# Solar-terrestrial relation and space weather

Mateja Dumbović
Hvar Observatory, University of Zagreb
Croatia

# Space weather

From Wikipedia, the free encyclopedia

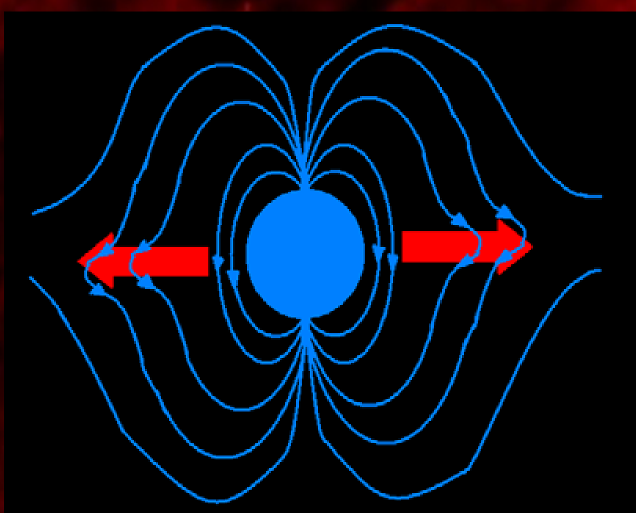
**Space weather** is the time varying environmental conditions within the solar system, including the solar wind, and especially the space surrounding the Earth, including conditions in the near-Earth space defined by the magnetosphere down to the ionosphere and thermosphere. Space weather is distinct from the terrestrial weather of the Earth's atmosphere (troposphere and stratosphere). The science of space weather is focused in two distinct directions: fundamental research and practical applications. The term *space weather* was not used until the 1990s. Prior to that time, activities now known as *space weather* were considered to be part of physics or aeronomy or space exploration.

- Planets
- Comets
- Solar wind
- Interplanetary magnetic field
- Cosmic rays
- Satellites
- Astronauts
- …

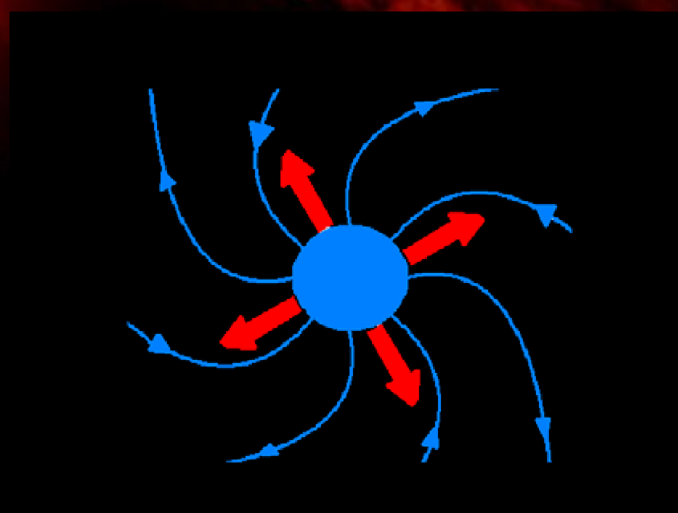
# HELIOSPHERE = Solar wind + Interplanetary magnetic field (IMF)

Solar wind is constant streaming of the solar plasma from the uppermost layers of the solar atmosphere. It is interrelated to interplanetary magnetic field, a continuation of the solar mag. field into the interplanetary space. The space dominated by the two defines heliosphere.

