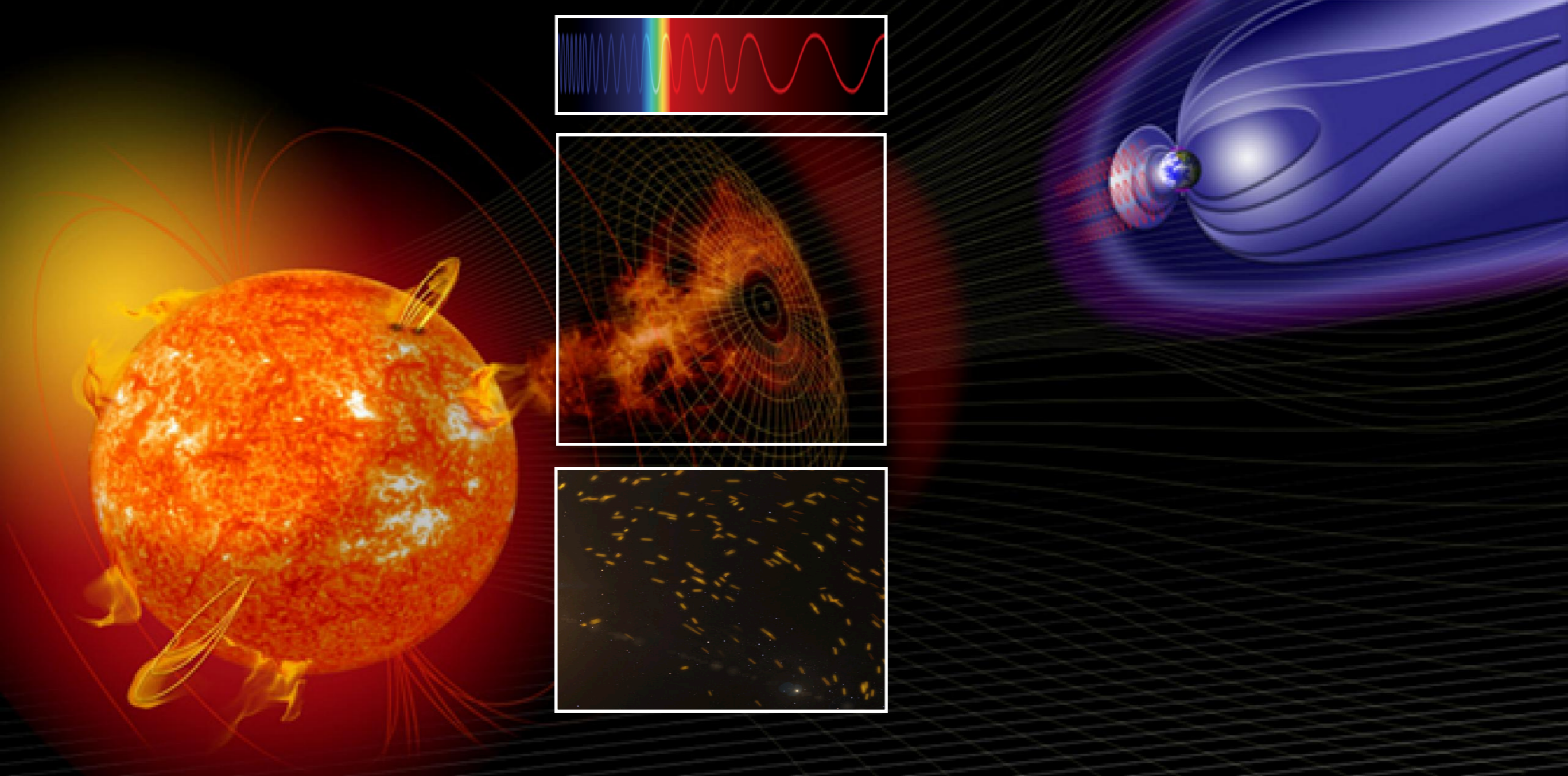


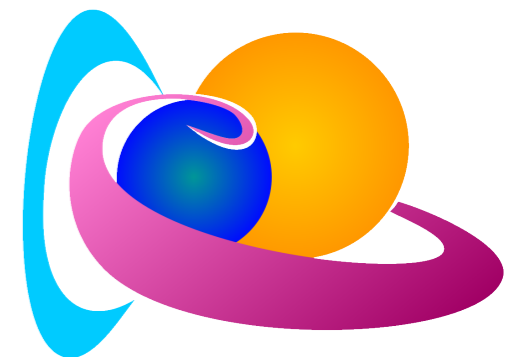
Role of the Ionosphere & SPWx in Military Communications





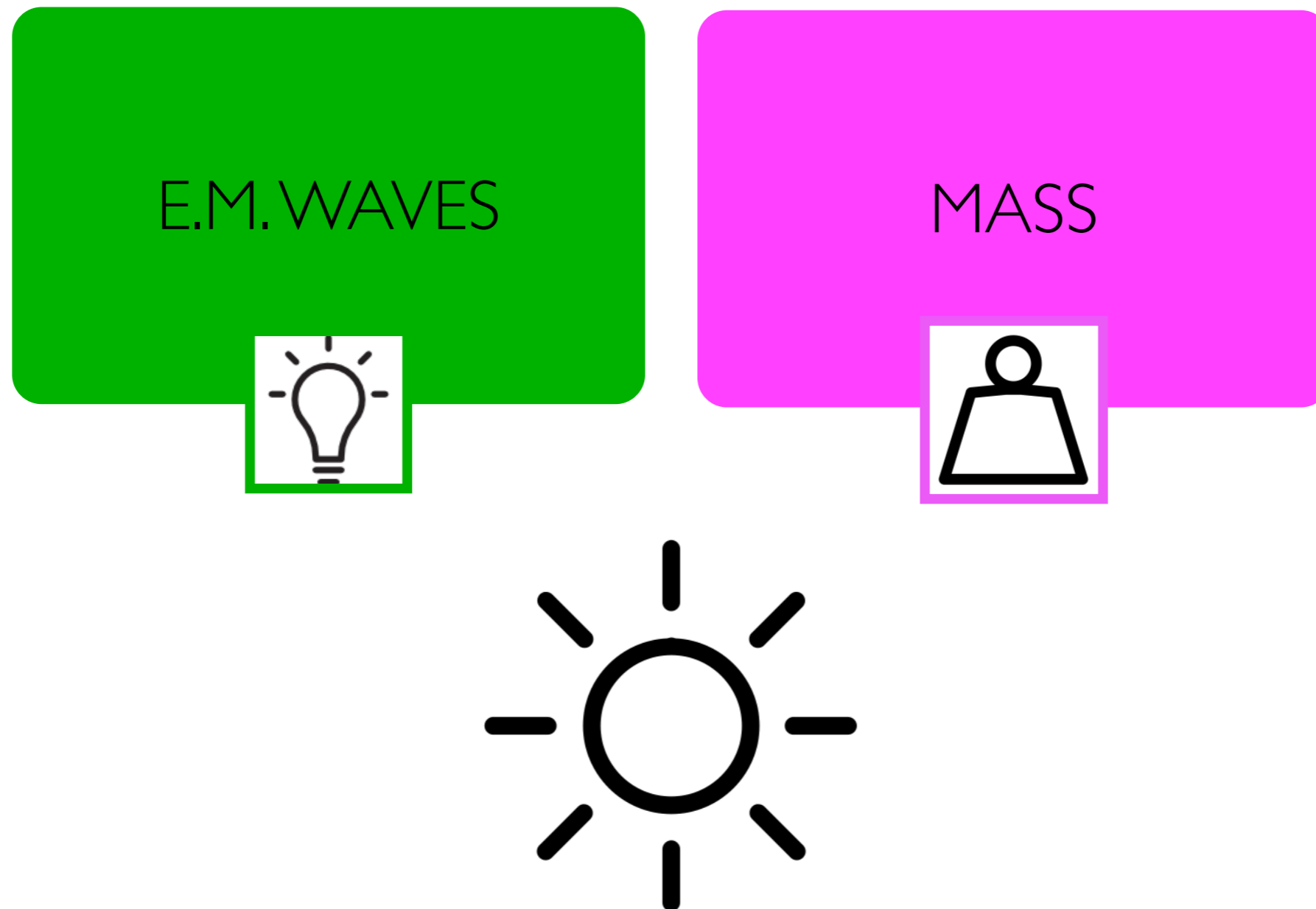
SOLAR DRIVERS

Petra Vanlommel
Solar-Terrestrial Centre of Excellence (STCE)

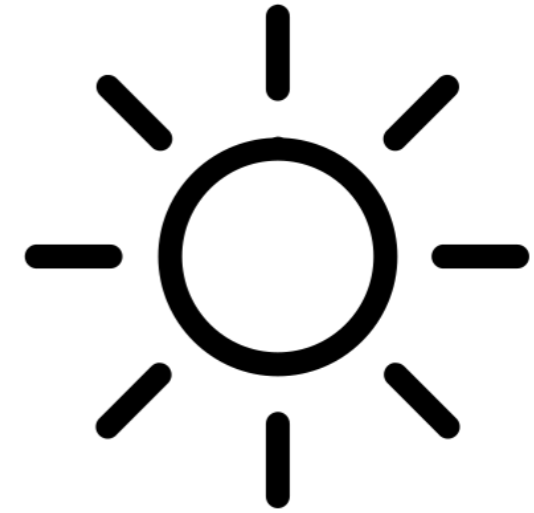


THE SUN AS A BALL OF ENERGY

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



THE SUN AS A BALL OF ENERGY



E.M. RADIATION



PLASMA



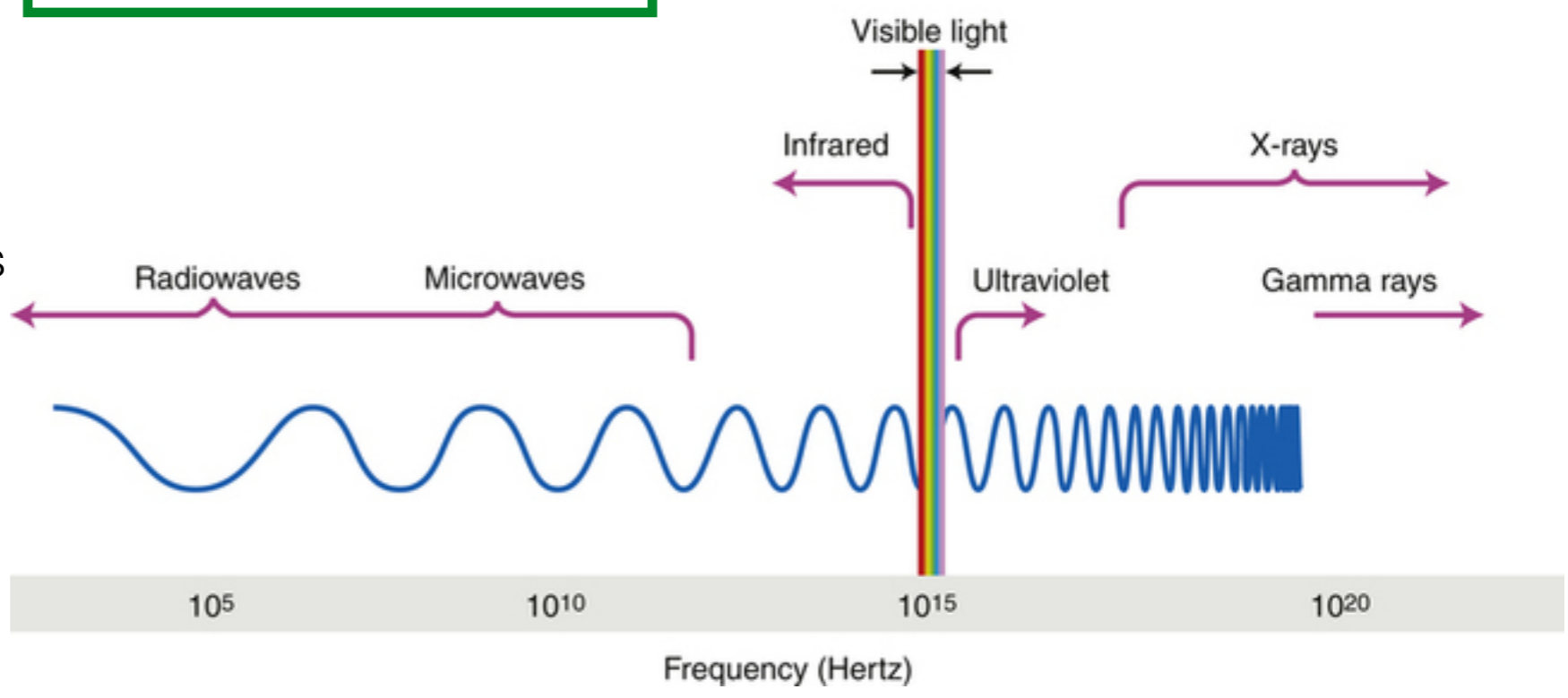
ENERGETIC
PARTICLES



Electromagnetic radiation

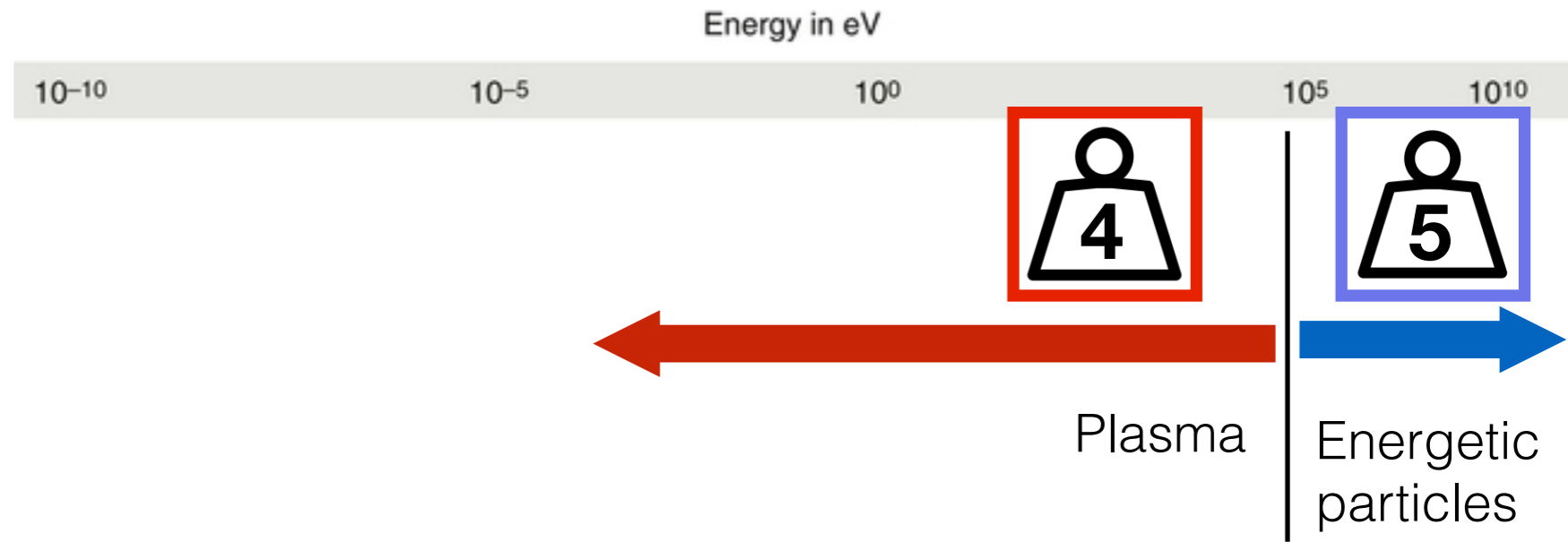


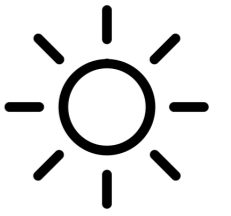
- Photons / electromagnetic waves
- Speed of light



Particles

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





3 SPACE WEATHER PHENOMENA

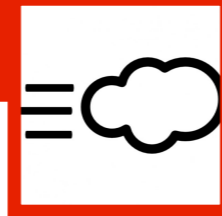
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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

