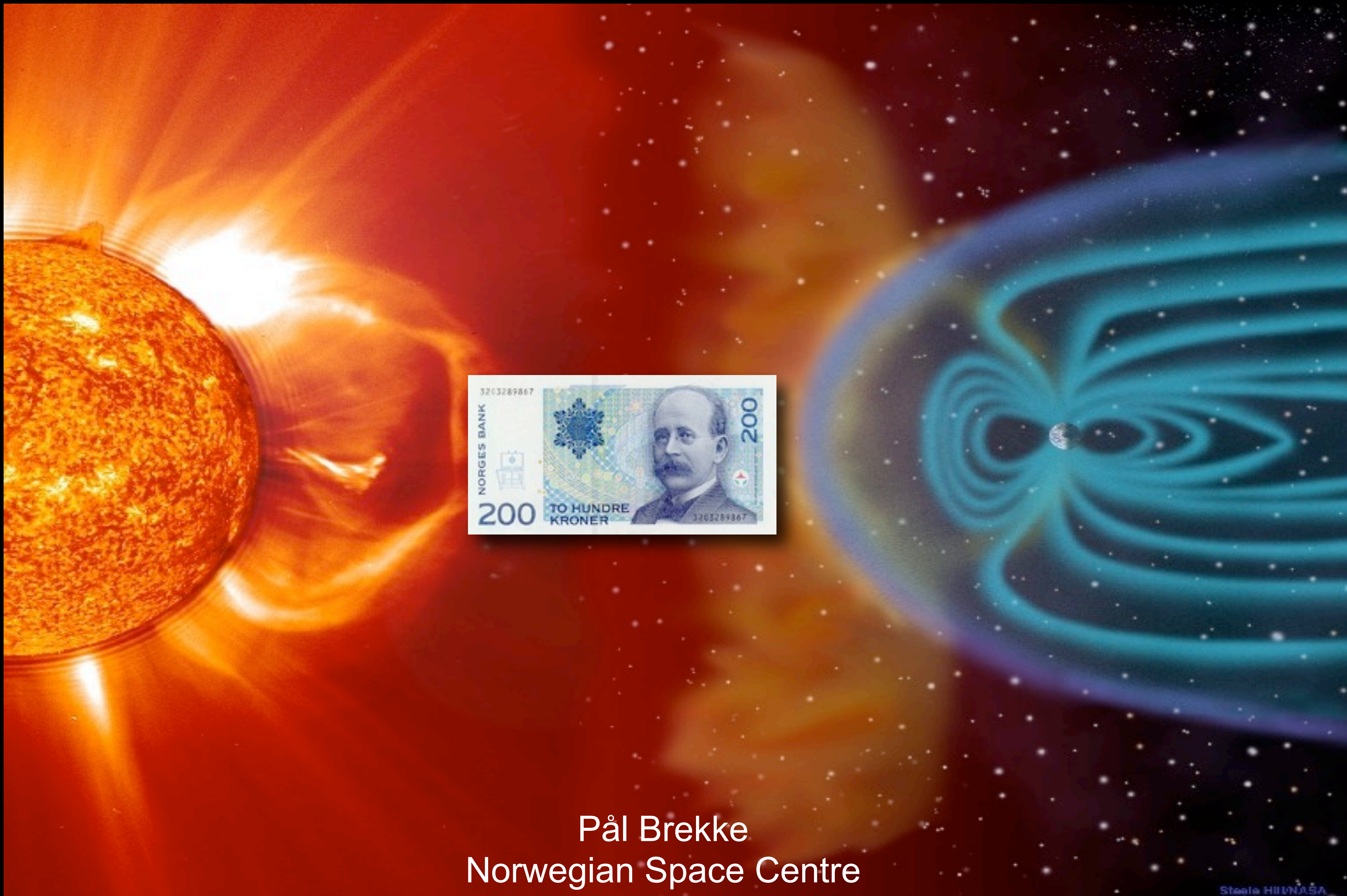
The Stormy Sun
From Birkeland to Space Weather Hazards



Pål Brekke
Norwegian Space Centre

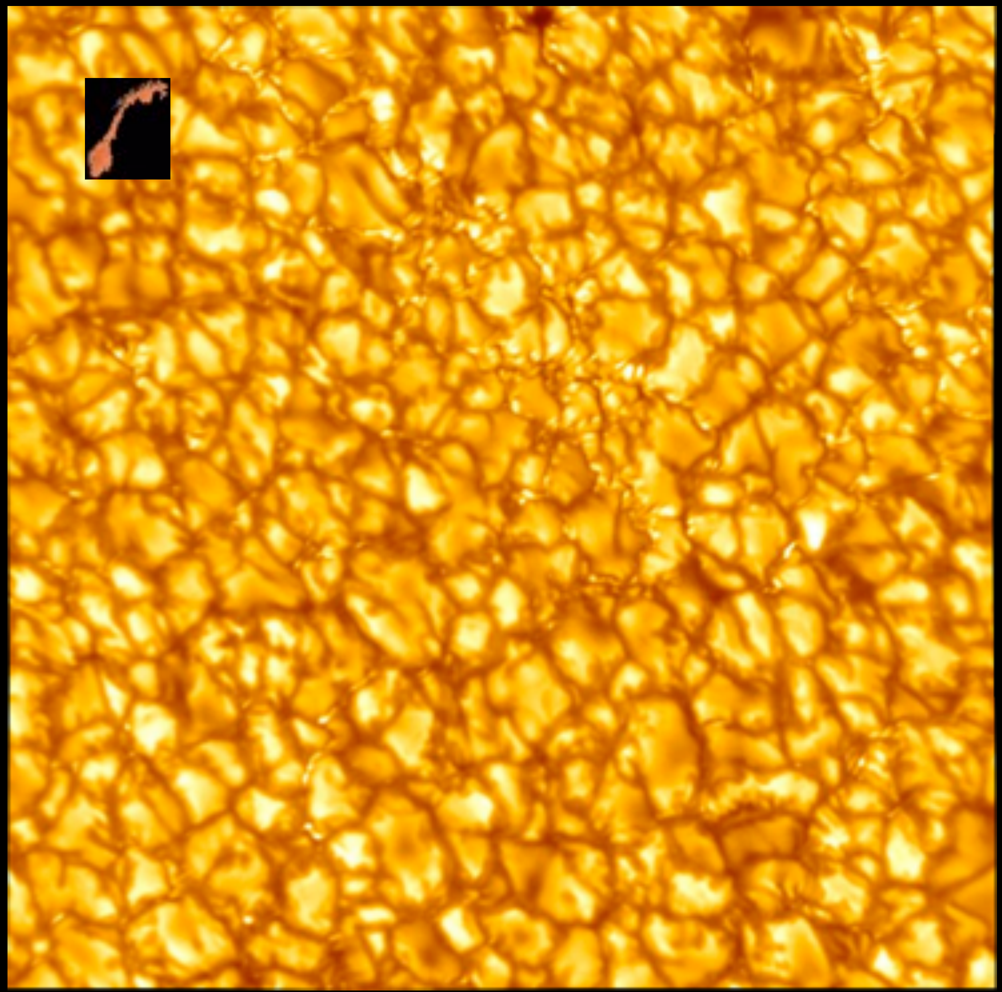
The Sun

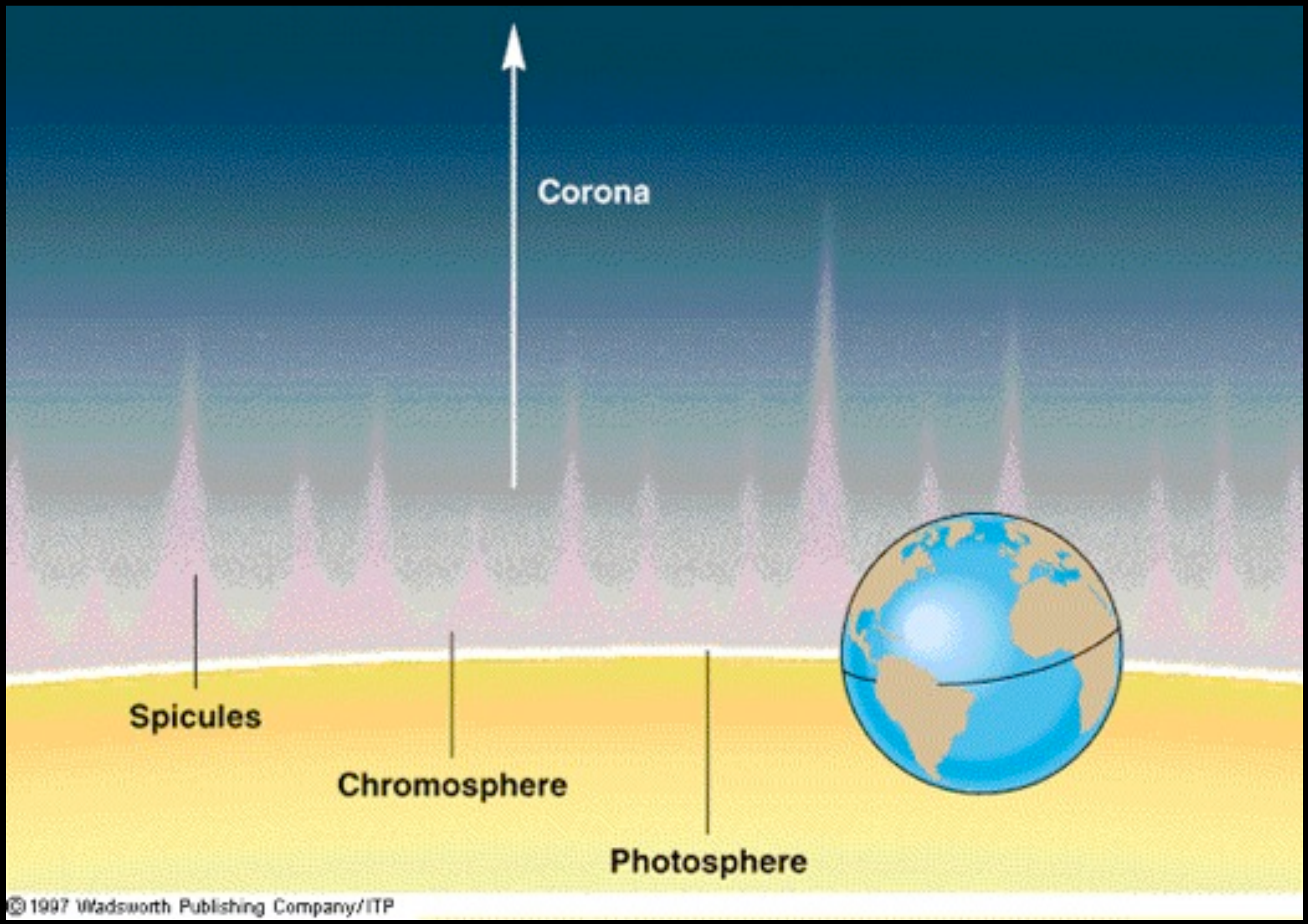
Forskning.no/UiO

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.





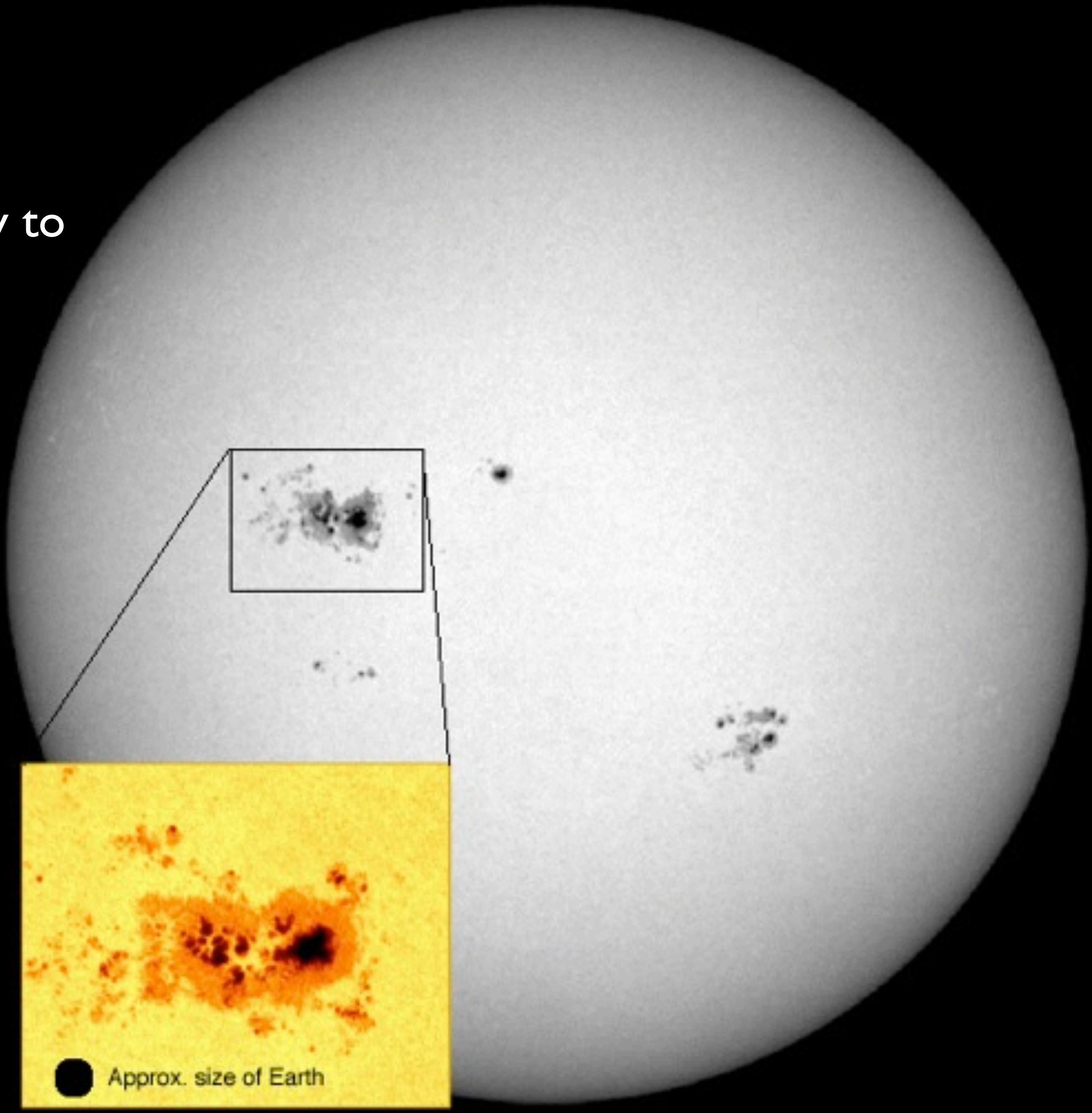
SUNSPOTS

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.

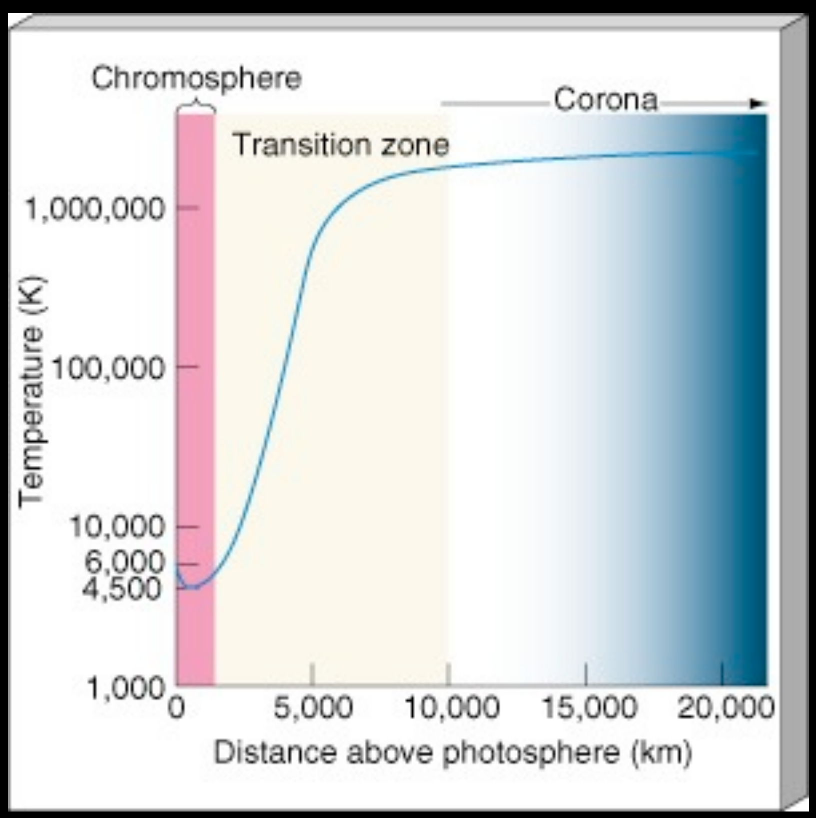
NASA

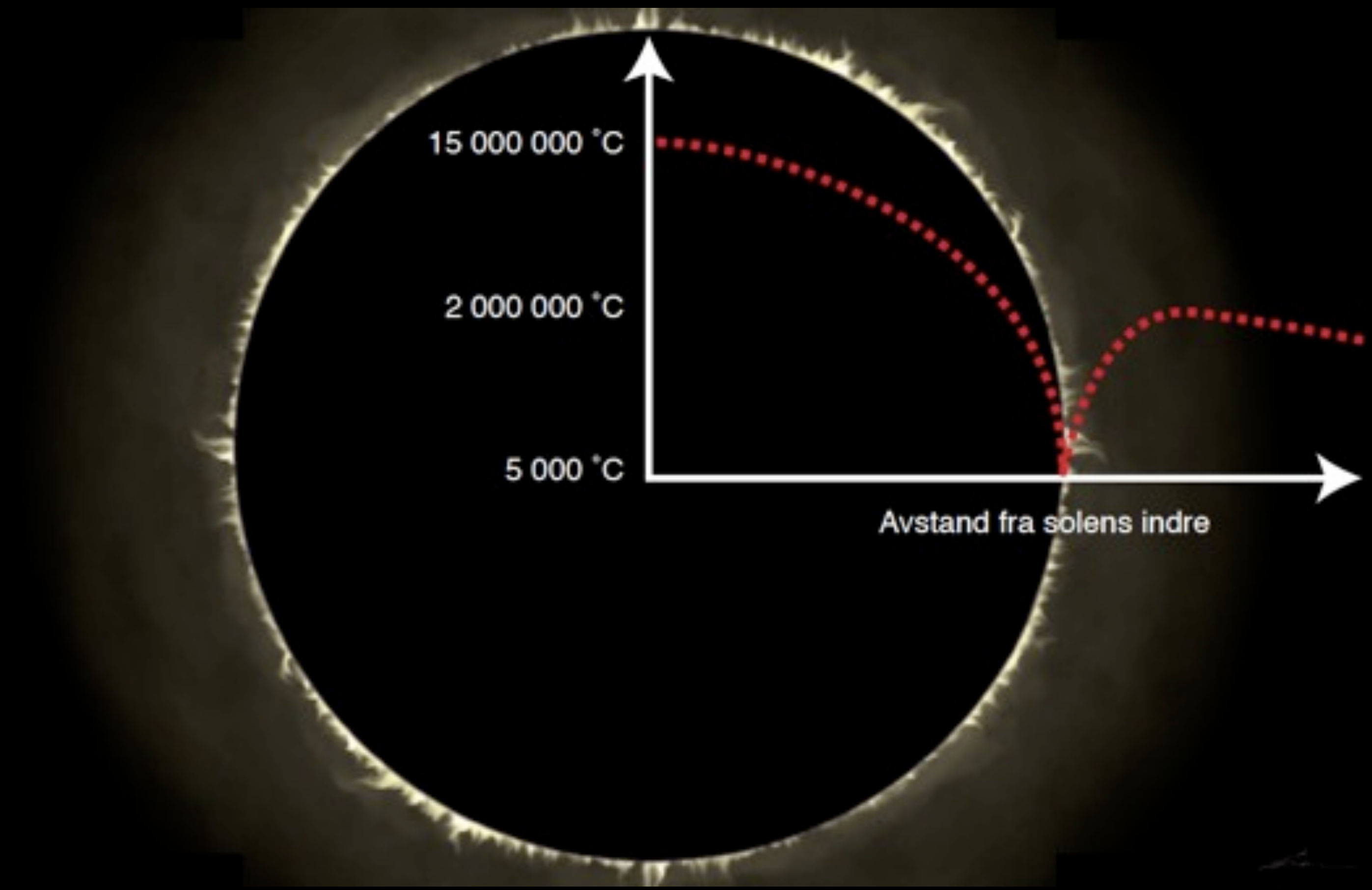


NASA/ESA/S. Hill

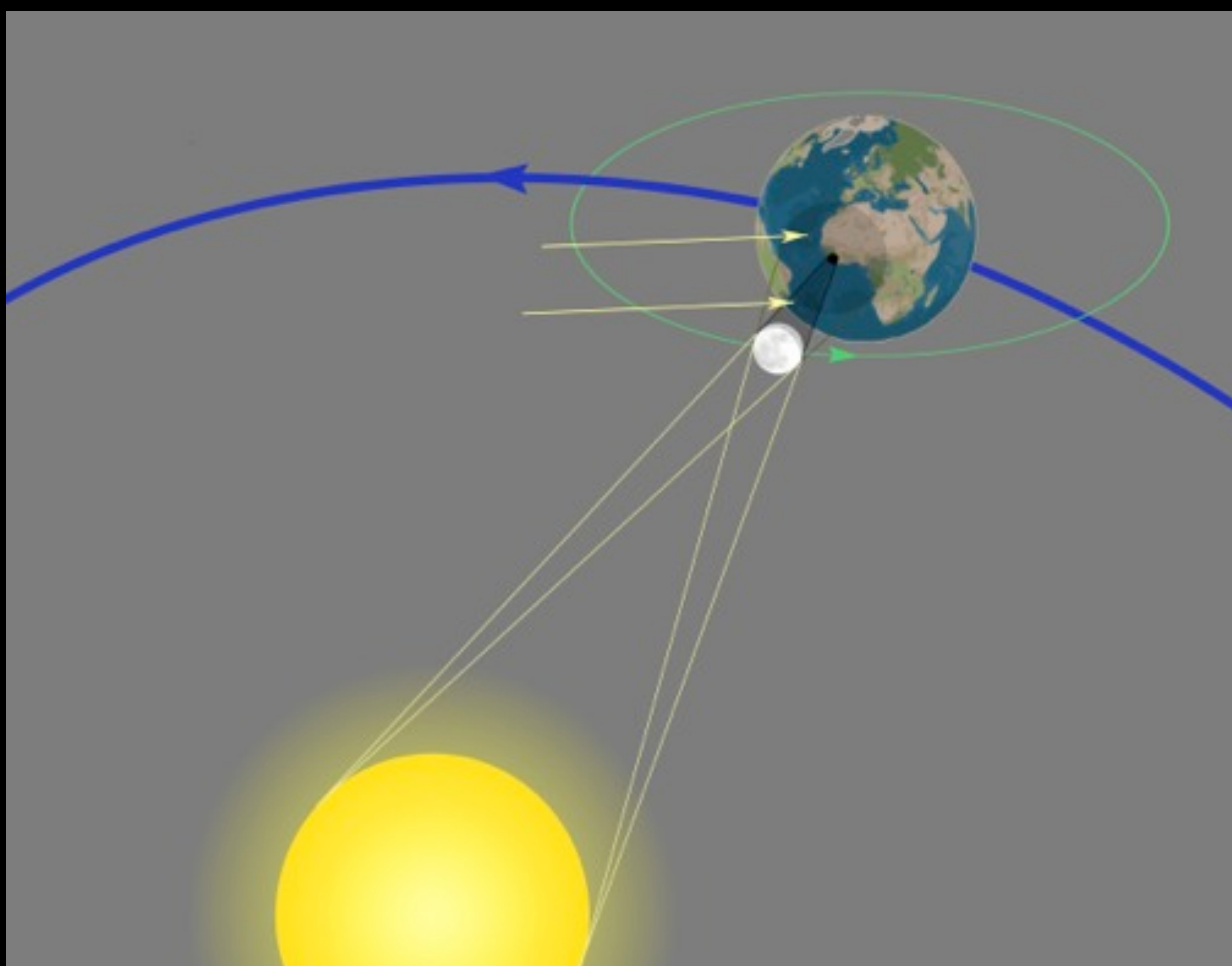
The Sun's hot atmosphere

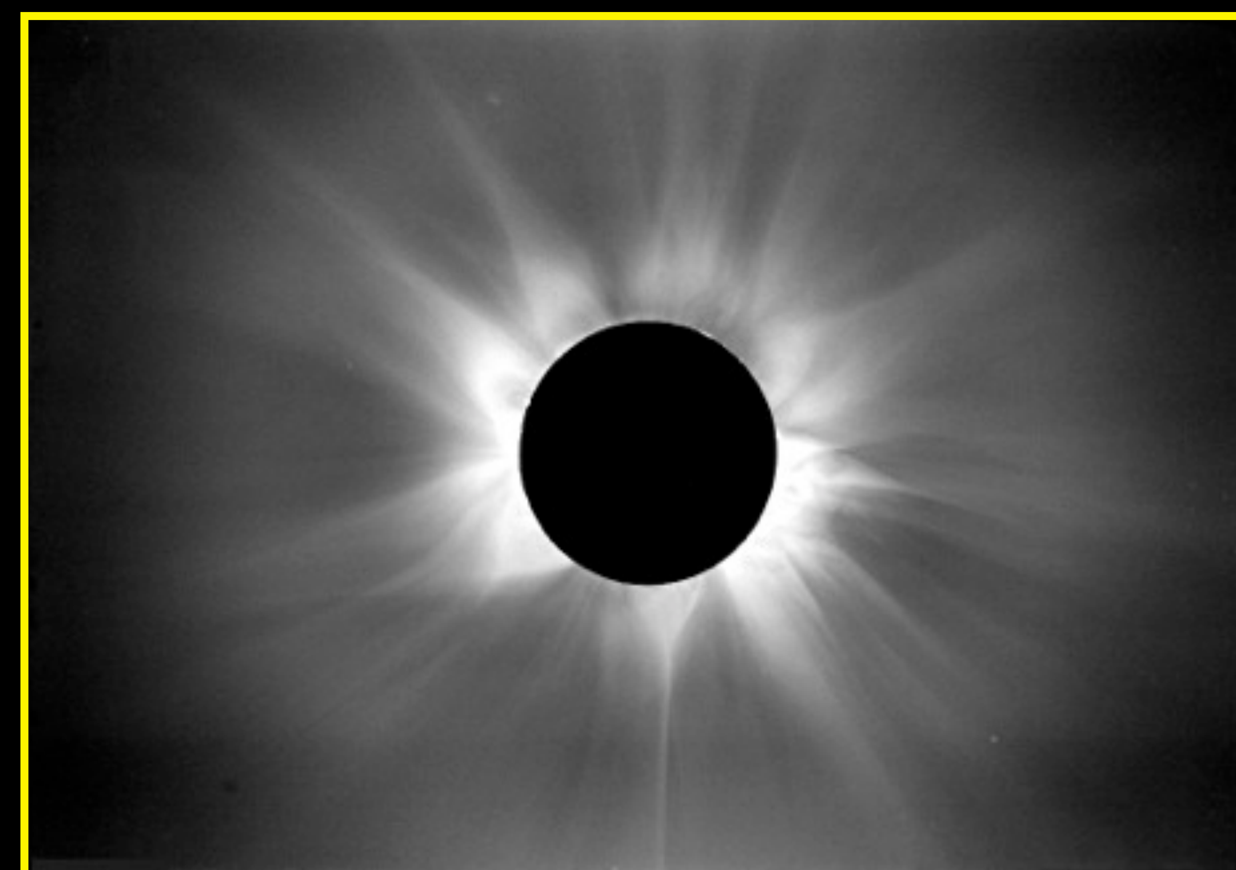
- Surprisingly the solar atmosphere is hotter than the surface/photosphere
- How can that be?





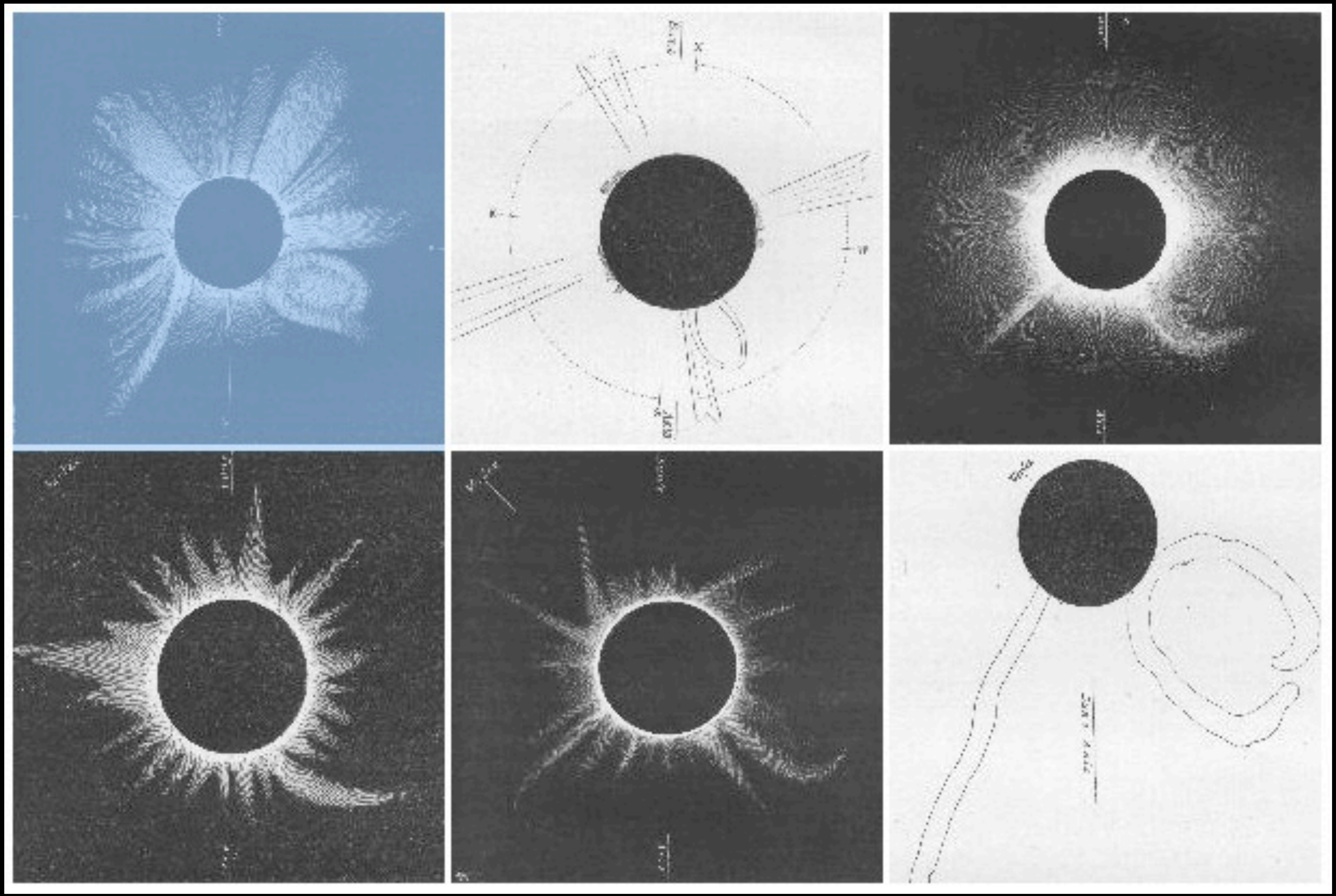
THE CORONA - DURING ECLIPSES





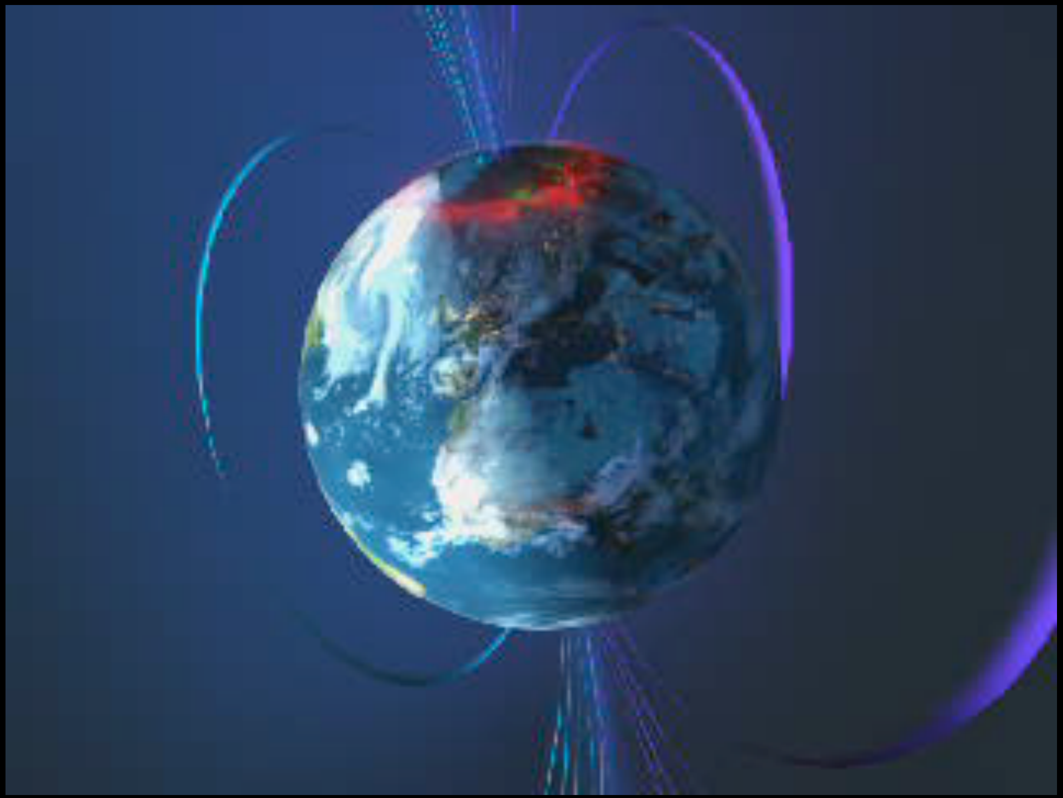
First observations of a coronal mass ejection

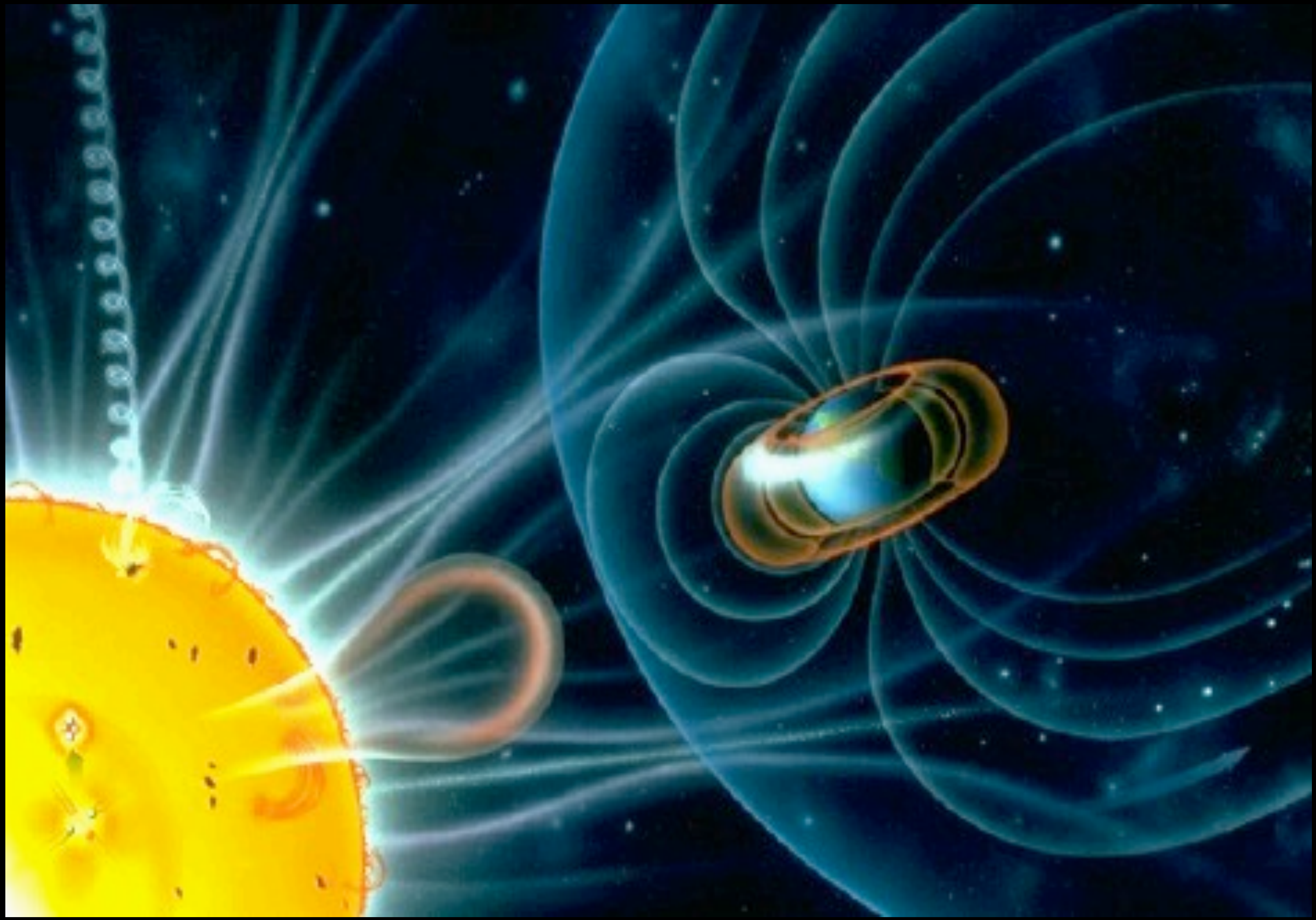
The total solar eclipse of 18 July 1860 was probably the most thoroughly observed eclipse up to that time.



