National Aeronautics and Space Administration

The Heliophysics Big Year

Dr. Sten Odenwald, Astronomer

NASA Heliophysics Education Activation Team

NASA's Big Questions

1. **What causes the Sun to vary?**
2. **How do the Earth and the heliosphere respond?**
3. **What are the impacts on humanity?**

These Big Questions form the basis for the

Framework for Heliophysics Education

https://science.nasa.gov/learn/heat/big-ideas/

The Framework for Heliophysics Education

What are the impacts of the Sun on humanity?

1.1 The Sun is really big and its gravity influences all objects in the solar system. (PS2, ESS1)

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

1.3 The Sun's energy drives Earth's climate, but the climate is in a delicate balance and is changing due to human activity. (PS1, PS2, PS3, LS4, ESS2, ESS3)

How do the Earth, the solar system, and heliosphere respond to changes on the Sun?

2.1 Life on Earth has evolved with complex diversity because of our location near the Sun. It is just right! (PS3, PS4, LS1, LS2, ESS2)

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

2.3 The Sun is the primary source of light in our solar system.(PS1, PS2, PS3,PS4, ESS1)

What Causes the Sun to Vary?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

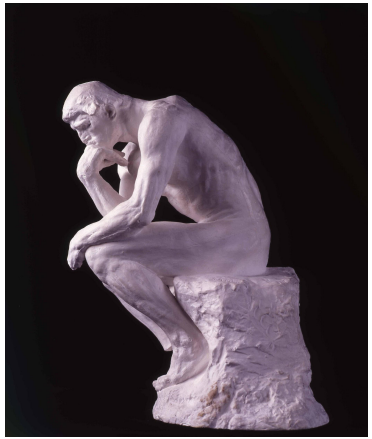
3.2 Energy from the Sun is created in the core and travels outward through the Sun and into the heliosphere. (PS1, PS3, PS4, ESS1, ESS2, ESS3)

3.3 Our Sun, like all stars, has a life cycle. (PS1, LS1, ESS1)

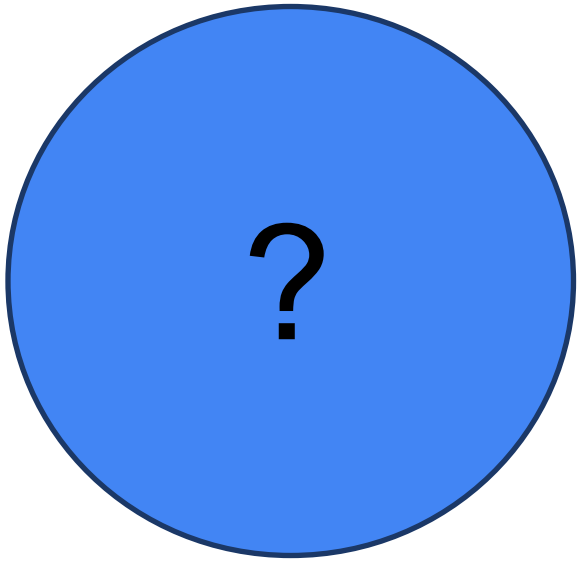
Before we can answer this question
we must first have a basic idea
what the 'geo' magnetic field looks like
and how it is produced.

You can't tell if your car is running out
until you know how a car works!

What does Earth's interior look like?



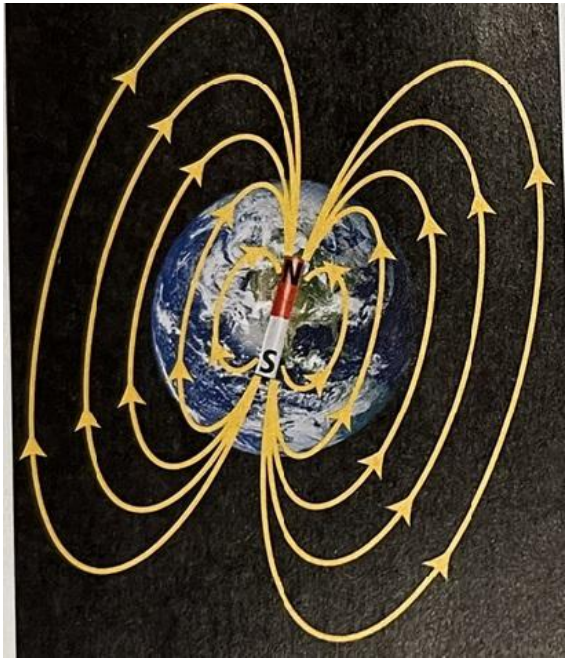
Mary Hill Museum



Typical textbook illustration

Earth Science:
Geology, The Environment & The Universe

McGraw Hill 2017 edition.



Typical textbook illustration

Earth Science:
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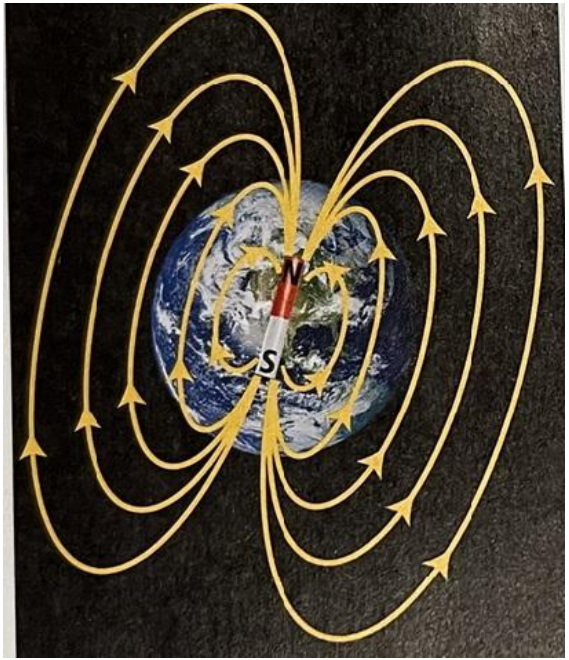
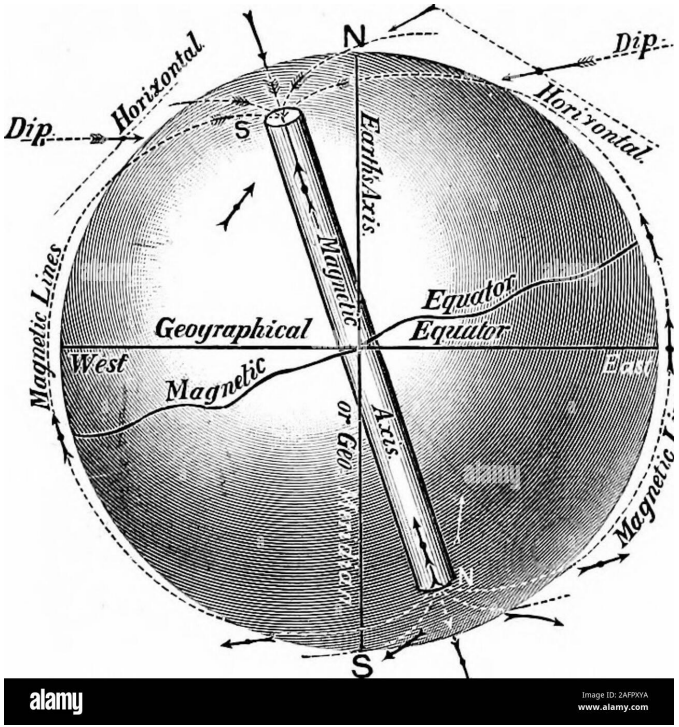
Wrong!



Is Earth's polarity about to flip? Geomagnetism

What does it look like?