*http://www.nasa.gov*



*Rotational axis cross section*

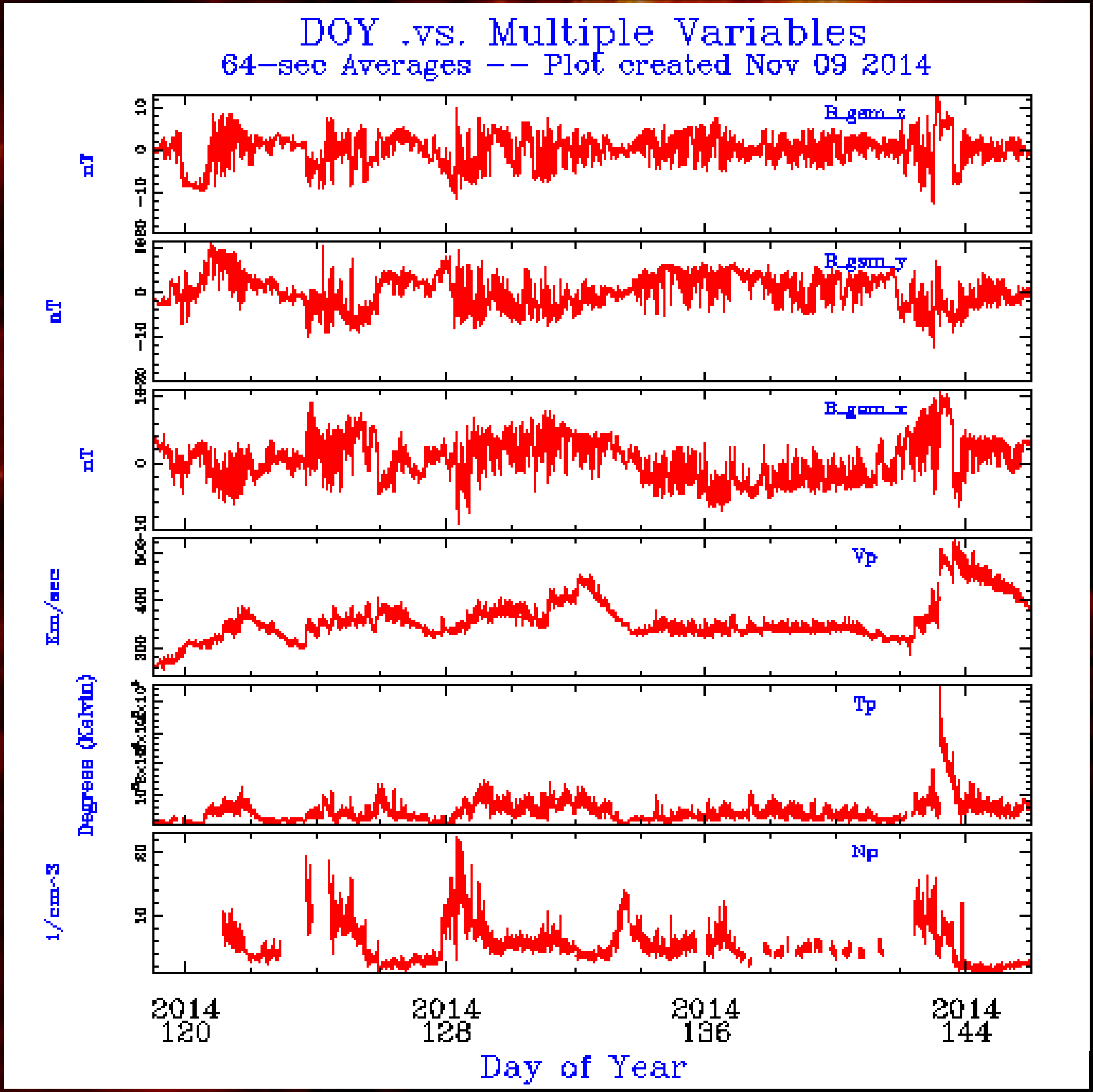


*Equatorial cross section*

Interplanetary magnetic field

Solar wind

# *In situ* measurements of solar wind and IMF

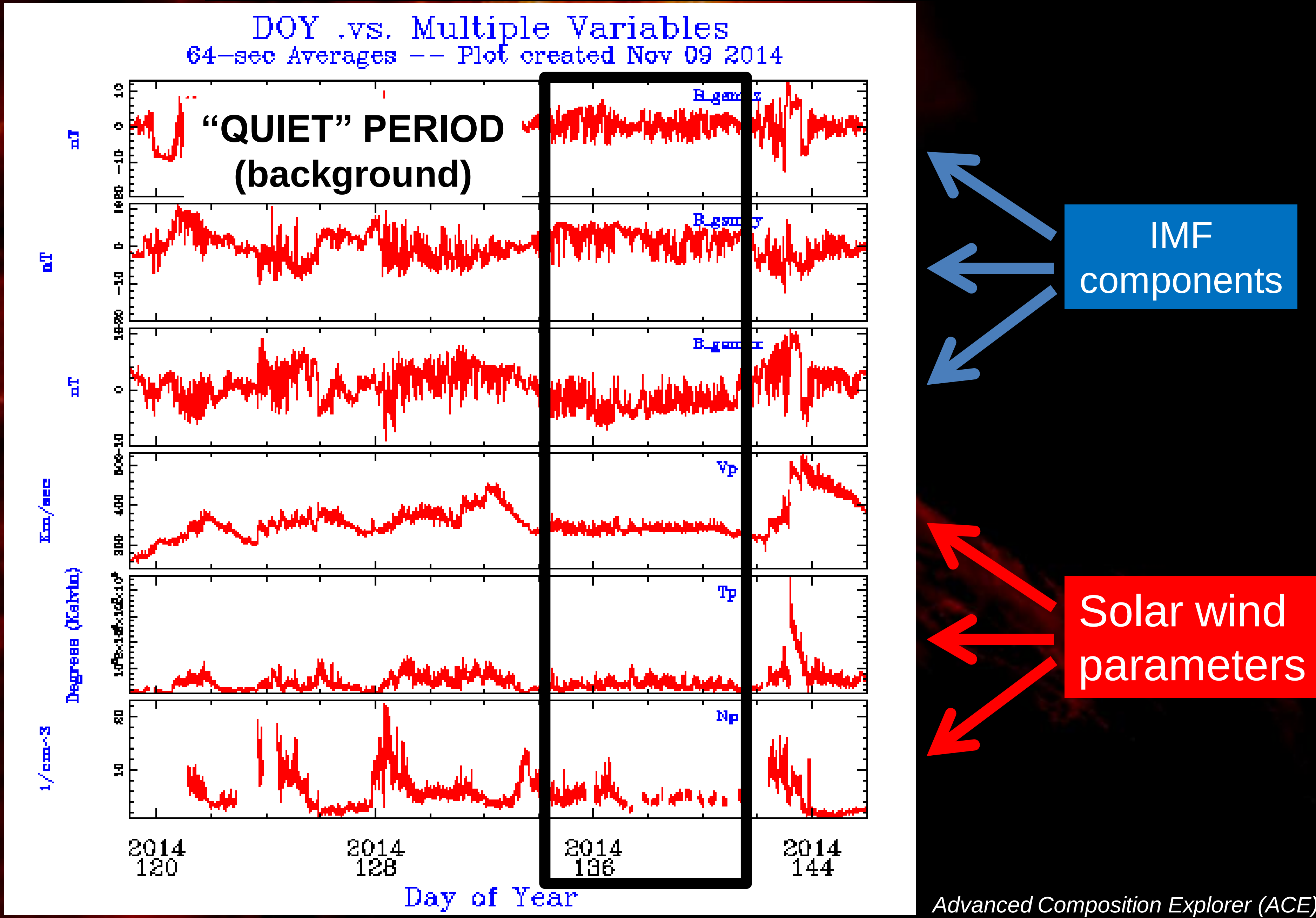



IMF components

Solar wind parameters

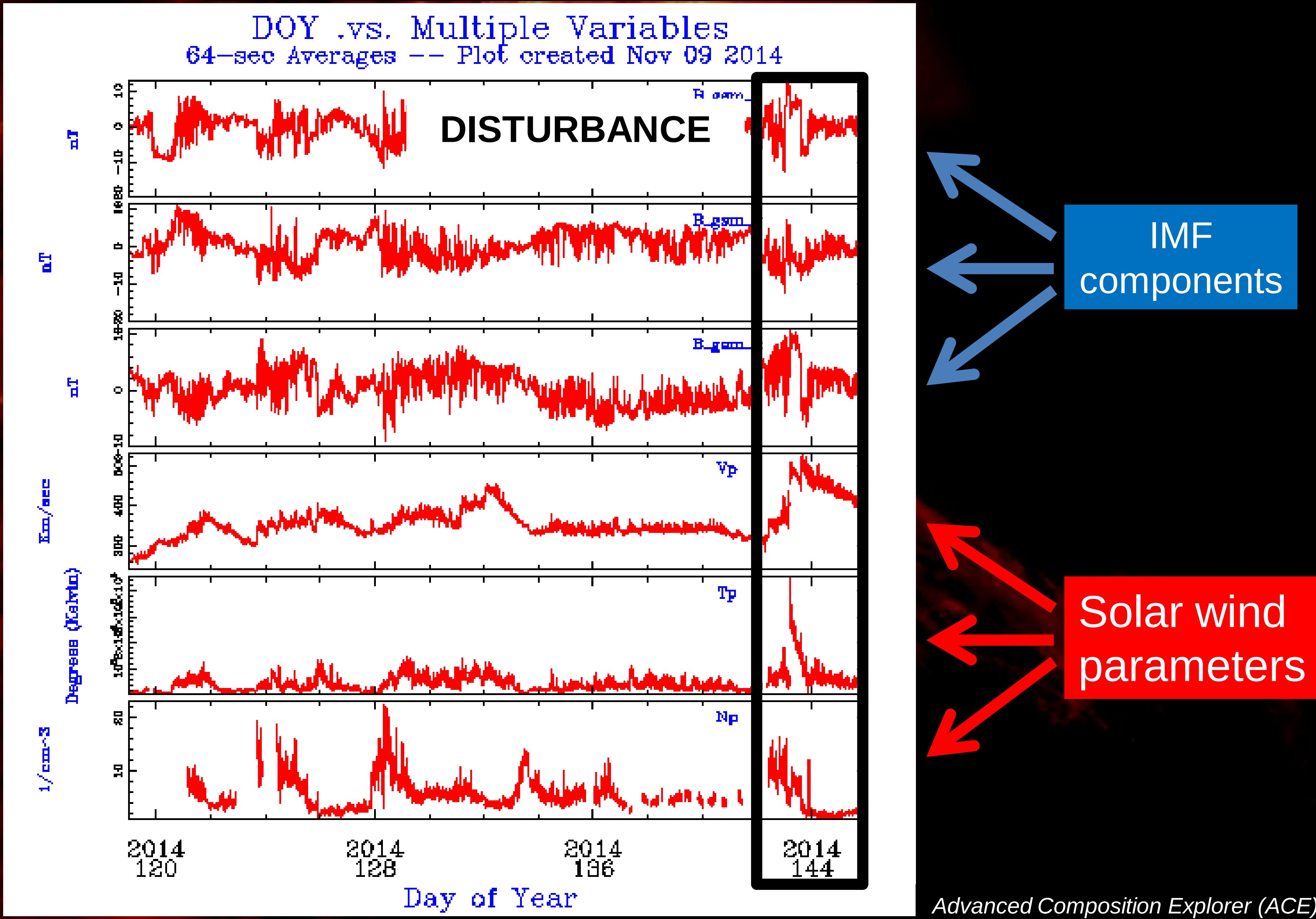
*Advanced Composition Explorer (ACE)*

# *In situ* measurements of solar wind and IMF



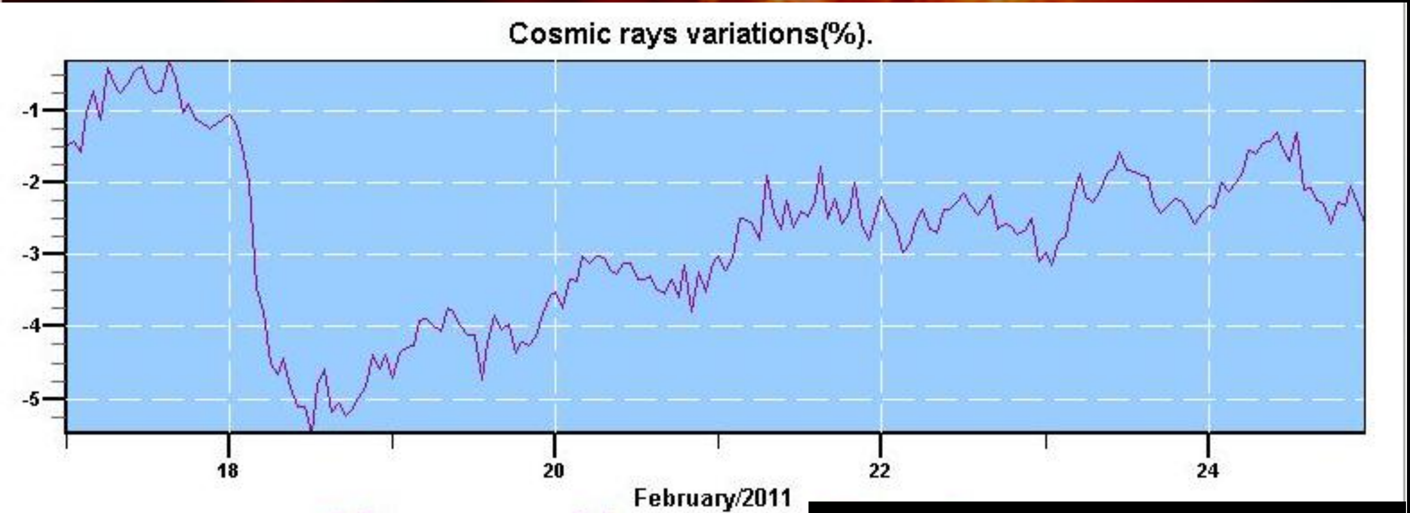

*Advanced Composition Explorer (ACE)*

# *In situ* measurements of Solar wind and IMF



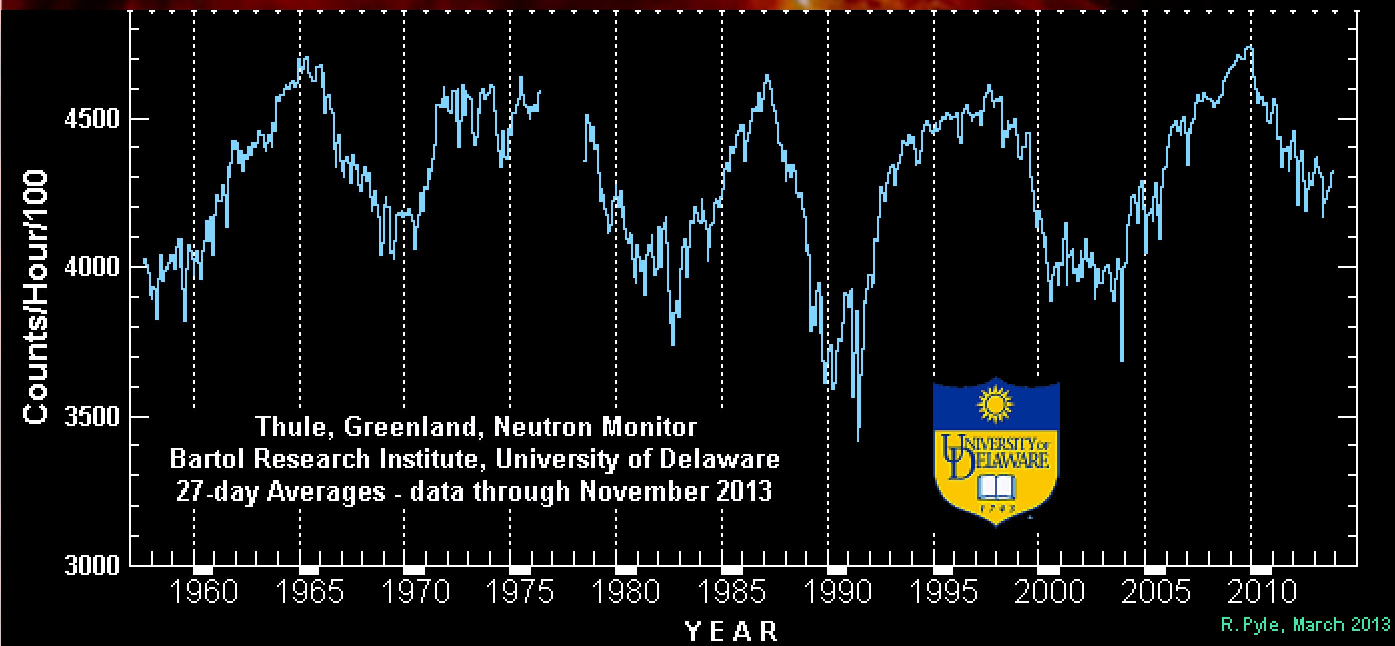

*Advanced Composition Explorer (ACE)*

# Solar wind & IMF modulate cosmic ray flux



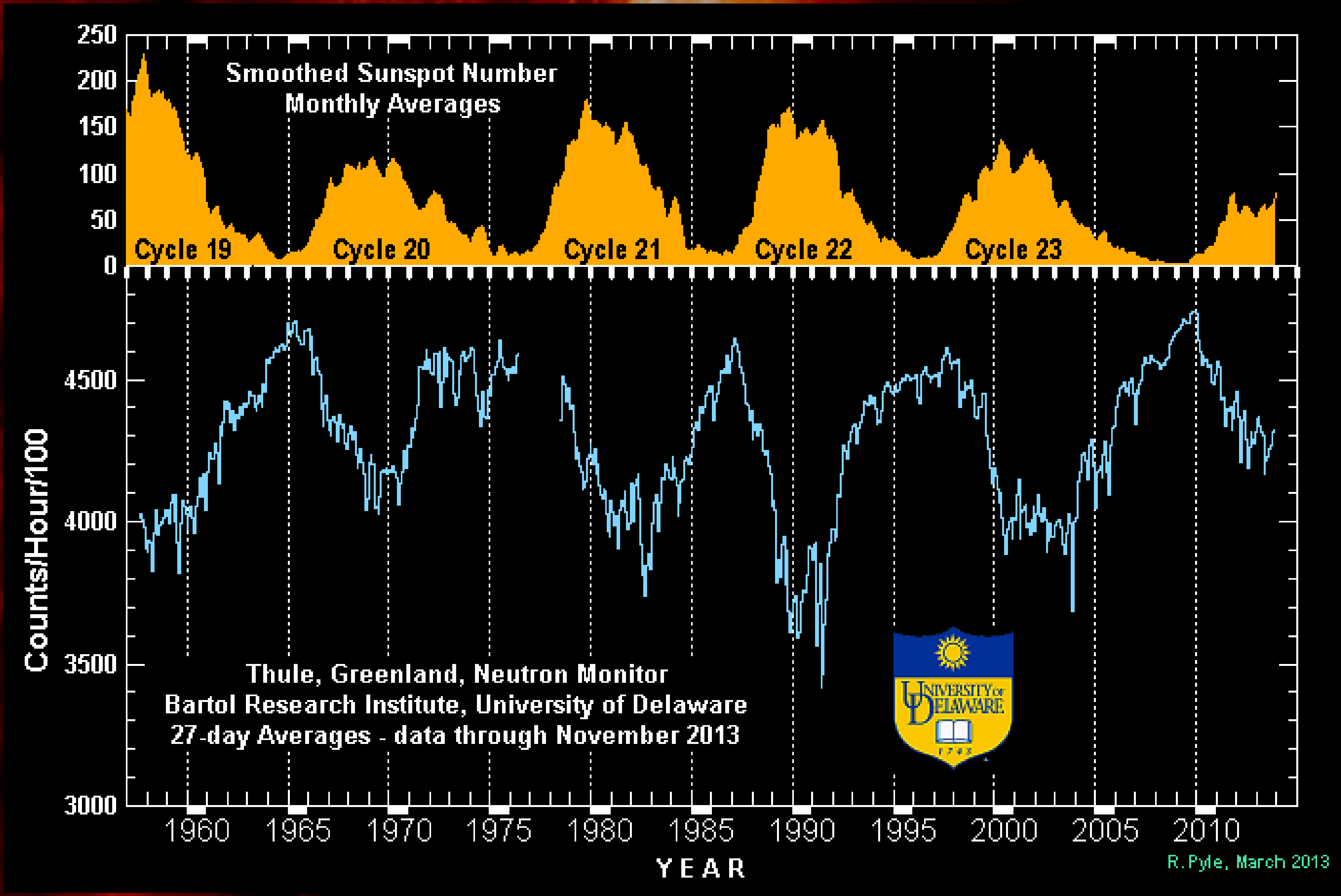

*Moscow neutron monitor (Izmiran)*

On short scales

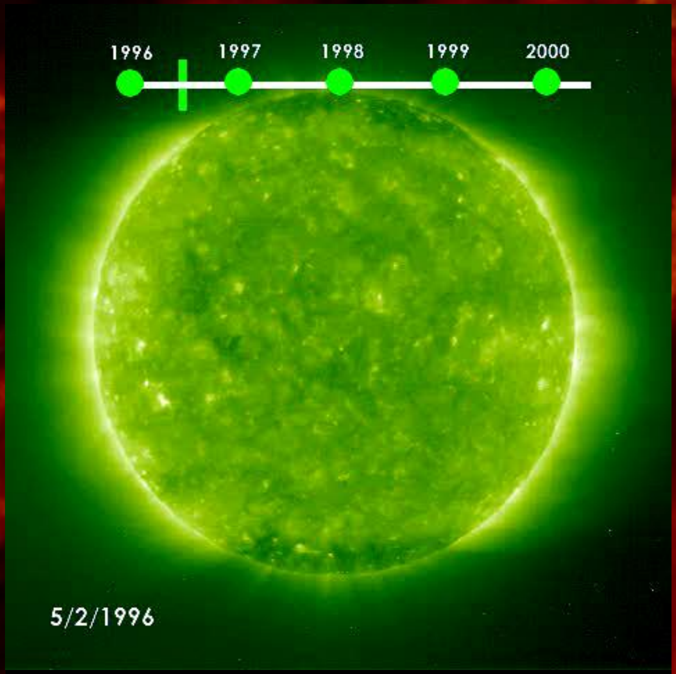



And long scales

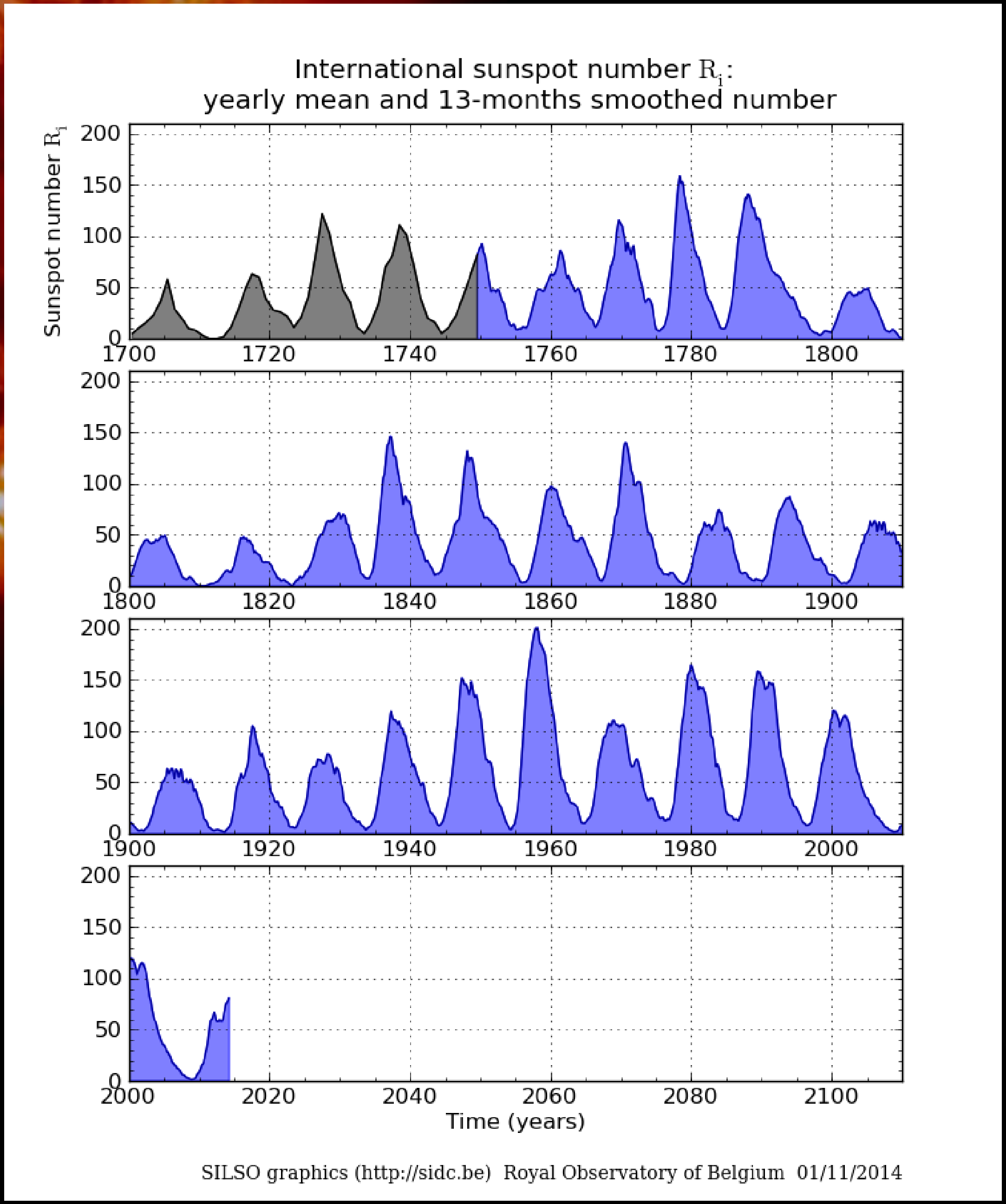
