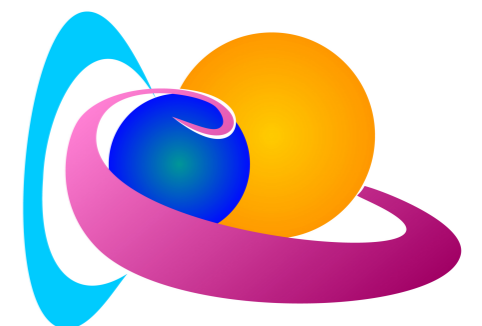
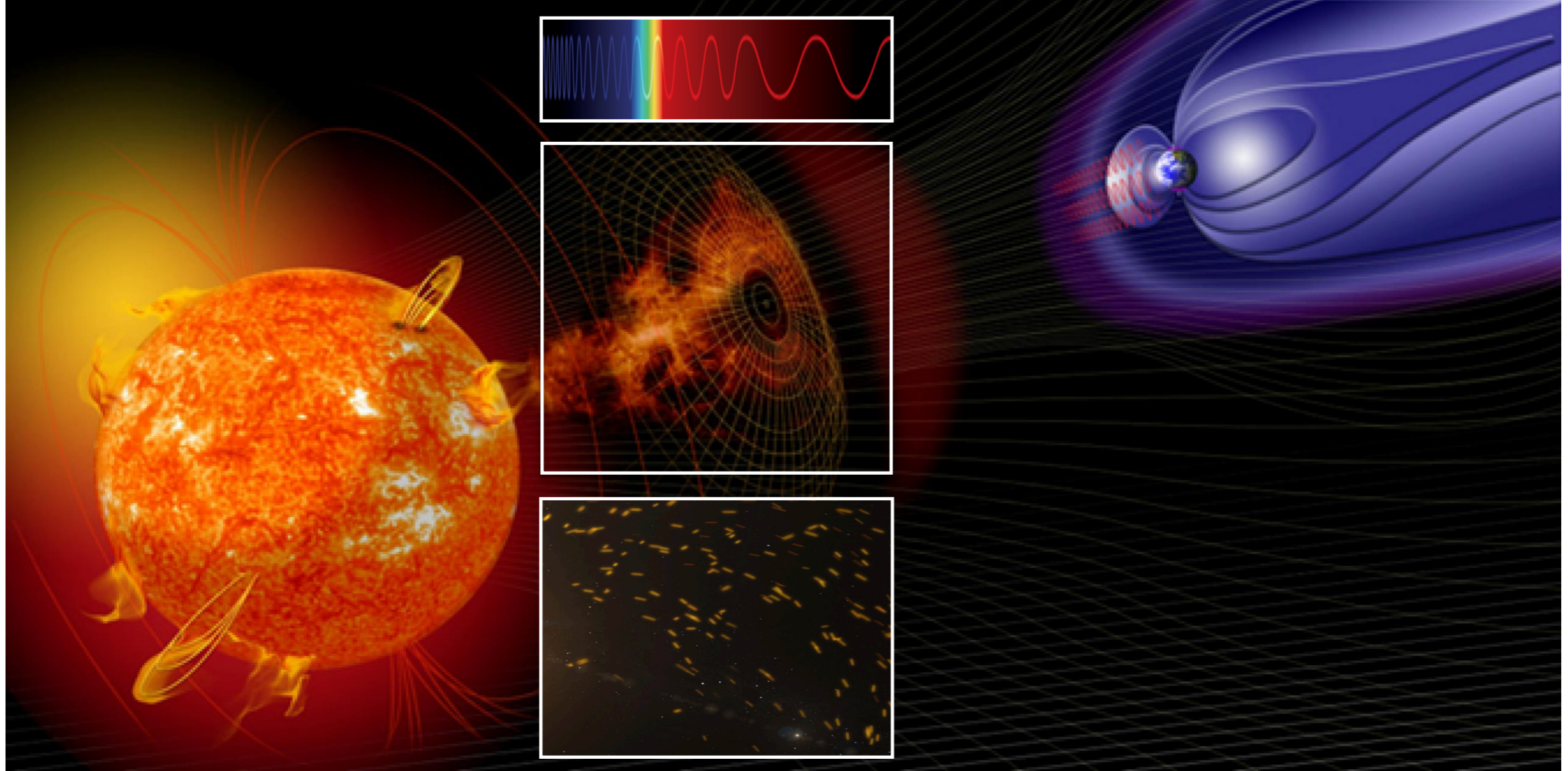


Space Weather impacts on Aviation

PECASUS advisories for ICAO

Course by the
Solar-Terrestrial Centre of Excellence



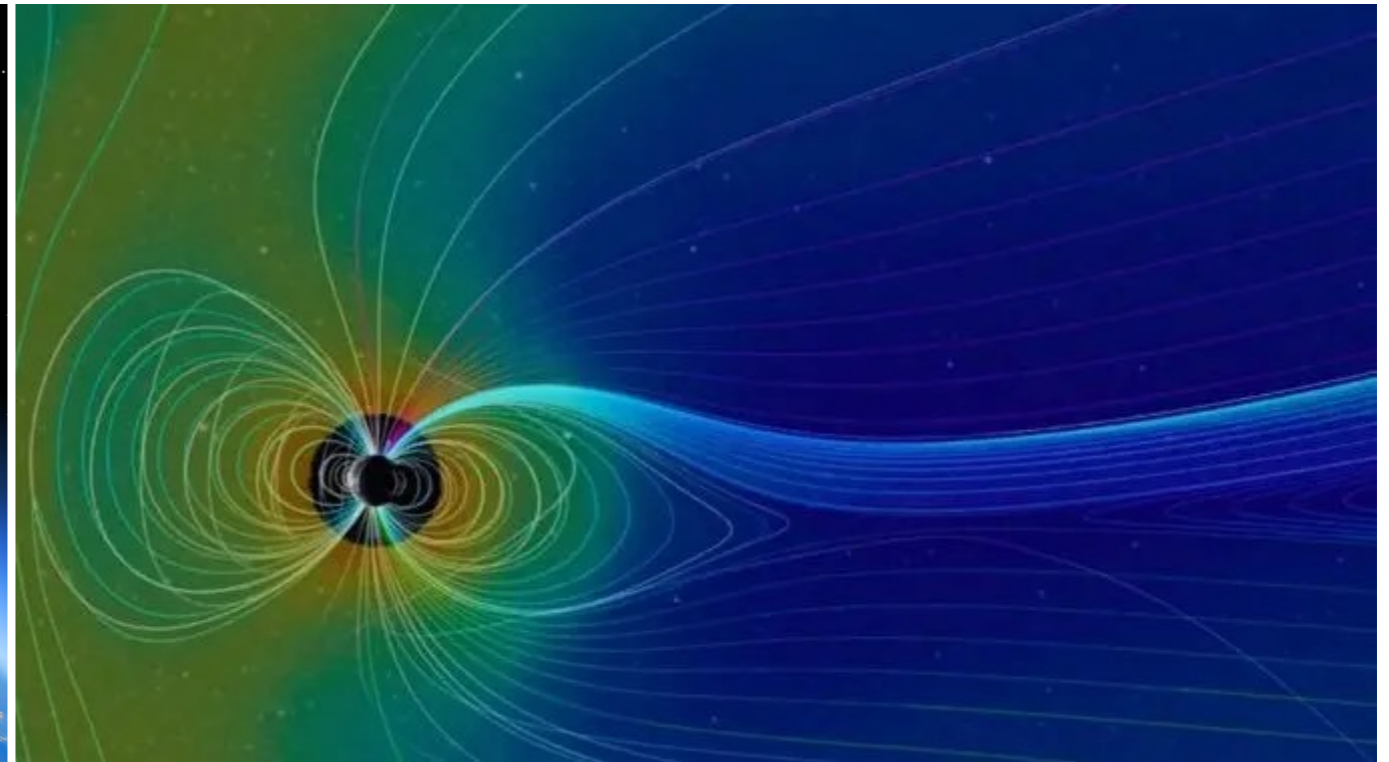


SPACE WEATHER

Introduction

Space Weather

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



THE SUN AS A BALL OF ENERGY

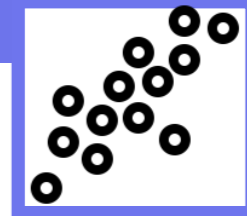
E.M. RADIATION



PLASMA

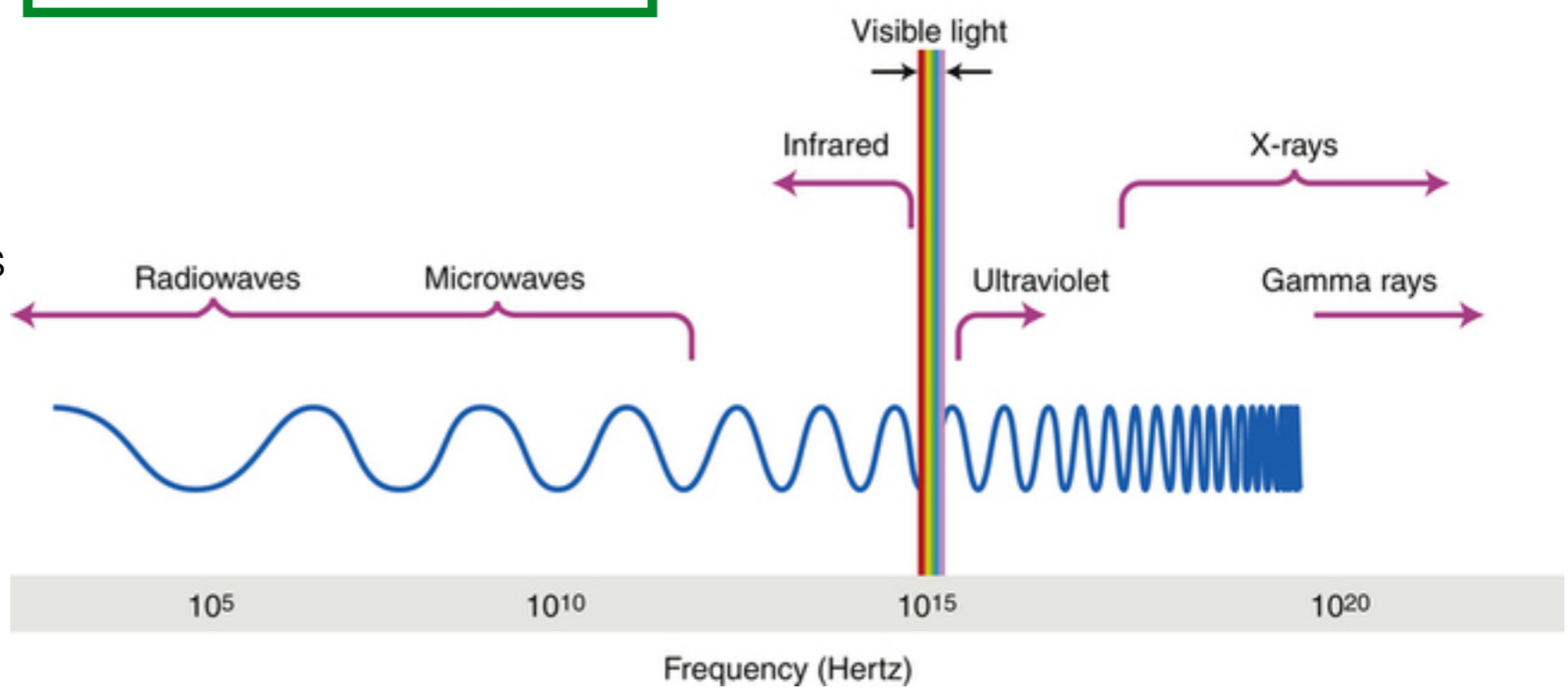


ENERGETIC
PARTICLES



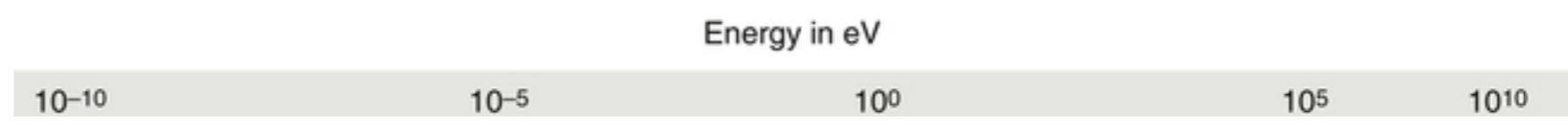
Electromagnetic radiation

- Photons / electromagnetic waves
- Speed of light



Particles

- Atomic & sub-atomic particles
- km/s to fractions of speed of light
- Magnetic Field



3 SPACE WEATHER PHENOMENA

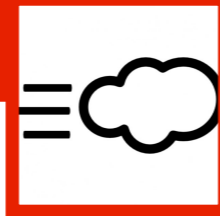
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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

