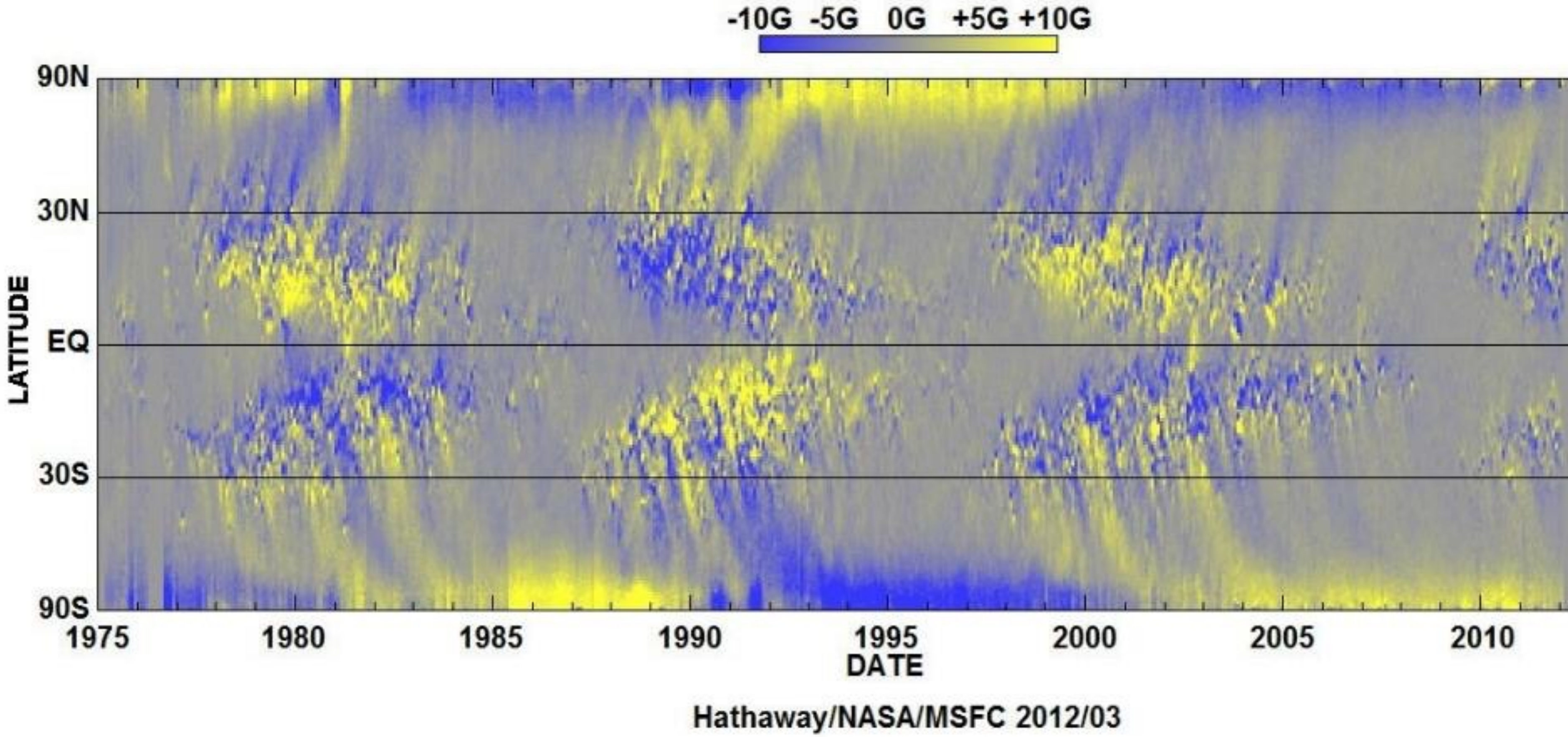
The Sun

I. **Basic Features**
Mass, Size, Elemental make-up, 8 major Parts: CRCPCTCW

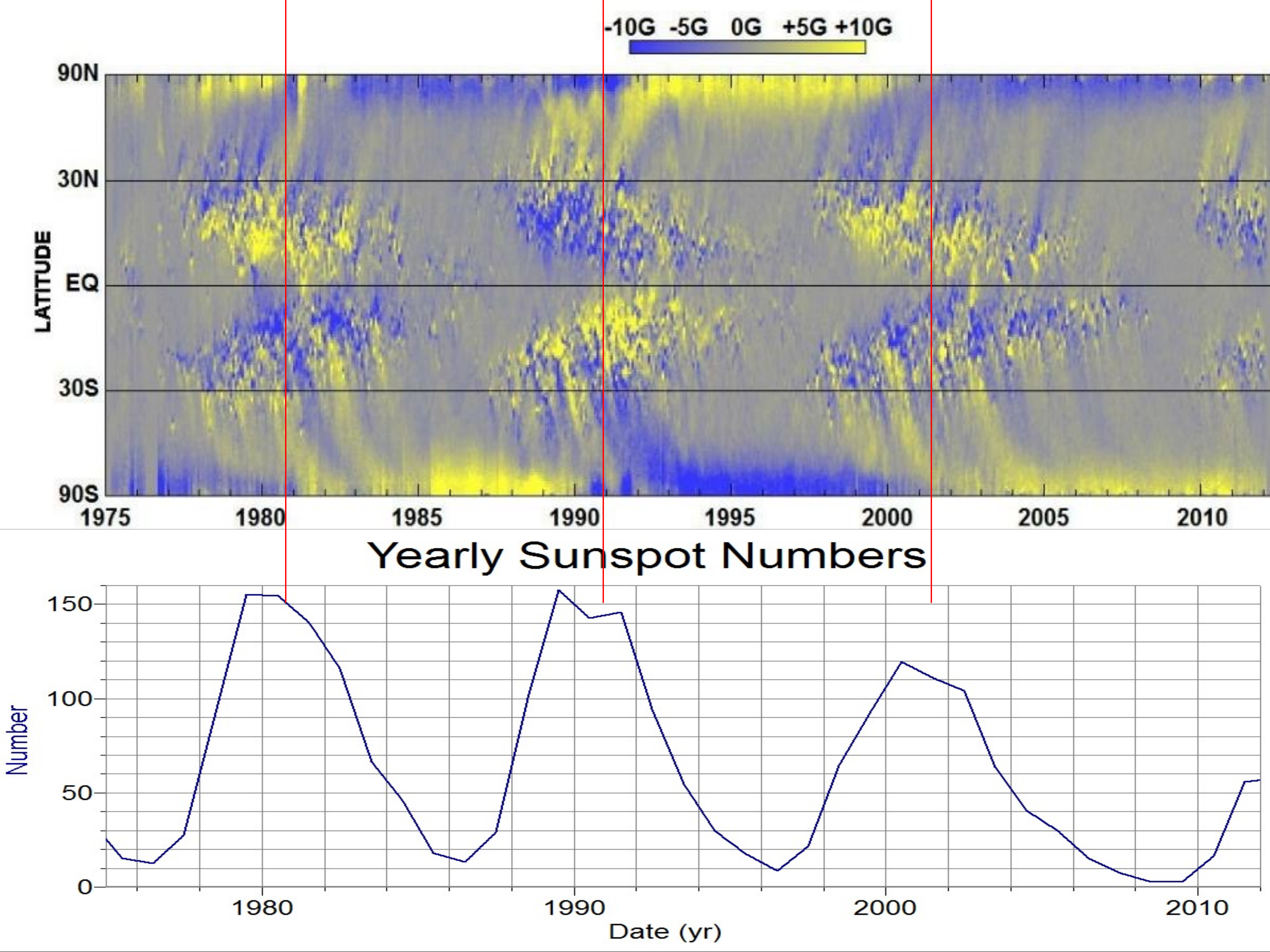
II. **Quiet Sun**
Continuous Features, Energy Production, Fusion Rx's

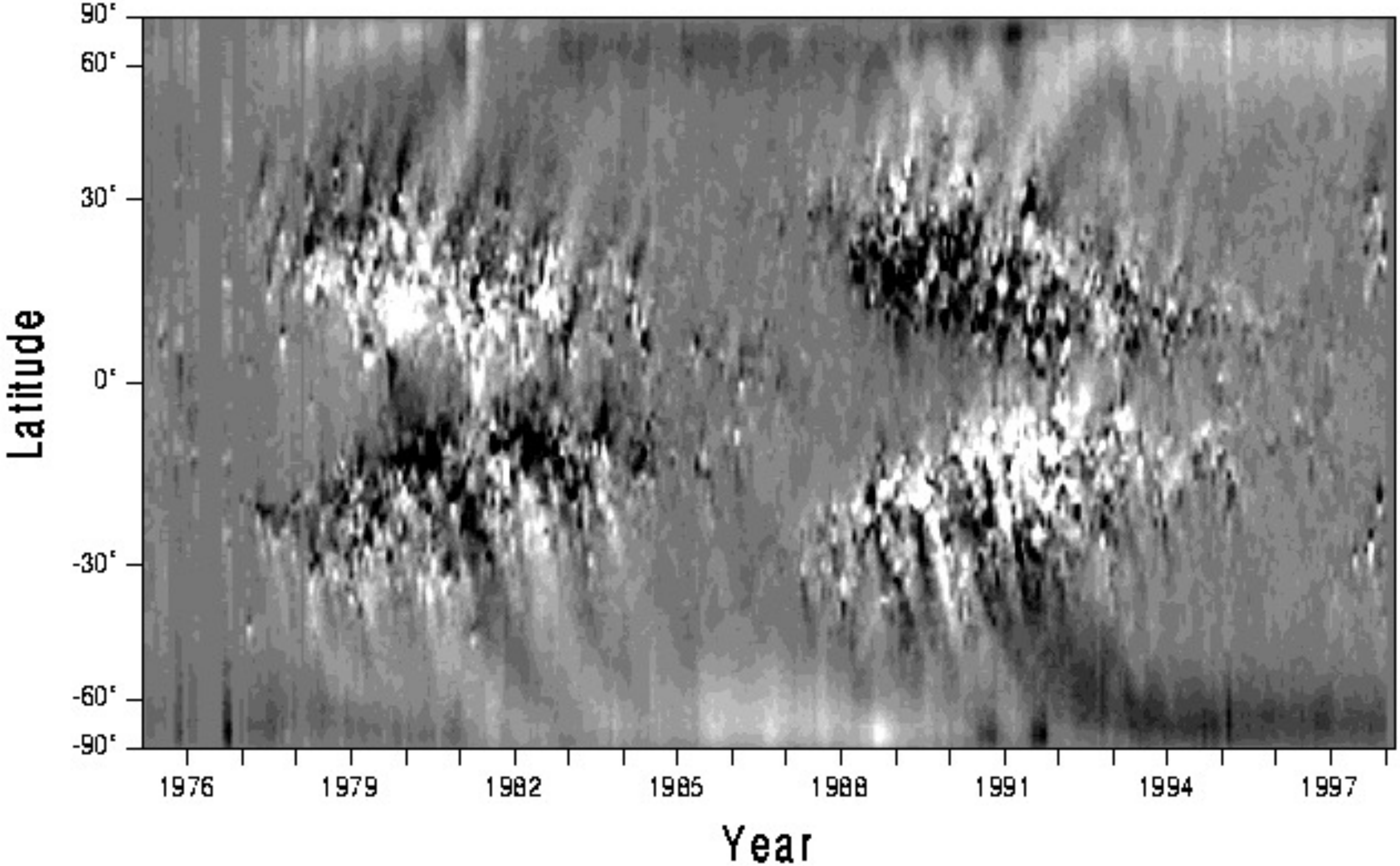
III. **Active Sun**
Solar Cycle, Sunspots, Transient Features, Magnetic Dynamo

	The student will be able to:	HW:
1	Describe the overall structure of the Sun in terms of its core, radiation zone, convection zone, photosphere, chromosphere, transition zone, corona, and solar wind.	1 – 8
2	Describe the basic properties and composition of each part of the Sun listed above.	
3	Explain and describe granulation and supergranulation.	
4	Explain what is meant by helioseismology and describe how it has yielded information about the Sun's structure.	9, 10
5	Define, explain, and state the approximate values of the solar constant and the Sun's luminosity.	11 – 19
6	Describe mechanisms by which energy is transported from the core of the Sun to its exterior.	
7	Explain the process by which the Sun produces energy – fusion and relate this to the law of conservation of mass and energy and the strong nuclear force.	
8	Describe and explain the steps of the proton-proton chain in terms of reactions involving fundamental and subatomic particles.	
9	Describe efforts to obtain experimental evidence of the fusion process thought to power the Sun including measurements of solar neutrinos.	
10	Compare and contrast the concepts quiet Sun and active Sun.	20 – 23
11	Describe the appearance of sunspots and explain their formation in terms of the Sun's magnetic field.	
12	Define and explain the following concepts: sunspot cycle, solar cycle, solar minimum, and solar maximum.	
13	Describe and explain active regions of the Sun including prominences, and flares, spicules, and coronal mass ejections.	



