The Stormy Sun - How does it affect our technology based society

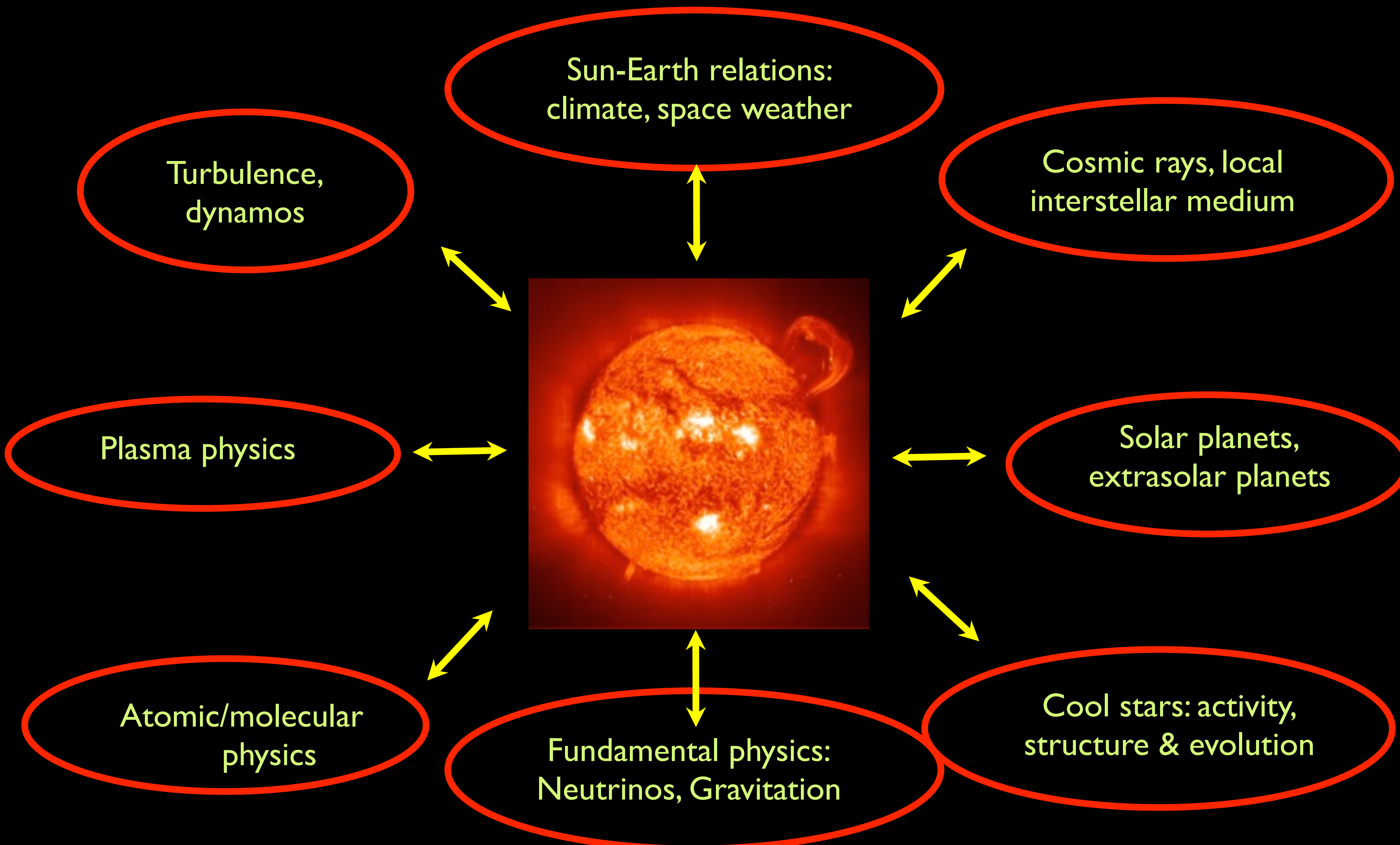
Pål Brekke
Norwegian Space Centre

Not every kind of storm shows up on weather radar...

The Sun

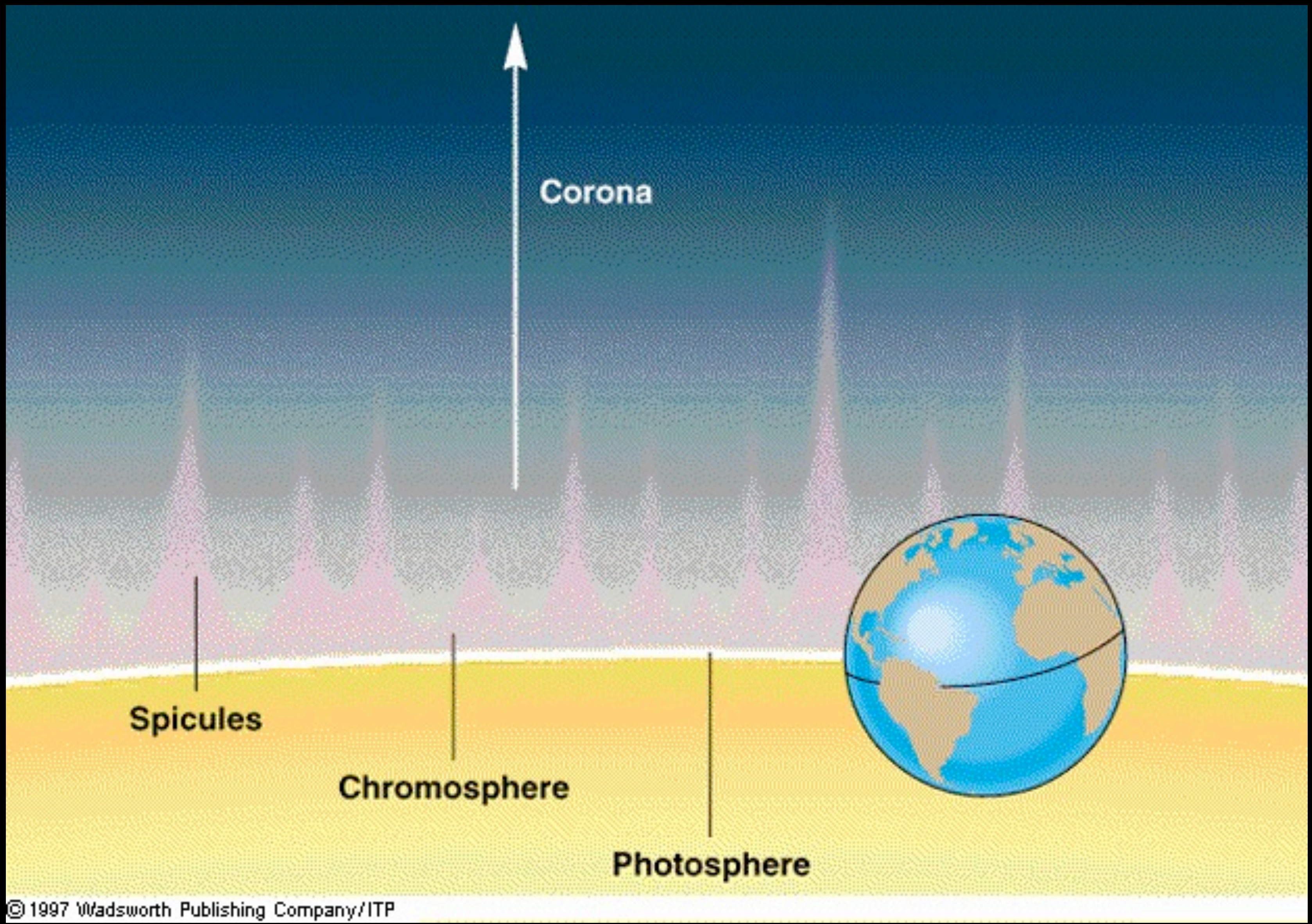
- The Sun is a normal star: middle aged (4.5 Gyr) main sequence star of spectral type G2
- The Sun is a special star: it is the only star on which we can resolve the spatial scales on which fundamental processes take place.
- The Sun is a special star: it provides almost all the energy to the Earth
- The Sun is a special star: it provides us with a unique laboratory in which to learn about various branches of physics.
- The Sun is a special star: affects our technology based society and climate

Solar Physics in Relation to Other Fields

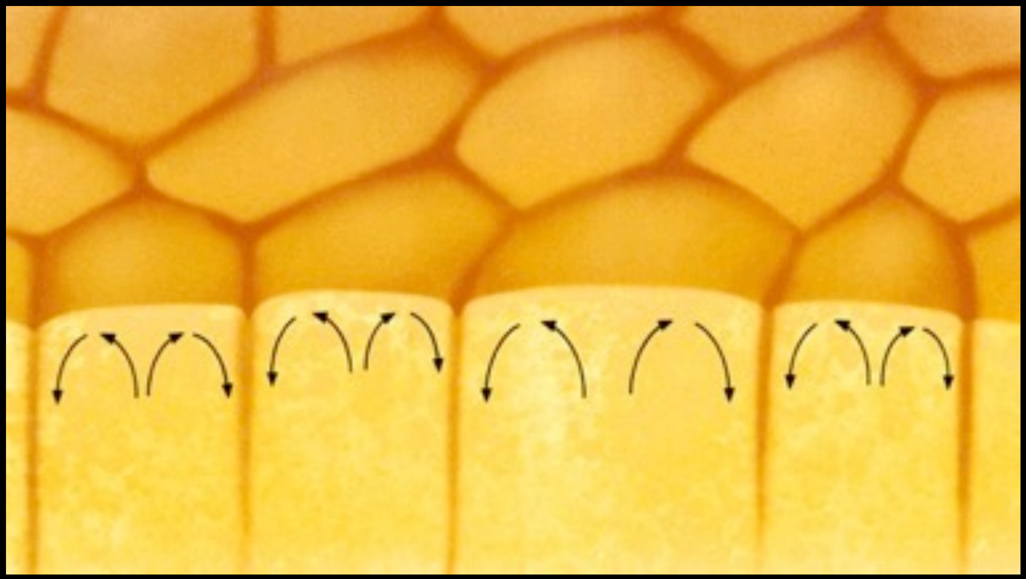


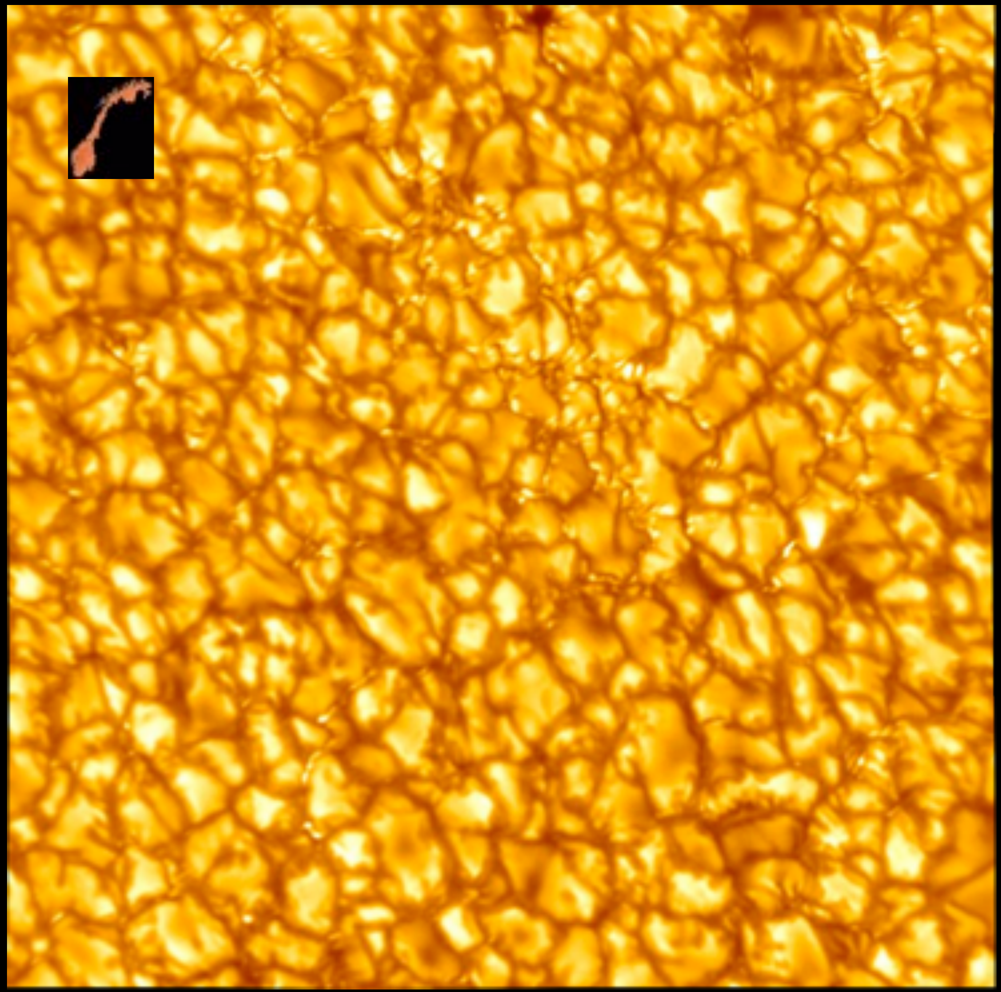
The Sun's atmosphere

- The solar atmosphere is generally described as being composed of multiple layers, with the lowest layer being the photosphere, followed by the chromosphere, the transition region and the corona.
- In its simplest form it is modelled as a single component plane-parallel atmosphere.



THE SOLAR SURFACE – THE PHOTOSPHERE


NASA

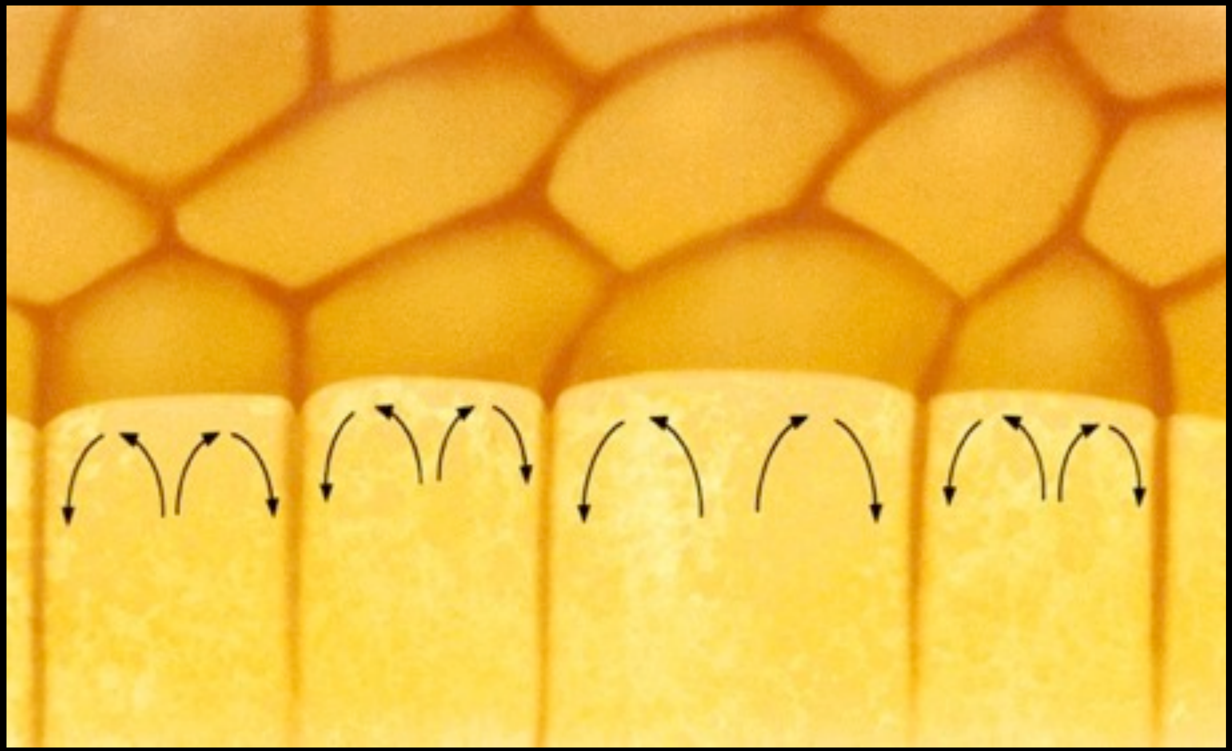

Hinode/NAOJ

Most of the energy from the Sun is radiation out from the surface, which we call the photosphere. This is the part of the Sun we actually can see from the Earth with the naked eye (see picture on the right). The photosphere is not a solid surface but a layer of gas and part of the Sun's atmosphere.

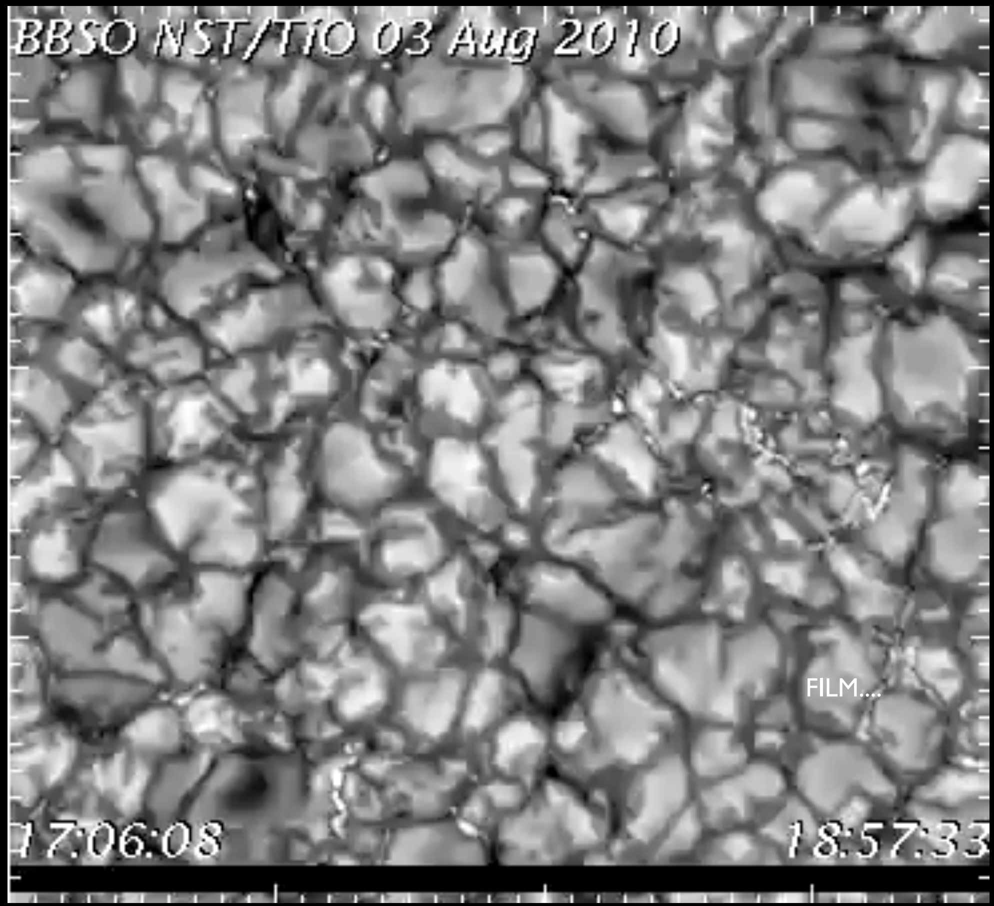
We still call this layer for the surface. It is about 400 kilometres thick and holds a temperature of about 5000 C. It is covered by a cell-like pattern we call granulation and shows how hot gas bubbles up from deeper layers, cools down at the surface and sinks down again in thin darker lanes. This is similar to what you can see in a pot of simmering soup.

The granules are about 1000 km in diameter with a lifetime of about 8 minutes. In recent years one has also discovered that the photosphere moves up and down about 15 km with different periods.

THE SOLAR SURFACE – THE PHOTOSPHERE



NASA



FILM....

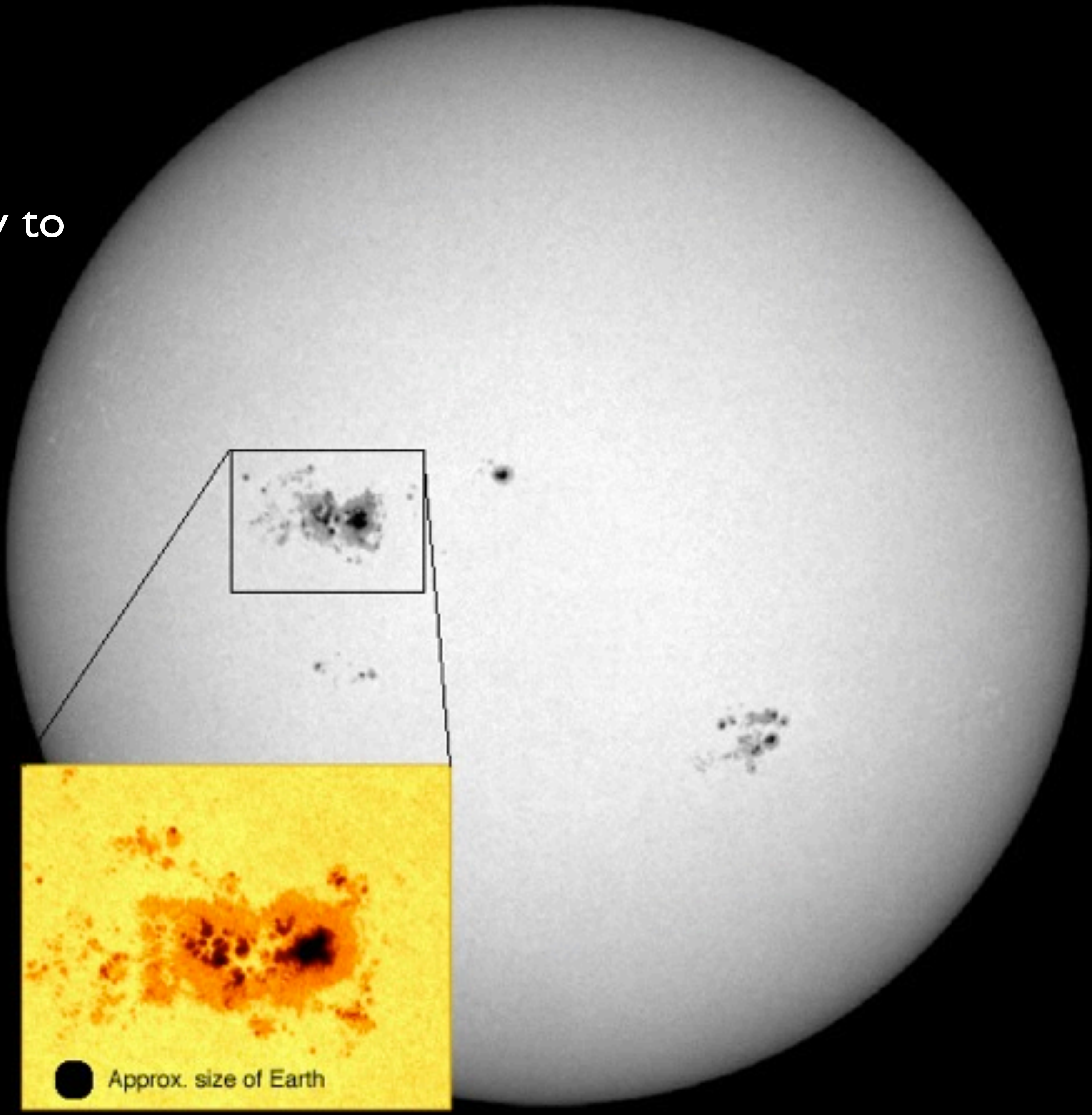
SUNSPOTS

Dark features on the solar surface

Casued by strong magnetic fields emerging from the solar interior.

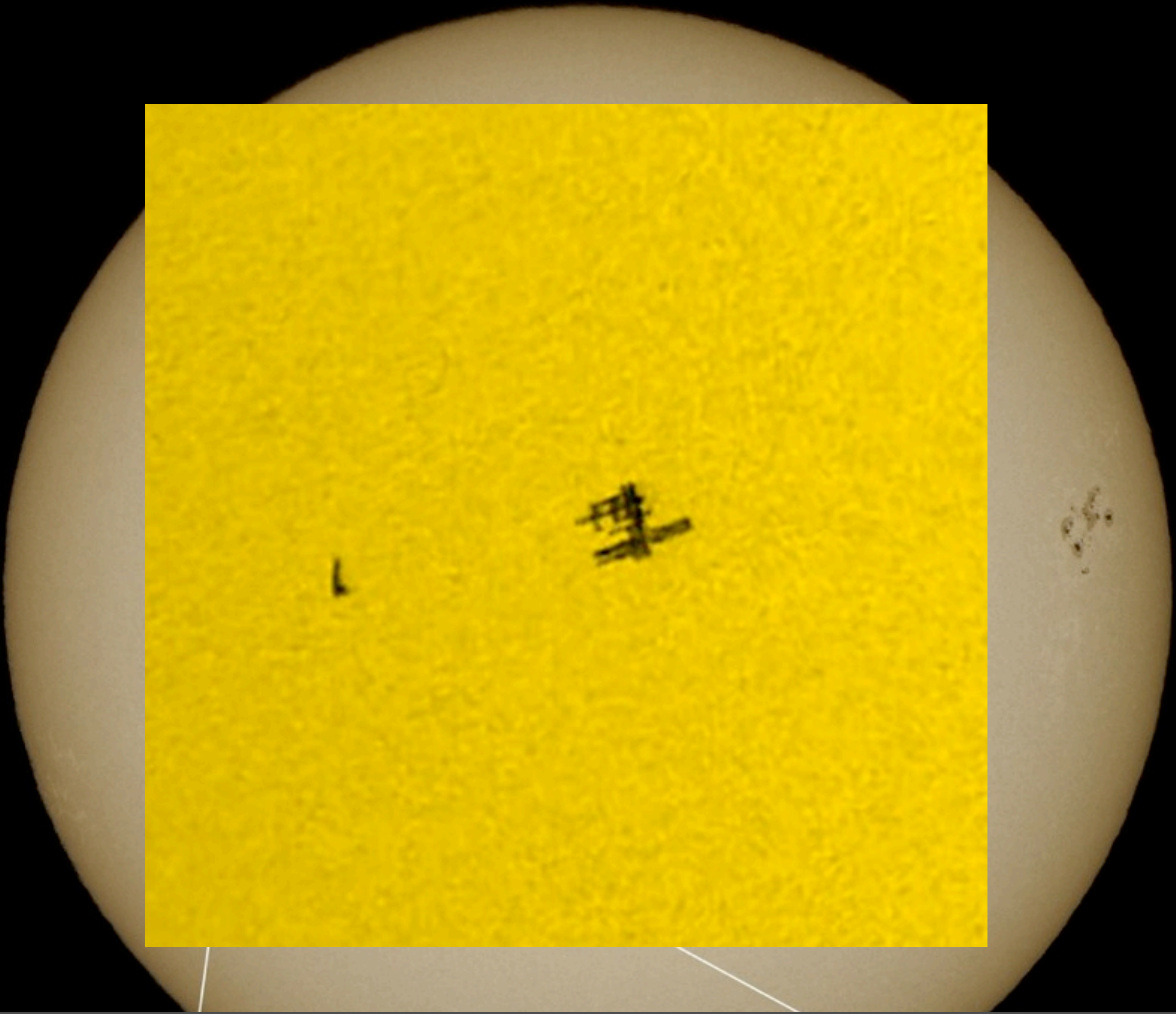
The strong magnetic fields blocks some of the energy to emerge from these regions.

NASA

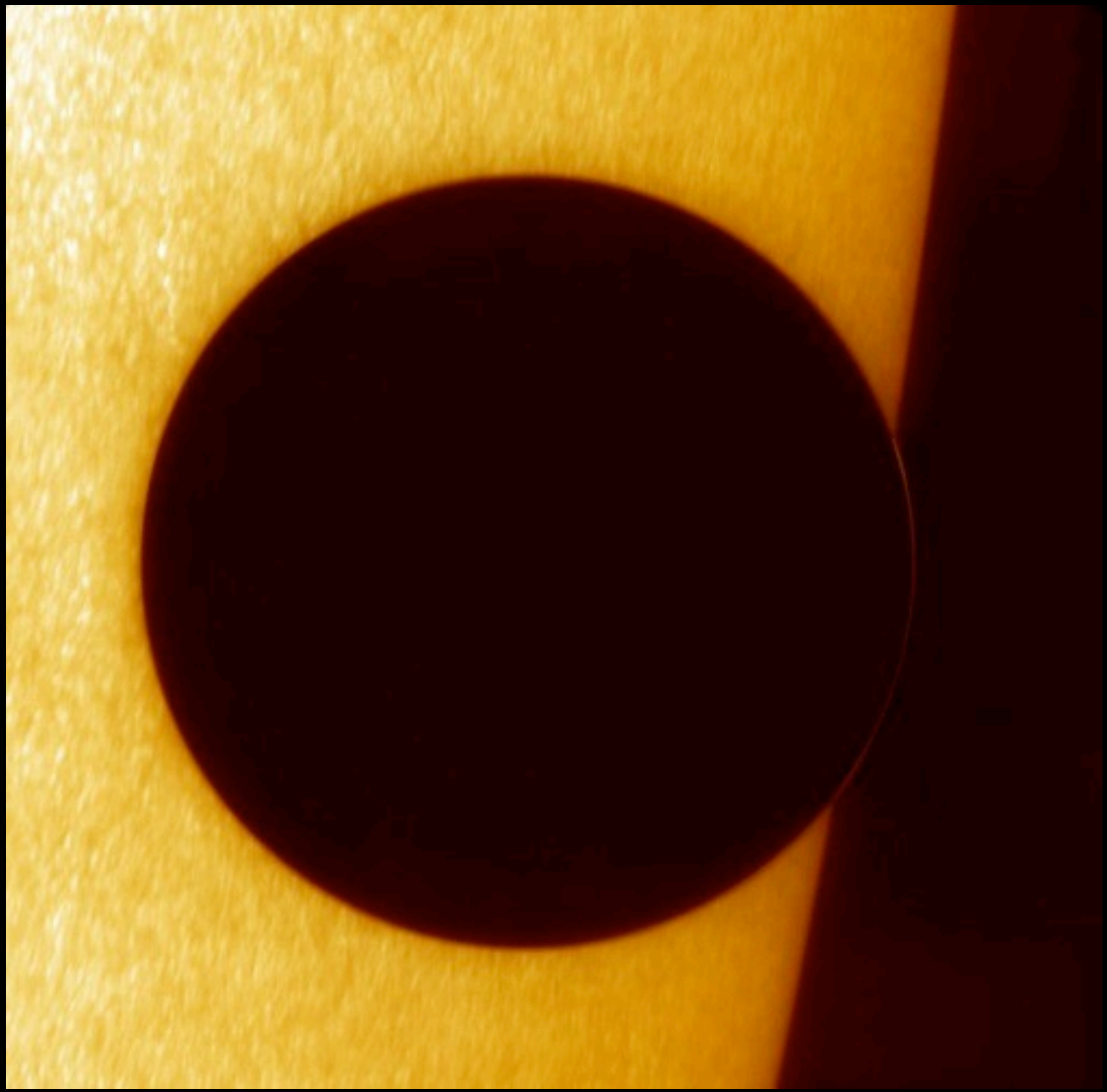


NASA/ESA/S. Hill

Sunspots???

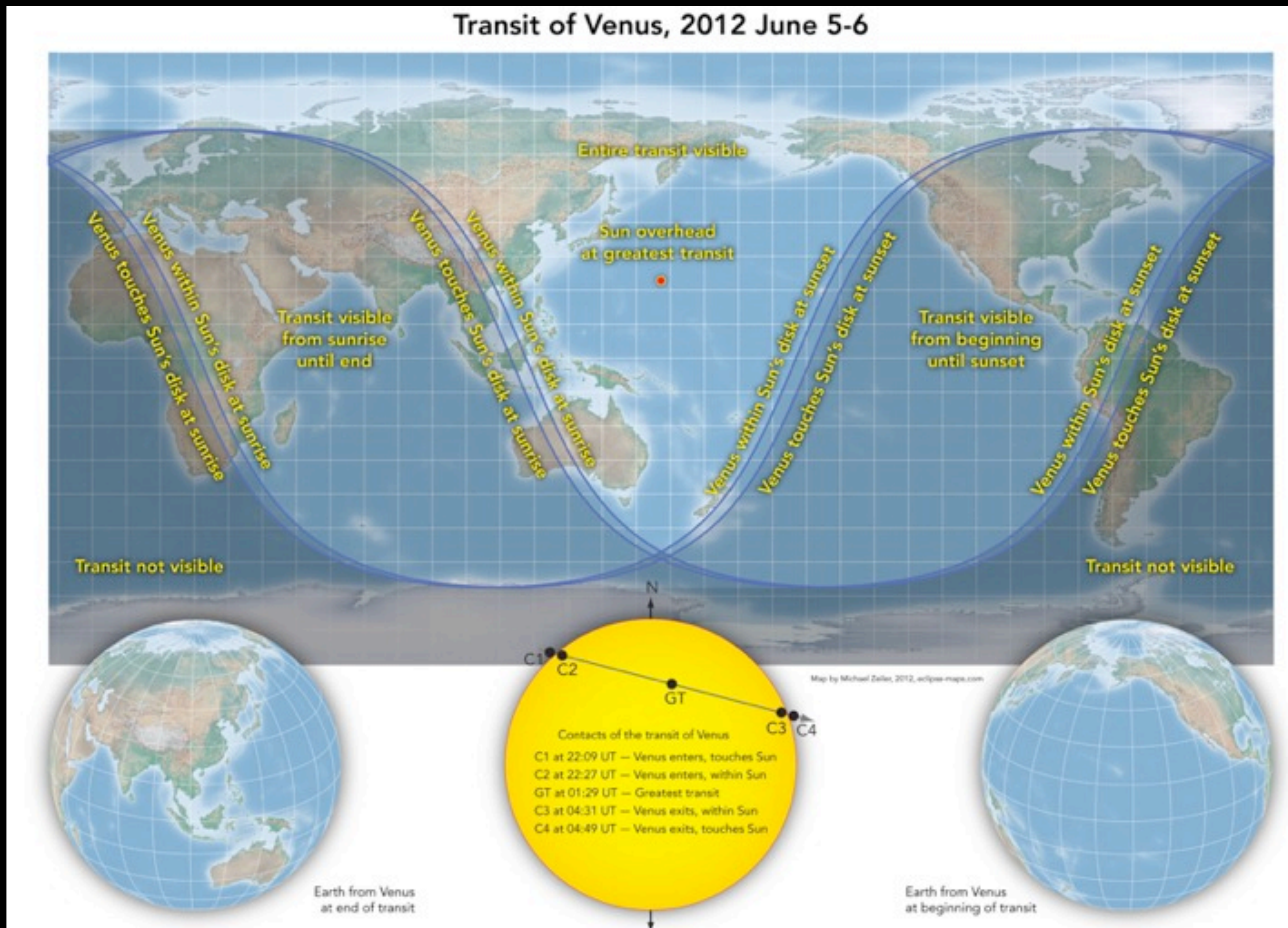


Venus transit 2004

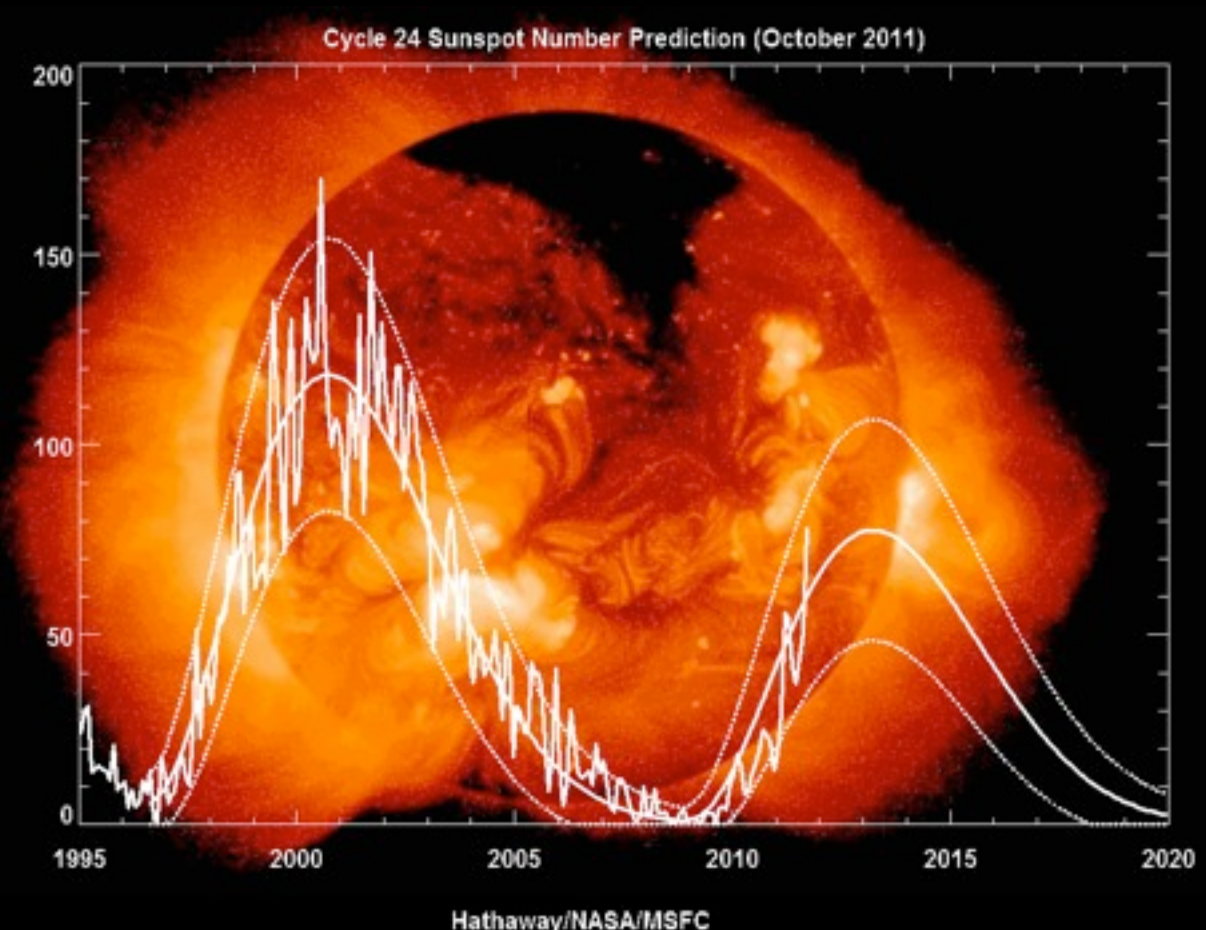


Historical Venus transit on 6 June 2012

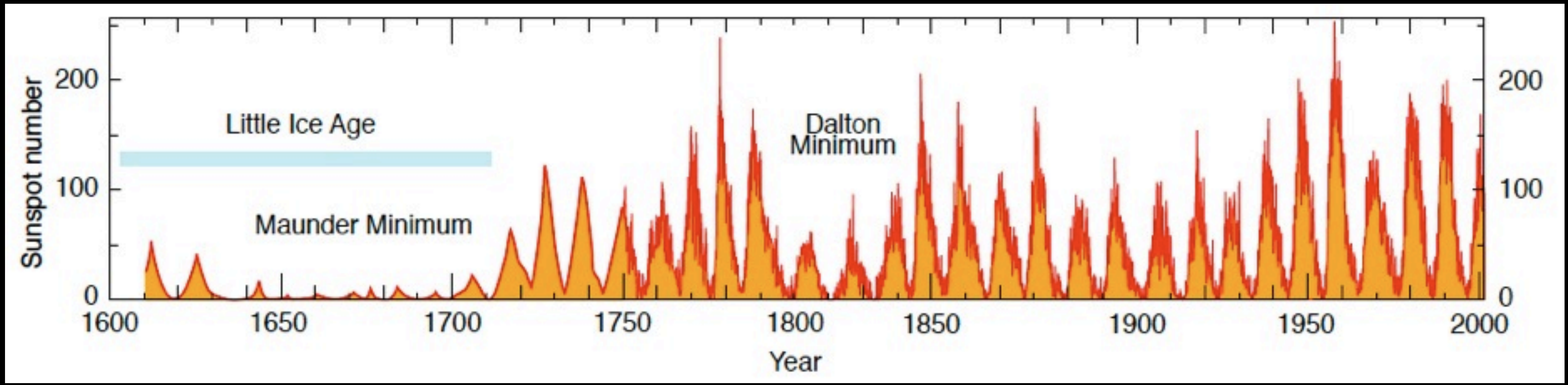
Next one in 2117



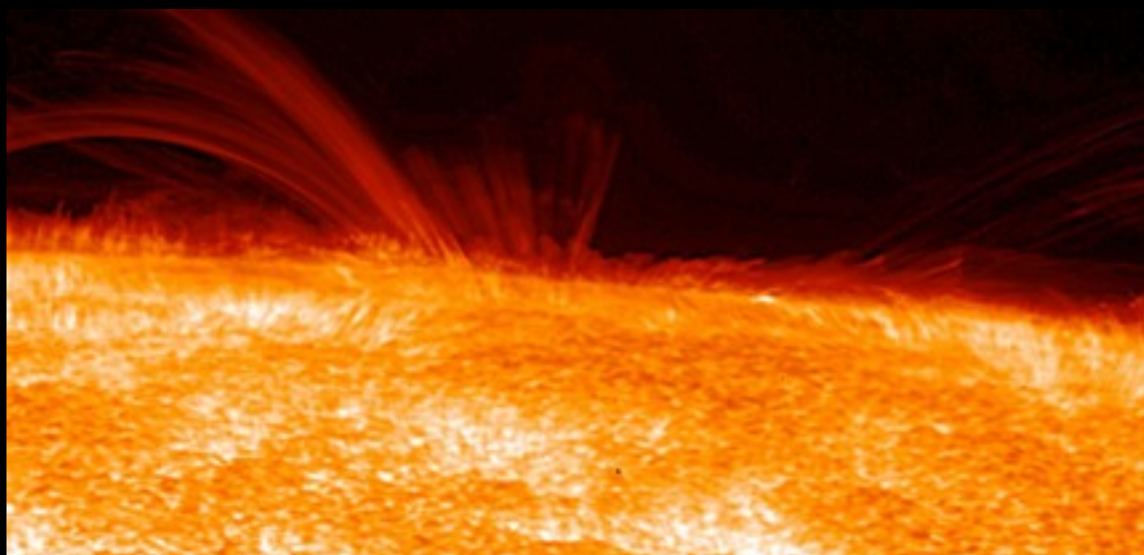
Historical sunspot records



I 1610 pekte Galileo og Thomas Harriot teleskopet mot Solen for første gang. Galileo skadet synet p.g.a. disse observasjonene.



THE SUN´S ATMOSPHERE – THE CHROMOSPHERE



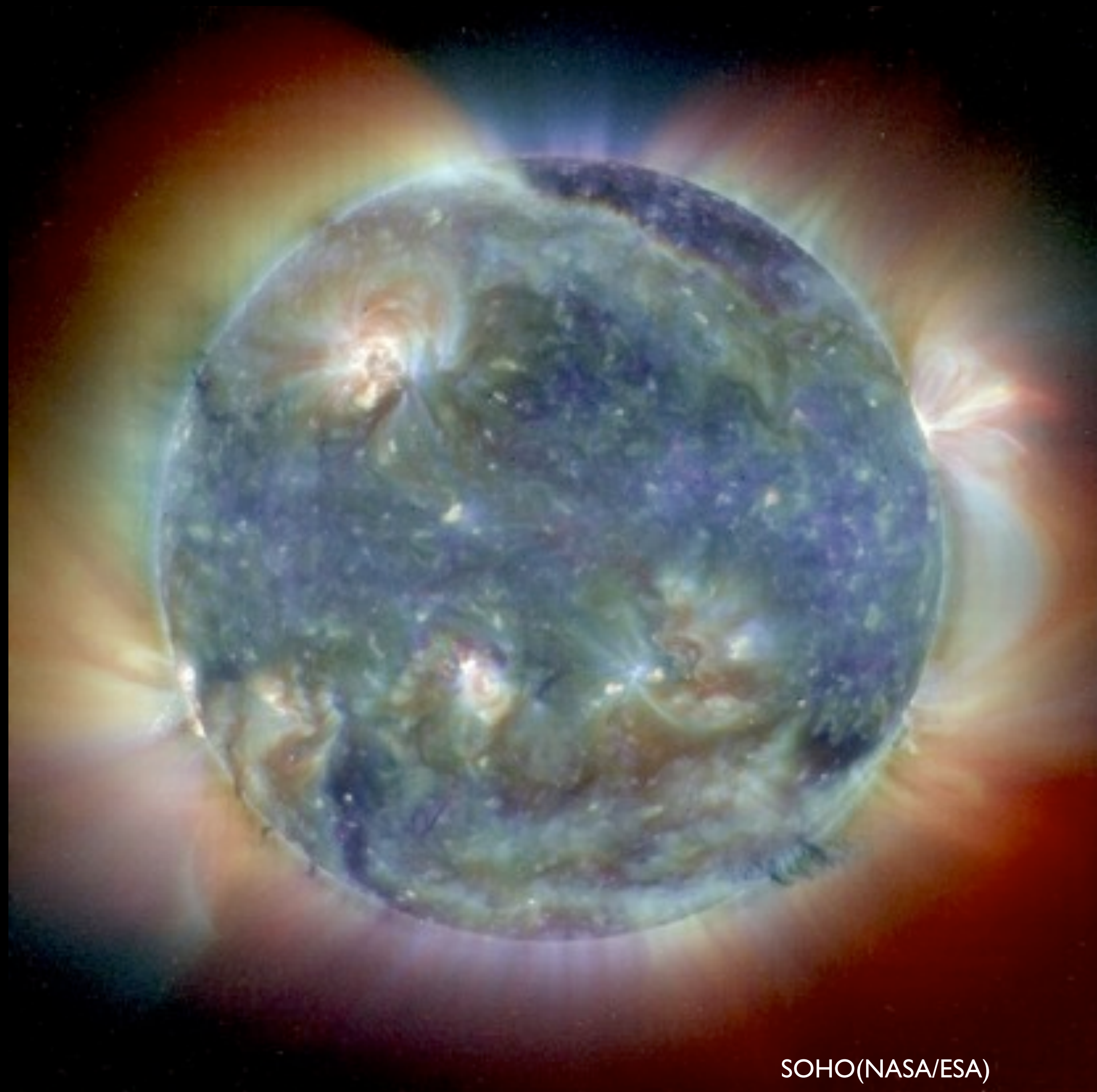
Hinode/Jaxa

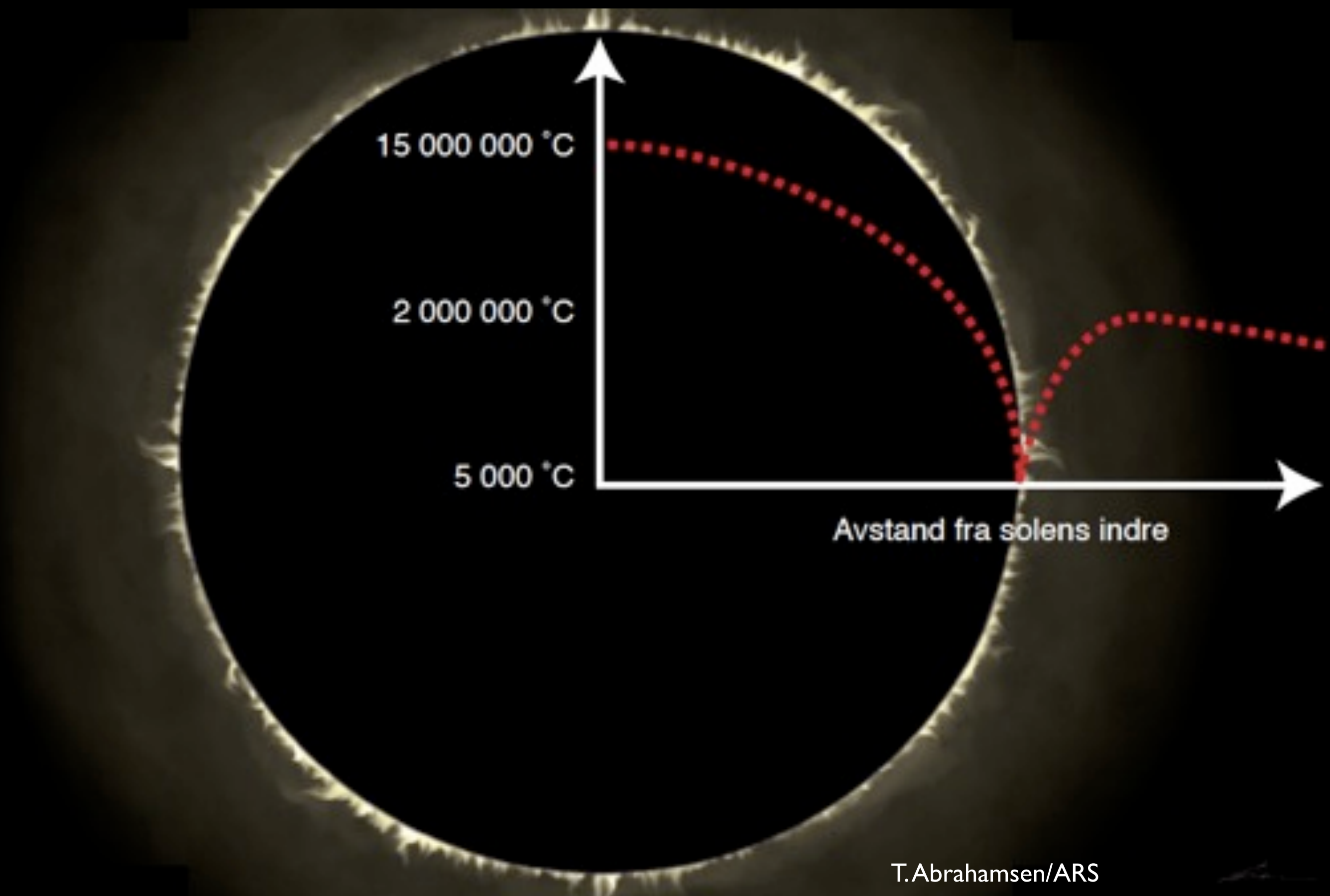
SOHO(NASA/ESA)

Above the photosphere we fond the lower solar atmosphere called the chromsopehre. It is a pinkish layer of gas that can only bee seen during a total eclipse or by using special telescopes preferable in space. The chromosphere means “colour sphere”. It extends 3000 km out from the photosphere

In the lowest part of the chromosphere the temperature continue to decrease down to about 4500 C. But then something strange happens – the temperature starts to increase again as we move further out. In the outer part of the chromosphere the temperature reaches 30,000 -70,000 degrees. This layer is mainly emitting ultraviolet radiation and thus, cannot be studied in detail from the ground.

THE OUTER SOLAR ATMOSPHERE – THE CORONA

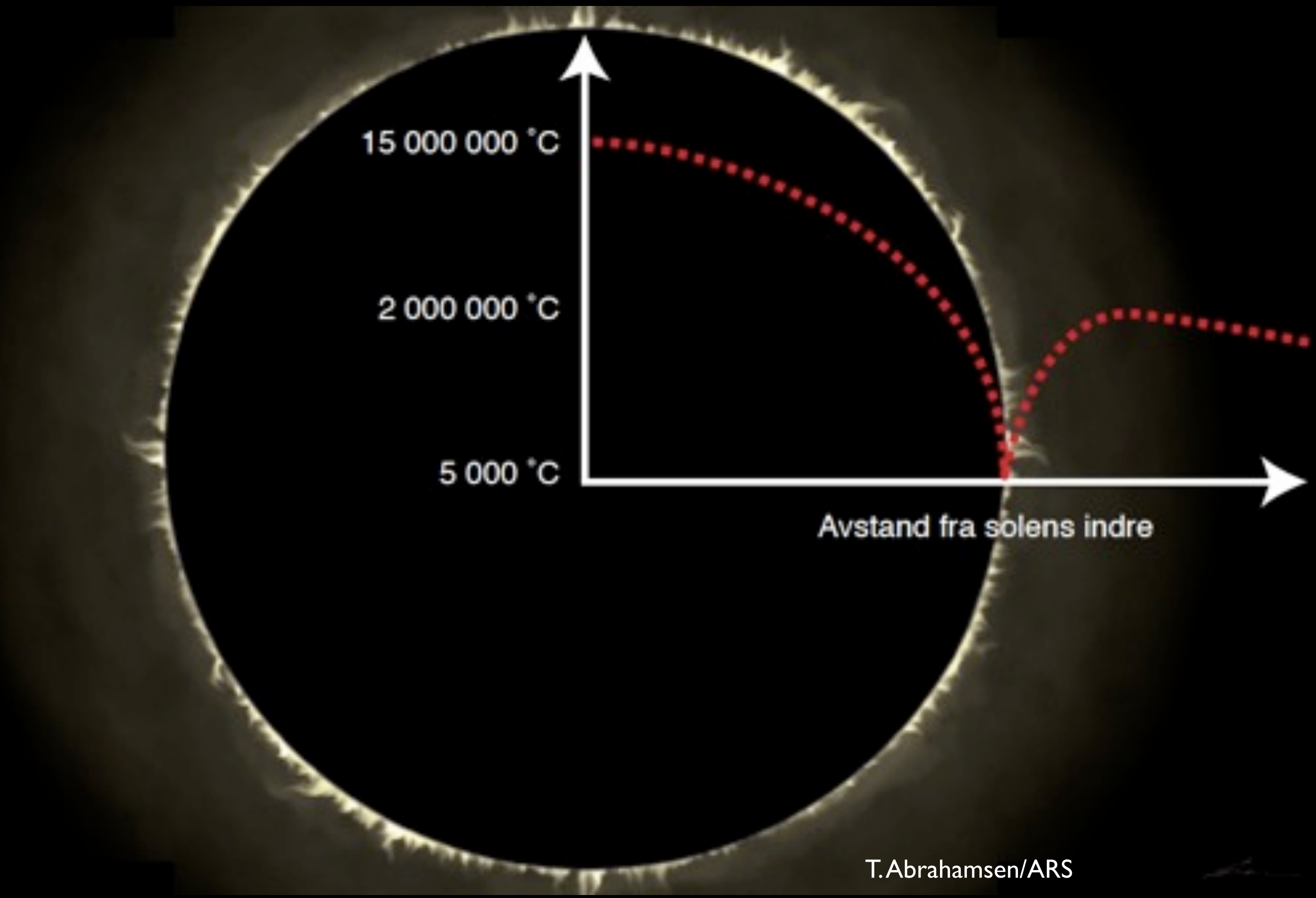




The corona is the outer part of the solar atmosphere and consists mostly of hydrogen gas. The temperature is between 1 and 2 million degrees. The density is very low, less than a millionth of the air density at Earth. The corona emits very little light so it is impossible to see it every day due to the strong light from the photosphere and the scattered light in the Earths atmosphere. Only during a total solar eclipse, when the Moon passes in front of the Sun and blocks the strong light from the photosphere, can we see the spectacular corona with the naked eye. With special telescopes that make artificial eclipses it is possible to study the corona.

WHY IS THE CORONA HOT?

SOT/Hinode



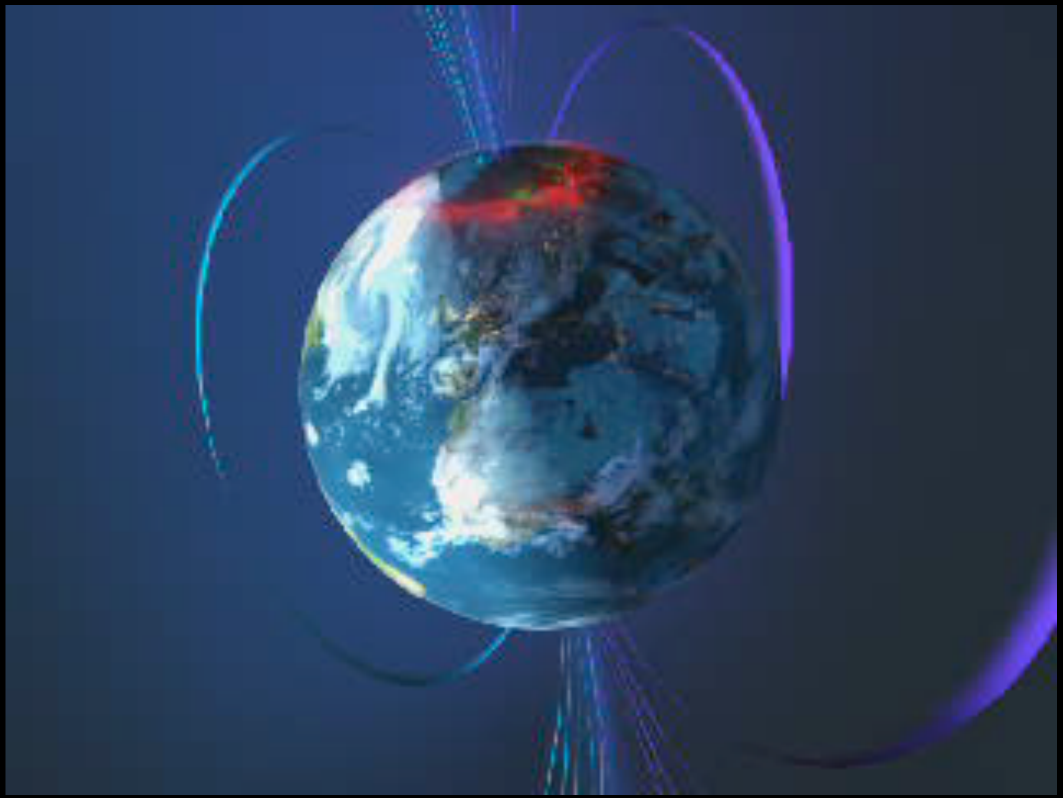
T.Abrahamsen/ARS

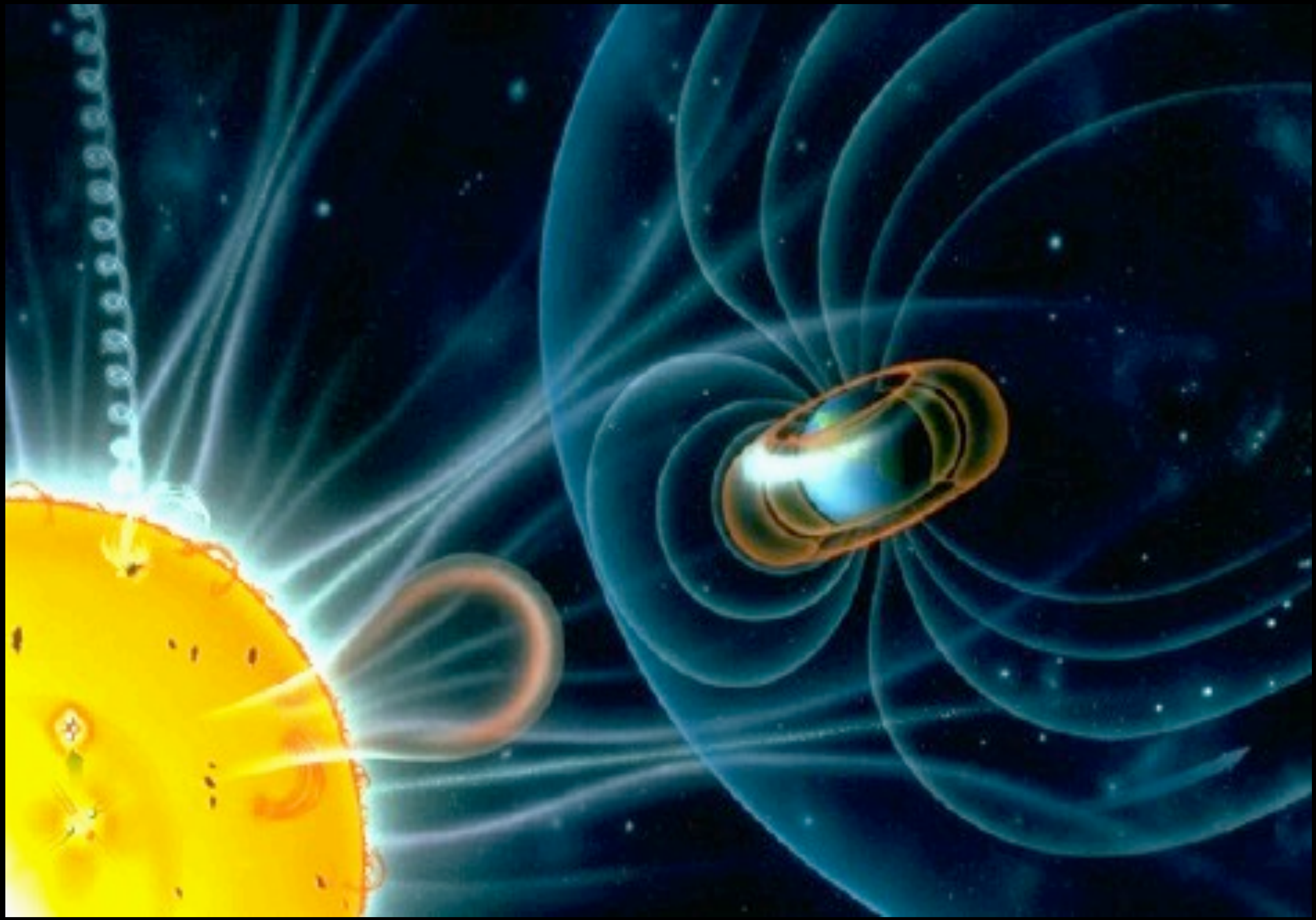
Most probably the heating is done via:

- Sound waves propagating up through the cromsophere
- Megnetic reconnections
- Super-spicules

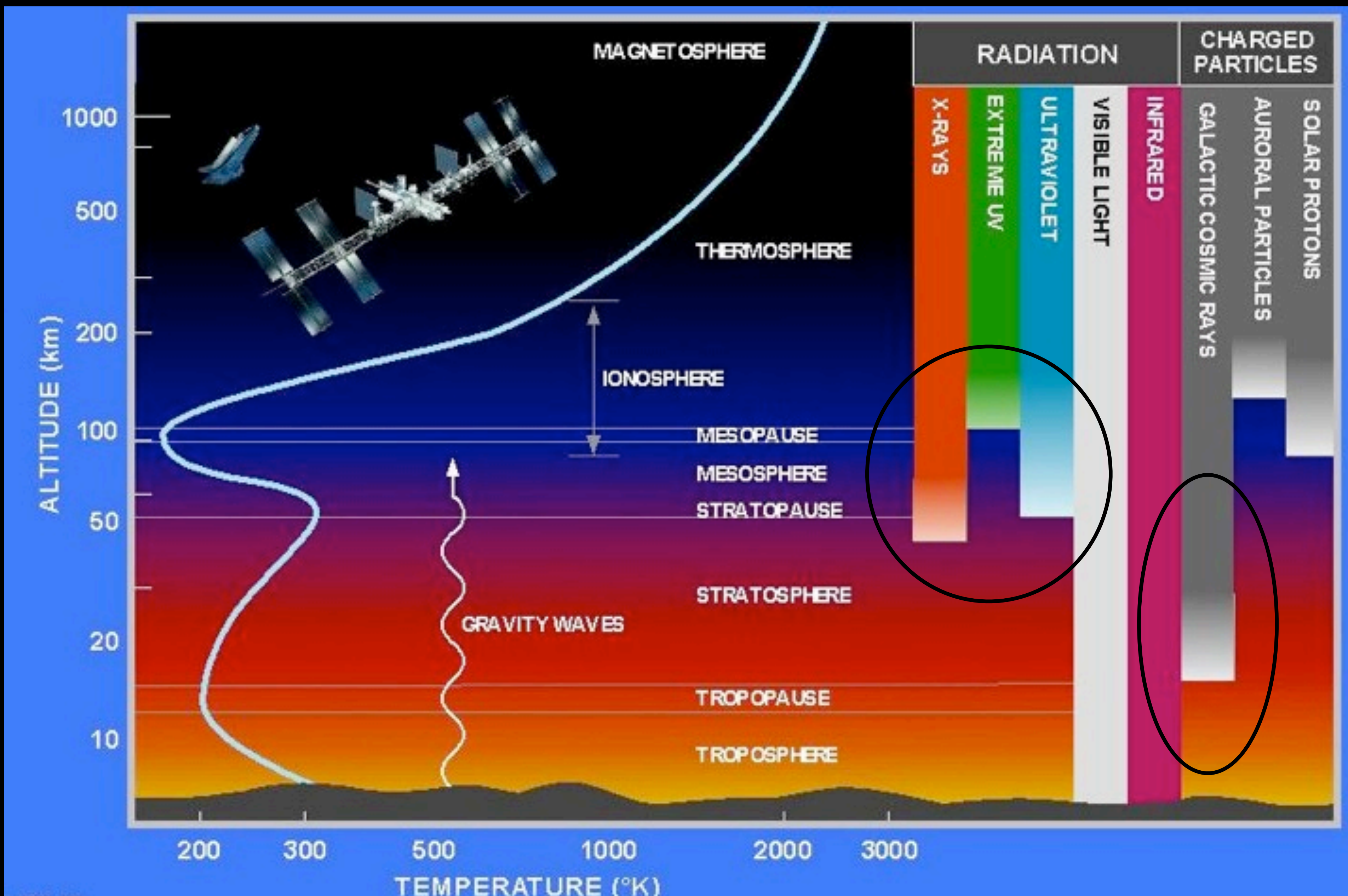
The Solar Wind

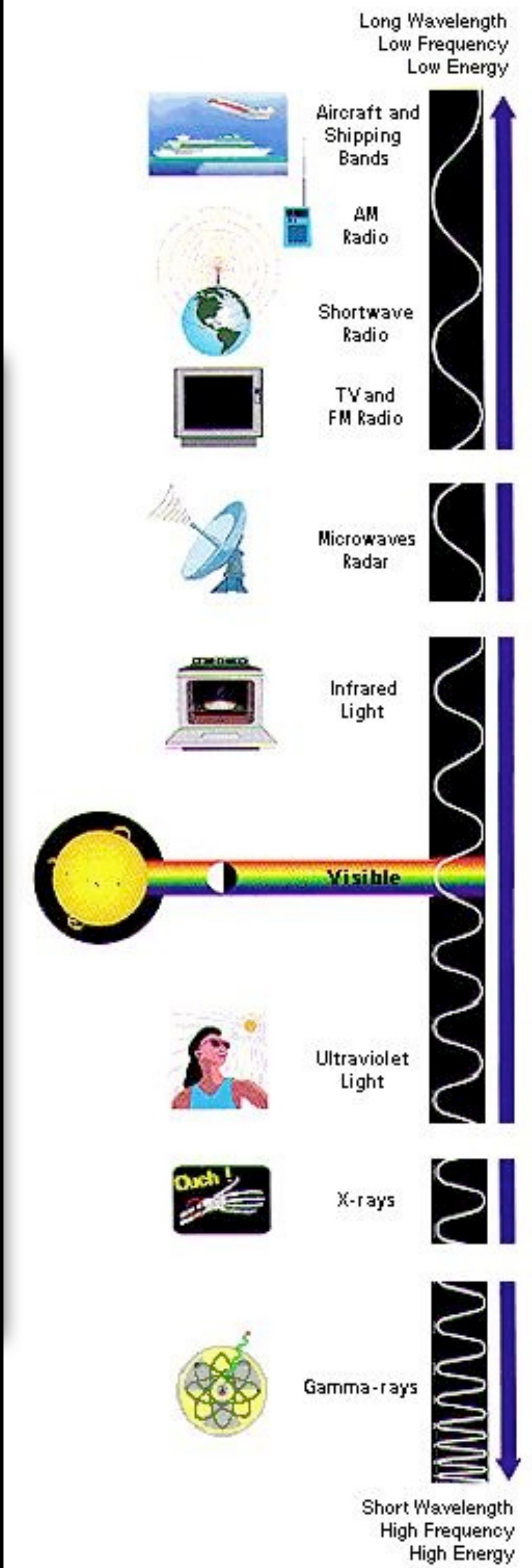
- A constant stream of particles flows from the Sun's corona, with a temperature of about a million degrees and with a velocity of about 1.5 million km/h.
- Gusts in the solar wind will buffet our magnetosphere and lead to a geomagnetic storm.





