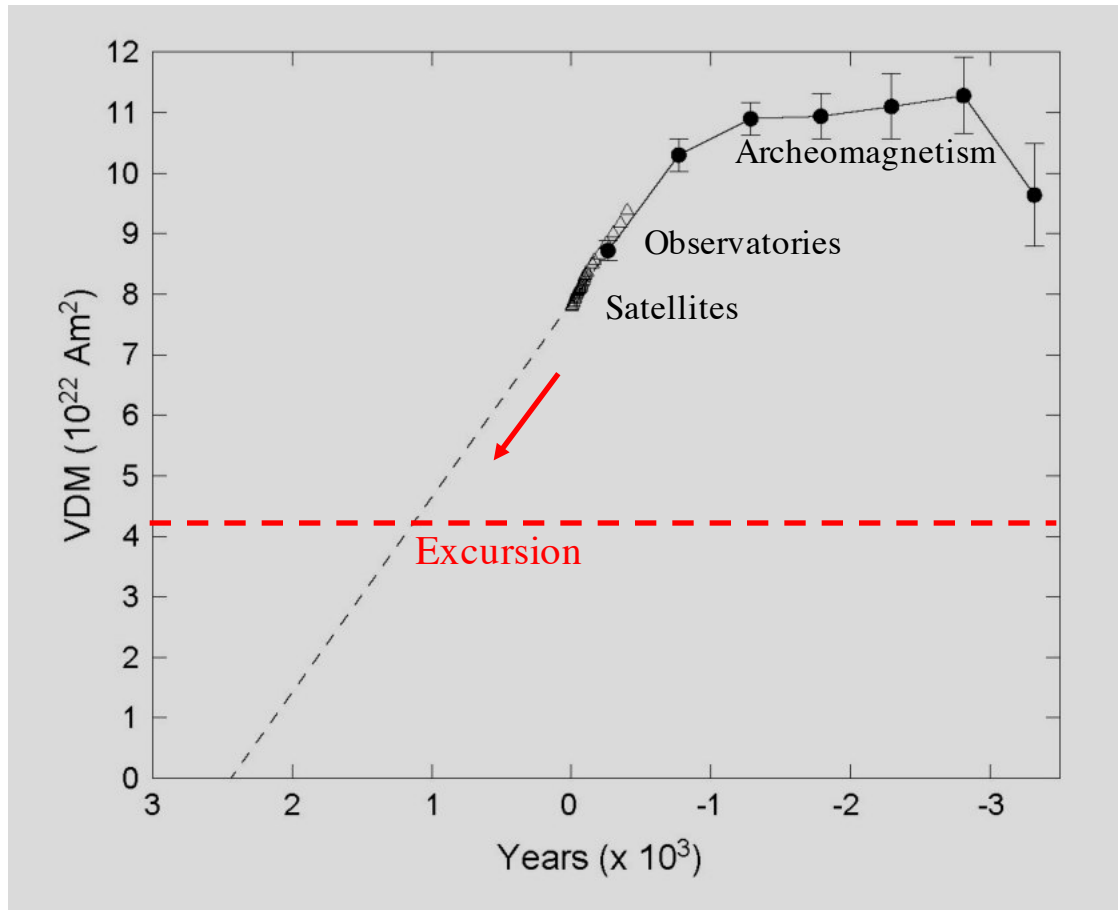


South Atlantic
Anomaly

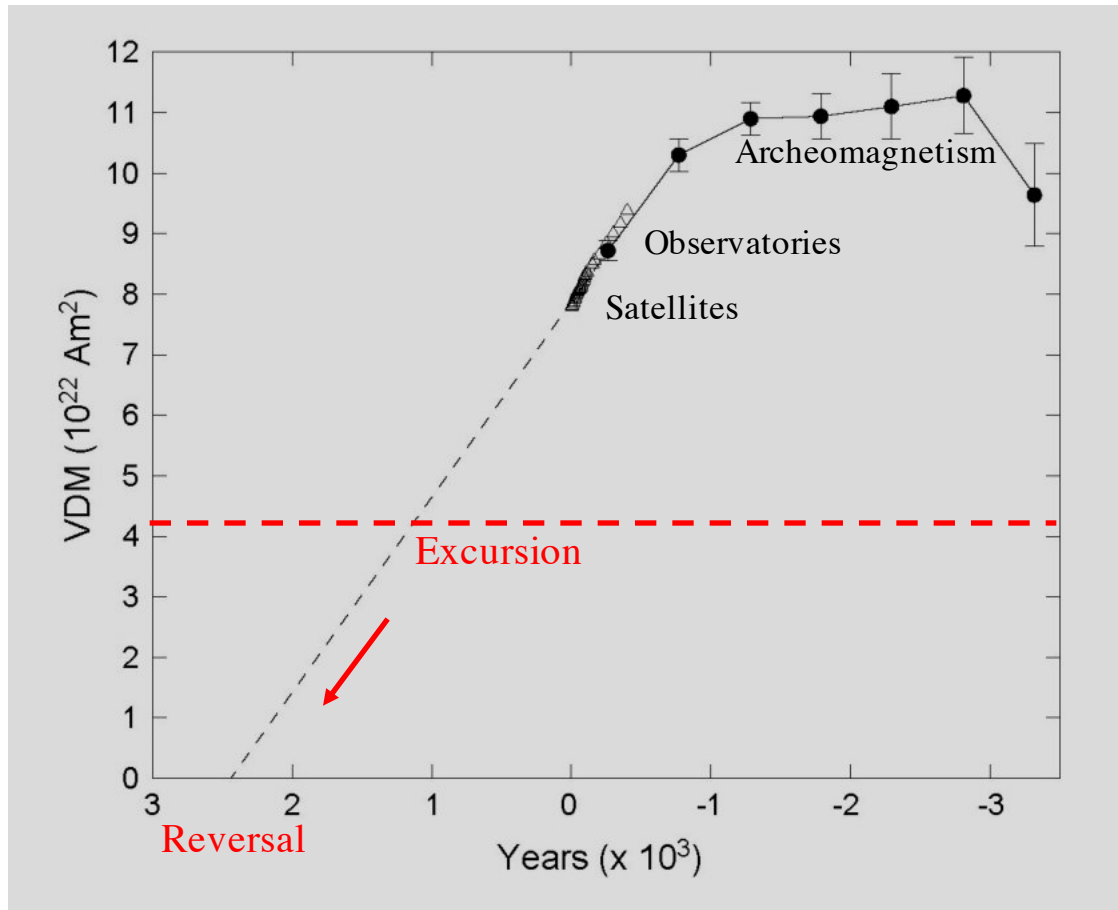
Region of weak
magnetic field



