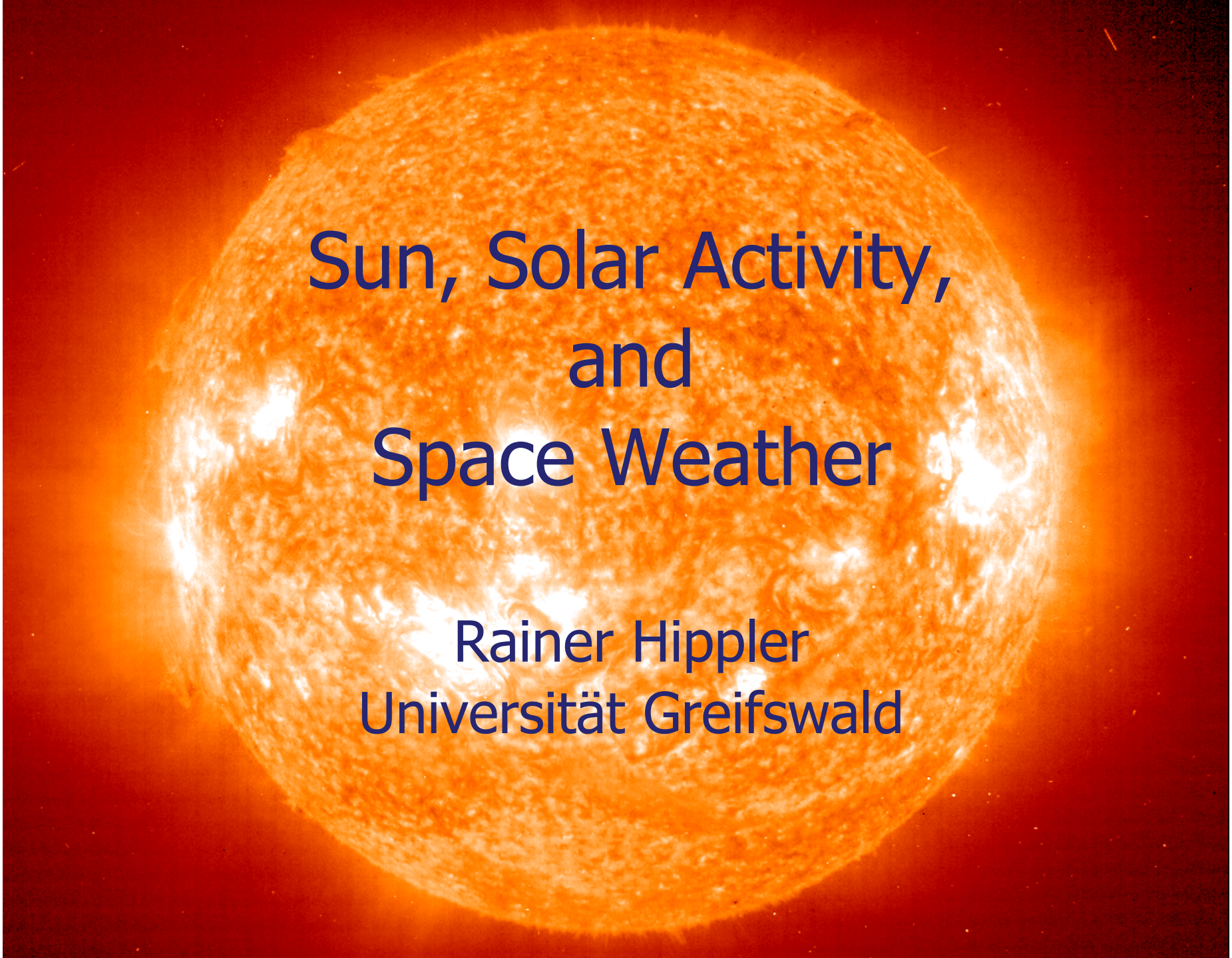
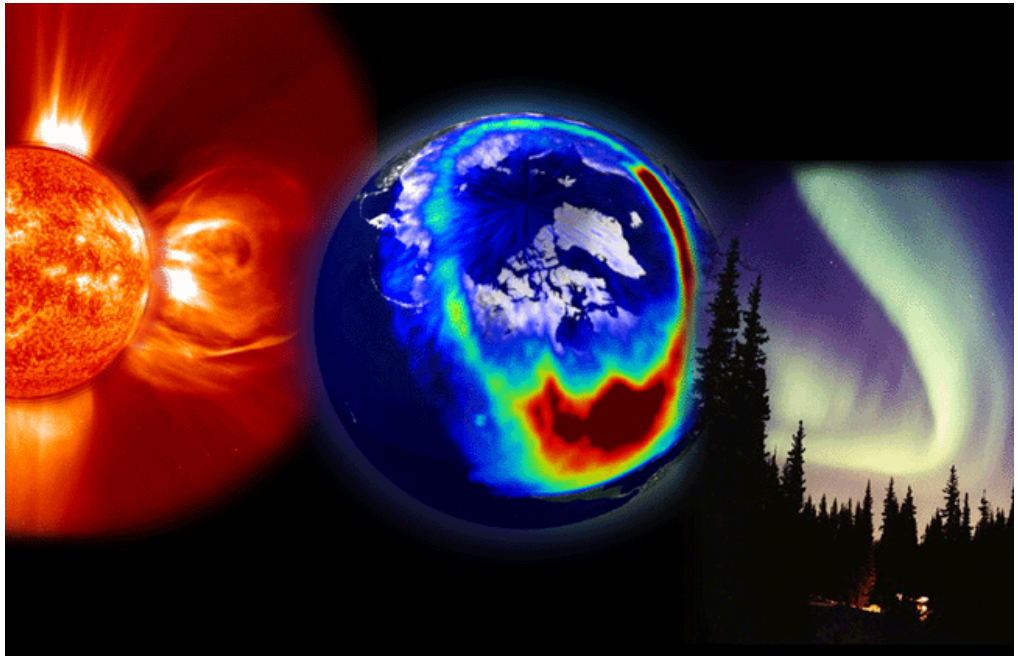


Sun, Solar Activity, and Space Weather

Rainer Hippler
Universität Greifswald

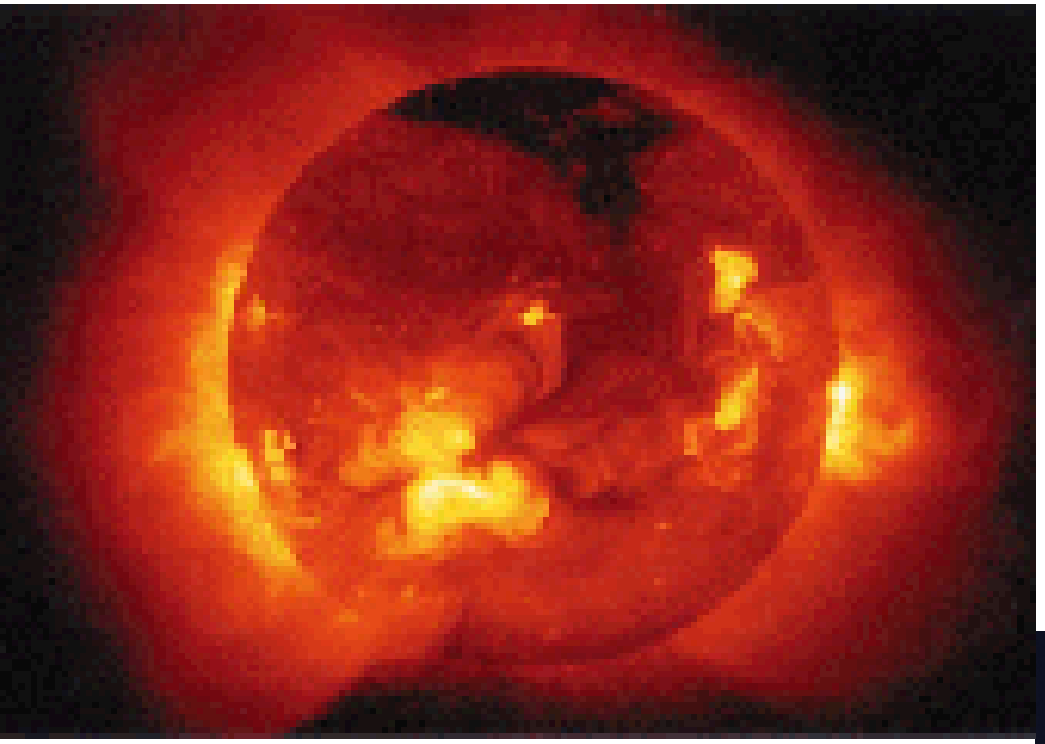
Space Weather



Space Weather originates mainly at the Sun. Space Weather is thus defined by the conditions on the Sun and in the Solar wind, and it affects the conditions on Earth, in particular in the Earth's magnetosphere, ionosphere, and thermosphere.

Space weather infleunces the performance and reliability of space-borne and ground-based technological systems, in particular communication and navigation, power lines, and oil and gas pipelines, and can endanger human life especially of aircraft crew and passangers and of astronauts.

The Sun

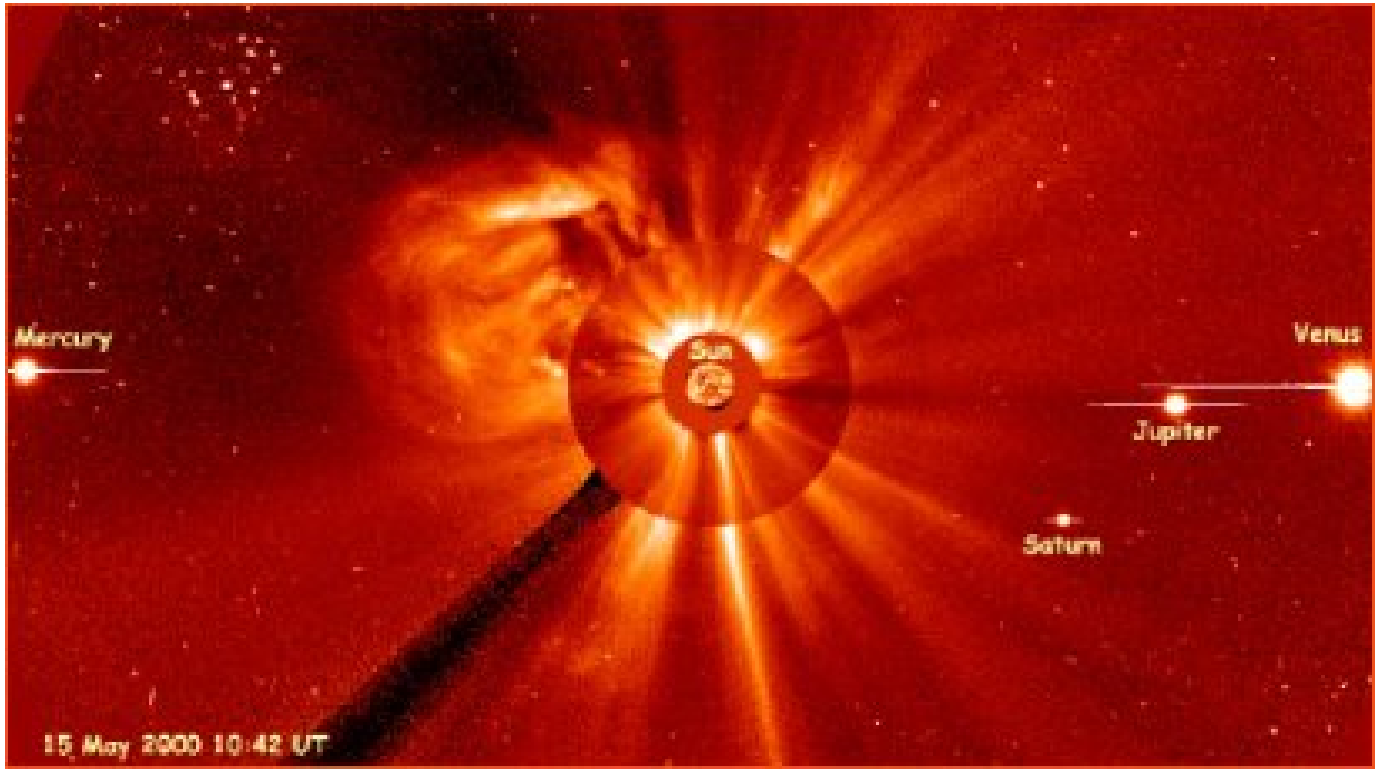


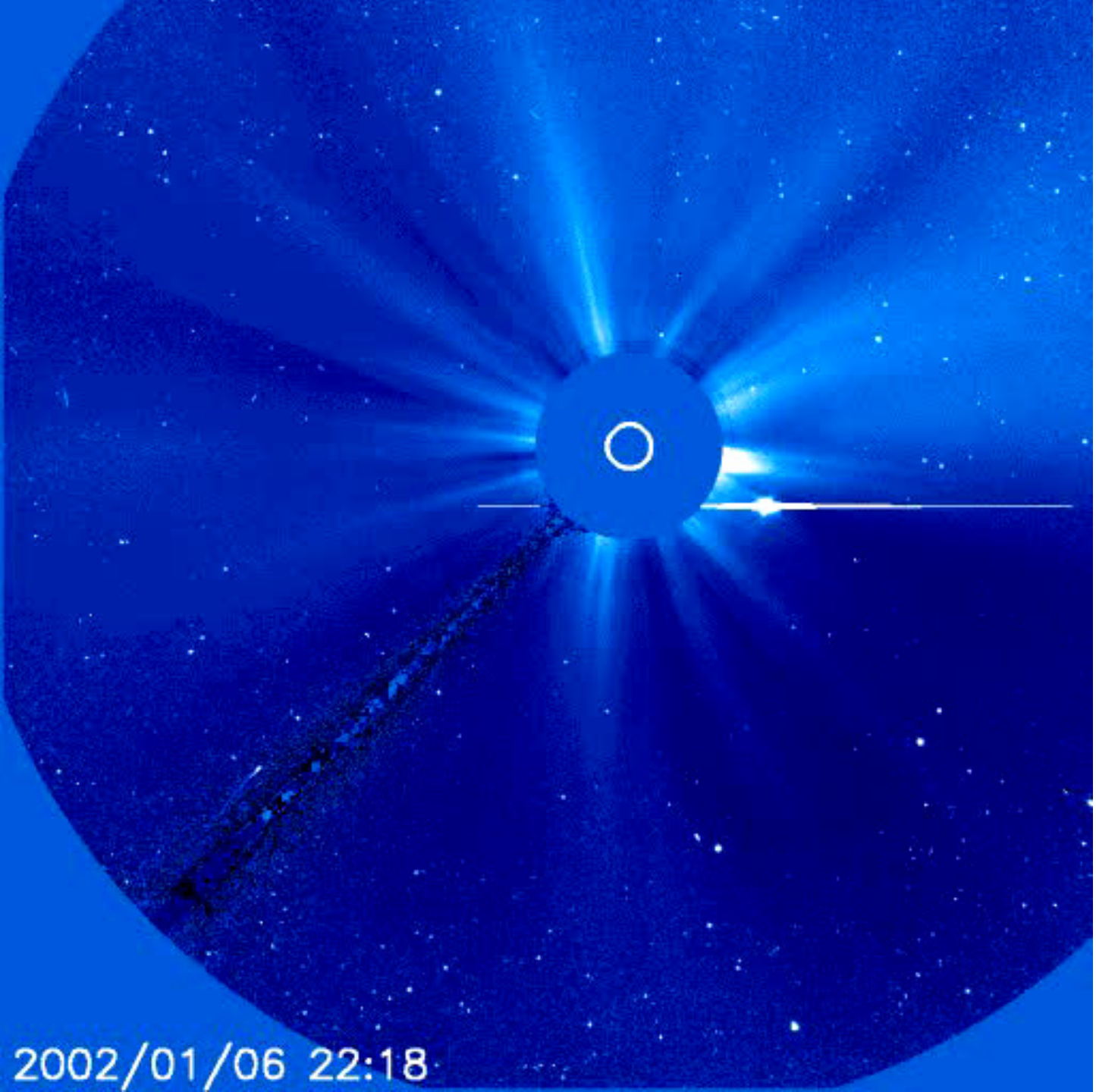
The solar core consists of a dense plasma with atmperature of 15 million degrees. The Sun gets ist energy by nucelar fusion of hydrogen to helium.

The Sun is surrounded by the solar corona. The corona is a dilute plasma with a temperature of 1-2 million degrees.

The Sun and its Surroundings

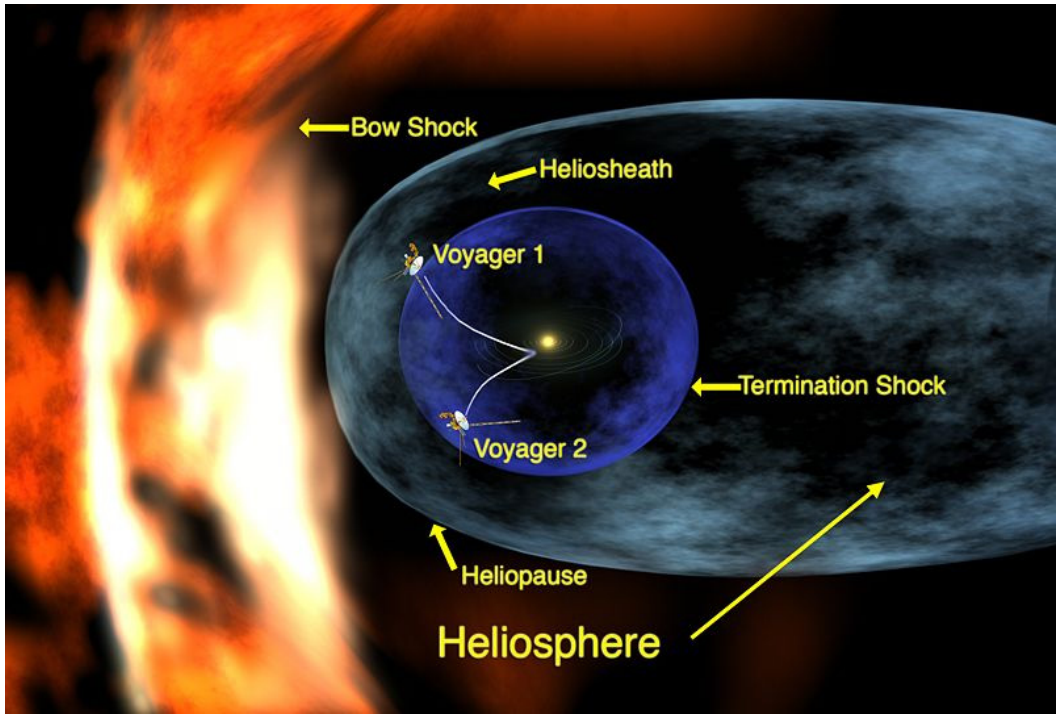
The Sun influences a large volume of space extending far beyond the planetary system. This volume is called the heliosphere.





