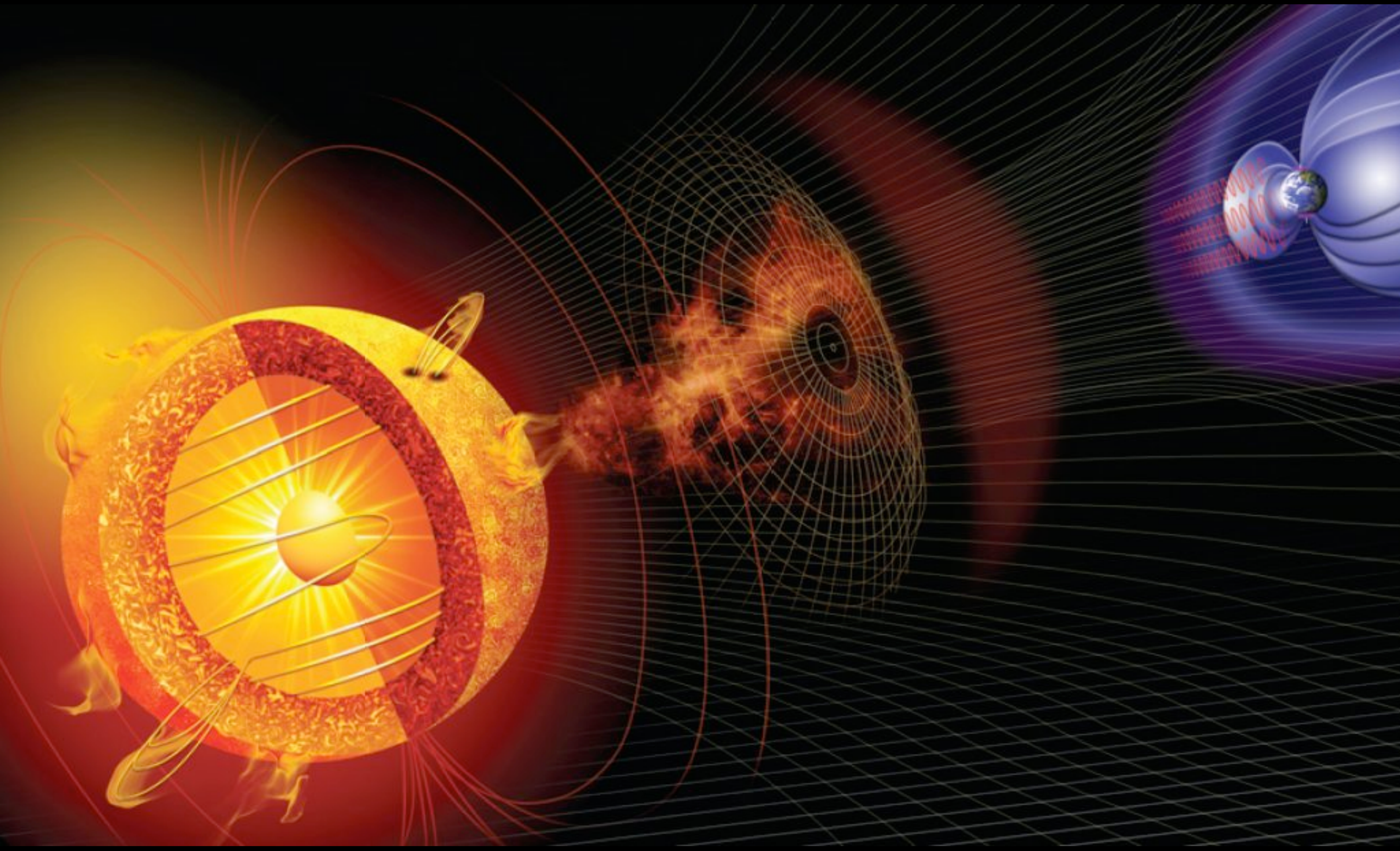
AFG216 - Space Weather

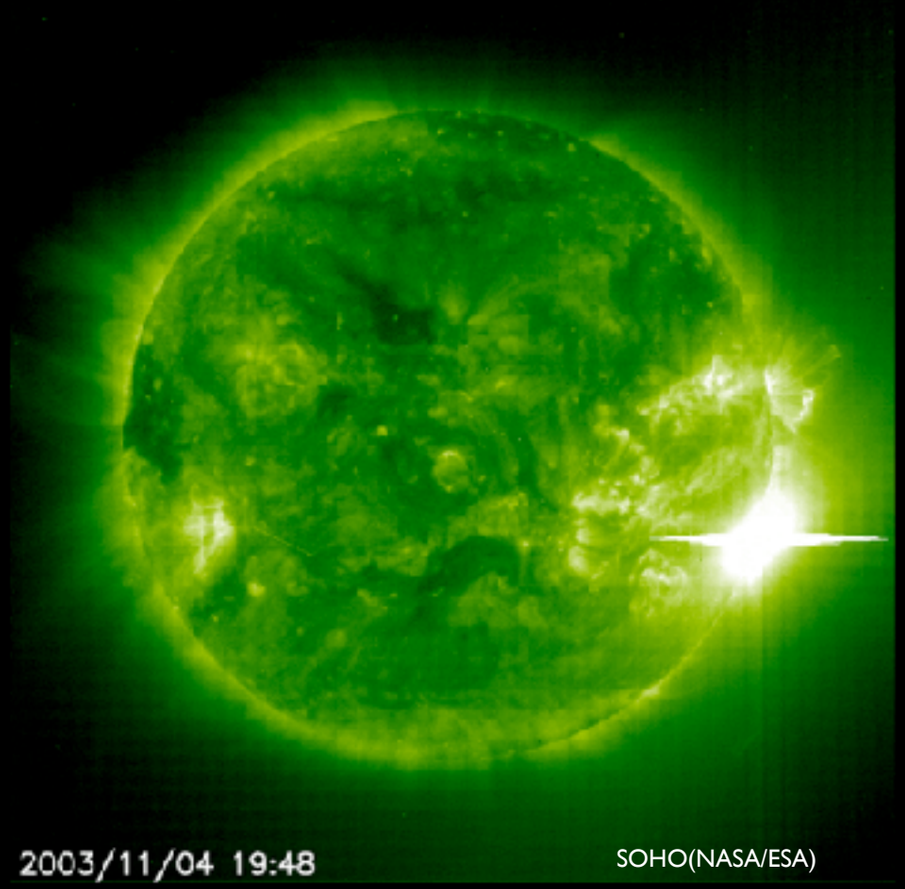
Pål Brekke
Norwegian Space Centre/UNIS

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

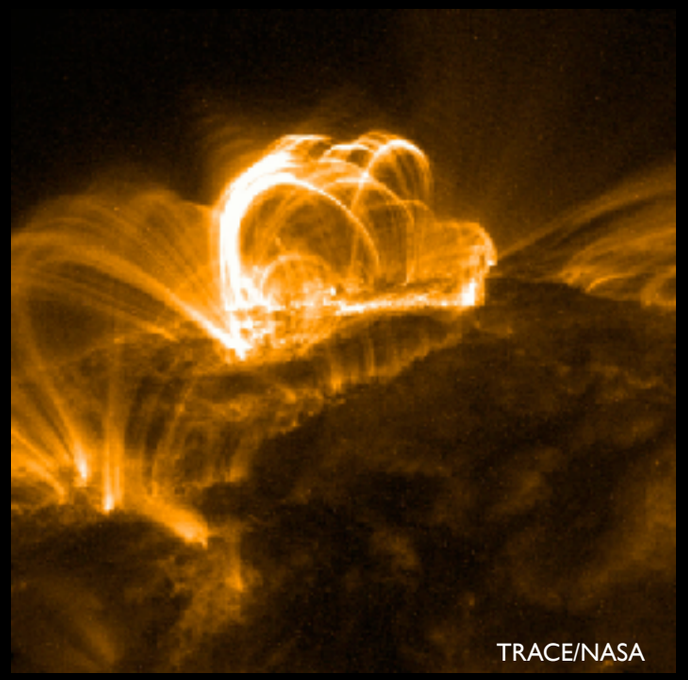
The Sun and the Earth

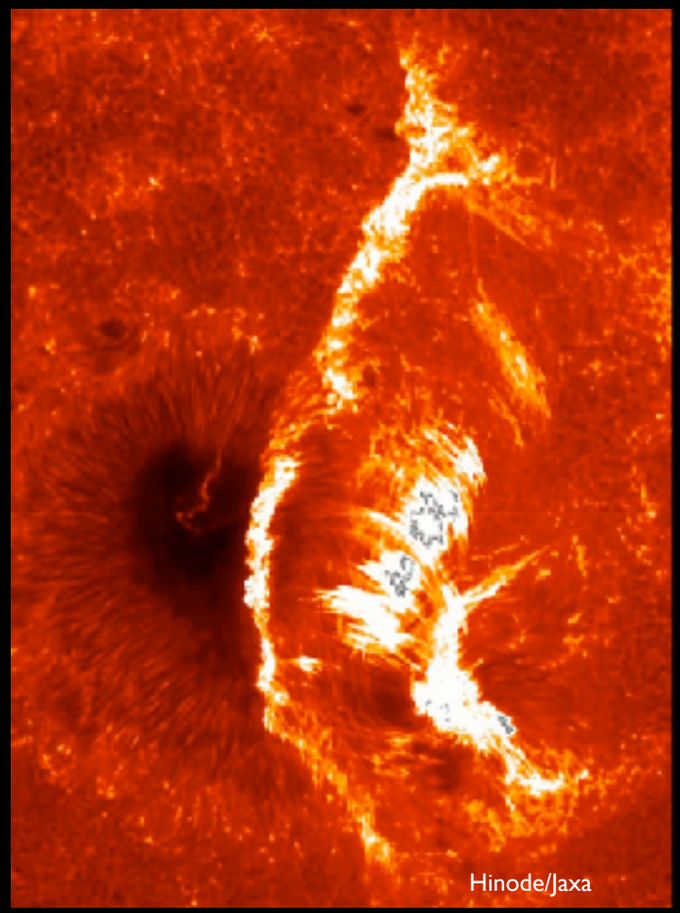


EXPLOSIONS ON THE SUN



SOHO(NASA/ESA)

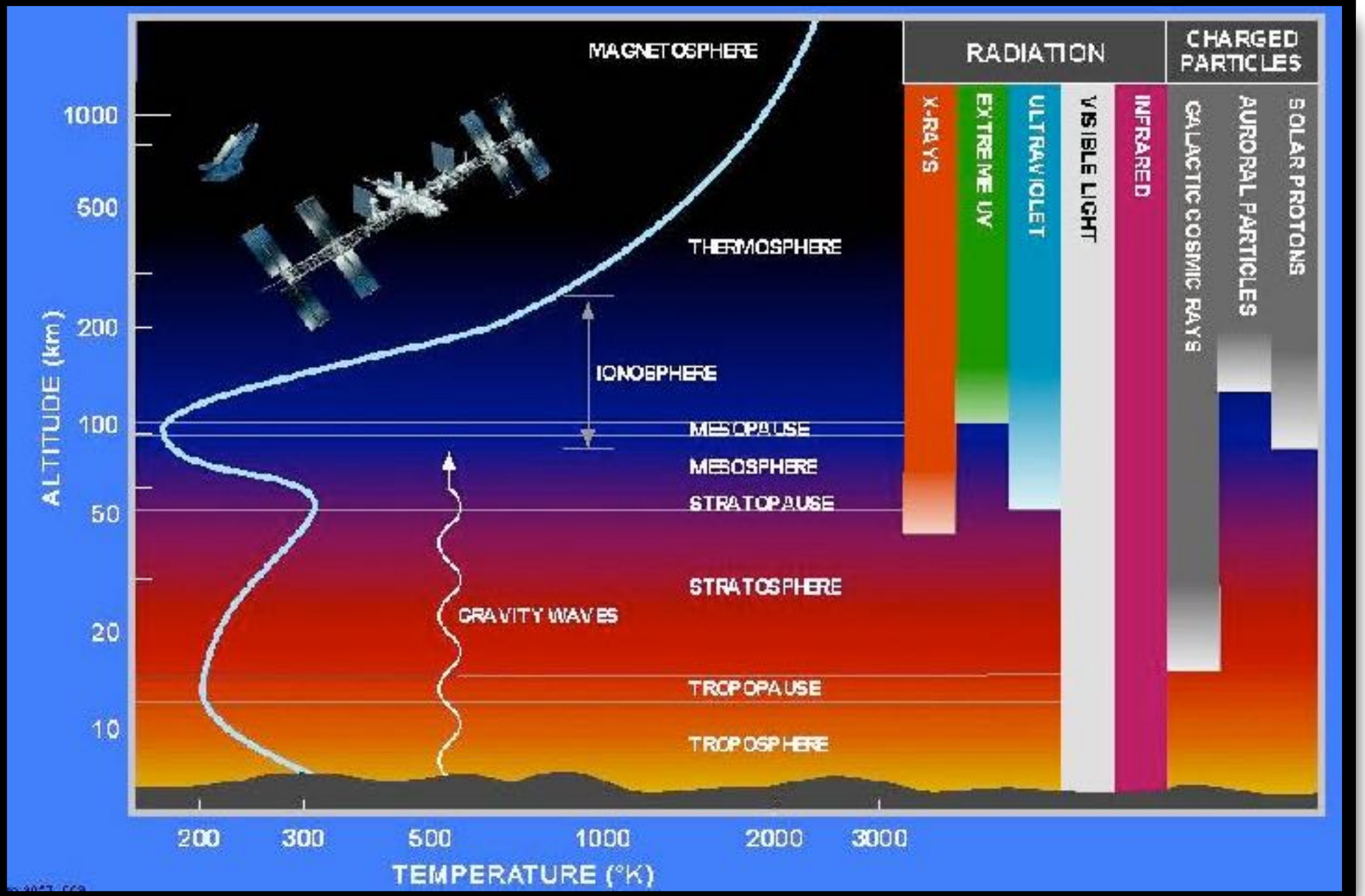

TRACE/NASA

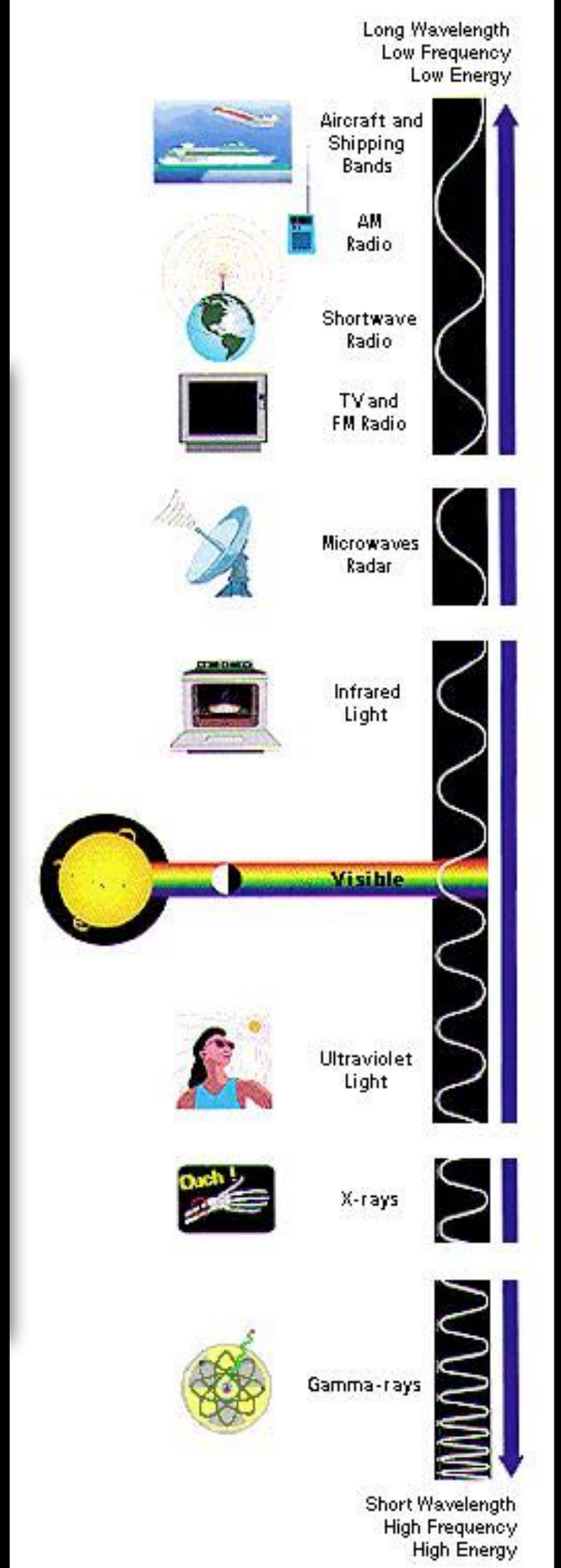

Hinode/Jaxa

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.

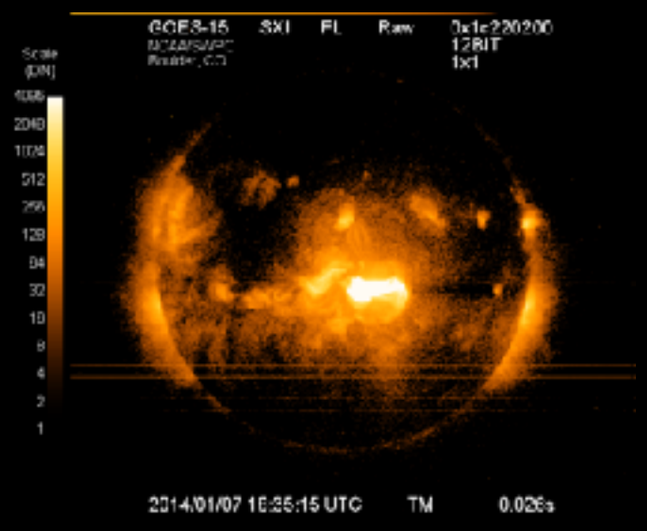
Electromagnetic radiation

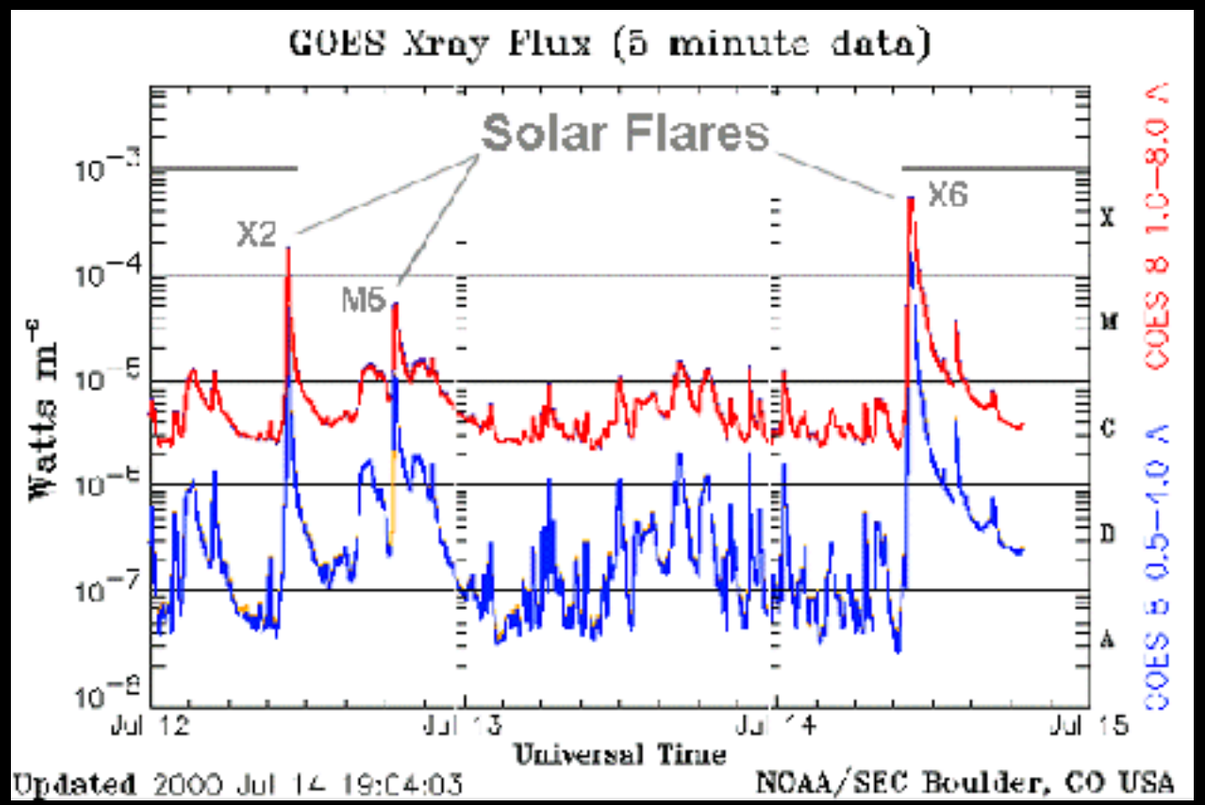


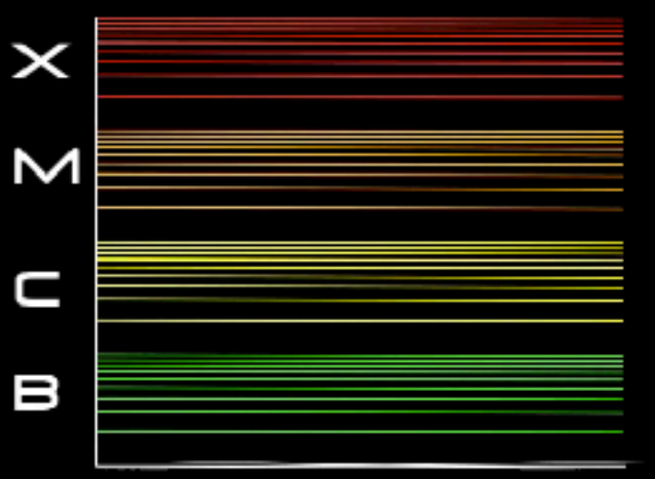


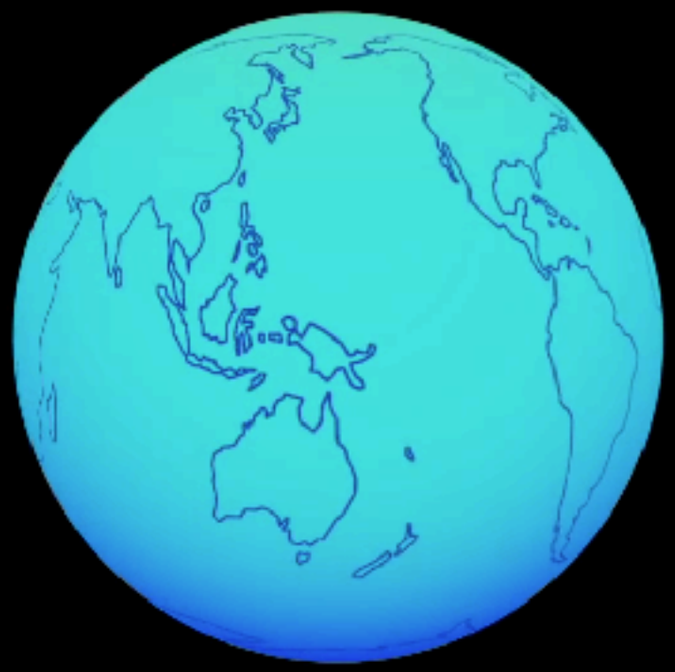
X-ray flux

Solar flares are classified as A, B, C, M or X according to the peak flux (in watts per square metre, W/m²) of 100 to 800 picometre X-rays near Earth, as measured on the GOES spacecraft.

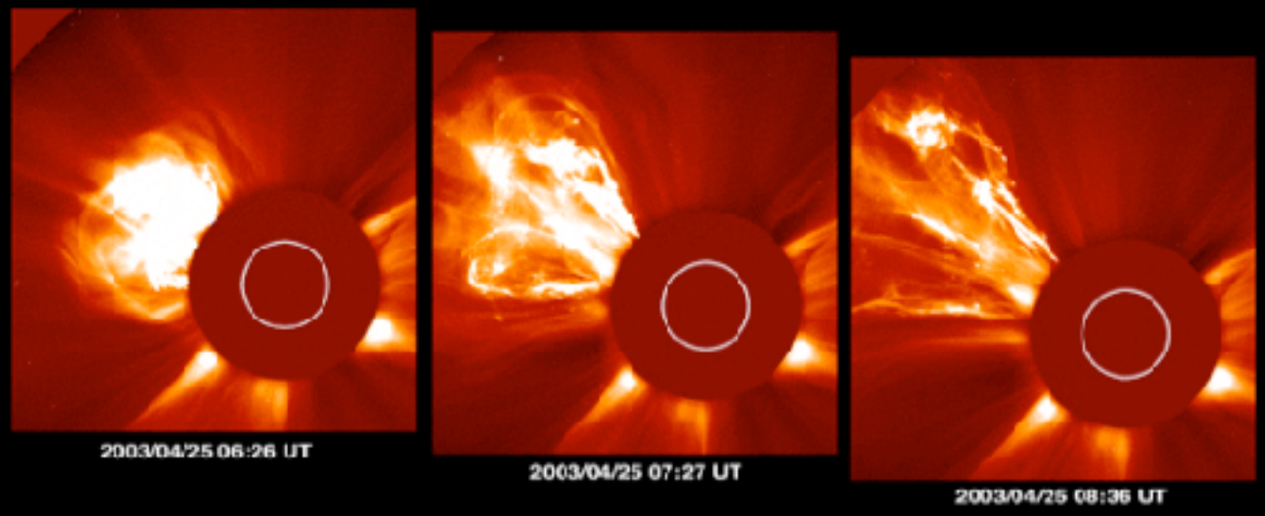




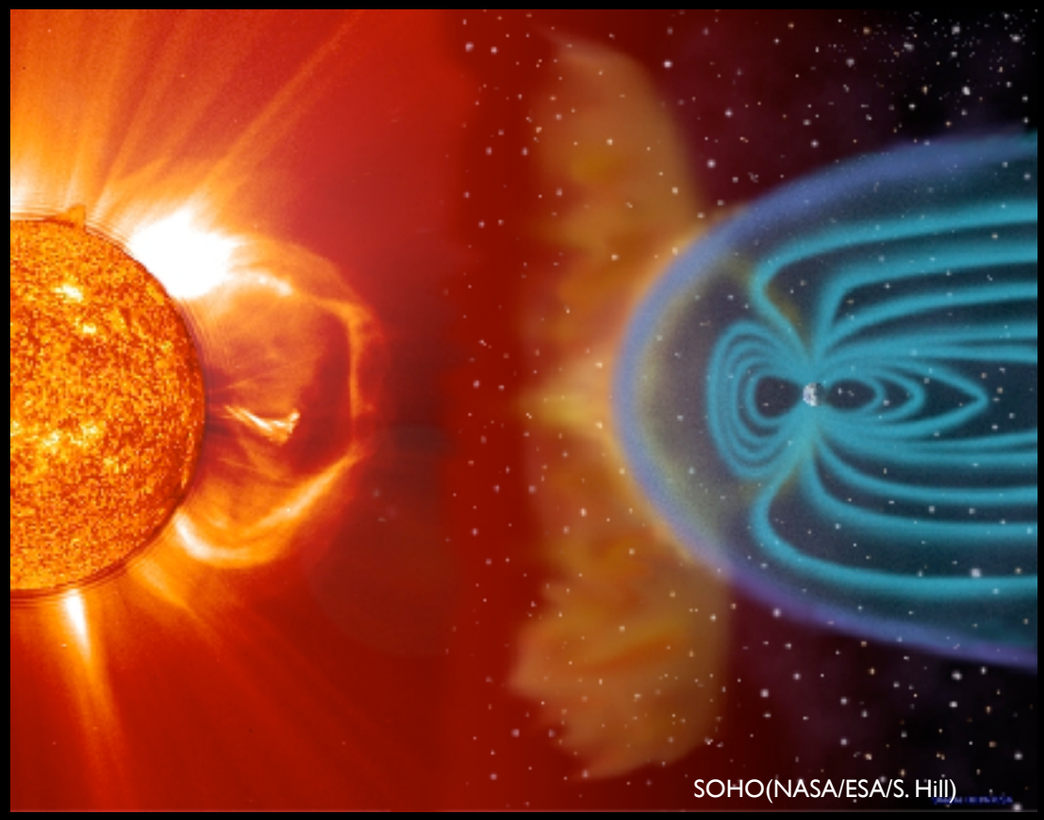




GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)



SOHO(NASA/ESA/S. Hill)

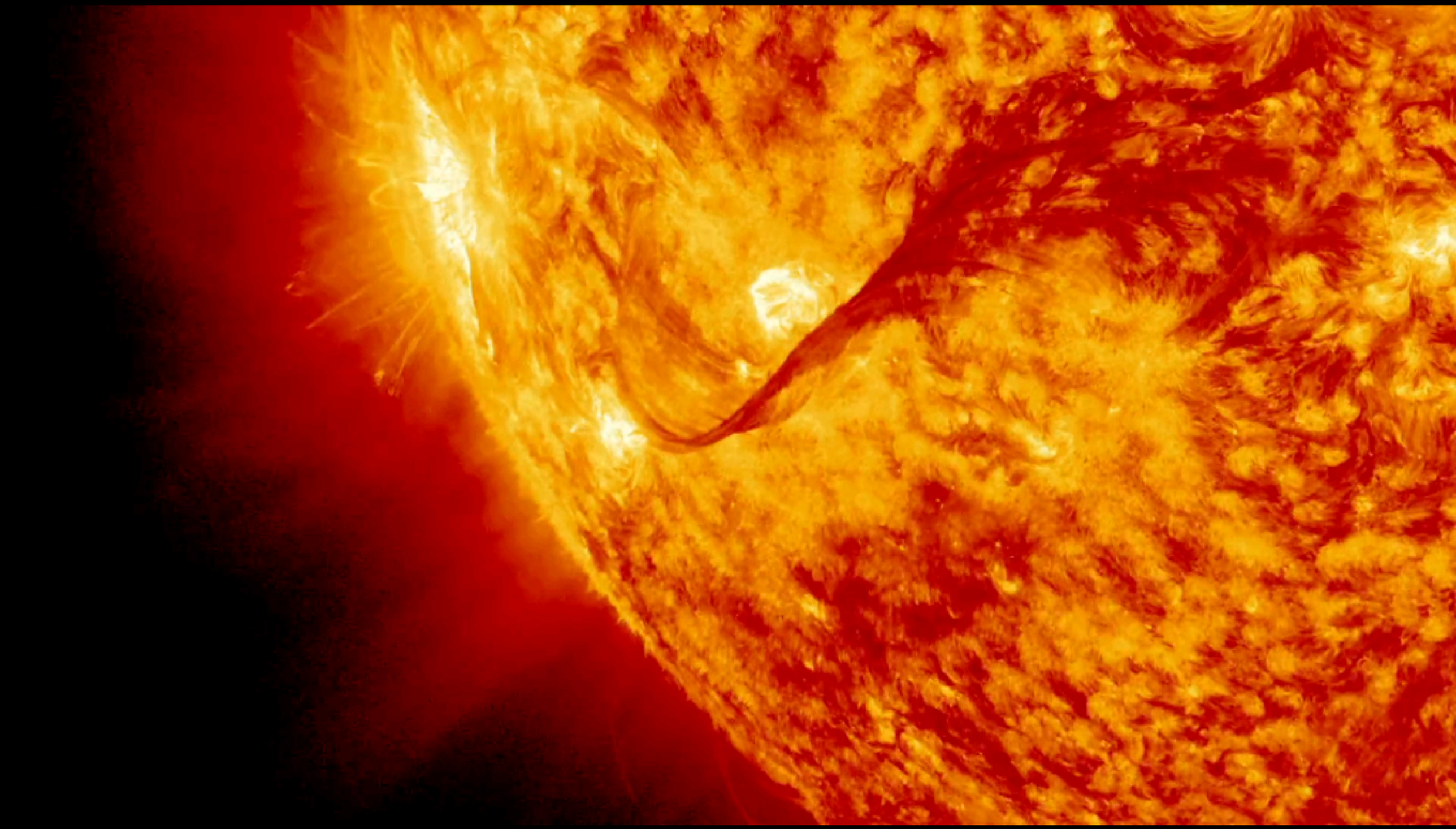


SOHO(NASA/ESA/S. Hill)

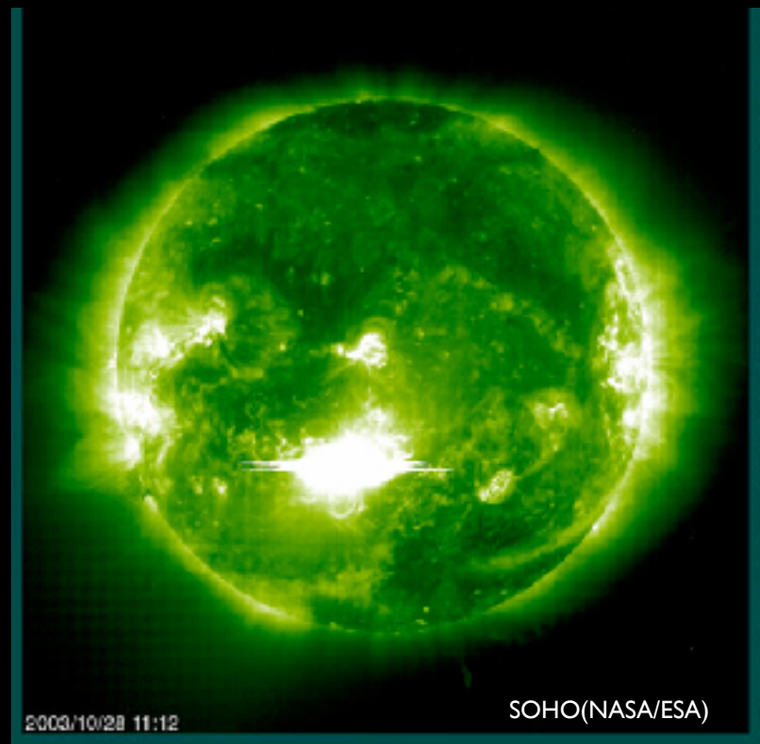
Sometimes large prominences can erupt and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called Coronal Mass Ejections or CMEs for short. The bubble of gas will 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.

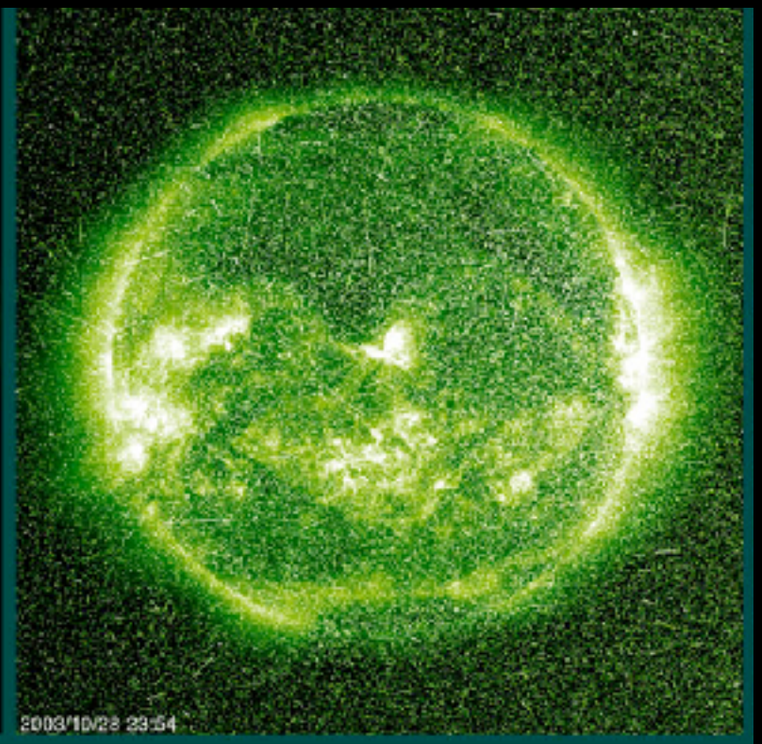
Eruption Prominences and CME's

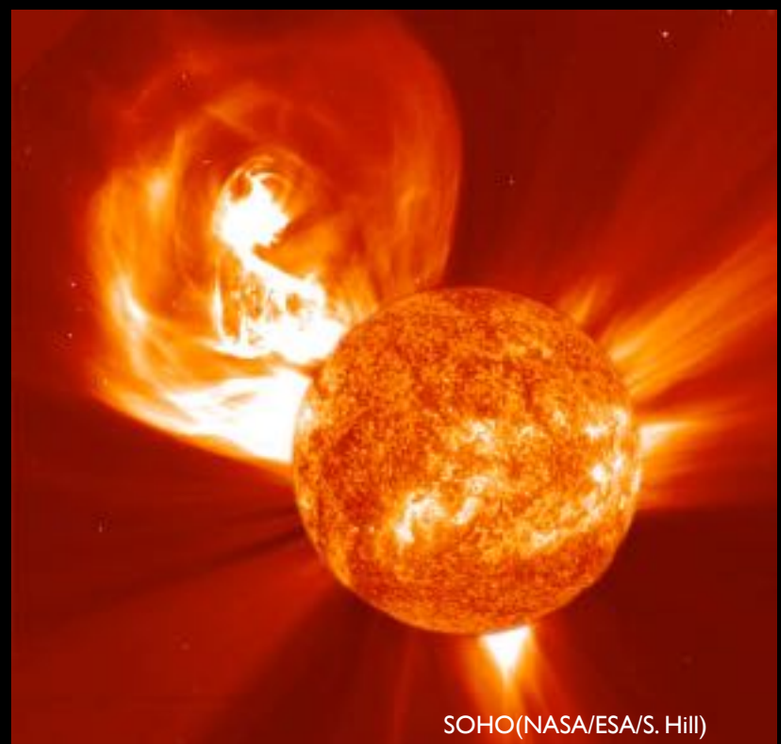


PARTICLE SHOWERS FROM THE SUN



SOHO(NASA/ESA)



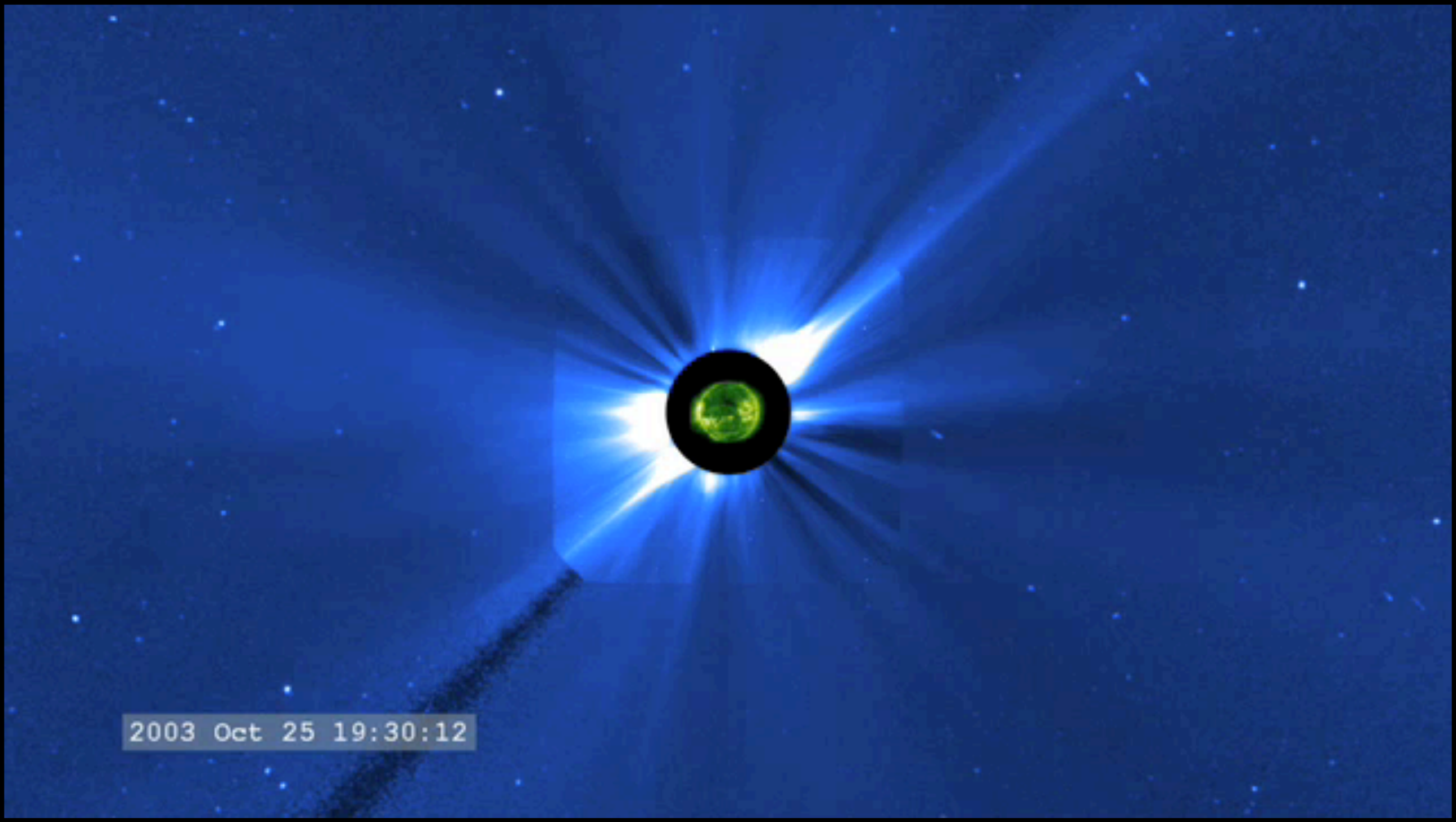


SOHO(NASA/ESA/S. Hill)

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.

