

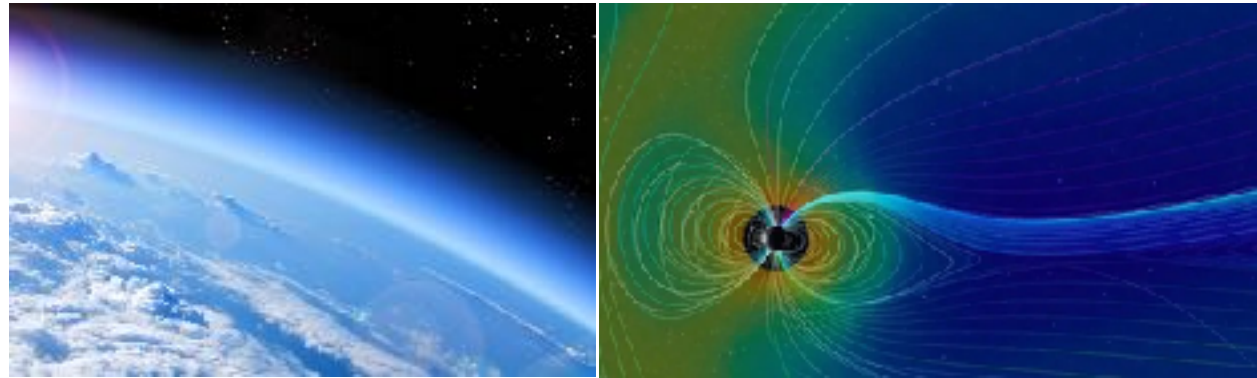
SPACE WEATHER

Introduction



Space Weather

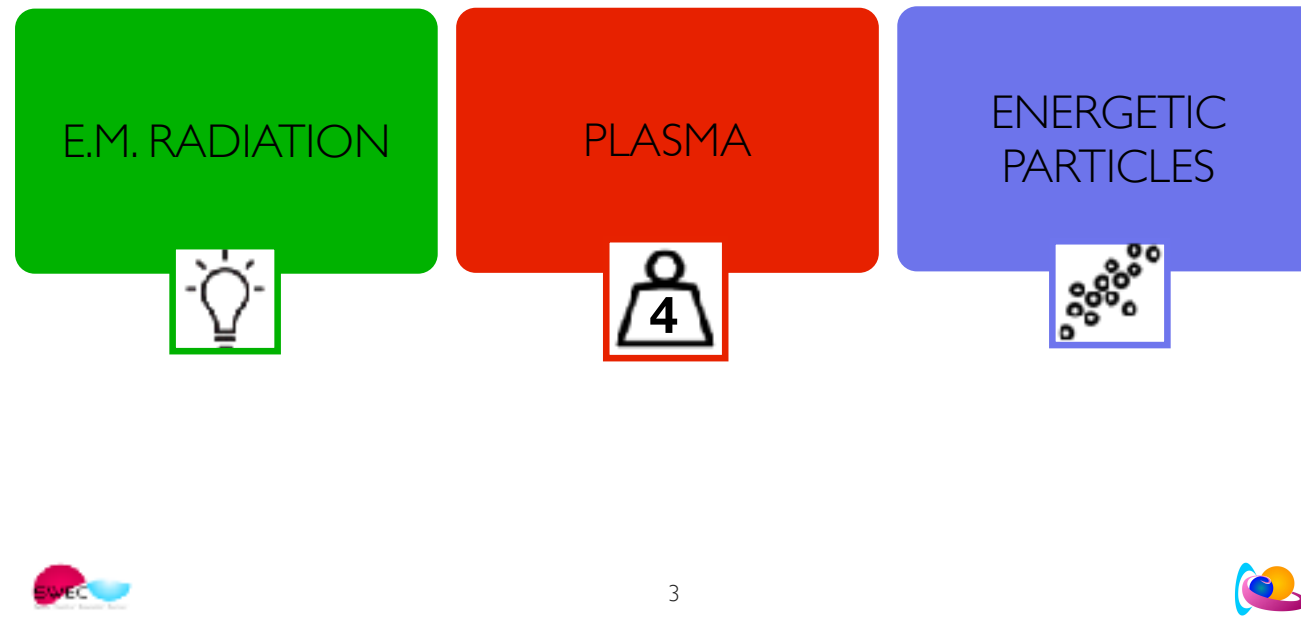
The Sun's energy impacting earth's atmosphere and magnetic shield.



As we go out into space, the atmosphere becomes very thin, until by the time we are in space, it has almost vanished. Almost, but not quite. Even in space there are some atoms which are often moving very quickly. Many forms of energy also move through **space** and it is the **interaction of energy and atoms that produces what we refer to as space weather**. In particular, space weather is the changes that occur in the space environment.

The **sun** is the source of 'normal' terrestrial weather. It is also the **primary (but not the only) source of space weather**. Most aspects of space weather affect us to some extent. The more our society becomes dependent on technology and the more we utilize space, the more we are affected by space weather. Some aspects of space weather are benevolent, and allow activities not otherwise possible such as long range radio communications. Some aspects are benign but fascinating such as the Aurora, and some are malevolent. **Like terrestrial weather, it depends on the situation and the event.**

THE SUN AS A BALL OF ENERGY



The sun is a gigantic ball of energy: magnetic energy, heat, moving plasma, ...

This energy is kept inside the Sun but also on its surface and in its atmosphere in magnetic structures like sunspots and magnetic loops, filaments or prominences ready to be released.

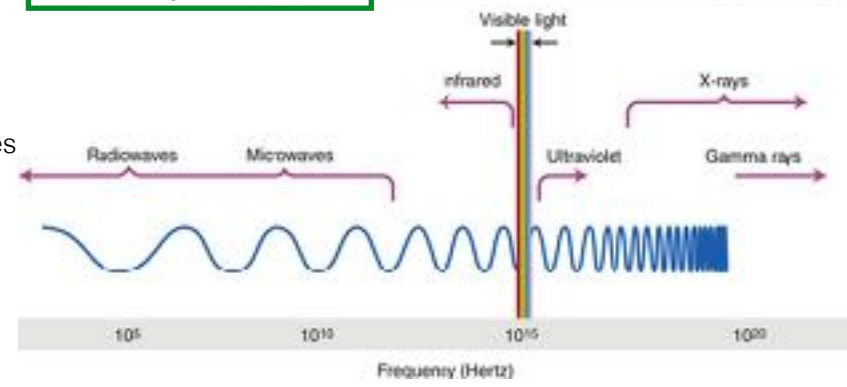
This energy is expelled, leaves the Sun to outer space and is carried away by electromagnetic waves, plasma and energetic particles.

Note: the solar plasma is hot. The plasma particles bump on each other. These collisions changes their kinetic energy. This change is emitted in the form of thermal radiation, light photons. Once these photons are at the solar surface, they can escape and move freely.

Thermal radiation is electromagnetic radiation generated by the thermal motion of particles in matter. You have thermal motion as soon as the temperature is above absolute zero.

Electromagnetic radiation

- Photons / electromagnetic waves
- Speed of light



Particles

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

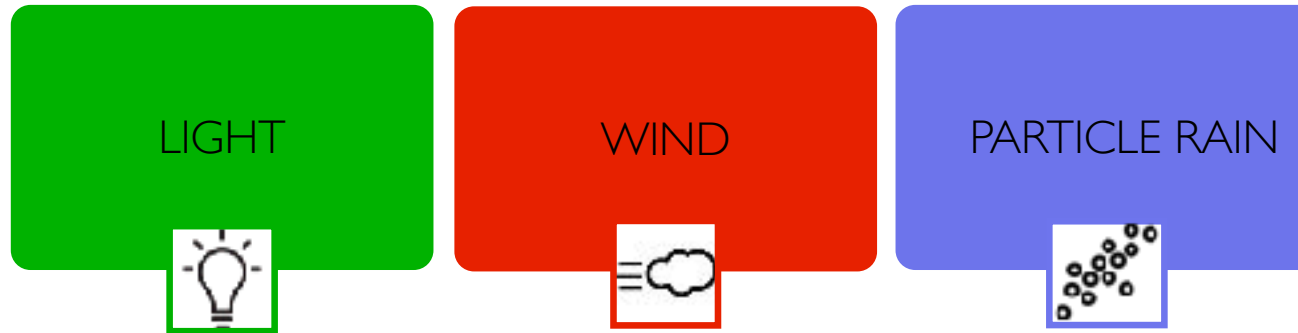


Plasma is the fourth state of matter. Plasma is a gas that is constituted of electrically charged particles. When the particles have energies above 100 keV, they don't behave as a gas but as an individual (energetic) particle.