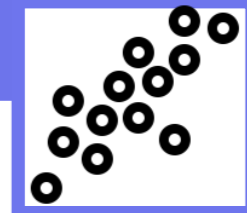
LIGHT



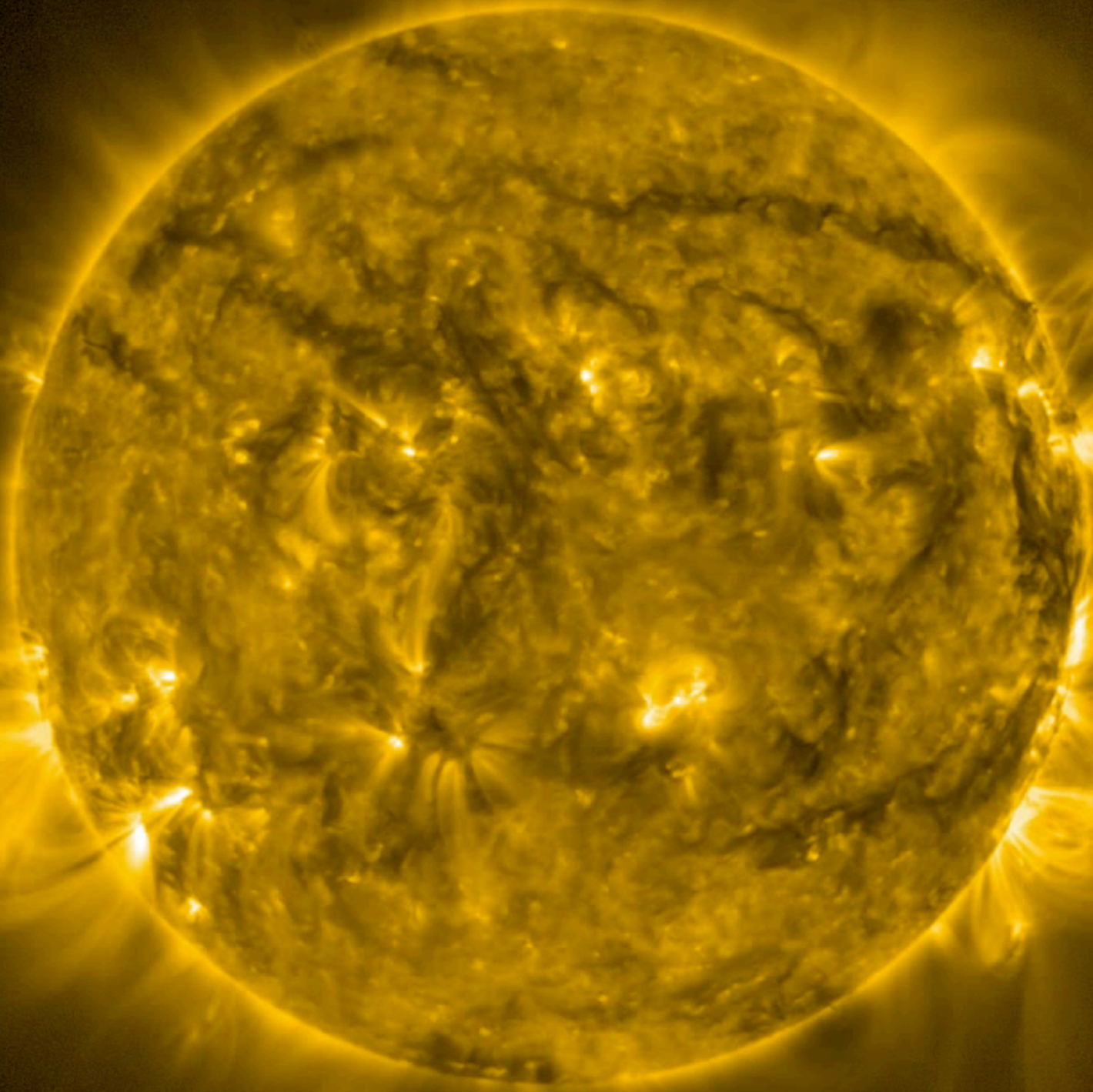
WIND



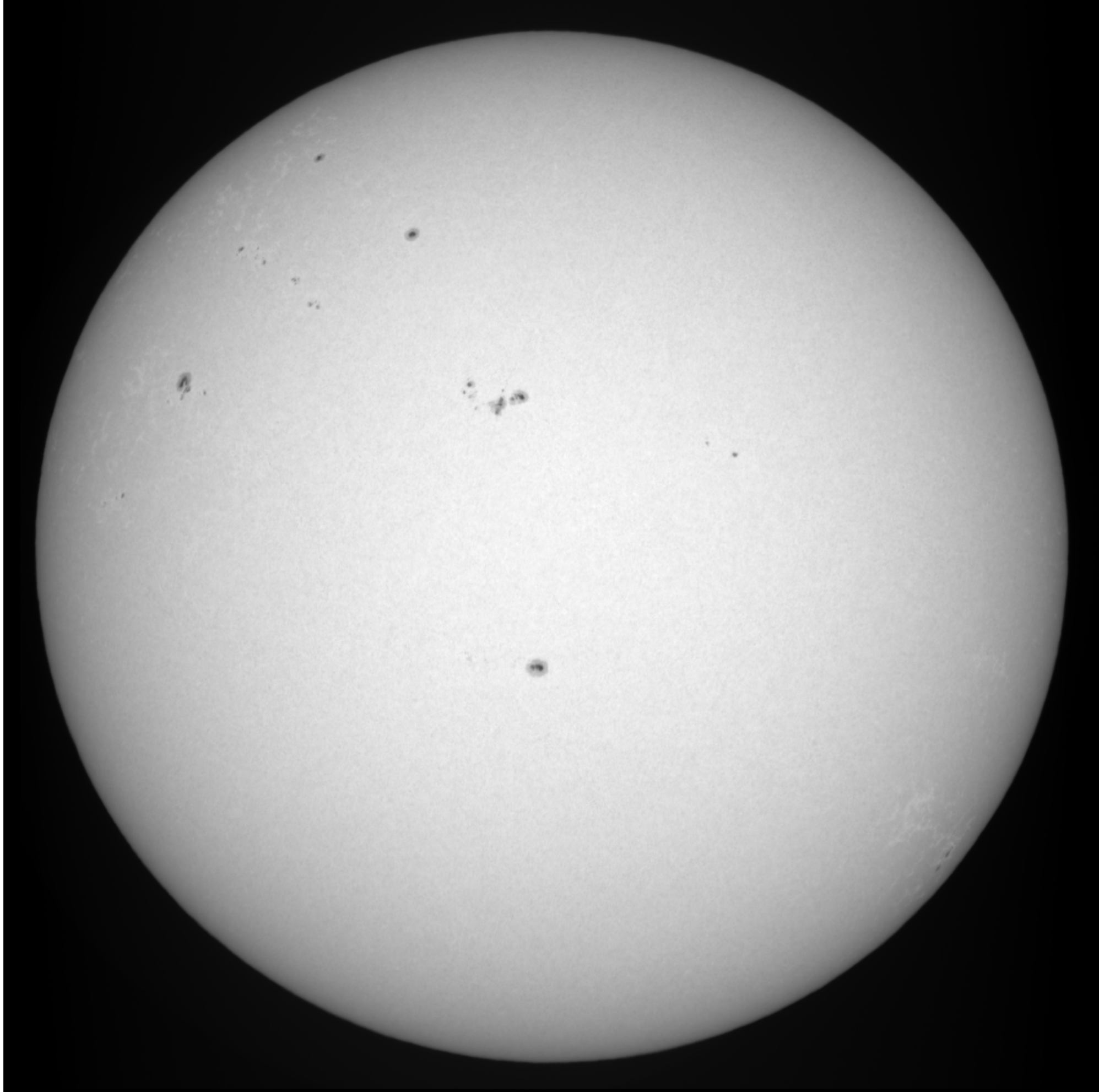
PARTICLE
SHOWER



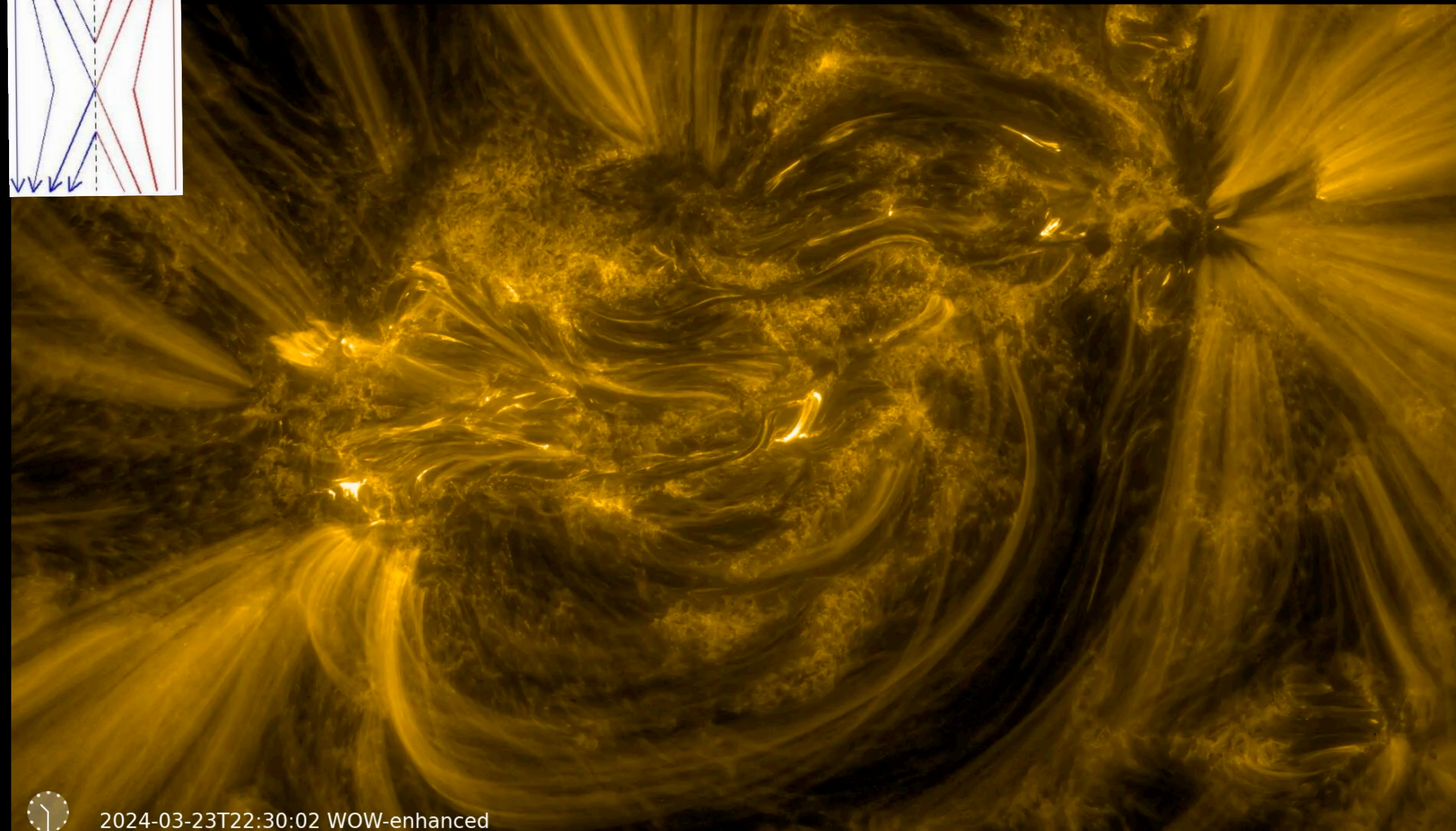
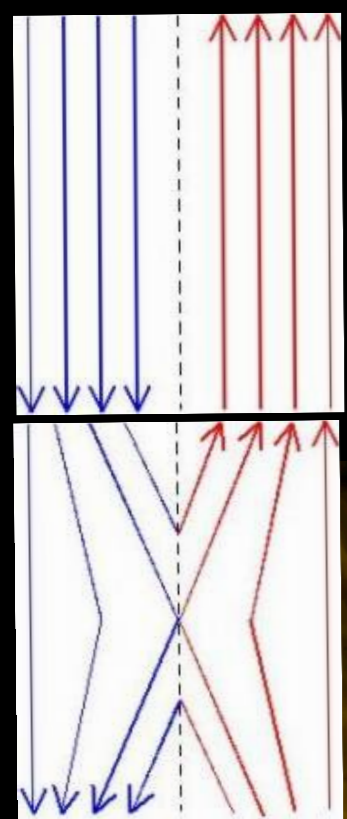
Magnetism drives the sun's dynamics



PROBA2/SWAP

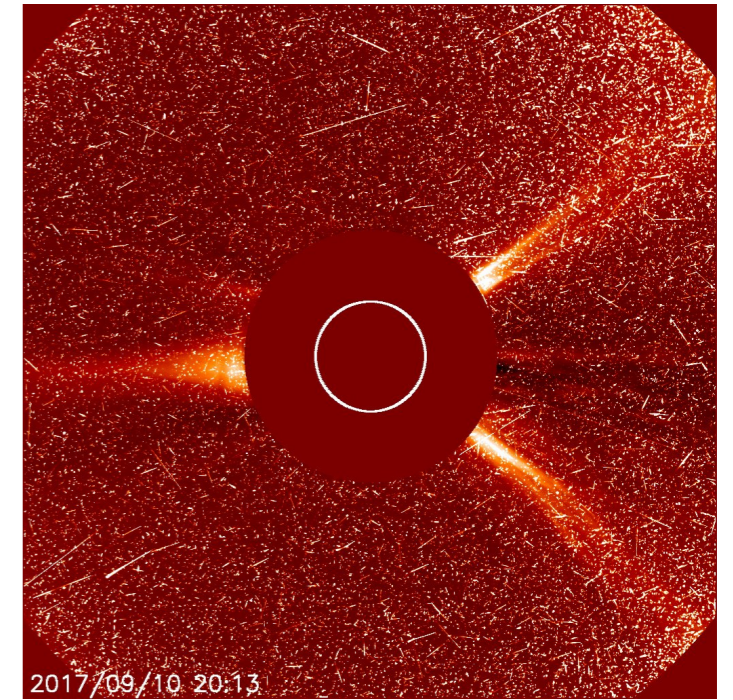
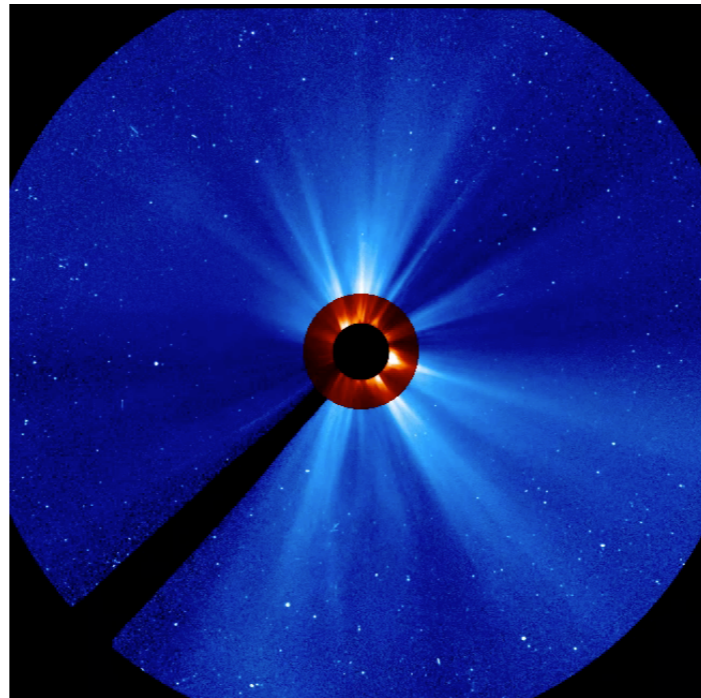
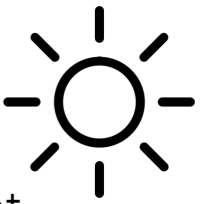


MAGNETIC RECONNECTION



SOLAR WEATHER & STORMS

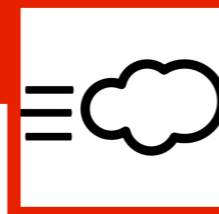
Energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection or CME, proton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



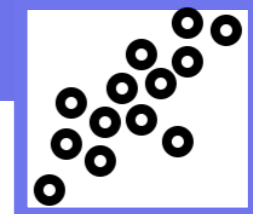
Flare



Coronal Mass Ejection

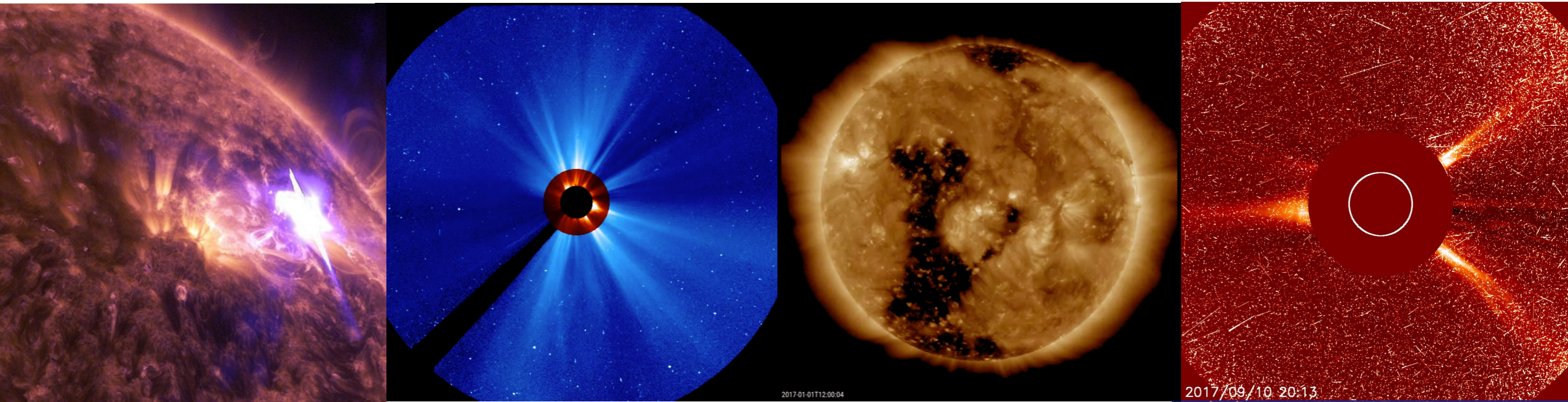
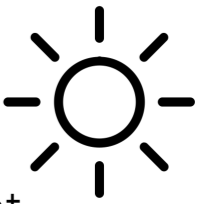


