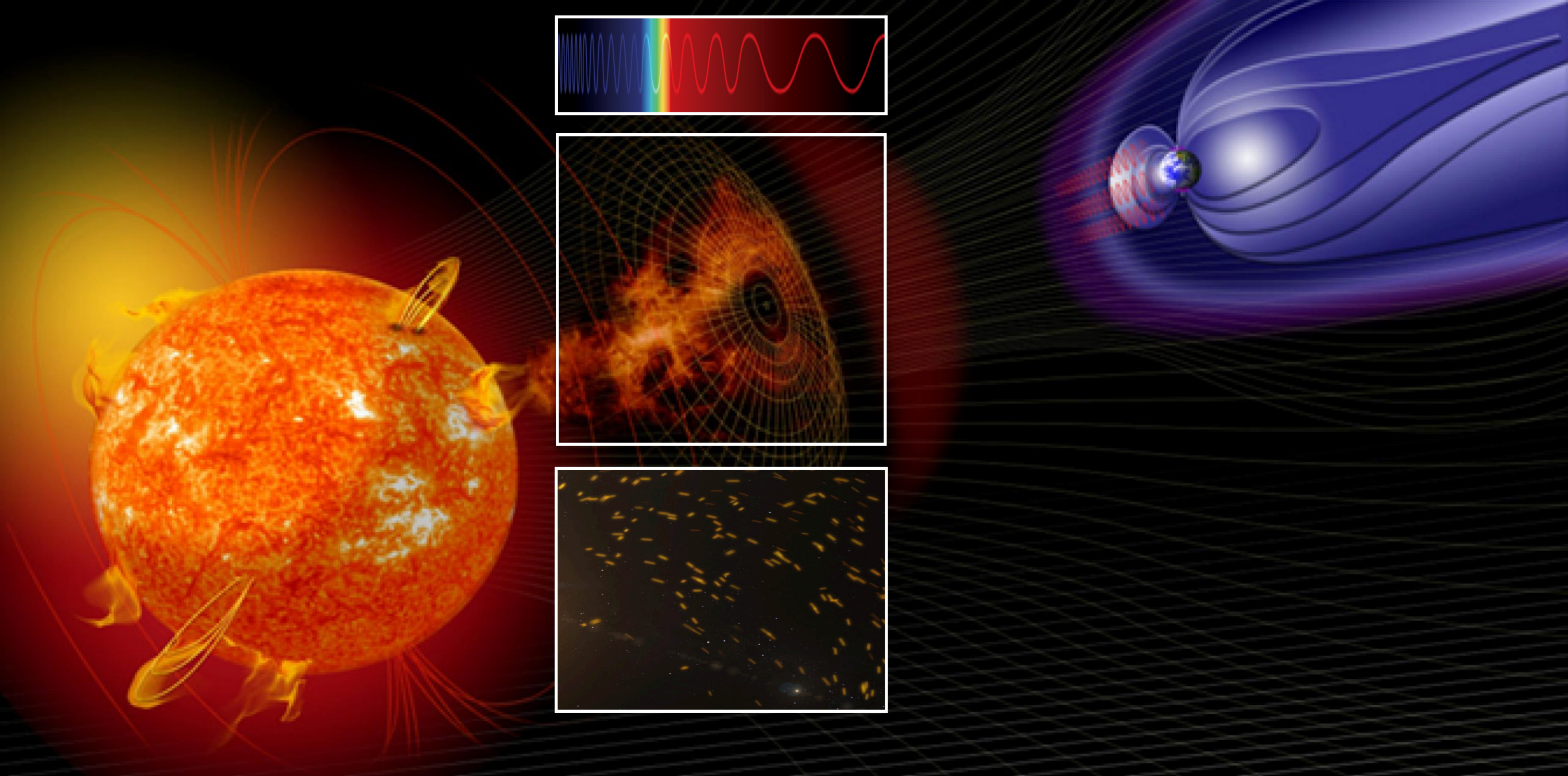


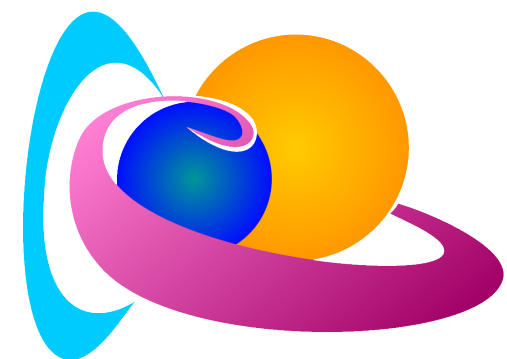
Role of the Ionosphere & SPWx in Military Communications





SOLAR DRIVERS

Petra Vanlommel
Solar-Terrestrial Centre of Excellence (STCE)



THE SUN AS A BALL OF ENERGY

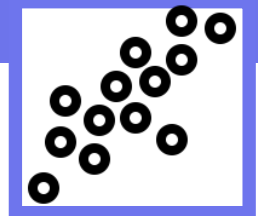
E.M. RADIATION



PLASMA

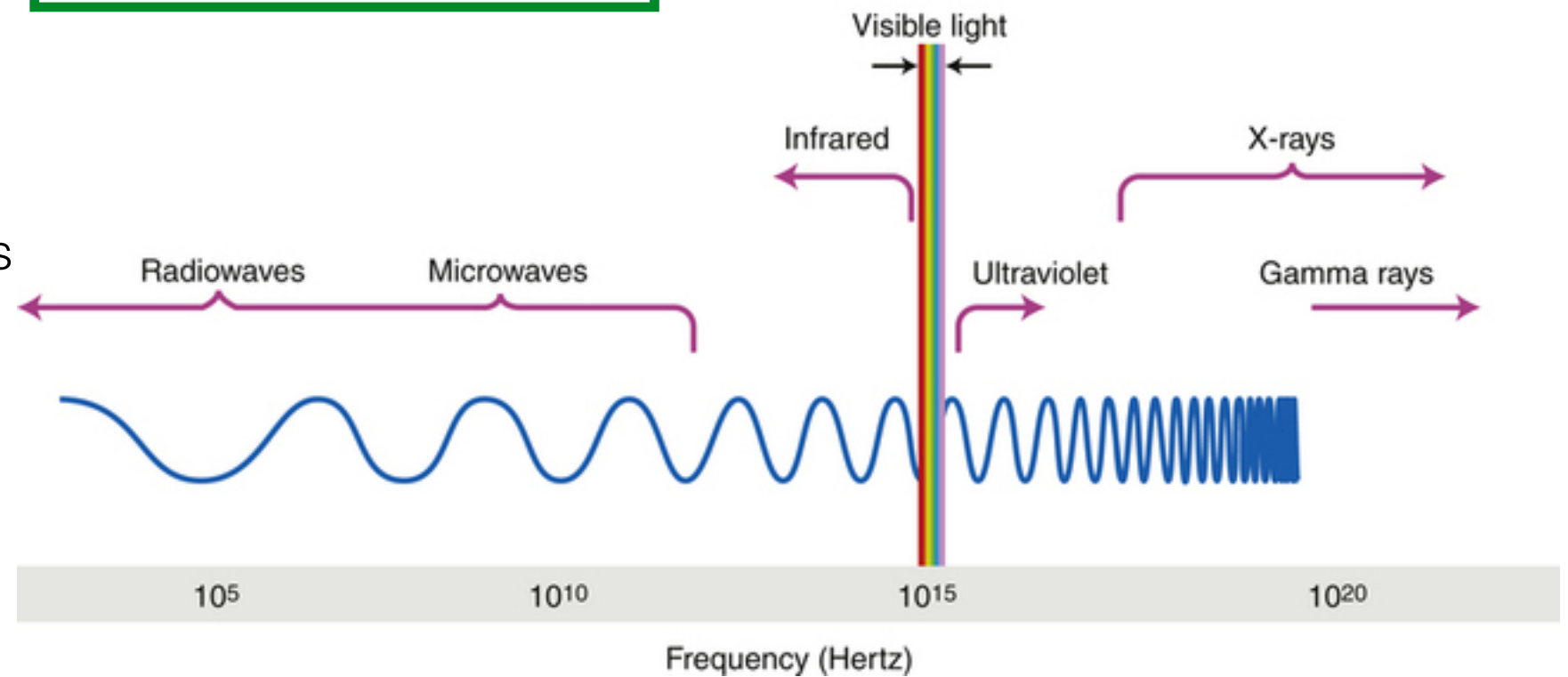


ENERGETIC
PARTICLES



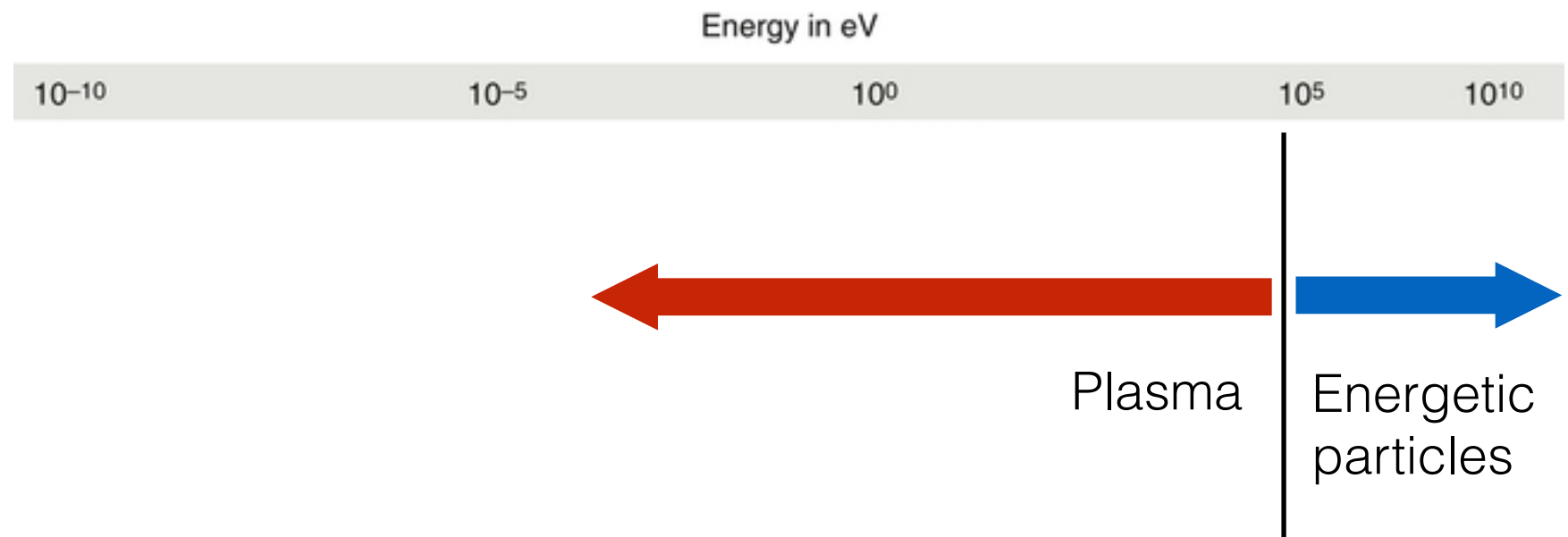
Electromagnetic radiation

- Photons / electromagnetic waves
- Speed of light



Particles

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



3 SPACE WEATHER PHENOMENA

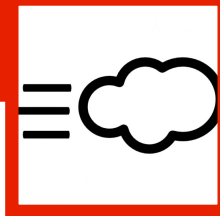
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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

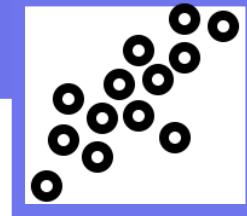
LIGHT



WIND

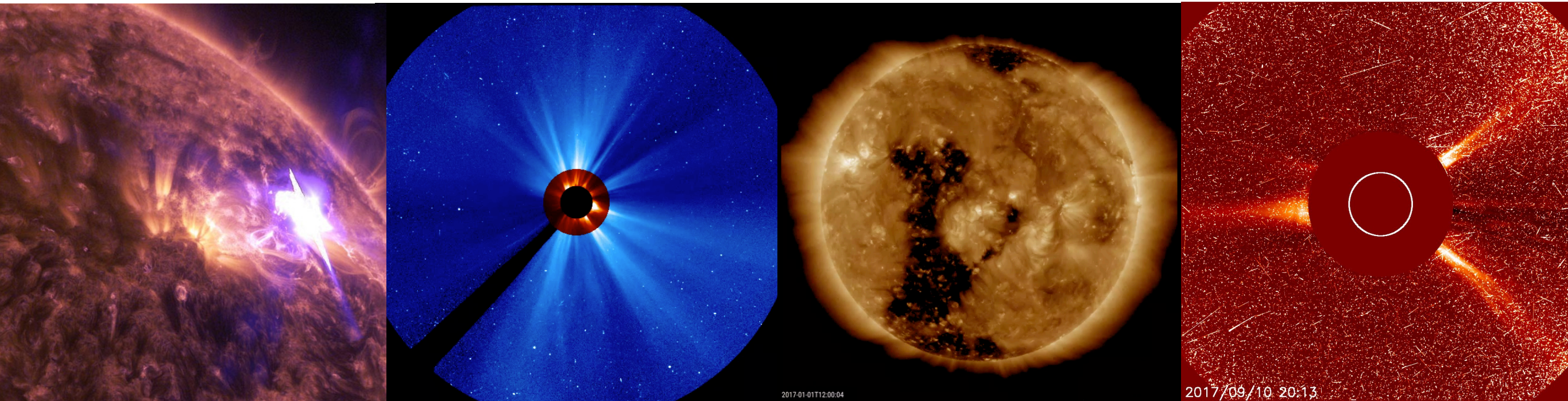
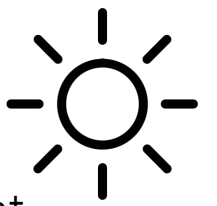


PARTICLE RAIN



SOLAR WEATHER & STORMS

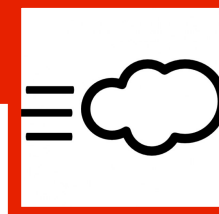
Energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection or CME, proton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



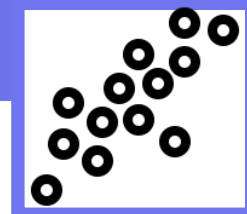
Flare



Coronal Mass Ejection
HSS

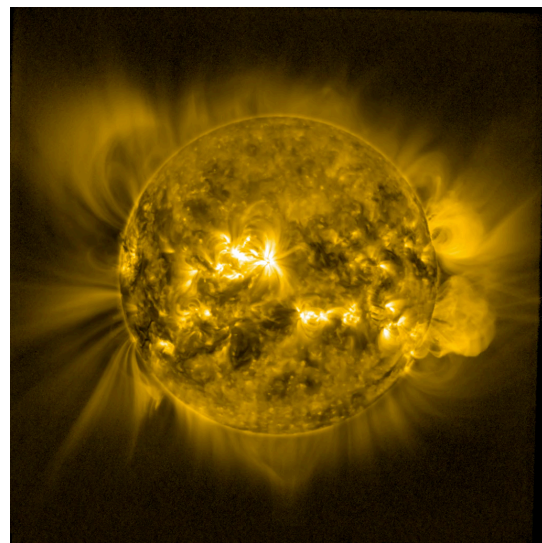
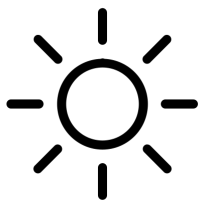


Particle Storm

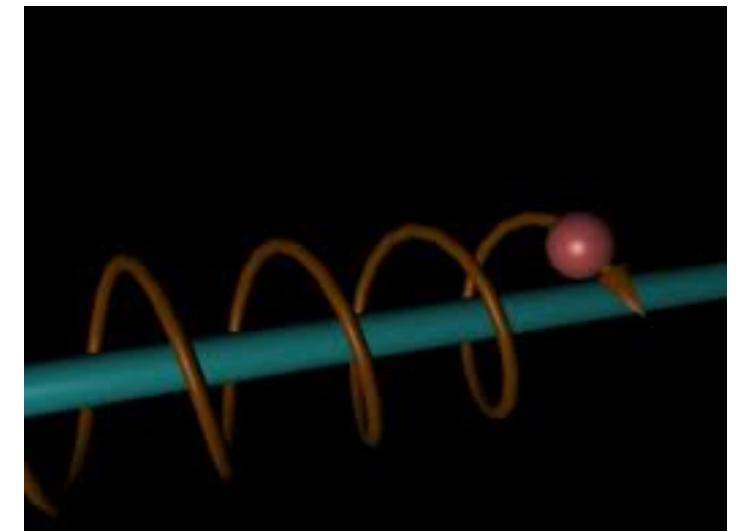
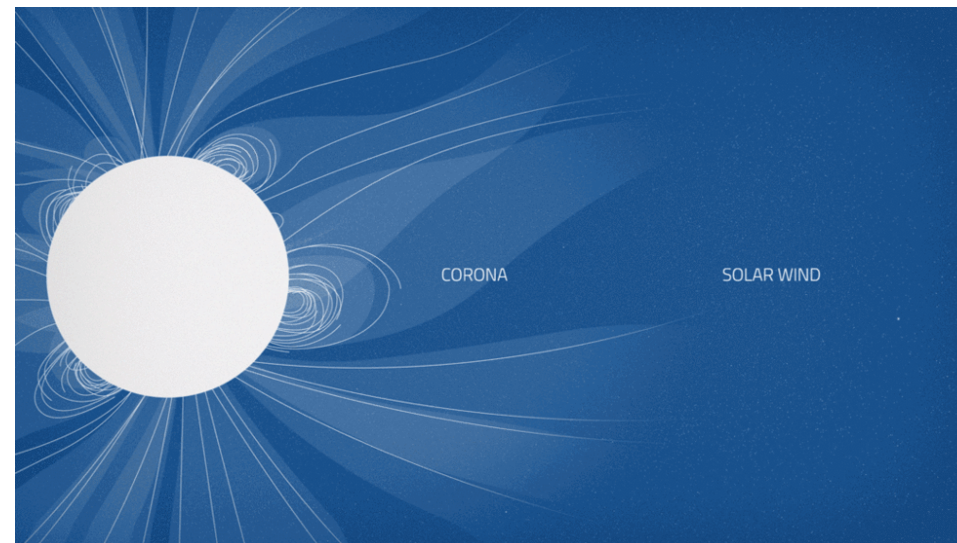


SOLAR SEASONS

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.



