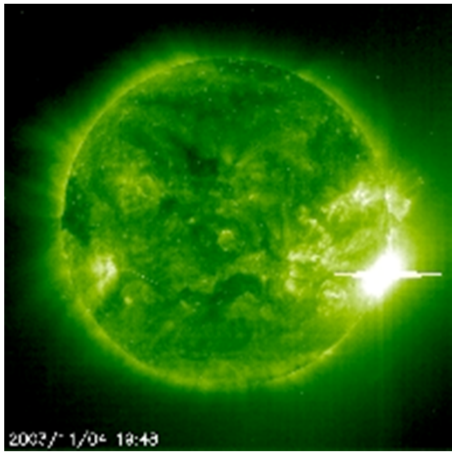
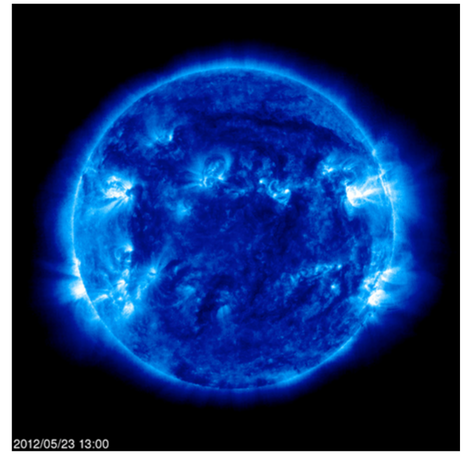




Space weather: From solar storm to magnetic storm...and damages for nanosats

A space weather for Nanosats Which specific risks?

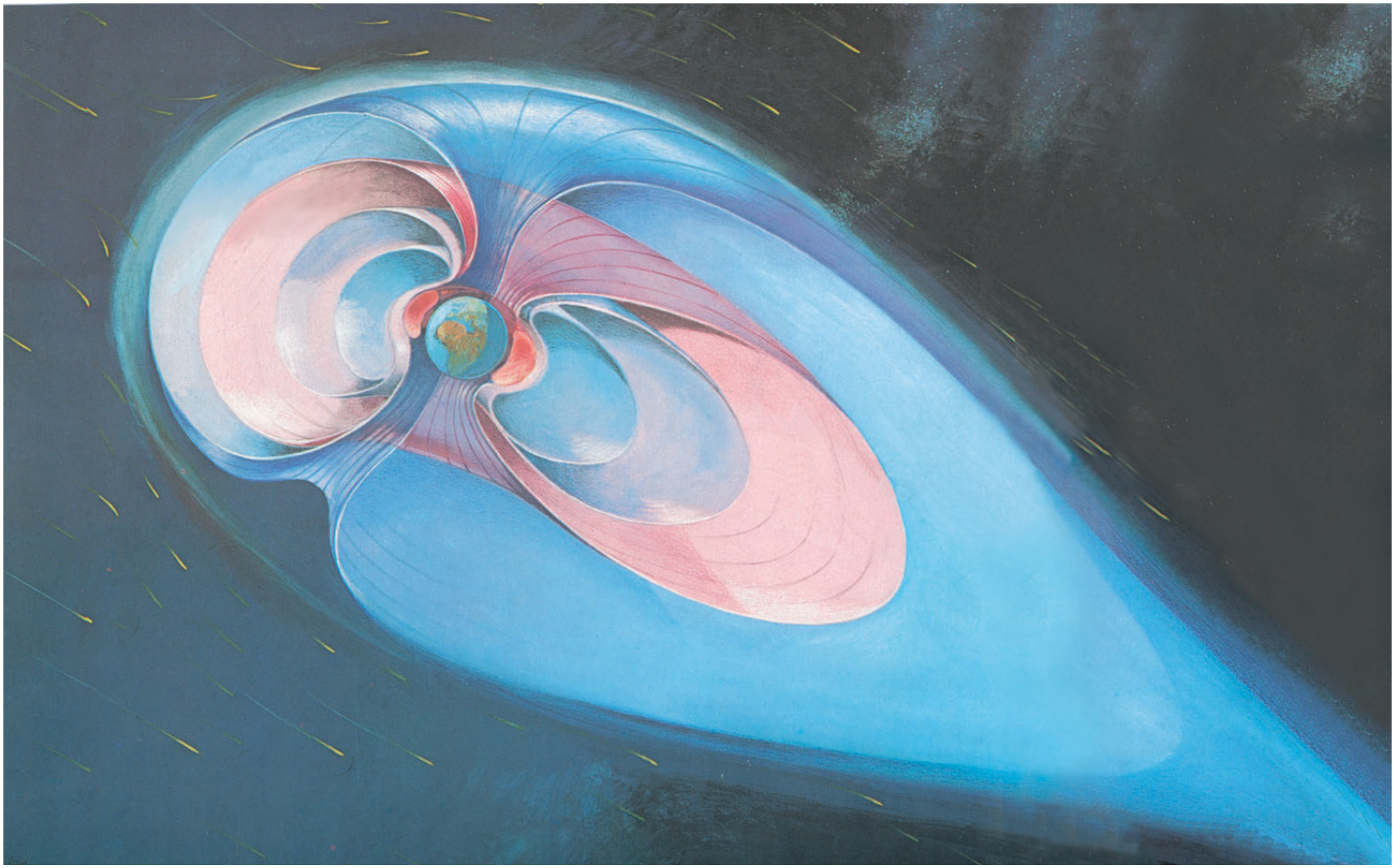
Mathieu Barthélemy IPAG(CNRS-UGA) and CSUG(UGA).

SERESSA 2015.

