Solstormer, nordlys og romvær

Hvorfor bry oss?

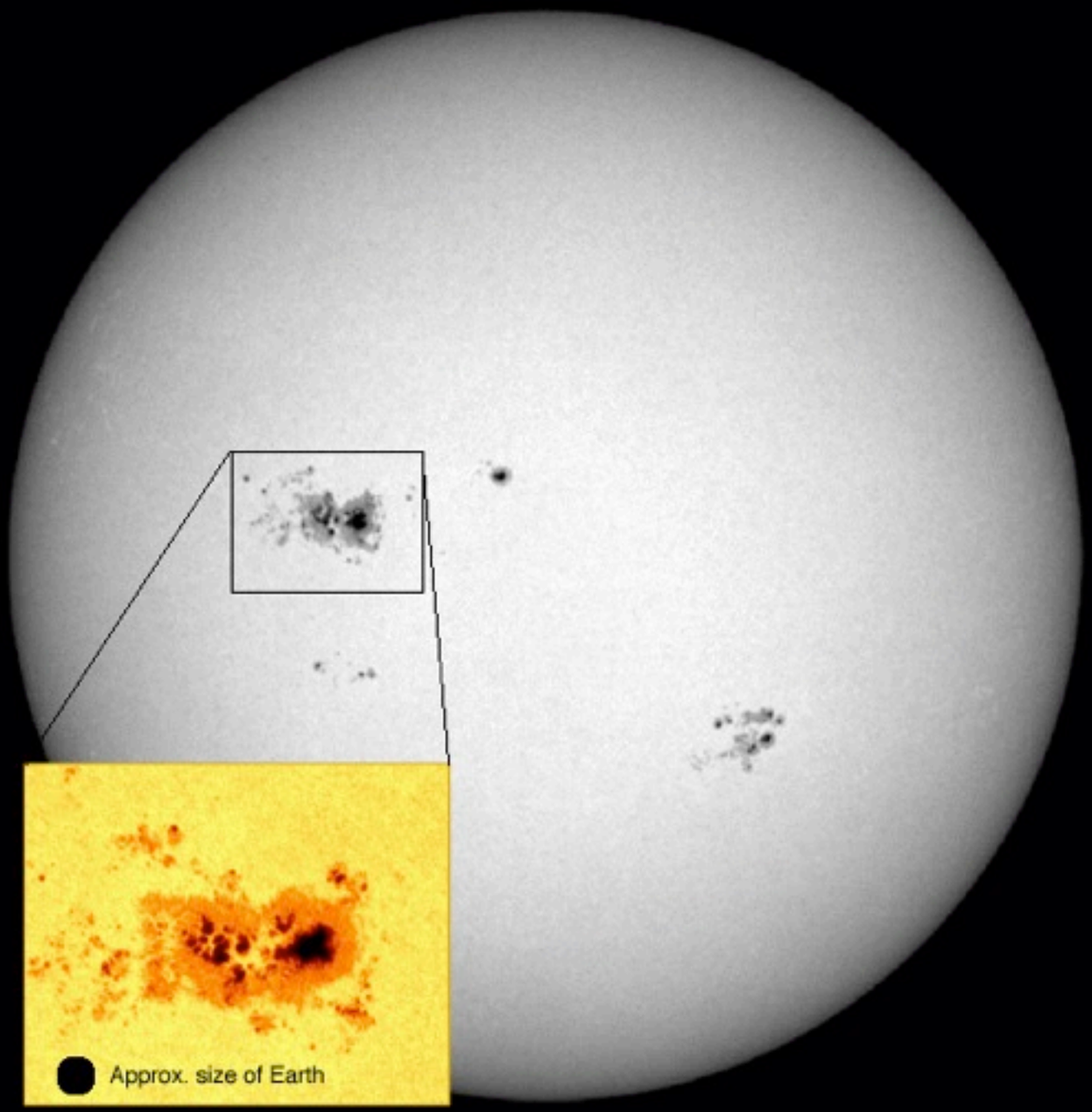
Not every kind of storm
shows up on weather radar...

Solflekker

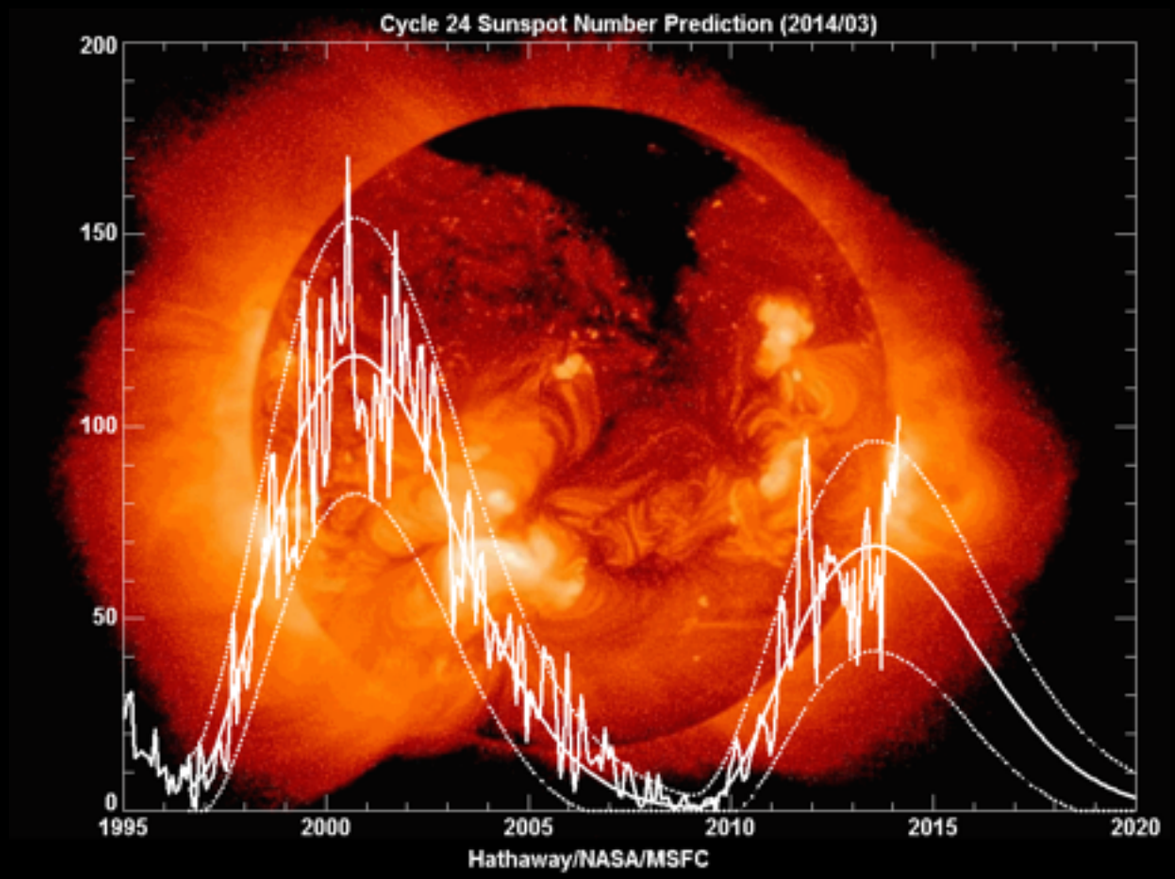
Mørke områder på Solas overflate

Skyldes kraftige magnetfelt som presser seg opp fra dypere lag

Magnetfeltet reduserer energistrømmen fra dypere lag

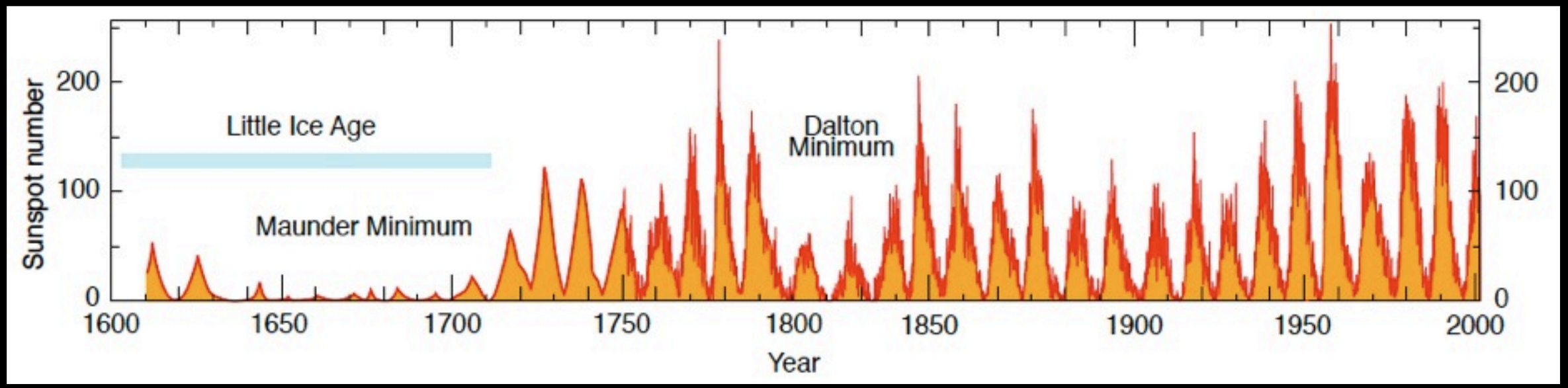


Historical sunspot records



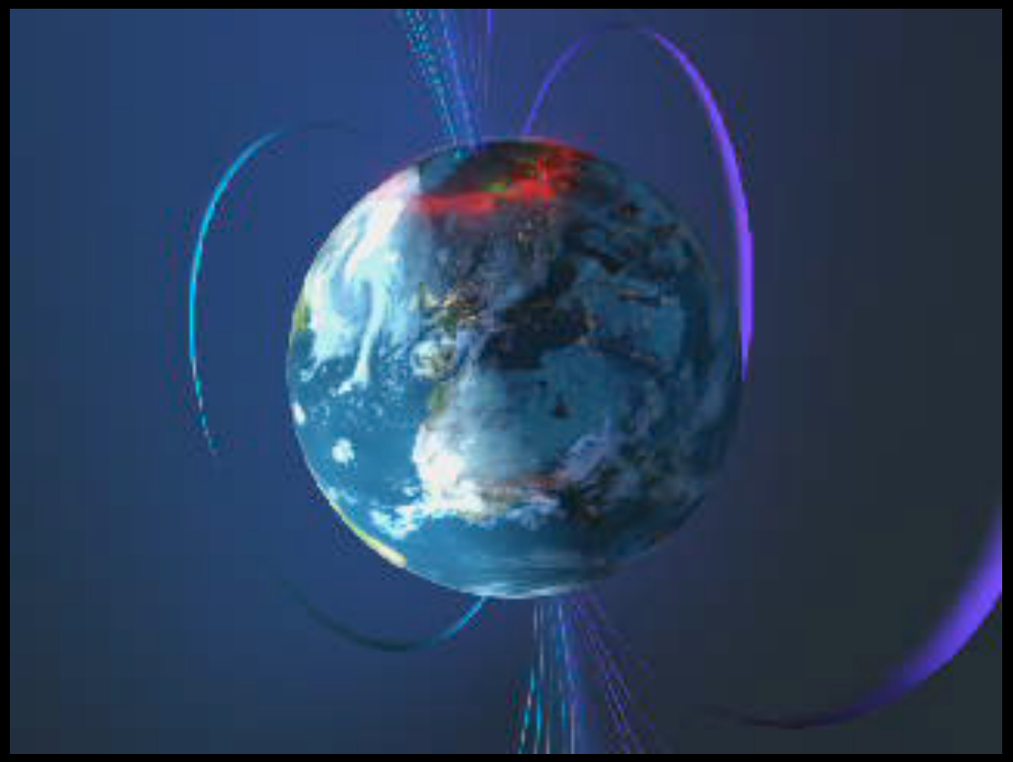
I 1610 pekte Galileo og Thomas Harriot teleskopet mot Solen for første gang.

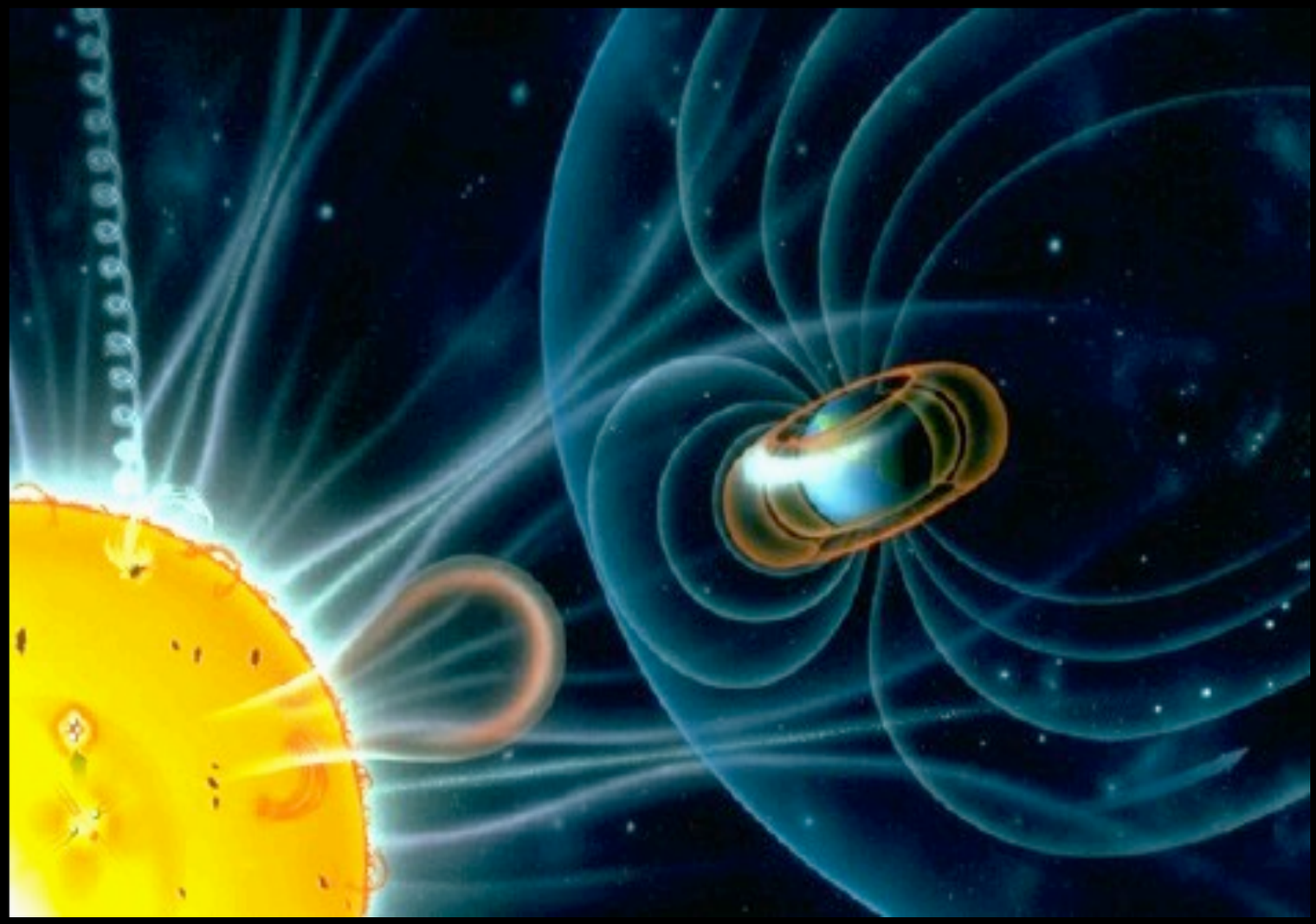
Galileo skadet synet p.g.a. disse observasjonene.



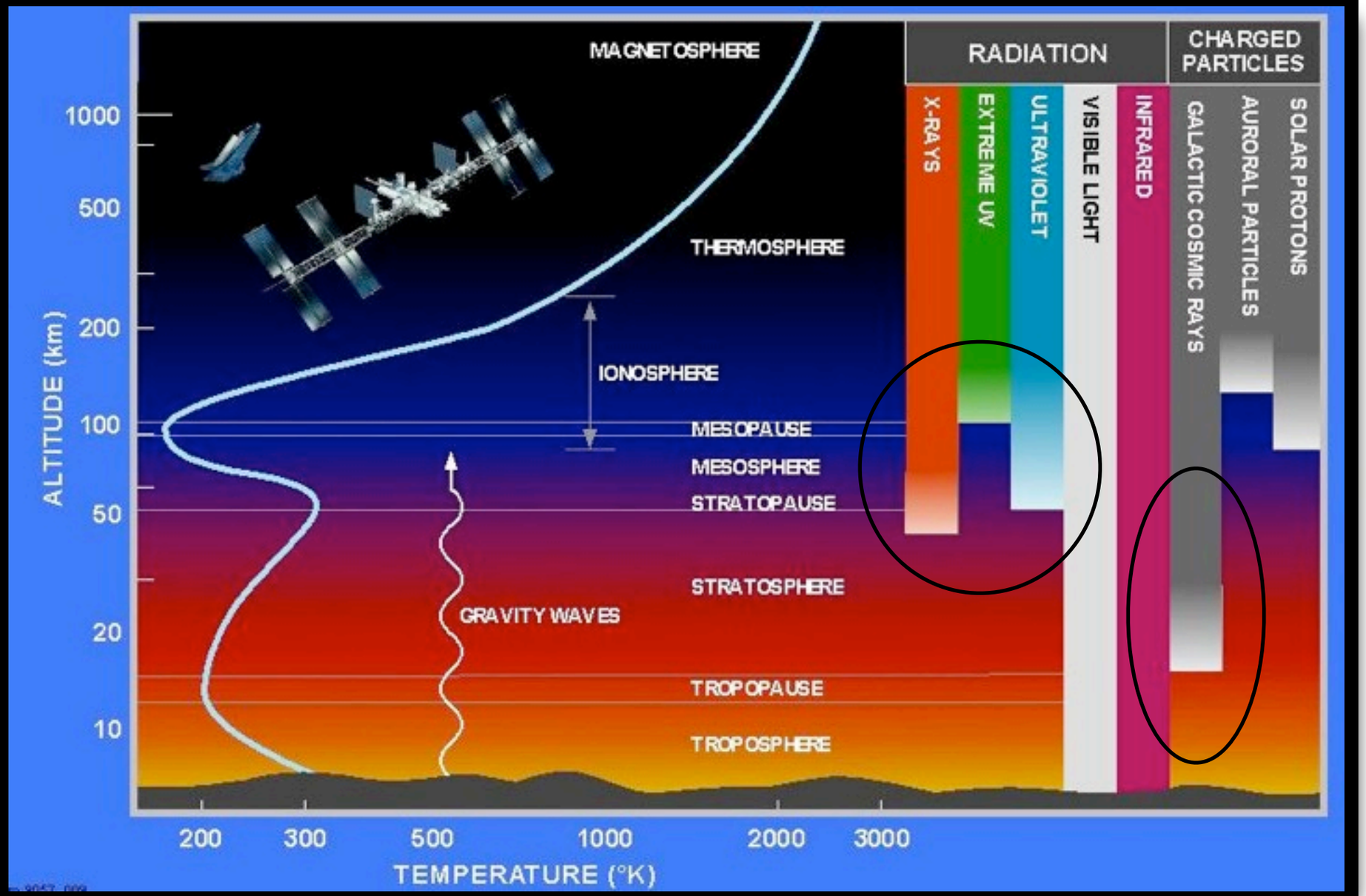
What is the Solar Wind?

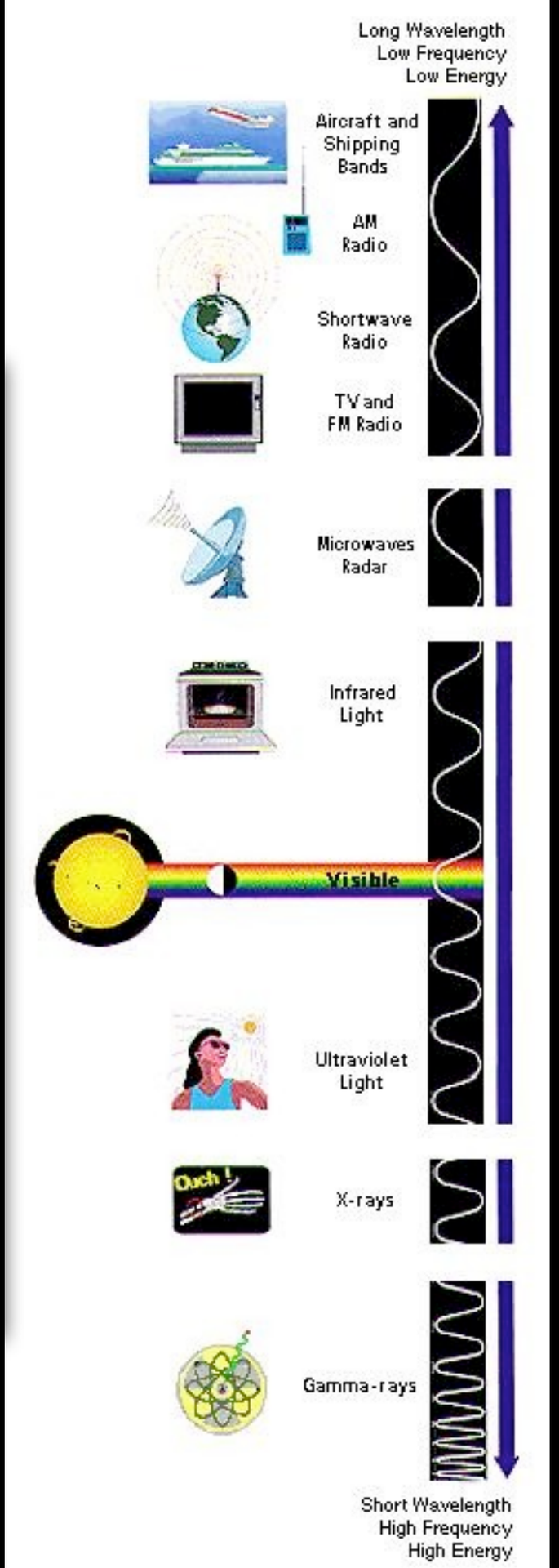
- A constant stream of particles «blowing» from the solar corona with a typical velocity of 1.5 million km/h (400 km/s). The solar wind reaches the outher part of the solar system and affects all planets. It pushes on our magnetosphere.





