Properties of Solar System Objects

With an overall goal of perhaps understanding the origins of the solar system, we begin to discuss some of the properties of objects within our solar system (focusing on the most interesting or dramatic examples)

- **Motion (Revolution and Rotation)**
- **Crust: Composition and Dynamics**
- **Core: Composition and Dynamics**
- **Atmosphere: Composition and Dynamics**
- **Magnetic Field**

Earth

We begin with Earth because it is the planet with which we have the most experience. What we understand about the Earth can help us interpret more remote evidence from other bodies.

For example our access to rocks and meteorites here on Earth and Meteorites allow us to estimate the age of the Earth at about 4.6 Billion years

Revolution of the Earth

In addition to previous evidence in support of the Kepler model, we know the Earth revolves around the Sun (Period approximately 365 days) because of the aberration of starlight

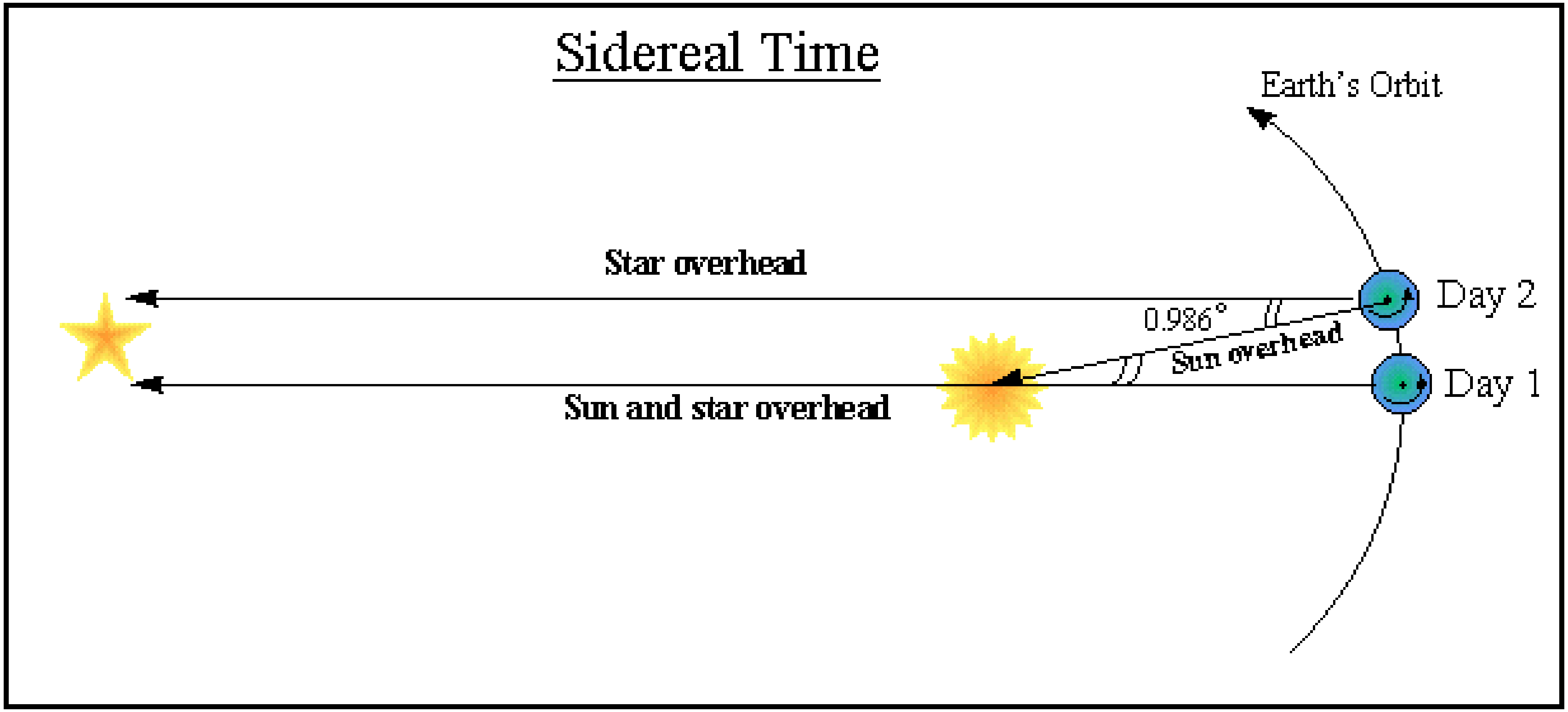
Aberration of Starlight is the apparent shift in the position of all stars (unlike stellar parallax) due to the motion of the Earth

Rotation of the Earth

The Earth completes one rotation (360 degrees) every 23 hours and 56 minutes (and ~4 seconds). This period is known as a Sidereal Day.

Due to its revolution about the Sun, the Earth must rotate a little more than 360 degrees for the Sun to appear in the same place. The time it takes for the Sun to appear at the same place is about 24 hours (Solar Day).

Sidereal and Solar Day



Our time keeping is based on the (Mean) Solar Day and thus stars a star that appears at one location at a certain time will be at that same location the next day approximately four minutes earlier.

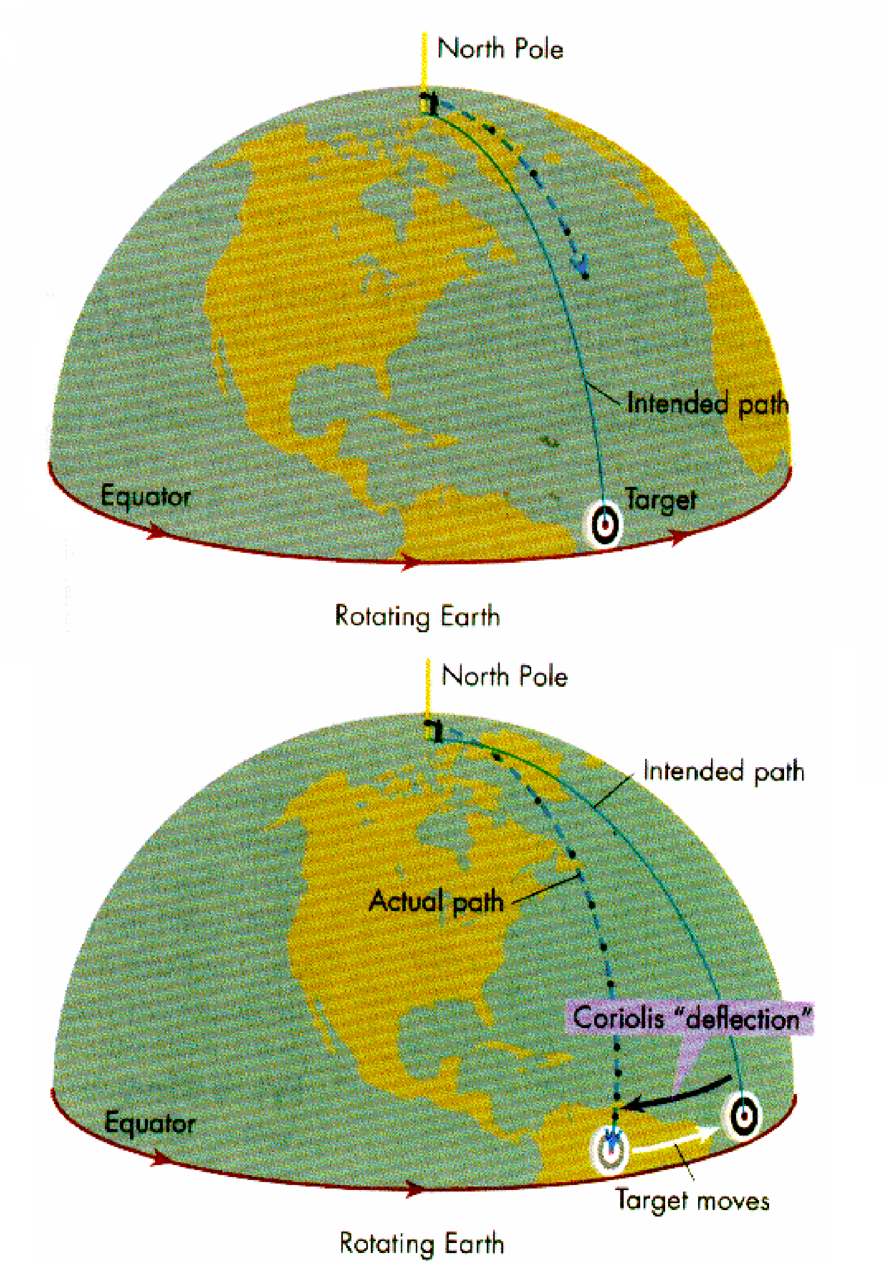
Coriolis Effect

The Coriolis effect is an apparent deflection of a moving object due to the rotation of the Earth. To us who are rotating with the Earth, it appears that the object experiences a force. However there is no push or pull on the object (we are actually experiencing the force).

Coriolis Effect

As observed by someone on Earth, the equatorward (southward) moving object appears to be "deflected" to the West.

If the object were moving polrward (northward), it would appear to be "deflected" to the East.



Rotation and Coriolis

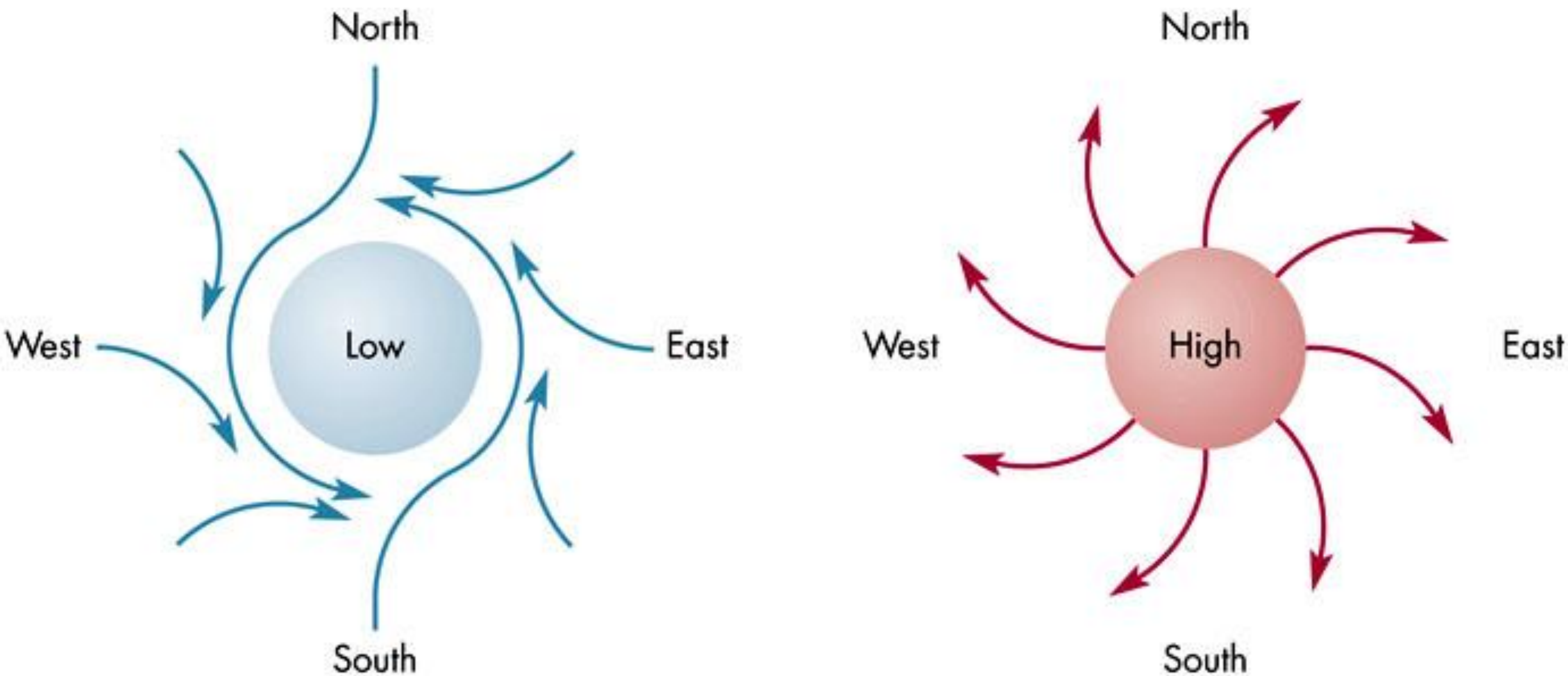
Suppose that there was a localized region of low pressure in the *northern hemisphere*. Since air (or any fluid) flows from high to low pressure, air would converge from all directions on the low pressure region.