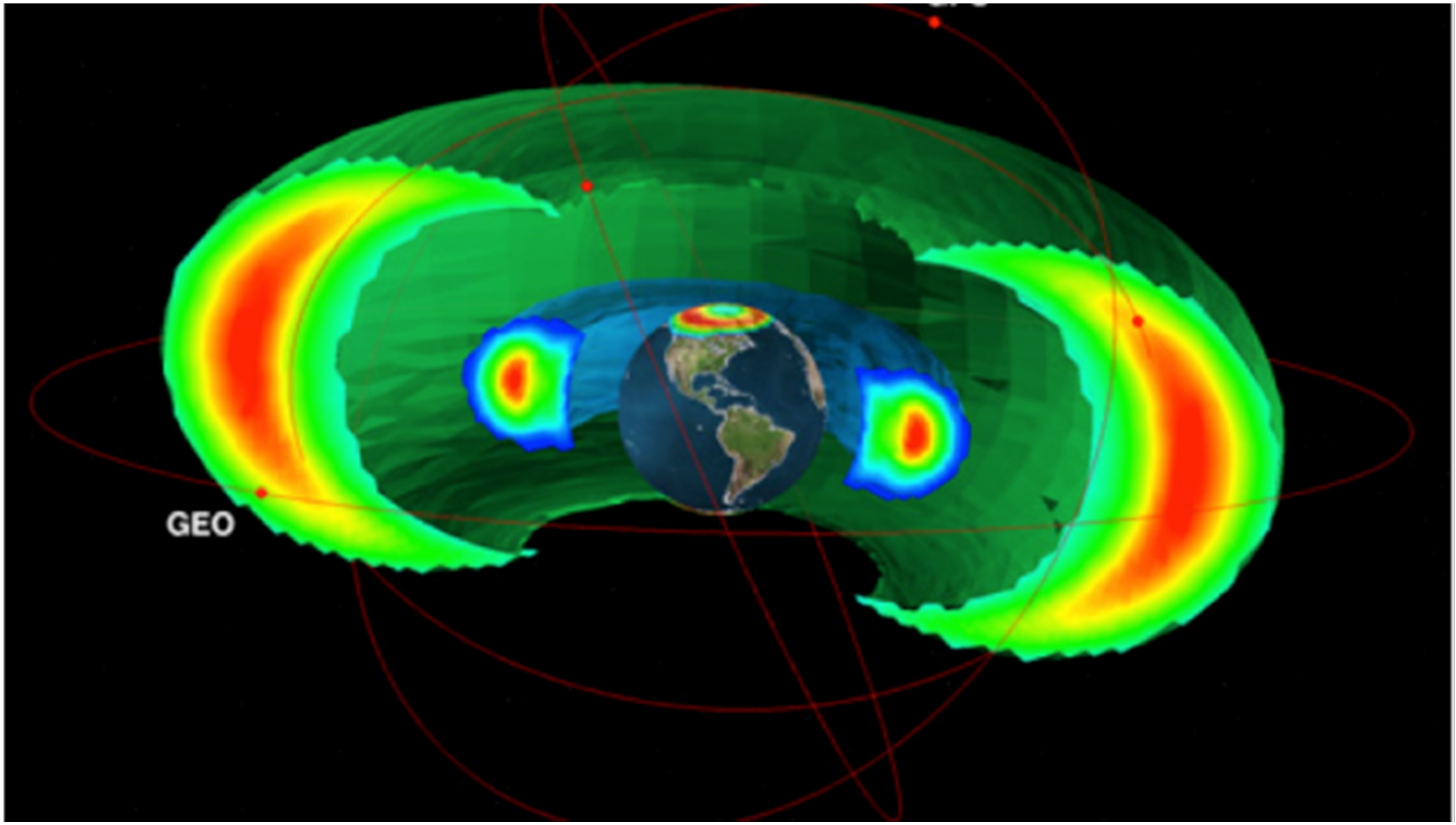
Three major energetic input concern the upper atmosphere

- Solar wind
  - Slow and fast (200 to 800 km/s): 3 days between Sun and Earth
    - – Permanent, 10^4 W.m-2
- EUV flux
  - From 1 to 120 nm. Totally non LTE. Strongly variable (up to a factor 1000)
    - – Permanent, ~10^5 W.m-2 in quiet period
- Eruptive events
  - Solar flare, CME (up to 3000 km/s): 20 hours from Sun to Earth.
    - – Sporadic, ~10^6 W.m-2

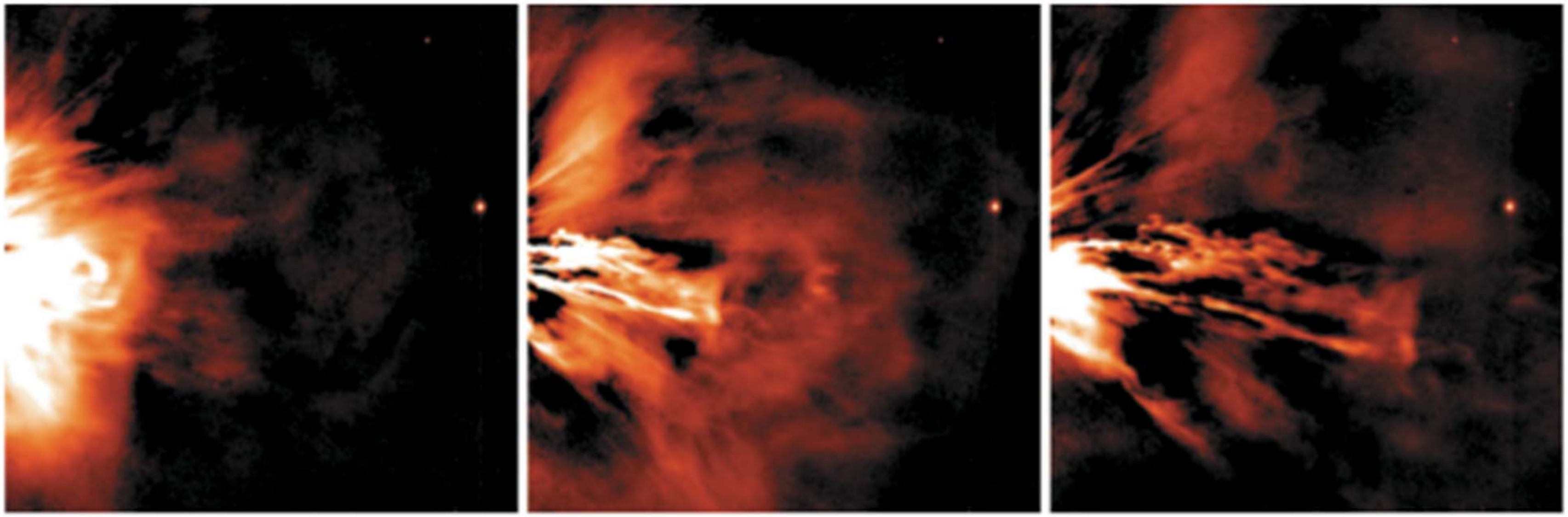
Interaction between Sun and Earth



Radiation belts



Credit: NOAA



J. DAVIES, STFC/RAL SPACE

This eruption of plasma from the Sun in June 2011, captured by instruments on the STEREO spacecraft, didn't cause a space weather storm on Earth. Others will.

Prepare for the coming space weather storm

We need to improve estimates of geomagnetic storm size, says **Mike Hapgood**, so we can be ready for huge disruptions to electrical systems.