The Solar Wind

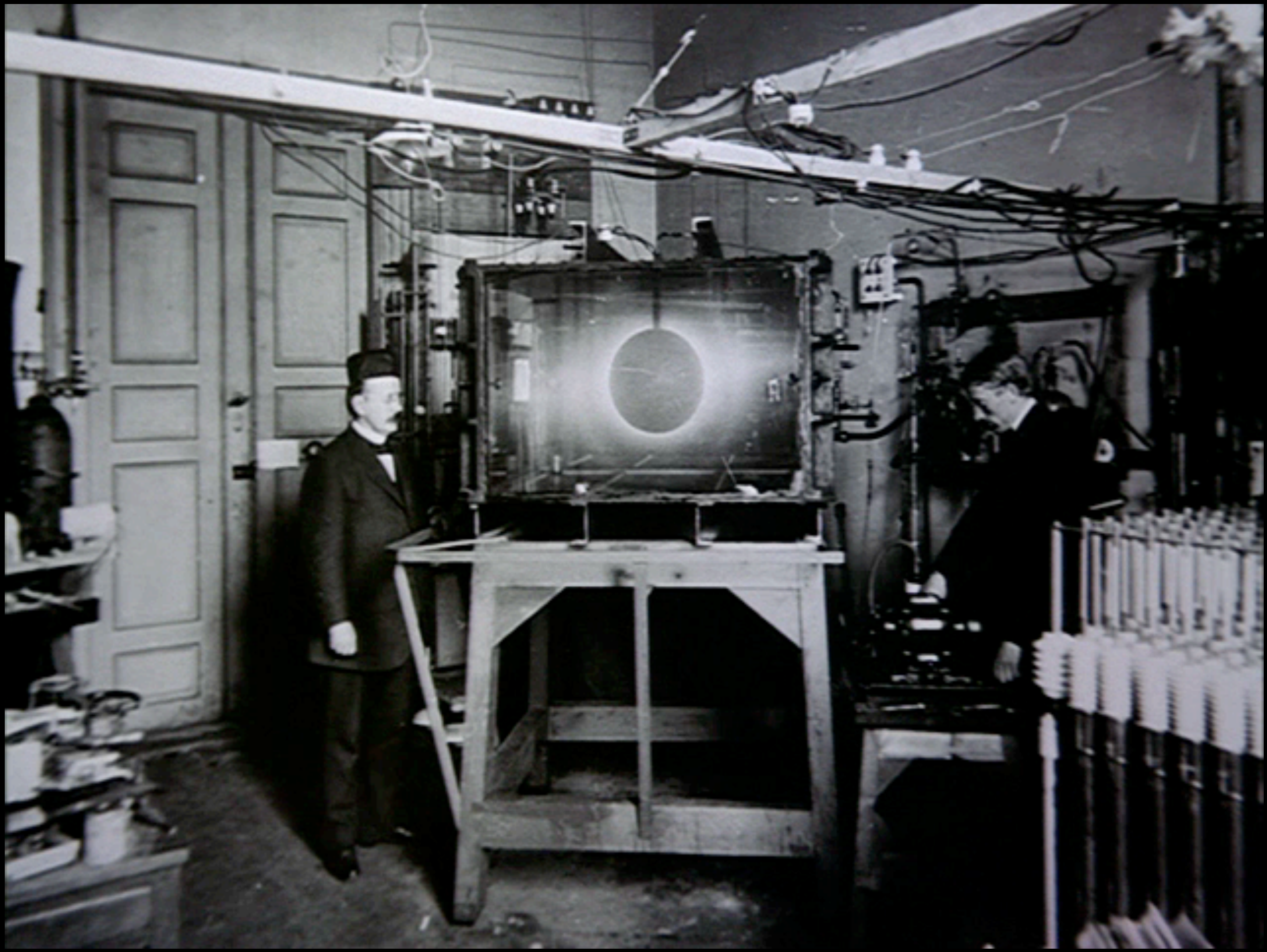
- A constant stream of particles flows from the Sun's corona, with a temperature of about a million degrees and with a velocity of about 1.5 million km/h.
- Gusts in the solar wind will buffet our magnetosphere and lead to a geomagnetic storm.

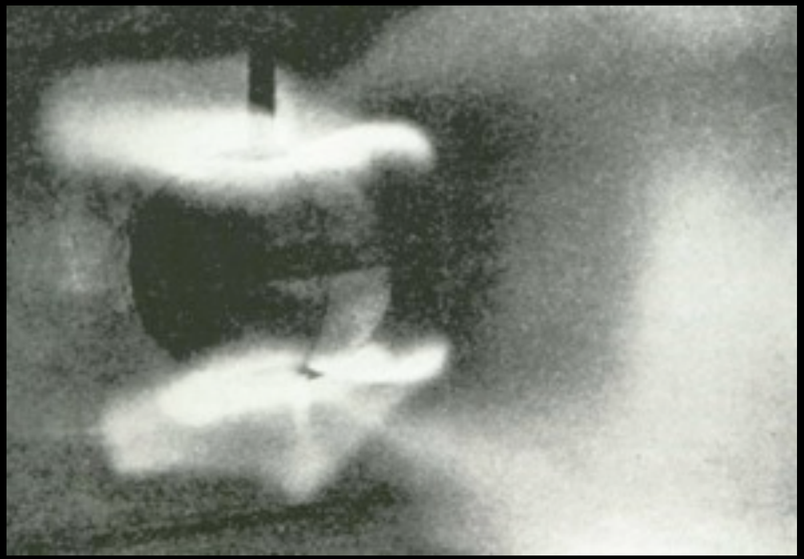




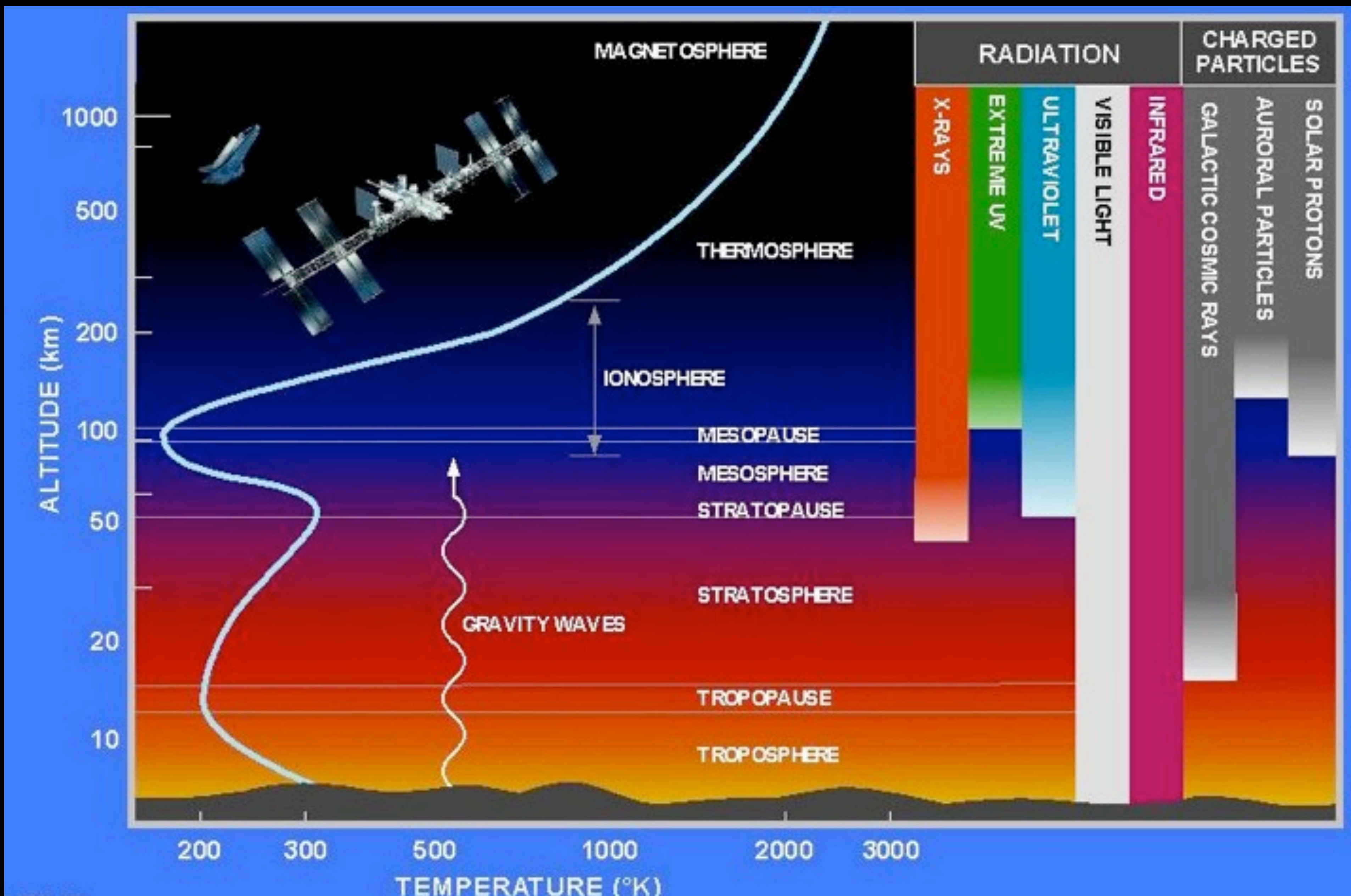
Kristian Birkeland (1867 - 1917)

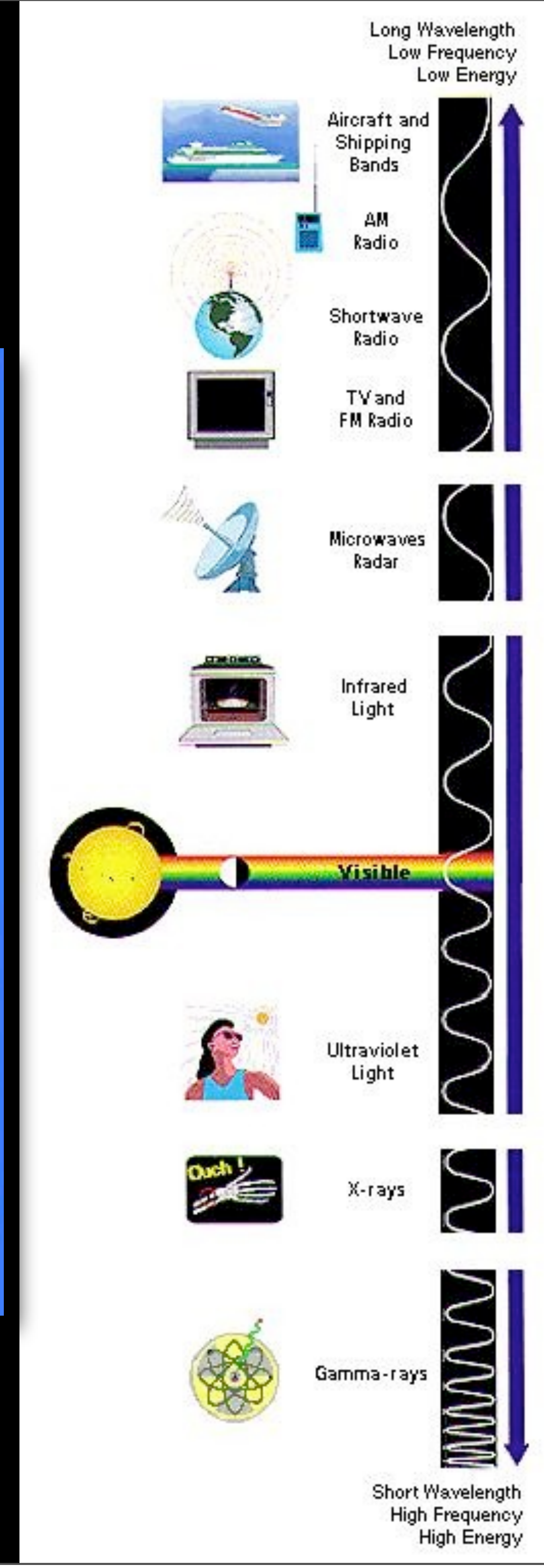
- The first realistic theory of the aurora: Electrical charged particles traveling with large velocities from sunspots. These were captured by the Earths magnetic fields and channelled down towards the polar regions.
- He supported his theory by creating artificial aurora in his laboratory in 1896.





Electromagnetic radiation

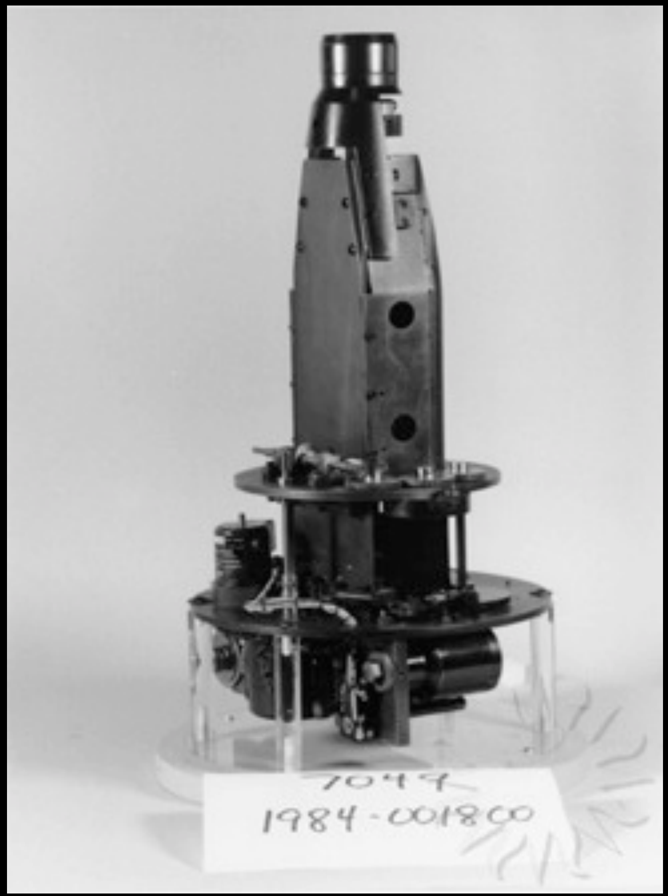




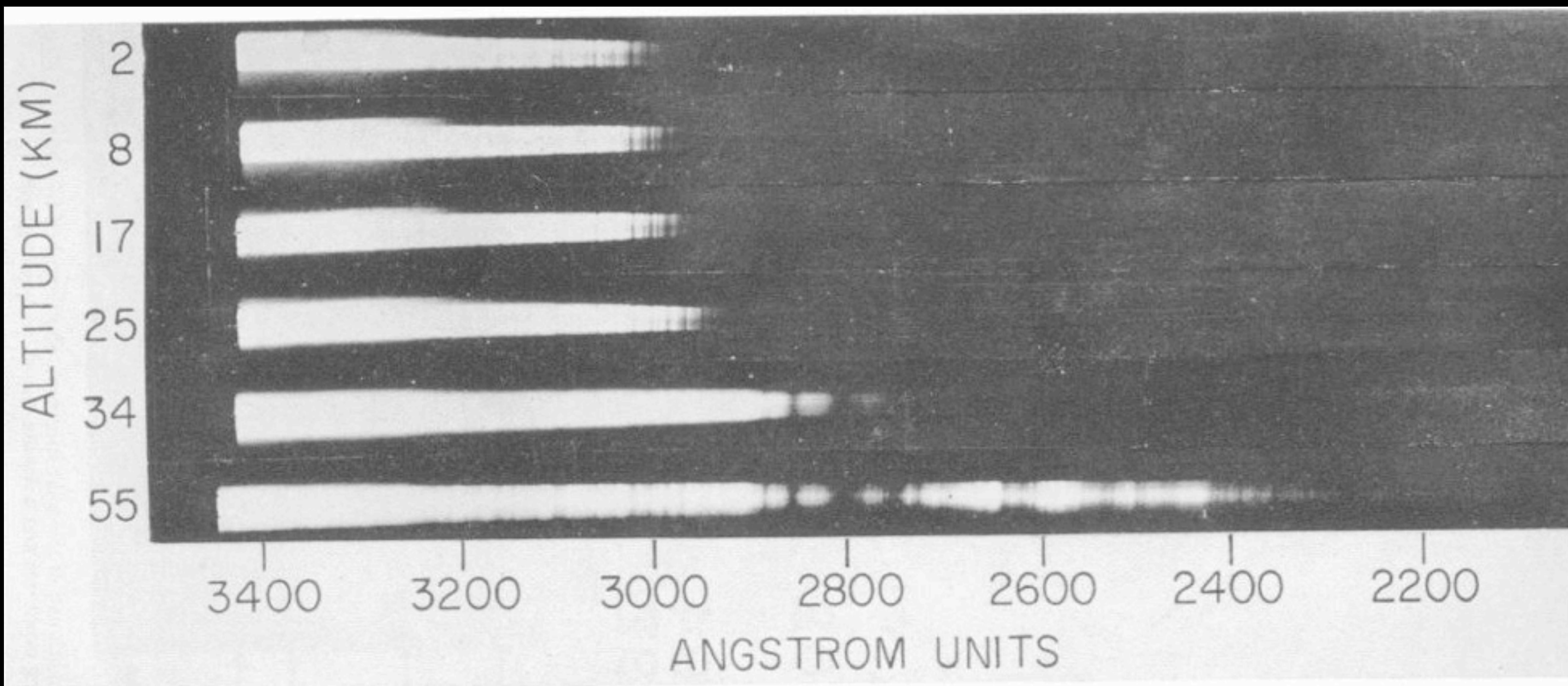
The Sun from Space

First Glimpse of the Sun from Space

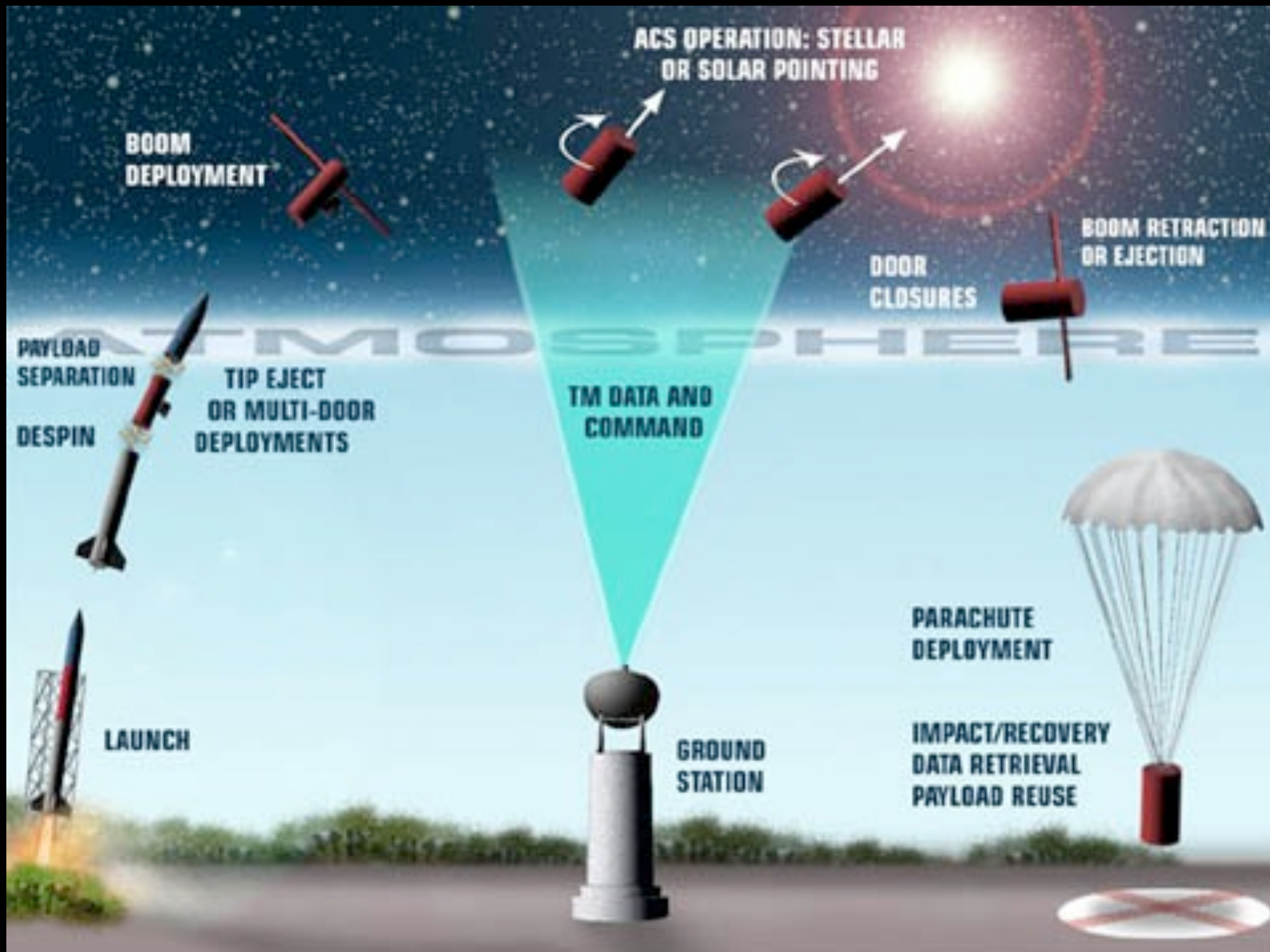
- After World War II, captured V2 rockets provided a means for sending scientific instruments above the bulk of the earth's atmosphere, which absorbed ultraviolet (UV) radiation.
- To study the nature of that absorption, and to examine the ultraviolet portion of the solar spectrum, a group at the Naval Research Laboratory (NRL) in Washington D.C. led by physicist Richard Tousey designed a rugged solar spectrograph to fly in the V2 warhead. 12 spectrometers were built
- The first successful flight of the NRL UV spectrograph was on October 10, 1946. The missile reached an altitude of 173 km and the series of spectra obtained during ascent showed the decrease in UV absorption with altitude and helped set the upper limit to the Earth's ozone layer.



First UV spectrum of the Sun

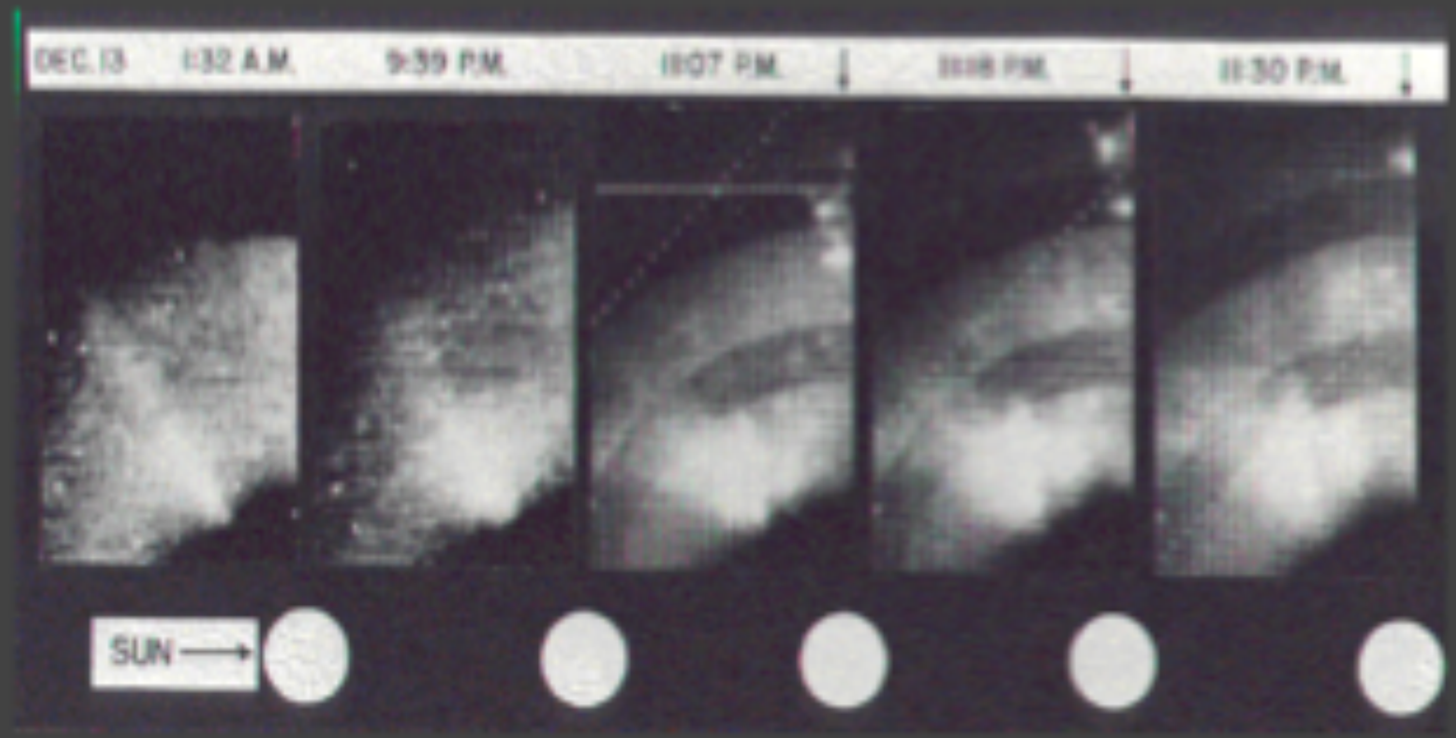


Sounding rockets still useful for Solar Observations



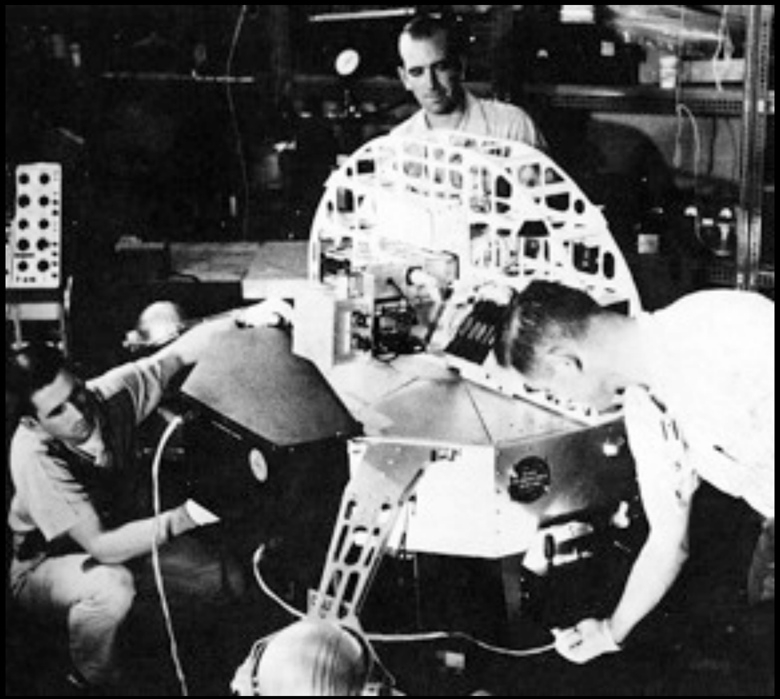
The OSO Satellites

- The Orbiting Solar Observatories were the earliest set of satellites designed to study the Sun. They arose from even earlier sounding rockets flights that showed the importance of getting above the Earth's atmosphere to observe the Sun.