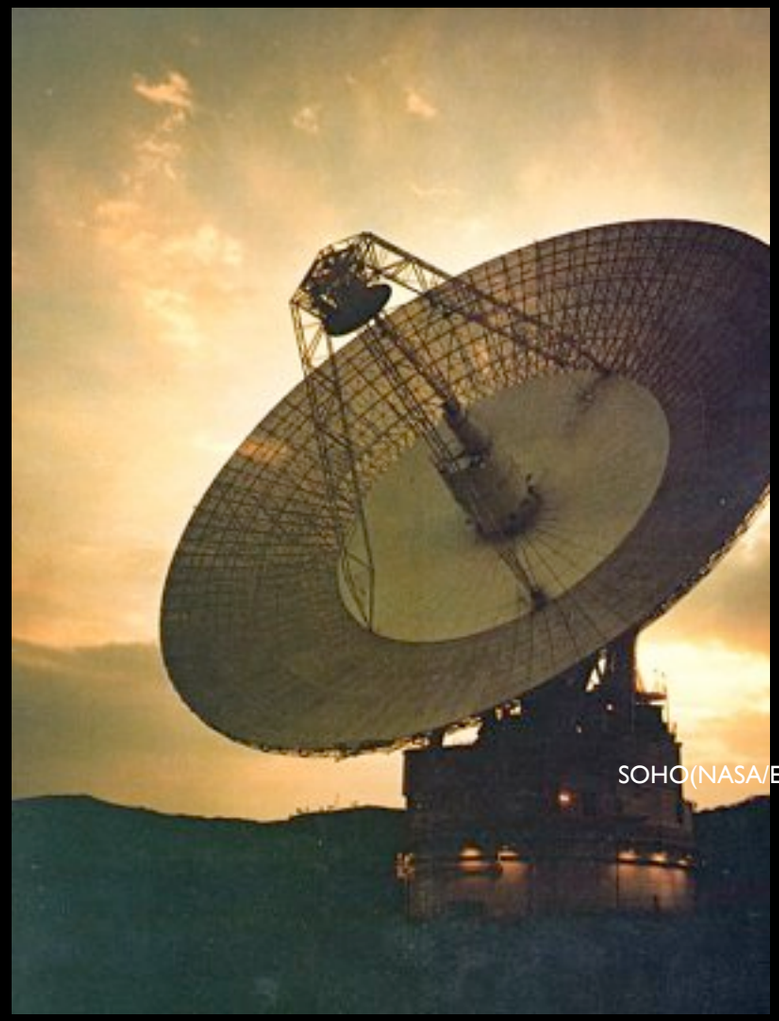
The protons have such high speed and energy that they can penetrate satellites and space ships. Thus, they can damage vital electronic equipment. They can also destroy the quality of images and scientific data from those satellites that are surveying the Sun as shown in the picture above. The particles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

Proton event

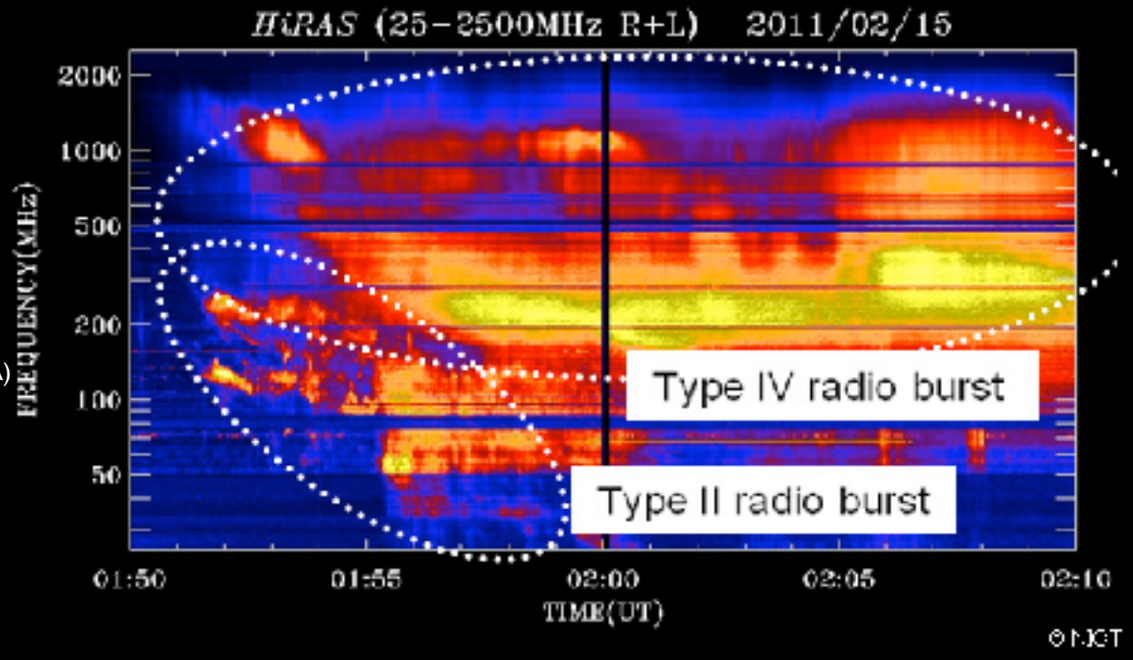


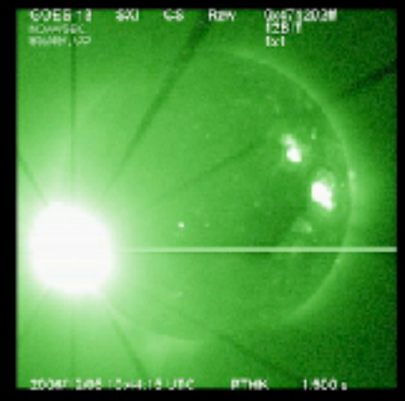
Proton event

RADIO-BURST



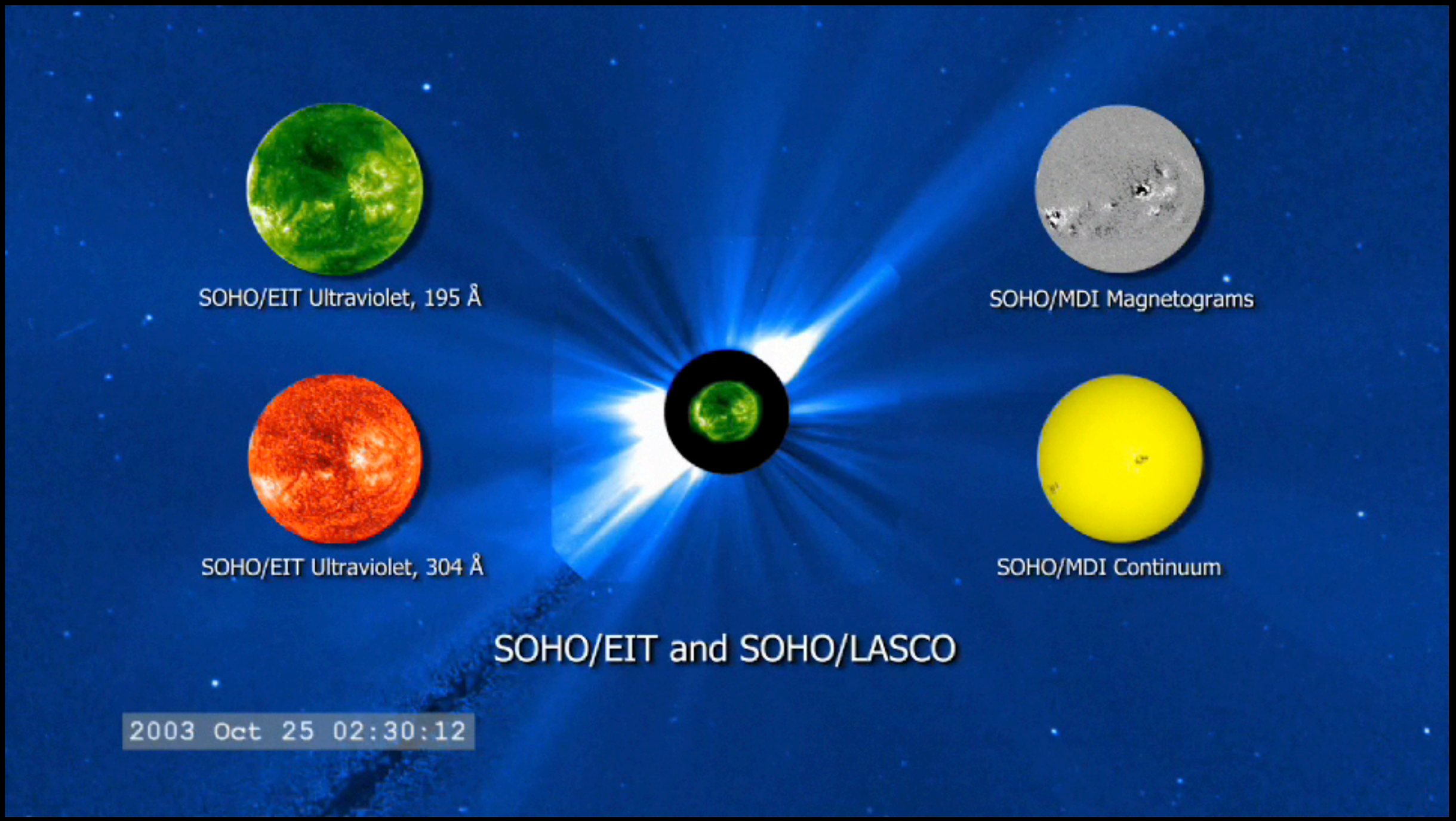
SOHO(NASA/ESA)





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



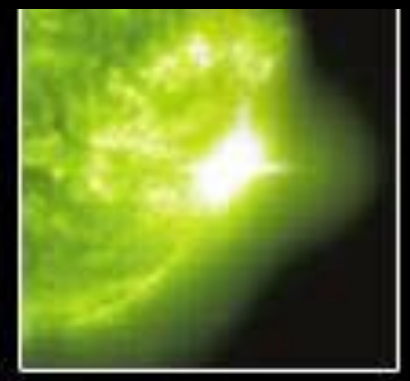
Flares - UV/X-Rays

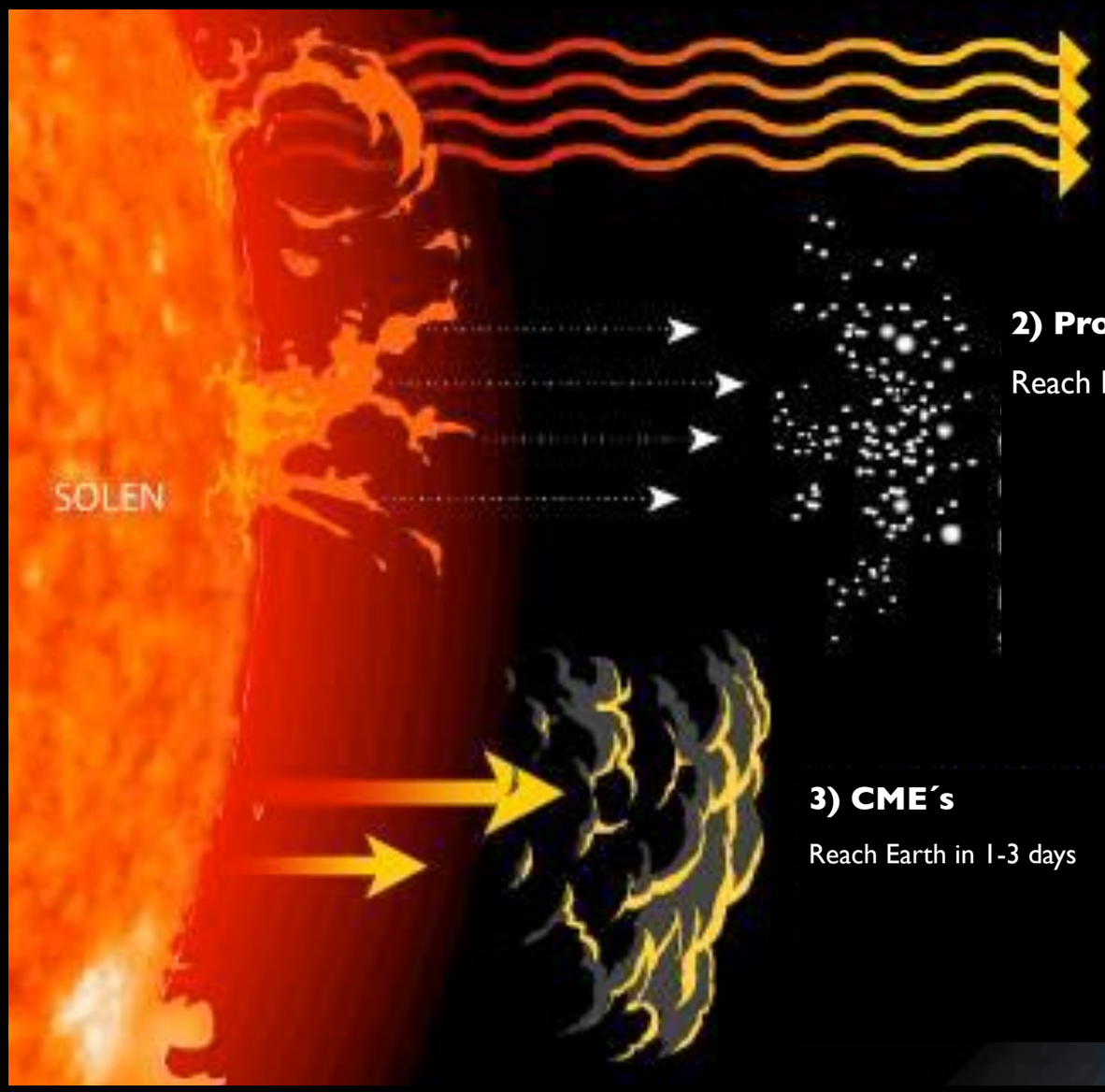
Four different types of events

1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

Flare observed from SOHO

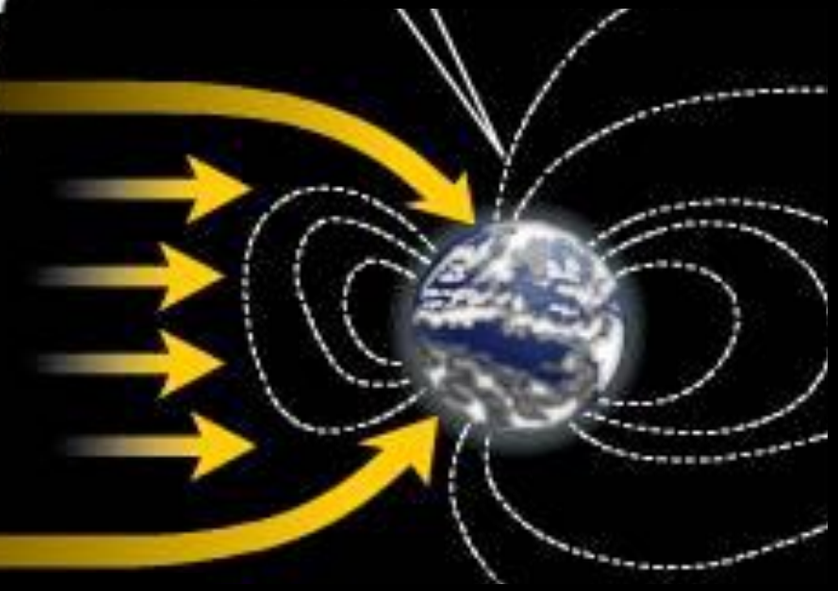




2) Proton shower

Reach Earth in 15-60 minutes

Earths magnetosphere

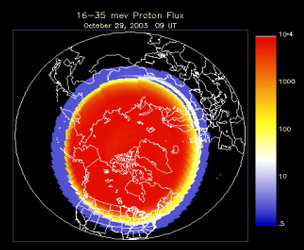


3) CME´s

Reach Earth in 1-3 days

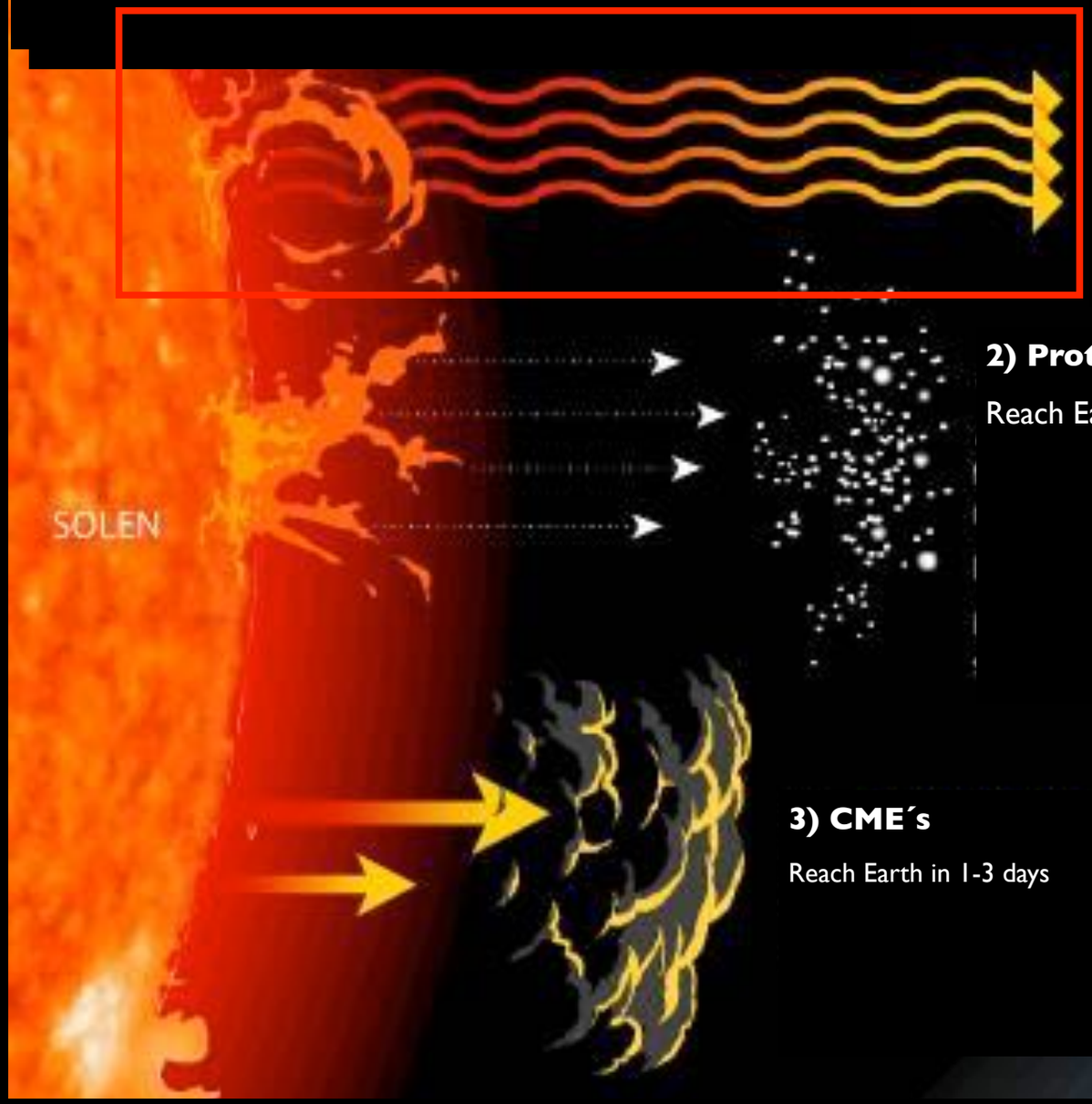
4) Radio burst

Reach Earth in 8 minutes



Flares - UV/X-Rays

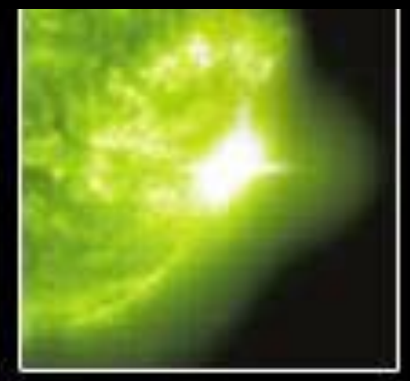
Four different types of events



1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

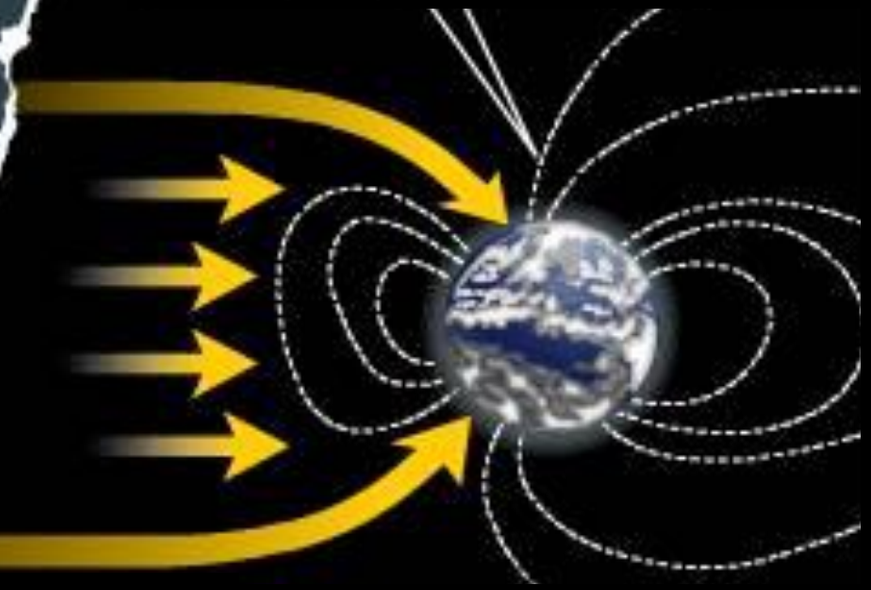
Flare observed from SOHO



2) Proton shower

Reach Earth in 15-60 minutes

Earths magnetosphere

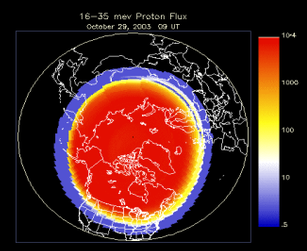


3) CME´s

Reach Earth in 1-3 days

4) Radio burst

Reach Earth in 8 minutes



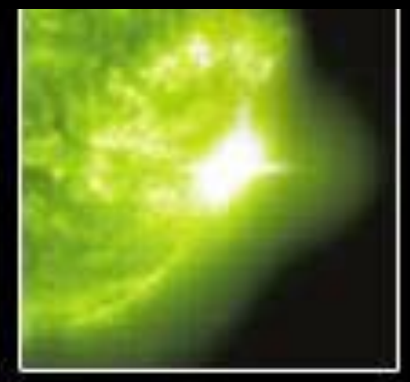
Proton shower

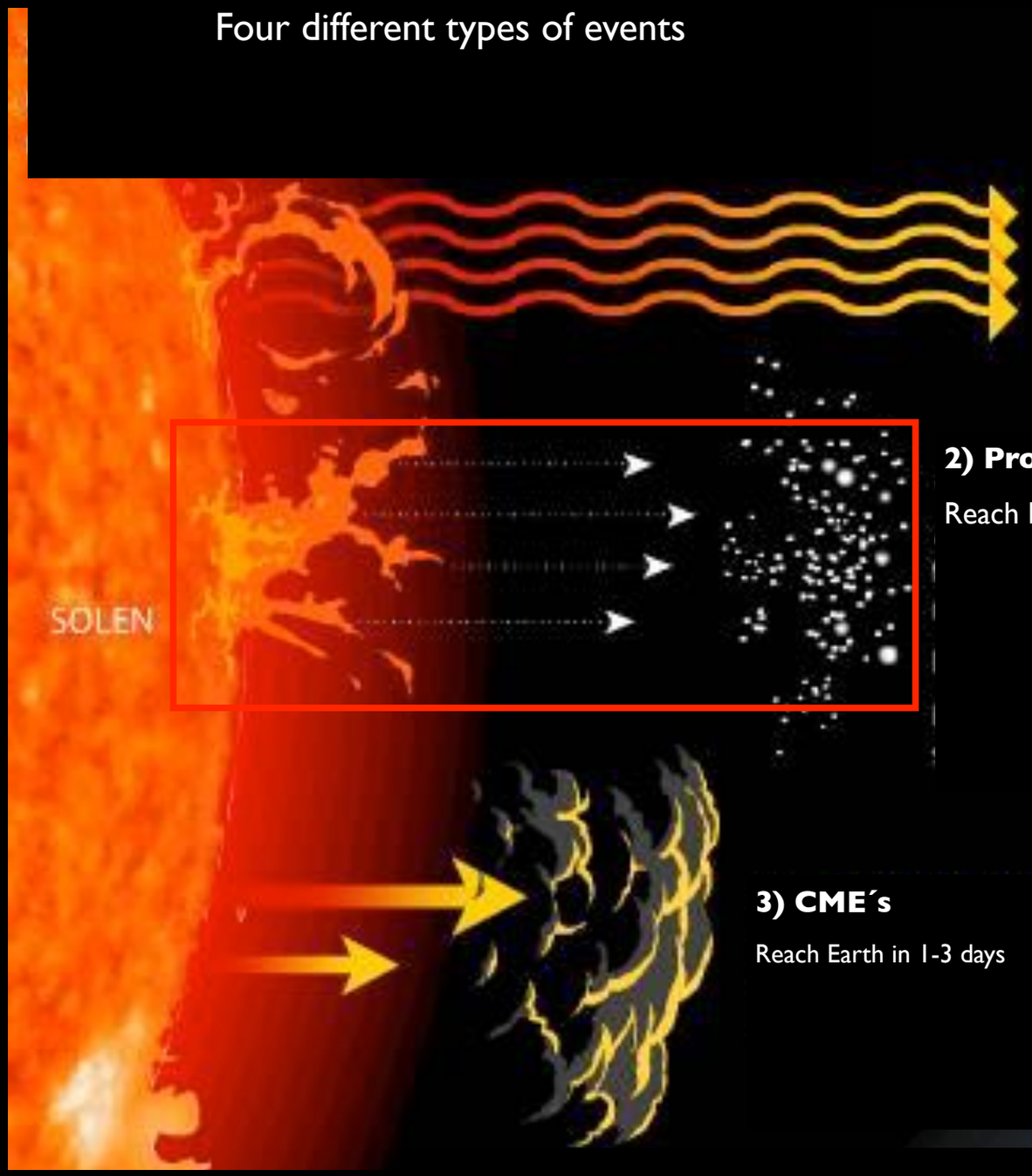
Four different types of events

1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

Flare observed from SOHO

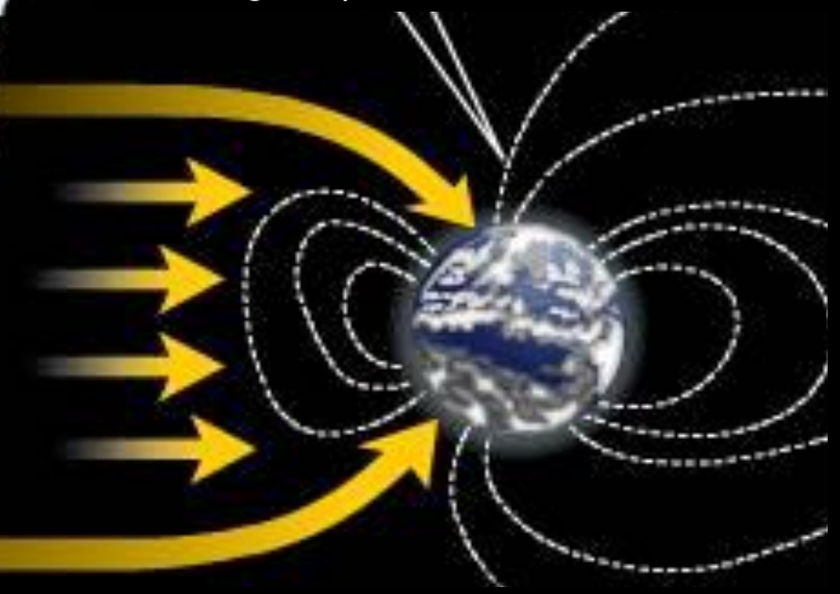




2) Proton shower

Reach Earth in 15-60 minutes

Earths magnetosphere

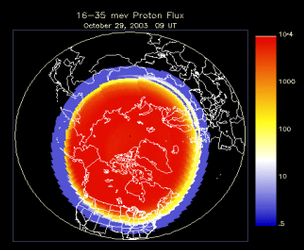


3) CME´s

Reach Earth in 1-3 days

4) Radio burst

Reach Earth in 8 minutes



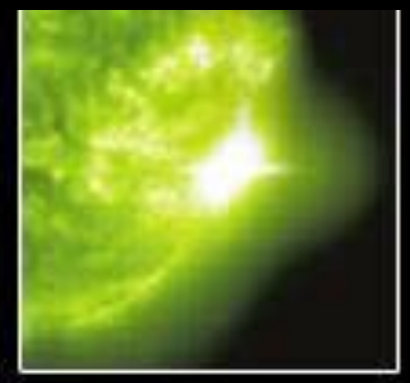
CMEs

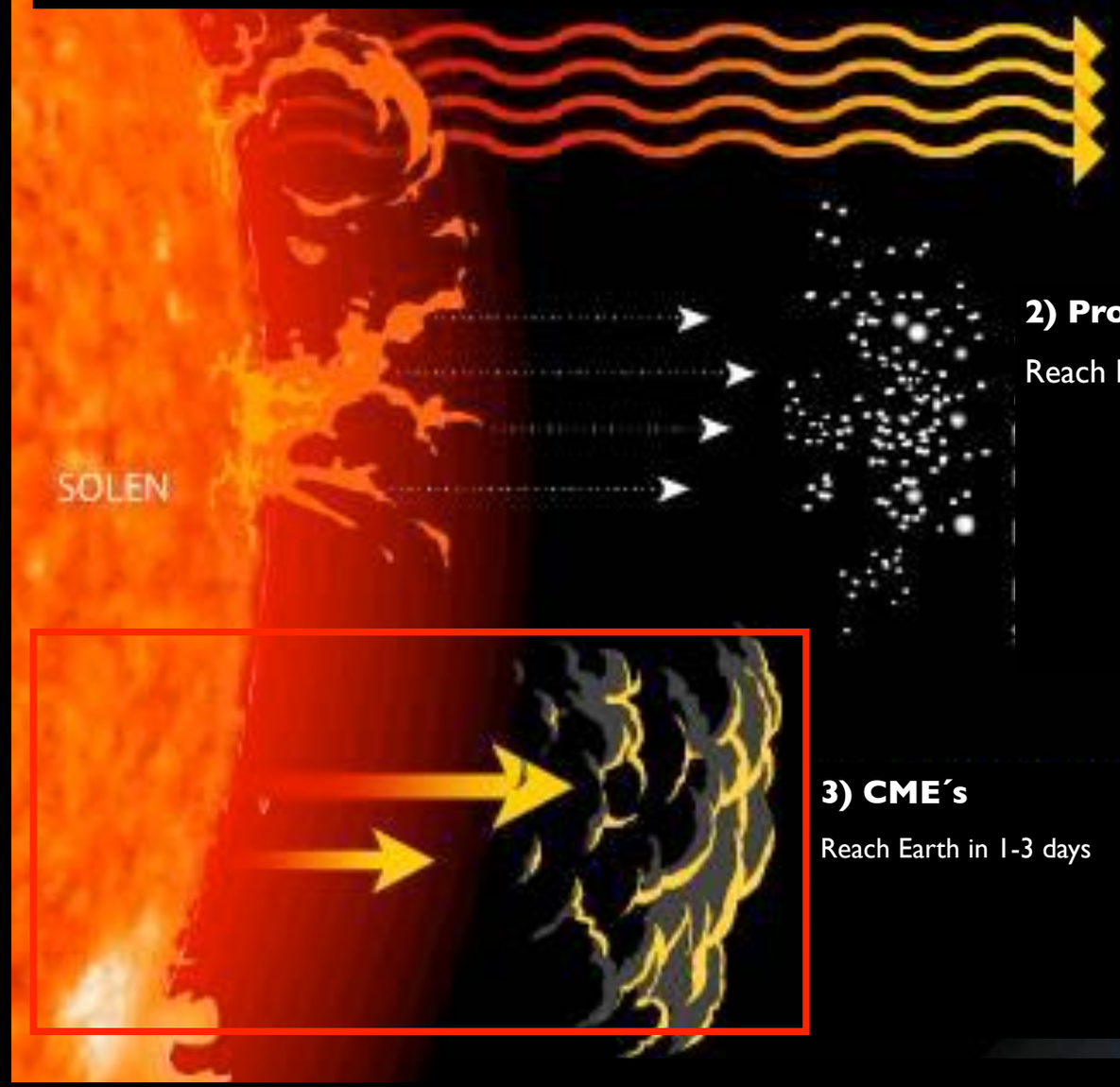
Four different types of events

1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

Flare observed from SOHO





2) Proton shower

Reach Earth in 15-60 minutes

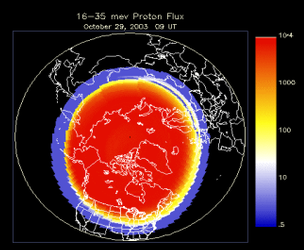
Earths magnetosphere

3) CME´s

Reach Earth in 1-3 days

4) Radio burst

Reach Earth in 8 minutes



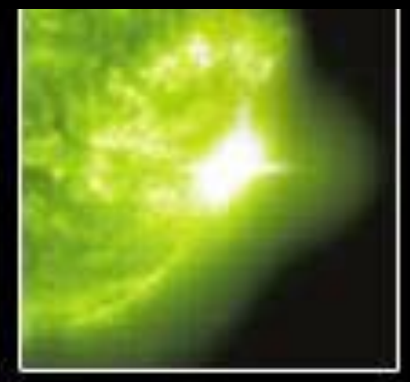
Radio Burst

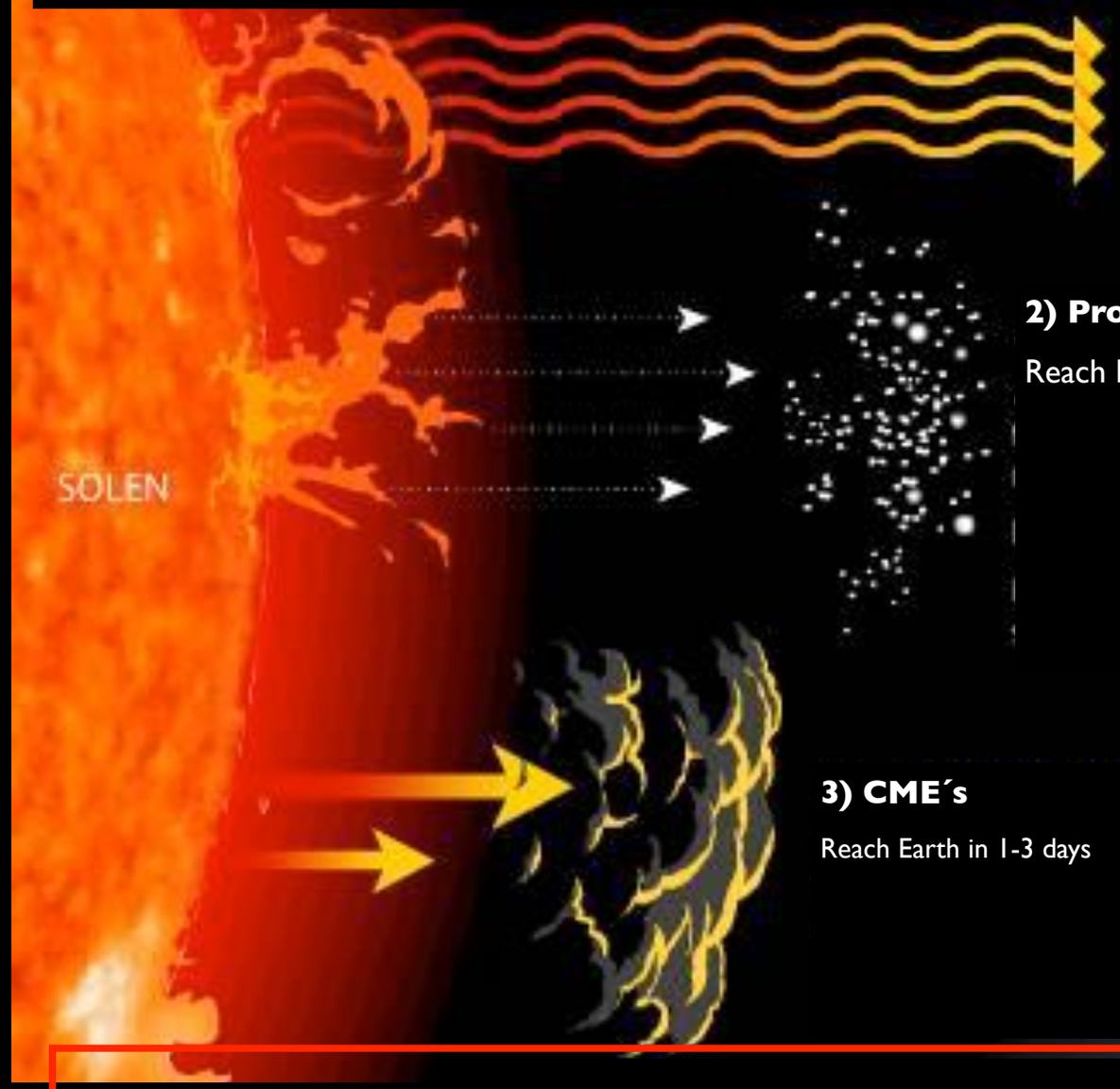
Four different types of events

1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

Flare observed from SOHO

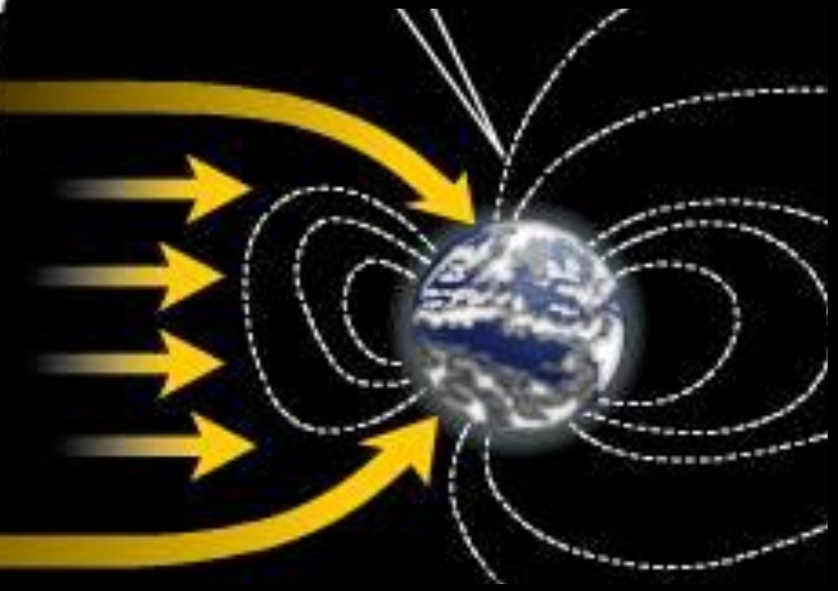




2) Proton shower

Reach Earth in 15-60 minutes

Earths magnetosphere

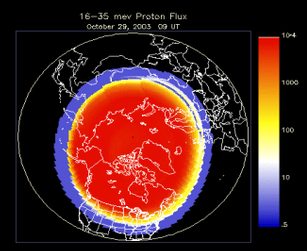


3) CME´s

Reach Earth in 1-3 days

4) Radio burst

Reach Earth in 8 minutes



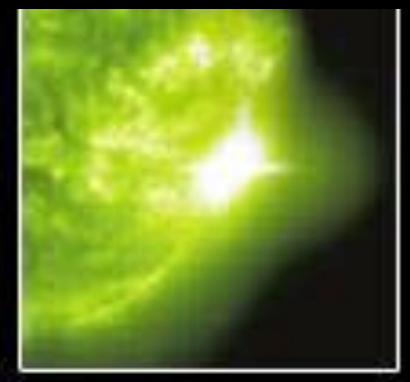
Radio Burst

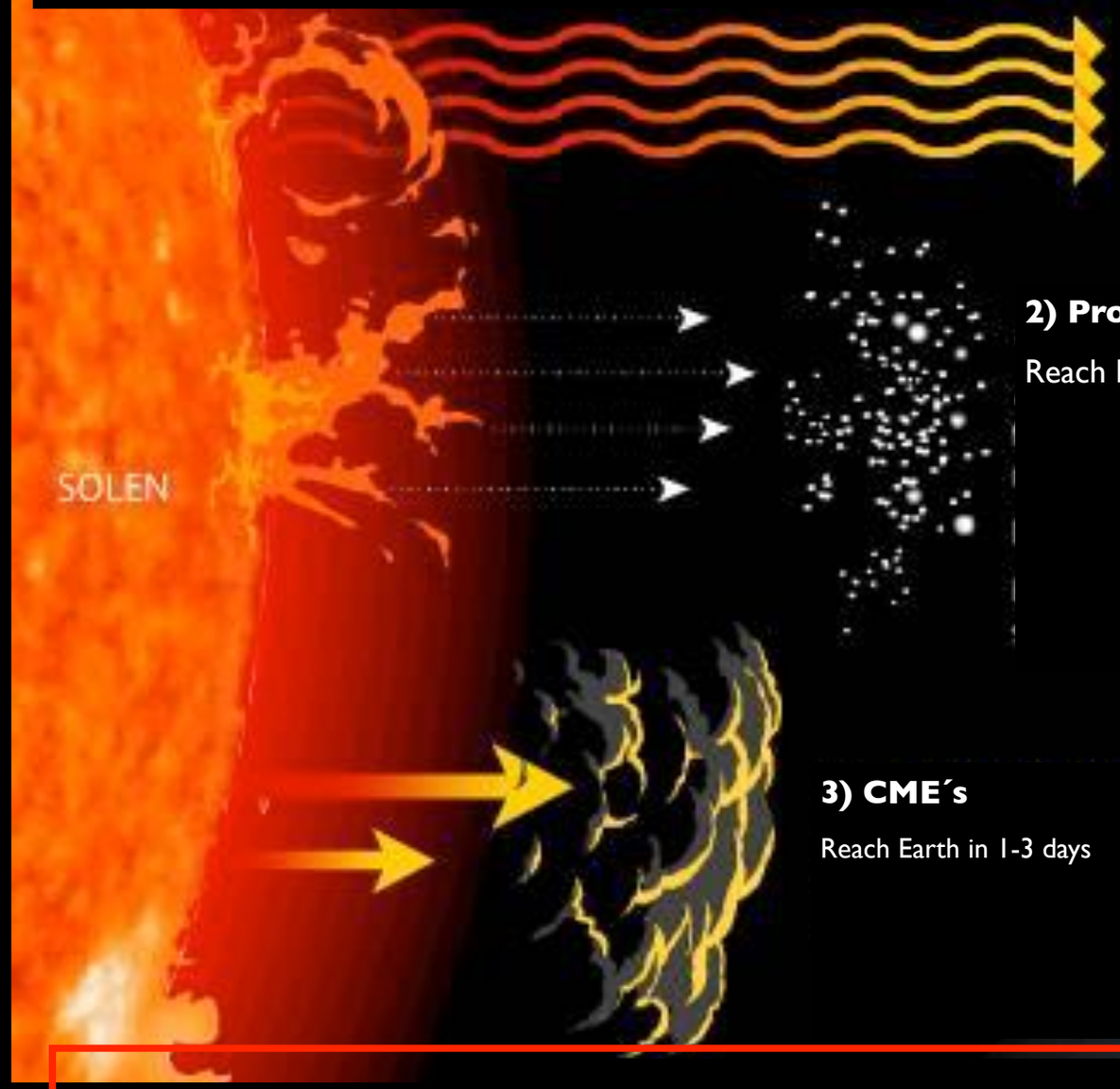
Four different types of events

1) FLARE: X-rays/EUV

Reach Earth in 8 minutes

Flare observed from SOHO

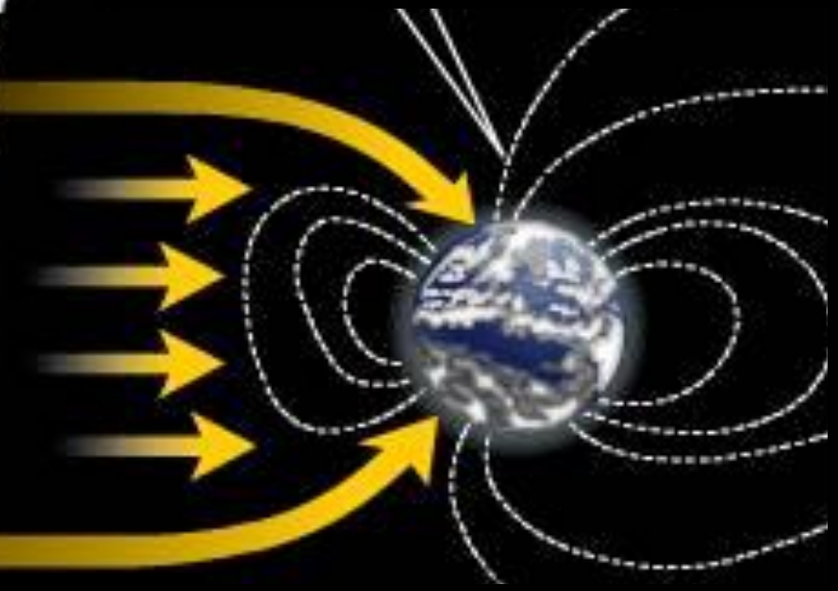




2) Proton shower

Reach Earth in 15-60 minutes

Earths magnetosphere

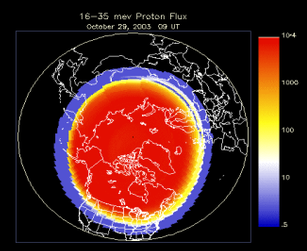


3) CME´s

Reach Earth in 1-3 days

4) Radio burst

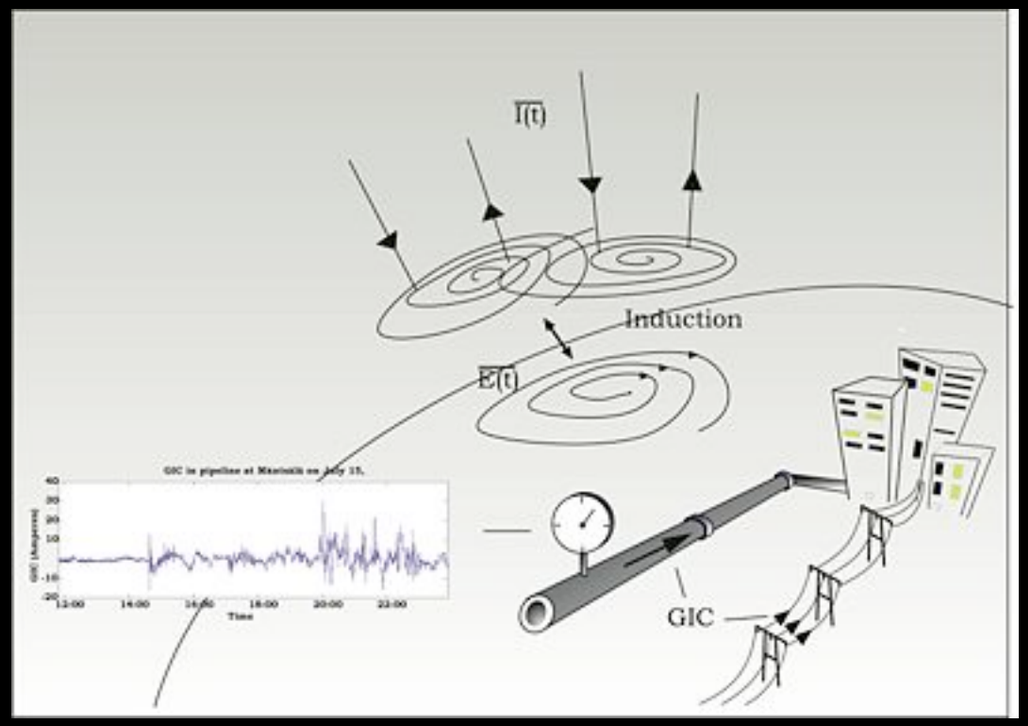
Reach Earth in 8 minutes



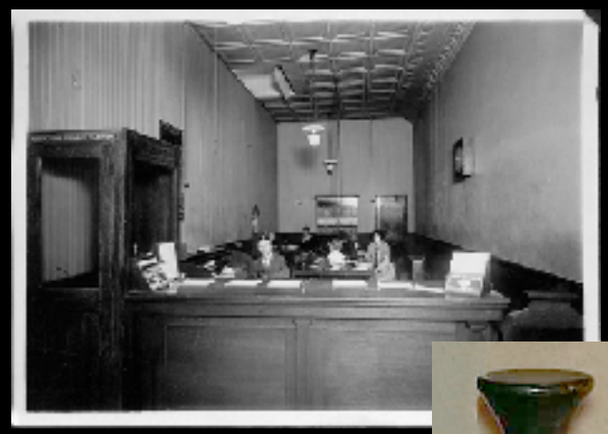
Early effects from Space Weather

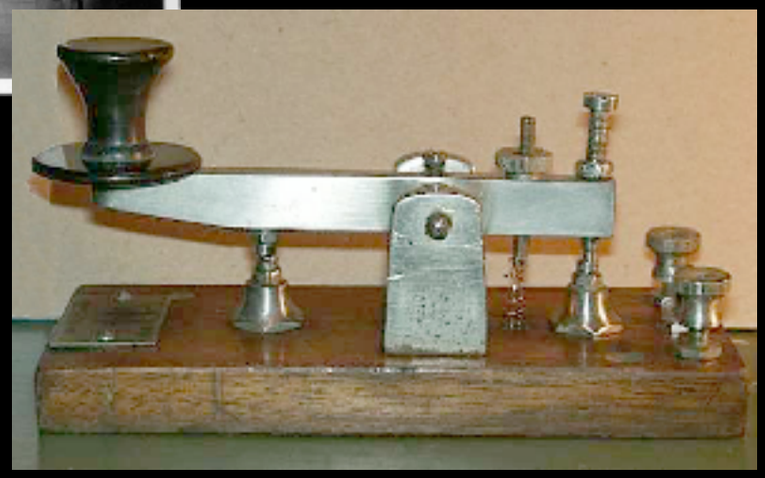
The first reported effects came from the telegraph operators.

- 17 november 1848: "Telegraph line between Piza og Firenze knocked out"
- September 1851: Telegraf system in New England disrupted.
- Sparks and fires reported due to strong induced currents.
- In Bosten (1859) they managed to rune the telegraph system without batteries or power.



