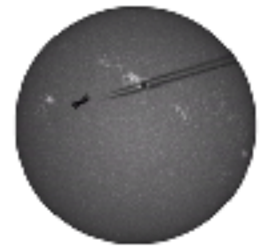


PECASUS

For civil aviation

SPACE WEATHER INTRODUCTORY COURSE

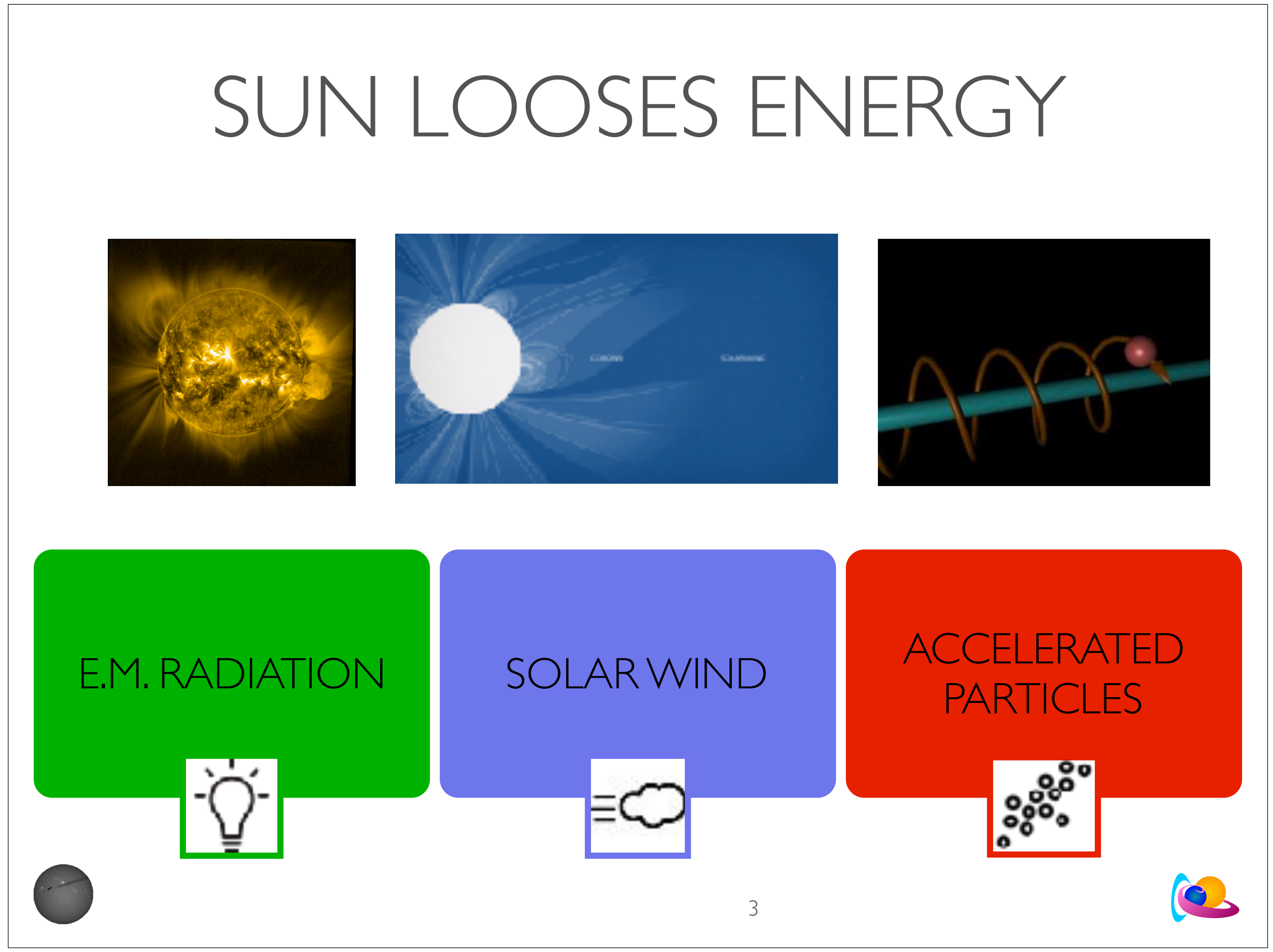
For space weather operators

Rehearsal

Example: presto alert of EG SOL

E.M. Radiation

Particle Radiation



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.

