PECASUS

For civil aviation

SPACE WEATHER INTRODUCTORY COURSE

For space weather operators

ICAO

Aviation decision makers must know if a space weather event will pose a hazard to the safety and efficiency of a flight operation.

Space weather events can result in a number of distinct phenomena that can adversely affect the **communications, navigation, and surveillance systems** used for international aviation operations. In addition, under certain circumstances, space weather events may lead aircrew members and passengers to be **exposed to elevated levels of ionizing radiation**.

Drivers of space weather - overview

PECASUS consortium

Task of PECASUS = advisories

It all started with

SPACE WEATHER

The source of weather

We are all familiar with terrestrial tropospheric weather. It is what we experience all around us; our atmospheric environment. It may be fine, cloudy, stormy or sunny. It may rain or hail. We know about temperature and pressure and humidity. This is all about weather in the lowest 10 km of our atmosphere.

Wikipedia
Weather is the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy.
Most weather phenomena occur in the lowest level of the atmosphere, the troposphere, just below the stratosphere. **Weather refers to day-to-day** temperature and precipitation **activity**, whereas climate is the term for the averaging of atmospheric conditions over longer periods of time.

The main source of space weather

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.**

SPACE WEATHER

Space weather describes the conditions in space that affect Earth and its technological systems. Space weather storms originate from the Sun and occur in space near Earth or in the Earth's atmosphere. These storms generally occur due to eruptions on the Sun known as solar flares, proton storms and the solar wind.

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Including magnetosphere, ionosphere, thermosphere and exosphere.

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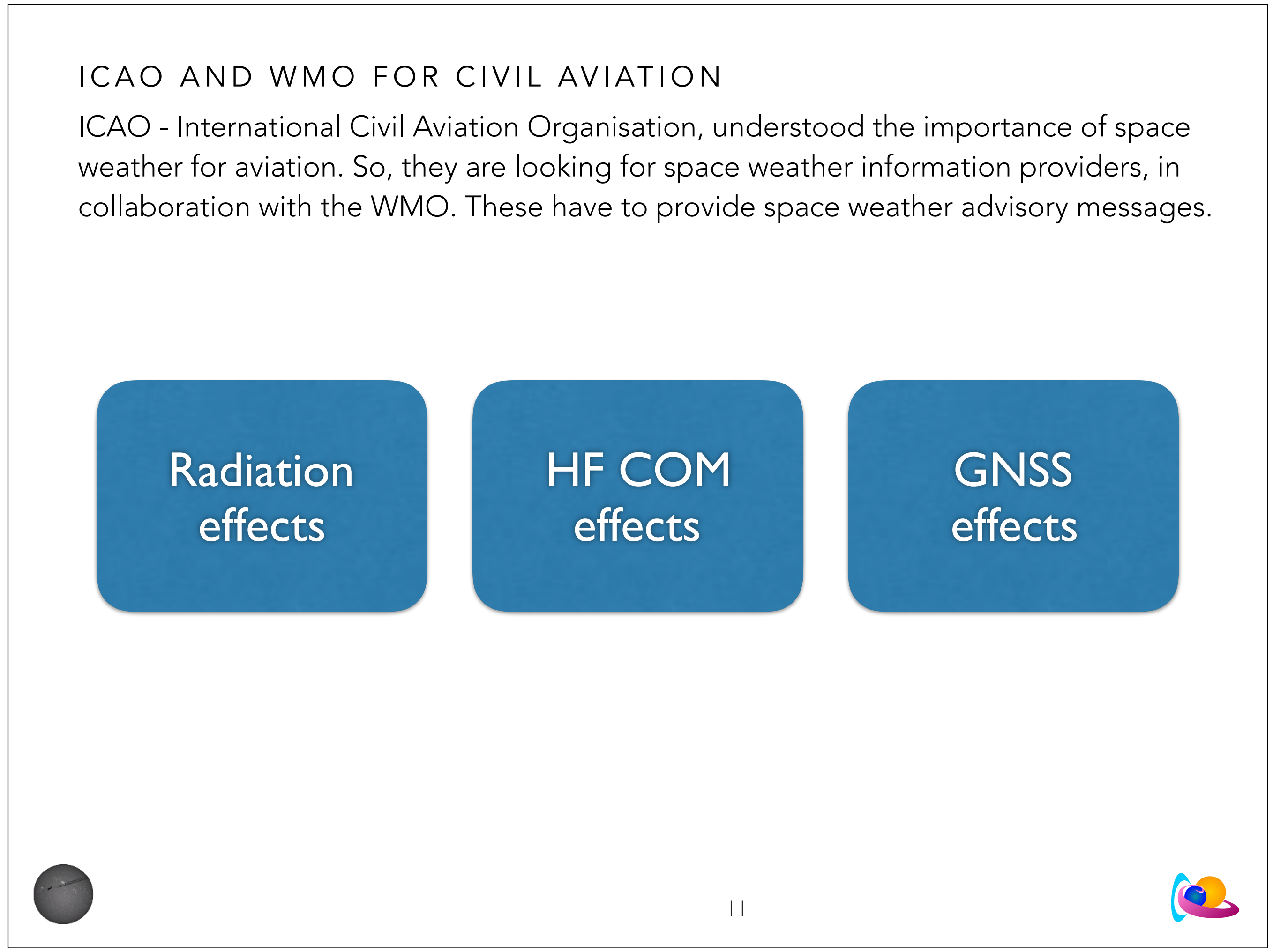
SPACE WEATHER BY WMO

The physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments.

This includes eruptive and non-eruptive events, e.g. Galactic Cosmic Rays, high-speed solar wind streams.



General capabilities

PECASUS SWxC will provide information on prevailing and forthcoming SWx in advisories compatible with the standardized ICAO formats. The advisories will be given by a 24/7 service and in the areas of (c.f. [RD03])

1. High Frequency (HF) communications
2. Navigation and surveillance based on Global Navigation Satellite Systems (GNSS), and
3. Radiation exposure at flight altitudes

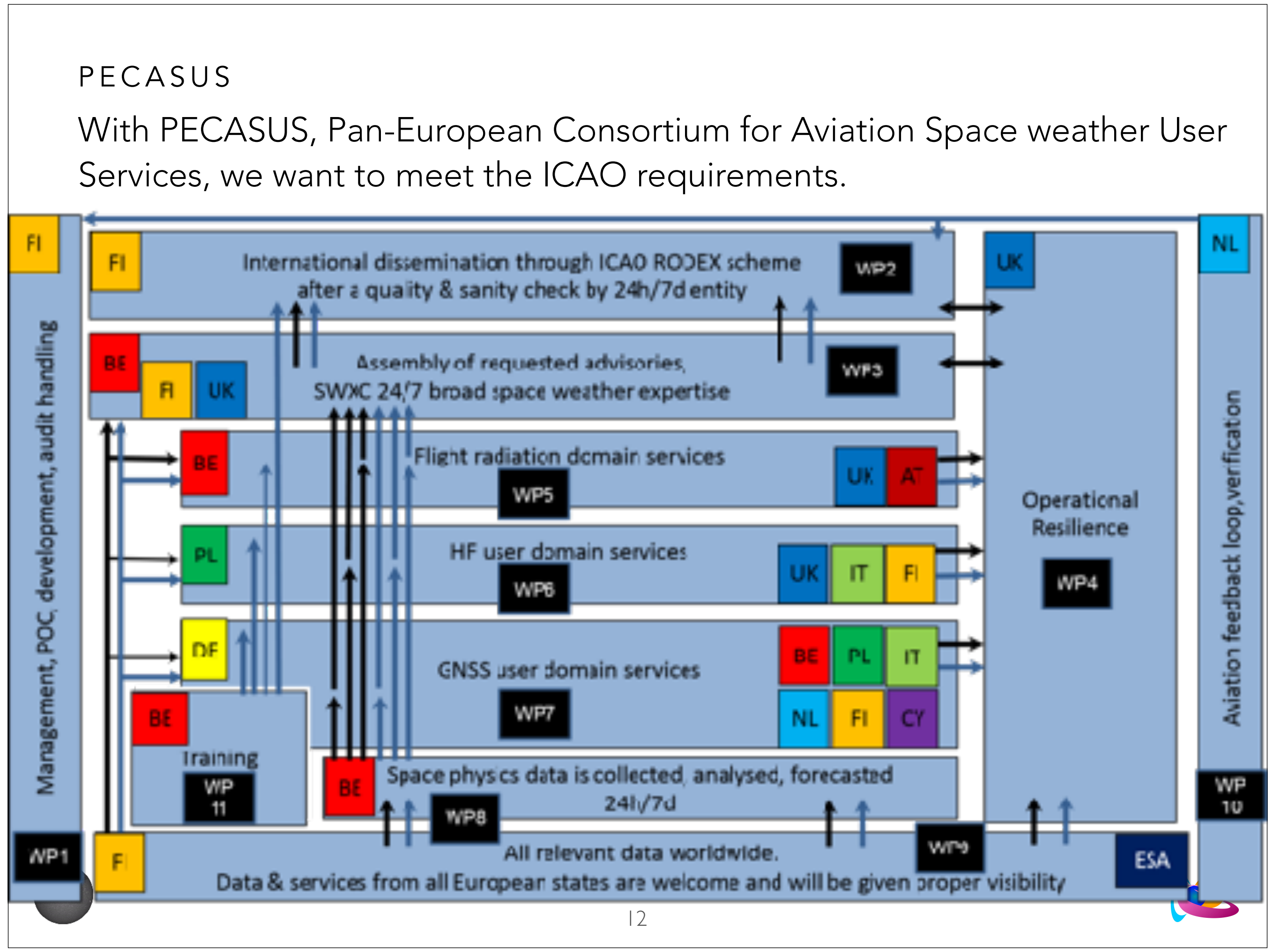
Advisories will be based on Near-Real-Time (NRT) observations of (c.f. [RD01])

- Solar wind=Coronal mass ejections (CMEs) and high-speed streams
- Geomagnetic storms
- Solar radiation storms
- Solar flares
- Solar radio bursts
- Ionospheric activity

End-users Characteristics

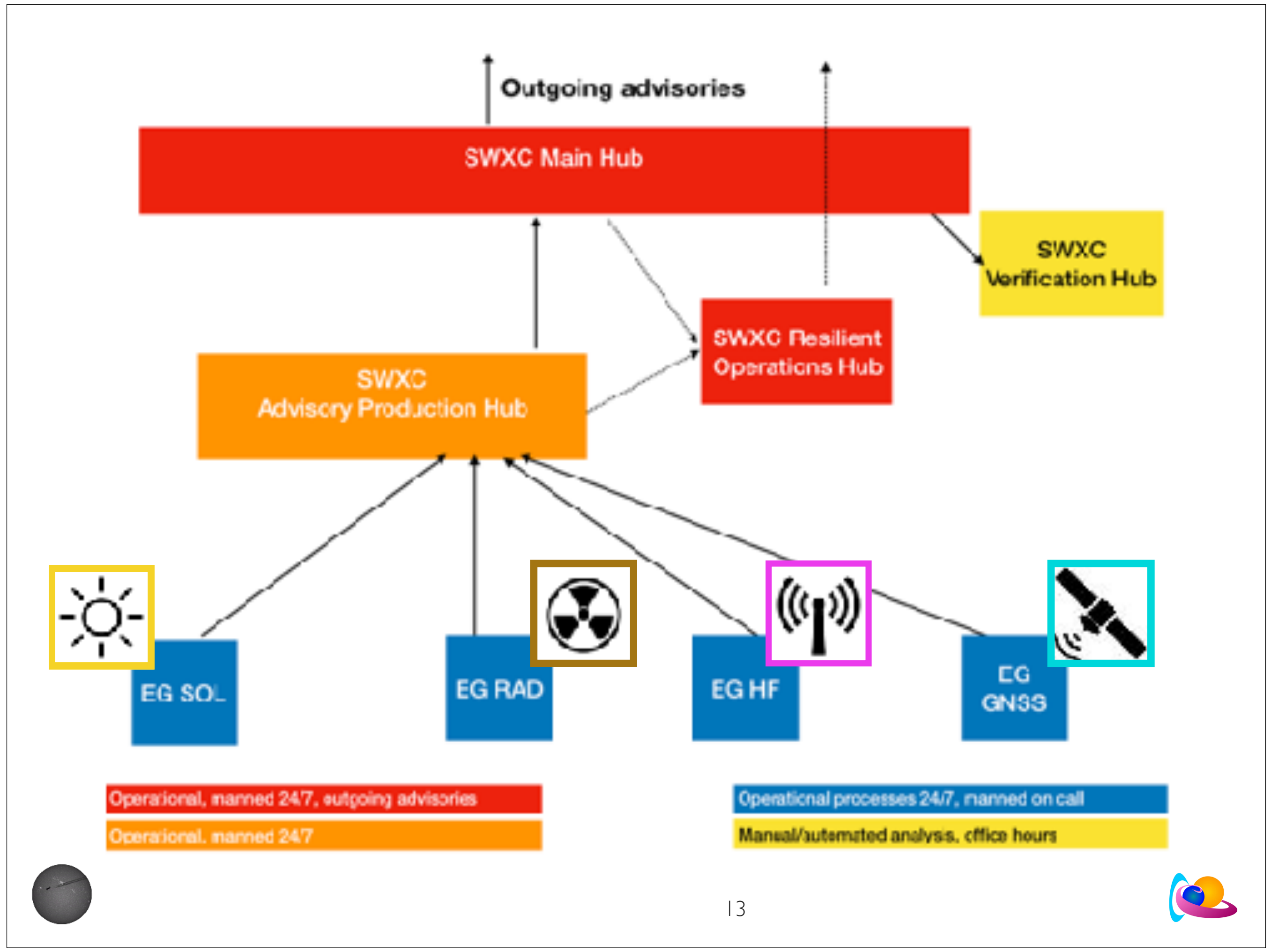
For <u>aviation decision-makers</u>
- Operators: flight planners, dispatchers
- Air Traffic Service
- Civil Aviation Authorities

For <u>Flight crew</u>



WP3 - set up of space weather center "SWXC" — ruimteweerbureau:

- Produces the advisories
- Maintains 24h/7d SWXC broad space weather awareness
- Brings together the input from the user domain (EG RAD, EG HF, EG GNSS) and from the physical space domain (EG SOL).
- Collects the status of the components in the network, identifies mal-functionings and contacts the responsibles
- Is manned and operational 24h/7
- Is hosted and operated by STCE



The operational components of PECASUS and their availability.
Gateway —> Management and Dissemination Group, MDG
SWxC: Space Weather Center —> Advisory Production Group, APG
SWxB —> BackuP Group, BPG

SLA - Service Level Agreement

SPACE WEATHER ADVISORY MESSAGES

- Radiation effects
- HF COM effects
- GNSS effects

Monitoring & forecasting space weather should result in 3 advisory messages.