1895



Principles of Physics, Alfred Gage, Figure 416

Almy Stock Photo 2AFPXYA – No copyright; Public Domain

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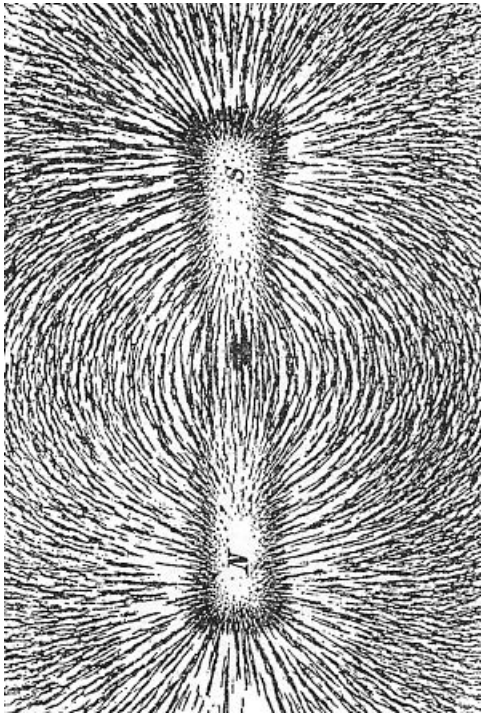
Wrong Visual Model

The source is not a simple bar magnet

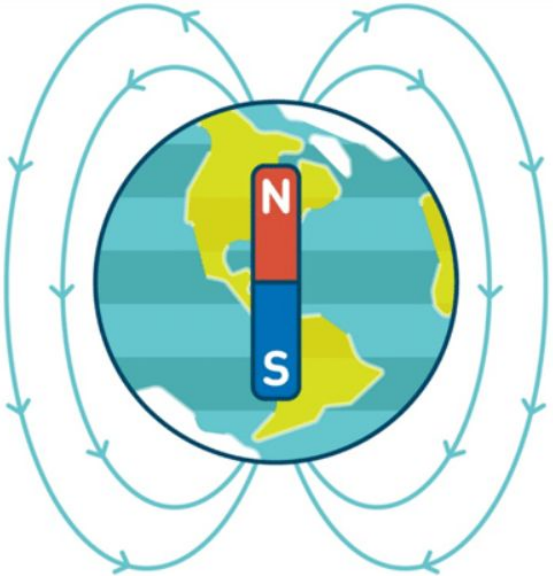


Wikipedia: Bar magnet

Wrong Visual Model

The source is not a simple bar magnet

The polarity is not North-type just because compass needles 'point North'



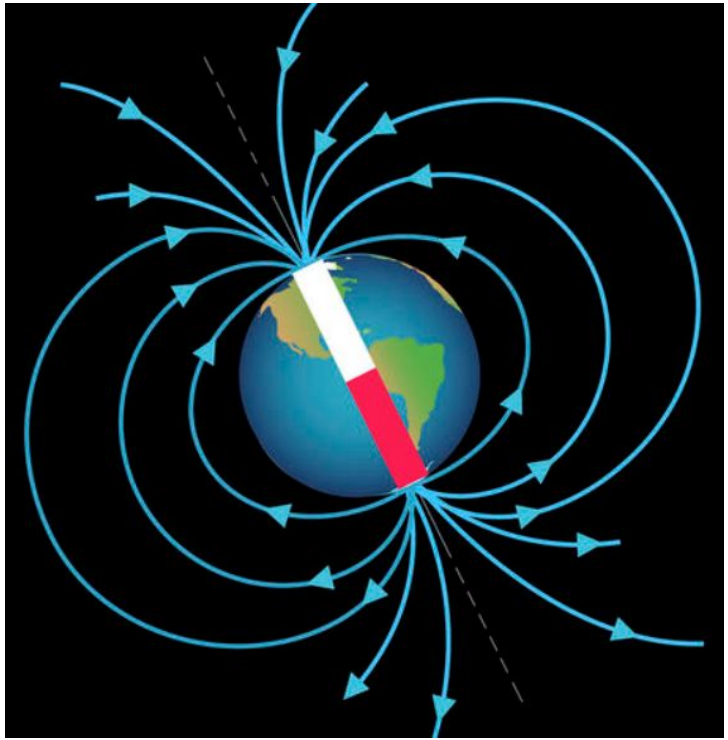
Credit: Shalom Education.
https://www.shalom-education.com/courses/gcse-physics/lessons/magnetism-and-electromagnetism/topic/the-earths-magnetic-field-2/

Wrong Visual Model

The source is not a simple bar magnet

The polarity is not North-type just because compass needles 'point North'

The field does not originate near the surface



https://mrlilholt.wordpress.com/5th-grade-text/chapter-7/7-5-earths-magnetic-field/

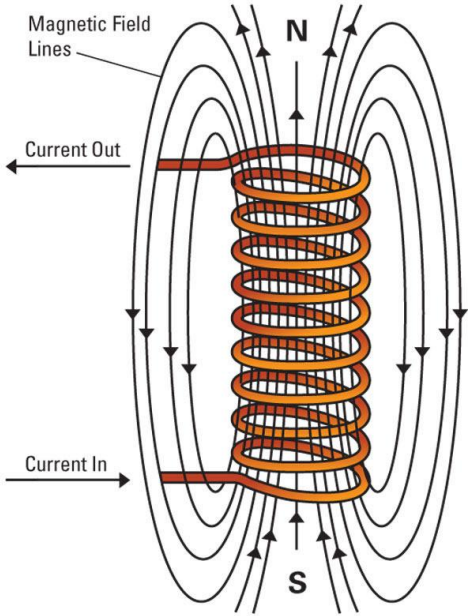
Wrong Visual Model

The source is not a simple bar magnet

The polarity is not North-type just because compass needles 'point North'

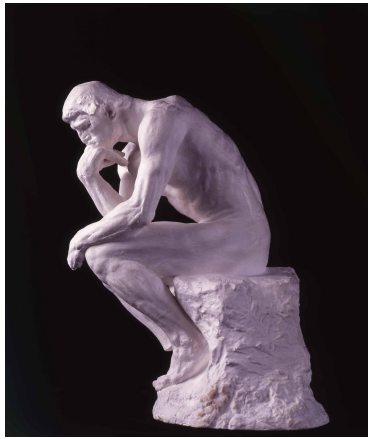
The field does not originate near the surface

The field is not a simple electromagnet

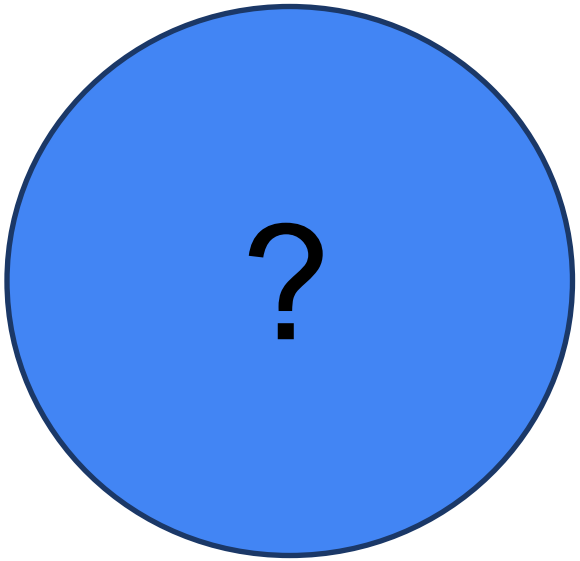


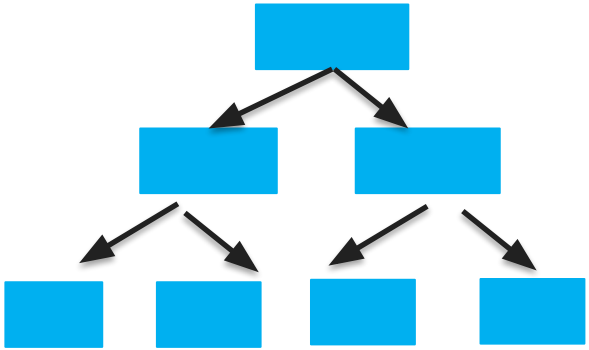
Credit: https://www.hvrmagnet.com/blog/solenoid-electromagnet-commonly-asked-questions/

What are some basic properties of Earth?



