Space Weather From the Sun to the Earth the key role of GNSS

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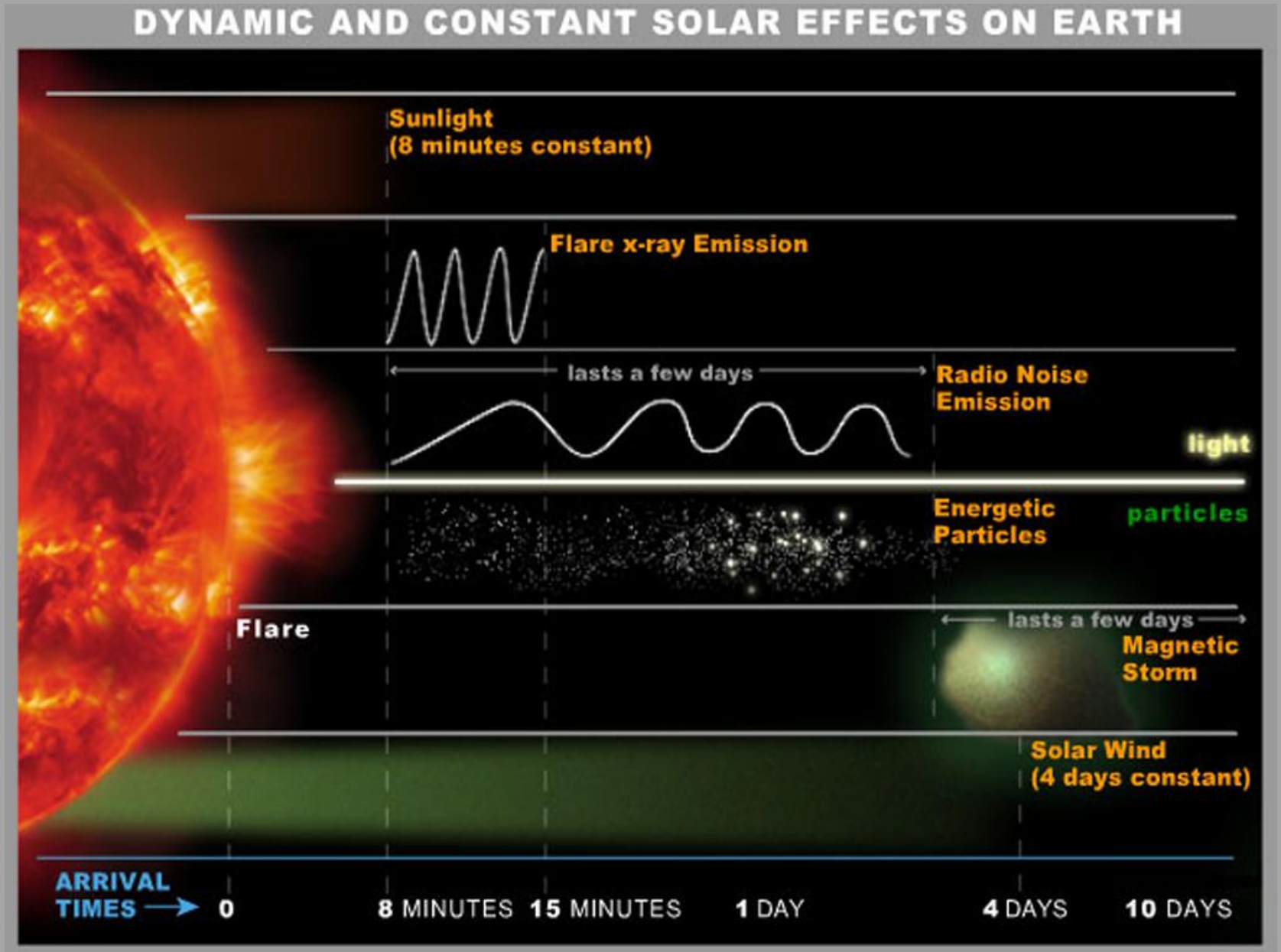
OUTLINES

- Emissions from the Sun
- Why Space Weather ?
- Sun and Earth
- From the Sun to the Earth
  - Extra radiations : Solar Flare, Solar bursts
  - Solar wind and Auroral zone
  - CME , shock, High Speed Solar Wind Streams, CIR
- Impacts
  - Auroral zone => GIC
  - All the Earth and Equatorial region => disturbance of VTEC
- Scintillations
- Training and ISWI network
- Conclusion on the importance of GNSS for research

EMISSIONS FROM THE SUN

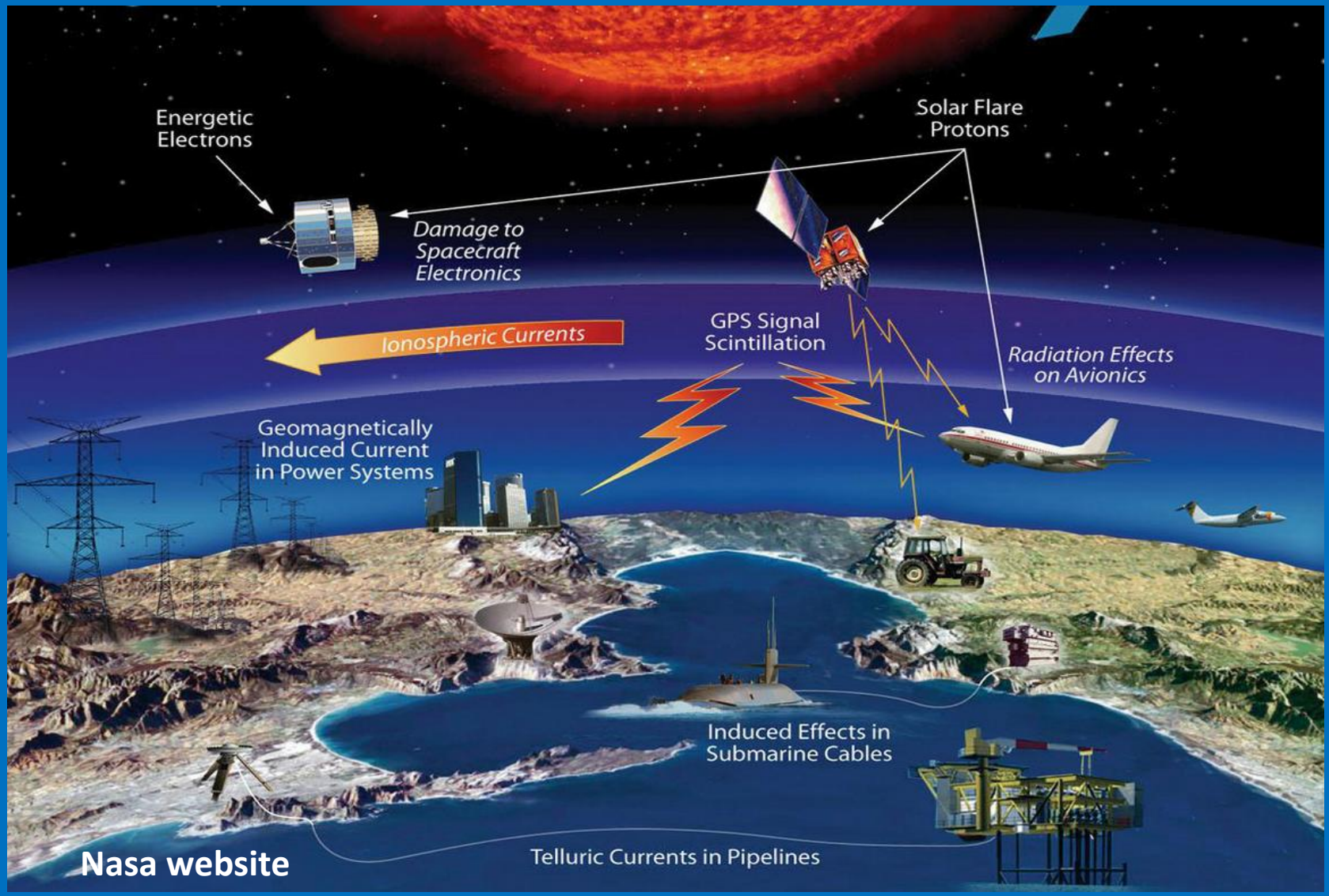


from Nasa website

Between the Sun and the Earth : the IONOSPHERE

Ionosphere is a ionized layer around the Earth (from ~ 50 km up to 800 km)

The ionosphere is the largest source of perturbations for GNSS signals



Nasa website

SUN : a magnetic body in motion

Physical process : Dynamo

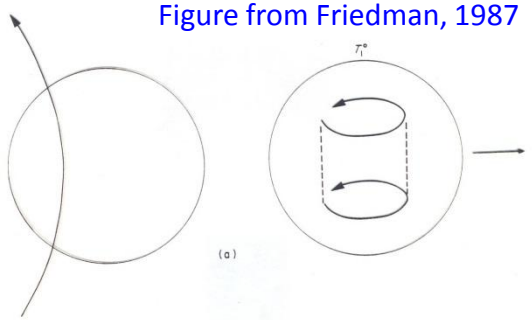
*The sun turns on itself.

