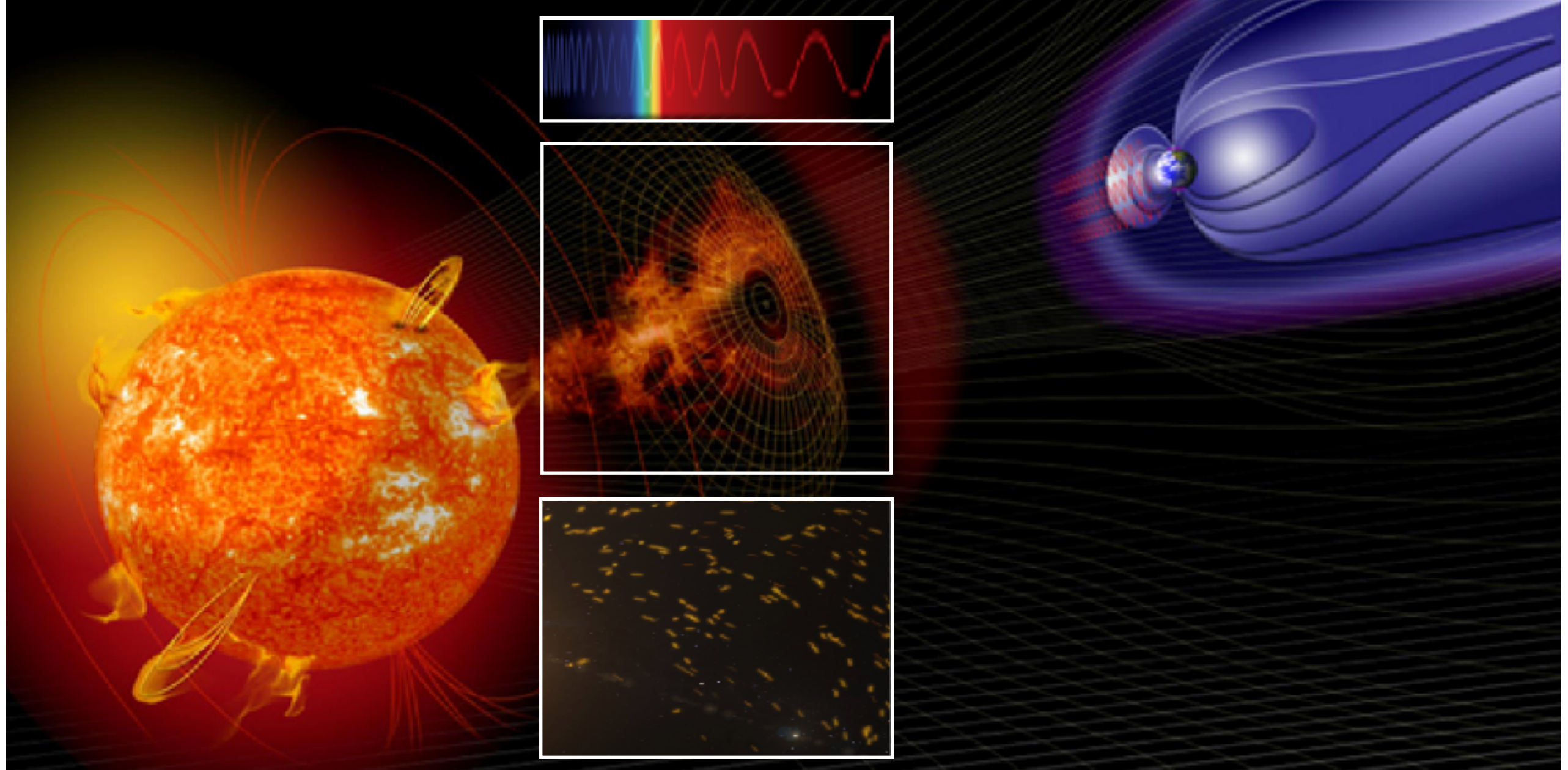


Space Weather impacts on Ionospheric wave propagation

-

Focus on GNSS and HF





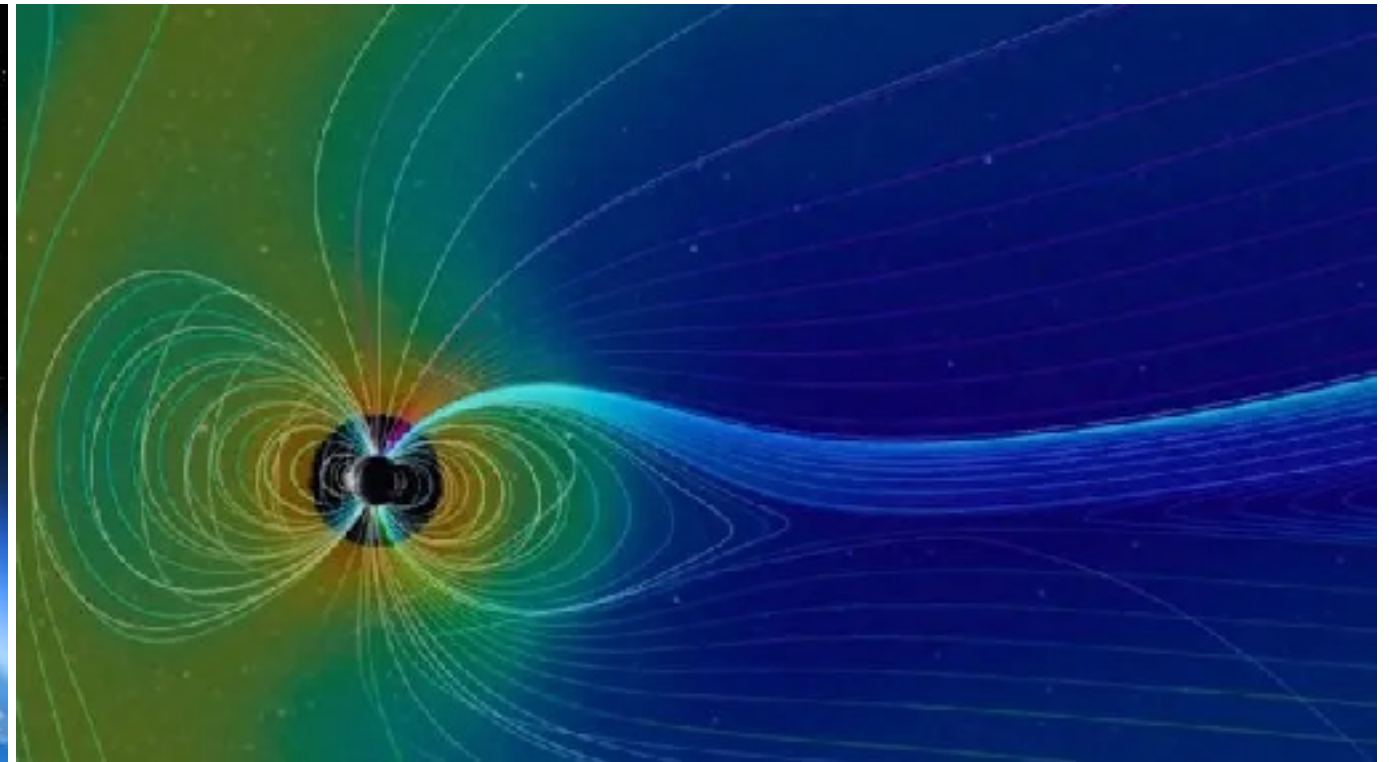
SPACE WEATHER

Introduction

Petra Vanlommel

Space Weather

The Sun's energy impacting earth's atmosphere and magnetic shield.

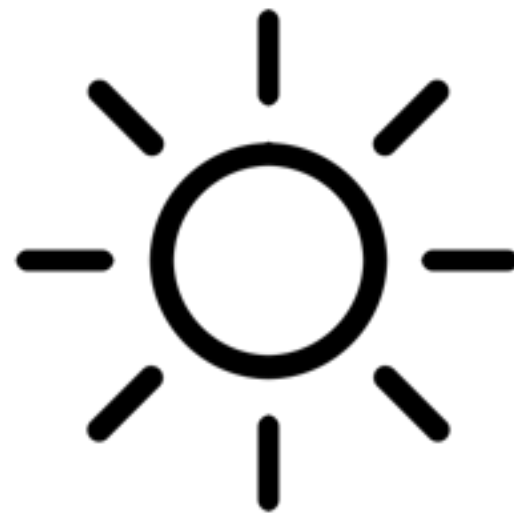


THE SUN AS A BALL OF ENERGY

The sun emits continuously energy which is expelled to outer space in the form of electromagnetic waves and particles.

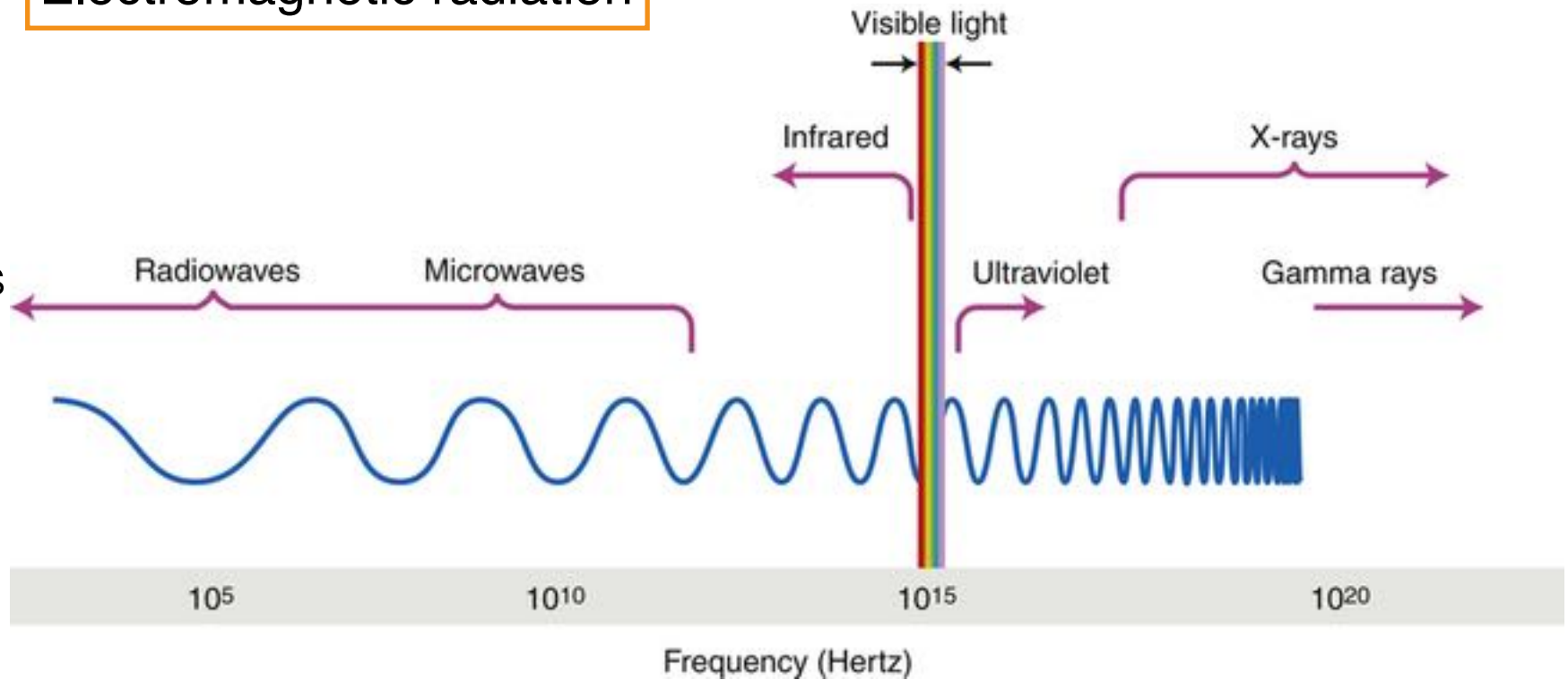
E.M. WAVES

PARTICLES



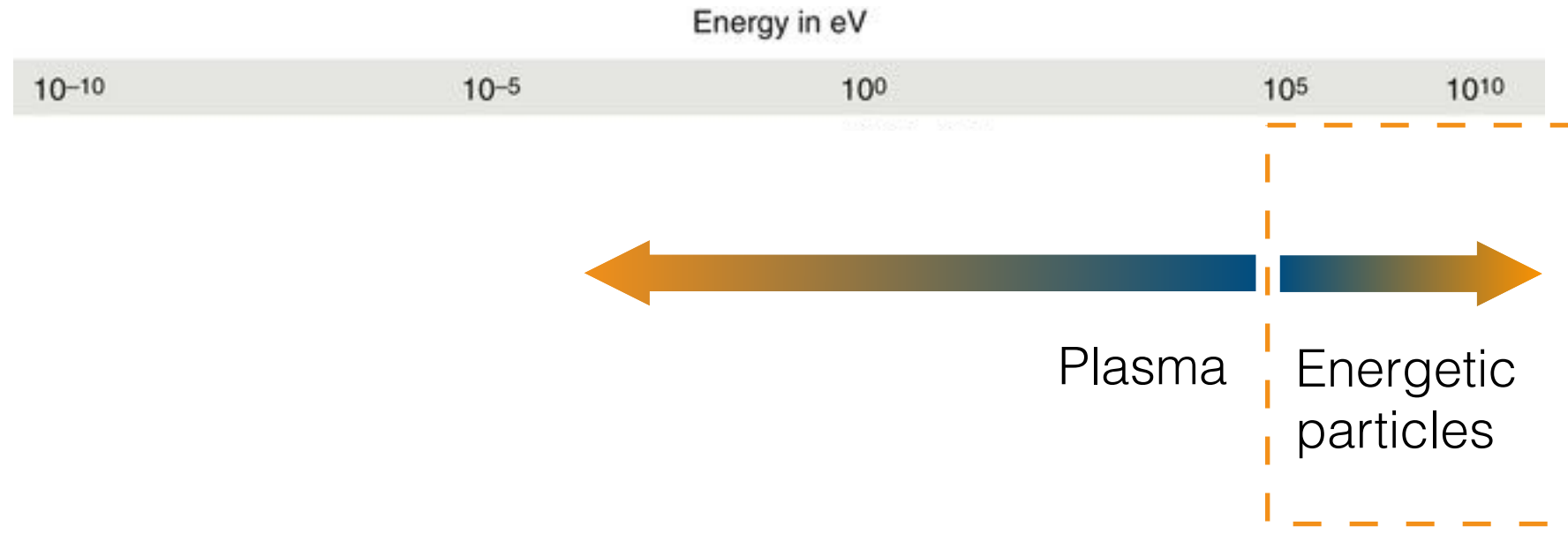
Electromagnetic radiation

- Photons / electromagnetic waves
- Speed of light



Particle radiation

- Atomic & sub-atomic particles
- m/s to fractions of speed of light

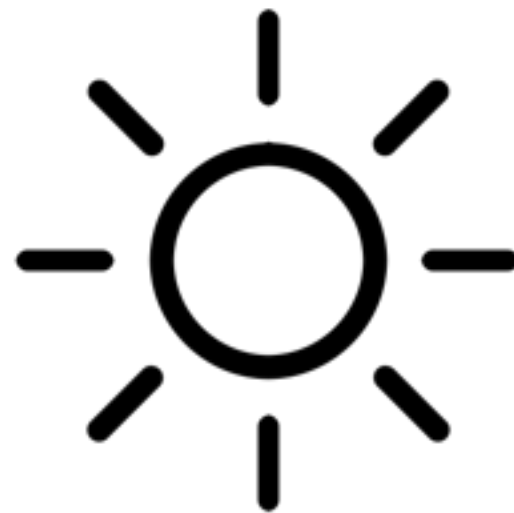


THE SUN AS A BALL OF ENERGY

E.M. WAVES

PLASMA

ENERGETIC
PARTICLES



3 SPACE WEATHER PHENOMENA

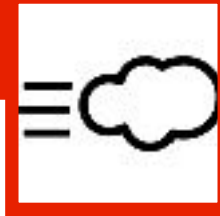
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

How and where the interaction occurs depends on the type of energy.