Mary Hill Museum





Right Visual Model

Earth is a rotating body

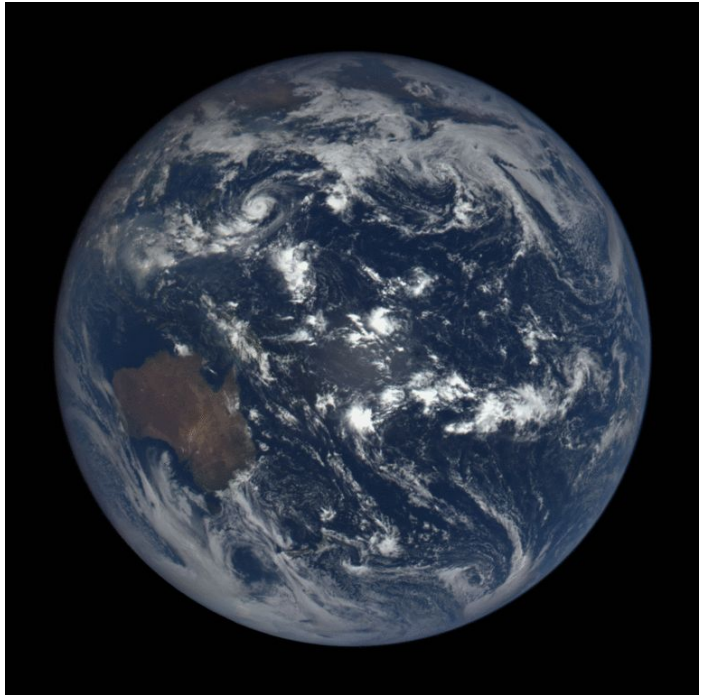


Image by Wikipedia: Earth's rotation; NASA/EPIC

Right Visual Model

Earth is a rotating body

Rotation produces Coriolis forces

Image by Wikipedia: Coriolis Effect

Right Visual Model

Earth is a rotating body

Rotation produces Coriolis forces

Coriolis forces produce rotating columns of currents in Earth's conducting outer core

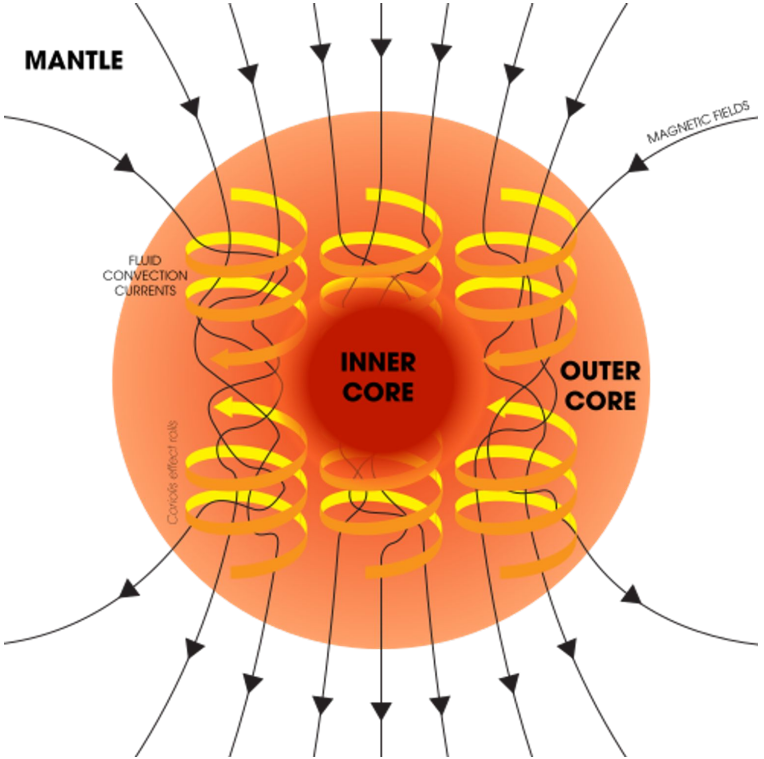


Image by Wikipedia: Dynamo Theory; USGS

Is Earth's polarity about to flip? Magnetic Dynamo

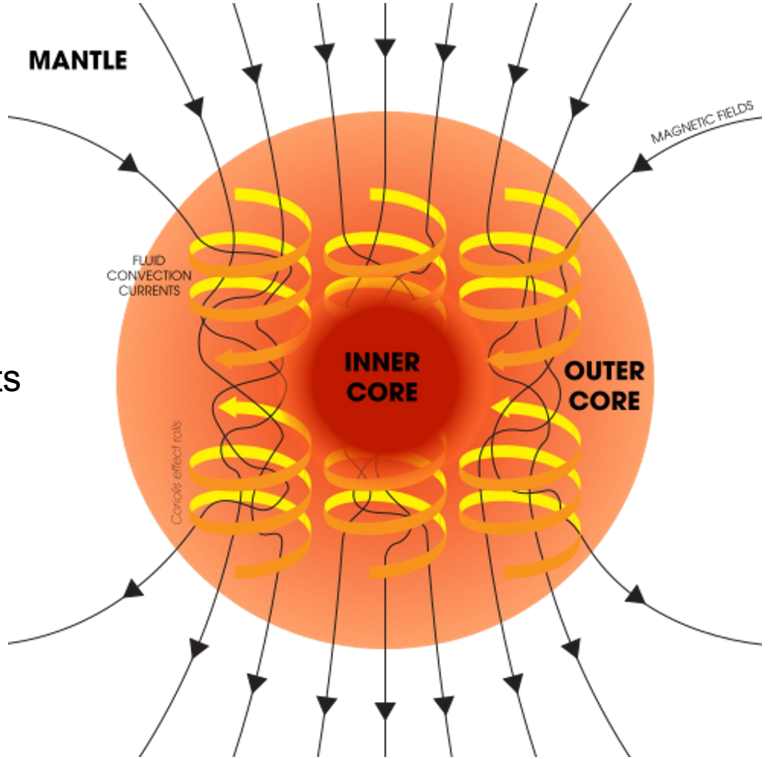
Right Visual Model

Earth is a rotating body

Rotation produces Coriolis forces

Coriolis forces produce rotating columns of currents

Each column generates its own 'bar magnet' field



https://planet-earth-2017.com/the-true-source-of-earth-magnetic-field/

Image by Wikipedia: Dynamo Theory; USGS

Is Earth's polarity about to flip? Magnetic Dynamo

Right Visual Model

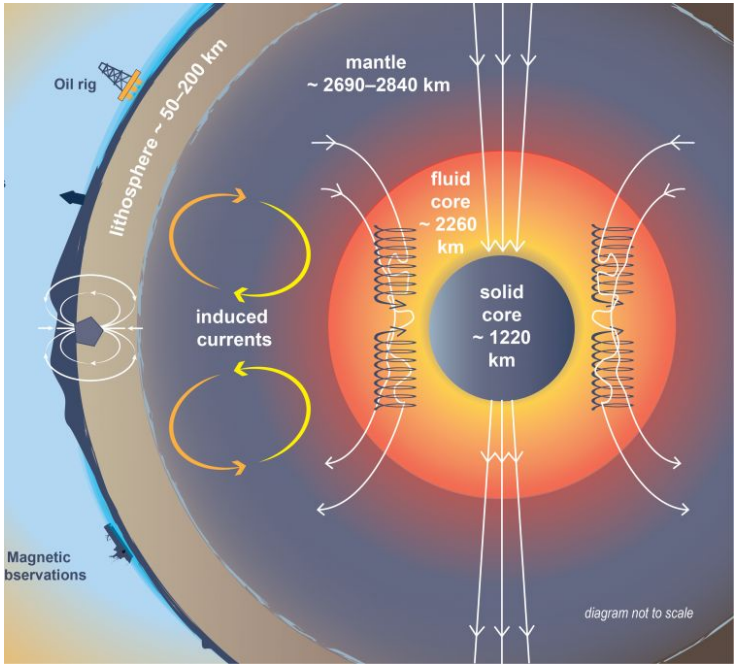
Earth is a rotating body

Rotation produces Coriolis forces

Coriolis forces produce rotating columns of currents

Each column generates its own 'bar magnet' field

These individual fields merge together in the outer mantle



Earth's magnetic structure. Courtesy of NOAA NCEI.