3 SPACE WEATHER PHENOMENA

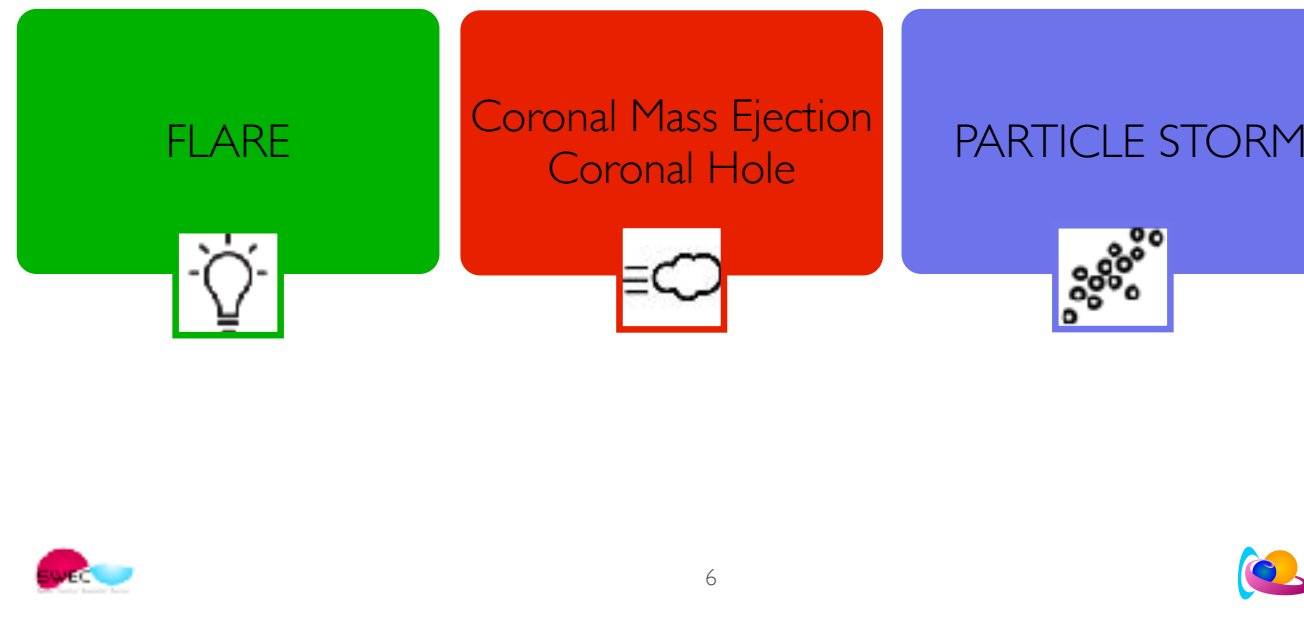
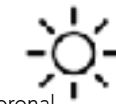
The sun's energy reaches the earth in 3 forms: light, moving gas and particle precipitation. This energy interacts with the magnetosphere and the atmosphere of the earth. This is space weather.

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



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).



Change in solar energy output on the scale of minutes, hours, days – this is solar weather.

A Flare is a sudden strong increase of the solar e.m. radiation. The light flash is localised on the solar surface.

Examples of Solar wind disturbances:

A Coronal Mass Ejection is a plasma cloud that is ejected into space. It is superimposed on the background solar wind. It can go faster/as fast as/slower than the background solar wind. When it is faster, you will see a shock in front of the cloud. This is exactly the same as the shock you see in front of a speed boat.

A coronal hole is a structure in the solar corona that you see as a black area in the EUV. It looks black because there is less plasma present that radiates in the EUV. The magnetic field lines are open, i.e. fan out into space. There are no magnetic loops above a coronal hole. The solar wind emanating from a CH is faster compared to the usual solar wind.

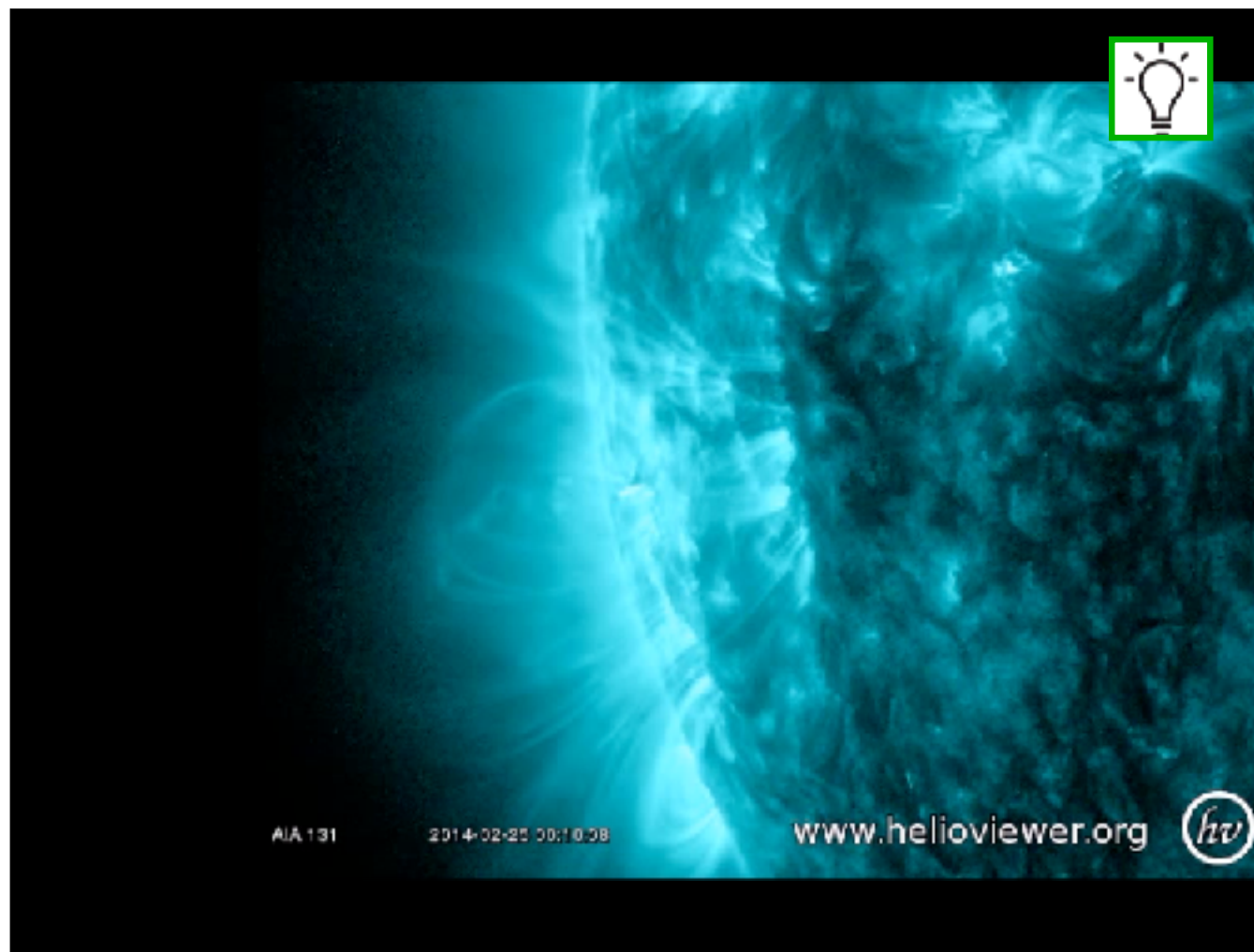
SDO/AIA

Particle storm

A particle storm is a bunch of electrically charged particles that are accelerated in the solar atmosphere to very high velocities by a large-scale magnetic eruption often causing a CME and/or solar flare. They gyrate around a magnetic field line.