LIGHT



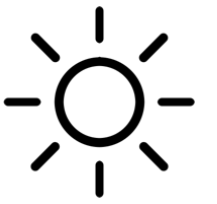
WIND



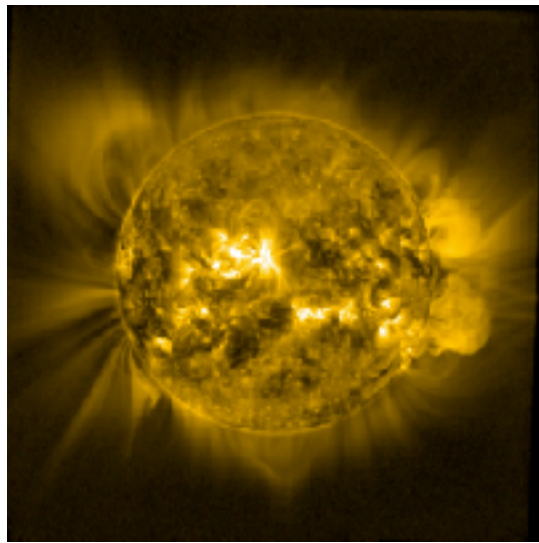
RAIN



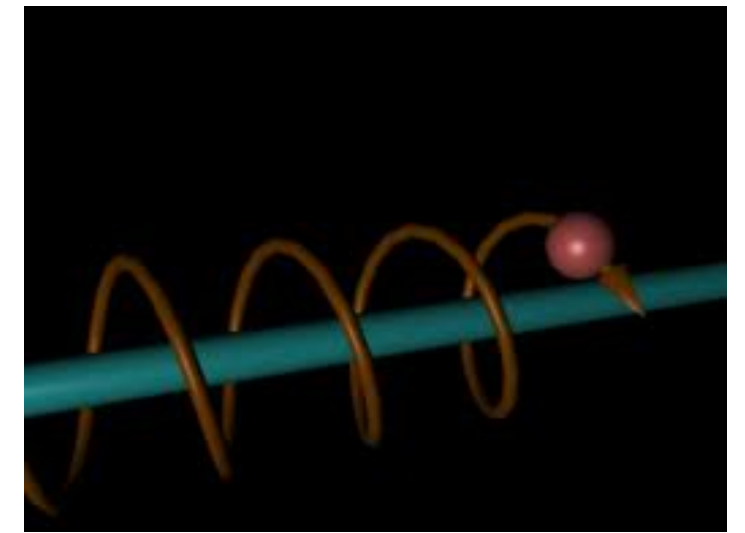
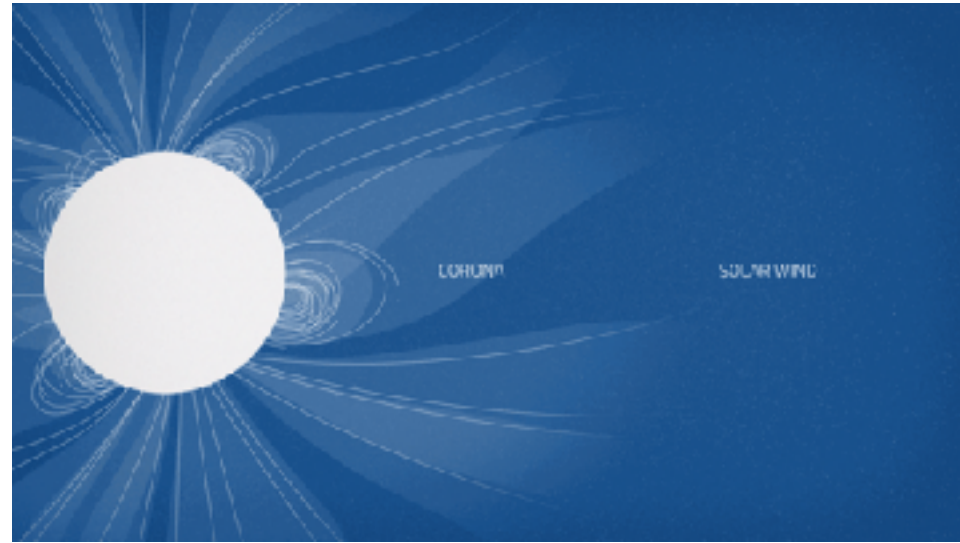
SOLAR SEASONS



The sun has 2 seasons: an active and a low season with the typical variations in the three space weather phenomena. This seasonal variation is called the solar cycle and takes around 11 years.



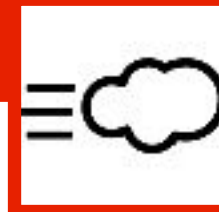
 **PROBA2/SWAP**



E.M. WAVES



SOLAR WIND



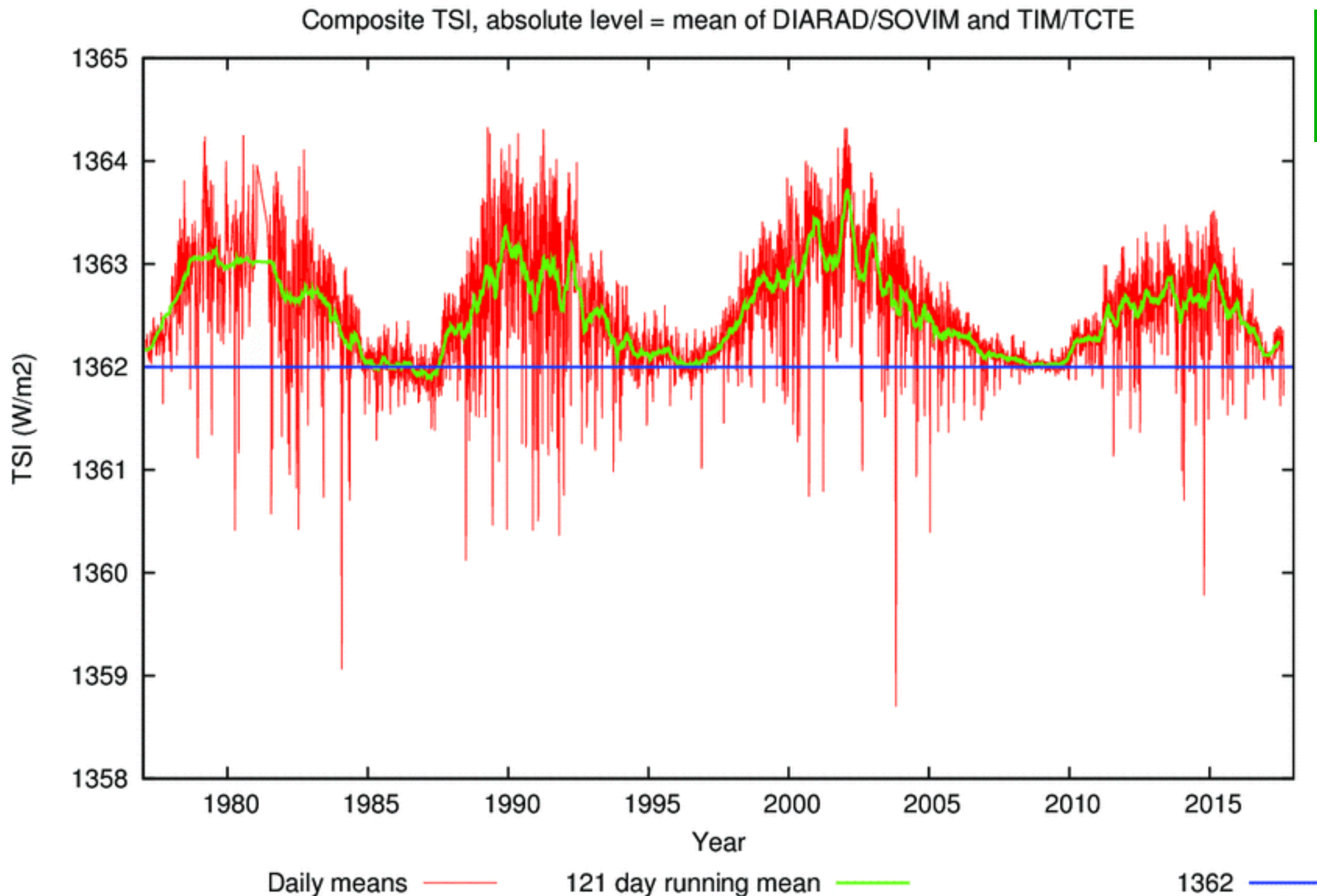
SOLAR PARTICLES



SEASONAL BEHAVIOUR OF LIGHT

The solar irradiance, i.e. all the solar light, varies over the solar seasons.

The sun radiates stronger in the high season compared to the low season.



SEASONAL BEHAVIOUR OF THE SOLAR WIND

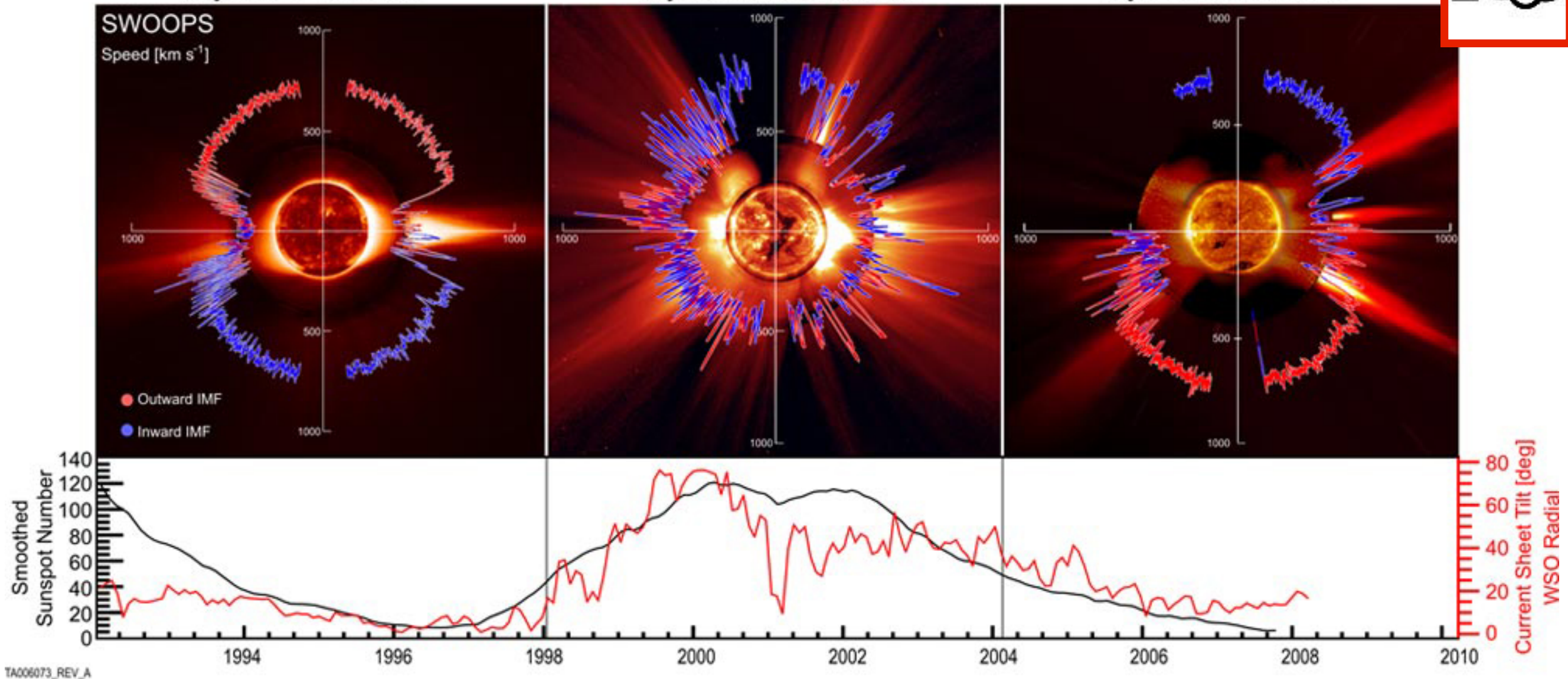
The solar wind varies over the solar seasons. The variation depends on the solar latitude. In the low season, the solar wind is slower near the equator compared to the higher latitudes and is more nicely structured. In the high season, the solar wind varies over all latitudes.



Ulysses First Orbit

Ulysses Second Orbit

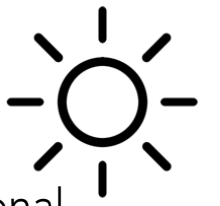
Ulysses Third Orbit



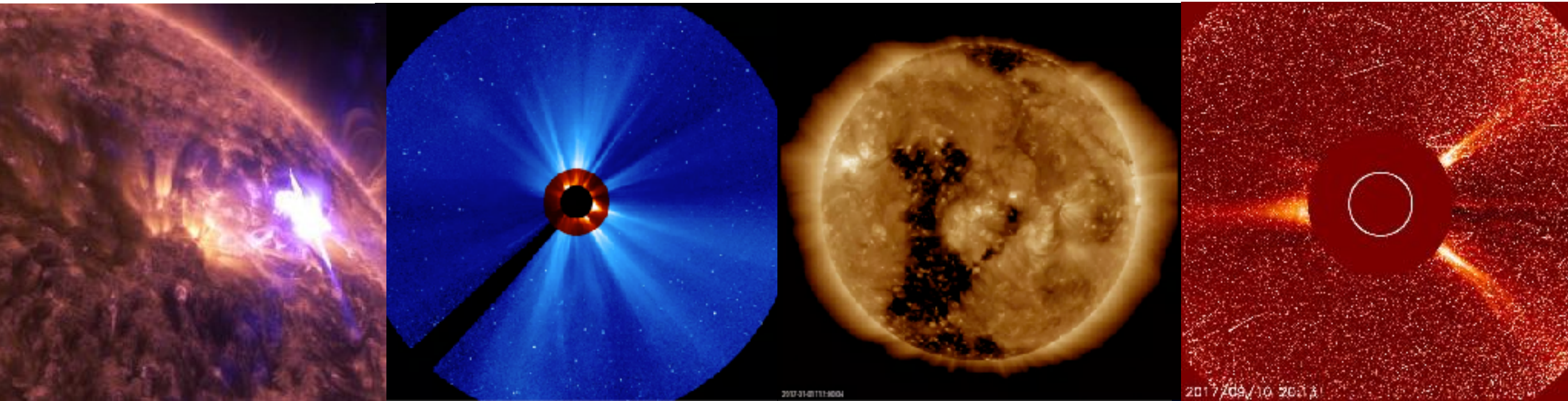
TA006073_REV_A



SOLAR WEATHER & STORMS



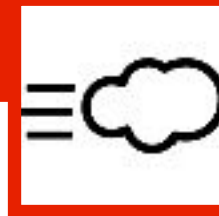
At a certain moment, energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection or CME, proton storm) or in a non-eruptive manner (Coronal Hole - CH).