# Solar wind & IMF modulate cosmic ray flux



# Long term Solar activity: 11 year Solar activity cycle

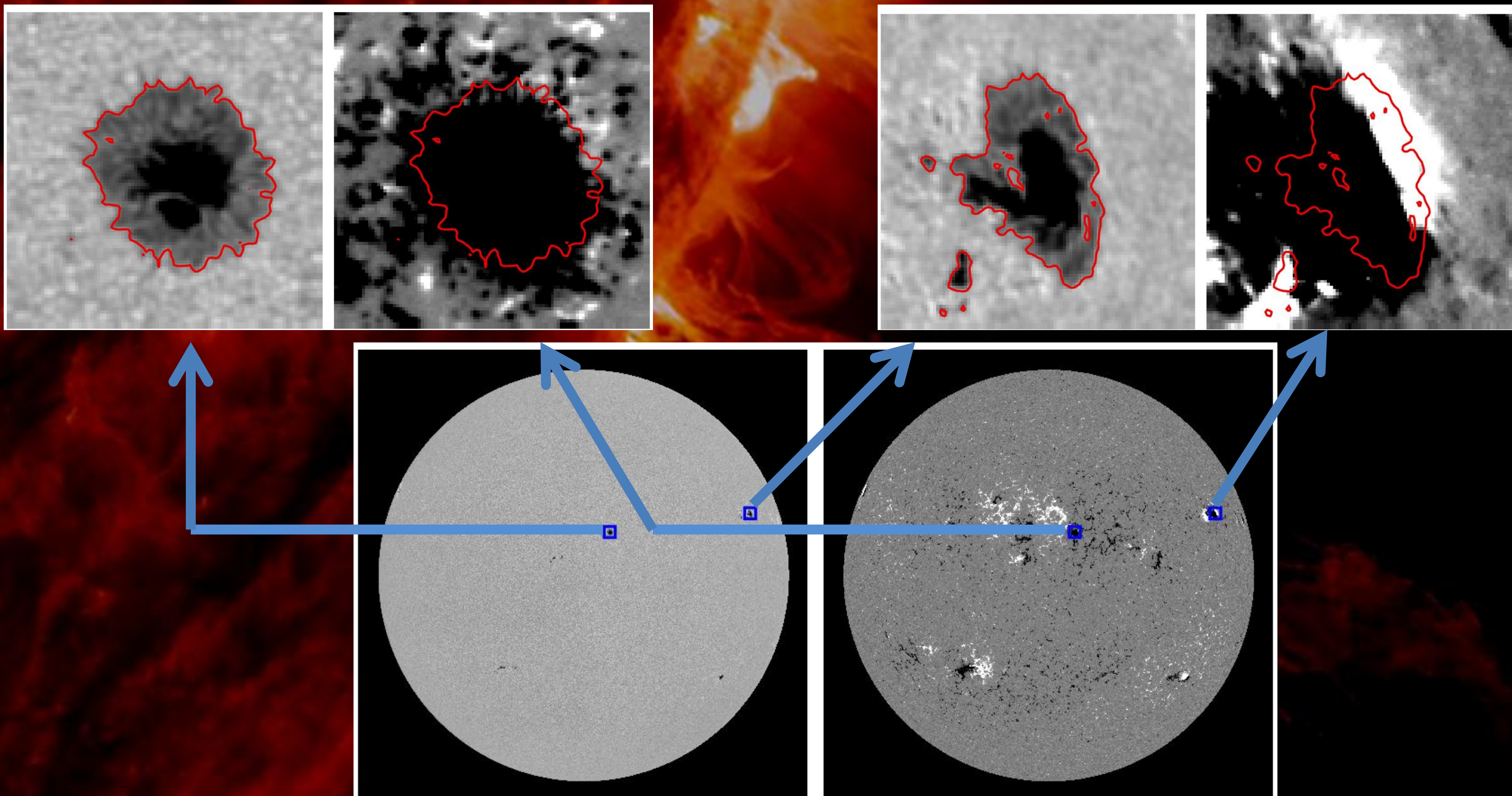



*EIT – EUV imager onboard Solar and Heliospheric Observatory (SOHO)*




Solar activity is reflected by the change in the sunspot number (*cca* 11 year cycles), in EUV images of solar corona – increased number of bright active regions (towards the solar maximum)

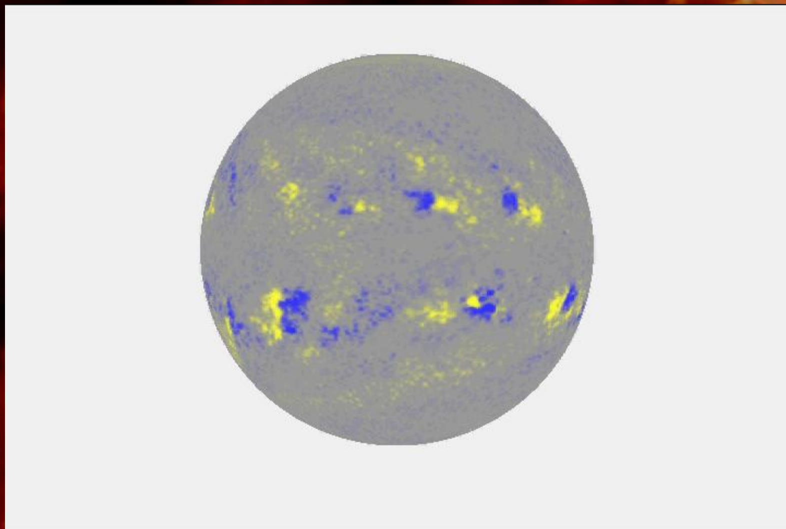
# Long term Solar activity: 11 year Solar activity cycle



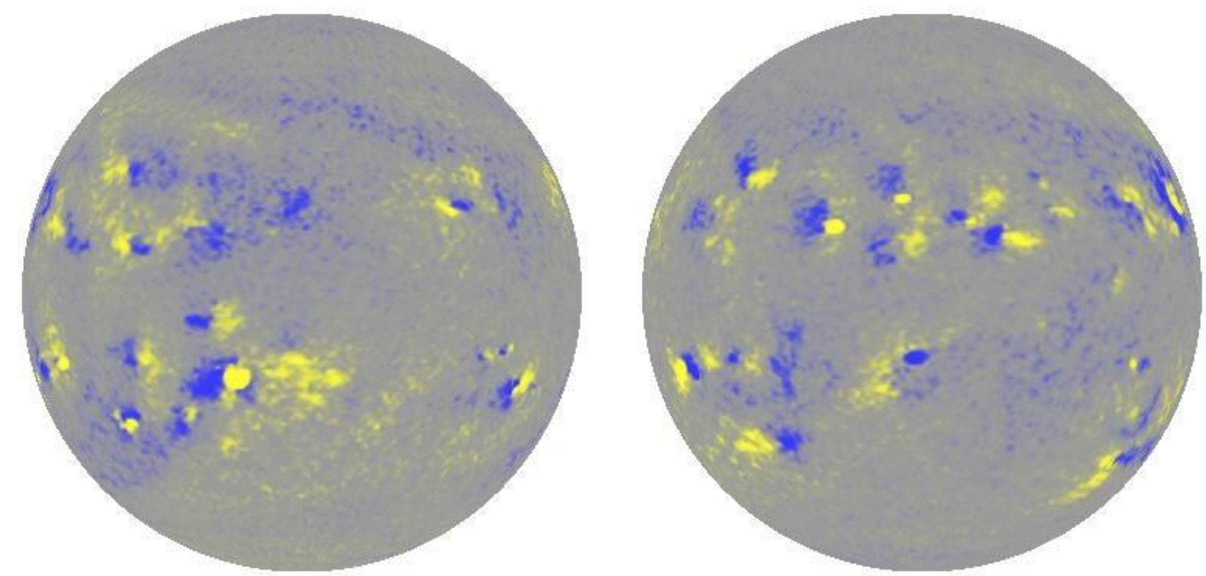
Sunspots correspond to areas of enhanced magnetic field

*Figures: Yeo, K.L. et al. A&A, 550, A95 (2013) arXiv:1302.1442 [astro-ph.SR]*

# Long term Solar activity: 22 year Solar activity cycle



Hale's polarity law:
-sunspots come in pair of opposite polarity
-opposite leading polarities at opposite hemispheres
-Leading polarities change with every cycle
=> 22 year cycle



