Celestial Magnetic Fields

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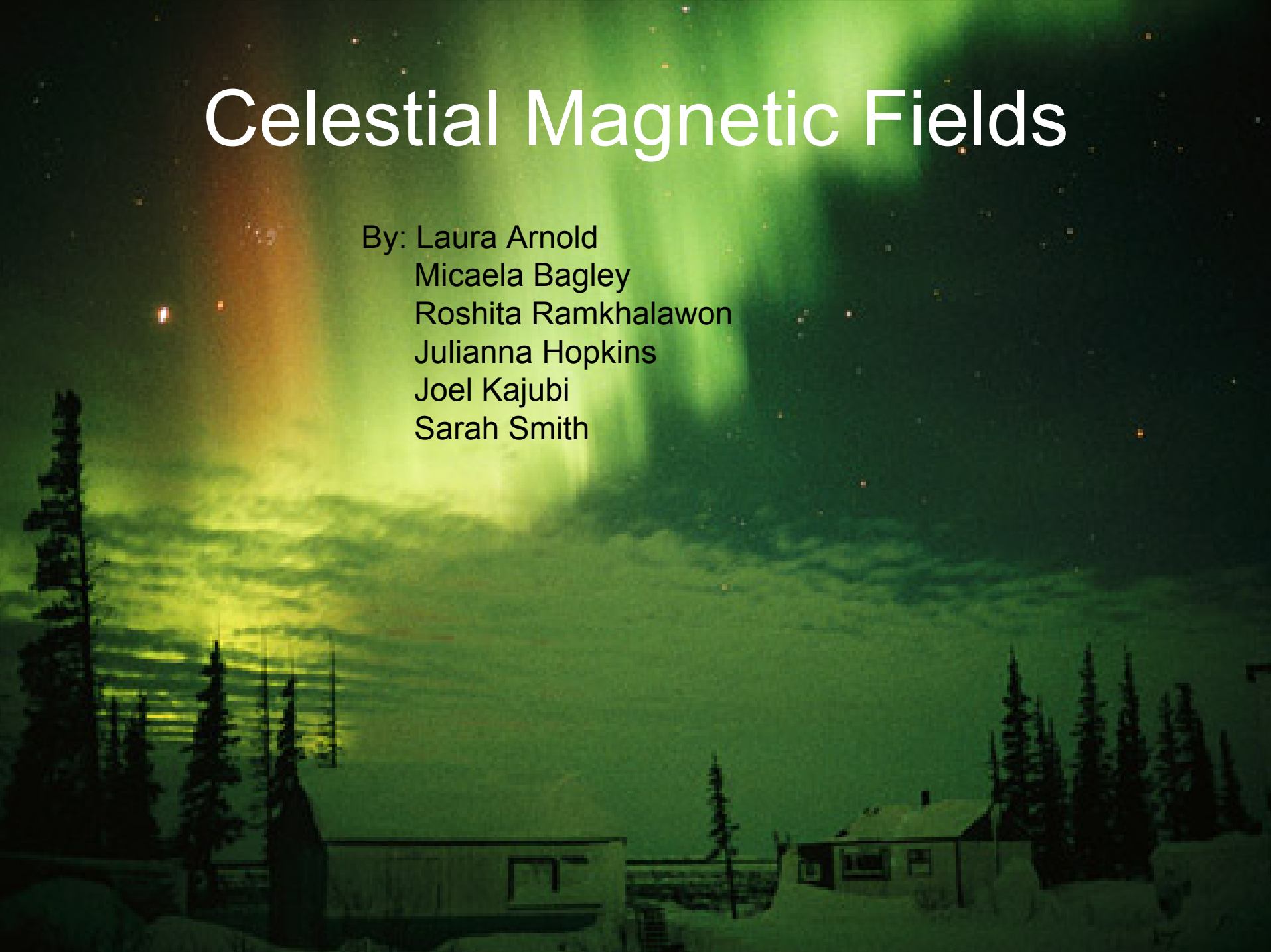
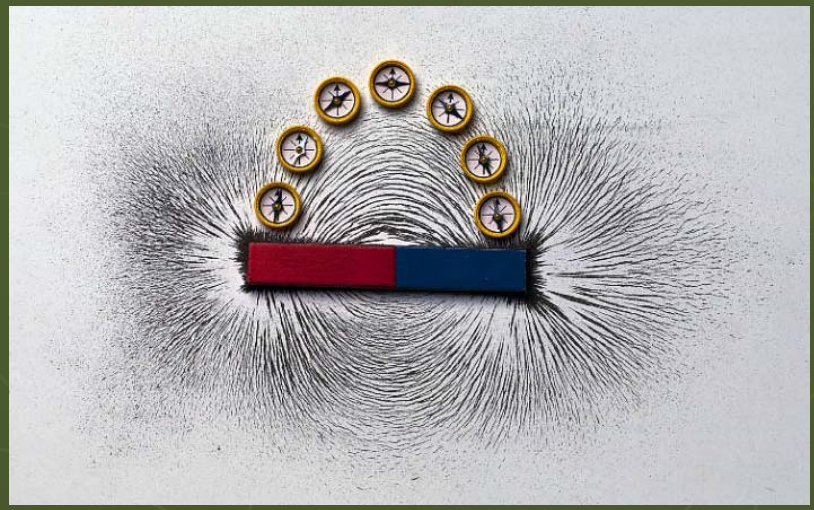


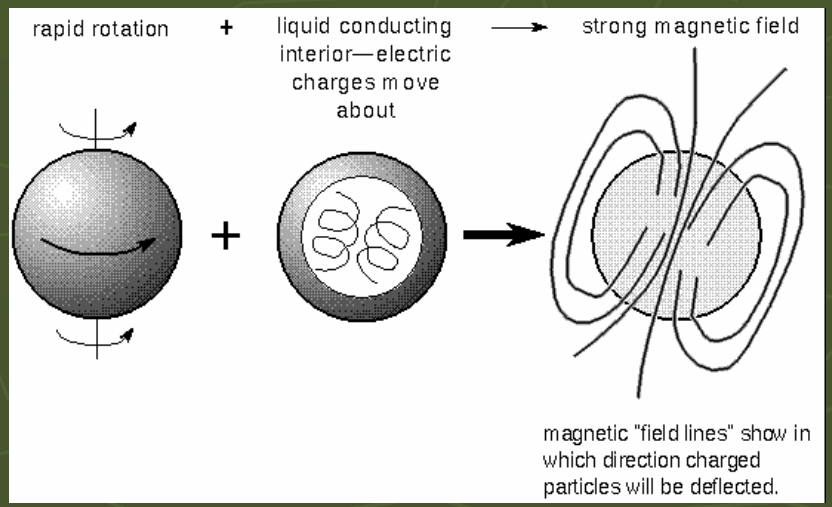
Origins of Magnetic Fields

- Iron Core?



http://www.dkimages.com/discover/previews/942/50511242.JPG

- Dynamo Theory?



http://www.jb.man.ac.uk/distance/strobel/solarsys/solsysa_files/magfield.gif

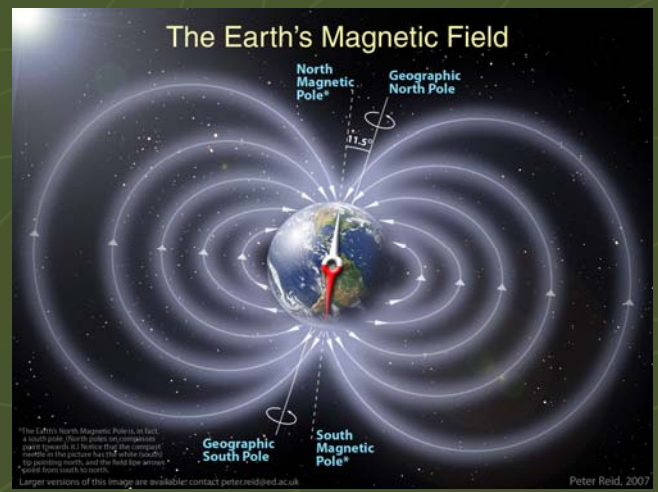
Iron and Magnetic Fields

- Ferromagnetic
  - External **B** field orients spins of electrons in domains in the same direction → Iron has long range order

Alignment of domains multiplies $\mathbf{B}_{ext}$ by a factor called the relative permeability

http://concice.britannica.com/ebc/art-87848

Is Earth's **B** field like that of an iron bar magnet?