Comet Machholz swinging by the Sun.

Interplanetary medium and Heliosphere

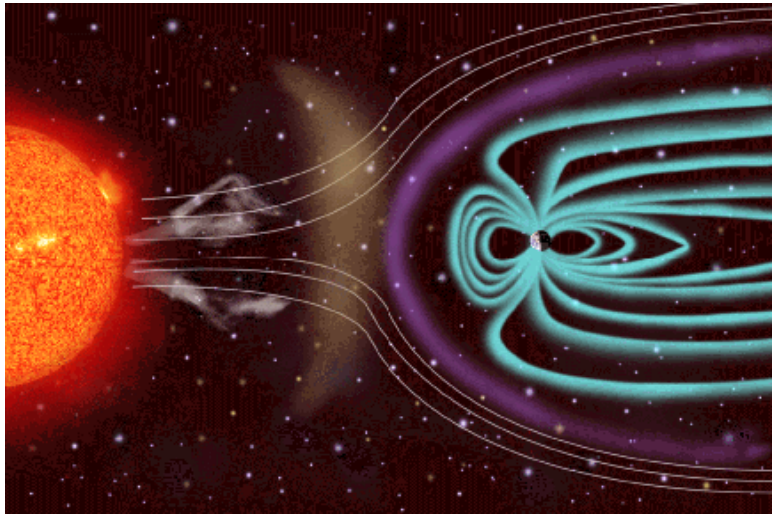


In addition to Sun and planetary bodies, the main constituents of the interplanetary medium are the hot plasma of the solar wind, dust, cosmic rays, electromagnetic radiation (light), and the interplanetary magnetic field (IMF) originating at the Sun.

The so-called heliosphere extends out to 80-100 AU (1 AU = Sun-Earth distance). The heliosheath is the region where the outflowing solar wind is slowed down by the inflowing cosmic rays from the Galaxy.

Solar wind

The **solar wind** is a stream of charged particles —a plasma — that is ejected from the upper atmosphere (corona) of the Sun. It consists mostly of electrons and protons with energies of about 1 keV. These particles are able to escape the sun's gravity, in part because of the high temperature of the corona, but also because of high kinetic energy that particles gain through a process that is not well-understood yet.



Many phenomena are related to the solar wind, including geomagnetic storms that can knock out power grids on Earth, the aurorae such as the Northern Lights, and the plasma tails of comets that always point away from the Sun.

Solar wind

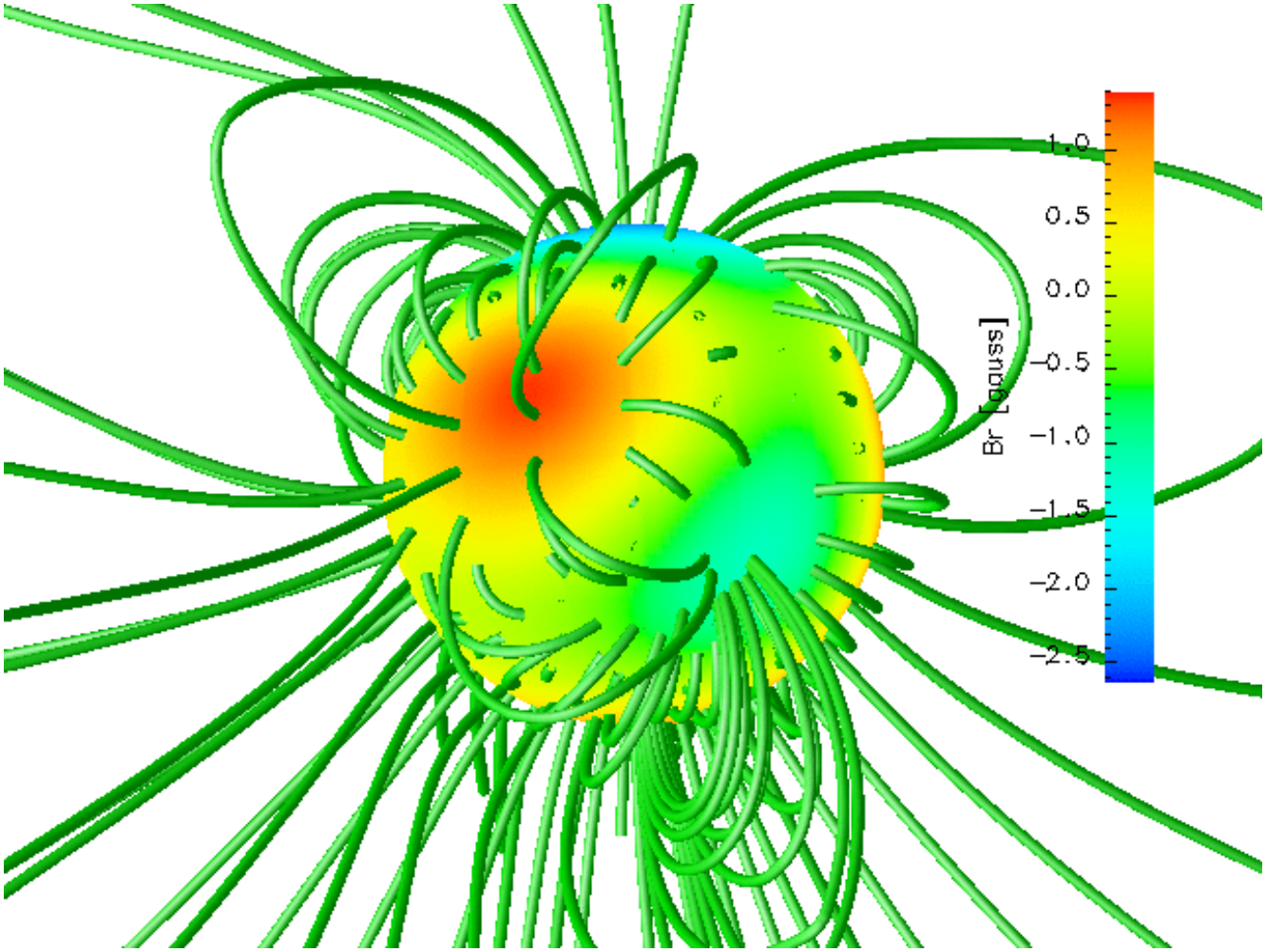
The solar wind is a fast outflow of hot plasma from the sun in all directions. Above the sun's equator it typically attains 400 km/s; above the sun's poles, up to twice as much.

The flow is powered by the million-degree temperature of the sun's corona, for which no generally accepted explanation yet exists. Its composition resembles that of the Sun—about 95% of the ions are protons, about 4% helium nuclei, with 1% of heavier matter (C, N, O, Ne, Si, Mg... up to Fe), and enough electrons to maintain charge neutrality.

At Earth's orbit its typical density is 6 ions/cm^3 (variable, as is the velocity), and it contains a variable interplanetary magnetic field (IMF) of (typically) 2–5 nT.

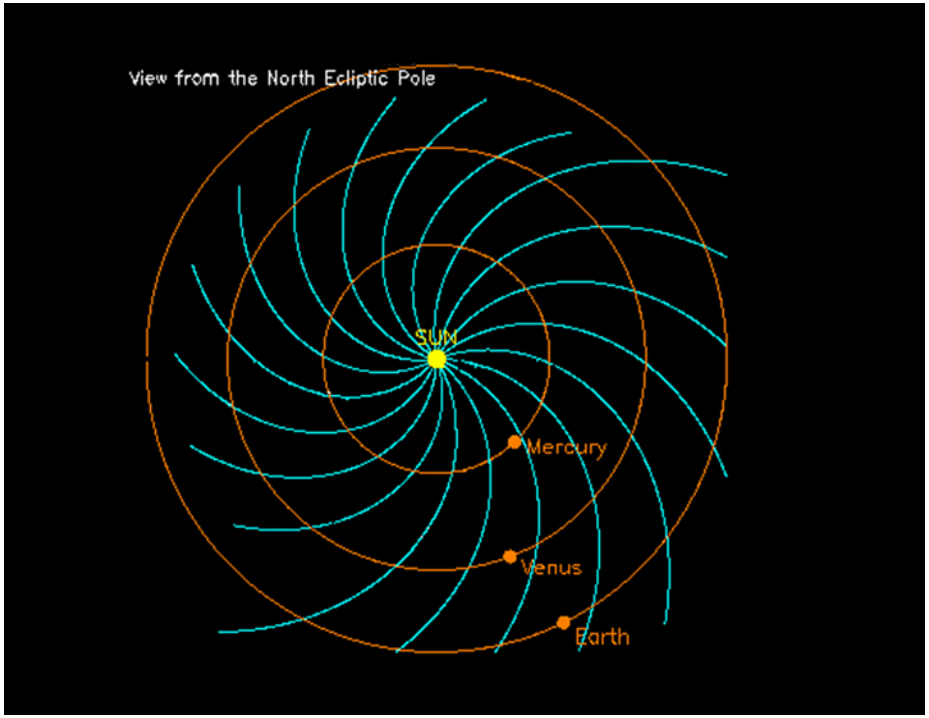
The IMF is produced by stretched-out magnetic field lines originating on the Sun.

Solar magnetic field



Three-dimensional reconstruction of the solar magnetic field. From Carla Jacobs (CPA, K.U.Leuven).

Interplanetary Magnetic Field



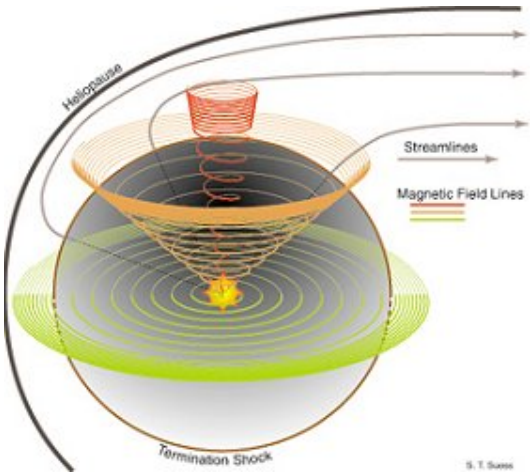
The solar wind carries the Sun's magnetic field throughout the heliosphere and becomes the interplanetary magnetic field (IMF). The IMF is "frozen" inside the solar wind plasma moving through interplanetary space with a velocity of typically a few hundred km/s.

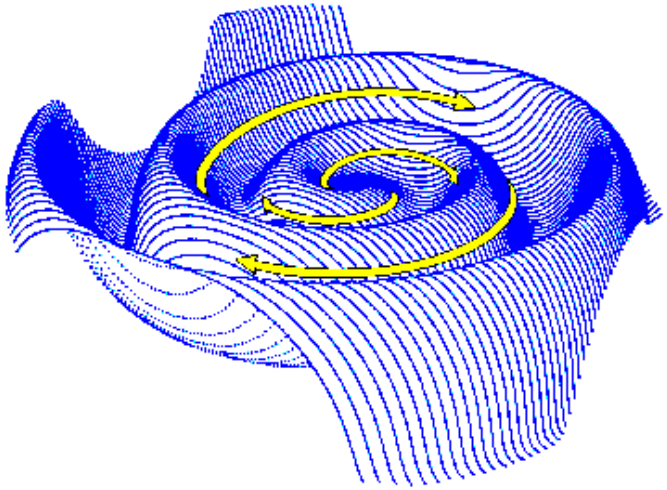
Due to solar rotation and the radial outflow of the solar wind from the solar corona the IMF develops a spiral shape. The solar wind is very inhomogeneous and varies strongly with respect to time. The heliosphere has a cometary like shape and is rather extended - about 15 billion km or

100 times the Sun – Earth distance.

Solar wind

The energy density of solar wind is larger than energy density of interplanetary magnetic field (IMF). Solar wind carries the Sun's magnetic field throughout the solar system. IMF field lines are "frozen" in solar wind plasma moving in interplanetary space with velocities of typically several hundreds to few thousands of km/s. Due to solar rotation and radial outflow of solar wind from corona the IMF lines have spiral shape.

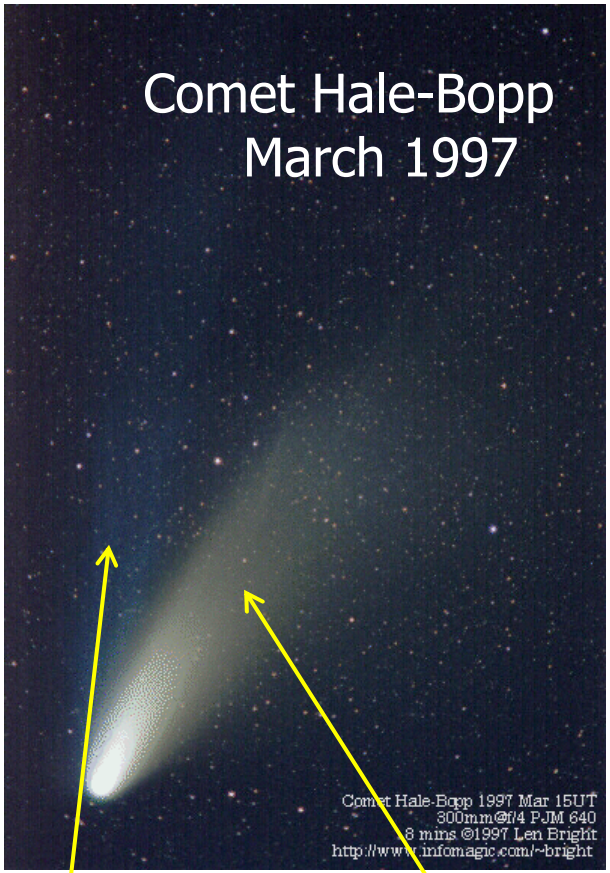




Cometary tails

As a comet comes closer to the Sun, ice from the nucleus (composed of dust and ice of frozen gases) is vaporized, forming a cloud (coma) surrounding the comet. Pressure from the visible sunlight "pushes" the coma dust into a diffuse dust tail. The ultraviolet portion of the sunlight and the solar wind turn part of it into a plasma of electrically charged particles of ions and electrons. The magnetic field in the solar wind picks up comet ions and direct them into a long, blue plasma tail. Since this tail is stretched very long, it is much fainter than the dust tail.

If the magnetic field is disrupted, the plasma tail may be disconnected. Comet Hale-Bopp's orbit is tilted relative to the Sun's equator with the comet moving from North to South and thus crossing the Sun's equatorial plane, where the Sun's magnetic field lines change direction. As Hale-Bopp passes through this plane, its ion tail may disconnect because of the change in direction of the magnetic field.



Plasma tail

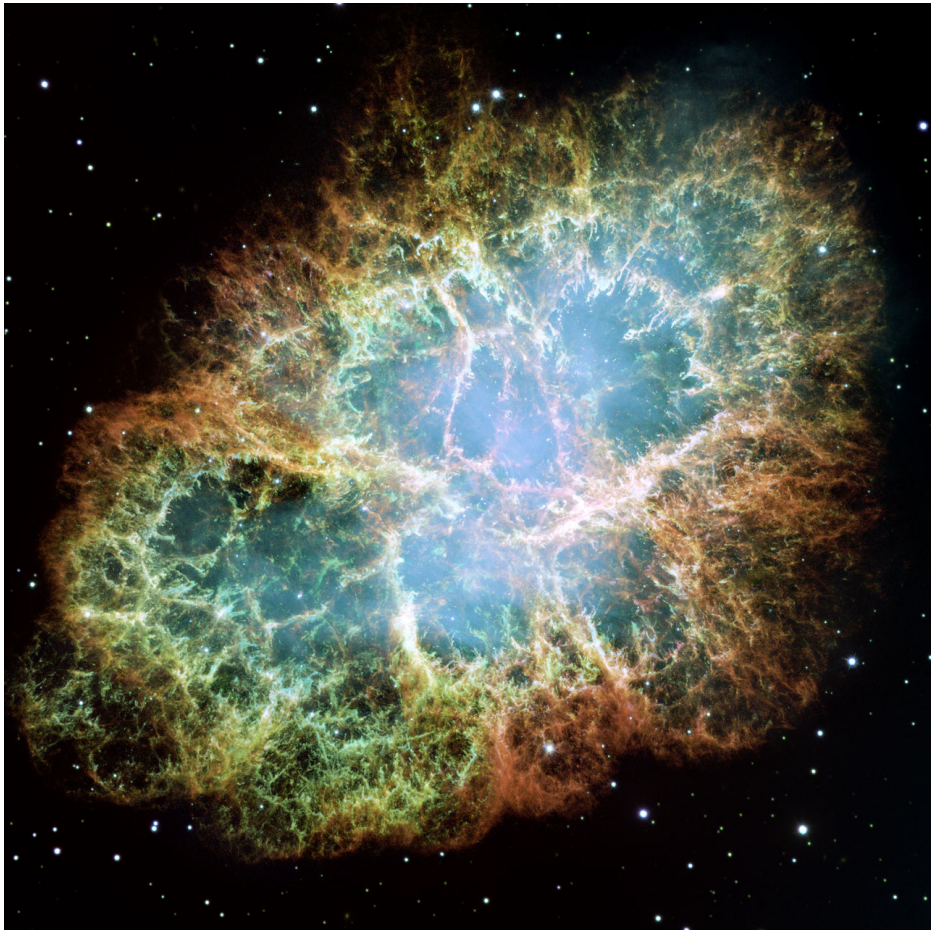
Dust tail

Cosmic Rays

There are different types of cosmic rays:

- **Galactic cosmic rays** are probably accelerated in the blast waves of supernova remnants in the Milky Way Galaxy.
- **Solar cosmic rays** are produced in high energy processes at or near the Sun after a violent eruption at the Sun.
- **Composition** of galactic cosmic rays:
  - Protons: 87 %
  - Helium nuclei: 12 %
  - Heavy atomic nuclei: 1 %

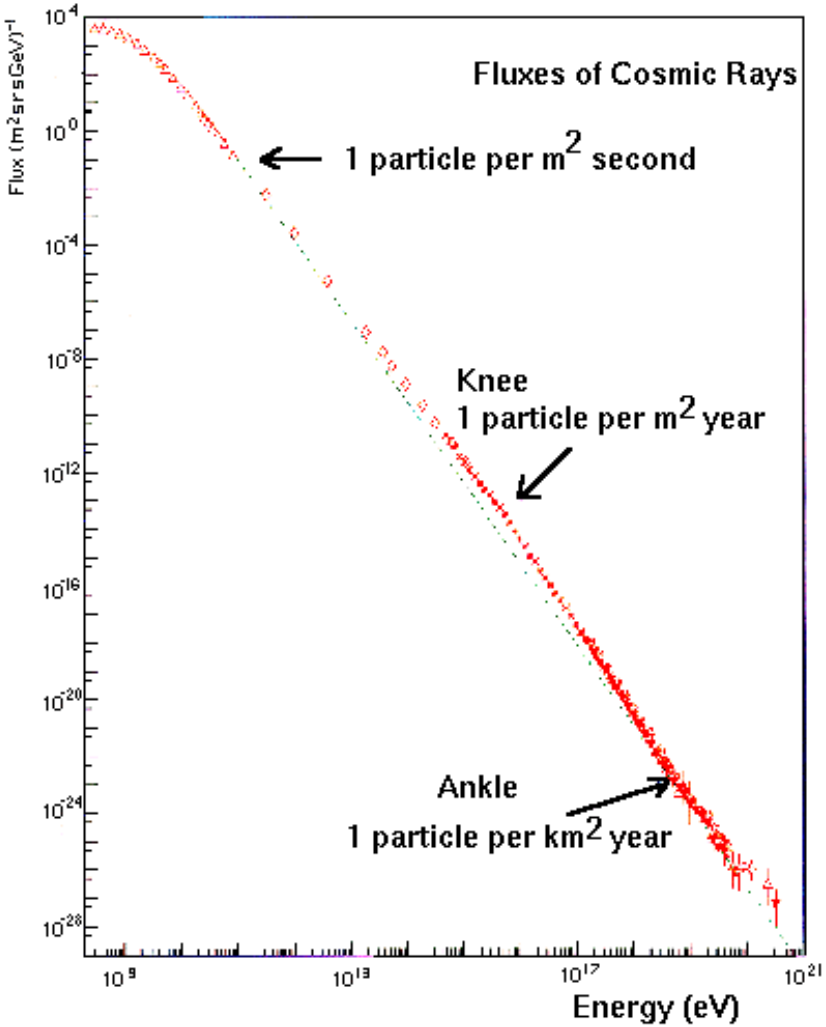
Galactic Cosmic Rays



Stars originate from interstellar dust and gas. During supernova explosions (one possible end of stellar evolution), the star‘s material is accelerated to very high energies and cosmic ray particles are created.