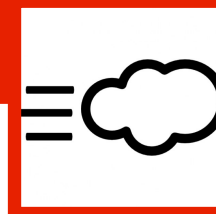
PROBA2/SWAP



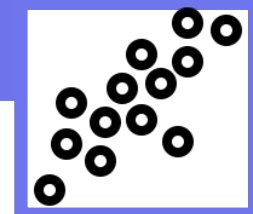
E.m. Radiation
Flares



Solar Wind
CME - CH



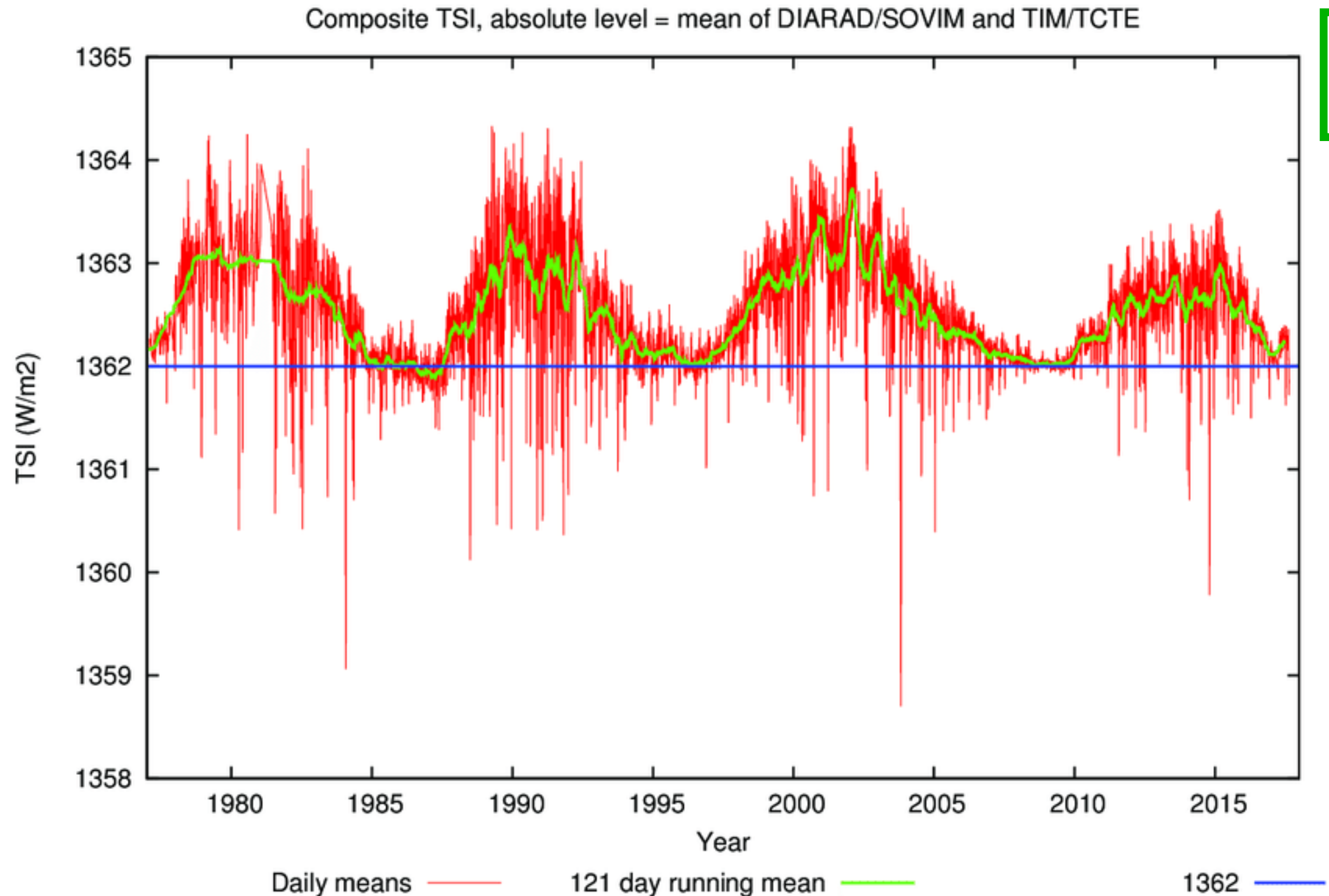
Solar Energetic
Particles



SEASONAL BEHAVIOUR OF LIGHT

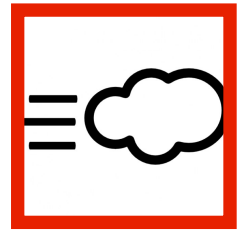
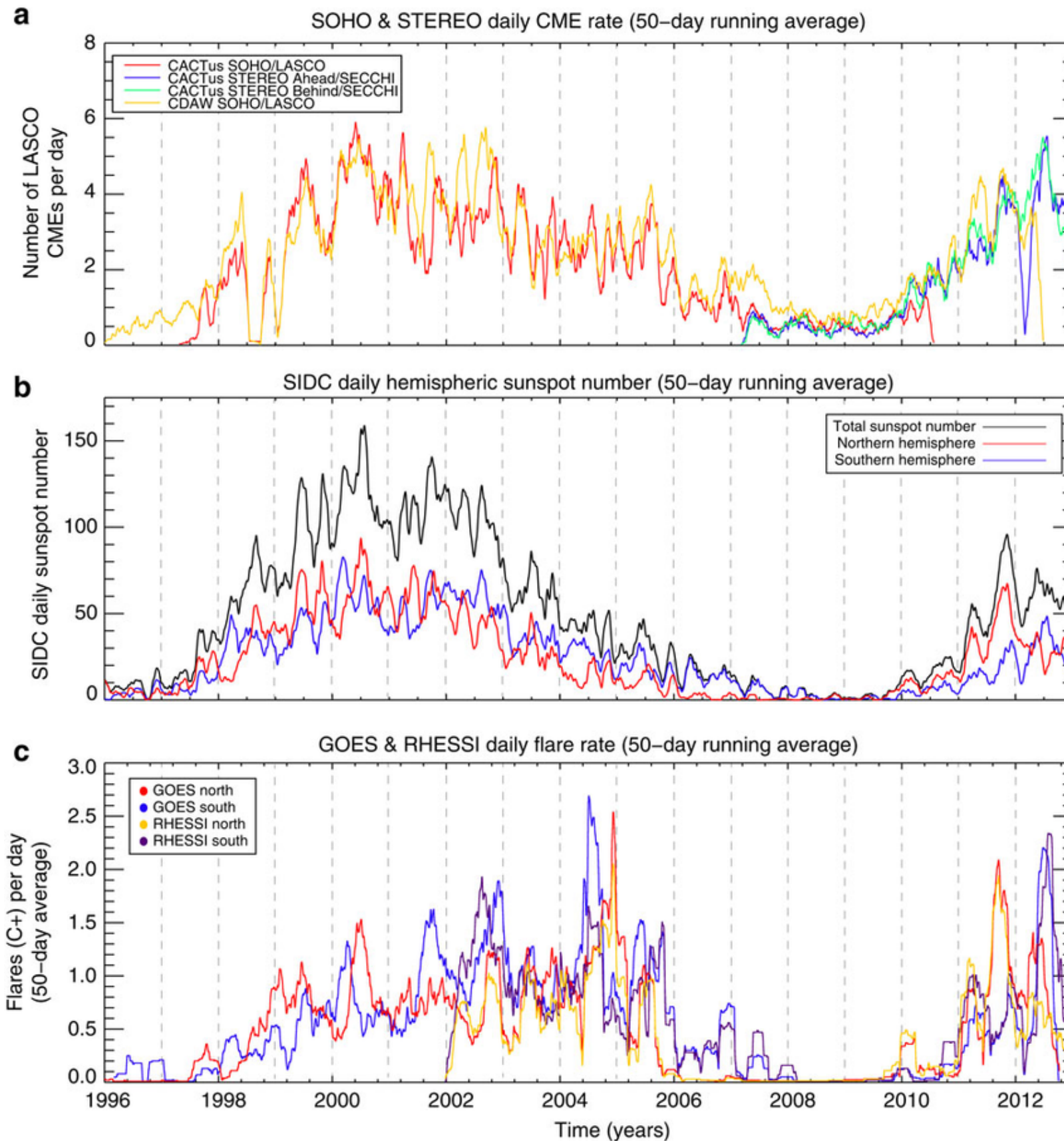
The solar irradiance, i.e. all the solar light, varies over the solar seasons.

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



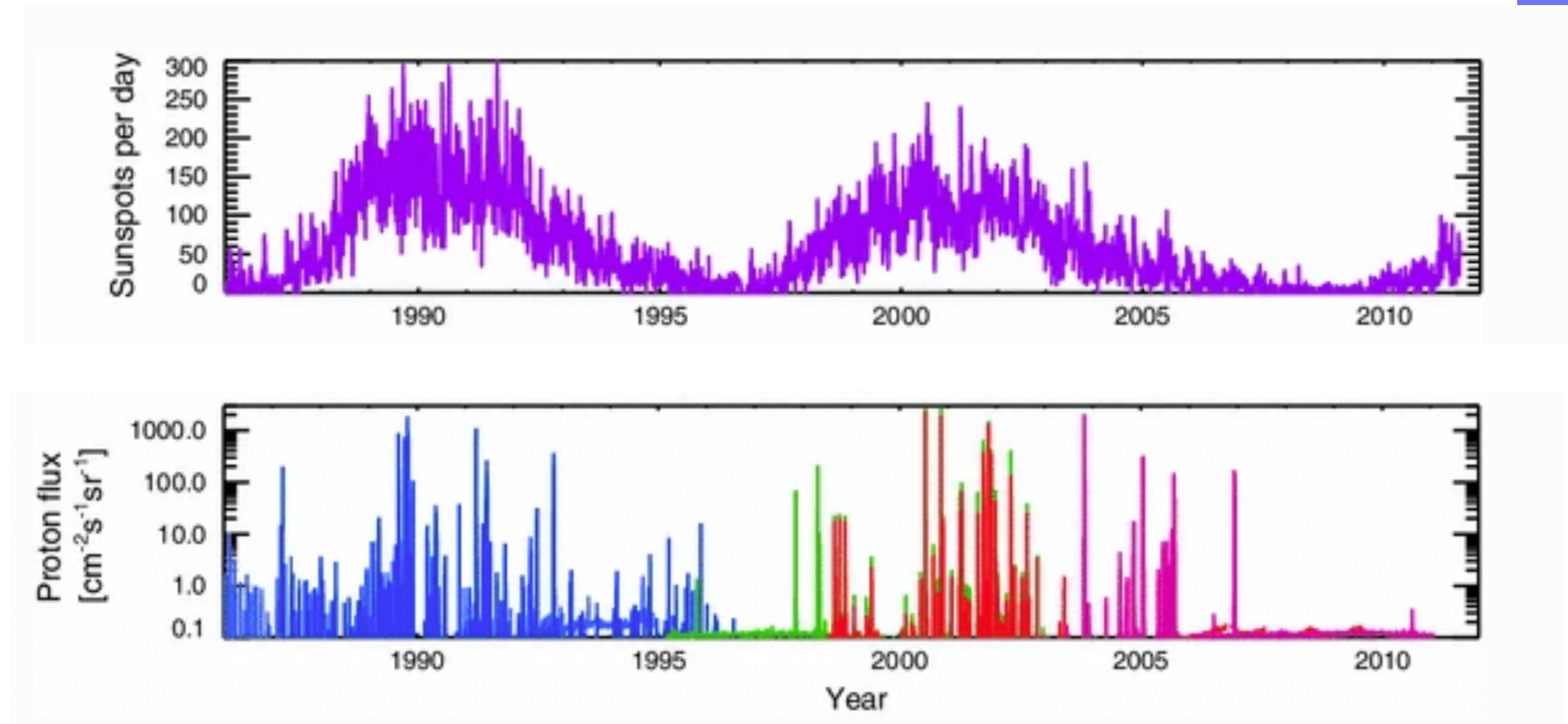
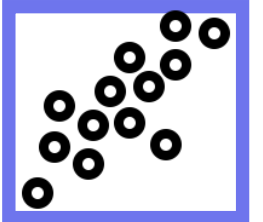
SEASONAL BEHAVIOUR OF SOLAR LIGHT & WIND STORMS

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.



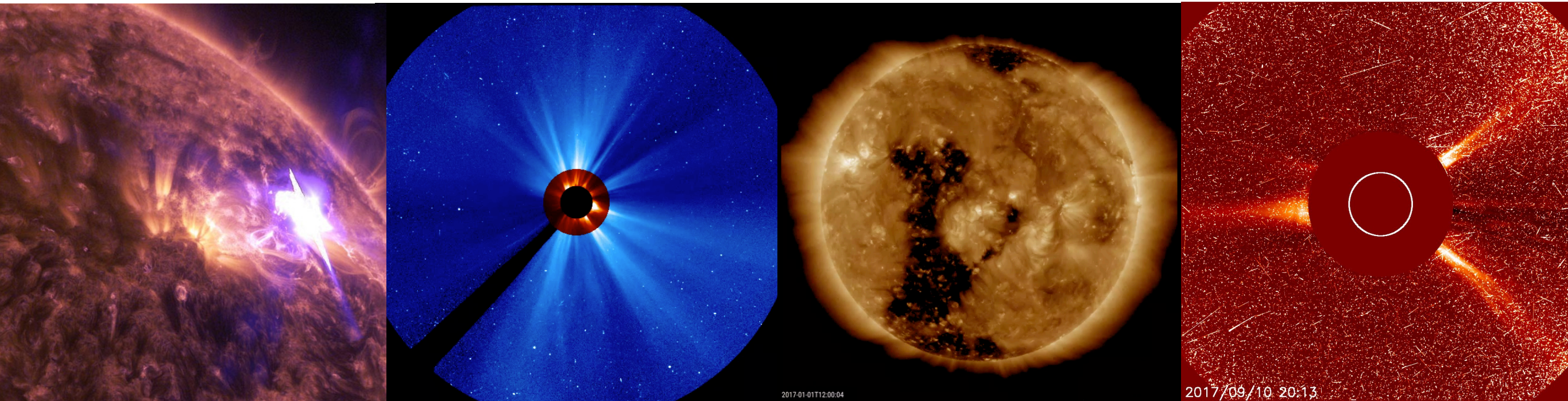
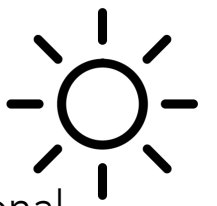
SEASONAL BEHAVIOUR OF SOLAR PARTICLE STORMS

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

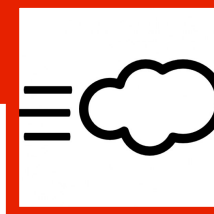
At a certain moment, energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass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



