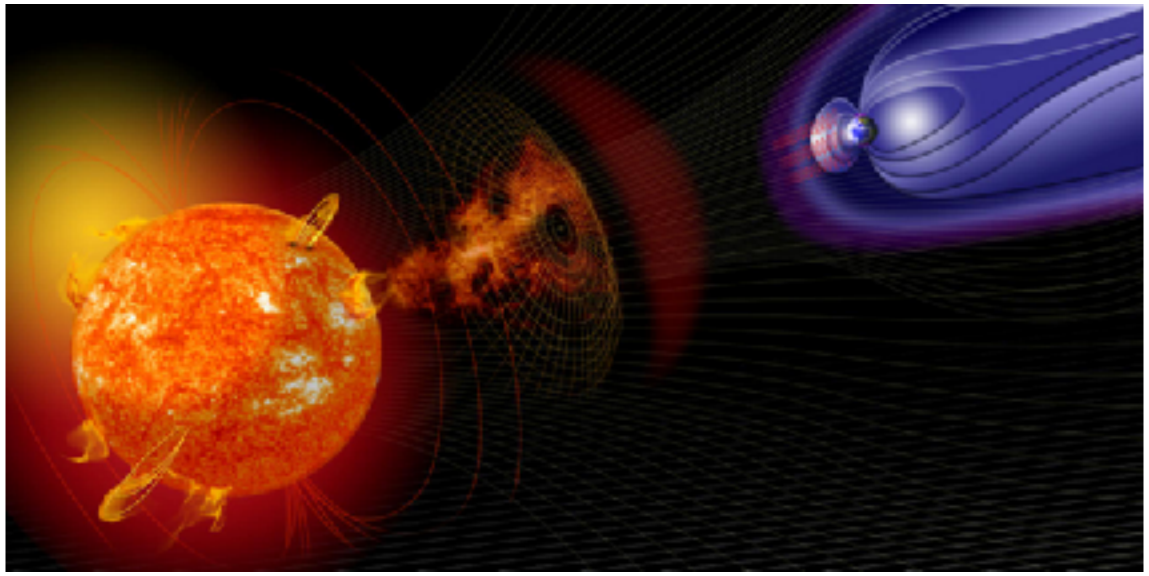


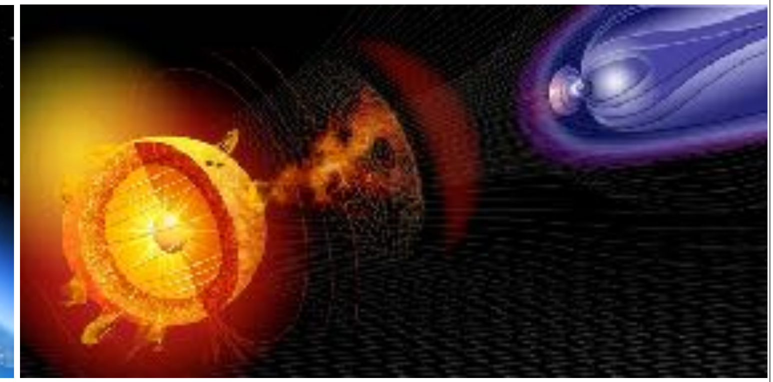
SPACE WEATHER

Introduction

Petra Vanlommel

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.**

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

light= electromagnetic waves, energy transmitted in the form of photons/ EM waves

Wind= moving gas, in this case moving plasma

EPP = particle has high energy and precipitates along the geomagnetic field.

<100 kEV : plasma

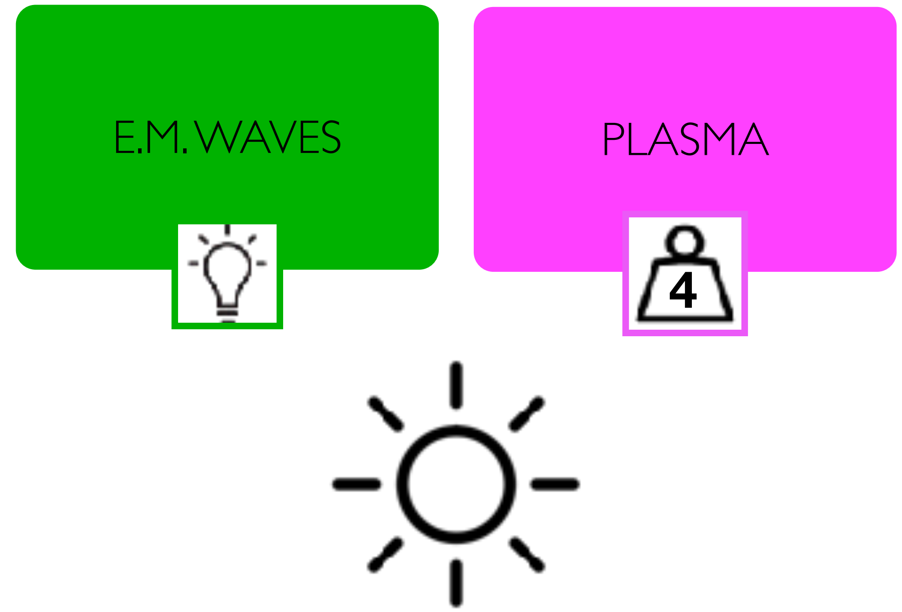
Particle precipitation - energy transmitted in the form of fast-moving atomic or sub-atomic particles

Energy expressed in eV= 1.602 10^-19 J

https://lasp.colorado.edu/home/mag/research/energetic-particle-precipitation/

Focus on solar energetic particles

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



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

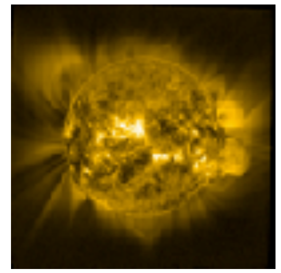
This energy is kept inside the Sun but also on its surface and in its atmosphere in magnetic structures like sunspots and magnetic loops, filaments or prominences ready to be released.

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

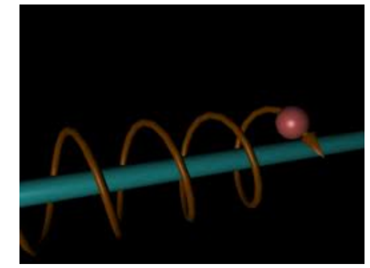
Note: the solar plasma is hot. The plasma particles bump on each other. These collisions changes their kinetic energy. This change is emitted in the form of thermal radiation, light photons. Once these photons are at the solar surface, they can escape and move freely.
Thermal radiation is electromagnetic radiation generated by the thermal motion of particles in matter. You have thermal motion as soon as the temperature is above absolute zero.

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

The energy expelled in the form of plasma takes two forms: solar wind and solar particles.

The outward flow of solar particles and magnetic fields from the Sun. Typically at 1 AU, solar wind velocities are near 375 km/s and proton and electron densities are near 5 cm−3. The total intensity of the interplanetary magnetic field is nominally 5 nT.

TSI, e.m. radiation is not linked to the IMF. It doesn't follow the magnetic field lines.
PROBA2/SWAP, the sun in the EUV.

However, plasma containing ions and electrons has to follow the magnetic field lines. Or you can also say that the magnetic field lines guide the plasma.
The solar wind plasma is glued to the IMF – or the IMF is glued to the plasma.
The plasma in the solar wind is considered as a gas, a group of particles behaving and moving in group. You don't speak about that particular particle in the solar wind, you speak about the solar wind, a whole bunch together.
Cartoon

Electrically charged particles have to follow the IMF. These electrically charged particles are considered as individuals and behave as individuals.
Cartoon

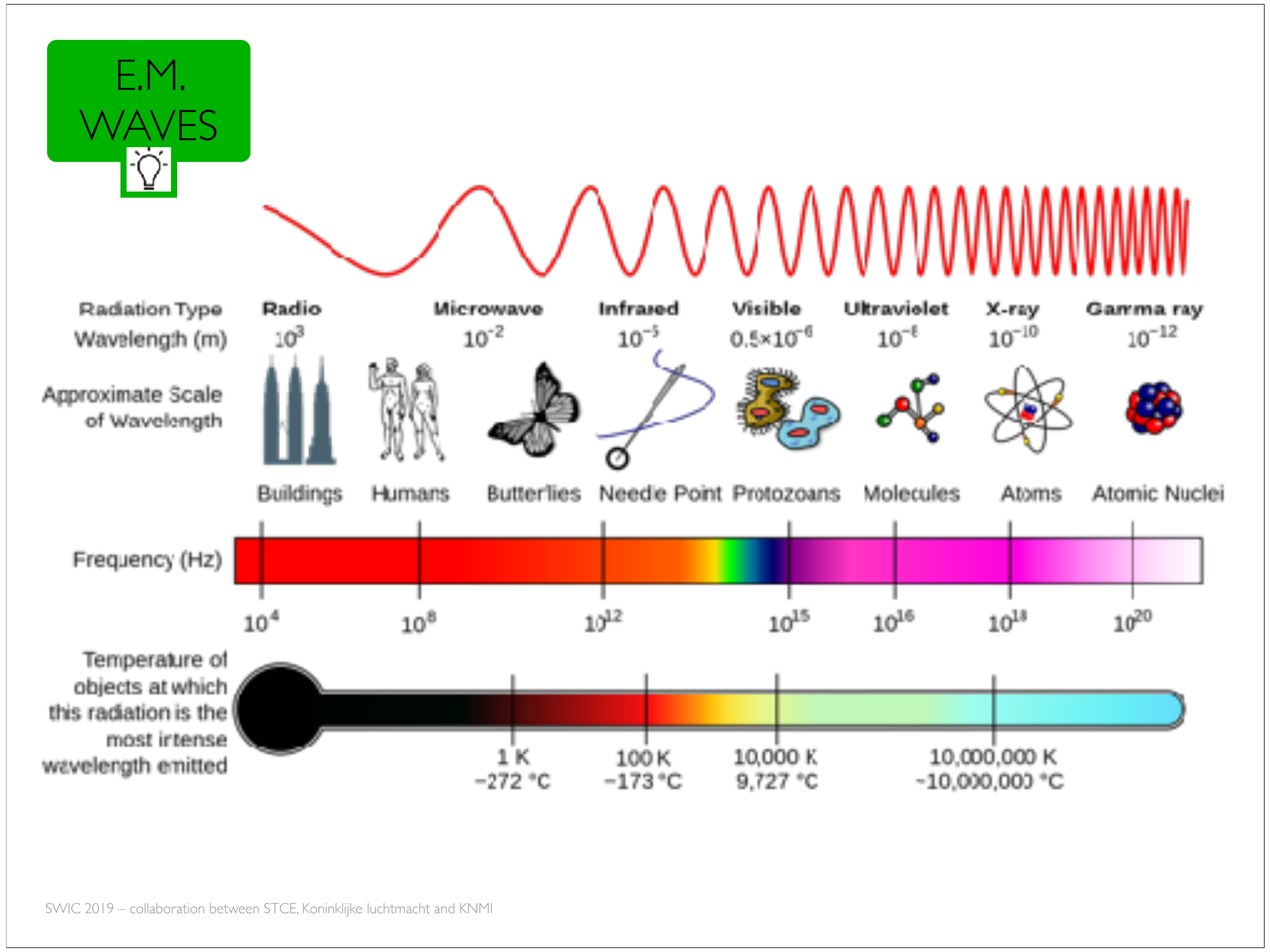
Near Earth, the IMF still controls the solar wind and its movement. Much much further away from the Sun, the IMF becomes very weak and doesn't control the solar wind anymore. But, this is not important for us. At 1AU, the IMF influences the plasma and the plasma the IMF.