Antti Pulkkinen



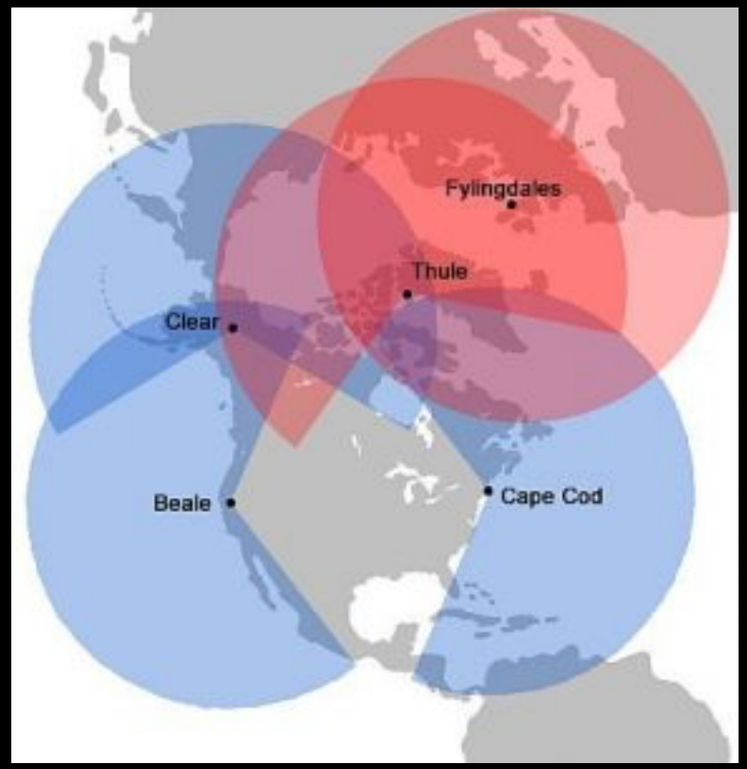


The 1967 solar storm - almost started a nuclear war

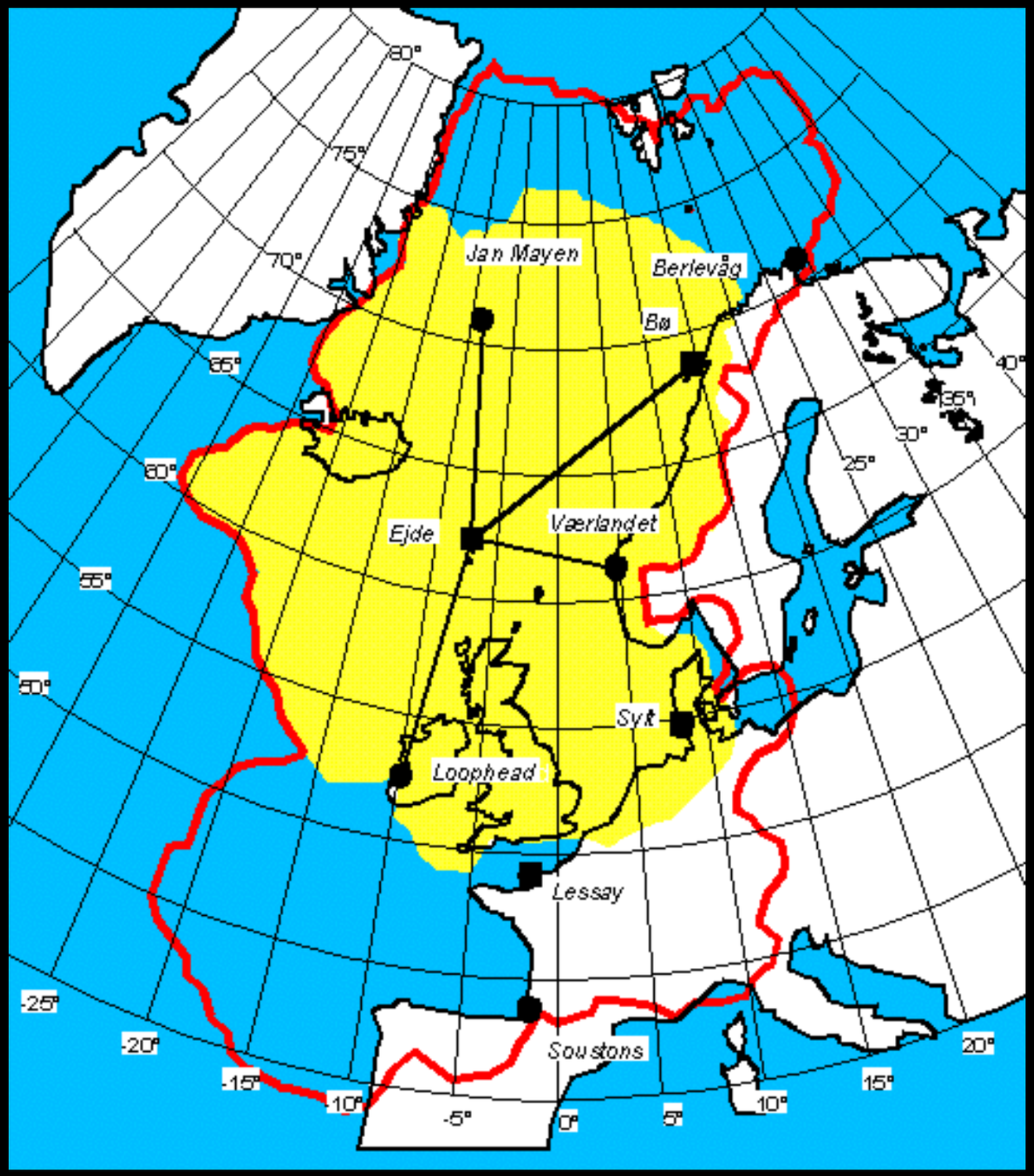
- On May 23, 1967, the Air Force prepared aircraft for war, thinking the nation's surveillance radars in polar regions were being jammed by the Soviet Union.

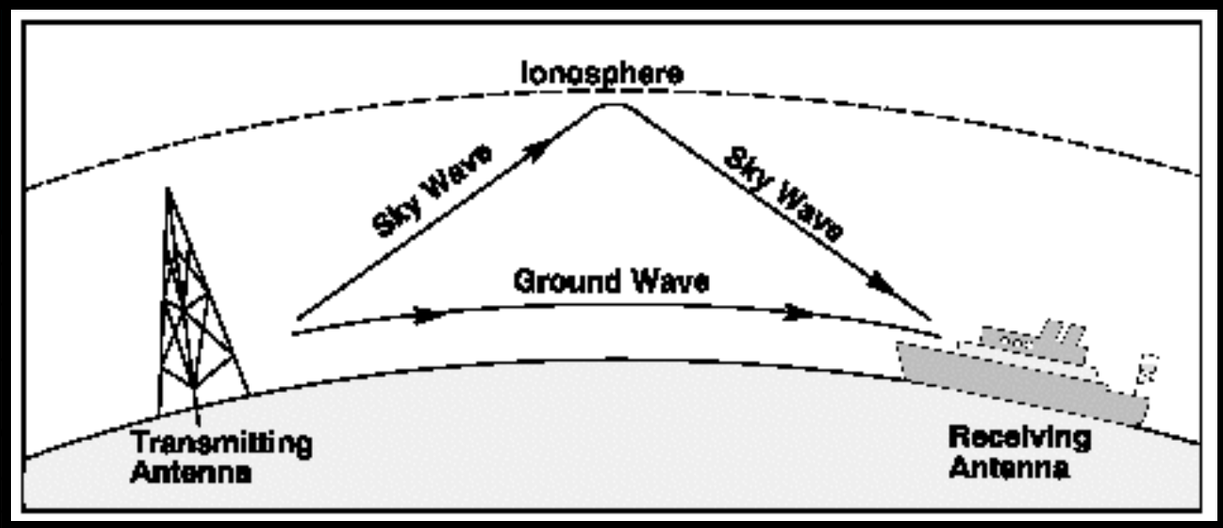
- Just in time, military space weather forecasters conveyed information about the solar storm's potential to disrupt radar and radio communications.

As the solar flare and radio burst event unfolded on May 23, radars at all three Ballistic Missile Early Warning System (BMEWS) sites in the far Northern Hemisphere were disrupted. These radars, designed to detect incoming Soviet missiles, appeared to be jammed. Any attack on these stations – including jamming their radar capabilities – was considered an act of war.



Navigation systems - LORAN C





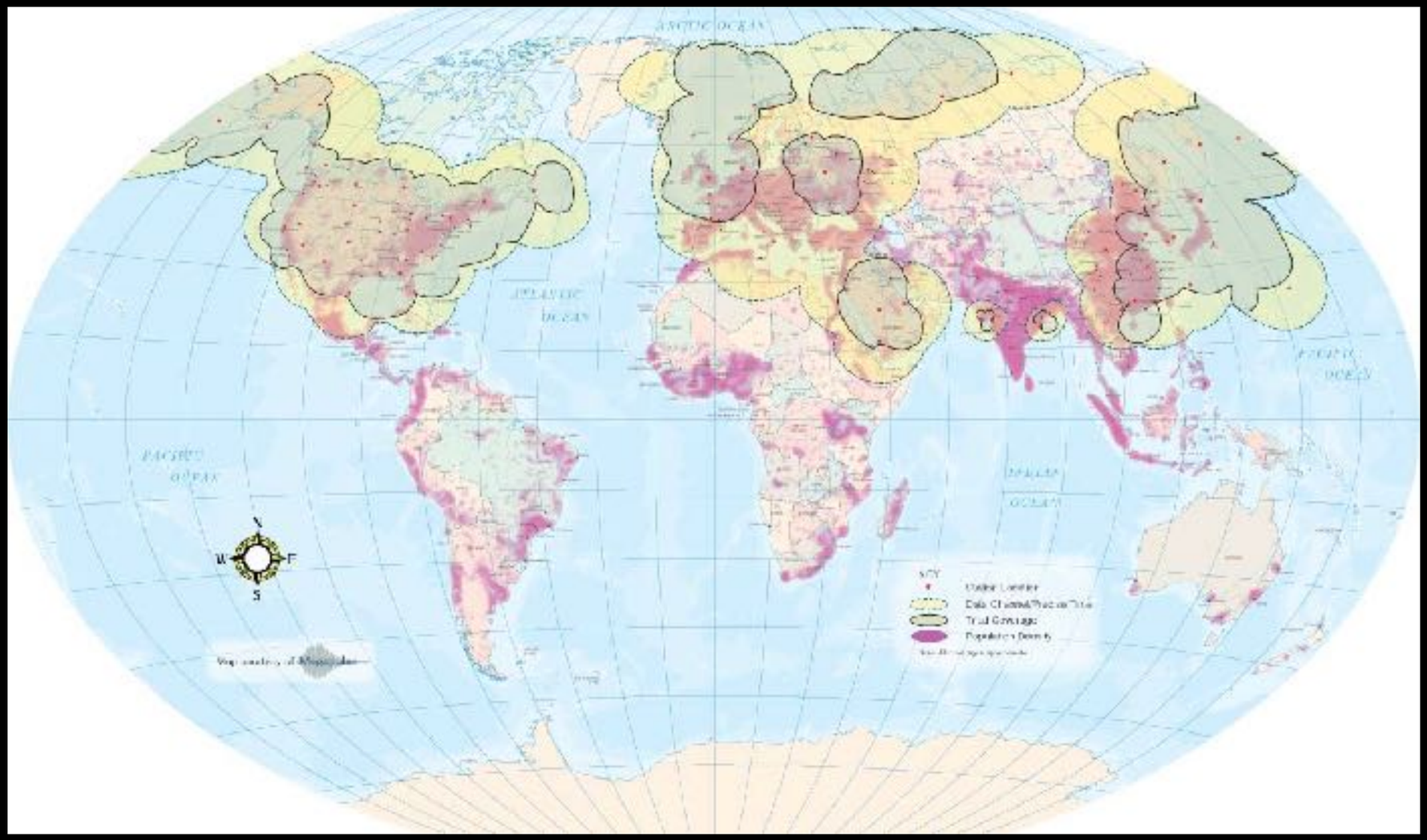
Feil i posisjonering fra 1-12 km

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

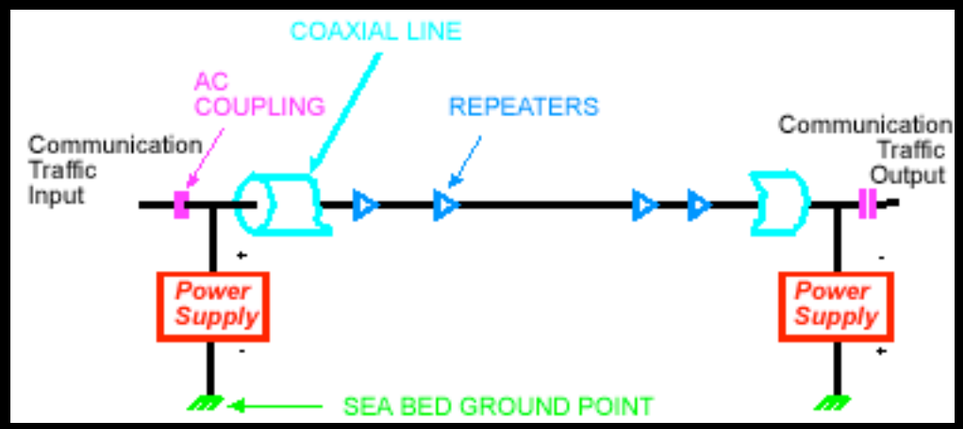
Normal accuracy is about 0.2 km. During solar storms it can be degraded to about 5 km.
Loran C can be useless for several ours in some cases.



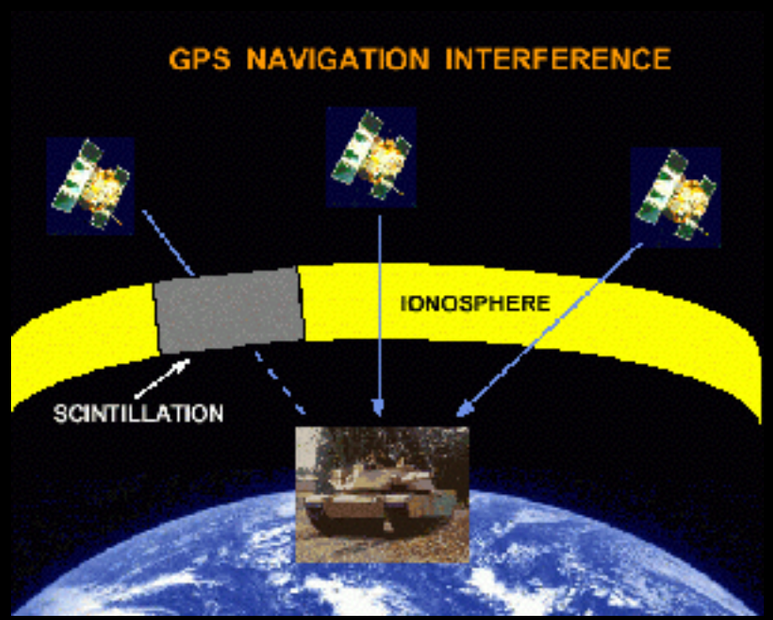
Effects on telecom cables

- Long land based cables
  - 4 august 1972, GIC knocked out an L4 coacsial cabel system in Illinois (USA). Thus, At&T re-designed theyr systems after that.
- Longe sub-sea telecom cables are affected.
  - 10 februar 1958: cable from New Foundland to Skottland was affected and sound was distorted.
- Optical fiber cables not affected by GIC.
  - However the voltage in the signal amplifiers can be affected.

Image about the installation of a sea cable. Figure credit: AT&T.

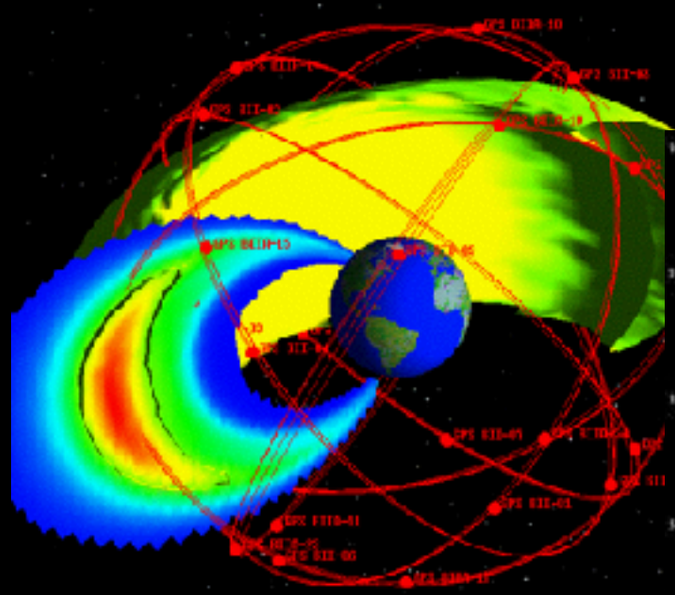


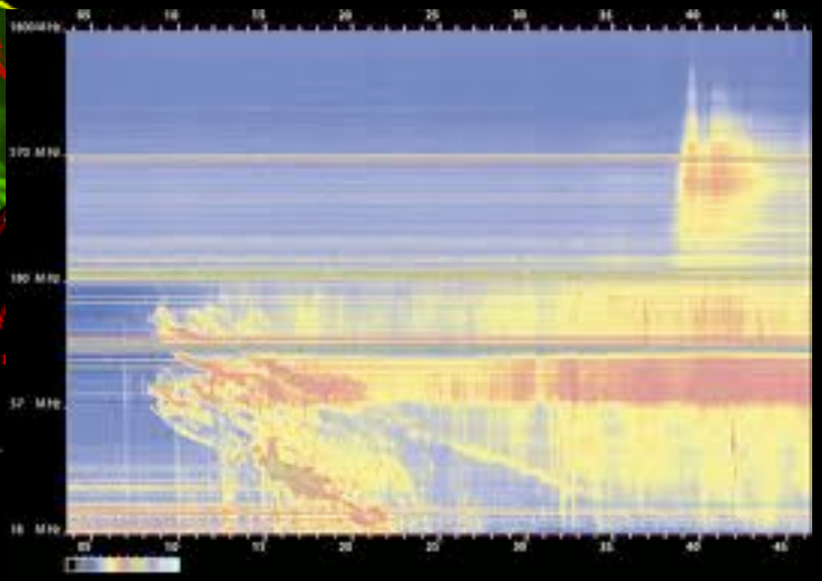
Navigation systems (GPS)

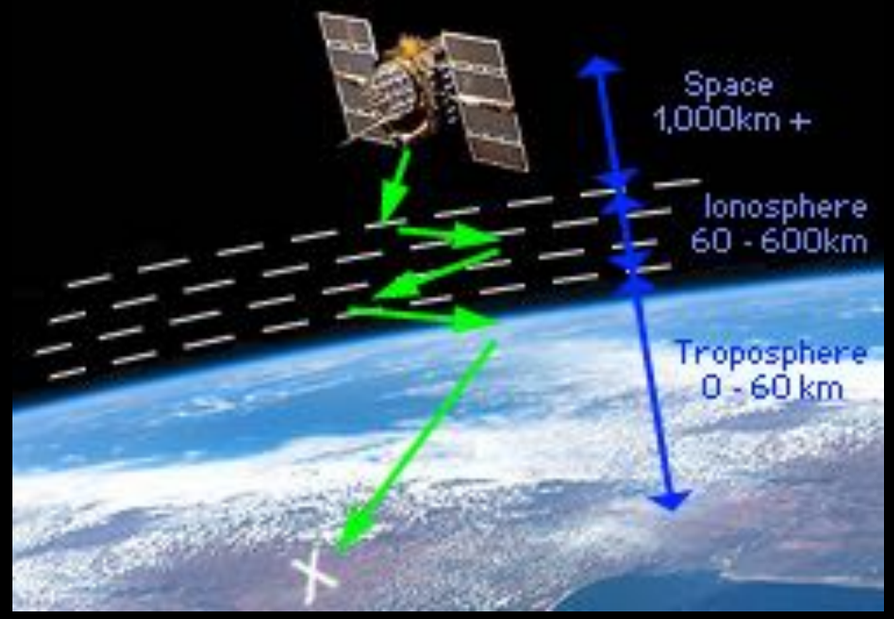


- Turbulence in the ionosphere causes scintillation in the satellite signal and can disrupt the reception.
- Total amount of electrons (TEC) along the path of the signal can introduce errors up to 100 meters.

- Radio bursts can «jam» the signals.

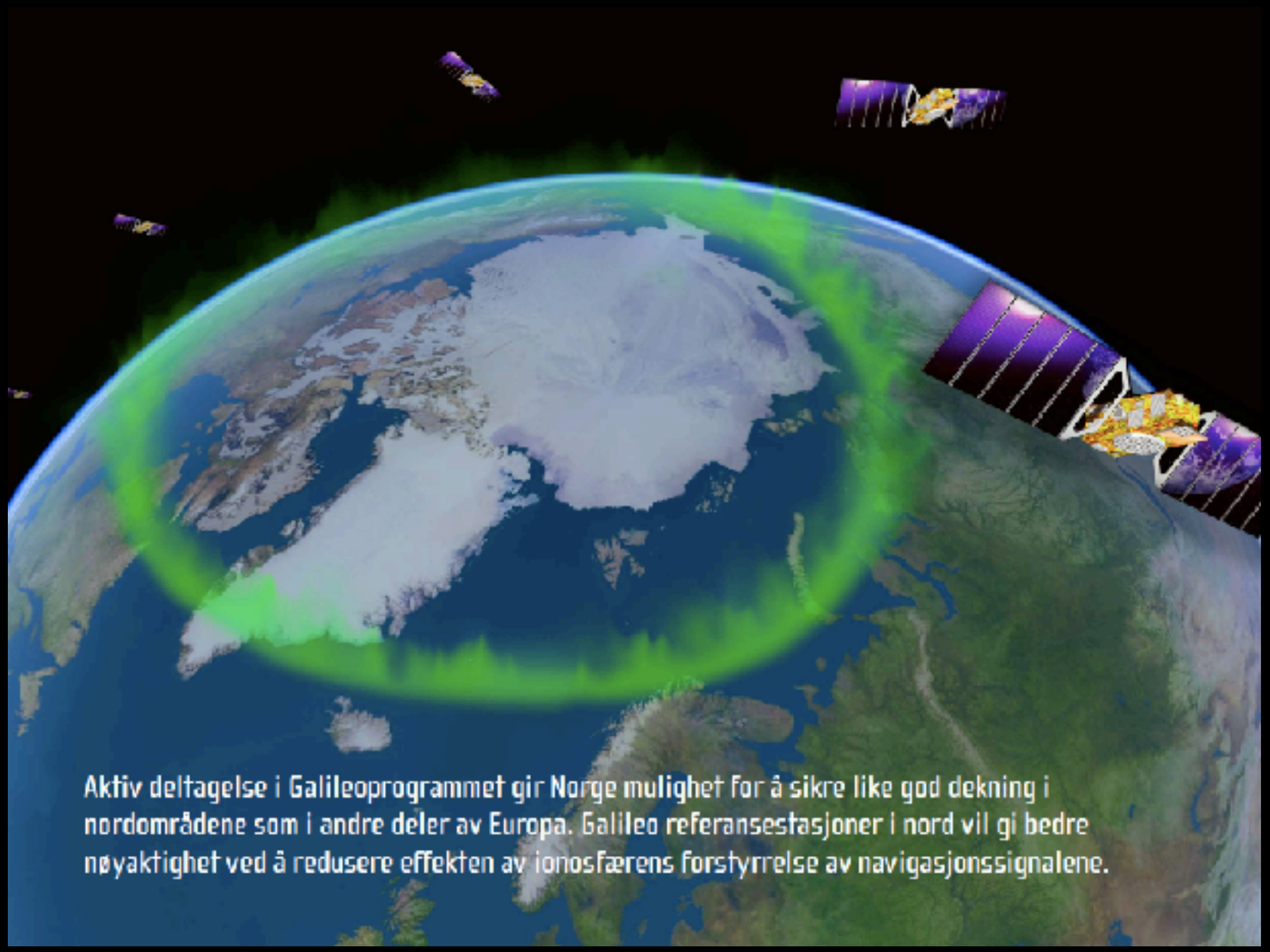


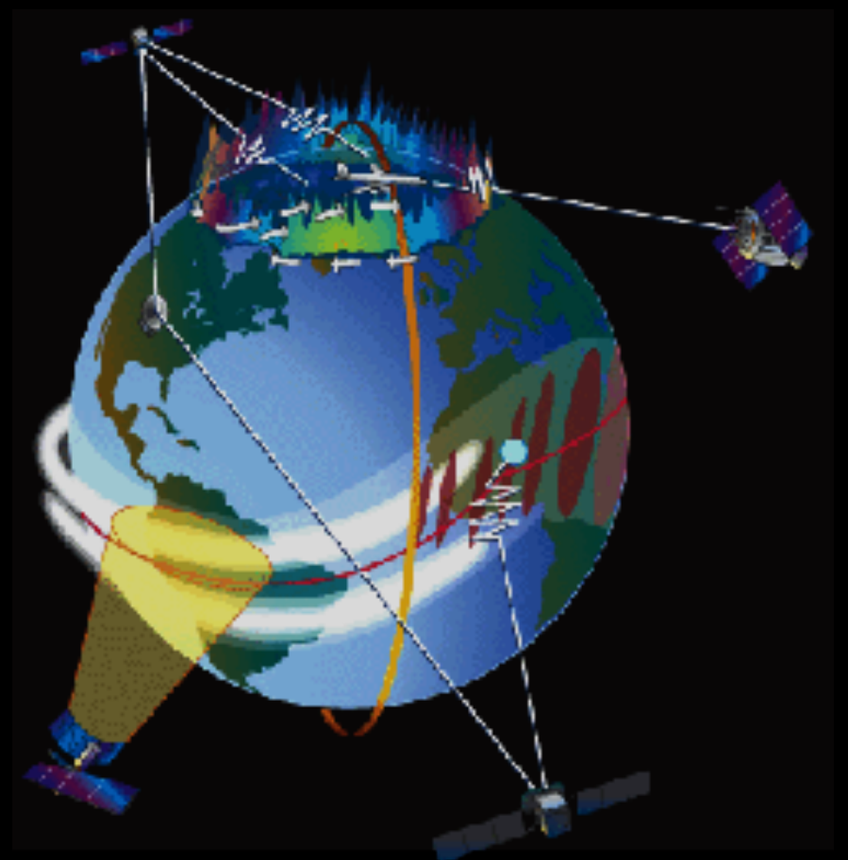




Challenges in the High North

- GPS/Galileo satellites are located low in the sky as seen from the Arctic and signals will pass through a lot more atmosphere.
- EGNOS corrections in the arctic used to have insufficient coverage. However, Norway has contributed with two new stations at Jan Mayen and Svalbard.





Some don´t care about GPS accuracy

For others it is critical

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

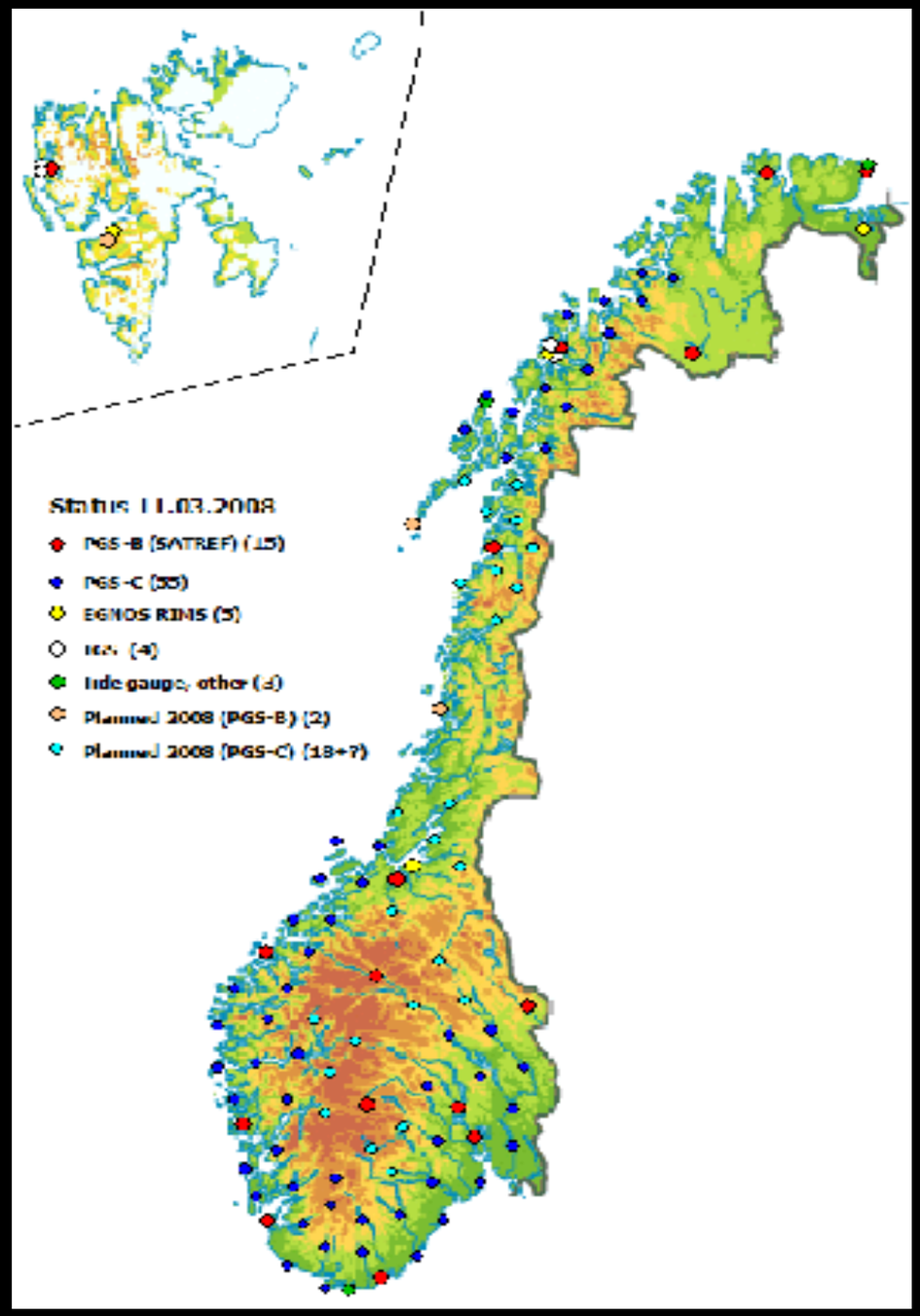
High precision positioning problematic

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

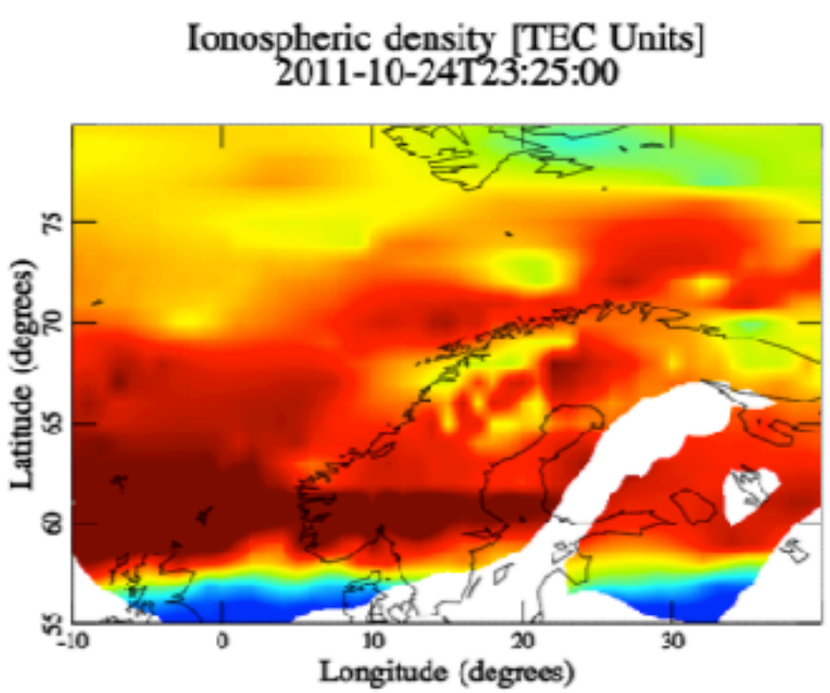
Corrections of GPS positions

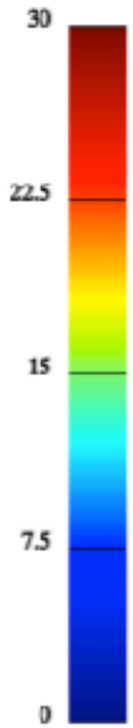
- In Norway the Norwegian Mapping Authority has the national responibility for providing corrections to GPS users.
- They monitor the Sun and have developed an ionospheric modeld that improve these corrections and warn their customers.

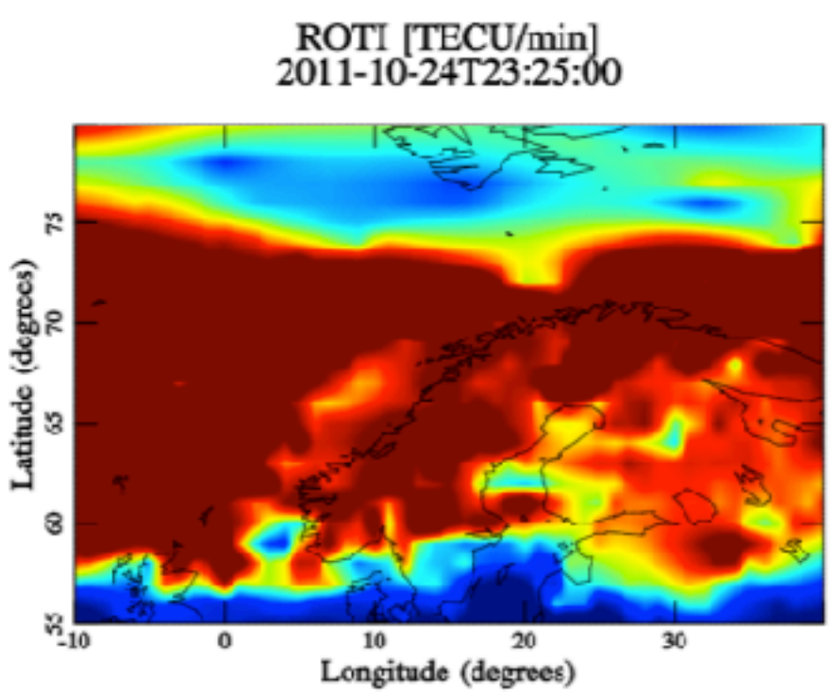
SATREF Control Centre

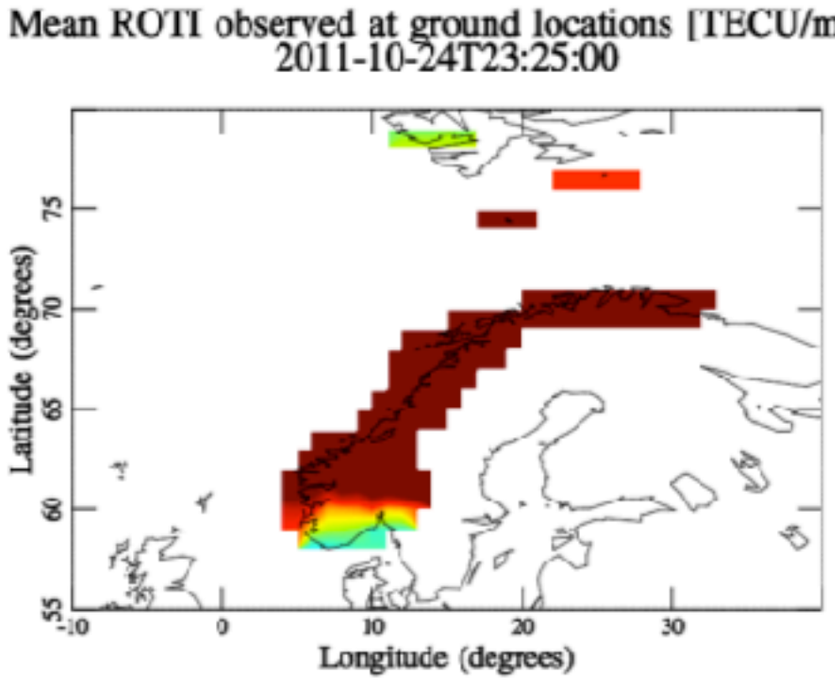


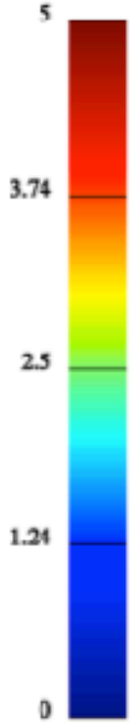
Recent solar storm - affected GPS

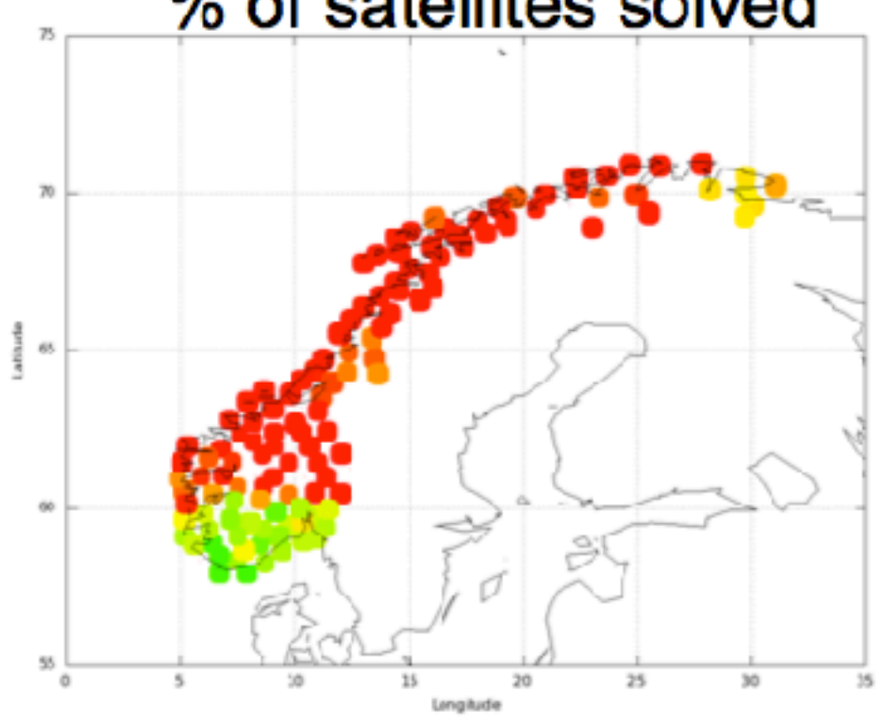






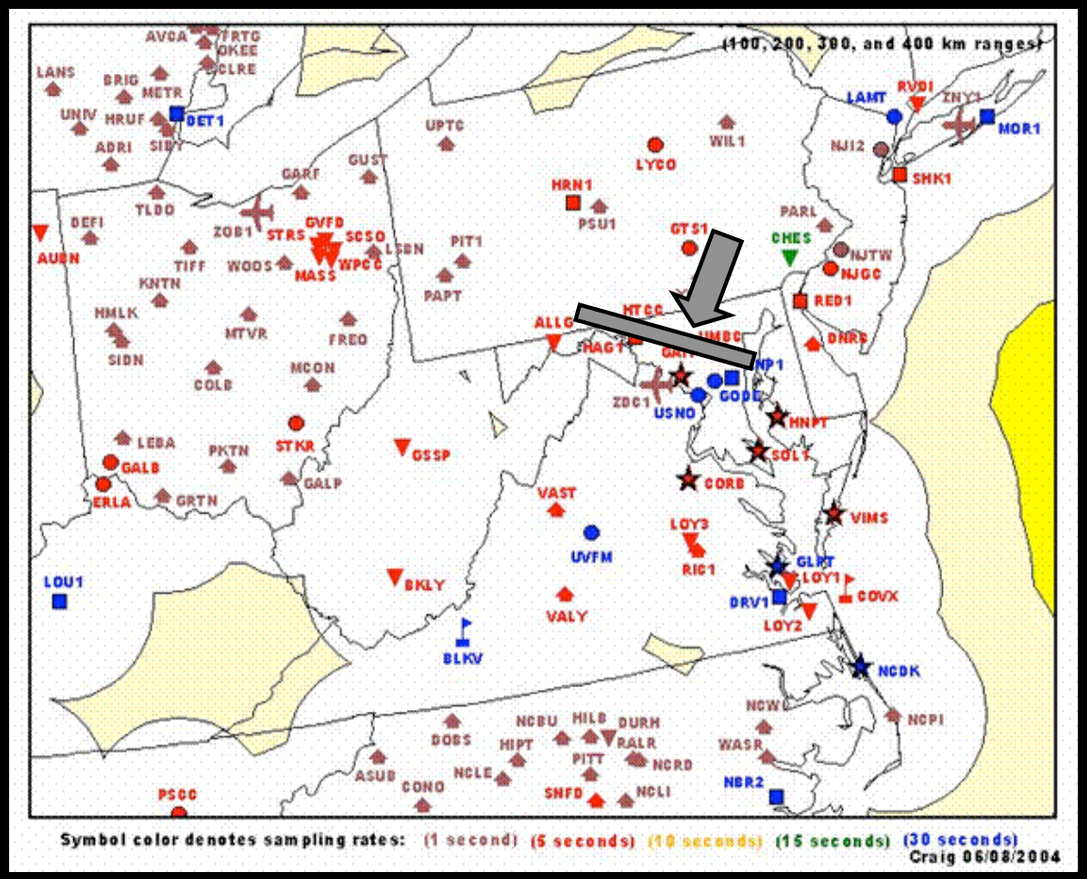






Ionospheric Challenges

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

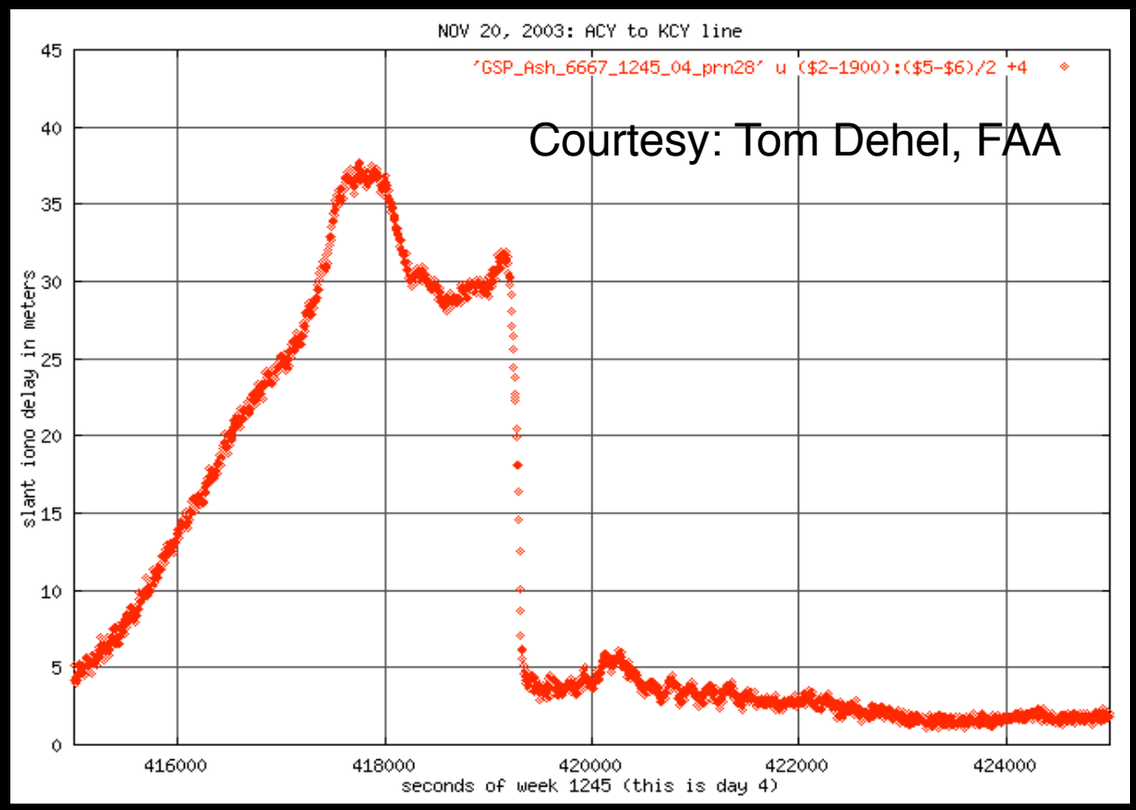


TEC “walls”:
130 TEC units over only 50 km

25 m of GPS delay;

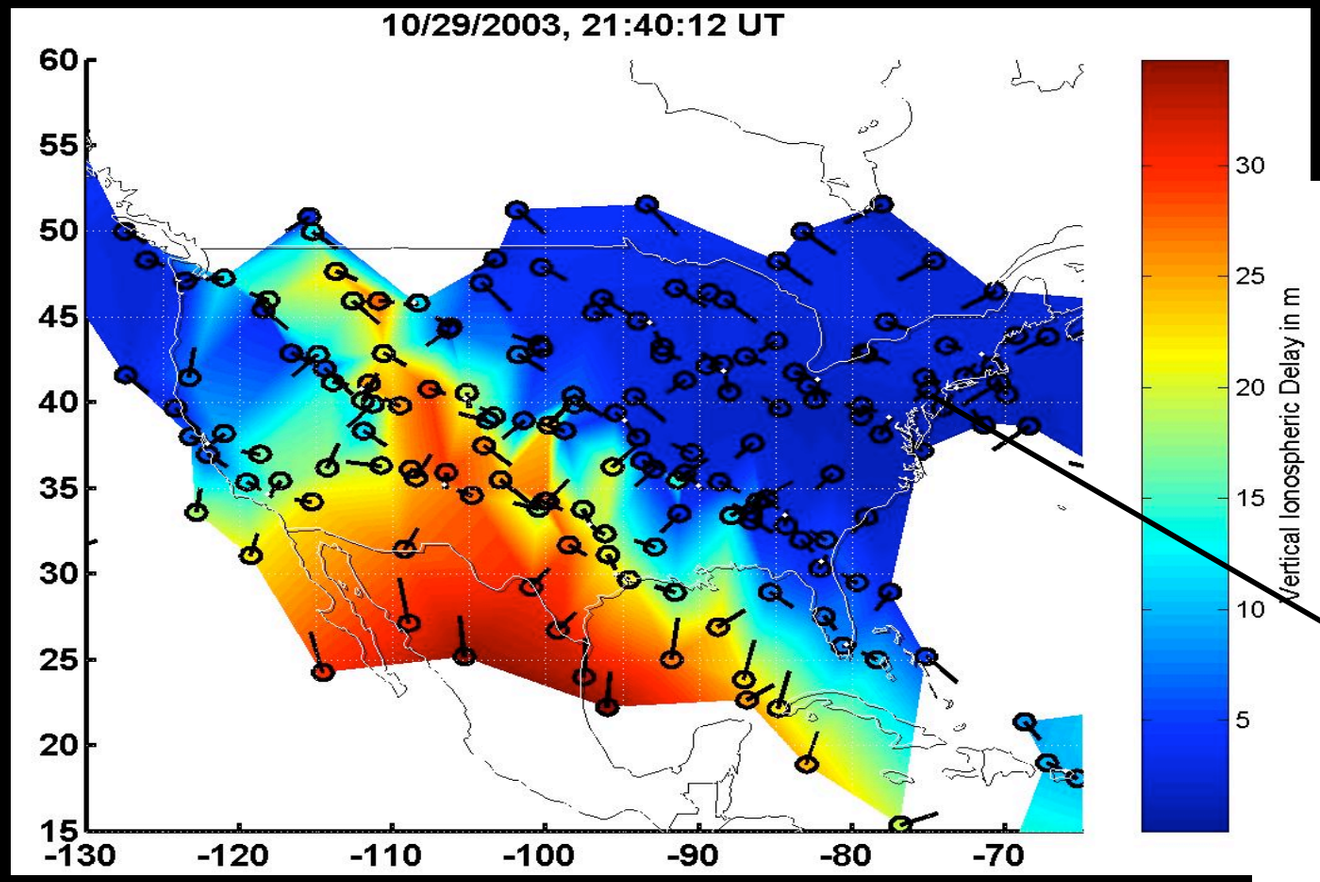
walls move 100 to 500 m/s

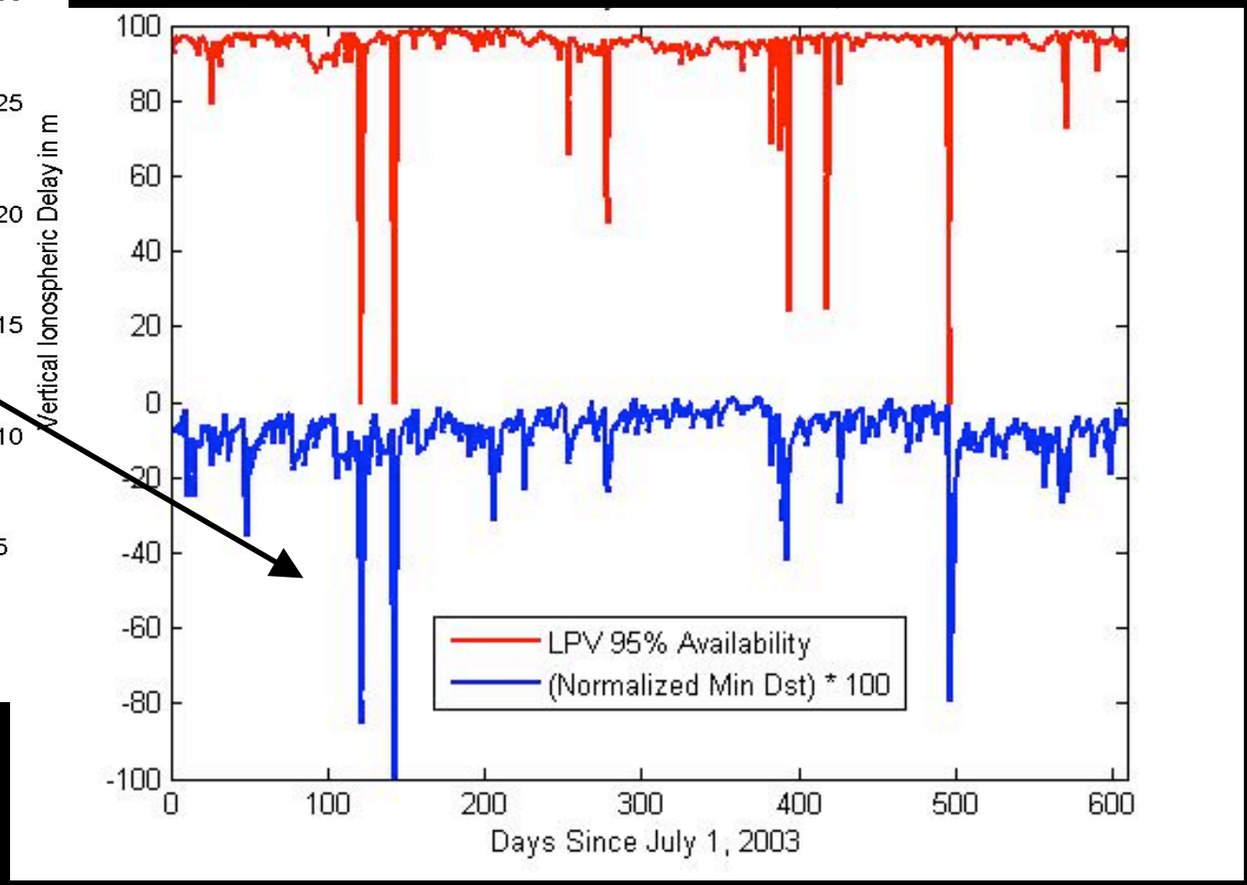
October 29th, 2003
“walls” of TEC challenge provision of integrity with differential GPS



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.