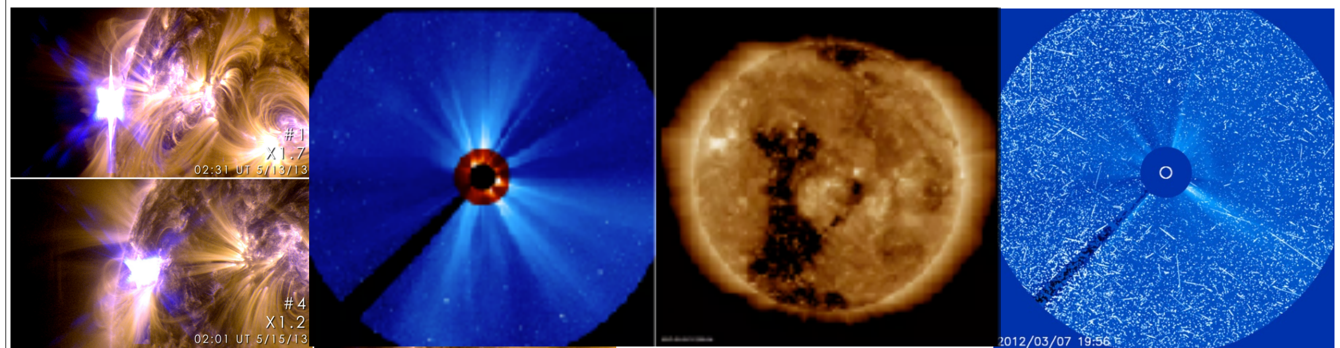
About the animated gif:
Conceptual animation (not to scale) showing the sun's corona and solar wind.
Credits: NASA's Goddard Space Flight Center/Lisa Poje

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



FLARE
-
SOLAR RADIO BURST

CME or CLOUD
-
FAST WIND from CORONAL HOLE

SEP

Magnetic reconnection triggers a sudden release of energy in the form of a flare, CME, particle event.

Space weather is the change 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

