Solar and solar terrestrial physics

Louise K Harra

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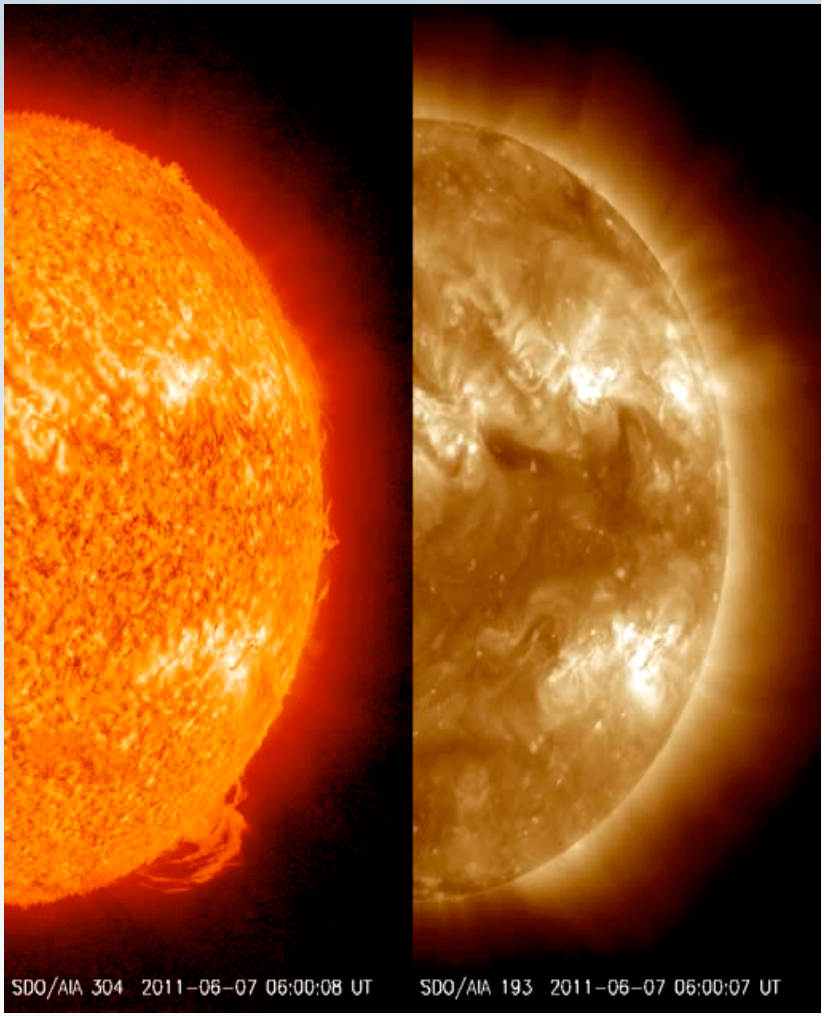
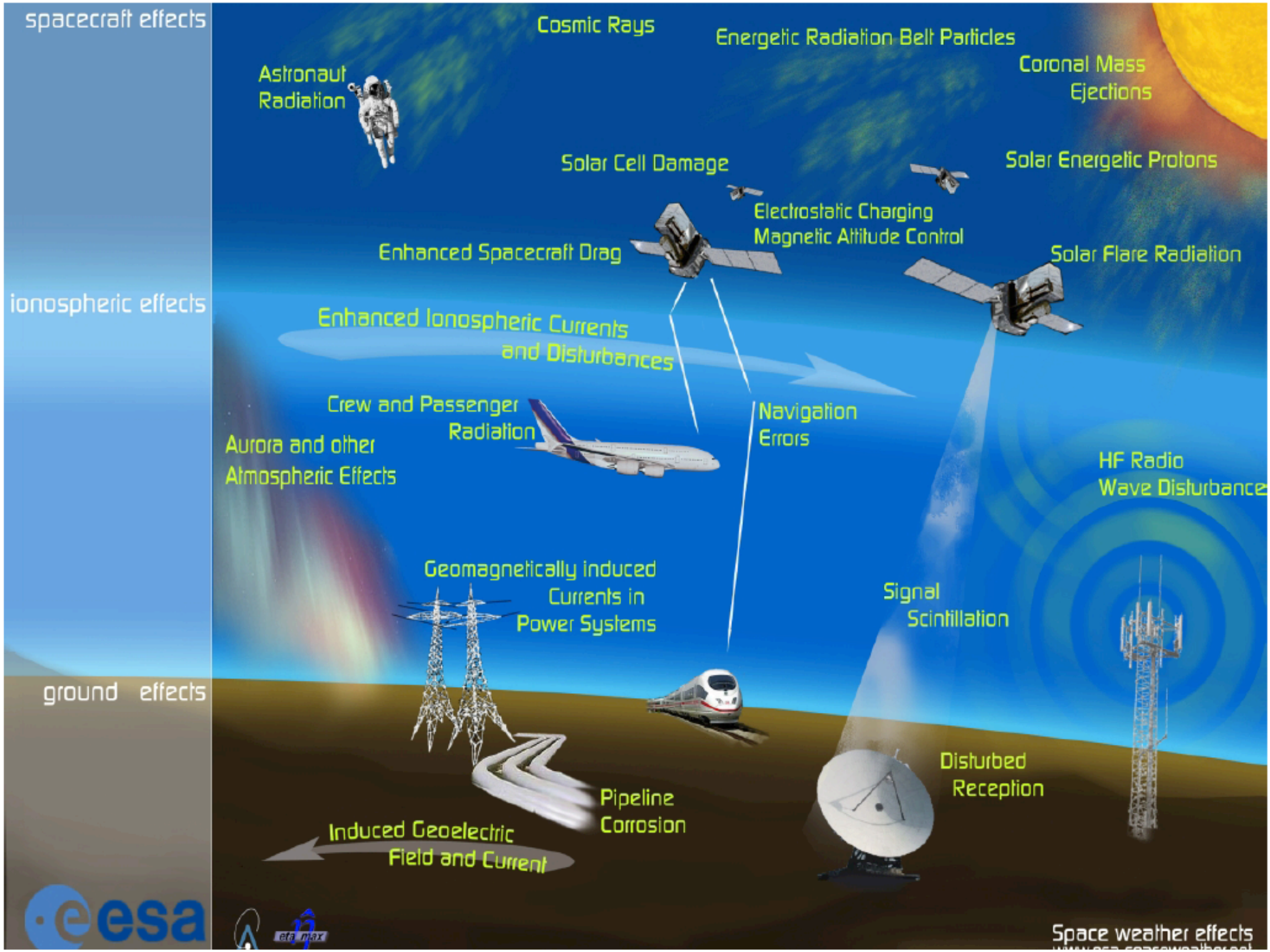
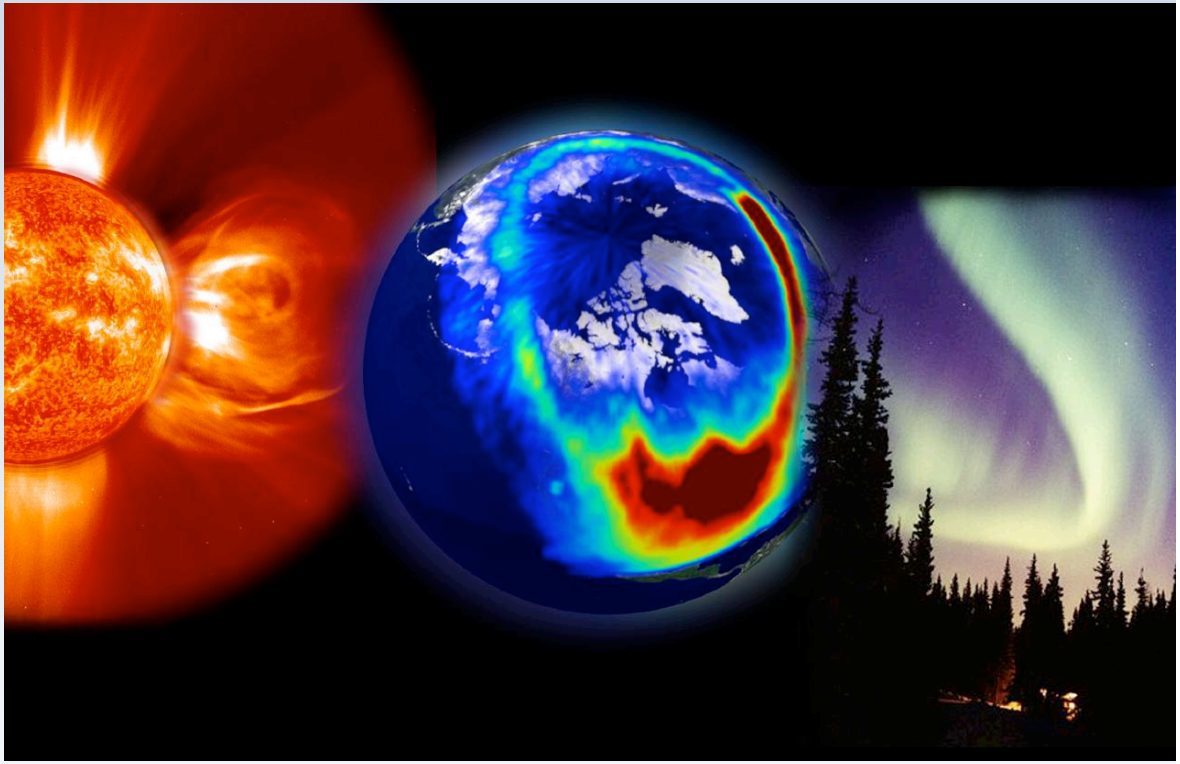


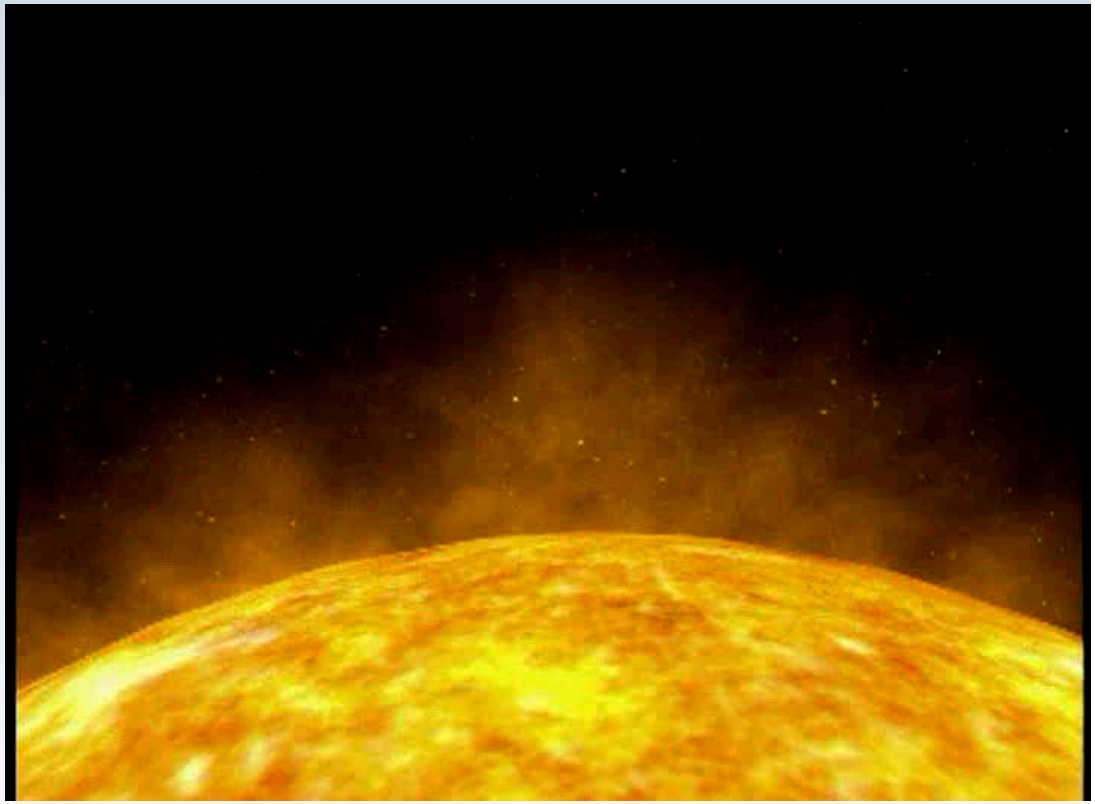

spacecraft effects
ionospheric effects
ground effects
Cosmic Rays
Energetic Radiation Belt Particles
Coronal Mass Ejections
Astronaut Radiation
Solar Cell Damage
Solar Energetic Protons
Electrostatic Charging
Magnetic Attitude Control
Enhanced Spacecraft Drag
Solar Flare Radiation
Enhanced Ionospheric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

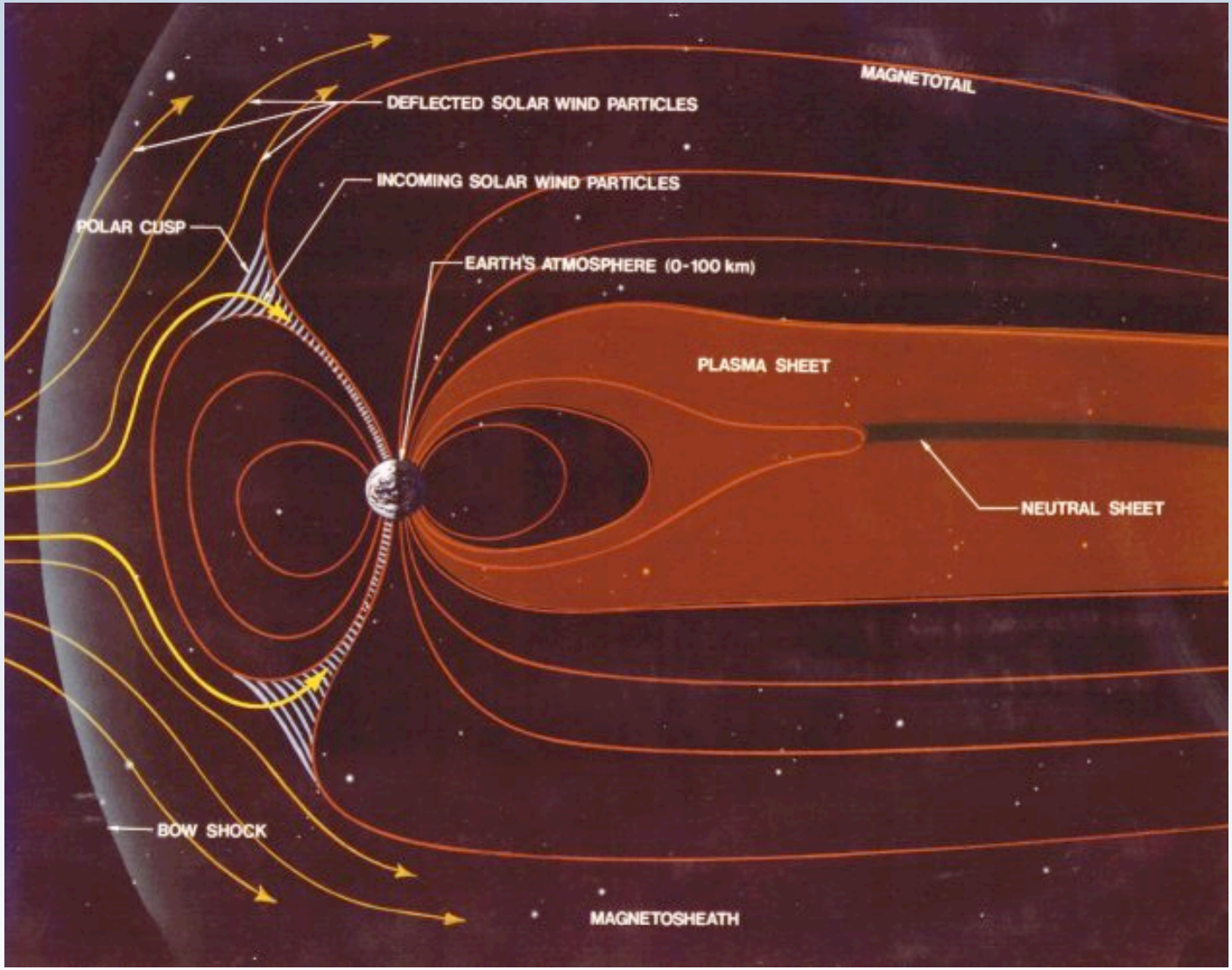
- Origins of space weather
  - Solar activity
  - solar wind
  - flares
  - CMEs
- Manifestations
  - aurora
  - geomagnetic storms
  - ionospheric effects
  - SEPs



Origins of space weather

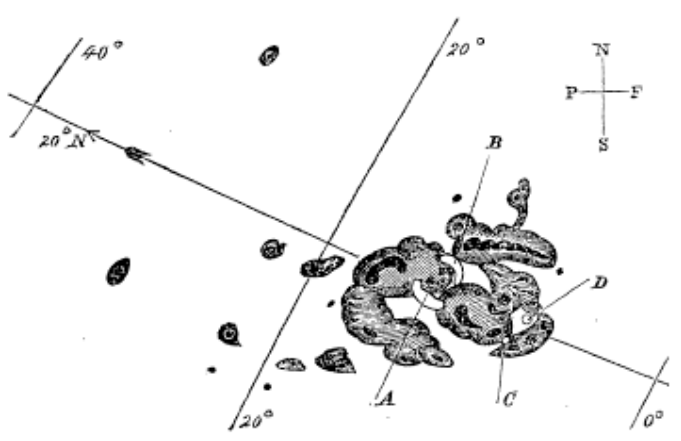
- Ultimately the existence of space weather is due to the existence of both a solar and a terrestrial magnetic field, and the Earth's atmosphere.
- Without a solar magnetic field there would be no solar wind, no solar flares and no CMEs to interact with the Earth's magnetic field.