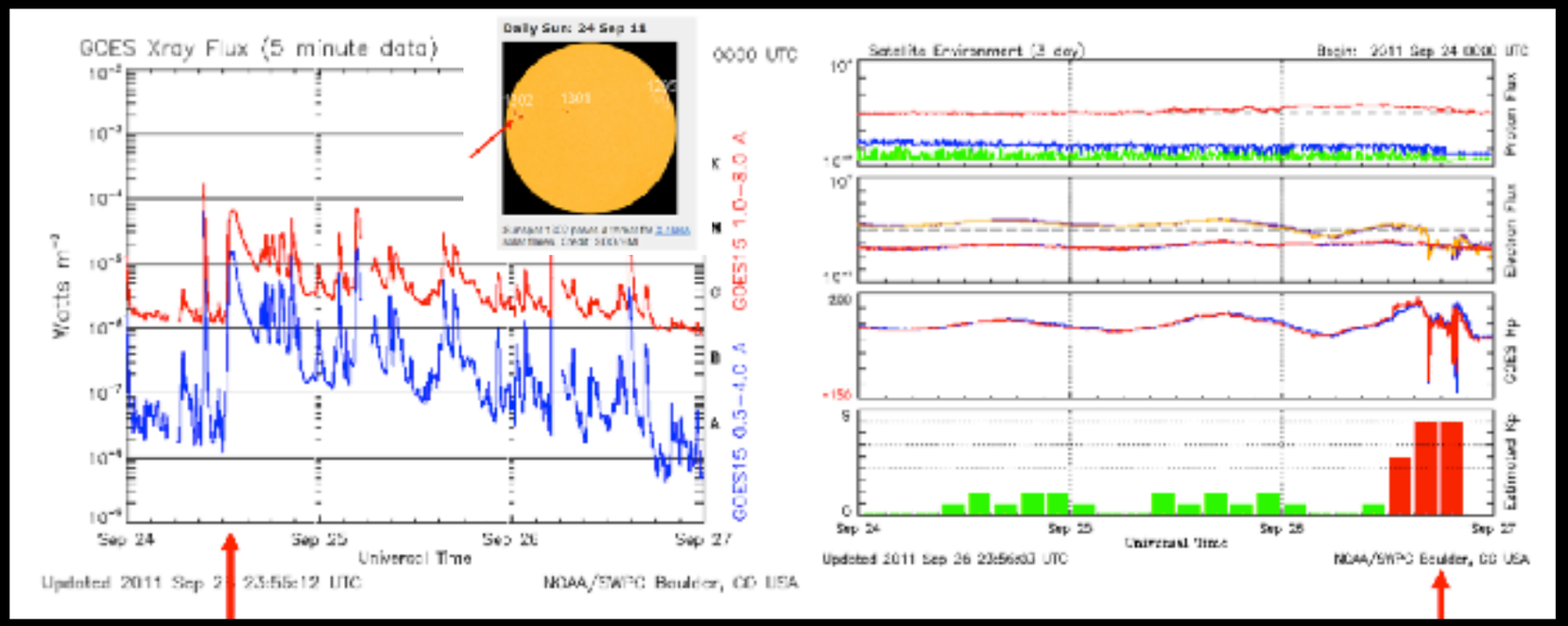




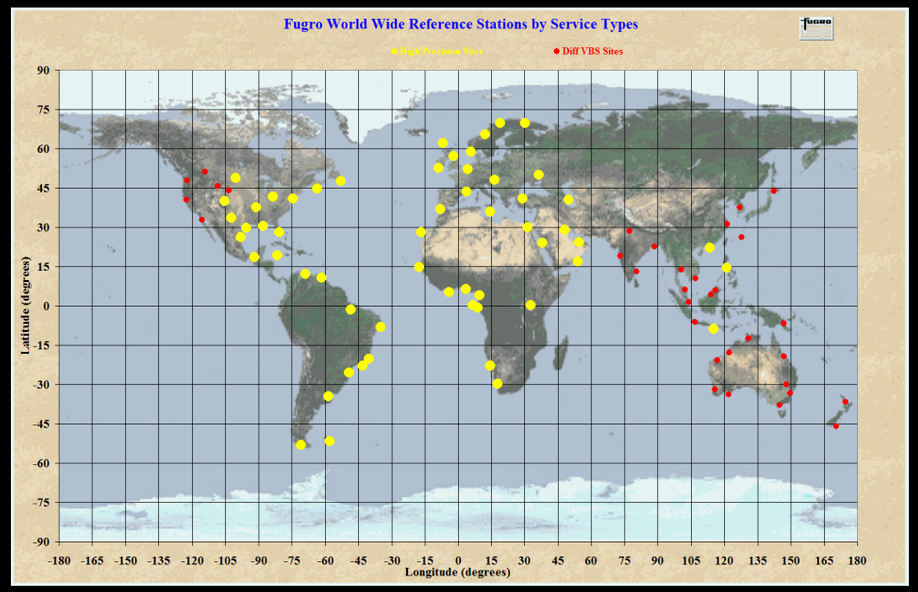
15 hour loss on 10/29; 11.3 hour loss on 10/30, shorter losses on 11/20/2003

Radio burst «jammed» the GPS system

- 24 September 2011 - a radioburst affected the GPS network on the day-side of Earth.

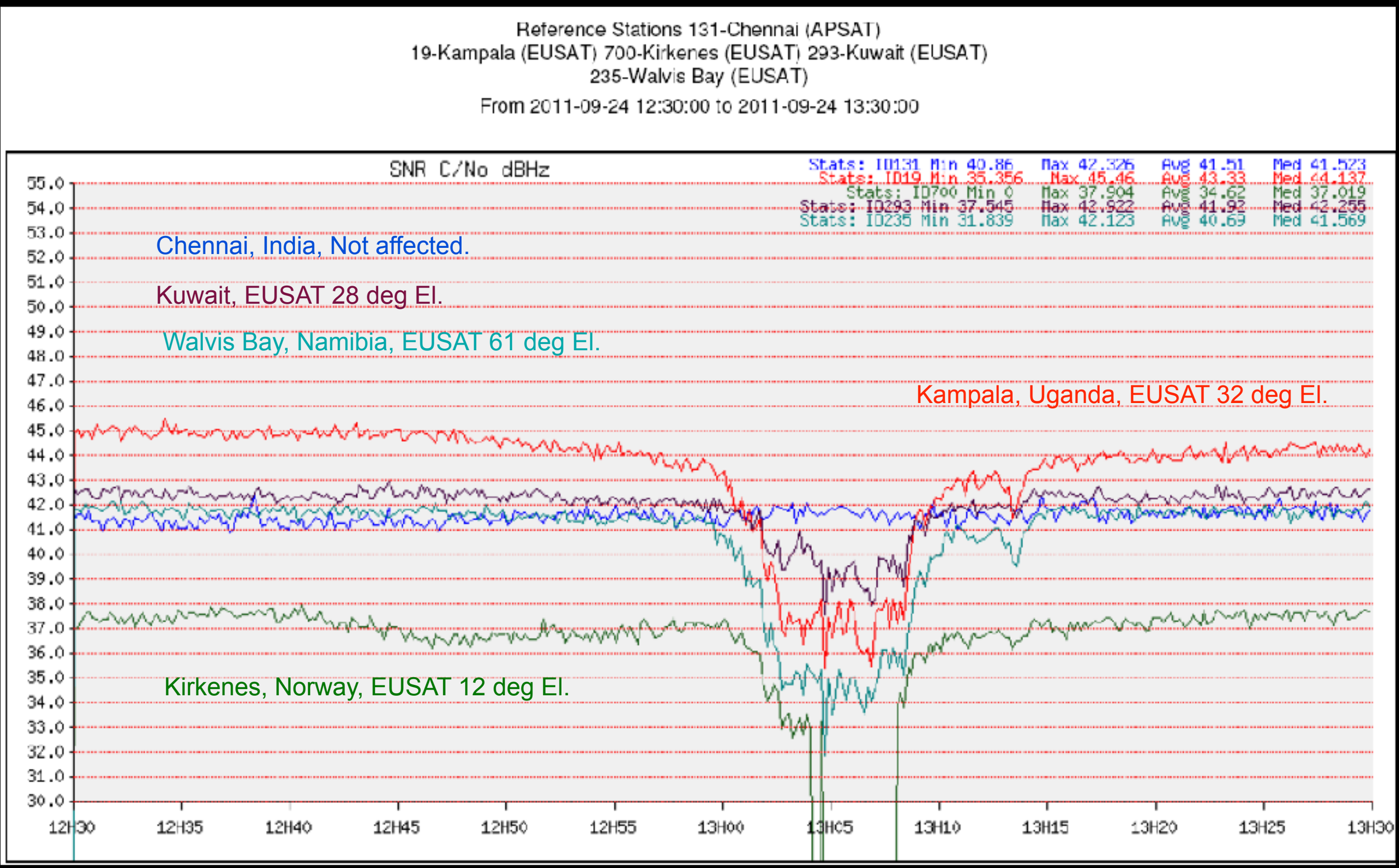


#Even.	Begin	Max	End	Obs	O	Type	Loc/Frq	Particulars		Reg#
3590	1231	1313	1409	SAG	G	RBR	245	4800	CastelliU	1302
3590	1231	1253	1406	SVI	G	RBR	8800	1300	CastelliU	1302
3590	1231	1307	1410	SAG	G	RBR	610	80000	CastelliU	1302
3590 +	1232	1302	1411	SVI	G	RBR	2695	12000	CastelliU	1302
3590	1232	1253	1358	SVI	G	RBR	4995	1400	CastelliU	1302
3590 +	1232	1313	1410	SAG	G	RBR	610	69000	CastelliU	1302
3590 +	**1233**	**1320**	**1410**	**G15**	**5**	**XRA**	**1-8A**	**M7.1**	**2.9E-01**	**1302**
3590	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

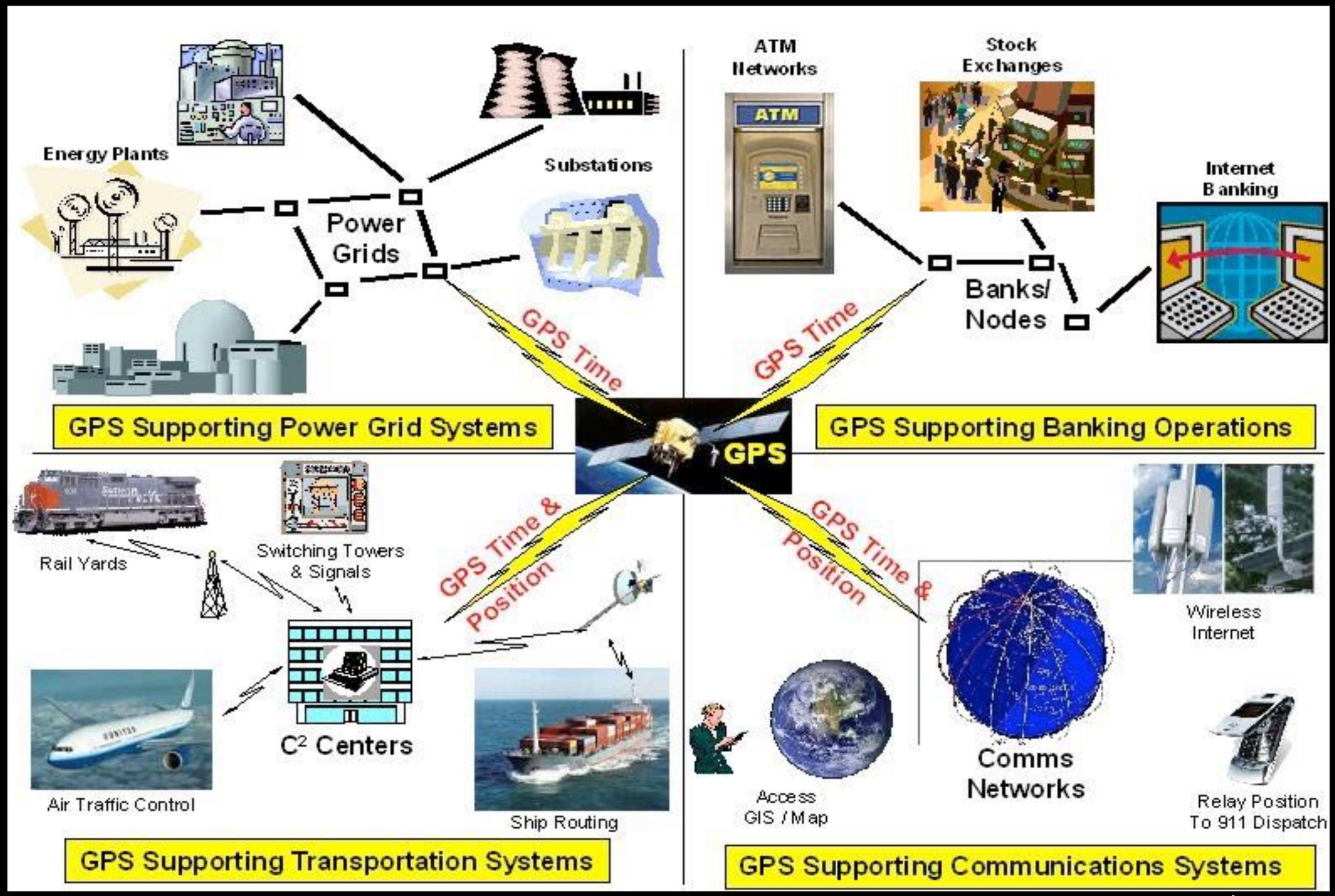


Fugro L-Band tracking EAME 24 Sept

www.fugro.no



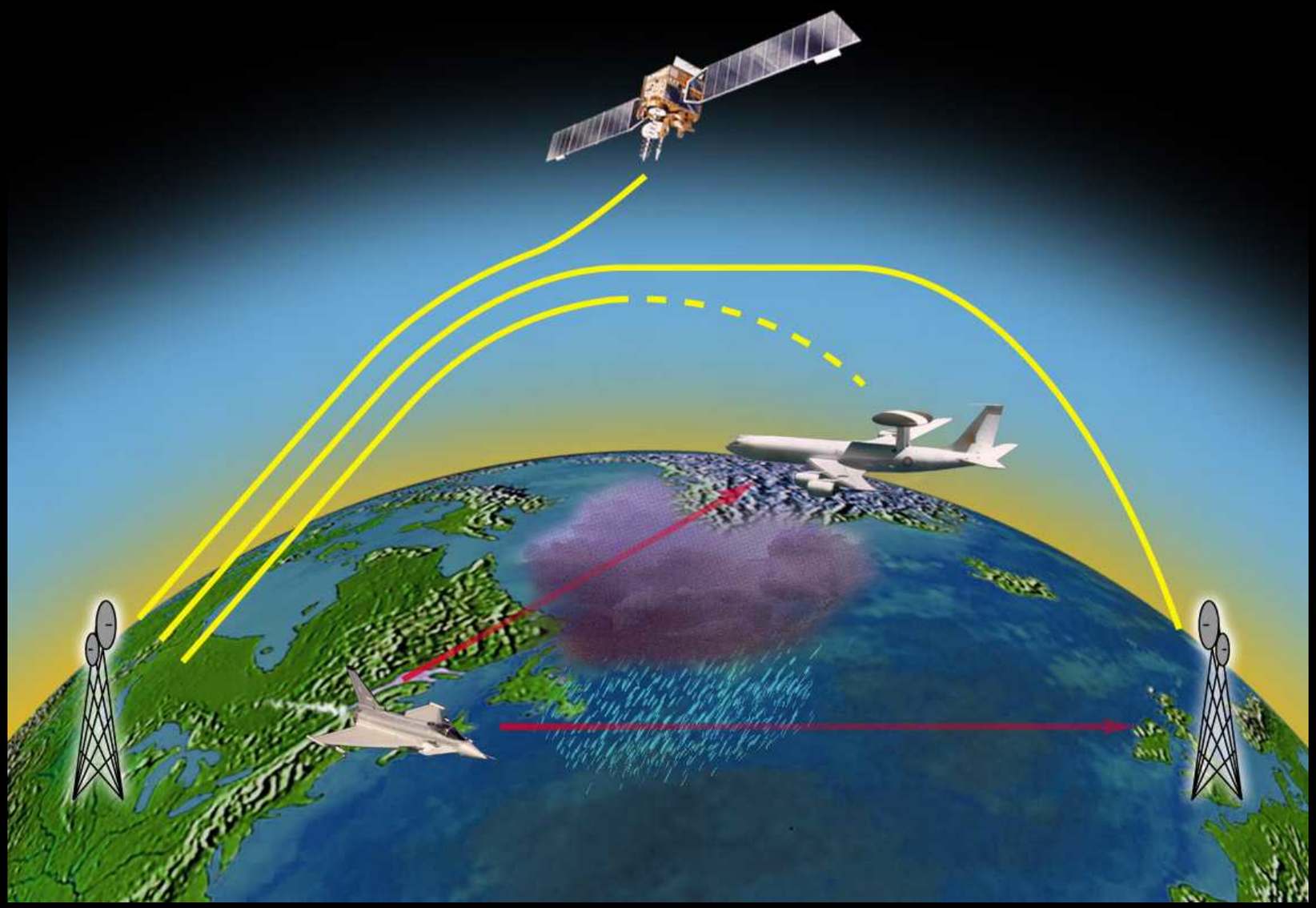
Extent of GPS Dependencies



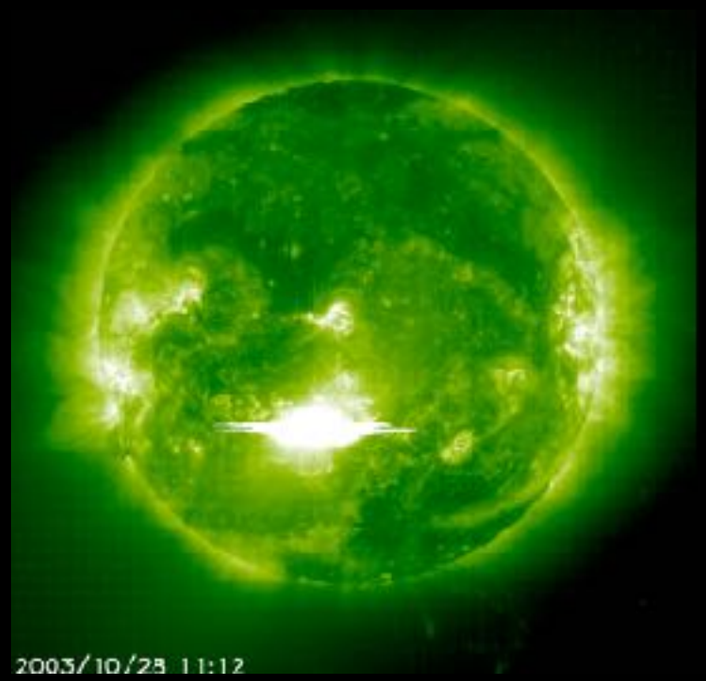
K. VanDyke, DOT

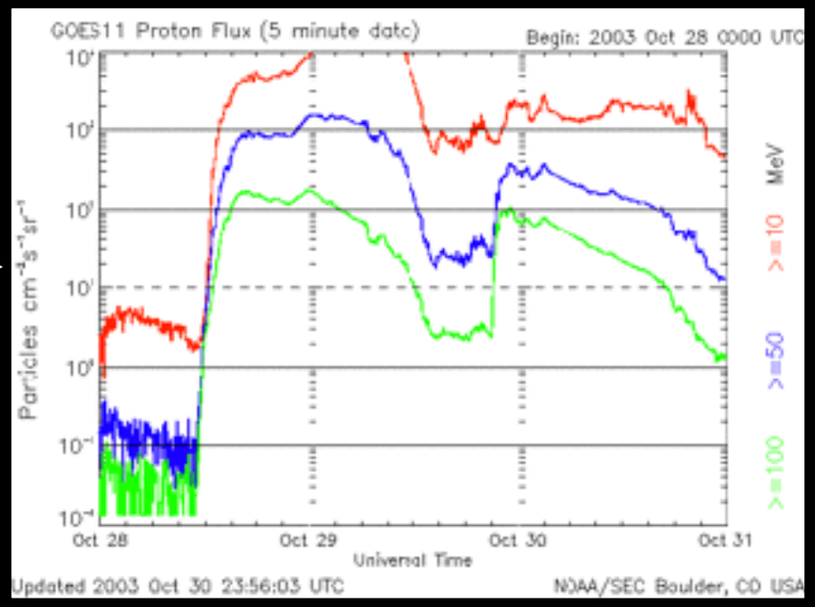
The accurate timing messages from the GSP satellites can also be used to provide a reference clock for computers and computer networks. GPS is currently the preferred reference for many NTP network time server appliances and reference clock devices.

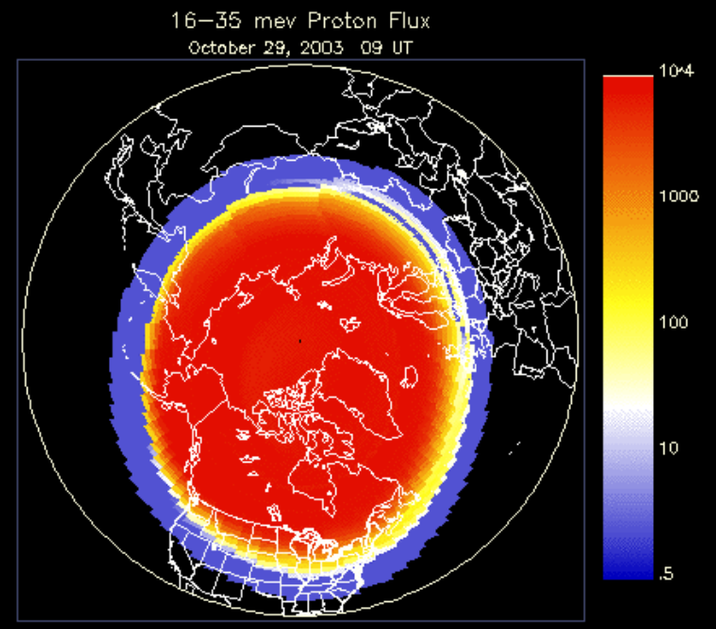
Radiocommunication i polar regions difficult



Radiation Storms = degraded comm







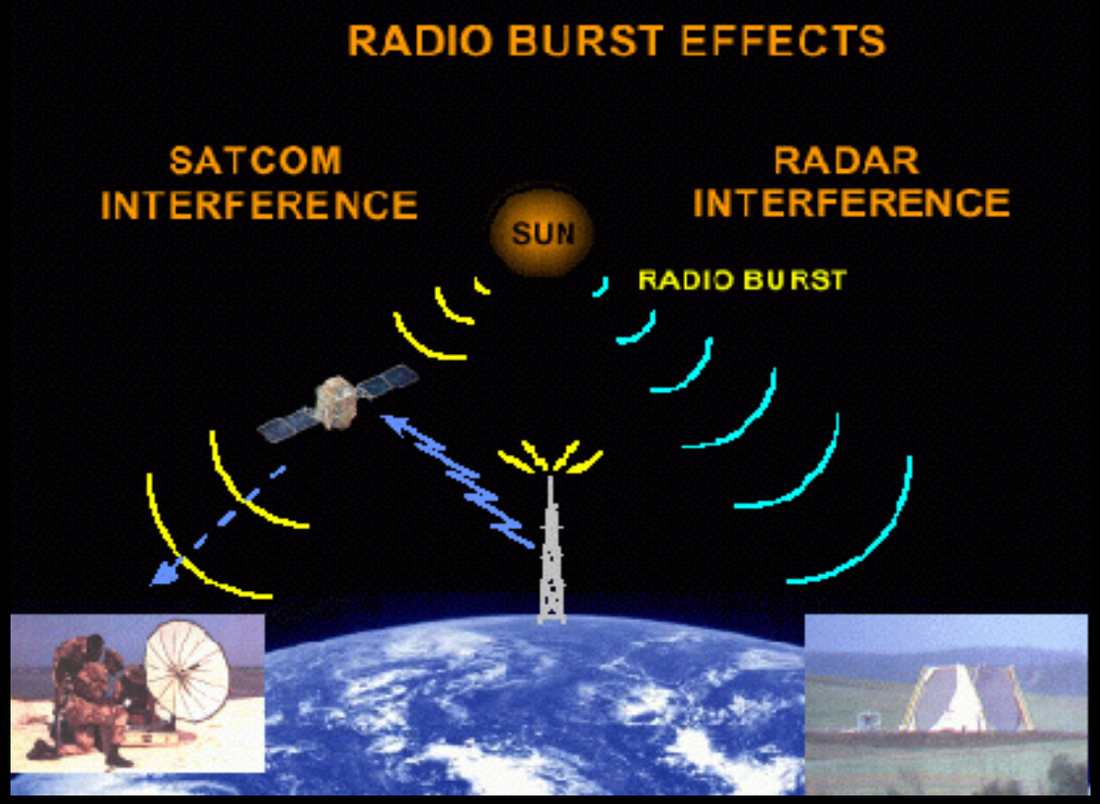
Radiation storms cause extended periods (hours to days) of HF communication blackout at higher latitudes

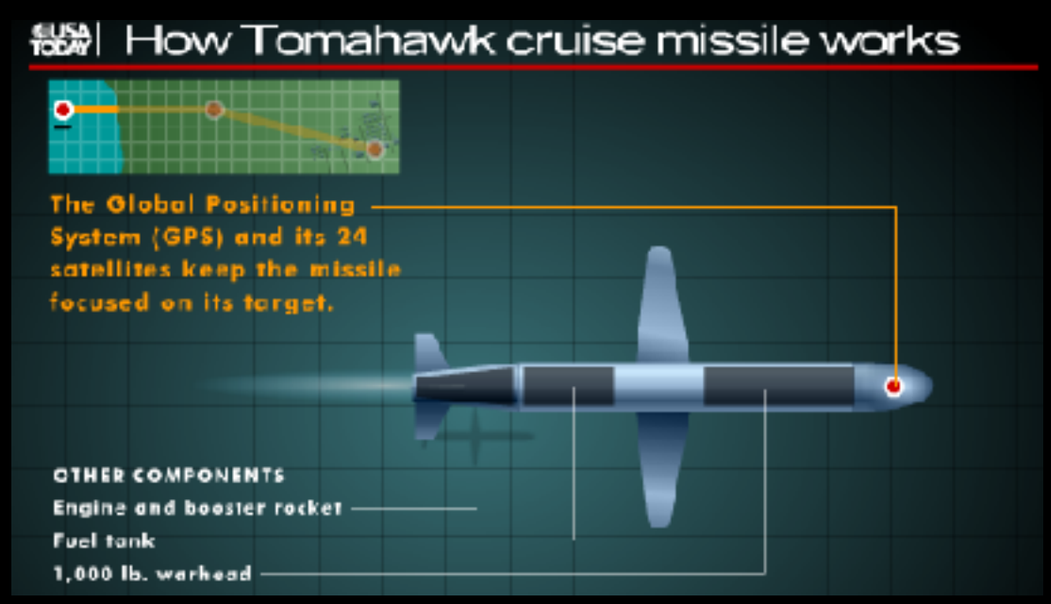
Conditions are usually worse on daylight side

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

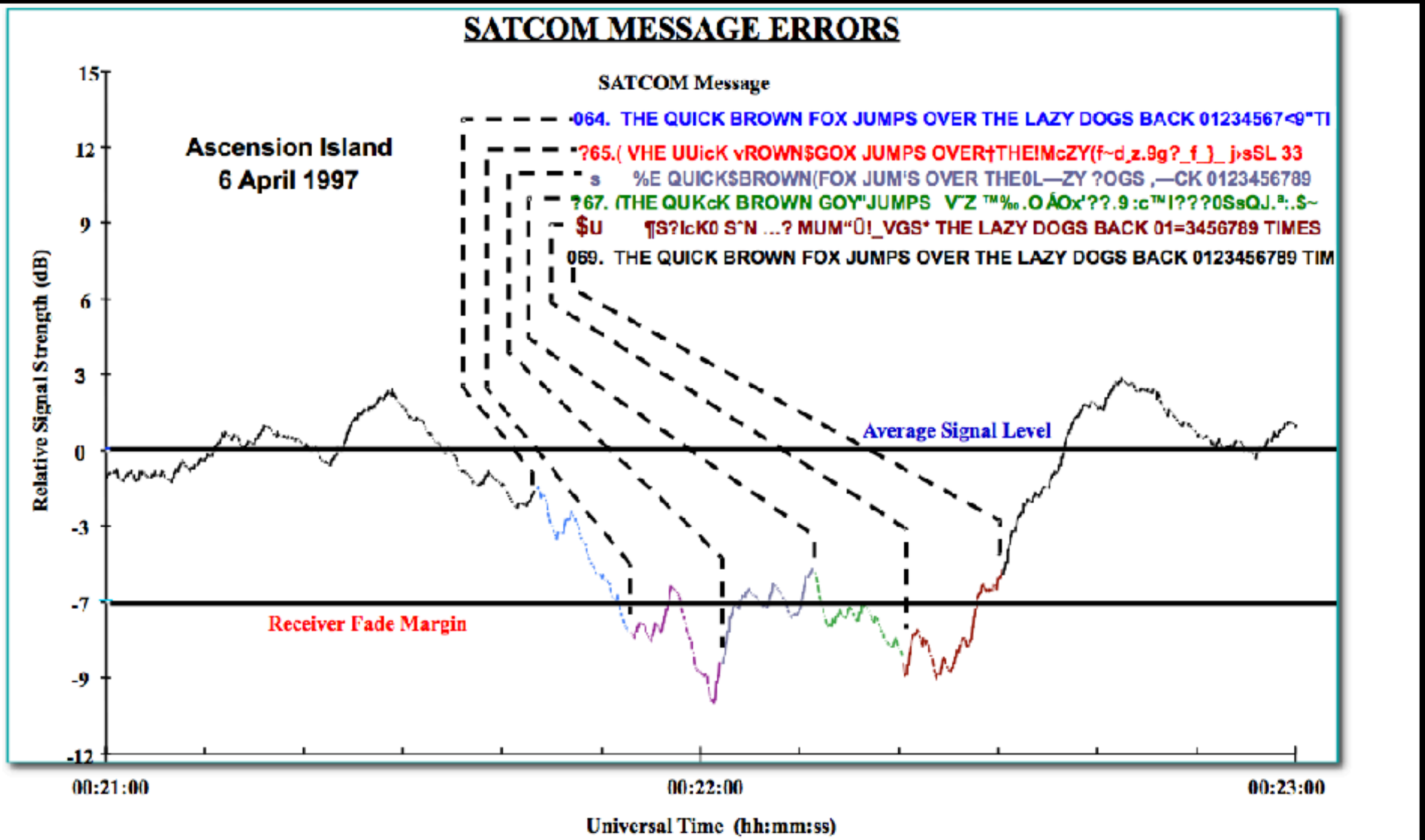
Effects on military systems

- HF satellite 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

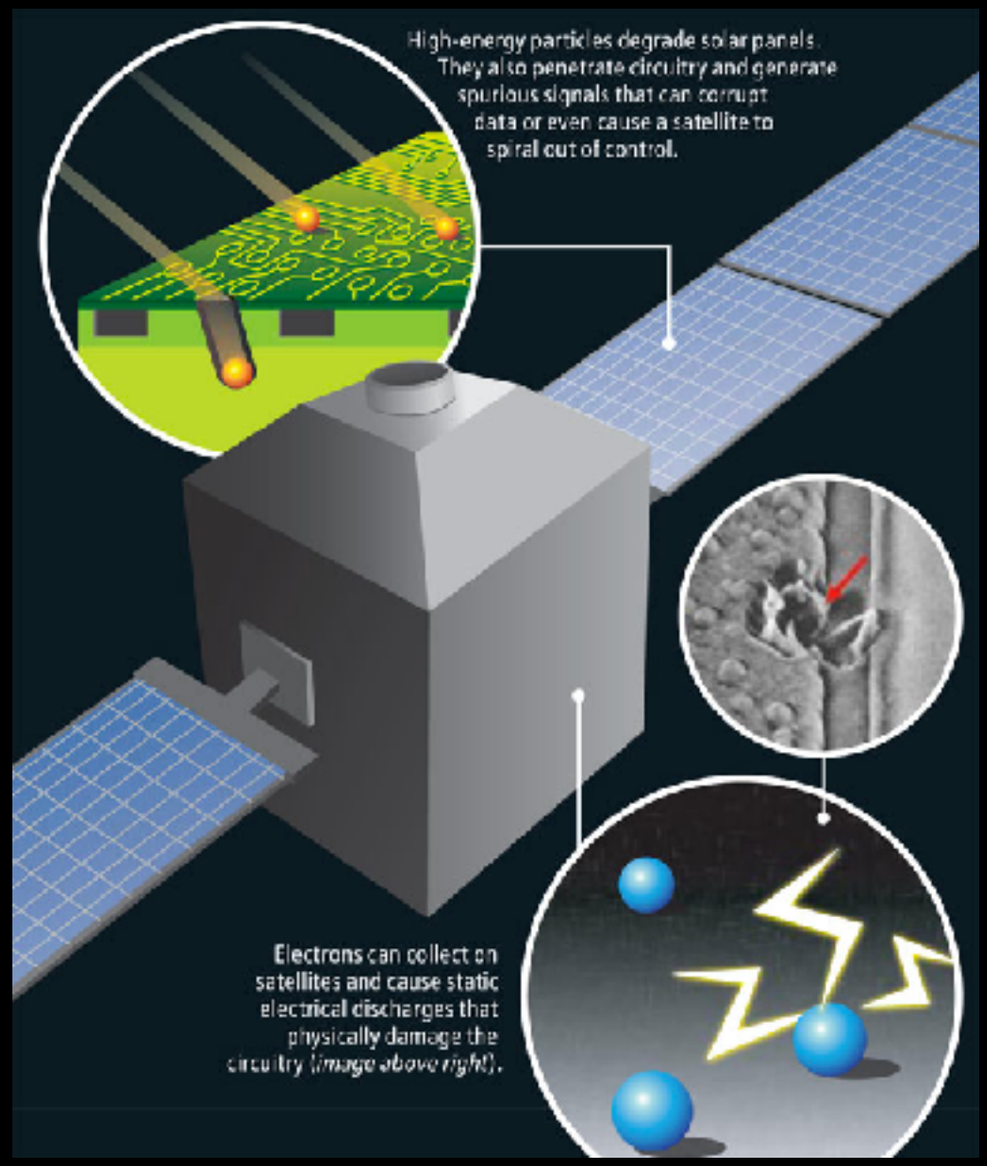


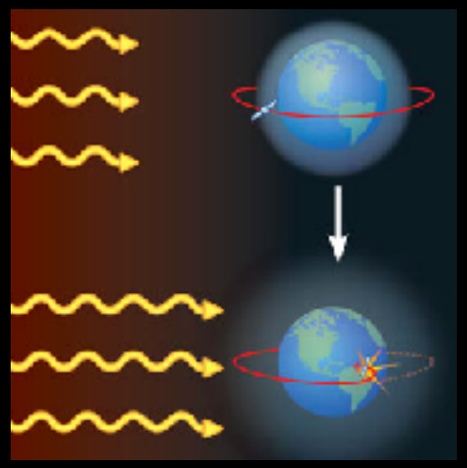
S. Basu, private communication

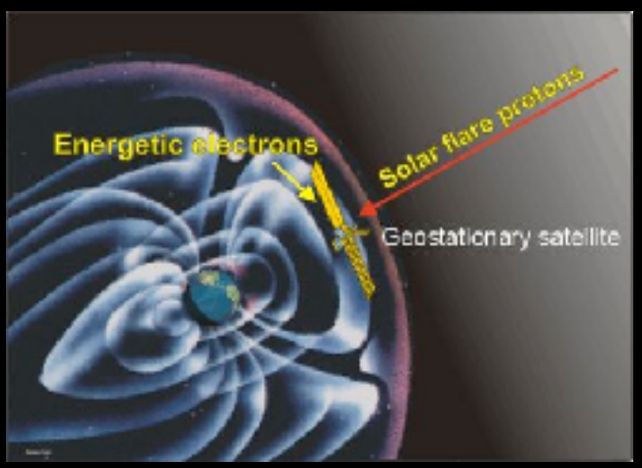
Effects on Satellites

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

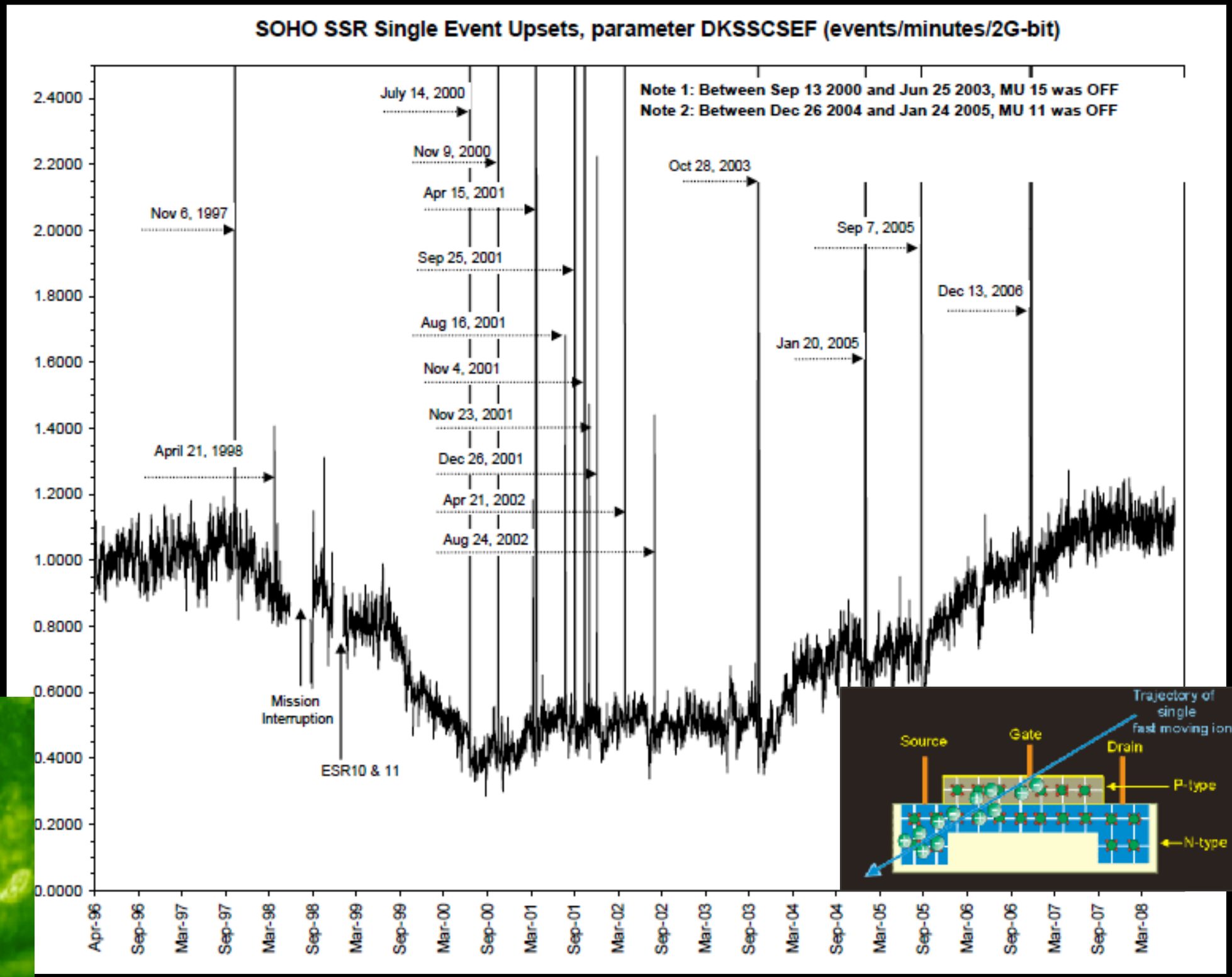


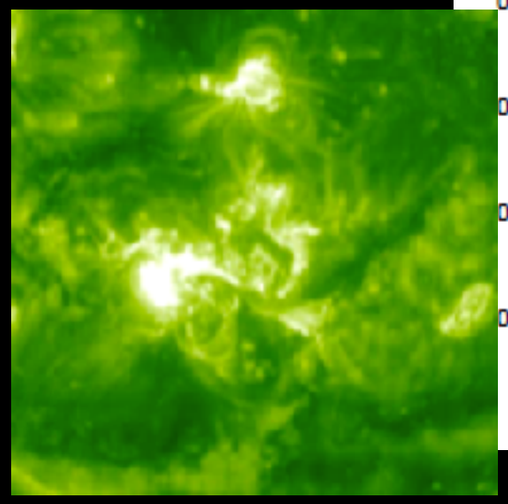




Single Event Upsets

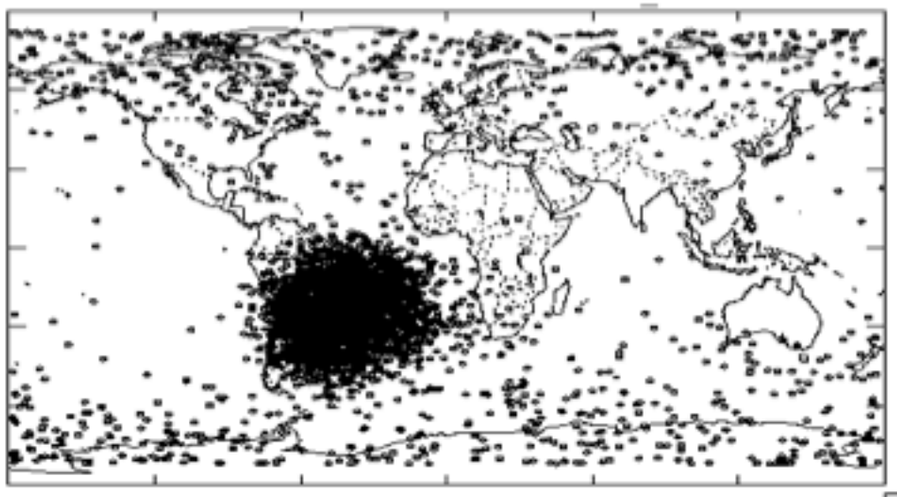
High energy particles can penetrate satellites and damage sensitive electronics.





