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Space environment

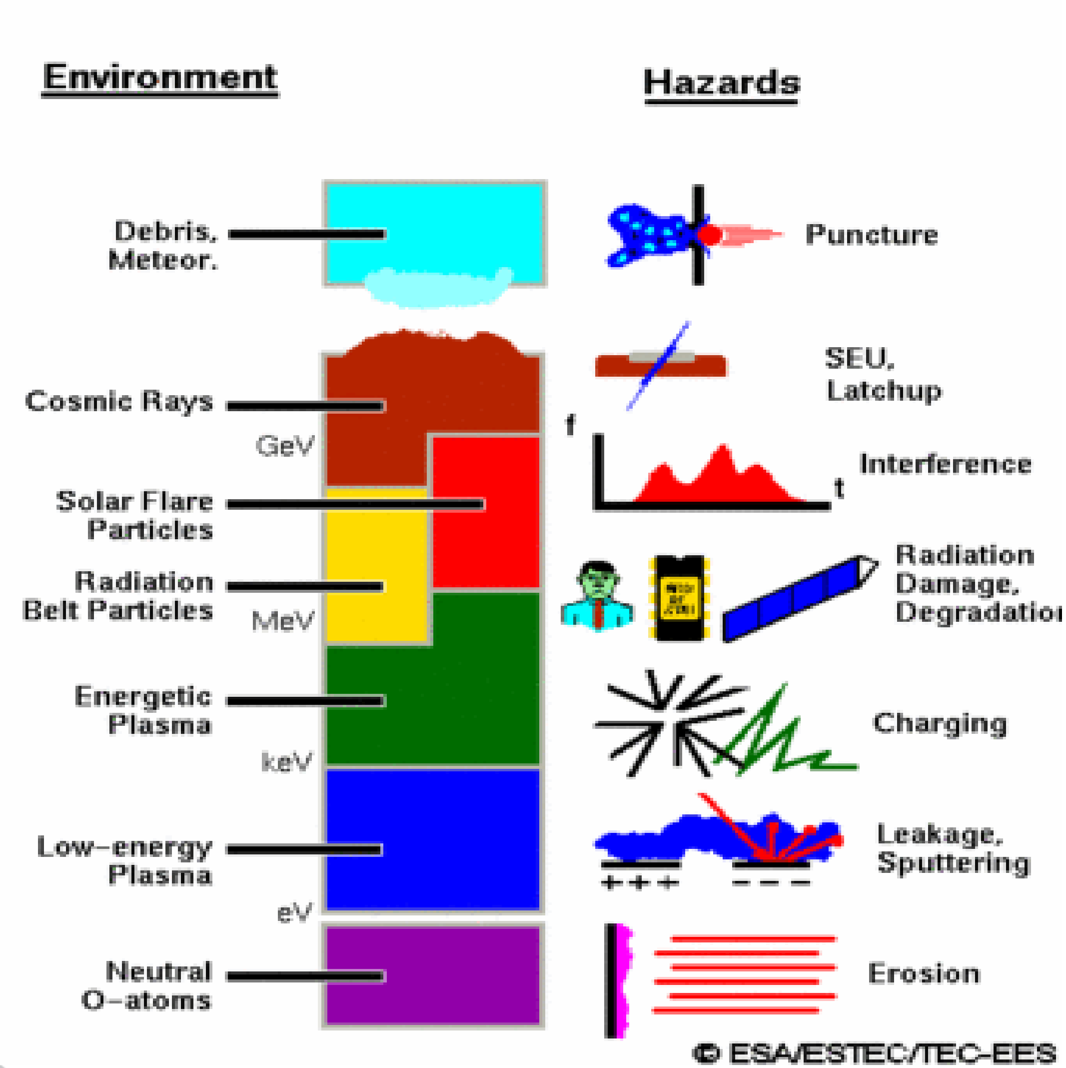
Space Technology I

Vendela Paxal

Impacted bodies

- Satellites in orbit
- Space crafts
- Space stations
- Missions to outer space
- Humans
- Equipment on earth

Space environment



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Main types of satellite constellations and altitudes

Low Earth Orbit : ~160 km < LEO < 2000 km

- any type of orbit, also polar
- earth observation
- niche type communication
- International Space Station (ISS)
- Hubble telescope

Medium Earth Orbit: 2000 km < MEO < GEO

- any type of orbit, also polar
- also called Intermediate Circular Orbit (ICO)
- navigation, e.g. GPS with an altitude of 20,200 kilometers

Geostationary Earth Orbit : GEO: ~ 36000 km

- always equatorial
- communication
- broadcasting

Highly Elliptical Orbit: HEO: an elliptic orbit

- characterized by a relatively low-altitude perigee and an high-altitude apogee
- long dwell times at a point in the sky during the approach to and descent from apogee
- can “emulate” non-equatorial GEO
- communications satellites.

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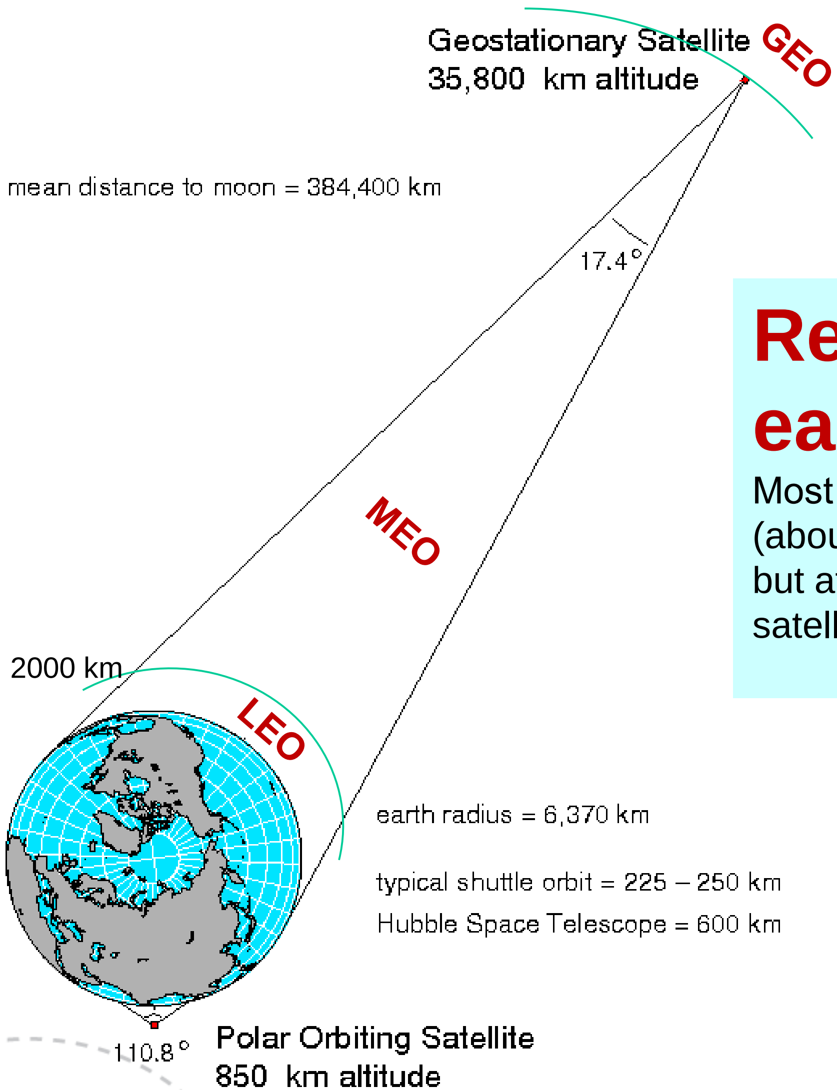
From http://www.freebase.com/view/spaceflight/satellite_orbit_type

Satellite orbits



Relative distances from the earth to orbiting satellites

Most of earth's atmosphere is below 30 km
(about the thickness of the earth countour line on the figure),
but atmospheric drag will have a significant impact on
satellites below approximately 200 km.

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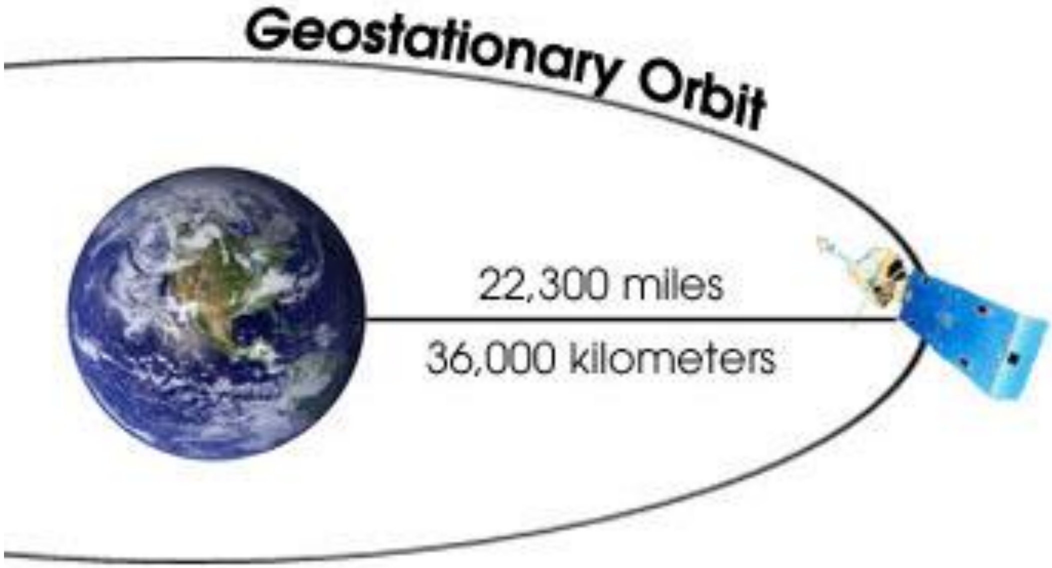
From http://www.rap.ucar.edu/~djohnson/satellite/coverage.html#introduction

GEO satellites



- The point with a Geostationary or Geosynchronous satellite is that the satellite shall appear as being still in the sky when seen from the surface of the Earth.
- The stallite is moving in an orbit with 24h period.
- The only "place" where such an orbit is possible, is in the equatorial plane at a distance of 36000 km.

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Environmental effects

- Mechanical
  - Irregularities of the earth's gravitational field
  - The gravitational field of the sun and the moon
  - Radiation pressure
  - Debris in space
- Thermal influence: sun, earth, cold space
- Radiation
  - The earth's magnetic field
  - Solar flares
  - Radiation from space
  - Radiation from the earth

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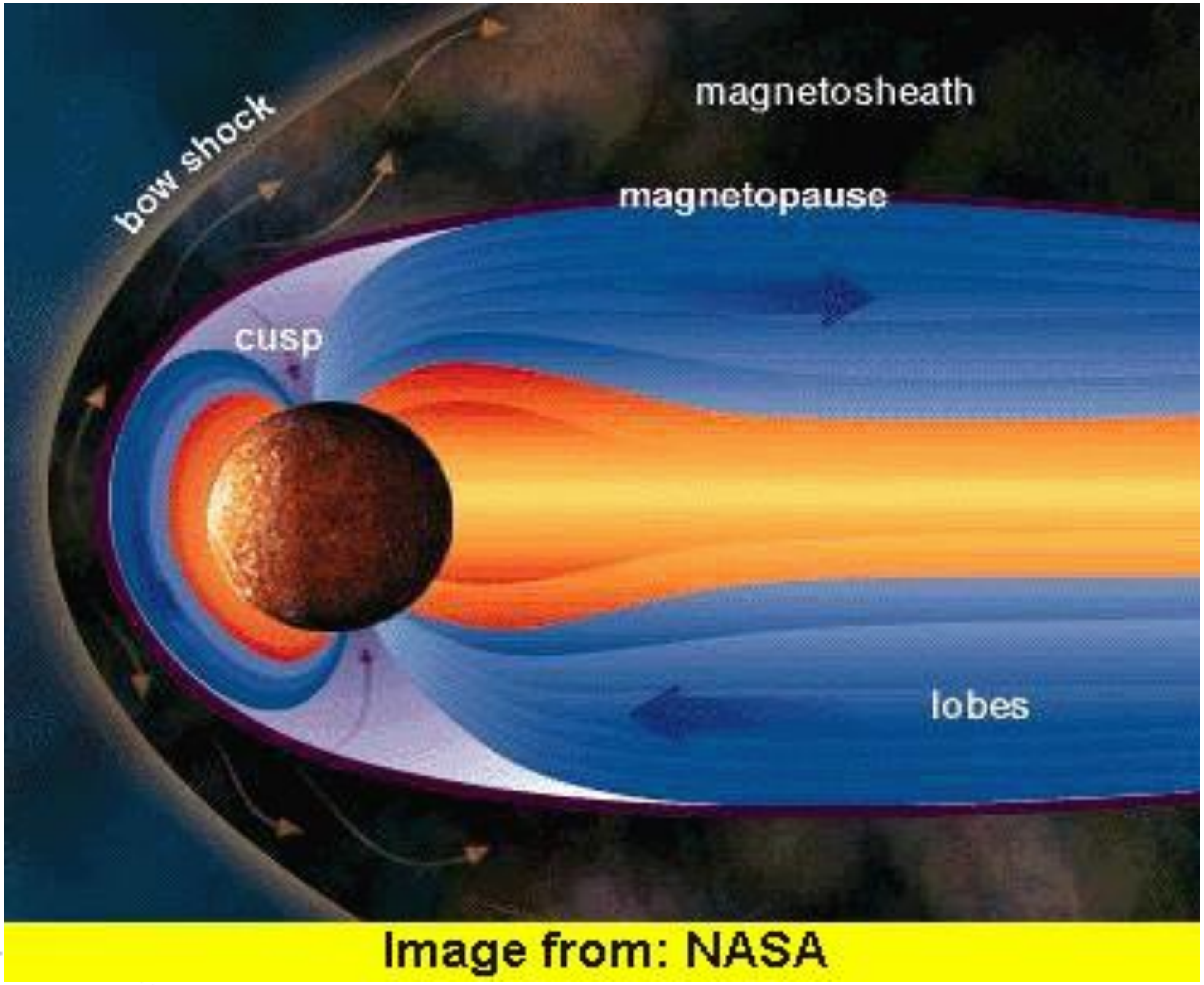
Radiation from the sun

- Solar flares
- Solar pressure
- Thermal

Earth's protection: the magnetosphere



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Earth's Magnethosphere

- The non spherical shape is determined by:
  - Earth's internal magnetic field
  - Solar winds (plasma)
  - Interplanetary magnetic field

- Contains free charged particles
  - From solar winds
  - From earth's ionosphere
  - Confined by electric and magnetic forces stronger than gravity and collisions

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Magnetosphere shape

- Bounded by the Magnetopause
- Bullet shaped
- Varies with the intensity of the solar winds
- Day side: 10-12 R_E
- Night side: 15 R_E abreast, forms a ”cylinder” with radius 20-25 R_E. Tail region streches past 200 R_E

1R_E = Earth radii = 6370 km
Moon is at 60 R_E from Earth
Distances given from Earth centre

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Earth magnetism

- Driven by rotation of the liquid metal (Fe) in the core of the Earth and electric currents in the Magnetosphere
- Dipole field
- Inclined by ~11° to the rotation axis
- Magnetism of about 30-60 µT at the Earth surface
- Magnetism is decreasing by $1/d^3$ at a distance *d* from the Earth
- Higher harmonics exist but diminish faster

Examples:

5 mT is the typical strength of a refrigirator magnet

3T is the strength of an MRI system.

