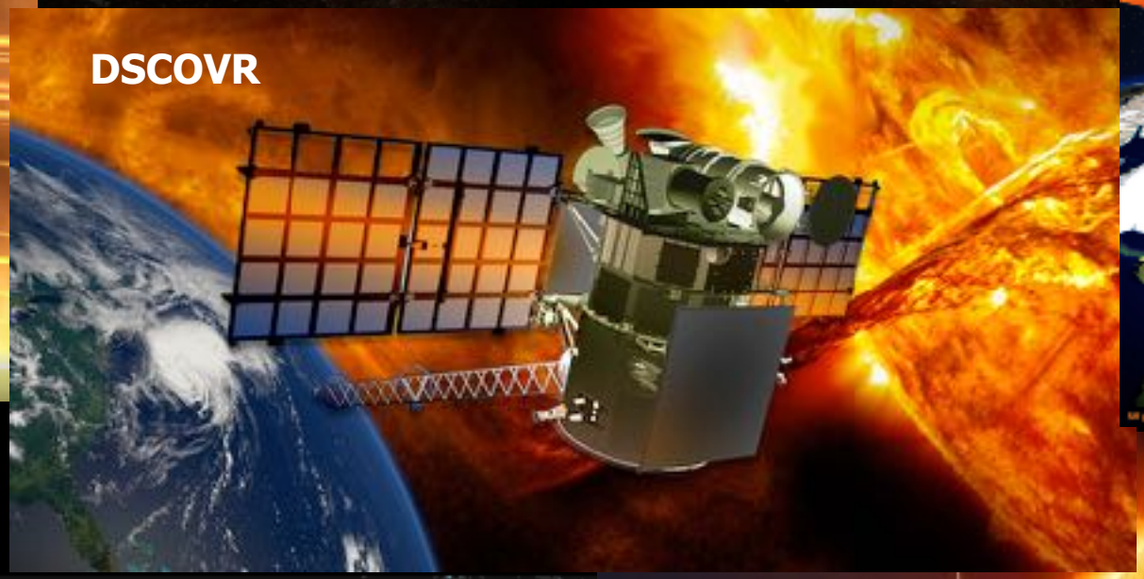
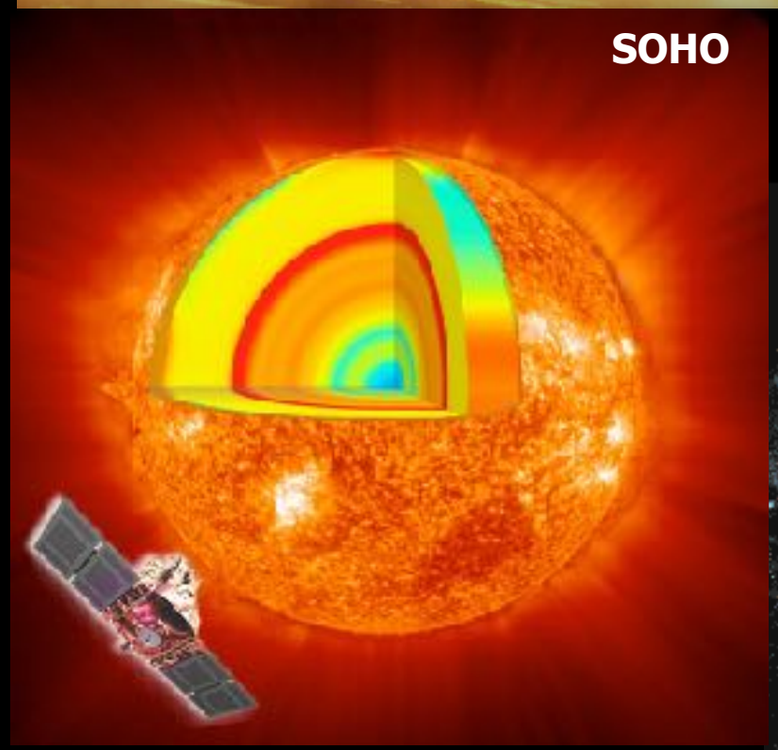
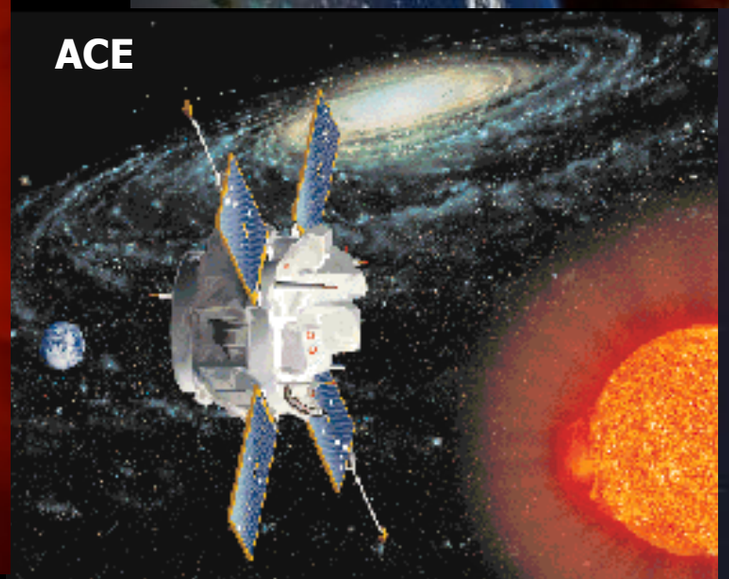
Solar Storms and Northern lights - how to predict Space Weather and the Aurora

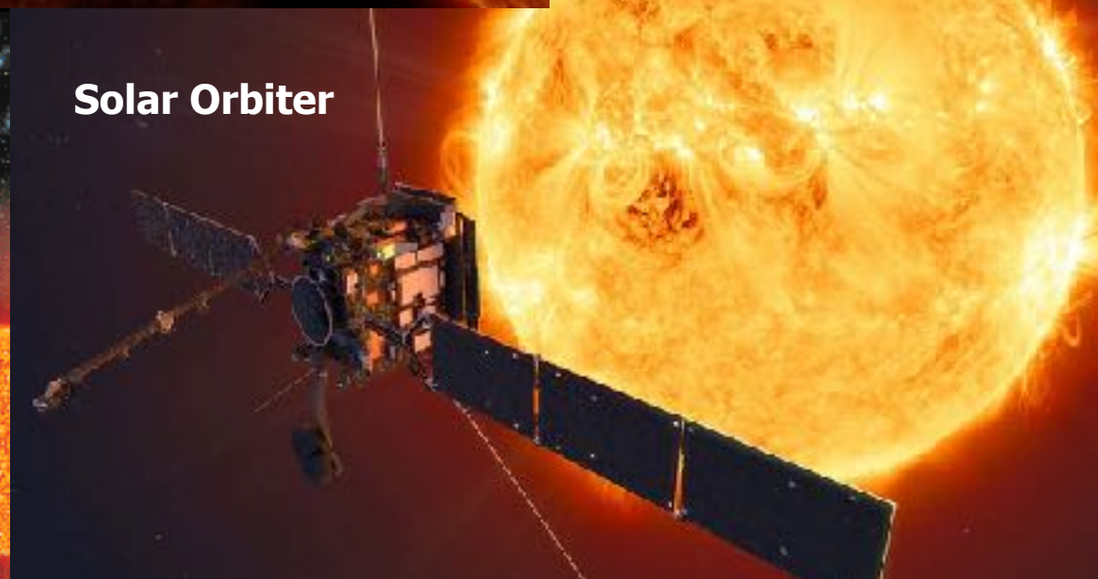
Pål Brekke
Norwegian Space Centre/UNIS

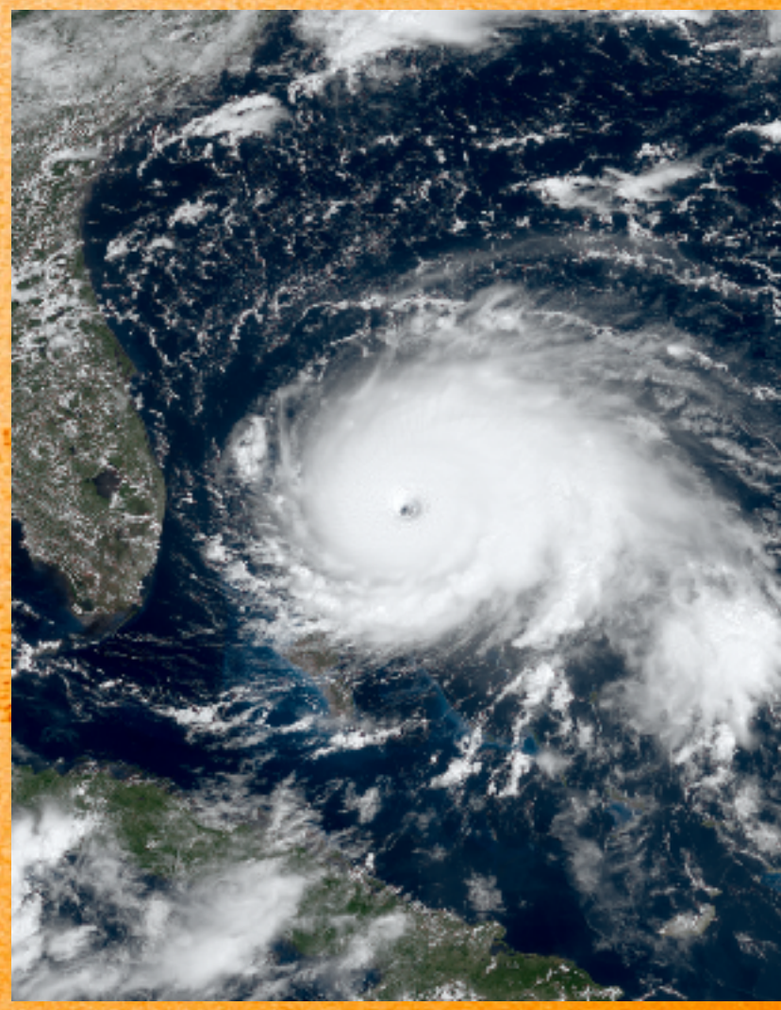
Fleet of satellites watching the Sun





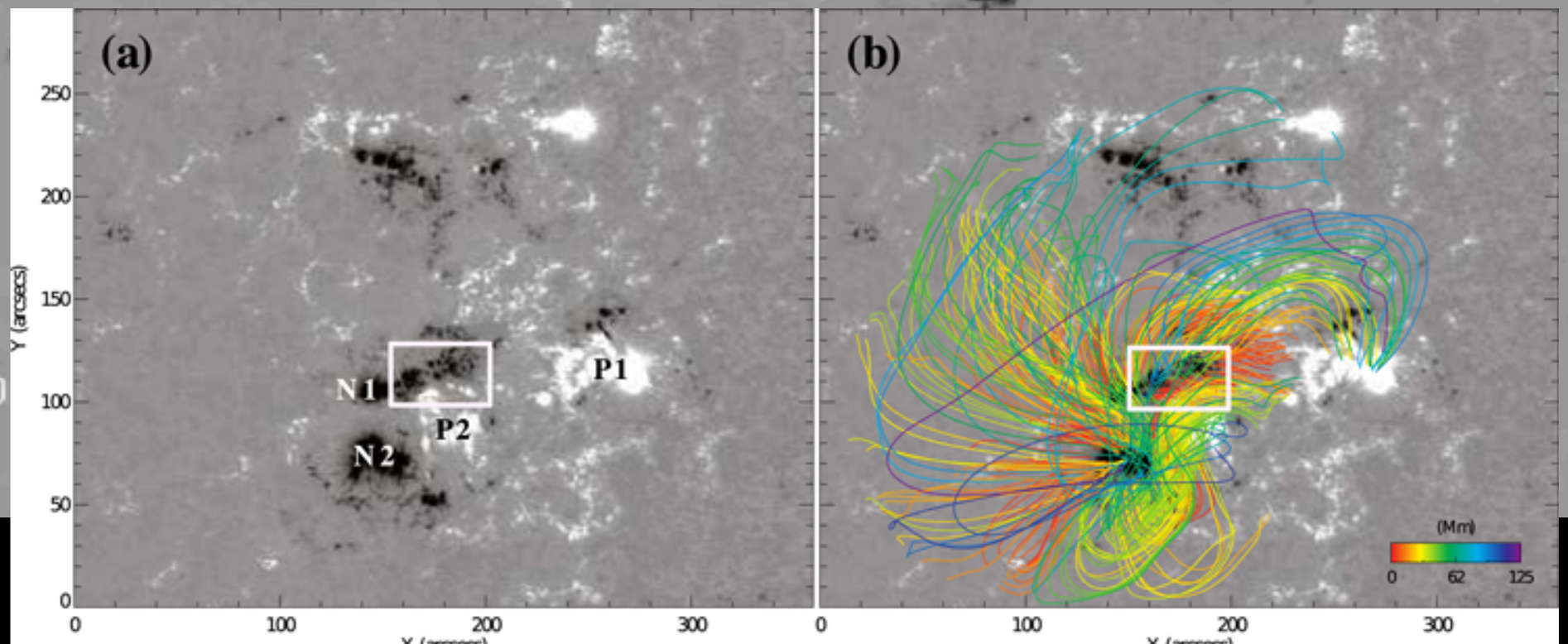






Monitoring the Sunspot magnetic field

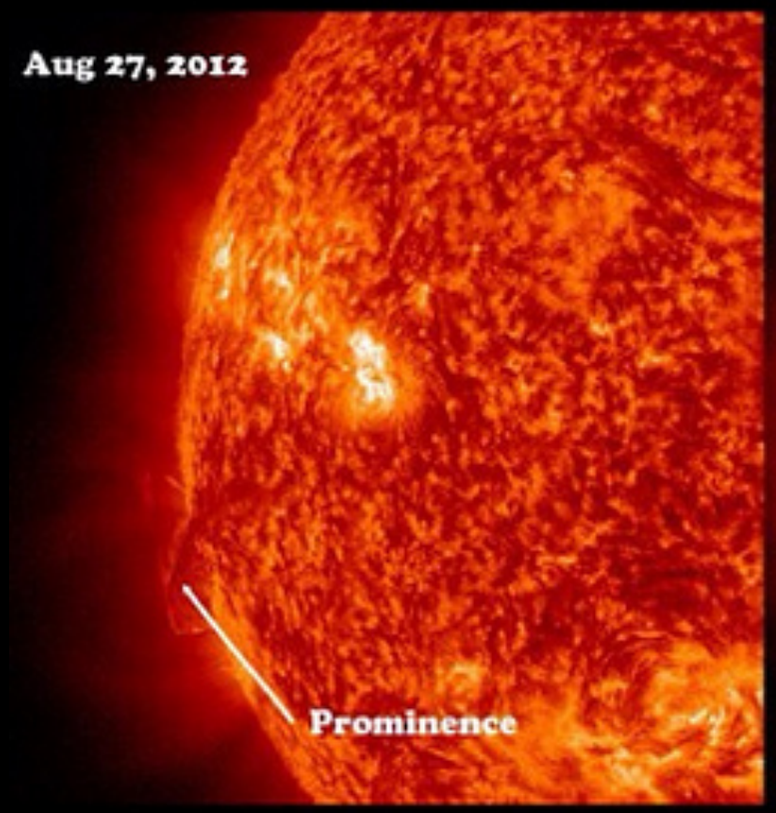
As flares are powered from the stressed field rooted in the photosphere, a study of the photospheric magnetic complexity can be used to both predict activity and understand the physics of the magnetic field.

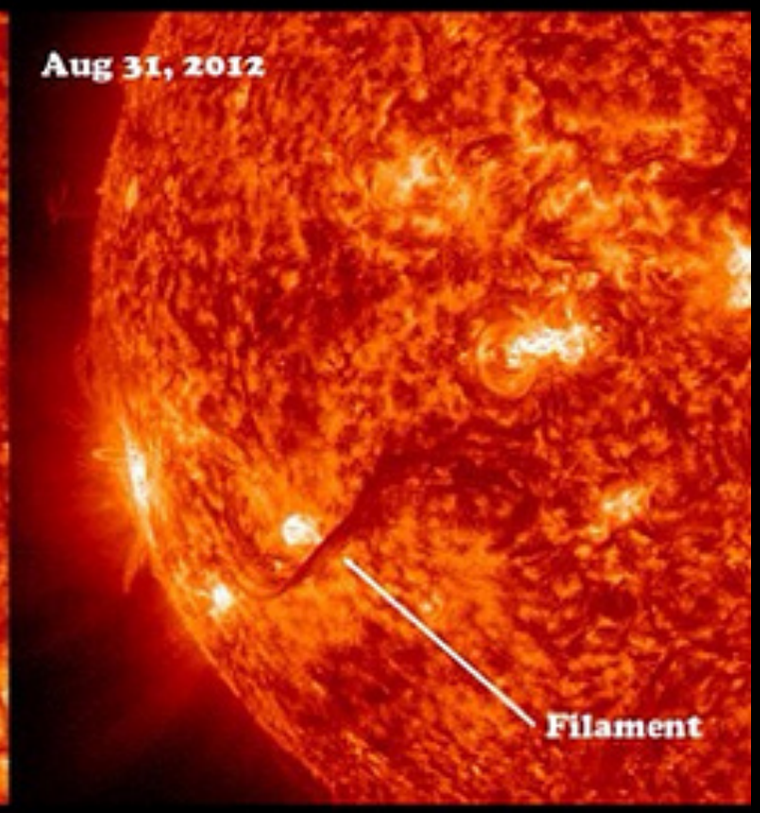


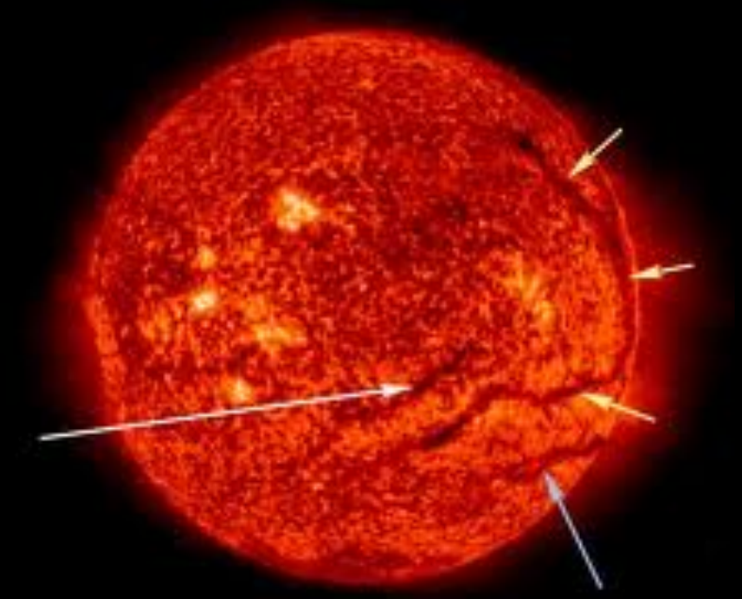
2010

Look for filaments on the disk

When filaments get unstable they can erupt - so by monitoring filaments near the center of the disk can give some warning about possible eruptions.

