

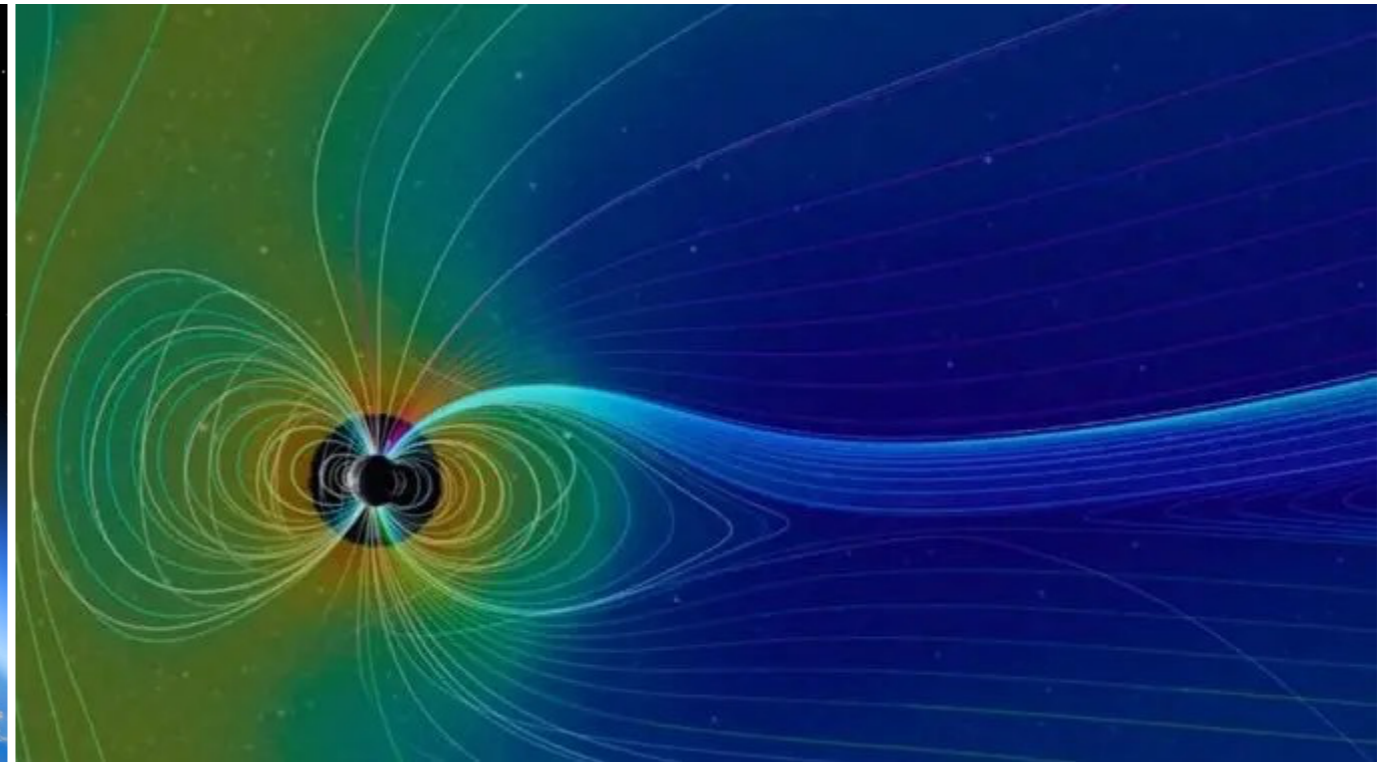
# SPACE WEATHER

Introduction

*Petra Vanlommel*

# Space Weather

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



# THE SUN AS A BALL OF ENERGY

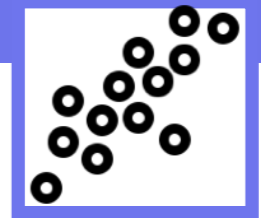
E.M. RADIATION



PLASMA

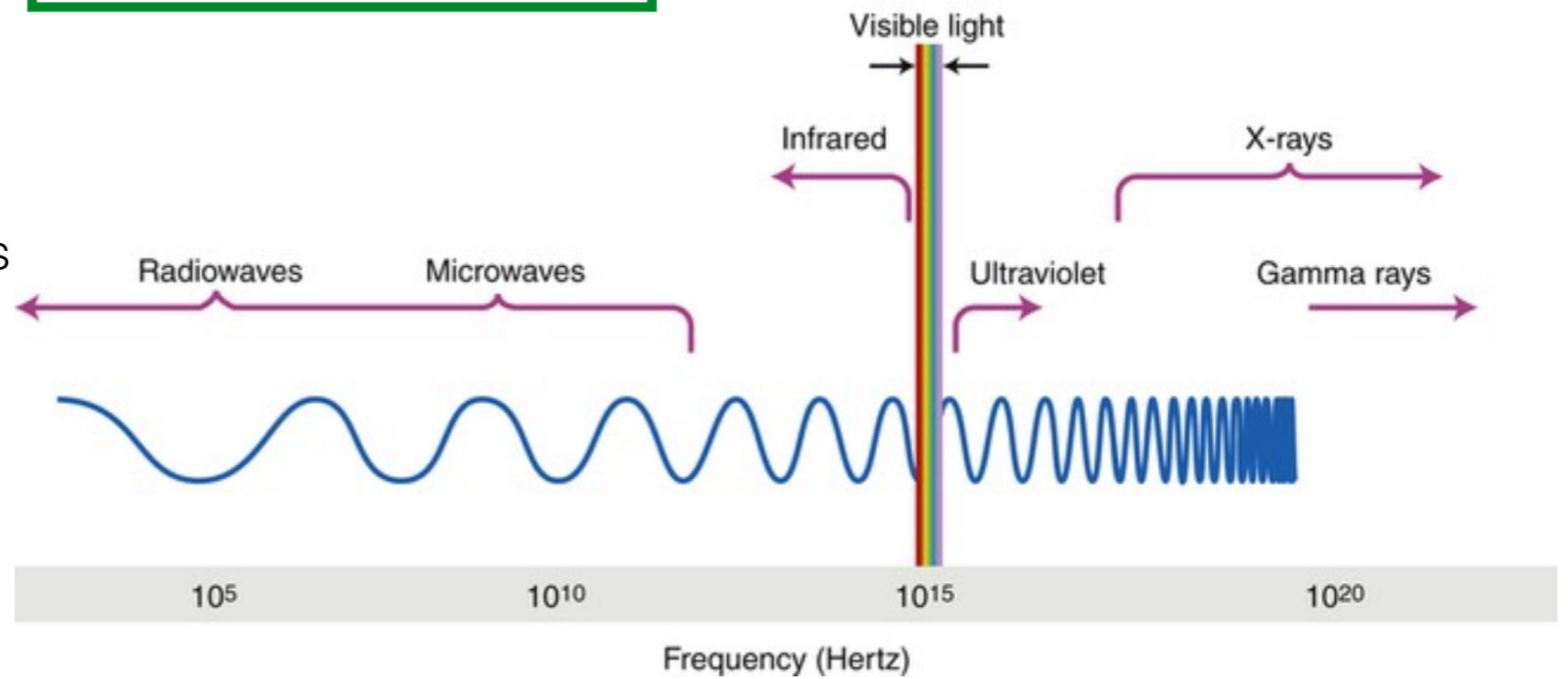


ENERGETIC  
PARTICLES



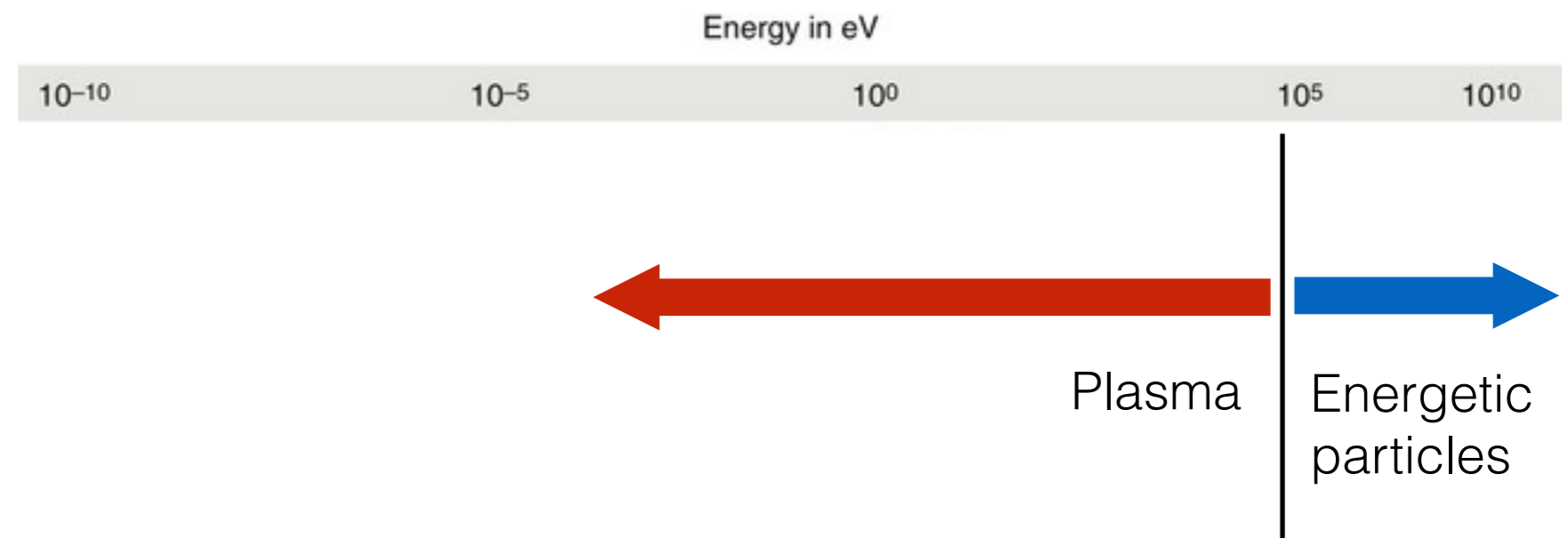
# Electromagnetic radiation

- Photons / electromagnetic waves
- Speed of light



# Particles

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



### 3 SPACE WEATHER PHENOMENA

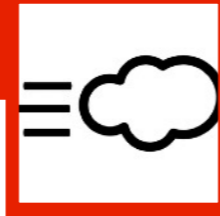
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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

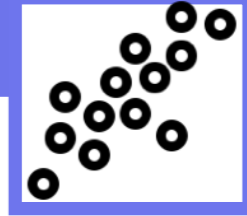
LIGHT



WIND



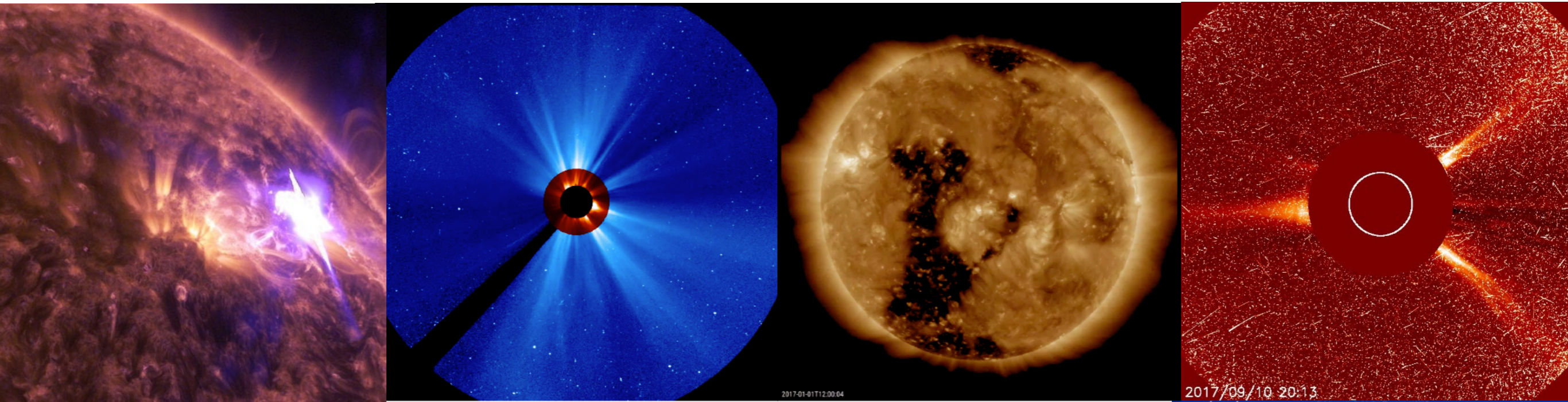
PARTICLE RAIN



# SOLAR WEATHER & STORMS



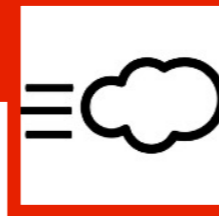
At a certain moment, energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass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



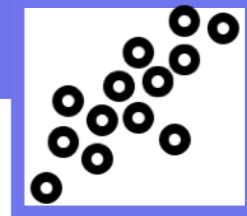
Flare



Coronal Mass Ejection  
Coronal Hole



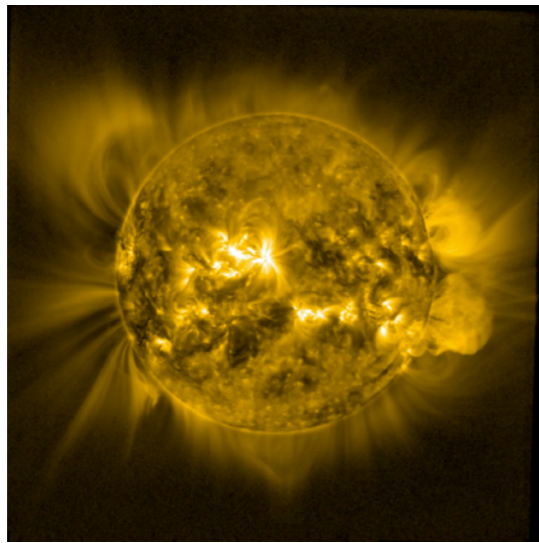
Particle Storm



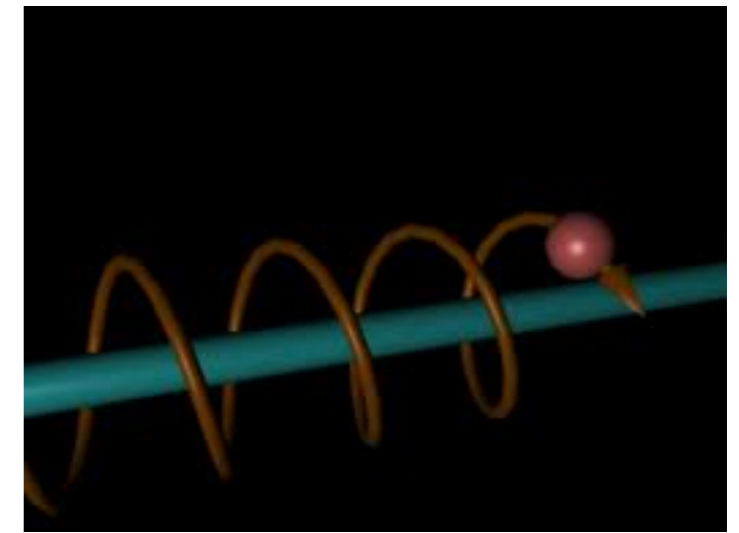
# SOLAR SEASONS



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.