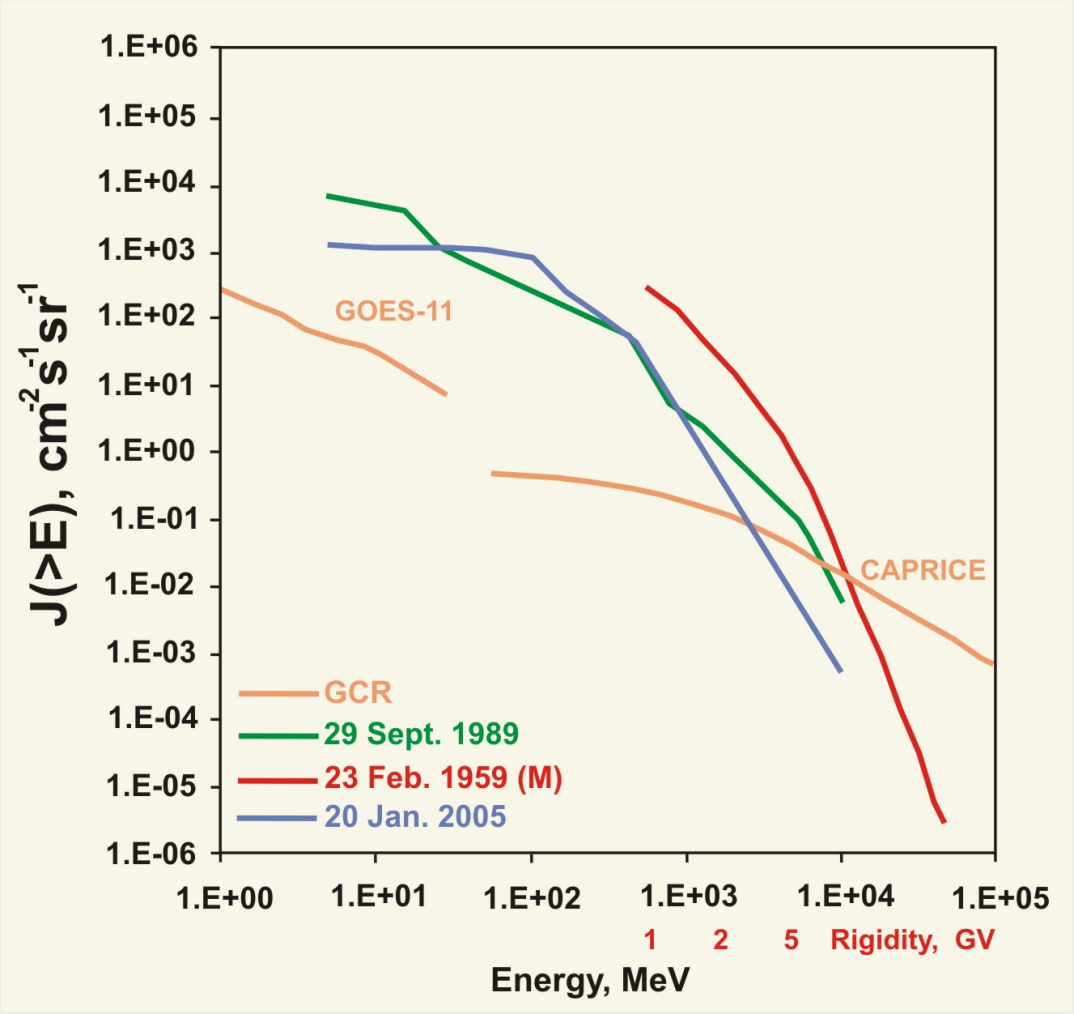
The Crab Nebula is a six-light-year-wide expanding remnant of a star's supernova explosion. Japanese and Chinese astronomers witnessed this violent event in 1054 nearly 1,000 years ago.

Galactic Cosmic Rays



Galactic cosmic rays (GCR) originating from the Galaxy are accelerated to the highest energies known.

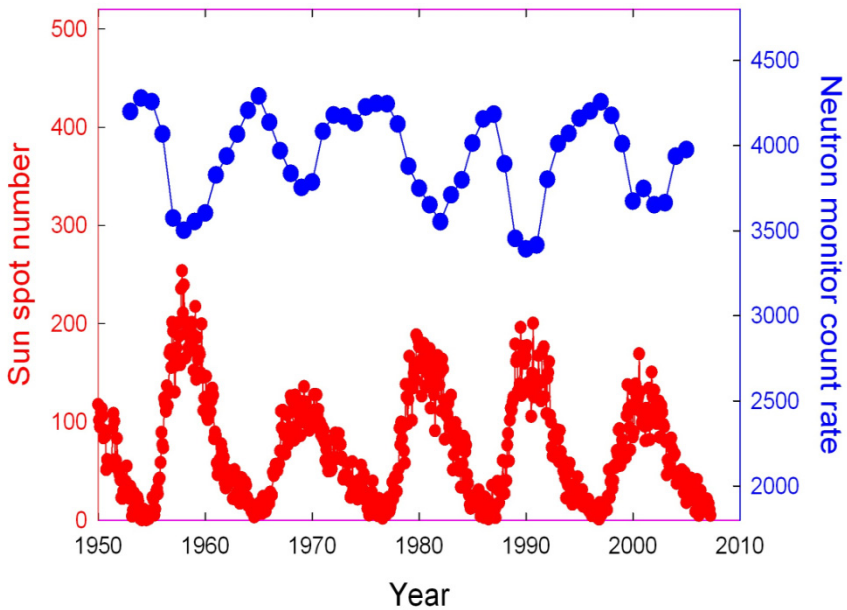
Solar cosmic rays

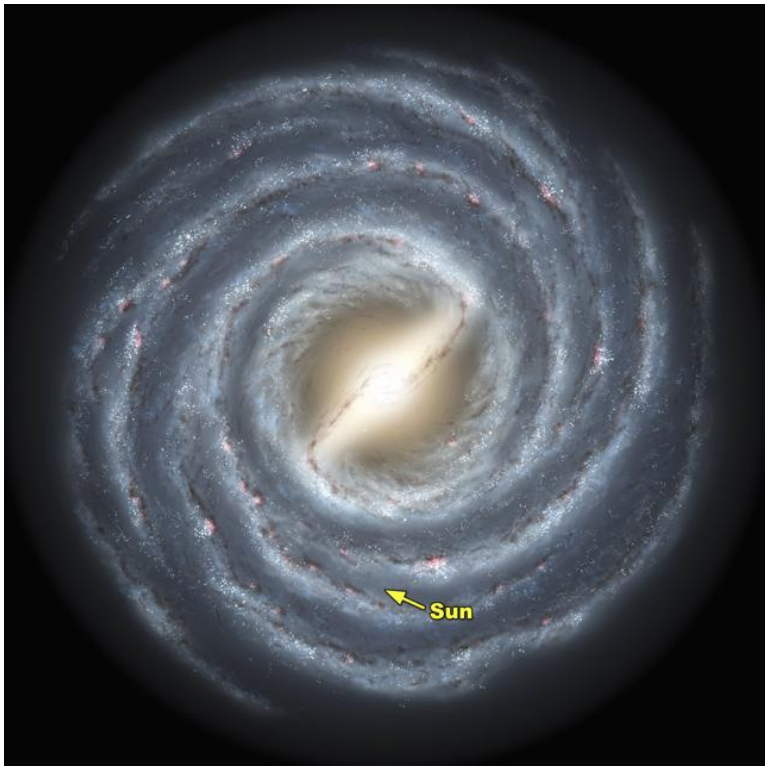


Solar cosmic rays (SCR) originate from energetic solar particle events (SEP). SCR have a steeper energy dependence and do not extend to as large energies as GCR.

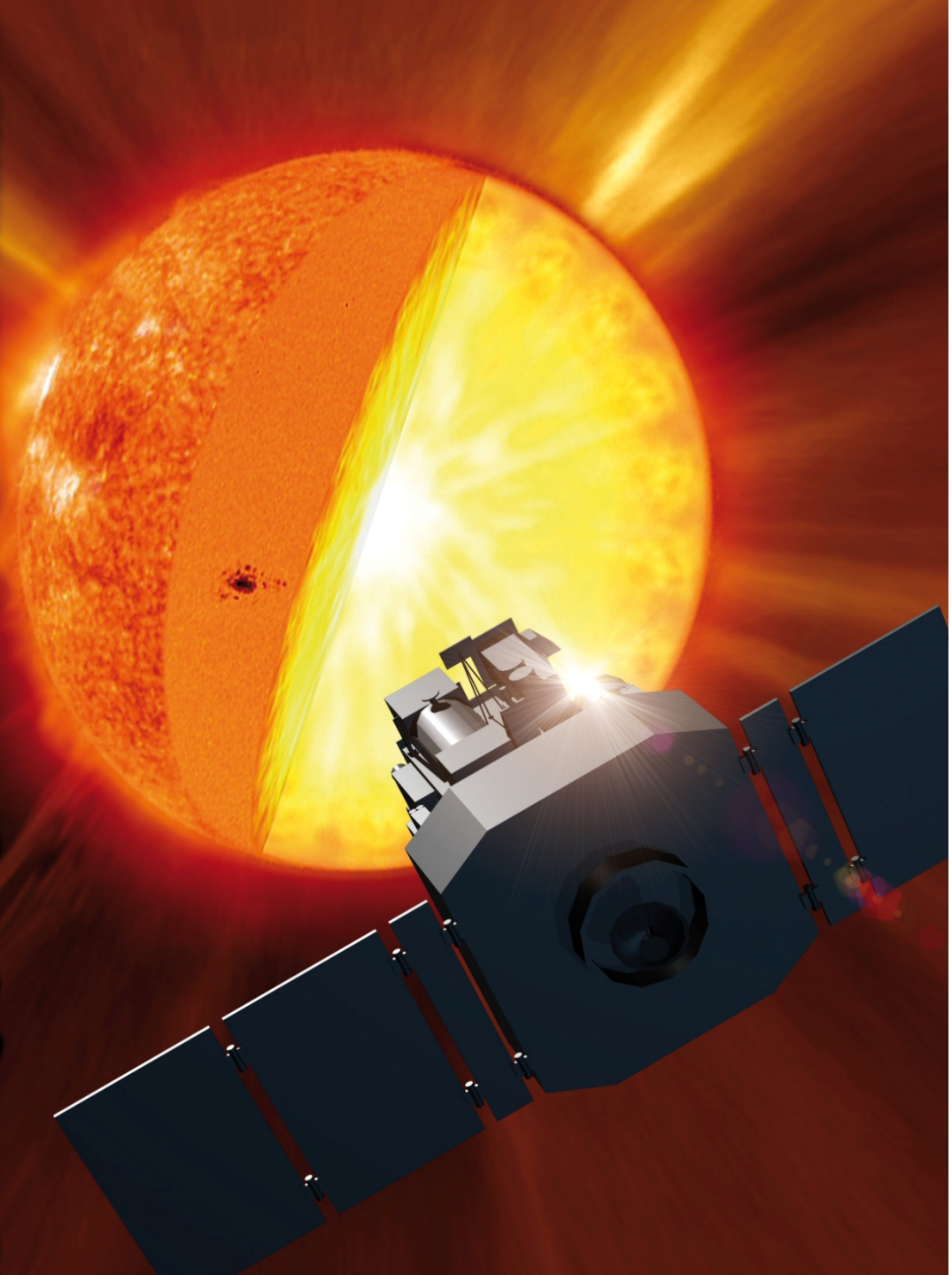
Solar Activity and Cosmic Rays

Galactic cosmic rays travel through the Galaxy, reach the heliosphere and the Earth.



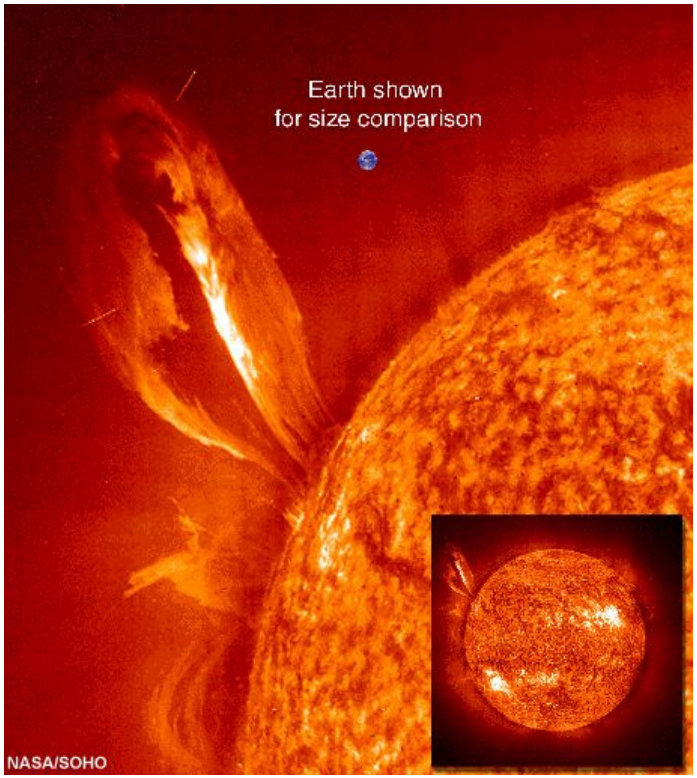


The intensity of galactic cosmic rays at the Earth is at maximum when solar activity is at minimum and vice versa.