Electromagnetic radiation

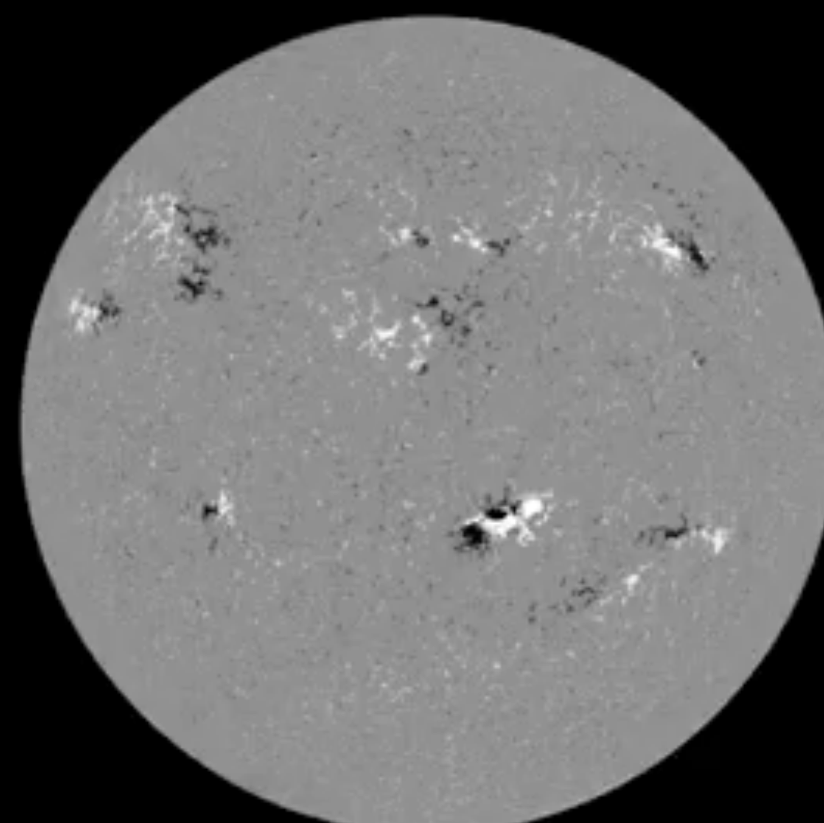




The Sun from Space

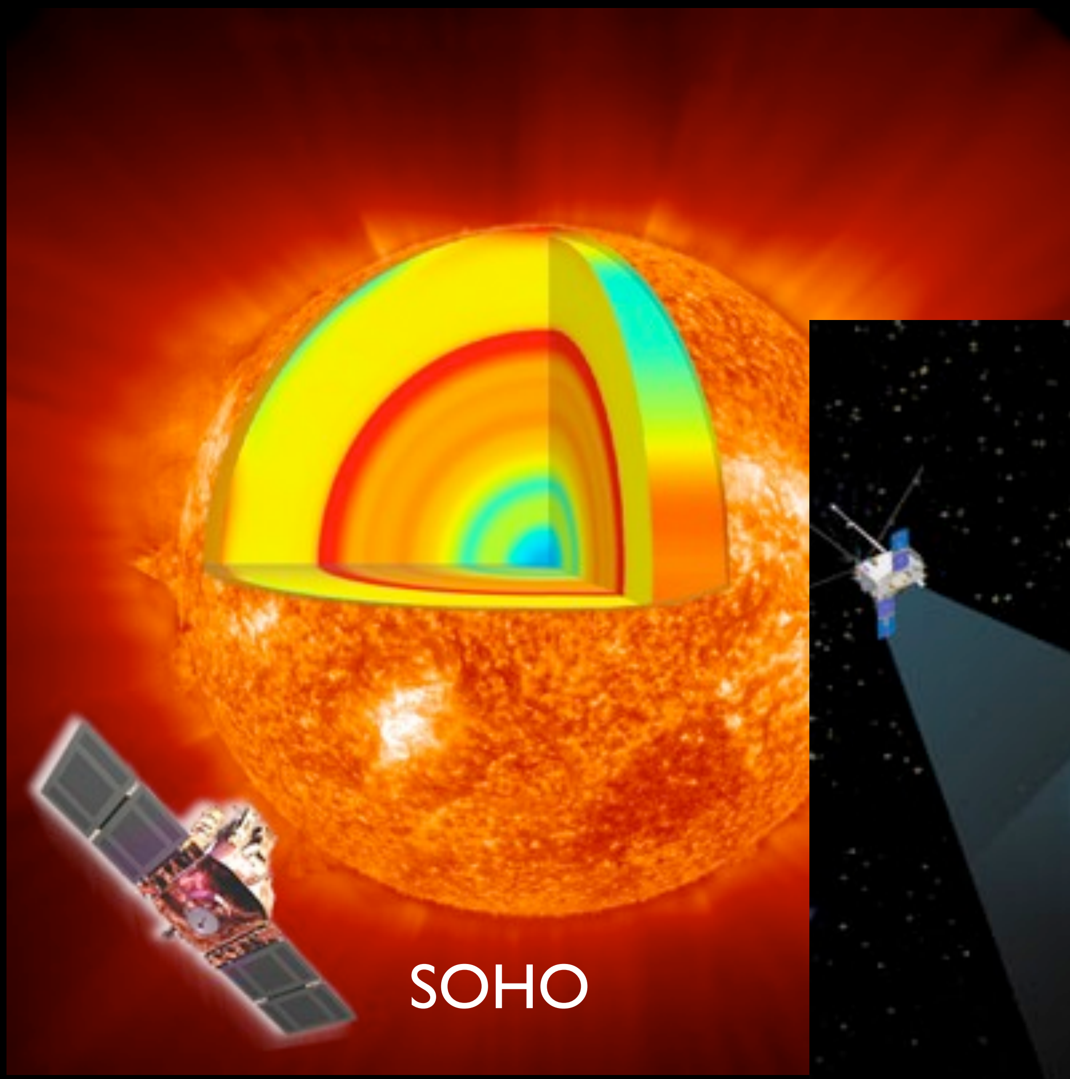
Spektral avbilding

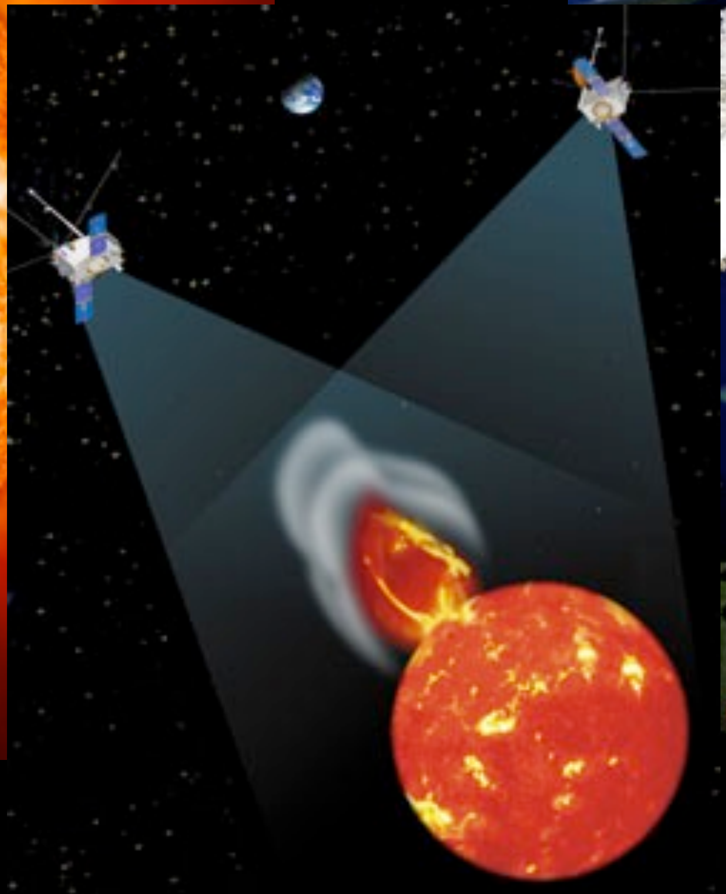
← Ulike spektrale bilder av en syklist

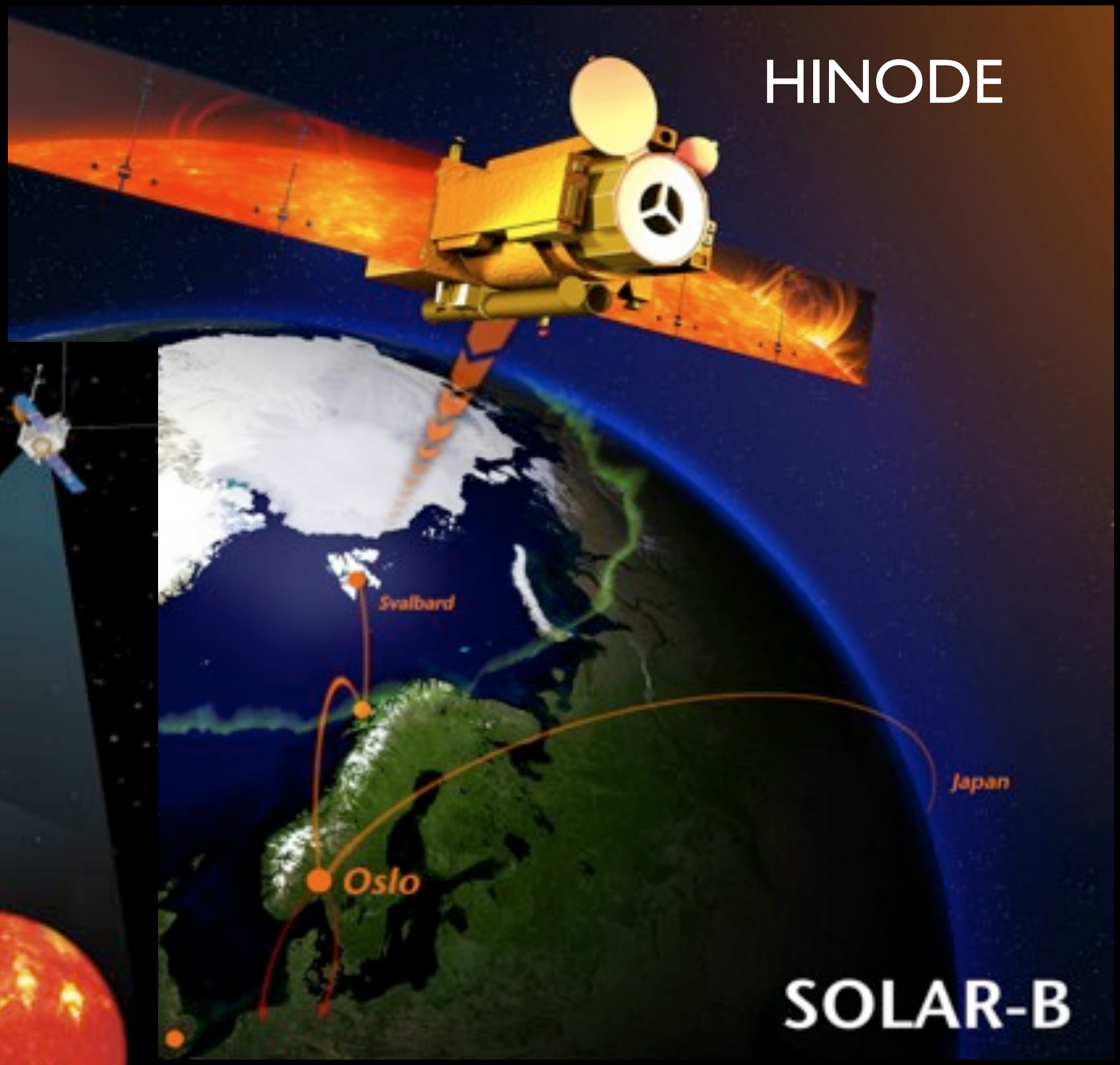


Modern space observatories

Today, new satellites are monitoring the Sun 24 hours every day. They provide space weather forecasts and warn about solar storms that may hit Earth just like the weather forecasts we see on TV every day about the weather.



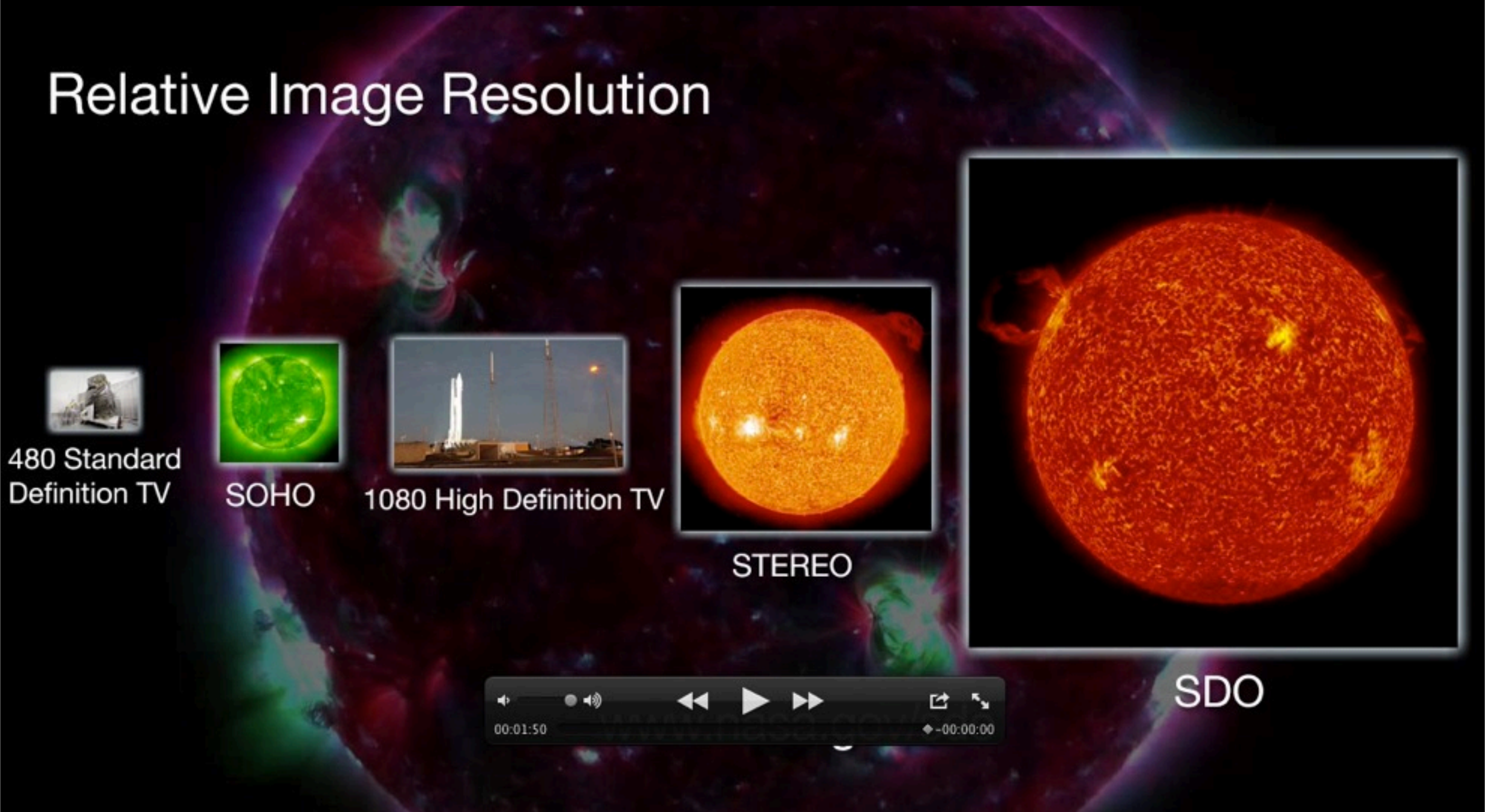


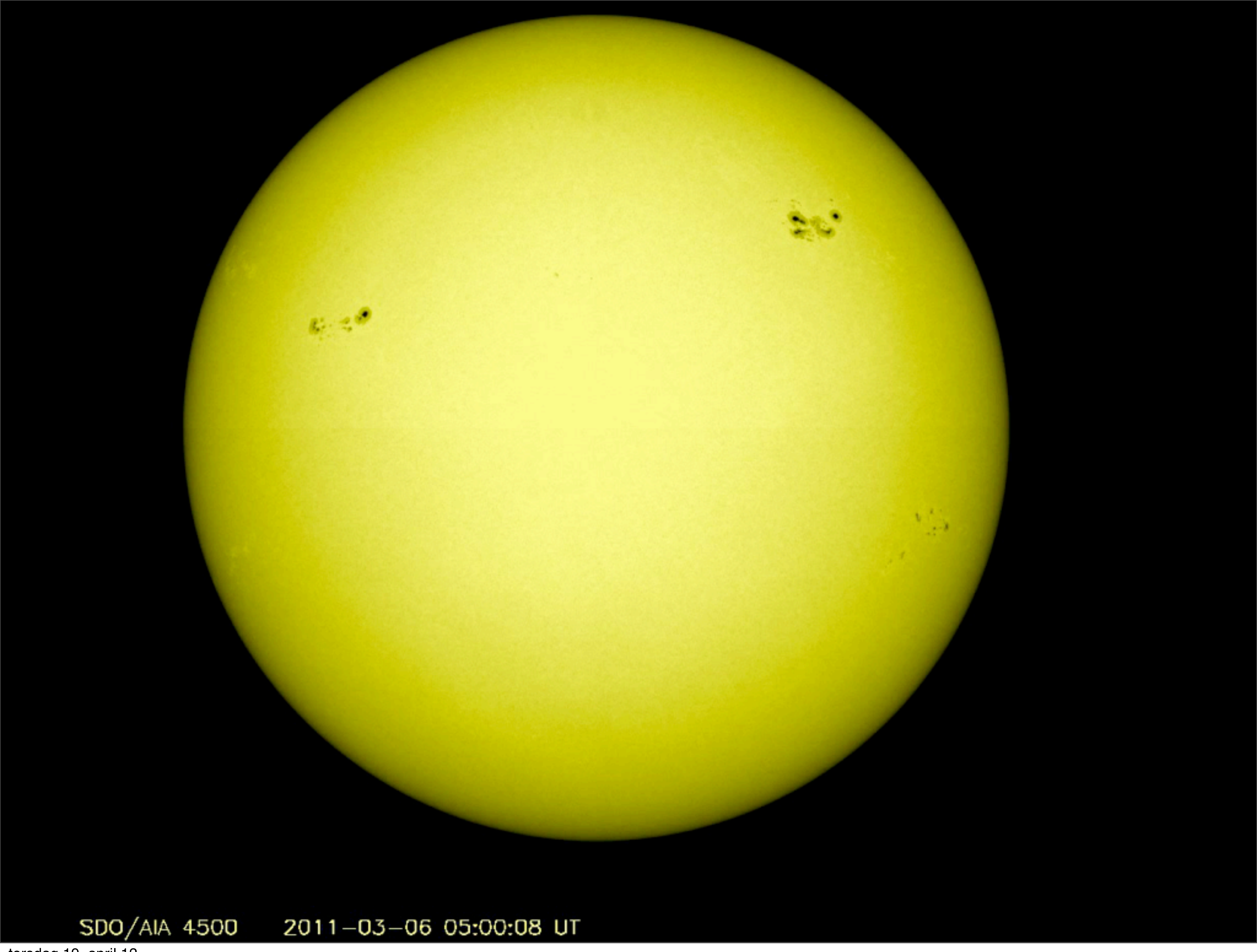


Solar Dynamics Observatory

NASA

Solar Dynamics Observatory

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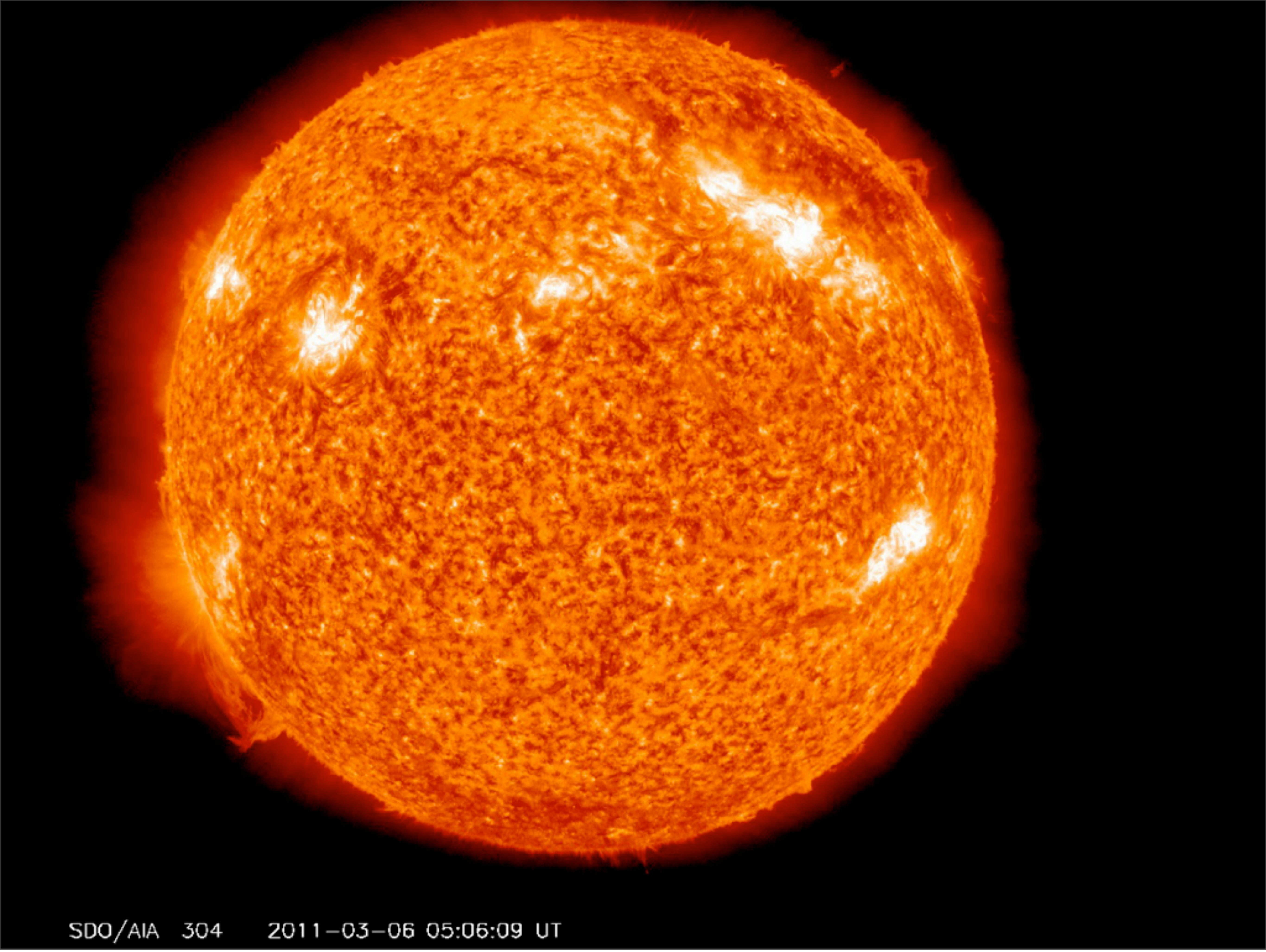
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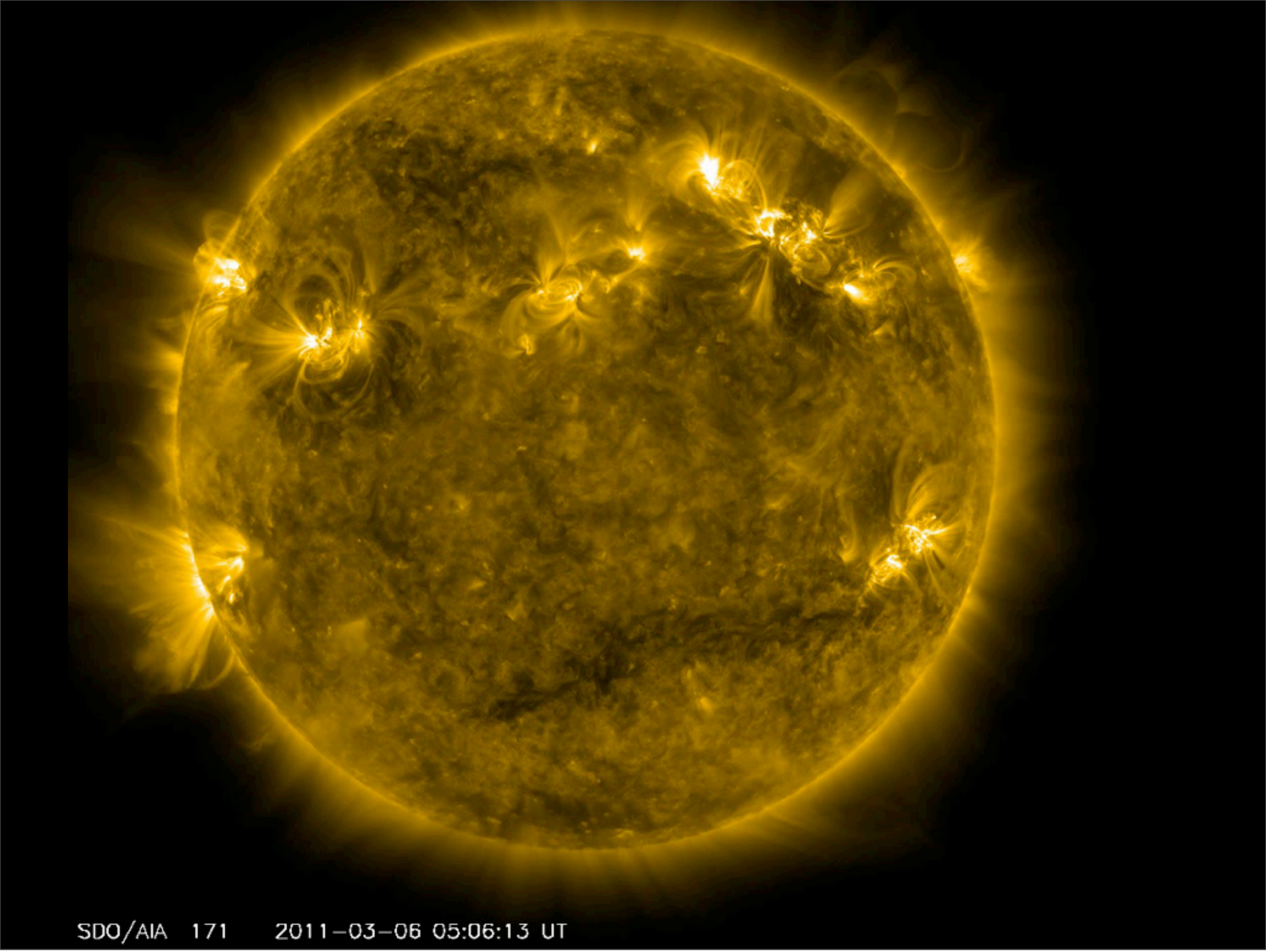
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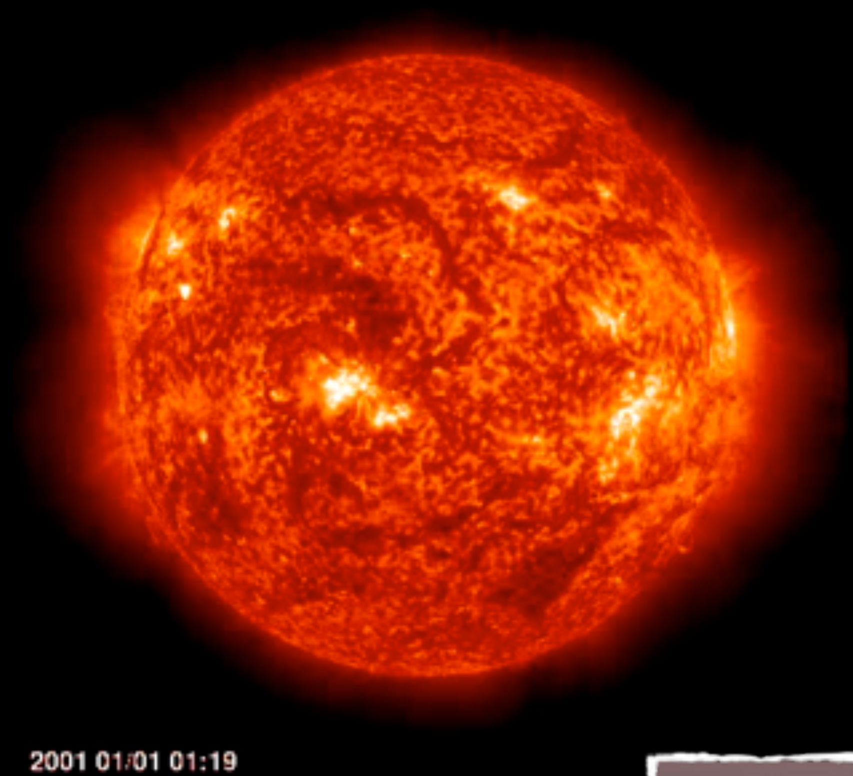
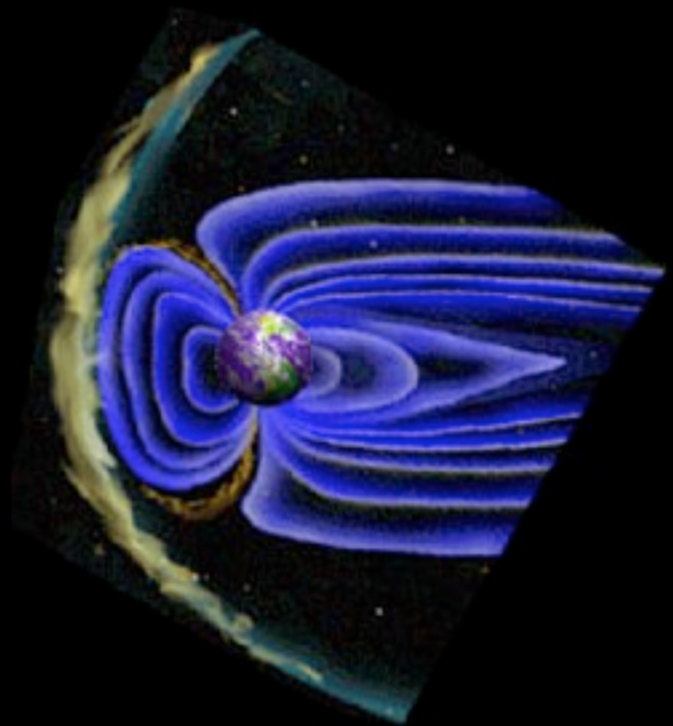
The Sun-Earth Connected System

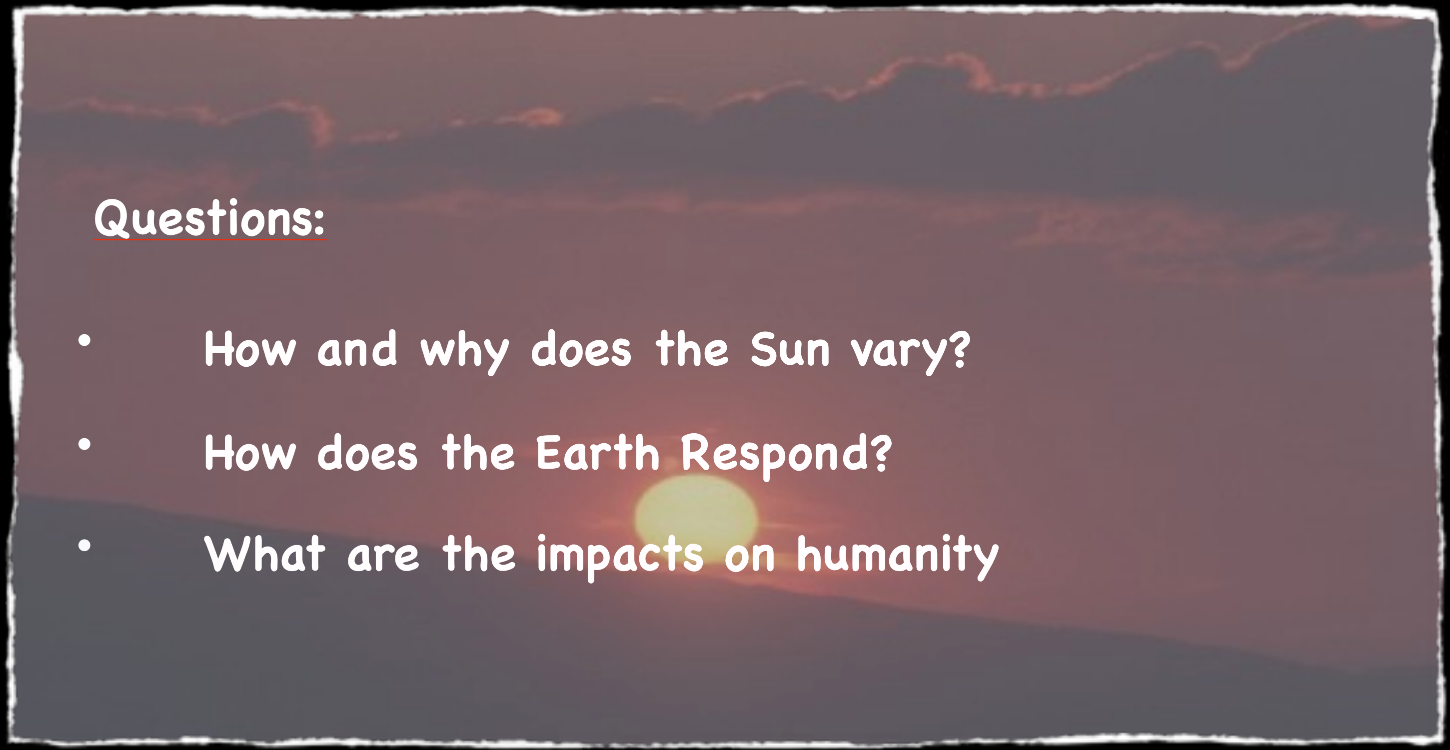
We live in the extended atmosphere of a variable star



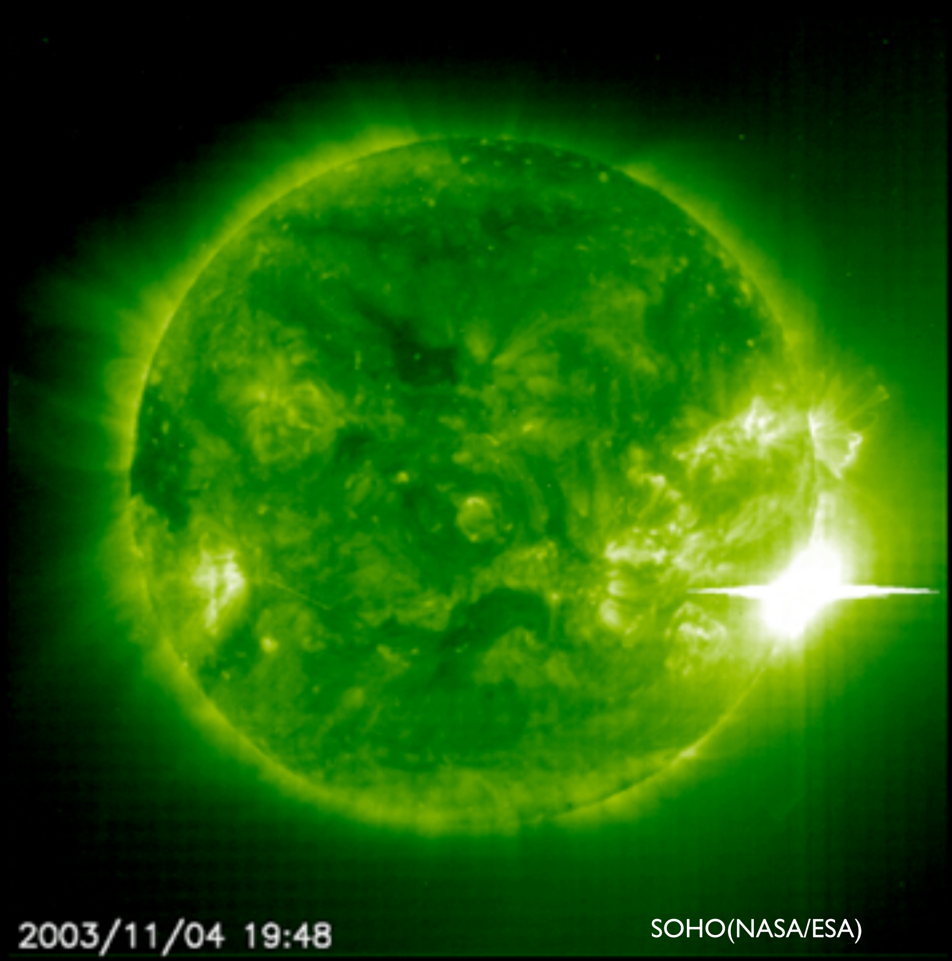
Varying

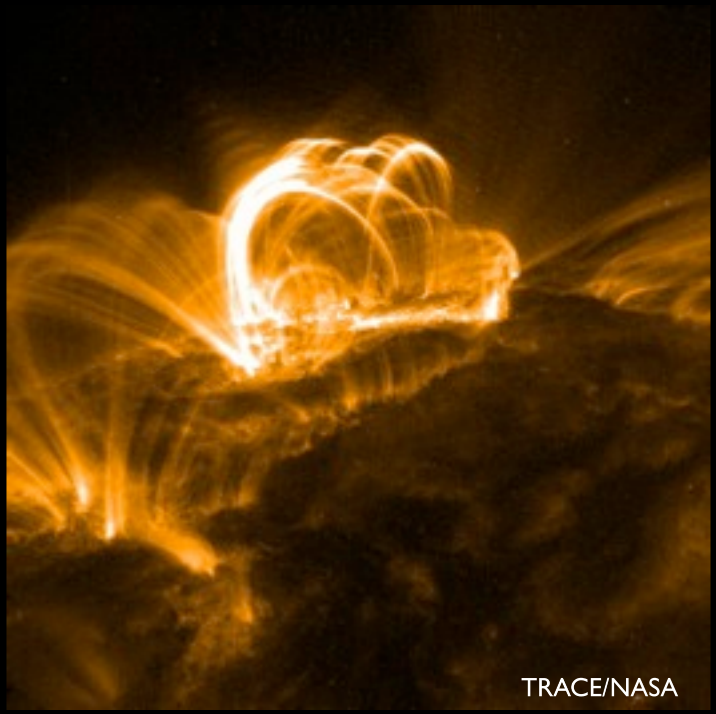
- **Radiation**
- **Solar Wind**
- **Energetic Particles**

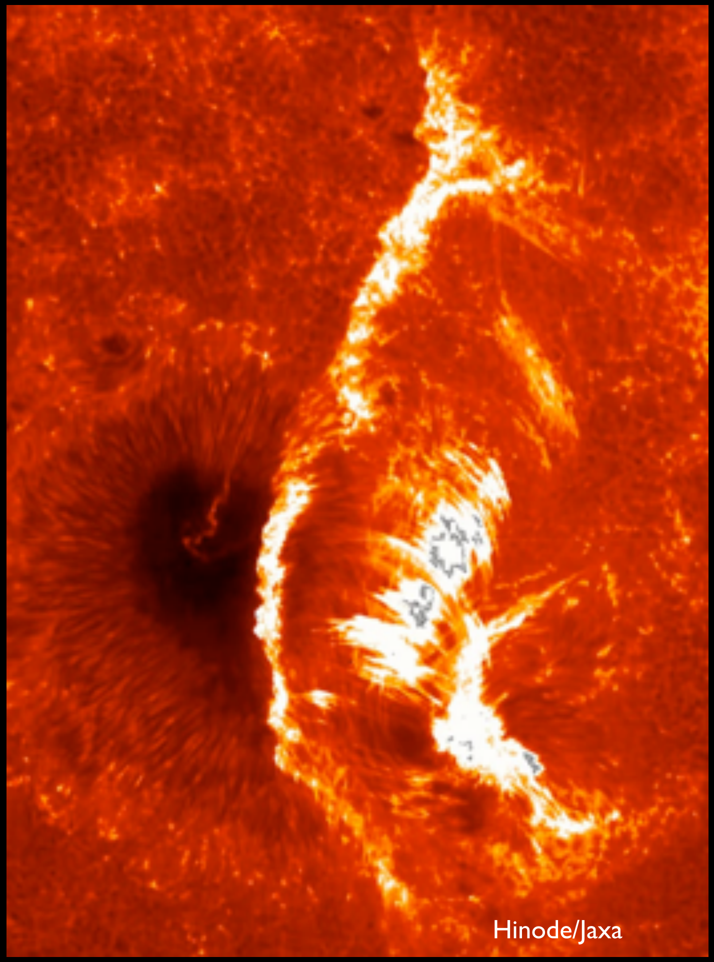




EXPLOSIONS ON THE SUN - FLARES



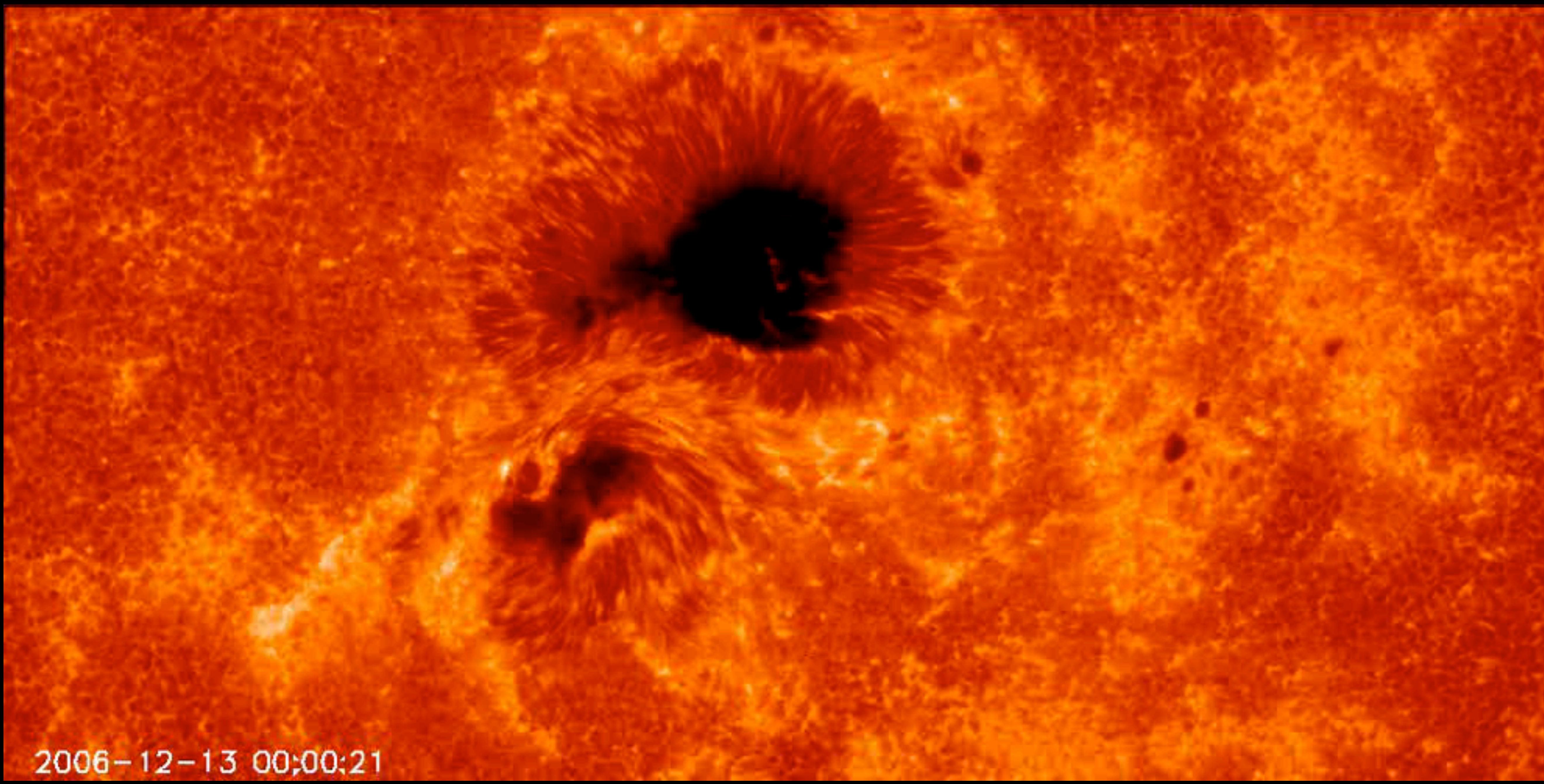




The magnetic field in large active regions on the Sun often gets unstable. This can result in violent explosions in the solar atmosphere – called “flares”. A flare can release in seconds energy corresponding to several billion megatons of TNT. During such explosions the gas is heated to 20 million degrees.

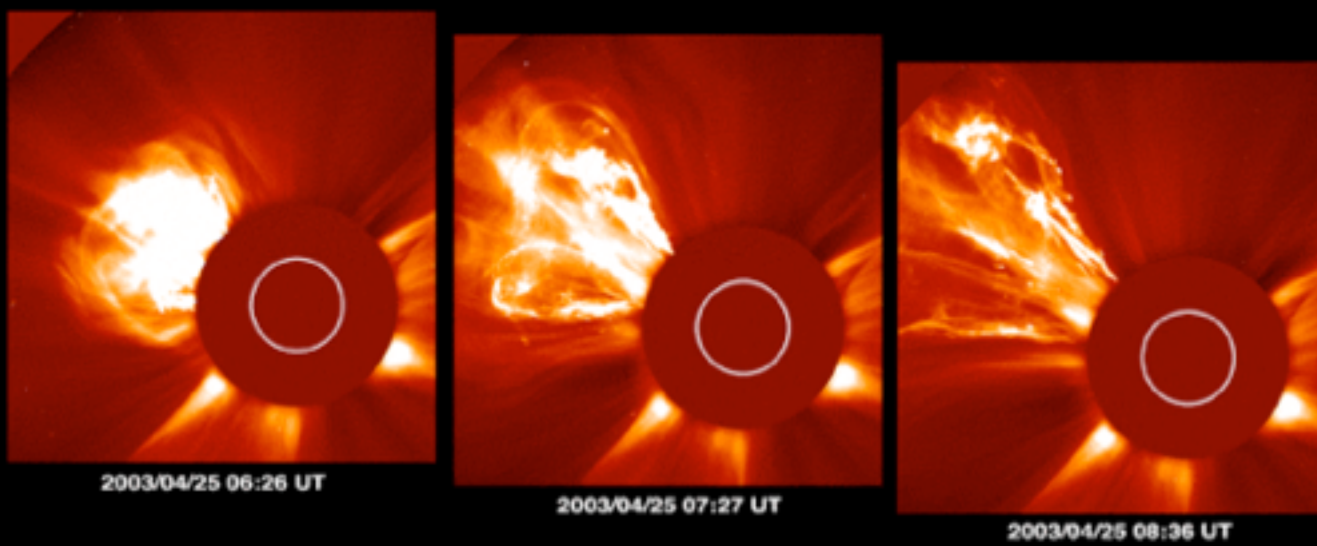
This super heated gas will emit large amount of UV radiation and X-rays. The radiation travels with the speed of light and hits the Earths atmosphere 8 minutes 20 seconds later. Luckily, this hazardous radiation is blocked by gases in our protective atmosphere such as ozone. As will be described later such explosions can affect radio communication and satellite communication.

Close up of a flare!

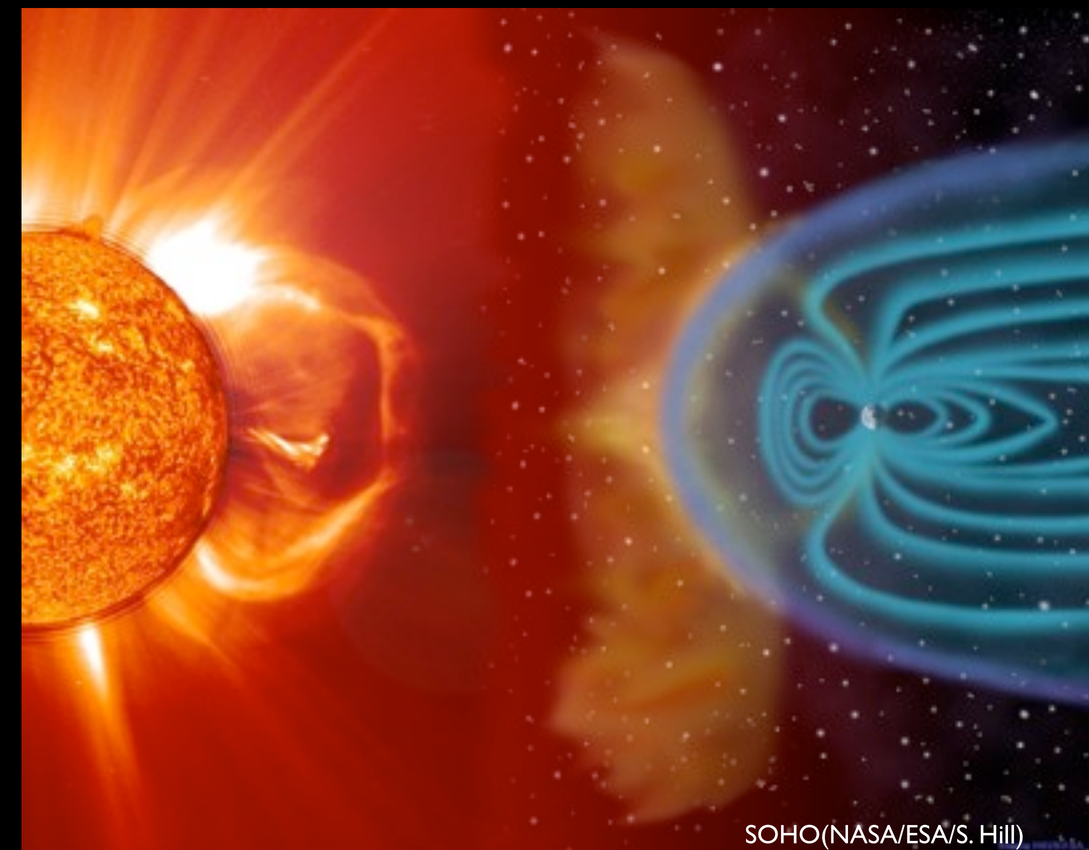


Hinode

GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)



SOHO(NASA/ESA/S. Hill)

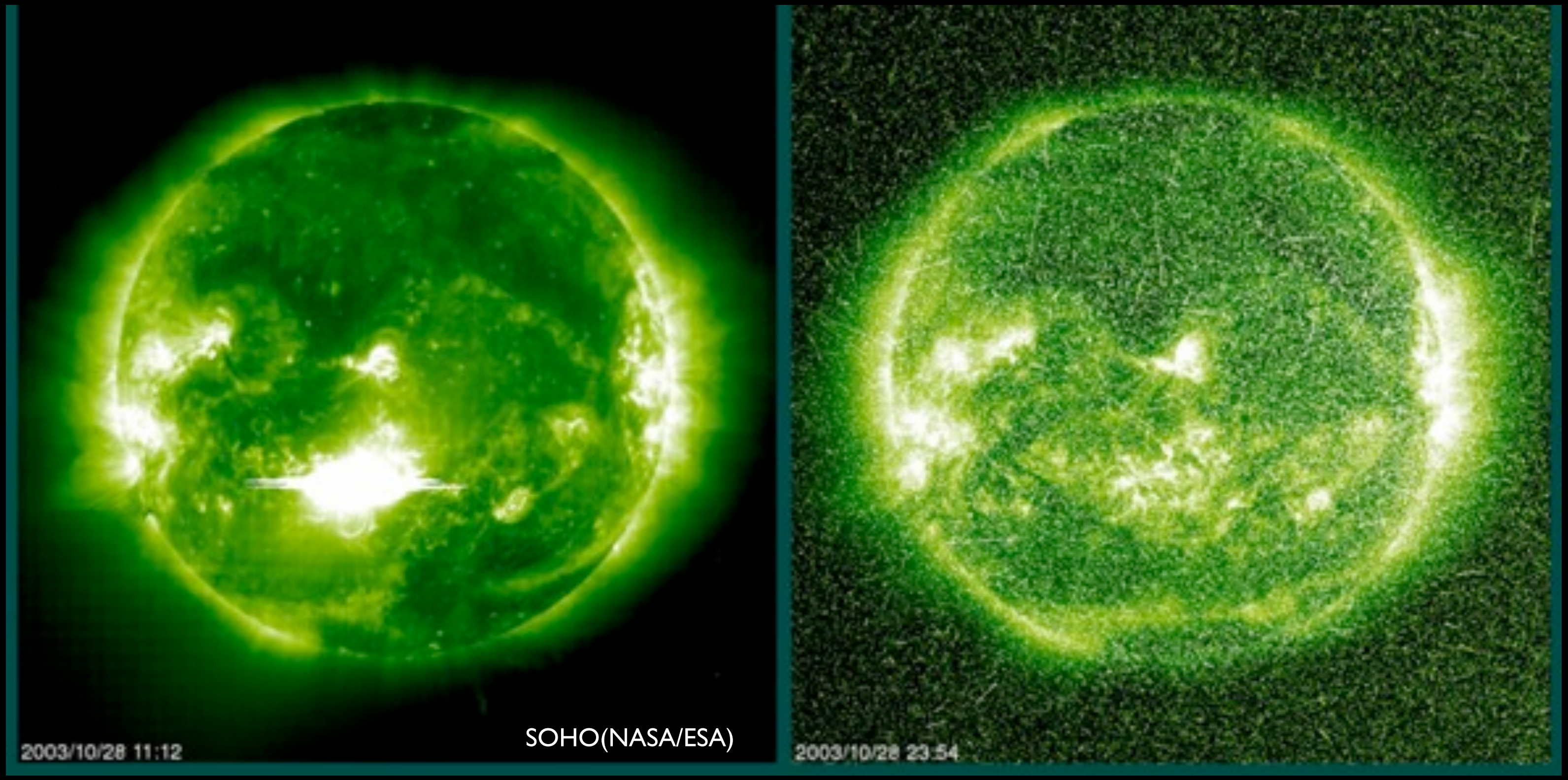


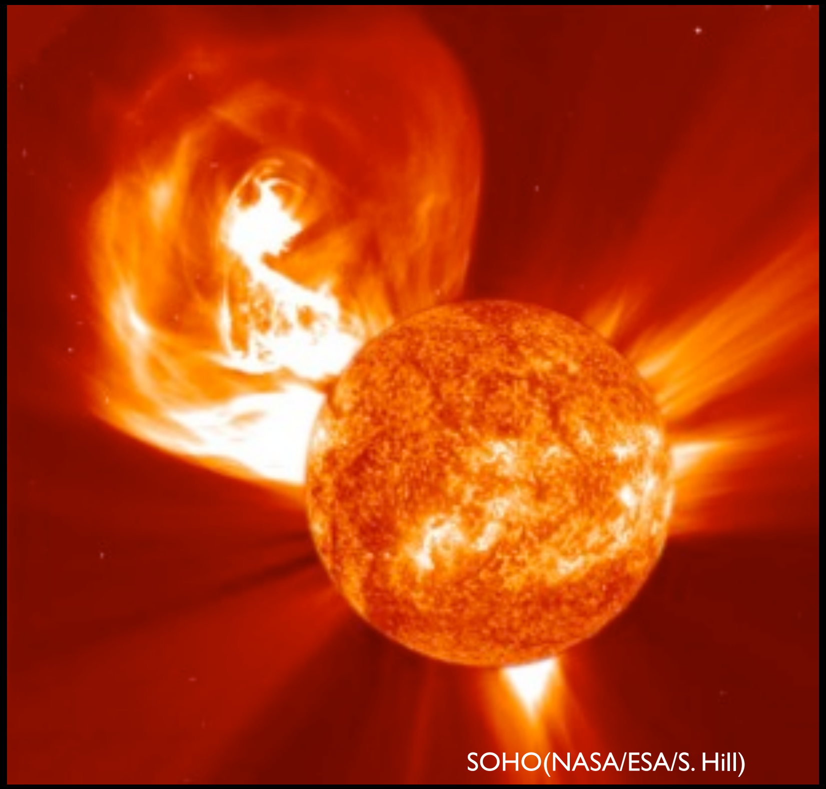
Sometimes large prominences can erupt and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called Coronal Mass Ejections or CMEs for short. The bubble of gas will expand out in space and can reach velocities up to 8 million km/h. Still it would take almost 20 hours before it reach the Earth. Usually the solar wind spends three days on this journey.

If such an eruption is directed towards the Earth the particles will be deflected by our magnetosphere. The cloud of gas will push and shake the Earths magnetic field and generate a kind of “storm” which we call geomagnetic storms.

GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)

PARTICLE SHOWERS FROM THE SUN



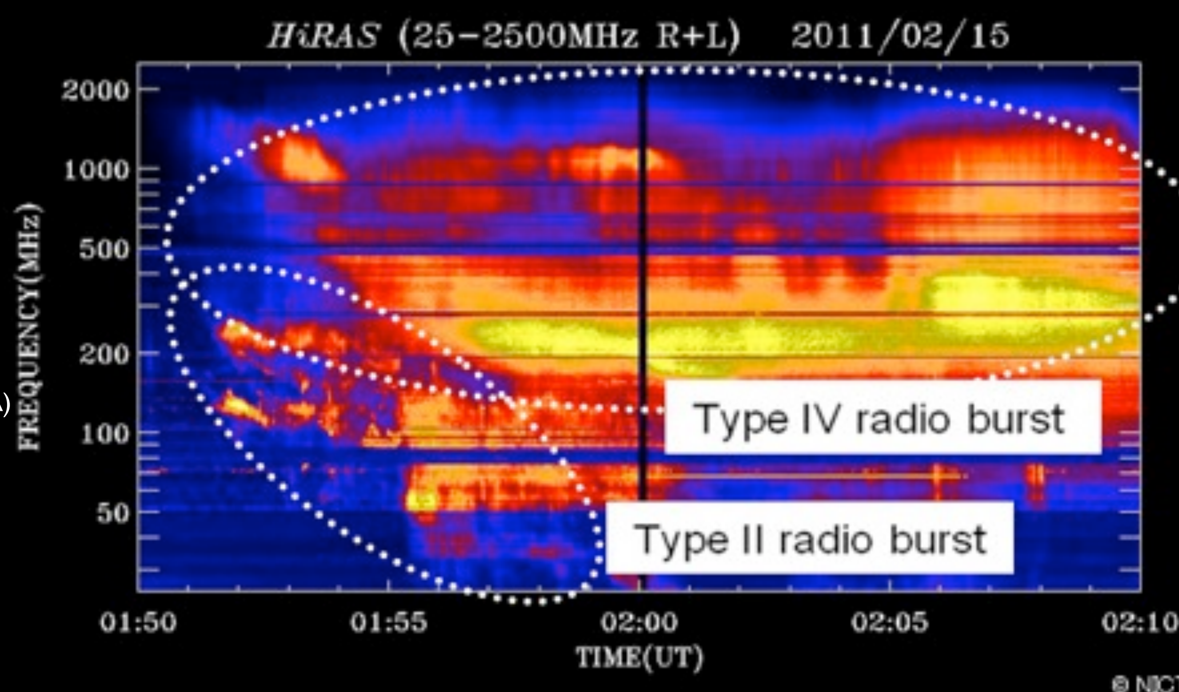


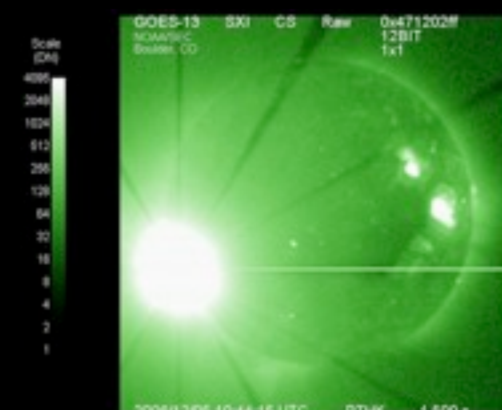
A few times explosions or eruptions will accelerate large amount of particles that travel at almost the speed of light. Such showers of particles consist mostly of protons and it takes less then an hour to reach Earth.

The protons have such high speed and energy that they can penetrate satellites and space ships. Thus, they can damage vital electronic equipment. They can also destroy the quality of images and scientific data from those satellites that are surveying the Sun as shown in the picture above. The particles “blind” the digital cameras and we see a large amount of noise in the images.

RADIO-BURST

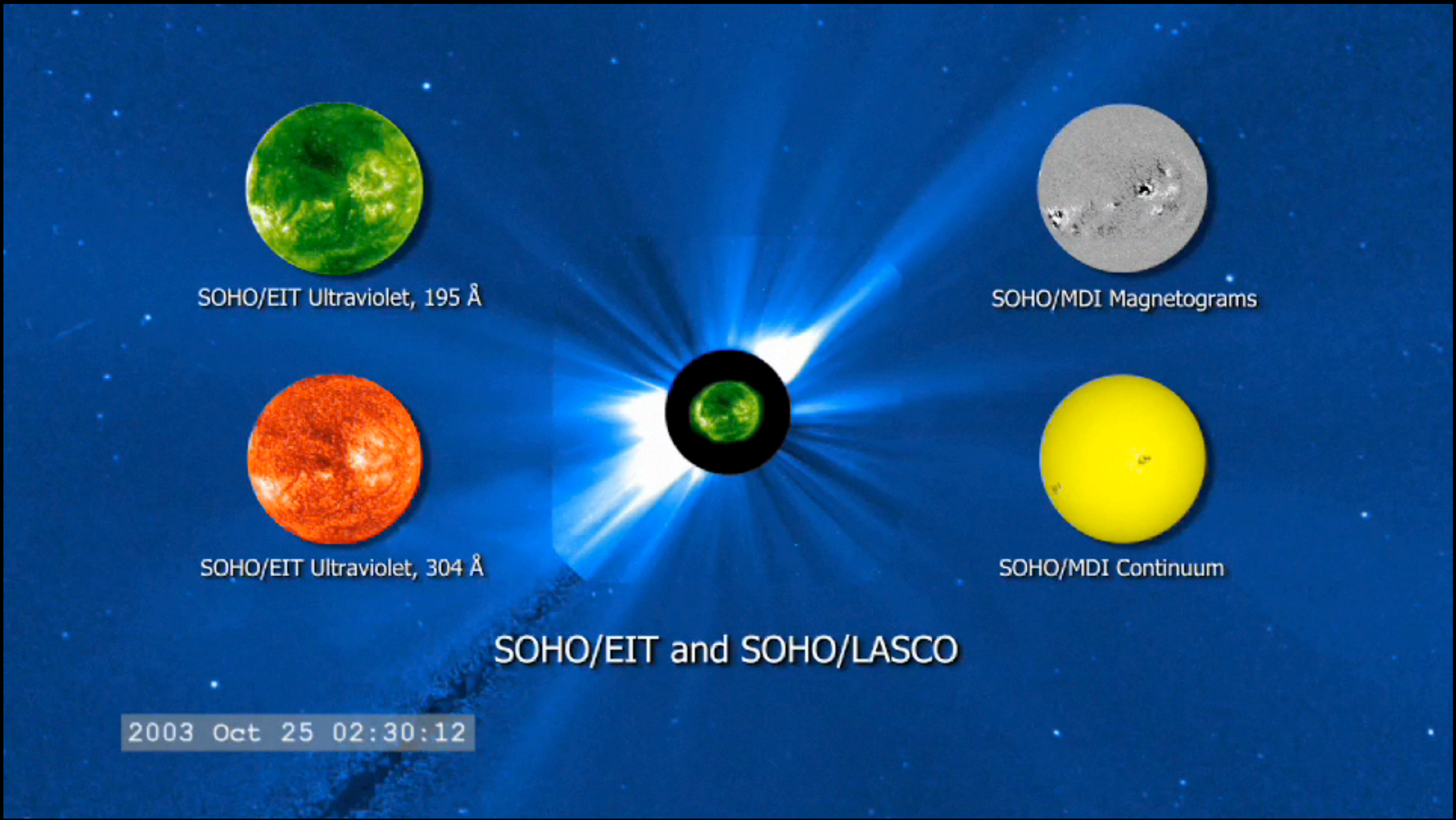
SOHO(NASA/ESA)



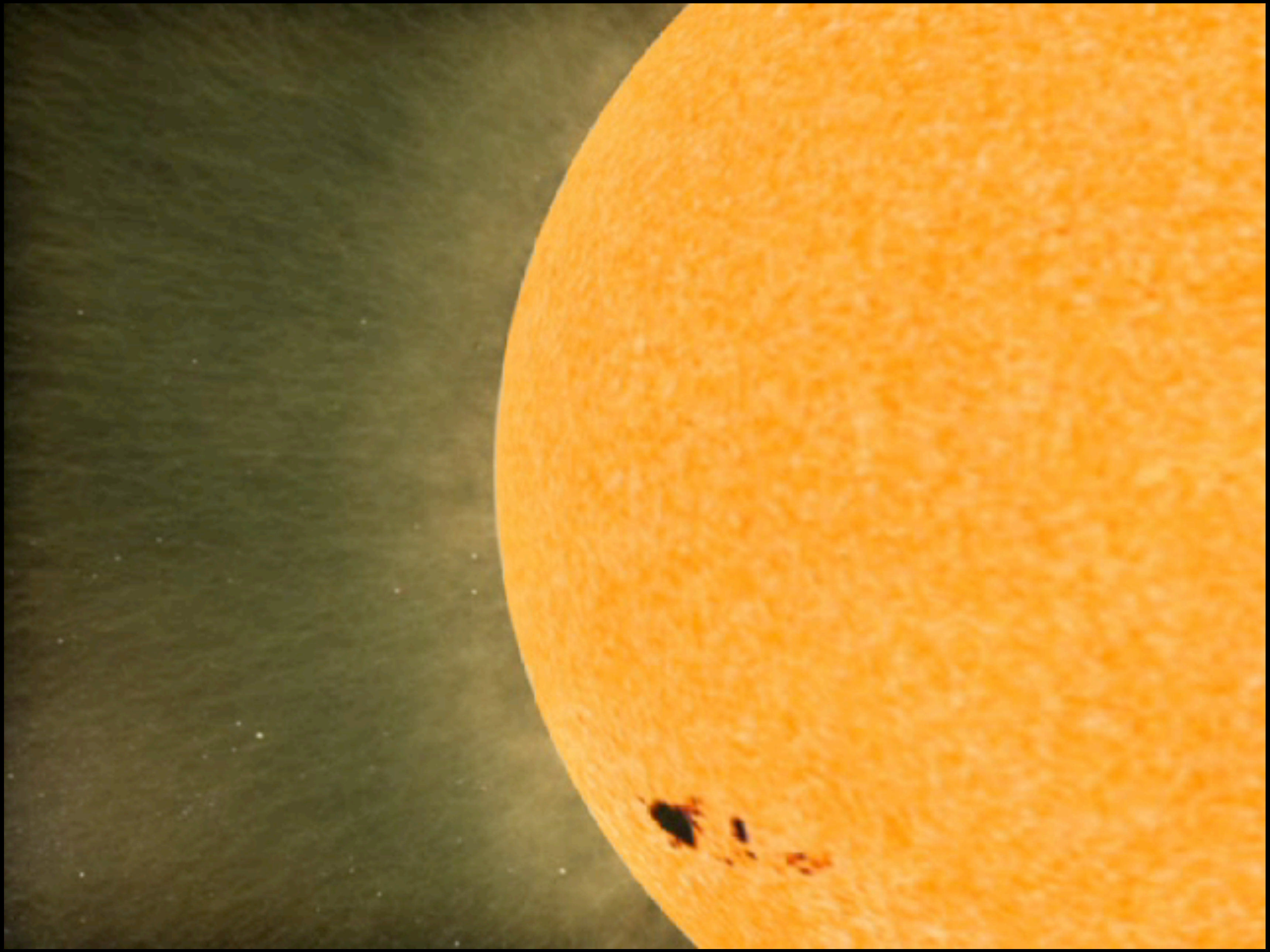


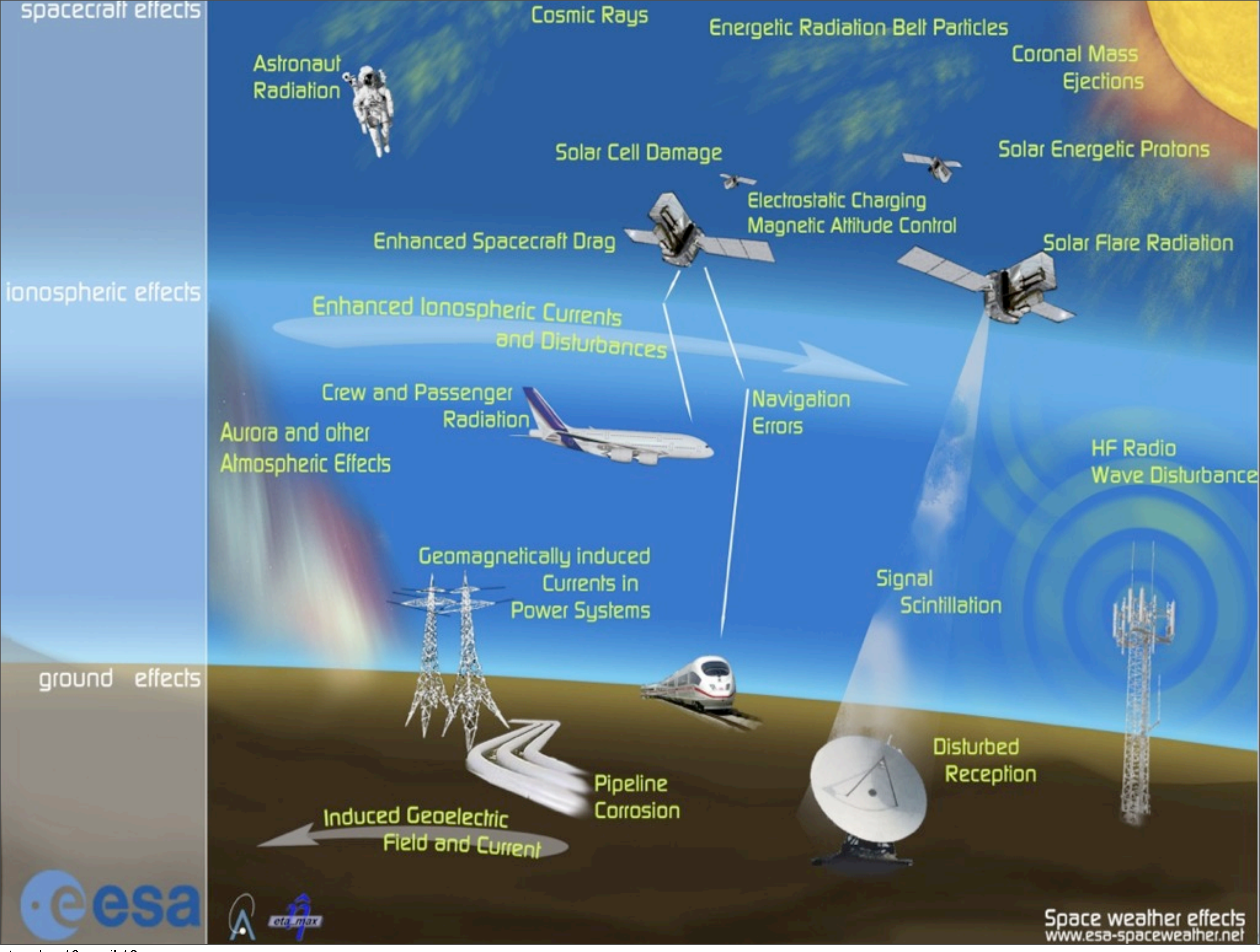
A few times eruptions on the Sun will generate strong burst of radio waves - often with the same frequencies as communications systems we use on Earth as well as the GPS frequency.

The dynamic Sun

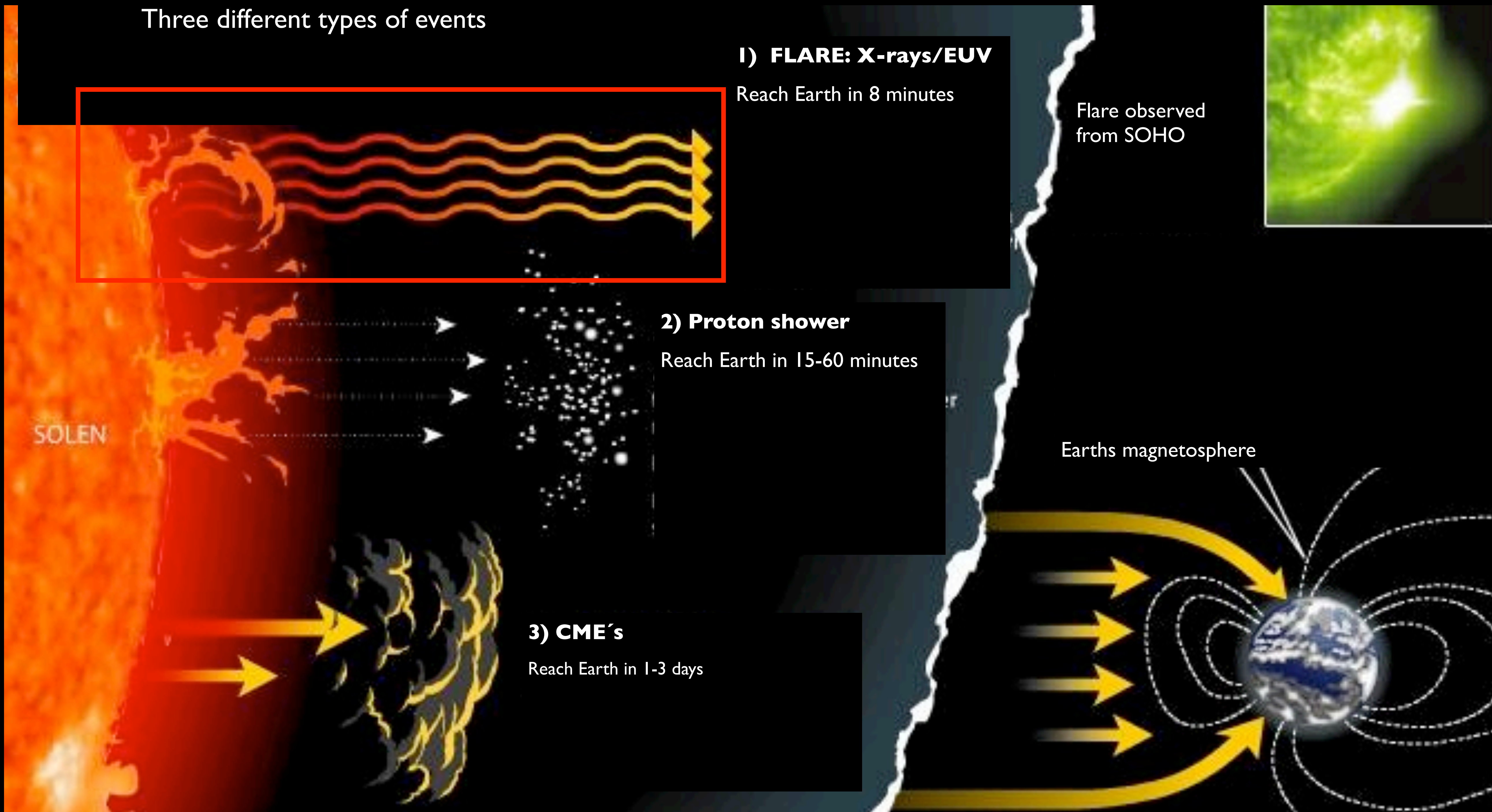


Flare/CME and Proton event

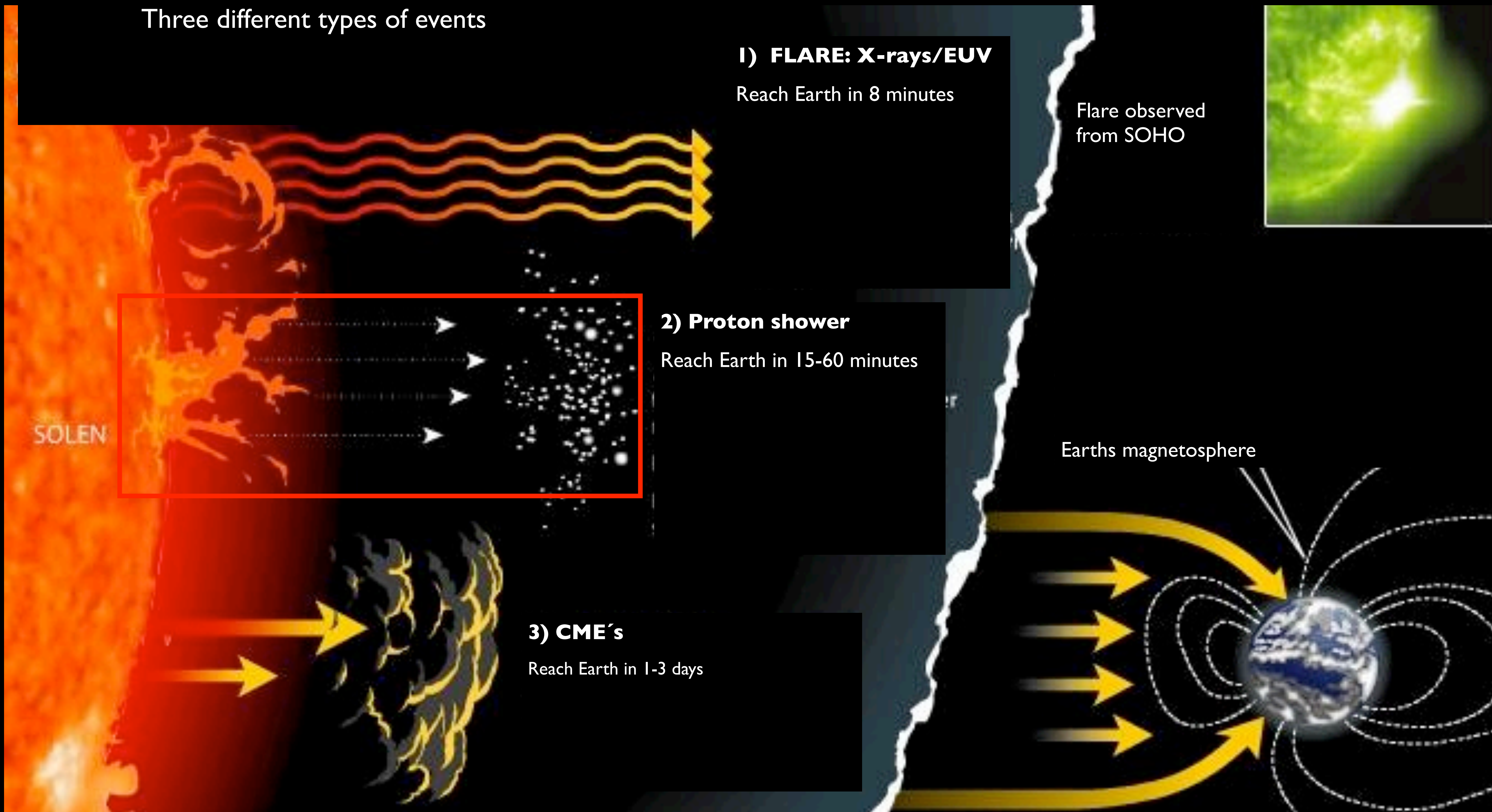



spacecraft effects
ionospheric effects
ground effects
Cosmic Rays
Energetic Radiation Belt Particles
Coronal Mass Ejections
Astronaut Radiation
Solar Cell Damage
Solar Energetic Protons
Electrostatic Charging
Magnetic Attitude Control
Enhanced Spacecraft Drag
Solar Flare Radiation
Enhanced Ionospheric Currents and Disturbances
Crew and Passenger Radiation
Navigation Errors
Aurora and other Atmospheric Effects
HF Radio Wave Disturbance
Geomagnetically induced Currents in Power Systems
Signal Scintillation
Disturbed Reception
Pipeline Corrosion
Induced Geoelectric Field and Current
esa
eta_max
Space weather effects
www.esa-spaceweather.net

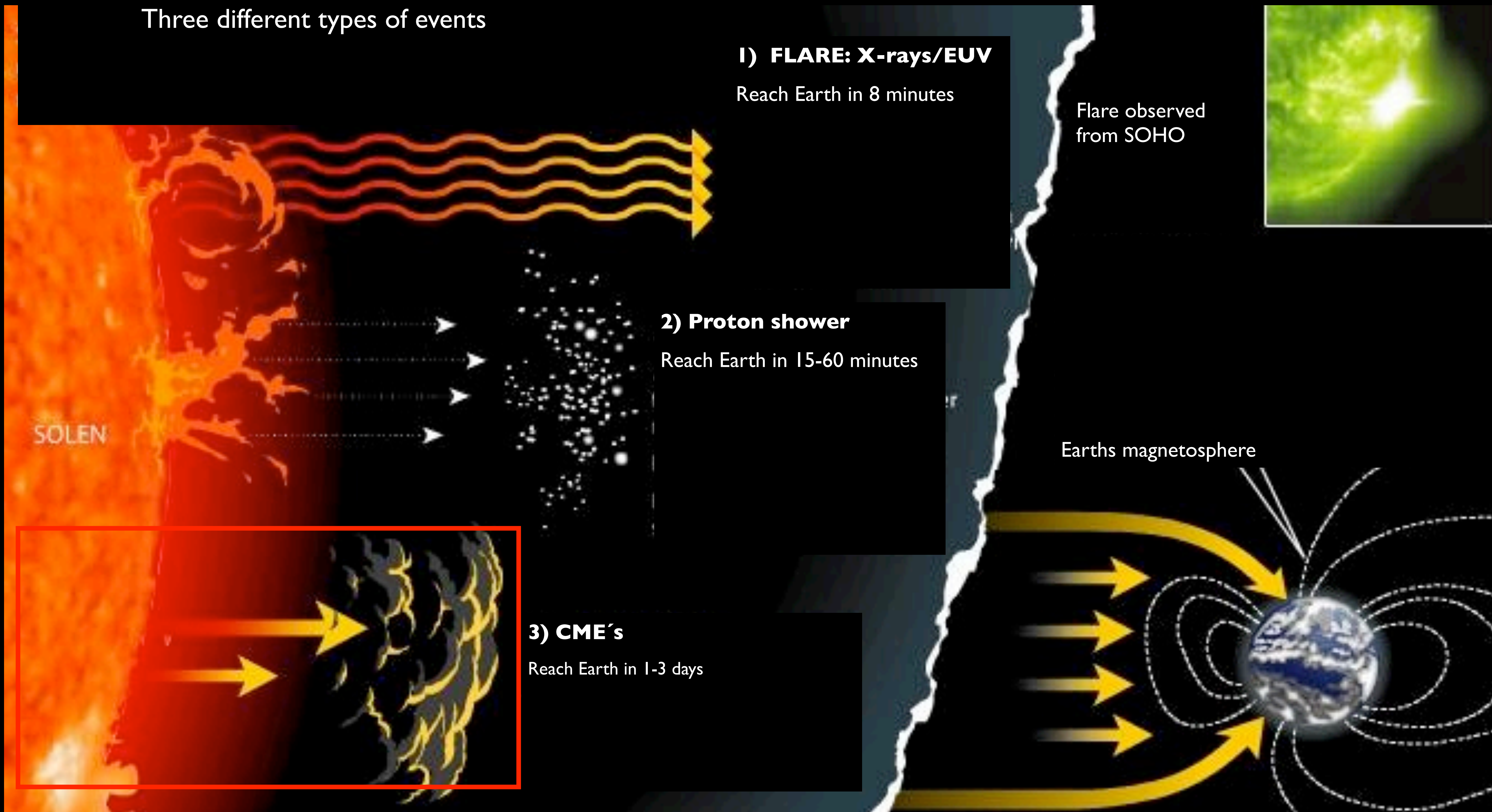
Flares - UV/X-Rays



Proton shower



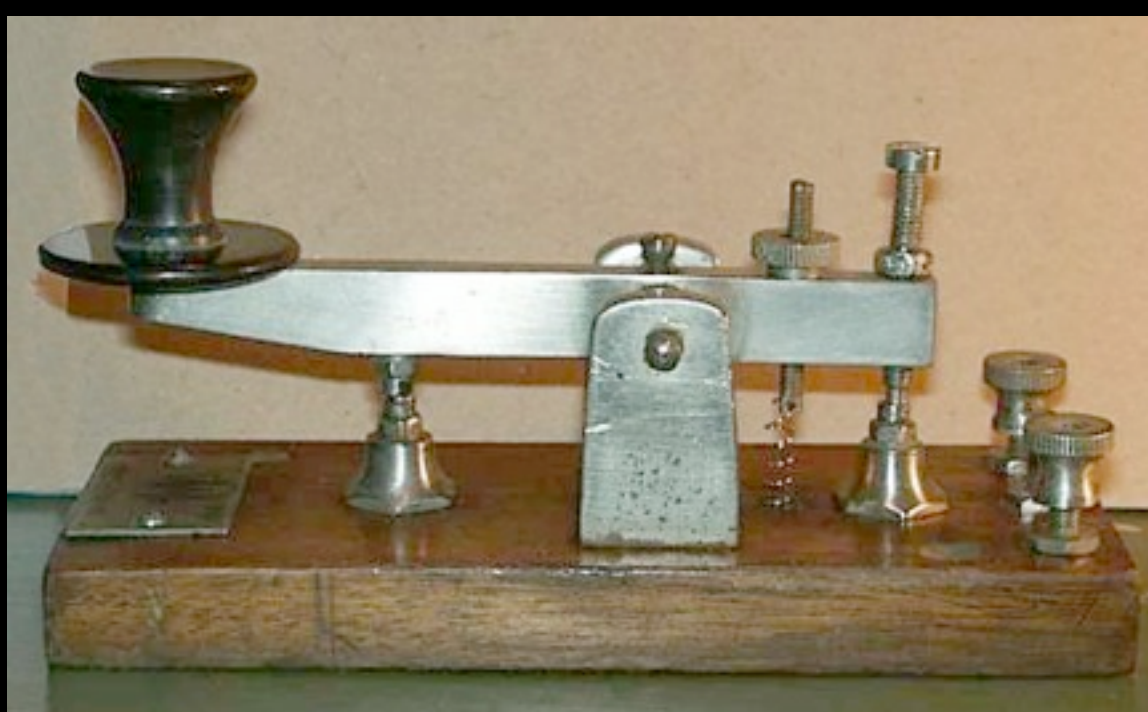
CMEs


Three different types of events
1) FLARE: X-rays/EUV
Reach Earth in 8 minutes
Flare observed from SOHO
2) Proton shower
Reach Earth in 15-60 minutes
SOLEN
Earths magnetosphere
3) CME´s
Reach Earth in 1-3 days

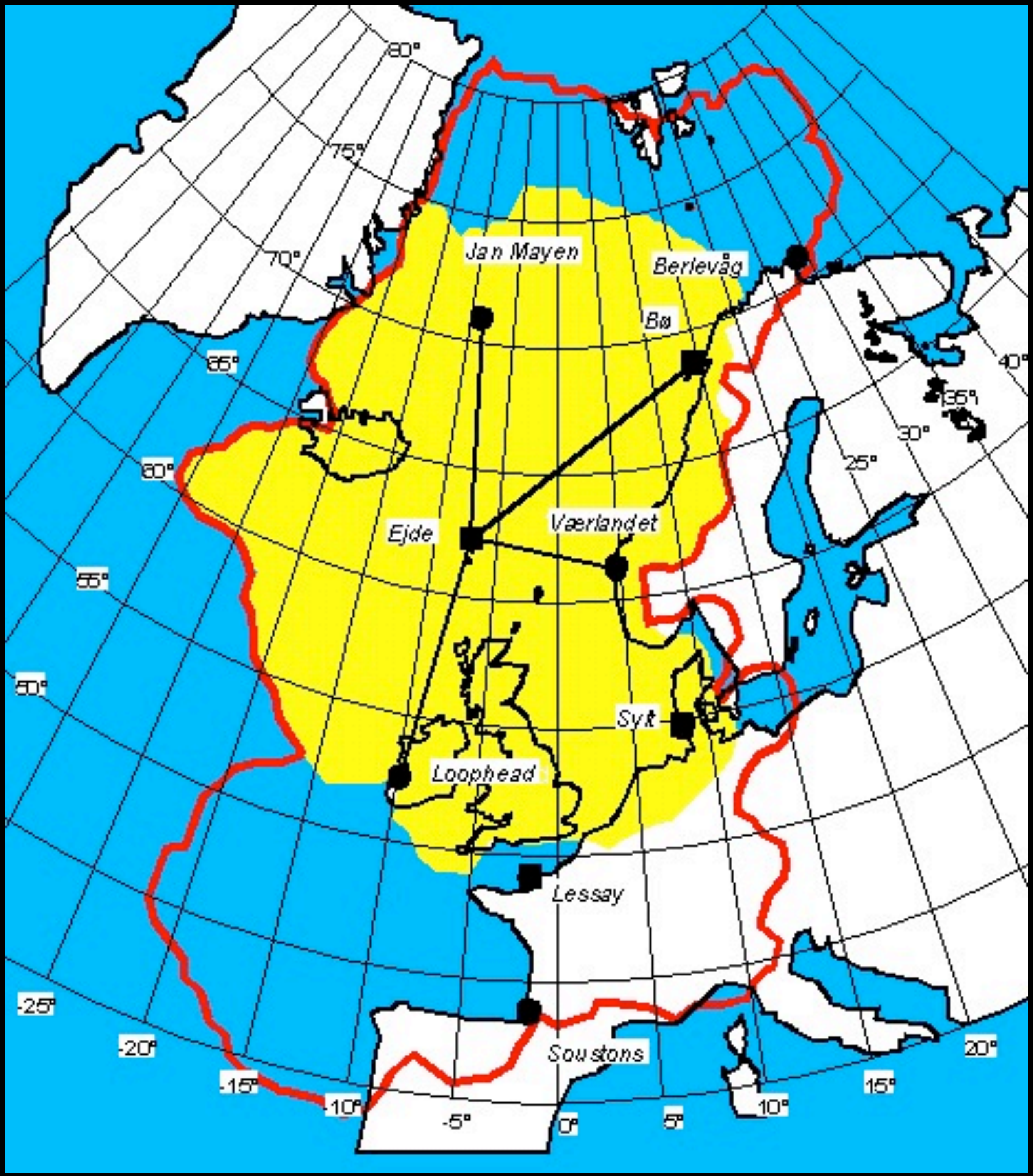
Early effects from Space Weather

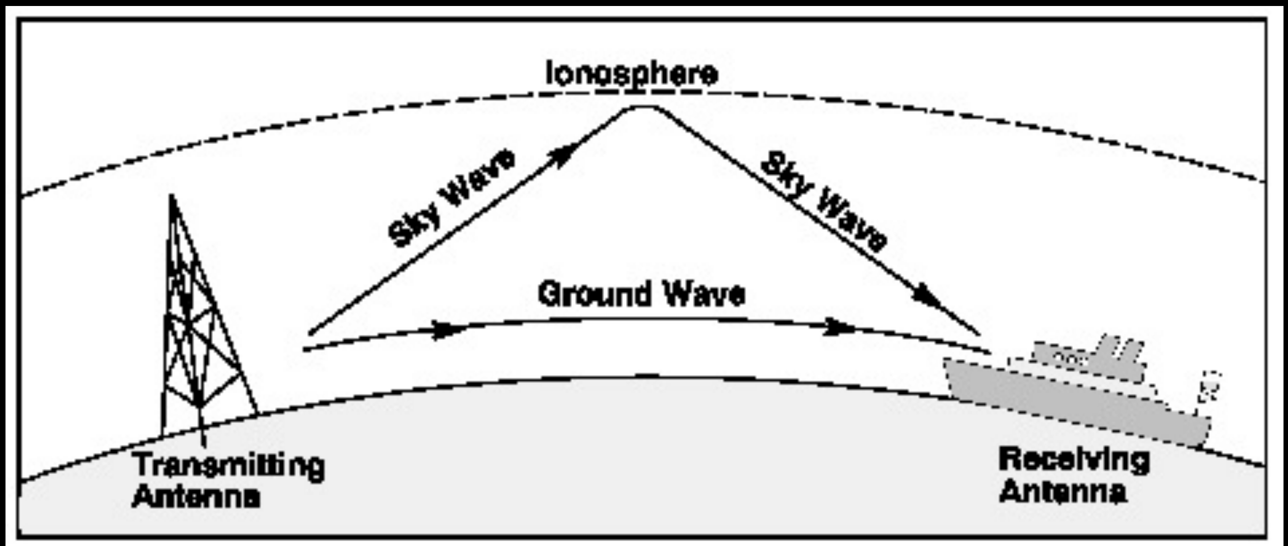
Romværseffekter på installasjoner på jorden er ikke noe nytt fenomen.

- 17 november 1848: "Telegraflinjen mellom Piz og Firenze slått ut"
- September 1851: Telegrafnettet i New England slått ut.
- Gnister og branntilløp beskrevet p.g.a. krafig indusert strøm.
- I Bosten (1859) kjørte de telegraflinjen uten batterier/strøm



Navigation systems - LORAN C





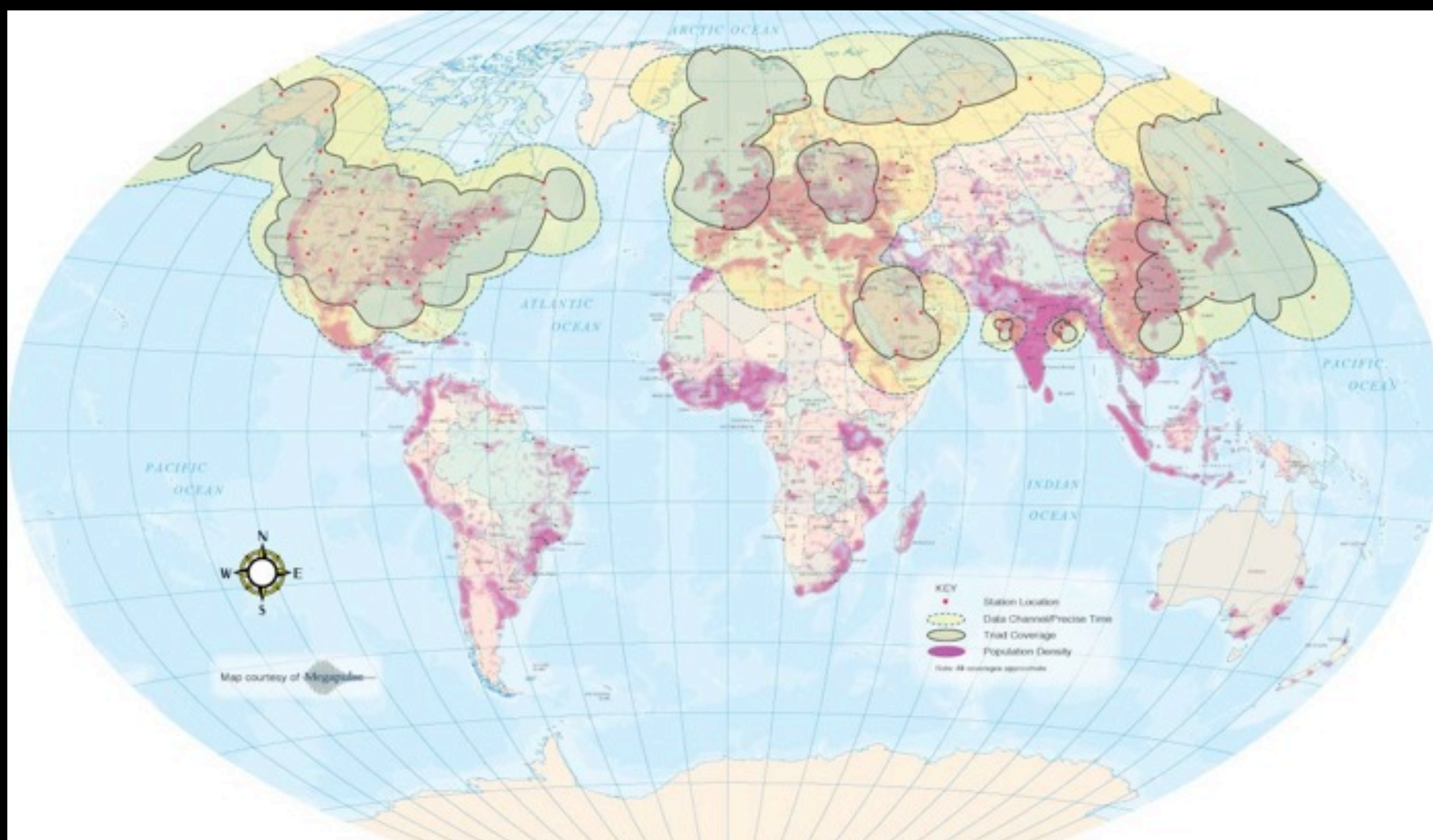
Feil i posisjonering fra 1-12 km

Image Credit: M. A. Shea, Geophysics Directorate, Philips Laboratory

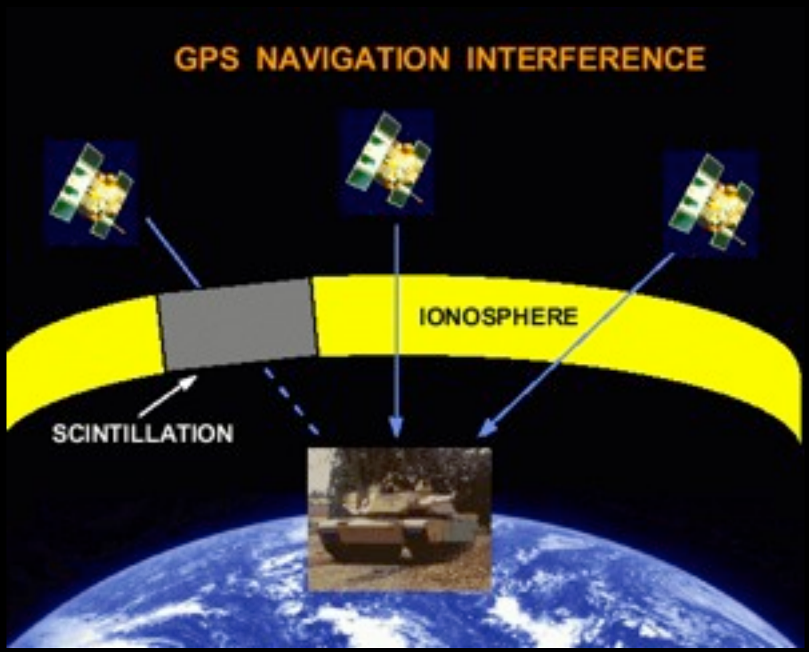
Degradation of LORAN C

- X-rays/Flares - affects the dayside of the Earth (sunlit side)
- Proton showers - affects the dayside of the Earth (sunlit side)
- Geomagnetic storms - day and night + globally

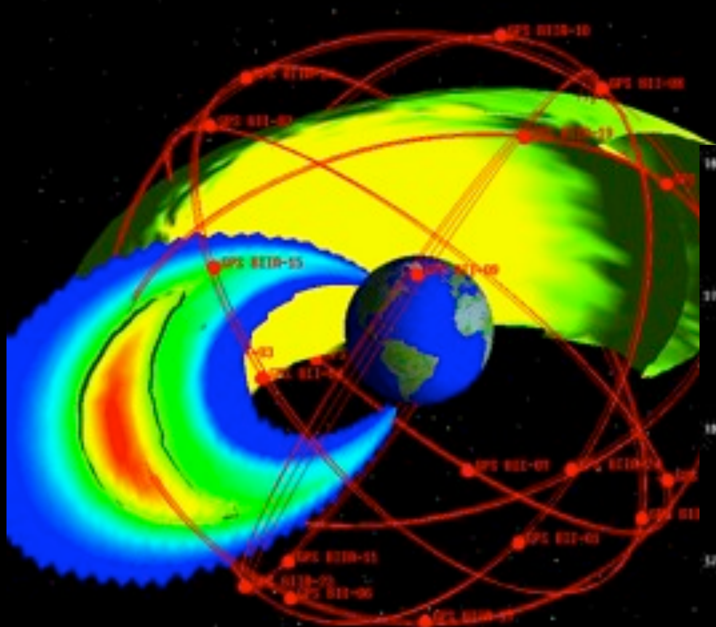
Normal accuracy is about 0.2 km. During solar storms it can be degraded to about 5 km.
Loran C can be useless for several ours in some cases.

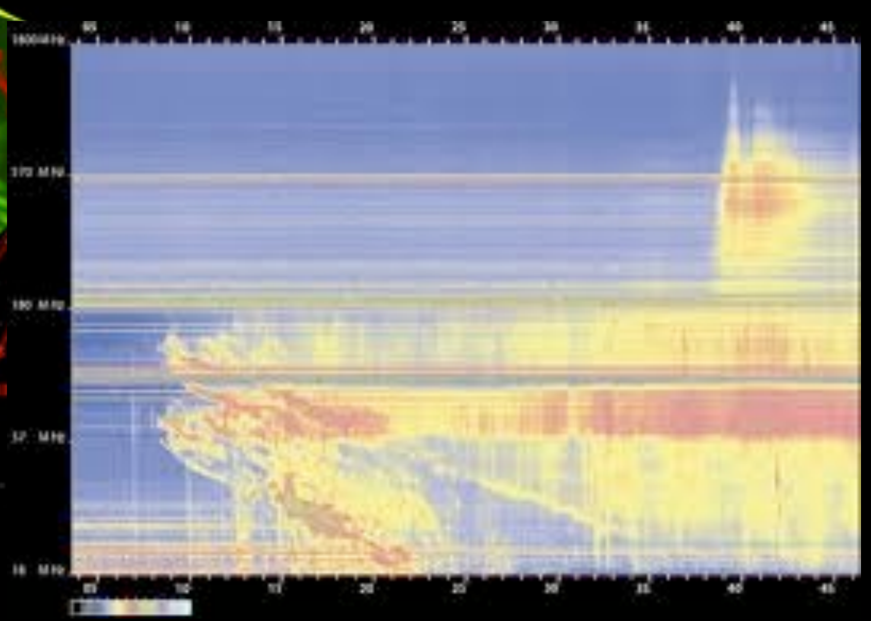


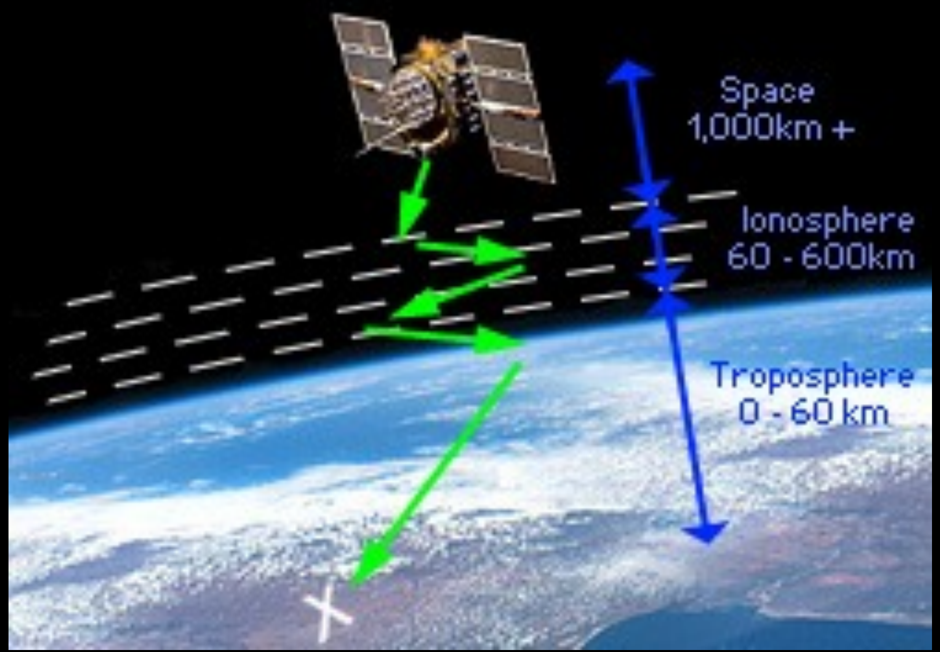
Navigation systems (GPS)



- Turbulence in the ionosphere causes scintillation in the satellite signal and can disrupt the reception.
- Total amount of electrons (TEC) along the path of the signal can introduce errors up to 100 meters.
- Radio bursts can «jam» the signals.

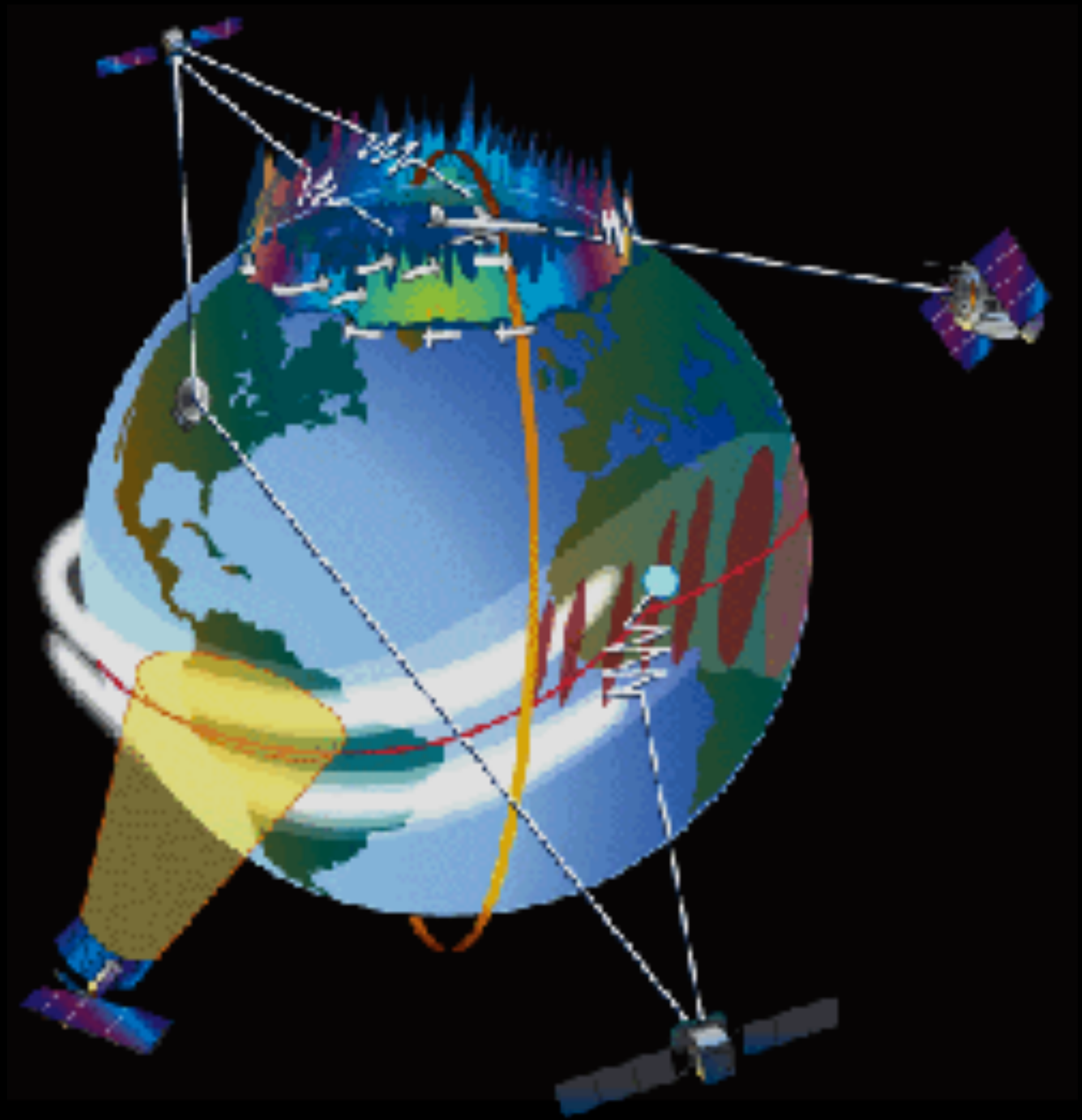






GPS problens in the High North

- Ionospheric disturbances are most severe along the equator and polar regions.



Some don´t care about GPS accuracy

For others it is critical

- Errors in GPS based systems can be a serious problem.

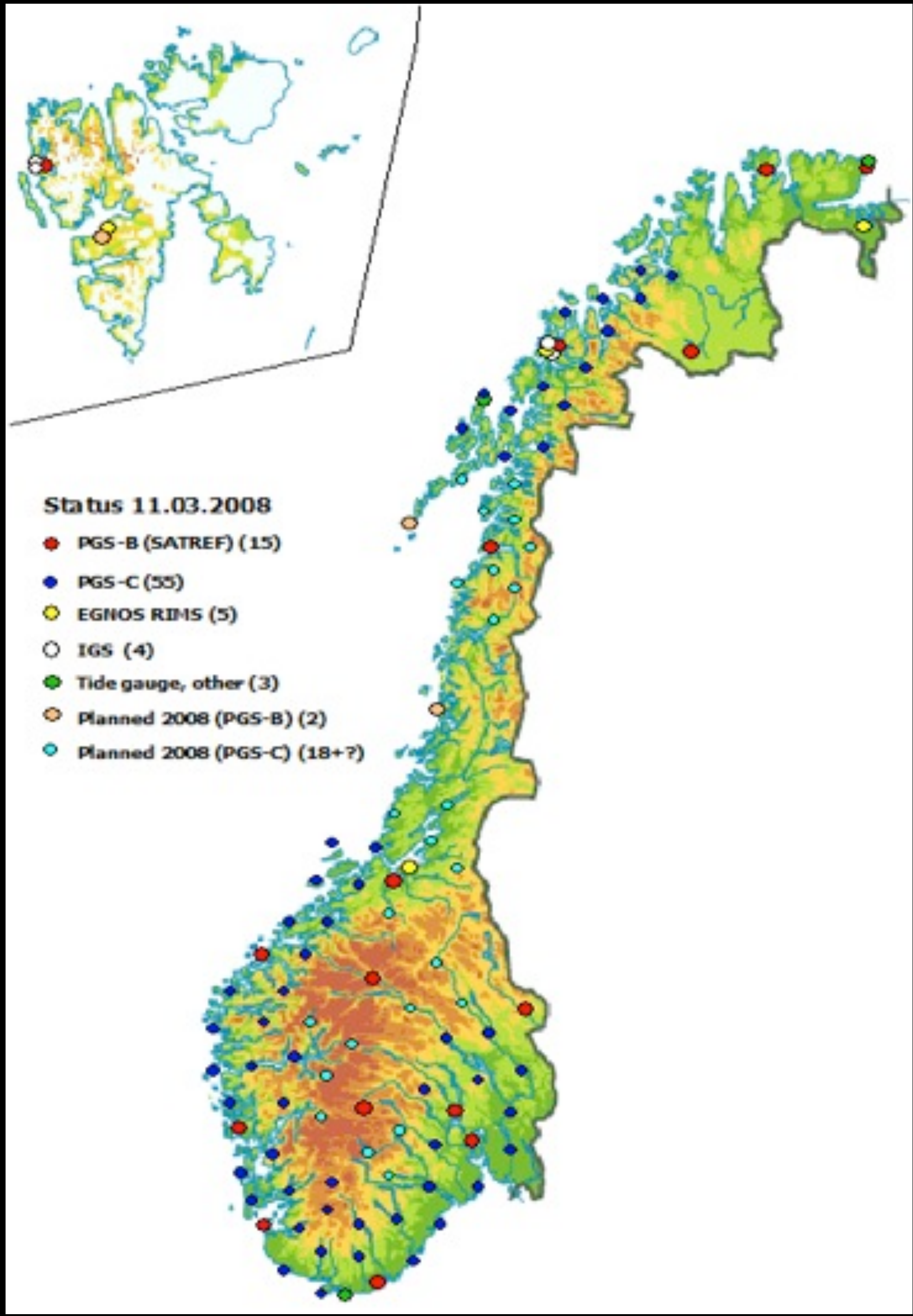
High precision positioning problematic

- Kongsberg Seatex - world leading within dynamical positioning. They experiences often disruption outside the coast of Brasil. This causes interuption of the operation.

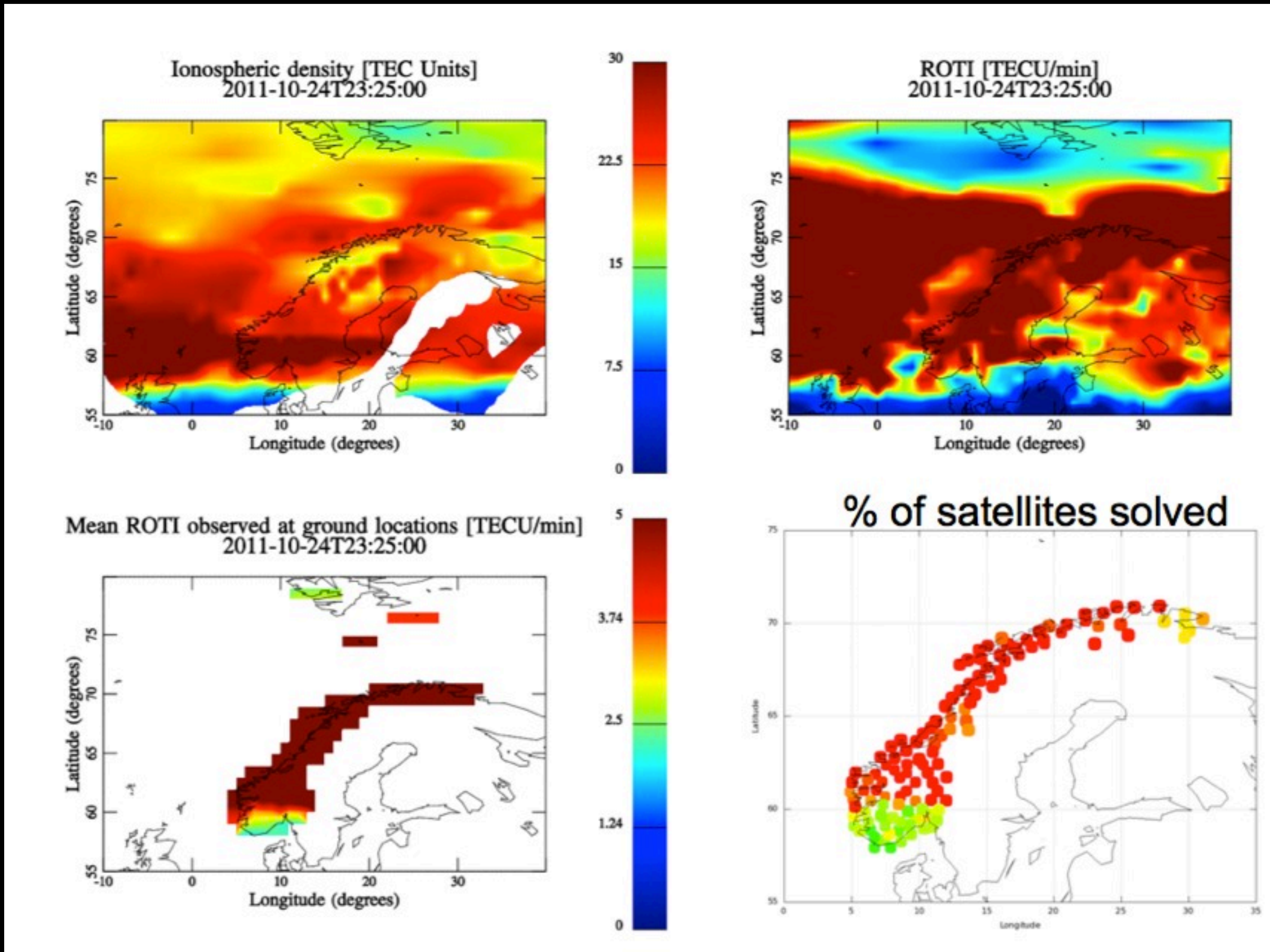
Corrections of GPS positions

- In Norway the Norwegian Mapping Authority has the national responibility for providing corrections to GPS users.
- They monitor the Sun and have developed an ionospheric modeld that improve these corrections and warn their customers.