-10G -5G 0G +5G +10G
90N
30N
EQ
30S
90S
LATITUDE
1975
1980
1985
1990
1995
2000
2005
2010
DATE
Hathaway/NASA/MSFC 2012/03


-10G -5G 0G +5G +10G
90N
30N
EQ
30S
90S
LATITUDE
1975
1980
1985
1990
1995
2000
2005
2010
Yearly Sunspot Numbers
150
100
50
0
Number
1980
1990
2000
2010
Date (yr)



90°
60°
30°
0°
-30°
-60°
-90°
Latitude
1976
1979
1982
1985
1988
1991
1994
1997
Year

Use helioviewer.org

- Compare photosphere, magnetism, & activity:

2002/08/13 Observatory = SOHO
3 layers: MDI continuum,
MDI magnetogram
EIT any wavelength

2014/04/17 Observatory = SDO
3 layers: HMI continuum,
HMI magnetogram
AIA any wavelength

Use helioviewer.org

- Compare photosphere, magnetism, & activity:

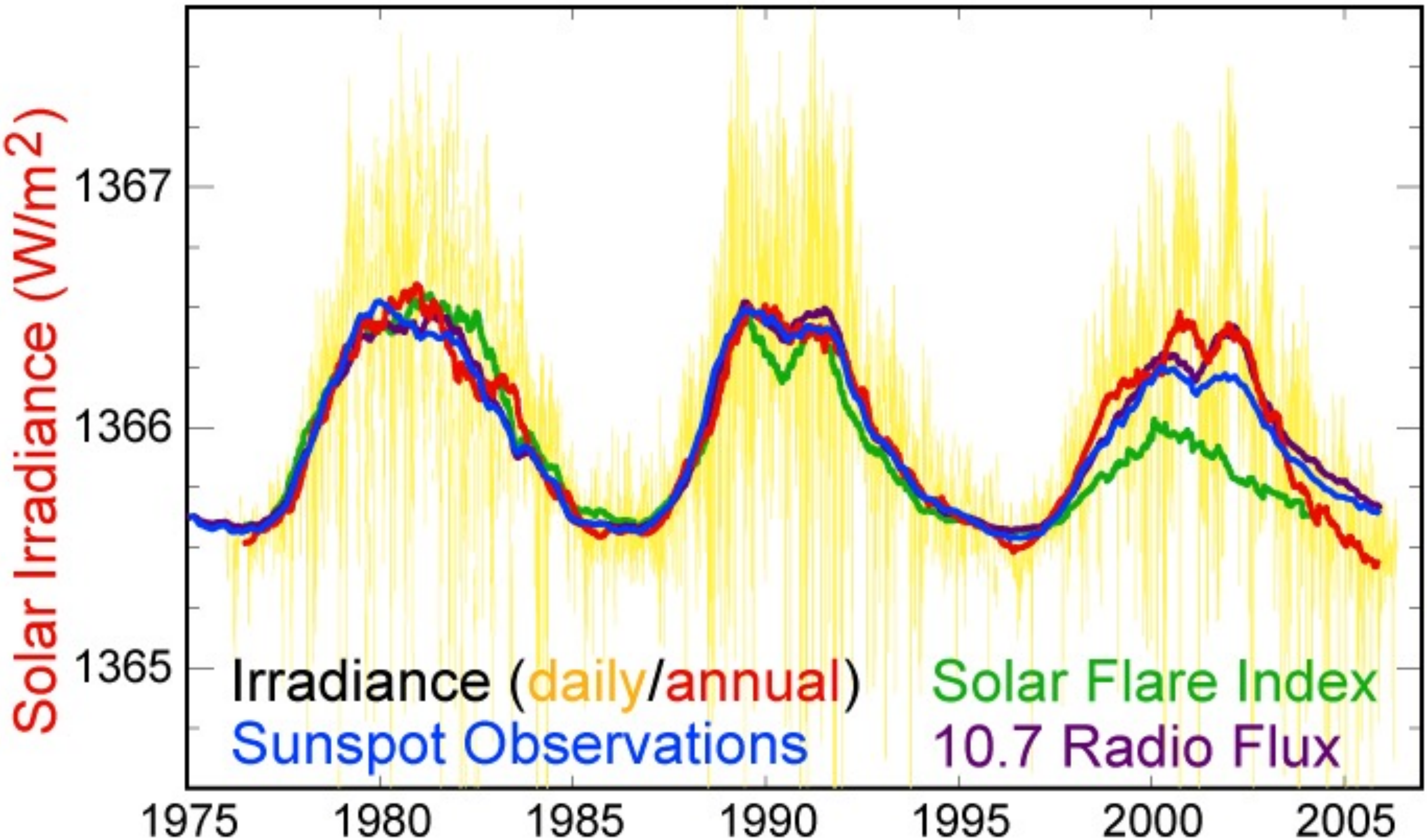
2012/08/31 Observatory = SDO
3 layers: HMI continuum,
HMI magnetogram
AIA any wavelength

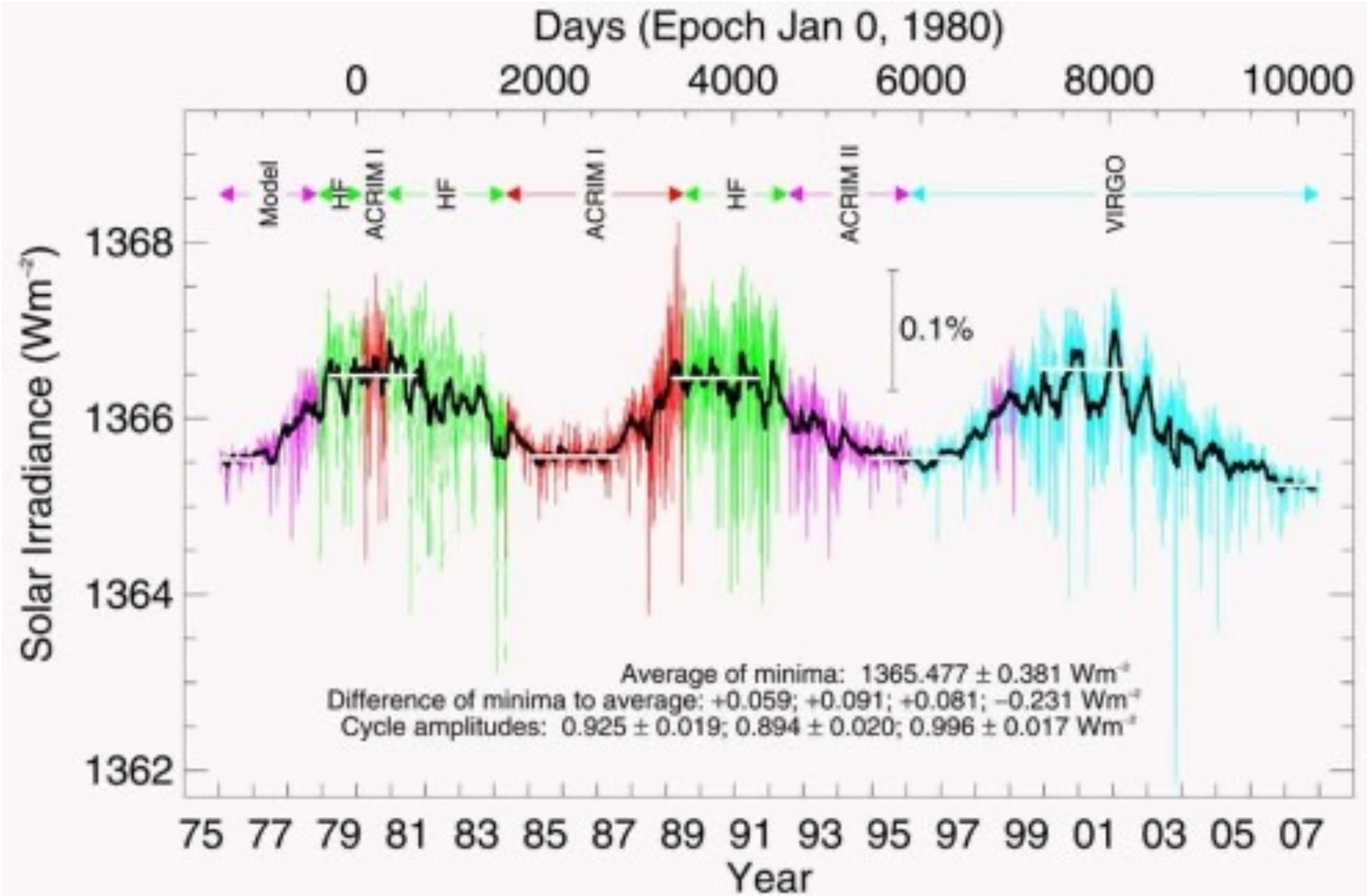
2021/10/28 Observatory = SDO
3 layers: HMI continuum,
HMI magnetogram
AIA any wavelength

Solar Cycle

- It is found that the magnetic polarity of the Sun reverses every 11 years.
- The Sun's magnetic north and south poles swap position every 11 years.
- The sunspots of one solar maximum have opposite polarity to the sunspots of the next solar maximum.
- The Sun's magnetic field undergoes a complete cycle of changes every 22 years – this is called the **solar cycle**.

Solar Cycle Variations





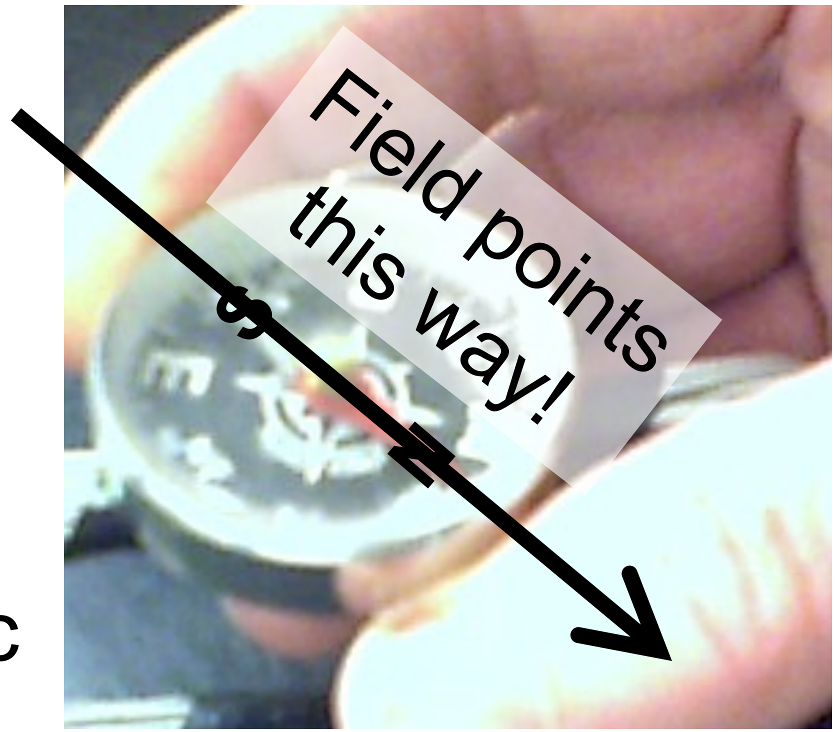
Days (Epoch Jan 0, 1980)
0
2000
4000
6000
8000
10000
Model
HF
ACRIM I
HF
ACRIM I
HF
ACRIM II
VIRGO
0.1%
Solar Irradiance (Wm⁻²)
1368
1366
1364
1362
Average of minima: 1365.477 ± 0.381 Wm⁻²
Difference of minima to average: +0.059; +0.091; +0.081; −0.231 Wm⁻²
Cycle amplitudes: 0.925 ± 0.019; 0.894 ± 0.020; 0.996 ± 0.017 Wm⁻²
75 77 79 81 83 85 87 89 91 93 95 97 99 01 03 05 07
Year

Mini-Lab: Magnetic Fields

- What is a magnetic field and how is it defined?
- What creates a magnetic field and what is affected by a magnetic field?
- How does the Sun generate a magnetic field and how does it explain the observed phenomena?

Mini-Lab: Magnetic Fields

A compass needle is a magnet. The side that points to Earth's North Pole is the north pole of that magnet.



By definition, a magnetic field points the same direction as the compass. Earth generates the magnetic field that causes the compass needle to point in a particular direction.

The Sun

Spacecraft data: SOHO, SOHO: latest, SOHO: gallery, SDO, SDO: gallery, Solar Orbiter, Parker Solar Probe

Helioviewer - Views of the Sun at various wavelengths from various sources

Space Weather - Conditions of the Sun affecting the Earth

Solar Physics on the Web - Info and hyperlinks

TRACE - Home page of Transition Region and Coronal Explorer spacecraft

Solar Cycle Progression - Interactive graphs of sunspot and radio flux data

Sunspot Plotter - Java applet to graph sunspot data

Magnetic Field of Bar Magnet - Interactive mapping

Magnets & Electromagnets - Simulation of Magnetic Fields

The Sun's Power - Text and animation explaining energy output

Solar Neutrinos - Links to other sites

Various Animations - Fusion, Blackbody Radiation

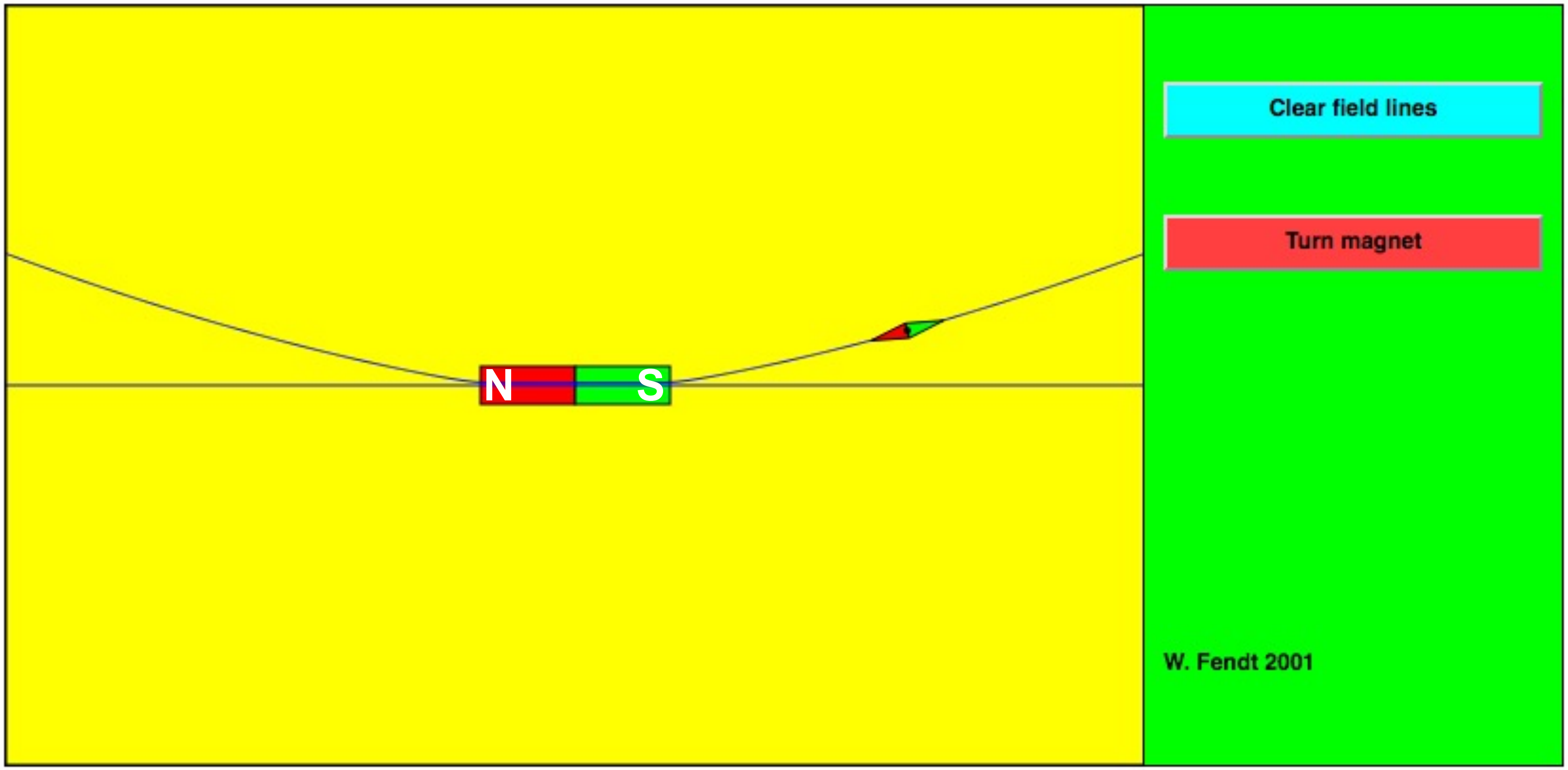
Sunspot Plotter - Java applet to graph sunspot data