FLARE



CORONAL MASS
EJECTION
HSS and CIRs

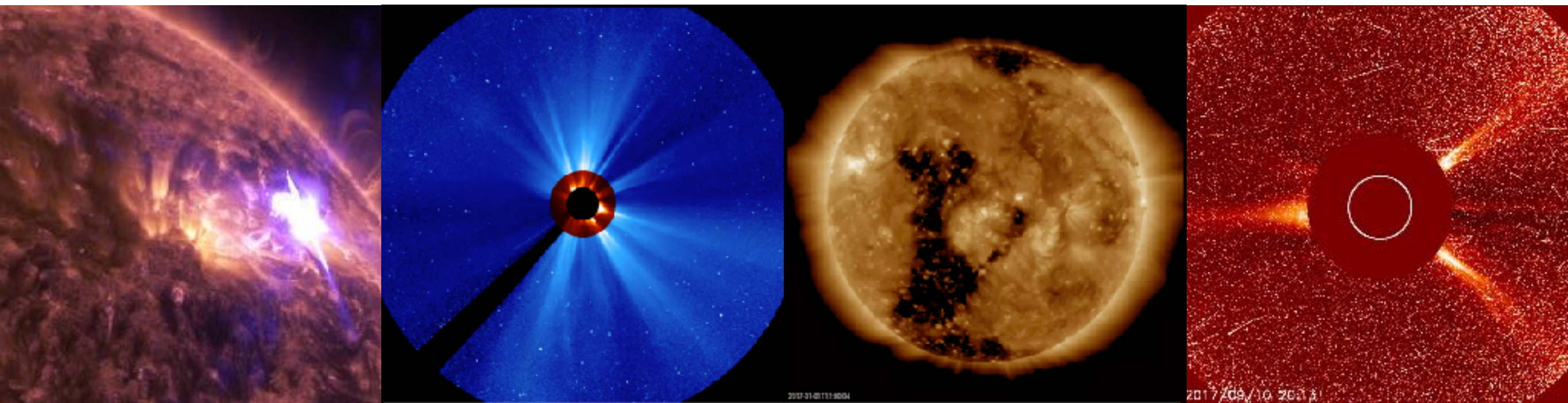
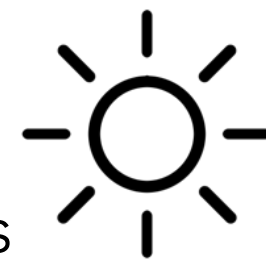


PARTICLE STORM



AU TRANSIT TIME

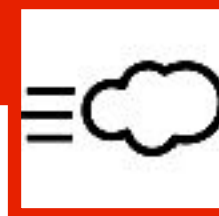
The energy released during a solar storm moves through space, each with its own typical speed: speed of light, order of a few 100 km/s, relativistic speeds.



8 MIN



DAYS

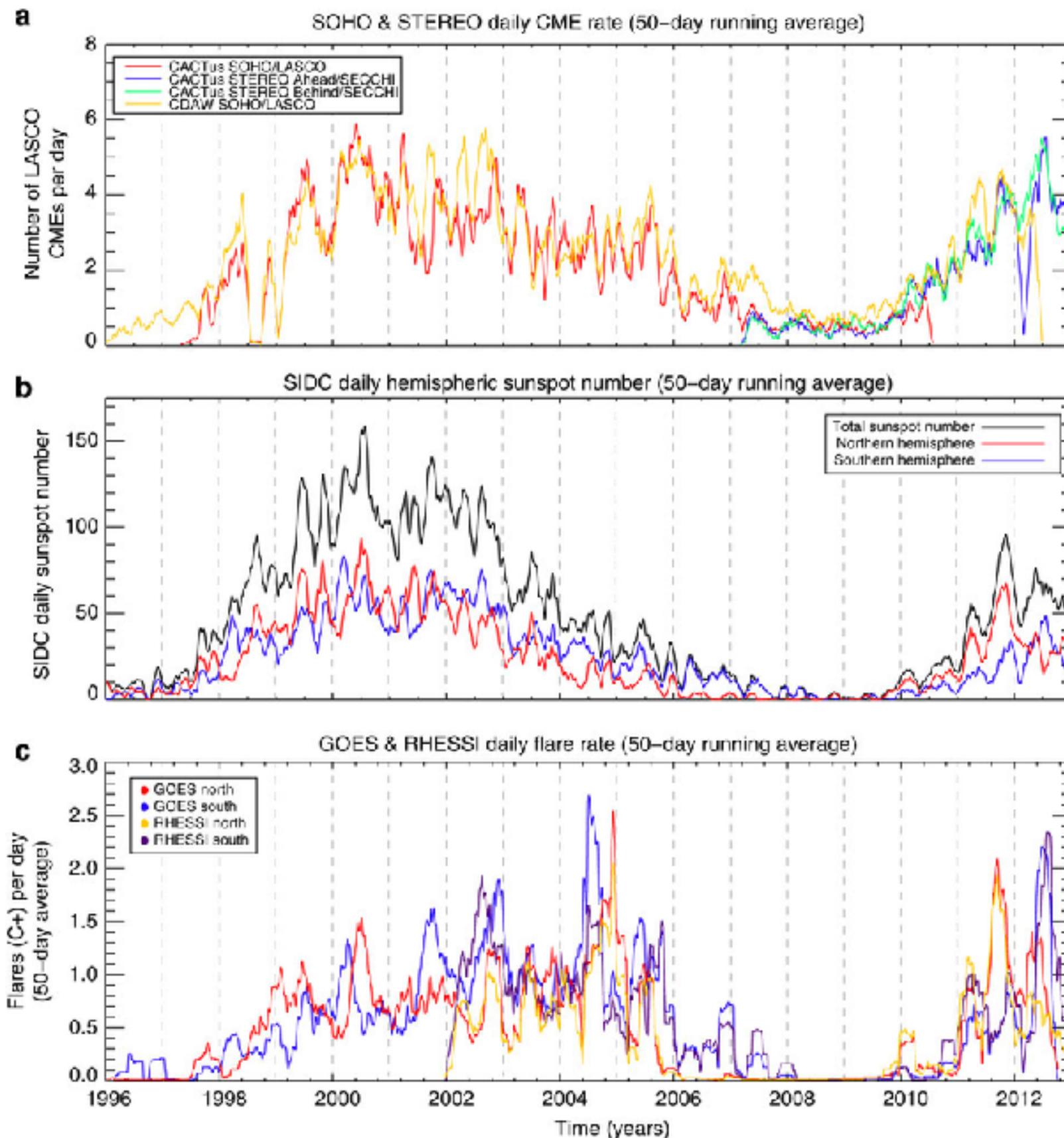


HOUR



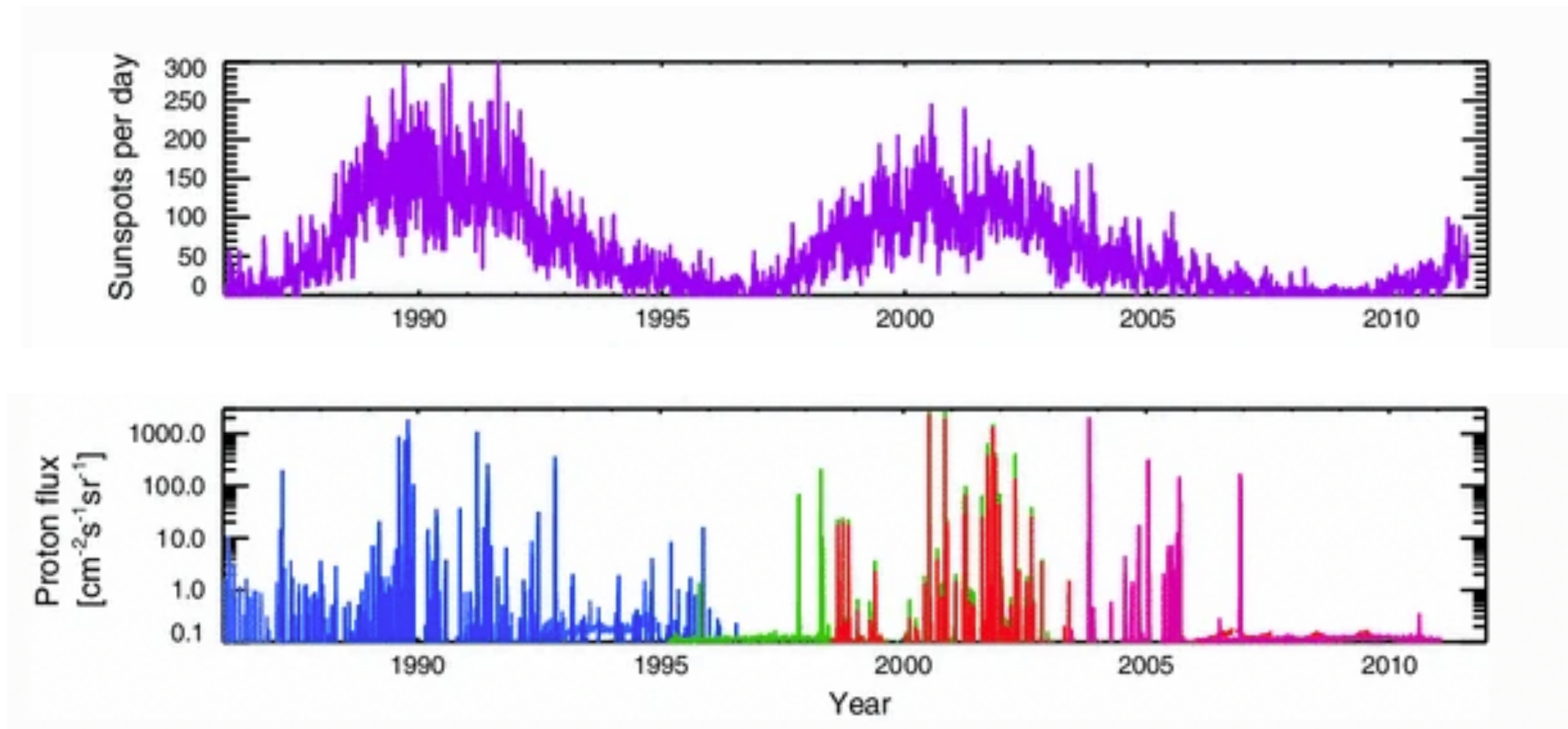
SEASONAL BEHAVIOUR OF SOLAR LIGHT & WIND STORMS

The seasonal behaviour is also visible in the variability of the Sun's eruptive output. You see here a comparison of the variation in the CME and flare rates over solar cycle 23 with the sunspot number.



SEASONAL BEHAVIOUR OF SOLAR PARTICLE STORMS

The seasonal behaviour is also visible in the variability of the Sun's eruptive output. You see here a comparison of the variation of the proton flux over solar cycle 23 with the sunspot number.



SPACE WEATHER

Our atmosphere and magnetosphere can respond in a dramatic way to solar storms. A solar storm can initiate space weather processes in our atmosphere and magnetosphere or directly impact technological systems. Space weather and the strength of a space storm is measured near or on Earth.

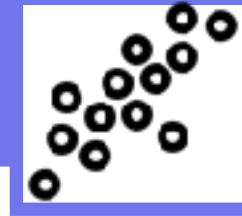
Radio blackout



Geomagnetic storm



Solar radiation storm



AREA OF IMPACT

Note that the solar wind can change the geomagnetic field by reconnection processes and by adding pressure. Reconnection is possible because the solar wind is magnetised. Charged particles follow simply the magnetic highways.