**Its rotation speed is faster at the equator than at the poles (~ 27 days against ~ 31 days).

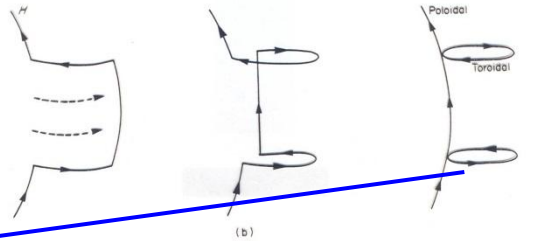
***This differential rotation twists the lines of the poloïdal magnetic field and generates magnetic loops called sunspots

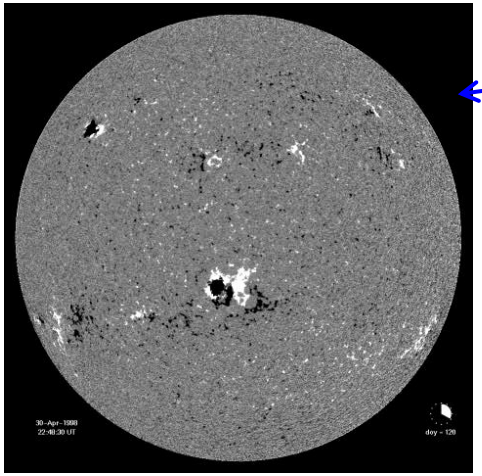
Figure from Friedman, 1987

Poloïdal component
~ 10 G

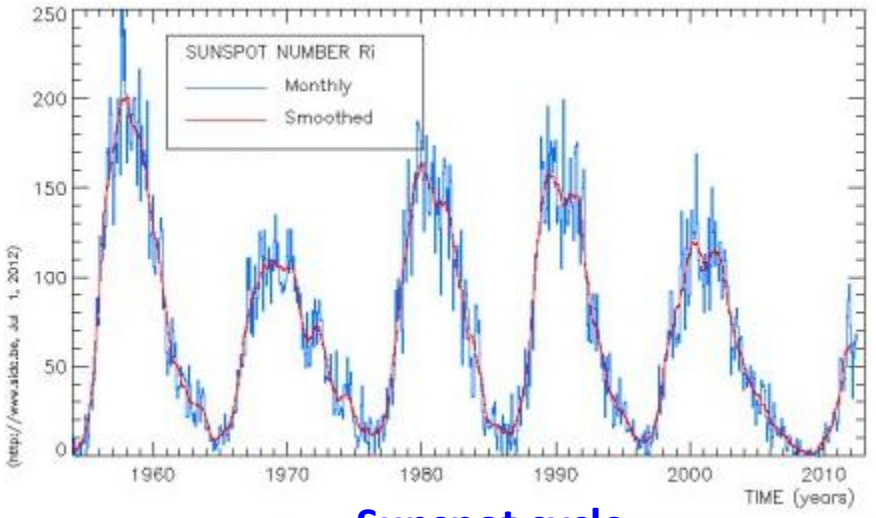


Toroïdal component
Sunspot
~ 3-5 kG





Magnetogram of the Sun
SOHO satellite data



Sunspot cycle

The two main channels

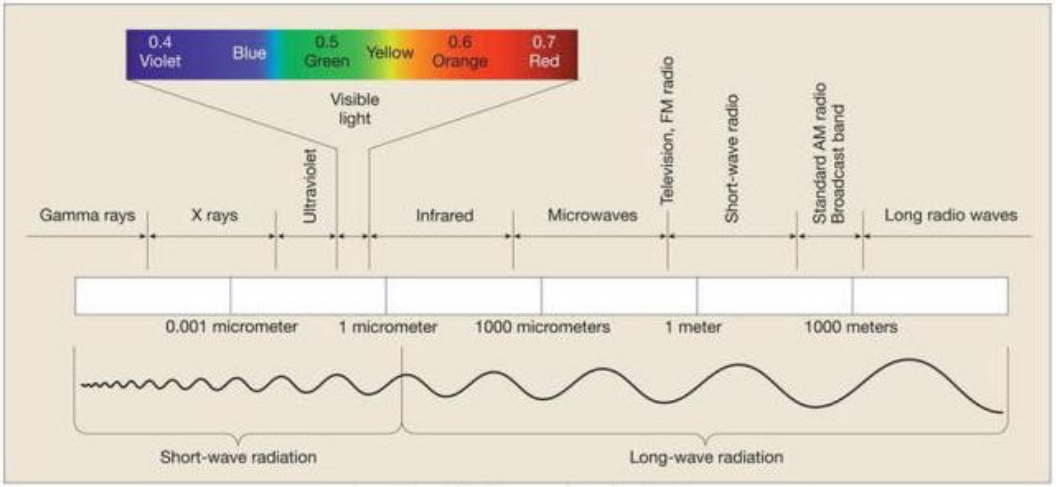
RADIATIONS (LIGHT 8')

*Regular

**Disturbed

Solar flare: X rays

Solar bursts : Radio emissions



SOLAR WIND - PARTICLES [1-4 days]

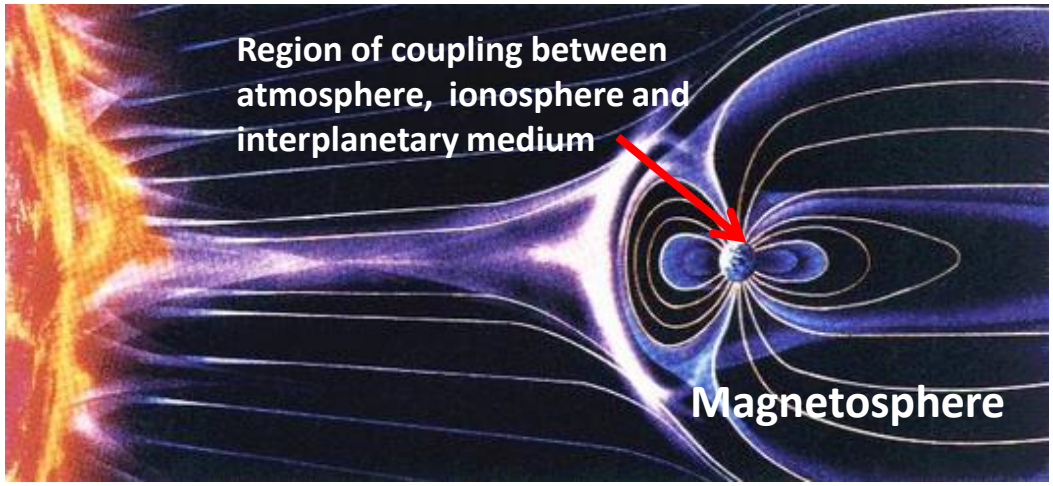
*Regular

**Disturbed by

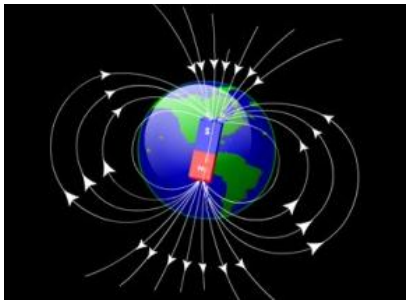
Coronal Mass Ejection

High speed solar wind from coronal hole, etc…

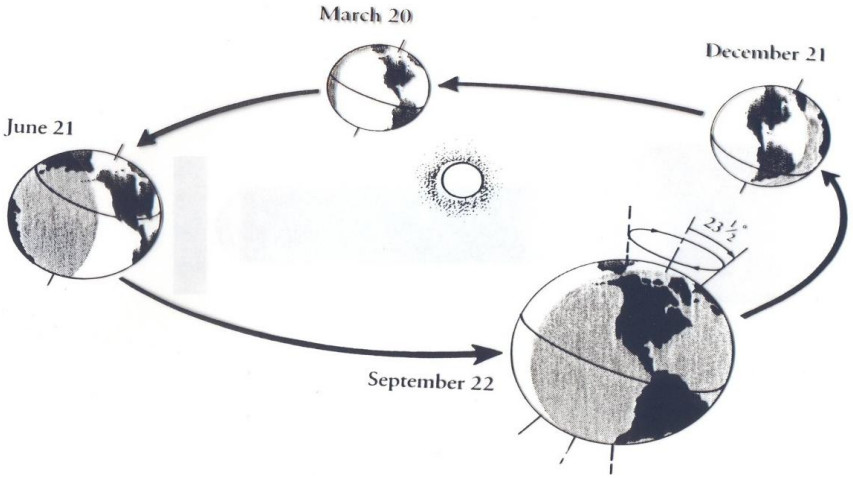
The solar wind is the constant stream of solar coronal material that flows off the sun. Its consists of mostly electrons, protons and alpha particles with energies usually between 1.5 and 10 kEV



The Earth's magnetic field acts as a shield for solar wind particles. However, there are regions of the ionosphere that are directly connected with the interplanetary medium and thus the solar wind flow

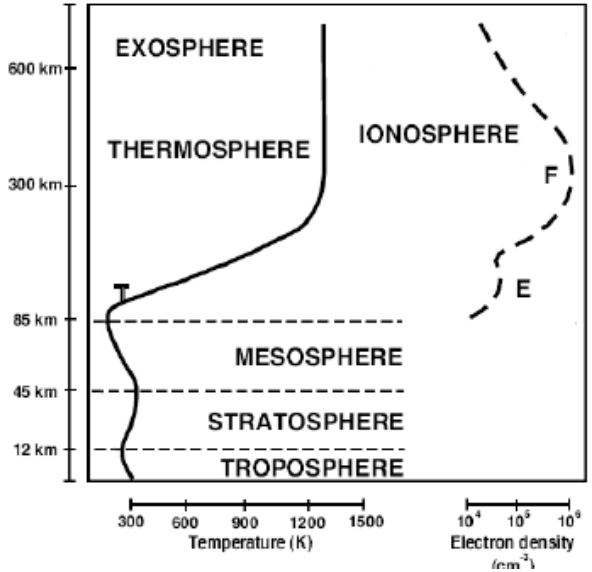


EARTH : a magnetic body in motion



Physical process : Photo ionisation

The ionosphere is created by ionization of the atmosphere by UV, EUV and X radiations in the altitude range from 50 km up to ~800 km