About the animated gif:
Conceptual animation (not to scale) showing the sun's corona and solar wind.
Credits: NASA's Goddard Space Flight Center/Lisa Poje

The solar wind is a continuous radial stream of solar plasma that leaves the sun and moves away from it. It fils the space between the planets with solar mass. The solar wind reaches the boundaries of the heliosphere, a magnetic shield around the Sun. In the heliosphere, the Sun sets the rules and you have solar weather. Outside the heliosphere, you have the rest of the galaxy. Earth is in the heliosphere.

A nice movie is found on
https://www.nasa.gov/feature/goddard/2016/images-from-sun-s-edge-reveal-origins-of-solar-wind

https://youtu.be/QYM2_ytkjQo



Wave: wavelength, amplitude

Speed of light in vacuum

Doesn’t need a medium to propagate

Doesn’t need to follow magnetic field

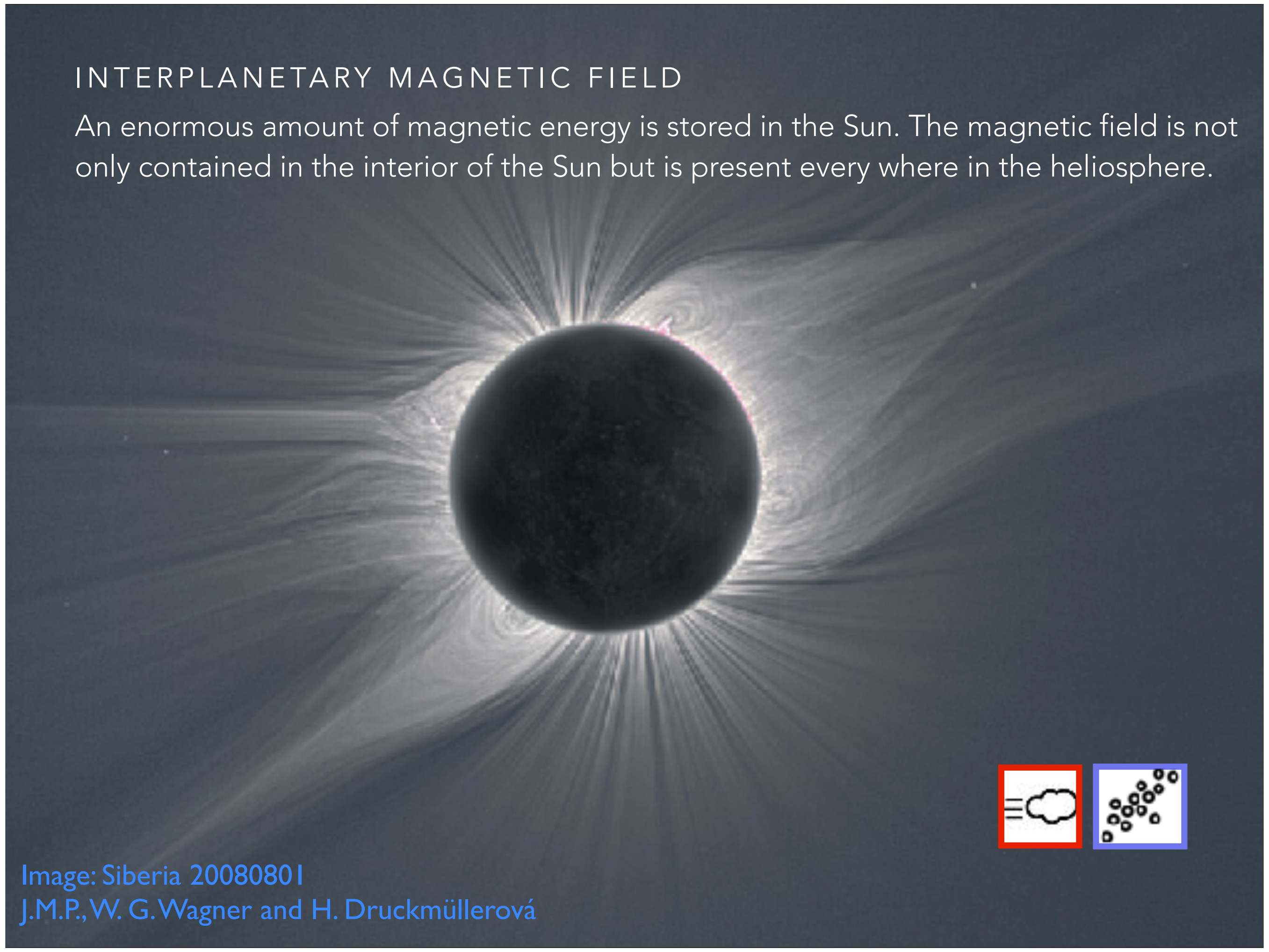
H-alpha 656.28 nm - rood - 9000 °K

C II K 3933.7Å - 393.37 nm - blauw -

zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGeGrBIV

UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom



The interplanetary magnetic field plays a key role for the energy transport in the form of plasma.

Plasma is a gas with charged particles. They have to listen to the magnetic field, which expels a force on moving electric particles.

Magnetic signature visible here is at a large length scales.

Large spatial and time scale: Solar dipole – visible during a solar eclipse, near the solar surface, it is more pronounced at solar minimum. The dipole 'flips' every 11 years.

SOLAR WIND

continuous radial outflow of plasma

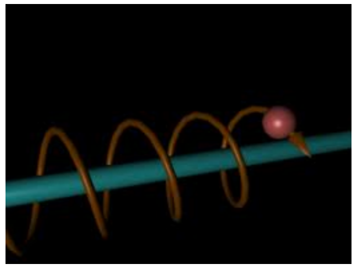
shapes the interplanetary magnetic field.

Can carry magnetic structures

Both constitute the solar wind – like a human: soul and body, like a horse and carrots.
You can’t think one without the other
The solar wind plasma is glued to the IMF – or the IMF is glued to the plasma.

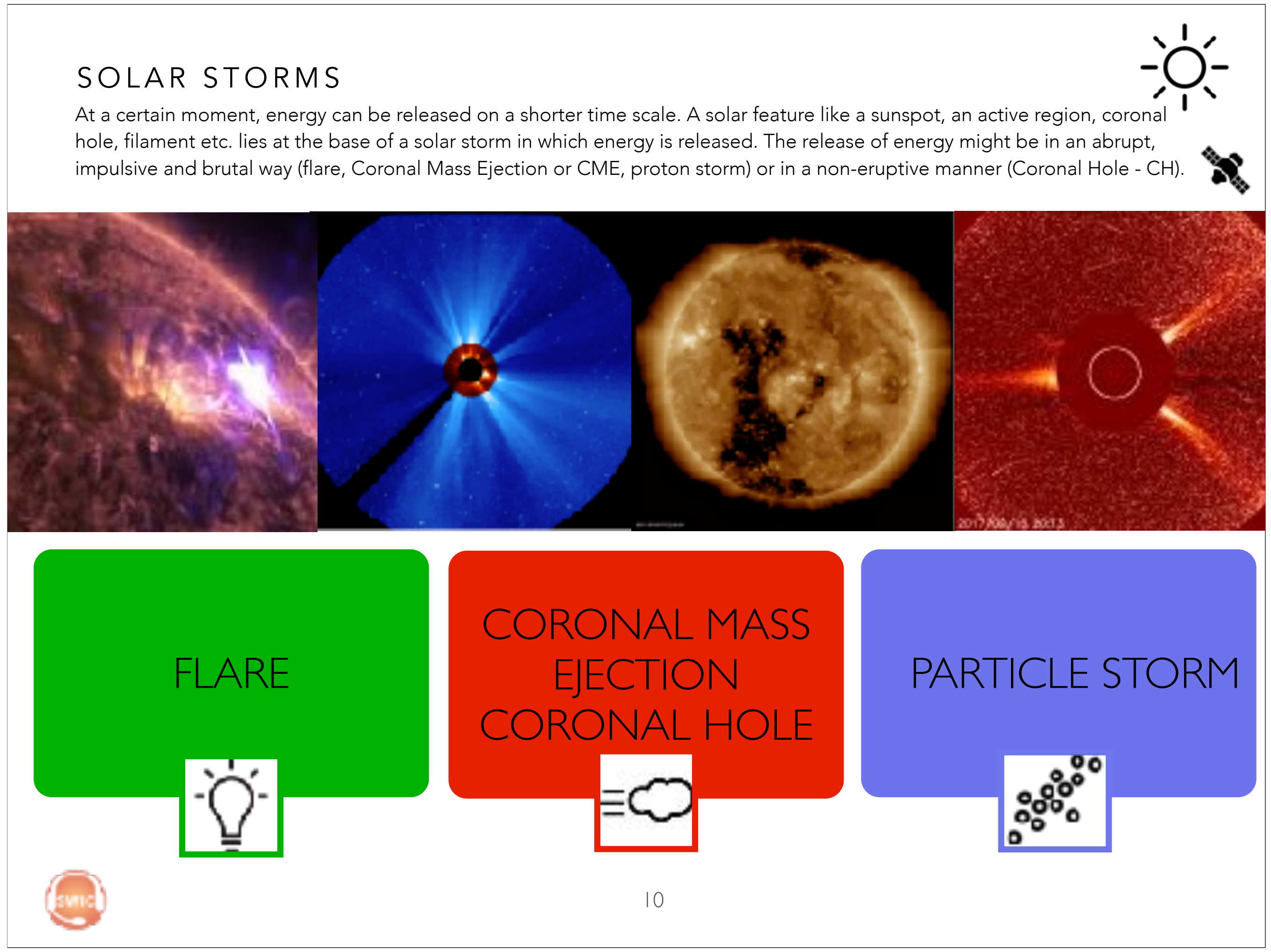
The solar wind is a continuous radial stream of solar plasma that leaves the sun and moves away from it. It fils the space between the planets with solar mass. The solar wind reaches the boundaries of the heliosphere, a magnetic shield around the Sun. In the heliosphere, the Sun sets the rules and you have solar weather. Outside the heliosphere, you have the rest of the galaxy. Earth is in the heliosphere.