In situ means that you measure a parameter local. Remote sensing means that you look at something from a distance.

Near Earth, the IMF still controls the solar wind and its movement. If we would go much much further, the CME magnetic bag with solar plasma would be almost empty (all the solar material is spread over an immense volume) and the magnetic bag would have evaporated. But, this doesn't matter for us. We are at 1AU and at 1AU the IMF and solar plasma make space weather in a normal way, in an extreme way.

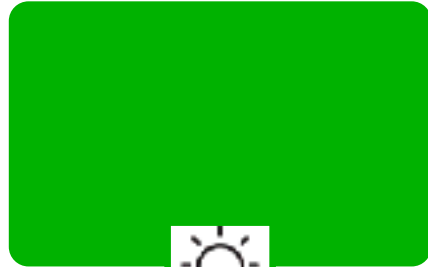


Light storms

During a flare, an area in the solar corona lights up. This is a movie from the EUV imager AIA onboard of SDO.

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

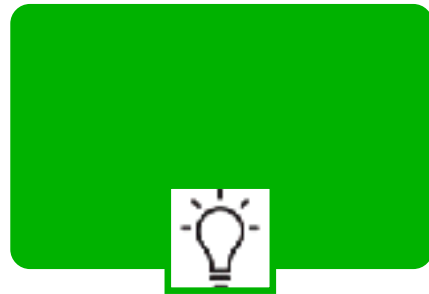
The energy released during a solar storm moves through space, each with its own typical speed: speed of light, order of a few 100 km/s, relativistic speeds.



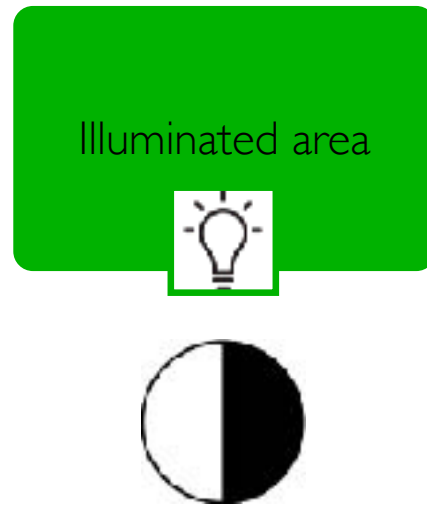
8 MIN



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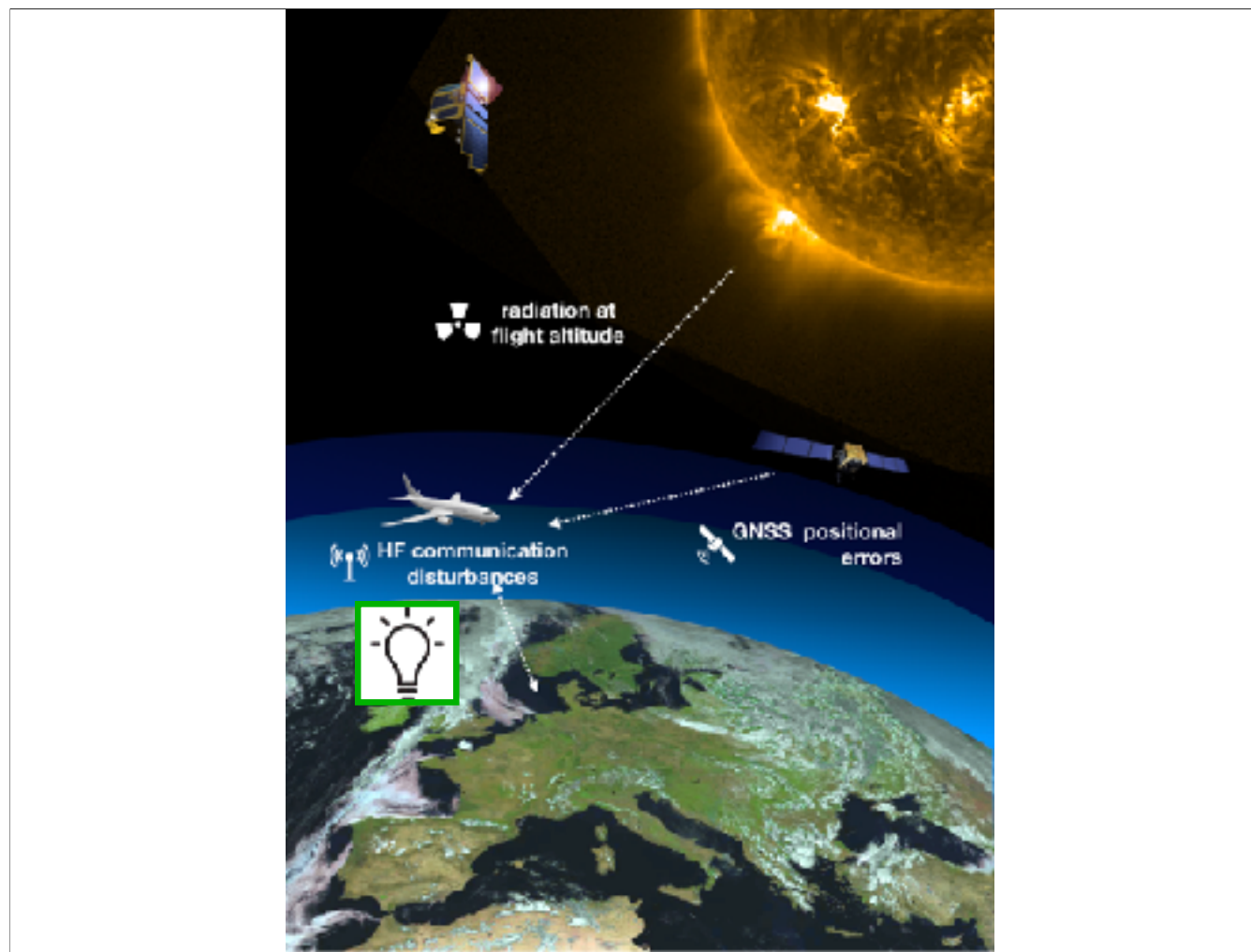
The icon represent the Earth. White is the day-side, black is the night side.
When you 'see'/detect a flare, you can be impacted.