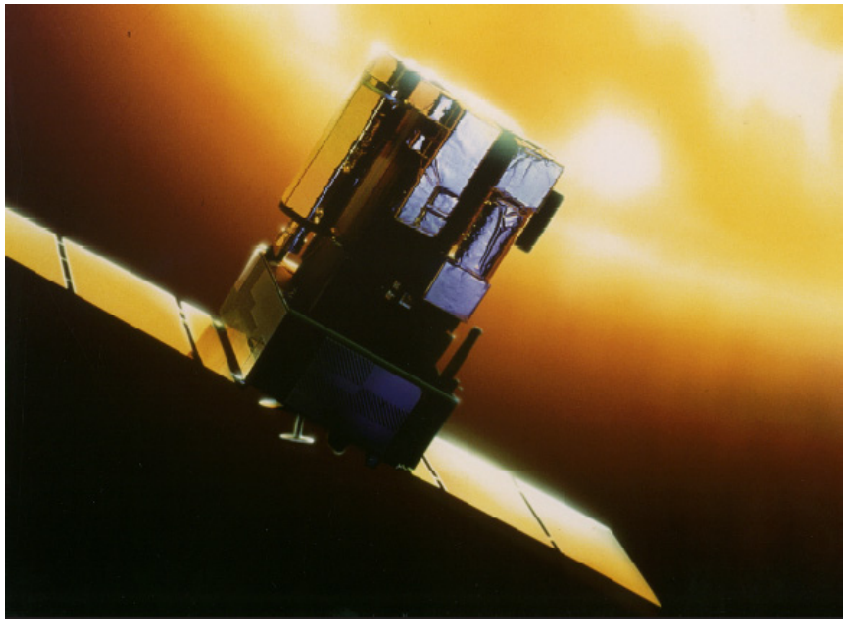


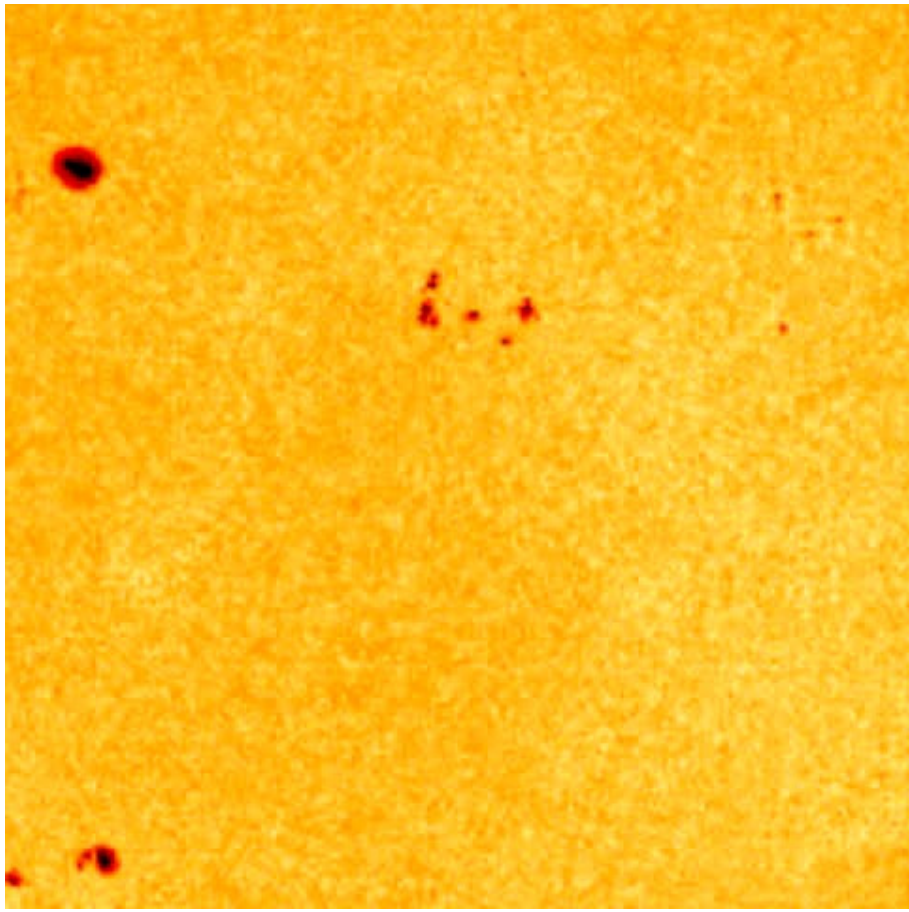
SOHO

An artist's impression of the SOlar Heliospheric Observatory SOHO



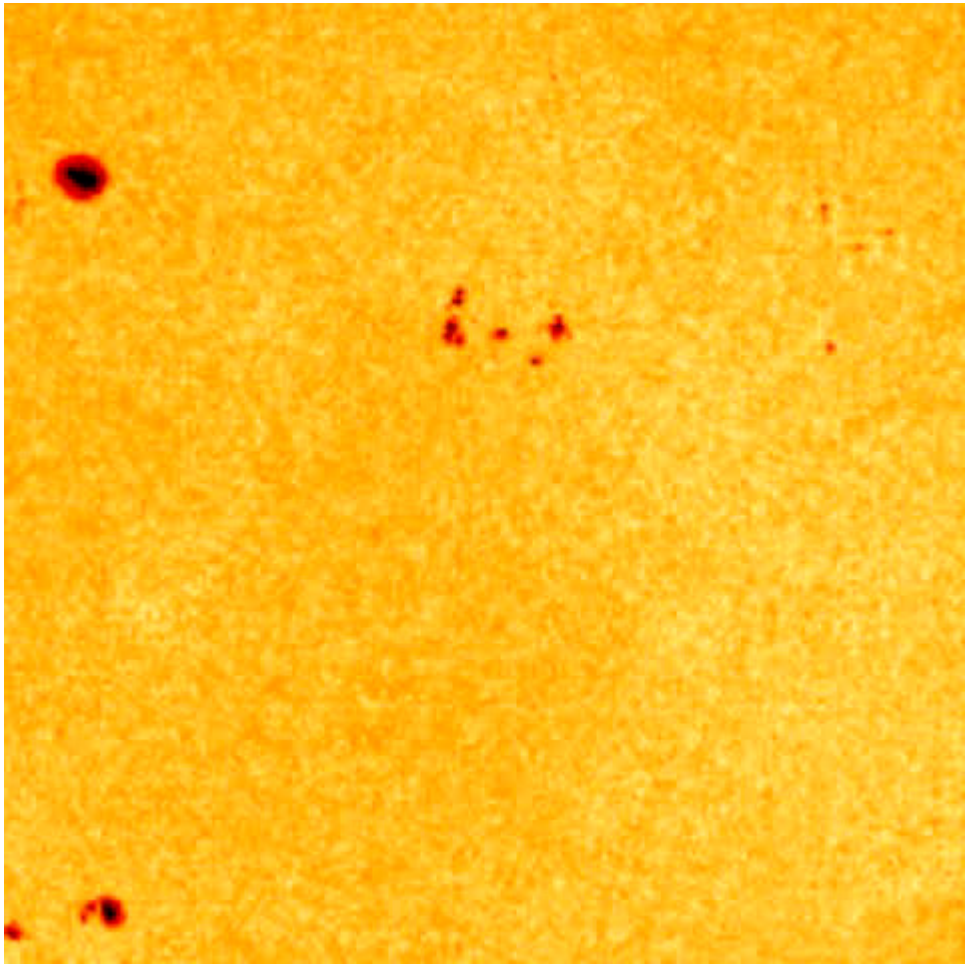
SOHO





SOHO is taking pictures of the Sun with different instruments and in different spectral regions that correspond to different temperature regimes.

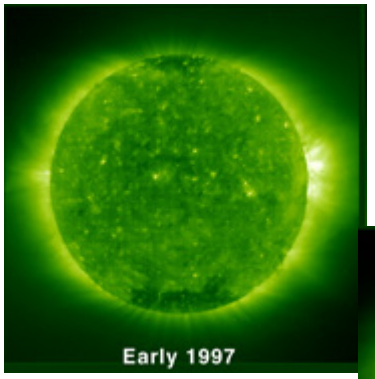
Sun Spots



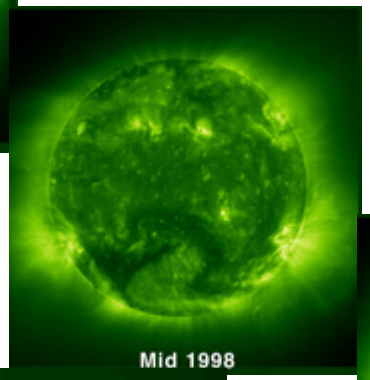
Sun spots are active regions on the Sun and constitute the origins of so-called solar storms.

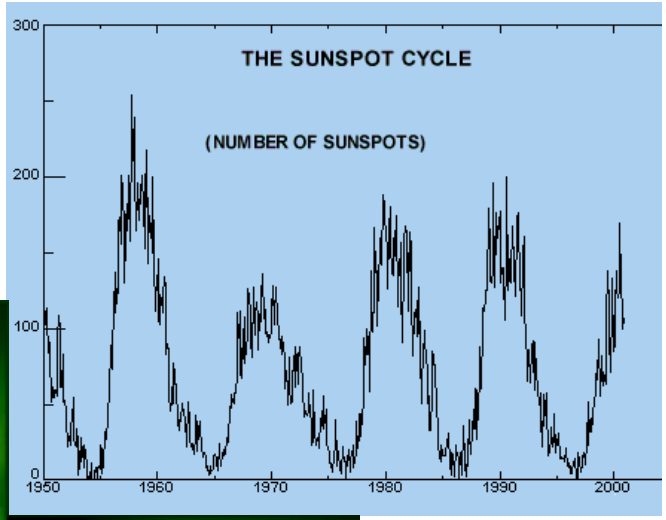
Sun spots appear dark in visible light, but appear as bright spots in the more energetic ultraviolet and soft x-ray light.

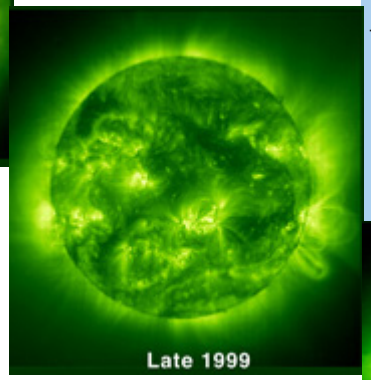
Solar activity and Sun spots

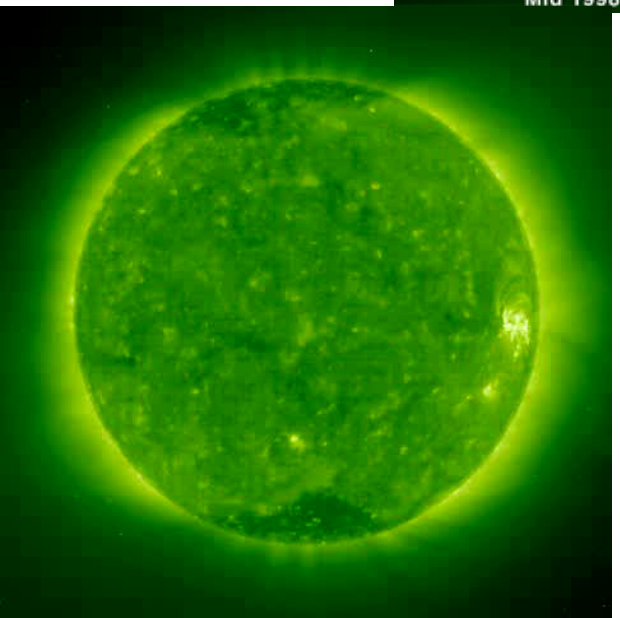


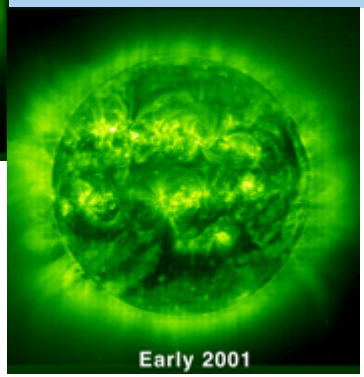
Solar activity is directly connected with the number of sun spots. The sun spot number varies with an 11-year cycle.



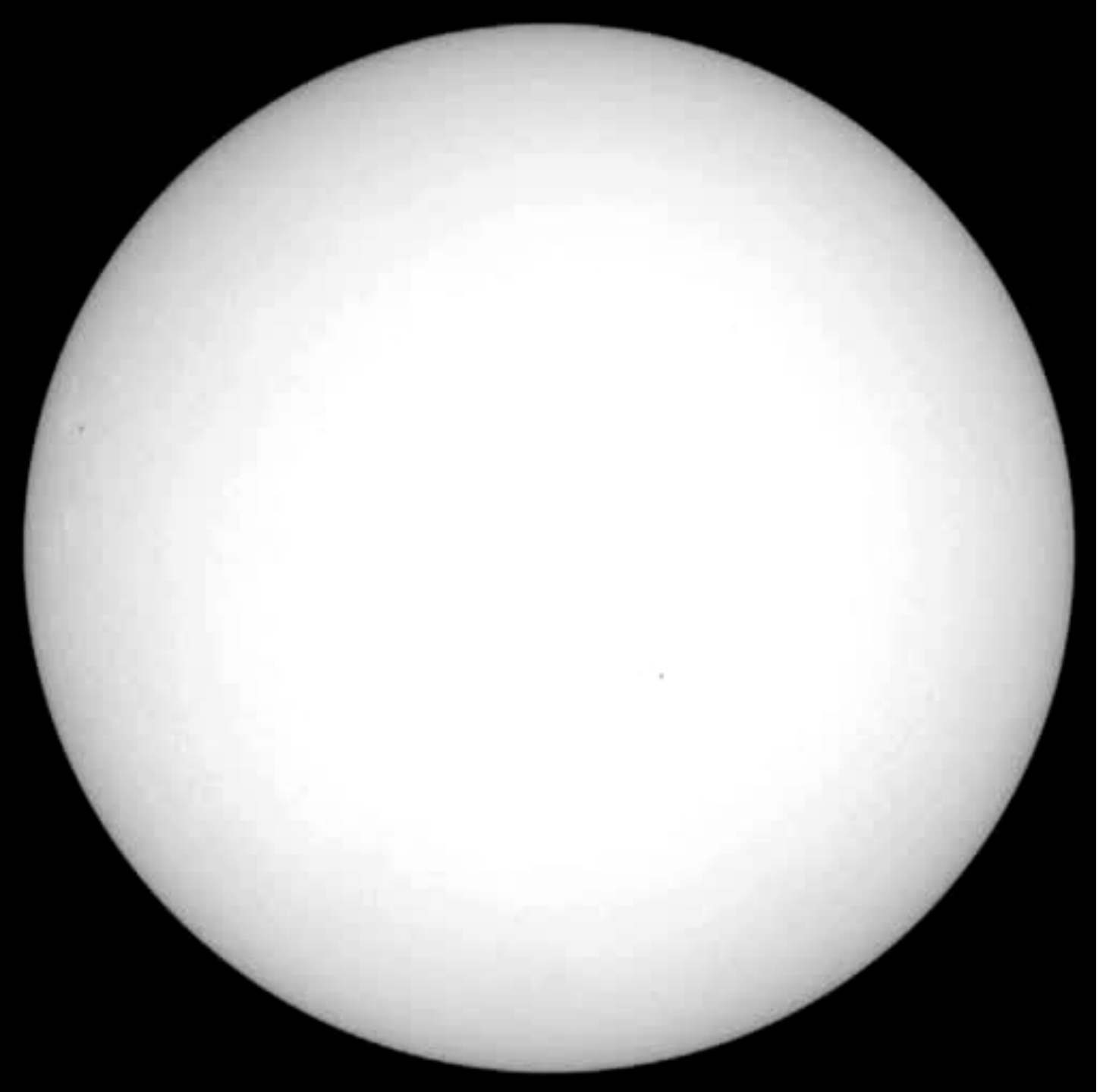








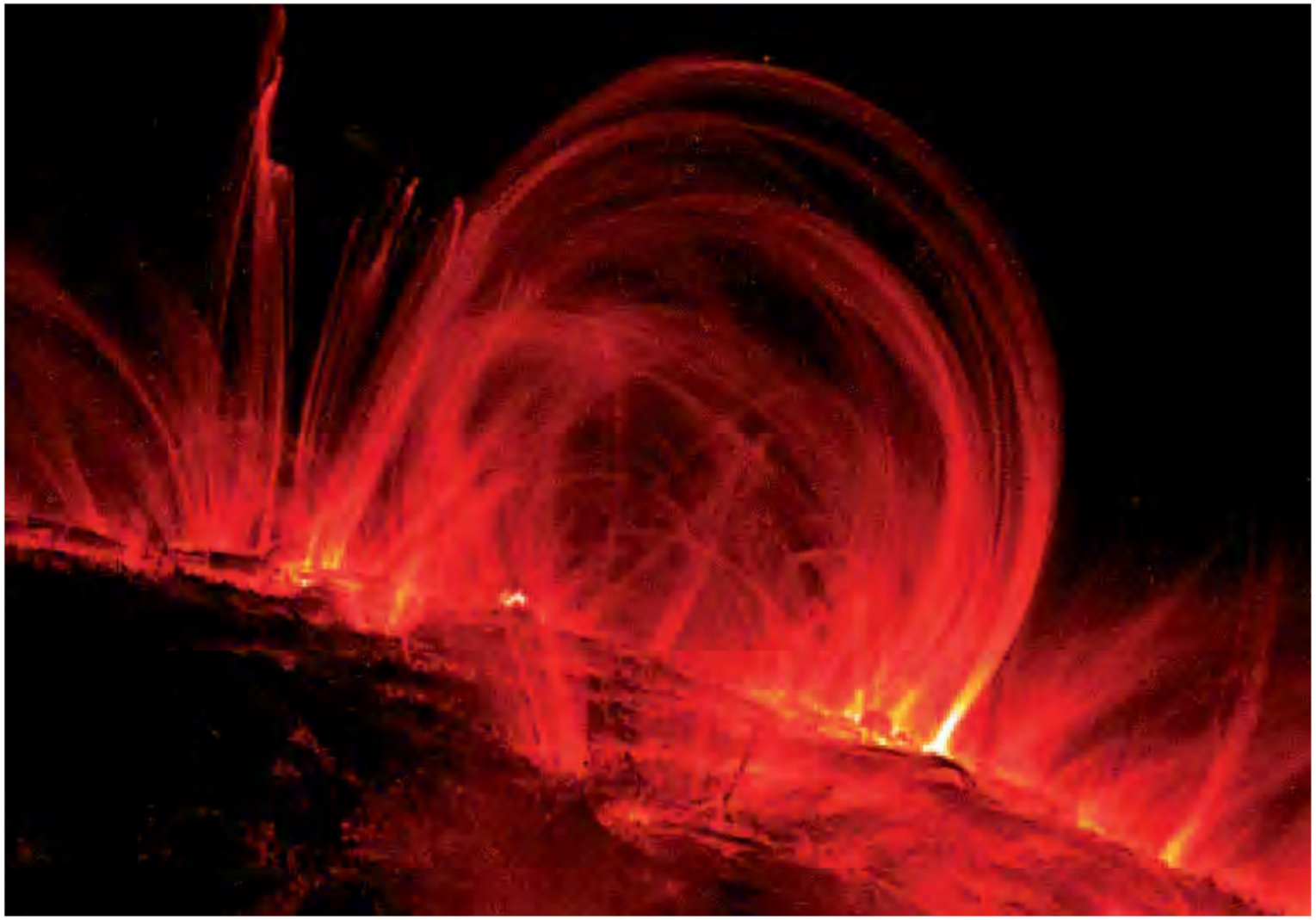
The larger the sun spot number the larger the solar activity.



Solar storms originate from points of large solar activity, e.g., sun spots.

ESA/NASA SOlar Heliospheric Observatory SOHO

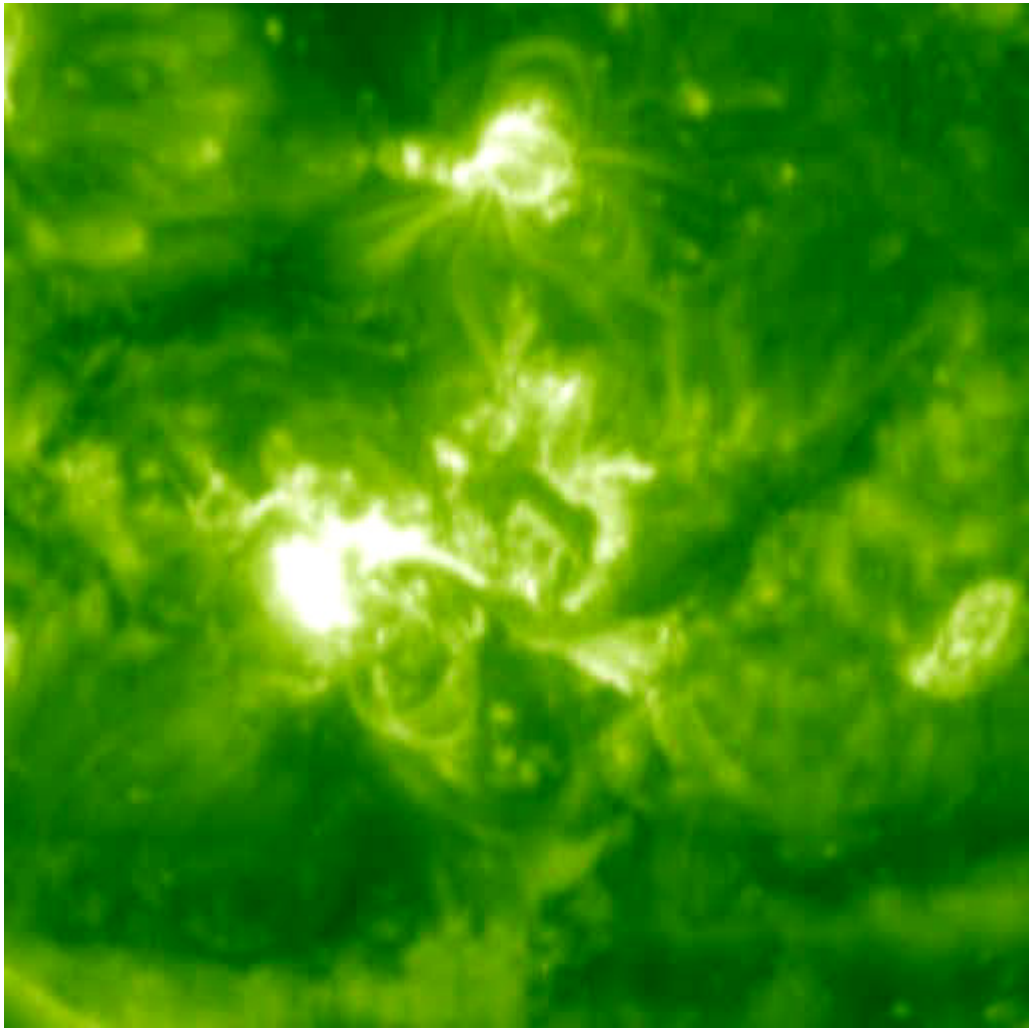
Magnetized Plasma at the Sun's Surface



TRACE, NASA

Rund 30-mal so groß wie der Erddurchmesser sind diese im extrem ultravioletten Spektralbereich (Wellenlänge: 17 nm) sichtbaren Bögen in der Sonnenkorona.