Elektromagnetisk stråling



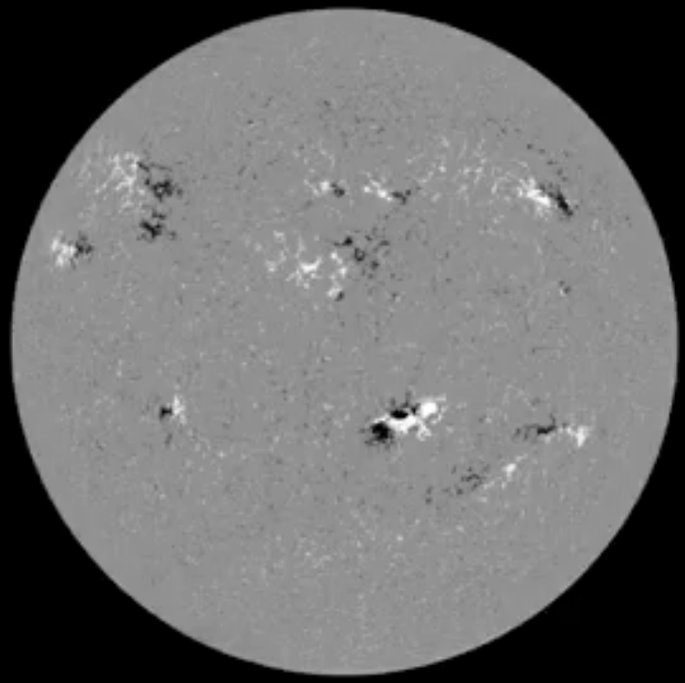


Sola sett med UV briller

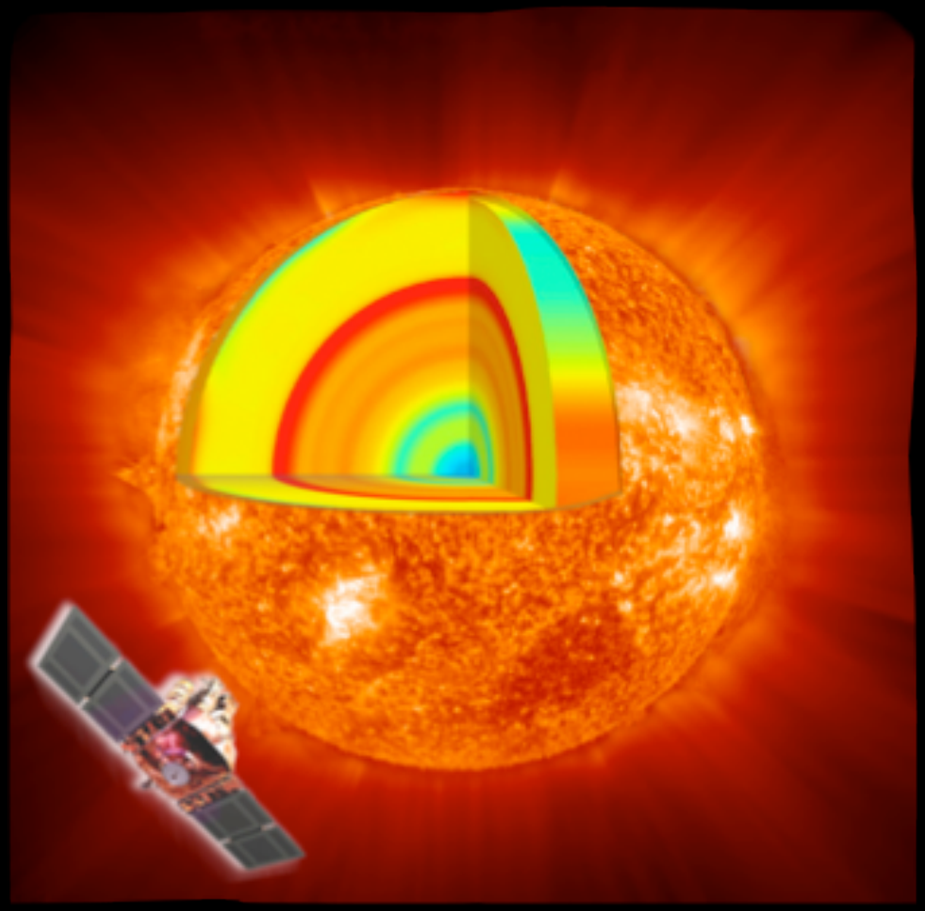
Spectral Imaging

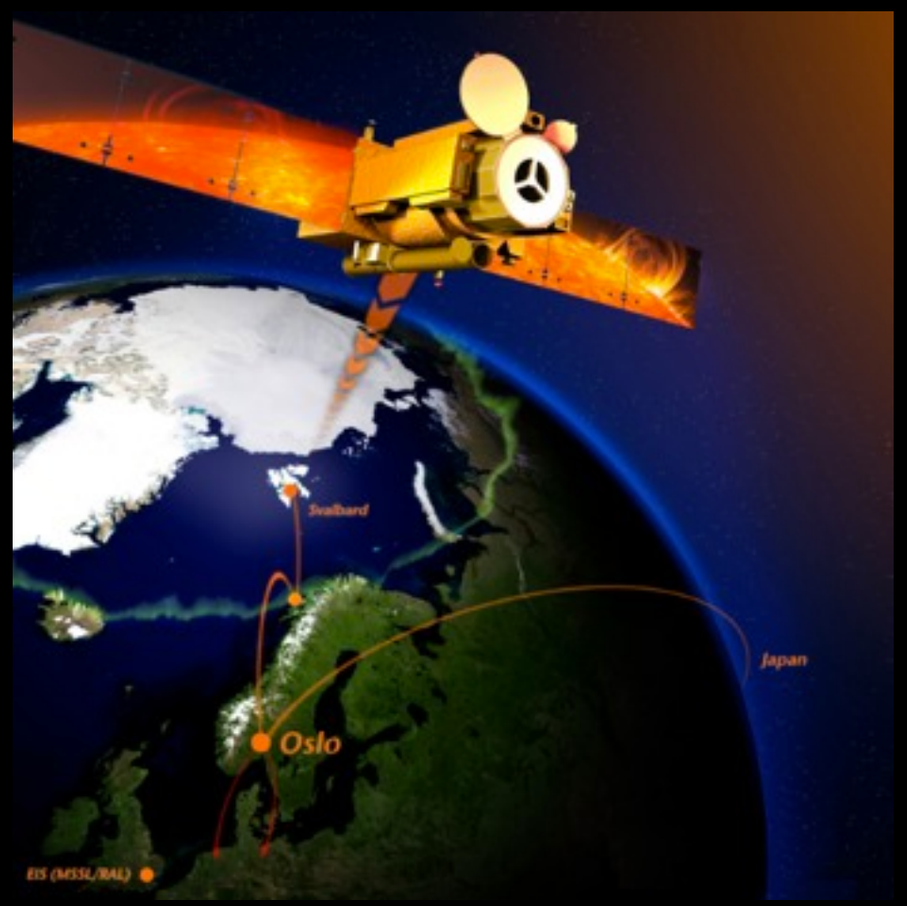
← Different spectral images of a biker

Different spectral images of the Sun



SOHO og Hinode

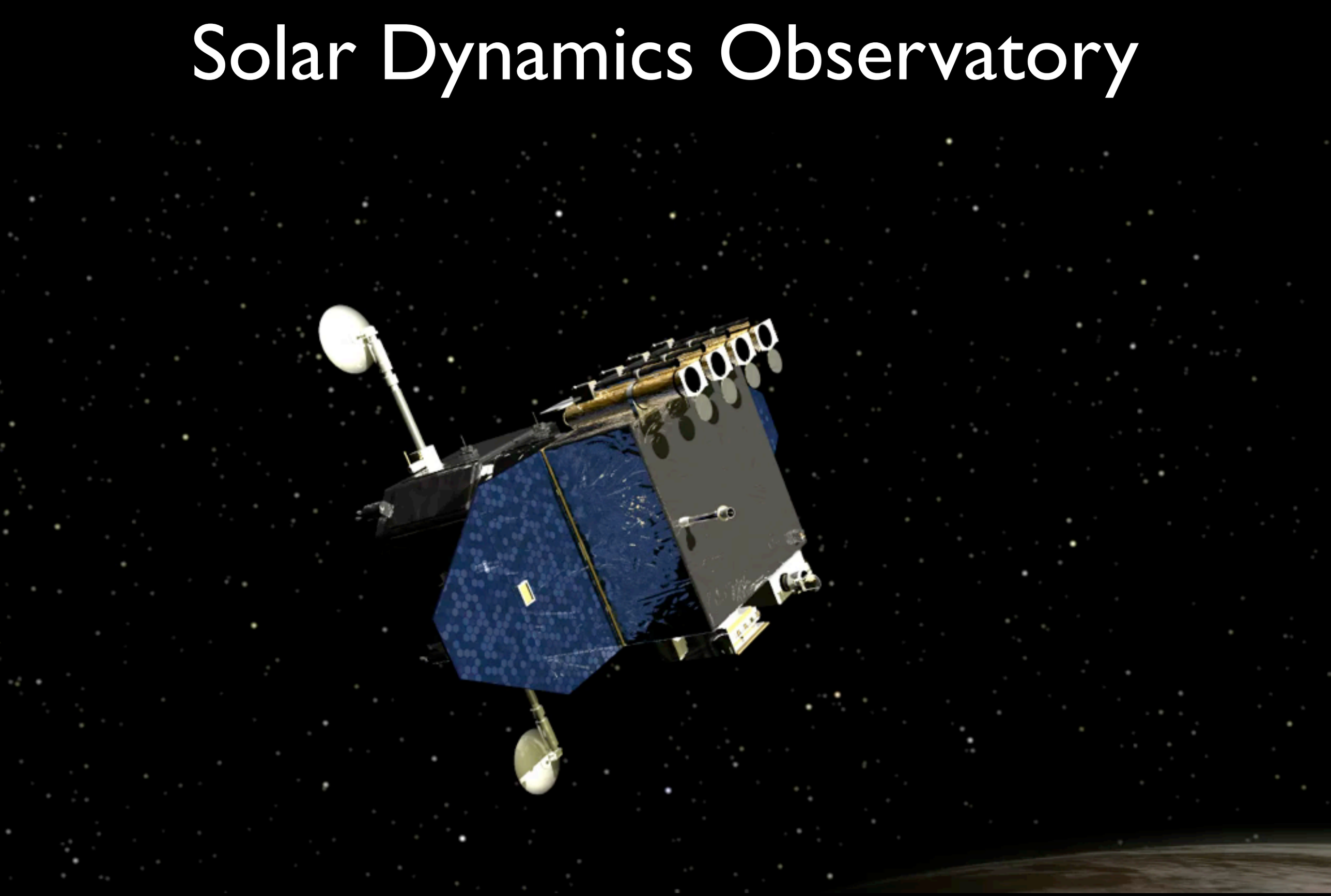




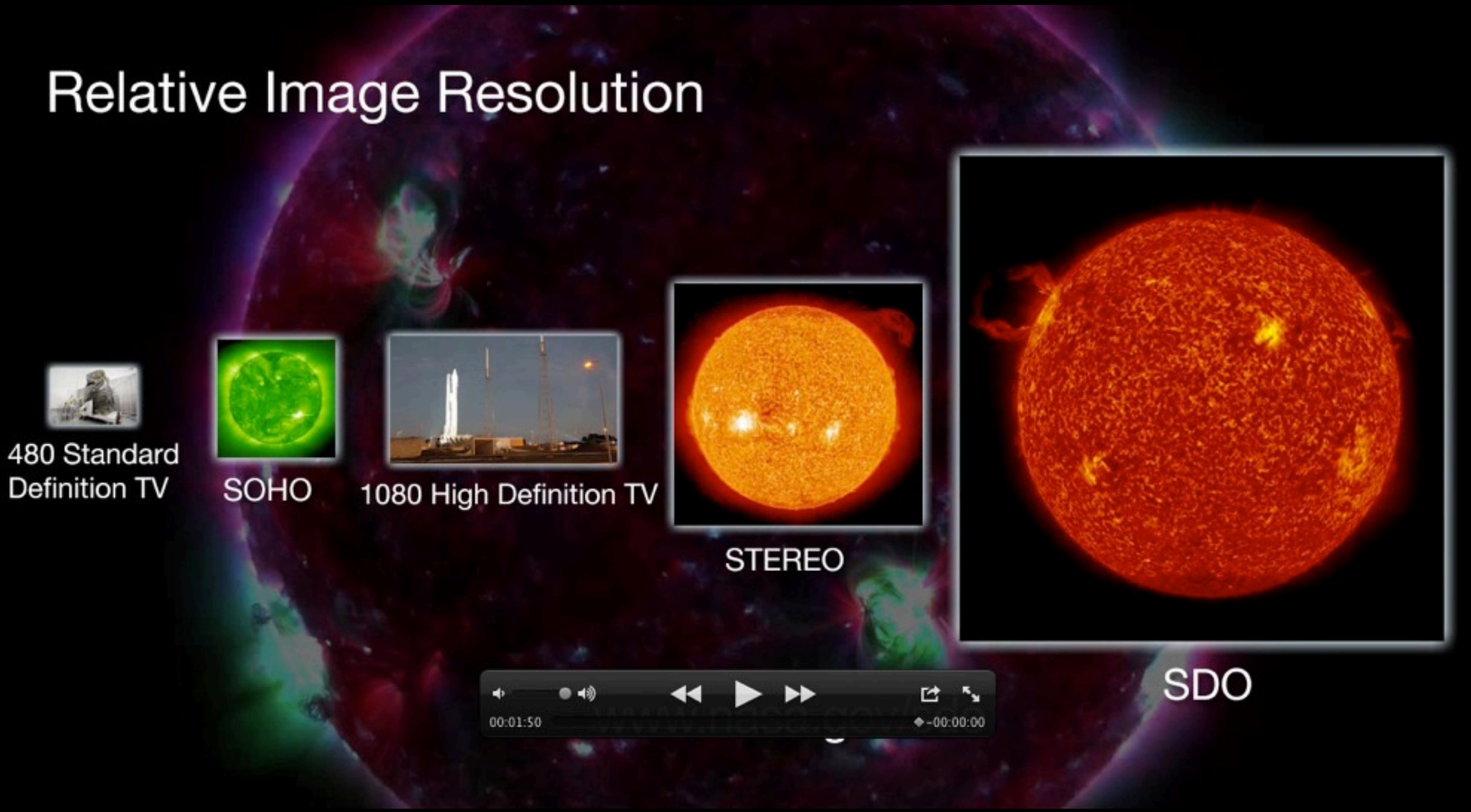
Mange av dagens mest spektakulære bilder av Sola kommer fra romobservatoriet SOHO (Solar and Heliospheric Observatory). SOHO ble skutt opp 2 desember 1995 og er plassert 1.5 millioner km vekk fra jorda (4 ganger lengere vekk enn månen) mellom oss og Sola. Her kan den studere Sola i detalj både dag og natt. Fra rommet kan vi se lag av atmosfæren som vi ikke kan se fra jordoverflaten. Dette skyldes at det meste av strålingen fra kromosfæren og koronaen blokkeres av Jordas atmosfære.

HINODE er et japansk solobservatorium som ble skutt opp i 2006. Satellitten har færre instrumenter enn SOHO, men har nyere teknologi og kan se mye mindre detaljer på Sola enn SOHO. Norske forskere deltar på begge prosjektene og alel data fra HINODE overføres til verdesn forskere via den norske satellittstasjonen på Svalbard.

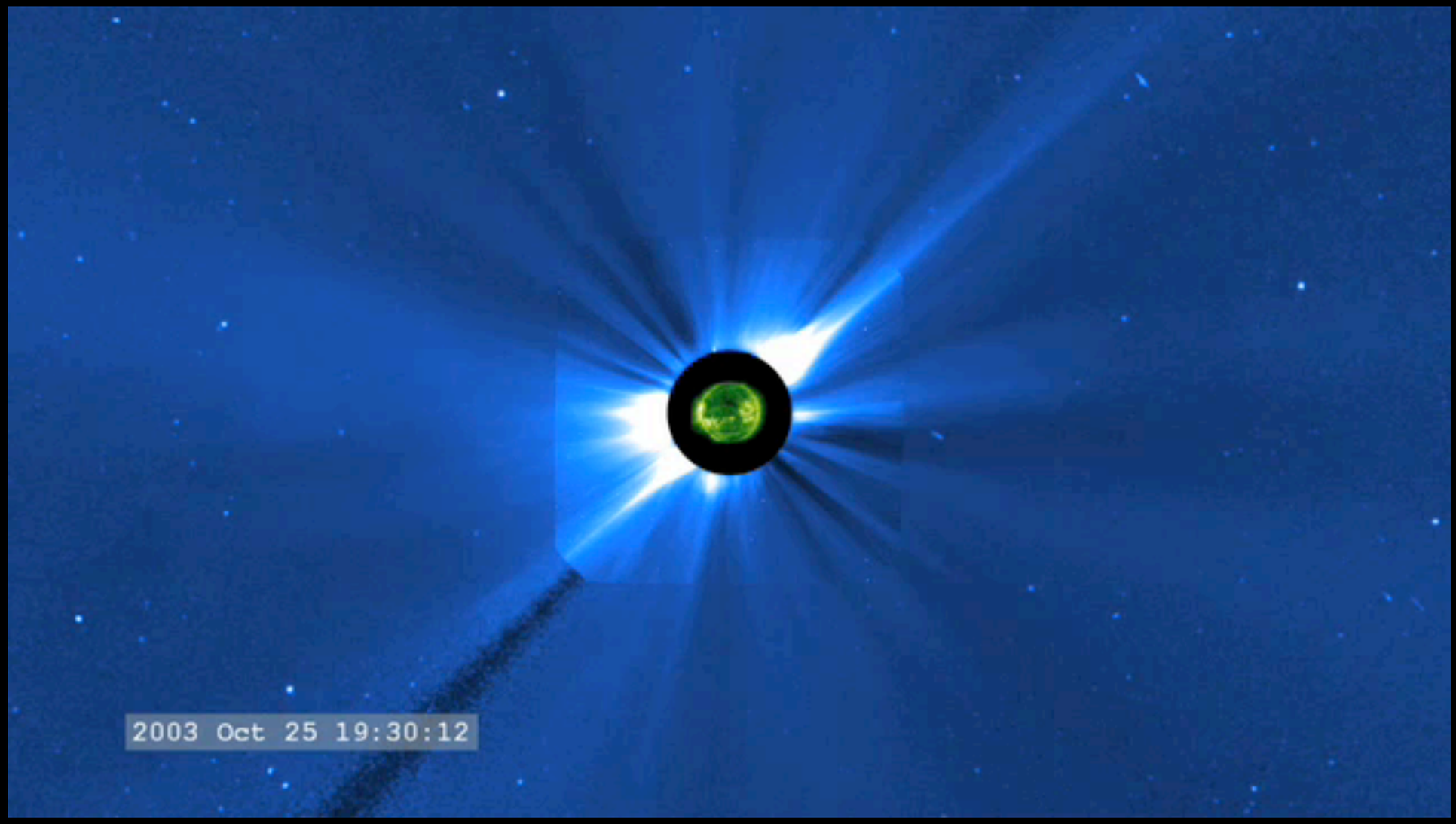
Solar Dynamics Observatory



Solar Dynamics Observatory



Solvind og solstormer

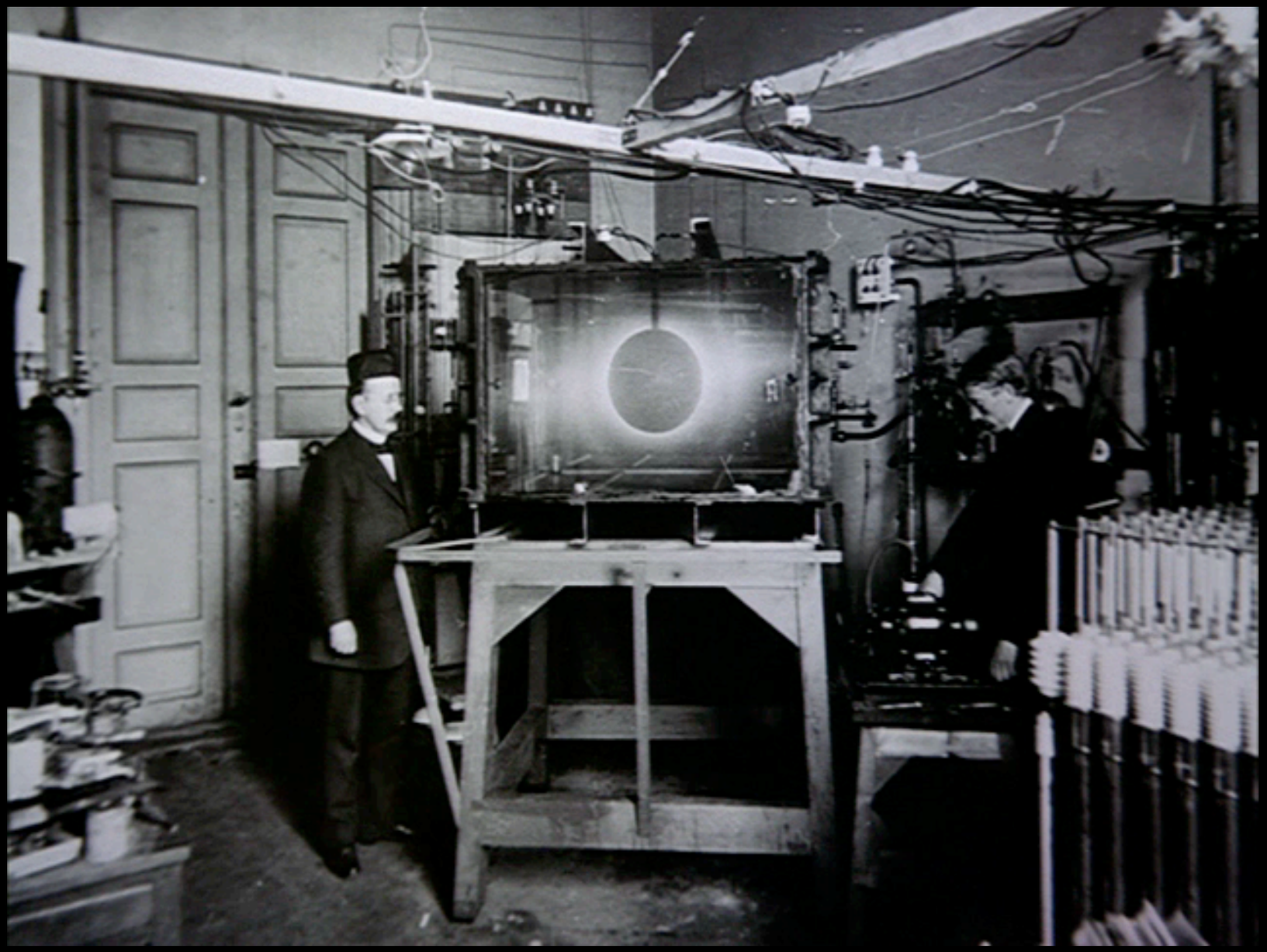


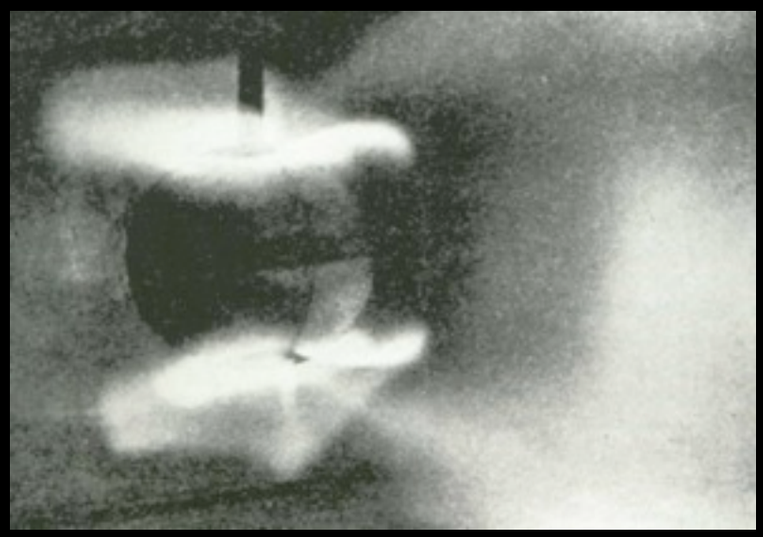
Nordlys over Oslo 12 april 2010

Morten Ross

Kristian Birkeland (1867 - 1917)

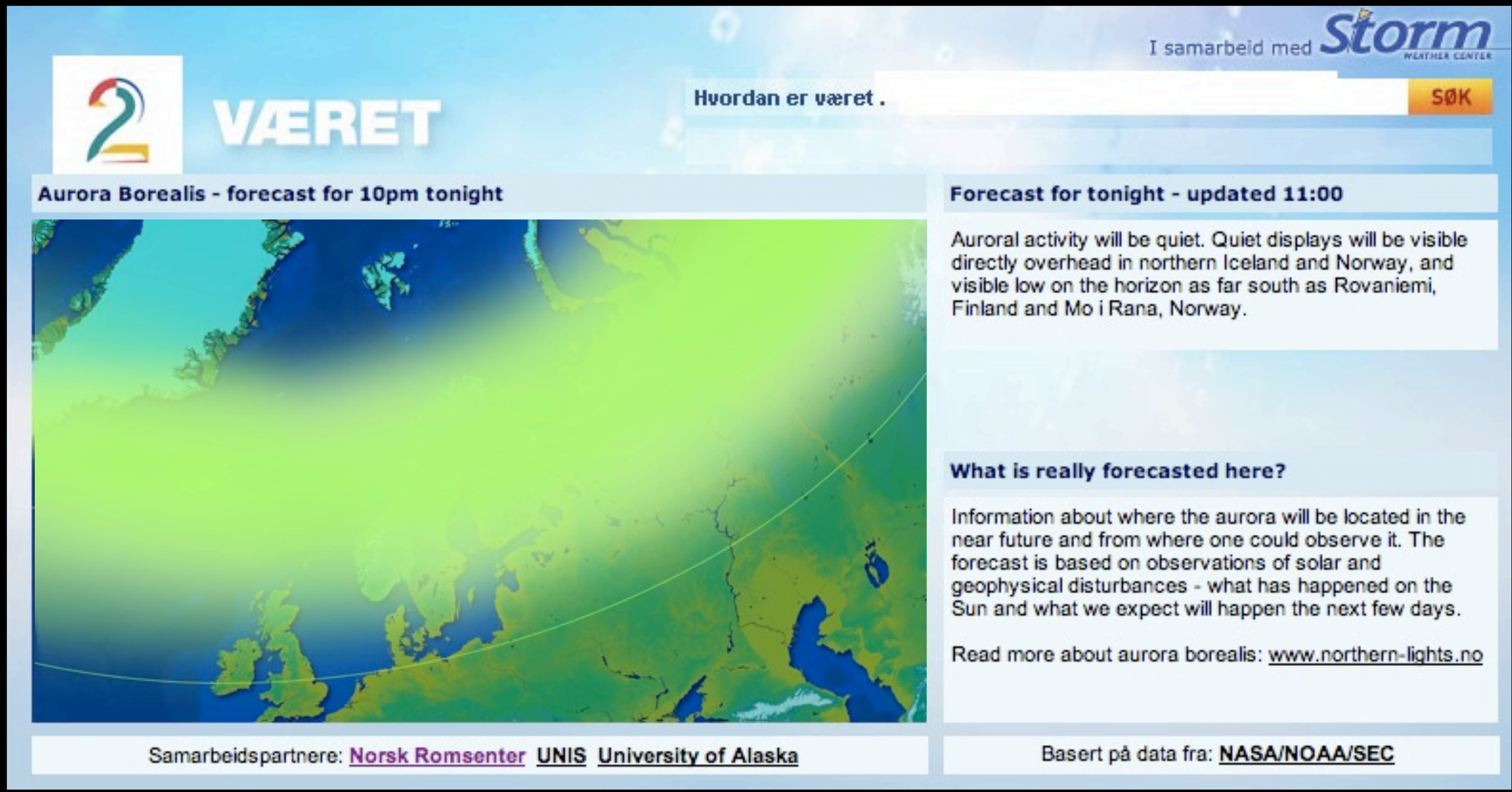
- The first realistic theory of the aurora: Electrical charged particles travelling with large velocities from sunspots. These were captured by the Earths magnetic fields and channelled down towards the polar regions.
- He supported his theory by creating artificial aurora in his laboratory in 1896.