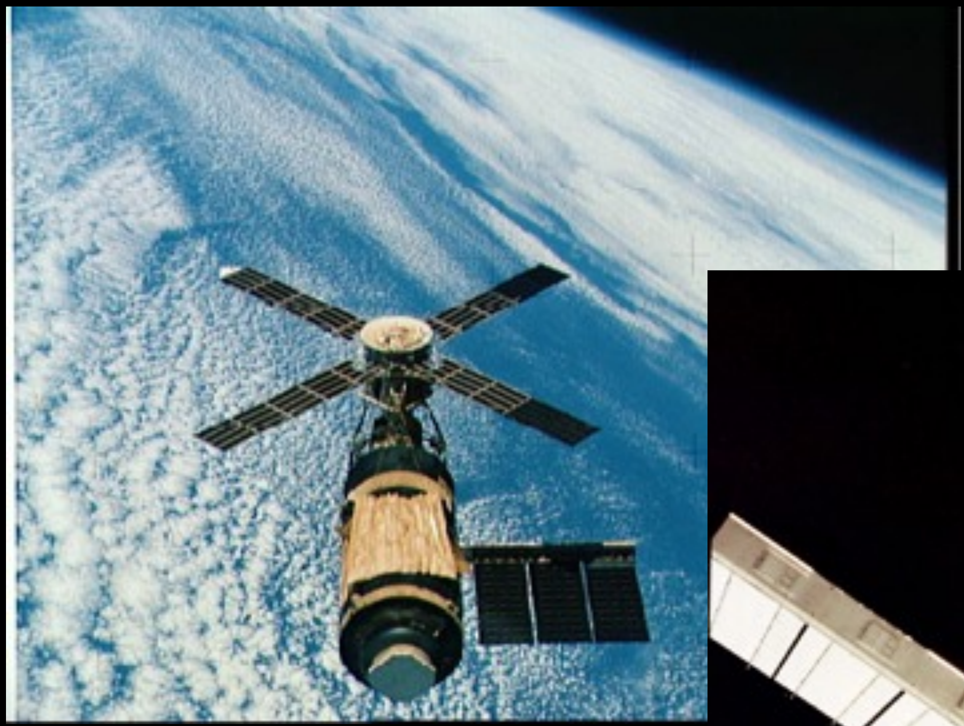
1971 Dec13: First observation of a coronal mass ejection (CME) from OSO-7

Naval Research Laboratory



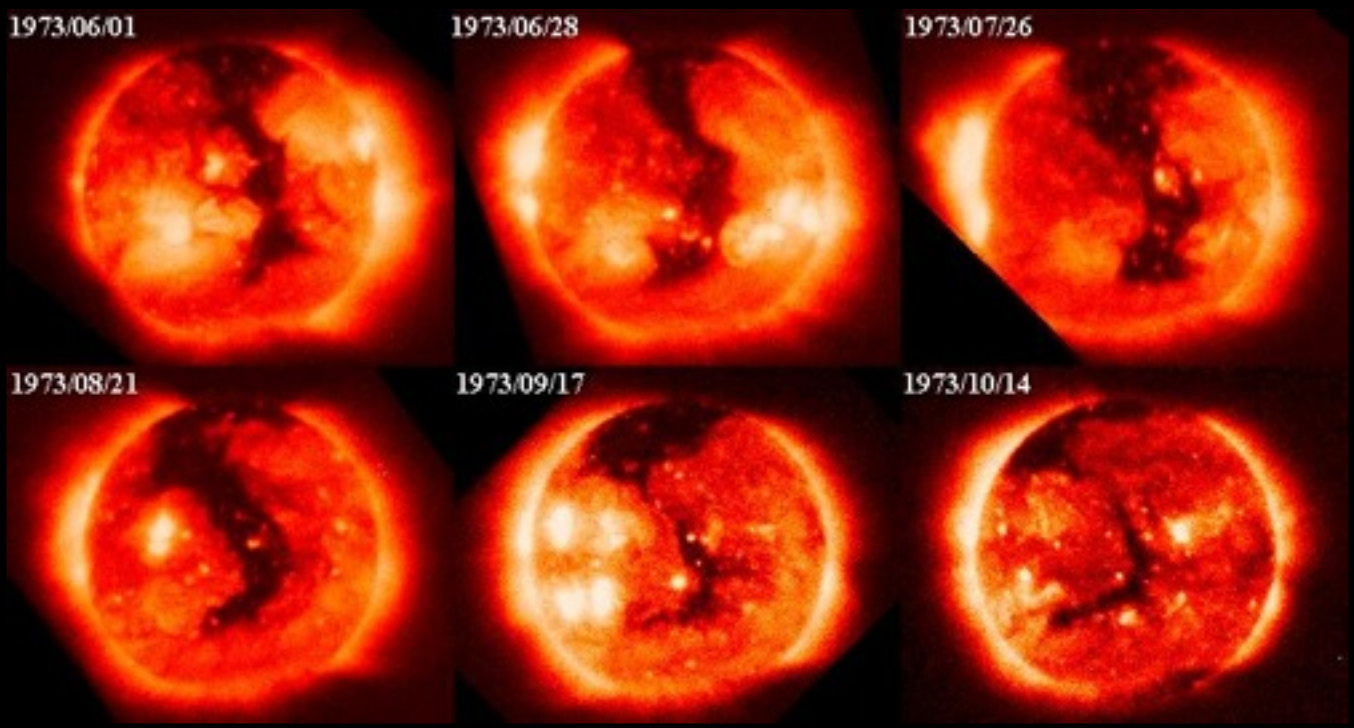
Skylab – Apollo Telescope Mount

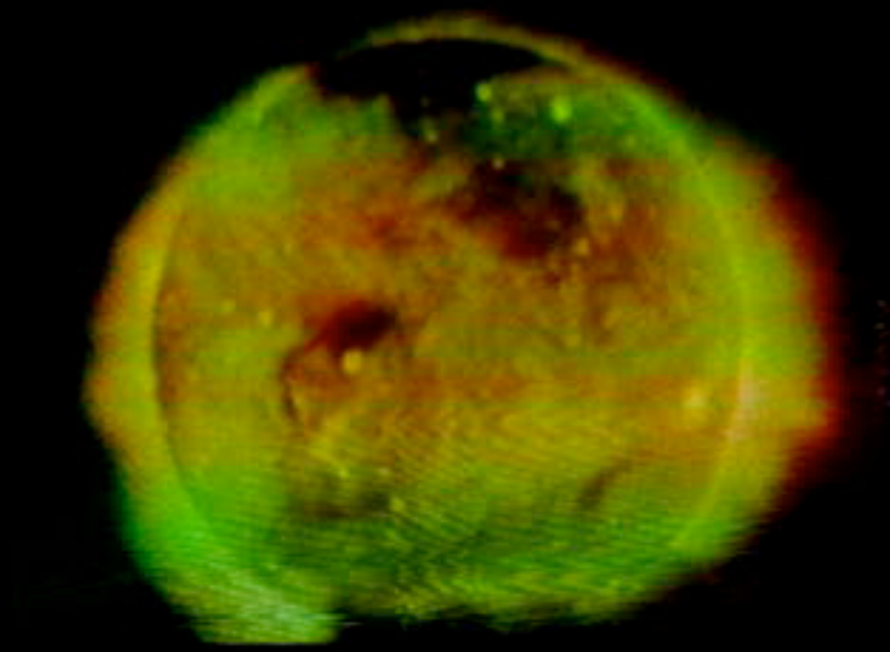
- *Skylab,* the first US space station, was launched into orbit on May 14, 1973 as part of the Apollo program. This 91 metric ton structure was 36 meters (four stories) high, 6.7 meters in diameter and flew at an altitude of 435 km (270 miles).
- When Skylab was launched it lost a solar panel and part of its external shielding. Skylab astronauts had to rig a "golden umbrella" to keep their habitat comfortable. Skylab re-entered the Earth's atmosphere in 1979 over Australia. This re-entry was a year or two earlier than expected.

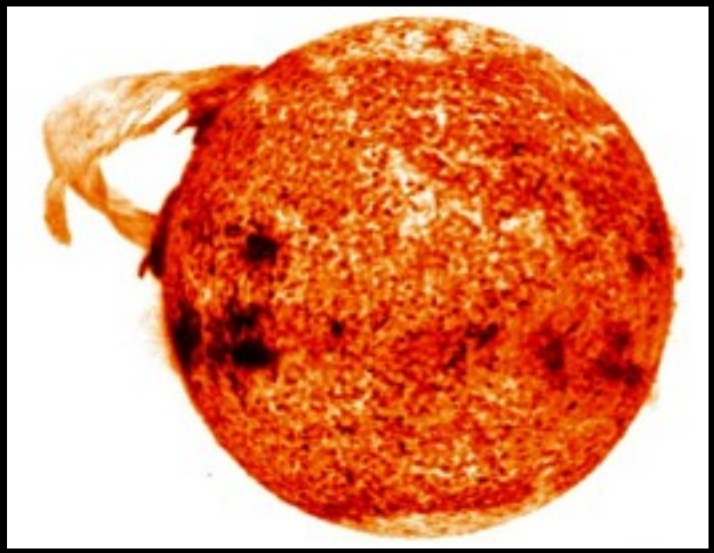



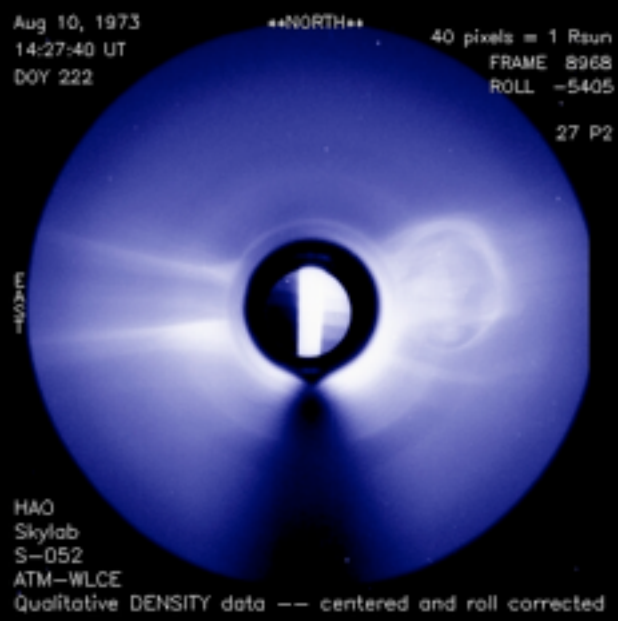

Skylab – Apollo Telescope Mount

- *Skylab* included eight separate solar experiments on its Apollo Telescope Mount: two X-ray telescopes (an X-ray and extreme ultraviolet camera); an ultraviolet spectroheliometer; an extreme ultraviolet spectroheliograph and an ultraviolet spectroheliograph; a white light coronagraph; and two hydrogen-alpha telescopes



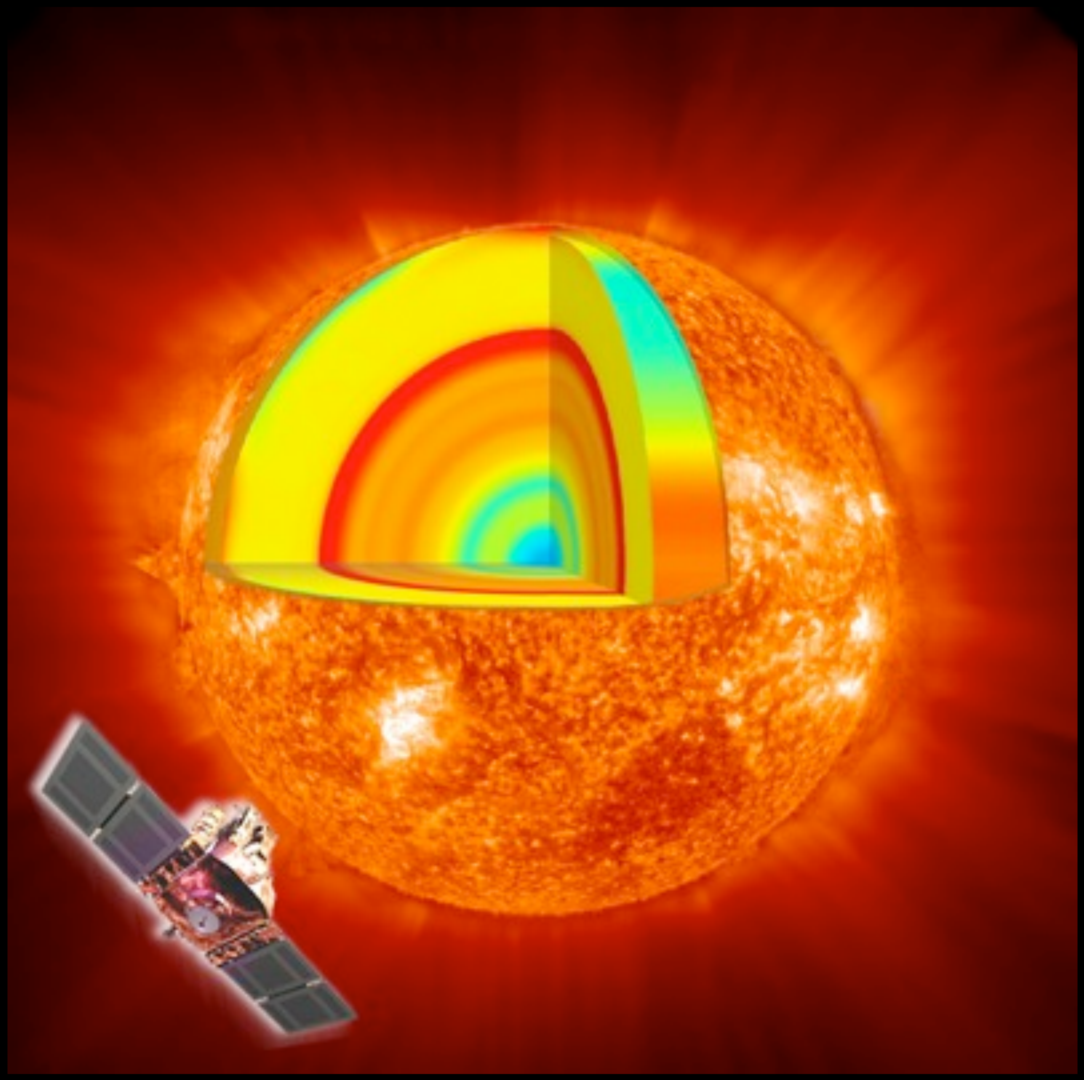




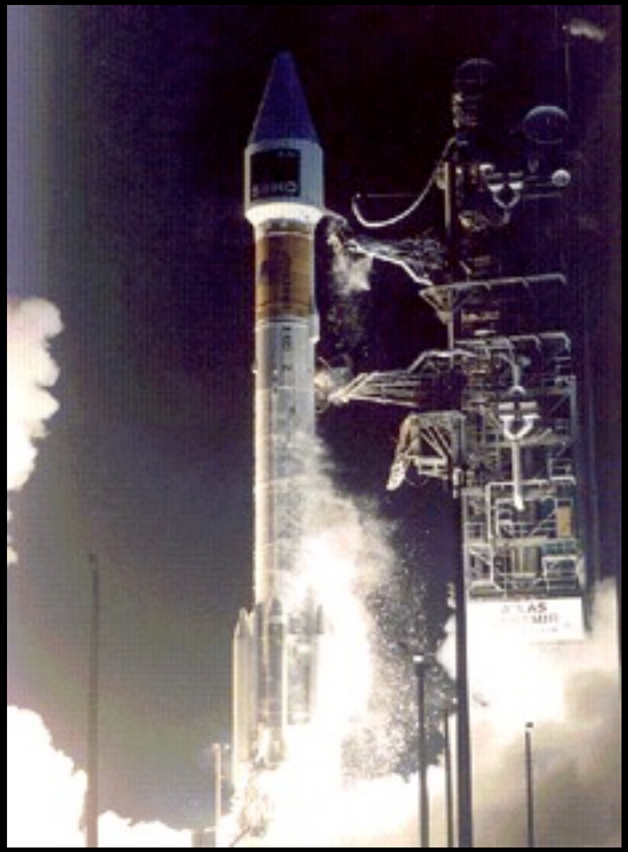


The SOHO Mission

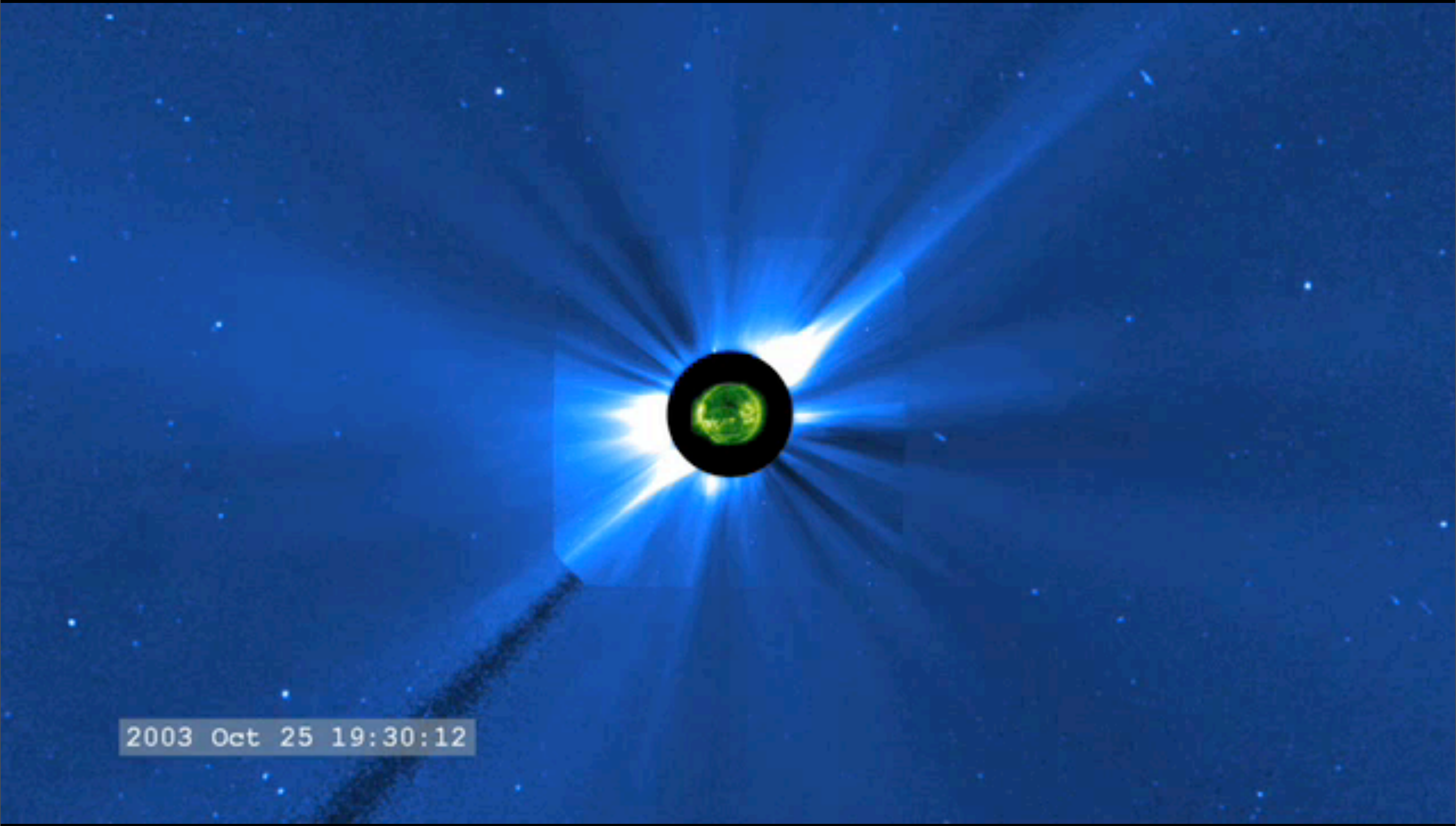
- Joint program between the European Space Agency (ESA) and NASA.
  - An industry team led by Matra Marconi Space built SOHO in Europe. It's instruments were provided by nine European and three U.S. Principle Investigators
  - ESA: responsible for SOHO's procurement, integration, and testing
  - NASA: provided launch and mission operations (at Goddard Space Flight Center)



Launch 2 December 1995



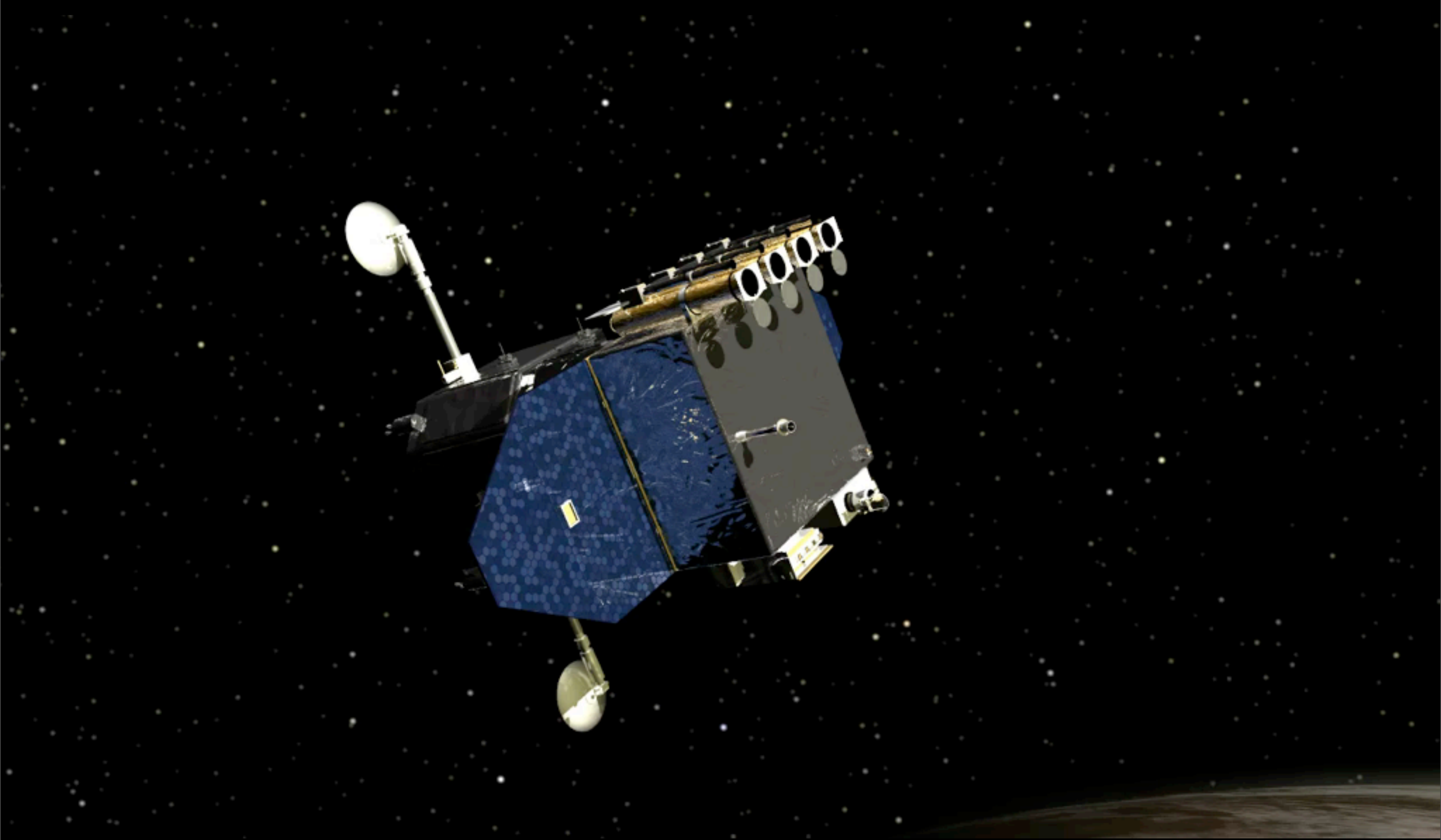
SOHO LASCO CORONAGRAPH



SOHO/ESA/NASA

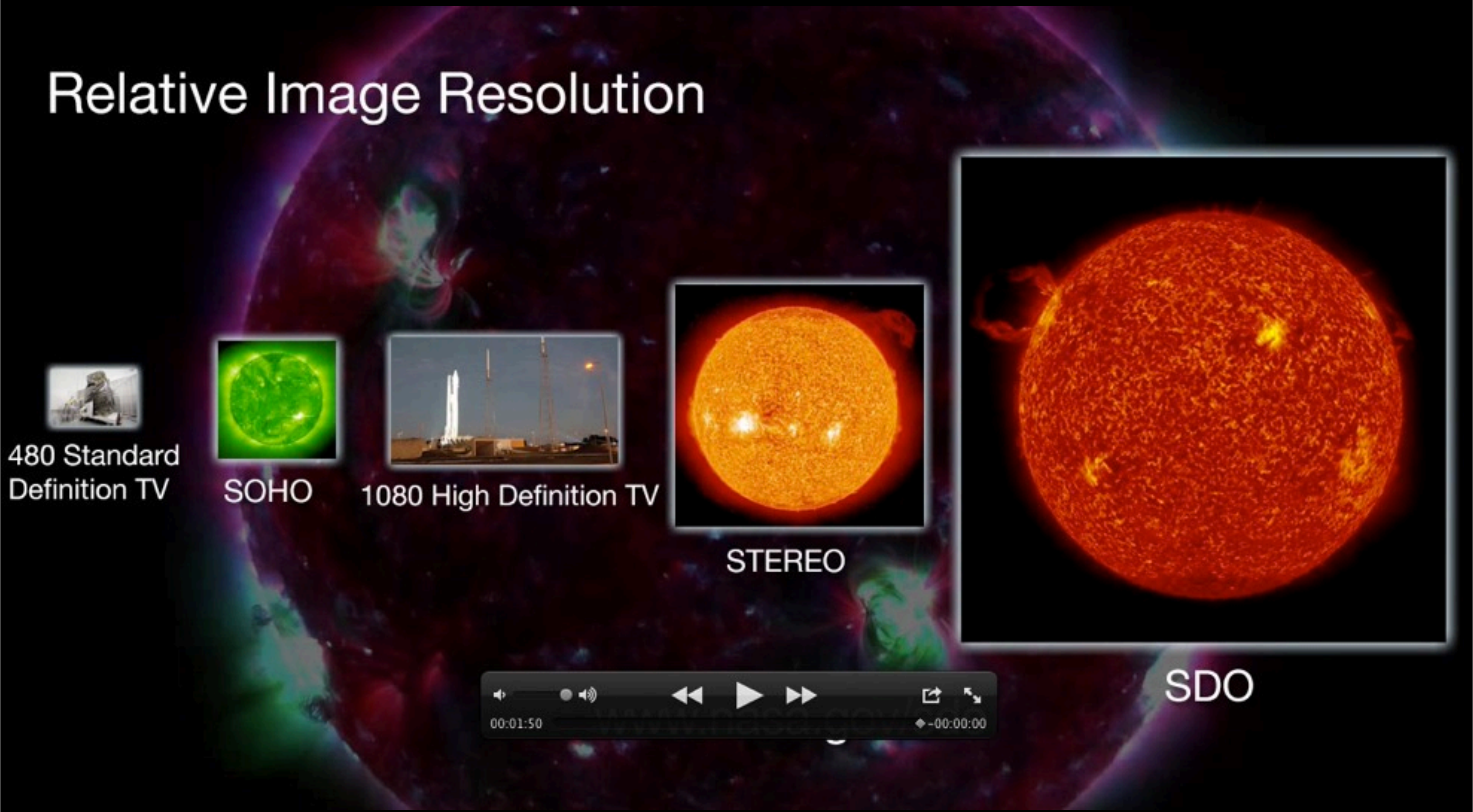
HINODE

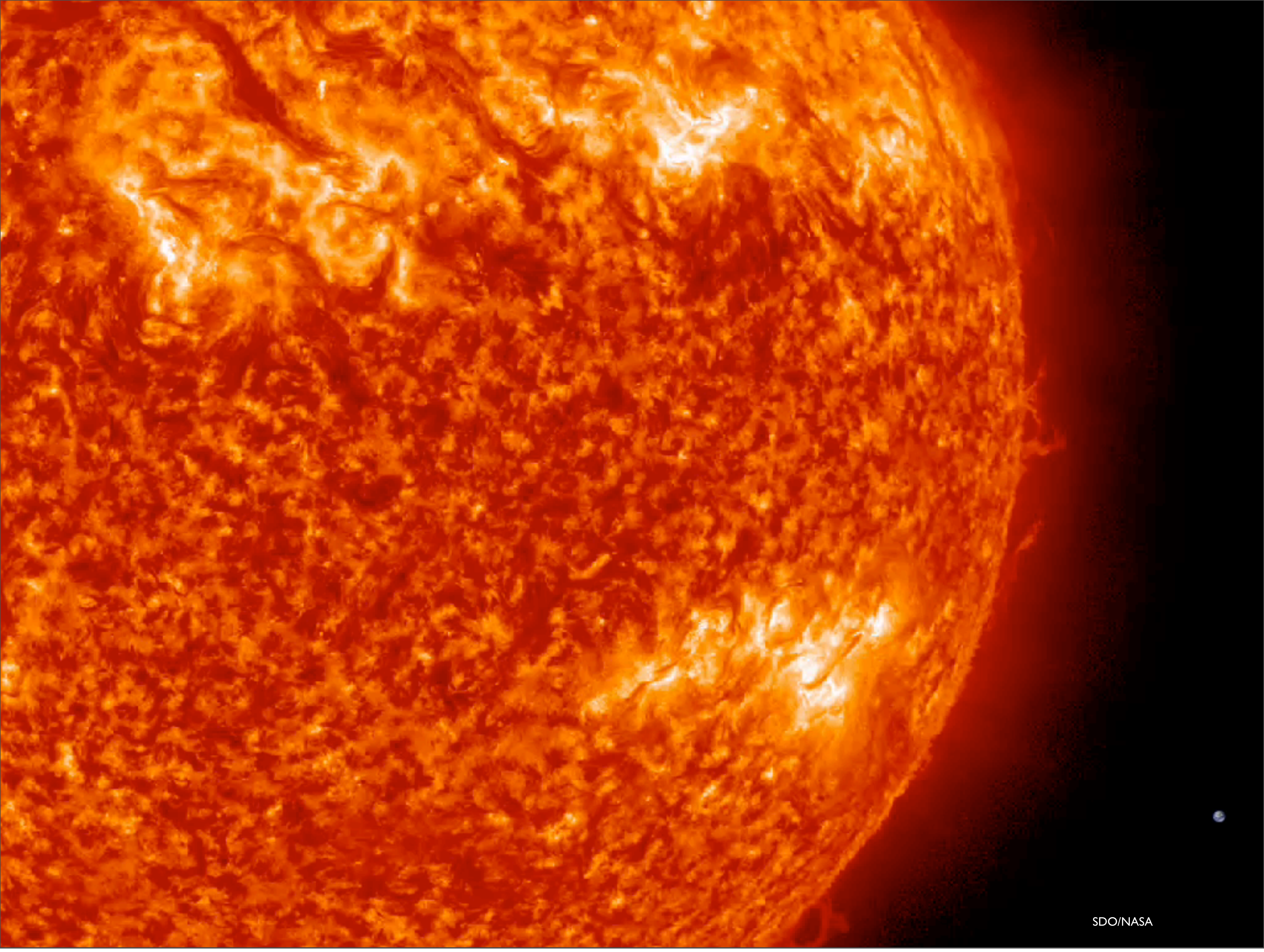
Solar Dynamics Observatory

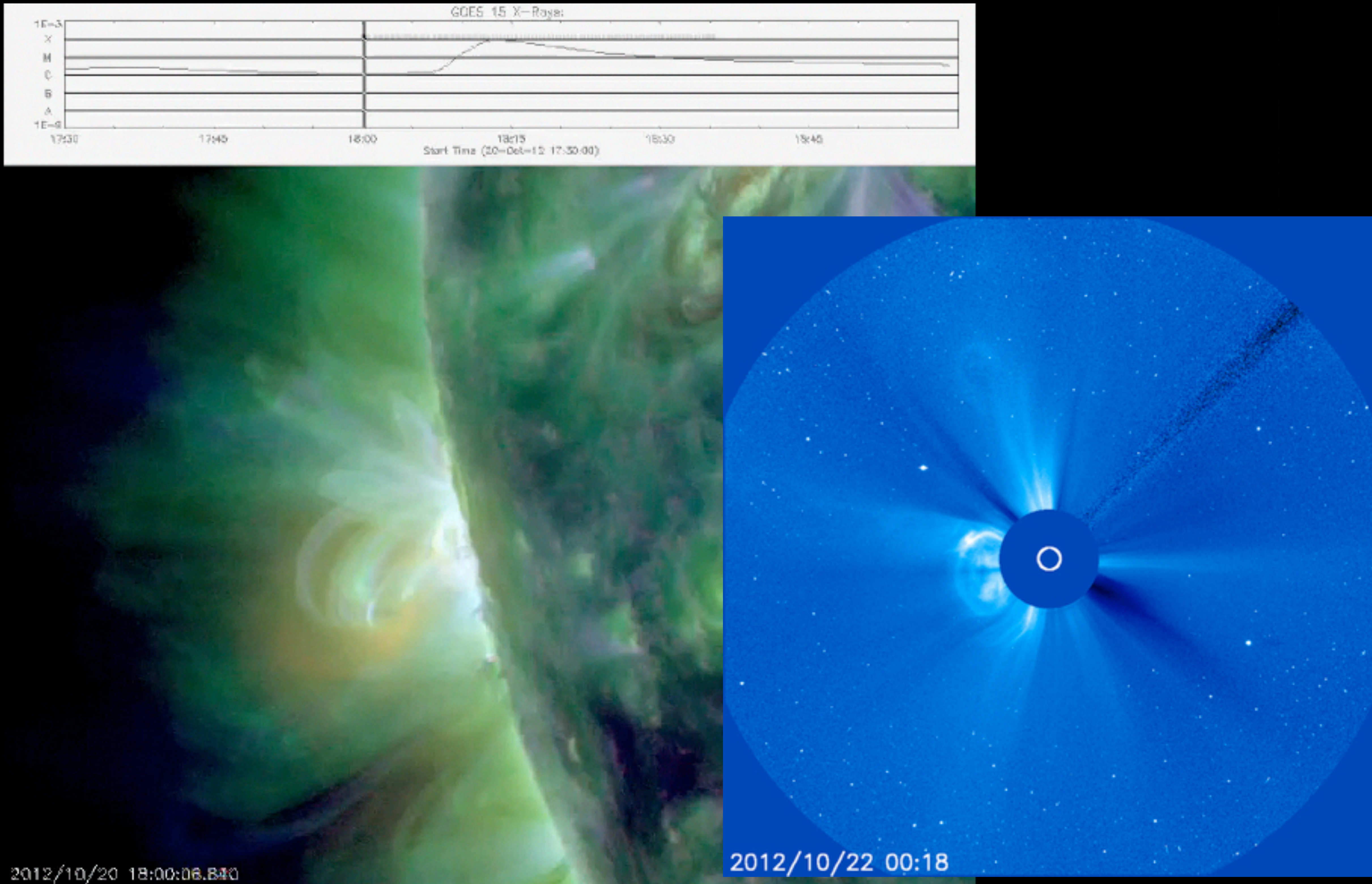


SDO/NASA

Solar Dynamics Observatory




SDO/NASA


GOES 15 X-Rays:
1E-3
X
M
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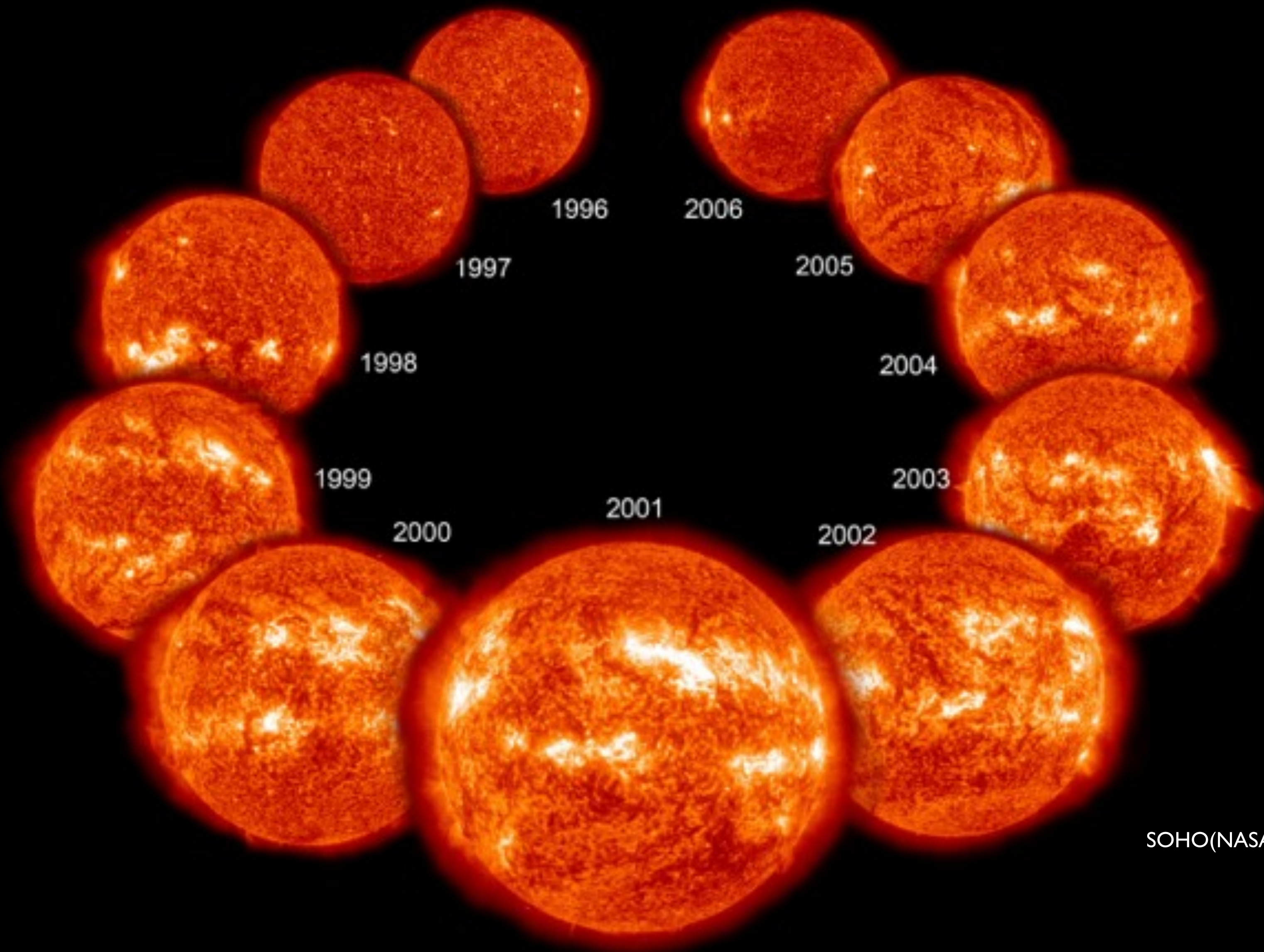
A
1E-9
17:30
17:45
18:00
18:15
18:30
18:45
Start Time (20-Oct-12 17:30:00)
2012/10/20 18:00:06.840
2012/10/22 00:18