SATREF Control Centre

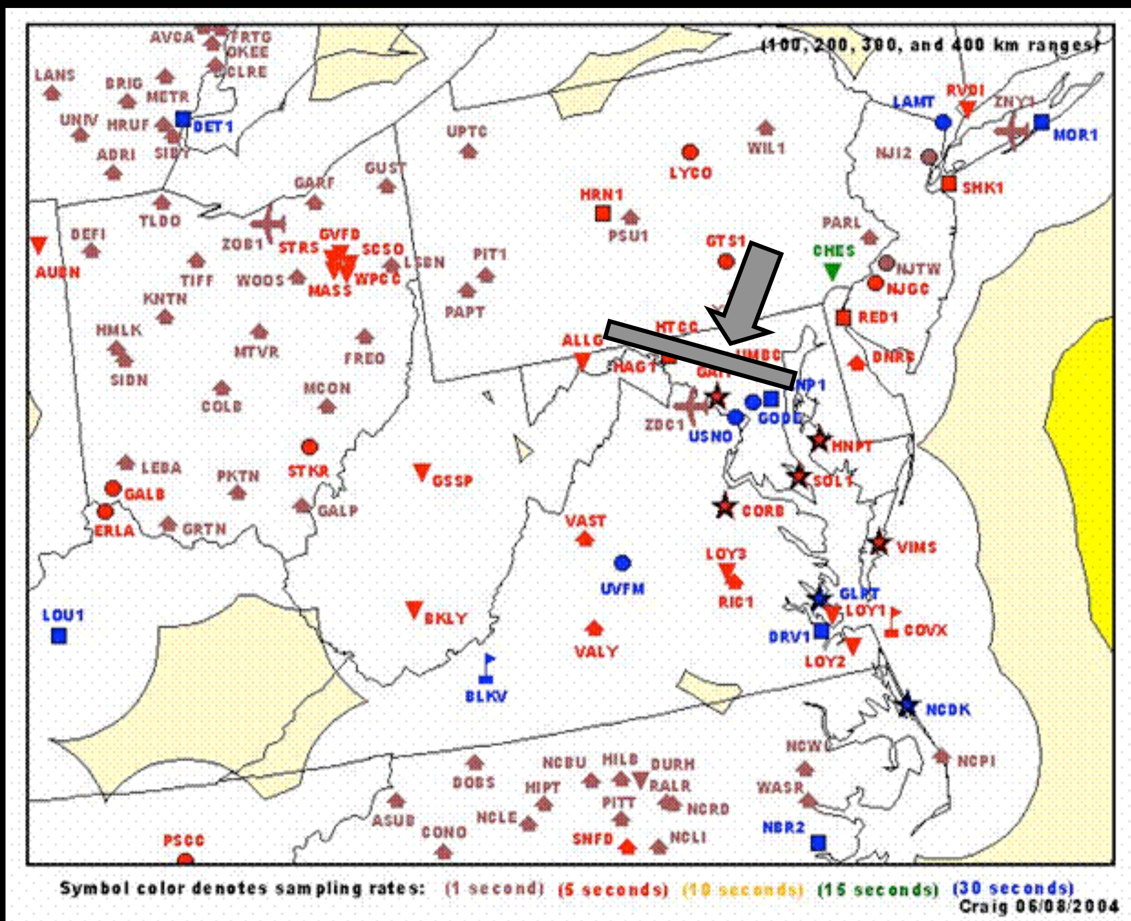


Recent solar storm - affected GPS

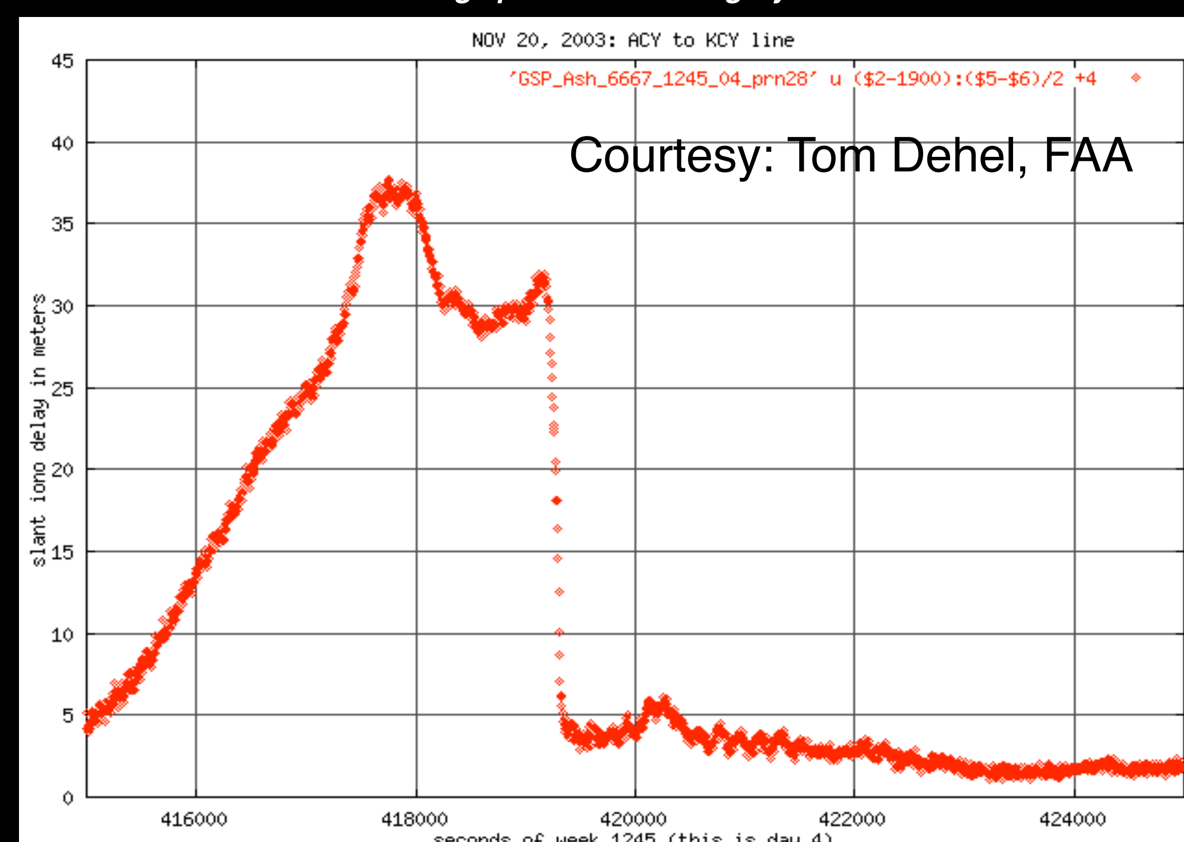


Ionospheric Challenges

- TEC Walls - here an example of ionospheric delay over USA



October 29th, 2003
"walls" of TEC challenge provision of integrity with differential GPS



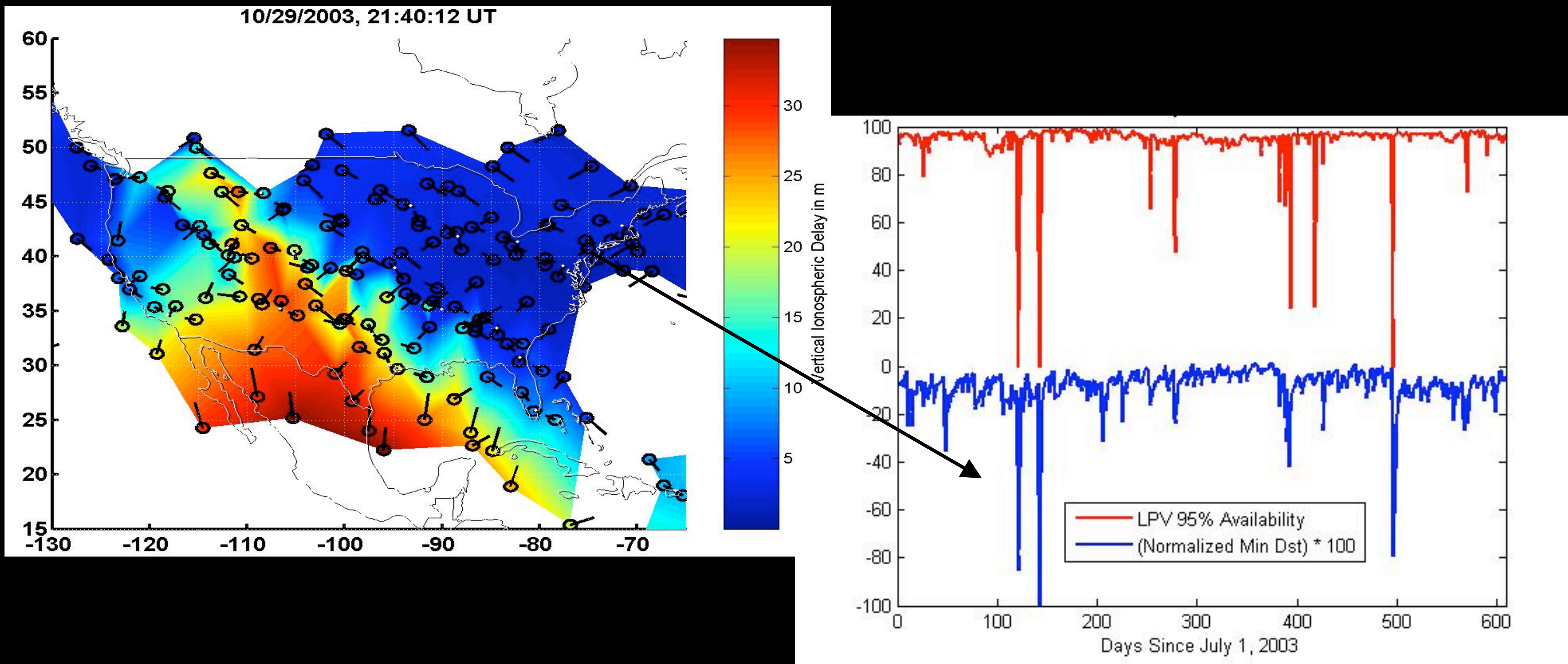
TEC "walls":
130 TEC units over only 50 km

25 m of GPS delay;

walls move 100 to 500 m/s

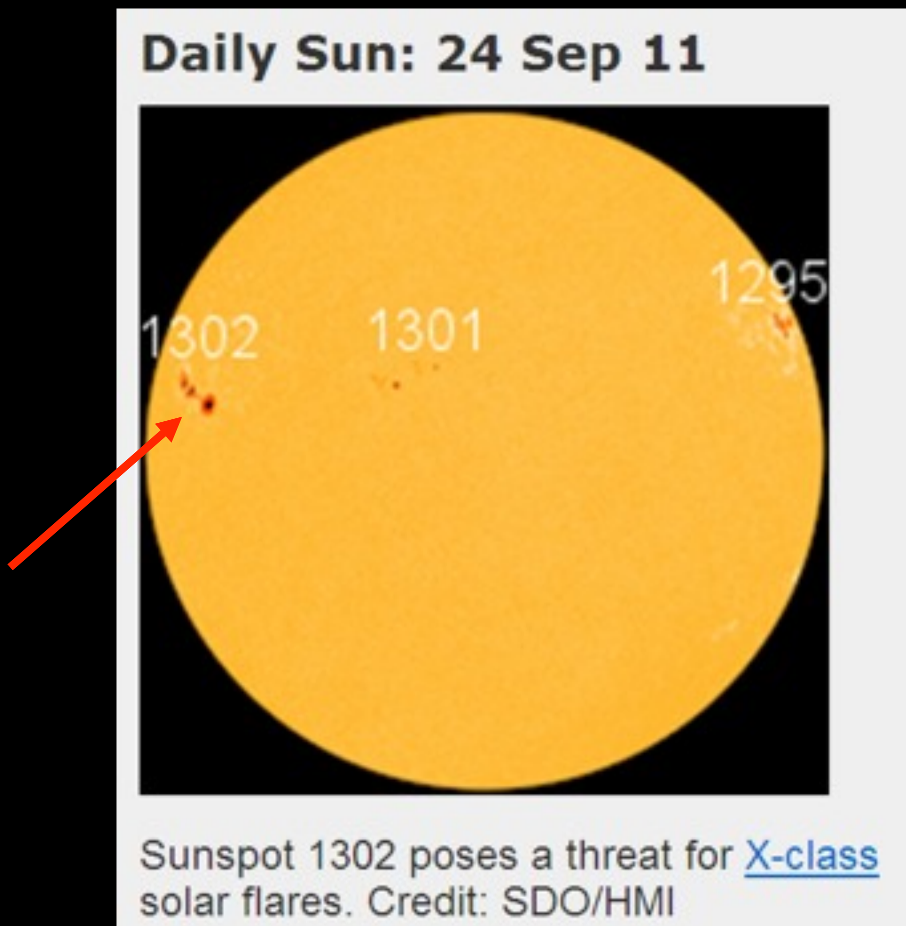
Navigation systems (WAAS)

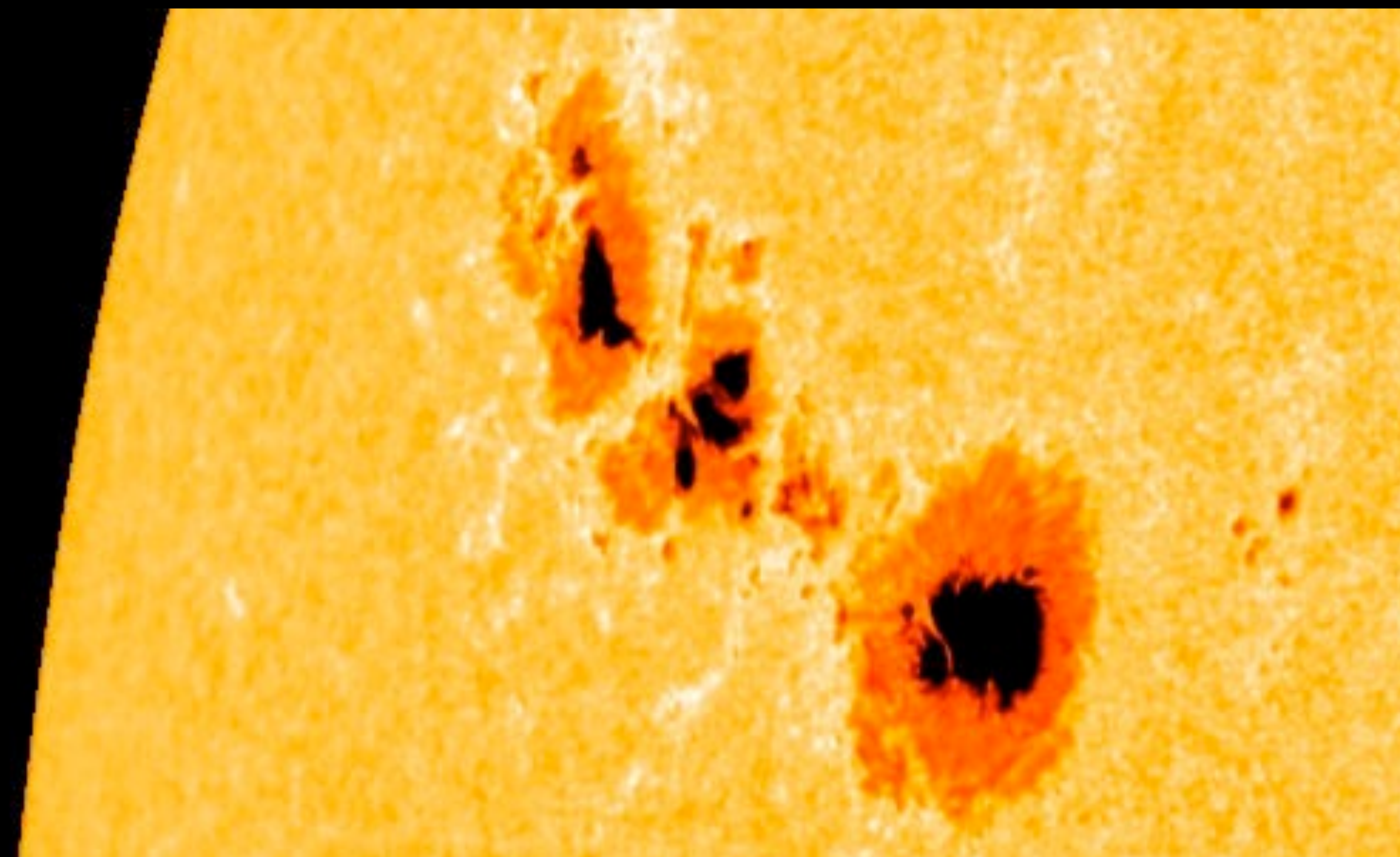
- WAAS - Wide Area Agumentation System. A US-FAA navigation service using a combination of GPS and the WAAS geostationary satellites to improve navigational service provided by GPS.



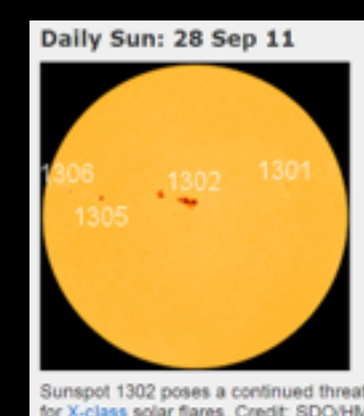
15 hour loss on 10/29; 11.3 hour loss on 10/30, shorter losses on 11/20/2003

Sunspot region 1302 on 24 Sept

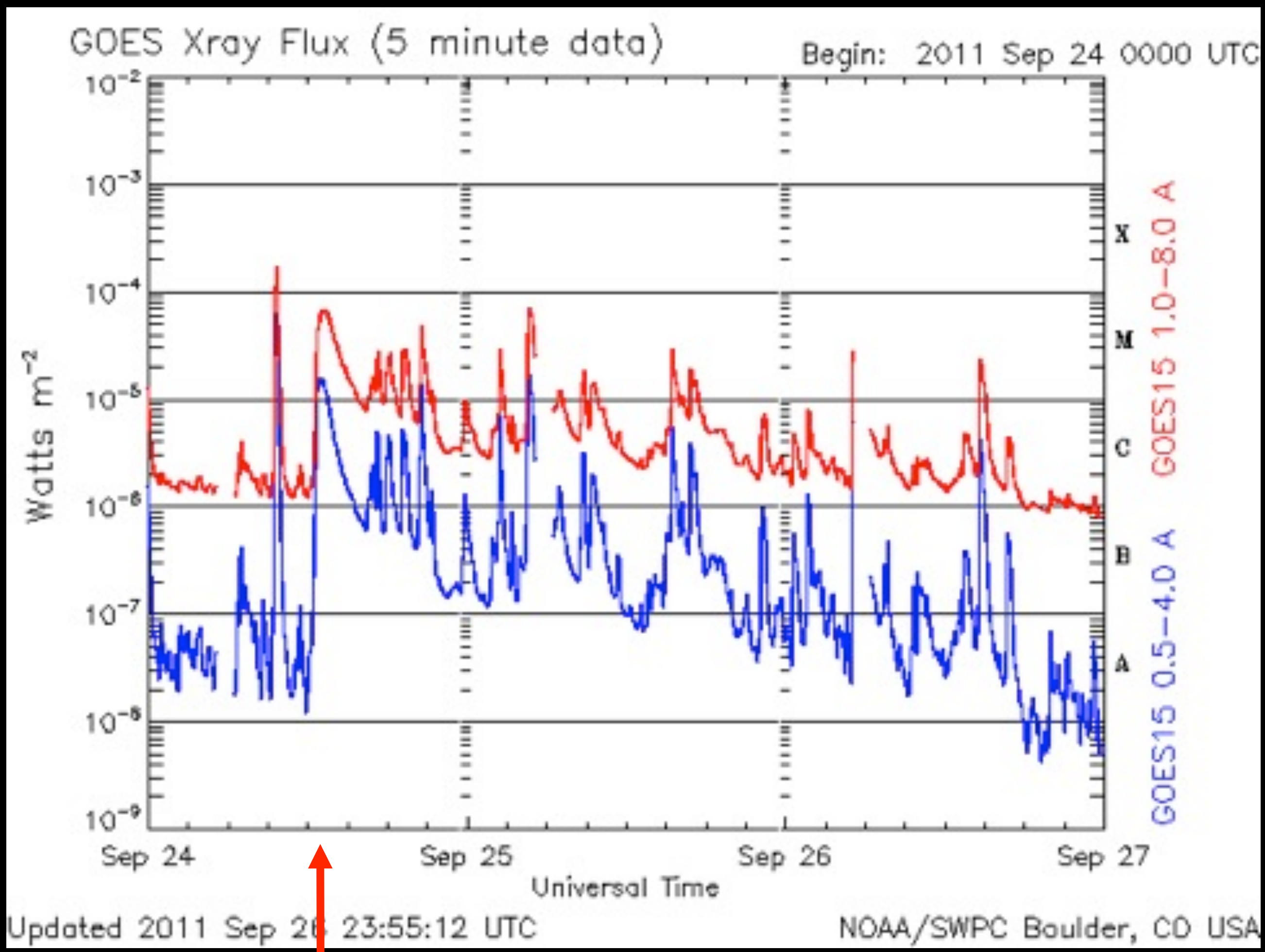


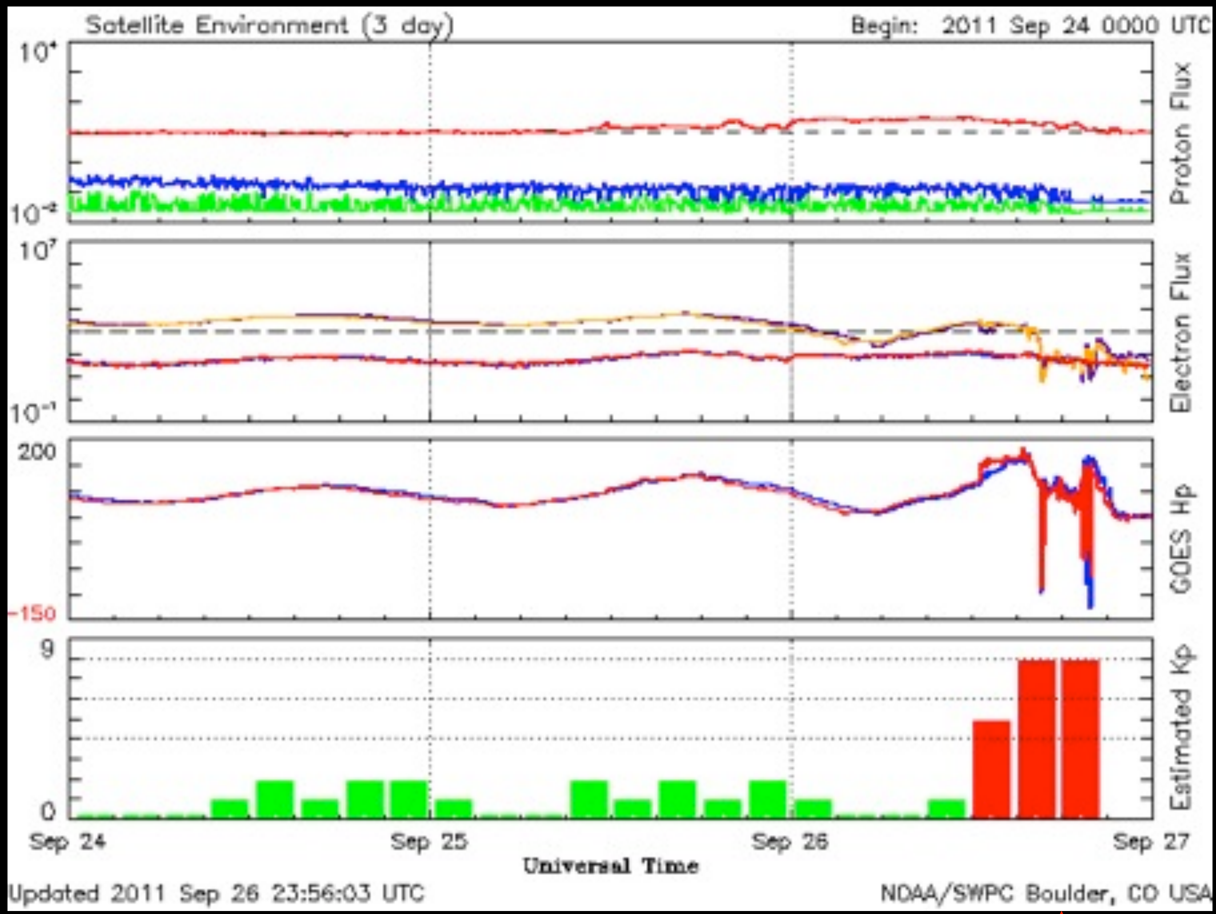


Each of the dark cores in this snapshot from the Solar Dynamics Observatory is larger than Earth, and the entire active region stretches more than 100,000 km from end to end.



X-Ray and Kp index 24-27 Sept





Burst of X-Rays (M7.1) and energy
in many frequency bands. Arrives after 8 minutes
and creates interference in receivers

Two days later the solar
wind from the same flare
reaches earth.
This creates magnetic
storms and Aurora

Event 3590 from sunspot 1302, 24 Sept. 2011

#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
3590	1231	1313	1409	SAG	G	RBR	245	4800	CastelliU	1302
3590	1231	1253	1406	SVI	G	RBR	8800	1300	CastelliU	1302
3590	1231	1307	1410	SAG	G	RBR	610	80000	CastelliU	1302
3590 +	1232	1302	1411	SVI	G	RBR	2695	12000	CastelliU	1302
3590	1232	1253	1358	SVI	G	RBR	4995	1400	CastelliU	1302
3590 +	1232	1313	1410	SAG	G	RBR	410	69000	CastelliU	1302
3590 +	***1233***	***1320***	***1410***	***G15***	***5***	***XRA***	***1-8A***	***M7.1***	***2.9E-01***	***1302***
3600	1233	1233	1233	SVI	G	RBR	15400	51		
3590 +	***1234***	***1304***	***1405***	***SAG***	***G***	***RBR***	***1415***	***110000***	***CastelliU***	***1302***
3590	1234	1251	1415	SAG	G	RBR	15400	840	CastelliU	1302

Solar Cycle 24:
Start: 2009
Maximum: 2013

RBR = Fixed-frequency radio burst

RBR: The peak value above pre-burst background of associated radio bursts at frequencies 245, 410, 610, 1415, 2695, 4995, 8800 and 15400 MHz

MHz

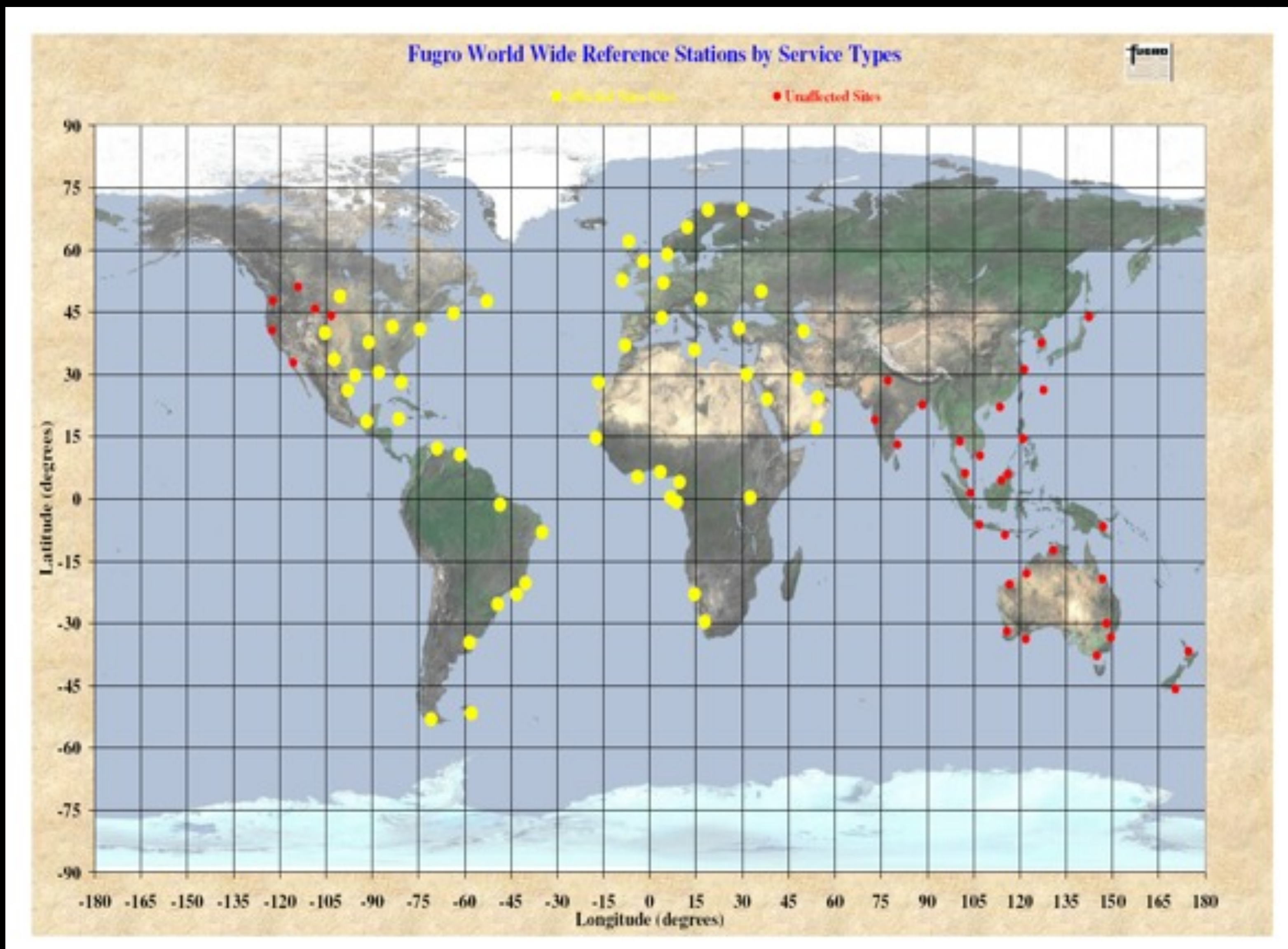
1 flux unit = 10^{-22} Wm^{-2} Hz^{-1}

This shows that there was a lot of energy at the frequency 1415 MHz peaking at 1304 UTC

http://www.swpc.noaa.gov/ftpdir/indices/events/20110924events.txt

Fugro reference stations affected

www.fugro.no



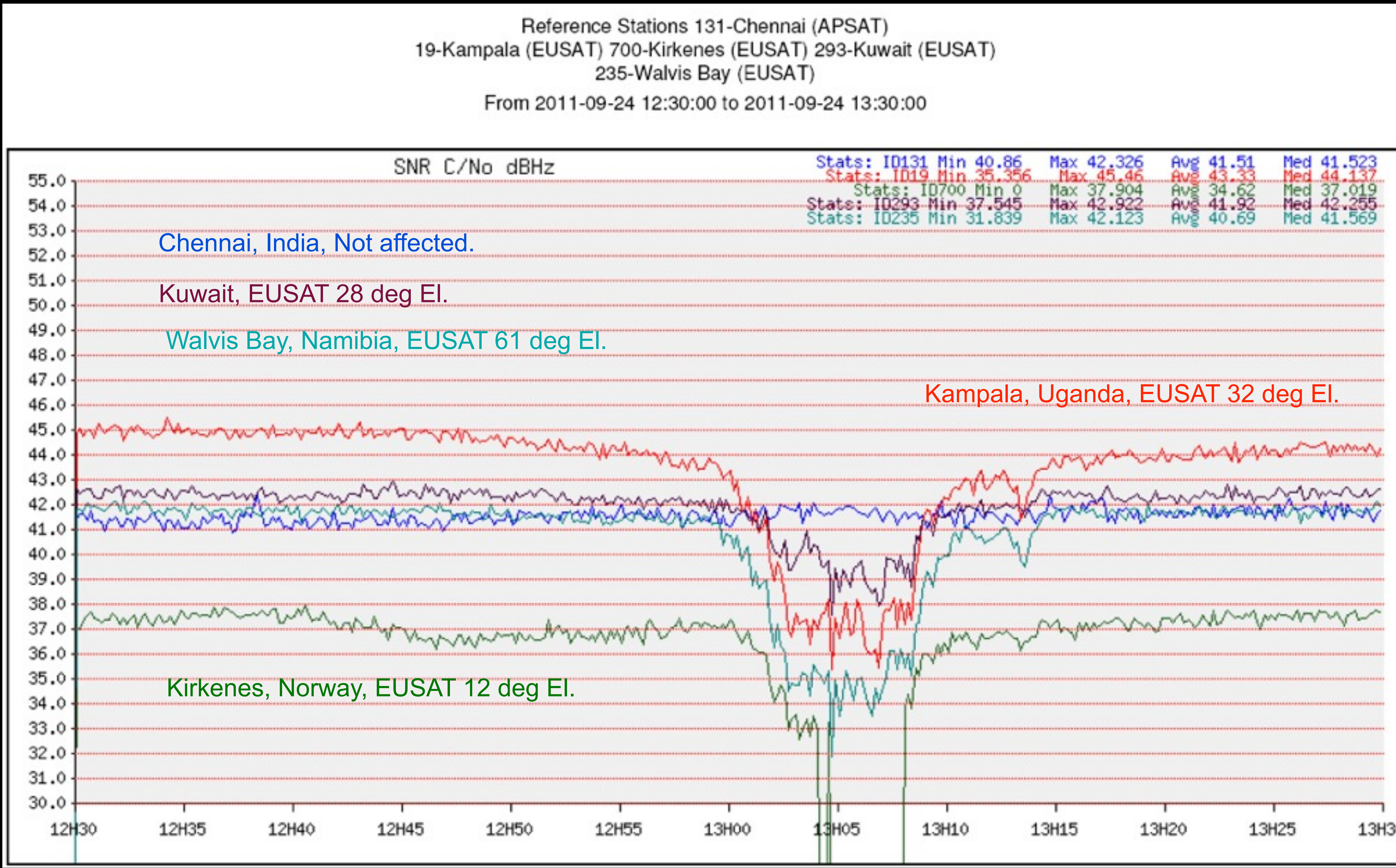
Fugro L-Band broadcast read backs affected in yellow

Daytime region on 24 Sept

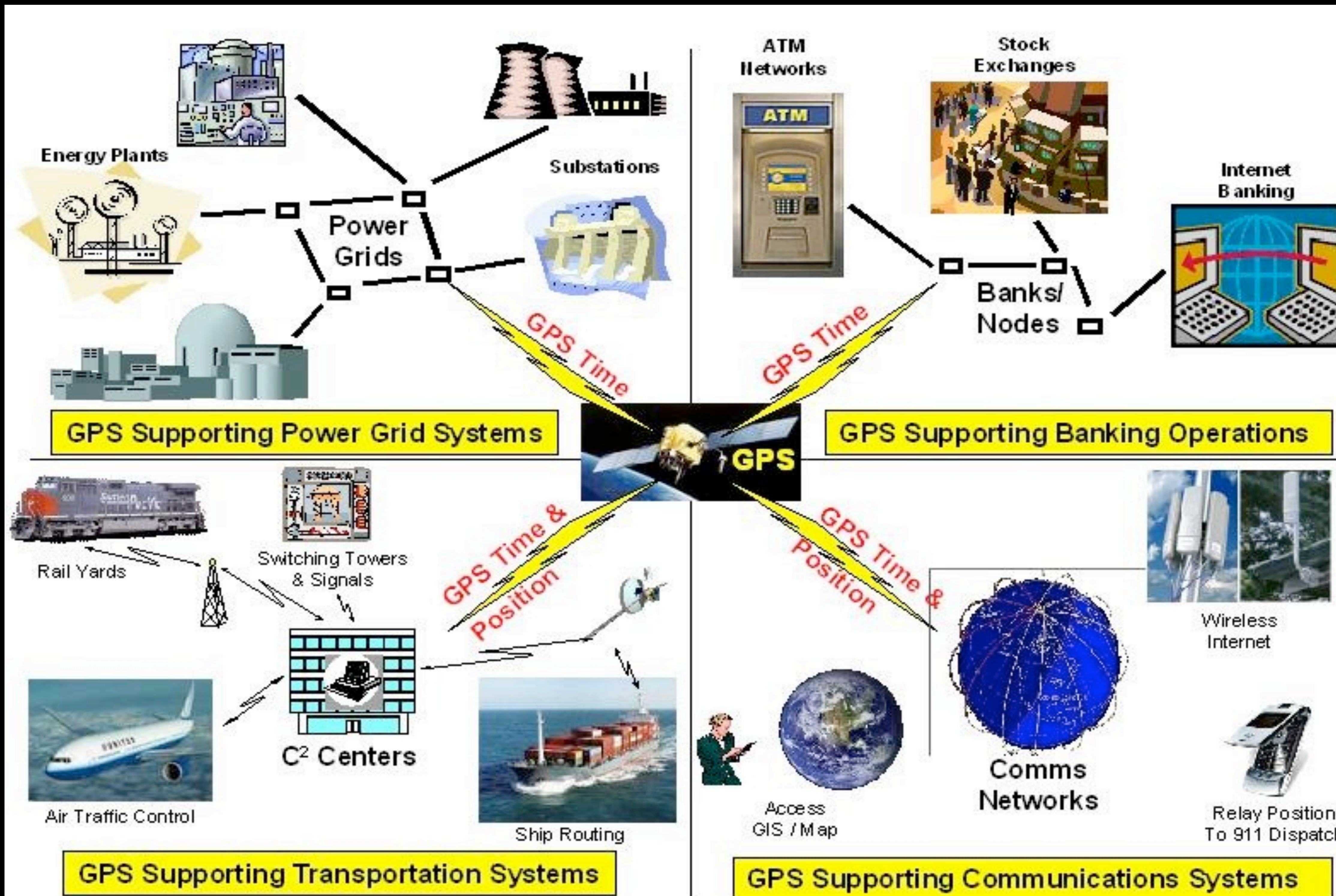
All the receivers on the sunlit part of the earth were affected.

Fugro L-Band tracking EAME 24 Sept

www.fugro.no

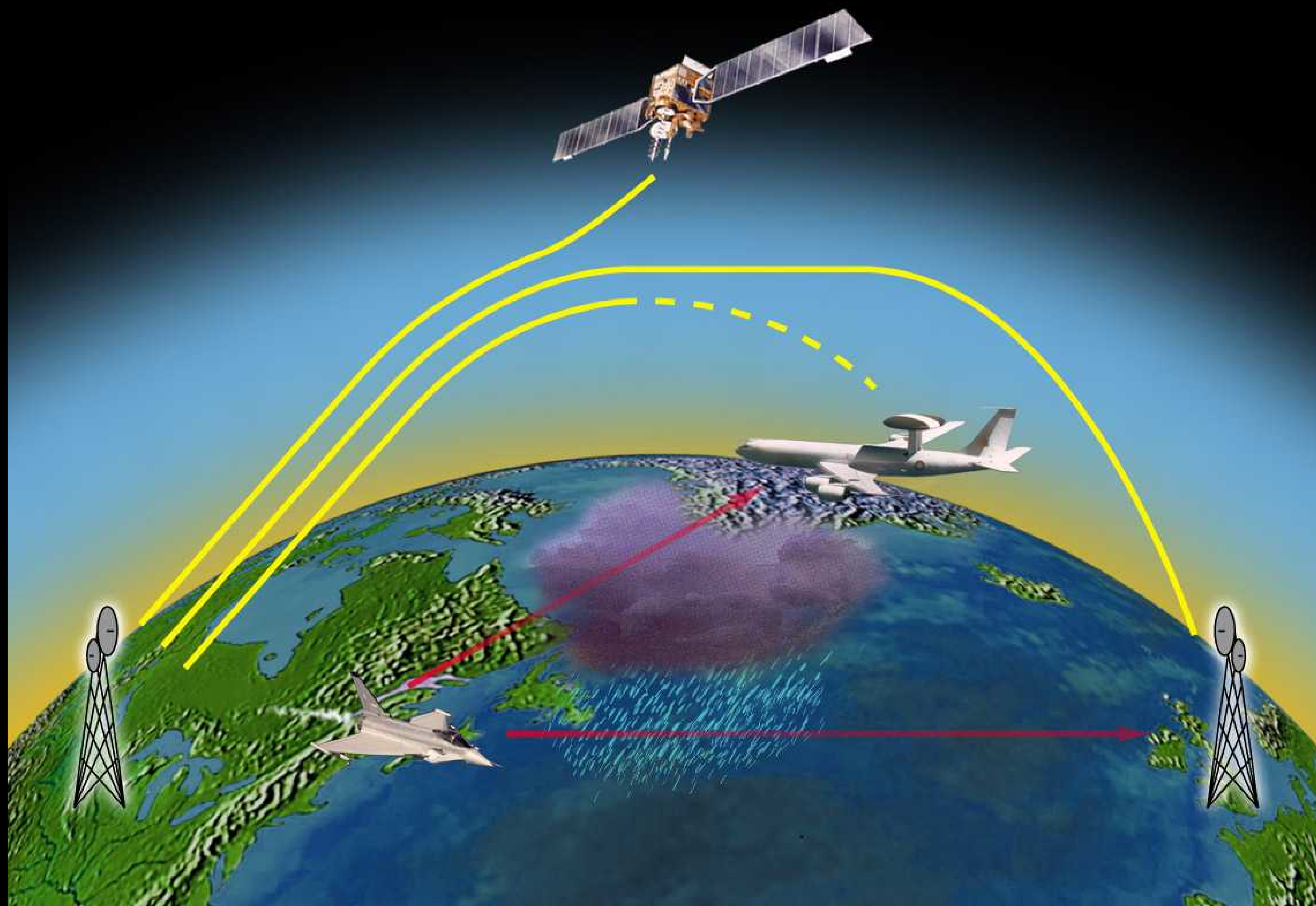


Extent of GPS Dependencies

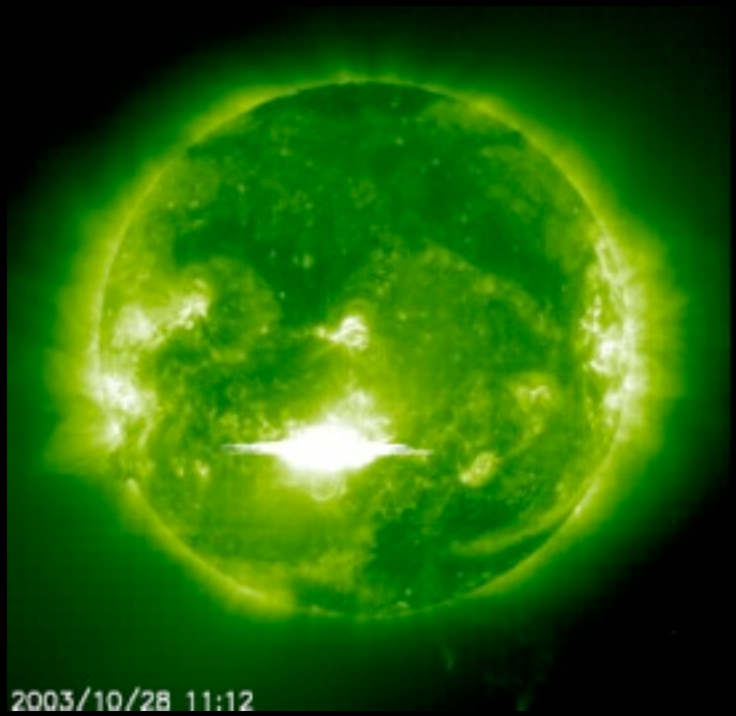


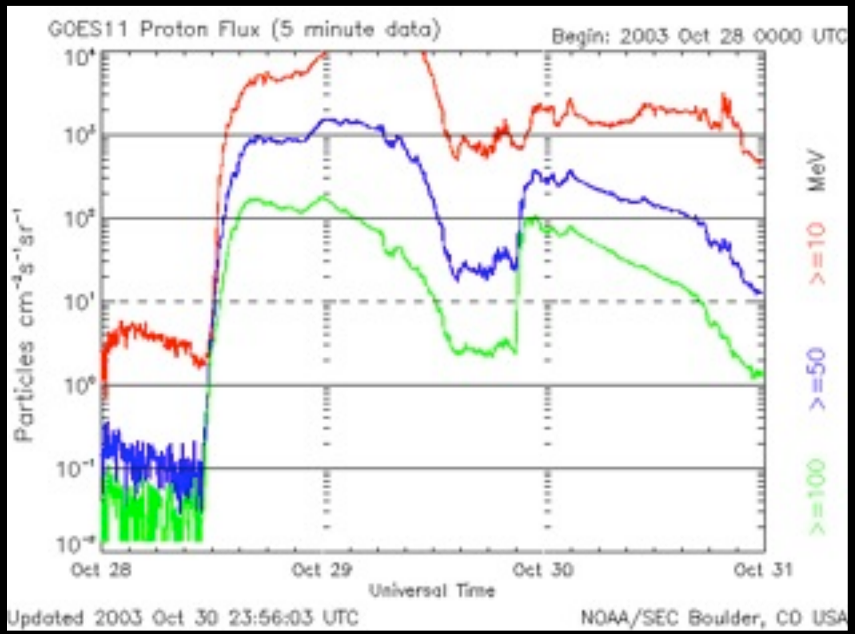
K. VanDyke, DOT

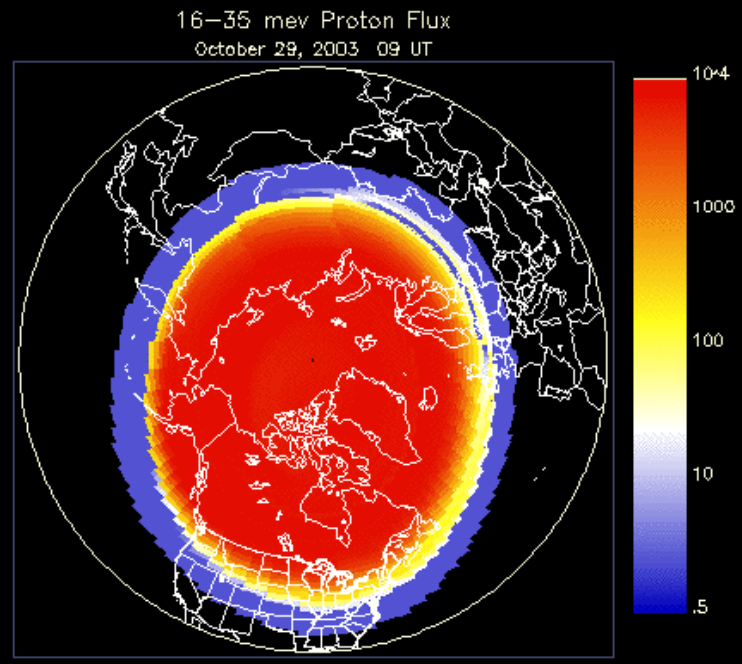
Radiocommunication i polar regions difficult



Radiation Storms = degraded comm







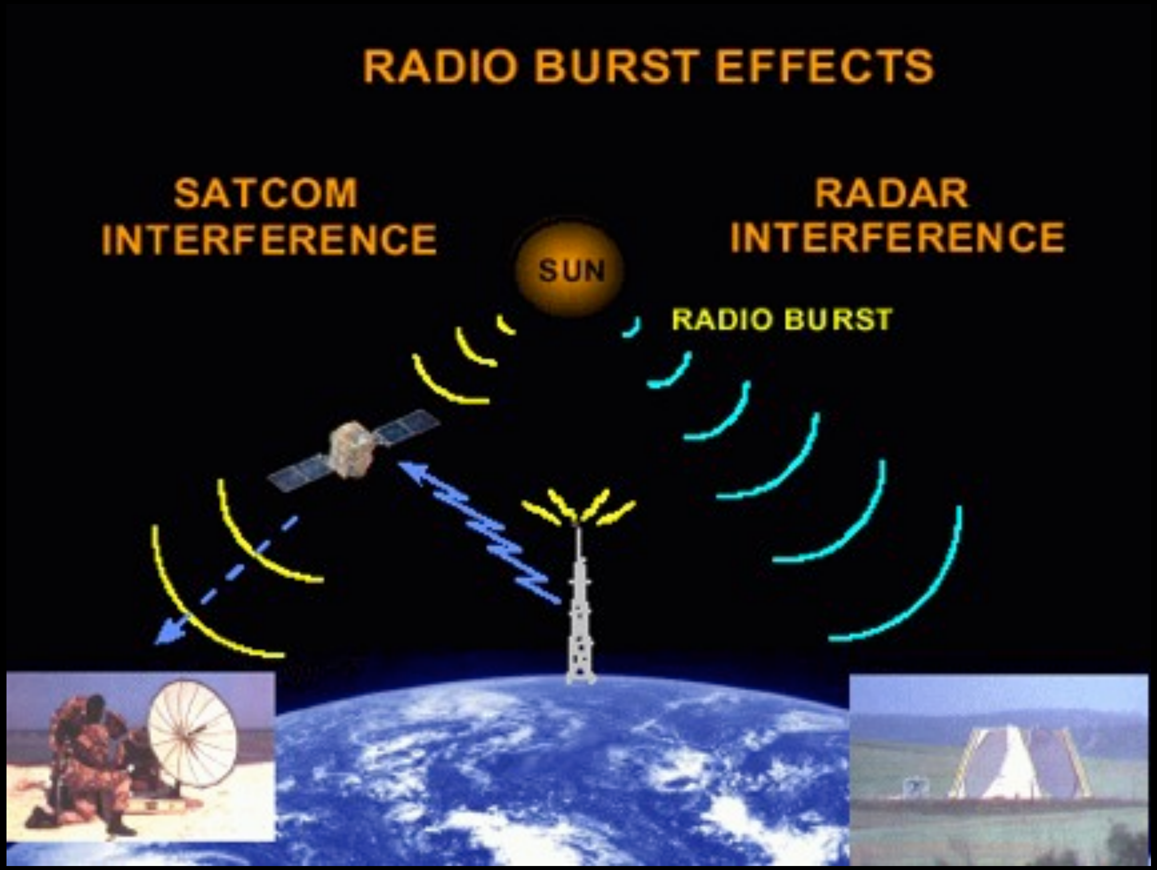
Radiation storms cause extended periods (hours to days) of HF communication blackout at higher latitudes

Conditions are usually worse on daylight side

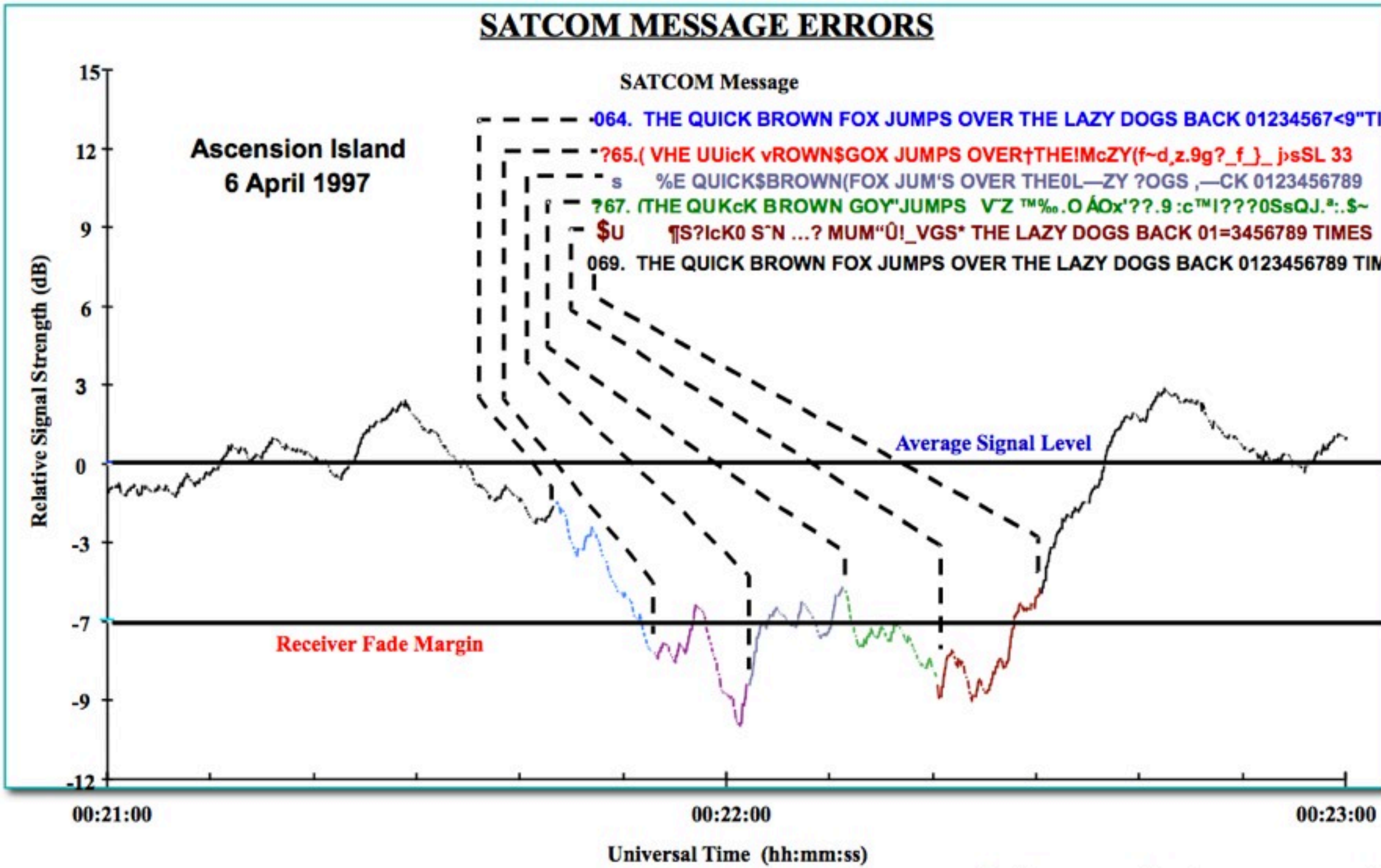
A geomagnetic storm occurring at the same time as a radiation storm can increase the hazard at lower latitudes

Effects on military systems

- HF satelite communication (SATCOM) can be disrupted for several hours during strong flares.
- Some weapon systems use GPS for navigation.
- Military satellite systems
- Early warning systems
- Search and rescue



SATCOM problems



S. Basu, private communication

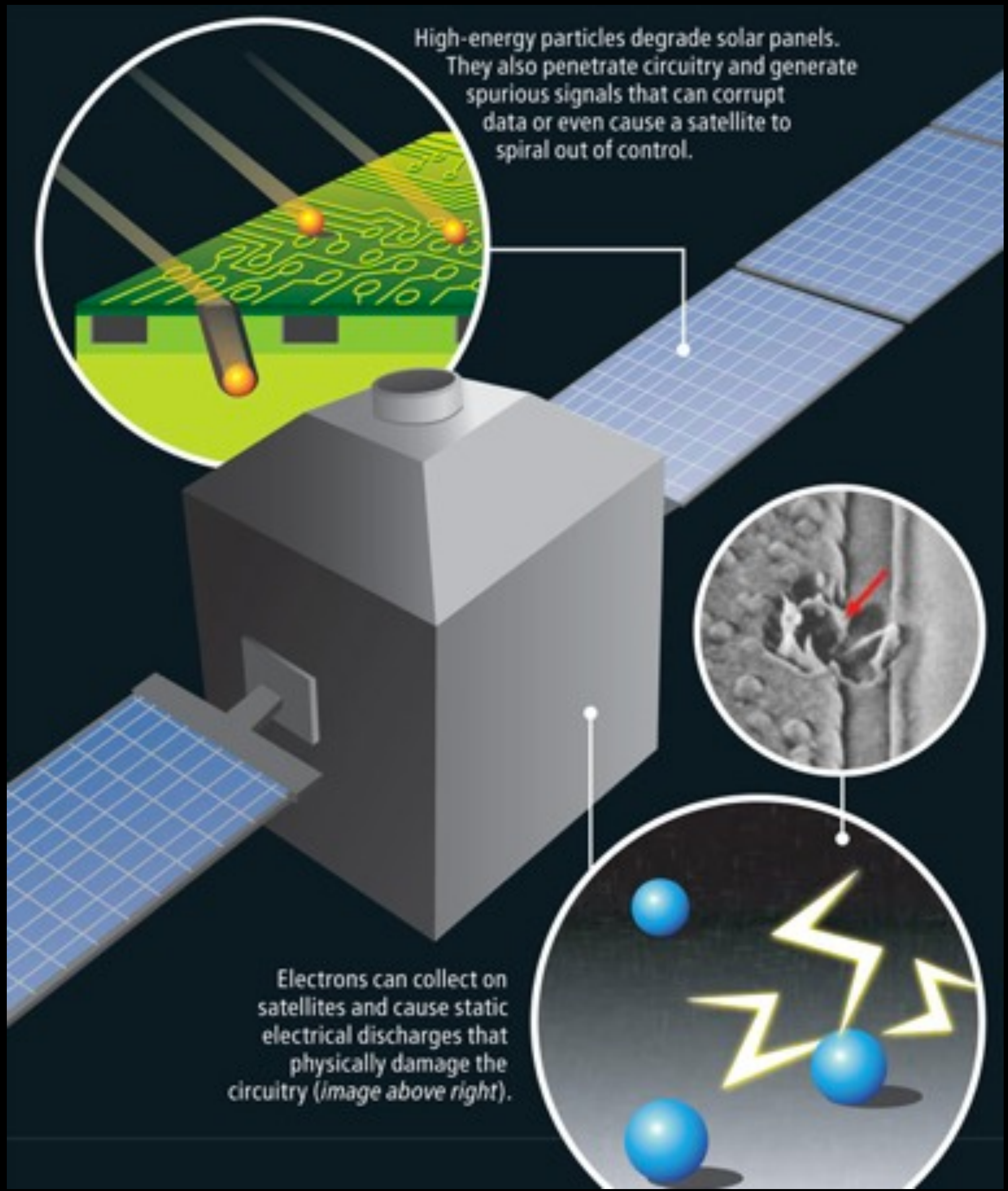
Effects on cell-phones

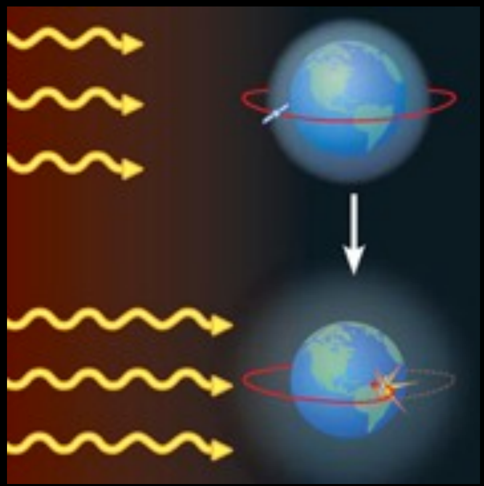
- Radioburst from the Sun can interupt cell phone calls.
  - If your base station is in the direction of the Sun (evening/morning) due to interference.
  - Can lead to "dropped calls"
  - In areas where teh signal is already weak - this can cause more problems.

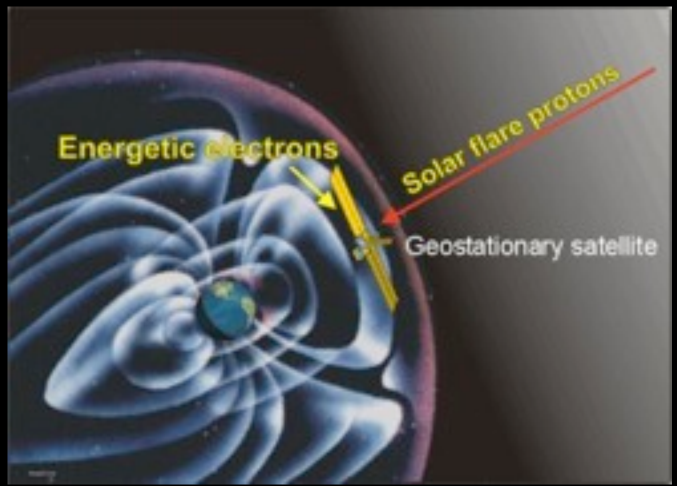
Effects on Satellites

Examples:

- Surface charging
- Single Evente Upset (from high energy particles)
- Increased drag
- Interference and scintillasjon of the signal
- Space debris
- Orientation problems
- Nosie on the star trackers/navigation systems.
- Degradation of material/solar cells
- Hits by micro meteorites

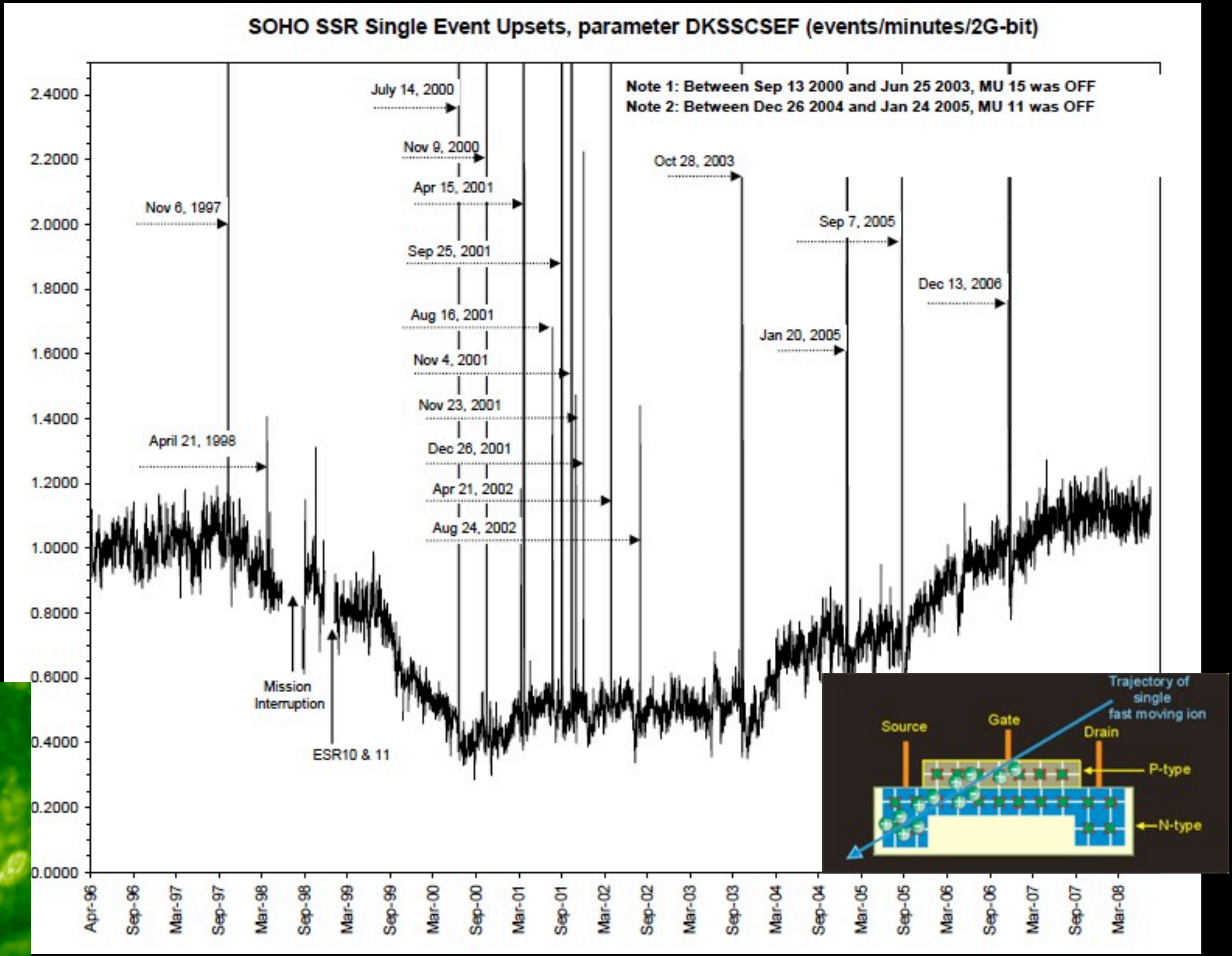


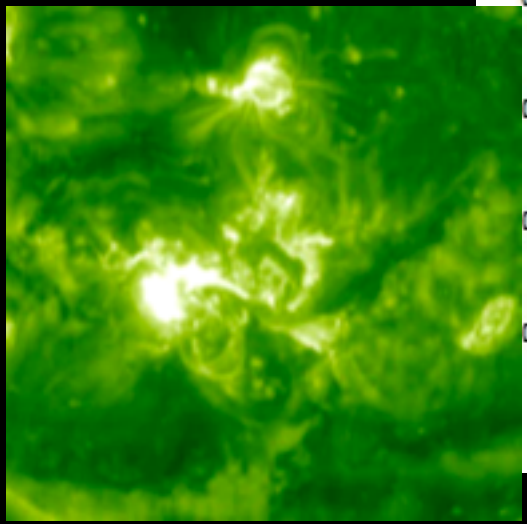




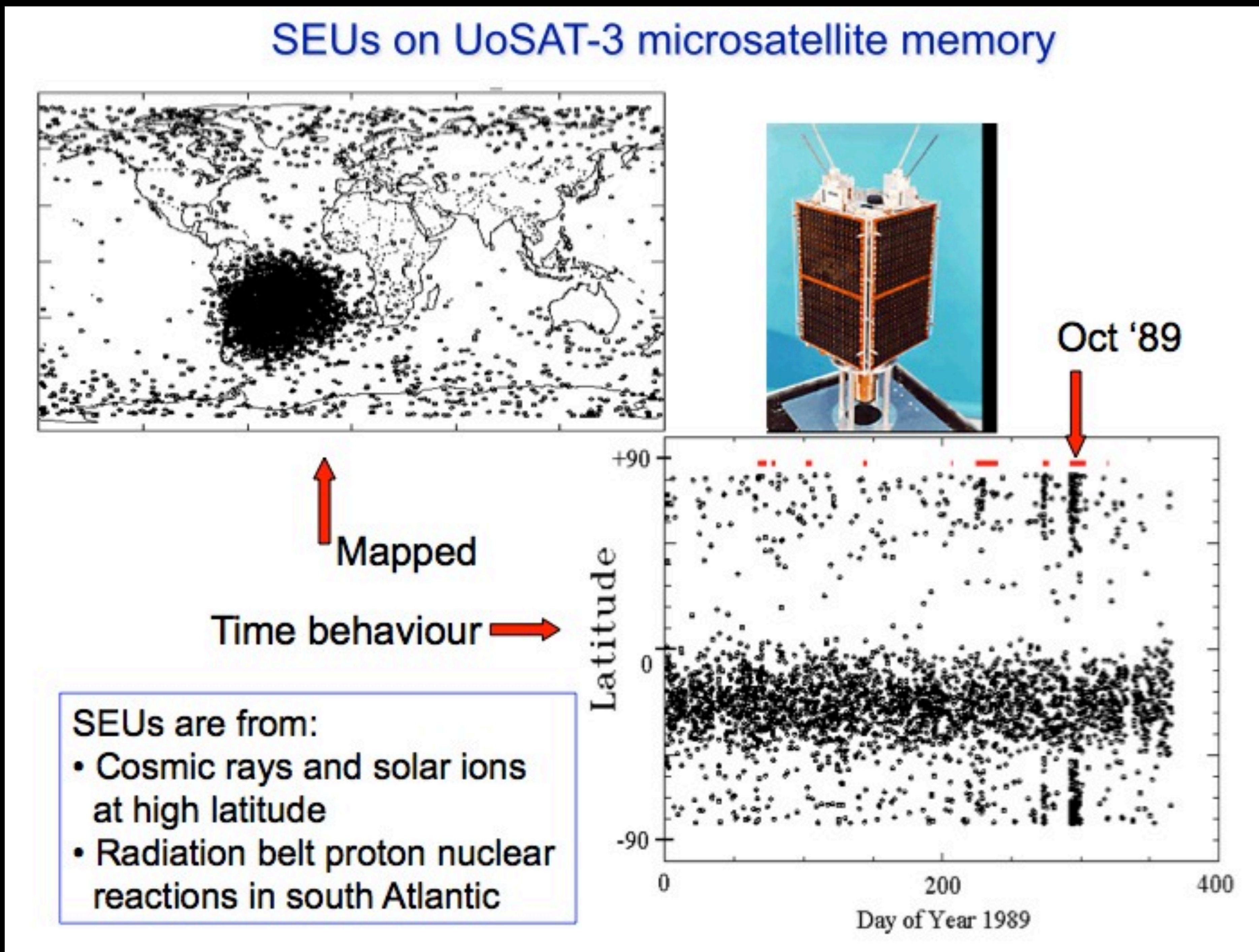
Single Event Upsets

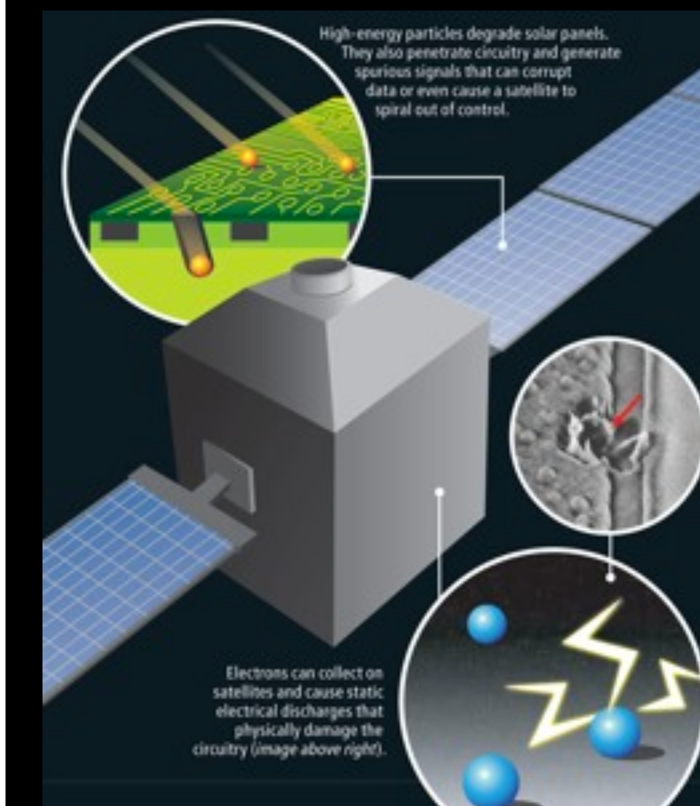
High energy particles can penetrate satellites and damage sensitive electronics.