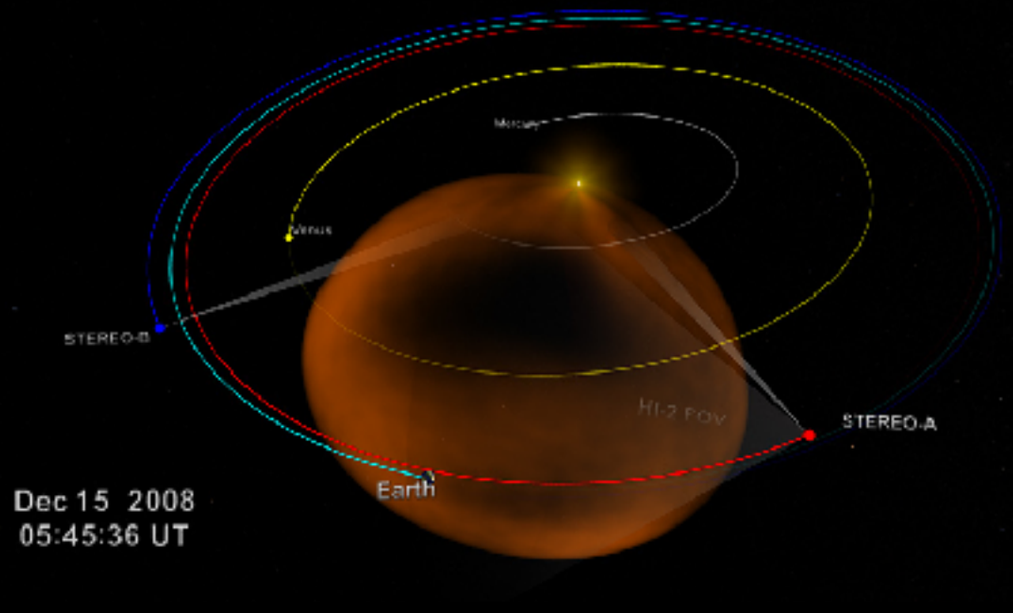


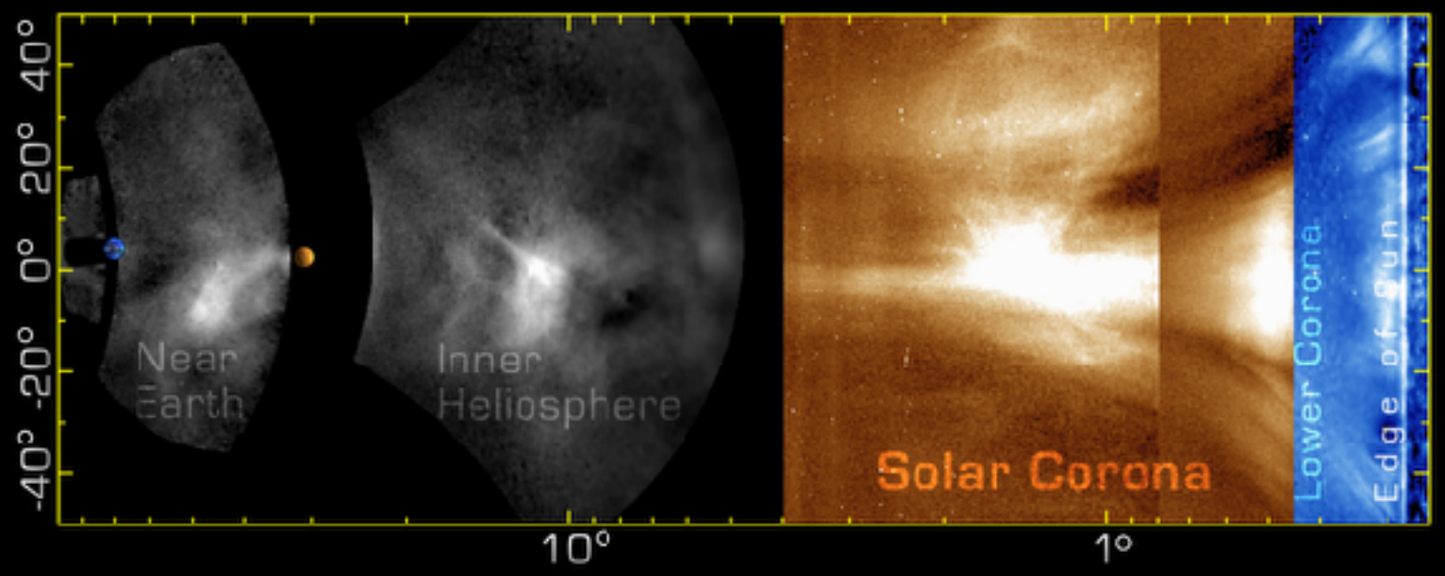




Follow a CME from the Sun to the Earth

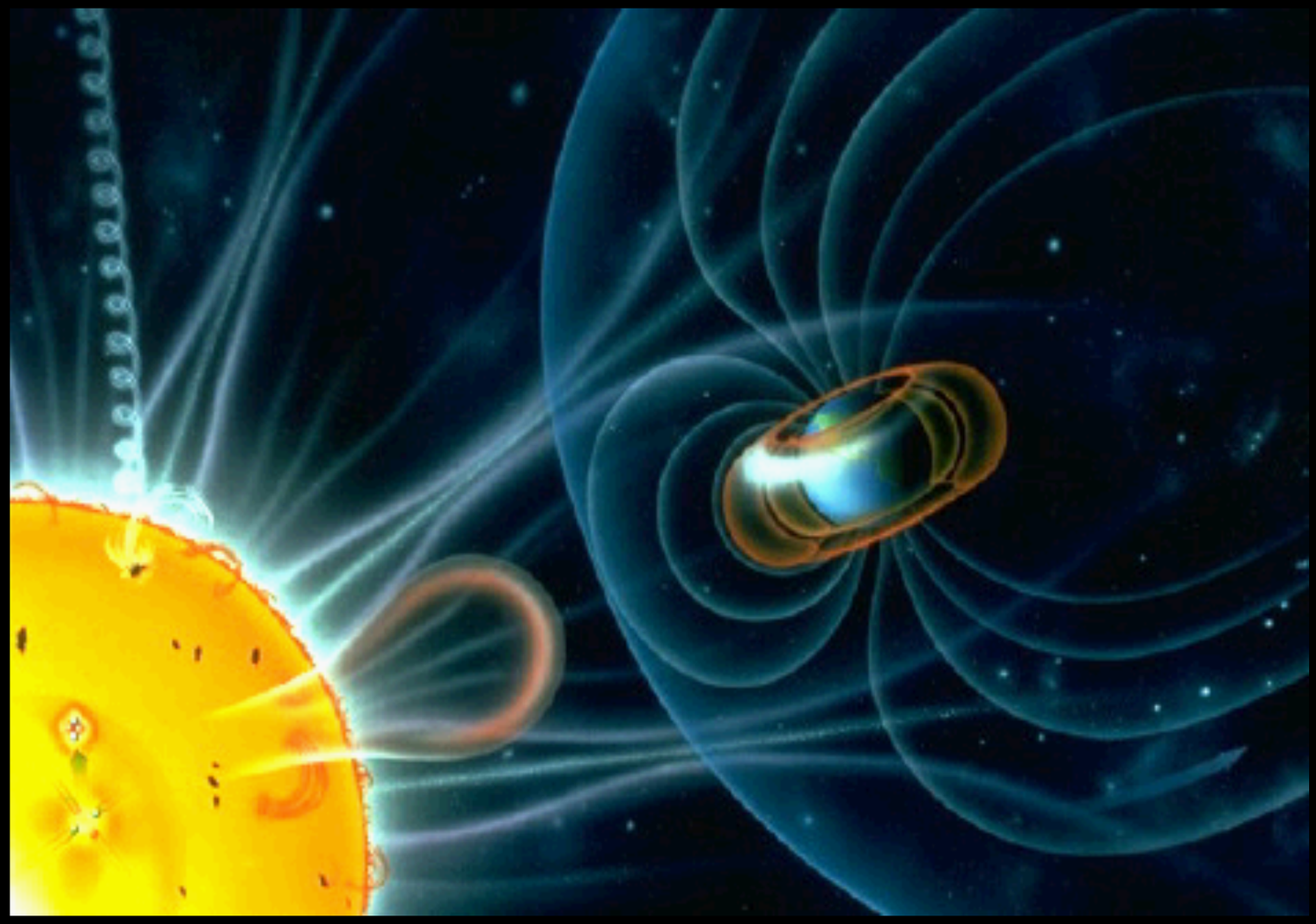
STEREO (Solar Terrestrial Relations Observatory) is a solar observation mission. Two nearly identical spacecraft were launched in 2006 into orbits around the Sun that cause them to respectively pull farther ahead of and fall gradually behind the Earth. This enables stereoscopic imaging of the Sun and solar phenomena, such as coronal mass ejections.



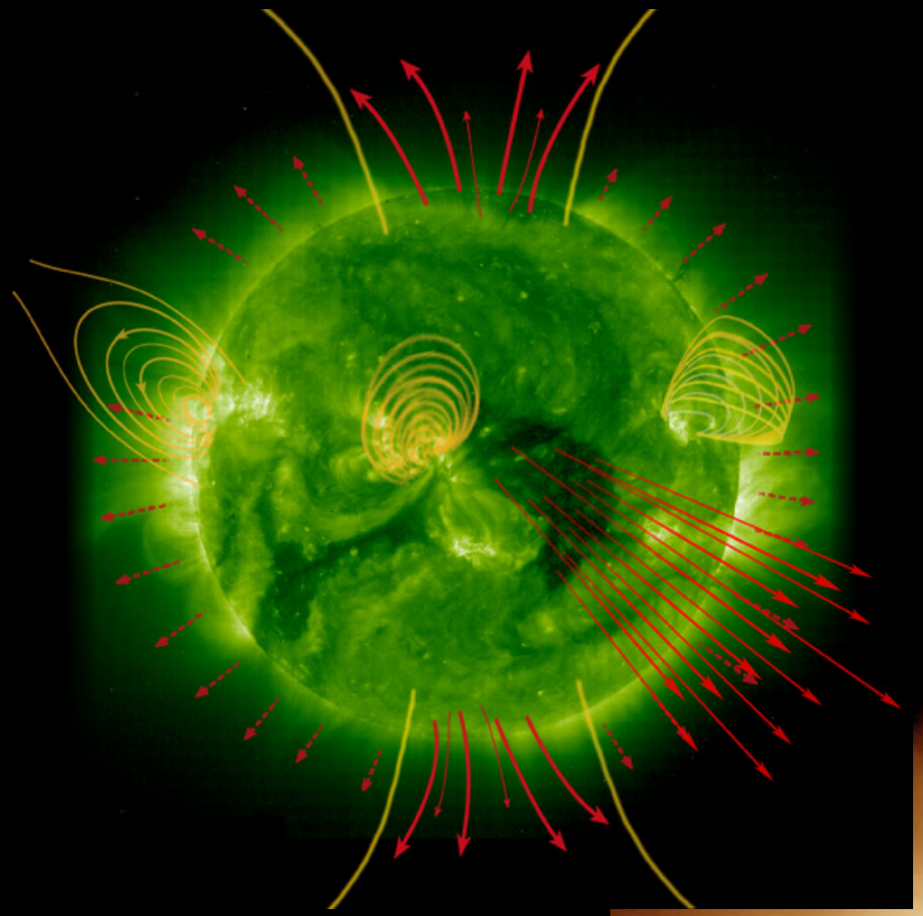


The Solar Wind also Creates Northern Lights

- 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.

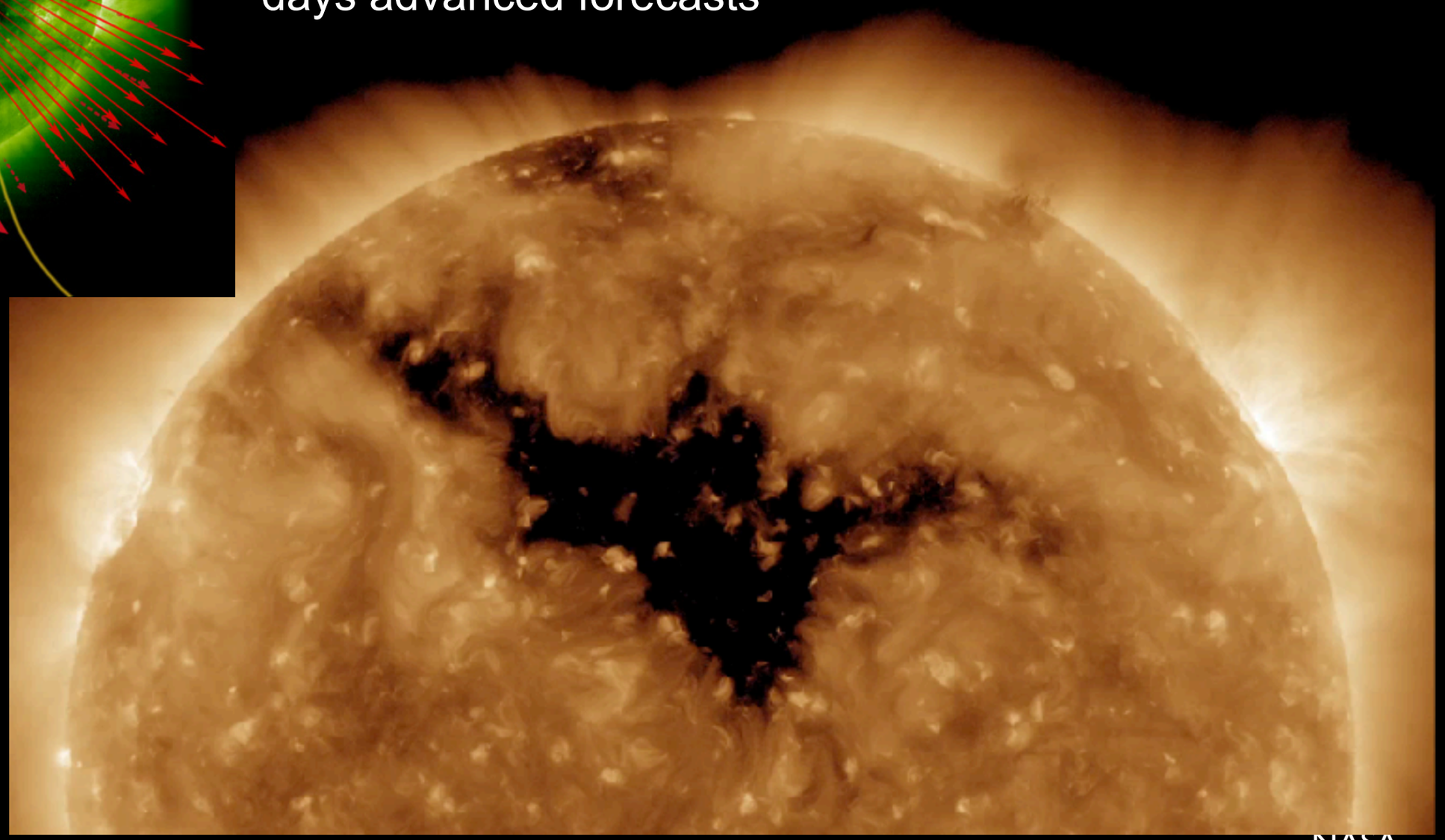


Predicting Auroras - Coronal Holes



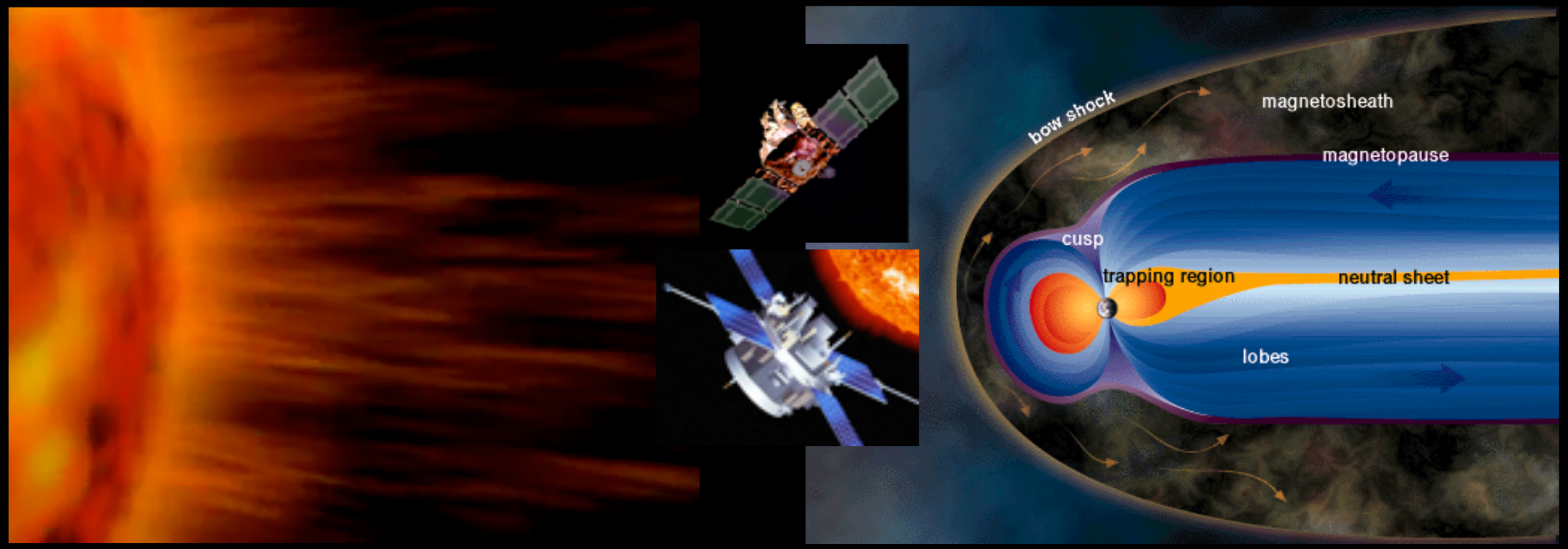
The fastest solar wind originates from the dark areas on the image, called coronal holes. Such holes often occur close to the polar regions, but can sometimes also be observed close to the equator.

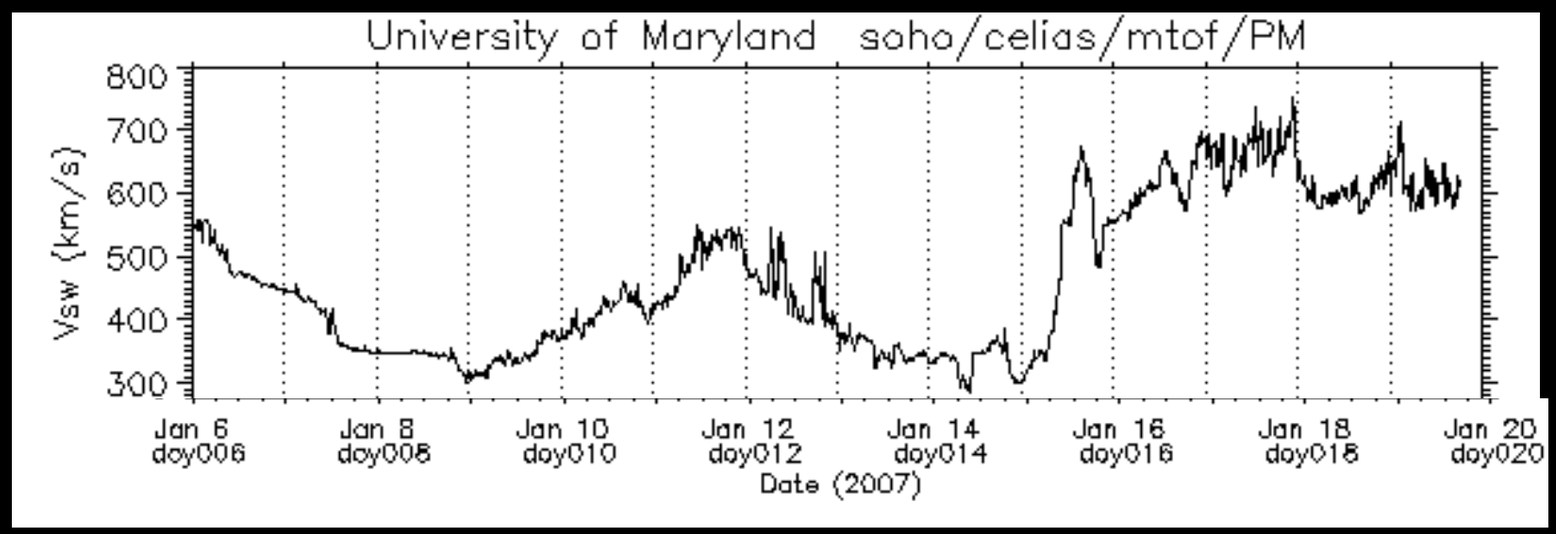
By tracking coronal holes one can provide several days advanced forecasts