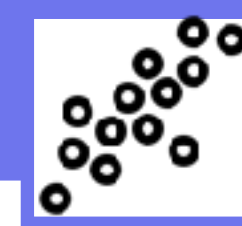
Illuminated area

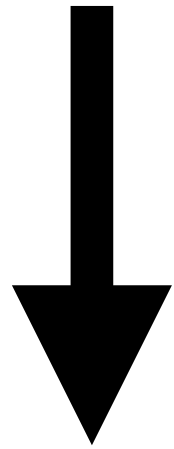


High Latitude



High Latitude
High Altitude





Radio blackout



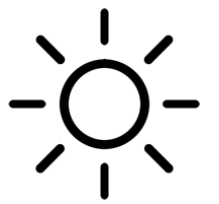
Geomagnetic storm



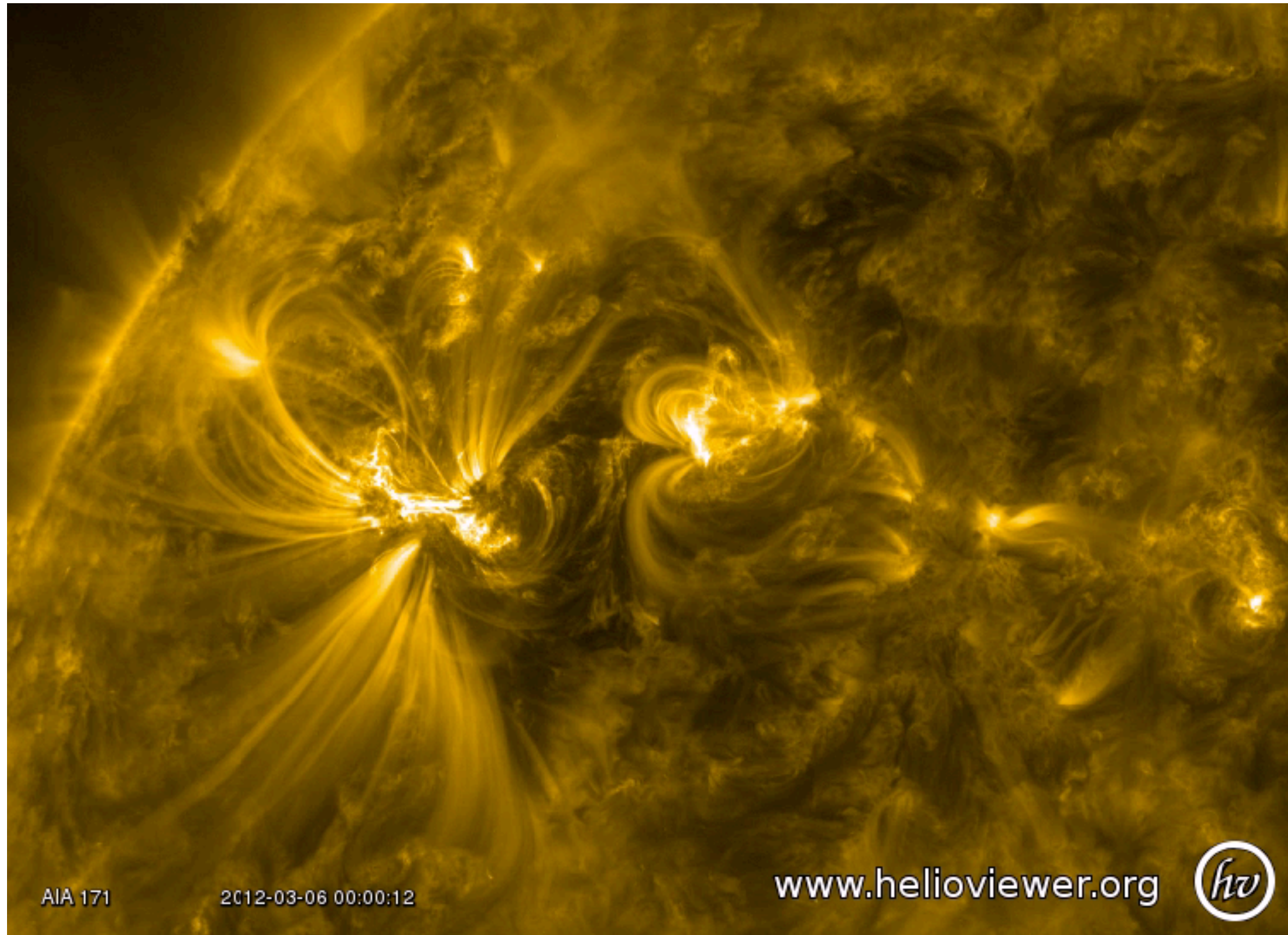
Solar radiation storm



SOLAR FLARES



A flare is a light flash near an active region. A volume of plasma is suddenly heated and therefore lights up.



SDO/AIA

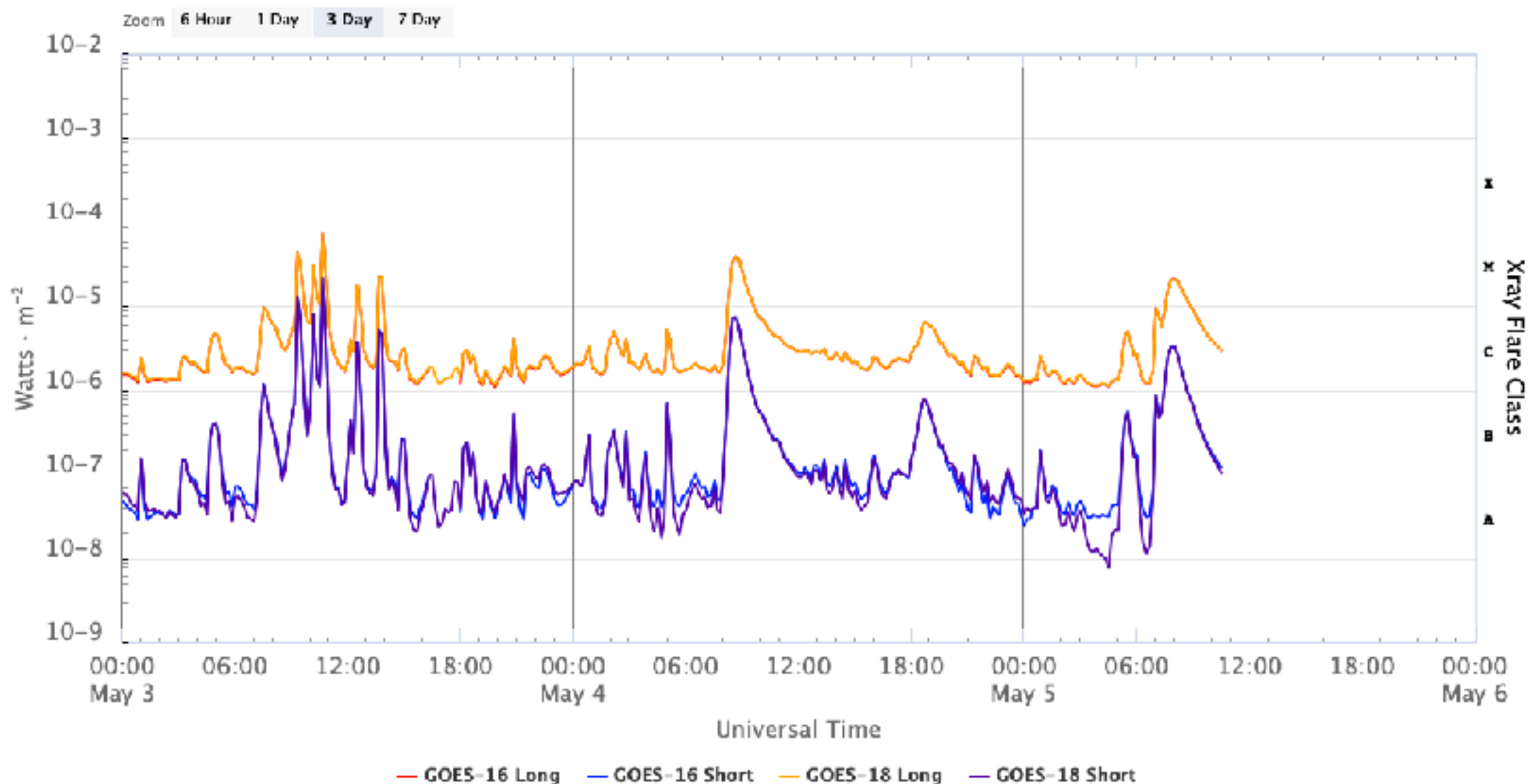




FLARE CATEGORIES & SW SCALES

A flare is identified by its x-ray flux. Flares are put into logarithmisch categories.

GOES X-Ray Flux (1-minute data)

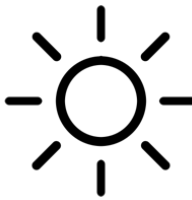


Updated 2023-05-05 10:34 UTC

Space Weather Prediction Center

FLARE FORECAST

The sidc/STCE flare predictions refer to the full solar disk.



```
:Issued: 2023 Jun 01 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#
SIDC URSIGRAM 30501
SIDC SOLAR BULLETIN 01 Jun 2023, 1230UT
SIDC FORECAST
```

SOLAR FLARES : M-class flares expected (probability >=50%)

GEOMAGNETISM : Active conditions expected (A<=20 or K=4)

SOLAR PROTONS : Quiet

PREDICTIONS FOR 01 Jun 2023 10CH FLUX: 162 / AP: 013

PREDICTIONS FOR 02 Jun 2023 10CH FLUX: 162 / AP: 019

PREDICTIONS FOR 03 Jun 2023 10CH FLUX: 162 / AP: 007

Solar Active Regions and Flaring: The solar disk. The newly numbered M (over the east limb) is the one producing including the largest flare of the period on 31 May. NOAA AR 3315 and 3319 are active. More M-class flares can be possible.

Coronal mass ejections: No Earth-directed were detected in the past 24 hours.

Coronal holes: A positive polarity crossed the central meridian on 29 May. A stream may arrive to the Earth in the

Solar winds: The Earth is inside slow has started to increase (currently at magnetic field around 7 nT. In the next the arrival of the high speed stream coronal hole in the southern hemisphere in latitude, so we don't expect a strong effect of the fast solar wind).

Geomagnetism: The geomagnetic conditions over the past 24 hours reached active levels (K_Belgium and Kp up to 4). More active to minor storm periods can be expected for the next 24 hours.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux was at nominal levels and is expected to remain so in the next 24 hours.

Electron fluxes at GEO: The greater than 2 MeV electron flux was below the 1000 pfu threshold over the past 24 hours and is expected to remain so in the next 24 hours. The 24h electron fluence was at normal levels and is expected to remain at normal levels over the next 24 hours.

- No forecast
- Quiet conditions (<50% probability of C-class flares)
- C-class flares expected, (probability >=50%)
- ✓ M-class flares expected (probability >=50%)
- X-class flares expected (probability >=50%)
- Proton flares expected (proton flares expected, probability >=50%)
- Warning condition (activity levels expected to increase, but no numeric forecast given)

X-RAY FLUX NOW

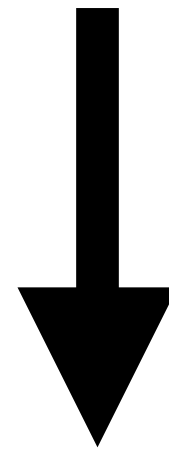
Flare



<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



GOES



Radio blackout



Geomagnetic storm



Solar radiation storm



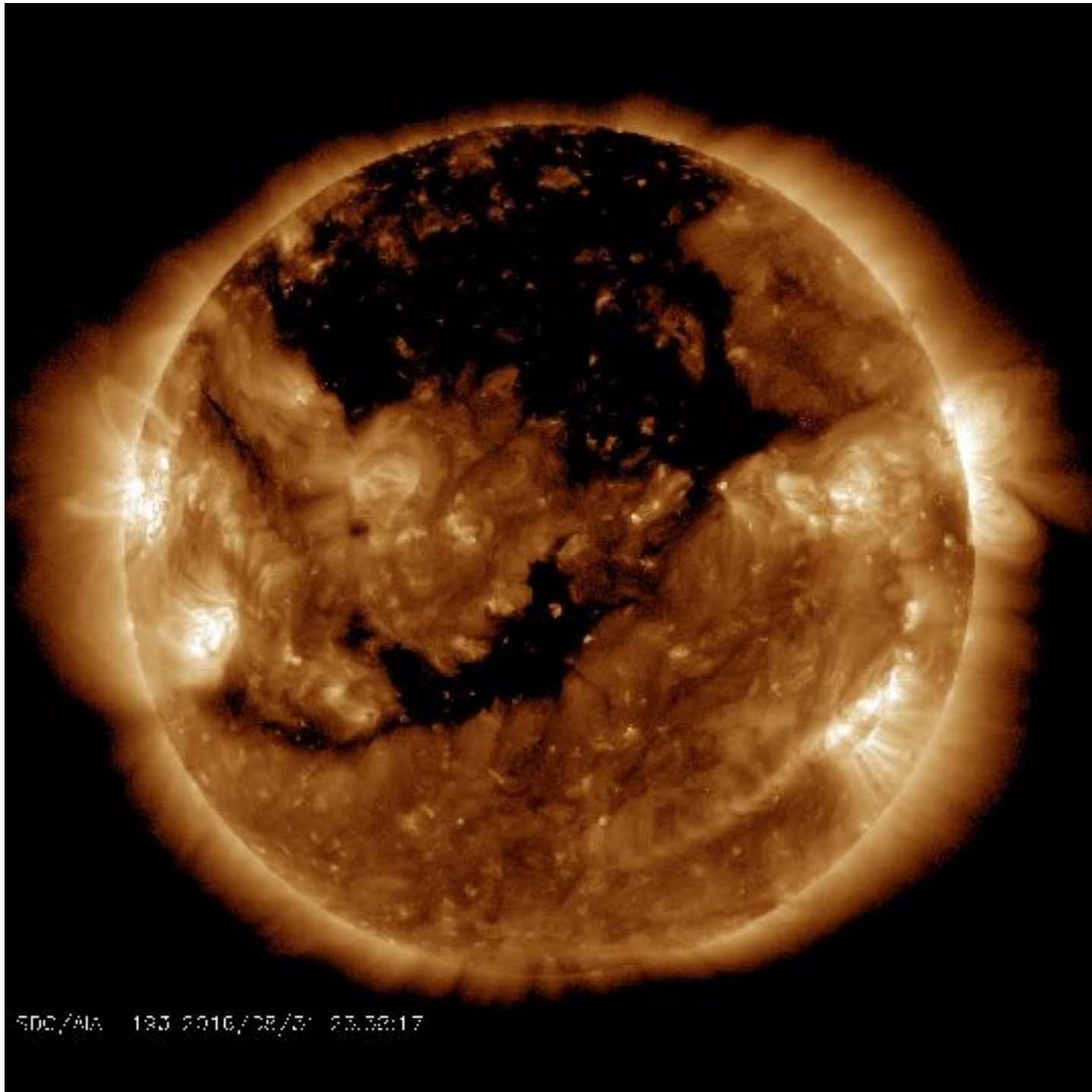
SOLAR WIND



Continuous radial outflow of plasma

Shapes a magnetic field.