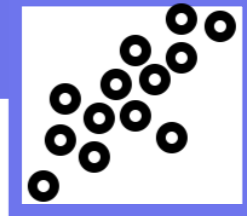
LIGHT



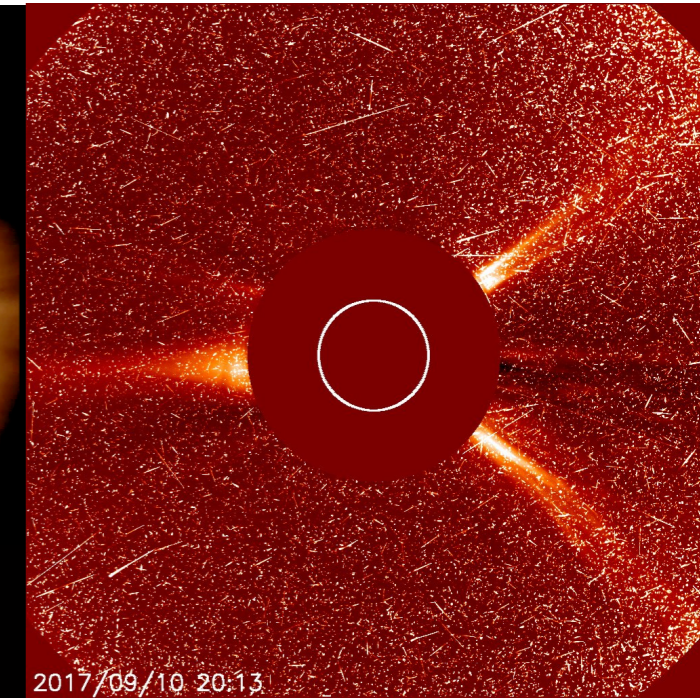
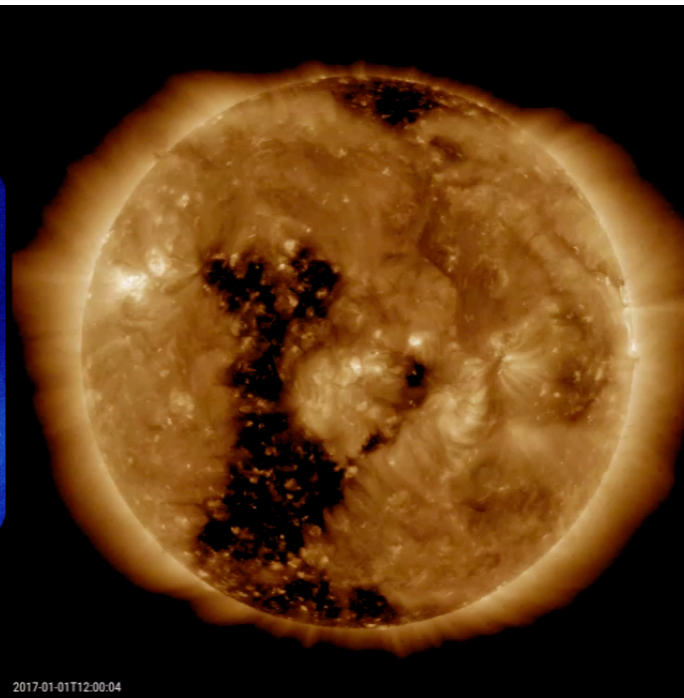
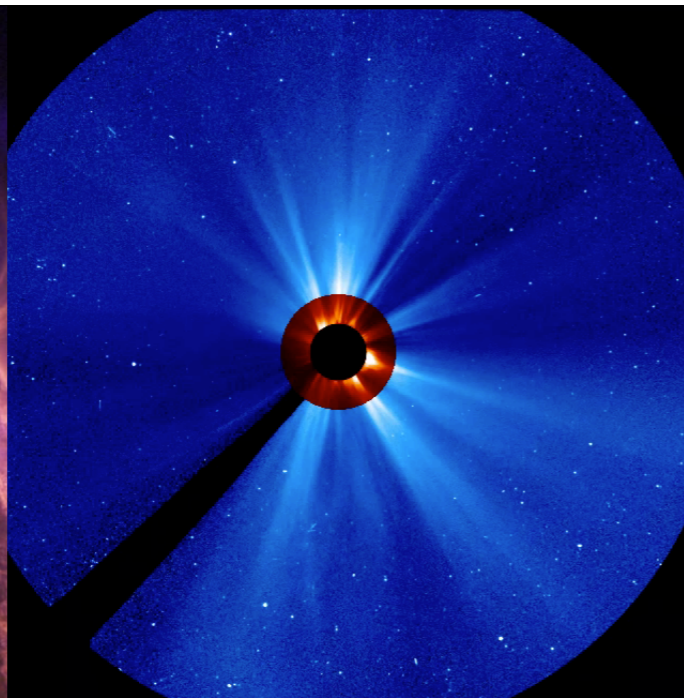
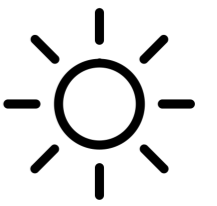
WIND



PARTICLE RAIN



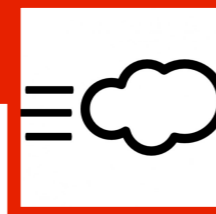
SOLAR WEATHER EVENTS



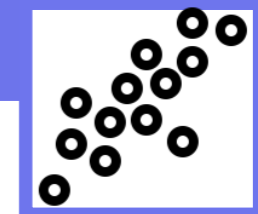
Flare



Coronal Mass Ejection
HSS

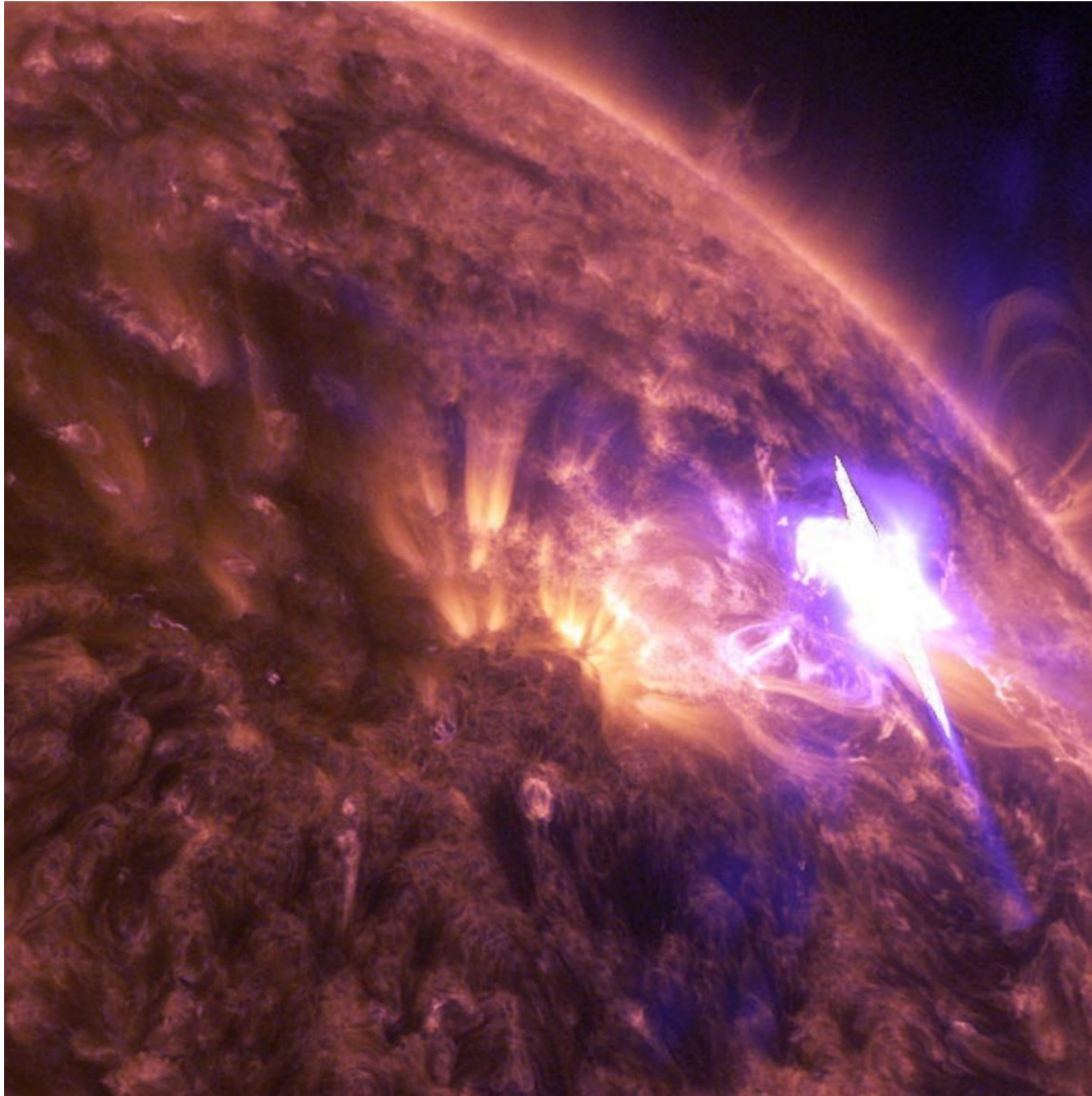


Shower of energetic
particles



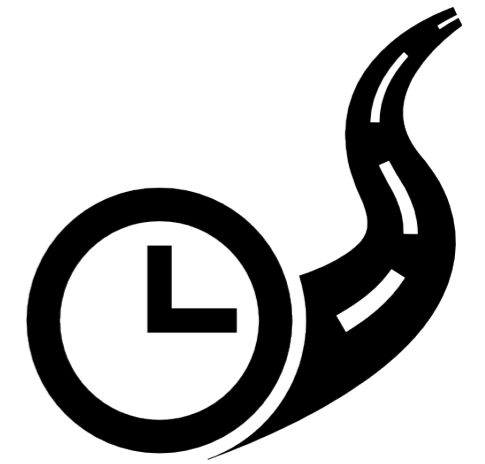


A flare is a light flash near an active region. A volume of plasma is suddenly heated and therefore lights up.



AU TRANSIT TIME

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



8 MIN



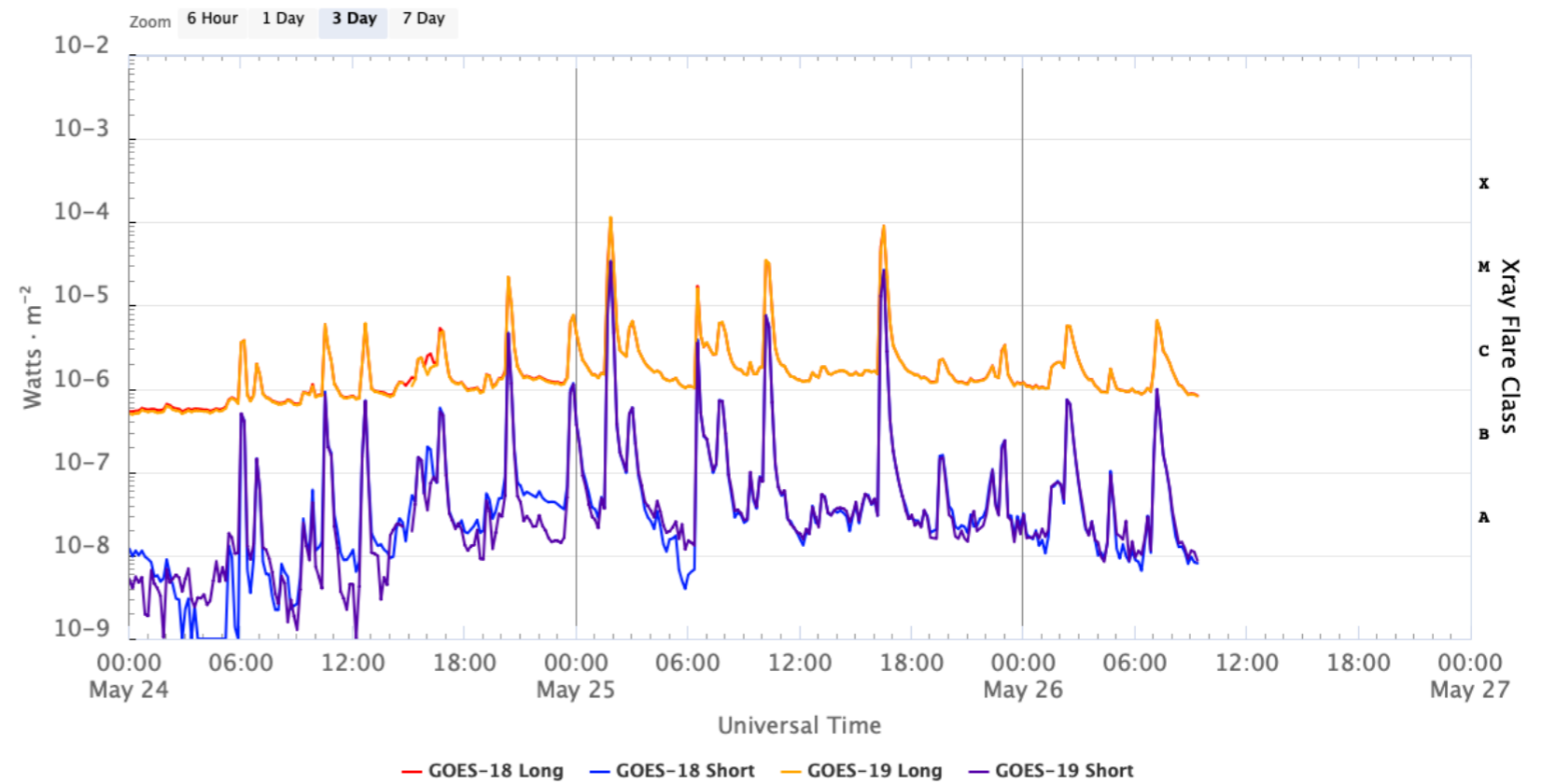
SCALE



A,B,C,M,X



GOES X-Ray Flux (1-minute data)



Updated 2025-05-26 09:23 UTC

Space Weather Prediction Center

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



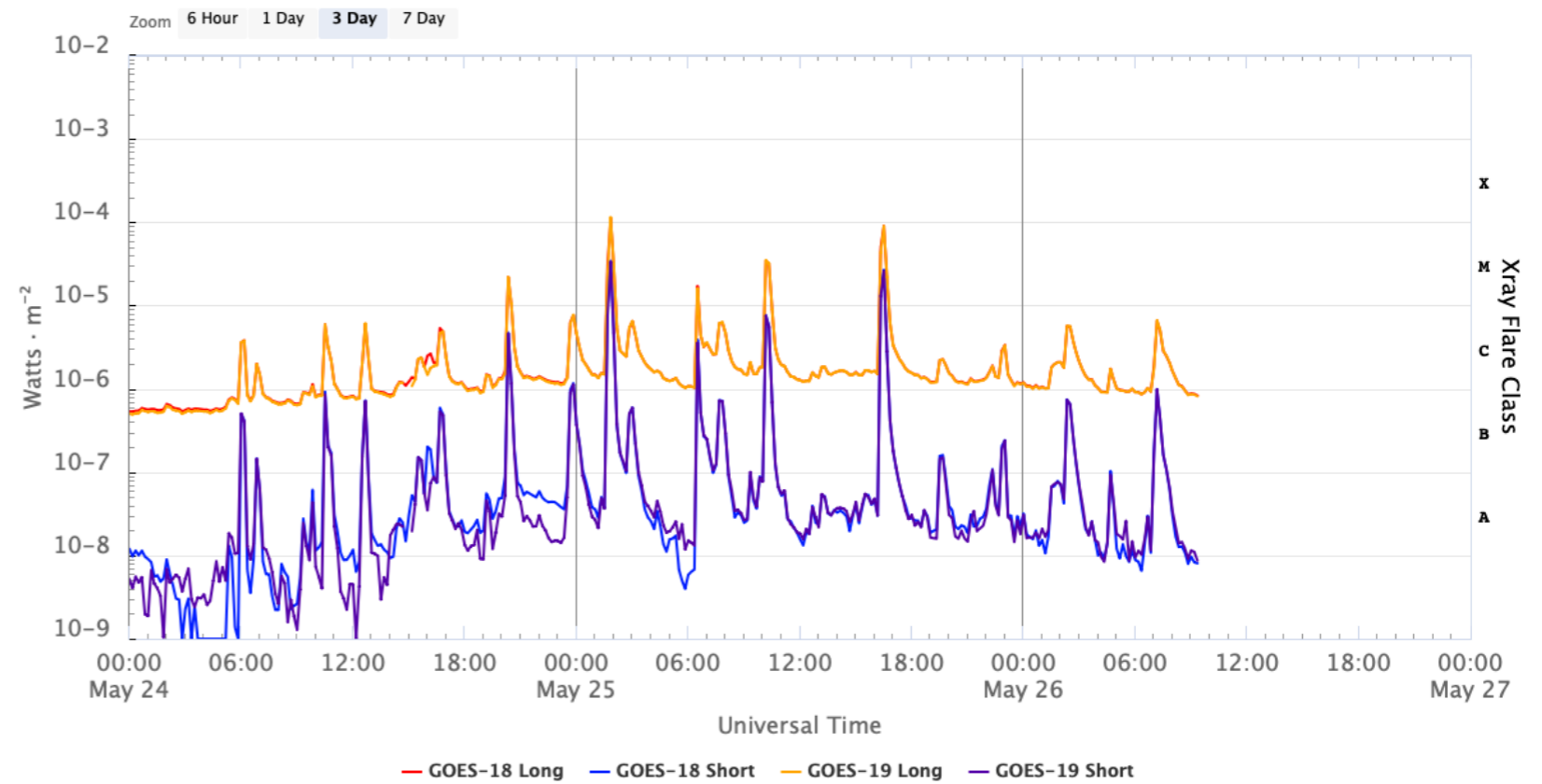
DURATION



MINs to HOUR



GOES X-Ray Flux (1-minute data)



