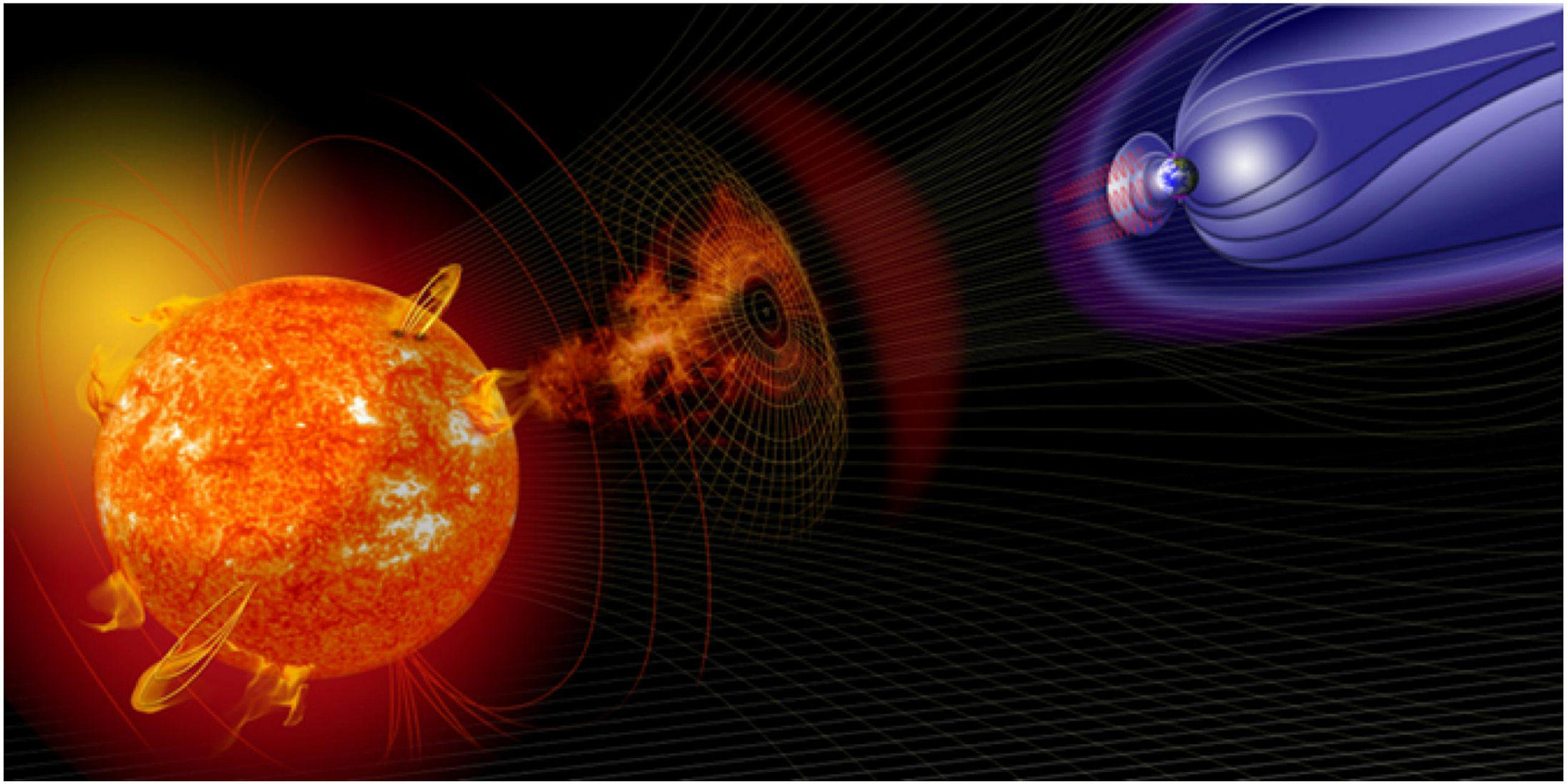


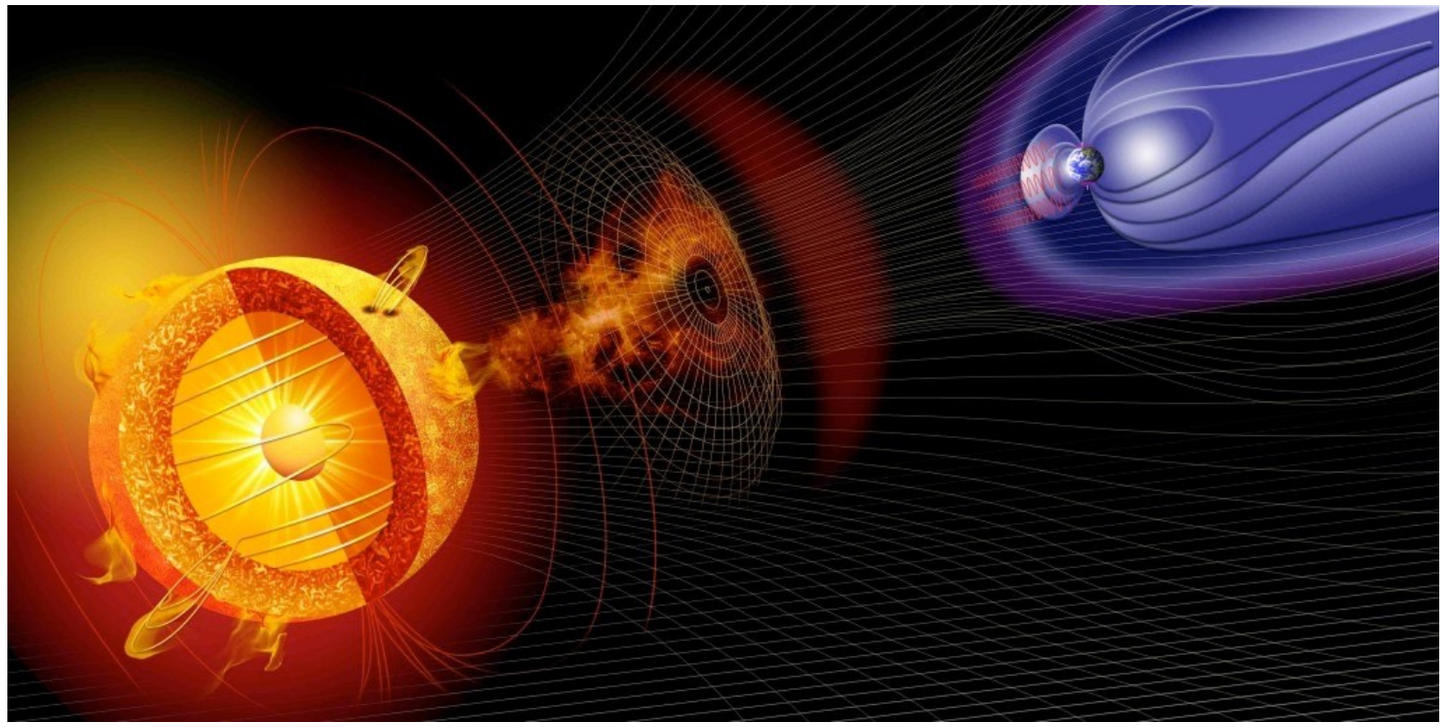
SPACE WEATHER

Introduction

Petra Vanlommel

Space Weather

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



SUN'S ENERGY

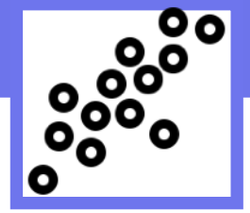
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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

LIGHT

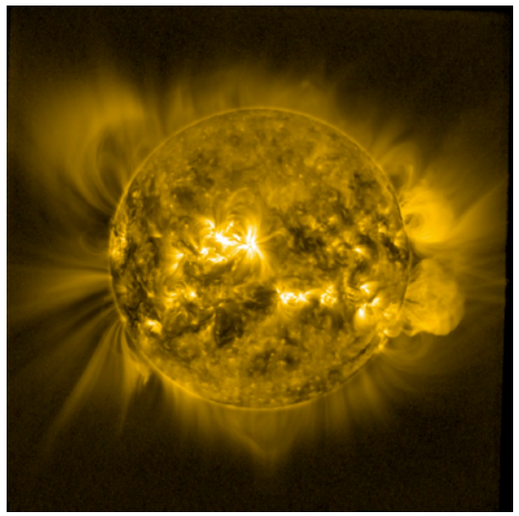
WIND

ENERGETIC PARTICLE PRECIPITATION

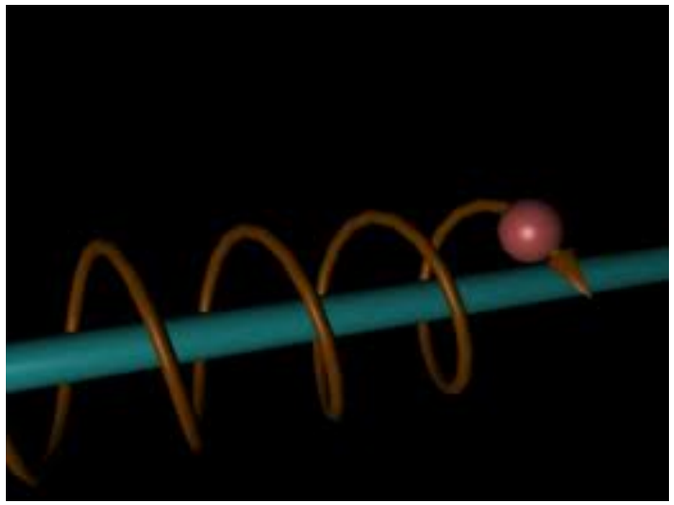


SPACE CLIMATE

The emitted energy creates a space climate that has 2 seasons: a more active and a less active. This seasonal variation is called the solar cycle and takes around 11 years.