Magnetic Field of Bar Magnet - Interactive mapping

Magnets & Electromagnets - Simulation of Magnetic Fields

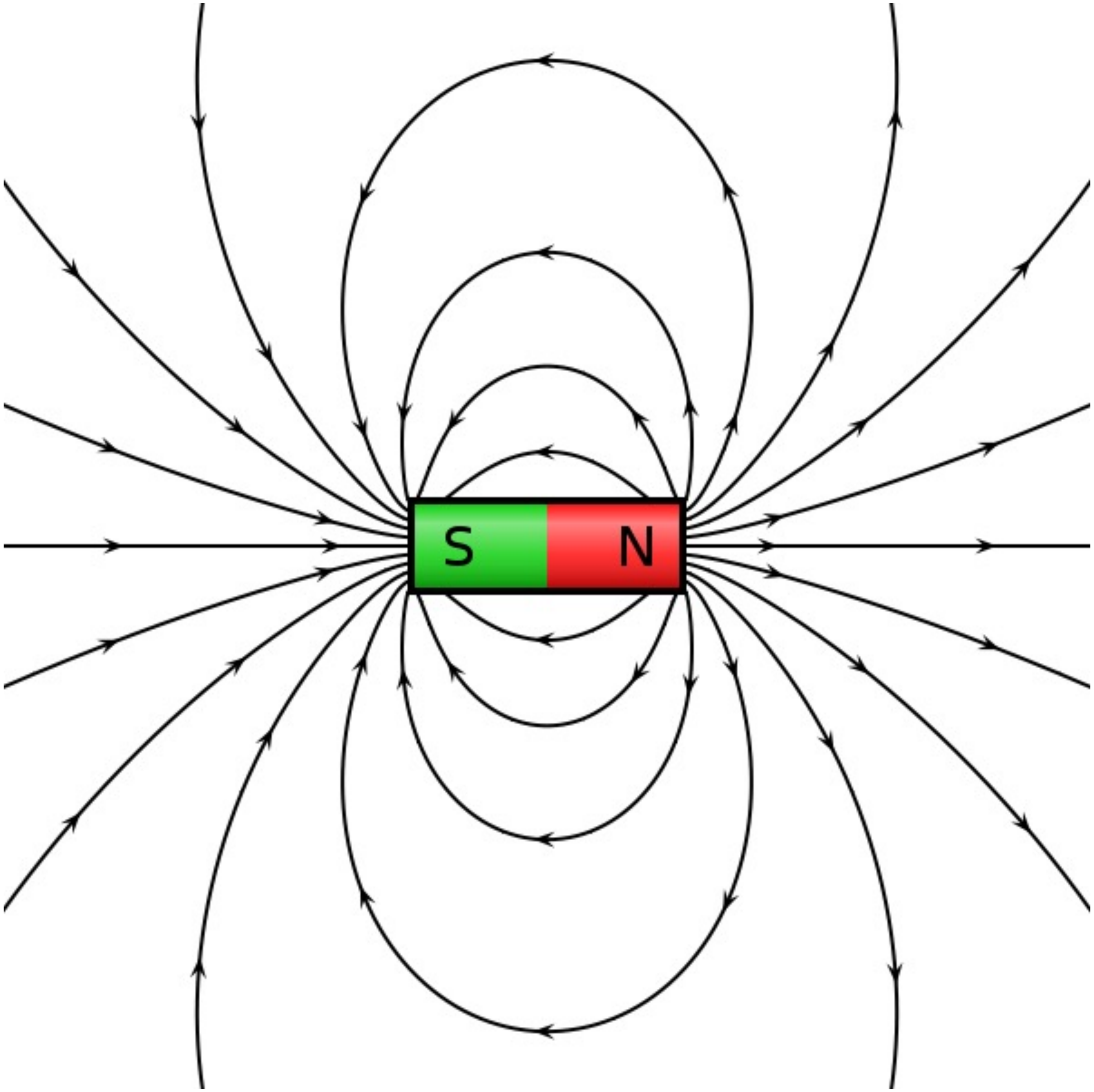
The Sun's Power - Text and animation explaining energy output

Use the simulation to create a picture of the magnetic field of the bar magnet. Drag and release the small "compass needle".



Field points away from which pole?
toward which pole?

Field of Bar Magnet



Credit: Geek3, Wikipedia

The Sun

Spacecraft data: SOHO, SOHO: latest, SOHO: gallery, SDO, SDO: gallery, Solar Orbiter, Parker Solar Probe

Helioviewer - Views of the Sun at various wavelengths from various sources

Space Weather - Conditions of the Sun affecting the Earth

Solar Physics on the Web - Info and hyperlinks

TRACE - Home page of Transition Region and Coronal Explorer spacecraft

Solar Cycle Progression - Interactive graphs of sunspot and radio flux data

Sunspot Plotter - Java applet to graph sunspot data

Magnetic Field of Bar Magnet - Interactive mapping

Magnets & Electromagnets - Simulation of Magnetic Fields

The Sun's Power - Text and animation explaining energy output

Solar Neutrinos - Links to other sites

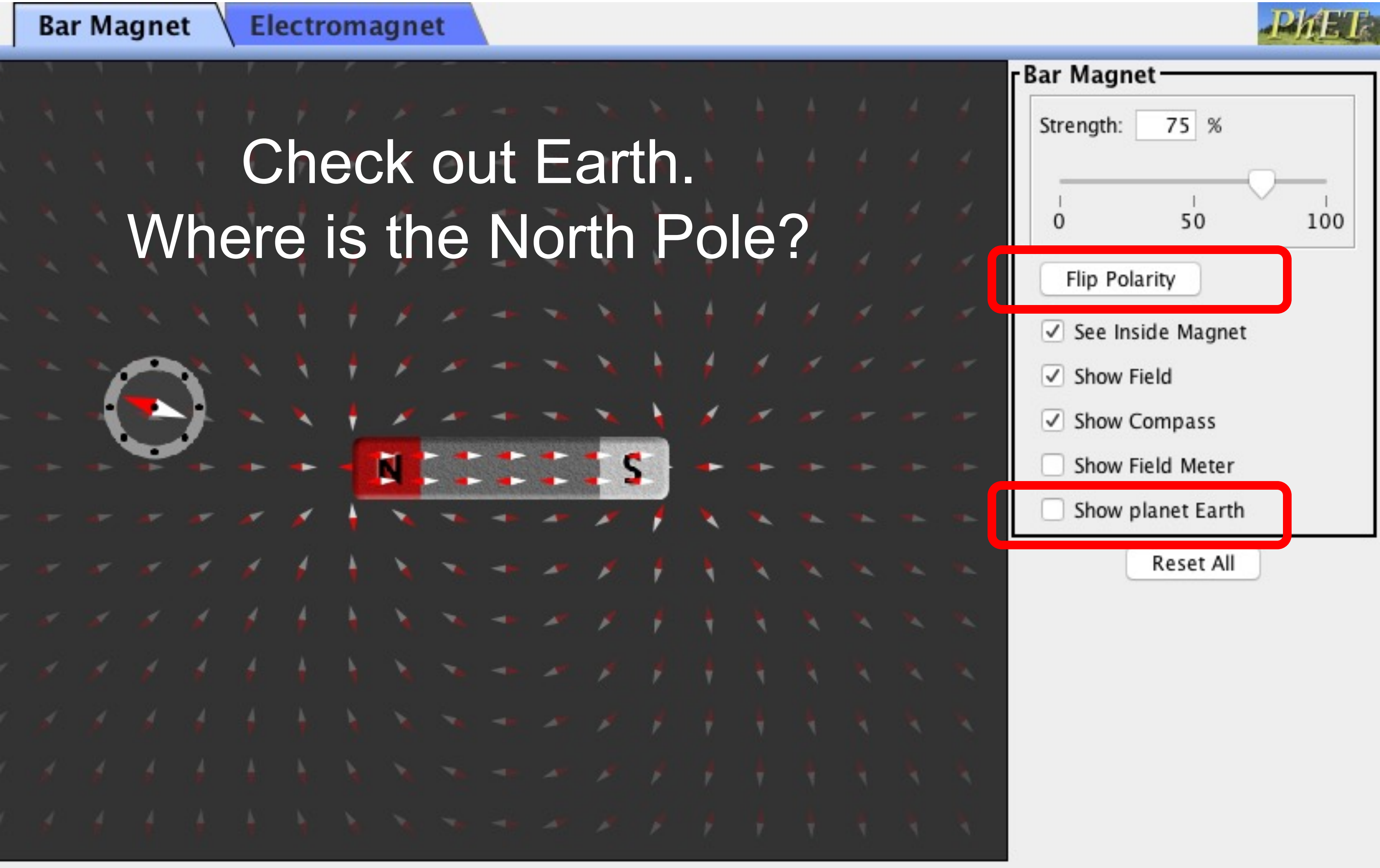
Various Animations - Fusion, Blackbody Radiation

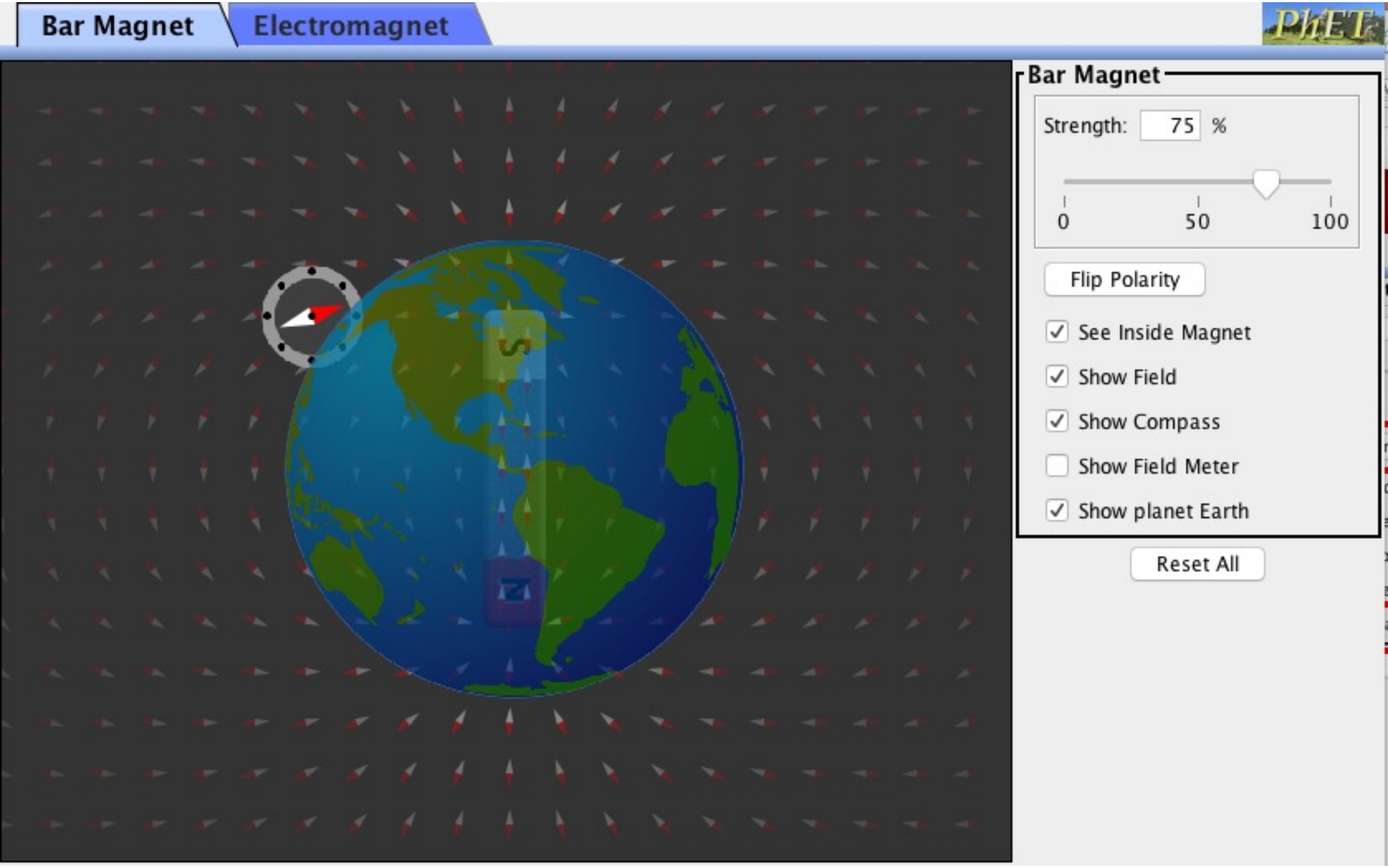
Sunspot Plotter - Java applet to graph sunspot data