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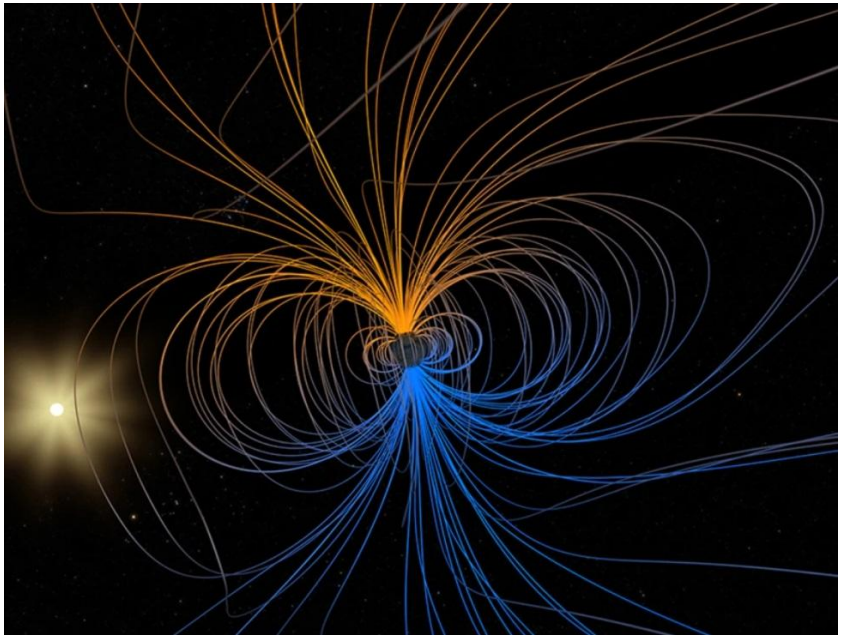
Is Earth's polarity about to flip? Magnetic Dynamo

Right Visual Model



Earth is a rotating body

Rotation produces Coriolis forces

Coriolis forces produce rotating columns of currents

Each column generates its own 'bar magnet' field

These individual fields merge together in the outer mantle

The resulting exterior field looks like a bar magnet

Image by NASA

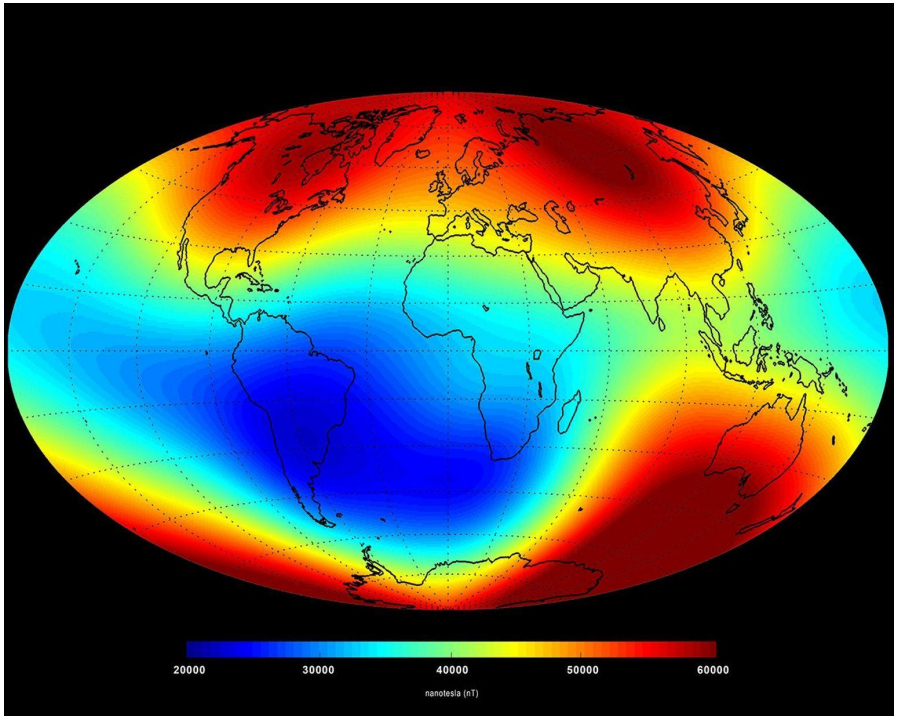
Is Earth's polarity about to flip? Surface Field

Earth's field is not uniform

ESA SWARM satellite map of
Earth's surface field. January-June 2014

Red = +60,000 nT SOUTH-Type

Blue = -60,000 nT NORTH Type



European Space Agency/Technical University of Denmark (ESA/DTU Space)

Is Earth's polarity about to flip? Surface Field

Earth's difference field is not uniform either

ESA SWARM satellite map of
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Red = +40 nT SOUTH-Type

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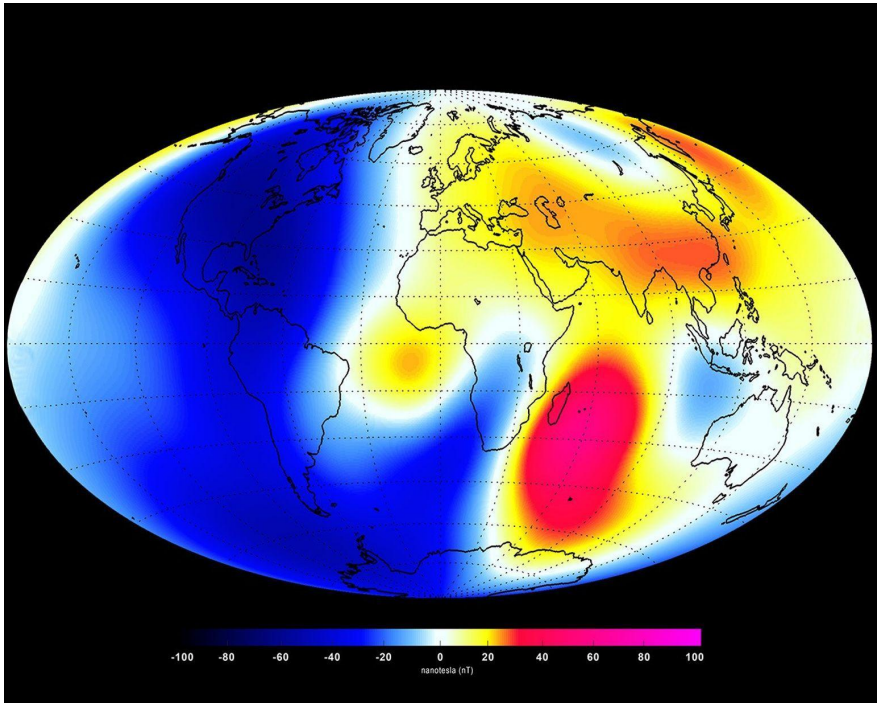

European Space Agency/Technical University of Denmark
(ESA/DTU Space)

https://science.nasa.gov/science-research/earth-science/earths-magnetosphere-protecting-our-planet-from-harmful-space-energy/