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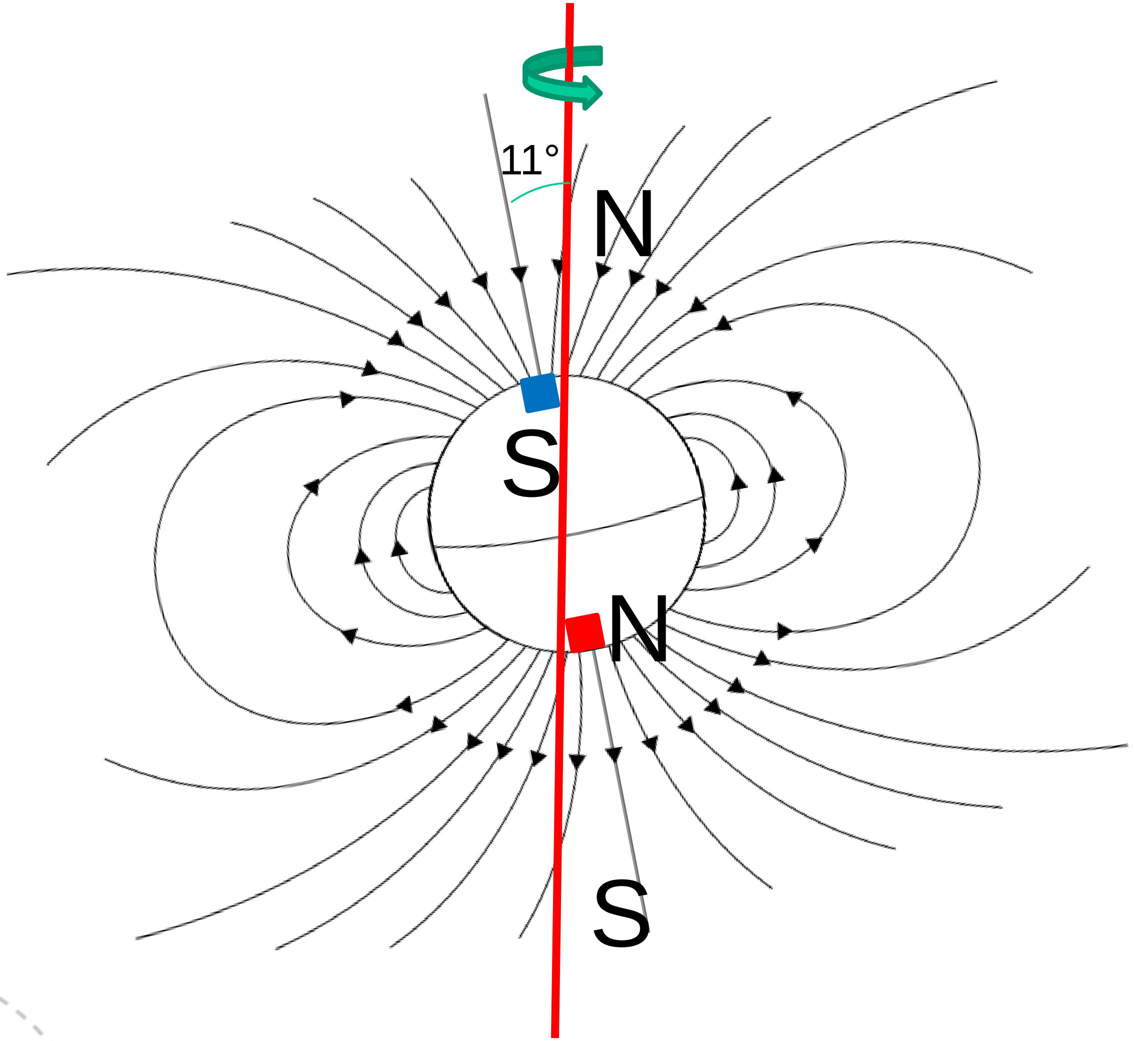
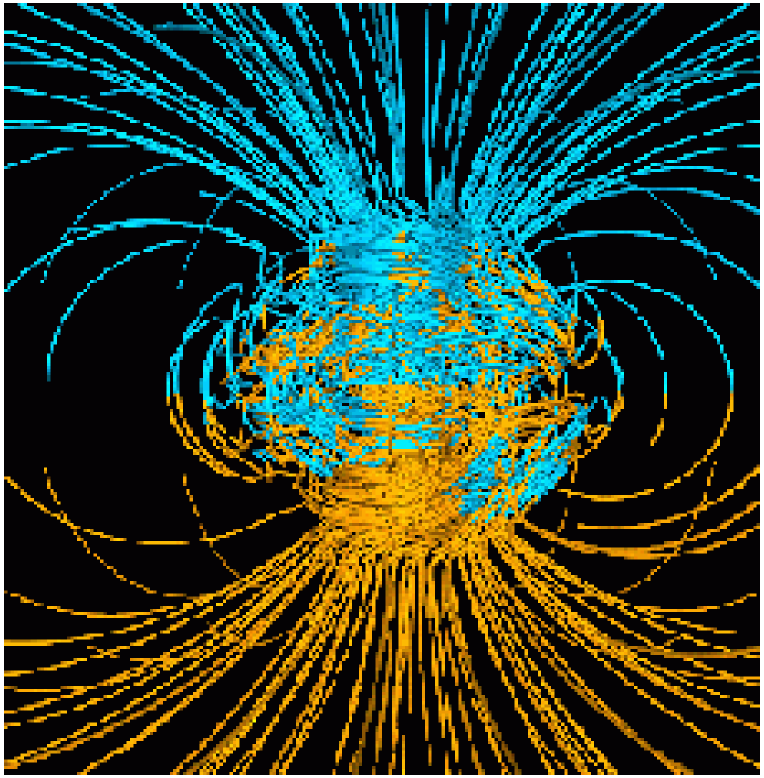
Earth = magnetic dipole



The geodynamo



Magnetic field structure simulated with the Glatzmaier-Roberts geodynamo model. Magnetic field lines are blue where the field is directed inward and yellow where directed outward.

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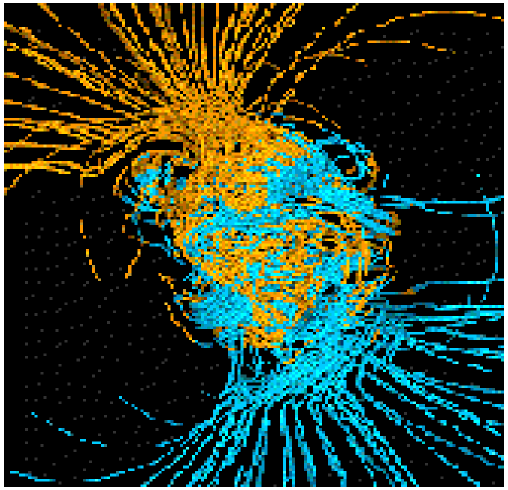
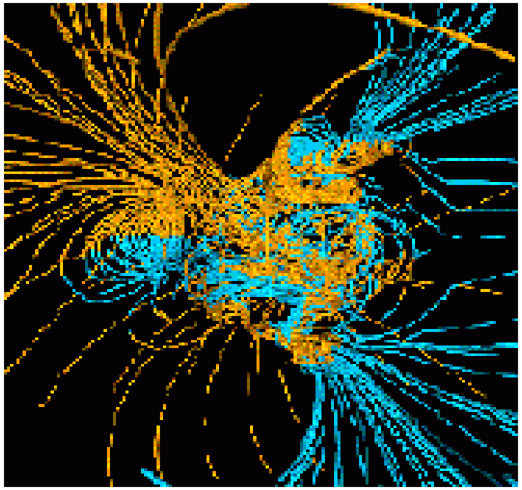
http://www.es.ucsc.edu/~glatz/geodynamo.html

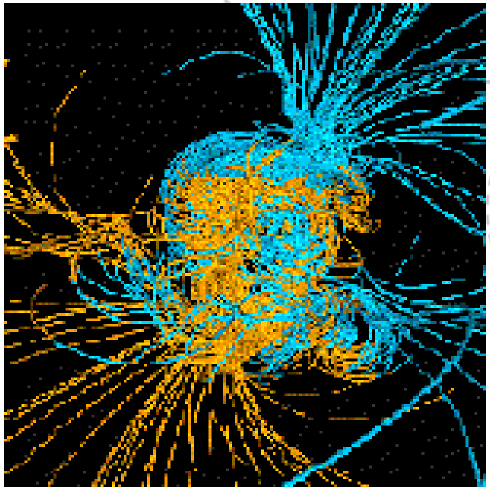
Magnetic field reversal scenario



500 years before the middle of a magnetic dipole reversal,



at the middle of the reversal,



and 500 years after the middle of the reversal.

Magnetopause, Magnetotail, Magnetosheath

- Difficult for solar wind plasma to mix with terrestrial plasma, the boundary is the Magnetopause
- The magnetotail is formed by the pressure from the solar winds on the Magnetosphere
- A temporary weakening in the Magnetotail results in an injection of solar plasma into the inner Magnetosphere giving aurora and ring current
- Collision free bow shock forms in the solar wind ahead of the Earth. The region behind the shock is the Magnetosheath

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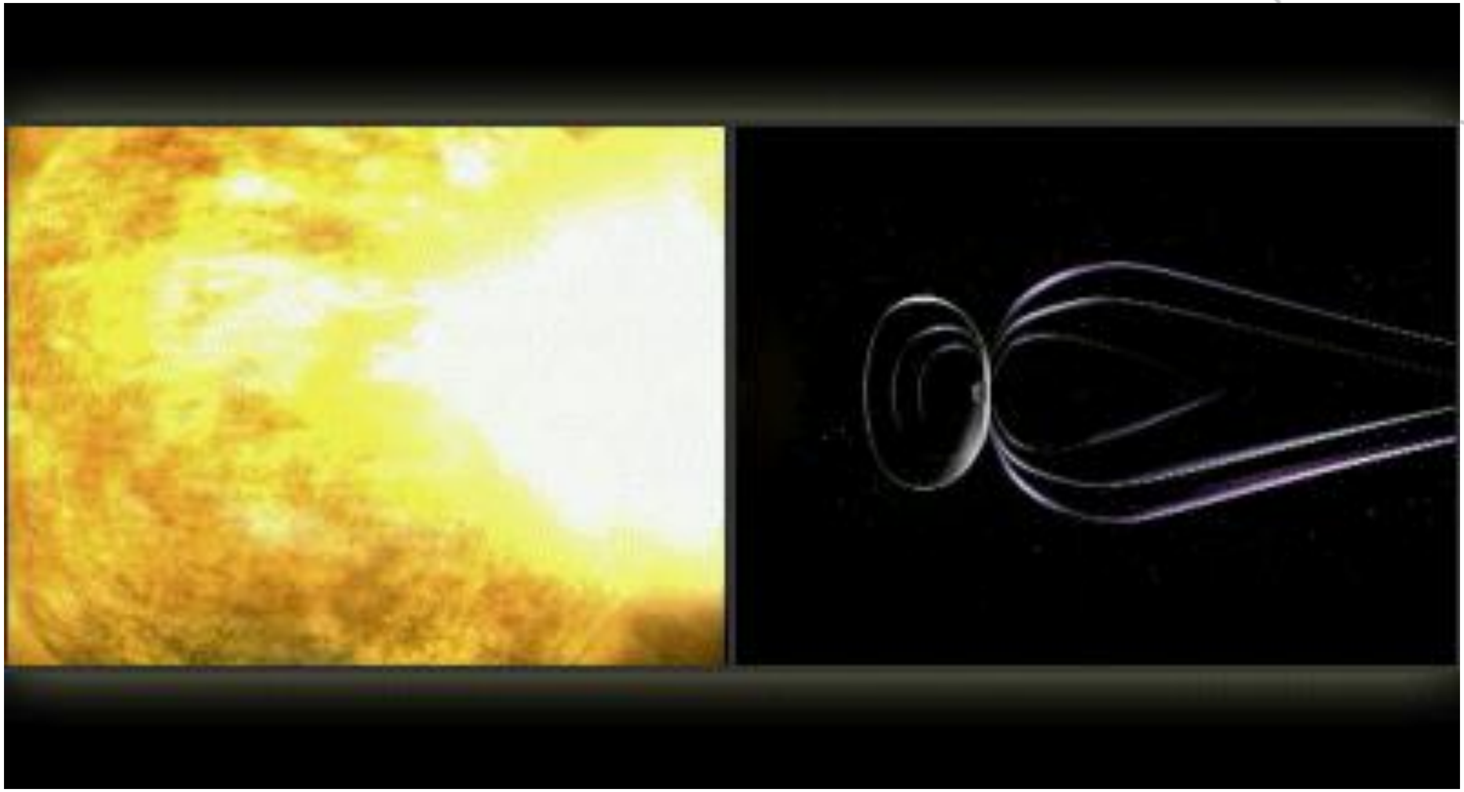
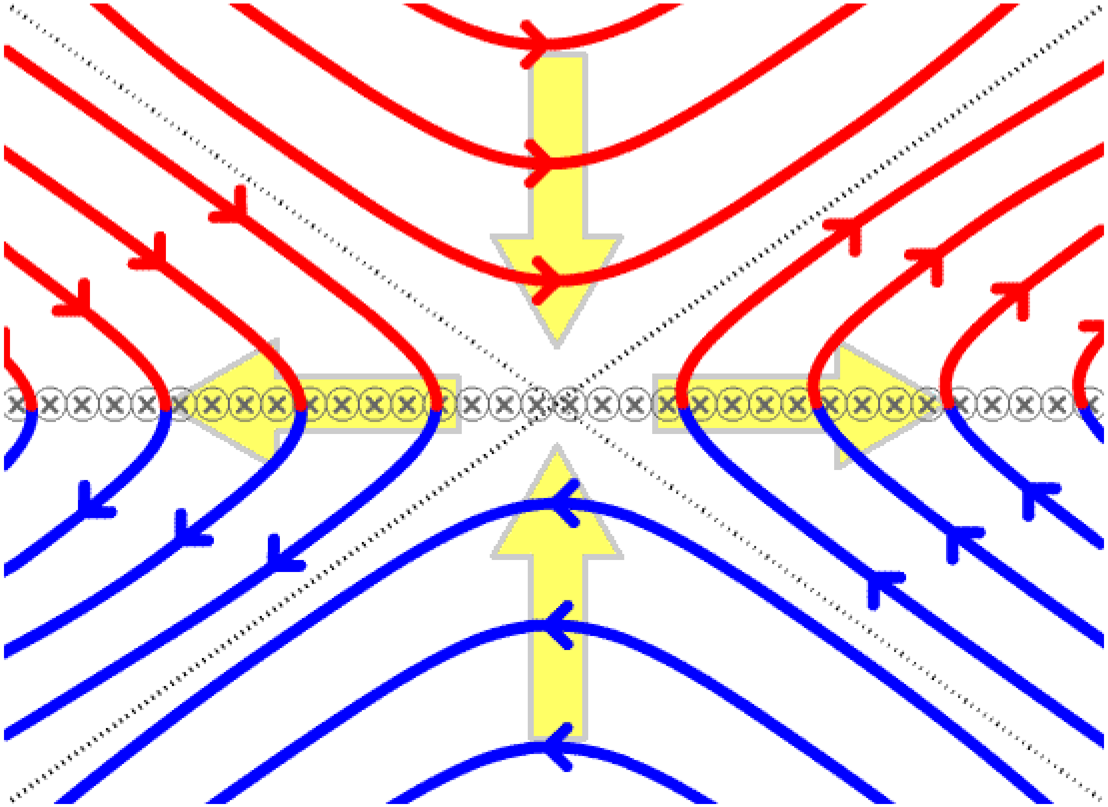
Solar winds meet the magnetosphere

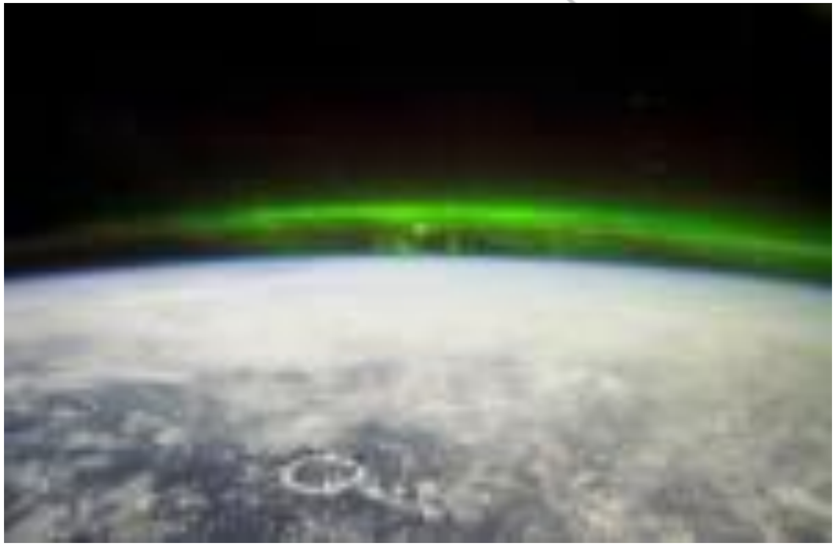


http://www.esa.int/esaCP/SEMF75BNJTF_index_0.html

Magnetic reconnection



Solar flares giving auroras



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Solar flares

- Due to magnetic reconnection
- Several classes of solar flares depending on their peak flux.
- Occur mostly in or around sun spots
- The result of intense magnetic fields emerging from the Sun's surface into the corona
- Can take several days to build up, but only minutes to release.