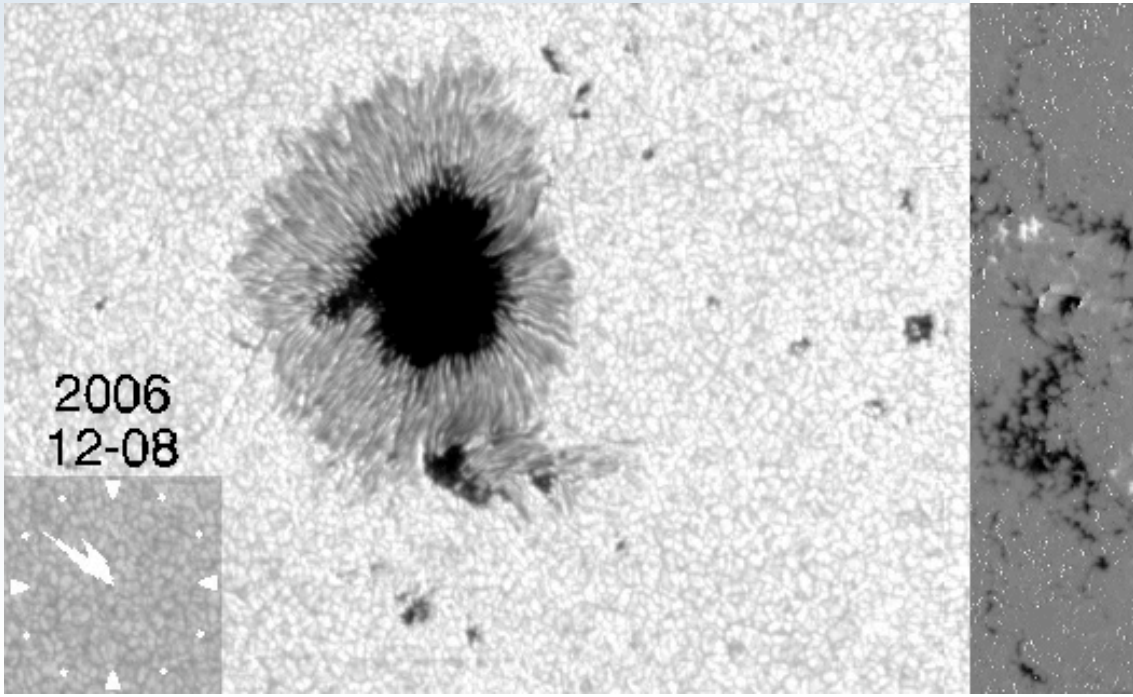



MAGNETOTAIL
DEFLECTED SOLAR WIND PARTICLES
INCOMING SOLAR WIND PARTICLES
POLAR CUSP
EARTH'S ATMOSPHERE (0-100 km)
PLASMA SHEET
NEUTRAL SHEET
BOW SHOCK
MAGNETOSHEATH

The ‘first’ space weather event

- The first solar flare was observed in 1859 in England by Carrington.
- When he went to Kew Observatory he then noticed the compass needle deflection….
- Telegraph wires shorted causing widespread fires in the US and Europe



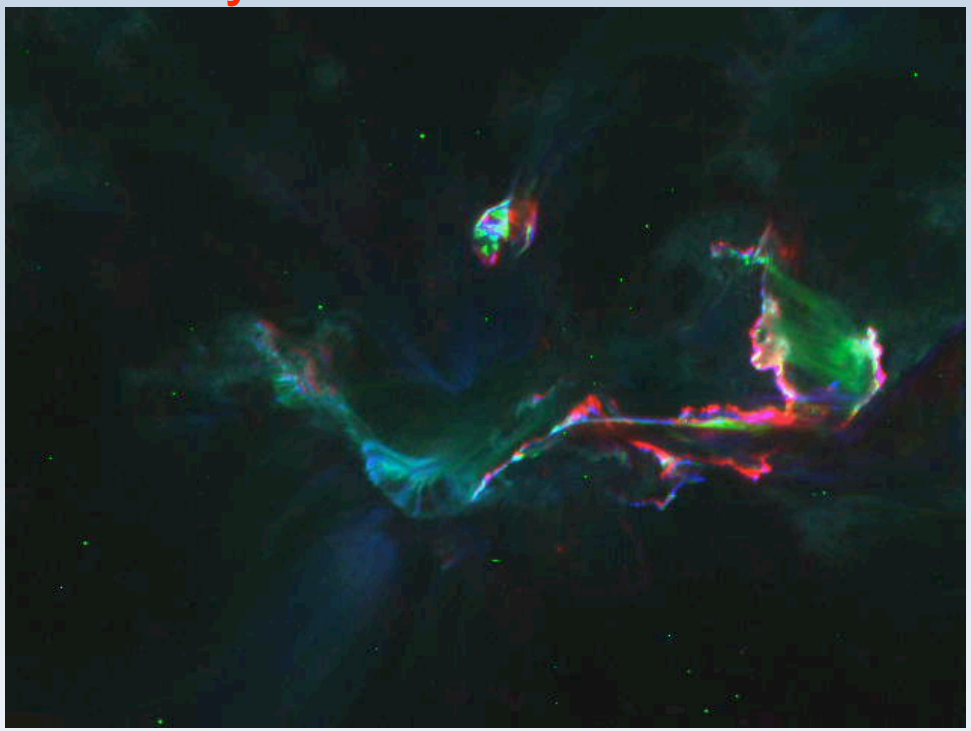


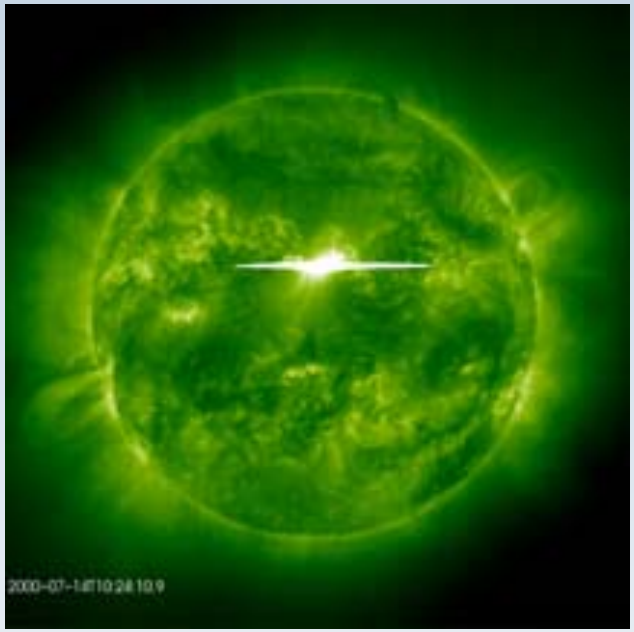
The ‘first’ space weather event: 1859

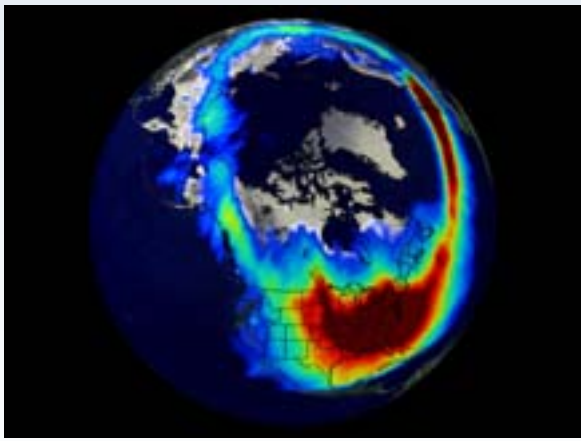
On Sep 2 1859 campers in the Rocky mountains were awakened by a very bright aurora.
‘Some of the party insisted it was daylight and began preparation of breakfast’

Telegraph networks around the world faced disruption.

Bastille day event



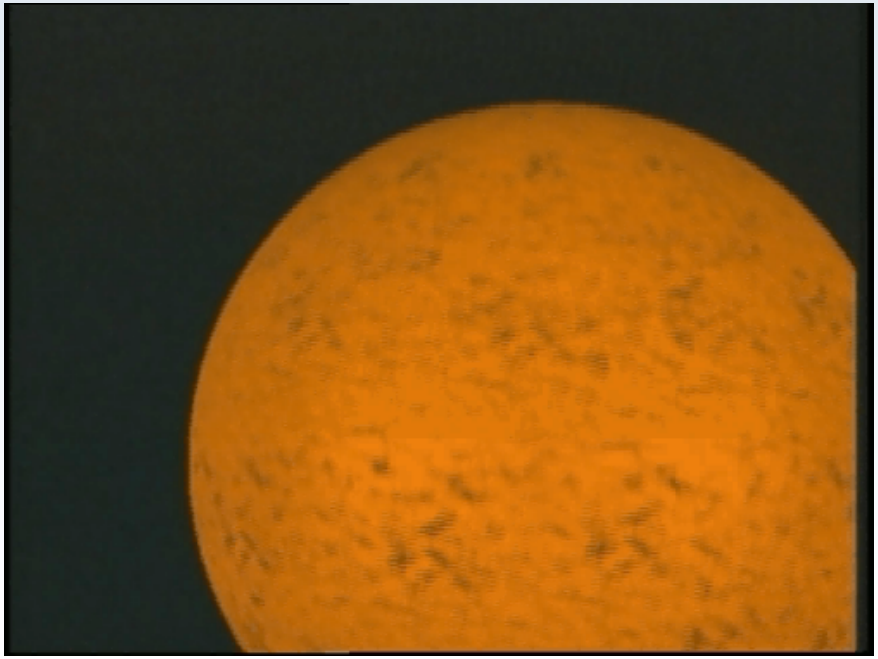


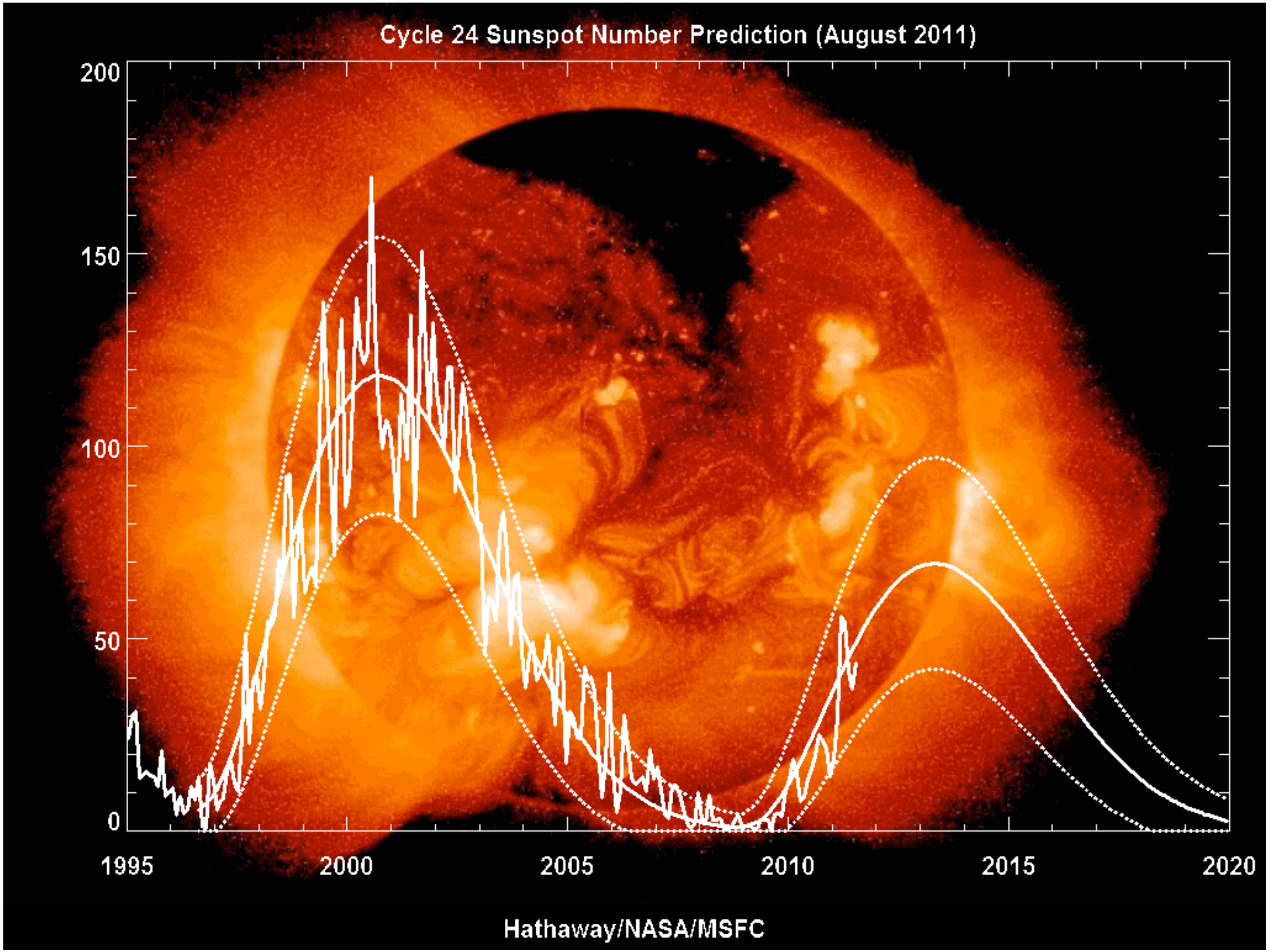


ACE detectors blinded
ASCA was sent tumbling in orbit
GPS was degraded for several hours
Many spacecraft were temporarily shut down
One transformer was damaged

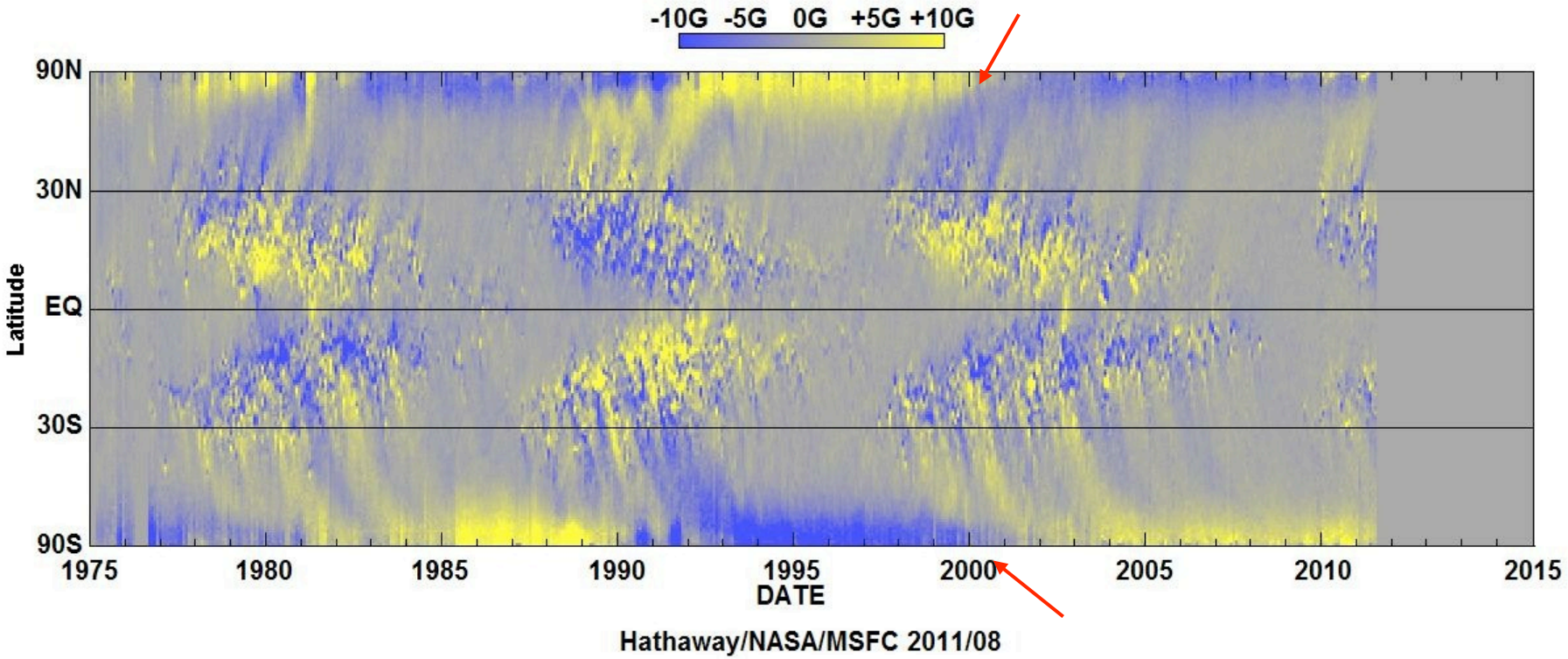
Solar activity

- Sunspot activity shows an 11 year cycle with new spots appearing at high latitudes and gradually migrating towards the equator as the cycle progresses.
- The sunspot cycle forms half of the 22-year solar cycle over which time the magnetic field evolves from a poloidal field to a toroidal field & back to a poloidal field of opposite polarity (11 years). Then through another sunspot cycle back to the starting polarity (22 years).




Cycle 24 Sunspot Number Prediction (August 2011)
200
150
100
50
0
1995
2000
2005
2010
2015
2020
Hathaway/NASA/MSFC

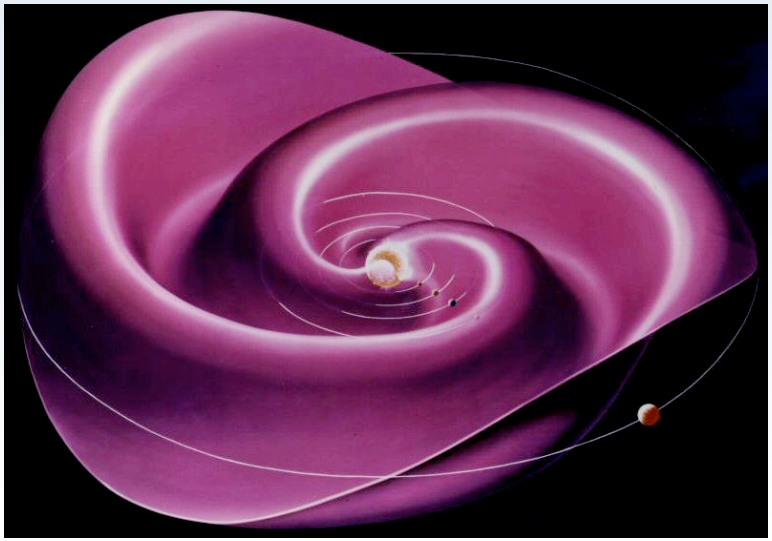
Polar field reversal



The poles change polarity ~ 1-2 years after the solar maximum
They are most extended and have the highest total magnetic flux just before the sunspot minimum.