STORM SCALE

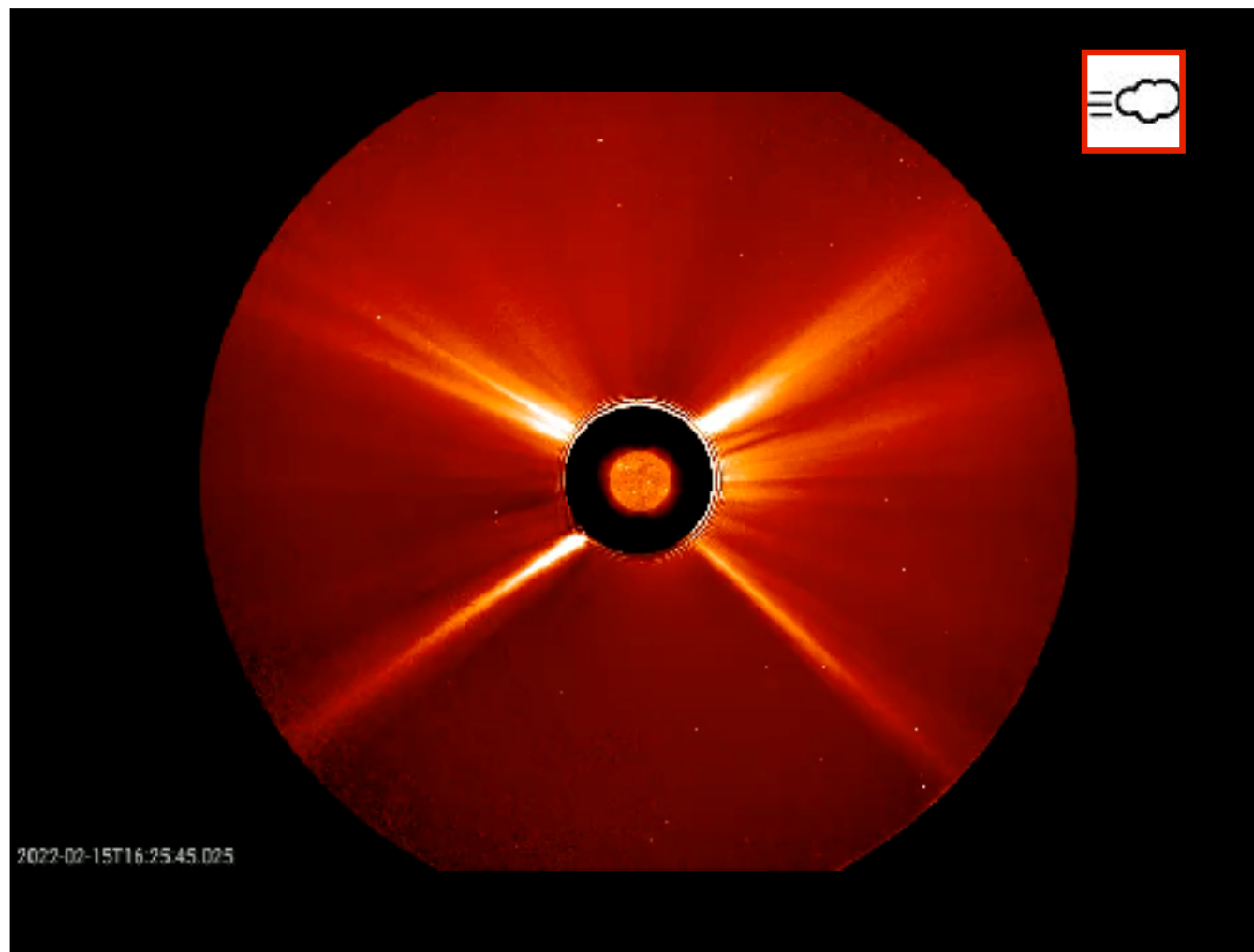
A,B,C,M,X



The scale of a flare is defined by its X-ray flux. The X-ray flux is measured by the geostationary satellite GOES.



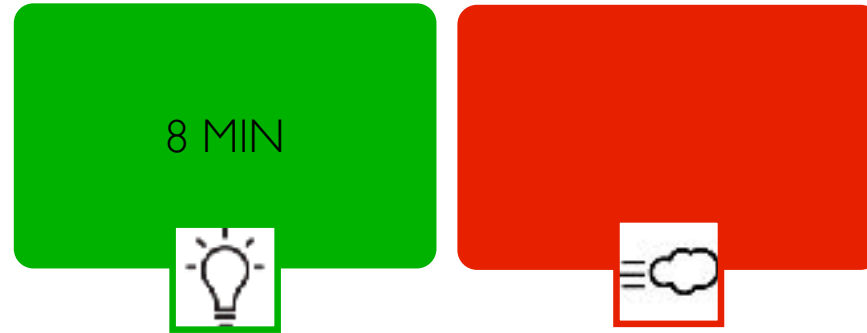
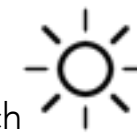
The ionising part of the flare, can cause a Short Wave Fadeout on the dayside of the Earth.
The HF radio signal is being (partially) absorbed while passing through the D-layer of the ionosphere.



A CME is visible as a white cloud in corona graphic images like the one on the slide. A coronagraph is a telescope that creates an artificial eclipse and makes pictures in the visible light of the region around the sun.
SOHO/LASCO C2

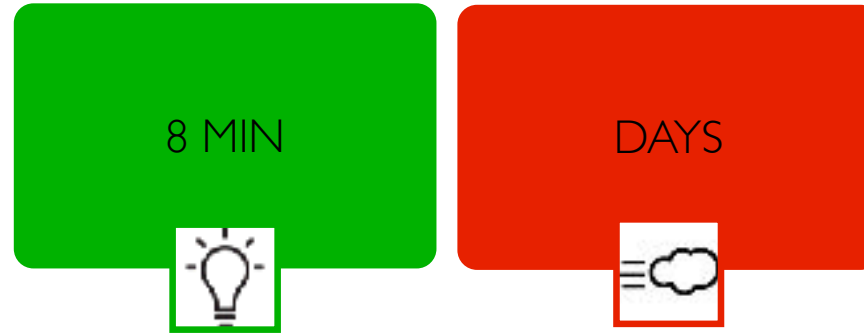
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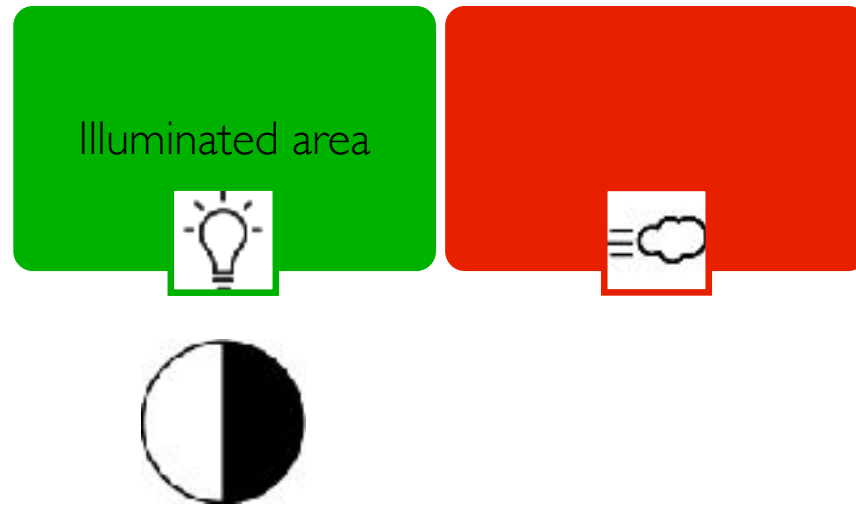