Transients - disturbances

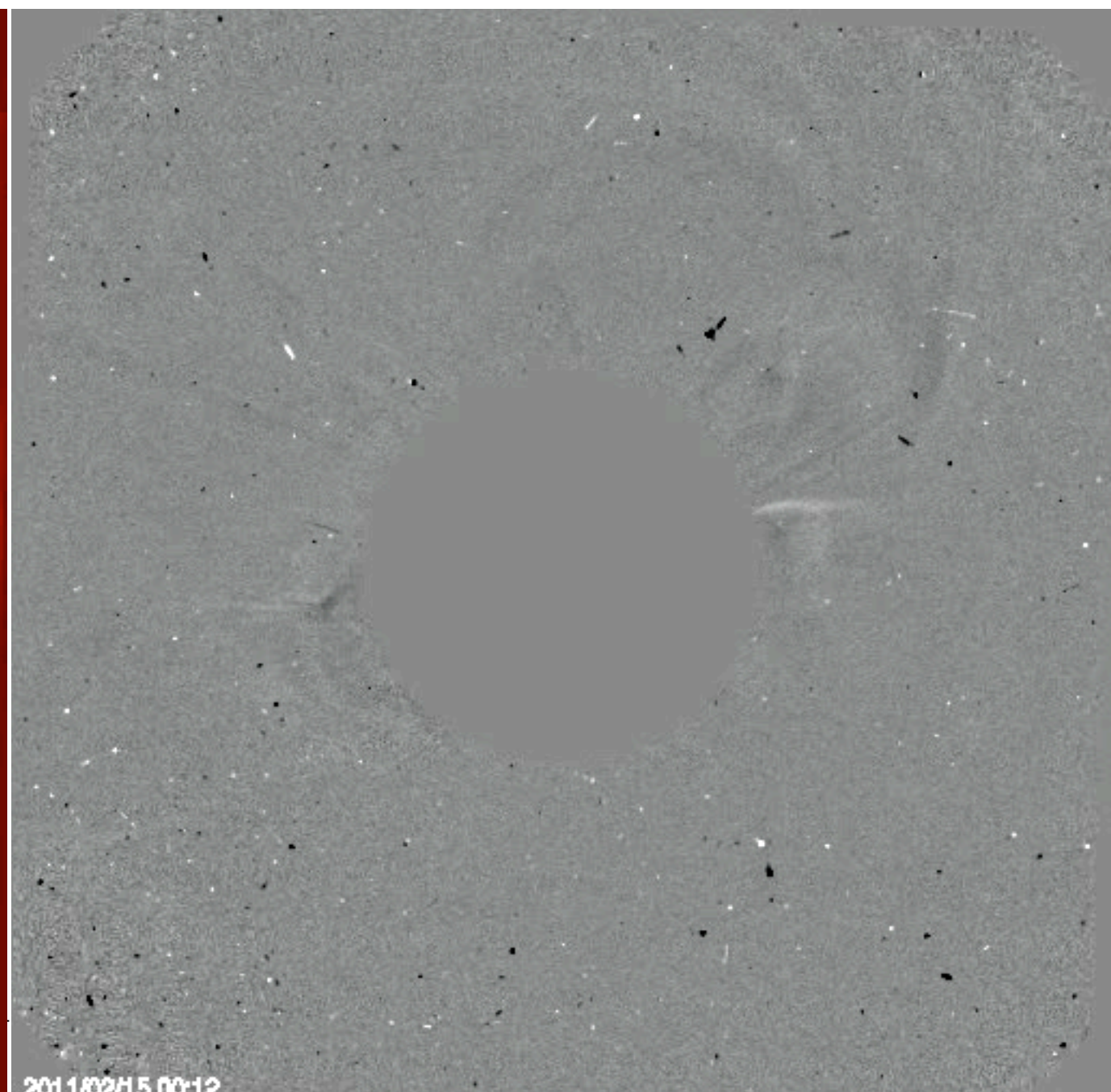
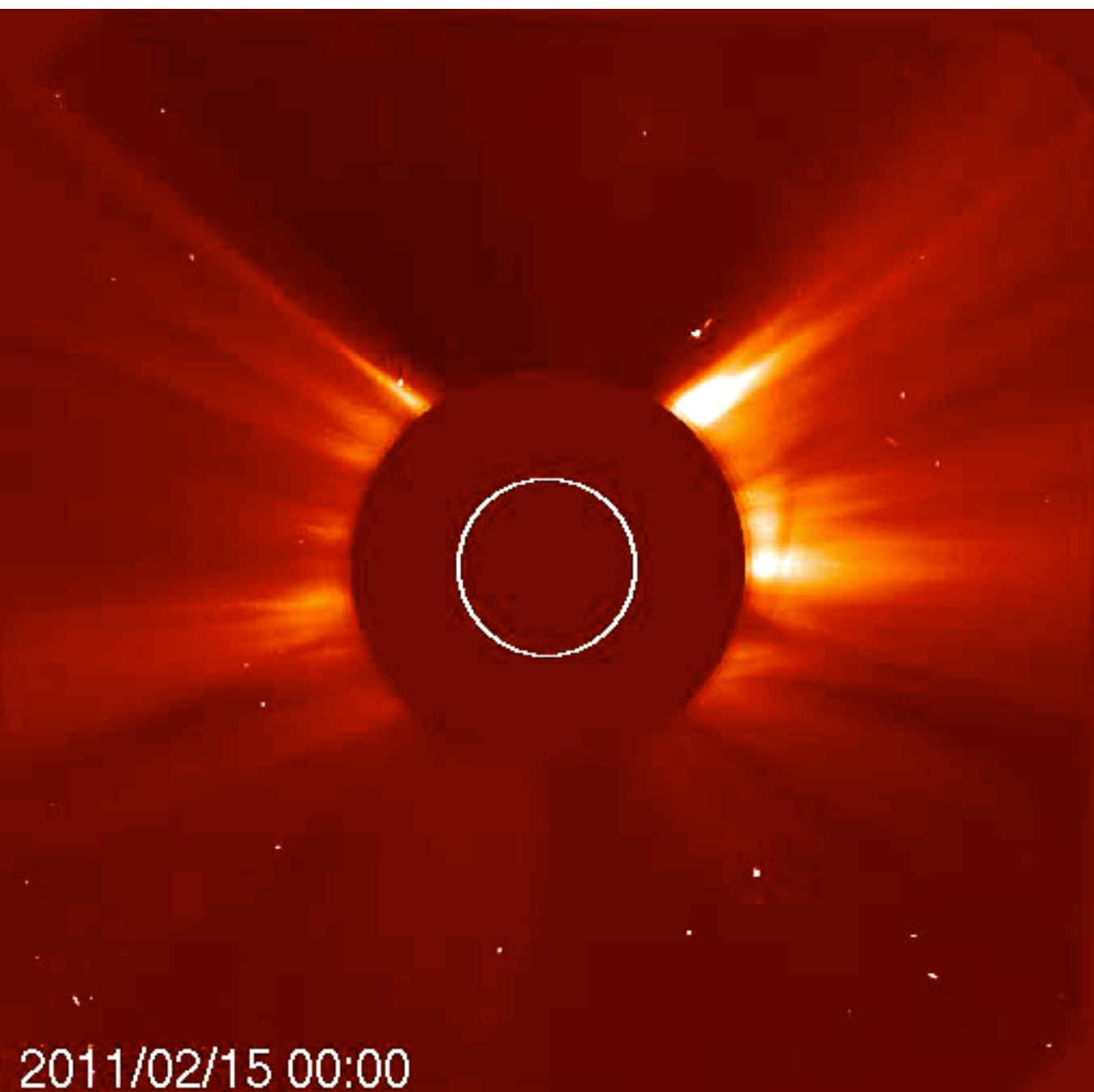


Transients
High Speed Streams (HSSs)
And
Co-rotating Interaction
Regions (CIRs)



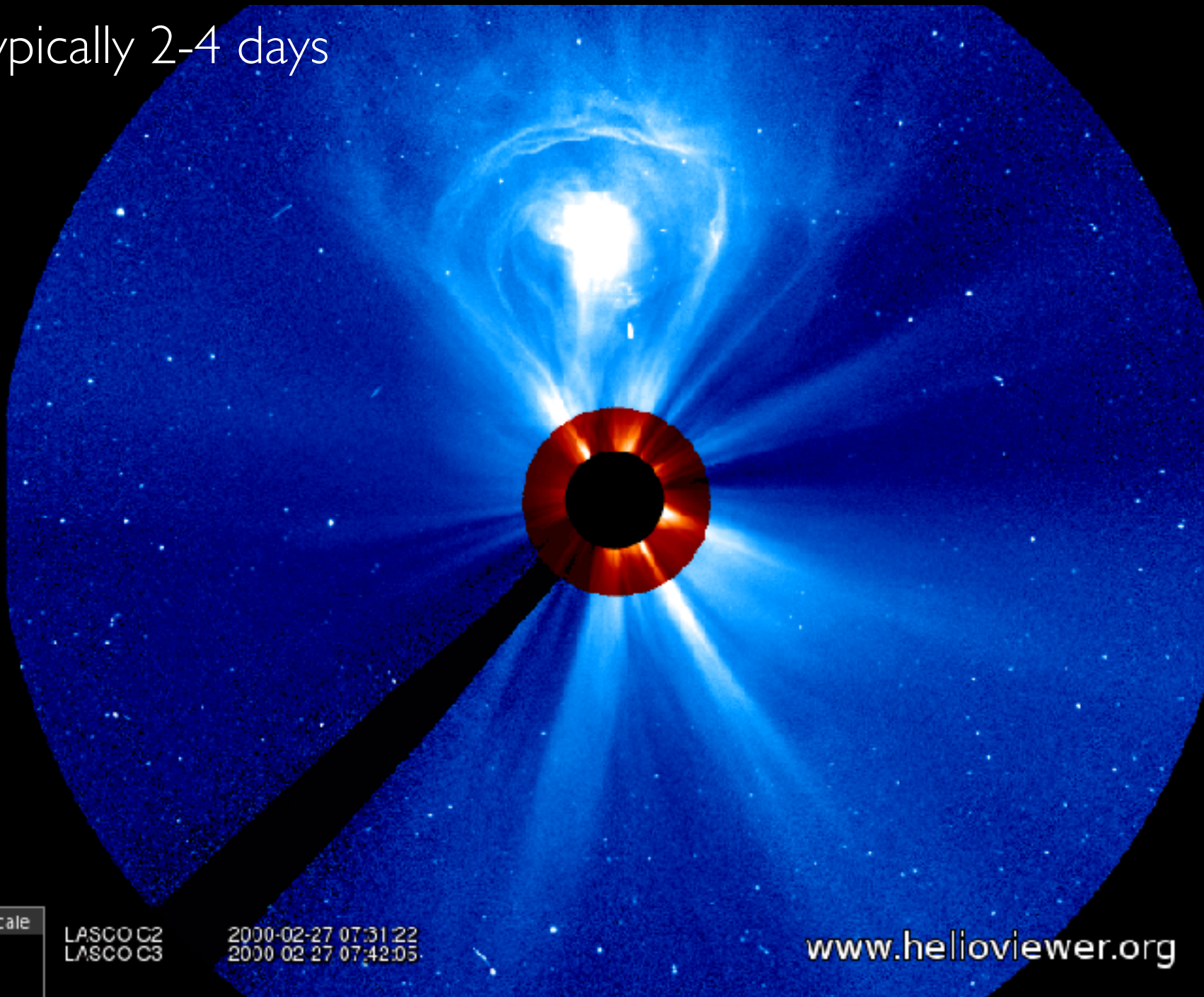
Transients

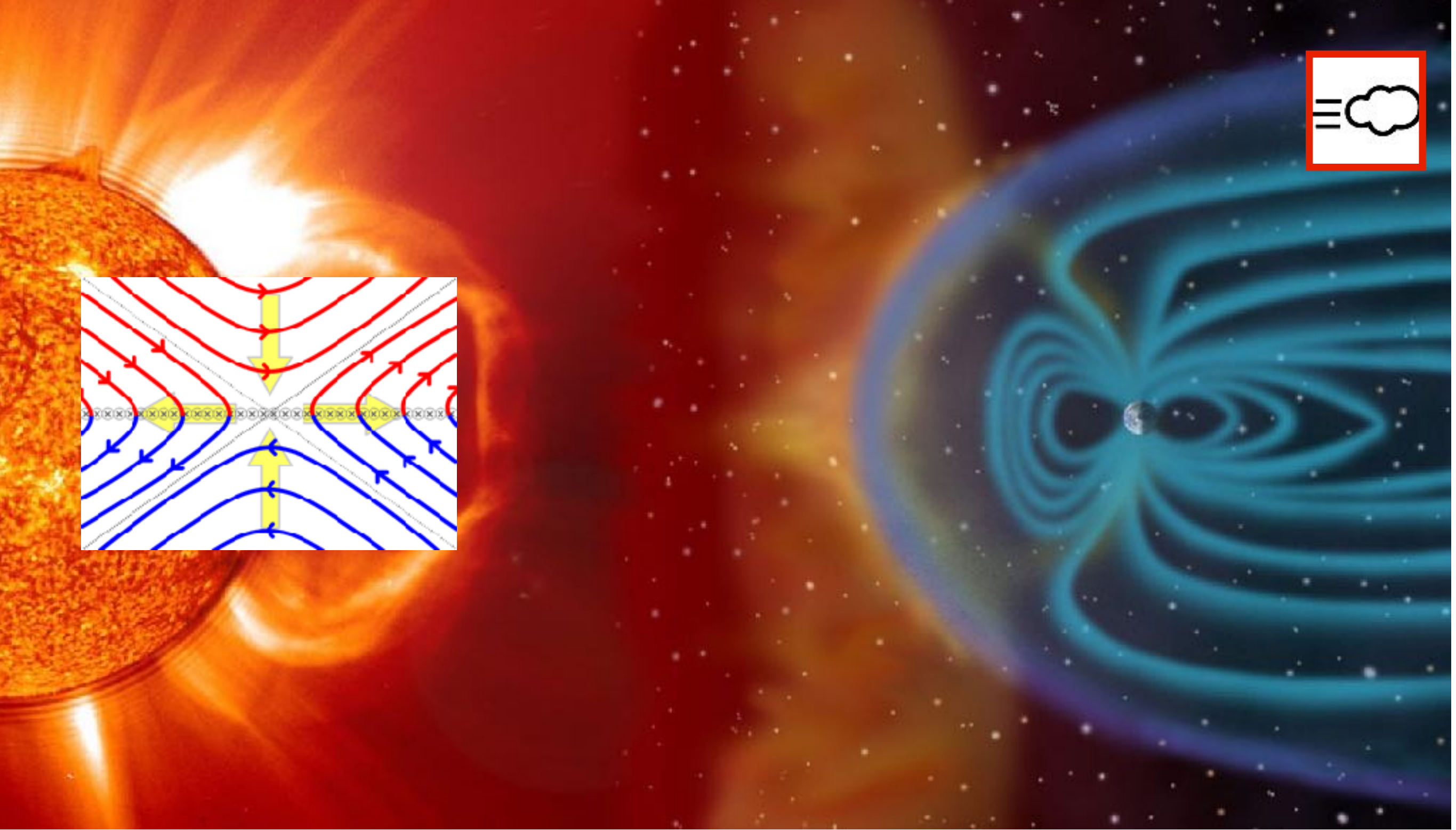
Coronal Mass Ejections

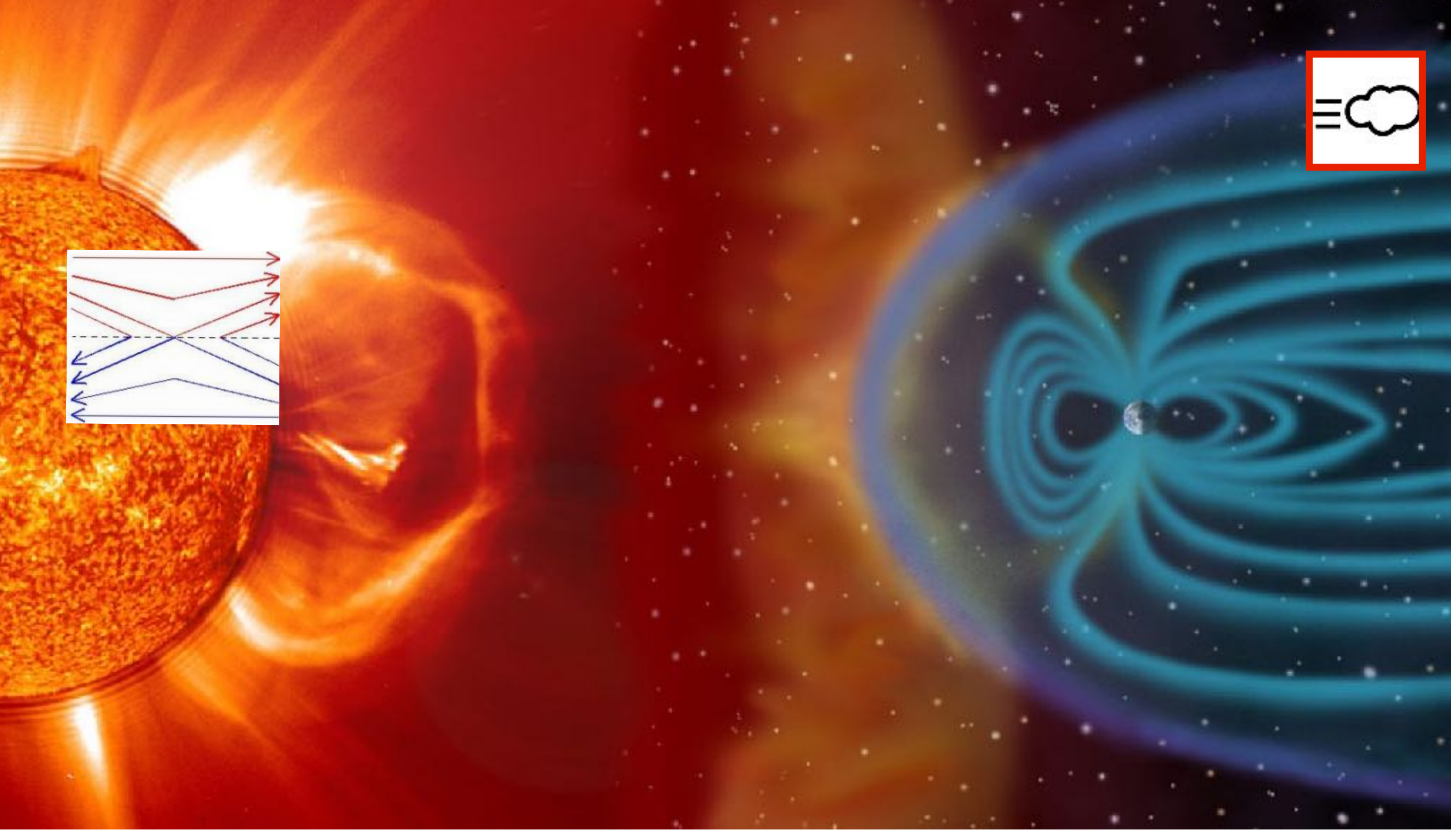




- Trigger the strongest geomagnetic storms
- < 1 /day during solar min, ~ 3 during solar max
- V between 400 and 2000 km/s
- Travel time typically 2-4 days