Heliospheric current sheet

- Dipole field of the Sun is drawn out radially & wound into the Parker spiral at low latitudes by solar rotation.
- Separating opposite polarity hemispheres lies the *heliospheric current sheet.*
- At solar minimum the dipole axis is aligned with the rotation axis but gradually tilts & inverts over the course of the cycle.
- The tilt can bring high speed wind down into the ecliptic leading to high speed streams being emitted in the same direction as the slow speed wind.



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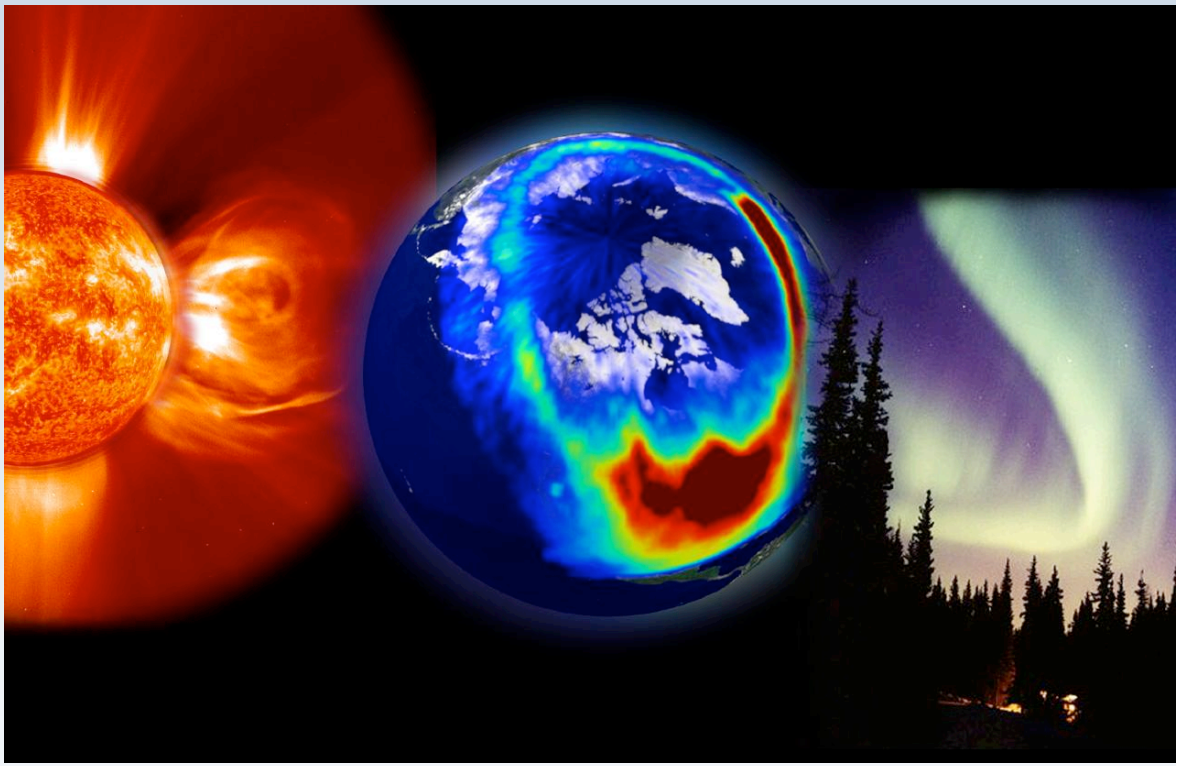
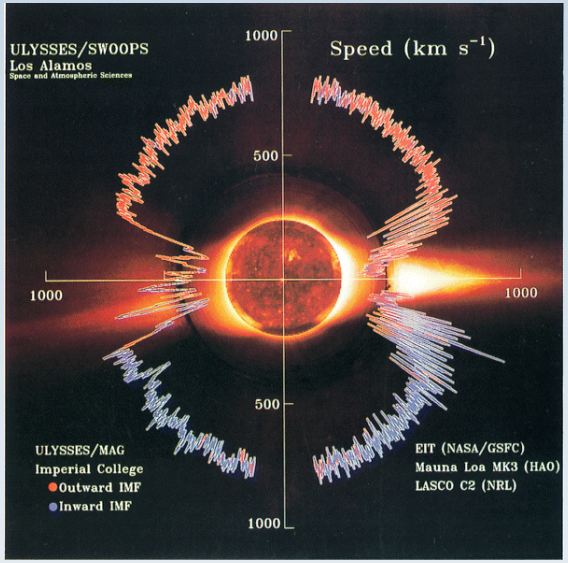
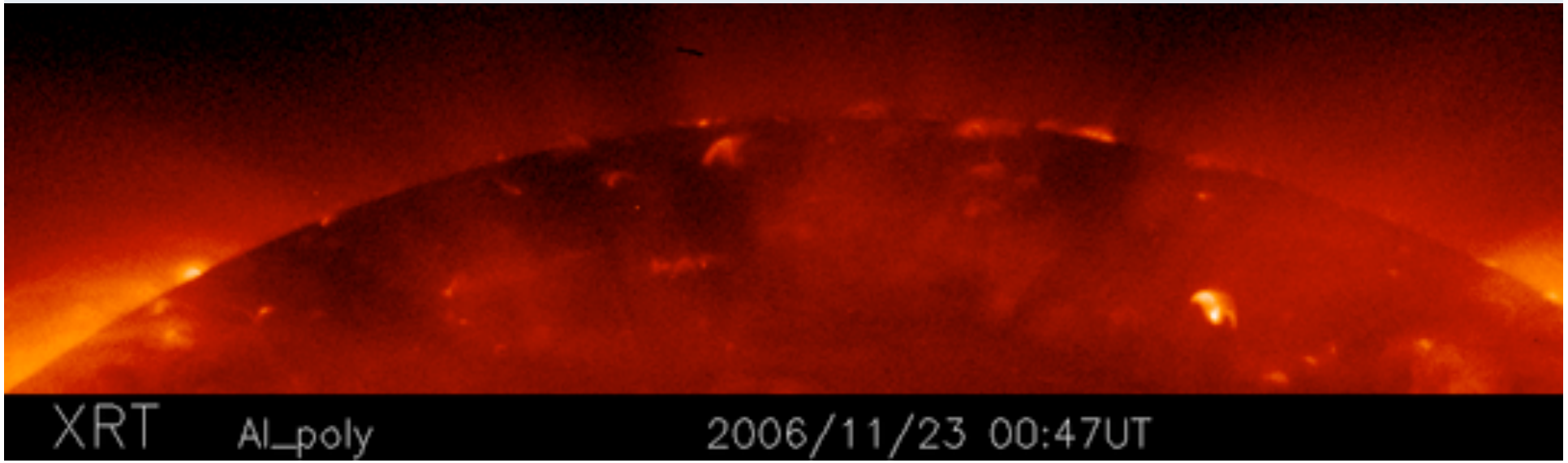


FAST SOLAR WIND



High speed solar wind
Ulysses
(McComas etal 2000)

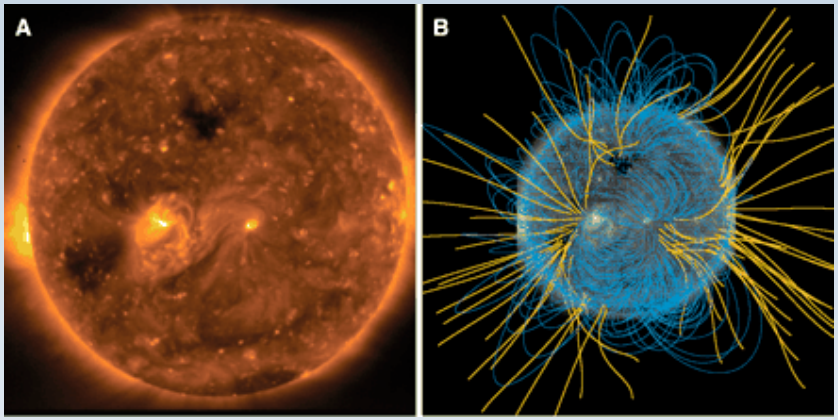
High coronal activity in polar region
(Cirtain etal 2007)

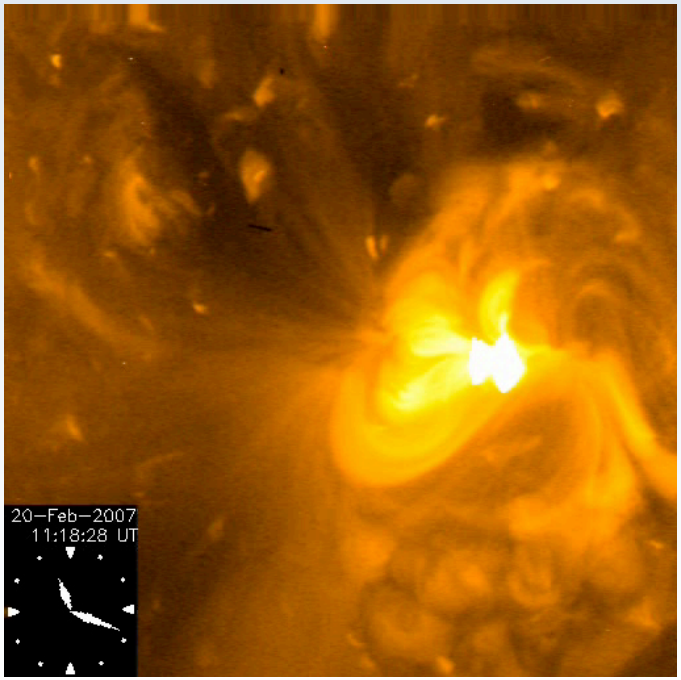


A source of the slow solar wind?

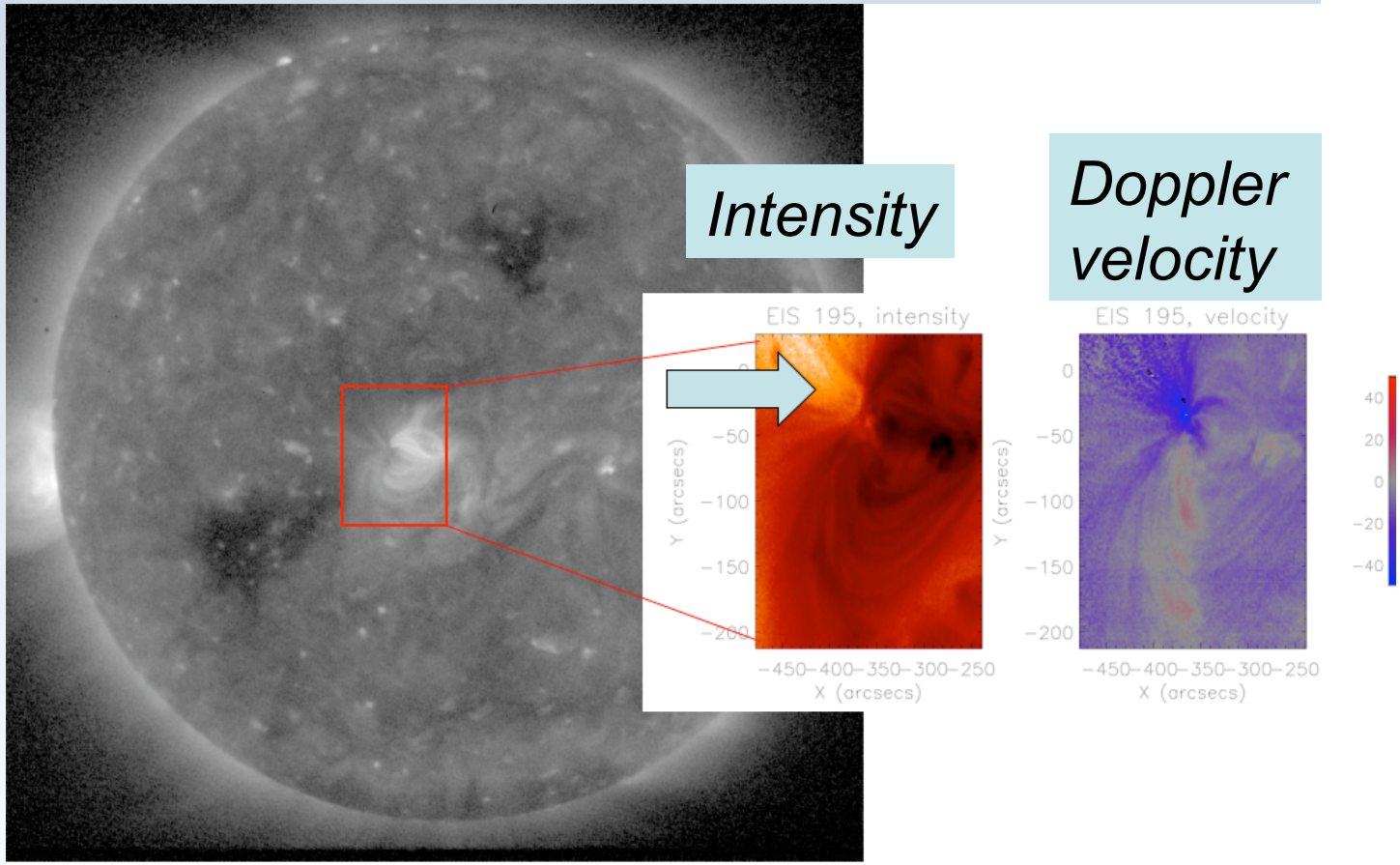
Sakao et al. 2007,
showed steady 'spurting' streams of plasma from the edges of active regions.

We estimated about 25% of the slow solar wind could come from such regions.

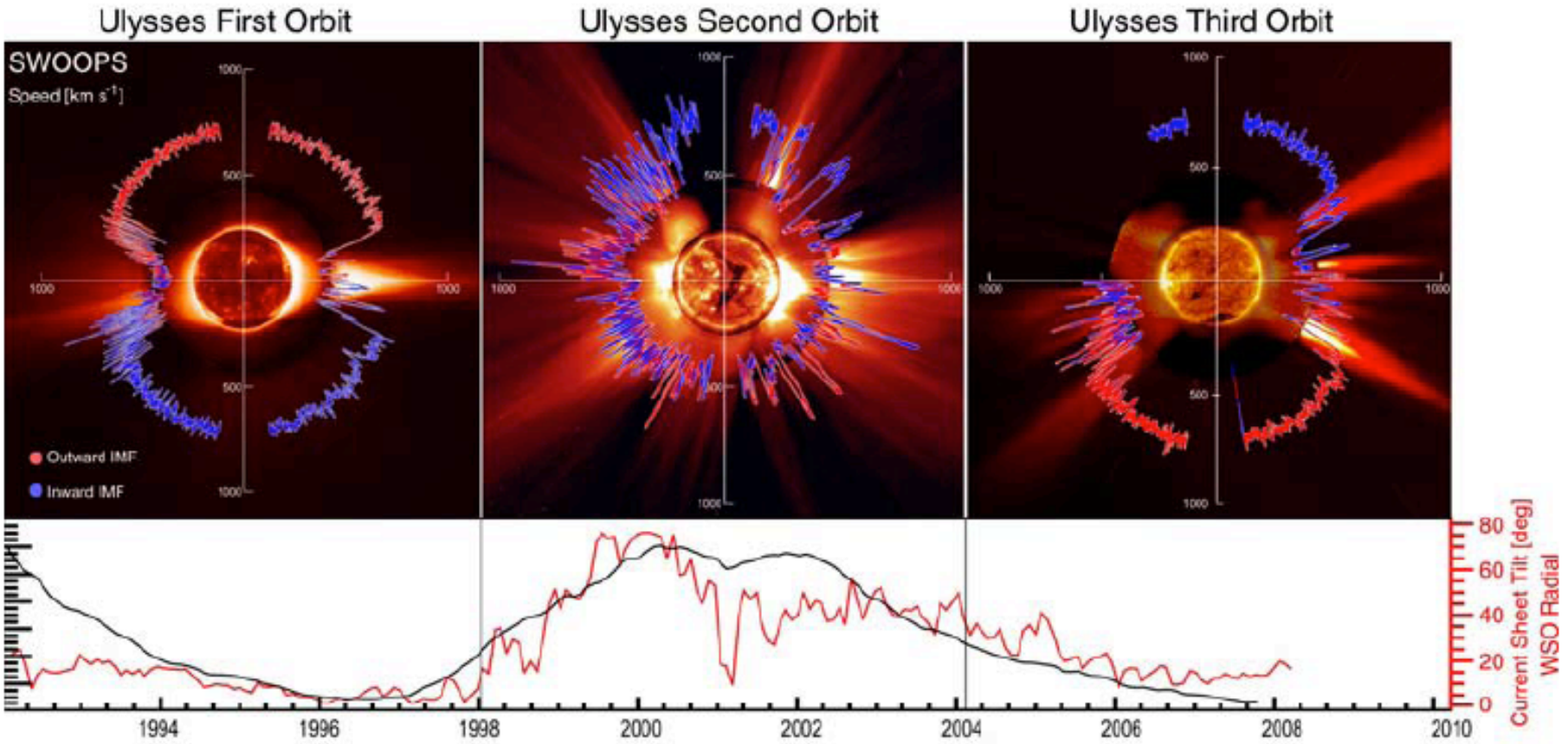




Outflows of up to 50 km/s are seen in the region of outflow in XRT, Harra et al. (2008).