Cycle 22
1989 August 02

Cycle 23
2000 June 26

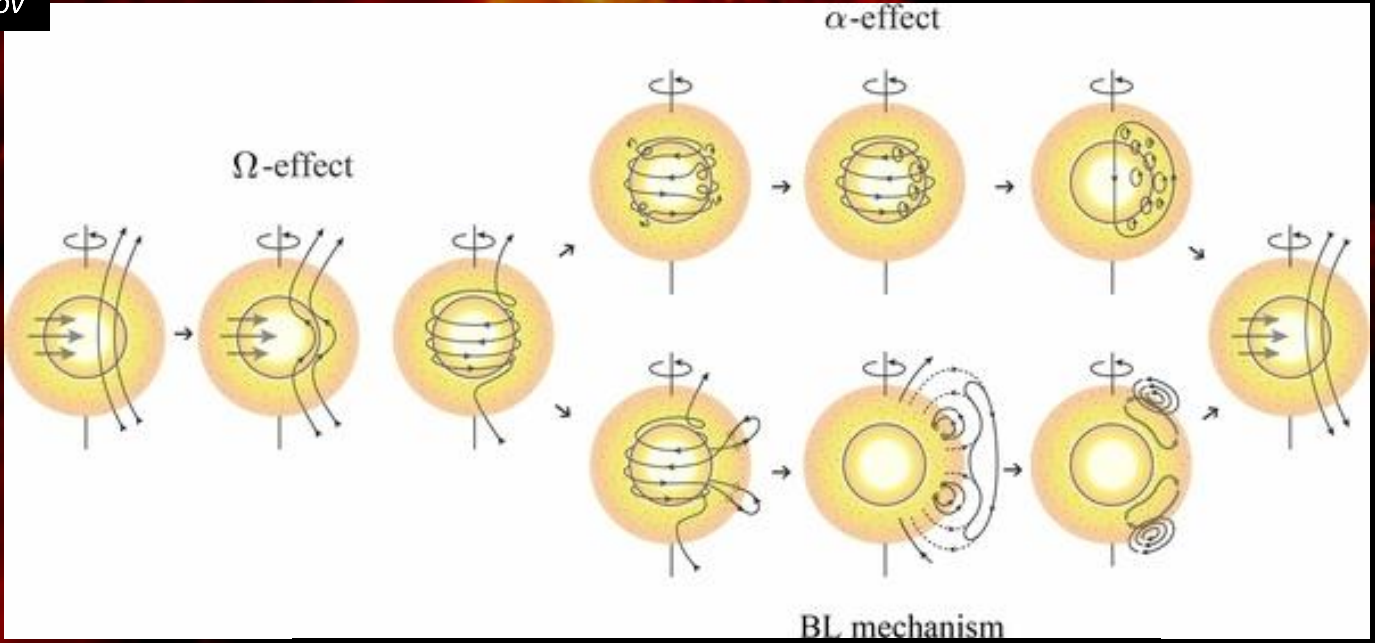
*Hathaway D.H., "The Solar Cycle", Living Rev. Solar Phys.* ***7****, (2010)*

# Long term Solar activity: Solar dynamo process

*http://www.nasa.gov*

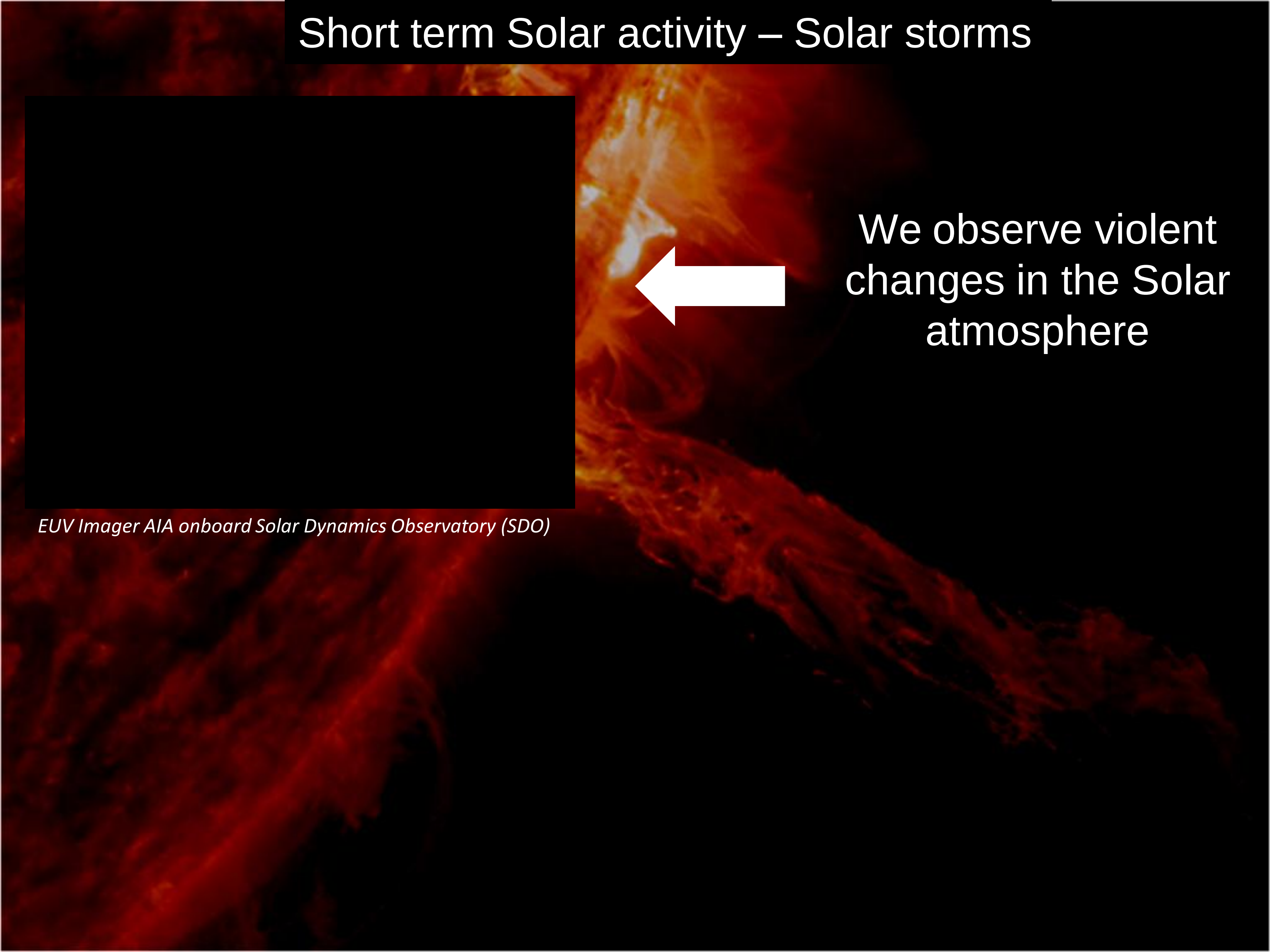
- It is widely believed that the Sun's magnetic field is generated by a magnetic dynamo within the Sun.

- dynamo – conversion of kinetic into electromagnetic energy




*Sanchez et al. ApJ. 781 (2013) 8 arXiv:1306.4561 [astro-ph.SR]*

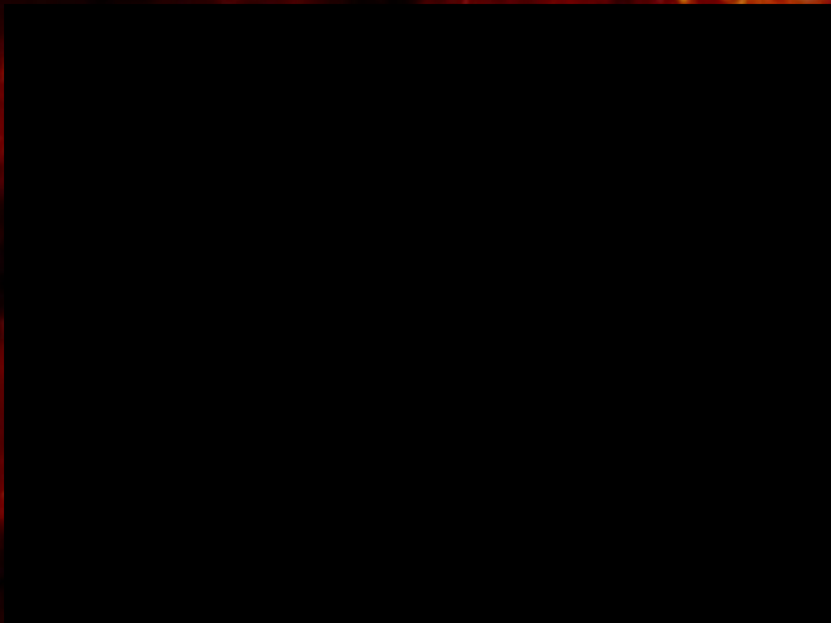
# Short term Solar activity – Solar storms



*EUV Imager AIA onboard Solar Dynamics Observatory (SDO)*

We observe violent changes in the Solar atmosphere

# Short term Solar activity – Solar storms



*EUV Imager AIA onboard Solar Dynamics Observatory (SDO)*

We observe violent changes in the Solar atmosphere

Release of the magnetic energy

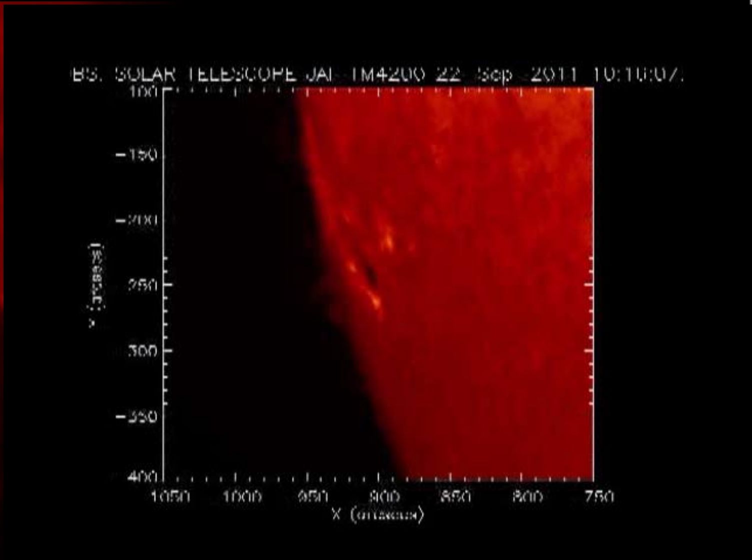
*http://www.nasa.gov*

# Solar storms: Solar flares

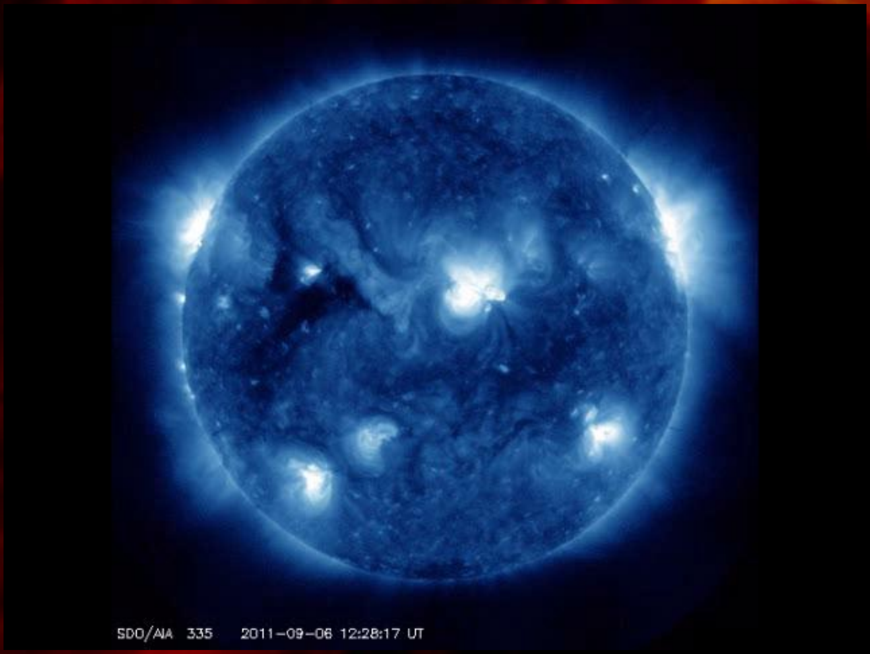
Eruptive phenomena in the solar atmosphere: they emit a broad spectrum of electromagnetic radiation (from radio waves to gamma rays)

Most often seen in EUV, Xray and H-alpha line

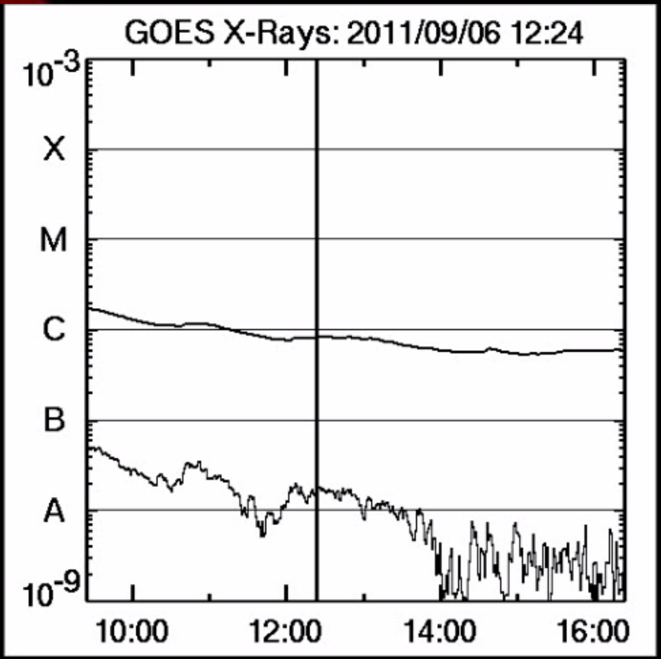
Also release solar energetic particles (SEPs)