Updated 2025-05-26 09:23 UTC

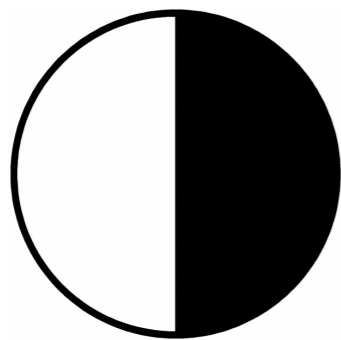
Space Weather Prediction Center

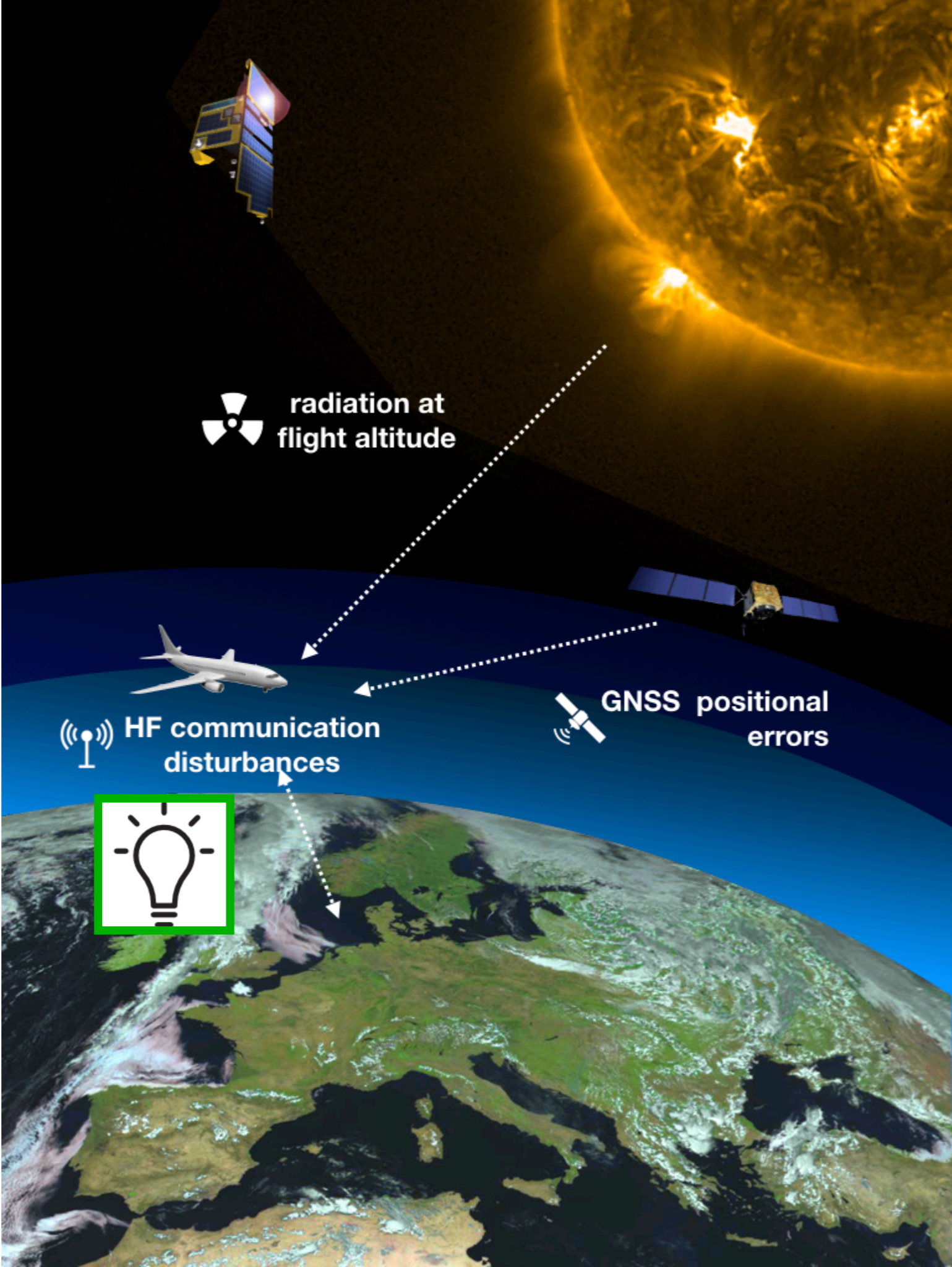



AREA OF IMPACT



Illuminated area



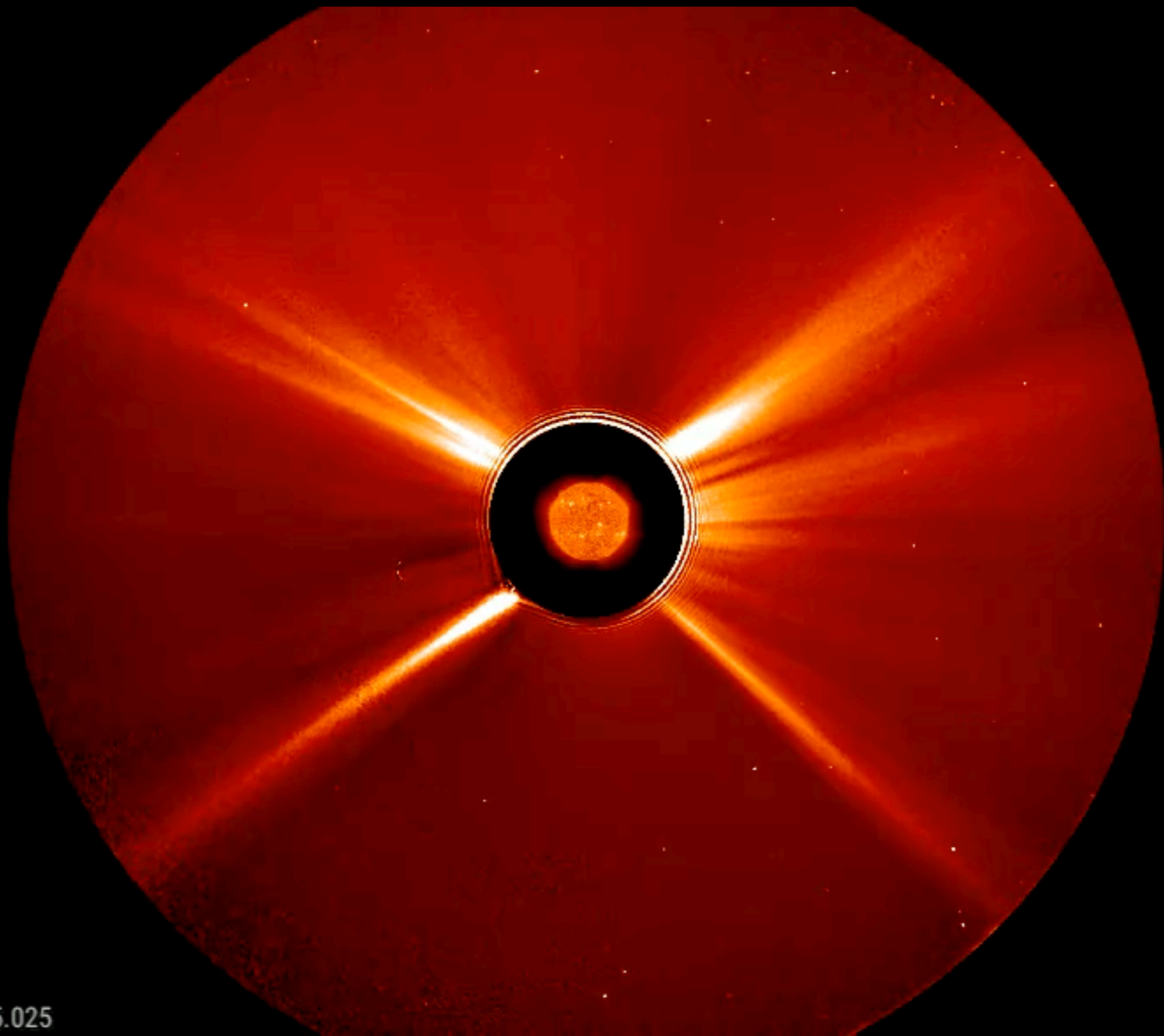
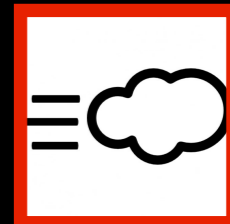


 radiation at flight altitude

 HF communication disturbances

 GNSS positional errors

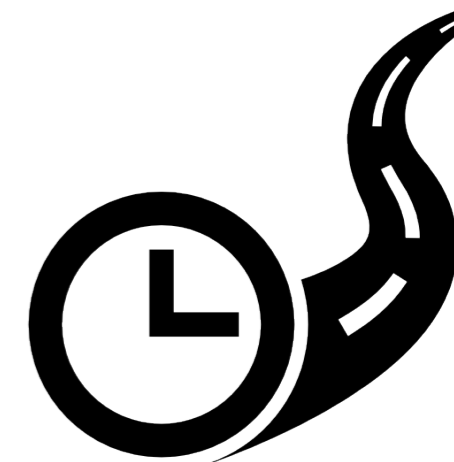




2022-02-15T16:25:45.025

AU TRANSIT TIME

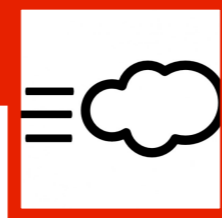
The energy released during a solar storm moves through space, each with its own typical speed: speed of light, order of a few 100 km/s,.....