HF COM effects

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	HF COM SEV
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z DAYLIGHT SIDE
FCST SWX +6 HR:	20121108/0700Z DAYLIGHT SIDE
FCST SWX +12 HR:	20161108/1300Z DAYLIGHT SIDE
FCST SWX +18 HR:	20161108/1900Z DAYLIGHT SIDE
FCST SWX +24 HR:	20161109/0100Z DAYLIGHT SIDE
RMK:	PERIODIC HF COM ABSORPTION HAS BEEN OBSERVED AND IS LIKELY TO CONTINUE IN THE NEAR TERM. COMPLETE AND PERIODIC LOSS OF HF ON THE SUNLIT SIDE OF THE EARTH EXPECTED. CONTINUED HF COM DEGRADATION LIKELY OVER THE NEXT 7 DAYS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	20161108/0700Z

HF COM effects

Forecasts up to 24 HR

We can use also 'NIGHTSIDE'

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	HF COM SEV
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z DAYLIGHT SIDE
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FCST SWX +24 HR:	20161109/0100Z DAYLIGHT SIDE
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NXT ADVISORY:	20161108/0700Z

Update provided at least after 6 HR

Additional info on a web-site

Radiation effects

Element		Range	Resolution
Flight Level		250-600	30
Longitudes for advisories:	(degrees) (minutes)	000 – 180 00	15' 0
Latitude bands for advisories:	High latitudes northern hemisphere (HNH)	N9000 - N6000	30'
	Middle latitudes northern hemisphere (MNH)	N6000 - N3000	
	Equatorial latitudes northern hemisphere (EQN)	N3000 - N0000	
	Equatorial latitudes southern hemisphere (EQS)	S0000 - S3000	
	Middle latitudes southern hemisphere (MSH)	S3000 - S6000	
	High latitudes southern hemisphere (HSH)	S6000 - S9000	

(communication header)	
SWX ADVISORY	
DTG:	20161108/0000Z
SWXC:	(to be determined)
SWX EFFECT:	RADIATION MOD
ADVISORY NR:	2016/2
FCST SWX:	20161108/0100Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	RADIATION LEVELS HAVE EXCEEDED 100 PERCENT OF BACKGROUND LEVELS AT FL350 AND ABOVE. THE CURRENT EVENT HAS PEAKED AND LEVELS ARE SLOWLY RETURNING TO BACKGROUND LEVELS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

HNH : High latitudes northern hemisphere, i.e. N9000- N6000
MNH : Middle latitudes nothern hemisphere, I.e. N6000- N3000
EQN
EQS
MSH
HSH : High latitudes Southern hemisphere

HF COM effects

GNSS effects

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	GNSS MOD AND HF COM MOD
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	LOW-LEVEL GEOMAGNETIC STORMING IS CAUSING INCREASED AURORAL ACTIVITY AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVAILABILITY IN THE AURORAL ZONE. THIS STORMING IS EXPECTED TO SUBSIDE
	IN THE FORECAST PERIOD. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

WORKFLOW

From now until end of 2018

DRIVERS OF SPACE WEATHER

From now until end of 2018

By watching – in different circumstances, at special events
Visible light

The solar atmosphere is very big —–> probably, the corona is very hot.
The earths atmosphere is a thin layer. —> it is much cooler compared to the solar atmosphere.

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

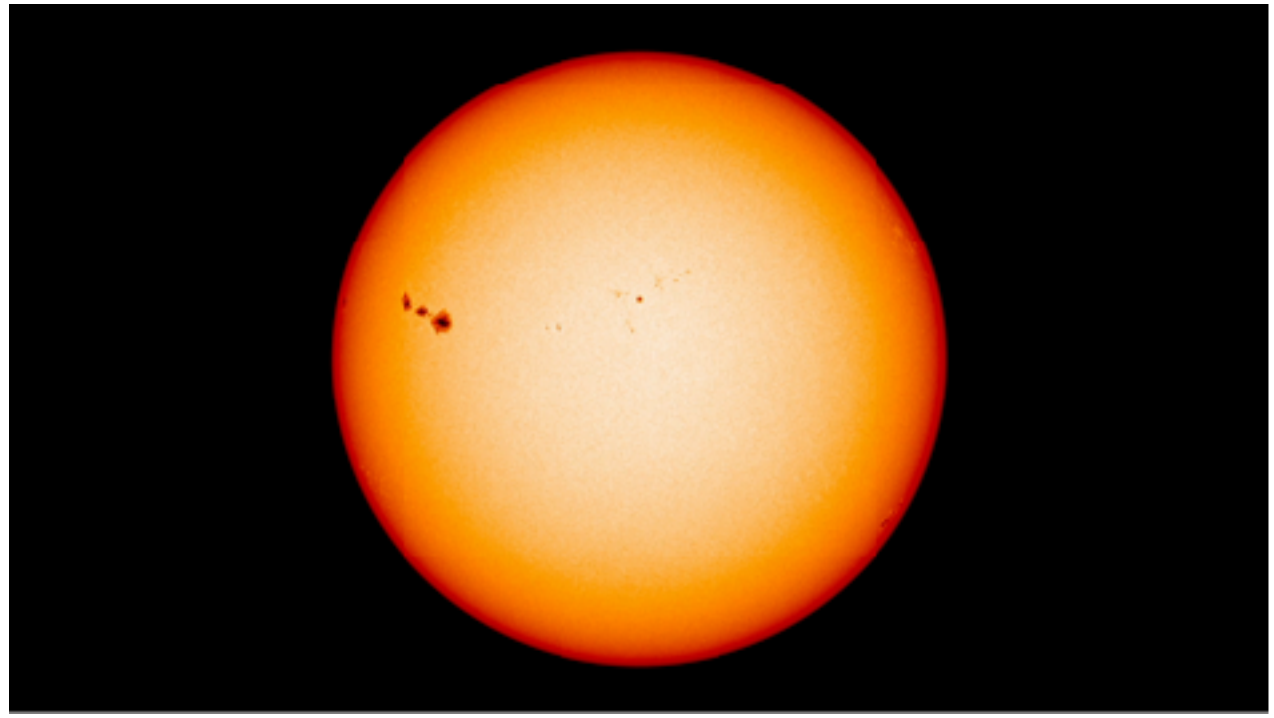
ELECTROMAGNETIC SPECTRUM

To study an object, we take pictures.
A doctor can use an x-ray camera to take a special picture of your bones.

These pictures can show doctors parts of your body that they can't normally see.

Each wavelength give other information.

ELECTROMAGNETIC SPECTRUM



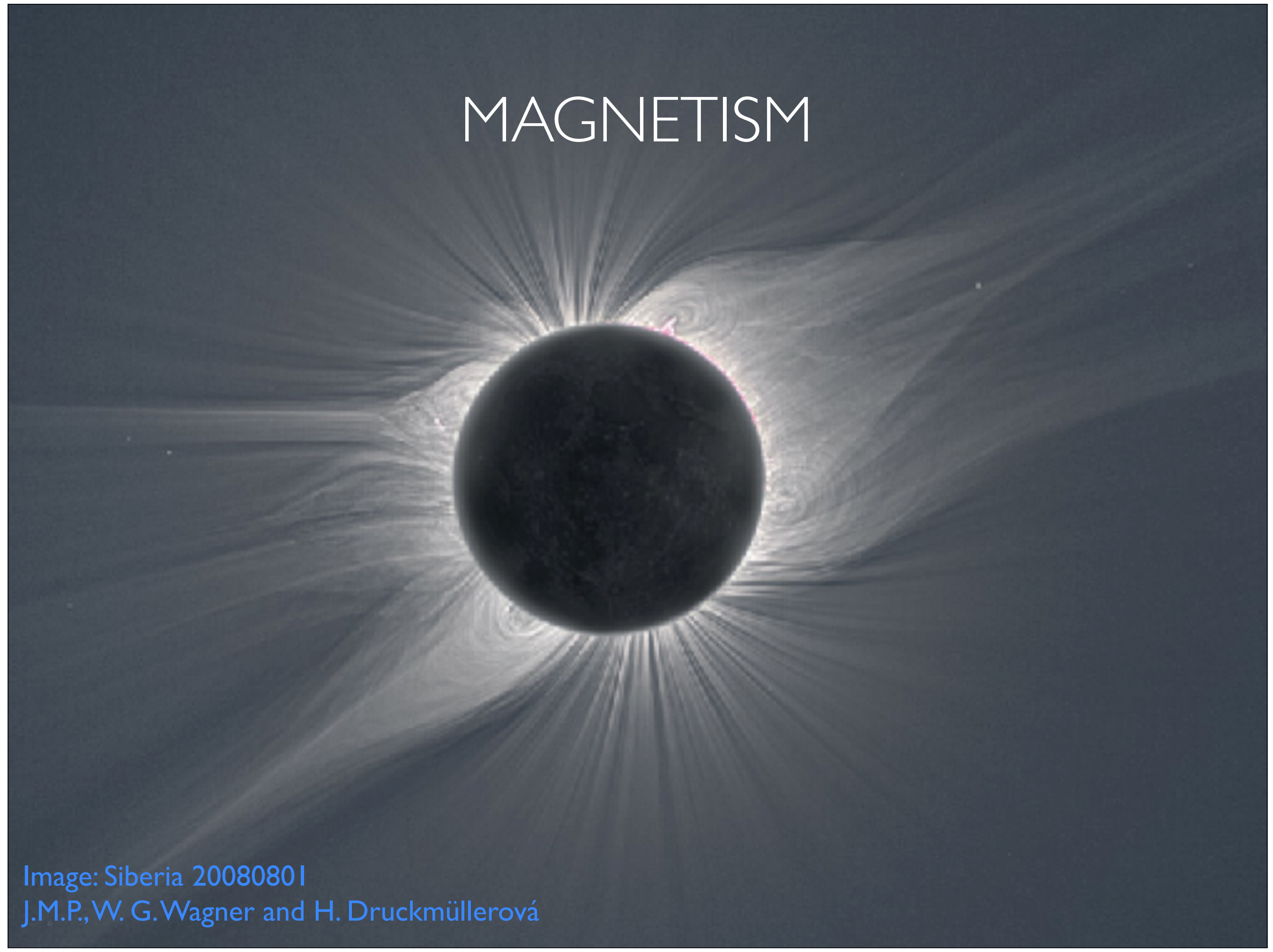
We use many tricks to observe the Sun and its activity. One of them is to look at the Sun using different parts of the light spectrum, thus in different wavelengths. From Earth, with the naked eye, we see the surface of the Sun in white light like this.

However, now that I start the movie, you can see how looking at the Sun in other wavelengths from space reveals very different structures and complexity. For this we mainly use extreme ultraviolet wavelengths because we are studying the hot outer region of the Sun, the corona. We see active regions, these are the bright patches, that show up in EUV wavelengths where the sunspots were first seen in white light. We also see the effects of the sun's magnetic field in the many loops above these sunspots. Each wavelength shows us different aspects and different layers of the solar atmosphere and by combining them, we try to build a complete picture of the solar activity.

Therefore, we have many instruments in space to observe the solar atmosphere.

credits: This movie was made combining different observations from the AIA telescope on board the Solar Dynamics Observatory.

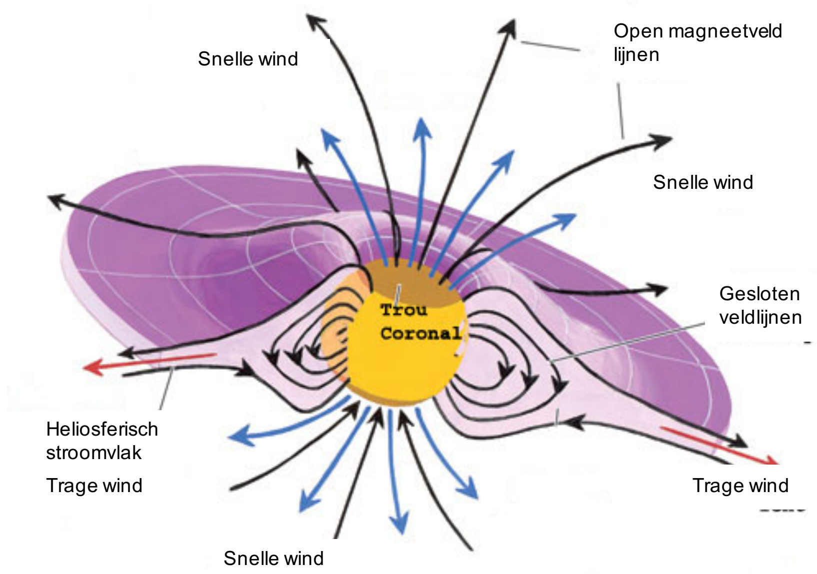
The Sun has a hidden part that became only visible at the start of the space age. From the moment, we could inspect the Sun in other wavelengths, the Sun showed its dynamic, explosive and magnetic personality.



It is the magnetic field that lies at the base of all solar activity: eruptions on a short time scale, up to the phenomenon of the 11 year solar cycle.

Magnetic forces are present on the sun in all possible length scales. These magnetic structures vary on different time scales: from minutes, to hours, to days, to years.

The sun is a gigantic dipole.