Solar storms originate at sun spots



Solar storms are frequently composed of

Solar Flares

which emit

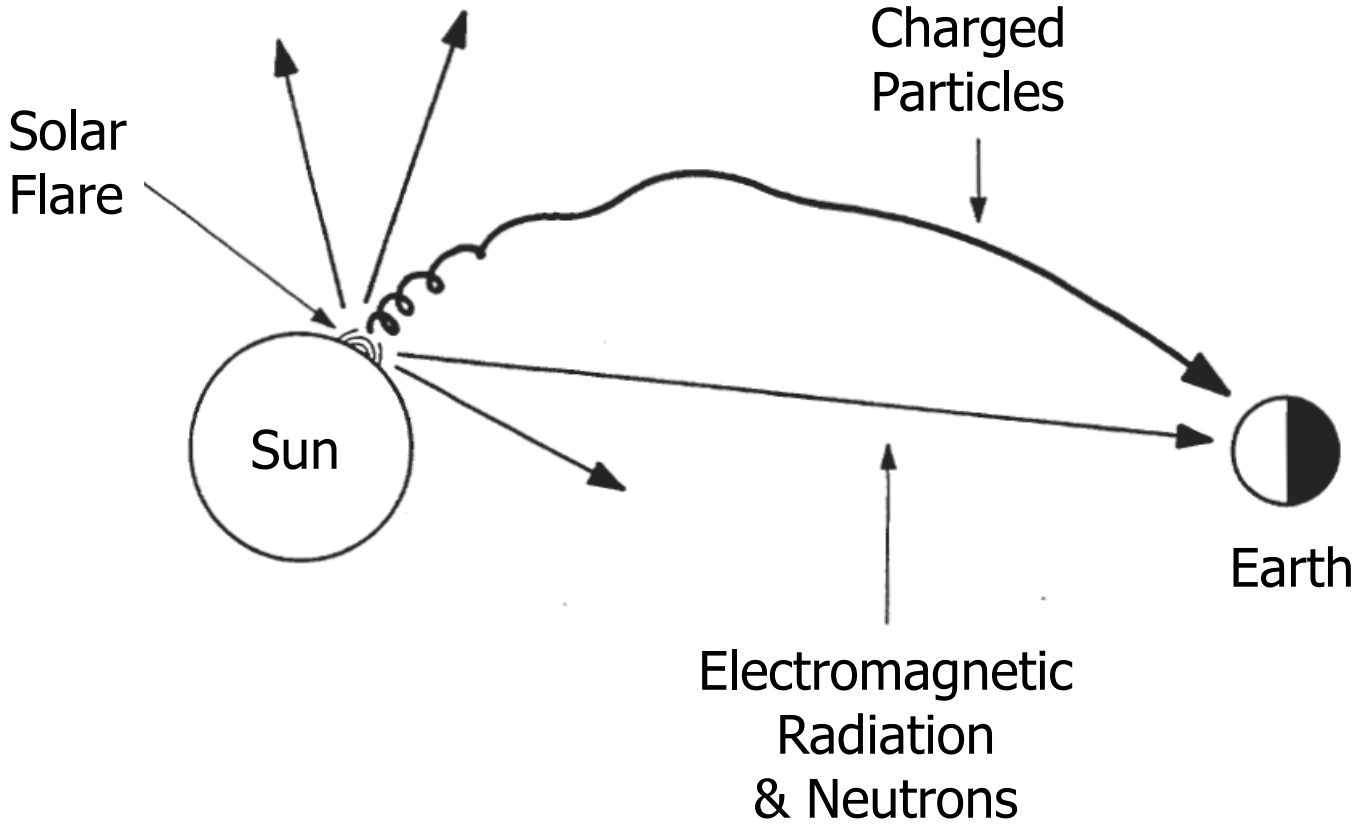
- x-rays,
- energetic particles (protons), and

sometimes produce

- Coronal Mass Ejections (CME)

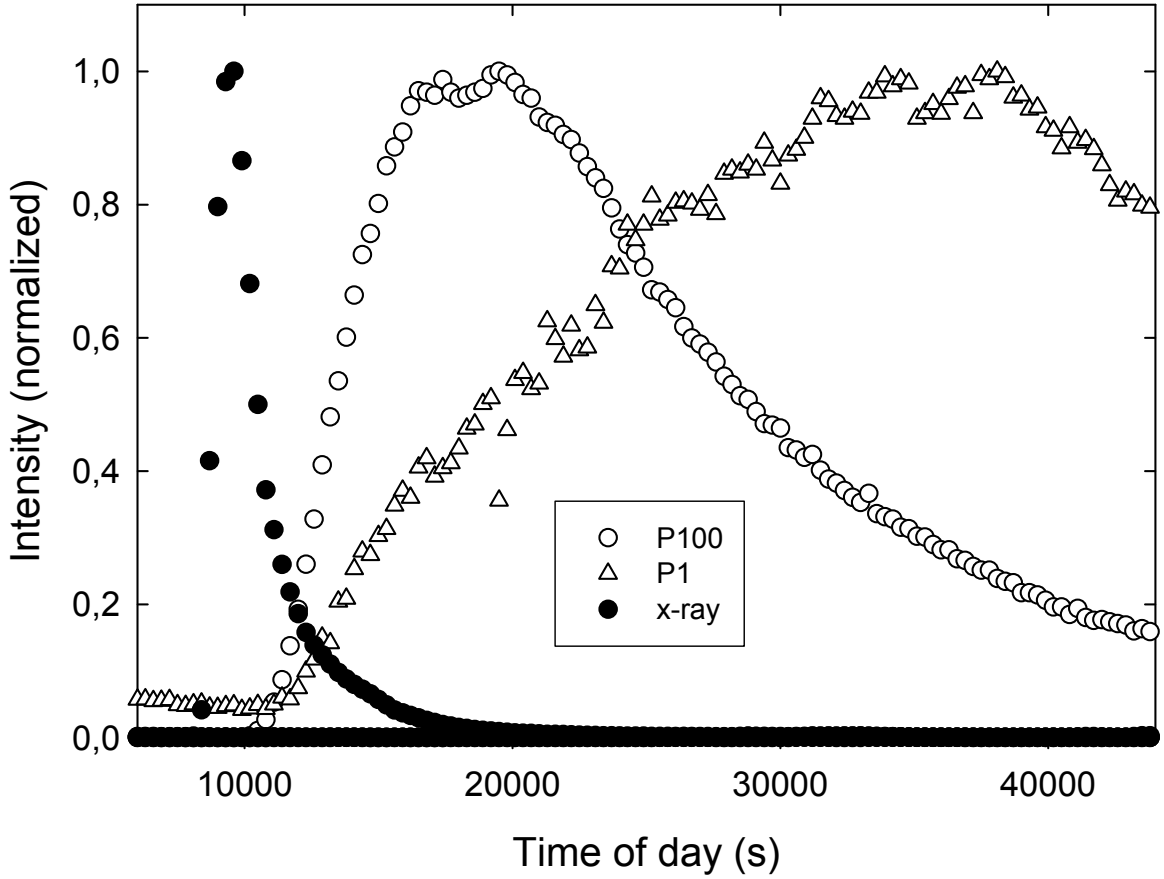
SOHO (ESA & NASA)

Propagation of Solar Cosmic Rays

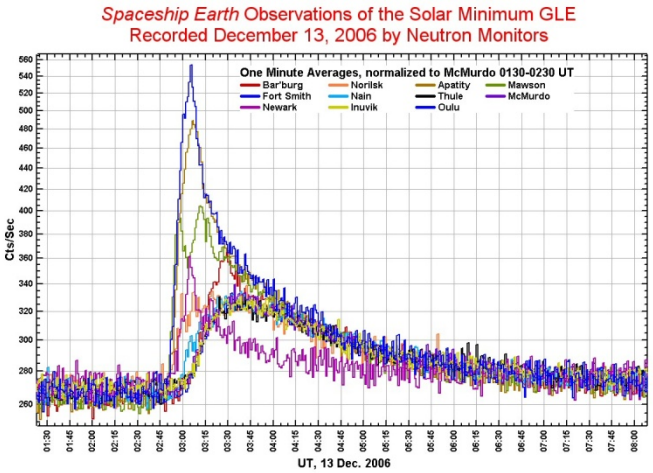


13 December 2006

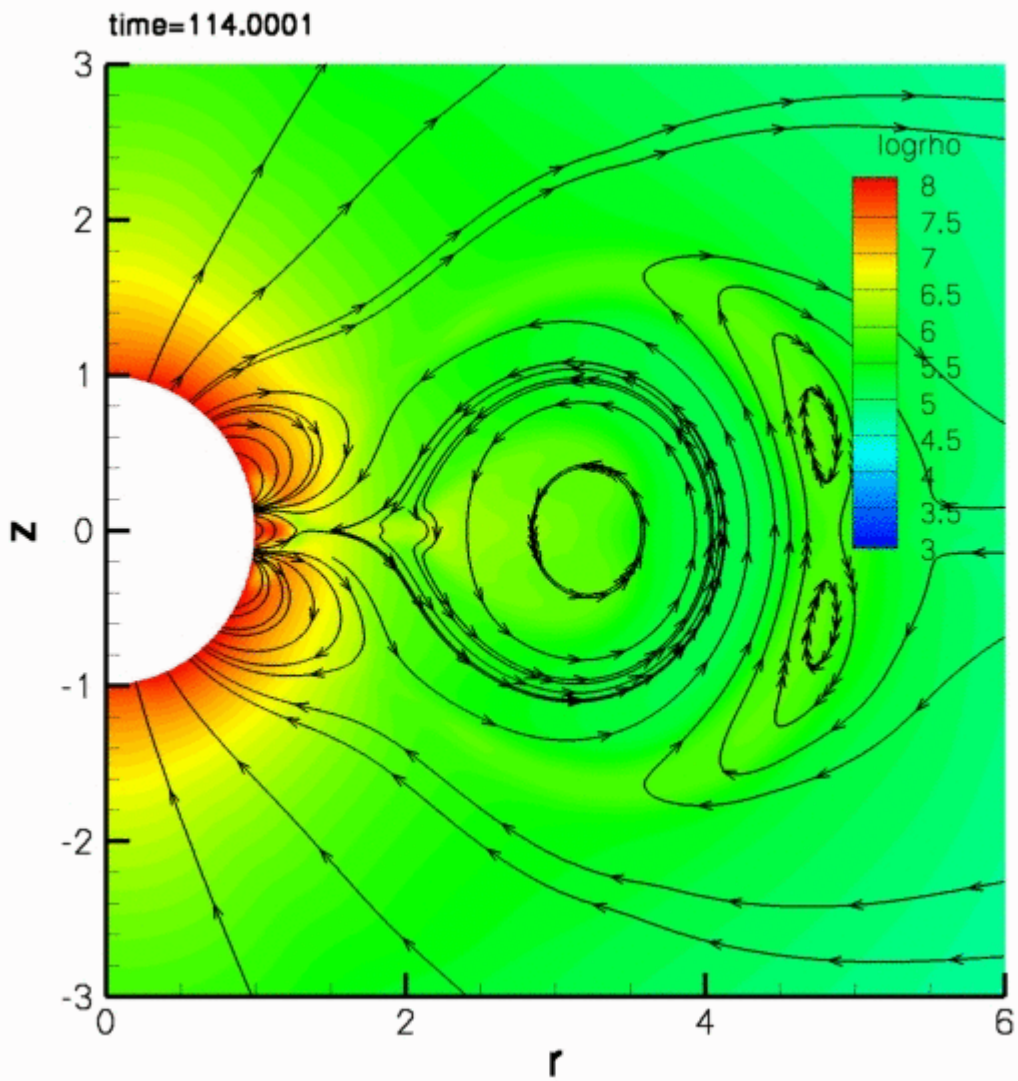
GOES-11 satellite



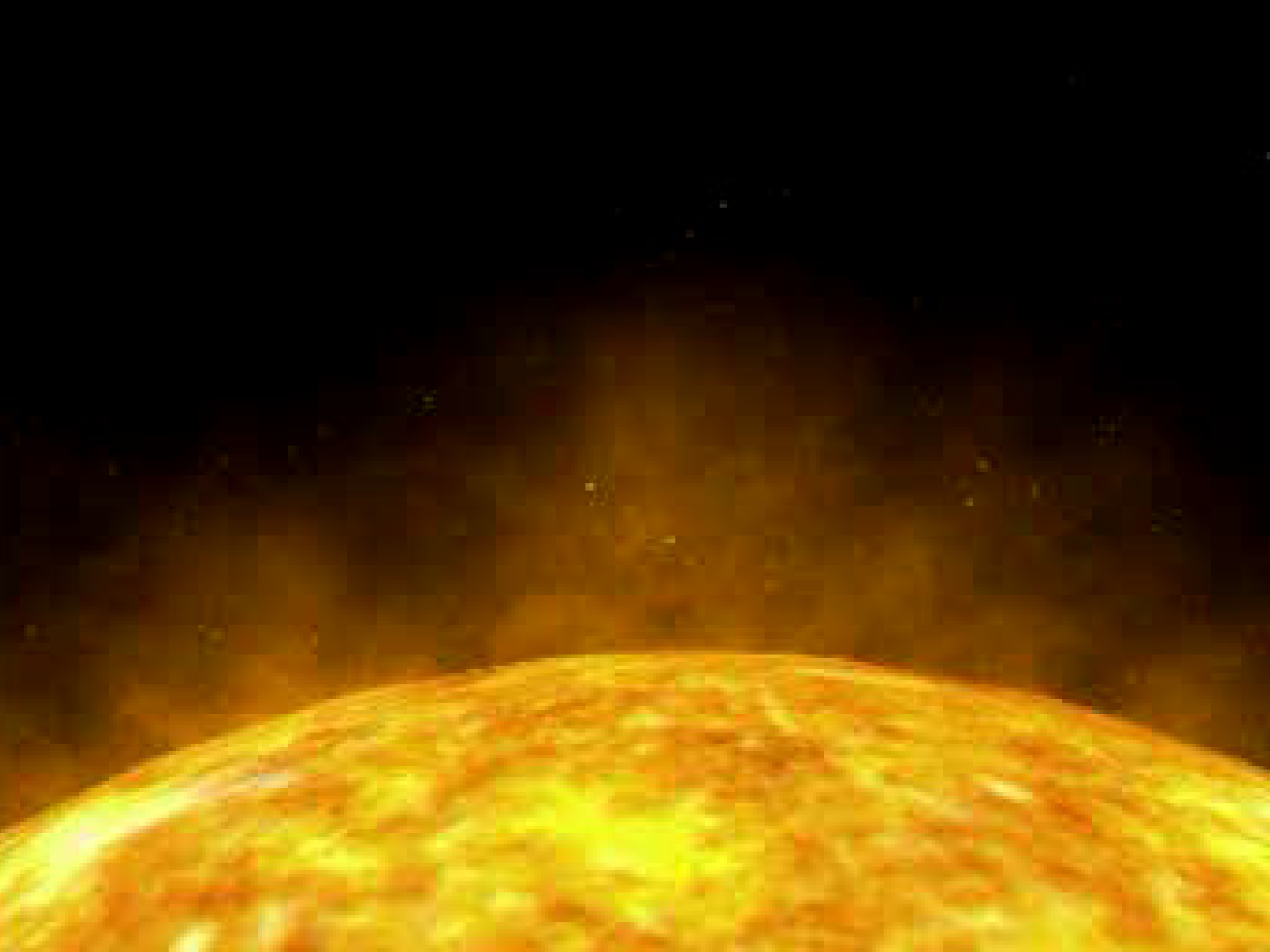
Ground-based neutron monitors

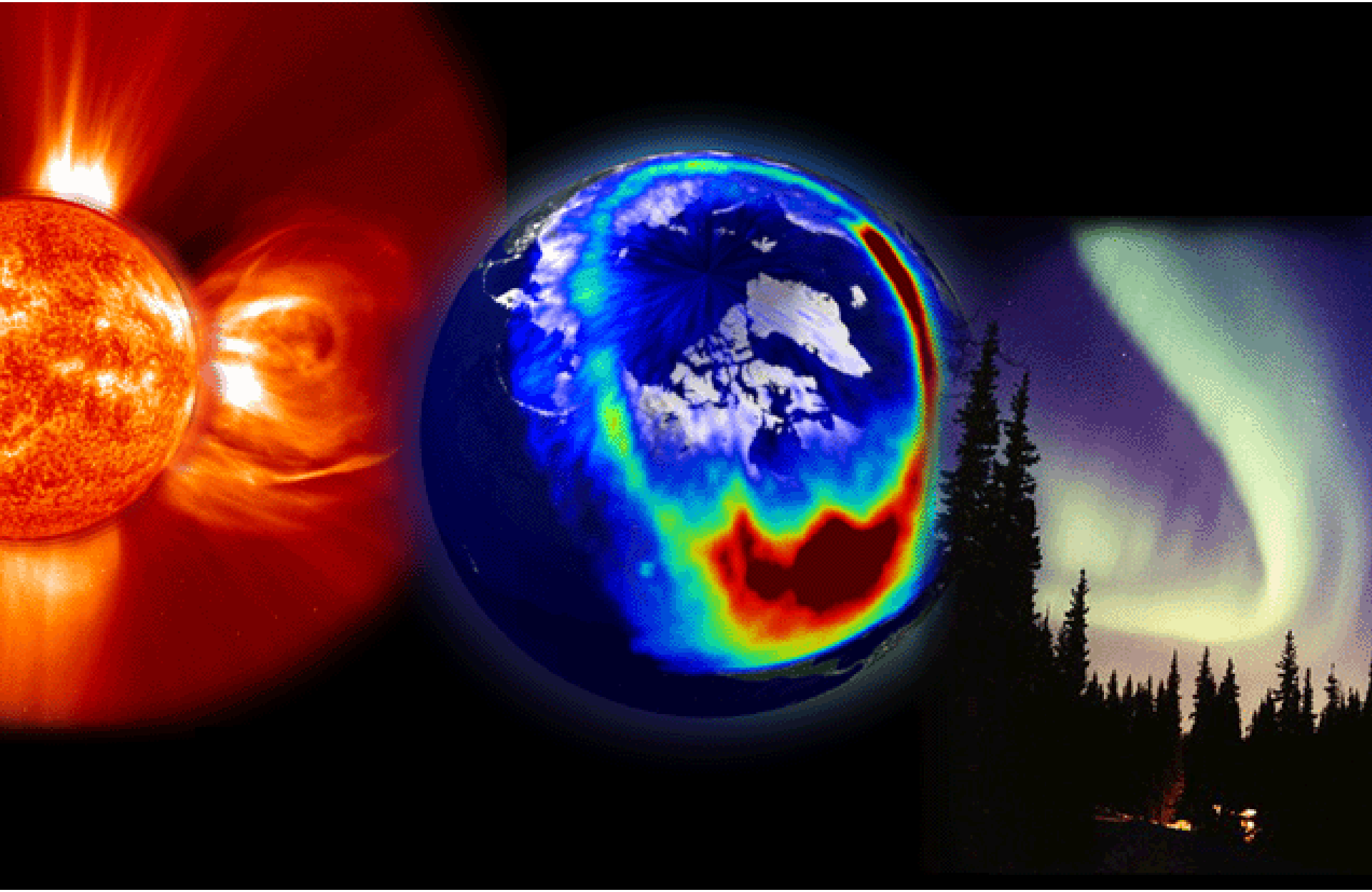


Computer simulations of space weather events



Time evolution of a computer simulation of the onset of a CME triggered by foot point motions (the so-called 'break-out model'). Colour scale: density (logarithmic scale). Black lines with arrows indicate magnetic field lines.
Comparisons of such simulations with observational data yield important information of the triggering mechanism and the initial evolution properties CMEs. From Carla Jacobs.