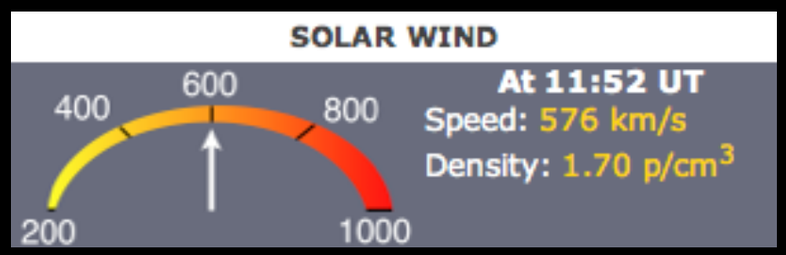


NASA

Monitoring the Solar Wind and IMF

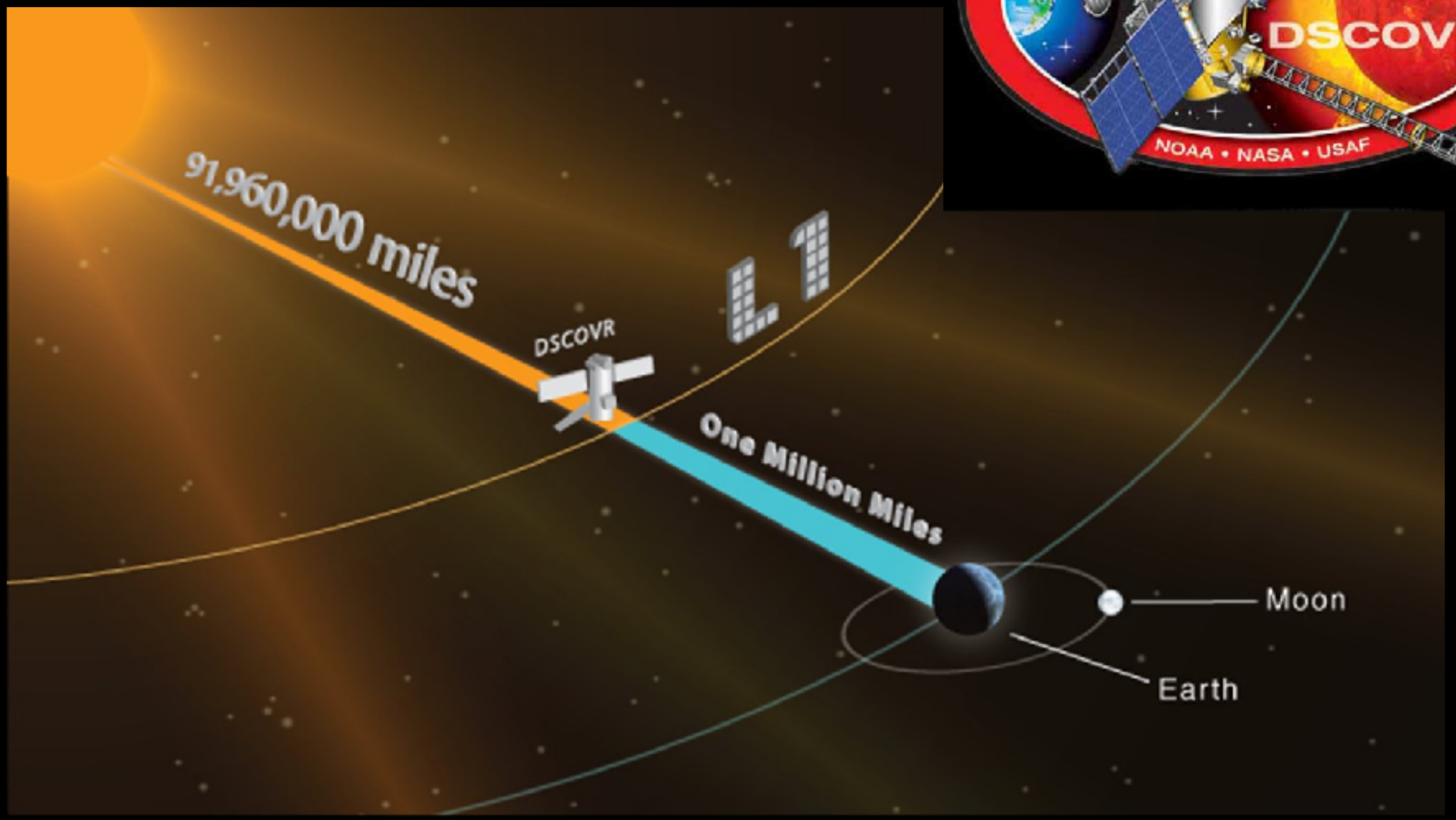






DSCOVR

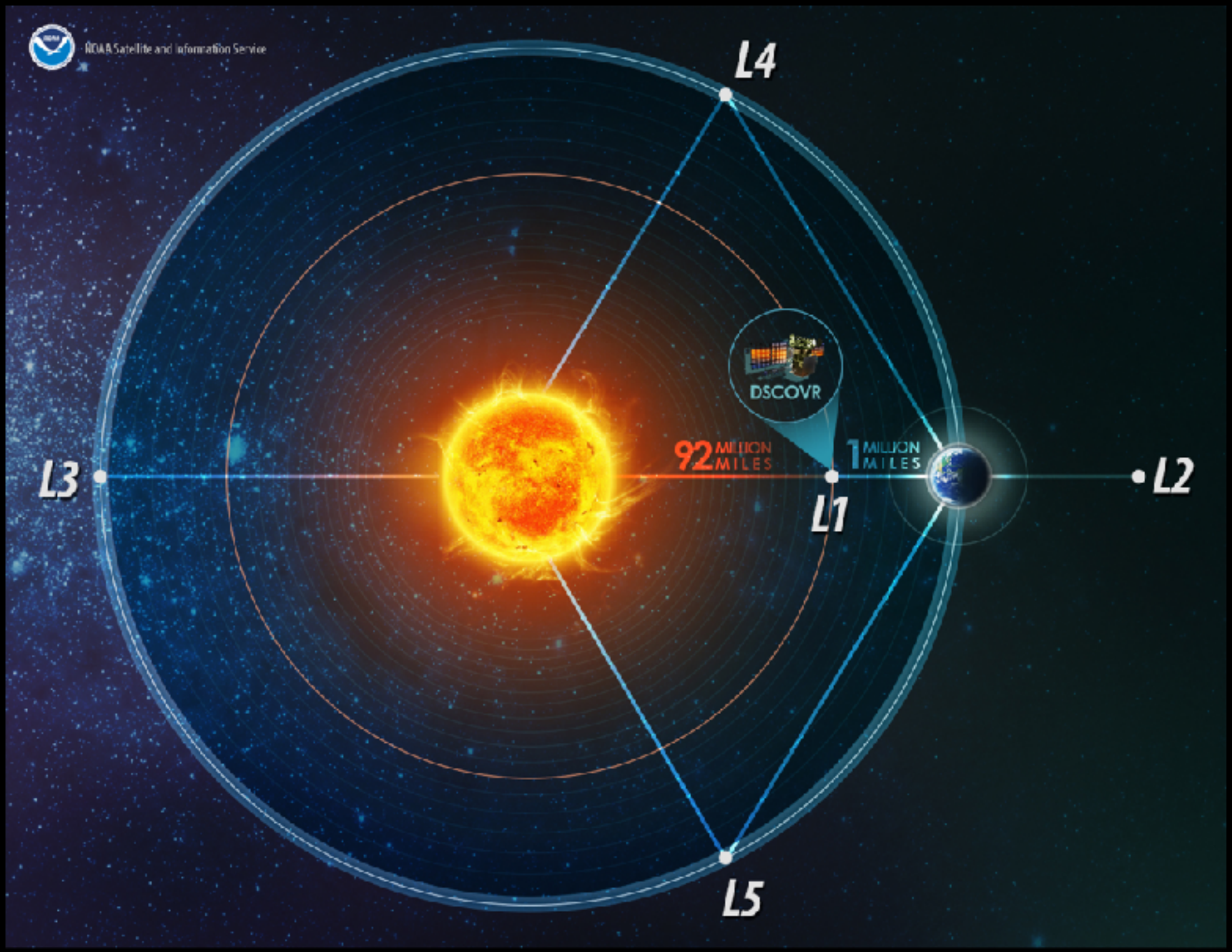
Deep Space Climate Observatory



NASA

DSCOVR

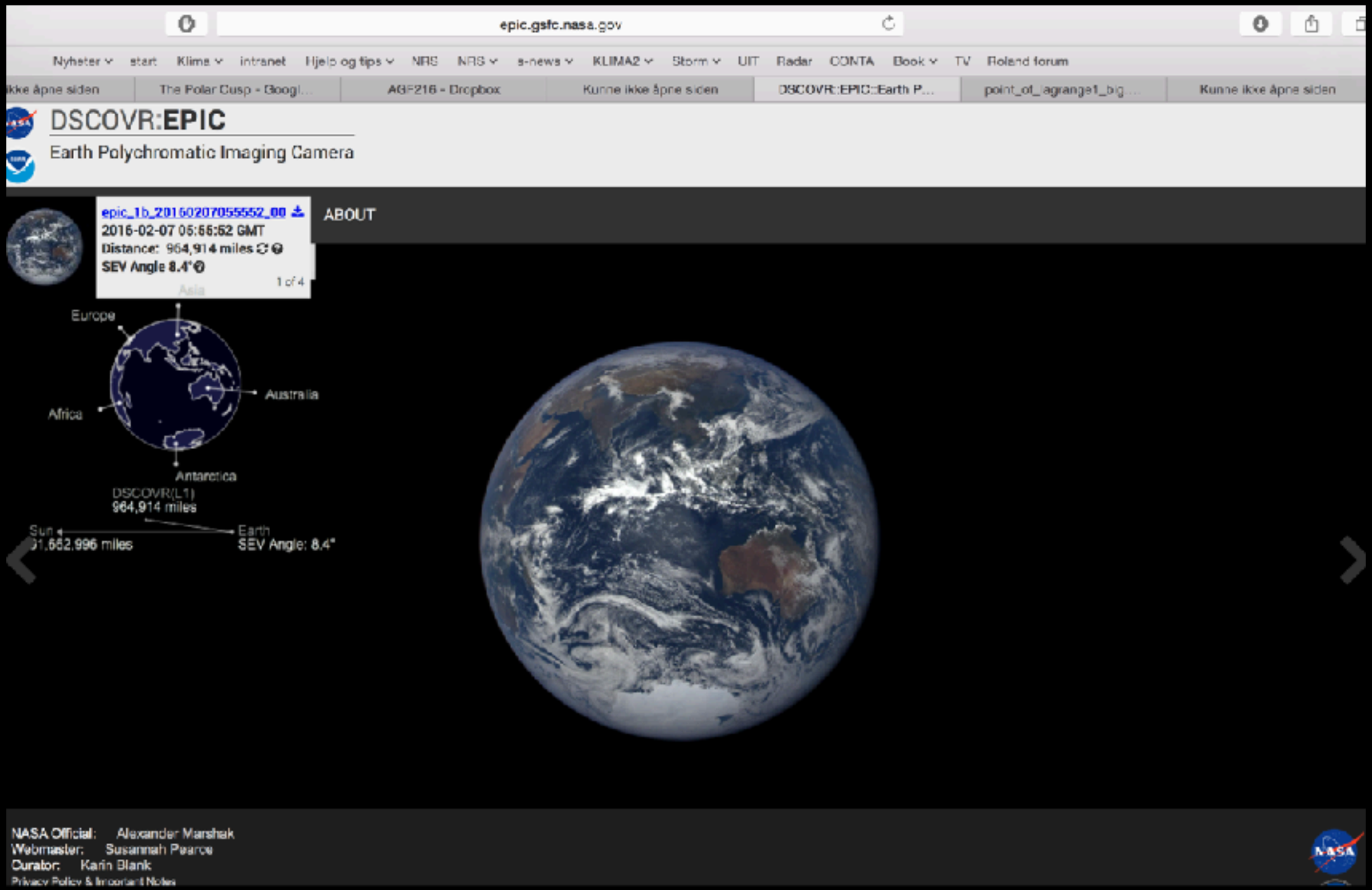
Deep Space Climate Observatory



NASA

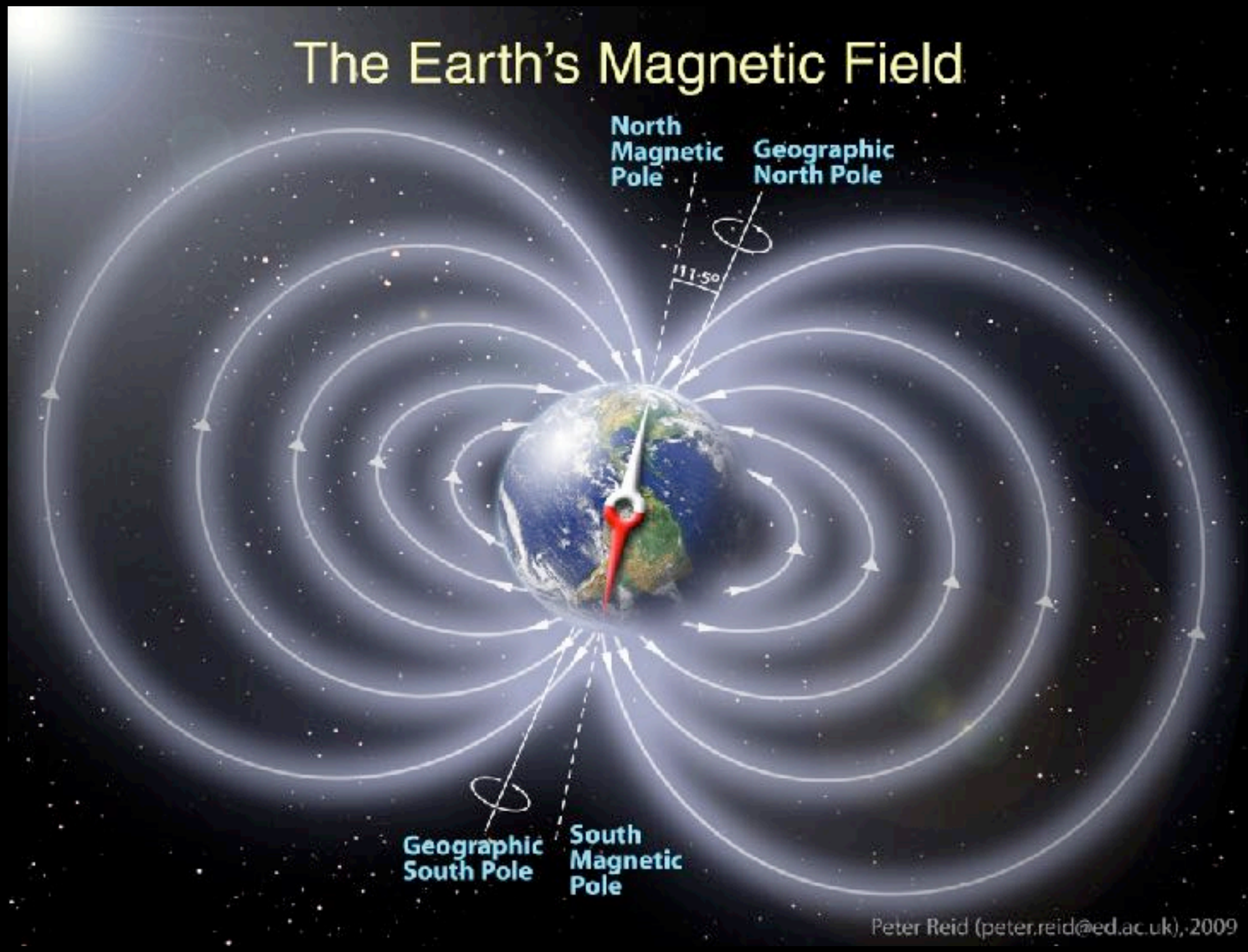
DSCOVR

Deep Space Climate Observatory



NASA

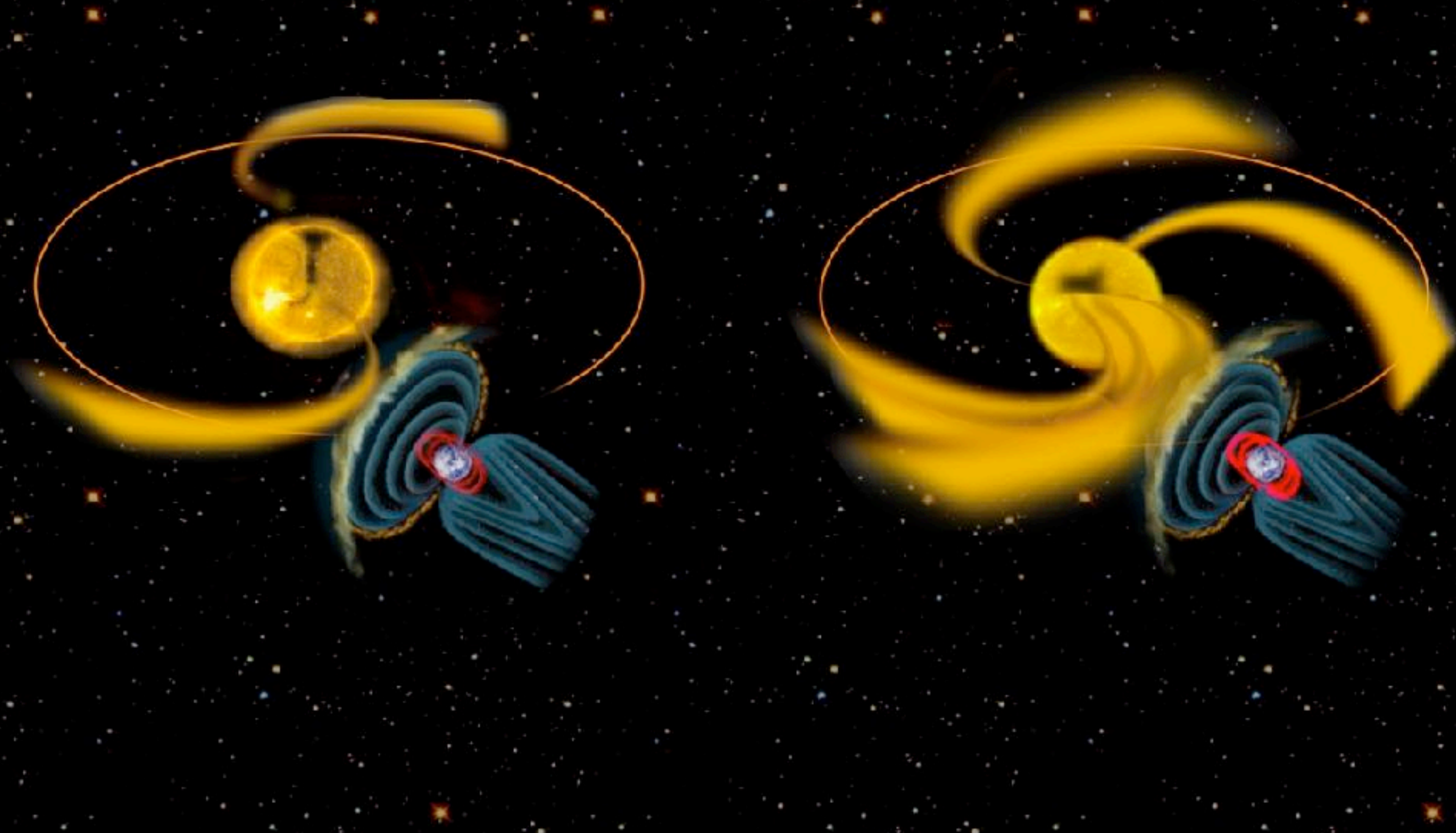
The magnetosphere



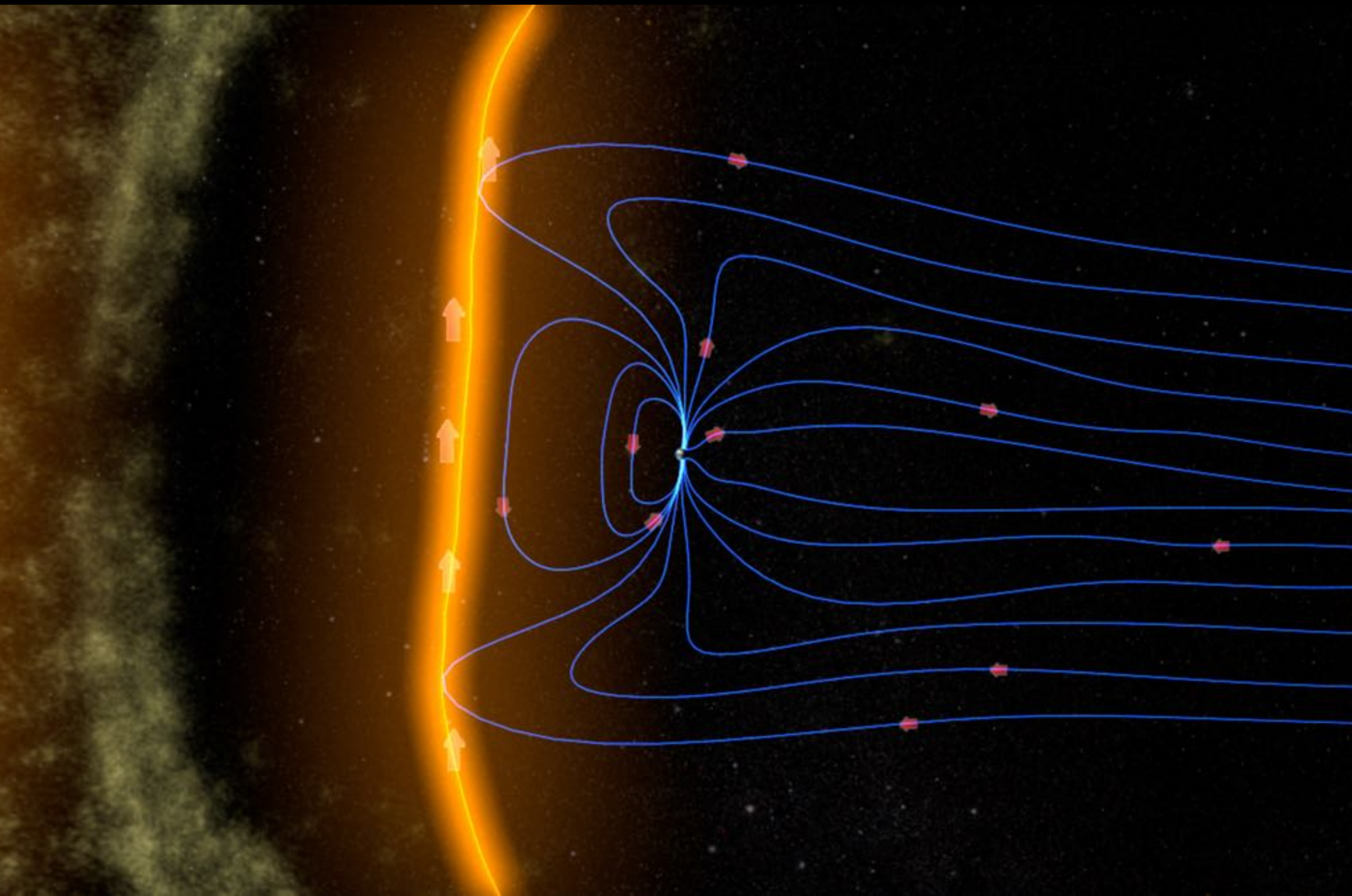
The magnetosphere

Interplanetary Magnetic Field

The **interplanetary magnetic field** (**IMF**), now more commonly referred to as the heliospheric magnetic field (HMF), is the component of the solar magnetic field which is dragged out from the solar corona by the solar wind flow to fill the Solar System.



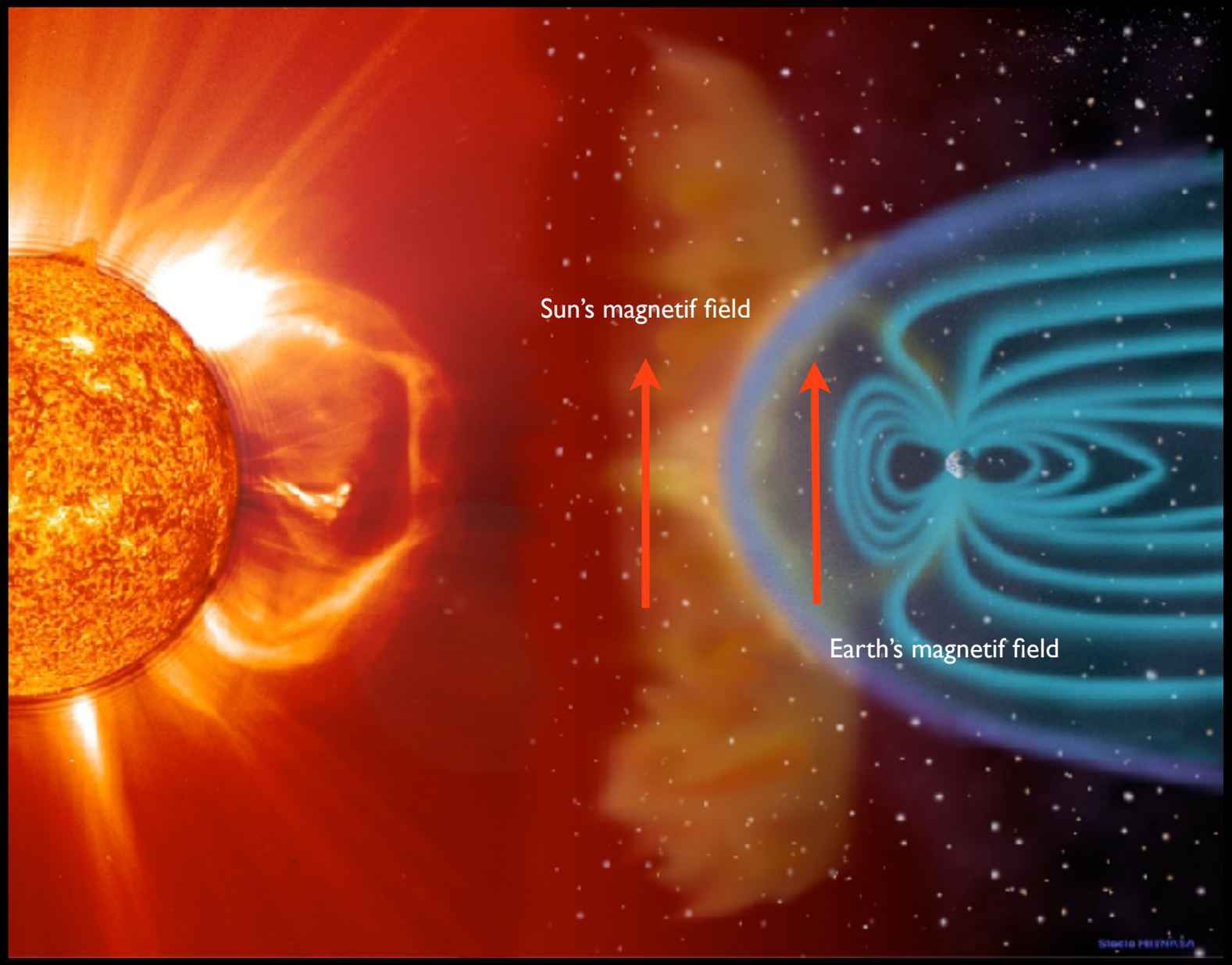
When do strong storms occure?