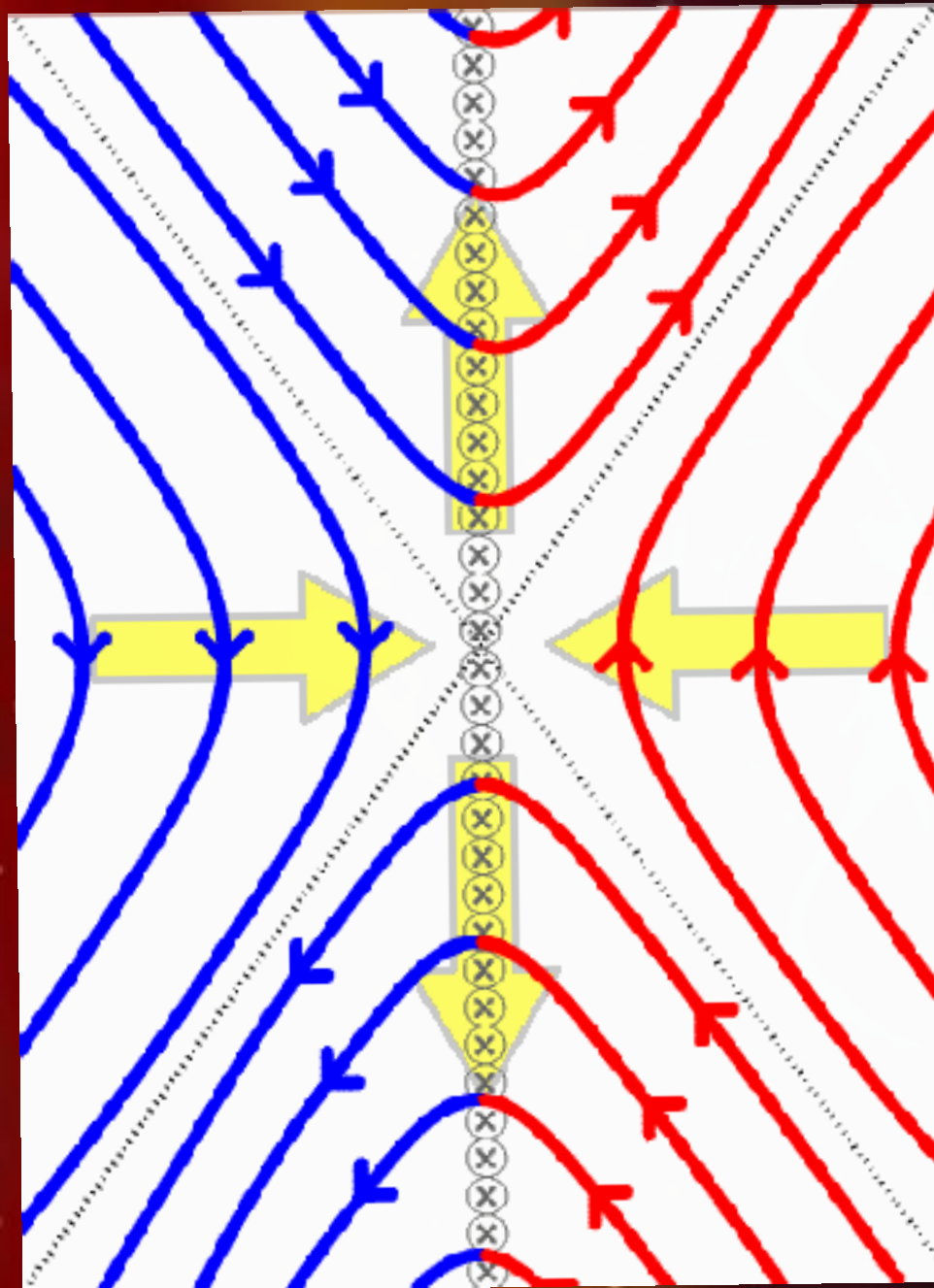
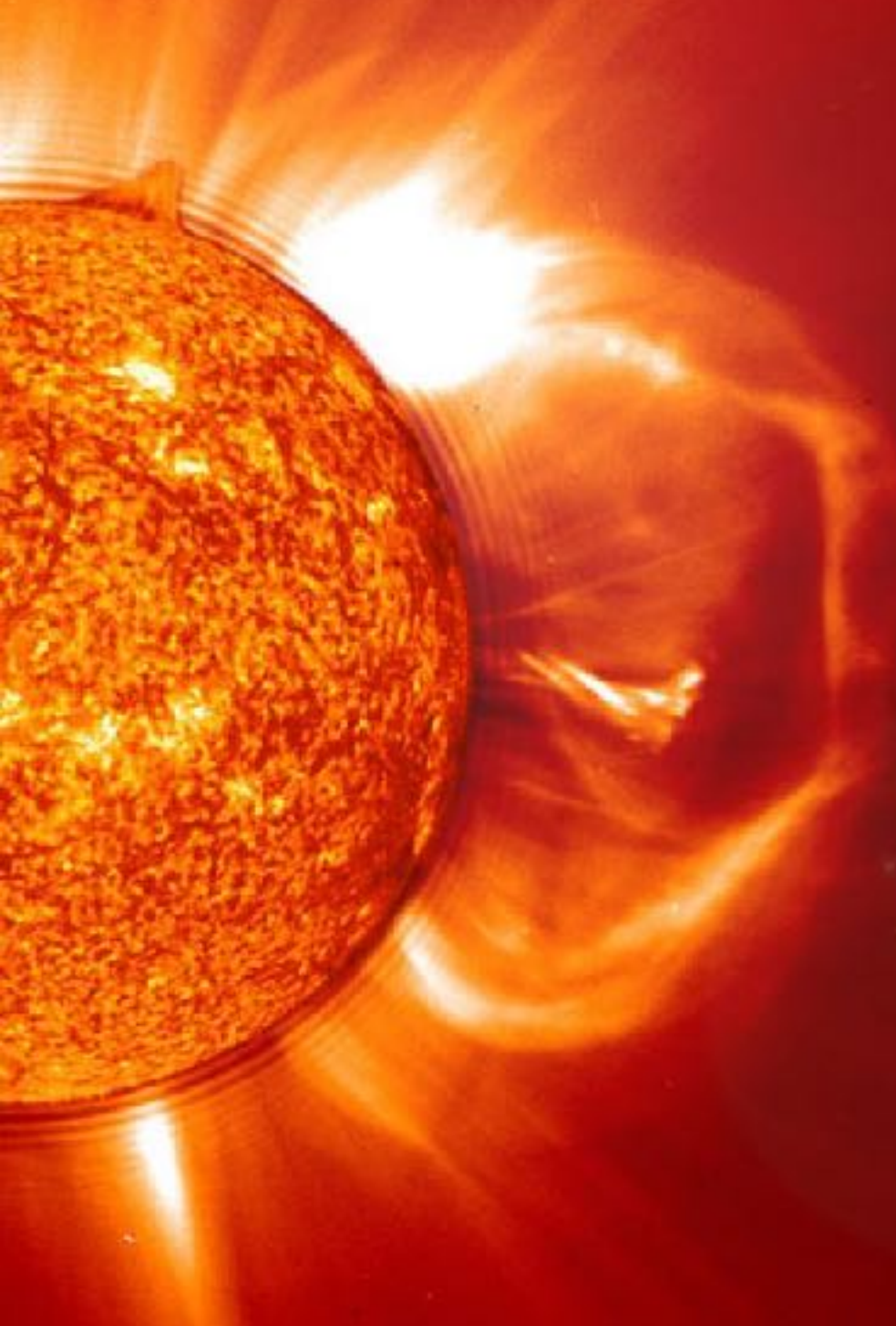






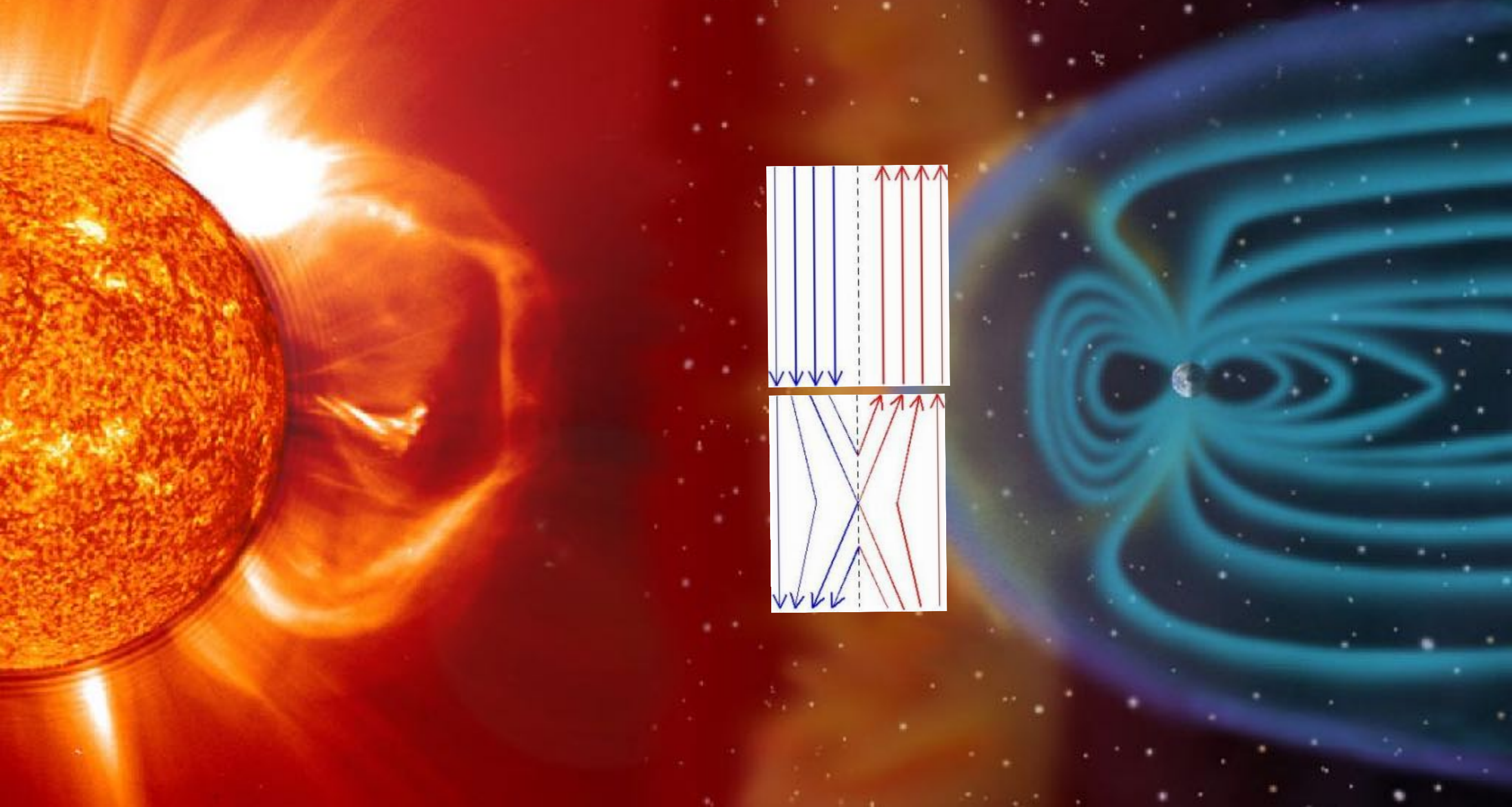
Solar wind meets Earth Geoeffectivity





RECONNECTION

The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.