Solar cycles
THE SUN – A VARIABLE STAR



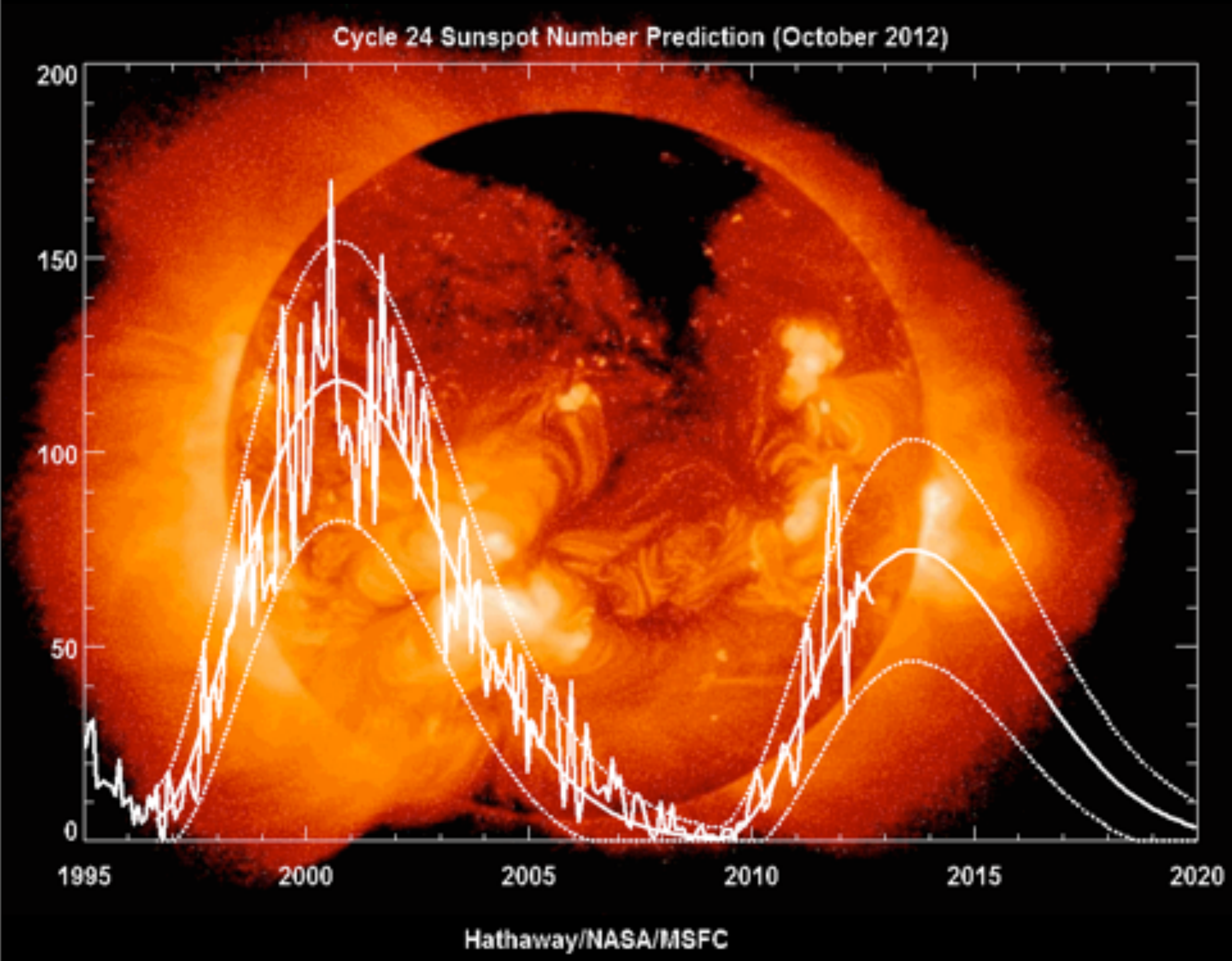
SOHO(NASA/ESA/S. Hill)

Seen from the Earth with the naked eye the Sun appears to be quite static and calm, yellow disk on the sky. However, the Sun is a very variable and stormy star and contributes with much more than just heat and light. It is the source of the fascinating auroras and it can affect our technology-based society. It also affects the climate since the amount of energy is varying. That is why it is so important to increase our knowledge about the Sun – our life supporting star.

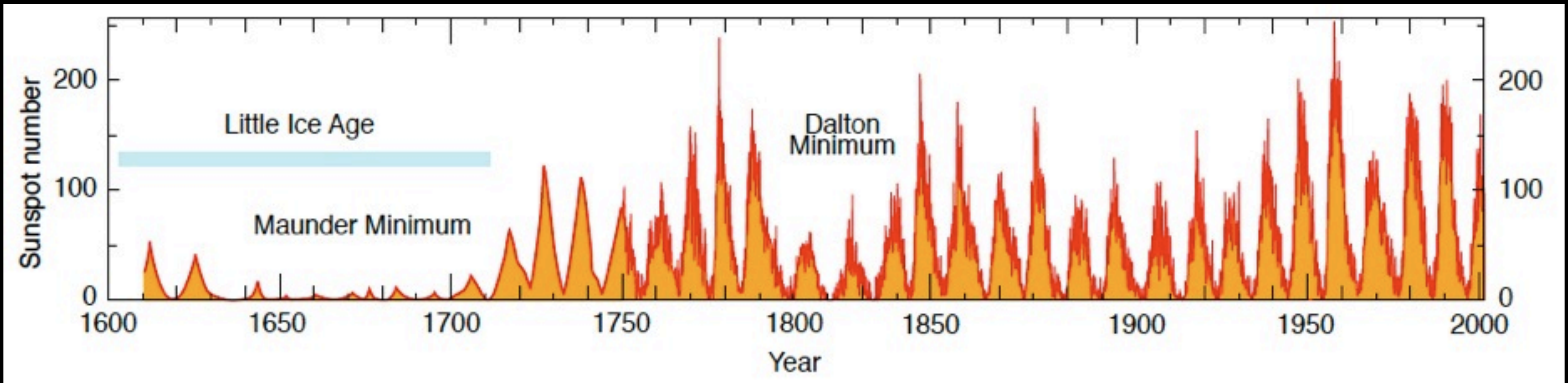
Sunspot and Sunspot cycles

NASA

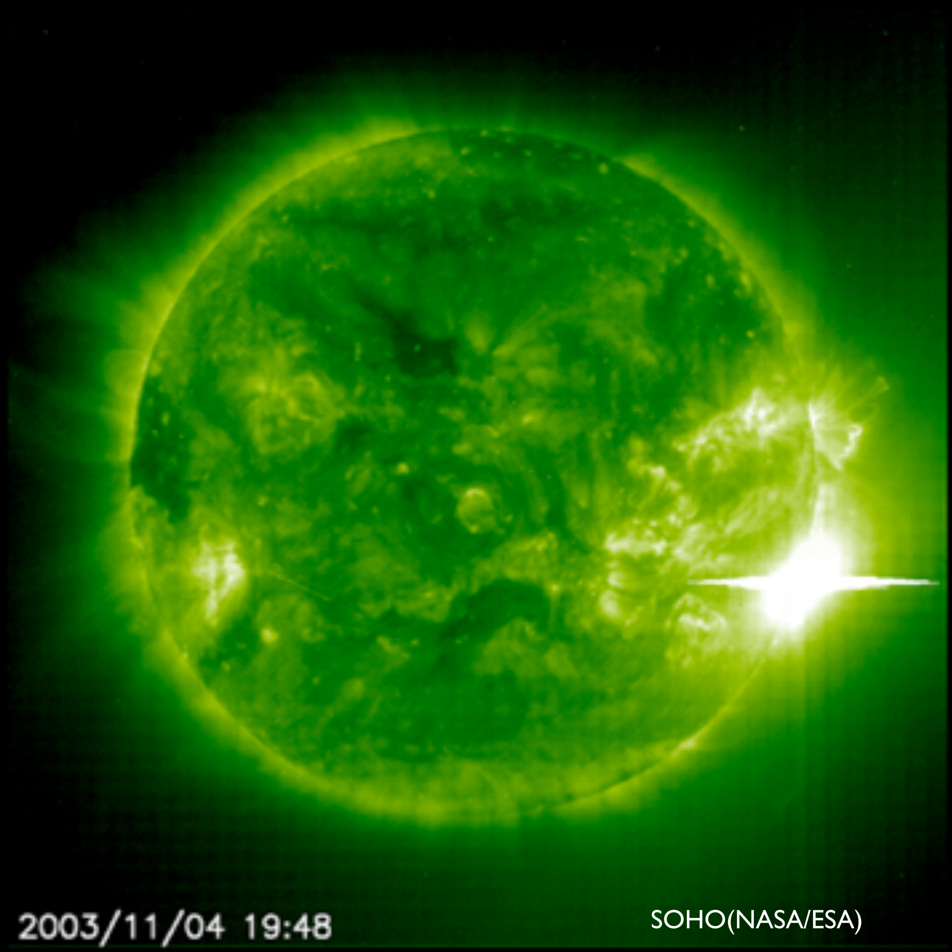
Historical sunspot records

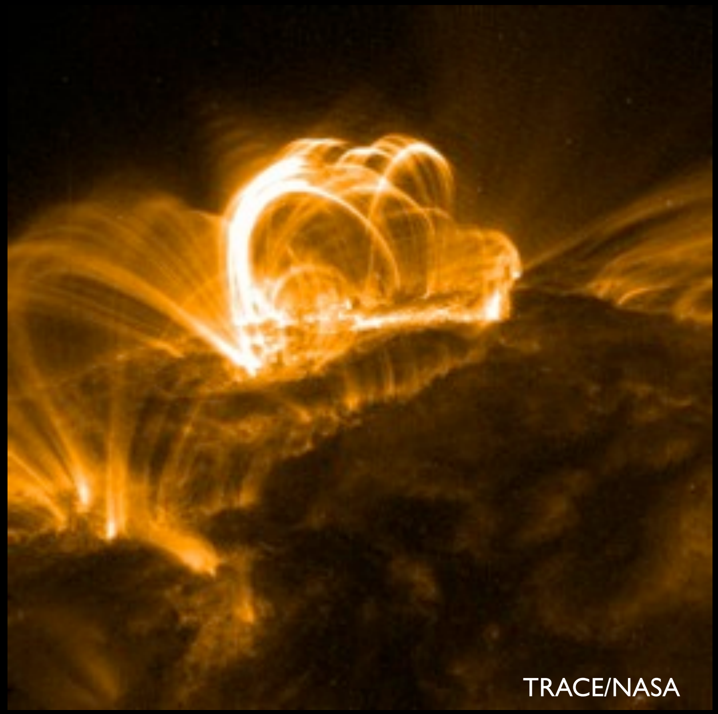


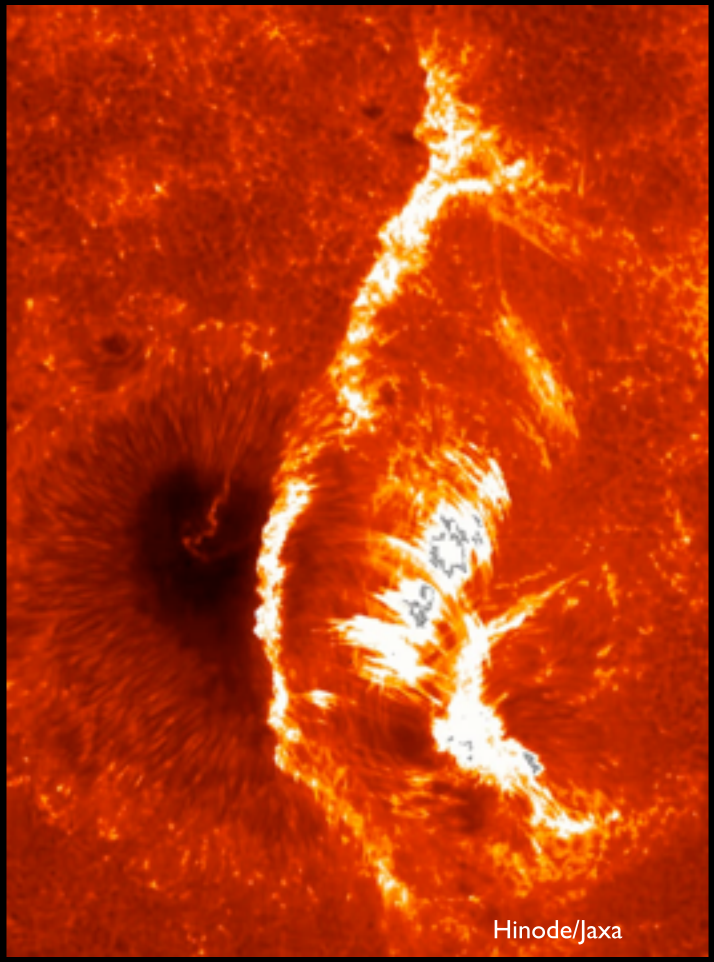
I 1610 pekte Galileo og Thomas Harriot teleskopet mot Solen for første gang. Galileo skadet synet p.g.a. disse observasjonene.



EXPLOSIONS ON THE SUN



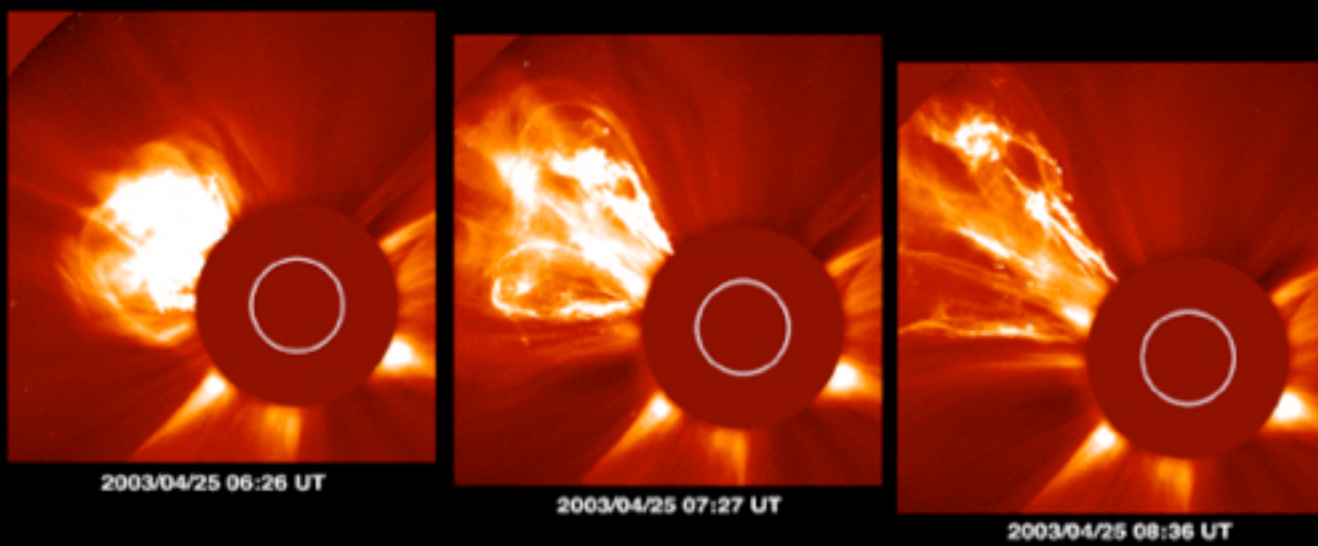




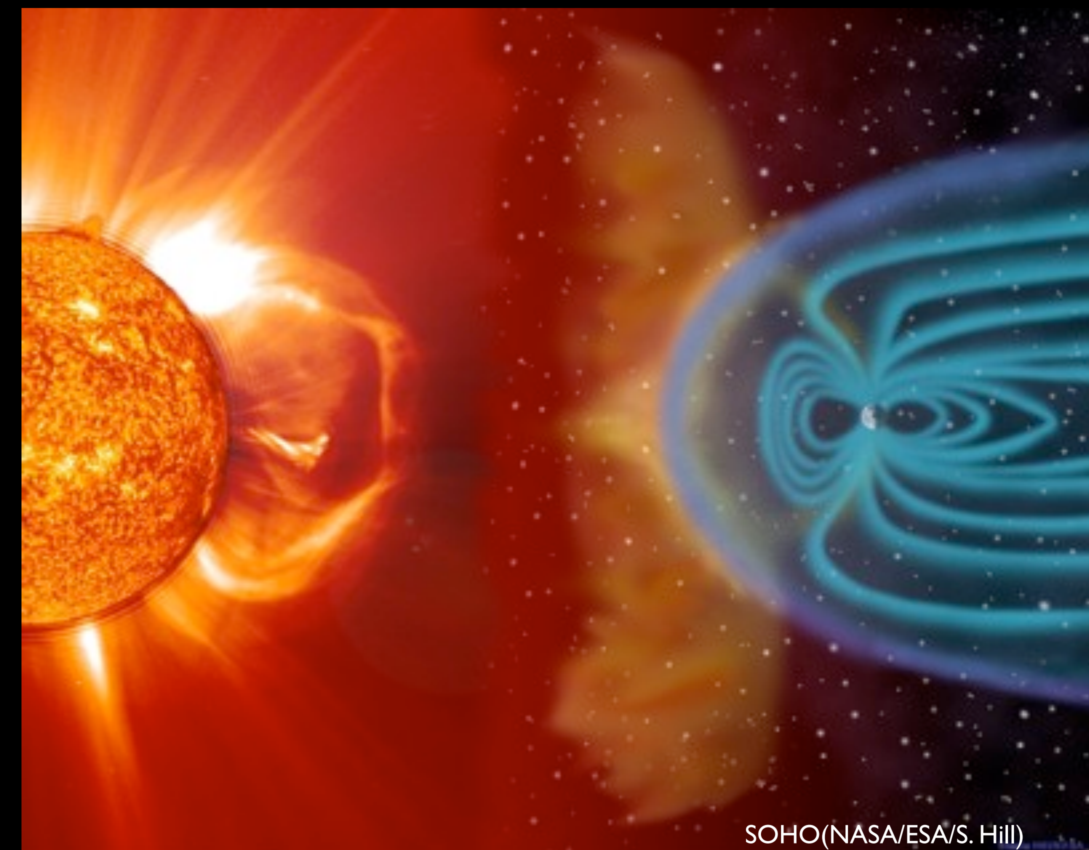
The magnetic field in large active regions on the Sun often gets unstable. This can result in violent explosions in the solar atmosphere – called “flares”. A flare can release in seconds energy corresponding to several billion megatons of TNT. During such explosions the gas is heated to 20 million degrees.

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.

GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)



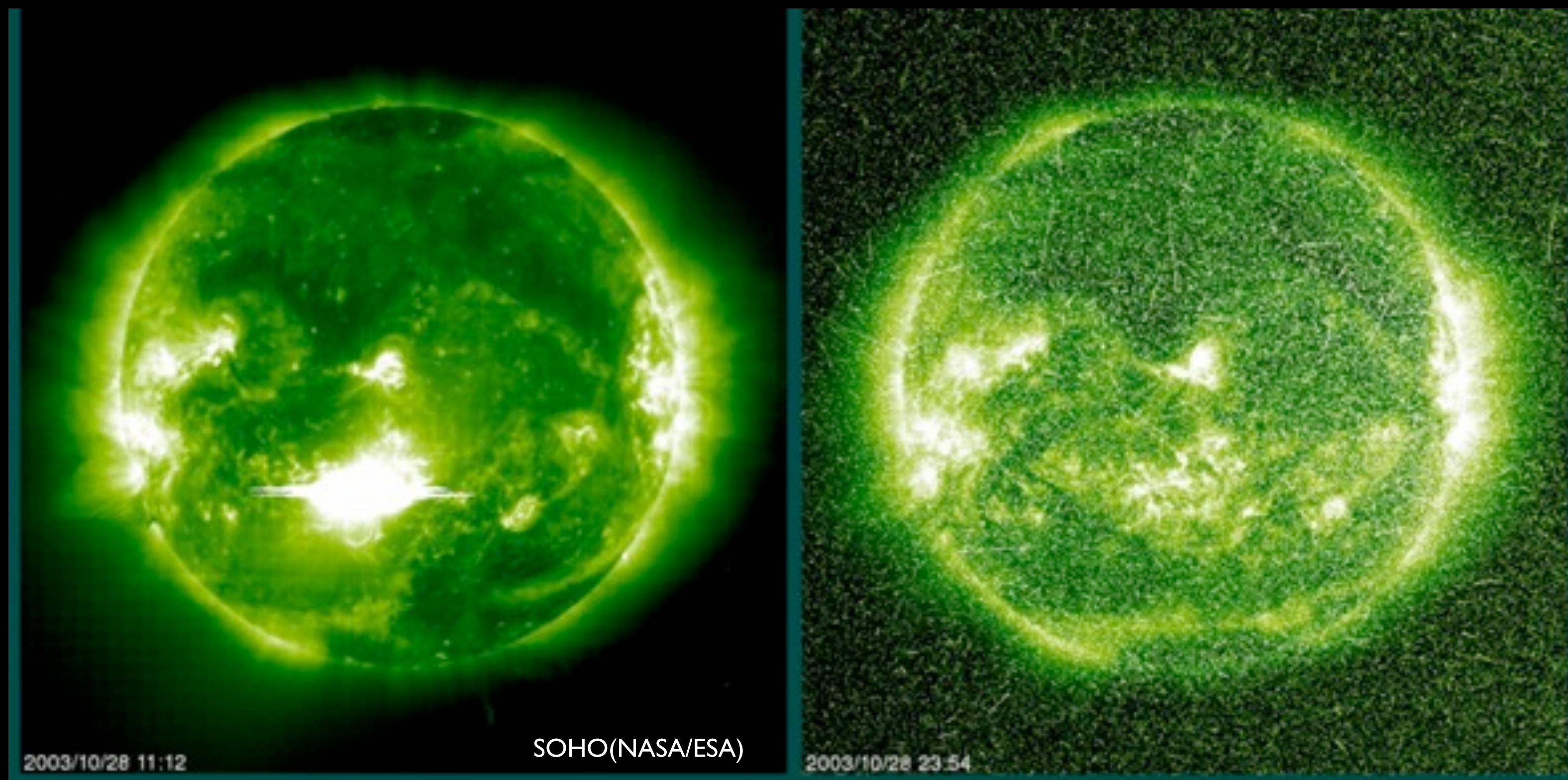
SOHO(NASA/ESA/S. Hill)

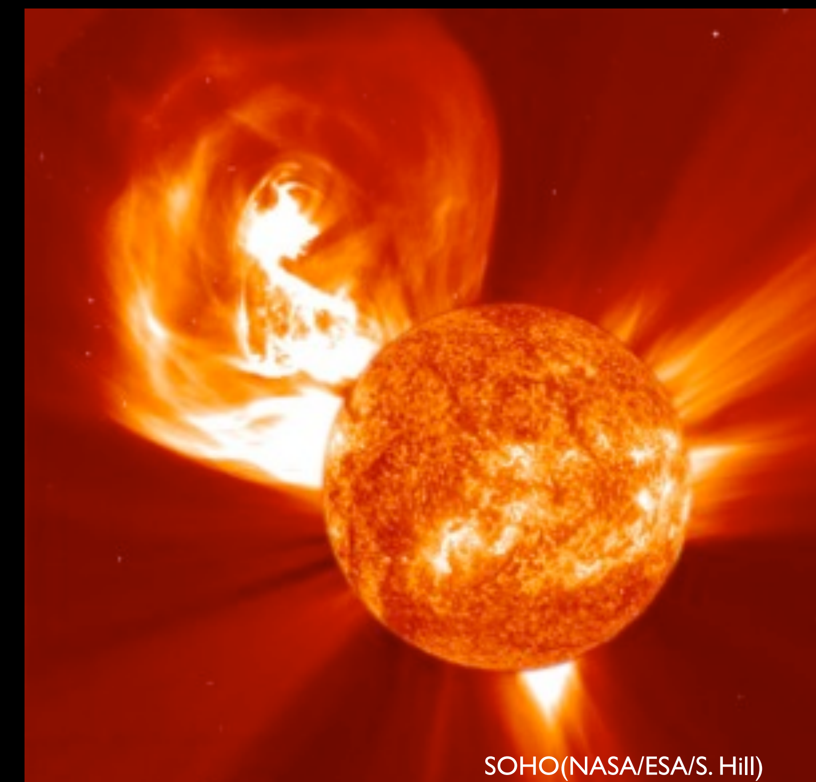


Sometimes large prominences can erupt and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called Coronal Mass Ejections or CMEs for short. The bubble of gas will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

PARTICLE SHOWERS FROM THE SUN

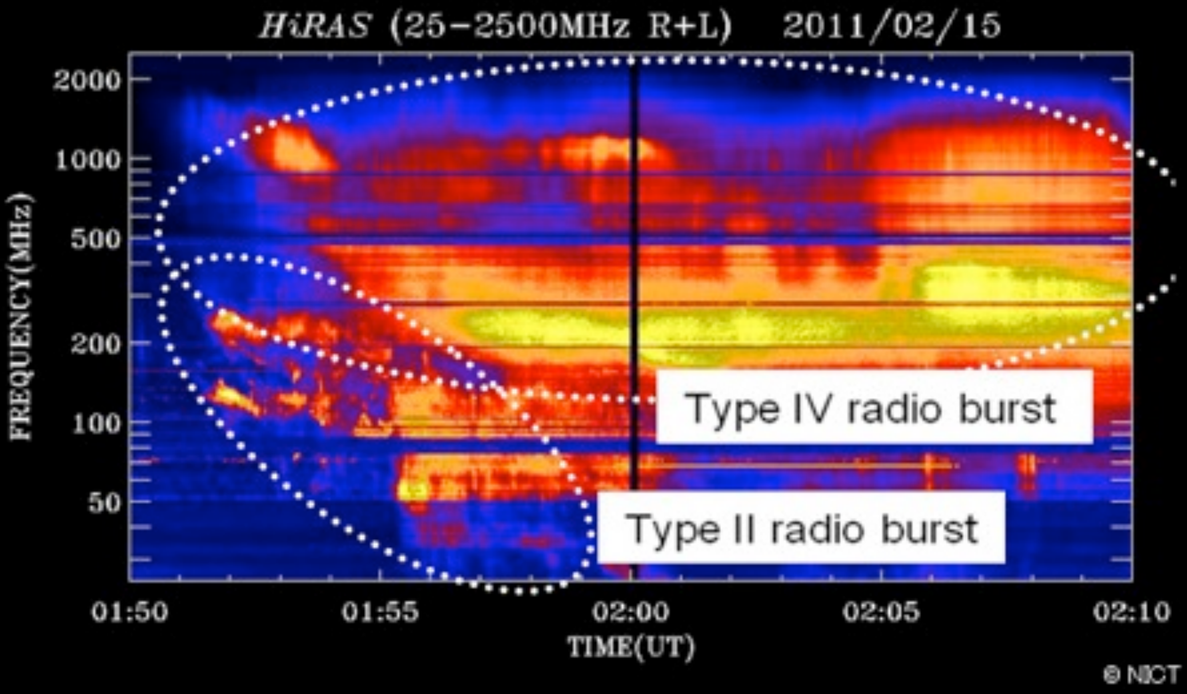


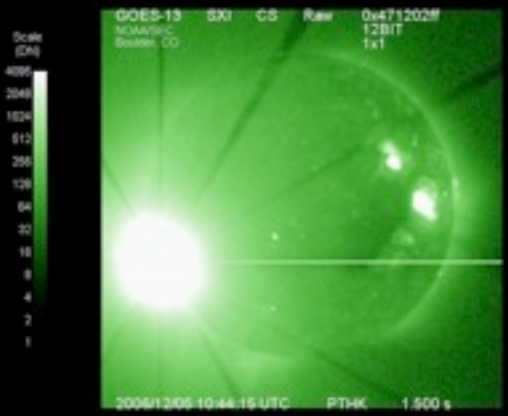


A few times explosions or eruptions will accelerate large amount of particles that travel at almost the speed of light. Such showers of particles consist mostly of protons and it takes less then an hour to reach Earth.

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





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.