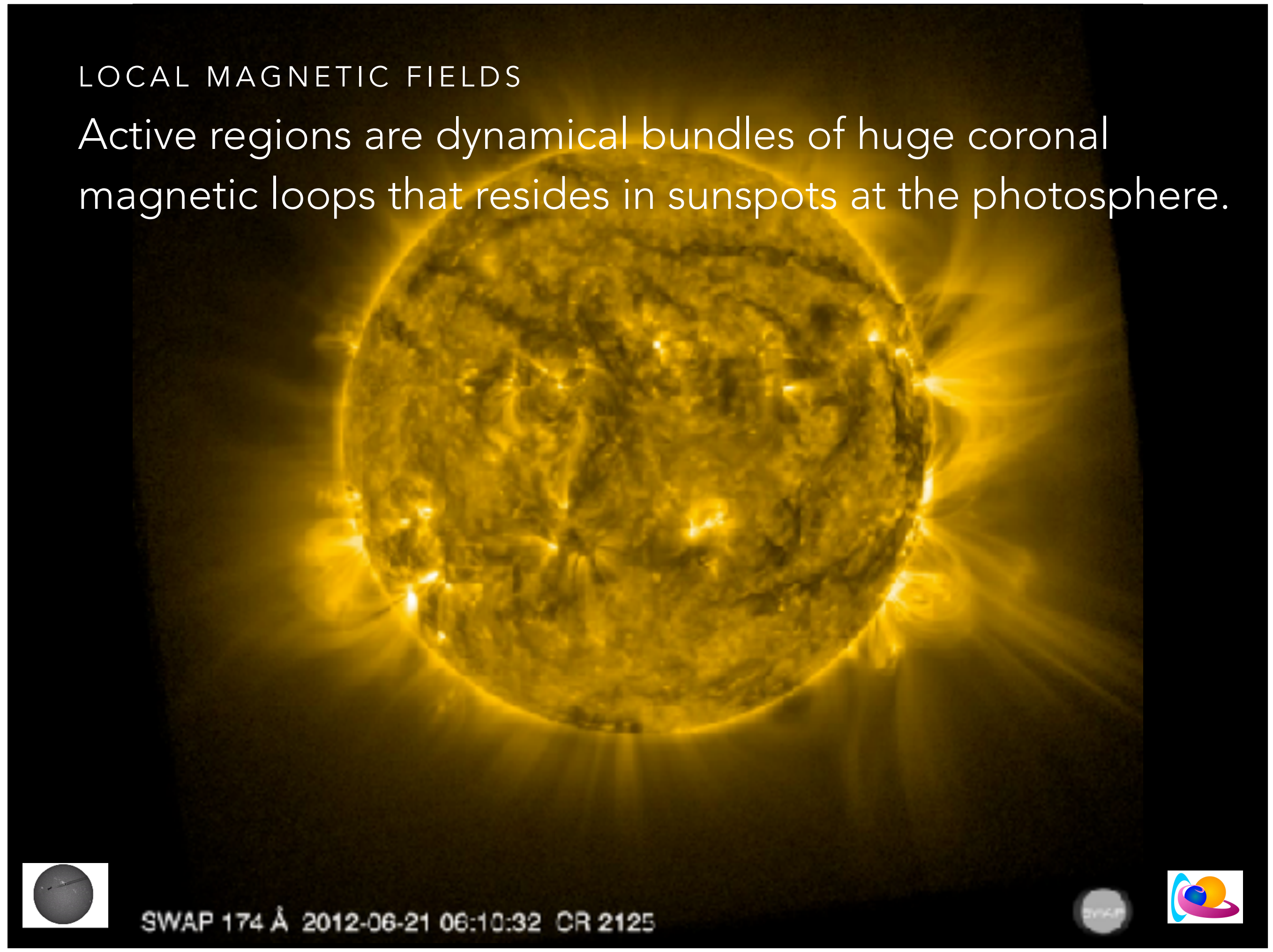


Large spatial and time scale: Solar dipole – visible during a solar eclipse, more pronounced at solar minimum, orientation and geometry vary during the solar cycle.

Magnetic field lines have a direction, i.e. you can draw an arrow. A magnetic field line that comes through the solar surface, goes ‘in’ or ‘out’.
we have ‘closed’ and ‘open’ magnetic field lines.
Open magnetic field lines goes from the sun into space. An open magnetic field line is positive (pointing away from the sun) or negative (pointing towards the sun).
Loops are closed magnetic field lines: a line leaves the sun, bends and turns back into the sun.

The Sun is a large magnetic dipole:

- you have positive magnetic field lines leaving the sun and negative magnetic field lines pointing to the sun. It is the solar plasma that moves away from the sun that drags the magnetic field lines into space creating an open magnetic field structure. Or you can also say that the open magnetic field lines guide the solar plasma into space. This will become clear further one.
- above the equator, these field lines bend and create loops.



On a smaller spatial scale, local magnetic field – the magnetic field can have a more complex geometry, multi polar.
Active region – magnetic loops in the corona, coronal part of a magnetic structure that appears as a sunspot on the photosphere.

In het EUV zien we dat die structuren erg dynamisch en beweeglijk zijn. Dit is een filmpje over enkele zonnerotaties.

De zon varieert
Film over een paar zonnerotaties
Actieve gebieden kunnen net zoals zonnevlekken ontstaan, groeien, verdwijnen.

THE SUN LOOSES ENERGY

RADIATION

MASS

PARTICLES

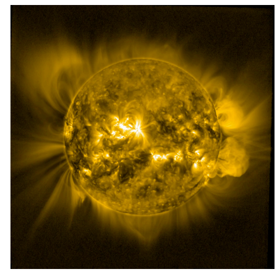
The sun is a gigantic ball of energy: magnetic energy, heat, moving plasma, …
Four states of matter are observable in everyday life: solid, liquid, gas, and plasma.
Plasma is the fourth state of matter. When you have solid material and you heat it, it becomes liquid. You keep on meeting it, it becomes a gas. When you still add heat, the atoms split into ions and electrons. The gas becomes electrically conductive creating electrical and magnetic field.

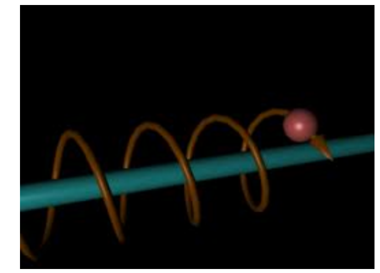
This energy is kept inside the Sun but also on its surface and in its atmosphere in magnetic structures like sunspots and magnetic loops, filaments or prominences ready to be released.

This energy is expelled, leaves the Sun to outer space in the form of electromagnetic radiation, kinetic, electric and magnetic energy.

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 charged particles in matter. You have thermal motion as soon as the temperature is above absolute zero.

ENERGY IN SOLAR JARGON





TOTAL SOLAR IRRADIANCE

SOLAR WIND

FAST PARTICLES

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

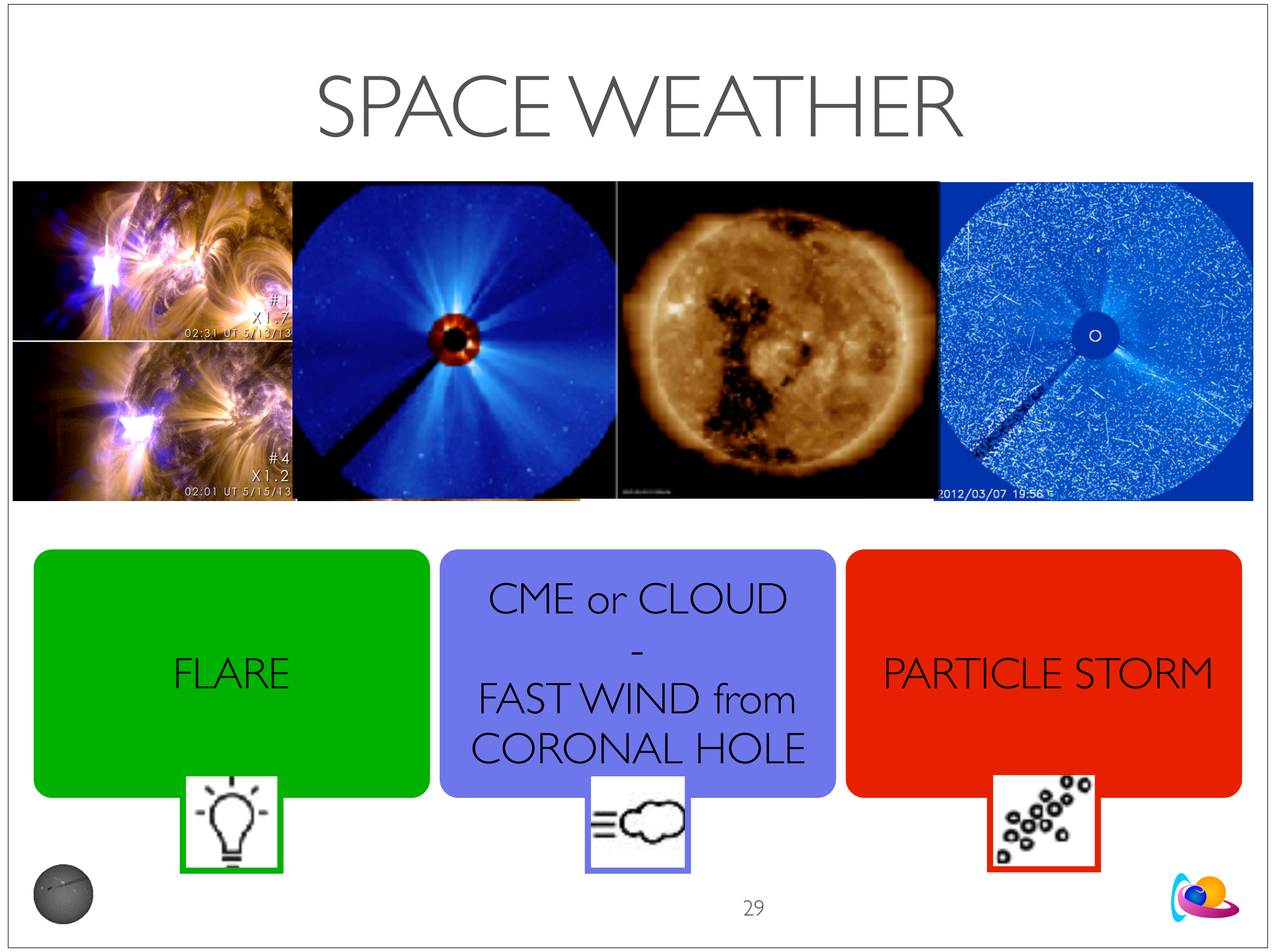
Near Earth, the IMF still controls the solar wind and its movement. Much much further away from the Sun, the IMF becomes very weak and doesn't control the solar wind anymore. But, this is not important for us. At 1AU, the IMF influences the plasma and the plasma the IMF.

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



Space weather is the changes 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)

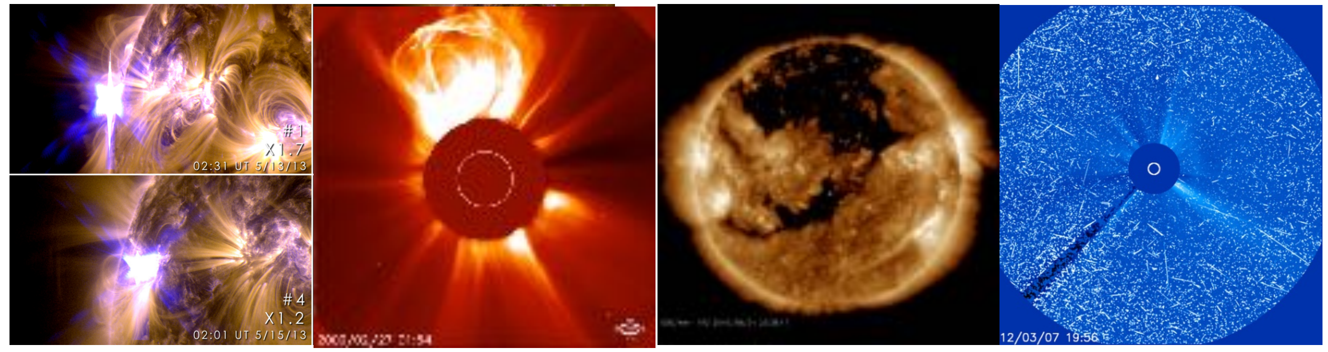
A coronal hole is a structure in the solar corona that you see as a black area in the EUV. It looks black because there is less plasma present that radiates in the EUV. The magnetic field lines are open, i.e. fan out into space. There are no magnetic loops above a coronal hole. The solar wind emanating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

A particle storm is a bunch of electrically charged particles that circle around the IMF lines into space. 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.

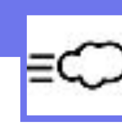
Near Earth, the IMF still controls the solar wind and its movement. If we would go much much further, the CME magnetic bag with solar plasma would be almost empty (all the solar material is spread over an immense volume) and the magnetic bag would have evaporated. But, this doesn't matter for us. We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

TIME SCALES OF SW



8 MIN

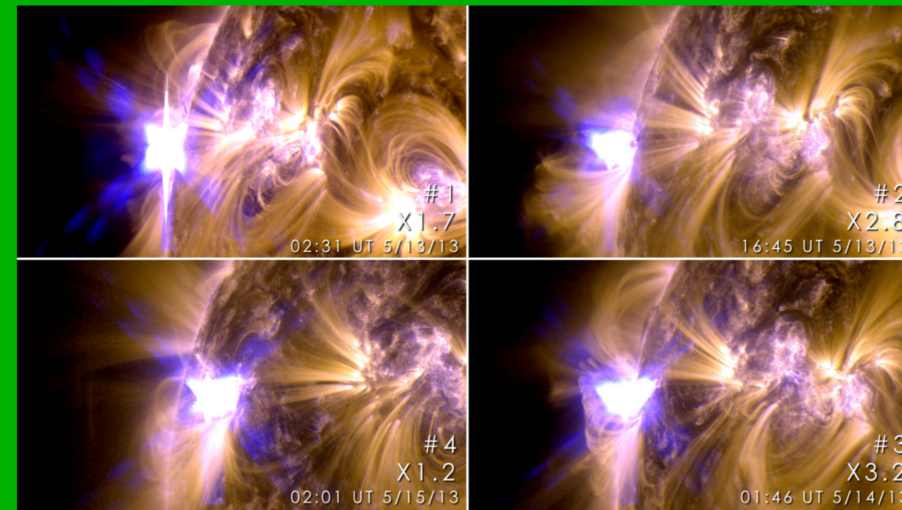
DAYS



HOUR

OUR NATURAL PROTECTION

The earth magnetic field protects human and biological live against the solar wind.
The earth magnetic field guides the solar protons that reach the Earth’s magnetosphere and ionosphere towards the poles.
The earth atmosphere protects human and biological live against solar e.m. radiation.
The earth atmosphere is not blown away by the solar wind thanks to the magnetosphere.