Ionosphere is a ionized part of the **atmosphere**
1 atom among 1 000 000

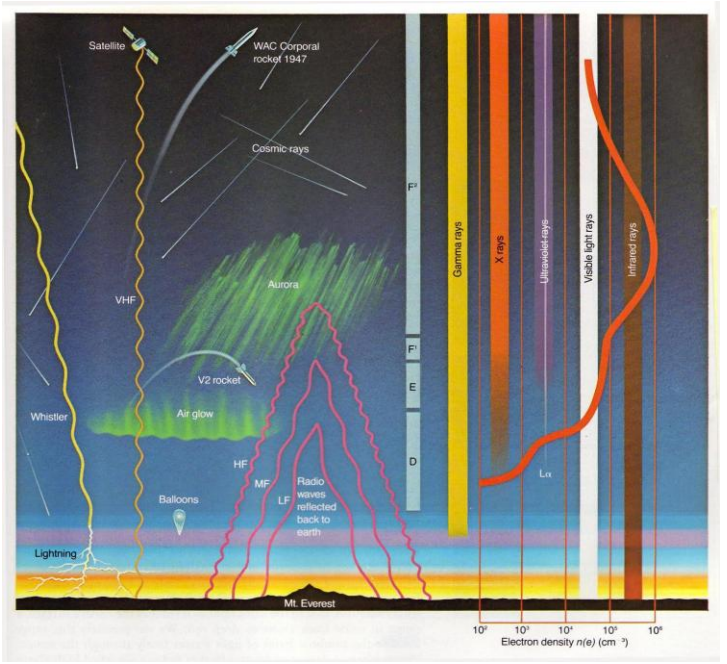
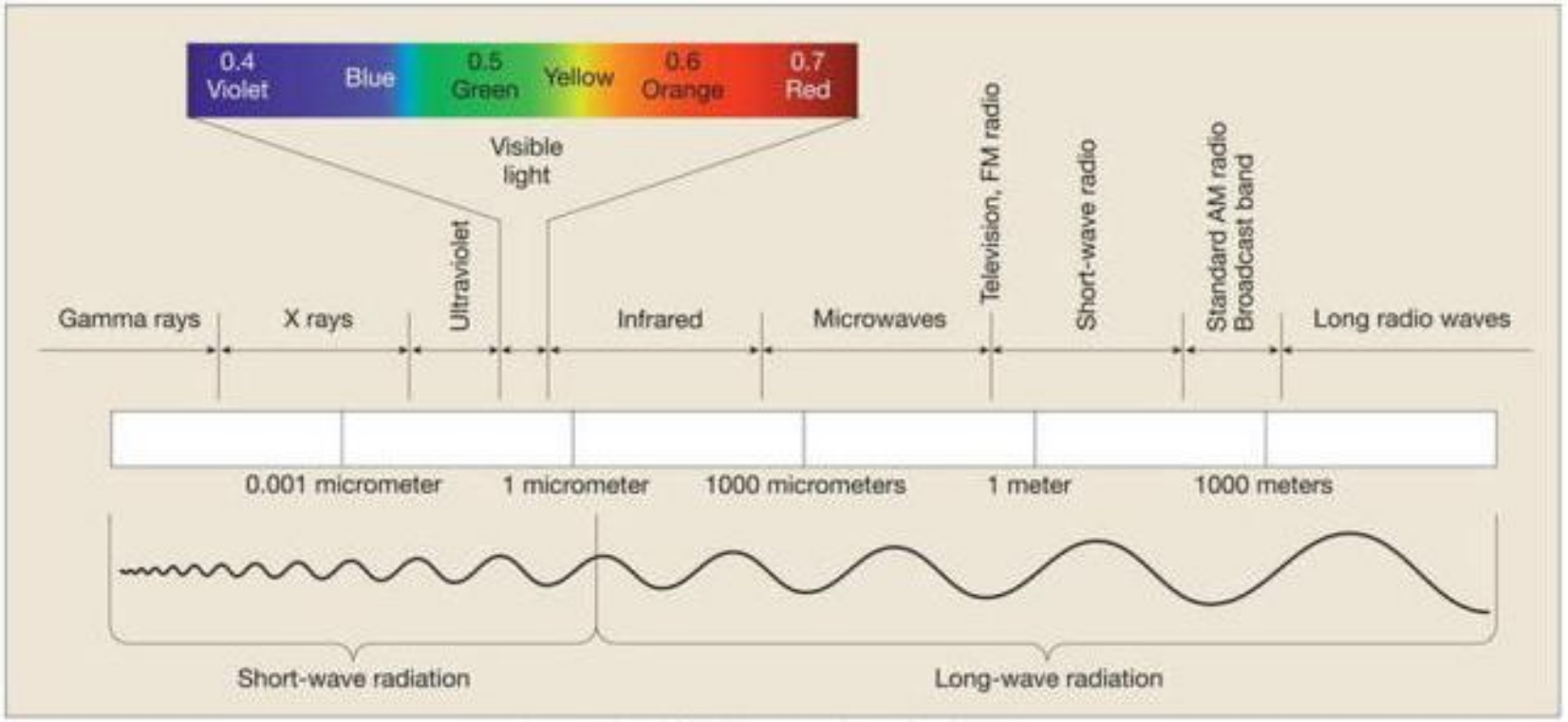


Figure from Friedman, 1987

RADIATIONS [8’]



SOLAR FLARE
extra X ray

SOLAR BURST
extra radio waves

SOLAR FLARE (8′)

Physical processes

extra Solar Radiation => Photo ionisation

The extra X-rays emitted by the solar Flare directly ionize the atmosphere and thus increase the electron density and the TEC.

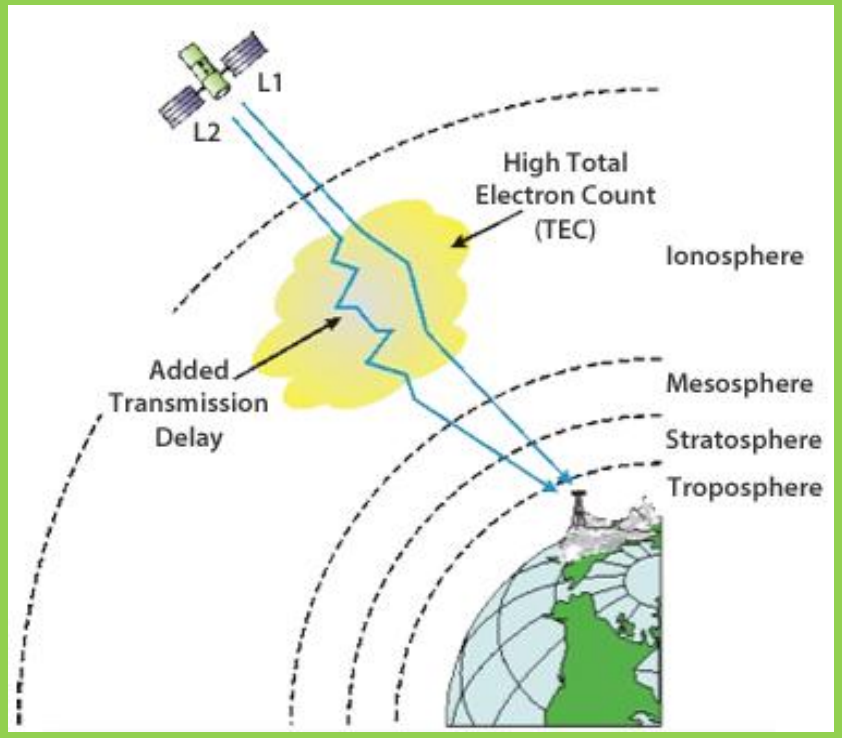
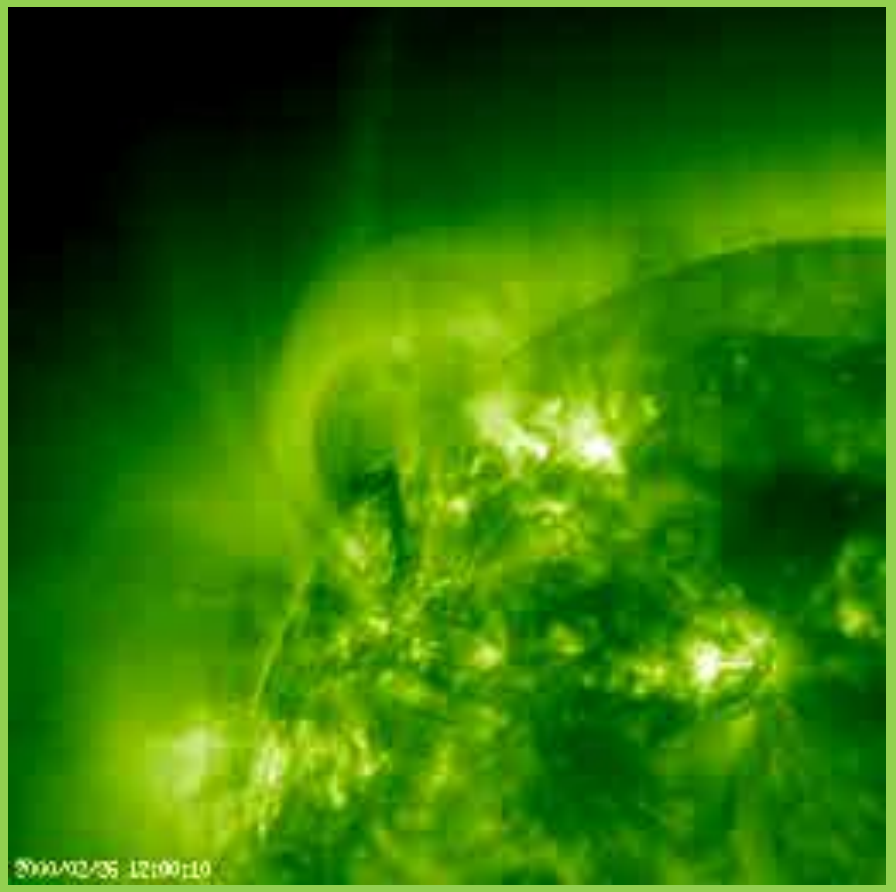