How effective will the storm be?

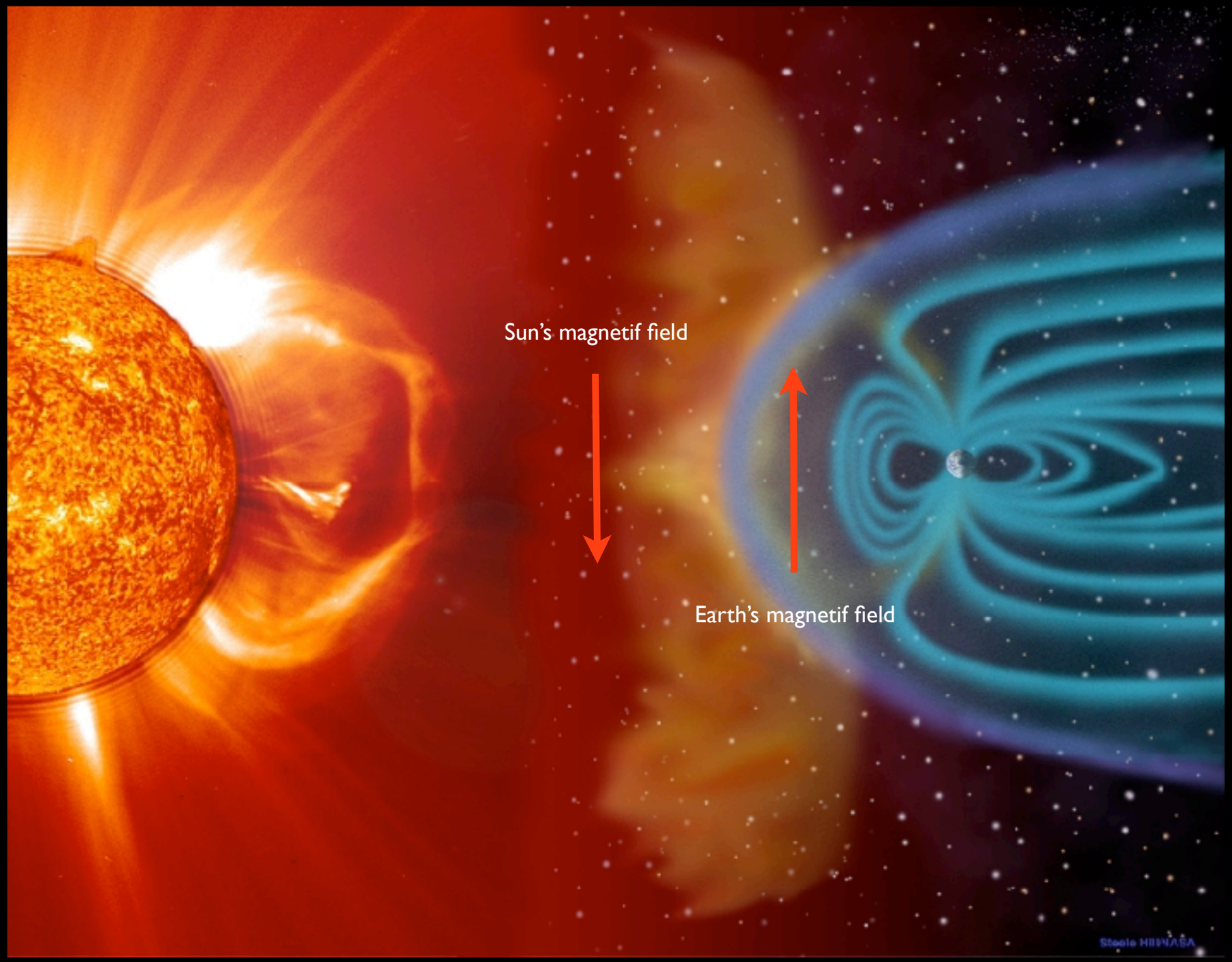
The solar wind also carries with it the magnetic field of the Sun. This field will have either a North or South orientation. If the solar wind has energetic bursts, contracting and expanding the magnetosphere, or if the solar wind takes a southward polarization, geomagnetic storms can be expected. The southward field causes magnetic reconnection of the dayside magnetopause, rapidly injecting magnetic and particle energy into the Earth's magnetosphere

Same direction - weak interaction - CME «glides by»

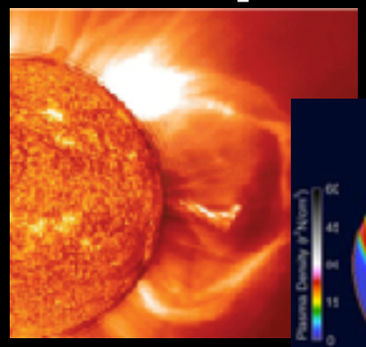


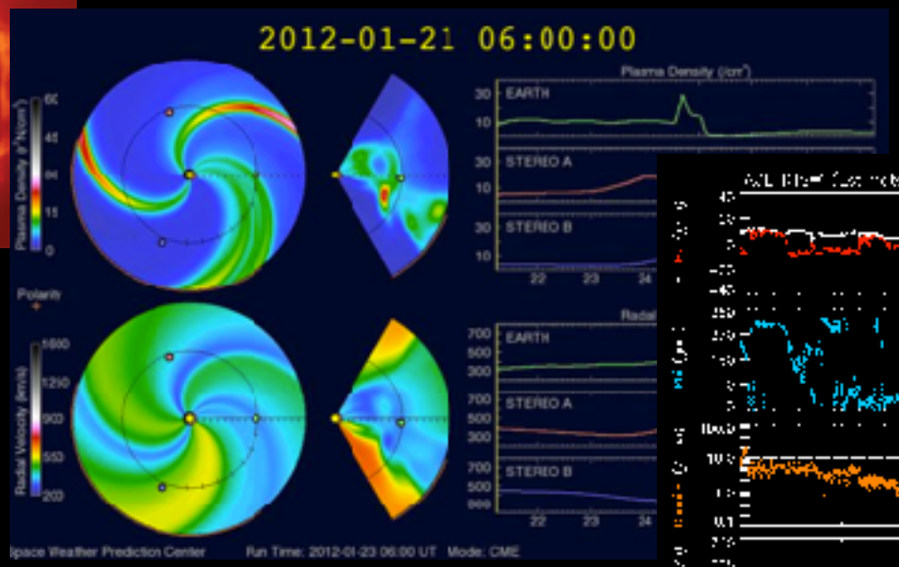
How effective wil the storm be?

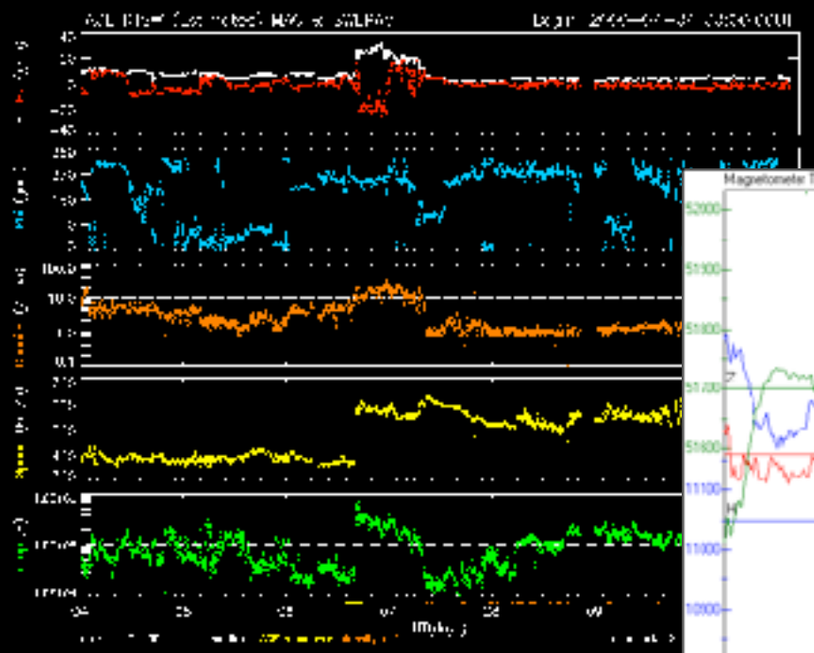
Opposite direction - strong interaction - strong geomagnetic storm

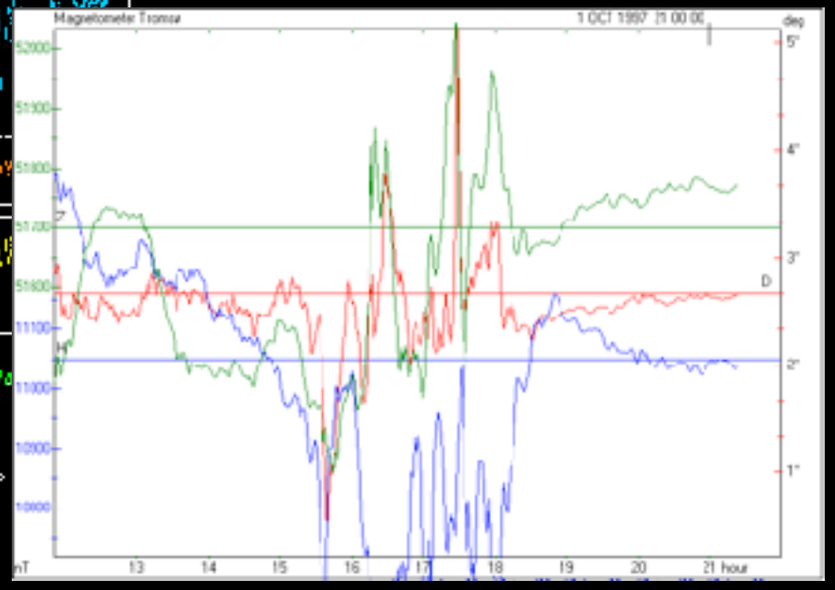


Sequence of events for Geomagnetic Forecast









Analysis and Prediction (Geomagnetic Storm Watch Products Issued)

→

ACE Observation (Geomagnetic Storm Warning Issued)

→

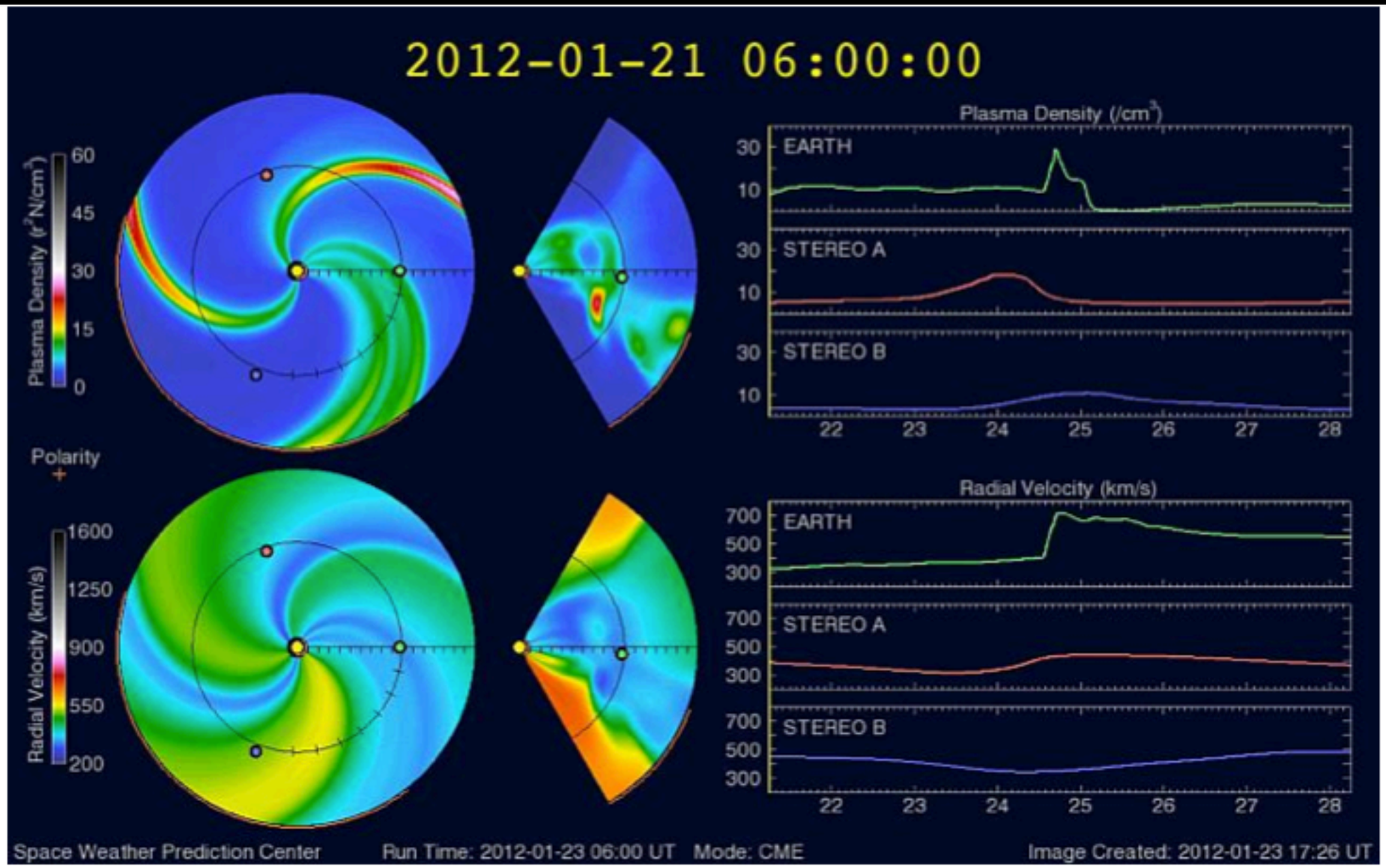
Event Onset/ Ground-Based Observation (Geomagnetic Storm Alert Issued)

Watches: The conditions are favorable for occurrence (1-4 days)

Warnings: Disturbances that are imminent, expected in the near future with high probability (Minutes to a few hours)

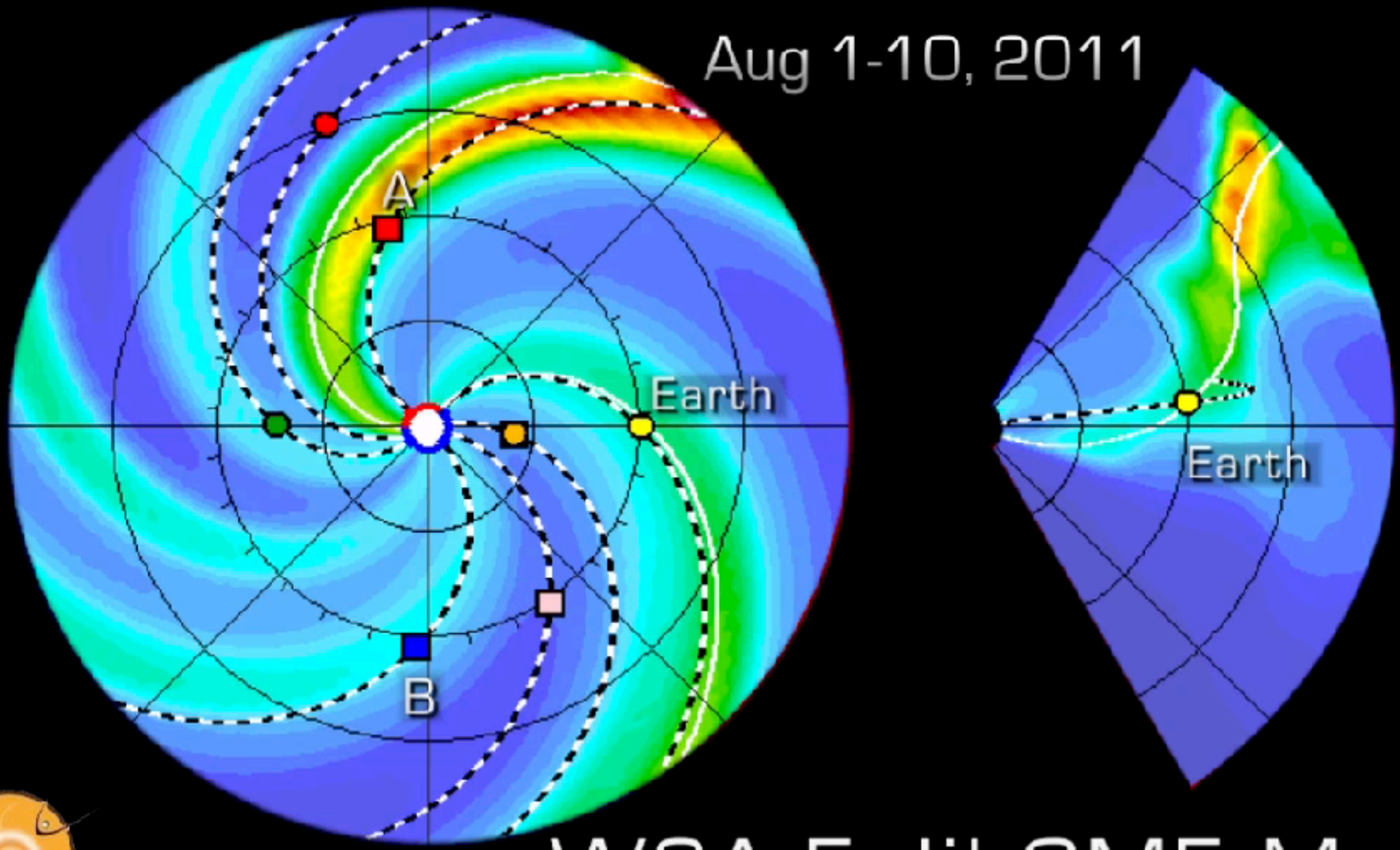
Alerts: Observed conditions meeting or exceeding thresholds

Space Weather Forecasts



- Watch the trajectory of CMEs
- www.swpc.noaa.gov/wsa-enlil/
- This gives 2-3 days warning

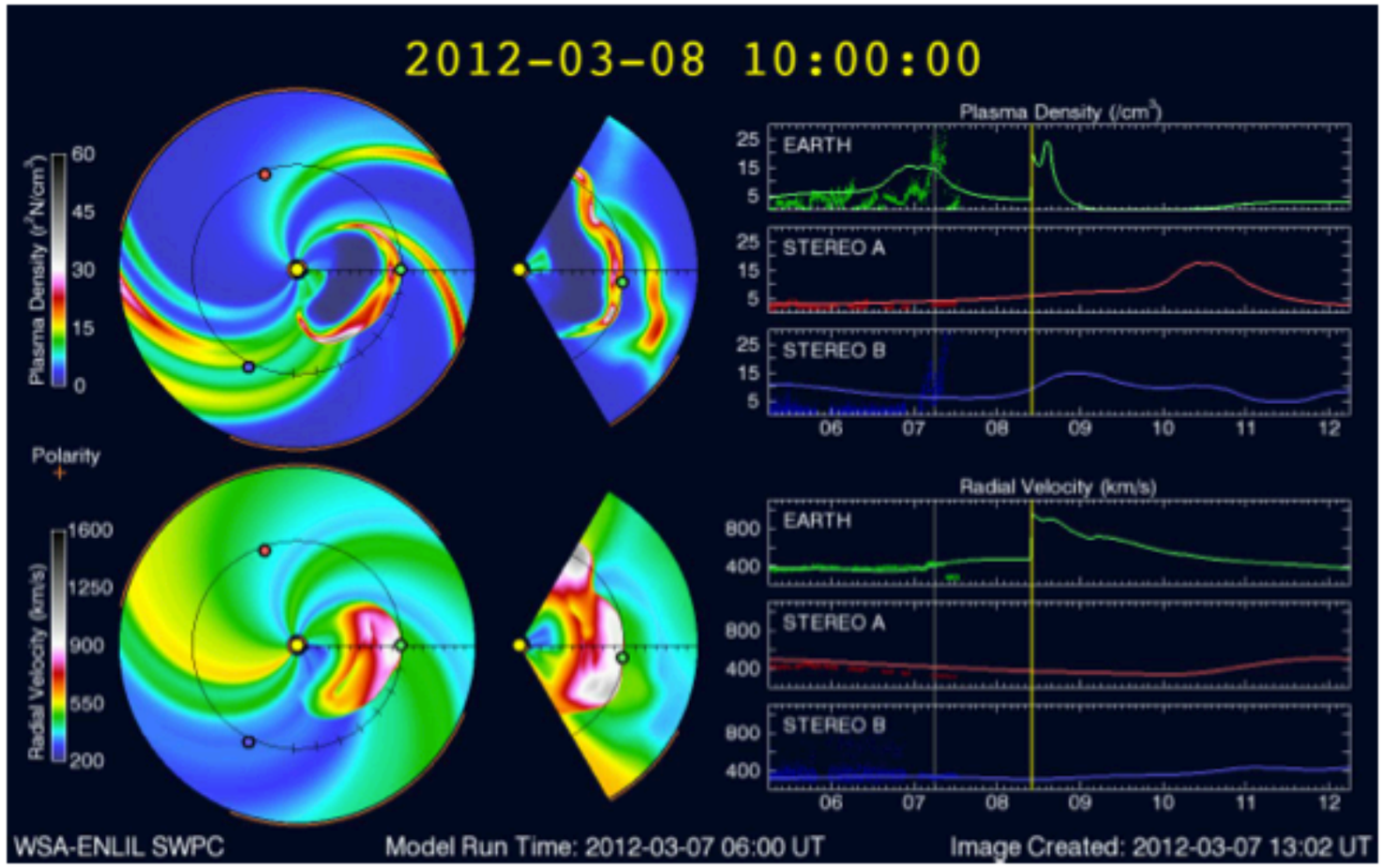
Space Weather Forecasts



WSA-Enlil CME Model

Space Weather Forecasts

- WSA/Enlil model indicated Mar 8, 10UTC arrival at Earth.
- A “G3 Watch” was issued Mar 7 at 17:42UTC…17 hours before the storm onset.
- Stronger storming was expected on Mar 8, but solar wind not suitable for stronger storming until Mar 9.