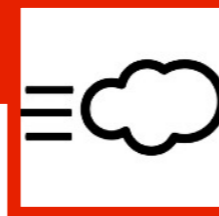
 PROBA2/SWAP



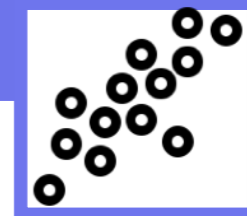
E.m. Radiation  
Flares



Solar Wind  
CME - CH



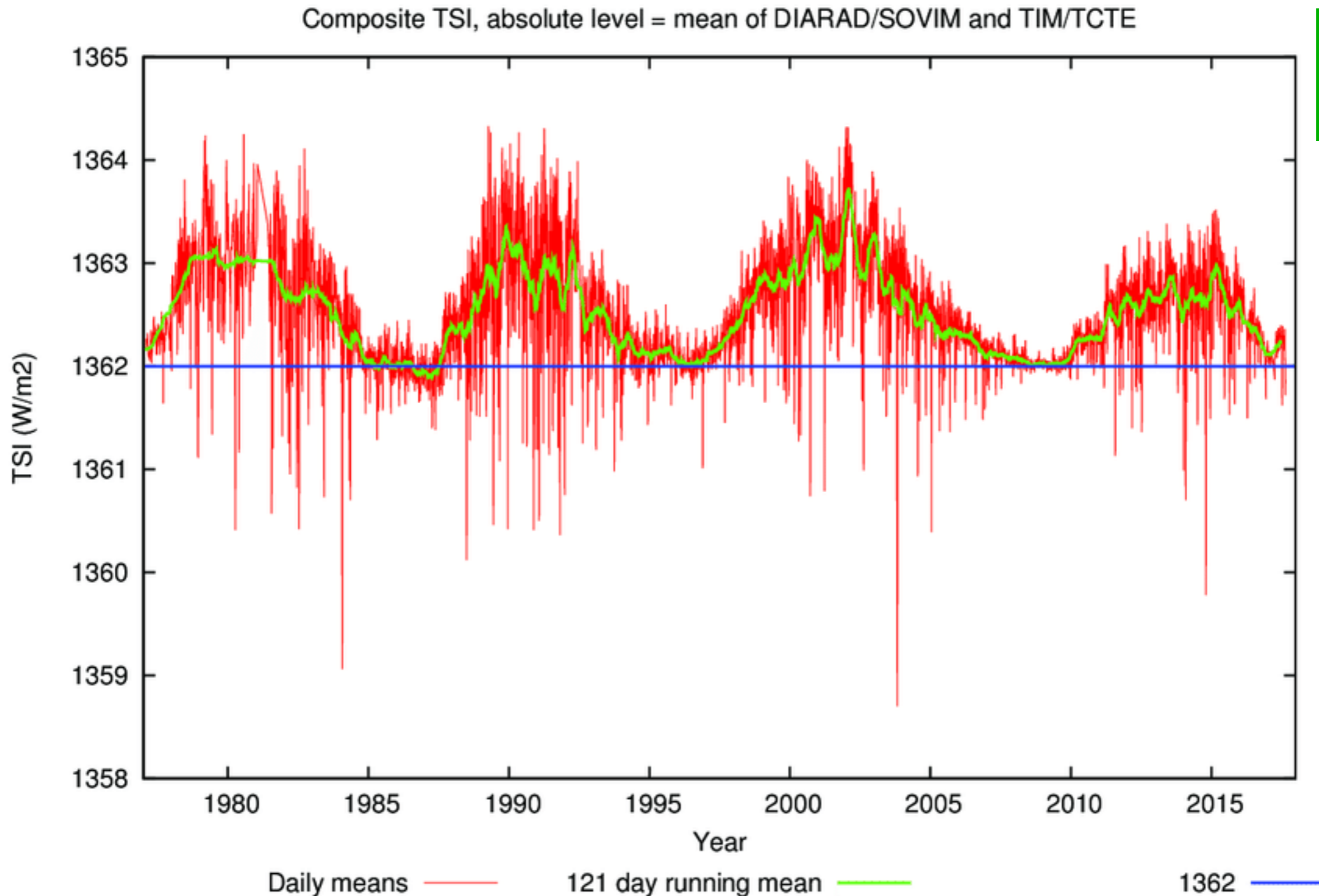
Solar Energetic  
Particles



# 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

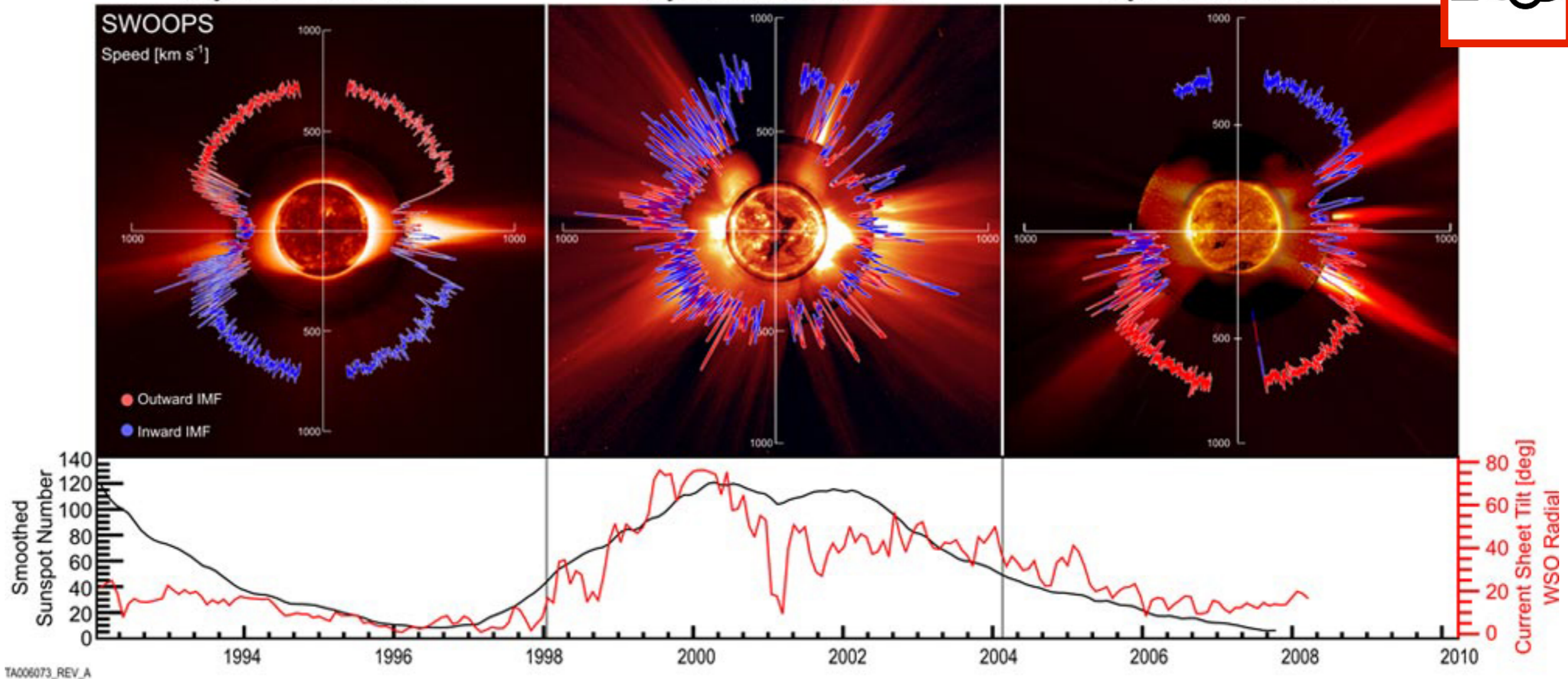
The solar wind varies over the solar seasons. The variation depends on the solar latitude. In the low season, the solar wind is slower near the equator compared to the higher latitudes and is more nicely structured. In the high season, the solar wind varies over all latitudes.



Ulysses First Orbit

Ulysses Second Orbit

Ulysses Third Orbit

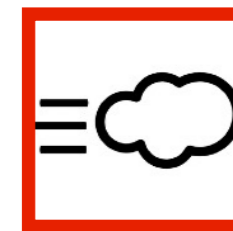
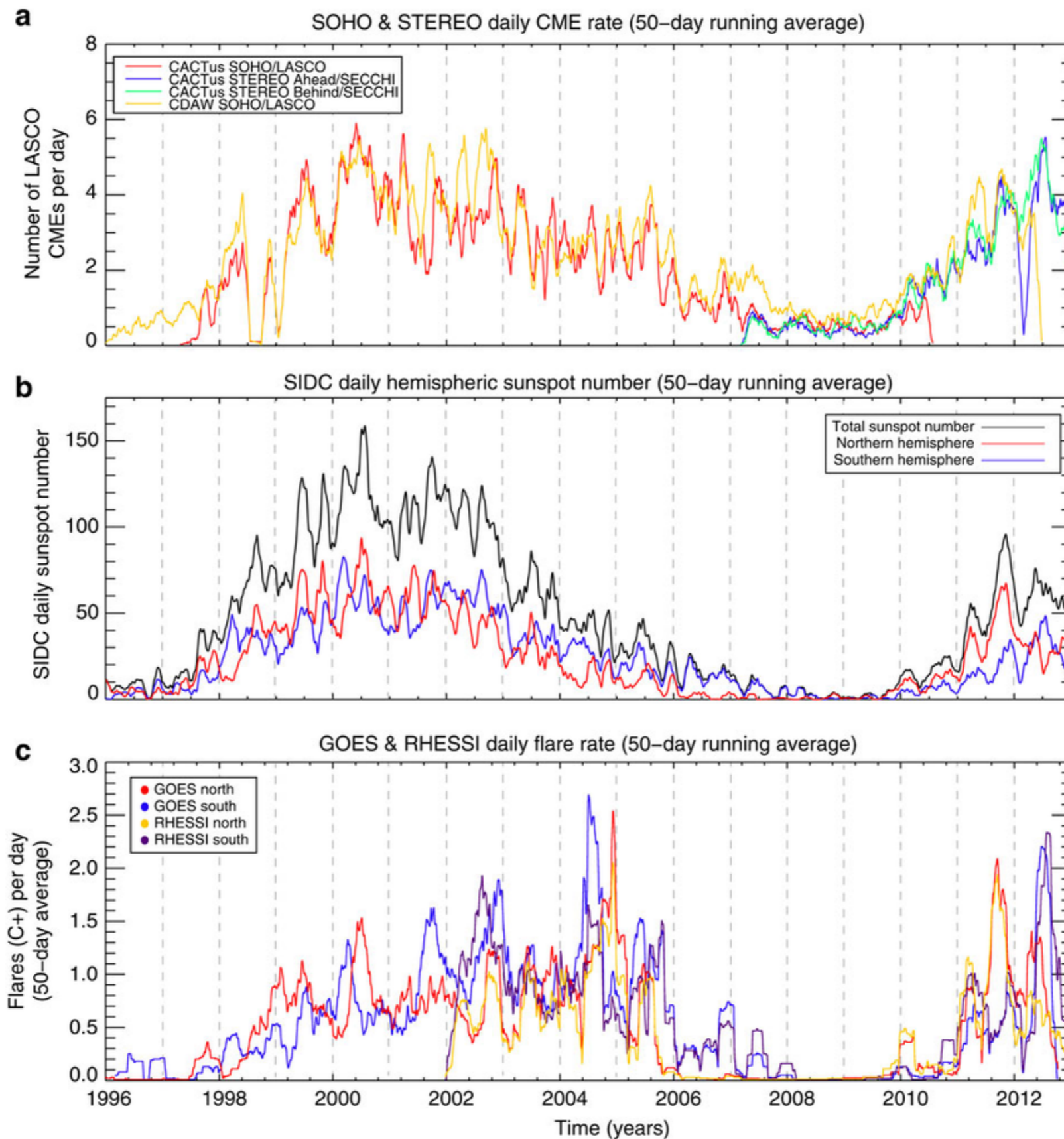