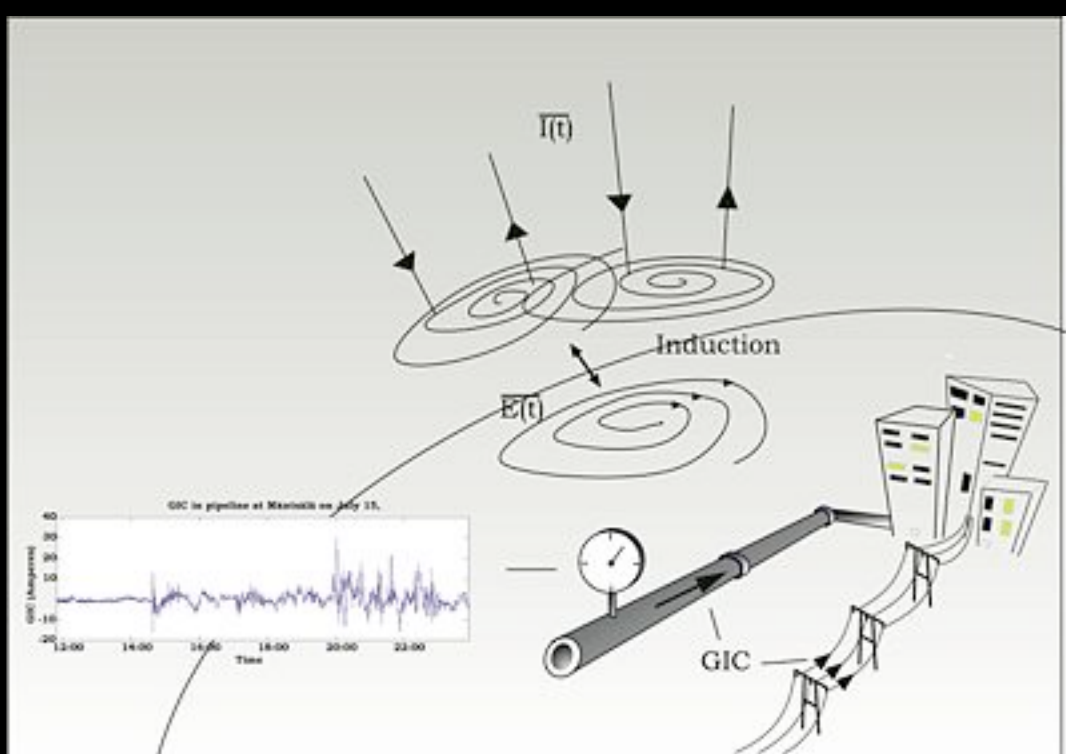
Space Weather

From the book «Our Explosive Sun» (P. Brekke)

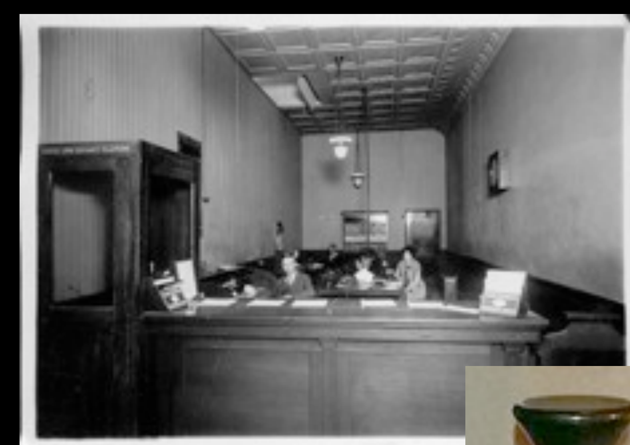
Early effects from Space Weather

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

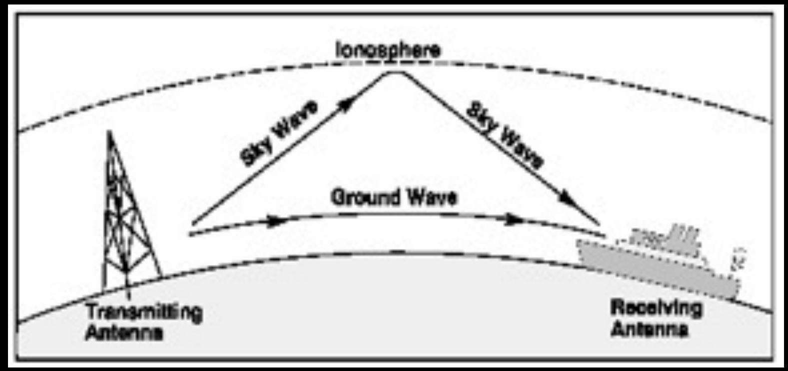


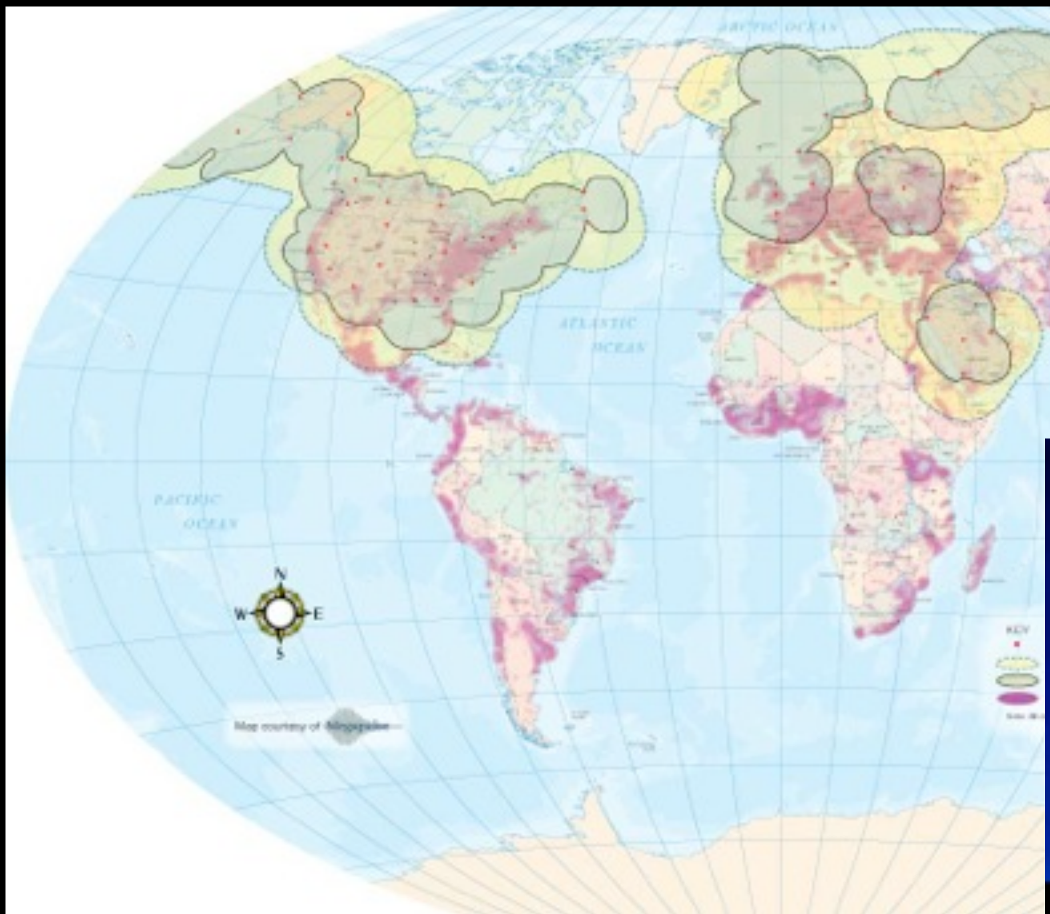
Degradation of LORAN C

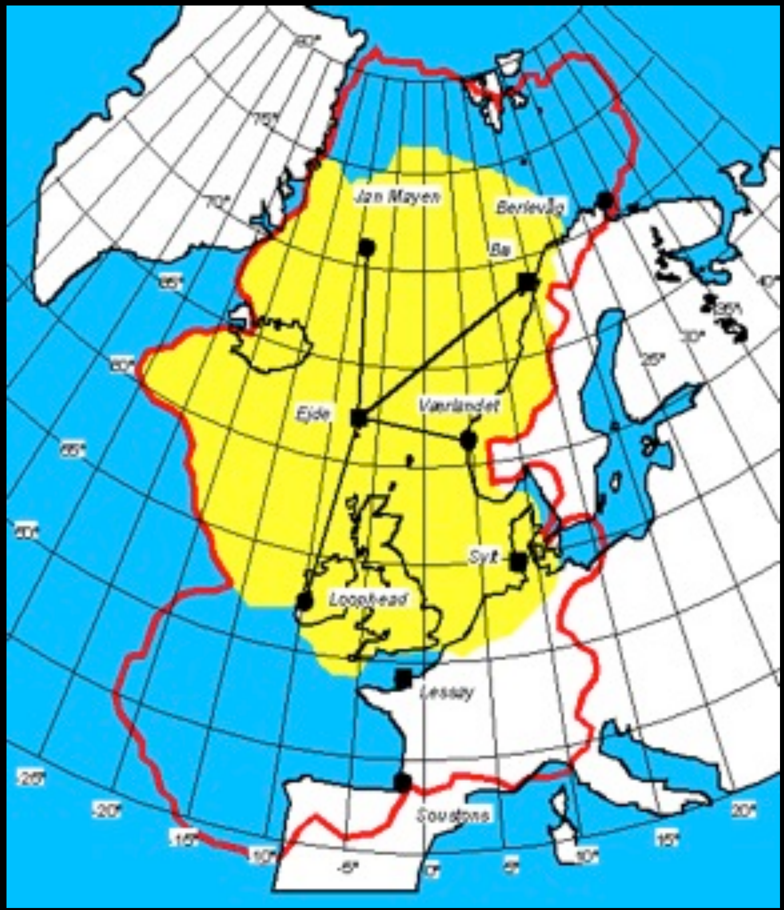
- X-rays/Flares - affects the dayside of the Earth (sunlit side)
- Proton showers - affects the dayside of the Earth (sunlit side)
- Geomagnetic storms - day and night + globally

Normal accuracy is about 0.2 km. During solar storms it can be degraded to about 5 km.

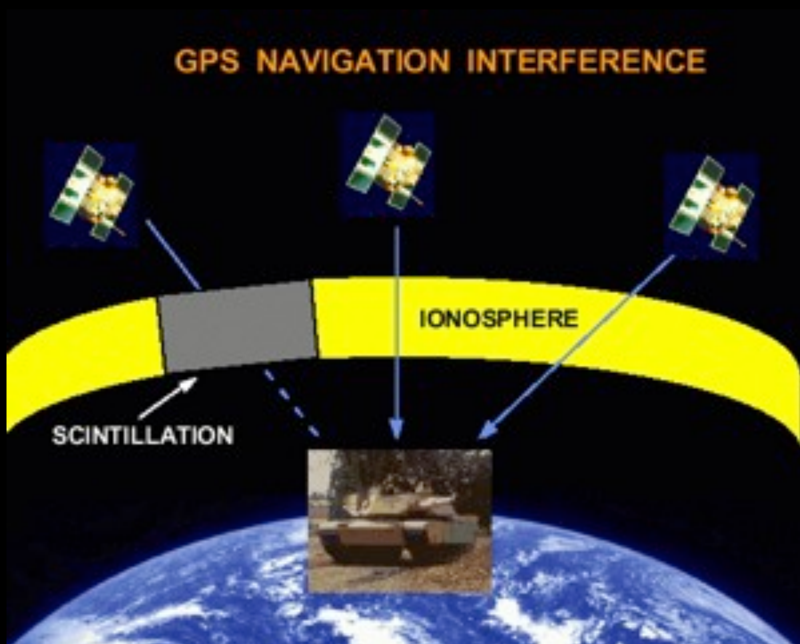
Loran C can be useless for several ours in some cases.





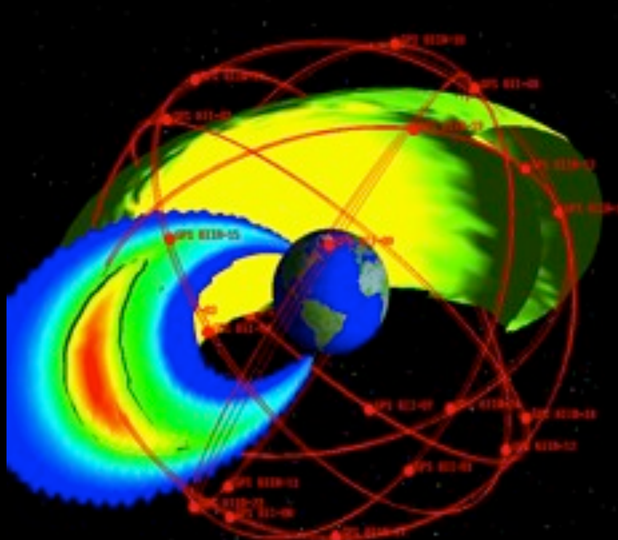


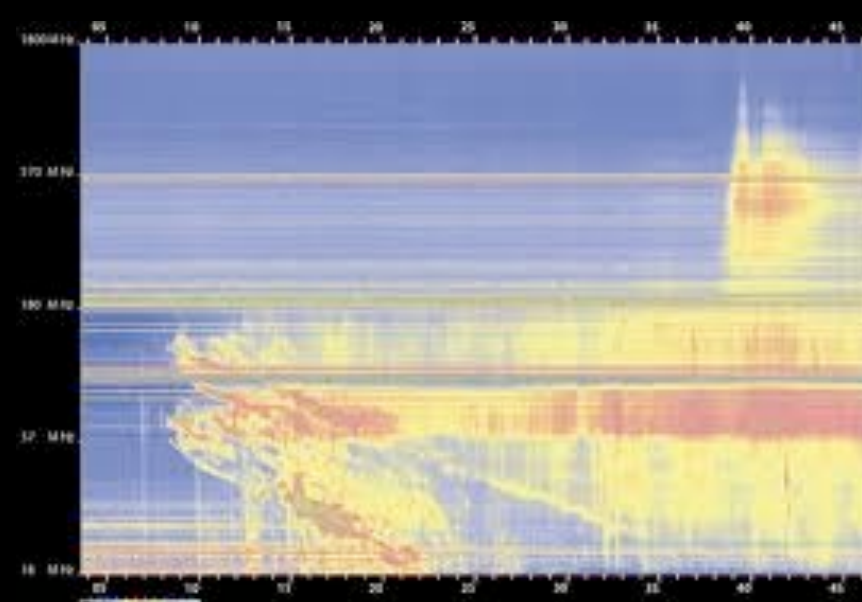
Navigation systems (GPS)

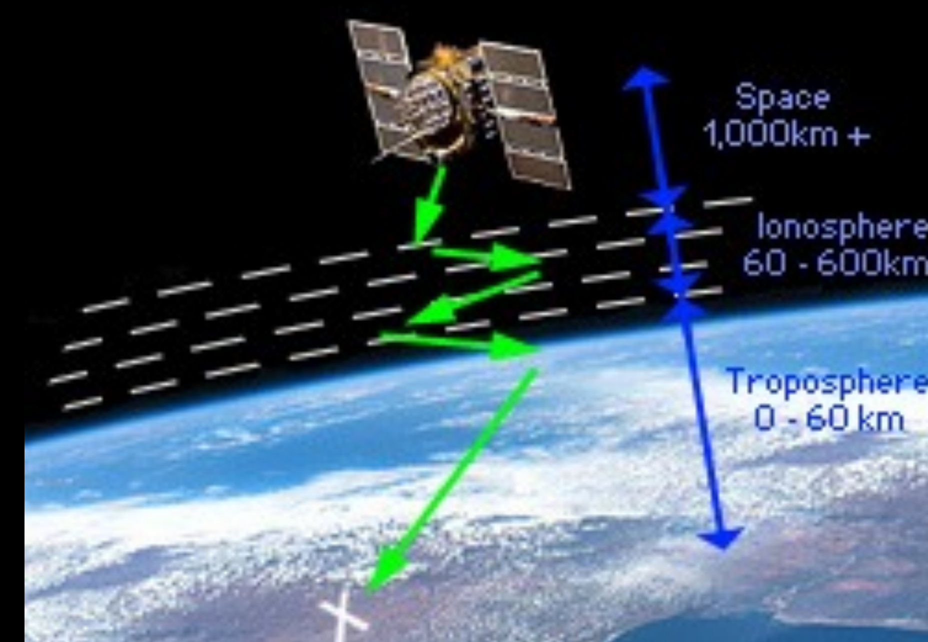


- Turbulence in the ionosphere causes scintillation in the satellite signal and can disrupt the reception.
- Total amount of electrons (TEC) along the path of the signal can introduce errors up to 100 meters.

- Radio bursts can «jam» the signals.

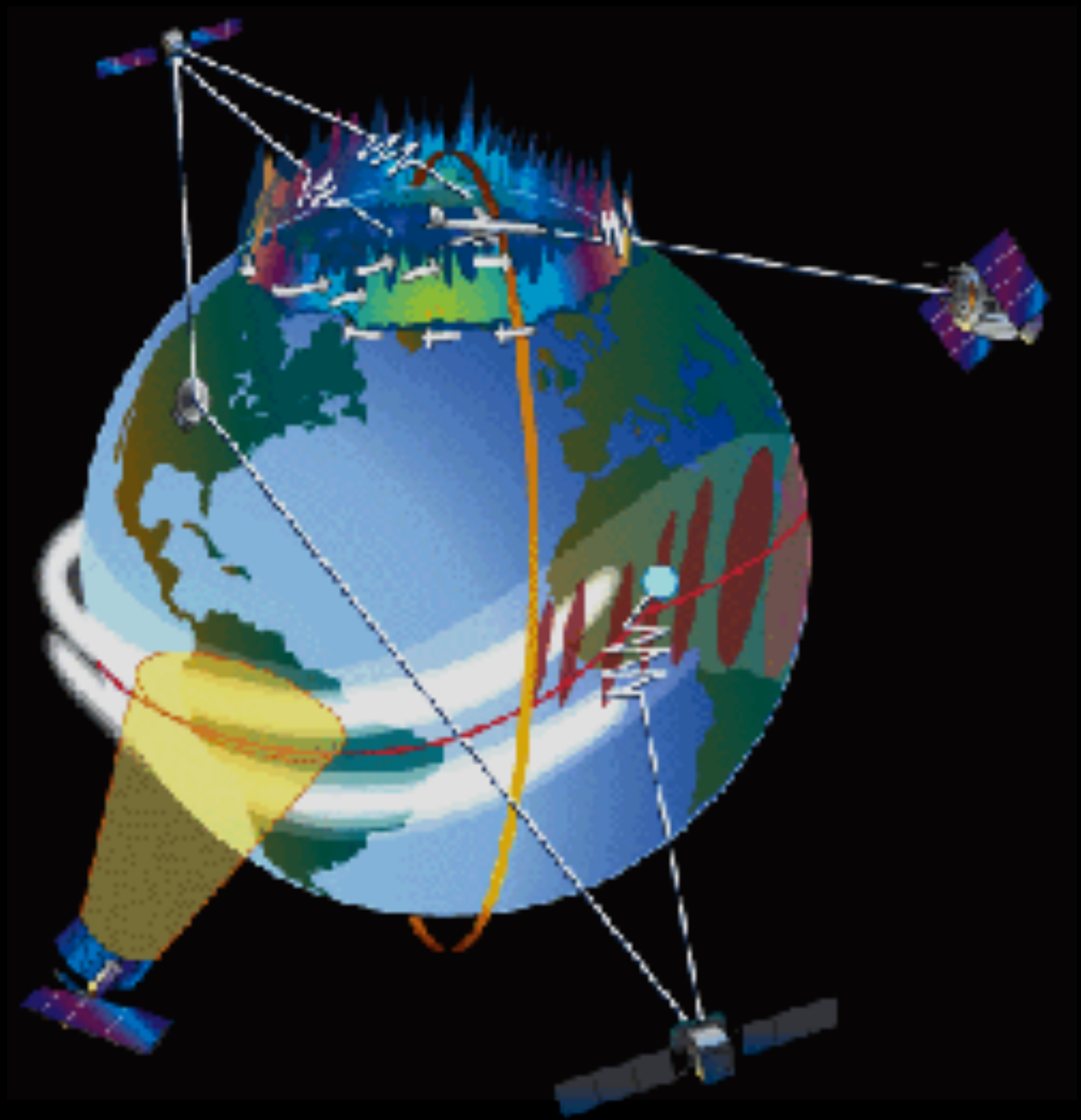






GPS problems in the High North

- 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.

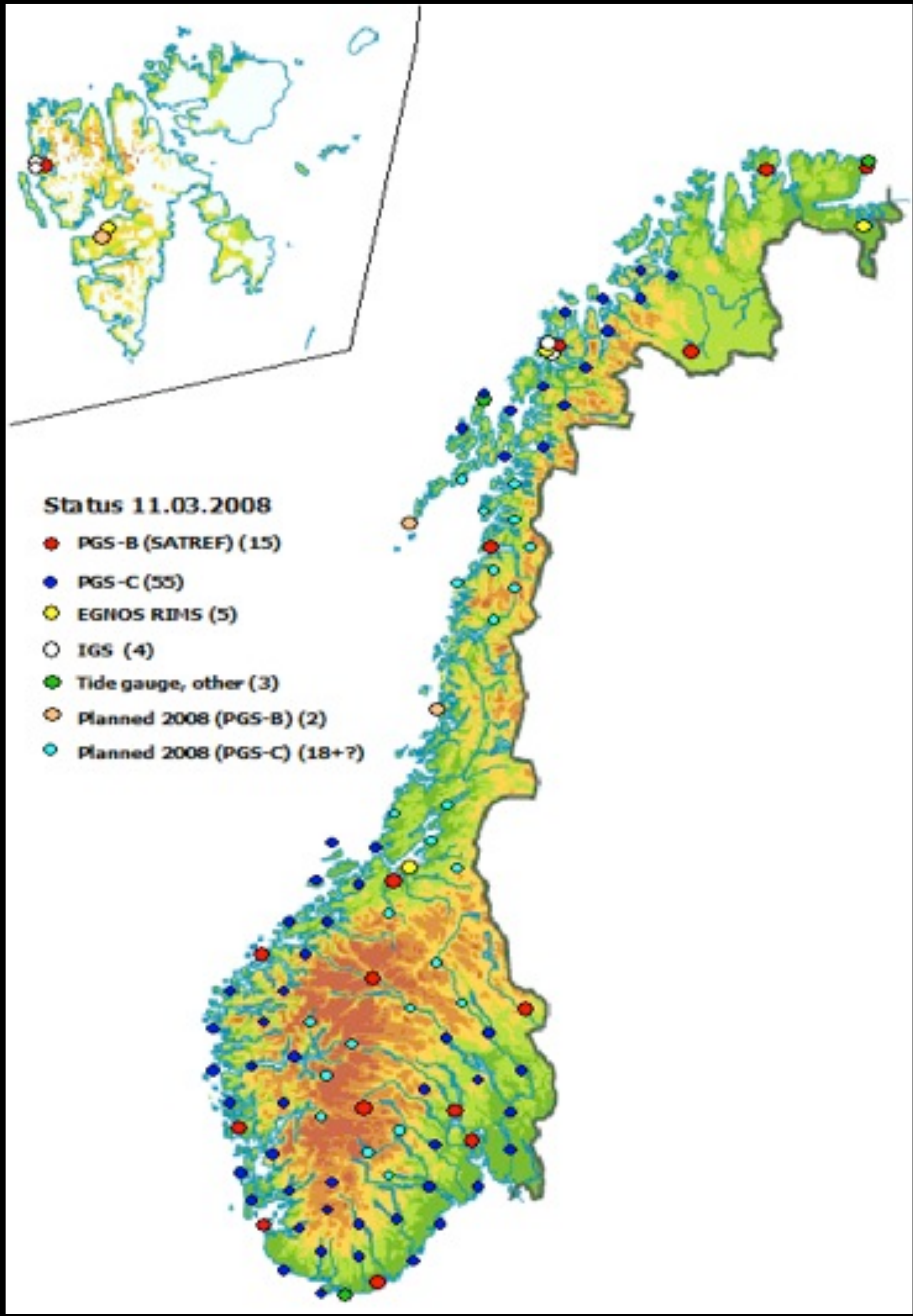
High precision positioning problematic

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

Corrections of GPS positions

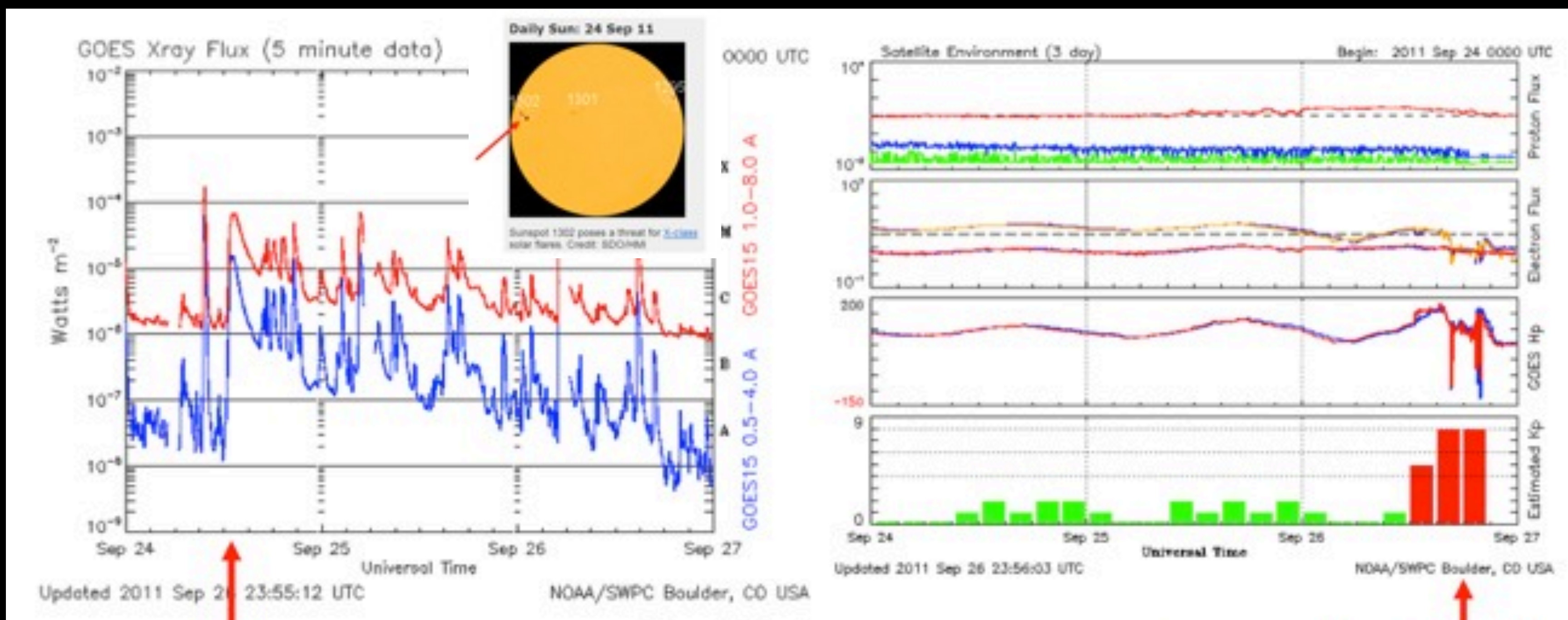
- In Norway the Norwegian Mapping Authority has the national responibility for providing corrections to GPS users.
- They monitor the Sun and have developed an ionospheric modeld that improve these corrections and warn their customers.

SATREF Control Centre

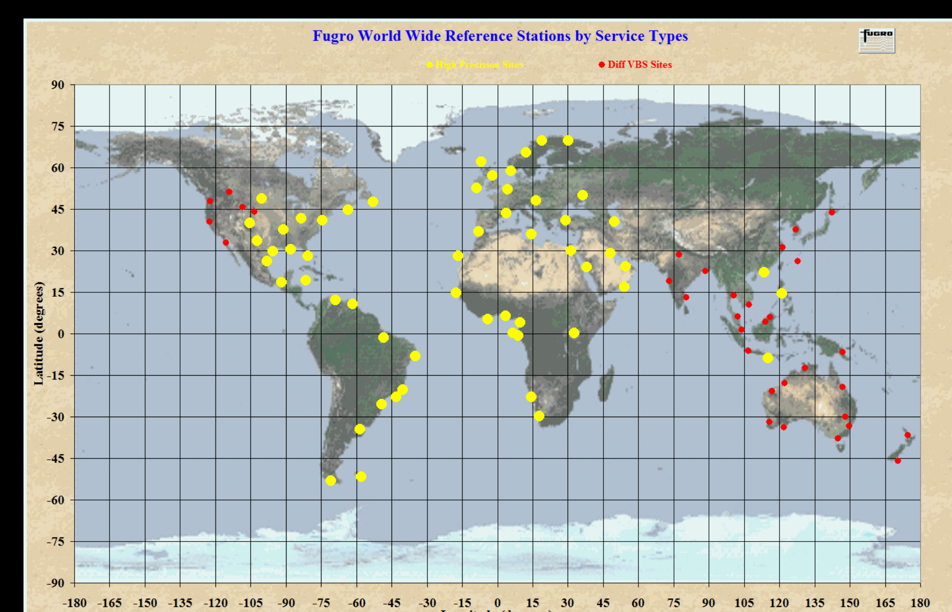


Radio burst «jammed» the GPS system

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

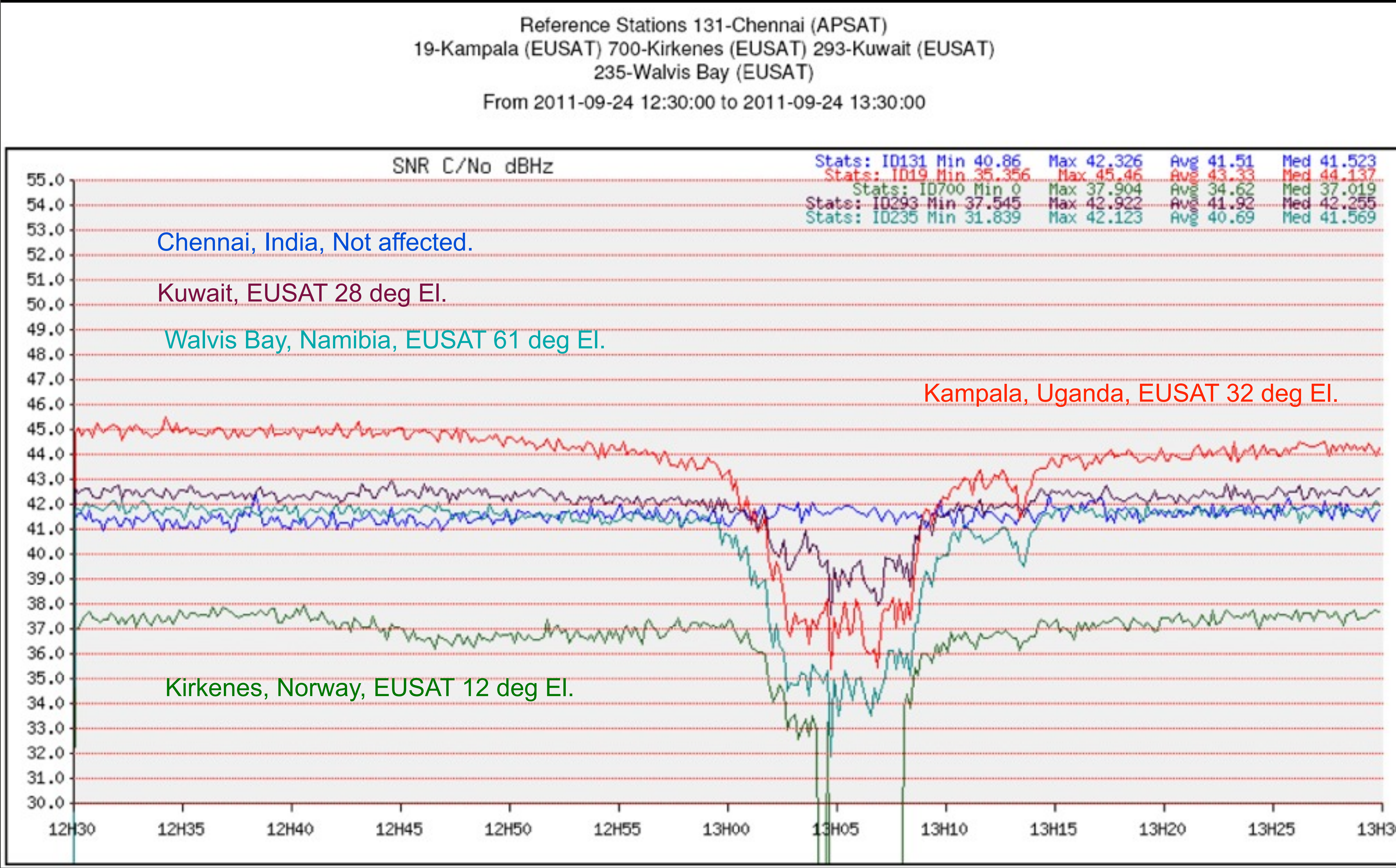


#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
3590	1231	1313	1409	SAG	G	RBR	245	4800	CastelliU	1302
3590	1231	1253	1406	SVI	G	RBR	8800	1300	CastelliU	1302
3590	1231	1307	1410	SAG	G	RBR	610	80000	CastelliU	1302
3590 +	1232	1302	1411	SVI	G	RBR	2695	12000	CastelliU	1302
3590	1232	1253	1358	SVI	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