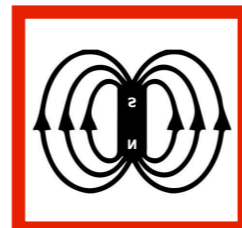
8 MIN



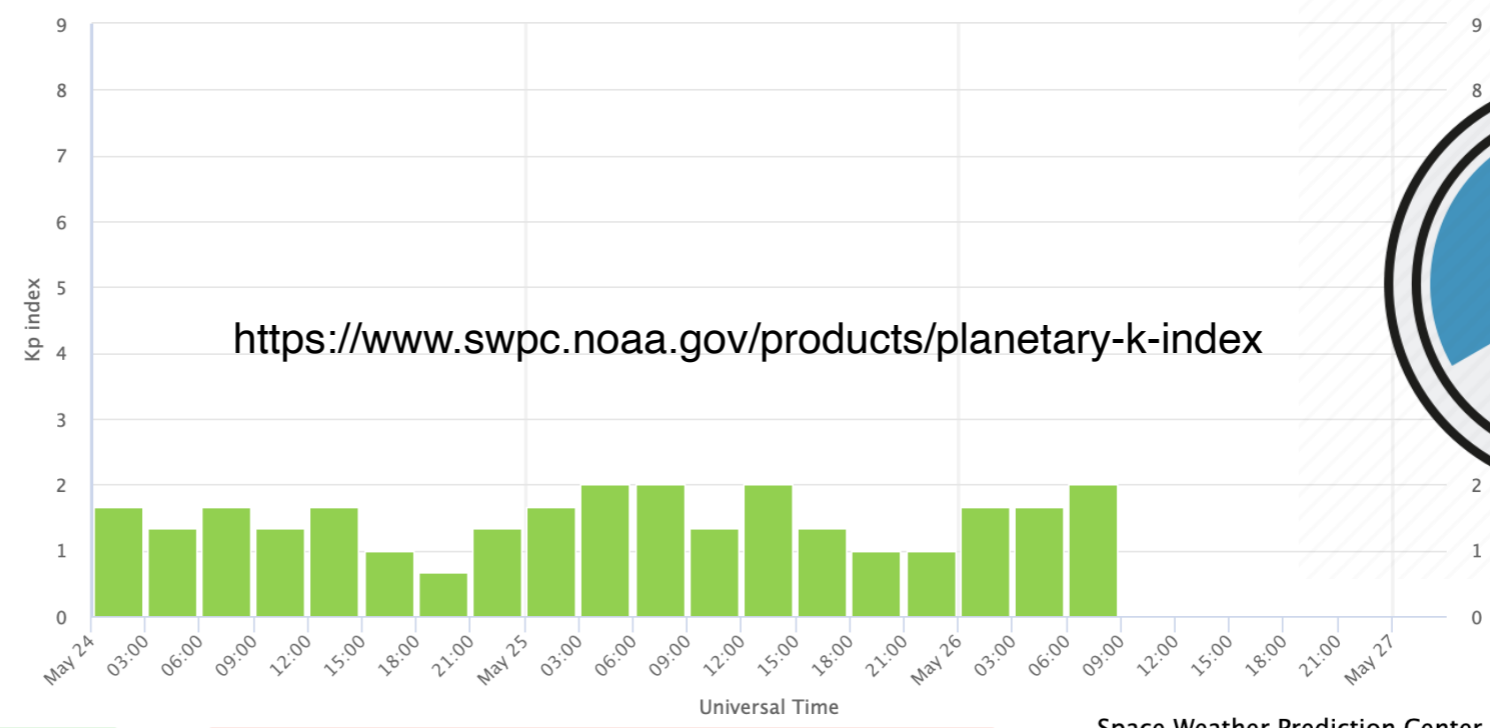
DAYS



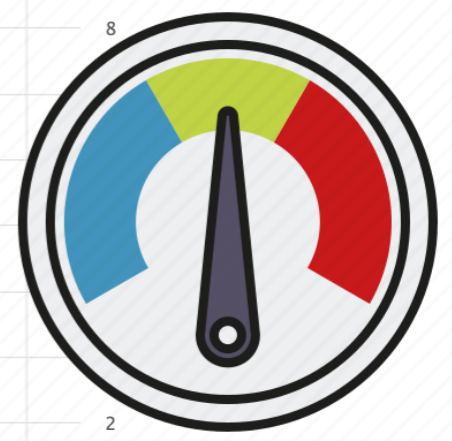
STRENGTH



SCALE



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

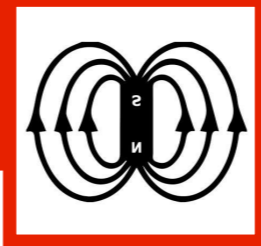


Space Weather Prediction Center

A,B,C,M,X



Kp - K_local
0 - 9



DURATION

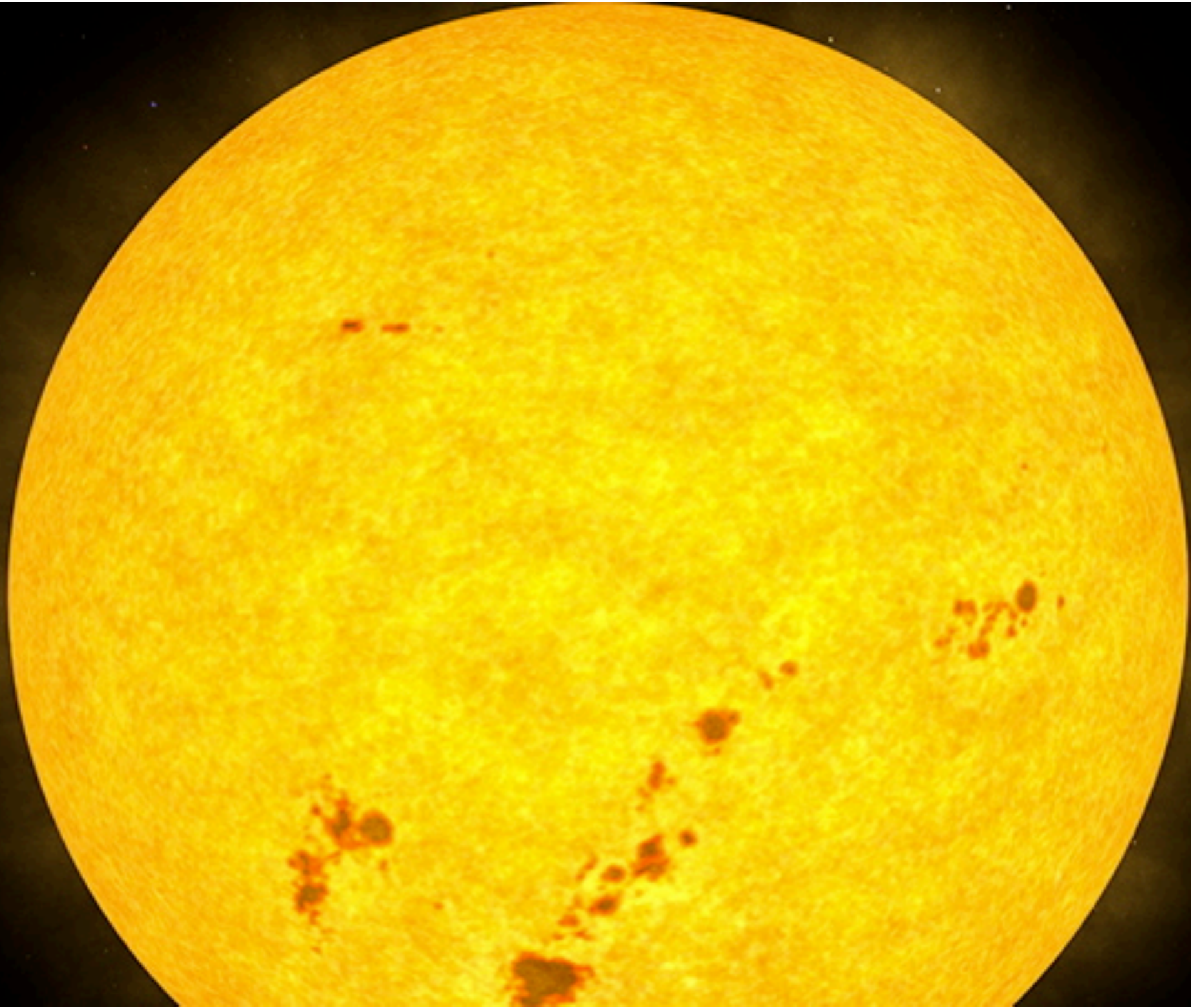
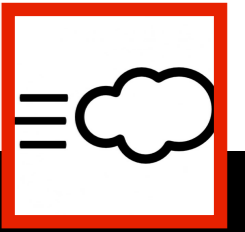


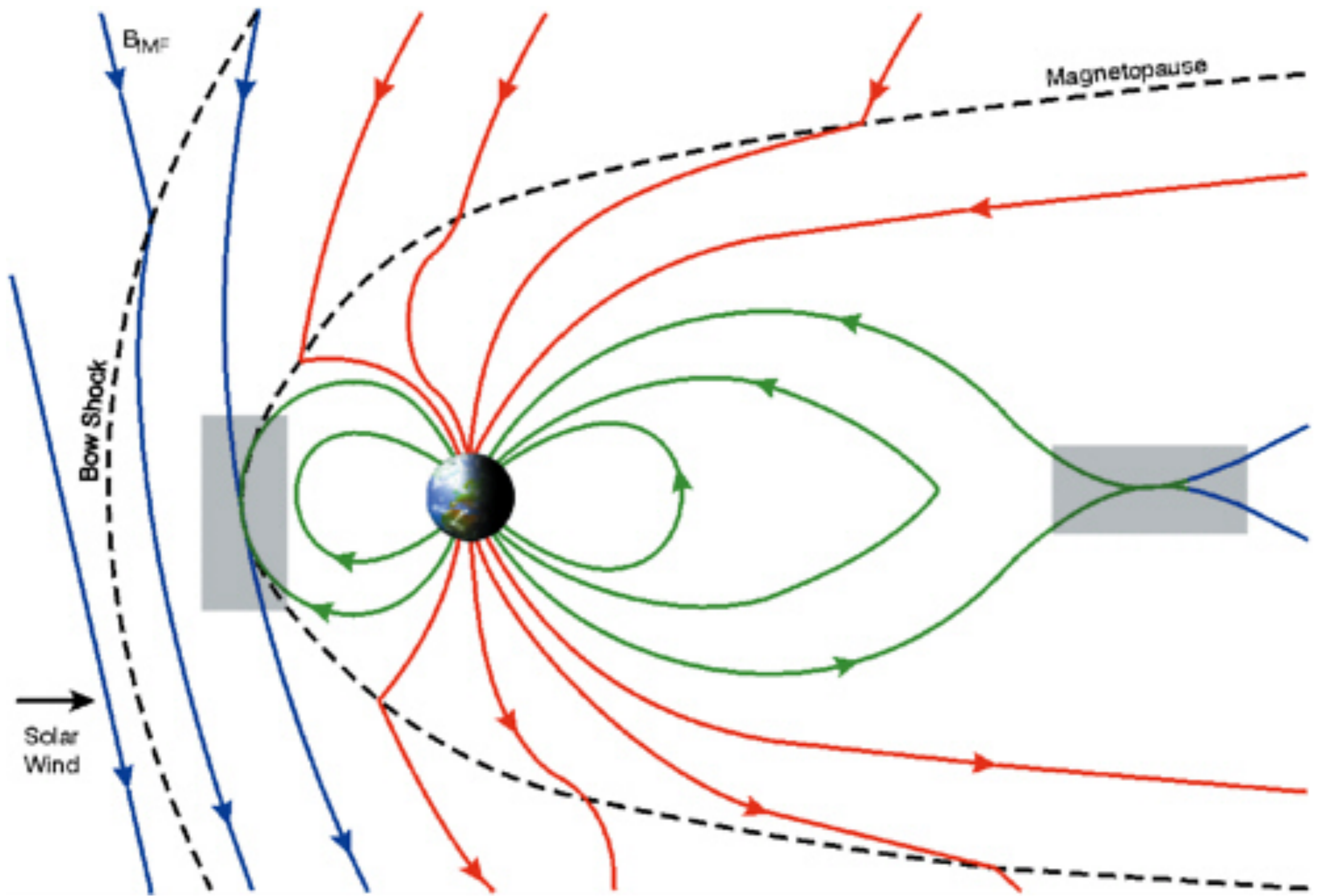
MINs to HOUR

A white square icon containing a black outline of a lit lightbulb, representing an idea or a short-term event.

DAY+

A white square icon containing a black diagram of magnetic field lines with arrows, representing a long-term or continuous process.





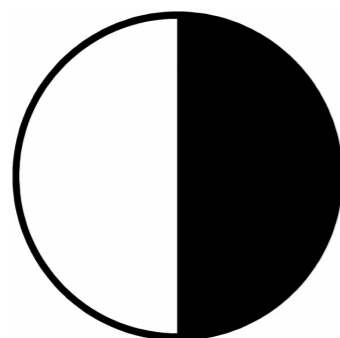
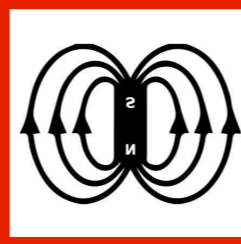
AREA OF IMPACT

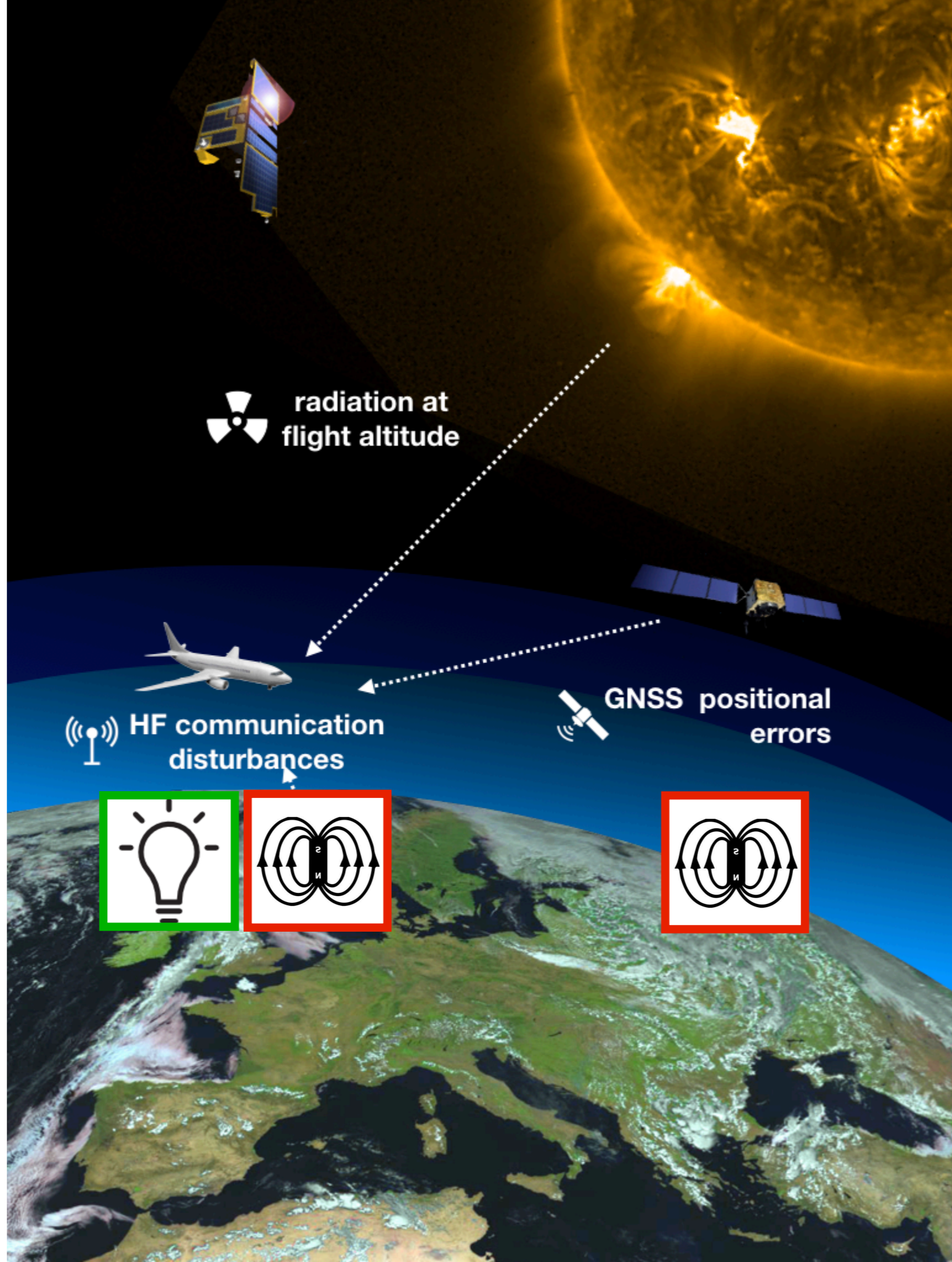



Illuminated area



Polar Cap

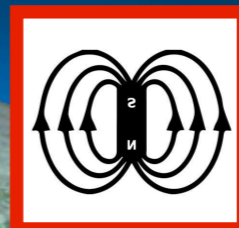
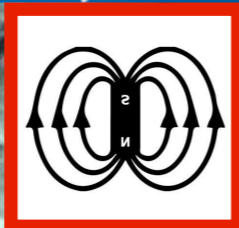