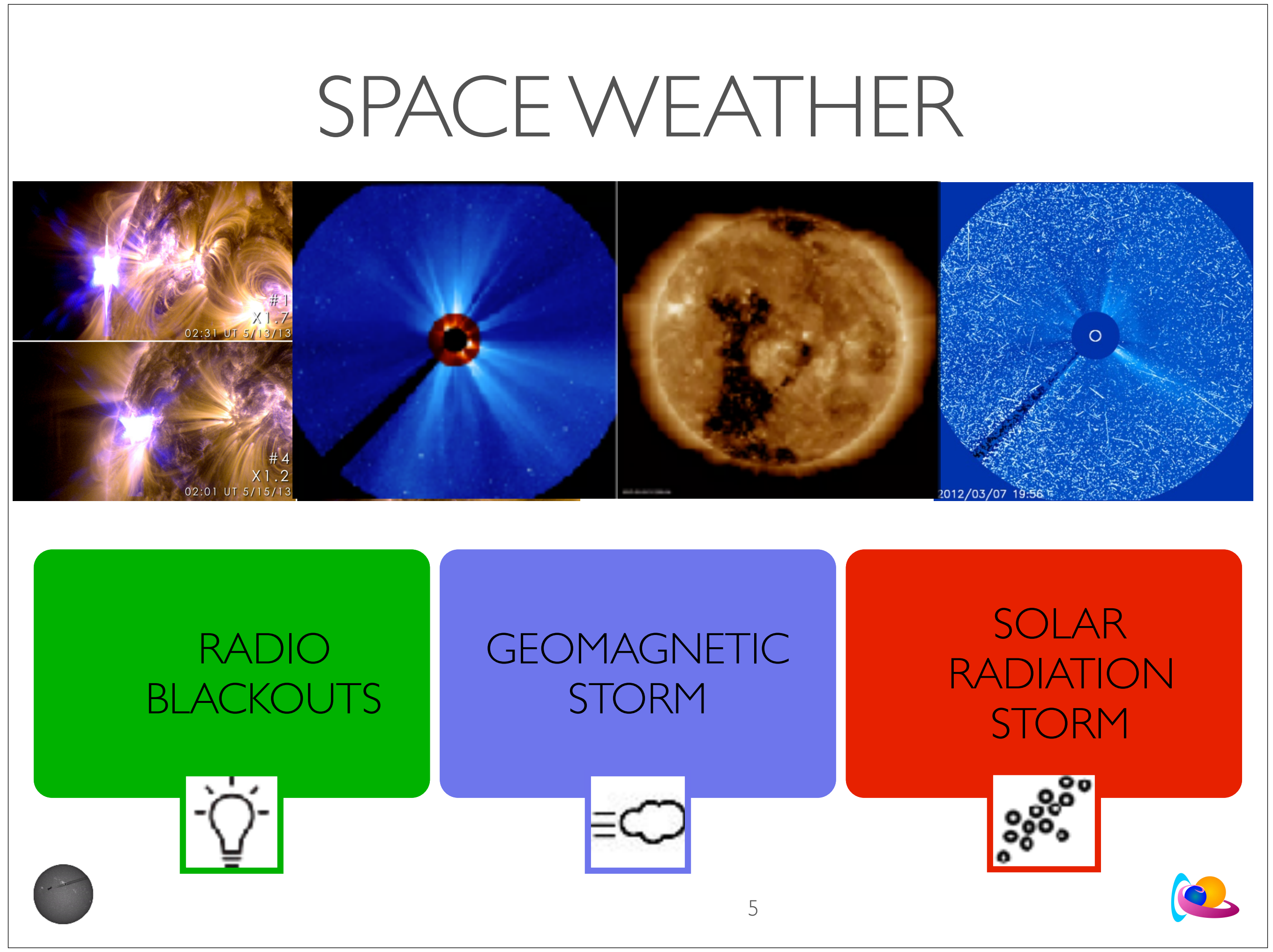
A Coronal Mass Ejection is a plasma cloud that is ejected into space. You consider it as a cloud and not as a bunch of individual particles. It is superimposed on the background solar wind. You can see a CME as a complex magnetic bag with different magnetic layers with plasma in it that travels as a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



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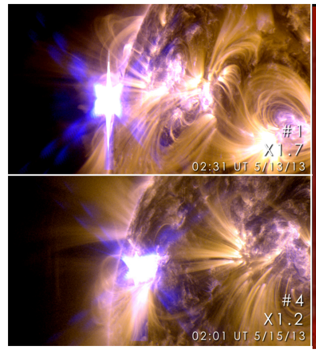
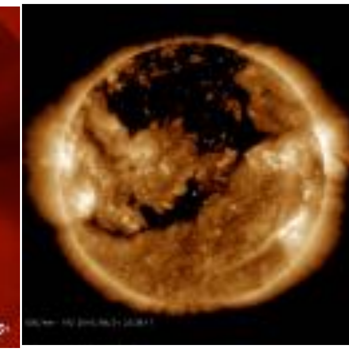
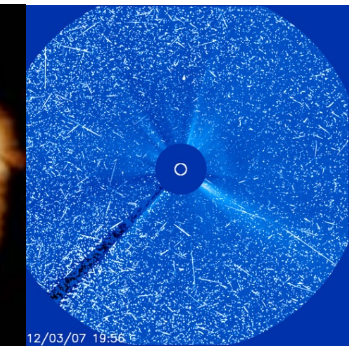
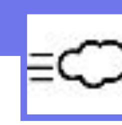
TIME SCALES OF SW