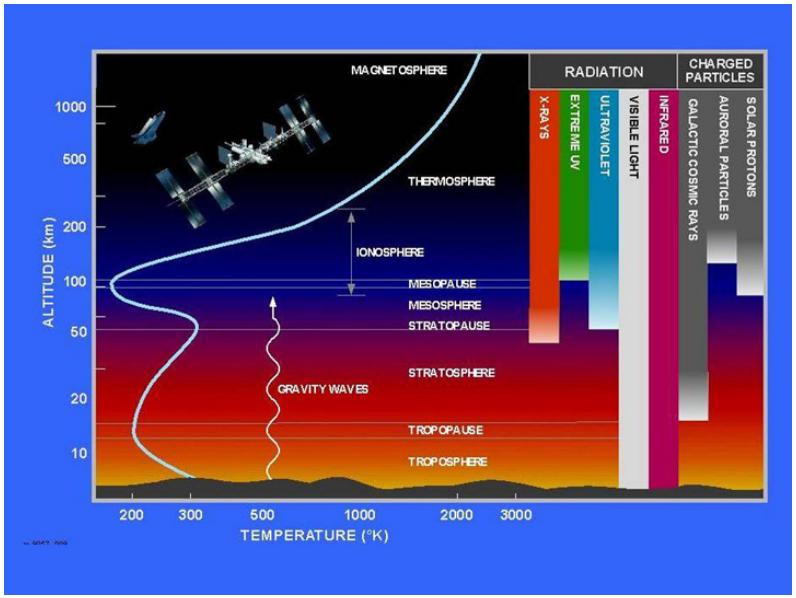


Polar light (Aurora)

Polar light

Magnetosphere, Ionosphere and Atmosphere

Life on Earth depends on energy from the Sun. The higher frequency parts of the energy spectrum from the Sun are extremely energetic and would create a hostile environment for life. However, we can enjoy the Sun because we are protected by the Earth's magnetosphere, ionosphere, and atmosphere.



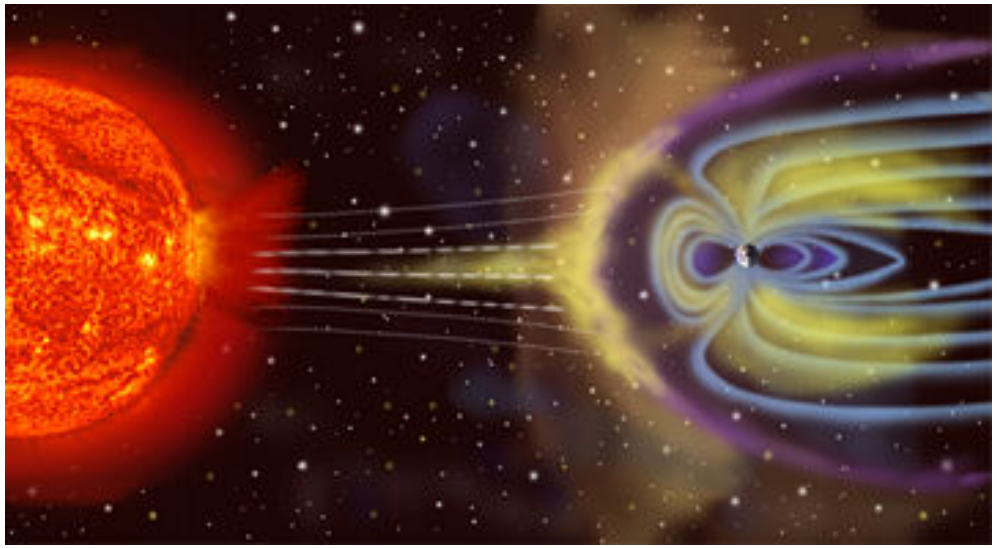
The dense atmosphere protects us by absorbing ultra violet solar radiation and reducing temperature extremes between day and night. The upper atmosphere, at heights of above 80 km, is ionized by extreme ultra violet radiation and is called the ionosphere.

Magnetosphere

A magnetosphere is the region around an astronomical object in which phenomena and processes are dominated by its magnetic field.

- Earth is surrounded by a magnetosphere,
- as are the magnetized planets Mercury, Jupiter, Saturn, Uranus and Neptune.

The term "magnetosphere" has also been used to describe regions dominated by the magnetic fields of celestial objects, e.g. pulsar magnetospheres.

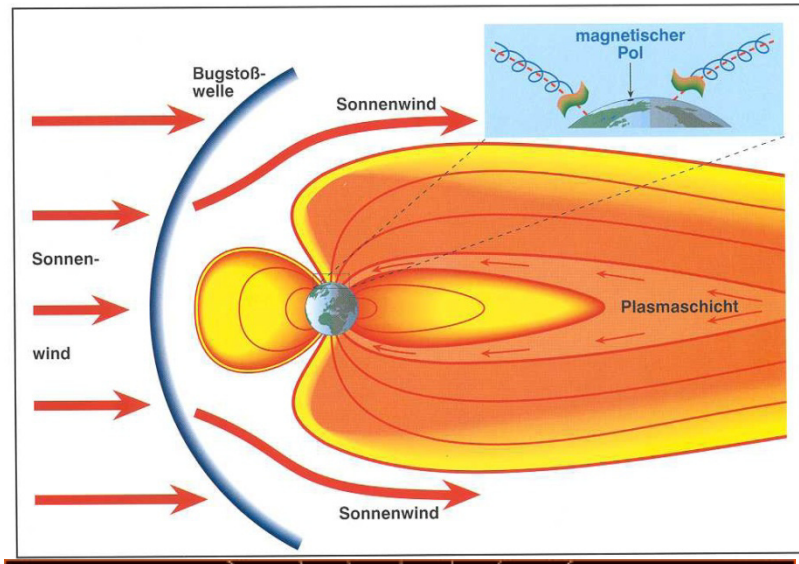


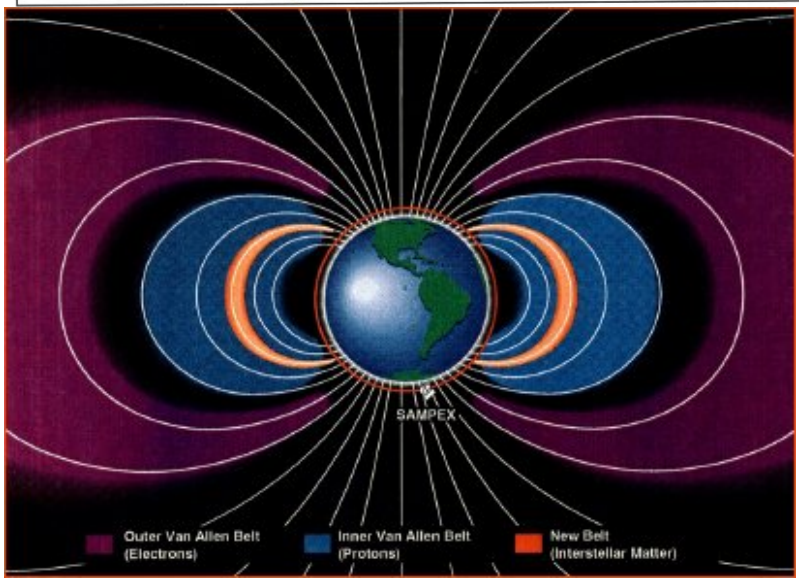
Magnetosphere

The internal magnetic field of the Earth appears to be generated in the Earth's core by a dynamo process, associated with the circulation of liquid metal in the core, driven by internal heat sources.

Its major part resembles the field of a bar magnet ("dipole field") inclined by about 10° to the rotation axis of Earth. The dipole field has an intensity of about 30,000-60,000 nanoteslas (nT) at the Earth's surface.

Its intensity diminishes like the inverse of the cube of the distance, i.e. at a distance of R Earth radii it only amounts to $1/R^3$ of the surface field in the same direction.

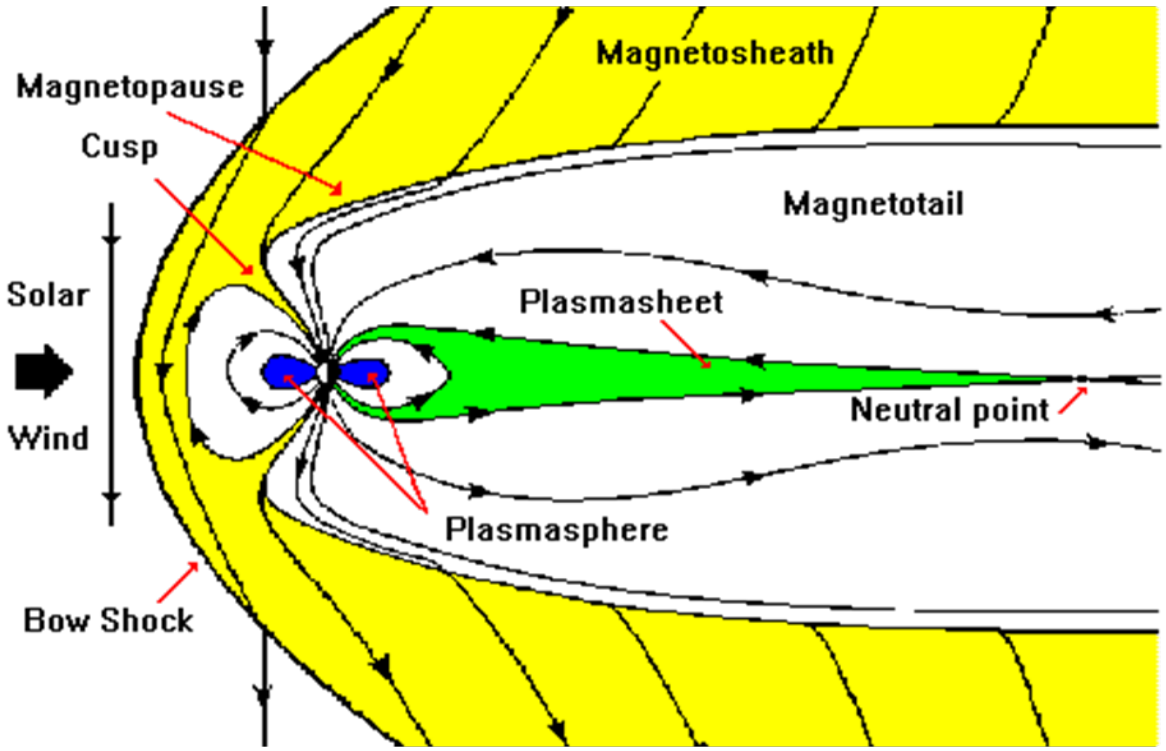




Magnetosphere

In the absence of any external drivers, the geomagnetic field can be approximated by a dipole field with an axis tilted about 11 degrees from the spin axis.

The forcing by the solar wind modifies this field, creating the cavity called the magnetosphere. This cavity shelters the surface of the planet from the high energy particles of the solar wind.

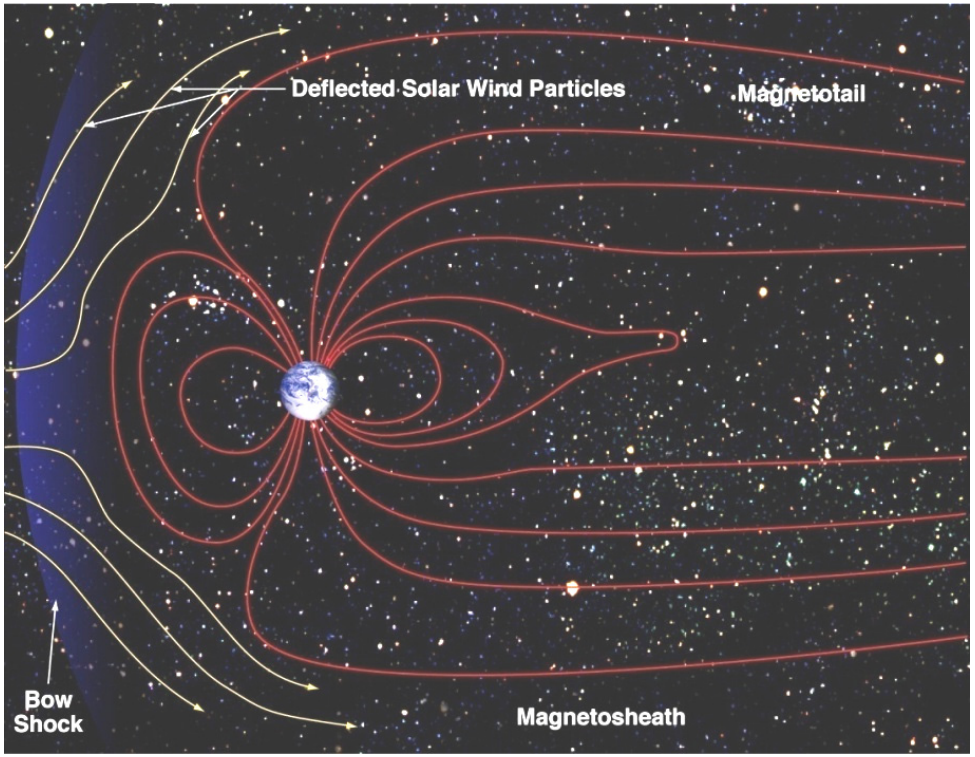


The magnetosphere is filled with plasma that originates both from the ionosphere and the solar wind.

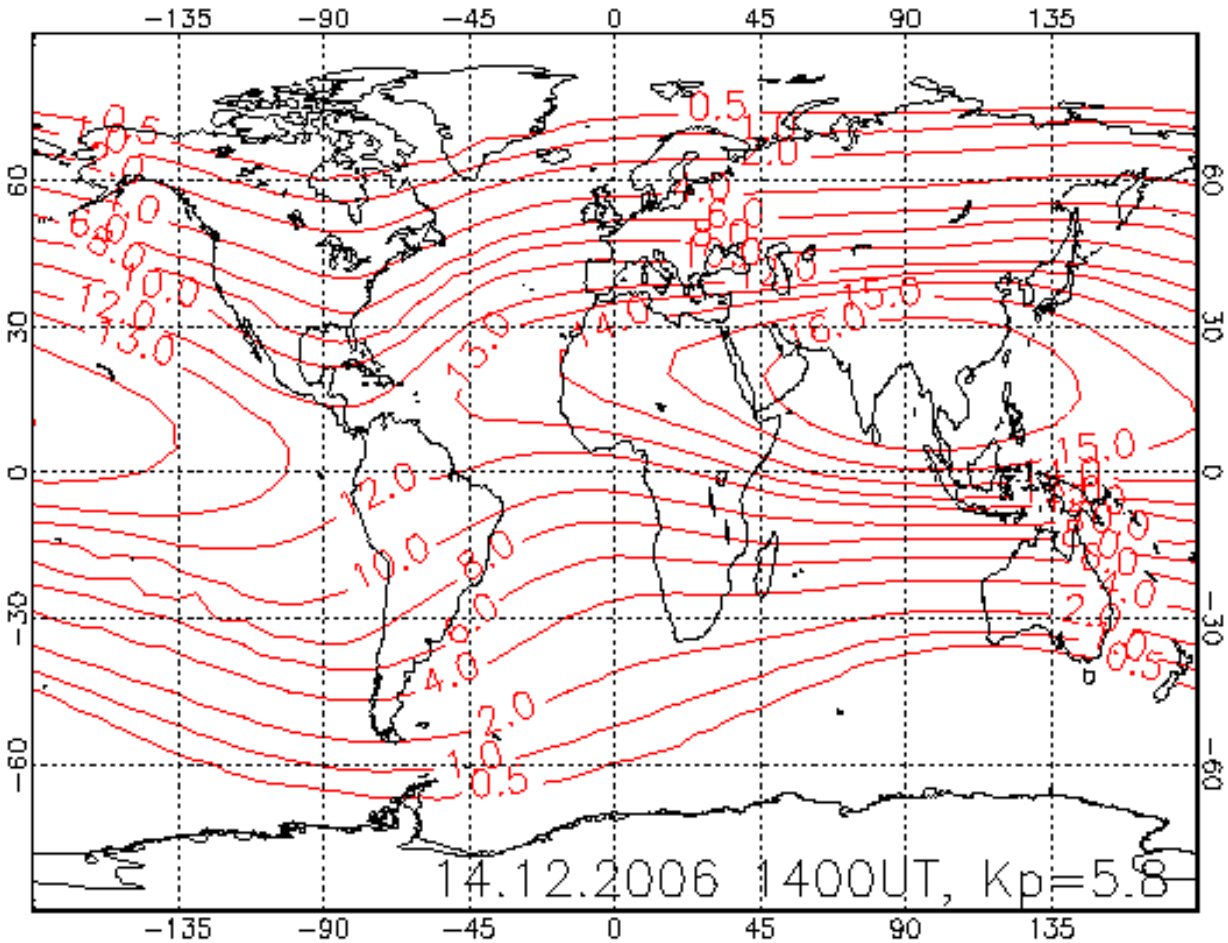
Magnetosphere

In the magnetosphere, a mix of free ions and electrons from both the solar wind and the Earth's ionosphere is confined by magnetic and electric forces. In spite of its name, the magnetosphere is distinctly non-spherical.