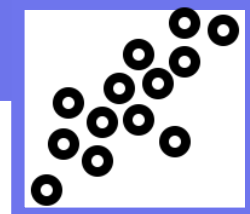
FLARE

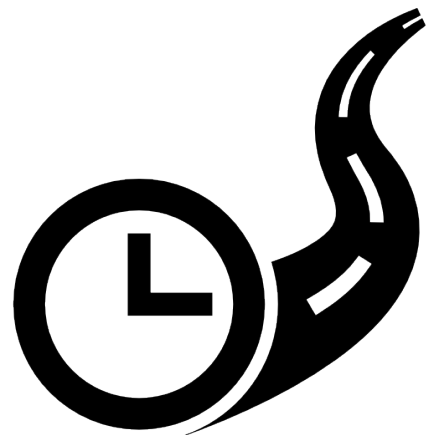


CORONAL MASS
EJECTION
CORONAL HOLE

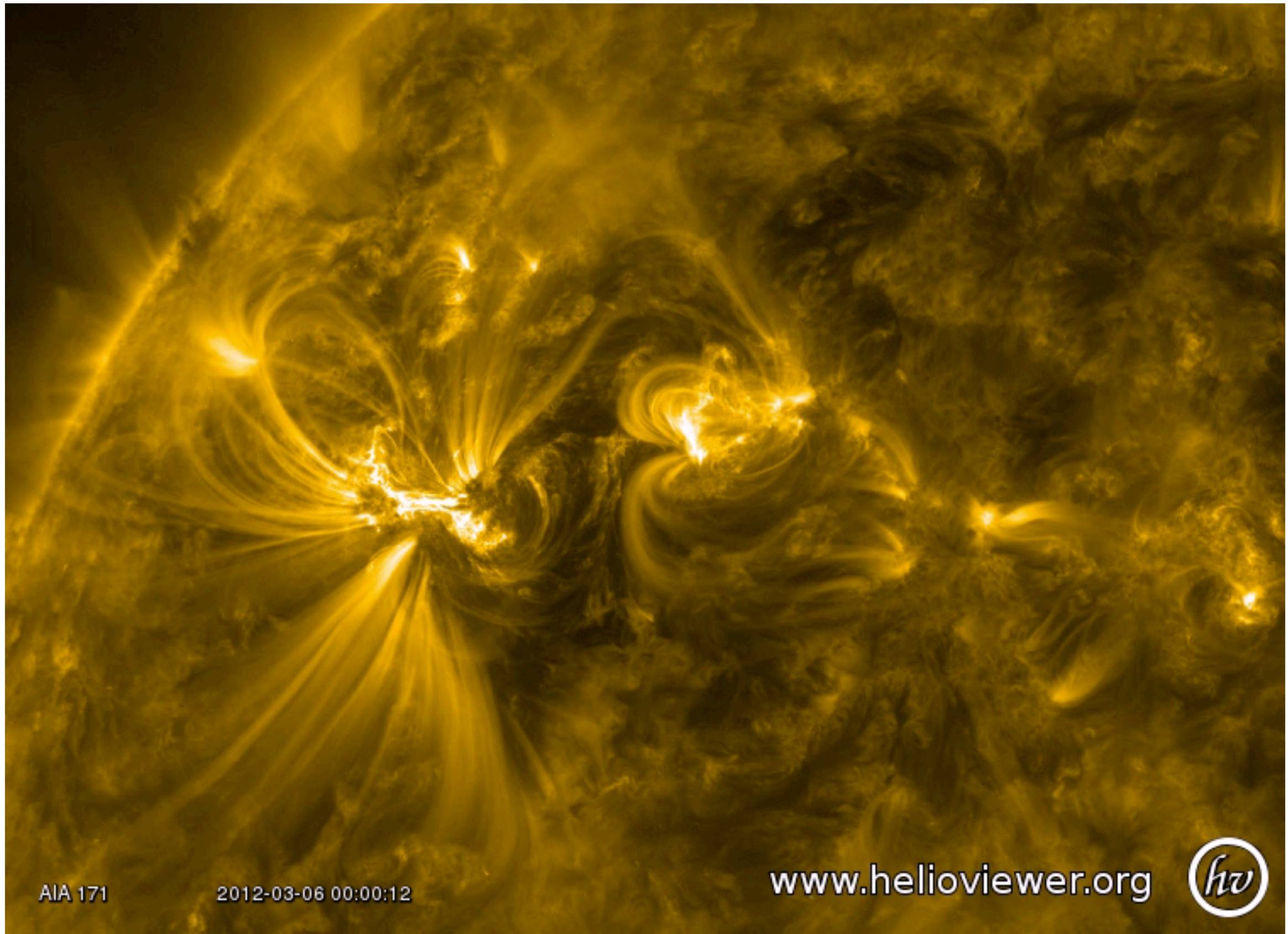


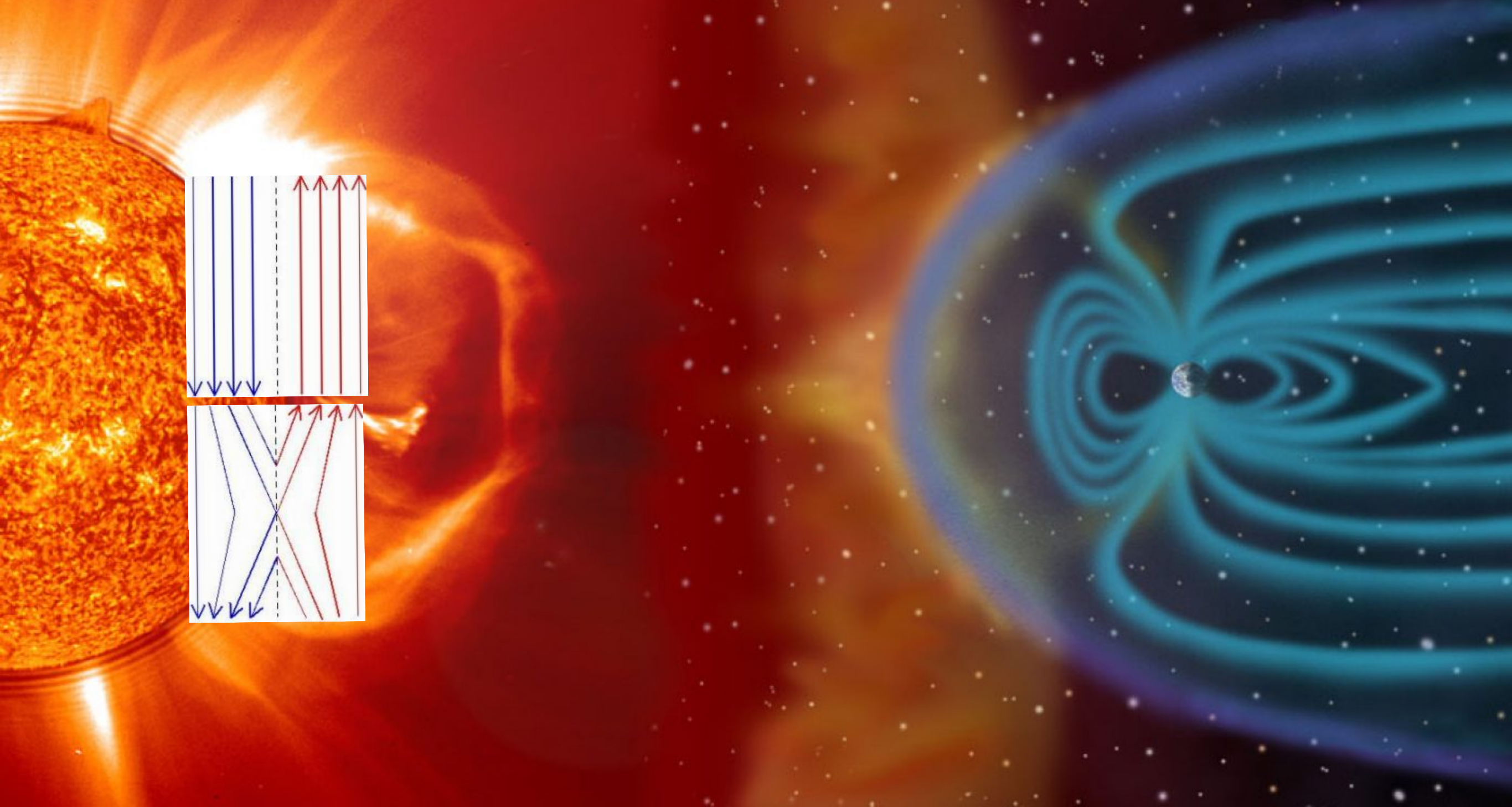
PARTICLE STORM





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, ...

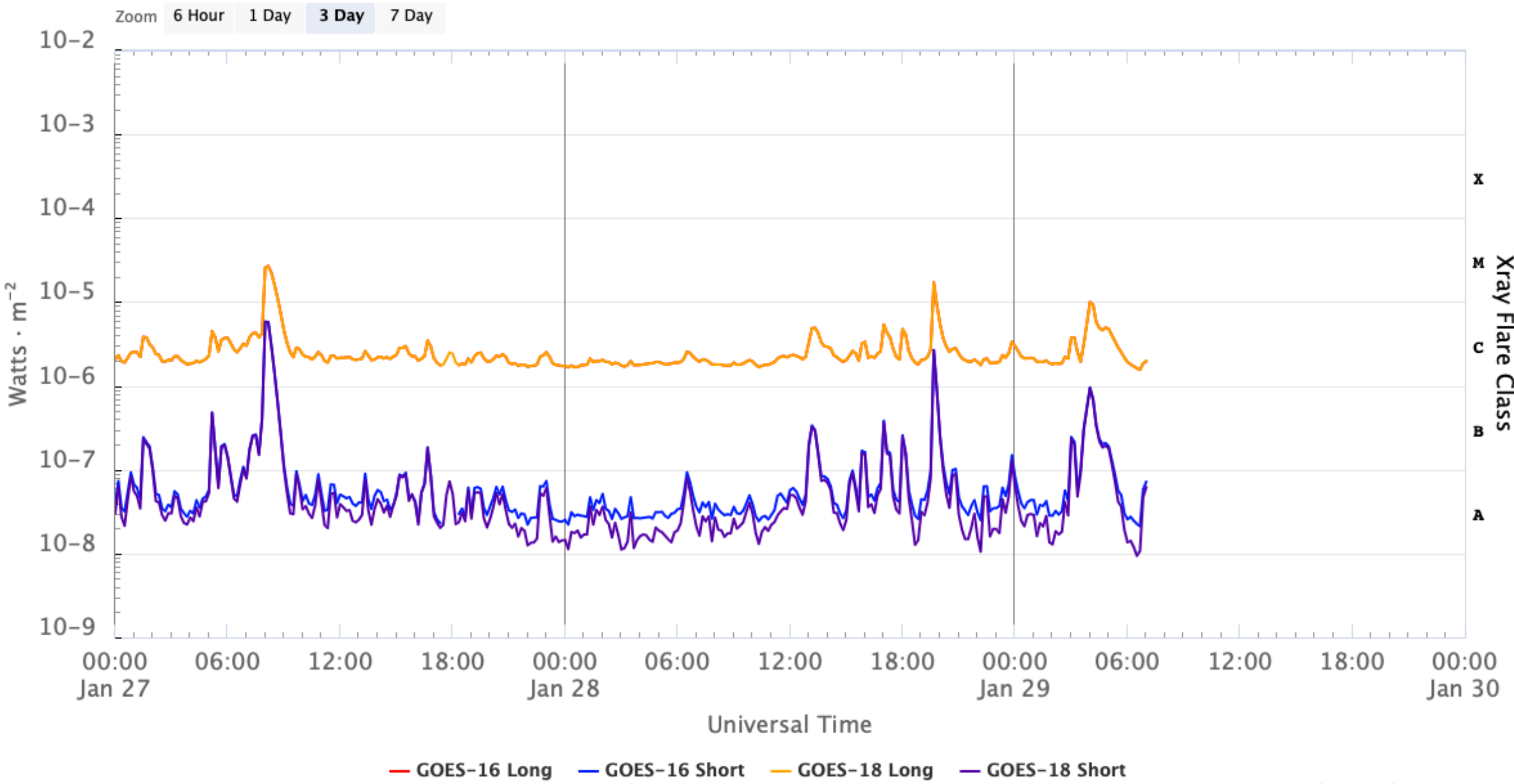
8 MIN



STORM SCALE



GOES X-Ray Flux (1-minute data)



Updated 2025-01-29 07:00 UTC

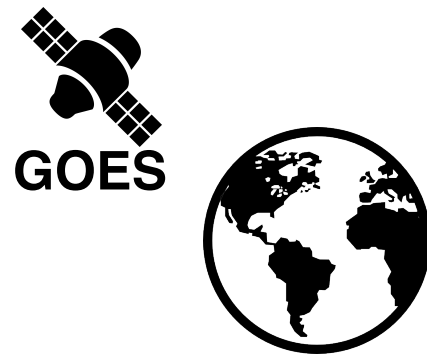
Space Weather Prediction Center



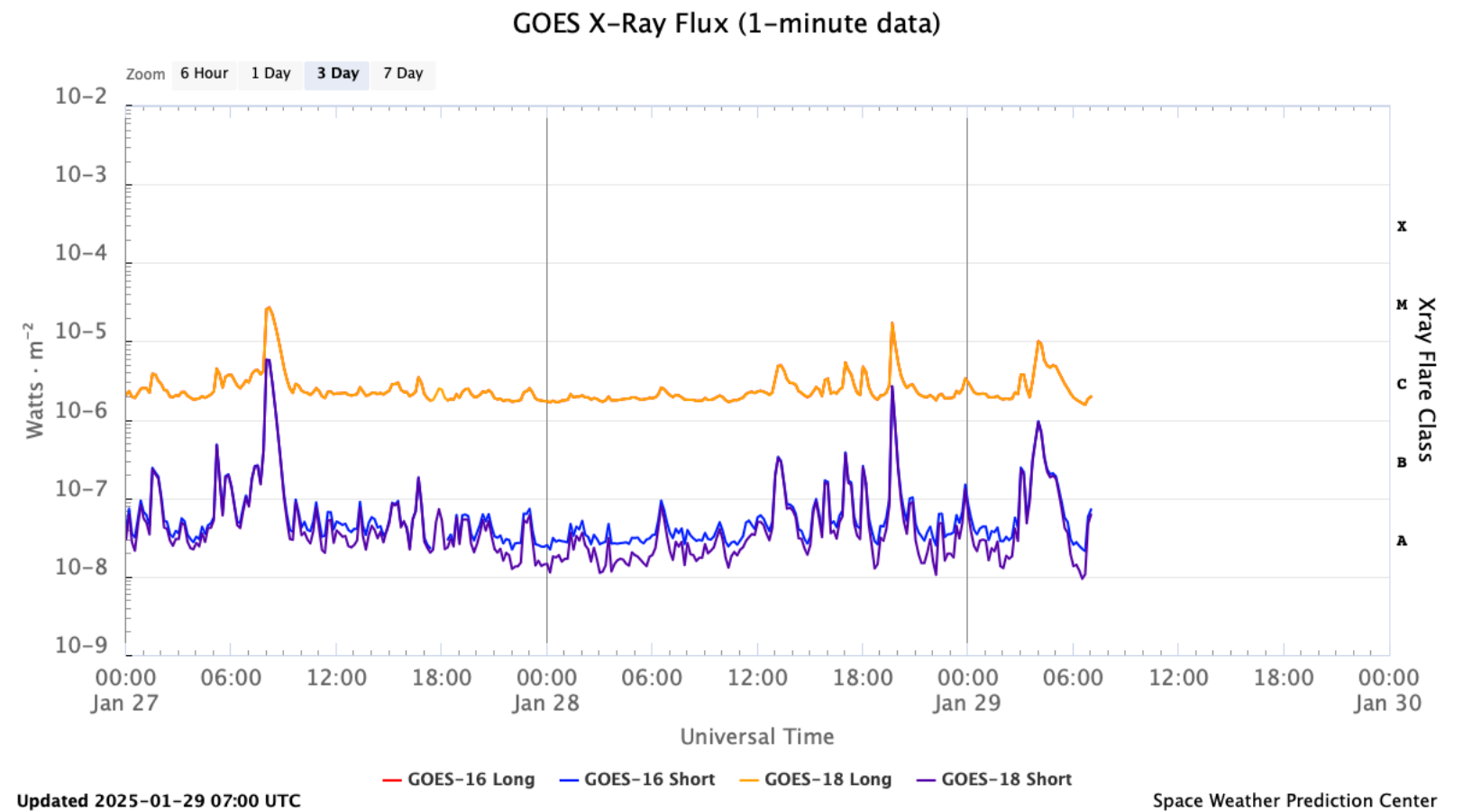
<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