The solar wind is weaker…

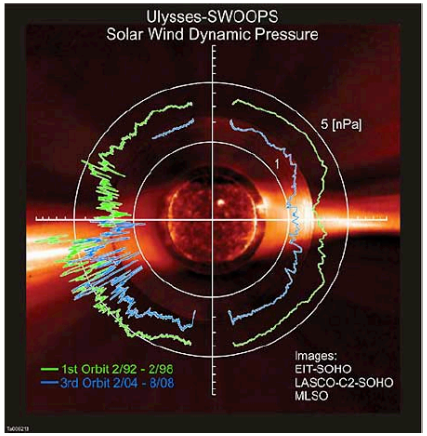


McComas et al, (2008)

Differences between previous minimum and this one

In this minimum the solar wind
- Lower wind speed by 3%
- Less dense (17%)
- Cooler (14%)
- Lower mass flux (20%)
- Lower dynamic pressure (22%)
- Lower thermal pressure (25%)

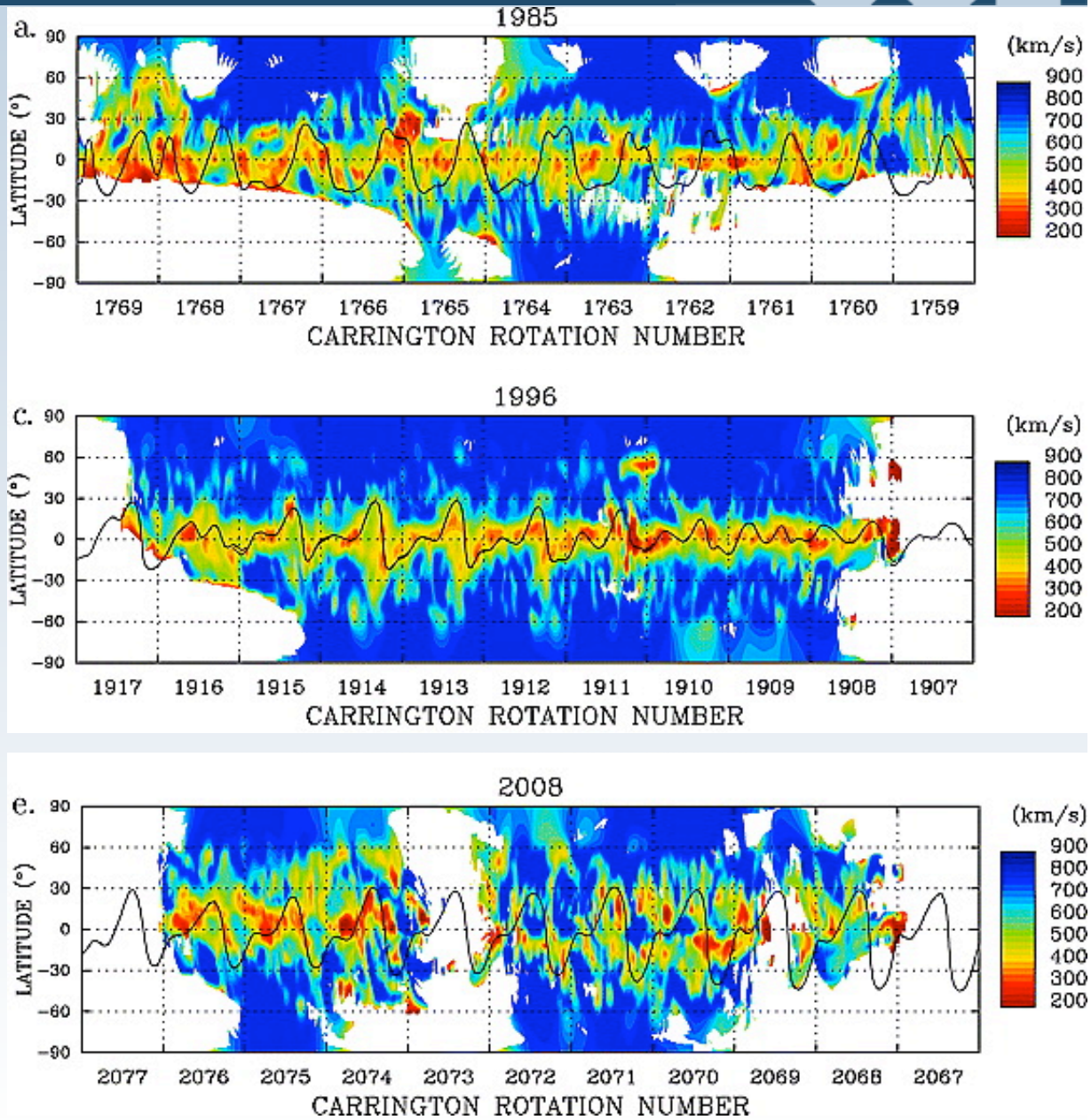
~22% reduction in solar wind dynamic pressure



The heliosphere is likely to be smaller now.
Both polar and ecliptic observations show similar variations – the changes are global not just polar.

Solar cycle evolution of the solar wind

The fast wind regions in ’08 show a marked increase at lower latitudes
It also showed decrease at high latitudes.
This difference is likely to be due to weaker polar fields during the ‘08 minimum.
Tokumaru et al., 2010

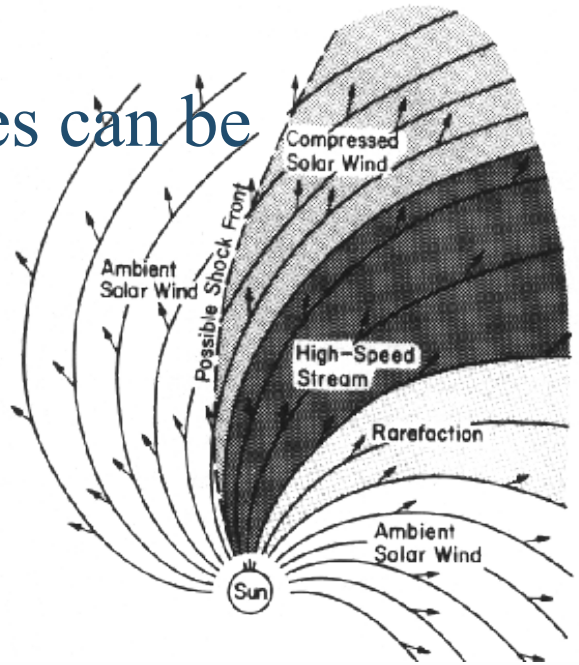


Co-rotating Interaction Regions

- When fast speed streams interact with slow streams they produce ***co-rotating interaction regions.***
- Plasma & magnetic field fluctuations are compressed & intense magnetic fields are produced.
- A pair of shocks can form at the edges of the CIR -forward and reverse.
- Observations have shown that particles can be accelerated at both shocks.

CIRs probably account for most of 27-day recurrent geomagnetic activity.

From Hundhausen (1972)



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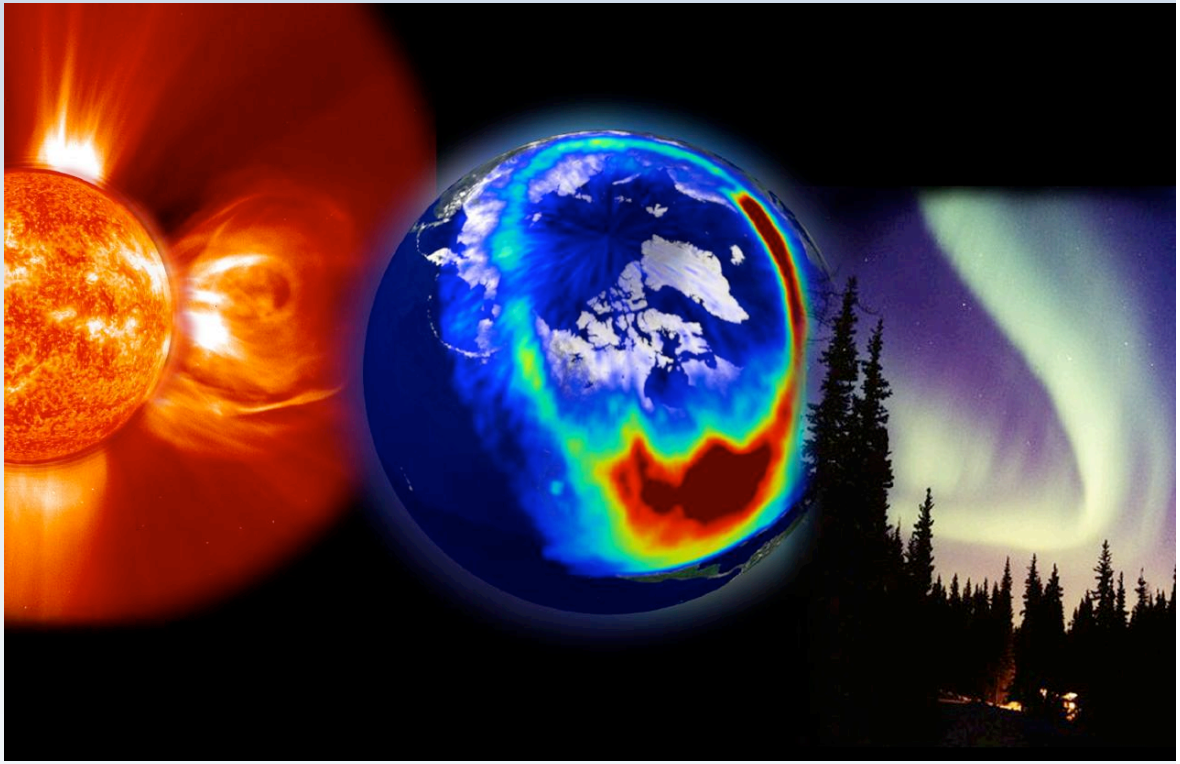
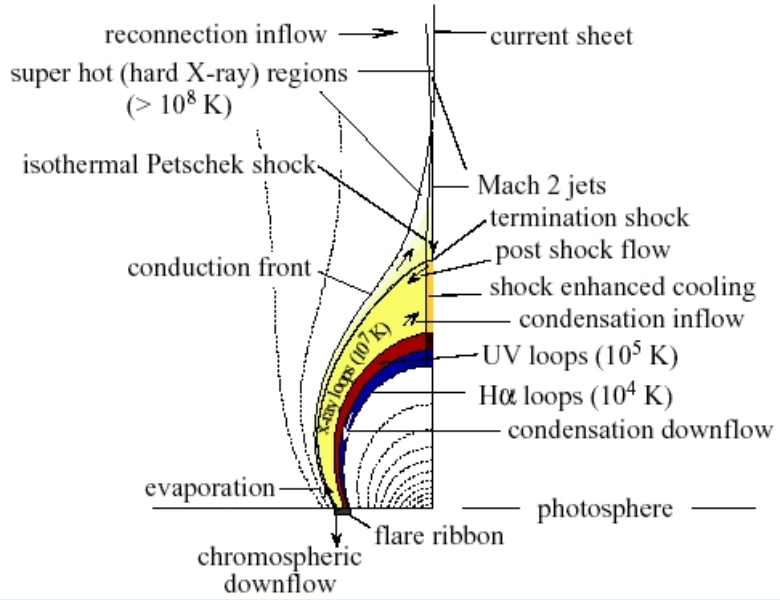
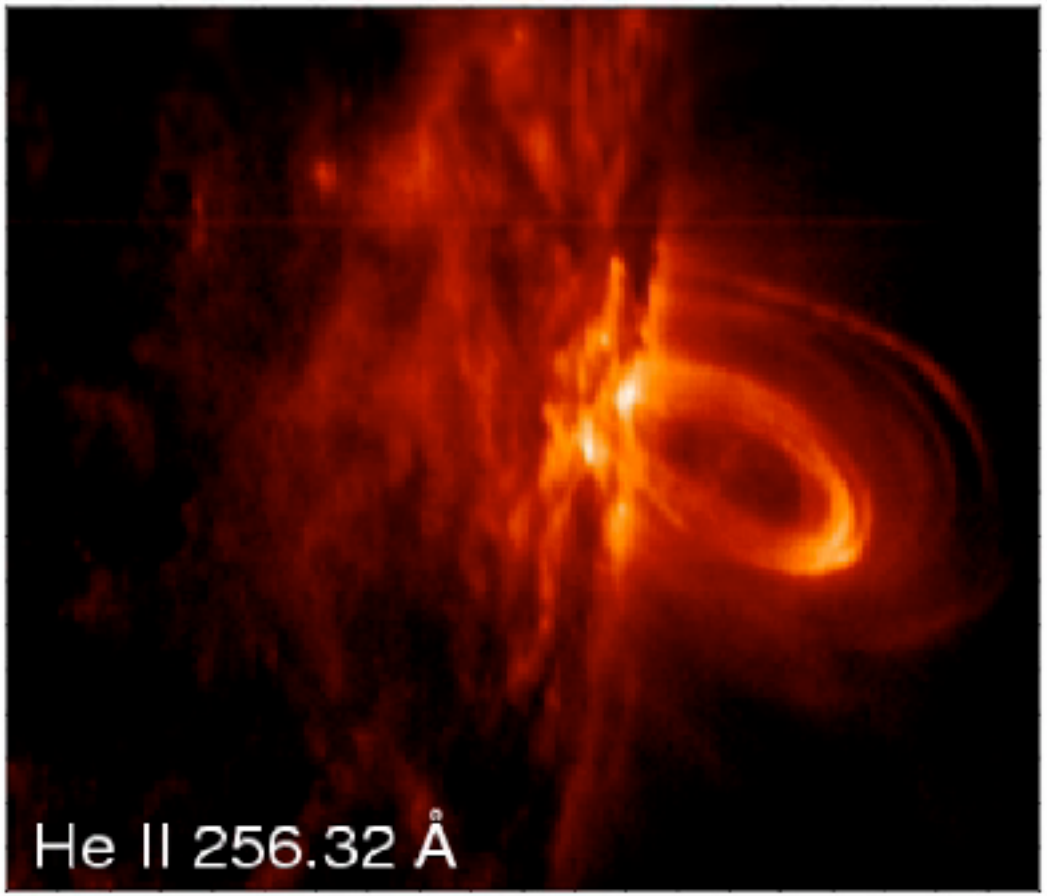