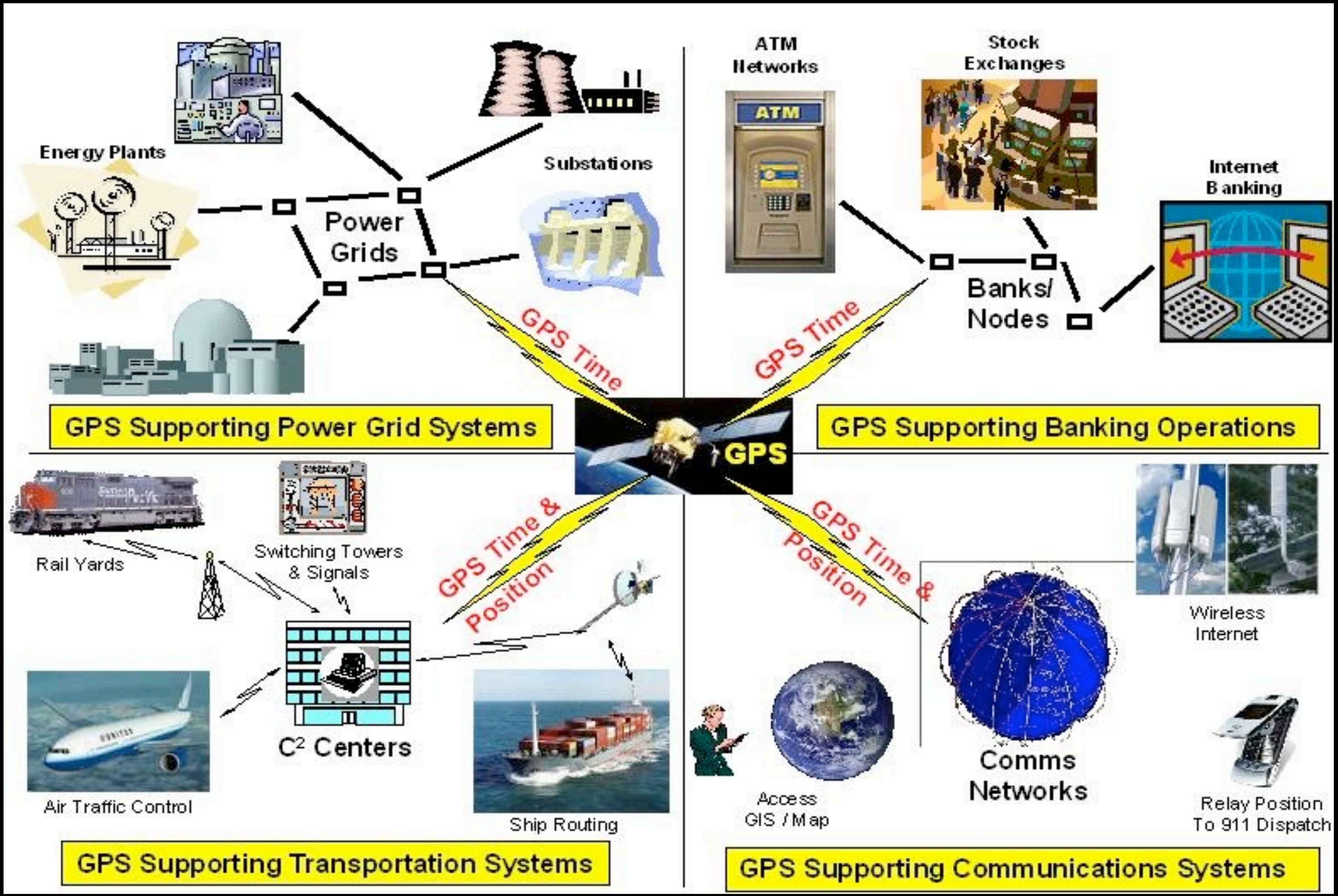


Fugro L-Band tracking EAME 24 Sept

www.fugro.no

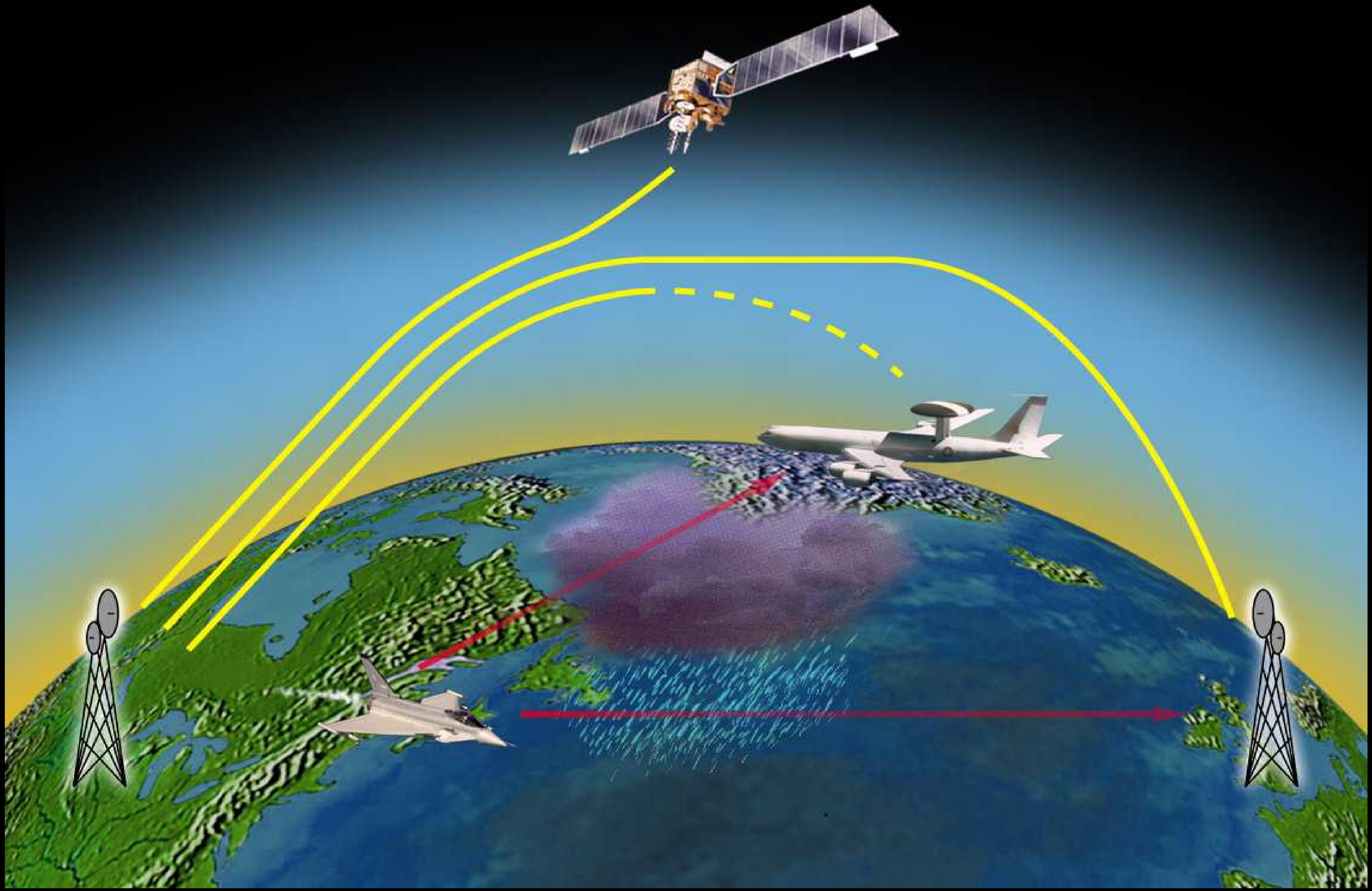


Extent of GPS Dependencies

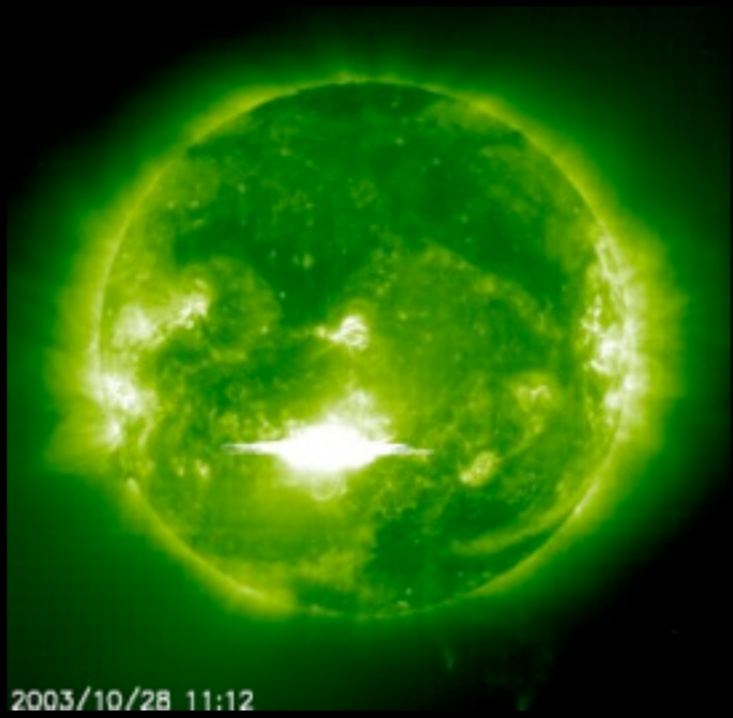


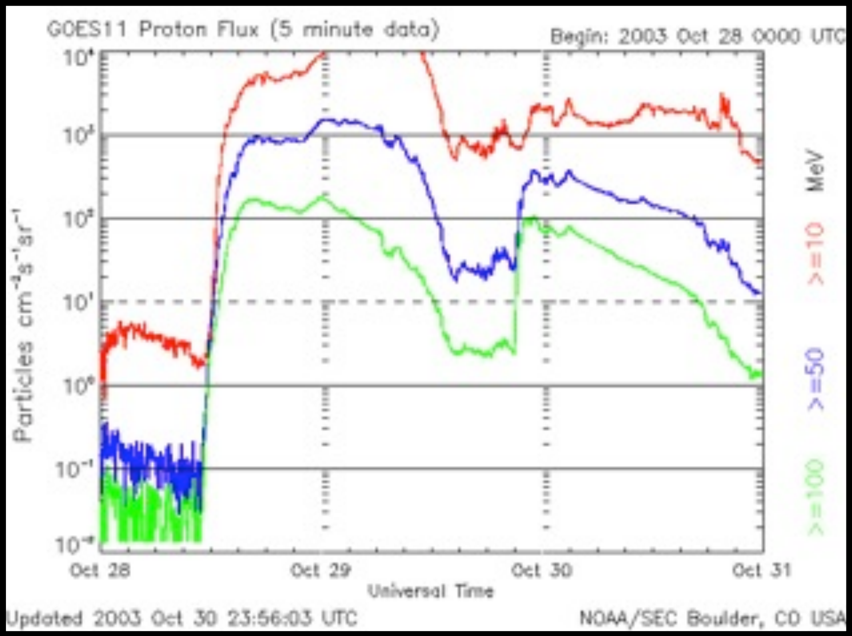
K. VanDyke, DOT

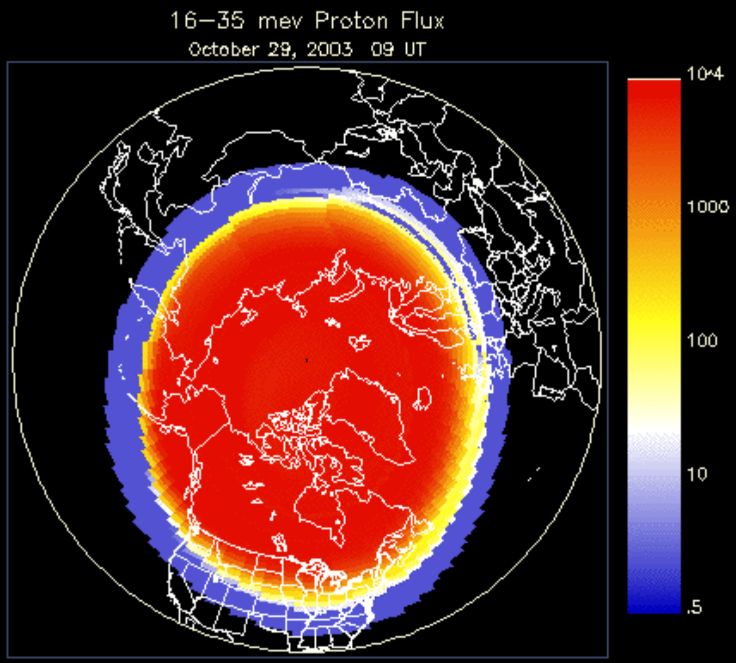
Radio communication i polar regions



Radiation Storms = degraded comm







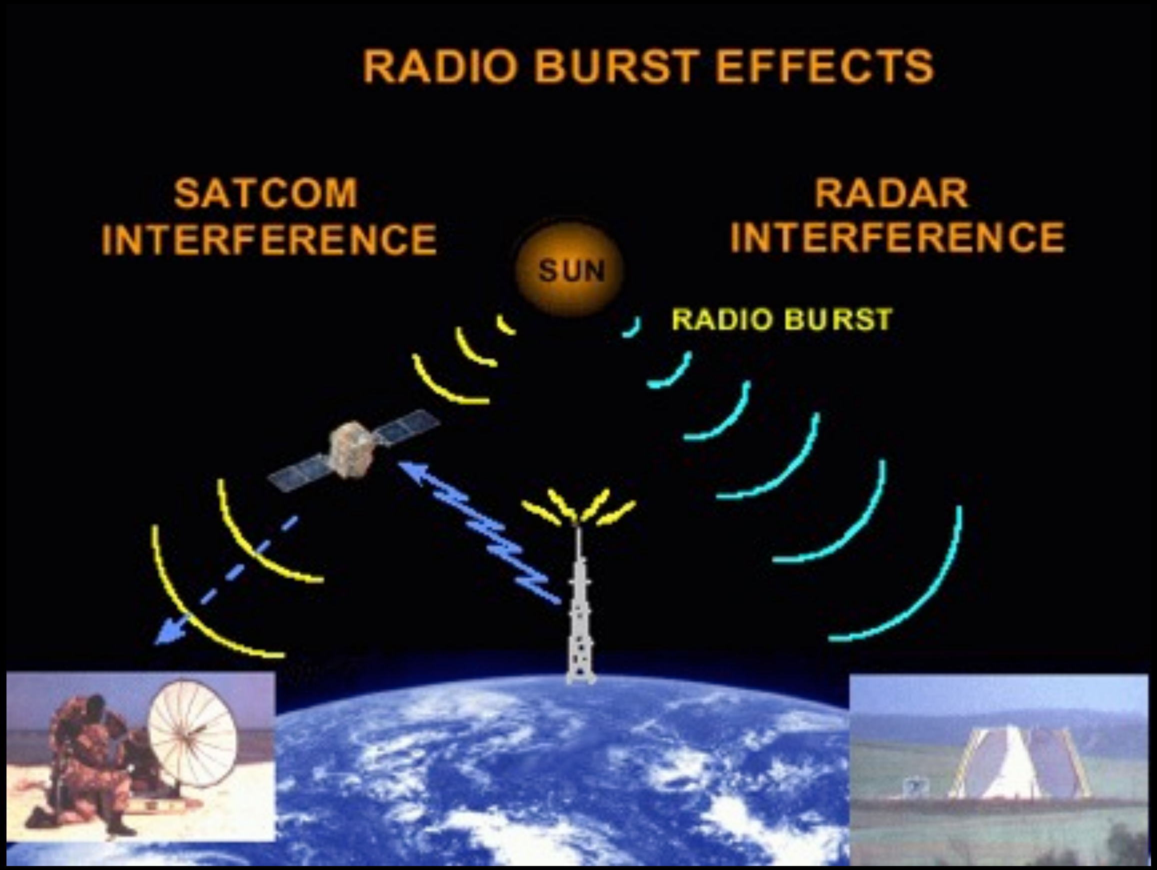
Radiation storms cause extended periods (hours to days) of HF communication blackout at higher latitudes

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



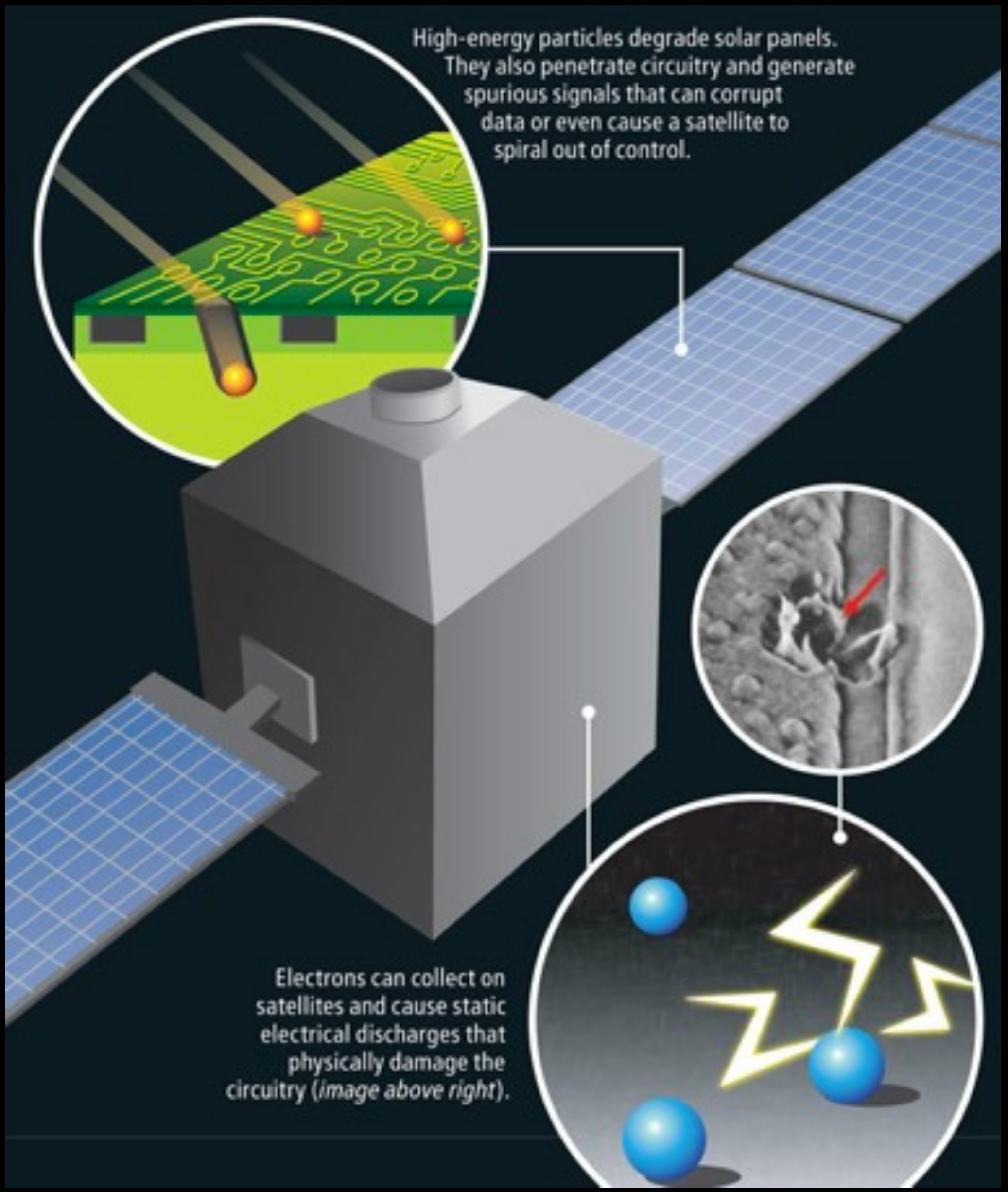
Effects on cell-phones

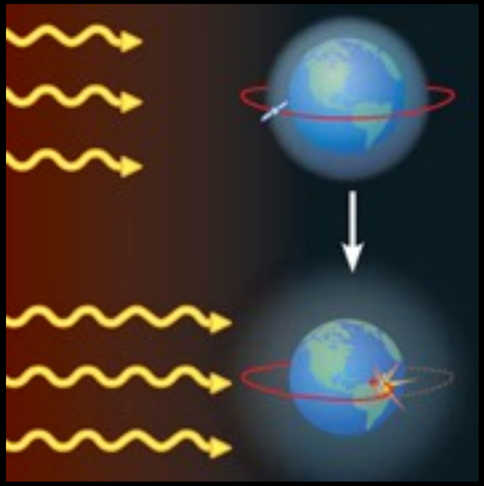
- Radio burst from the Sun can interrupt cell phone calls.
  - If your base station is in the direction of the Sun (evening/morning) due to interference.
  - Can lead to “dropped calls”
  - In areas where teh signal is already weak - this can cause more problems.

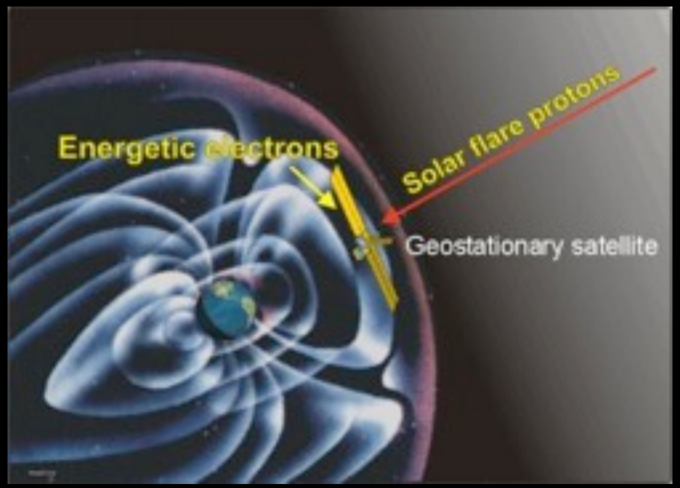
Effects on Satellites

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



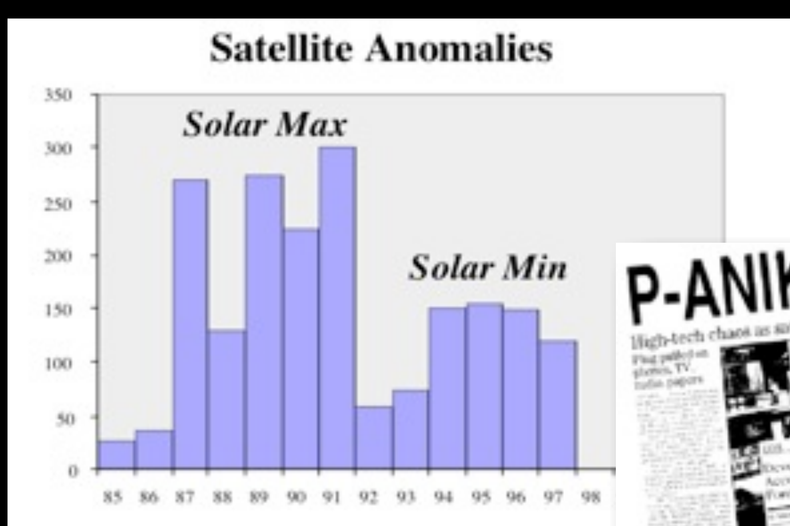




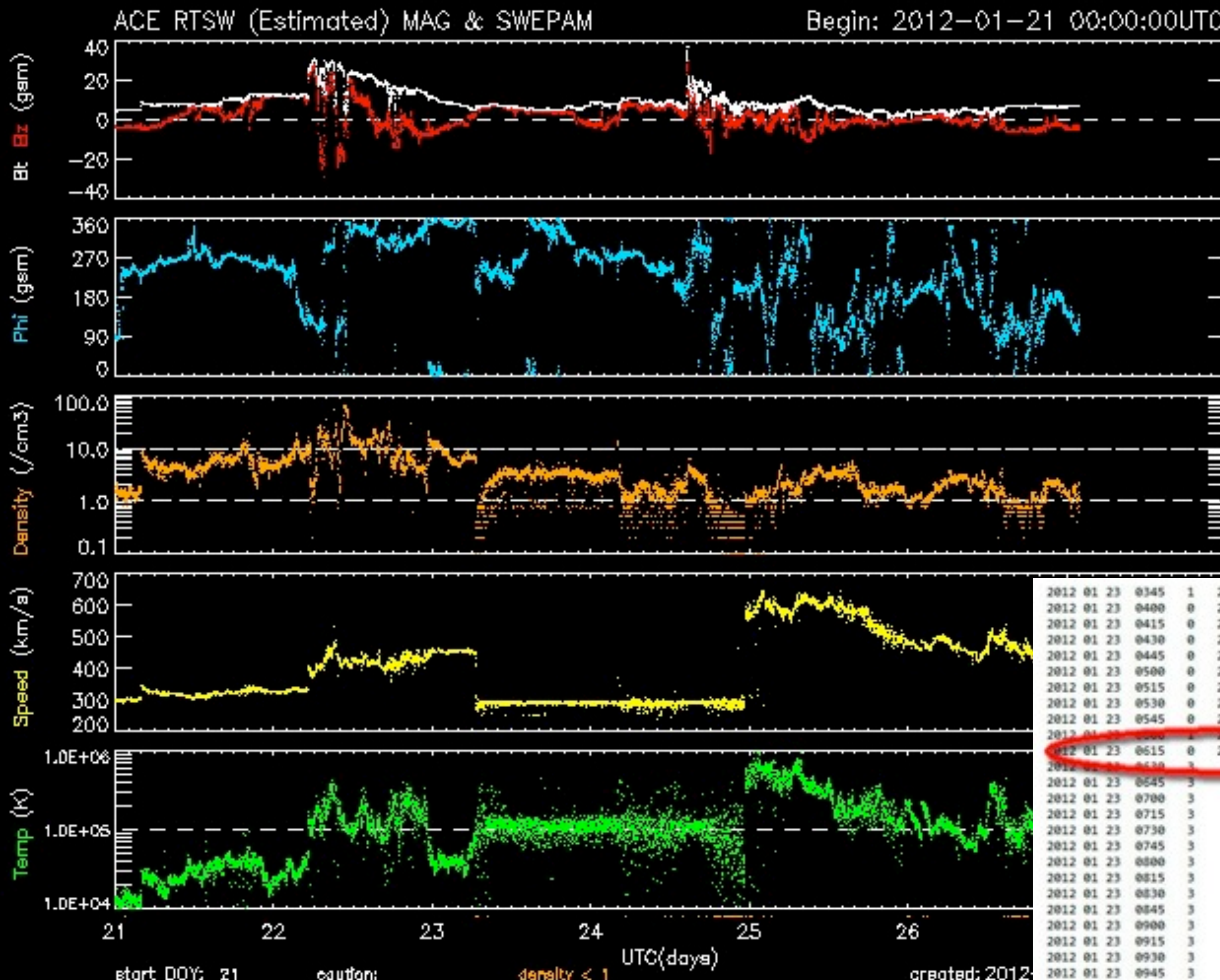
Damage to satellites

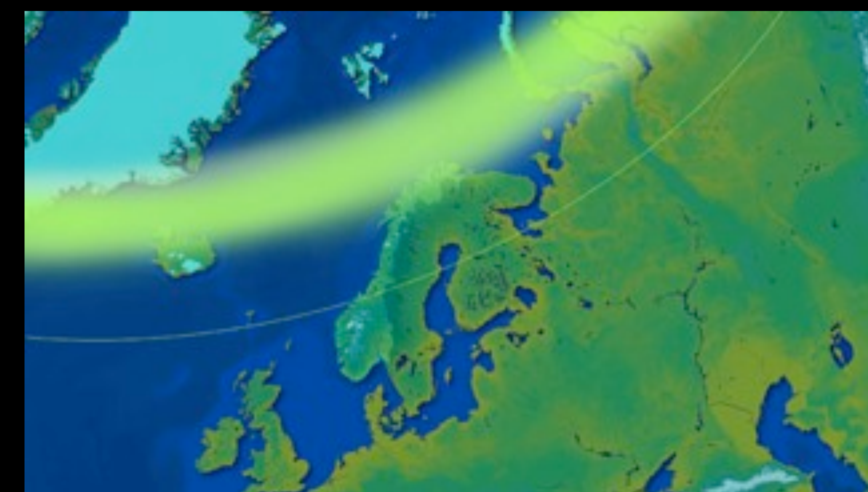
Some examples

- 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



Particle storm «blinded» ACE

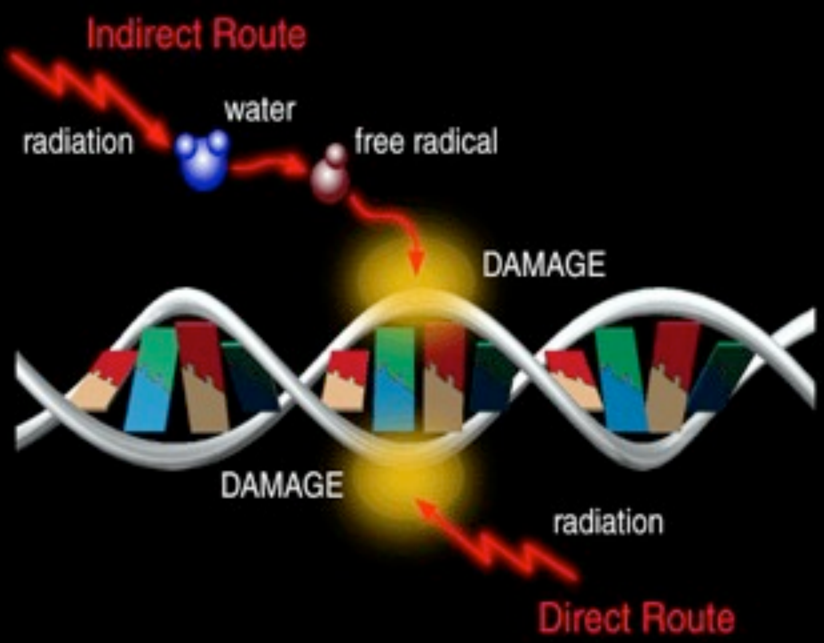




Etter klokken 7.15 norsk tid mandag har det bare lagt -1 i listen med observasjoner fra NOAA. ACE-satellitten fungerer ikke lenger som den skal. *Foto: NASA / NOAA*

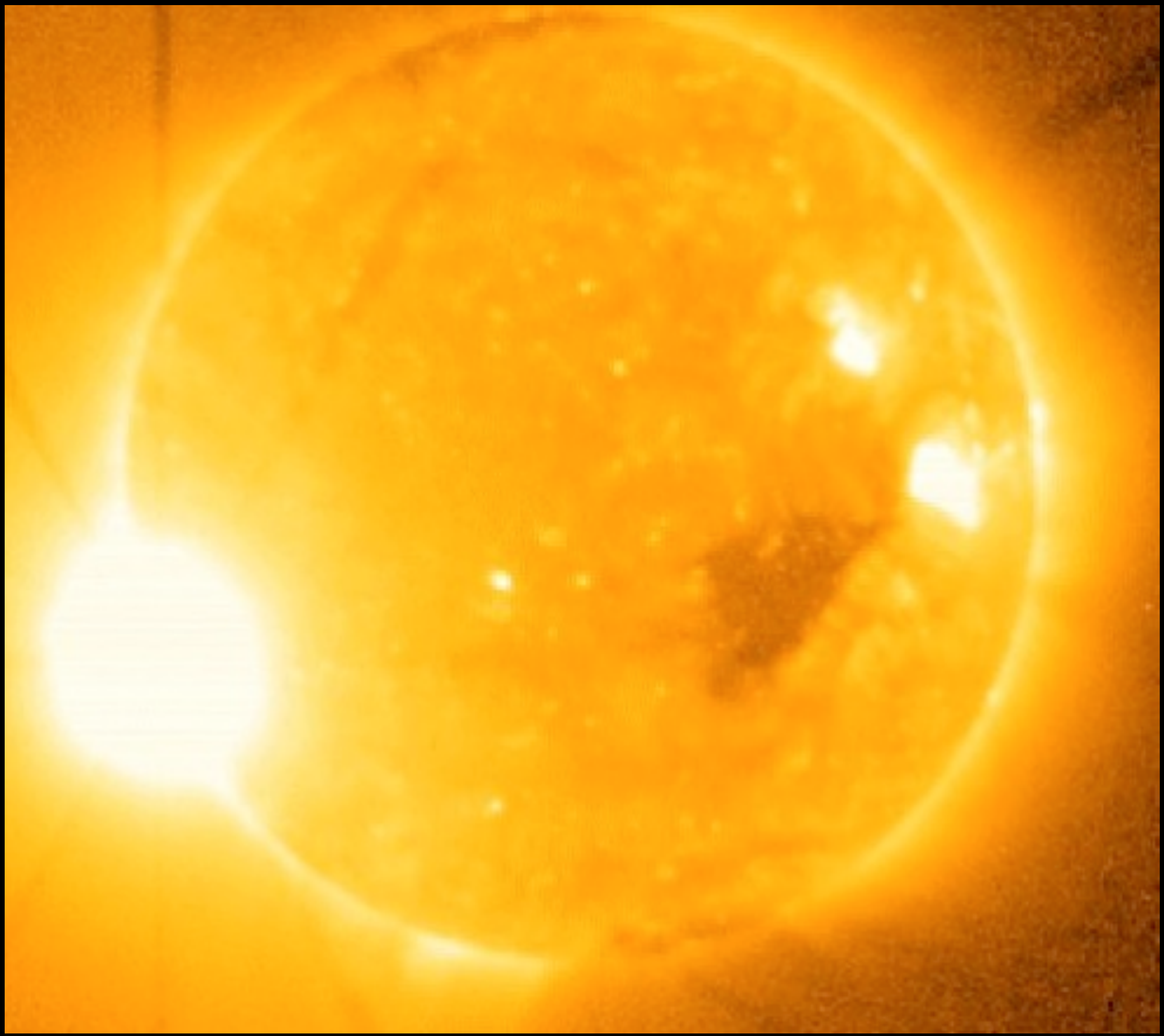
Utbruddet på solen ødela nordlysvarslene

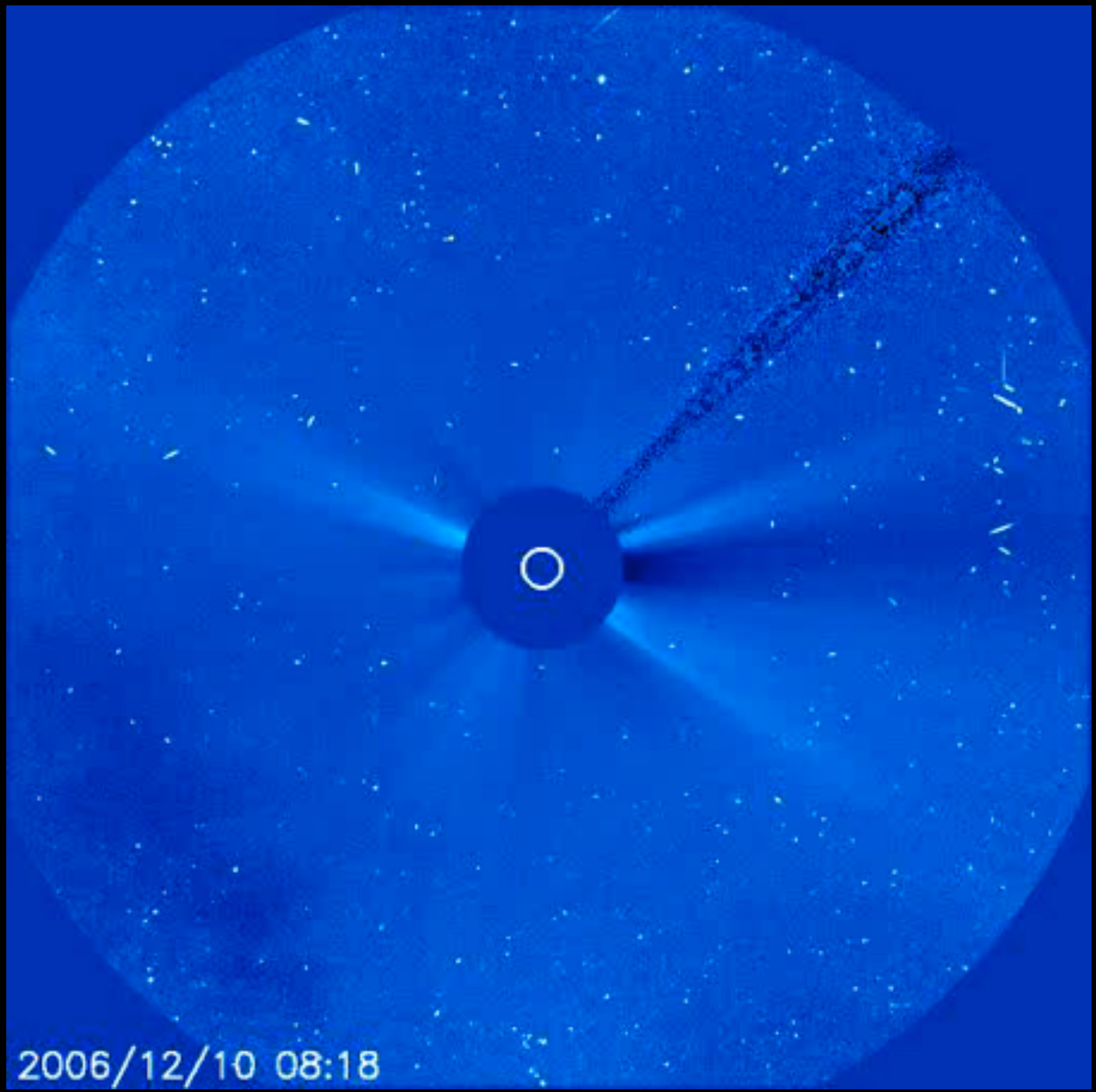
Radiation hazards



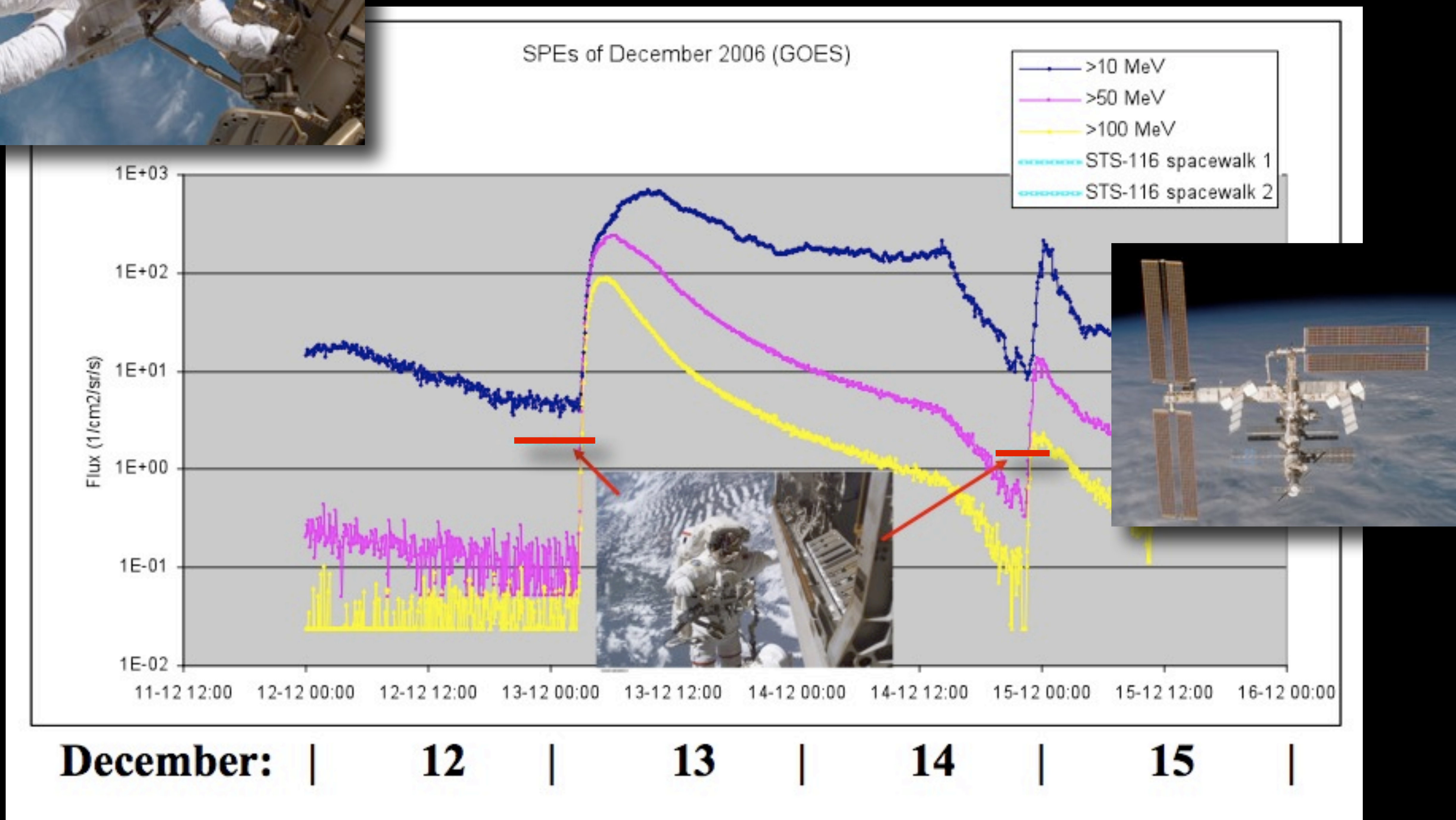
- Humans in space
  - Space Shuttle, International Space Station, missions to the Moon and Mars