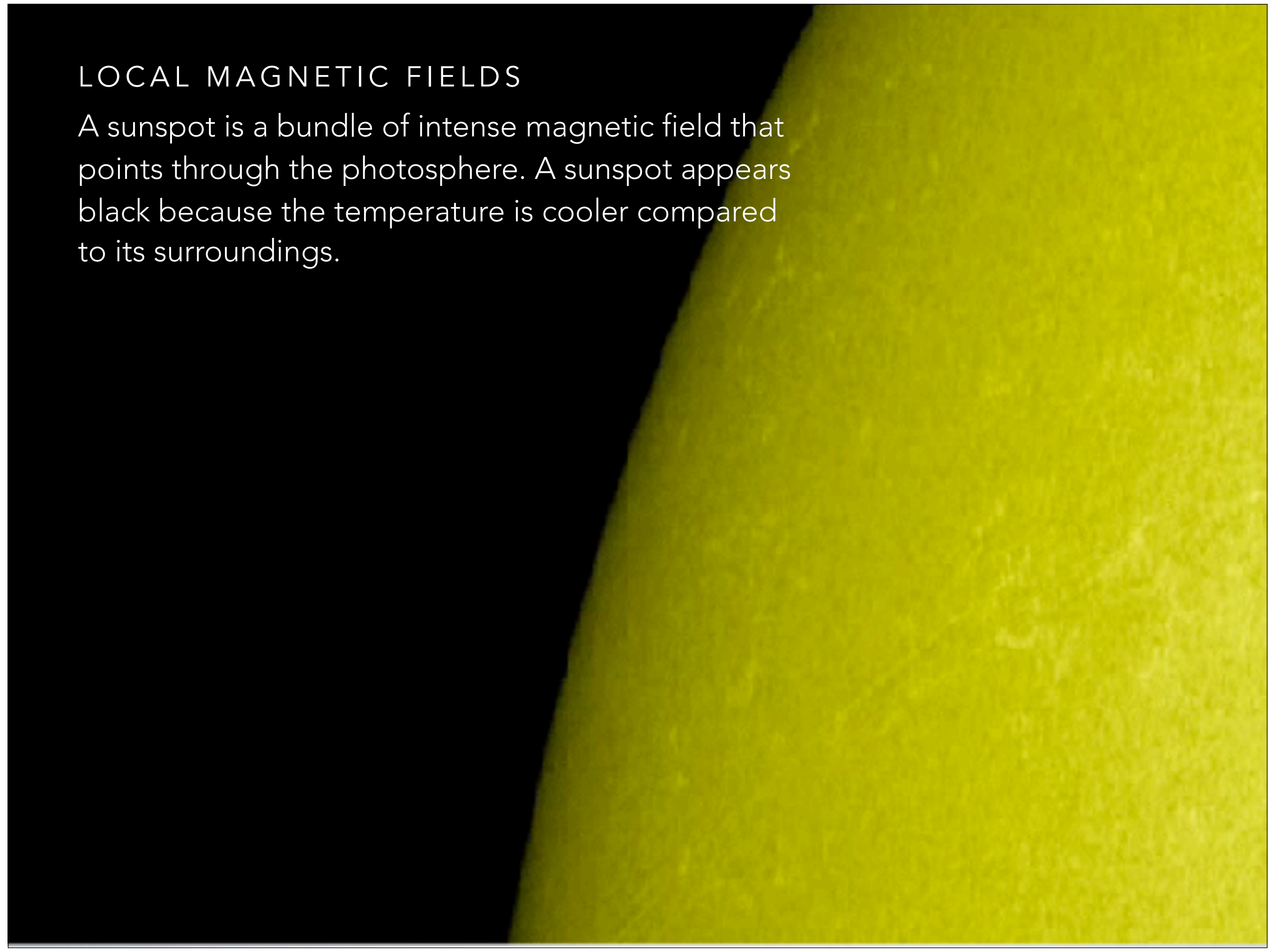


FLARES

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

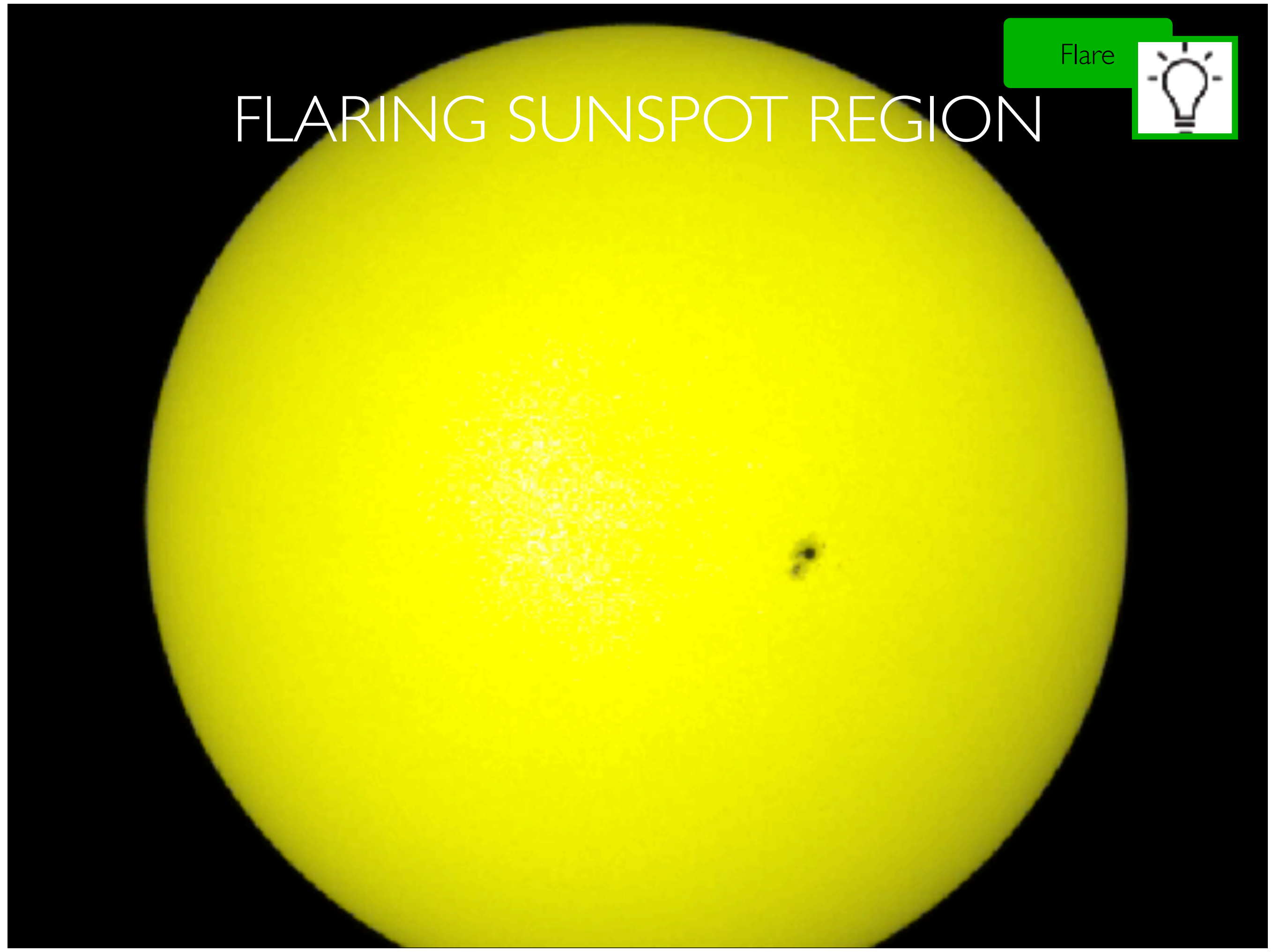
A solar flare is an intense burst of radiation coming from the release of magnetic energy associated with sunspots. Flares are our solar system's largest explosive events. They are seen as bright areas on the sun and they can last from minutes to hours.

In these images, the flare is visible in the EUV: in that particular wavelength, the e.m. radiation increased suddenly. The plasma on that spot started to radiate very intense in the EUV. A short time, pixels that see the flare are overexposed and blinded. You see a vertical flash in the top/left. It is vertical because the pixels are read out in this direction.



Vlekkengroepen zijn plaatsen waar de onderliggende intense magneetvelden de dunne laag van de fotosfeer doorboort.

•Ze hebben een dipolaire globale structuur die overeenkomt met het voetstuk van het magnetisch gewelf dat zich tot hoog tot in de zonneatmosfeer ontwikkelt. De dipool is steeds oost-west georiënteerd.

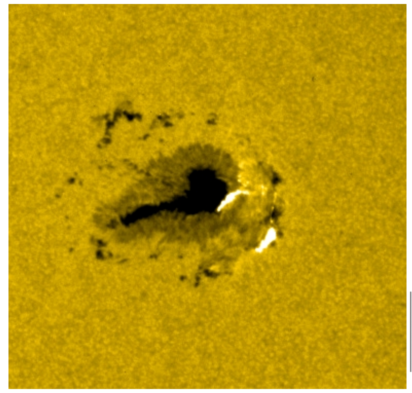


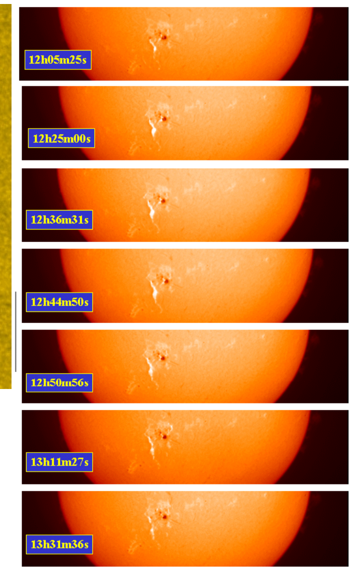
A solar flare is a sudden, localised increase in brightness on the solar disc.

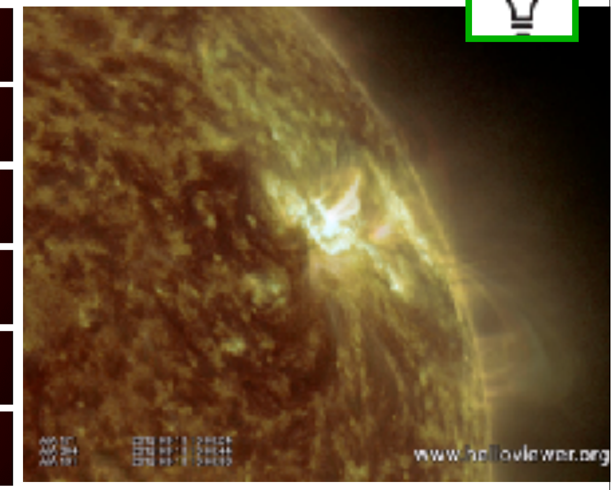
A limited plasma volume in the solar atmosphere is suddenly heated to at least 10^7 K. The heating is caused by a fast and brutal reconfiguration and reorganisation of the magnetic field. This happens in sunspots near the neutral line between areas of opposite polarity.

The first measurements of solar flares date from mid 19th century. These are white light flares and rather exceptional.
Flares occur in areas with a strong magnetic field (≥ 0.1T = 100 Gauss). In the corona we call them active regions, at the photosphere they appear as black sunspots.

Flare







FLARES

Visible in different layers
Photosphere - Chromosphere - Corona

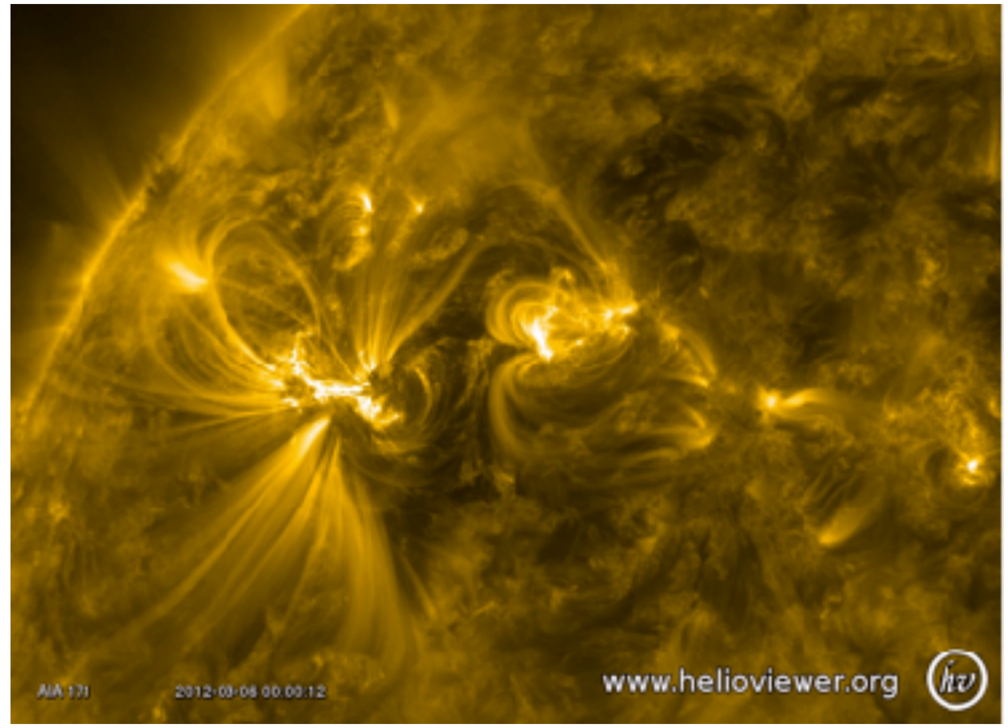
The key to understanding and predicting solar flares is the structure of the magnetic field around sunspots. If this structure becomes twisted and sheared then magnetic field lines can cross and reconnect with the explosive release of energy.
E.m. emission come from all layers in the solar atmosphere and thus linked to the different structures associated with the eruption.

Photosphere:
Only in rare cases, emission is seen at the level of the photosphere.
Chromosphere:
Red (H-alpha) or Blue (Calcium II) line
During the eruption, bright faculae near the neutral line appear.
The intensity increases with a factor larger than 3 (up to 10) compared to the quiet chromosphere.
Corona:
In the corona, a flare is seen as a local and short EUV light flash. Depending on the wavelength, the intensity can increase with a factor 100 up to 1000.
Magnetic coronal loops restructure during the impulsive first phase of the flare. This takes 1 to 10 minutes.
In the main or second phase, an arch of bright loops above the neutral line develops. This can last from minutes to hours (i.e. Long Duration Event).
When the flare is really intense, you might see a shock wave, this is a signature of a CME.