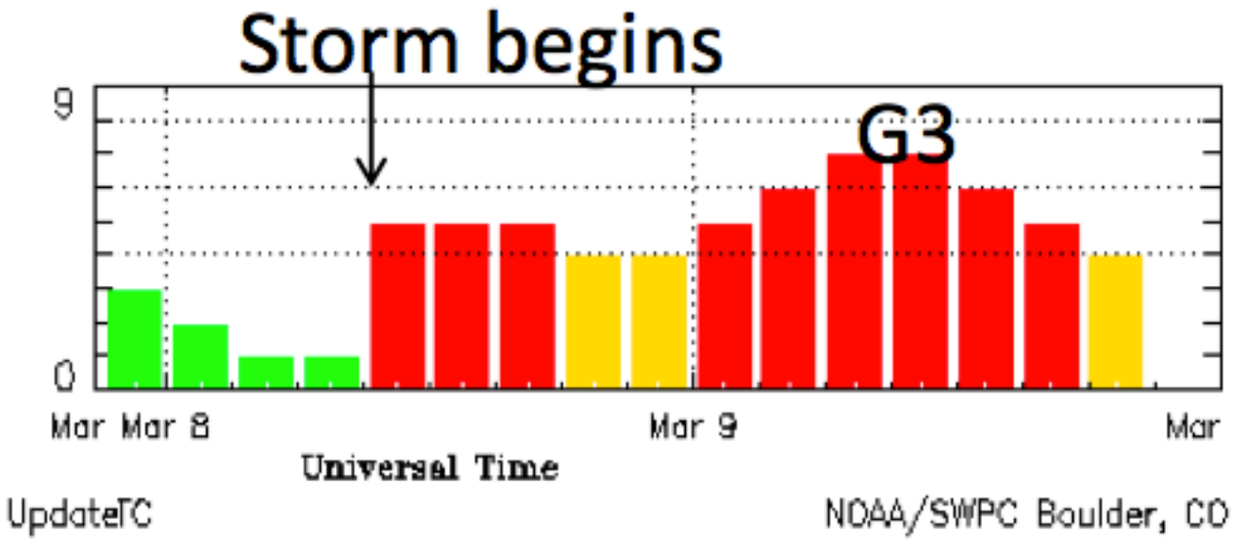


Geomagnetic Storm Forecast:

“The arrival time is estimated to be Mar 8 at 06:00-10:00UTC.”

“Periods reaching the G3 (Strong) Level Likely”

Actual: Arrival: Mar 8, 11:05UTC
Intensity: G3 storm



Space Weather Scales

NOAA Space Weather Scales

Category	Scale	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems can experience complete collapse or blackouts. Transformers can experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.)**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and southern California (typically ~50° geomagnetic lat.)**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.)**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbital predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.)**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine)**	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.
** For specific locations around the globe, see geomagnetic.ki.edu/tools/ovation/ (experimental) or www.swpc.noaa.gov/Aurora/

Solar Radiation Storms			≥10 MeV particles (pfu)*	Number of events when fluence level was met (number of storm days)**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extravehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: satellites may be overwhelmed, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems, star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight solar panel efficiency decline possible. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crews in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

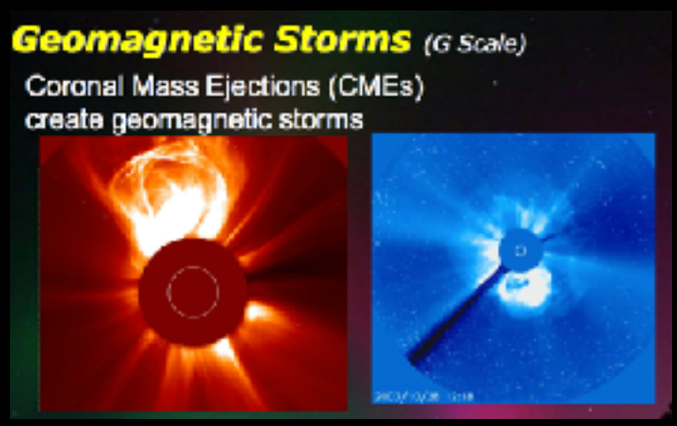
* Flux levels are 5 minute averages. Event based on this measure, but other physical measures are also considered.
** Time events can last more than one day.
*** High energy particles (>400 MeV) pose substantial radiation risk to passengers and crews. Pregnant women are particularly susceptible.

Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when fluence level was met (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	450 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux measured in the 0.1-0.8nm range in W/m^2. Based on this measure, but other physical measures are also considered.
** Other frequencies may also be affected by these conditions.

URL: www.swpc.noaa.gov/NOAAscales/

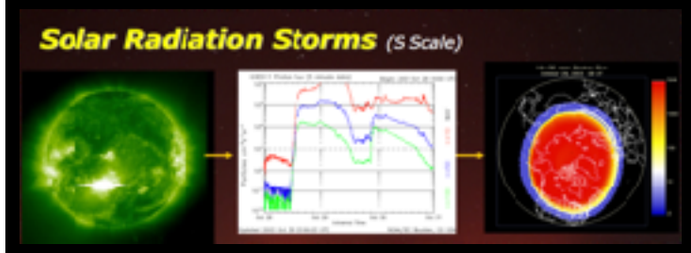
April 7, 2001



Arrival: 20 - 90 hours
Duration: hours to a day

IMPACTS:

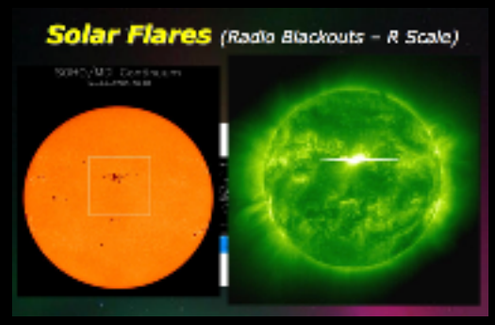
- Power grid operations
- Satellite operation
- Aircraft operations
- GPS
- Pipelines



Arrival: 30 min to several hours
Duration: hours to days

IMPACTS:

- Satellite operation/loss
- Aviation (comm/exposures)
- HF outage (polar regions)
- Manned spaceflight



Arrival: 8 min 20 s
Duration: minutes to 3 hours

IMPACTS:

- GPS network
- Communication (ground/Space)
- Radar
- Manned spaceflight

Space weather warnings

http://www.swpc.noaa.gov/

SPACE WEATHER PREDICTION CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Tuesday, November 08, 2016 07:03:07 UTC

HOME | ABOUT SPACE WEATHER | PRODUCTS AND DATA | DASHBOARDS | MEDIA AND RESOURCES | SUBSCRIBE | ANNUAL MEETING | FEEDBACK

Search

SPACE WEATHER CONDITIONS on NOAA Scales

24-Hour Observed Maximums: R none | S none | G none

Latest Observed: R none | S none | G none

Predicted 2016-11-08 UTC: R1-R2 1% | R3-R5 1% | S1 or greater 1% | G1 minor

Solar Wind Speed: **295** km/sec

Solar Wind Magnetic Fields: Bt **5** nT, Bz **4** nT

Noon 10.7cm Radio Flux: **77** sfu

G1 (Minor) Watch in Effect for the 8 November UTC-day
published: Monday, November 07, 2016 17:58 UTC
A G1 (Minor) geomagnetic storm watch is in effect for the 8 November, 2016 UTC-day.

Executive Order to Prepare Nation for Space Weather Events
published: Monday, November 07, 2016 16:51 UTC
An Executive Order to coordinate efforts to prepare the nation for space weather events was signed by President Obama on 13 Oct. Read the full ord

NWS Fall Safety Campaign is On
published: Monday, November 07, 2016 16:50 UTC
As the days get shorter and temperatures fall, a new round of weather hazards are on the rise.

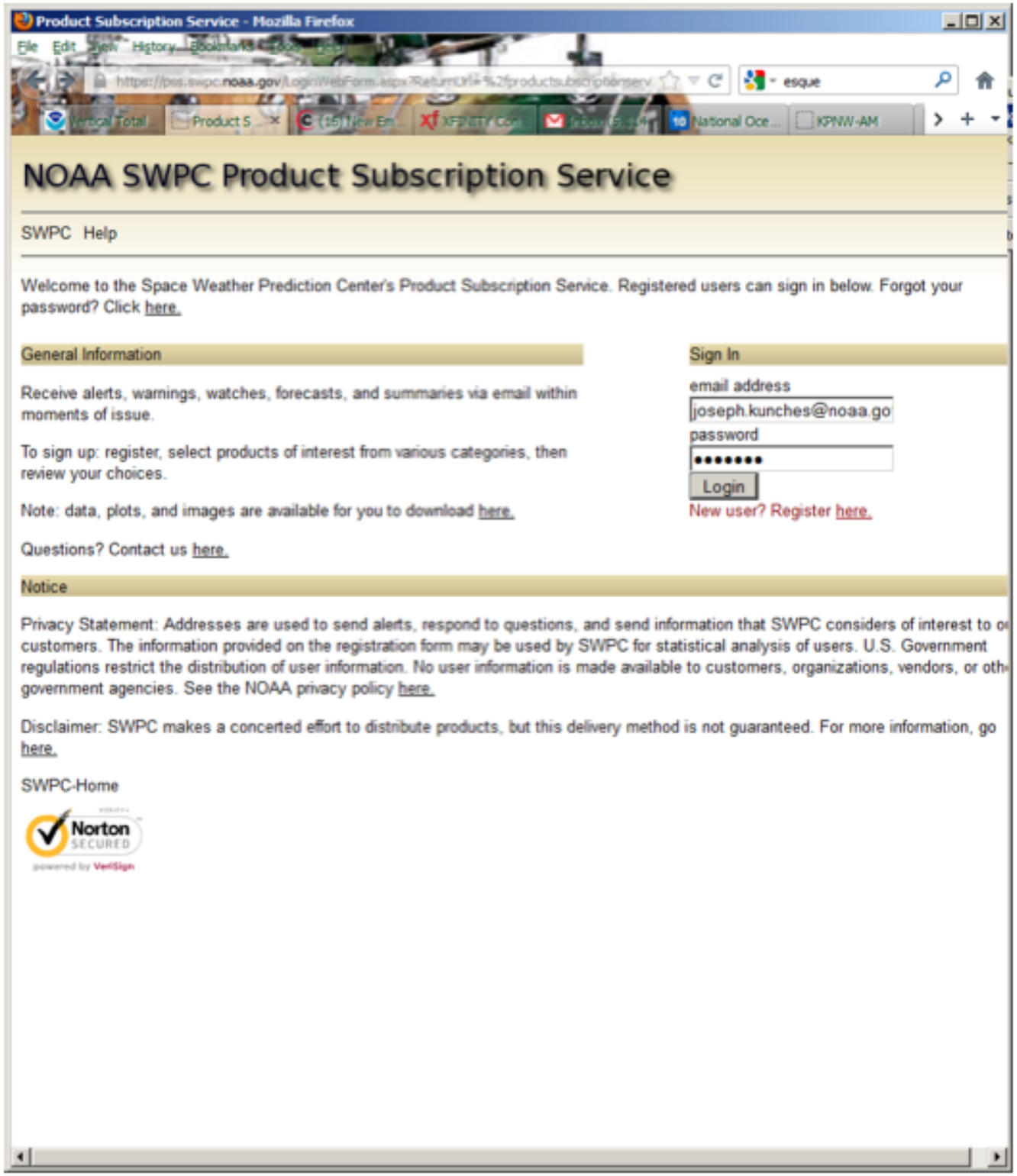
New Experimental Regional Geomagnetic Products Available
published: Monday, November 07, 2016 14:22 UTC
SWPC deployed experimental products from the new operational Geospace model on Oct 5th.

SERVING ESSENTIAL SPACE WEATHER COMMUNITIES

Aviation
Radio Communications
Electric Power
Satellites
Emergency Management
Space Weather Enthusiasts
Global Positioning System (GPS)

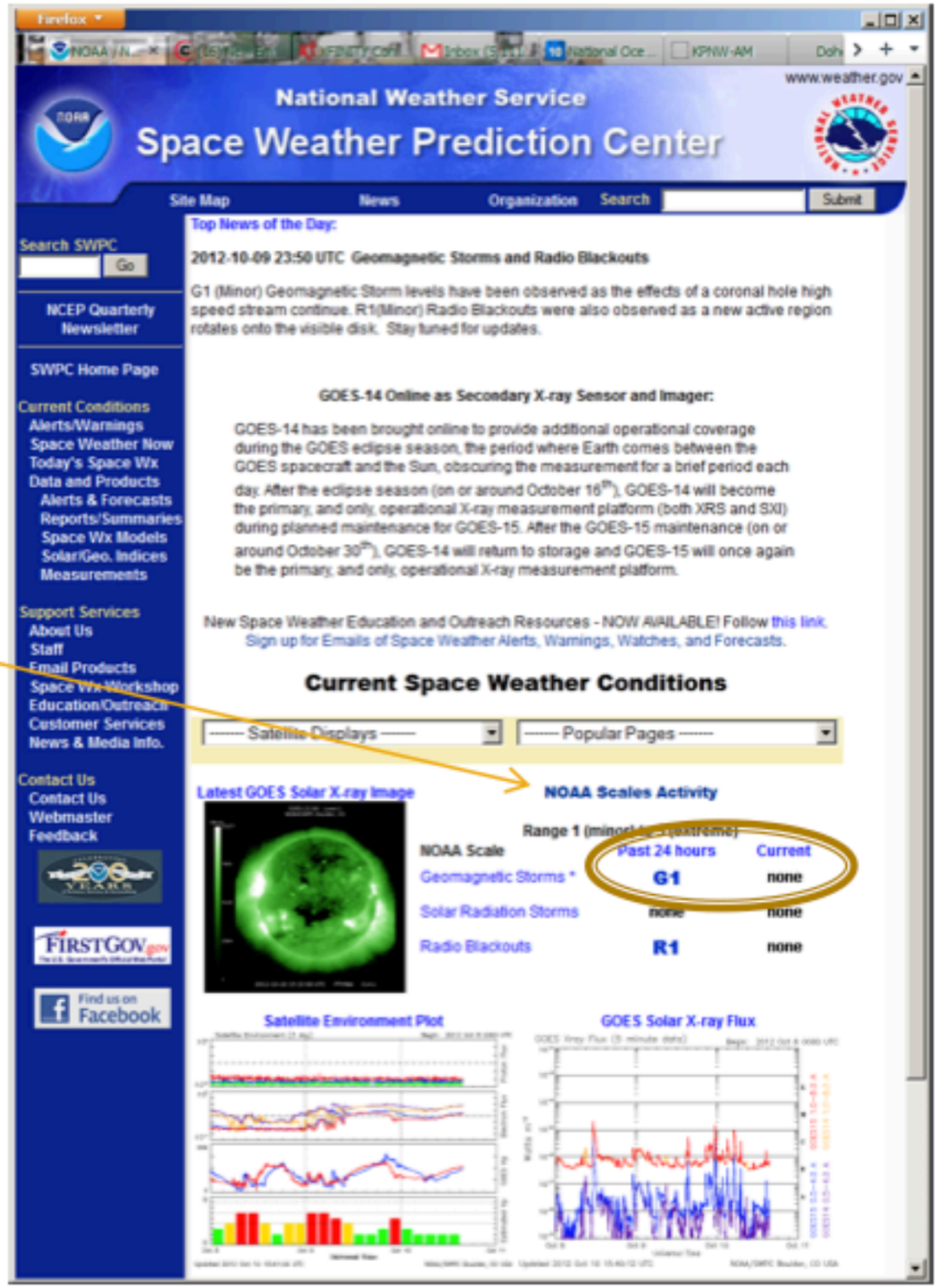
Space Weather Forecasts

- Subscribe to email alerts, warnings, and watches
- Suggest a Geomagnetic Storm Scale threshold of G2 or greater



Space Weather Forecasts

- Go to SWPC web site www.swpc.noaa.gov
- Focus on NOAA Scale
- If G2 or greater, possible impact to GNSS operations



ESA SSA Space Weather

http://sidc.oma.be/

esa space situational awareness

ESA SSA SWE NEO SST

About SWE
- What is Space Weather
- SSA Space Weather Activities
- Current Space Weather
- Contact

Service Domains
- Spacecraft Design
- Spacecraft Operation
- Human Space Flight
- Launch Operation
- Transionospheric Radio Link
- Space Surveillance and Tracking
- Power Systems Operation
- Airlines
- Resource Exploitation System Operation
- General Data Service

Expert Service Centres
- ESC Solar Weather
- ESC Space Radiation
- ESC Ionospheric Weather
- ESC Geomagnetic Conditions
- ESC Heliospheric Weather

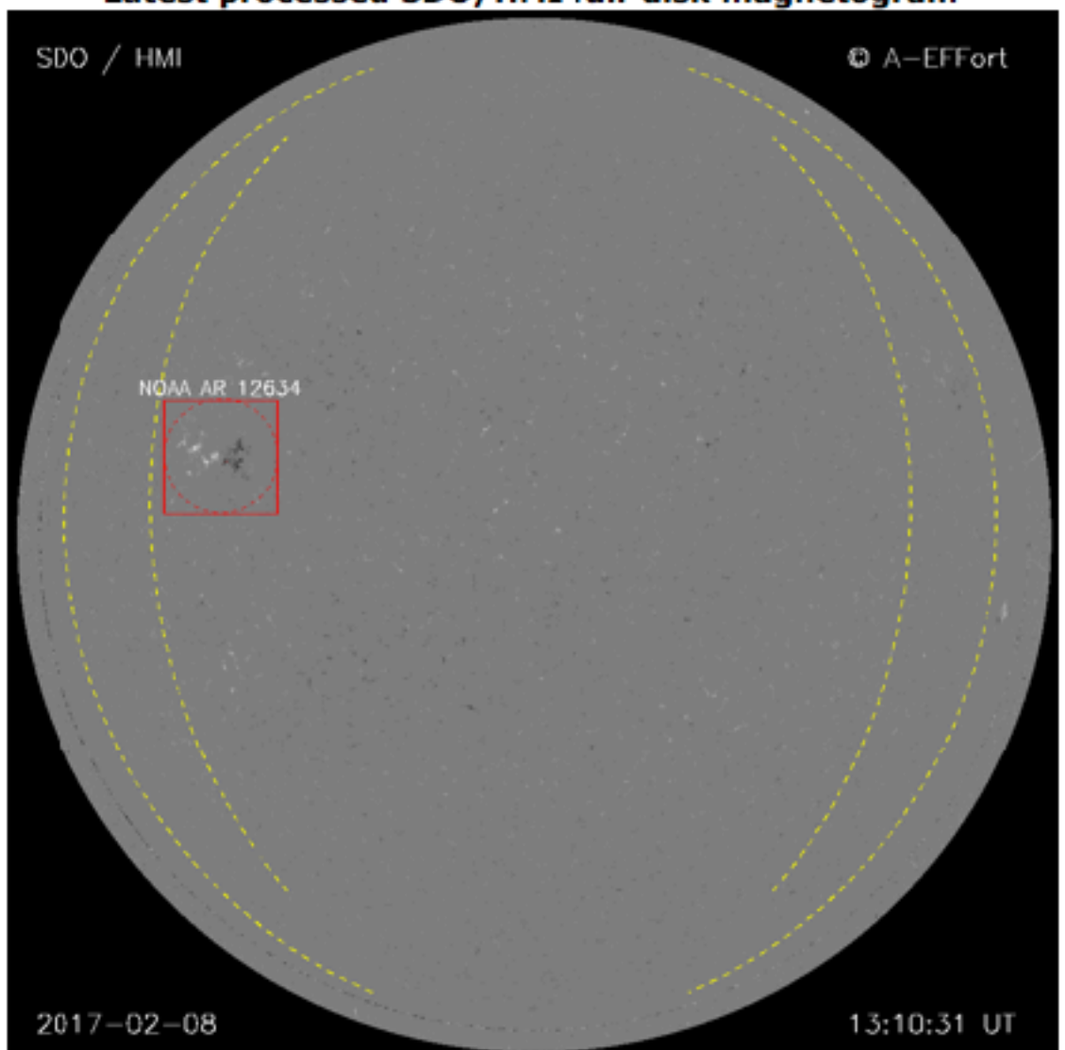
Other Resources
- Documents
- SWWT
- SWEN NewsLetter
- Upcoming Events

Welcome to the SSA Space Weather Service Network

Please note that all SSA-SWE Services are under review/construction

WC-Belgium forecast of 08 Feb 2017, Flares: Quiet, Geomagnetism: Active,

Latest processed SDO/HMI full-disk magnetogram



Norwegian Center for Space Weather

http://site.uit.no/spaceweather/

UiT THE ARCTIC UNIVERSITY OF NORWAY

Norwegian Center for Space Weather

Search this website...