http://www.scifun.ed.ac.uk/card/images/left/earth-magfield.jpg

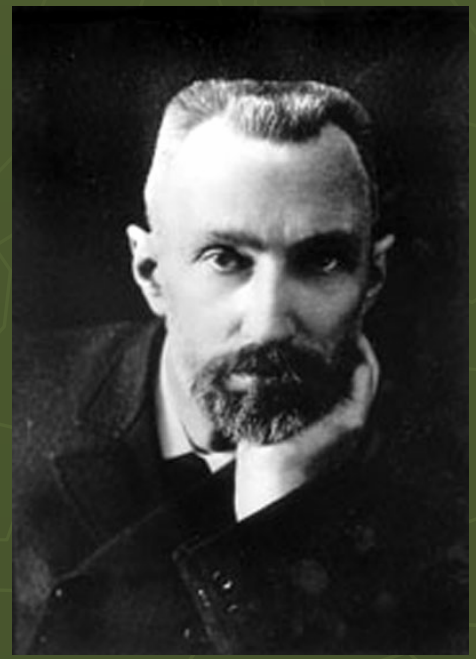
The Curie Temperature

The temperature at which the long range order of a ferromagnetic material disappears

→ Electron spin orientations = randomized

Curie temperature for iron:

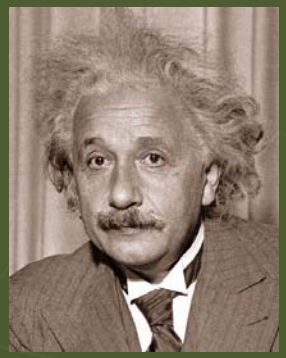
1043 K << temp of Earth's core



∴ Ferromagnetic properties of iron do not explain the origin/existence of Earth's **B**

Dynamo Theory

- 1905: Einstein
- 1919: Joseph Larmor
- Before: Carl Gauss



Definition: the process through which motion of a conductive body in the presence of a magnetic field acts to regenerate that magnetic field

Dynamo Theory

- Liquid outer core circulates due to heat convection and the Coriolis effect from Earth's rotation

Currents are aligned in rolls along the North-South axis

Electrically conducting fluid moving relative to Earth's **B** field

Induces electric currents

http://geomag.usgs.gov/faqs.php

A Chain Reaction

Faraday's Law: $\nabla \times \mathbf{E} = -d\mathbf{B}/dt$

Maxwell-Ampere Law: $\nabla \times \mathbf{B} = \mu_o \mathbf{j} + \mu_o \varepsilon_o d\mathbf{E}/dt$

Moving current → Changing **E**

Changing **E** → Curling **B**

In this way, the Earth's **Magnetic Field** is **self-sustaining**.

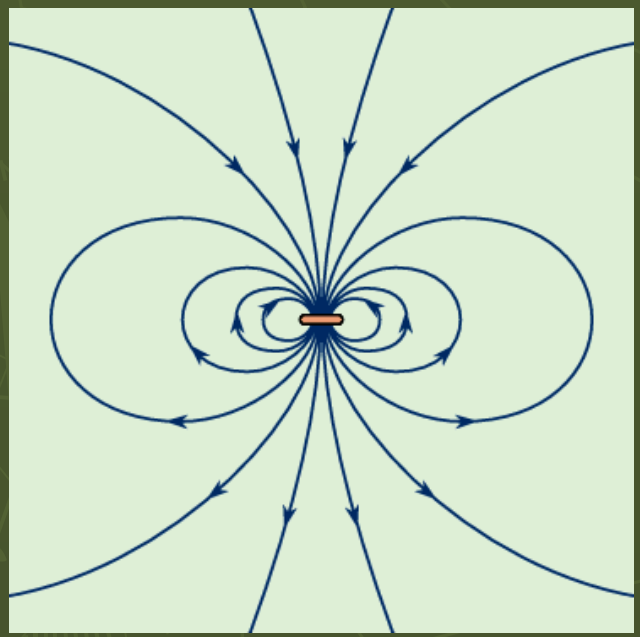
The Magnetic Field Flips??!!!

- Rotation of the Earth causes generates forces that replenish the Magnetic Field.
- Sometimes, however, these forces will line up in the opposite direction decreasing the Magnetic field.
- As the field in the opposite directions increases in strength, it will eventually cancel out the original field and take over, causing the field to appear to flip!

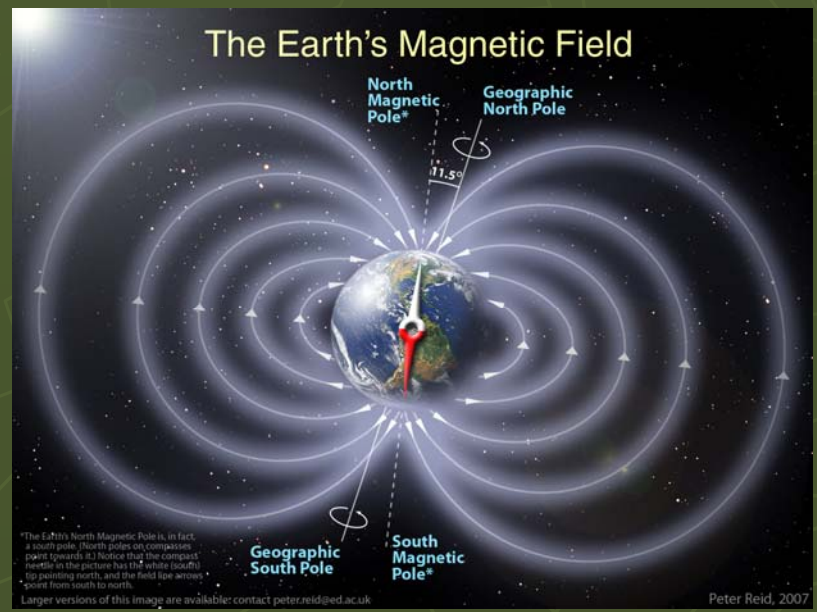
http://www.pbs.org/wgbh/nova/magnetic/reversals.html

We've Seen This...

- The circulating, electrically conductive outer core acts as a current loop.



http://www.britannica.com/eb/art-1348



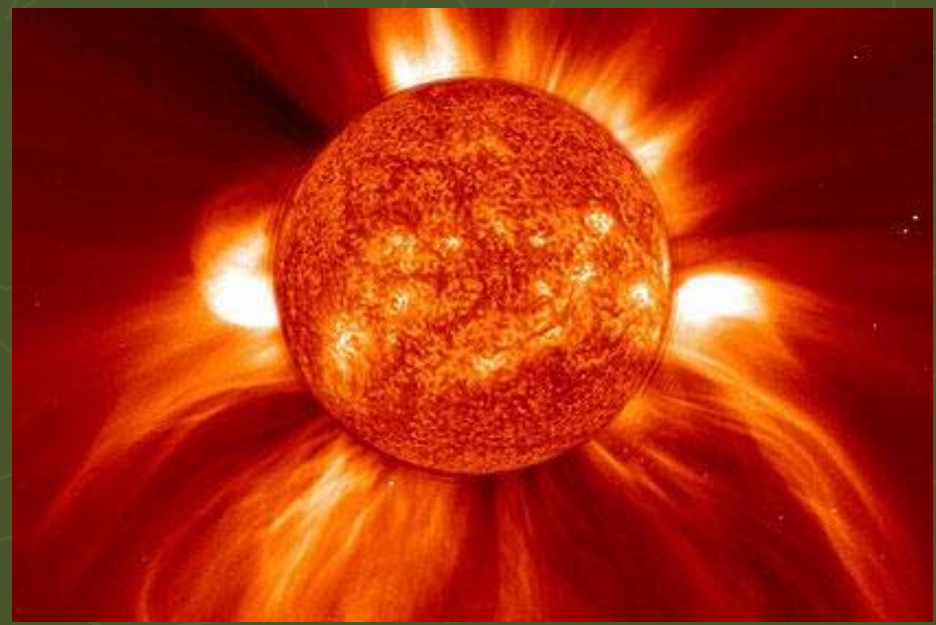
http://www.scifun.ed.ac.uk/card/images/left/earth-magfield.jpg

The Sun's Magnetic Field

<u>The Basics:</u>

Solar activity caused by its magnetic field.