PROBA2/SWAP

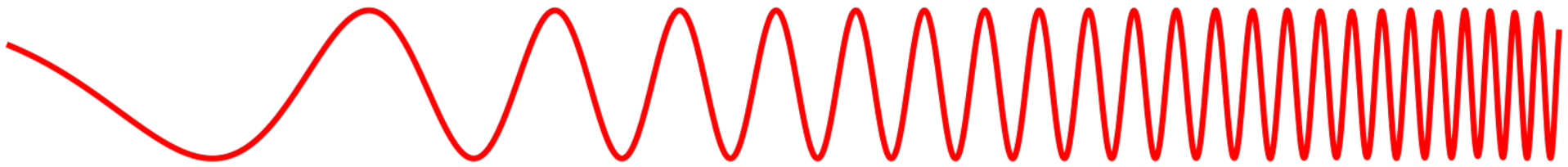


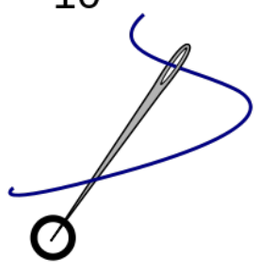
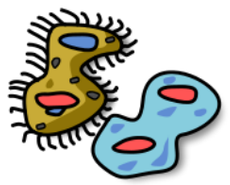
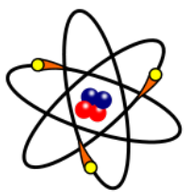
E.M. WAVES

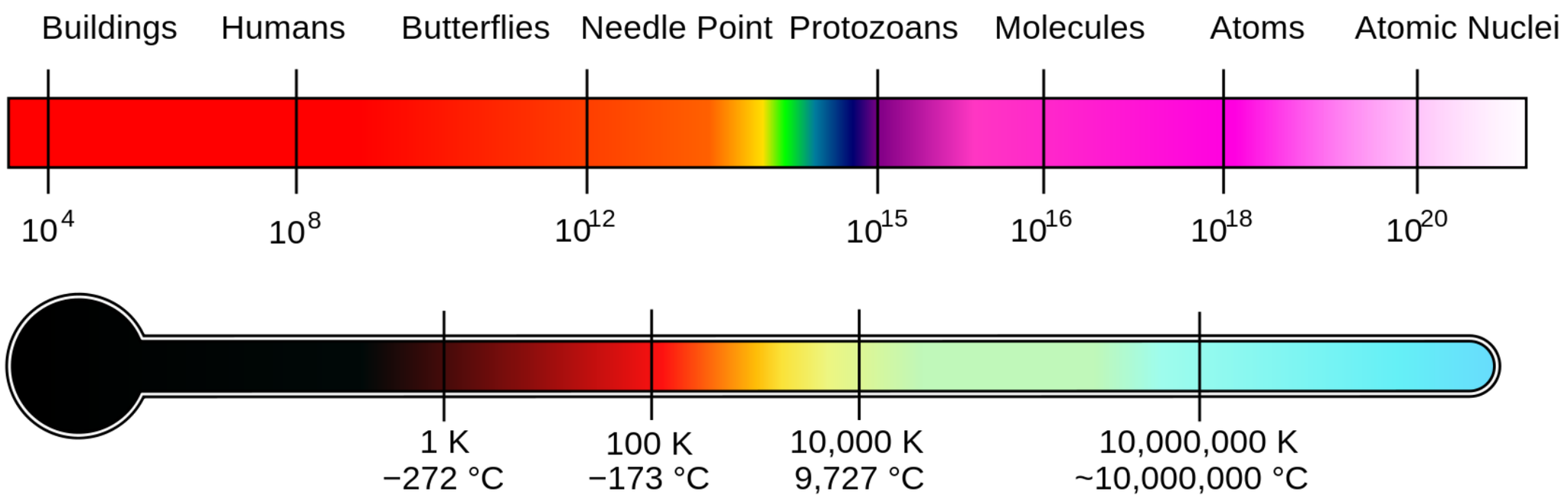
SOLAR WIND

SOLAR PARTICLES

E.M. WAVES



Radiation Type	Radio		Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma ray
Wavelength (m)	10^{3}		10^{-2}	10^{-5}	0.5×10^{-6}	10^{-8}	10^{-10}	10^{-12}
Approximate Scale of Wavelength								



INTERPLANETARY MAGNETIC FIELD

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

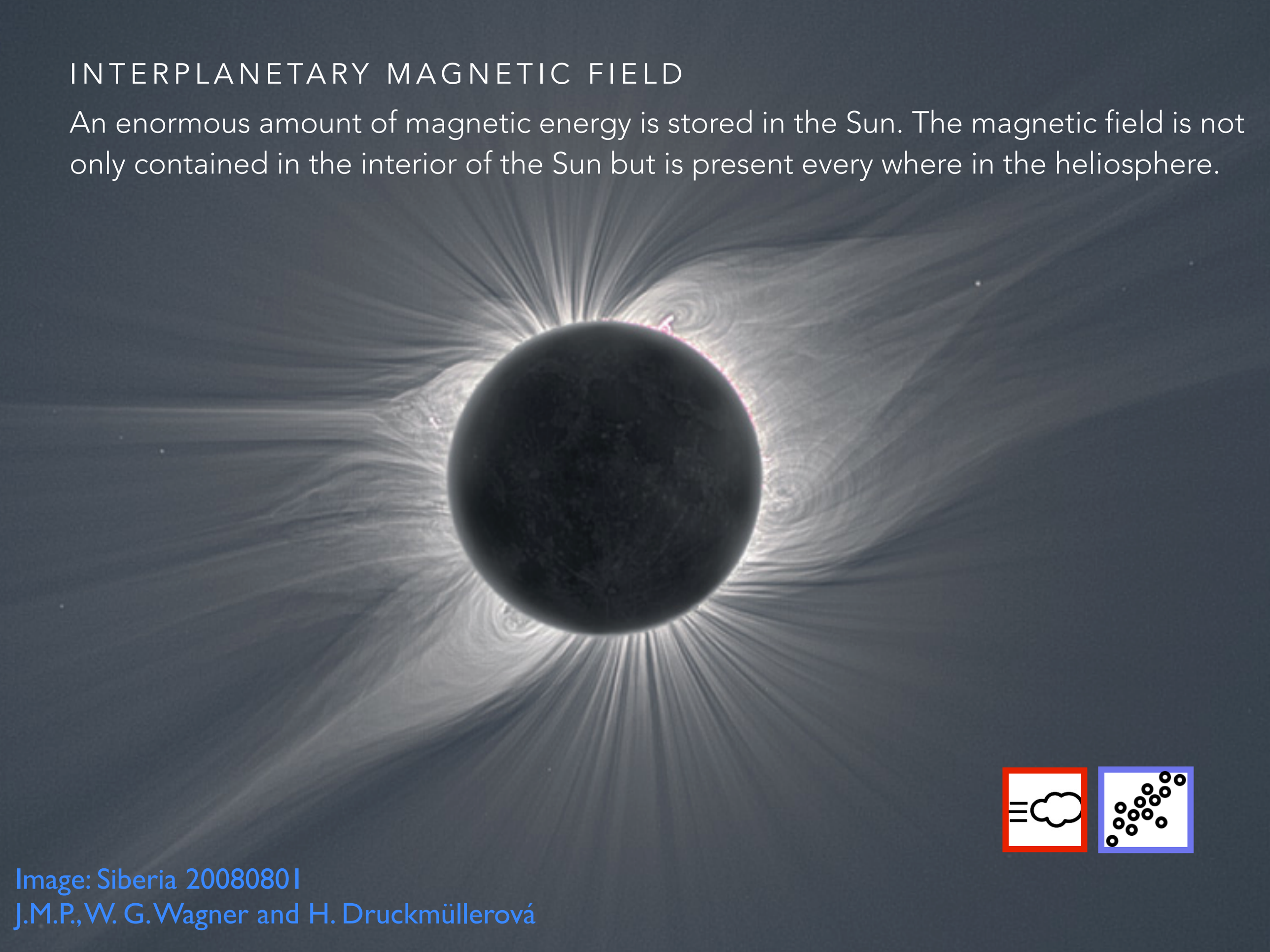


Image: Siberia 20080801
J.M.P., W. G. Wagner and H. Druckmüllerová

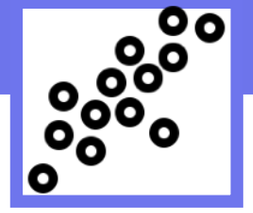
SOLAR WIND

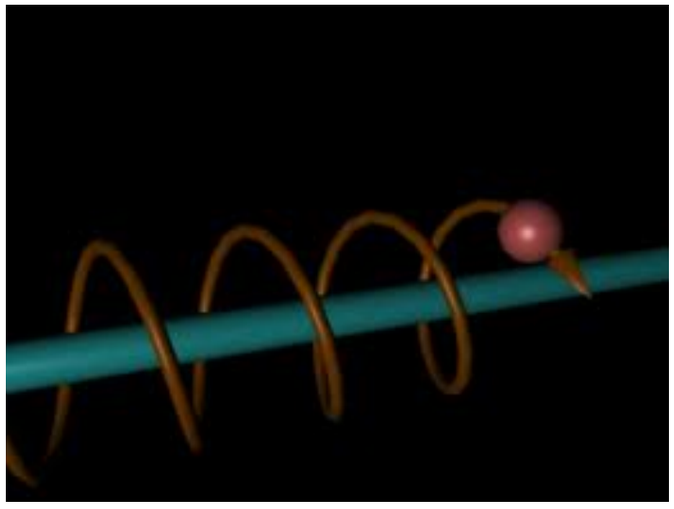
continuous radial outflow of plasma

shapes the interplanetary magnetic field.