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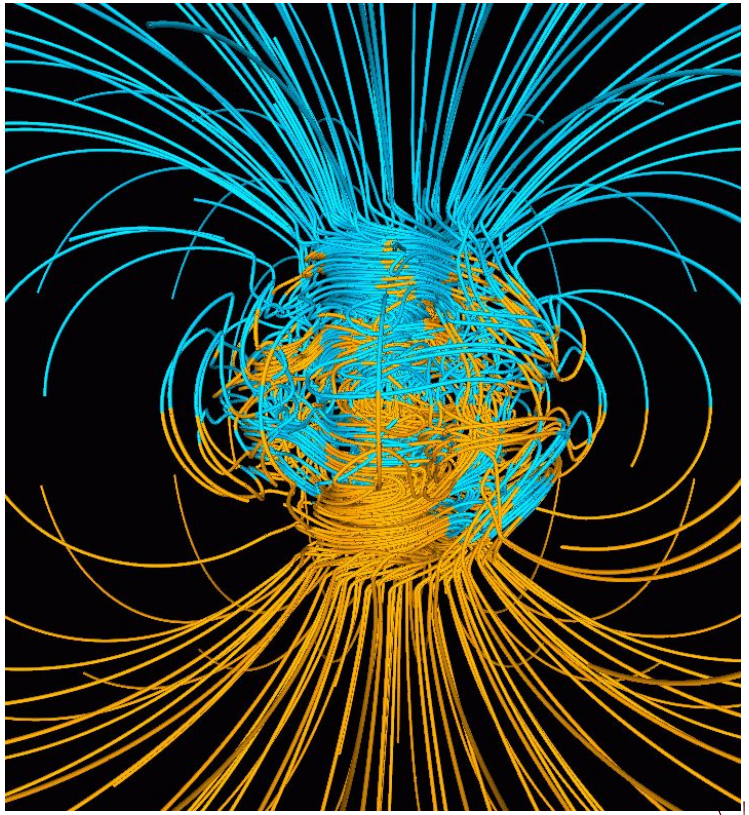
Is Earth's polarity about to flip? Dynamo Instability

A supercomputer simulation of the Earth's field in a period of normal polarity.

The lines represent magnetic field lines, blue (South-type) gold (North-type).

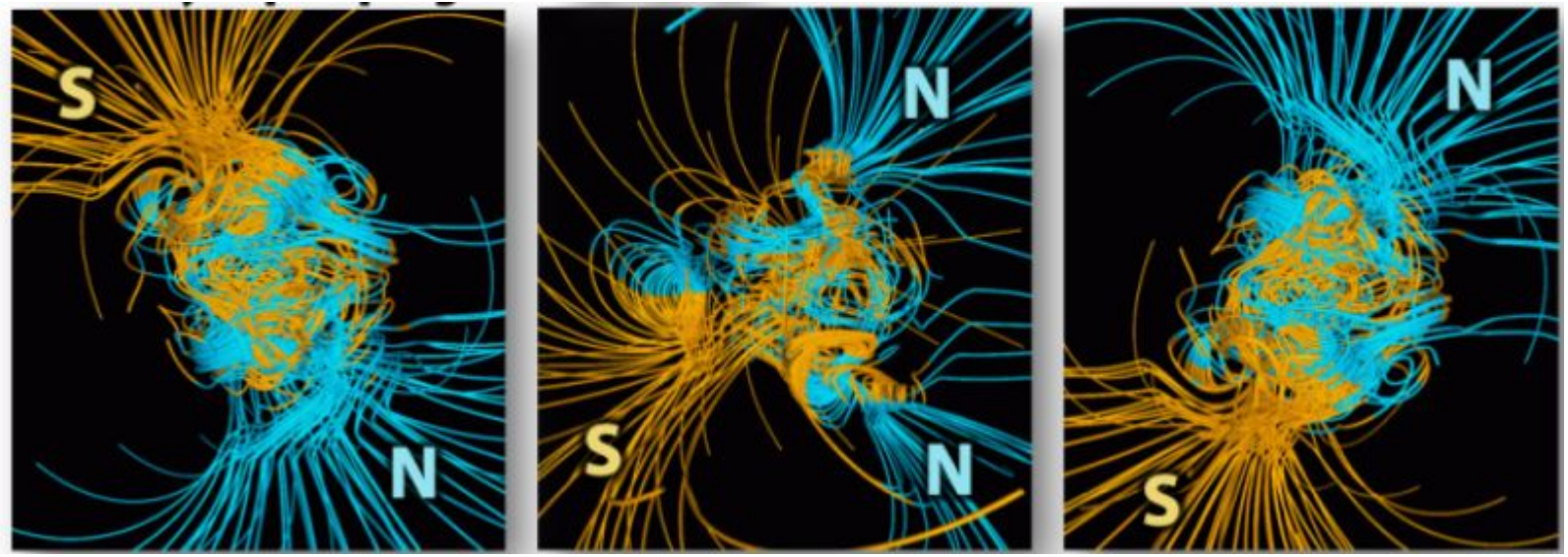
Irregularities at Earth's surface field are caused by chaotic changes in interior currents.



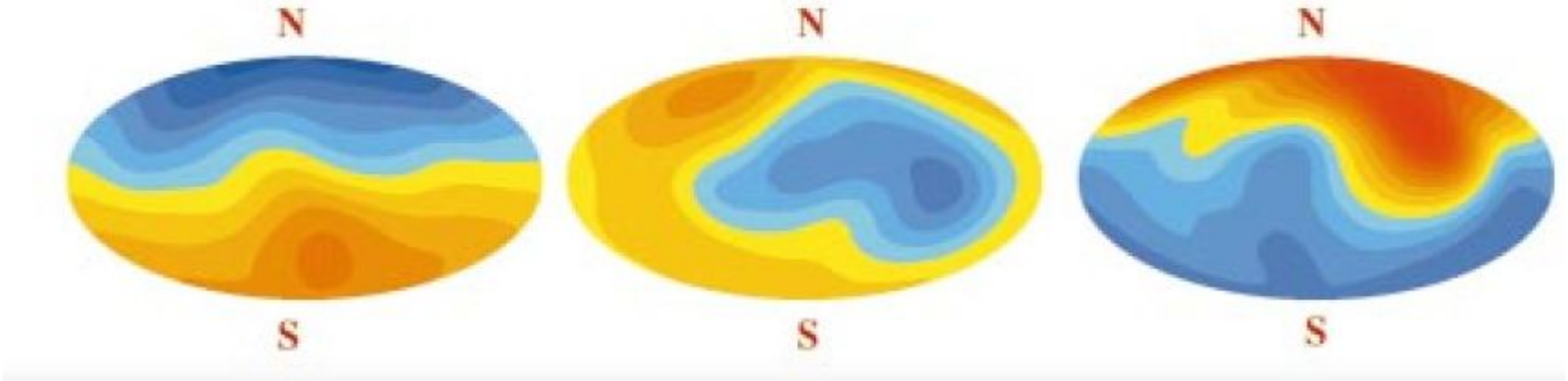
Dr. Gary A. Glatzmaier - Los Alamos - U.S. DoE.

Is Earth's polarity about to flip? Actual reversal

Supercomputer model of evolution of geomagnetic field dynamo.



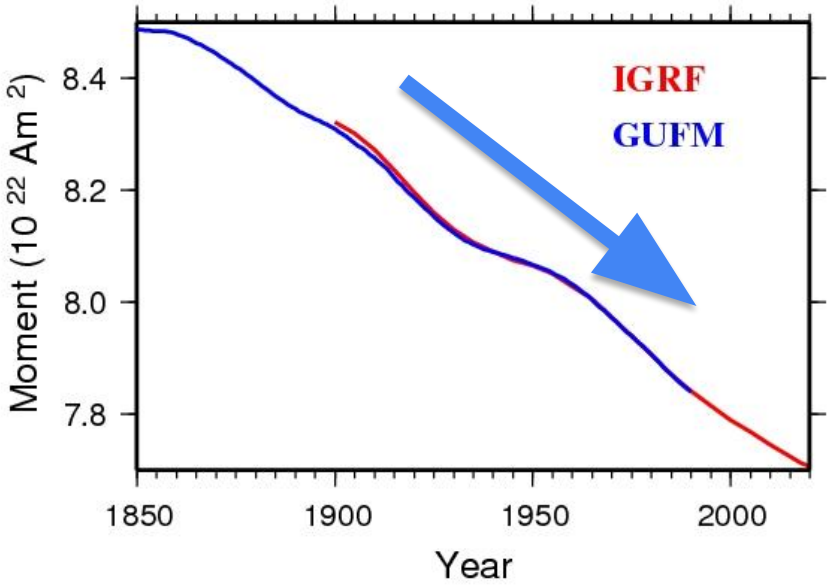
Is Earth's polarity about to flip? Actual reversal