Due to the Coriolis Effect air moving equatorward toward the low pressure region would be "deflected" to the West.

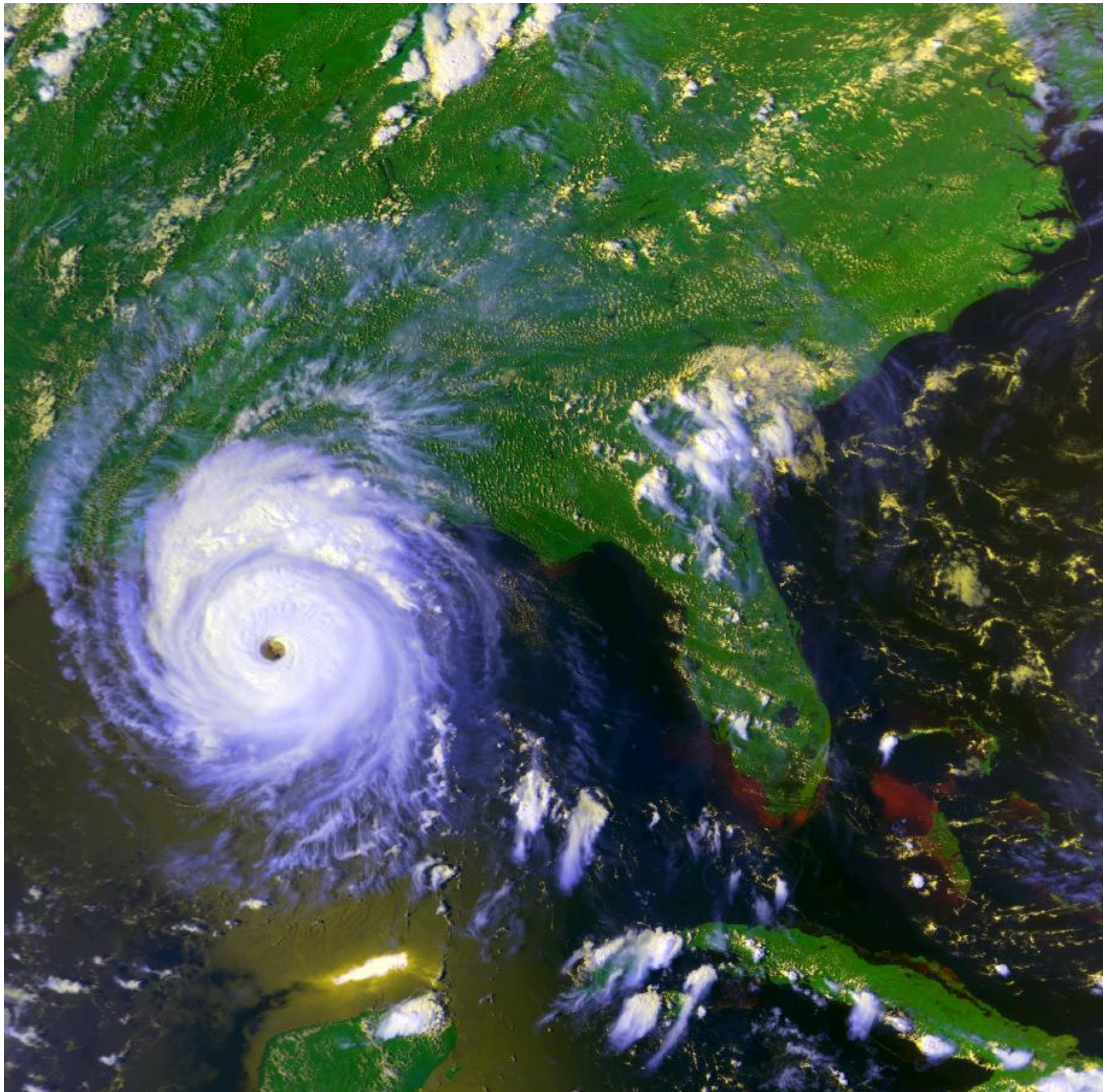
Due to the Coriolis Effect air moving poleward toward the low pressure region would be "deflected" to the East.

Looking down on the Earth a counterclockwise circulation pattern (such as that observed with a hurricane) would be established. (Clockwise circulation is established in the *southern hemisphere*.)

The Circulation Pattern Around Low-Pressure and High Pressure Regions



A Low-pressure region in northern hemisphere **B** High-pressure region in northern hemisphere



Hurricane Andrew

NOAA AVHRR 2020 UTC August 25, 1992
Red: 0.65 μm, Green: 0.9 μm Blue: -11.0 μm

NASA Goddard Laboratory for Atmospheres
Hasler, Pierce, Palaniappan, Manyin

Surface and Interior

The composition and structure of the Earth can hold some clues to the properties and origins of the planets and solar system. Much of the understanding in this area is achieved through geological studies. However a brief overview of the general structure of the Earth is important.

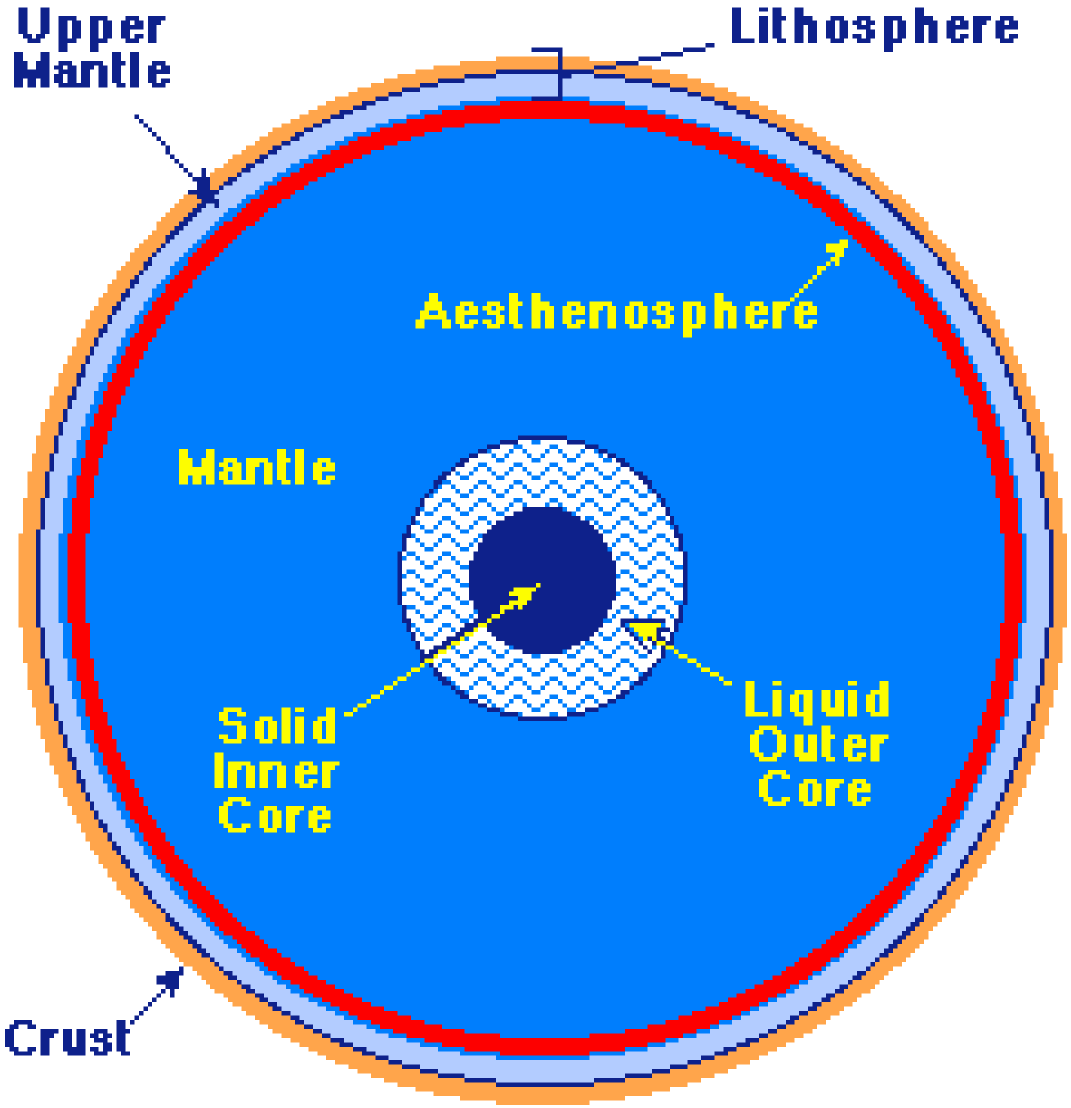
Earth Surface and Interior

The Earth's surface and interior may be divided into four regions:

Crust: Outer most layer consisting of rock with a thickness of ~30 km. Along with the upper mantle (upper mantle and crust form the lithosphere) dynamic region with plate motion and sea floor spreading etc.

Mantle: Consists of the upper mantle, aesthenosphere and mantle. Approximately 2800 km thick. Temperature ranges from about 1000 C to 3700 C (melting point of iron 1800 K)

Earth Surface and Interior



Earth Surface and Interior

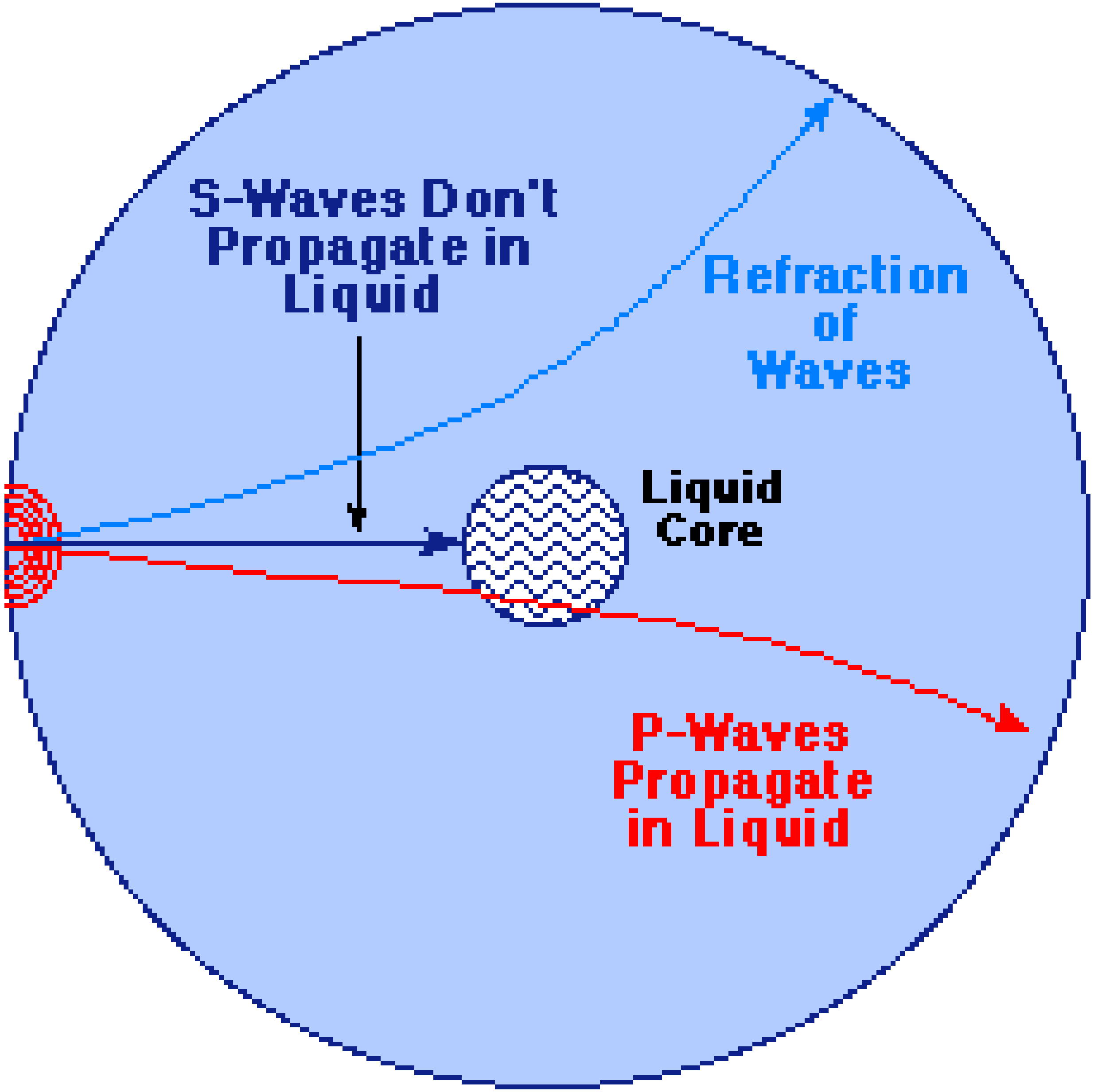
The Earth's surface and interior may be divided into four regions:

Outer Core: The outer core is metallic (iron and nickel) because of the high density of this material and liquid. This region is approximately 1300 km thick and the temperature ranges from about 3700 C to 4300 C. This region is likely the source of the Earth's magnetic field.