SOLAR PARTICLES



Solar energetic particles are guided by the IMF.

They have to go where the magnetic field takes them.



Change in energy output on the scale of minutes, hours, days.

Remote sensing (seeing) – in situ (taste and touch the ambient space)

Space weather is the change of energy that occur in the space environment.

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

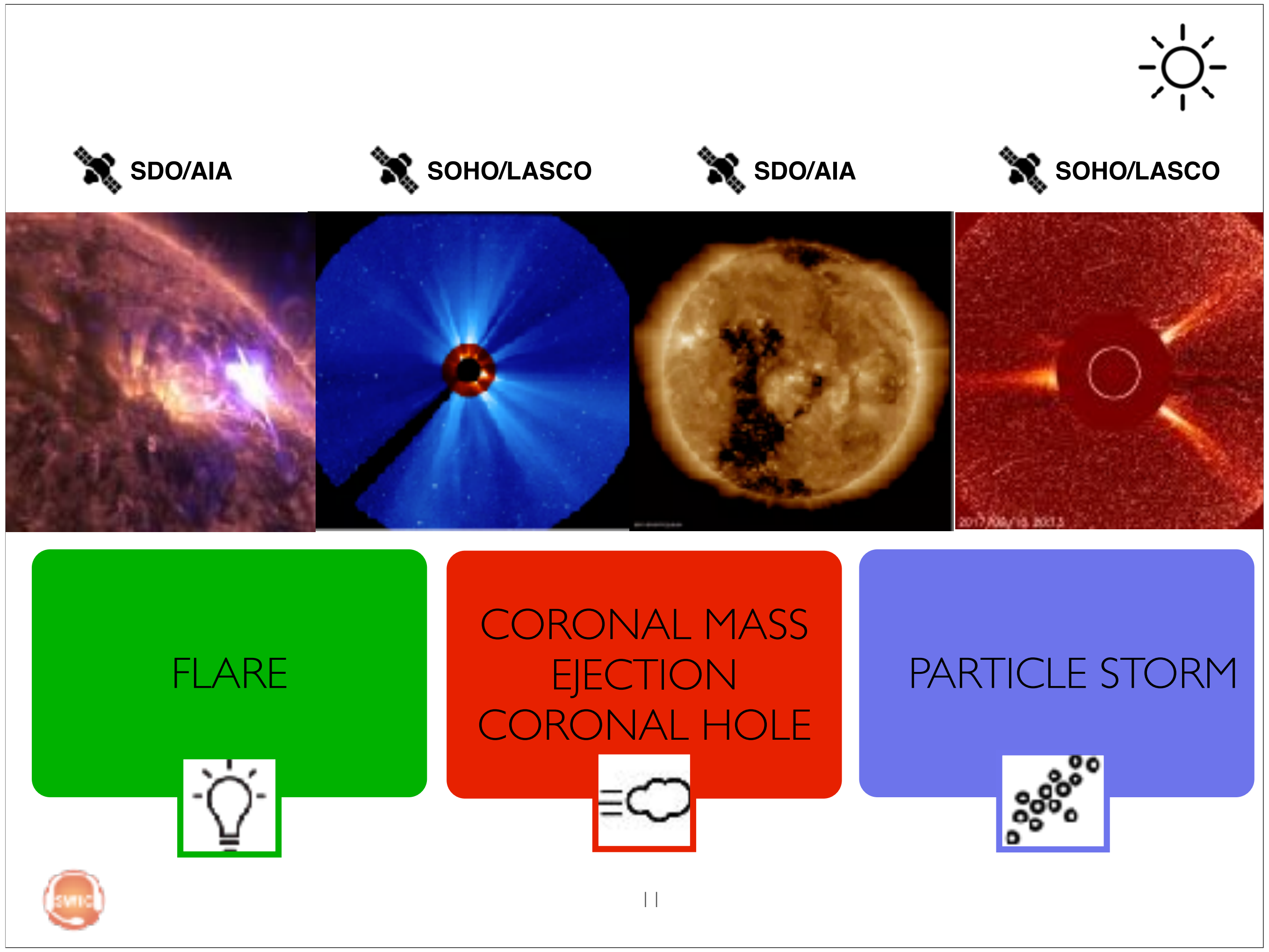
A Coronal Mass Ejection is a plasma cloud that is ejected into space. You consider it as a cloud and not as a bunch of individual particles. It is superimposed on the background solar wind. You can see a CME as a complex magnetic bag with different magnetic layers with plasma in it that travels as a tsunami through space. 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 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 (red) and LASCO C3 (blue)

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

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 follow the IMF
They may impact telescopes. They are seen as white stripes and dots: this are particles that fall into the lens and blind the pixel(s). During that particular moment, the telescope can't see anymore through the impacted pixels. You can say that the dots and stripes represent a sort of in situ measurement.

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.



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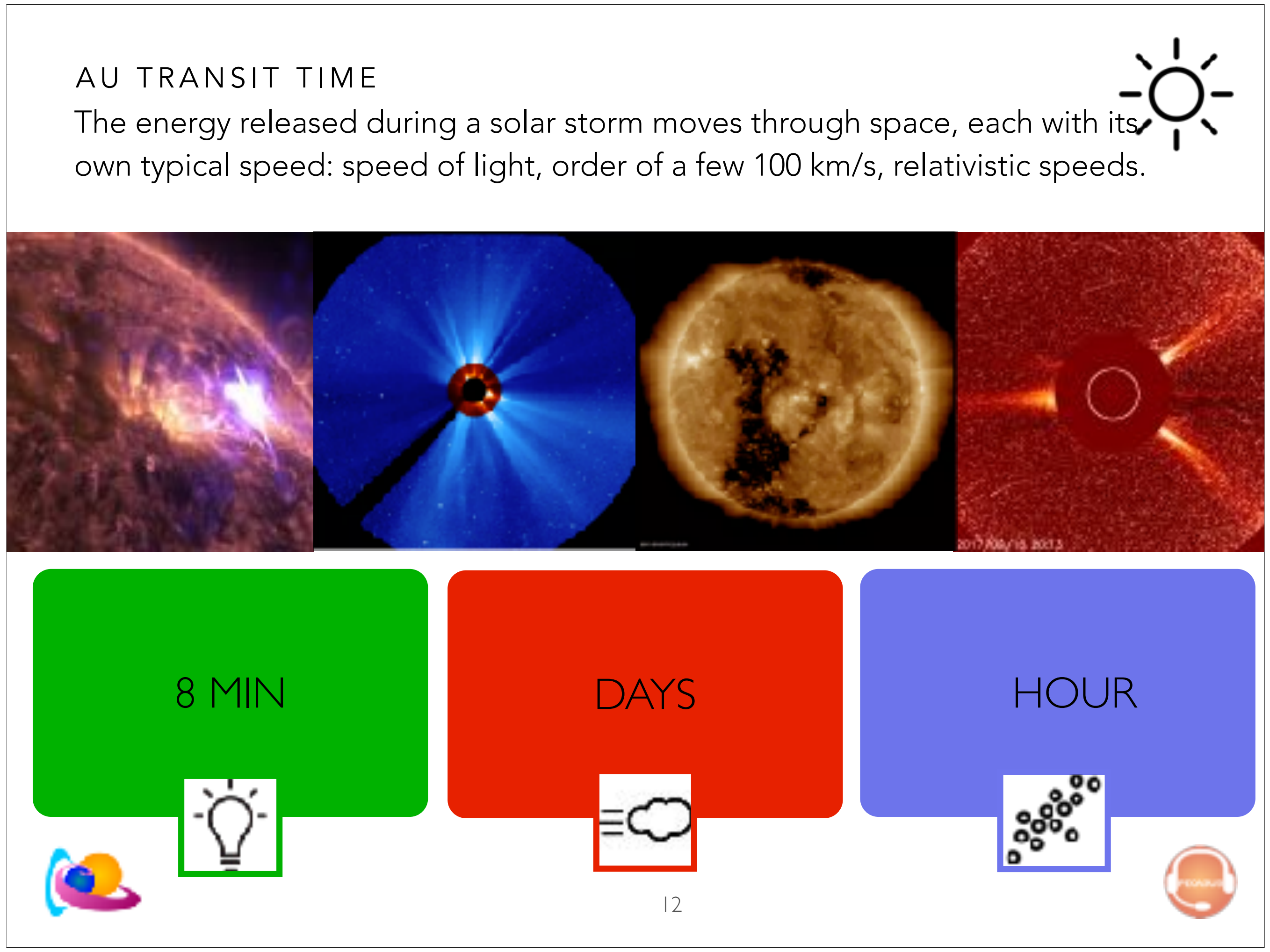

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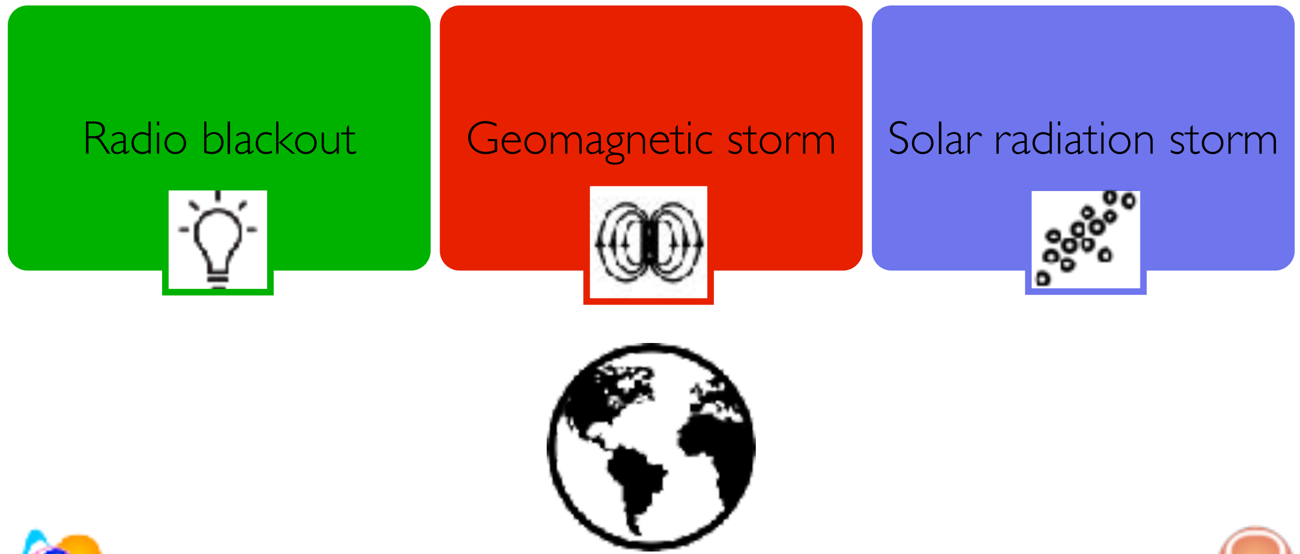
SPACE WEATHER

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.