Particles from the solar wind and from cosmic rays are deflected by the magnetoshpere away from Earth. The magnetosphere thus provides a shielding from incoming energetic particles.



Cut-off rigidities (in GV)

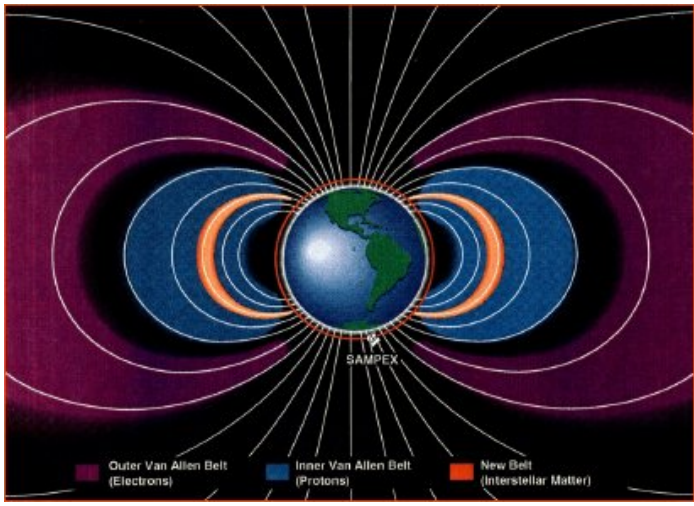


Cut-off rigidity is the energy a vertically incoming proton must have to reach ground.

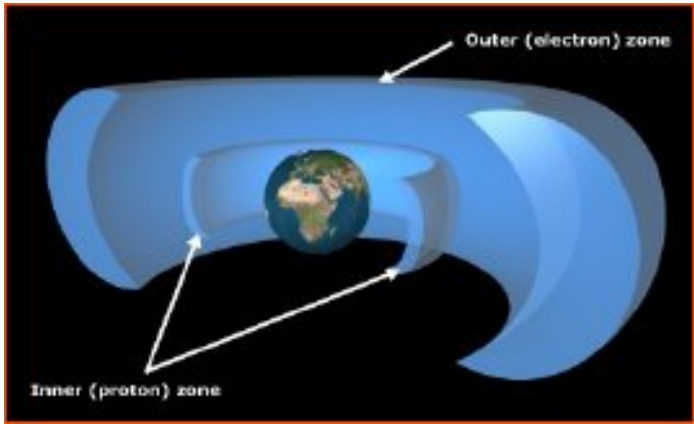
Cut-off rigidities decrease towards the poles and are largest near-by the equator.

The Radiation Belts of the Earth

The radiation belts (also called the Van Allen belts) are layers of intense particle fluxes trapped by the Earth's magnetic field. These particles are brought to Earth by the solar wind or are produced by the interaction of high-energy galactic cosmic rays with the atmosphere of the Earth. There is an inner and outer radiation belt.



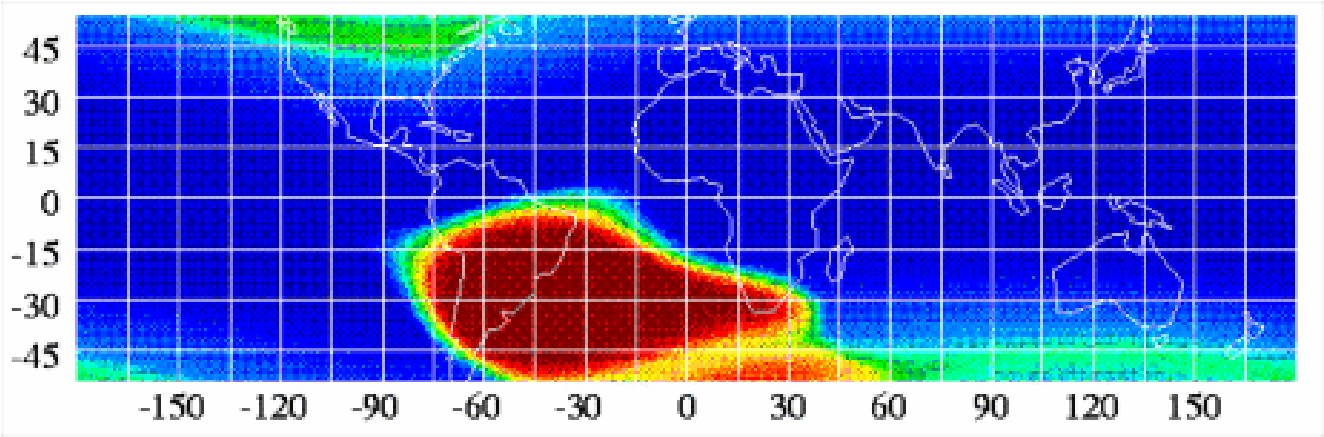
The inner belt (blue) contains predominantly high-energy protons and extends from the equator, up to 30° latitude at an altitude of about 1,000 - 10,000 km.



The outer belt, which contains high-energy electrons (purple), lies at an altitude of about 20,000 - 30,000 km and reaches 60° latitude. The intense particle fluxes in the radiation belts are hazardous to satellites, astronauts, and their equipment.

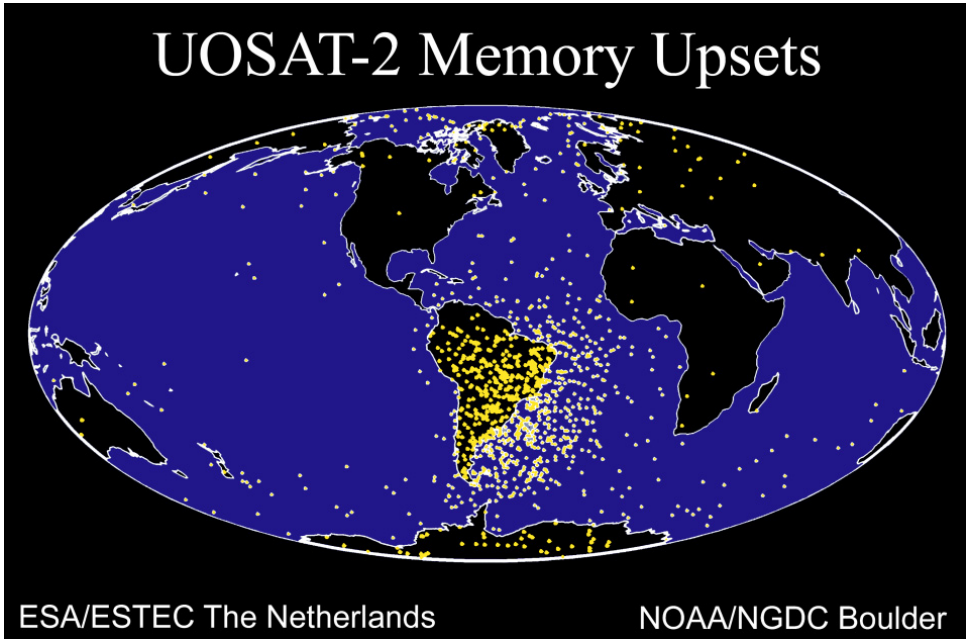
South Atlantic Anomaly

The Earth’s radiation belts are aligned with the magnetic axis of the Earth, which is tilted by 11 degrees from the rotation axis of the Earth, and are thus not symmetrically placed with respect to the Earth's surface. While the inner surface 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, the close portion of the Van Allen Belt forms what is called the South Atlantic Anomaly.



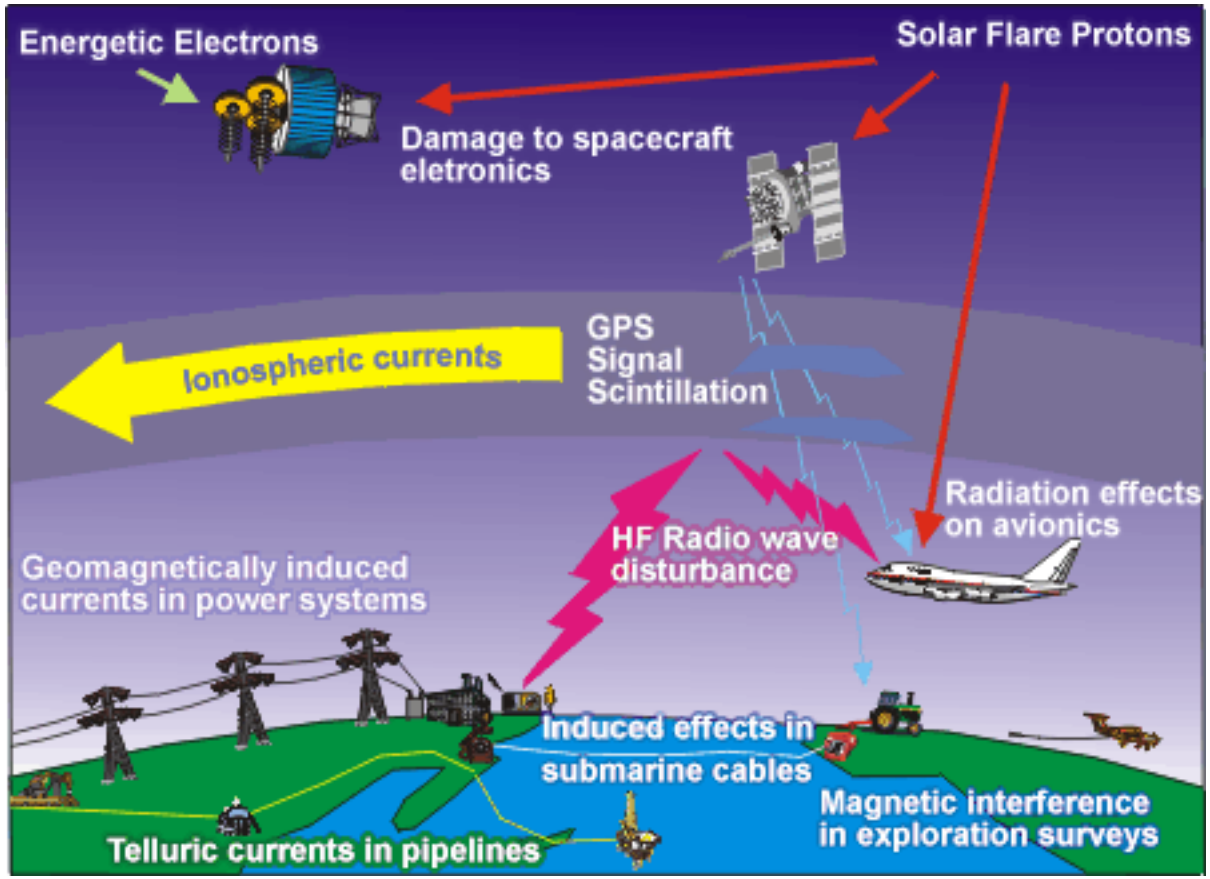
South Atlantic Anomaly

Satellites and other spacecraft passing through this region of space actually enter the Van Allen radiation belt and are bombarded by protons exceeding energies of 10 million electron volts at a rate of 3000 'hits' per square centimeter per second. This can produce 'glitches' in astronomical data, problems with the operation of on-board electronic systems, and premature aging of computer, detector and other spacecraft components.



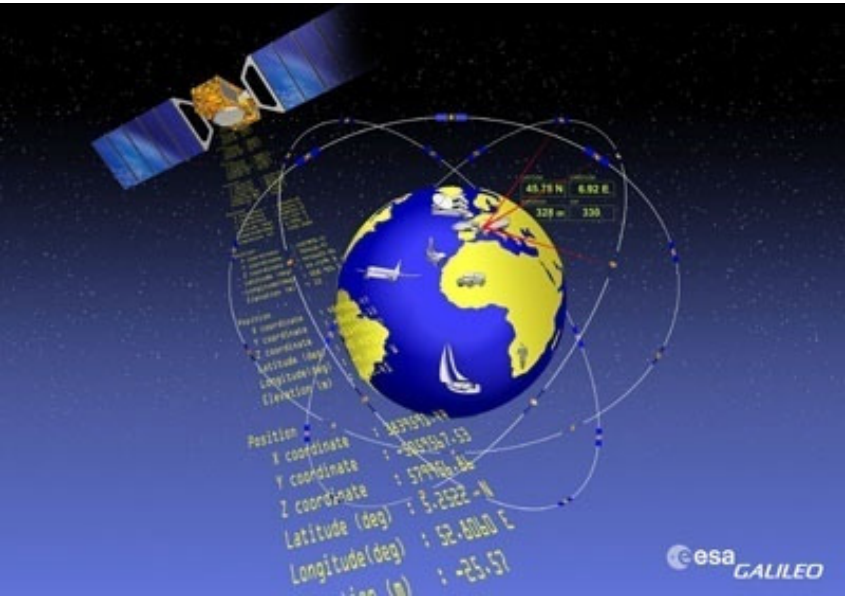
The Hubble Space Telescope passes through the 'SAA' for 10 successive orbits each day, and spends nearly 15 percent of its time in this hostile region. Astronauts are also affected by this region which is said to be the cause of peculiar 'shooting stars' seen in the visual field of astronauts.

Space weather can cause severe damages



- Electrical power grids and lines
- Oil and gas pipe lines
- Communication systems and satellites
- Navigation systems (GPS, Galileo)
- Enhanced radiation doses for aircraft crew and passengers and astronauts.

Space weather and spacecraft



Spacecraft and satellite are vulnerable to sapce weather events. We use satellites in geo-orbits for satellite-based navigation (GPS, Galileo), communication, satellite TV, weather and environmetal observagtions, etc.

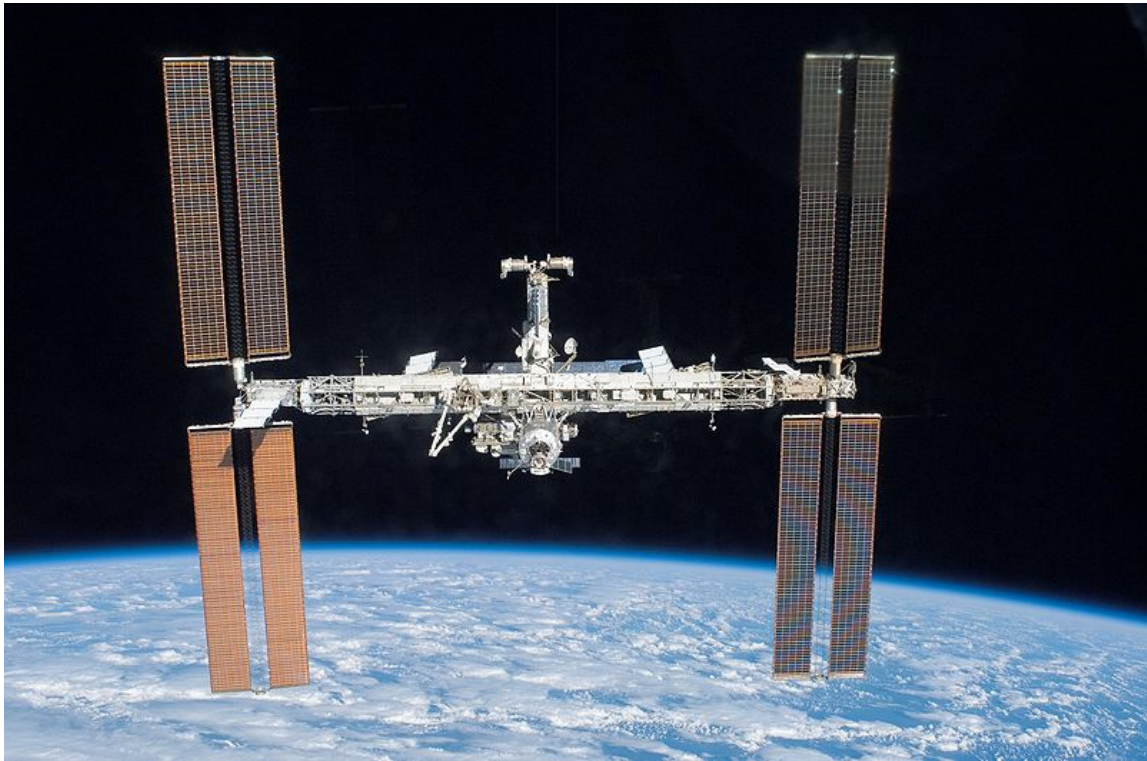
Example: Halloween Storms during October/November 2003

- 28 satellites damaged including 2 total losses
- Re-routing of aircraft due to navigation problems
- Power failure in Sweden

Space Weather and Spacecraft

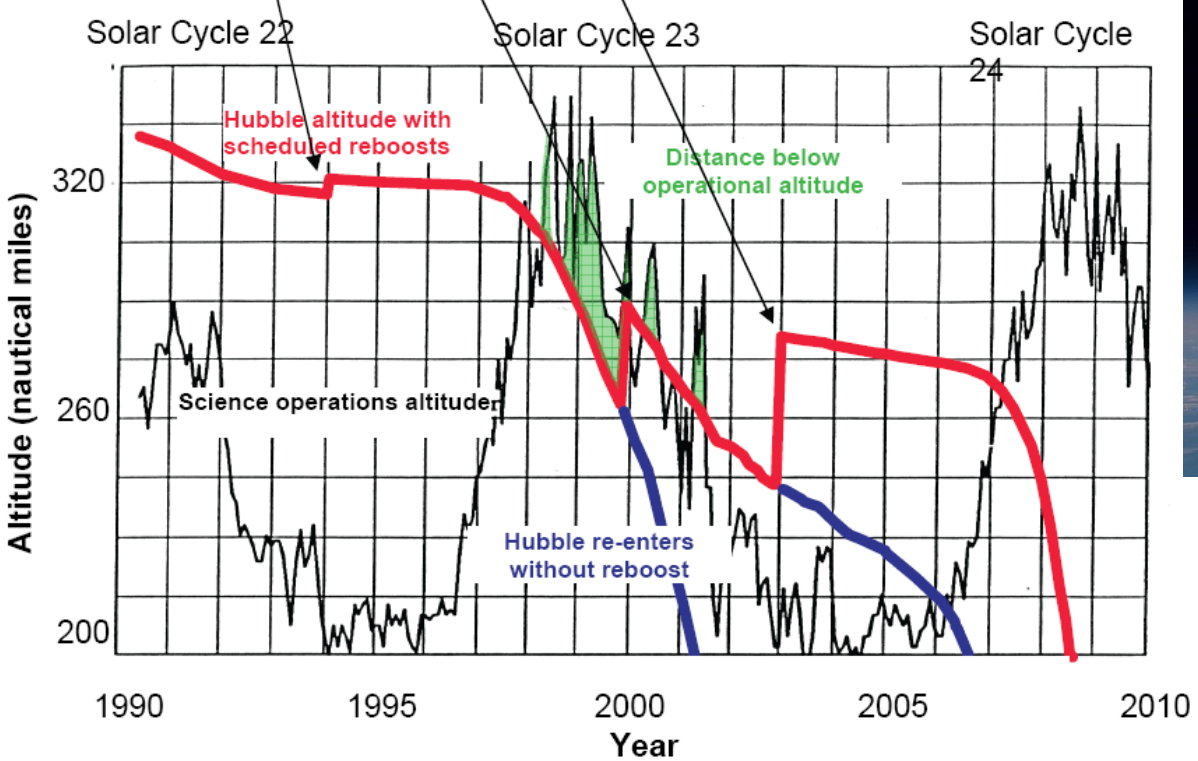
Skylab was 6 years in orbit.