Inner Core: Despite very high temperatures, the pressure is so great at this depth (think of going deeper in a pool) that the inner core is solid. This layer is approximately 1200 km thick.

Earth Surface and Interior

Earthquakes are one consequence of the active lithosphere (crust and outer mantle). Like a mallet ringing a bell, earthquakes produce waves in the Earth (seismic waves). The speed of these waves varies depending on the composition of the material that the pass through. Thus by analyzing seismic waves we can deduce the structure of the material that the pass through. This is how the regions of the Earth's interior were determined.


S-Waves Don't Propagate in Liquid
Refraction of Waves
Liquid Core
P-Waves Propagate in Liquid

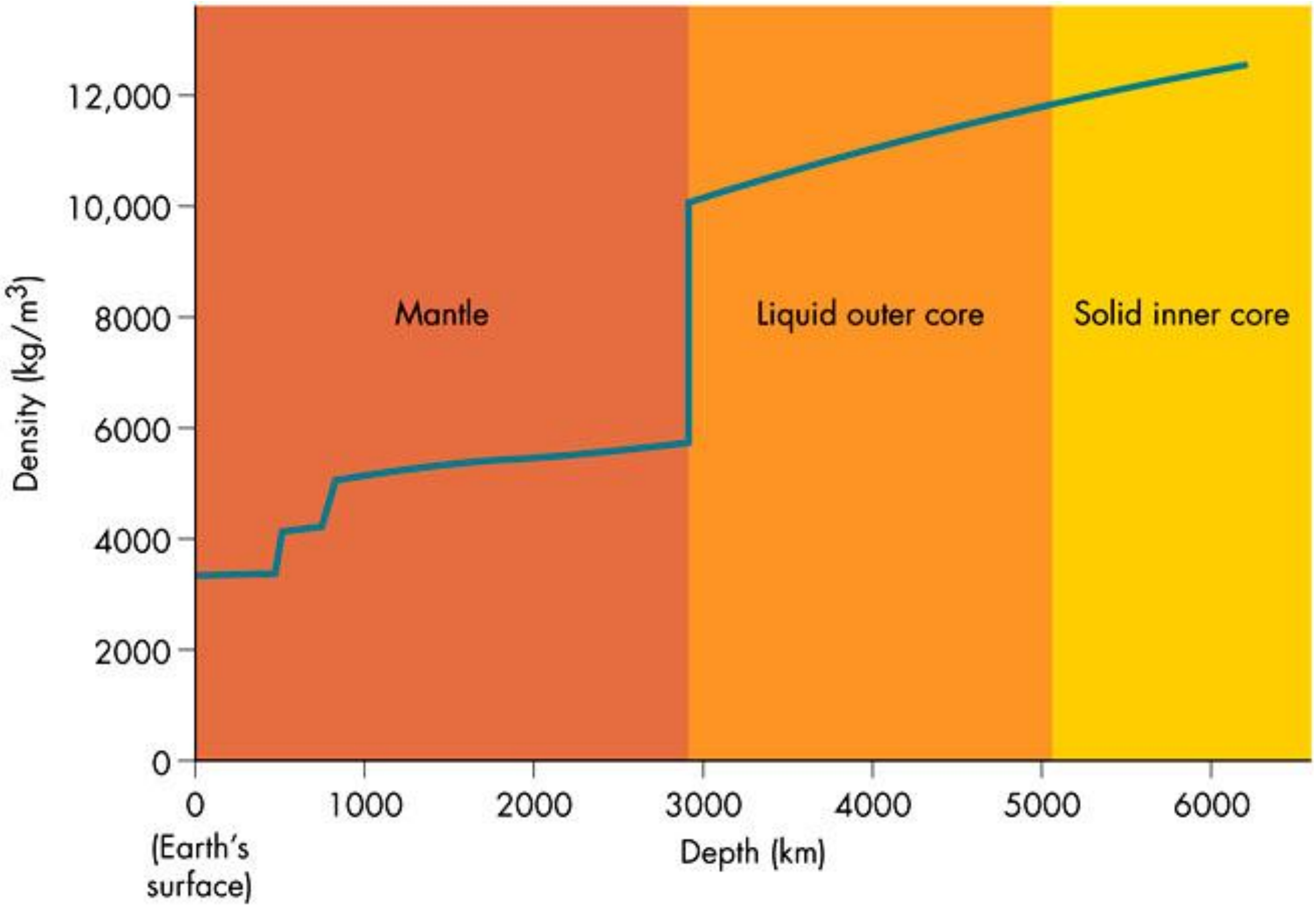
Earth Surface and Interior

The *average* density (mass divided by volume, cork small density, lead large density) of the Earth could have been determined in the 1800's. It is around 5500 kg/meter^3. (Water has a density of 1000 kg/meter^3.)

The average density of stuff found on the surface of the Earth is around 3000 kg/meter^3. Thus the density of the interior must be significantly greater than the average of 5500 kg/meter^3 to balance the less dense surface.

Differentiation is the variation in density with distance from the core.

Earth Surface and Interior



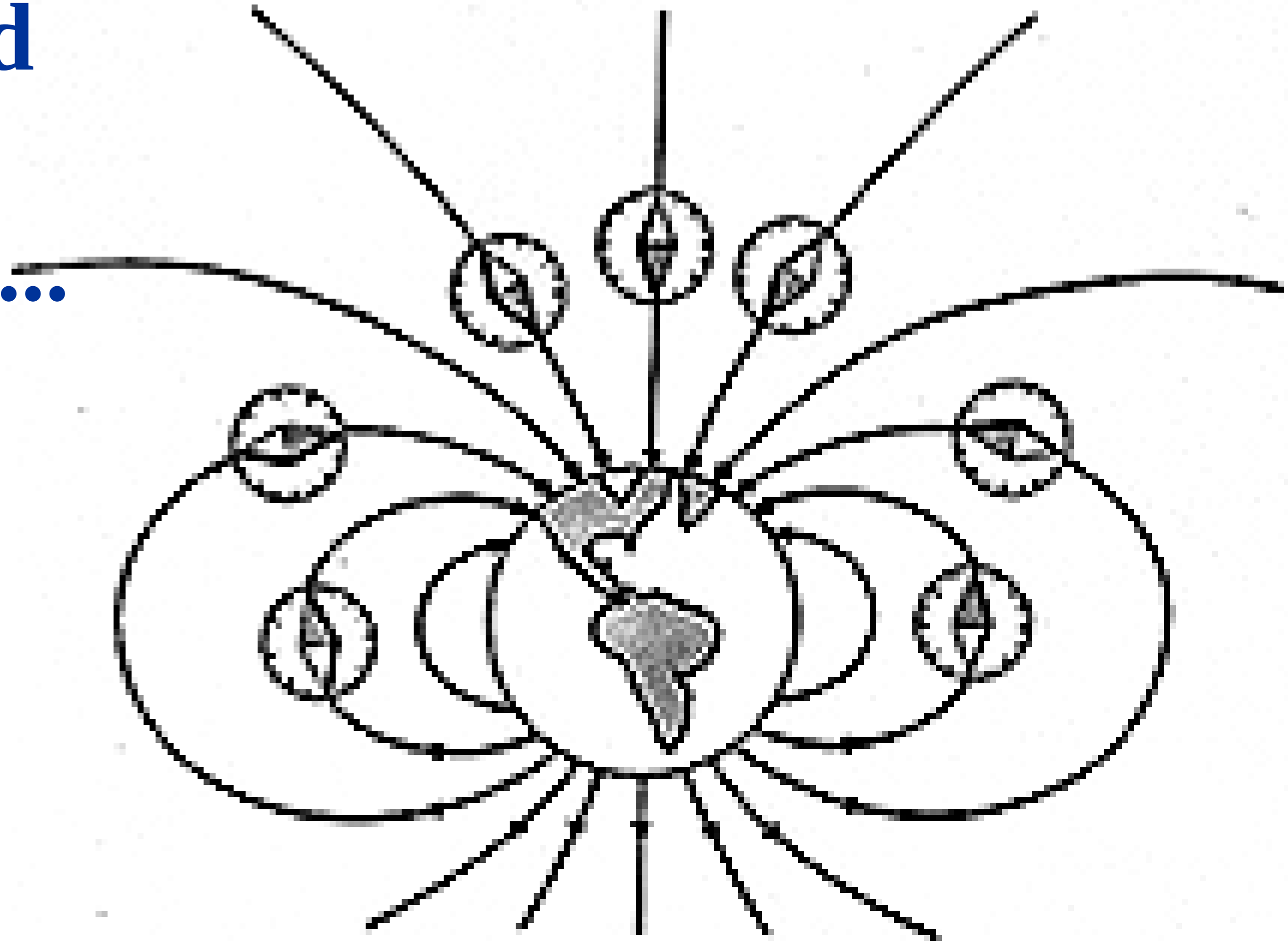
The density of material increases somewhat irregularly as you go deeper into the Earth

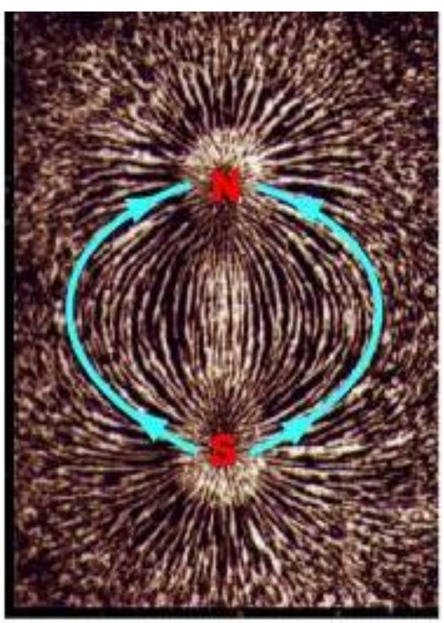
Magnetic Field

Magnetic Fields are produced by moving electric charges, that is, electric current. For example, a wire carrying electric current to light a lamp will produce a magnetic field the circles the wire.

Magnetic Fields are produced by *permanent magnets*. For example, a bar magnet. The fields produced by permanent magnets are actually generated by electric current on molecular scales. The overall shape of the magnetic field produced by a bar magnet is that of a magnetic dipole.

The Earth's Dipole Magnetic Field Is The Same Shape As A ......