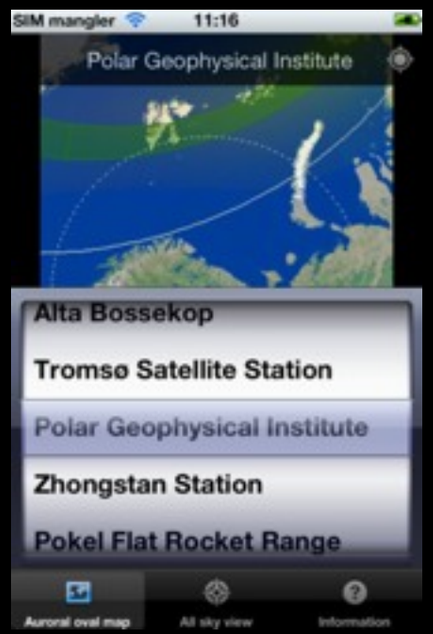


Aurora forecaster in Norway

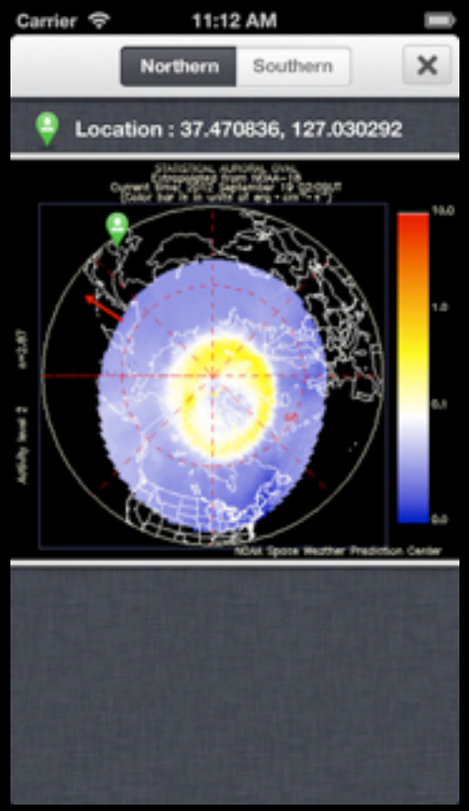
http://www.storm.no/nordlys/

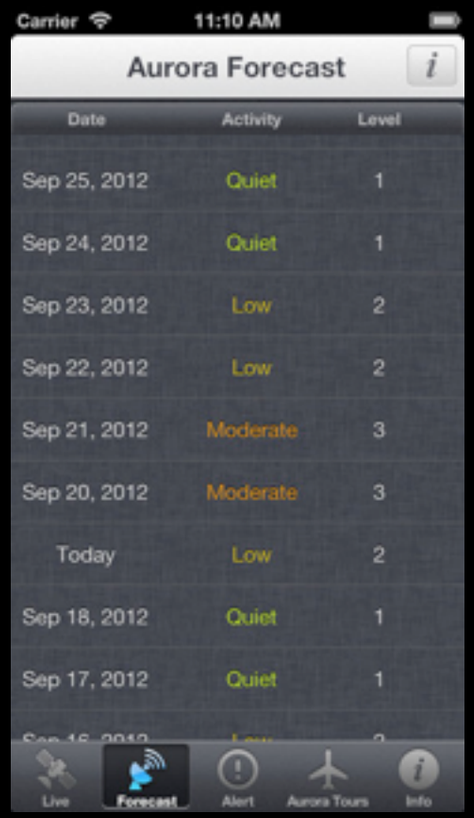


Smart Phone - Aurora forecaster



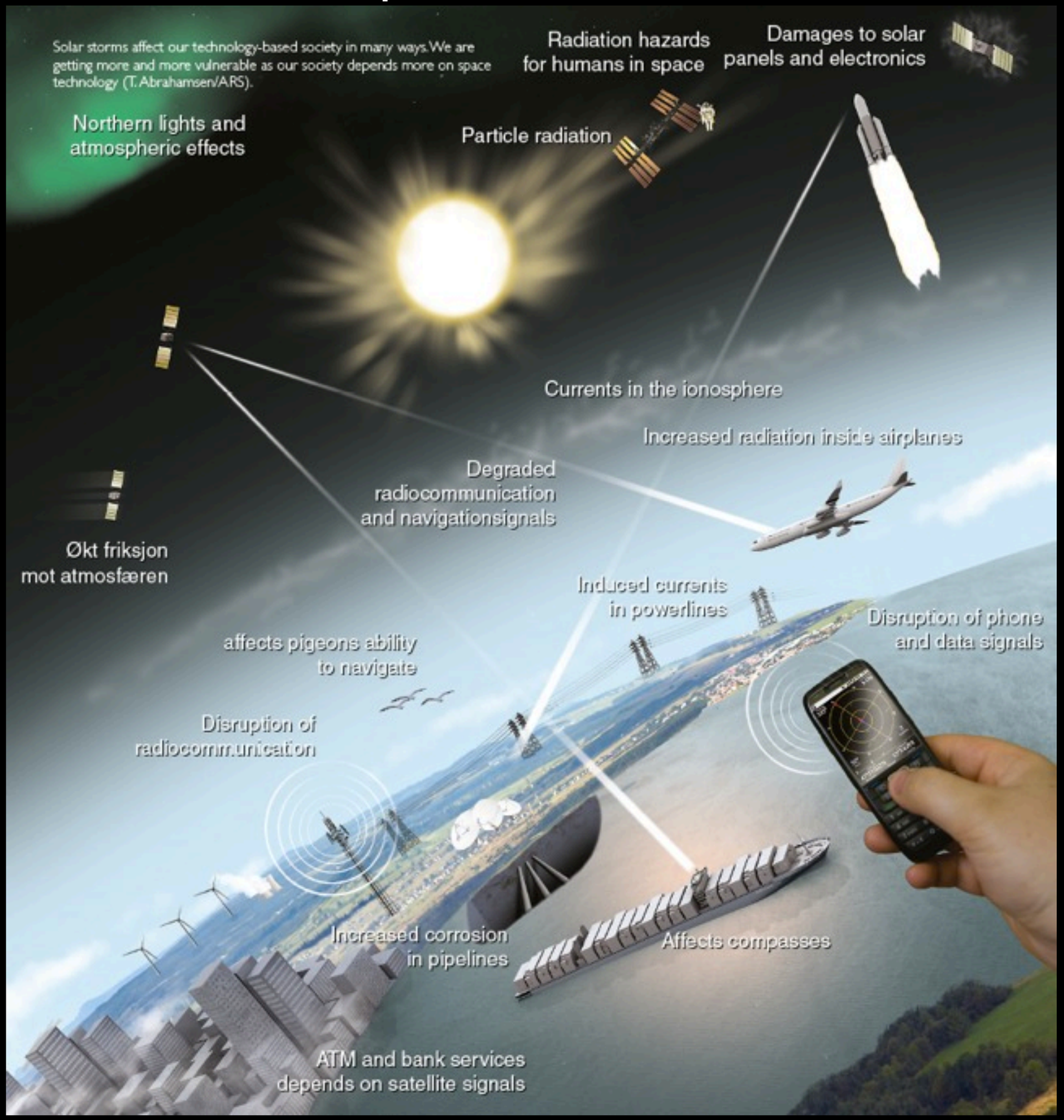
«Auroral Forecast»





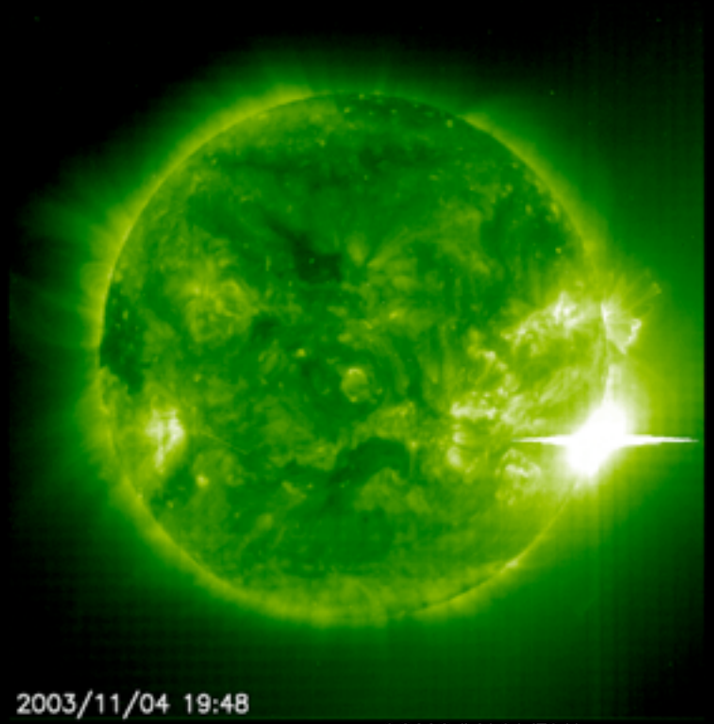
«Aurora Forecast»

Space Weather

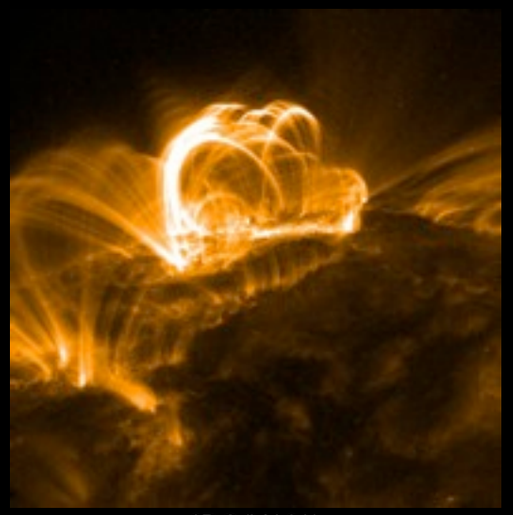


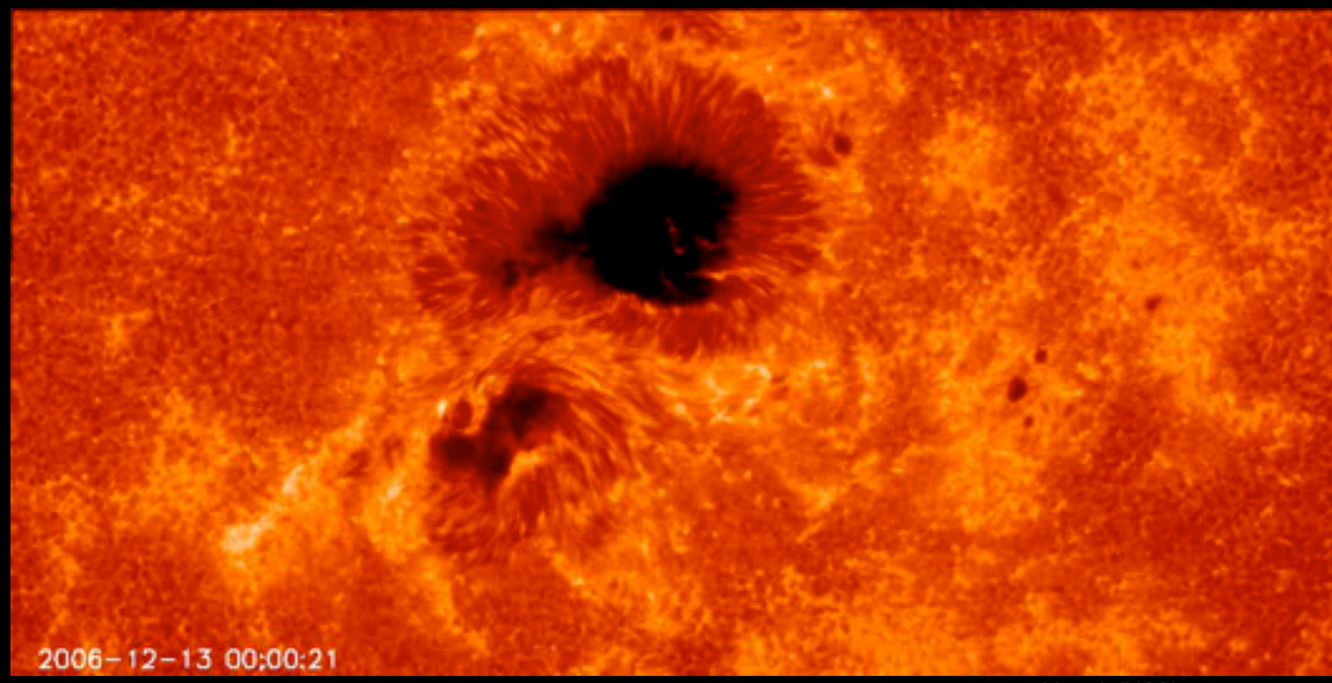
From the book «Our Explosive Sun» (P. Brekke)

EXPLOSIONS ON THE SUN



SOHO(NASA/ESA)


SDO(NASA)

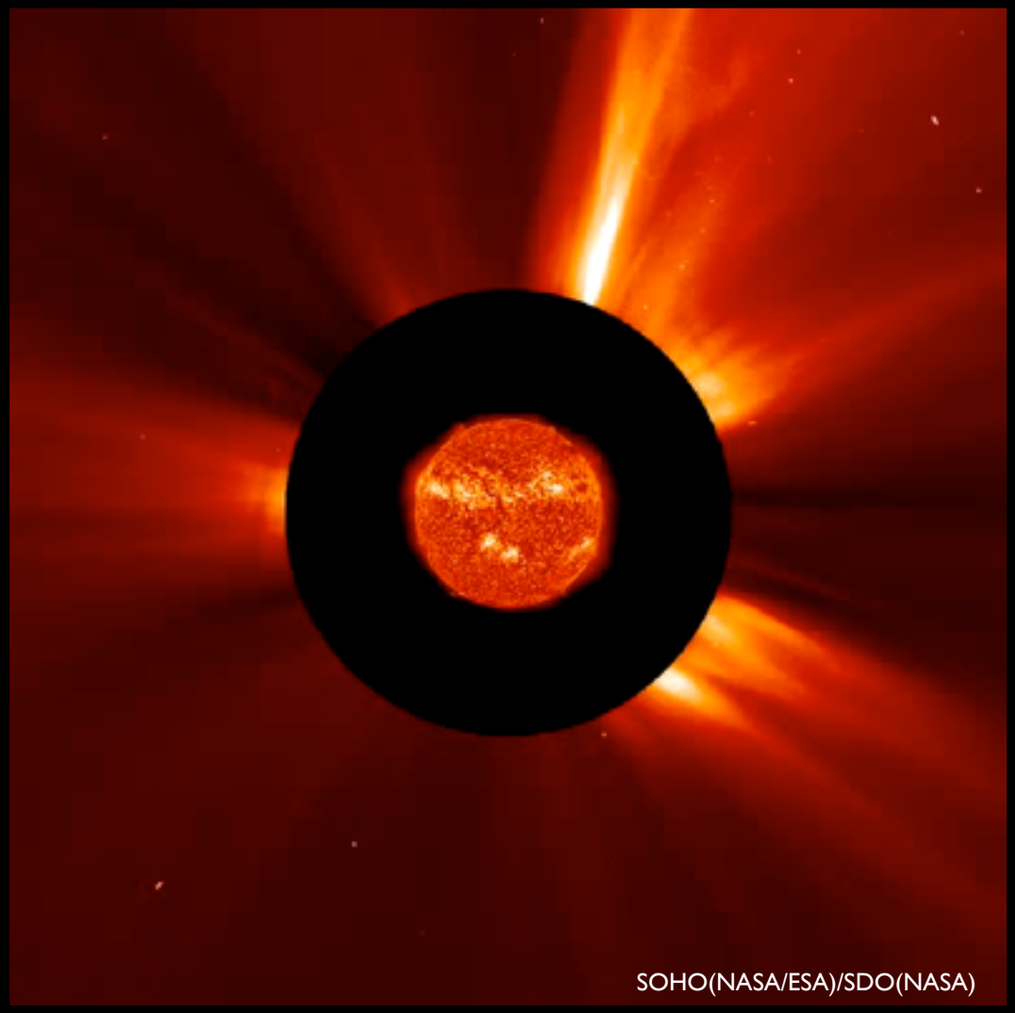


Hinode/JAXA

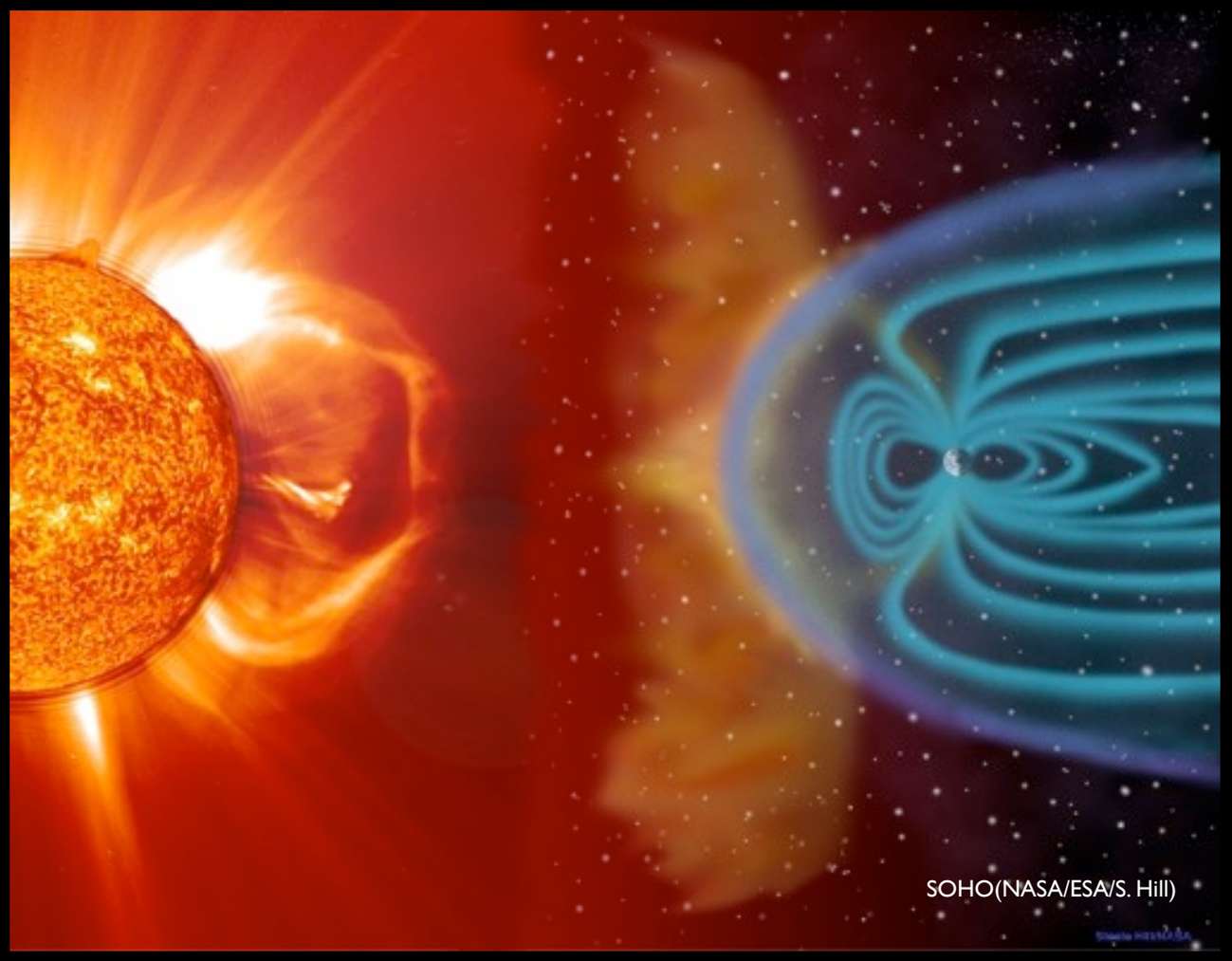
The magnetic field in large active regions on the Sun often gets unstable. This can result in violent explosions in the solar atmosphere – called “flares”. A flare can release in seconds energy corresponding to several billion megatons of TNT. During such explosions the gas is heated to 20 million degrees.

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.

GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)



SOHO(NASA/ESA)/SDO(NASA)

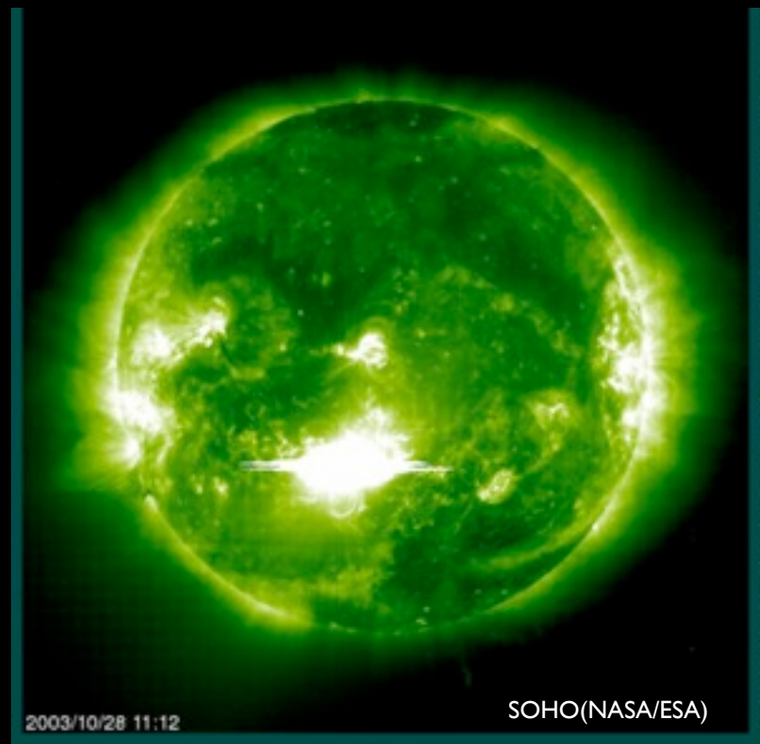


SOHO(NASA/ESA/S. Hill)

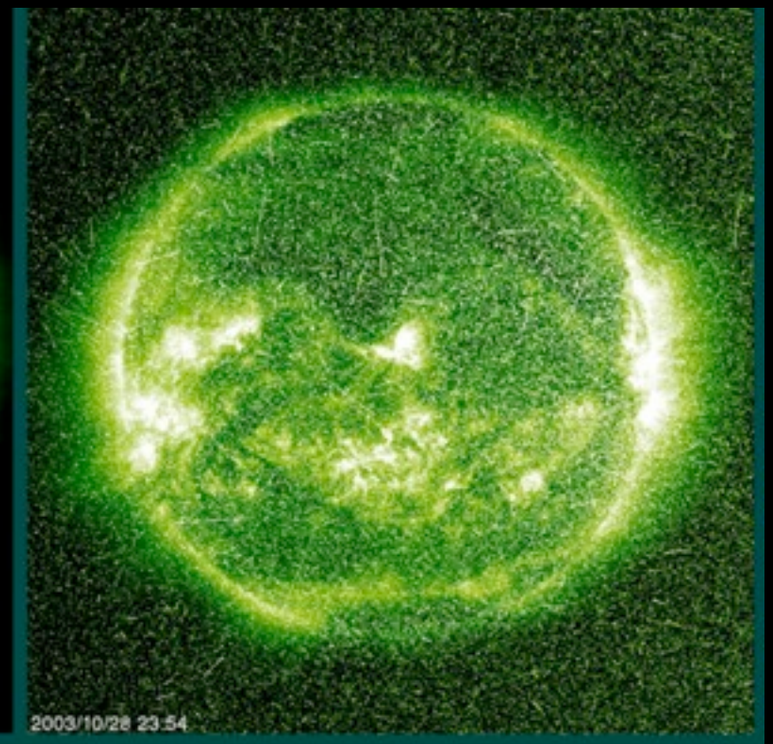
Sometimes large prominences can erupt and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called Coronal Mass Ejections or CMEs for short. The bubble of gas will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

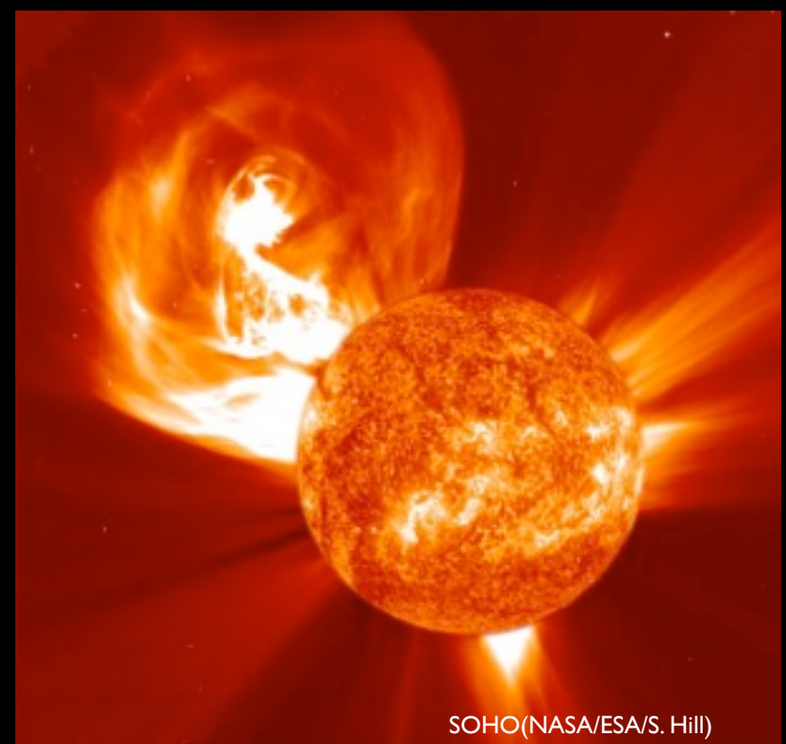
If such an eruption is directed towards the Earth the particles will be deflected by our magnetosphere. The cloud of gas will push and shake the Earths magnetic field and generate a kind of “storm” which we call geomagnetic storms.