The magnetic field has several physical effects:
1) it exerts a force
2) it stores energy
3) acts a thermal blanket
4) it channels fast particles and plasma
5) it drives instabilities and support waves



A coronal mass ejection (CME) blasted from the Sun (credit: NASA/ESA)

Flux

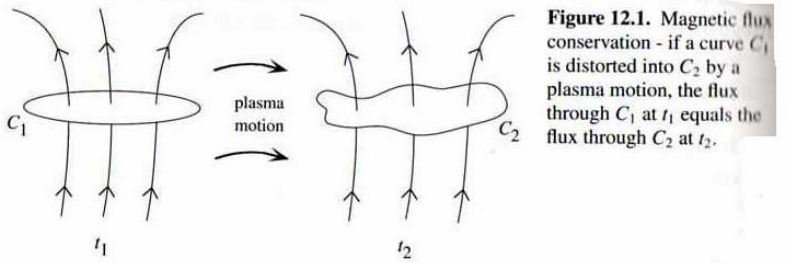


Figure 12.1. Magnetic flux conservation - if a curve C_1 is distorted into C_2 by a plasma motion, the flux through C_1 at t_1 equals the flux through C_2 at t_2.

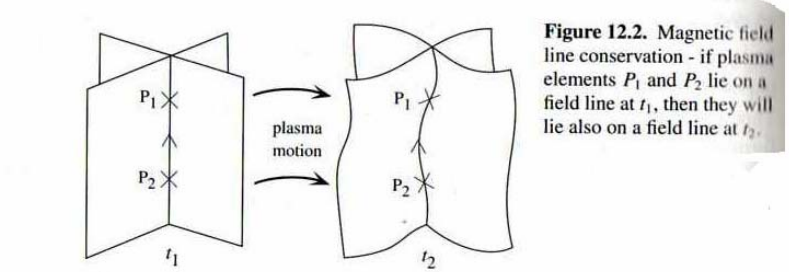


Figure 12.2. Magnetic field line conservation - if plasma elements P_1 and P_2 lie on a field line at t_1, then they will lie also on a field line at t_2.

- Flux Tubes/Ropes – "concentrated bundles of field lines"
- Magnetic Flux

  Magnetic Field Lines

  Their Conservative Properties

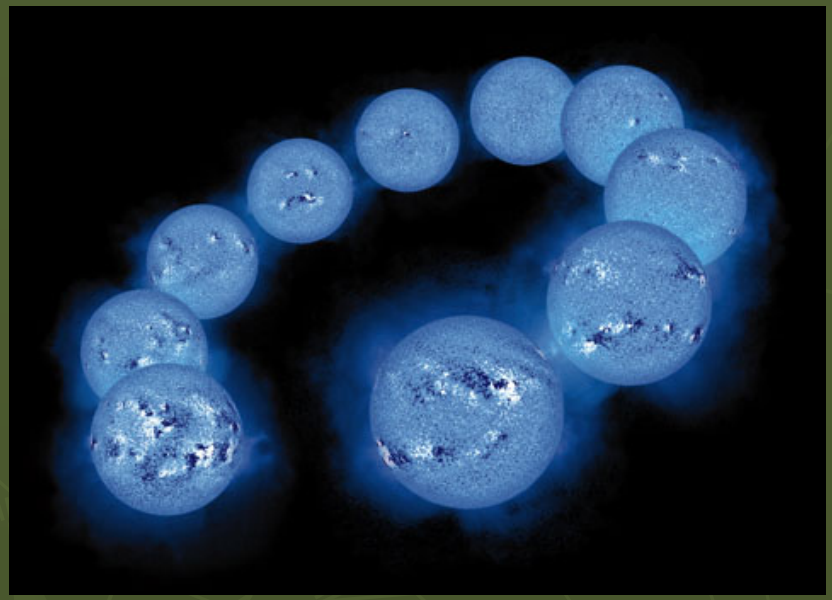
Dynamic Sun pg,222

Strength (F) of a flux tube is the amount of magnetic flux crossing a section.

$$\mathbf{F} = \int \mathbf{B} \cdot d\mathbf{S}$$

This is constant along a tube.

Solar Activity

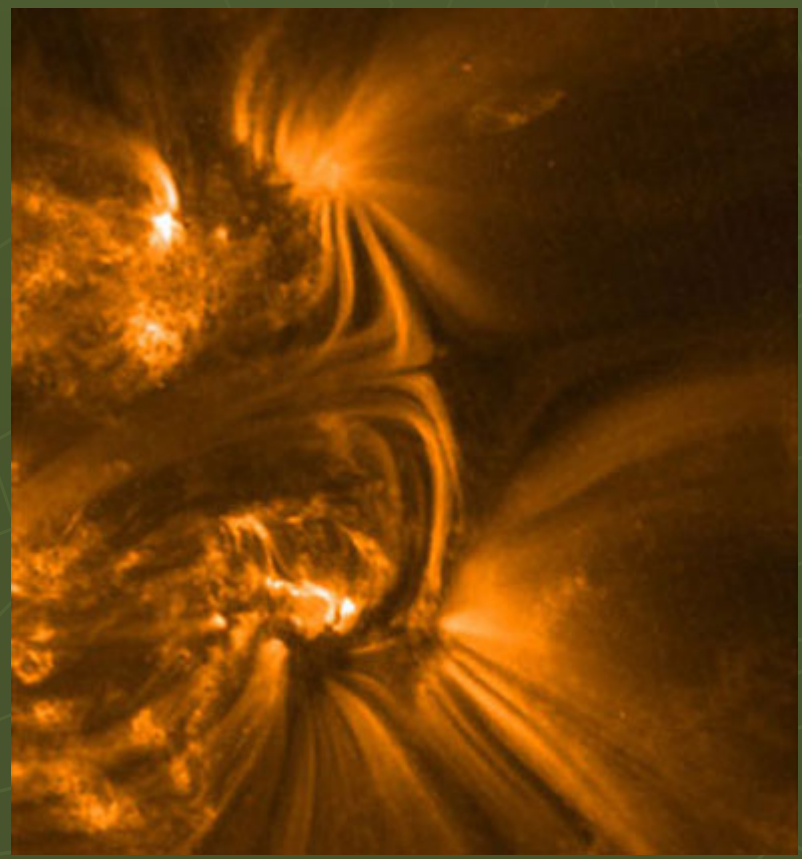


www.amnh.org/.../sunscapes/sunscapes.xml.html

Magnetic Cycles

Reversing of the magnetic Poles:

Every 11 years



Sunspots !

areas of highly concentrated magnetic fields

Solar Activity

Flares:

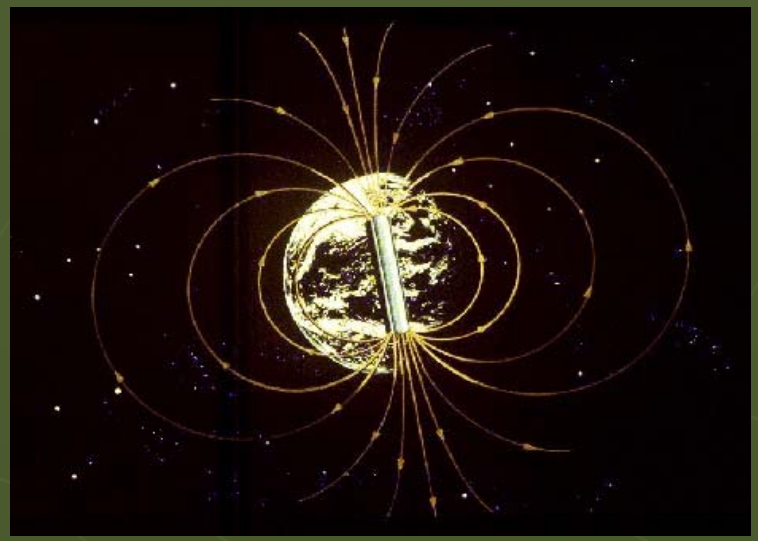
either eruptive or confined

Coronal Mass Ejections:

breaking of the field lines

astro.swarthmore.edu/~cohen/hotstarwinds.html

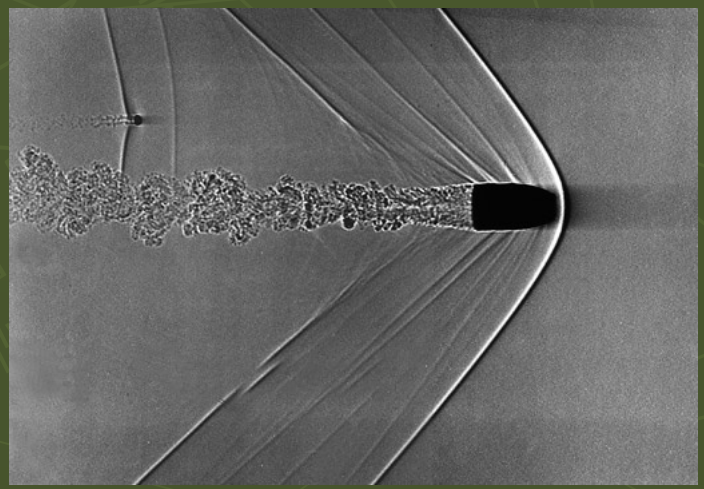
Magnetospheres

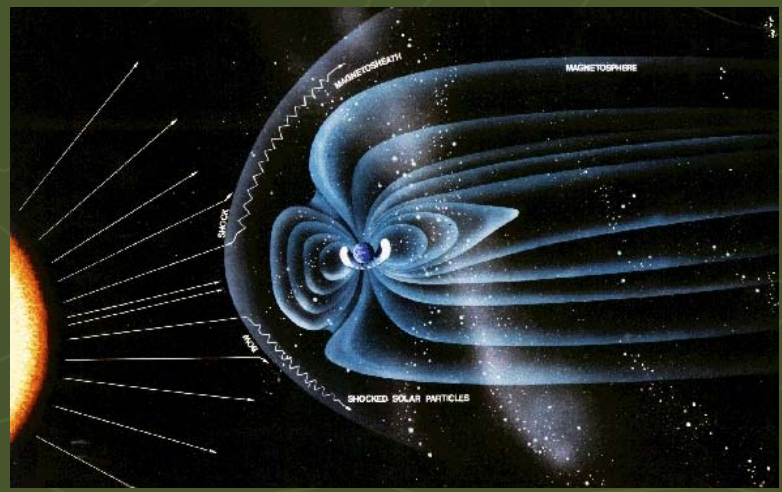


- An area of space that is controlled by a planet's magnetic field
- Planets having magnetospheres: Earth, Jupiter, Saturn, Uranus, Neptune
- The bullet shape of the magnetosphere is the result of being blasted by the solar wind
- Factors that determine the structure and behavior of magnetosphere:
  - The internal field of the earth
  - The solar wind
  - Interplanetary magnetic field

Shape of the Magnetosphere

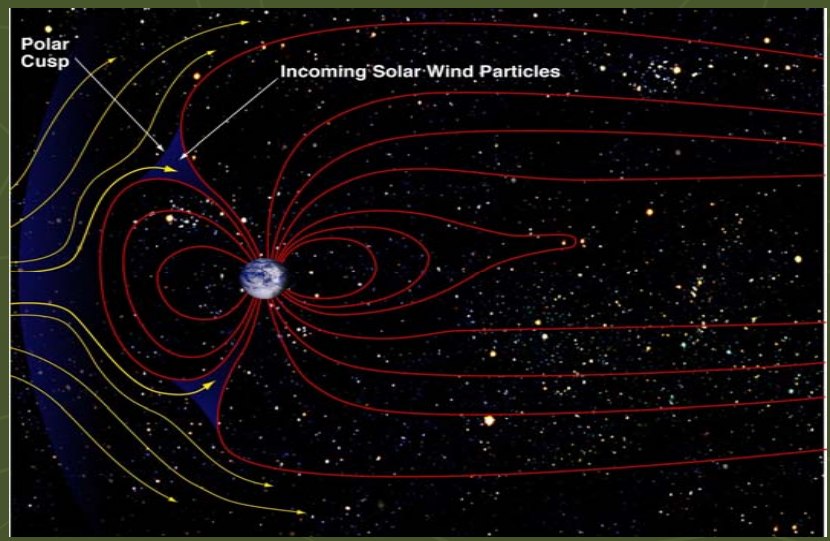
- The earth's magnetic field is like a dipole magnet only close to the surface but extends far out into space for thousands of miles
- Phenomena caused by the sun affects the shape of magnetosphere
- The extremely hot plasma of the sun consists of charged particles, mostly electrons and protons
- The electrified particles from the solar magnetic field travelling to the earth is the solar wind
- In the Earth's magnetosphere, a mix of free ions and electrons from both the solar wind and the earth's ionosphere is trapped by magnetic and electric forces





The Magnetosphere is Dynamic

- The magnetosphere is a complex configuration of plasma regions, particles, and electric currents
- Magnetosphere of earth reacts to events on the Sun
- When the magnetic field coupling with the solar wind is enhanced dramatically, periods of instability occur, known as substorms
- Rapid sequence of substorms constitutes a full-scale magnetic storm
- When the plasma sheet is disturbed, accelerated particles move along the Earth's magnetic field and form the auroral ovals

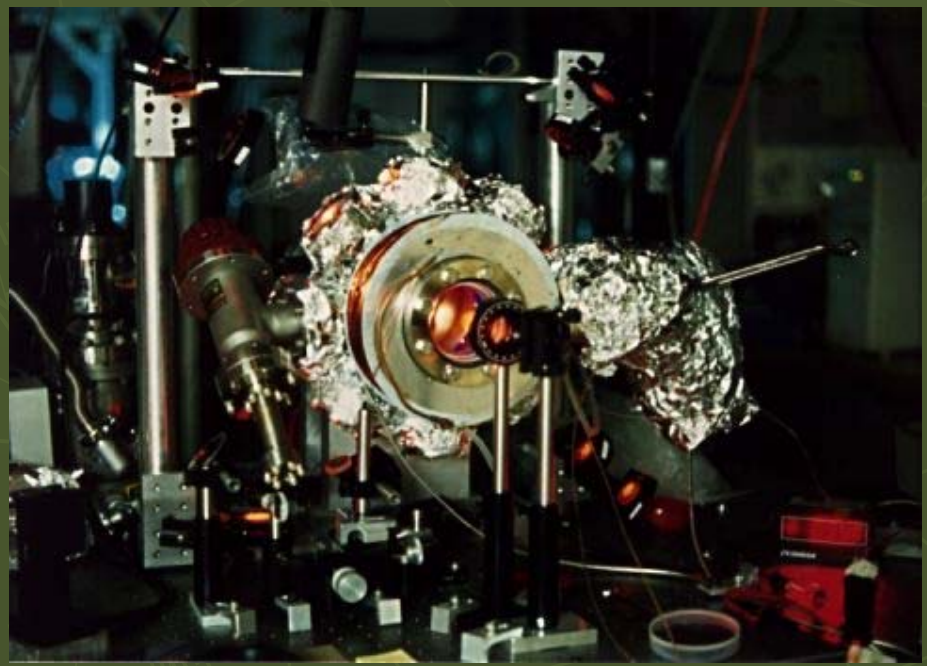


Auroras

- Auroras occur when highly charged electrons from solar wind interact with the earth's atmosphere
- Auroras generally occur along the "auroral ovals" which center on the magnetic poles (NOT the geographic poles)
- Solar winds reach the earth about 3 days after leaving the sun and flows through the magnetosphere
- Color of aurora depends on which atom is struck and the altitude of meeting
- Magnetic and electrical forces react with one another in constantly shifting combinations. Shifts and flows can be seen as the "Aurora' s dance"
- Laura saw one and she said it was pretty.