Magnetic Field of Bar Magnet - Interactive mapping

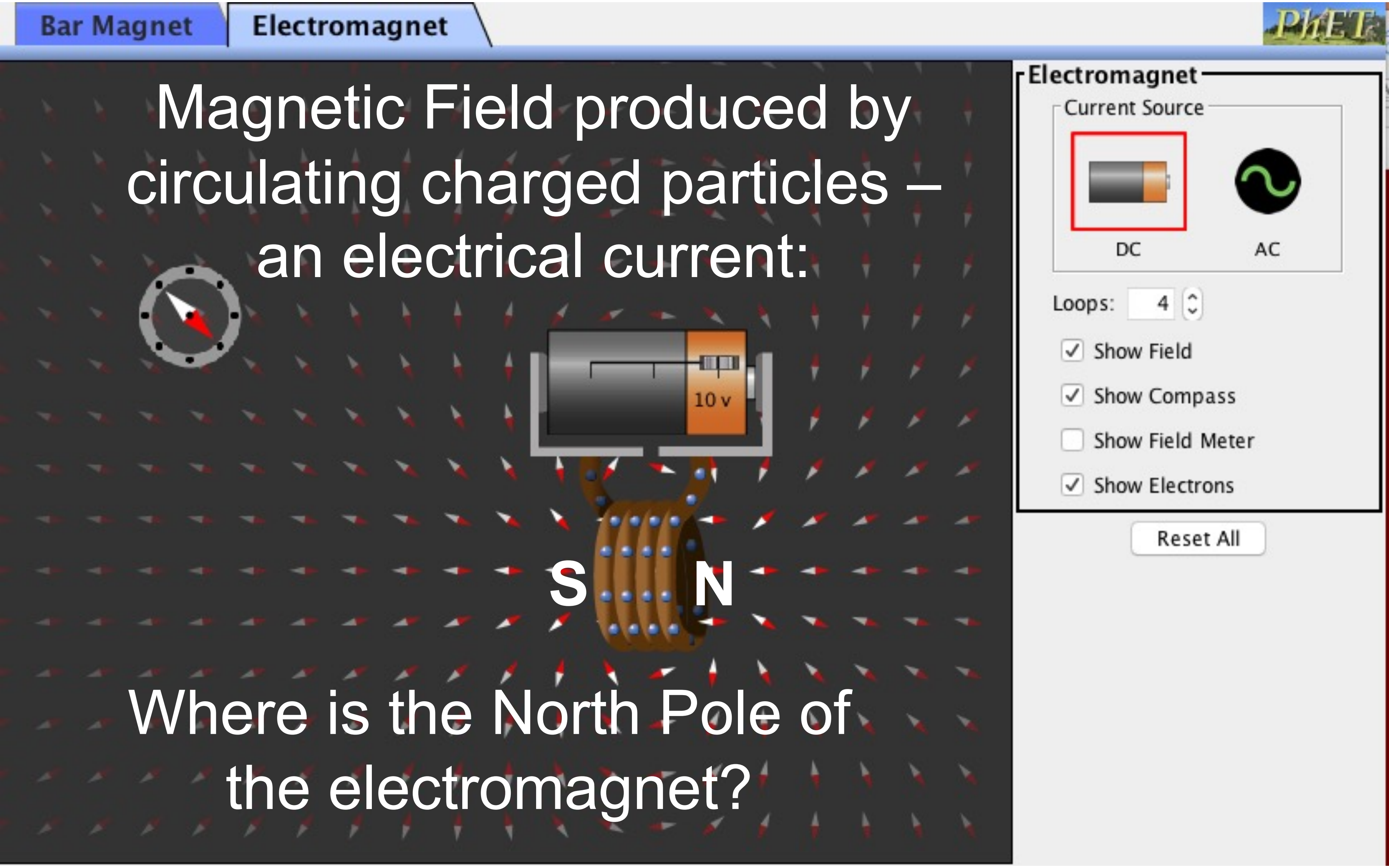
Magnets & Electromagnets - Simulation of Magnetic Fields

The Sun's Power - Text and animation explaining energy output


Bar Magnet
Electromagnet
PhET
Check out Earth.
Where is the North Pole?
N
S
Bar Magnet
Strength: 75 %
0
50
100
Flip Polarity
See Inside Magnet
Show Field
Show Compass
Show Field Meter
Show planet Earth
Reset All


Bar Magnet
Electromagnet
PhET
Bar Magnet
Strength: 75 %
0
50
100
Flip Polarity
See Inside Magnet
Show Field
Show Compass
Show Field Meter
Show planet Earth
Reset All
S
N

Magnetic Field produced by circulating charged particles – an electrical current:

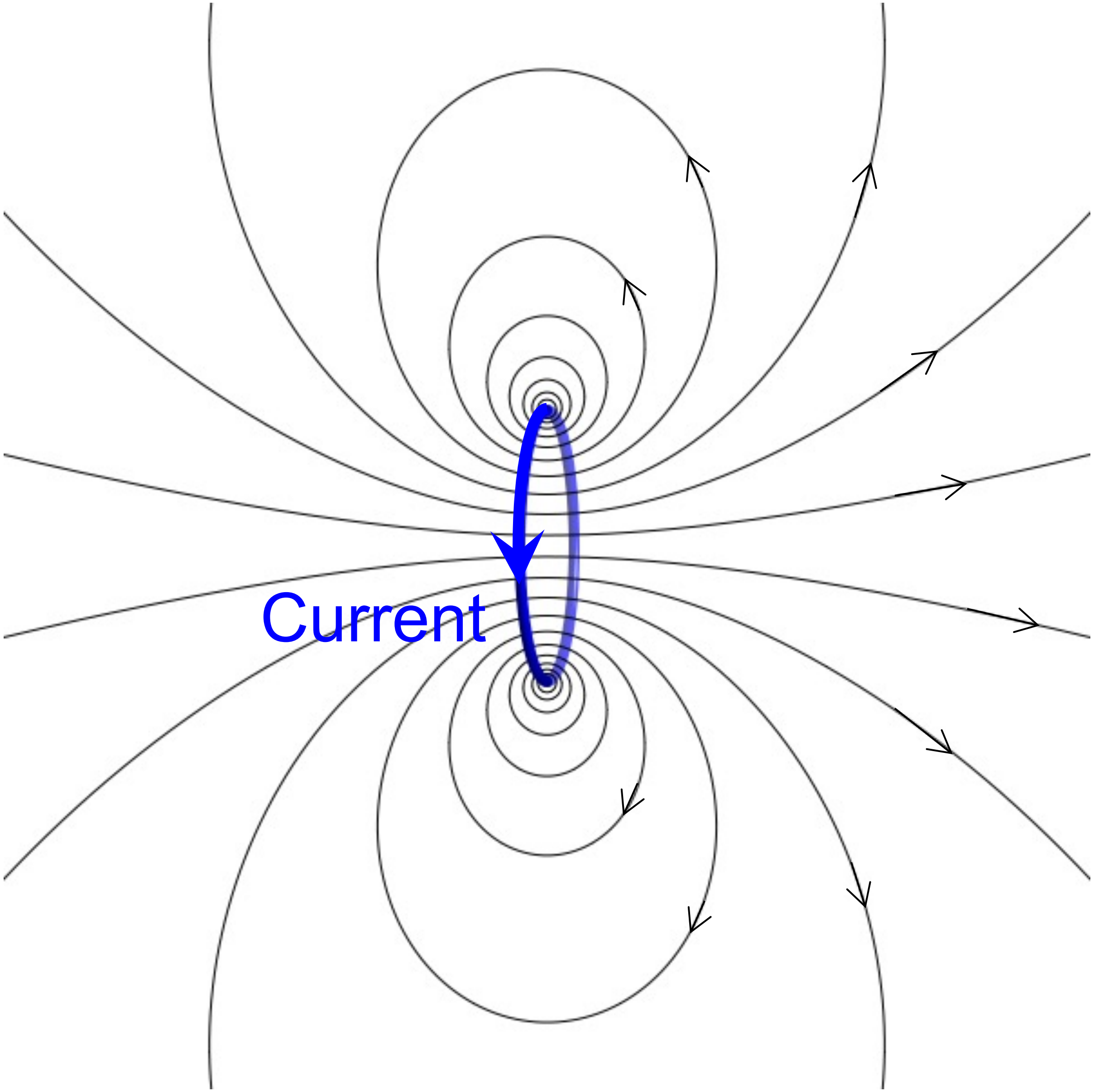


Where is the North Pole of the electromagnet?

Mini-Lab: Magnetic Fields

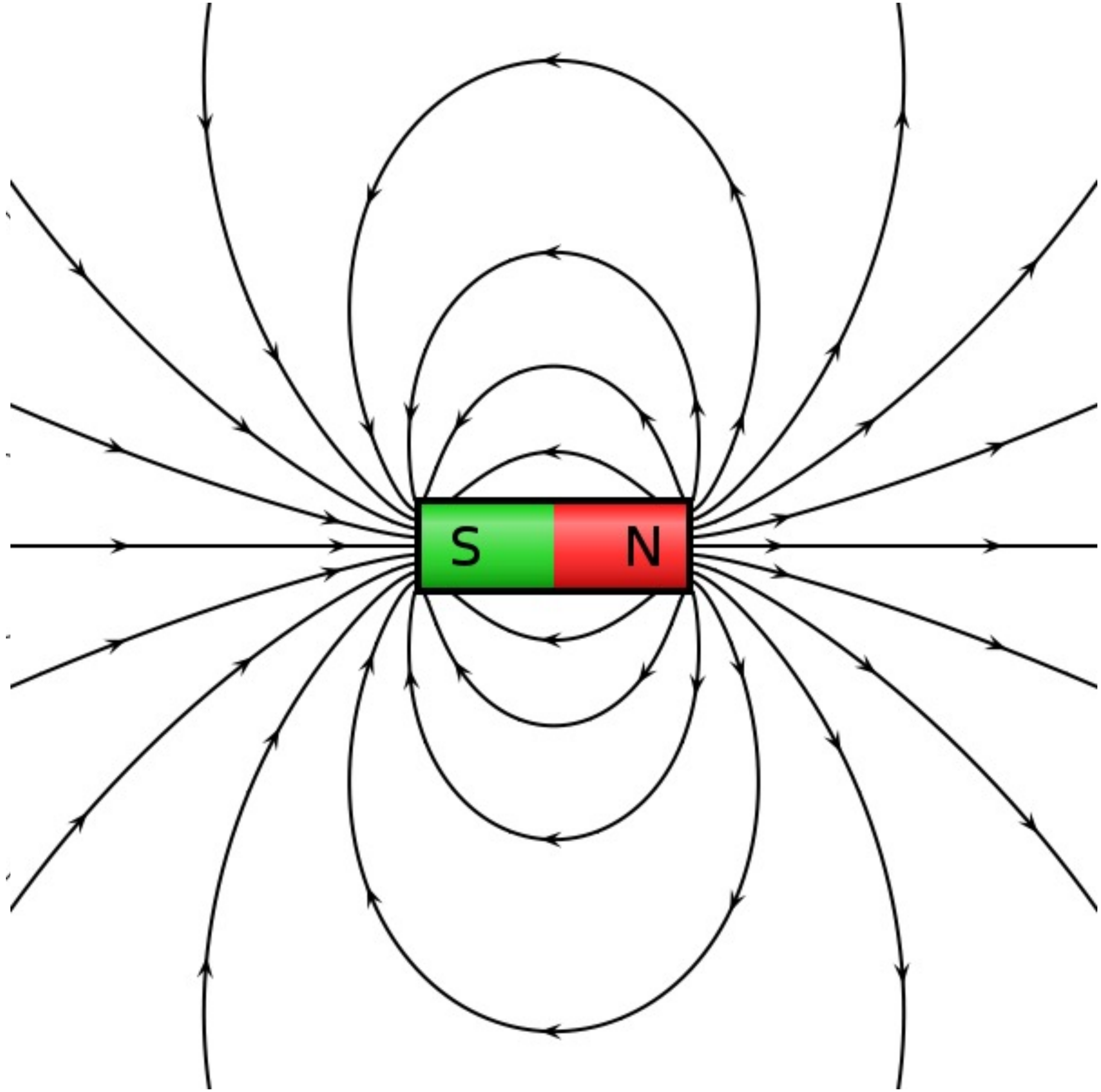
1. What does the field of the coil of current look like? Is it at all similar to that of the bar magnet?
2. Would the coil of current exert a force on the bar magnet? And vice versa?
3. What might be happening in the Sun to produce a magnetic field?
4. How might magnetic fields explain the active features of the Sun?