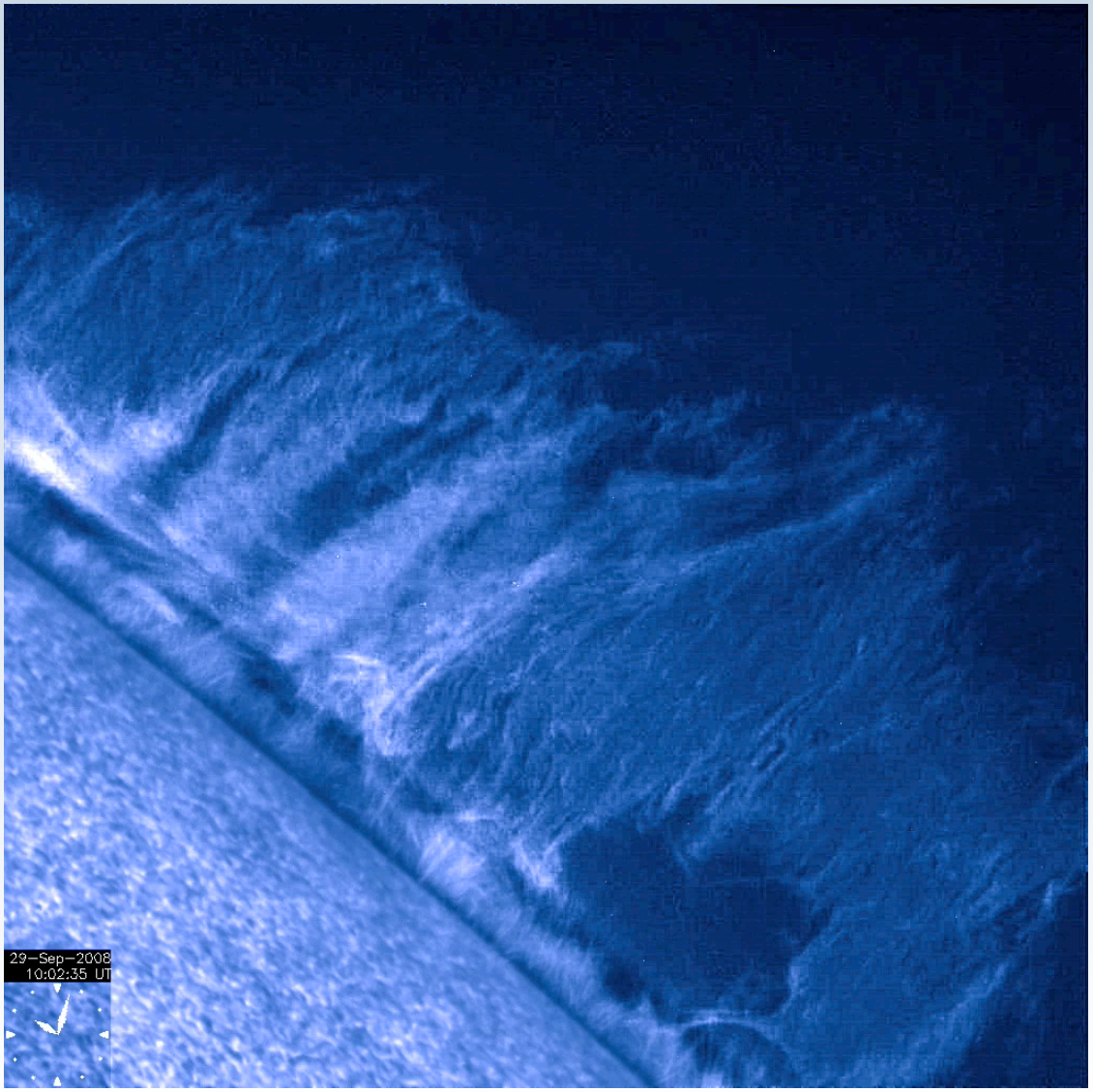
The flare itself



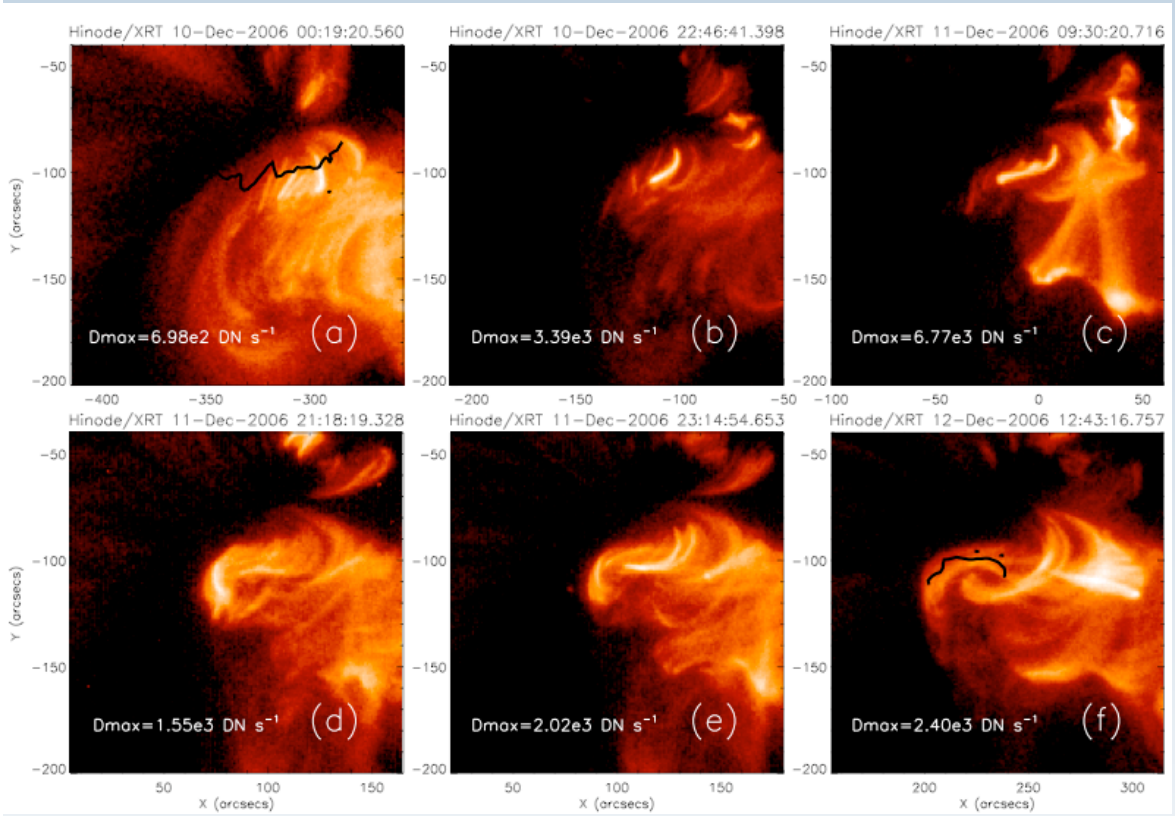


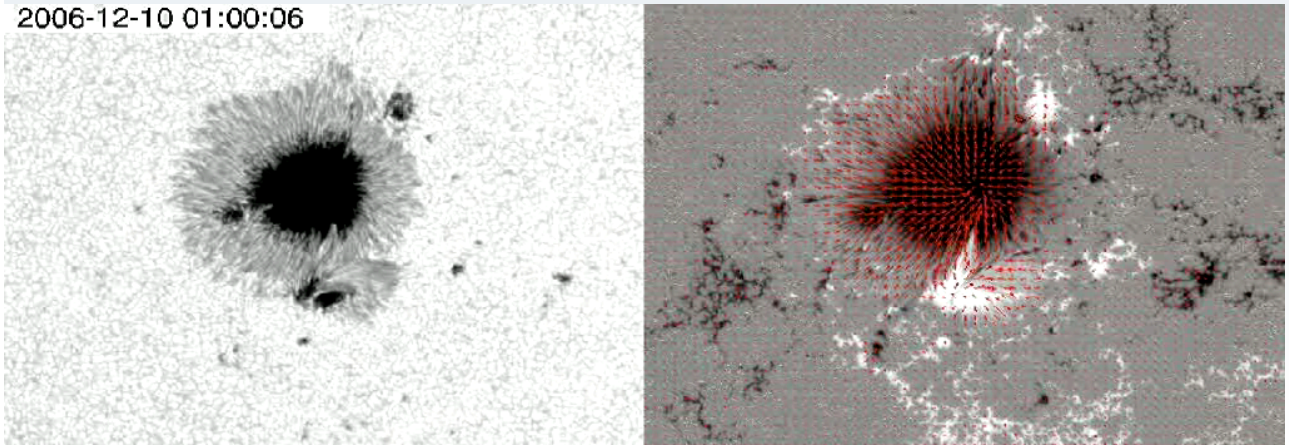
The cooler emission lies below the hotter emission…

Prominences - cool material ‘held’ by magnetic fields in the corona.



Evolution of the sheared core in X-rays (Su et al. 2007)





XRT observations of sheared field formation:

From

00:19 UT on Dec 10

To

12:43 UT on Dec 12

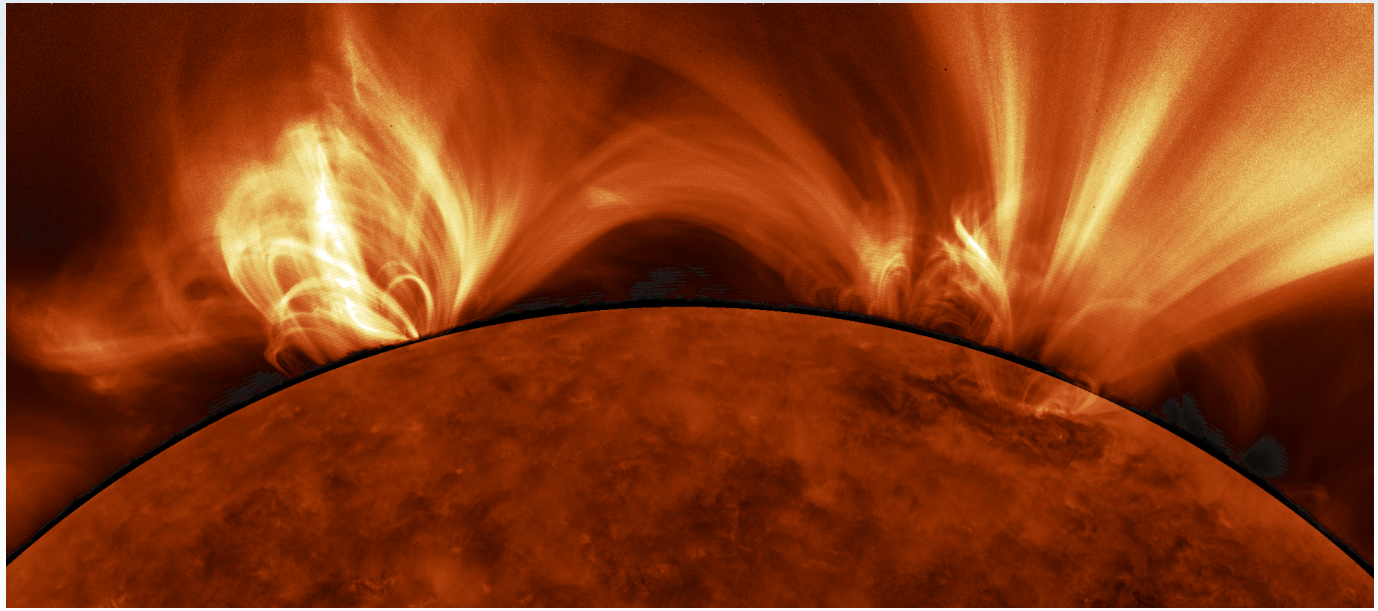
SOT observations of

1. Emerging flux
2. West-to-east Motion
3. CCW Rotation

in the Lower sunspot

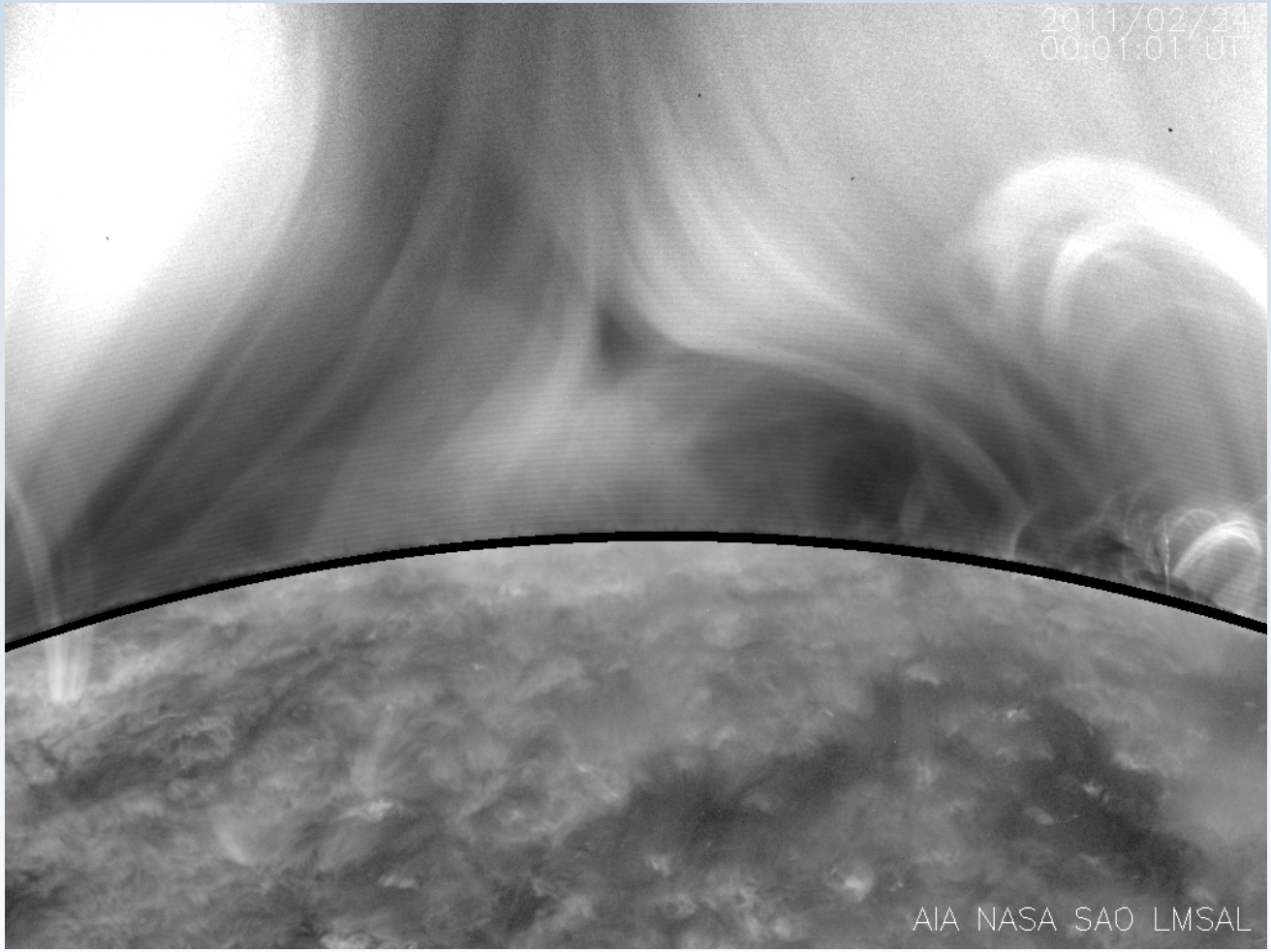
What about on a larger scale?

- Large-scale trans-equatorial coronal loops have been observed for decades.
- They are sometimes related to coronal mass ejections (Khan and Hudson)
- Zhou et al. (2005) find that trans-equatorial filaments erupt in 13% of halo CMEs and trans-equatorial loops in 40% of cases.



Trans-equatorial filaments

Wang et al.(2005) show that the Bastille day flare is not isolated to the active region. Activation of the huge trans-eq filament precedes the simultaneous filament eruption and flare in the source active region.


2011/02/24
00:01:01 UT
AIA NASA SAO LMSAL

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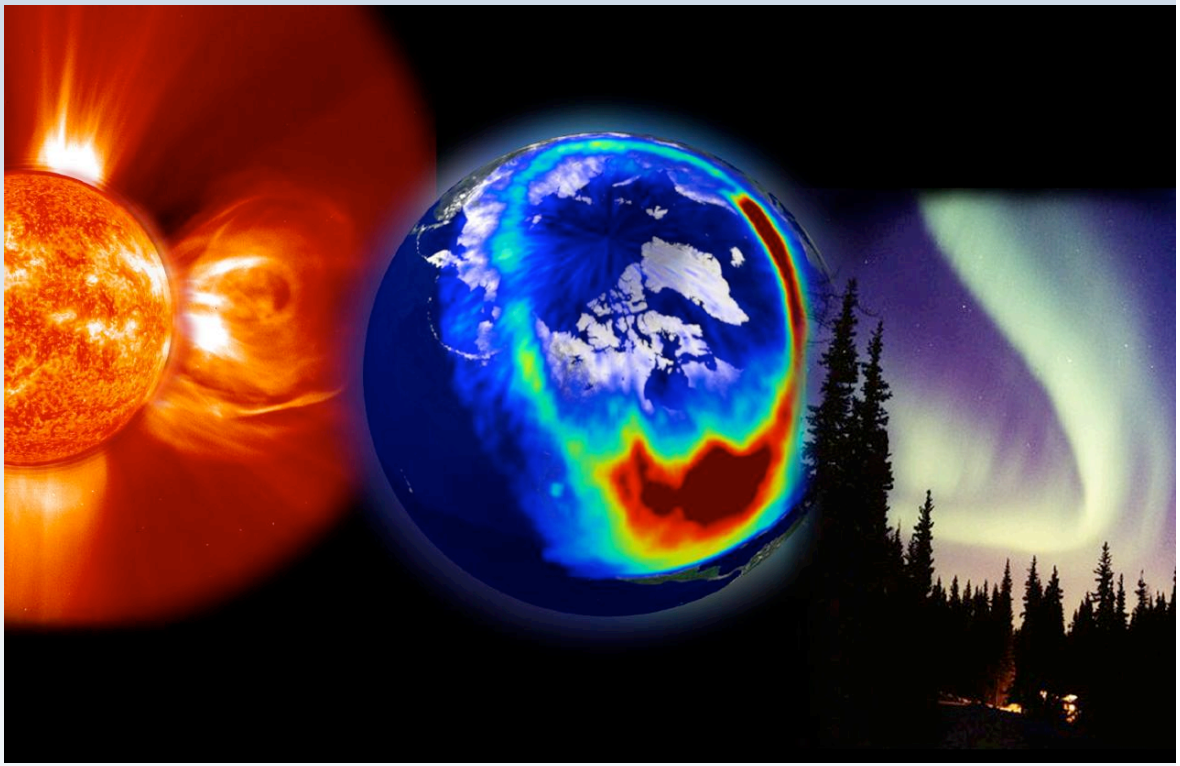
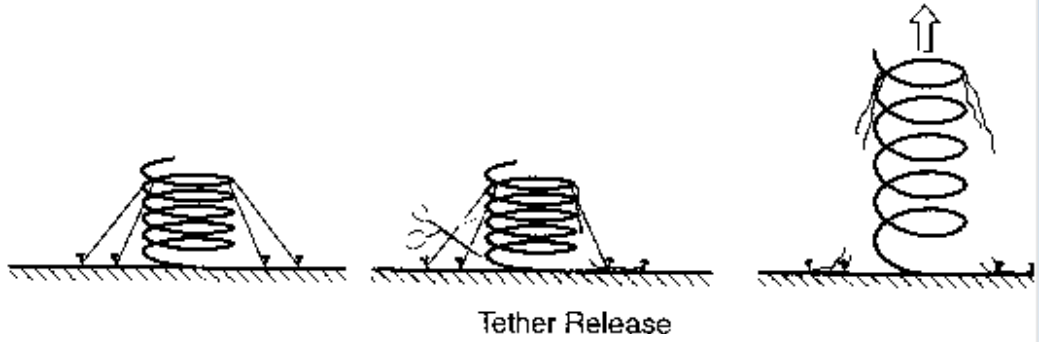
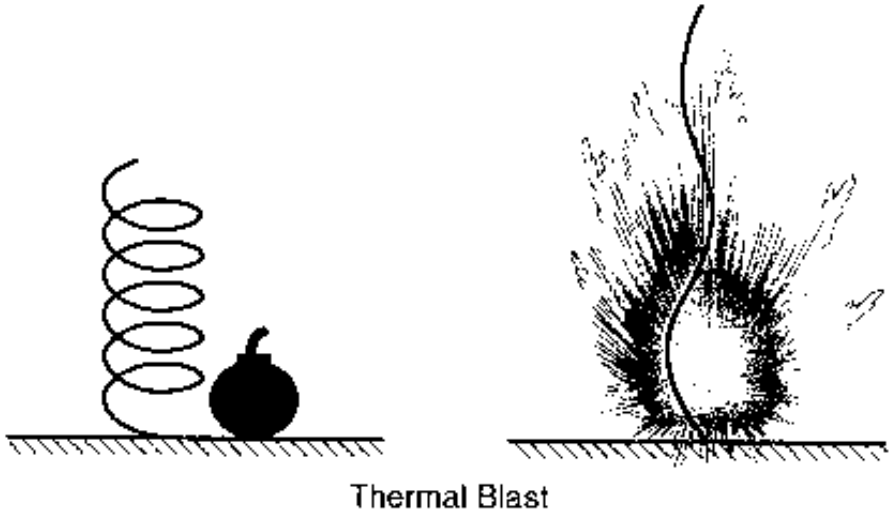


CME models



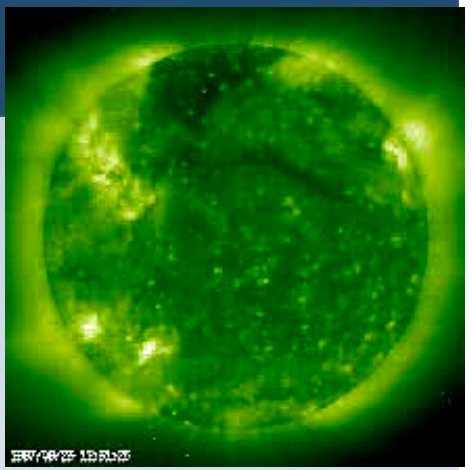
Tether cutting – essentially the standard 2 ribbon flare model.