PARTICLE SHOWERS FROM THE SUN



SOHO(NASA/ESA)



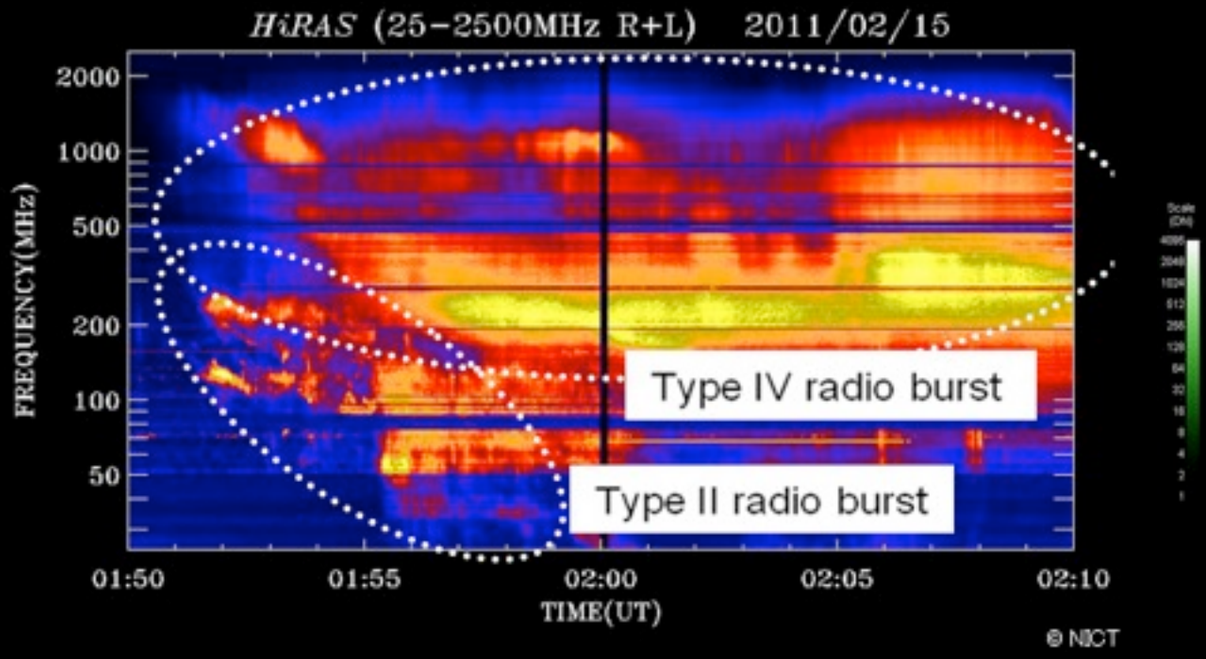


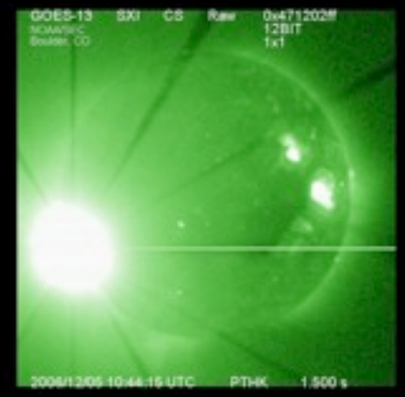
SOHO(NASA/ESA/S. Hill)

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.

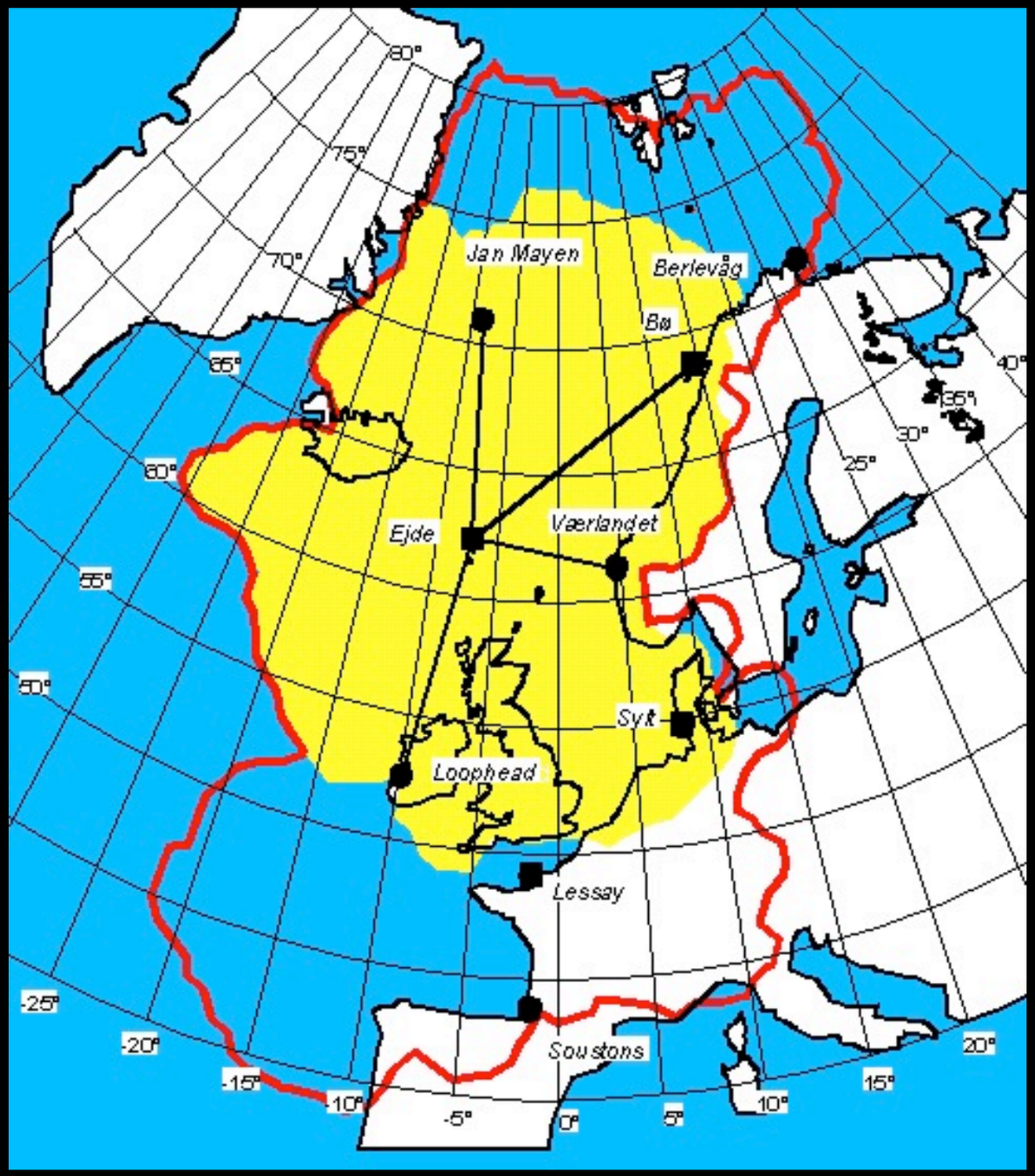
RADIO-BURST

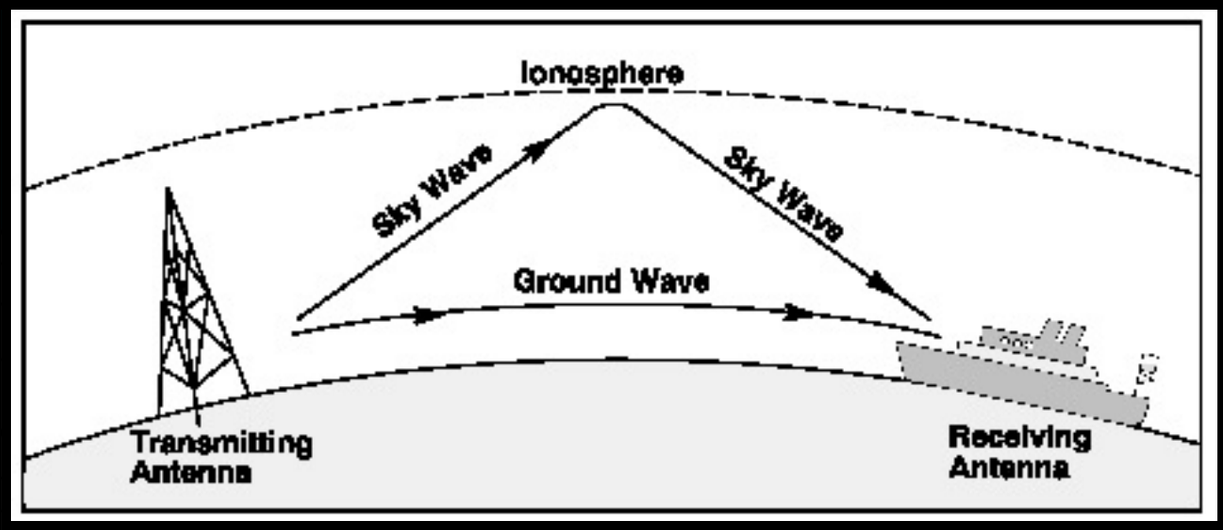




A few times eruptions on the Sun will generate strong burst of radio waves - often with the same frequencies as communications systems we use on Earth as well as the GPS frequency.

Navigation systems - LORAN C

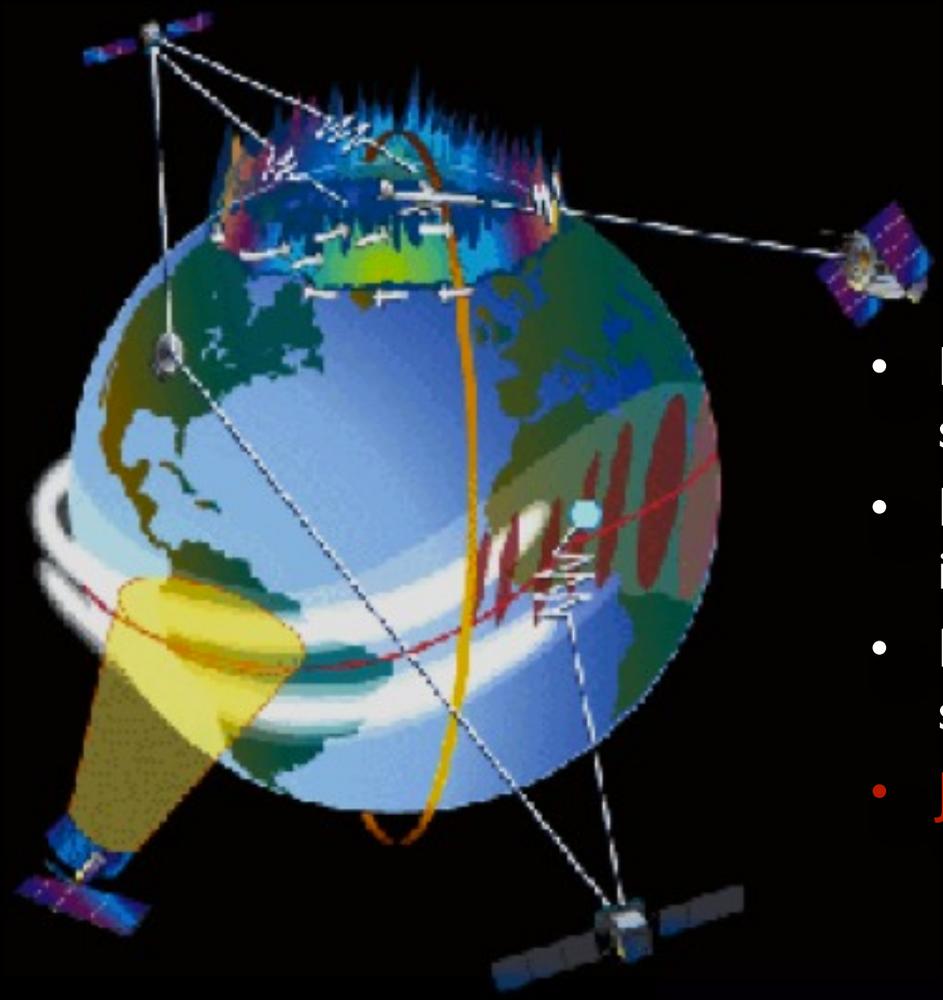




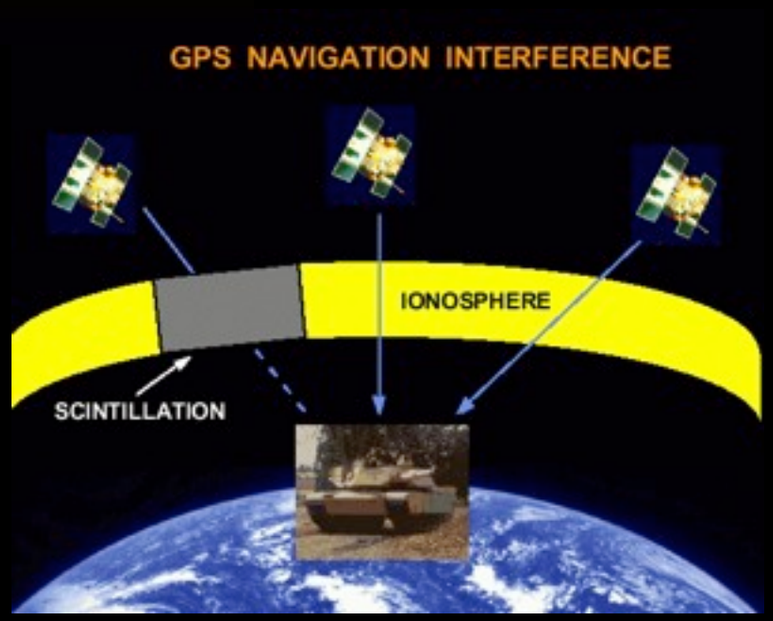
Feil i posisjonering fra 1-12 km

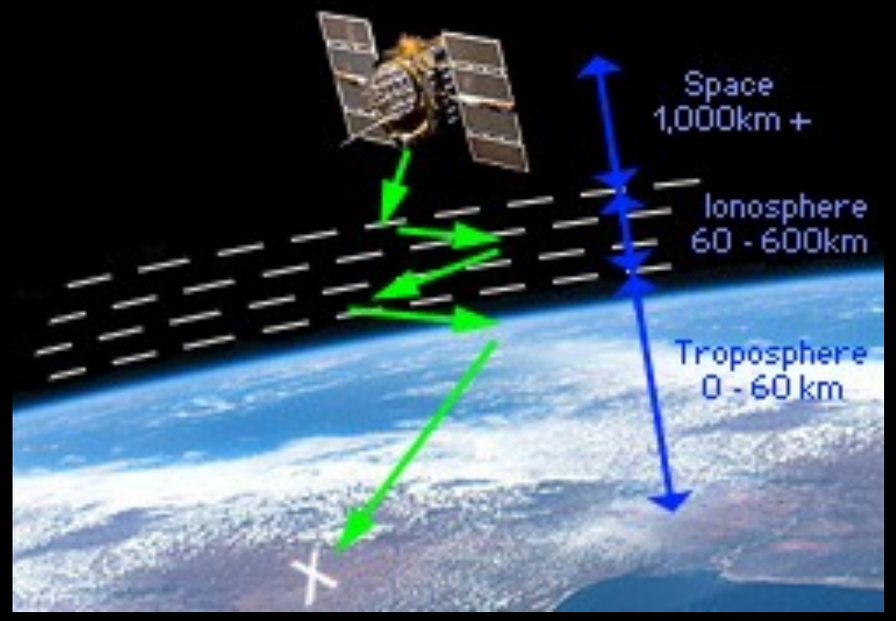
Image Credit: M. A. Shea, Geophysics Directorate, Philips Laboratory

Navigation systems (GPS)



- Når ionosfæren blir turbulent det oppstå scintallasjoner i signalet som dermed kan bli vanskelig å motta.
- Den totale mengen elektroner (TEC) langs signalbanen kan introduserer feil (opp til 100 m)
- Feil i GPS signalet kan bli et stort problem for fremtidige systemer som skal basere seg på GPS.
- Jamming av GPS signalet





Noen bryr seg lite om nøyaktig GPS

For andre er det kritisk.....

- Feil i GPS signalet kan bli et stort problem for fremtidige systemer som skal basere seg på GPS.

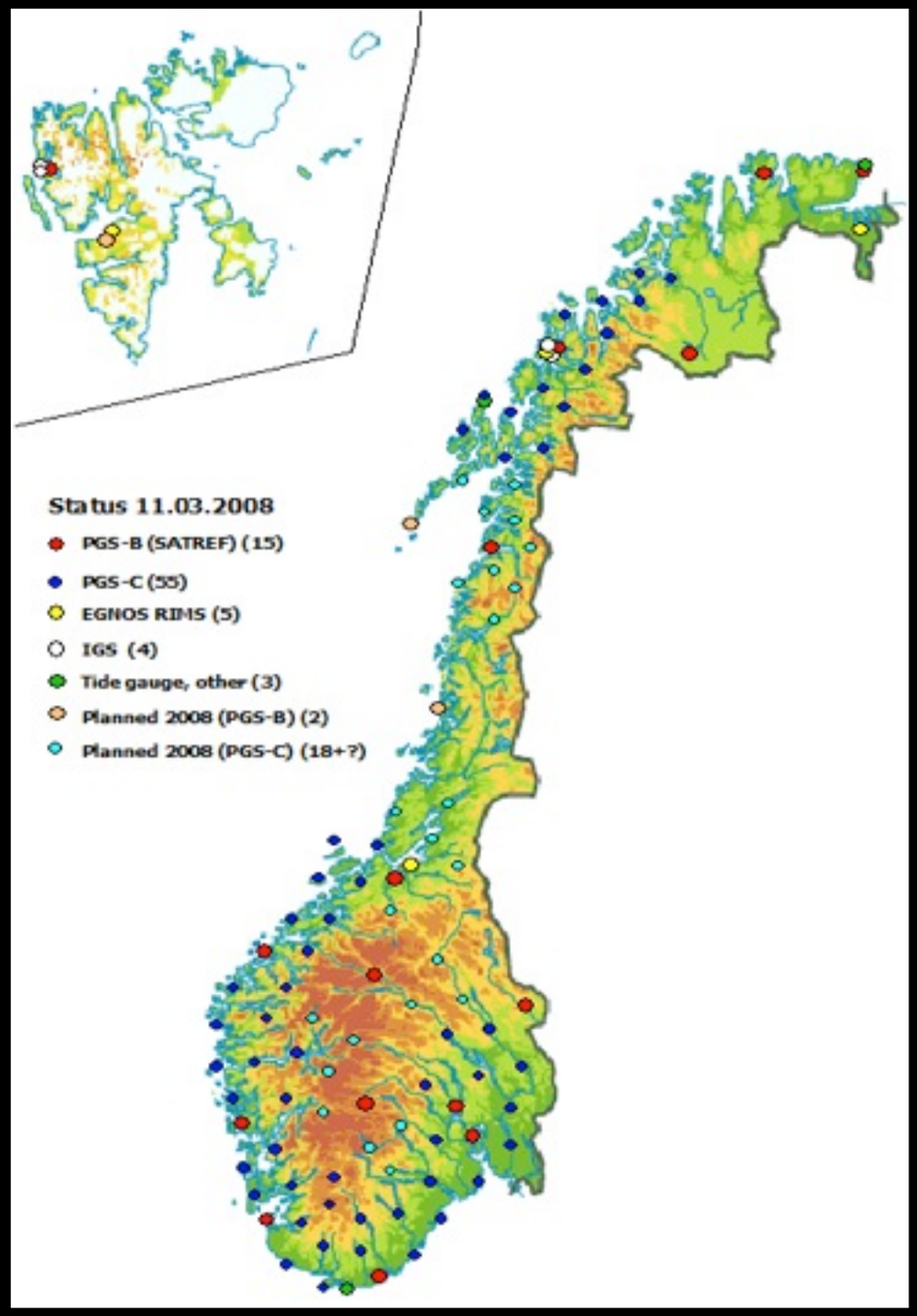
Nøyaktig posisjonering - problematisk

- Kongsberg Seatex - markedsledende innen dynamisk posisjonering. Opplever GSP signalbrudd utenfor Brasil som fører til stans i operasjonen.

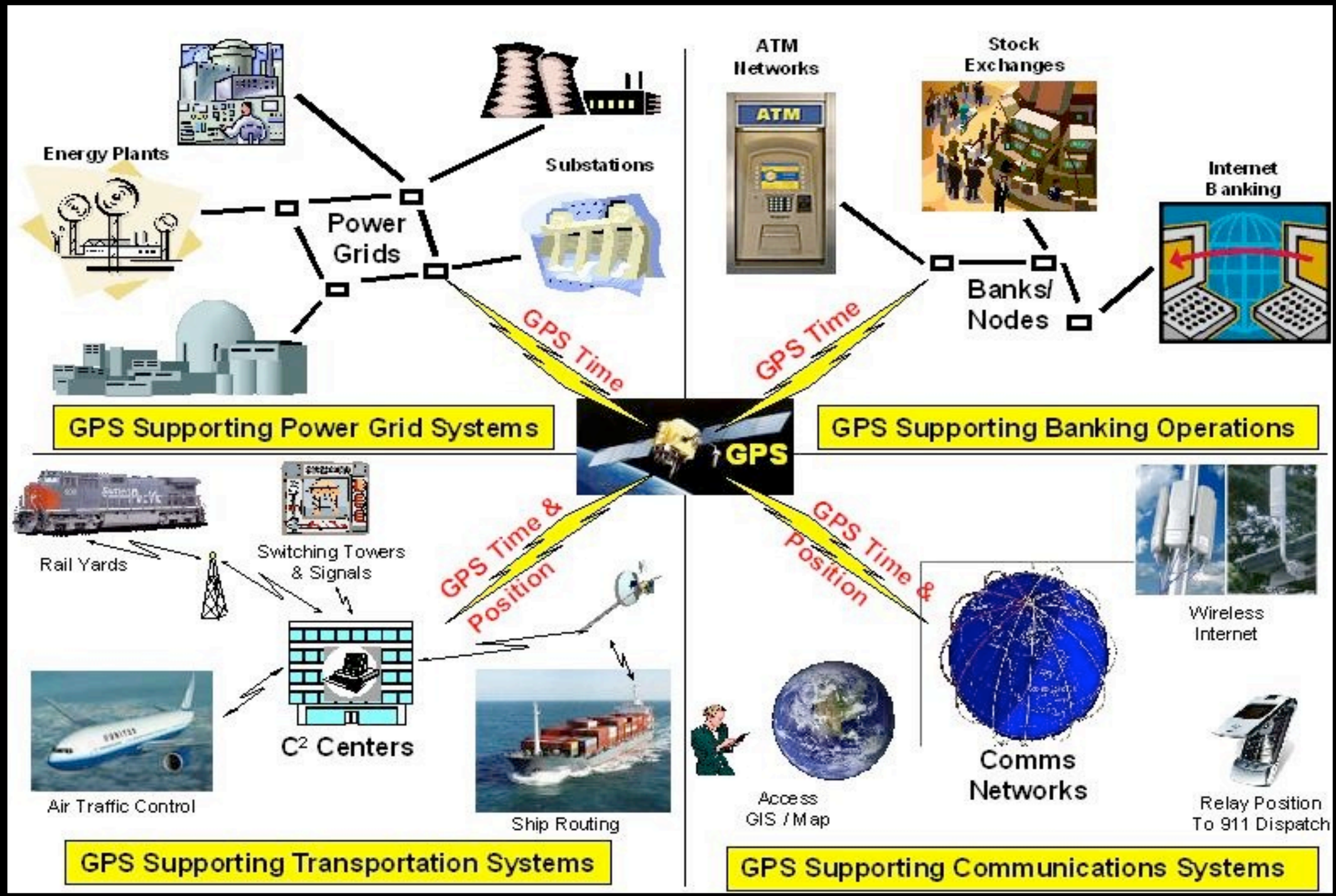
Corrections of GPS positions

- 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



Extent of GPS Dependencies

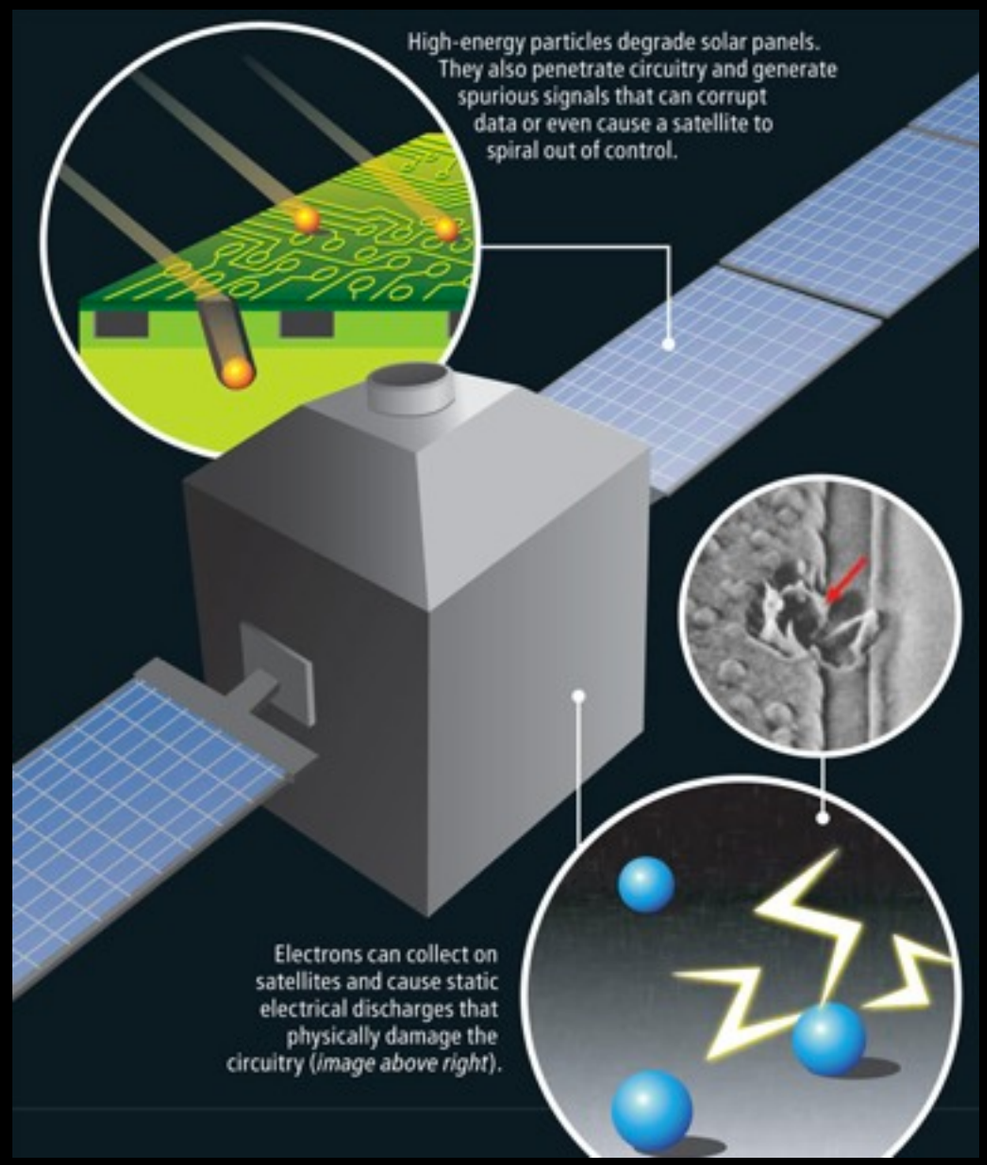


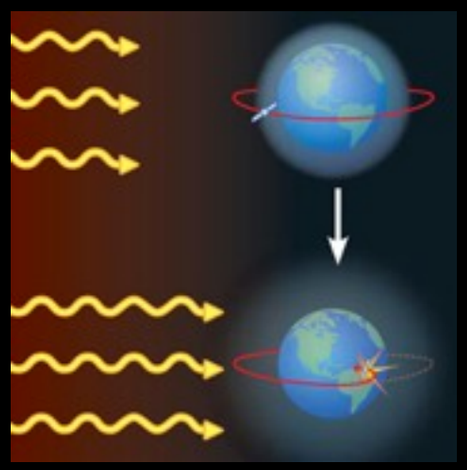
K. VanDyke, DOT

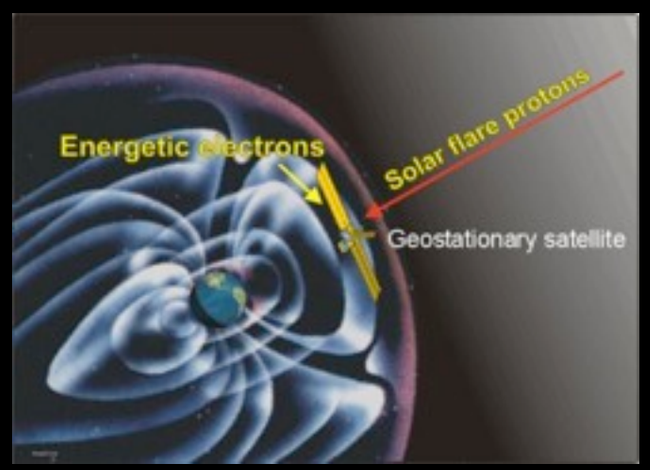
Effekter på satellitter

Eksempler på effekter:

- Overflateladning
- Single Evente Upset (fra høyenergetiske partikler
- Økt friskjon (Drag)
- Interferens og scintillasjon av signalet
- Romsøppel
- Orienteringsproblemer
- Støy på stjernetrackere/navigasjonssystemer
- Degradring av materialer/solpaneler
- Treff fra mikrometeoritter



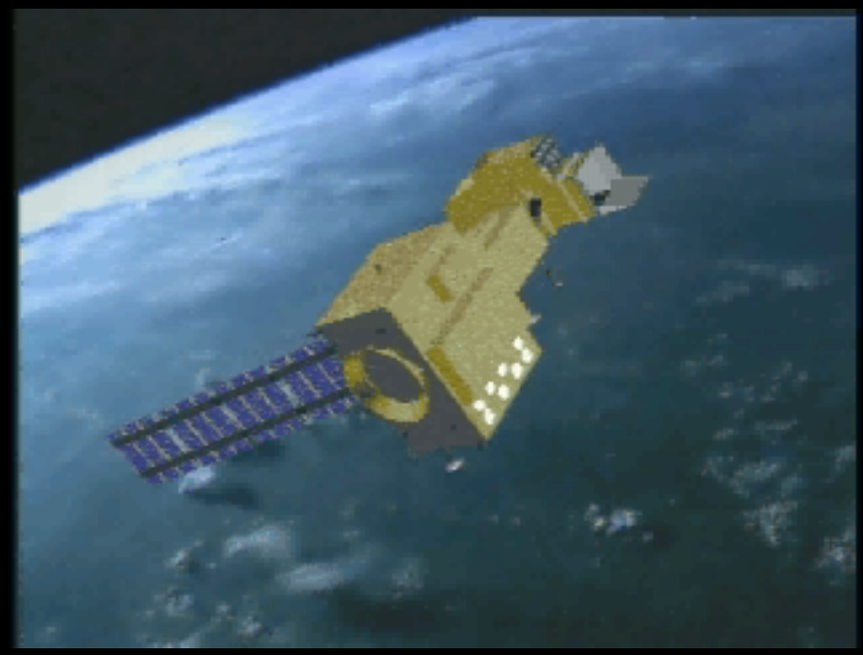


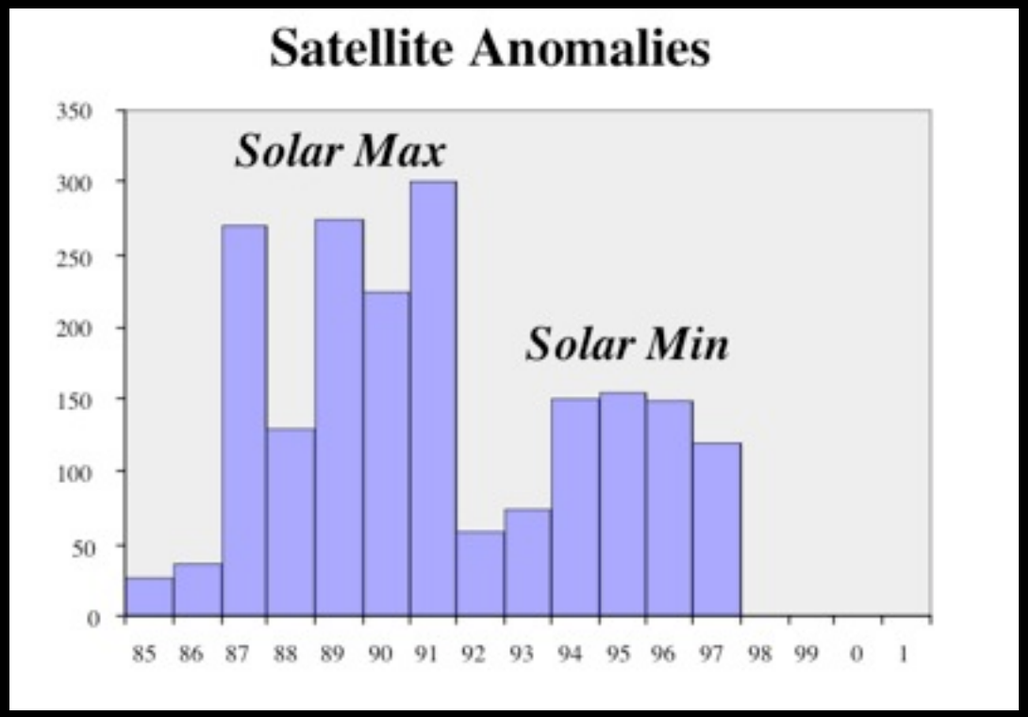


Skader på satellitter

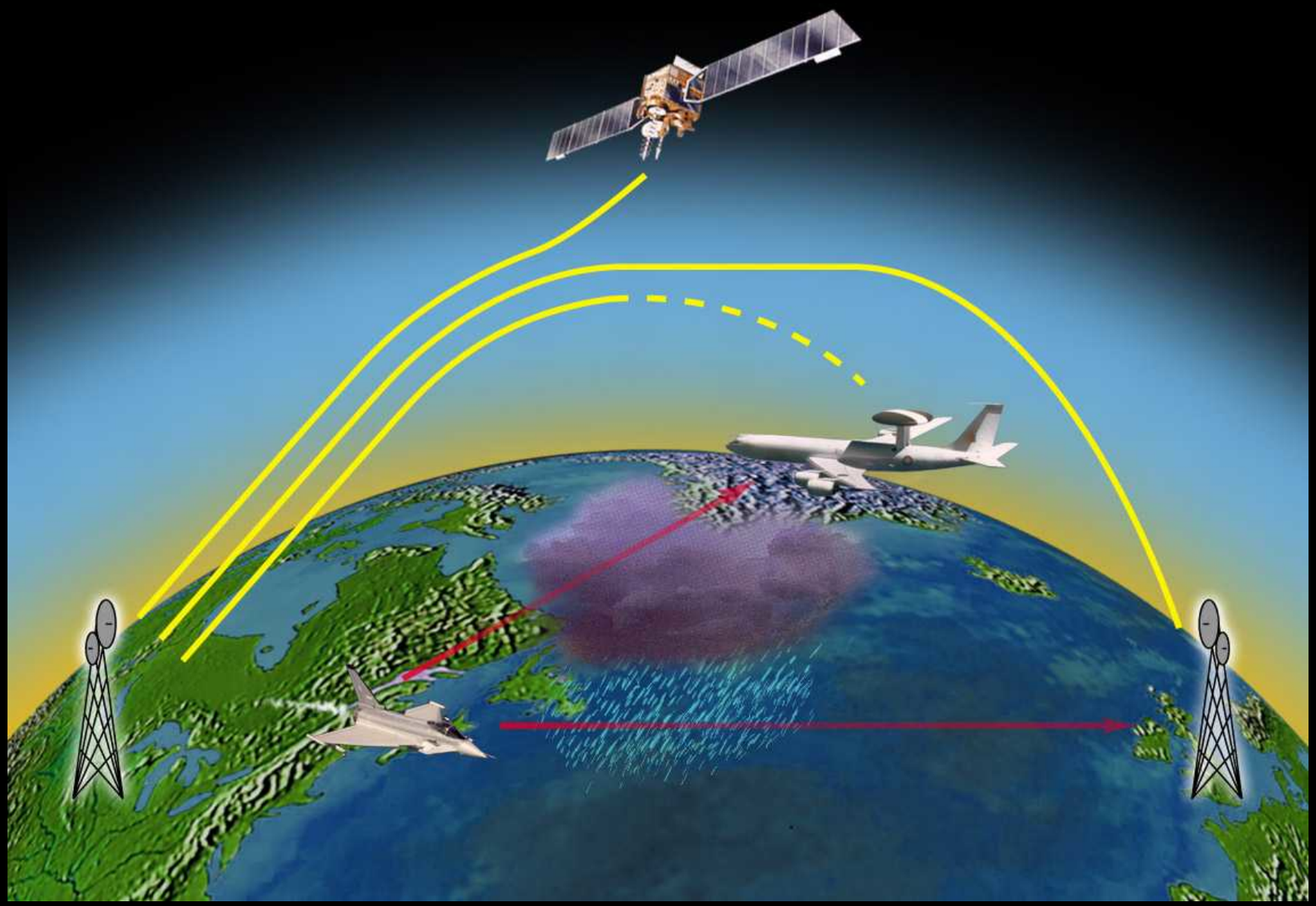
Eksempler på skader:

- Telestar 401 (Jan 11 1997)
- Galaxy IV (1998) – kostet 250 millioner USD
  - 80% av alle personsøkere i USA falt ut
  - PC-Direct (internet)
  - CBS's radio and TV feeds
  - CNN's Airport Network
- En rekke satellitter tapt p.g.a. romvær
- Årlige tap kan overskride $500 millioner.

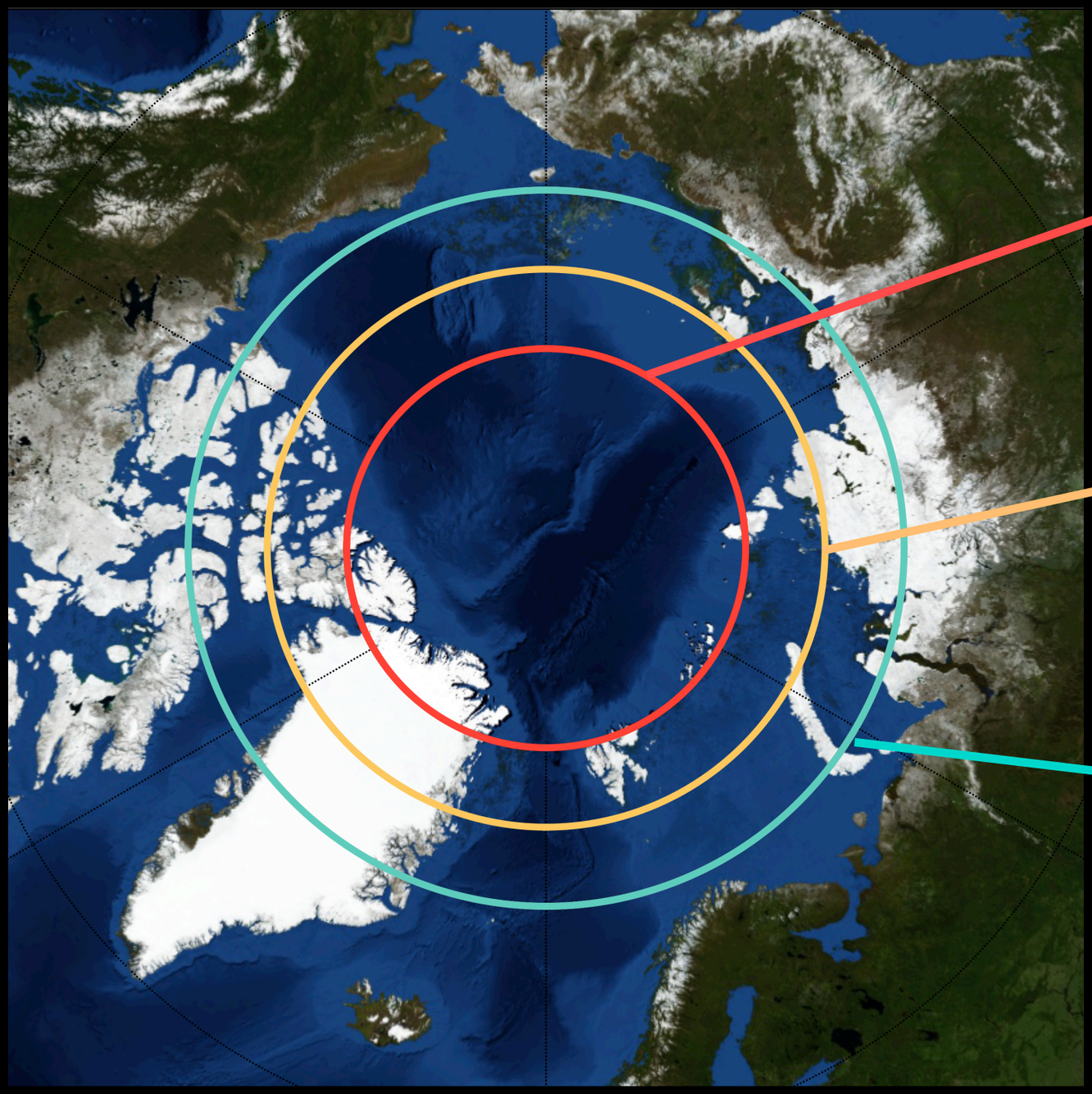




Radiokommunikasjon - problematisk i nordområdene



Limited Broadband in the North



Theoretical (80º)

Practical (80º)

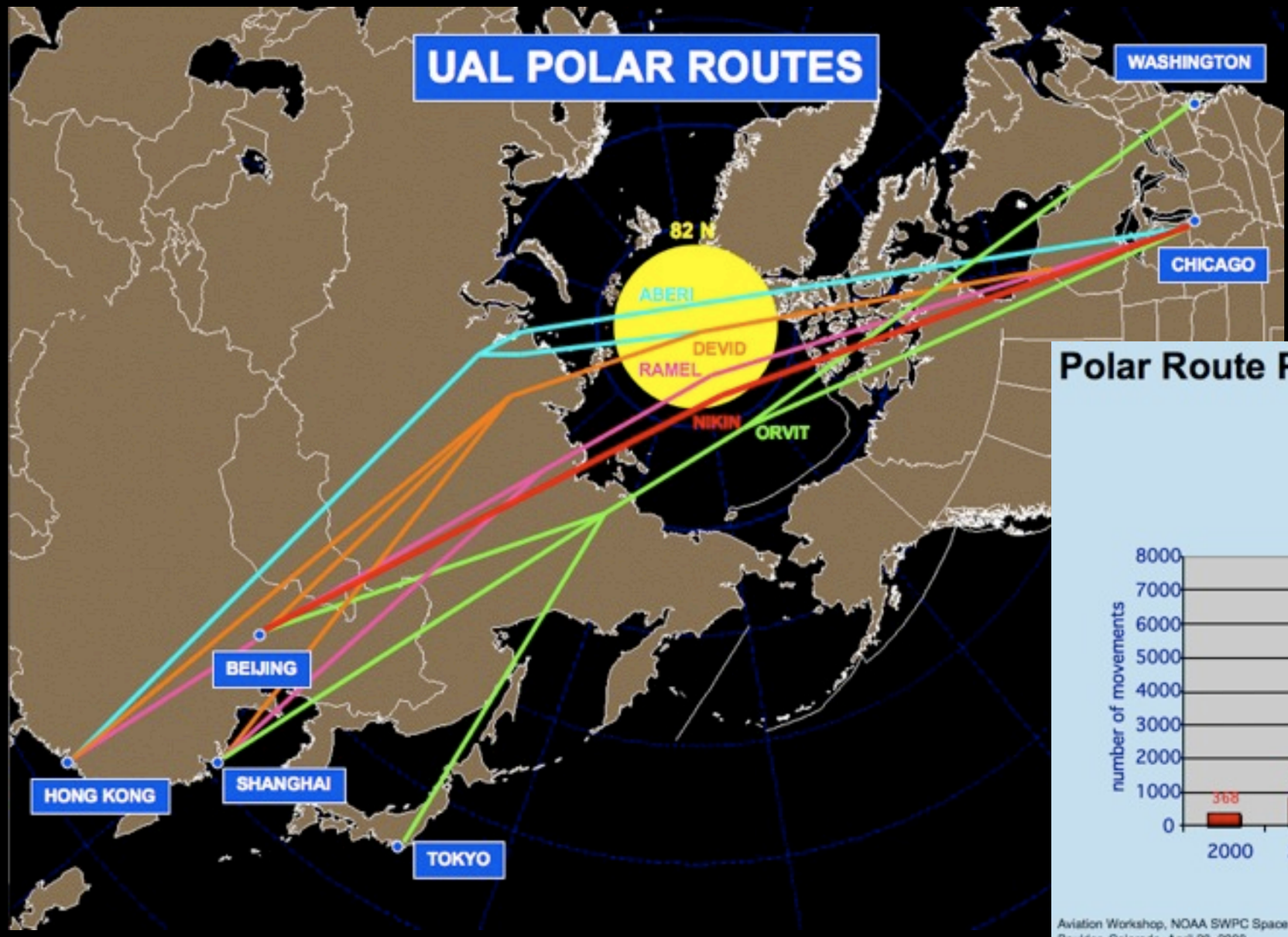
Problems Occur (80º)

Effekter på flytrafikk

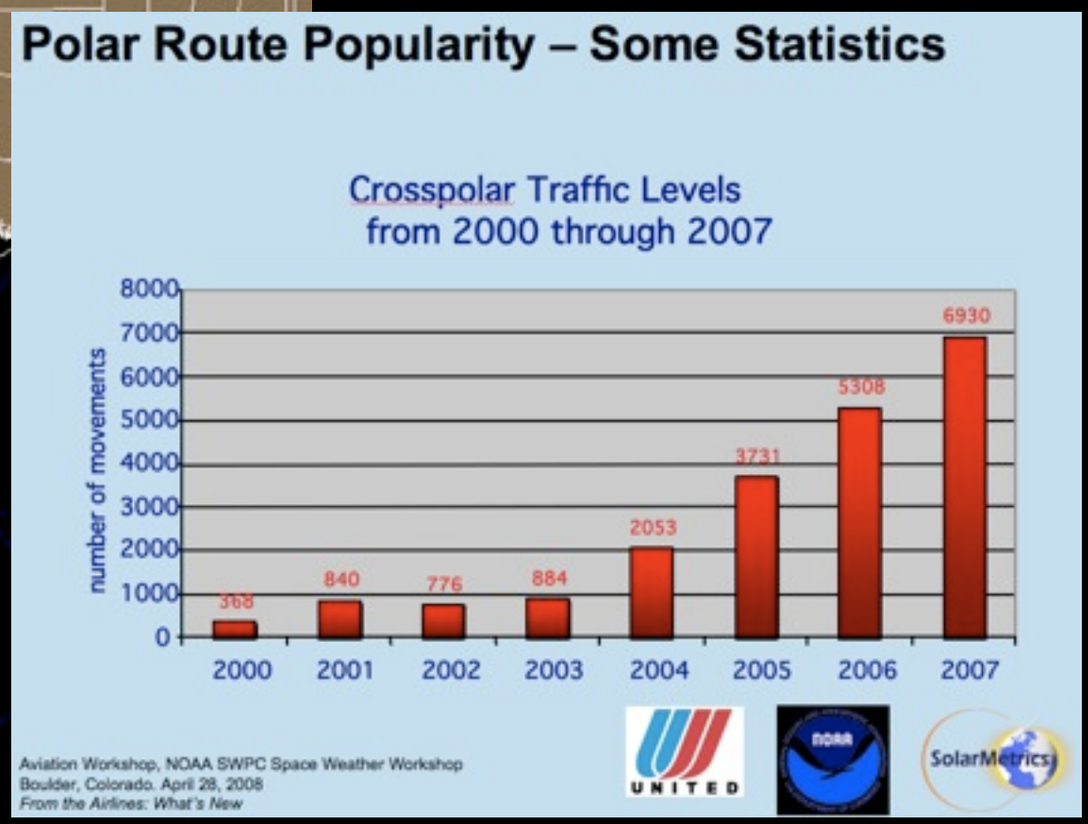
- HF kommunikasjon
- Høyenergetisk stråling (effekter på elektronikk og mennesker)
- GPS/navigasjon

Effekter på flytrafikk

- Polare ruter: ca 8000 flyvninger per år i 2008 - meget trangt
- Satellittkommunikasjon virker ikke nord for 82 N. GPS kan osgå bli ustabil.