... giving.....

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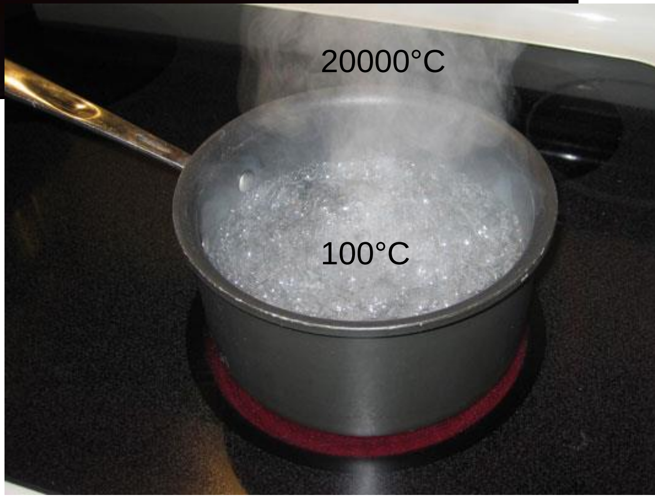
www.space.com

...... Solar winds

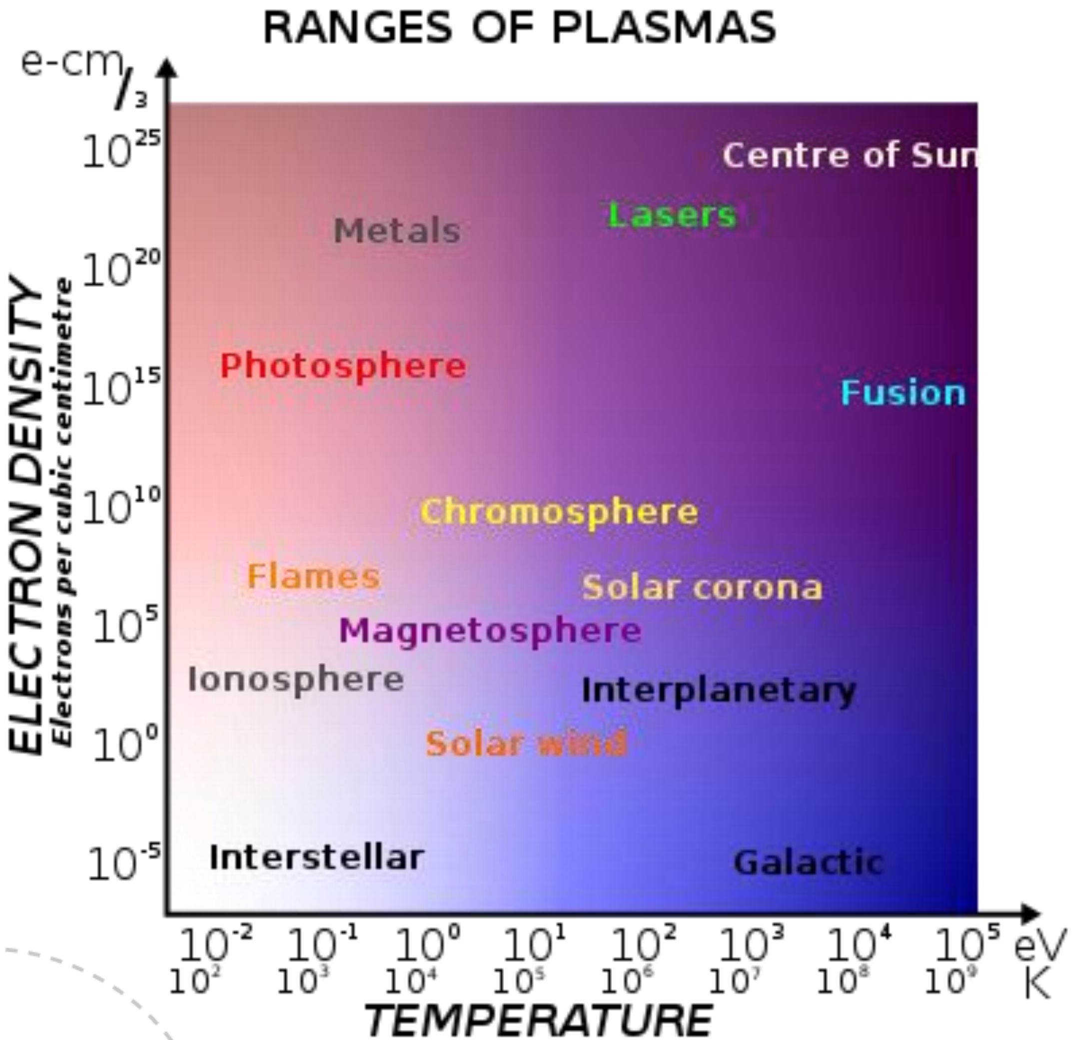
- The magnetic energy released by magnetic reconnection provides the energy that is needed to drive the solar wind and propel it into the depths of the solar system
- Speeds of 450 km/s
- Takes 150 days for it to reach the orbit of Pluto
- May reach 1700 km/s or more if there is a powerful coronal mass ejection going on
- The solar wind is composed of the same atoms that make up the Sun itself, and in nearly the same abundances: about 75% hydrogen atoms and 23% helium atoms
- Eventually, the solar wind collides with atoms from interstellar gases surrounding the solar system out beyond Pluto, forming a shock front and a vast bubble.



  - Why is the corona so hot?
  - The surface of the Sun : temperature of about 6000°C
  - The temperature of coronal gases: over $1.2 \cdot 10^6$ ° C
  - The answer may be the constant creation and destruction of magnetic loops of energy all across the surface of the Sun

What is plasma?

- Neutrally charged gas with ionised particles



The effect on space environment

- Radiation belts (Van Allen belts) discovered in 1958 with Sputnik and Explorer 1&3
- Two radiation belts
  - Inner belt mainly of protons, but also electrons, at ~1.5R_E
  - Outer radiation belt mainly of electrons and some protons at ~2.5 – 8 R_E

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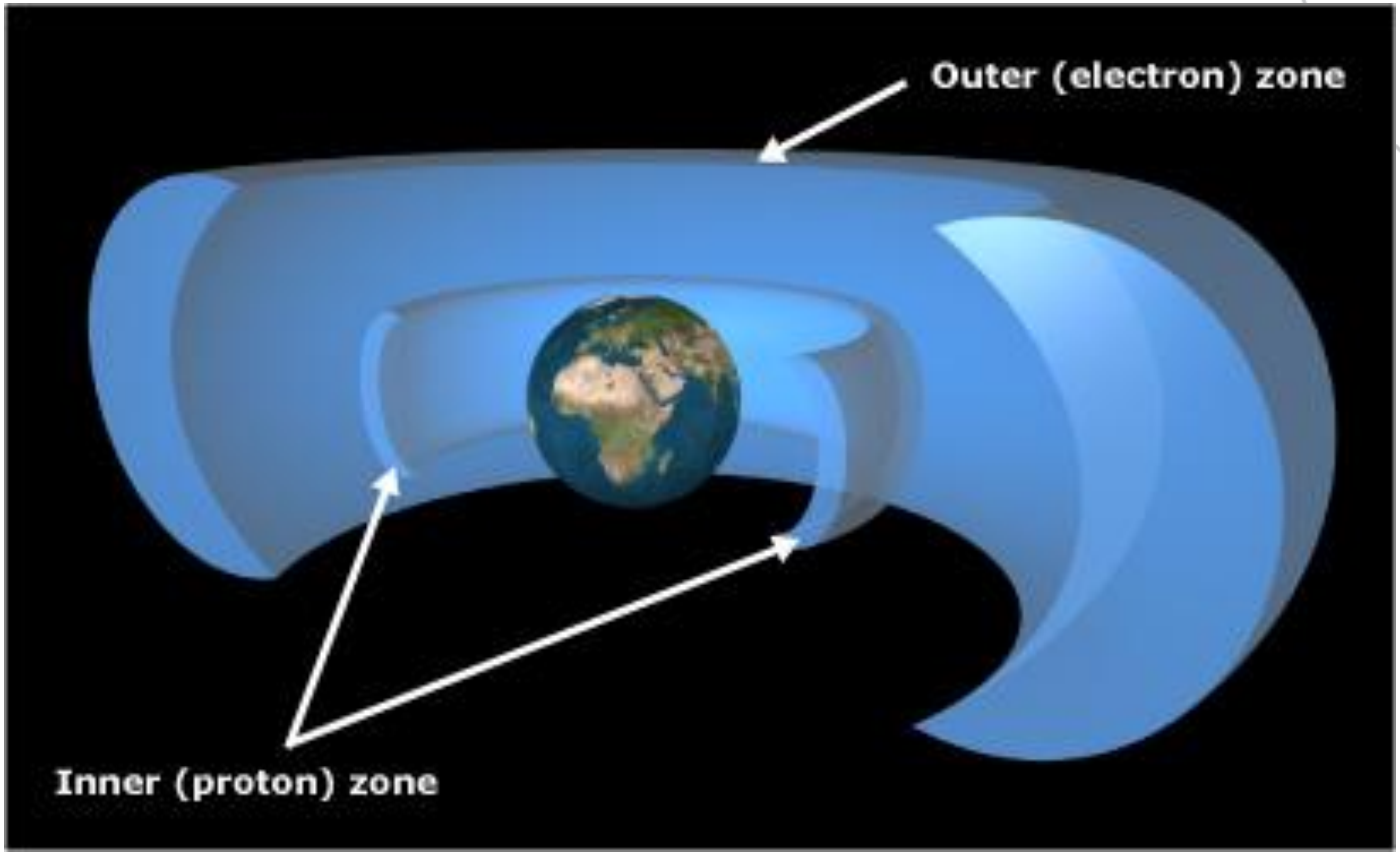
Van Allen Belts



The origin of the inner belt

- Belt of protons and electrons following the magnetic field lines of Earth
- Energy 10-100 MeV
- Stable ionised particles (plasma) building up over years
- Due to
  - albedo neutron decay, a secondary effect of the interaction of cosmic rays with the upper atmosphere (ionosphere)
  - solar winds

1 electronvolt (eV) is the amount of energy acquired by an electron accelerating through a potential difference of one volt (1V).

It is a very small amount of energy: 1 eV = 1.6×10^{-19} J

Examples:

$>10^{20}$ eV: highest energy cosmic ray Ultra-high-energy cosmic ray

200 MeV: total average energy released in nuclear fission of one U-235 atom

13.6 eV: energy required to ionize atomic hydrogen.

Molecular bond energies are on the order of an eV per molecule.

0.025 eV: the thermal energy at room temperature.

A single molecule in the air has an average kinetic energy 0.03 eV.

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The origin of the outer belt

- Belt of mainly electrons following the magnetic field lines of Earth
- Energy ~1 MeV
- Unstable particles
  - entering into frequent collisions
  - forming currents due to particles bouncing between the magnetic poles
- Due to break-down of the magnetic field around earth, closely related to the auroras

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The safe zone

- the gap between the two radiation belts
- caused by low-frequency radio waves that eject any particles that would otherwise accumulate there
- solar outbursts can pump particles into the gap but they drain again in a matter of days
- may be due to instability in the radiation belts or may be a result of lightening in the atmosphere

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http://www.crystalinks.com/vanallenbelt.html

The earths plasma fountain

- Solar flares can cause oxygen and other gases to escape from Earth's upper atmosphere
- Pressure from the solar flare squeezes gas out of the ionosphere
- This is often called the Earth's plasma fountain
- Oxygen, helium, and hydrogen ions gush into space from regions near the Earth's poles
- The amount of gases lost may amount to a few hundred tons.
- Much of the gas ejected is caught in Earth's wake, and then flows back toward the Earth while being heated and accelerated by the same processes that create auroral particles and the radiation belts.
- This means that the Earth's own ionosphere is contributing to space storms although initially exited by a solar flare
- The faint yellow gas shown above the north pole represents gas lost from Earth into space; the green gas is the aurora borealis-or plasma energy pouring back into the atmosphere
- It was first observed and explained in 1998 with NASA's Polar spacecraft, although leakage from the atmosphere has been known since the early 1980s.