Particle Storm



SOLAR WEATHER & STORMS

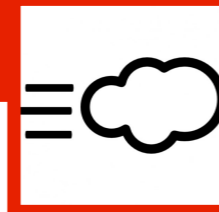
Energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass Ejection or CME, proton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



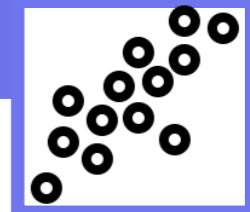
Flare



Coronal Mass Ejection
HSS

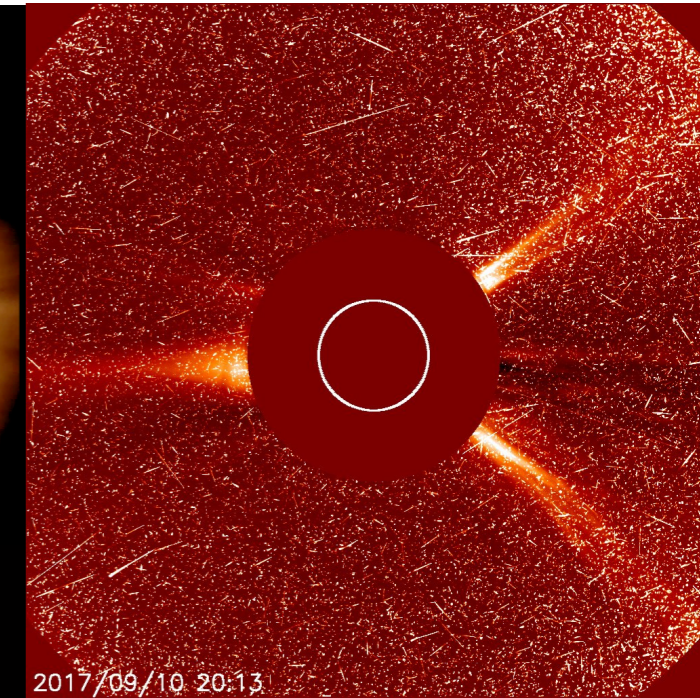
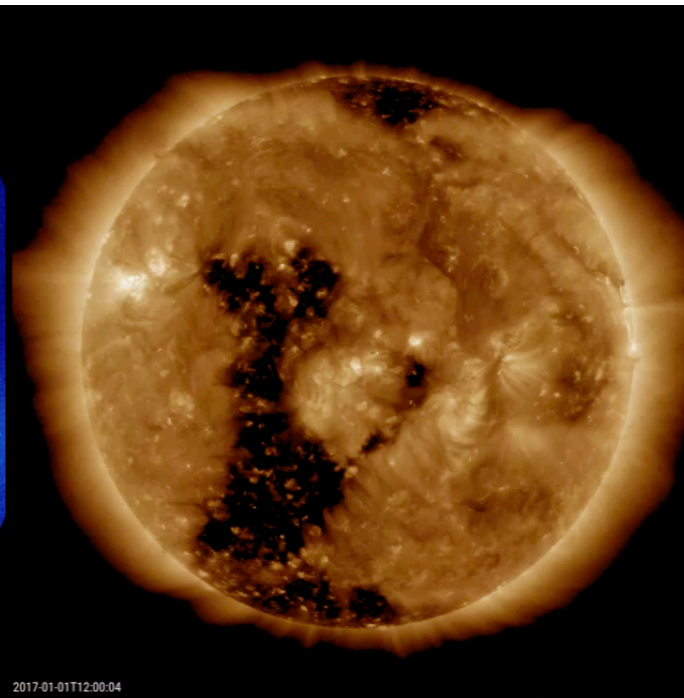
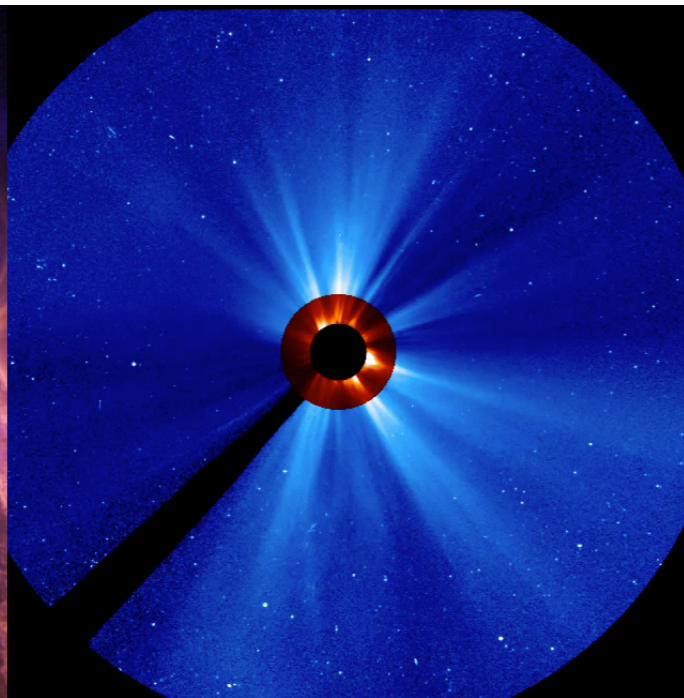
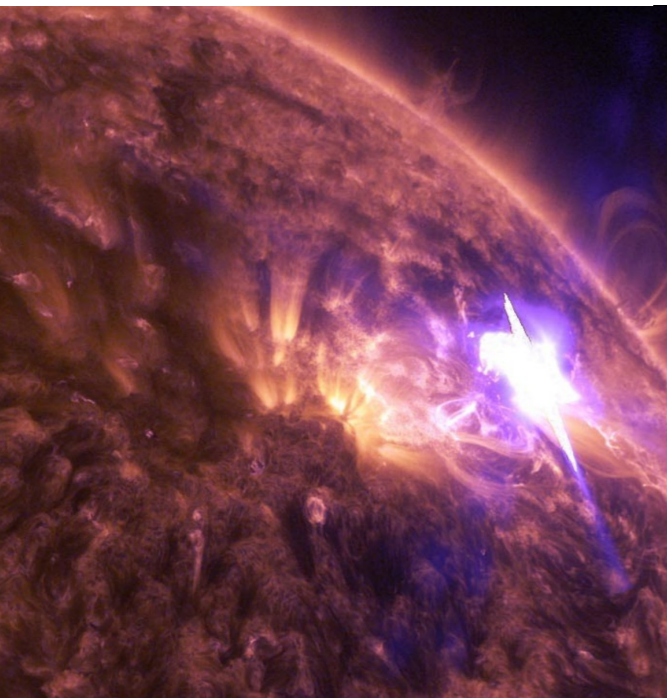
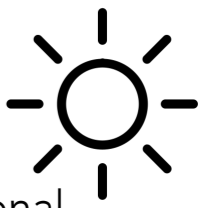


Particle Storm



SOLAR WEATHER & STORMS

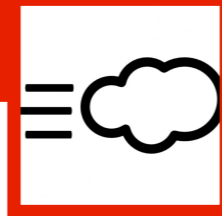
At a certain moment, energy can be released on a shorter time scale. A solar feature like a sunspot, an active region, coronal hole, filament etc. lies at the base of a solar storm in which energy is released. The release of energy might be in an abrupt, impulsive and brutal way (flare, Coronal Mass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



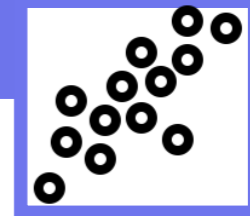
FLARE

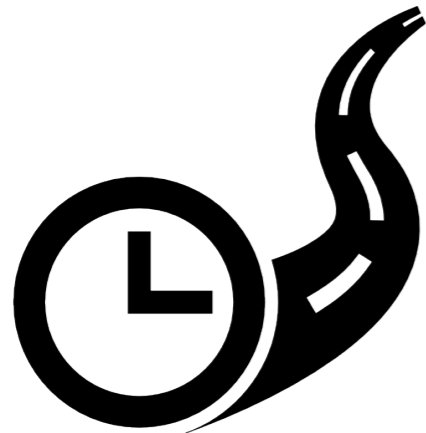


CORONAL MASS
EJECTION
CORONAL HOLE

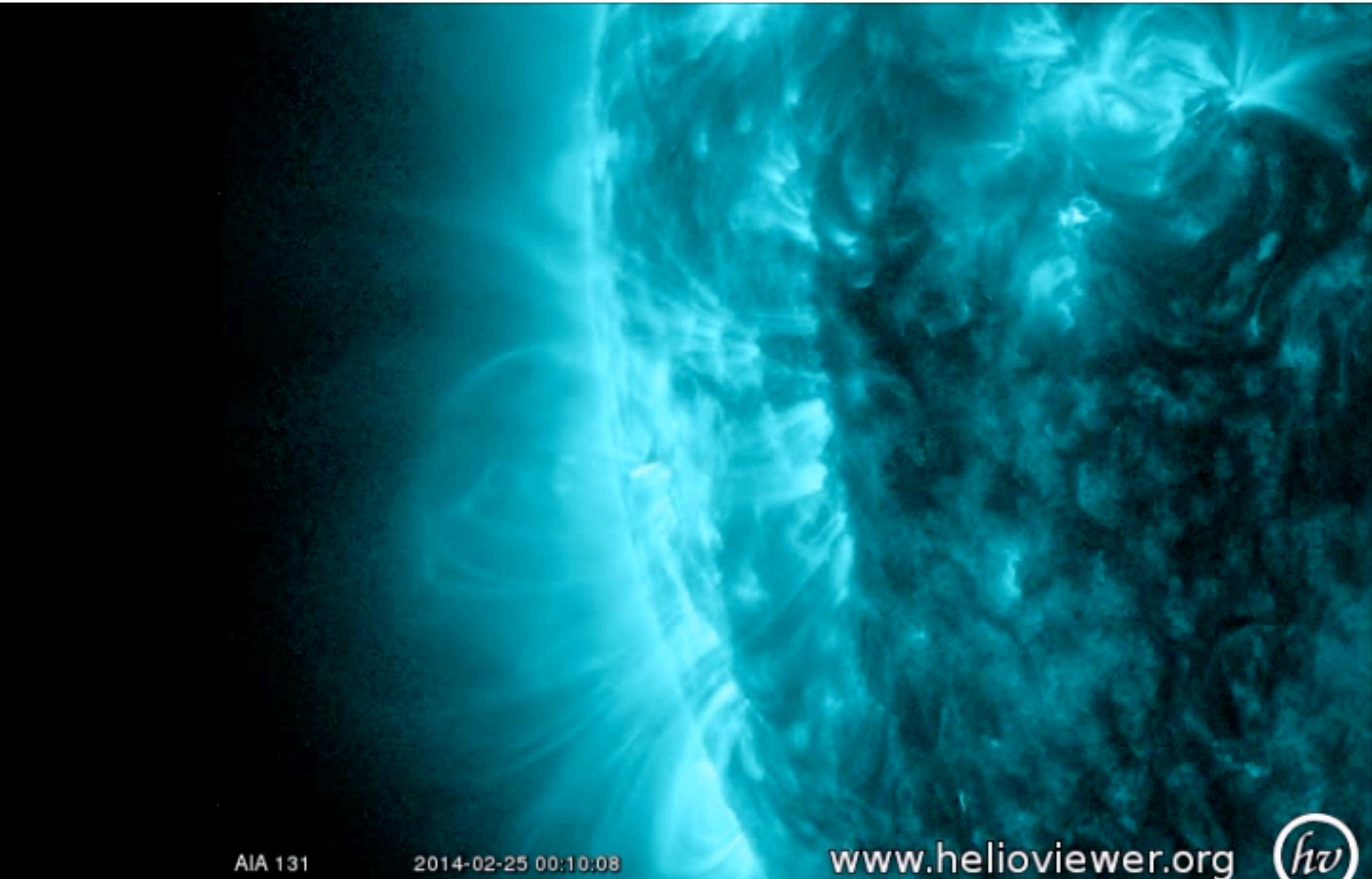


PARTICLE STORM





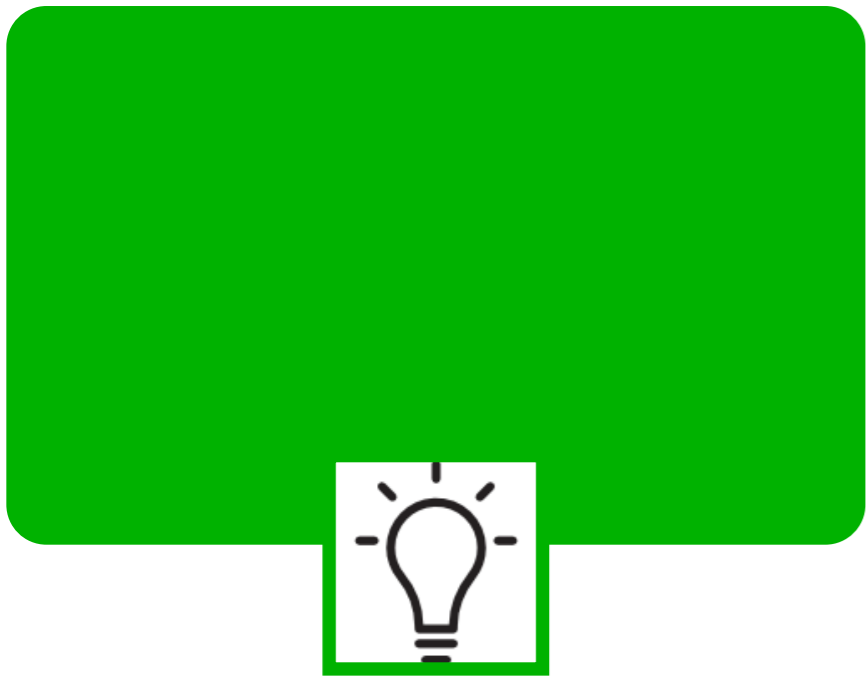
A flare is a light flash near an active region. A volume of plasma is suddenly heated and therefore lights up.





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



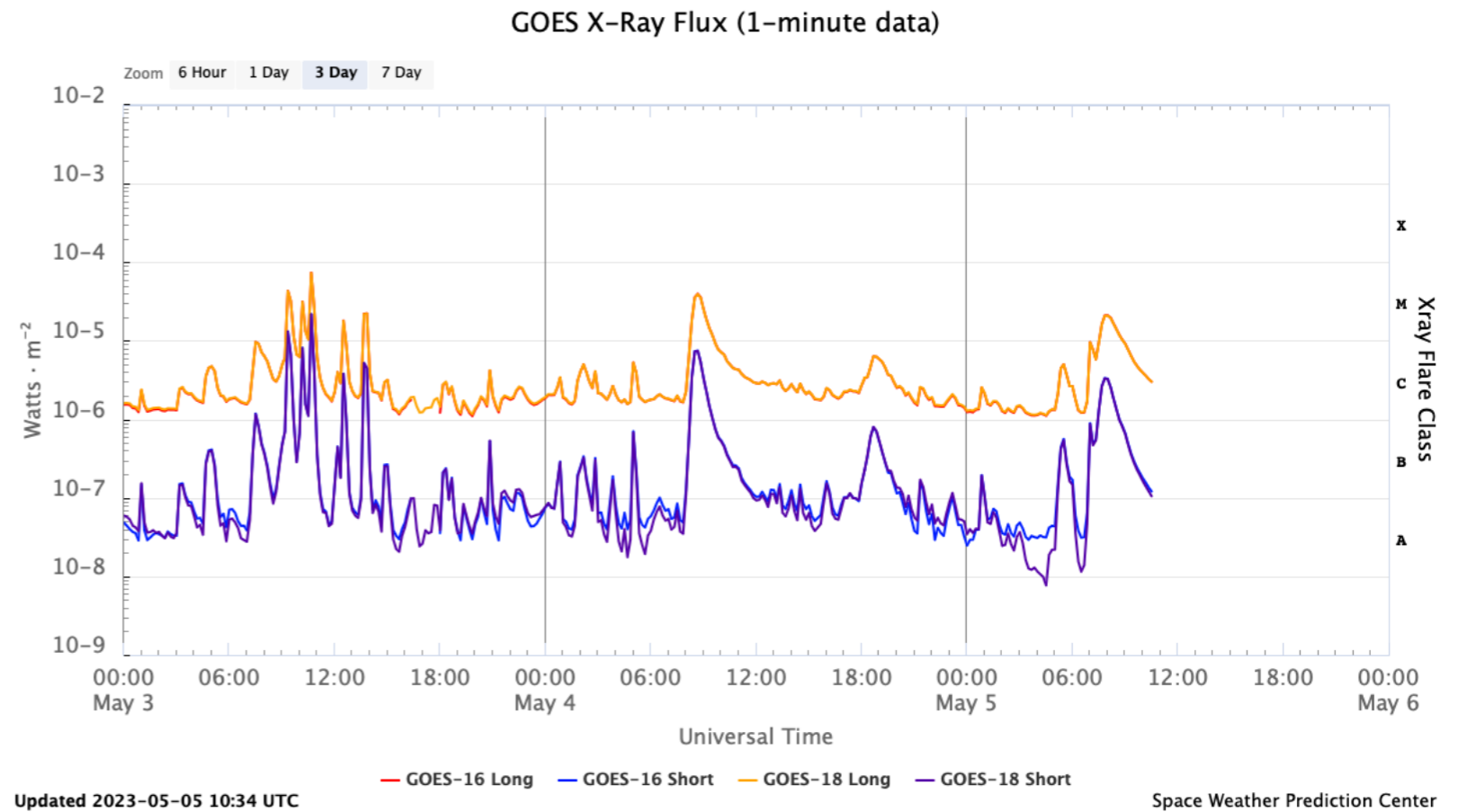
<https://www.swpc.noaa.gov/products/goes-x-ray-flux>