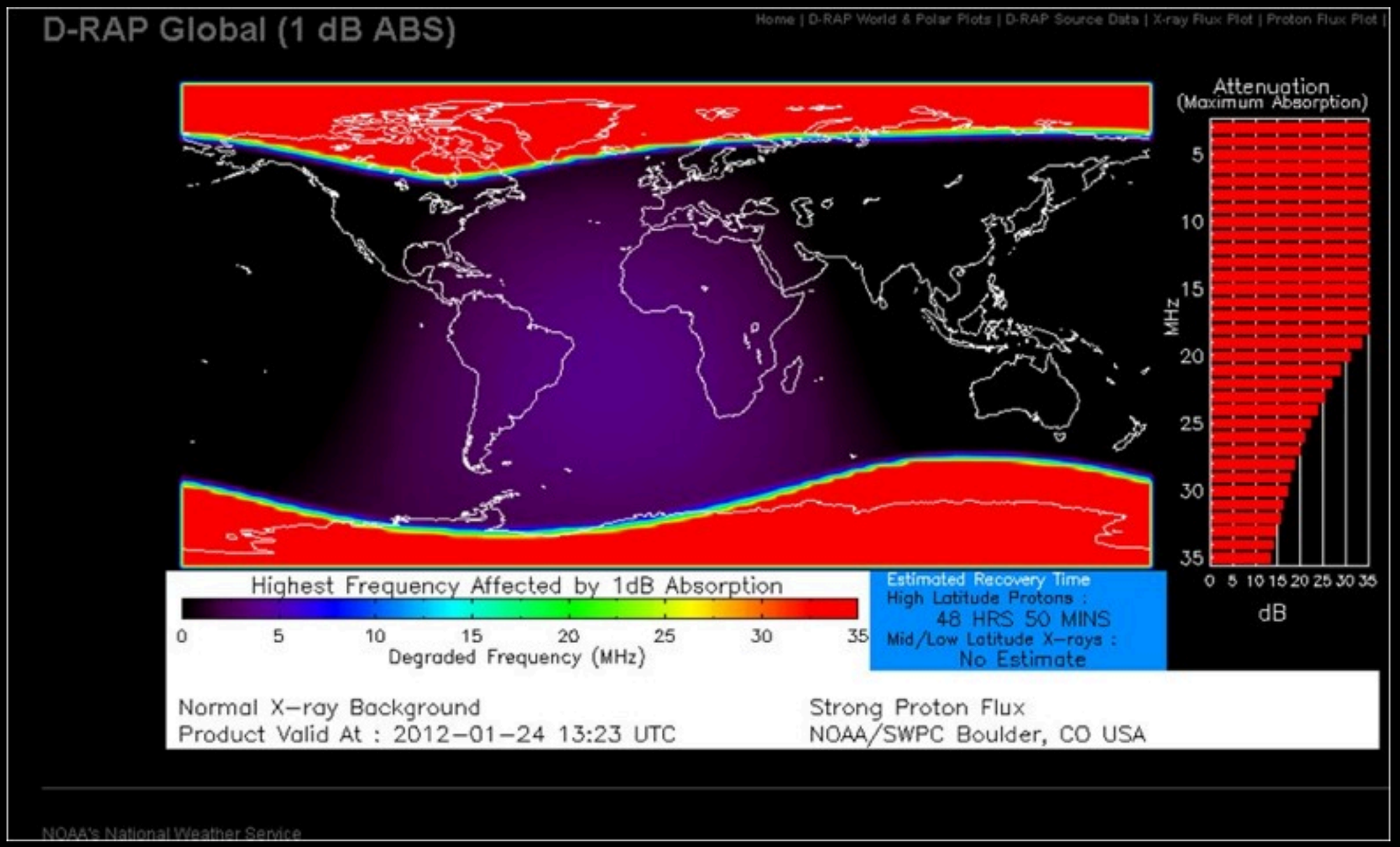


M.Stills, United Airlines



Flights were diverted

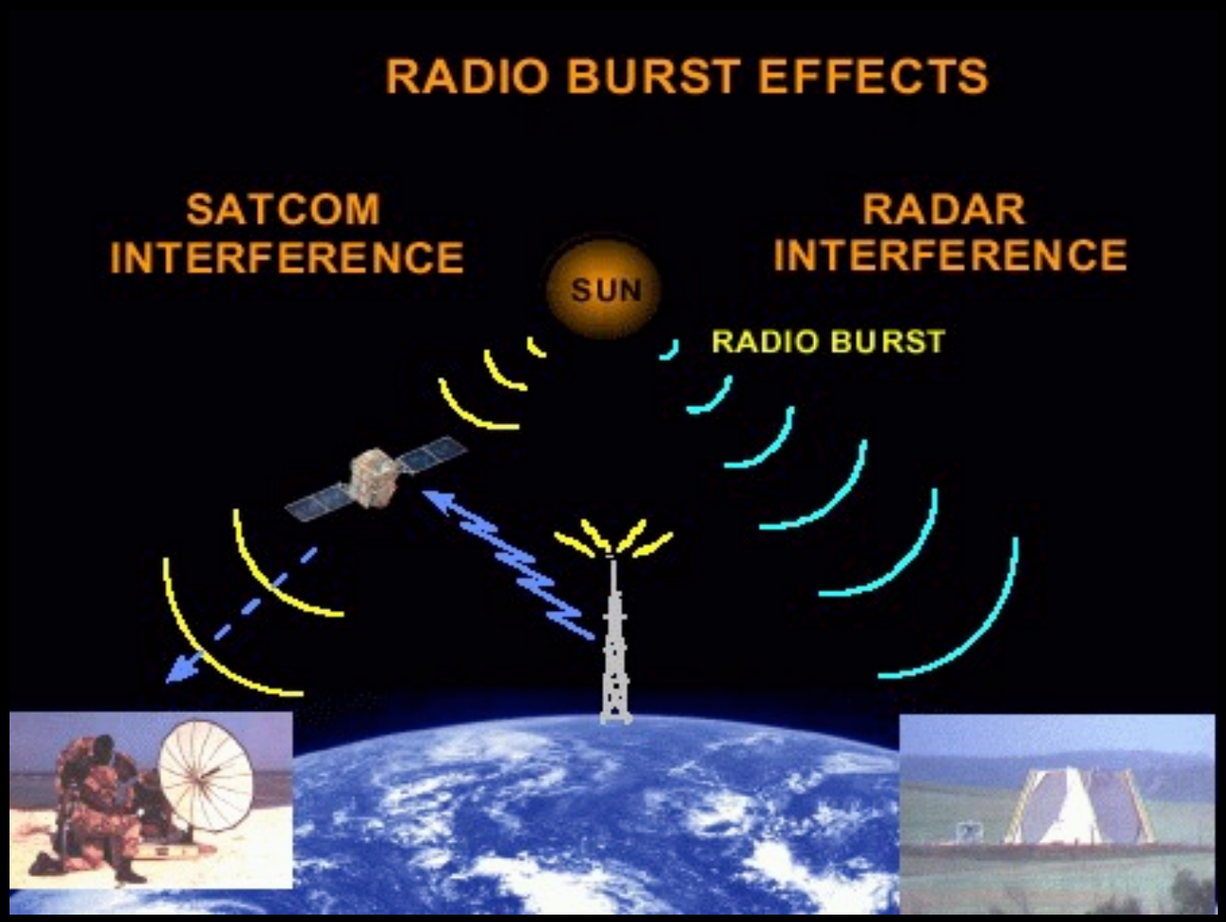
- Delte Airlines and United diverted some of their polar flights to avoid radio communication problems and increased radiation doses for the crew.
- The South pole was without radiocommunication for two days (where satellite communication is unavailable).



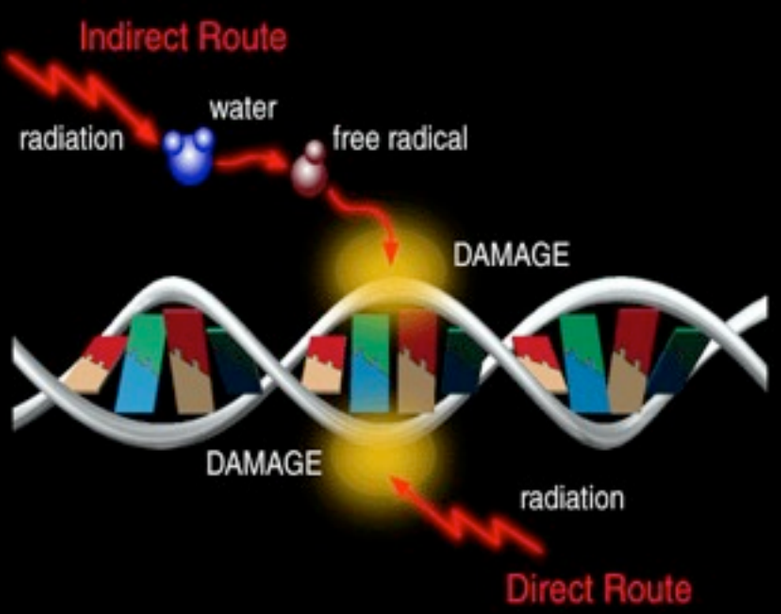
This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles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

Effekter på militære systemer

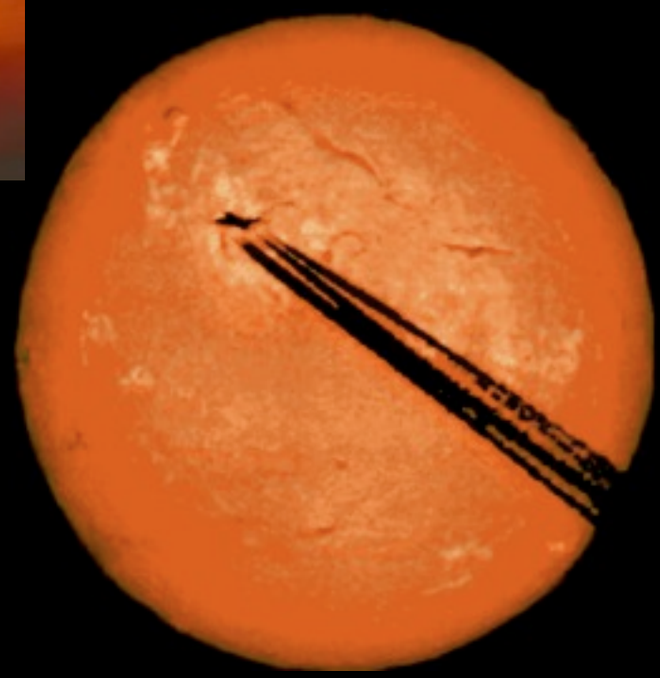
- HF satellittkommunikasjon slås ut i flere timer etter kraftige flares og protonskurer.
- Kan påvirke styringssystemer på missiler (bruker GPS).
- Påvirker moderne kommunikasjon, navigasjon og overvåkningssystemer
- Skade militære rombaserte systemer/satellitter
- Search en rescue
- Early Warning systems



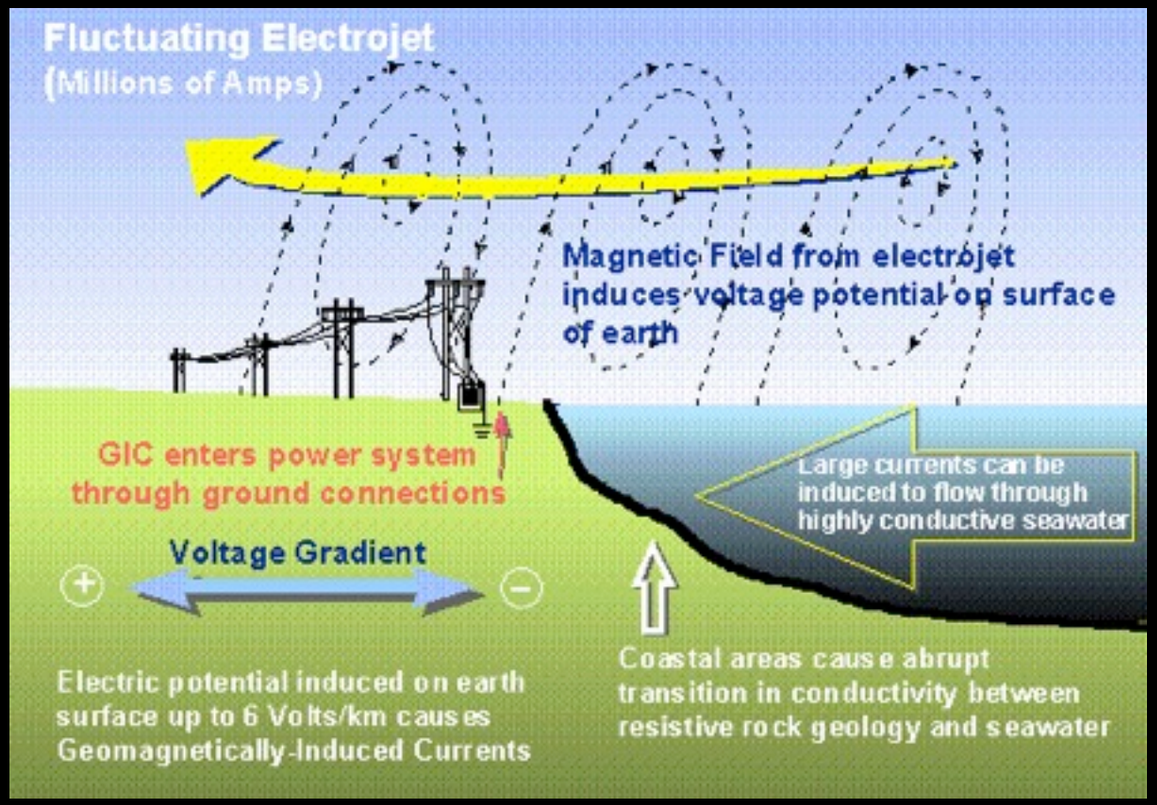
Høyenergetiske partikler - fare for mennesker



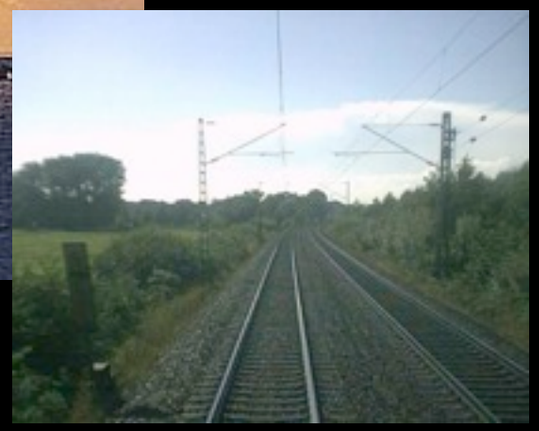
- Mennesker i rommet
  - Space Shuttle, International Space Station, ferder til Mars
- Crew/Passasjerer på polare ruter
  - Passasjerer kan motta stråling tilsvarende et røntgenbilde av kroppen.
  - EU direktiv (EURATOM pålegger alle flyseslkap å informere besetningen om strålefarer og måle dosene de mottar.
    - Årlig dose skal ikke overskride 6 mSv, for gravide besetningsmedlemmer er grensen 1 mSv
    - Hong Kong - New York: 0.09 mSv (GCR)
  - Concorde hadde måleutstyr ombord med alarm

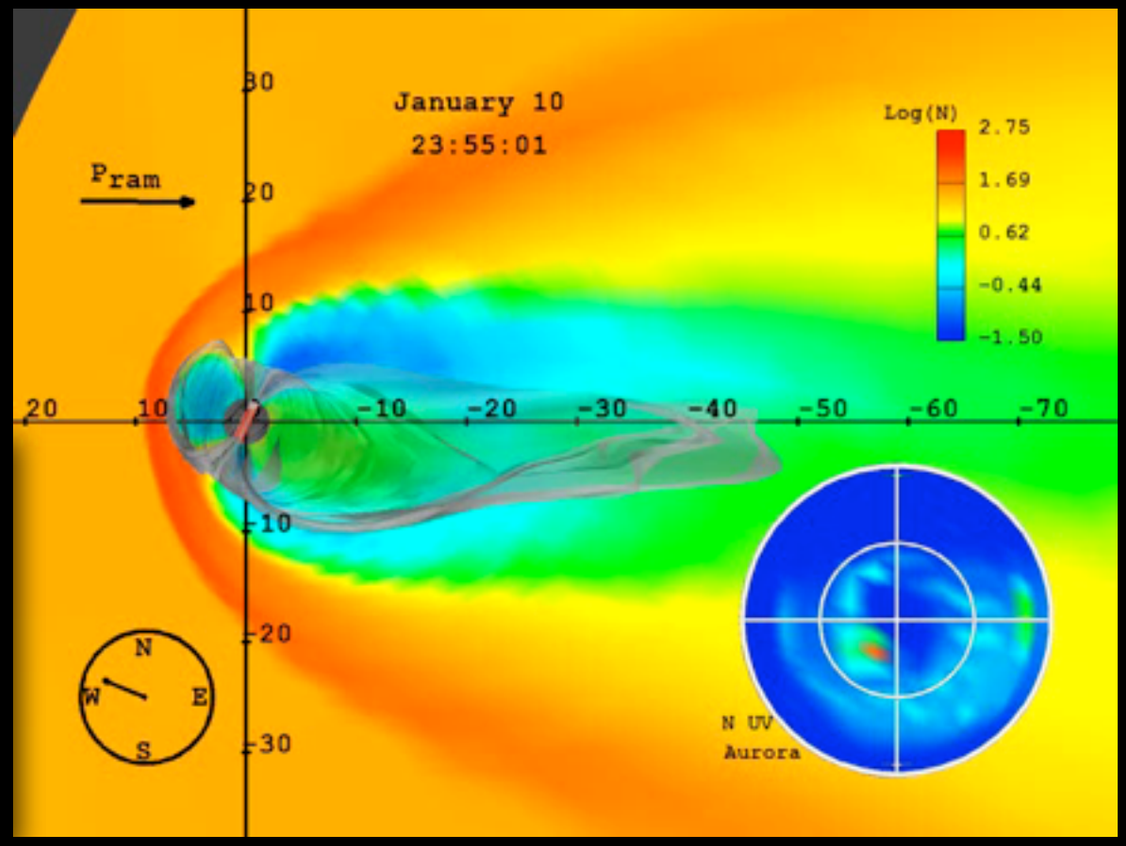


Geomagnetisk industerte strømmer



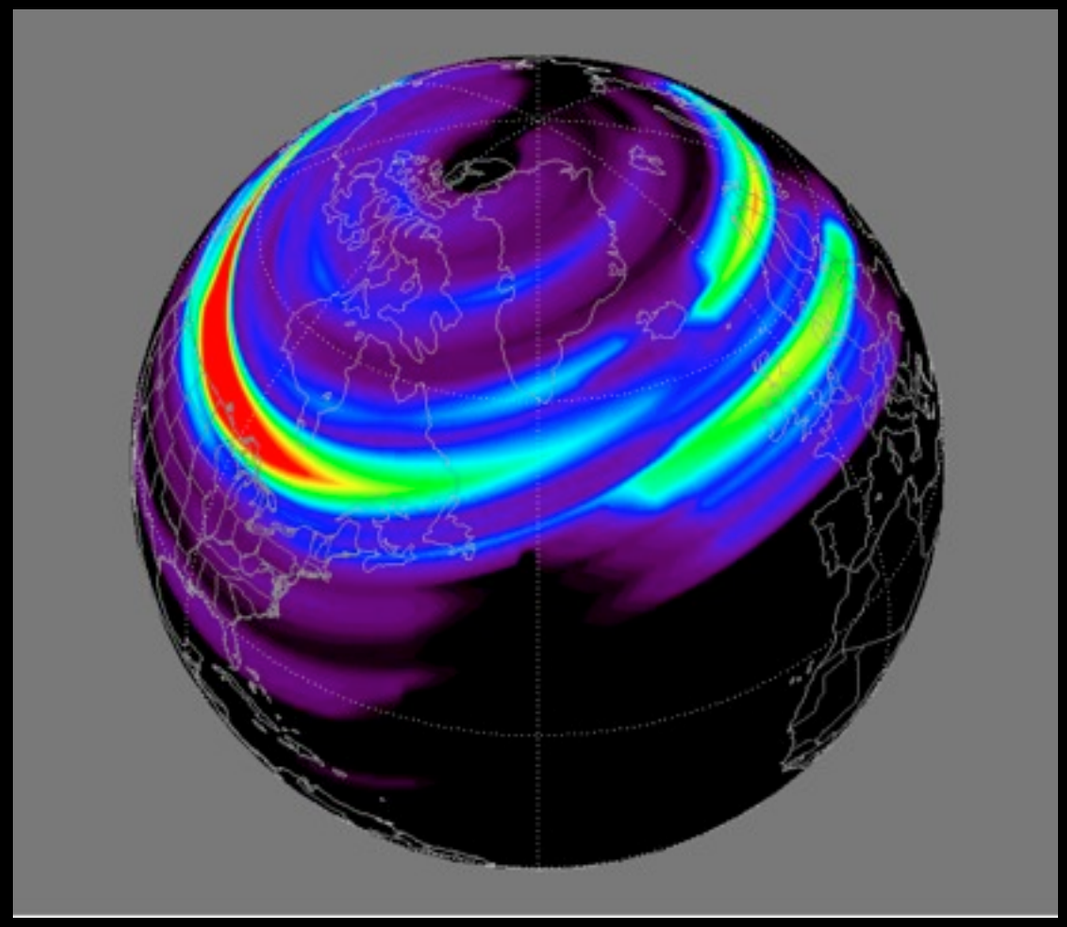
- Slike strømmer vil lekke inn i alle lange ledere:
  - Kraftledninger
  - Olje og gassrørledninger (økt korrosjon)
- Signalsystem for tog kan også påvirkes (to dokumenterte tilfeller i Sverige)

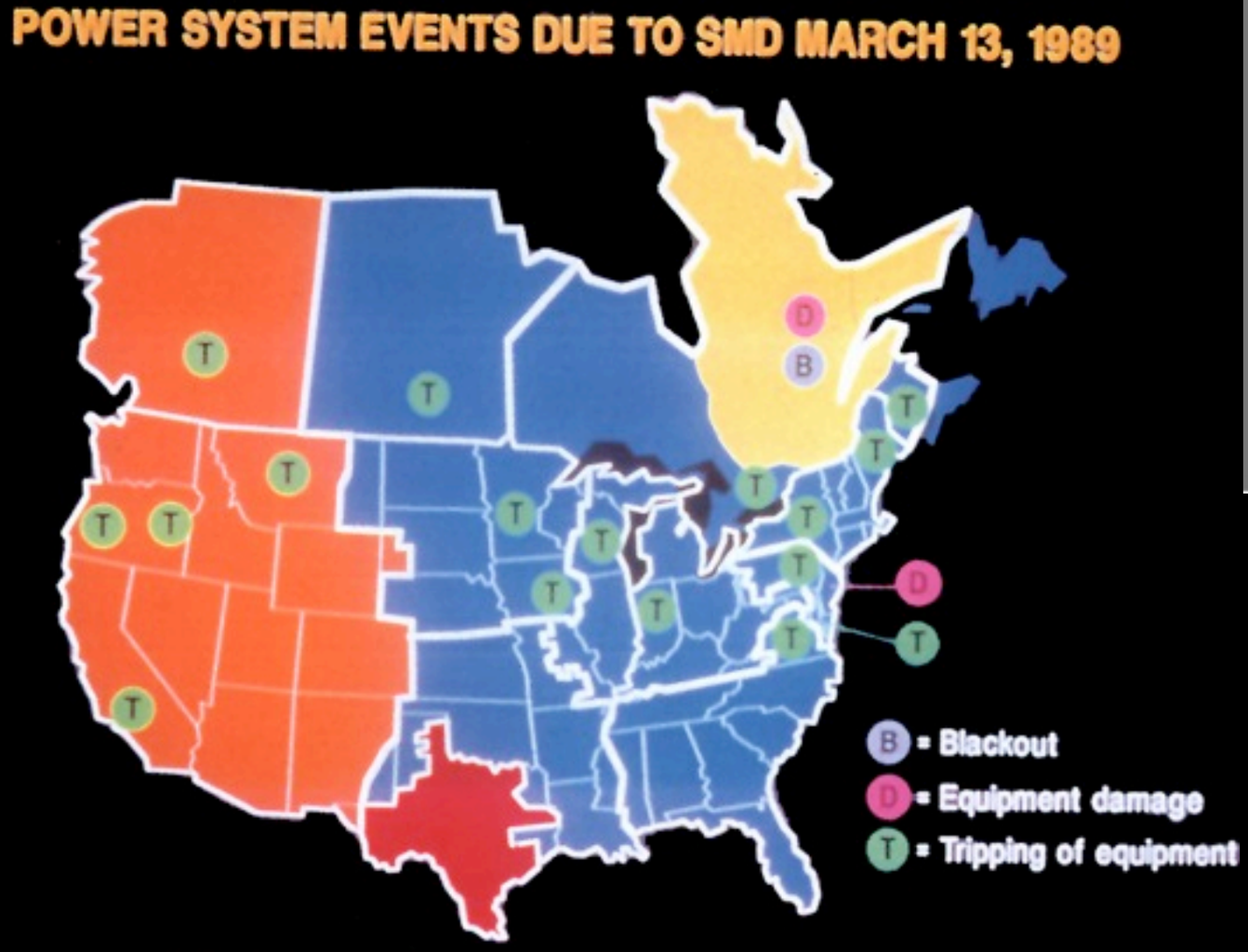




Kraftnett kollapser p.g.a. solstorm

- ElectroJet under stormen i 1989
- Dette er en Hall-effekt strøm som kan øke til over en million ampere.

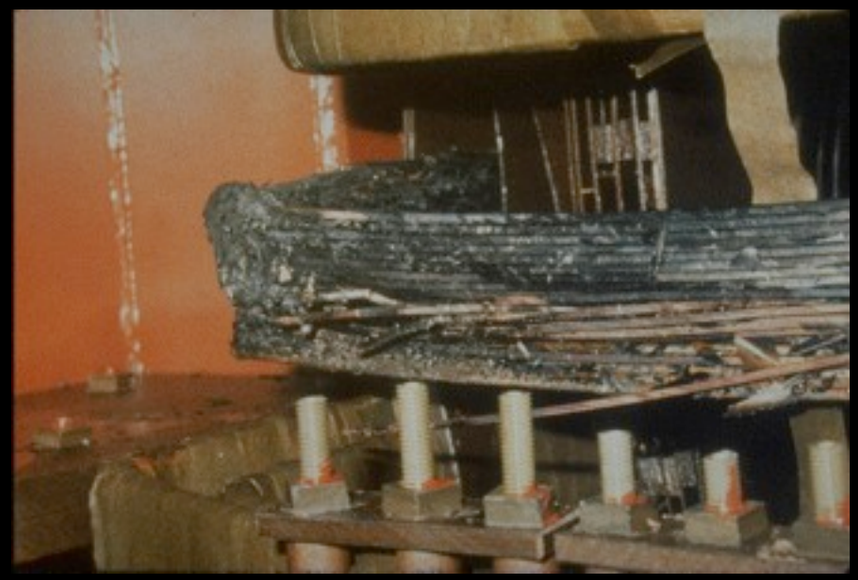




Kollapsen var nær på å spre seg inn i USA

Her ville det ført til et estimert tap på $3-6 milliarder

Skader etter 1989 stormen



Skader på en trafo i Delaware, New Jersey i mars 1989.

Kostnad: 10 millioner USD Reparasjon kan ta et år.