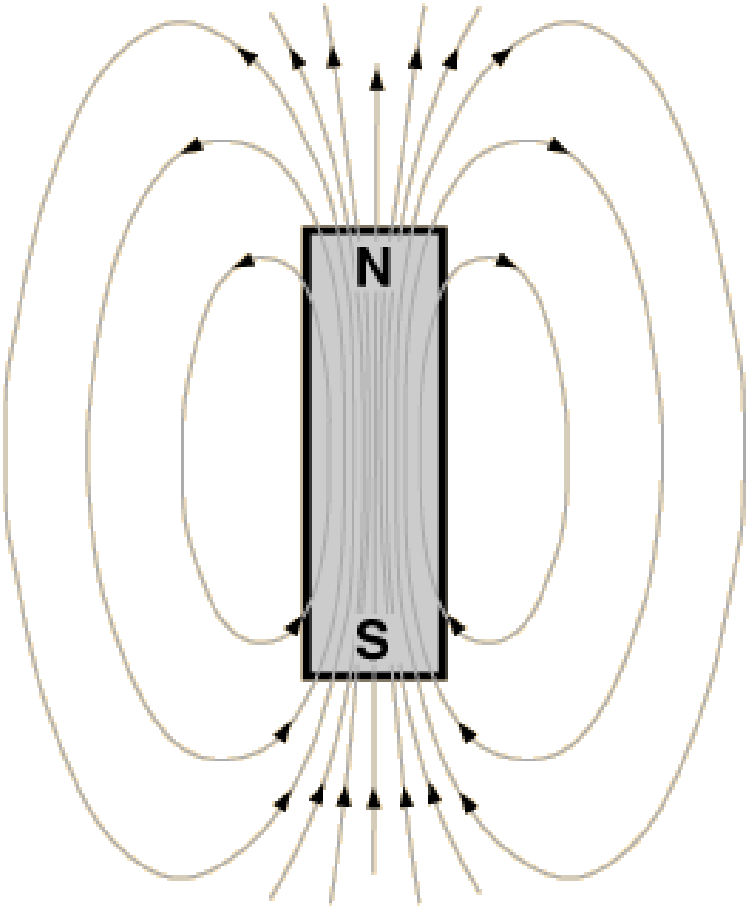
... Simple Bar Magnet

Magnetic Field Representation

•Magnetic field lines (e.g., for the bar magnet in the figure) indicate the shape and direction of the magnetic field.

•Direction: is along the field lines as indicated by the arrows.

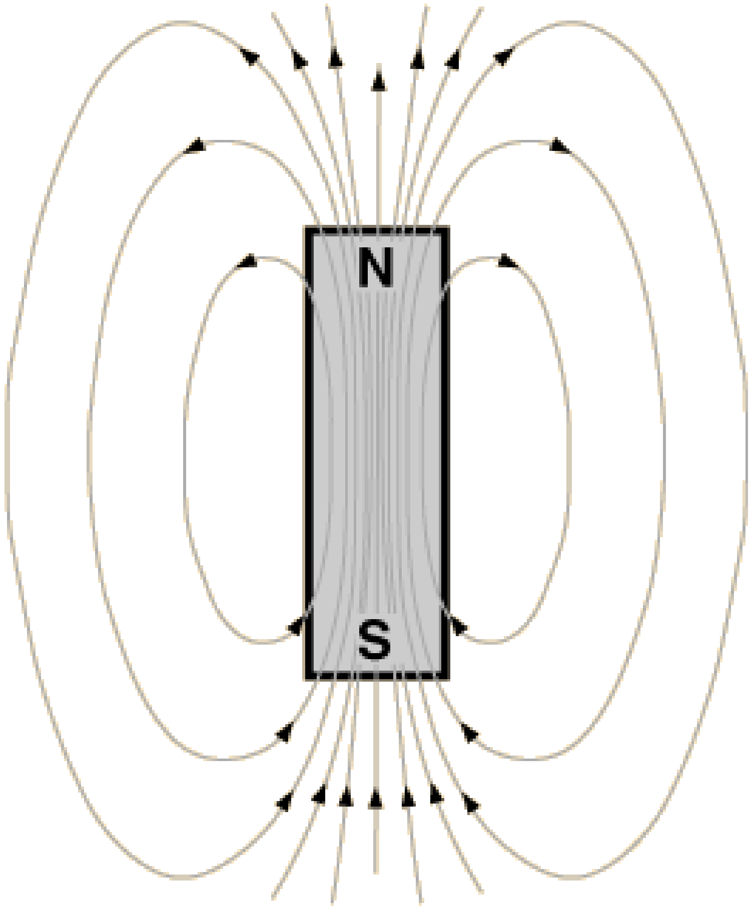
•Strength: the magnetic field is strongest where the field lines are closest together.



Magnetic Field Representation

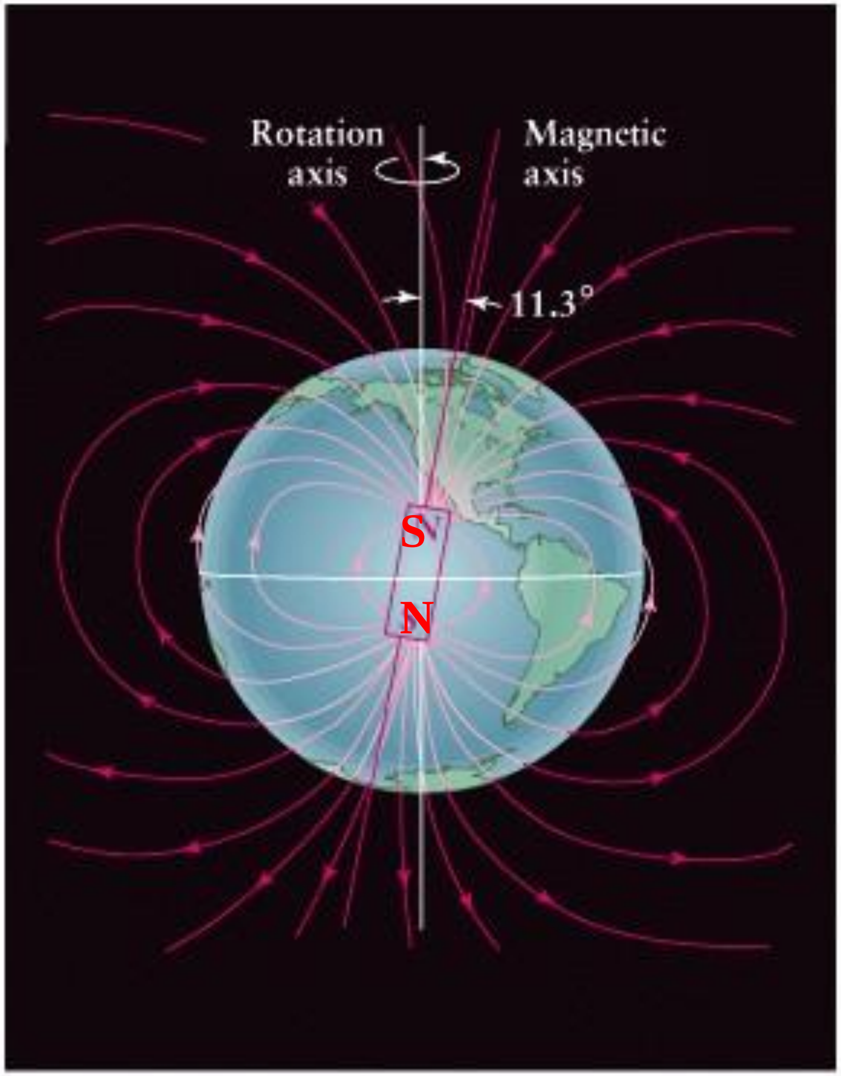
•By convention, magnetic field lines originate on the North Pole of the magnet and terminate on the South Pole of the magnet

•From experience, you are likely aware that when like poles of magnets (e.g., North and North) are brought together, there is a strong repulsive force.



Magnetic Field

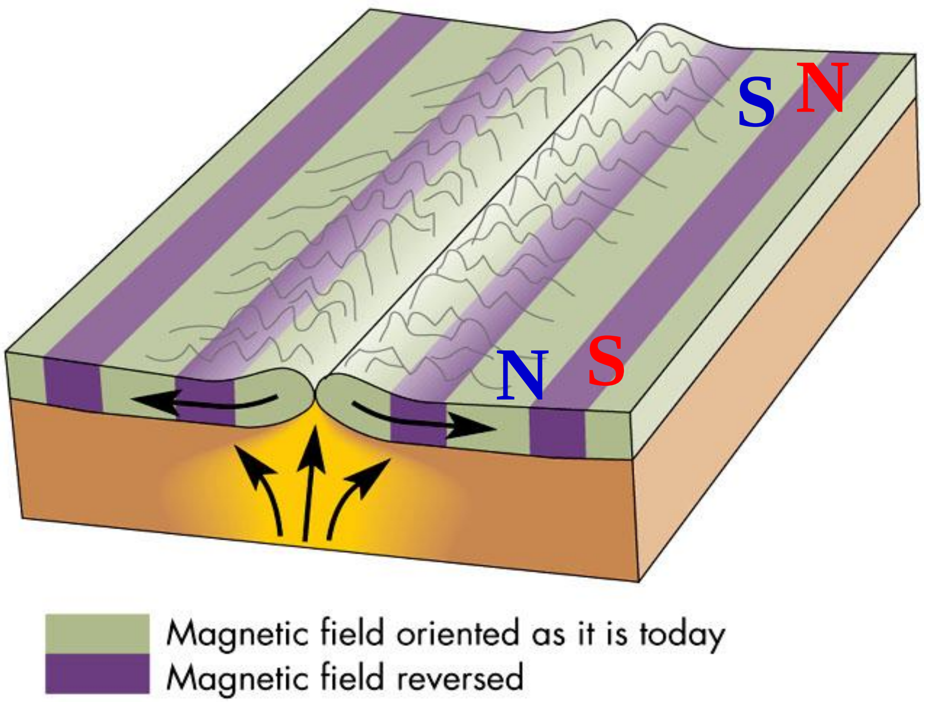
Note that the Earth's Magnetic Dipole Axis is tilted by about 11 degrees with respect to the rotational axis



b

Sea Floor Spreading

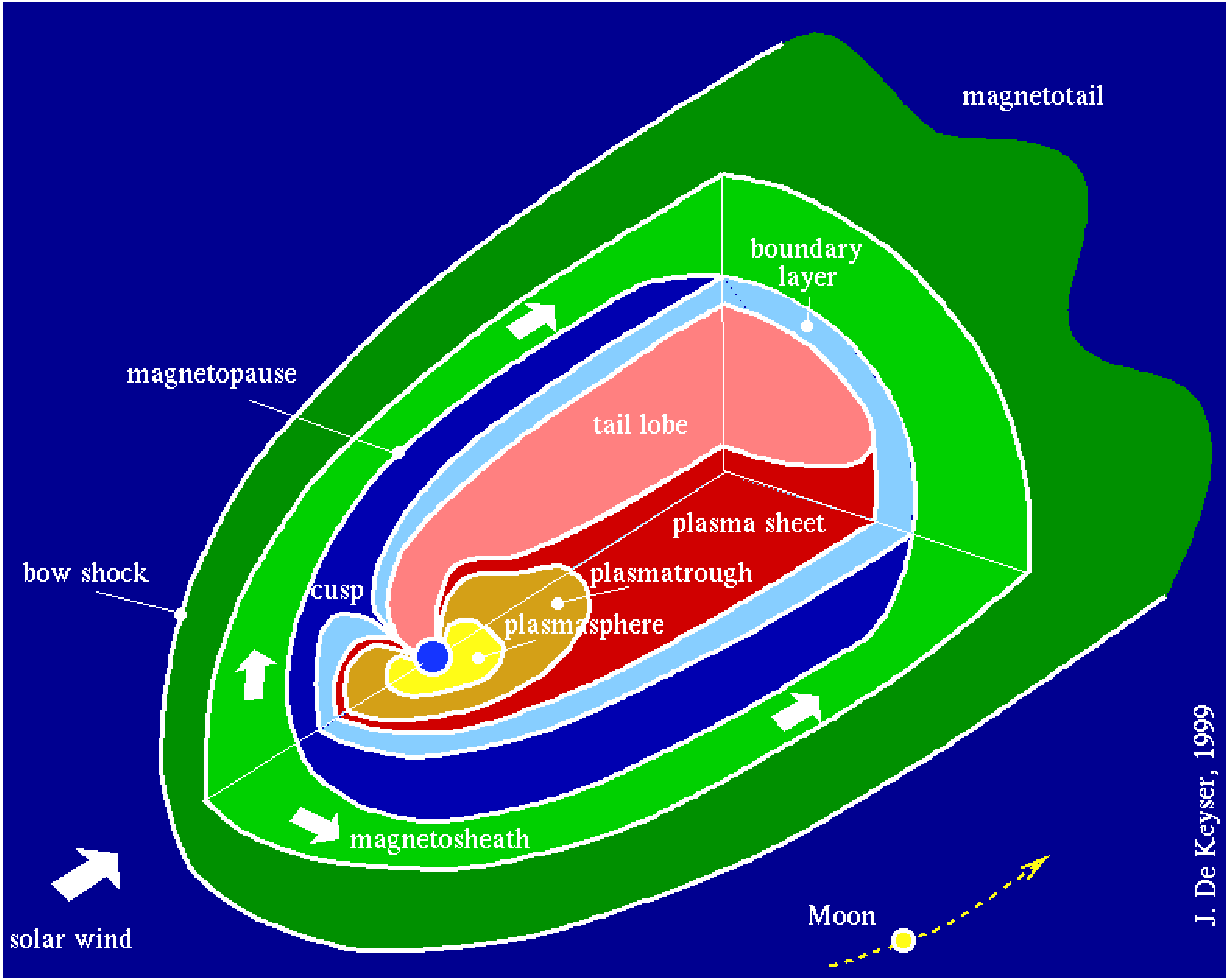
Throughout Earth's history, the magnetic field of the Earth has undergone periodic reversals on time scales of hundreds of thousands of years. The magnetic record is in magnetic materials embedded in cooled lava that are aligned to the magnetic field of the earth at the time they cooled.