Credit: Glatzmaier et al., 1999 ;
https://www.semanticscholar.org/paper/Geodynamo-theory-and-simulations-Roberts-Glatzmaier/5bb472aa711d5b445101862a23f71981f30c57de

Is Earth's polarity about to flip? Weakening field

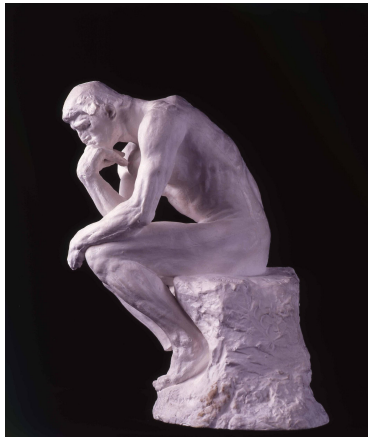
The strength of Earth's dipole field is weakening

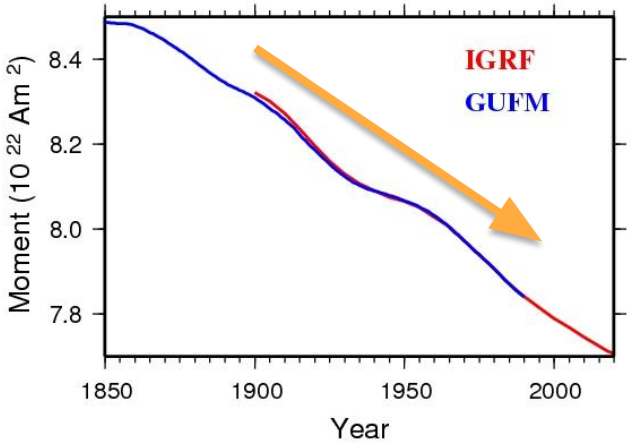


NASA HEAT

Is Earth's polarity about to flip? Weakening field

Are we headed for a reversal?





Yes?	No?

Mary Hill Museum and LNG in Northern BC

Is Earth's polarity about to flip? Beginners - trends

The strength of Earth's dipole field

1850 value = 8.45 x 10^{22} Am^2

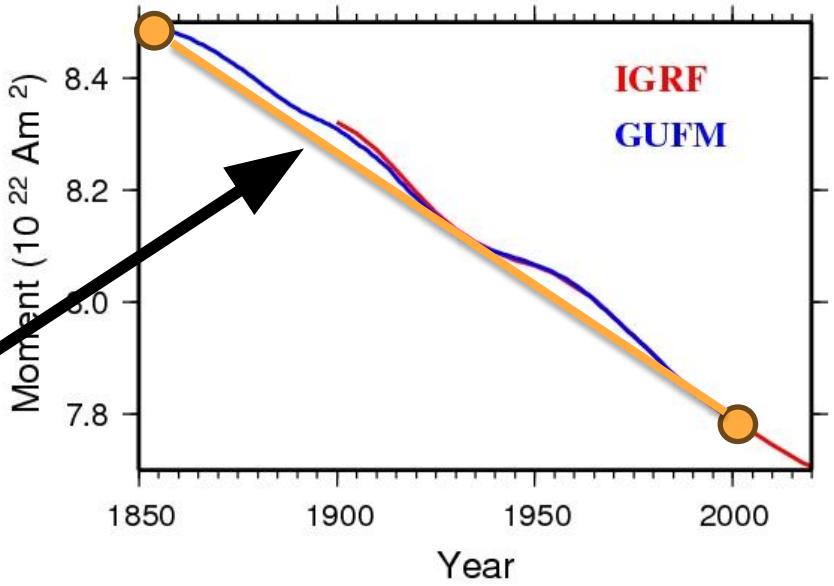
2000 value = 7.8x10^{22} Am^2

Linear Equation:

M = (7.8-8.45) / (2000 – 1850)
M = -0.0043

Y = Mx + b

Y = -0.0043 (T-1850) + 8.45



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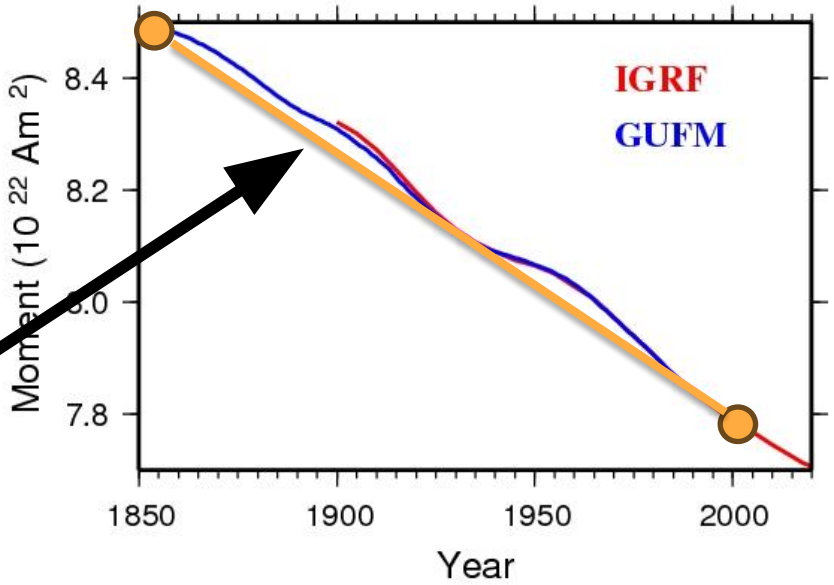

Y = 0 in the year **T = 3815 CE**

NASA HEAT

Is Earth's polarity about to flip? Beginners - trends

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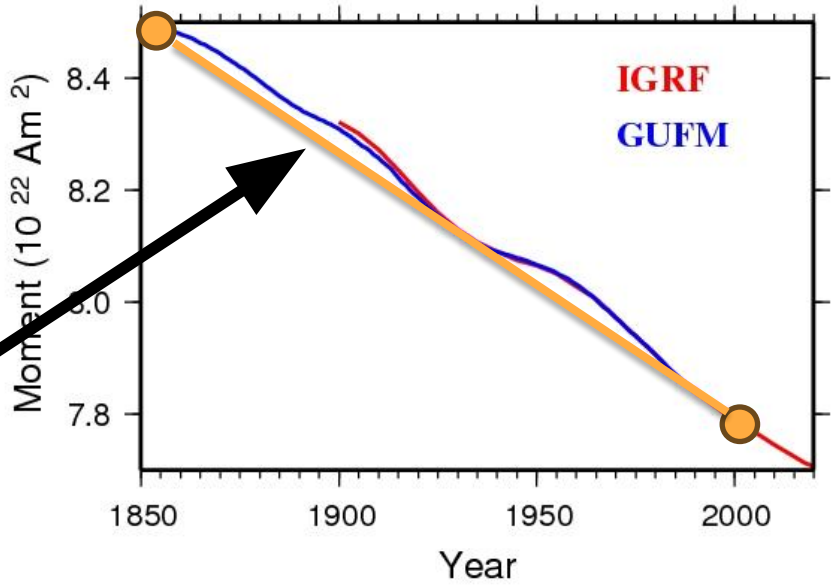

But wait! It's not that simple!!!