Proton shower 14 desember 2006





Christer Fuglesang - Proton event



Christer Fuglesang - radiation

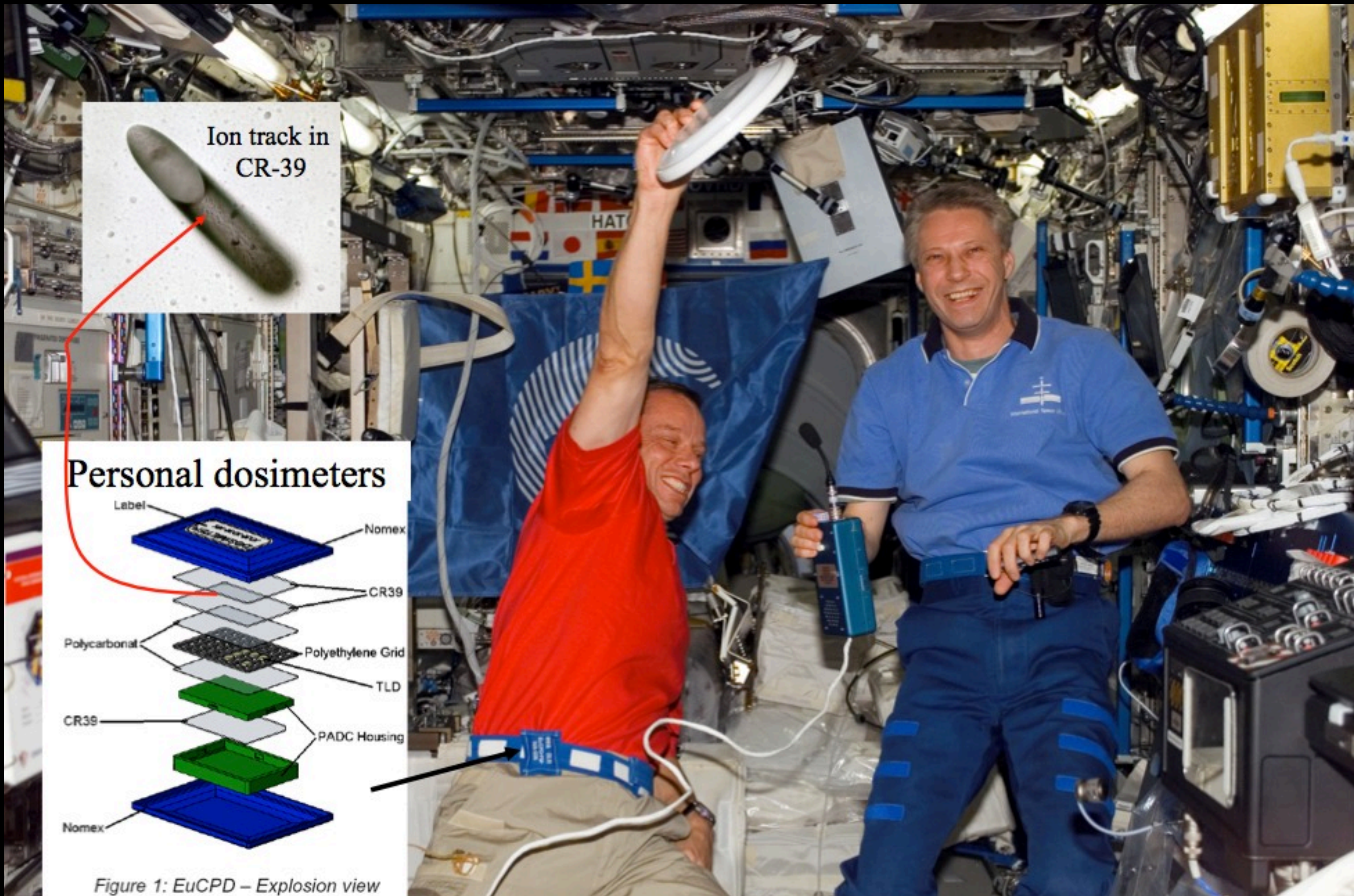


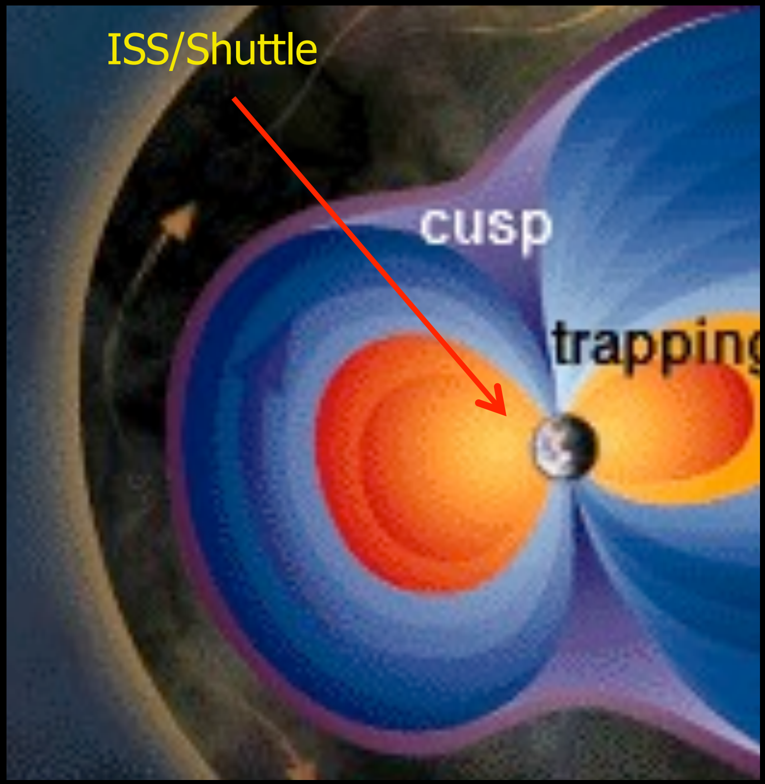
Figure 1: EuCPD – Explosion view

The Apollo program - pure luck?

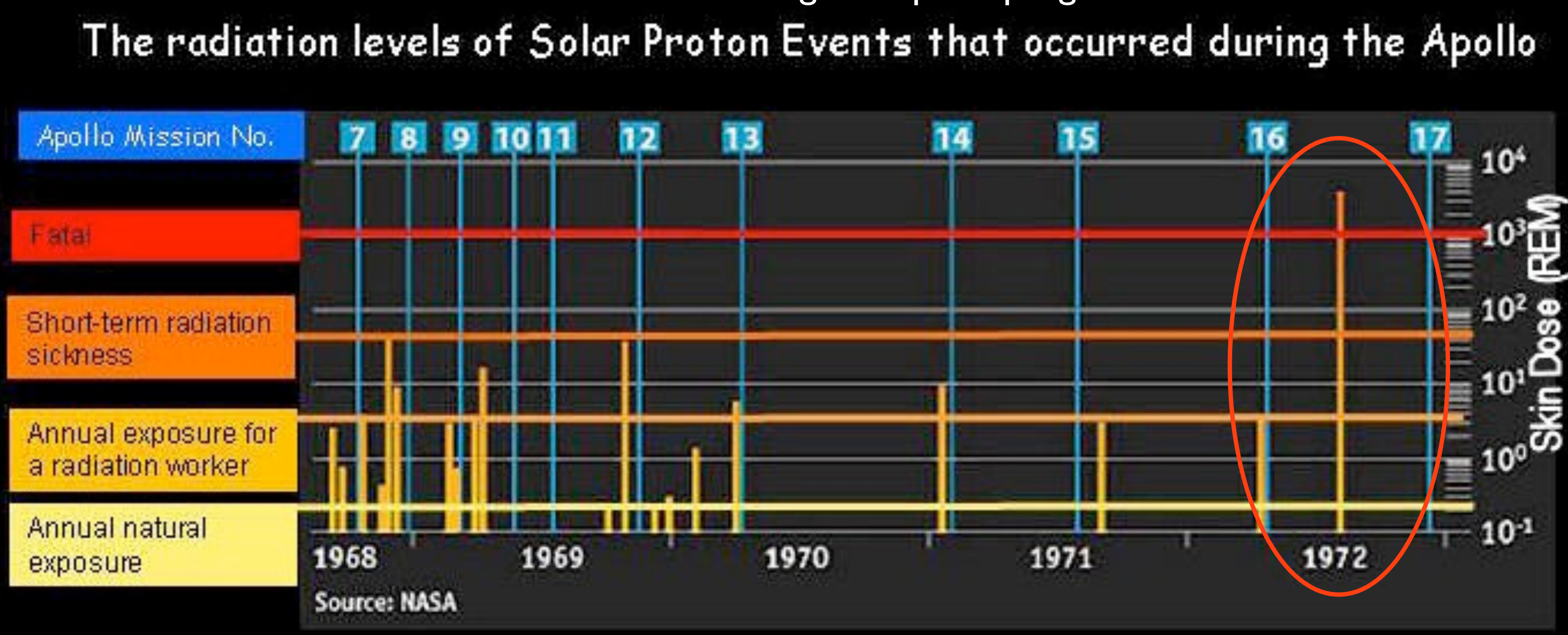
- Humans have limited experience from deep space muíssions. Onlu a few short trips to the Moon with Apollo.
  - ISS og and the space shuttle were protected fairly well by the magnetosphere.

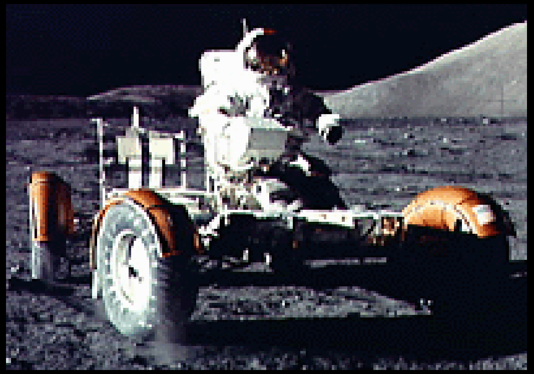
- The Apollo sucess could have been different if the very strong proton shower in August 1972 occured during the Apollo 16 or 17. This could have produced a leathal dose for the astronauts.

- 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





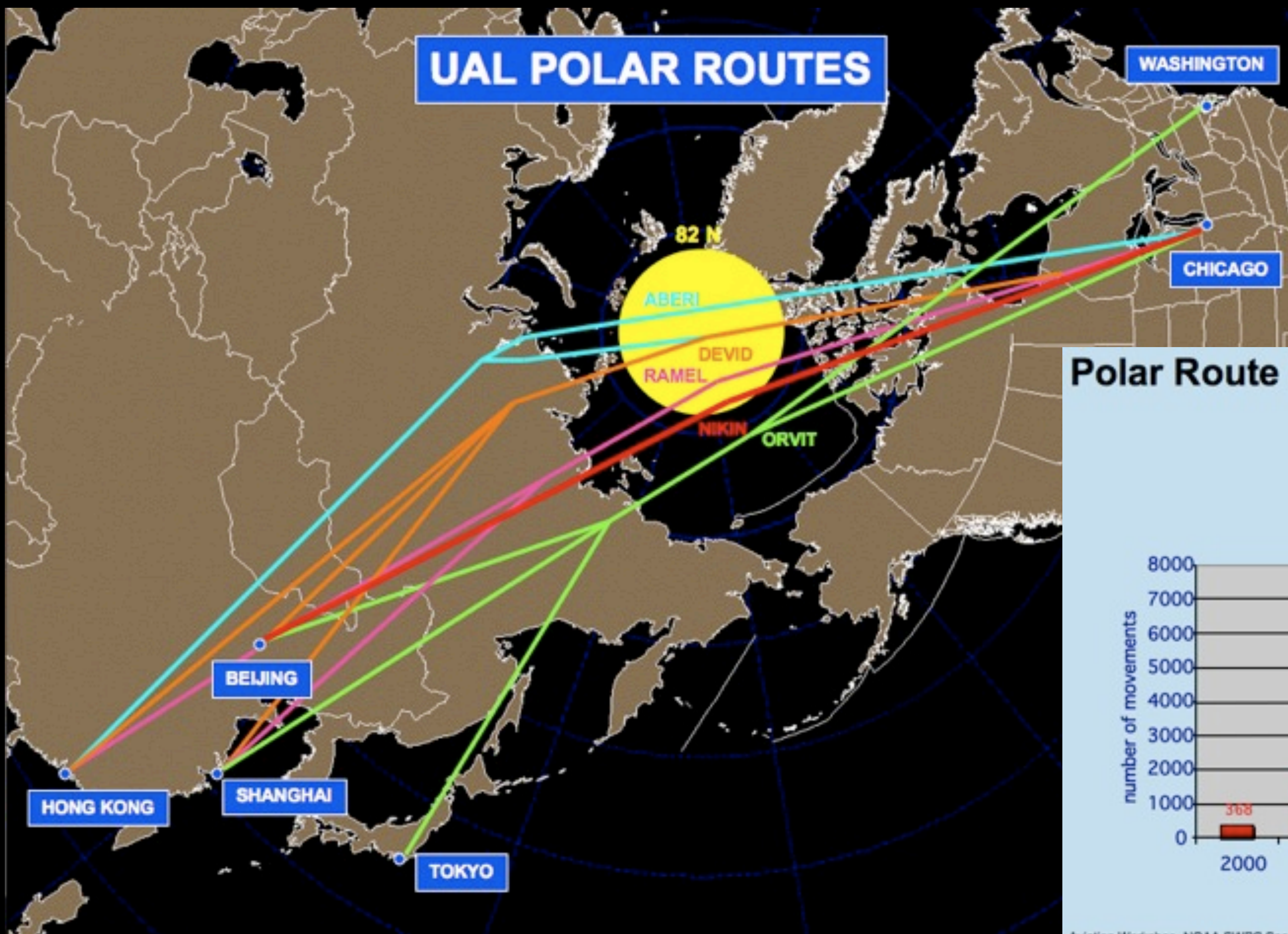
1972 event: 4000 REM in space suit, 1000 REM in Lunar Module

Effects on airplanes

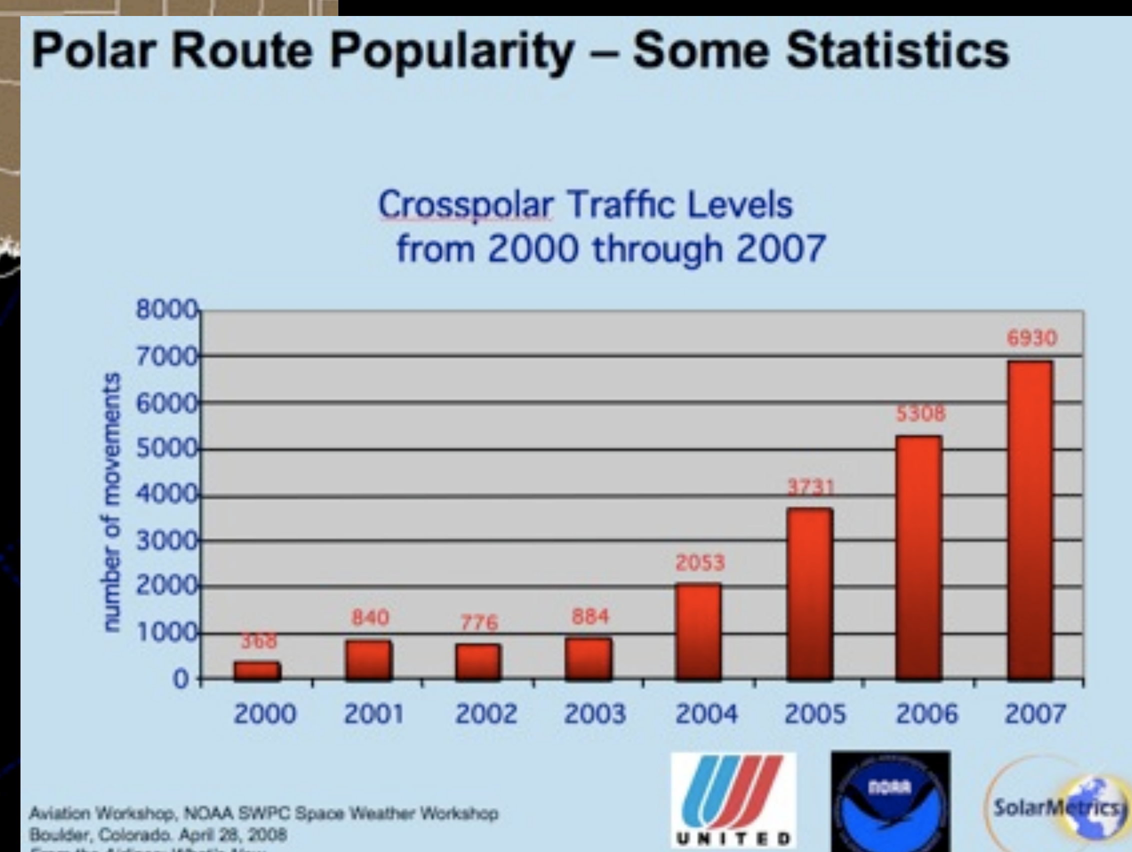
- Disruption of HF communication on polar transatlantic flights
- Energetic particles (affects humans and avionics)
- GPS and navigation
- NextGen, SESAR

Effects on polar routes

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

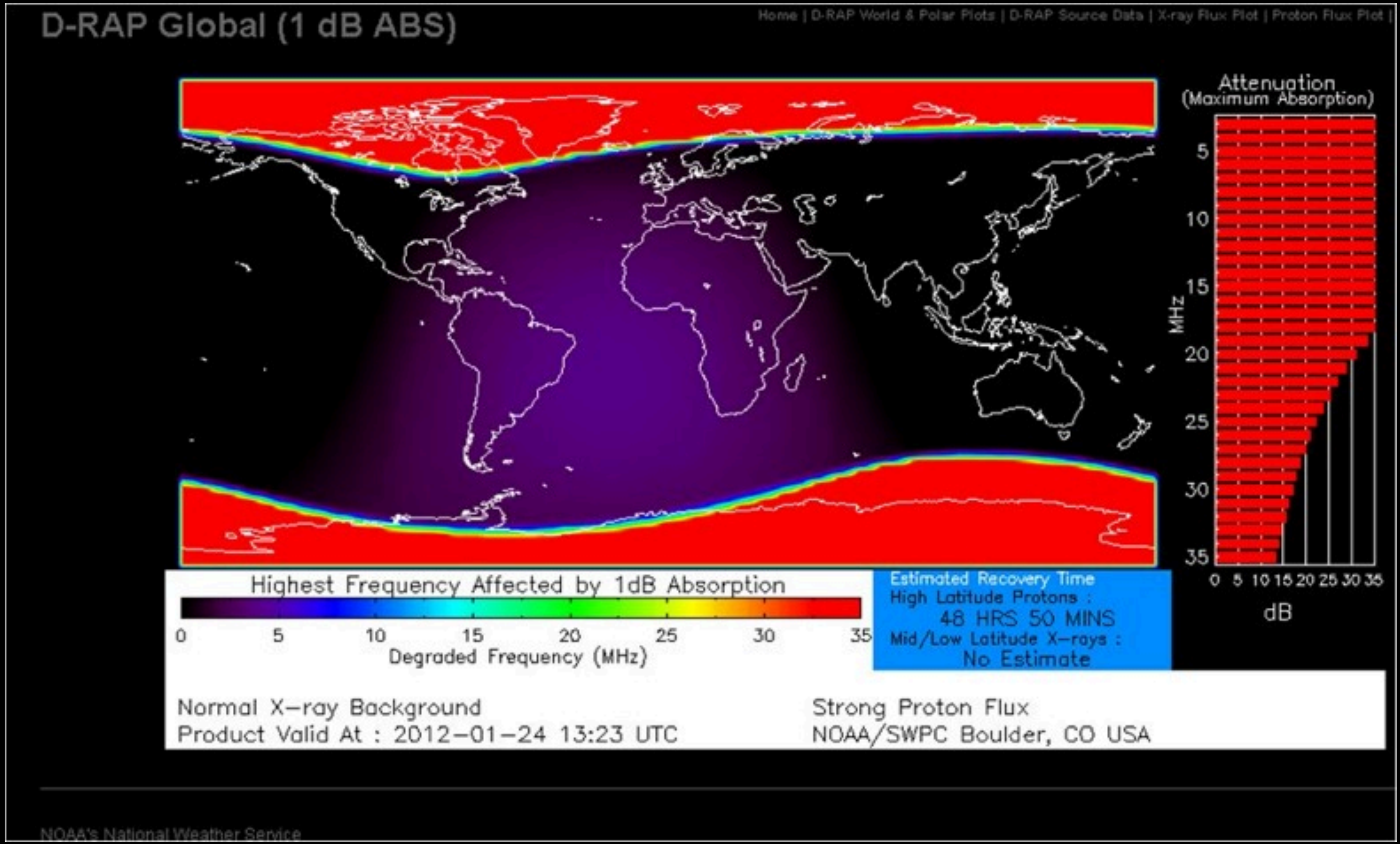


M.Stills, United Airlines



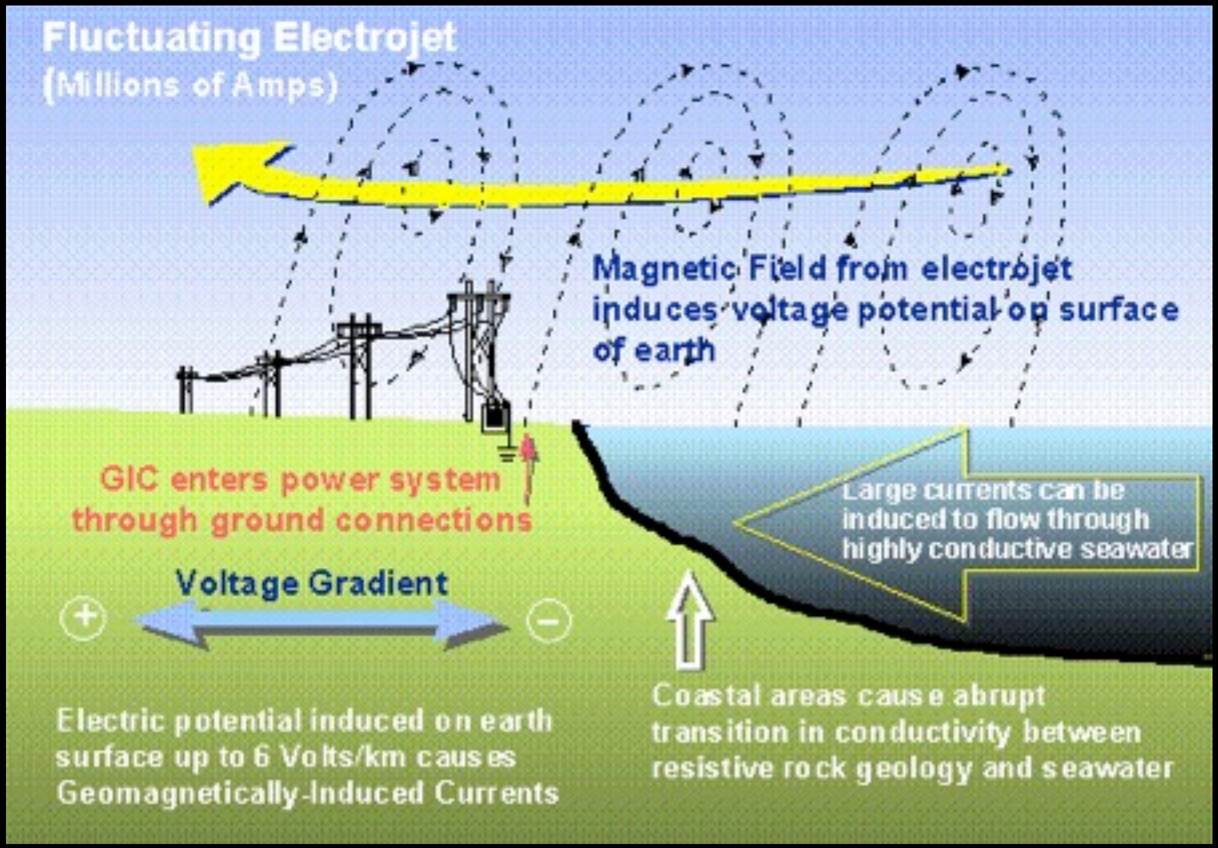
Flights were diverted

- 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).

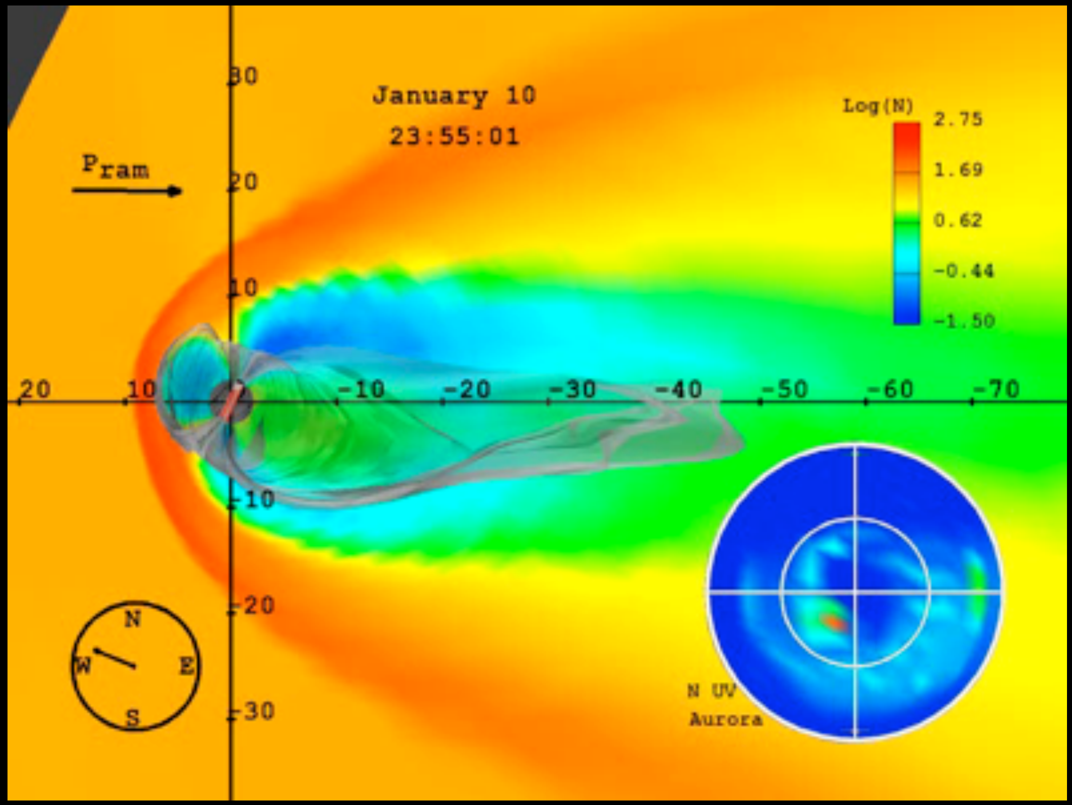


This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles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

Disruption of power grids

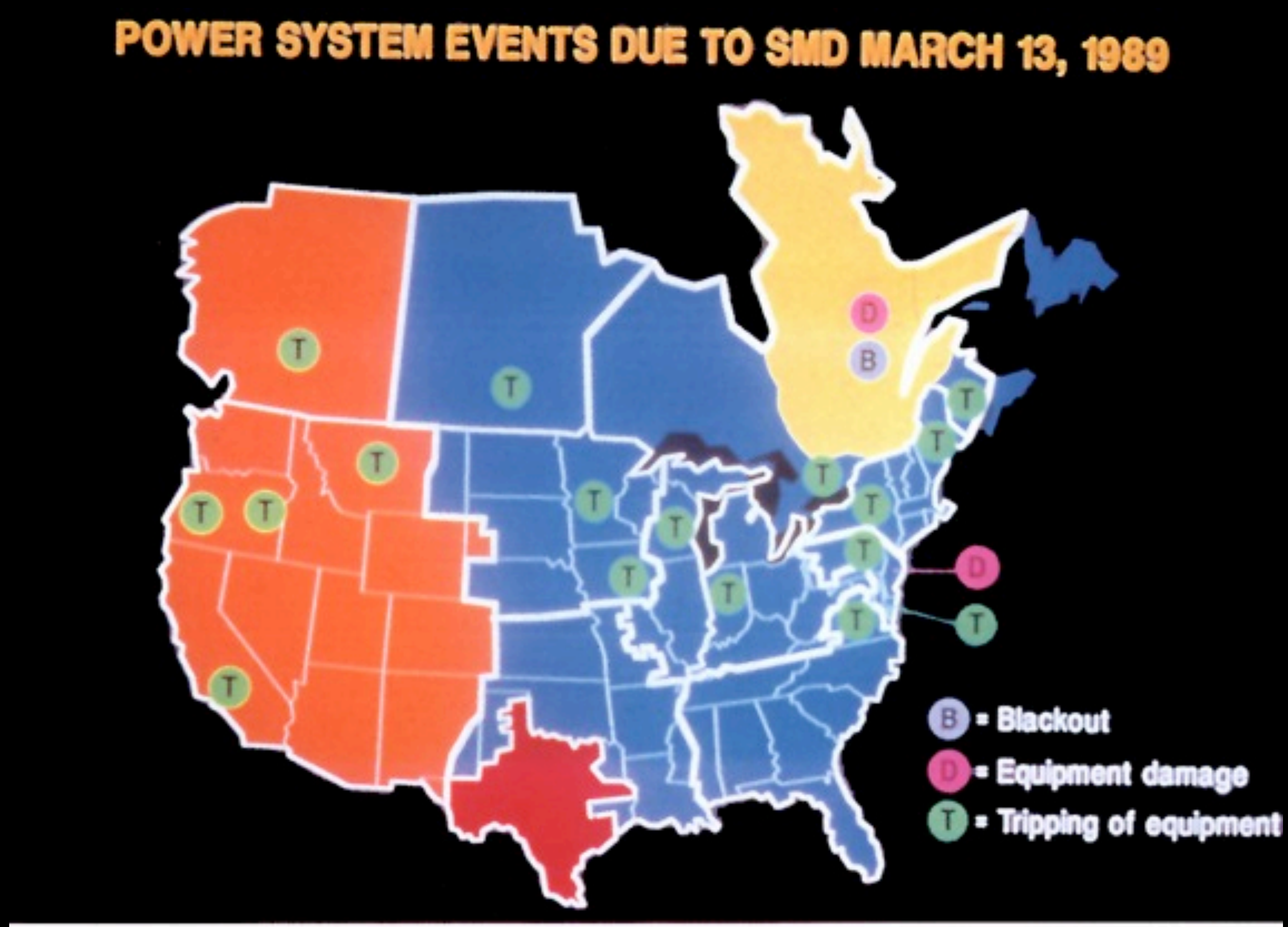


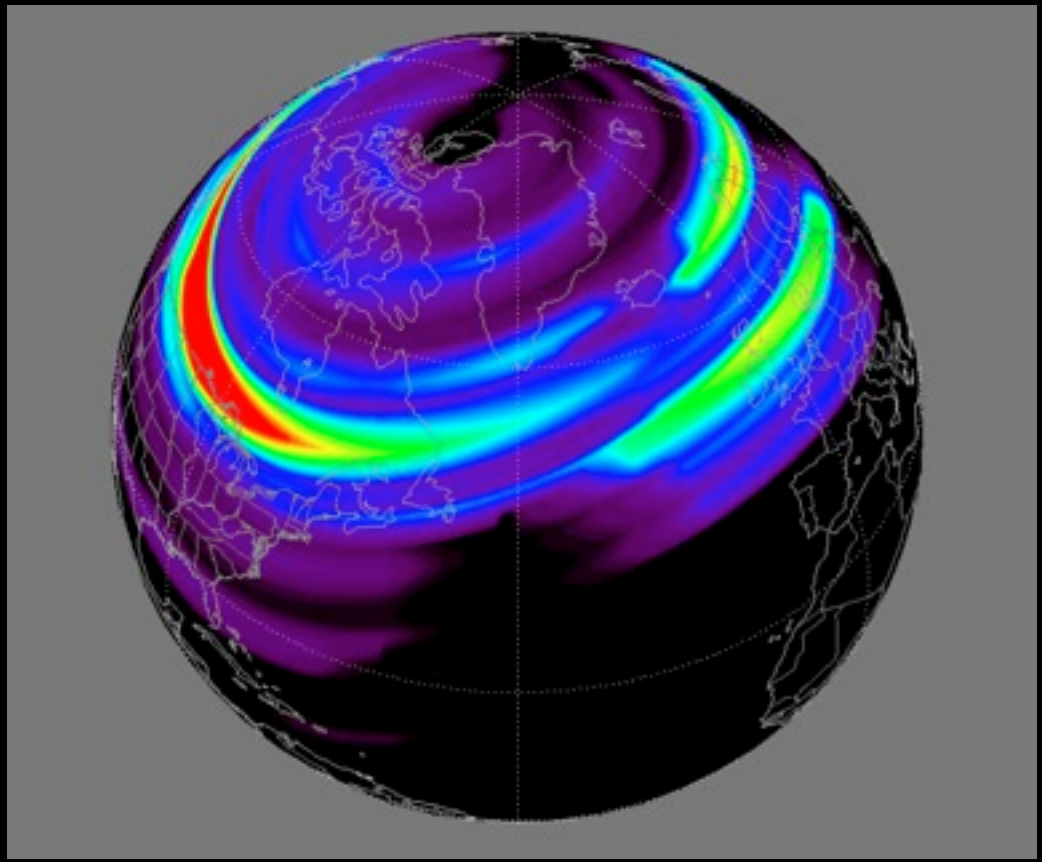
- These currents leaks into all lang conductors:
  - Power grids
  - Oil- and gas pipelines

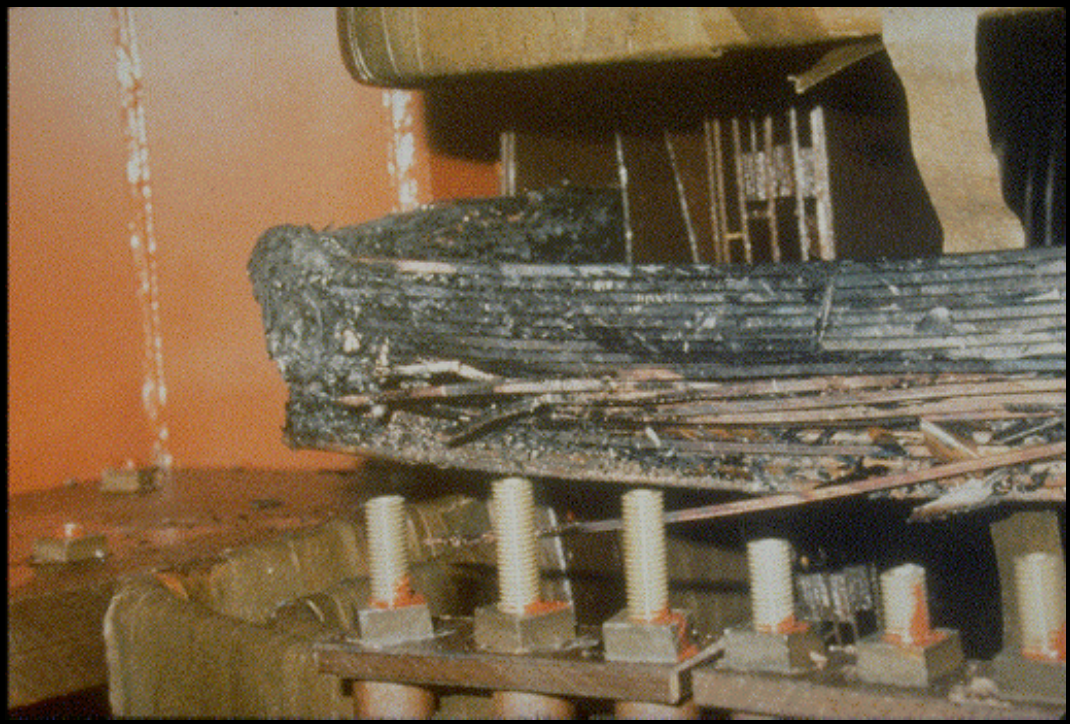


Power failure March 1989

- 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.