STORM SCALE



A,B,C,M,X



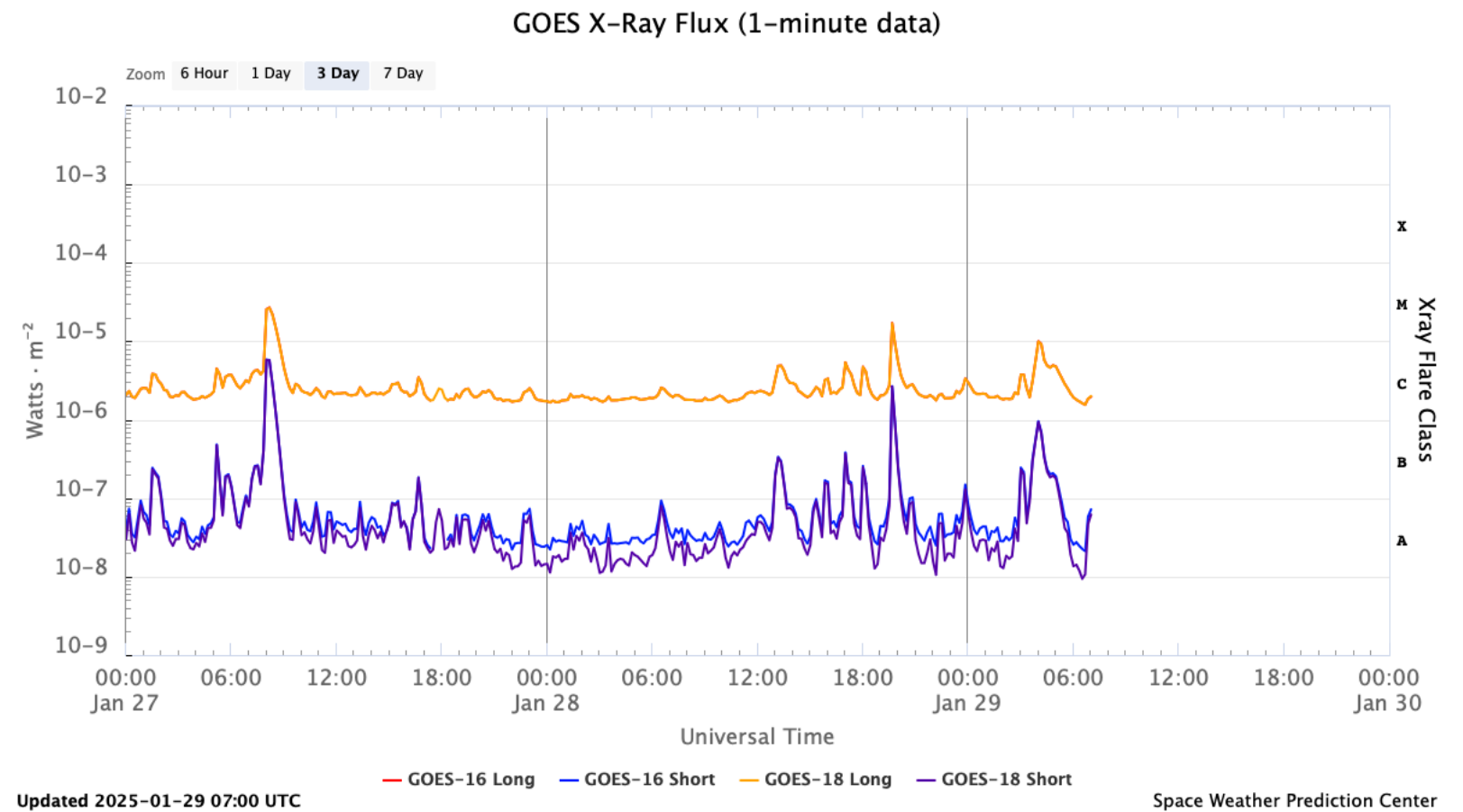
<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



DURATION



MINs to HOUR

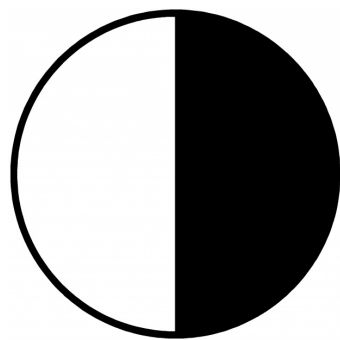


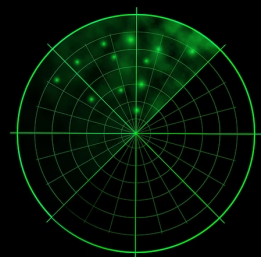
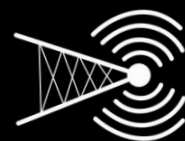
AREA OF IMPACT

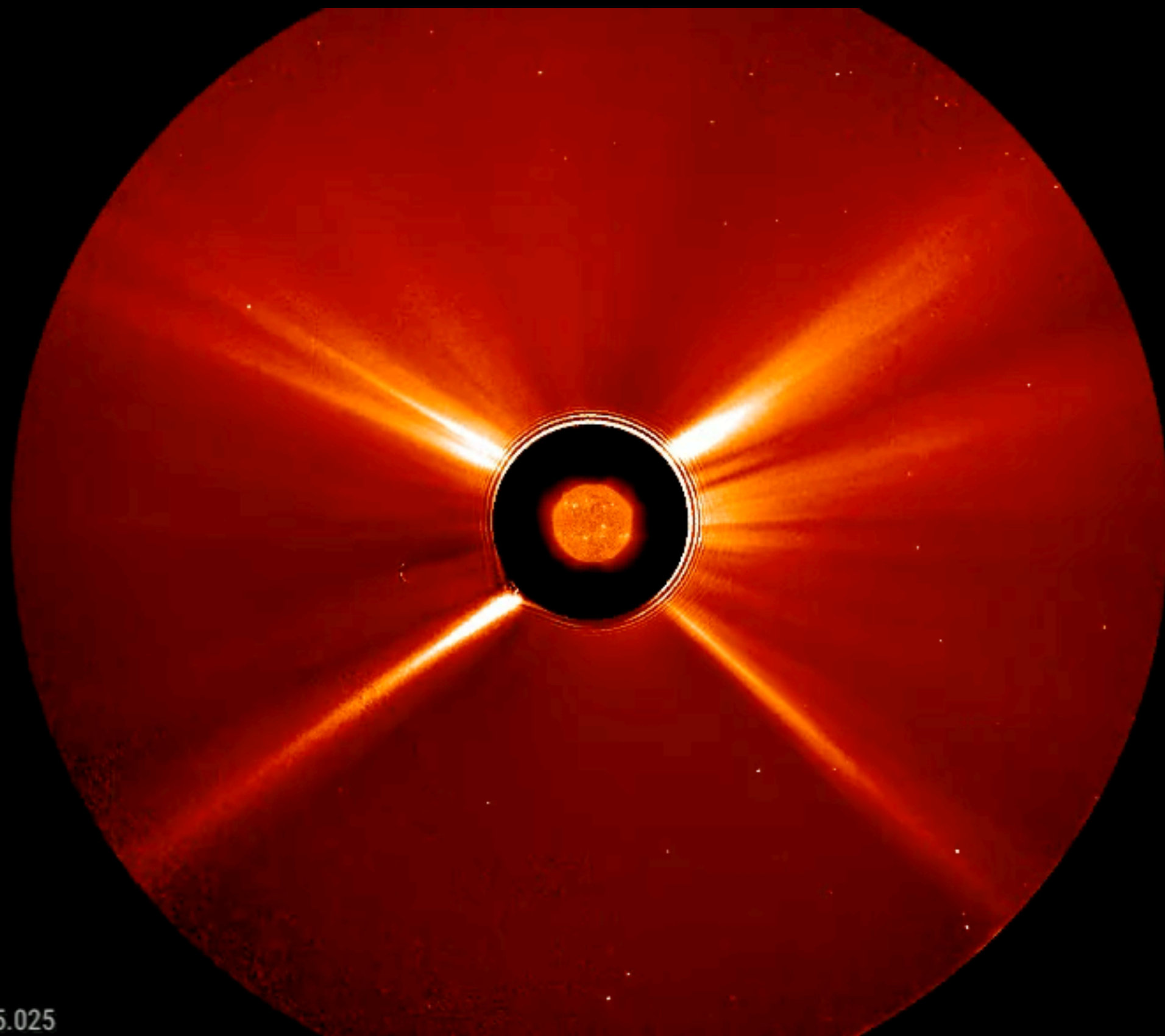
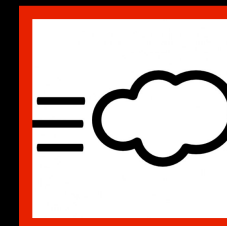


AREA OF IMPACT

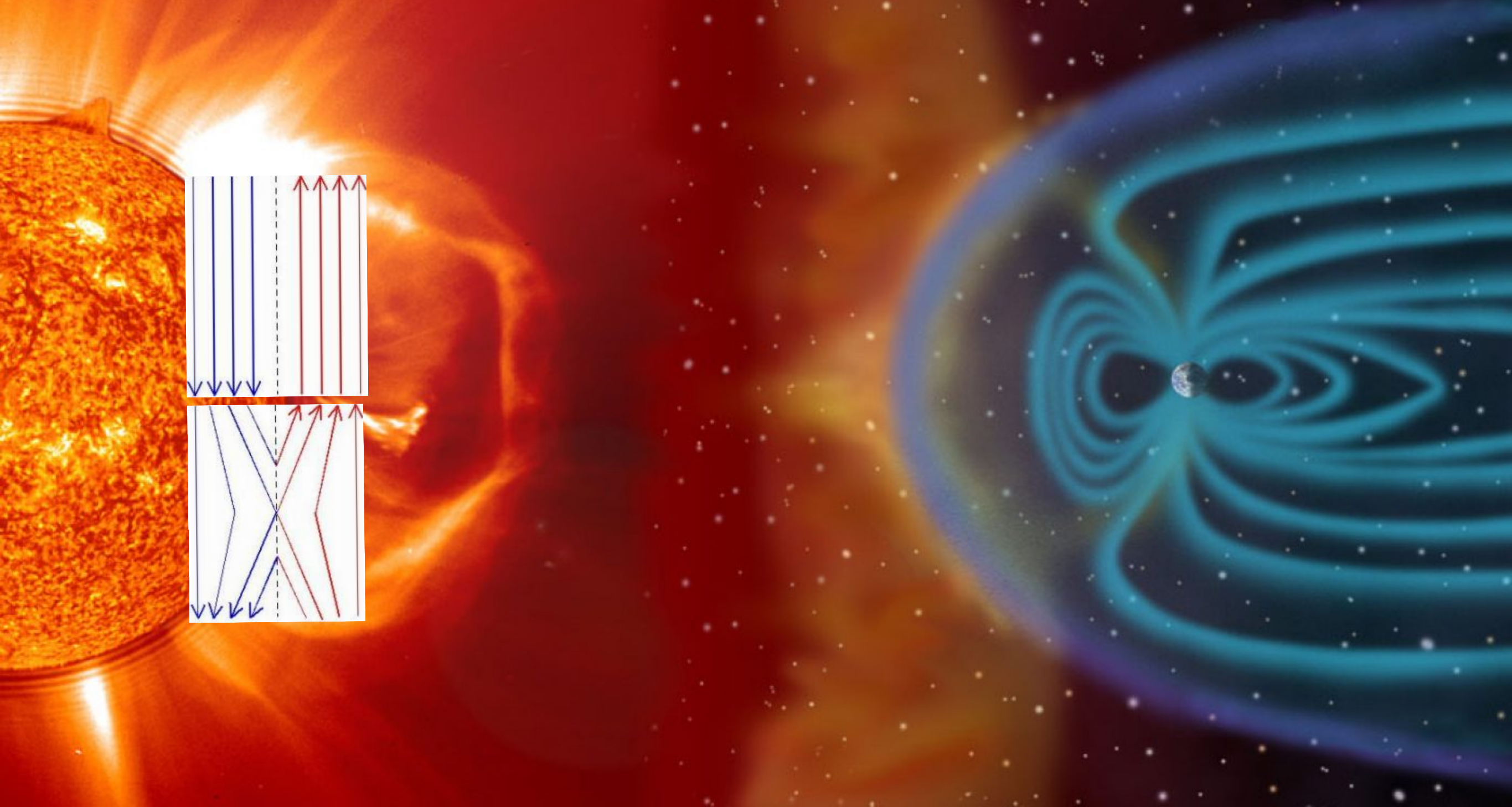
Illuminated area







2022-02-15T16:25:45.025



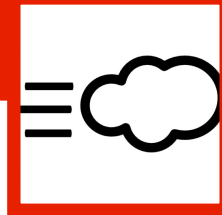
MAGNETIC RECONNECTION



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





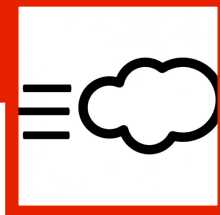
AU TRANSIT TIME

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.

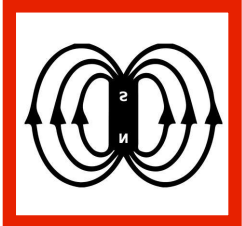
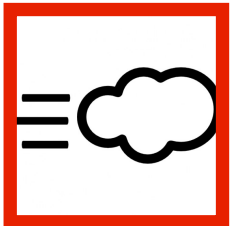
8 MIN



DAYS



STORM SCALE - GEOMAGNETIC STORM

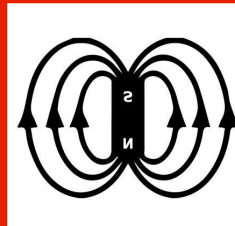


STORM SCALE



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

A,B,C,M,X

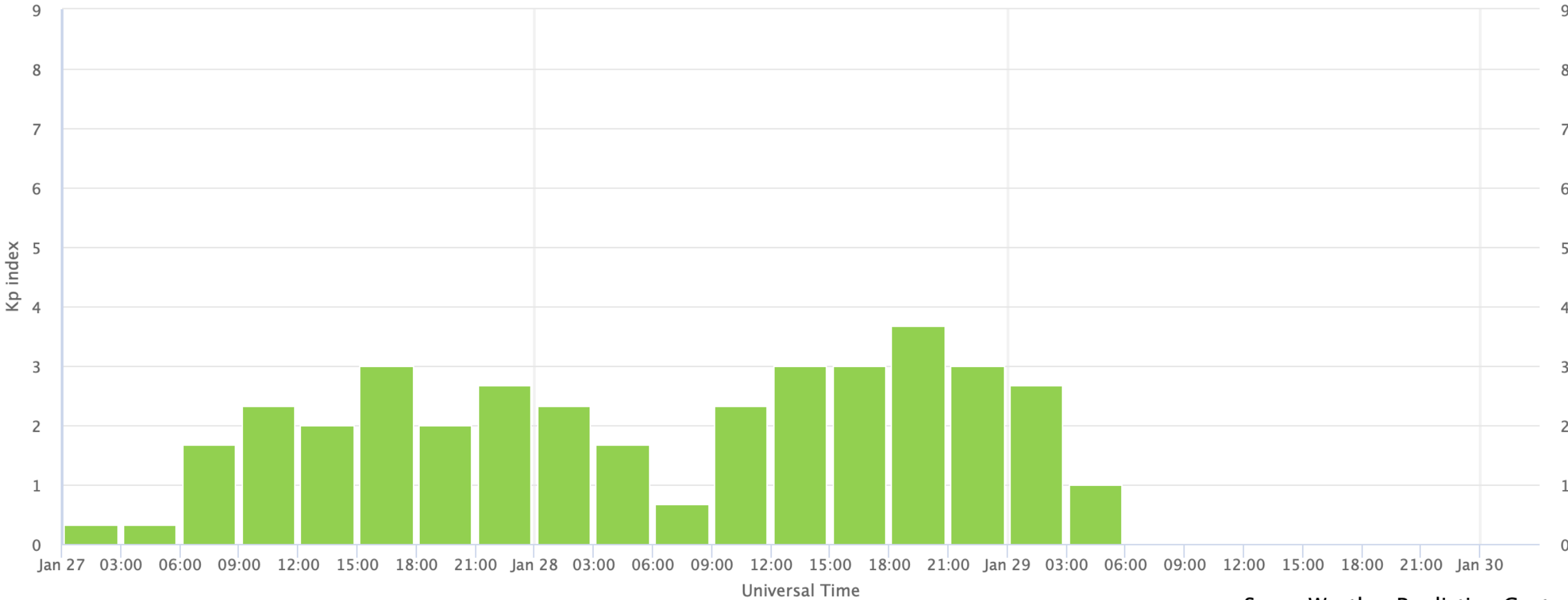


STORM SCALE



Estimated Planetary K index (3 hour data)

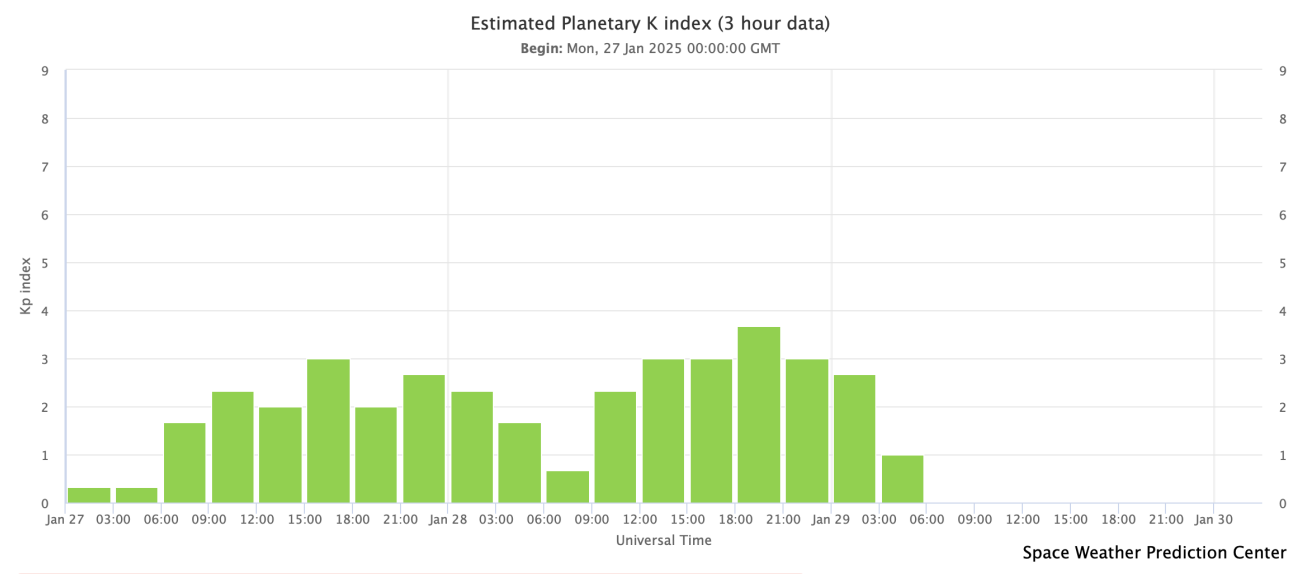
Begin: Mon, 27 Jan 2025 00:00:00 GMT



Space Weather Prediction Center



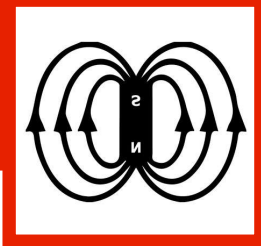
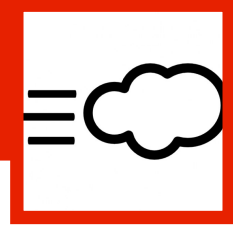
STORM SCALE