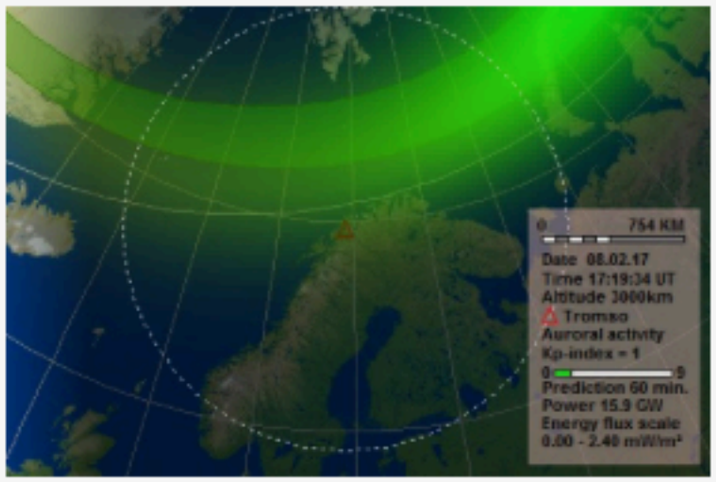
HOME | DATA AND PRODUCTS | BLOG | LINKS | CONTACT

GEOMAGNETIC SUMMARY AND FORECAST

	Last 24-3 h	Last 3-1 h	Last 1h	Now	Next 1h
Auoral zone (Tromsø)	Moderate	quiet	quiet	quiet	quiet
Sub-Auroral zone (Dombås)	quiet	quiet	quiet	quiet	quiet

Updated Wed Feb 8 16:27:00 UTC 2017

NORTHERN LIGHTS IN THE NEXT HOUR



NOSWE
event analysis tool

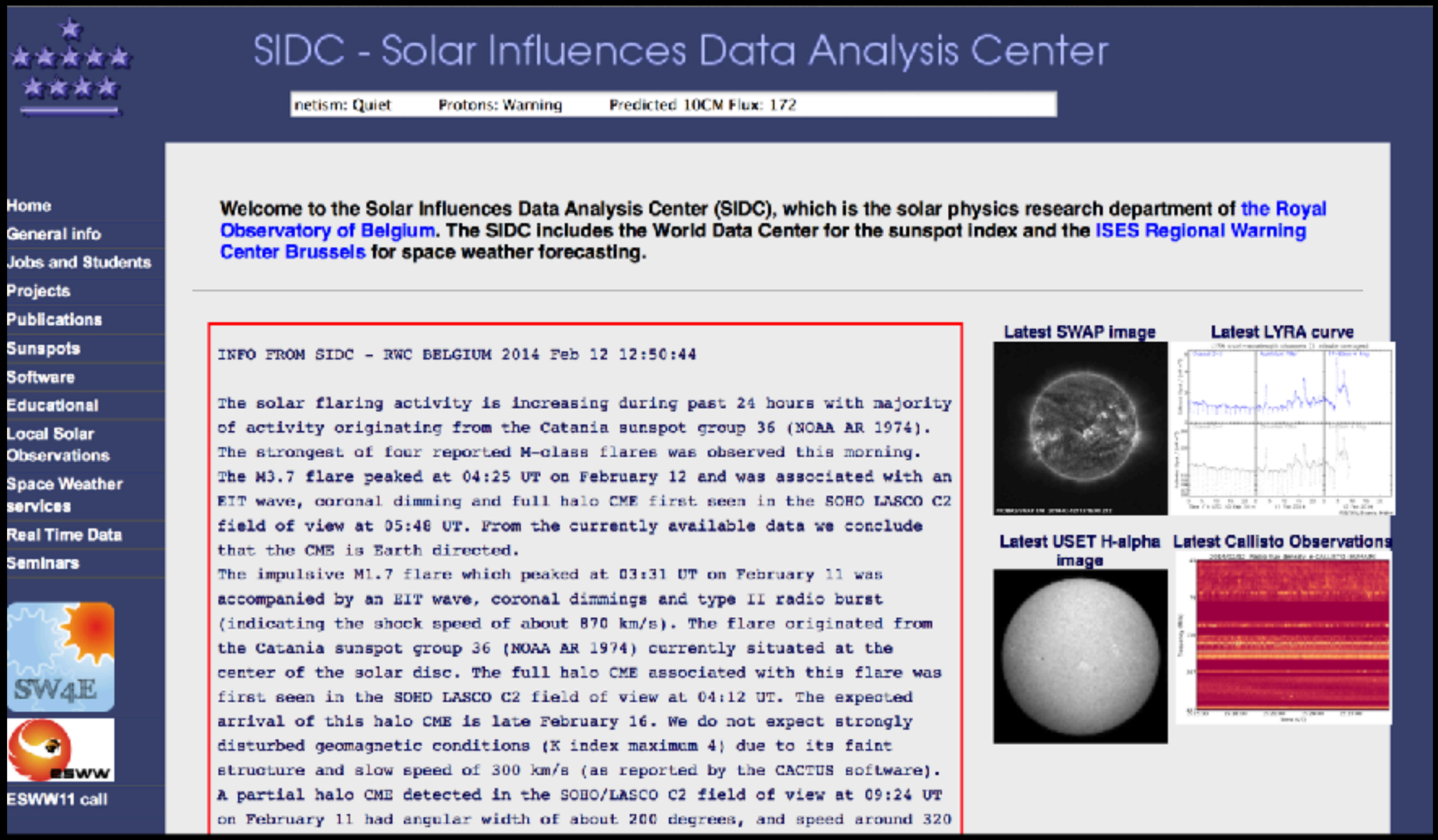
Solar Wind conditions

V_x:	465.4 km/s
B_z:	4.1 nT
X-Ray:	6.51e-08 W/m^2

[Ref. NOAA Space Weather Prediction Center]

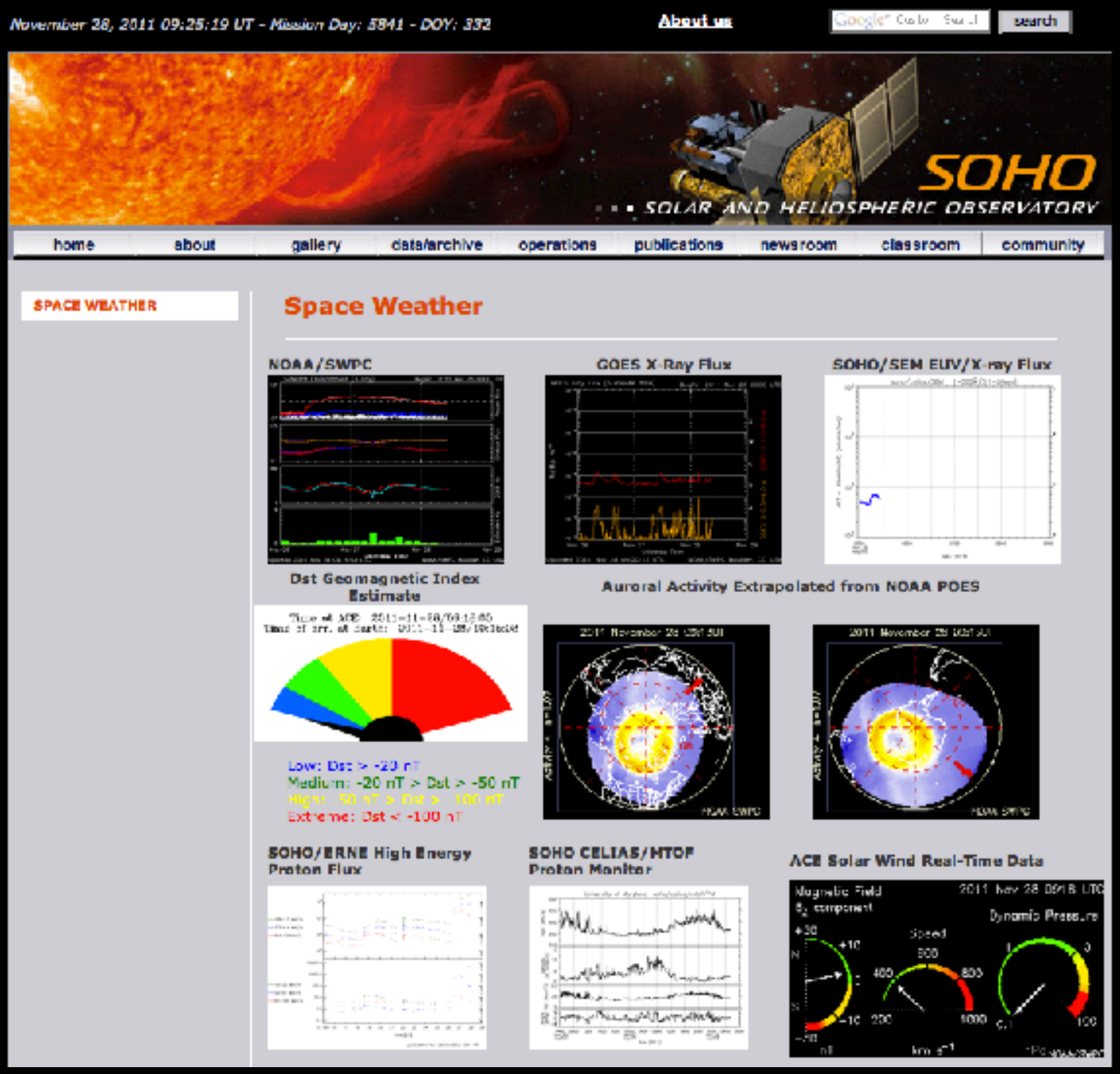
-Last Updated: 2017-02-08 1615 UTC

http://sidc.oma.be/



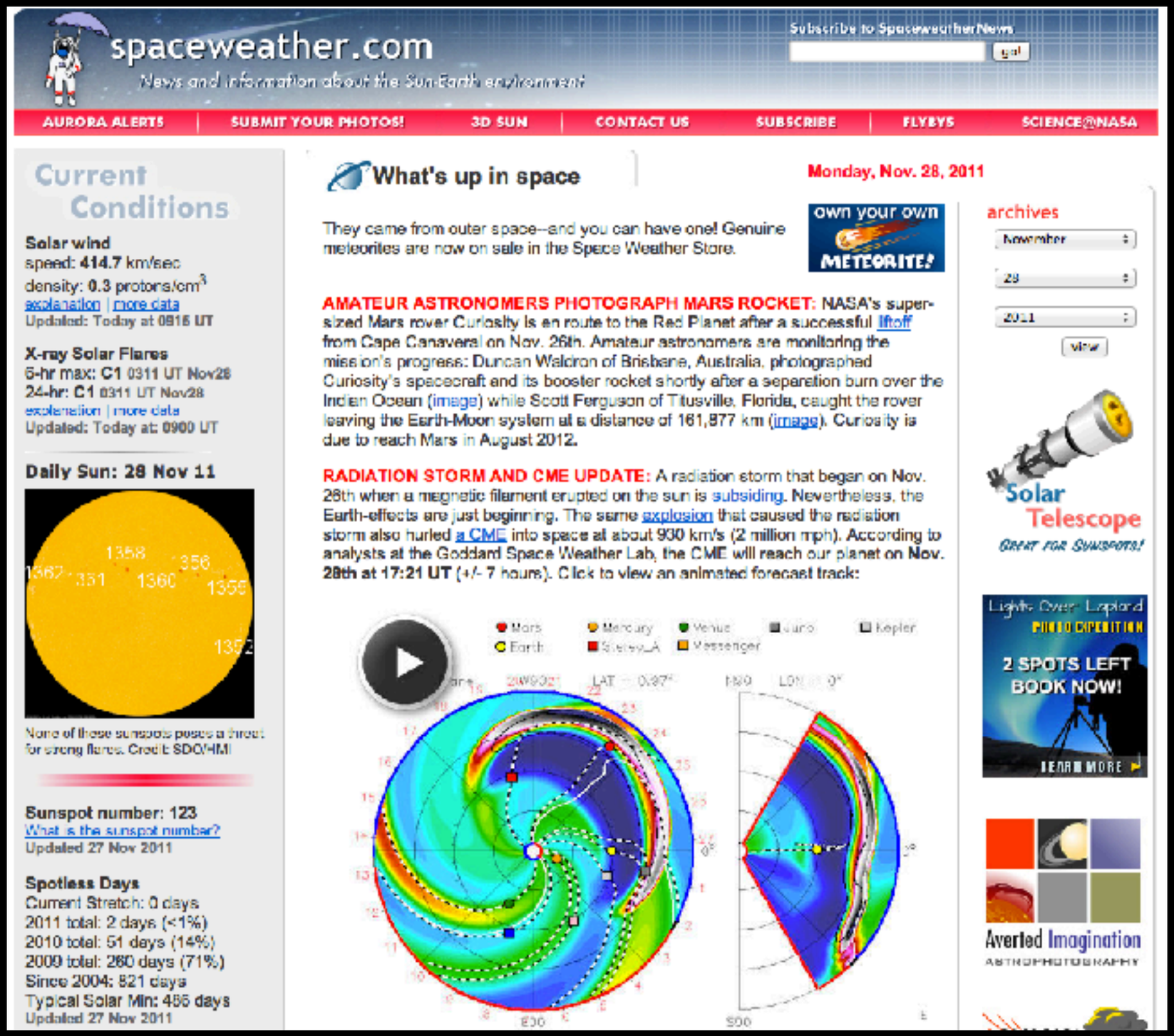
Space weather warnings

http://soho.nascom.nasa.gov/spaceweather/



Space weather warnings

www.spaceweather.com



The aurora over North-America tonight

http://www.gi.alaska.edu/AuroraForecast

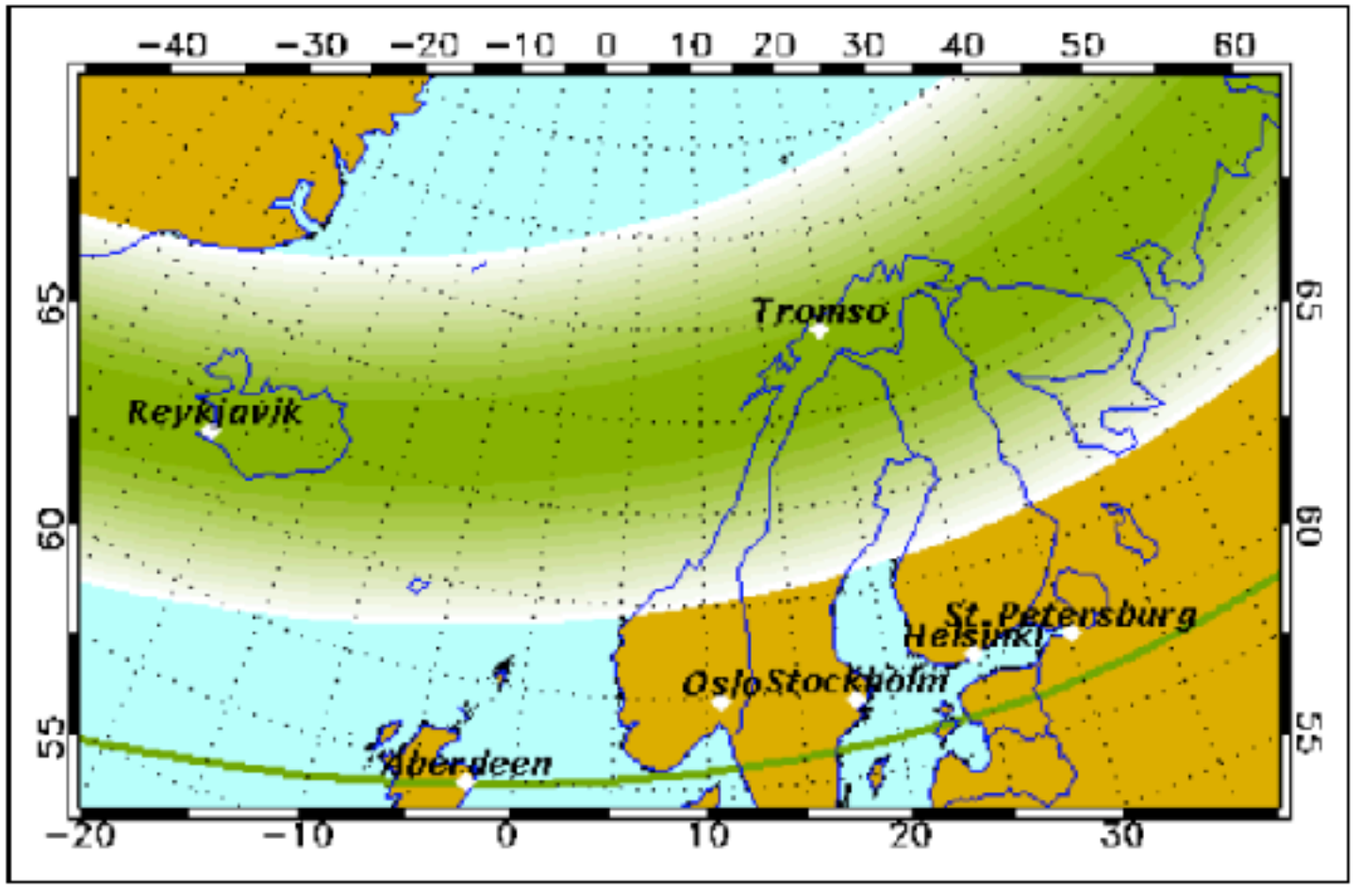
UNIVERSITY OF ALASKA FAIRBANKS

Search Sites/Directory

Geophysical Institute

home | about | public information | research | facilities | students | administration | giving

Aurora Forecast for night of Wednesday, February 8, 2017



Previous | Today | Next

Explore

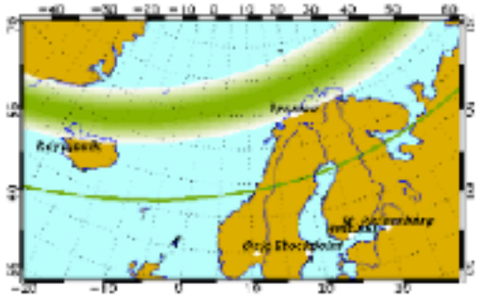
- Can I See the Aurora?
- Viewing Aurora in the Northern Summer
- Traveler's Guide to the Aurora
- FAQ
- Links
- 28 Day Forecast

Short-Term (1-hour) Forecast

Feb 08, 2017 16:15 GMT

(February 08, 2017 07:15 AST)

Quiet

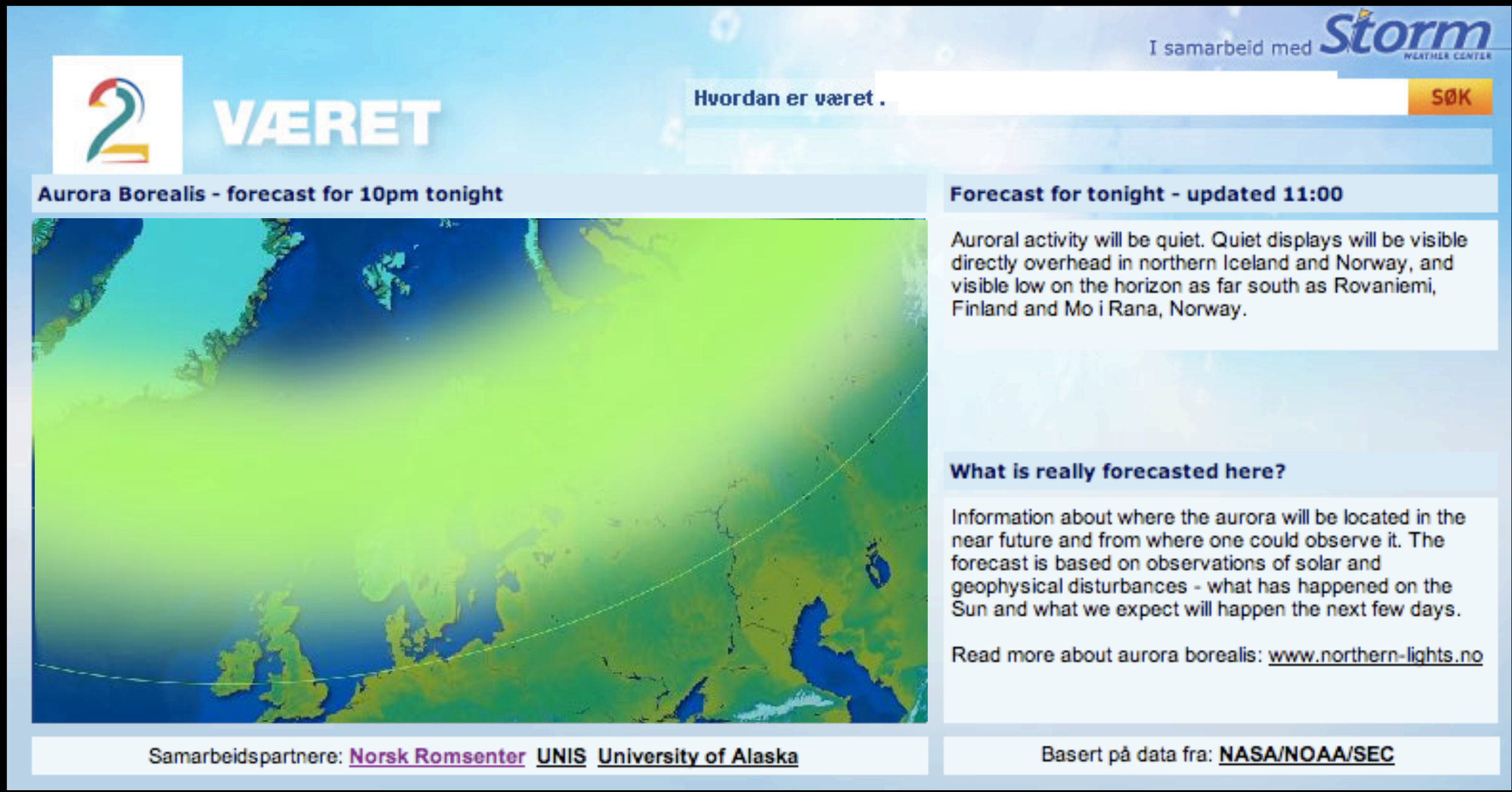


Active: 0 1 2 3 **4** 5 6 7 8 9

Forecast: Auroral activity will be active. Weather permitting, active auroral displays will be visible overhead from Tromsø, Norway to as far south as Umea, Sweden and Trondheim, Norway, and visible low on the horizon in Oslo, Stockholm and Helsinki.