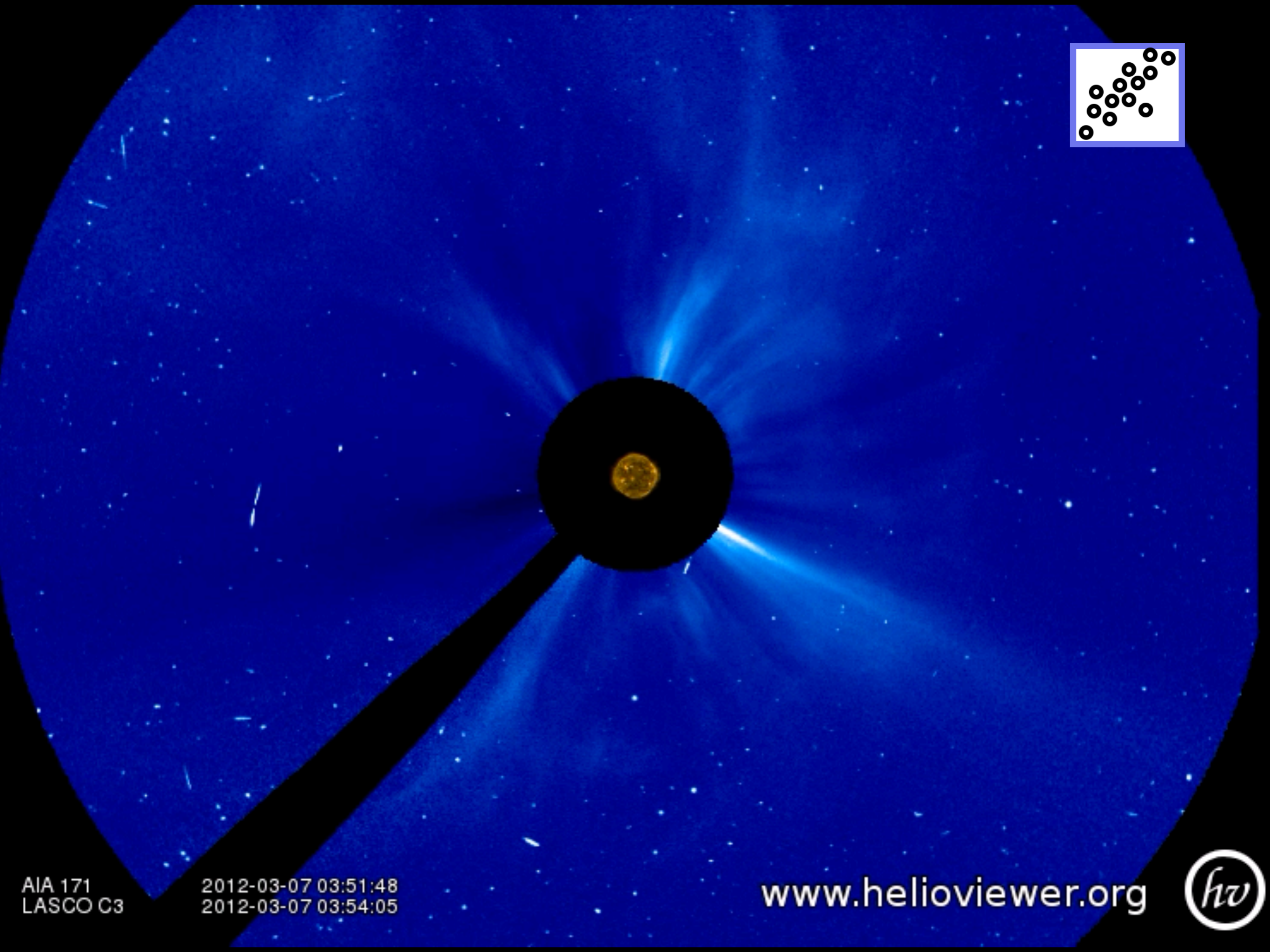
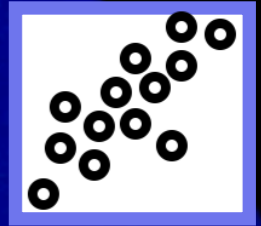


 radiation at flight altitude

 HF communication disturbances

 GNSS positional errors



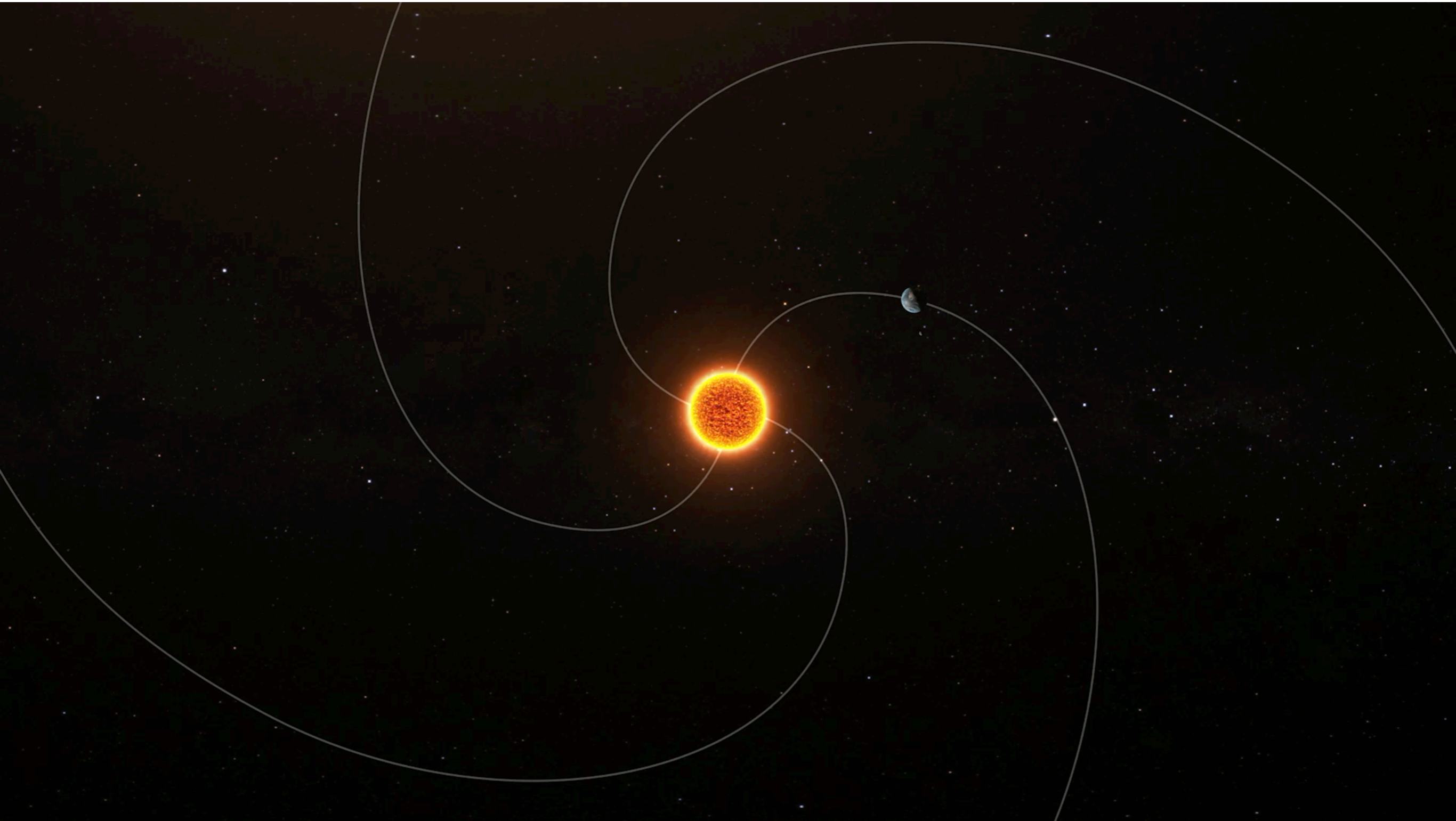


AIA 171
LASCO C3

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

www.helioviewer.org





AU TRANSIT TIME

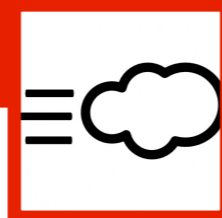
The energy released during a solar storm moves through space, each with its own typical speed: speed of light, order of a few 100 km/s, relativistic speeds.