Can carry magnetic structures

SOLAR PARTICLES

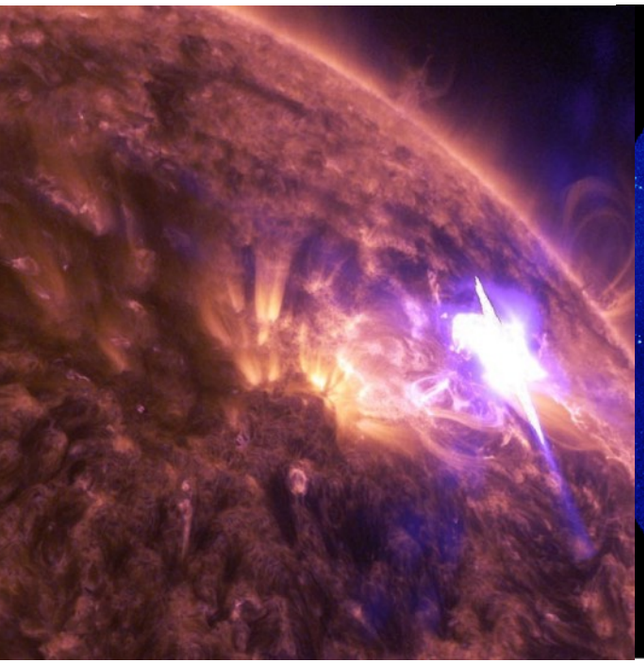


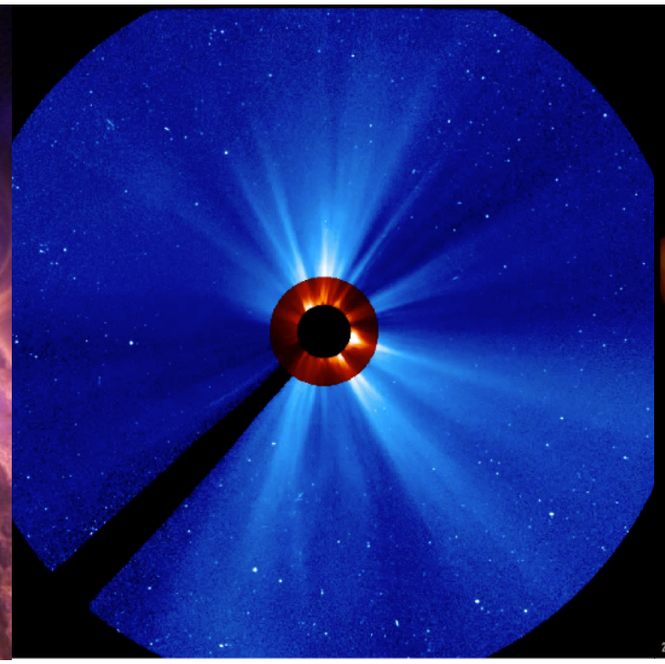


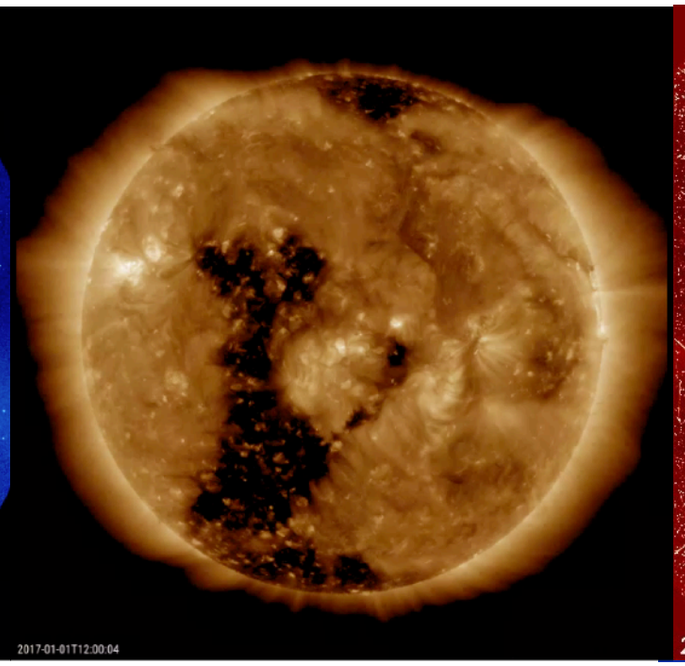
Solar energetic particles are guided by the IMF.

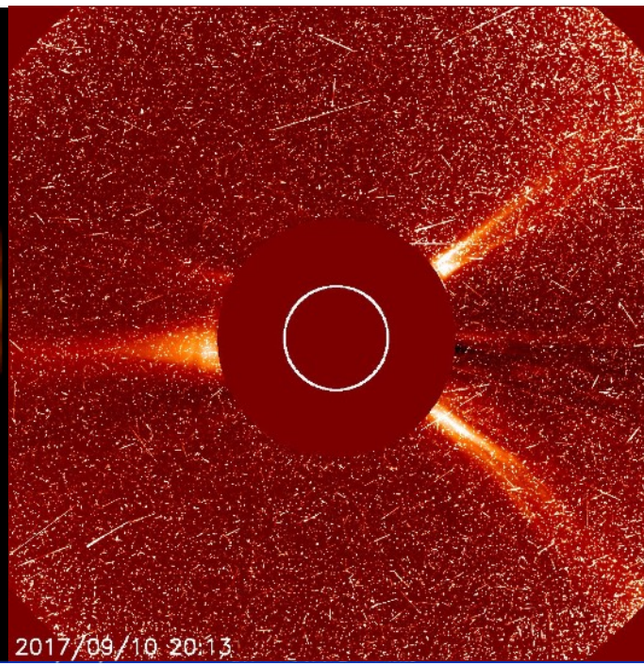
SOLAR STORMS

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).