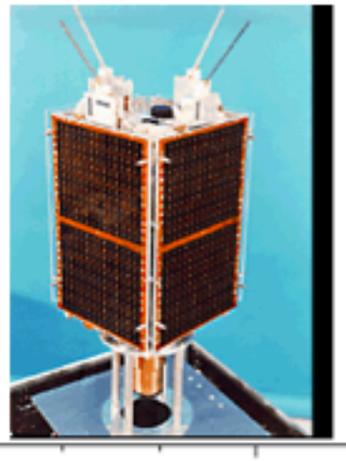
Single Event Upsets

SEUs on UoSAT-3 microsatellite memory

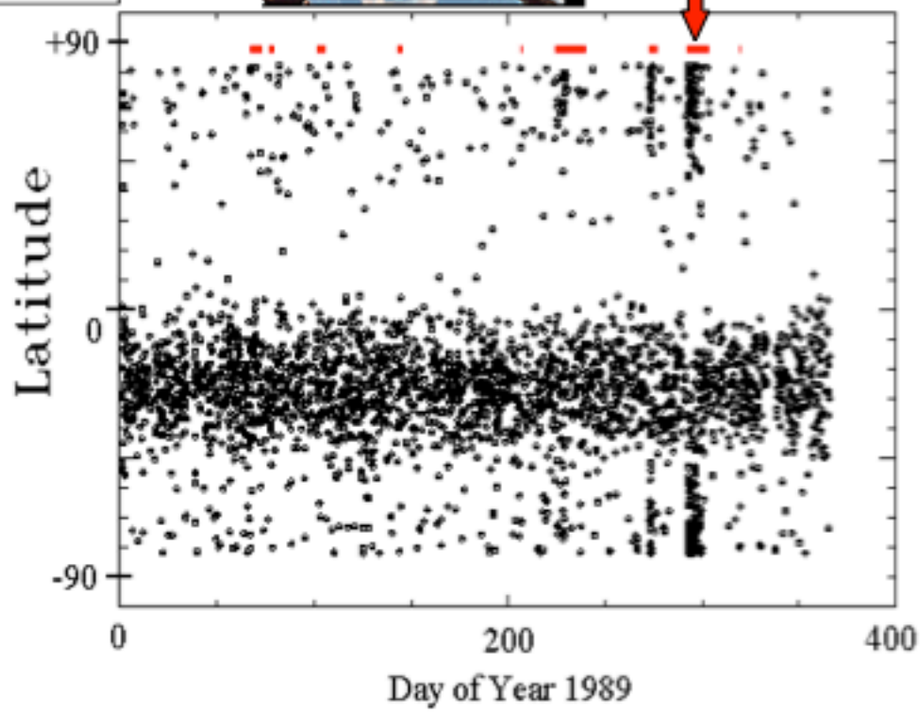


Mapped

Time behaviour →



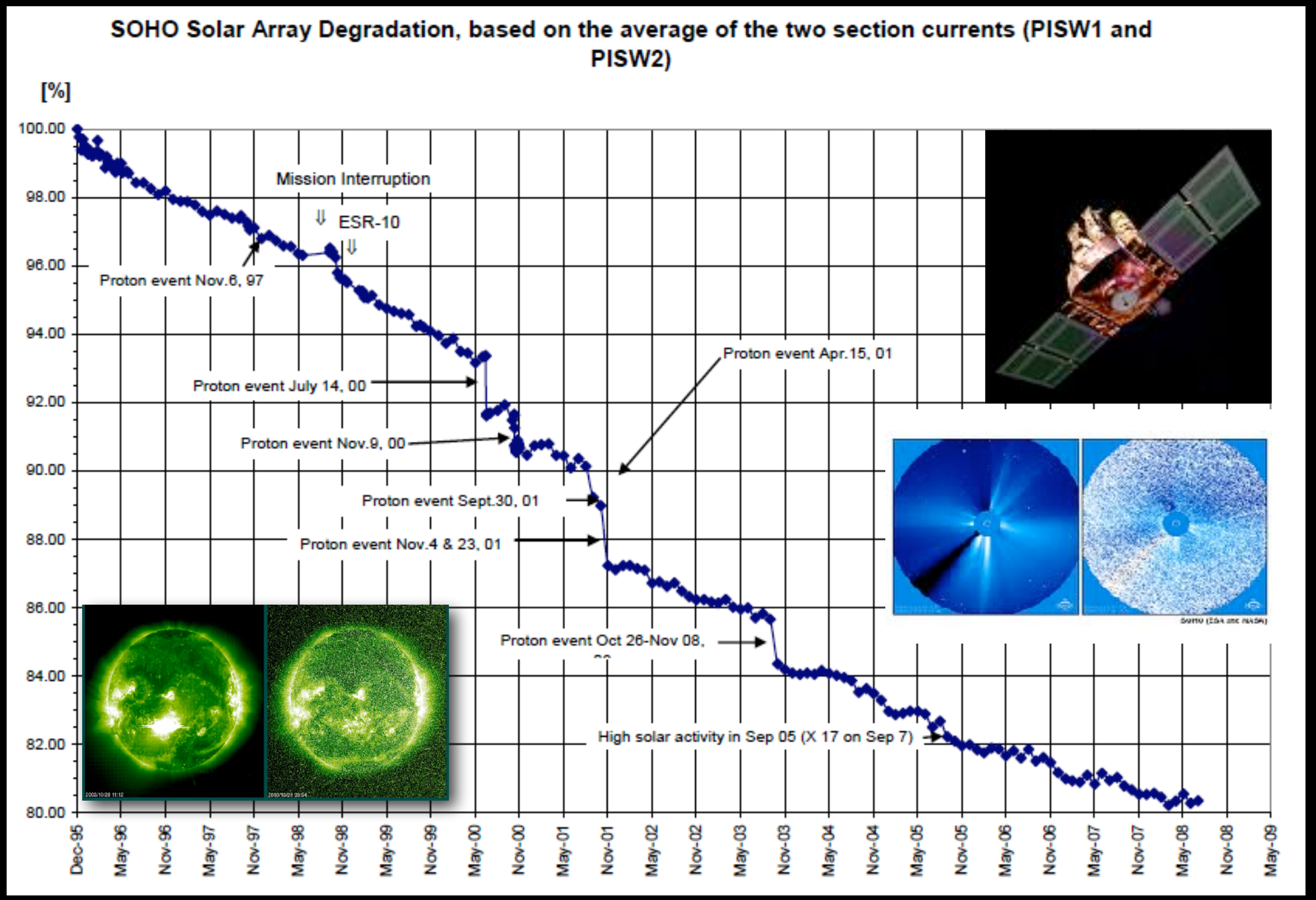
Oct '89



SEUs are from:

- Cosmic rays and solar ions at high latitude
- Radiation belt proton nuclear reactions in south Atlantic

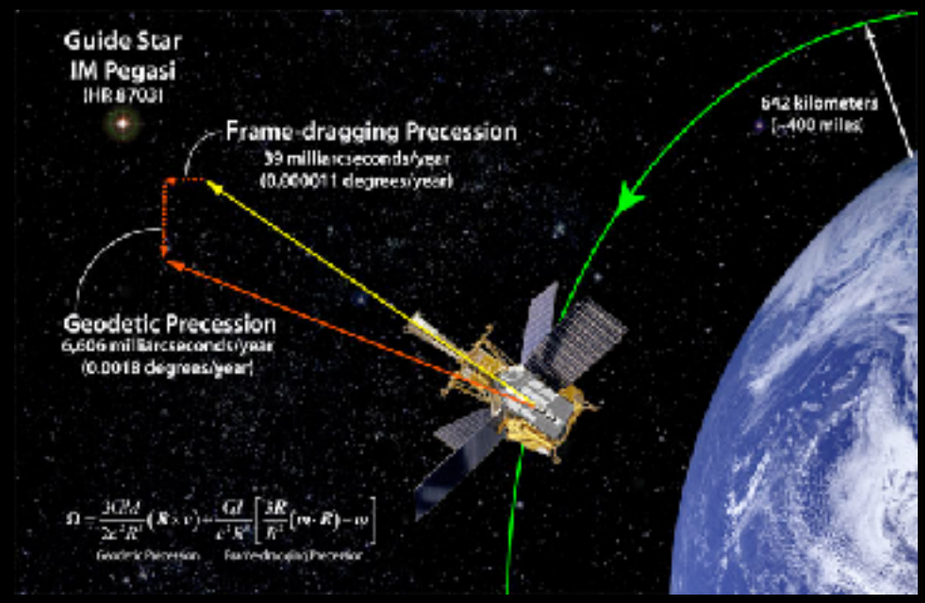
Degradation of the SOHO solar cells during proton events.



Orientation problems

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

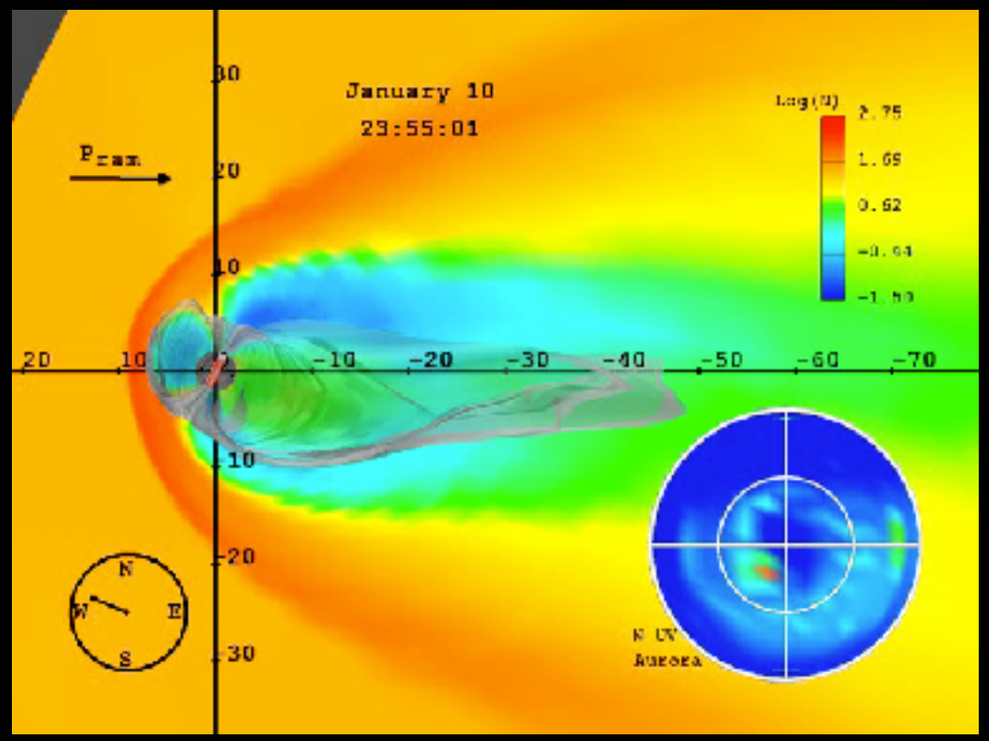
Star trackers can easily be «tricked» by false stars created by high energy protons hitting the CCD camera.



Før protonskur

Etter protonskur

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



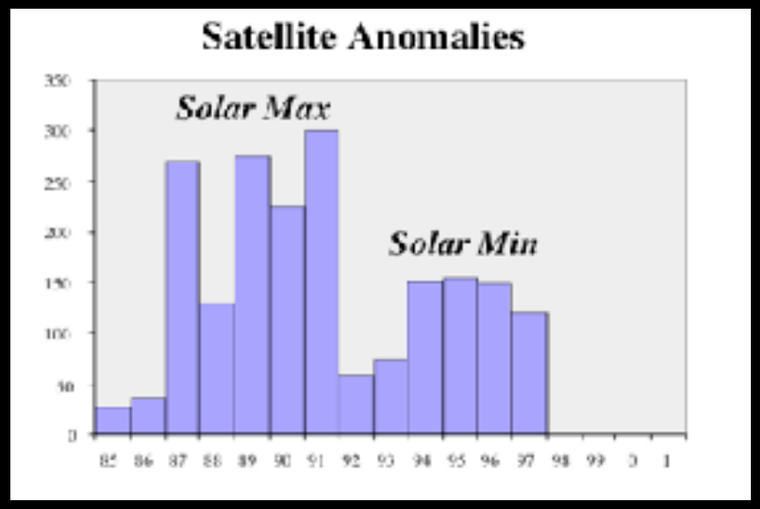
Surface Charging

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

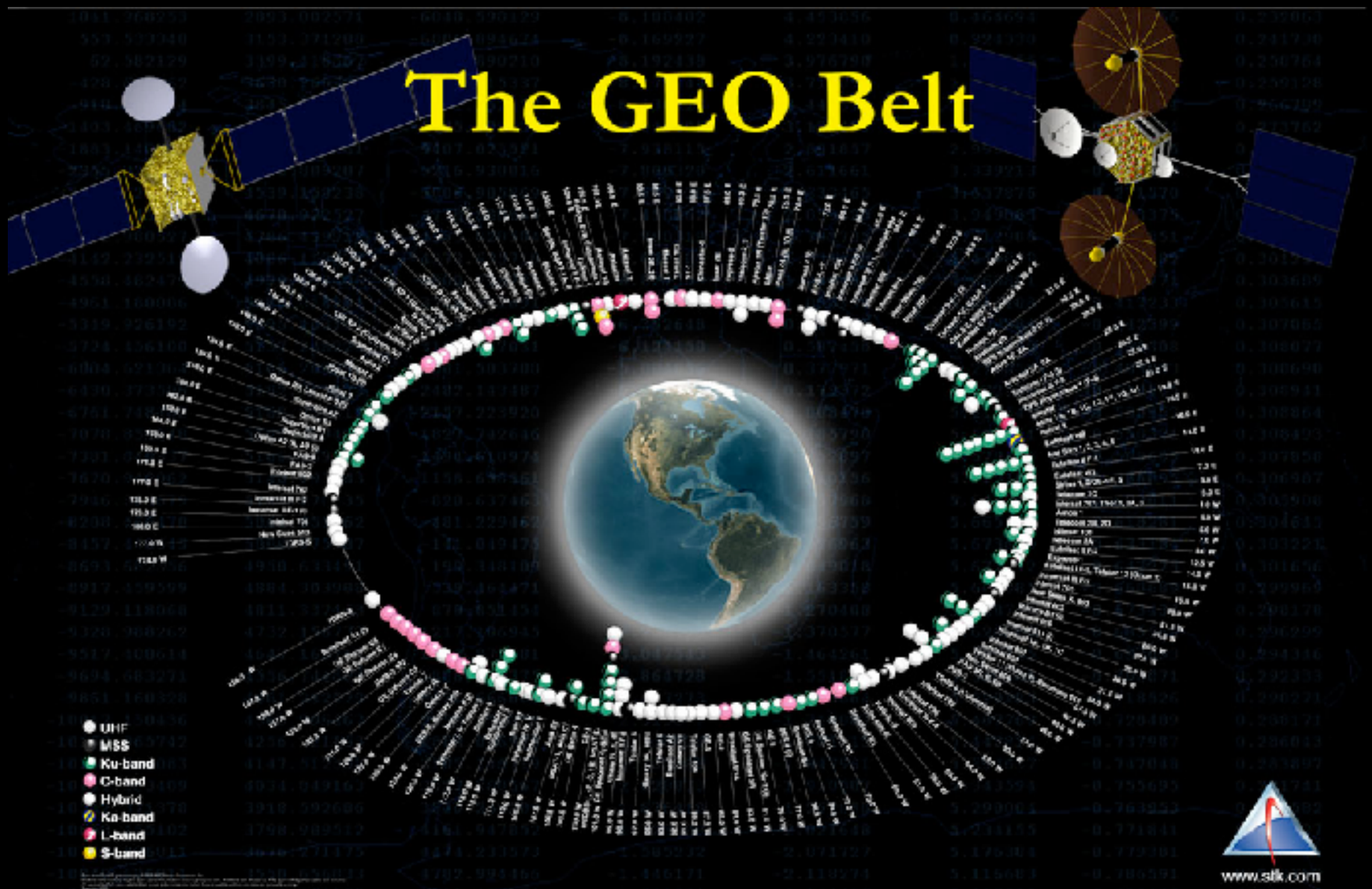


Galaxy 15 - «zombiesat»

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..



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.

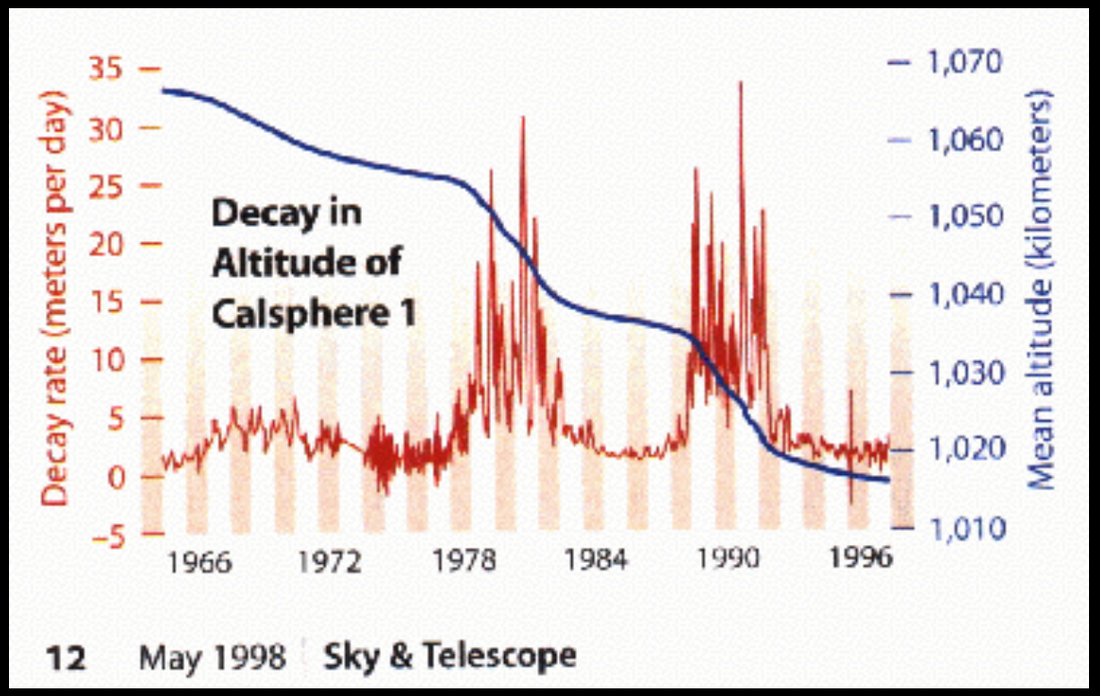


Image Credit: Skylab image courtesy of NASA. Newspaper image courtesy of L. J. Lanzerotti, Bell Laboratories, Lucent Technologies, Inc.

SMM – Solar Maximum Mission

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

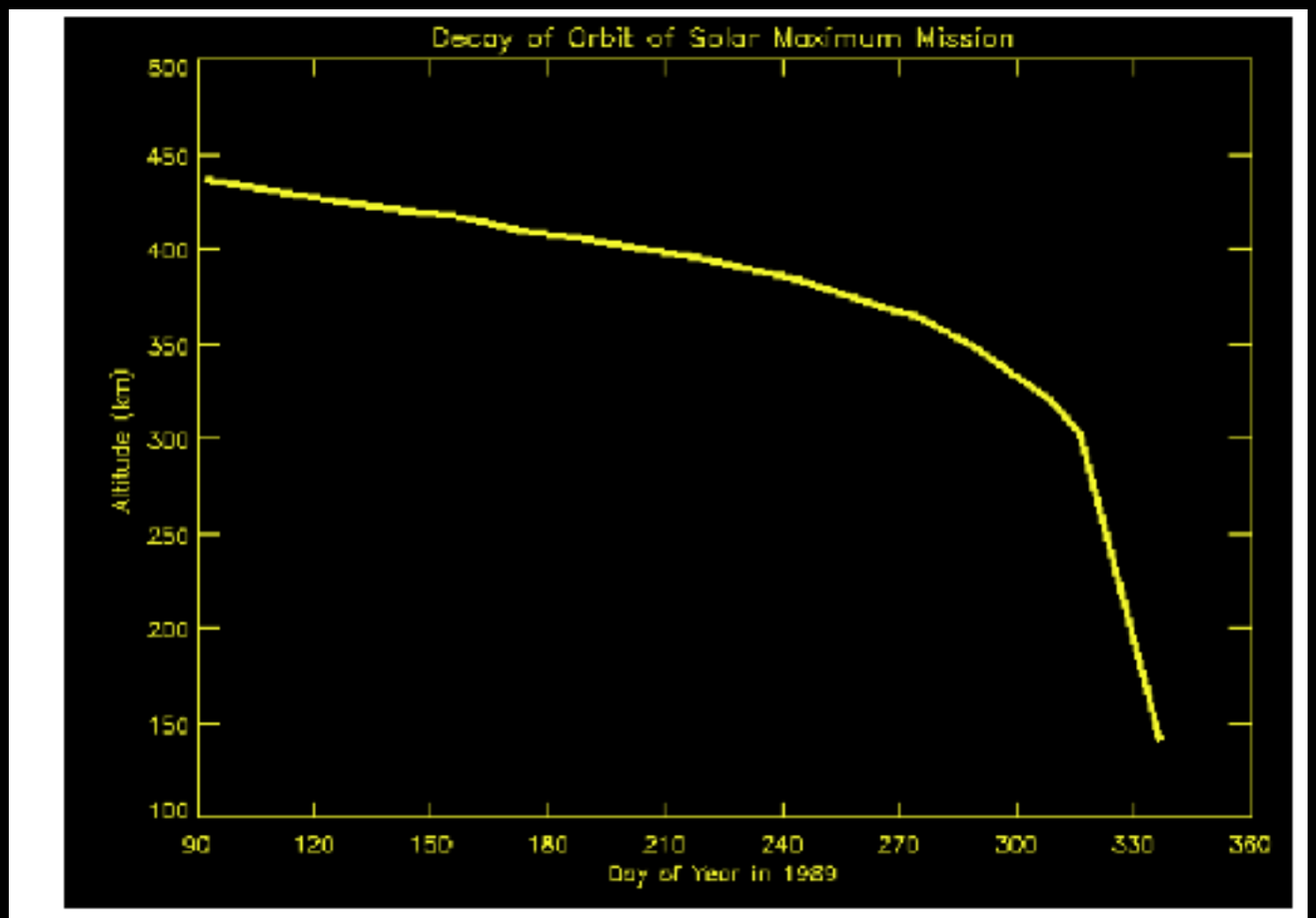
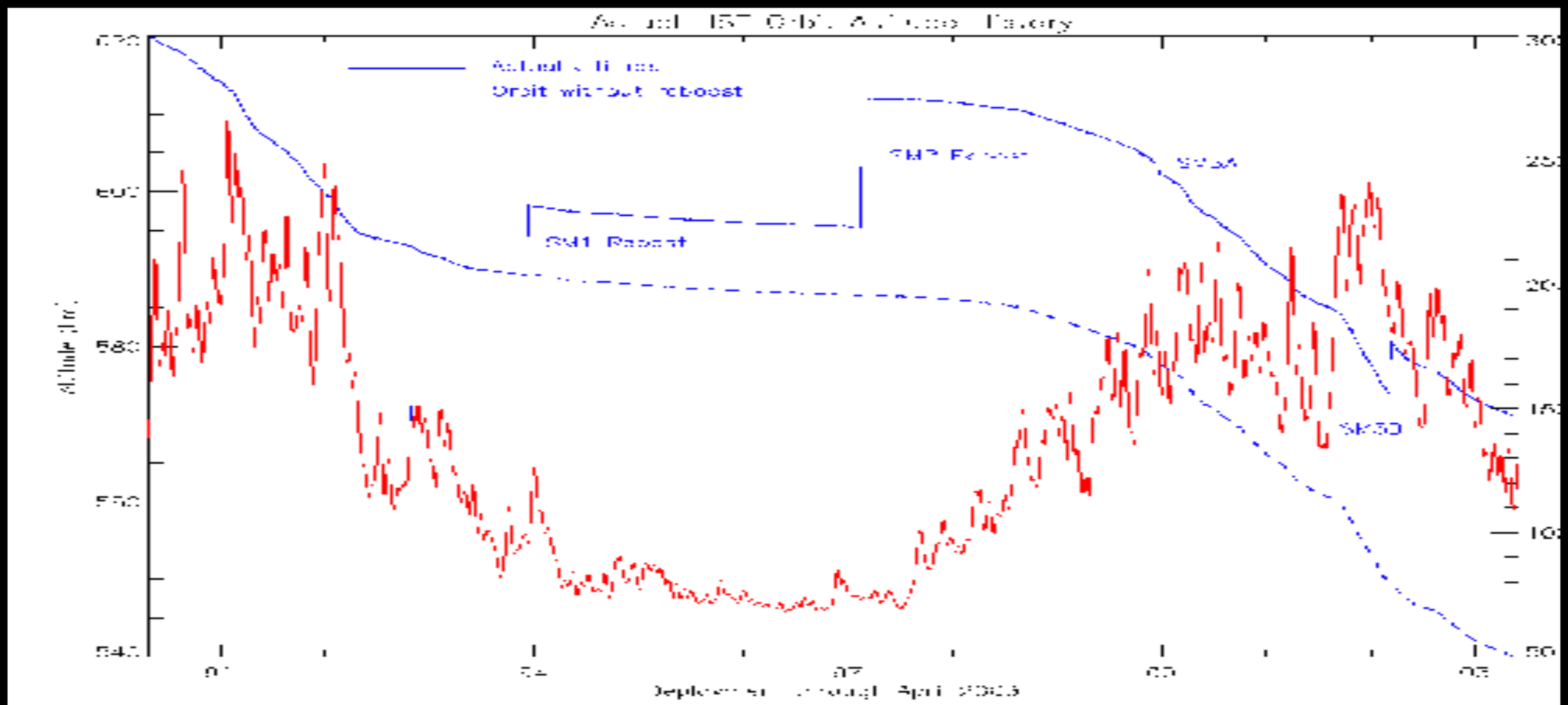


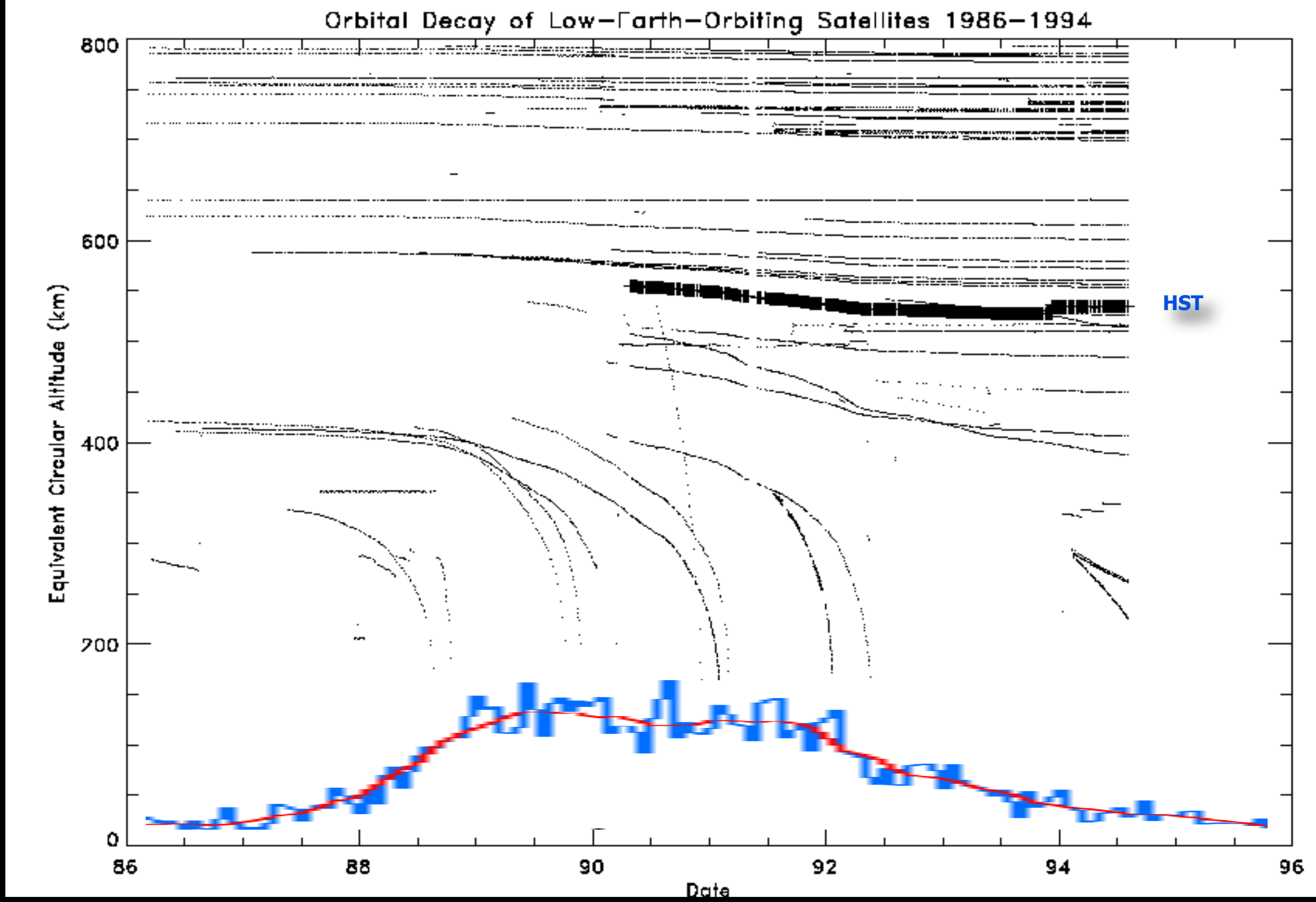
Figure 3:
Actual decay curve for the Solar Maximum Mission satellite which re-entered the Earth's atmosphere at the beginning of December 1989. The satellite was the first spacecraft to be serviced in orbit by a crew from the Space Shuttle. Notice how the satellite decays slowly at higher altitudes,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

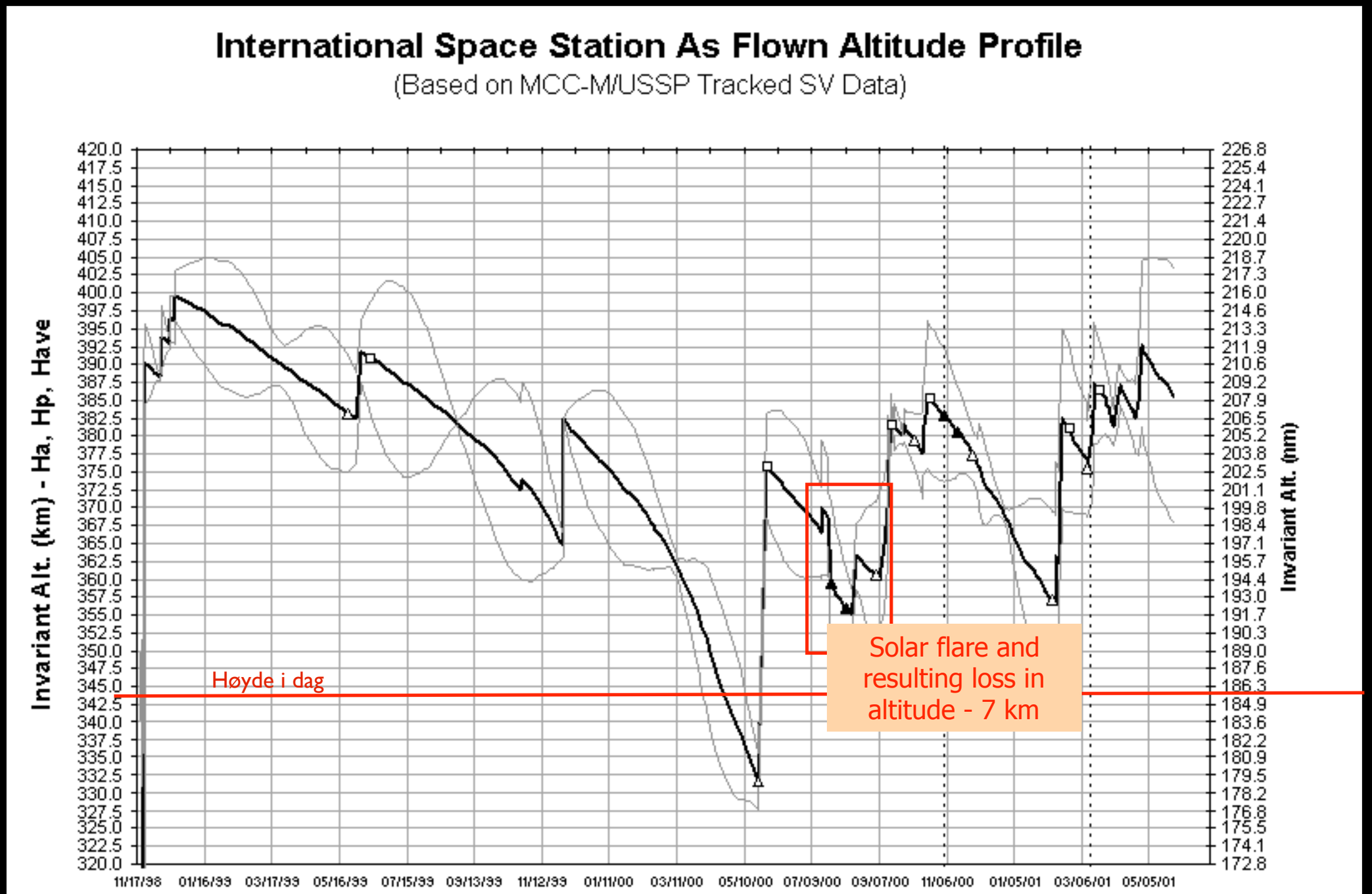


Low orbit satellites suffer

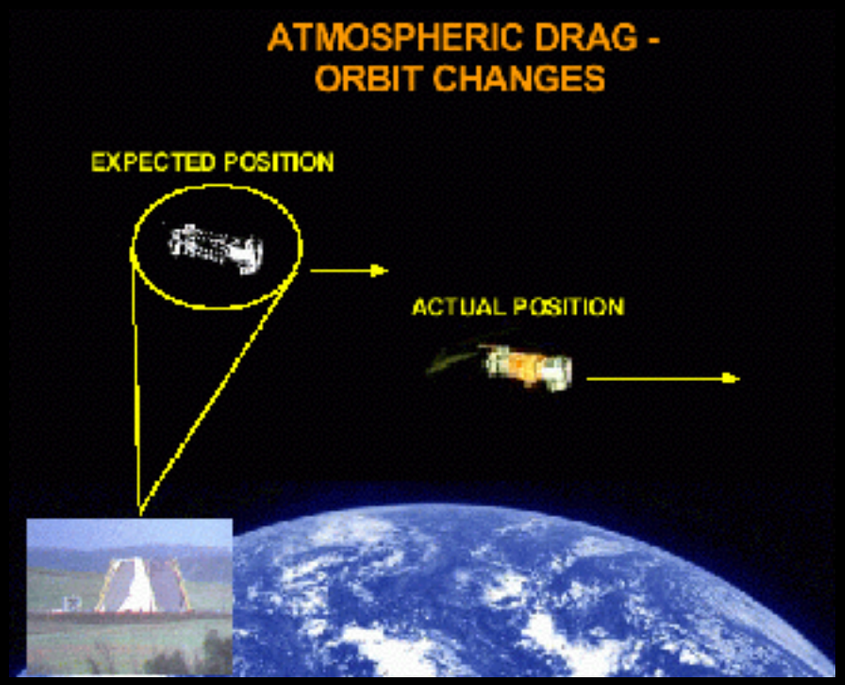


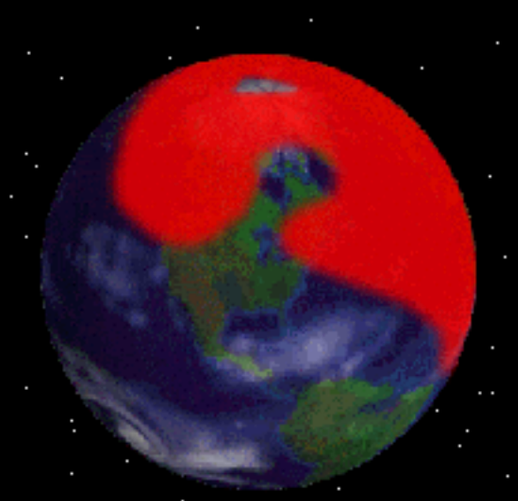
Drag: Altitude history ISS

ISS altitude 15 November 2007: 343 km

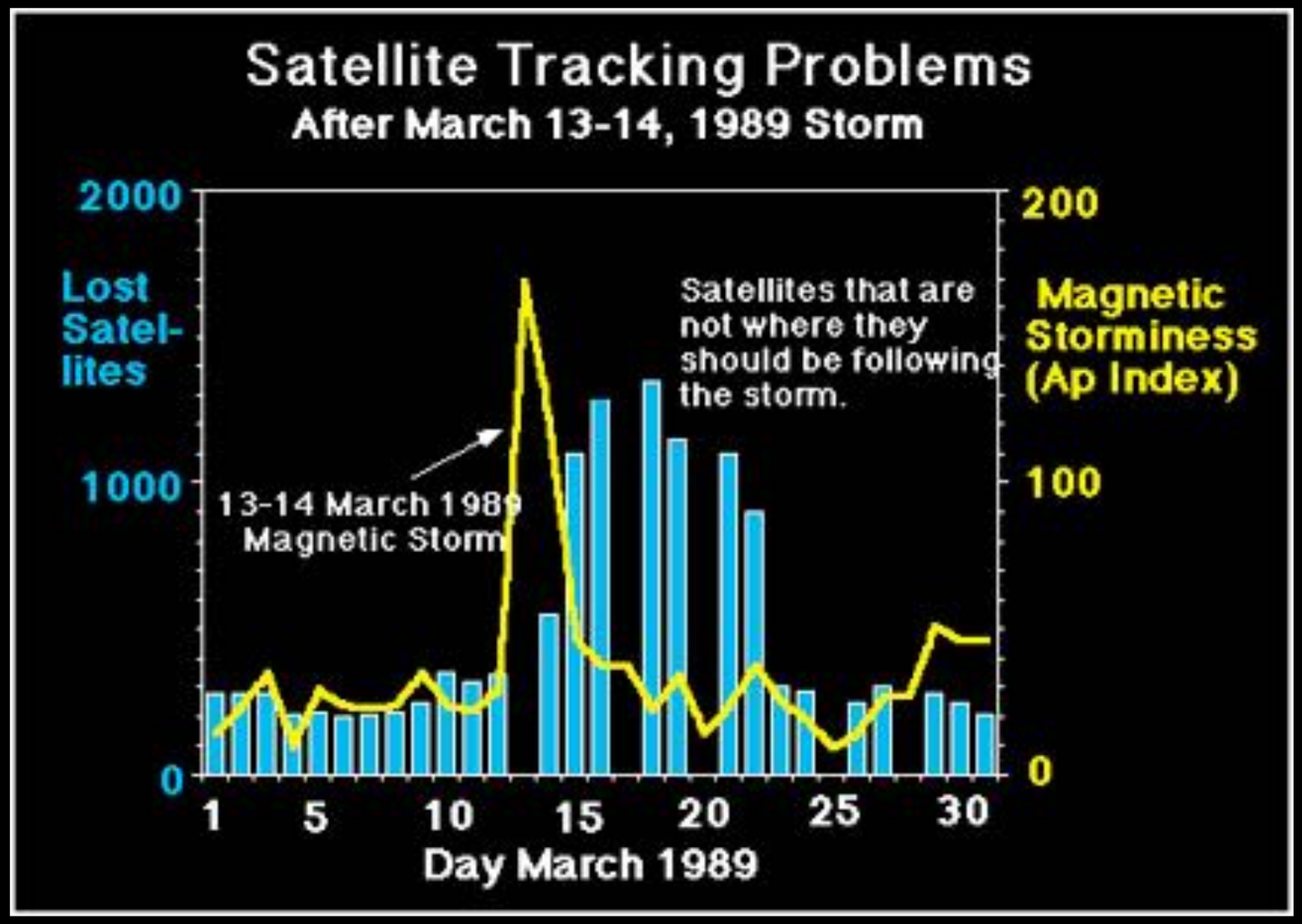


Orbital tracking of satellites



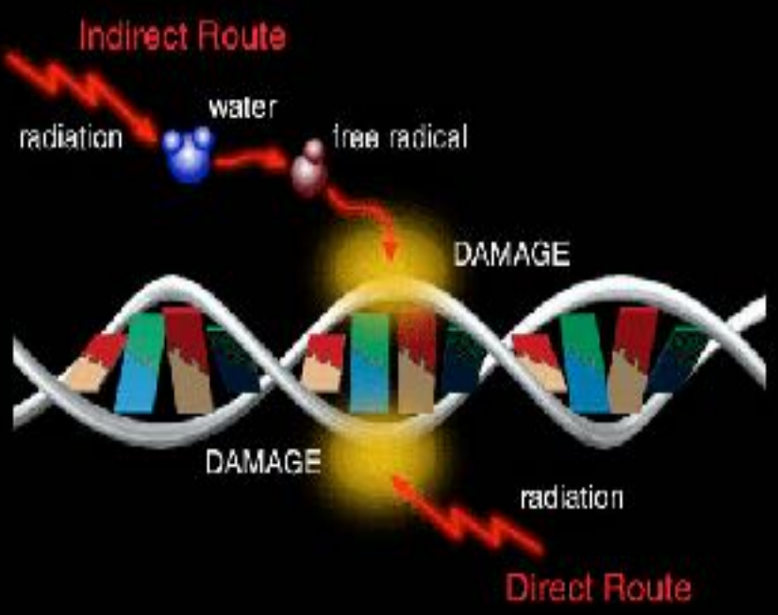


Increased friction leads to inaccurate calculation of orbits - which again leads to increased danger for collisions.



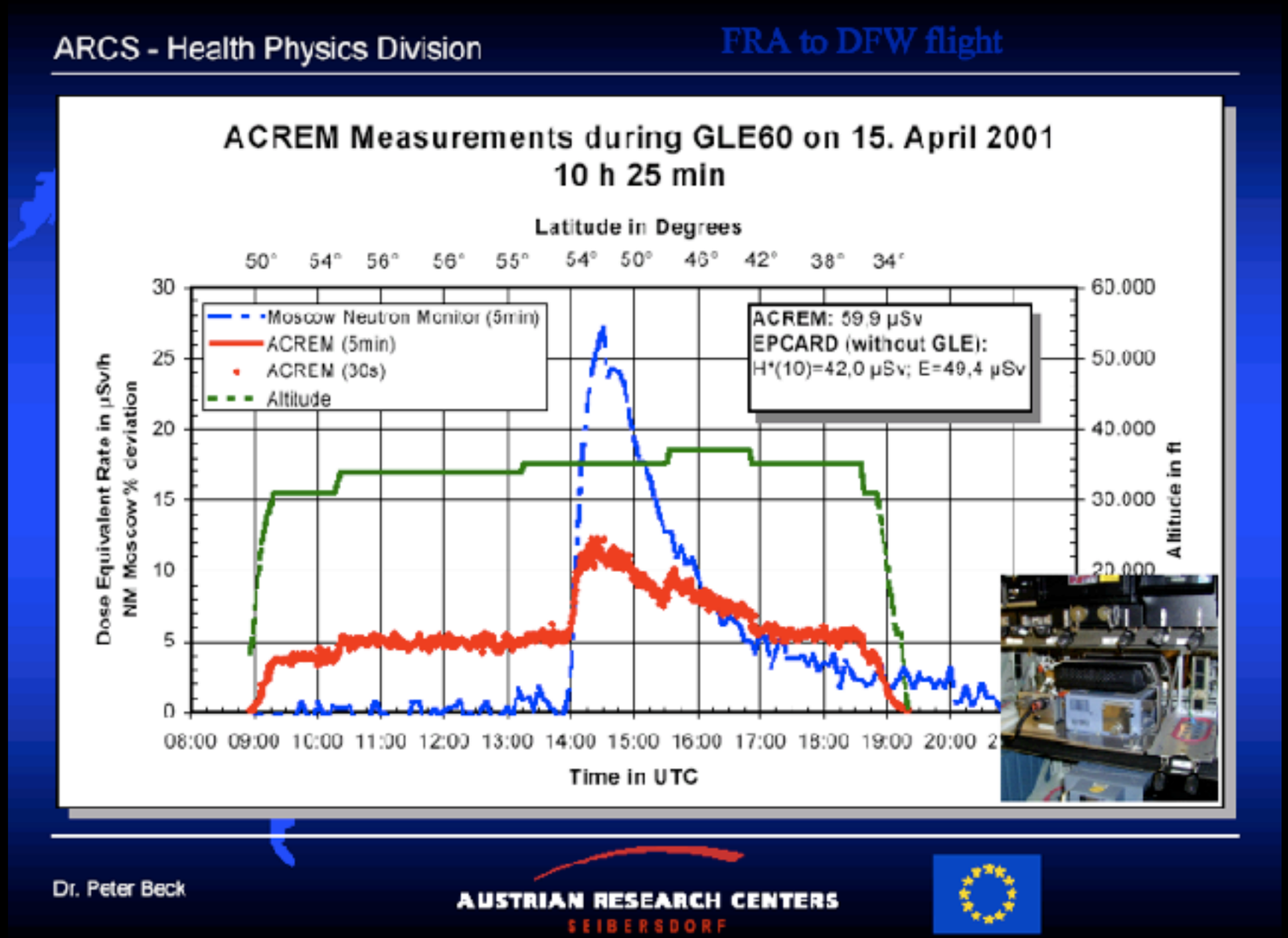
During a solar storm in 1989 one lost 1300 of 8000 objects being tracked.