*H alpha solar telescope (Hvar Observatory)*




*EUV Imager AIA onboard Solar Dynamics Observatory (SDO)*



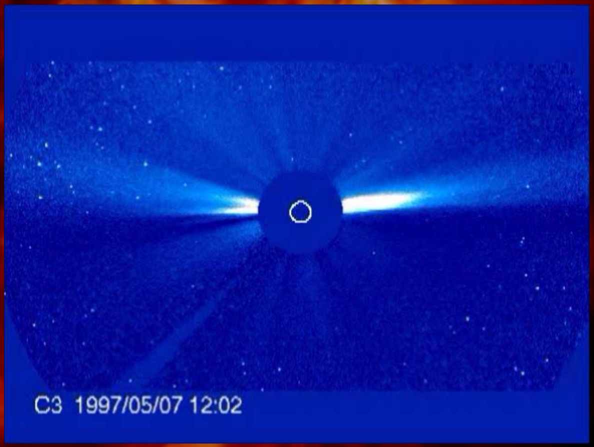

*X ray flux measurement from GOES satellite*

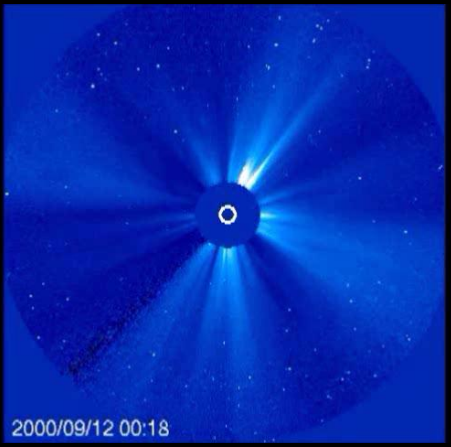
# Solar storms: Prominences

*UV Imager EIT onboard Solar and Heliospheric Observatory (SOHO)*

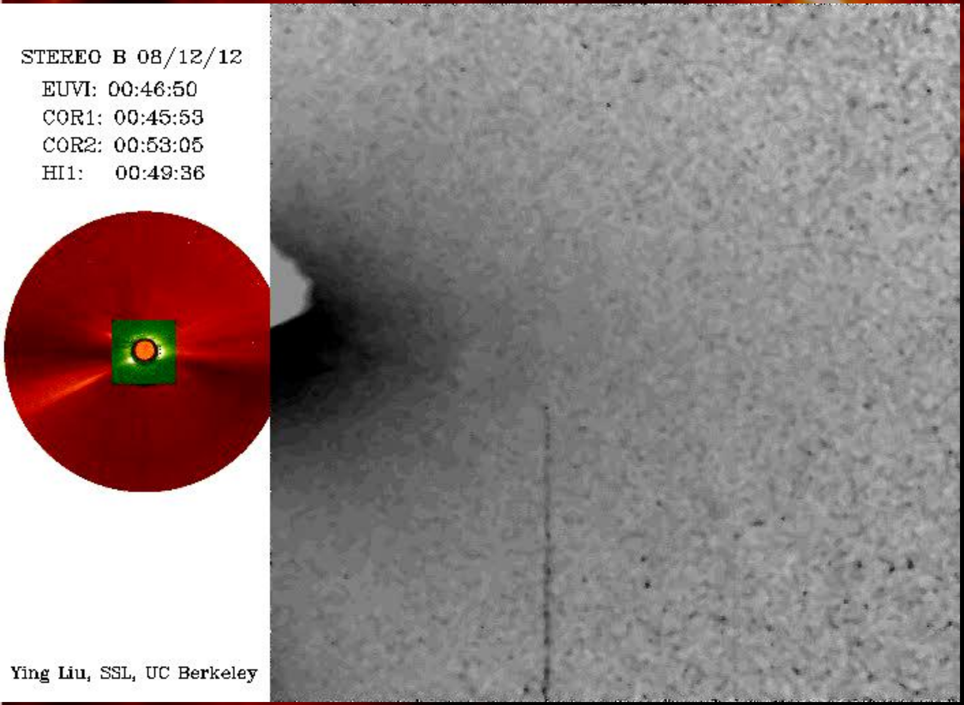
Eruptions of plasma from lower layers of the solar atmosphere (denser and cooler),
Time scales from hours to weeks

# Solar storms: Coronal Mass Ejections (CMEs)

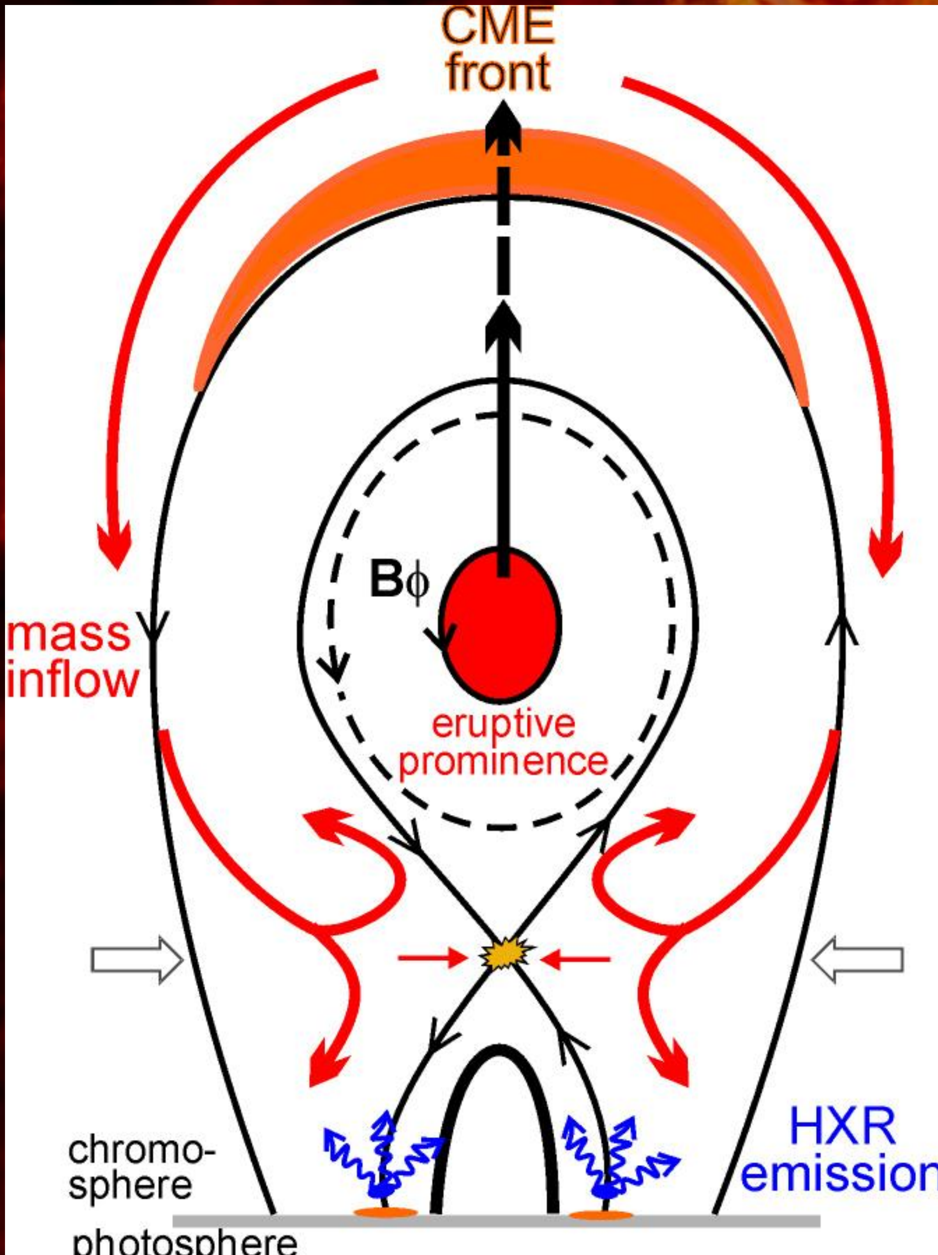

*LASCO C3 coronagraph onboard Solar and Heliospheric Observatory (SOHO)*




Magnetized plasma ejection from the solar corona (seen in coronagraphs and heliospheric imagers by white light emitted by scattered electrons as it moves trough)

*Composite of EUV imager, coronagraph & heliospheric imager onboard Solar Terrestrial Observatory (STEREO )*

# Solar storms: CME-flare-prominence connection




*Temmer et al. (2010)*

magnetic field structure (CME) starts to expand due to loss of equilibrium

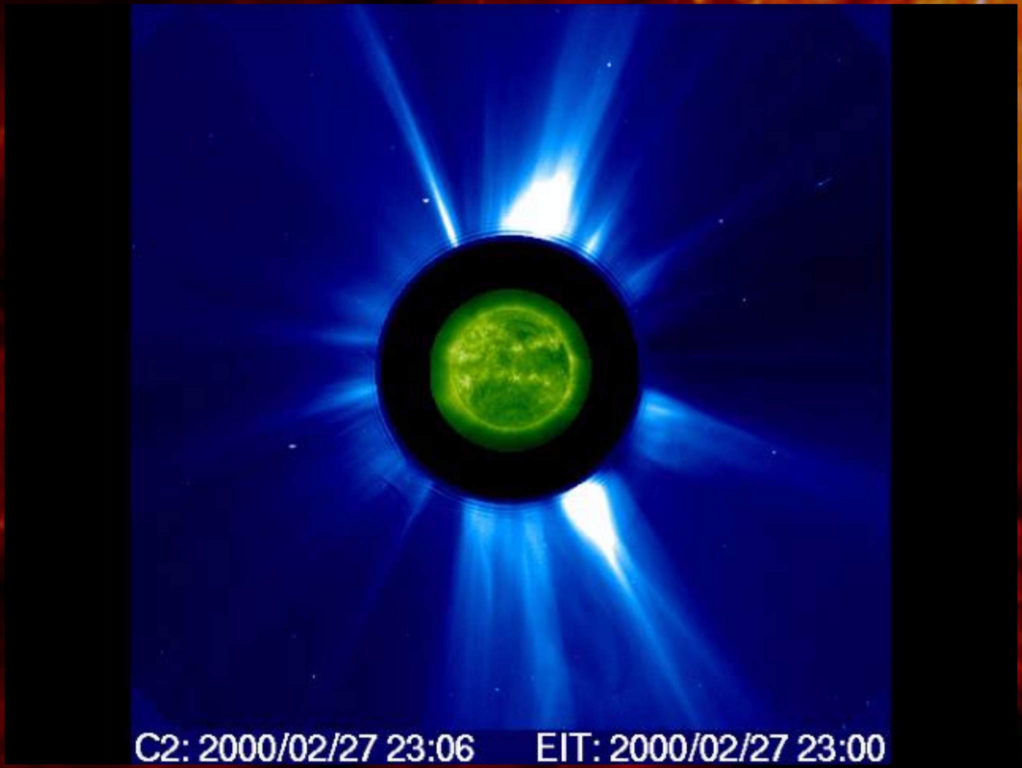
Stretching of the overlying magnetic field, reconfiguration (MAGNETIC RECONNECTION)

Particle acceleration from the reconnection site – SEPs & electromagnetic radiation (Solar flare)

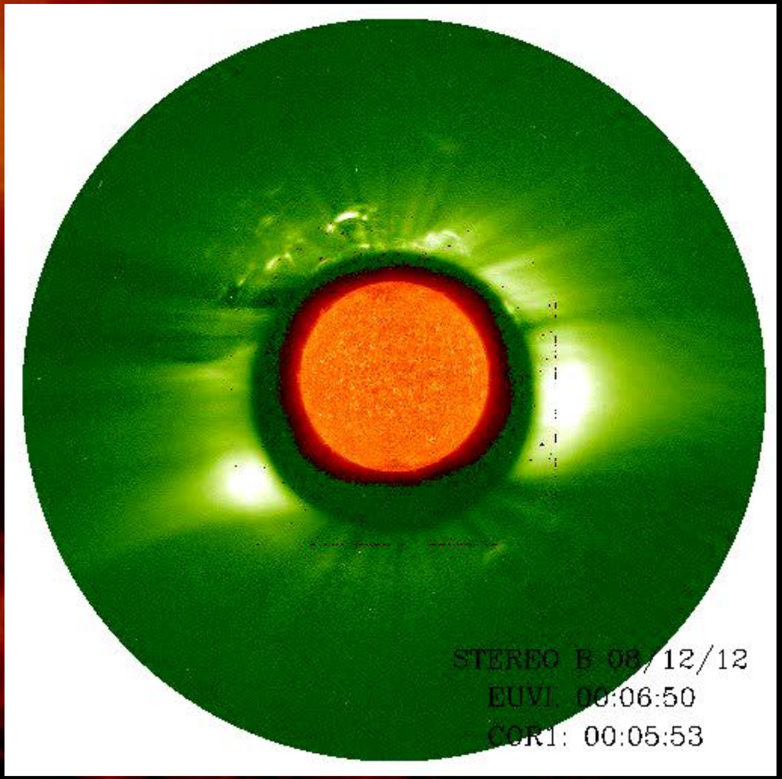
CME liftoff enabled by reducing the tension of the overlying field, plasma pile-up at the front