RECONNECTION

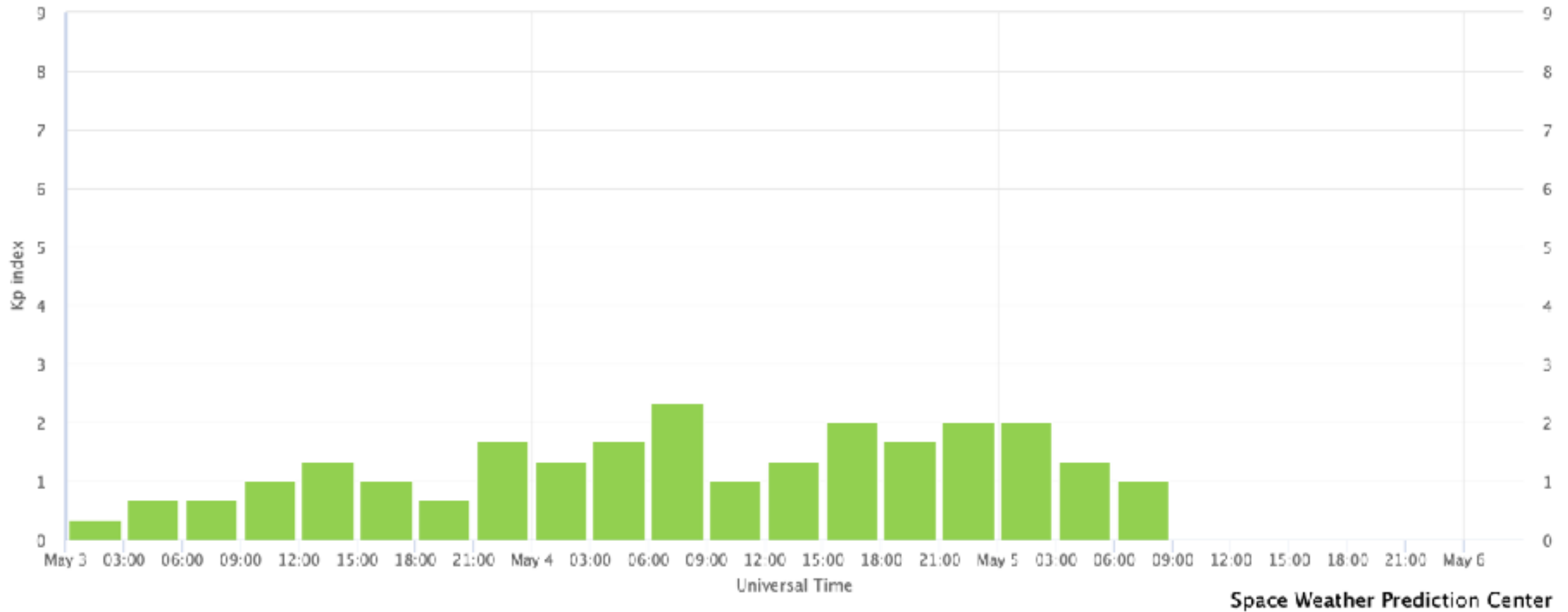
The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.

GEOMAGNETIC STORM

The effect of a geomagnetic storm depends on how strong the geomagnetic field is disturbed. This is described by an index Kp. This is an index that describes the conditions of the geomagnetic field at planetary level.



Estimated Planetary K index (3 hour data)
Begin: Wed, 03 May 2023 00:00:00 GMT



GEOMAGNETISM



A K-index can be translated in an equivalent a-index value. The average of the a-indices over a day is called the A-index. Since K-index values are interpreted locally, the computed A-index is also local.



```
:Issued: 2023 Jun 01 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#
SIDC URSIGRAM 30601
SIDC SOLAR BULLETIN 01 Jun 2023, 1230UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Active conditions expected (A>=20 or K=4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 01 Jun 2023 10CH FLUX: 162 / AP: 013
PREDICTIONS FOR 02 Jun 2023 10CH FLUX: 162 / AP: 019
PREDICTIONS FOR 03 Jun 2023 10CH FLUX: 162 / AP: 007
```

Solar Active Regions and Flaring: There are ten visible active regions on the solar disk. The newly number (over the east limb) is the one including the largest flare of on 31 May. NOAA AR 3315 and 33 activity. More M-class flares possible.

Coronal mass ejections: No Ear were detected in the past 24 h

Coronal holes: A positive pole crossed the central meridian of stream may arrive to the Earth

Solar winds: The Earth is inside has started to increase (current magnetic field around 7 nT. In the arrival of the high speed coronal hole in the southern hemisphere in latitude, so we don't expect

Geomagnetism: The geomagnetic active levels (K_Belgium and K periods can be expected for the next 24 hours.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux was at nominal levels and is expected to remain so in the next 24 hours.

Electron fluxes at GEO: The greater than 2 MeV electron flux was below the 1000 pfu threshold over the past 24 hours and is expected to remain so in the next 24 hours. The 24h electron fluence was at normal levels and is expected to remain at normal levels over the next 24 hours.

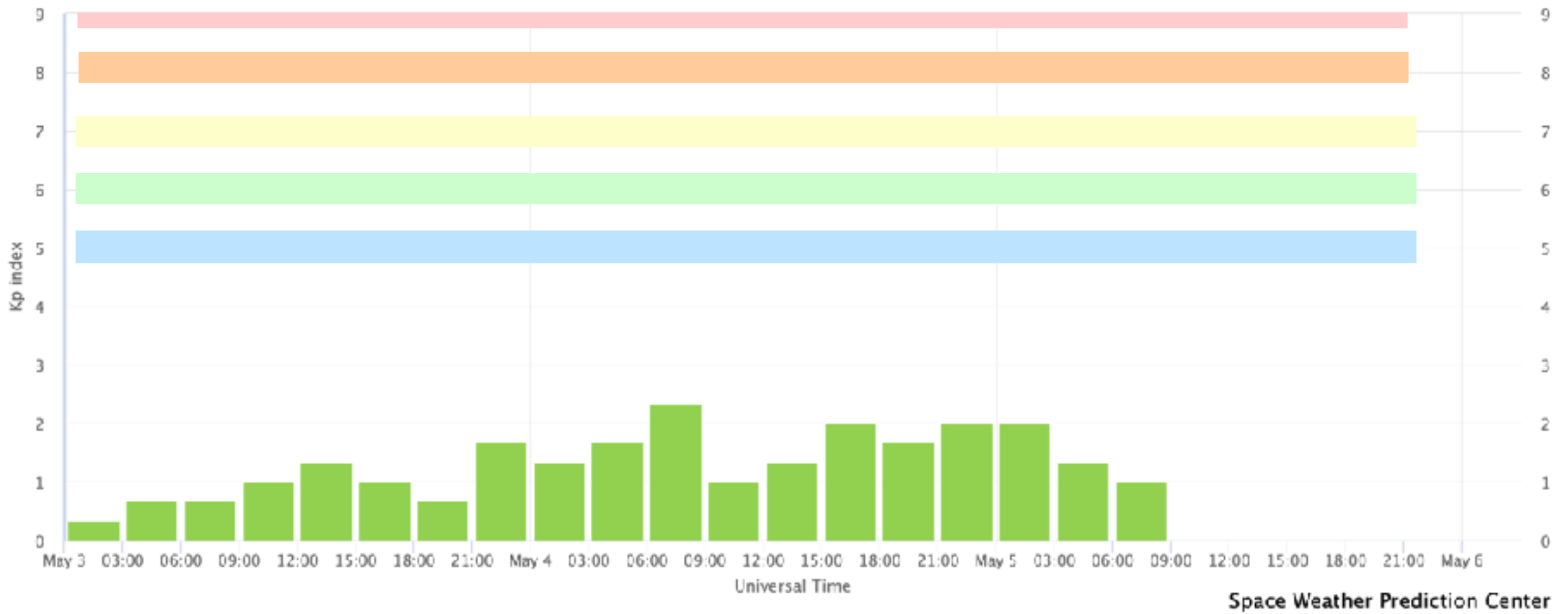
- No forecast
- Quiet (A<20 and K<4)
- ✓ Active conditions expected (A>=20 or K=4)
- Minor storm expected (A>=30 or K=5)
- Moderate (ISES: Major) magstorm expected (A>=50 or K=6)
- Major (ISES: Severe) magstorm expected (A>=100 or K>=7)
- Warning condition (activity levels expected to increase, but no numeric forecast given)

GEOMAGNETIC STORM DESCRIBED BY KP



Estimated Planetary K index (3 hour data)

Begin: Wed, 03 May 2023 00:00:00 GMT



GEOMAGNETIC STORM - KP INDEX NOW



<https://www.swpc.noaa.gov/products/planetary-k-index>





Radio blackout



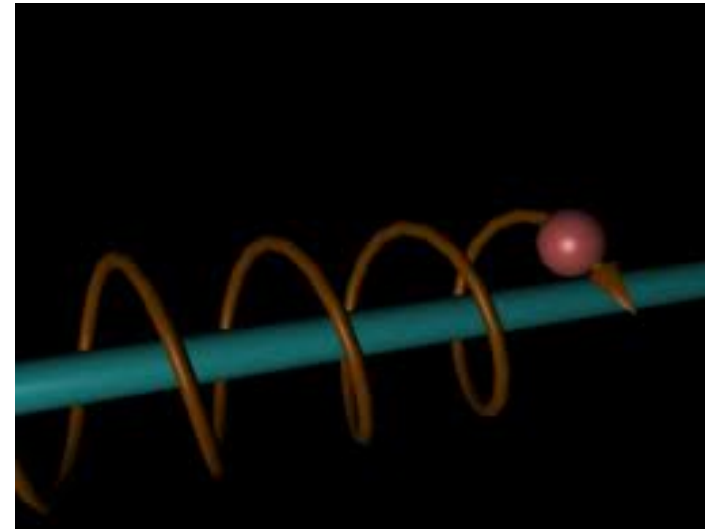
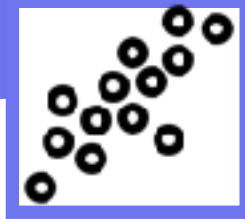
Geomagnetic storm



Solar radiation storm

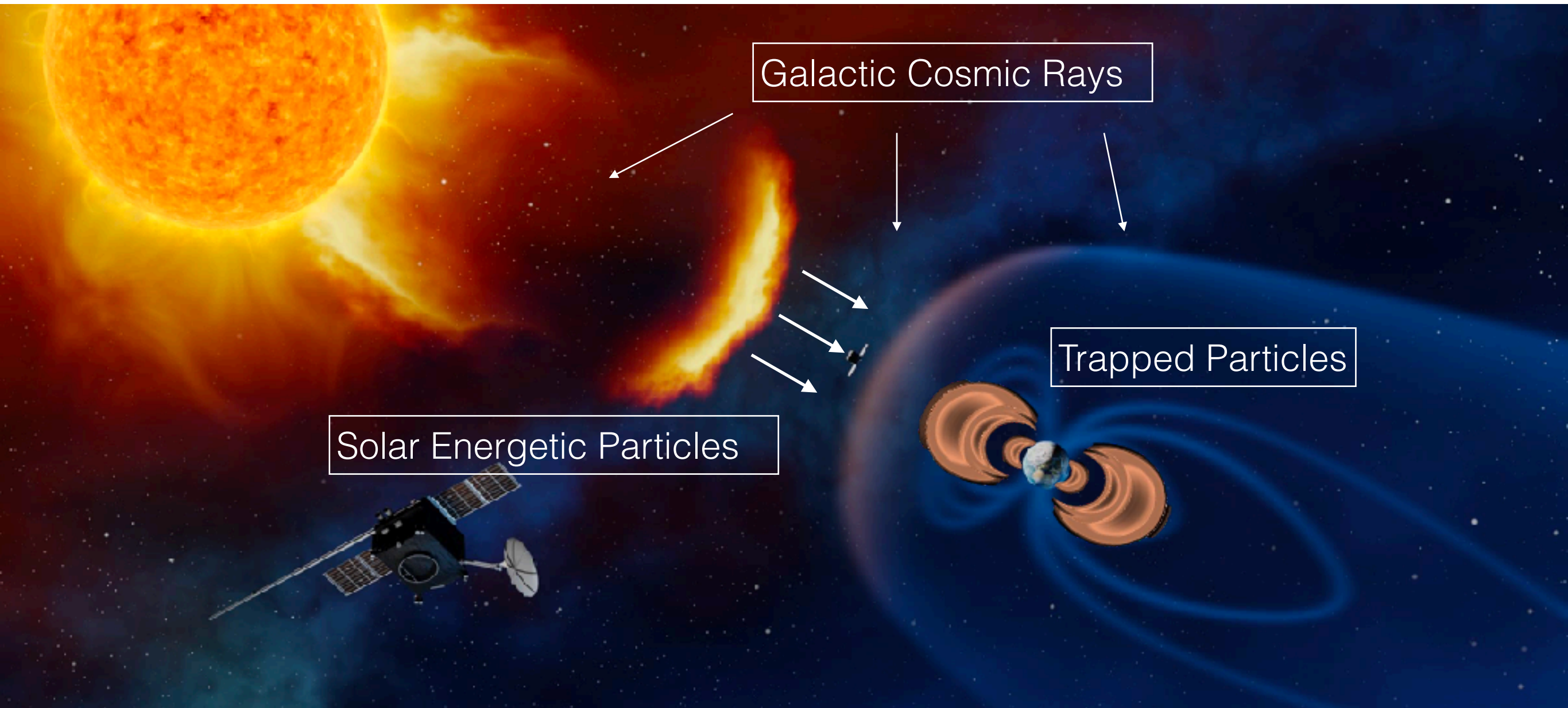


SOLAR PARTICLES



Solar energetic particles follow magnetic field lines.

ENERGETIC PARTICLES IN THE NEAR-EARTH ENVIRONMENT



INTERPLANETARY MAGNETIC FIELD

An enormous amount of magnetic energy is stored in the Sun. The magnetic field is not only contained in the interior of the Sun but is present every where in the heliosphere.