Flare

SOLAR FLARES

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

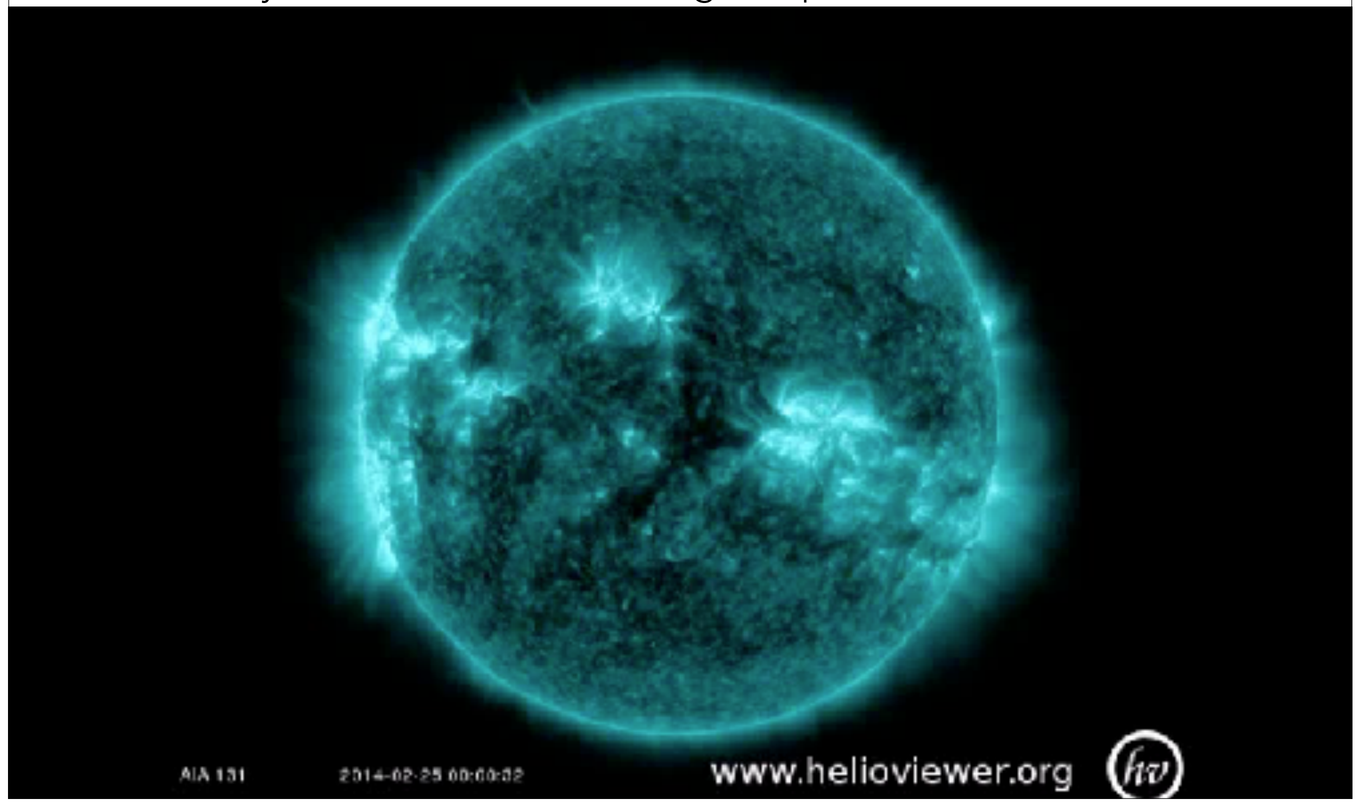


Een zonnevlam bestaat uit een brutale en kortstondige verhitting van een beperkt plasmavolume van de zonneatmosfeer, dat tot minstens 107 K wordt verhit. Deze verhitting is een gevolg van een snelle herschikking of reorganisatie van het magneetveld.

Flare

SOLAR FLARES

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



131 angstrom
of 13,1 nm

1700 Angstrom

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

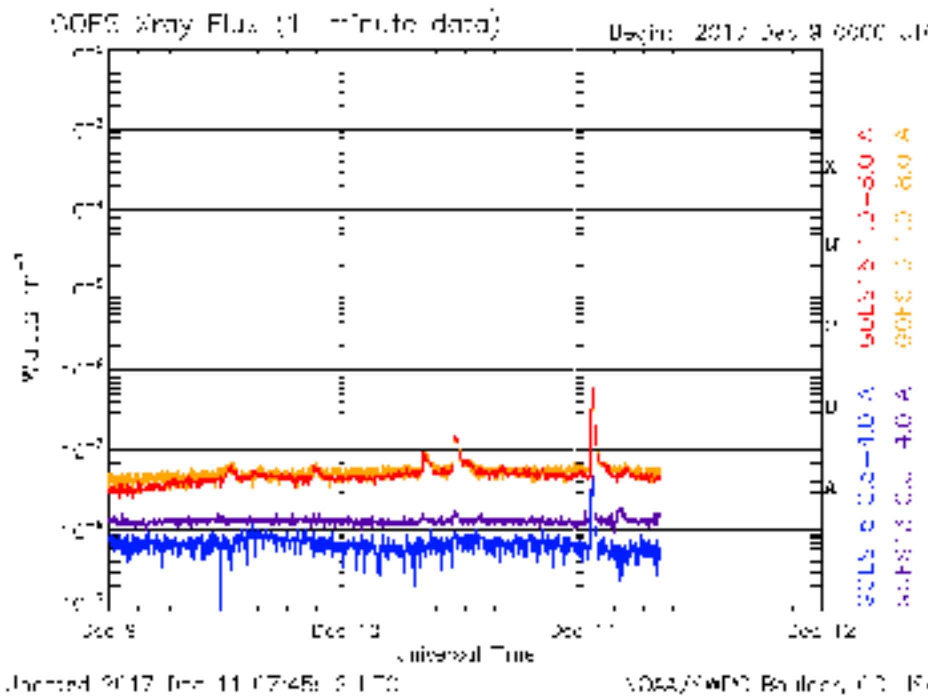
UV: 380 - 10 nm / 3800 - 100 Angstrom

EUV: 100 - 10 nm / 1000 - 100 Angstrom

Flare

X-RAY FLUX

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



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.

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.

Flare

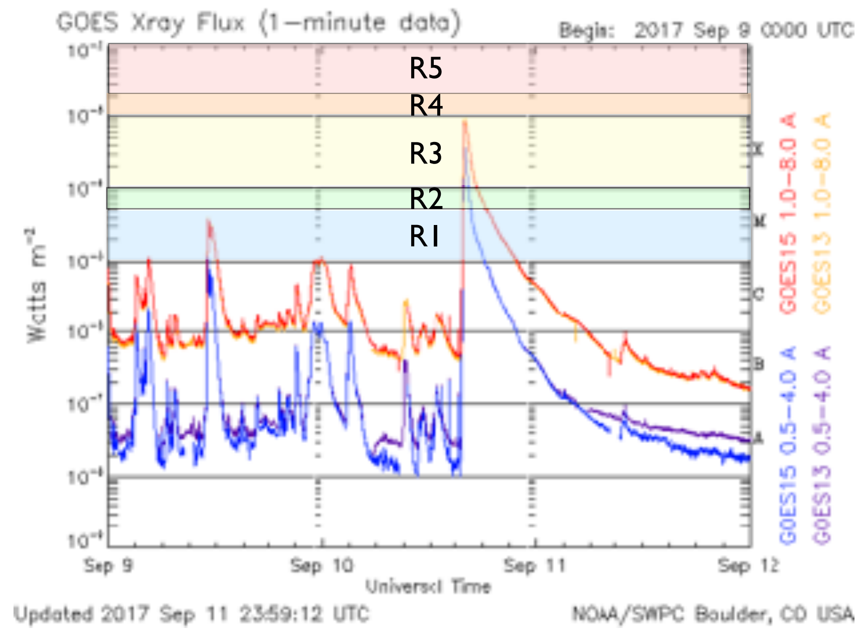
The impact of a flare depends on the intensity of the x-ray flux.

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

FLARE CATEGORIES & SW SCALES



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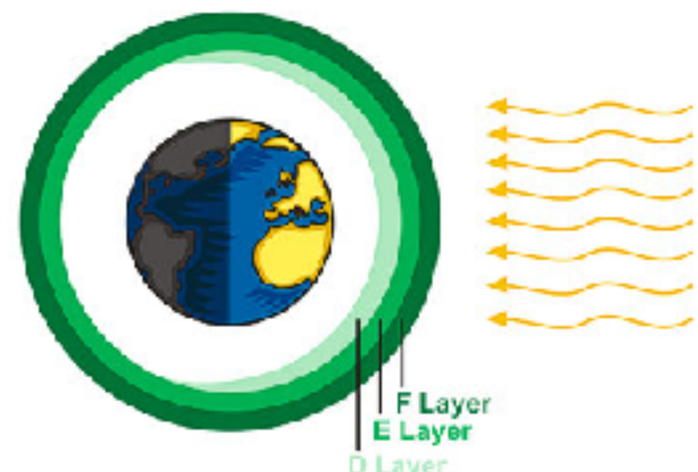
IMPACT

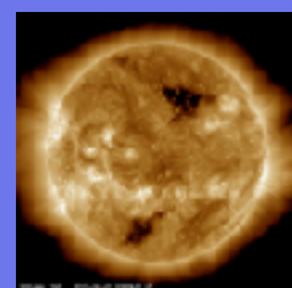
- GNSS
- Radio communication
- Drag on satellites

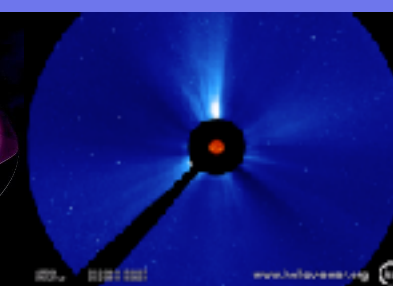


Global Navigation Satellite System

SOLAR WIND VARIATIONS INTRODUCING SPACE WEATHER

Non-eruptive	Eruptive
Coronal Hole Sector Boundary Crossing	Coronal Mass Ejection





The variations in the solar wind introduce space weather events.

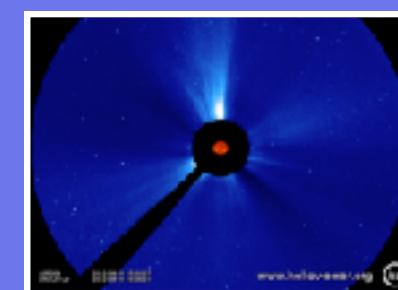
CME – suddenly, a mass is ejected into space. A CME is an eruptive event. You can have filament eruptions or plasma ejections associated with flares. We come back to this.

A CH is not eruptive. A CH is present, it doesn’t pop up suddenly. A CH can of course slowly appear or disappear, become bigger, become smaller but not on time scale of a few minutes. It is also not the case that a CH ejects material and a little bit later, not any more. The solar wind continuously emanated from a CH.
A sector boundary crossing is also not eruptive.

SOLAR WIND VARIATIONS
INTRODUCING SPACE WEATHER

Eruptive

Coronal Mass Ejection



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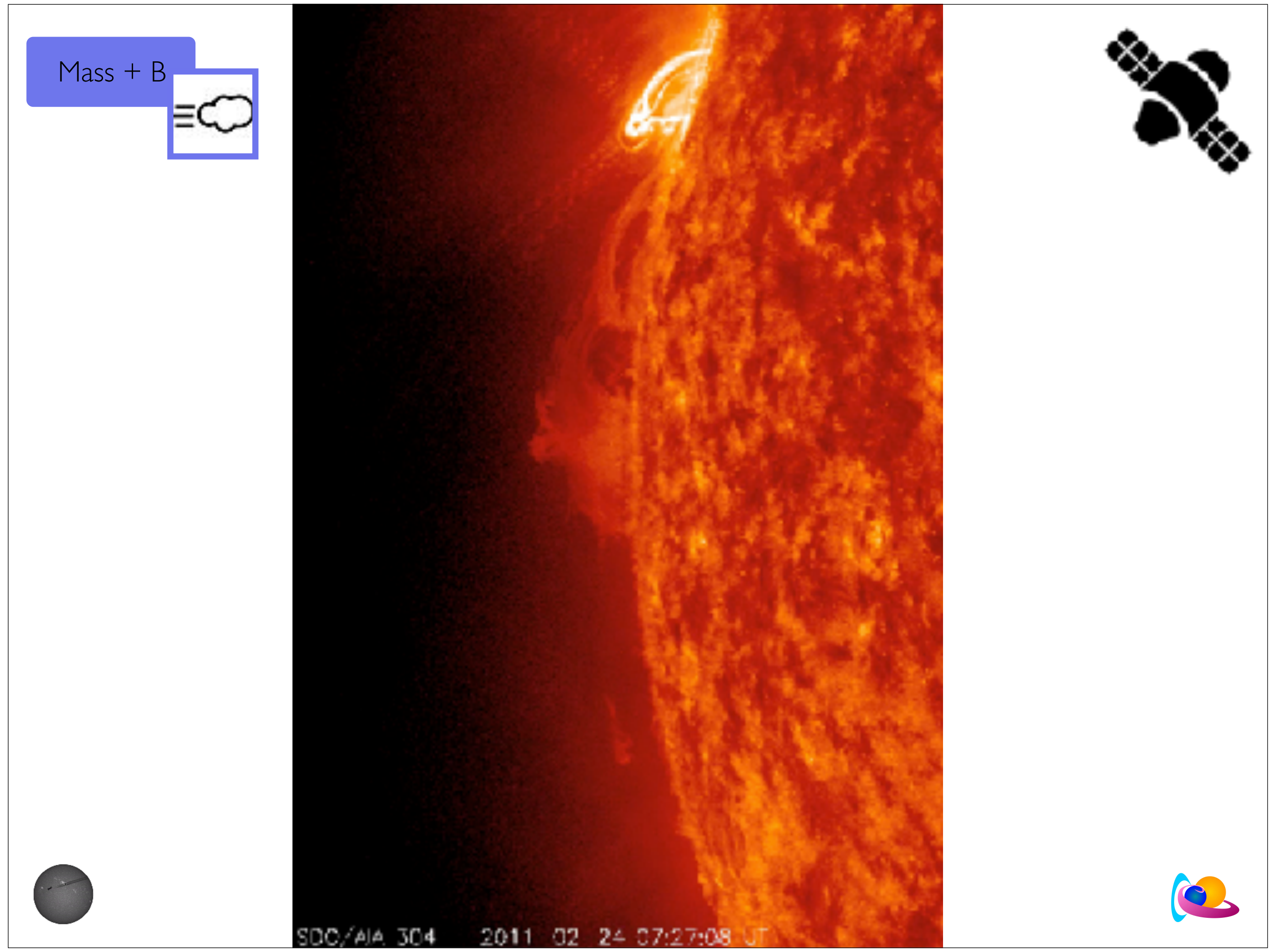