Magnetosphere

The magnetic field of a planet can tell us something about the interior of the planet for example it suggests a rotating conductive core.

Additionally,
The terrestrial magnetic field forms a protective cavity about the Earth in which the Earth's magnetic field dominates. The cavity is known as the magnetosphere and it also protects us from very high energy solar particles.


magnetotail
boundary layer
magnetopause
tail lobe
plasma sheet
bow shock
cusp
plasmatrough
plasmasphere
magnetosheath
solar wind
Moon
J. De Keyser, 1999

Earth's Atmosphere

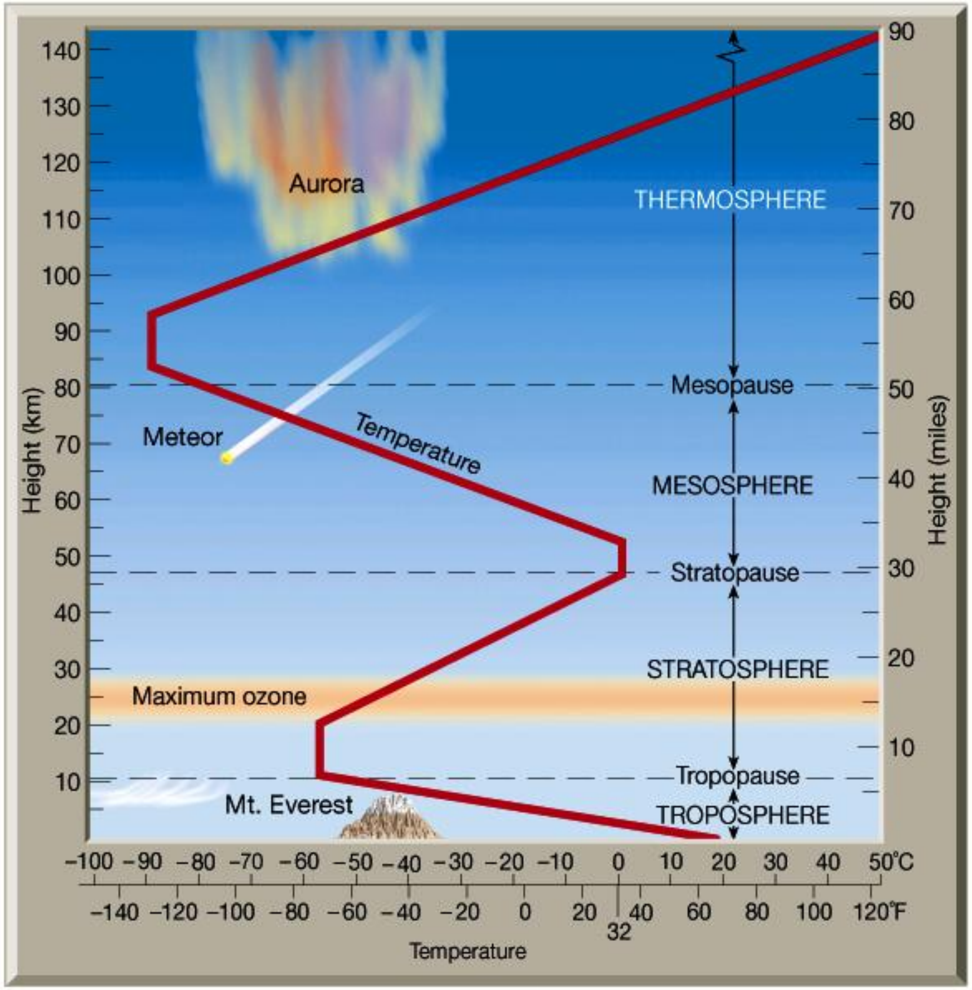
At the base of the Earth's atmosphere (sea level), the pressure is about 15 lb/in^2.

The pressure and density fall of steadily with increasing altitude.

The composition of the Earth's atmosphere (which does change with altitude above 100 km) is approximately:

Earth:	**78% Nitrogen**	**21% Oxygen**	**1% Argon**
Venus:	**4% Nitrogen**	**0% Oxygen**	**96% $C0_2$**
Mars:	**3% Nitrogen**	**0% Oxygen**	**95% $C0_2$**

Earth’s Atmosphere



Troposphere

The troposphere is the lowest 10 km of our atmosphere.

The main source of heat for the troposphere is through contact with the ground, thus the temperature falls as we increase in altitude (lapse rate on the order of 1 degree every 150 m).

Warm air rises and cools then sinks setting up vertical convection pattern.

Statosphere

The stratosphere occurs between 10 and 50 km altitude.

The temperature in the stratosphere increase with altitude to about 50 km.

The ozone layer peaks around 20 km and extends up to 50 km. Ozone absorbs ultraviolet radiation (generally low energy UV radiation which penetrates the upper atmosphere) which heats the atmosphere.

Mesosphere

The mesosphere occurs between 50 and 90 km altitude.

As the mesosphere is above the ozone layer and there is thus no source of heating, the main feature of the mesosphere is the systematic decrease in temperature with altitude.

Thermosphere

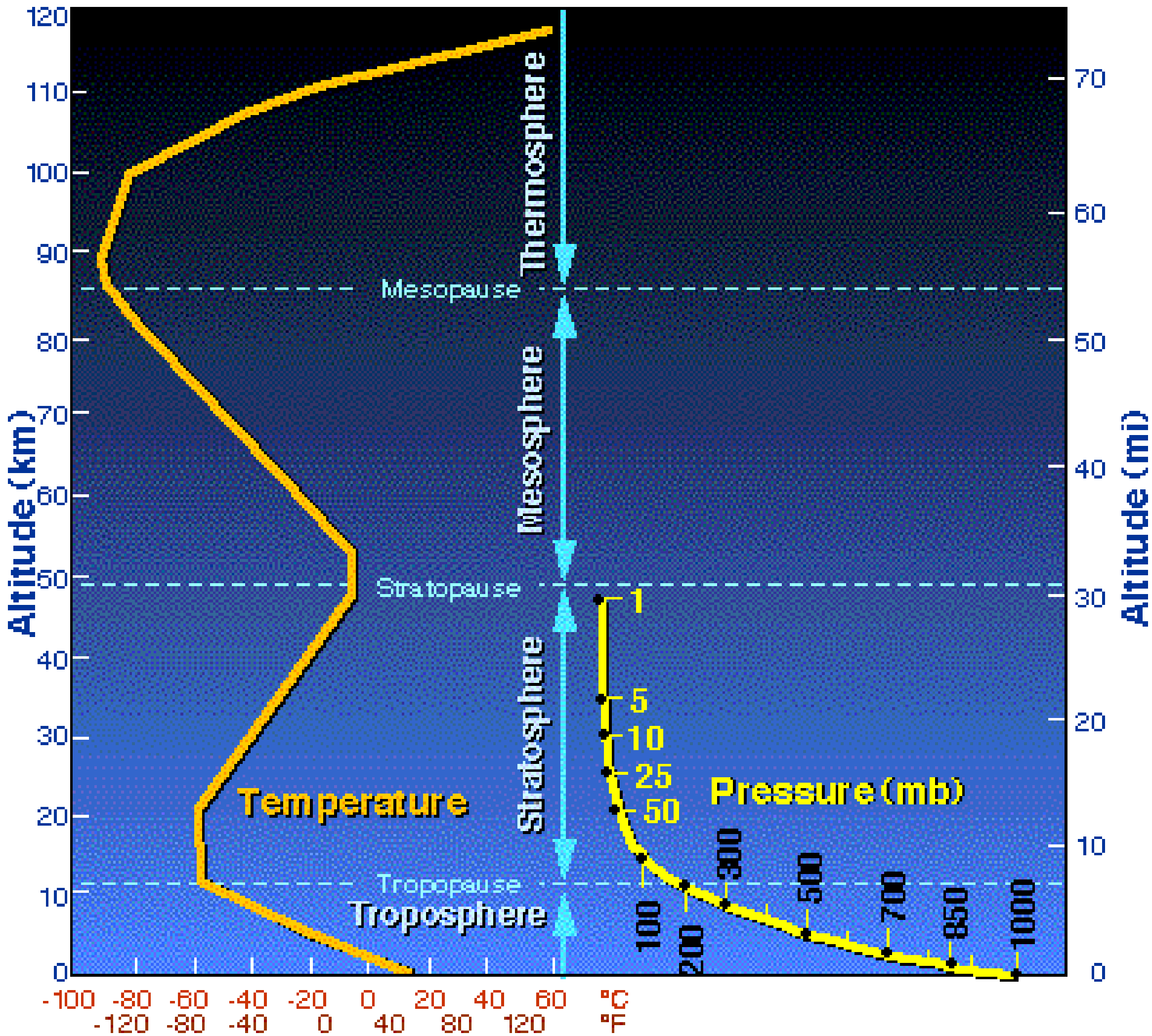
The thermosphere occurs above 90 km altitude (to say 1000 km).

High energy UV radiation is absorbed in this region and thus the temperature increases with altitude.

The radiation also ionizes the gases of the upper atmosphere. Thus a gas of electrically charged particles is embedded in the thermosphere. This is known as the ionosphere.

In the thermosphere, the gases start to stratify according to their mass with the heavier gases (O2, N2) on the bottom and the lighter gases O on top.