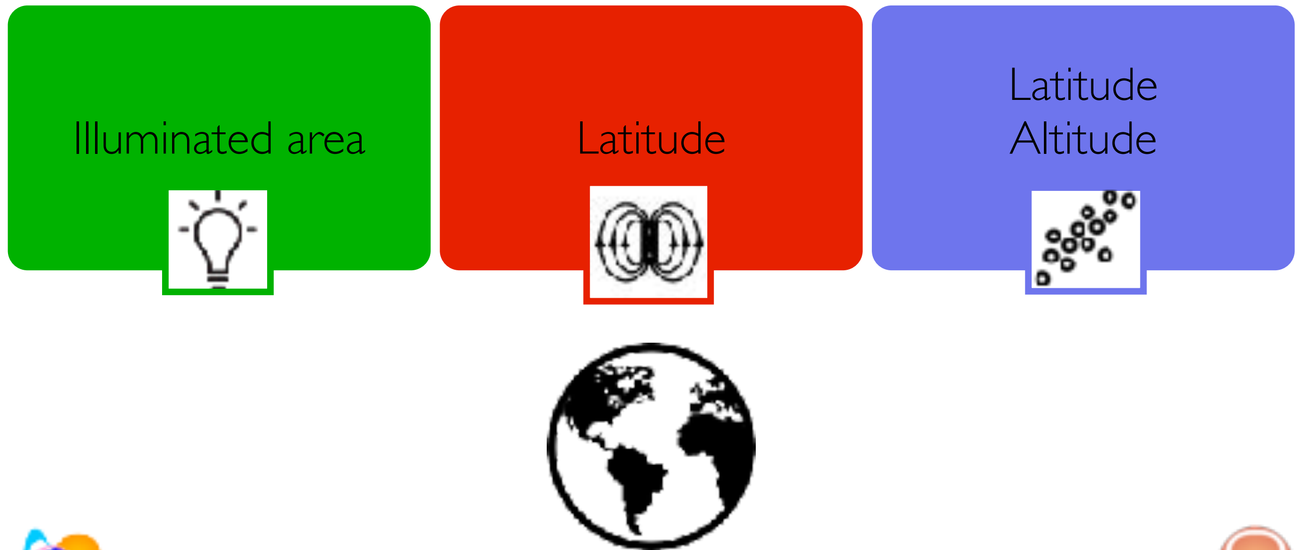
The consequence of a solar flare is a radio black out

The consequence of a troubled solar wind, is a geomagnetic storm.

The consequence of a particle storm, is a solar radiation storm.
Not a geomagnetic storm. An individual particle doesn’t carry a magnetic field that can couple or disturb the magnetic field of Earth.

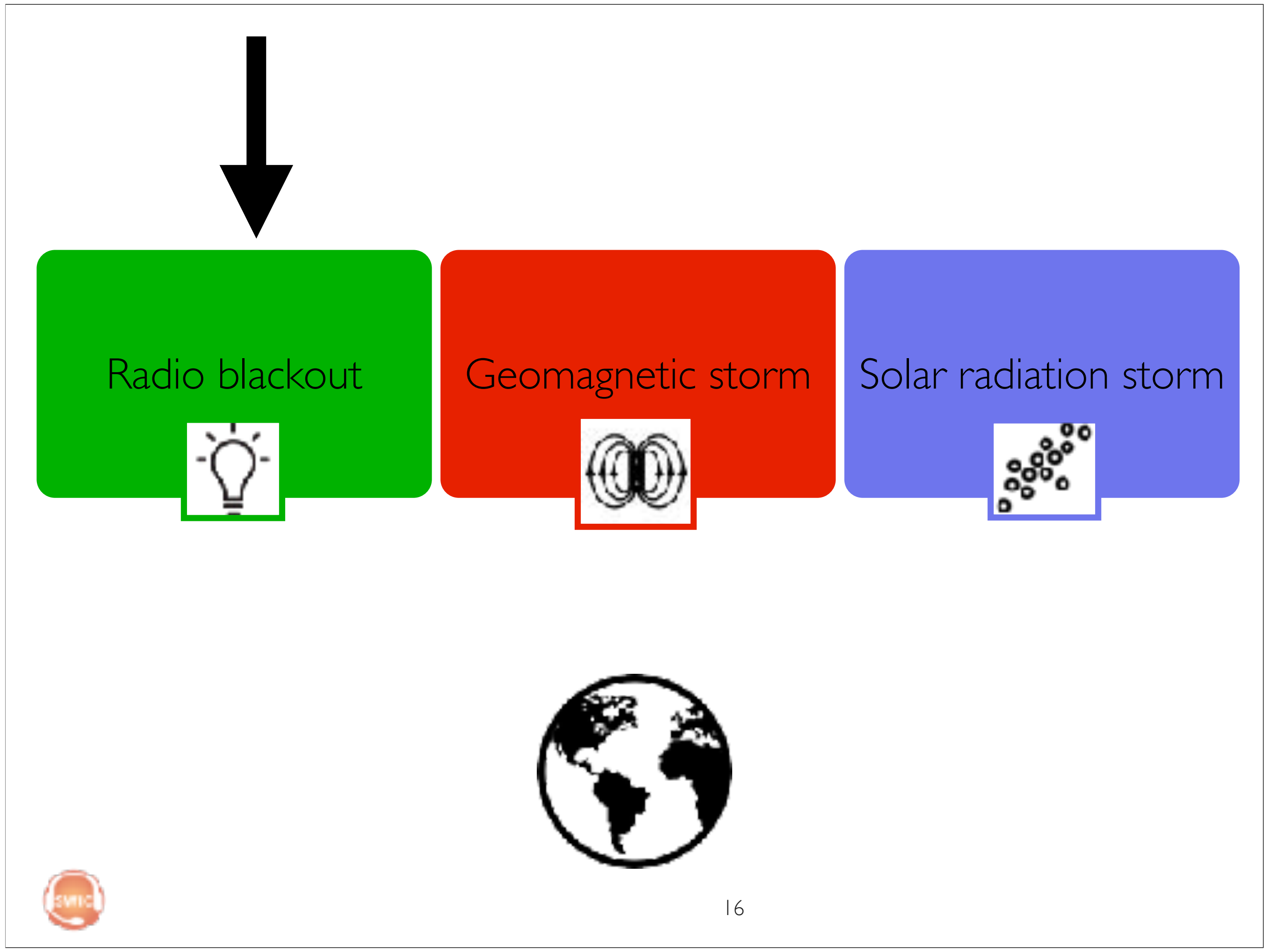
AREA OF IMPACT

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.



Solar wind - day and night side because of reconnection processes.
Particles - mainly on the day side.

BREAK



The impact of a solar flare is a radio black out

The impact of a solar wind disturbance, is a geomagnetic storm.

The solar wind disturbs the earth magnetic field

The impact of a particle storm, is a solar radiation storm.

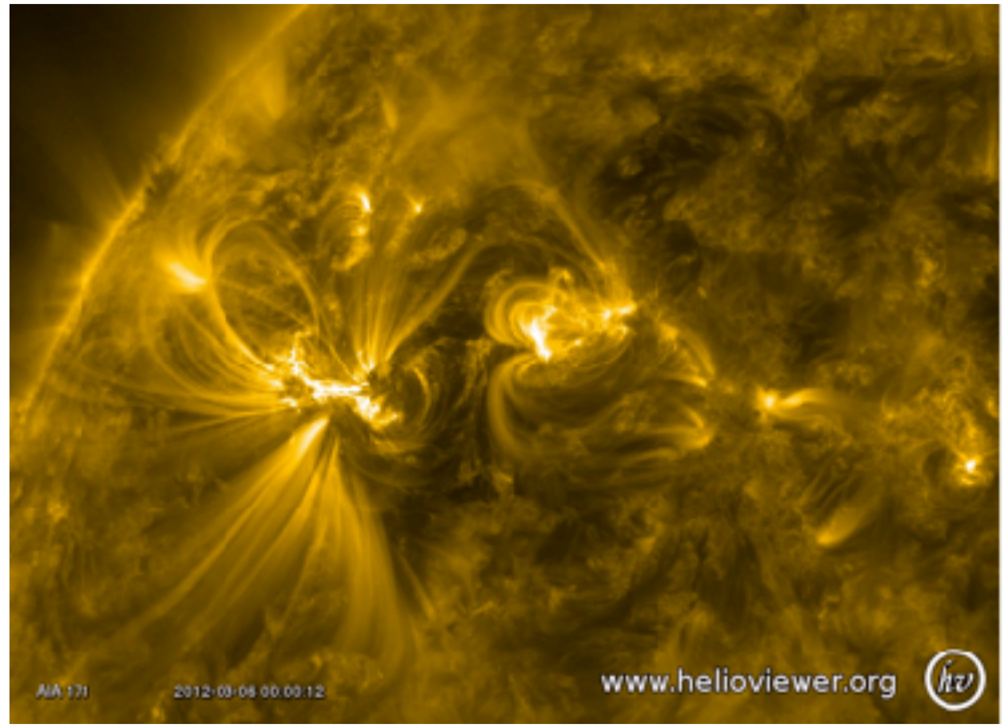
Not a geomagnetic storm. An individual particle doesn’t carry a magnetic field that can couple or disturb the magnetic field of Earth.