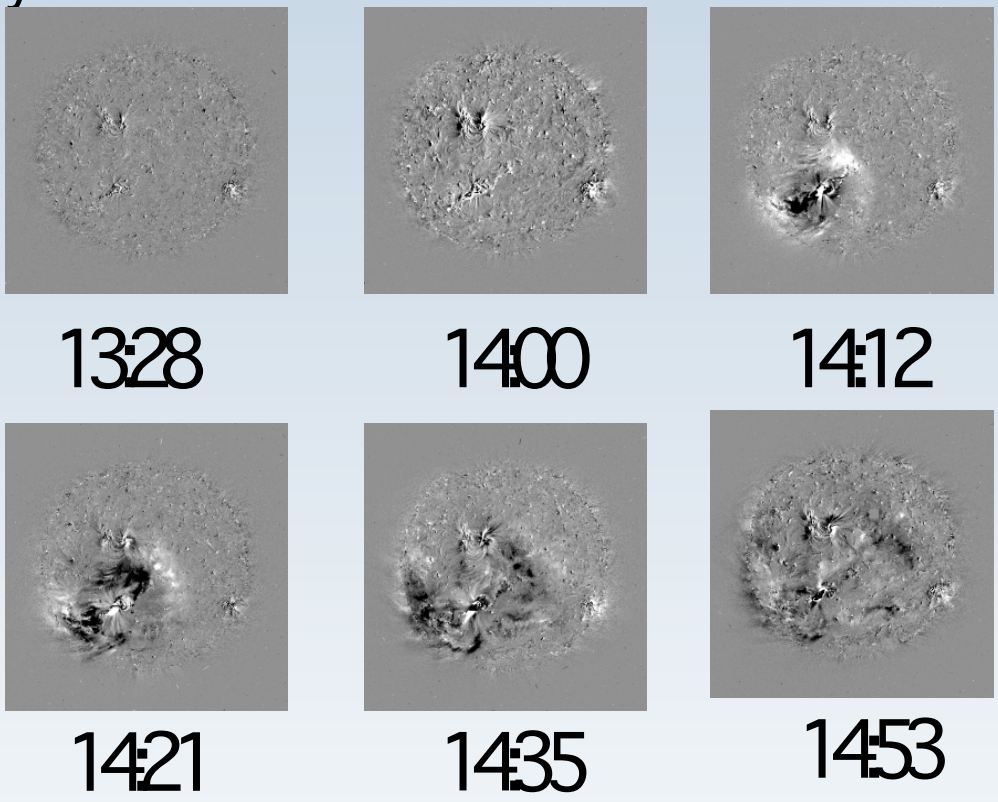


Flare driven thermal blast.

From Klimchuk

‘EIT’ waves are always linked to CMEs - but what are they?

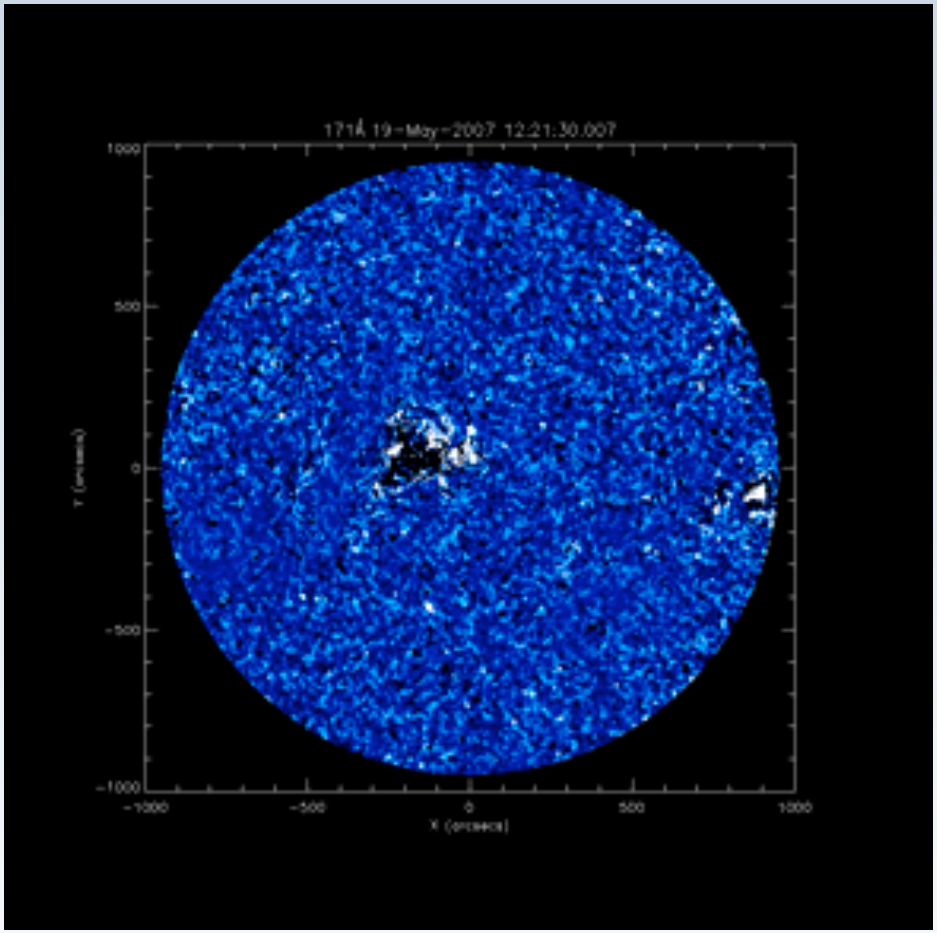




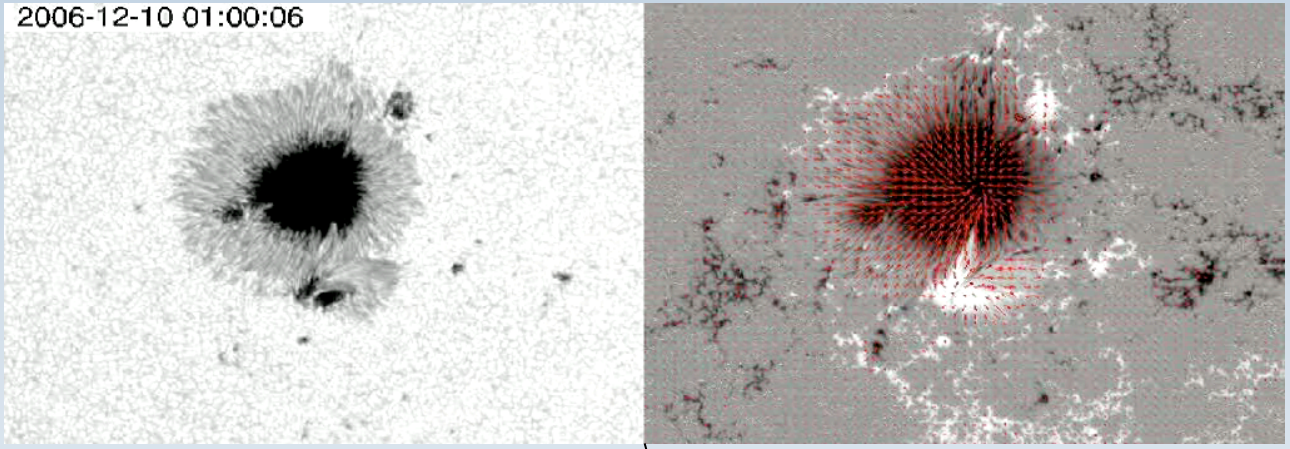
- Fast mode shock wave related to a flare (e.g Uchida’s work, Warmuth et al. (2004)?
- Opening of field lines related to a CME (e.g. Delannee and Aulanier,)?

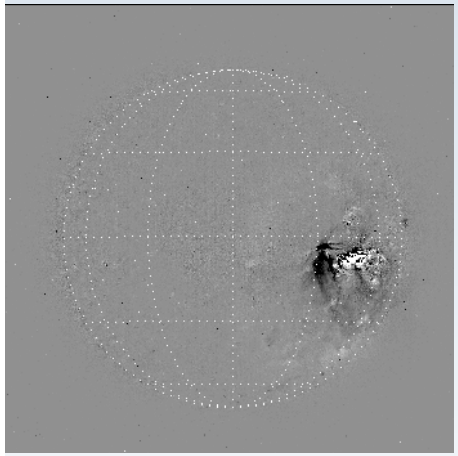
Large scale ‘waves’

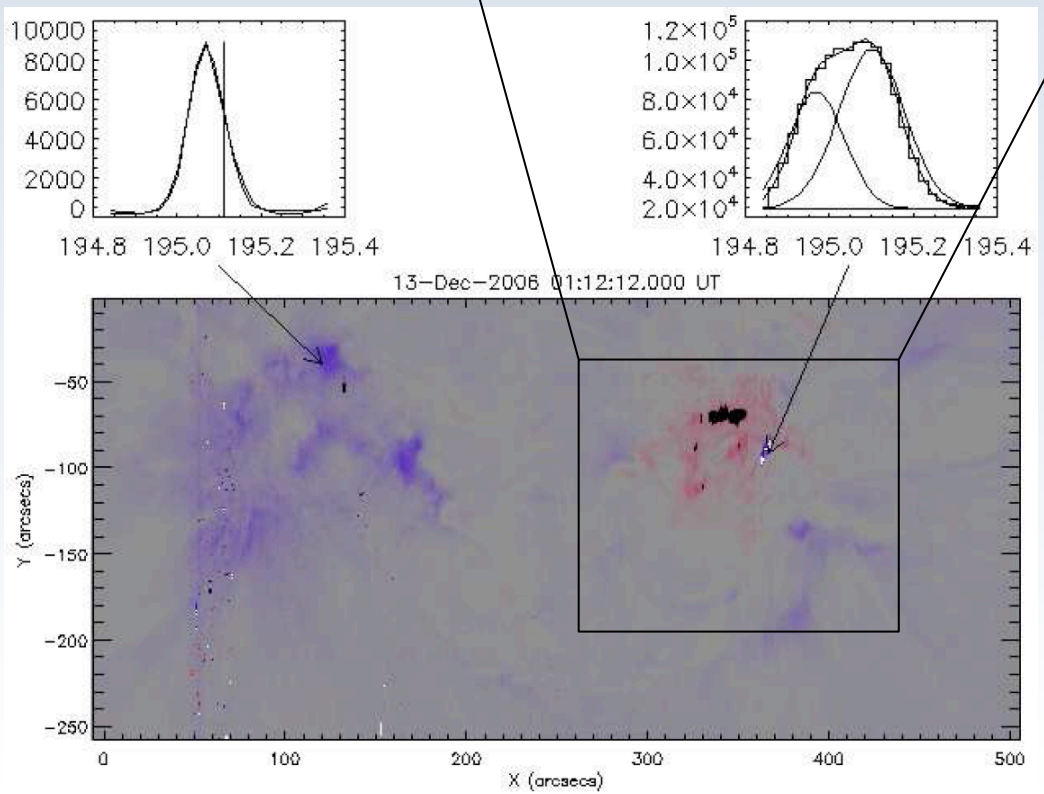
- These are correlated strongly with CMEs.
- STEREO is showing that these waves can ‘reflect’ off other magnetic structures. (Long et al., 2008, Veronig et al., 2008).
- Suggestive of wave initiation by the CME.
- This was related to a weak flare.



CME following large flux emergence

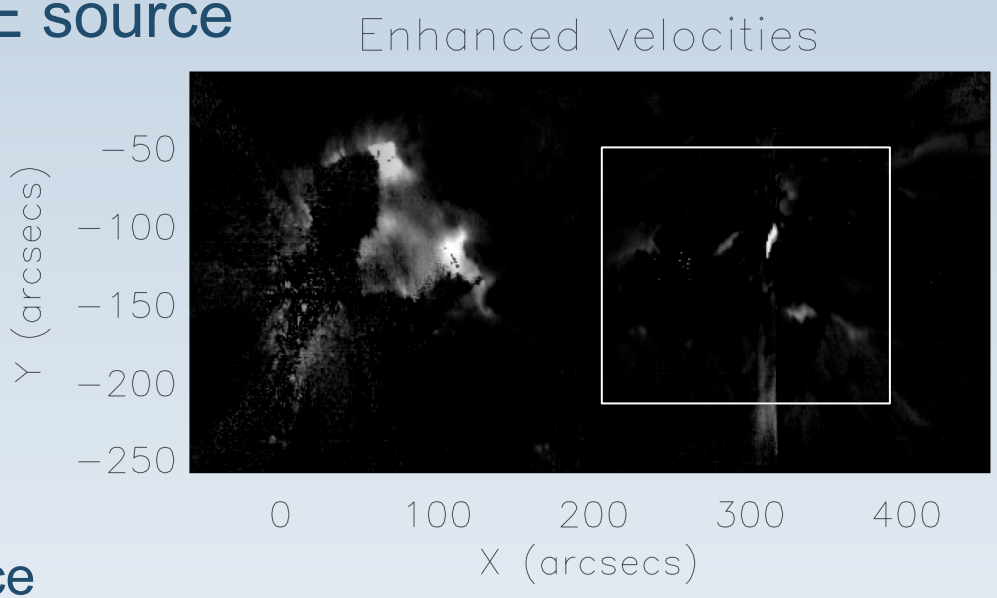


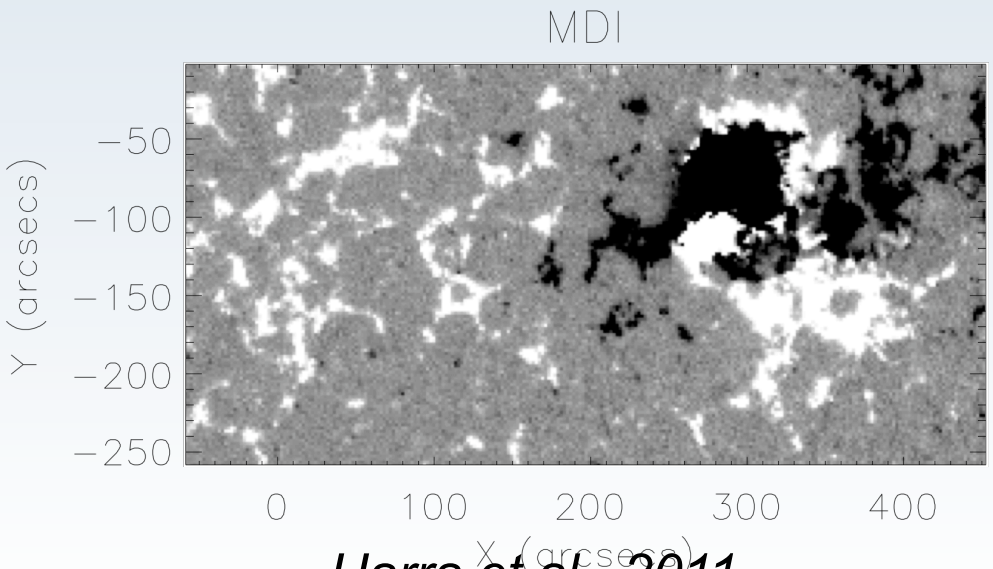




The magnetic flux of the CME source

- The velocity difference image highlights the regions with the strongest upflow.
- The magnetic flux was determined from the solar source can be determined from the velocity difference.
- The magnetic flux form these regions matches that from the ICME assuming a velocity difference > 40 km/s.