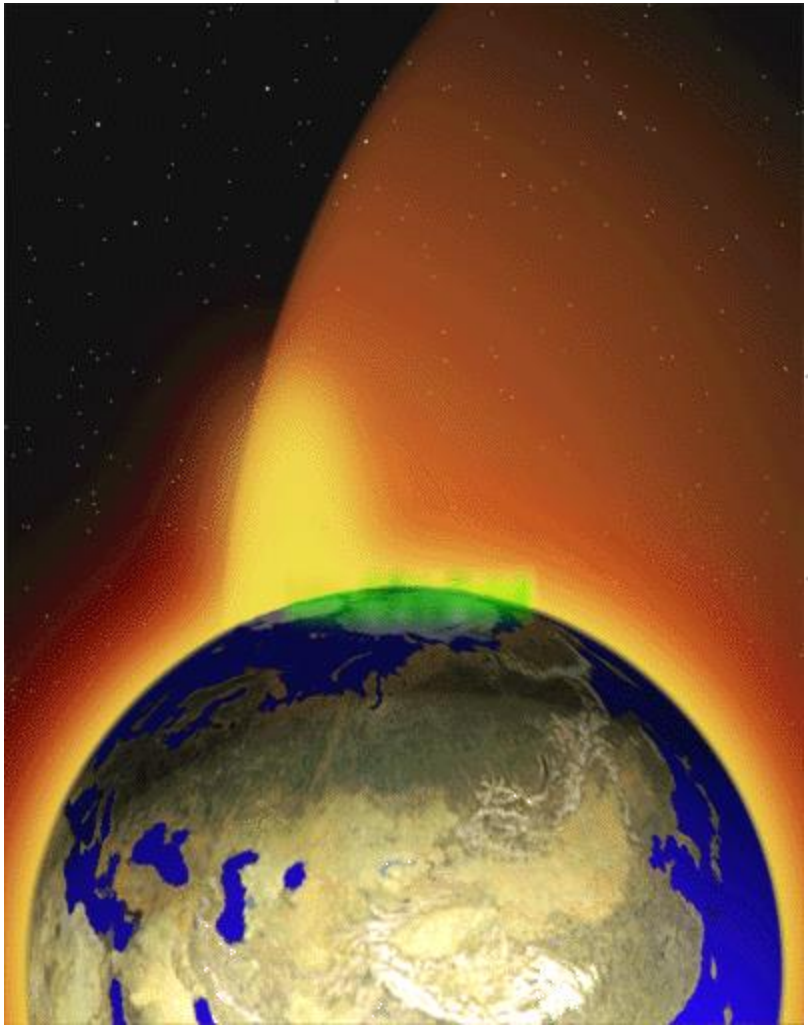

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Image credit: NASA http://pwg.gsfc.nasa.gov/istp/news/9812/solarwind.html

Impacts on space travel and satellites

- Vulnerable to radiation:
  - solar cells
  - integrated circuits
  - sensors
  - humans
- Miniaturization and digitization of electronics and logic circuits have made satellites more vulnerable to radiation, as incoming ions may be as large as the circuit's charge.
- Electronics on satellites must be hardened against radiation to operate reliably.
- Examples:
  - The Hubble Space Telescope often has its sensors turned off when passing through regions of intense radiation.
  - A satellite shielded by 3 mm of aluminum in an elliptic orbit (300 by 30000 km) passing through the radiation belts will receive about 25 Sv (Sievert [J/kg]) per year. Almost all radiation will be received while passing the inner belt. For acute full body equivalent dose;
    - 1 Sv causes nausea
    - 2-5 Sv causes epilation or hair loss, hemorrhage and will cause death in many cases
    - more than 3 Sv will lead to death in 50% of cases within 30 days
    - over 6 Sv survival is unlikely

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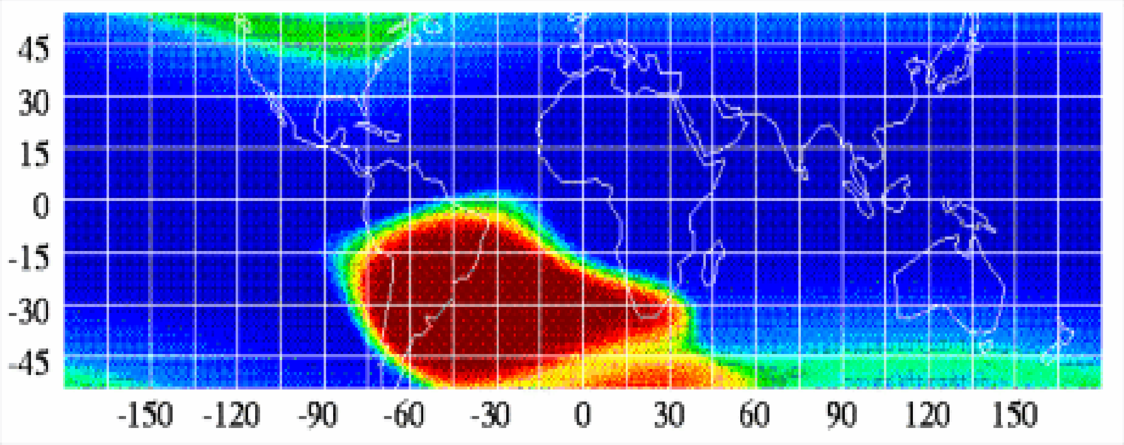
South Atlantic Anomaly

- The inner surface of the inner Van Allen belt is:
  - 1200 - 1300 kilometers from the Earth's surface on one side of the Earth
  - on the other it dips down to 200 - 800 kilometers
- Above South America, about 200 - 300 kilometers off the coast of Brazil, and extending over much of South America



- Satellites and spacecraft passing through
  – are bombarded by protons exceeding energies of 10 MeV
  – at a rate of 3000 'hits' per square centimeter per second
  – produce 'glitches' in astronomical data, problems with the operation of on-board electronic systems, and premature aging of computers, detectors and other spacecraft components
- The Hubble Space Telescope passes through the SAA for 10 successive orbits each day, and spends nearly 15 percent of its time in the SAA
- Astronauts are also affected by this region which is said to be the cause of peculiar 'shooting stars' seen in the visual field of astronauts

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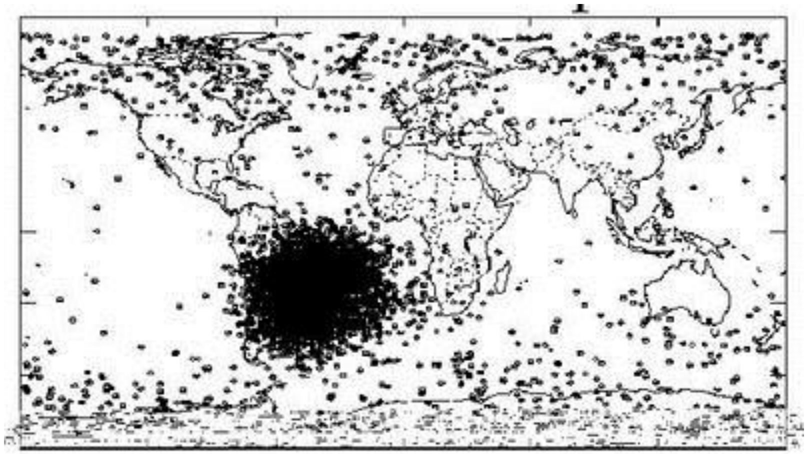
SEU due to charged particles



Single Event Upset for Uosat 3 spacecraft.
LEO at 780 km above Earth's surface.

Charged particles may have the following consequences:
- Bit flip - SEU
- Material damage
- Sputtering
- Electronic components damage
- Solar cells damage
- Secondary radiation and interference

Ionised particles from three sources:
- Radiation belts (mainly protons and electrons)
- Solar event particles (mainly protons, some ions)
- Cosmic rays (protons and ions)

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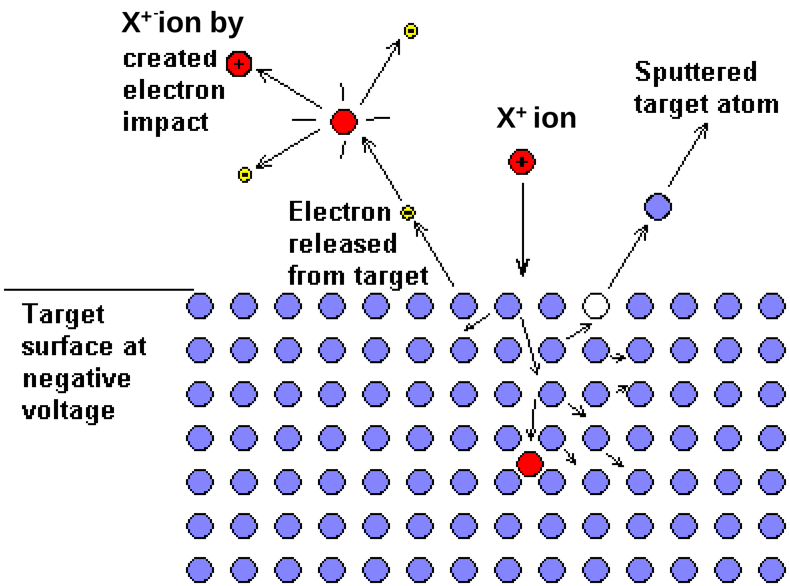
From http://www.esa.int/TEC/Space_Environment/

Sputtering



- Driven by momentum exchange between the ions and atoms in the material, due to collisions
- Result in collision cascades
- Recoil and reach the target surface
- If the energy is above the surface binding energy, an atom can be ejected
- If the target is thin on an atomic scale the collision cascade can reach the back side of the target and atoms can escape the surface binding energy `in transmission‘
- The average number of atoms ejected from the target per incident ion is called **the sputter yield** and depends on:
  - the ion incident angle,
  - the energy of the ion
  - the masses of the ion and target atoms
  - the surface binding energy of atoms in the target
  - the orientation of the crystal axes with respect to the target surface if the target is crystalline
- The binding energy of a surface atom is typically in the range 10–100 eV

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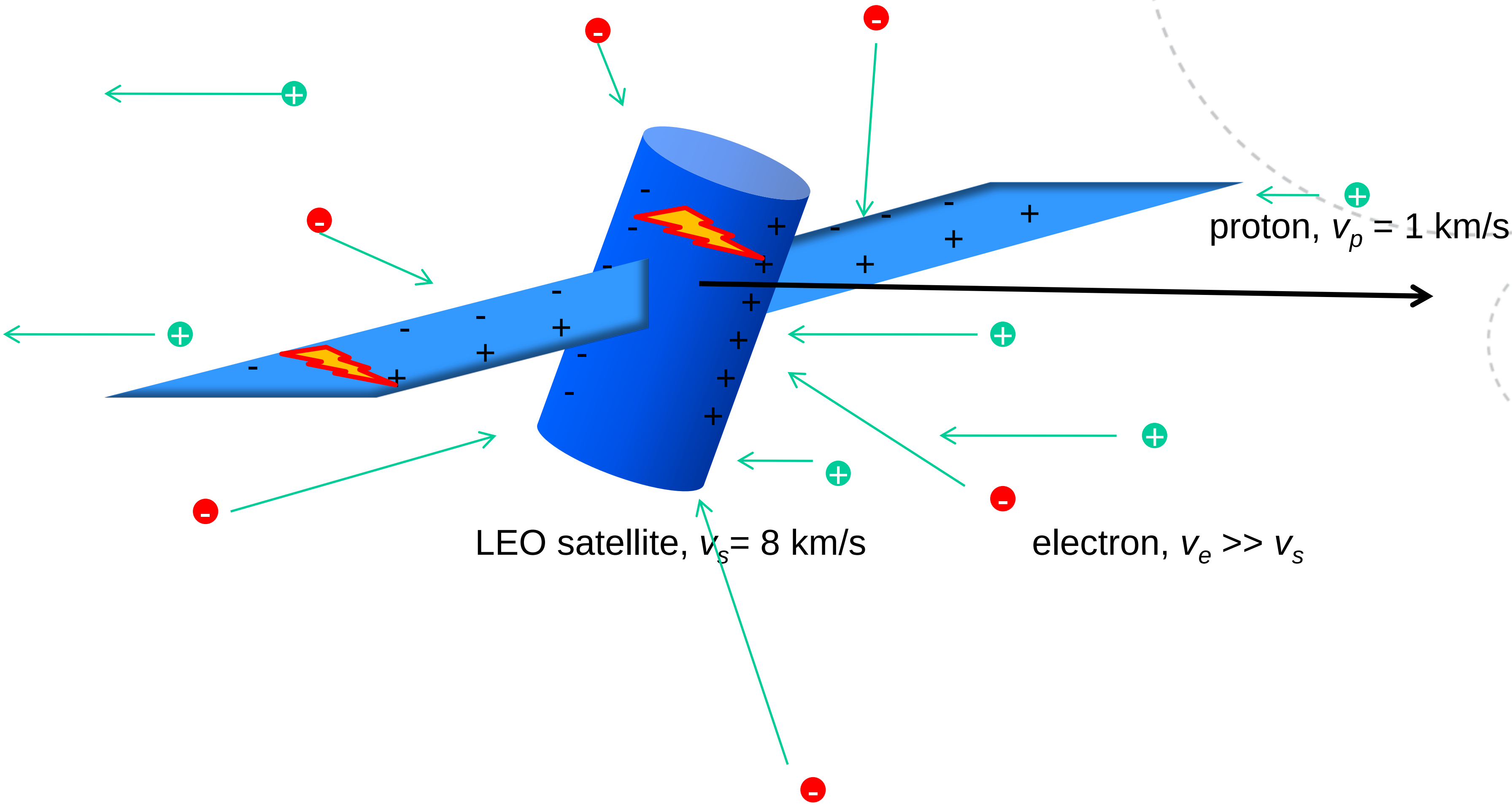
Moving in plasma → electric discharge