http://www.fusedglasselements.com/images/217_AuroraAnimation.gif

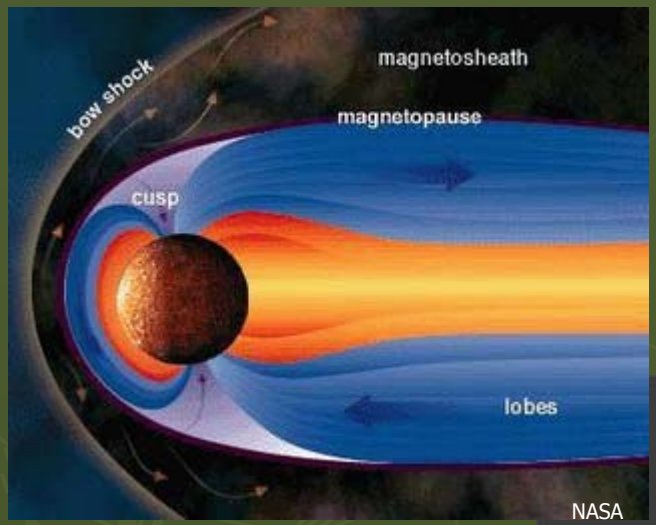
Earth



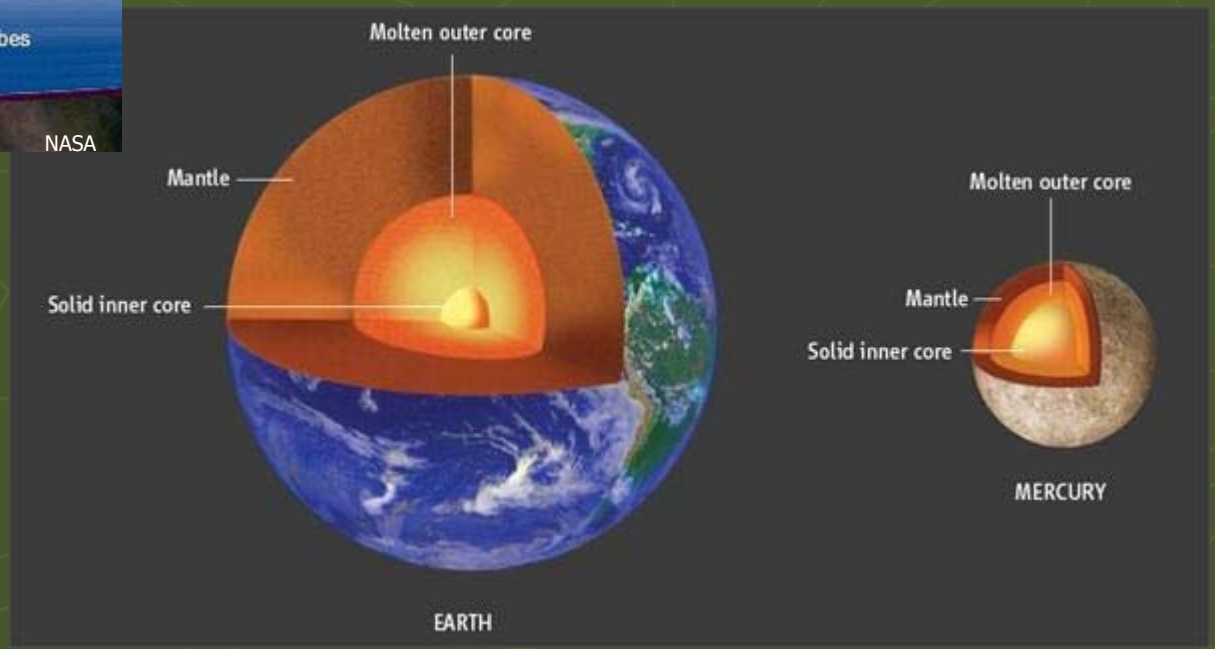
http://www.pas.rochester.edu/~catgroup/

- .6 mT
- Effects on Earth
  - Direction
  - Aurora
  - Life
  - More on those later…
- The Bigelow Group