Solar flares and geomagnetic storms Stürme heat the upper atmosphere. During expansion, spacecraft in low orbits (a few 100 km) experience an enhanced drag and loose height. A careful monotoring of süpacecraft orbits is required and orbits needs to be corrected by “lifting” the spacecraft.



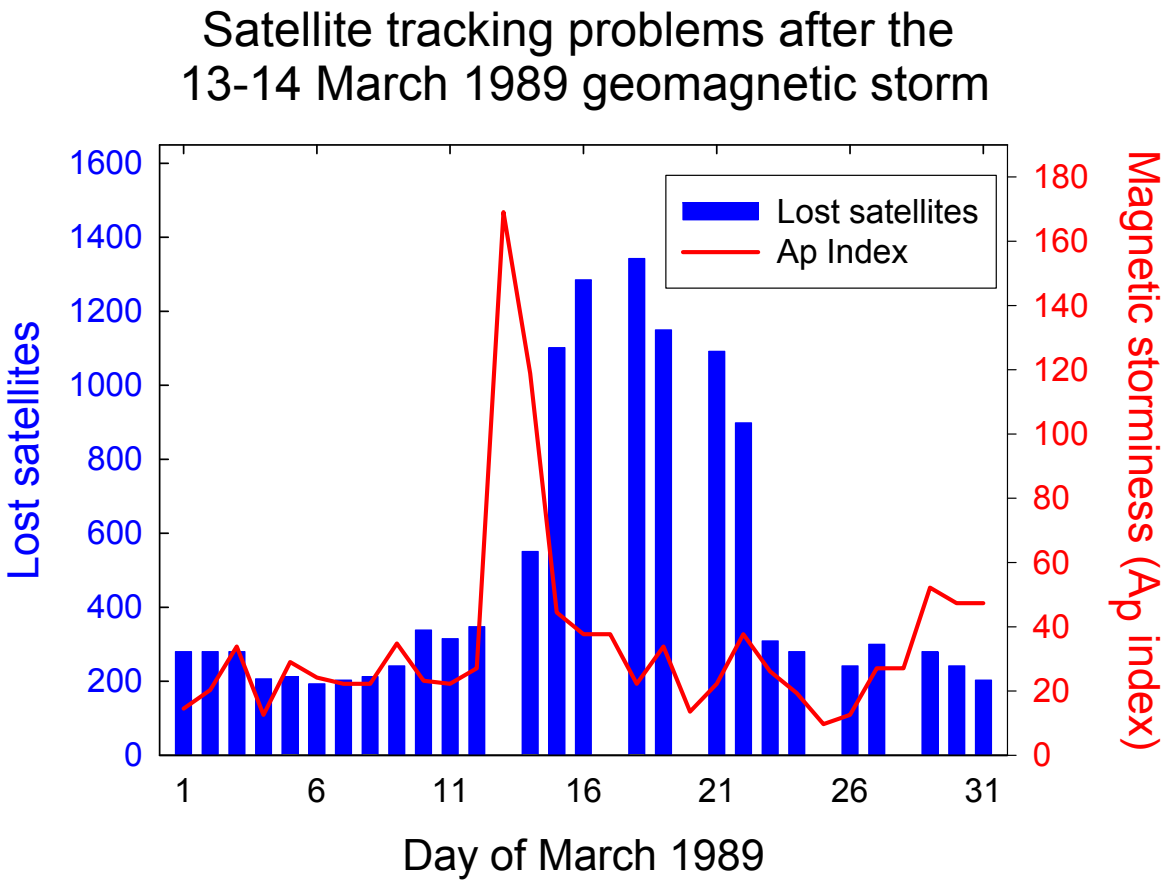
Hubble Space Telescope (HST)

Due the drag in the atmosphere the orbits decay which results in a loss of altitude. The four HST servicing missions in 1993, 1997, 1999 and 2002 were enormous successes. Without those servicing missions and the "boosting of the orbits" the Hubble Space Telescope would have downed as illustrated below by the blue lines. Boosting the orbits has extended HST's lifetime.



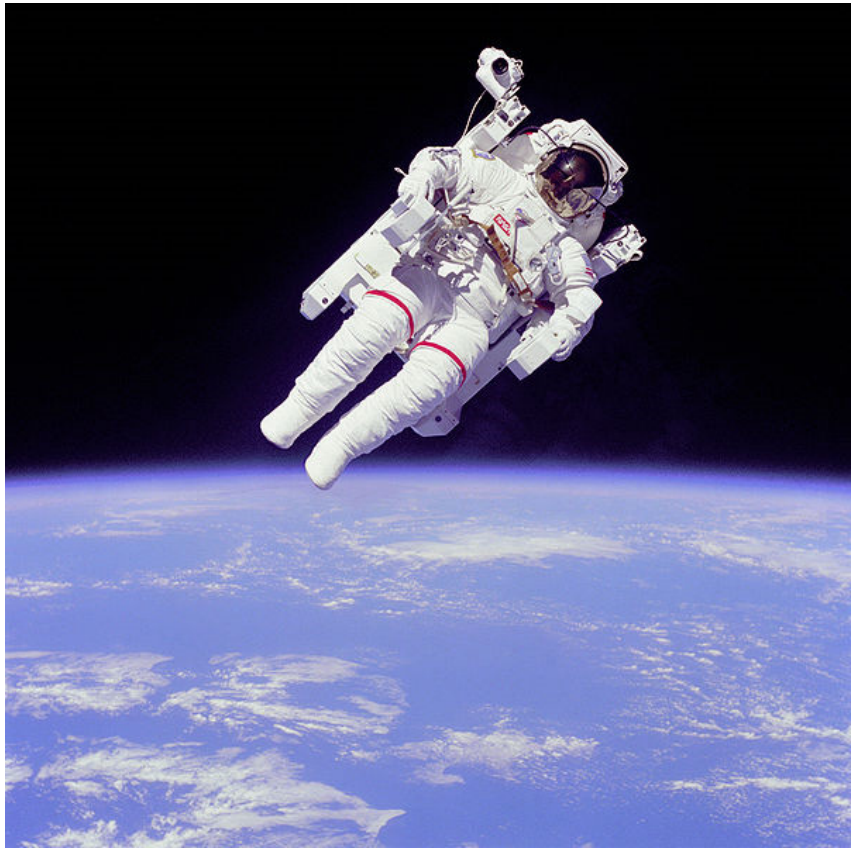
Credit G. Withbroe, NASA

Satellite positions



Tracking of satellite becomes more difficult during geomagnetic storms.

Space Weather and manned space mission.



During 13 December 2006 astronauts of the Discovery's STS-116 Space Shuttle Mission had to abandon a planned space walk and instead had to hide in better protected areas of the ISS to escape of massive X-3 Solar Flare followed by a Solar Energetic Particle Event (SEP).

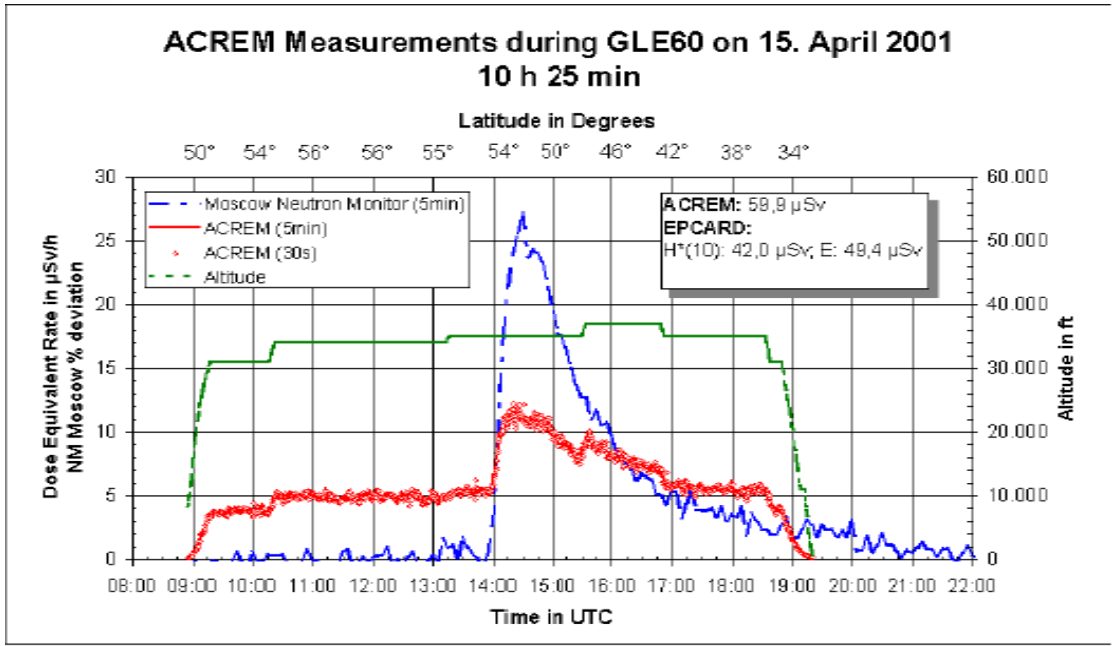
Protected areas are the shuttle middle deck, the Destiny module and the Zvezda module.

It is not clear yet how astronauts can be protected against the radiation doses due to space weather during long mission to other planets, e.g., to Mars.

Space Weather and Air Traffic

With increasing height above sea level the intentsity of Cosmic Rays increases and so does the radiation dose for aircraft crew and passengers.

Radiation dose during a flight from Frankfurt to Dallas during 15 April 2001



Solar flares and coronal mass ejections give rise to an additional radiation dose.

Geomagnetic Storms

Geomagnetic storms were first observed in 1847 in telegraph lines. Geomagnetic storms originate from Coronal mass ejections (CME) hitting Earth. Geomagnetic storms induce electrical currents in power grids and oil or gas pipelines ands can cause significant damage.

A strong geomagnetic storm at Easter Sunday 1940 lasting for more than 6 hours disrupted several telegraph and power lines in North America.

Geomagnetic storms

A rather severe geomagnetic storms – one of the biggest ever reported – destroyed on 13 March 1989 an high voltage transformer of the Hydro-Quebec electricity company in Canada. It caused an overburdening of the entire electrical power grid and a disruption of the control centers in Chibougamau, la Verendrye, Nemiscau and Albanel. It was not possible to compensate the resulting voltage loss and all of James Bay power line connections capable to carry 19 GW collapsed. The black-out lasted for 9 hours.

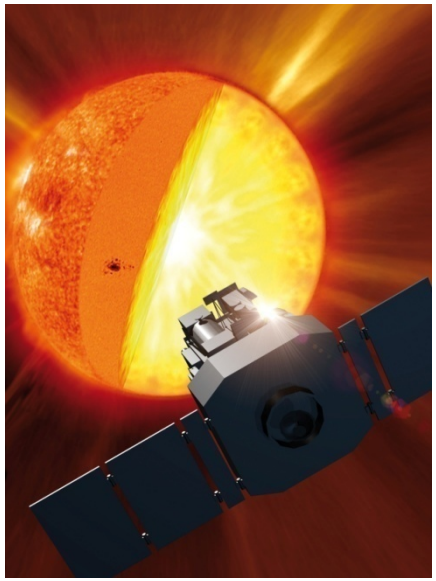
As a consequence of the 1989 Quebec Blackouts the Hydro-Quebec electricity company invested more than 1.2 billion $, by installation of, e.g., capacitor banks to suppress the geomagnetic storm-induced currents (GIC) in the power grids.

Geomagnetic storms and pipelines

Corrosion of oil and gas pipelines can prevented through the application of cathodic potential (voltage).

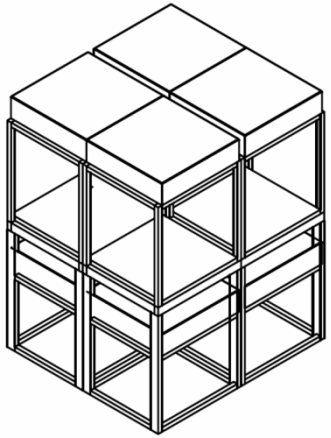
Geomagnetic storms suppress this prevention mechanism leading to an enhanced corrosion. The Alaska oil pipeline had thus to be closed in April 2006.

Space Weather Forecast



It is not yet possible to provide a reliable forecast of space weather events. Most forecasts are based on satellite observations, making usage of satellites like SOHO, STEREO, GOES, and ACE.

Forecast of space weather events could eventually be provided by a network of ground-based particle detectors, e.g., the Greifswald muon telescope MuSTAnG.



SWEETS

Space Weather and Europe -
an Educational Tool with the Sun

Home Contact Imprint

www.sweets2007.net

- Home
- Activities
- Media
- Arts & Space Weather
- Consortium
- Contact
- Links

SWEETS Coordinator

Prof. Dr. Rainer Hippler
Institut für Physik
Universität Greifswald
Felix-Hausdorff-Str.6
17489 Greifswald
Germany

E-mail: Hippler@physik.uni-greifswald.de

Telephone: +49-3834-864780
Telefax: +49-3834-864701

Space Weather and Europe - an Educational Tool with the Sun (SWEETS)

Space Weather and Europe - an Education Tool with the Sun (SWEETS) is related to Space Weather and Solar Activity.

SWEETS is funded by the European Commission within the 6th framework programme.

SWEETS is supported by COST actions 724 & 296 and by the International Heliophysical Year (IHY) 2007.

Space Weather

Space weather is defined by the conditions on the Sun and in the solar wind, the Earth's magnetosphere, ionosphere, and atmosphere. Space weather is primarily an astronomical phenomenon due to solar activity and cosmic rays and its study is by nature interdisciplinary and encompasses various fields of physics, engineering, and human activity. As such, space weather has significant impacts on our technological infrastructure, in particular on communication and navigation systems, has caused satellite failures and losses, electricity cut-offs, increases pipeline corrosion, and enhanced radiation exposure to aircraft crew and passengers and to astronauts.

SWEETS

SWEETS is a public outreach activity and encompasses some of the activities of the International Heliophysical Year (IHY). The SWEETS consortium has 17 members from all over Europe including Austria, Belgium, France, Germany, Latvia, The Netherlands, Norway, Poland, Portugal, Slovakia and Turkey.

SWEETS Activities

Main activities of SWEETS are

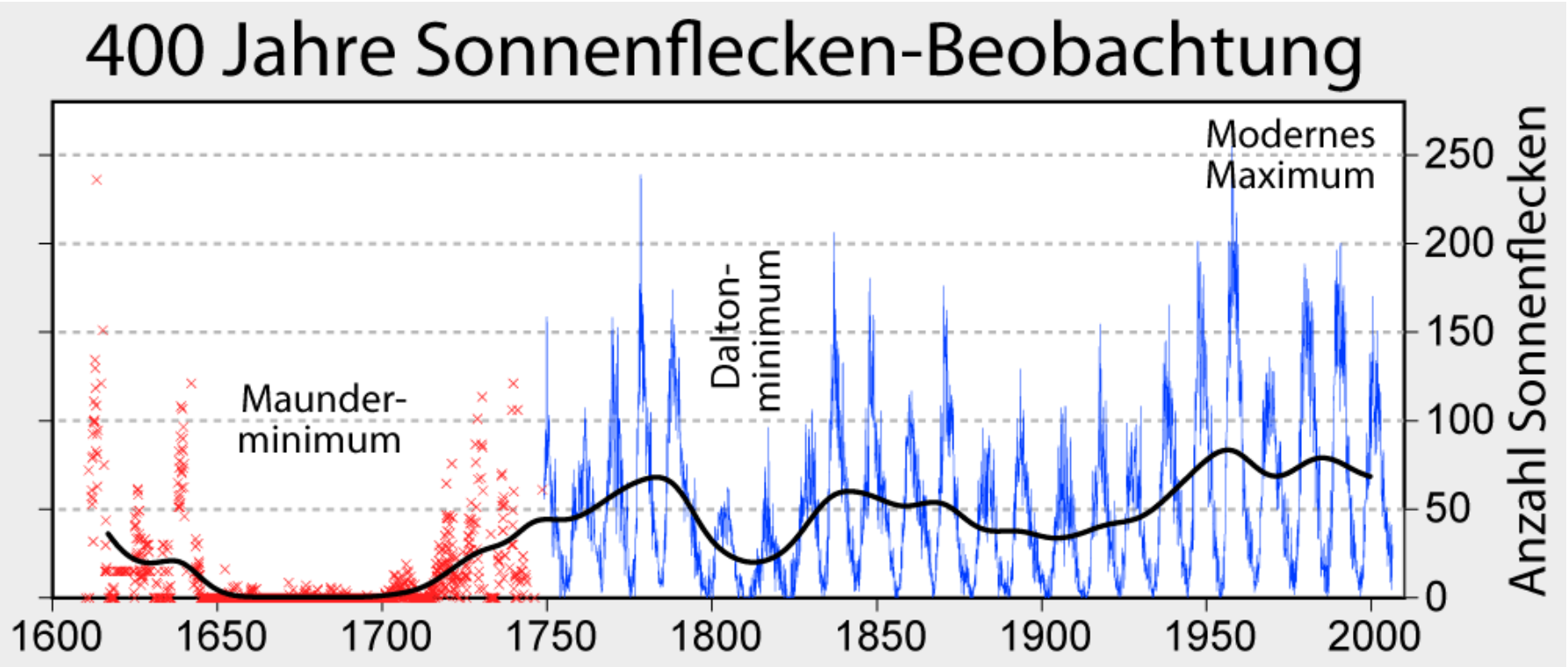
i. Organisation of a Space Weather Science Festival/Forum and a Space Weather Fair during the European Science Week in November 2007 featuring
ii. a "Solar Storm" dance show, and
iii. a video link connecting to the Muon Space Weather Telescope Site in Hobart (Australia),
iv. a Space Weather mobile bus tour through Europe including a Space Weather poster panel exhibiton,
v. Support of local science festivals on Space Weather all over Europe,
vi. Organisation of a web quiz on Space Weather. Local winners are invited by participating institutions, the main winner was invited to a
vii. Rocket launch at Andoya Rocket Range (Norway) in August 2007
viii. a "Space Weather" film,
ix. a Space Weather Planetarium show, and
x. a Space Weather DVD.

SWEETS Final Report (pdf, 10 MB)

AUSTRIAN RESEARCH CENTERS

www.sweets2007.eu

Space weather and climate ?




Thank
You