A,B,C,M,X



Kp
0 - 9



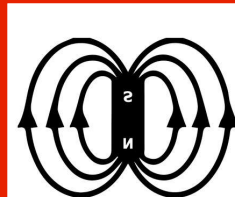
DURATION



MINs to HOUR



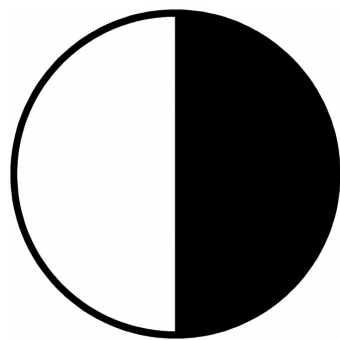
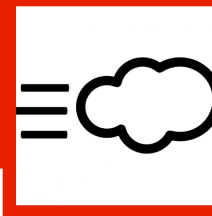
DAY+

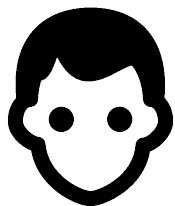
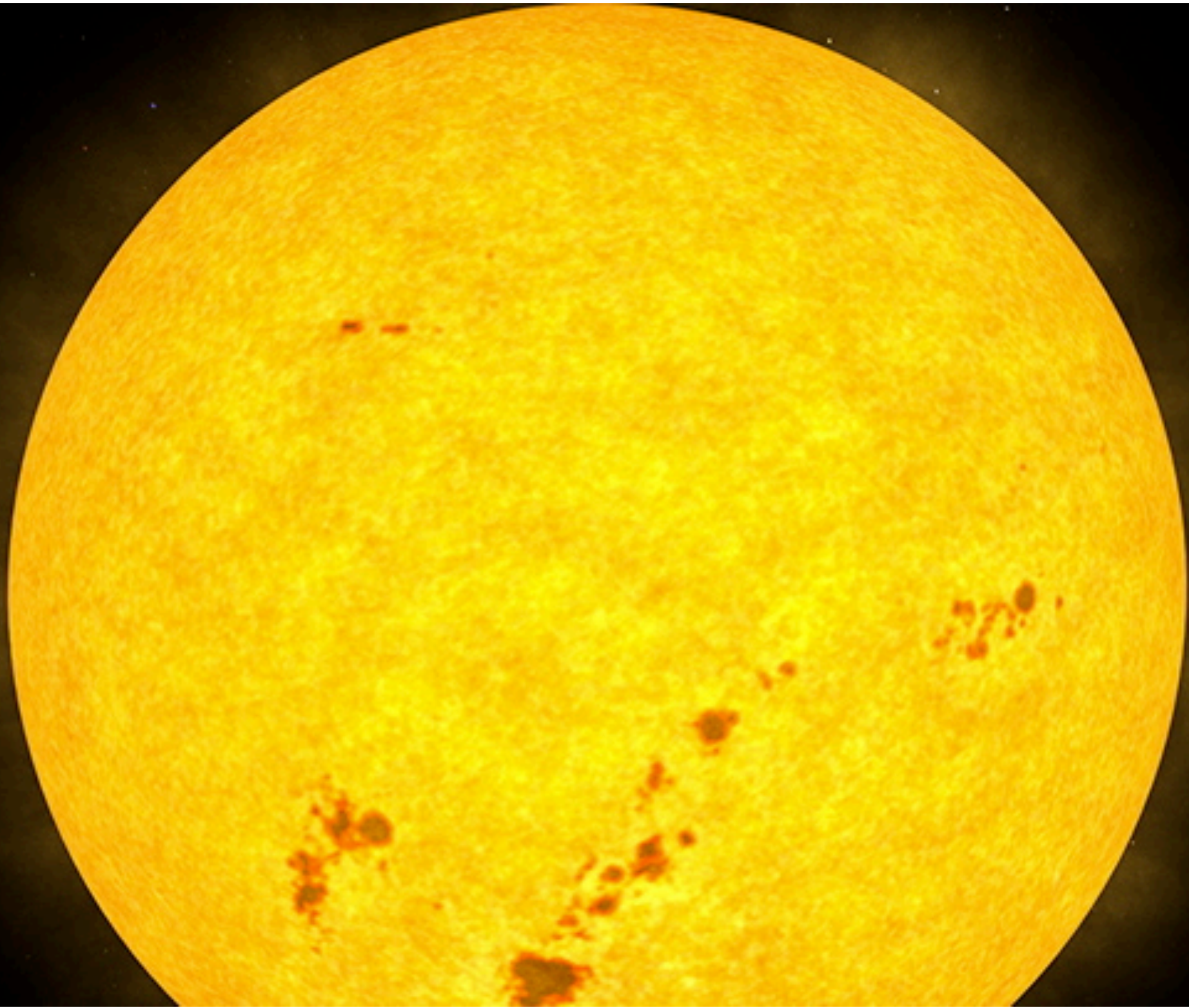
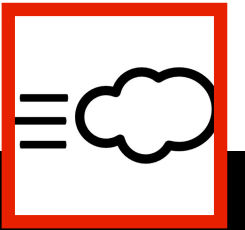


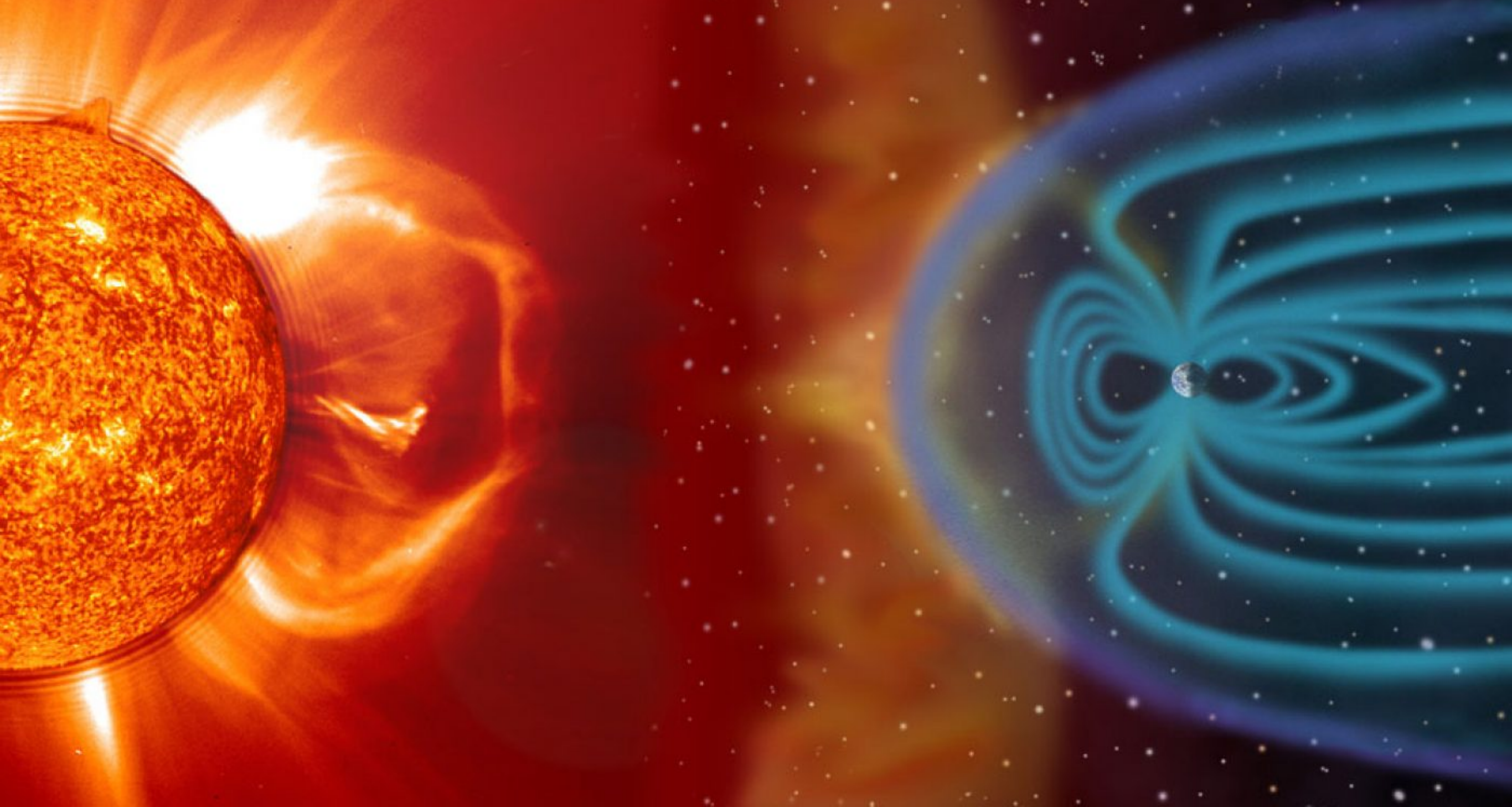
AREA OF IMPACT



Illuminated area

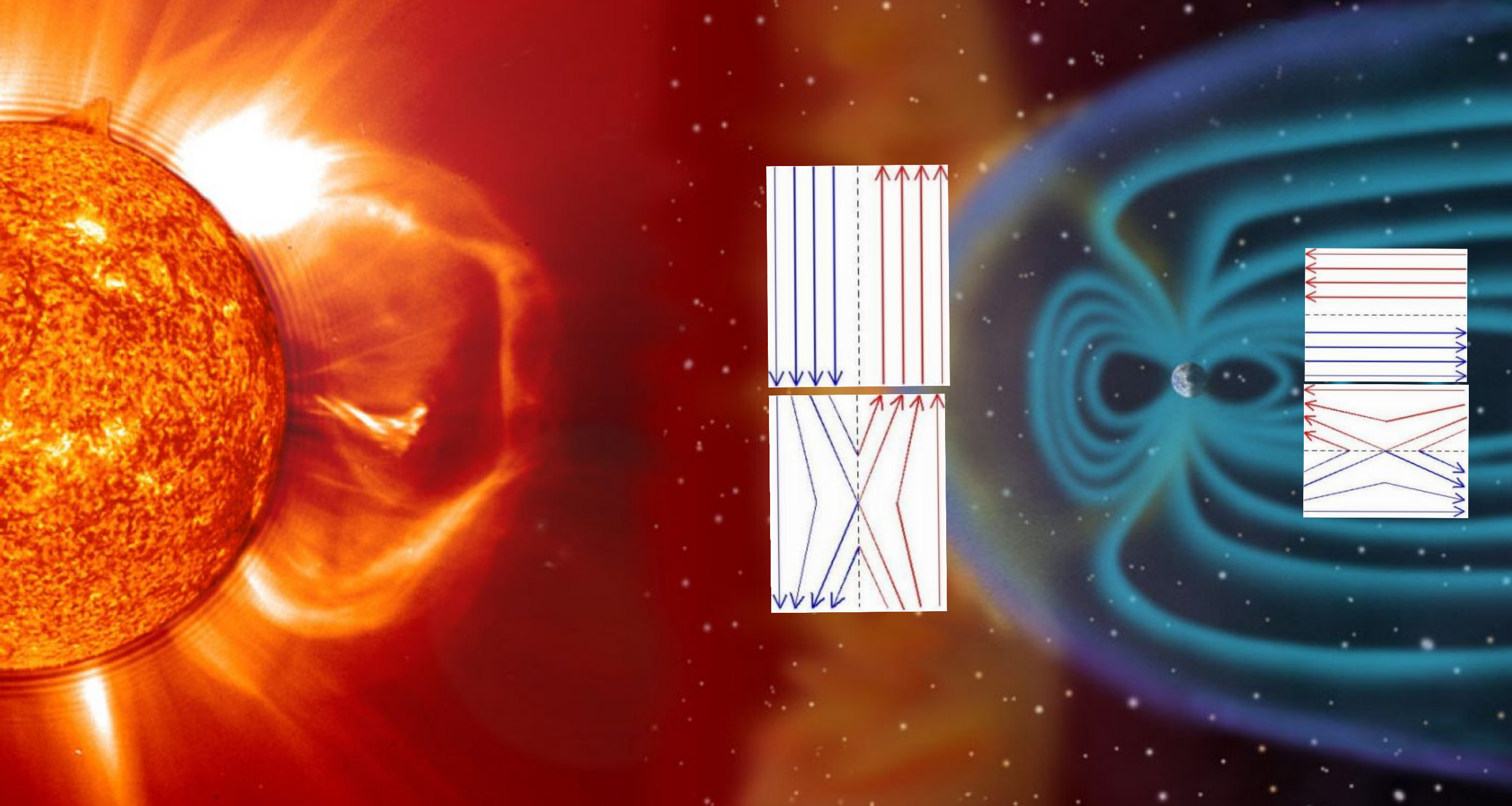






RECONNECTION

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.

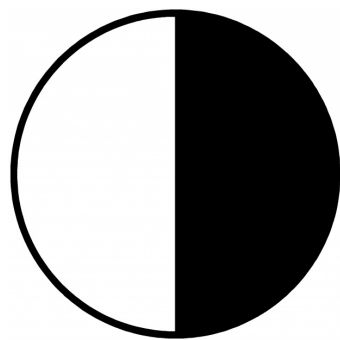


RECONNECTION

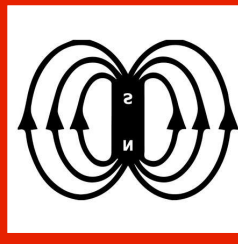
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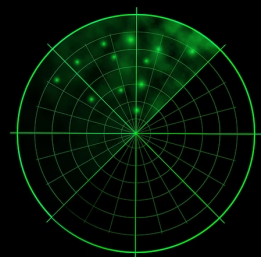
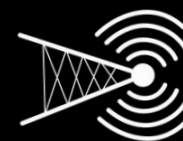
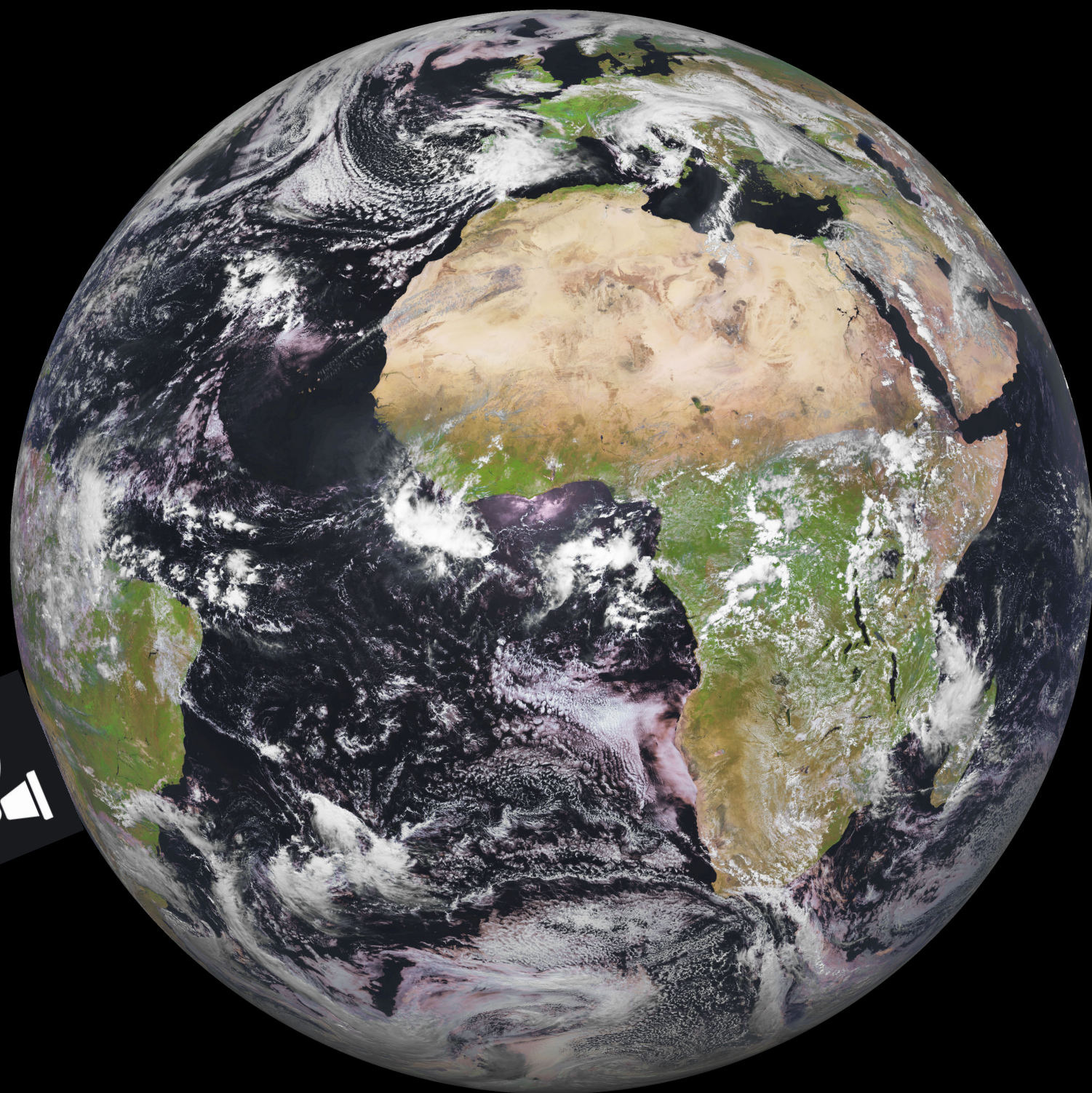
AREA OF IMPACT