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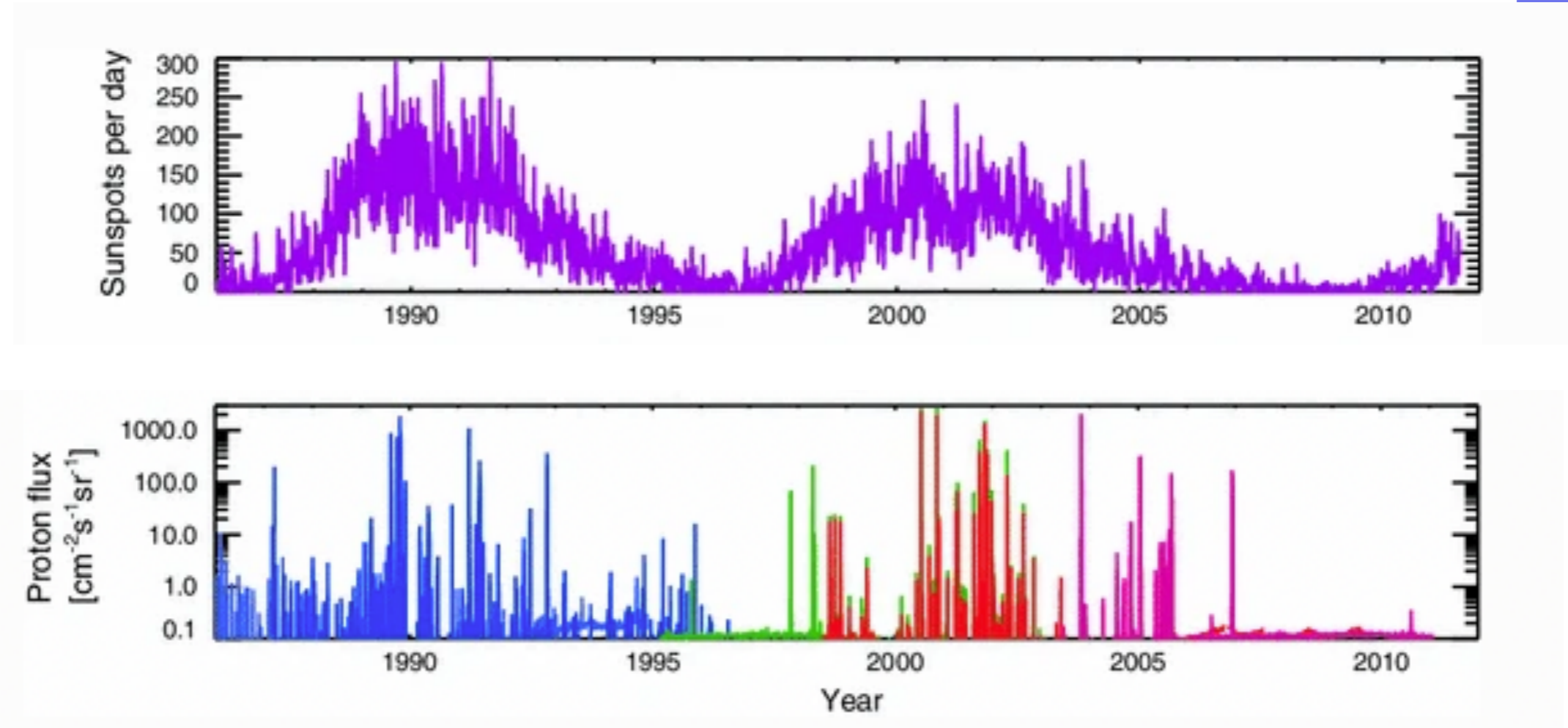
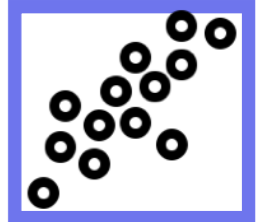
# SEASONAL BEHAVIOUR OF SOLAR LIGHT & WIND STORMS

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.



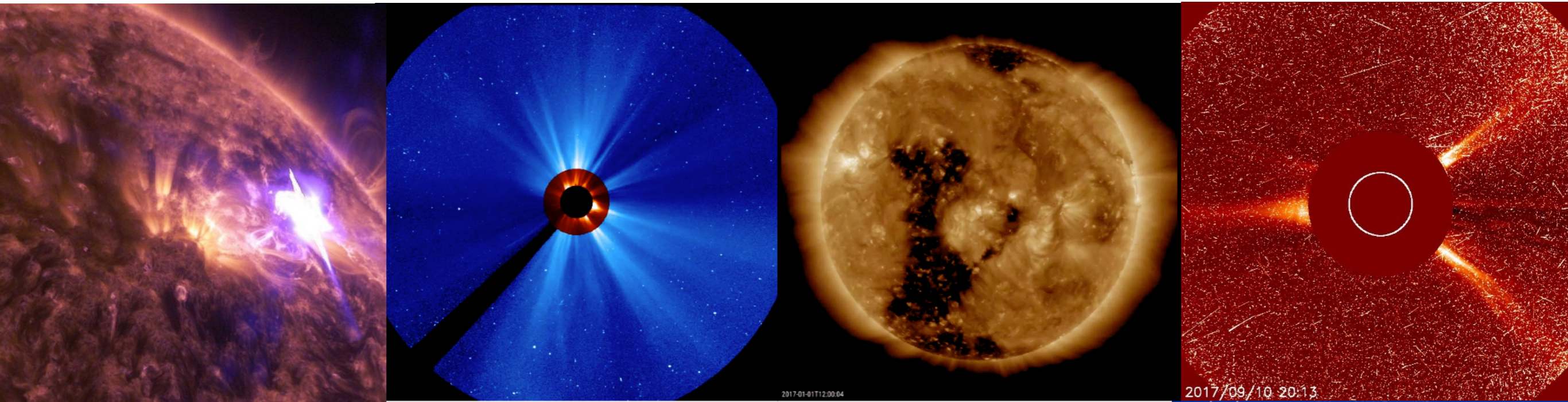
# SEASONAL BEHAVIOUR OF SOLAR PARTICLE STORMS

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.



# SOLAR WEATHER & STORMS

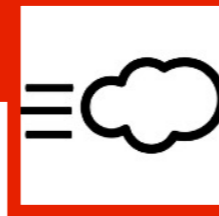
At a certain moment, energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass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



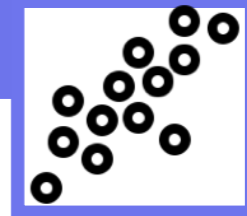
FLARE



CORONAL MASS  
EJECTION  
CORONAL HOLE

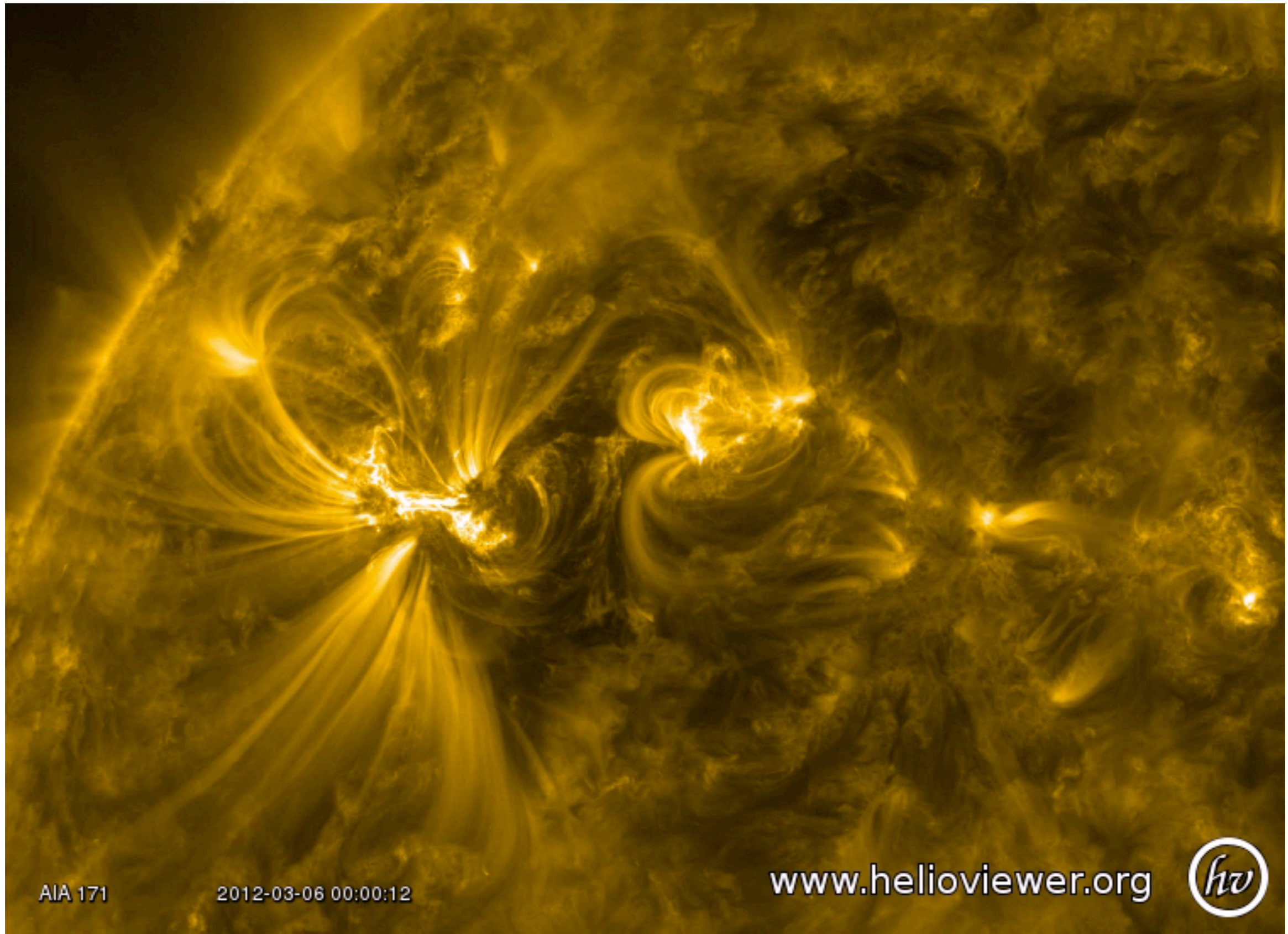


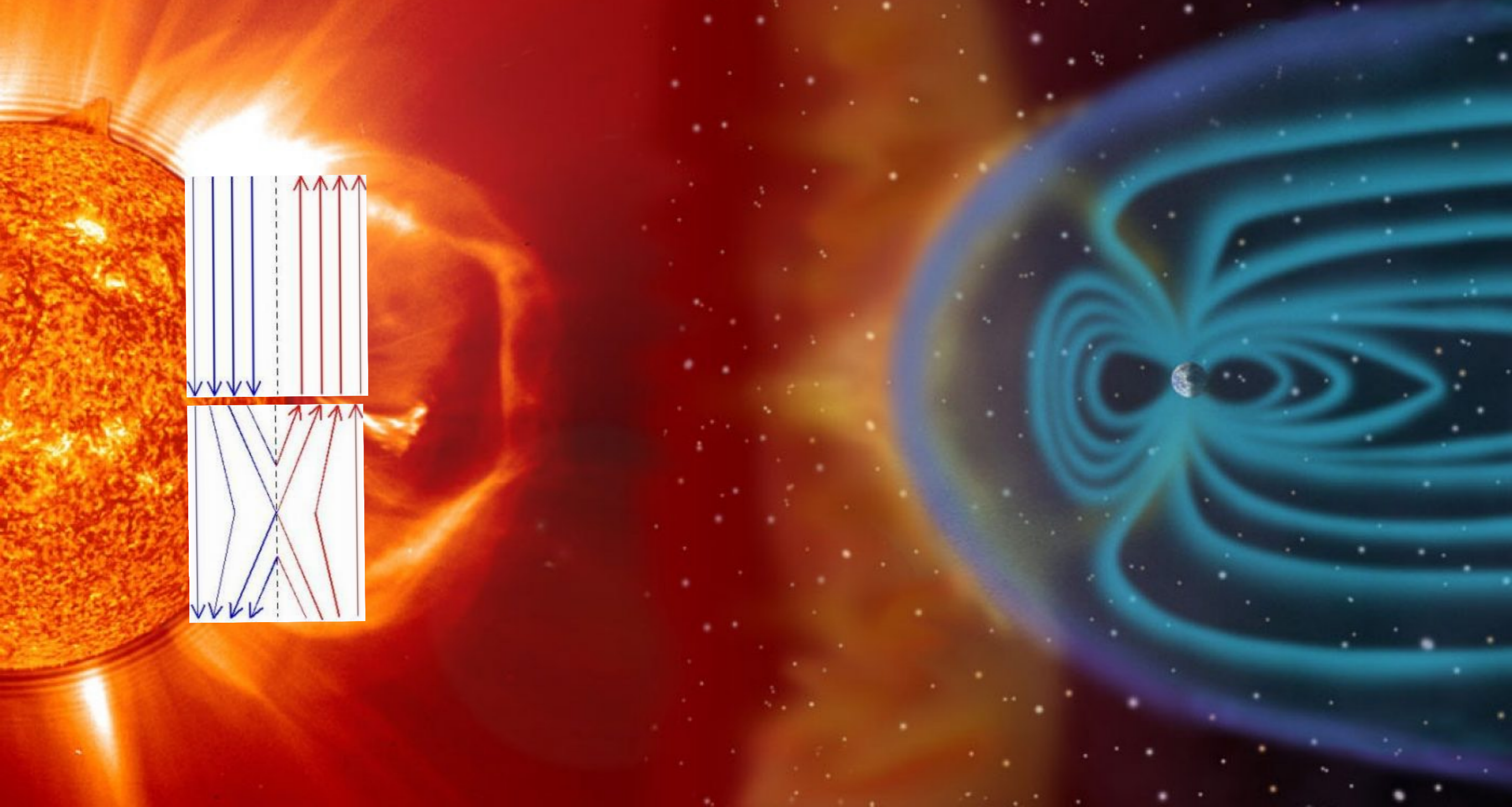
PARTICLE STORM





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



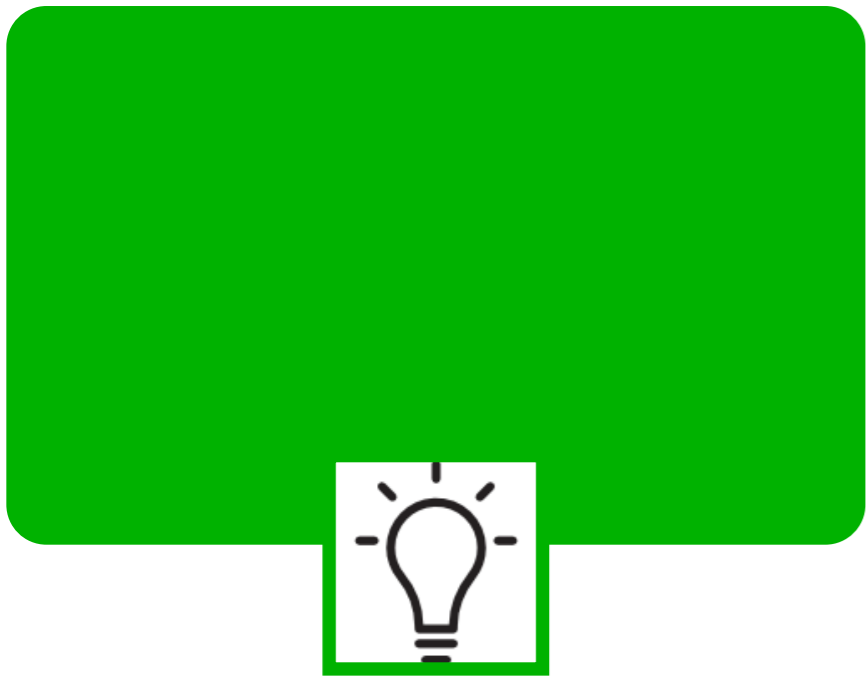


## MAGNETIC RECONNECTION



## AU TRANSIT TIME

The energy released during a solar storm moves through space, each with its own typical speed: speed of light, ....