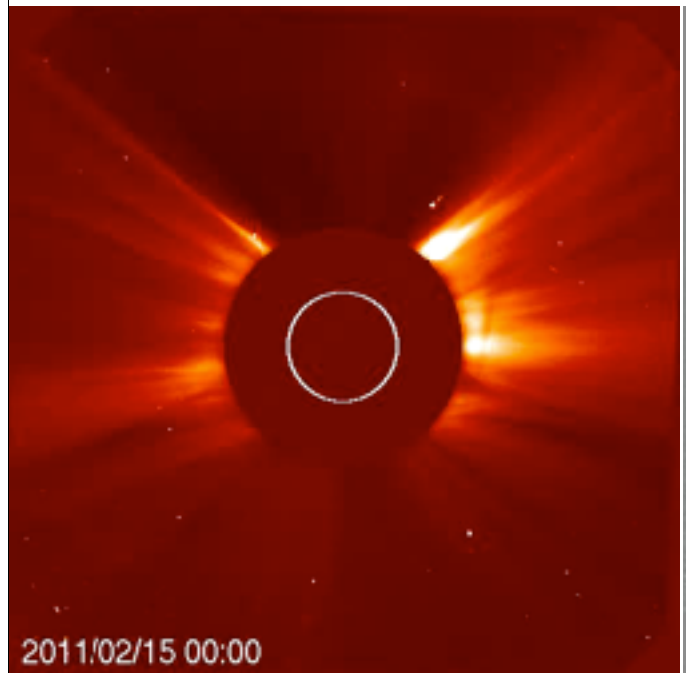
zichtbaar licht: 780 - 380 nm / 7800- 3800 Angstrom / ROGBIV

UV: 380 - 10 nm / 3800 - 100 Angstrom

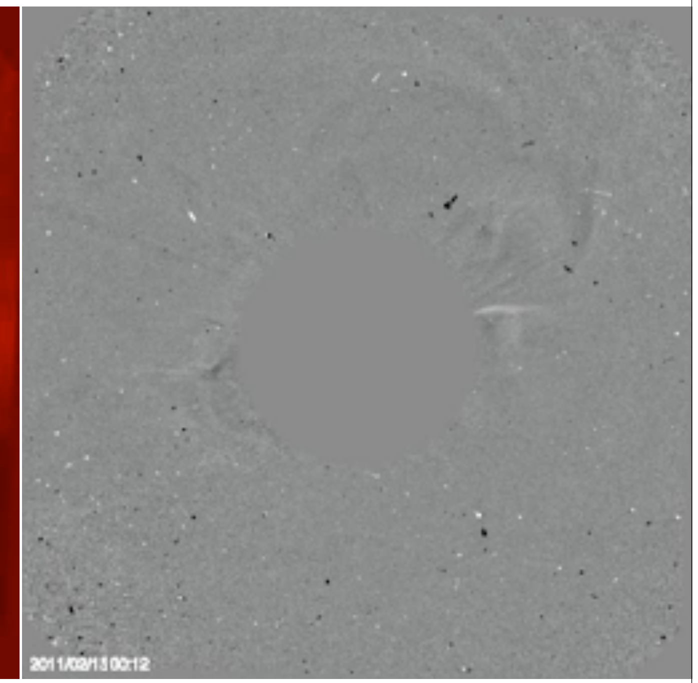
EUV: 100 - 10 nm / 1000 - 100 Angstrom

Mass + B

CORONAL MASS EJECTION



SOHO / LASCO c2

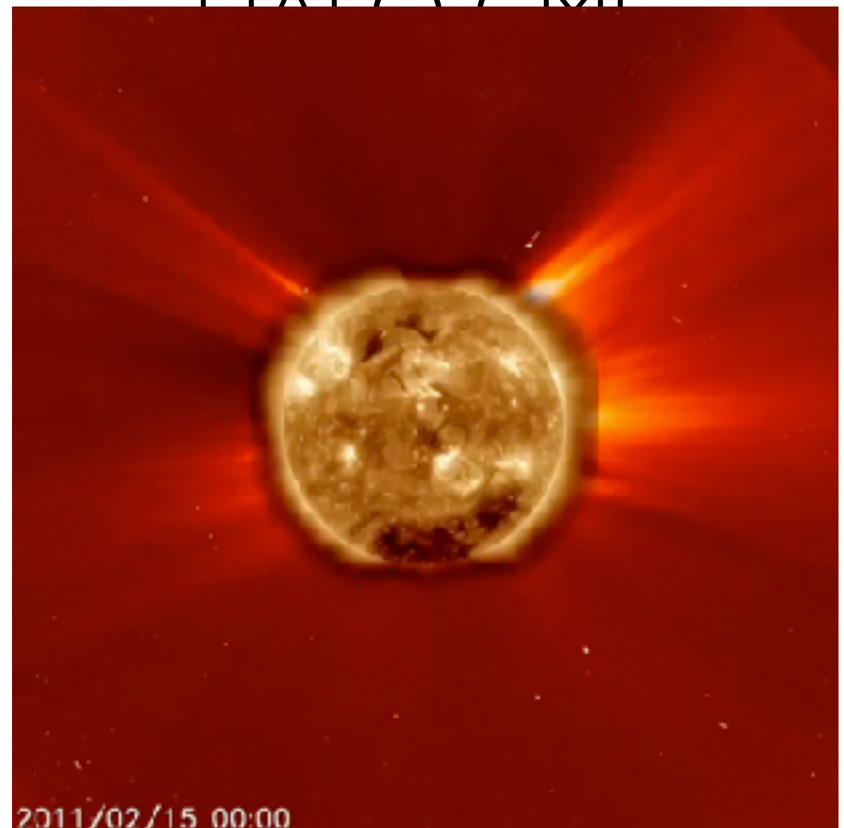


running difference

CMEs cause the most extreme geomagnetic storms. Therefore, there is great interest in understanding the properties of CMEs, especially when they have a halo signature around the solar disk that indicates the CME is aimed at Earth.
Furthermore, if the CME results in a magnetic cloud with a strong and out of ecliptic magnetic field,forecasts are likely for strong to extreme storms.

Mass + B

HALO CME



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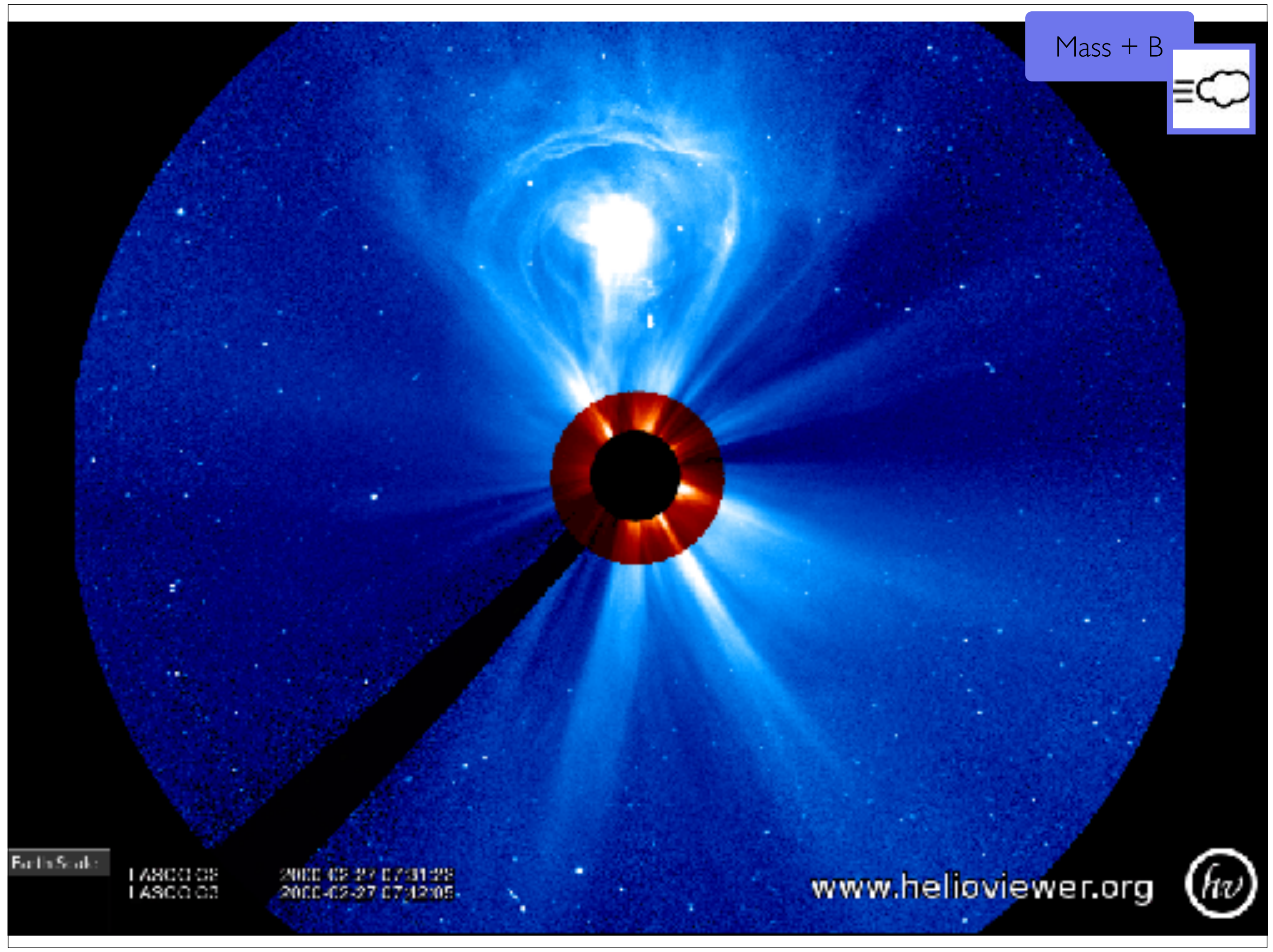
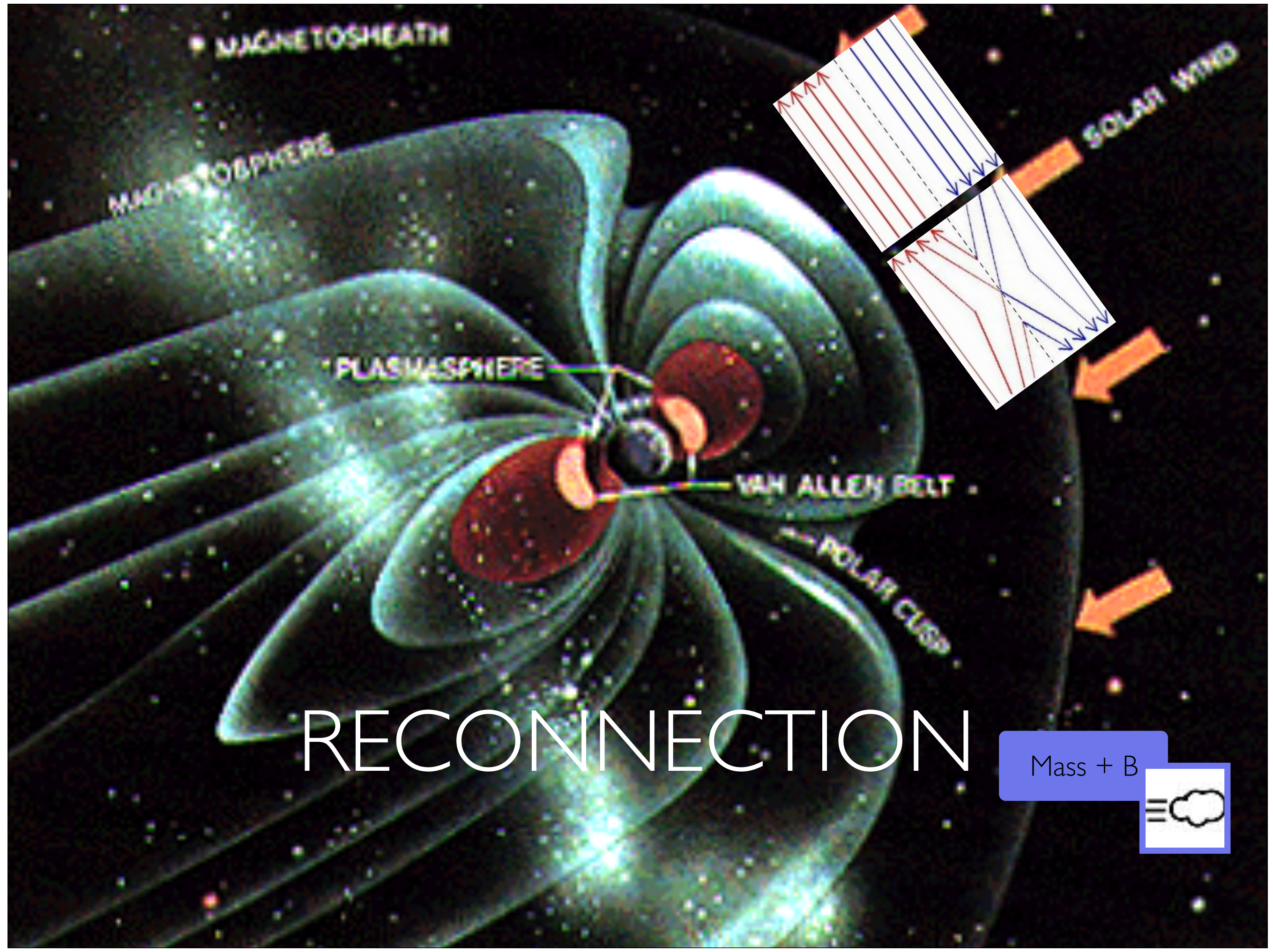


Transient: only lasting for a short time

Low density, but enormous and therefore massive.

CME is large: compare its size with the size of the sun.



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.

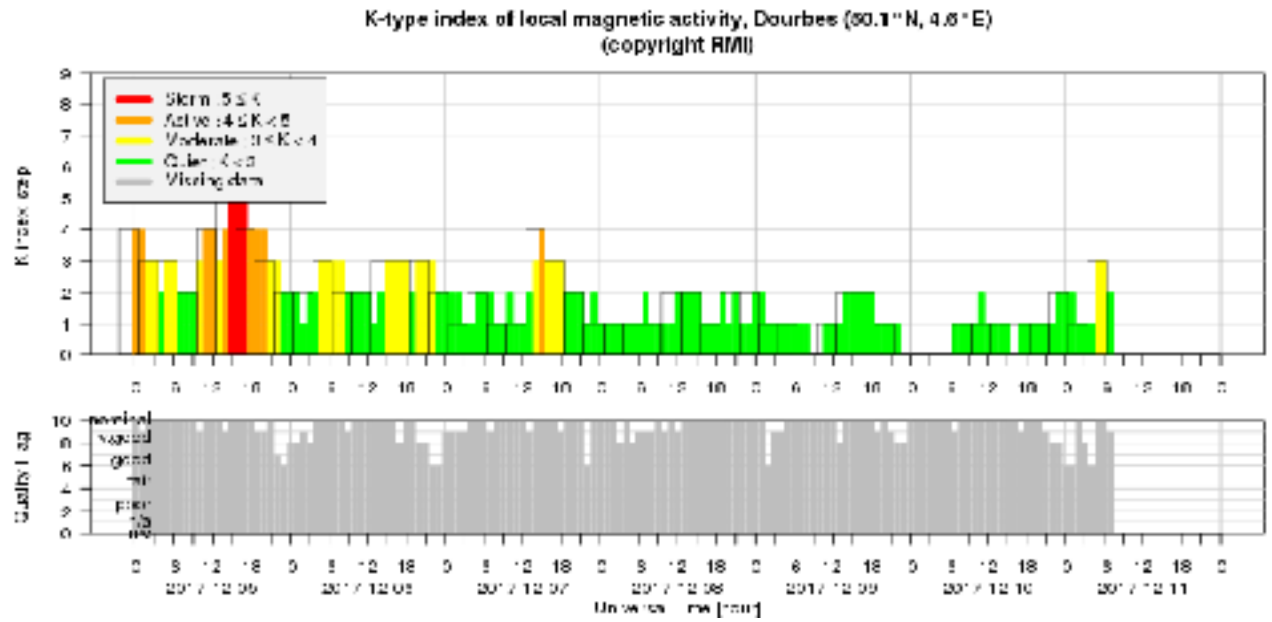
A magnetic field is imbedded in the solar wind. This magnetic field can interact with the magnetic field of the earth at the boundaries of the earth magnetosphere. This interaction is called reconnection. It happens when 2 magnetic regions are confronted with each other.