Radiation hazards

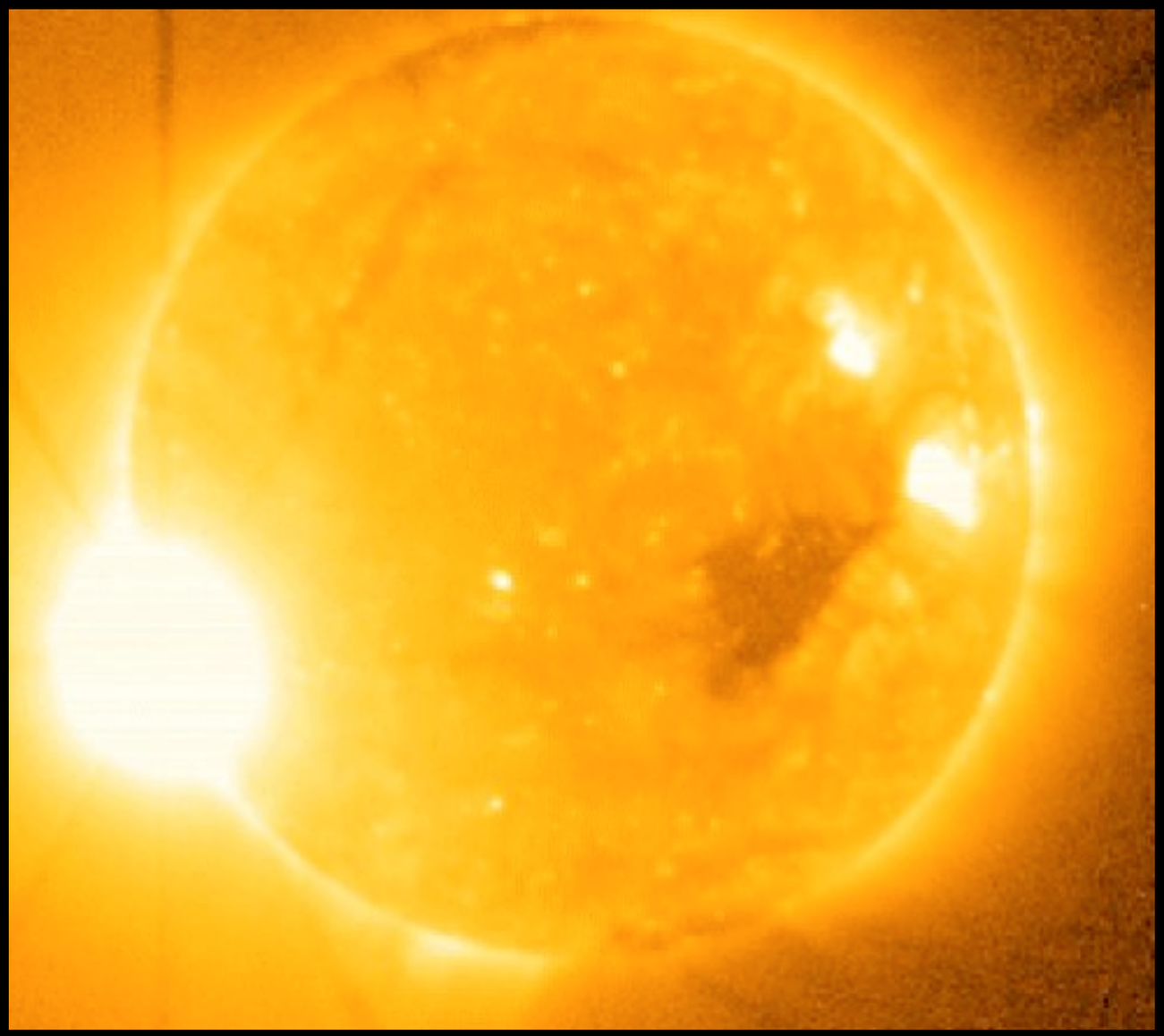


- Polar flights
- Humans in space
  - Space Shuttle, International Space Station, missions to the Moon and Mars

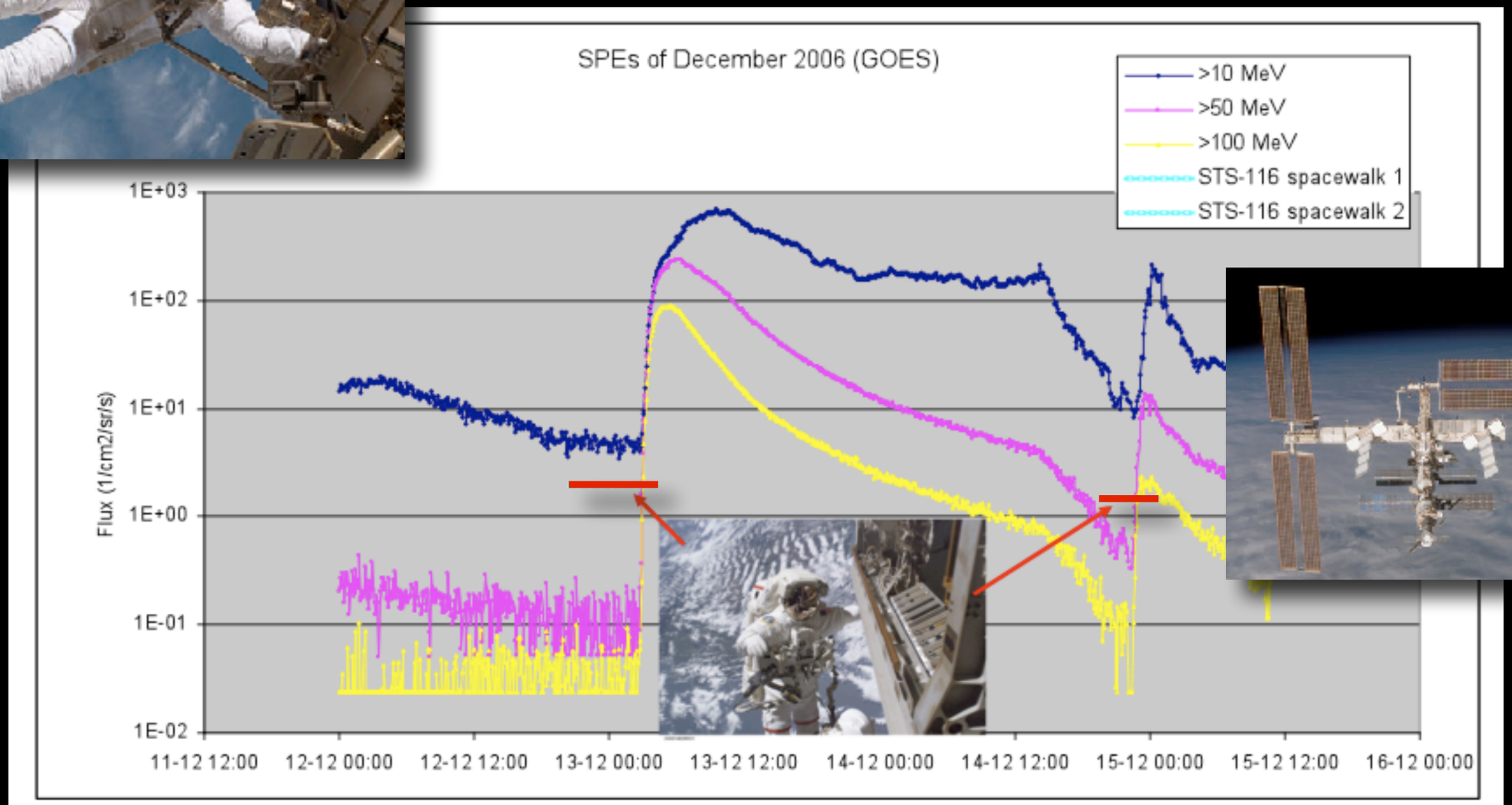
Effects on passengers



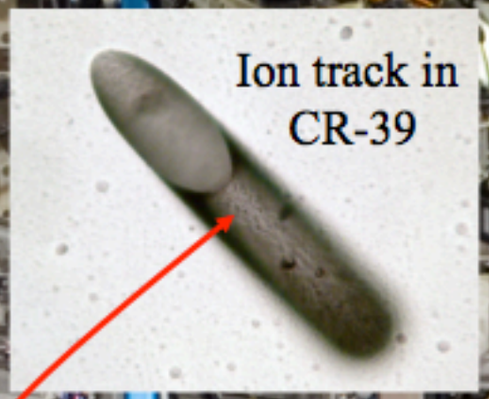
Solstorm 14 desember 2006



Christer Fuglesang - Proton event



Christer Fuglesang - radiation



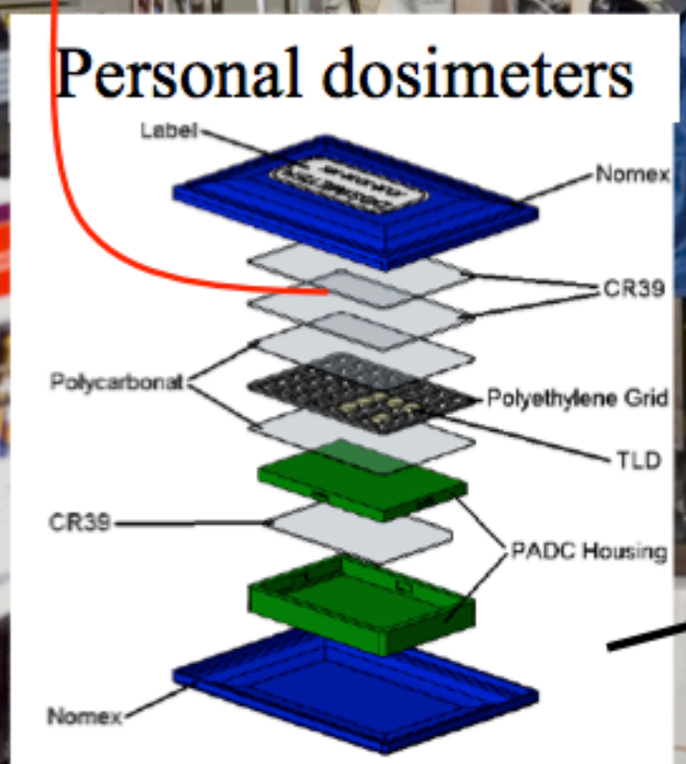


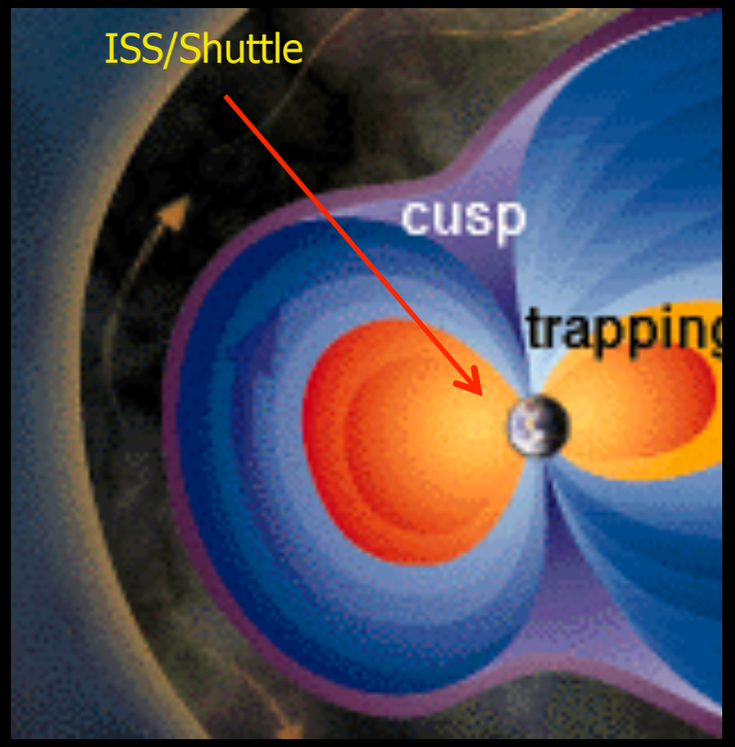
Figure 1: EuCPD – Explosion view

The Apollo-programme - pure luck?

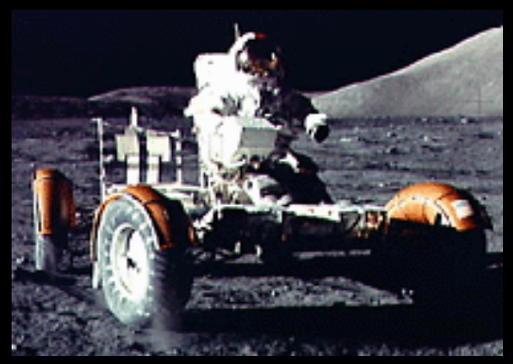
- Humans have limited experience from deep space muíssions. Only a few short trips to the Moon with Apollo.
  - ISS og and the space shuttle were protected fairly well by the magnetosphere.

- 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.



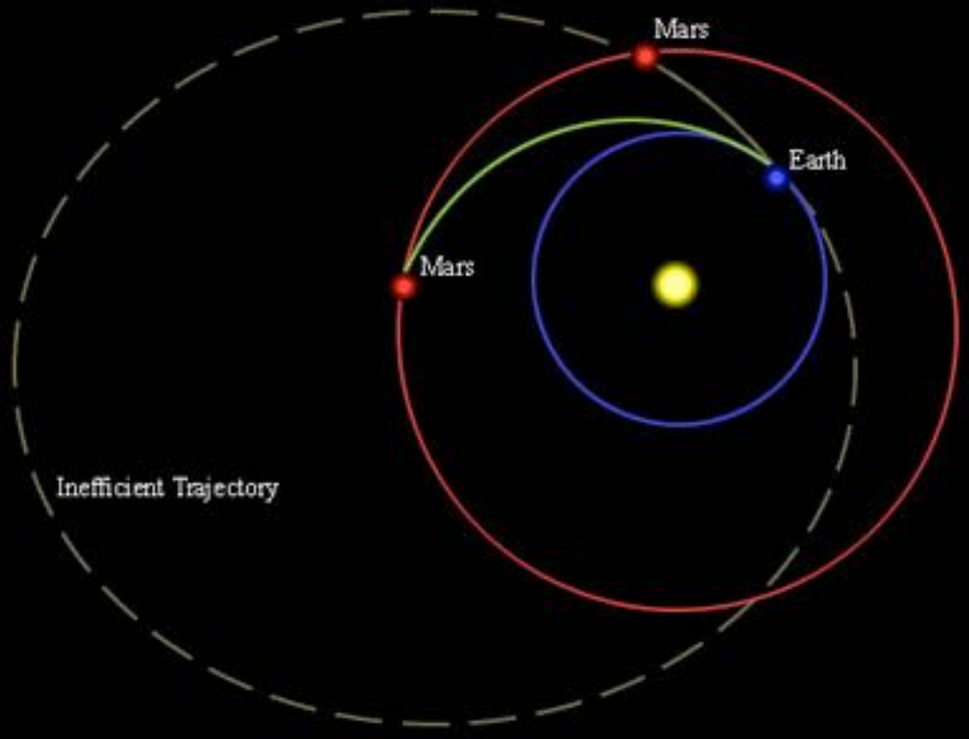
Proton events during the Apollo program

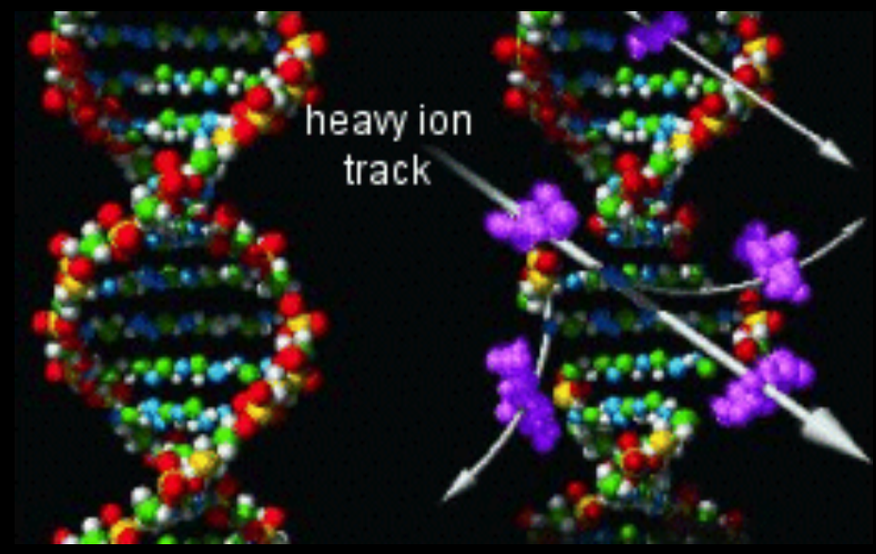


1972 event: 4000 REM in space suit, 1000 REM in Lunar Module

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

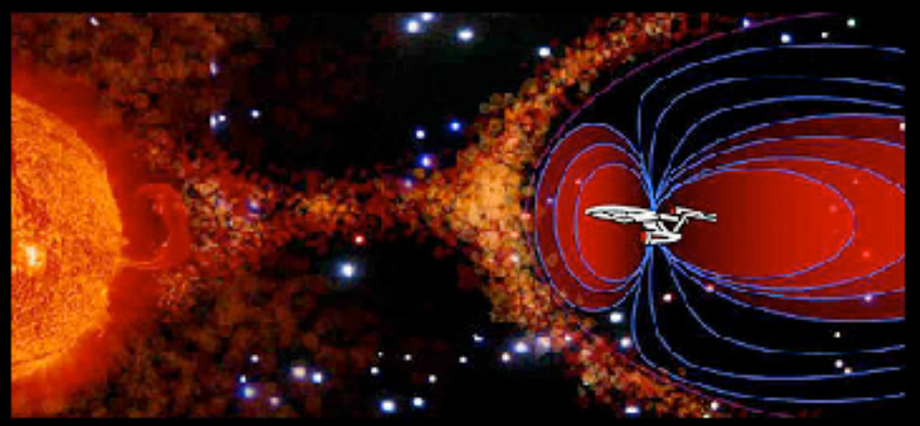
- Radiation doses from solar storms and cosmic rays since Mars lack a magnetosphere.

- Harmful for humans and electronics

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

- Better space weather warnings important.

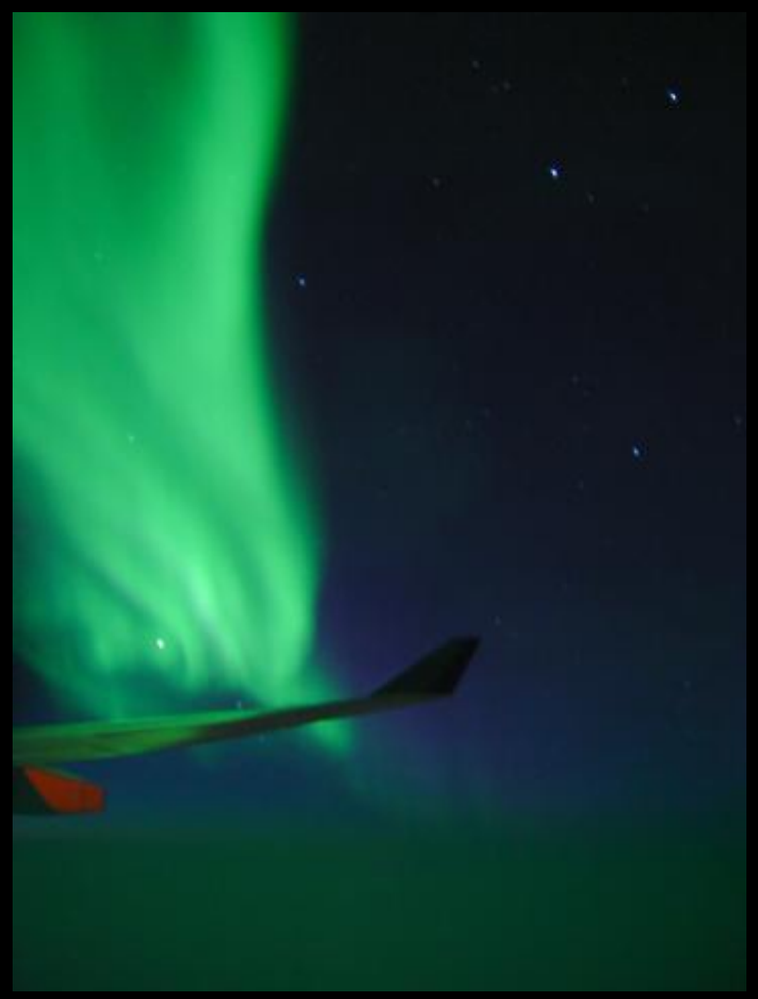
- Communication problems with the Earth during solar flares (ionization in the Mars atmosphere



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

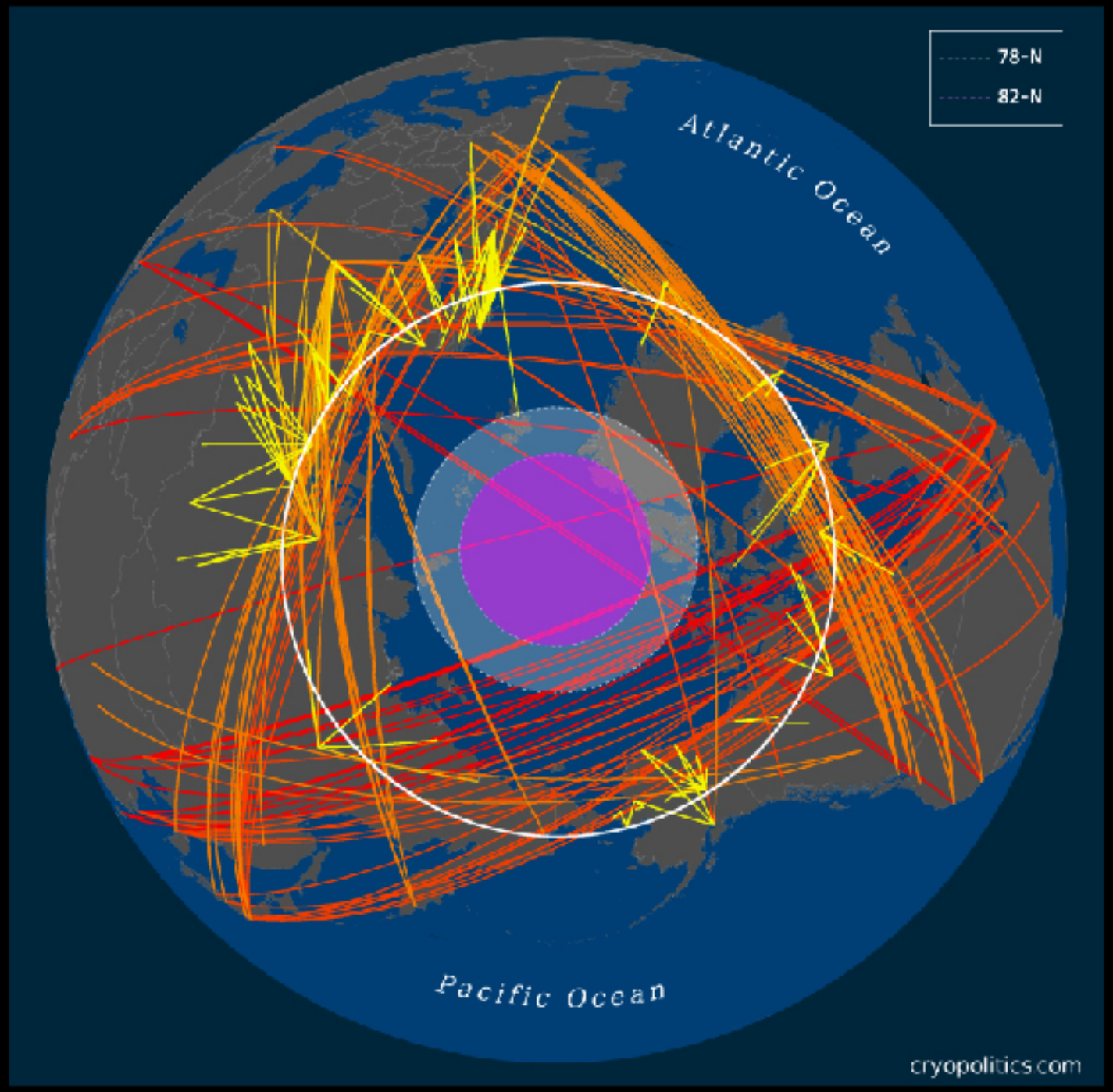
Effects of airplanes

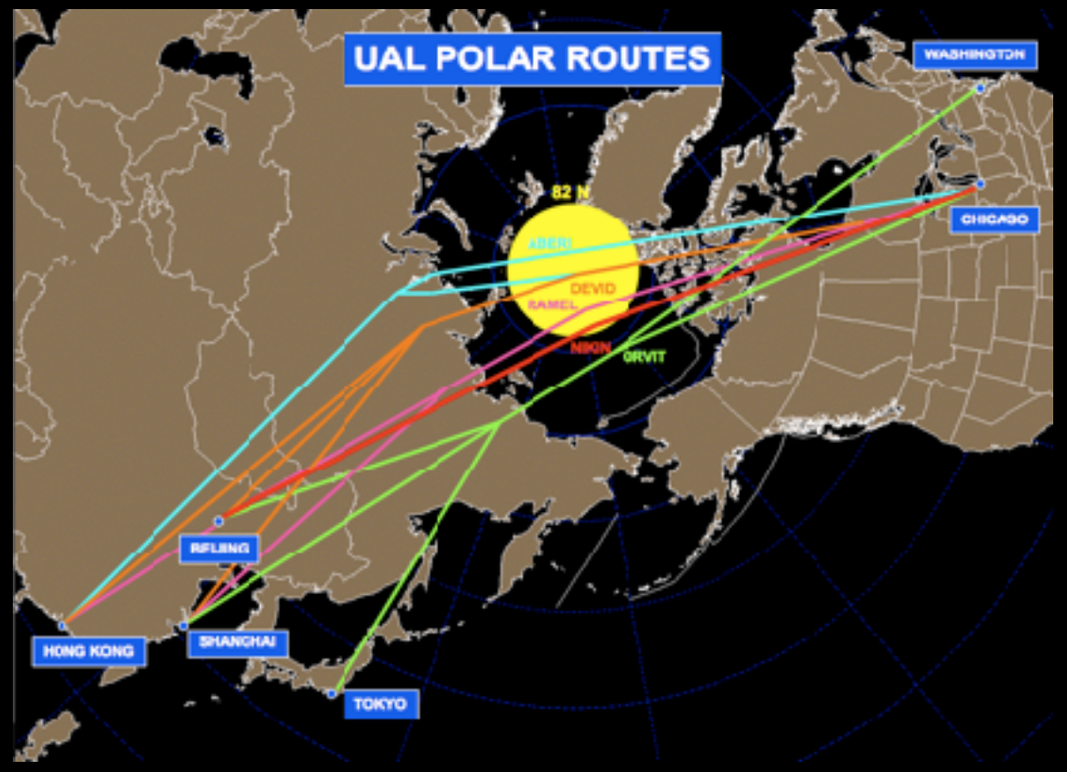
- Disruption of HF communication on polar transatlantic flights
- Energetic particles (affects humans and avionics)
- GPS and navigation

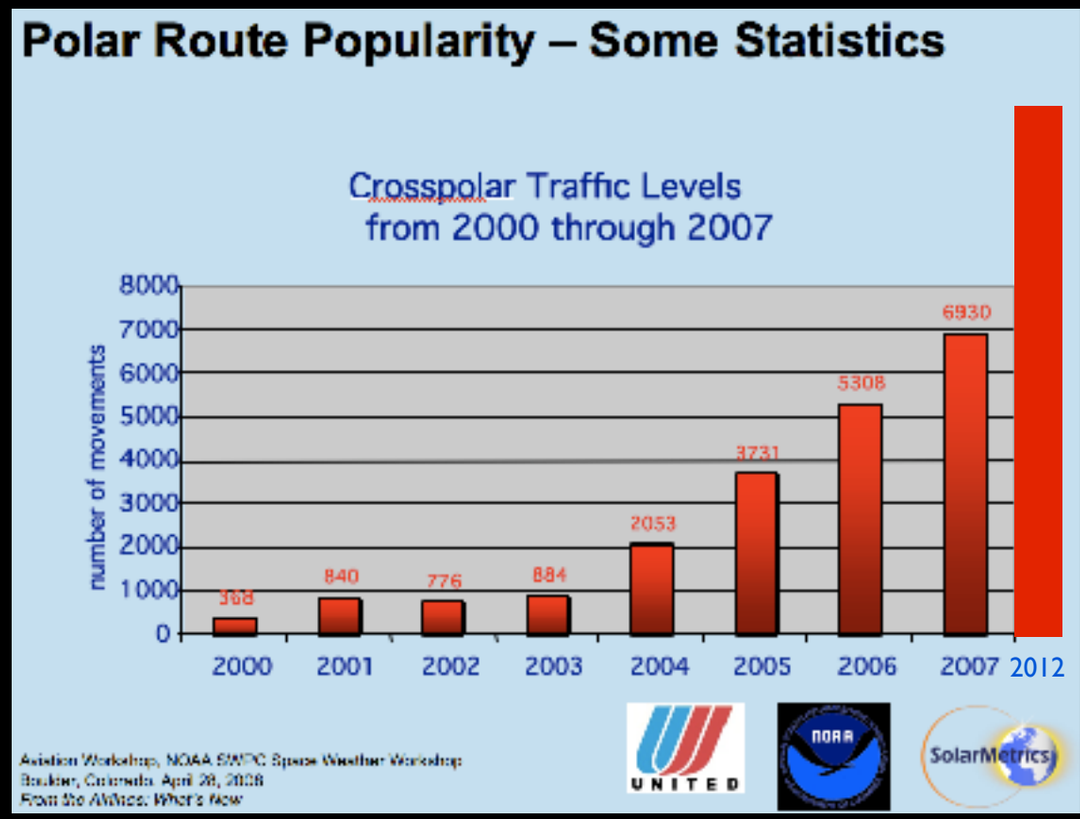


Polar routes

- Polar routes : 11.214 flights in 2012 (3,365,000 passengers)
- No satellite communication north of 82 degree
- GPS can get unstable.







Arctic - Highway in the Sky

65 000 transits over Norwegian airspace

Increasing by >15% annually

Bodø Oceanic Control – main controll

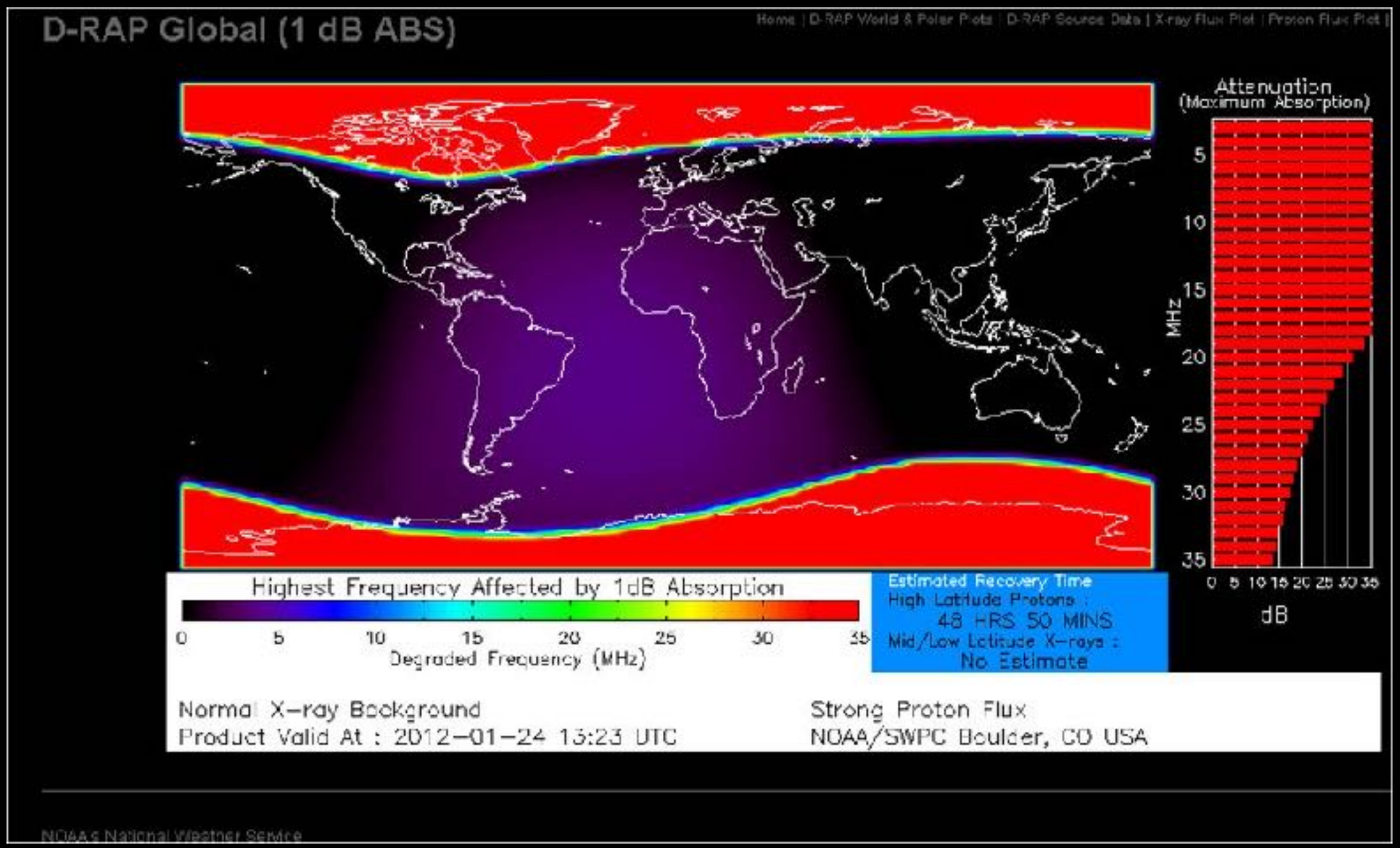
Need high quality navigation and communication

Figure 3.1. Arctic Flight Information Regions as designated by the International Civil Aviation Organization. Source: based on information from the ICAO website.

Norsk Romsenter
NORWEGIAN SPACE CENTRE

Flights 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.

Radio burst affected flight radars

FOX NEWS World

Home Video Politics U.S. Opinion Business Entertainment Tech Science Health Travel Lifestyle World On Air

World Home U.N. Conflicts Terrorism Disasters Global Economy Envi

WORLD

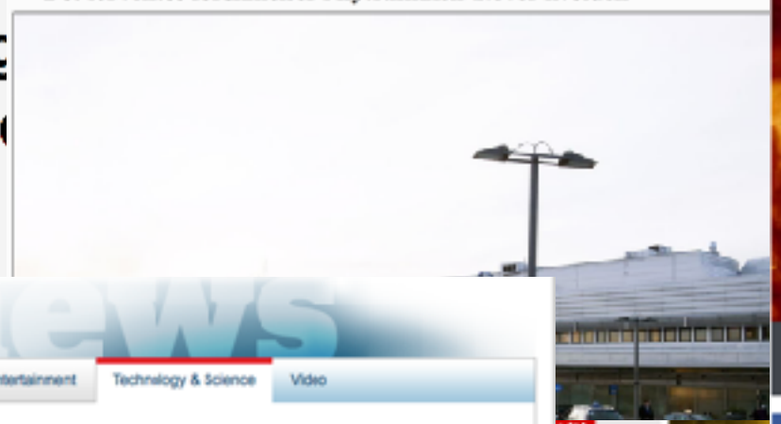
Solar storm knocks out flig systems in Sweden, groun across country

Published Novemb

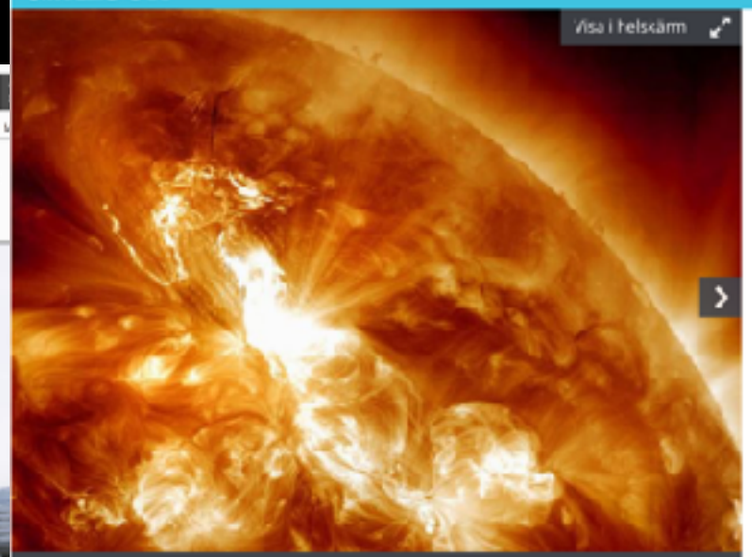
VG NYHETER

Solstorm slo ut flyradarer i Sverige

Det forventes forsinkelser i flytrafikken utover kvelden



AULT OM RESOR RESMÅL TYP AV RESA FLYG HOTELL RESFAKTA



Flygtrafiken i Sverige stoppades på onsdagen på grund av solstormar.

Foto: AP

CBC news | Technology & Science

Home Opinion World Canada Politics Business Health Entertainment Technology & Science Video

Technology & Science Quirks & Quarks Blog Spark Photo Galleries

Solar storm knocks out flight control systems in Sweden, grounds planes

Flights disappeared from radar screens

The Associated Press Posted: Nov 04, 2015 3:38 PM ET | Last Updated: Nov 04, 2015 3:40 PM ET

2154 shares

Facebook

Twitter

Reddit

Google

Share

Aviation officials say a solar storm knocked out the air traffic control systems in Sweden on Wednesday, prompting them to close the country's airspace for more than an hour.

The civil aviation authority said the

Parked aircraft are seen at st Stockholm Arlanda Airport in a

ADVERTISEMENT

Publicerad 4 nov 2015 17.27

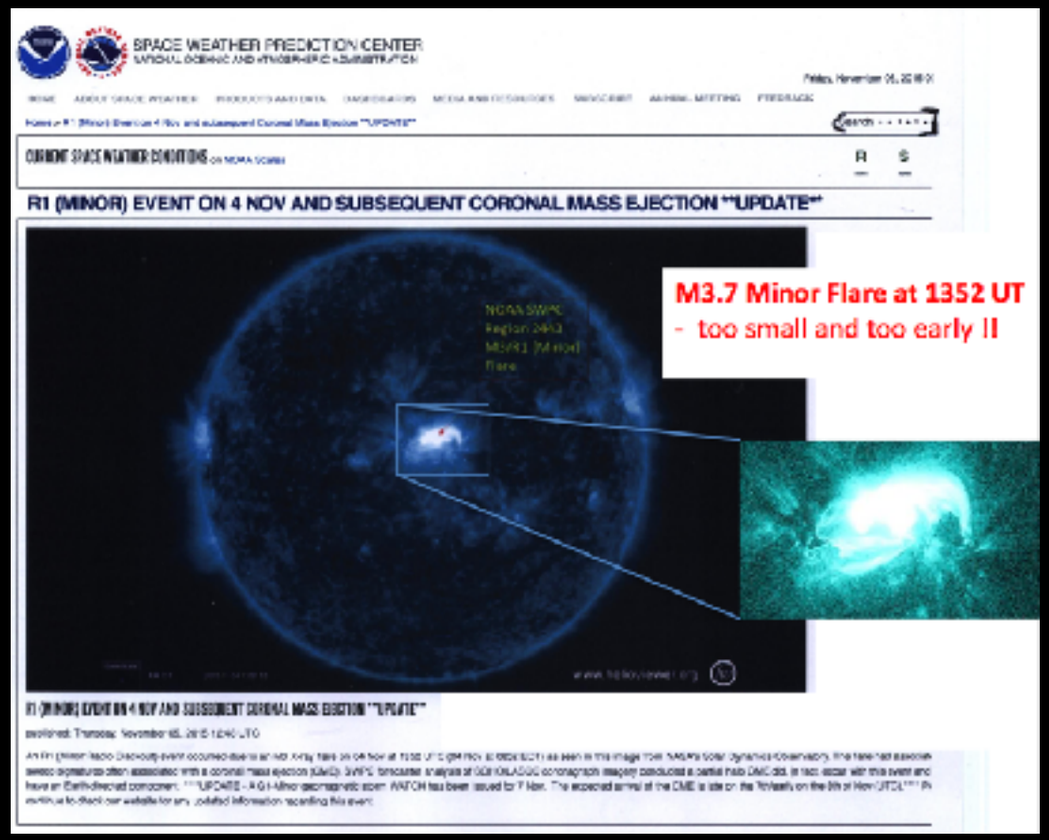
Sverige mer utsatt för solstormar

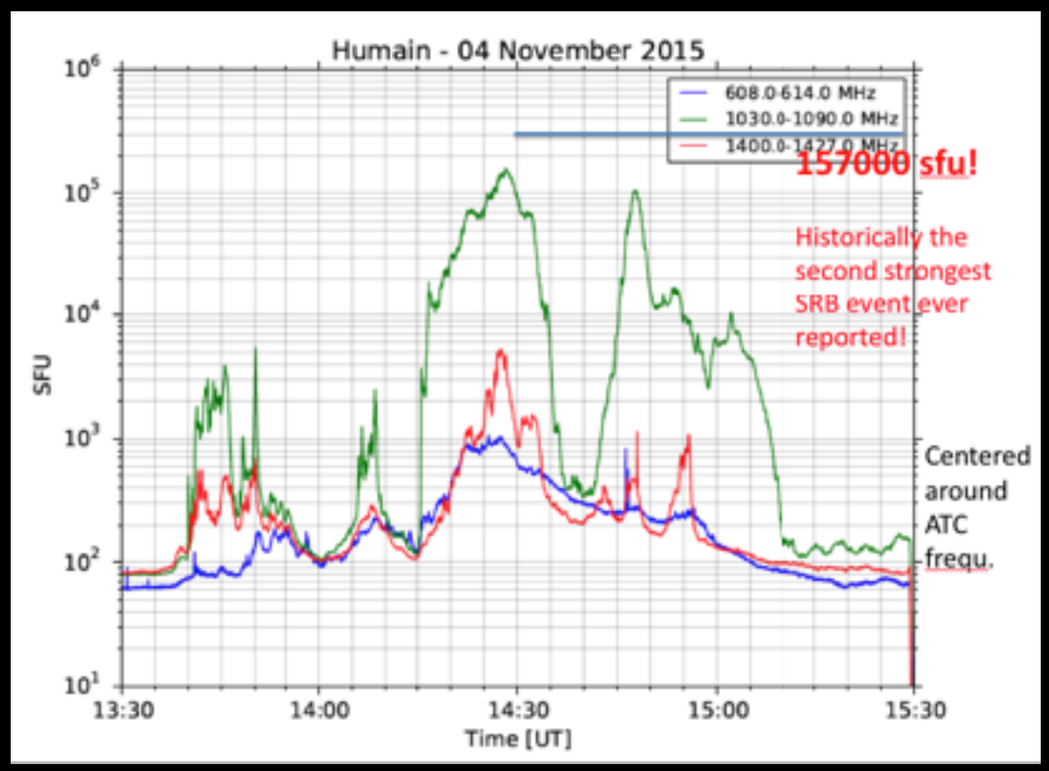
Solstormar stoppade tidvis flygtrafiken under onsdagen.
Men vad är en solstorm?
Här får du svar på dina frågor om fenomenet.

SLIK HAR DU ALDRI SETT SOLA FØR: Onsdag ettermiddag meldte svenske medier at alle flyvninger til og fra Sverige foreløpig er innstilt grunnet en solstorm. Solen er selv ligger 149 000 000 kilometer unna jorda, kan solstormene utgjøre en fare for oss. Her ser du et unikt innblikk i hvordan solen ser ut. Video: NASA

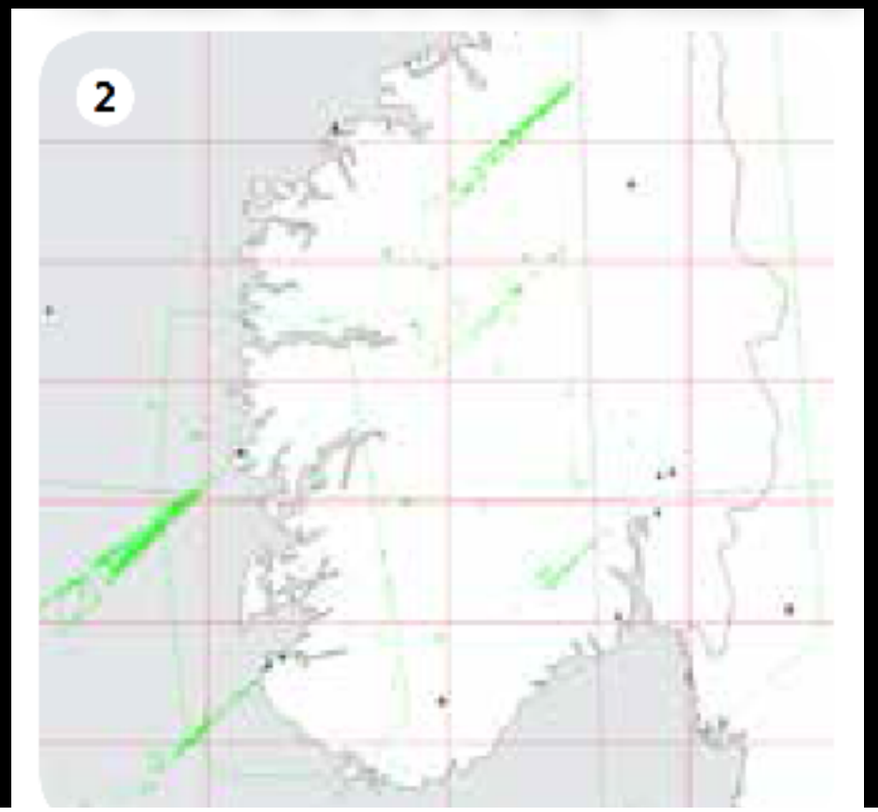
Solstorm fikk radarsystemet til å kollapse. Stoppet all flytrafikk til og fra Sverige

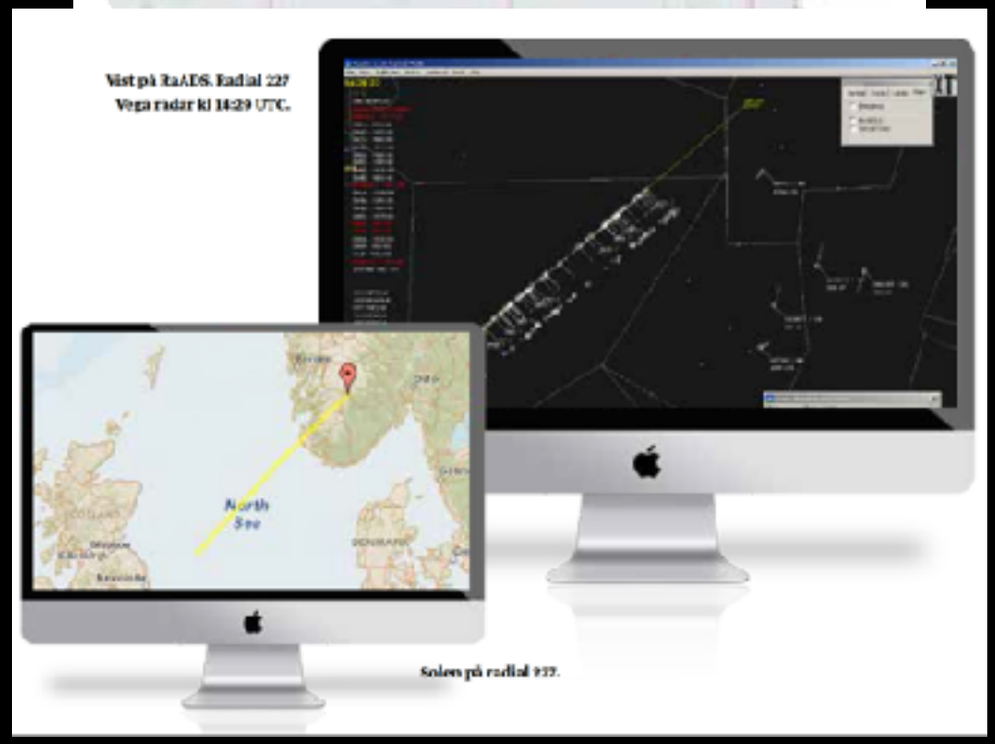
Radio burst affected flight radars
4 November 2015





The event led to 5776 delay-minutes for SAS

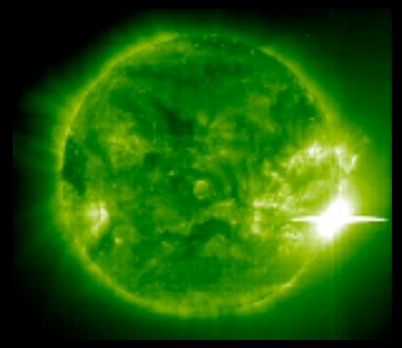




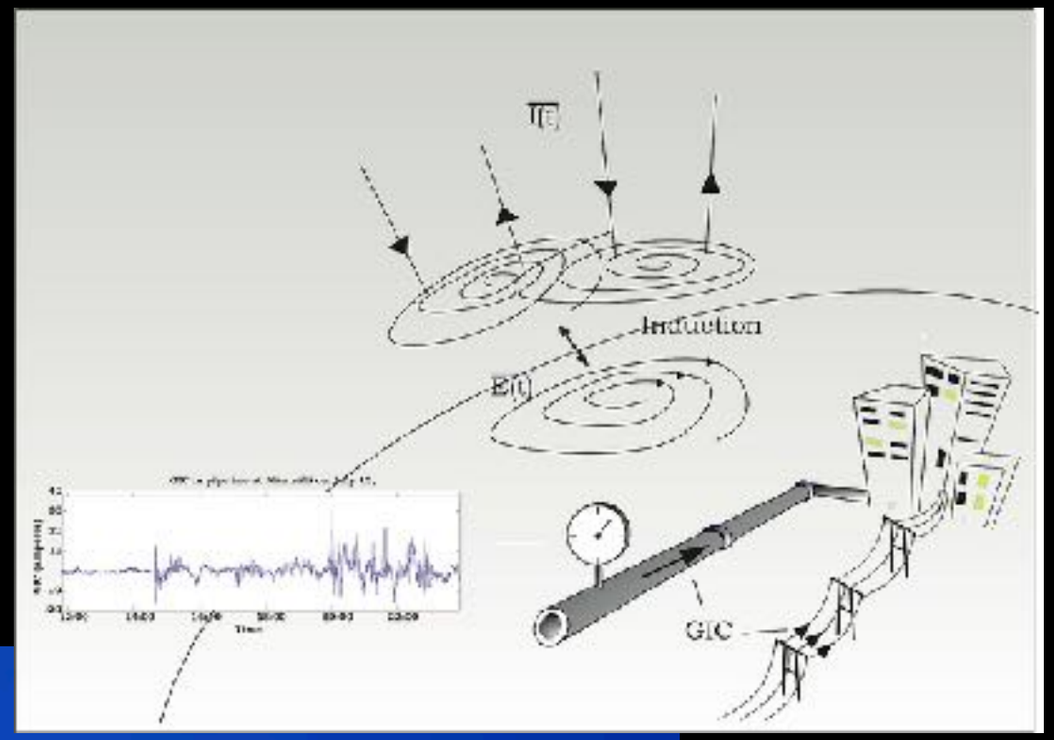
Avinor

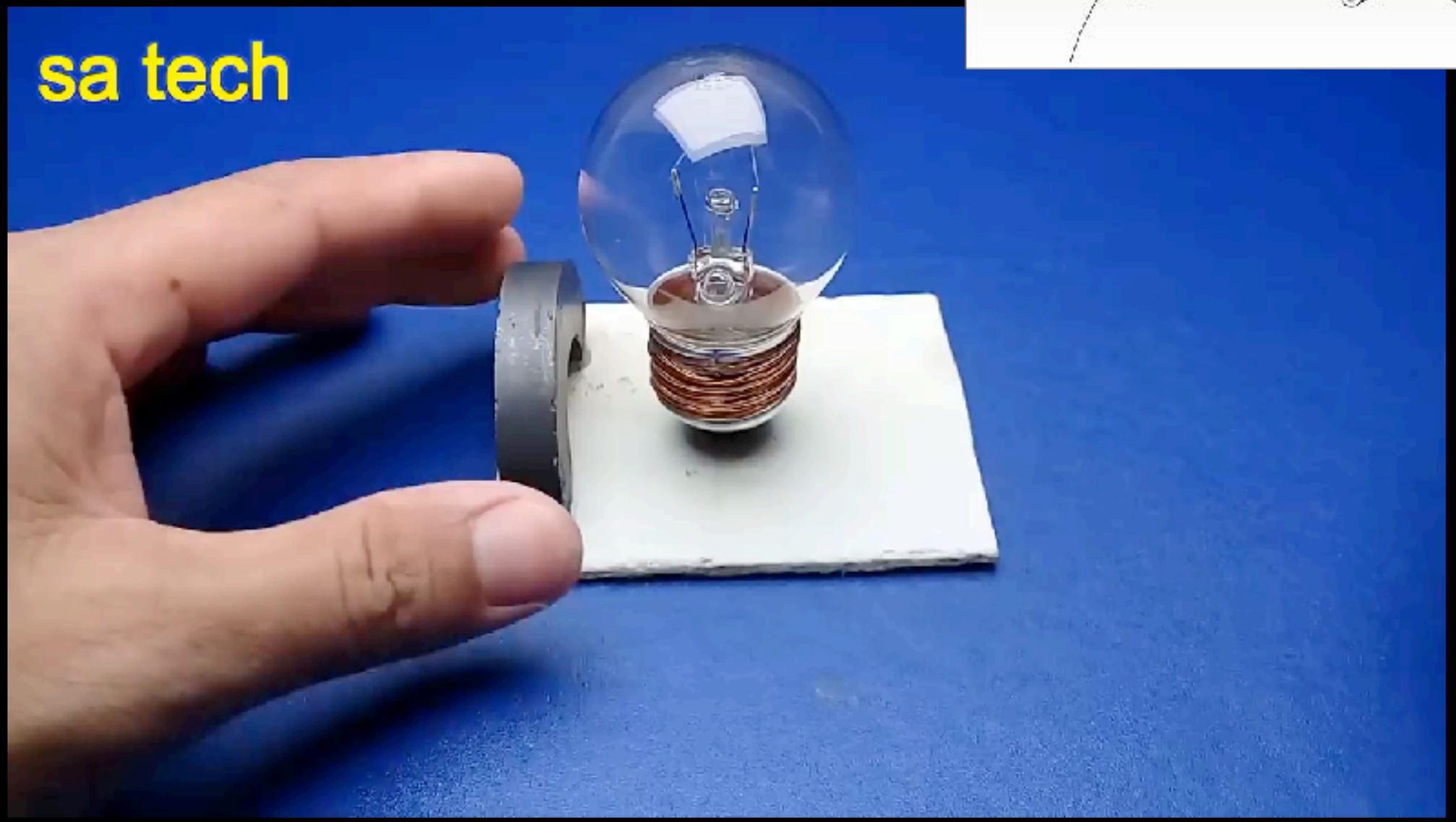
Effects on cell-phones

- Radioburst from the Sun can interrupt 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.