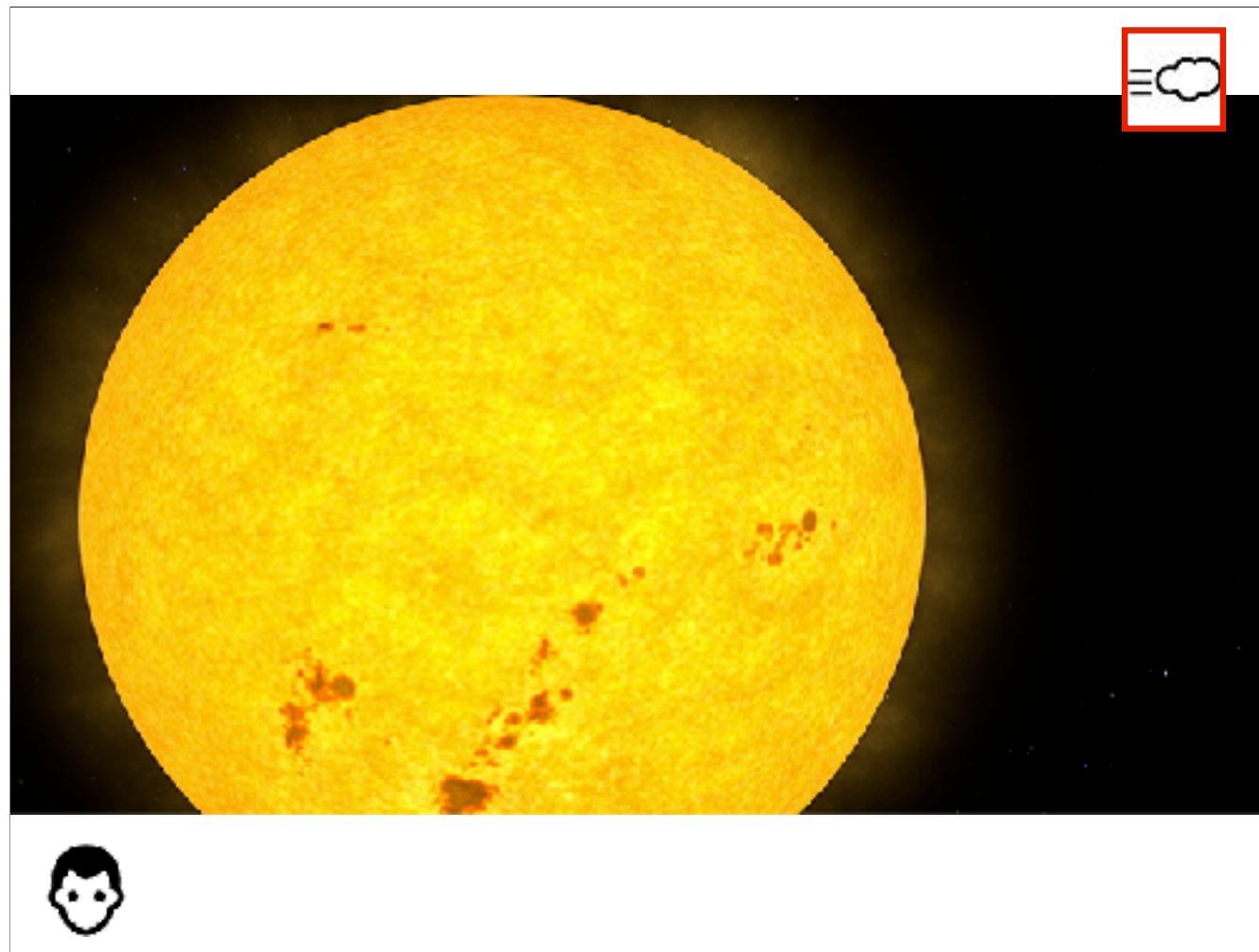
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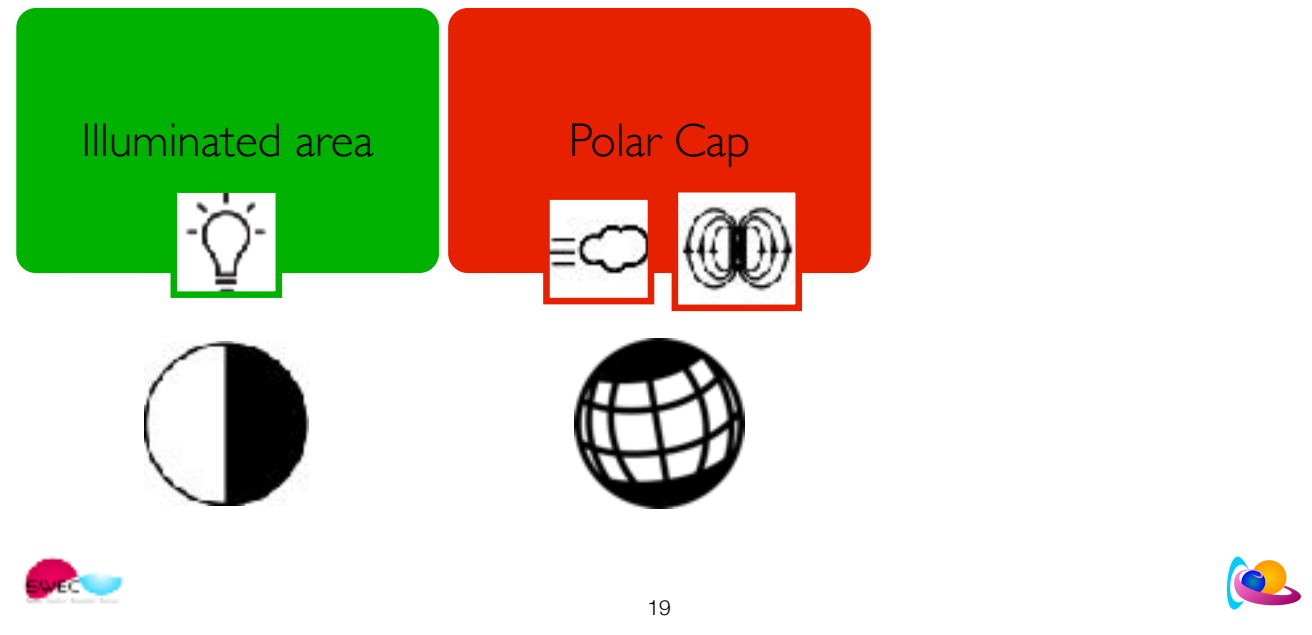
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A CME that hits the Earth's magnetosphere.
Precipitating electrons coming from the tail of the magnetosphere gyrate along the Earth's magnetic field and drop into the atmosphere in the auroral oval.
These electrons have no solar origin, they are present in the plasmasphere of the Earth.

AREA OF IMPACT



The magnetic field carried by the solar wind can reconnect on the day side with the magnetic field of Earth.
On the night side, magnetic reconnection between opposite magnetic field of the magnetosphere of Earth. (No solar magnetic field involved.)


The icon of the dipole represents the Earth dipolar field.

The result is that the Earth's magnetic field is disturbed and most strong in the polar regions.


STORM SCALE



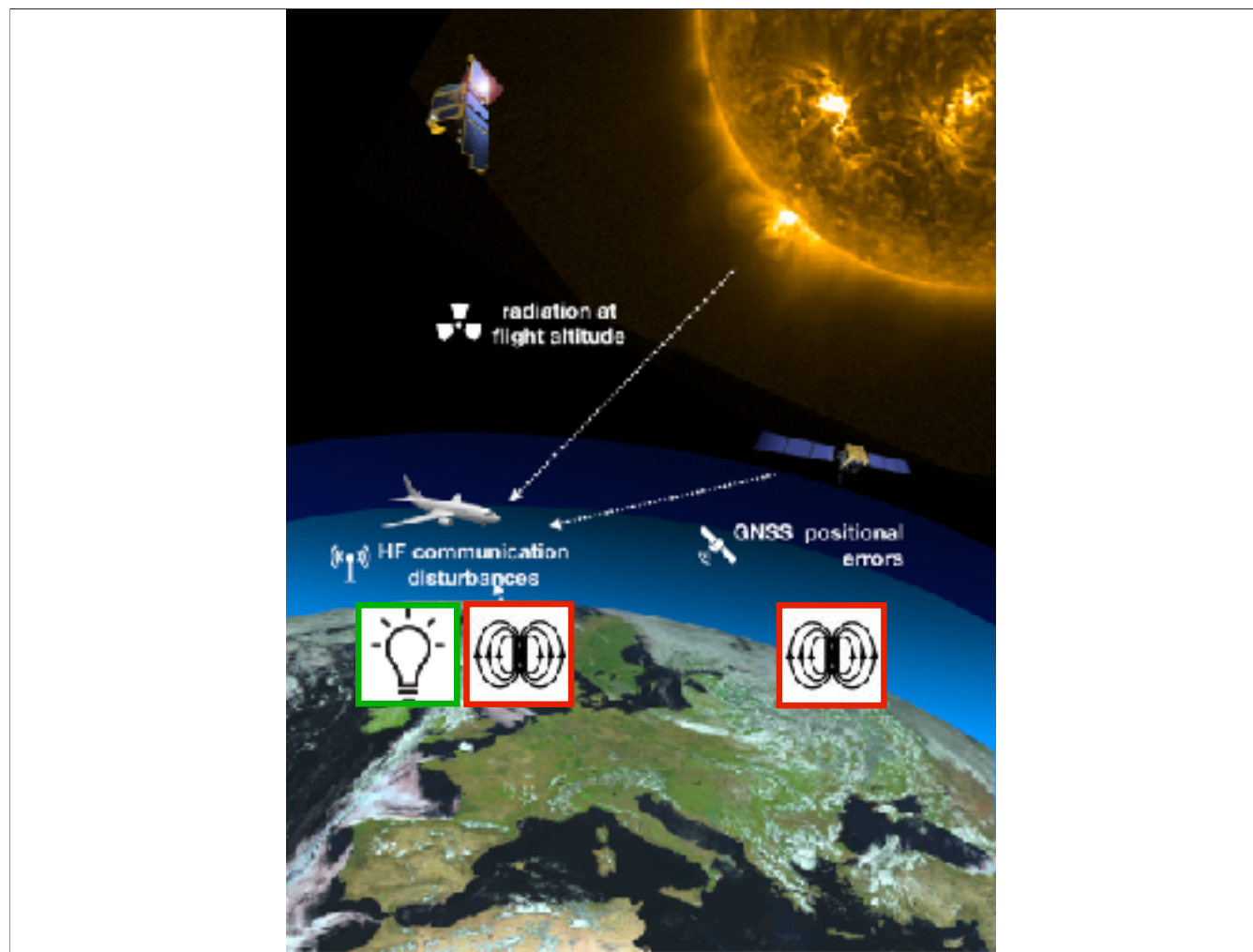
A,B,C,M,X



Kp
0 - 9



The Kp index is an index that quantifies the disturbance of the magnetic field of Earth. It ranges between 0 and 9, with 0 no disturbance and 9 an extreme disturbance.