Nature, 19 APRIL 2012 | VOL 484

2 types of impacts

- Short term:
  - Satellite loss or damage.
  - GIC on large networks (pipelines, electrical, etc)
  - Radiations (Airplanes)
  - GPS positioning
  - Radar blackout
- Long term
  - Atmospheric escape

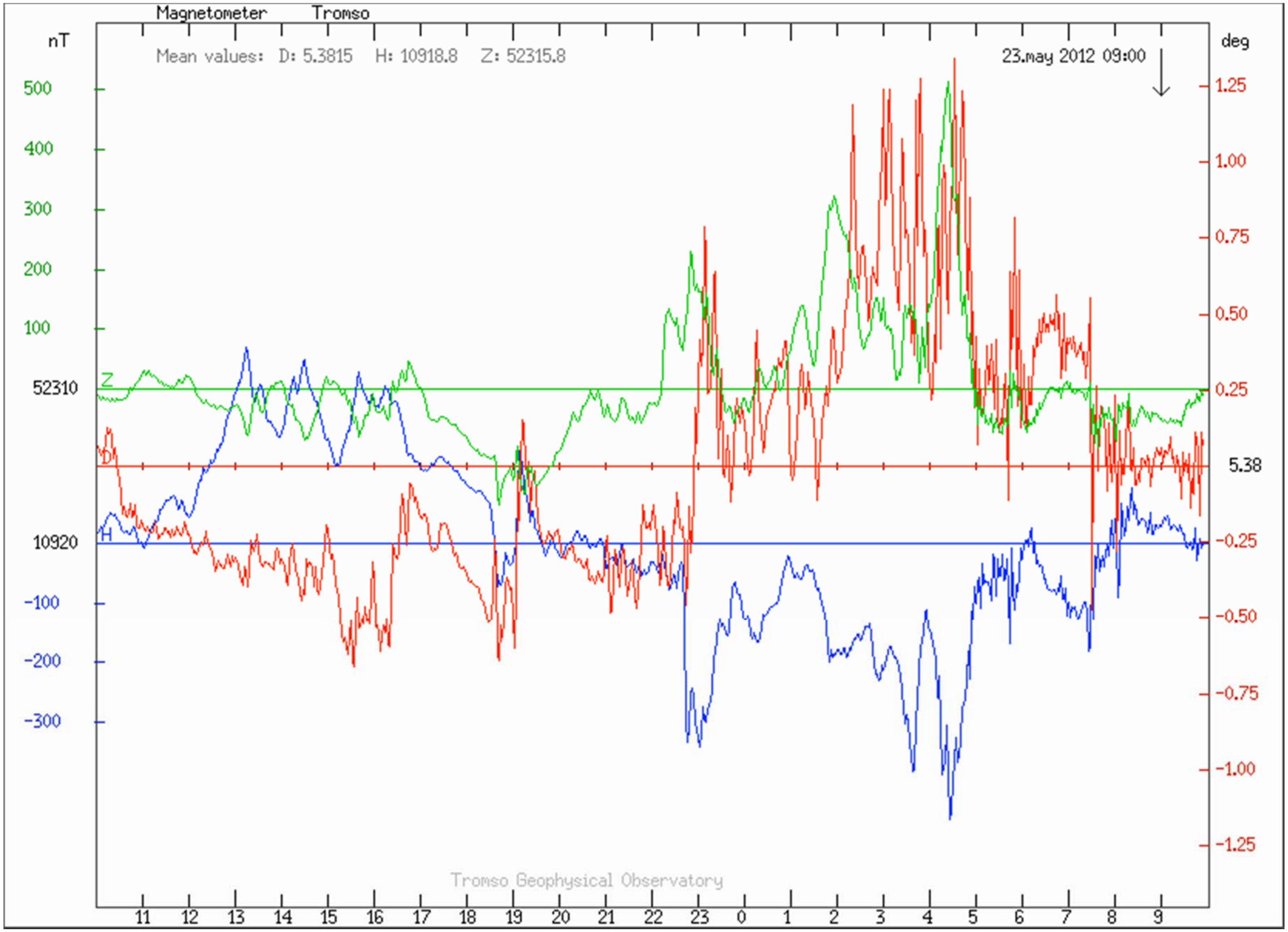
Polar light seen from the ISS (ESA/NASA).

Impact on satellites

- **Charging** (Dielectric) – Energetic Electrons (E>1MeV). Possible uncontrol discharges in satellites.
- **Tumbling** – Low Earth orbit (LEO).
- **At the magnetopause** (MPE) – SCAO pb
- **Magnetic storm and sub-storms:** particle impact on electronics (Protons, electrons)
- **Drag**: Variation of upper atmosphere density (especially for ISS but also for nanosats).

Spacecraft	Time	Comment	Reference
DSP		Anomalies associated with >1.2 MeV electrons	Vampola, 1994
SCATHA		Internal discharges associated with outer radiation belt	Garrett and Whittlesey, 1996
ATS 5 and ATS 6		Charged to 10 kV in eclipse at GEO	SMASS Report
NOAA spacecraft	from 1971	Contains 2779 events from 1971to 1988	Wilkinson, 1994
Goddard space-craft	1993-1995	More than 400 anomalies	Remez and McLeod, 1996; Walter, 1995
Voyager 1		Power-on resets	Leung et al., 1986
Pioneer		Severe space weather near Jupiter	SMASS Report
GPS		Clock shift, false commands	James et al., 1994
Intelsat 3 and 4		Spin up	James et al., 1994
GOES 2			Lauriente et al., , 1996, 1998
GOES 3		Upsets	
GOES 4	Nov 26, 1982	Instrument failed on arrival of 110-500 MeV protons	Vampola 1994
Intelsat K	Jan 20 1994	Loss of attitude control in GEO	Baker et al. 1994
ANIK E1 and ANIK E2	Jan 20-21 1994	Loss of attitude control due to high energy electrons	Baker et al. 1996
ANIK E1	Mar 26 1996	Array of solar power panels disconnected	ISTP Newsletter, Vol 6, no 2, 1996.
DRA-delta		Phantom commands	Wrenn and Sims, 1996
CTS		Short circuit	James et al., 1994
DSCS II		Spin up, amplifier gain	James et al., 1994
DMSP 7		Charged to 300 V in less than a second- associated with a sharp drop in ion density	Stevens and Jones, 1995
GOES 5	July 22 1984	Failure during high energetic electron fluxes	Baker
DMSP F13		Problems while passing through an aurora	Anderson and Koons, 1996
Hispasat 1A and 1B	Sep 1992 and July 1993		Selding, 1998
Telstar 401	Jan 11 1997	Failure probably due to coronal mass ejection	Anselmo, 1997
Telstar 402		Spacecraft charging	Lanzerotti et al., 1996
Topex/Poseidon		Failures due to electrostatic discharges and SEUs caused by high energy protons	Lauriente and Vampola 1996
Intelsat 511	Oct 7 1995	Lost Earth lock	http://www.astro.lu.se/~henrik/spacew4b.html
GOES 8	Feb 14 1995	Attitude control difficulty	http://www.astro.lu.se/~henrik/spacew4b.html
TDRSS 1	1988-1991	SEUs anticorrelated with solar cycle	Wilkinson 1994
CRRES	1990	674 reported anomalies	Violet & Frederickson 1993
Tempo 2	11 Apr 1997	Temporary power fluctuations.	http://www.seds.org/spaceviews/970515/tech.html
Olympus	11/12 Aug 1993	Affected by the 1993 Perseid meteor shower?	See 2.1.5 above