Mercury

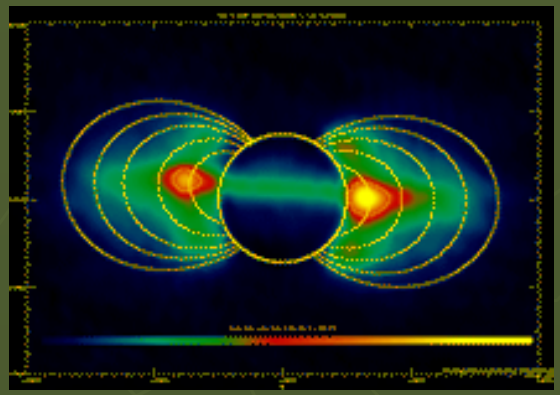


- Day: 59 Earth Days
- Magnetosphere!?
- Variation

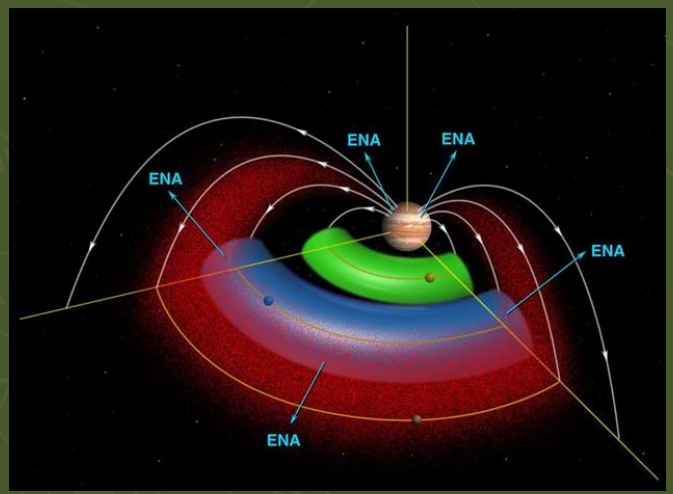


http://space.newscientist.com/data/images/ns/cms/dn11782/dn11782-1_600.jpg

Jupiter

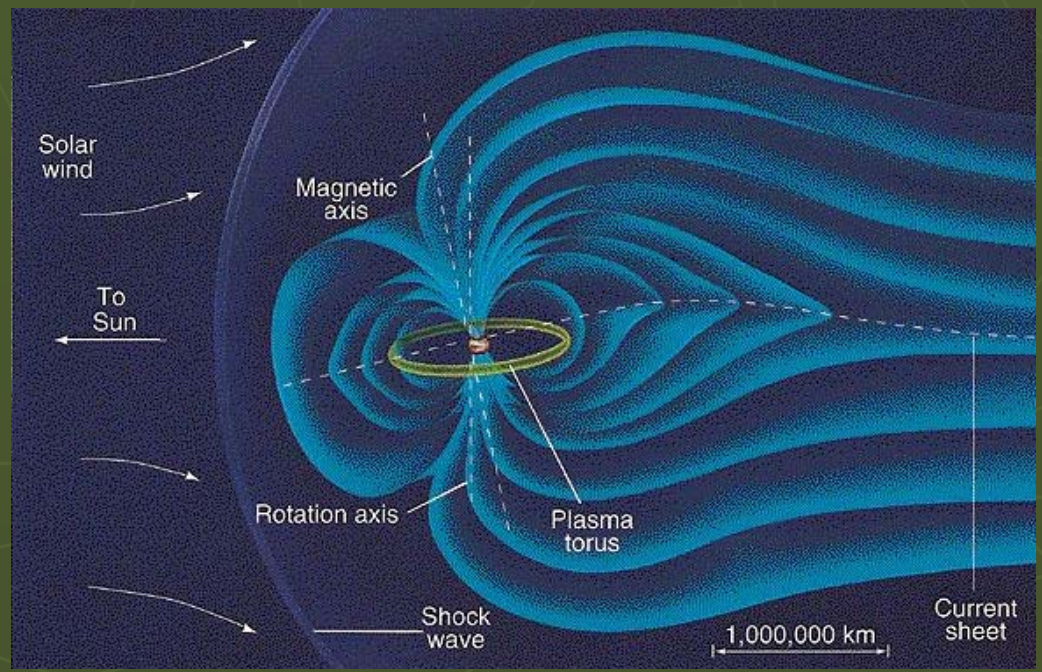


- 20,000 times Earth's
- Day: 10 hours
- Dicimentric Radiation

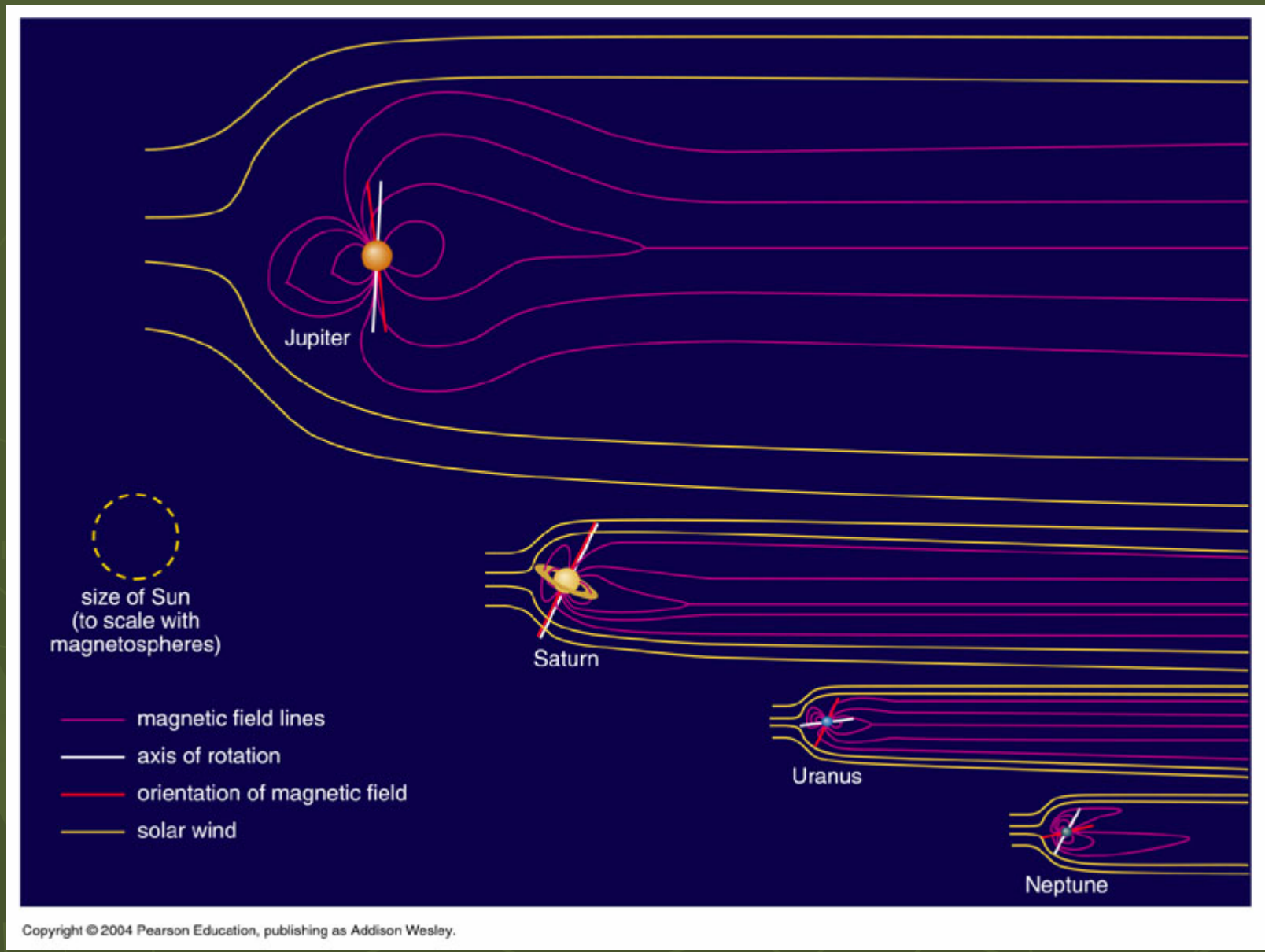


http://photojournal.jpl.nasa.gov/catalog/PIA04433

- Torus Shaped

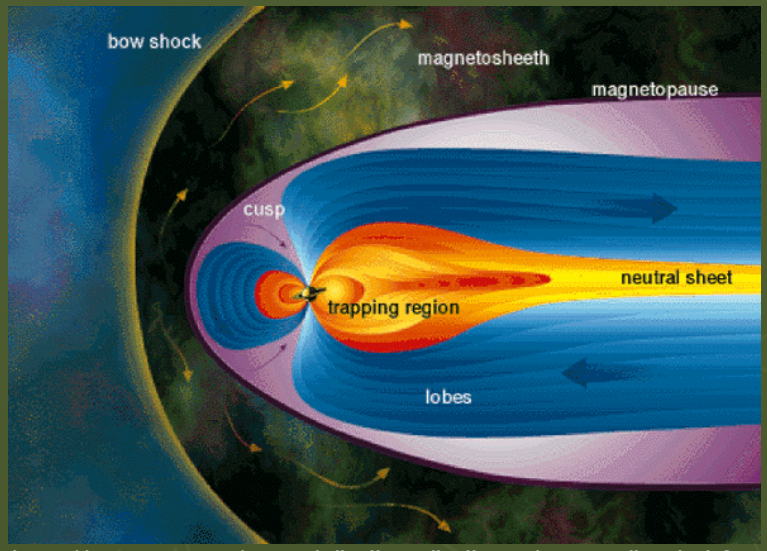


http://burro.cwru.edu/Academics/Astr201/Jovian/jupmagfield.jpg



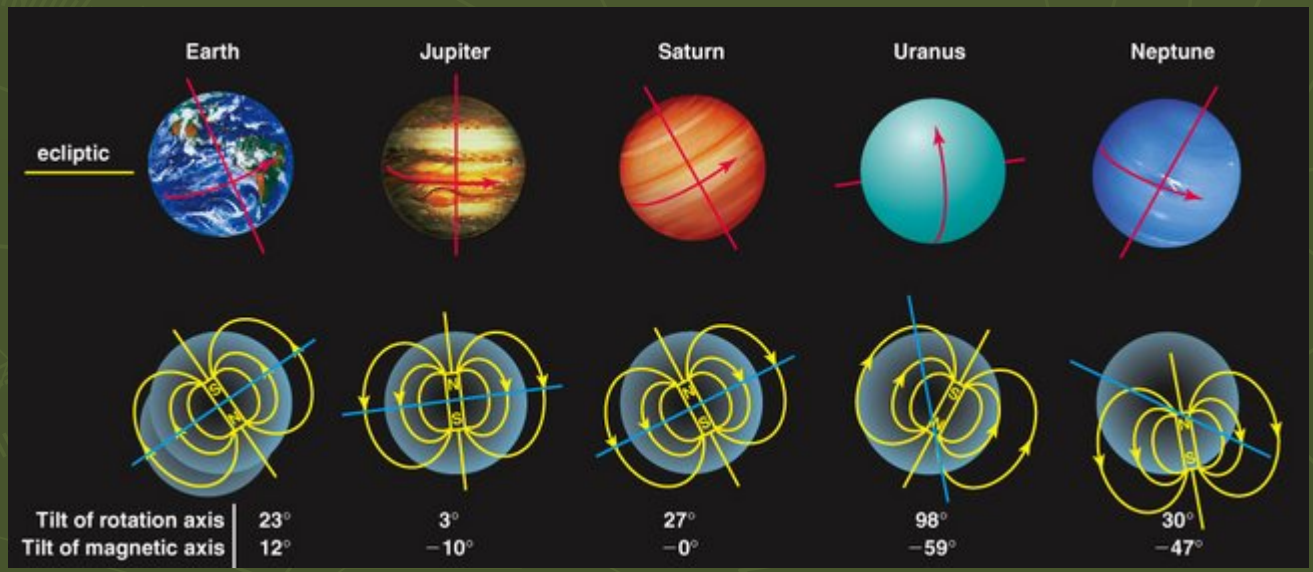
http://www.physast.uga.edu/~jss/1010/ch11/12-15.jpg

Saturn



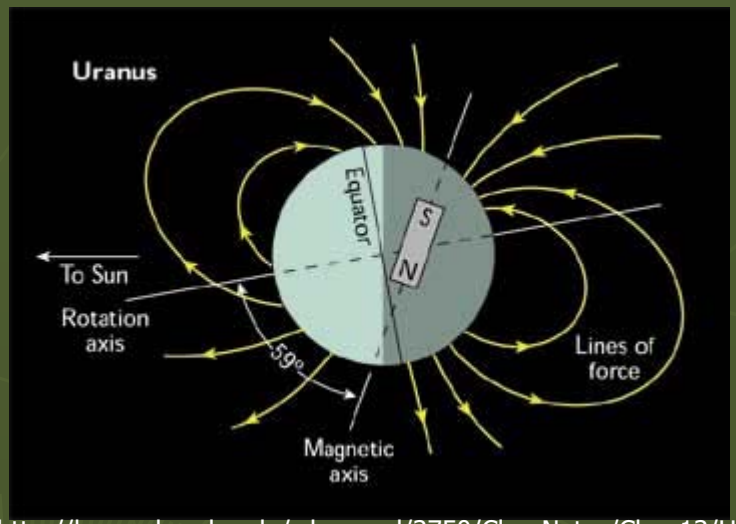
http://www.esa.int/esapub/bulletin/bullet92/images/b92kohf18.gif