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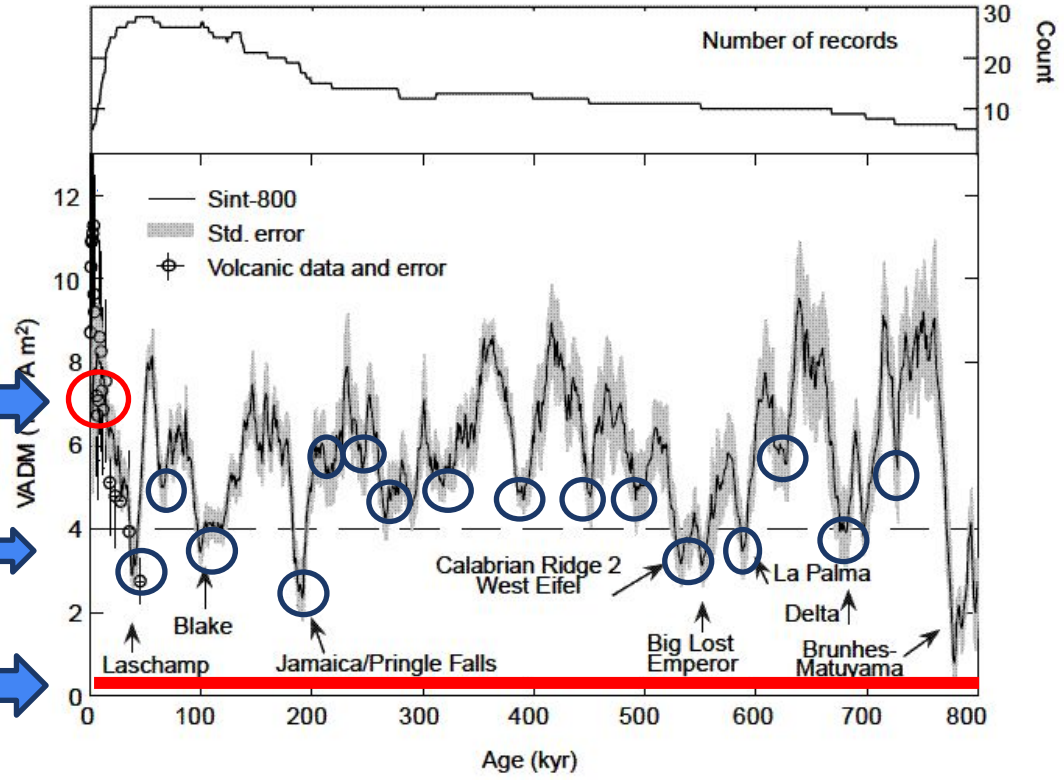
Is Earth's polarity about to flip? Reversal vs Excursion

All reversals are excursions
but
not all excursions are reversals

2000 CE

Magnetic Excursions
No reversal

Full Reversal of polarity
Bruhes/Matuyama



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Is Earth's polarity about to flip? Intermediate - odds

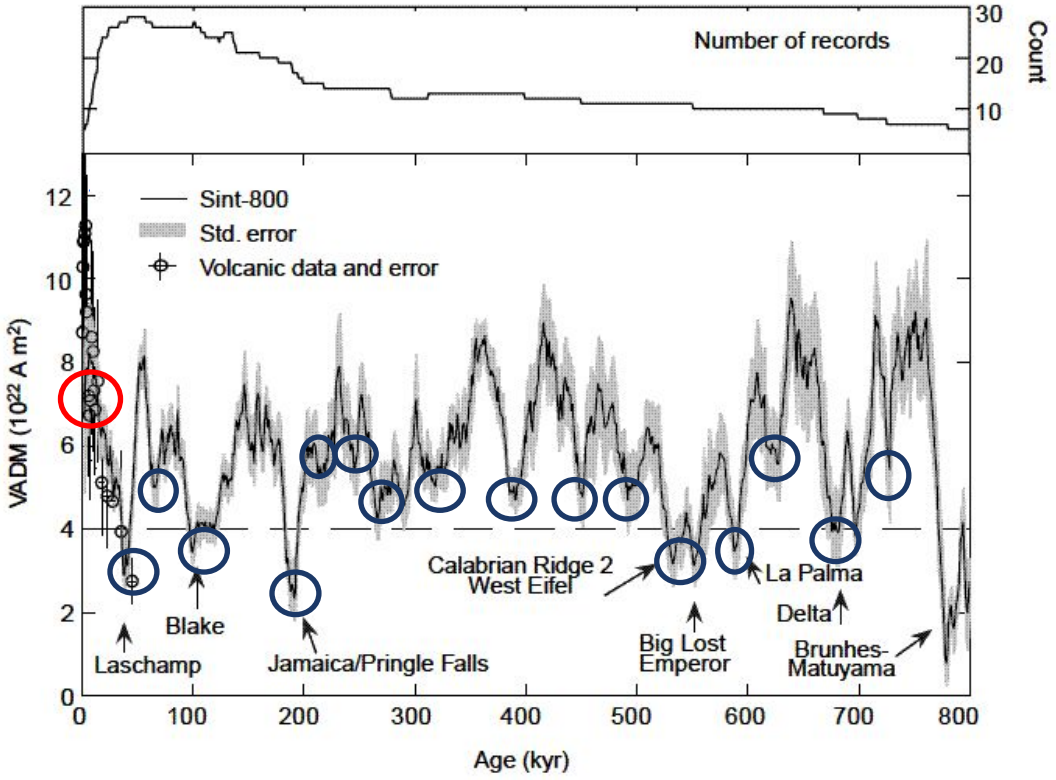
In 800,000 years there have been

1- magnetic reversal
16 –magnetic excursions

Calculating the odds:

Excursion: 16/17 = **16 in 17 odds**

Reversal: 1/17 = **1 in 17 odds**



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Is Earth's polarity about to flip? Intermediate - odds

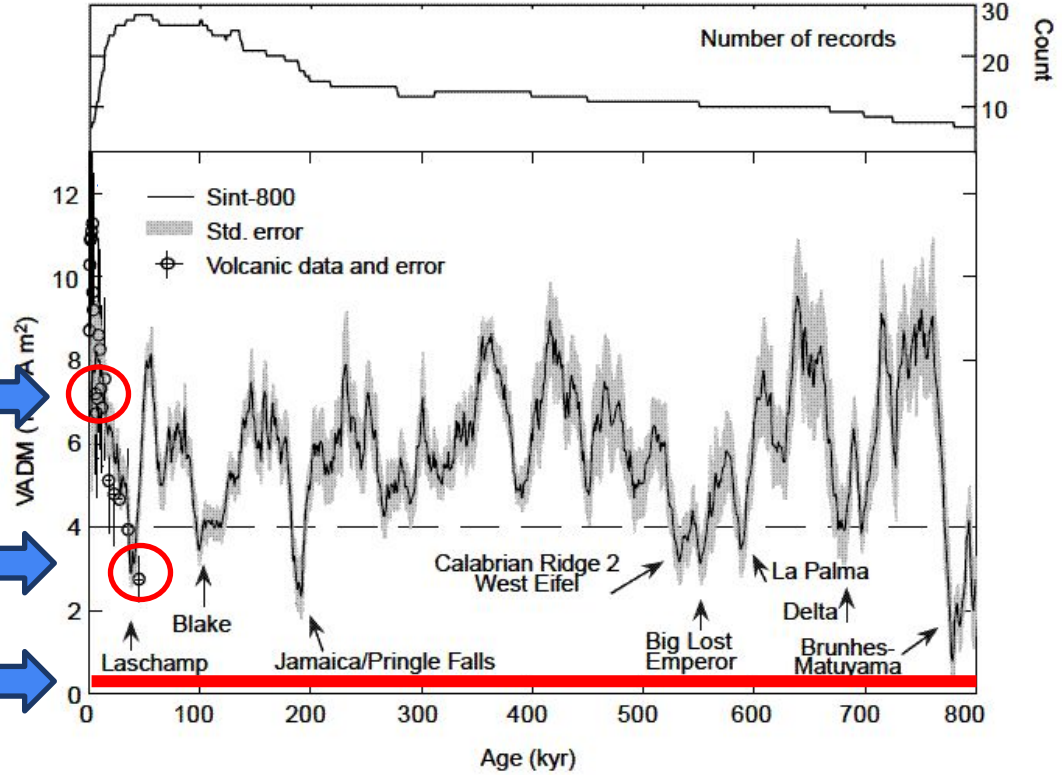
Earth's field is declining
But it has a long way to go
before it gets as low as the
most recent Laschamp Excursion.