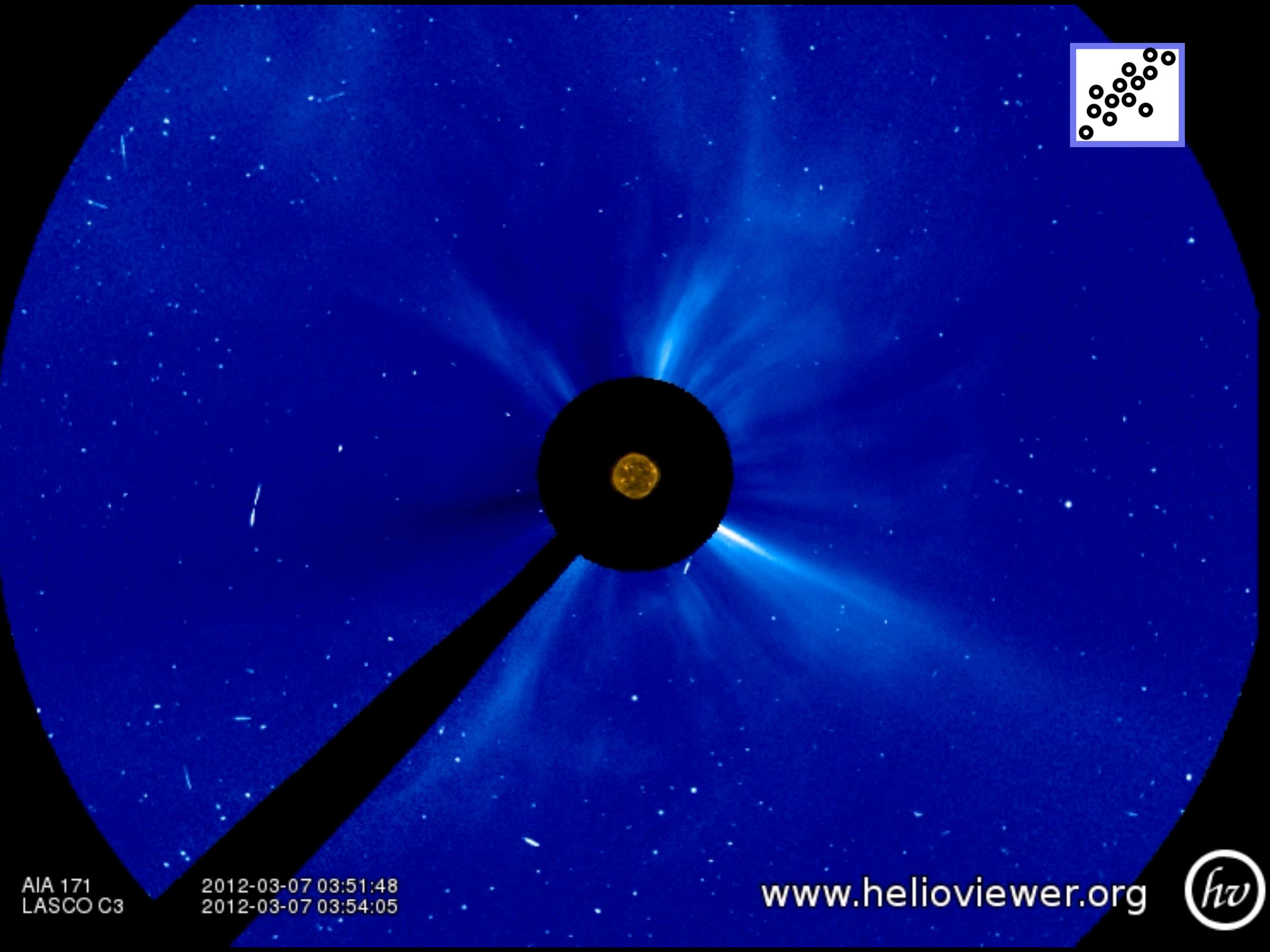
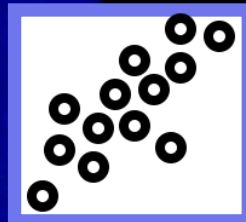
Illuminated area



Polar Cap







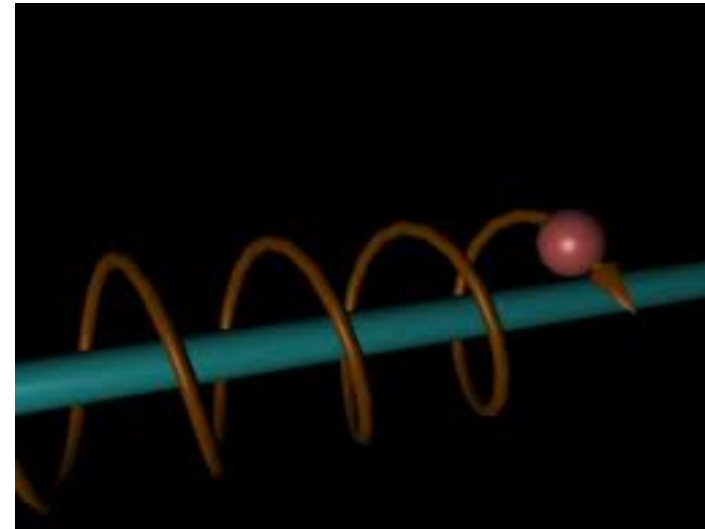
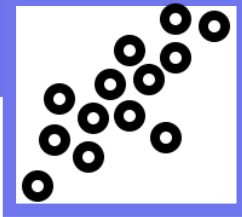
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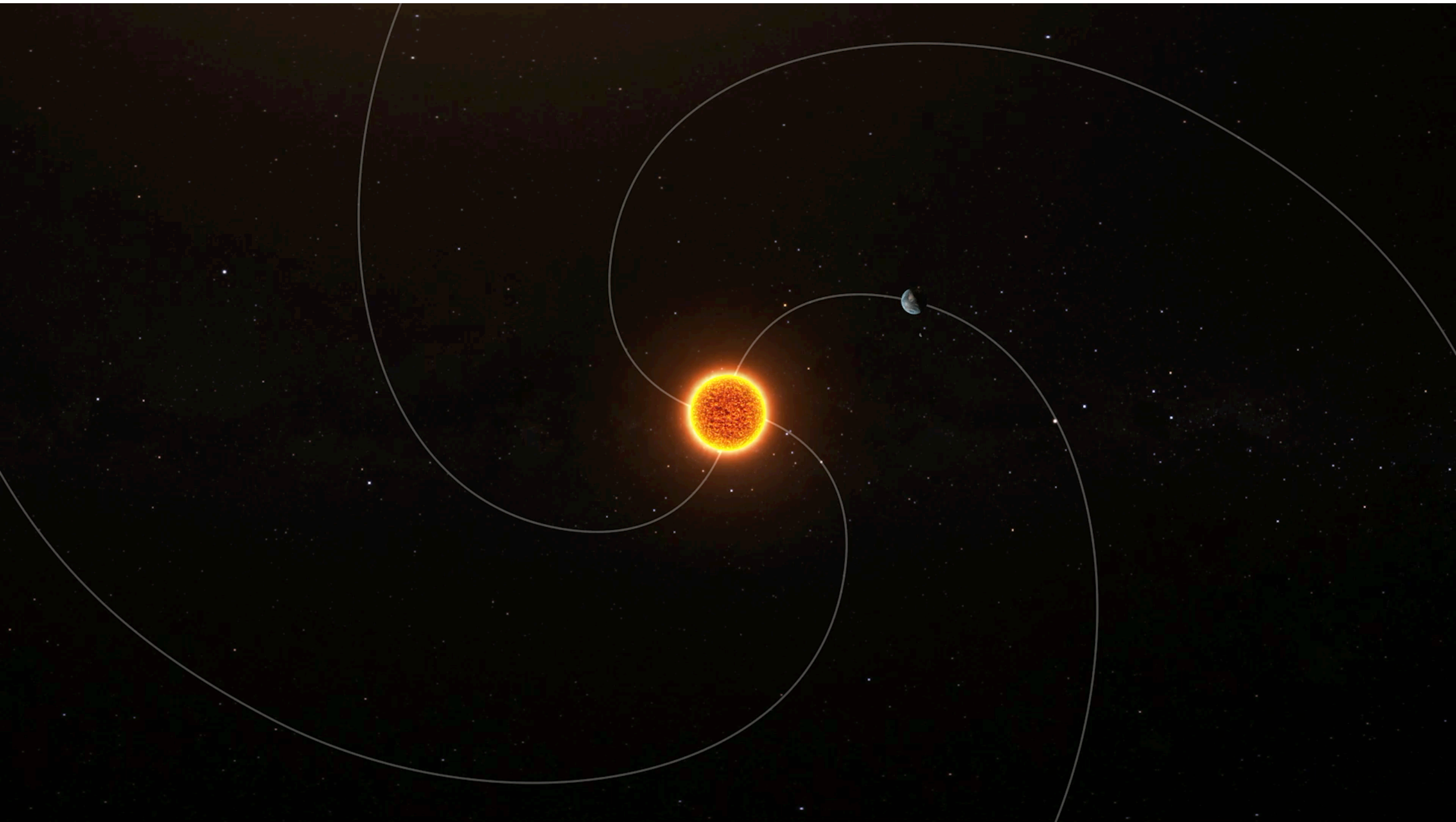
www.helioviewer.org



SOLAR PARTICLES



Solar energetic particles follow magnetic field lines.





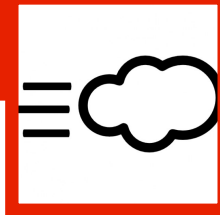
AU TRANSIT TIME

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





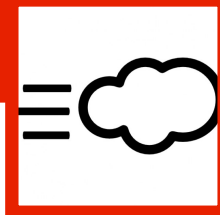
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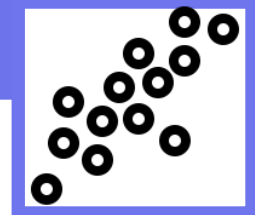
8 MIN



DAYS



HOUR



STORM SCALE

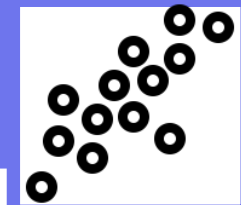
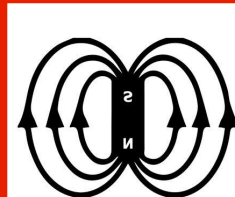


<https://www.swpc.noaa.gov/products/goes-proton-flux>

A,B,C,M,X



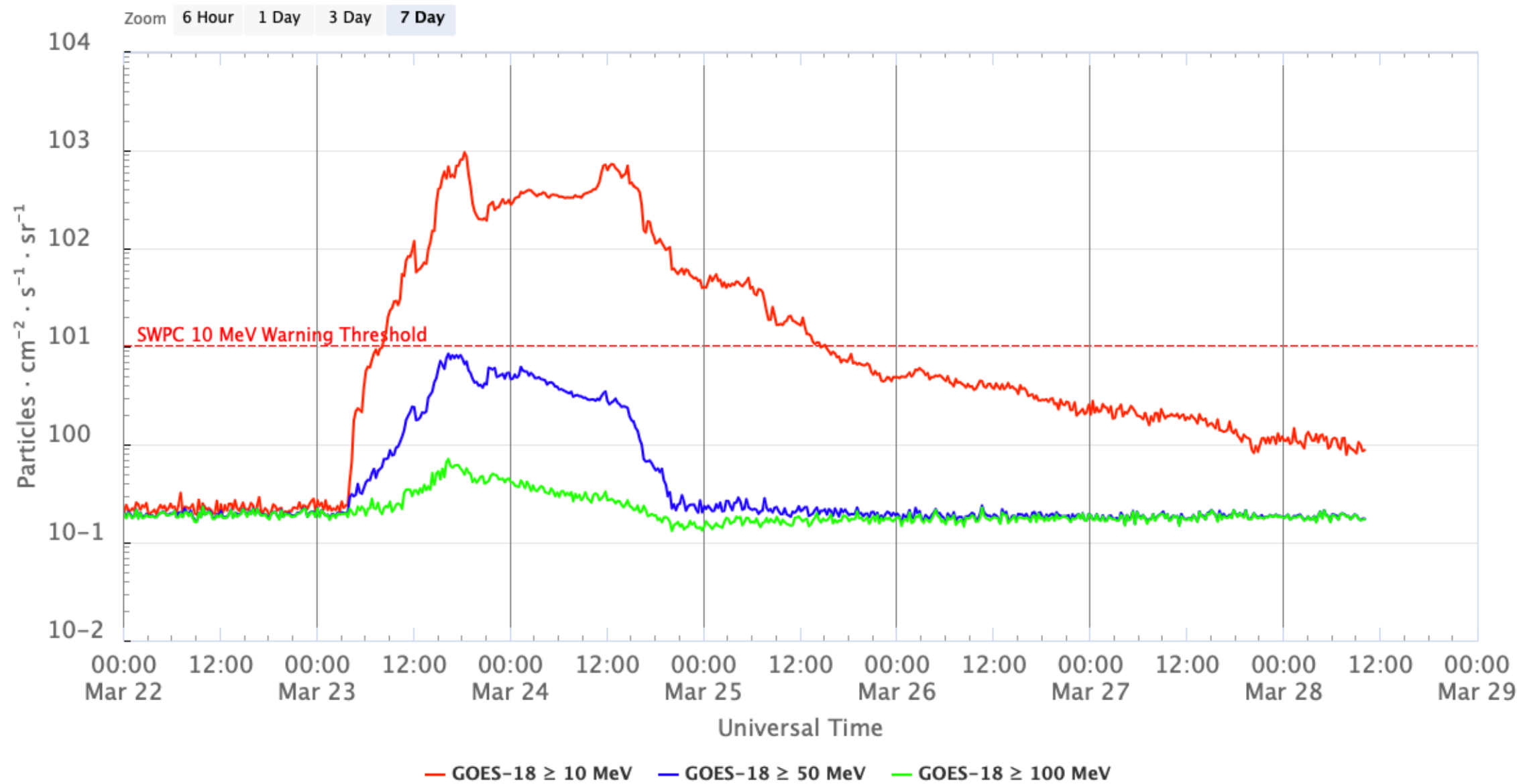
Kp
0 - 9



STORM SCALE



GOES Proton Flux (5-minute data)