## AU TRANSIT TIME

The energy released during a solar storm moves through space, each with its own typical speed: speed of light, ...

8 MIN



# STORM SCALE



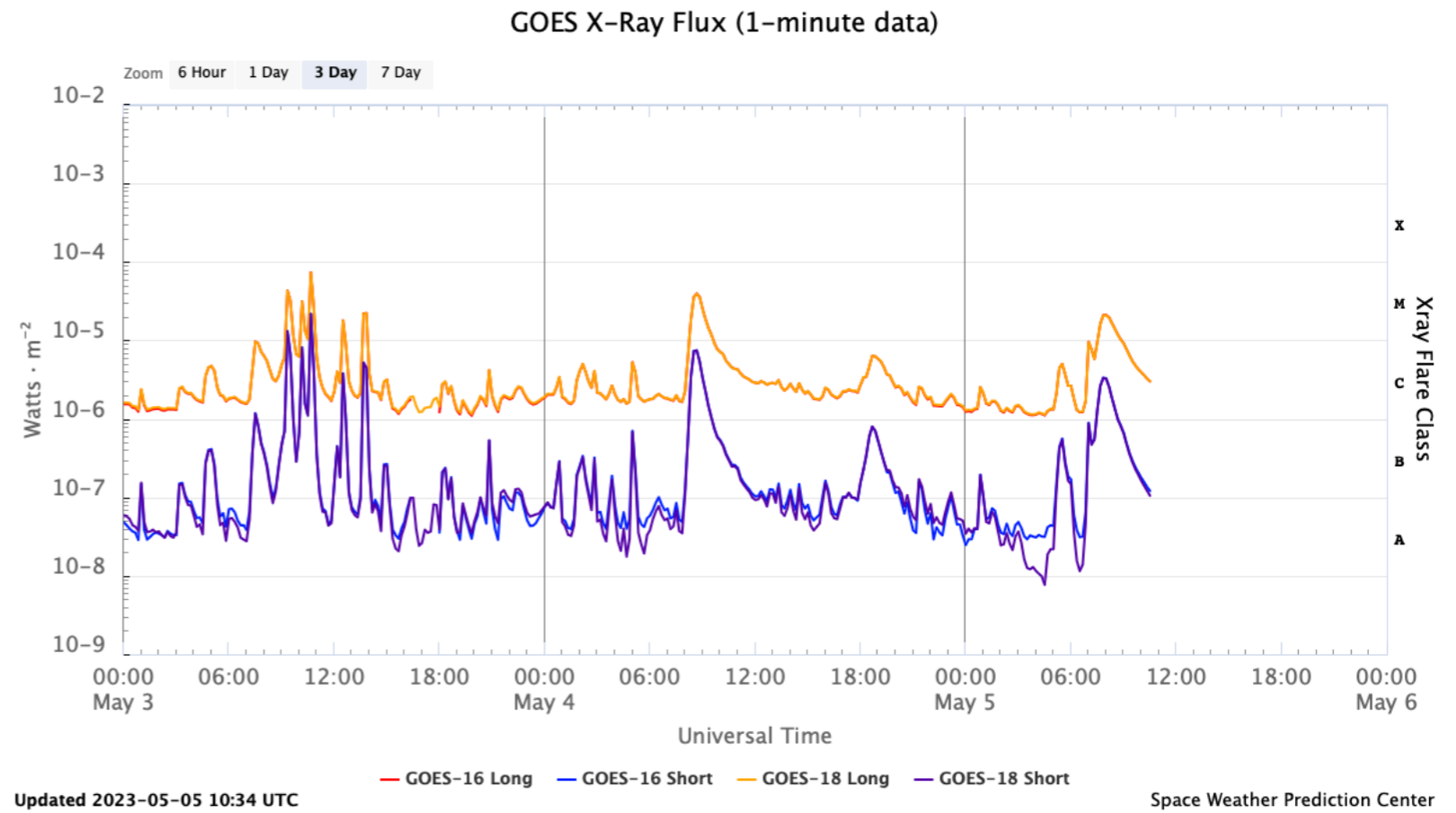
<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



# STORM SCALE



A,B,C,M,X



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



# 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 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 10CM FLUX: 162 / AP: 013
PREDICTIONS FOR 02 Jun 2023 10CM FLUX: 162 / AP: 019
PREDICTIONS FOR 03 Jun 2023 10CM 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. stream may arrive to the Earth in the

Solar wind: 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)



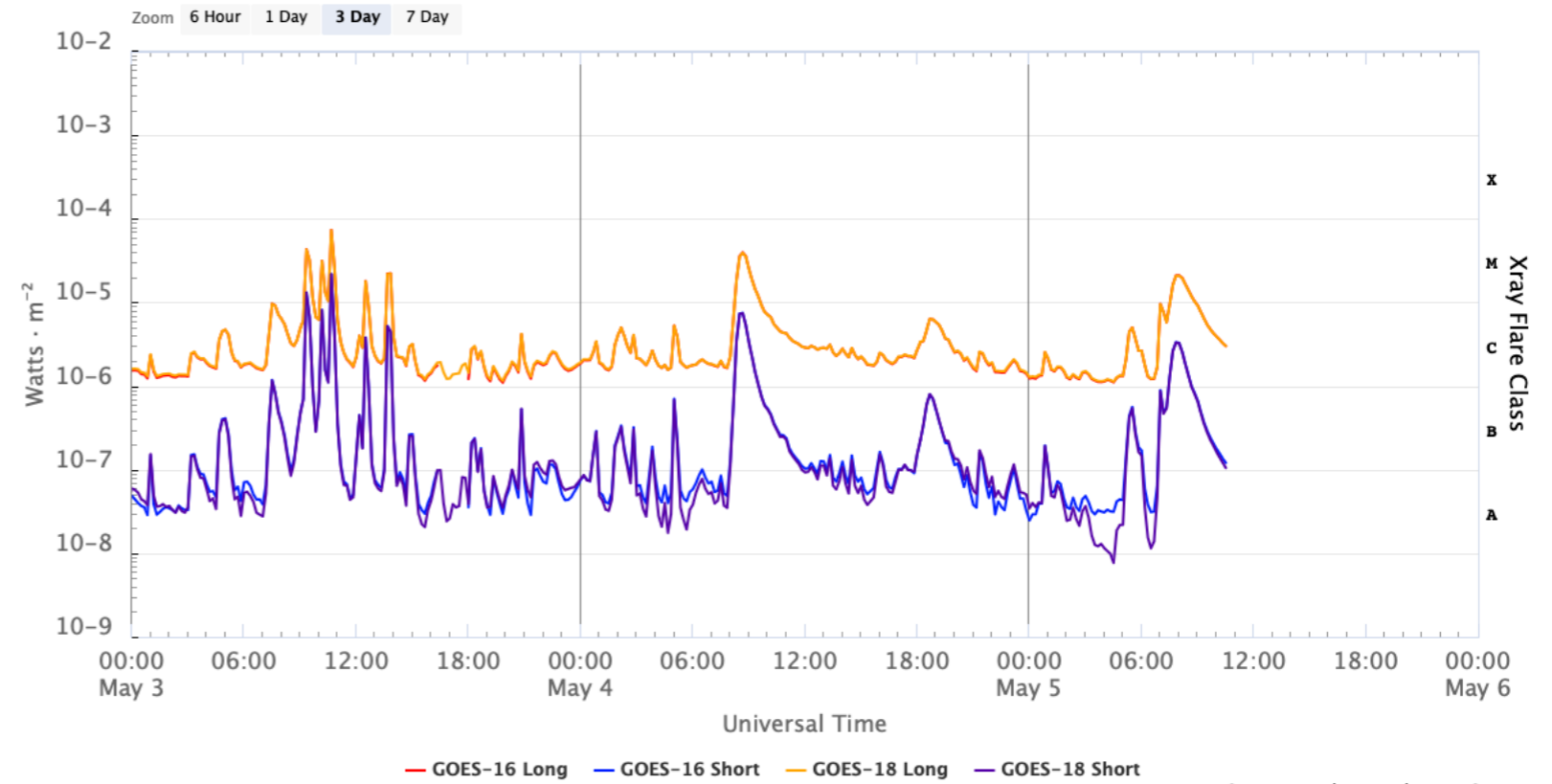
# DURATION



MINs to HOUR



GOES X-Ray Flux (1-minute data)

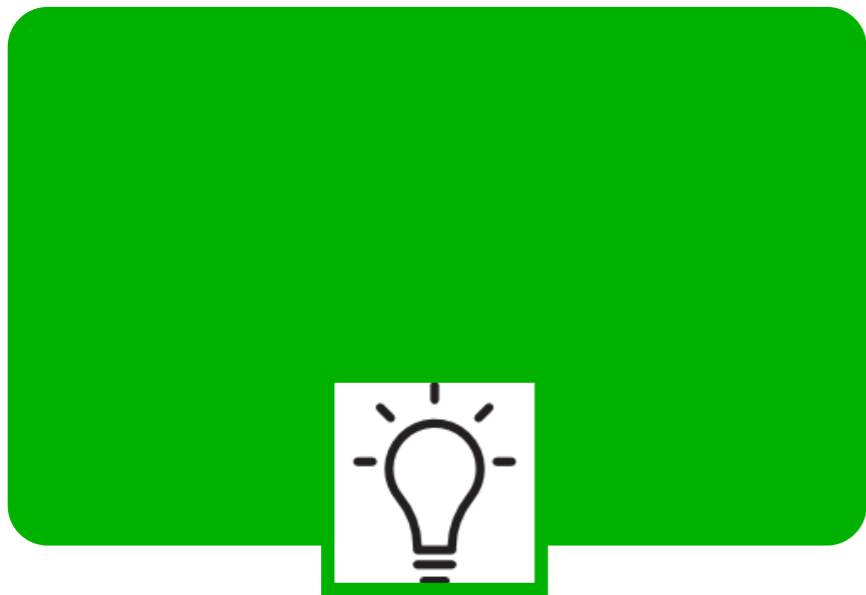


Updated 2023-05-05 10:34 UTC

Space Weather Prediction Center

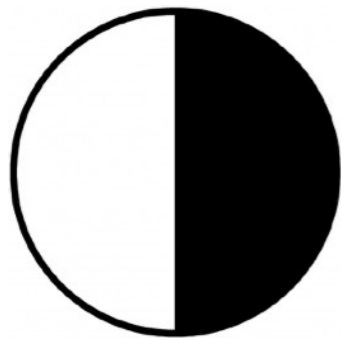


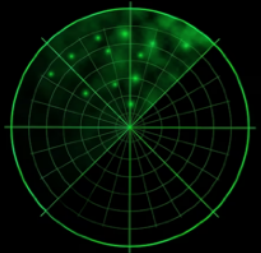
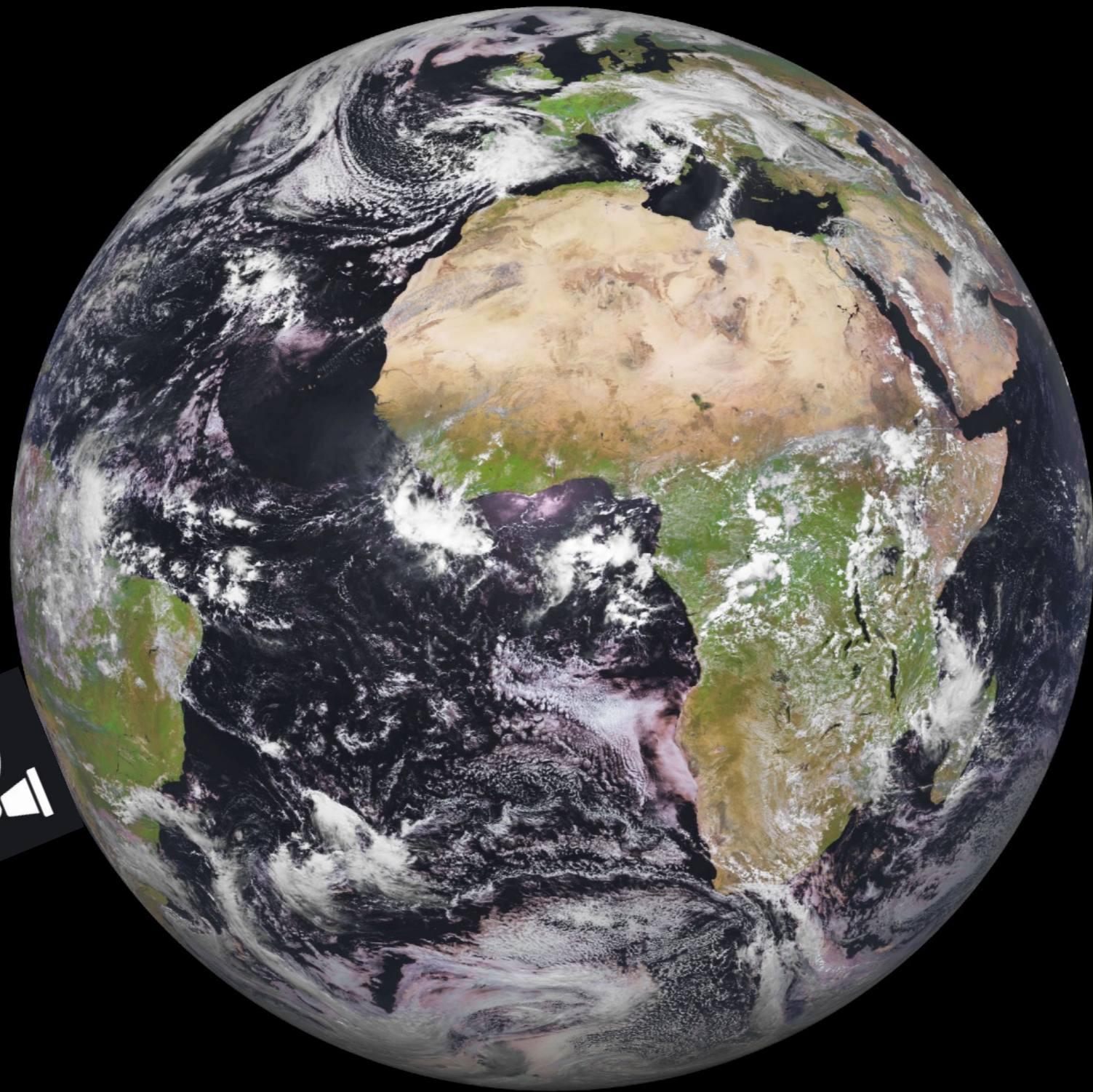
# AREA OF IMPACT