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 T) - strength of Earth's magnetic field at 0° latitude (North/South), 0° longitude (west/east)

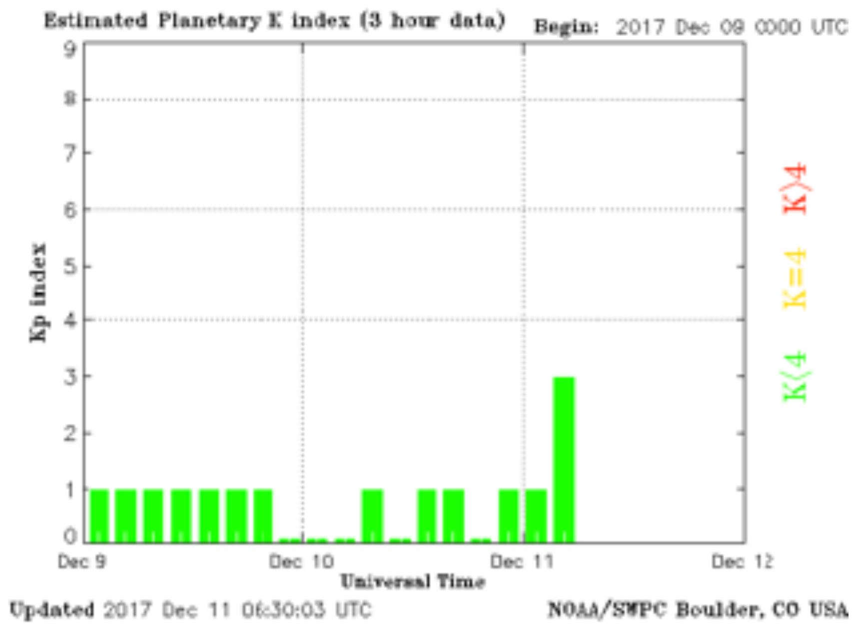
Mass + B

GEOMAGNETIC STORM



Mass + B

GEOMAGNETIC STORM



Mass + B

NOAA SPACE WEATHER SCALES

The effect of a geomagnetic storm depends on how strong the geomagnetic field is disturbed. This is described by an index K.

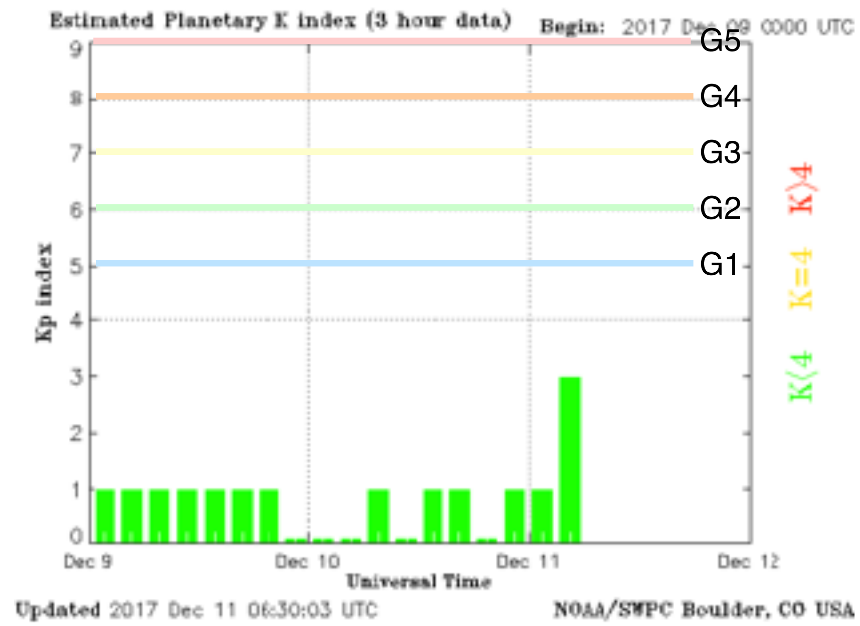
Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread 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.sec.noaa.gov/Aurora)

GEOMAGNETIC STORM

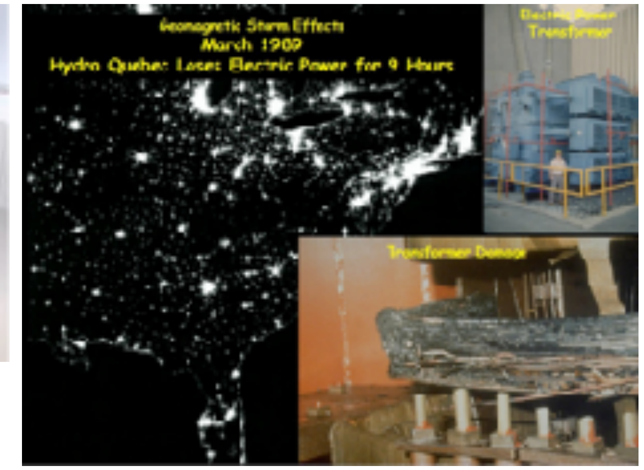
Mass + B



Mass + B

IMPACT

- GIC
- GNSS
- Aurora
- Drag on satellites



Malmö Blackout - Oct 30, 2004

- About 50 000 customer were without electricity in Malmö, Sweden for 20-50 minutes
- First known power grid blackout due to GIC in Europe
- An overcurrent relay was too sensitive to the third harmonic of 50 hZ. It has been replaced by a less sensitive relay later.

Global Navigation Satellite System

September 2, 1859, disruption of telegraph service.
One of the best-known examples of space weather events is the collapse of the Hydro-Québec power network on March 13, 1989 due to geomagnetically induced currents (GICs). Caused by a transformer failure, this event led to a general blackout that lasted more than 9 hours and affected over 6 million people. The geomagnetic storm causing this event was itself the result of a CME ejected from the sun on March 9, 1989.

Galaxy 15 is an American telecommunications satellite which is owned by Intelsat. It was launched for and originally operated by PanAmSat, and was subsequently transferred to Intelsat when the two companies merged in 2006. It was originally positioned in geostationary orbit at a longitude of 133° West, from where it was used to provide communication services to North America. **In April 2010, Intelsat lost control of the satellite, and it began to drift away from its orbital slot, with the potential to cause disruption to other satellites in its path.**

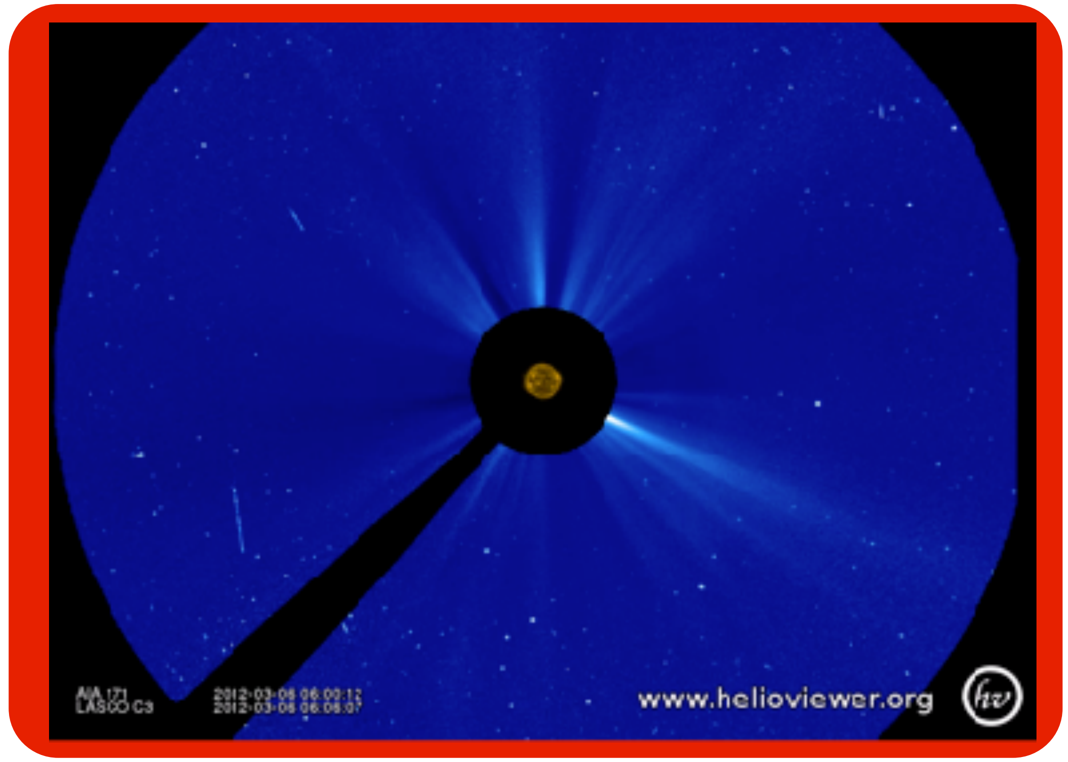
3 april : B7 zonnevlam, CME-flank kan eventueel langs de aarde afschampen

5 april : K=5,6 — Galaxy 15 anomaly

near equinox en op moment net aan middernacht kant aarde, langs de kant van zonsopkomst (dawn)

On 27 December 2010, Intelsat reported that the satellite had rebooted as per design and the command unit was responding to commands again. In addition, the satellite had been secured in safe mode and the potential for interference issues from Galaxy 15 had ceased.[1] [2] On 14 January 2011 the satellite was located near 93° west,[3][4] where further testing is scheduled to be performed.[5] On March 18, 2011, Galaxy 15 has been re-certified from the FAA and is now sending GPS signal corrections. Intelsat repositioned Galaxy 15 back to its original location on April 4, 2011.[6][*dated info*]

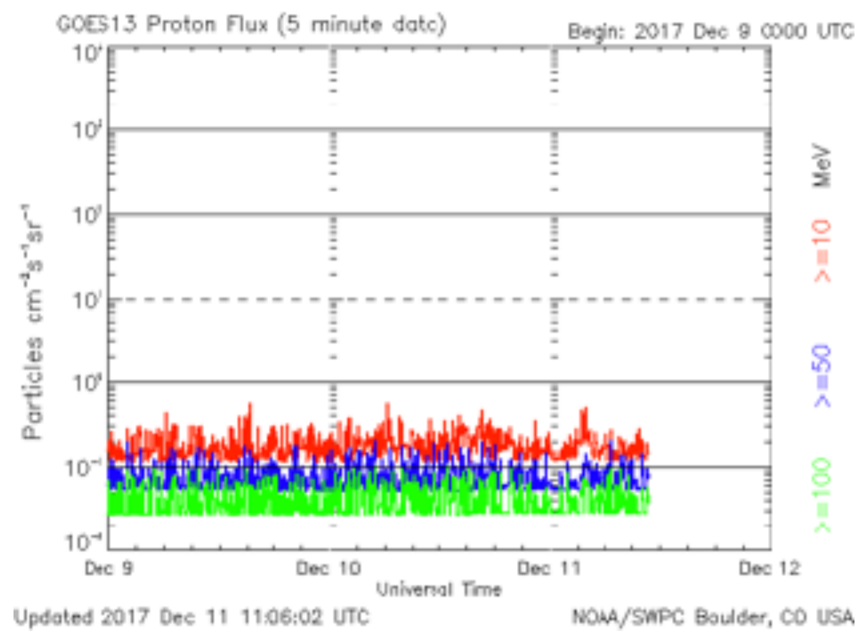
PROTON STORM



Electrically charged particles that are ejected by the Sun. They spiral around magnetic field lines.
They are ejected during an flare or CME event. The solar event accelerates the particles.

Solar radiation storms occur when a large-scale magnetic eruption, often causing a coronal mass ejection and associated solar flare, accelerates charged particles in the solar atmosphere to very high velocities. The most important particles are protons which can get accelerated to 1/3 the speed of light or 100,000 km/sec. At these speeds, the protons can traverse the 150 million km from sun to Earth in just 30 minutes. When they reach Earth, the fast moving protons penetrate the magnetosphere that shields Earth from lower energy charged particles. Once inside the magnetosphere, the particles are guided down the magnetic field lines such that they penetrate the atmosphere near the north and south poles.
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.
Solar Radiation Storms cause several impacts near Earth. When energetic protons collide with satellites or humans in space, they can penetrate deep into the object that they collide with and cause damage to electronic circuits or biological DNA. During Solar Radiation Storms at the S2 or higher level passengers and crew in high flying aircraft at high latitudes may be exposed to radiation risk. When the energetic protons collide with the atmosphere, they ionize the atoms and molecules thus creating free electrons. These electrons create a layer near the bottom of the ionosphere that can absorb High Frequency (HF) radio waves making radio communication difficult or impossible.