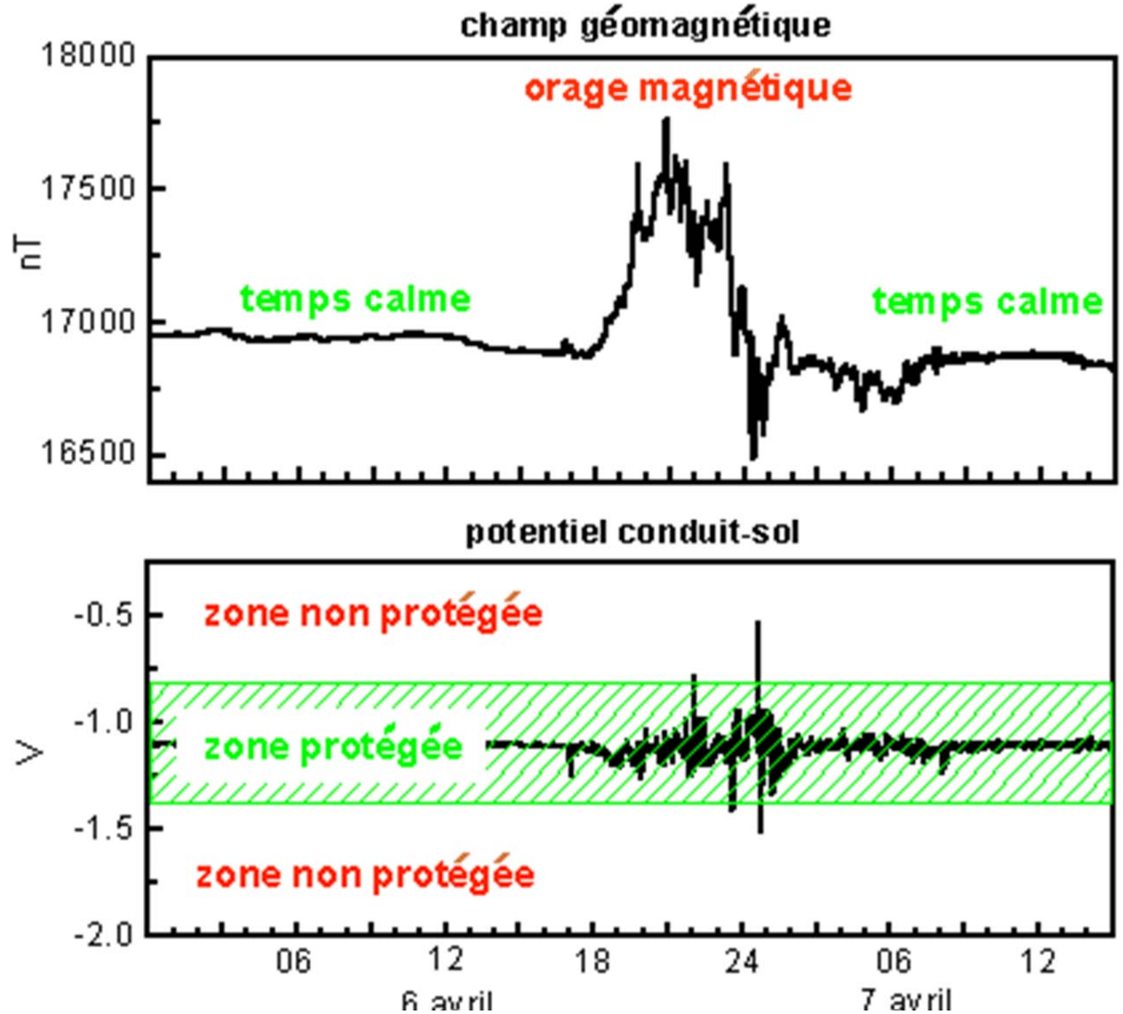
Ground Induced Currents



Ground Induced Currents

Quebec 1989.

Ground induced currents



http://www.spaceweather.gc.ca/tech/pipelines/se-pip-fra.php

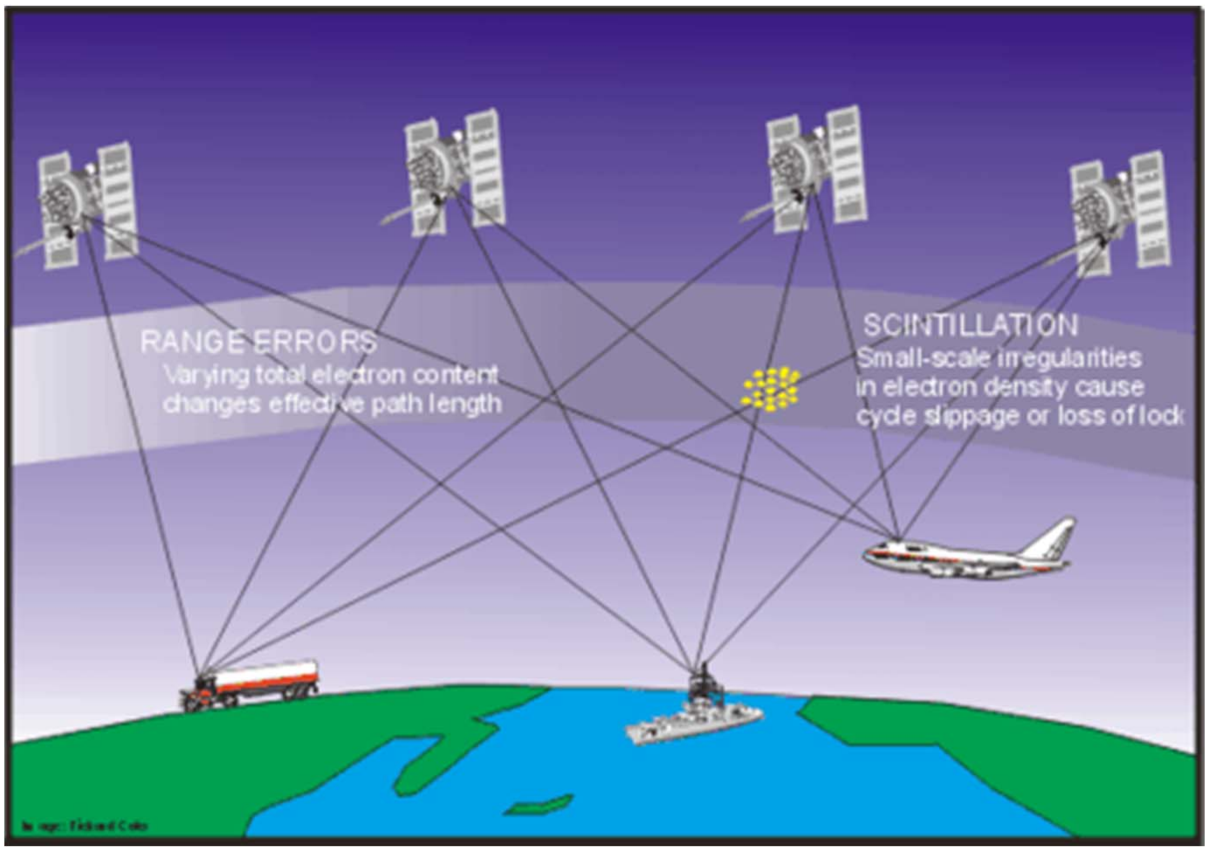
Around 2000

Ground Induced currents

- Long distances cables
  - 4 august 1972: Transamerican cable cut-off in the middle of Canada
  - Maximal variation rate 2 200 nT/min, observed at magnetic observatory of Meanook.
  - Induce electric field: 7V/km.