Aurora forecaster in Norway

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



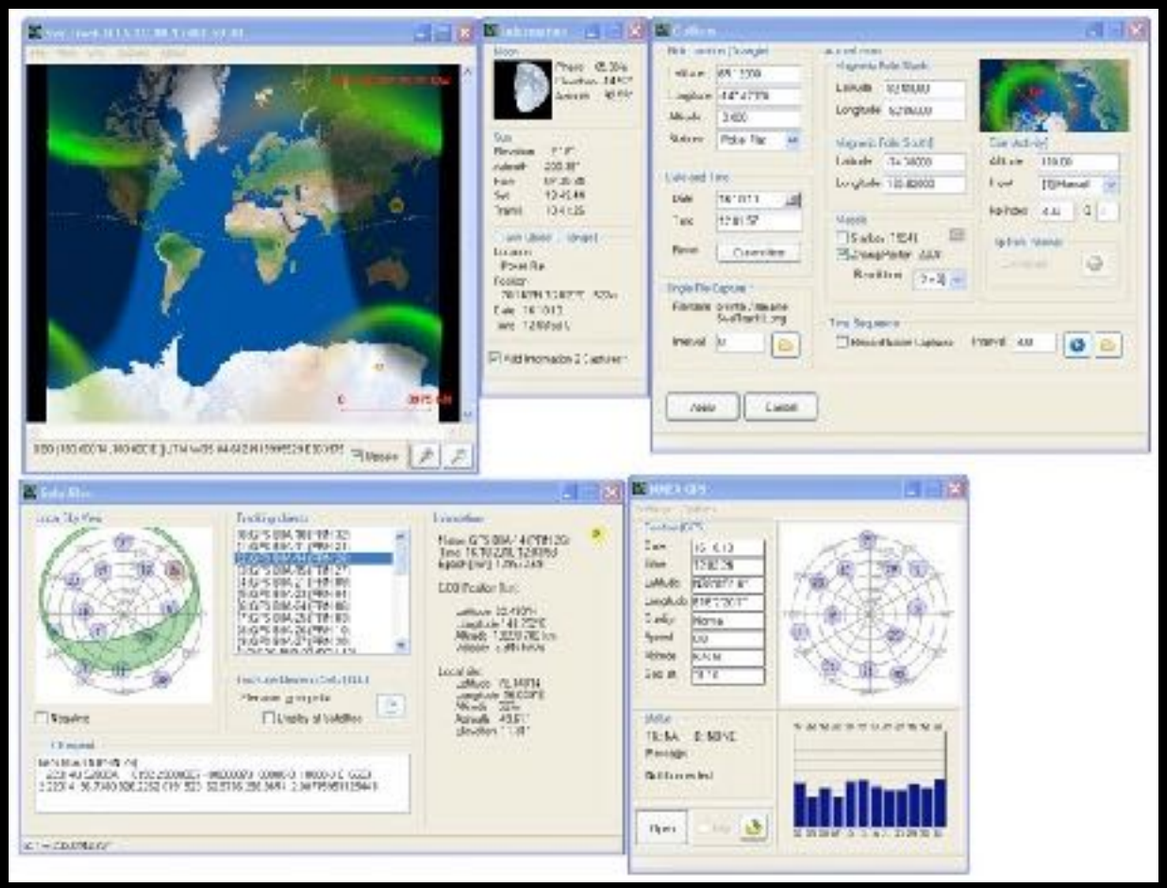
The UNIS Aurora forecaster

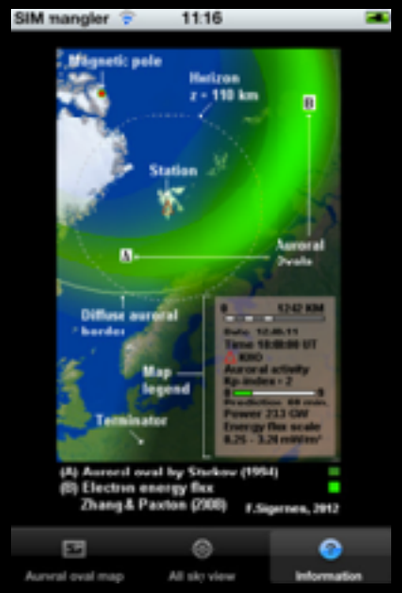
Download at: http://kho.unis.no/

Real time aurora oval forecasting - SvalTrackII

F. Sigernes [1], M. Dyrland [1], P. Brekke [2], E. K. Gjengedal [3], S. Chernouss [4], D. A. Lorentzen [1], K. Oksavik [1] and C. S. Deehr [5]

The 37th Annual European Meeting on Atmospheric by Optical Methods, Valladolid, Spain, 23 - 27 August 2010.

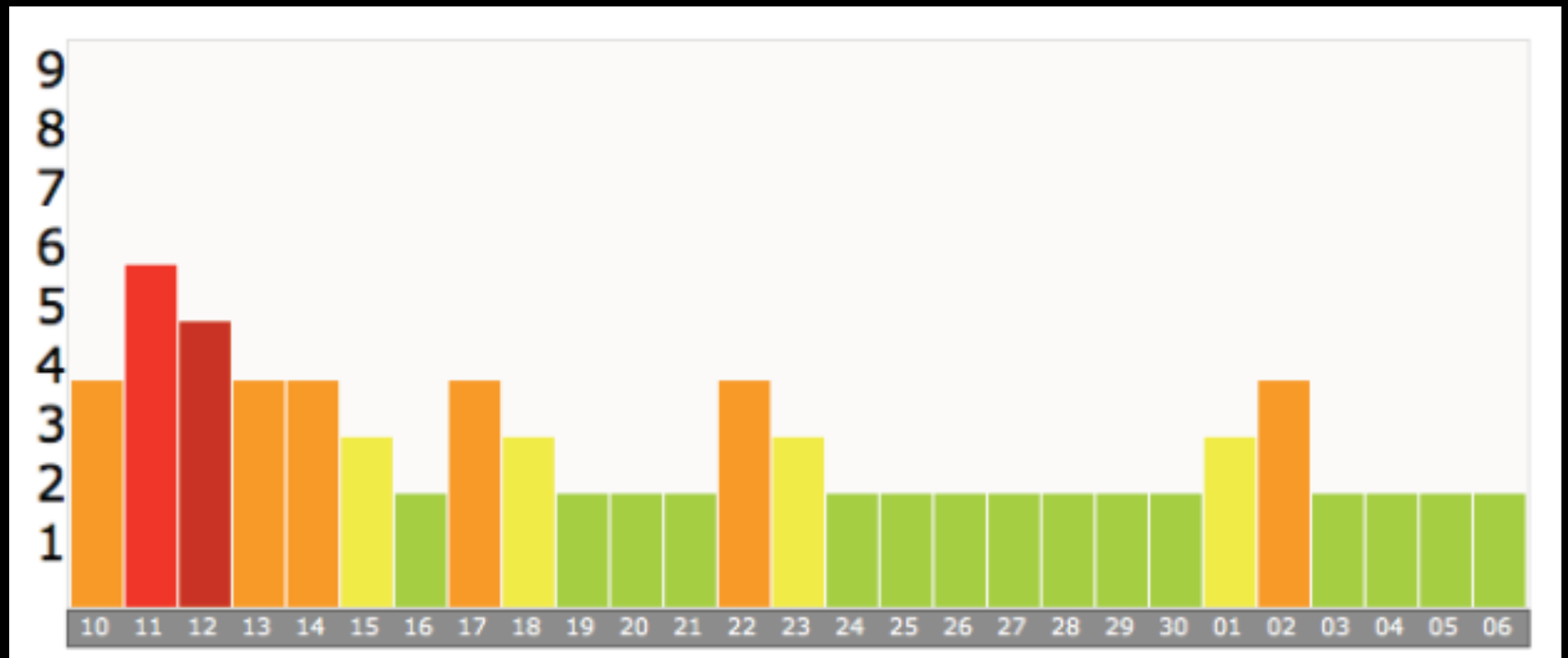


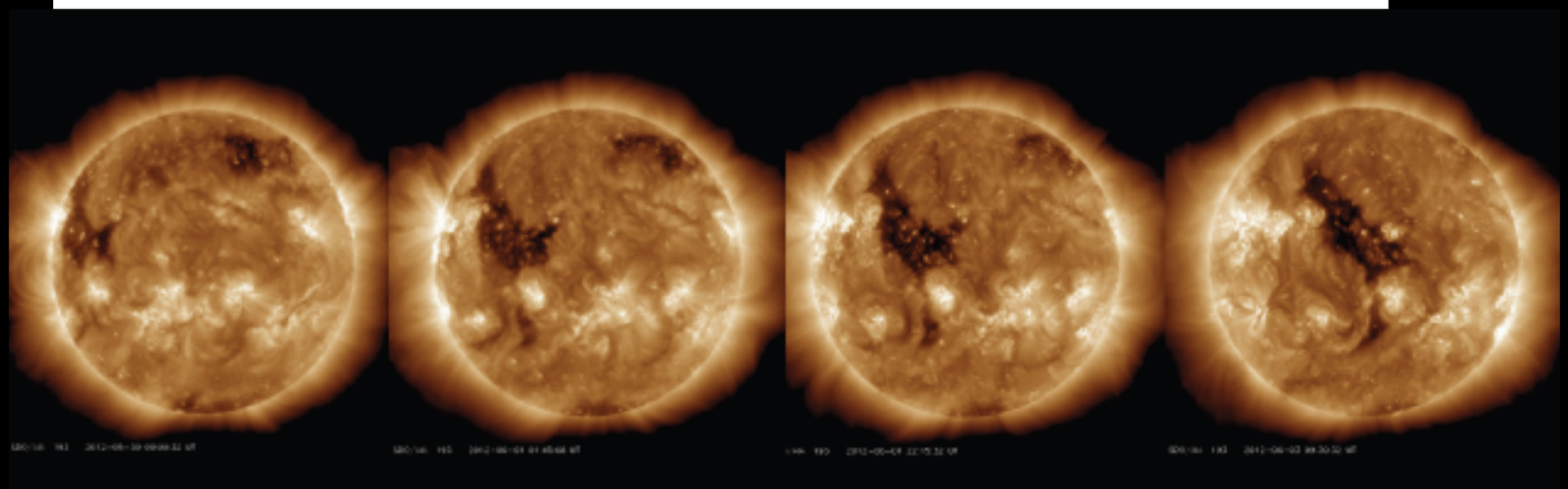


Long term forecasting

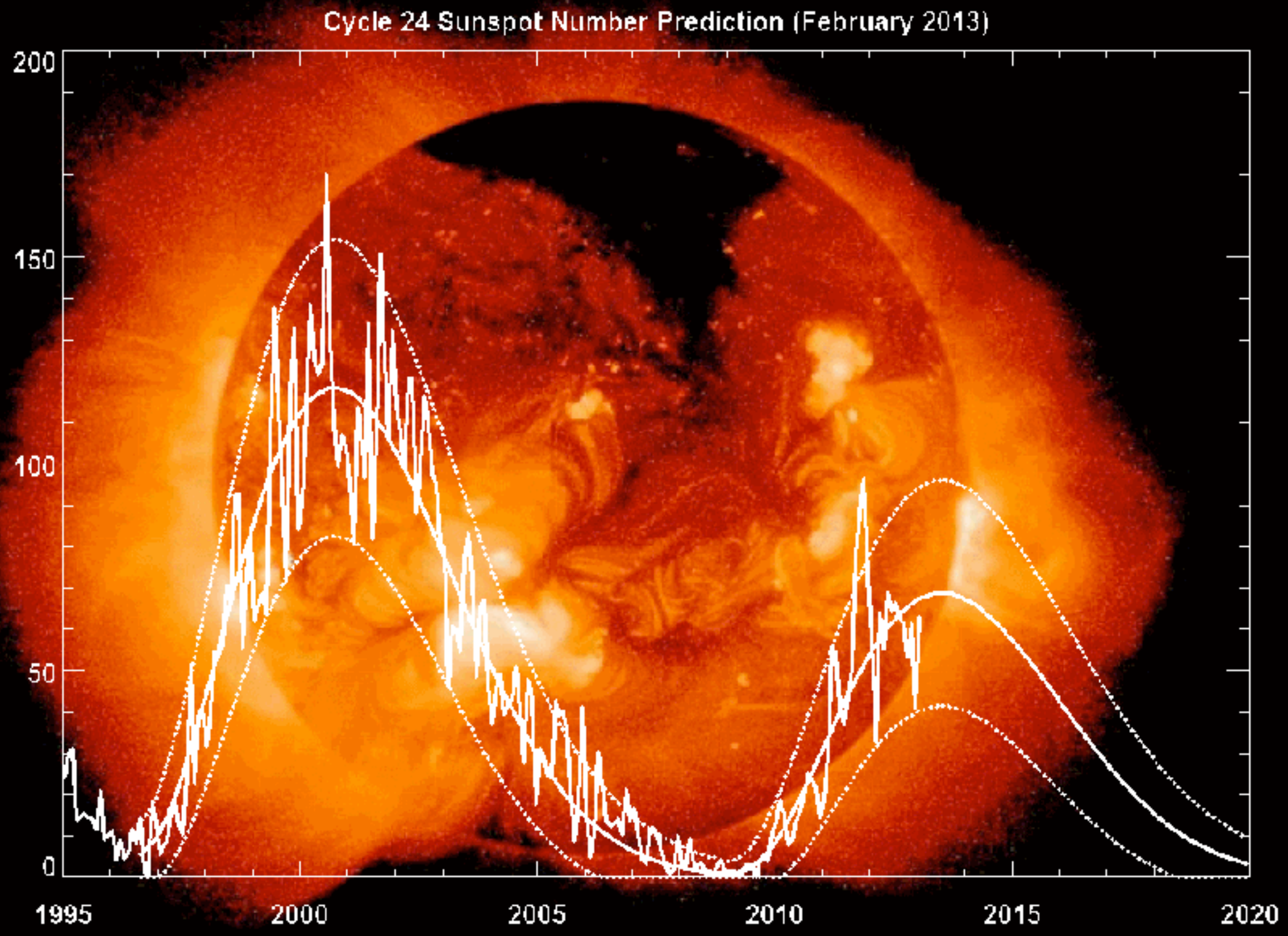
Coronal holes appear as dark areas in the solar corona in extreme ultraviolet (EUV) and soft x-ray solar images. They appear dark because they are cooler, less dense regions than the surrounding plasma and are regions of open, unipolar magnetic fields. This open, magnetic field line structure allows the solar wind to escape more readily into space, resulting in streams of relatively fast solar wind and is often referred to as a high speed stream in the context of analysis of structures in interplanetary space.

Persistent coronal holes are long-lasting sources for high speed solar wind streams.

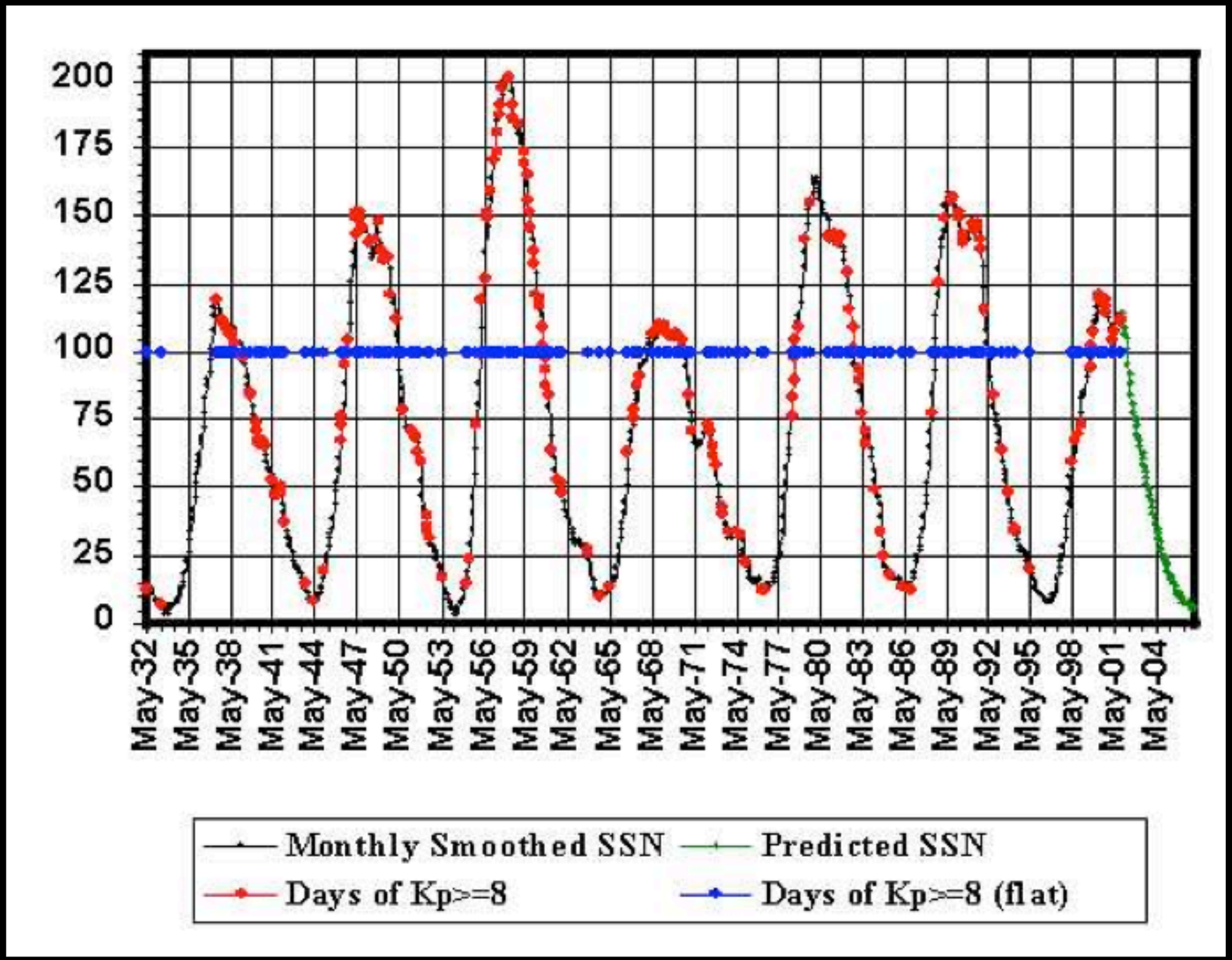




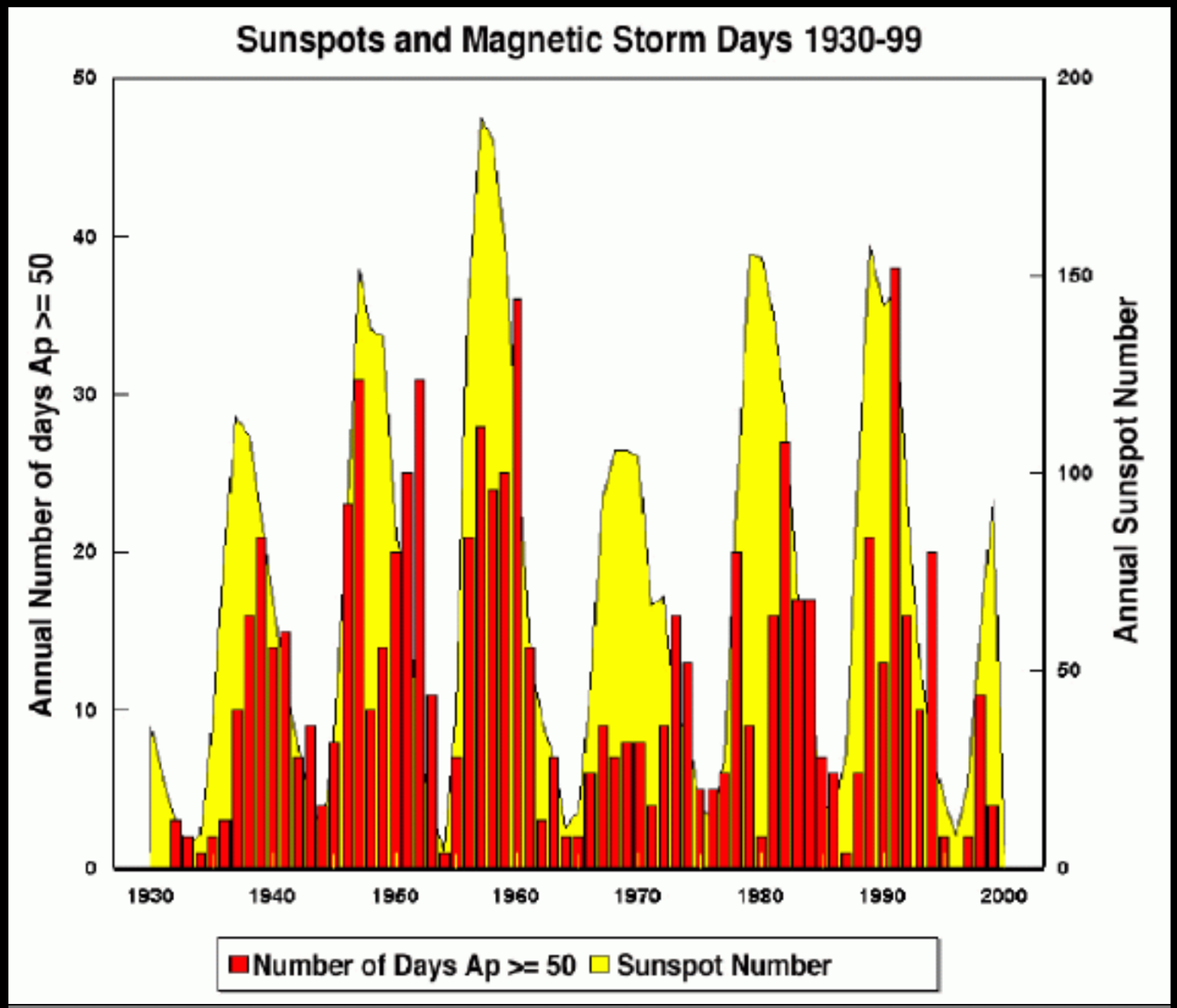
When do strong storms occure?



When do strong storms occure?



Solar cycle and geomagnetic disturbances

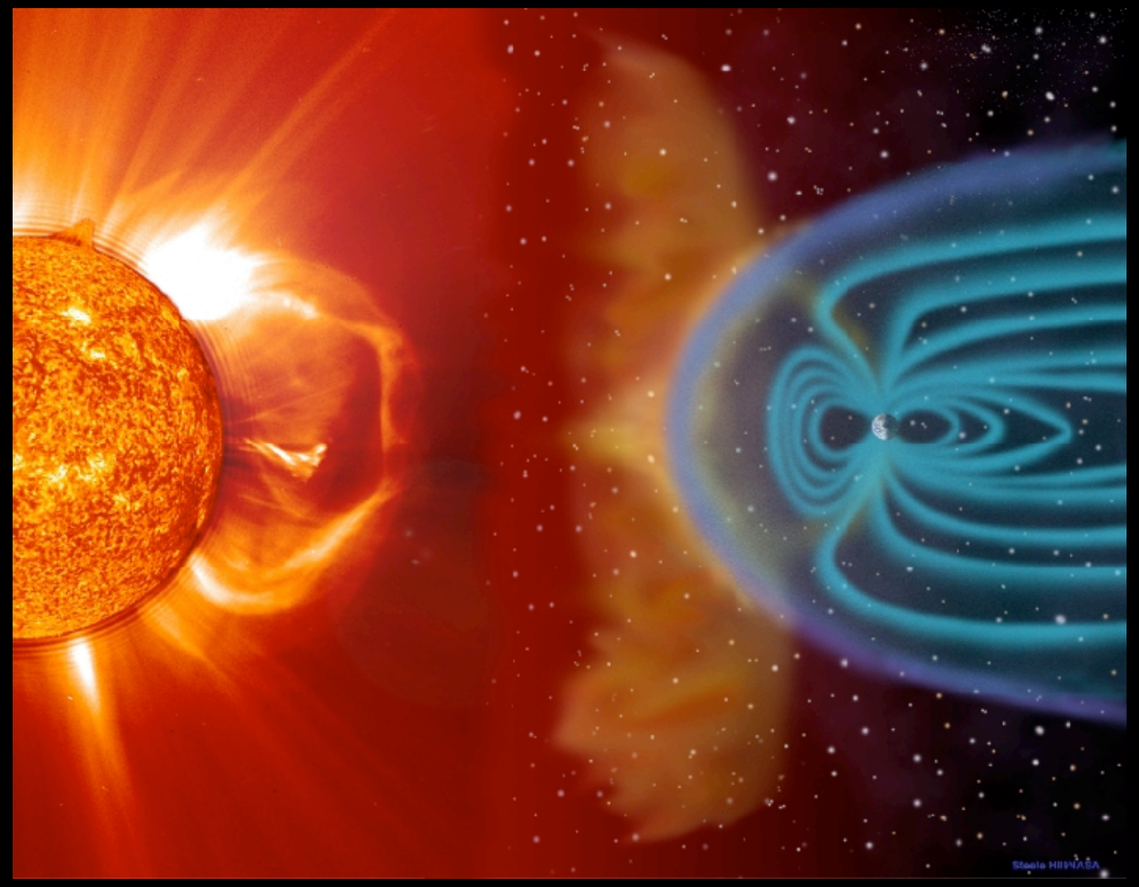


Extreme Solar Weather Has Happened Before

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.