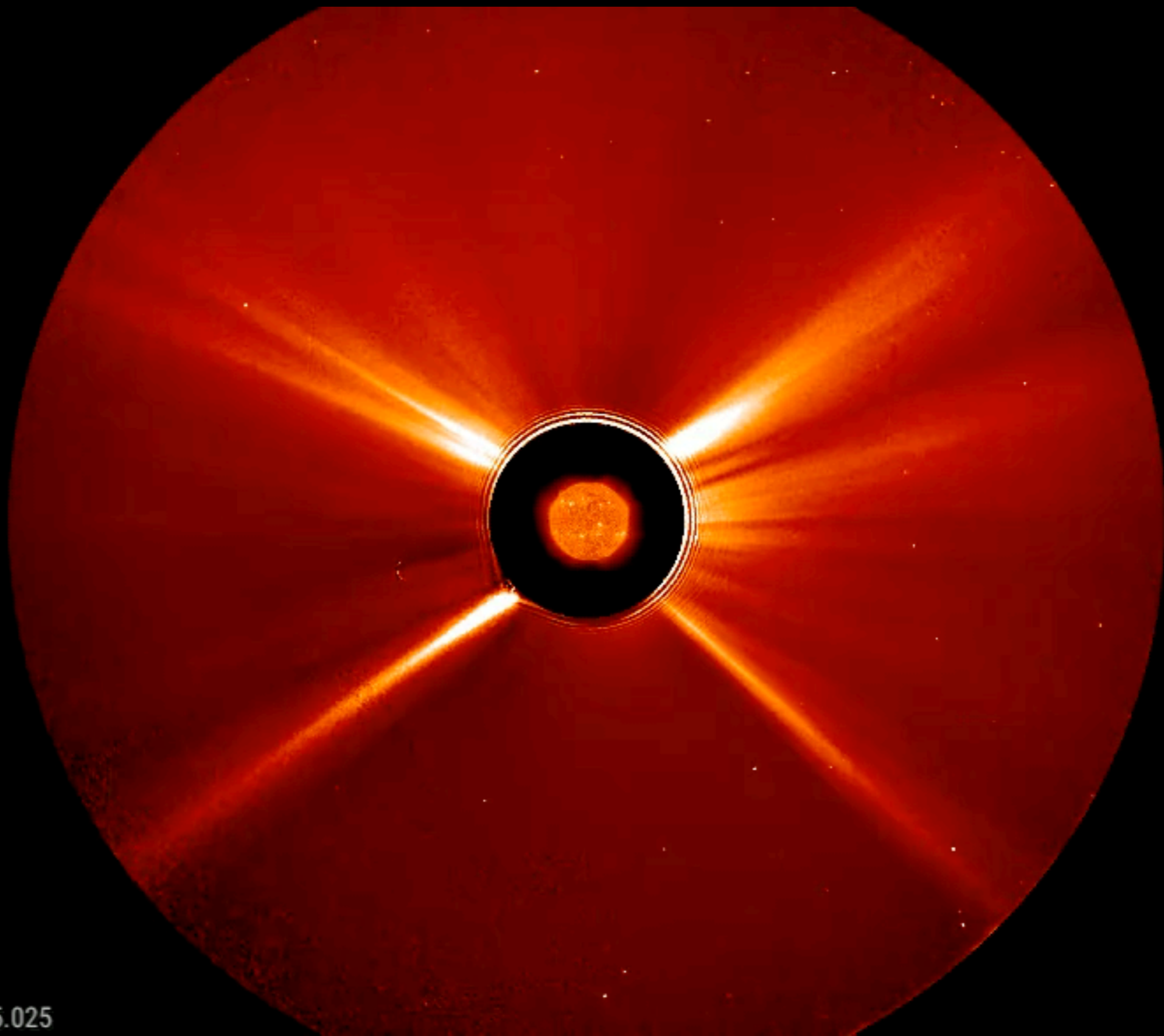
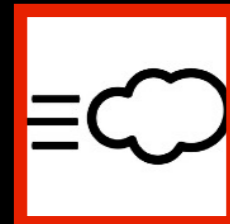


# AREA OF IMPACT

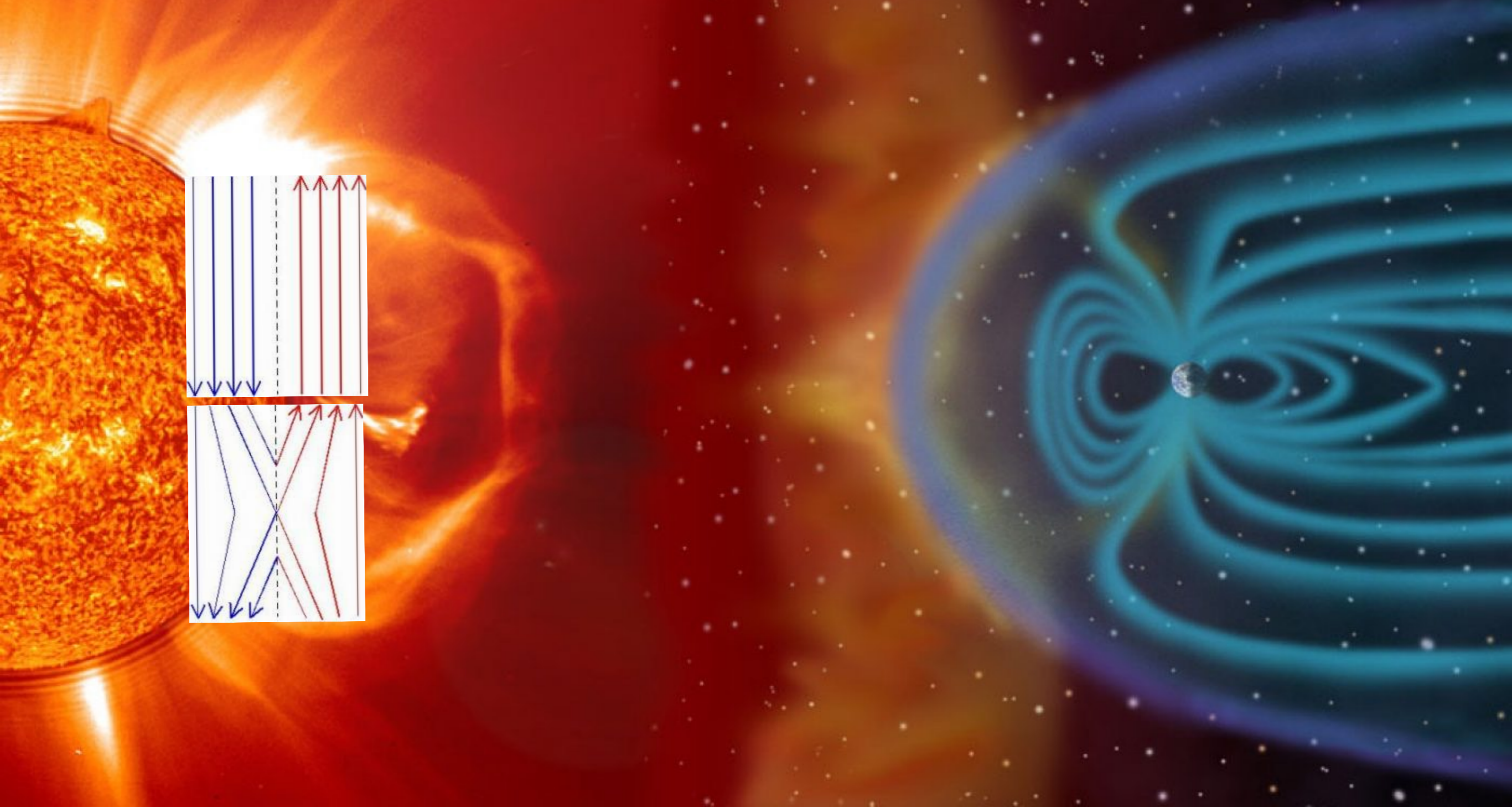
Illuminated area







2022-02-15T16:25:45.025



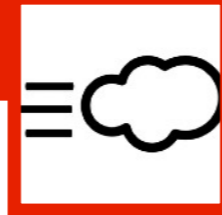
## MAGNETIC RECONNECTION



## 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,....

8 MIN





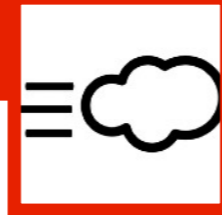
## AU TRANSIT TIME

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.

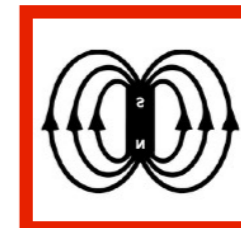
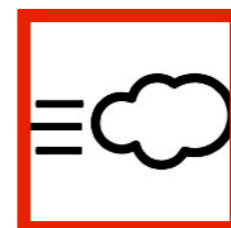
8 MIN



DAYS



# STORM SCALE - GEOMAGNETIC STORM

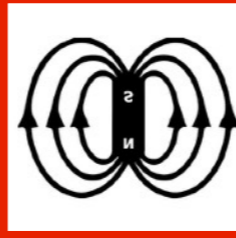


# STORM SCALE



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

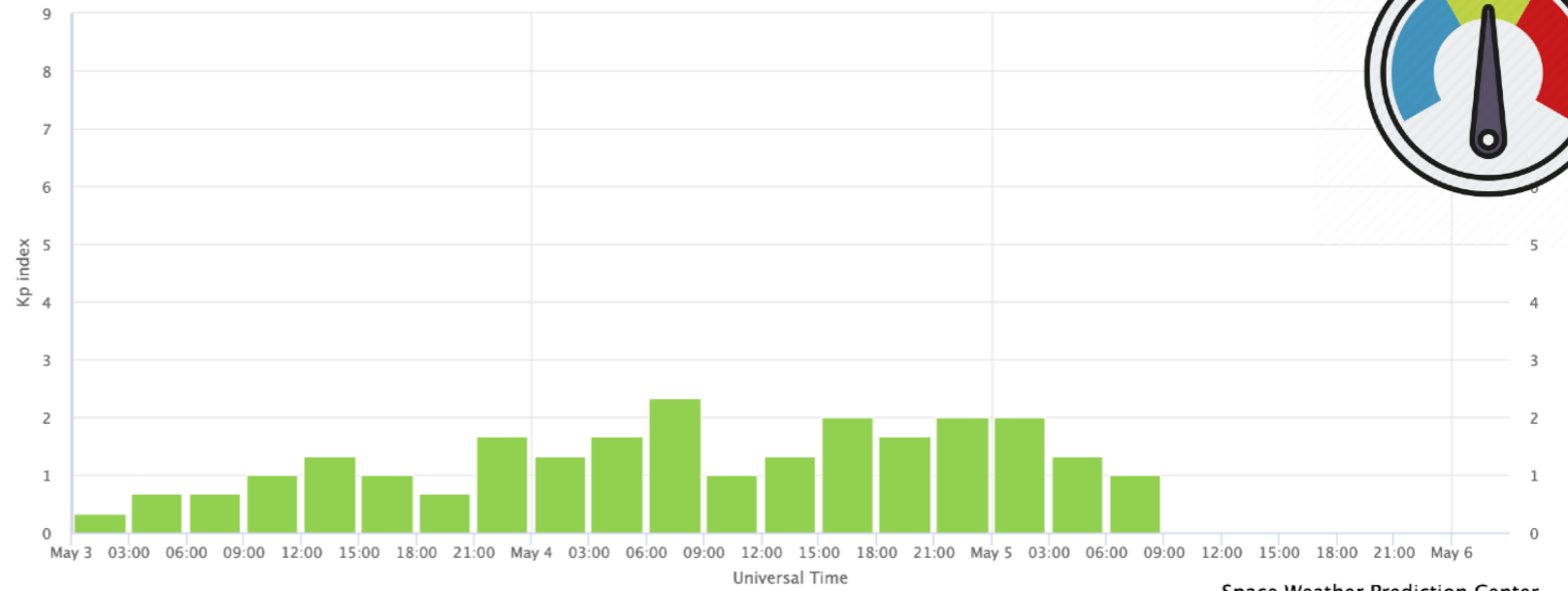
A,B,C,M,X



# STORM SCALE

Estimated Planetary K index (3 hour data)

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

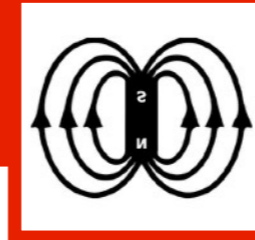


Space Weather Prediction Center

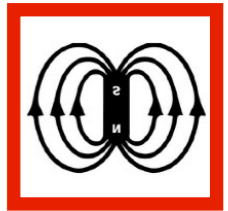
A,B,C,M,X



Kp  
0 - 9



# 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 10CM FLUX: 162 / AP: 013
PREDICTIONS FOR 02 Jun 2023 10CM FLUX: 162 / AP: 019
PREDICTIONS FOR 03 Jun 2023 10CM 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 pola crossed the central meridian o stream may arrive to the Earth

Solar wind: The Earth is insid has started to increase (curre magnetic field around 7 nT. In the arrival of the high speed coronal hole in the southern h in latitude, so we donâ€™t exp

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)



# DURATION



MINs to HOUR

A simple line-art icon of a lit lightbulb, representing an idea or short-term duration.