GPS positionning

- Local enhancement of the local electron density
- Modification of the propagation speed
    - > Error in positionning (More than 100m for large storm).



Major magnetic storm list since the Carrington event.

Table 1. Chronological List of Large Magnetic Storms[a]

Storm	Year	Month	Day	H Range,[d] nT	DST, nT	Station	Geomagnetic[e] Latitude N	Geomagnetic[e] Longitude E
1	1859	September	1–2	1720		Bombay	9.87°	142.7°
		September	1–2	>700[b,c]		Kew	54.47°	82.5°
2	1859	October	12	980		Bombay	9.87°	142.7°
3	1872	February	4	1020		Bombay	9.87°	142.7°
4	1882	November	17	450		Bombay	9.87°	142.7°
		November	17	>1090[b,c]		Greenwich	54.40°	82.8°
5	1903	October	31	820		Bombay	9.87°	142.7°
		October	31	>950[b,c]		Potsdam	52.66°	96.2°
6	1909	September	25	>1500[b,c]		Potsdam	52.66°	96.2°
7	1921	May	13–16	>700		Alibag	9.61°	142.7°
		May	13–16	1060[f]		Potsdam	52.66°	96.2°
8	1928	July	7	780		Alibag	9.61°	142.7°
9	1938	April	16	530		Alibag	9.61°	142.7°
		April	16	1900[b]		Potsdam	52.66°	96.2°
10	1957	September	13	580	−427	Alibag	9.61°	142.7°
11	1958	February	11	660	−426	Alibag	9.61°	142.7°
12	1989	March	13	640	−589	Kakioka	25.97°	205.1°

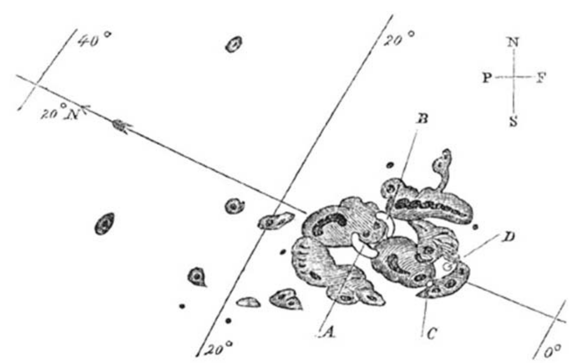
Tiré de Tsurutani et al. JGR 2003

The solar flare was followed by a magnetic storm at the Earth. The time delay was 17 hours and 40 min (stated in the Carrington paper (1859)). Red glows were reported as visible from within 23° of the geomagnetic equator in both north and southern hemispheres during the display of September 1 – 2

Characteristics of some event

- 1859: The strongest in the recent time
  - Fast CME (2400 km.s-1)
  - Problems on some telegraphics systems: fire of telegraphic stations.
  - Northern light around 20° N latitude (Cuba, Mumbay)
  - Registered magnetic trace in the ground.

(Carrington 1859)