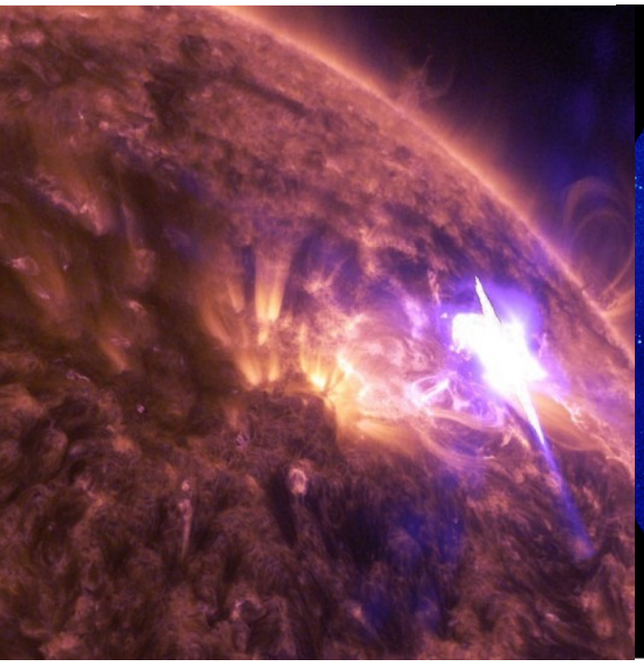


FLARE

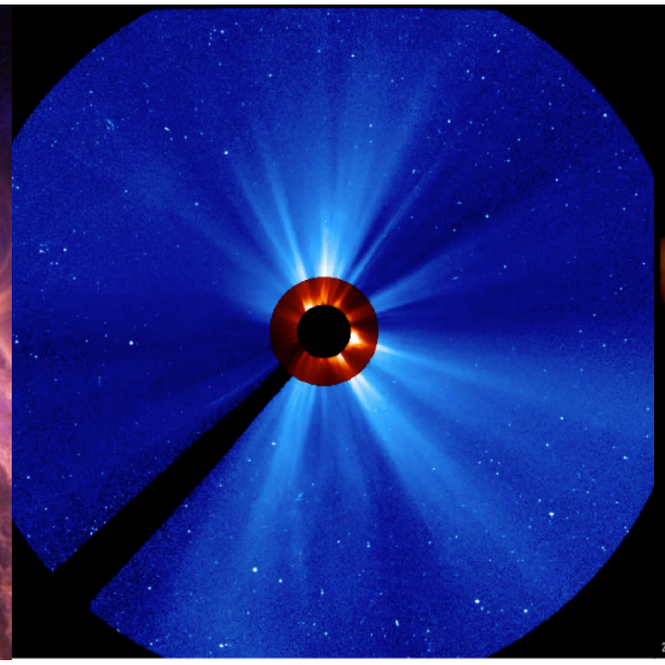
CORONAL MASS EJECTION
CORONAL HOLE

PARTICLE STORM

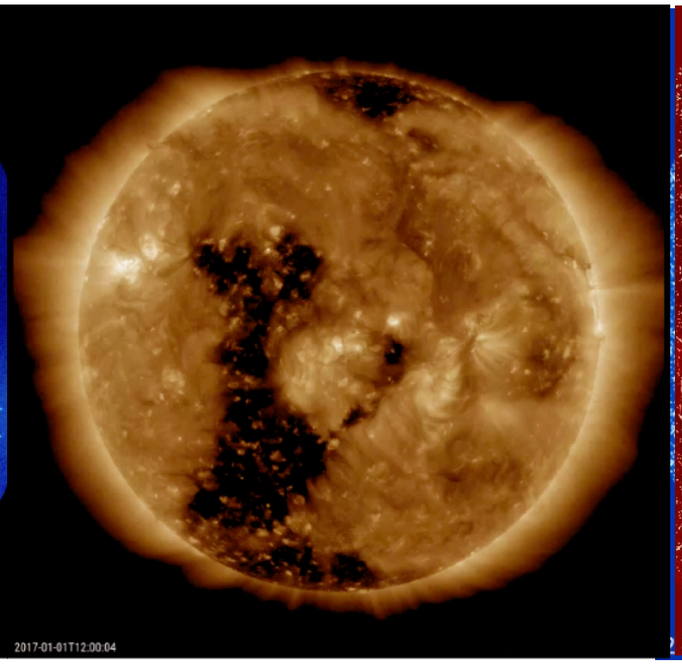
SDO/AIA



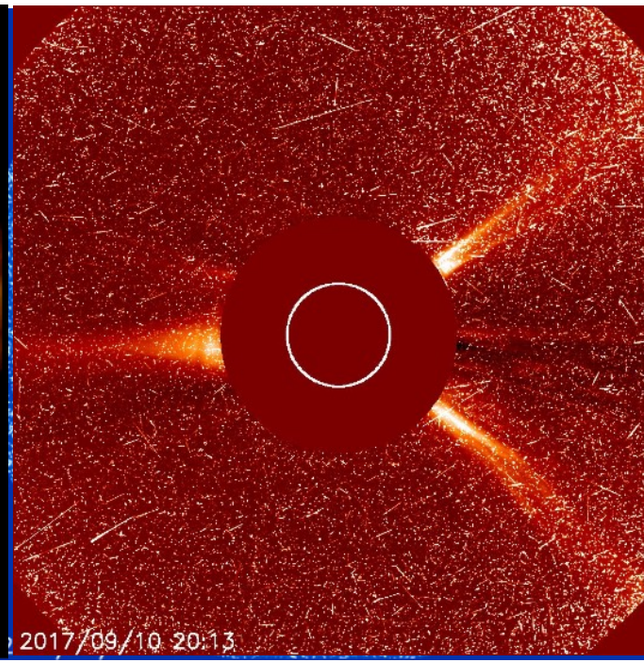
SOHO/LASCO



SDO/AIA



SOHO/LASCO



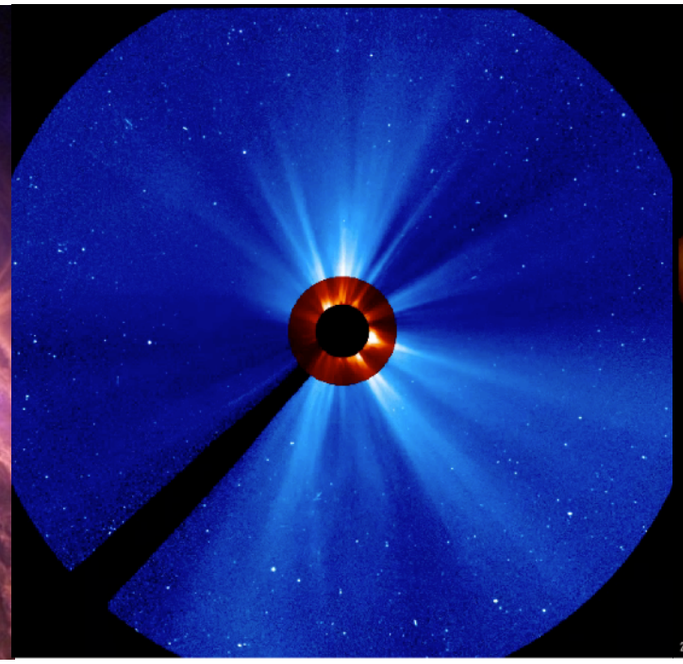
FLARE

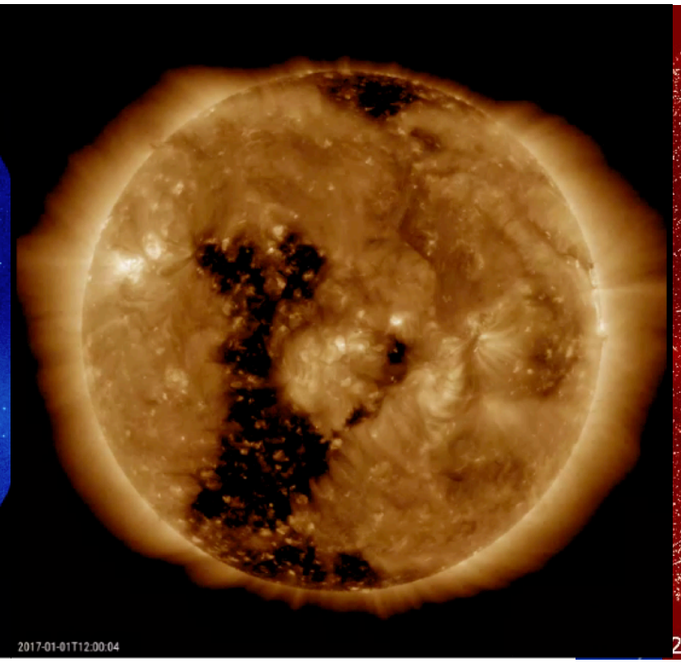
CORONAL MASS EJECTION
CORONAL HOLE

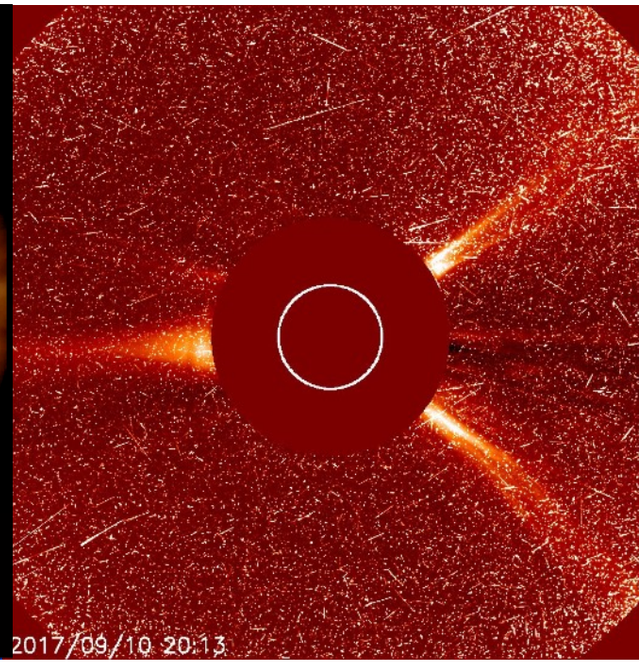
PARTICLE STORM

AU TRANSIT TIME

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







8 MIN

DAYS

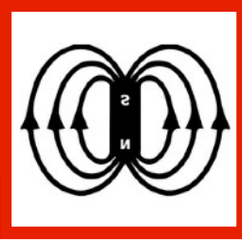
HOUR

SPACE WEATHER

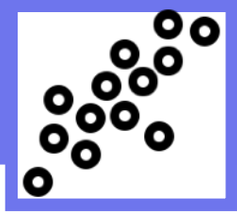
Our atmosphere and magnetosphere can respond in a dramatic way to solar storms. A solar storm can initiate space weather processes in our atmosphere and magnetosphere. This impact is measured near or on Earth and results in 3 sorts of space weather storms.

Radio blackout

Geomagnetic storm



Solar radiation storm

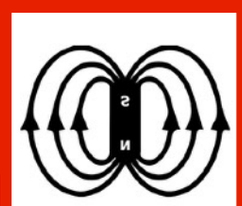


AREA OF IMPACT

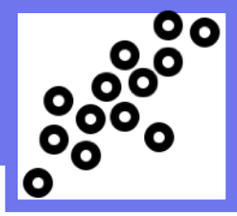
Note that the solar wind can change the geomagnetic field by reconnection processes and by adding pressure. Reconnection is possible because the solar wind is magnetised. Charged particles follow simply the magnetic highways.