Prominence material trapped by the poloidal magnetic flux

# Solar storms: CME-flare-prominence connection




*EUV imager EIT and LASCO C3 coronagraph onboard SOHO*



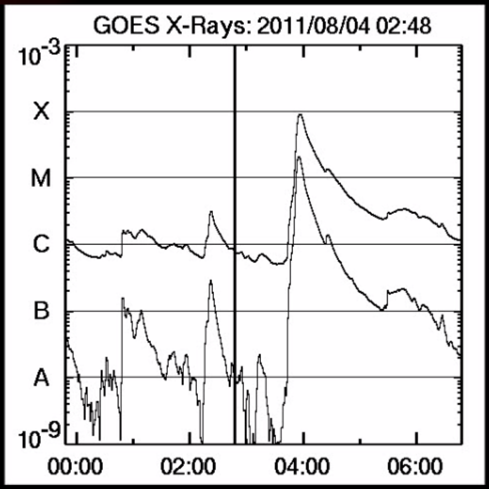

*EUV imager and COR1 coronagraph onboard STEREO*

CME three part structure:

1. Bright front - compressed material at the leading edge
2. Dark cavity - low-density, magnetic bubble
3. Bright core – dense prominence gas

# Solar storms: CME-flare-prominence connection


*EUV imager EIT and LASCO C3 coronagraph onboard SOHO (left-real, right-running difference)*

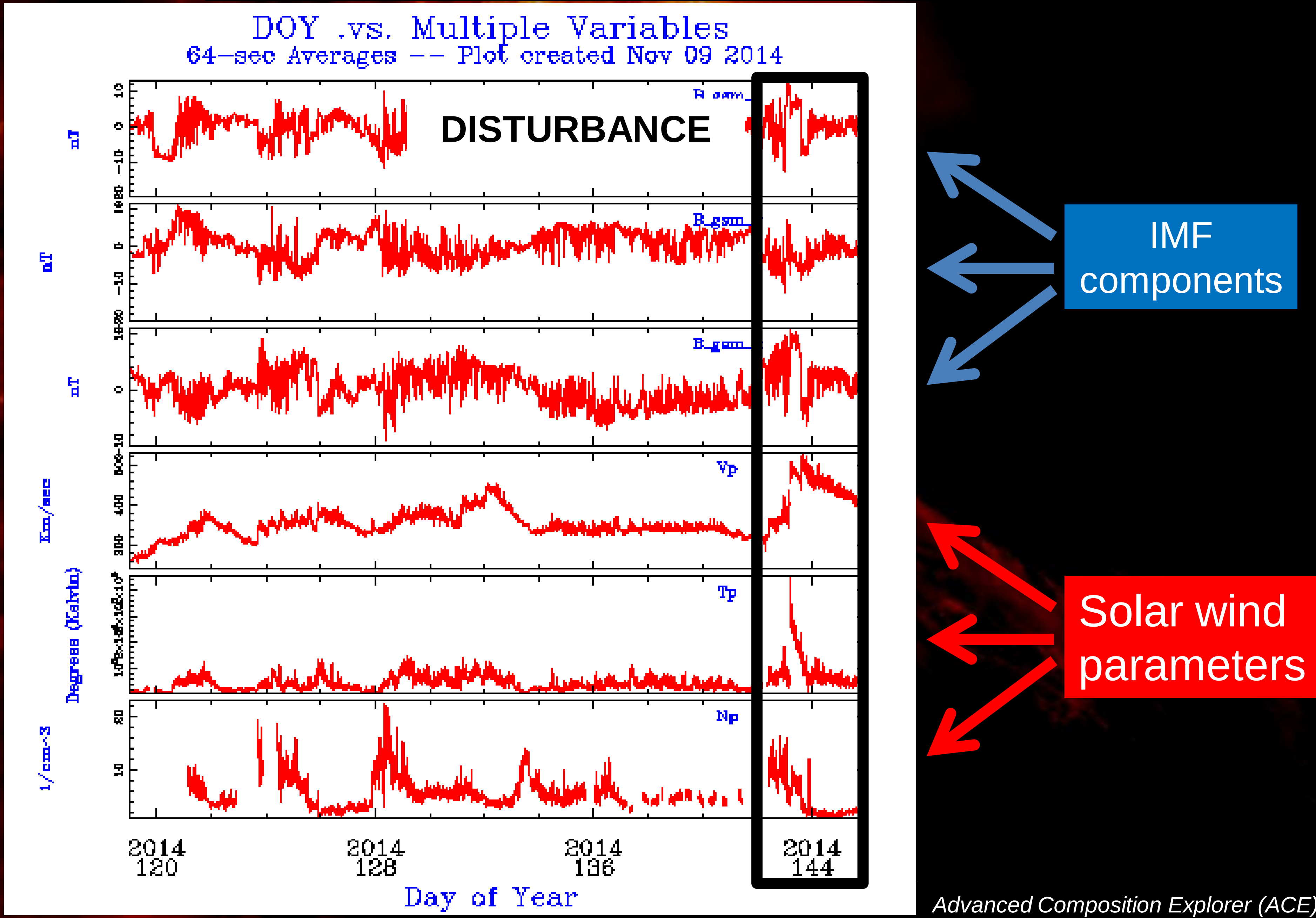



*X ray flux measurement from GOES satellite*

Time correspondence between Solar flare and CME

# Solar storms consequences for space weather?

# *In situ* measurements of Solar wind and IMF




*Advanced Composition Explorer (ACE)*

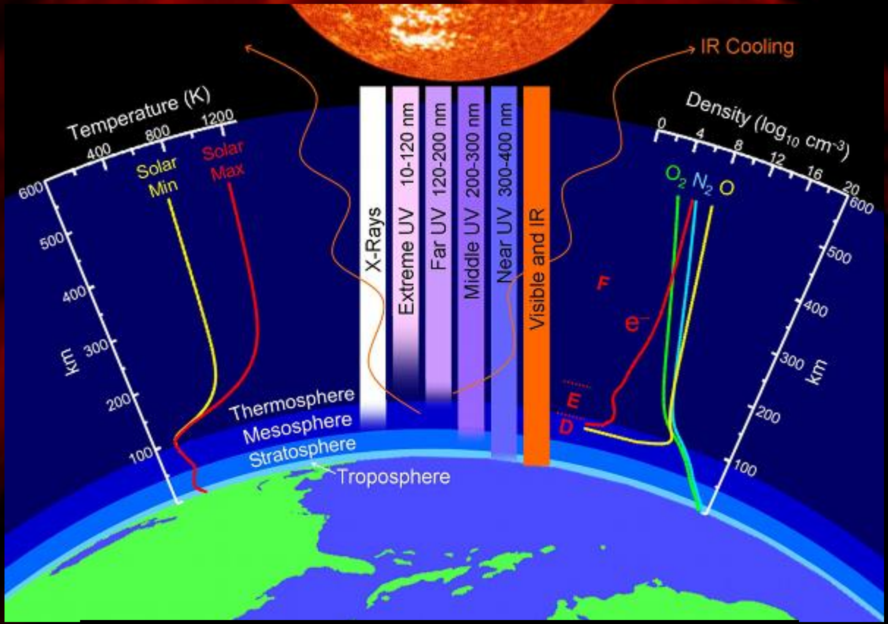
# Solar storms consequences at/near Earth

SOLAR FLARES → Electromagnetic radiation ~ 8 min

SOLAR FLARES → Solar energetic particles ~ 0.5 hour

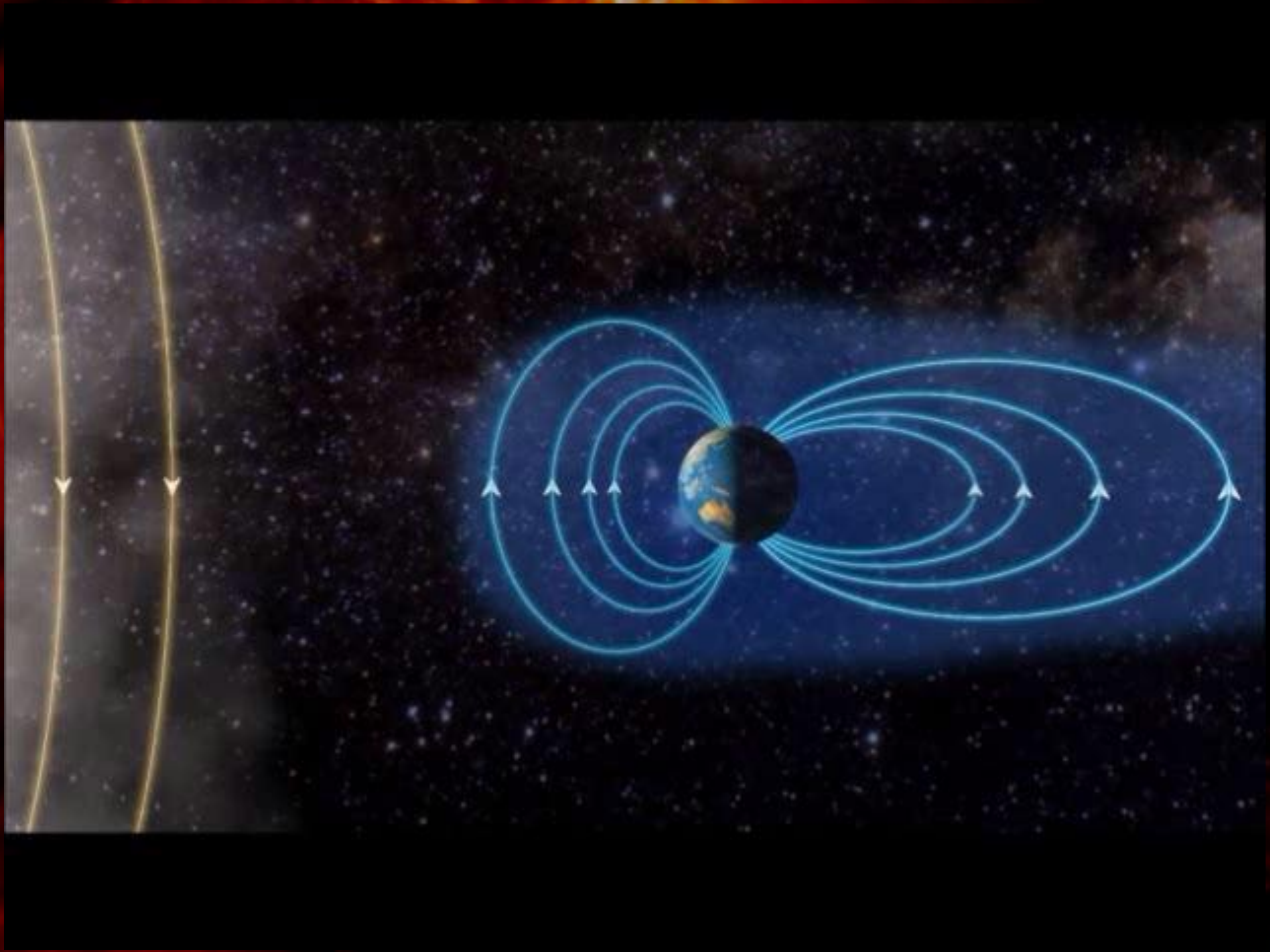
CMEs → Plasma carrying magnetic field ~ day

Influence on the IONOSPHERE




*John Emmert/NPL Astrobiologyonline magazine*

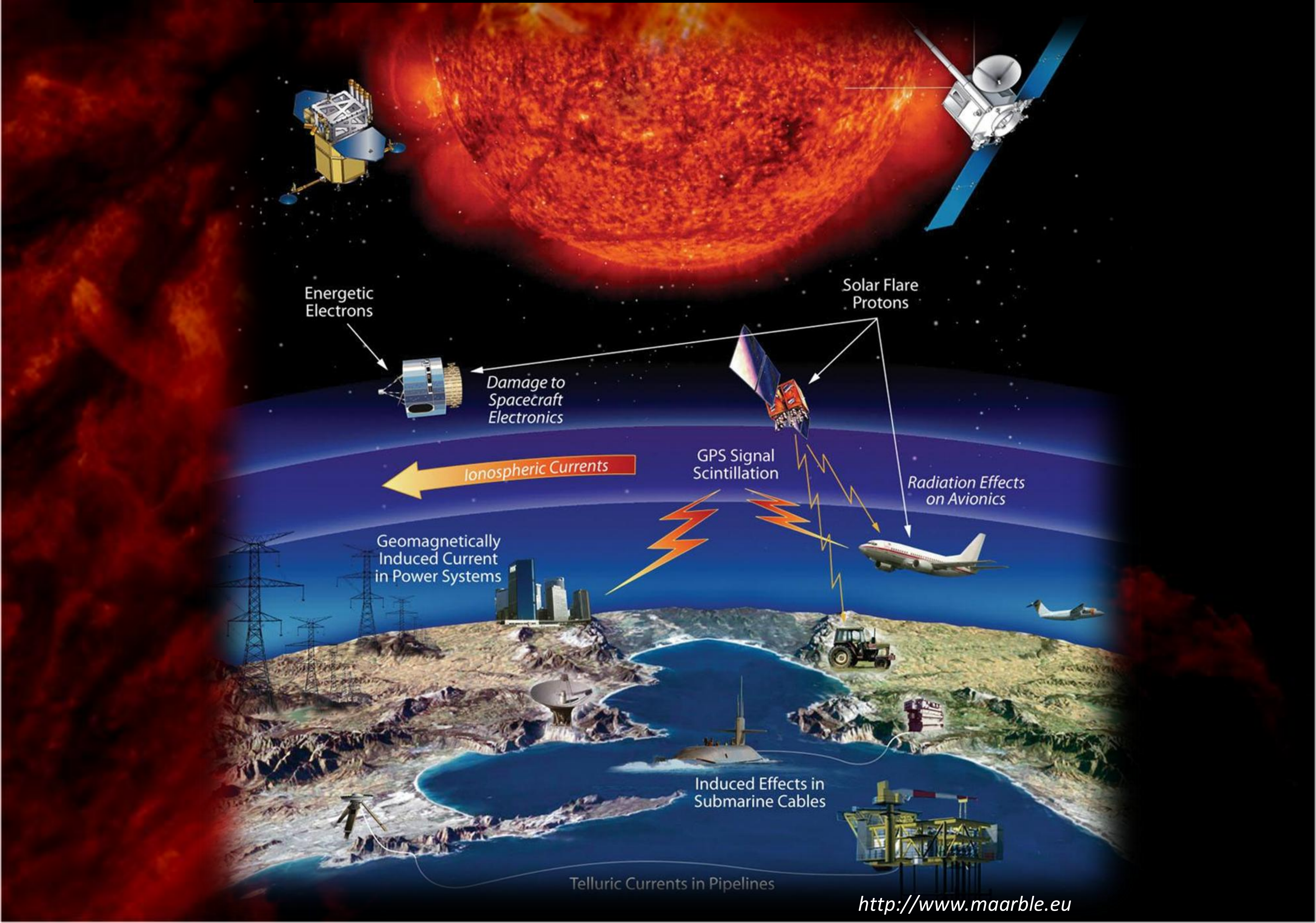
# Solar storms consequences at/near Earth