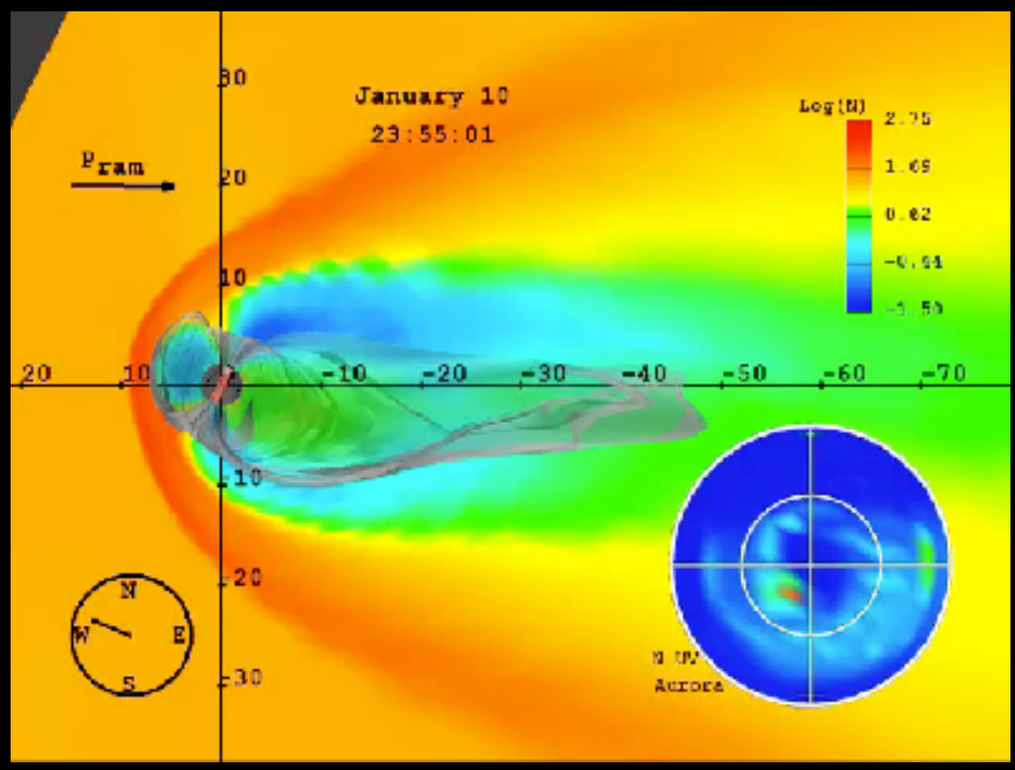
Induced currents in powerlines





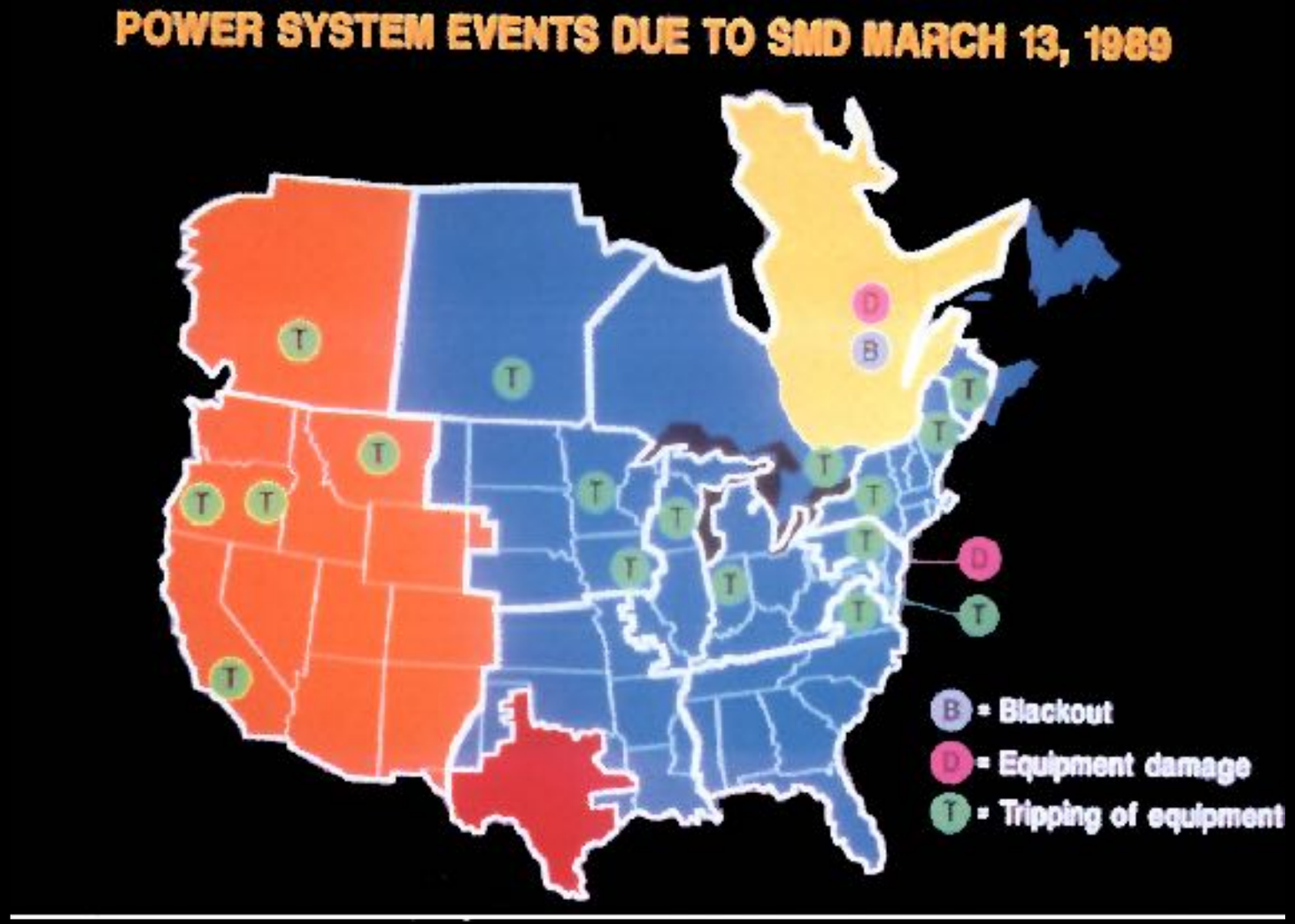
Disruption of power grids

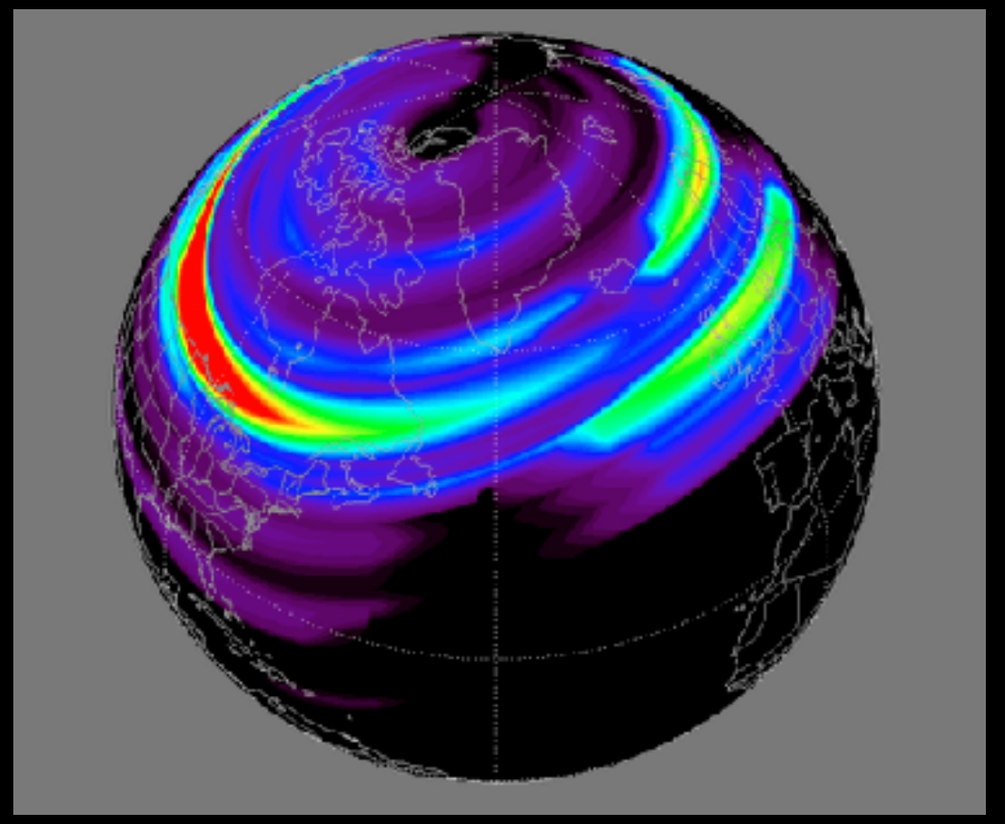
- These currents leaks into all lang conductors:
  - Power grids
  - Oil- and gas pipelines

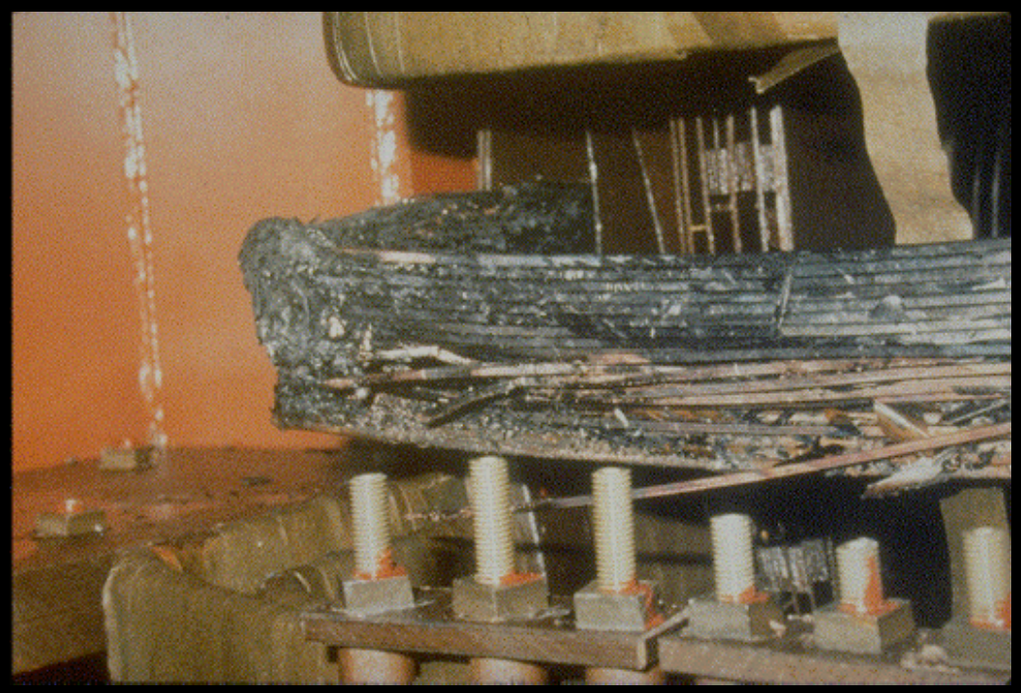


Power failure March 1989

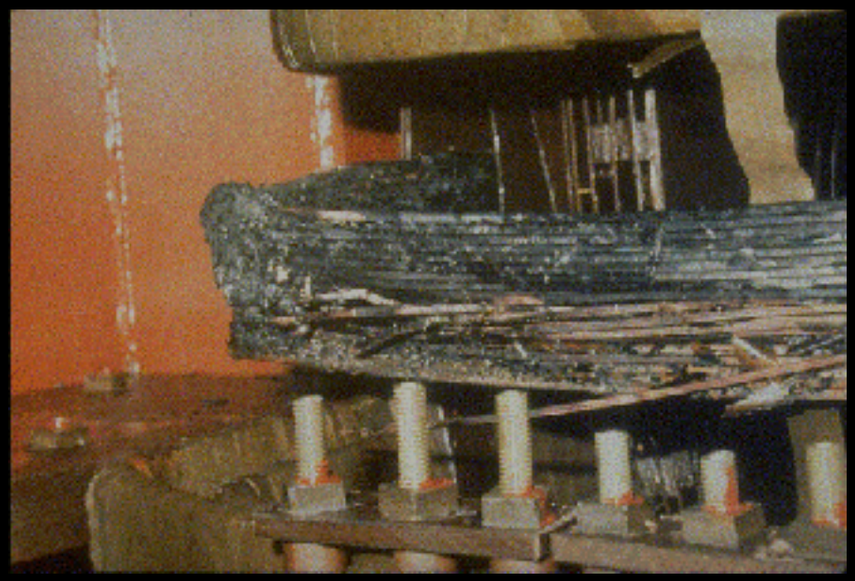
- The entire power grid in Quebec collapsed
- The collapse almoste spread into the NE USA
- Such a collapse would have had en estimated $3-6 billion impact on the US economy.







Damages after the 1989 storm



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

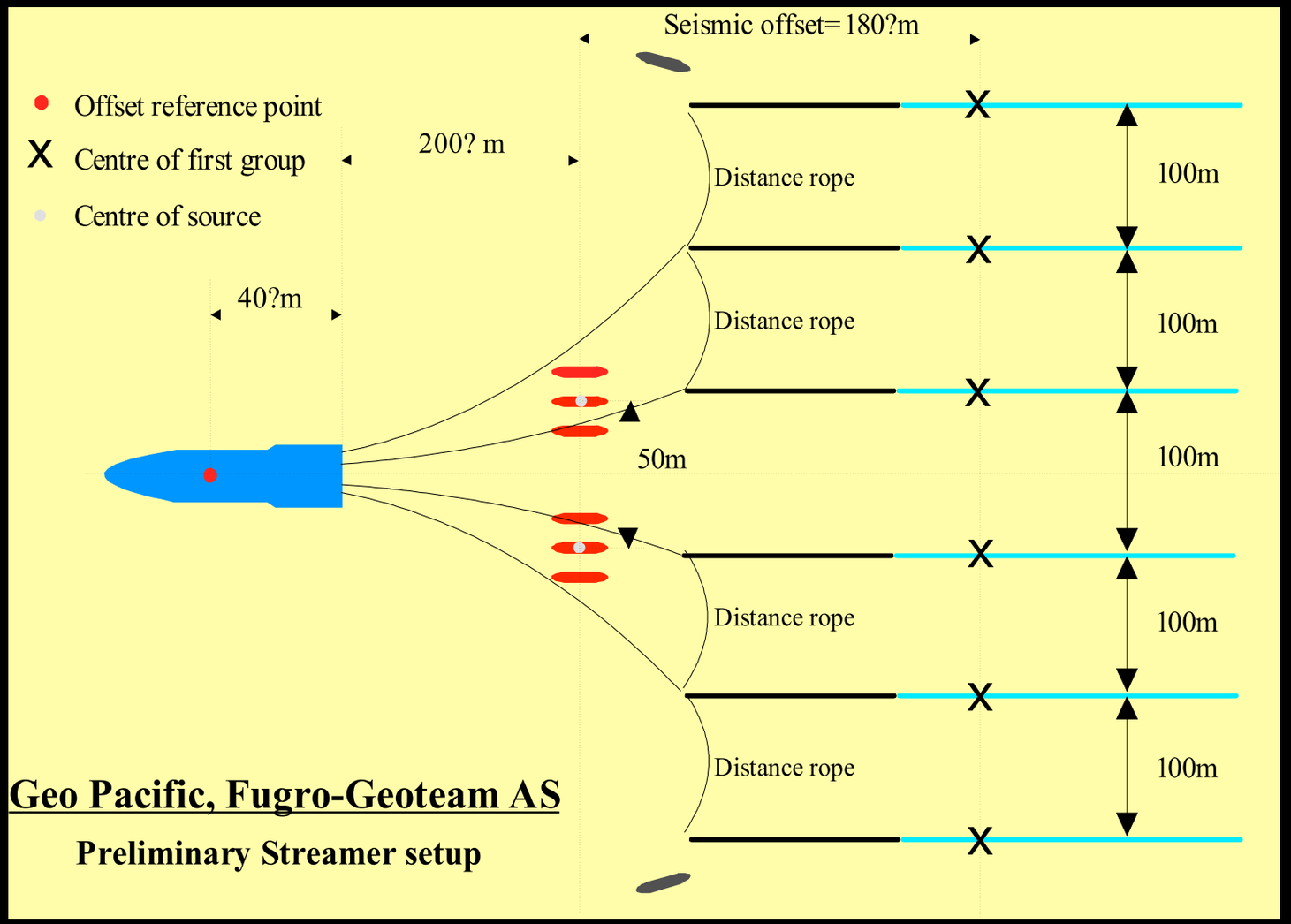
Cost: 10 million USD, repair can take one year.

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

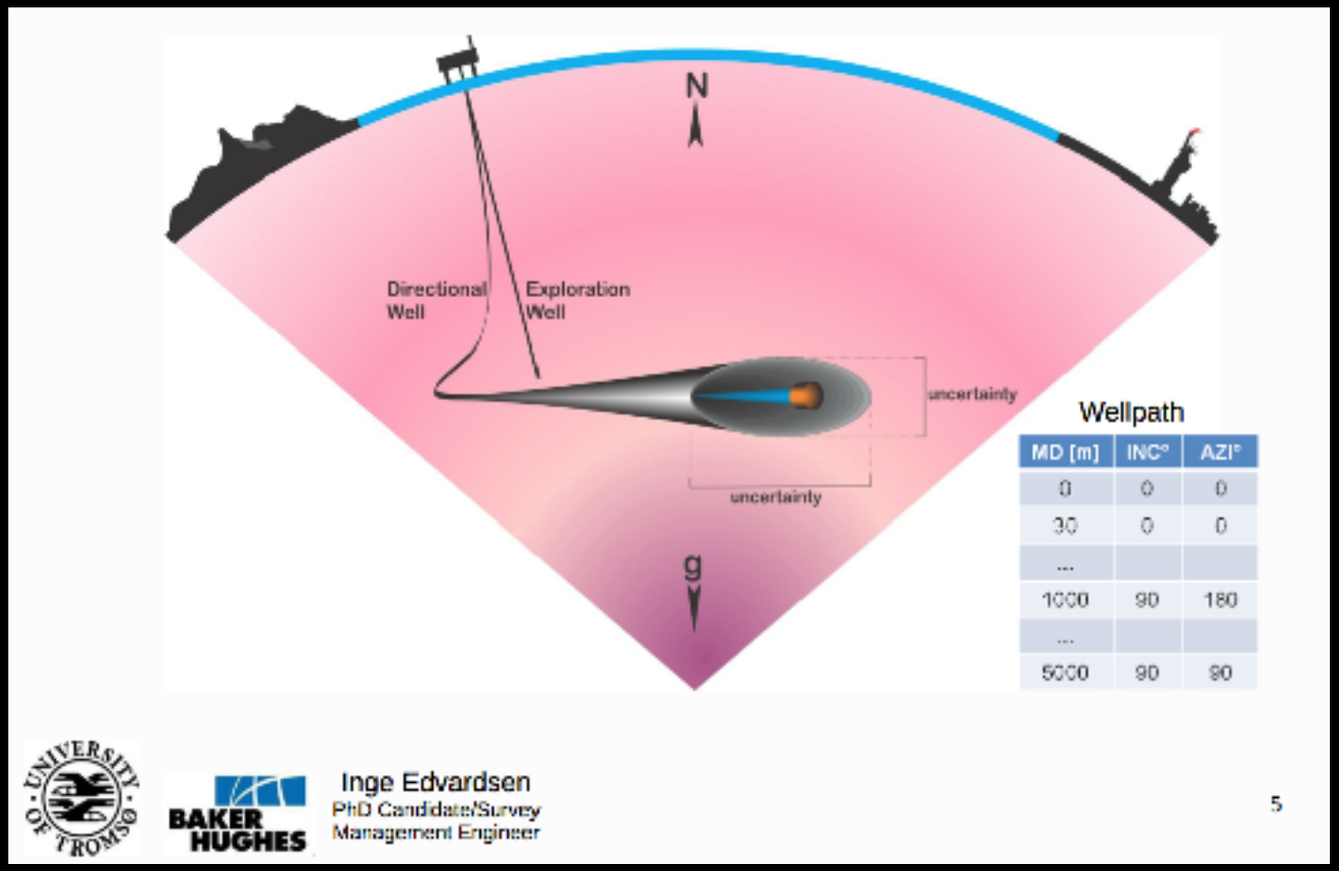


Fugro-Geoteam use ships with sensitive magnetometers on long cables.

Directional drilling

Directional drilling

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



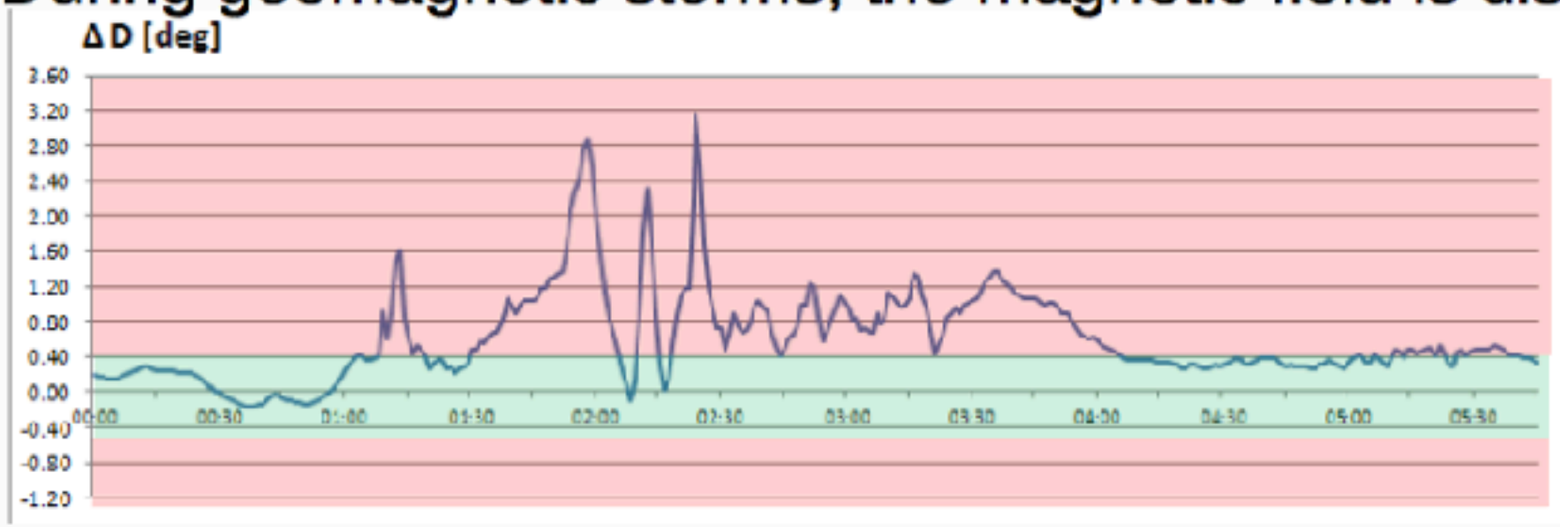
Wellpath

MD [m]	INC°	AZI°
0	0	0
30	0	0
...		
1000	90	180
...		
5000	90	90

Inge Edvardsen
PhD Candidate/Survey Management Engineer

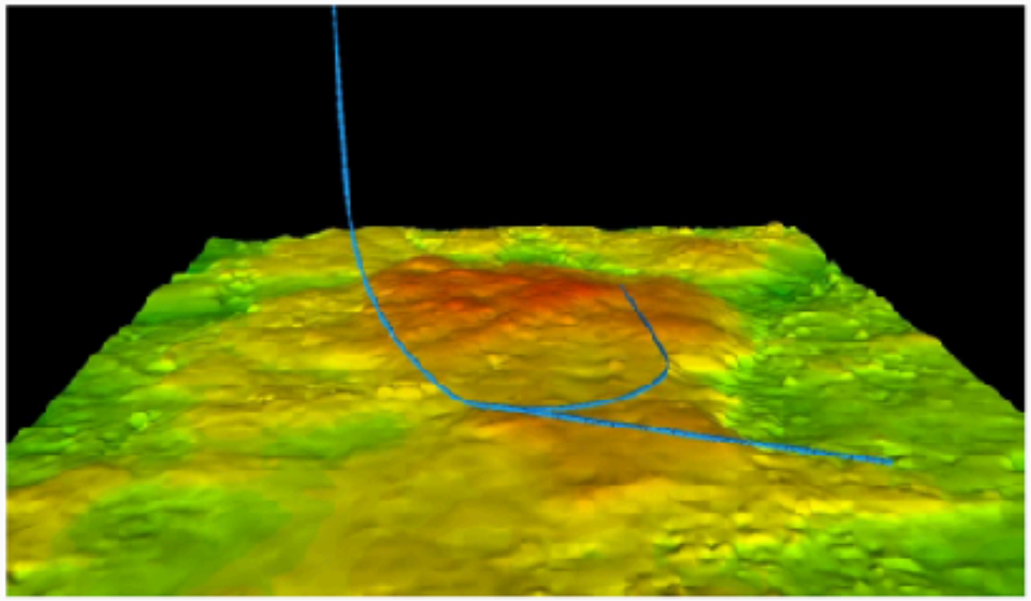
Directional drilling

During geomagnetic storms, the magnetic field is disturbed:

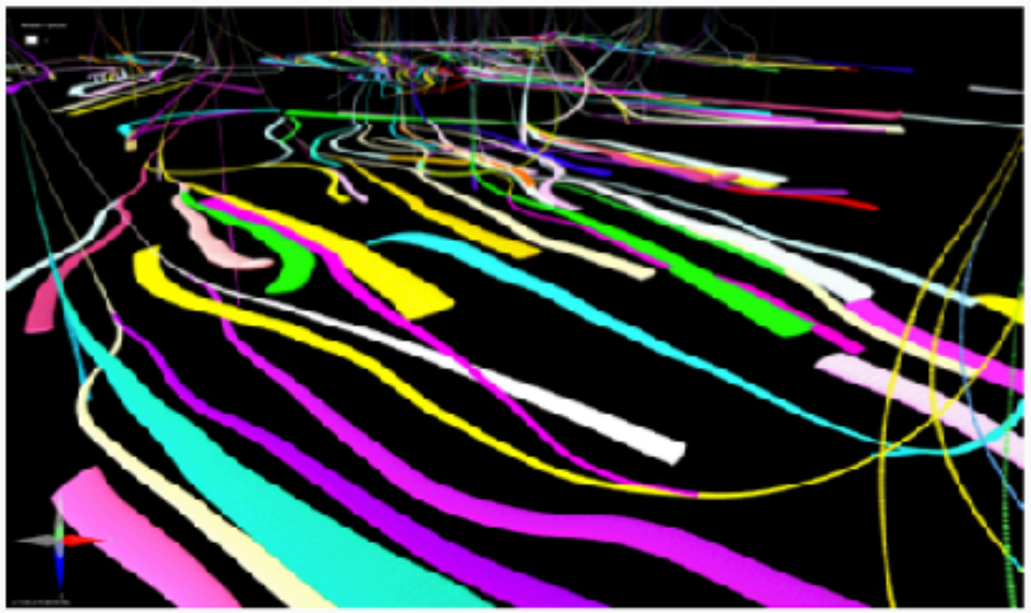


This has to be monitored and corrected for in order to:

Hit the Geological Target
(& maximize recovery)



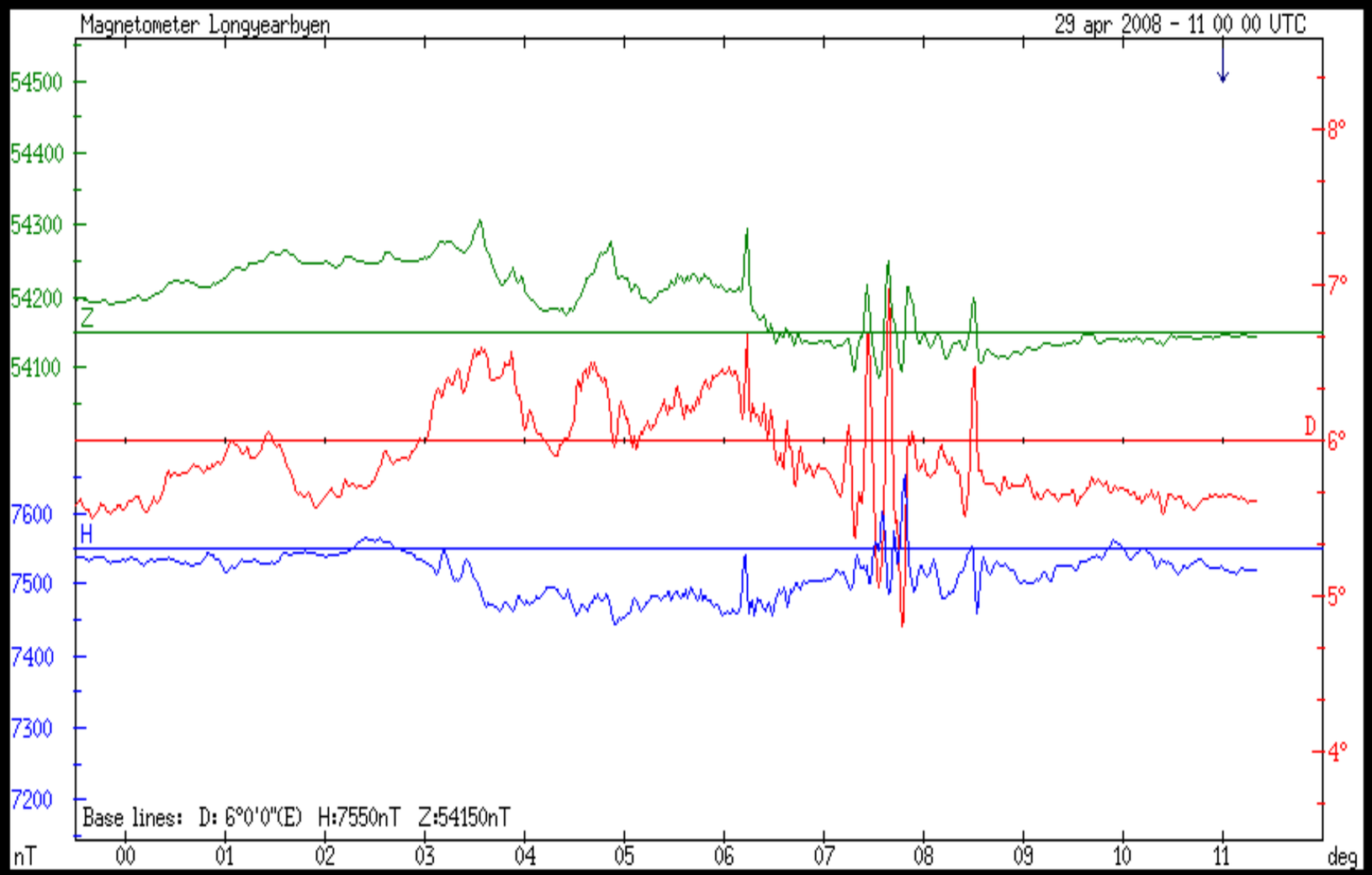
Avoid Other Wells



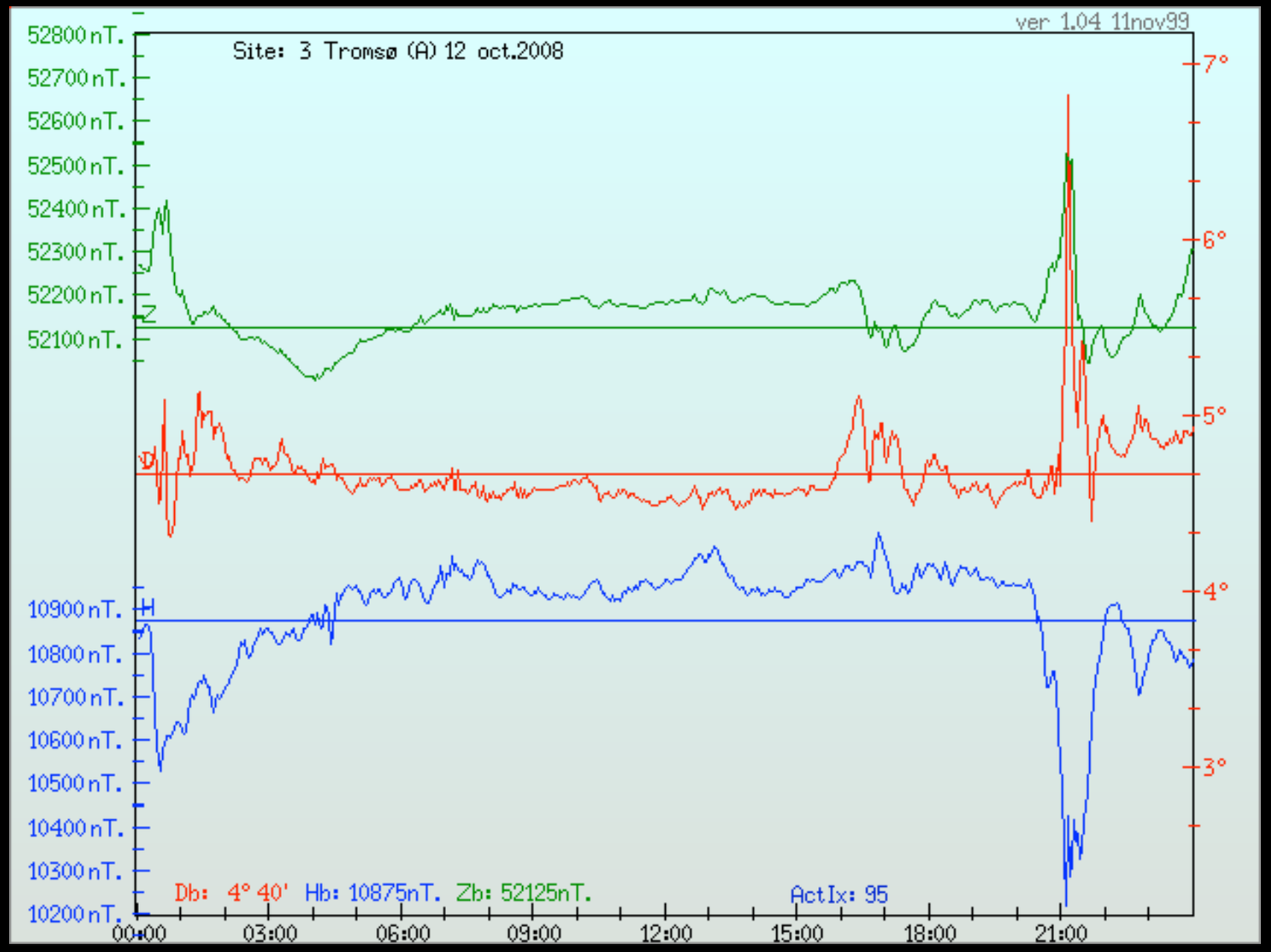
Inge Edvardsen
PhD Candidate/Survey
Management Engineer

Drilling companies are buying spaceweather data

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



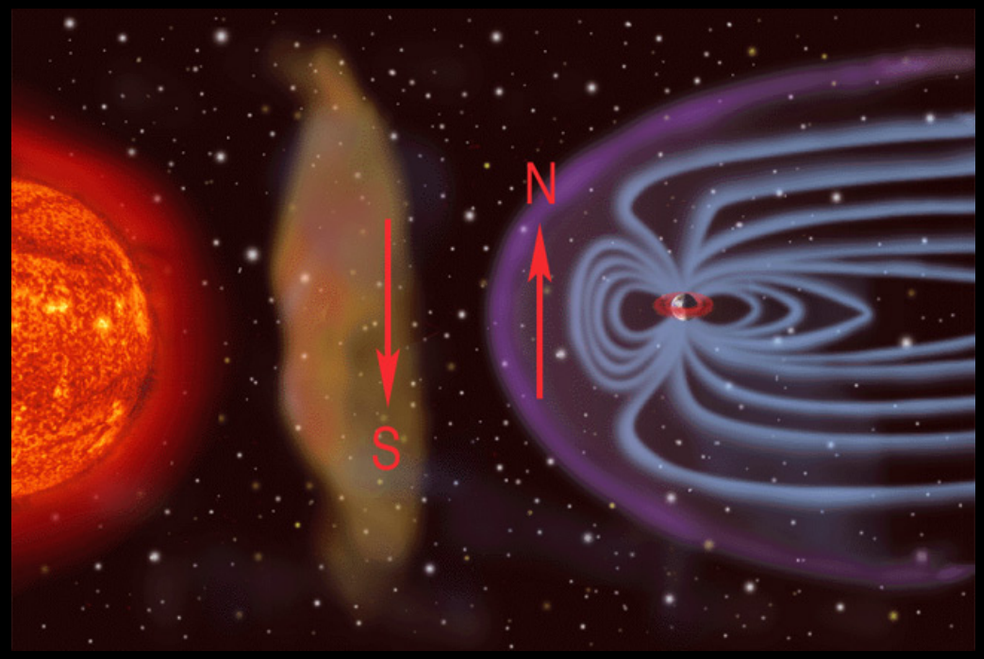
Effects on a compass

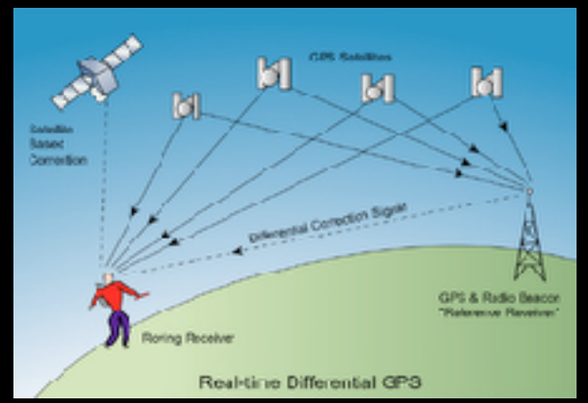


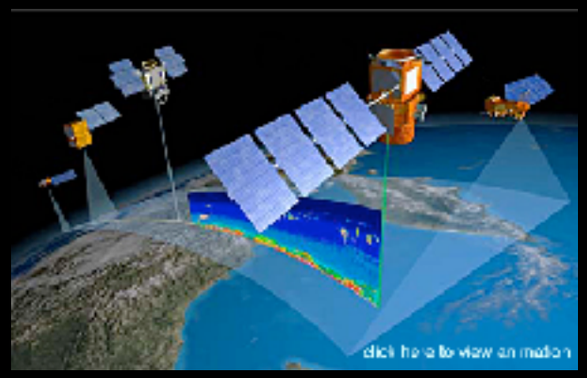
Impacts on animals

- 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.

Effects from the Halloween storms



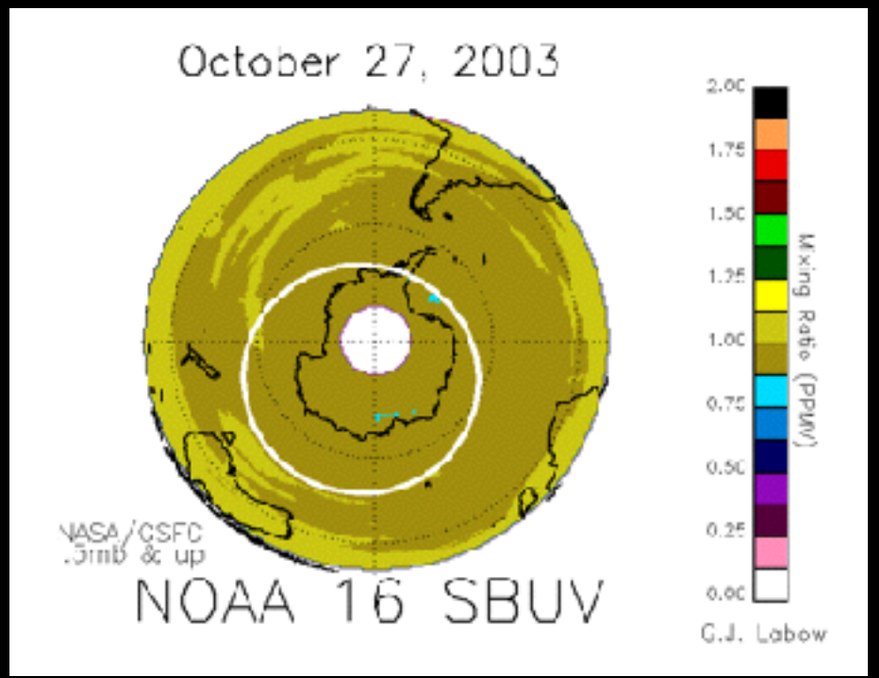


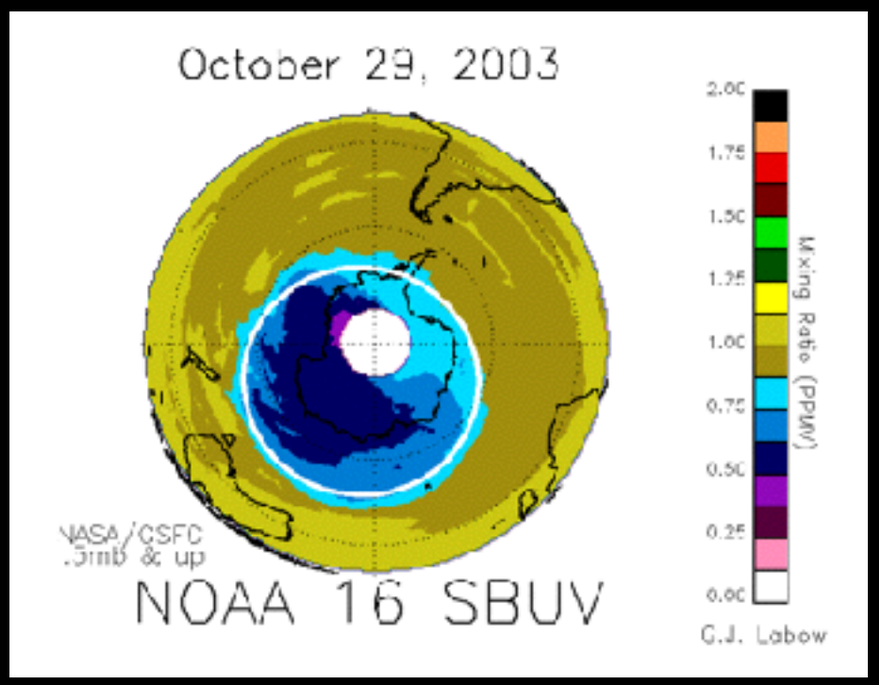


- More than 20 satellites and spacecrafts were affected (not including classified military instruments), Half of NASA satellites affected. One Japanese satellite lost
- Severe HF Radio blackout – affected commercial airlines
- FAA issued a first-ever alert of excessive radiation exposure for air travellers
- 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

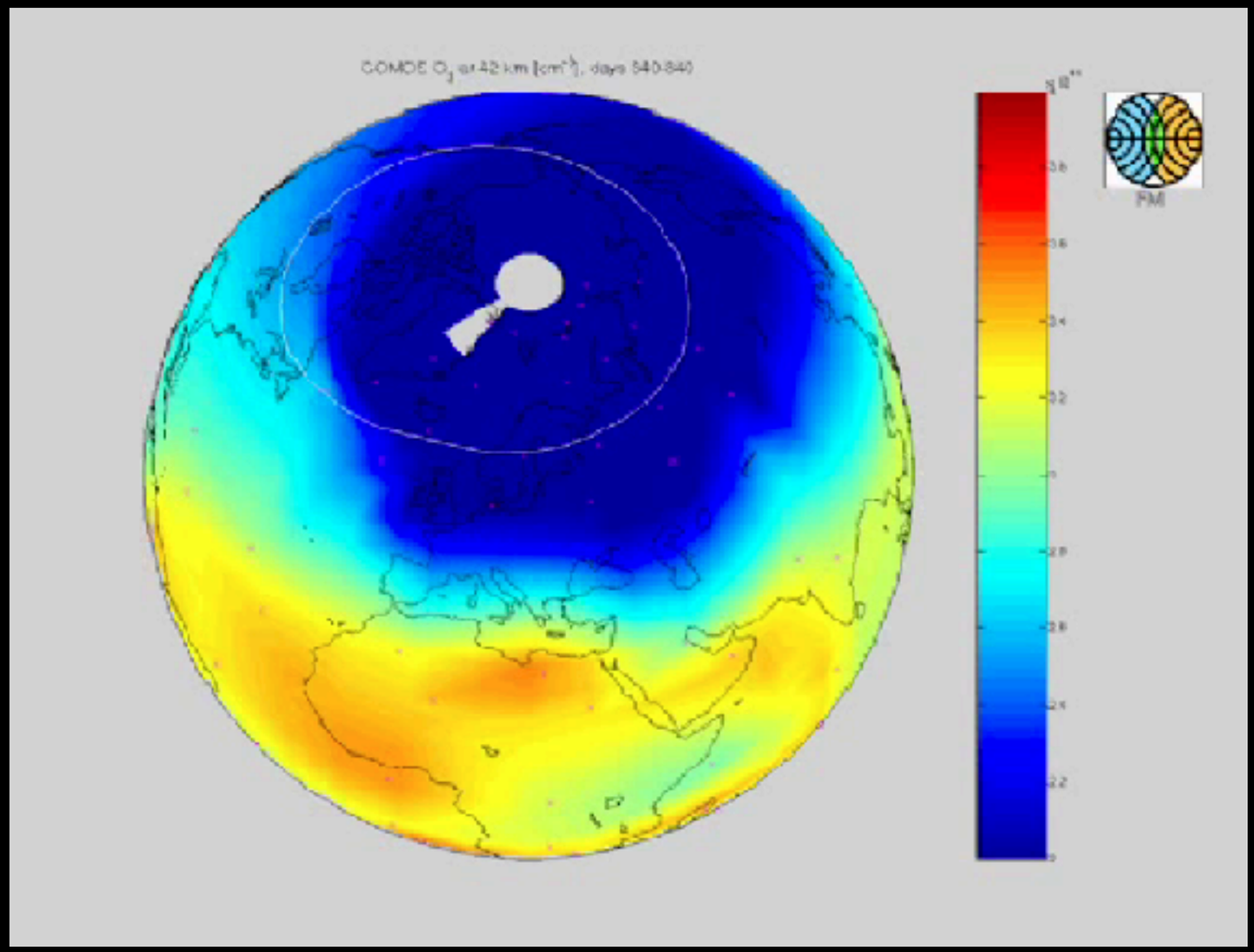
Protonevents affects the ozone-content

(ved 0.5 hPa eller ~55 km)





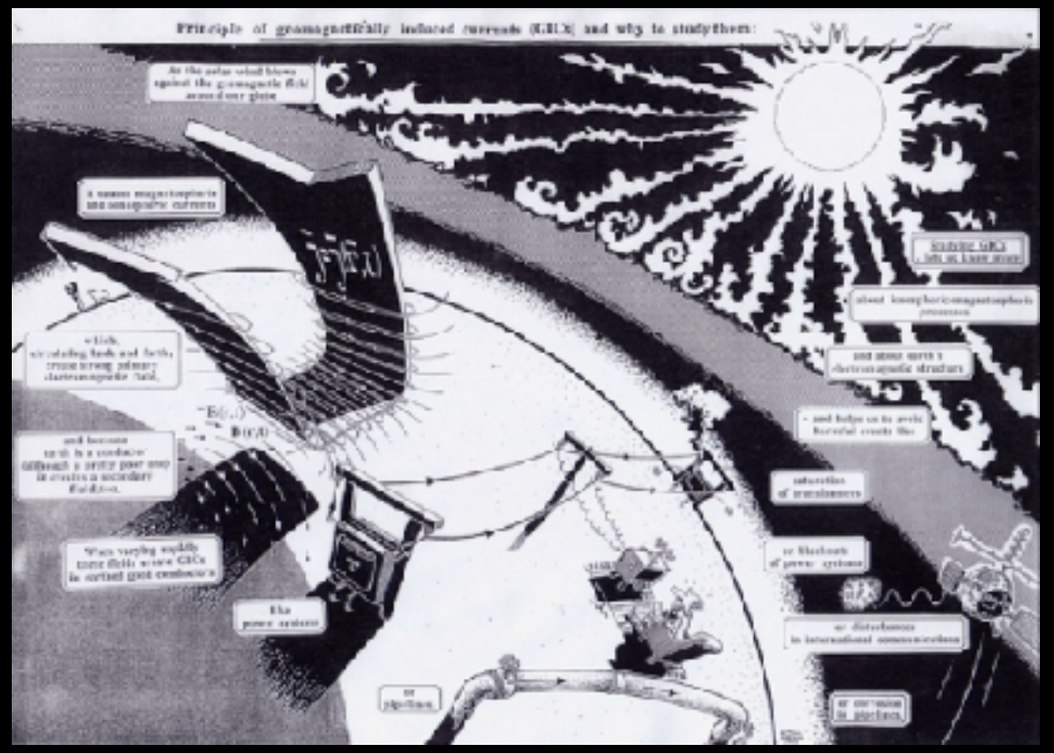
This event reduced the ozone content for 8 months (~42 km)



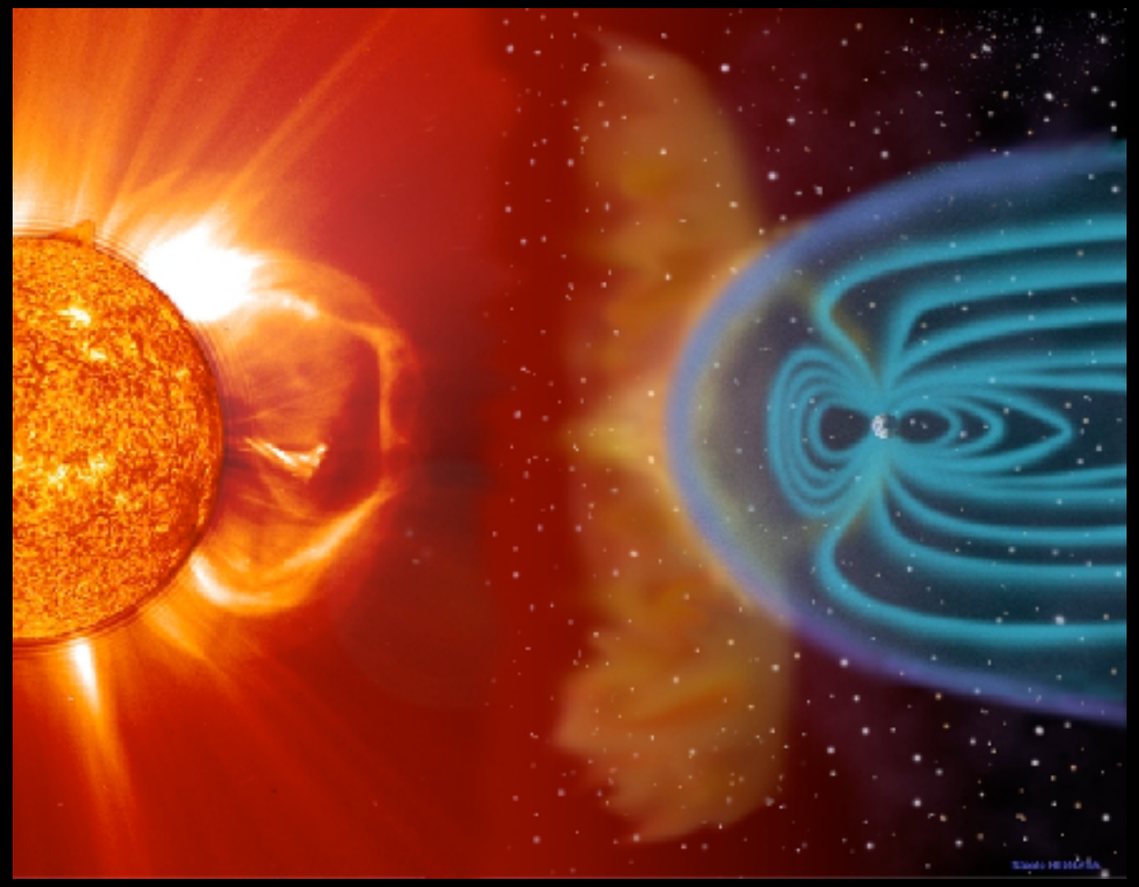
Source: Charles Jackman & Gordon Labow (NASA) og FMI

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 weather warnings will be even more important for our society in the future.