Illuminated area

Latitude

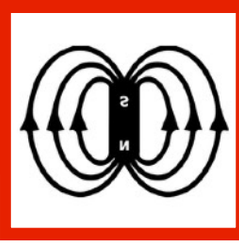


Altitude

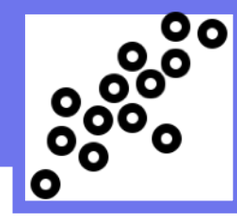


Radio blackout

Geomagnetic storm



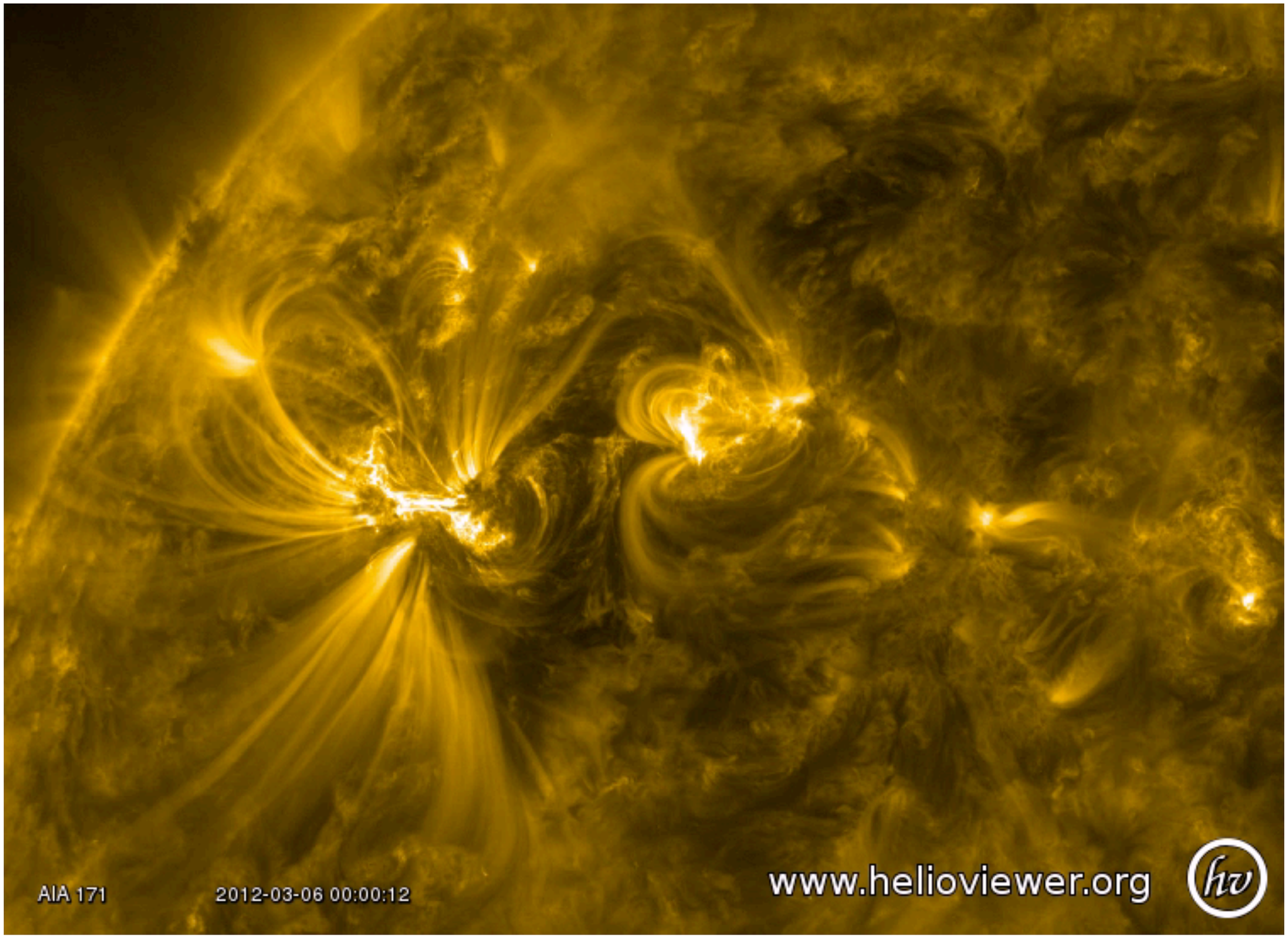
Solar radiation storm



SOLAR FLARES

Flare

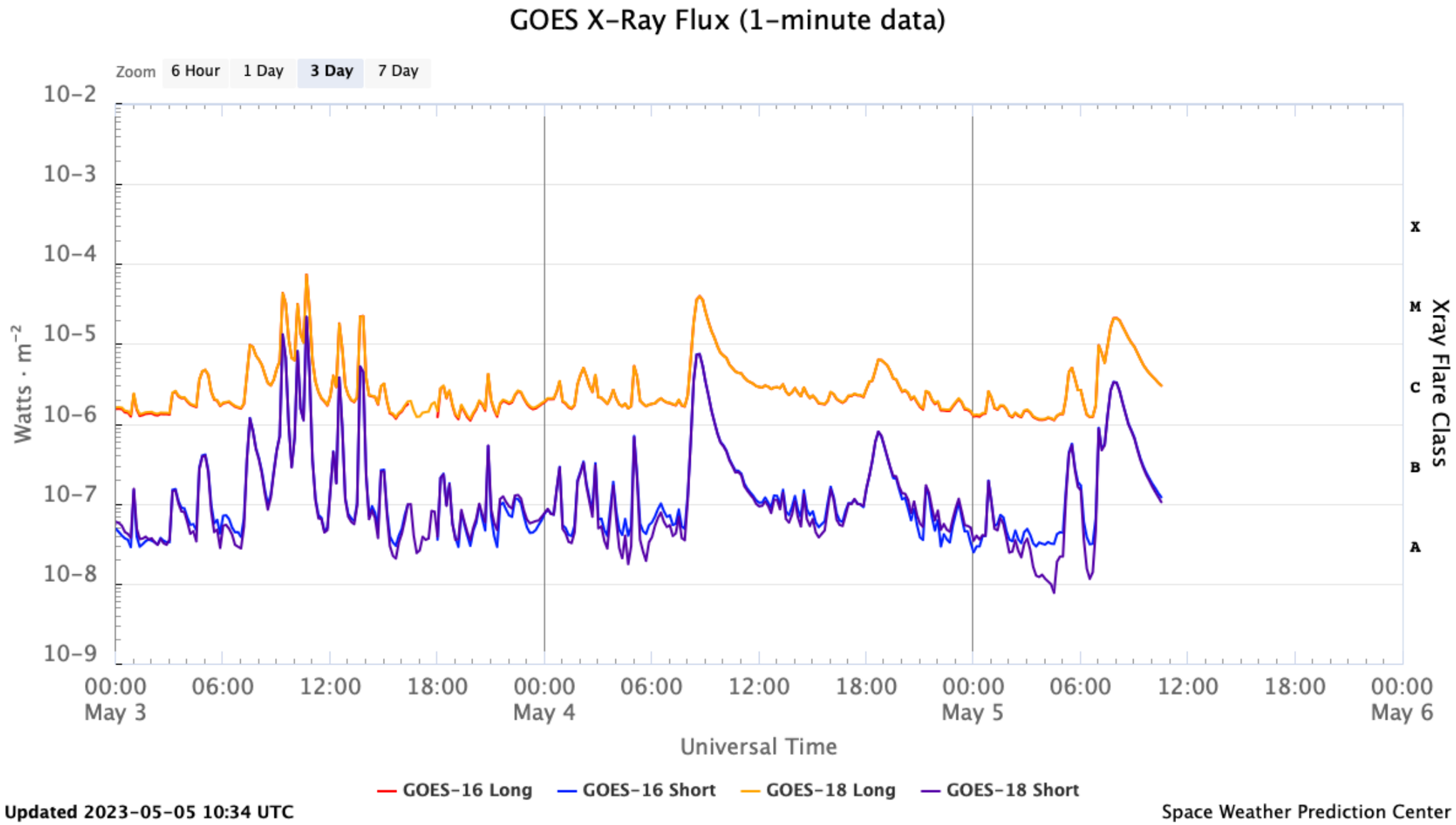
A flare is a light flash near an active region. A volume of plasma is suddenly heated and therefore lights up.



SDO/AIA

FLARE CATEGORIES & SW SCALES

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



NOAA SPACE WEATHER SCALES

Flare

The impact of a flare depends on the intensity of the x-ray flux.

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	**Descriptor**	**Duration of event will influence severity of effects**		
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.