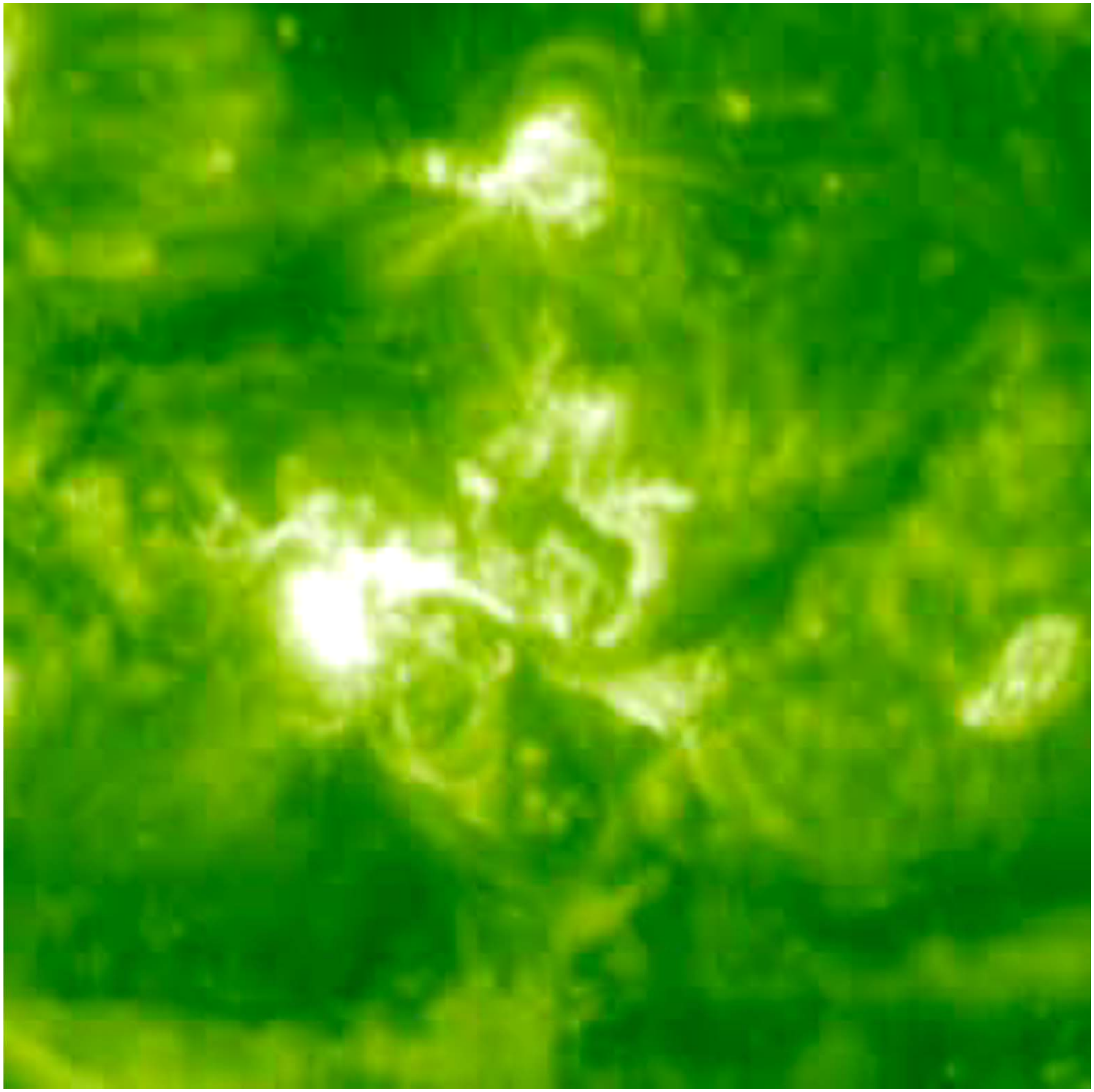


Characteristics of some event

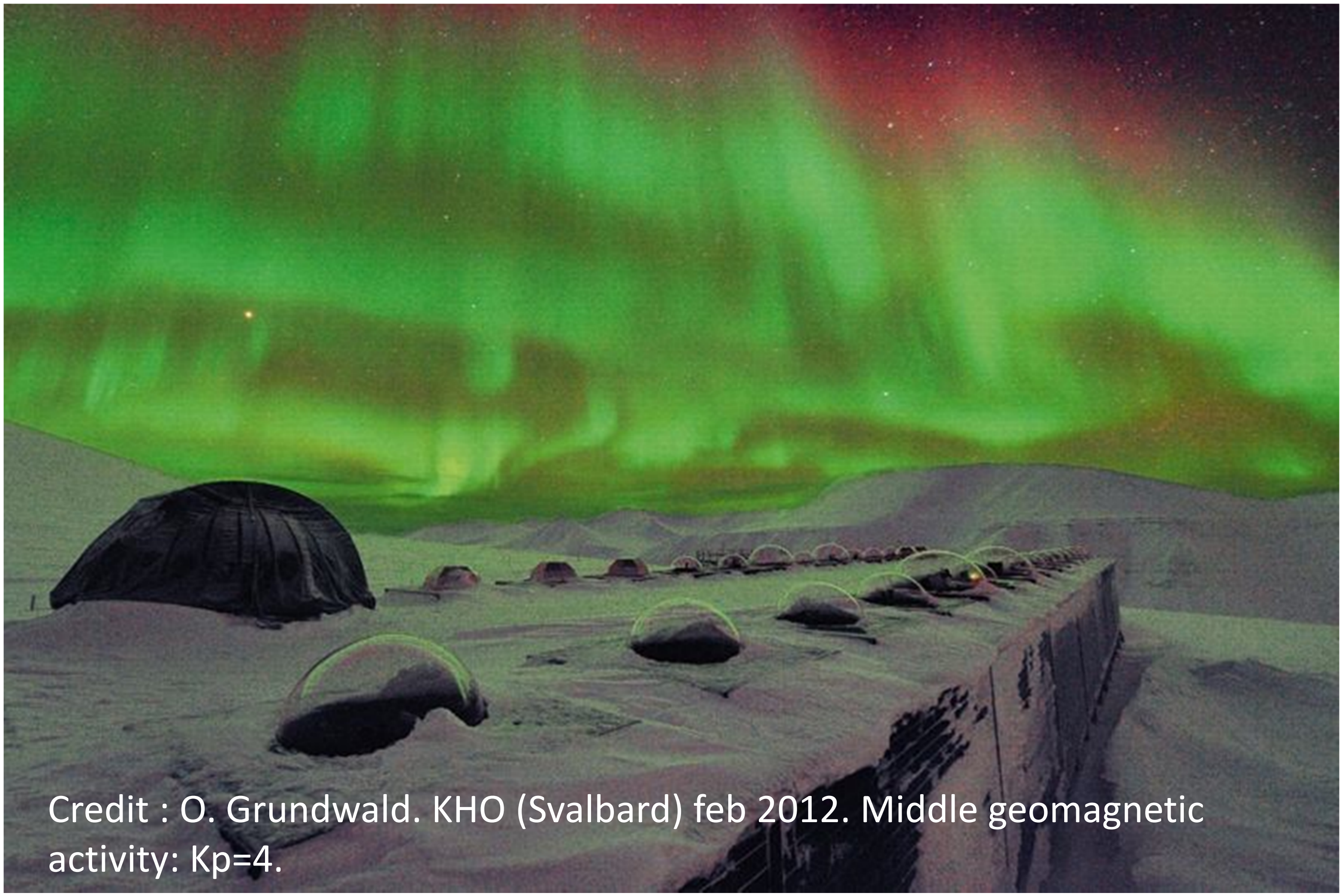
- 1989: The strongest for the last 40 years
  - Quebec electric network off
  - Very high atmospheric drag
  - But radiation flux not so high.
- 1956: One of the strongest in term of radiation. Untypical.
  - Very strong flux of E>1GeV particles
    - Strong problems for airplanes (All routes in Europe and Northern America dangerous).
  - Few geomagnetic activity

Characteristics of some event

- 2003: The second strongest of the last 40 years.
    - The most studied
    - Less electrical problems than the 1989 event due to the technologic devices built.
    - Changes in airplane routes above polar regions.
    - Strong problems on satellites (3 at least lost) and spatial probes (Mars Odyssey, Mars Express).



But it exists some nice consequences…



Credit : O. Grundwald. KHO (Svalbard) feb 2012. Middle geomagnetic activity: Kp=4.

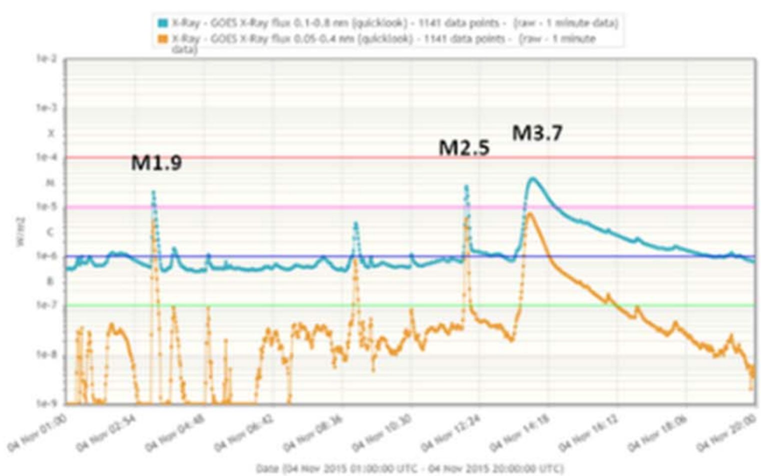
The most recent event with significant impact