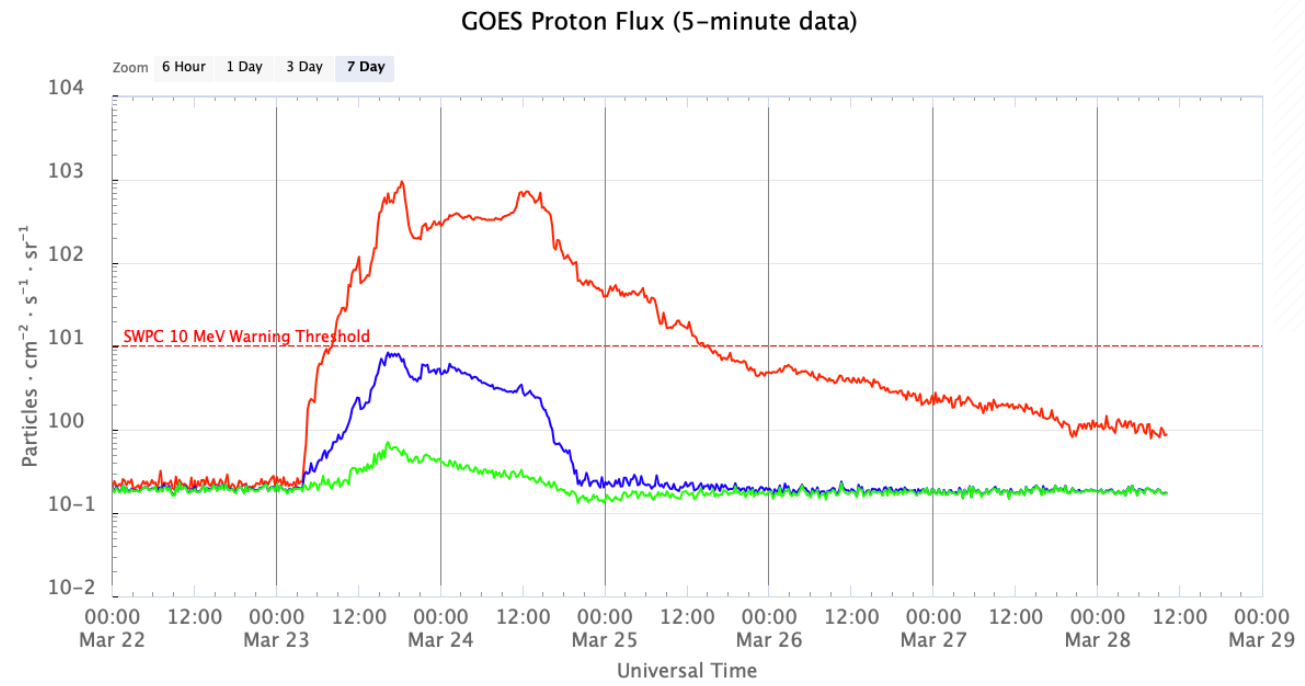


Updated 2024-03-28 10:10 UTC

Space Weather Prediction Center



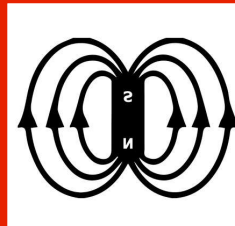
STORM SCALE



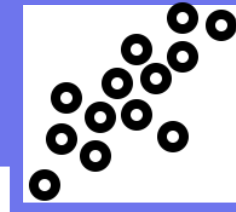
A,B,C,M,X



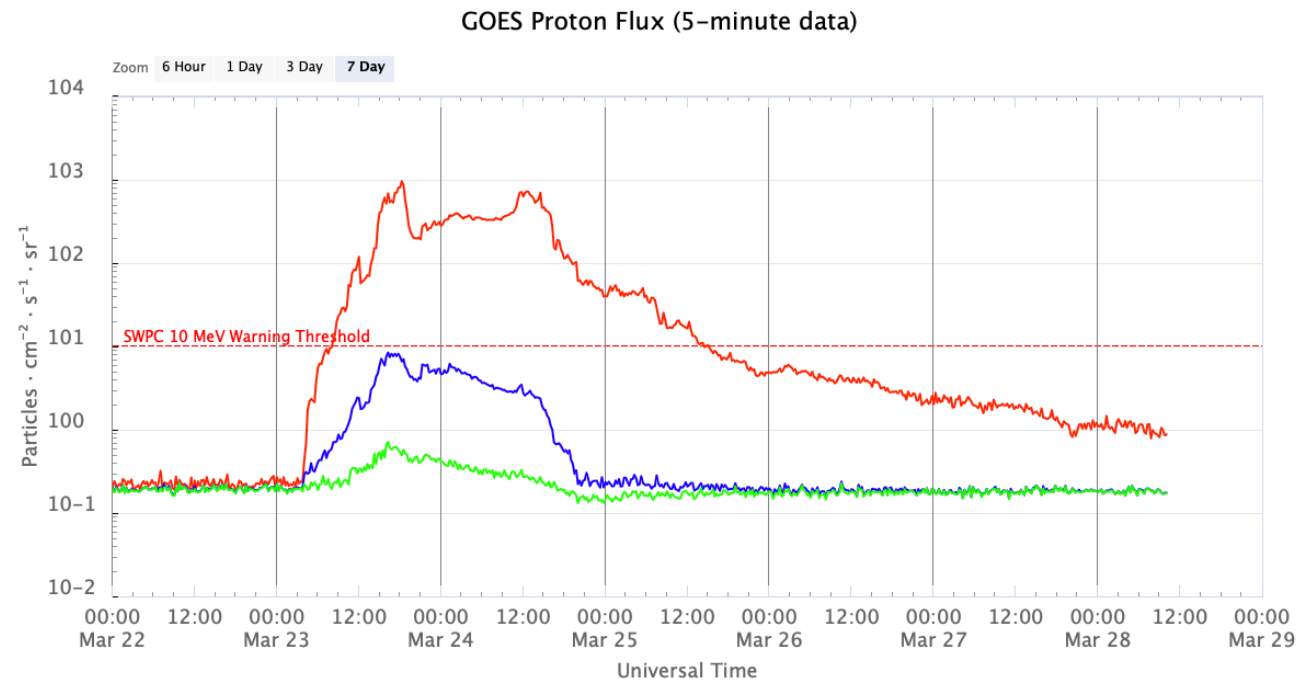
Kp
0 - 9



Storm - major storm



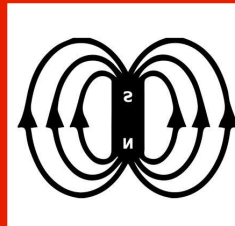
DURATION



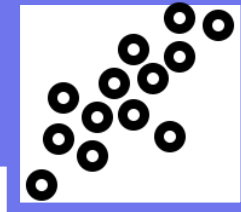
MINs to HOUR



DAY+



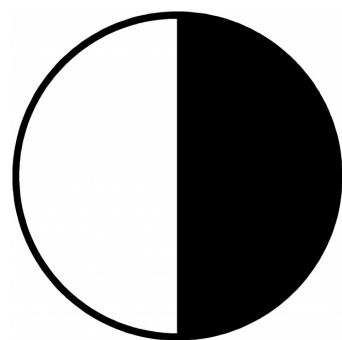
HOURS to DAYS



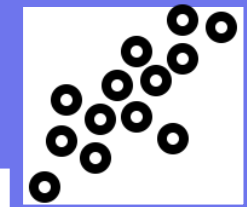
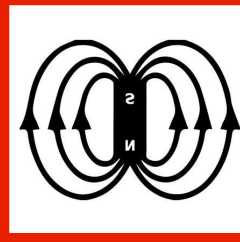
AREA OF IMPACT

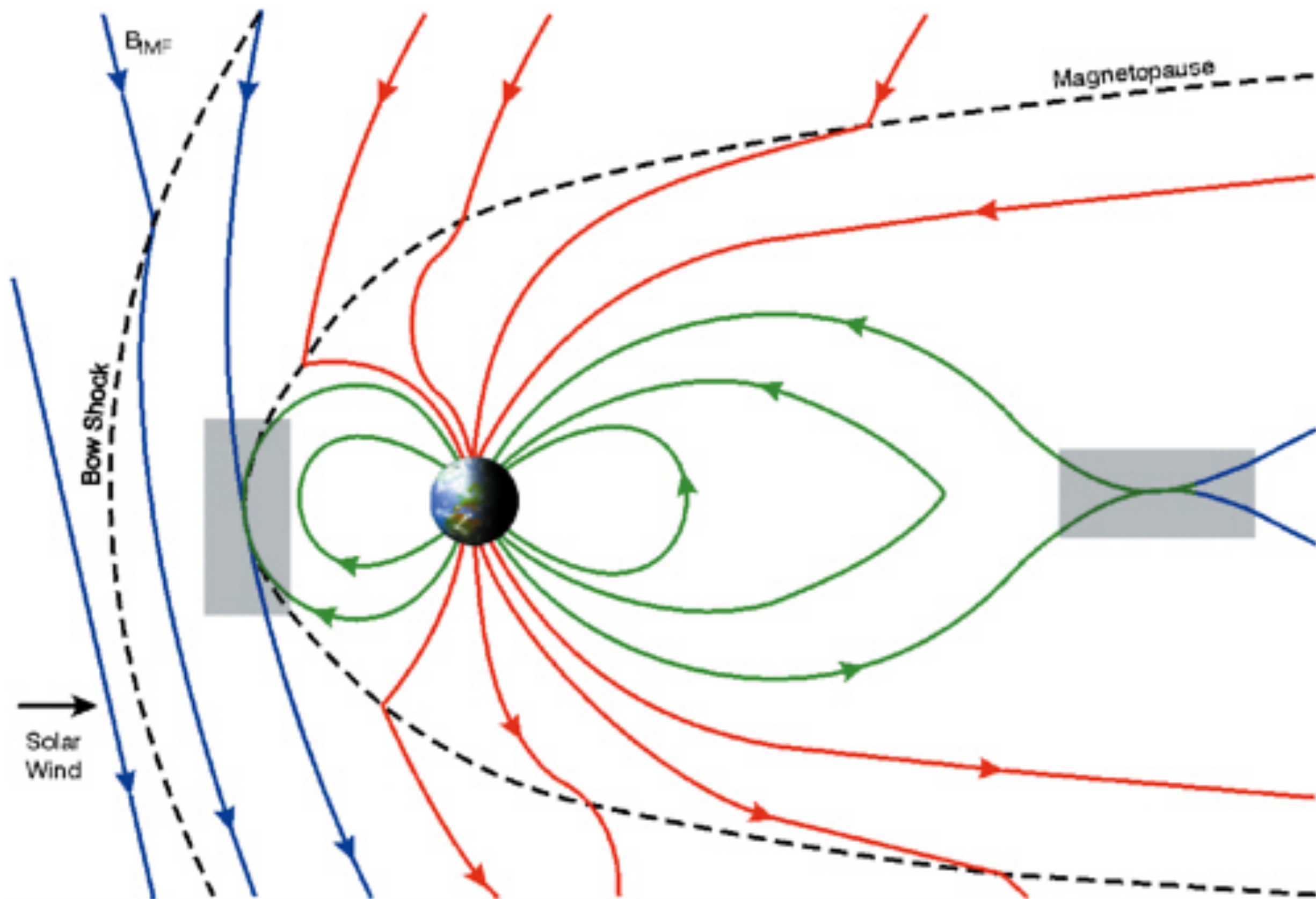


Illuminated area



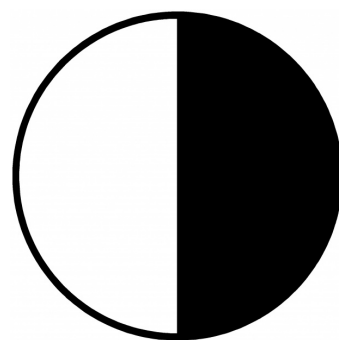
Polar Cap



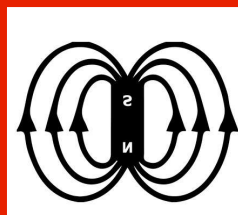


AREA OF IMPACT

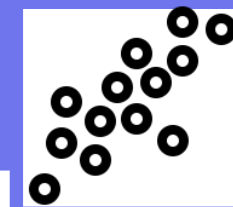
Illuminated area

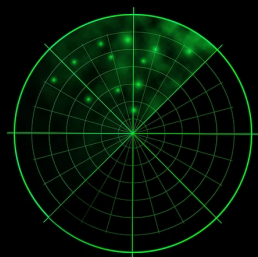
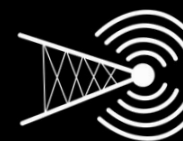
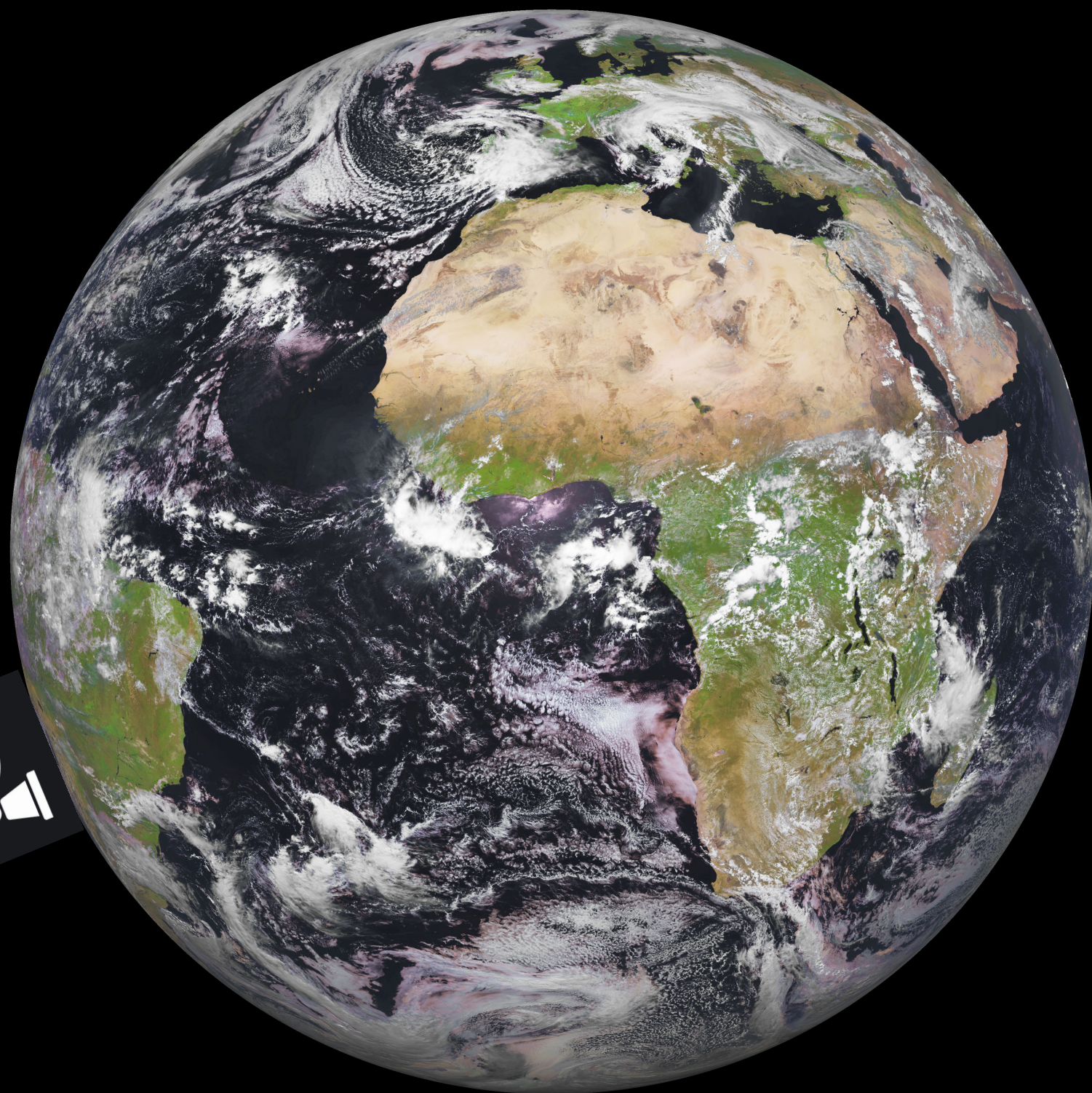


Polar Cap

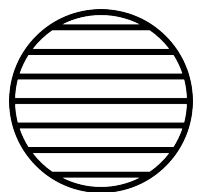
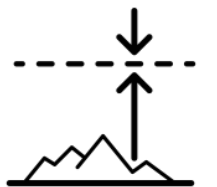
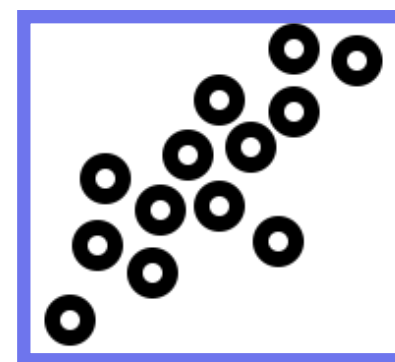
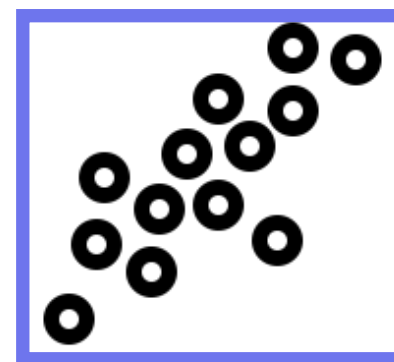
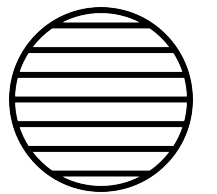
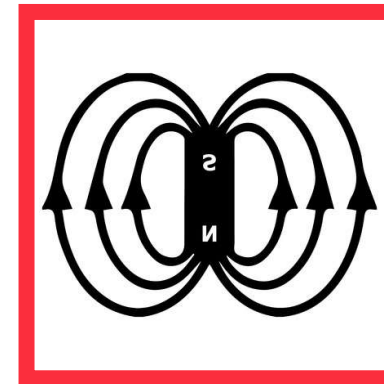
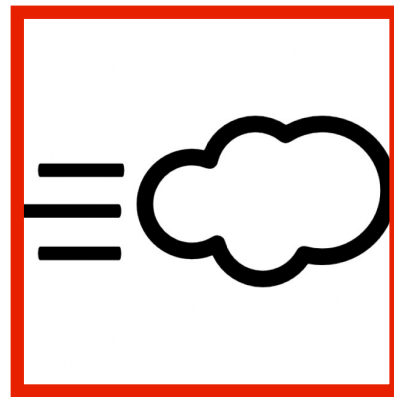
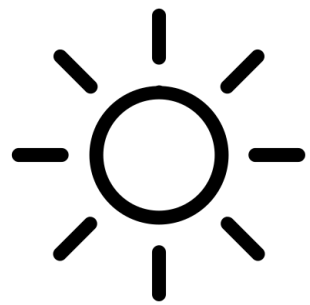
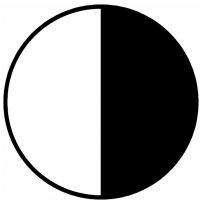