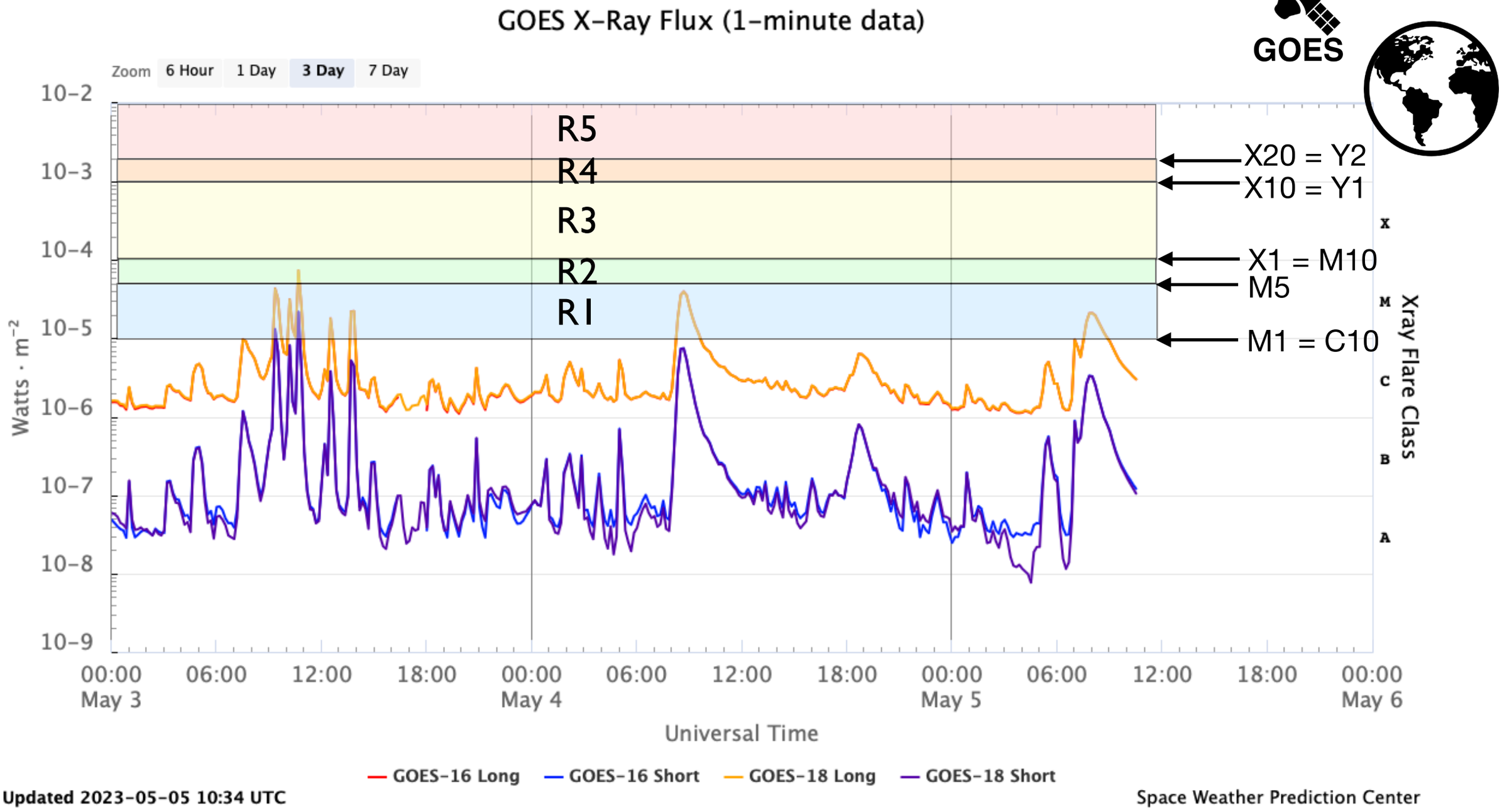
URL: *www.swpc.noaa.gov/NOAAscales*

April 7, 2011

FLARE CATEGORIES & SW SCALES

Flare

GOES



X-RAY FLUX NOW

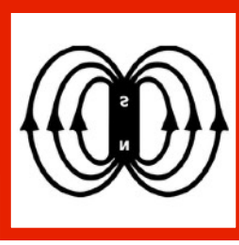
Flare

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

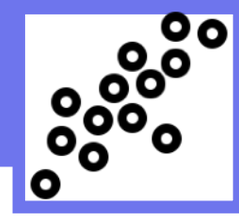
GOES

Radio blackout

Geomagnetic storm



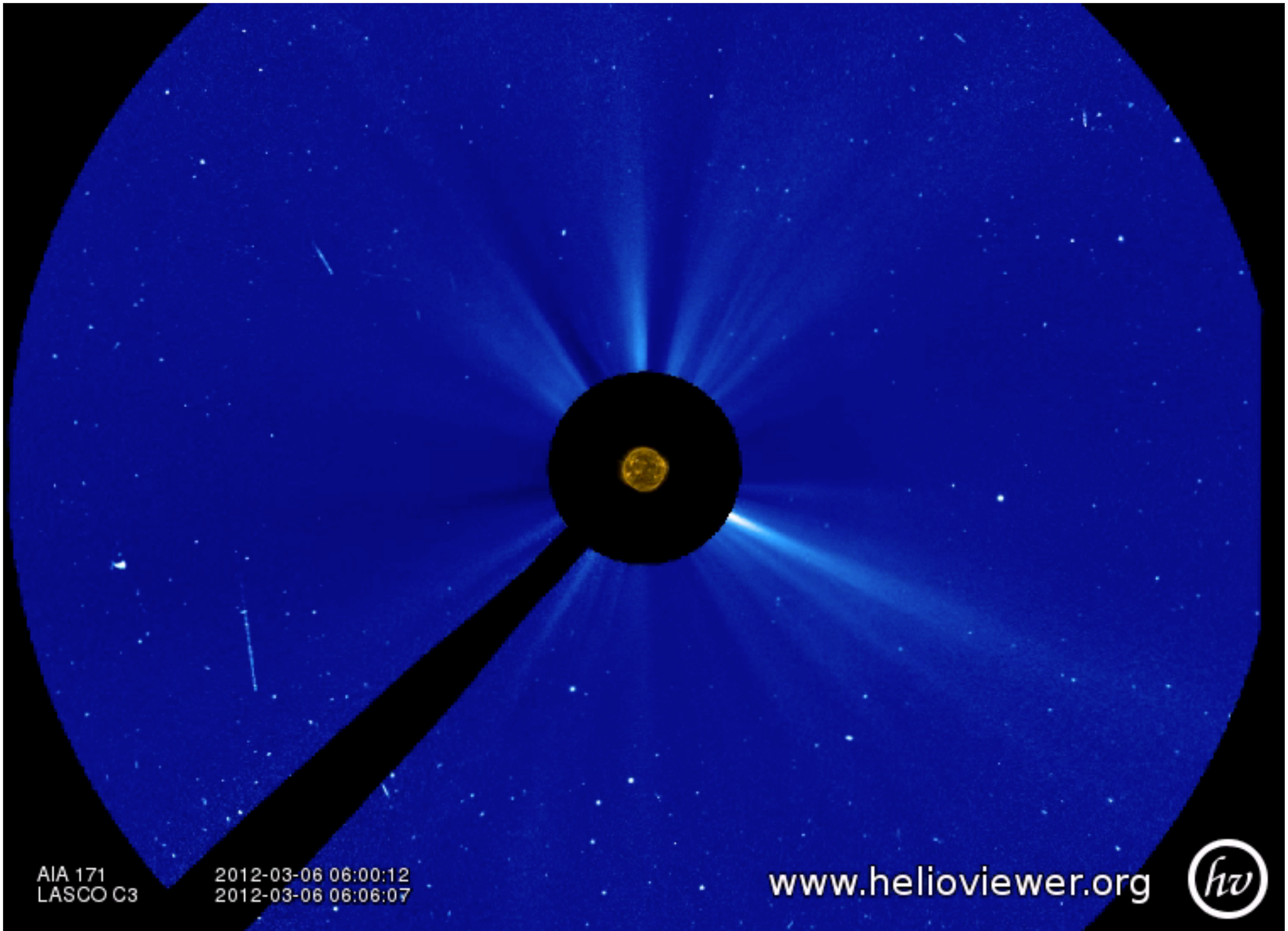
Solar radiation storm

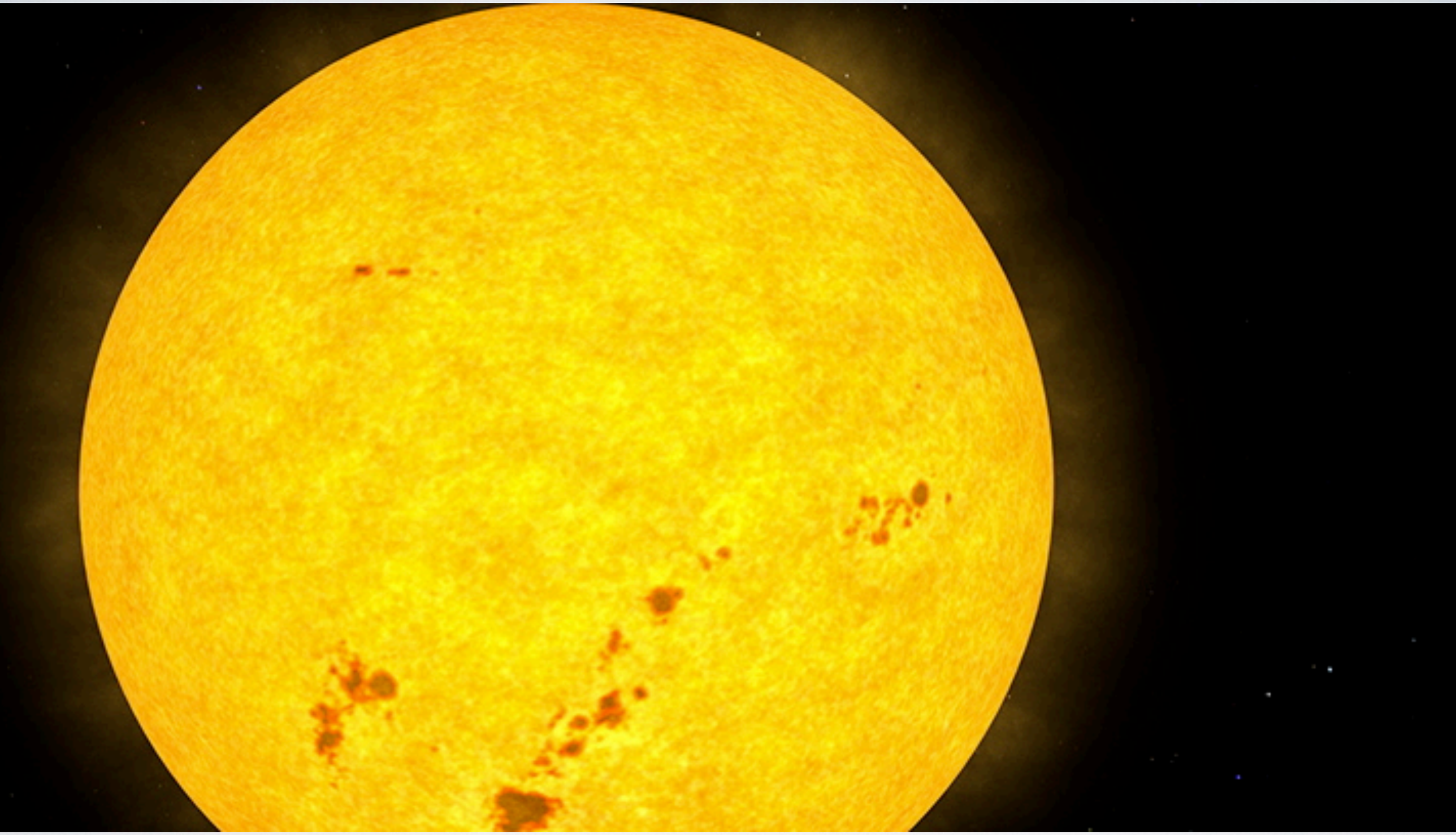


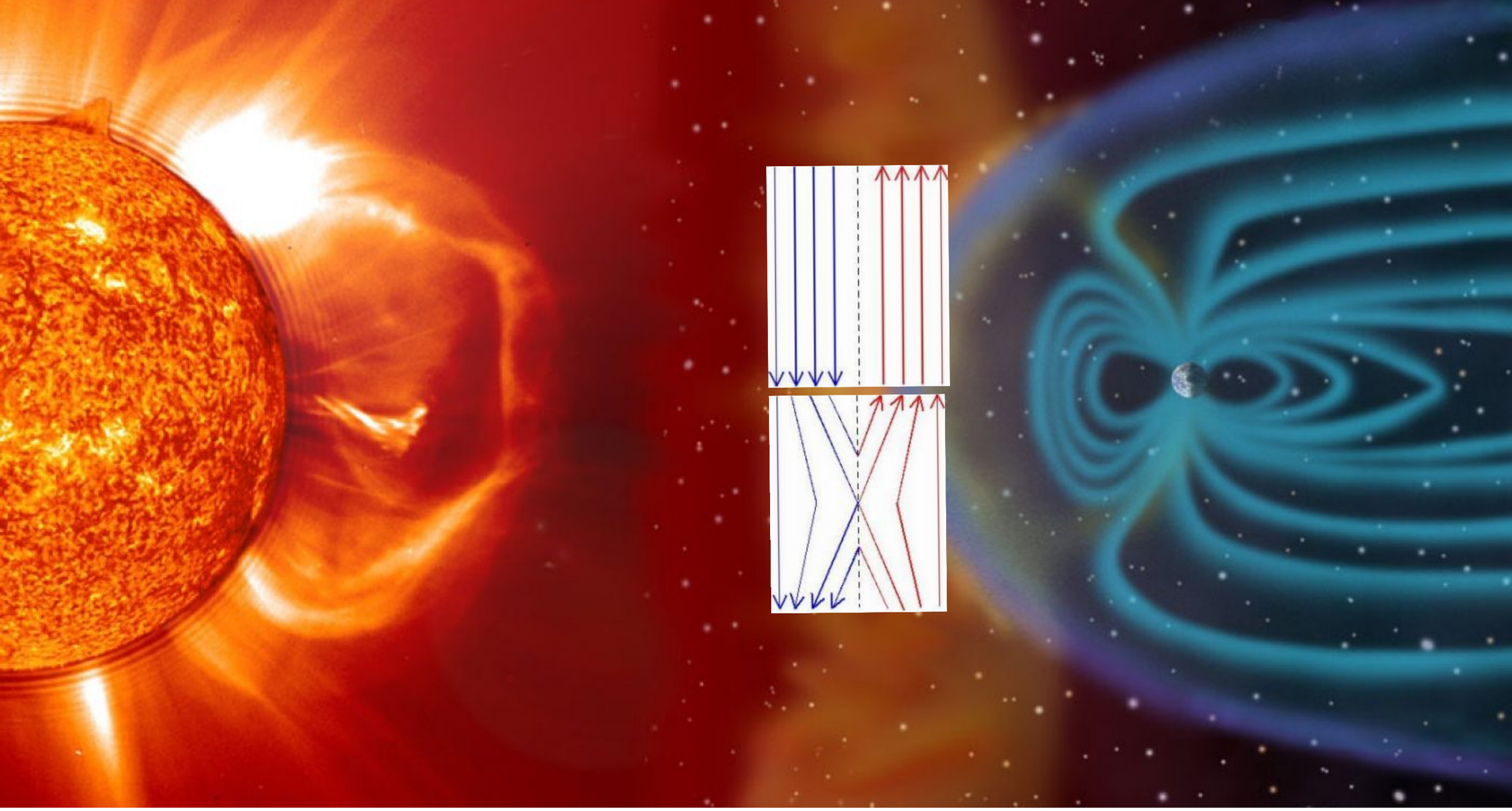
SOLAR STORMS