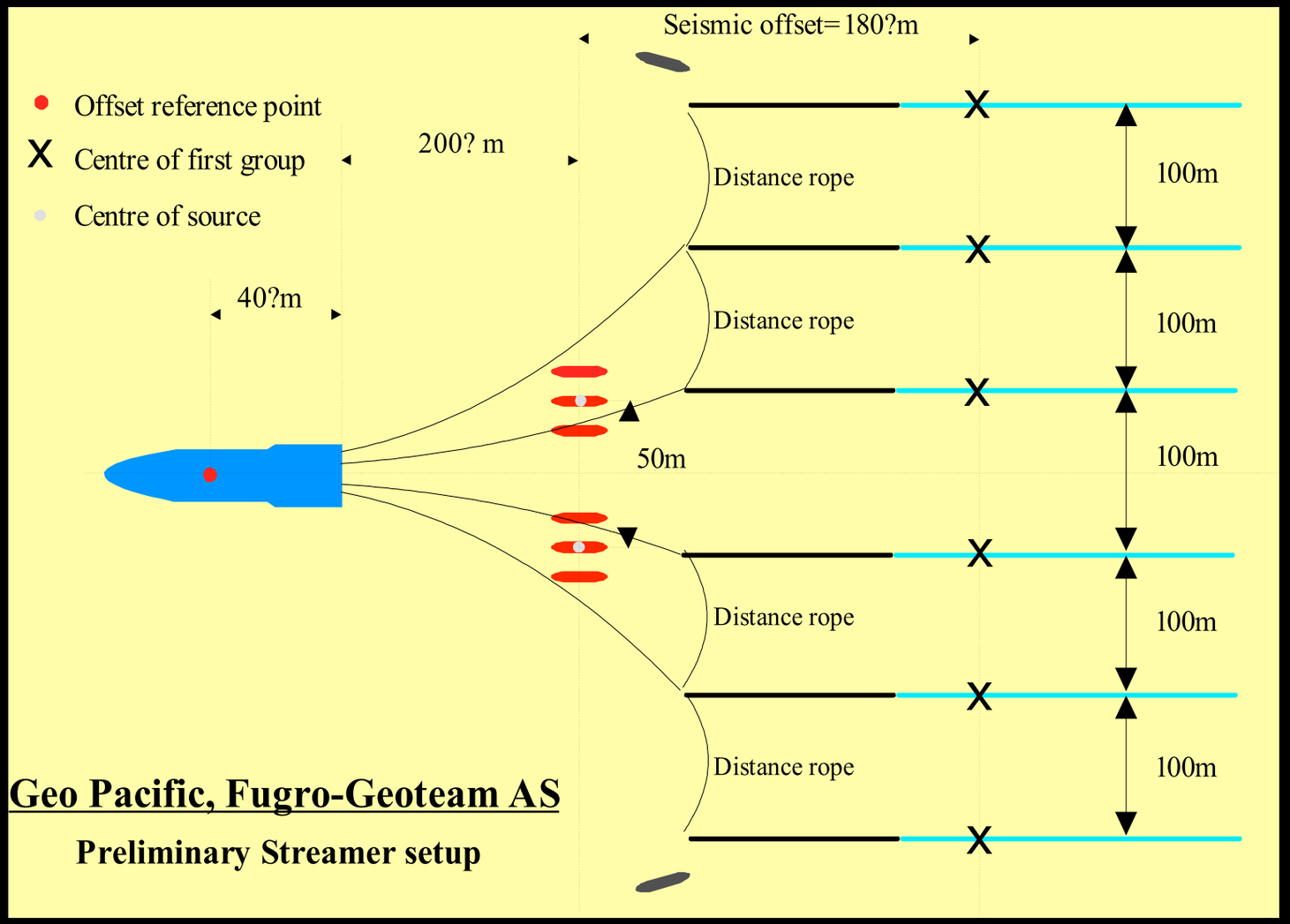
I dette tilfelle var de heldige og fikk tak i en brukt trafo og tok bare 6 uker.

Sverige: mistet kraften i seks 130 kV distribusjonslinjer

Chicago: Fem trafoer i Chicago skadet i april 94 p.g.a. geomagnetisk aktivitet

Statnett - overvåker effekter av romvær

Geomagnetiske undersøkelser - leting etter olje/gass

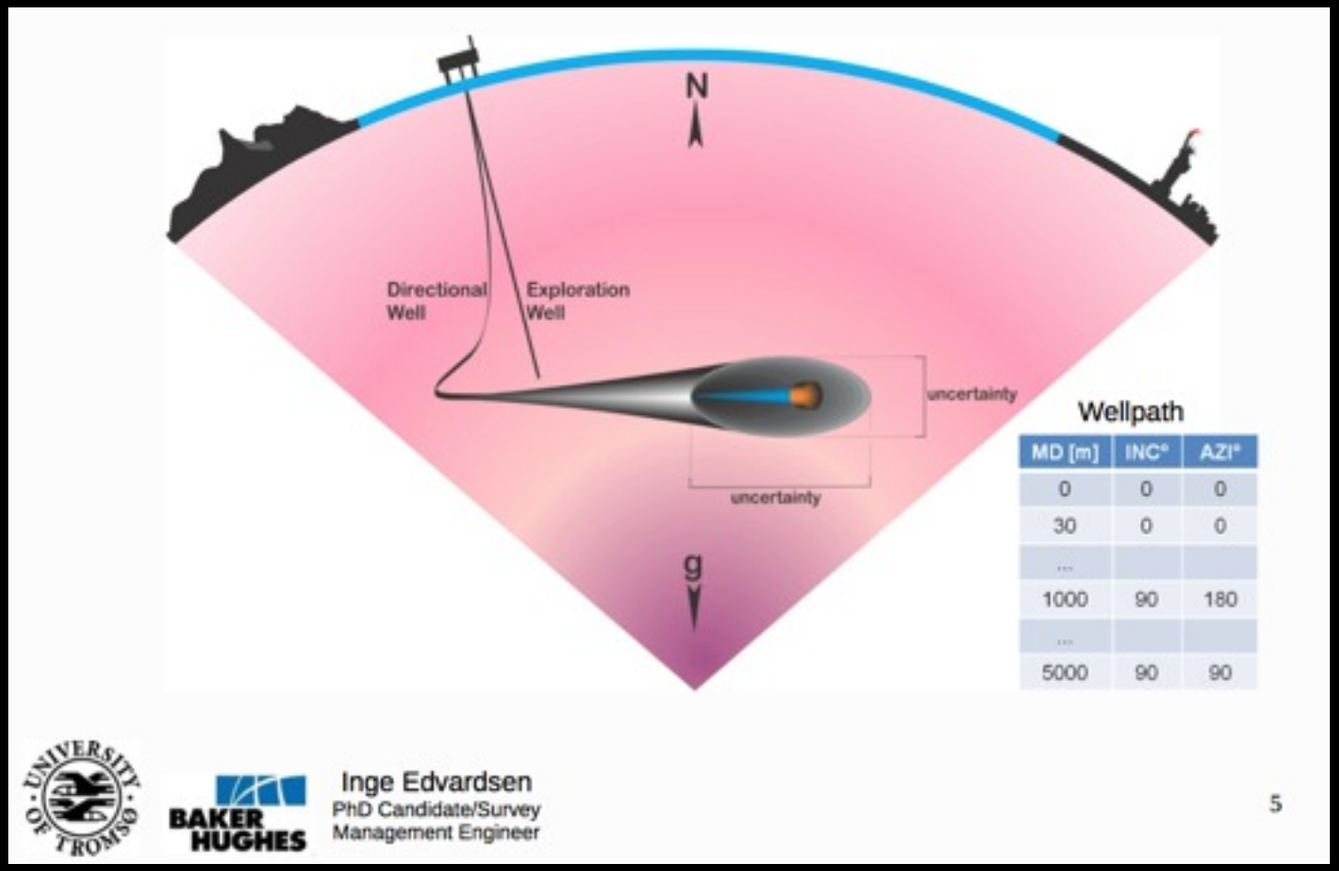


Fugro-Geoteam bruker fartøy med følsomme kompass hengende i lange kabler.

Directional drilling

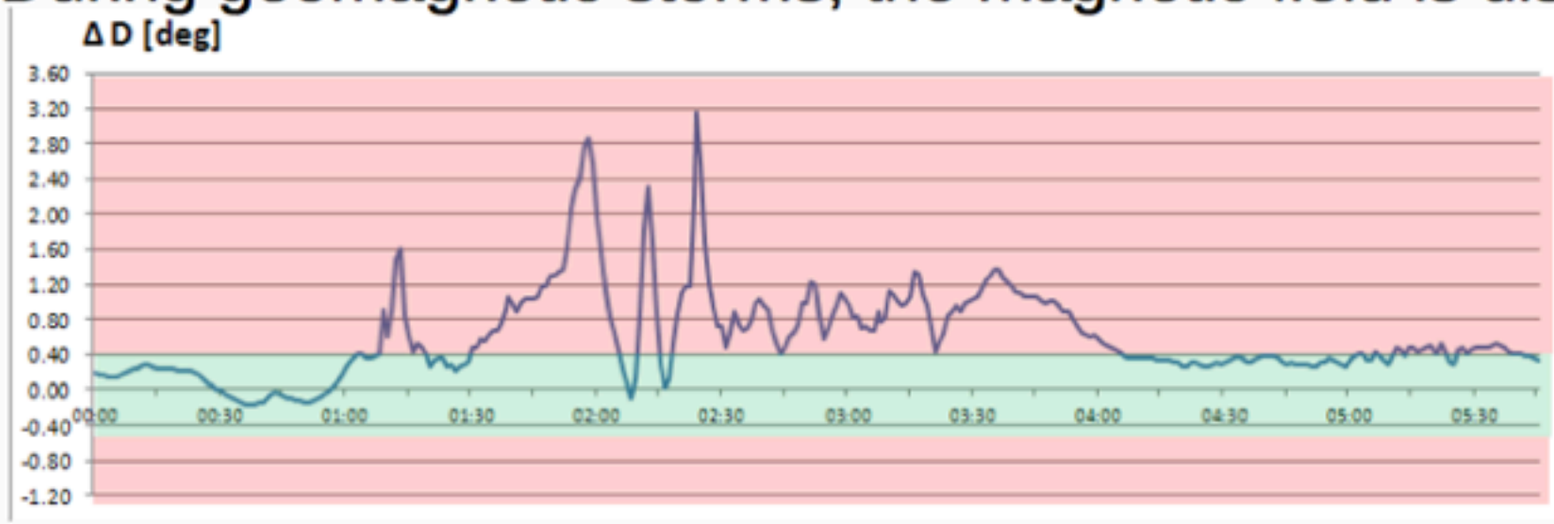
Directional drilling

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



Directional drilling

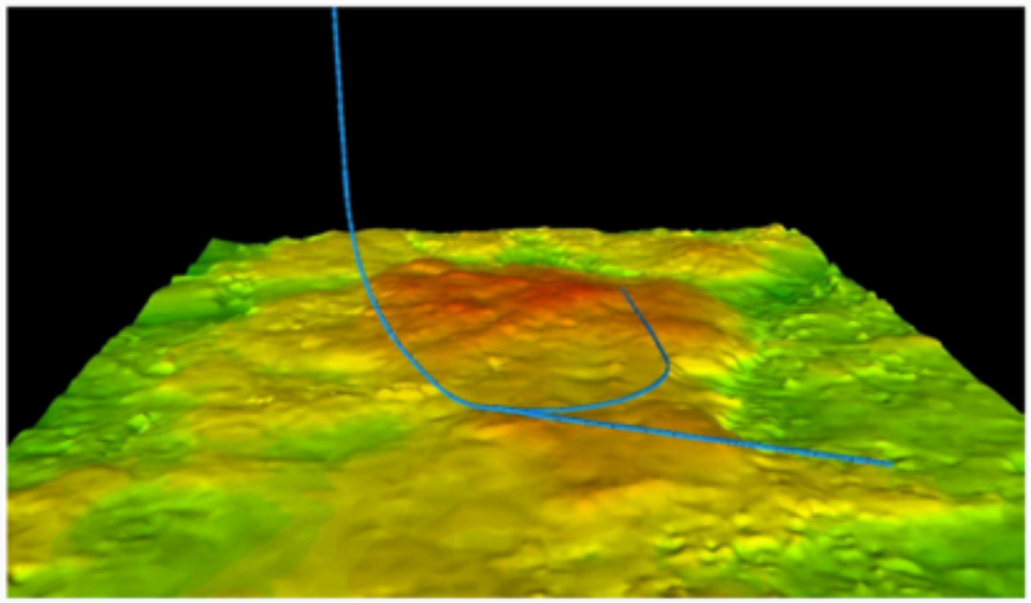
During geomagnetic storms, the magnetic field is disturbed:



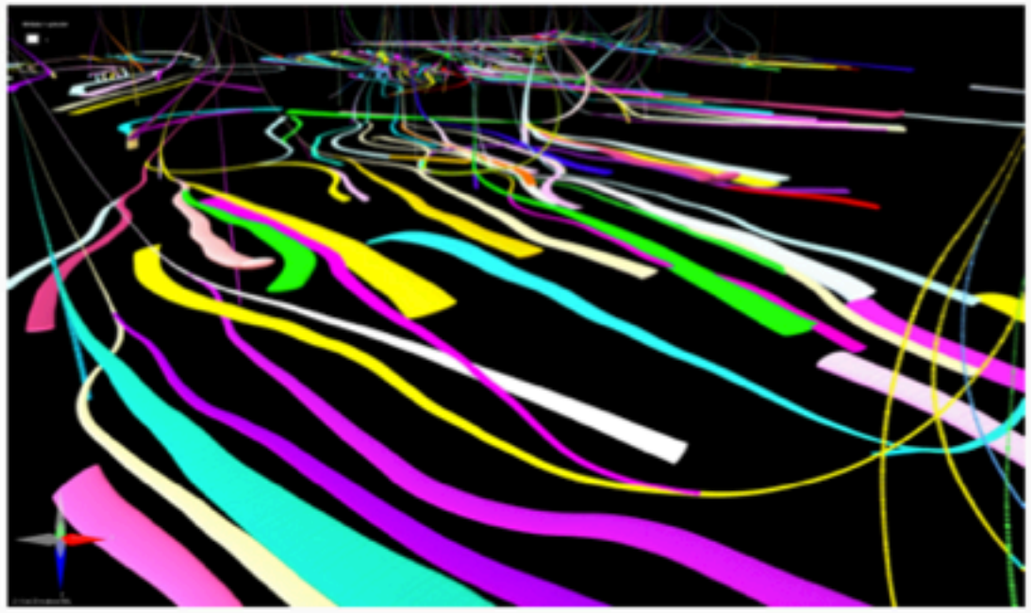
Error in compass needle direction

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

Hit the Geological Target
(& maximize recovery)



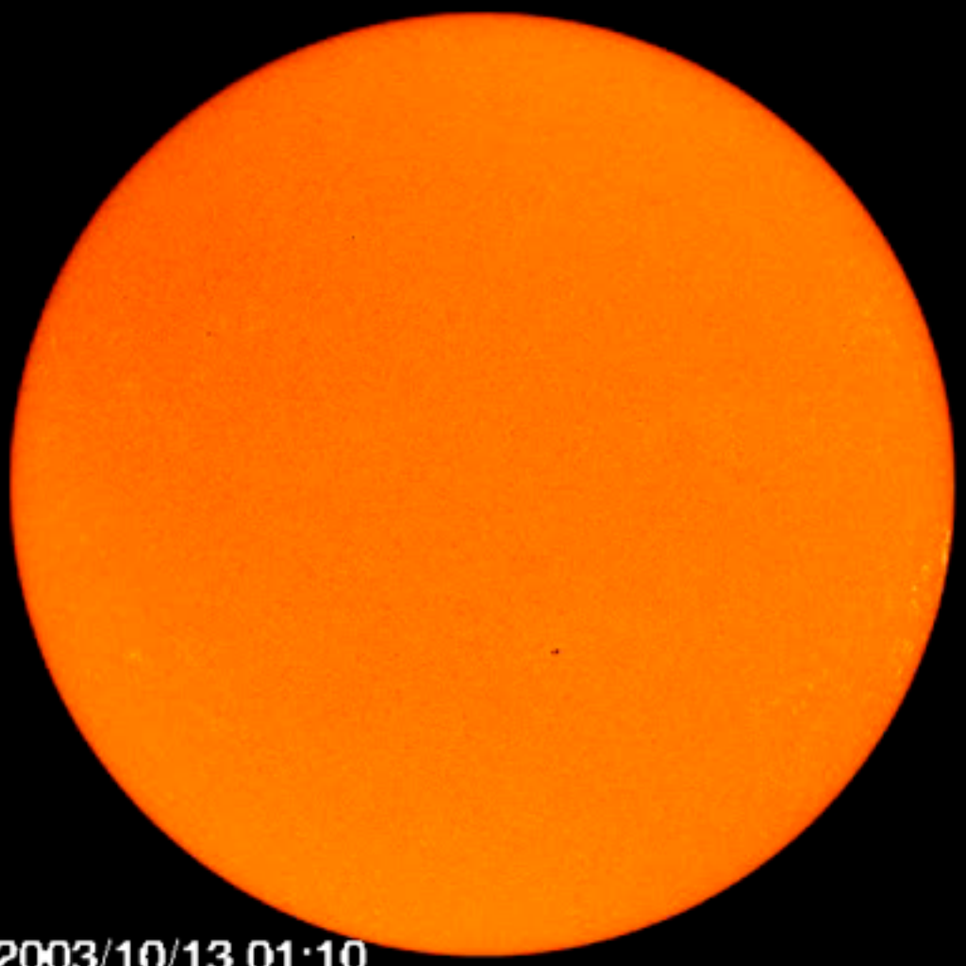
Avoid Other Wells



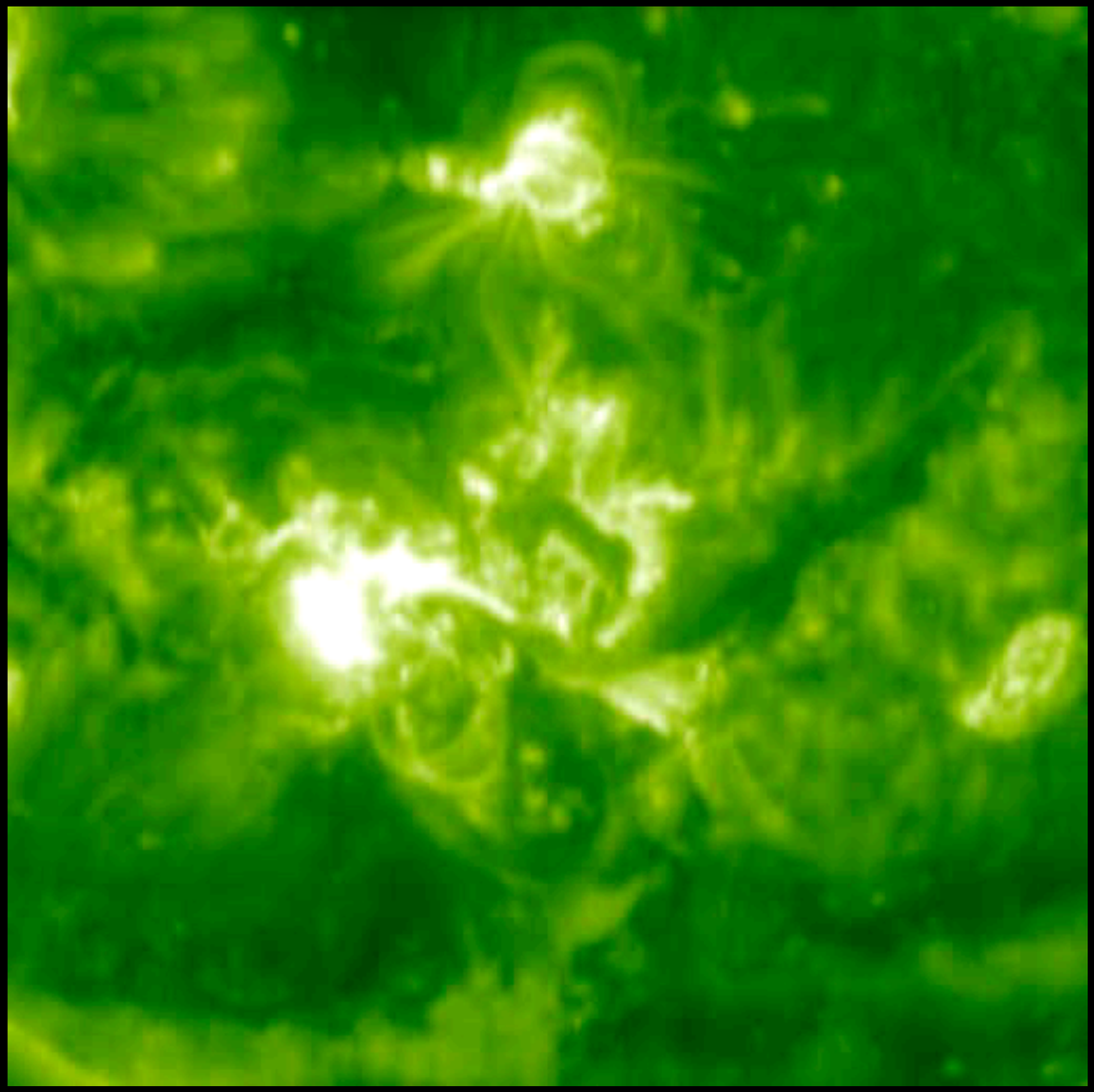
Inge Edvardsen
PhD Candidate/Survey
Management Engineer

The Halloween-storms

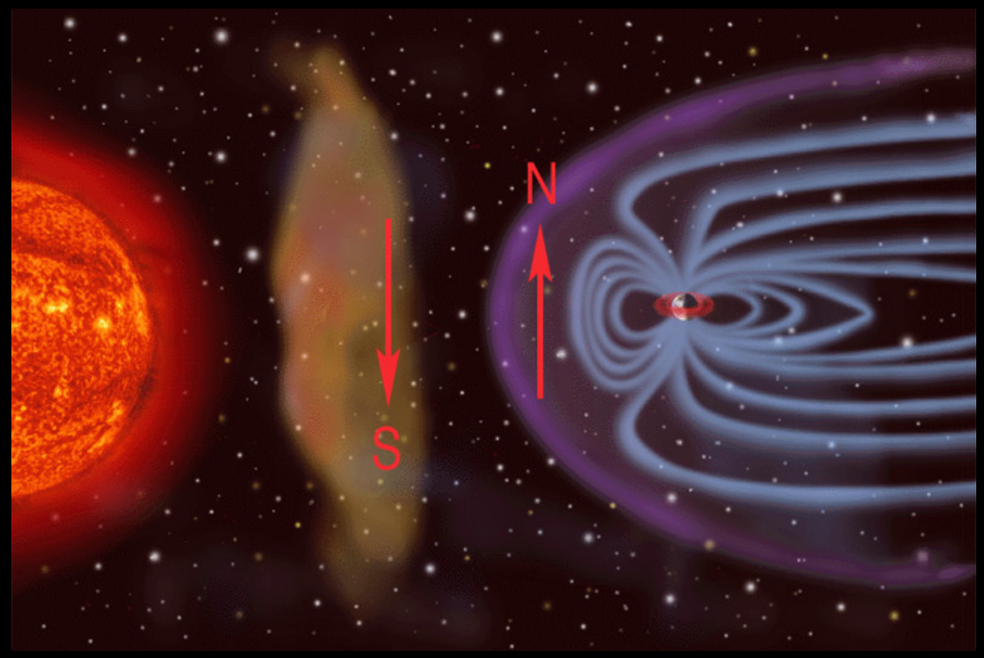
Giant sunspots developed

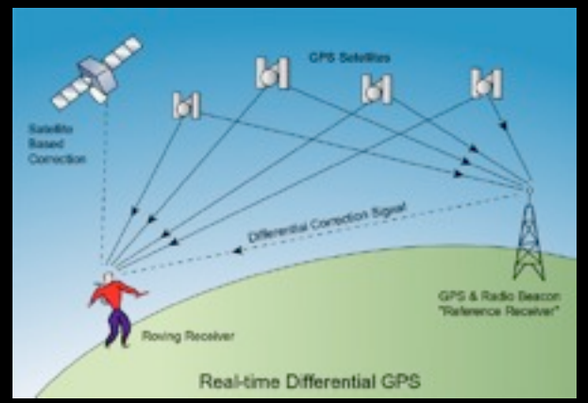


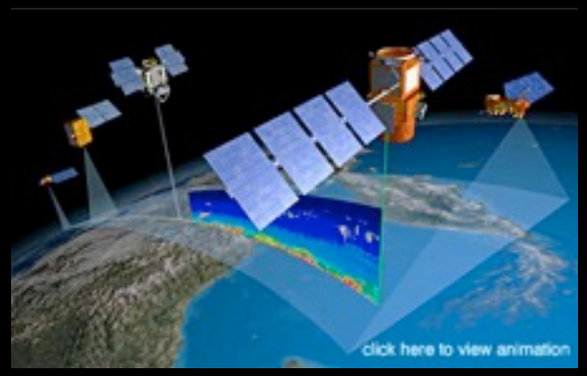
Solar storm 28th October 2003



Effects from the Halloween storms







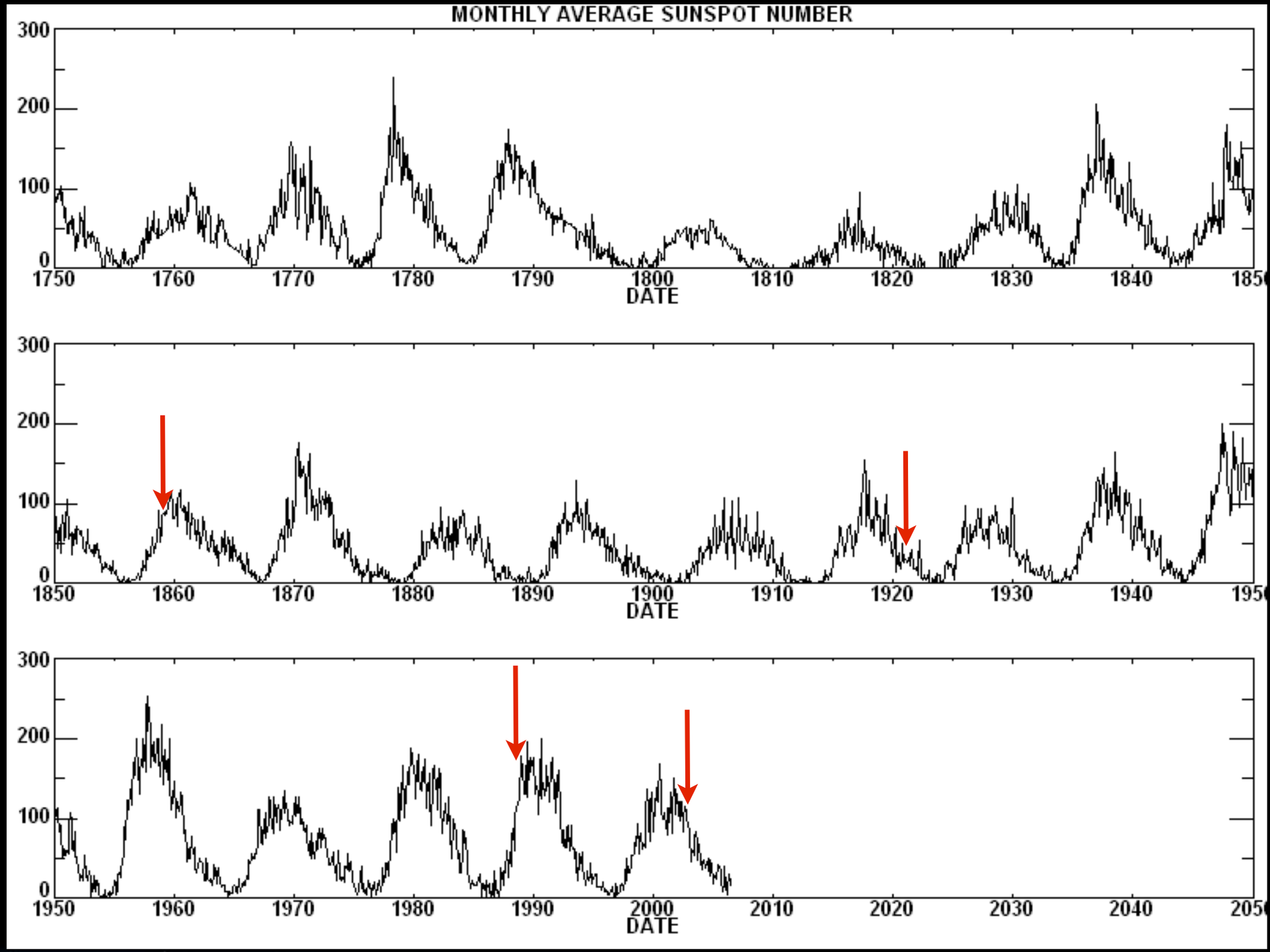
- More than 20 satellites and spacecrafts were affected (not including classified military instruments), Half of NASA satellites affected. One Japanese satellite lost
- Severe HF Radio blackout – affected commercial airlines
- FAA issued a first-ever alert of excessive radiation exposure for air travellers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