STORM SCALE



A,B,C,M,X



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



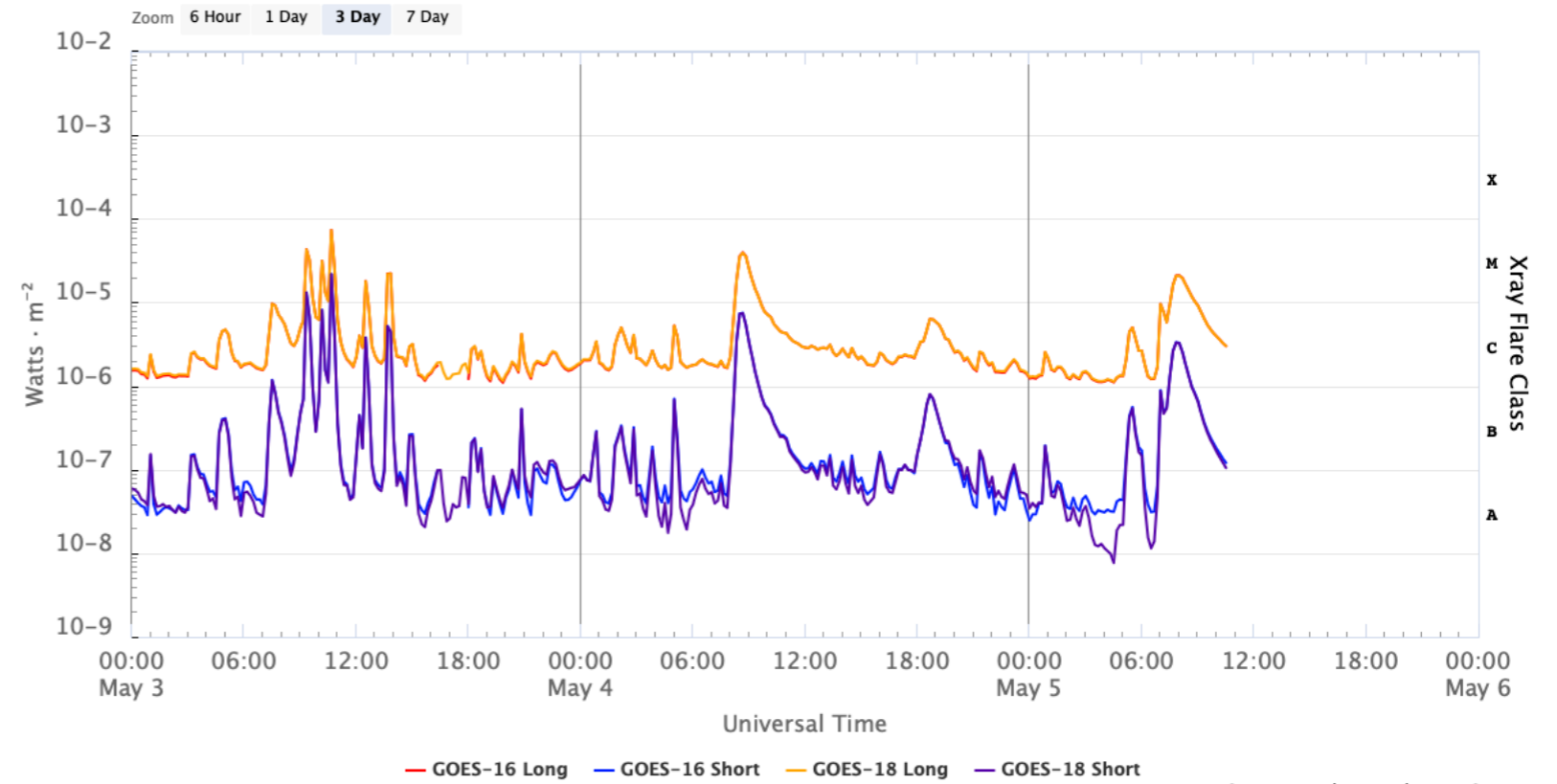
DURATION



MINs to HOUR



GOES X-Ray Flux (1-minute data)

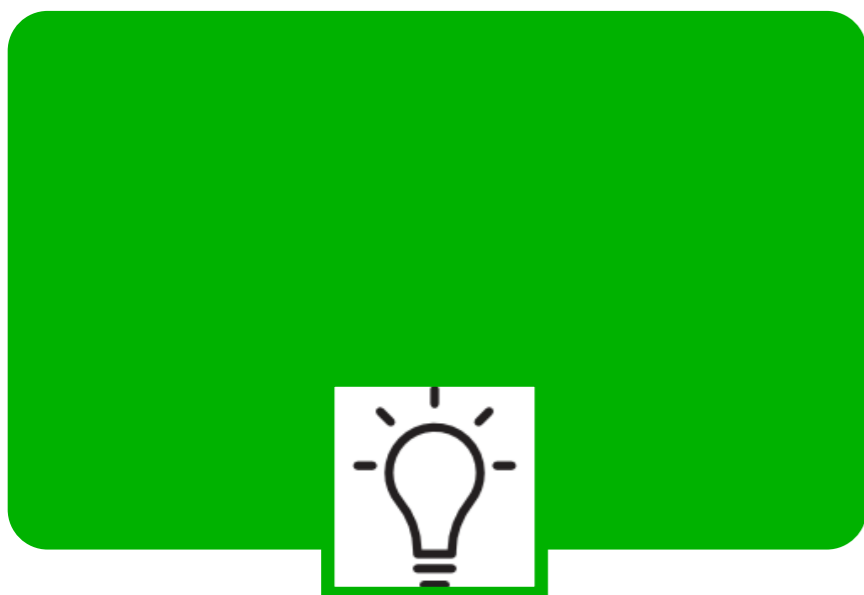


Updated 2023-05-05 10:34 UTC

Space Weather Prediction Center



AREA OF IMPACT



AREA OF IMPACT

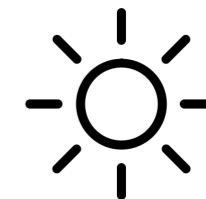
Illuminated area



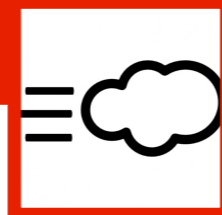
IMPACT

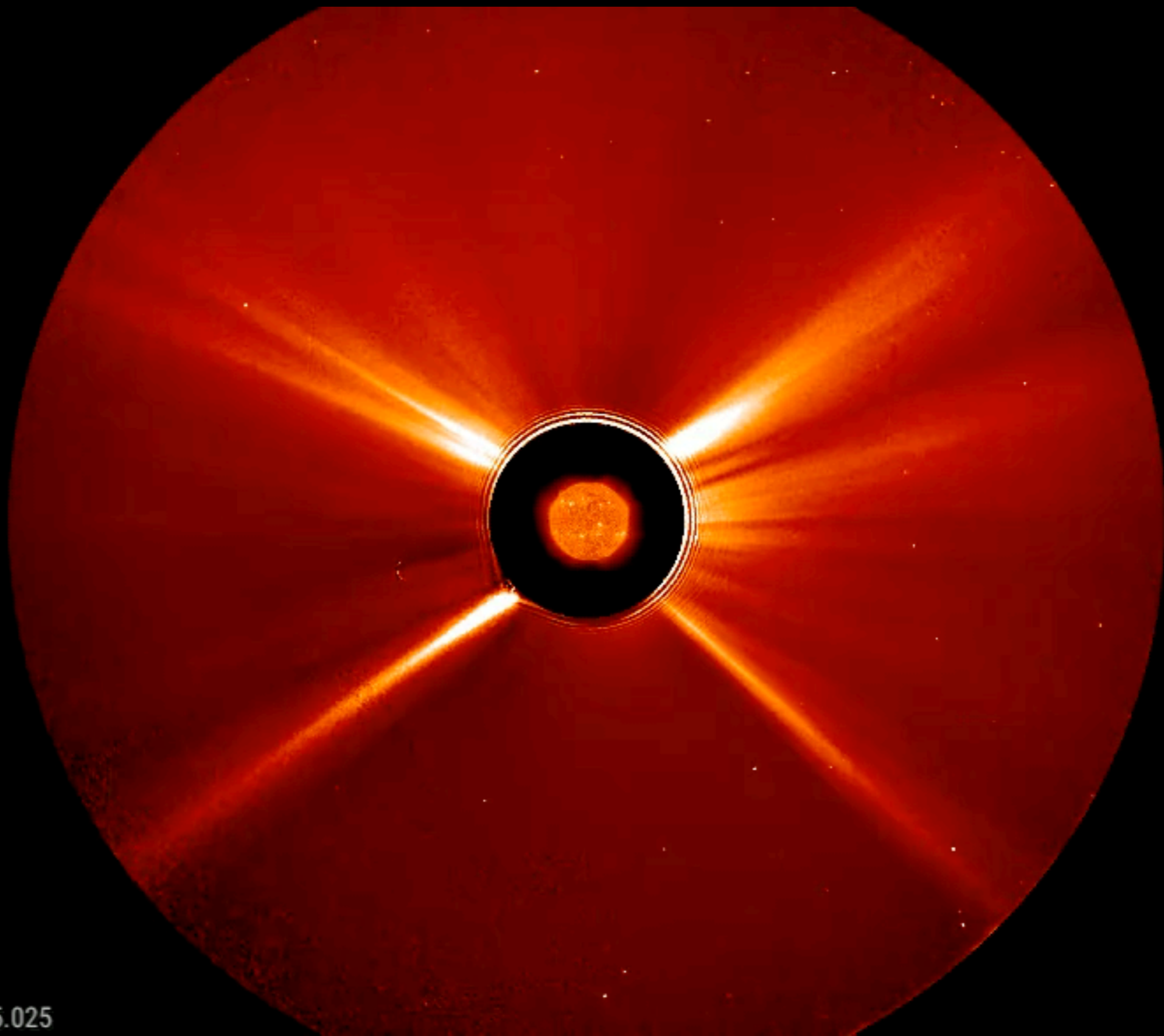
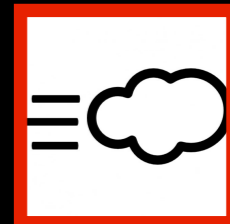
Ionisation



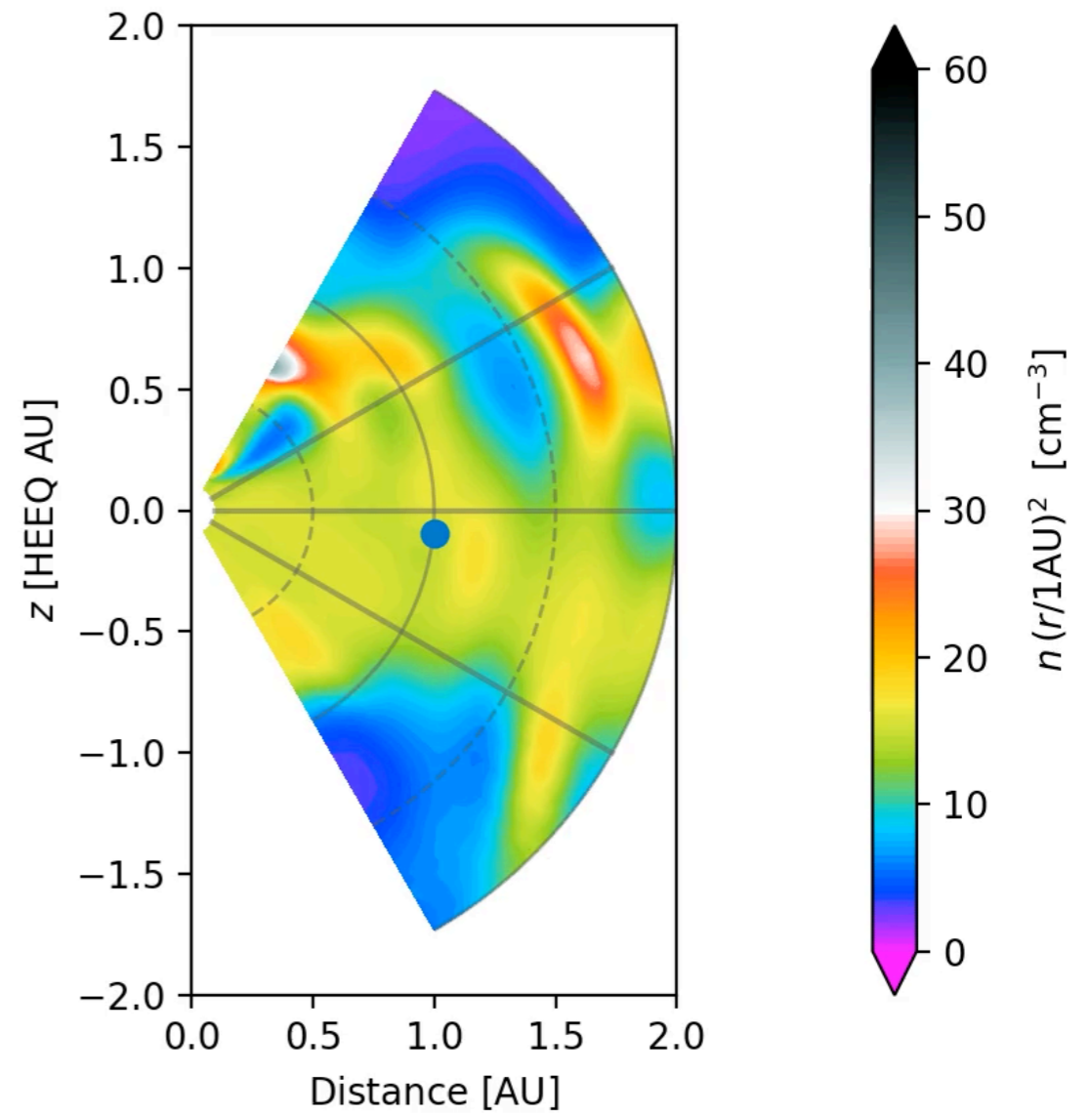
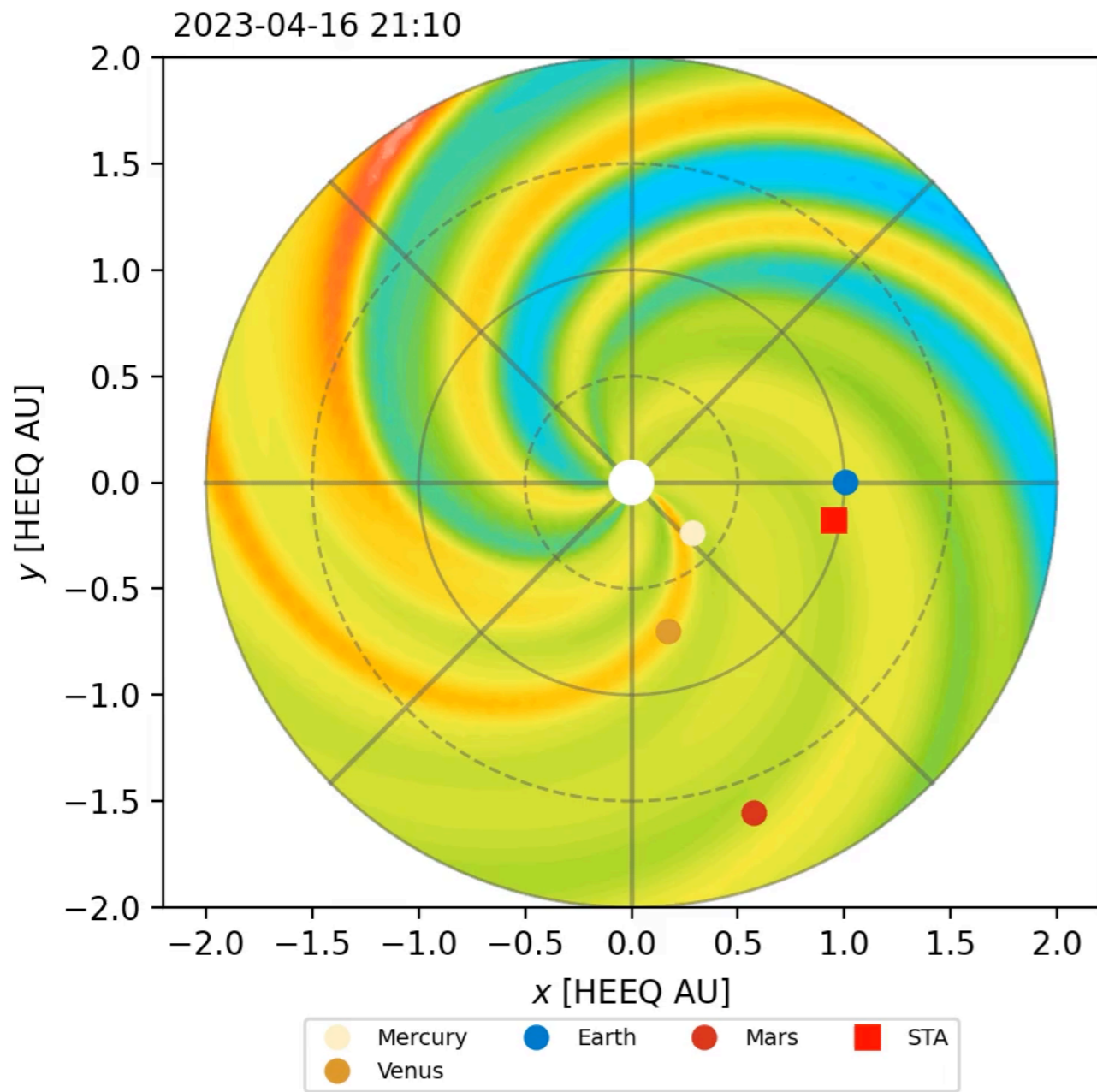
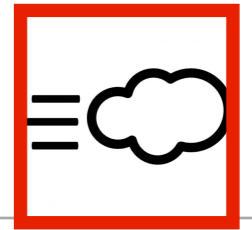