*www.forskning.no (University of Oslo)*

CMEs when they come to Earth can interact with geomagnetic field => geomagnetic storms, particles injected into the ionosphere

# Solar storms consequences at/near Earth



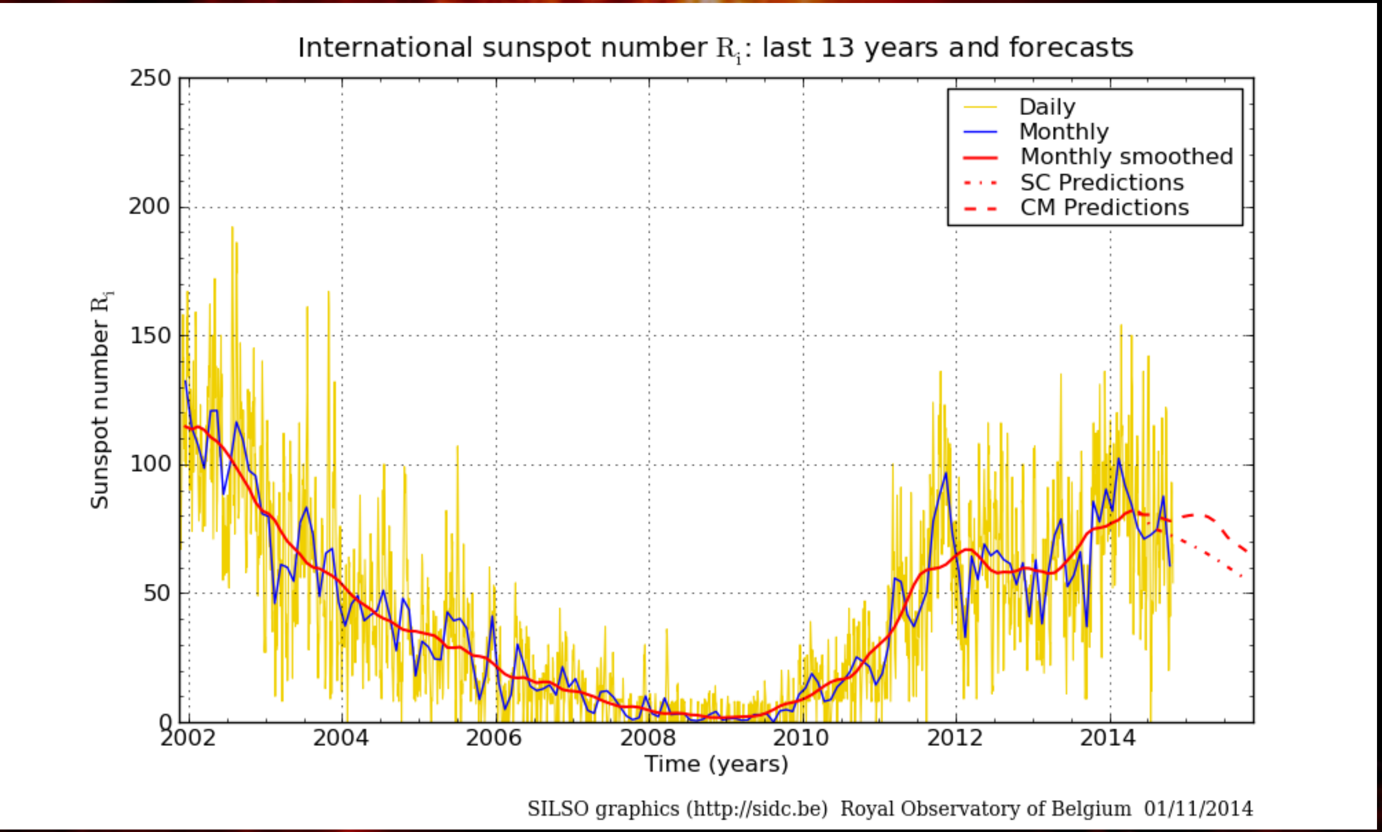

http://www.maarble.eu

# (Other) Solar storms consequences

- Planets – influence on planetary magnetospheres/ionospheres
- Comets – influence on cometary “magnetosphere”
- Solar wind - disturbed
- Interplanetary magnetic field - disturbed
- Cosmic rays – galactic CRs reduced, solar energetic particles
- Satellites – can be damaged, even failure of operations
- Astronauts – can be in danger
- … - power blackouts, GPS failure, increased radiation dose on transpolar flights, pipeline degradation, AURORAE…

Plenty of motivation for forecasting…

# Forecasting long-term solar activity




Mostly empirical – prediction of the new cycle based on the preceding one(s);
Employing solar dynamo theory?

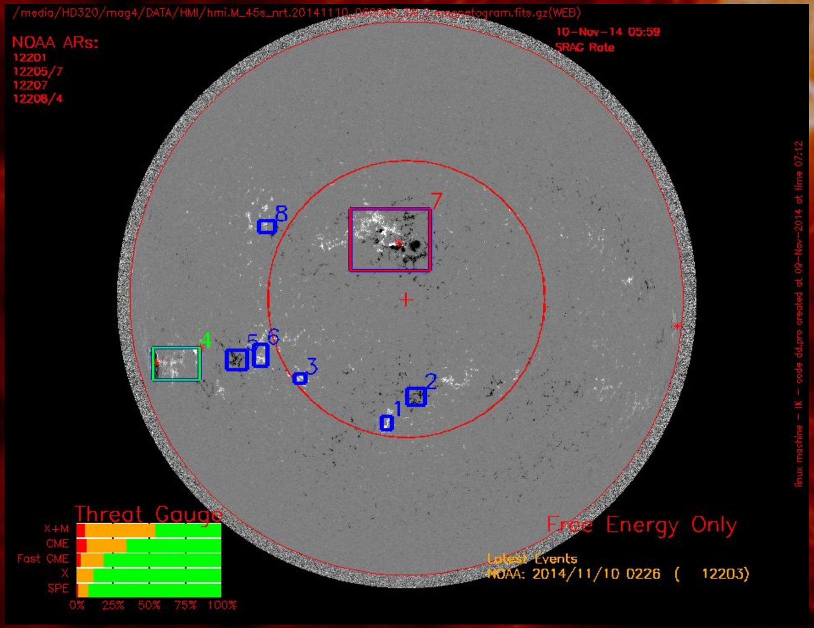
# Forecasting sunspot emergence

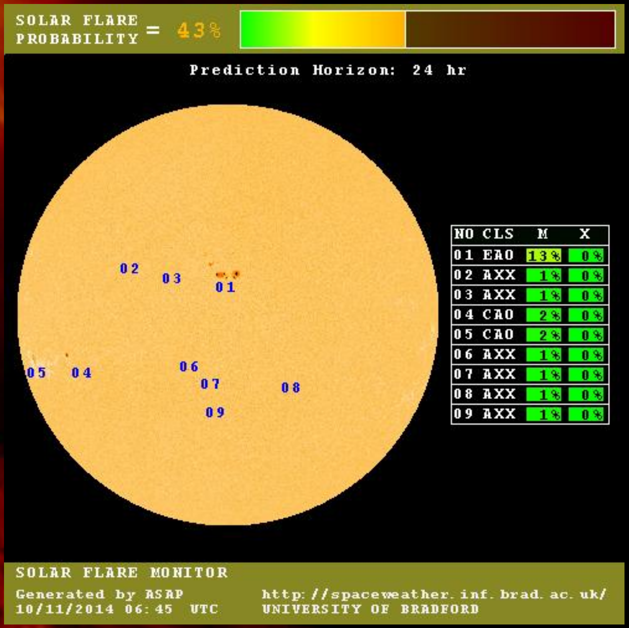

*http://www.nasa.gov*

Helioseizmology (doppler shift of photospheric absorption lines-acoustic waves)

The upper layer shows the photospheric magnetic field, and the lower layer shows the acoustic travel-time perturbations detected at a depth of about 60,000 km.

# Forecasting solar flare eruptions

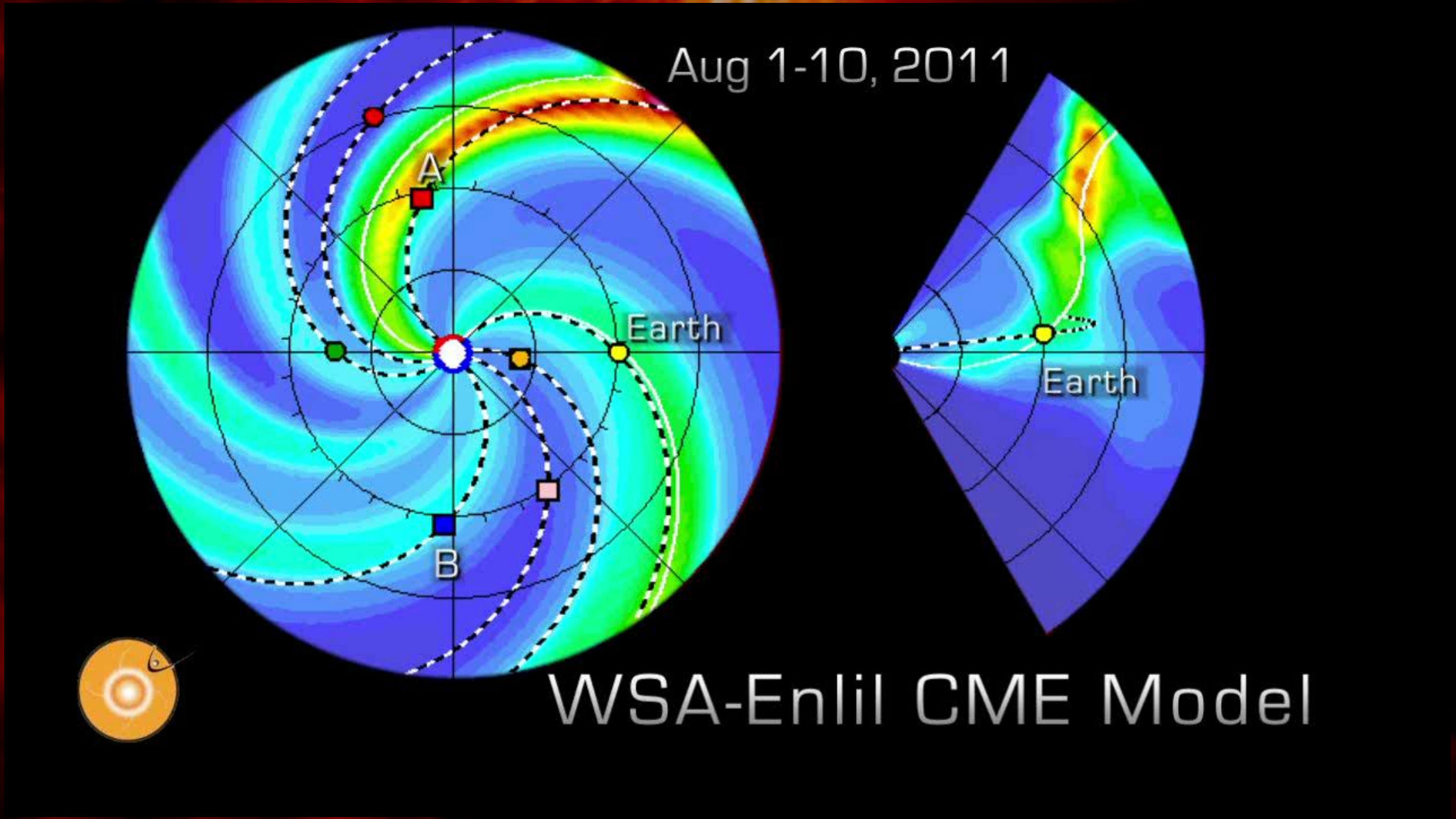



*From www.flareforecast.com*

Based on the photospheric field measurements and/or pattern recognition

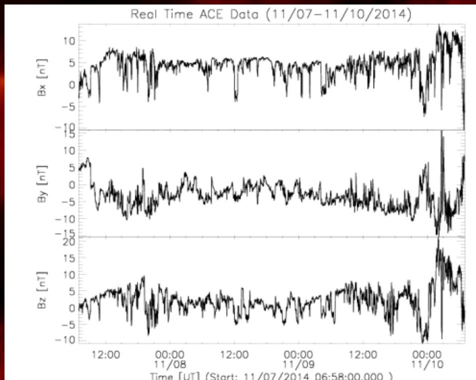
# Forecasting CME arrival and/or solar wind and IMF conditions