Figure from http://reflexions.ulg.ac.be



SOHO data

The Sweden Case: Airplanes disappear from radars due to "solar storm"

Posted by Adonai on November 05, 2015 in categories Featured articles, Geomagnetic storms, Solar activity

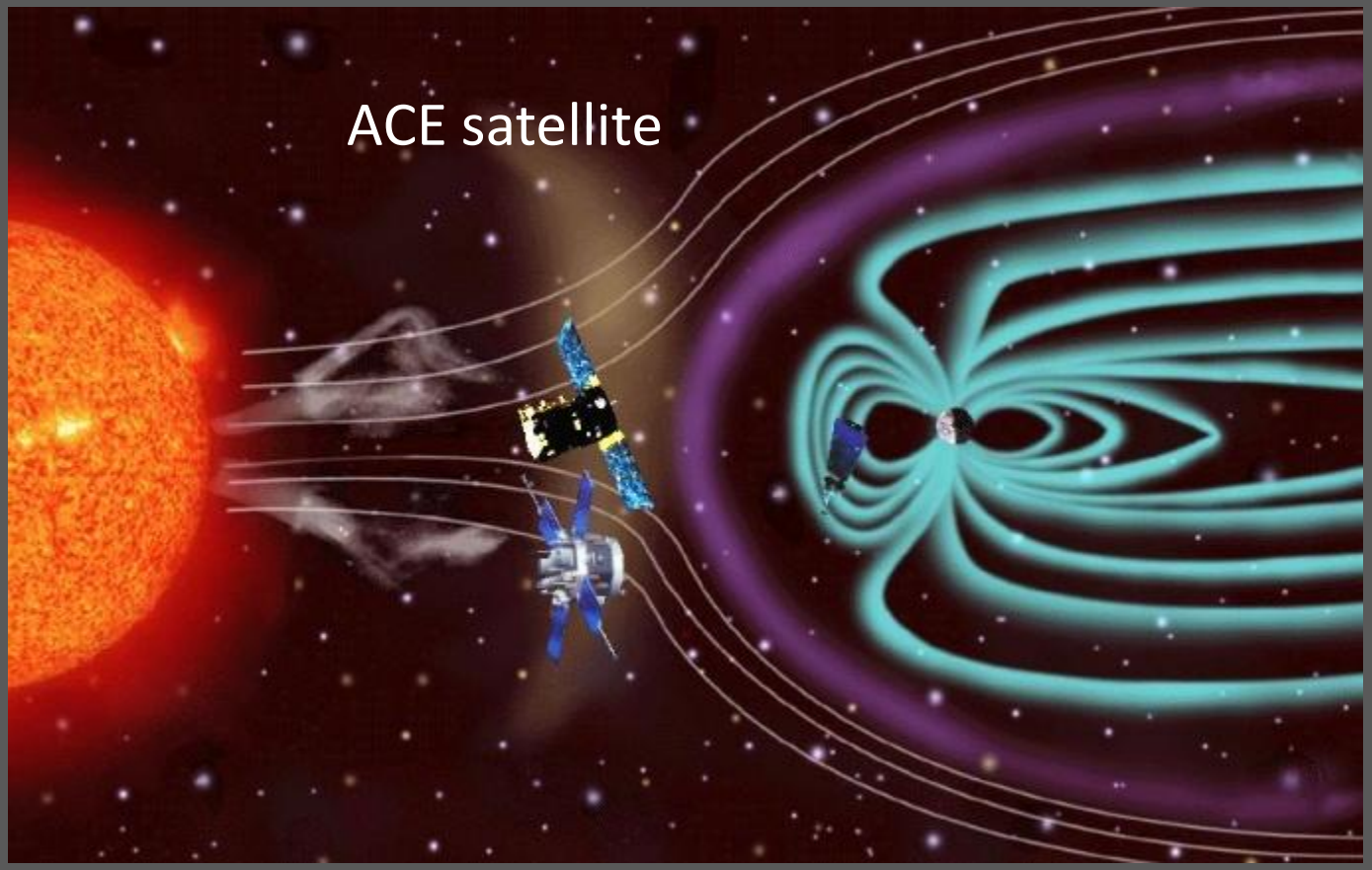
Follow @TheWatchers_

Radio Bursts : extra radio emission + Solar Flare: extra X ray

"The **2015 Nov. 4th** event was a radio burst **[15.30 to 16.30 LT]** exceeding everything before. It was so strong that neither GPS nor radar nor communication nor instrument landing system did work properly. All these receivers were completely saturated by the radio radiation, instruments went blind. "

from Christian Monstein

FROM THE SUN TO THE EARTH
SOLAR WIND /PARTICLES[1-4 days]



The solar wind carries part of the solar magnetic field towards the Earth : Interplanetary Magnetic Field, IMF.

INTERACTION BETWEEN THE SOLAR WIND and THE MAGNETOSPHERE

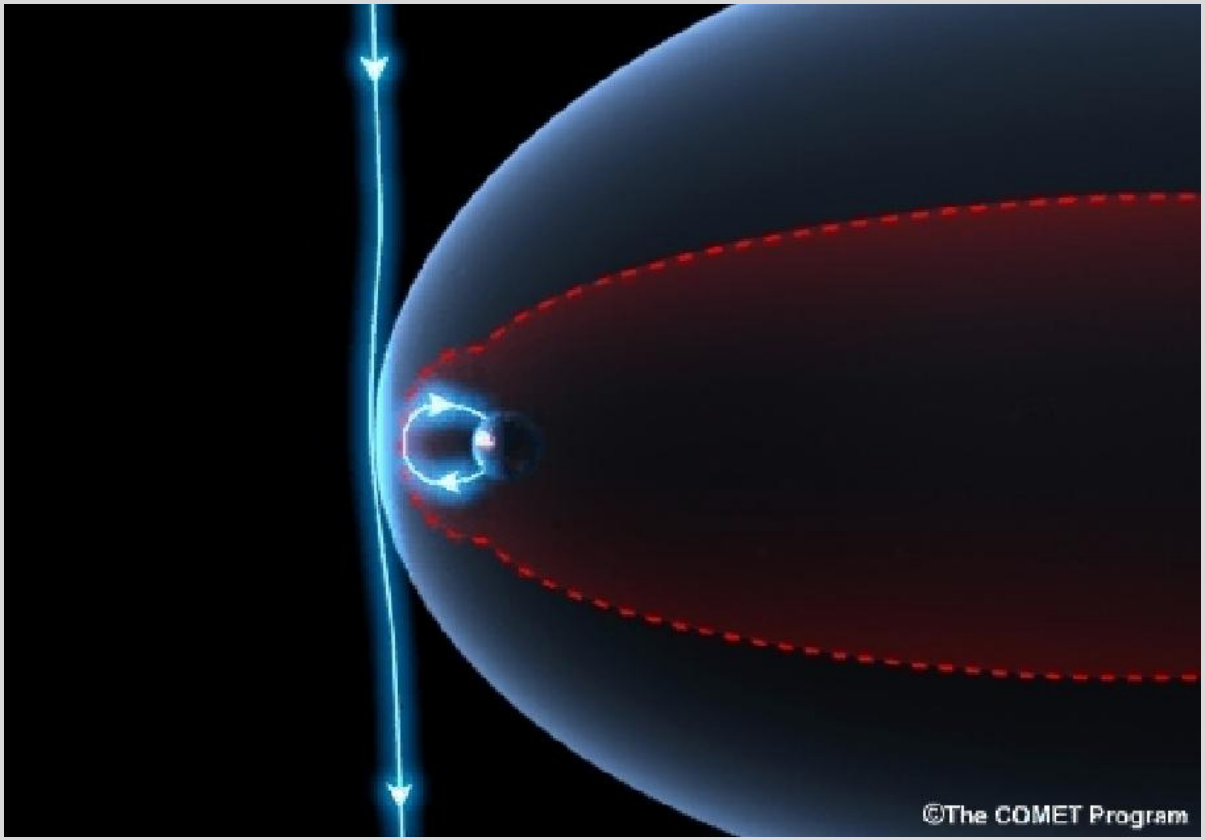
Physical processes : Reconnection and Dynamo

If the IMF field is opposite to the terrestrial magnetic field, i.e directed toward the South, there is reconnection between the IMF and the Earth's magnetic field and **there is a magnetic storm**.