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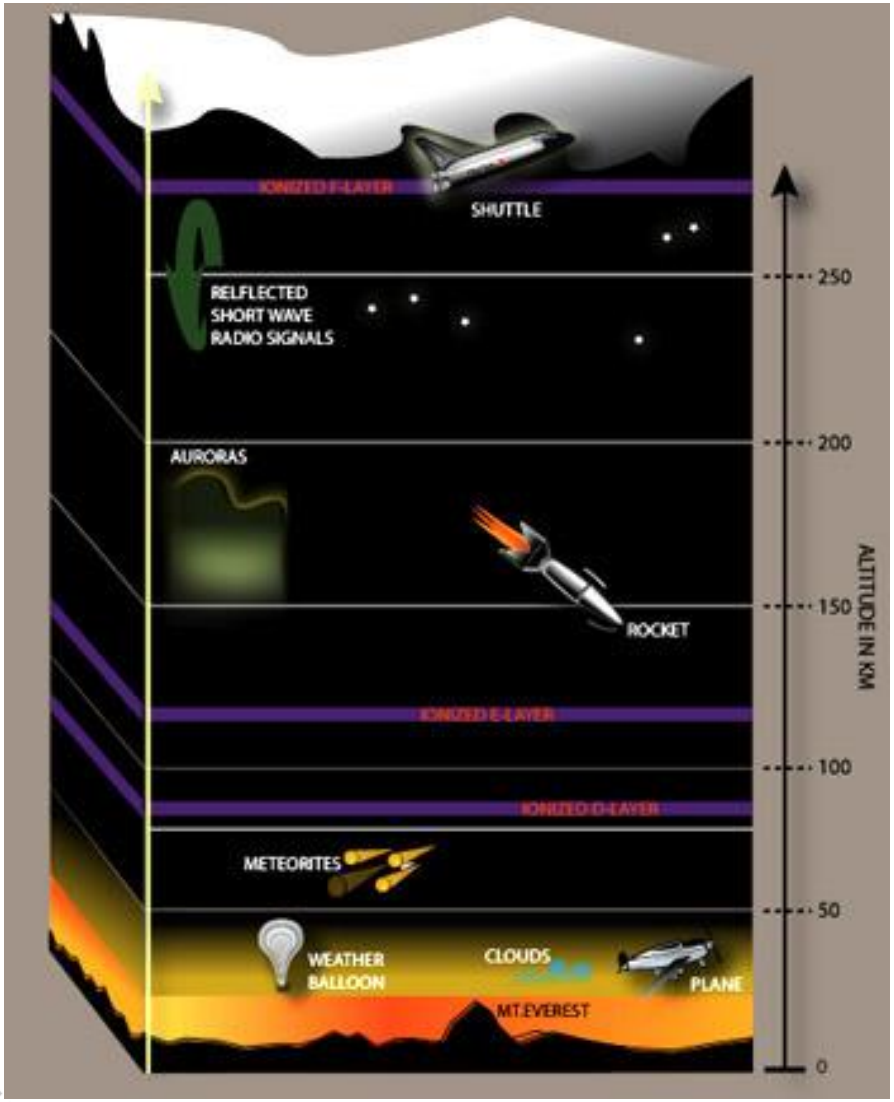
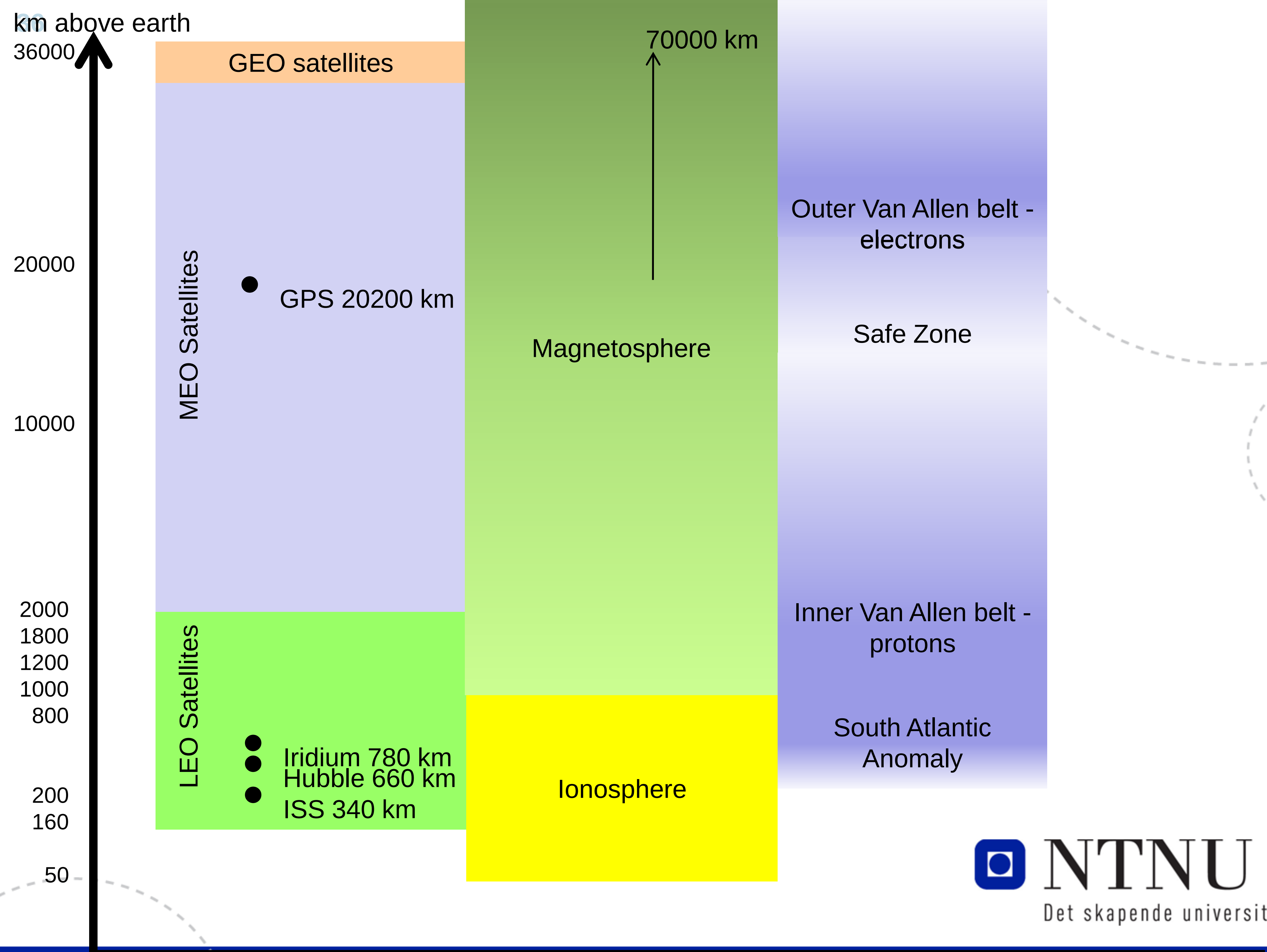
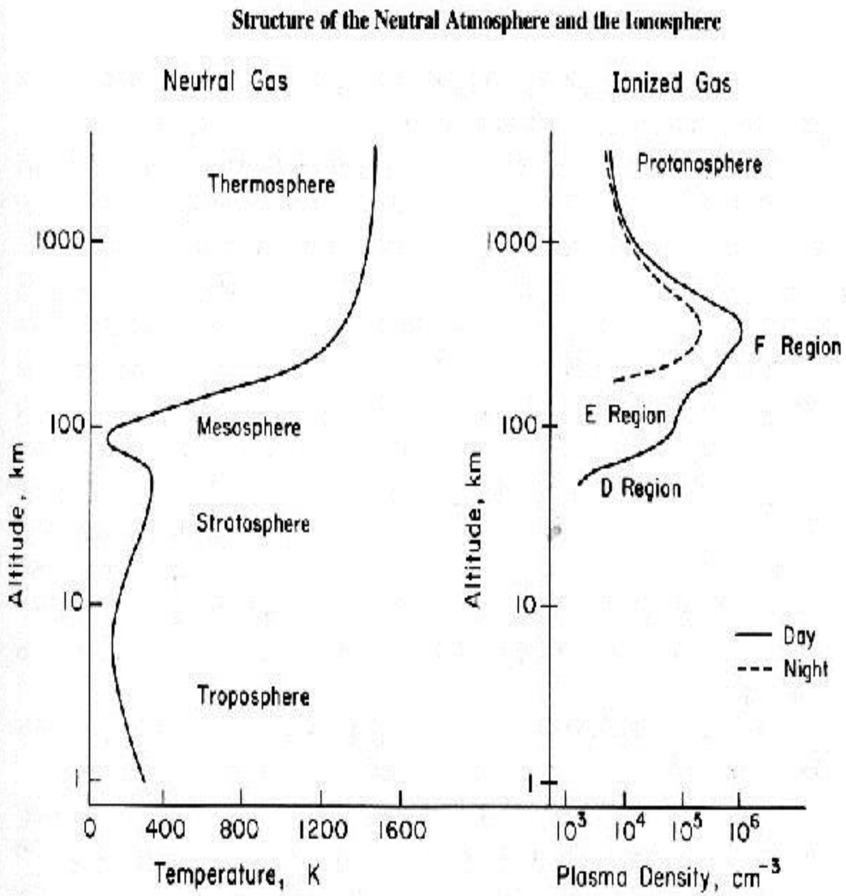
Relative hights




km above earth
36000
20000
10000
2000
1800
1200
1000
800
200
160
50
GEO satellites
MEO Satellites
GPS 20200 km
LEO Satellites
Iridium 780 km
Hubble 660 km
ISS 340 km
70000 km
Magnetosphere
Ionosphere
Outer Van Allen belt - electrons
Safe Zone
Inner Van Allen belt - protons
South Atlantic Anomaly

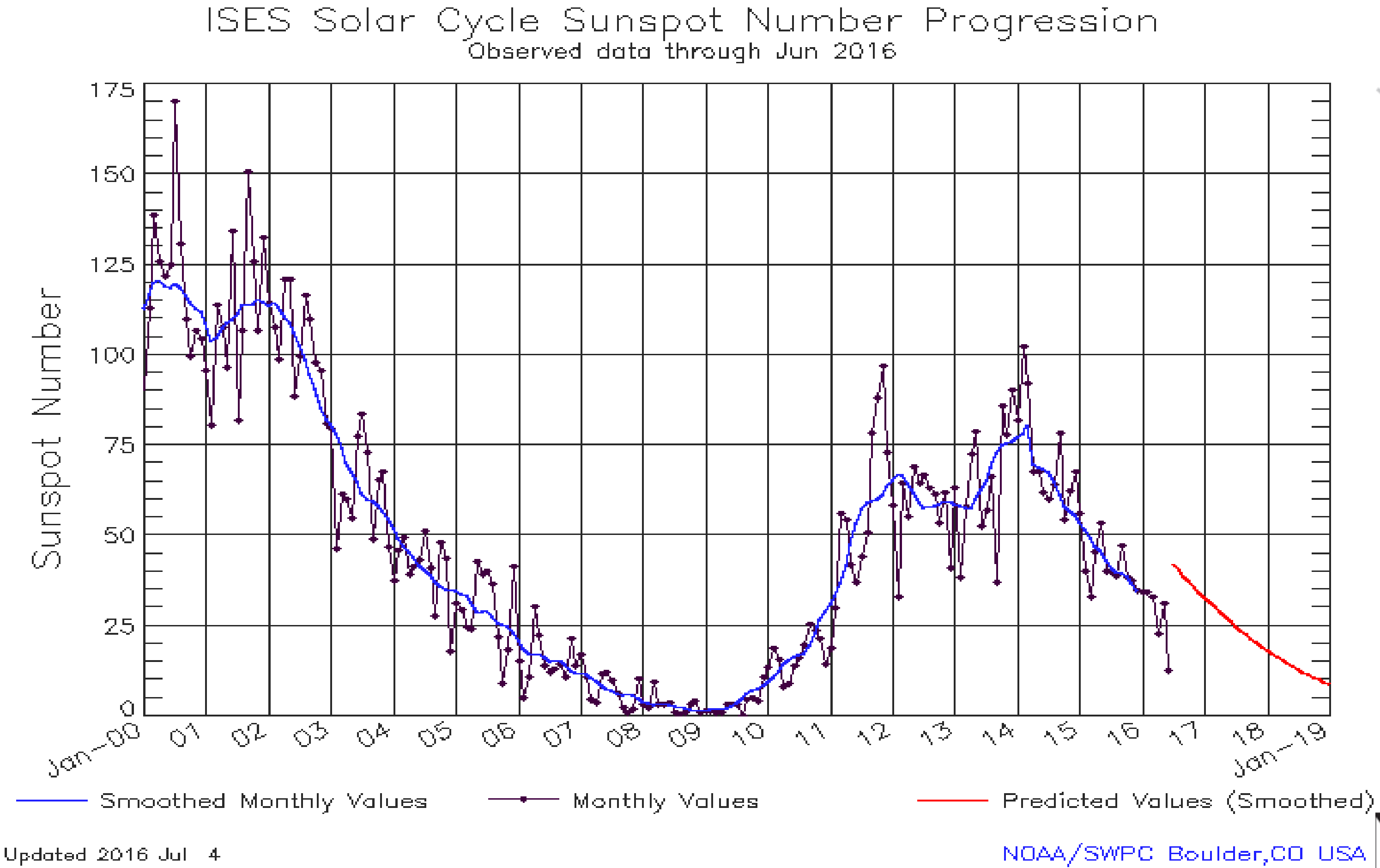
Ionosphere created by UV radiation



- Troposphere: up to 10 km
- Stratosphere: 10 km – 80 km, incoming UV creates the ozone layer
- Mesosphere: 80 km – 100 km
- Thermosphere above 100 km
- Ionosphere: 50 km – more than 1000 km, a shell of electrons and ions since the atmosphere is so thin that free electrons can exist for short periods of time before they are captured by a nearby positive ion

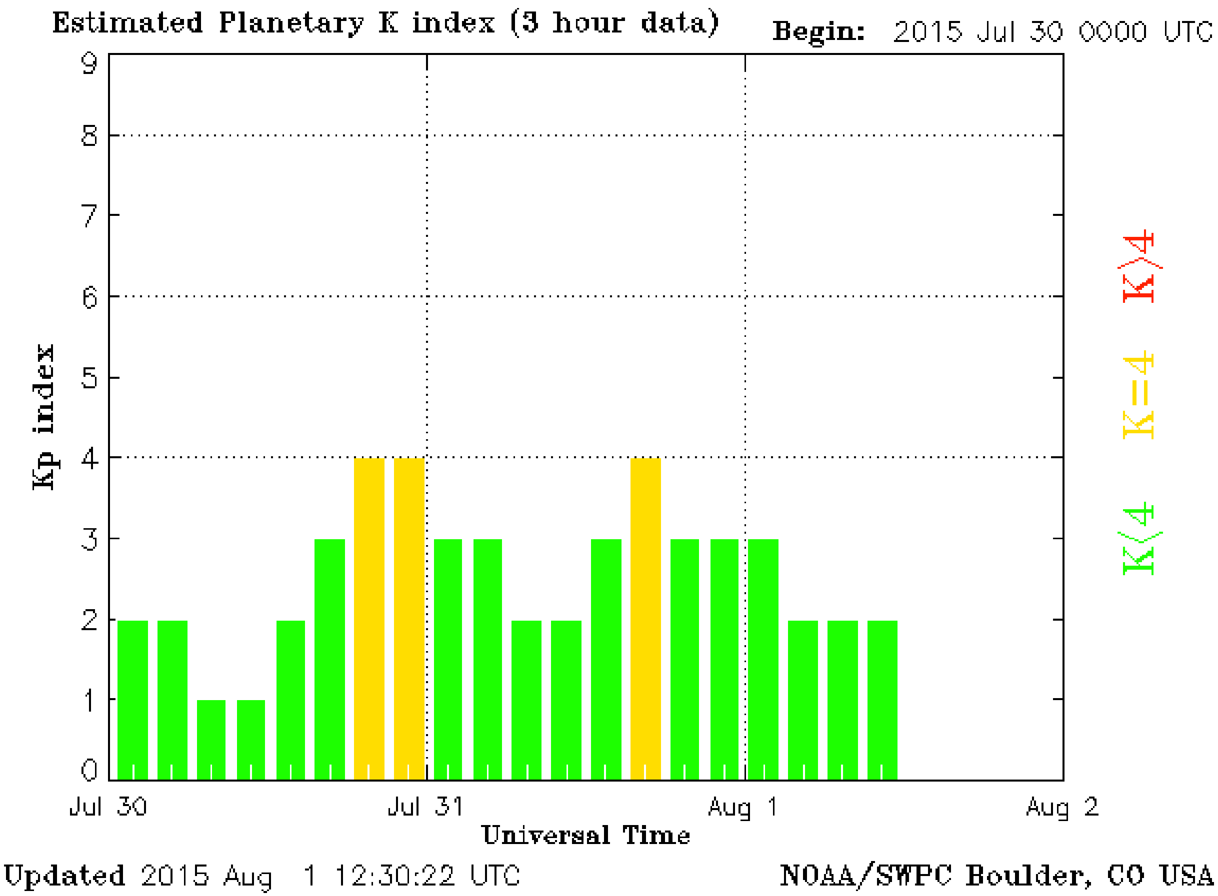
- The ionization depends:
  - sun activity
  - diurnal effect
  - seasonal effect
  - geographical location

Ionosphere activity is linked to solar cycles



Solar eruptions are most likely to appear at sun spot maximum and during the decrase.

Example: Space weather plots (I)



- From http://www.swpc.noaa.gov/today.html
- NOAA= National Oceanic and Atmospheric Administration, USA
- GOES 5-minute averaged integral proton flux (protons/cm2-s-sr) as measured by the SWPC primary GOES satellite for energy thresholds of >=10, >=50, and >=100 MeV. SWPC's proton event threshold is 10 protons/cm2-s-sr at >=10 MeV.
- Large particle fluxes have been associated with satellite single event upsets (SEUs).
- The Satellite Environment Plot combines satellite and ground-based data to provide an overview of the current geosynchronous satellite environment.