Strong radio event on 04 November

posted: November 11, 2015

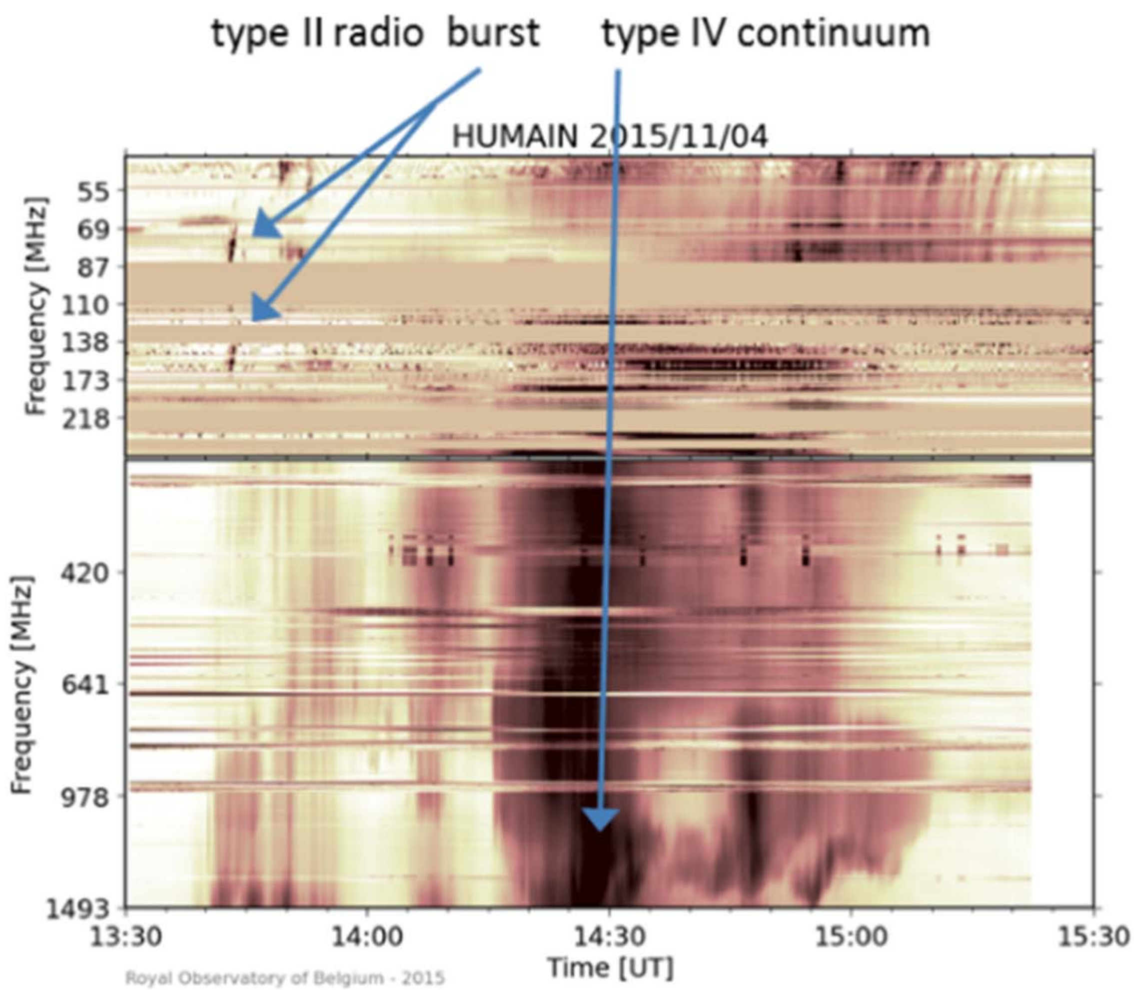
This news item was written by Dr Jasmina Magdalenic, scientist at the Royal Observatory of Belgium.

Although we are already in the declining phase of this solar cycle, the Sun was rather busy on 04 November. Three rather large eruptive phenomena (M-class flares) were observed on that day. The two smaller eruptions (i.e. M1.9 and M2.5) originated from active region NOAA 2445, while the largest one, the M3.7 flare, originated from the active region NOAA 2443 which was near disk centre at the time of the eruption. The GOES curves in the figure underneath show several solar flares recorded on 04 November. The most prominent ones were the three medium-sized M-class flares (with the maximum intensities above the pink horizontal line). All three events were associated with radio emission, but the most complex radio emission was linked to the long duration M3.7 flare.



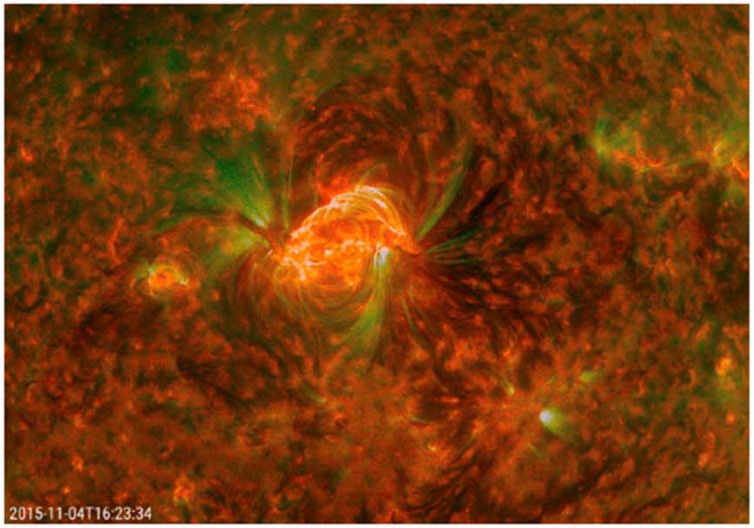
http://sidc.oma.be/news/326/welcome.html

The most recent with significant impact



The most recent with significant impact

The problems of the Swedish air traffic control (radars stopped showing airplanes) reported on 04 November, lasted about an hour starting from around 13:30UT. These phenomena temporarily coincided with the start of the intense radio emission observed by HSRS (see figure above). Therefore we can deduce that the apparently strong type IV radio emission which was observed on both GPS frequencies (around 1.5 GHz) and the civil air traffic control communication channels (about 120-140 MHz), might have been the source of the radio blackout experienced by the Swedish air traffic control.