Em waves
Flow of gas
Moving particles

SOLAR FLARES

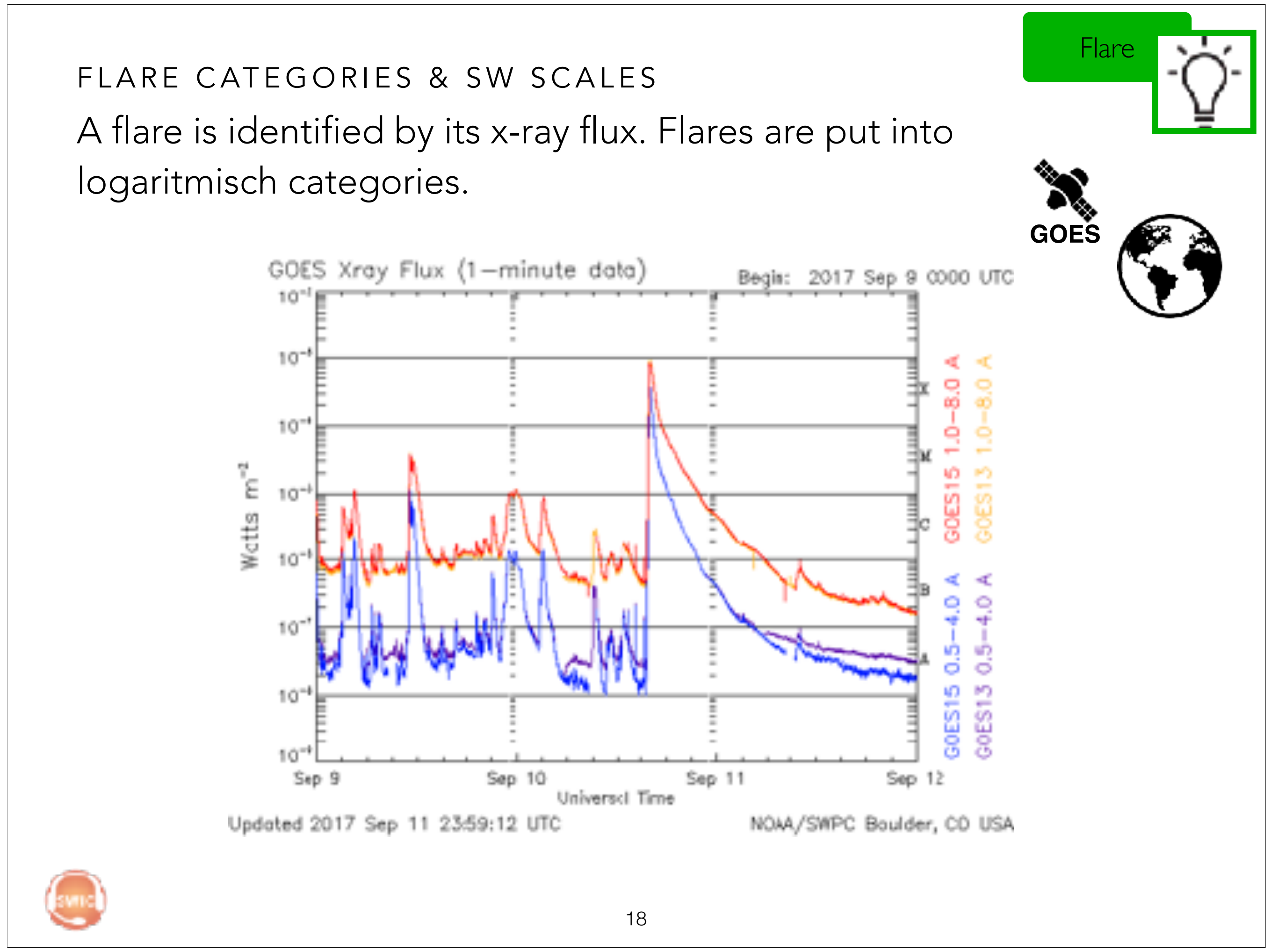
Flare

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



SDO/AIA

During a solar flare a particular plasma volume is heated. This happens in a brutal way and during a limited time. The volume is heated up to 107 K. The heating is a consequence of a fast reconnection and reorganisation of the local magnetic field.



In situ (taste and touch)

C1=1*10-6
C2=2*10-6
C3=3*10-6

M1=10-5=1*10*10-6=10*C1=C10
M2=2*10-5= 2*10*10-6=10*C2=C20
M3=3*10-5 = 3*10*10-6=10*C3=C30
...

X1=10-4=1*10*10-5=10*M1=M10 = 1*10*10*10-6=100*10-6=100*C1=C100
X2=2*10-4=2*10*10-5=10*M2=M20
...
Y1=X10
Y2=X20
Y8=X80
Y9=X90

GOES satellite, geostationary
http://www.swpc.noaa.gov/products/goes-x-ray-flux

During a flare, magnetic energy is transformed into e.m. waves.

GOES measures the full disk e.m. radiation (Energy per second per square meter) in a particular X-ray wavelength every minute. The more intense, the higher the curve.

Flares are put into X-ray flux categories. The X-ray flux is measured by GOES (meteo-satellites of NOAA). The classes are based on the enlargement factor of the X-flux in the spectral range 1 to 8 Å – logarithmic. This enlargement factor can go up to 10 000, typically between 10 and 100.

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 (2×10^{-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 (5×10^{-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)

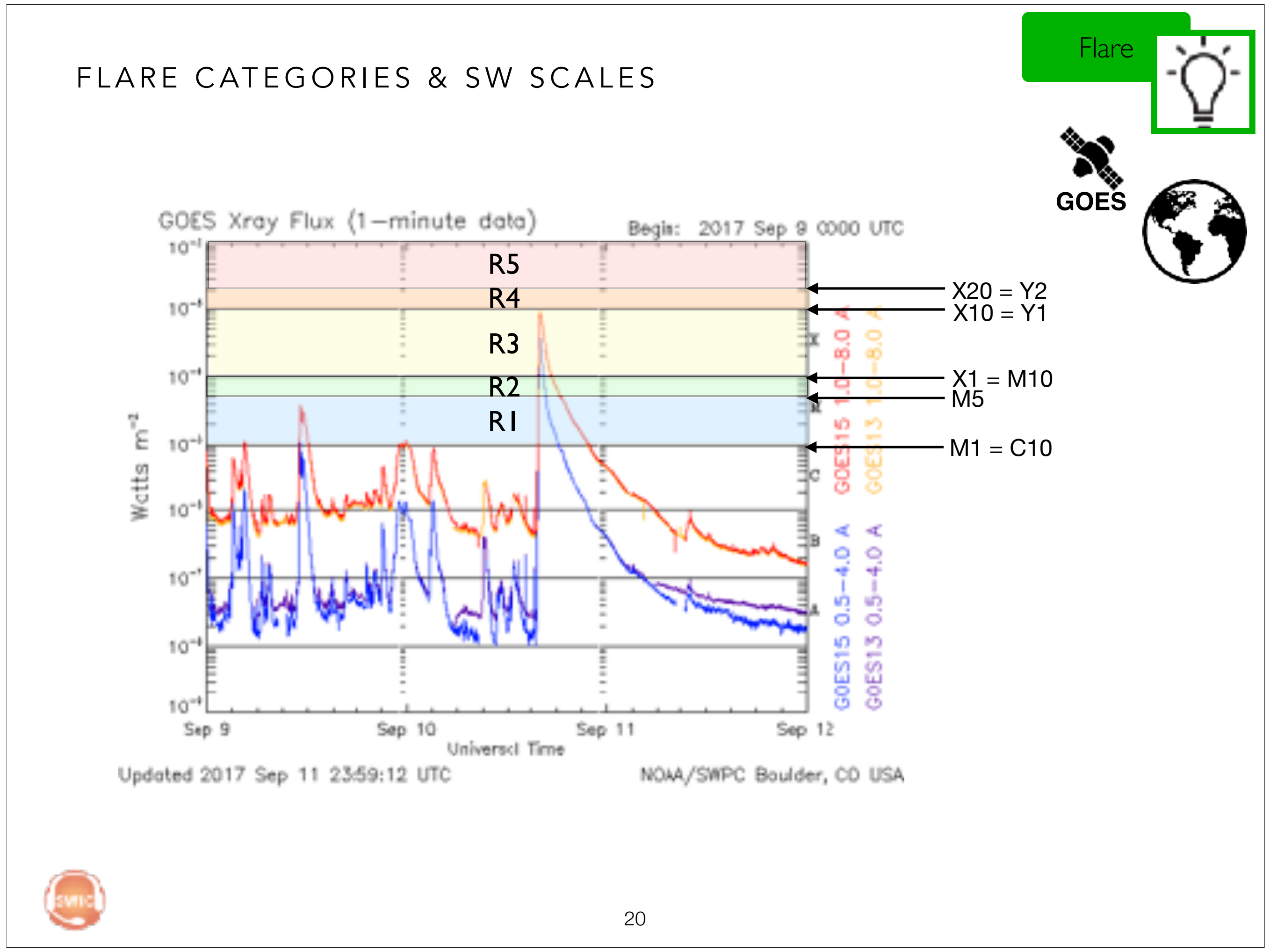
* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

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

URL: www.swpc.noaa.gov/NOAAscales April 7, 2011

There are several types of space weather that can impact HF radio communication. In a typical sequence of space weather storms, the first impacts are felt during the solar flare itself. The solar x-rays from the sun penetrate to the bottom of the ionosphere (to around 80 km). There the x-ray photons ionize the atmosphere and create an enhancement of the D layer of the ionosphere. This enhanced D-layer acts both as a reflector of radio waves at some frequencies and an absorber of waves at other frequencies. The Radio Blackout associated with solar flares occurs on the dayside region of Earth and is most intense when the sun is directly overhead.

A flare can also impact GNSS.



Y1=X10
Y2=X20
Y8=X80
Y9=X90

GOES satellite, geostationary
http://www.swpc.noaa.gov/products/goes-x-ray-flux

This graph was made on the fly with staff, a solar time lines viewer: http://staff.oma.be

During a flare, magnetic energy is transformed into e.m. waves.