A solar cloud hurling through space. Solar particles hit the coronagraph.

SOHO/LASCO
SDO/AIA





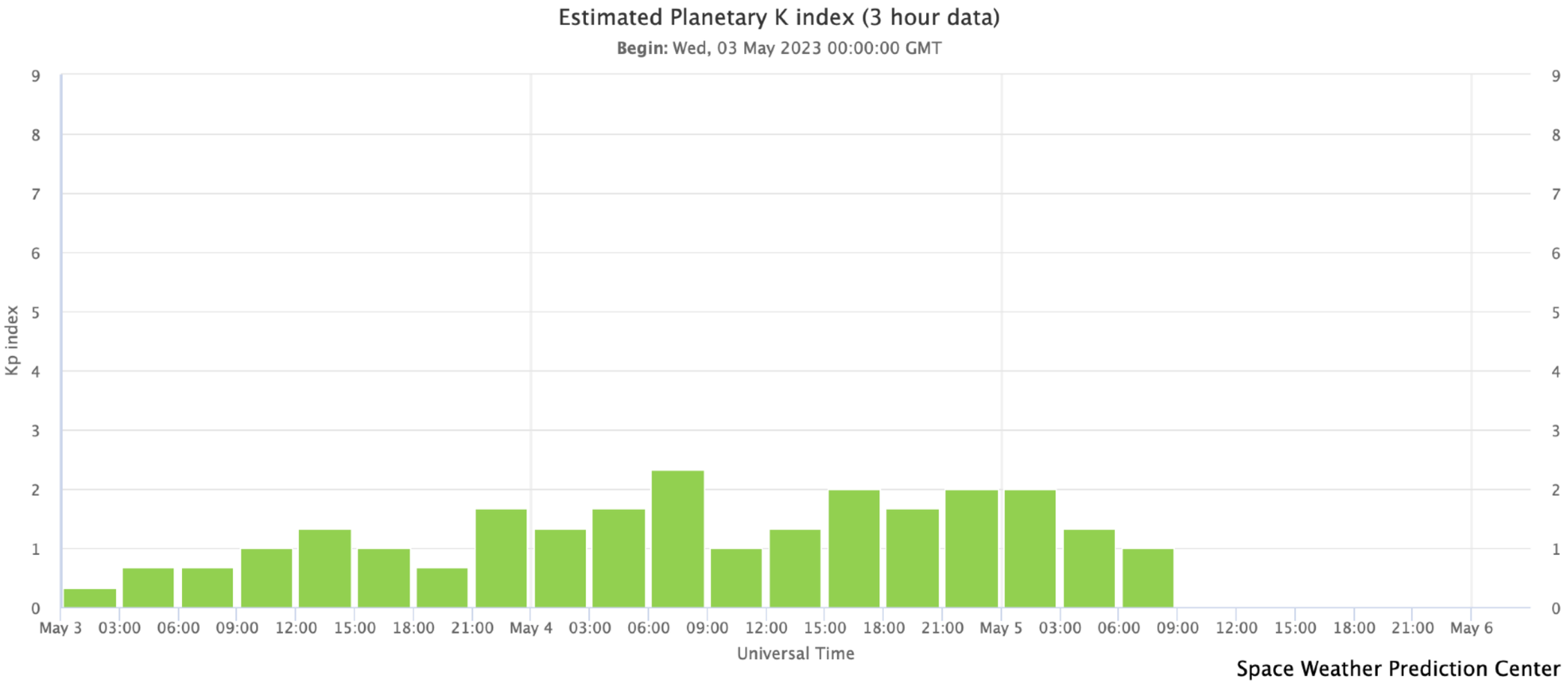


RECONNECTION

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

GEOMAGNETIC STORM

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



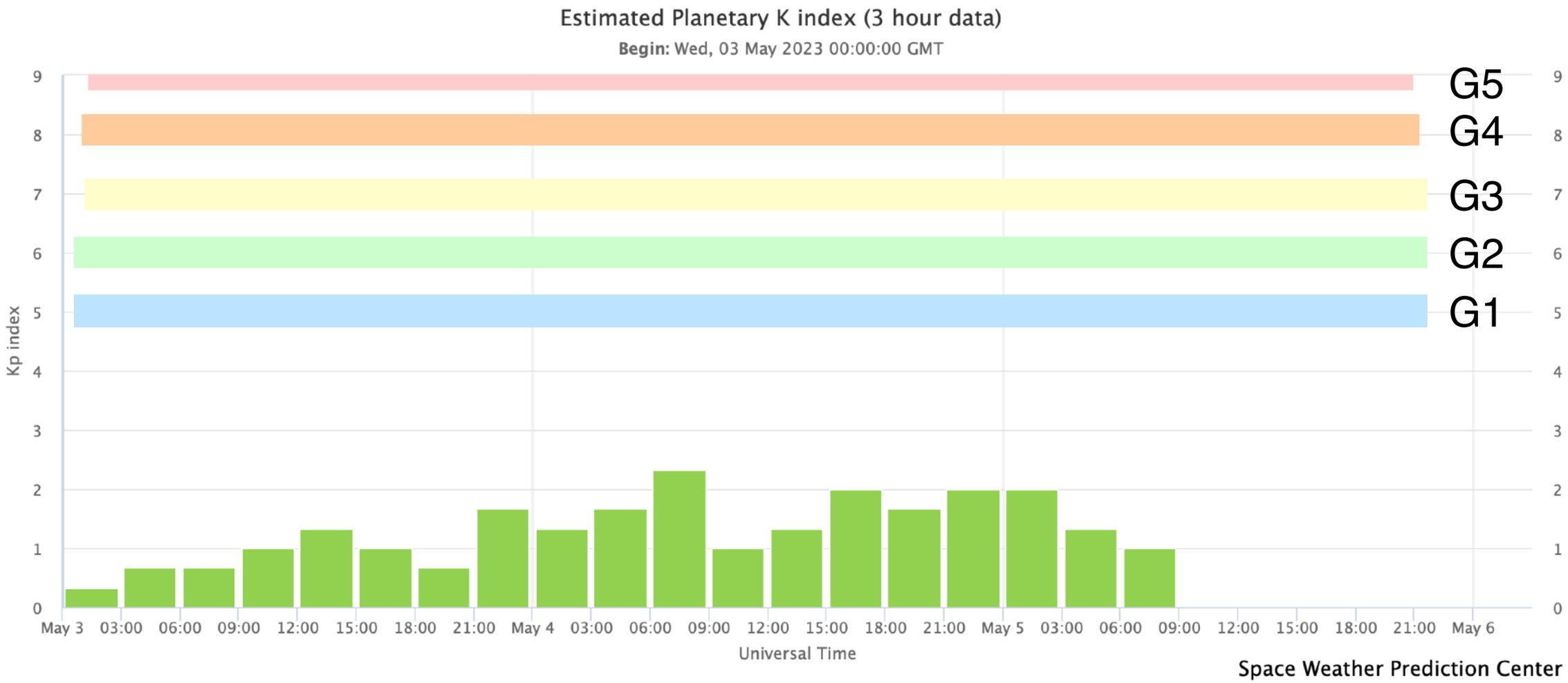
NOAA SPACE WEATHER SCALES

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	**Descriptor**	**Duration of event will influence severity of effects**		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.