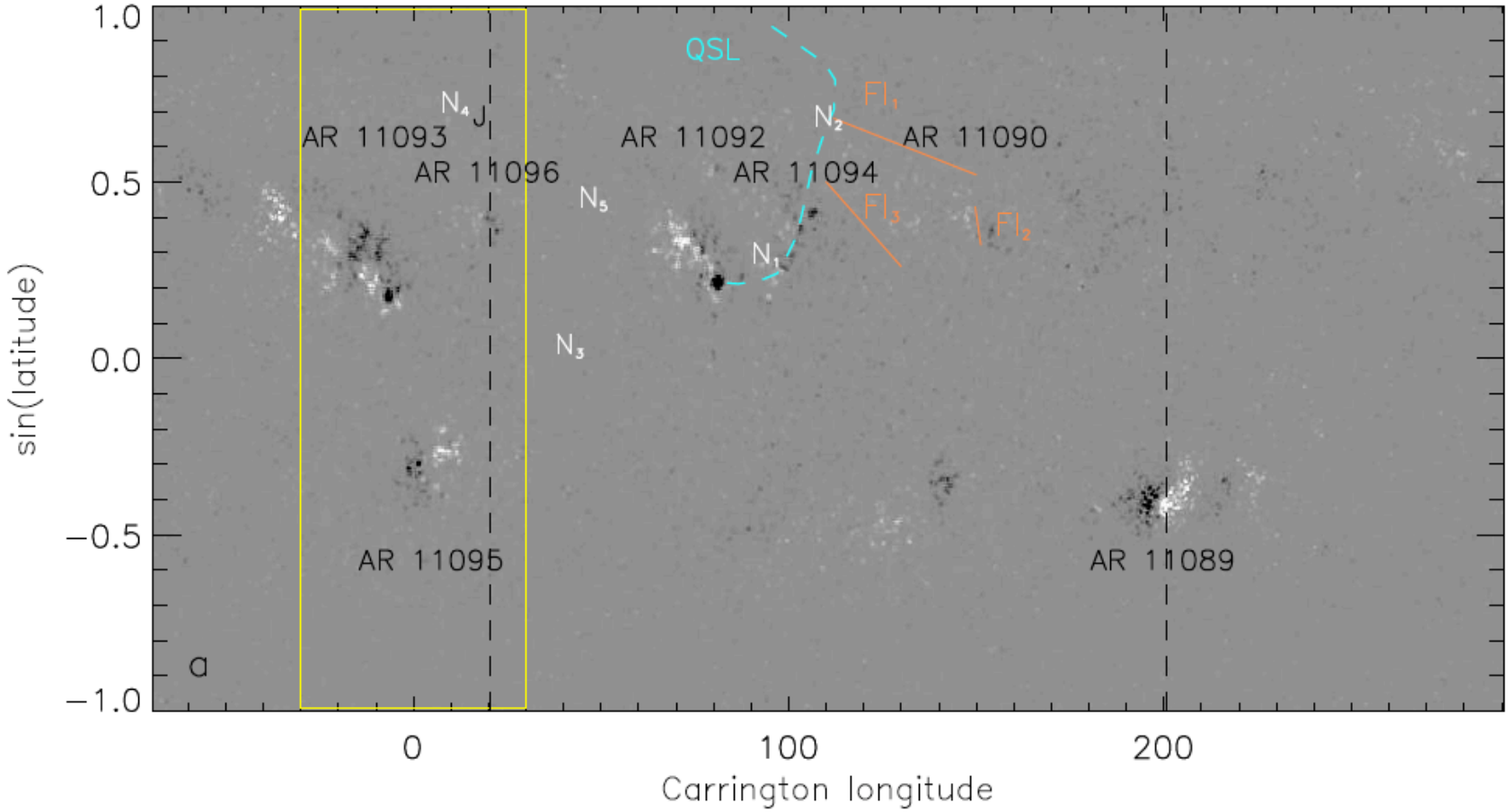


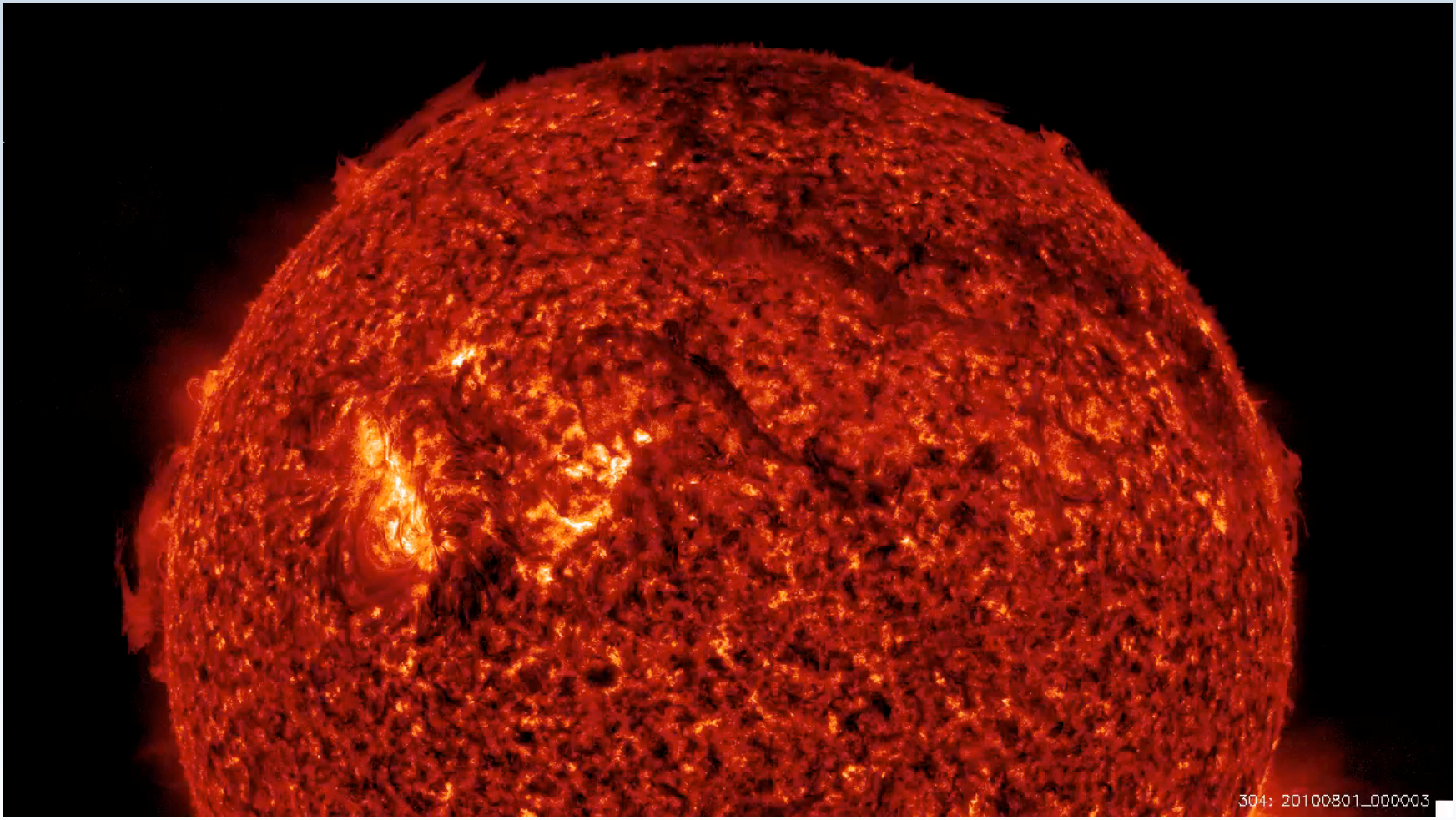


Harra et al., 2011

Global Eruptions

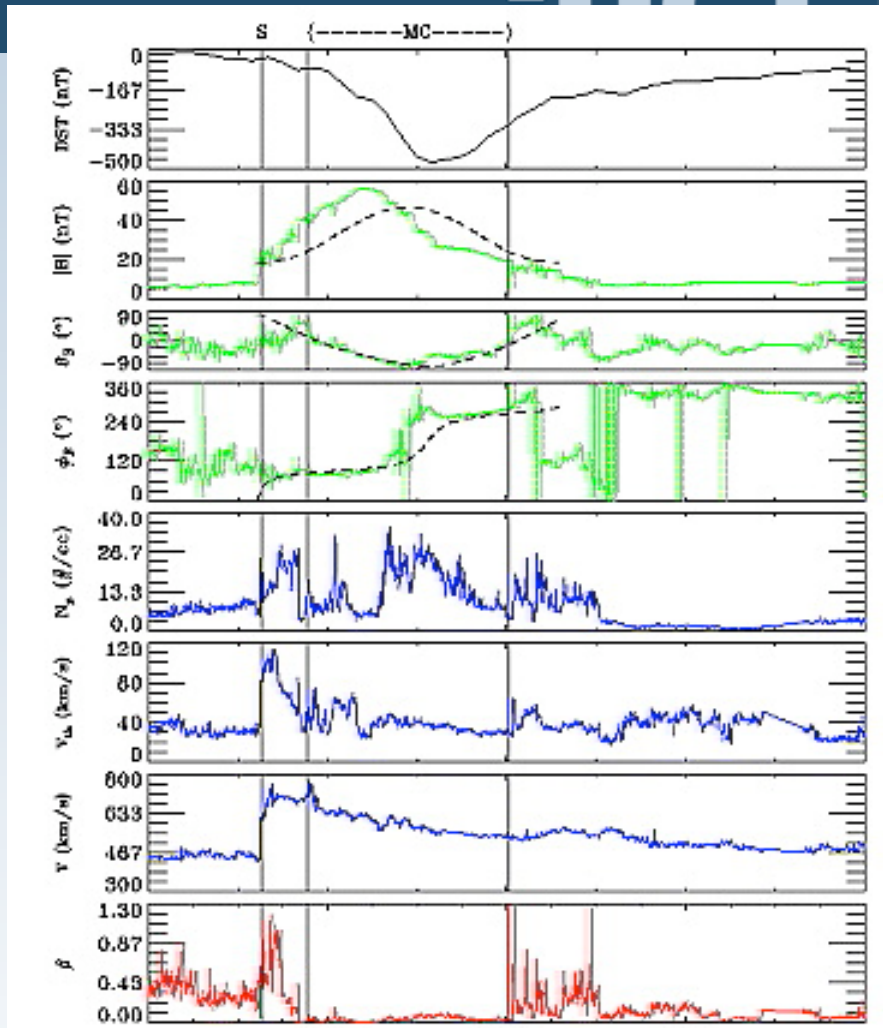
- New flux had emerged in several places on the backside hemisphere before rotating behind the Sun's western limb.
- AR11096 emerged on 27/8/10, AR 11093 shows no substantial growth, AR11095 shows increased activity starting at 31/7/10 (Schrijver and Title, 2011).

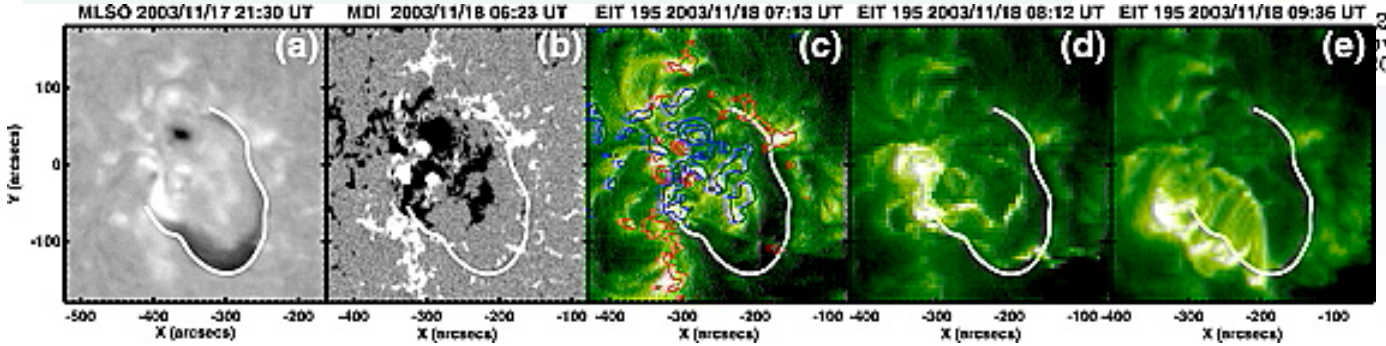



304: 20100801_000003

What makes a superstorm?

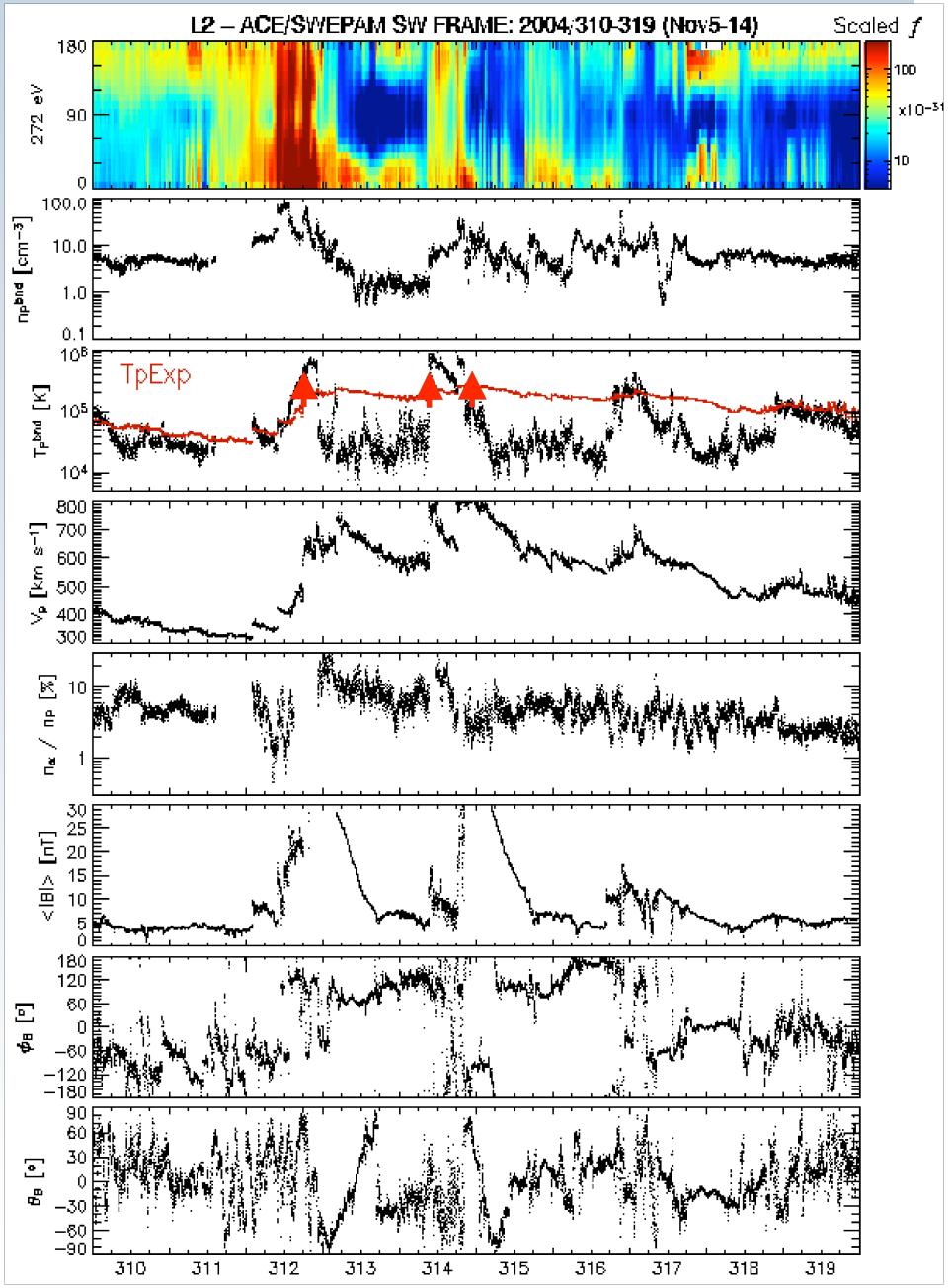
The largest geomagnetic storm of cycle 23 was caused by a fast and wide CME (Gopalswamy et al., 2005).
The origin was close to disk centre.
Resulted in a highly inclined MC with its axial field almost always pointing southward.
The field was unusually strong and the speed was above average.



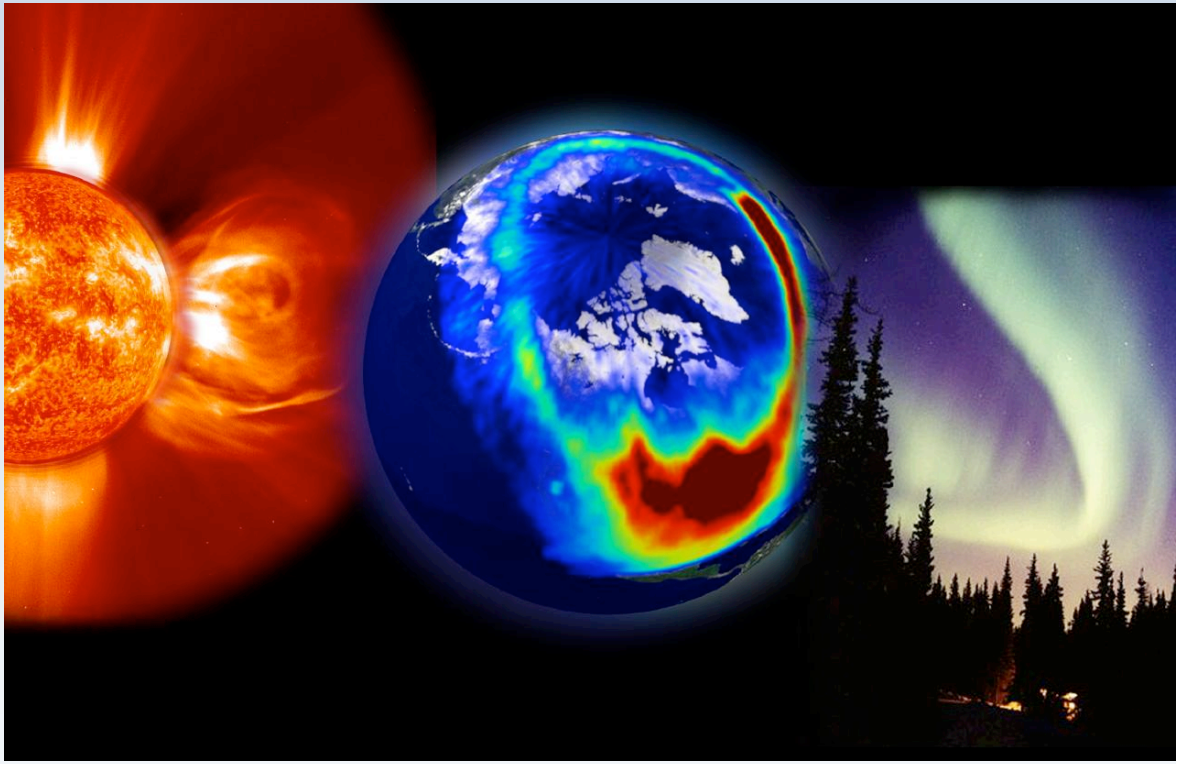


Interplanetary Shocks

- A shock occurs when the relative speed between a high speed stream and the background solar wind is higher than the characteristic speed of the medium.
- The solar wind vel and the magnetic field strength across the shock is correlated with the Dst index (Echer et al., 2004).
- Fast CMEs that propagate into the slower solar wind are subject to a drag force which leads to a deceleration of the CME as it travels towards 1AU (e.g. Cargill, 2004).