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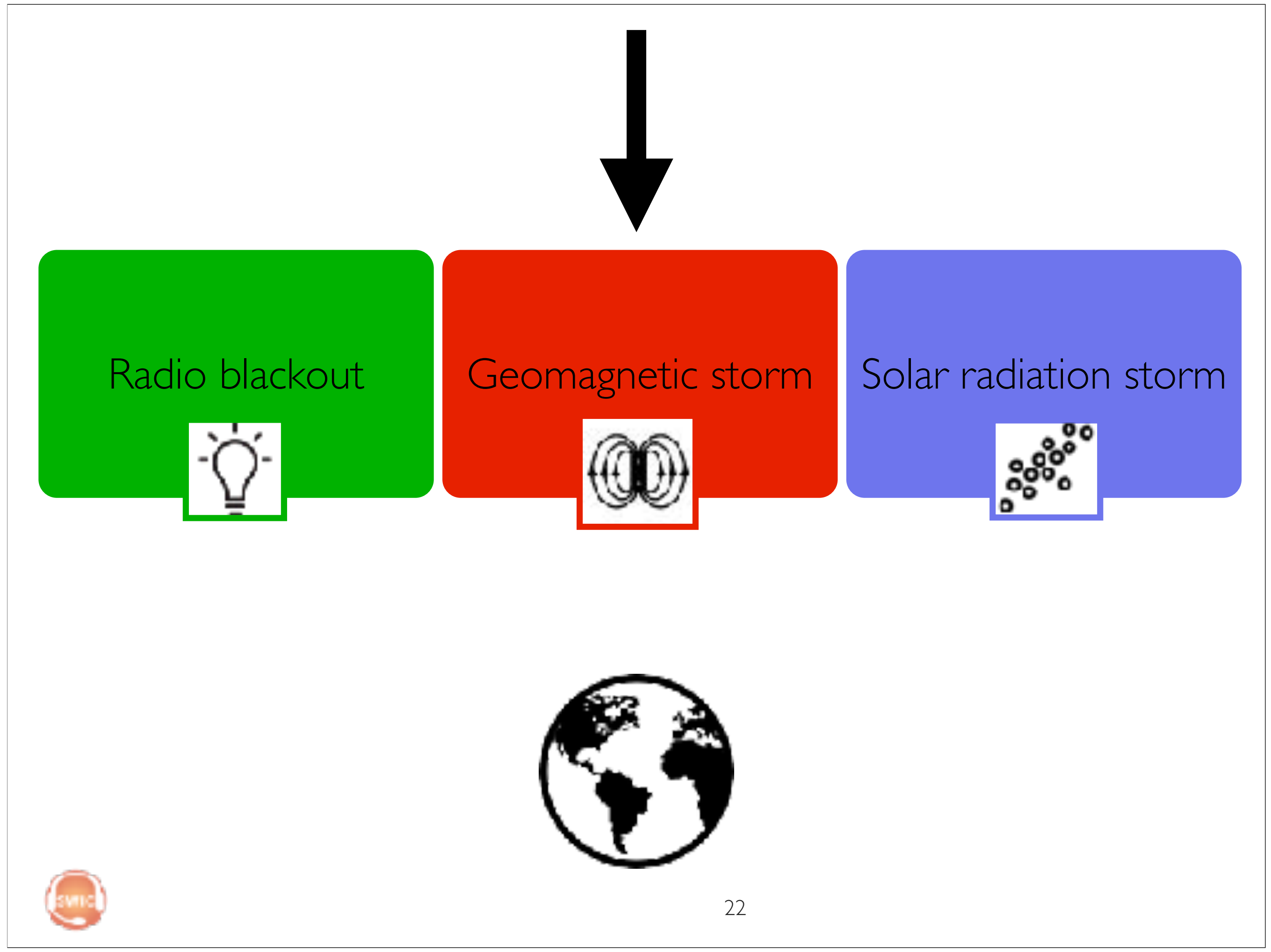
X-RAY FLUX NOW

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



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.

https://www.swpc.noaa.gov/phenomena/geomagnetic-storms
A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is a very efficient exchange of energy from the solar wind into the space environment surrounding Earth. These storms result from variations in the solar wind that produces major changes in the currents, plasmas, and fields in Earth's magnetosphere. The solar wind conditions that are effective for creating geomagnetic storms are sustained (for several to many hours) periods of high-speed solar wind, and most importantly, a southward directed solar wind magnetic field (opposite the direction of Earth's field) at the dayside of the magnetosphere. This condition is effective for transferring energy from the solar wind into Earth's magnetosphere.

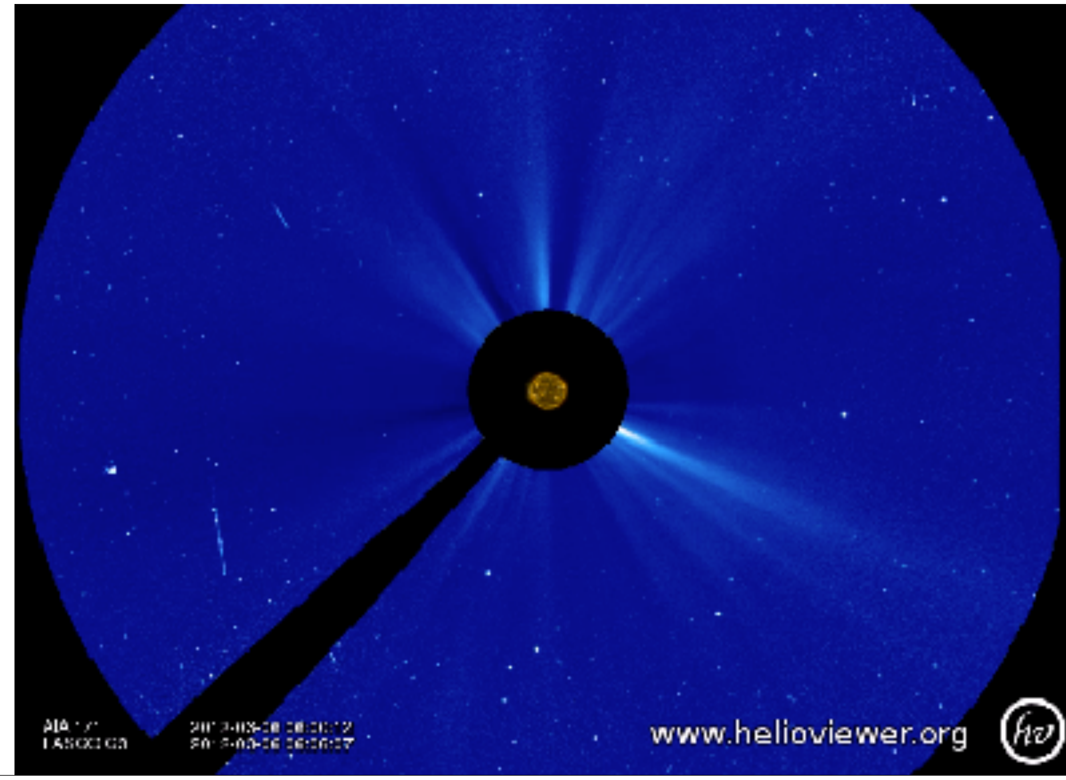
Storms also result in intense currents in the magnetosphere, changes in the radiation belts, and changes in the ionosphere, including heating the ionosphere and upper atmosphere region called the thermosphere. In space, a ring of westward current around Earth produces magnetic disturbances on the ground. A measure of this current, the disturbance storm time (Dst) index, has been used historically to characterize the size of a geomagnetic storm. In addition, there are currents produced in the magnetosphere that follow the magnetic field, called field-aligned currents, and these connect to intense currents in the auroral ionosphere. These auroral currents, called the auroral electrojets, also produce large magnetic disturbances. Together, all of these currents, and the magnetic deviations they produce on the ground, are used to generate a planetary geomagnetic disturbance index called Kp. This index is the basis for one of the three NOAA Space Weather Scales, the Geomagnetic Storm, or G-Scale, that is used to describe space weather that can disrupt systems on Earth.

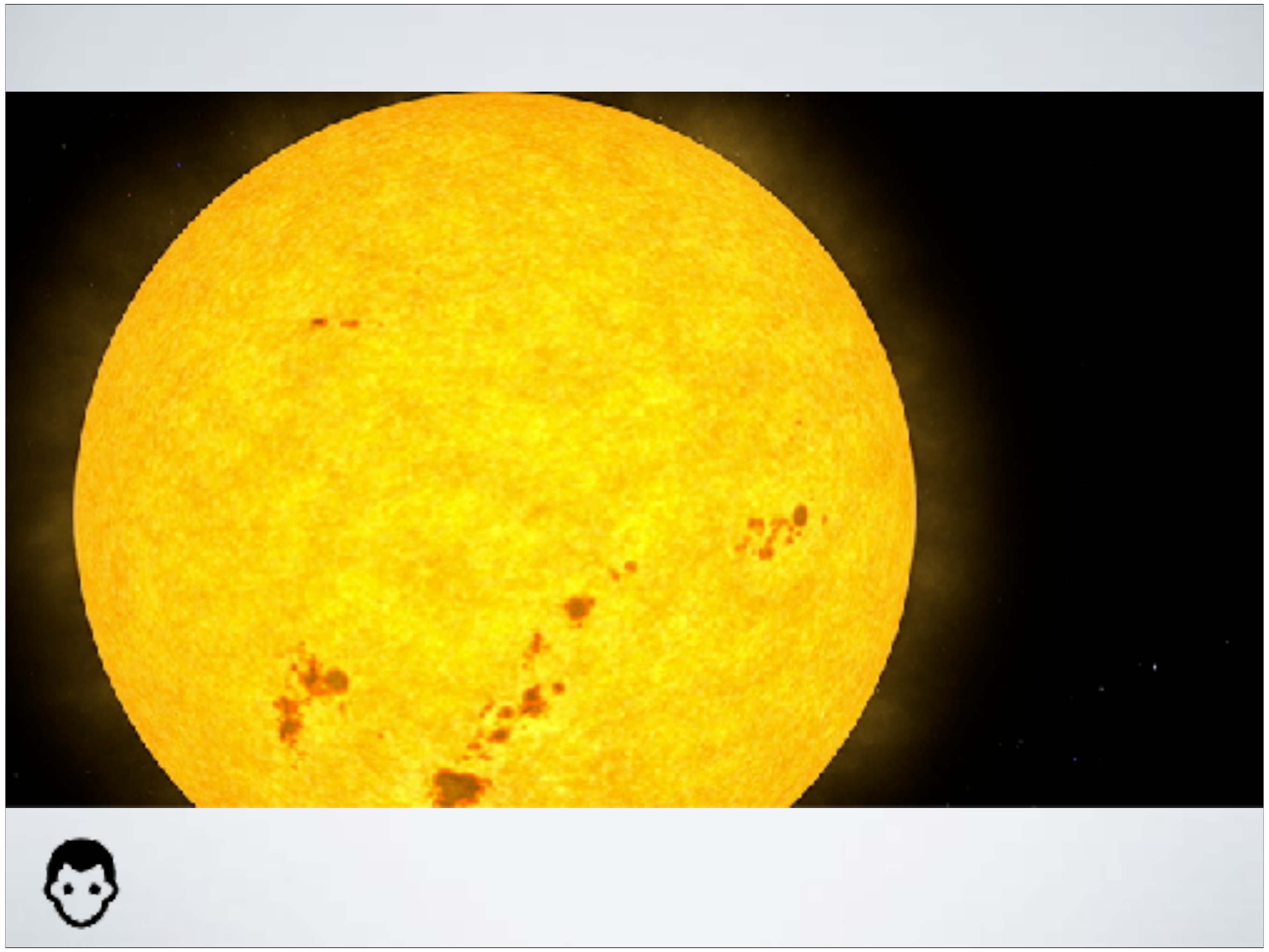
During storms, the currents in the ionosphere, as well as the energetic particles that precipitate into the ionosphere add energy in the form of heat that can increase the density and distribution of density in the upper atmosphere, causing extra drag on satellites in low-earth orbit. The local heating also creates strong horizontal variations in the ionospheric density that can modify the path of radio signals and create errors in the positioning information provided by GPS. While the storms create beautiful aurora, they also can disrupt navigation systems such as the Global Navigation Satellite System (GNSS) and create harmful geomagnetic induced currents (GICs) in the power grid and pipelines.