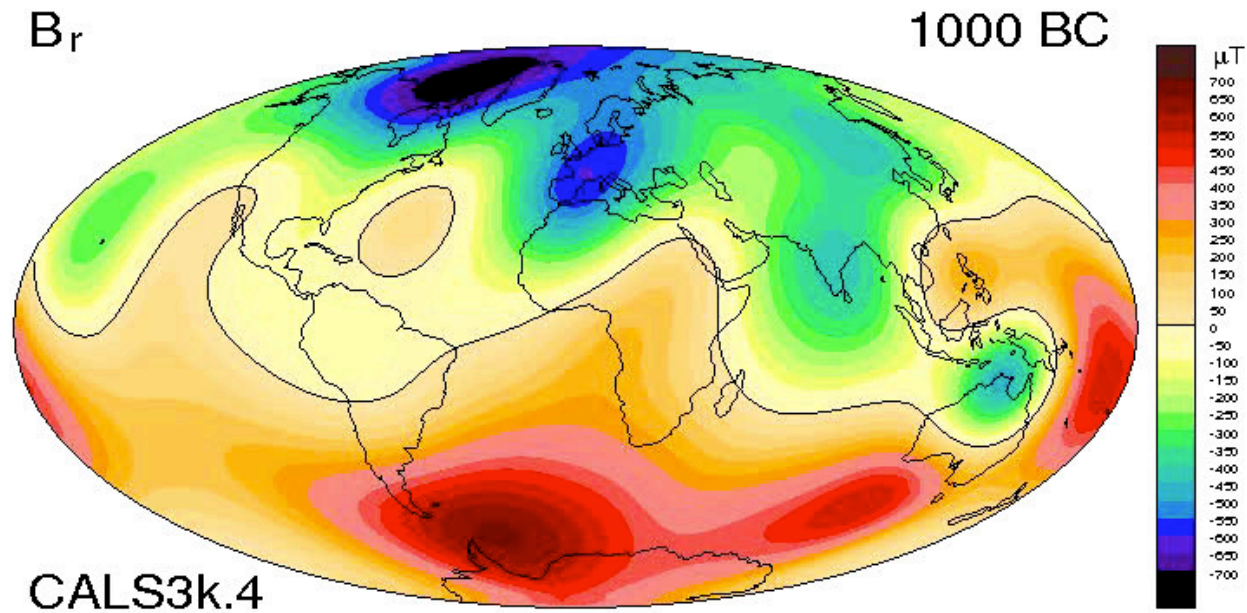
Earth's dipole magnetic field is weakening rapidly!



Earth's dipole magnetic field is weakening rapidly!