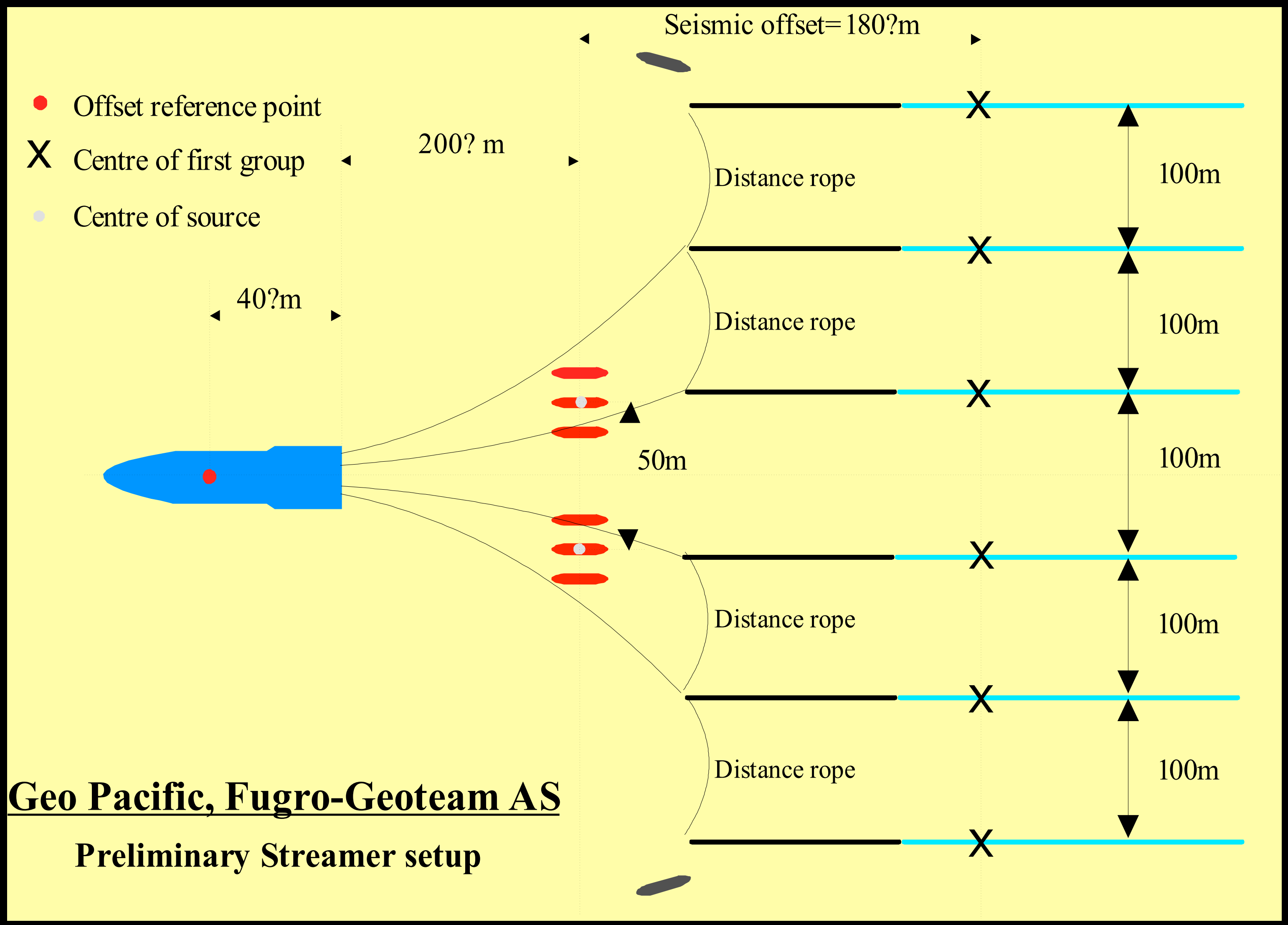
Cost: 10 million USD, repair can take one year.

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 trafo's in Chicago damaged in April 1994.

Geomagnetic surveys - search for oil and gas

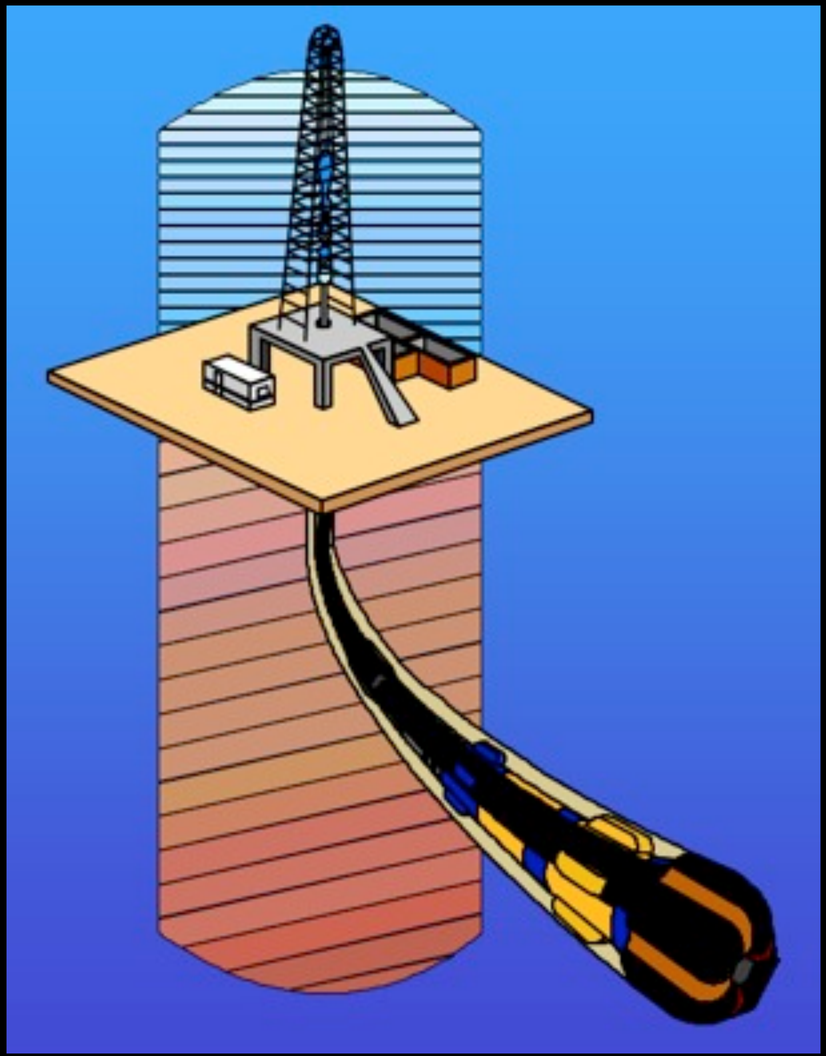


Fugro-Geoteam use ships with sensitive magnetometers on long cables.

Directional drilling

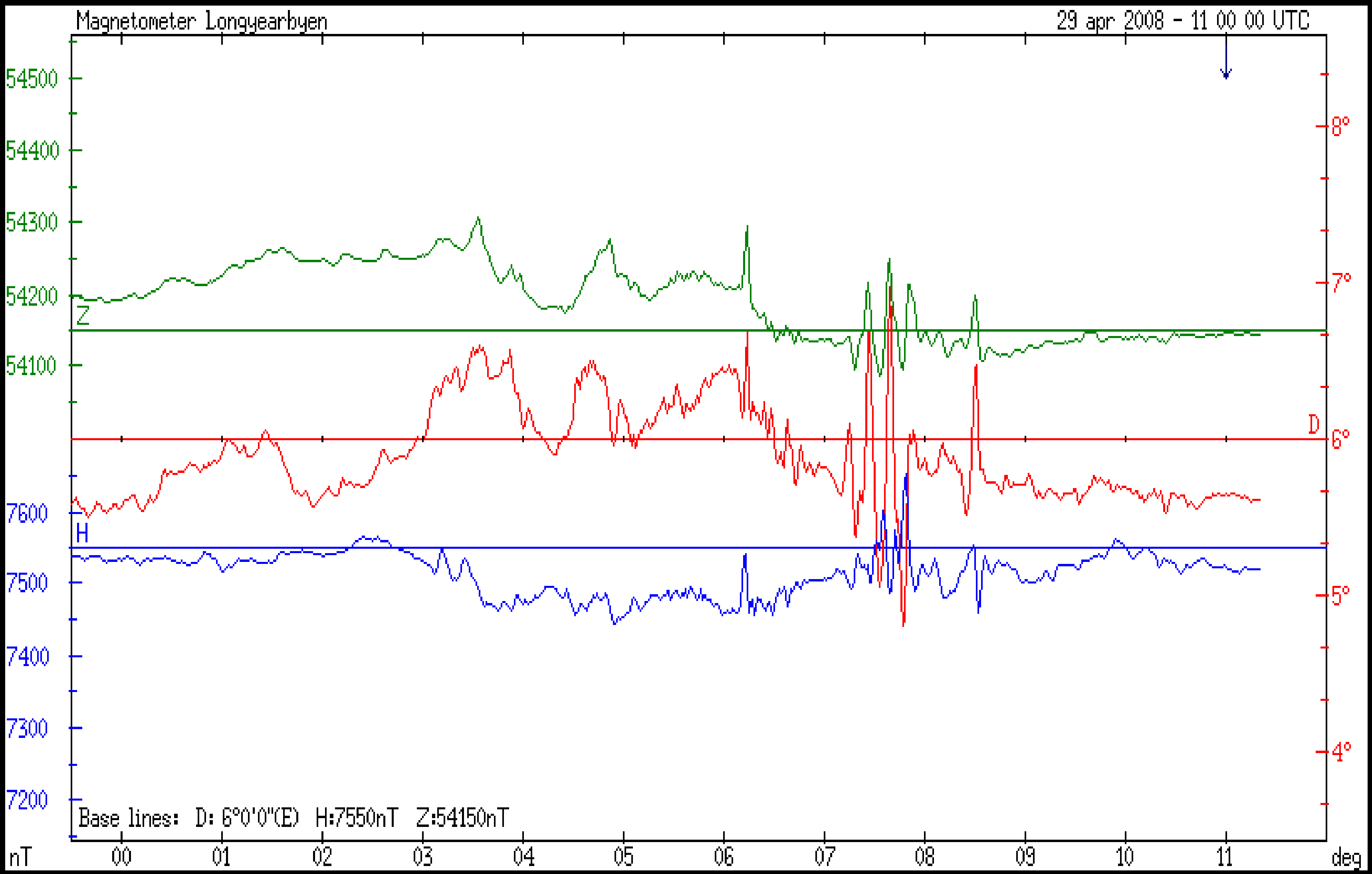
Directional drilling

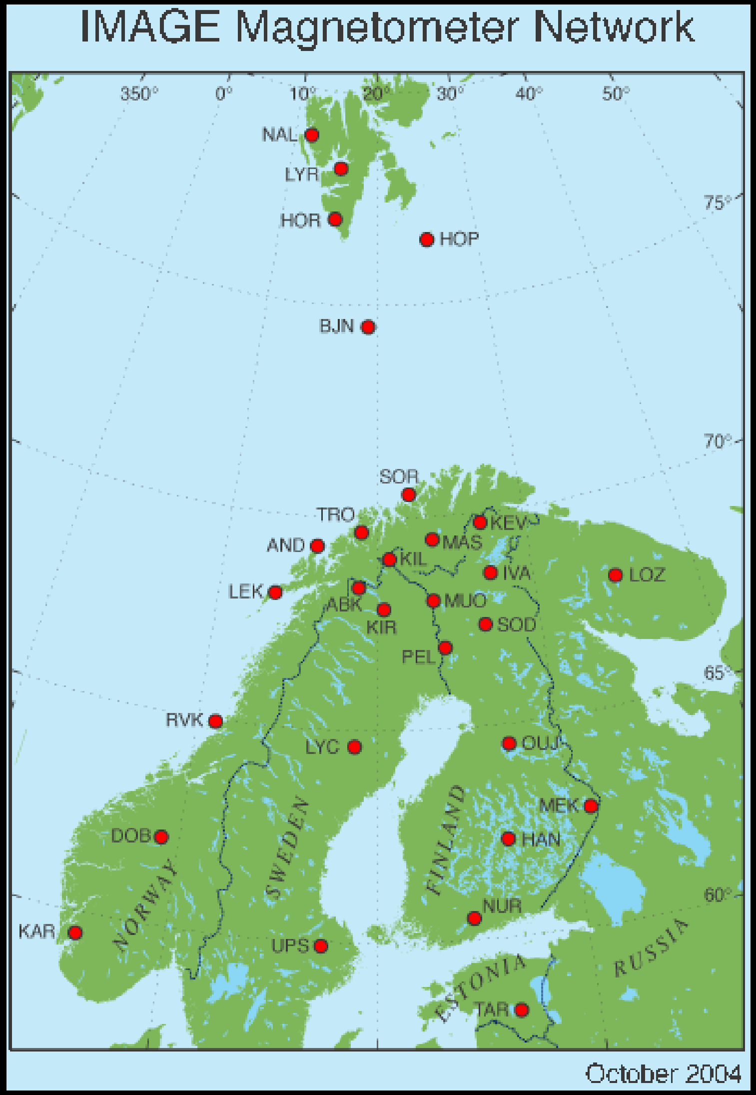
- Oil industry relies on geomagnetic maps to guide the drill and monitor the well direction.



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.



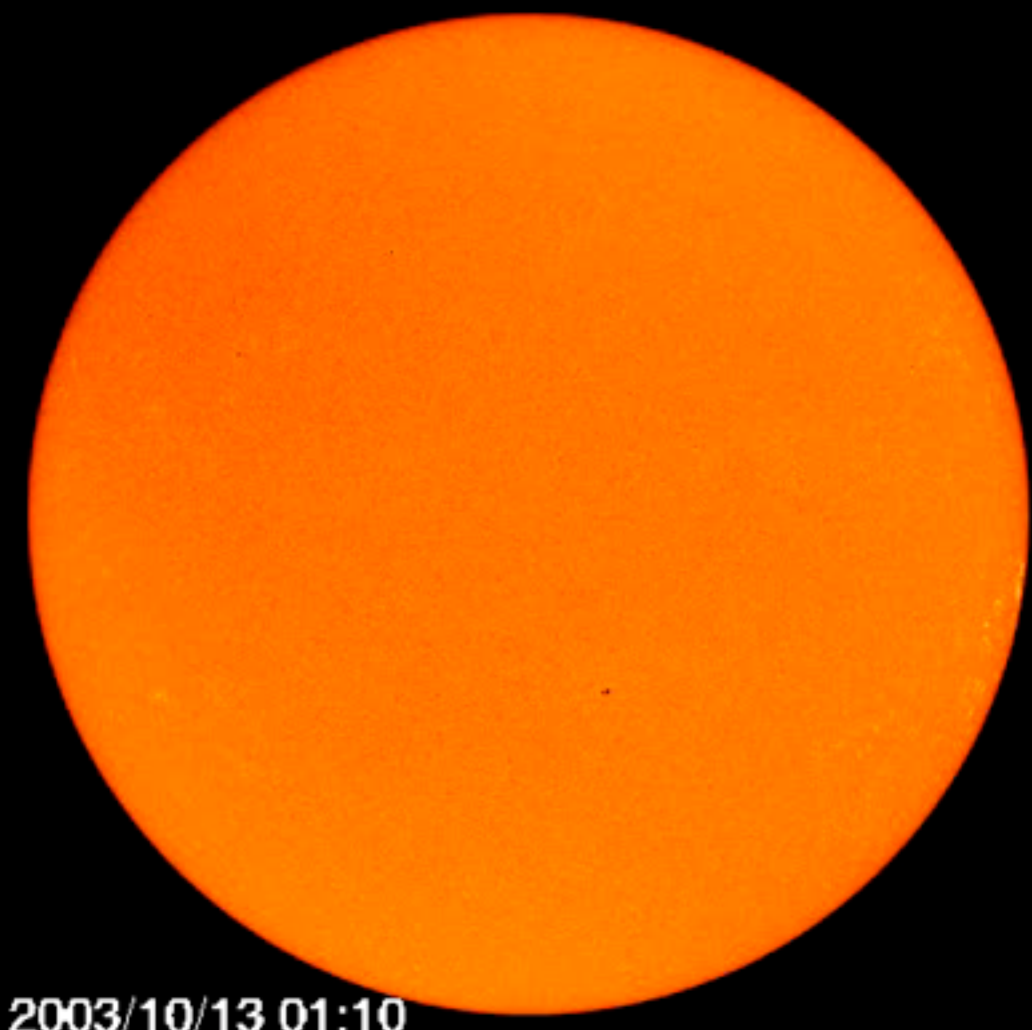


Impacts on animals

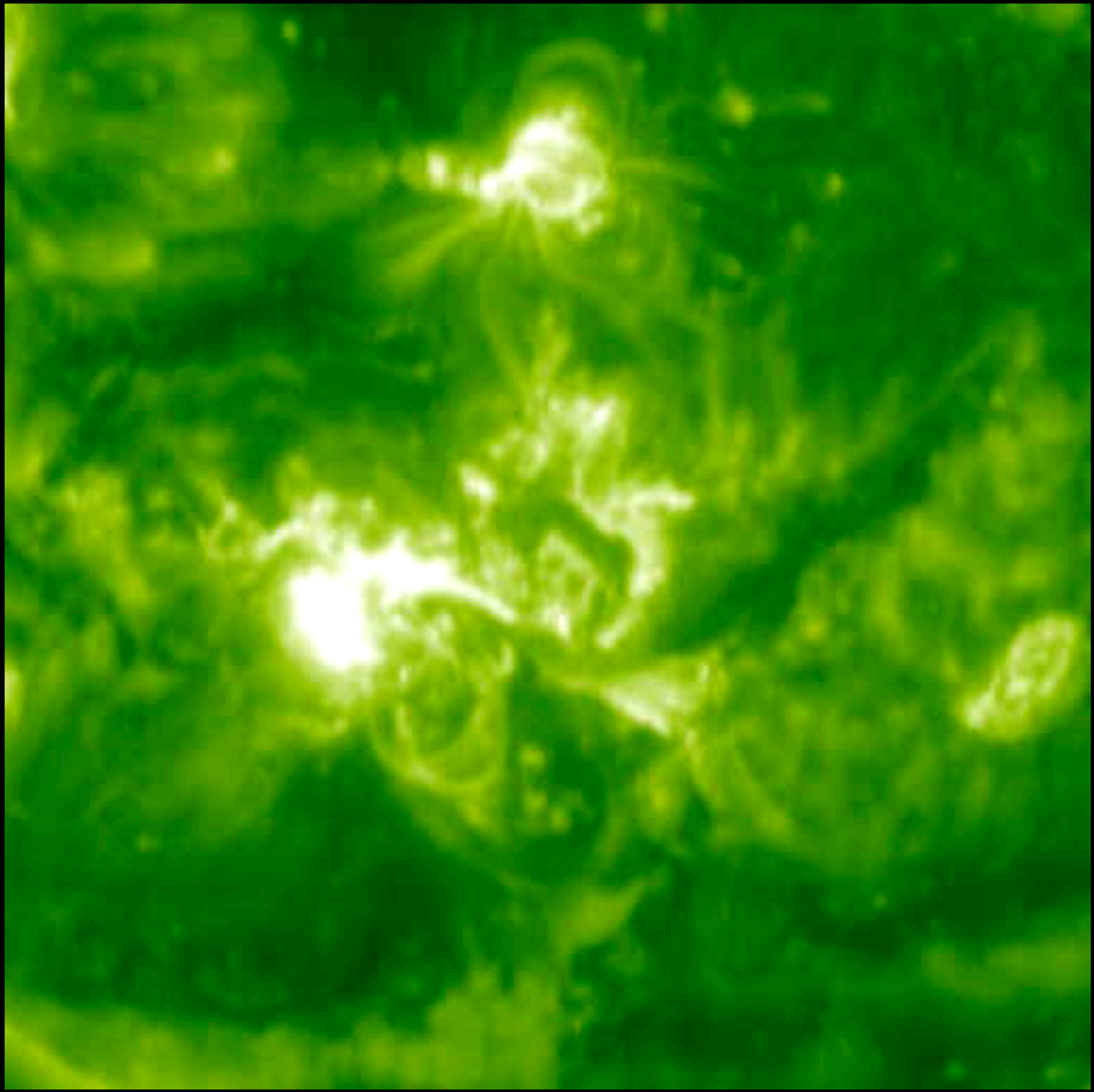
- The navigational abilities of homing pigeons are affected by geomagnetic storms
- Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells.

The Halloween-storms

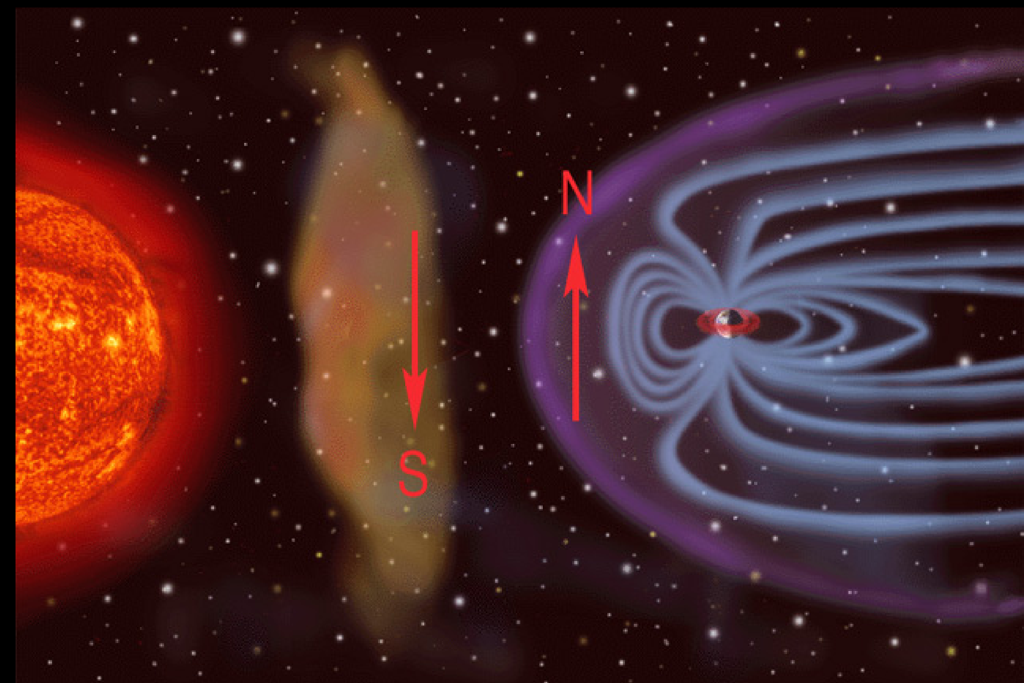
Giant sunspots developed

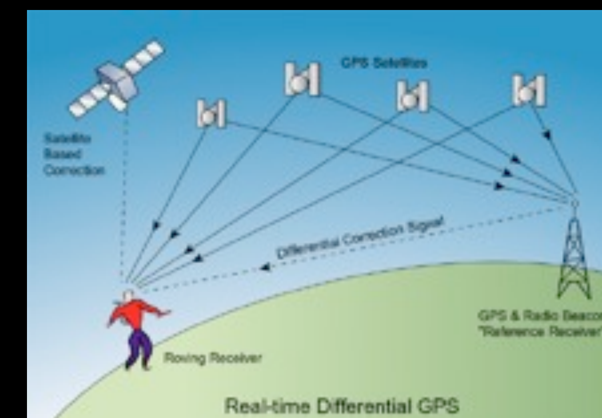


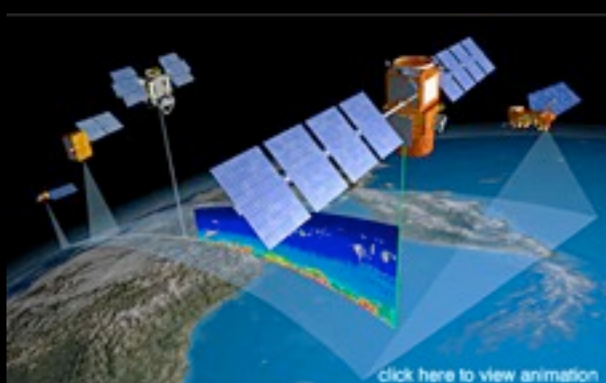
Solar storm 28th October 2003



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

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.

DSB - Nasjonalt Risikobilde

The Directorate for Civil Protection and Emergency Planning (DSB)

Solstorm.
Foto: ESA/NASA

5.6 SOLSTORM

BAKGRUNN

Solens overflate består av plasma som kan betraktes som en meget varm elektrisk ledende gass. Gassen strømmer kontinuerlig ut fra solen, og sammen med elektromagnetisk stråling, påvirker dette jorda og vårt nære verdensrom ved en rekke prosesser som med en fellesbetegnelse kalles romvær. Til tider oppstår voldsomme eksplosjoner i solas atmosfære, såkalte solstormer, hvor store mengder partikler, stråling og gass med magnetfelt slynges ut i verdensrommet. Jordas magnetfelt beskytter mot solstormer, men ved polområdene er denne beskyttelsen svakere.[72] Romvær og solstorm er derfor et særlig aktuelt tema for Norge siden vi ligger langt nord.

Den såkalte *Carrington-stormen* i 1859 refereres ofte til som den kraftigste solstormen man har hatt erfaring med. Telegrafsystemet ble kraftig rammet, operatørene fikk elektriske sjokk, og branner oppsto i telegrafbygninger som følge av solstormen. Også i 1921 opplevde man en stor solstorm. Denne solstormen var ikke så kraftig som den i 1859, men medførte samme type konsekvenser og utfordringer for datidens samfunn.

Flere kraftige solstormer har de siste 20 til 50 årene medført forstyrrelser og avbrudd i tele- og strømforsyning med ujevne mellomrom og ulik varighet. I 2003 var det mange kraftige elektromagnetiske stormer på sola. I forbindelse med de såkalte *Halloween-stormene* ble det meldt om tekniske problemer med satellitter og satellittelefoner fra flere deler av verden. På grunn av problemer med radiokommunikasjon ble internasjonal luftfart på trans-atlantiske og polare ruter midlertidig reduserte og trafikken omdirigert, og det ble sendt ut advarsel om økt strålefare for flypassasjerer. I USA ble også enkelte store krafttransformatorer skadet og ødelagt, og store områder ble mørklagt i noen timer. Kostnader som følge av solstormen ble anslått til å være minst fire milliarder dollar.

Også i Sverige mistet mange tusen mennesker strømmen i en kort periode som følge av denne solstormen.[73]

72 NATO/EAPC, working paper 30 August 2011; Norsk Romsenter (NRS); www.kriseinfo.no (14.12.2011).

73 National Research Council of the National Academies (2008): *Severe Space Weather Events-Understanding Societal and Economic Impacts.* Workshop Report; U.S. Department of Homeland Security, Federal Emergency Management Agency (FEMA), National oceanic and atmospheric administration (NOAA), US Department of Commerce, Swedish Civil Contingencies Agency (MSB) (2010): *Managing Critical Disasters in the Transatlantic Domain – The Case of a Geomagnetic Storm.* Workshop Summary, February 23.-24.2010.

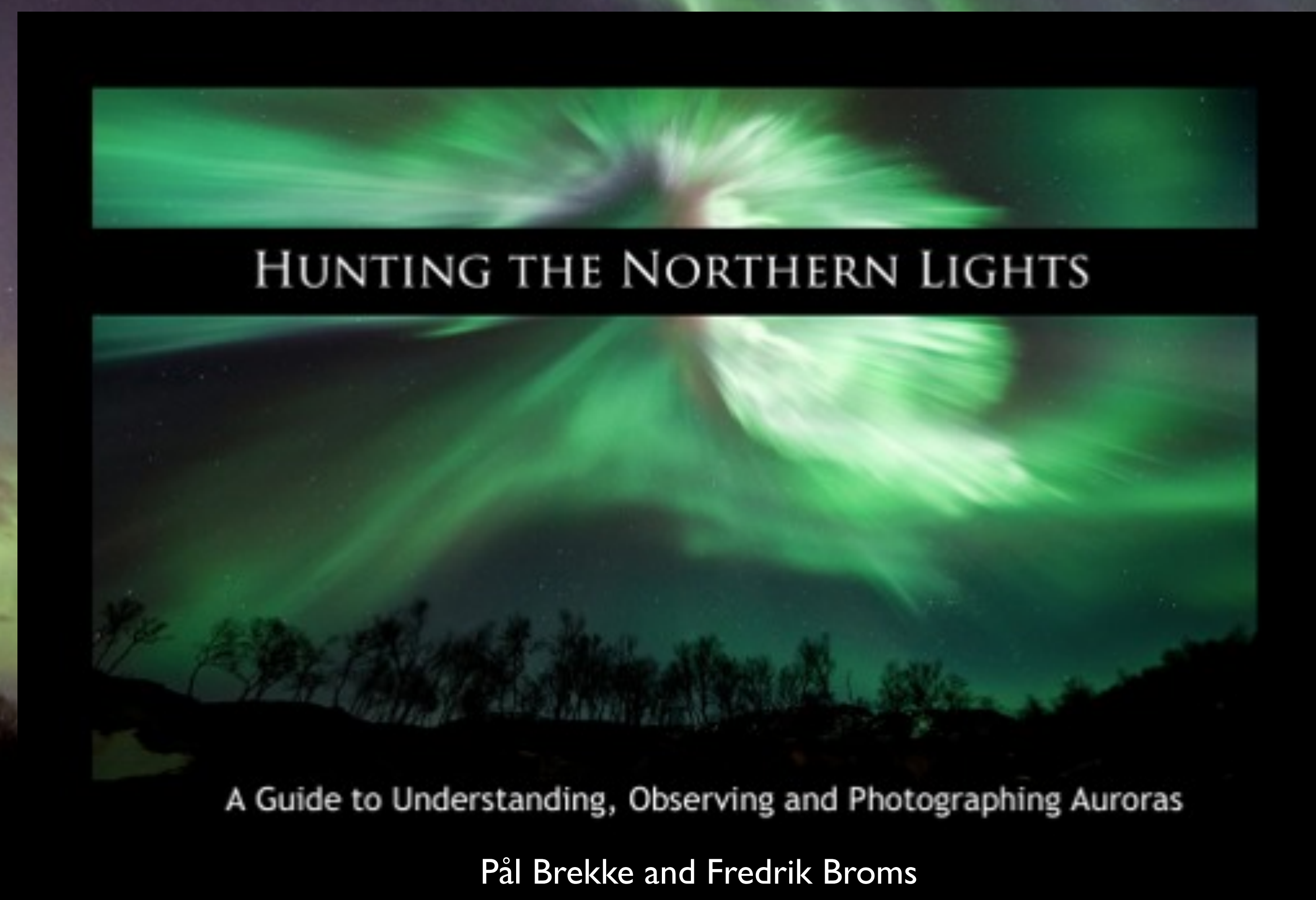
38

Solar storms on talks shows

Learn more about the Sun and the Aurora

New books

New: Feb 2013



http://www.solarmax.no/Aurora/Book.html

Fredrik Broms