Key parameters for Space Weather

Bz component of IMF

Vs : solar wind speed

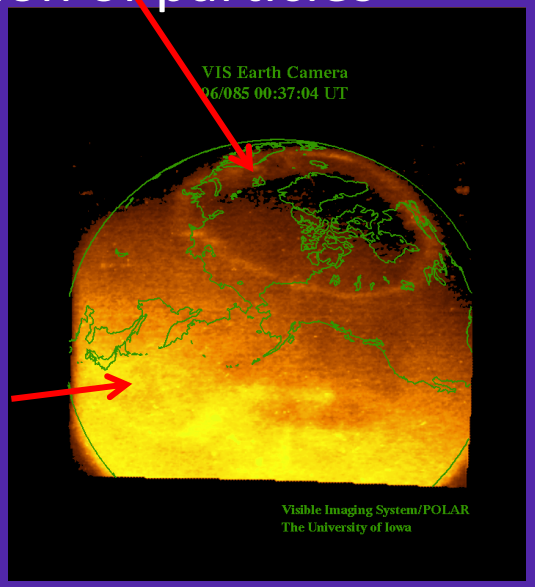


Solar wind – Magnetosphere Dynamo

movement is converted into electrical energy

AURORA : THE MOST SPECTACULAR PHENOMENON OF SPACE WEATHER

Regular auroral oval due to precipitation of particles



Dayside regular solar radiation photo ionisation

Physical processes : precipitation and ionization

The particles follow the lines of the earth's magnetic field and rush to the atmosphere where they ionize the atmosphere.

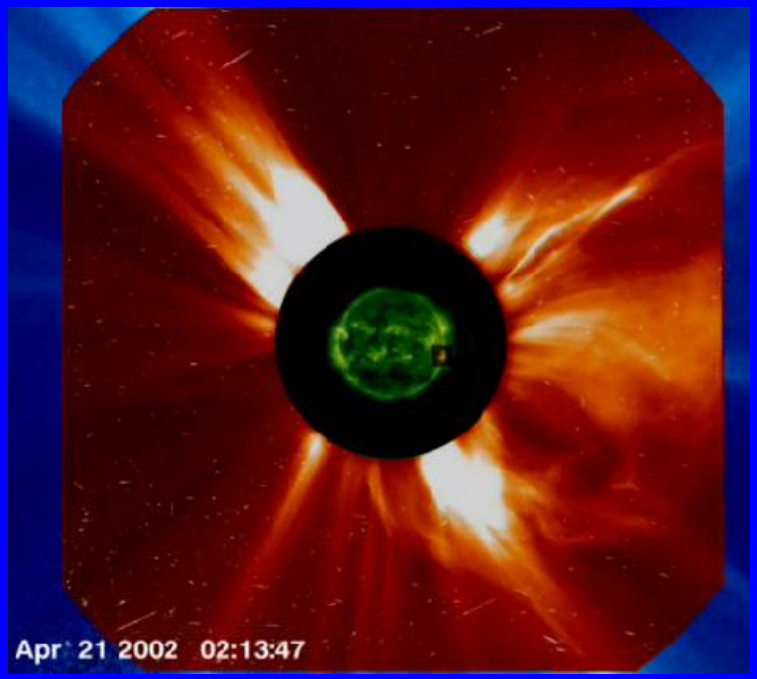
There is an increase in electronic density and TEC

CORONAL MASS EJECTION

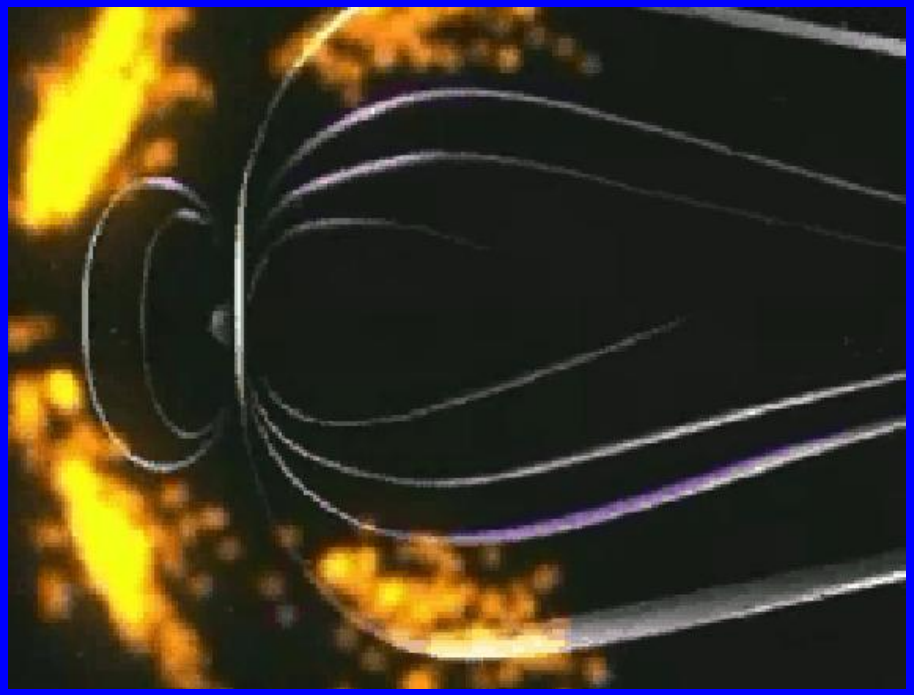
CME : billions tons of matter ejected from the sun

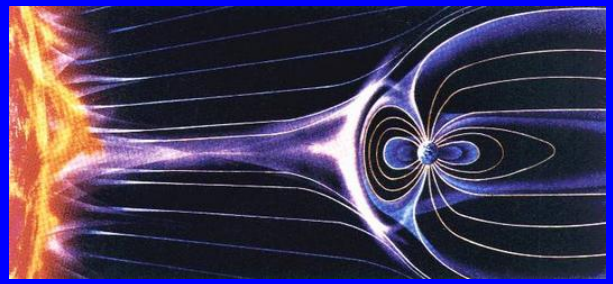
Near the sun

SOHO satellite data



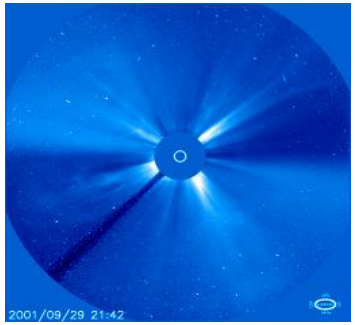
Arrival near the Earth





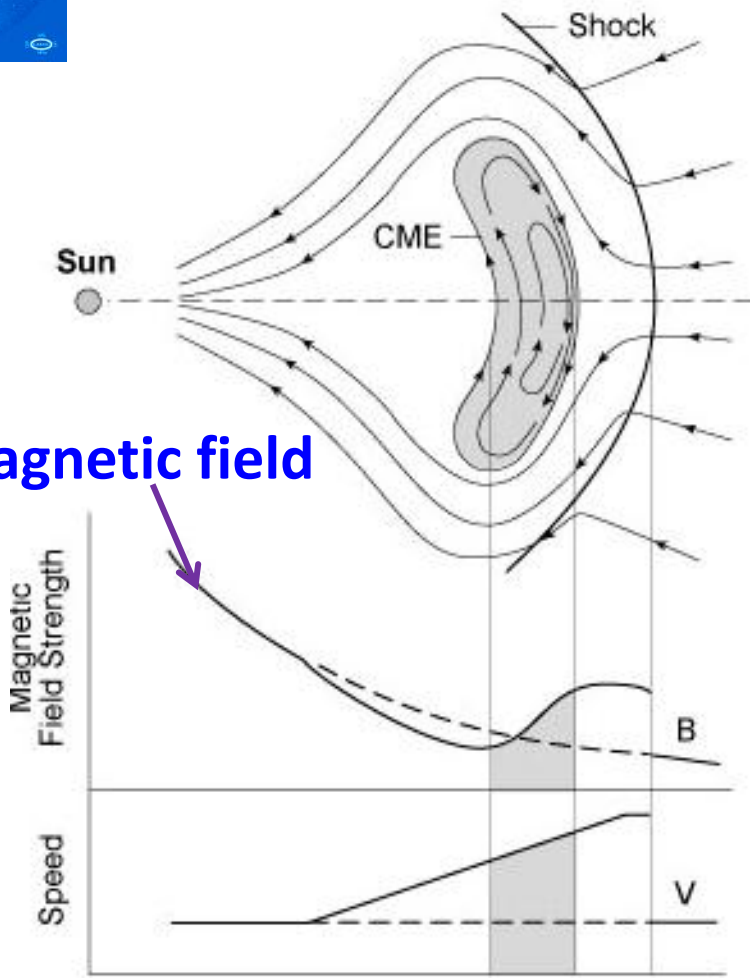
CME produce magnetic storms

if the IMF inside the CME is southward



Interplanetary CME Shocks

http://ase.tufts.edu/cosmos/pictures/sept09/



Strong magnetic field

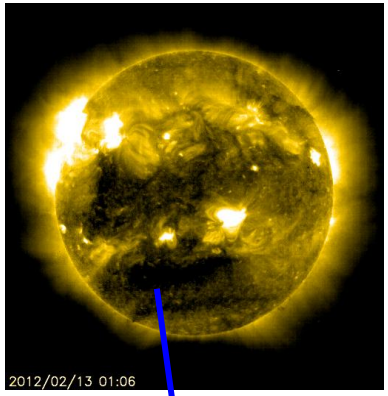
A fast coronal mass ejection CME pushes an interplanetary shock wave