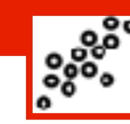




8 MIN

DAYS



HOUR



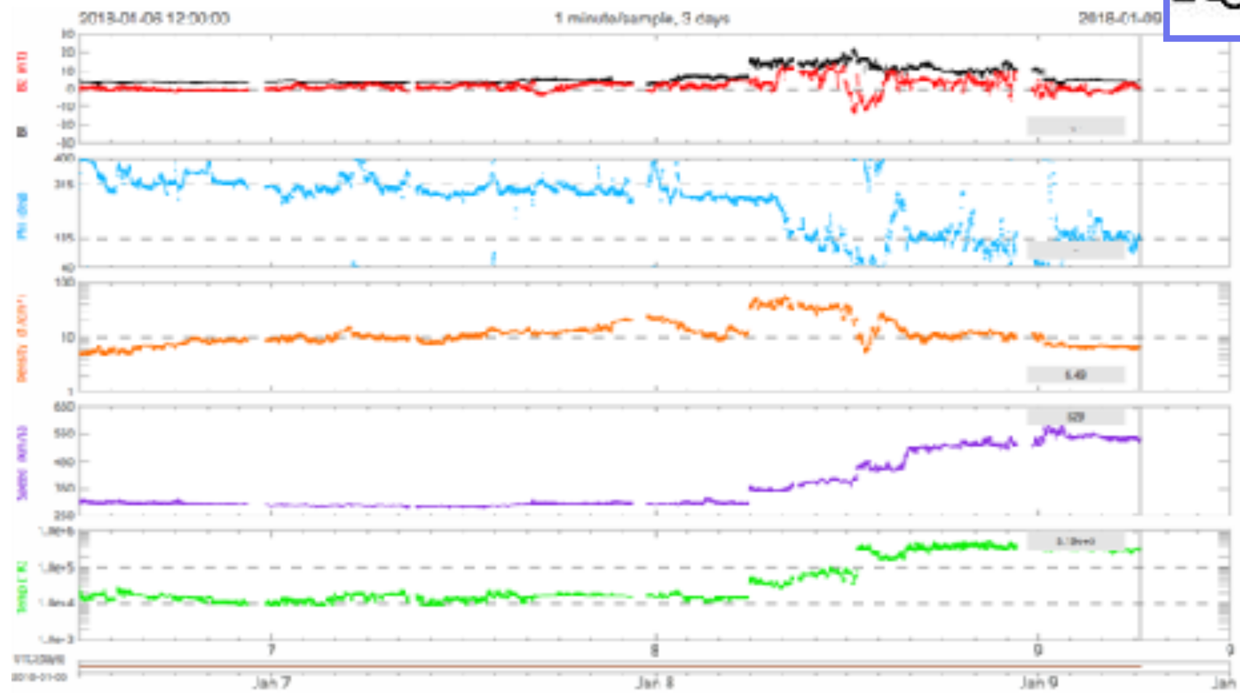
FORECAST AND ALERTS

Flare probability

Perturbations of the Geomagnetic field

Probability

```
:Issued: 2018 Jan 08 0857 UTC
:Product: documentation at http://www.sidc.be/products/presto
#--------------------------------------------------------------------#
# FAST WARNING 'PRESTO' MESSAGE  from the SIDC (RWC-Belgium)         #
#--------------------------------------------------------------------#
The in situ observations (from DSCOVR satellite) indicate arrival of the
interplanetary shock wave at 05:55 UT this morning. The sudden increase of
the solar wind speed (from about 290 to 350 km/s) was observed
simultaneously with the increase of the density, temperature and the
interplanetary magnetic field magnitude (from about 6 nT to 15 nT). Since
the solar wind speed was, and is still rather low, and the Bz component of
the interplanetary magnetic field was mostly positive, the shock arrival
did not induced disturbed geomagnetic conditions. The shock in the solar
wind is probably related with the expected arrival of the fast solar wind
associated with the low latitude extension of the northern polar coronal
hole which reached central meridian late evening of January 04.
```