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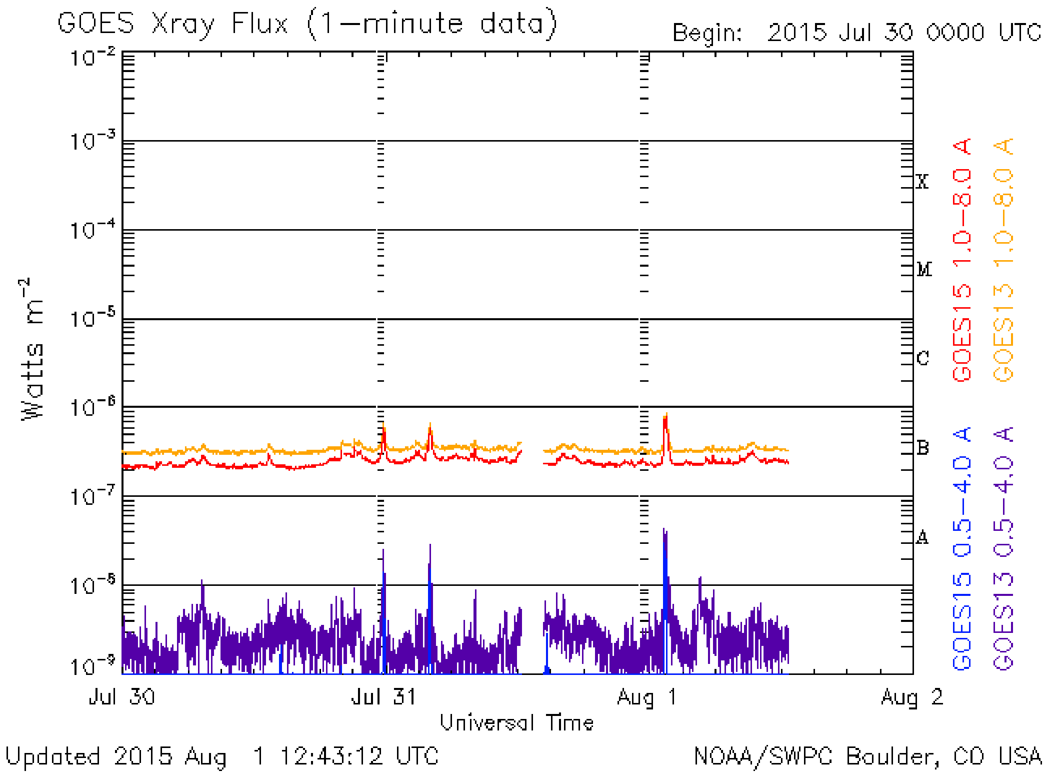
Space weather plot (II)



:Product: 3-Day Forecast
:Issued: 2015 Aug 01 1230 UTC
Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
A. NOAA Geomagnetic Activity Observation and Forecast
The greatest observed 3 hr Kp over the past 24 hours was 4 (below NOAA Scale levels). The greatest expected 3 hr Kp for Aug 01-Aug 03 2015 is 5 (NOAA Scale G1).
Rationale: G1 (Minor) geomagnetic storm conditions are likely on 01 August due to the influence of a recurrent negative polarity coronal hole high speed stream.
B. NOAA Solar Radiation Activity
Observation and Forecast Solar radiation, as observed by NOAA GOES-13 over the past 24 hours, was below S-scale storm level thresholds. Solar Radiation Storm Forecast for Aug 01-Aug 03 2015
Aug 01 Aug 02 Aug 03 S1 or greater 1% 1% 1%
Rationale: No S1 (Minor) or greater solar radiation storms are expected.
No significant active region activity favorable for radiation storm production is forecast.
C. NOAA Radio Blackout Activity and Forecast
No radio blackouts were observed over the past 24 hours.
Radio Blackout Forecast for Aug 01-Aug 03 2015
Aug 01 Aug 02 Aug 03 R1-R2 5% 5% 5% R3 or greater 1% 1% 1%
Rationale: No R1 (Minor) or greater radio blackouts are expected.
No significant active region flare activity is forecast.

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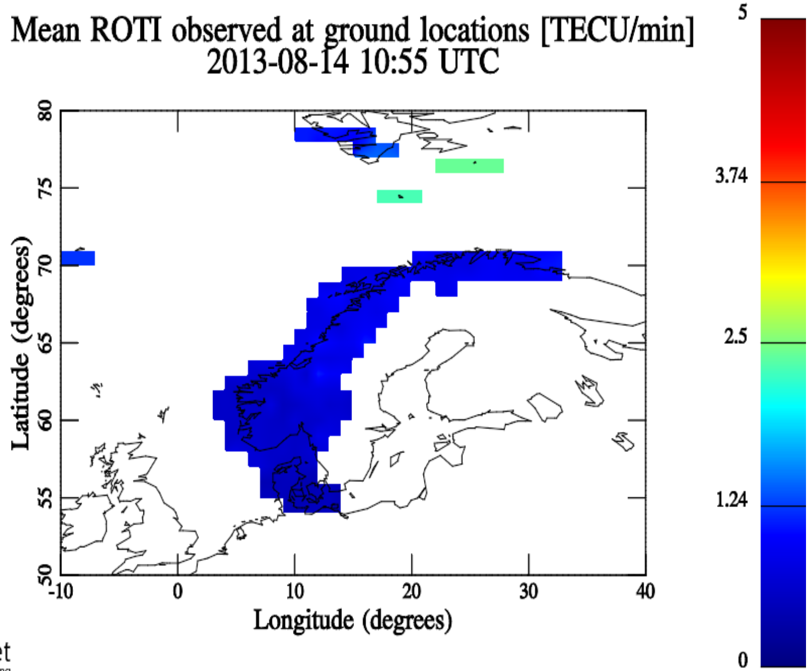
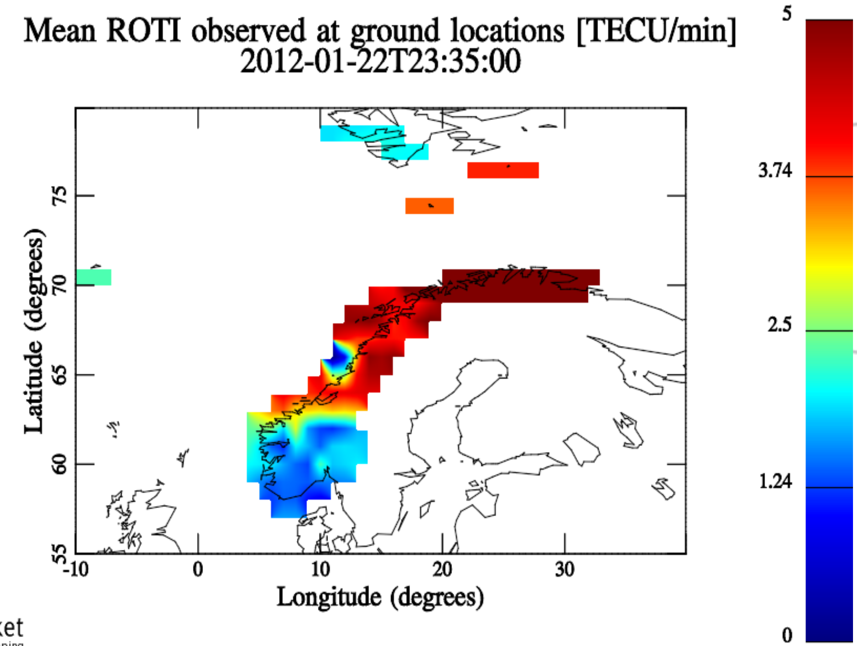
ROTI plots from Kartverket (Norwegian mapping authorities) Ionospheric measurements





ROTI: Rate of TEC Index, TEC: Total Electron Content

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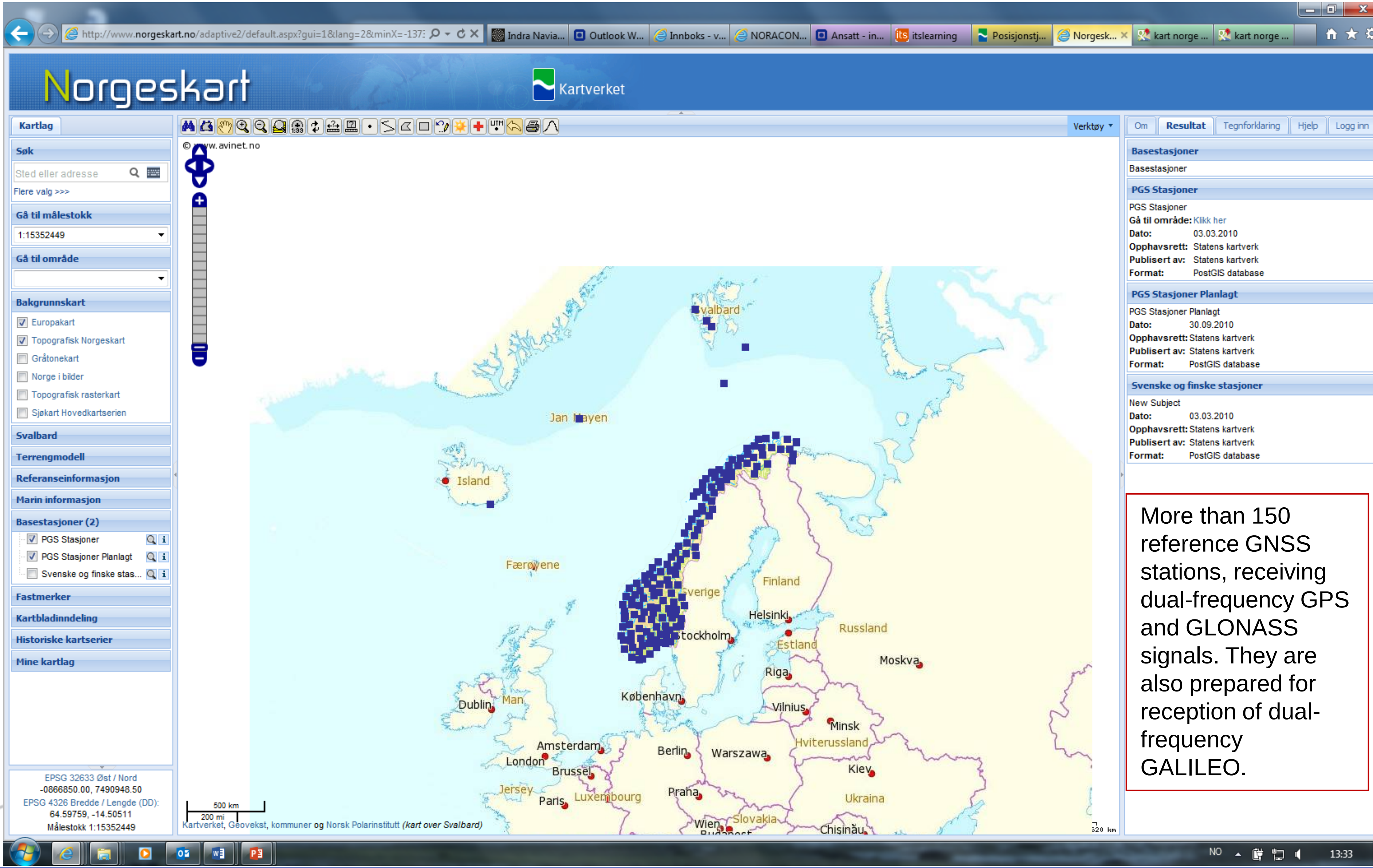
http://sesolstorm.kartverket.no/

Kartverket is measuring GNSS signals from a large range of GNSS receivers (GNSS: Global Navigation Satellite System)



More than 150 reference GNSS stations, receiving dual-frequency GPS and GLONASS signals. They are also prepared for dual-reception of dual-frequency GALILEO.

Satellite protection measures

- Orbital position
- Switch off equipment
- Orient satellite to protect vulnerable parts
- Equip the satellite to survive solar flares before launch

Solar radiation pressure

The force exerted by solar radiation on objects:

$F = (F_s/c) \cdot A_s \cdot (1+\rho) \cdot \cos(I)$

F_s = solar constant 1358 W/m^2 at earth's orbit

c = speed of light $3 \cdot 10^8$ m/s

A_s = illuminated surface area (m^2)

ρ = surface reflectance, $0 \leq \rho \leq 1$, 0:perfect absorber, 1:perfect reflector

I = incident angle to the sun

Example: to produce F = 5N near Earth, A_s = 1km^2

Note: 1N=1kg·m/s^2, 1N is equivalent to Earth's gravity on an object with mass 102g.

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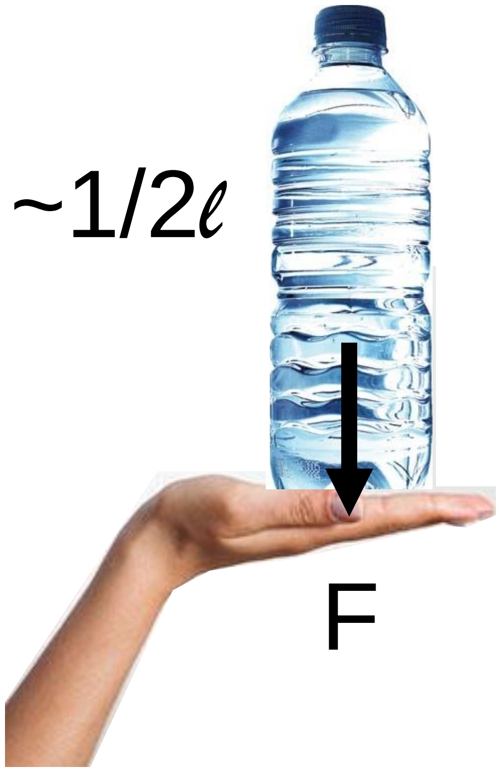
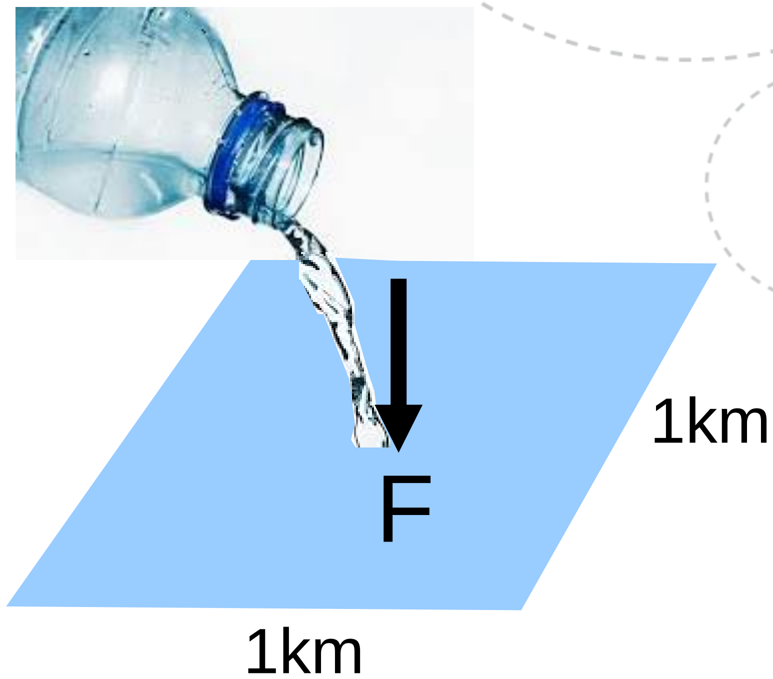
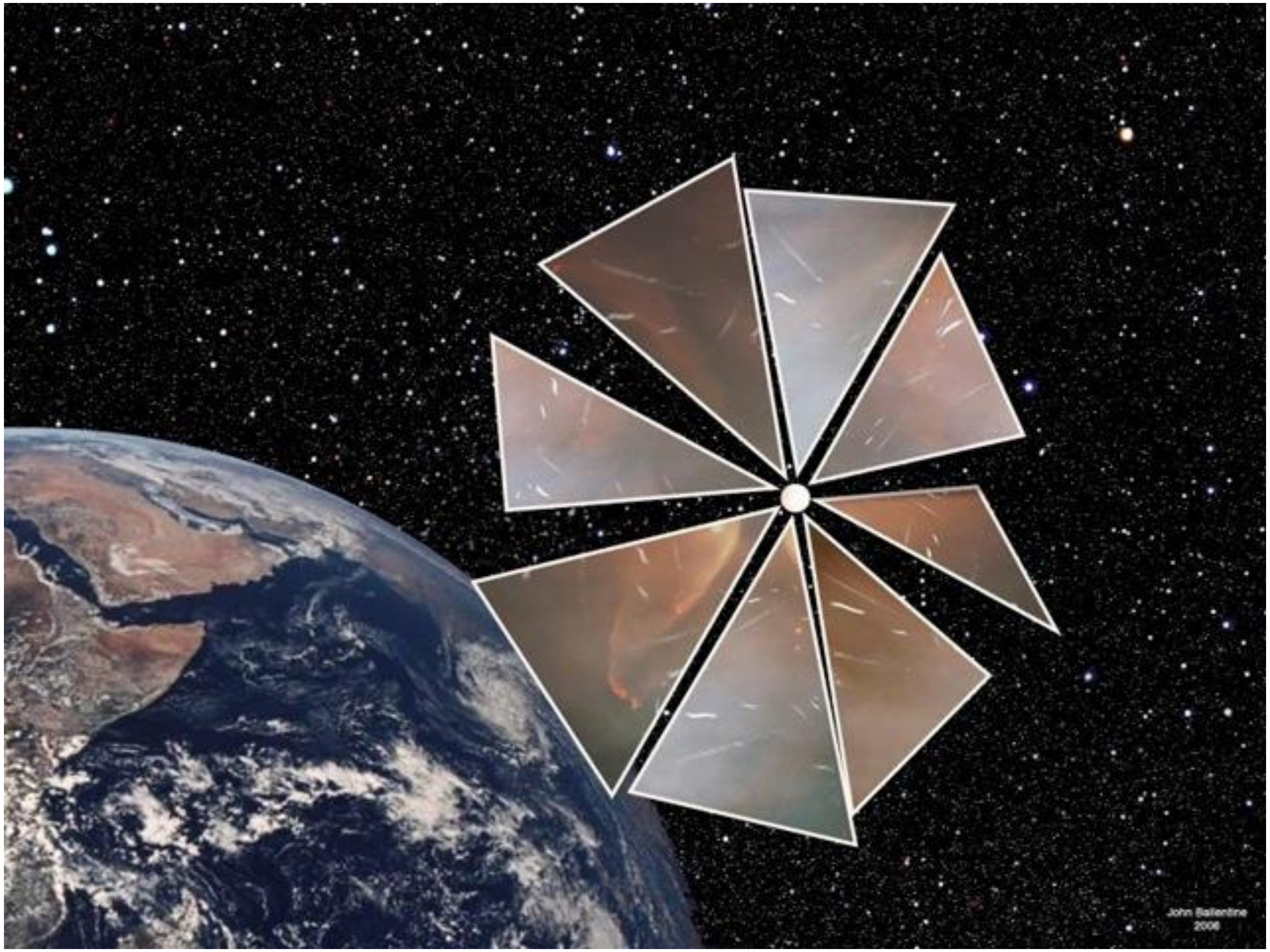