Average atmospheric temperature and pressure in the atmosphere



Aurora: Form and Color

Hugh Gallagher Jr. February 1992 Sondrestromfjord Greenland

Marko Gronroos, Turku, Finland, March 19, 2001

Tom Eklund,Valkeakoski,Finland, March 19, 2001

Jan Curtis, Fairbanks Alaska, March 20, 2001

Jan Curtis, Fairbanks Alaska, March 20, 2001

Jan Curtis, Fairbanks Alaska, March 20, 2001

Philippe Moussette, Quebec, Canada, October 28, 2001

Chuck Adams, Statesville, NC, November 5, 2001

John Russell, Nome, Alaska, October 28, 2001

Vesa Särkelä, Kemijärvi Finland, November 5, 2001

Jan Curtis
March 20,2001
Fairbanks Alaska

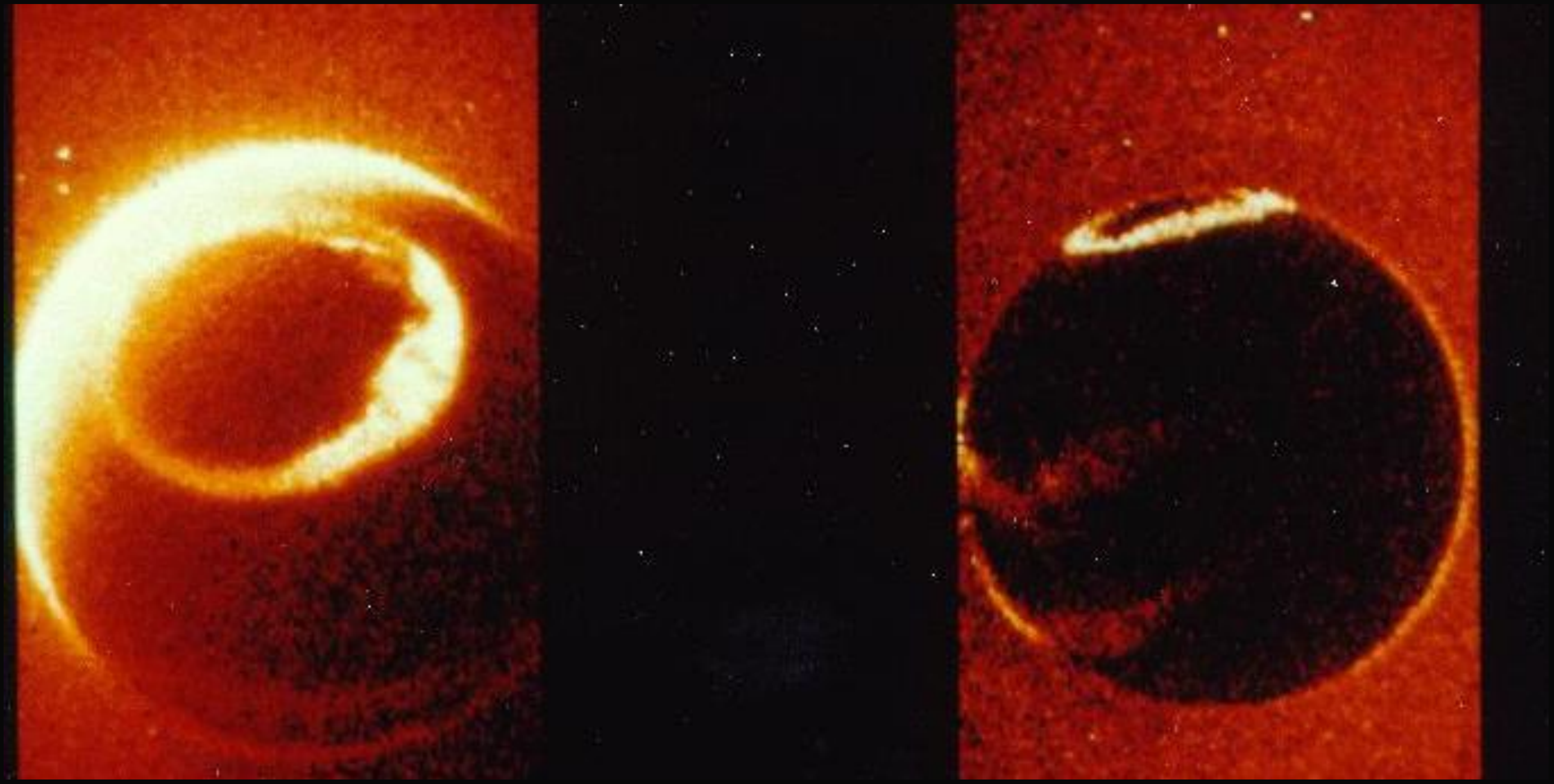
Brett Walker, Chippewa Falls, Wisconsin, November 5, 2001

Steven Lichti, West Lafayette, Indiana, November 5, 2001

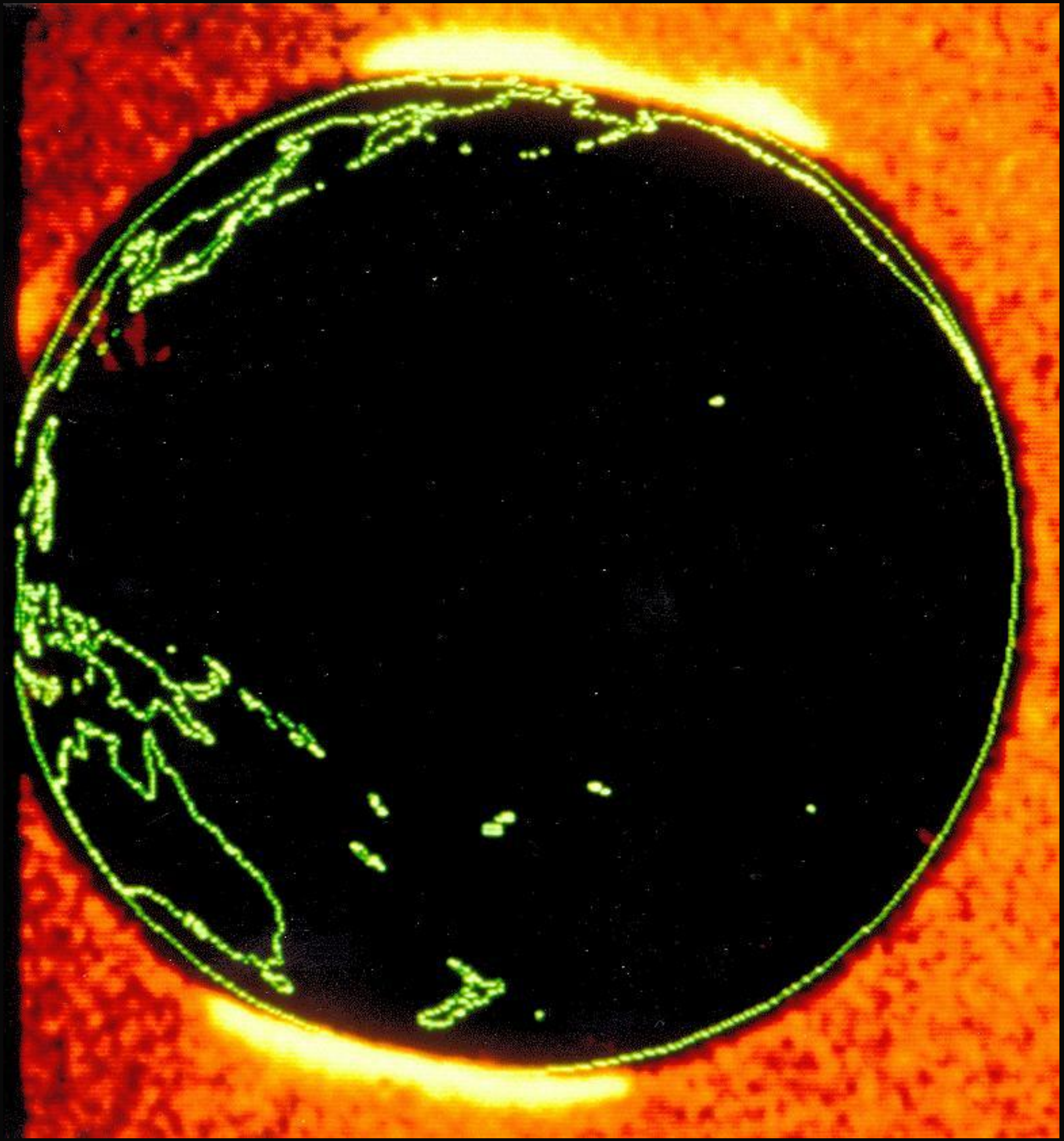
Dennis L. Mammana, San Diego, CA, November 5, 2001

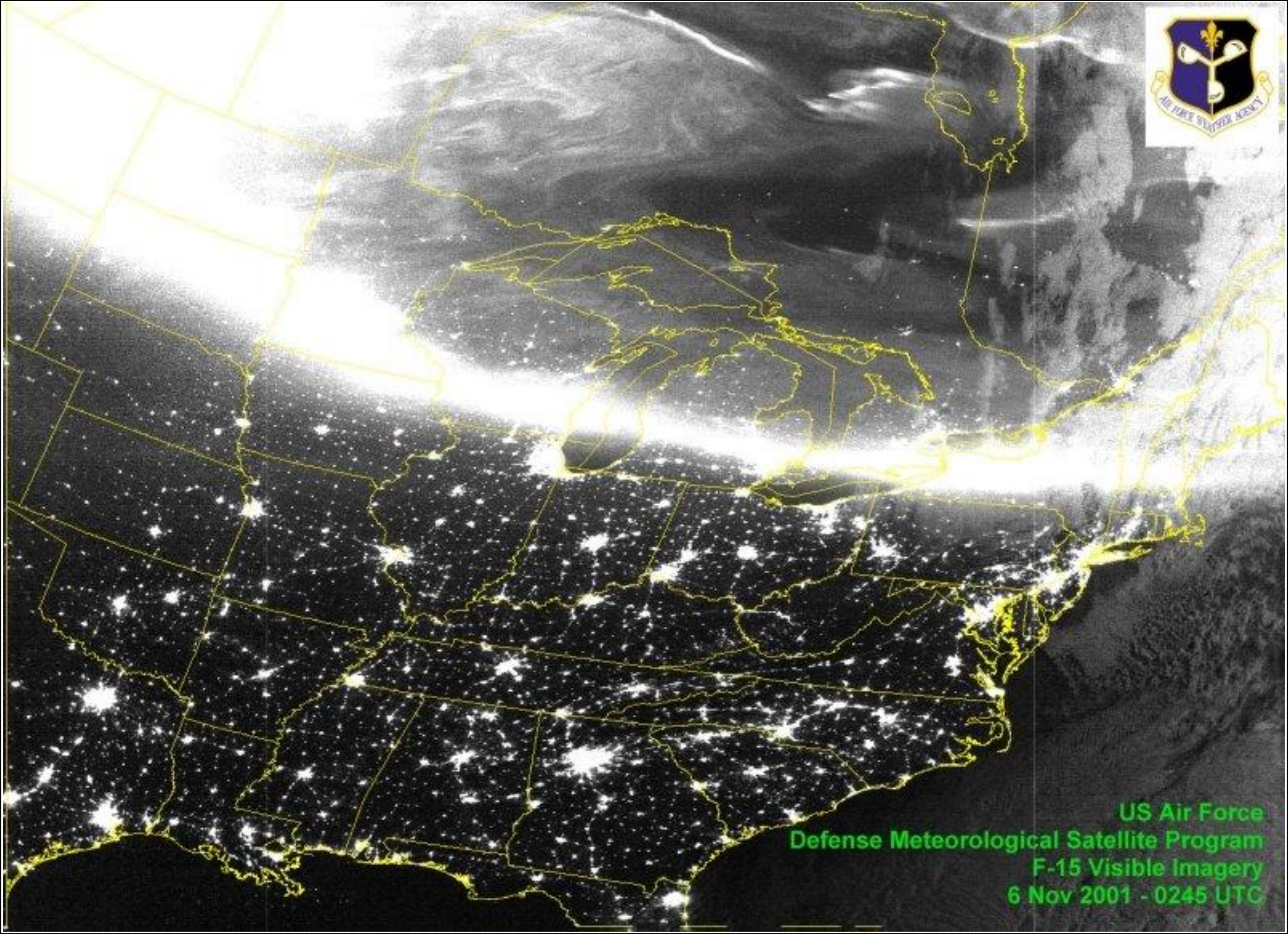
Aurora Borealis by Frederick Edwin Church, 1865