PROTON FLUX NOW



Particles

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
S 1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

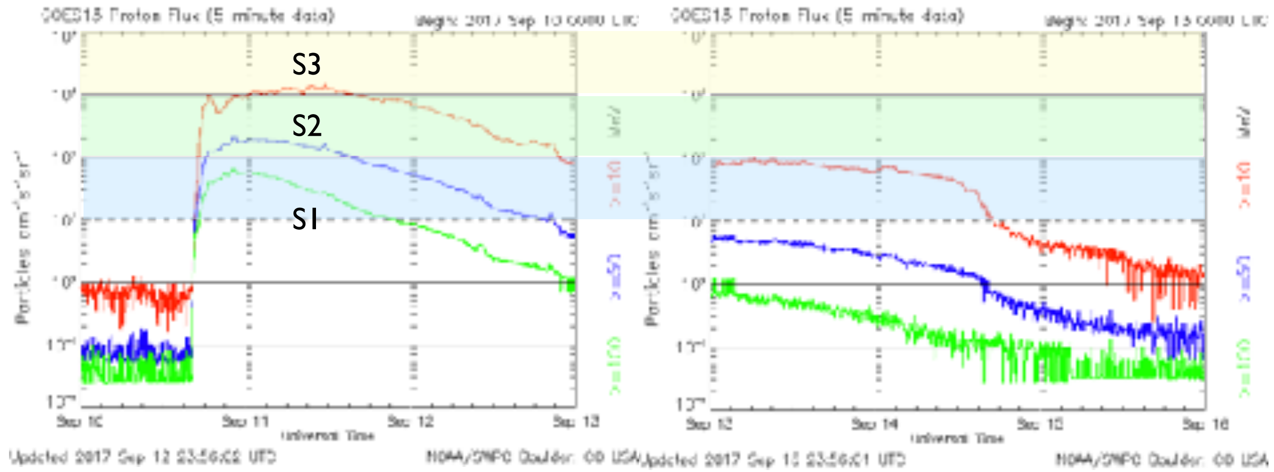
* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.

** 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.

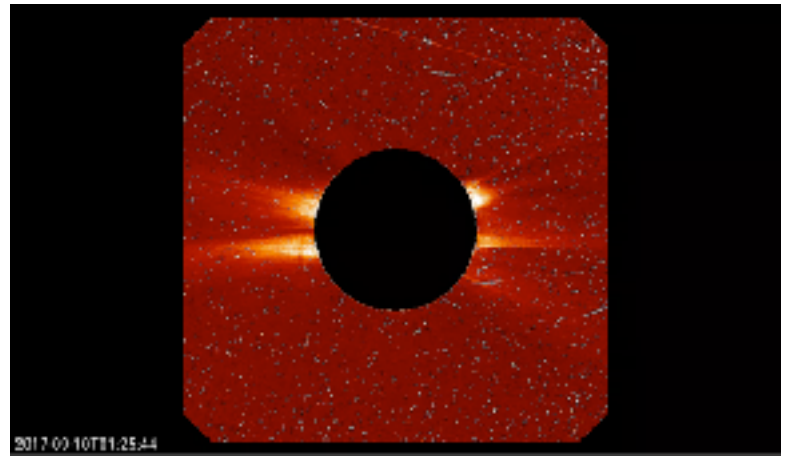
Particles

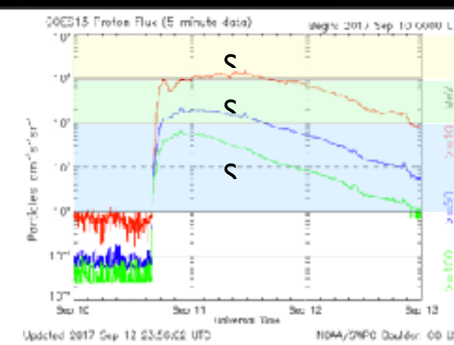
PROTON FLUX BY GOES

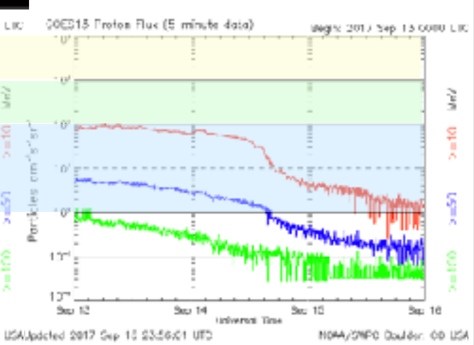


Particles

PROTON FLUX BY GOES

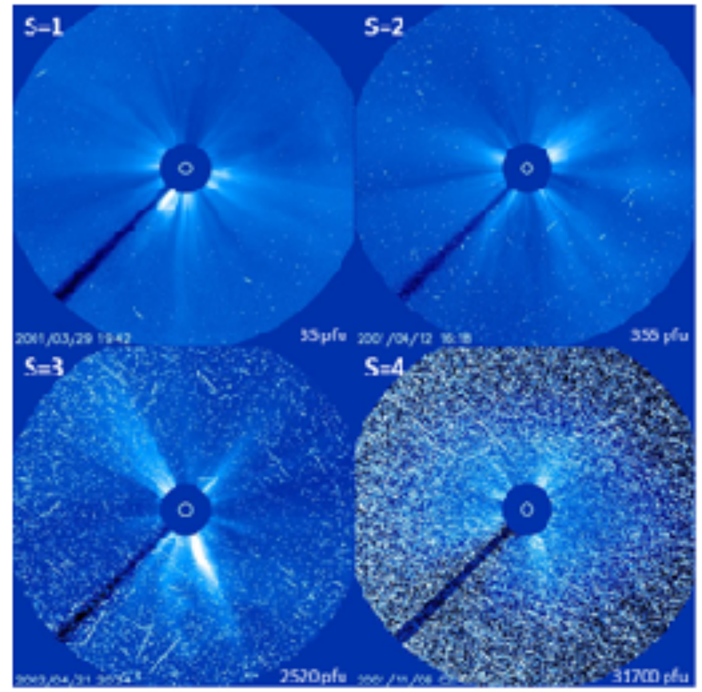






Particles

PROTON STORM



Electrically charged particles that are ejected by the Sun. They spiral around magnetic field lines.
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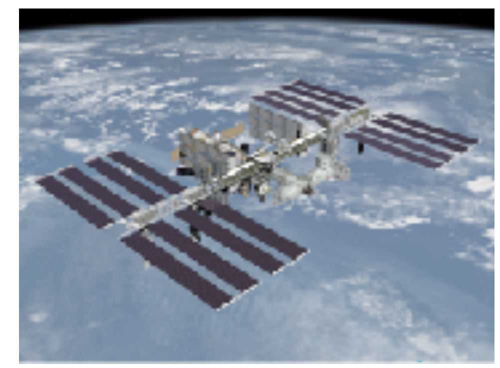
IMPACT

- Polar flights
- Astronauts
- Electronics
- Satellites: anomalies/loss

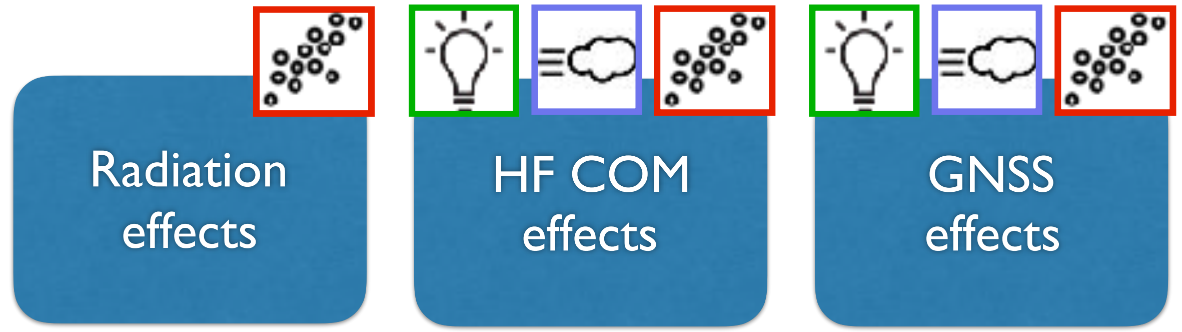


Today, airlines fly over 7,500 polar routes per year. These routes take aircraft to latitudes where **satellite communication cannot be used,** and flight crews must rely instead on high-frequency (HF) radio to maintain communication with air traffic control, as required by federal regulation. During certain space weather events, solar energetic particles spiral down geomagnetic field lines in the polar regions, where they **increase the density of ionized gas**, which in turn affects the propagation of radio waves and can result in **radio blackouts**. These events can last for several days, during which time aircraft must be diverted to latitudes where satellite communications can be used.

dodelijke stormen

No large Solar Energetic Particles events have happened during a manned space mission. However, such a large event happened on August 7, 1972, between the Apollo 16 and Apollo 17 lunar missions. The dose of particles would have hit an astronaut outside of Earth's protective magnetic field, had this event happened during one of these missions, the effects could have been life threatening.

SPACE WEATHER ADVISORY MESSAGES



Monitoring & forecasting space weather should result in 3 advisory messages.

HF COM effects

Forecasts up to 24 HR

We can use also 'NIGHTSIDE'

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	HF COM SEV
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z DAYLIGHT SIDE
FCST SWX +6 HR:	20121108/0700Z DAYLIGHT SIDE
FCST SWX +12 HR:	20161108/1300Z DAYLIGHT SIDE
FCST SWX +18 HR:	20161108/1900Z DAYLIGHT SIDE
FCST SWX +24 HR:	20161109/0100Z DAYLIGHT SIDE
RMK:	PERIODIC HF COM ABSORPTION HAS BEEN OBSERVED AND IS LIKELY TO CONTINUE IN THE NEAR TERM. COMPLETE AND PERIODIC LOSS OF HF ON THE SUNLIT SIDE OF THE EARTH EXPECTED. CONTINUED HF COM DEGRADATION LIKELY OVER THE NEXT 7 DAYS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	20161108/0700Z

Update provided at least after 6 HR

Additional info on a web-site

Radiation effects

Element		Range	Resolution
Flight Level:		250-600	30
Longitudes for advisories:	(degrees) (minutes)	000 – 180 00	15' 0
Latitude bands for advisories:	High latitudes northern hemisphere (HNH)	N9000 - N6000	30'
	Middle latitudes northern hemisphere (MNH)	N6000 - N3000	
	Equatorial latitudes northern hemisphere (EQN)	N3000 - N0000	
	Equatorial latitudes southern hemisphere (EQS)	S0000 - S3000	
	Middle latitudes southern hemisphere (MSH)	S3000 - S6000	
	High latitudes southern hemisphere (HSH)	S6000 - S9000	

(communication header)	
SWX ADVISORY	
DTG:	20161108/0000Z
SWXC:	(to be determined)
SWX EFFECT:	RADIATION MOD
ADVISORY NR:	2016/2
FCST SWX:	20161108/0100Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000 ABV FL350
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK:	RADIATION LEVELS HAVE EXCEEDED 100 PERCENT OF BACKGROUND LEVELS AT FL350 AND ABOVE. THE CURRENT EVENT HAS PEAKED AND LEVELS ARE SLOWLY RETURNING TO BACKGROUND LEVELS. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

HNH : High latitudes northern hemisphere, i.e. N9000- N6000
MNH : Middle latitudes nothern hemisphere, I.e. N6000- N3000
EQN
EQS
MSH
HSH : High latitudes Southern hemisphere

HF COM effects

GNSS effects

(communication header)	
SWX ADVISORY	
DTG:	20161108/0100Z
SWXC:	(to be determined)
SWX EFFECT:	GNSS MOD AND HF COM MOD
ADVISORY NR:	2016/1
OBS SWX:	20161108/0100Z HNH HSH E18000 – W18000
FCST SWX +6 HR:	20121108/0700Z HNH HSH E18000 – W18000
FCST SWX +12 HR:	20161108/1300Z HNH HSH E18000 – W18000
FCST SWX +18 HR:	20161108/1900Z HNH HSH E18000 – W18000
FCST SWX +24 HR:	20161109/0100Z NO SWX EXP
RMK.	LOW-LEVEL GEOMAGNETIC STORMING IS CAUSING INCREASED AURORAL ACTIVITY AND SUBSEQUENT MOD DEGRADATION OF GNSS AND HF COM AVAILABILITY IN THE AURORAL ZONE. THIS STORMING IS EXPECTED TO SUBSIDE
	IN THE FORECAST PERIOD. SEE WWW.SPACEWEATHERPROVIDER.WEB
NXT ADVISORY:	NO FURTHER ADVISORIES

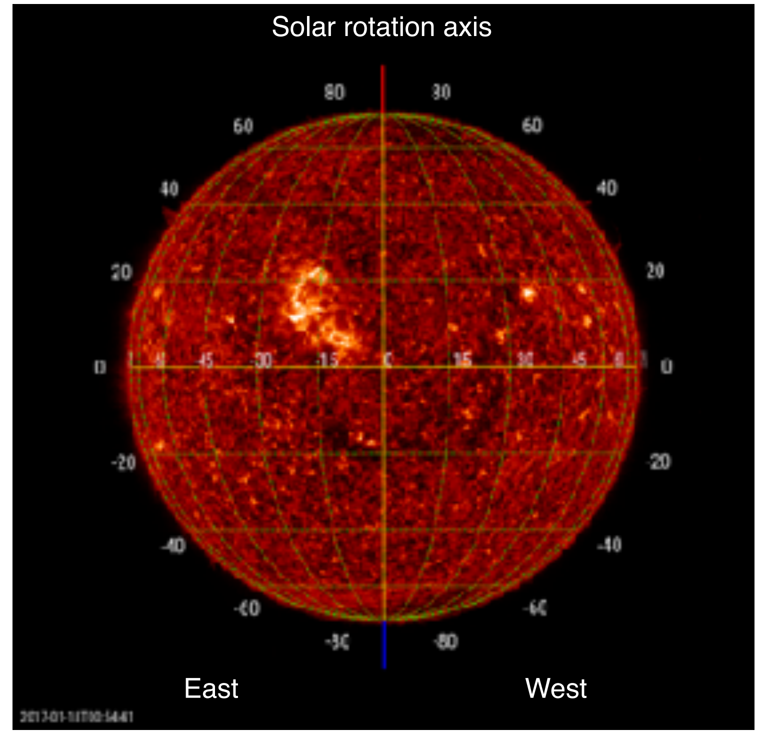
POSITIONING

Solar North Pole

Magnetic South Pole
positive/outward
yellow/white

Solar South Pole

Magnetic North Pole
negative/inward
blue/black



Northern hemisphere

Solar Equator

Southern hemisphere

Before going into more detail of flares (e.m. waves), CME's and CH's (solar plasma that moves through space) and SEPs (Solar Energetic Particles)/plasma storms (electrically charged particles that move along magnetic field lines through space), we have to be able to 'navigate' on the sun.

Two important circles/lines are: the central meridian and the solar equator.
You determine positions on the solar surface

Solar equatorial plane is not the ecliptic (plane in which the Earth orbits). The earth has a certain heliographic latitude. In summer and winter, the earth looks more on the poles. While in spring and autumn, earth is located in the solar equatorial plane.

magnetic reversal - at solar maximum: magnetic north pole becomes the magnetic south pole and reversed.
A magnetic cycle of 22 years.