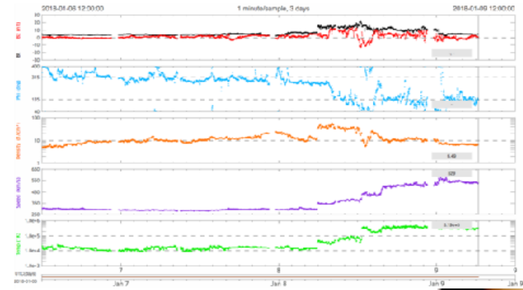

1 minute/sample, 3 days
Jan 7
Jan 8
Jan 9

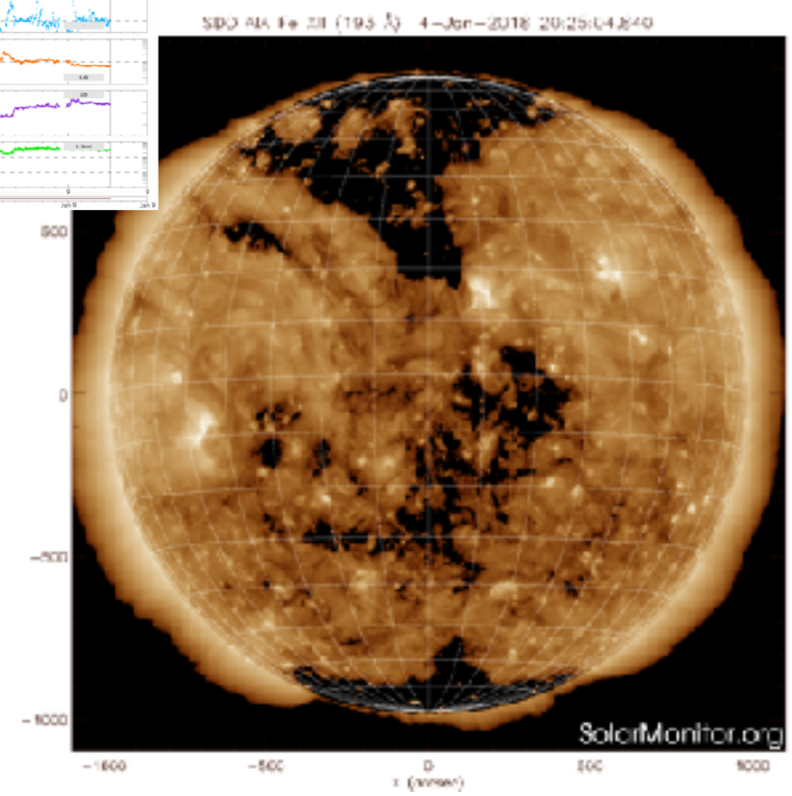
Time = Distance/Speed

CME travel times to earth assuming no deceleration

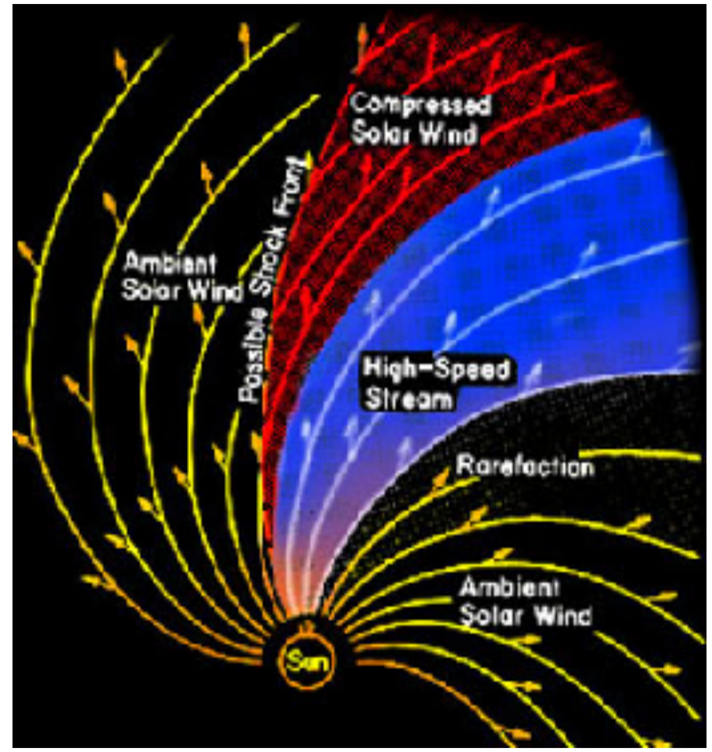
speed CME km/s	travel time (hr)	days	hours
300	138,88	5	18.88
400	104,16	4	8,16
500	83.33	3	11.33
600	69.44	2	21.44
700	59.52	2	11.52
800	52.08	2	4.08
900	46.30	1	22.30
1000	41.67	1	17.67
1100	37.88	1	13.88
1200	34.72	1	10.72
1300	32.05	1	8.05
1400	29.76	1	5.76
1500	27.78	1	3.78
1600	26.04	1	2.04
1700	24.51	1	0.51
1800	23.15	0	23.15
1900	21.93	0	21.93
2000	20.83	0	20.83
2100	19.84	0	19.84
2200	18.94	0	18.94