- Origins of space weather
  - Solar activity
  - solar wind
  - flares
  - CMEs
- Manifestations
  - aurora
  - geomagnetic storms
  - ionospheric effects
  - SEPs



Aurora

- The most permanent features of northern & southern polar night, existence relies on 3 factors:
  - solar wind
  - solar & terrestrial magnetic fields
  - Earth's atmosphere
- 2 step process involving excitation of atoms and molecules in the Earth's atmosphere by precipitating electrons & ions, followed by emission of photons as they relax.
- Light emitted by the Aurora tends to be dominated by emissions from atomic oxygen, resulting in a greenish glow (557.7 nm) and at higher altitudes - the dark-red glow (at 630.0 nm of wavelength).
- Those emitted by atomic and molecular nitrogen (blue and purple, respectively vary much faster and reveal the true dynamic nature of auroras.


from Earth


from Space

Magnetic storms

- von Humboldt (1808) reported results of an experiment to measure magnetic deflections of a compass needle every ½ hour from 00:00 to early morning Dec 21 1806 during aurora.
- When the aurora ceased so did the magnetic deflections.
- He called the event ‘magnetisches ungewitter’- a magnetic storm.
- Main average feature of a magnetic storm is a decrease in horizontal magnetic field intensity followed by subsequent recovery.

Geomagnetic indices

- D_{st} – hourly values of average global variation of the low-latitude horizontal component of the magnetic field.
- K - many observatories record a K index (over a 3 hr period) which represents the changes in H, D and Z elements of the magnetic field. 0 is small and 9 is the largest.
  - K_p – a planetary index which is derived from the average of selected observatories distributed across the Earth.
- A_p – A index is 24 hour average of converted K index reading with range 0-400. A_p is the global composite.

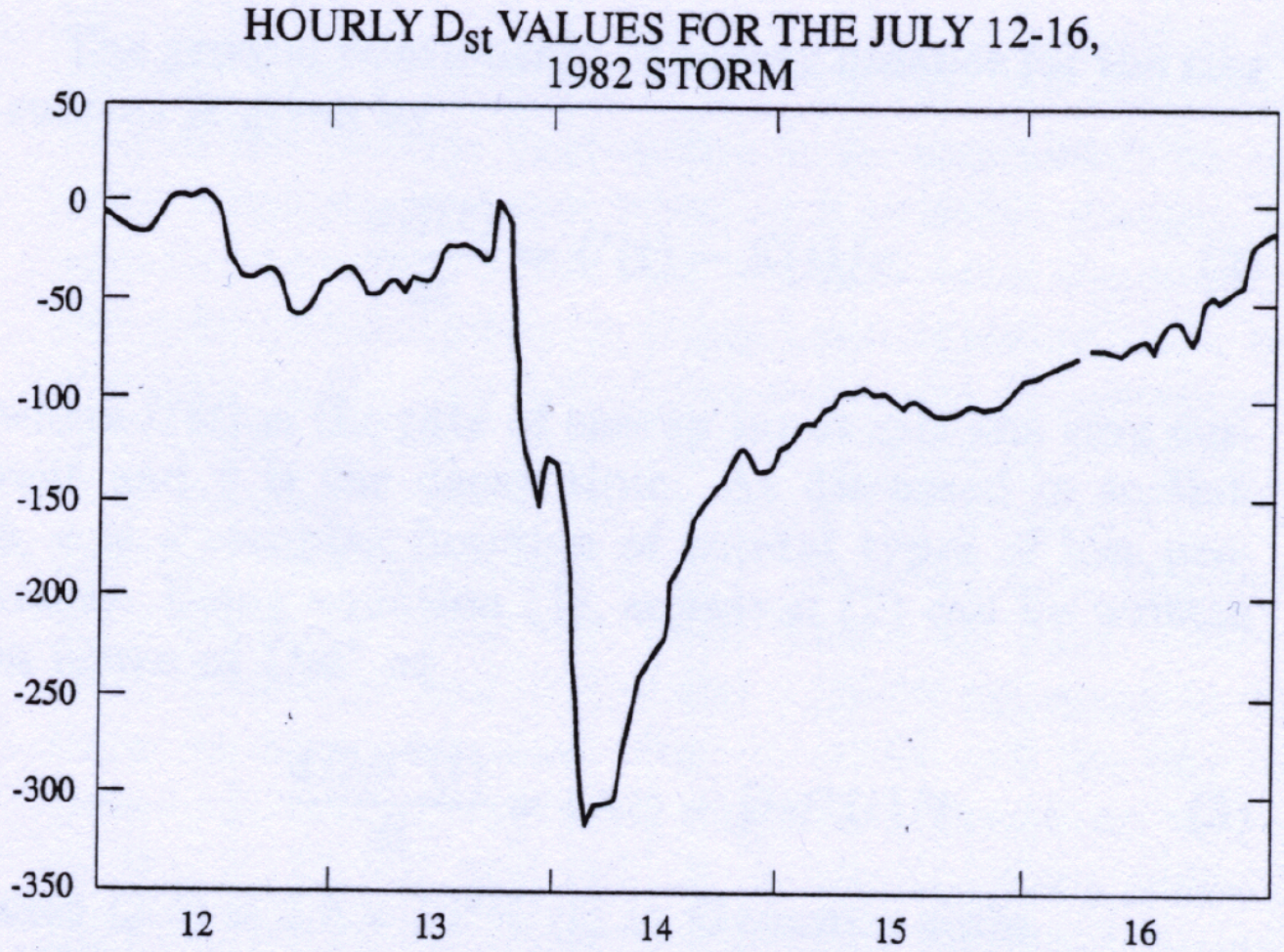
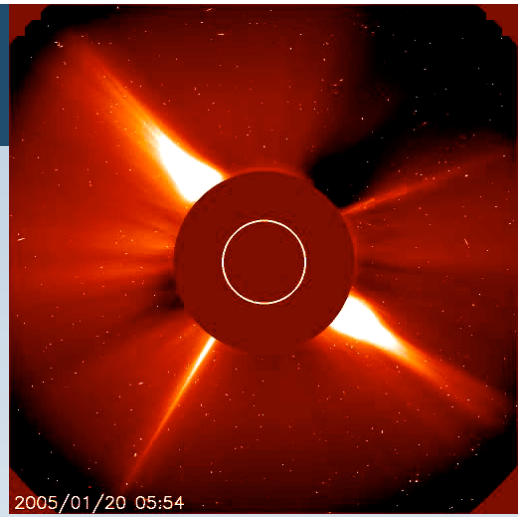


Figure 1. Great magnetic storm of July 12–16, 1982. The solar wind-pressure corrected *Dst** reached peak values around -440 nT.

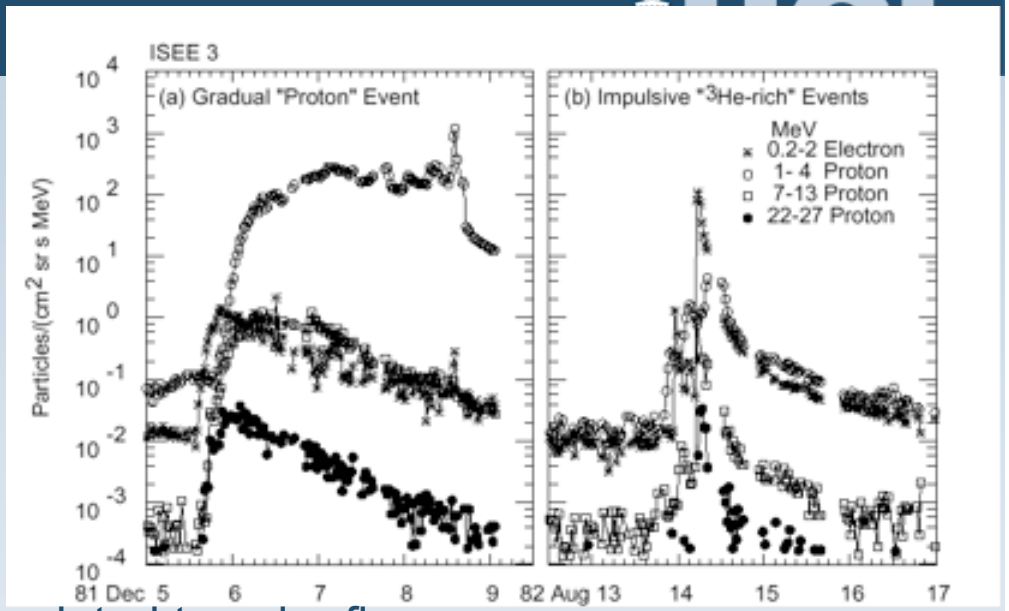
Ionospheric effects

- Ionosphere is the part of the Earth's upper atmosphere that contains free e^-s & protons produced by the Sun's ionizing radiation.
- Lies at the base of the magnetosphere - > 60km density is high enough to affect radio wave propagation.
- Maximum useable frequency of telecommunication and surveillance transmissions depends on N_e in ionosphere – variable.
- High ionization events associated with flares can cause radio blackouts.
- Scintillation effects, phase path changes & propagation delays can affect e.g. GPS, spacecraft telemetry.
- Heating due to enhanced EUV & X-ray radiation reduces rate of decay of N_e with height which can alter satellite orbits and cause premature re-entry.

SEPs

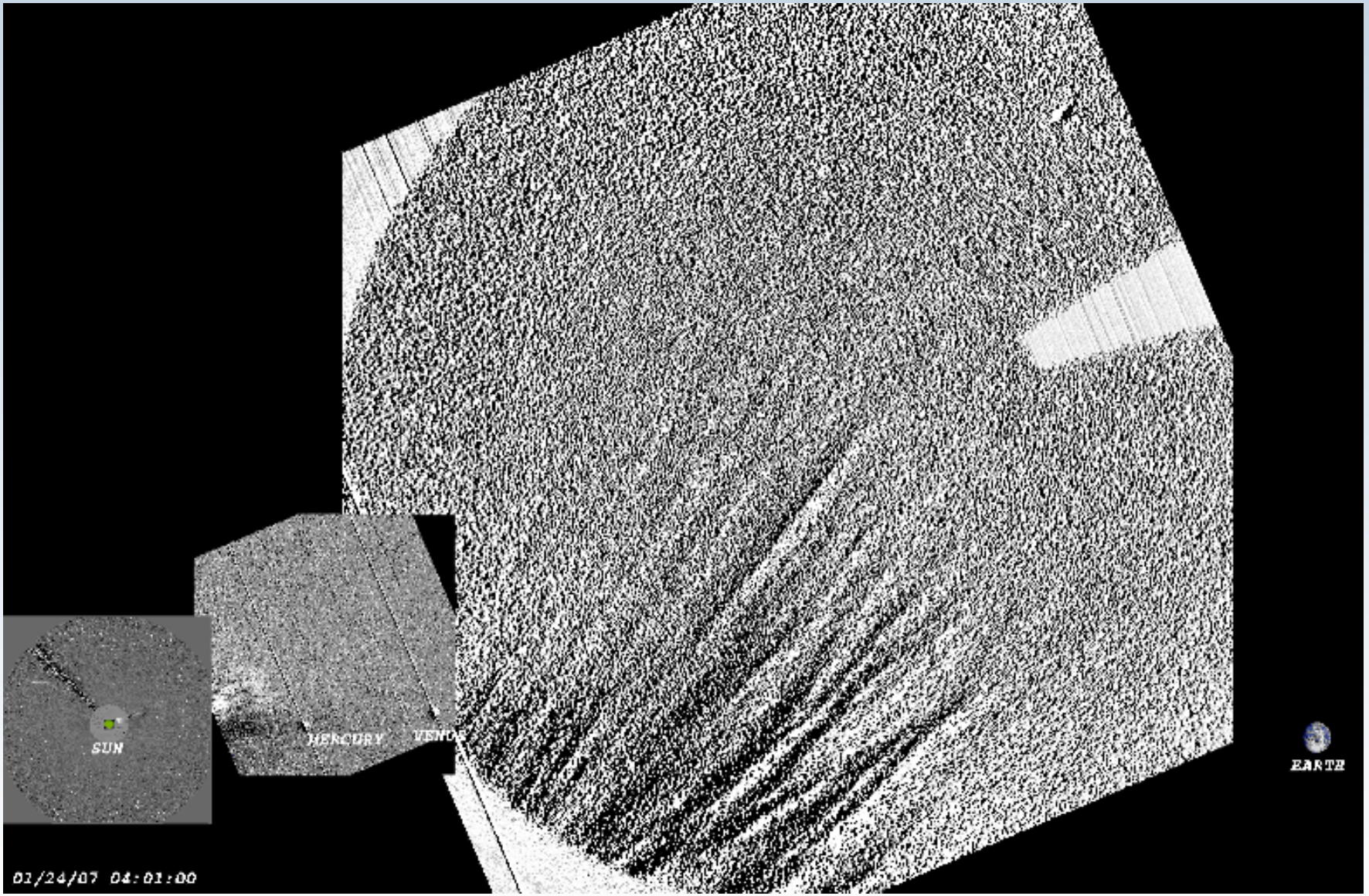


- High energy particles from the Sun first observed as sudden ↑ in ground level ion chambers in 1942 by Forbush.
- Balloon experiments in 50s demonstrated these were mainly protons.
- In late 70s, early 80s a high correlation (96%) found between large SEP events and Coronal Mass Ejections.



- 2 types of SEP:
  - impulsive
  - gradual
- Impulsive events believed to be associated to solar flares:
  - 1000 fold ↑ in $^3He/^4He$ ratio relative to coronal
  - enhancement in heavy ion population
  - believed to be caused by resonant wave-particle interactions at flare site
- gradual events believed to be associated with CMEs
  - most intense high energy particles accelerated at collisionless CME shocks
  - directly reflect abundances of un-heated corona.

➢ 2 different acceleration processes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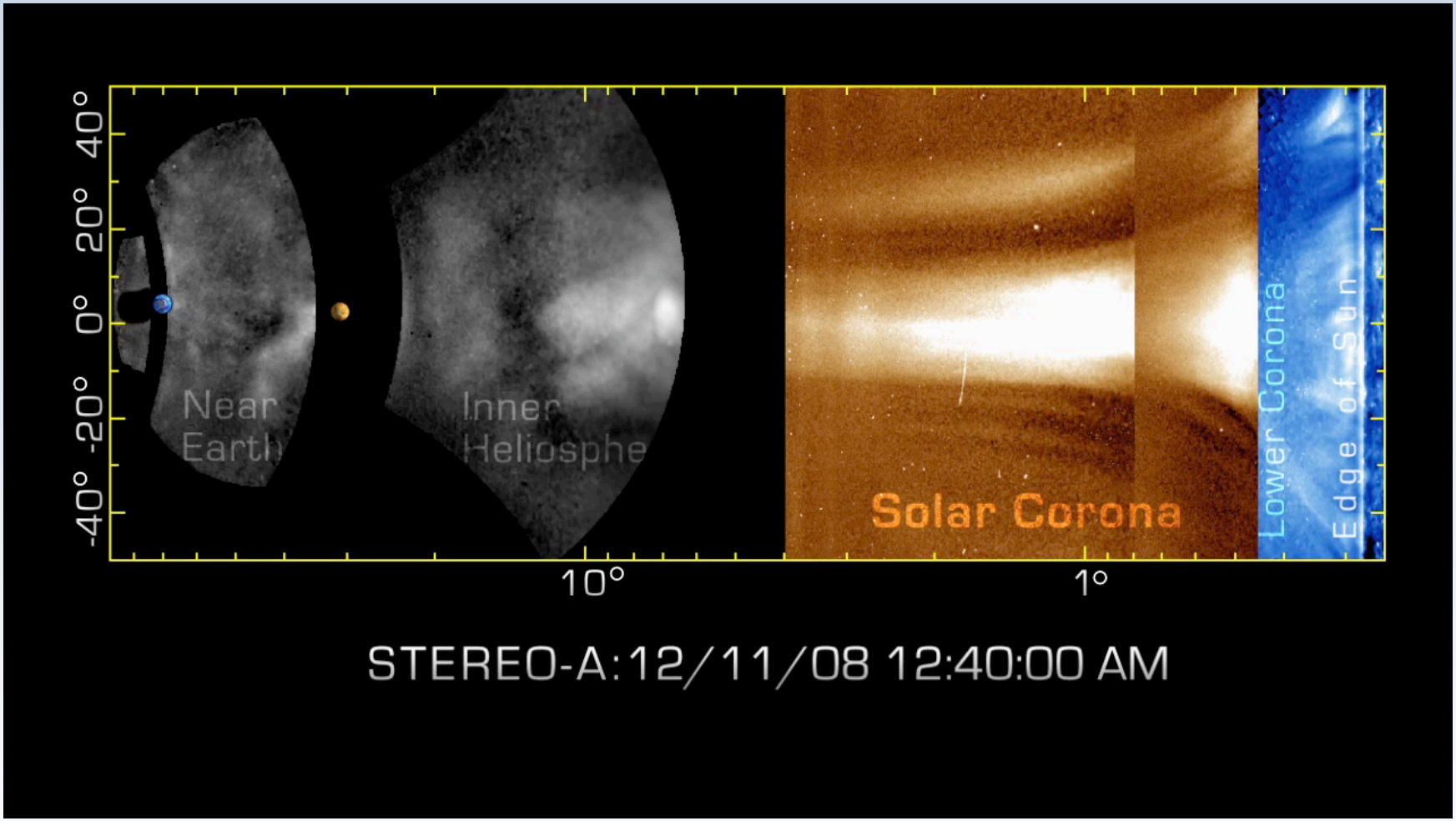
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Near Earth
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Mail Online

Freak space storm triggered by solar changes could scupper London Olympics

By Daily Mail Reporter
Last updated at 4:06 PM on 6th January 2011

With £9.3billion being spent on the Olympics, the organisers could be forgiven for thinking they had prepared for every eventuality.

But London could suffer a space storm during the games - causing power cuts, damaging communication satellites and forcing planes to divert.

London Olympics organisers admitted today they were 'monitoring the situation carefully' after the Met Office warned the next solar storm may occur during the games next year.

Chaos? London could suffer a space storm during the Olympics, potentially hitting the power supply, damaging communication satellites and forcing planes to divert

Weather experts told the Commons science and technology committee: 'Extreme space weather events typically occur at the solar maximum, which itself follows a roughly 11-year

Friday 17 June 2011

The Telegraph

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Science News

New Little Ice Age in store?

The Earth could enter a new 'Little Ice Age' in the coming years due to low solar activity, astronomers believe.

Could the sun be setting on a series of warm years? Photo: OLEG TOUMILOVITCH

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