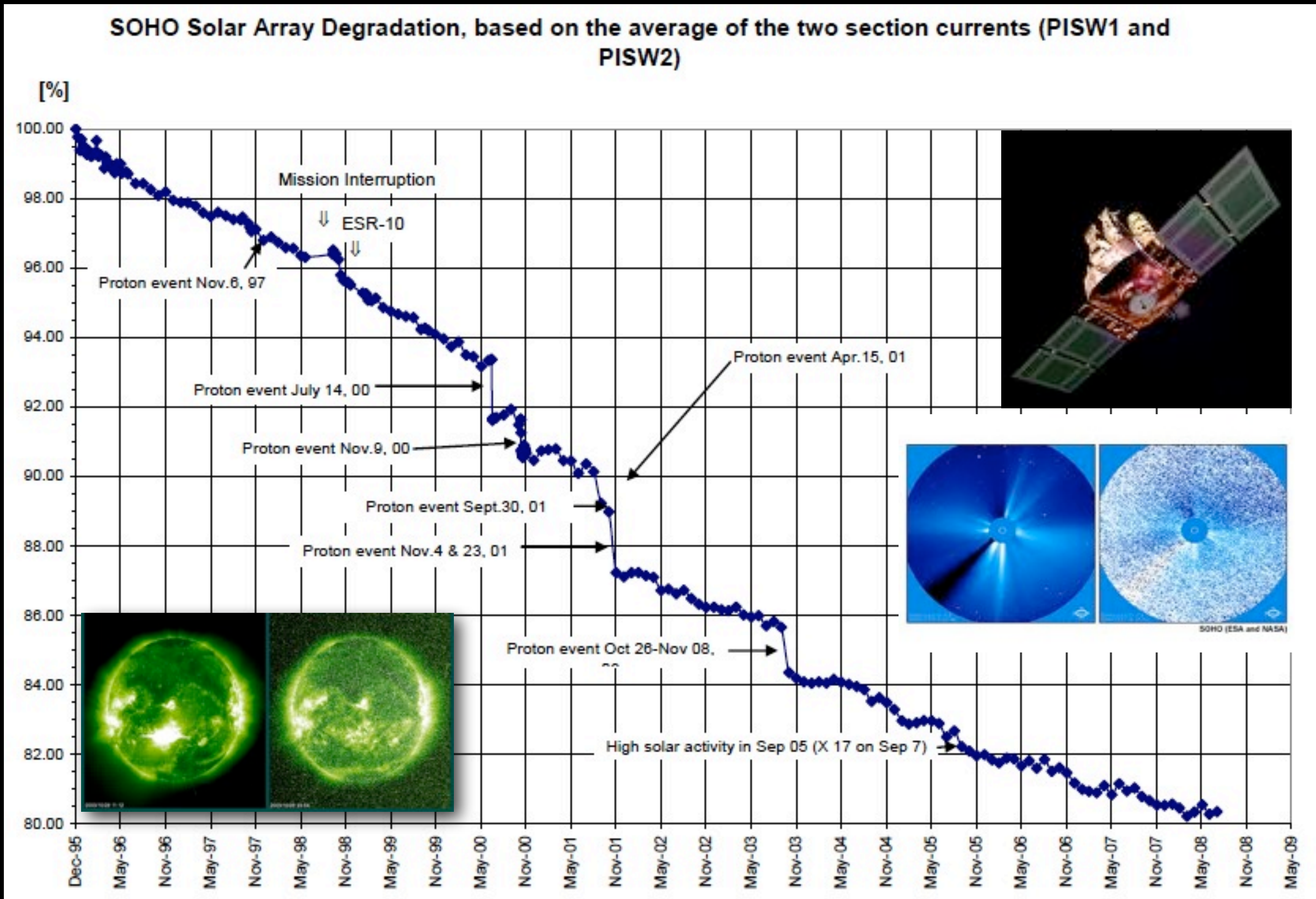


Single Event Upsets



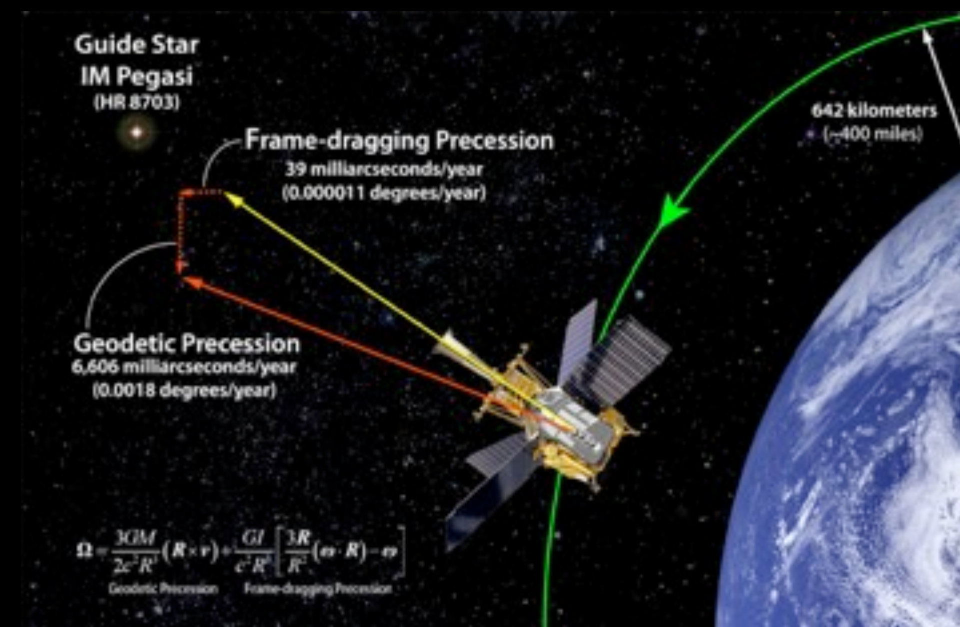


Degration of the SOHO solar cells during proton events.

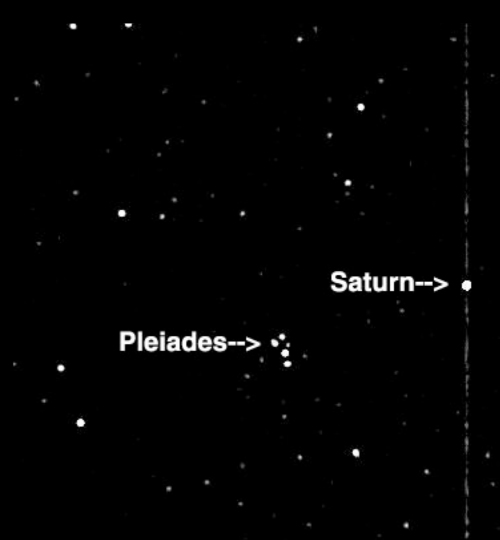


Orientation problems

Some satellites use star trackers to «lock» into stars for navigation, others use the Earths magnetic field.

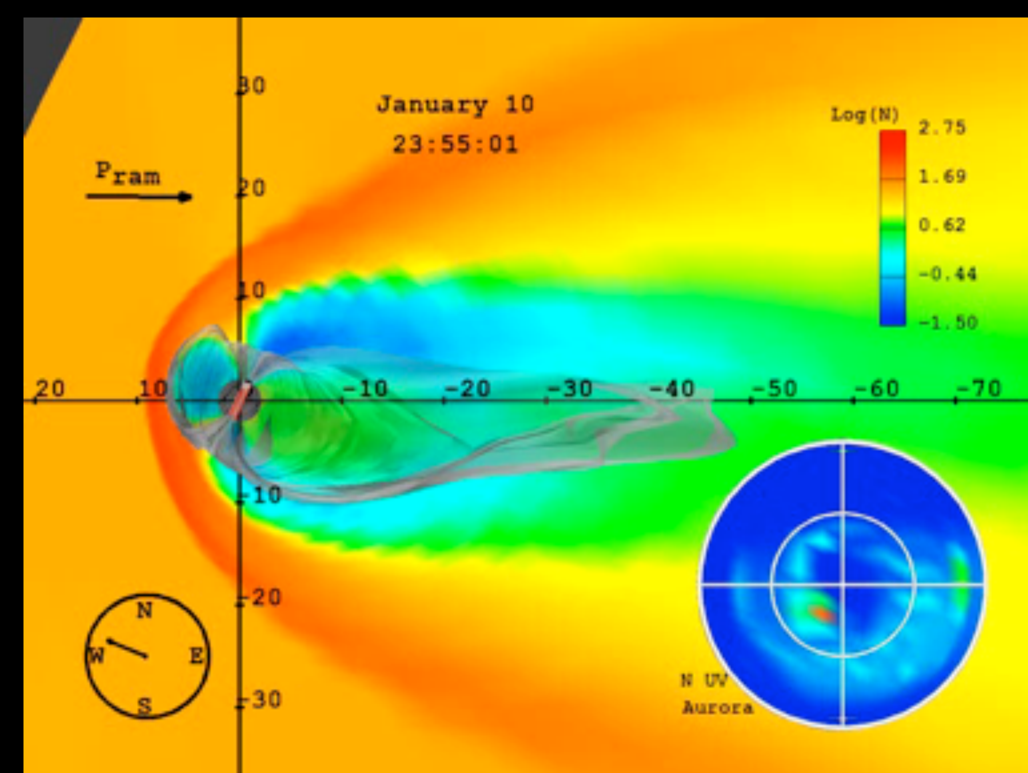


Star trackers can easily be «tricked» by false stars created by high energy protons hitting the CCD camera.



Før protonskur

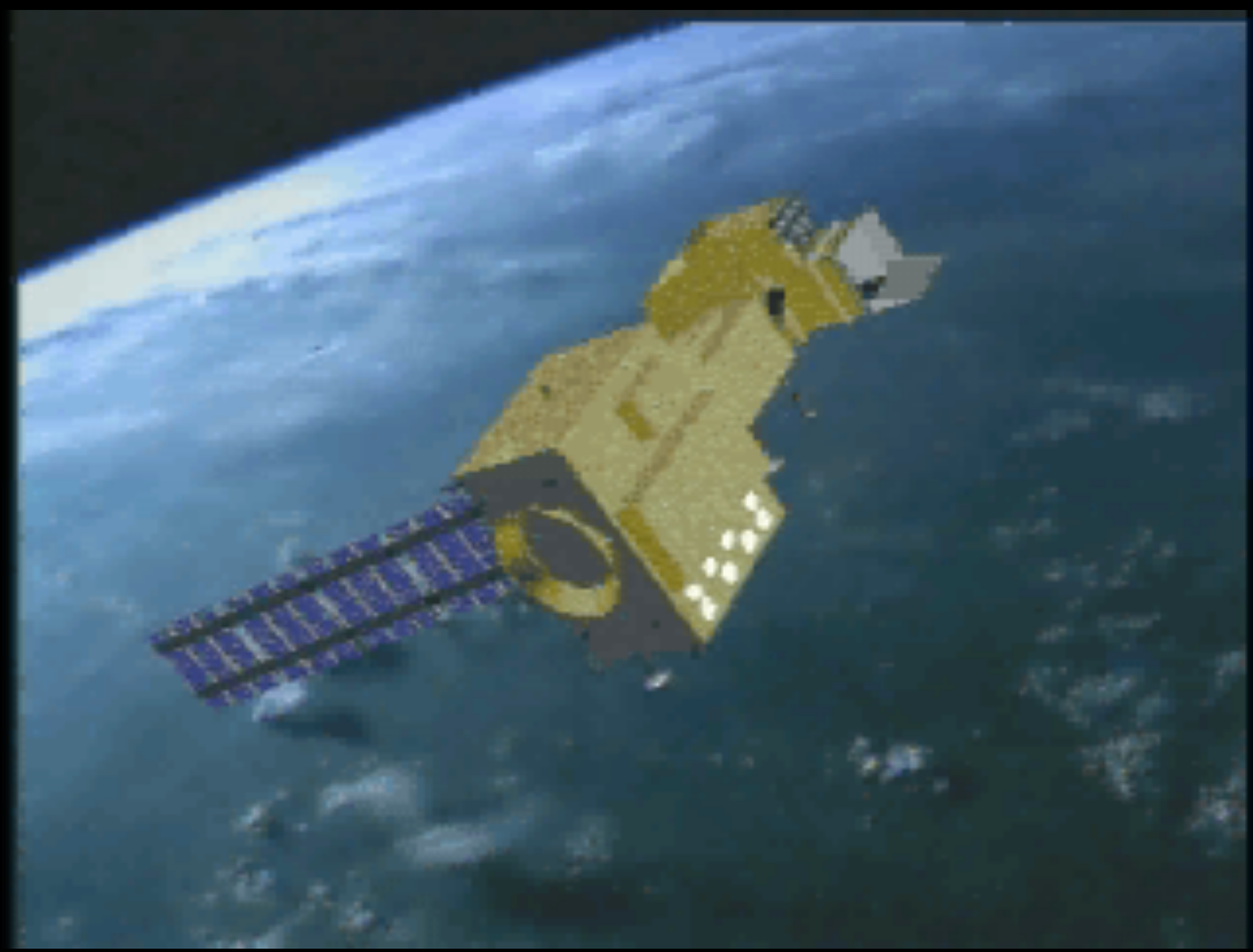
Etter protonskur



Magnetic navigation can be affected by dynamics in the Earths magnetic field.

Surface Charging

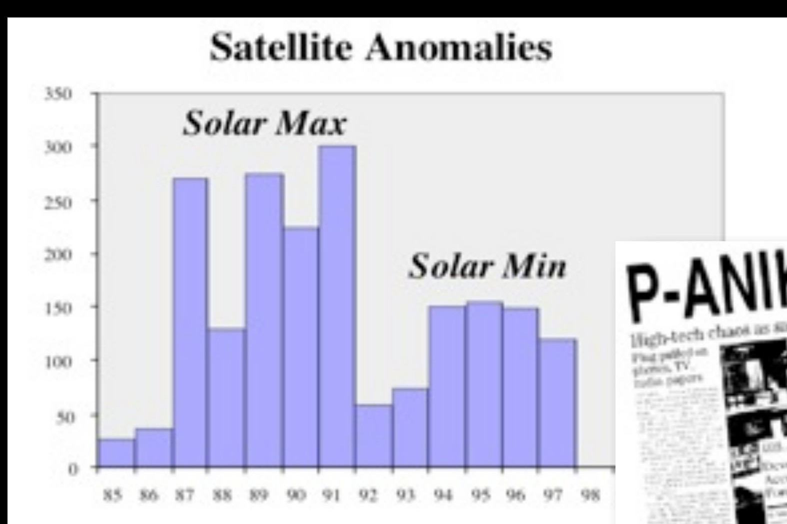
Variation in atmospheric density or high flux of electrons can lead to surface charging.



Damage to satellites

Some examples

- Telestar 401 (Jan 11 1997)
- Galaxy IV (1998) – cost 250 mill USD
  - 80% of all pagers in USA failed
  - PC-Direct (internet)
  - CBS's radio and TV feeds
  - CNN's Airport Network
- A number of satellites are damaged
- Annual loss can reach $500 millions



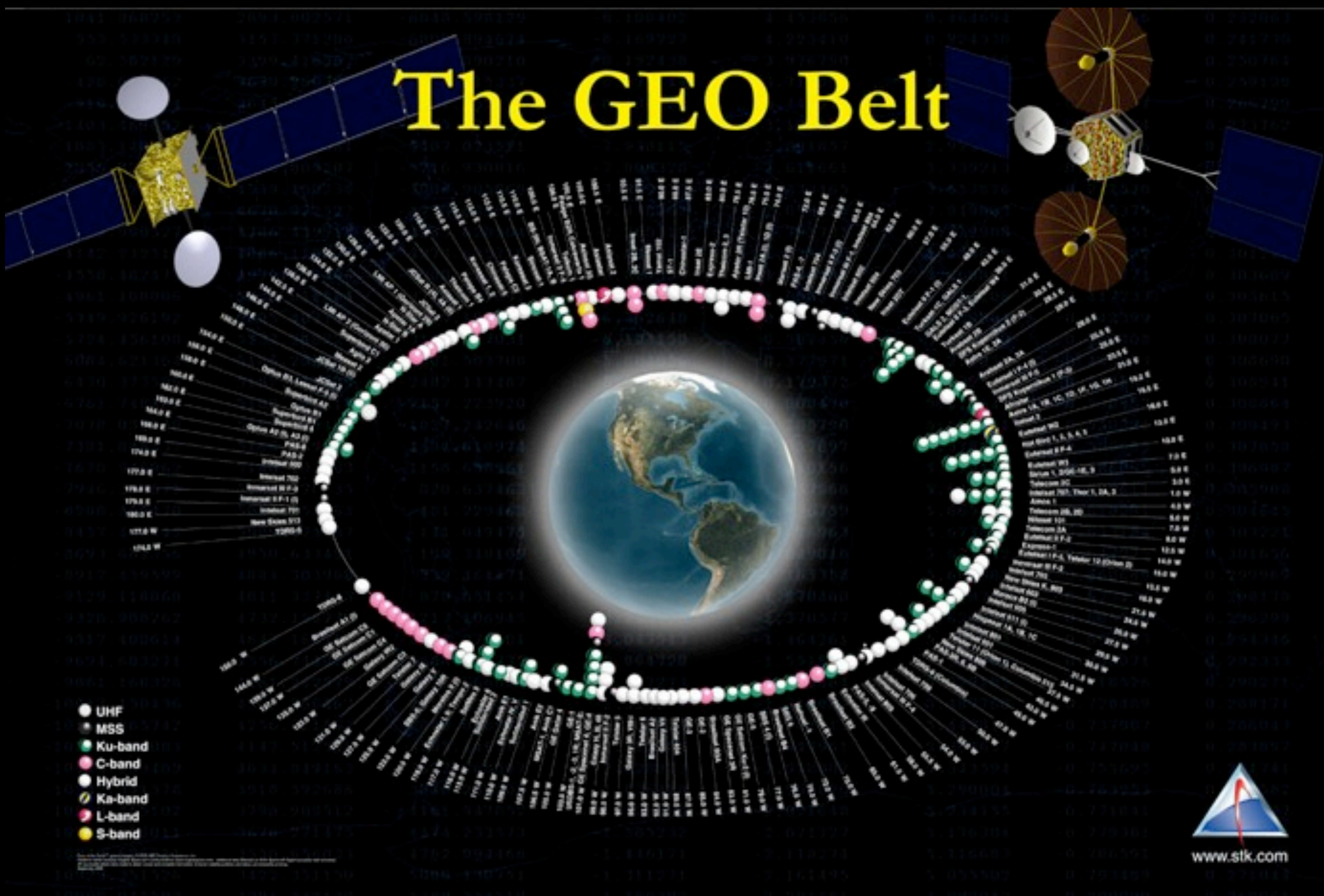
Galaxy 15 - «zombiesat»

Galaxy 15 (Intelsat) was disrupted by a solar storm 5 April 2010.

Continued to trasmit signals but it «refused» to accept commands.

Drifting uncontrolled towards other satellites and possibly ending up scrambling other satellites..

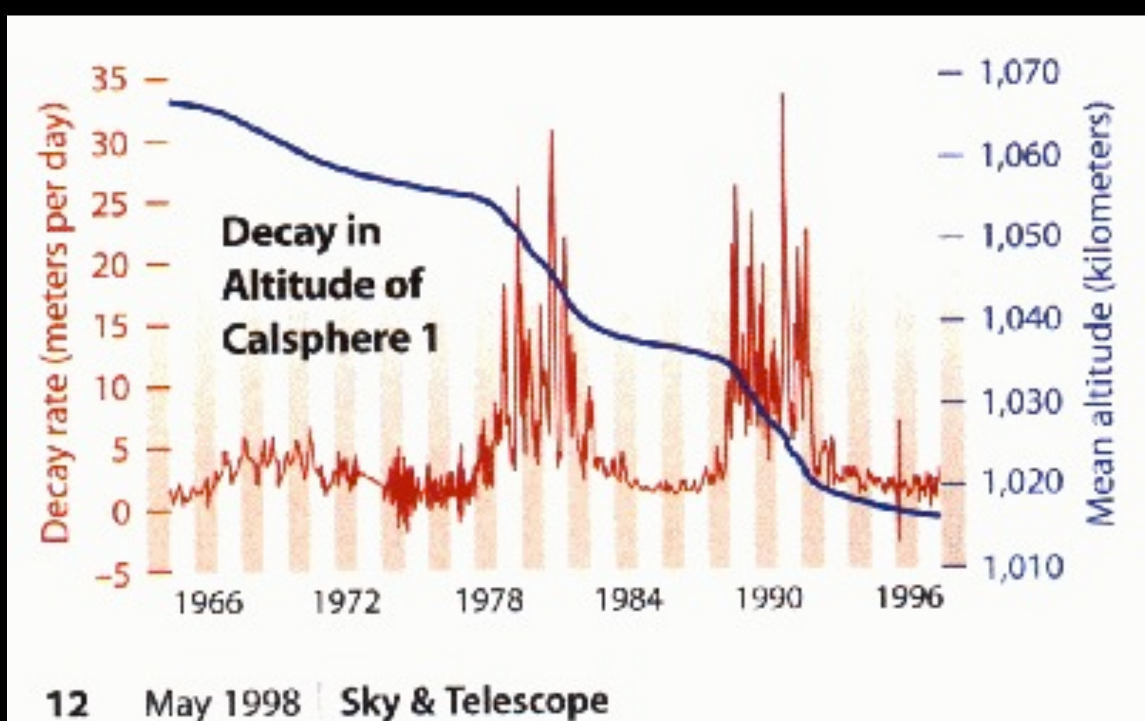
- 27 December 2010 Intelsat gained control over the satellite again...



Increased drag in the atmosphere

The atmosphere expands during increased UV/X-ray fluxes hitting the atmosphere.. This leads to increased drag/friction on low orbiting satellites. This again leads to a faster decay and can also cause them to loose control.

The space station SKYLAB fell down many years earlier than predicted due to an underestimation of the effect from solar activity on the atmosphere.



SMM – Solar Maximum Mission

- SMM dropped 5 km during a solar storm in March 1989
- SMM fell down and burned up 2 December 1989

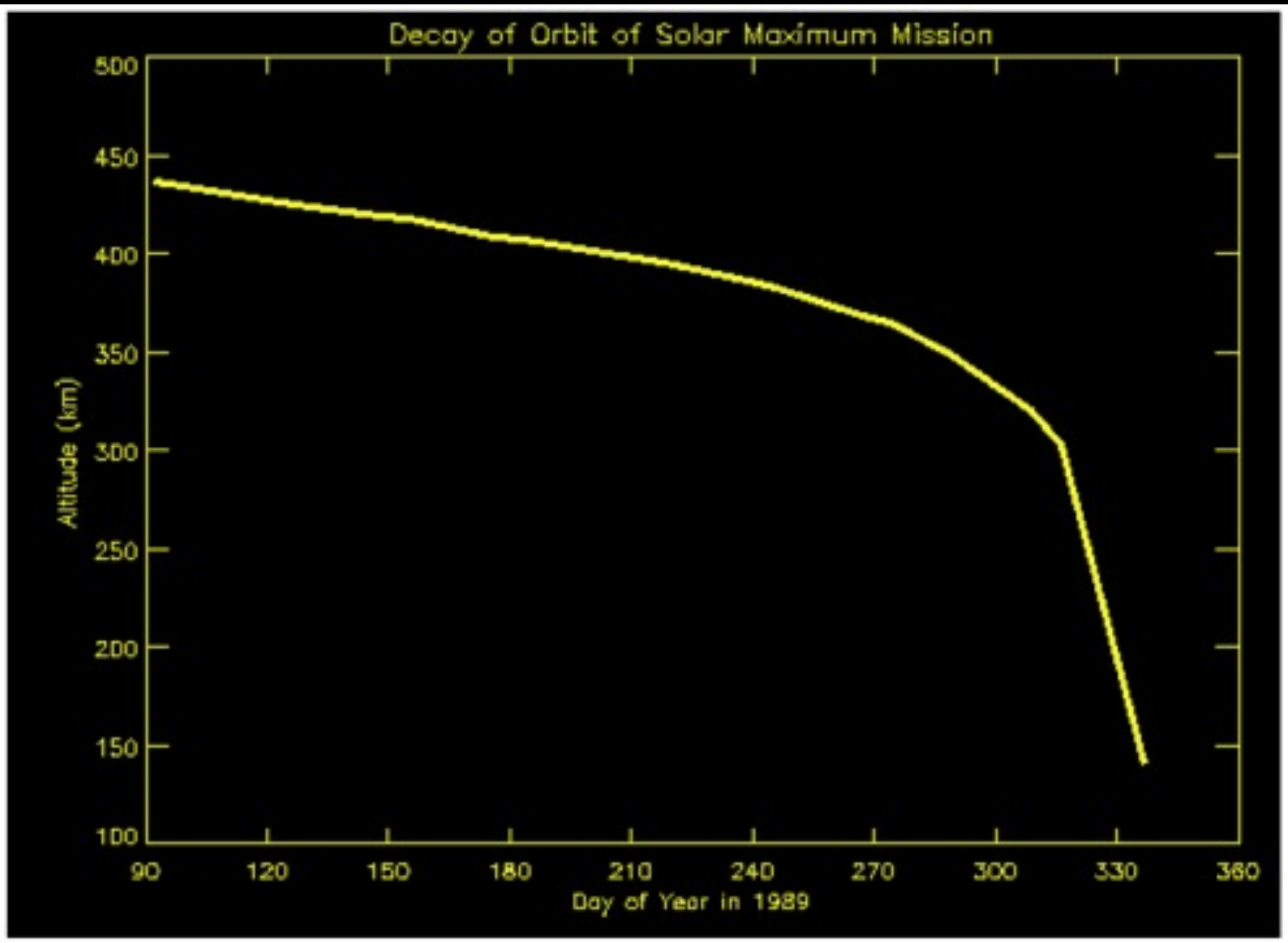
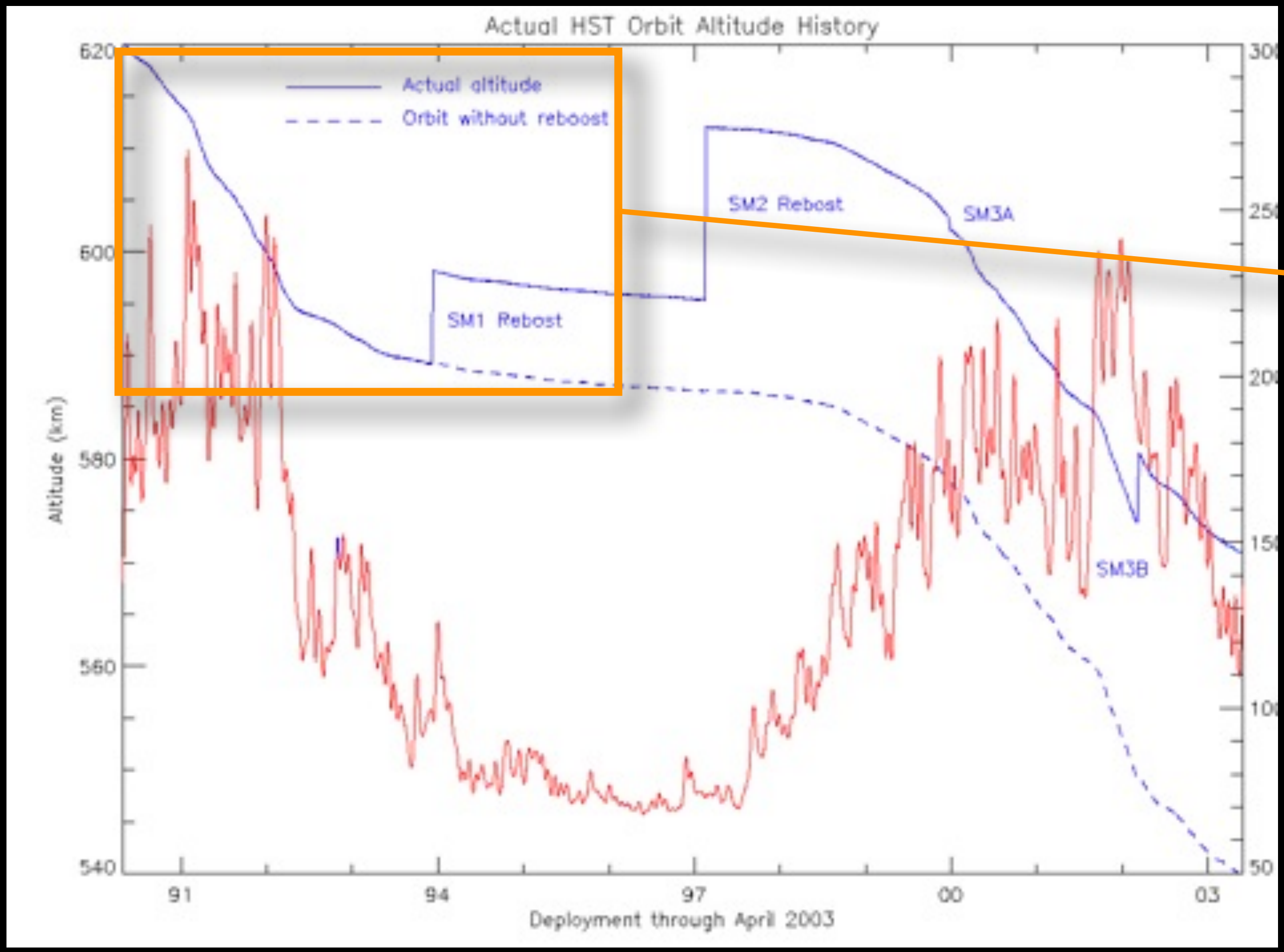
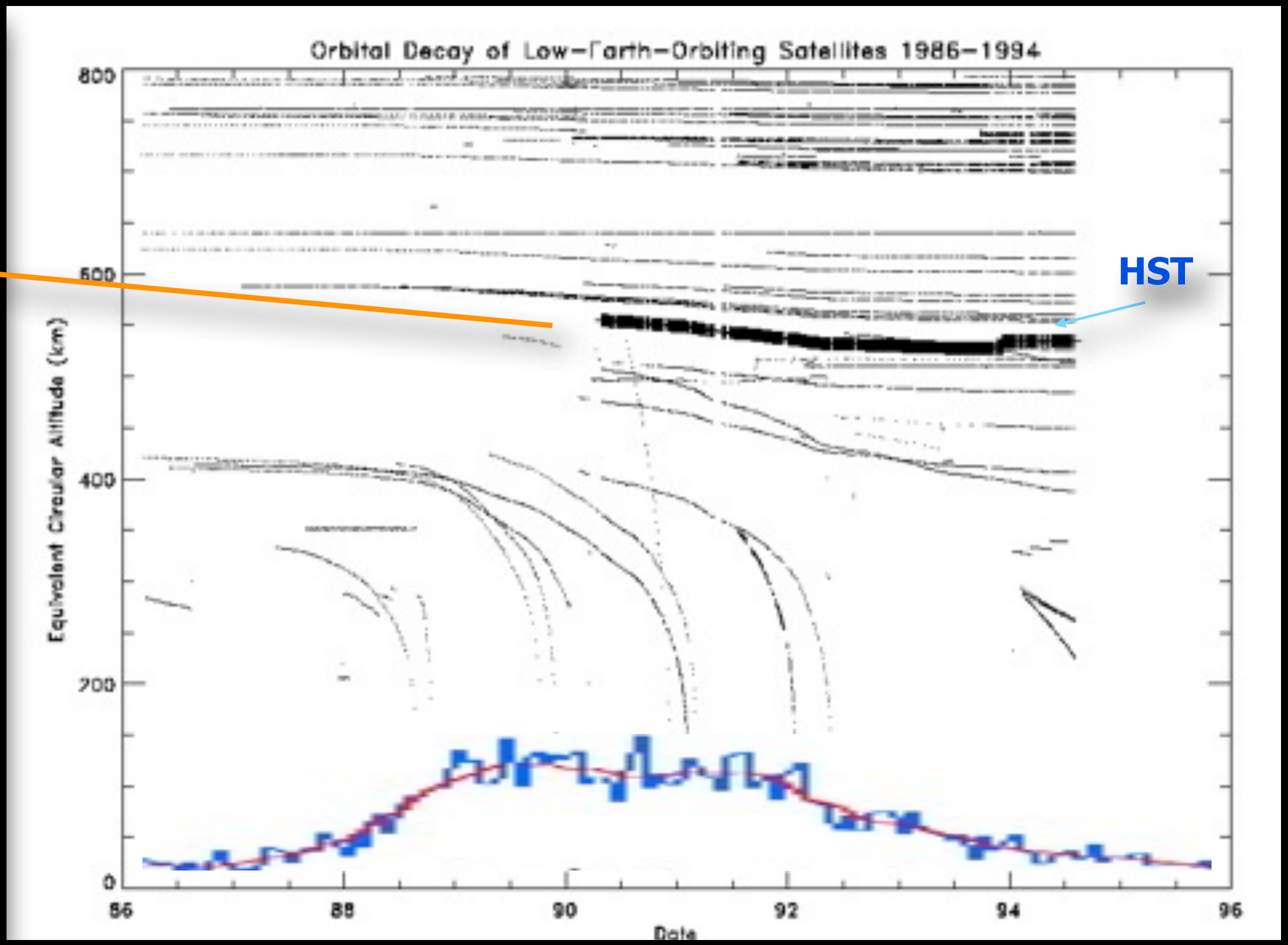


Figure 3:
Actual decay curve for the Solar Maximum Mission satellite which re-entered the Earth's atmosphere at the beginning of December 1989. The satellite was the first spacecraft to be serviced in orbit by a crew from the Space Shuttle. Notice how the satellite decays slowly at higher altitudes, then very rapidly towards the end of its life.

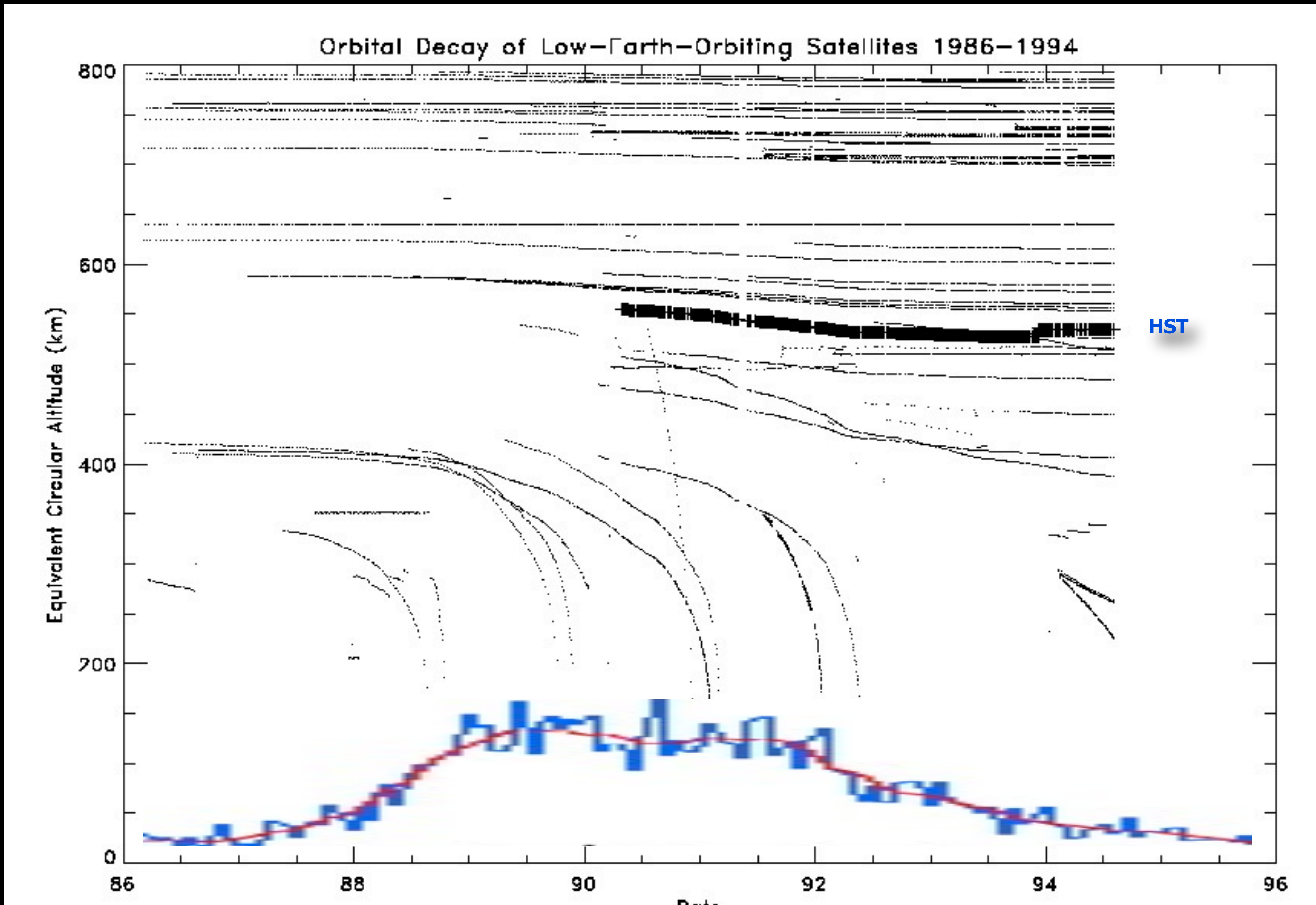
Hubble loosing altitude

- Hubble Space Telescope drops about 10-15 km per year and has been boosted four out of five sevining missions.



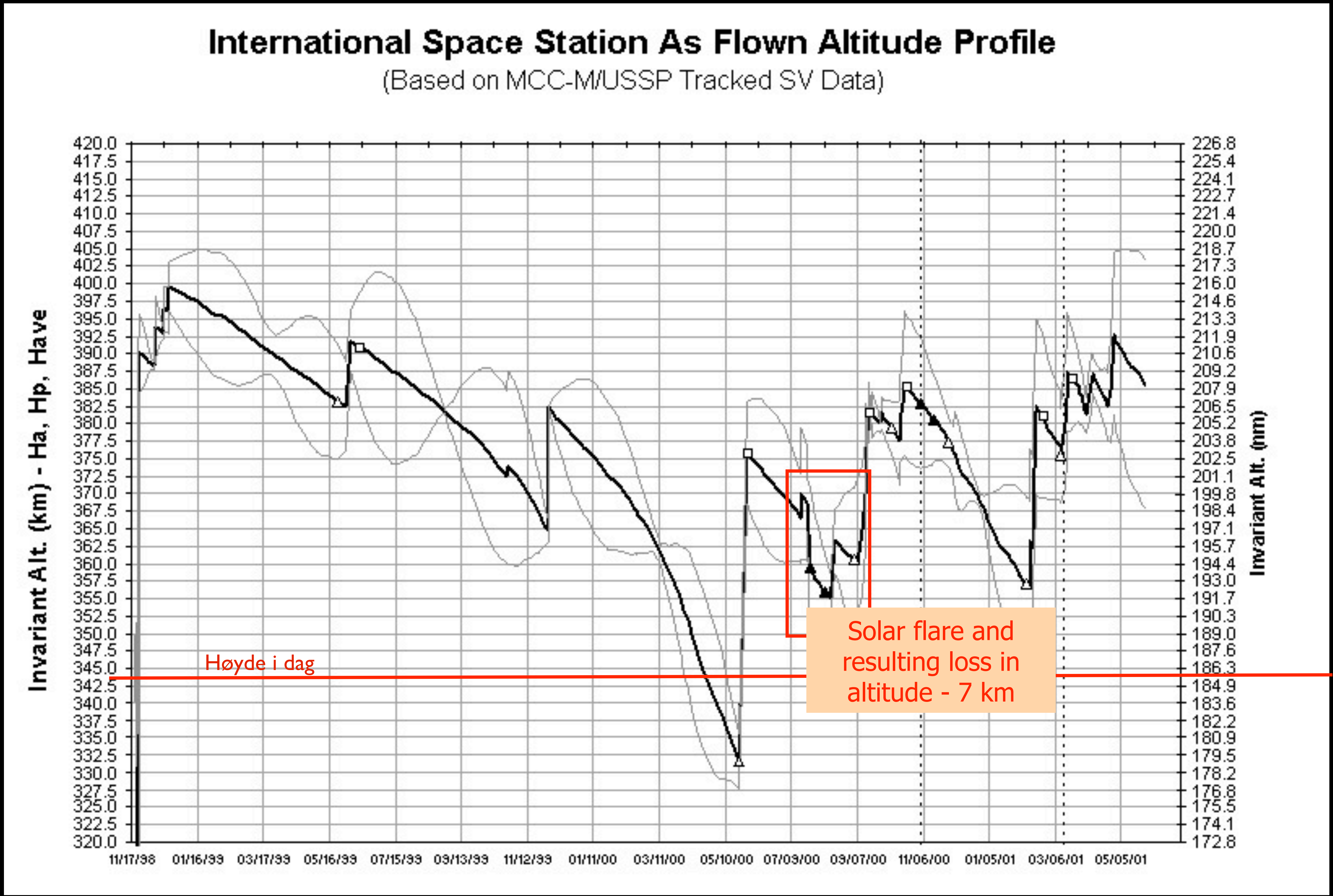


Low orbit satellites suffer



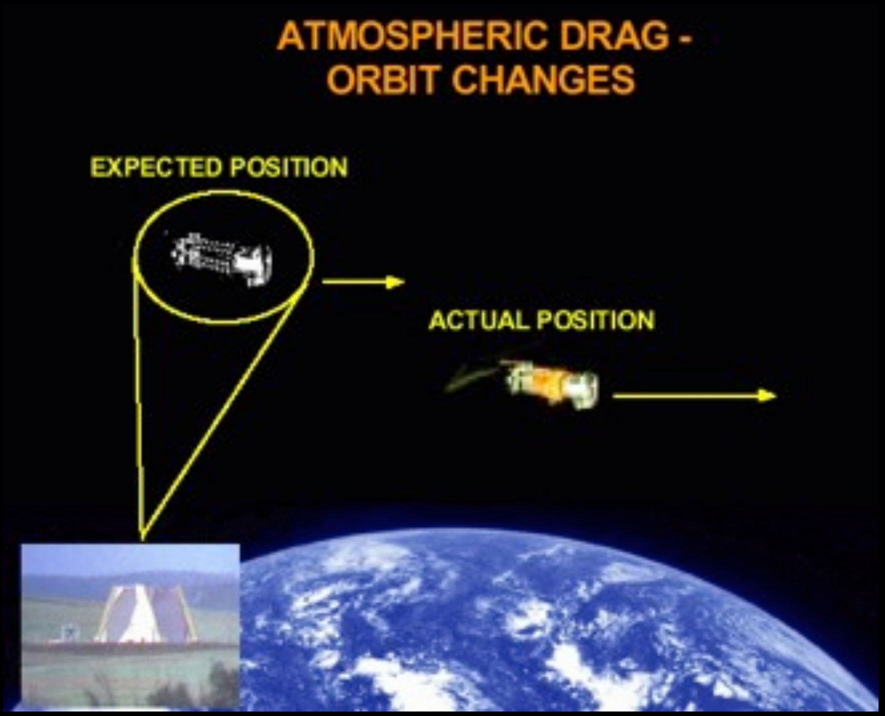
Drag: Altitude history ISS

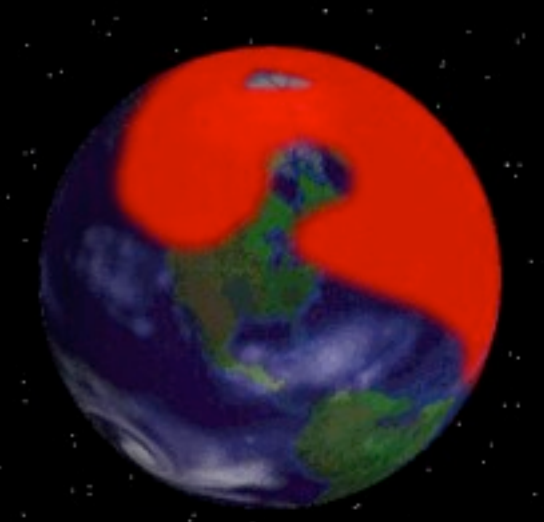
ISS altitude 15 November 2007: 343 km

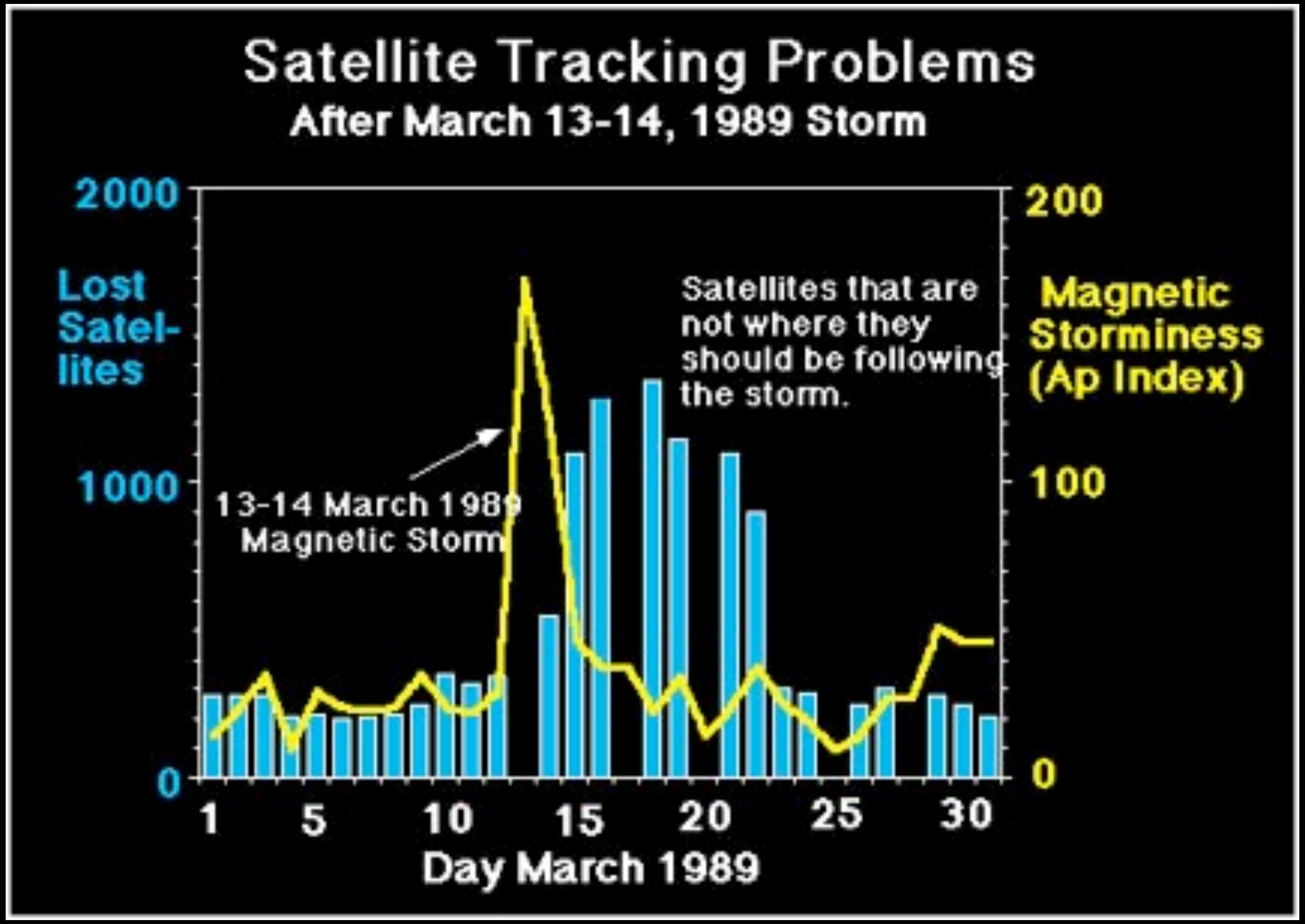


Orbital tracking of satellites

Increased friction leads to inaccurate calculation of orbits - which again leads to increased danger for collisions.







During a solar storm in 1989 one lost 1300 of 8000 objects being tracked.

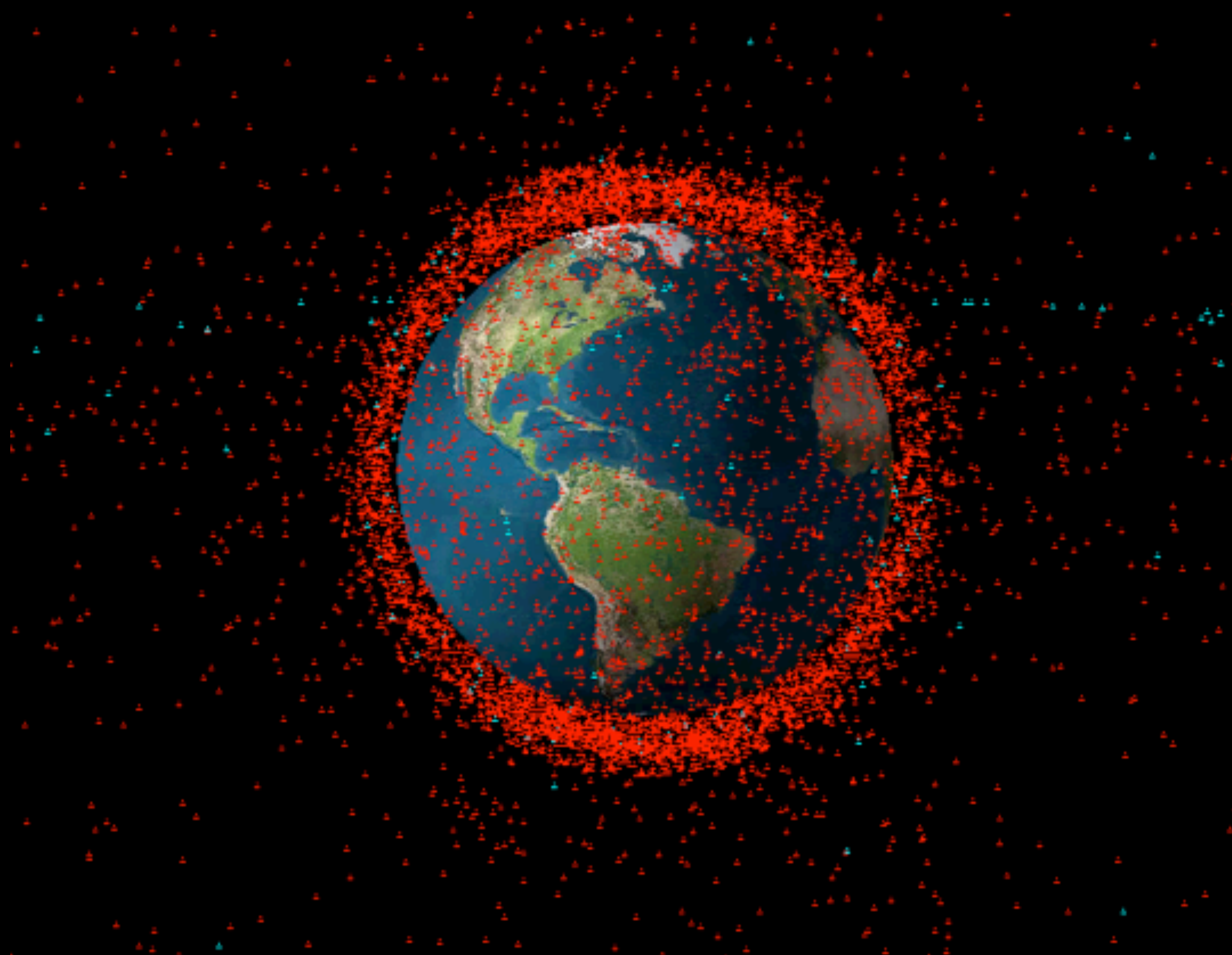
Space debris

How many satellites has been launched?

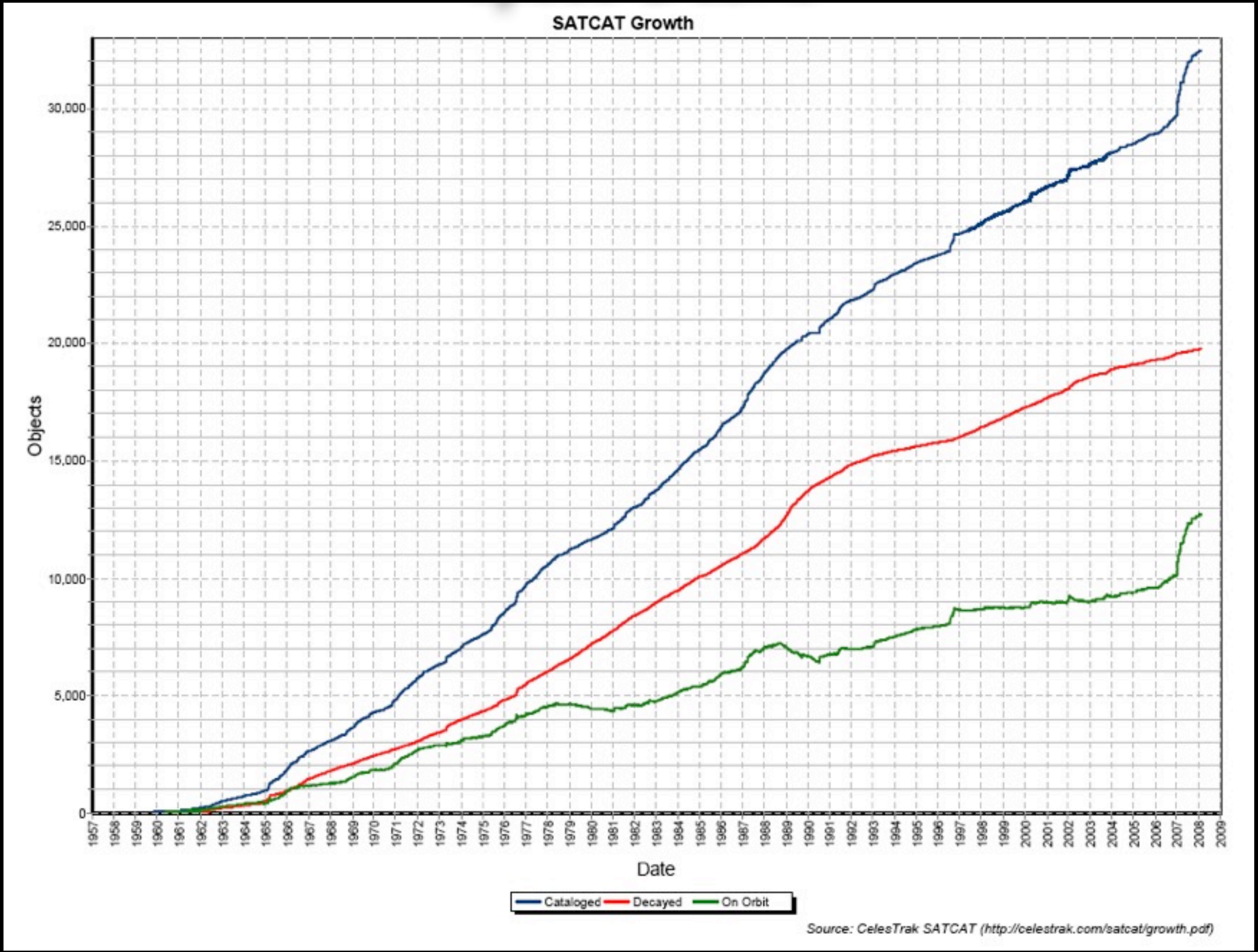
- Ca. 6000 satellites have been launched since Sputnik.
- 2700 still in orbit, about 1000 are in operation.

Space Debris

- Space debris consist of small and larger objects - parts from satellites and rockets (including paint specs gloves, tiles and solar panels).
- U.S. Space Command is maintaining a catalog with more than 12,500 objects to prevent collissions, but also to prevent ballistic rockets to be launched.
- There are about 660 000 small objects in orbit with size larger than 1 mm.