Magnetic Field – Ring of Current

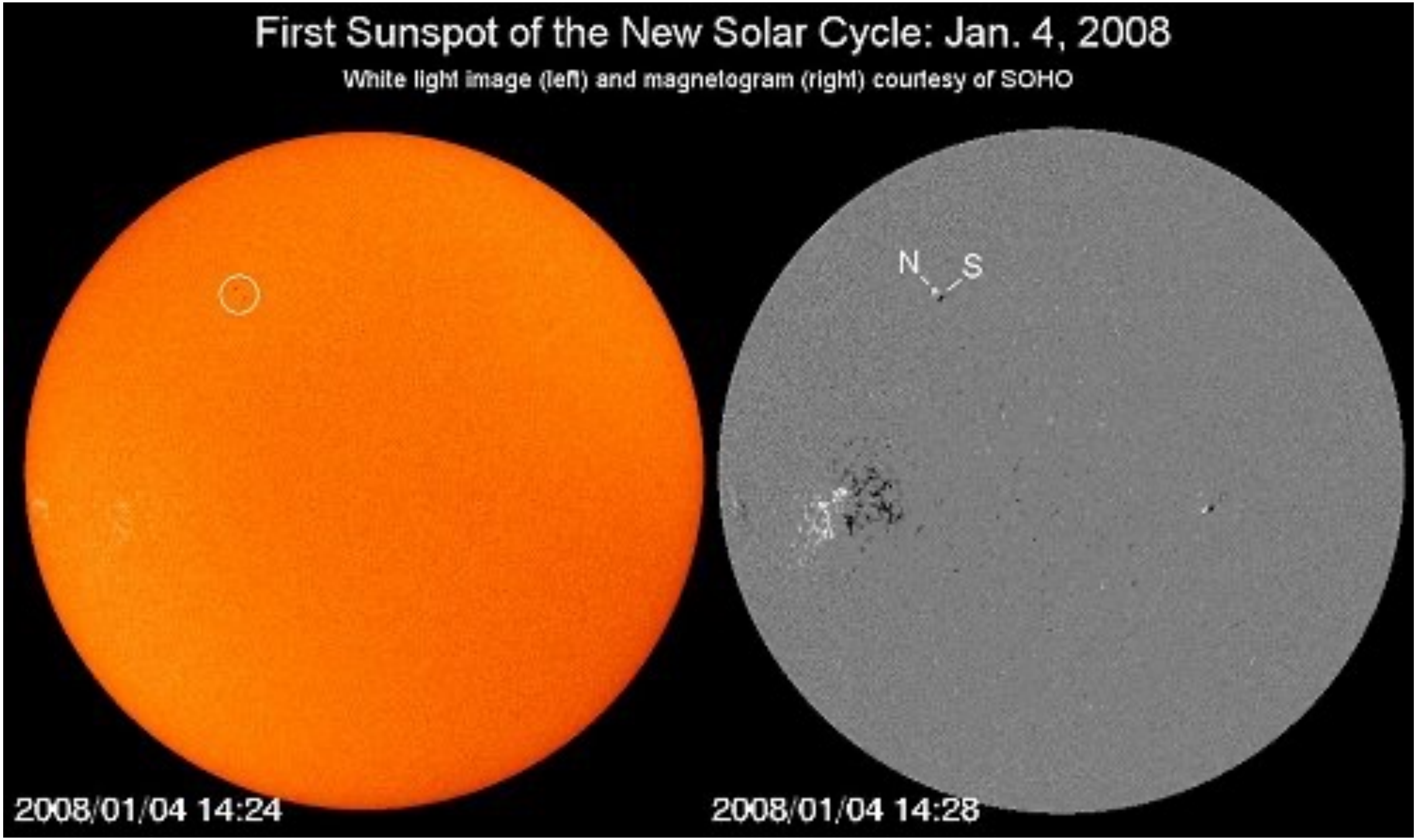


Credit: Geek3, Wikipedia

Fields – Ring of Current vs Bar Magnet

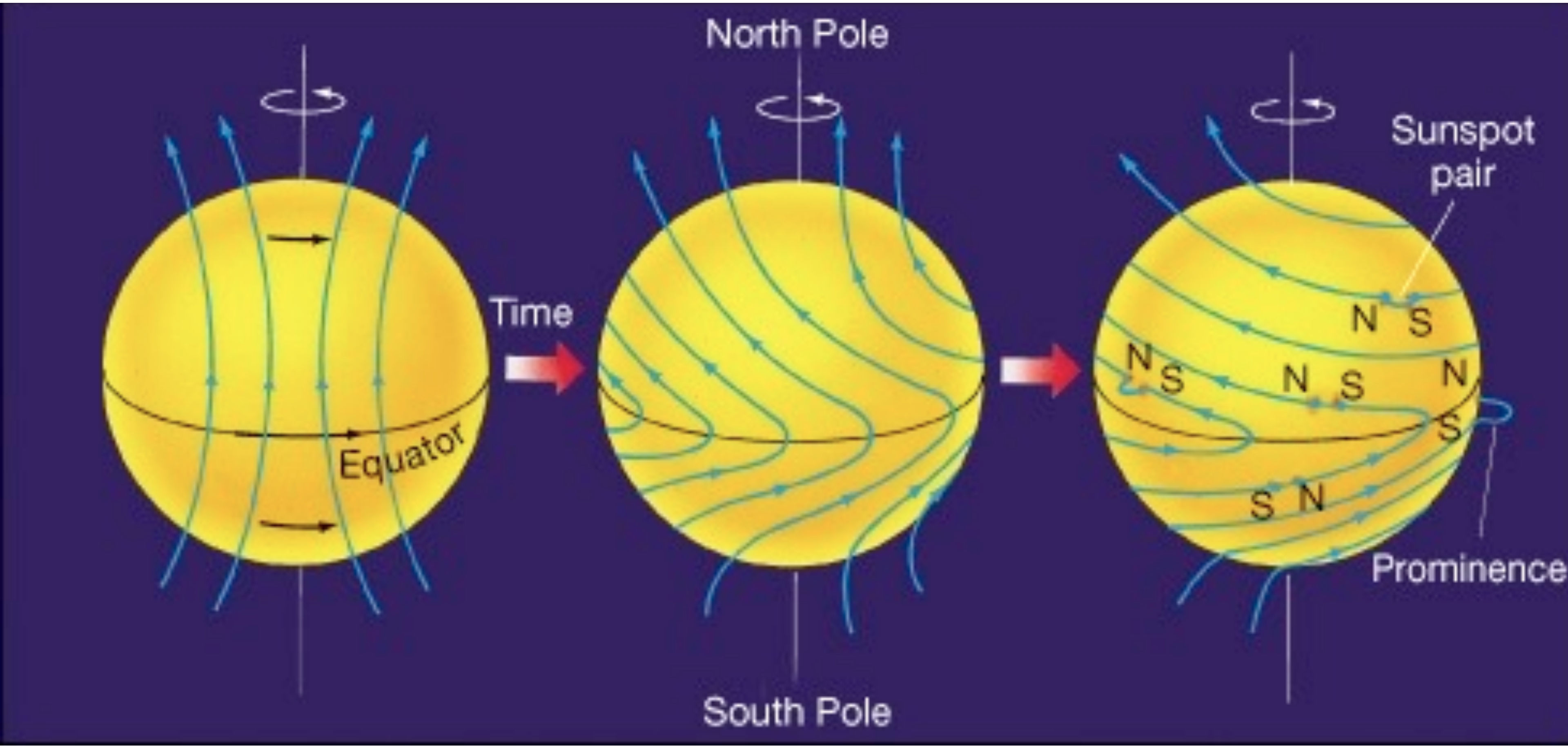


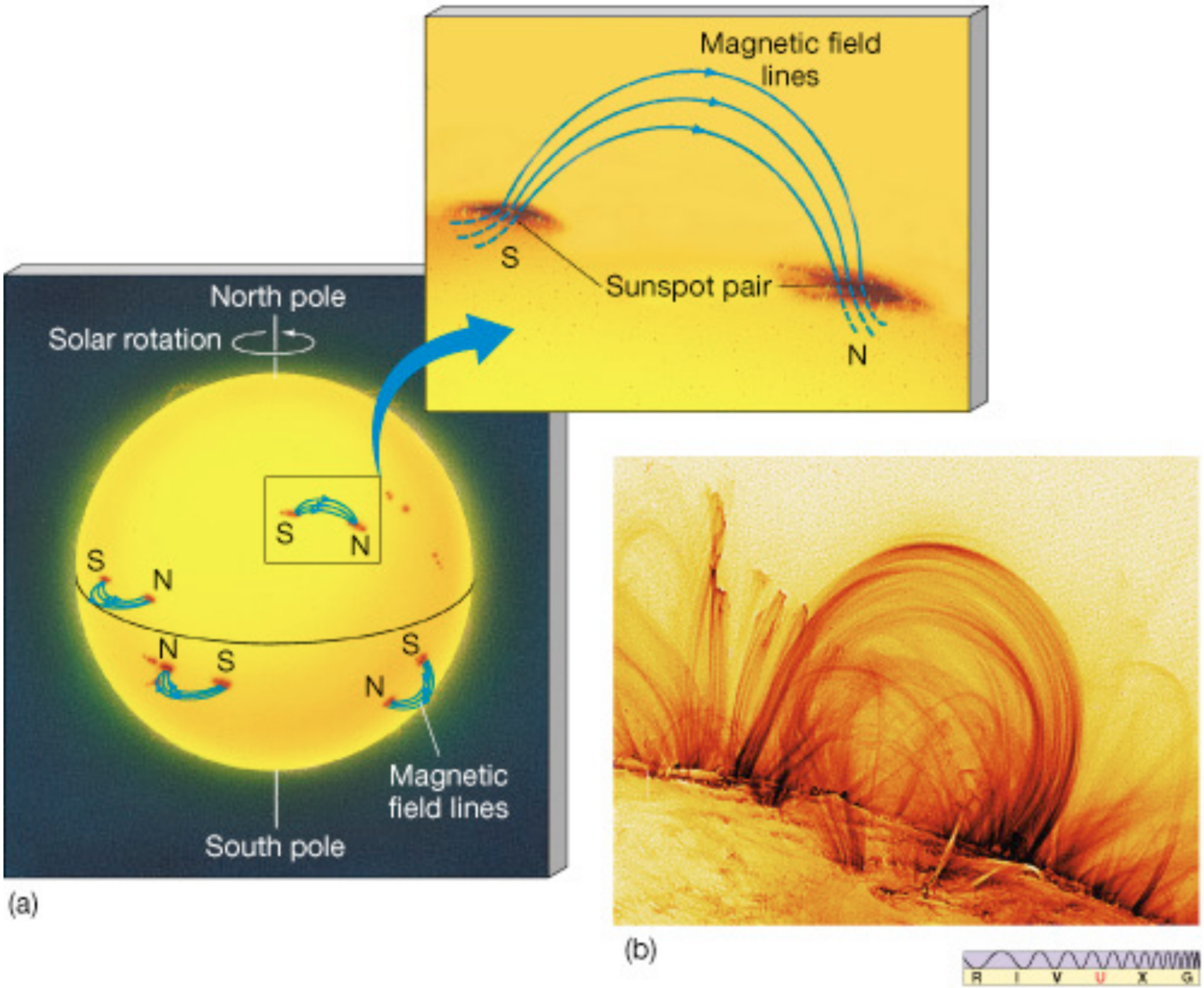
Credit: Geek3, Wikipedia

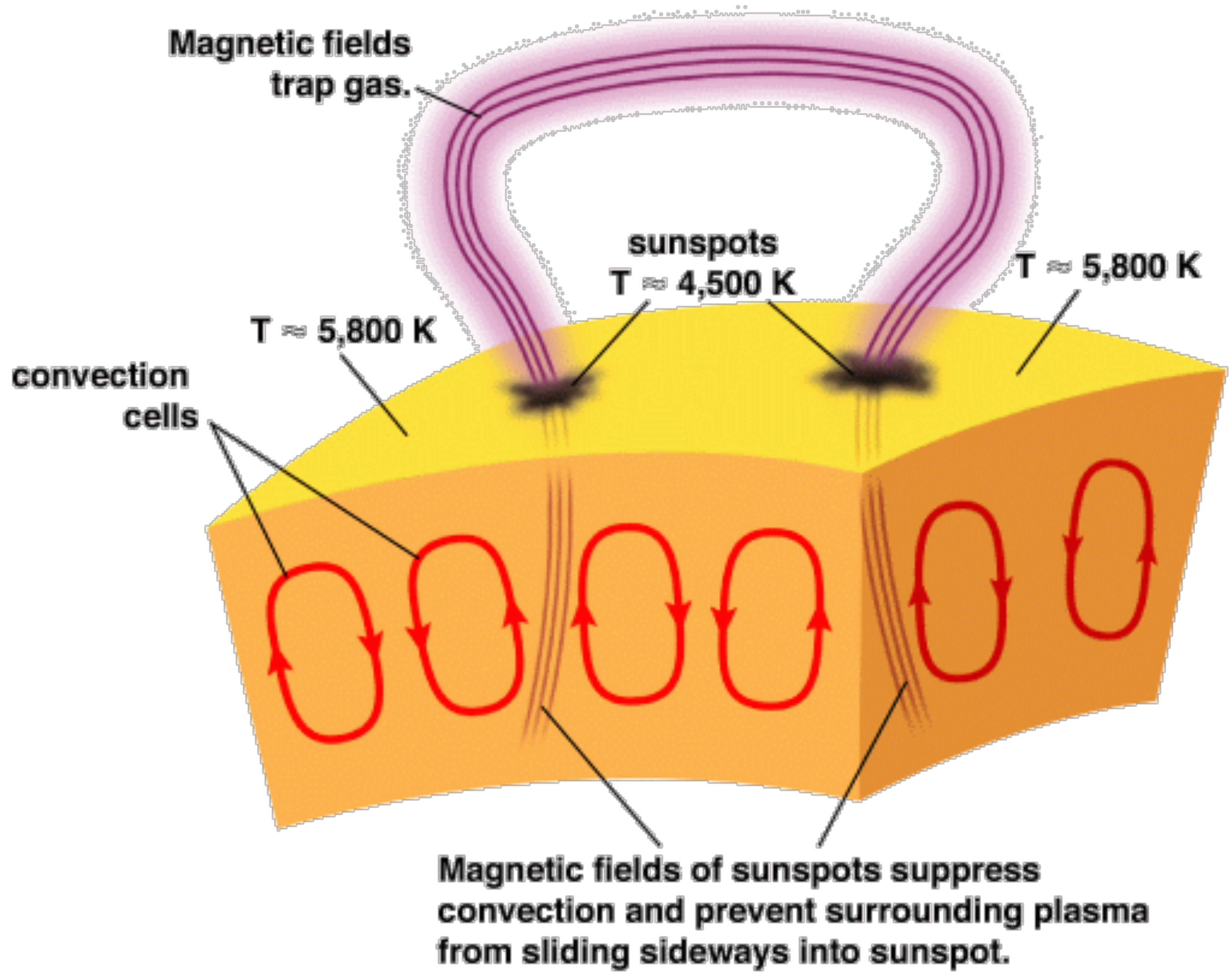

First Sunspot of the New Solar Cycle: Jan. 4, 2008
White light image (left) and magnetogram (right) courtesy of SOHO
N
S
2008/01/04 14:24
2008/01/04 14:28