Extreme Solar Weather Has Happened Before

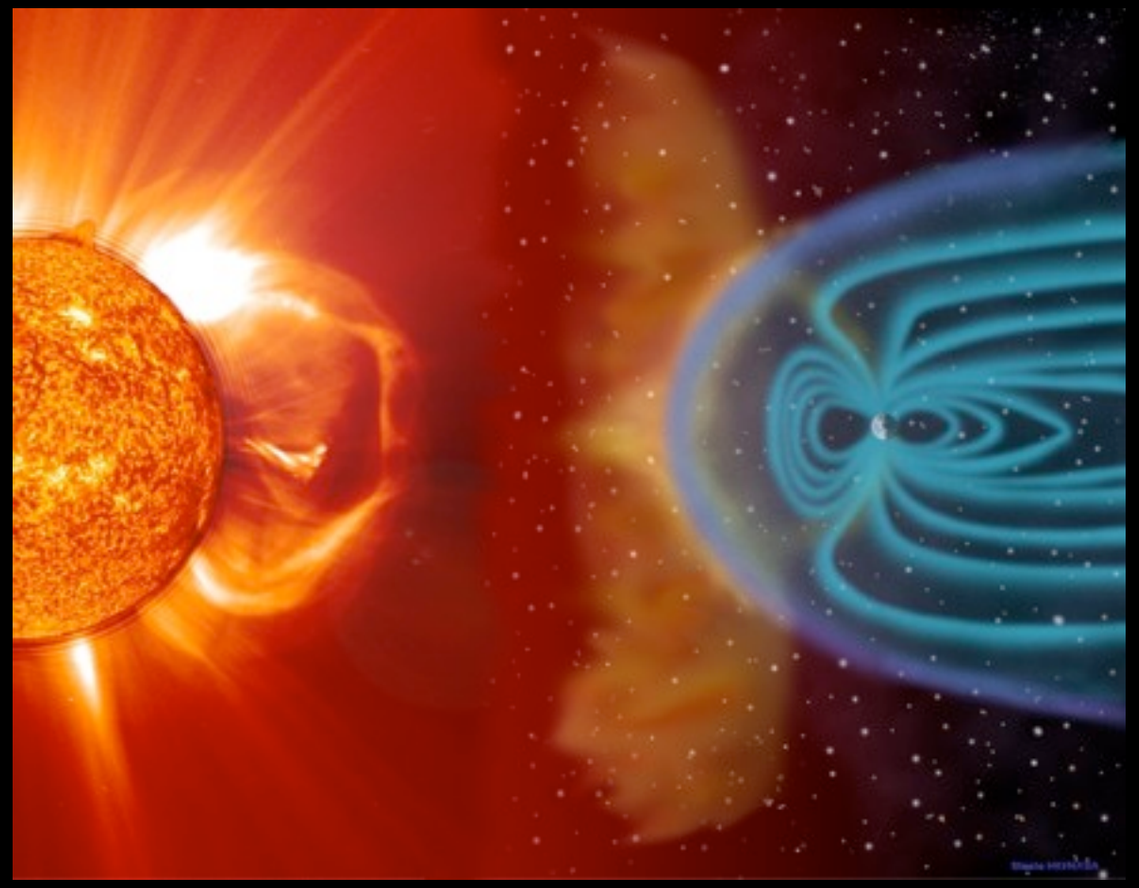
Morse Telegraph Table
Photo from www.telegraphlore.com

- **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.

Når inntreffer «superstormer»



Super Storms



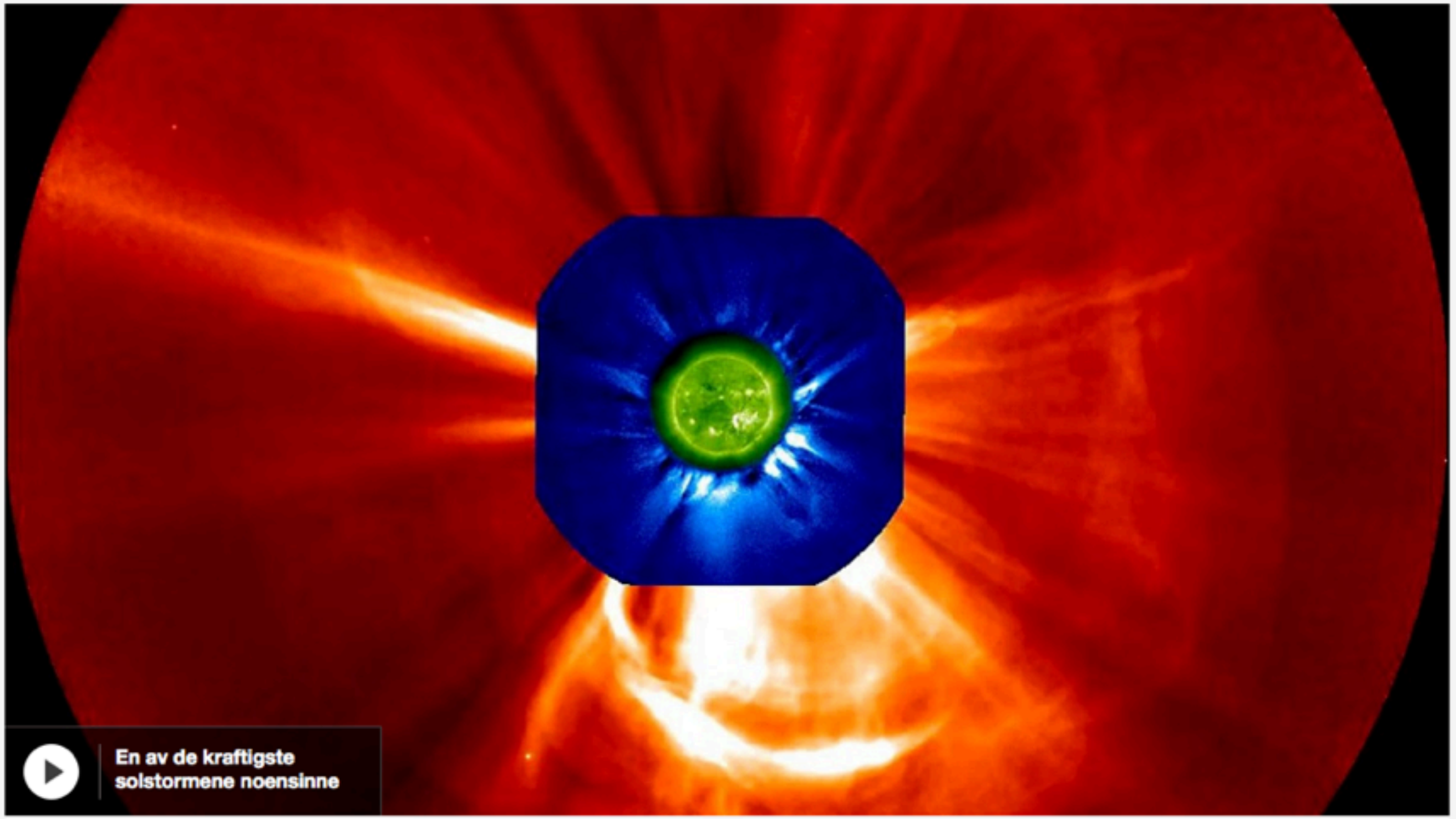
http://www.nap.edu/catalog.php?record_id=12507

En NASA-støttet workshop arrangert av amerikanske National Academy of Sciences, evaluerte hvor sårbare vi er hvis samfunnskritiske installasjoner blir slått ut av en ekstrem elektromagnetisk storm.

Kostnadene kan komme opp i flere billioner (1000 milliarder) USD

Kan ta 4-10 år å reparere skadene

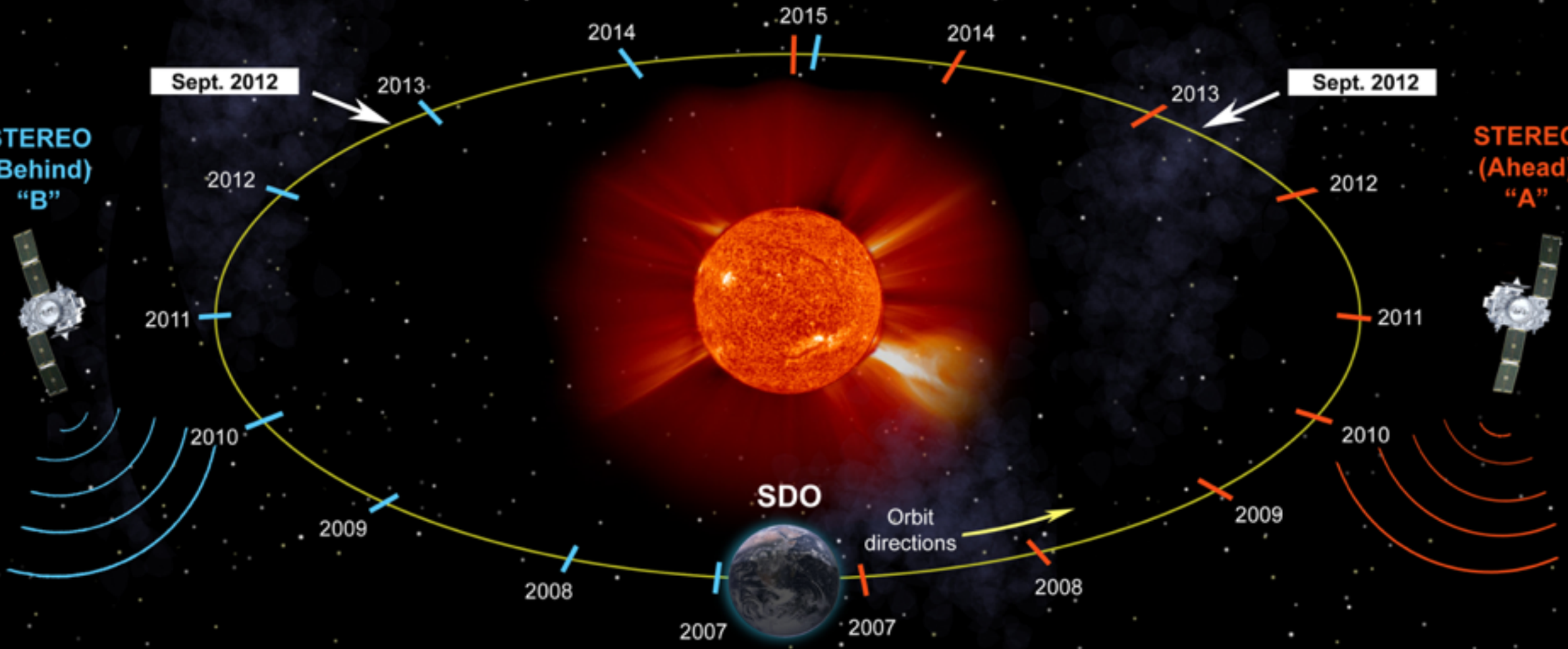
Viten



– Vi var ni dager unna en katastrofe

Den kraftigste solstormen på 150 år inntraff i 2012. Forskere hevder nå at stormen kunne slått ut hele den moderne verden hvis den hadde kommet ni dager tidligere.

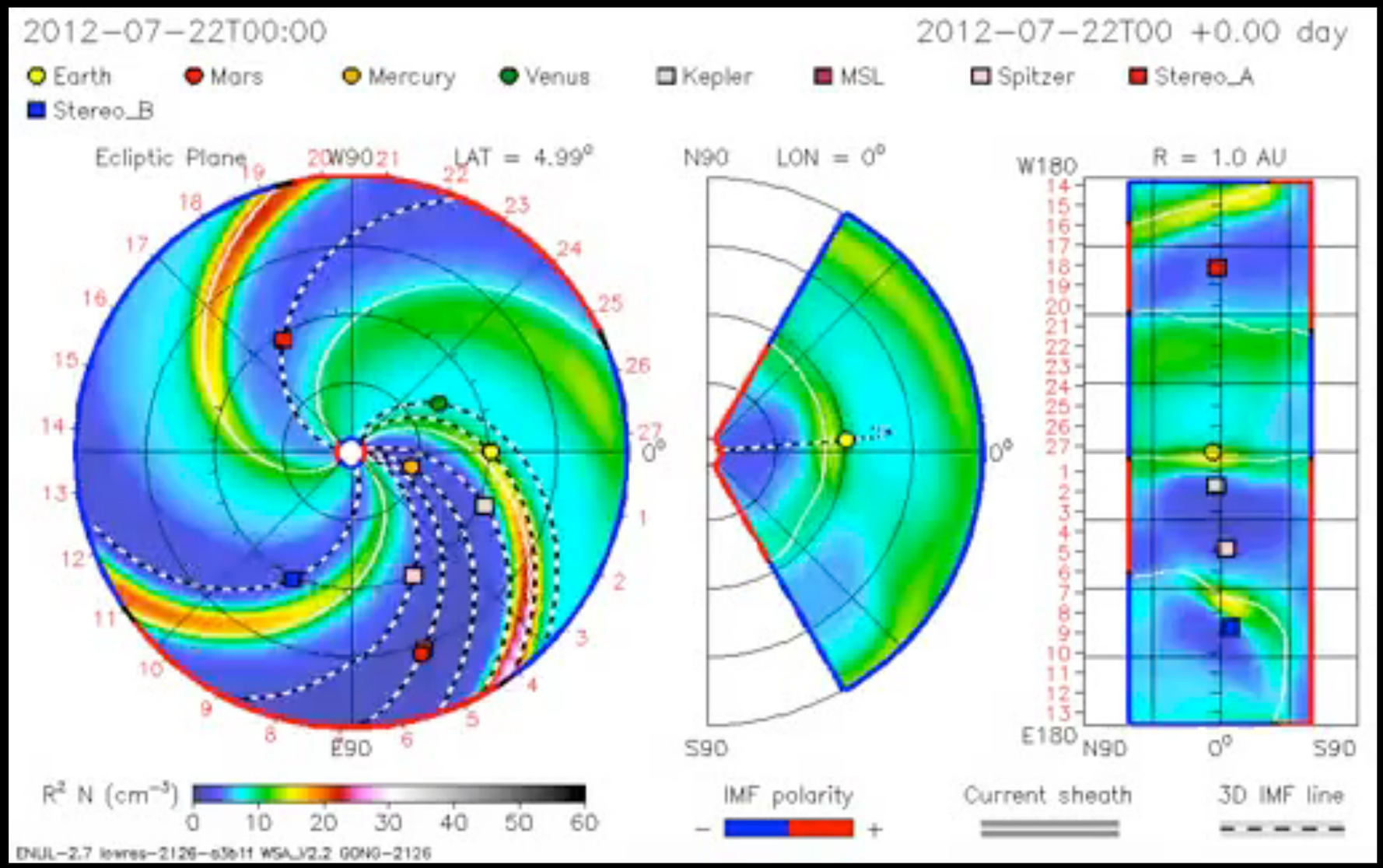
NASA's STEREO (with SDO) Sees the Entire Sun



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)

Superstorm 2012



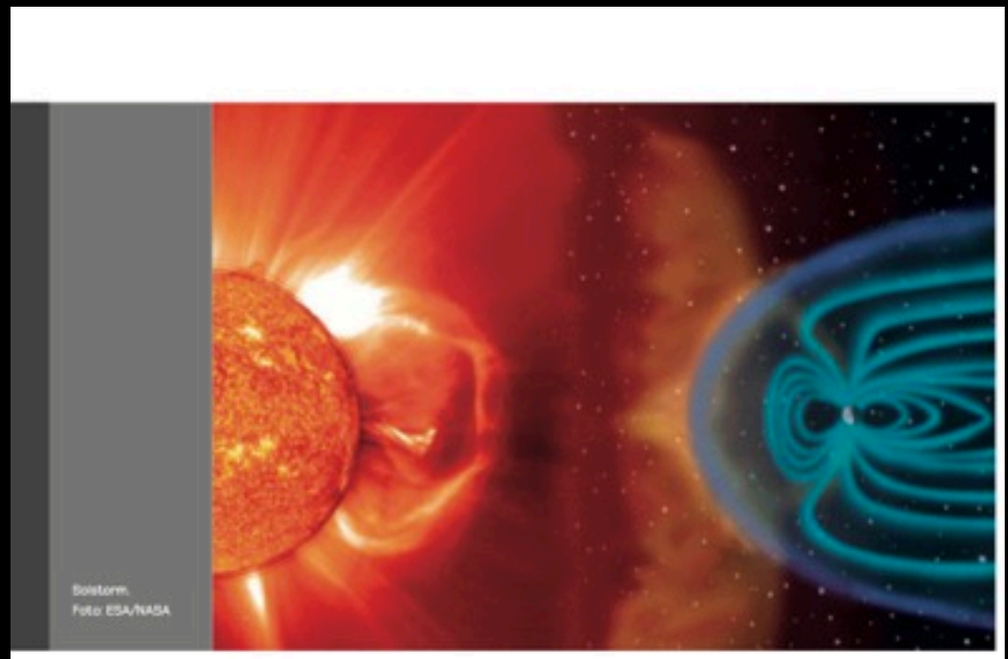
DSB - Nasjonalt Risikobilde

The Directorate for Civil Protection and Emergency Planning (DSB)

dsb
Direktoratet for samfunnssikkerhet og beredskap

TEMA

NASJONALT RISIKOBILDE 2012



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.[71] 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 brunner 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 kraft-transformatorer 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.krisinfo.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.

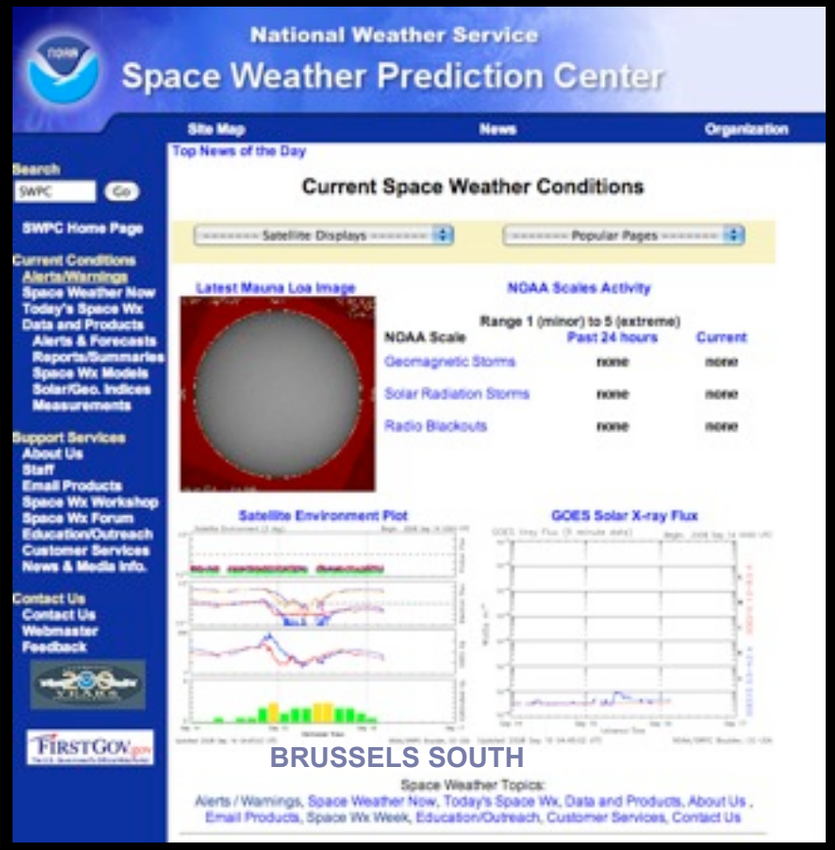
Users of Space Weather in Norway

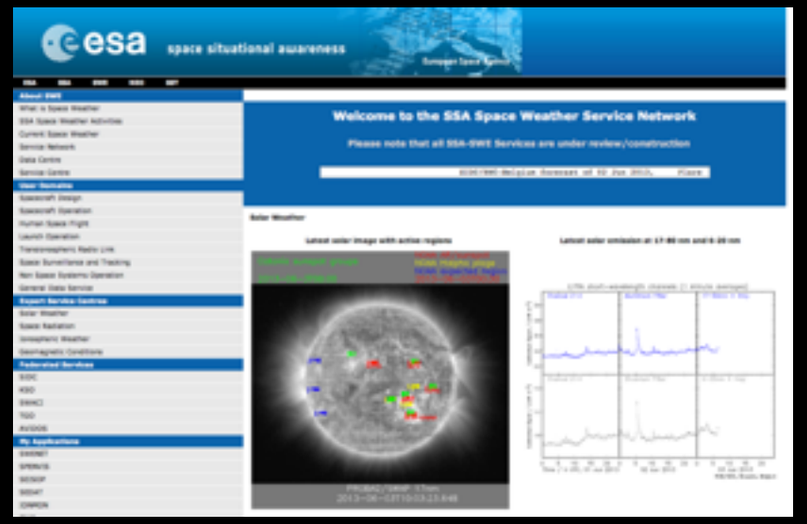
Who:	Why:
• Oil&Gas companies	Navigation, positioning and exploration activities
• Aviation	GNSS navigation and HF communication
• Maritime Sector	GNSS navigation and HF communication
• Power grid operators	Ground Induced Currents and GPS timing
• Satellite operators	Damages to systems
• Survey, Construction,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

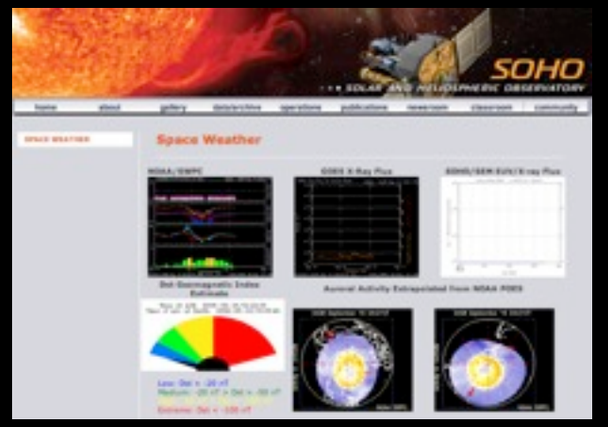
Romværvarsling

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

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

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

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

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

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

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

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

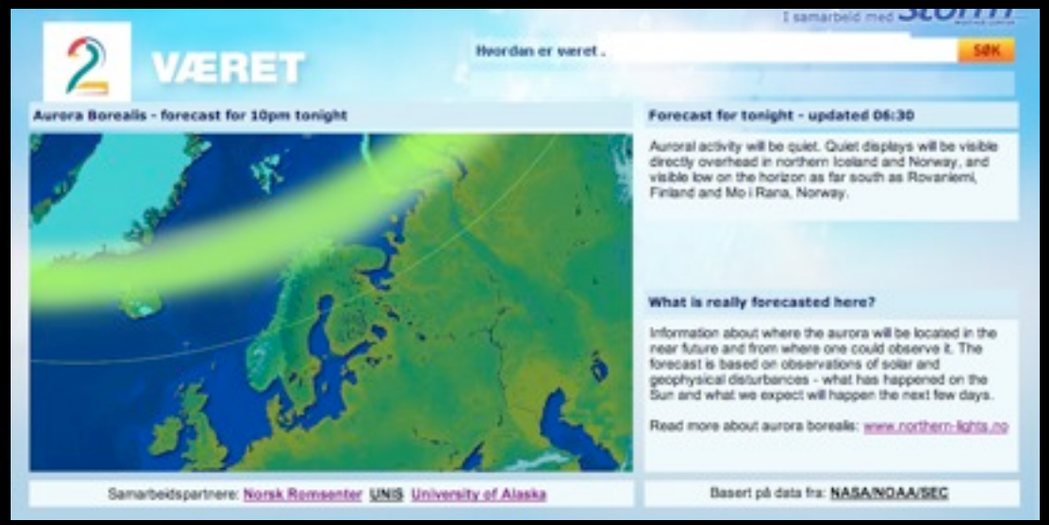






ESAs Space Situational Awareness - nytt program som inkluderer romvær

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



Norsk Romsenter
NORWEGIAN SPACE CENTRE