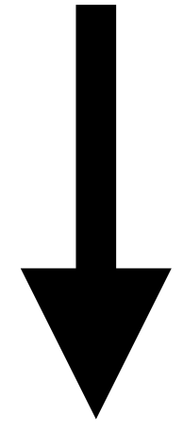
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

GEOMAGNETIC STORM DESCRIBED BY KP



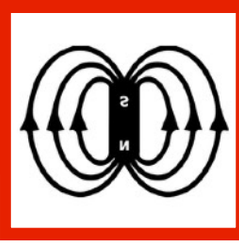
GEOMAGNETIC STORM - KP INDEX NOW

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

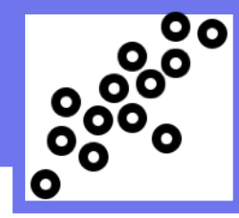


Radio blackout

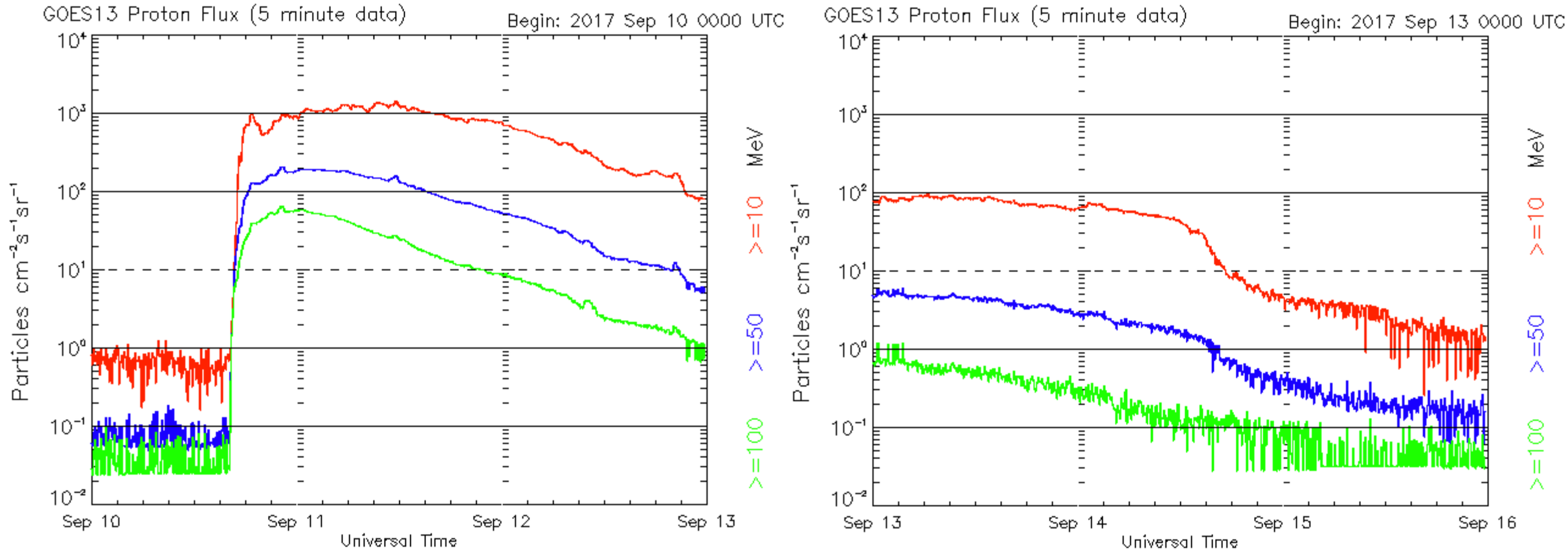
Geomagnetic storm



Solar radiation storm



PROTON FLUX BY GOES



GOES

NOAA SPACE WEATHER SCALES

The impact energetic particles depends on the flux of the stream of particles.

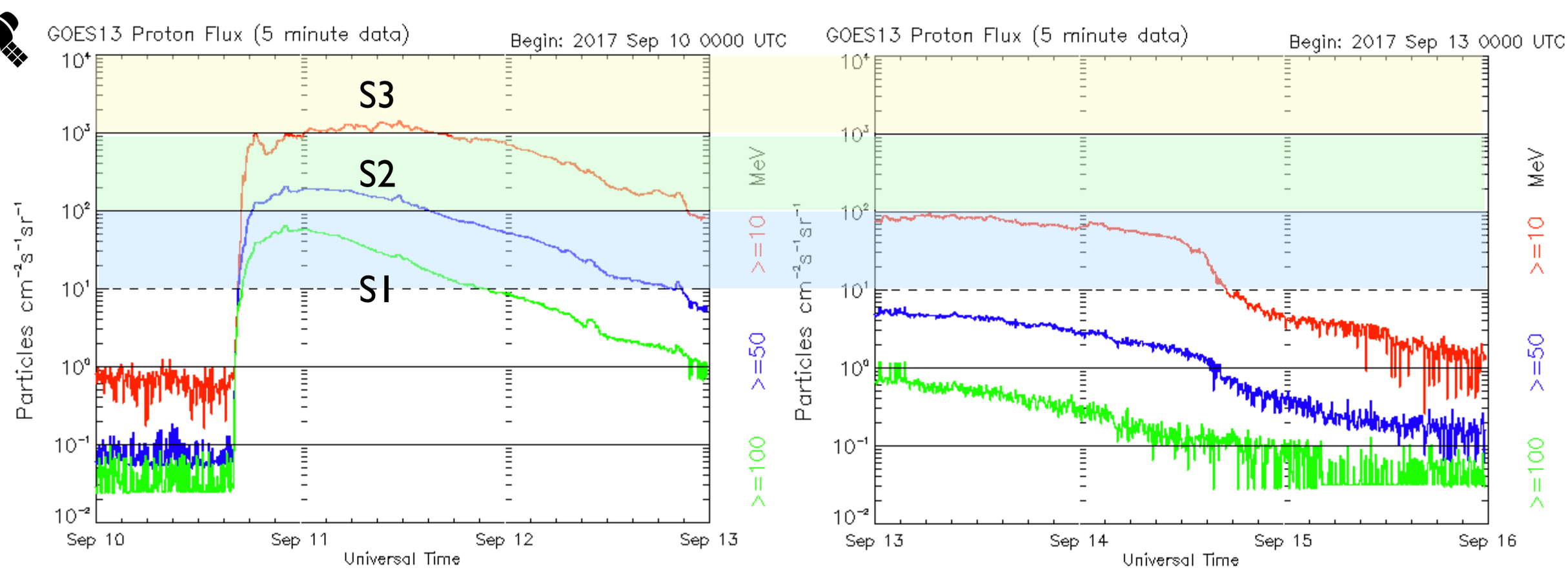
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: may experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.

** These events can last more than one day.

*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

PROTON FLUX BY GOES



GOES

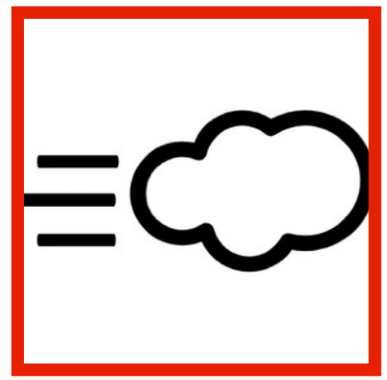
Proton flux now

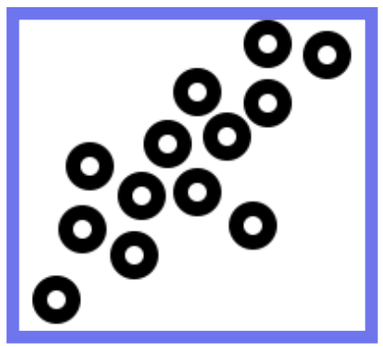
https://www.swpc.noaa.gov/products/goes-proton-flux

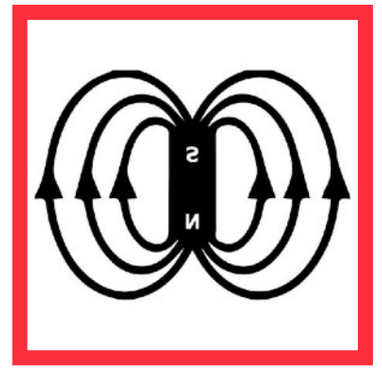
GOES

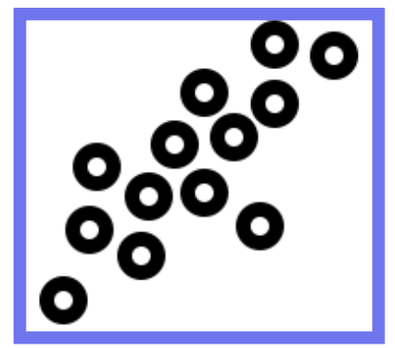
https://www.stce.be

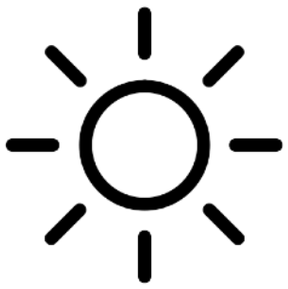
Overview











SDO/AIA

SOHO/LASCO

SOHO/LASCO

GOES

GOES