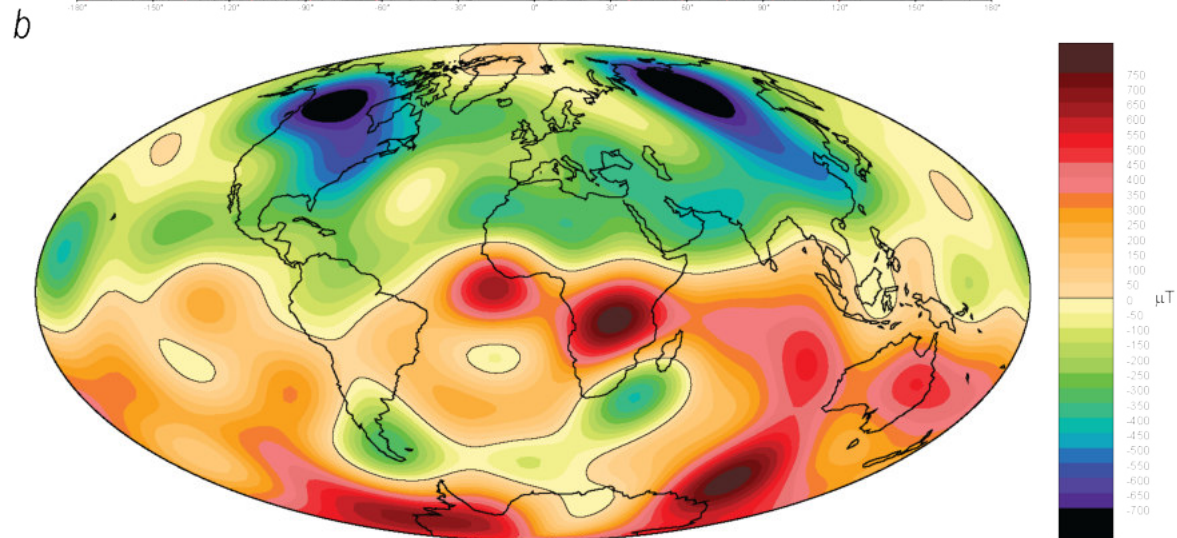
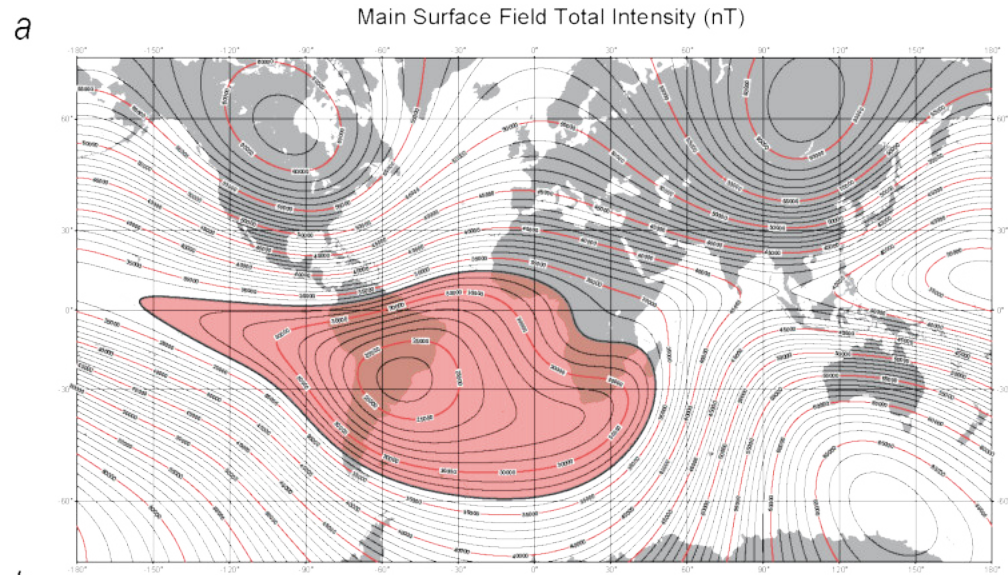
Earth's dipole magnetic field is weakening rapidly!