Polar Cap
High Altitude





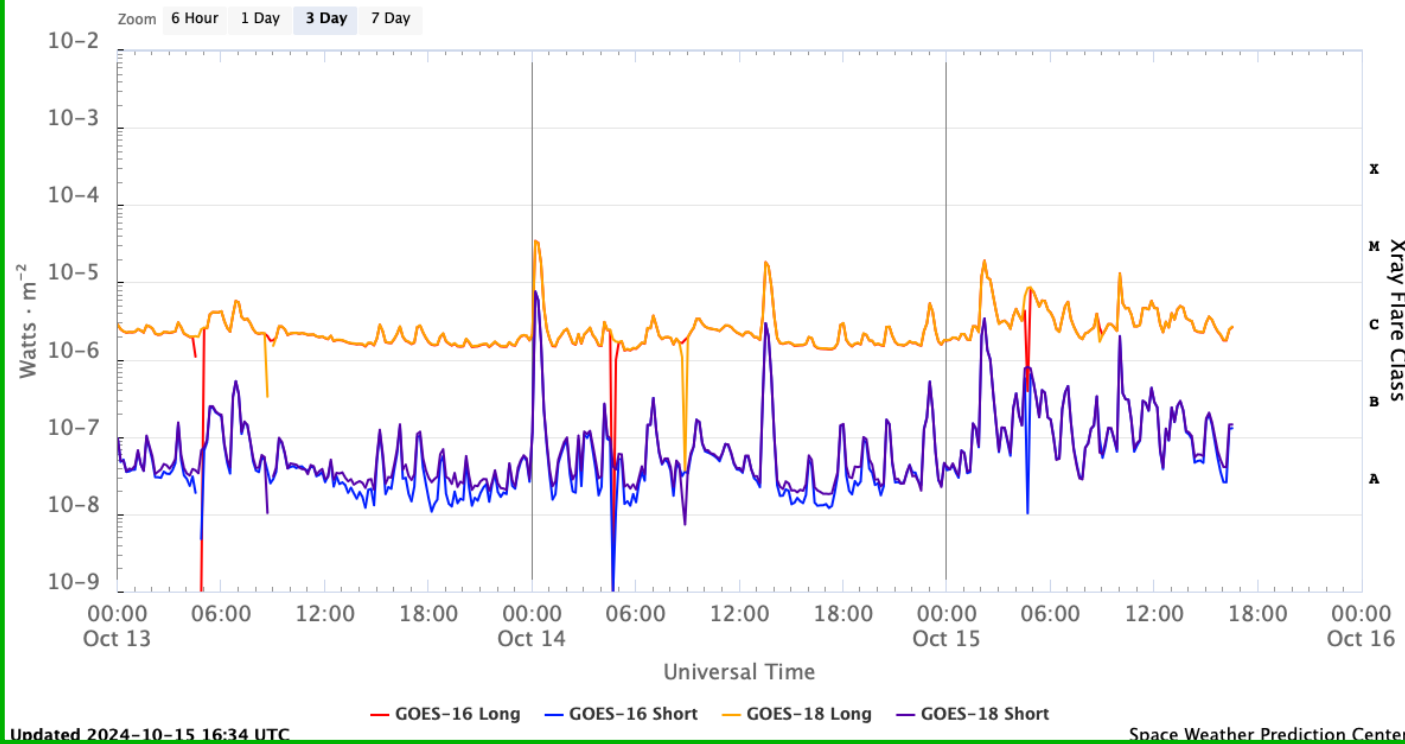
OVERVIEW



X-ray Flux Passport



GOES X-Ray Flux (1-minute data)



Type

X-ray output (0.1-0.8 nm and 0.05-0.4 nm) of the solar spectrum versus time.

Use

To quantify solar flares happening on the side of the Sun facing Earth.

Units

$W \cdot m^{-2}$
Integrated over 1 min

Data location

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

Sensor

GOES-16 satellite
GOES-18 satellite

Sensor location

Geostationary orbit

Cadence

Integrated over 1 min

Plot

X-axis: time in UTC

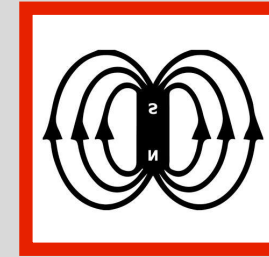
Y-axis: X-ray flux in W/m^2 , i.e. how much energy (Joule) passes in 1 sec ($W=Watt=J/s$) through 1 square meter at geostationary height.

Classes

The long wavelength (0.1-0.8 nm, red and orange) is the reference for identification of the class. The red is measured by GOES 18, orange by GOES 16.

The flare classes are indicated on the right of the graphs. When the peak of the red/orange curve is in blue/green/yellow/orange/red, it is a A/B/C/M/X-class flare.

Kp-index Passport



What

Kp-index (NOAA) represents the planetary geomagnetic condition or the state of the magnetic field of Earth. It is a planetary index and is valid for the globe.

Use

To quantify the disturbance of the magnetic field of Earth. The scale ranges from 0 to 9, with 0 indicating no disturbance and 9 the highest disturbance of the Earth magnetic field .

Plot

X-axis: data and time in UTC, time stamp every 3 hours. Ranges from 3 days in the left (left) to now (right).

Y-axis:

coloured bars of 3 hours wide, height= Kp-index (NOAA)
Height of a bar represents a number: 0, 0+, 1-, 1, 1+, 2-, 2, 2+, ... 8-, 8, 8+, 9-, 9.

With e.g. 2- = 1,70 and 2+ = 2,30 etc.

Estimated

by NOAA, US

Data location

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

Definitive

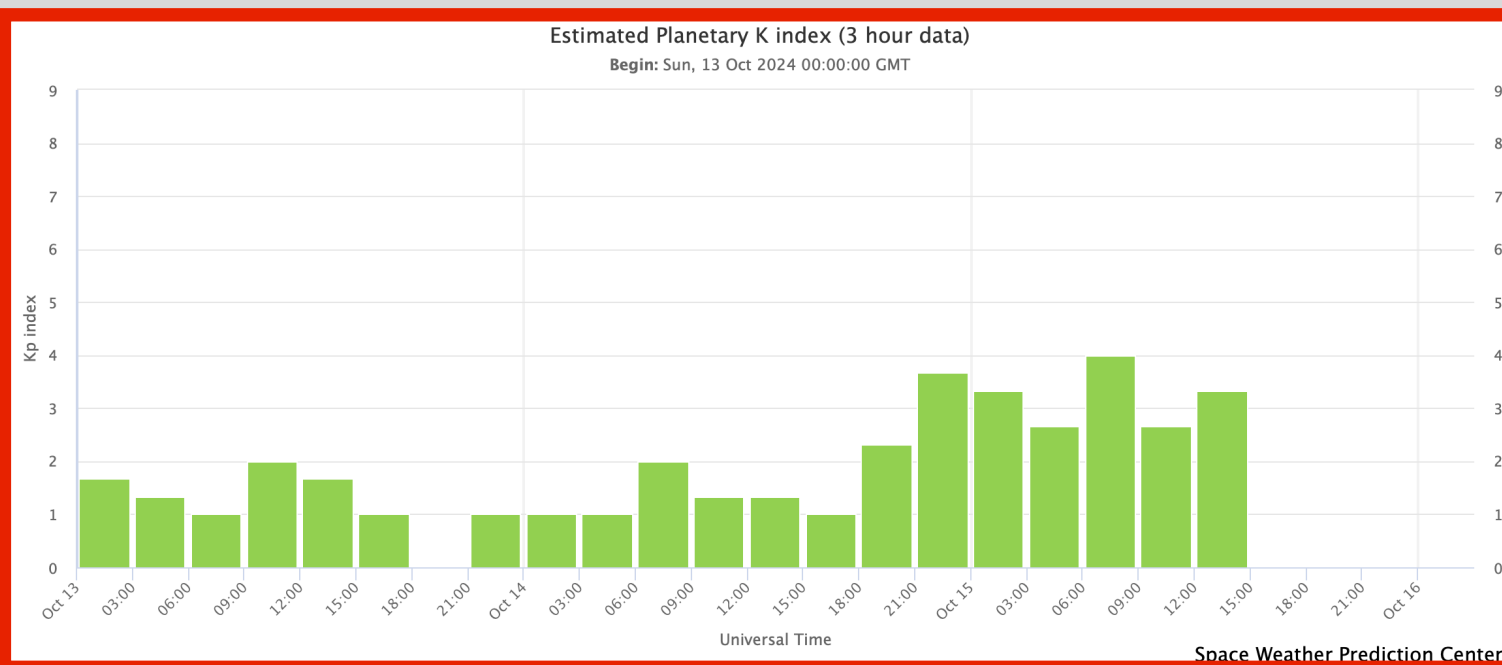
The values become definitive after calculation and confirmation by the German Research Centre for Geosciences, Potsdam.

Observatories

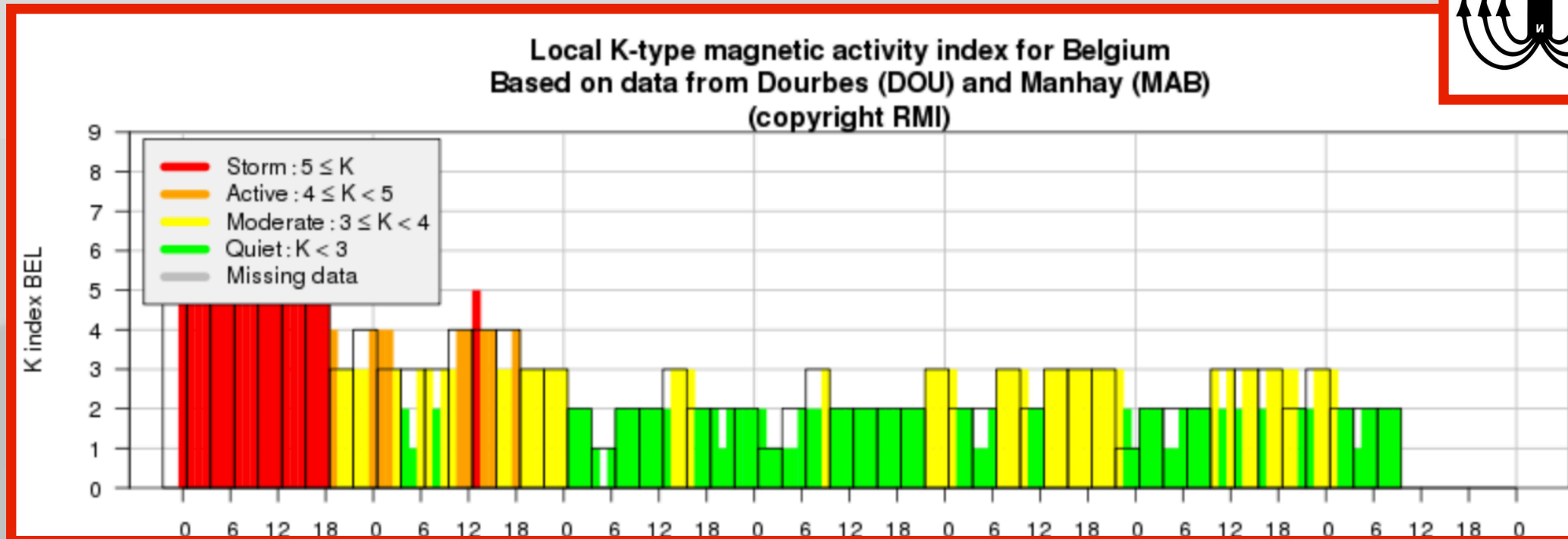
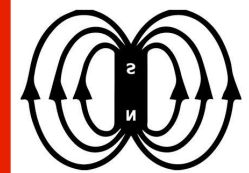
Thirteen (13) Geomagnetic Observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude.

Magnetometers

The calculation is based upon the measurements done by magnetometers.



K Belgium Passport



What

K Belgium represents the geomagnetic conditions or the state of the magnetic field of Earth above Belgium. It is an index for Belgium.

Use

To quantify the disturbance of the magnetic field of Earth. The scale ranges from 0 to 9, with 0 indicating no disturbance and 9 the highest disturbance of the Earth magnetic field .

Plot

X-axis: data and time in UTC. Ranges from 7 days in the left (left) to now (right).

Y-axis: coloured bars of 1 hour wide, height= K Belgium.

Height of a bar represents a natural number: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

Sensors

The calculation is based upon the measurements done by the Royal Meteorological Institute of Belgium based on the measurements done in Dourbes and Manhay, Belgium.

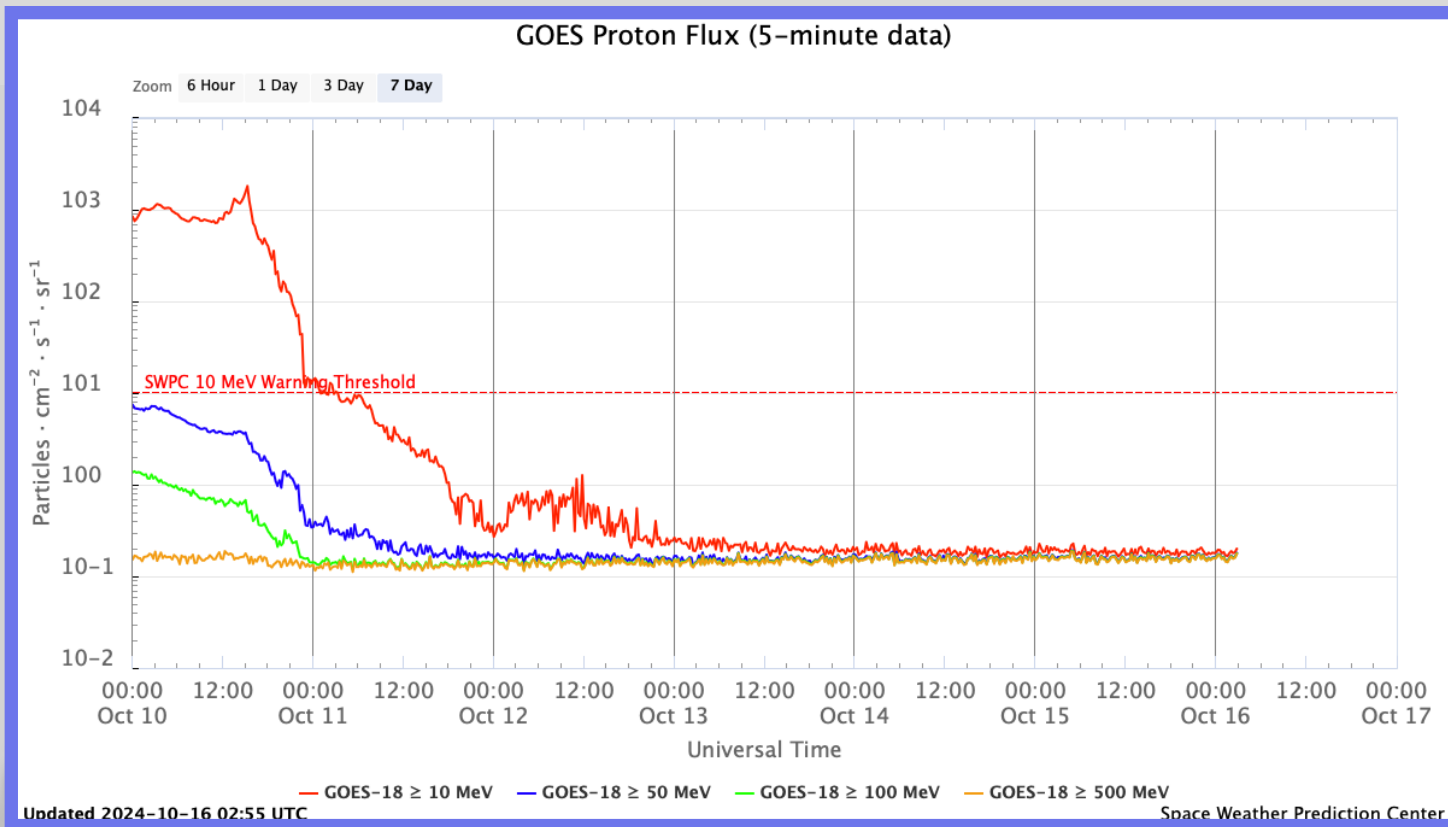
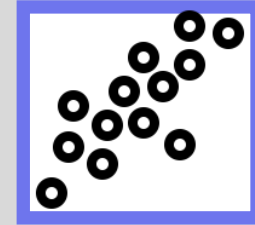
Provider

Royal Meteorological Institute of Belgium

Data location

http://ionosphere.meteo.be/geomagnetism/K_BEL/

Proton Flux Passport



Type

Graph, flux of solar protons versus time.

Use

To quantify proton events impacting Earth.

Units

Particles/($\text{cm}^2 \cdot \text{s} \cdot \text{sr}$) with s=second and sr=steradian

Sensor

GOES-18 satellite

Sensor location

Geostationary orbit

Cadence

Integrated over 5 min

Data location

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

Plot

X-axis: time in UTC

Y-axis: Particles/($\text{cm}^2 \cdot \text{s} \cdot \text{sr}$), i.e. how many solar protons with a particular energy (eV) pass in 1 sec through 1 square centimeter from a cone with the Sun at the apex. The count is done at geostationary height.

The 4 colours represent 4 energies.