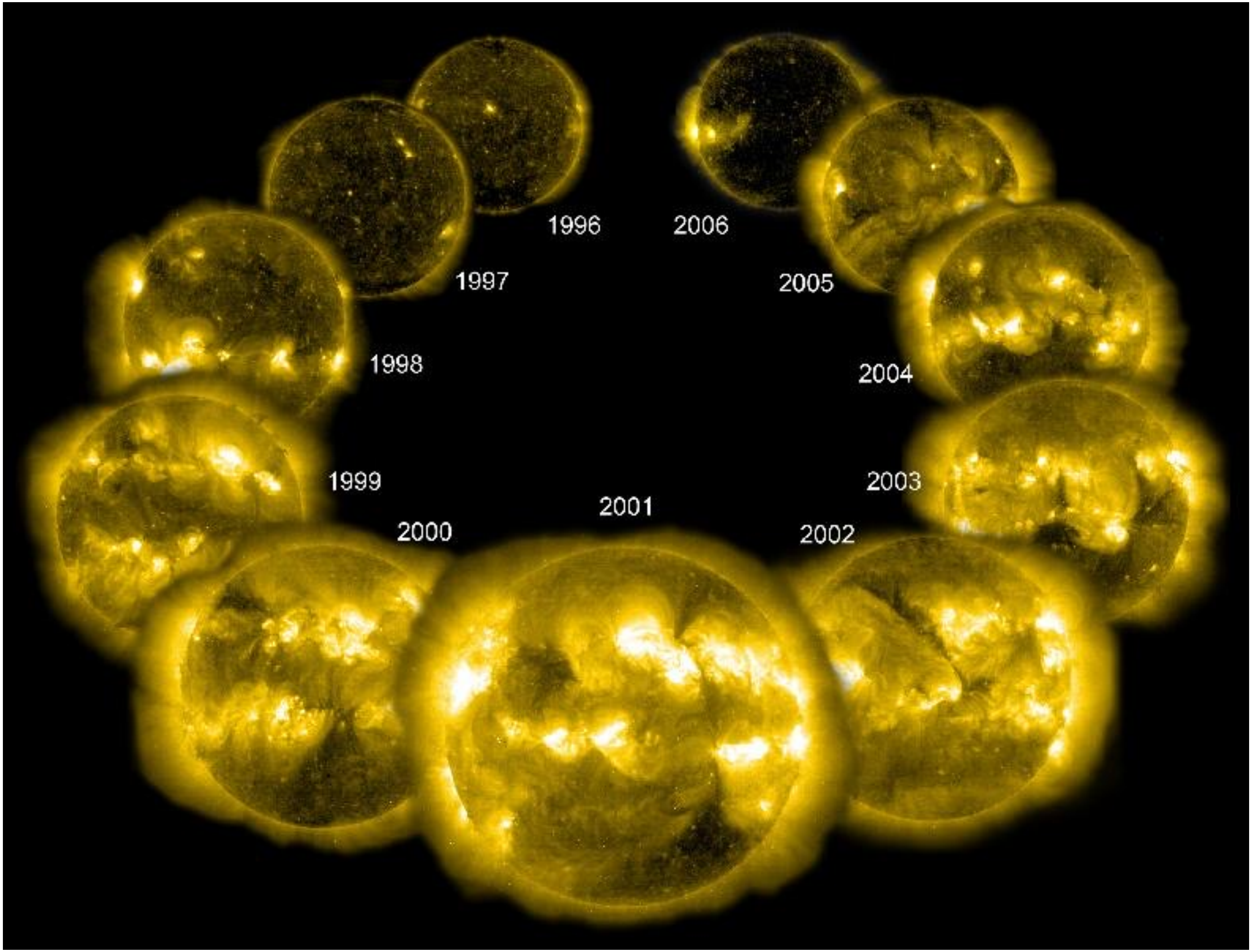
Rotation and Magnetosphere

- The Sun's interior rotates about once every 27 days.
- The outer layers of the Sun exhibit differential rotation ranging from a period of 25 days at the equator to about 36 days at the poles.
- The rotation combined with the electrical properties result in a large **dynamo effect**. The Sun has a very strong magnetic field.


North Pole
Time
Equator
Sunspot pair
N S
N S
N S
N
S
S N
Prominence
South Pole


Magnetic field lines
S
Sunspot pair
N
North pole
Solar rotation
S
N
S
N
N
S
S
N
Magnetic field lines
South pole
(a)
(b)
R I V U X G

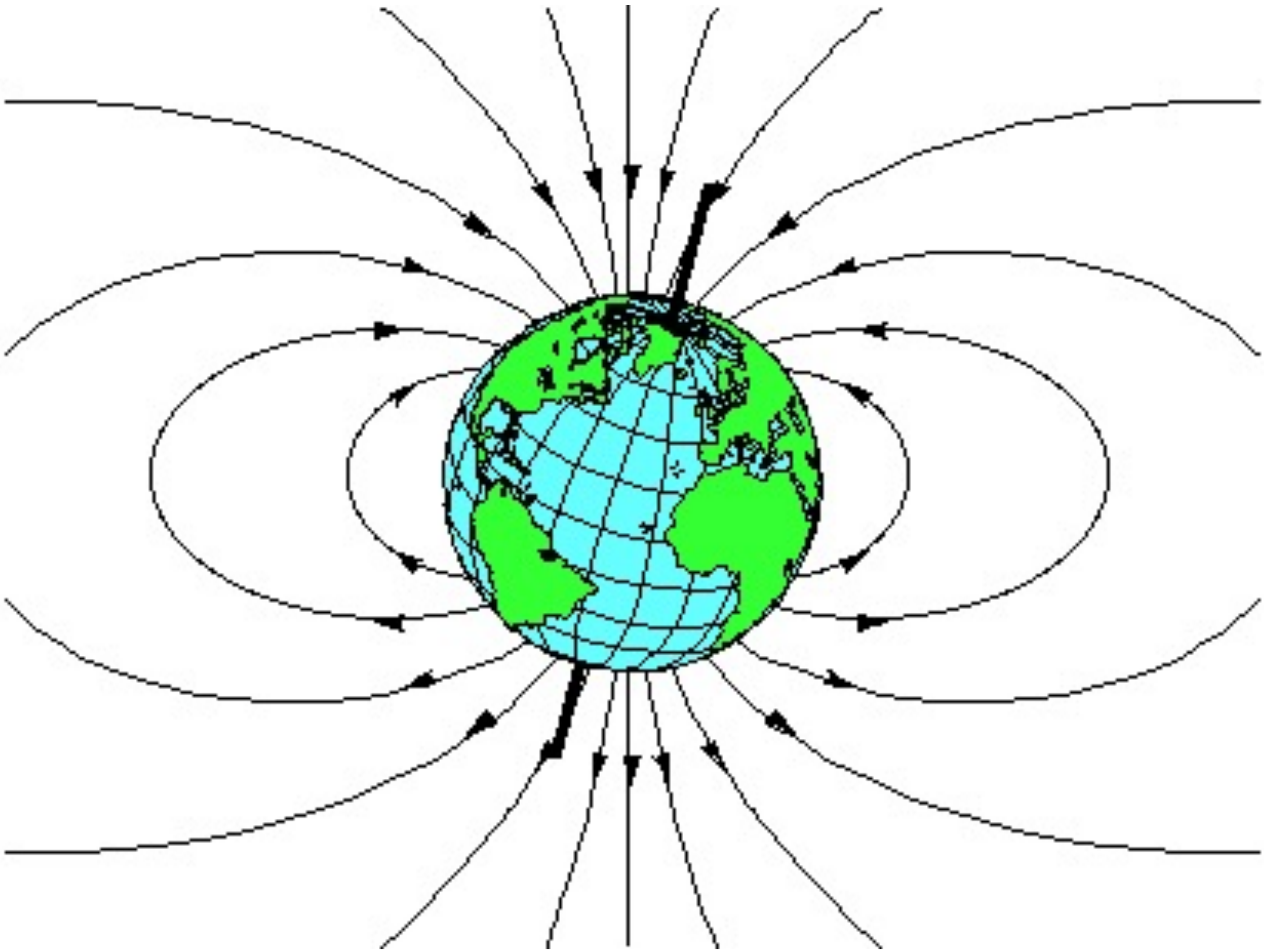

Magnetic fields
trap gas.
sunspots
T ≈ 4,500 K
T ≈ 5,800 K
T ≈ 5,800 K
convection
cells
Magnetic fields of sunspots suppress
convection and prevent surrounding plasma
from sliding sideways into sunspot.