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

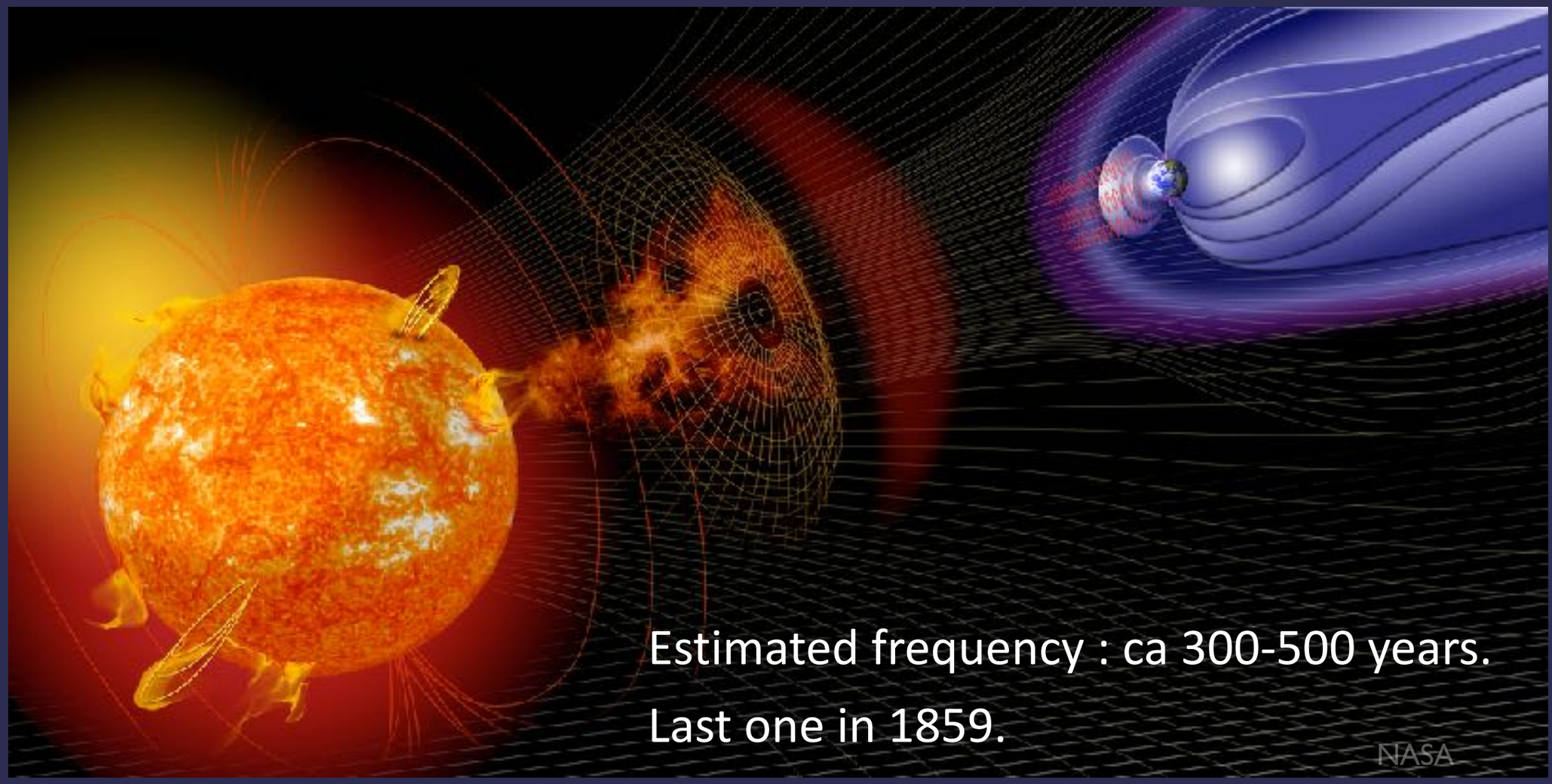
....and an estimate of $1 trillion to $2 trillion during the first year alone was given for the societal and economic costs of a “severe geomagnetic storm scenario” with recovery times of 4 to 10 years.

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.

How often does superstorms occur?

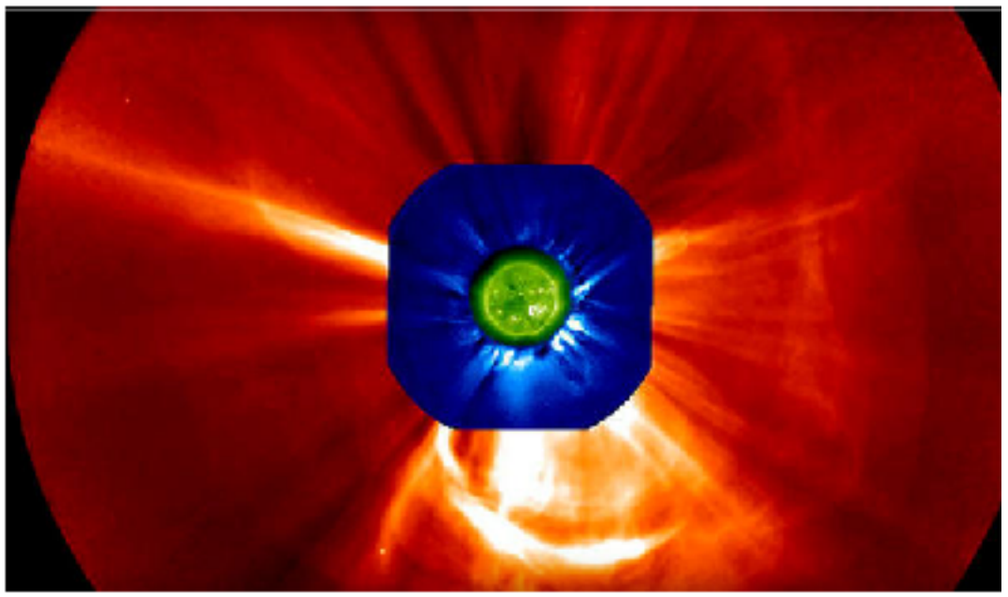


Norsk Romsenter
Norwegian Space Agency

CBSNEWS Video | US | World | Politics | Entertainment | Health | MoneyWatch | SciTech | Crime | Sports | Photos | More

By ELIENE AUGENBRAUN / CBS NEWS / July 25, 2014, 3:07 PM

Solar "superstorm" just missed Earth in 2012



One of the top five fastest coronal mass ejections (CME) that scientists have ever observed, and the fastest observed by STEREO, blasted away from the sun on July 22, 2012. / NASA/STEREO

Businessman sets up private toll road

Prince Charles' 'fury' as former

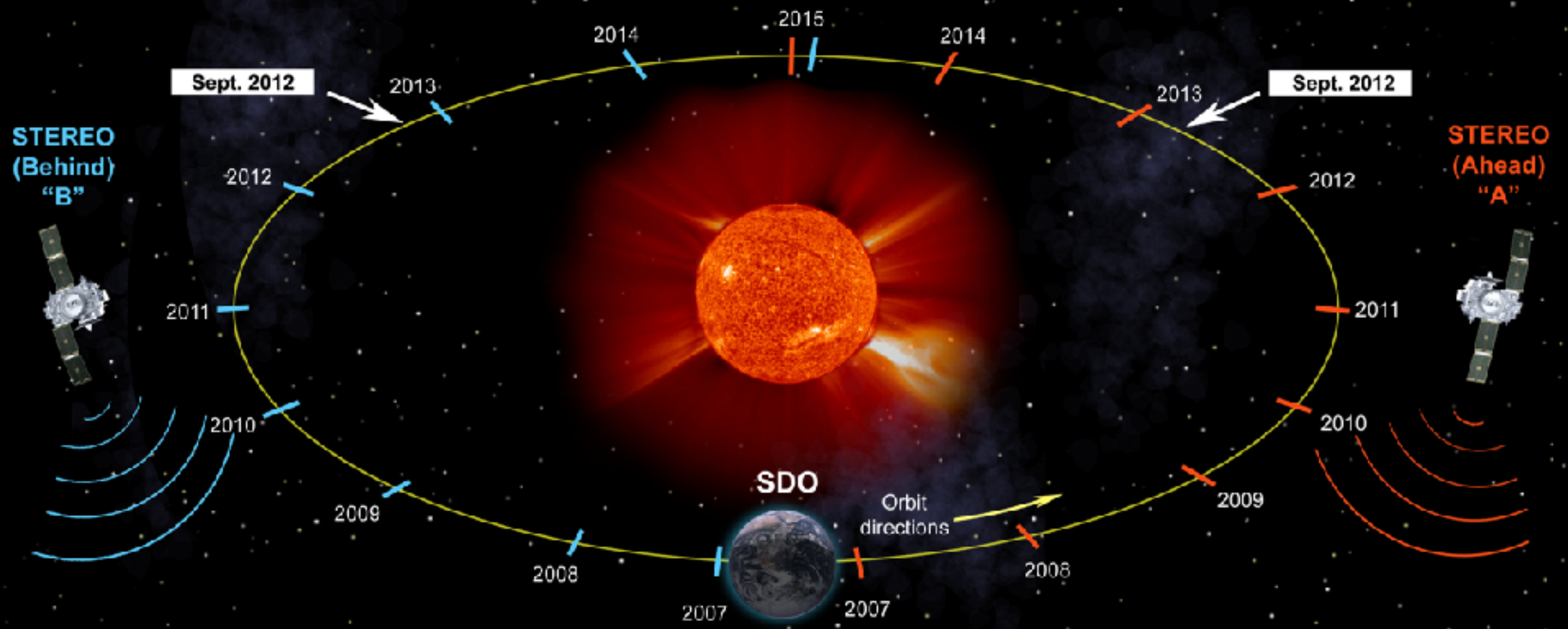
Diana's favourite DJ Mike Smith dies at

Best hotel in Britain is Birmingham's

Solar flare almost blasted Earth back to the dark ages two years ago, NASA scientists reveal

- Plasma cloud or 'CME' rocketed away from the sun as fast as 3000 km/s on July 23, 2012
- Had the eruption occurred just one week earlier, the blast site would have been facing Earth
- Direct hit could cause widespread power blackouts, disabling everything that plugs into a wall socket.
- Total economic impact could have exceeded $2 trillion or 20 times greater than the costs of a Hurricane Katrina

NASA's STEREO (with SDO) Sees the Entire Sun



The two **STEREO** spacecraft reach equidistant positions between themselves and Earth on Sept. 1, 2012.

Drawing gives the relative orbital positions of both STEREO spacecraft for each year from June 2007 to June 2015.
(Not to scale)

Norsk Romsenter
NORWEGIAN SPACE CENTRE

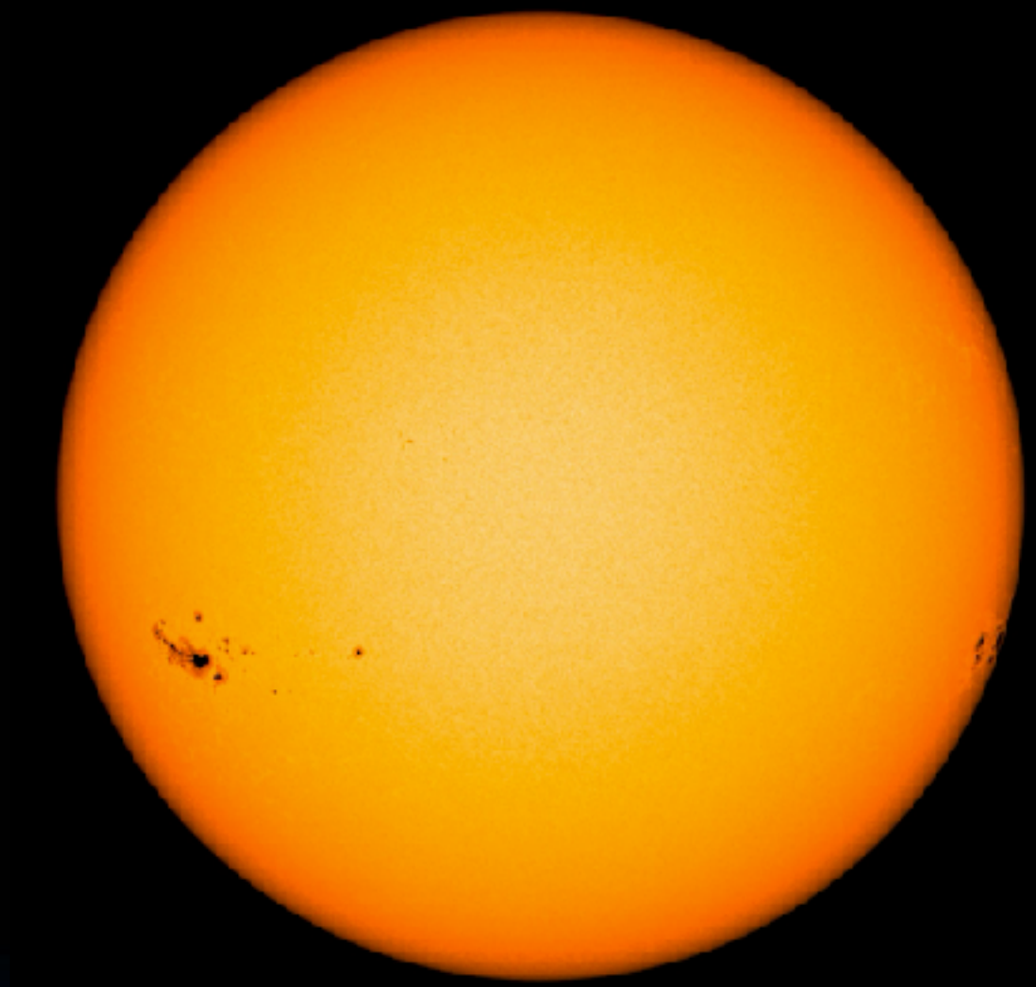
Nine days from a catastrophe?

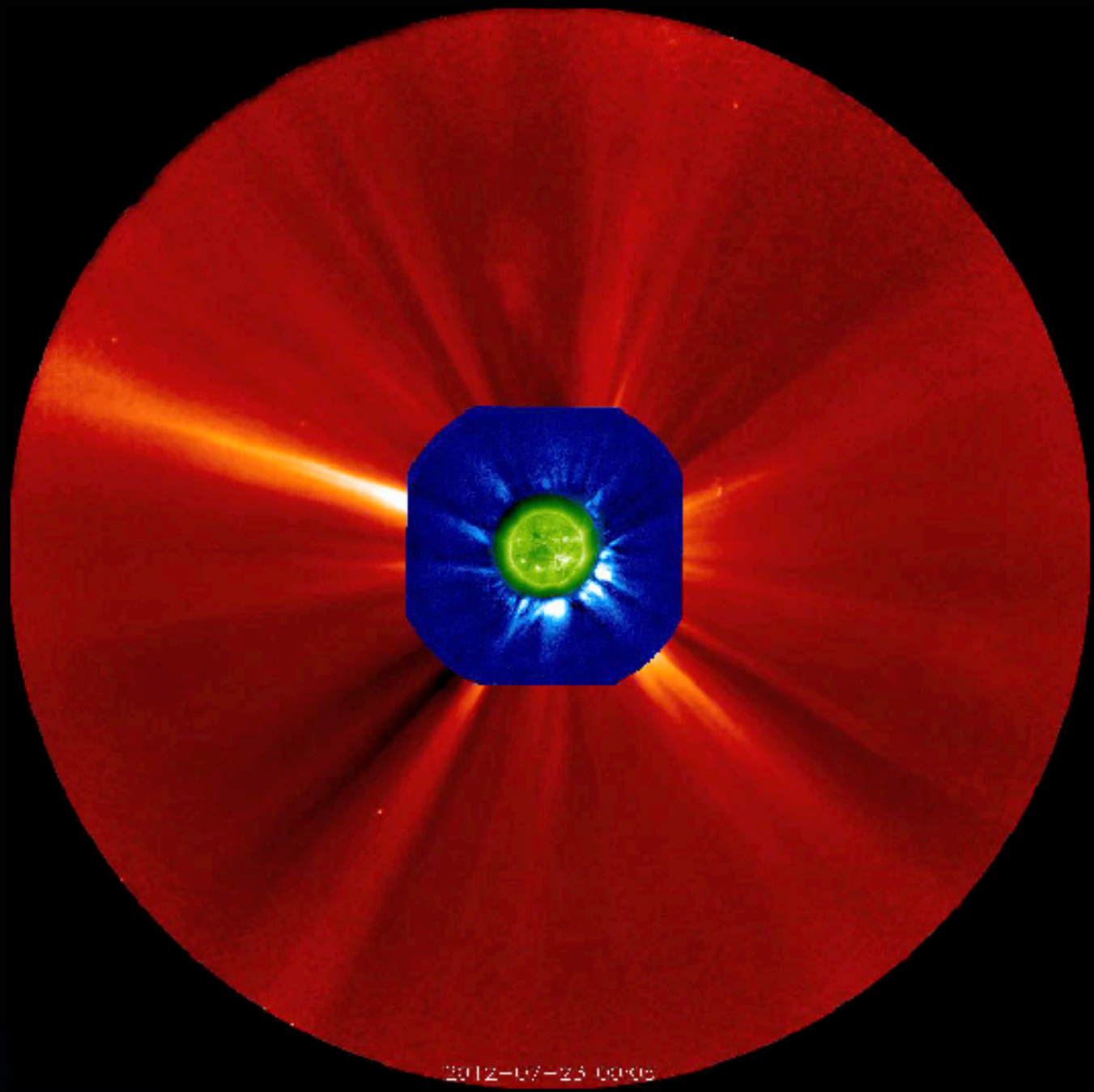
The superstorm seen from the far side of the Sun July 23 2012.

Without Stereo we would never know about this storm.

The Sun seen from Earth (SDO) the week before.

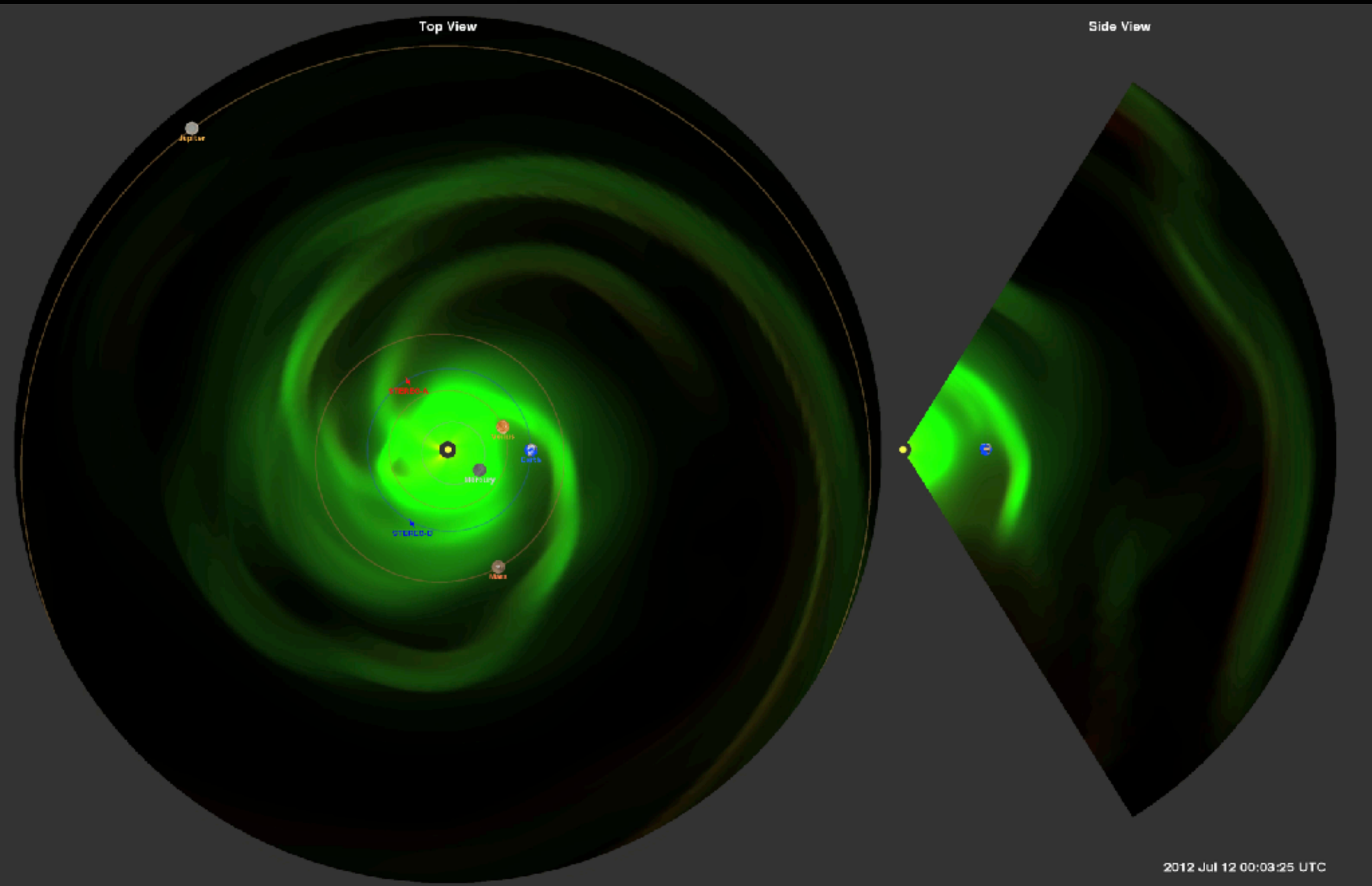
8 July - 20 July





Norsk Romsenter
NORWEGIAN SPACE CENTRE

Superstorm 2012



Users of Space Weather in Norway

Who:	Why:
• Oil&Gas companies	Navigation, positioning and exploration activities
• Aviation	GNSS navigation and HF communication
• Maritime Sector	GNSS navigation and HF communication
• Power grid operators	Ground Induced Currents and GPS timing
• Satellite operators	Damages to systems
• Survey, Construction, etc.	GNSS positioning
• Tourism sector	Aurora forecasts

Aviation

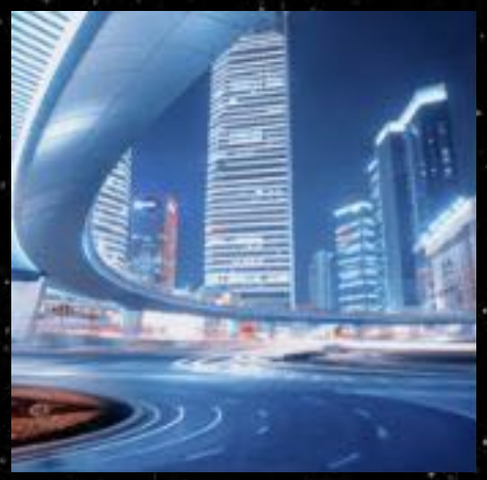
- Performance Based Navigation
- UAV precise positioning and orientation

Precision Agriculture

- Automatic steering
- Agrichemical distribution

Smart Cities and Ports

- Autonomous vehicles
- Inland waterway navigation
- Automatic transactions



Internet of Things

- Object-to-object communication

T. Onsager

Customer Growth
NOAA Space Weather Prediction Center – Product Subscription Service

Will there be a solar flare tomorrow?

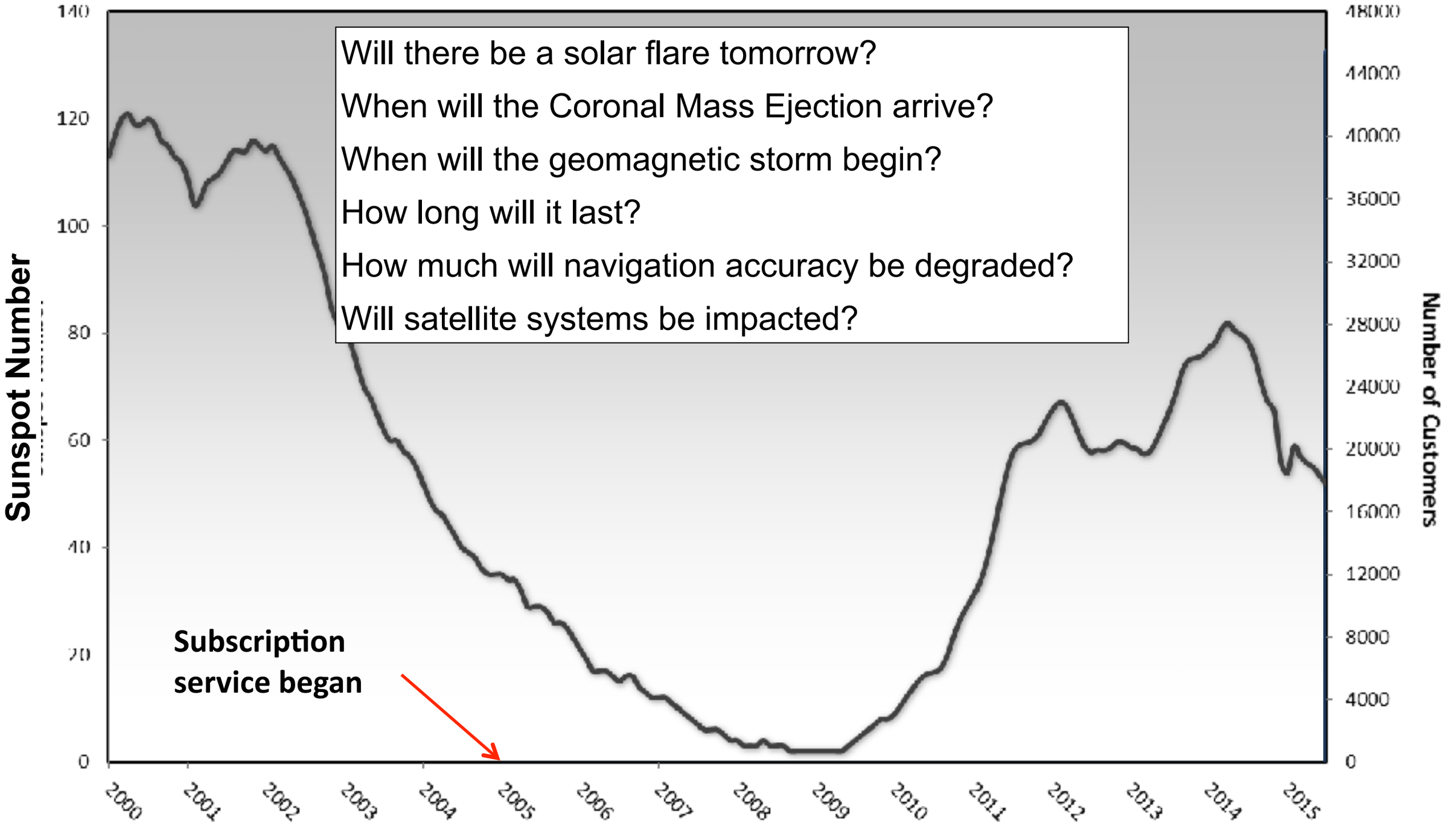
When will the Coronal Mass Ejection arrive?

When will the geomagnetic storm begin?

How long will it last?

How much will navigation accuracy be degraded?

Will satellite systems be impacted?



T. Onsager

The White House

Office of the Press Secretary

For Immediate Release

October 13, 2016

Executive Order -- Coordinating Efforts to Prepare the Nation for Space Weather Events

EXECUTIVE ORDER

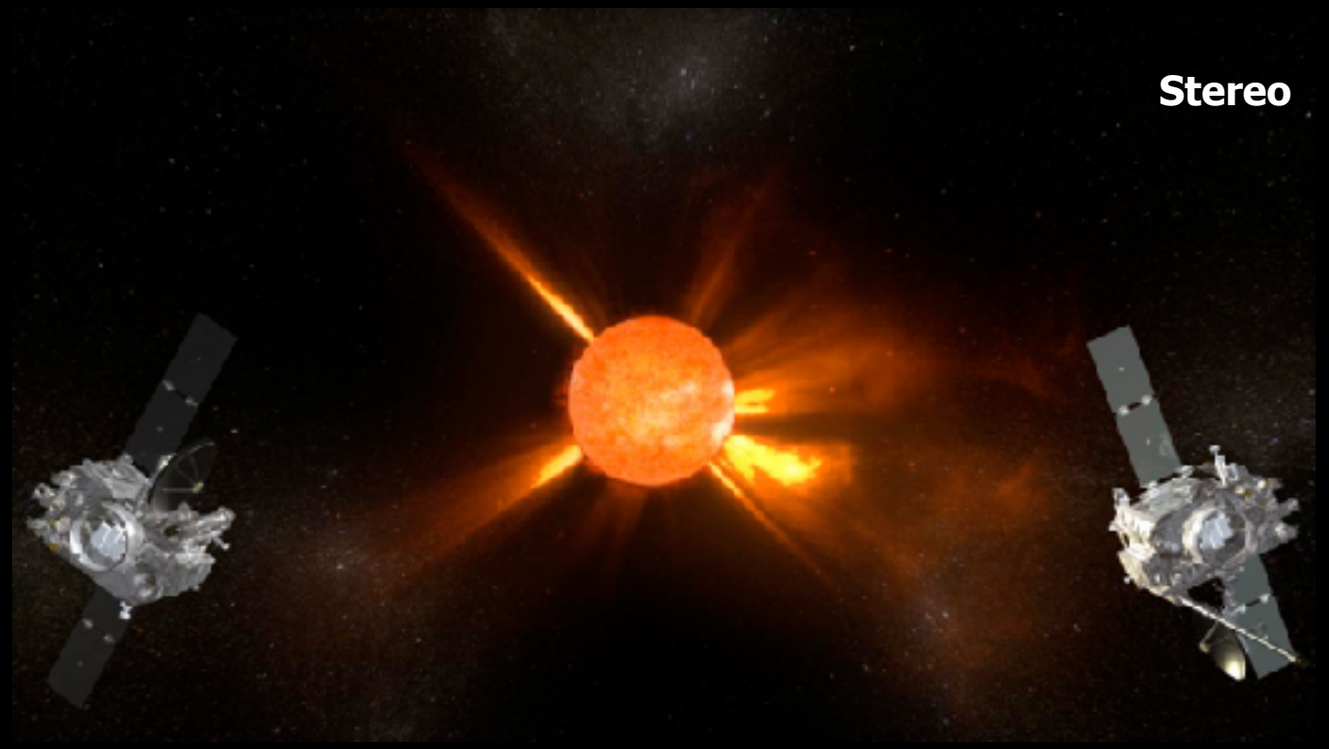
- - - - - - -

COORDINATING EFFORTS TO PREPARE
THE NATION FOR SPACE WEATHER EVENTS

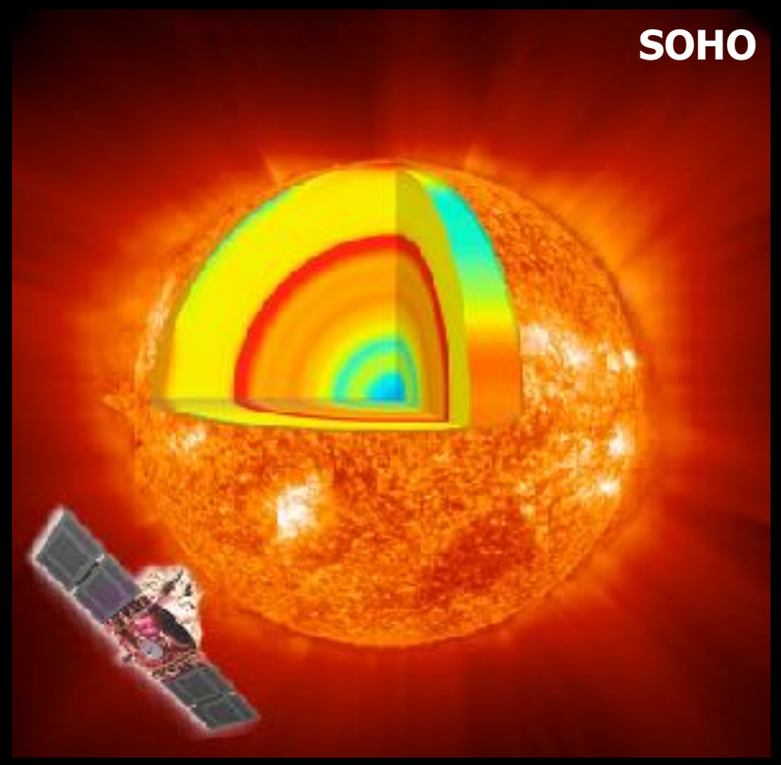
By the authority vested in me as President by the Constitution and the laws of the United States of America, and to prepare the Nation for space weather events, it is hereby ordered as follows:

Fleet of satellites watching the Sun

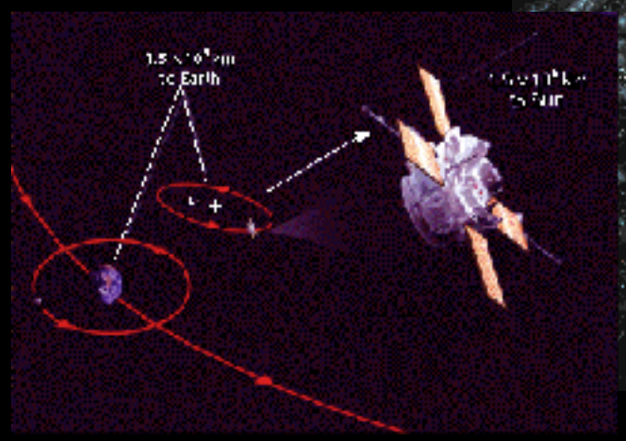
SDO

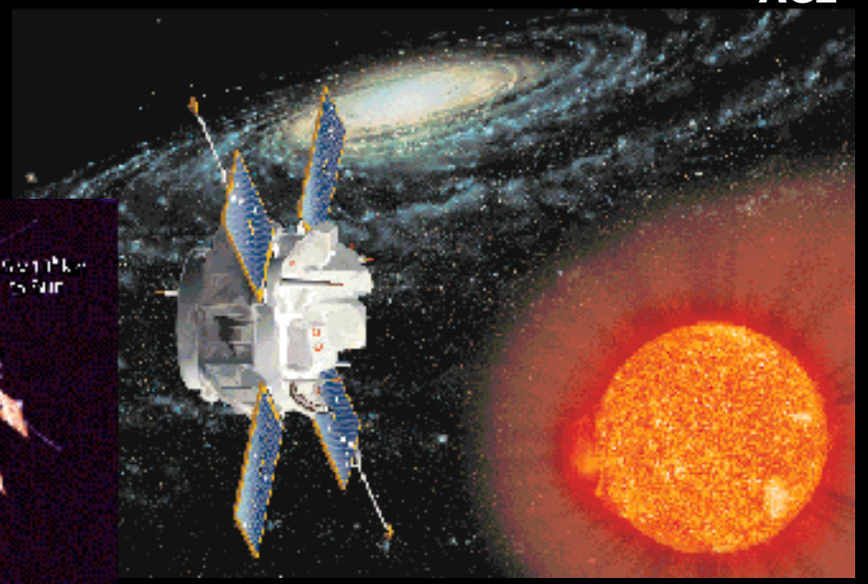


Stereo



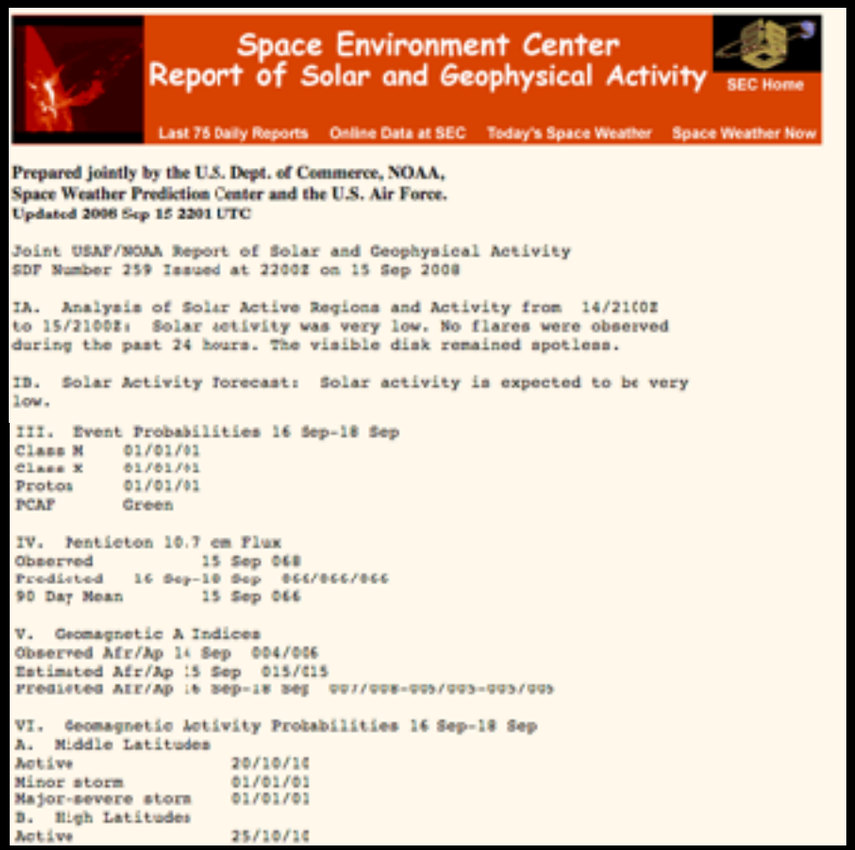
SOHO

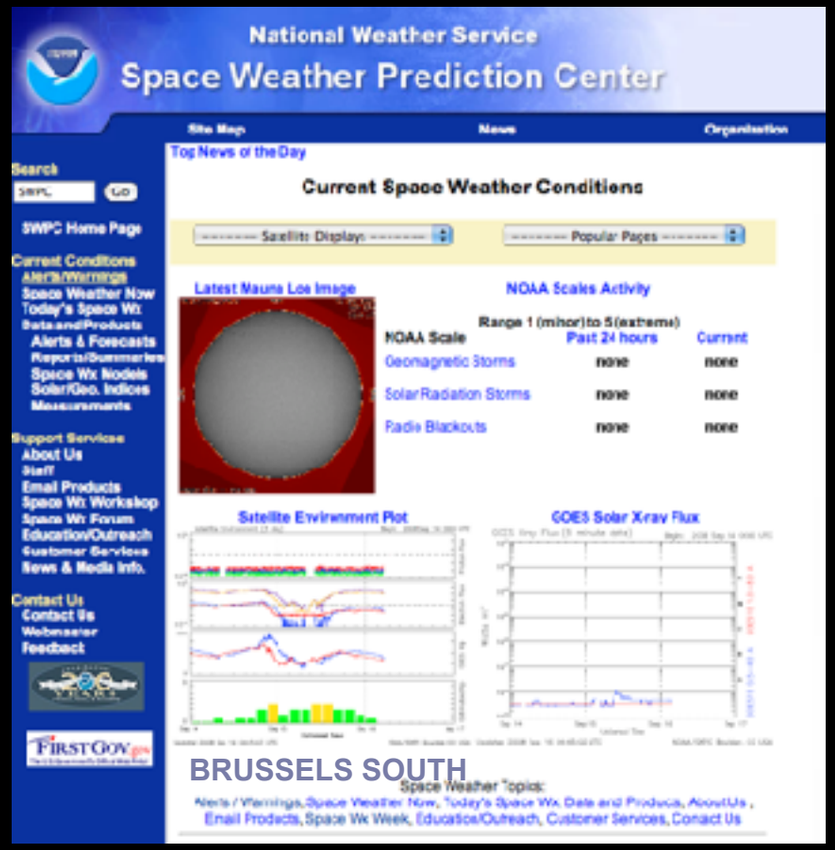


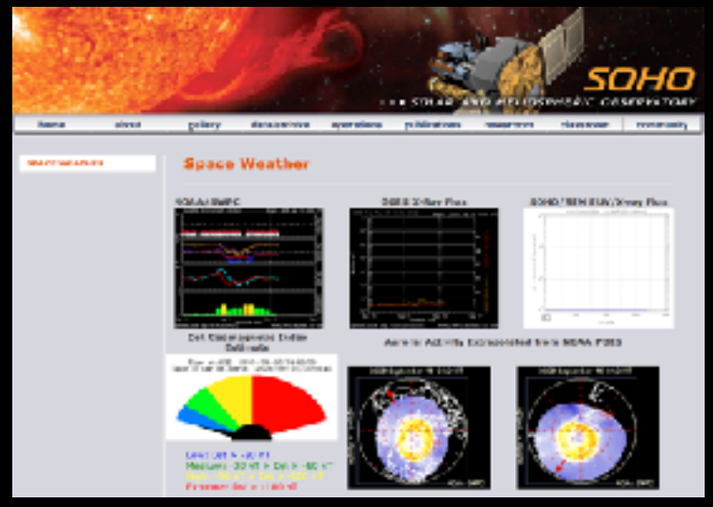


ACE

Space Weather Warnings/Forecasts







ESAs Space Situational Awareness - nytt program som inkluderer romvær

- **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**