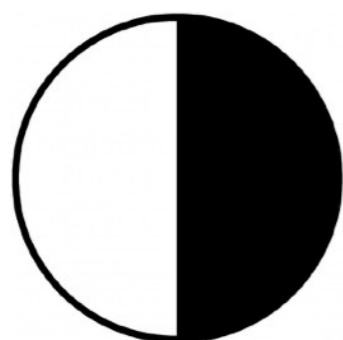
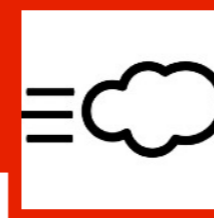
DAY+

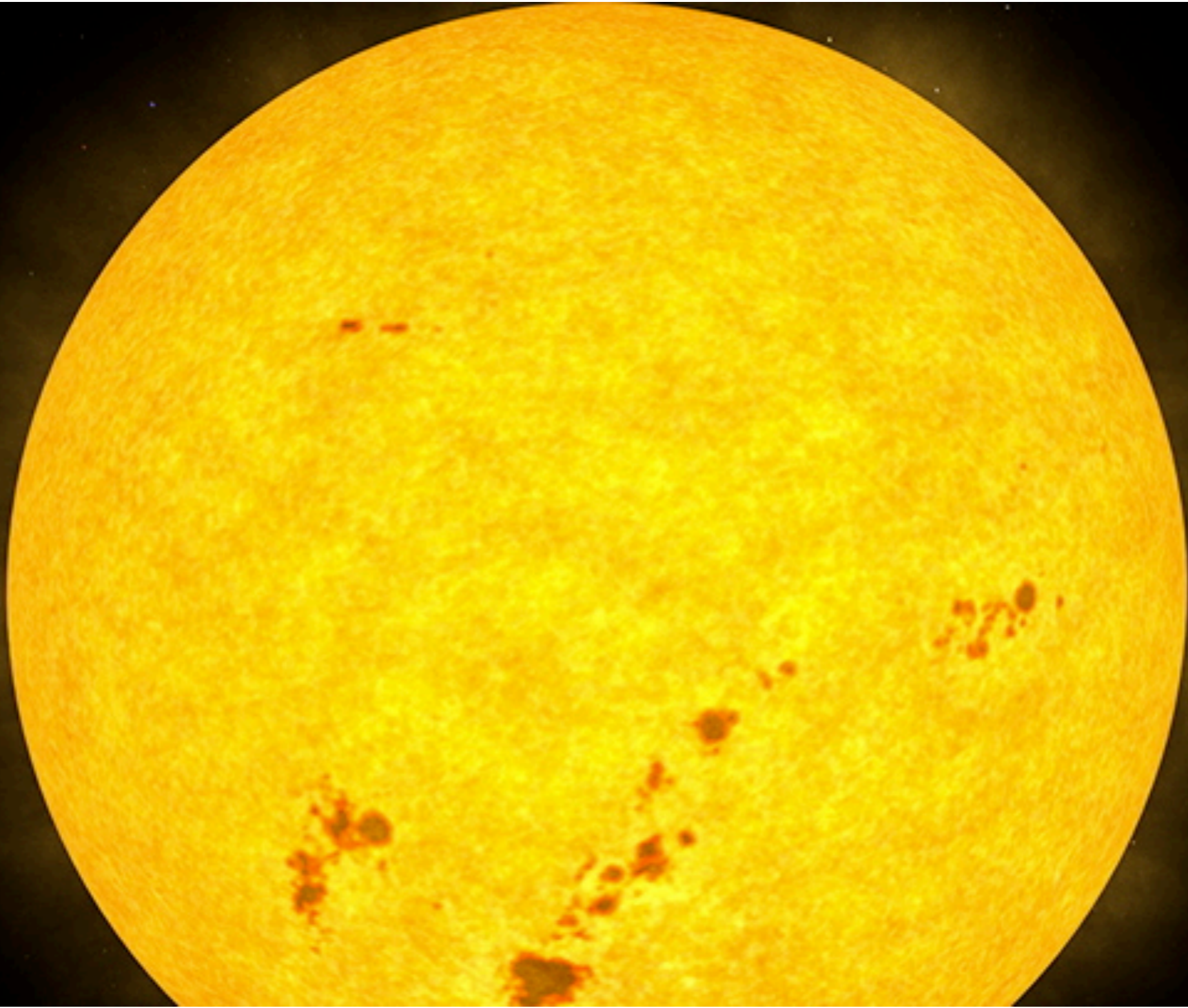
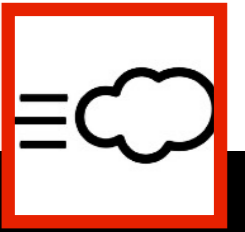
A diagram showing magnetic field lines with arrows, representing a long-term or extended duration.

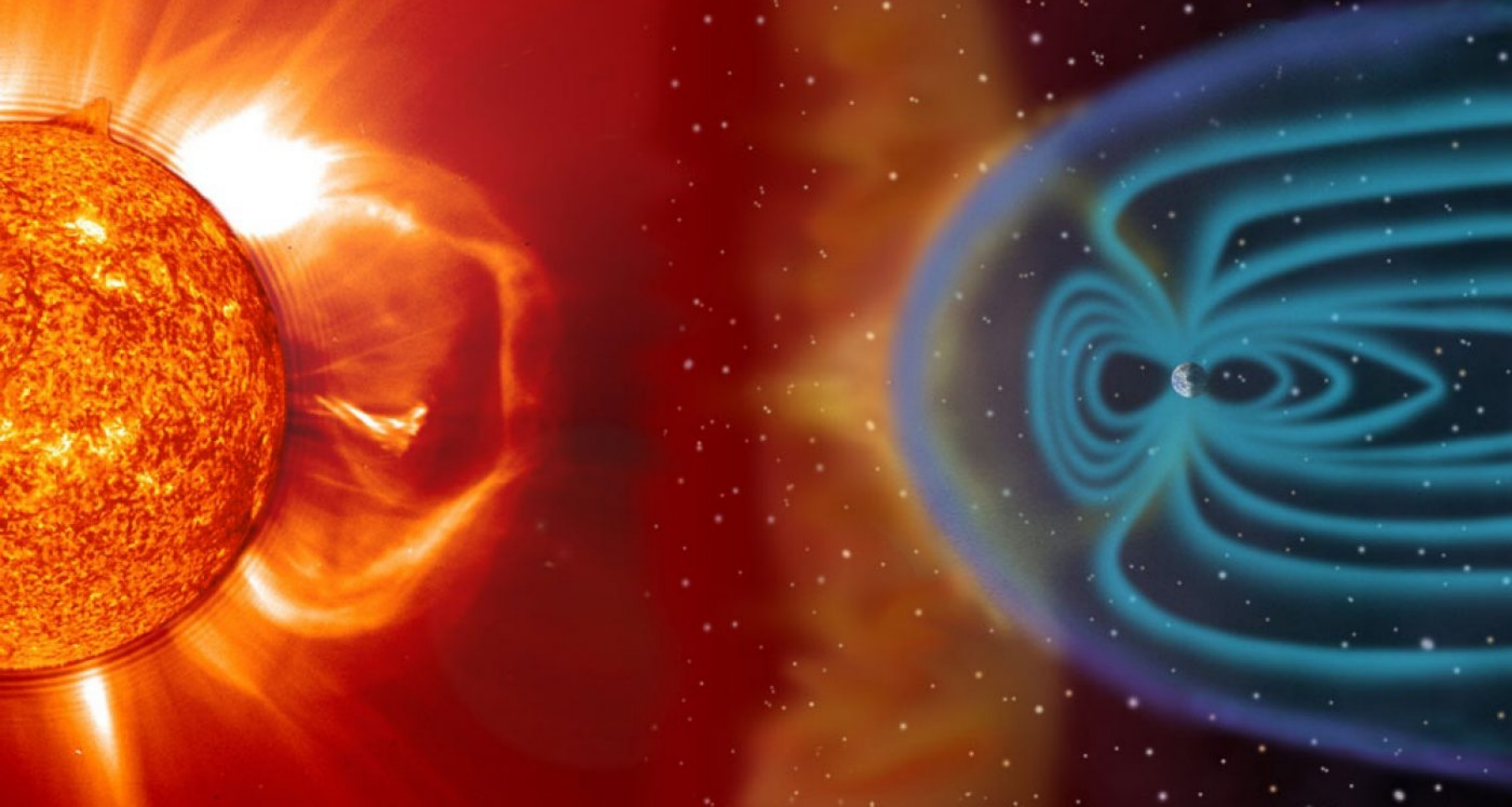
# AREA OF IMPACT



Illuminated area

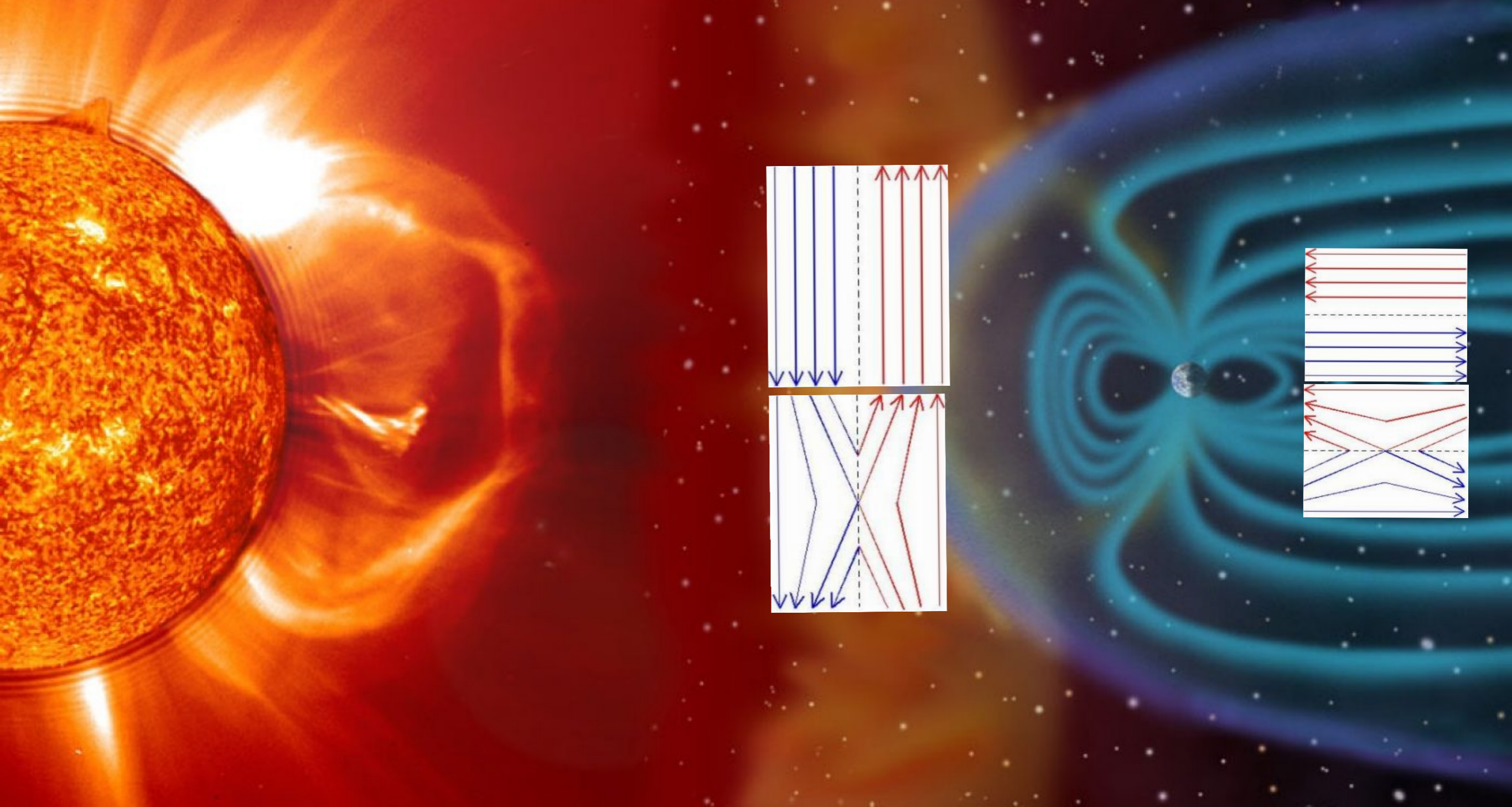






## RECONNECTION

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.

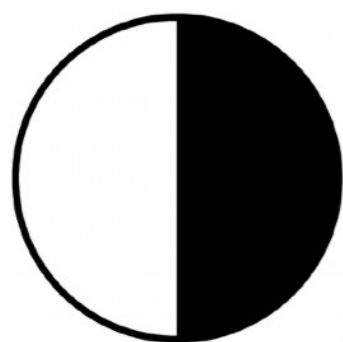


## RECONNECTION

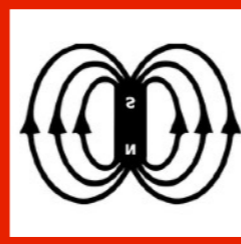
The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.

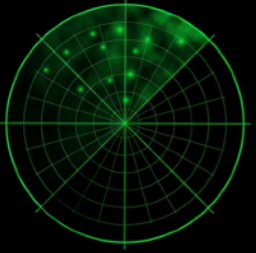
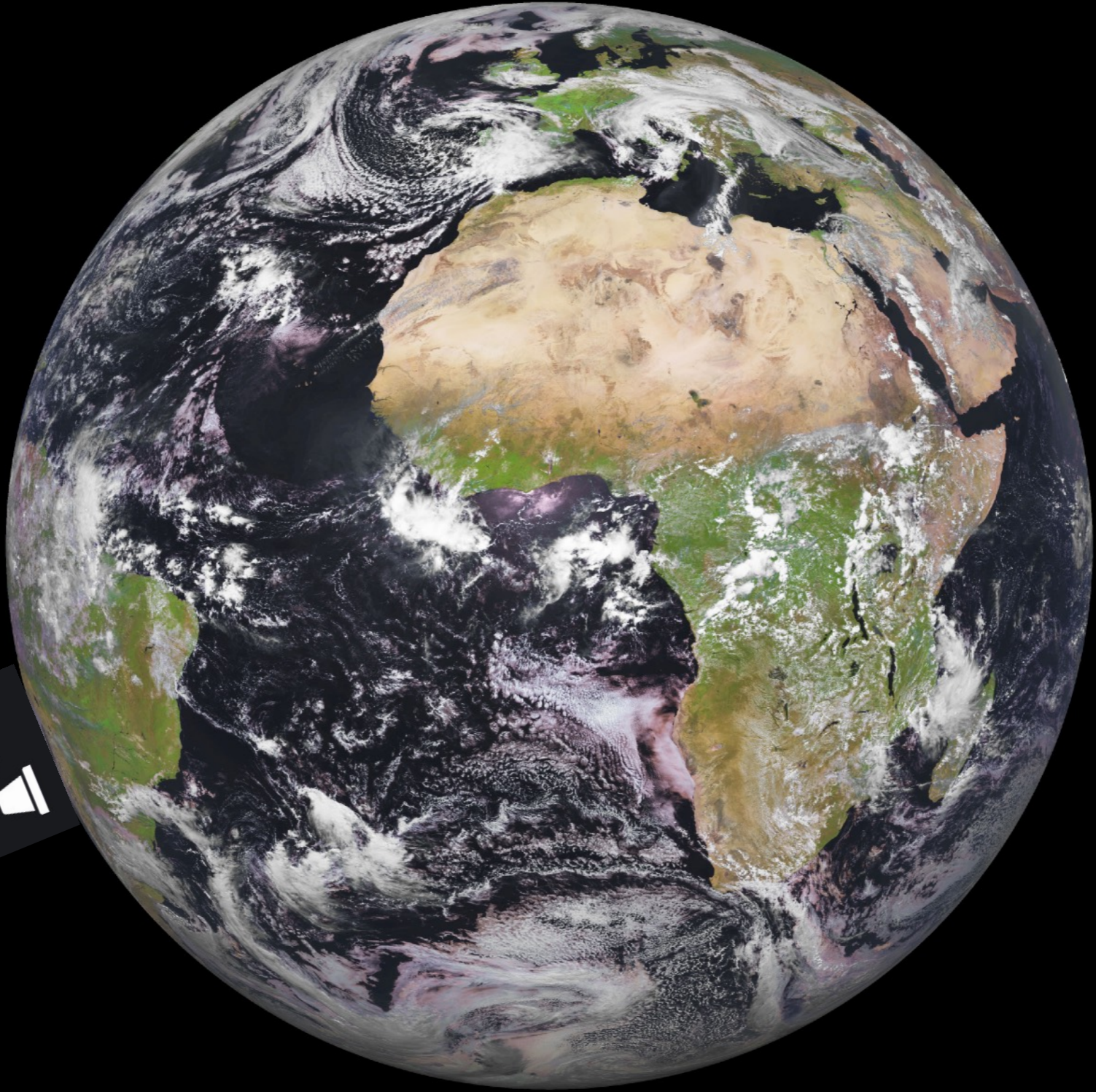
# AREA OF IMPACT