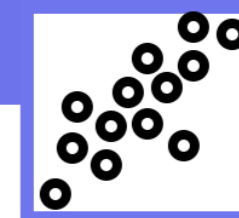
8 MIN



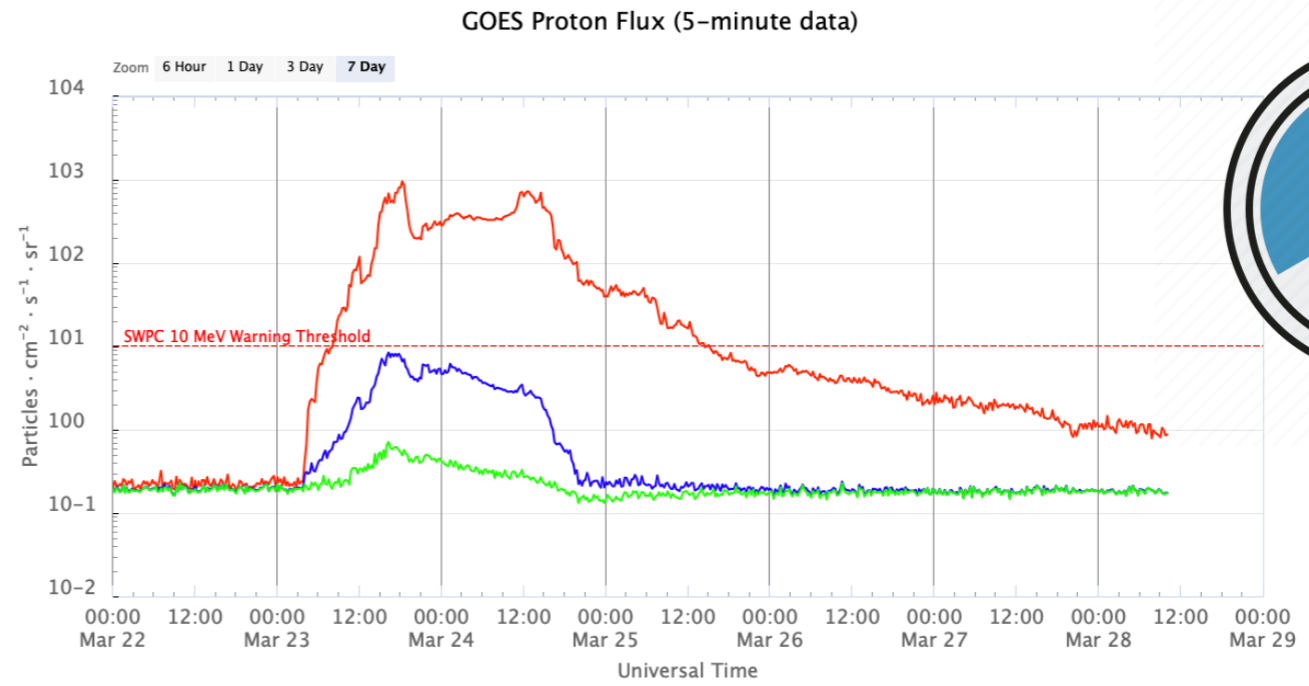
DAYS



HOUR



SCALE

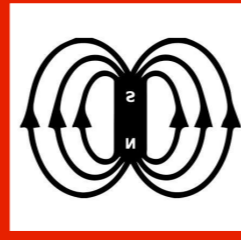


A,B,C,M,X



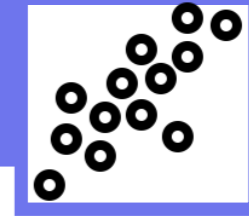
Updated 2024-03-28 10:10 UTC

Kp
0 - 9

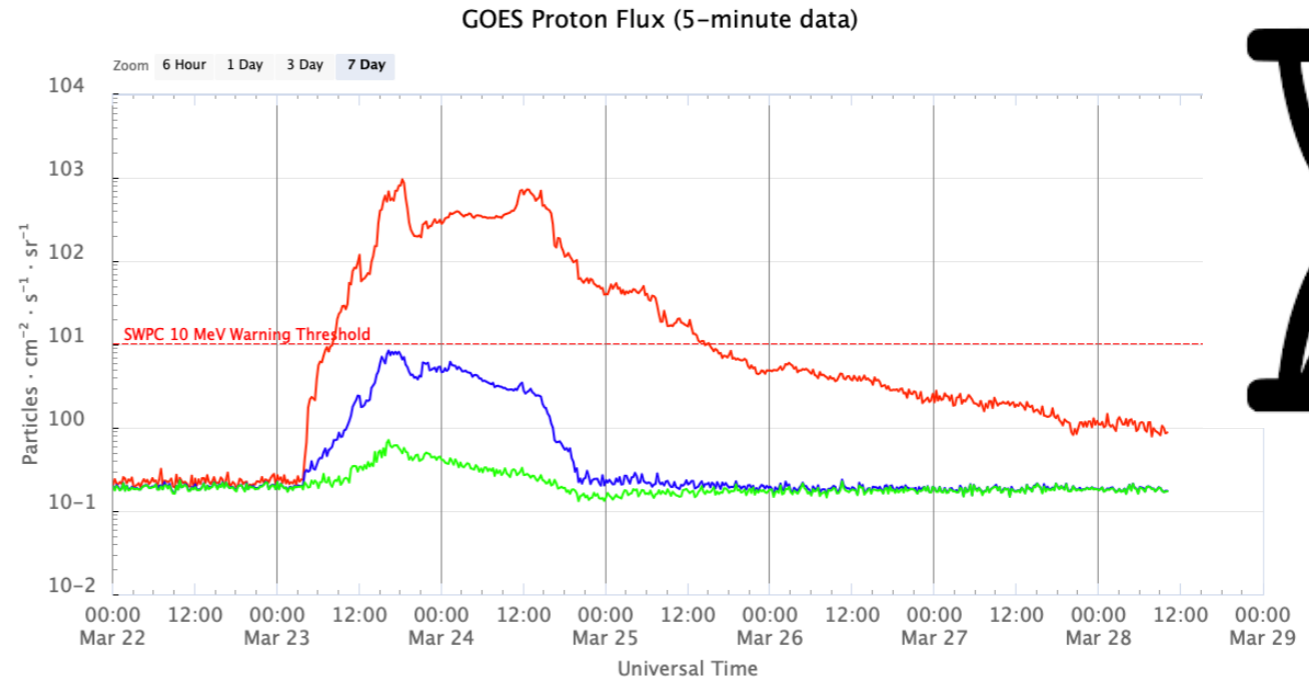


Space Weather Prediction Center

Storm - major storm



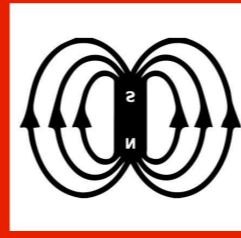
DURATION



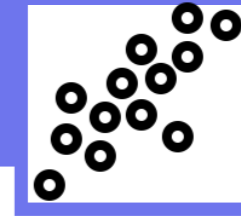
MINs to HOUR



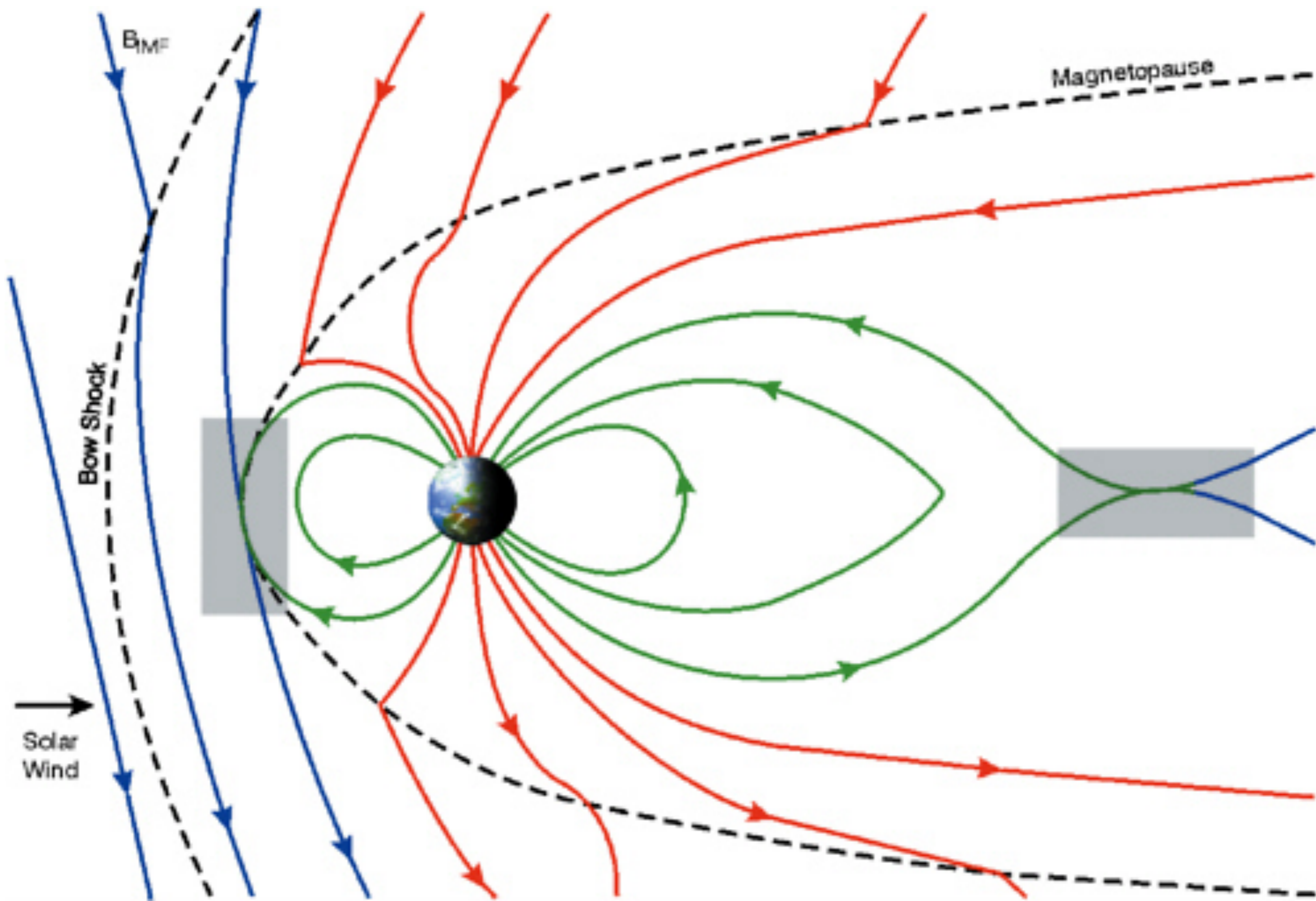
DAY+



HOURS to DAYS



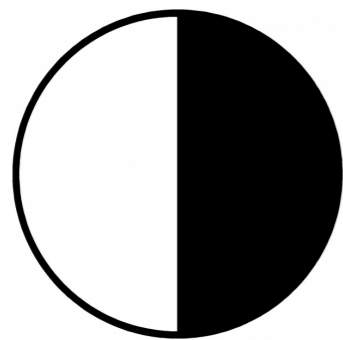
AREA OF IMPACT



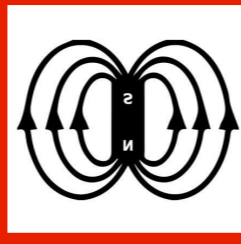
AREA OF IMPACT



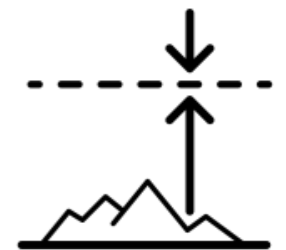
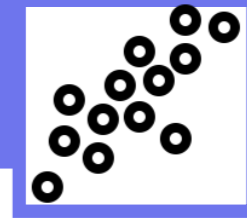
Illuminated area

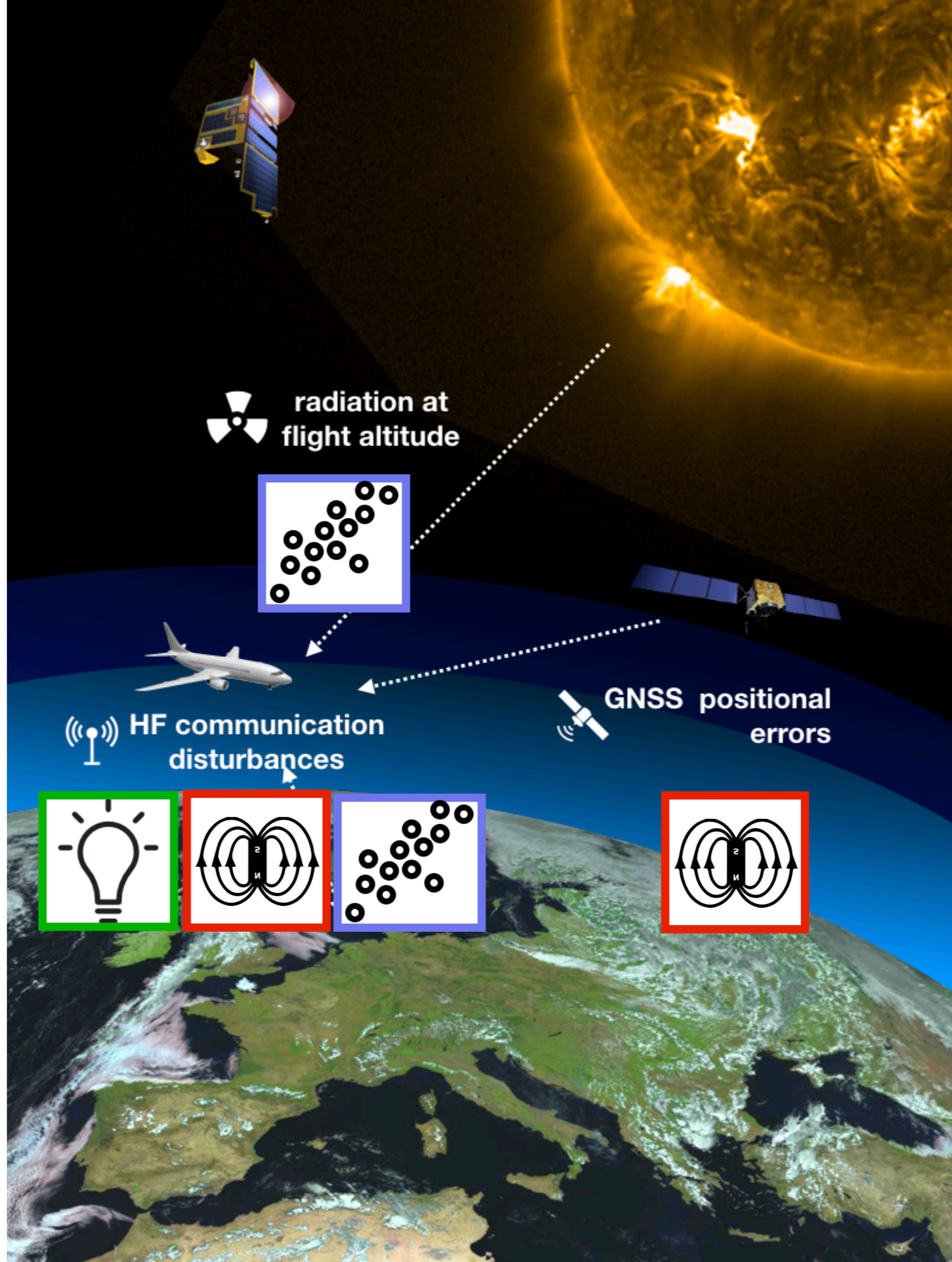



Polar Cap

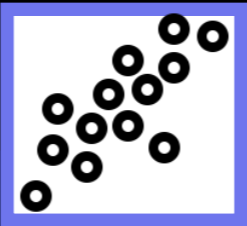


Polar Cap
High Altitude

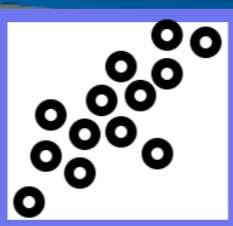
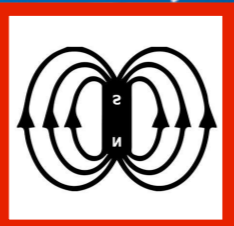




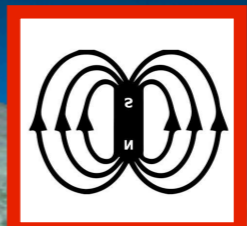
 radiation at flight altitude



 HF communication disturbances



 GNSS positional errors



OVERVIEW



8 min

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

Min to Hour

Illuminated area

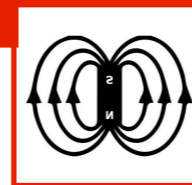


Days

Kp: 0 - 9

Day+

Polar Caps

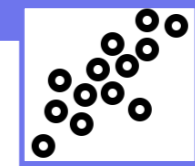


Hour

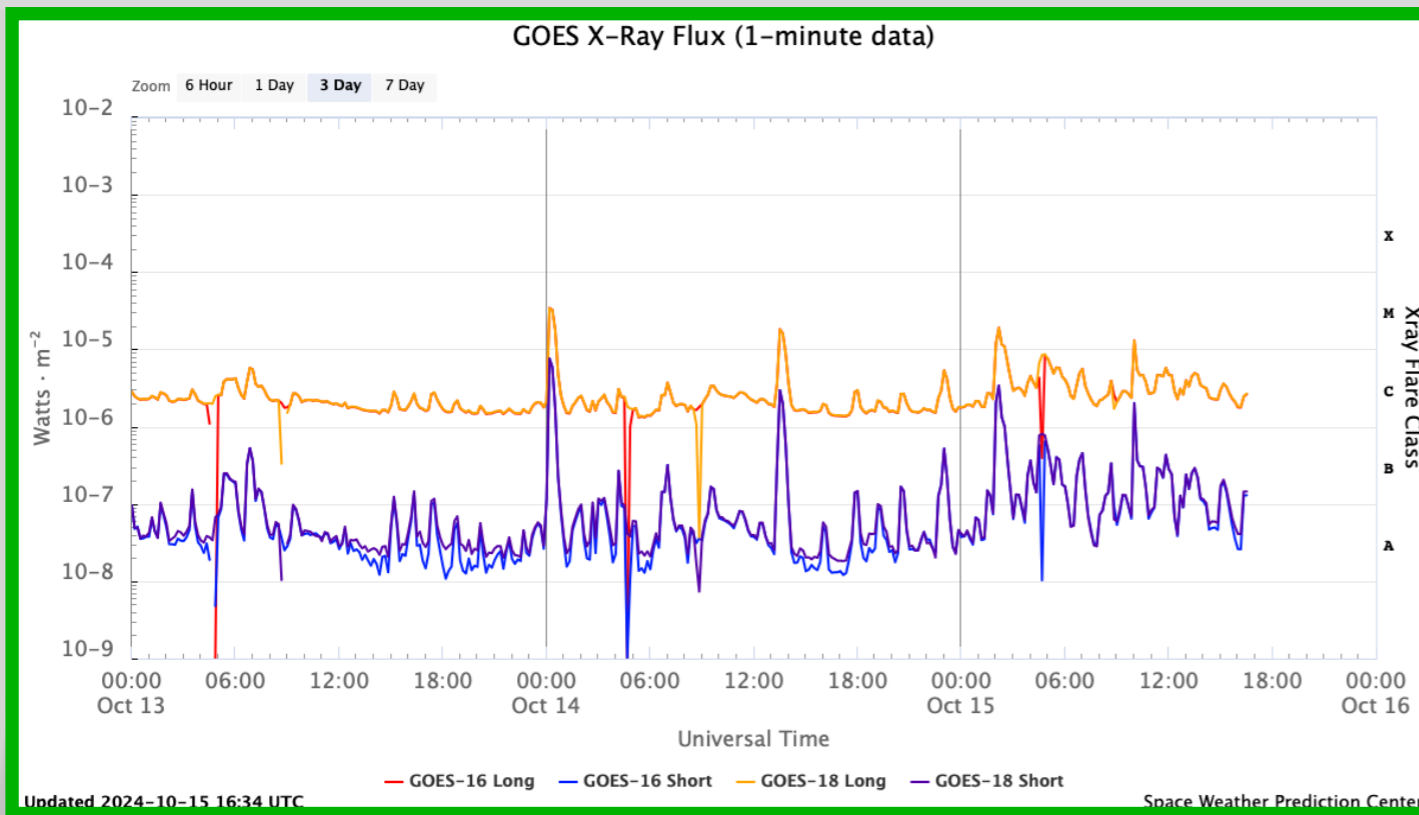
Protons:
Storm - Major Storm

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

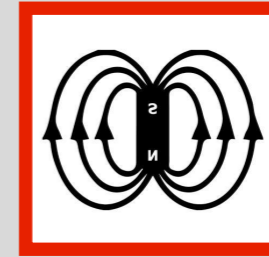
Y-axis: X-ray flux in W/m^2 , i.e. how much energy (Joule) passes in 1 sec ($W=Watt=J/s$) through 1 square meter at geostationary height.

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. The peak of the red/orange curve defines the flare class.

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.

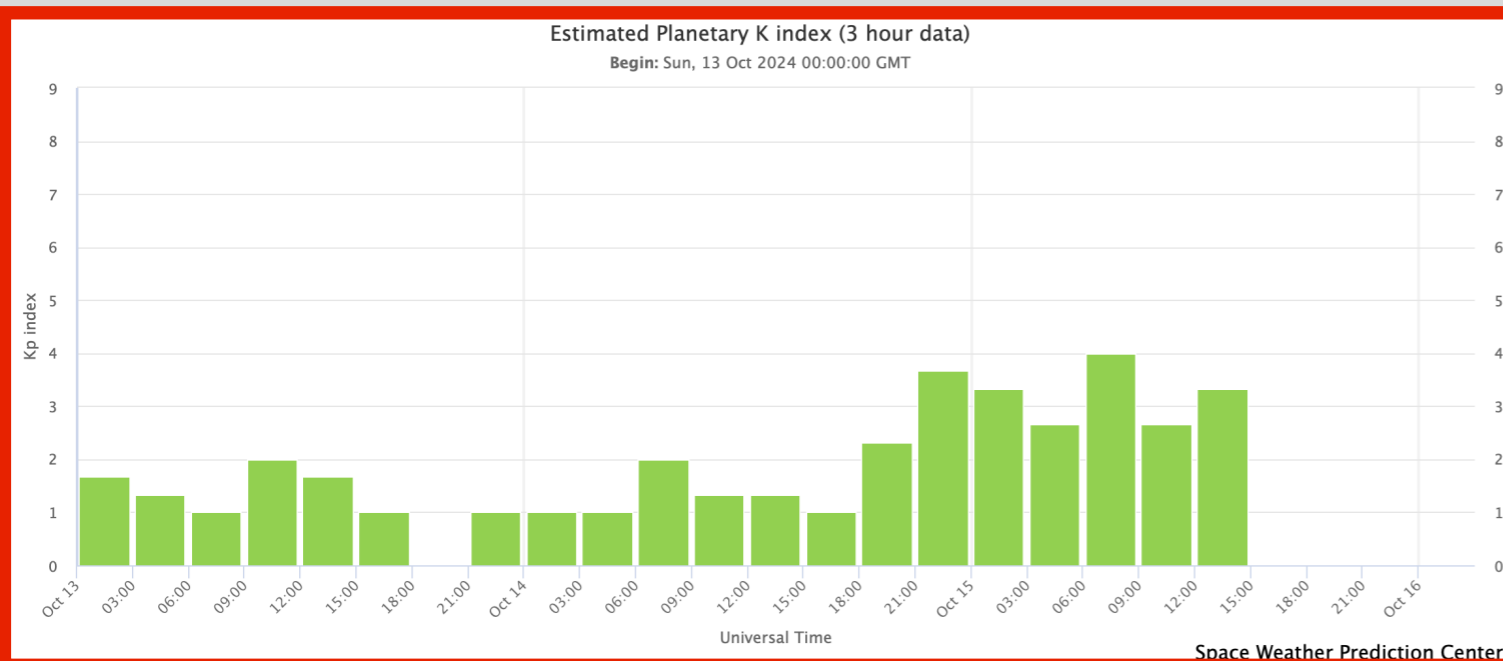
With e.g. 2- = 1,70 and 2+ = 2,30 etc.