~1/2ℓ
F

=


F
1km
1km

Use of the solar pressure in the future



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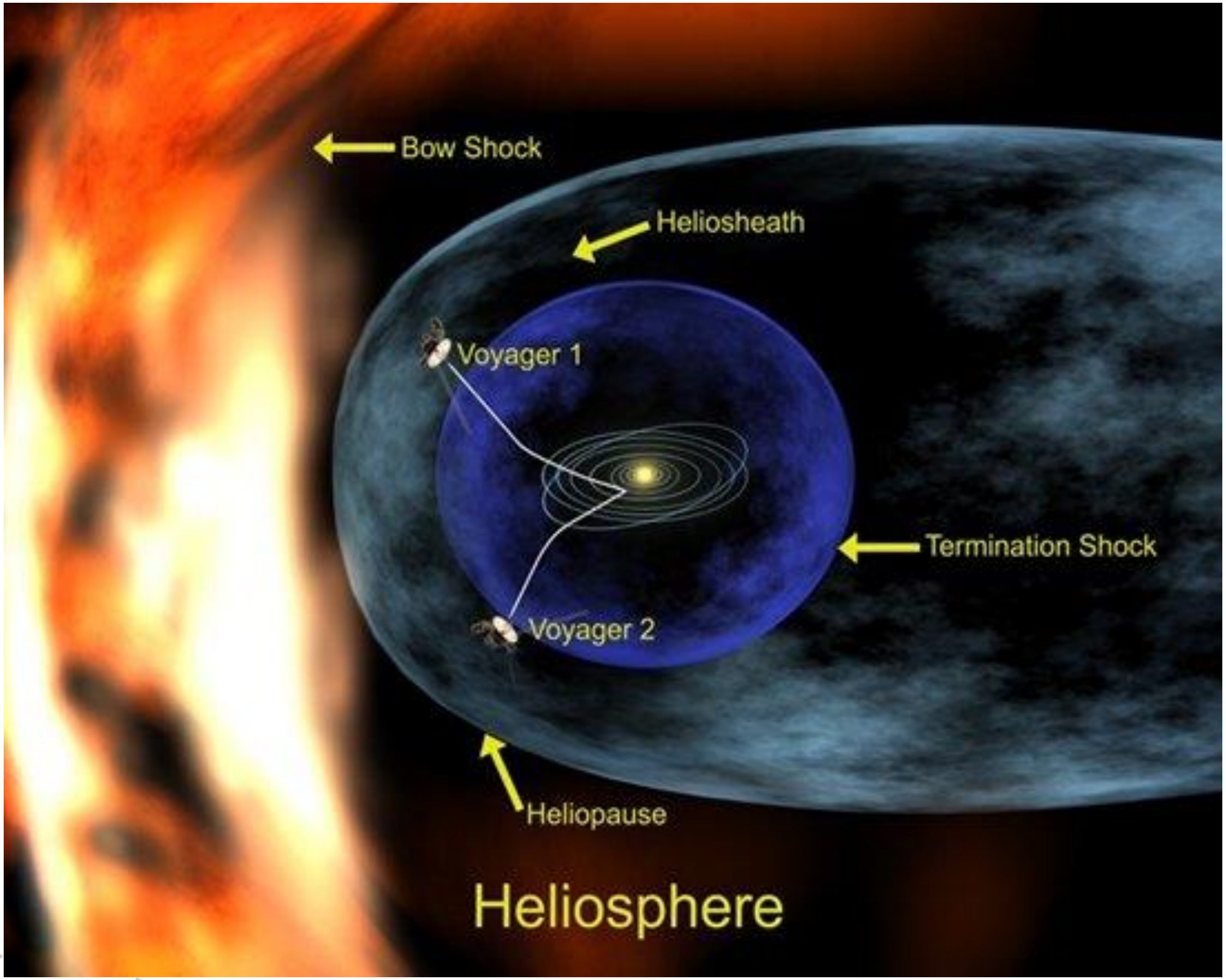
http://futurismic.com/wp-content/uploads/2008/04/solar-sail.jpg

Radiation from Space

- Cosmic rays
  - Thermal

Heliosphere



From http://science.nasa.gov/headlines/y2008/23sep_solarwind.htm

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Weakening of the solar winds

- **Sept. 23, 2008:** In a briefing today at NASA headquarters, solar physicists announced that the solar wind is losing power.
- "The average pressure of the solar wind has dropped more than 20% since the mid-1990s," says Dave McComas of the Southwest Research Institute in San Antonio, Texas. "This is the weakest it's been since we began monitoring solar wind almost 50 years ago."
- The heliosphere is a bubble of magnetism springing from the sun and inflated to colossal proportions by the solar wind. Every planet from Mercury to Pluto and beyond is inside it. The heliosphere is our solar system's first line of defense against galactic cosmic rays. High-energy particles from black holes and supernovas try to enter the solar system, but most are deflected by the heliosphere's magnetic field
- But any extra cosmic rays can have consequences. If the trend continues, astronauts on the Moon or en route to Mars would get a higher dose of space radiation. Robotic space probes and satellites in high Earth orbit face an increased risk of instrument malfunctions and reboots due to cosmic ray strikes. Also, there are controversial studies linking cosmic ray fluxes to cloudiness and climate change on Earth. That link may be tested in the years ahead.

Radiation from the earth

- Albedo, reflected radiation from the sun
  - Proper earth thermal radiation:

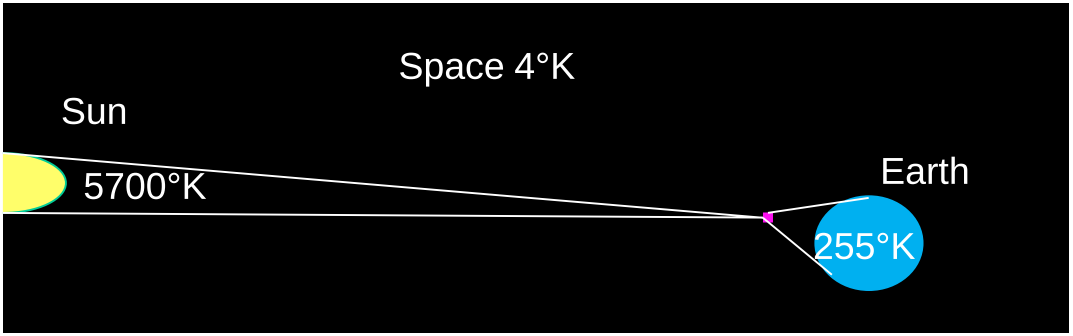
Earth temperature: 288°K

Atmosphere temperature when opaque: 218°K

=> Average temperature 255°K

Thermal effects

- Solar temperature: ~5700°K (black body)
- Earth temperature: ~255°K (infrared)
- Space temperature: ~4°K



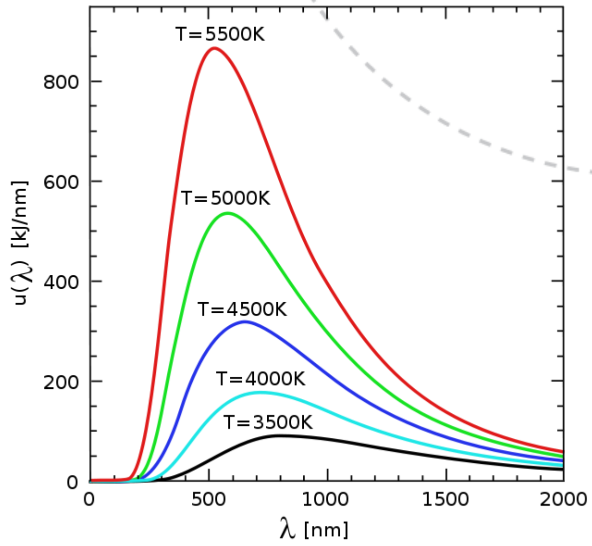


Fig. From Wikipedia

For a GEO satellite:
- Earth radiation at 40W/m²
- Solar radiation at 1371 W/m² (= 1IAU) (solar constant)

Aboslute temperature 0°K = - 273.15°C.

Black body: an object that absorbs all the electromagnetic radiation that strikes it. Blackbodies in thermal equilibrium emit energy to balance the energy they absorb and remain at a constant temperature. This energy is in the form of electromagnetic radiation.

The wavelengths at which an ideal blackbody emits electromagnetic radiation depends on the temperature and absolutely nothing else. That is why the radiation emitted by a blackbody is often called thermal radiation. A radiating blackbody emits energy at all wavelengths and the hotter a blackbody is, the more total energy it emits.

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From http://astrophysics.suite101.com/article.cfm/blackbodies_in_astrophysics

Operating temperature ranges

Batteries:	0 to 20°C
Solar panels:	-100 to 50°C
Electronics:	-10 to 60°C
Fuel:	10 to 50°C

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Measures to reduce thermal effect impact in a satellite/space craft

- Passive thermal control:

  Absorption of a sphere: $P_{abs} = C \cdot \alpha \cdot \pi \cdot r^2$

  c = solar constant, α = absorption coefficient,

  r = sphere radii

  Emission of a sphere: $P_{em} = \varepsilon \cdot 4 \cdot \pi \cdot r^2 \cdot \sigma \cdot T^4$

  ε = emission coefficient, σ = Stefan-Botzmann constant, T = temperature

  When the sphere is in thermal equilibrium $P_{abs} = P_{em,}$ giving the equilibrium temperature as a function of the material's ratio between the absorption and emission coefficients.

- Active thermal control:
  - Heat pipes, shields, electrical heating

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Other effects

- Electromagnetic
- Gravity
- Outgassing
- Erosion
- Debris

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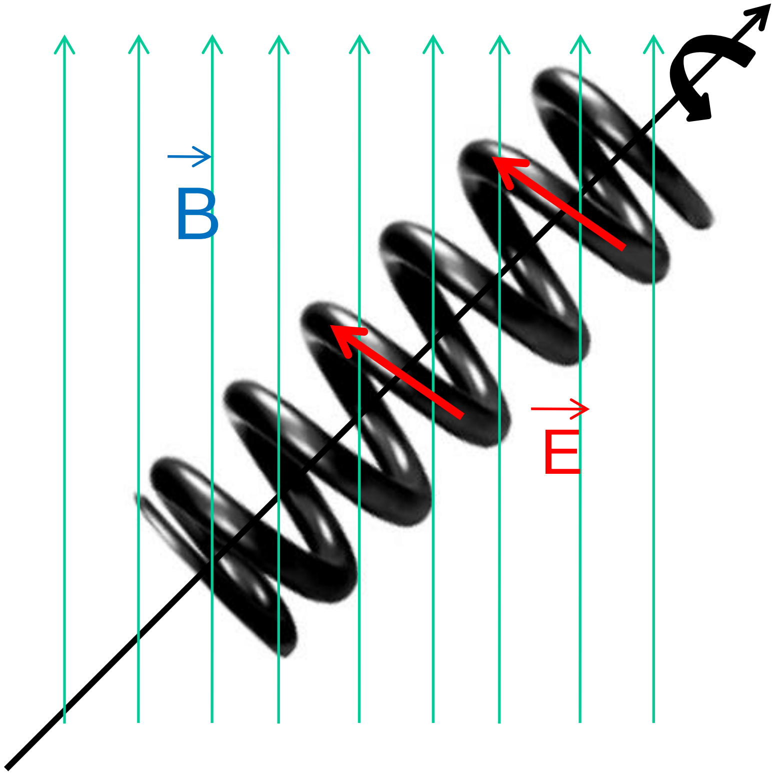
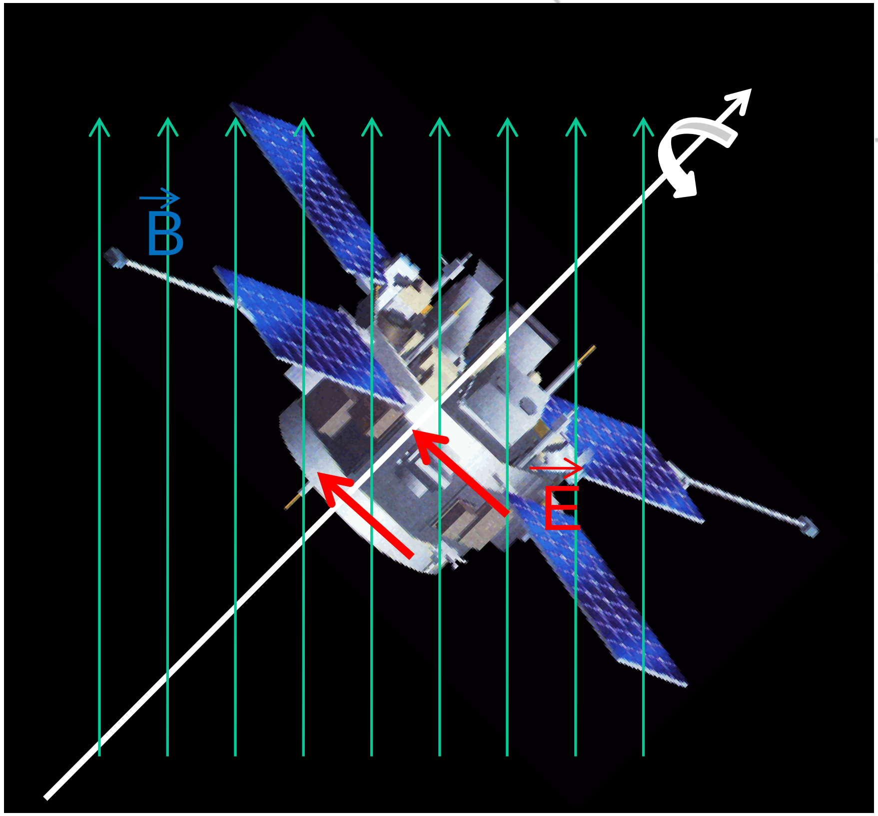
Magnetic field effect

A electrically leading material spinning in a magnetic field will induce electrical current. Electrical voltage induced in a LEO satellite may be up to 4V/m.