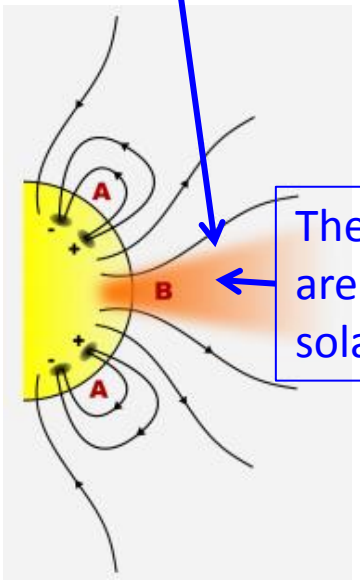
Increases of solar wind speed V and magnetic field strenght B by the interplanetary shock wave in front f the CME

Maximum occurrence of CME during the maximum of the solar sunspot cycle

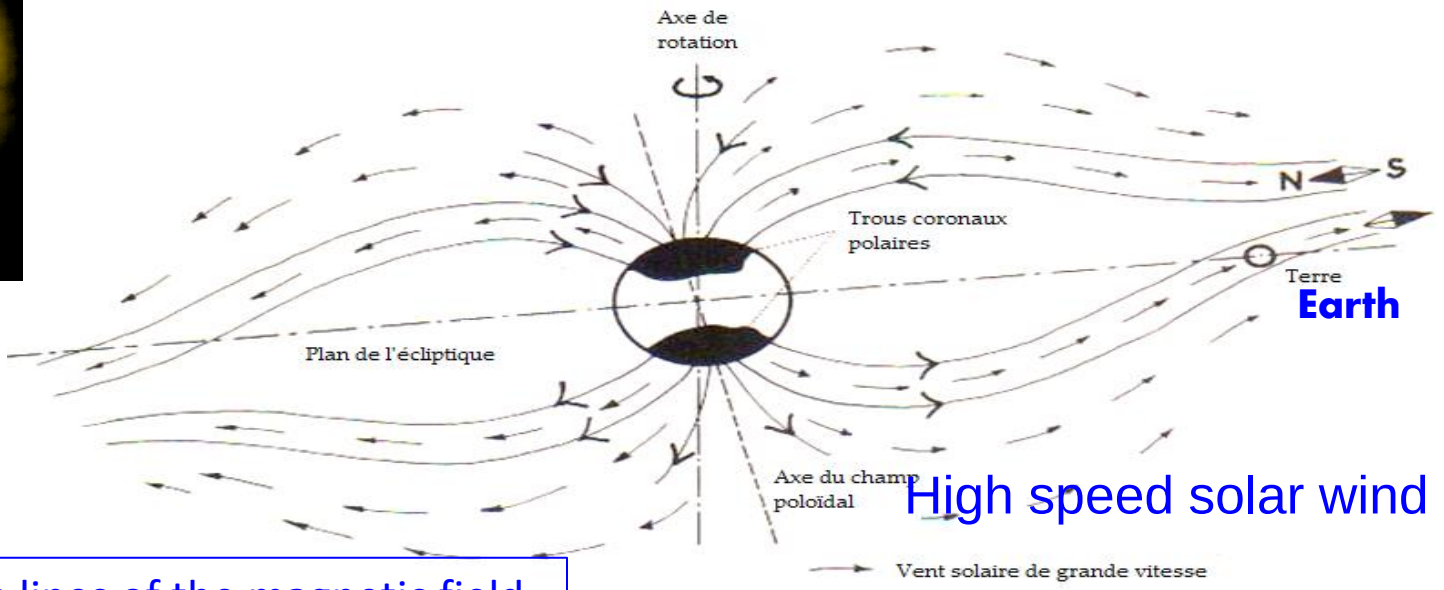
CORONAL HOLE

Picture of J-P Legrand, 1984

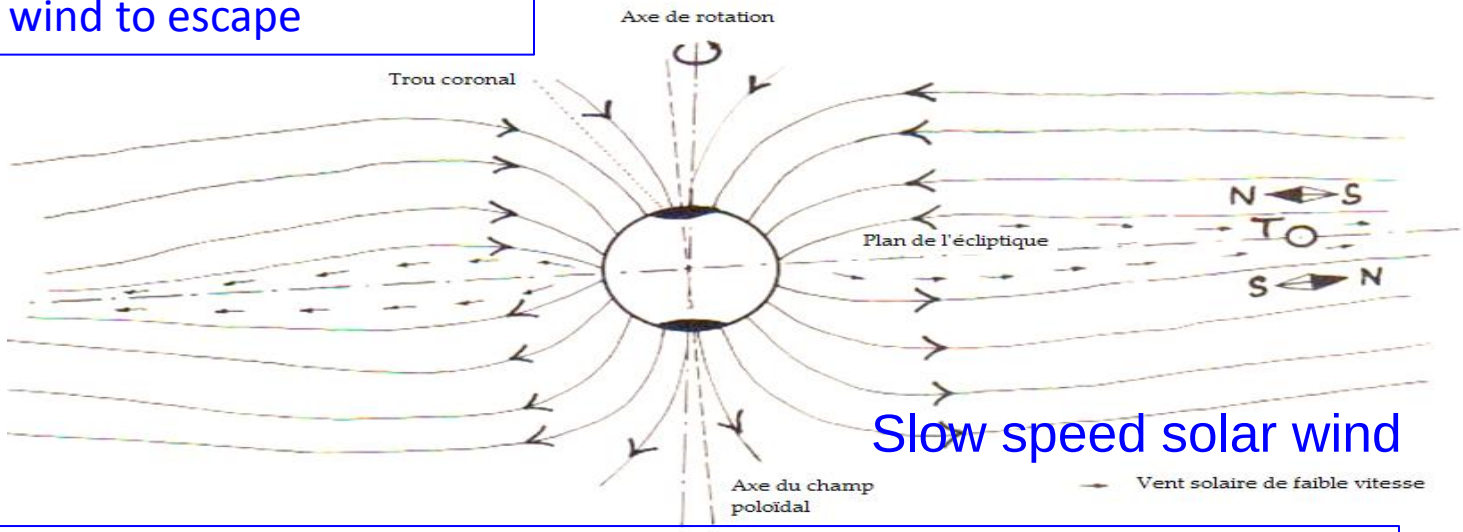




The lines of the magnetic field are open .This allows for the solar wind to escape



High speed solar wind

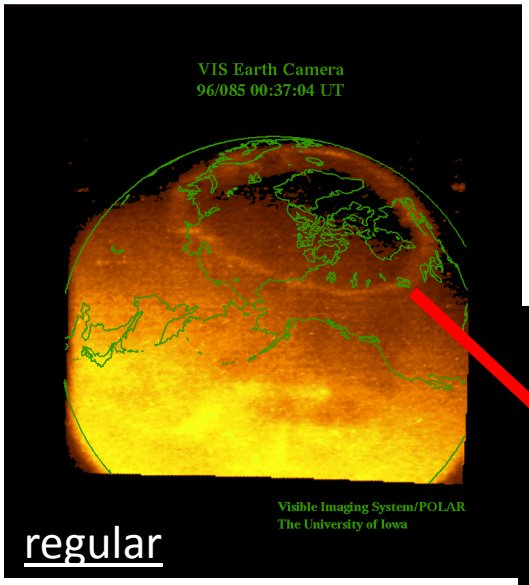


Slow speed solar wind

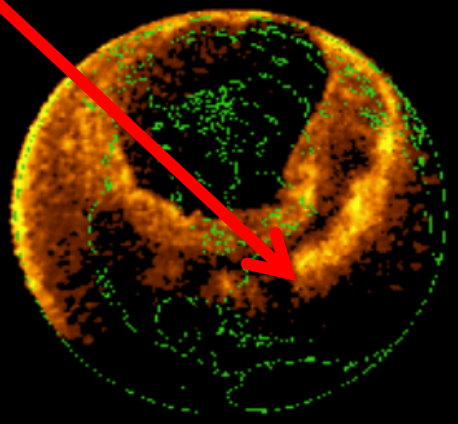
Maximum occurrence during the declining and minimum phases of solar sunspot cycle

MAGNETIC STORMS/Ionospheric electric currents

The auroral oval extends toward middle latitudes
the auroral ionospheric electric currents strongly affects low latitudes



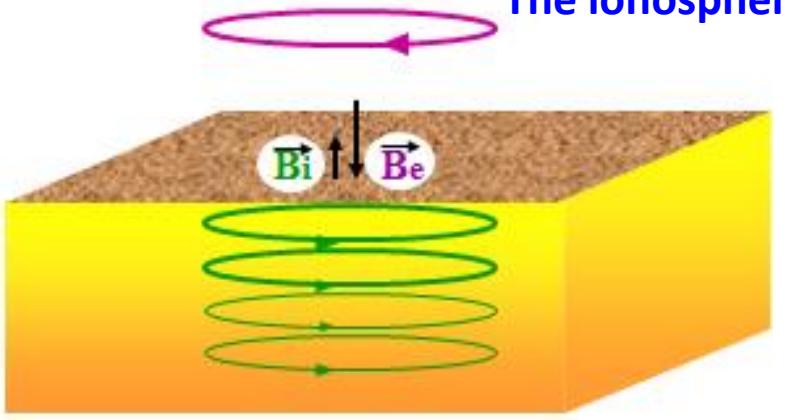
regular



disturbed

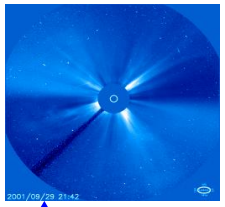
March 13, 1989 - The Quebec Blackout Storm - Most newspapers that reported this event considered the spectacular aurora to be the most newsworthy aspect of the storm. Seen as far south as Florida and Cuba, the vast majority of people in the Northern Hemisphere had never seen such a spectacle in recent memory. Electrical ground currents created by the magnetic storm found their way into the power grid of the Hydro-Quebec Power Authority and the entire Quebec power grid collapsed. Six million people were affected as they woke to find no electricity to see them through a cold Quebec wintry night. This storm could easily have been a $6 billion catastrophe affecting most US East Coast cities.