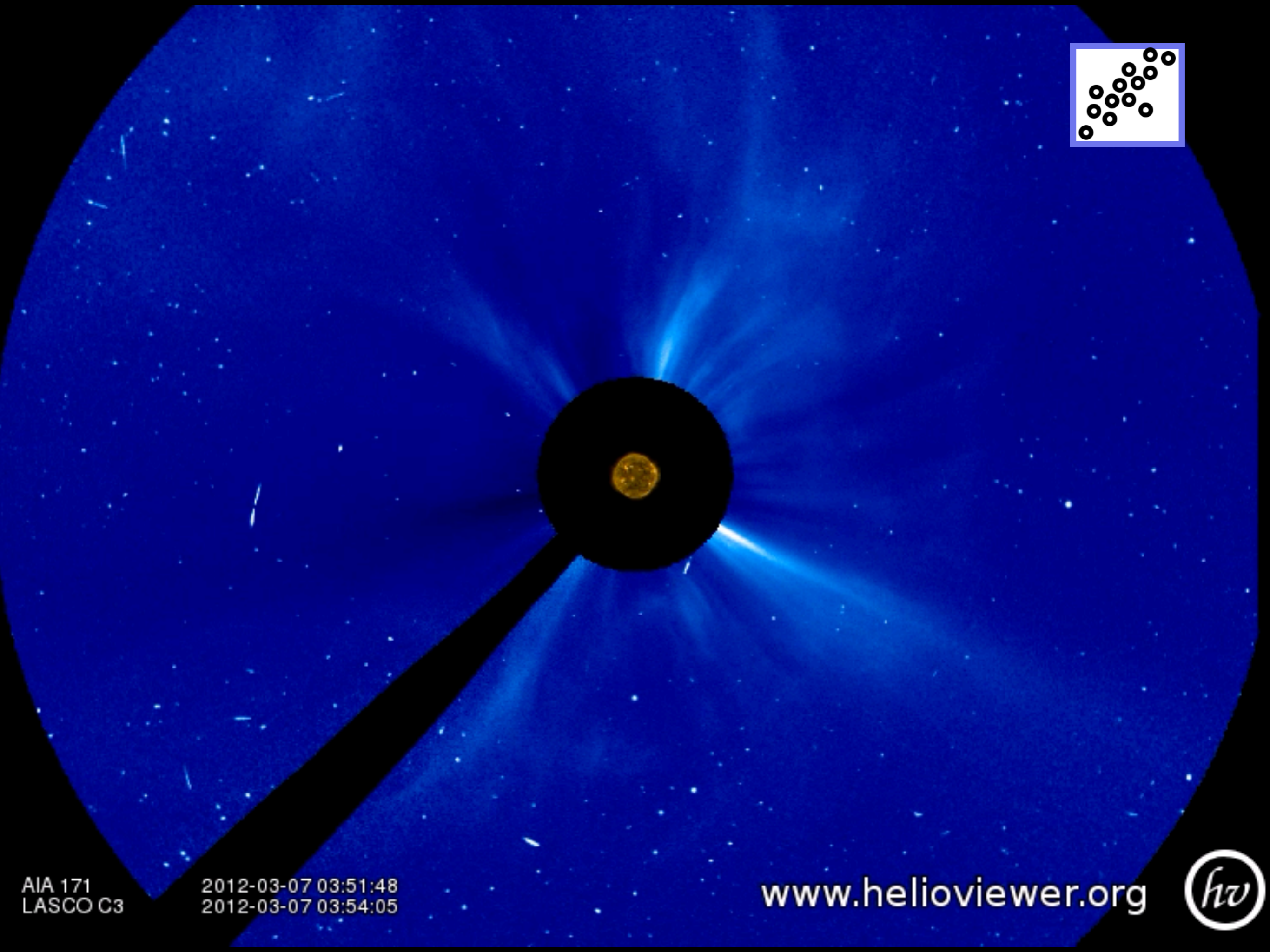
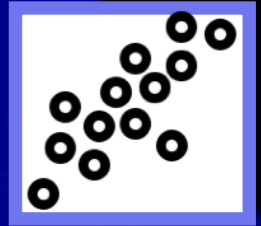
Illuminated area



Polar Cap







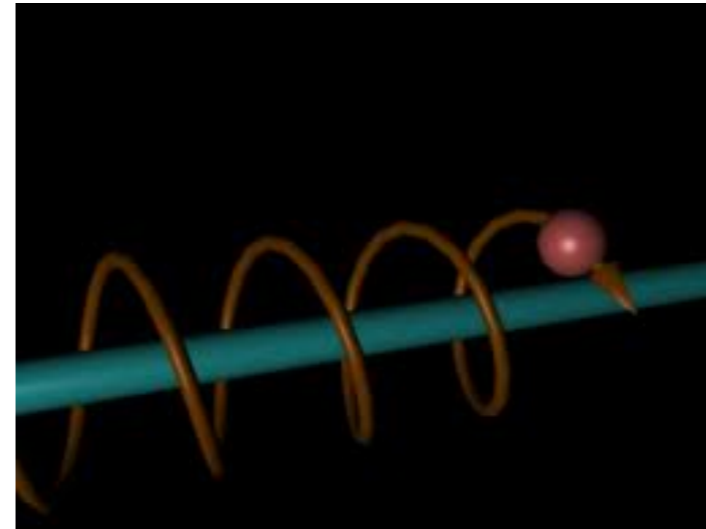
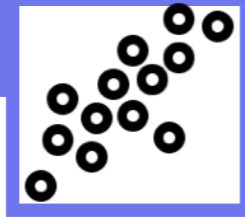
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LASCO C3

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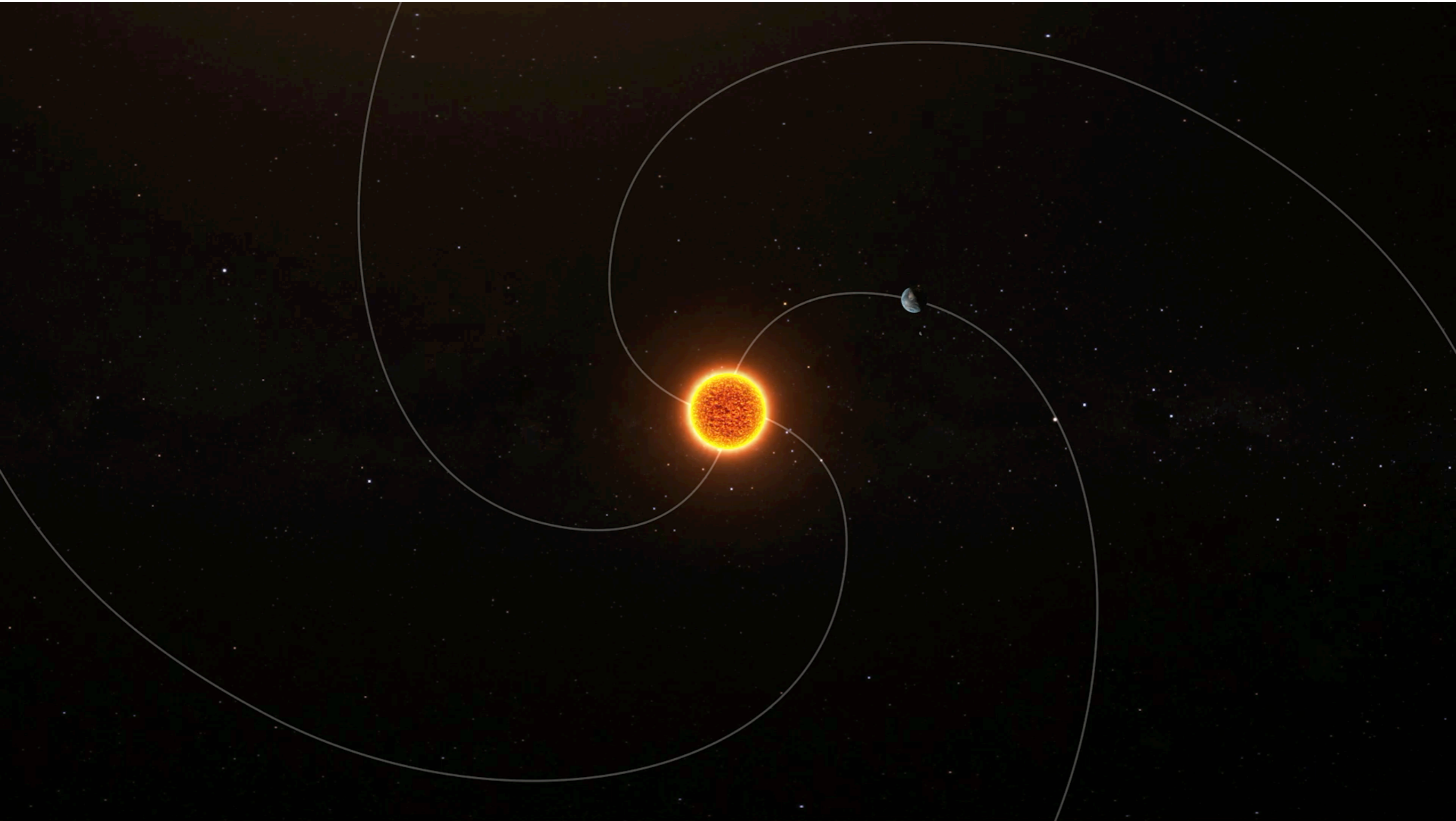
[www.helioviewer.org](http://www.helioviewer.org)



# SOLAR PARTICLES



Solar energetic particles follow magnetic field lines.





## 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





## 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.

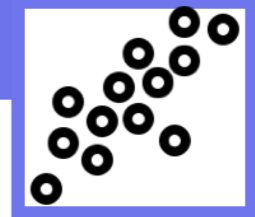
8 MIN



DAYS



HOUR



# STORM SCALE

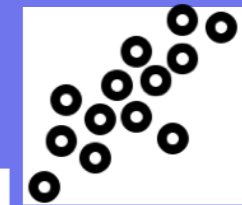


<https://www.swpc.noaa.gov/products/goes-proton-flux>

A,B,C,M,X

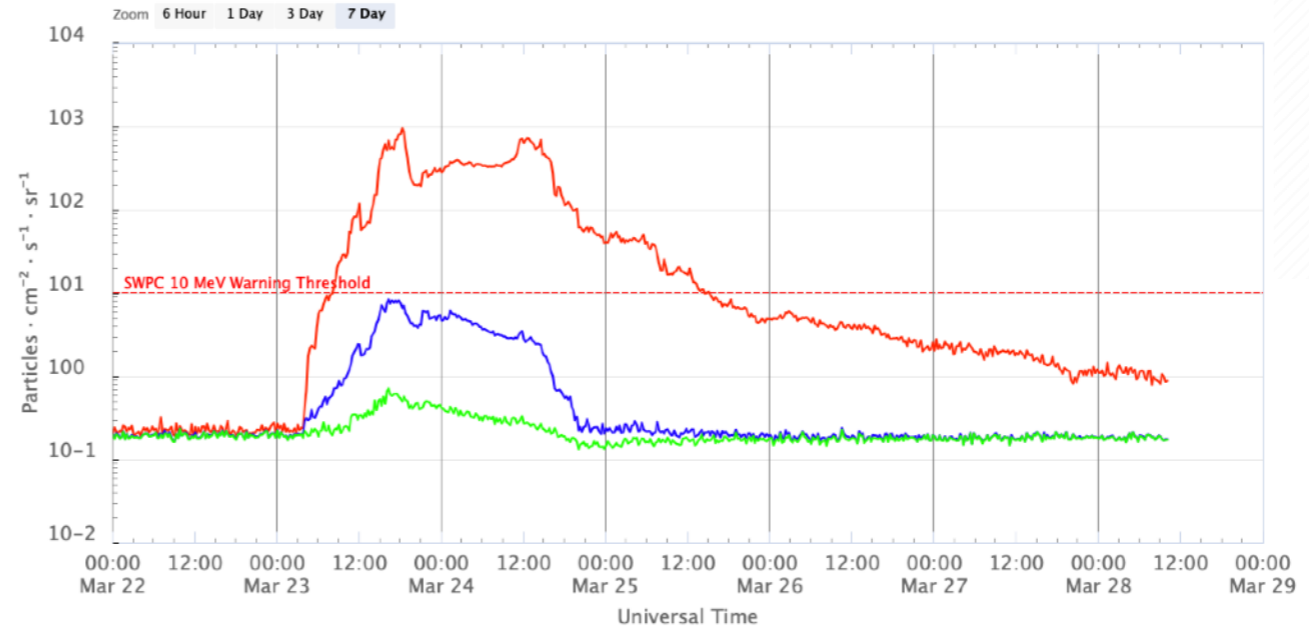


Kp  
0 - 9



# STORM SCALE

GOES Proton Flux (5-minute data)