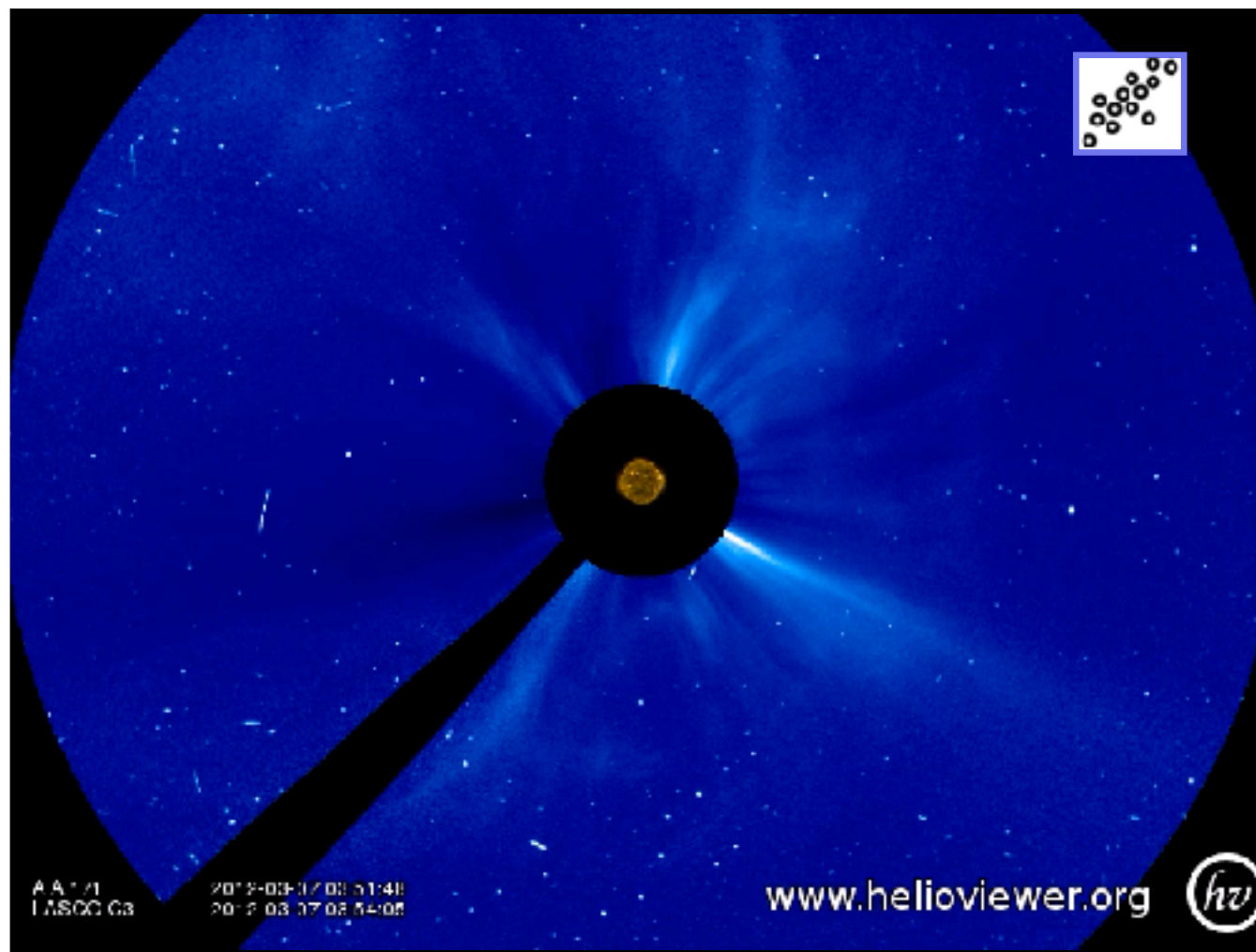


GNSS

- Amplitude or phase scintillation of the radio signal emitted by the GNSS satellites due to small scale irregularities. Scintillation might result in a loss of lock.
- VTEC - Increase the electron density (positive phase of a geomagnetic storm) such that the signal is not following its regular path and its speed is changed. This results in a delay.

HF com

- In the negative phase of a magnetic storm, an electron depletion occurs → higher frequency radio waves are not reflected anymore by the ionosphere and just pass into space.
- AA: induce extra ionisation in the D-layer of the ionosphere such that radio waves are being absorbed when they pass through the D-layer.



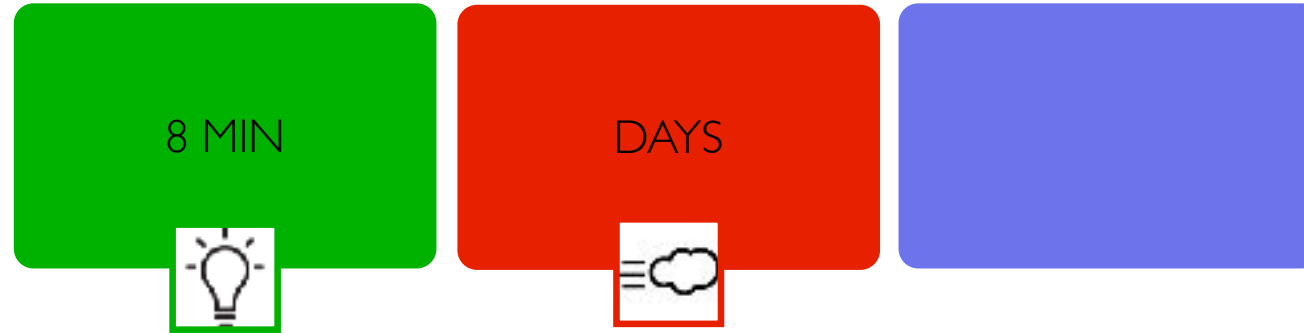
Particle showers

You see energetic particles that impact the telescope LASCO/C3 onboard of SOHO. They are seen as white stripes and dots: these are particles that fall into the lens, hit a pixel or more pixels. The impacted pixel is blinded. The dots and stripes represent an in situ measurement.

(The image in the middle of the occulter is an EUV image from the instrument AIA onboard of SDO.)