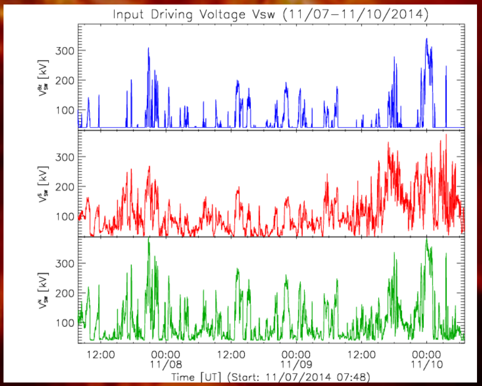


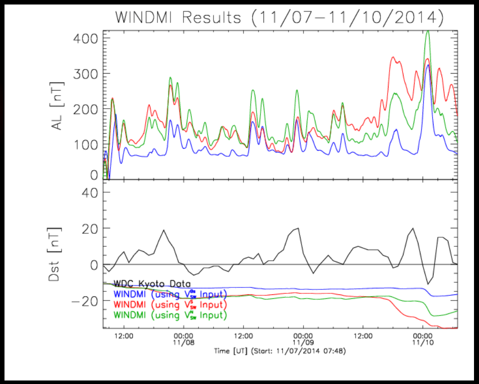

*Enlil model at http://ccmc.gsfc.nasa.gov*

Empirical and analytical (drag-based) for arrival, numerical (MHD) models for arrival + conditions (but evolution of B not solved!)

# Forecasting solar wind-magnetosphere coupling




*WINDMI model at http://ccmc.gsfc.nasa.gov*

numerical models that use *in situ* measurements as input

Predicting risk for power lines, pipelines, satellite operations, radiation dosage….

COMBINE EVERYTHING


*www.esa.int*

Solar-interplanetary-terrestrial connection

# Hvar Observatory
# (Faculty of Geodesy, Uni. Zagreb, Croatia)

solar group (6; theory & obs.):
- solar eruptive phenomena
- solar rotation & other large-scale phenomena

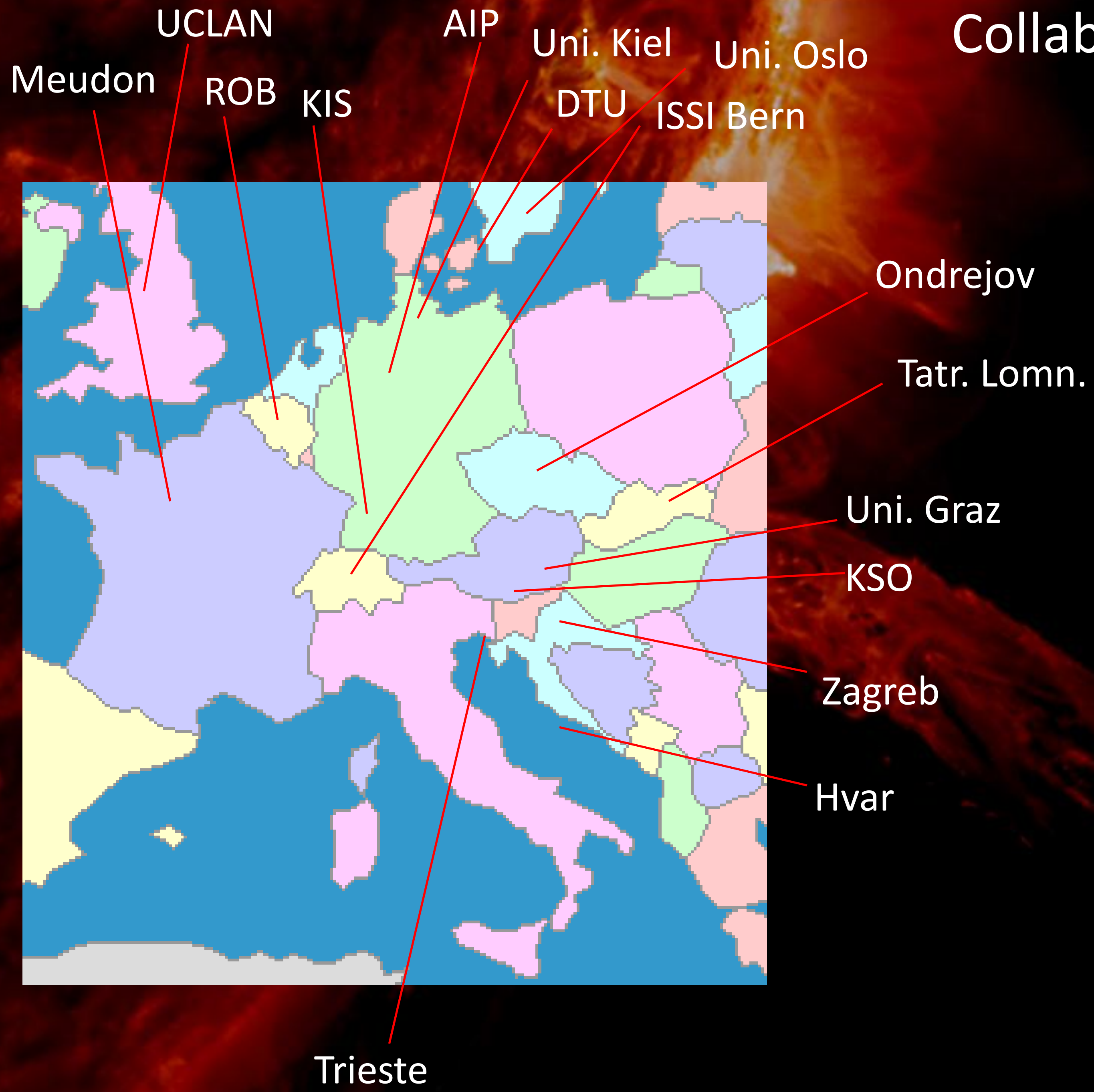
stellar group (3; obs.):
- variable stars
- Be stars

equipment:
- double solar t. (white light + H alpha)
- 65 cm photometric t.
- 1 m multi-purpose t.

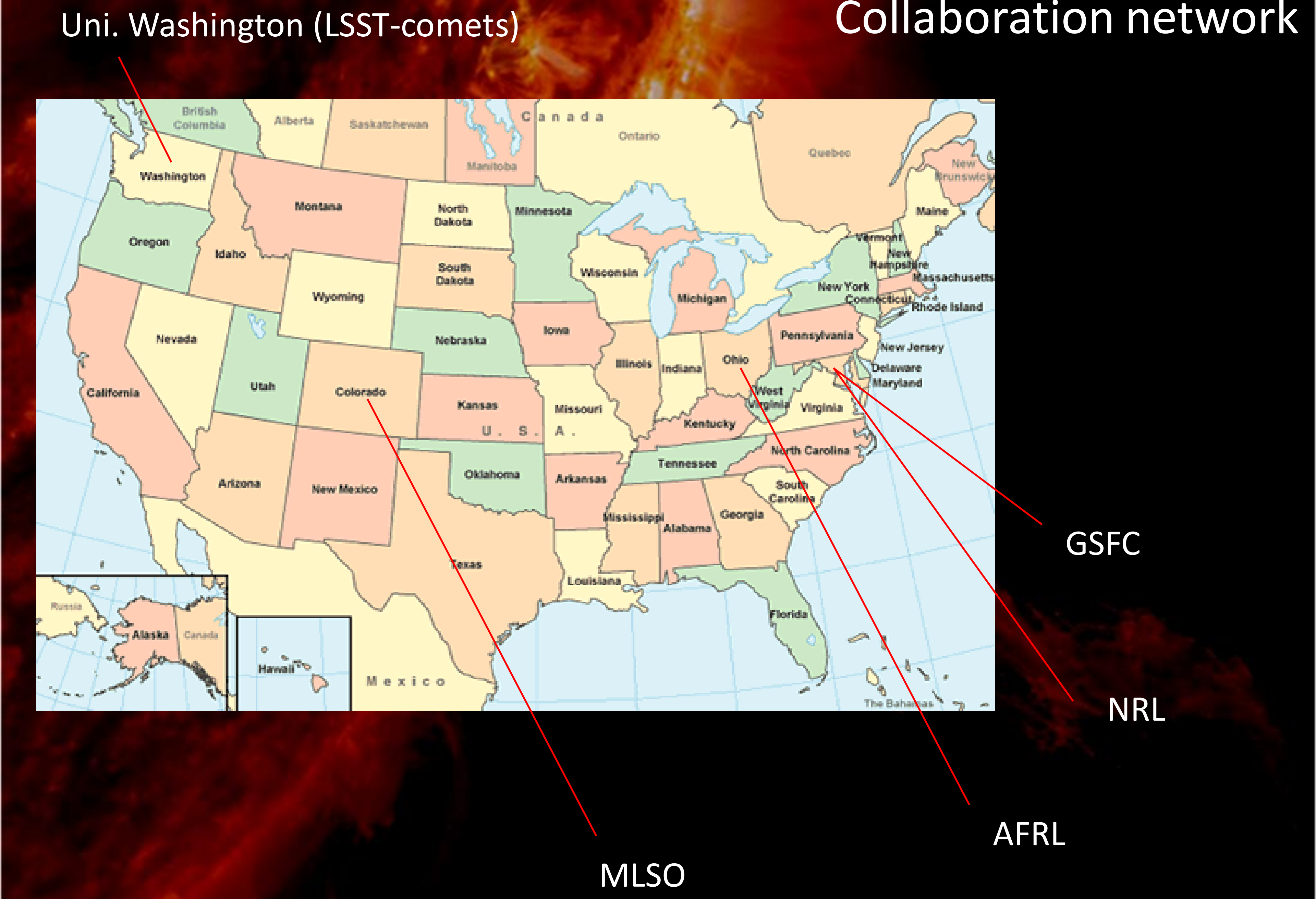

University of Zagreb
The Observatory

# The Observatory at Hvar Island

# Collaboration network



# Collaboration network

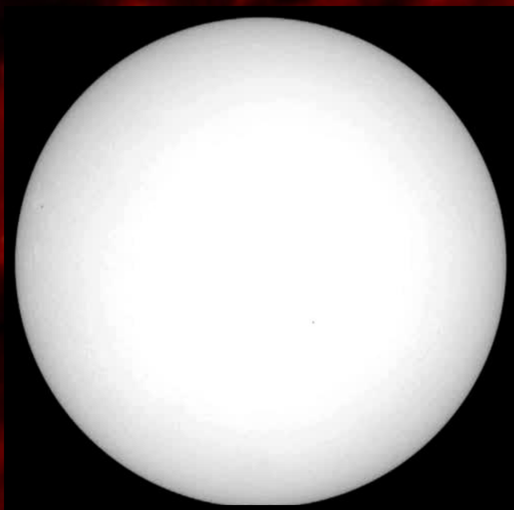


Ackgnowledgements:

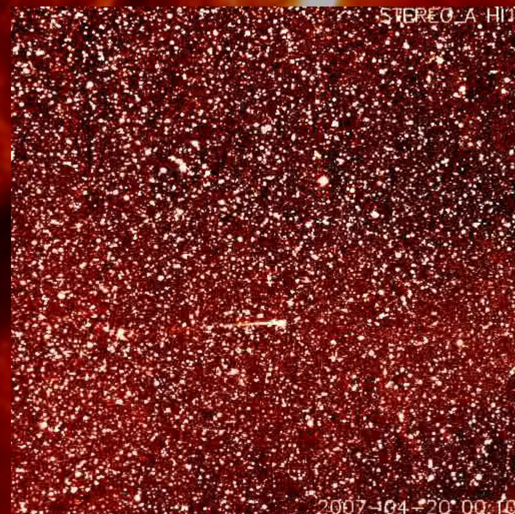
Hvar Observatory
Faculty of Geodesy
University of Zagreb

Croatian Science
Foundation

Željko Ivezić, ph.D.
University of Washington



*http://www.nasa.gov*



*http://www.nasa.gov*

*www.forskning.no (University of Oslo)*

# Thank you for your attention!