- Phew!
- 500 times Earth's
- Magnetic dipole axis: <1° (axisymmetric)
- Large Bow Shock



http://www.ifa.hawaii.edu/~barnes/ast110_06/gphah/0740_a.jpg

Uranus



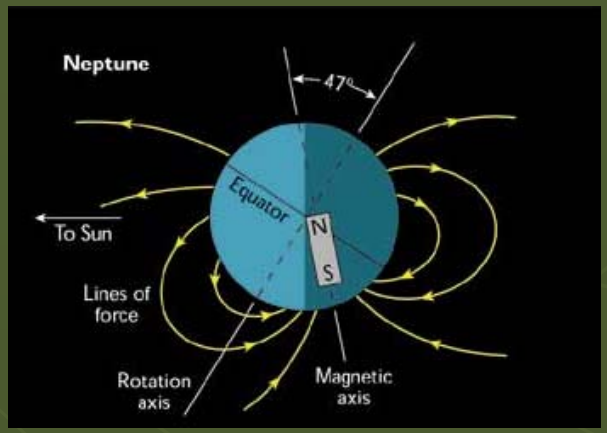
http://lasp.colorado.edu/~bagenal/3750/ClassNotes/Class13/UN.jpg

- 50 Times Earth's
- Day: 16-28 hours
- Rotation Axis: 98°
  Magnetic Axis: 59°
  Strange Things Happen!

<u>Note:</u> Voyager 2 - 1986

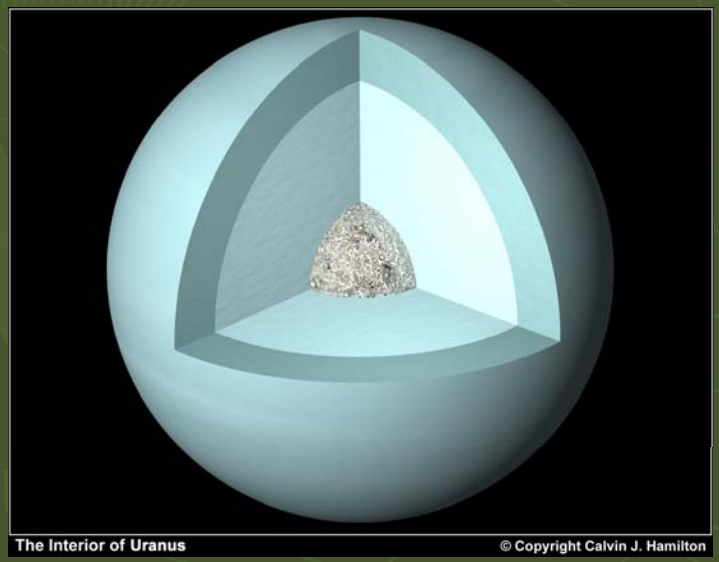
http://www.celestiamotherlode.net/catalog/images/screenshots/spacecraft/voyager2__jackhiggins.jpg

Neptune

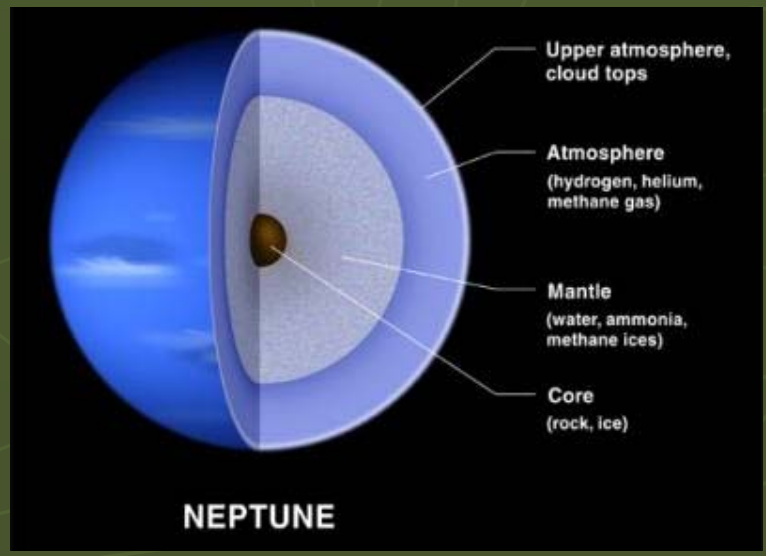


http://lasp.colorado.edu/~bagenal/3750/ClassNotes/Class13/UN.jpg

- 50 times Earth
- Day: 18-20 hours
- Auroras
- Dynamo Effect



http://www.solarviews.com/raw/uranus/uranusint.jpg

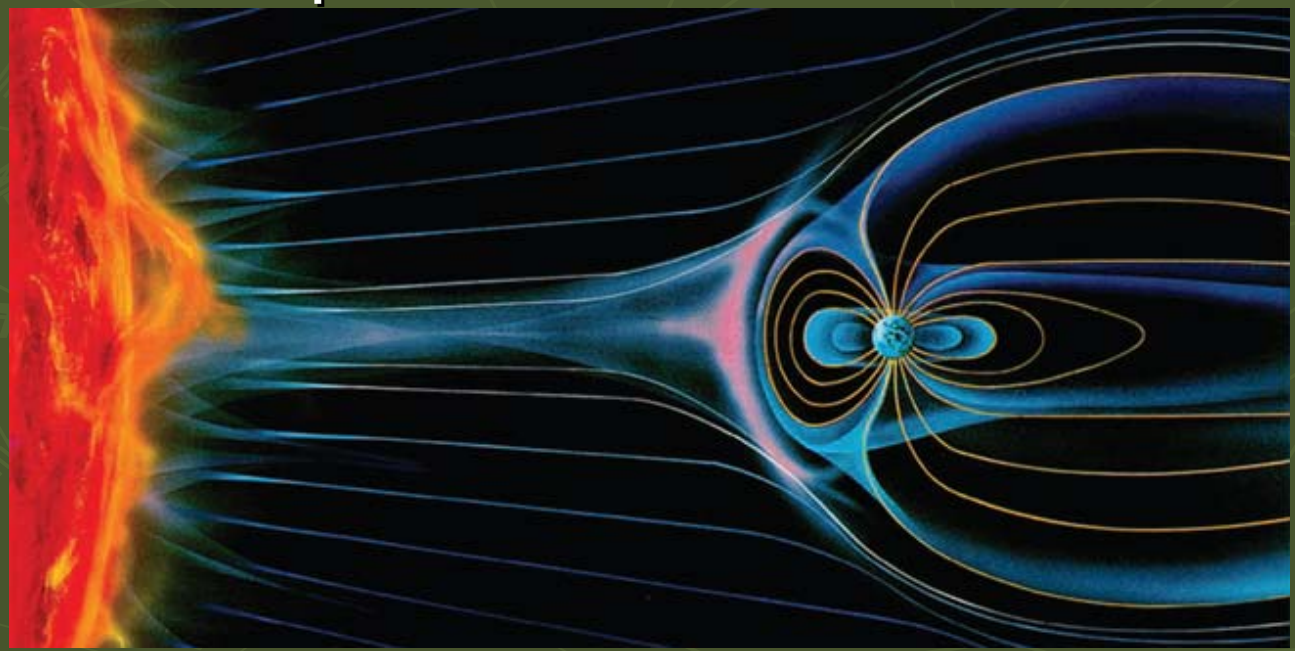


http://plus.maths.org/latestnews/jan-apr04/utune/Neptune_nasa.jpg

Magnetic Field = Life

Magnetic Field shields most of the habited parts of the planet

- Deflects the charged particles from solar wind toward the poles



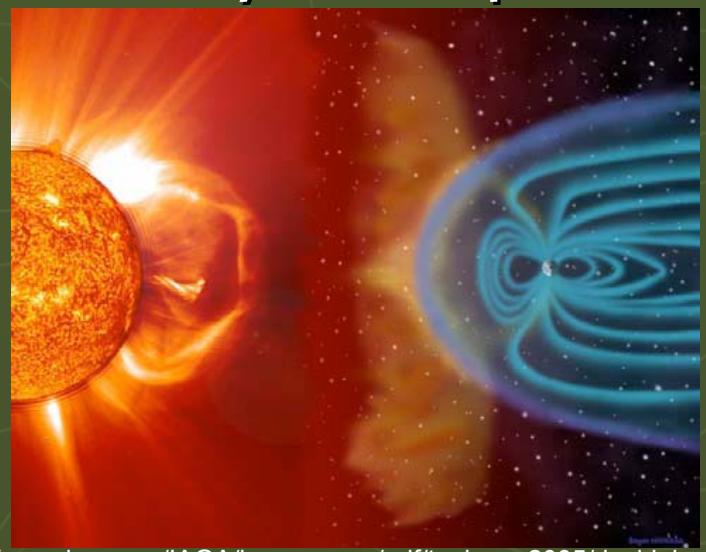
What Would Happen Without Our Magnetic Field?