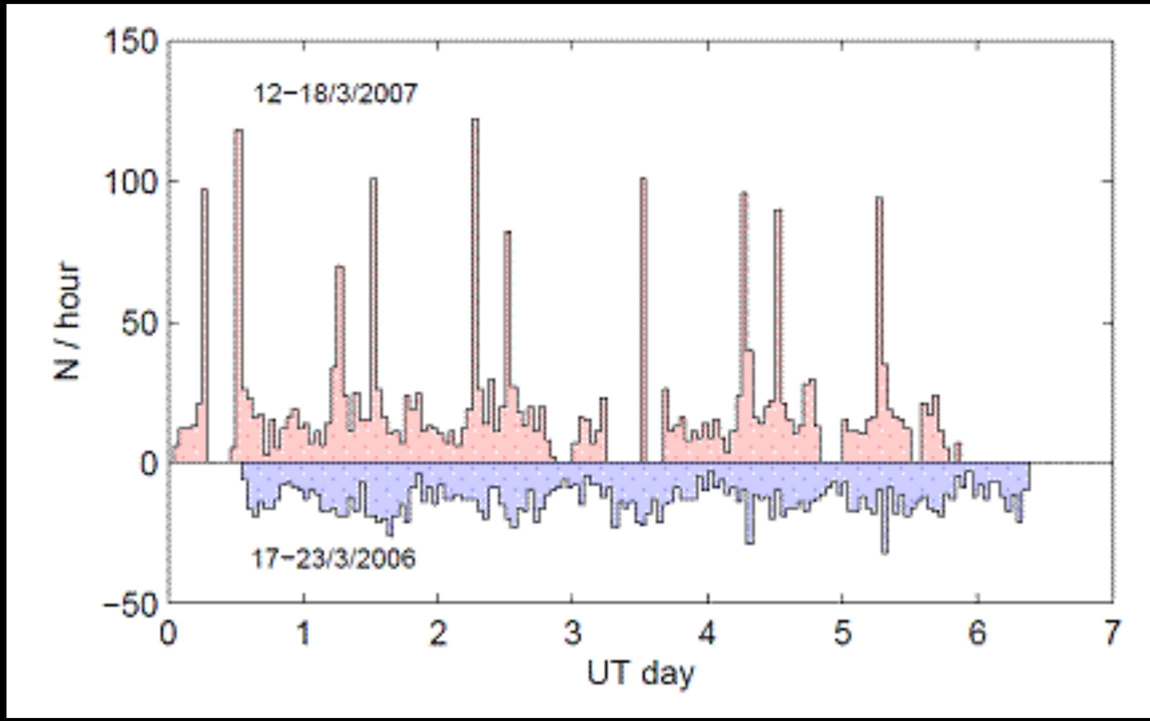


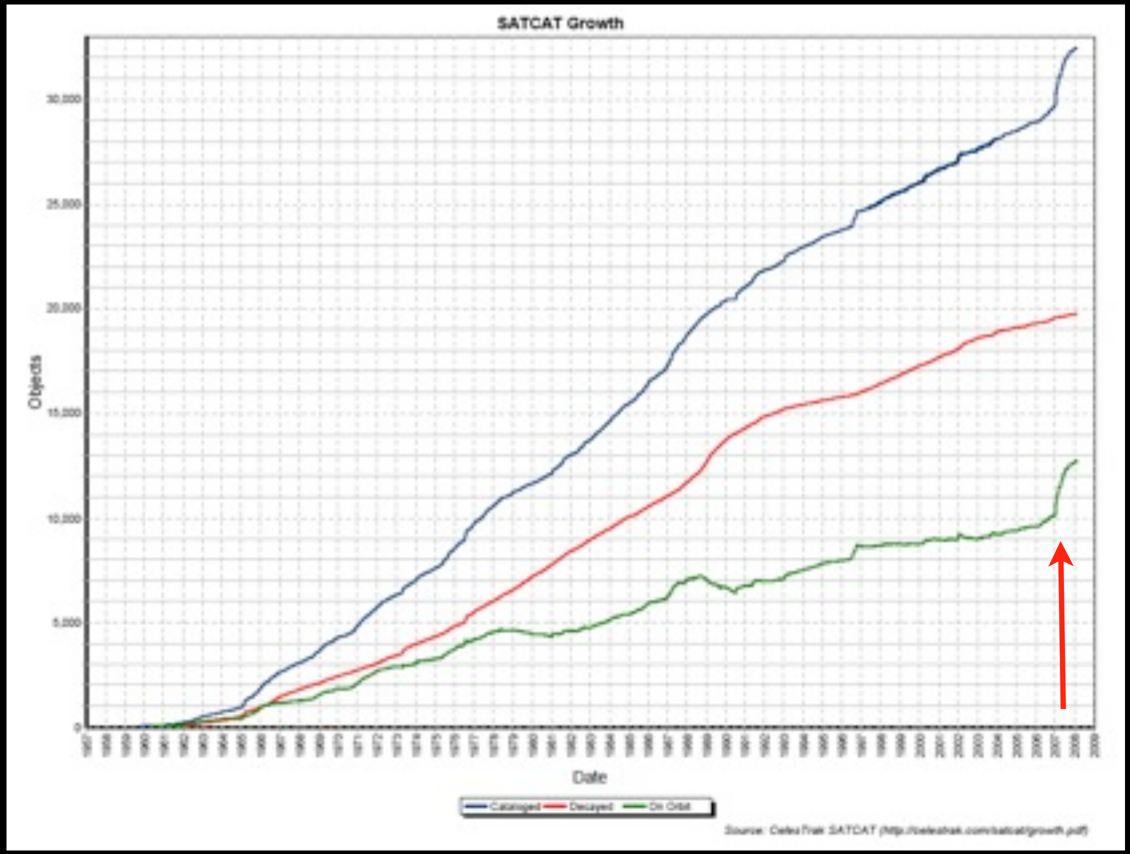
Space Debris

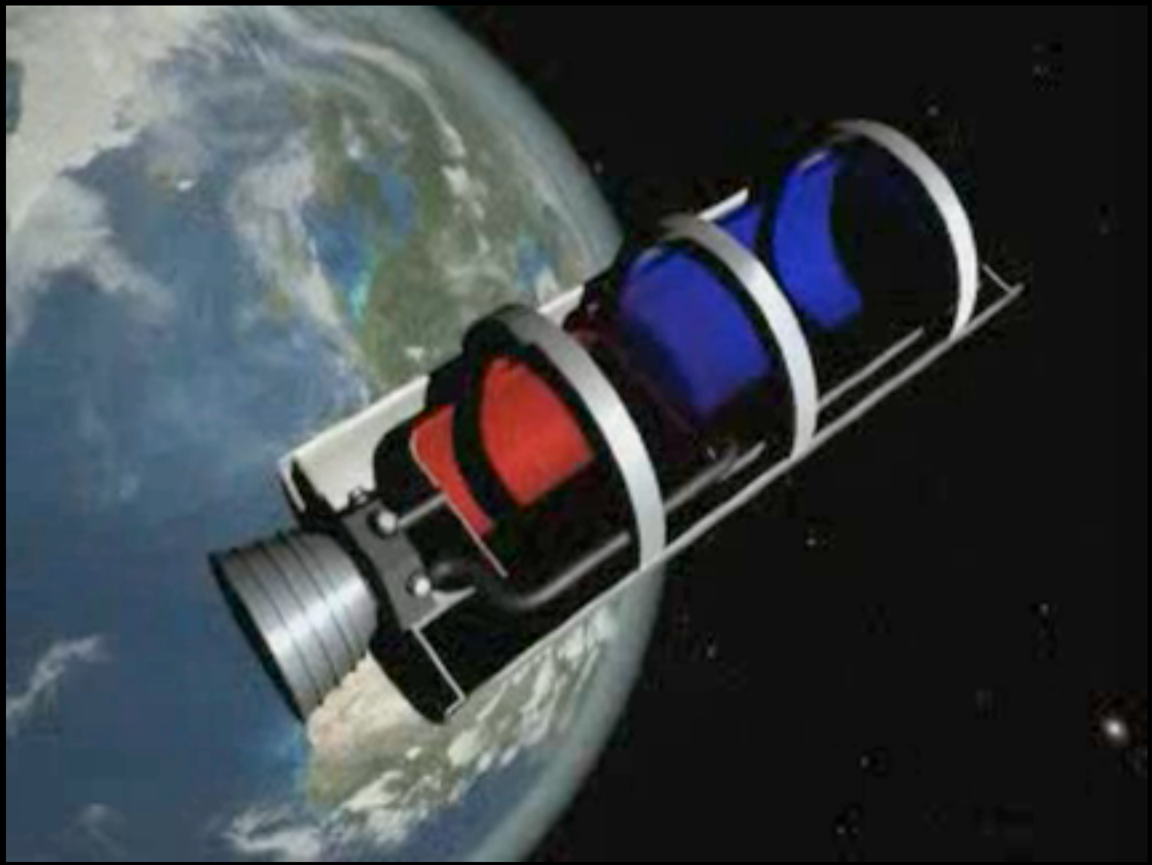


China caused space-environmental problems

- In 2007 China blowed up one of their communication satellites
- This led to 10.000 small pieces that will orbit the Earth for a long time.
- EISCAT observed this increase.

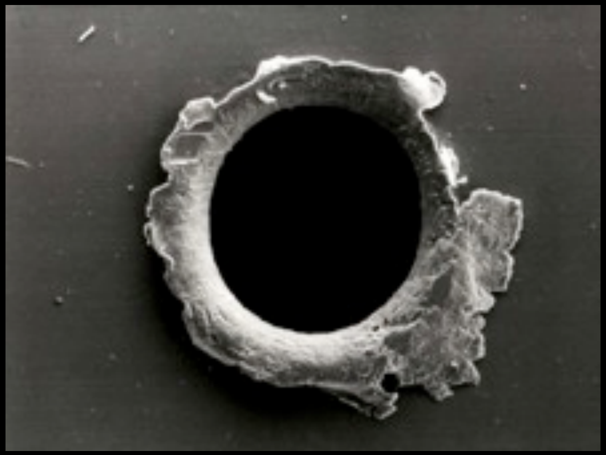


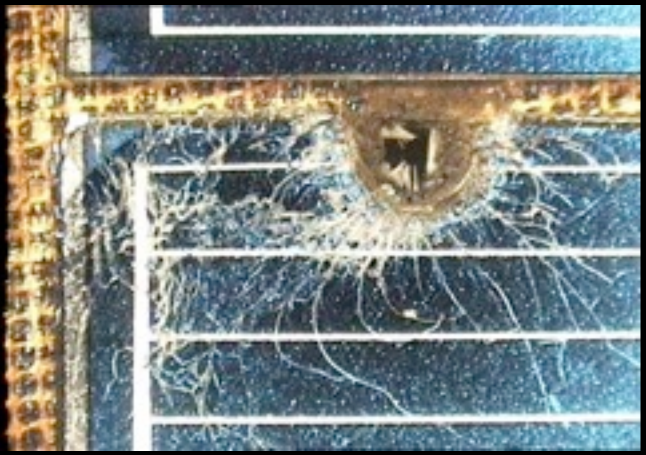


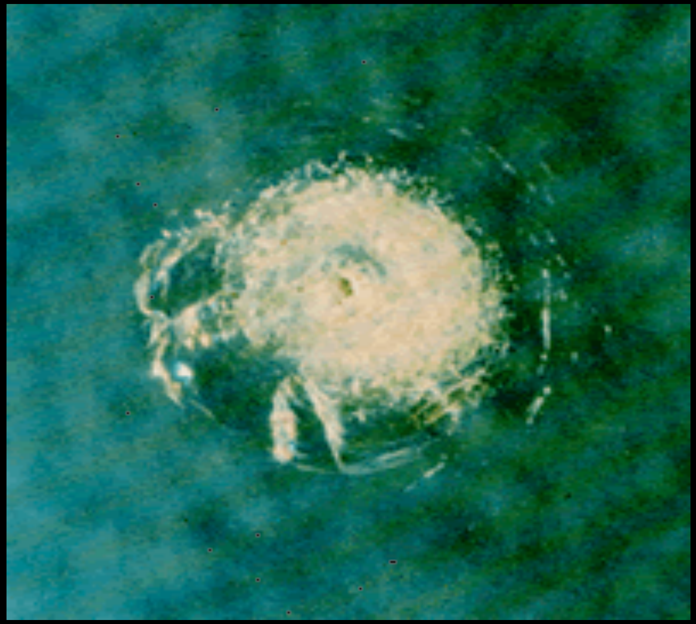


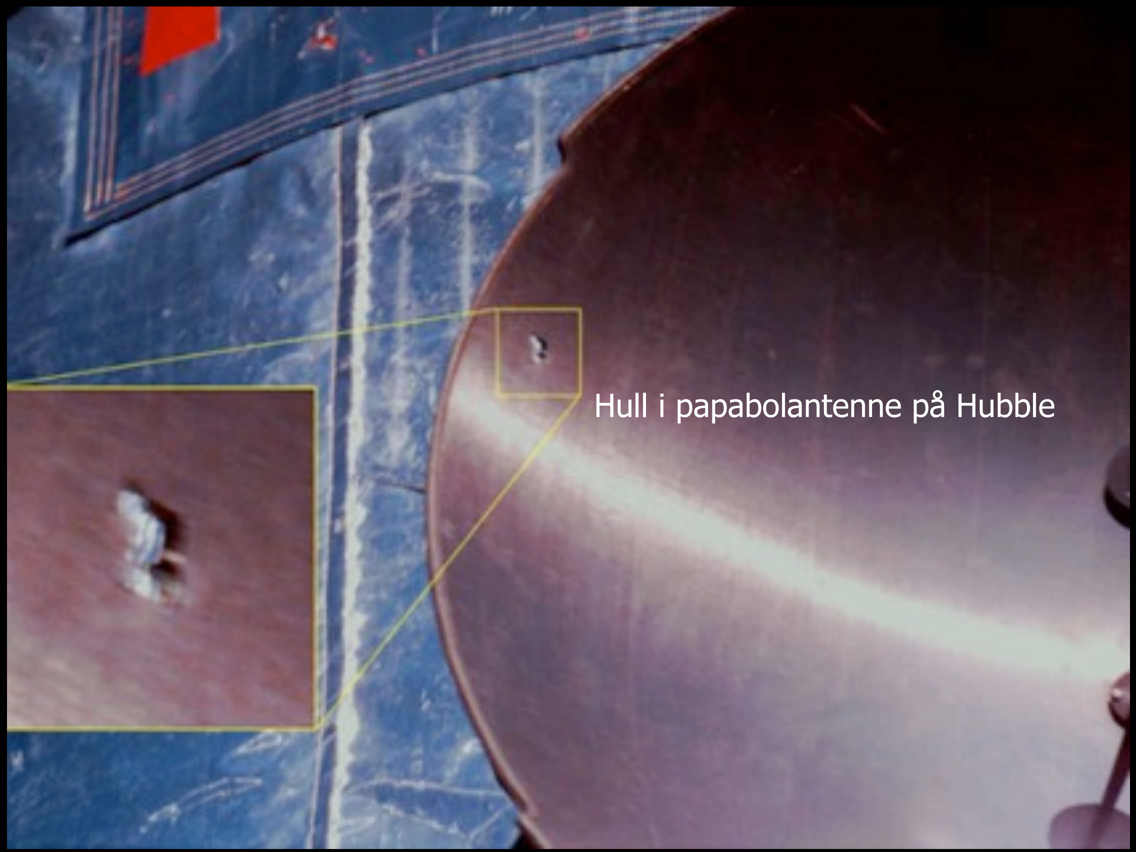
Space Debris

- Even small objects will cause large effects due to their large velocity.


Hull på Solar Maximum Mission satellitten

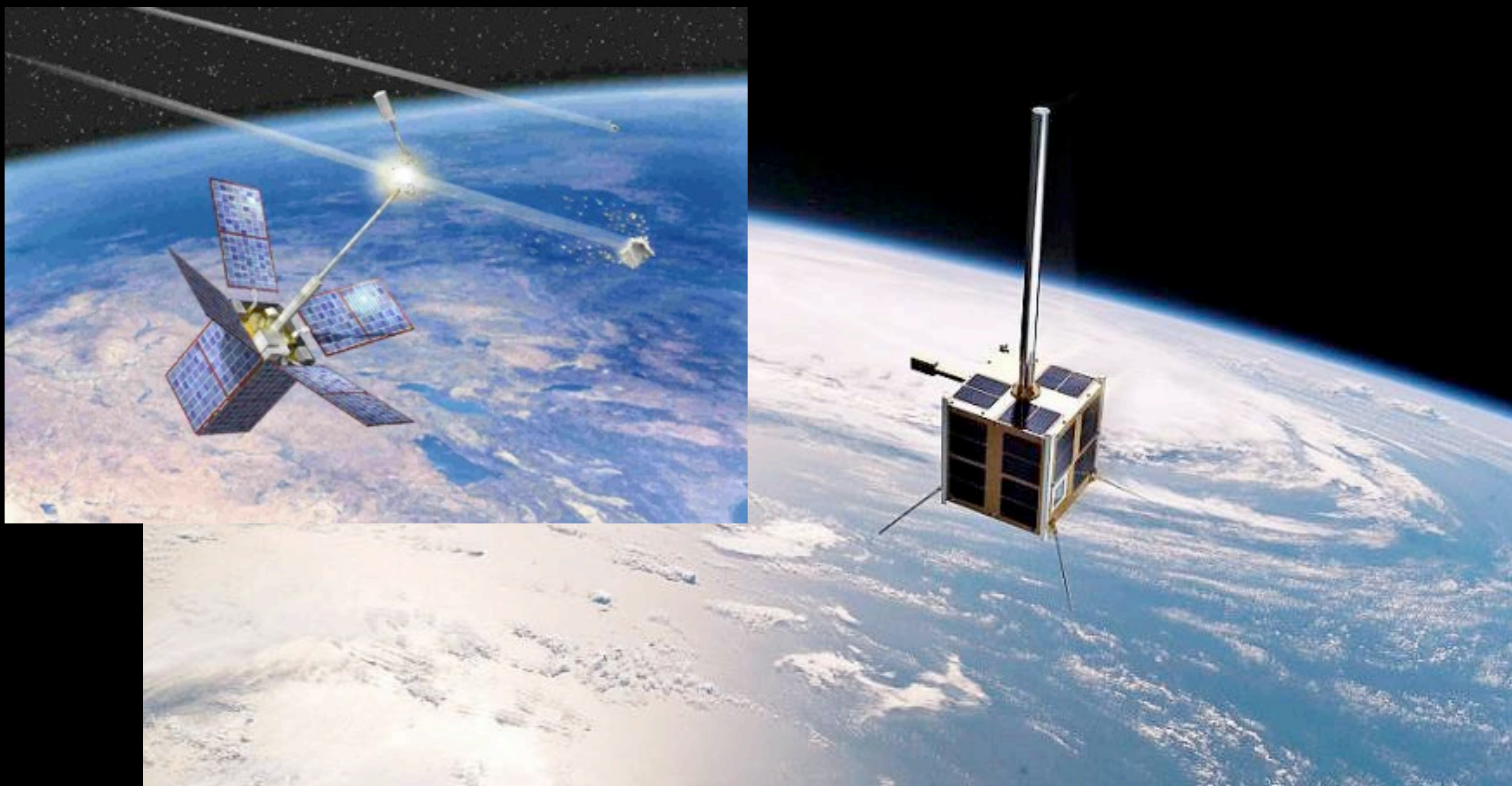

4 cm stor hull i solpanelet på romteleskopet.


Frontruta på romfergen: 4 mm krater fra et malingflak på 0.2 mm

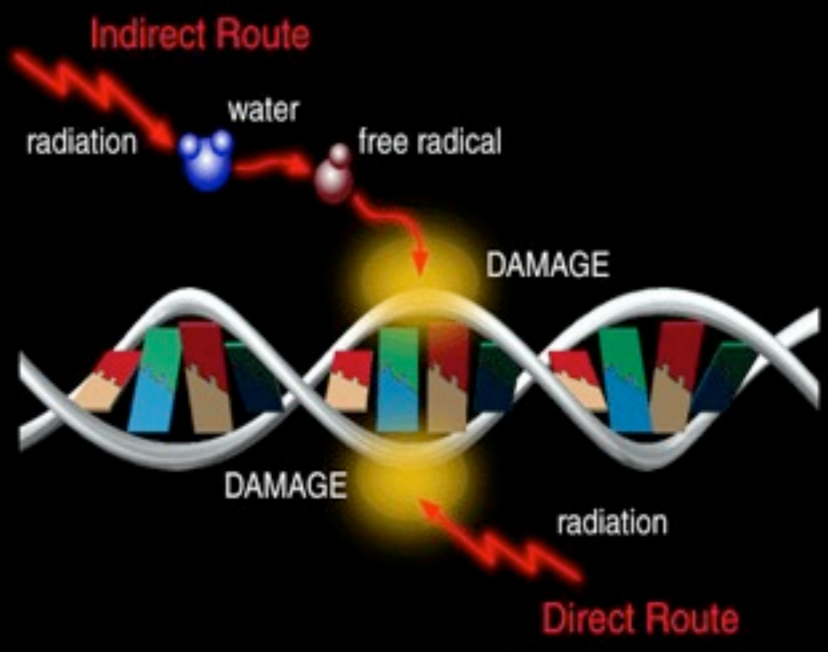

Hull i papabolantenne på Hubble

«Speeding» in Space

- The Norwegian AisSat1 is orbiting in an orbit where there are a lot of debris.
- Several times we have received notices from USA Space Command about close encounters..

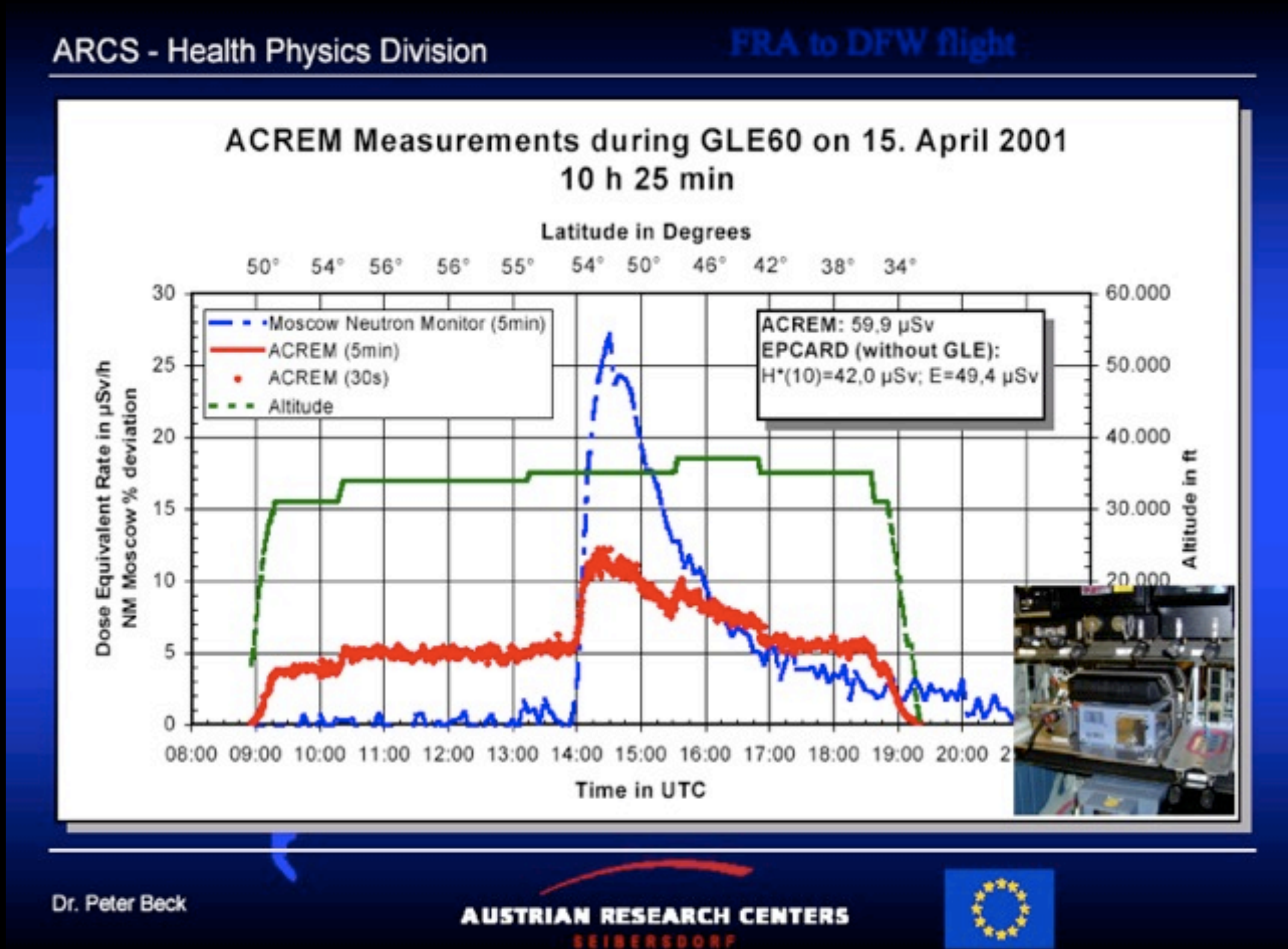


Radiation hazards

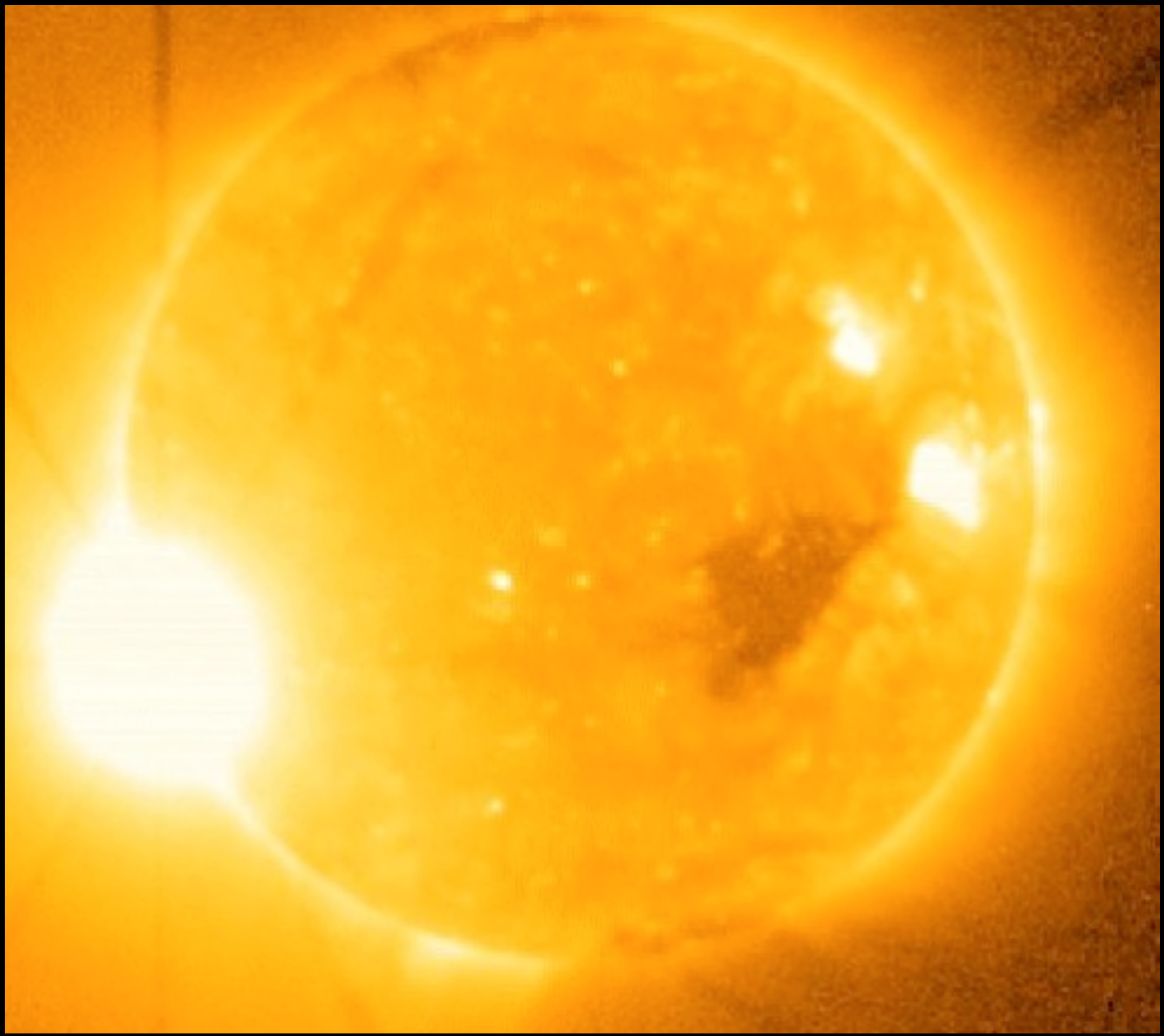


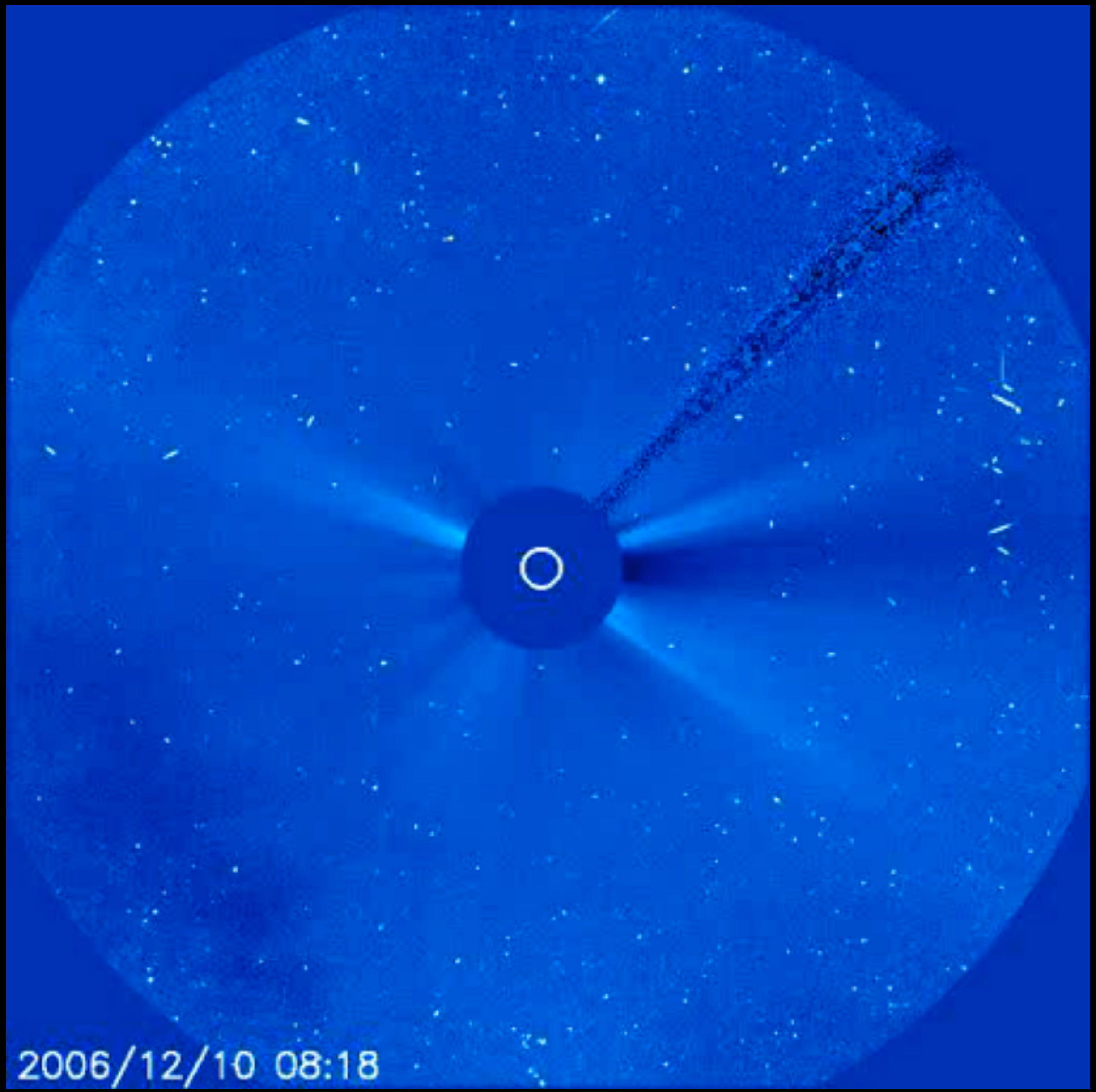
- Polar flights
- Humans in space
  - Space Shuttle, International Space Station, missions to the Moon and Mars

Effects on passengers

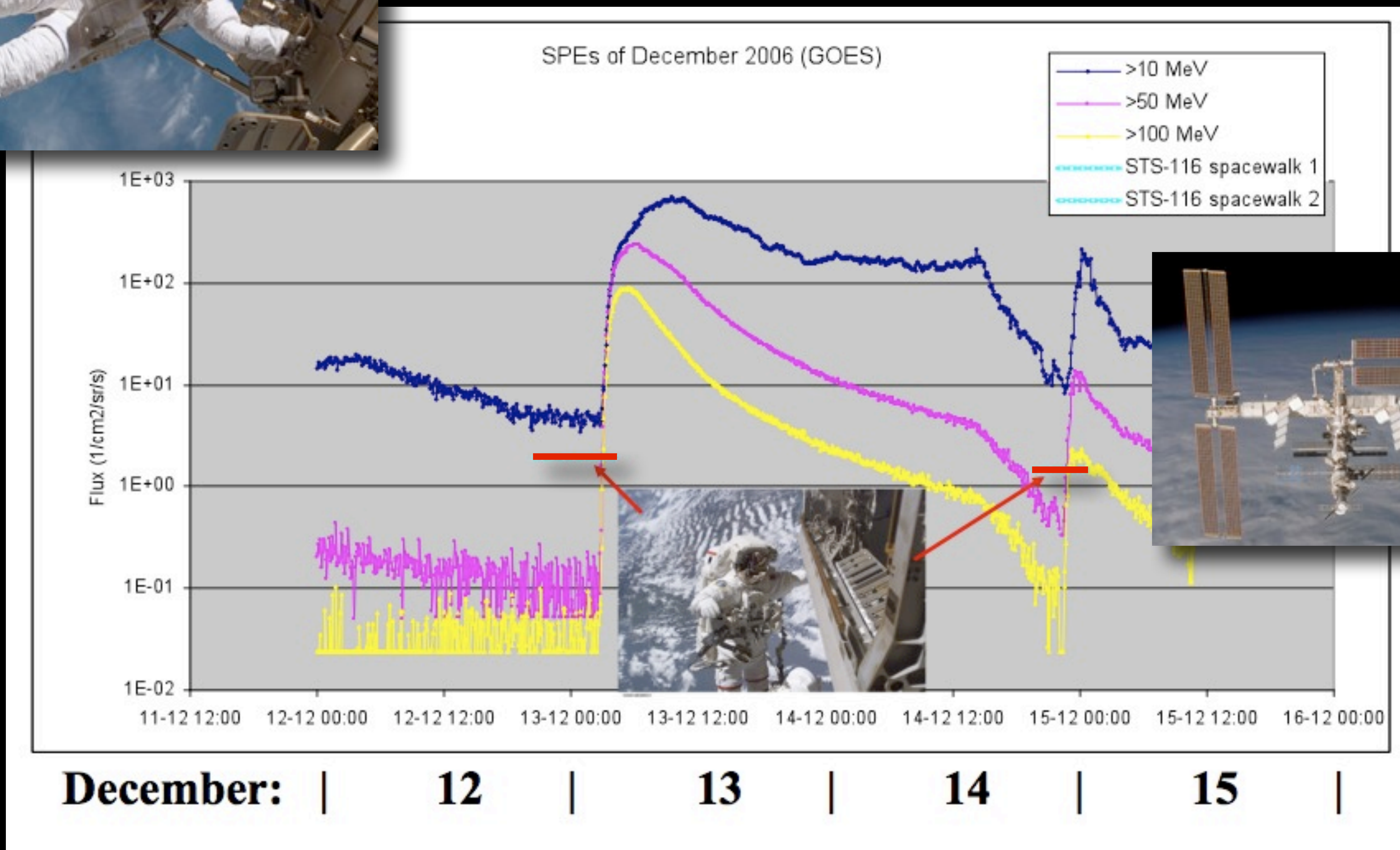


Solar Storm 14 desember 2006





Christer Fuglesang - Proton event



Christer Fuglesang - radiation

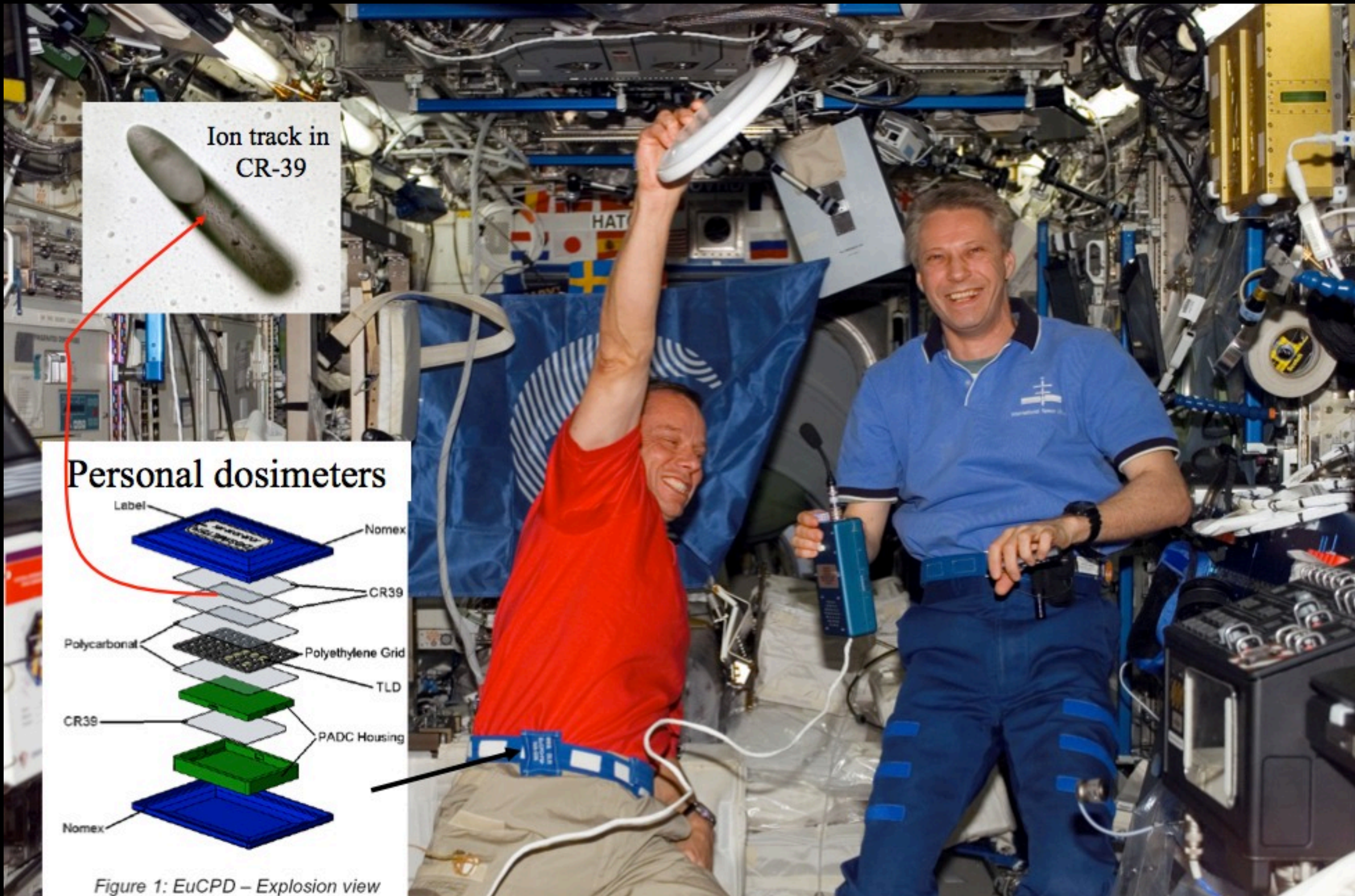
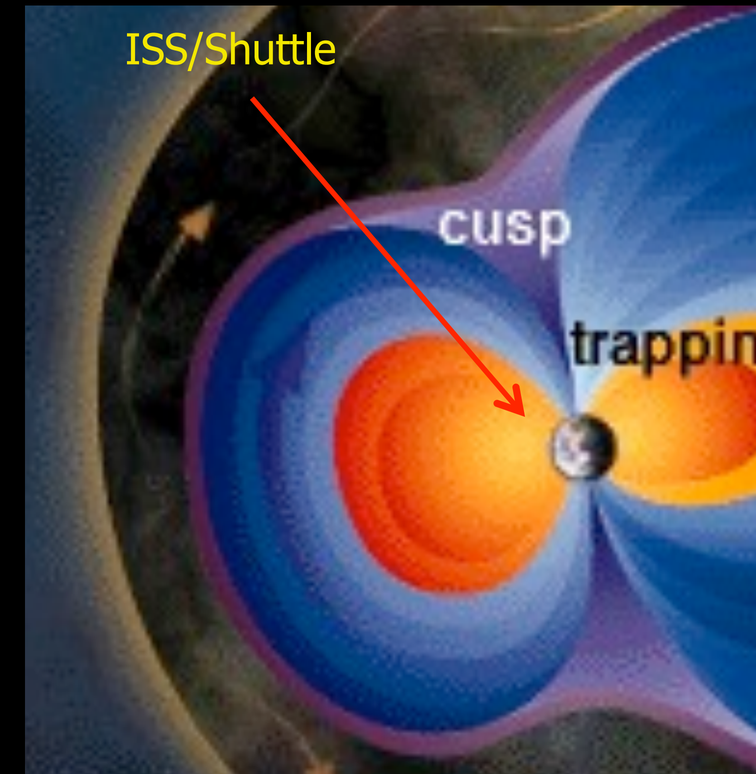


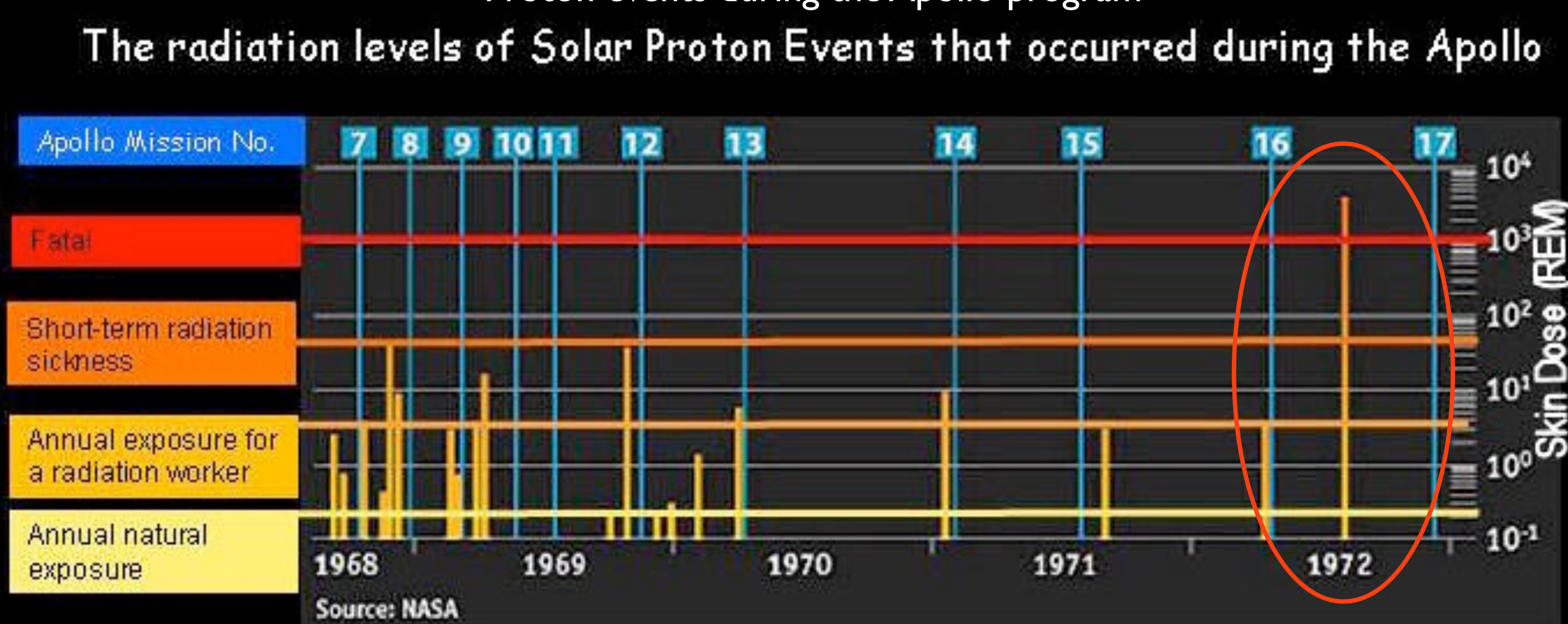
Figure 1: EuCPD – Explosion view

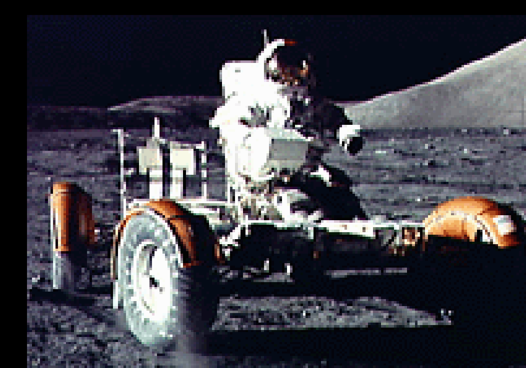
The Apollo-programme - pure luck?

- Humans have limited experience from deep space muíssions. Only a few short trips to the Moon with Apollo.
  - ISS og and the space shuttle were protected fairly well by the magnetosphere.
- The Apollo sucsess could have been different of the very strong proton shower in August 1972 would have occured during the Apollo 16 or 17. This could have produced a leathal dose for the astronauts.
- The proton showers in october 1989 and in 2003 may have led to a leathal dose on the surface of the Moon.



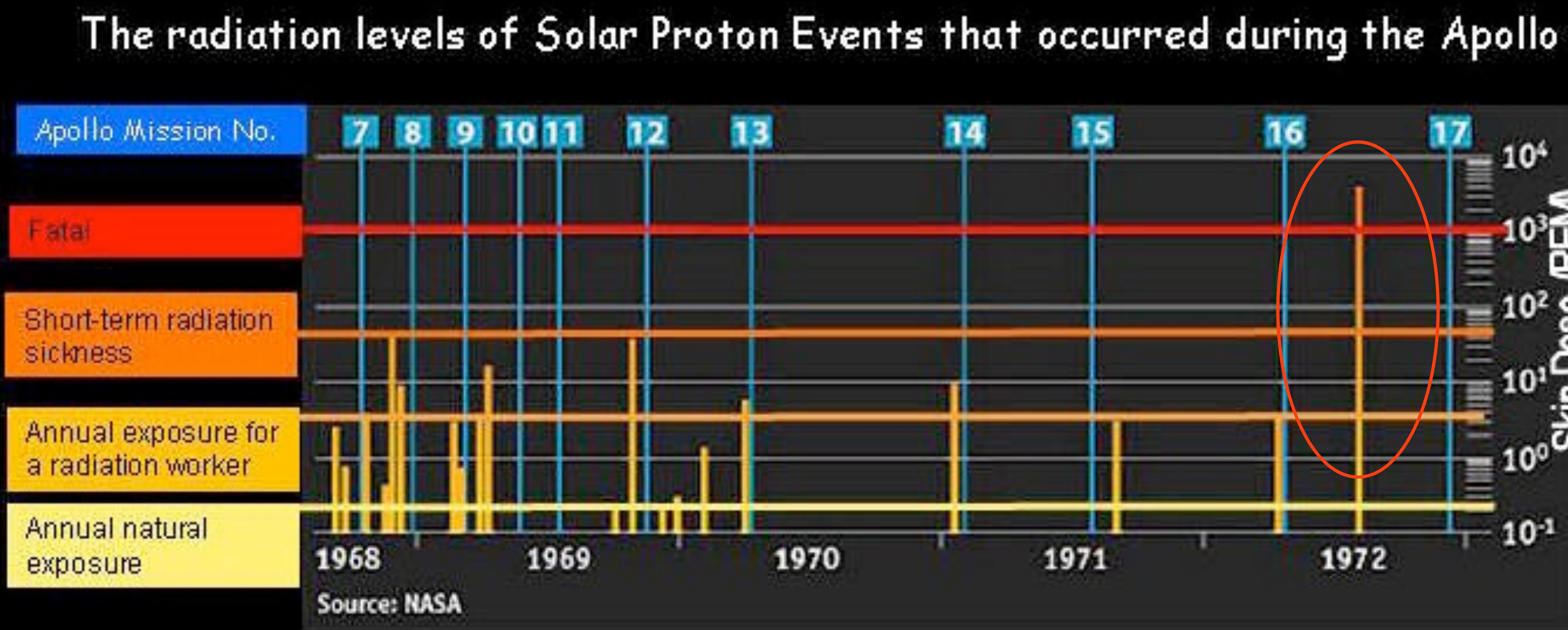
Proton events during the Apollo program





1972 event: 4000 REM in space suit, 1000 REM in Lunar Module

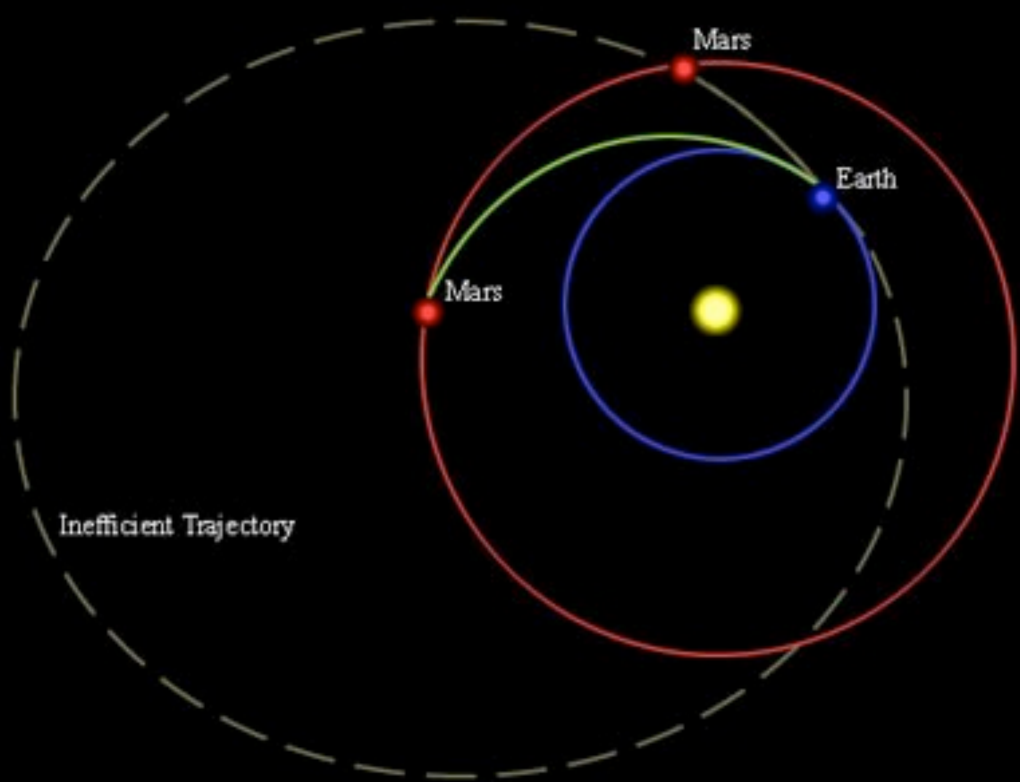
The Apollo-programme - pure luck?

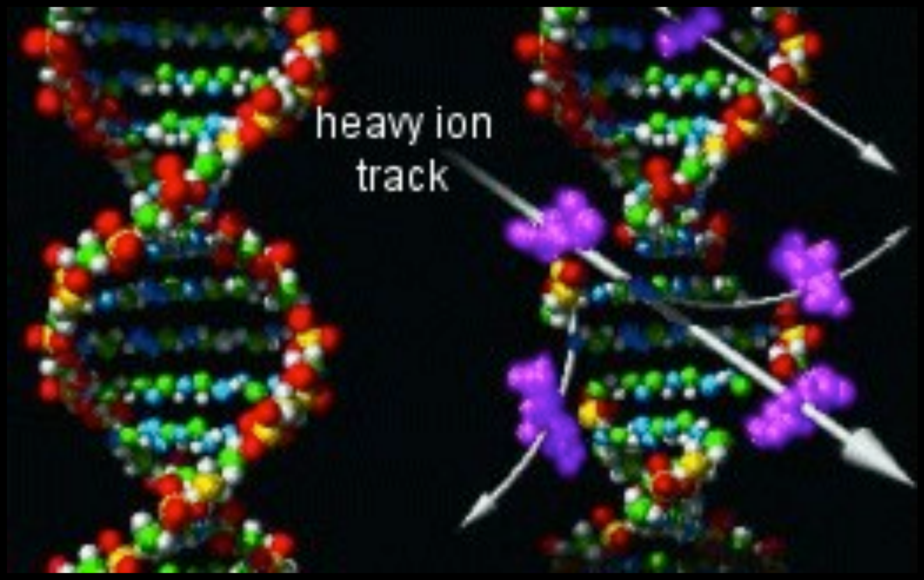


1972 event: 4000 REM in space suit, 1000 REM in Lunar Module

Missions to Mars

- Radiation hazards from a 1000 days mission to Mars and back is a big challenge.
- How to protect astronauts on the way and on Mars





Hazards on Mars

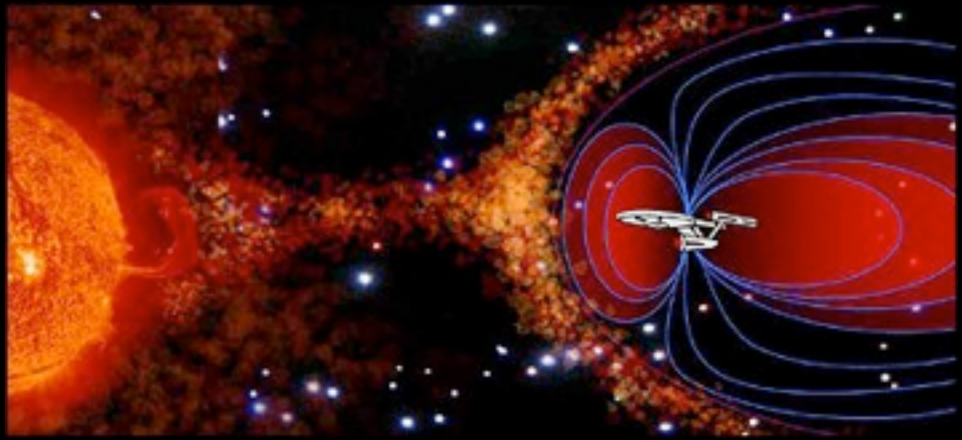
- Radiation doses from solar storms and cosmic rays since Mars lack a magnetosphere.

- Harmful for humans and electronics

- The modern electronics more affected than the old technology used on the Moon

- Better space weather warnings important.

- Communication problems with the Earth during solar flares (ionization in the Mars atmosphere



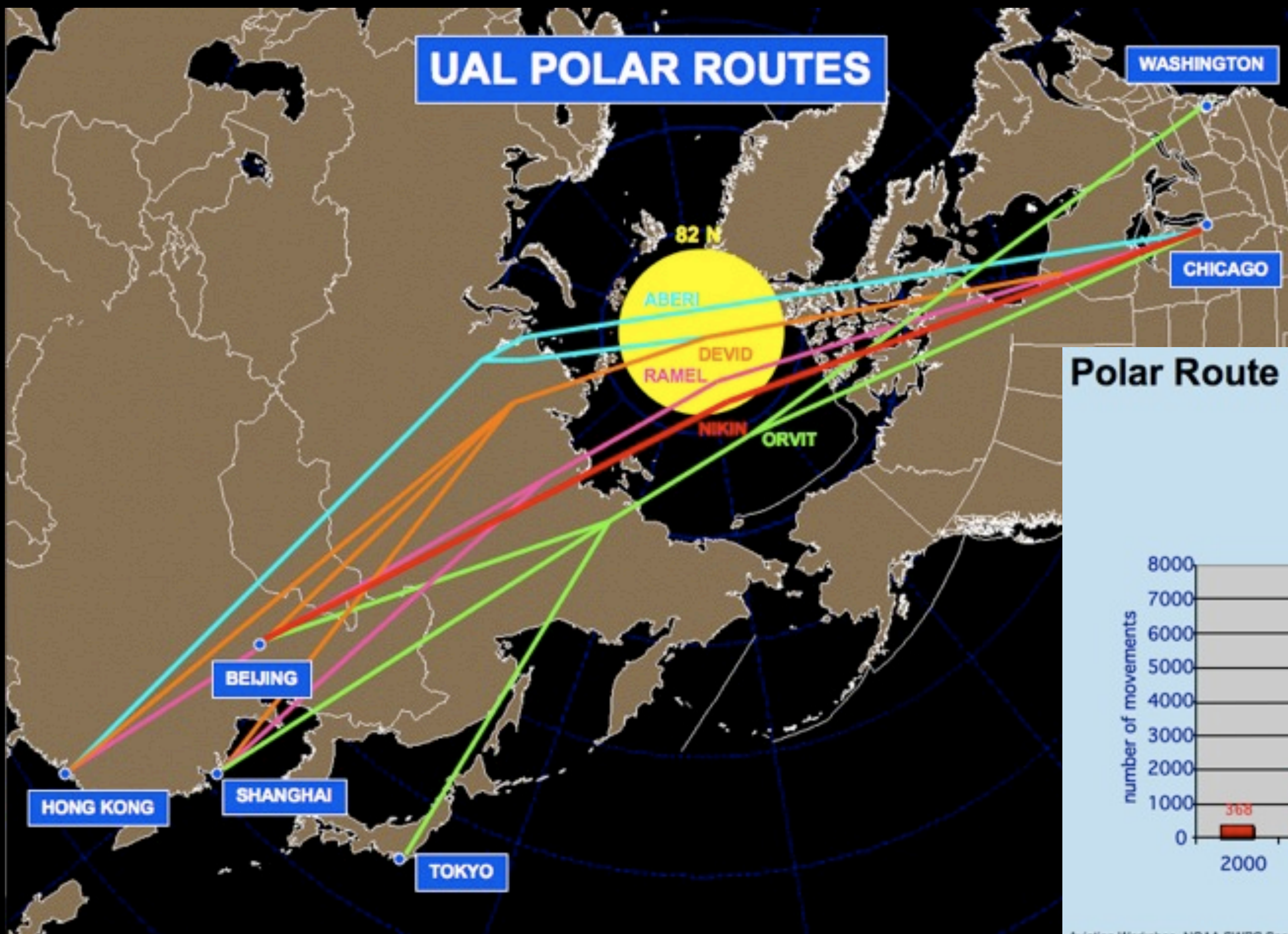
Could one generate a artificial megnetic field (shield) around a space craft?

Effects of airplanes

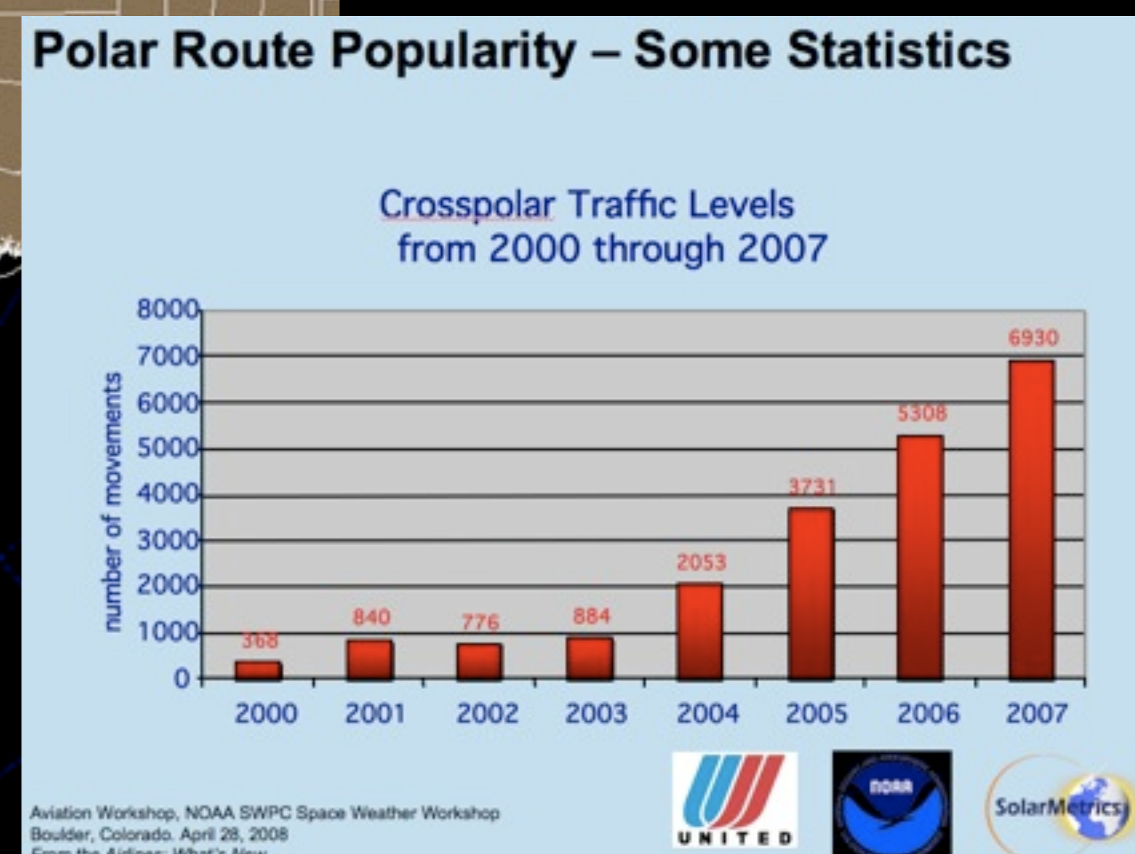
- Disruption of HF communication on polar transatlantic flights
- Energetic particles (affects humans and avionics)
- GPS and navigation

Effects on polar routes

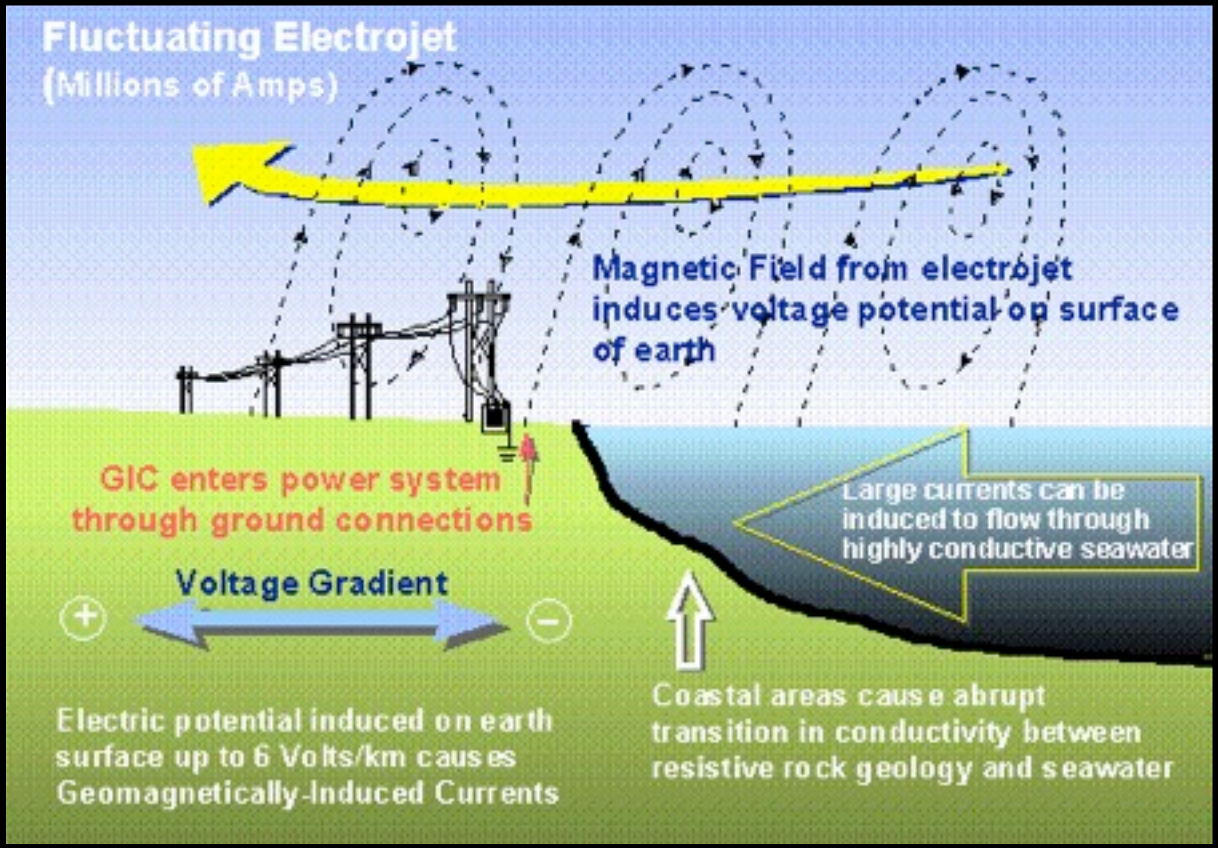
- About 8000 flights per year in 2008.
- No satellite communication north of 82nd degree N.
- GPS can get unstable.