SOLAR STORMS

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

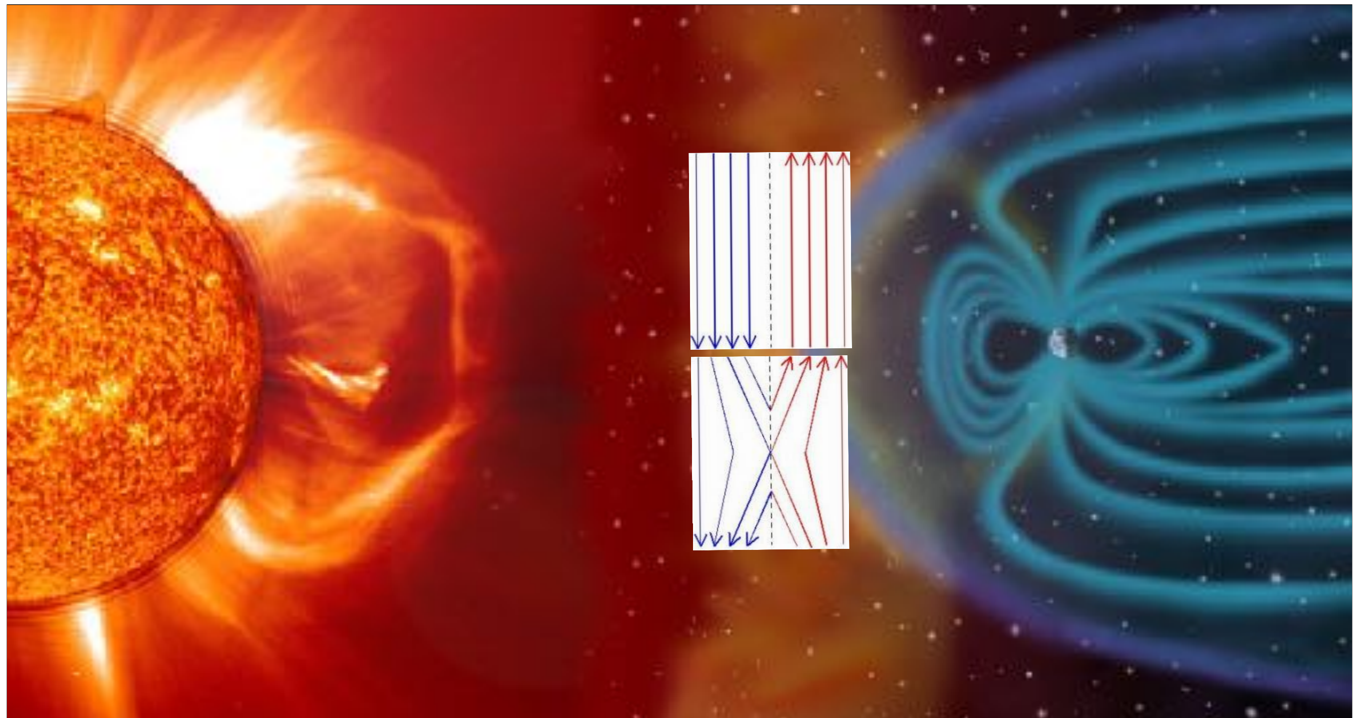
SOHO/LASCO
SDO/AIA





Precipitating electrons coming from the tail

Magnetopause: energy intake —> magnetotail: energy accumulation —> energy consumption (radiation belt & aurora) + energy discharge (to interplanetary space)



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.

This is the earths magnetosphere. The sun is somewhere far away in the right top corner.
The earth is a giant dipole – similar as the sun. Except, the solar magnetic dipole field reverses every 11 year. The Earths magnetic poles don't. They are already for ages like this.
The part of the earths dipole facing the sun/solar wind is pushed more together, while the part behind the earth is stretched and forms a tail. In front of the magnetic structure, you have a shock.

This is a structure similar like a shock in front of a speed boat that moves very fast over water: the water waves that the moving boat initiate are slower compared to the speed of the boat. The boat is super-water wave.
When a plane is super-sonic, there is also a shock in front of it. The pressure waves that the moving plane creates move much slower than the plane.

In the case of a speed boat, the boat moves through the water.
In our case, it is the solar wind that blows over the earth. It is just a matter of reference, but the result is the same: a shock.

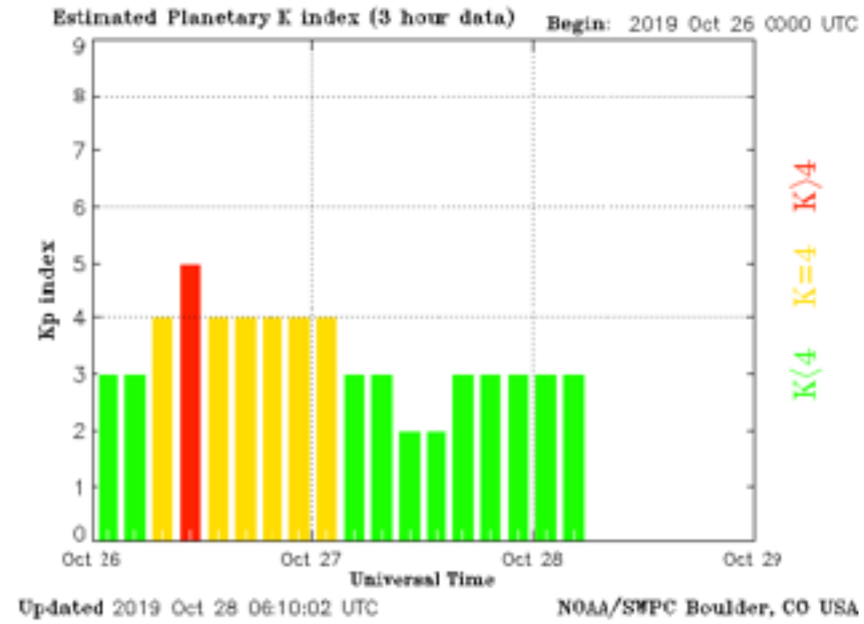
A magnetic field is imbedded in the solar wind. This magnetic field can interact with the magnetic field of the earth at the boundaries of the earth magnetosphere. This interaction is called reconnection. It happens when 2 magnetic regions are confronted with each other.

The blue magnetic field lines are imbedded in the solar wind.
The red magnetic field lines represent the earth magnetosphere.
The blue and the red magnetic region have to face each other. Opposite magnetic field lines can reconnect easily and 'open'. This causes geomagnetic storms. Magnetic field lines in the same direction interact less.
Therefore, it is very important to know how strong the

0.3 T – solar sunspot
5mT – strength of a typical refrigerator magnet
31.869 µT (3.1 × 10^{-5} T) – strength of Earth's magnetic field at 0° latitude (North/South), 0° longitude (west/east)
1 to 5 nT – IMF at L1

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.



Magnetometers

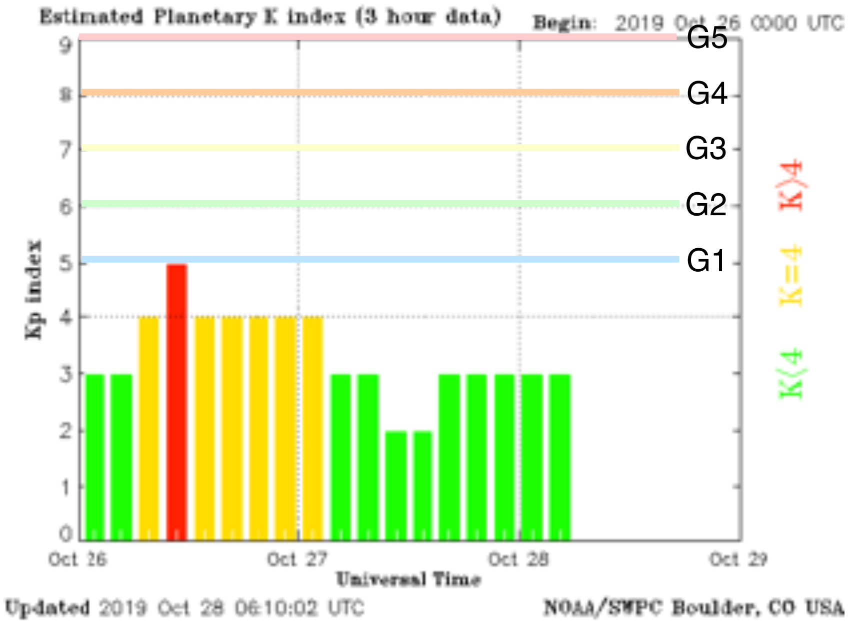
NOAA SPACE WEATHER SCALES

Category: Scale	Category: Descriptor	Effect (Duration of event will influence severity of effects)	Physical measure	Average Frequency (1 cycle = 11 years)
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.