From the record, it is **16-times more likely** we are headed for another Laschamp Excursion than a full reversal.

2000 CE

Laschamp Excursion

Reversal threshold



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Is Earth's polarity about to flip? Rotation axis too?

- Earth rotation on north-south axis from west to east
- Magnetic dipole axis closely aligned with rotation axis with South-type in Northern Hemisphere and North-type in Southern Hemisphere

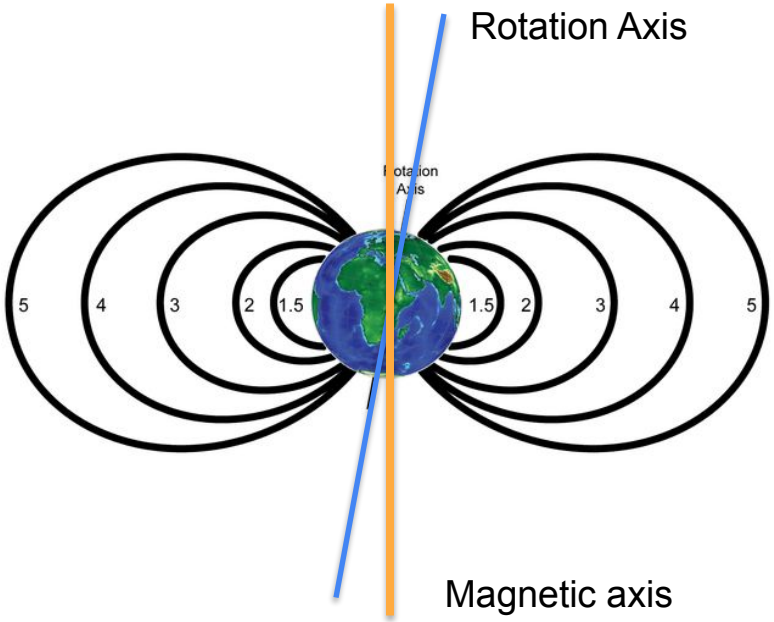
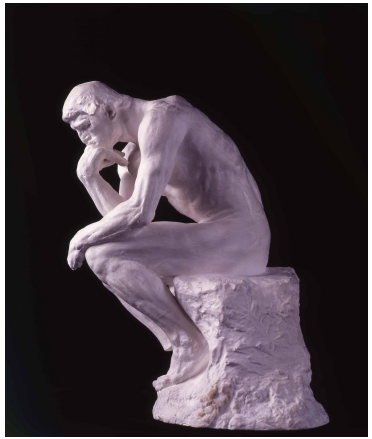
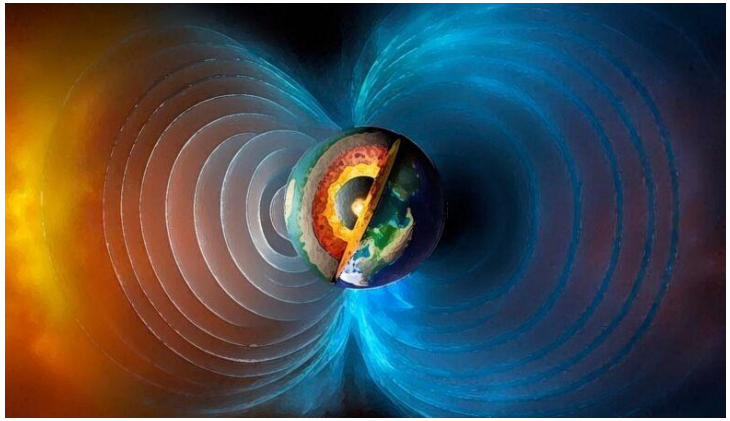


Image: Wikipedia/Dipole model of Earth's magnetic field

Is Earth's polarity about to flip?

Will the rotation axis also flip too?





Yes?	No?

Mary Hill Museum and LNG in Northern BC

Is Earth's polarity about to flip? Advanced - Energy

Energy stored in Earth's **magnetic field**:
Estimate:

$$E = \text{Volume} \times \frac{B^2}{8\pi}$$

B = 0.5 gauss

Volume = $4/3\ \pi\ (6378 \times 10^5)^3$
= 1.0×10^{27} cm^3

$E = 10^{27} \times (0.5)^2/25.1$

$E = 1.0 \times 10^{25}$ ergs.

$E = 1.0 \times 10^{18}$ Joules

Energy stored in **rotation** of Earth:

$E = \frac{1}{2}\ I\ \omega^2$

I = moment of inertia
ω = angular velocity in steradians/sec

I (Earth) = 9.7×10^{37} kg m^2

ω = $2\pi/24$hrs = 7.2×10^{-5} radians/sec

$E = 0.5 \times (9.7 \times 10^{37}) \times (7.2 \times 10^{-5})^2$

$E = 2.5 \times 10^{29}$ Joules

Is Earth's polarity about to flip? But NOT rotation

- Earth rotation on north-south axis from west to east
- Magnetic dipole axis closely aligned with rotation axis with South-type in Northern Hemisphere and North-type in Southern Hemisphere

If the magnetic polarity during a reversal changes, that does NOT cause rotational axis to 'flip'

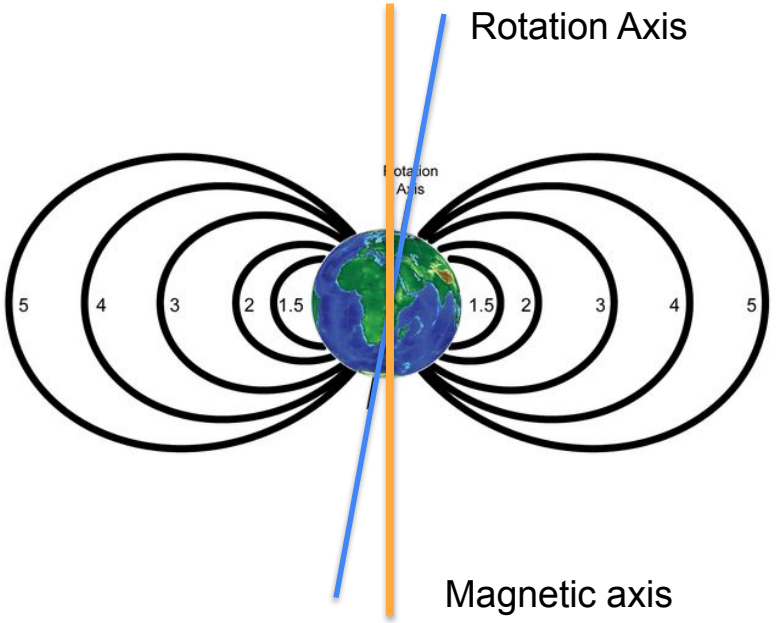


Image: Wikipedia/Dipole model of Earth's magnetic field

Is Earth's polarity about to flip? In the Media

Beware of web articles that confuse reversals and excursions.

Plenty of popularizations call Laschamp a reversal event. **It was, in fact, a magnetic excursion**.

University of Melborne 'When the Earth's magnetic field flipped'
https://pursuit.unimelb.edu.au/articles/when-the-earth-s-magnetic-field-flipped

New Scientist 'Earth's magnetic field flipping linked to extinctions 42,000 years ago
https://www.newscientist.com/article/2268520-earths-magnetic-field-flipping-linked-to-extinctions-42000-years-ago/

The Conversation – Why Earth's magnetic poles could be about to swap places and how it would affect us.
https://theconversation.com/why-the-earths-magnetic-poles-could-be-about-to-swap-places-and-how-it-would-affect-us-71910

Newsweek – The Earth's magnetic field will reverse one day.
https://www.newsweek.com/earth-magnetic-field-reversal-flip-1322291

Next time

Is there a solar superflare in our future?

You betcha!