The ionospheric electric currents induce telluric currents



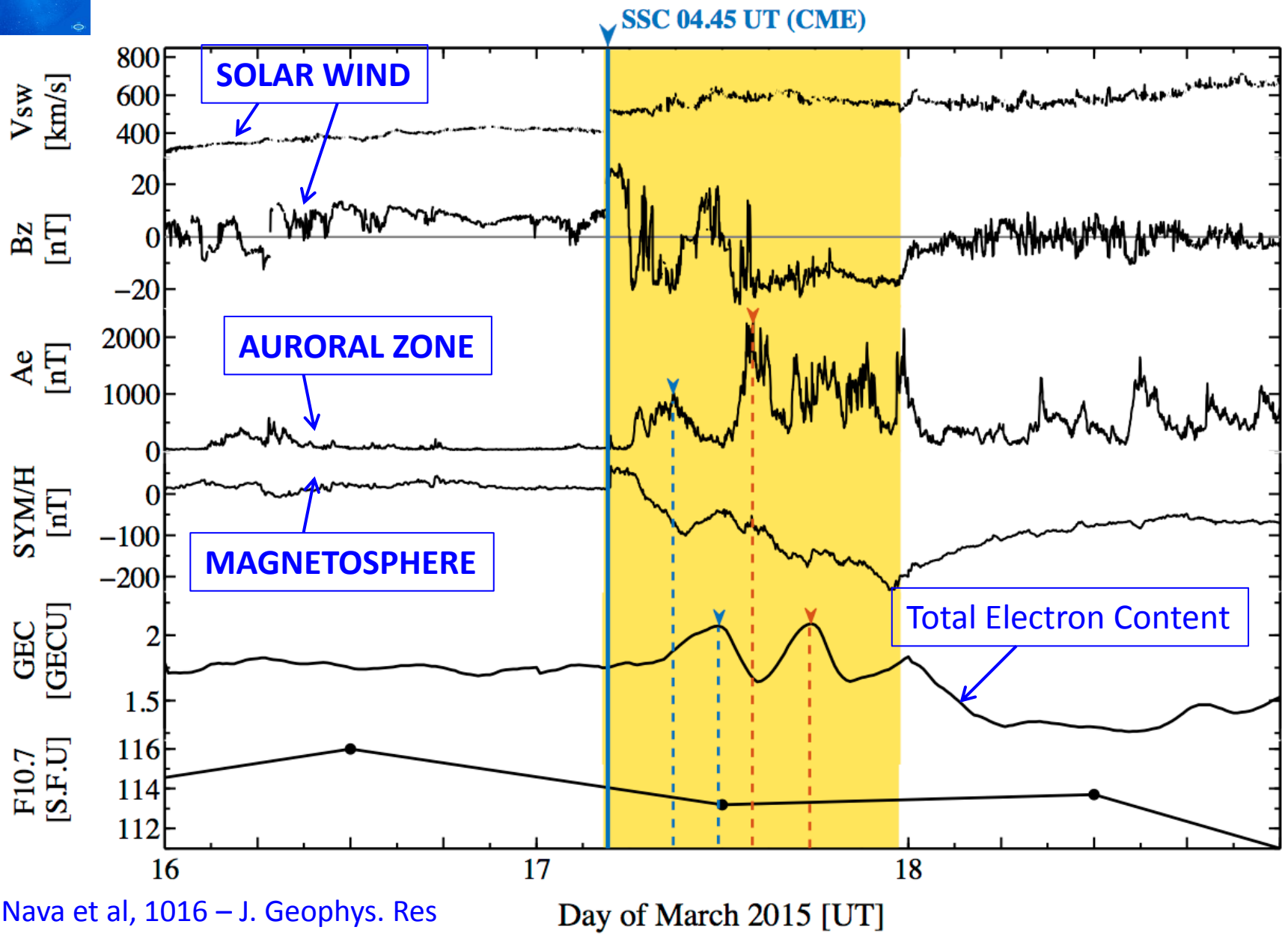
Power failure

Transformer damaged



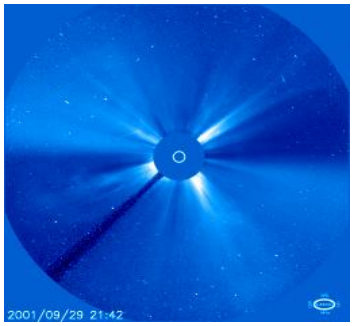
SUN

GLOBAL CONTEXT OF THE MAGNETIC STORM OF St PATRICK's DAY



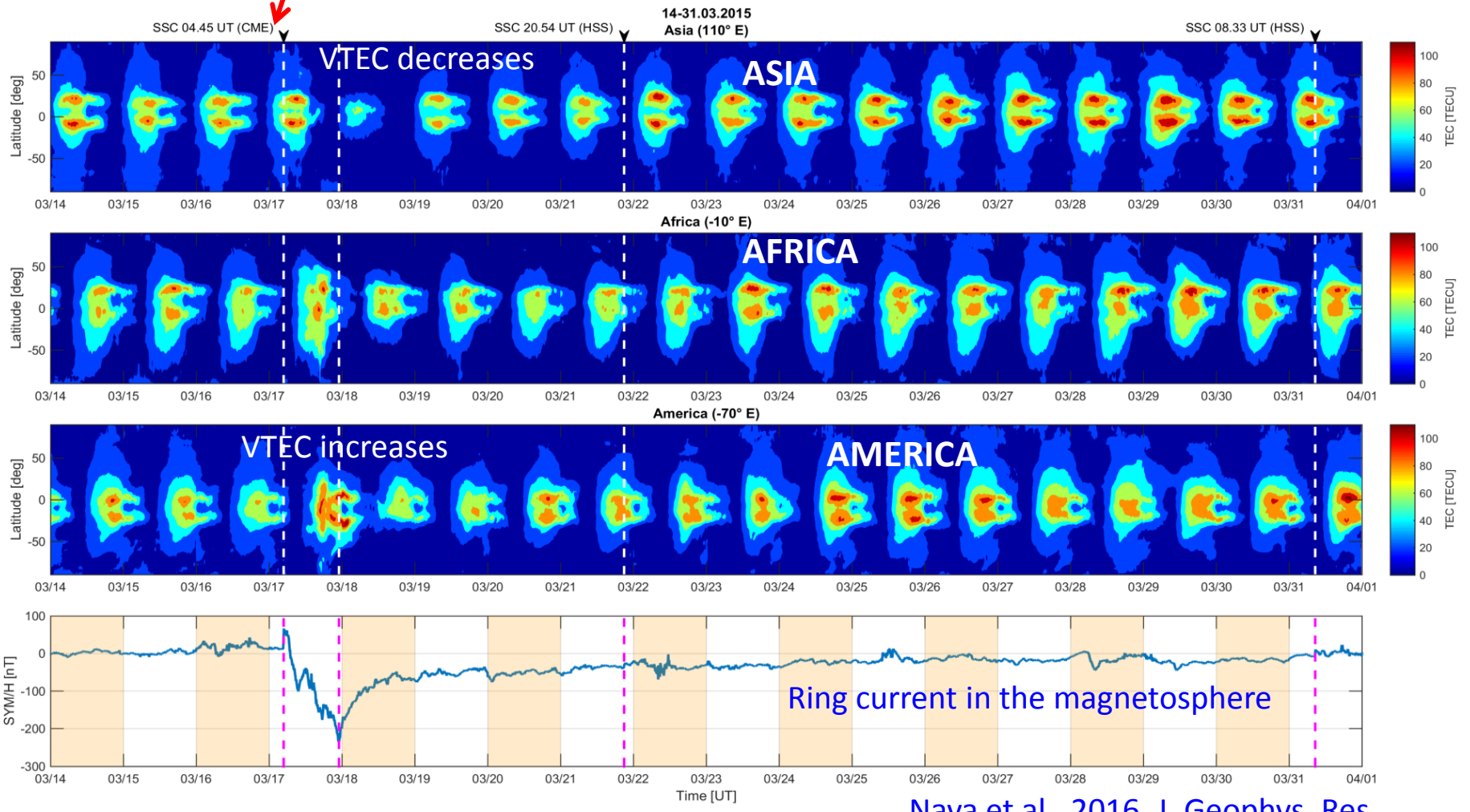
Nava et al, 1016 – J. Geophys. Res

MAGNETIC STORM of St PATRICK's DAY : MAPS of VTEC



Variations near the magnetic Equator due to a CME (~200 GPS stations)

Impact of a CME (solar event, on March 15 ~ 00.45 - 02.00UT)