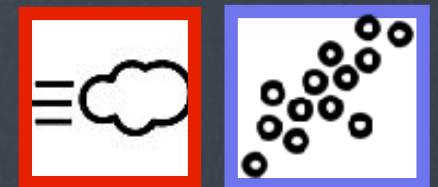
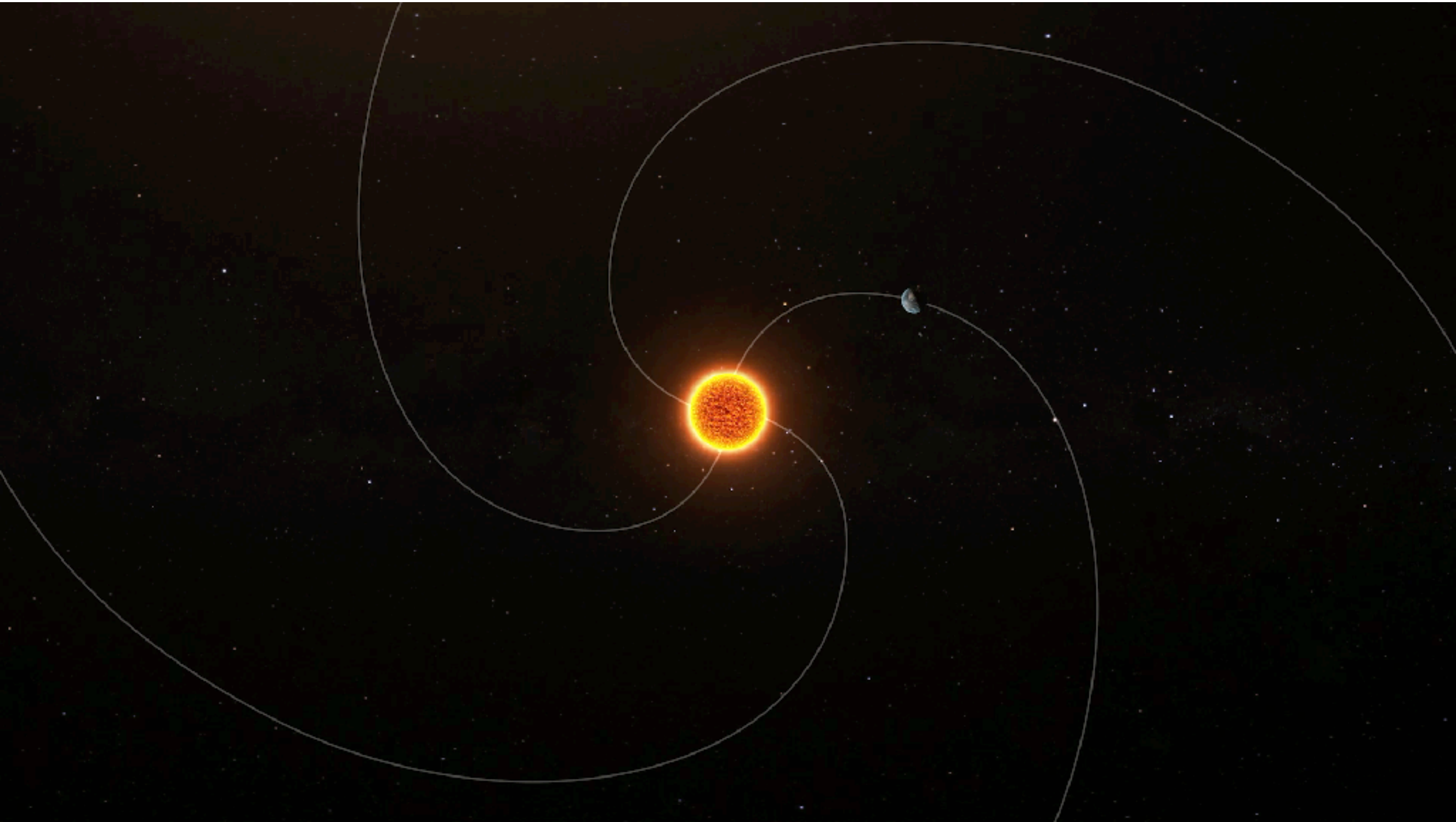
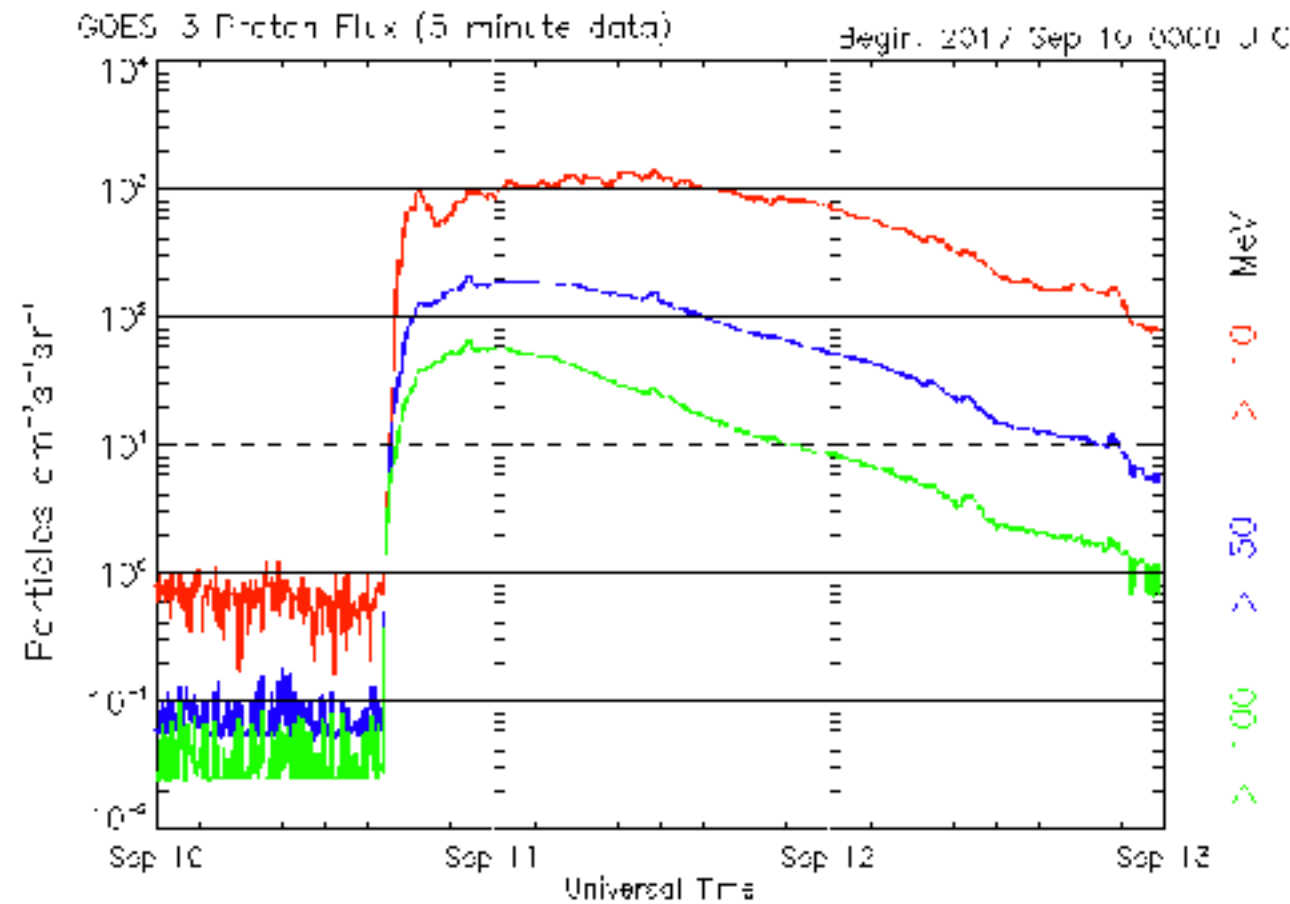


Image: Siberia 20080801

J.M.P., W. G. Wagner and H. Druckmüllerová

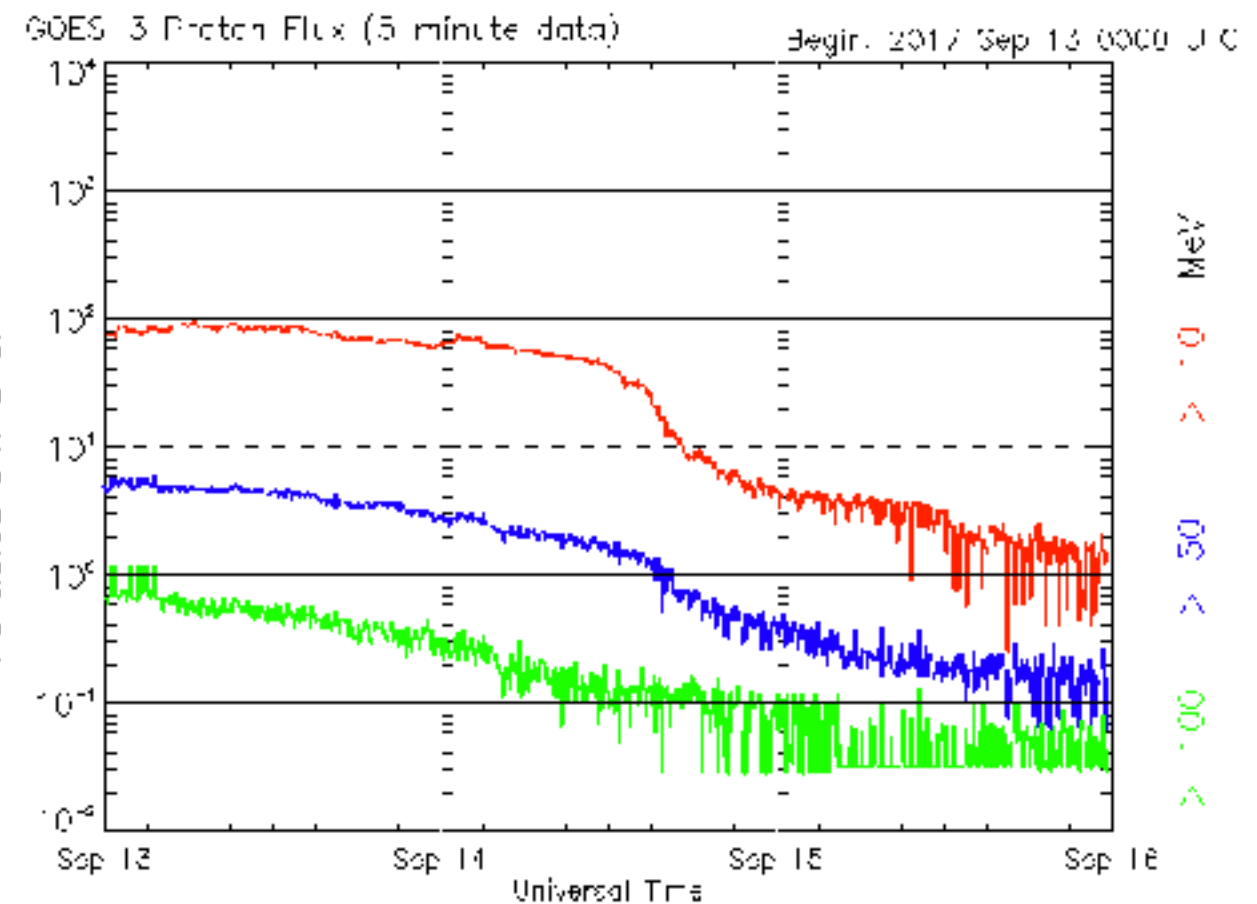


PROTON FLUX BY GOES



Updated: 2017 Sep 12 23:56:02 UTC

NOAA/SWPC Boulder, CO USA

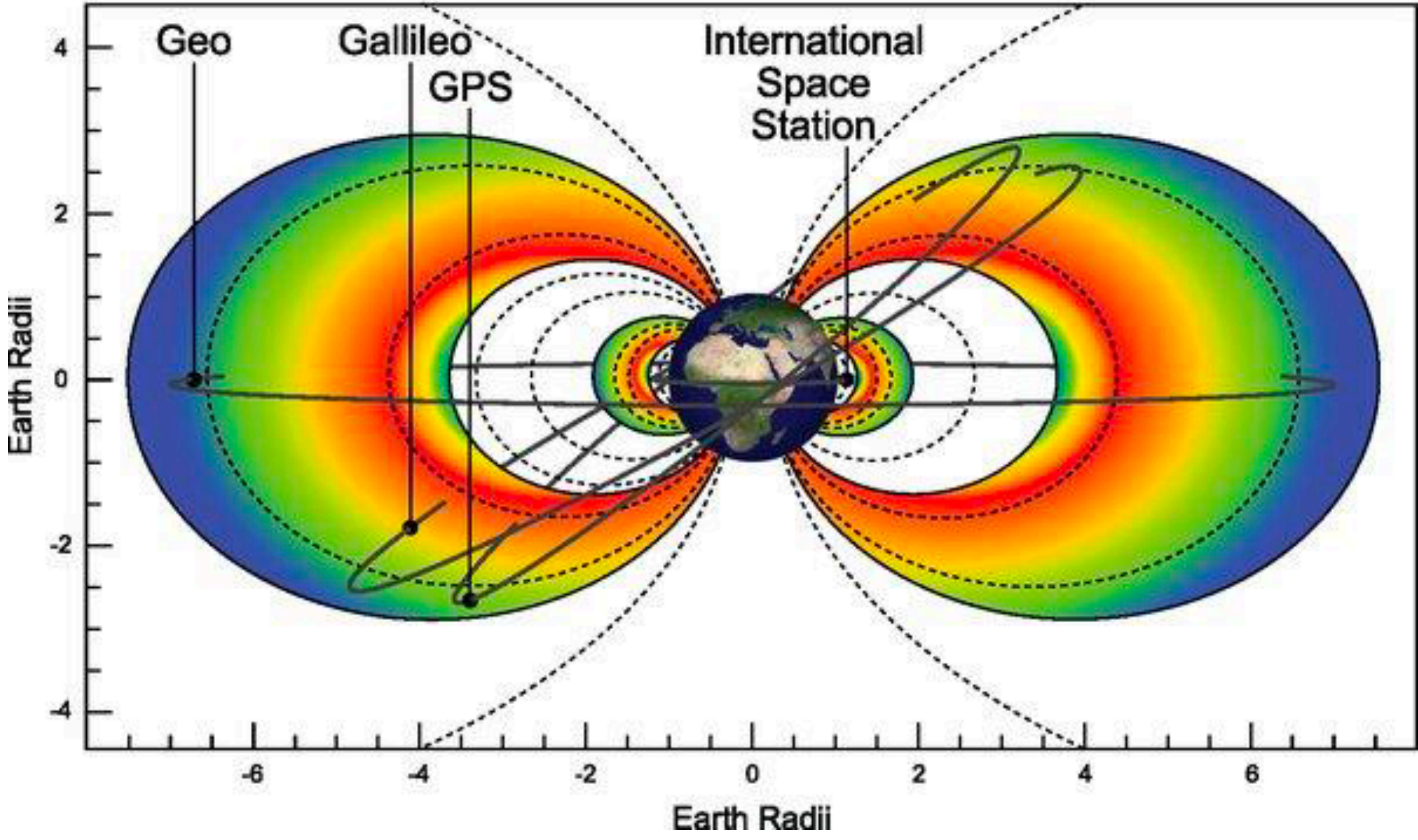


Updated: 2017 Sep 15 23:56:01 UTC

NOAA/SWPC Boulder, CO USA



GOES



SOLAR PROTON FLUX BY GOES



```
:Issued: 2023 Jun 01 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
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PREDICTIONS FOR 03 Jun 2023 10CH FLUX: 162 / AP: 007
```

Solar Active Regions and Flares: A new active region (AR 3315) is visible on the solar disk. The newly number (over the east limb) is the one including the largest flare of on 31 May. NOAA AR 3315 and 3316 activity. More M-class flares possible.

Coronal mass ejections: No Earth were detected in the past 24 hours.

Coronal holes: A positive polar stream may arrive to the Earth.

Solar winds: The Earth is inside has started to increase (current magnetic field around 7 nT. In the arrival of the high speed coronal hole in the southern hemisphere (it is located at 20 degrees south in latitude, so we don't expect a strong effect of the fast solar wind).

Geomagnetism: The geomagnetic conditions over the past 24 hours reached active levels (K_Belgium and Kp up to 4). More active to minor storm periods can be expected for the next 24 hours.

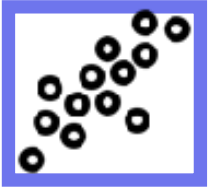
Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux was at nominal levels and is expected to remain so in the next 24 hours.

Electron fluxes at GEO: The greater than 2 MeV electron flux was below the 1000 pfu threshold over the past 24 hours and is expected to remain so in the next 24 hours. The 24h electron fluence was at normal levels and is expected to remain at normal levels over the next 24 hours.

- No forecast
- ✓ Quiet
- Proton event expected (10 pfu at >10 MeV)
- Major proton event expected (100 pfu at >100 MeV)
- Proton event in progress (>10 MeV)
- Warning condition (activity levels expected to increase, but no numeric forecast given)



PROTON FLUX NOW



<https://www.swpc.noaa.gov/products/goes-proton-flux>



GOES