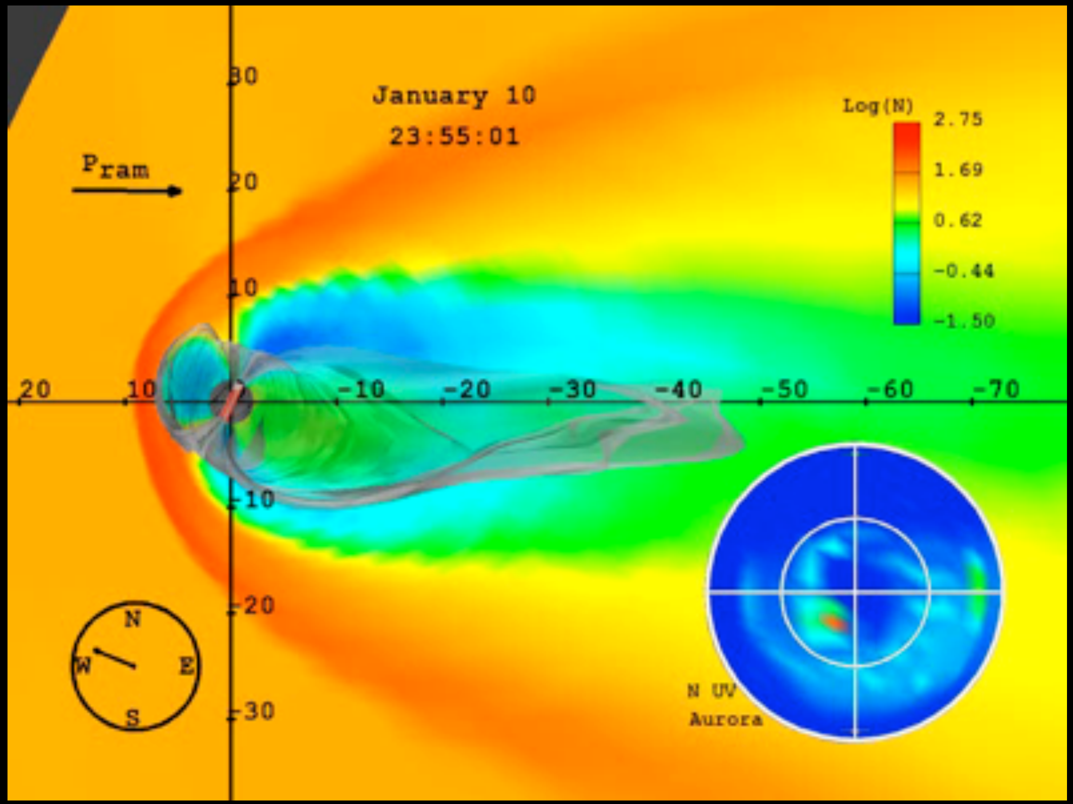
M.Stills, United Airlines



Disruption of power grids

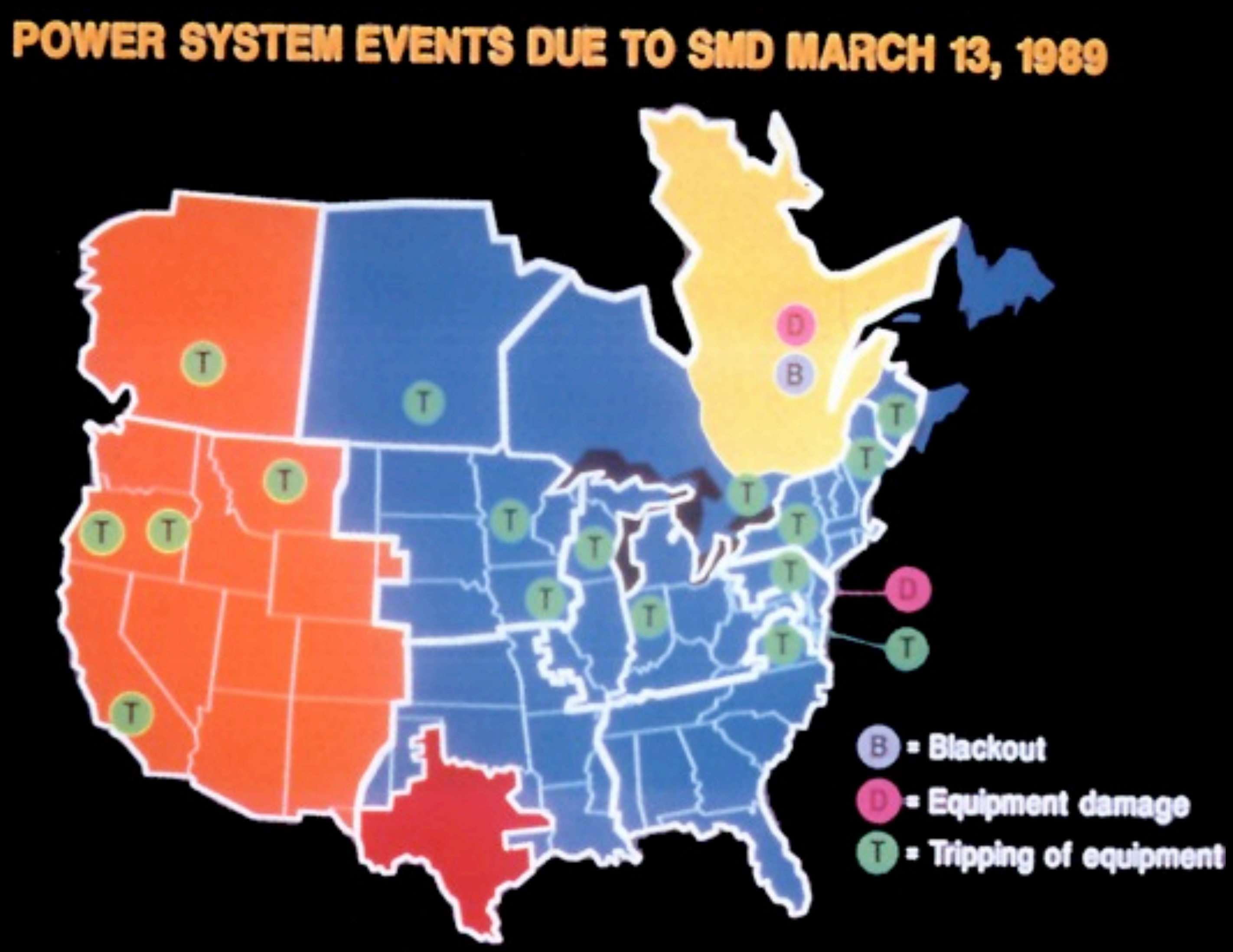


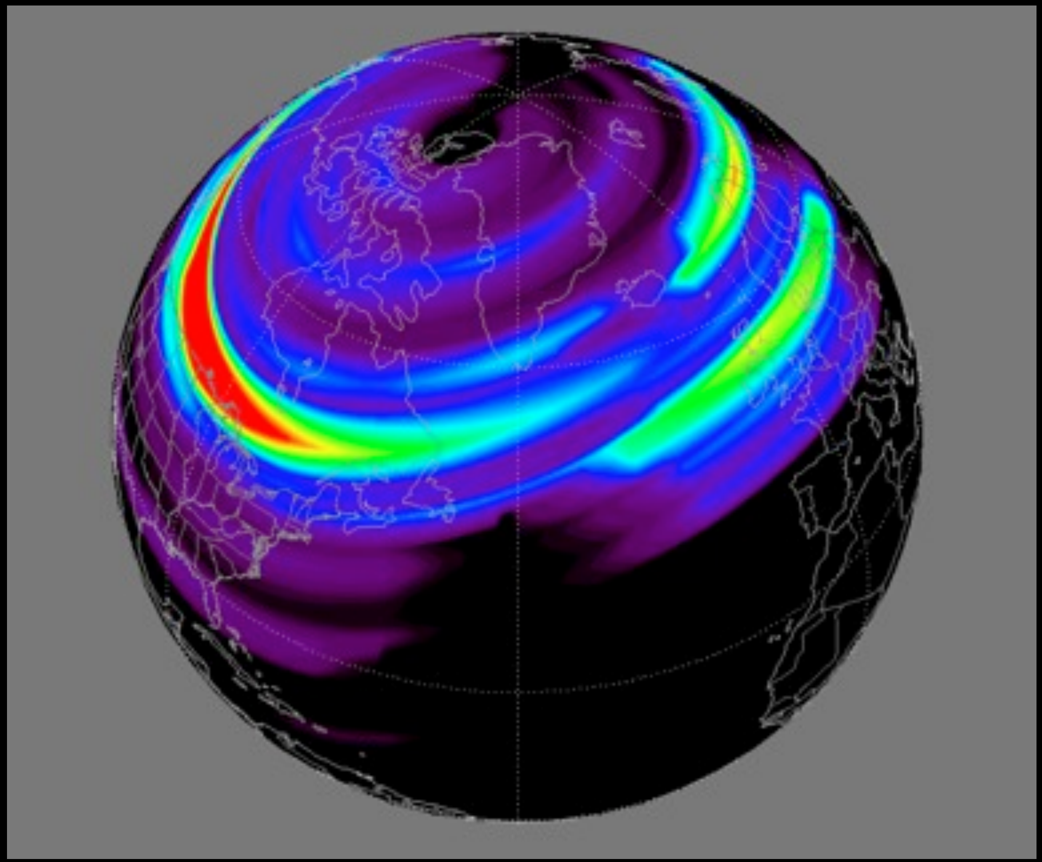
- These currents leaks into all lang conductors:
  - Power grids
  - Oil- and gas pipelines

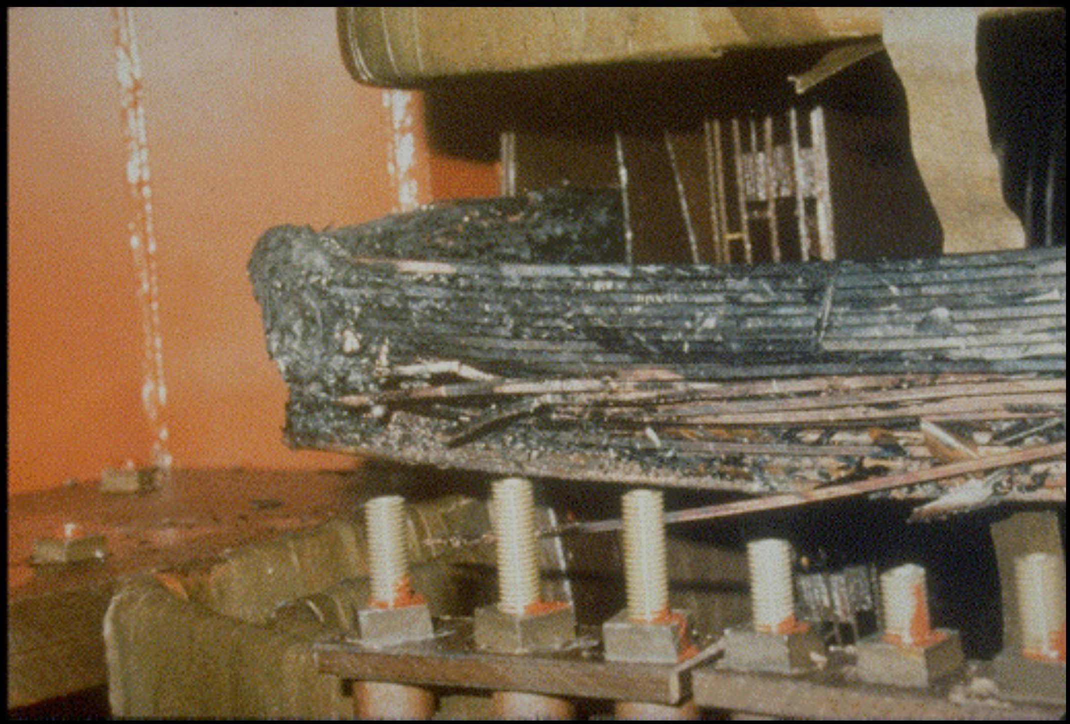


Power failure March 1989

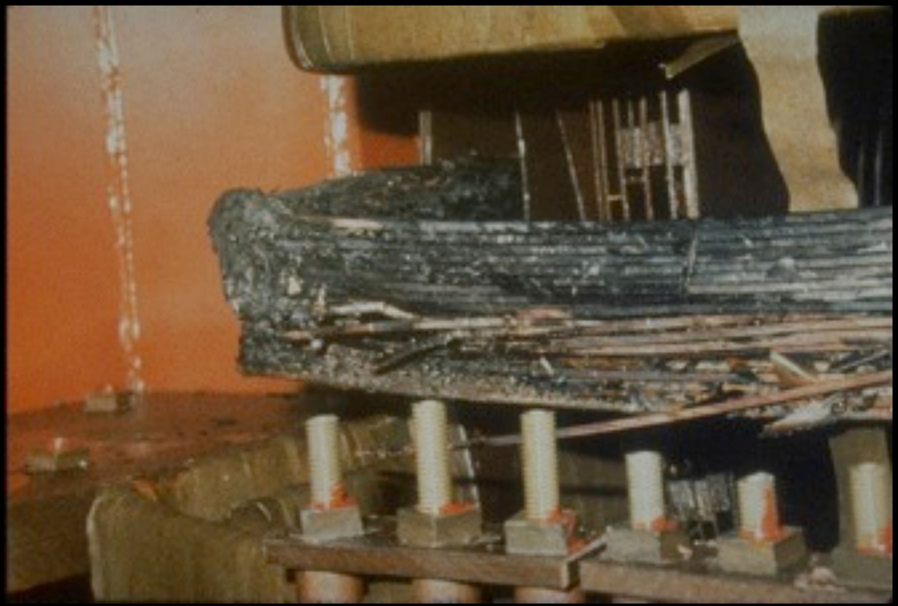
- The entire power grid in Quebec collapsed
- The collapse almoste spread into the NE USA
- Such a collapse would have had en estimated $3-6 billion impact on the US economy.







Damages after the 1989 storm



Damages to a trafo in Delaware, New Jersey in March 1989.

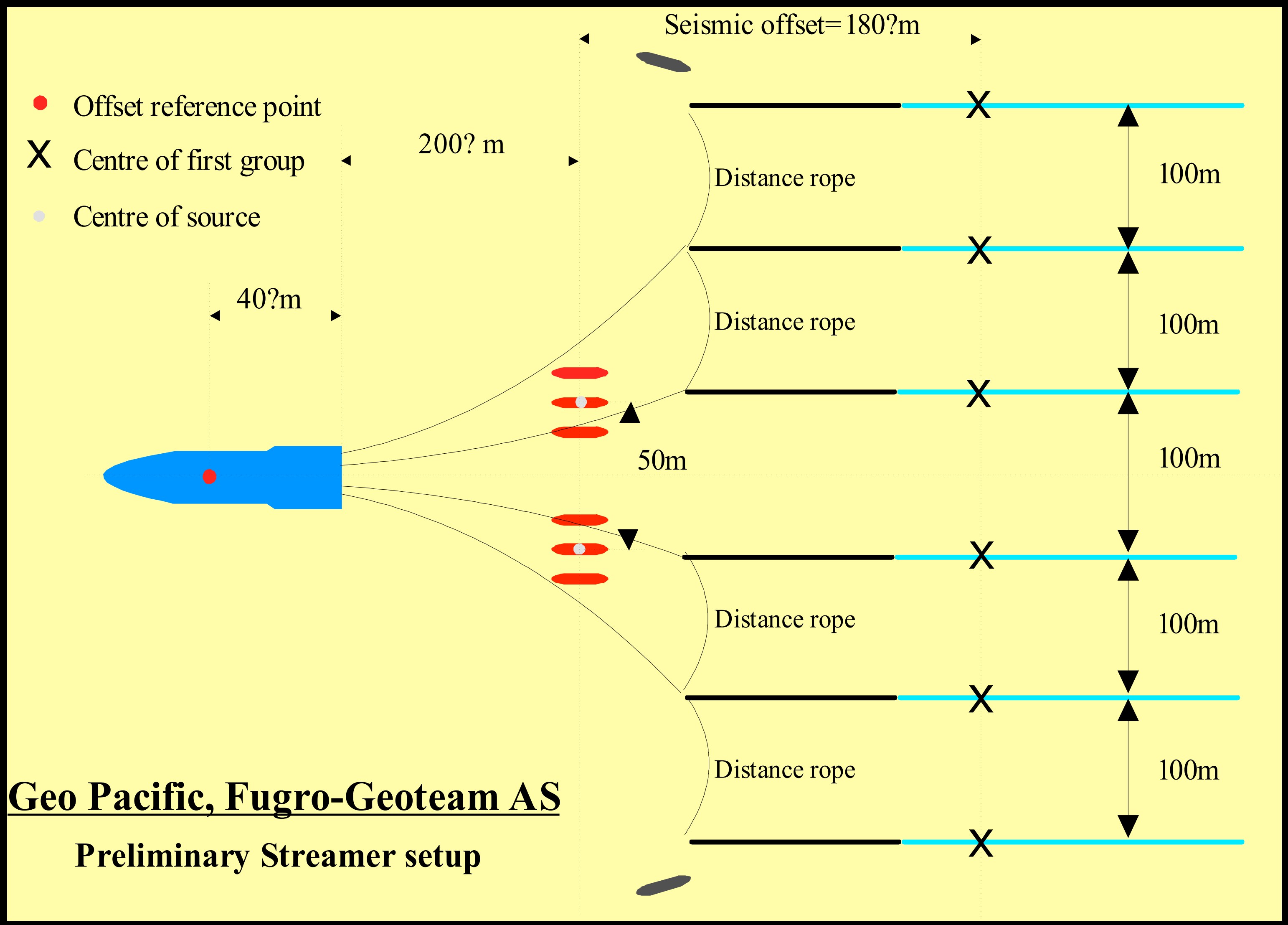
Cost: 10 million USD, repair can take one year.

In this case a used trafo was available and they swapped it in 6 weeks.

Sweden: lost power in six 130 kV distribution lines.

Chicago: Five trafoes in Chicago damaged in April 1994.

Geomagnetic surveys - search for oil and gas

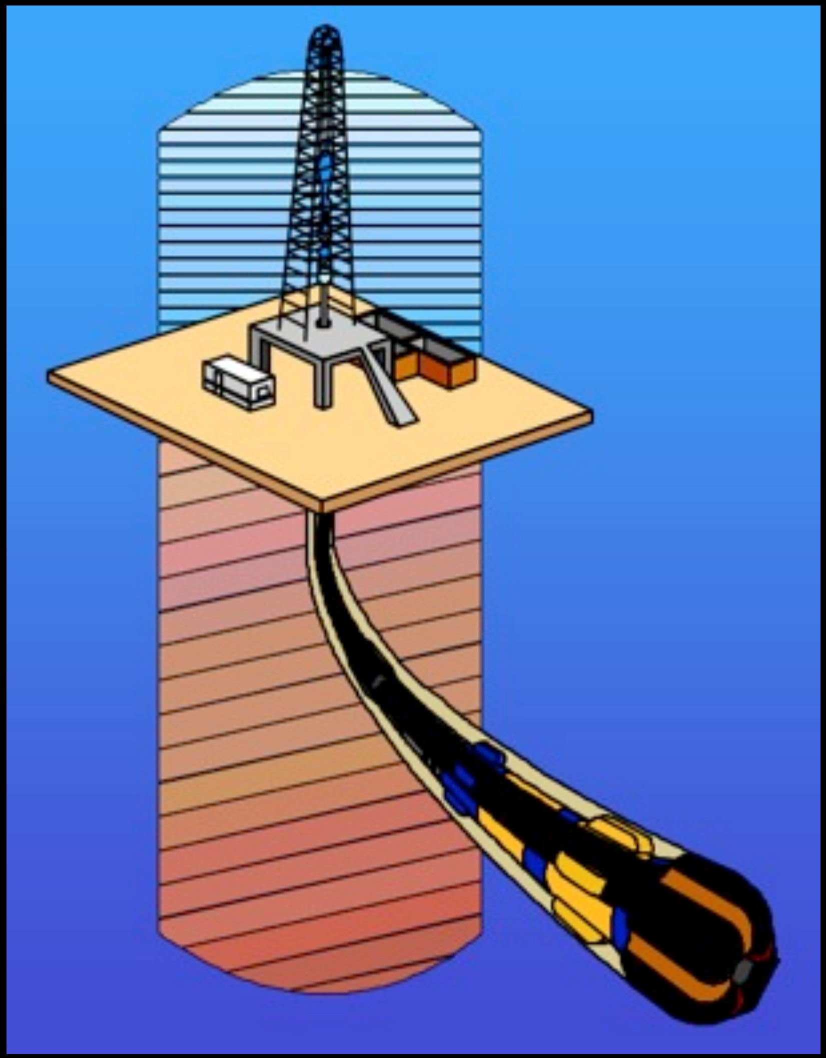


Fugro-Geoteam use ships with sensitive magnetometers on long cables.

Directional drilling

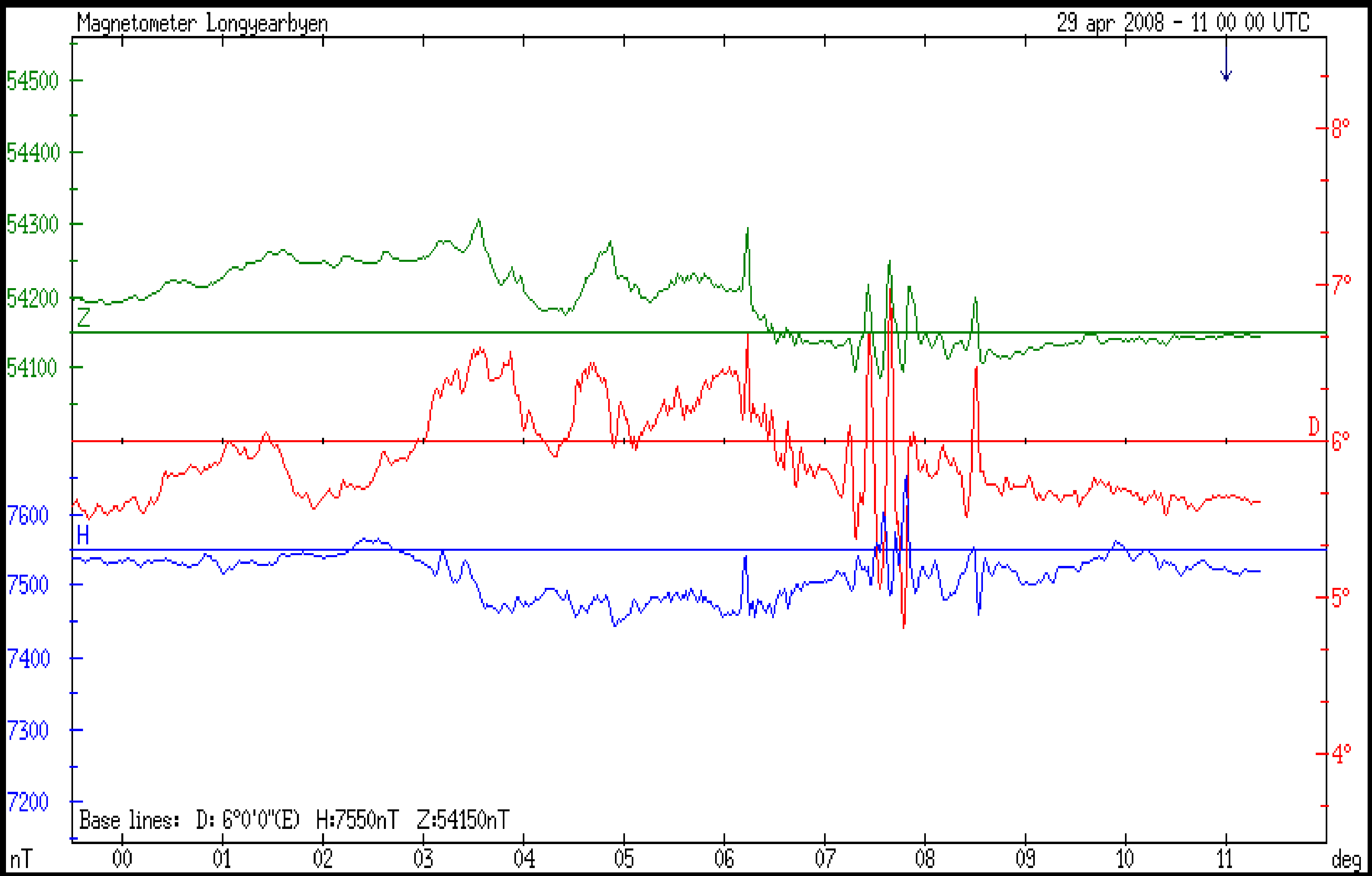
Directional drilling

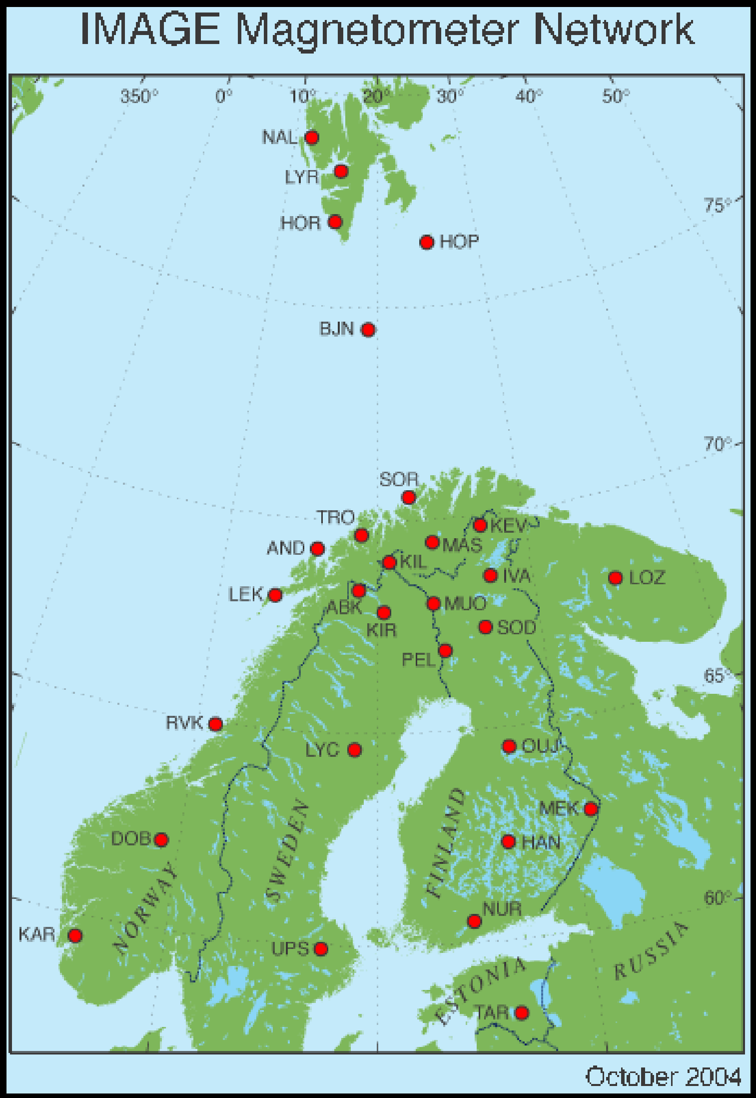
- Oil industry relies on geomagnetic maps to guide the drill and monitor the well direction.



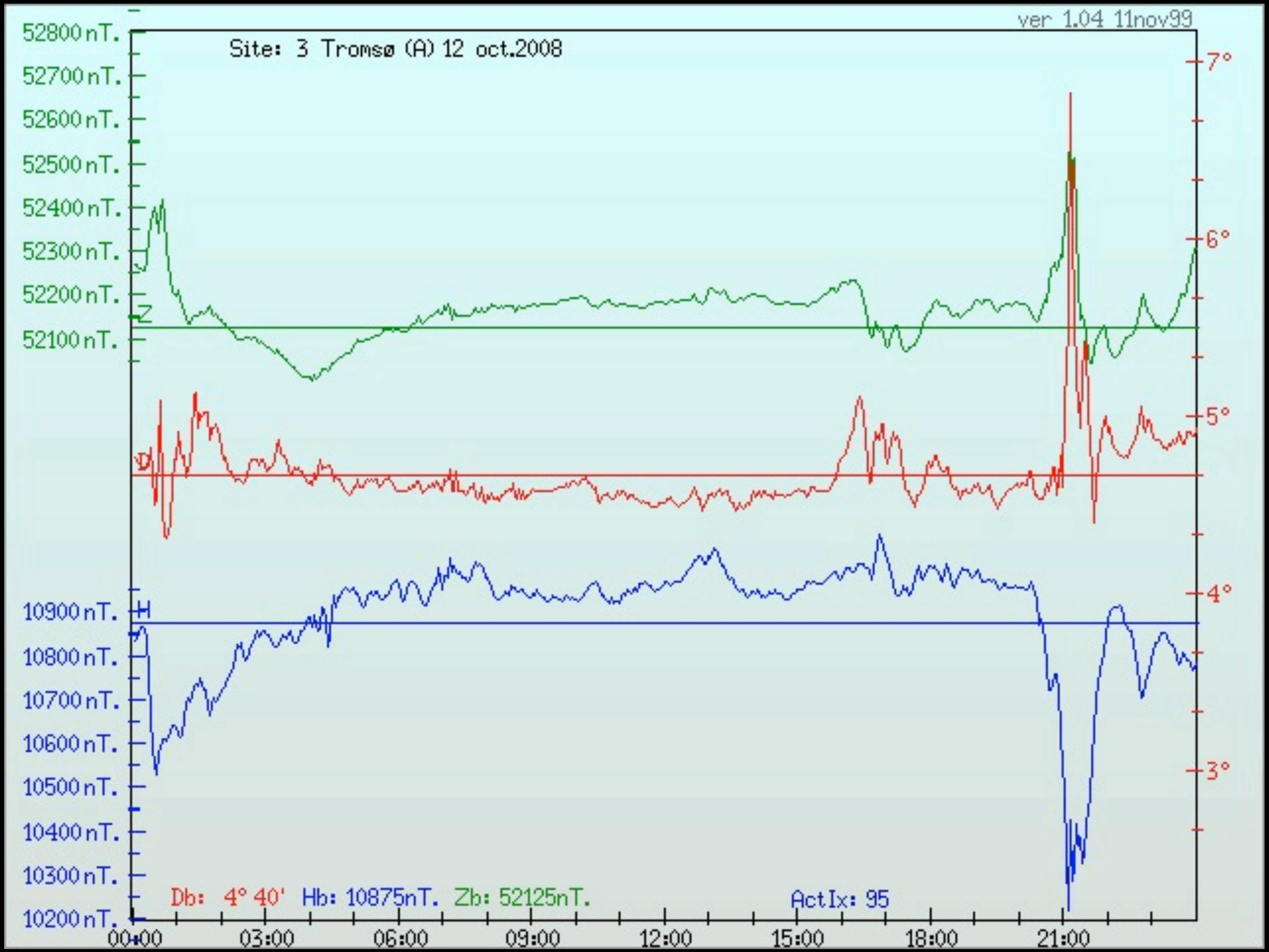
Drillin companies «buy» space weather data

- UiT delivers "real-time" magnetometer data to the drilling companies to eitehr correct or extend the time they cam operate.





Effects on a compass

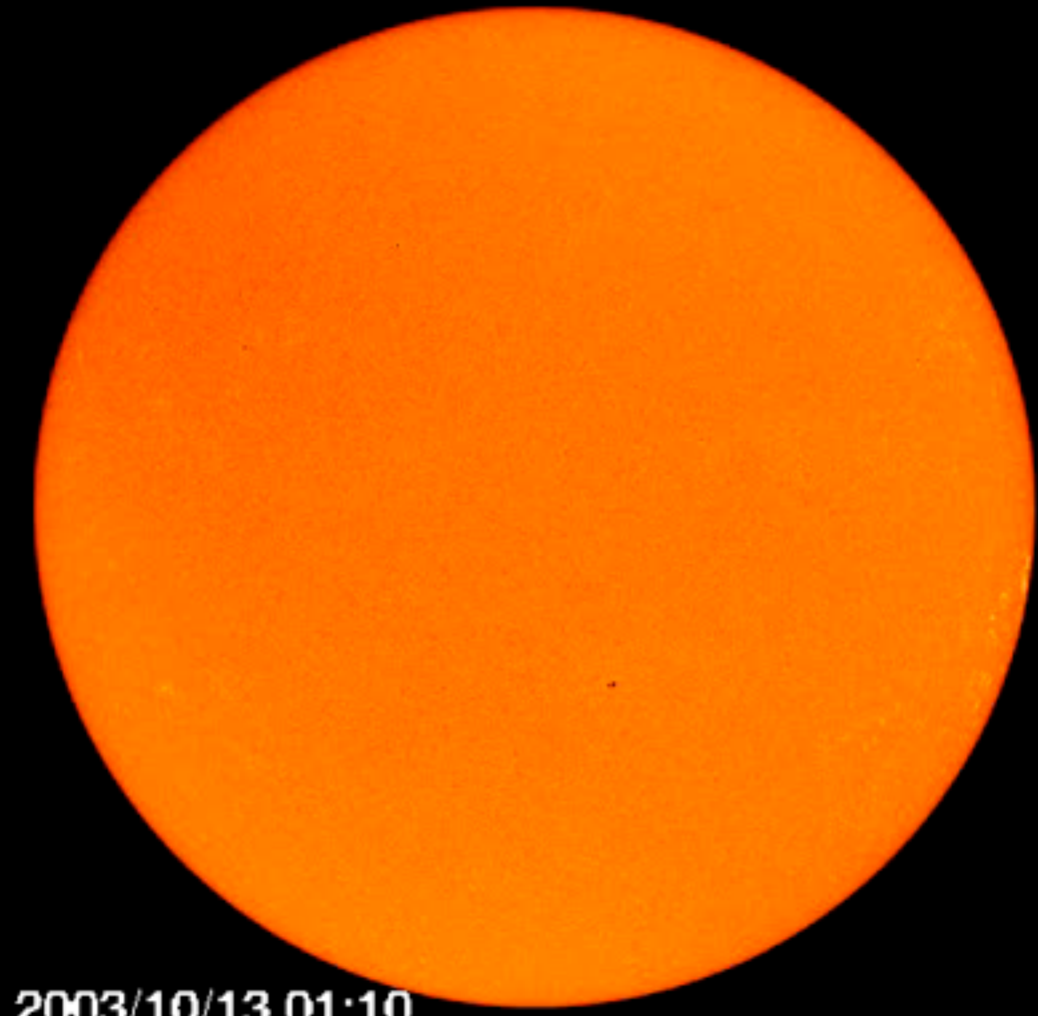


Impacts on animals

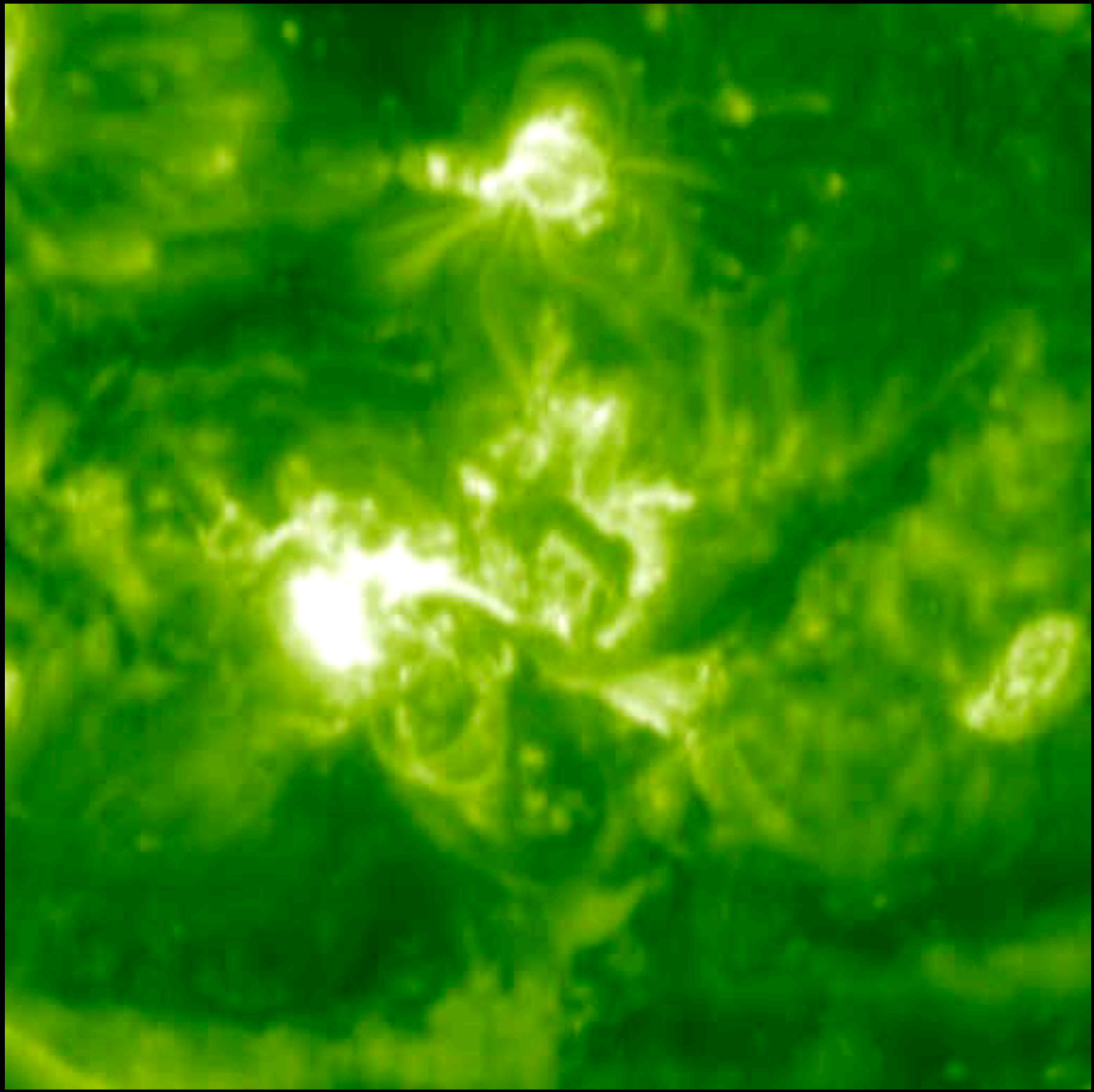
- The navigational abilities of homing pigeons are affected by geomagnetic storms
- Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells.

The Halloween-storms

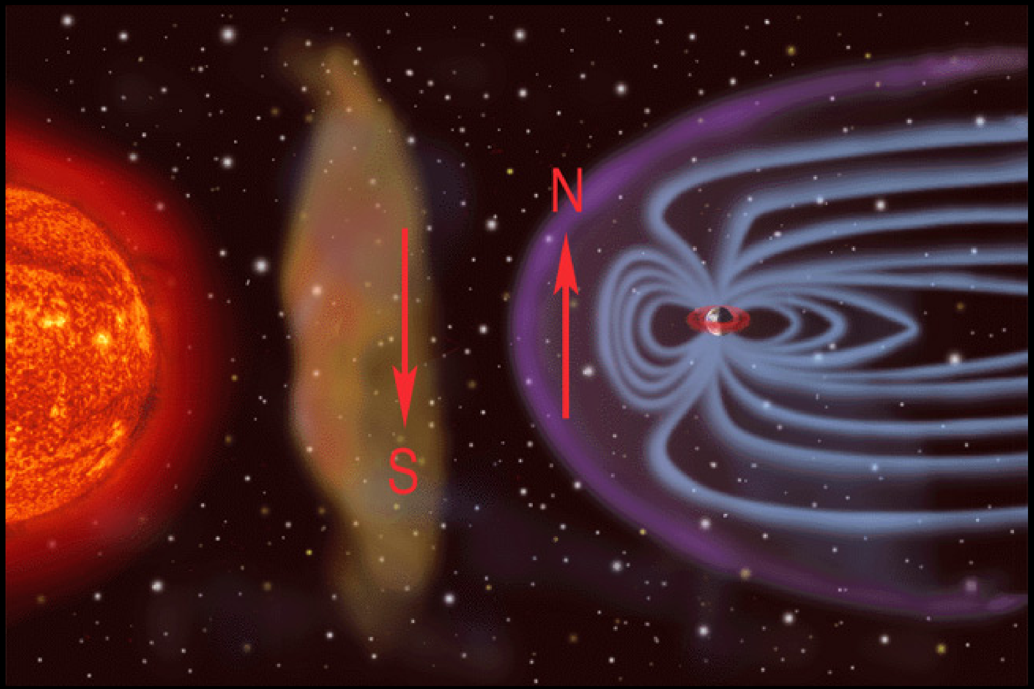
Giant sunspots developed

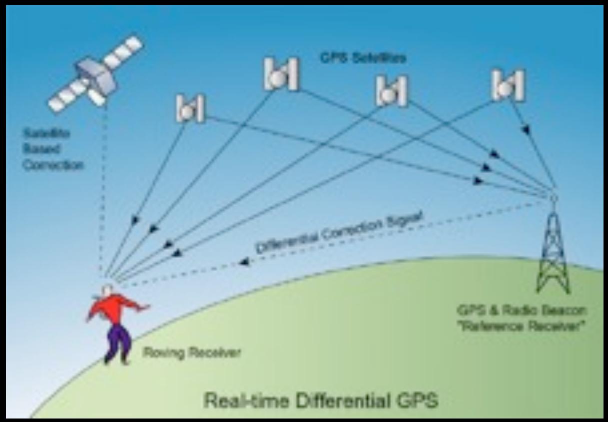


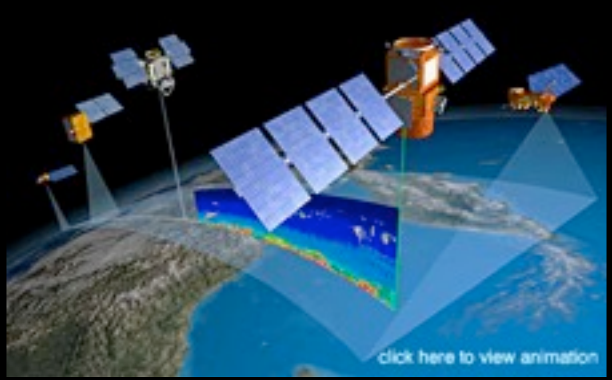
Solar storm 28th October 2003



Effects from the Halloween storms

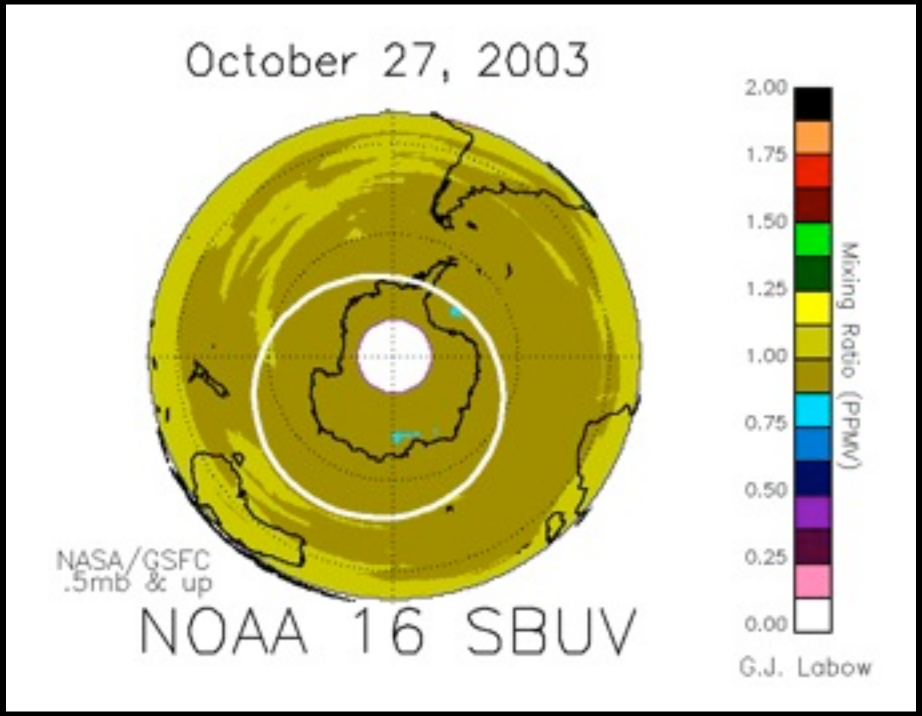


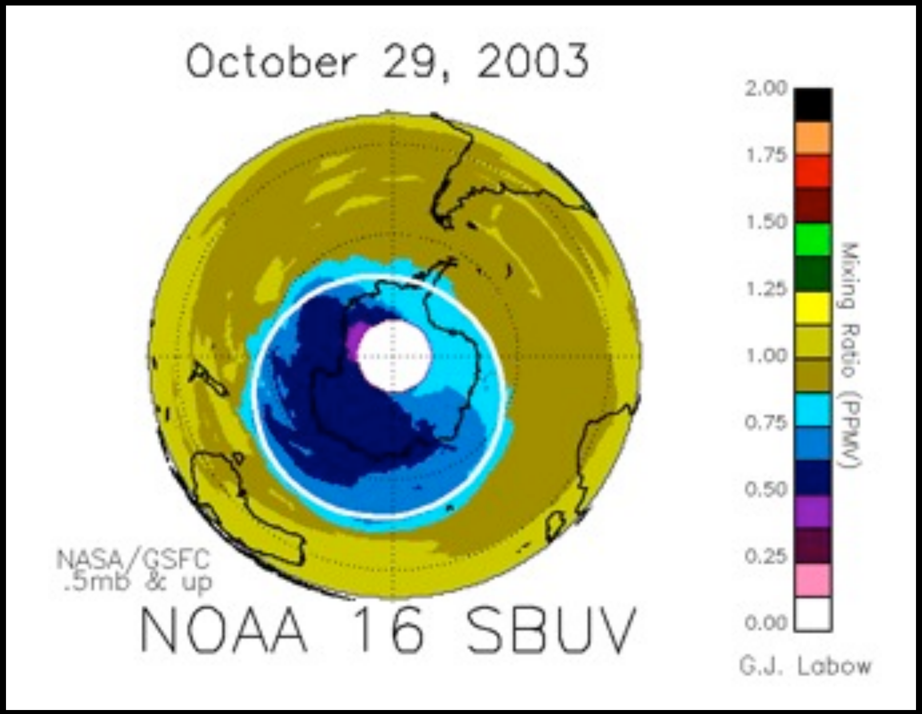




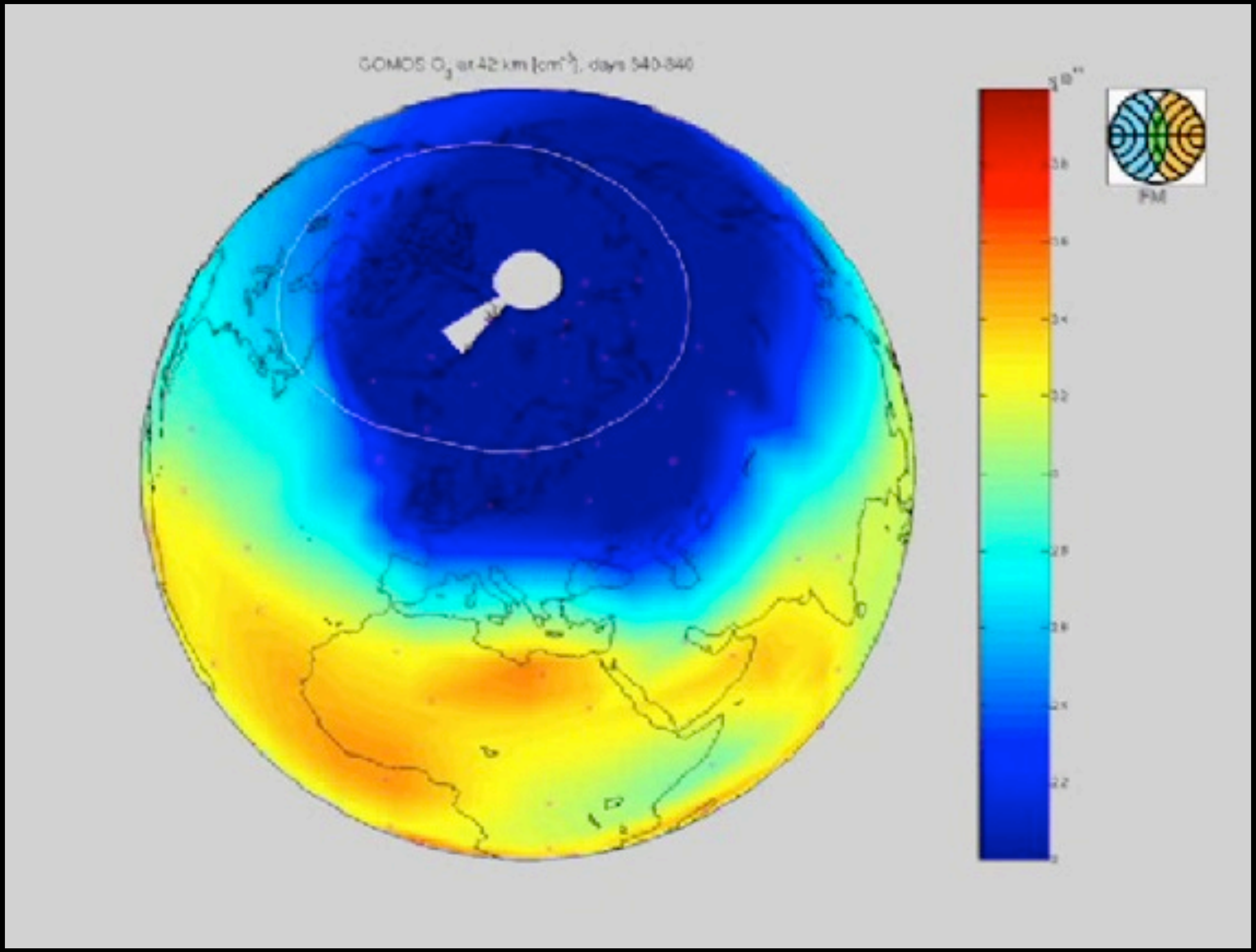
- More than 20 satellites and spacecrafts were affected (not including classified military instruments), Half of NASA satellites affected. One Japanese satellite lost
- Severe HF Radio blackout – affected commercial airlines
- FAA issued a first-ever alert of excessive radiation exposure for air travellers
- Power failure in Sweden
- Climbers in Himalaya experienced problems with satellite phones.
- US Coast Guard to temporarily shut down LORAN navigation system.
- Radiation monitor device on Mars Odyssey knocked out Parts of the Martian atmosphere escaped into space

Protonevents affects the ozone-content
(ved 0.5 hPa eller ~55 km)



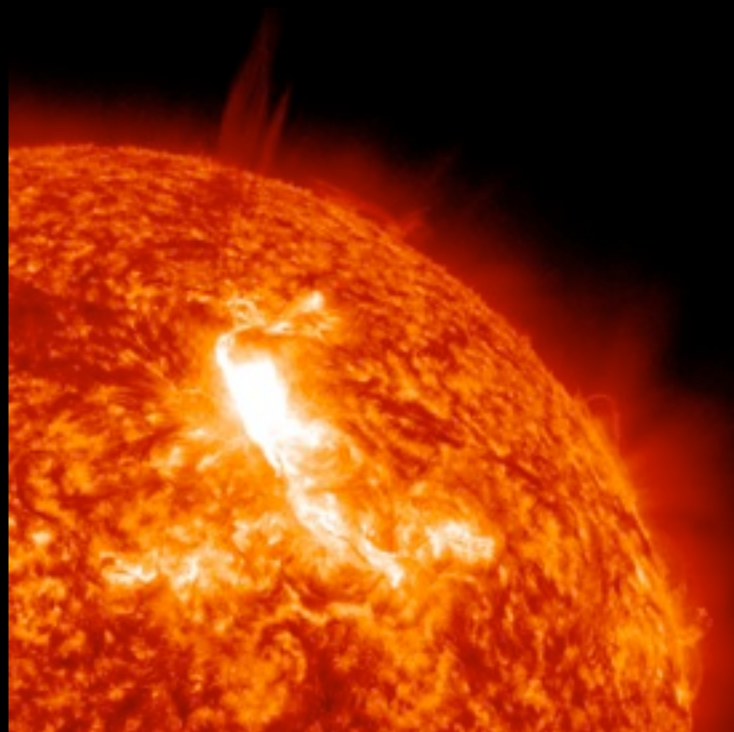


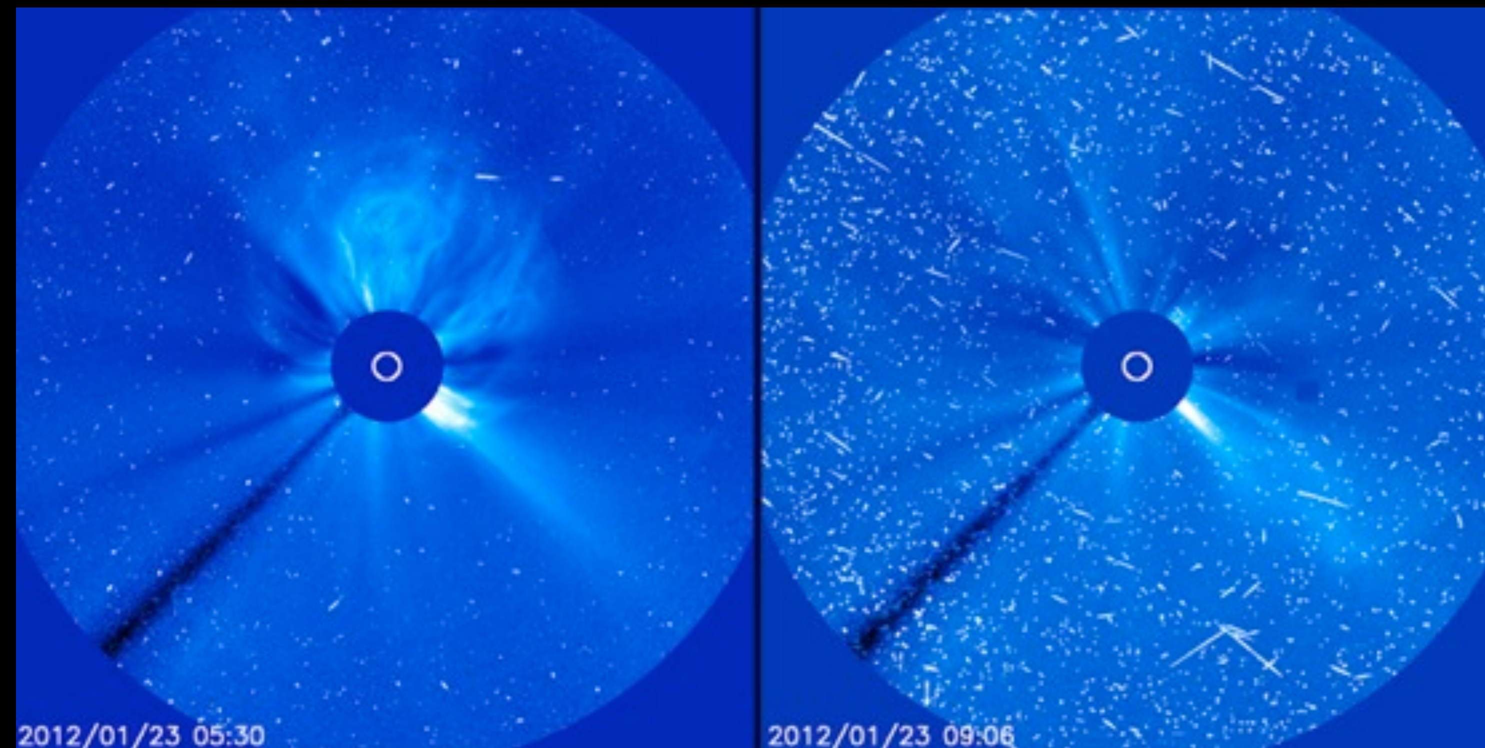
This event reduced the ozone content for 8 months (~42 km)

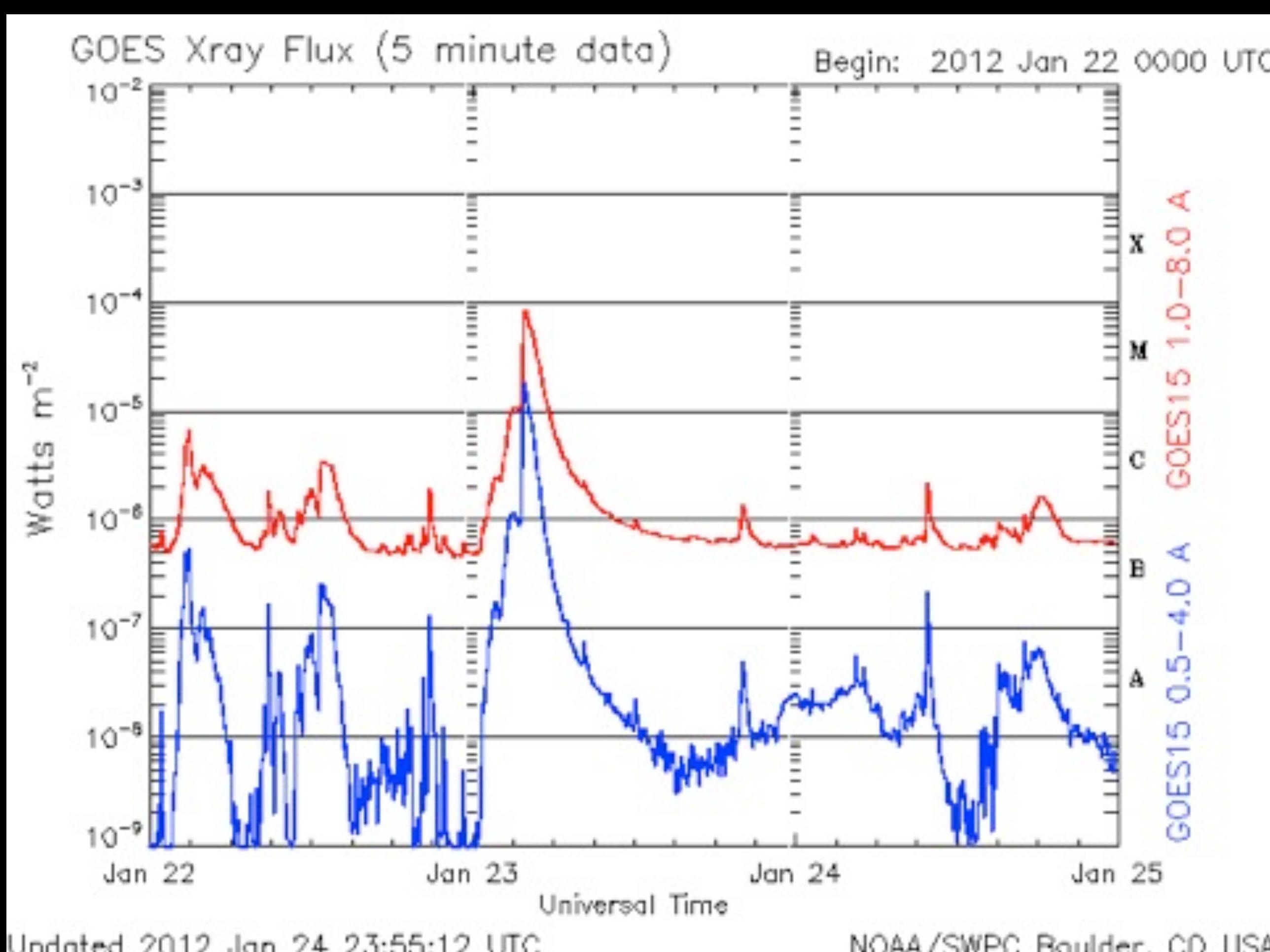


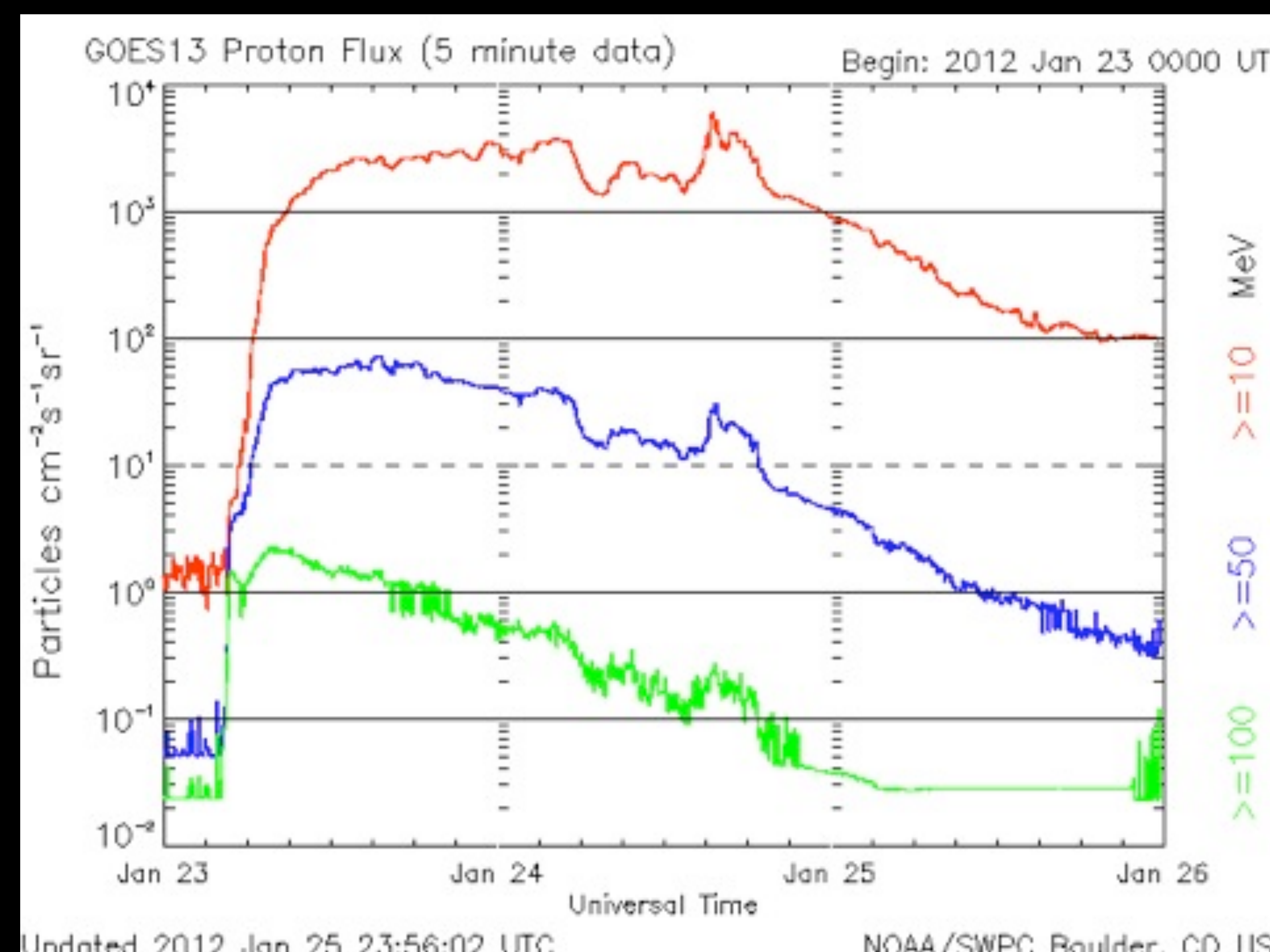
Source: Charles Jackman & Gordon Labow (NASA) og FMI