1996
2006
1997
2005
1998
2004
1999
2003
2001
2000
2002

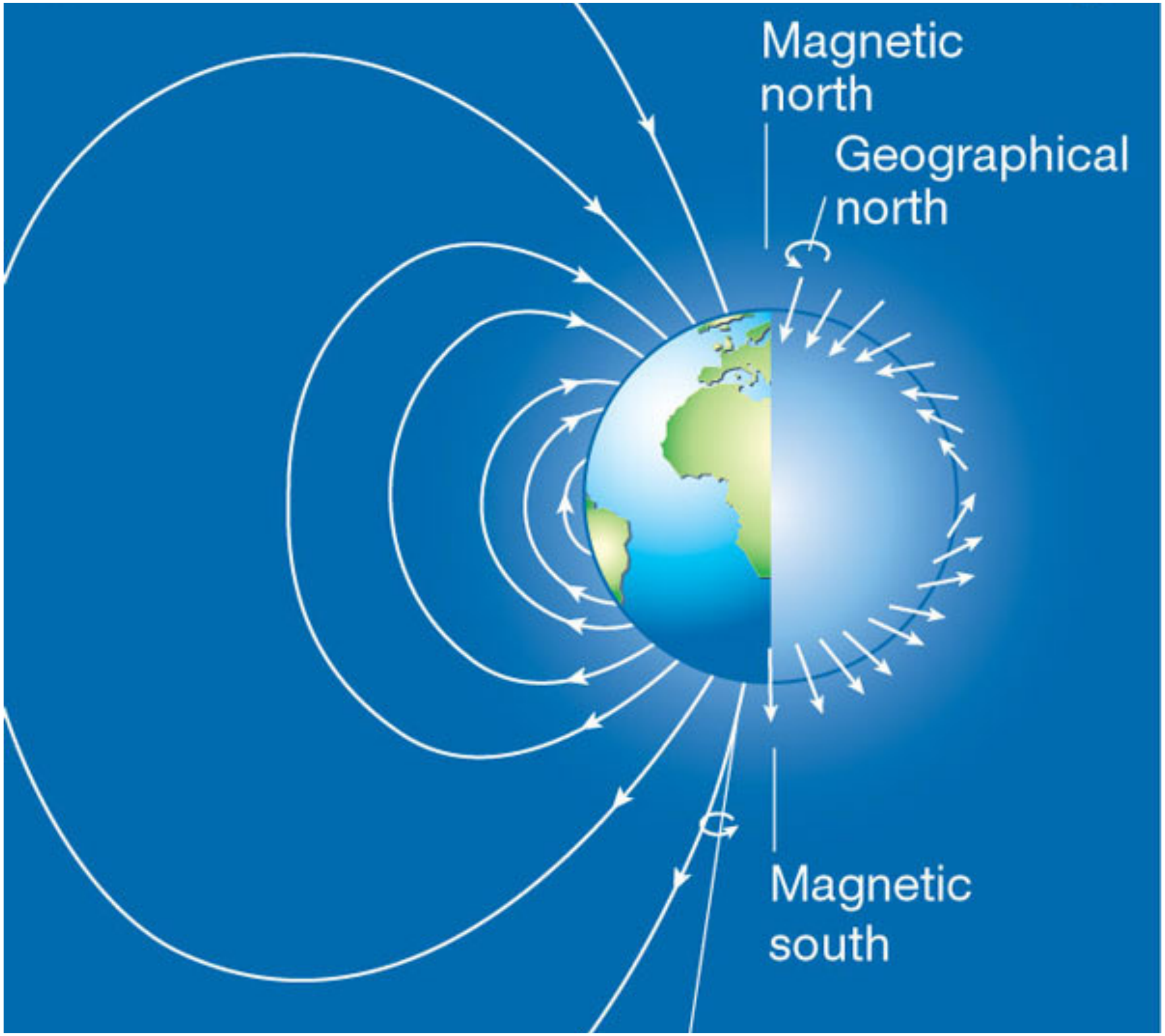
Solar Cycle

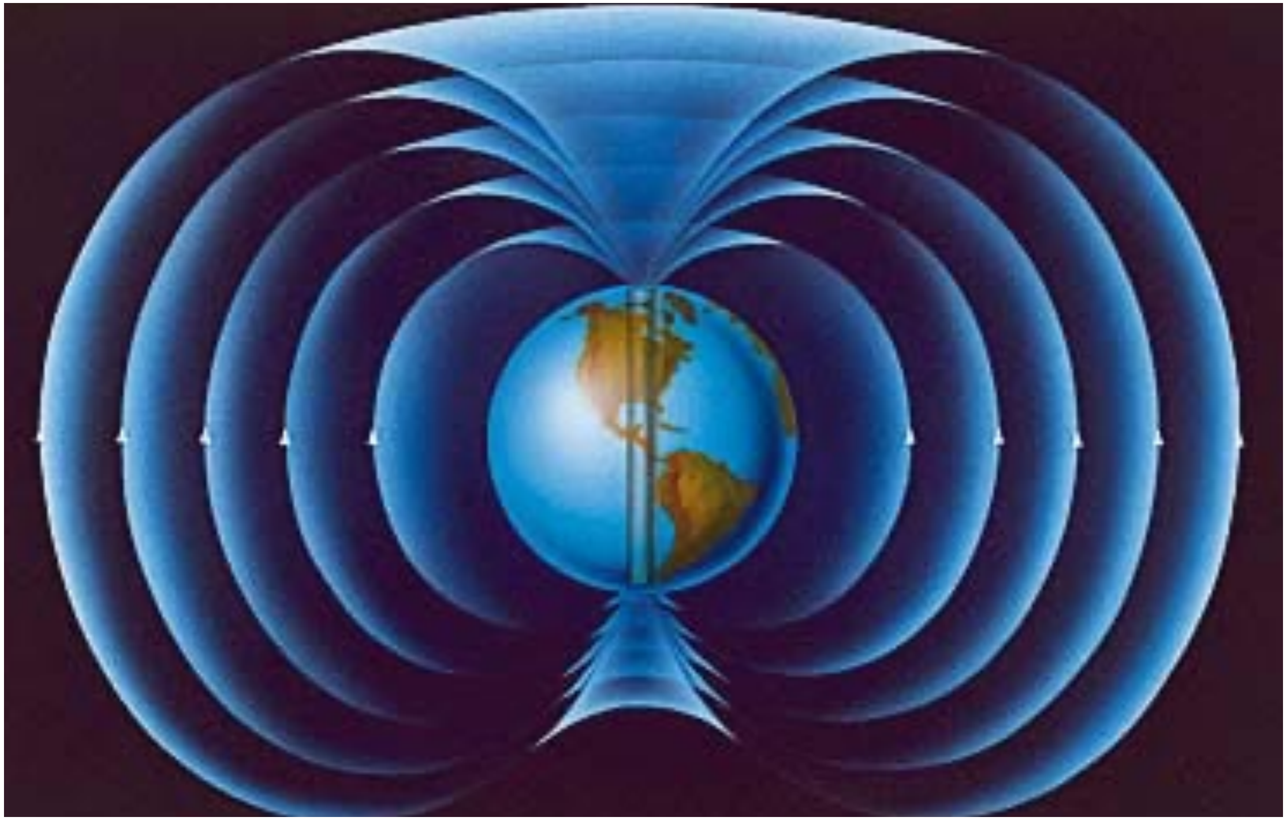
- It is now known that all of the active phenomena of the Sun are driven by the changes in its magnetic field.
- Whenever the number of sunspots is maximal so will be flares, prominences, CME's, etc.

Earth's Magnetic Field

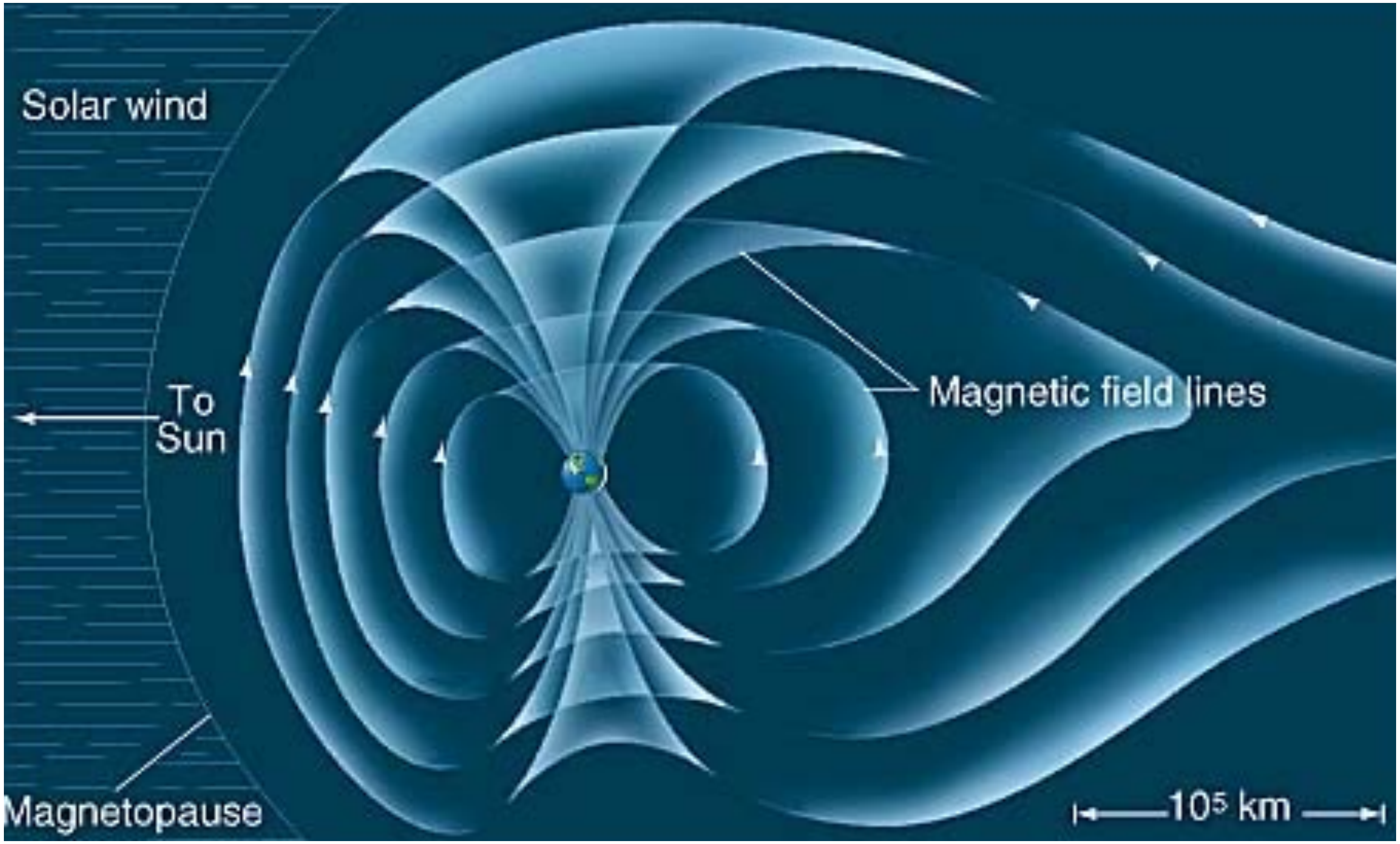


Externally it is very similar to that of a bar magnet.


Magnetic
north
Geographical
north
Magnetic
south



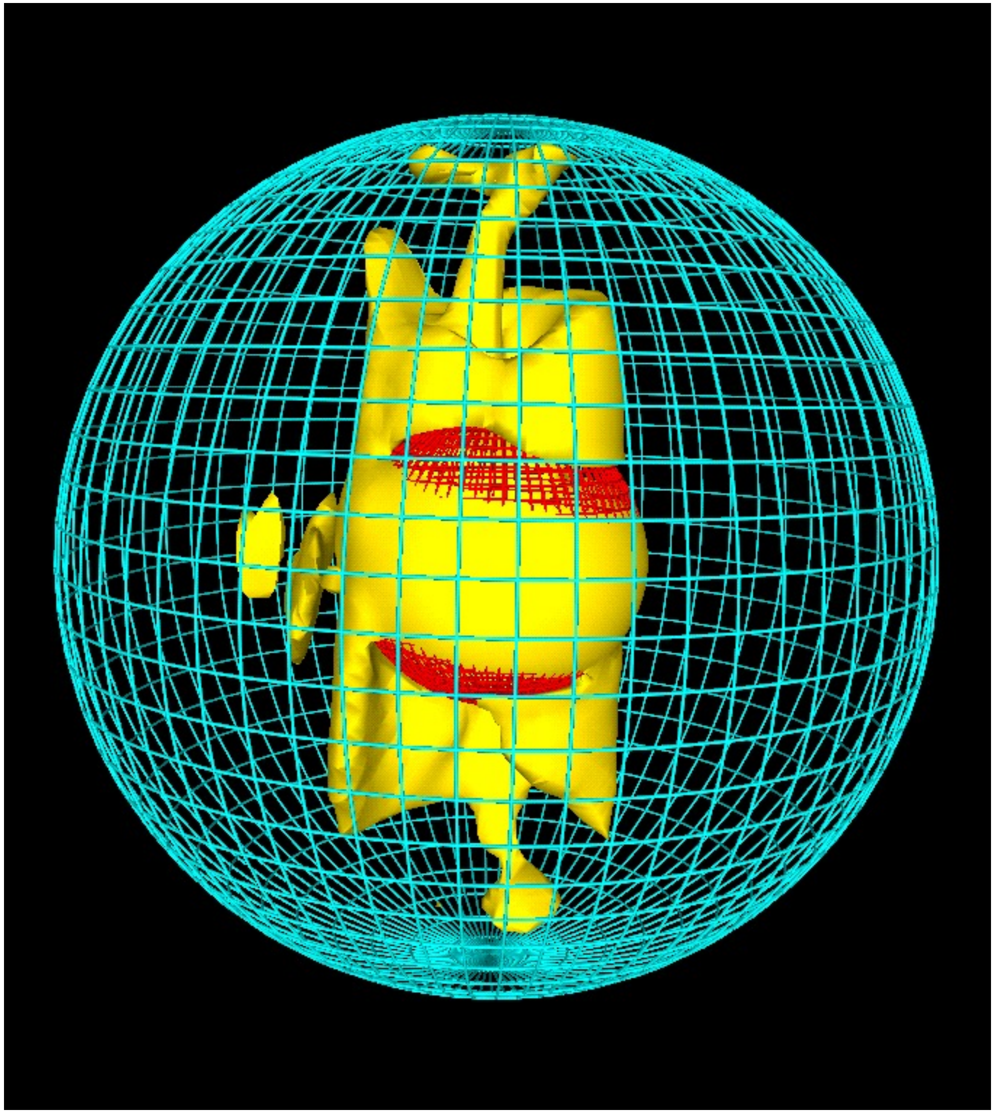
The arrows show the direction a compass would point if placed in the field. The field is strongest where the field lines are closest together.



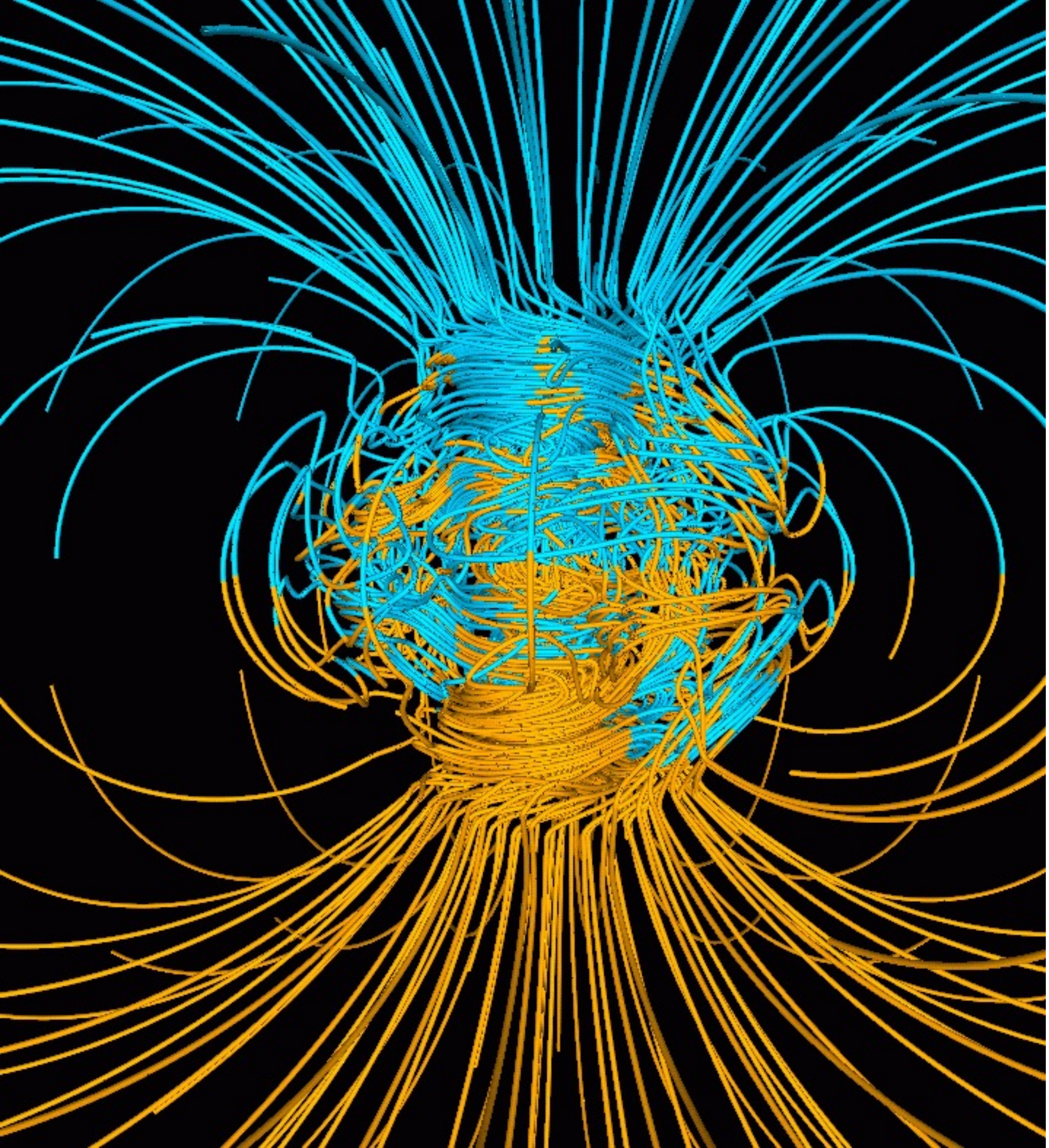
This is a more realistic view of Earth's magnetosphere. It is asymmetrical due to its interaction with the Solar wind and the Sun's magnetic field. The Solar "wind" consists of charged particles coming from the Sun.