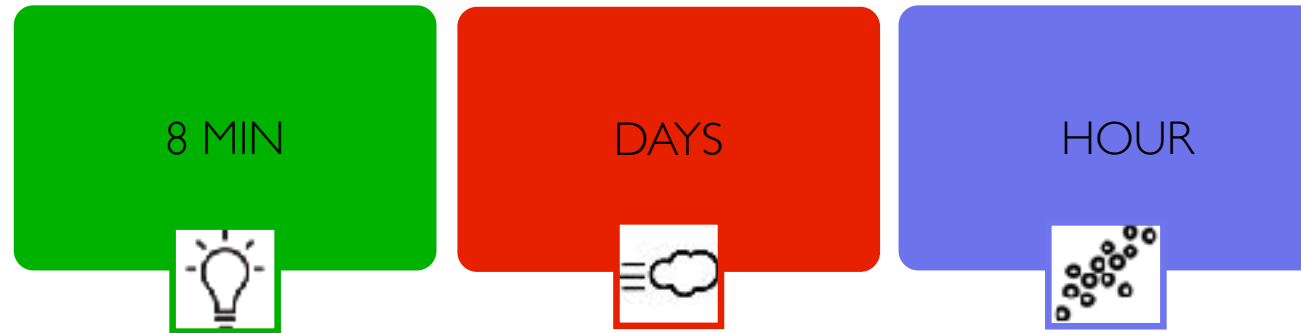
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AU TRANSIT TIME

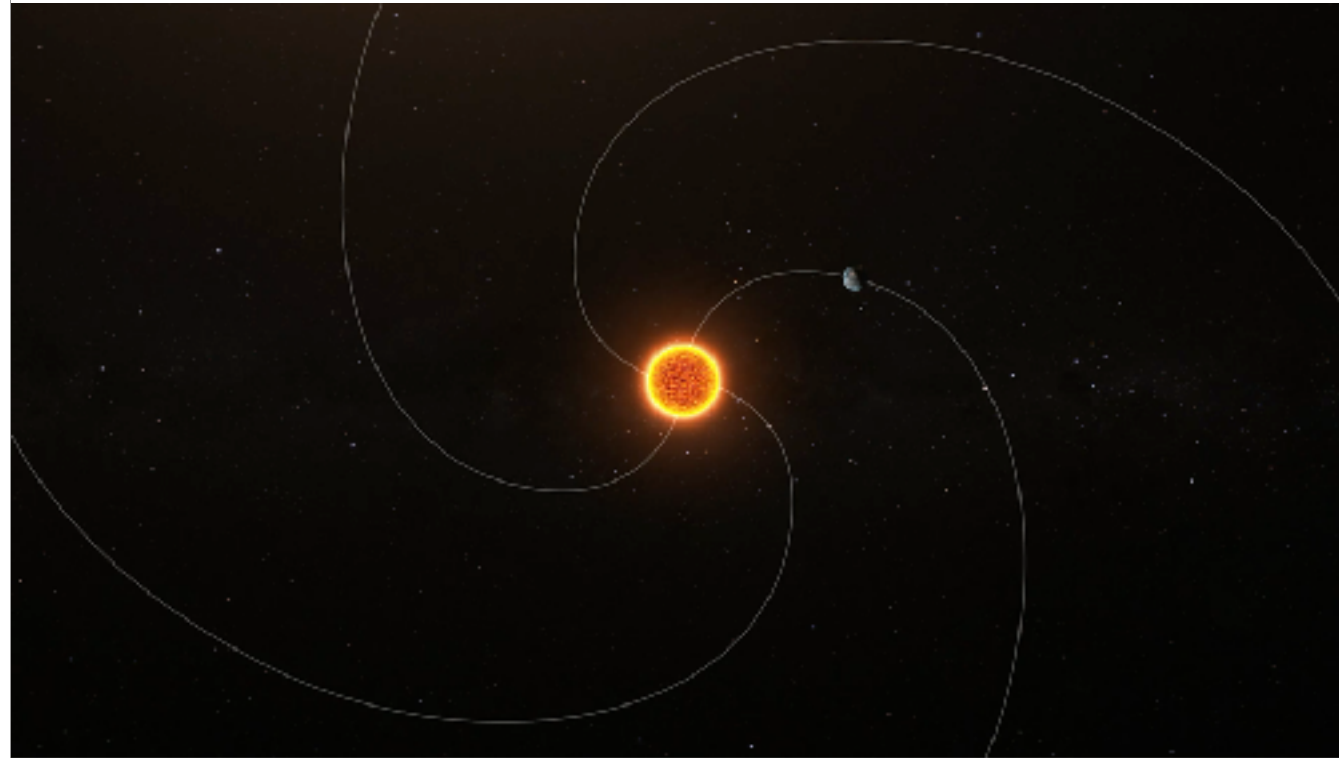
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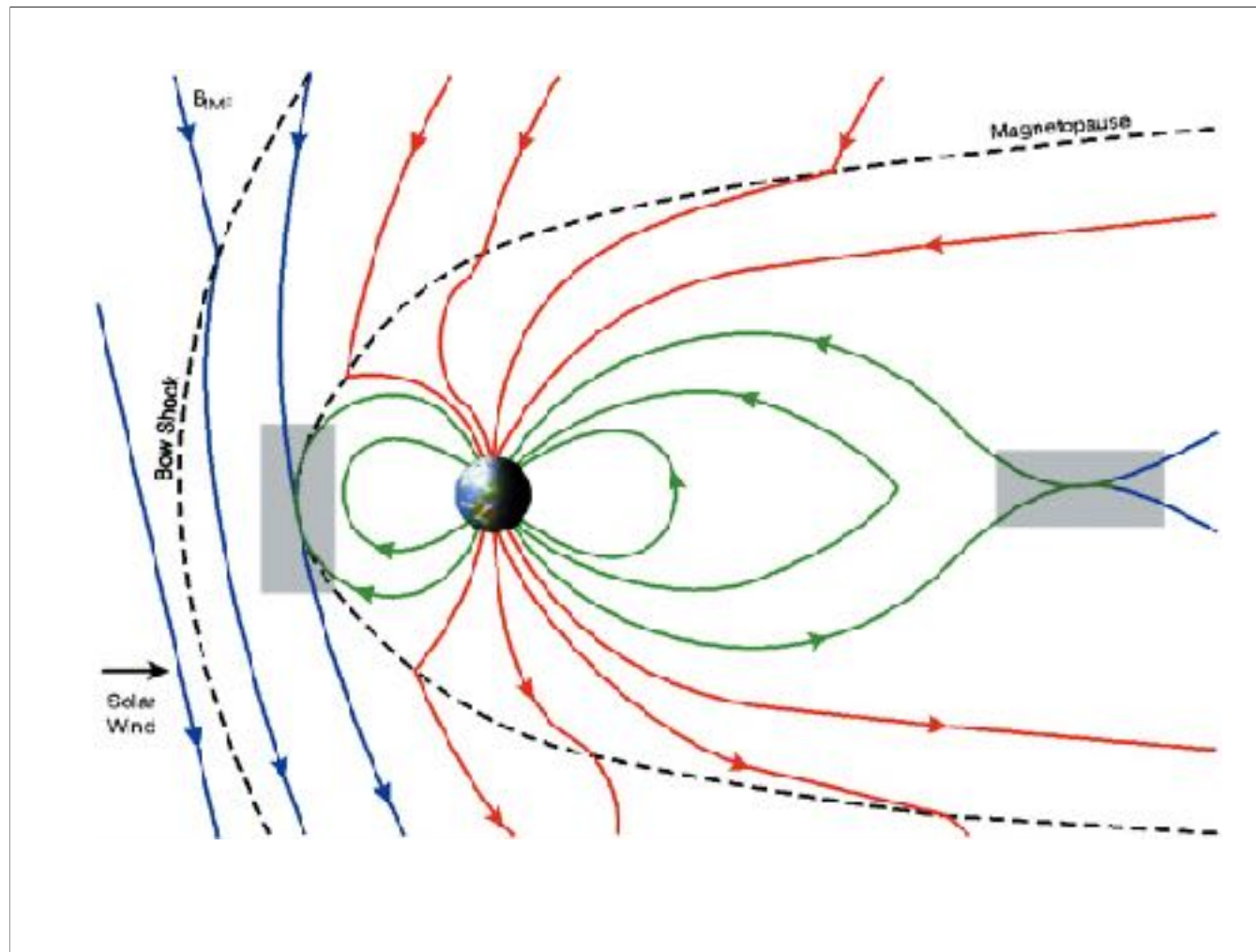