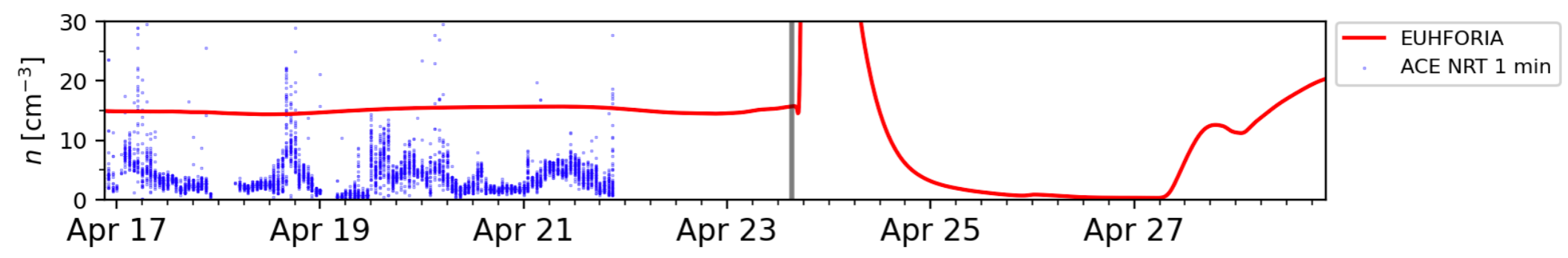
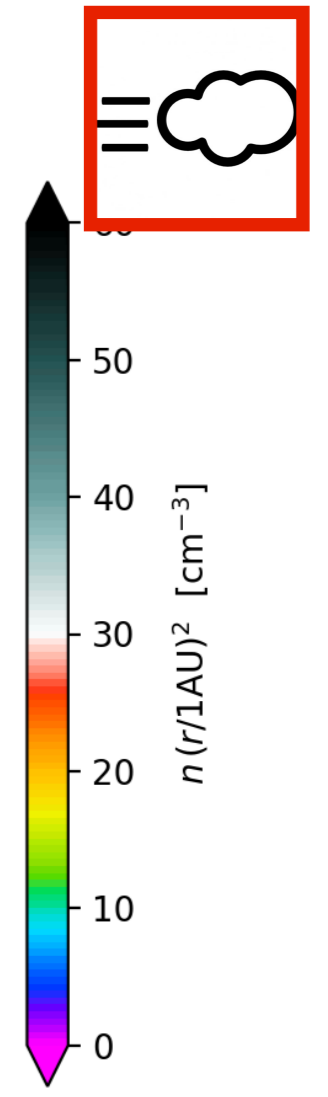
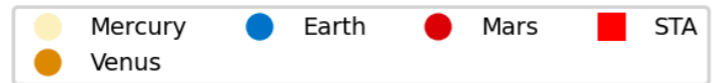
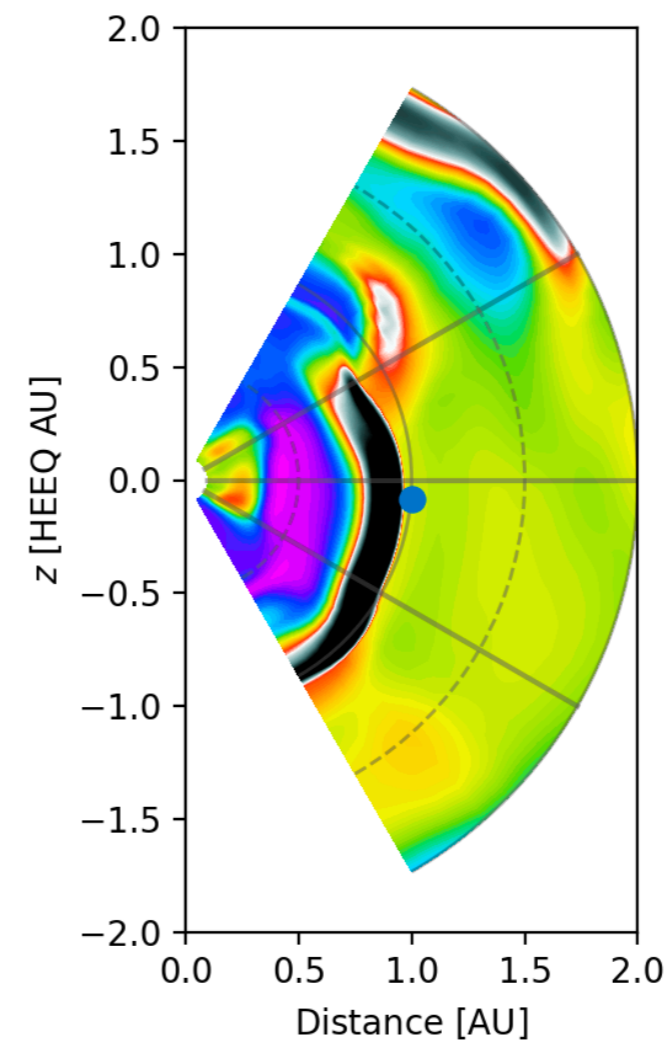
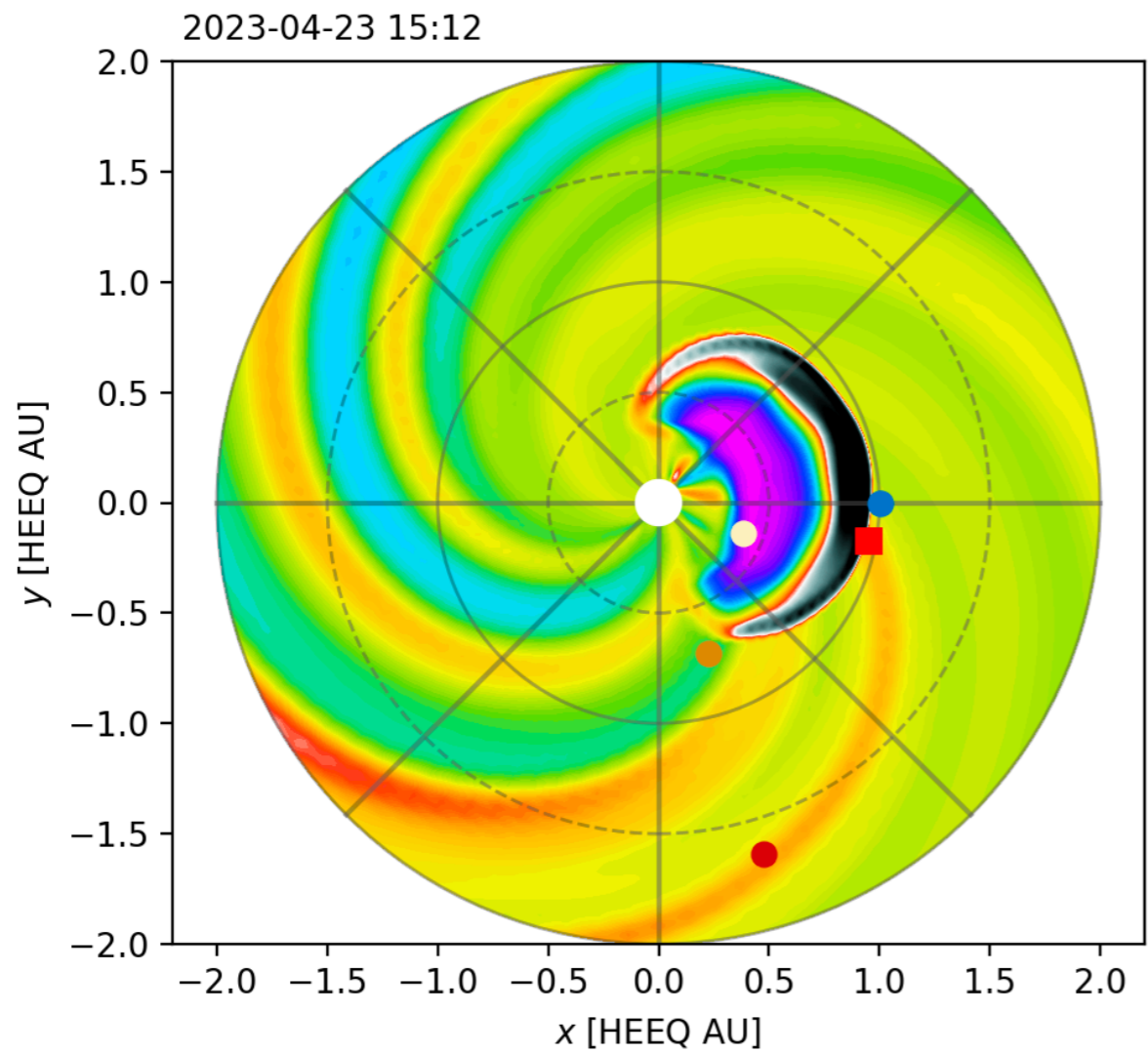
Solar wind
CME - HSS





2022-02-15T16:25:45.025



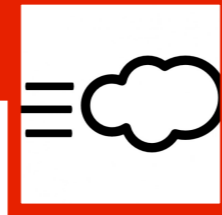




AU TRANSIT TIME

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





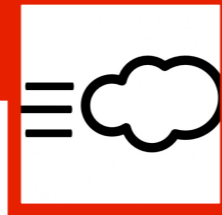
AU TRANSIT TIME

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.

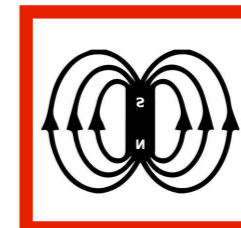
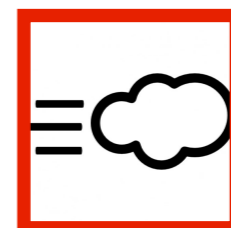
8 MIN

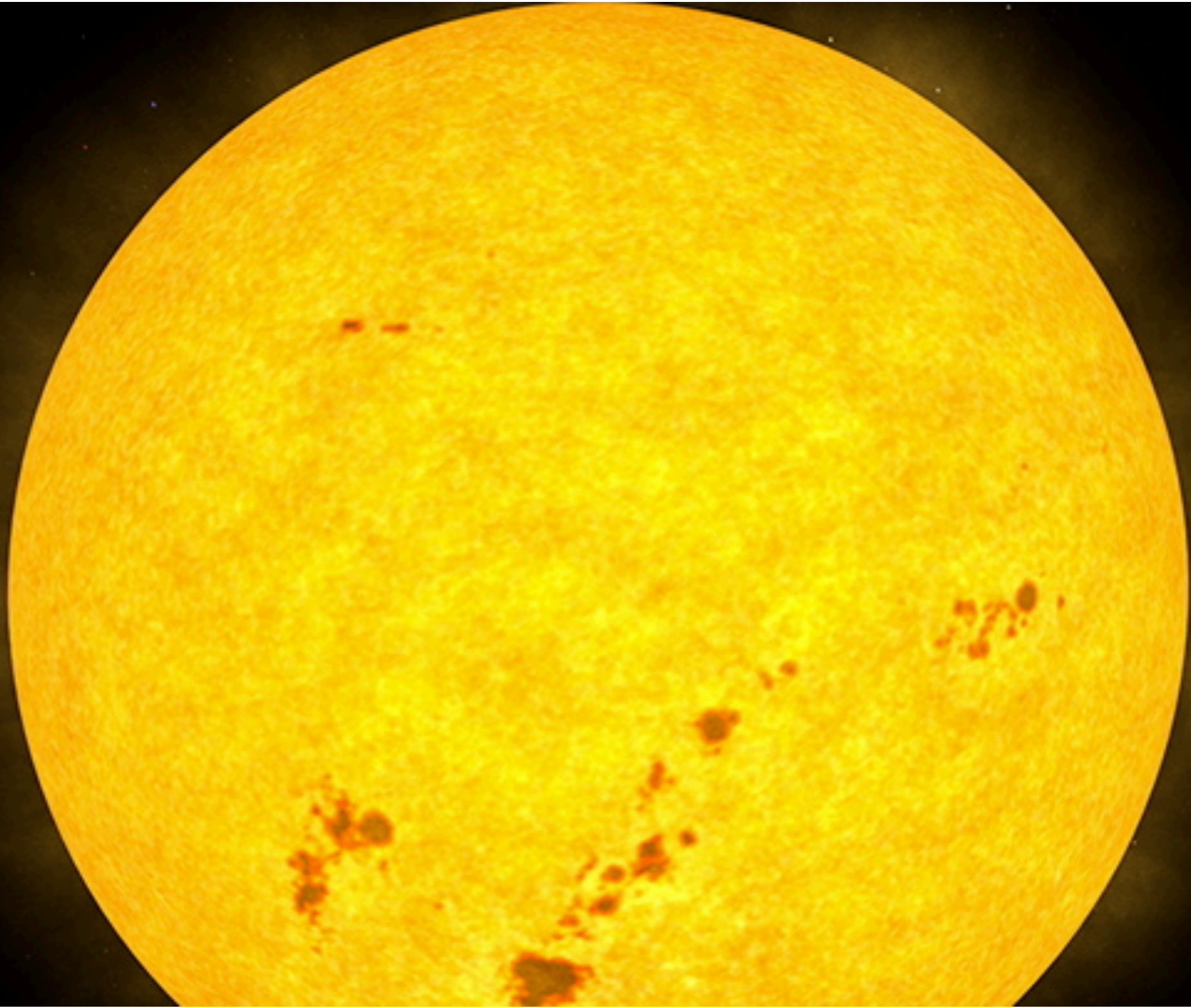
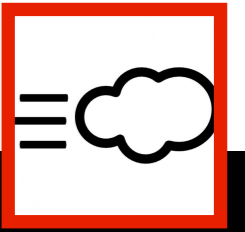