Dynamo Theory

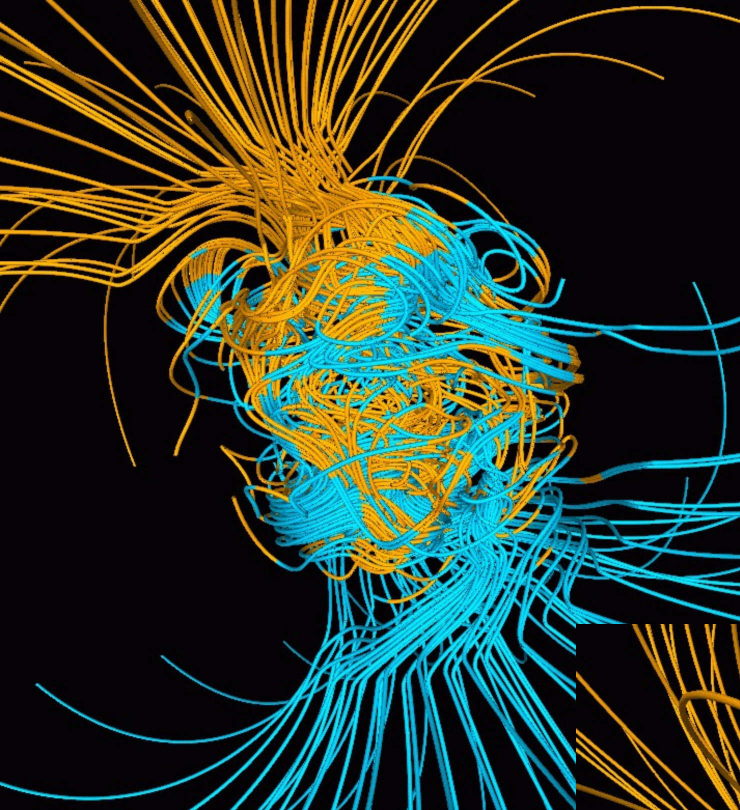
- Although the magnetic field is similar to a bar magnet, it is thought that the earth is not like a permanent magnet.
- Instead it is theorized that electric currents moving in loops in the Earth's core act like a huge electromagnet.
- These loops of current are powered by the rotation of the inner core relative to the rest of the Earth and also by convection within the outer core.

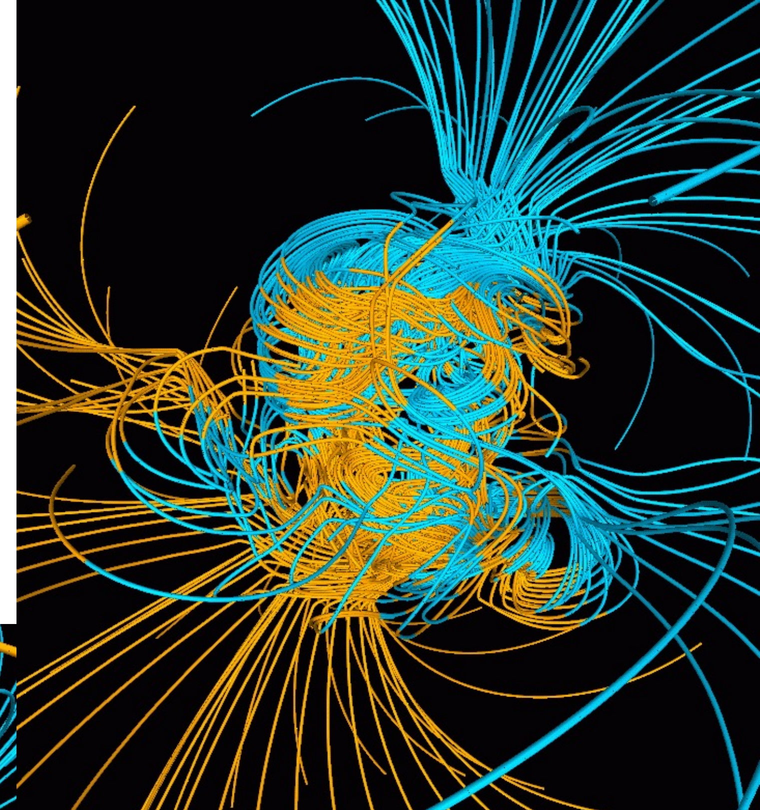


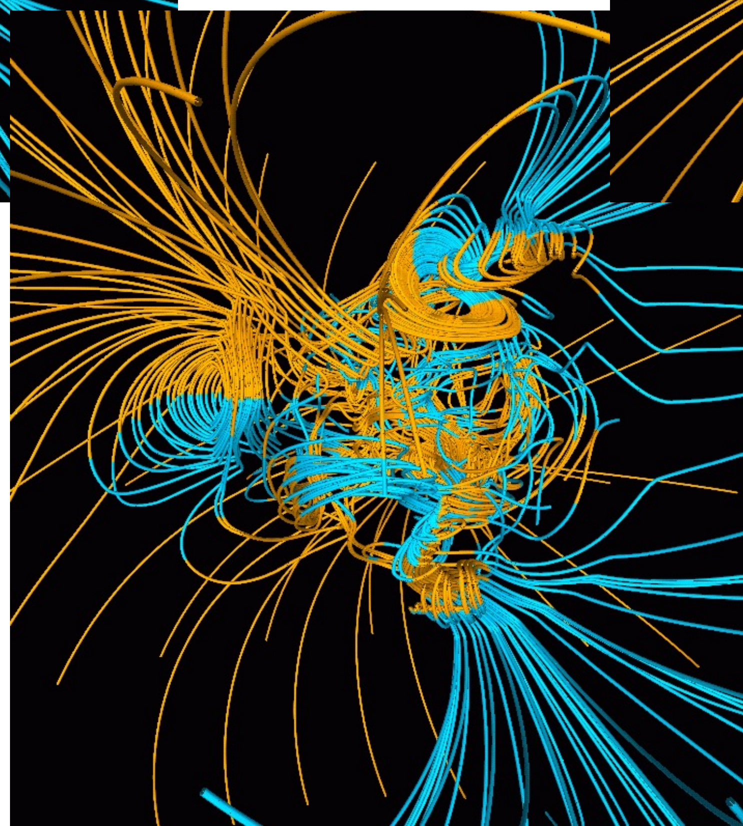
This is a computer simulation of the dynamo theory. The red grid is the inner core. The blue grid shows the extent of the outer core. The yellow cylinder shows a rotating "sheet" of electric current. The magnetic field that results from this computer simulation is in good agreement with the Earth's actual observed magnetic field.



This shows the resulting magnetic field based on the same computer simulation. Note that at the edges of the image the field looks very similar to a regular bar magnet. The simulated field in the core is much more complicated!

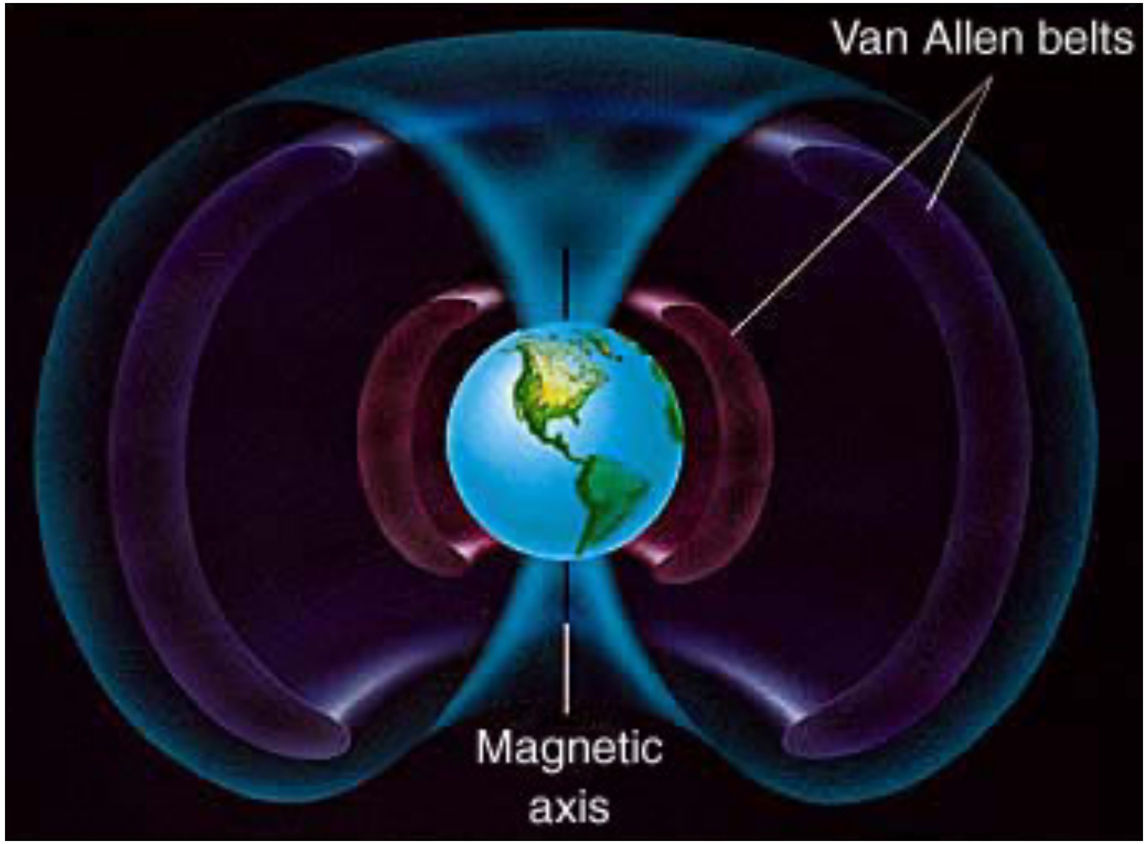




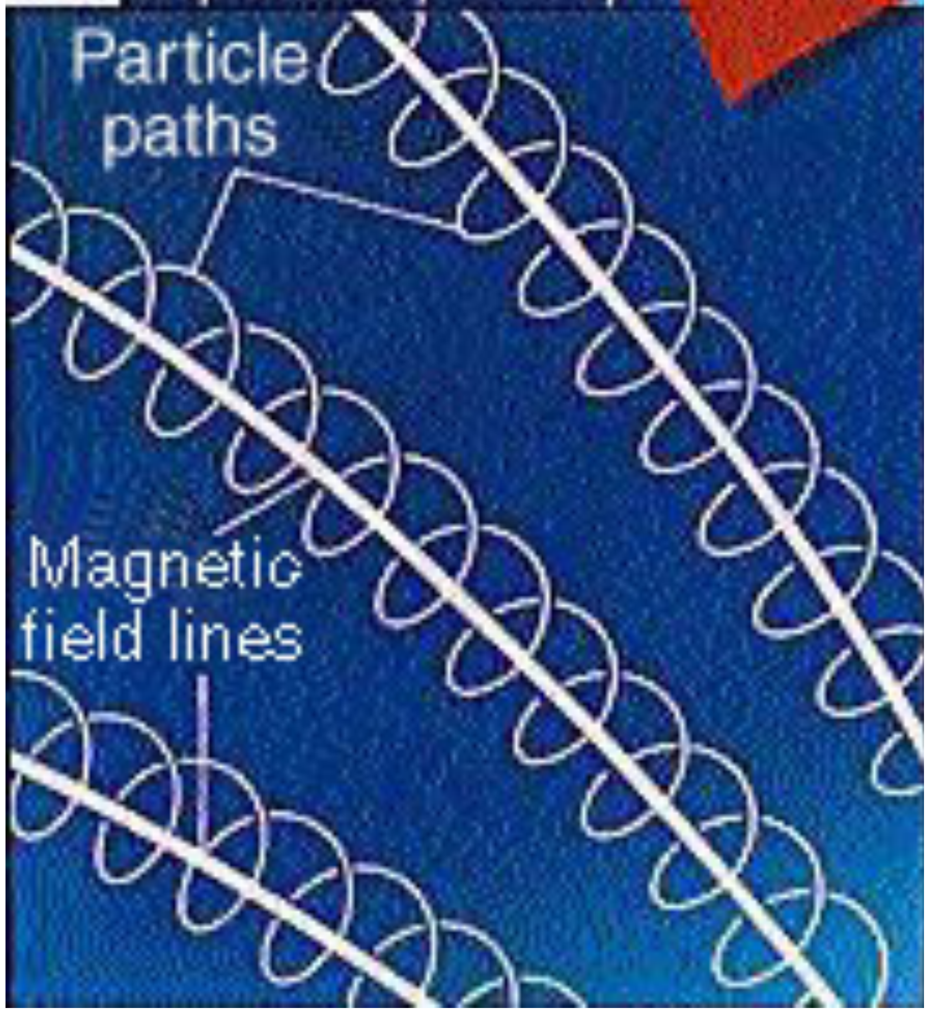


The same computer simulation predicts reversals of the Earth's magnetic field. The process takes 100's or 1000's of years.

There is physical geologic evidence that the Earth's magnetic field has indeed reversed many times in the past.



Trapped in Earth's magnetic field are two regions of charged particles called the Van Allen belts. The outer belt consists mainly of electrons. The inner belt has more protons than the outer belt. The Solar wind is the source of most of these charged particles.



Charged particles will tend to follow spiral paths about the magnetic field lines.

The result of an influx of charged particles interacting with the Earth's magnetosphere is a display known as an aurora. The colors are the result of spectral lines emitted by atmospheric molecules. These phenomena are most common near the north pole (*aurora borealis or Northern Lights*) and near the south pole (*aurora australis or Southern Lights*).