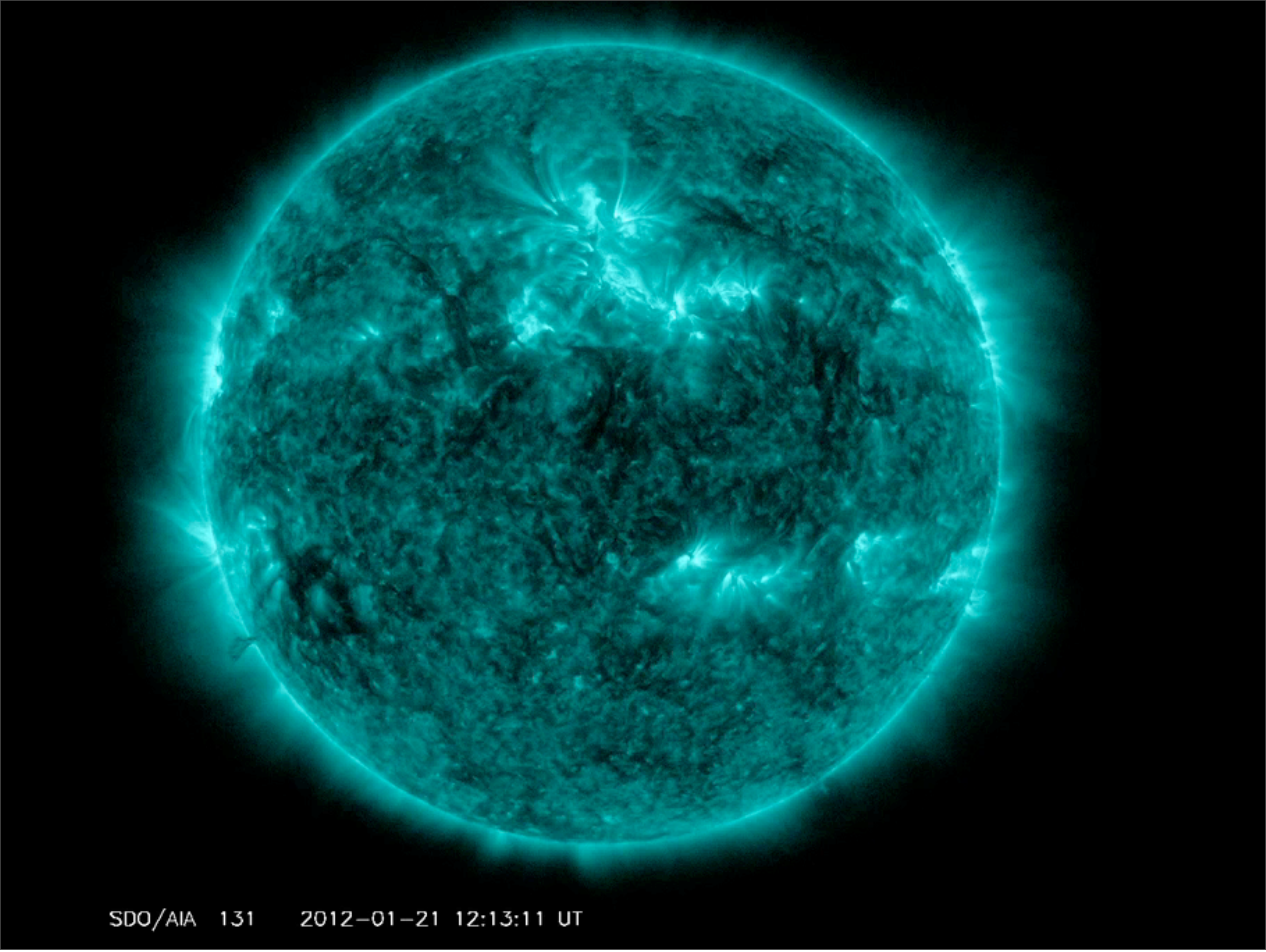
Solstorm 23 Januar 2012

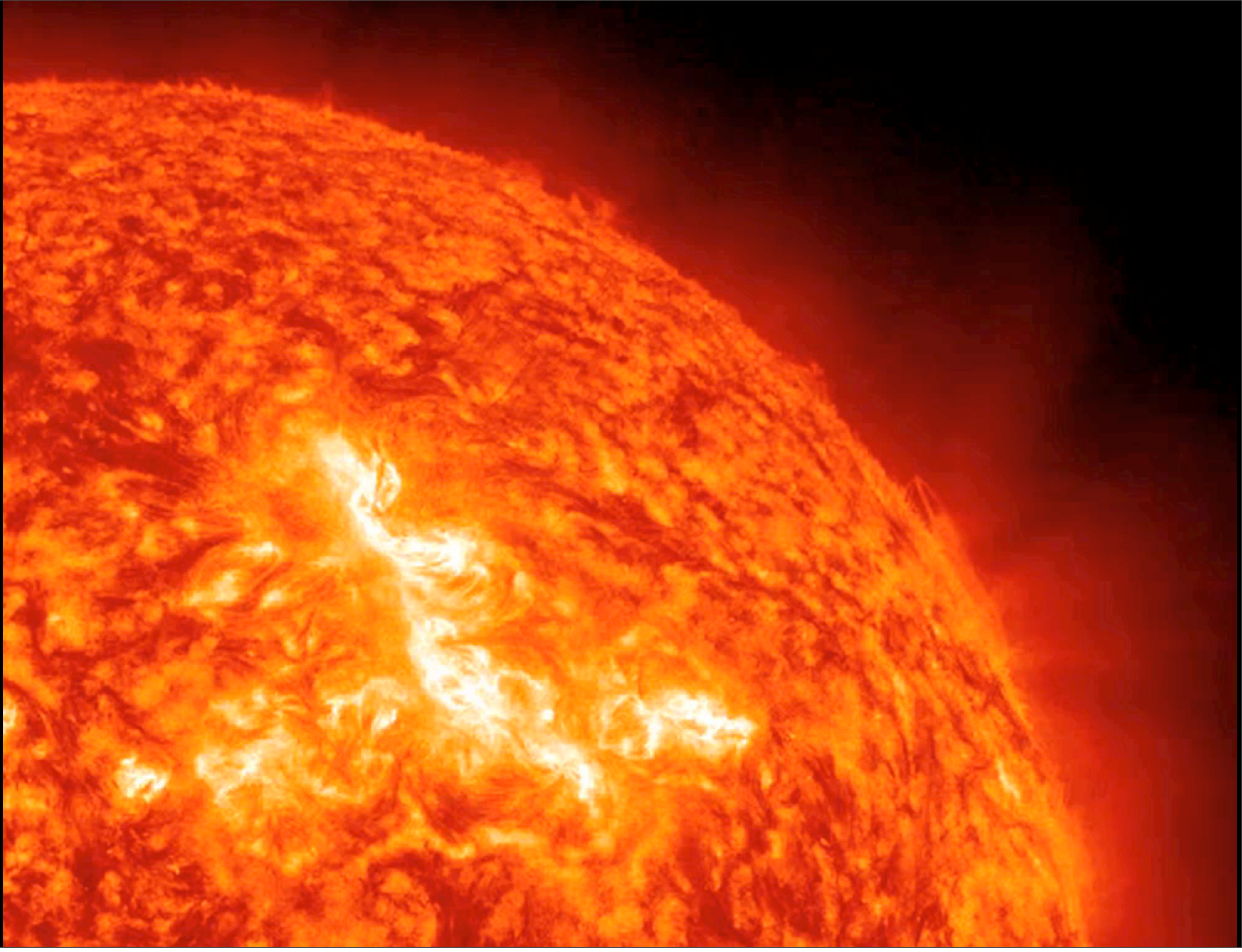


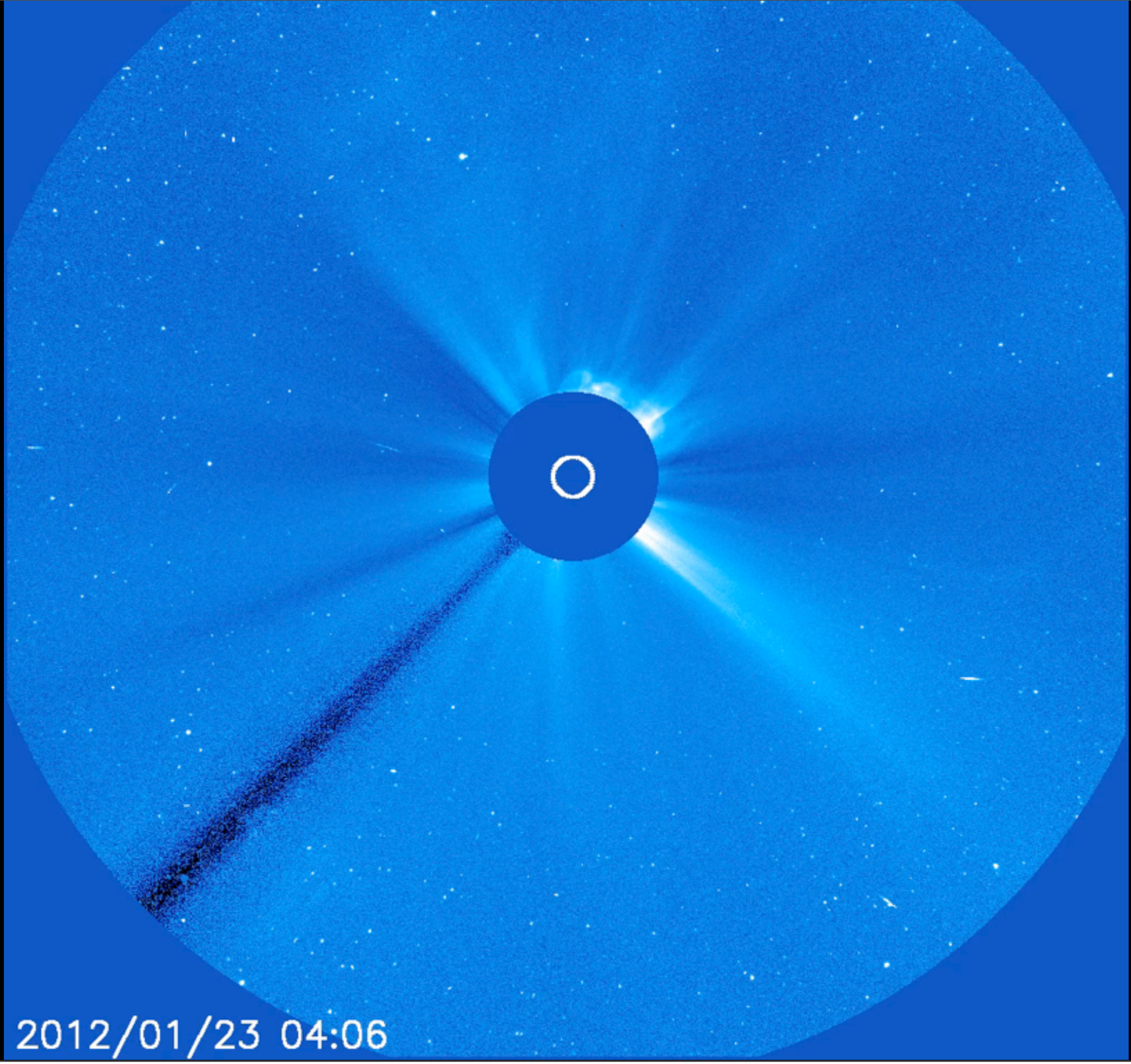




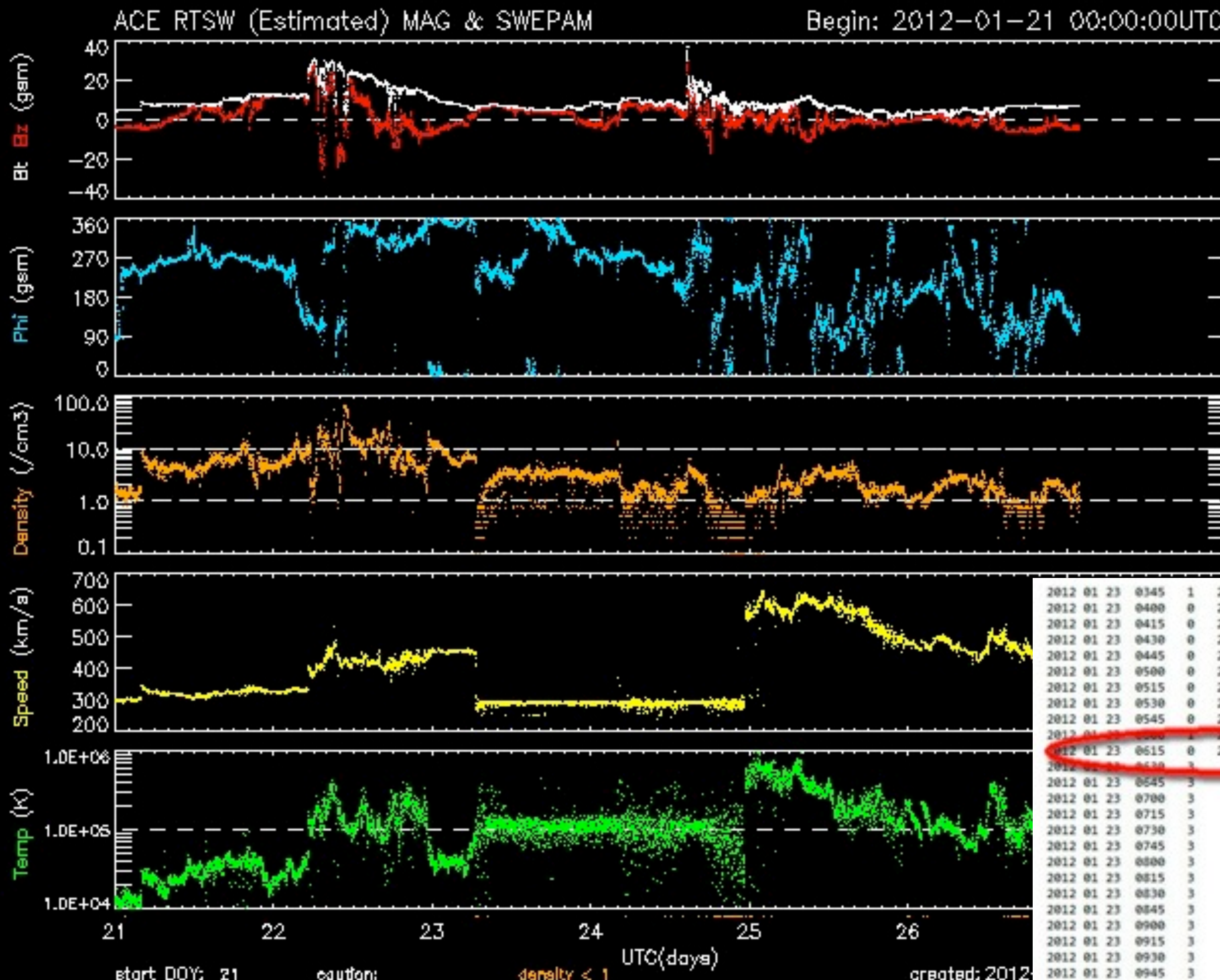


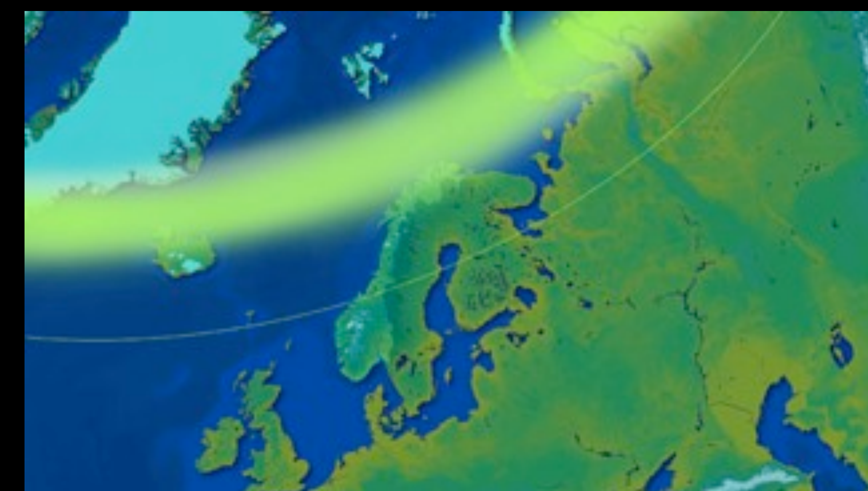

SDO/AIA 131 2012-01-21 12:13:11 UT




2012/01/23 04:06

Particlel storm «blinded» ACE



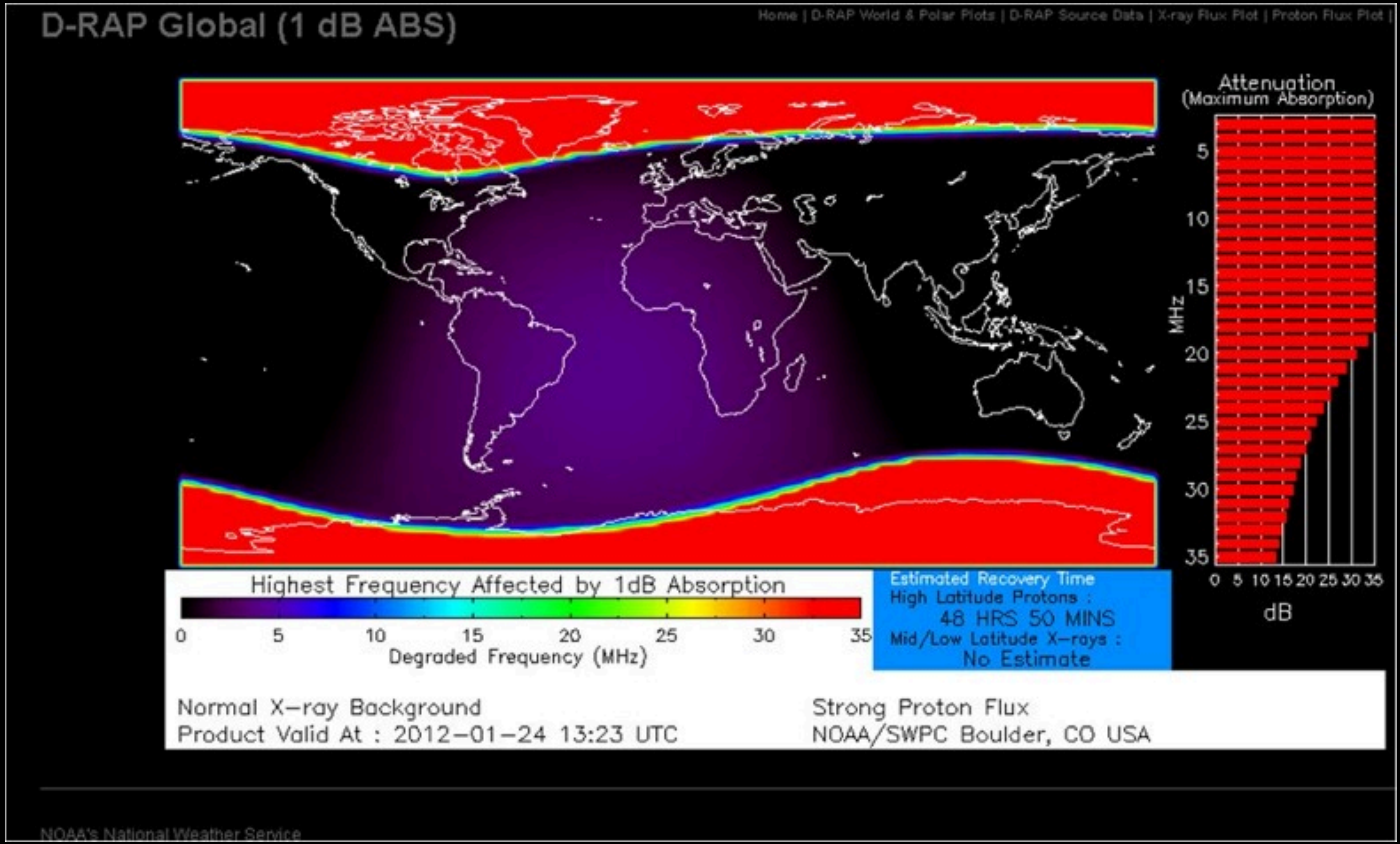



Etter klokken 7.15 norsk tid mandag har det bare lagt -1 i listen med observasjoner fra NOAA. ACE-satellitten fungerer ikke lenger som den skal. *Foto: NASA / NOAA*

Utbruddet på solen ødela nordlysvarslene

Fligths were diverted

- Delte Airlines and United diverted some of their polar flights to avoid radio communication problems and increased radiation doses for the crew.
- The South pole was without radiocommunication for two days (where satellite communication is unavailable).



This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles enter and where airliners and spacecraft, should try to avoid.

Space Weather - Why should we care?

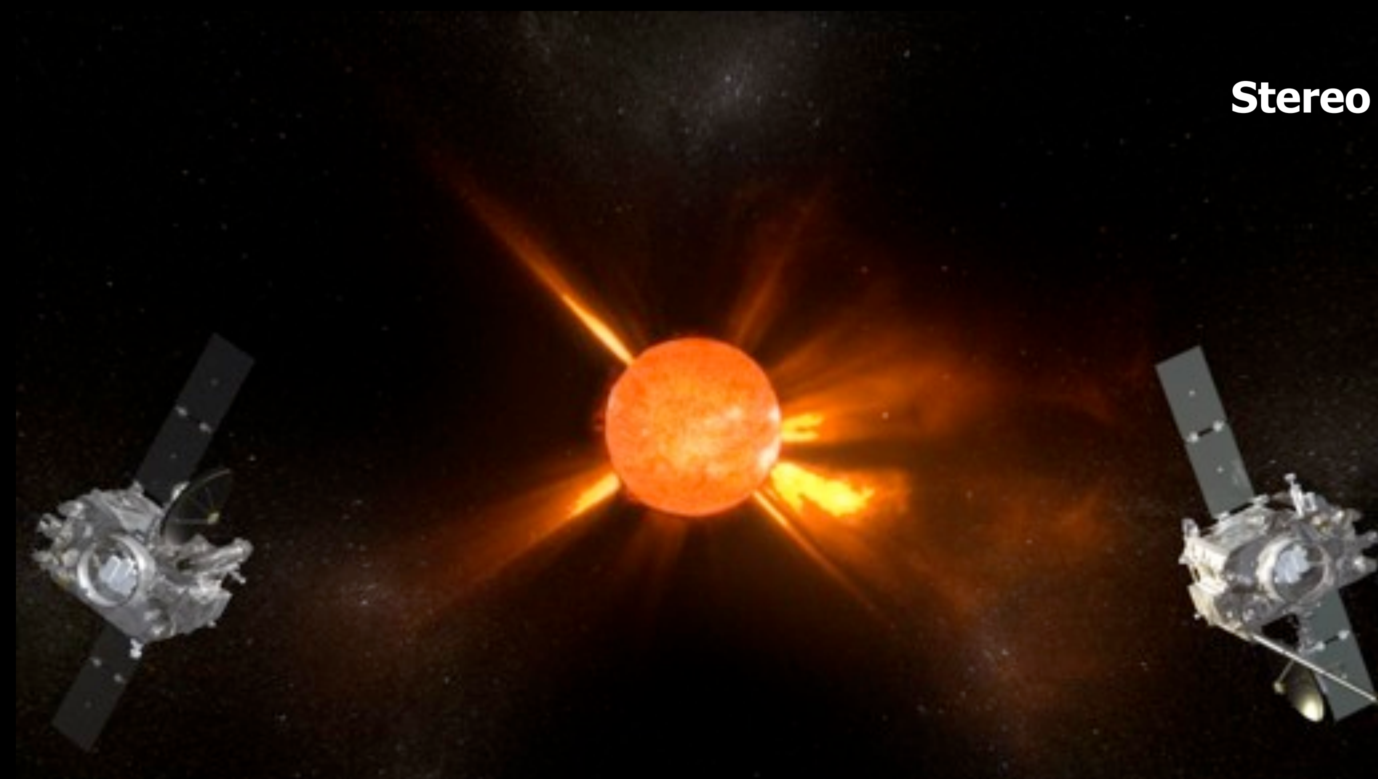
- The society is much more dependent on space technology
- Rapidly growing sector:
  - Broadcast TV/Radio,
  - Long distance phone, cell phones, pagers
  - Internet, finance-transactions
  - 350 million ++ users of GPS by 2015
- Change in technology
  - more sensitive payload
  - components with higher performance.
  - light and low cost components
- Humans in space
  - More and longer space flights
- Space wetaher warnings will be even more important for our society in the future.

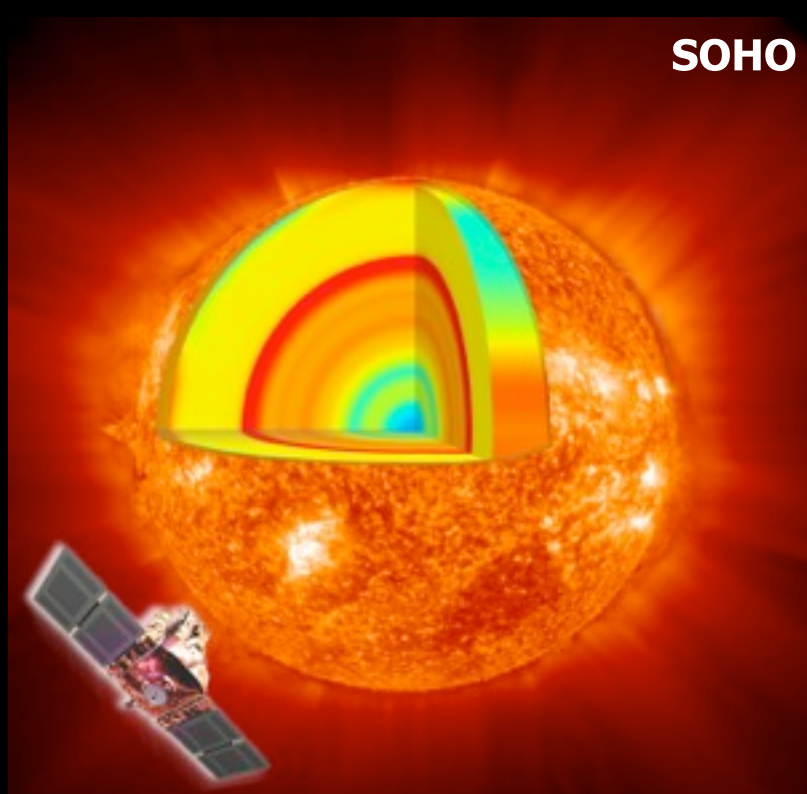
National Academy of Sciences, evaluated the impacts from a «super storm» and concluded that USA would be hit hard.

Damaged could reach 1000 billion USD

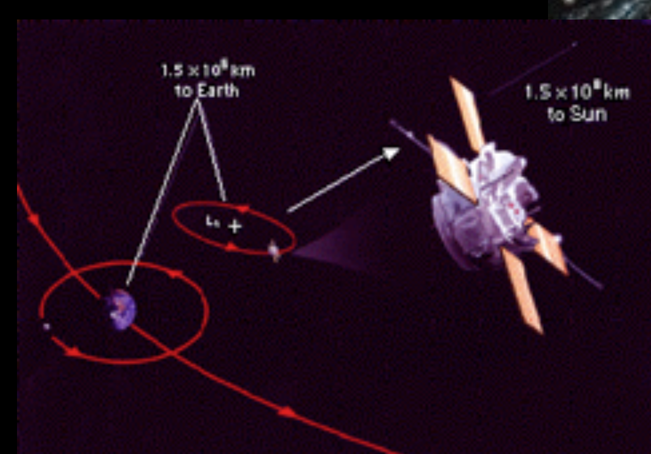
It could take 4-10 years to repair all damages.

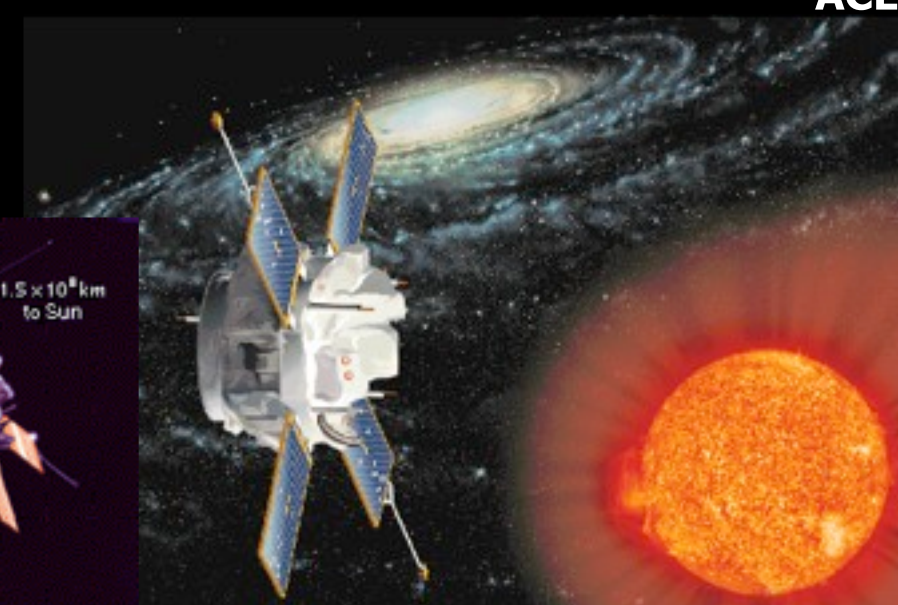
Fleet of satellites watching the Sun



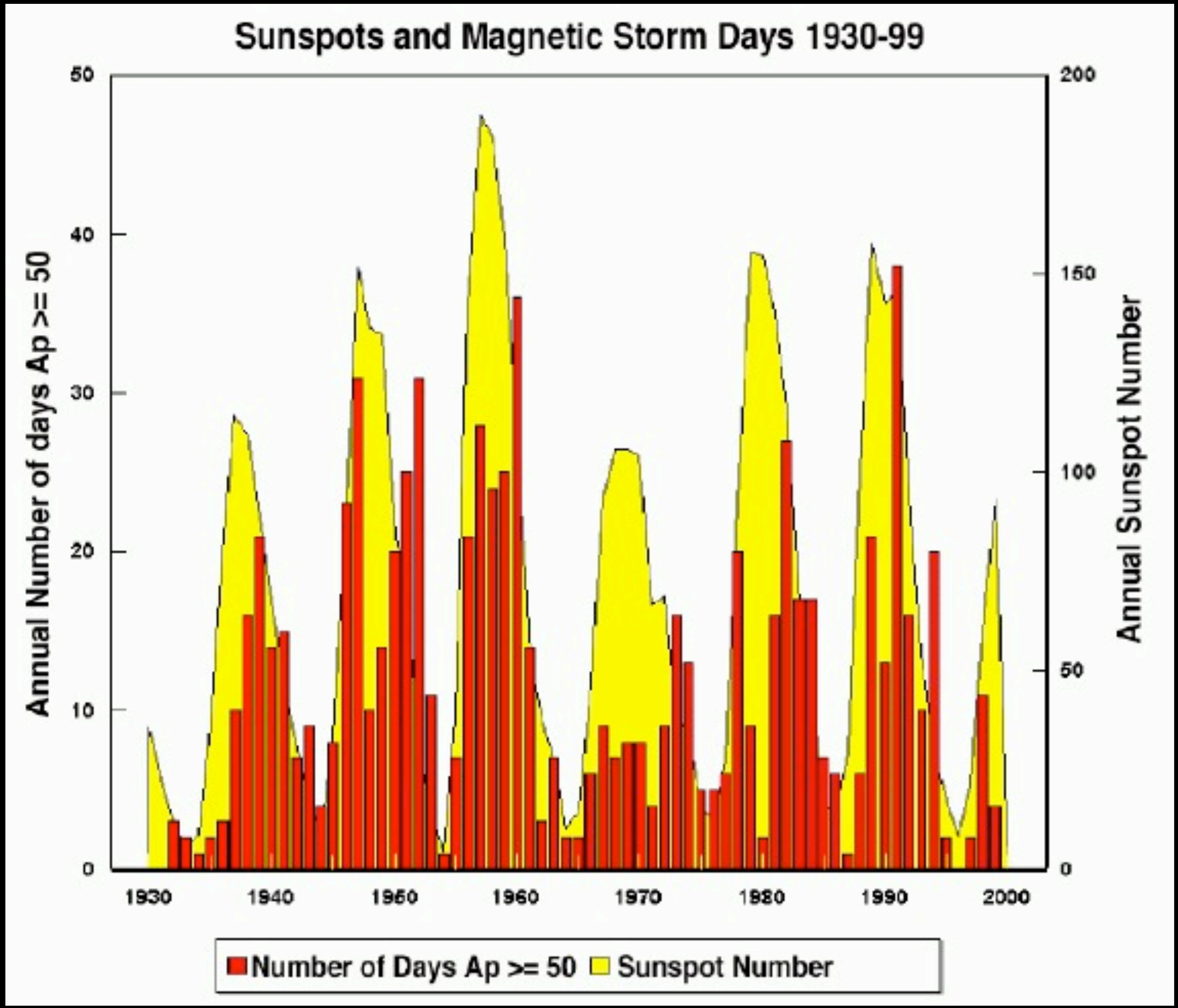


ACE





Solar cycle and geomagnetic disturbances



Space Weather Warnings

Prepared jointly by the U.S. Dept. of Commerce, NOAA,
Space Weather Prediction Center and the U.S. Air Force.
Updated 2008 Sep 15 2201 UTC

Joint USAF/NOAA Report of Solar and Geophysical Activity
SDF Number 259 Issued at 2200Z on 15 Sep 2008

IA. Analysis of Solar Active Regions and Activity from 14/2100Z
to 15/2100Z: Solar activity was very low. No flares were observed
during the past 24 hours. The visible disk remained spotless.

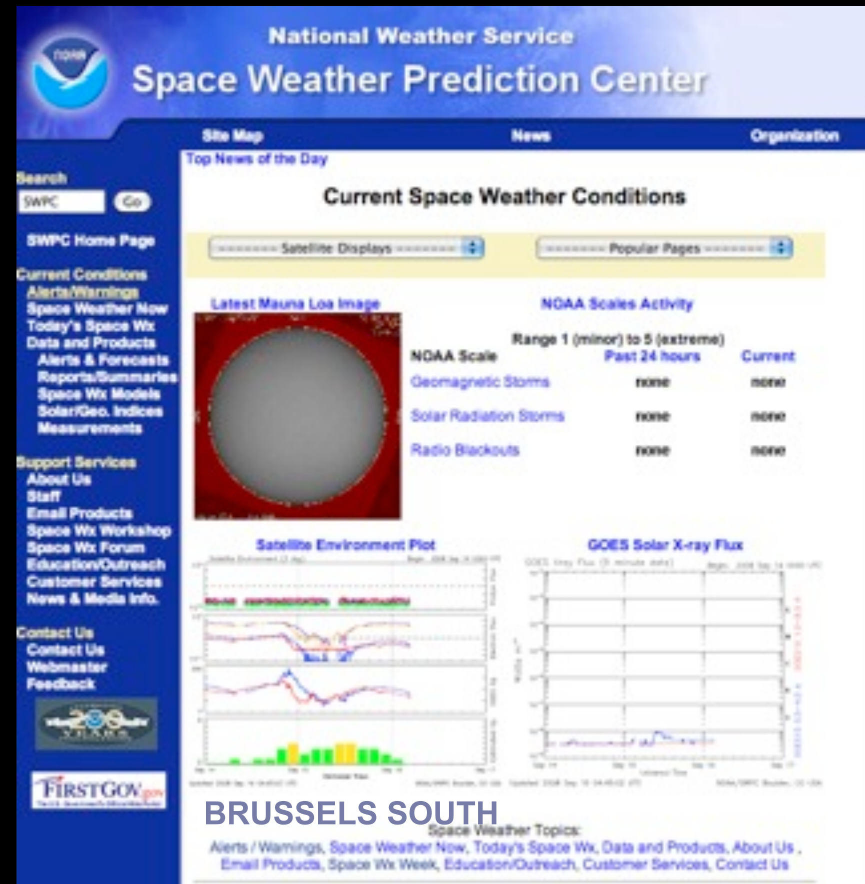
IB. Solar Activity Forecast: Solar activity is expected to be very
low.

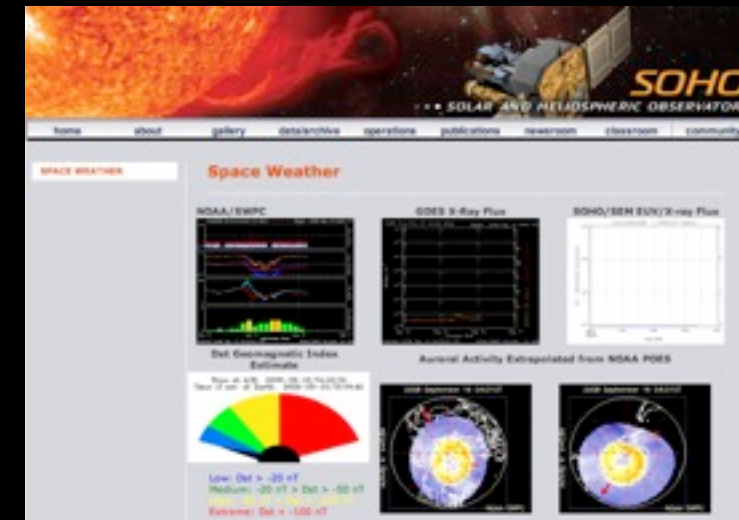
III. Event Probabilities 16 Sep-18 Sep
Class M 01/01/01
Class X 01/01/01
Proton 01/01/01
PCAF Green

IV. Penticton 10.7 cm Flux
Observed 15 Sep 068
Predicted 16 Sep-18 Sep 066/066/066
90 Day Mean 15 Sep 066

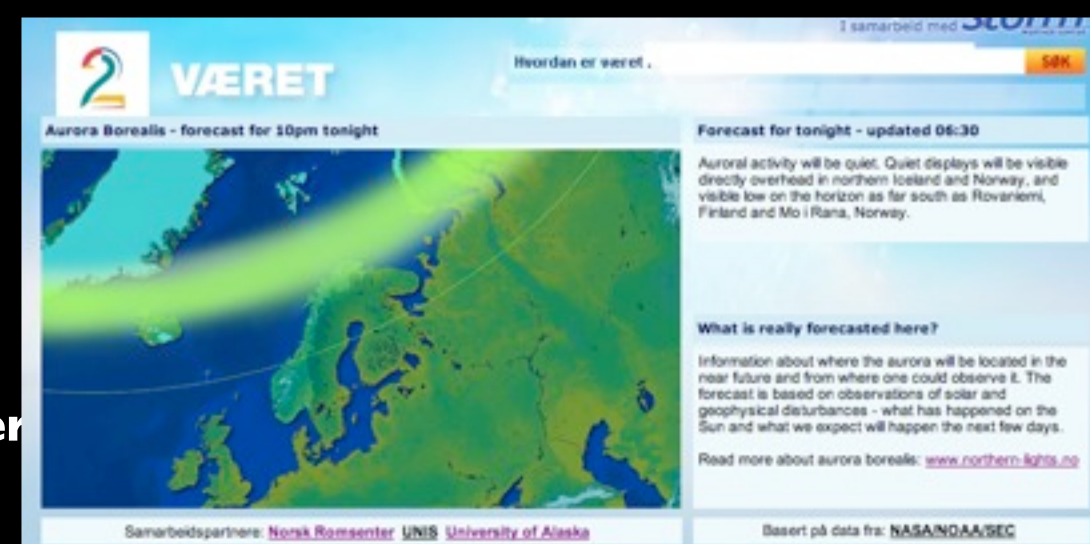
V. Geomagnetic A Indices
Observed Afr/Ap 14 Sep 004/006
Estimated Afr/Ap 15 Sep 015/015
Predicted Afr/Ap 16 Sep-18 Sep 007/008-005/005-005/005

VI. Geomagnetic Activity Probabilities 16 Sep-18 Sep
A. Middle Latitudes
Active 20/10/10
Minor storm 01/01/01
Major-severe storm 01/01/01
B. High Latitudes
Active 25/10/10



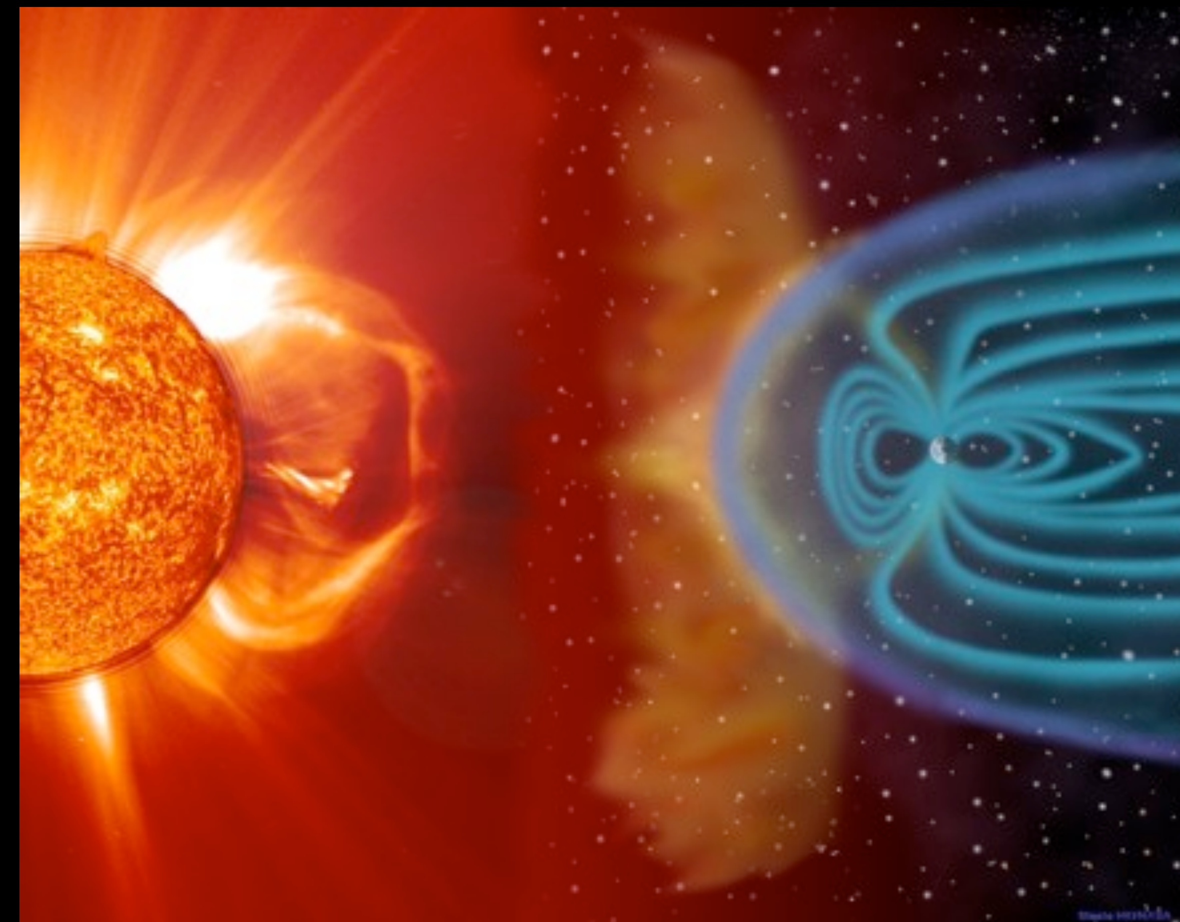


ESAs Space Situational Awareness - new European program including space weather



- http://sidc.oma.be/
- http://www.swpc.noaa.gov/
- http://soho.nascom.nasa.gov/spaceweather/
- http://www.spaceweather.com/
- http://full.storm.no/tv2ver/borealis.aspx (Nordlysvarsler

Super Storms



http://www.nap.edu/catalog.php?record_id=12507

According to a study by the Metatech Corporation, the occurrence today of an event like the 1921 storm would result in large-scale blackouts affecting more than 130 million people and would expose more than 350 transformers to the risk of permanent damage

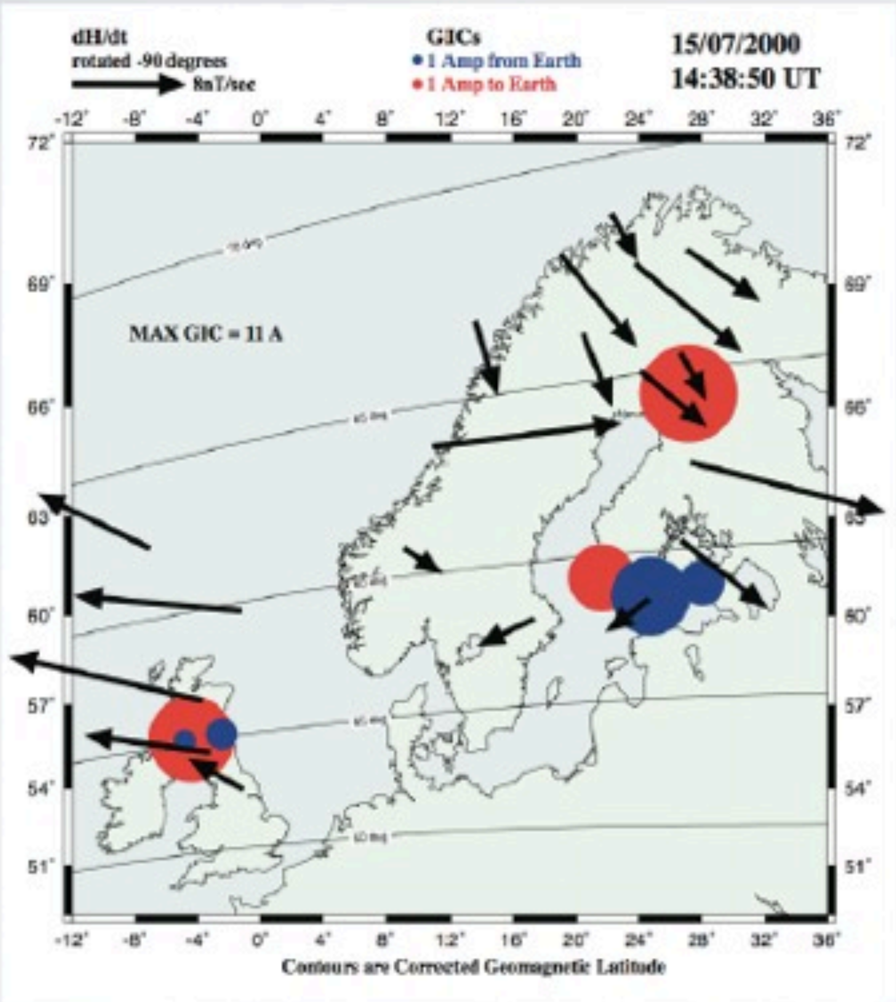
....and an estimate of $1 trillion to $2 trillion during the first year alone was given for the societal and economic costs of a “severe geomagnetic storm scenario” with recovery times of 4 to 10 years.

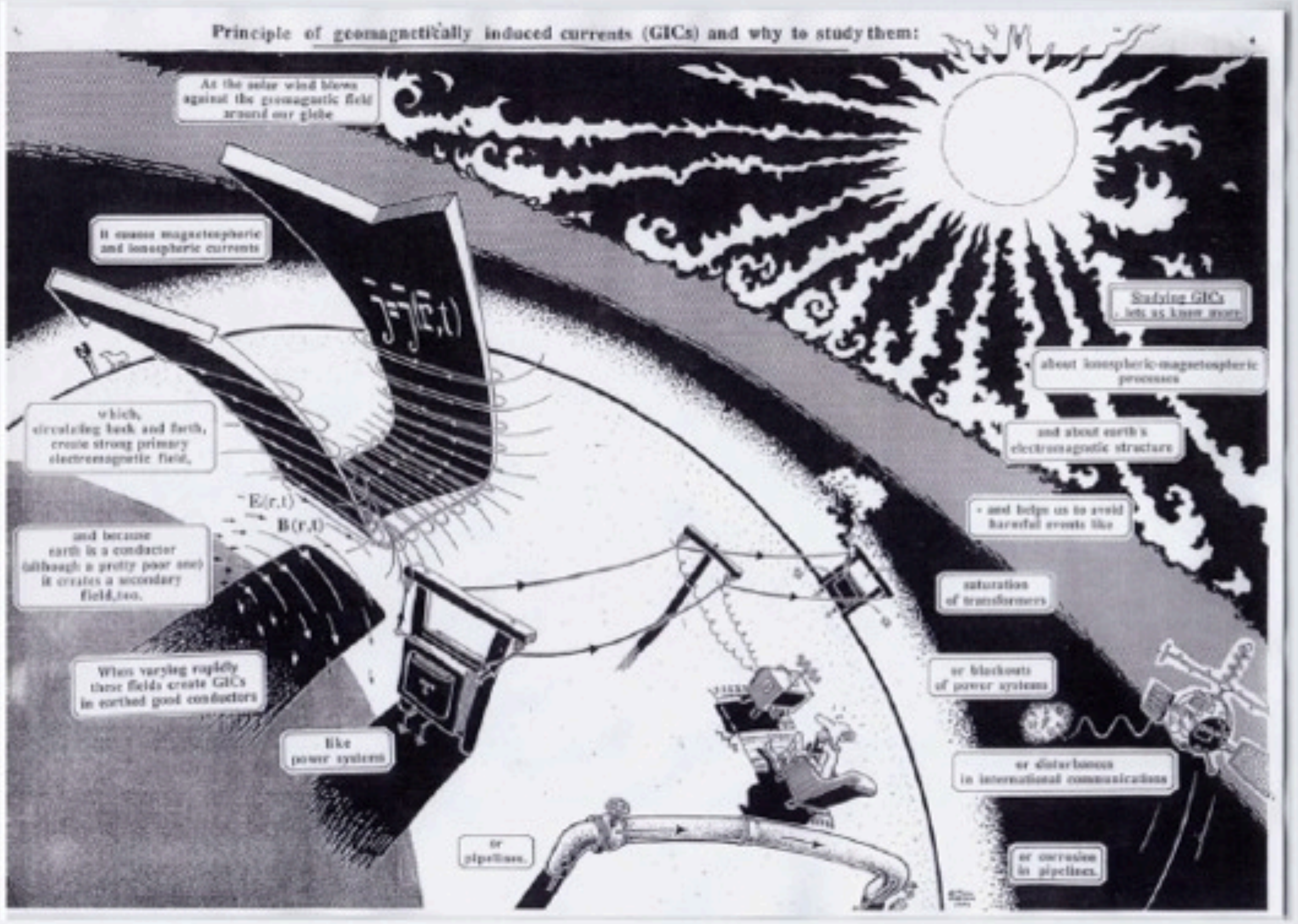
Extreme Solar Weather Has Happened Before

Morse Telegraph Table
Photo from www.telegraphlore.com

- 1847 – "Anomalous current" noted on telegraph line between Derby and Birmingham. First recorded impact of solar weather on technology.
- August 28-29, 1859 – Telegraph service disrupted worldwide by geomagnetic superstorm.
- September 1-2, 1859 – Carrington-Hodgson event is largest geomagnetic storm in 500 years.
- May 16, 1921 – The "Great Storm" disrupted telegraph service, caused fires, burned out cables. **Storms like this may occur roughly every 100 years.**
- March 13, 1989 – Geomagnetic storm collapsed Quebec power grid. Northeast U.S. and Midwest power grid came within seconds of collapse.
- October 19 – November 7, 2003 – "Halloween Storms" interrupted GPS, blacked out High Frequency (HF) radio, forced emergency procedures at nuclear power plants in Canada and the Northeastern United States, and destroyed several large electrical power transformers in South Africa.

FP7: EURISGIC (2011–2014) EUROPEAN RISK FOR GIC

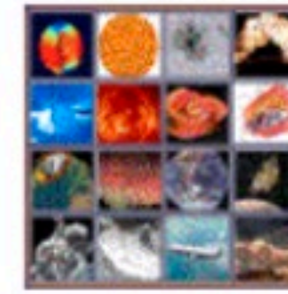




Coordinator: Finnish Meteorological Institute (FMI)

Participants: British Geological Survey (BGS), NeuroSpace, Swedish Institute of Space Physics (IRF), Geodetic and Geophysical Research Institute (GGRI), Polar Geophysical Institute (PGI), Catholic University of America (CUA)

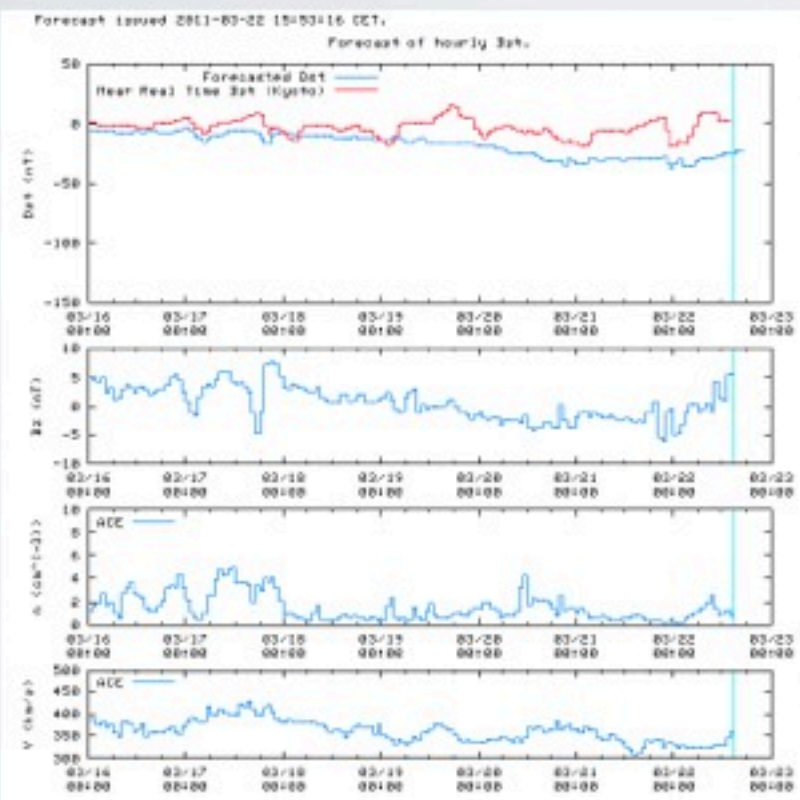
Regional Warning Center Sweden
of
International Space Environment Service



Glossary and Dictionary

- Solar and space weather glossary
- Visual space weather dictionary
- NOAA space weather scales

ISES, Director: David Boteler (Canada); Deputy director: Henrik Lundstedt (IRF)



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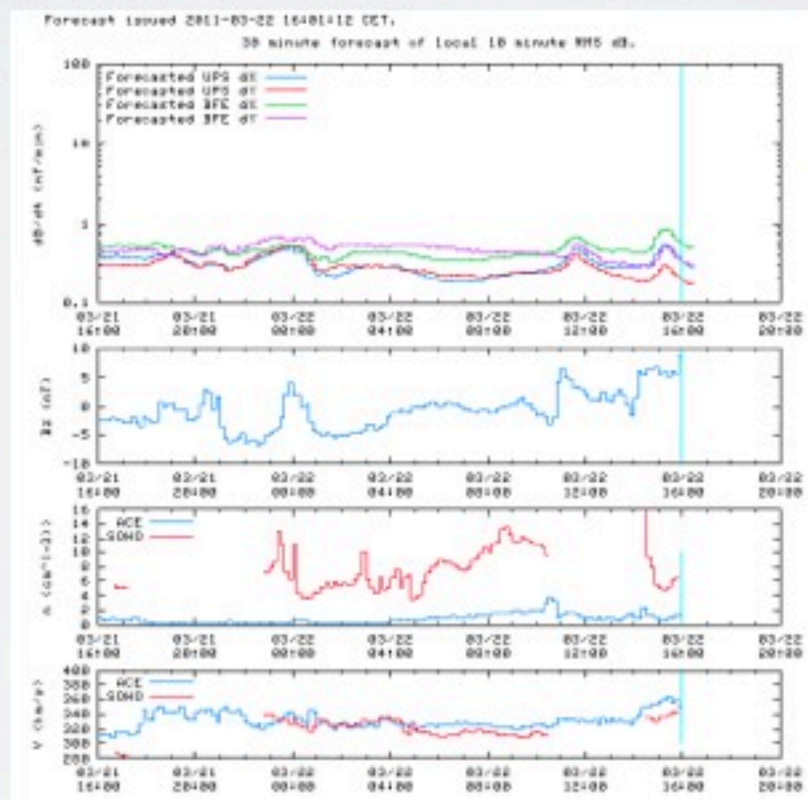

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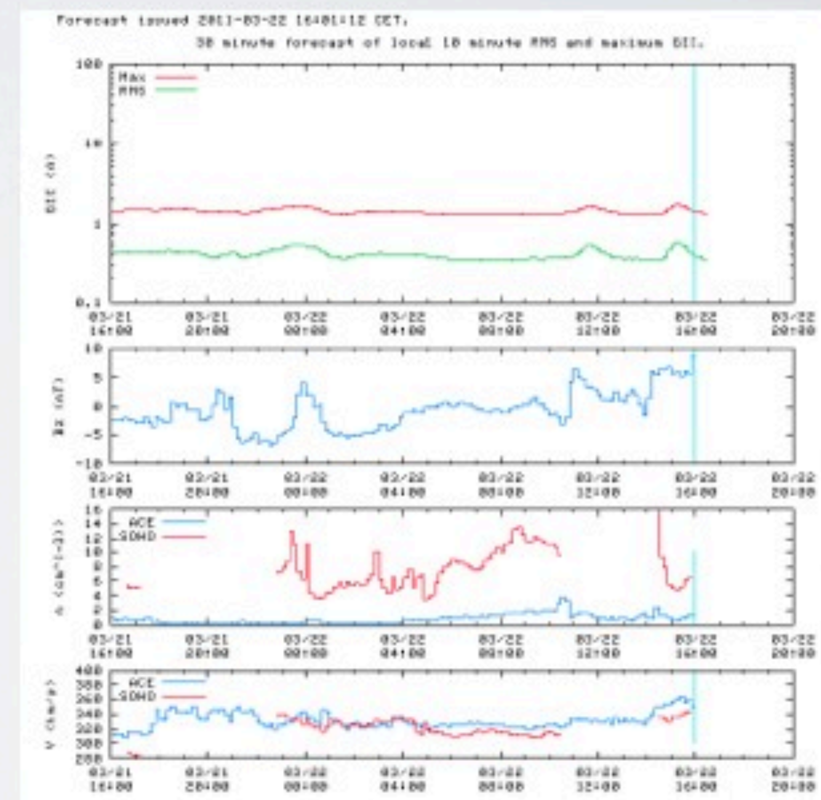


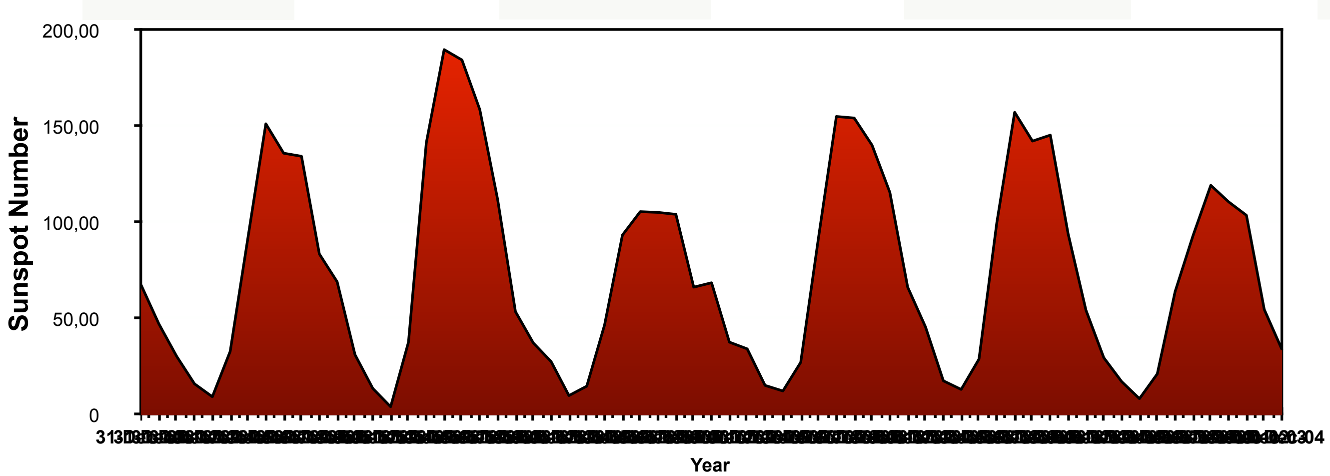
GIC

Swedish Institute of Space Physics

Growth of Space Weather Users and Customers

NOAA Space Weather Prediction Center

Commercial Space Transportation
Airline Polar Flights
Microchip technology
Precision Guided Munitions
Cell phones
Atomic Clock
Satellite Operations
Carbon Dating experiments
GPS Navigation
Ozone Measurements
Aircraft Radiation Hazard
Commercial TV Relays
Communications Satellite Orientation
Spacecraft Charging
Satellite Reconnaissance & Remote Sensing Instrument Damage
Geophysical Exploration.
Pipeline Operations
Anti-Submarine Detection
Satellite Power Arrays
Power Distribution
Long-Range Telephone Systems
Radiation Hazards to Astronauts
Interplanetary Satellite experiments
VLF Navigation Systems (OMEGA, LORAN)
Over the Horizon Radar
Solar-Terres. Research & Applic. Satellites
Research & Operations Requirements
Satellite Orbit Prediction
Solar Balloon & Rocket experiments
Ionospheric Rocket experiments
Short-wave Radio Propagation



Sunspot Cycles

<u>2008</u>

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Thanks to ESA and NASA for images/animations