Super Storms

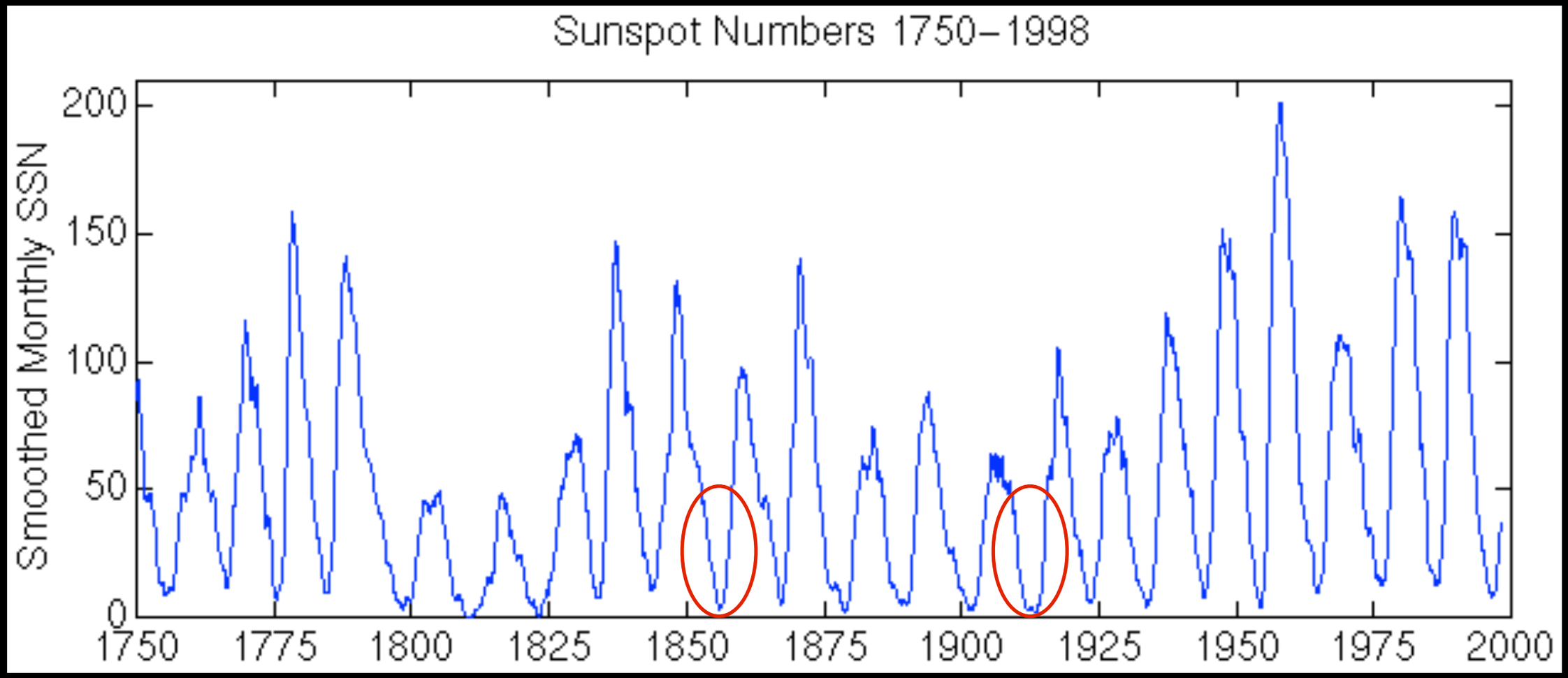


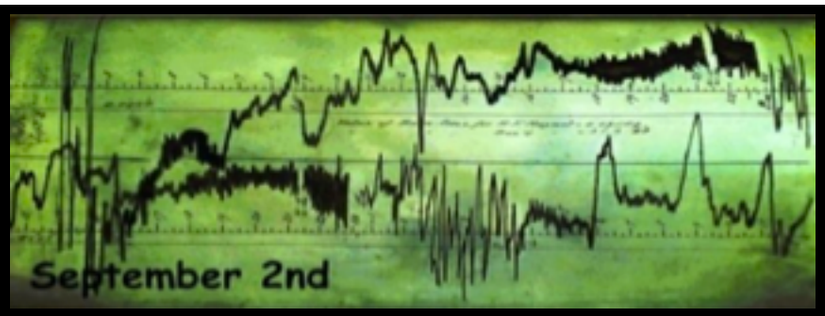
http://www.nap.edu/catalog.php?record_id=12507

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.

When do strong storms occure?





1859 Storm

1921 Storm

Current Space Weather conditions

SPACE WEATHER PREDICTION CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Wednesday, February 08, 2017 09:54:29 UTC

HOME | ABOUT SPACE WEATHER | PRODUCTS AND DATA | DASHBOARDS | MEDIA AND RESOURCES | SUBSCRIBE | ANNUAL MEETING | FEEDBACK

Search

SPACE WEATHER CONDITIONS on NOAA Scales

	R	S	G
24-Hour Observed Maximums	none	none	none
Latest Observed	none	none	none

Predicted 2017-02-08 UTC

R1-R2	1%	S1 or greater	1%	G none
R3-R5	1%			

Solar Wind Speed: **486** km/sec

Solar Wind Magnetic Fields: Bt **4** nT, Bz **0** nT

Noon 10.7cm Radio Flux: **72** sfu

Latest GOES Satellite now in Successful Orbit; Re-designated GOES-16
published: Thursday, December 01, 2016 21:47 UTC
On November 29, 2016, the newest GOES satellite was successfully placed into geostationary orbit (approximately 22,000 miles away from Earth) and h

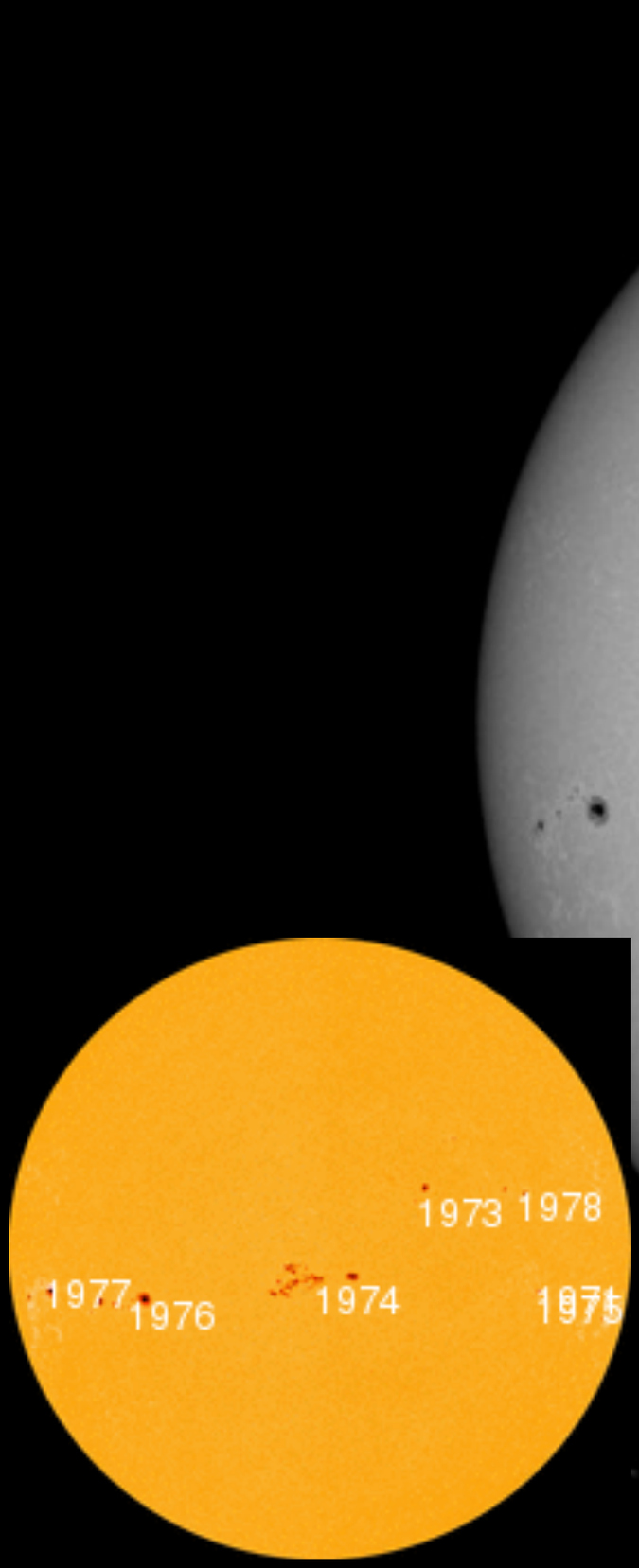
Winter Weather Preparedness and Safety Tips from the NWS
published: Thursday, December 01, 2016 05:18 UTC
Winter can bring with it a wide variety of potentially dangerous weather that can impact roadways, outdoor activities, infrastructure, and more. Be

Executive Order to Prepare Nation for Space Weather Events
published: Monday, November 07, 2016 16:51 UTC
An Executive Order to coordinate efforts to prepare the nation for space weather events was signed by President Obama on 13 Oct. Read the full ord

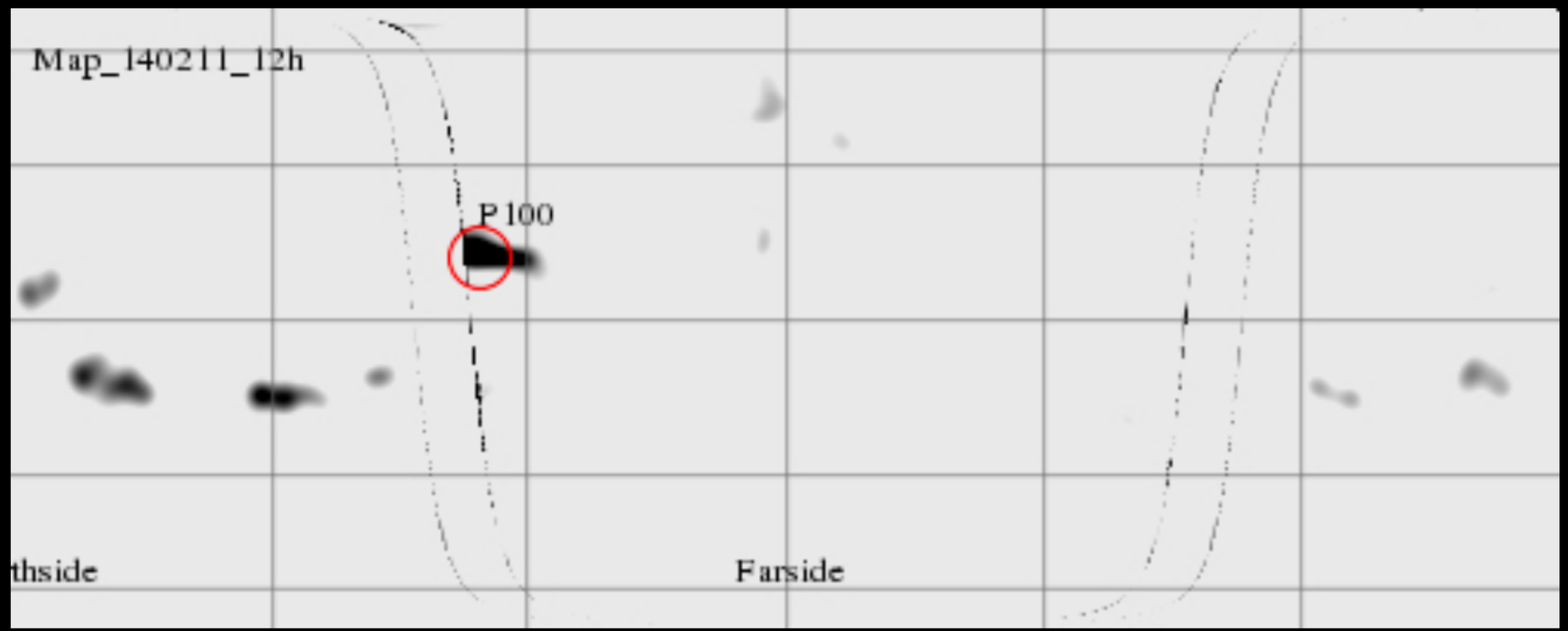
New Experimental Regional Geomagnetic Products Available
published: Monday, November 07, 2016 14:22 UTC
SWPC deployed experimental products from the new operational Geospace model on Oct 5th.

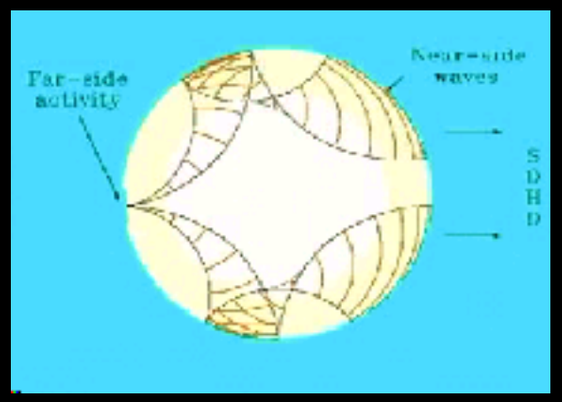
http://www.swpc.noaa.gov

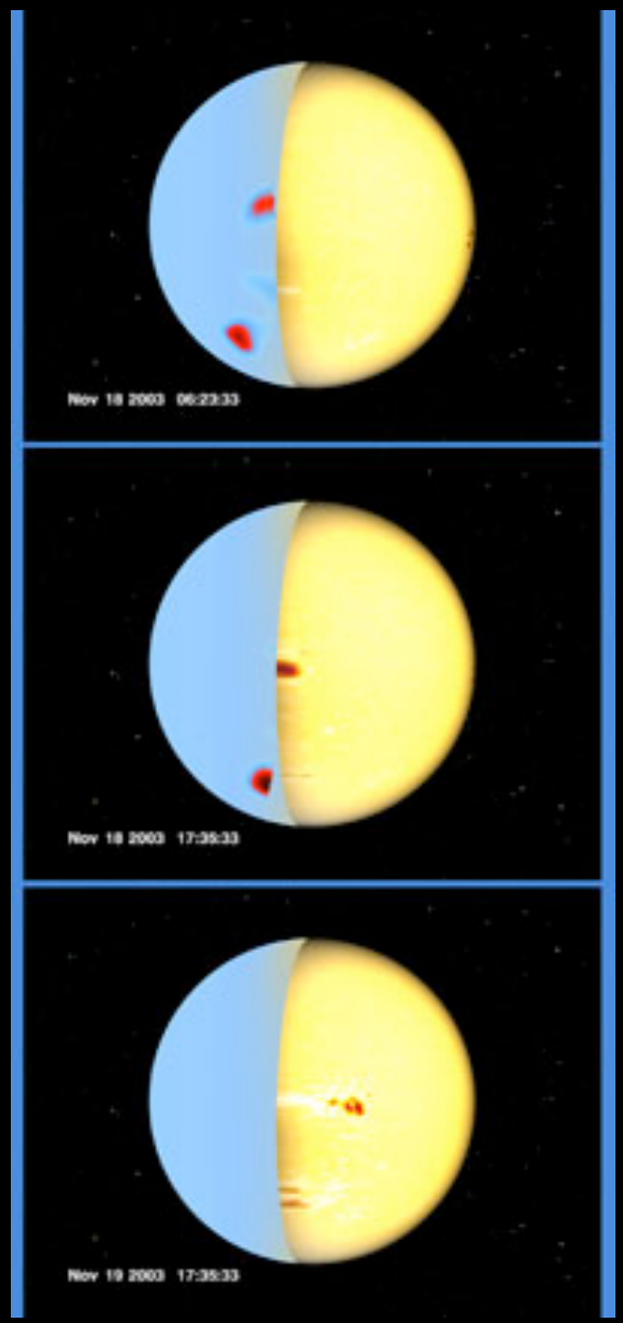
Current Solar conditions

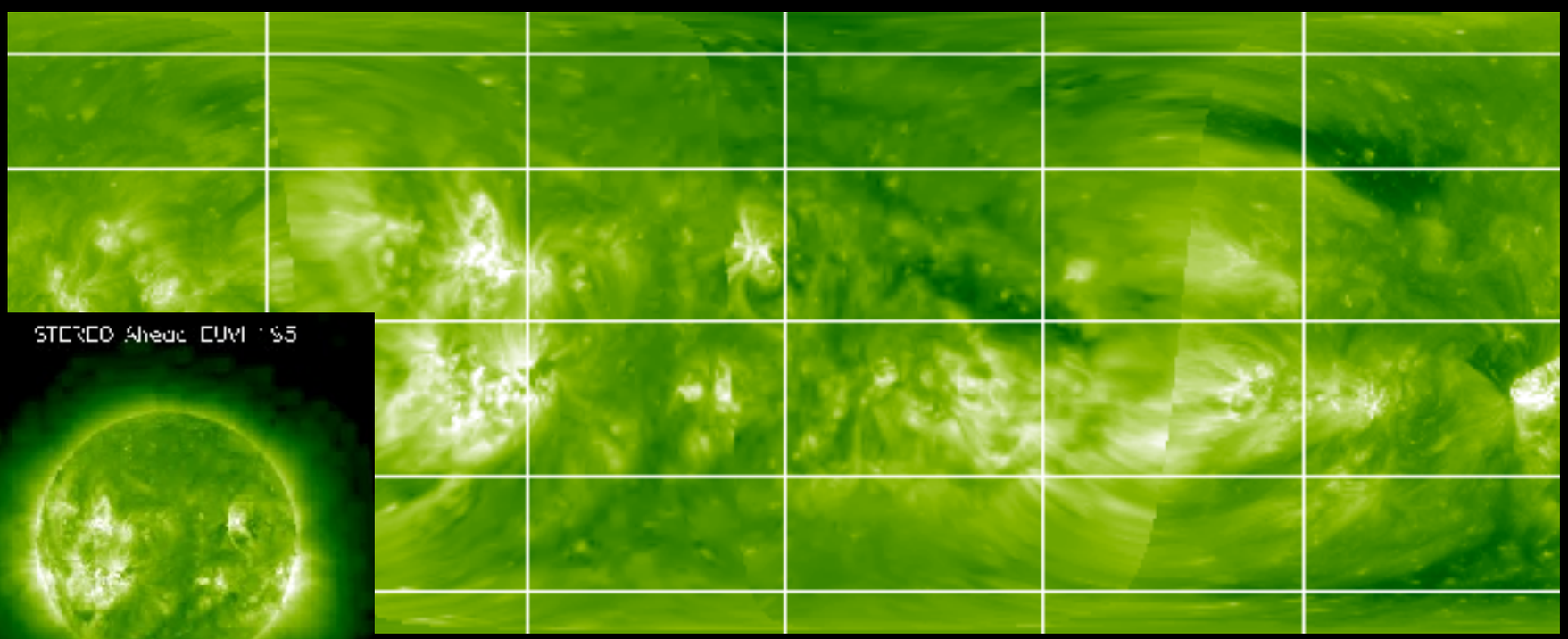


Current Solar conditions - far side









Current Solar conditions

:Issued: 2014 Feb 11 2303 UTC
:Product: documentation at http://www.sidc.be/products/presto
#----------#
FAST WARNING 'PRESTO' MESSAGE from the SIDC (RWC Belgium)
#----------#
The impulsive M1.7 flare peaked at 03:31 UT on February 11 was accompanied by an EIT wave, coronal dimmings and a very faint halo CME. The flare originated from the Catania sunspot group 36 (NOAA AR 1974) currently situated at the center of the solar disc. The full halo CME associated with this flare was first seen in the SOHO LASCO C2 field of view at 04:12 UT. The expected arrival of this halo CME is late February 16. We do not expect strongly disturbed geomagnetic conditions (K index maximum 4) due to its faint structure and slow speed of 300 km/s (as reported by the CACTUS software).
#----------#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491
# #

:Issued: 2014 Feb 11 2336 UTC
:Product: documentation at http://www.sidc.be/products/presto
#----------#
FAST WARNING 'PRESTO' MESSAGE from the SIDC (RWC Belgium)
#----------#
A partial halo CME was detected in the SOHO/LASCO C2 field of view at 09:24 UT on February 11. The CME had angular width of about 200 degrees, and speed around 320 km/s (as reported by the CACTUS software). It was associated with an eruption of a filament situated between the Catania sunspot group 35 (NOAA AR 1973) and newly emerged, unnumbered active region situated on the west from the Catania sunspot group 35. The eruption was accompanied by coronal dimmings and a post-eruption arcade observed by SDO/AIA. The bulk of the CME mass was directed northward of the Sun-Earth line, so we expect the arrival of only a CME-driven shock at the Earth, probably on February 16. It may result in active to minor storm geomagnetic conditions.
#----------#
Solar Influences Data analysis Center - RWC Belgium
Royal Observatory of Belgium
Fax : 32 (0) 2 373 0 224
Tel.: 32 (0) 2 373 0 491