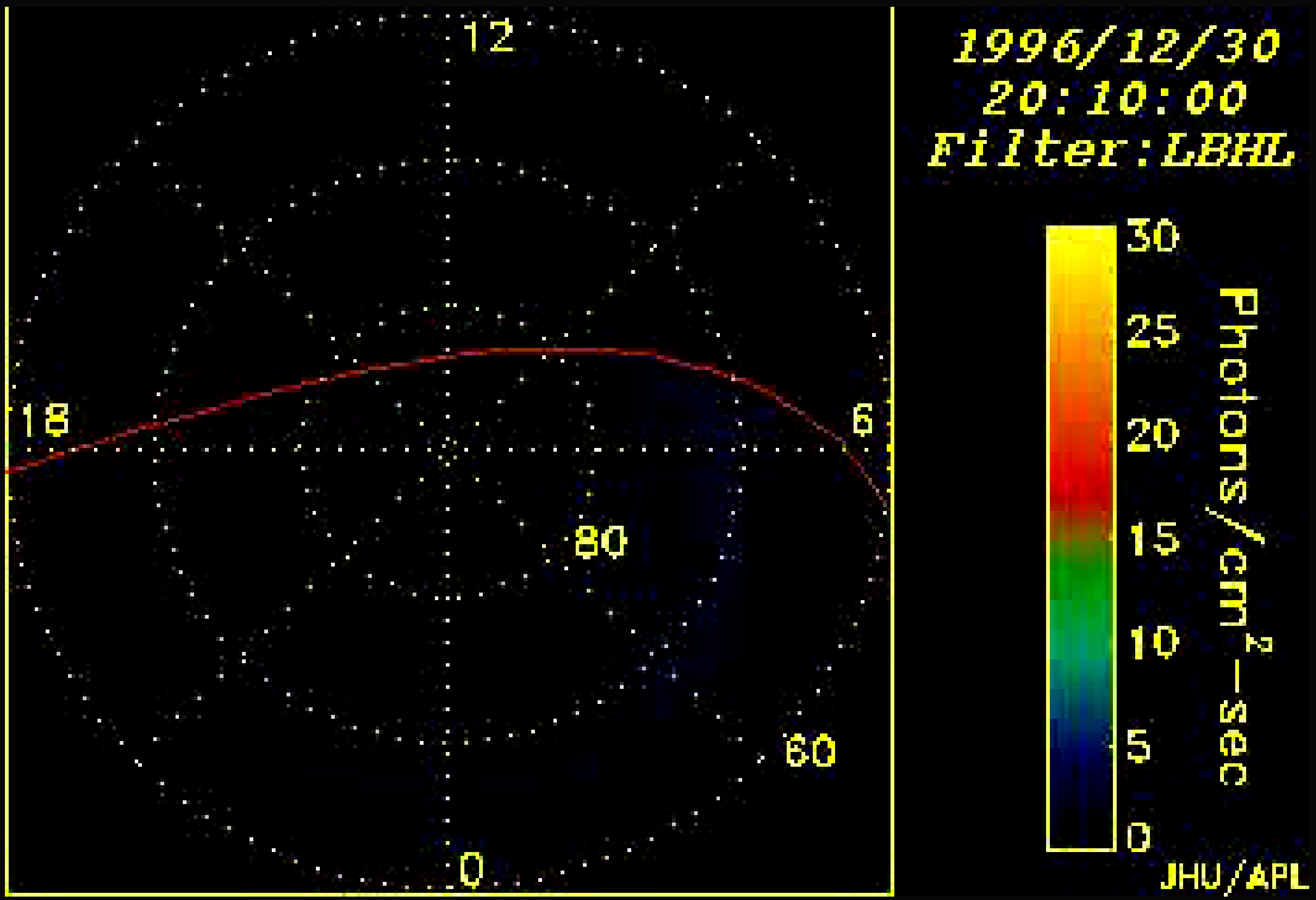
Dynamics Explorer Satellite
Dr. Lou Frank, University of Iowa



DE: Simultaneous Northern and Southern Lights

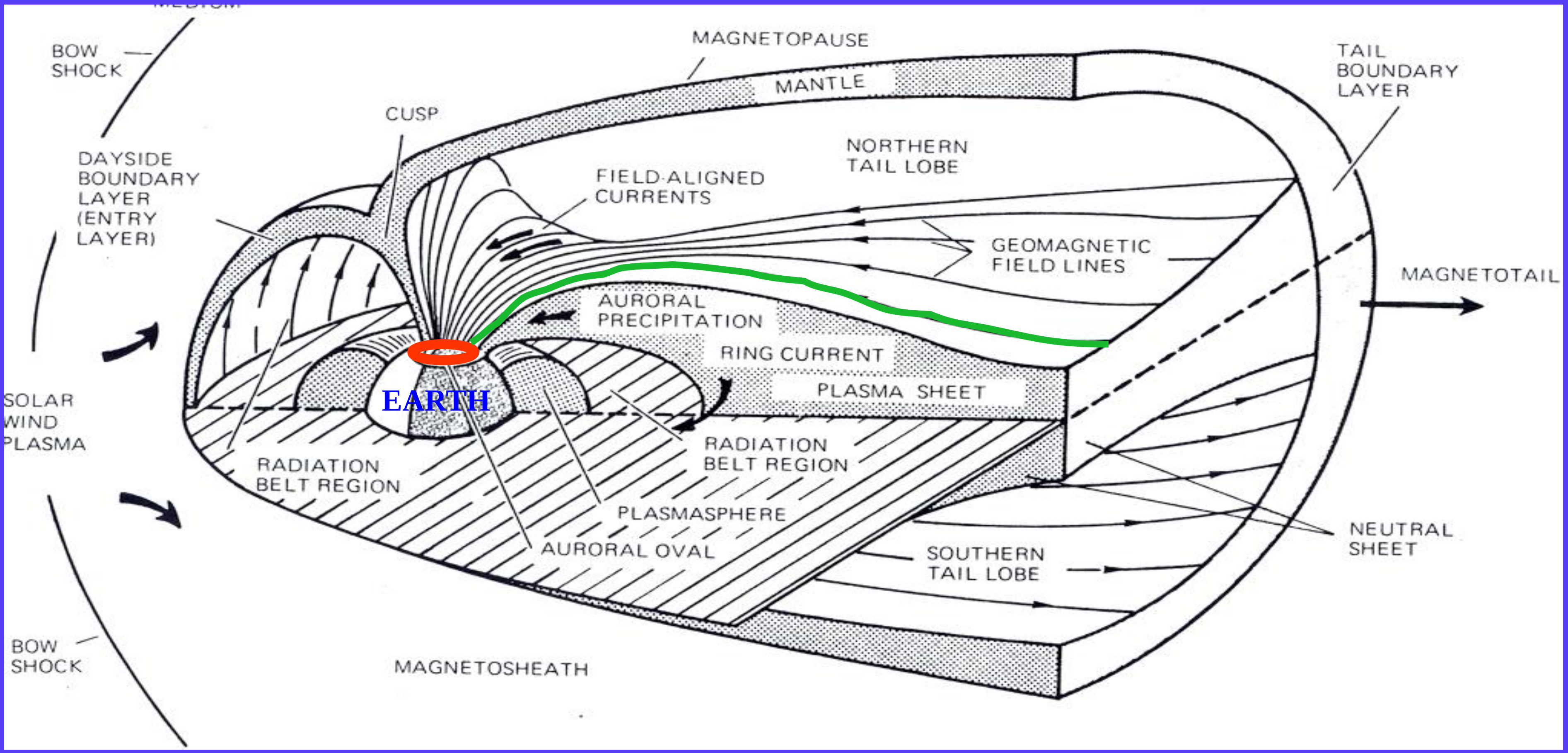



US Air Force
Defense Meteorological Satellite Program
F-15 Visible Imagery
6 Nov 2001 - 0245 UTC

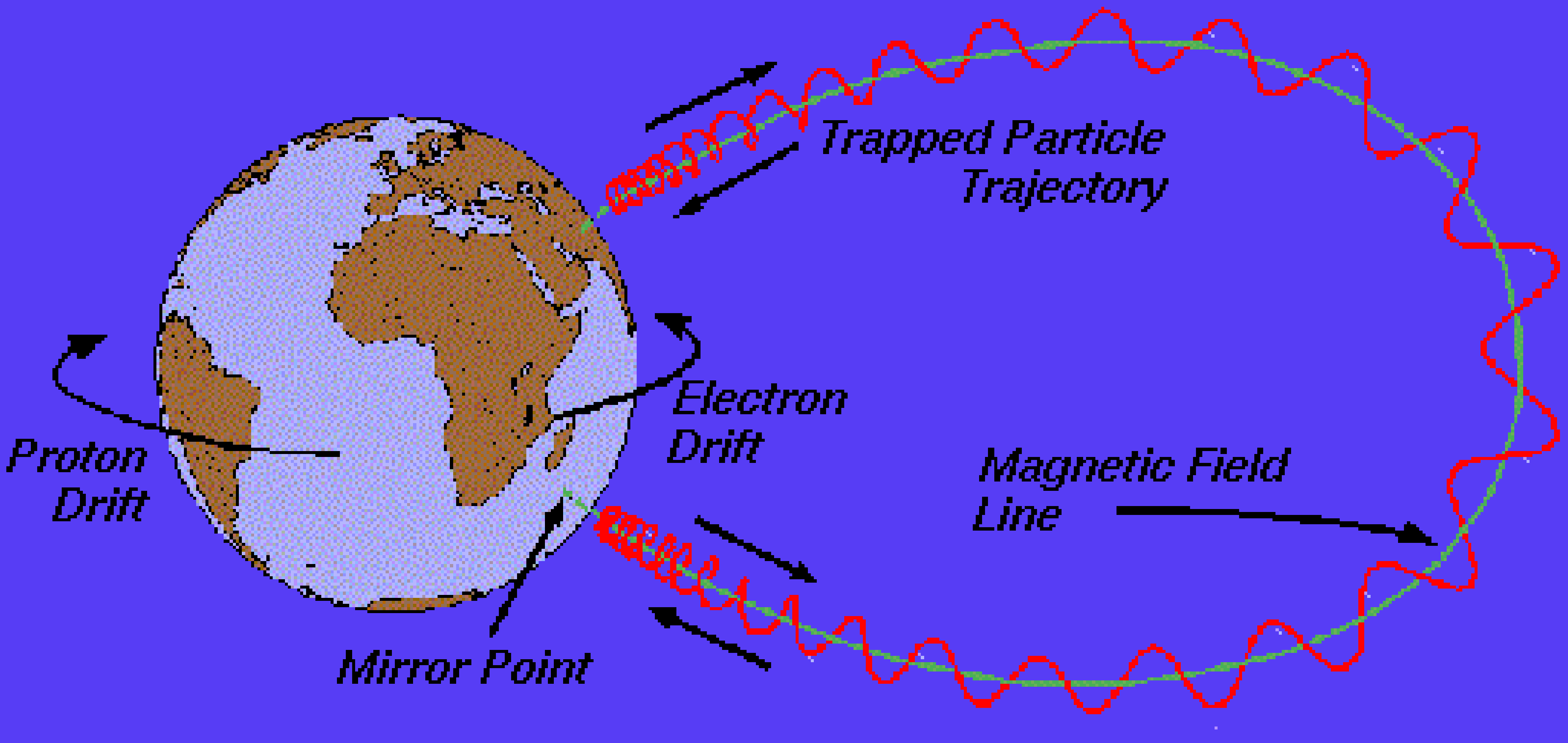


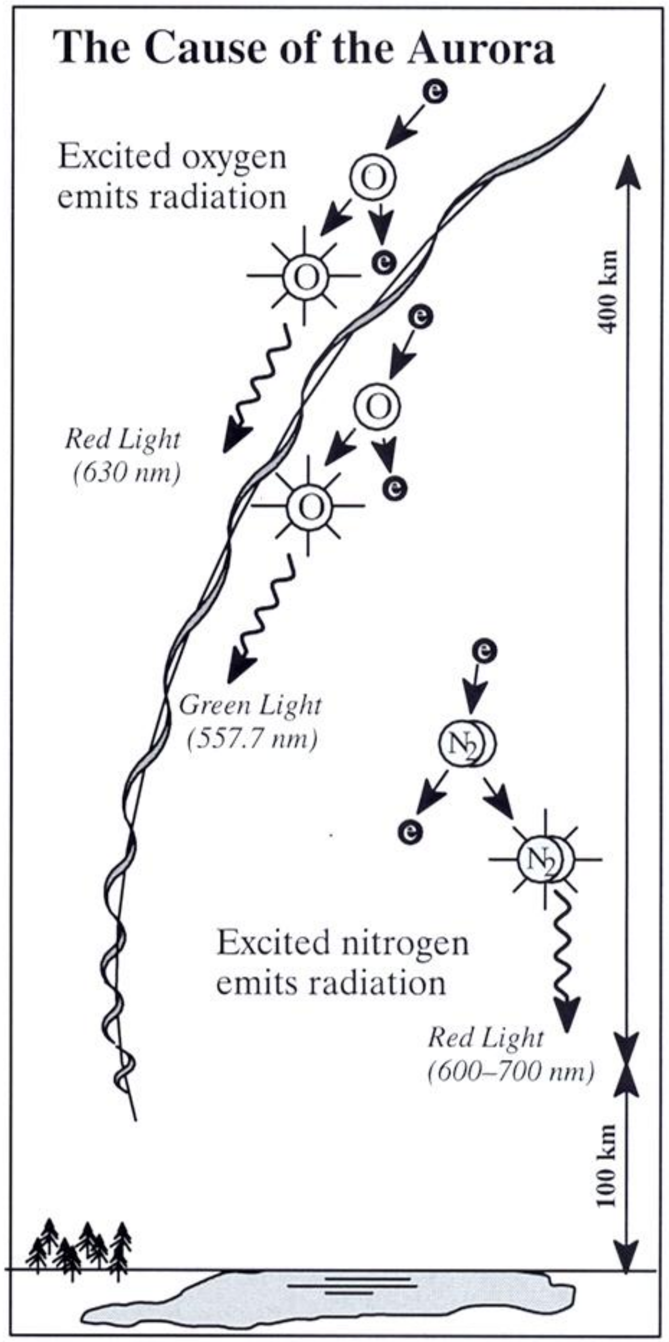
12
18
6
80
60
0
1996/12/30
20:10:00
Filter:LBHL
30
25
20
15
10
5
0
Photons/cm²-sec
JHU/APL