- Cosmic radiation
  - Knock out of power grids
  - Loss of Communication with Spacecrafts
  - Increased hole in the Ozone
- More aurora activity
- Many animals use Magnetic Fields for Navigation
  - Birds
  - Turtles
  - Bees

http://imdb.com/gallery/ss/0389790/BEE005.jpg.html?seq=36

Effects of Solar Wind

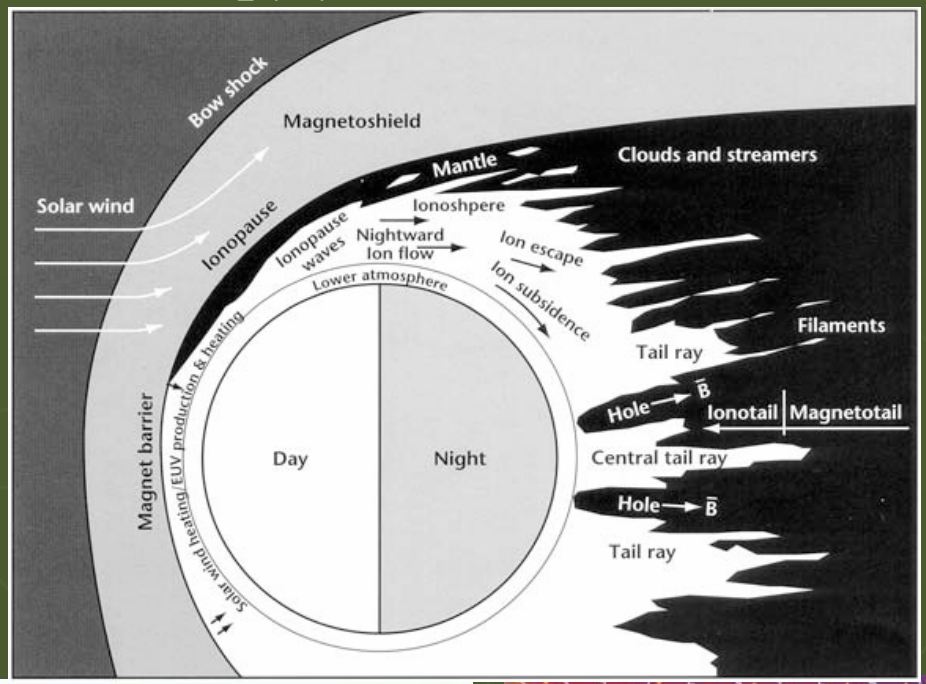
- Solar Wind Strips the Planet of Valuable elements
  - Hydrogen and Oxygen
    - Recipe for Water (necessary for Life)
  - CO_2 is too heavy to be pulled away



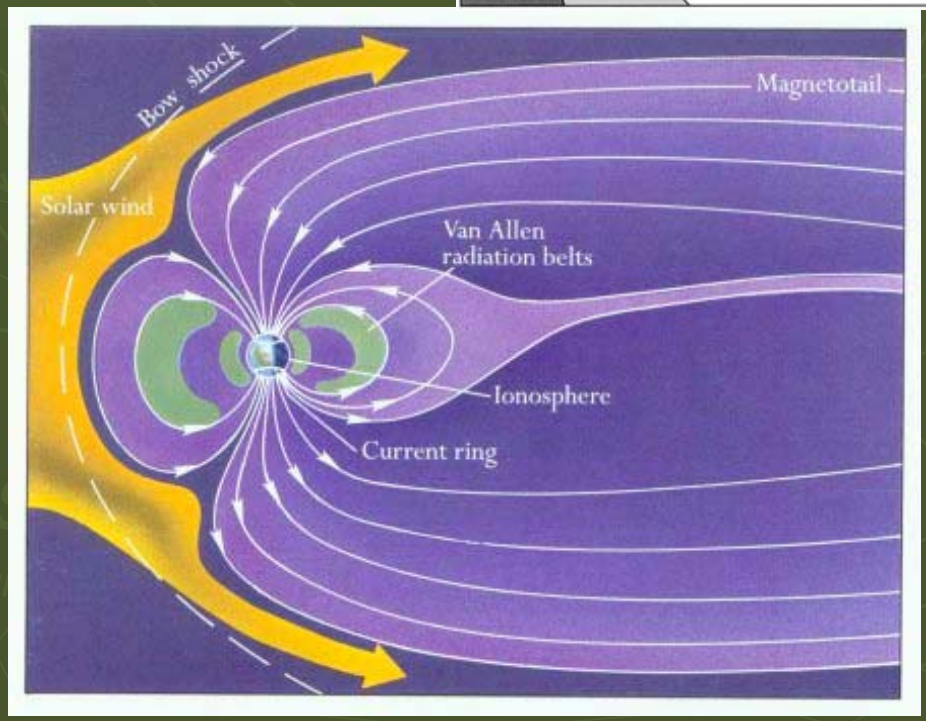
http://www.iugg.org/IAGA/iaga_pages/pdf/toulouse2005/david_loper.pdf

http://www.iugg.org/IAGA/iaga_pages/pdf/toulouse2005/david_loper.pdf

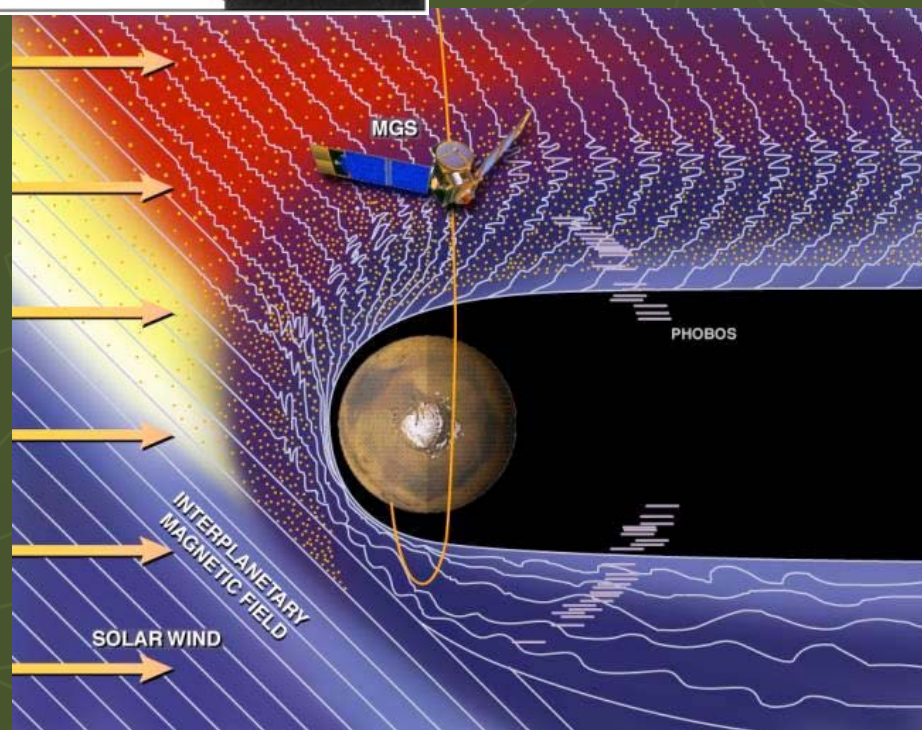
←Venus



↓ Earth



↓ Mars



Life on Mars??

- Mars has a weak magnetic field and can therefore not form a Magnetosphere.
- It is not protected from the Solar Wind
- However, evidence shows it has a stronger Magnetic field earlier its history
  - Therefore it was possible to have water.
  - As the field decreased, the water escaped into outer space or was frozen into the Mantel of the planet.
- Inner Core was not hot enough to create sufficient enough convection currents to maintain its Magnetic Field (Failure of Dynamo theory)

Overall where do we stand?

Up to now it appears that we are alone in this universe

However, planets similar to ours such as Gliese 581 C have been discovered.

These new planets may not possess all the qualities for life, but that doesn't mean there aren't others out there.