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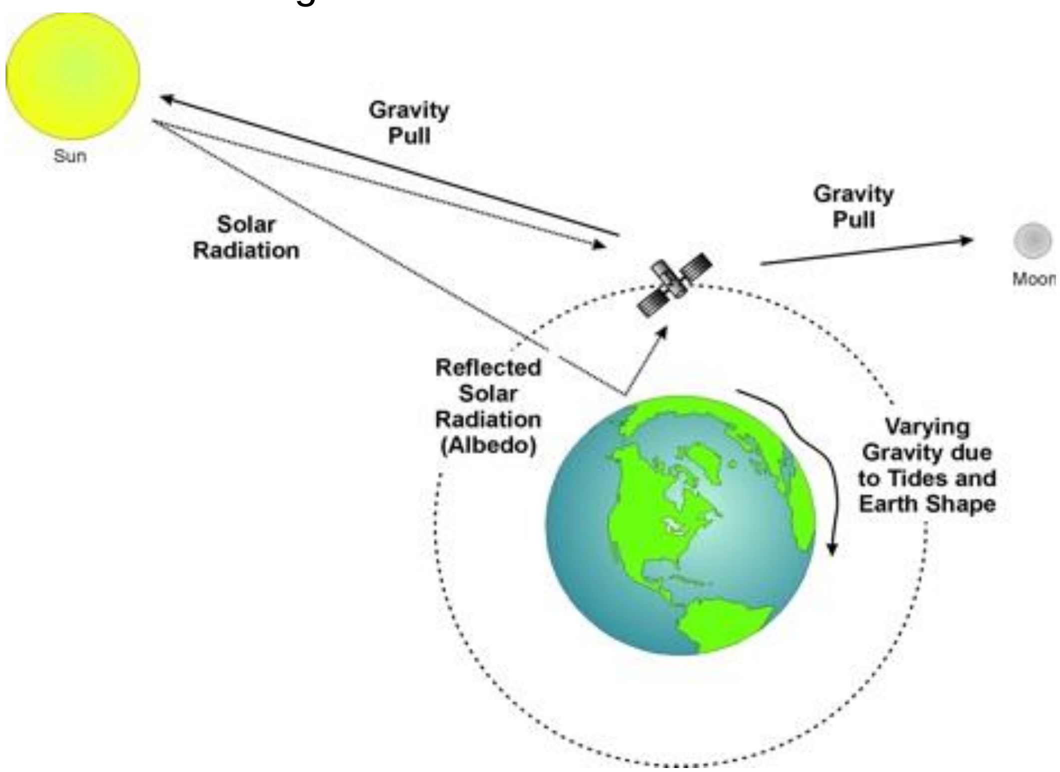
Gravitational effects

Perturbing forces on satellites due to gravitational fields from:

- the sun
- other planets
- fluctuations in the Earth's gravitational field

Gravitational fields from other celestial bodies are called third body effects. The satellite's orbital path is modified by the gravitational forces from stars, moons and planets, such as the Earth's moon and the Sun.

The satellite orbit is also changed by fluctuations in the Earth's gravitational field. These variations occur due to tide changes and variations in the surface and shape of the Earth.



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From http://www.wirelessdictionary.com/wireless_Dictionary_GPS_Satellite_Perturbing_Forces_Definition.html

Outgassing in vacuum

Outgassing is the slow release of a gas that was trapped, frozen, absorbed or adsorbed in some material including:

- sublimation and evaporation which are phase transitions of a substance into a gas
- desorption, seepage from cracks or internal volumes and gaseous products of slow chemical reactions

Absorption is the incorporation of a substance in one state into another of a different state (e.g. liquids being absorbed by a solid or gases being absorbed by a liquid).
Adsorption is the physical adherence or bonding of ions and molecules onto the surface of another phase (e.g. reagents adsorbed to solid catalyst surface).

Consequences of outgassing in vacuum

- Outgassing is a challenge to creating and maintaining clean high-vacuum environments
- Outgassing products can condense onto optical elements, thermal radiators, or solar cells and obscure them
- Contamination from outgassing, venting, leaks and thruster firing can degrade surfaces on which contaminants deposit
- The contaminant cloud can also disrupt payload operations such as telescopes
- On-orbit contamination may modify surfaces and invalidate measurements
- High contaminant levels may also contribute to the onset of electrostatic discharge.

Examples:

- Contamination is a serious problem for International Space Station payloads - both contaminant deposition on experiments and contaminants in fields of view of telescopes.
- NASA maintains a list of low-outgassing materials to be used for spacecraft.

Atomic oxygene erosion (LEO)

Interactions between spacecraft surfaces and atomic oxygen can, through erosion and oxidation, produce:

- significant changes in mass
- significant changes in surface properties
- generate a flux to the spacecraft surfaces with significant energy of about 5 eV
- Low Earth Orbital systems are particularly vulnerable.

Numerous events can occur when atomic oxygen impacts a surface:

- The atomic oxygen may elastically scatter from the surface in a specular manner,
- it may energy and momentum accommodate to the surface and then be ejected in a diffuse manner
- it may attach to the surface and react with other arriving species to form excited nitrogen oxide, which de-excites to cause the glow phenomenon
- it may chemically react with the surface

Examples: Space tests indicate that the probability of chemical reaction of atomic oxygen with carbon is only 13%, and with silver, greater than 62% . In the case of carbon, the unreacted atomic oxygen is predominantly ejected in a diffuse or near cosine distribution with an ejection peak shifted slightly in the specular direction. The actual probability of reaction of atomic oxygen with silver may be quite high for clean silver surfaces. However, silver oxide formation may contribute to shielding of the underlying silver or may serve as a catalytic surface for reassociation of the atomic oxygen. Possible atomic oxygen reactions with polymers in low Earth orbit, include hydrogen abstraction, oxygen addition to form excited radicals followed by hydrogen elimination, oxygen insertion into the C-H bonds, and replacement by formation of alkoxy radicals.

From http://www.spenvis.oma.be/spenvis/help/background/atmosphere/erosion.html

Space debris

- 20000 tons of natural material hit earth every year (dust, meteoroids, asteroids, comets....)
- Earth's space debris amounts to about 3000 tons
- In low earth orbit, a piece of debris may move at 7 km/s or more
- Only space debris with a size above 10 cm in diameter is tracked
- Never ending accumulation......Kessler syndrome

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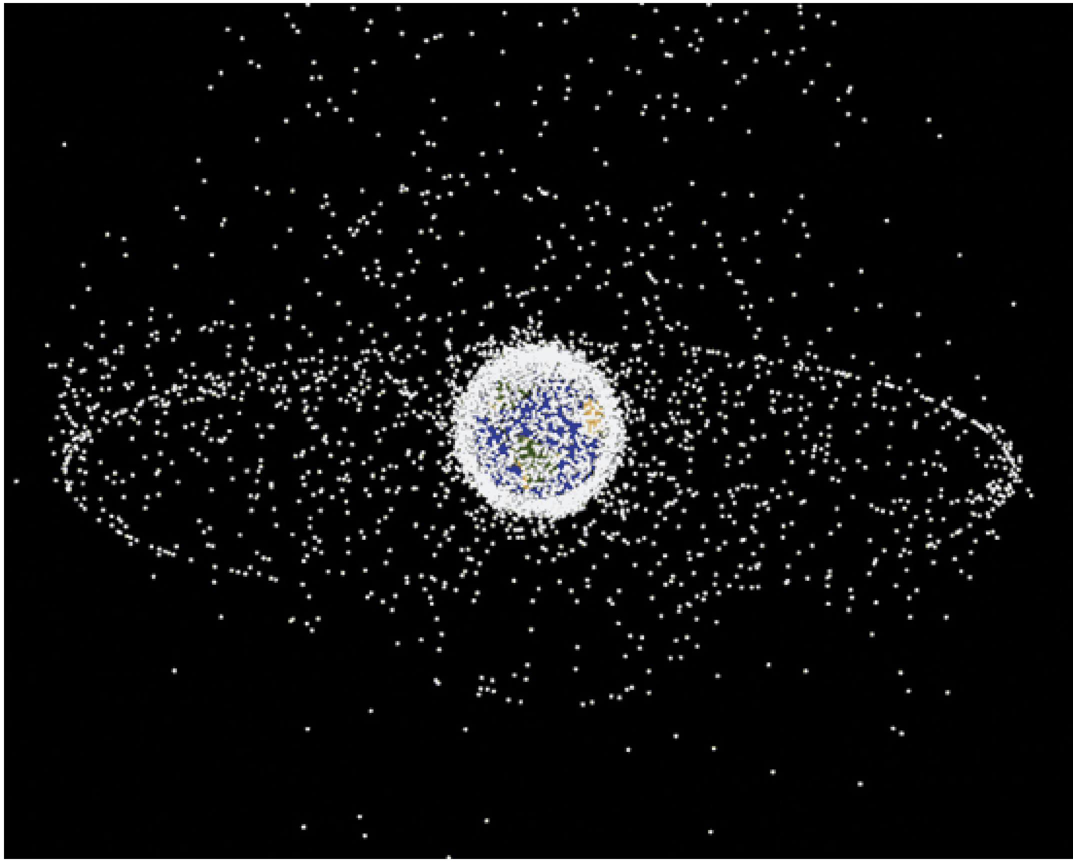
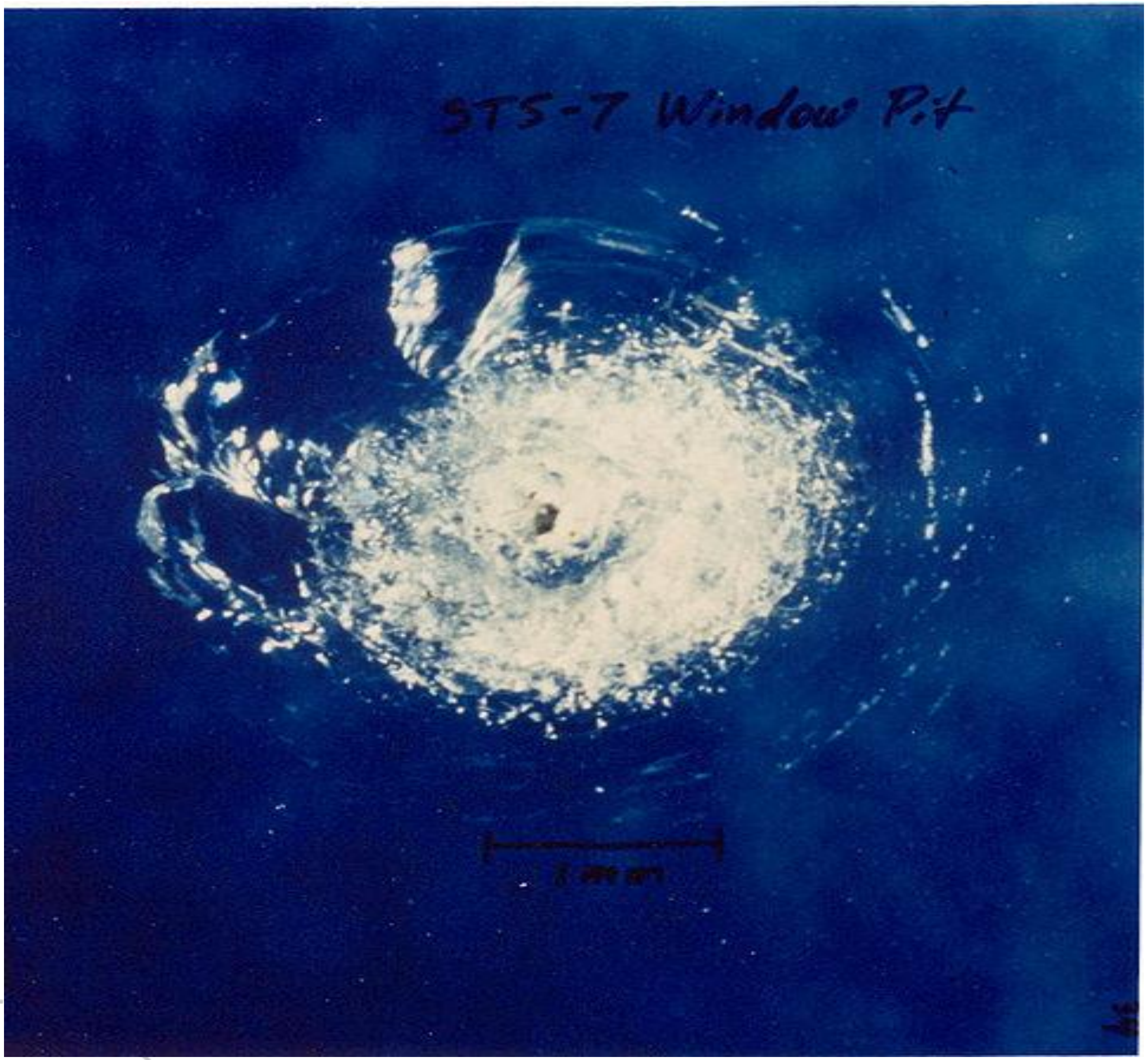
Iridium Cosmos collision in 2009, http://www.vimeo.com/3284935

Space debris

- A graveyard orbit is significantly above the GEO orbit
- Satellites left in a graveyard orbit will slowly break apart as micrometeorites hit them, and the smaller fragments may filter back down to lower altitudes
- De-orbiting a geostationary satellite requires a speed change of about 1500 m/s
- Re-orbiting it to a graveyard orbit requires about 11 m/s
- For GEO satellites, the graveyard orbit is a few hundred kilometers above the operational orbit
- Transfer to graveyard orbit above geostationary orbit however requires the same amount of fuel that a satellite needs for approximately three months of station keeping
- It also requires a reliable attitude control during the transfer maneuver
- While most satellite operators try to perform such a maneuver at the end of the operational life, only one-third succeed in doing so



Debris hole in Challenger 1983 caused by a flake of paint 0.2mm in diameter



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Summary

Space is hostile to humans and space crafts/satellites:

- Radiation
  - ionisation
  - sputtering
- Thermal effects
- Space debris and collisions
- Vacuum – outgassing
- Orbital disturbance from gravitational forces and solar pressure
- Erosion and air drag

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This is the environment we are entering when we leave Earth....

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