At the Base of the Magnetosphere: The Auroral Oval



Motion of Charged Particles in the Presence of a Magnetic Field

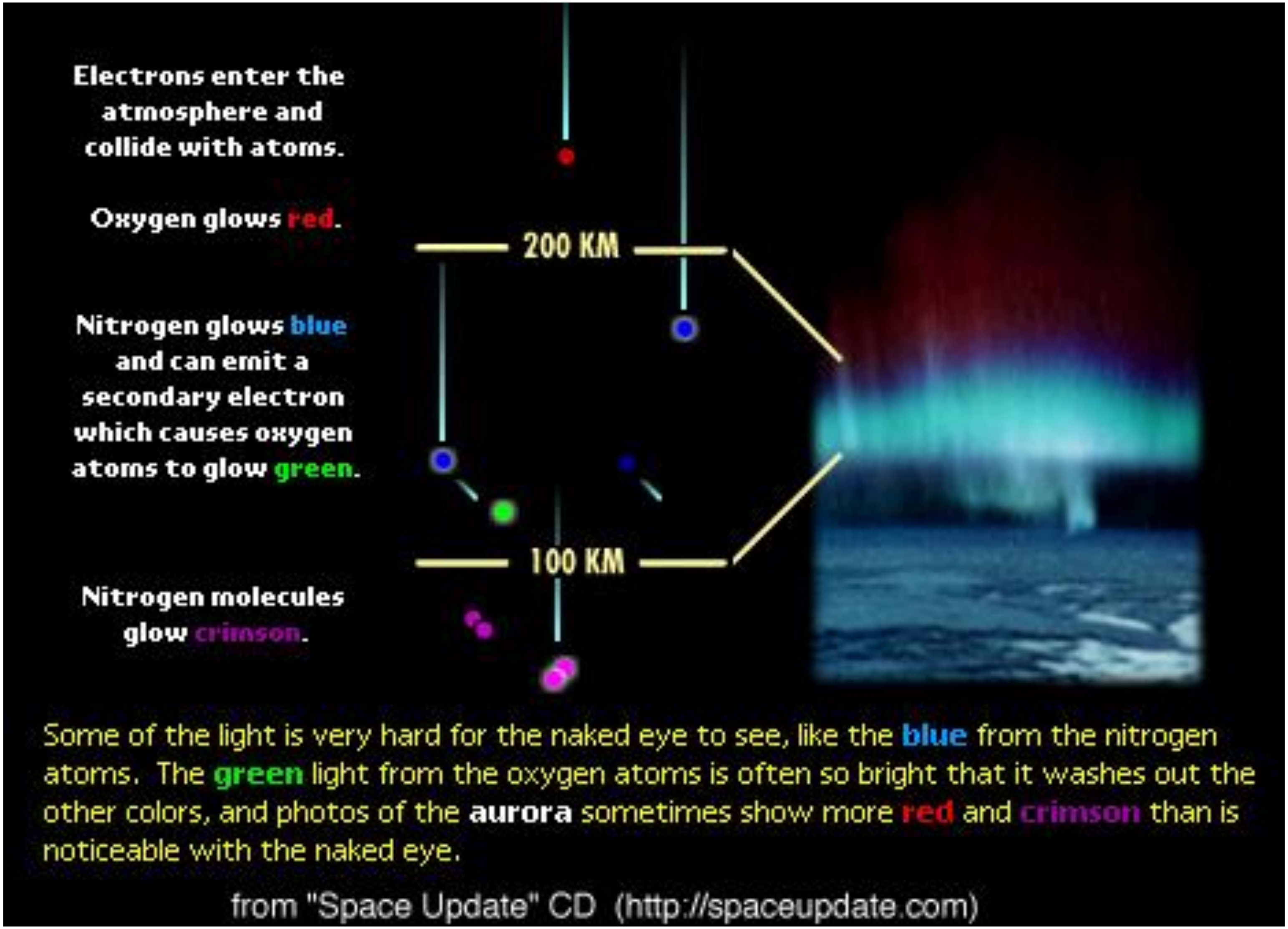




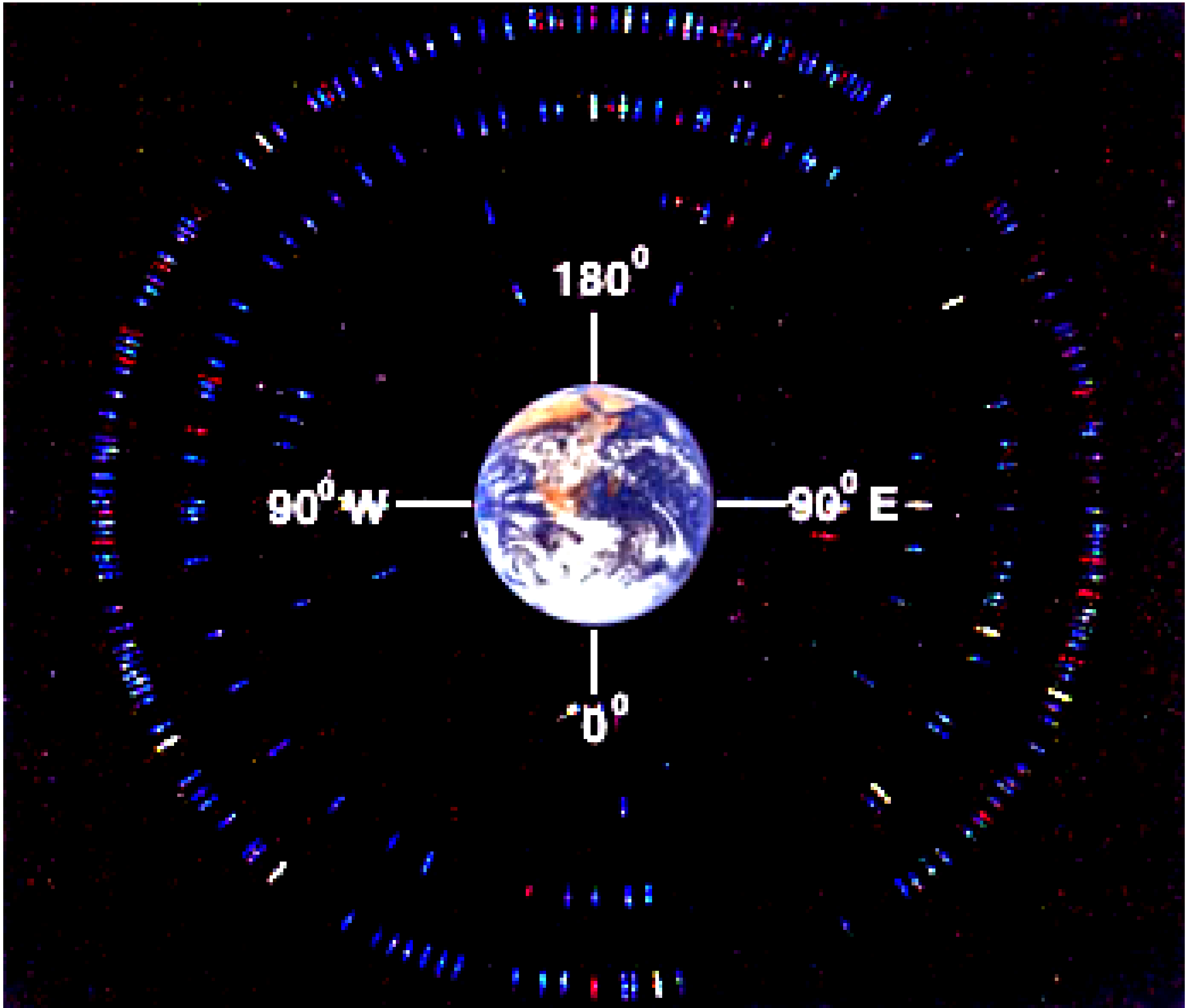
Charged particles from the outer magnetosphere are guided towards the polar regions by the Earth's magnetic field.

Through collisions, the charged particles excite the atoms and molecules of the upper atmosphere which subsequently emit the auroral light.

The color of the auroral emissions depends on the composition of the upper atmosphere and thus the altitude where the emissions are produced.



Electrons enter the atmosphere and collide with atoms.
Oxygen glows red.
200 KM
Nitrogen glows blue and can emit a secondary electron which causes oxygen atoms to glow green.
100 KM
Nitrogen molecules glow crimson.
Some of the light is very hard for the naked eye to see, like the blue from the nitrogen atoms. The green light from the oxygen atoms is often so bright that it washes out the other colors, and photos of the aurora sometimes show more red and crimson than is noticeable with the naked eye.
from "Space Update" CD (http://spaceupdate.com)



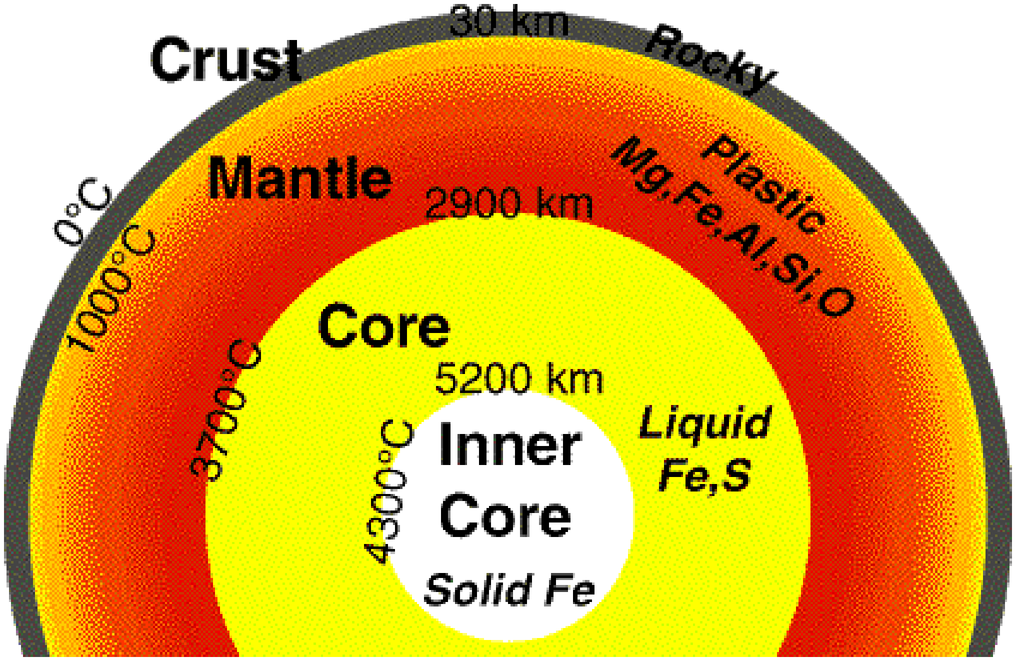
180°
90° W
90° E
0°

Coriolis Effect

In the Northern Hemisphere:

An object moving equatorward is deflected towards the West.

An object moving poleward is deflected towards the East.


Crust
30 km
Rocky
Mantle
2900 km
Plastic
Mg,Fe,Al,Si,O
0°C
1000°C
Core
5200 km
3700°C
Liquid
Fe,S
Inner
Core
4300°C
Solid Fe

http://szyzyg.arm.ac.uk/~spm/neo_map.html

http://maps.jpl.nasa.gov/

http://www.scsr.nevada.edu/~mssmith/solar.html

http://cfa-www.harvard.edu/afoe/simulation/e3.html

http://www.jpl.nasa.gov/proto/solar_system_images.html

http://csep10.phys.utk.edu/astr161/lect/

http://www.fourmilab.to/cgi-bin/uncgi/Solar/action?sys=-Sf