The magnetic field at the core-mantle boundary

Korte and Constable, G-cubed, 2011

Cool colors - Northern Hemisphere
Hot colors - Southern Hemisphere



What is the historical context?

Almost no archeomagnetic data from the Southern Hemisphere

A view from southern Africa



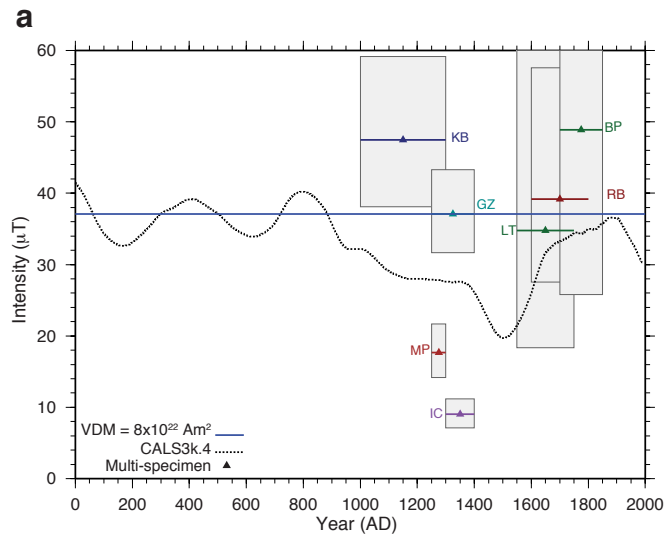
Limpopo River Valley



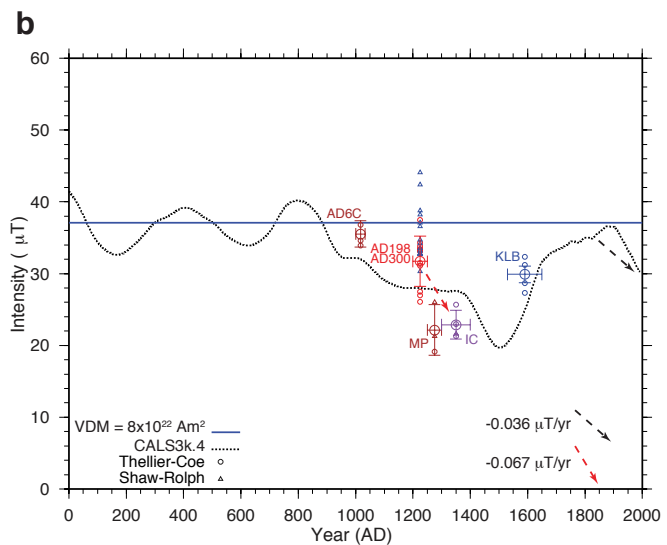


We can identify burnt hut floors and grain bins and sample them for magnetic analysis