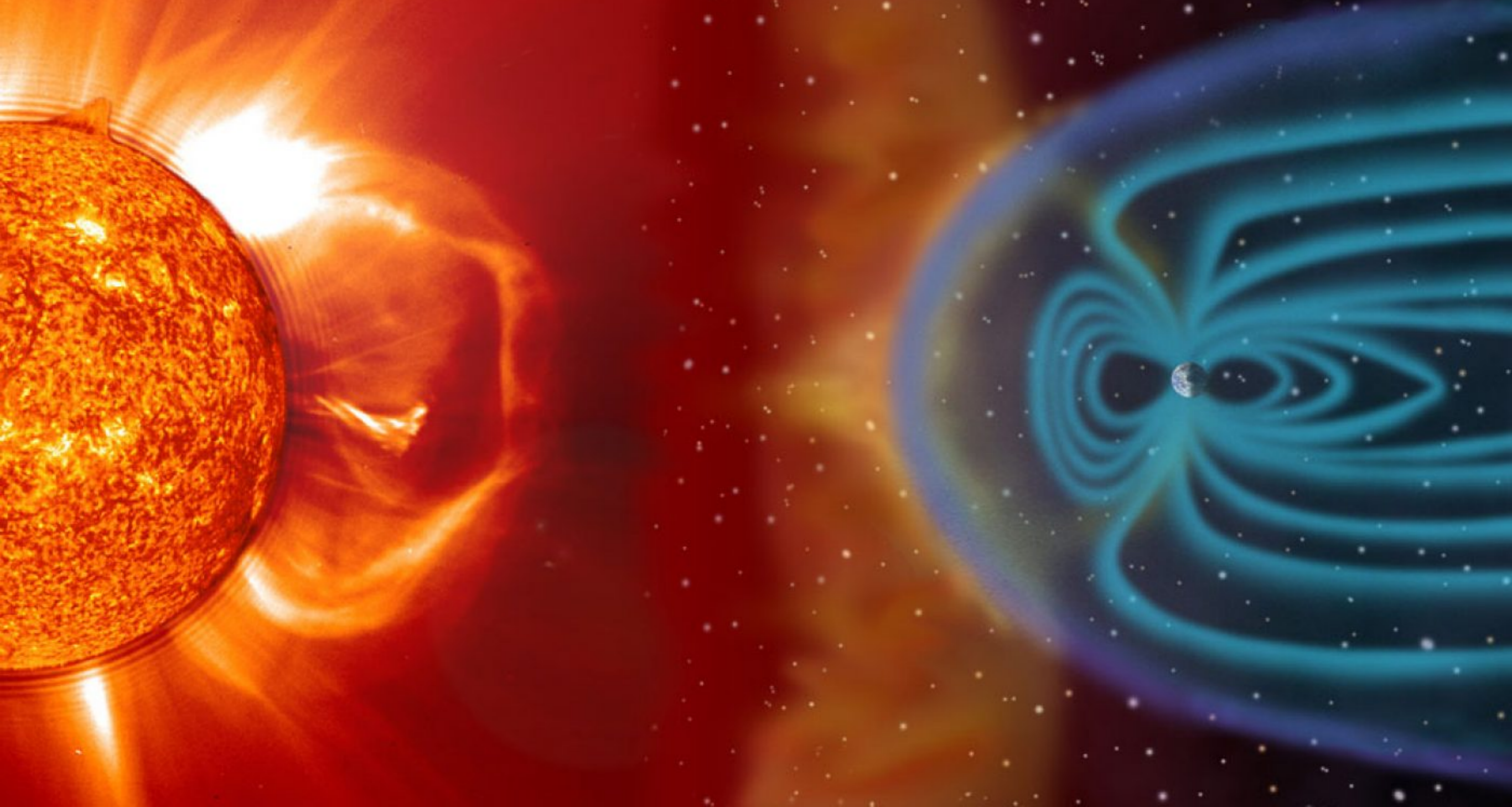
DAYS



STORM SCALE - GEOMAGNETIC STORM

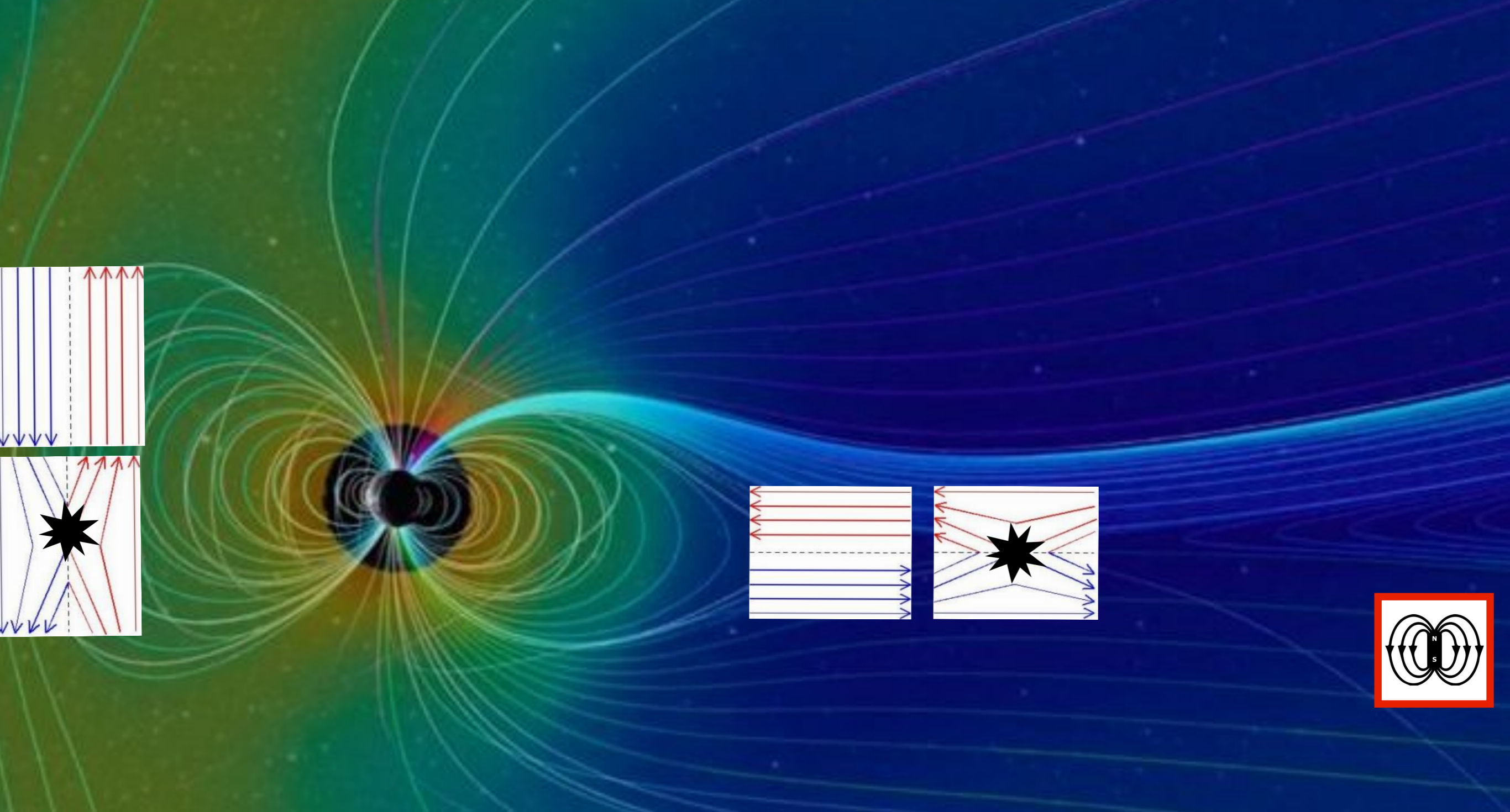






RECONNECTION

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

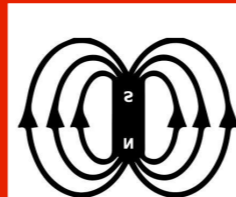
The magnetic field carried by the solar wind can couple with the magnetic field of Earth. This coupling is stronger when the solar wind magnetic field is opposite to the magnetic field of Earth.

STORM SCALE



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

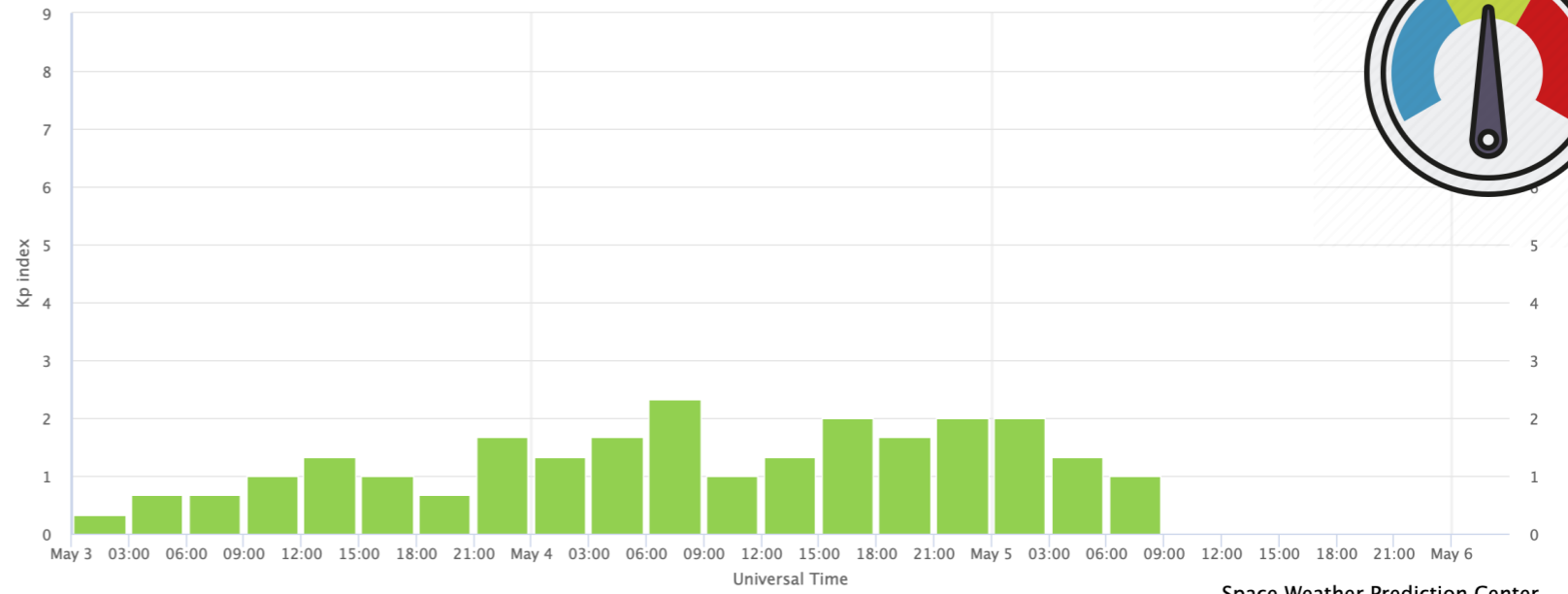
A,B,C,M,X



STORM SCALE

Estimated Planetary K index (3 hour data)

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

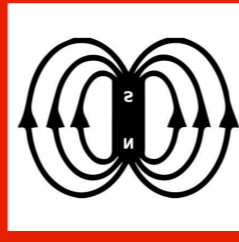


Space Weather Prediction Center

A,B,C,M,X



Kp
0 - 9



DURATION



MINs to HOUR

A simple line-art icon of a lit lightbulb, representing a short duration or immediate action.

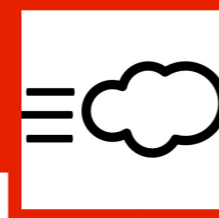
DAY+

A diagram showing magnetic field lines around a central vertical bar with a '+' sign at the top and a '-' sign at the bottom, representing a long duration or extended period.

AREA OF IMPACT



Illuminated area

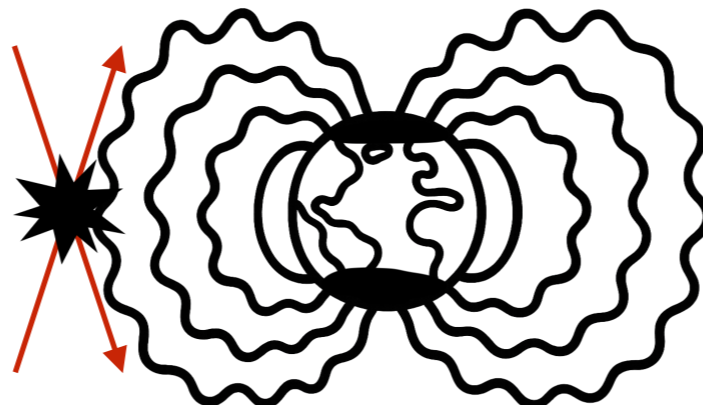
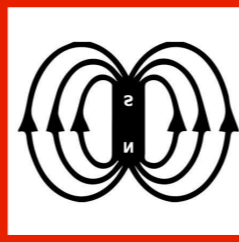


AREA OF IMPACT

Illuminated area



Polar Cap & more

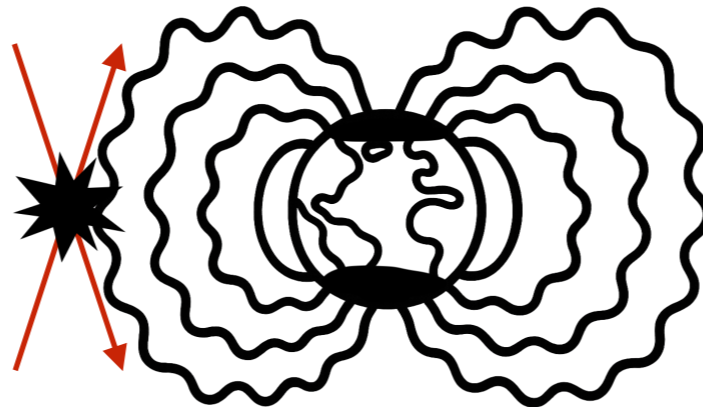
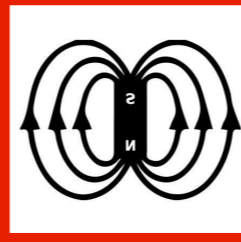


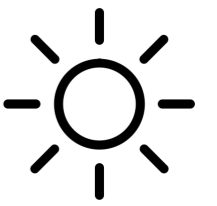
IMPACT

Ionisation

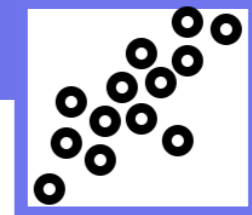


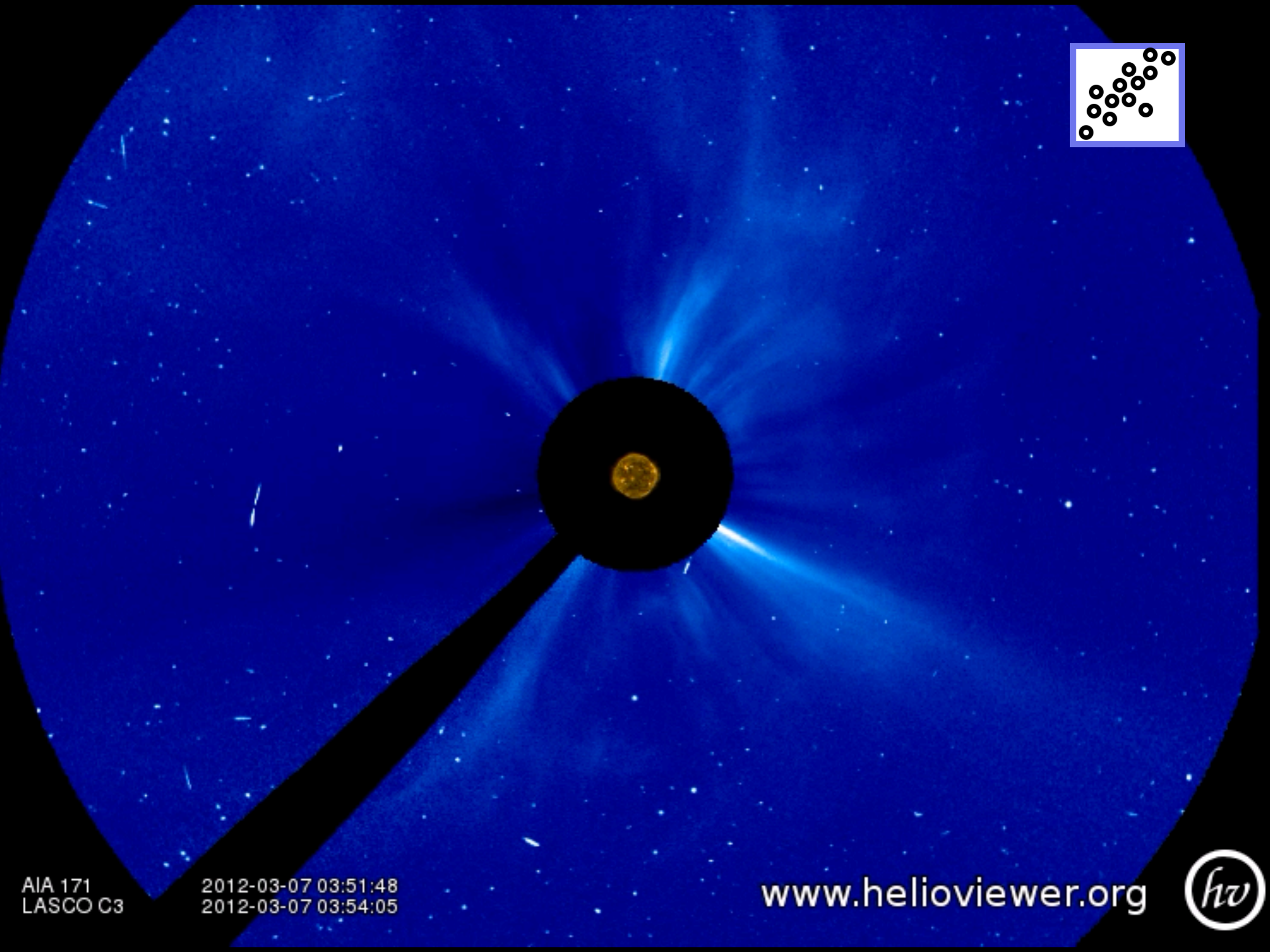
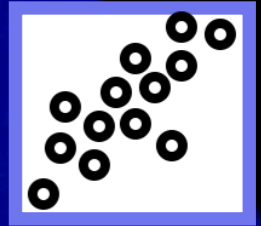
Electron content





Solar Energetic Particles





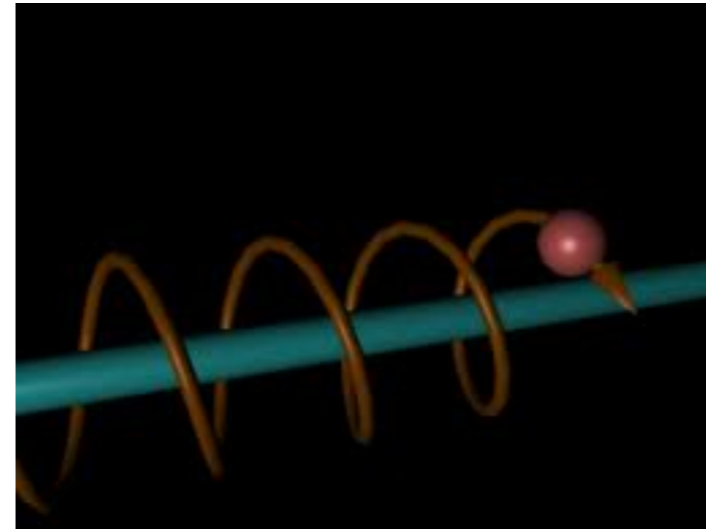
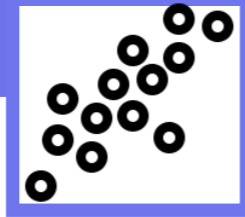
AIA 171
LASCO C3