PARTICLES FOLLOW THE PARKER SPIRAL



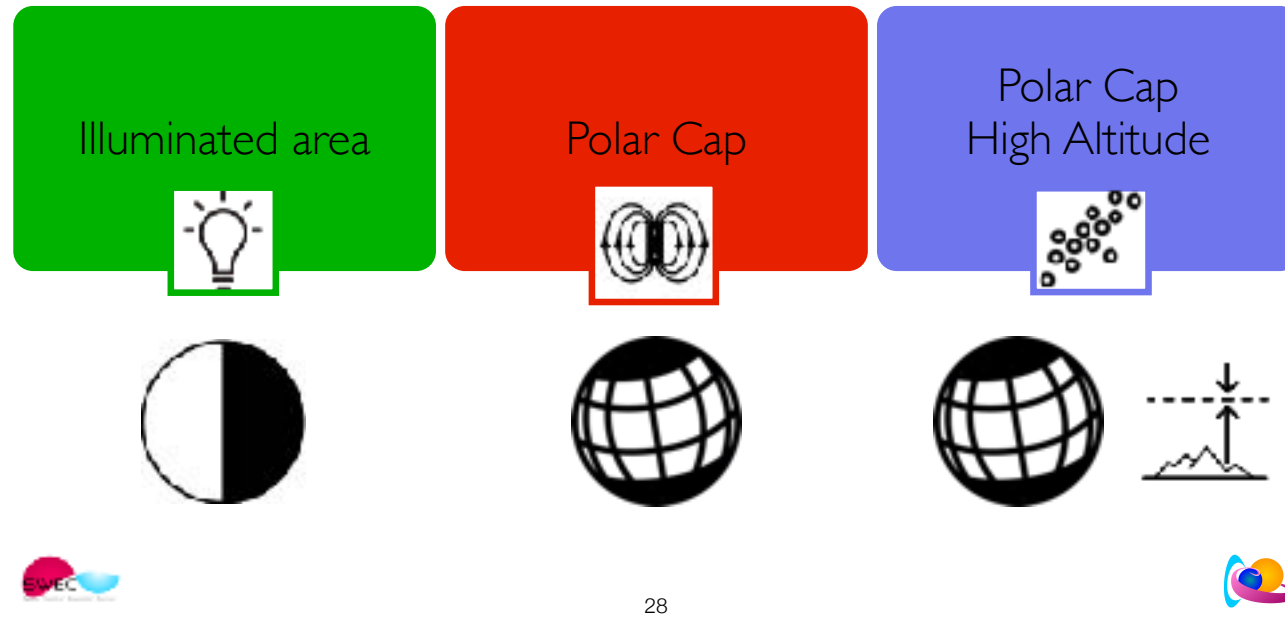
<https://svs.gsfc.nasa.gov/20320>

An intense solar eruptive event has many parts. This animation starts with a solar flare, which sends light and energy in straight paths, traveling at the speed of light. A coronal mass ejection, or CME, appears next – this is a giant cloud of solar particles that also expands in a straight direction with speeds up to two thousand miles an hour. The eruption also generates solar energetic particles, with speeds nearly reaching the speed of light, following the spiral shape of the solar wind's magnetic fields into interplanetary space.



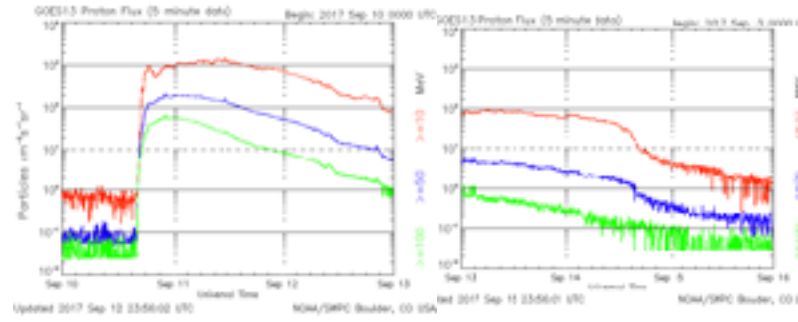
The solar energetic particles catch up with a magnetic field line of the earth's magnetosphere and gyrate down towards the polar regions. They mainly drop in in the area with open magnetic field lines (red).






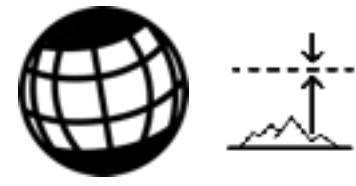


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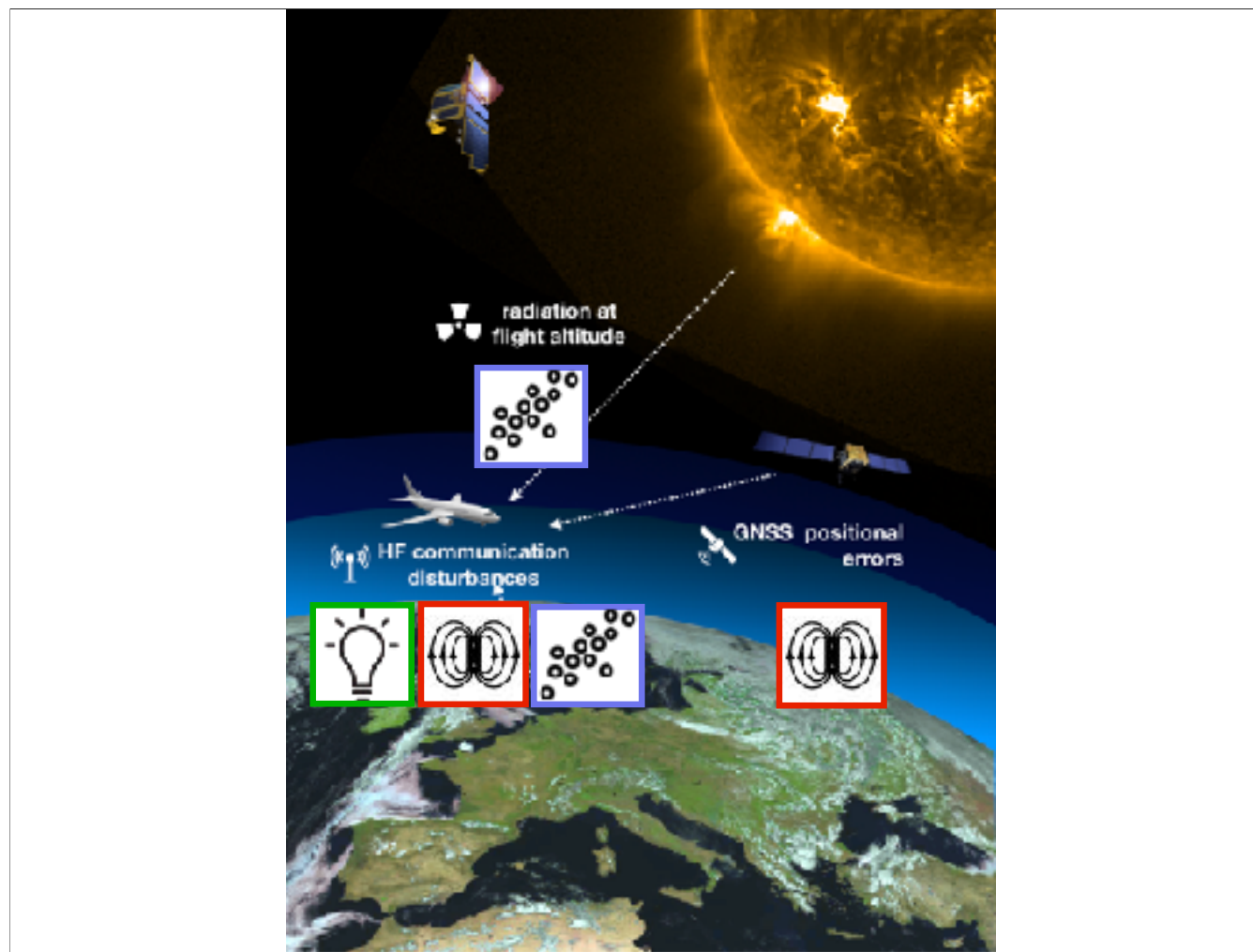
The higher the energy, the deeper they can penetrate into the Earth's atmosphere.

STORM SCALE



A,B,C,M,X	Kp 0 - 9	Proton Flux
		
		
	29	

The GOES satellite measures the proton flux. When the >10MeV proton flux passes the 10 sfu (solar flux units), the storm level is reached.



Impact
Radiation at flight altitude

HF com

- Polar Cap Absorption. The incoming energetic particles induce extra ionisation in the D-layer resulting in possible absorption of the HF radio waves that pass through.