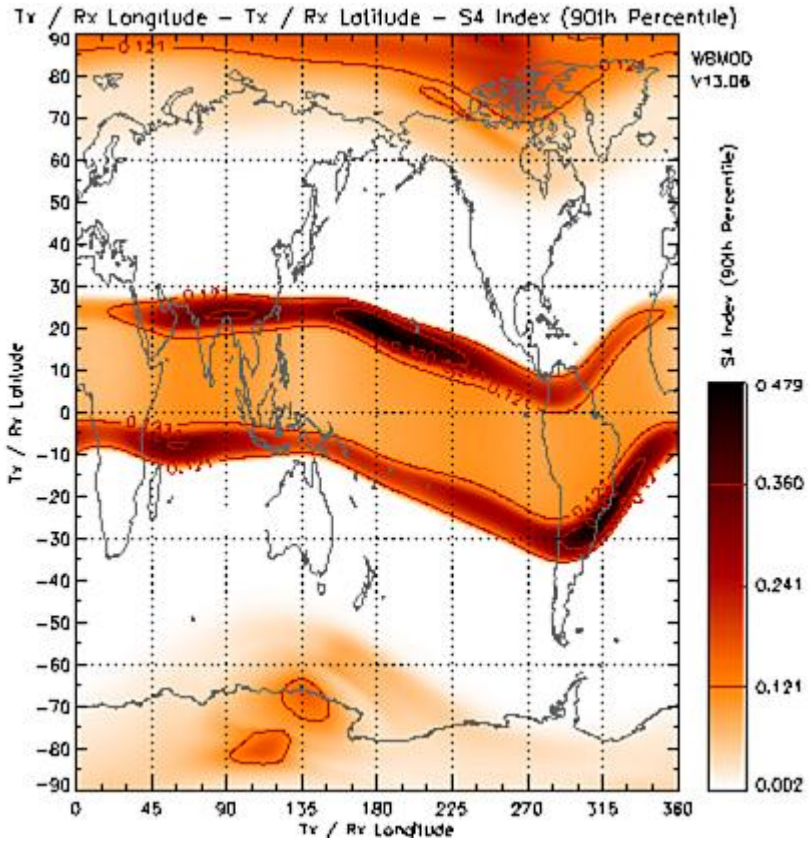


Nava et al., 2016, J. Geophys. Res.

Scintillations a regular phenomenon

Ionospheric scintillation is the rapid modification of radio waves caused by small scale structures in the ionosphere

Physical Process : Instabilities in Plasma



Scintillation index at GPS L1 (1575.42 MHz) assuming constant local time 23.00 at all longitudes (from http://www.sws.bom.gov.au)

Indice of scintillation

$$s4 = \sqrt{\frac{< I^2 > - < I >^2}{< I >^2}}$$

"Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon, although it can (and does) occur at lower intensity at all latitudes.
Ionospheric scintillation generally peaks in the sub-equatorial anomaly regions, located on average ~15° either side of the geomagnetic equator."

some solar perturbations inhibite the scintillations and facilitate radio transmissions (Azzouzi et al., 2015)

Training on GNSS/ training on the physics on the Sun Earth's system scientific network

- **INTERNATIONAL**

- GNSS Master -> Regional Schools of UN
  - *Training GNSS and ionospheric effects, January 16-20, 2017, CRASTE-LF / Morocco*
- 2 School/Workshop each year at ICTP
  - *URSI-ICTP school on radio Physics, March 27-31, 2017*
  - *Extended workshop on Space Weather effects on GNSS operation, May 22 to June 2, 2017*
- Each 2 years a SCOTEP/ISWI school in the world
  - *Last one in India from November 7-18*
- Each 2 years an ISWI-MAO / School in Africa
  - *Next one in Abidjan/Côte d'Ivoire, from October 16-28 2017*
- Each year from 2010 to 2016 : Training on GNSS at the National school of Telecom/France
  - *Next one in Brest/France, from February 1- 17, 2017*

- **NATIONAL**

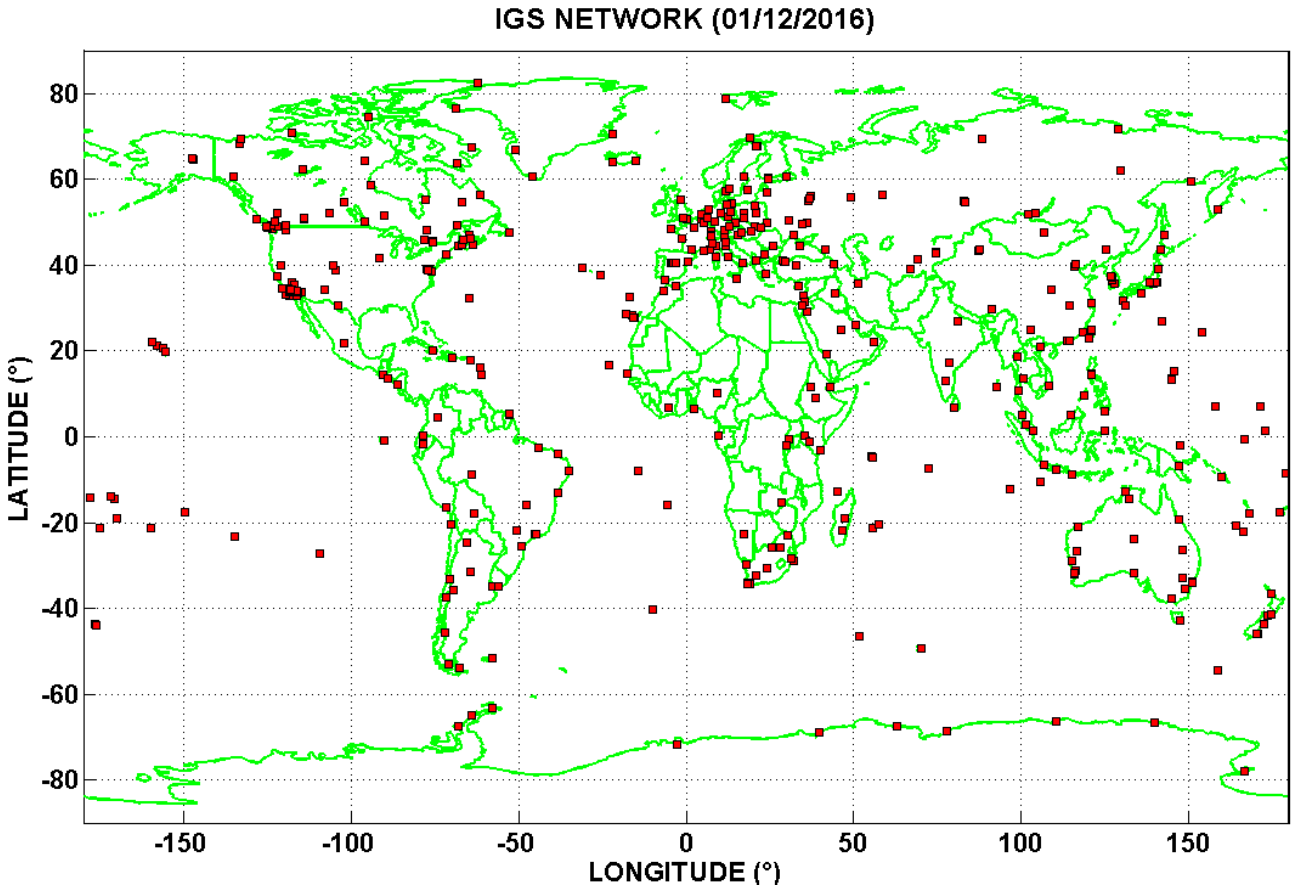
- National schools in many African countries and all over the world
- Curricula in many African Universities, mainly on the Physics of the Sun Earth's Systemand over the world

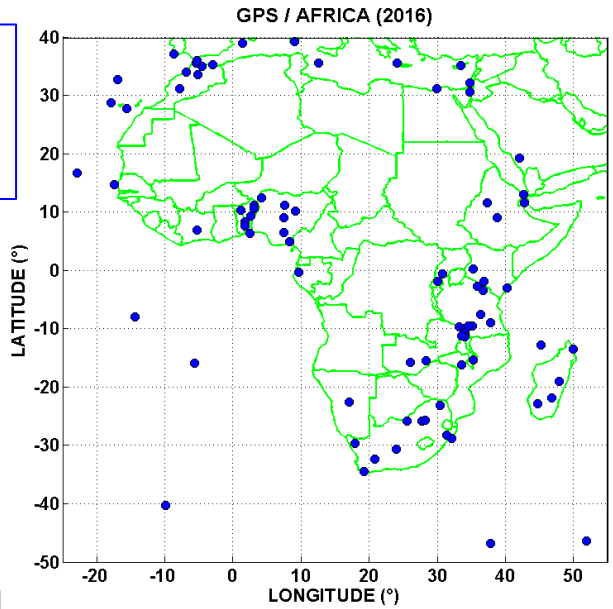
ISWI project => scientific ISWI network
http://www.iswi-secretariat.org

1. Distribution of scientific tools
2. Training schools / GNSS and Physics of the Sun Earth's System
3. PhD => position in the country
4. Curricula in Universities

GNSS for research studies in developing countries play a key role

The GNSS receiver is cheap, it is easy to install, it allows to develop very different research (ionosphere, climate, earthquakes etc…) it offers many applications for the society





GPS in Africa available on the web are increasing

Many countries have national network of GPS


Thank you