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.

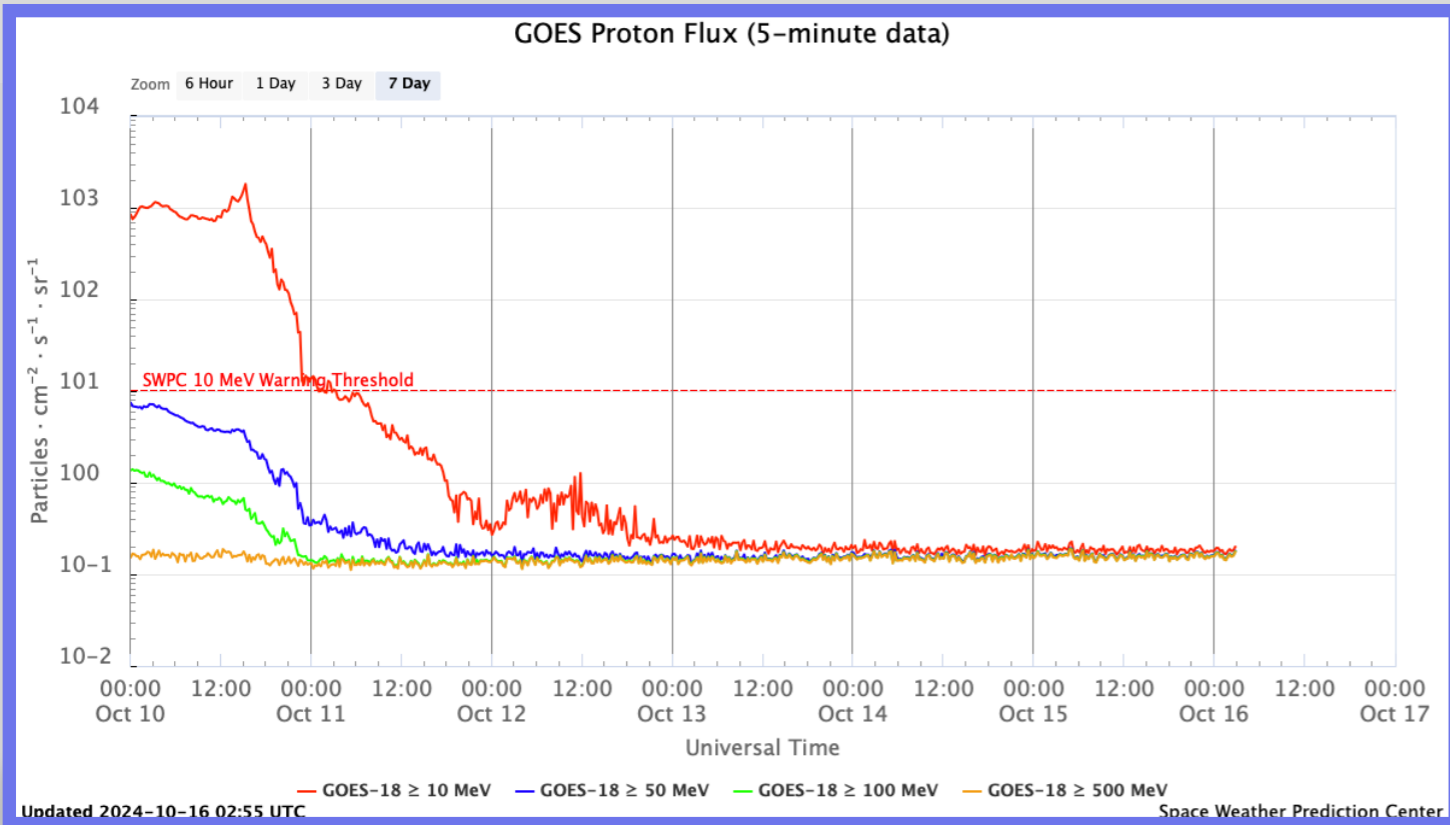
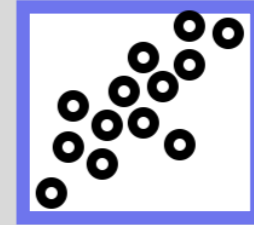
Observatories

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.

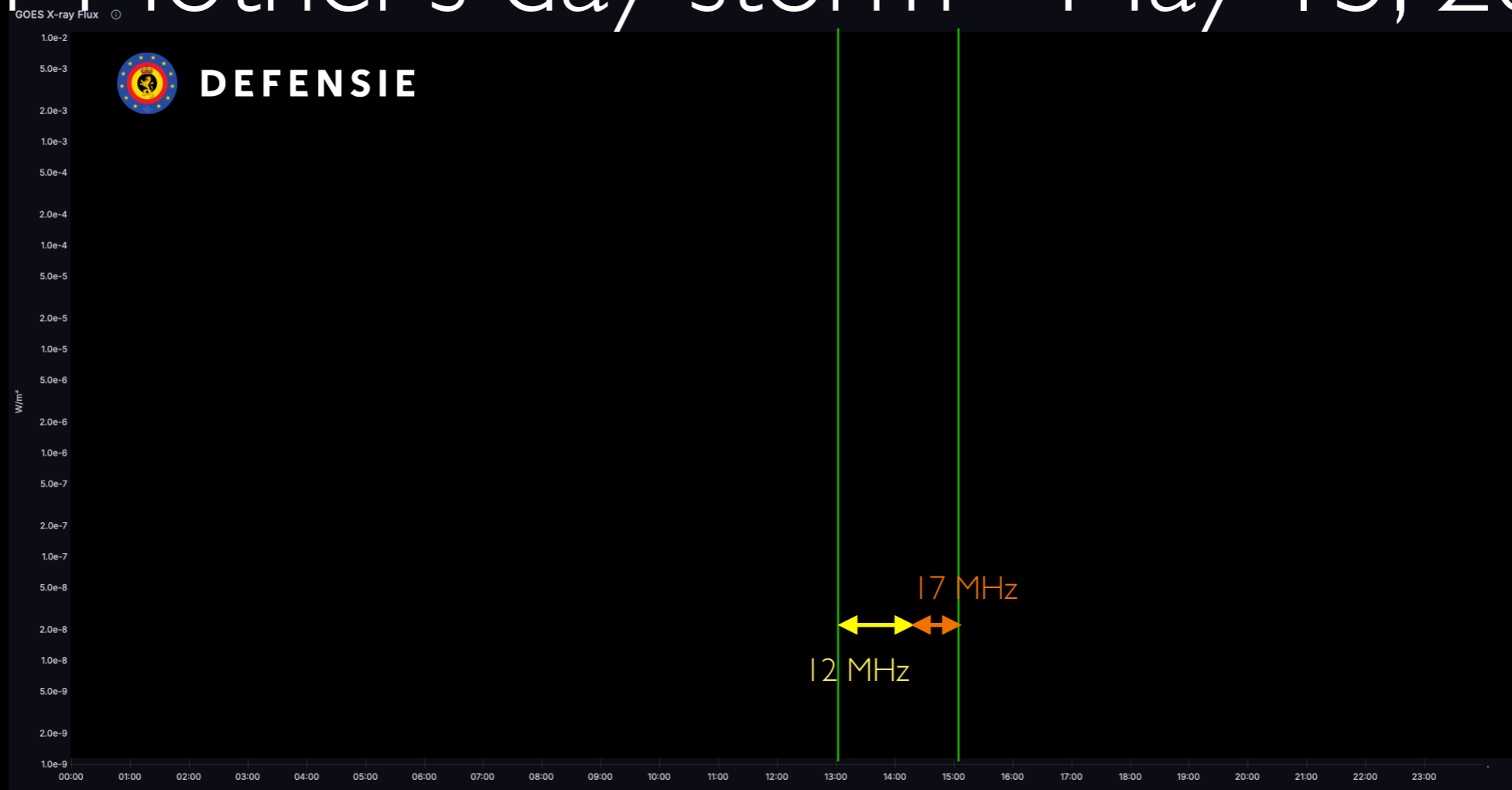
The 4 colours represent 4 energies.