“Mini-magnetic observatories from the Iron age”



We see a rapid drop in magnetic field intensity after at 1250 AD, similar to modern changes in the South Atlantic Anomaly region

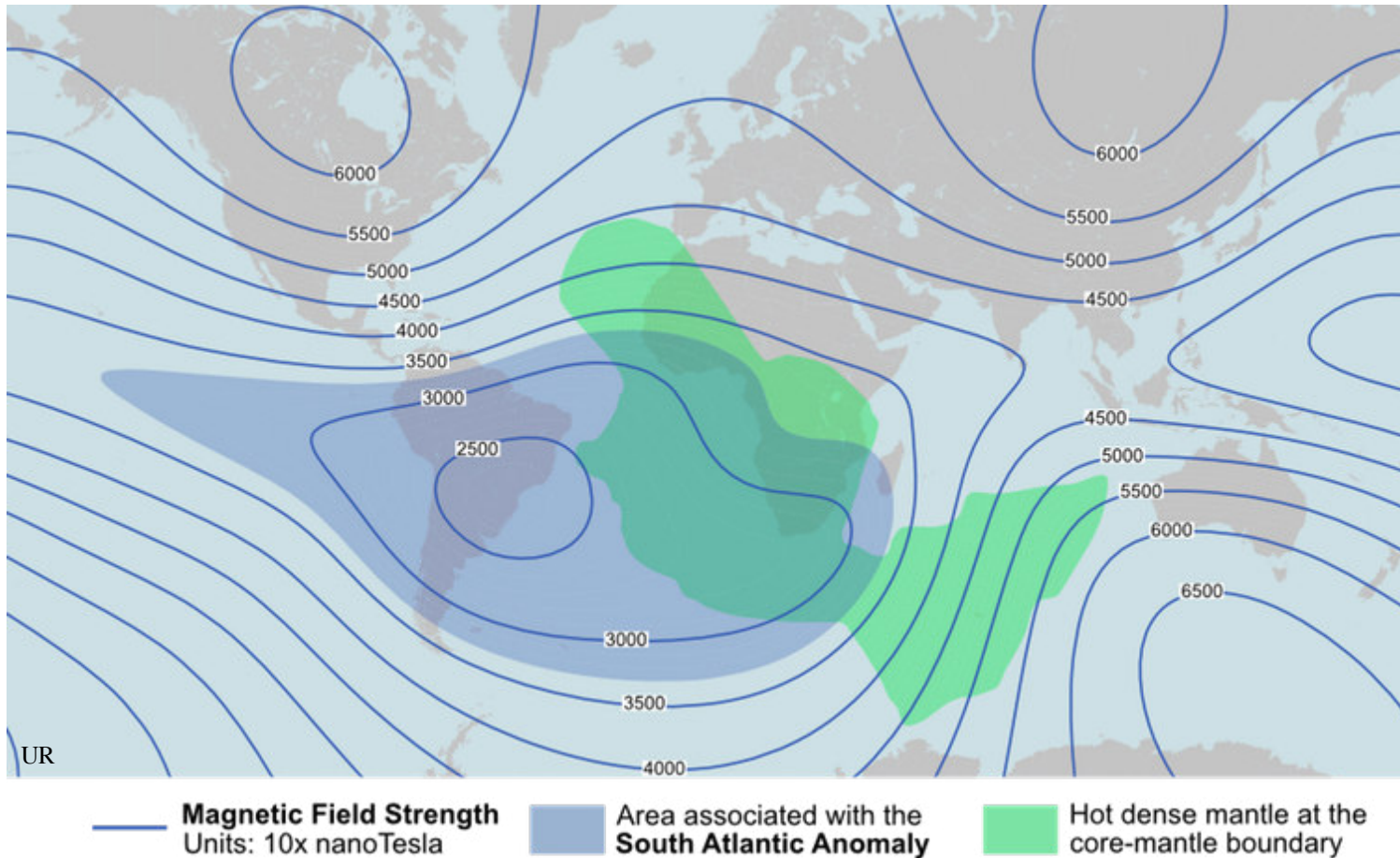


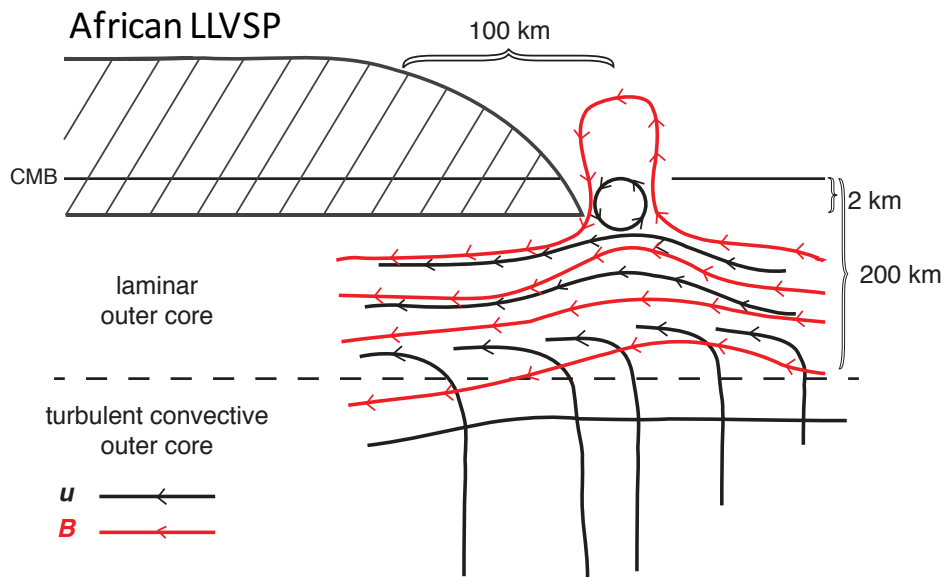
Recurrent behavior

Why in this region?

Tarduno et al., Nature Communications, 2015

The mantle above the core beneath southern Africa is unusual
Large Low Shear Velocity Province (LLSVP)





$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{u} \times \mathbf{B}) + \eta_m \nabla^2 \mathbf{B} \quad \text{For } L=2 \text{ km}, R_M=0.3$$

Hypothesis:

1. The dense mantle under Africa perturbs core flow creating a geomagnetic anomaly
2. Anomalies should be created in the past
3. Eventually one of the anomalies will grow and create a magnetic reversal



Does an anomaly in the Earth's magnetic field portend a coming pole reversal?

February 5, 2017 11:52pm EST Updated February 17, 2017 10:09pm EST

Review

Rapid decrease in dipole magnetic field

Concentrated loss in South Atlantic Anomaly region

Field is reversed in patches at the core-mantle boundary

Similar behavior in the past

Are we in the early phases of a geomagnetic reversal and will this affect life?

Too early to tell, but the rate of decay and pattern implies this is not normal field change but more characteristic of an excursion or reversal

If the field continues to decrease, even without reaching a reversal there will be societal impacts in coming decades to centuries

- damage to satellites
- damage to infrastructure (power grids)

If the field reaches $\frac{1}{2}$ current strength (excursion), could see atmospheric Effects (ozone loss) and attendant increases in skin cancer rates (but no mass extinctions!)

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Come to the Great Debate – Thursday, 1:30-3:30 pm Room E1

EGU GDB5 "Natural versus anthropogenic threats for life on Earth"



Acknowledgements:

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