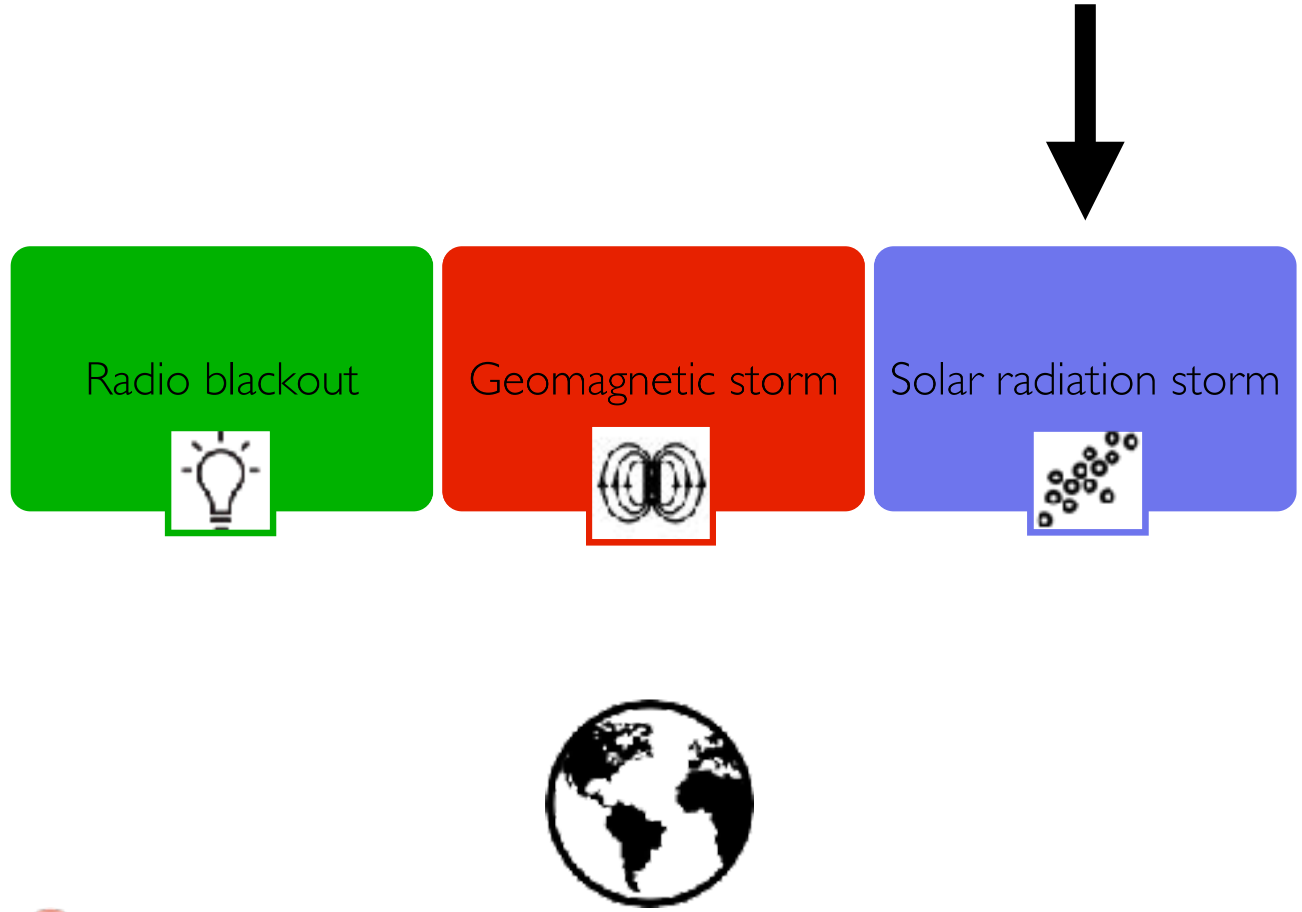
** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.sec.noaa.gov/Aurora)

GEOMAGNETIC STORM DESCRIBED BY KP

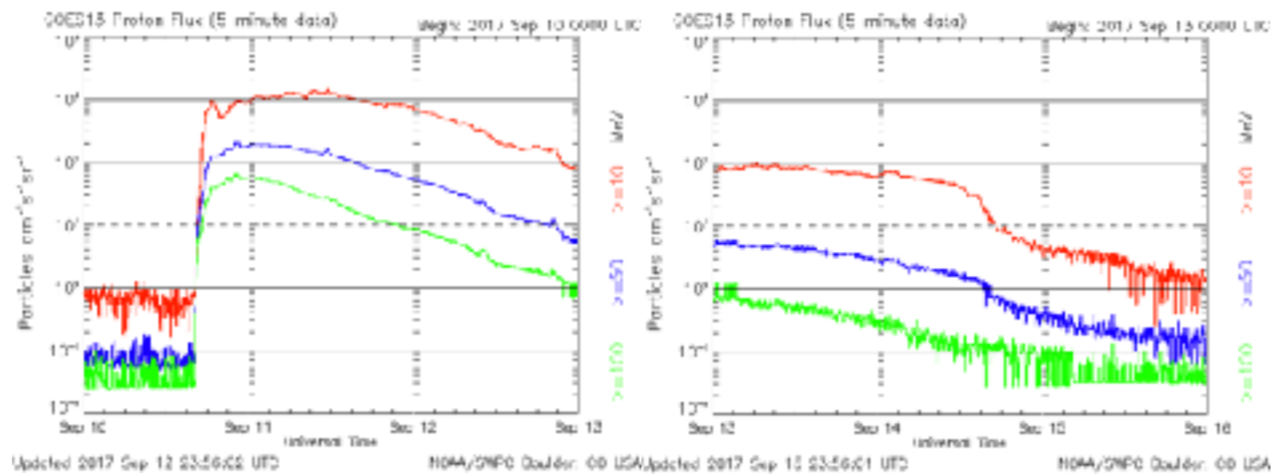


GEOMAGNETIC STORM - KP INDEX NOW

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


Radio blackout
Geomagnetic storm
Solar radiation storm

Proton flux by GOES



In situ (taste and touch)

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.

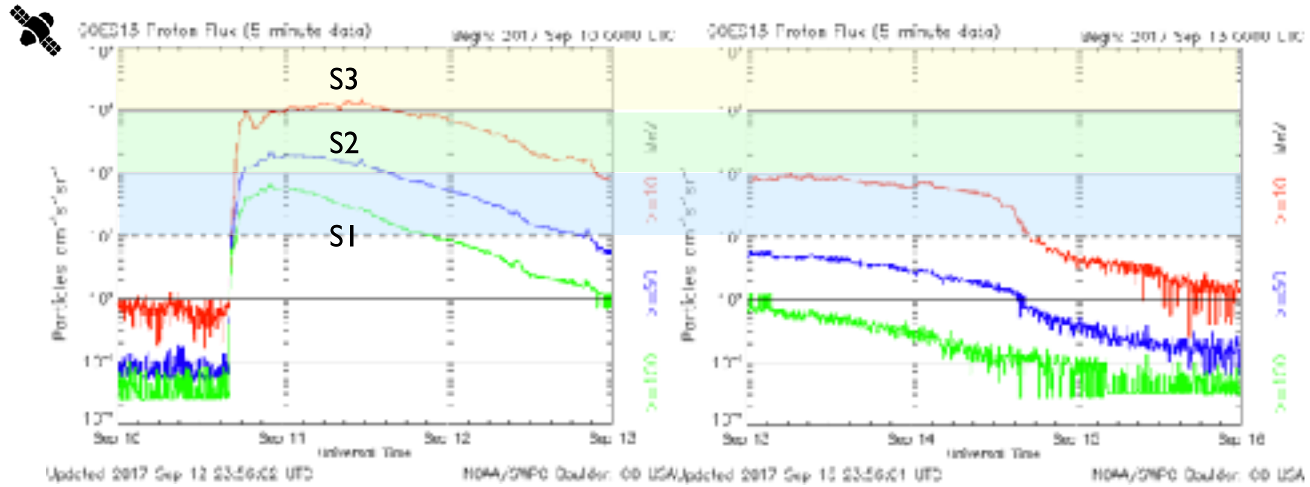
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

NOAA categorizes Solar Radiation Storms using the NOAA Space Weather Scale on a scale from S1 - S5. The scale is based on measurements of energetic protons taken by the GOES satellite in geosynchronous orbit. The start of a Solar Radiation Storm is defined as the time when the flux of protons at energies ≥ 10 MeV equals or exceeds 10 proton flux units (1 pfu = 1 particle*cm-2*s-1*ster-1). The end of a Solar Radiation Storm is defined as the last time when the flux of ≥ 10 MeV protons is measured at or above 10 pfu. This definition allows multiple injections from flares and interplanetary shocks to be encompassed by a single Solar Radiation Storm. A Solar Radiation Storm can persist for time periods ranging from hours to days.

HF radio communication

Another type of space weather, the Radiation Storm caused by energetic solar protons, can also disrupt HF radio communication. The protons are guided by Earth's magnetic field such that they collide with the upper atmosphere near the north and south poles. The fast-moving protons have an affect similar to the x-ray photons and create an enhanced D-Layer thus blocking HF radio communication at high latitudes. During auroral displays, the precipitating electrons can enhance other layers of the ionosphere and have similar disrupting and blocking effects on radio communication. This occurs mostly on the night side of the polar regions of Earth where the aurora is most intense and most frequent.

PROTON FLUX BY GOES



PROTON FLUX NOW

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

https://en.wikipedia.org/wiki/Steradian

Steradian is a dimensionless unit, the 3D version of the 2D radian.
Radian is the unit for a solid angle and links the angle to a length on a circumference.

For a circle
Circumference length = angle * radius
SI unit of length is m.
With angle in radian, dimensionless
The angle of a complete circle is 2*pi, the circumference of a circle with radius R is 2*pi*r

For a sphere
Sphere surface = area subtended * radius^2
SI unit of a surface is m^2
With area subtended in steradian, dimensionless
Area subtended of a complete sphere is 4*pi, the surface of a sphere with radius r is 4*pi*r^2

Flux is 'something' through a surface - everything in SI units.
E.g. magnetic flux: the number of magnetic field lines through a surface.
When 'something' moves, you speak about that something per second through a surface, a flow rate.
E.g. flow rate of a river: the volume water that flows per second through a m^2-surface.

Proton-flux has a direction. This is expressed by using the word steradian. You count all the protons that are present in the cone defined by the area subtended. The apex of the cone is the Sun.

You take only the perpendicular flow through the surface: so only the protons from the cone.

For a flux, you need a vector-field: magnetic flux, flow (velocity field)
It is the component perpendicular to the surface that contributes to the flux. The component parallel to the surface doesn't contribute to the flux.
In our case, it is the cone with apex located at the Sun (which is a simple point at such a distance).

OVERVIEW