After Mother's day storm - May 15, 2024

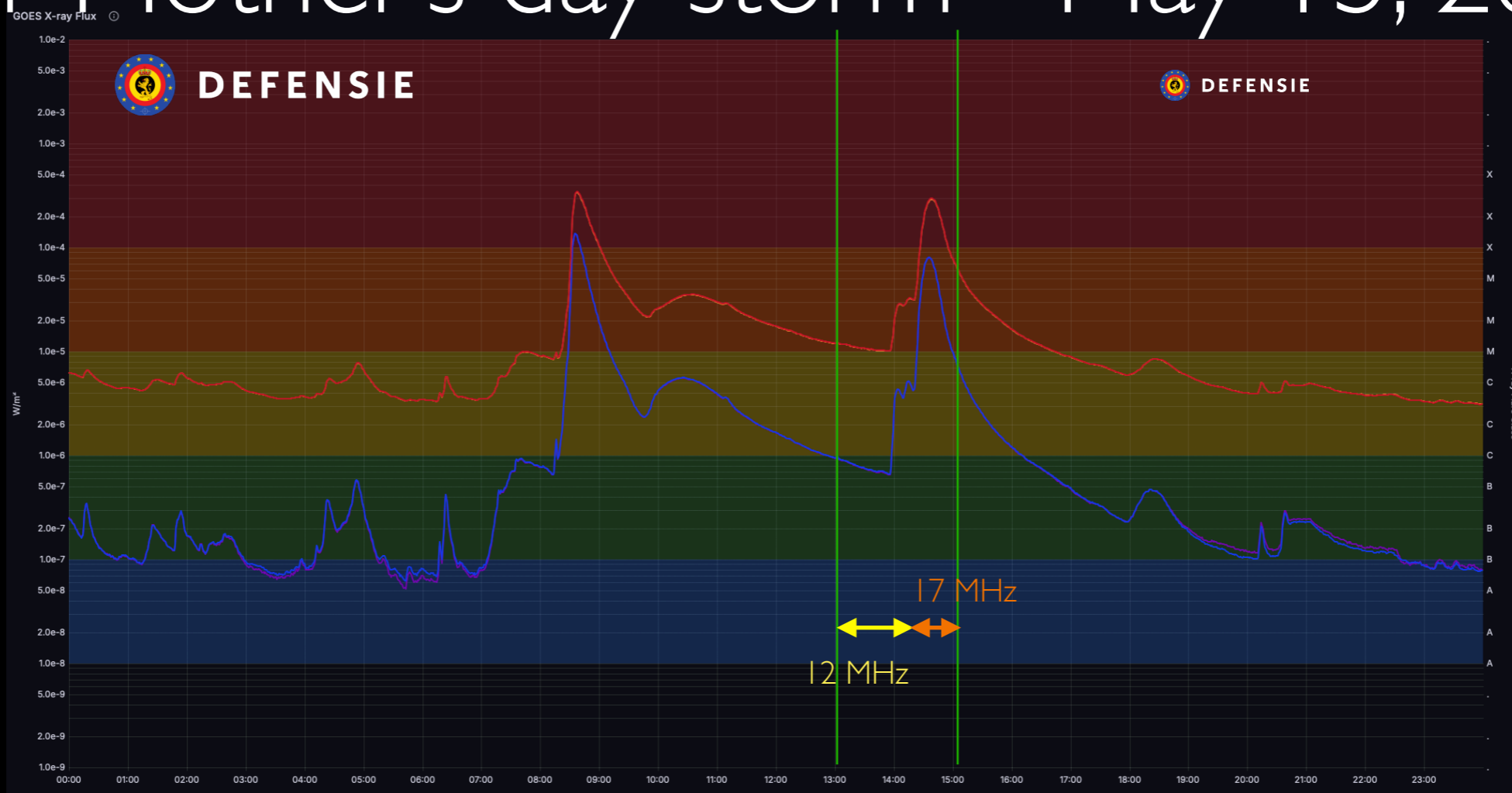


DEFENSIE

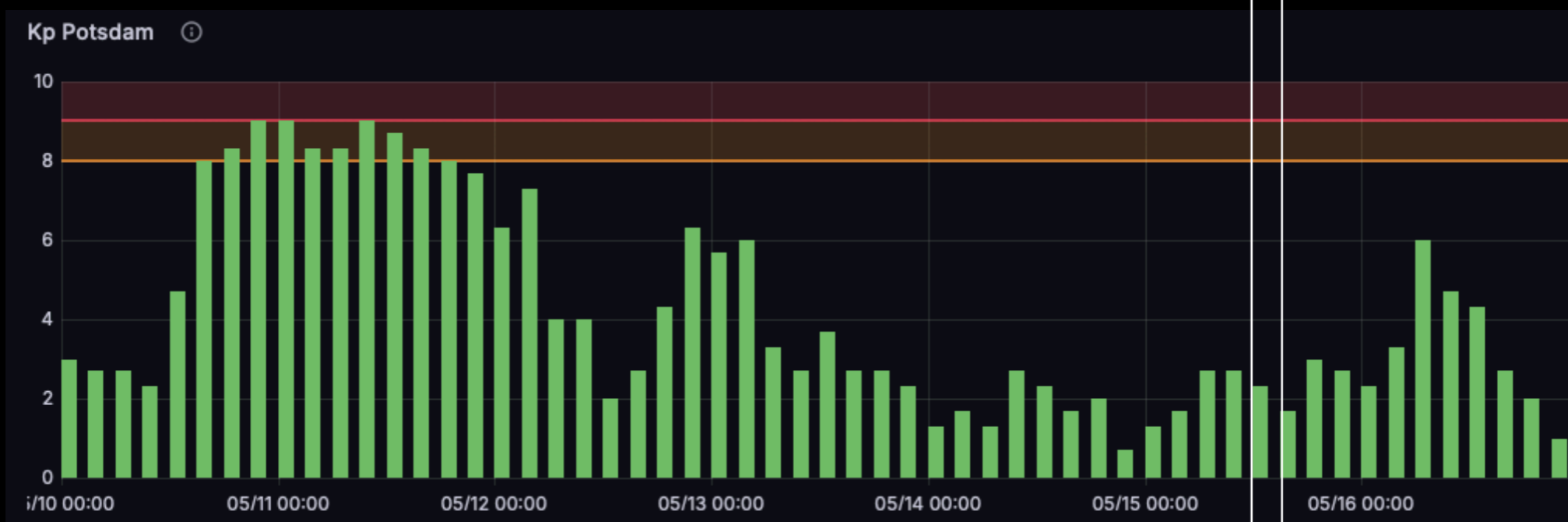
After Mother's day storm - May 15, 2024



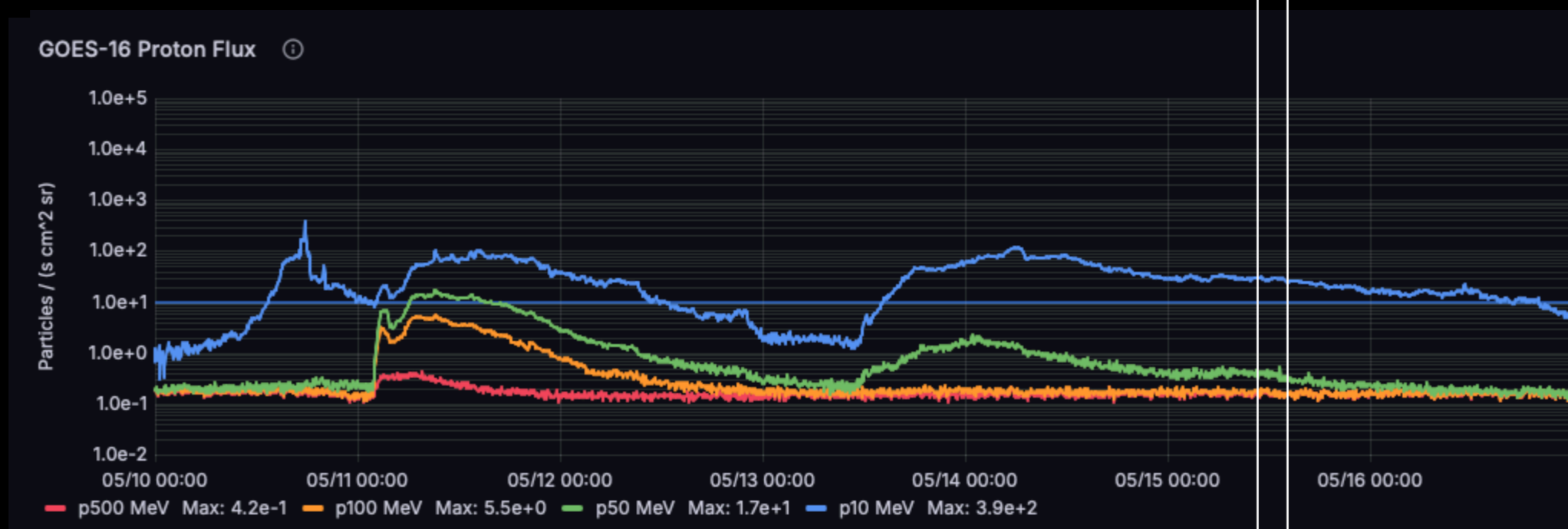
After Mother's day storm - May 15, 2024

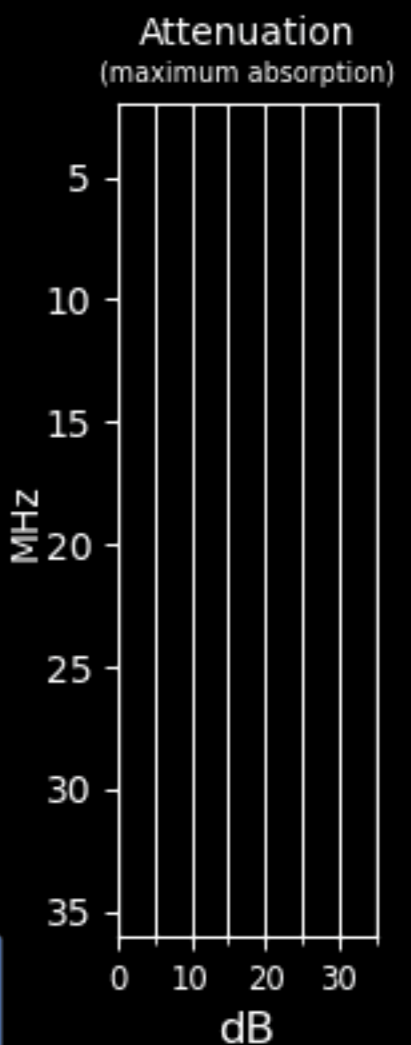
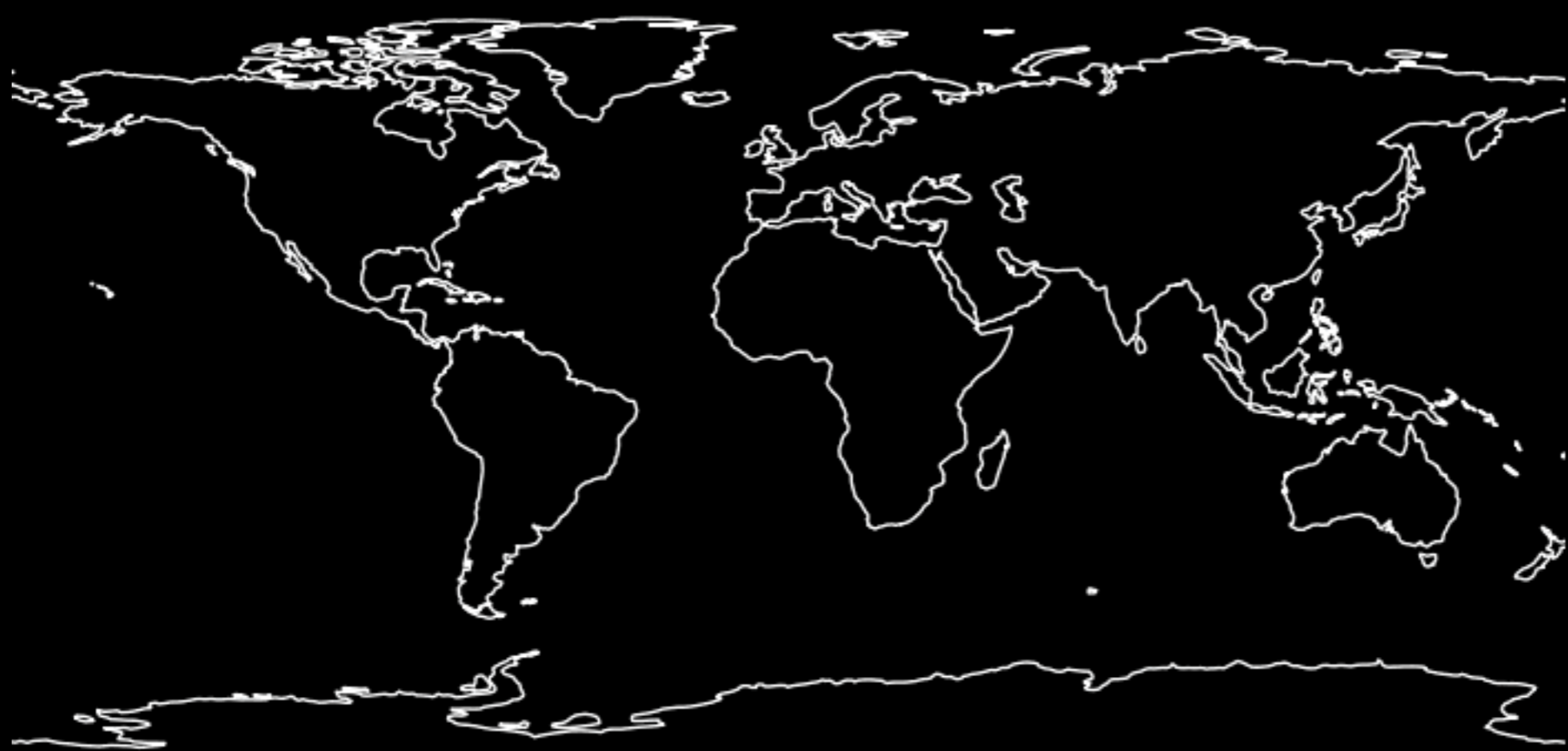


After Mother's day storm - May 15, 2024



After Mother's day storm - May 15, 2024





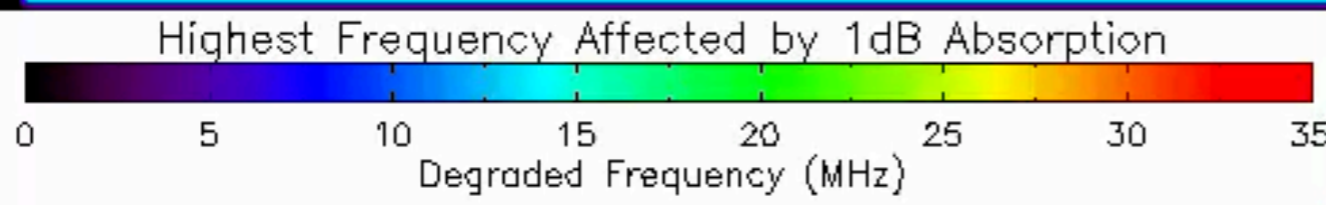
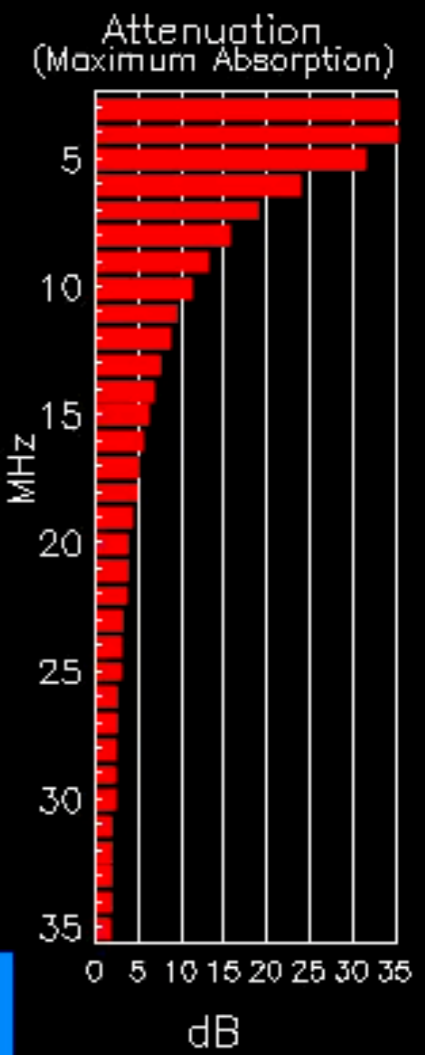
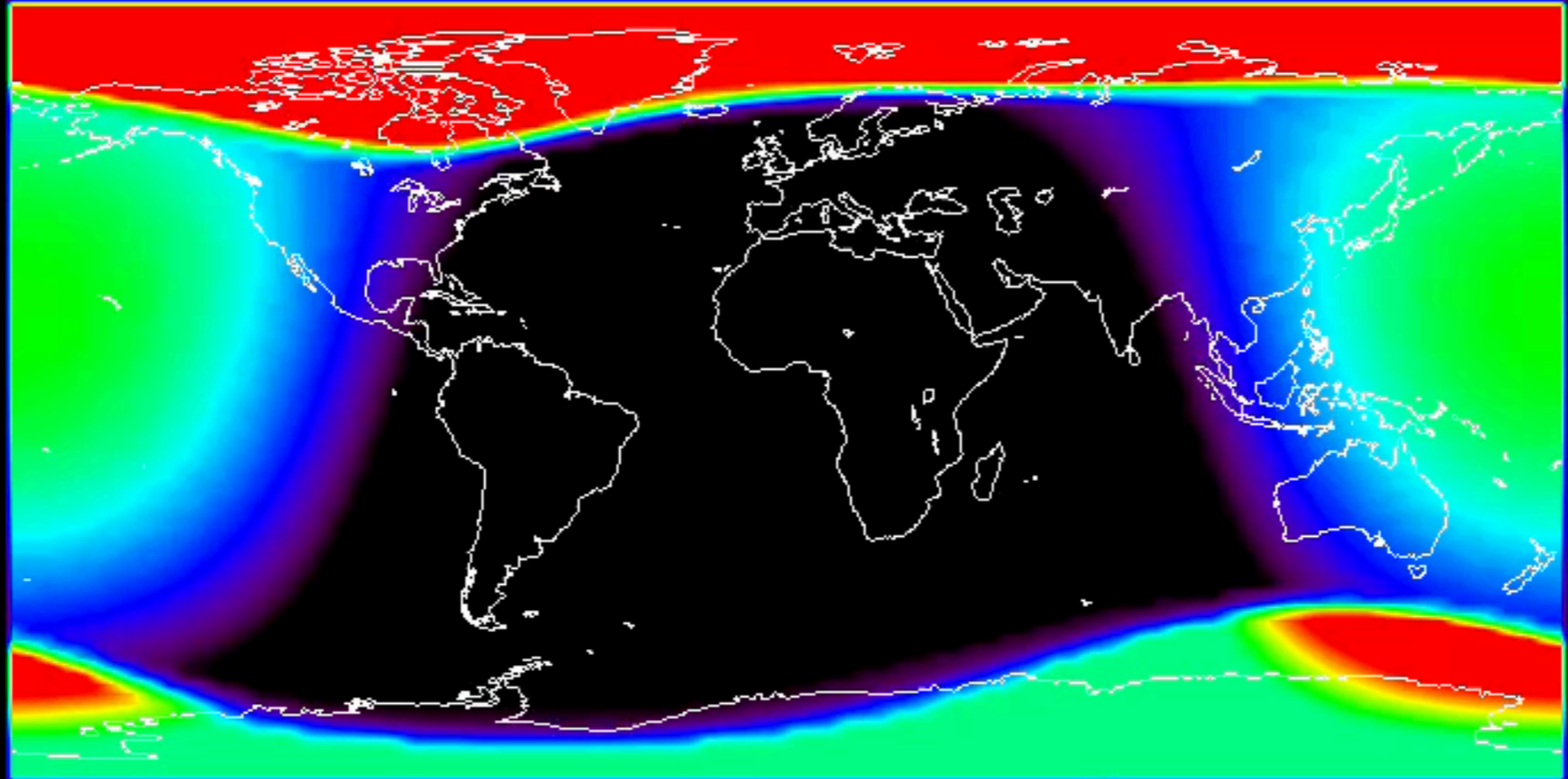
Absorption at 30 MHz (30,000 kHz)

1 5 10 15 20 25 30 35 dB

Estimated recovery time
High latitude protons:
Mid/low latitude X-rays:
No estimate

Normal X-ray background
Product valid at: 2025-05-23 21:00 UTC

Normal proton background
Met Office, Exeter, UK



Estimated Recovery Time
 High Latitude Protons :
 5 HRS 47 MINS
 Mid/Low Latitude X-rays :
 No Estimate

Elevated X-ray flux
 Product Valid At : 2024-05-15 00:00 UTC

Minor Proton Flux
 NOAA/SWPC Boulder, CO USA