2012-03-07 03:51:48
2012-03-07 03:54:05

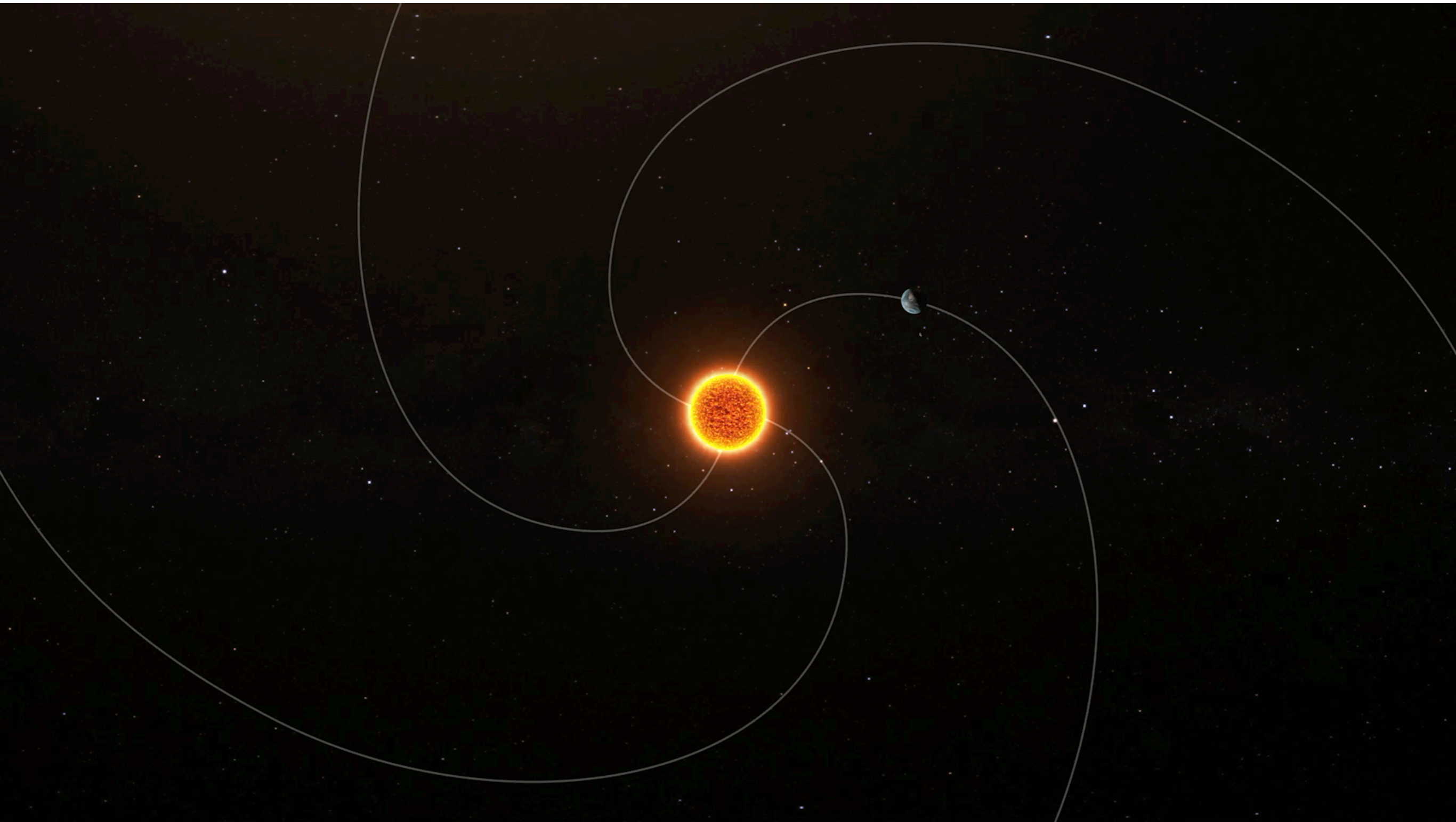
www.helioviewer.org



SOLAR PARTICLES



Solar energetic particles follow magnetic field lines.





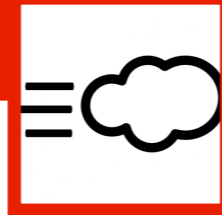
AU TRANSIT TIME

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





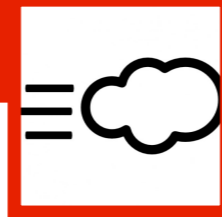
AU TRANSIT TIME

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.

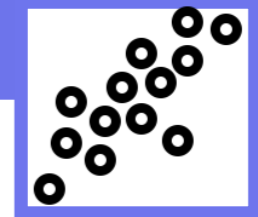
8 MIN



DAYS



HOUR



STORM SCALE

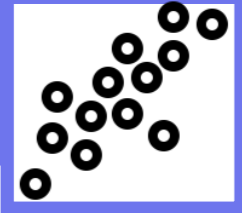
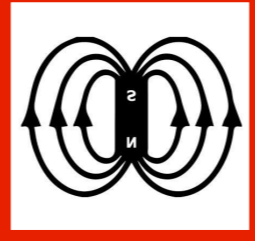


<https://www.swpc.noaa.gov/products/goes-proton-flux>

A,B,C,M,X

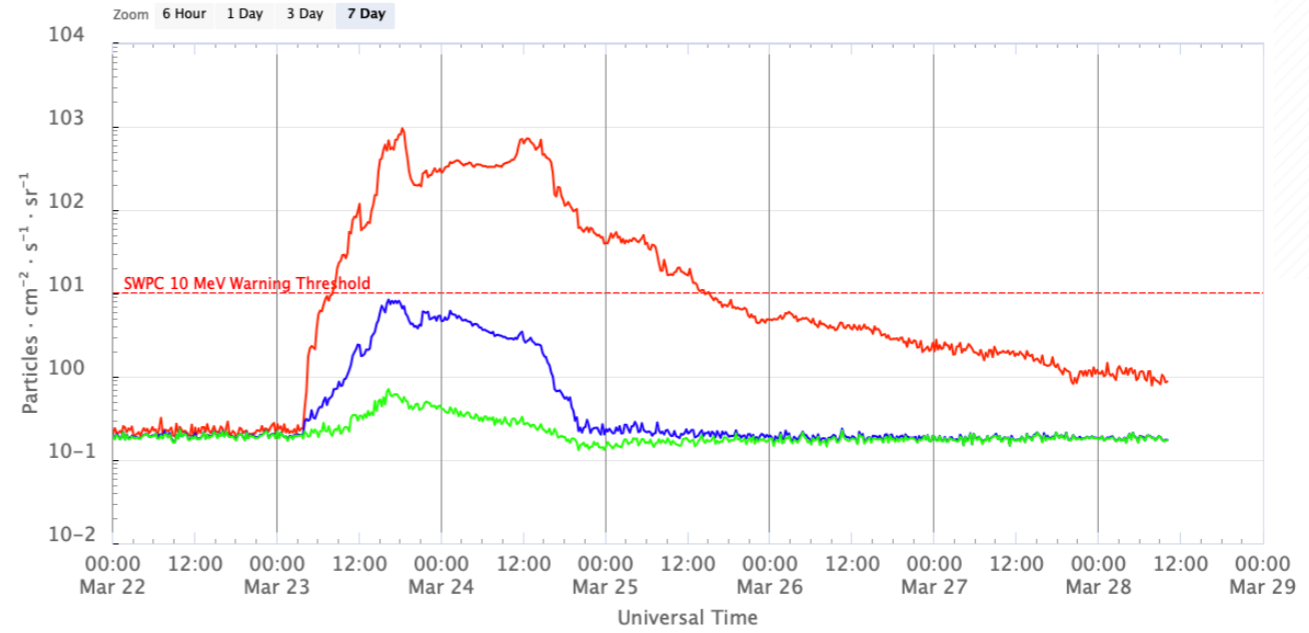


Kp
0 - 9



STORM SCALE

GOES Proton Flux (5-minute data)

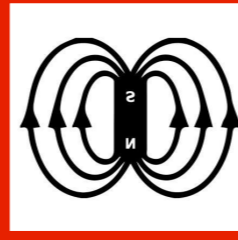


A,B,C,M,X



Updated 2024-03-28 10:10 UTC

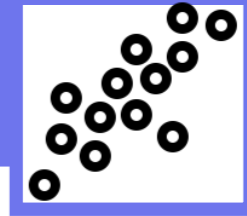
Kp
0 - 9



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

Space Weather Prediction Center

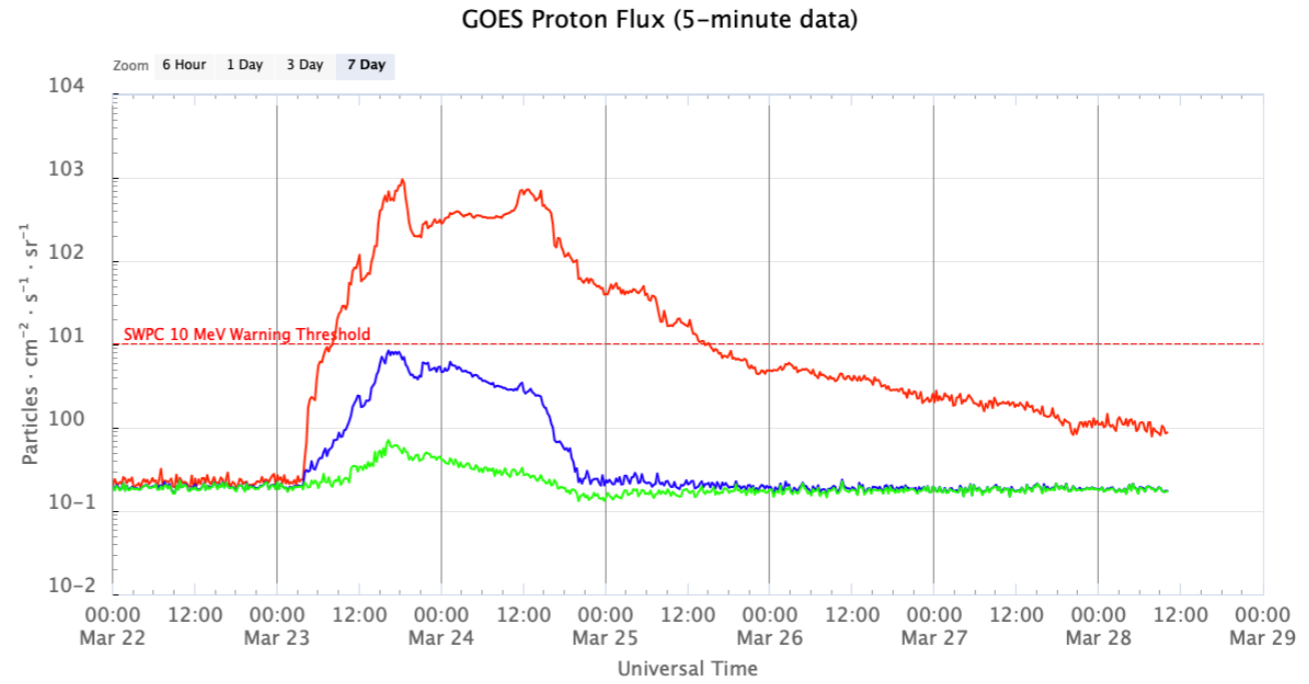
Storm - major storm



GOES



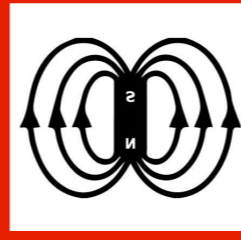
DURATION



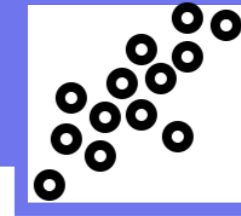
MINs to HOUR



DAY+



HOURS to DAYS



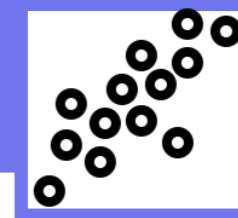
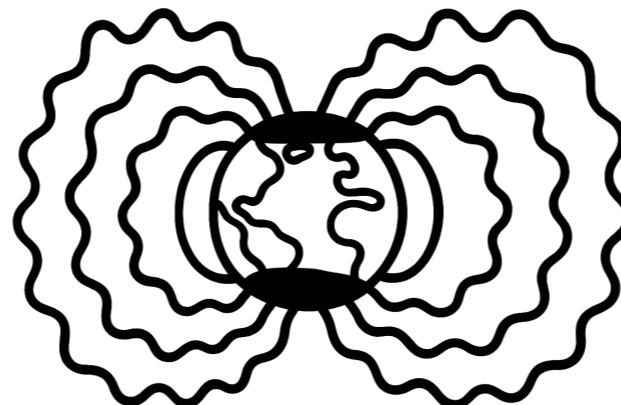
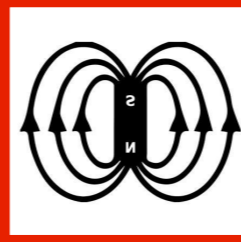
AREA OF IMPACT

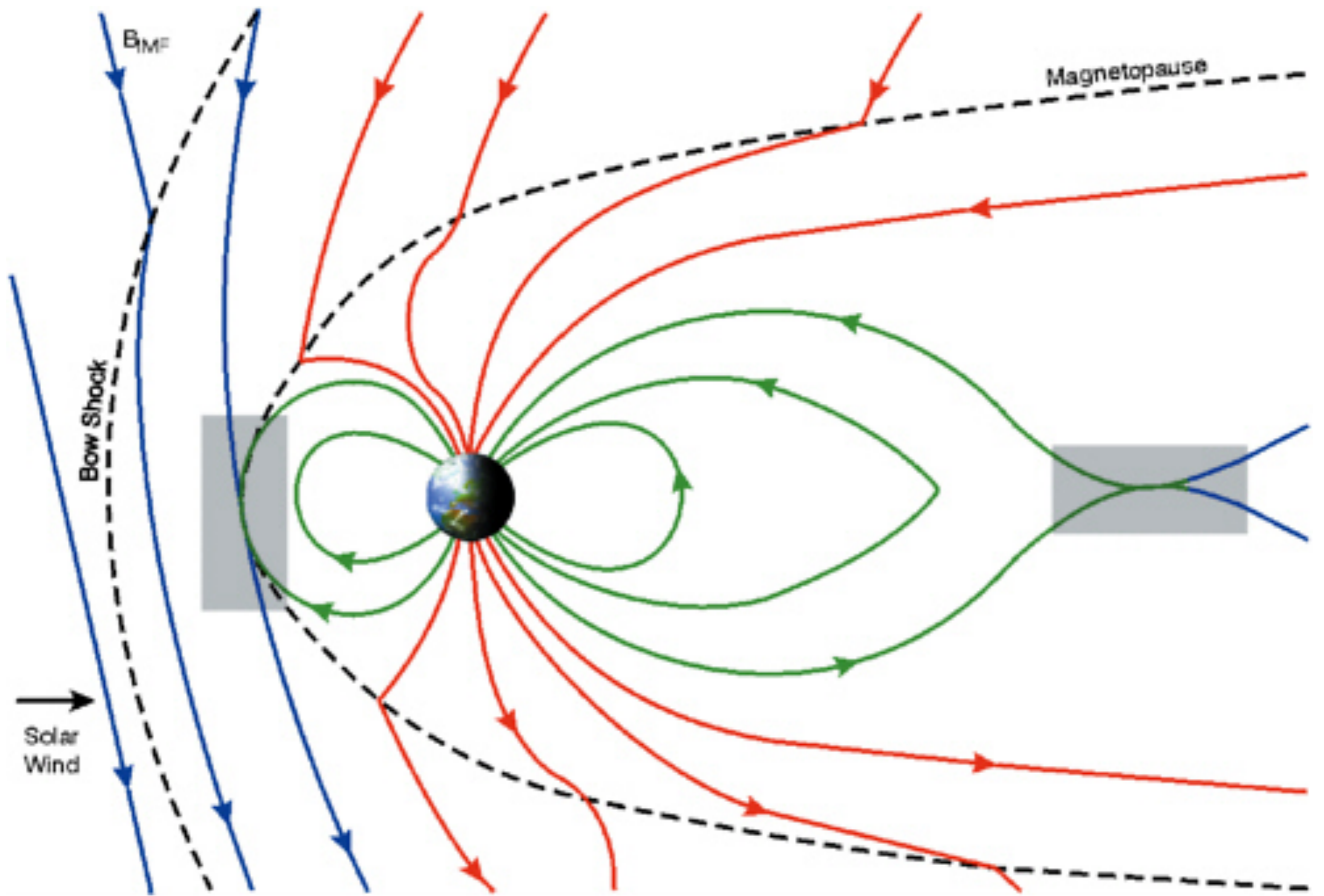


Illuminated area



Polar Cap



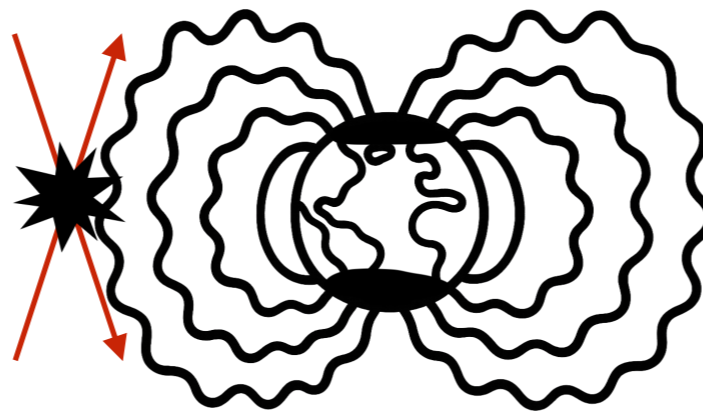
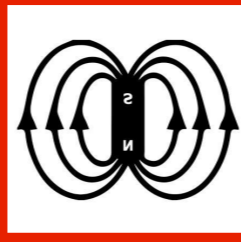