A,B,C,M,X

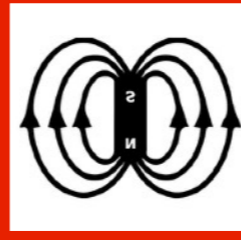


Updated 2024-03-28 10:10 UTC

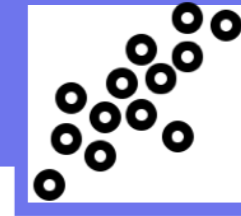
— GOES-18 ≥ 10 MeV — GOES-18 ≥ 50 MeV — GOES-18 ≥ 100 MeV

Space Weather Prediction Center

Kp  
0 - 9



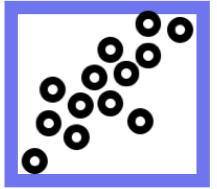
Storm - major storm



GOES



# SOLAR PROTON FLUX BY GOES



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: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 10CM FLUX: 162 / AP: 013
PREDICTIONS FOR 02 Jun 2023 10CM FLUX: 162 / AP: 019
PREDICTIONS FOR 03 Jun 2023 10CM FLUX: 162 / AP: 007
```

Solar Active Regions and flaring activity (AR 3315 and 3316) are visible over the solar disk. The newly numbered AR 3316 (located over the east limb) is the one including the largest flare of the day on 31 May. NOAA AR 3315 and 3316 activity. More M-class flares are possible.

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

Coronal holes: A positive polarity coronal hole crossed the central meridian on 31 May. A high speed stream may arrive to the Earth on 02 Jun.

Solar wind: The Earth is inside the high speed stream emanating from a positive polarity 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.

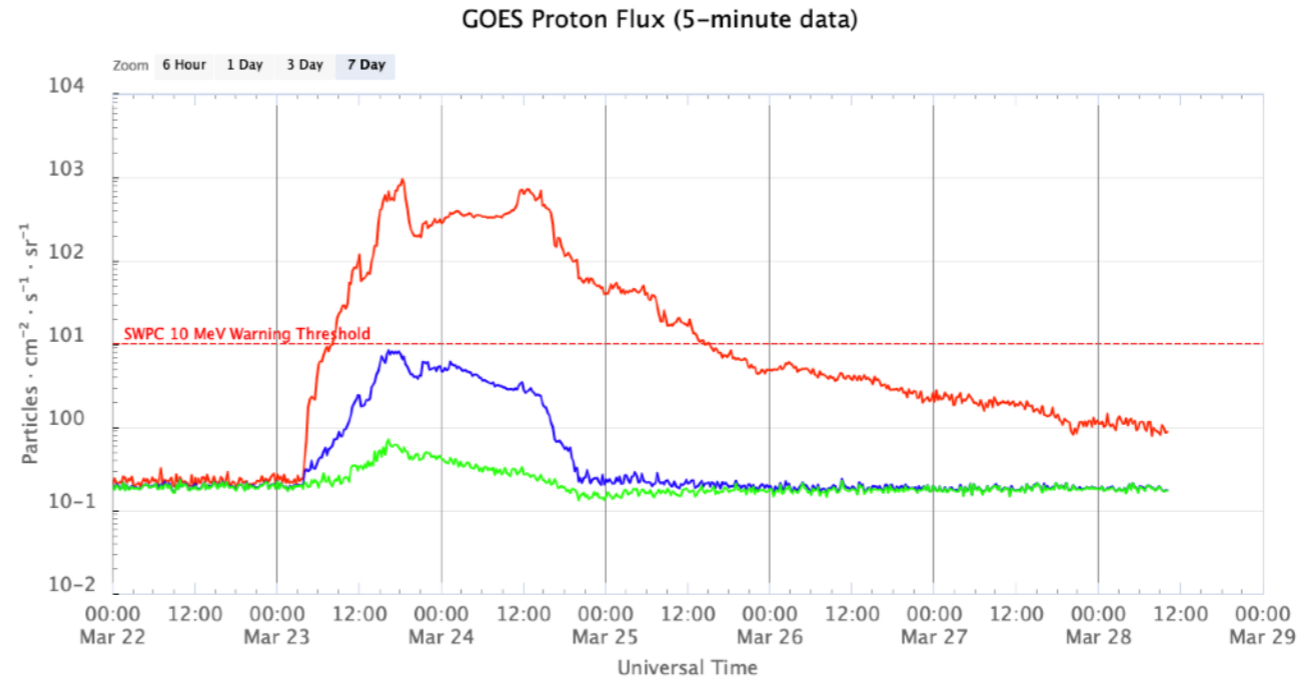
Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux was at nominal levels and is expected to remain so in the next 24 hours.

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)



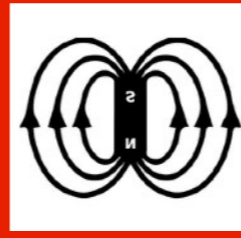
# DURATION



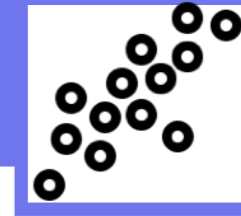
MINs to HOUR



DAY+



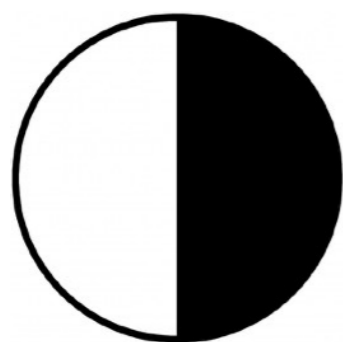
HOURS to DAYS



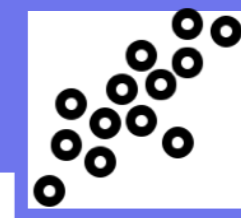
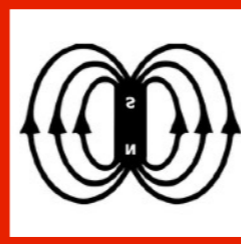
# AREA OF IMPACT

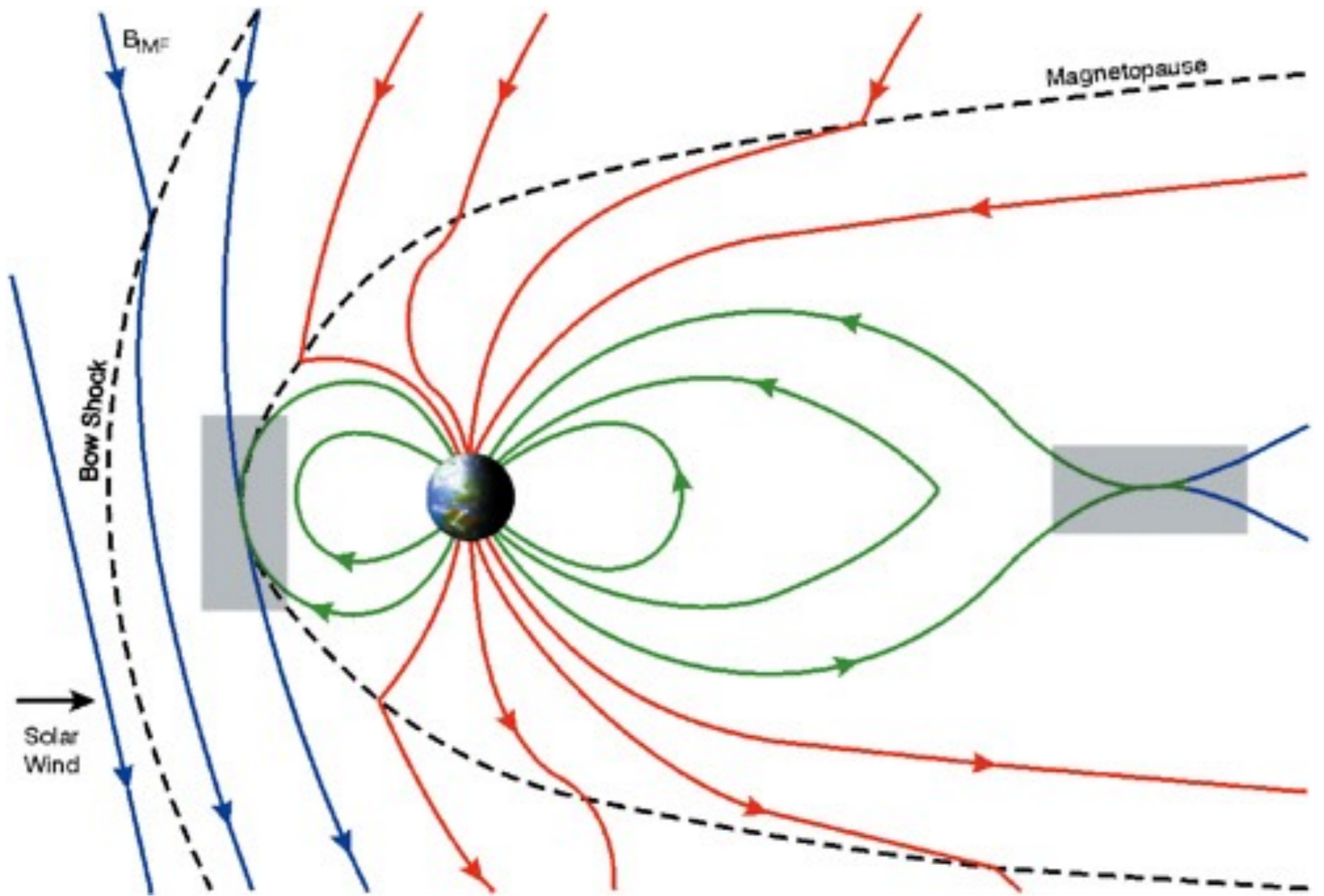


Illuminated area



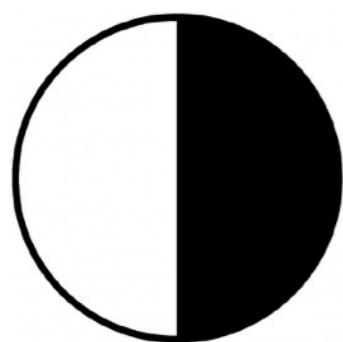
Polar Cap



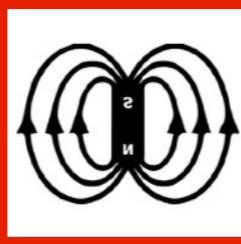


# AREA OF IMPACT

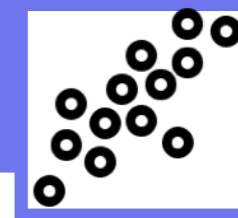
Illuminated area

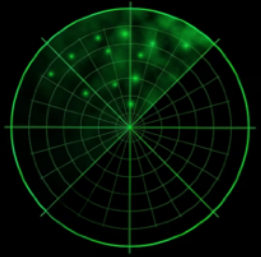
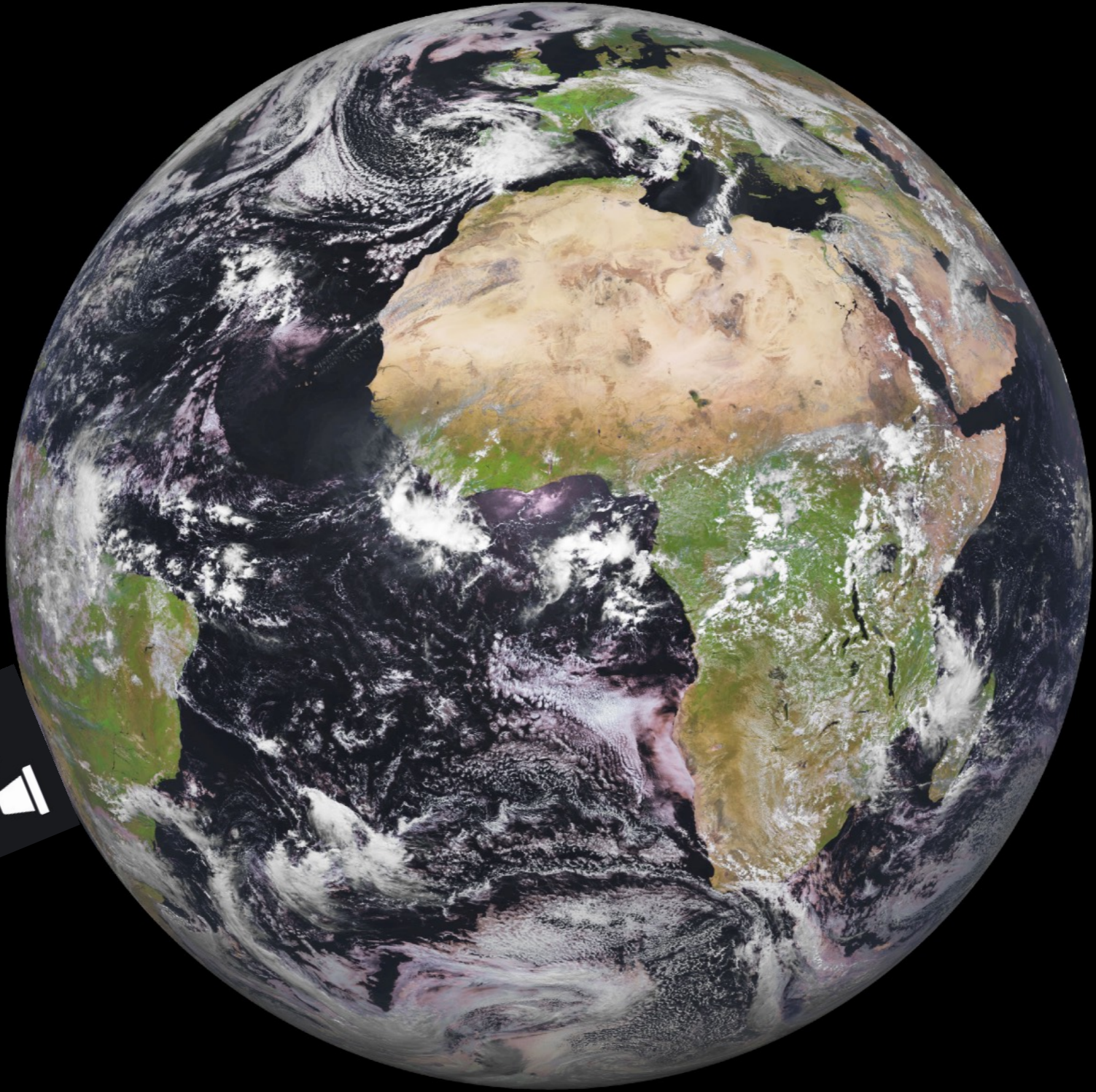


Polar Cap



Polar Cap  
High Altitude





# OVERVIEW