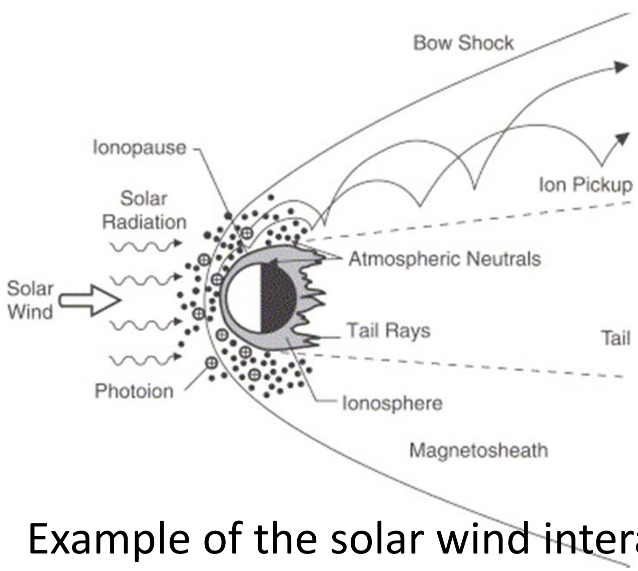


The animation above combines SDO/AIA 171 & 304 imagery (extreme ultraviolet) of NOAA 2443 on 04 November between 13:00 and 18:00UT.

Confirmation at the ESWW12 by H. Opgenoorth

Long term consequences

- Atmospheric escape
  - Evolution of the planetary atmospheres.
    - Uncertain relation with activity and solar wind?
    - Important role of the magnetic field.



Very long time scale (~1GY)

Example of the solar wind interaction with the planet.

Planetary space weather

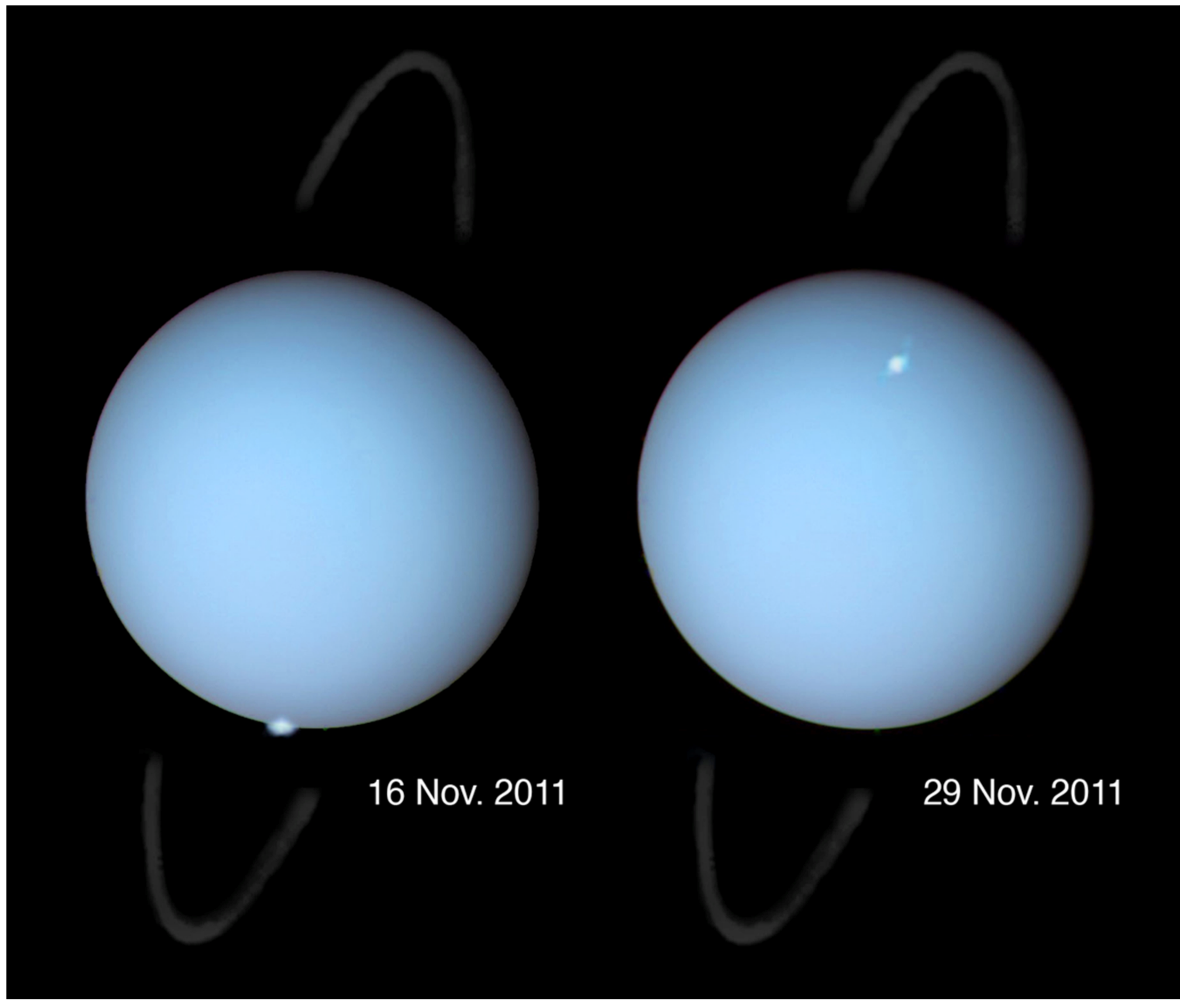
- Different magnetospheric configurations
  - Jupiter
    - Very unsensitive to the solar wind but very harsh conditions
      - » Io volcanism.
  - Mars
    - Strong erosion of the atmosphere.
      - » See Maven results (GRL and Sciences special issues, 2015)

Planetary space weather

- Uranus

HST detection of auroral spots (FUV)

Lamy et al. 2012



Planetary space weather

- Why is it interesting?
  - Planetary atmosphere erosion and evolution

  - But also space missions
    - JUICE, Mars express, MAVEN for example
      - » for example, Galileo mission lost ½ of its instruments by crossing the Io Torus
        - Sulfur atoms (E up to 5 MeV/nu)

Back on nanosats

- What specific problems compare to large satellites
    - Charging
        - Nanosats are small.
            - » Surface charging is very quick and discharge can occurs more easily.
    - Tumbling
        - Easy rotation and small SCAO systems
    - Shielding
        - More difficult to shield due to weight constraints.
        - Re-booting problems for OBC. Occur more frequently than with regular satellites
- Need for new architectures and some orbits are very

Back on nanosats

- Atmospheric drag
  - Strong problem for nanosats
    - » No propulsion for the moment (Some have been developed but none flew to my knowledge).
  - – Strongly reduce the mission duration.

Conclusions

- Events are strongly variable especially extreme events
    - Some with strong very energetic particle fluxes
    - Some not with important GIC but few energetic particles
    - Small flare but strong radio burst.

  – A difficult task to forecast satellite risk especially for nanosats

Conclusions

- Particles (see next talk) are the most problematic for satellites
    - » Total dose (Low energy)
    - » Single events (High energy particles)
  - – Critical for nanosats (few shielding)
- But also
  - – Charging or tumbling.
    - » More problematic for nanosats than for regular satellites
- And drag could be important
    - » No propulsion in nanosats for the moment (and very few energy)