AREA OF IMPACT

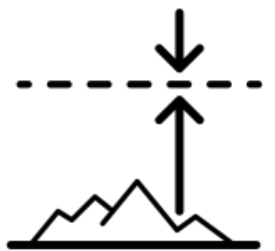
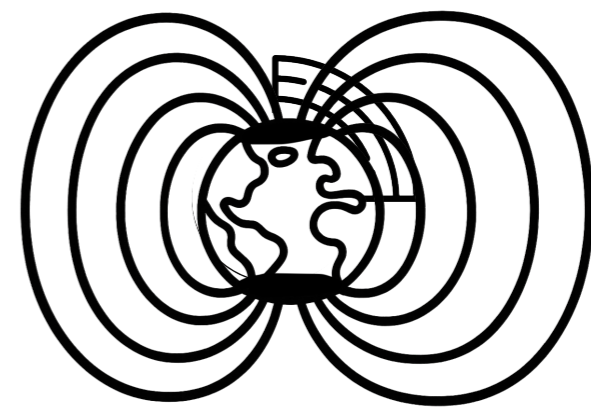
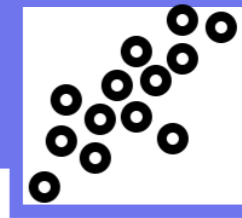
Illuminated area



Polar Cap & more



Polar Cap
High Altitude

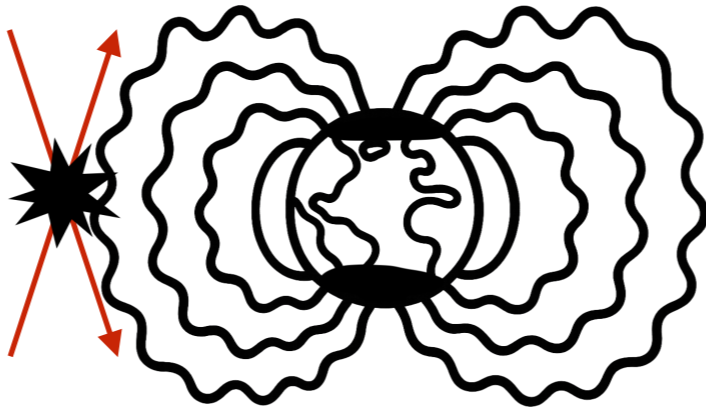
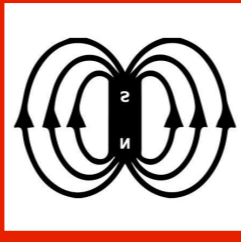


IMPACT

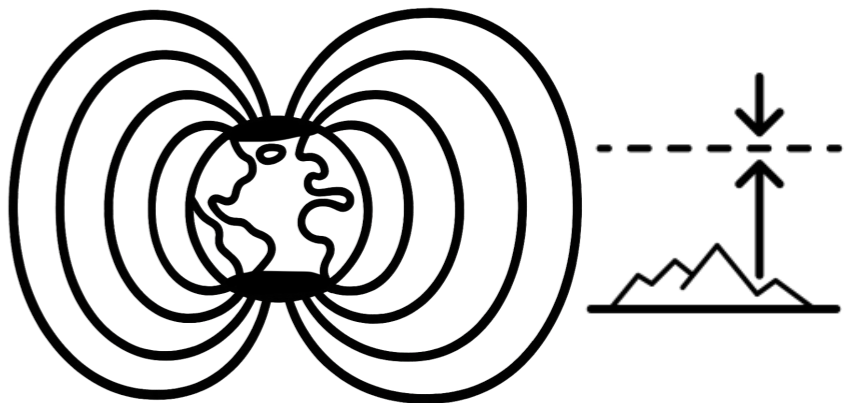
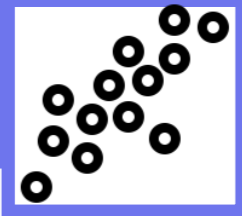
Ionisation



Electron content



Ionisation & body



OVERVIEW



8 min

X-ray: A,B,C,M,X

Min to Hour

Illuminated area

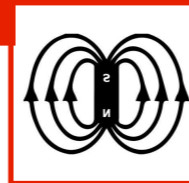


Days

Kp: 0 - 9

Day+

Polar Caps

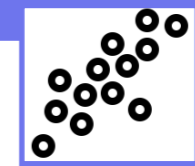


Hour

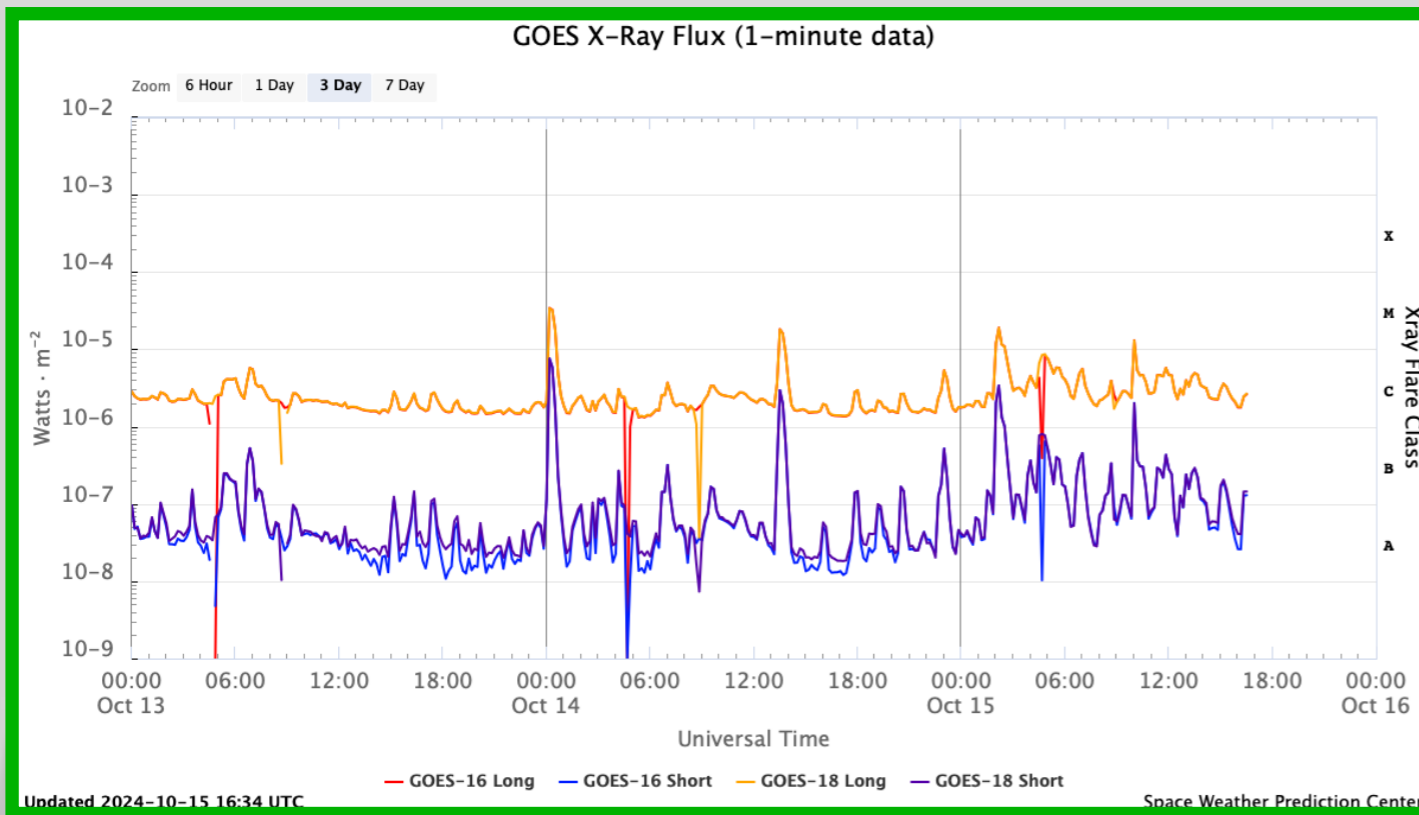
Protons:
Storm - Major Storm

Hours to Days

Polar Caps
High Altitude



X-ray Flux Passport



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

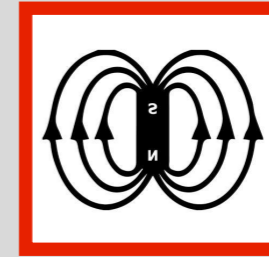
Y-axis: X-ray flux in W/m^2 , i.e. how much energy (Joule) passes in 1 sec ($W=Watt=J/s$) through 1 square meter at geostationary height.

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.

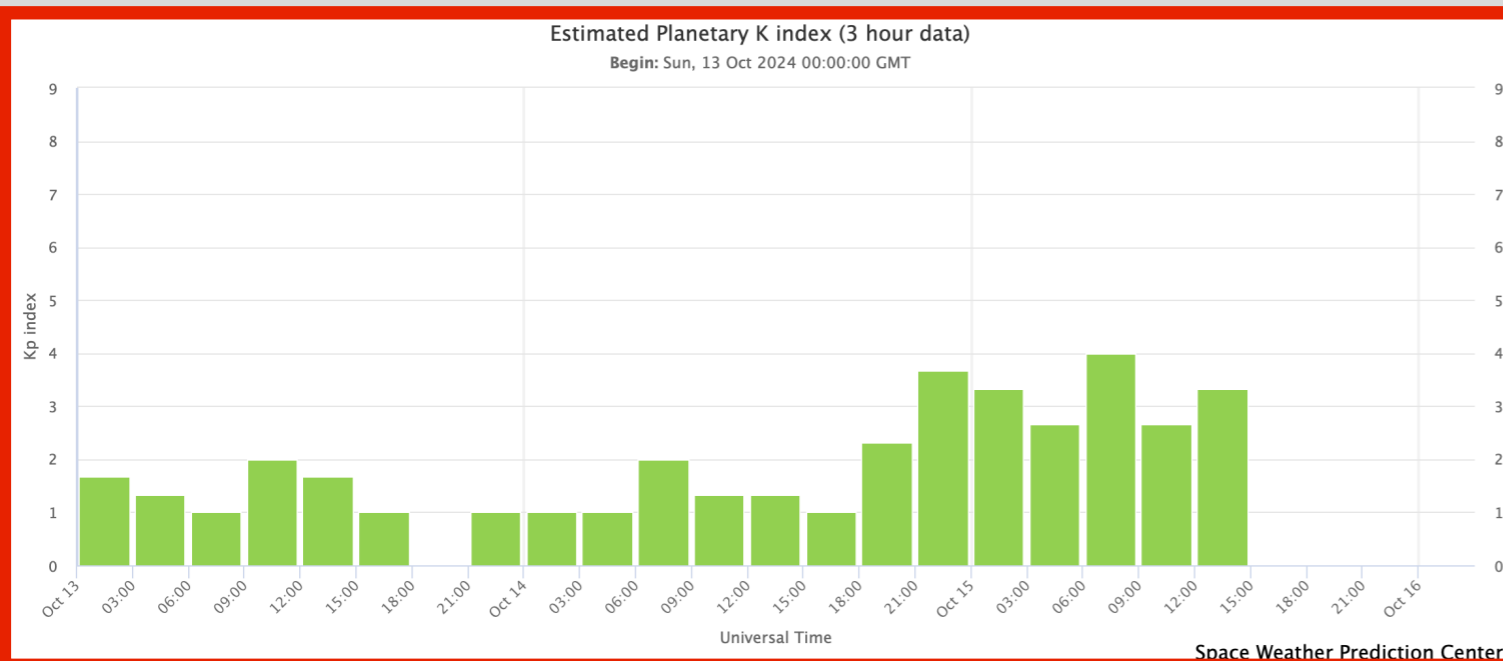
With e.g. 2- = 1,70 and 2+ = 2,30 etc.

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.

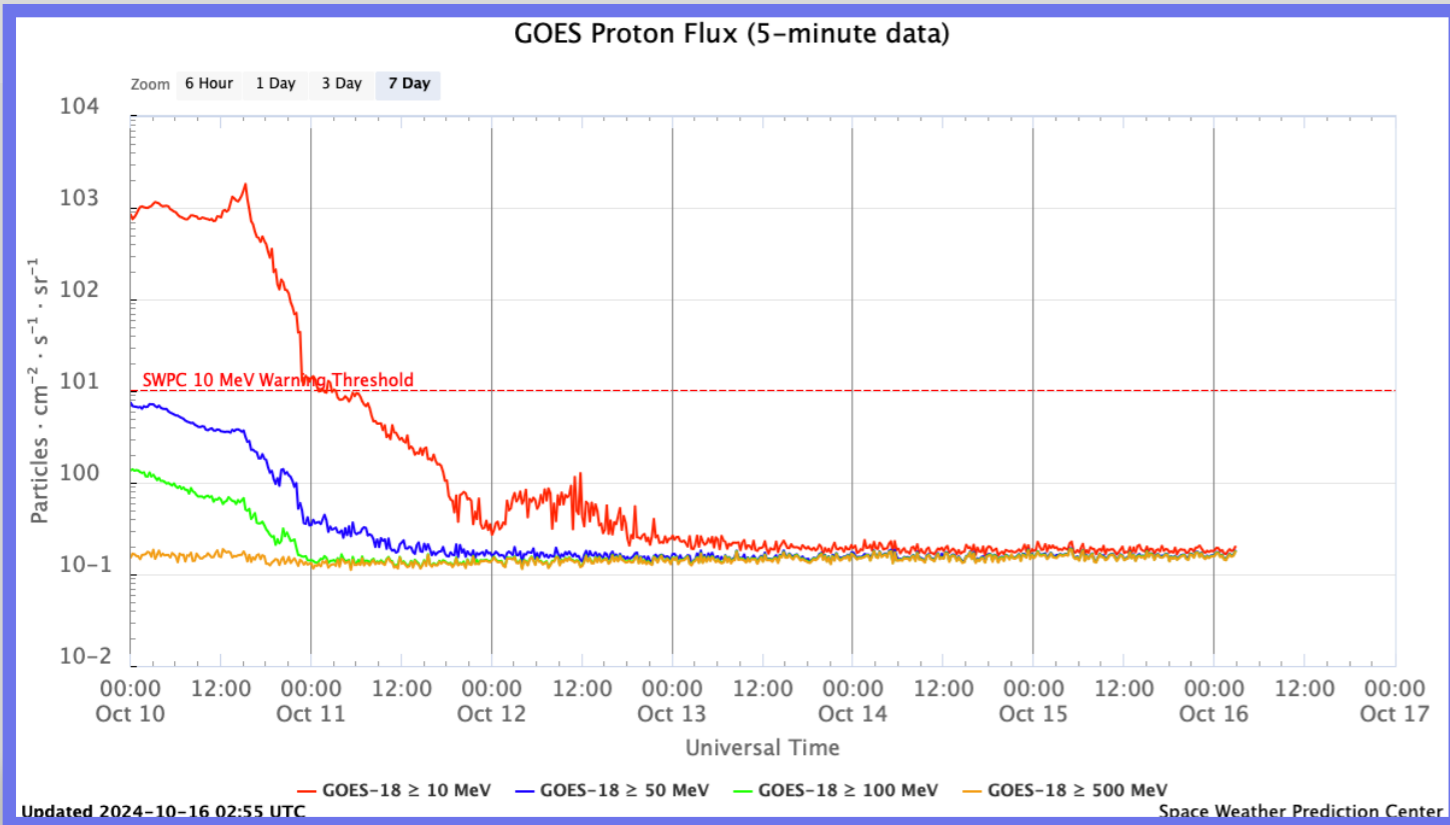
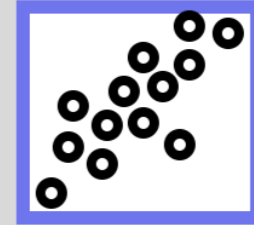
Observatories

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.

Proton Flux Passport



Type

Graph, flux of solar protons versus time.

Use

To quantify proton events impacting Earth.

Units

Particles/(cm²*s*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/(cm²*s*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.