http://www.sidc.be/rwc/cor2speed/cor2speed.html#canvas_position




SolarMonitor.org

Slow and Fast solar wind

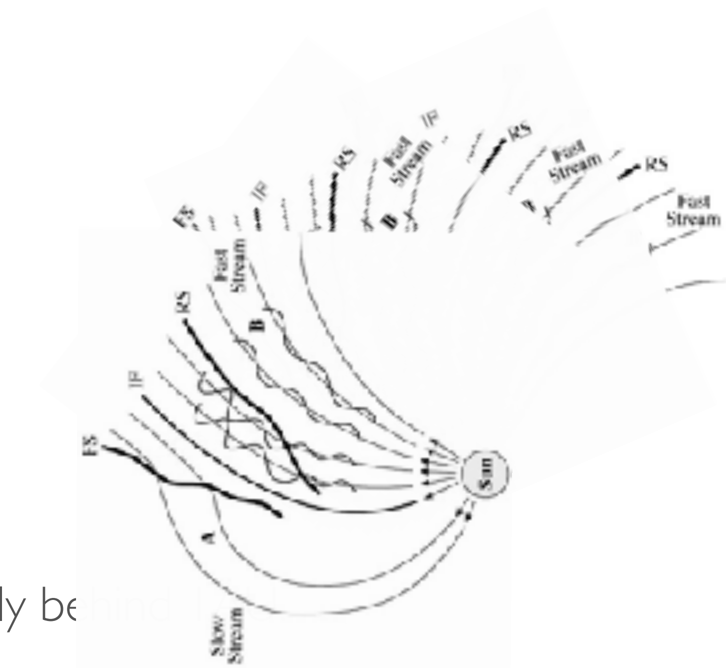


The Dst is a **geomagnetic index** which monitors the world wide magnetic storm level. It is constructed by averaging the horizontal component of the geomagnetic field from mid-latitude and equatorial magnetograms from all over the world. Negative Dst values indicate a magnetic storm is in progress, the more negative Dst is the more intense the magnetic storm. The negative deflections in the Dst index are caused by the storm time **ring current which flows around the Earth from east to west in the equatorial plane**. The ring current results from the differential gradient and curvature drifts of electrons and protons in the near Earth region and its strength is coupled to the solar wind conditions. Only when there is an eastward electric field in the solar wind **which corresponds to a southward interplanetary magnetic field (IMF)** is there any significant ring current injection resulting in a negative change to the Dst index. Thus, by knowing the solar wind conditions and the form of the coupling function between solar wind and ring current, an estimate of the Dst index can be made.

The **Auroral Electrojet Index, AE,** is designed to provide a global, quantitative measure of **auroral zone magnetic activity produced by enhanced Ionospheric currents** flowing below and within the auroral oval.

CORONAL HOLE

- Co-rotating structure
- Radial!
- No extra mass-flux
- Shocks are present, usually be



als zon niet ronddraait, haalt de snelle zonnewind de trage niet in want die zit er niet achter.

doordat de zon roteert, creëer je dit profiel.

Cartoon showing the interaction of a fast and a slow stream. The fast stream runs into the slow wind, forming a compression region between the two, which results eventually in the formation of a forward-reverse shock pair.

As the wind expands radially, the flow follows the same spiral pattern, but fast wind "catches up" to slow wind and crashes into it. At the interface between the fast and slow wind (b), a large pressure pulse forms and eventually steepens to create a forward and reverse shock pair. The thin boundaries separating the streams are called co-rotating interaction regions or CIRs.

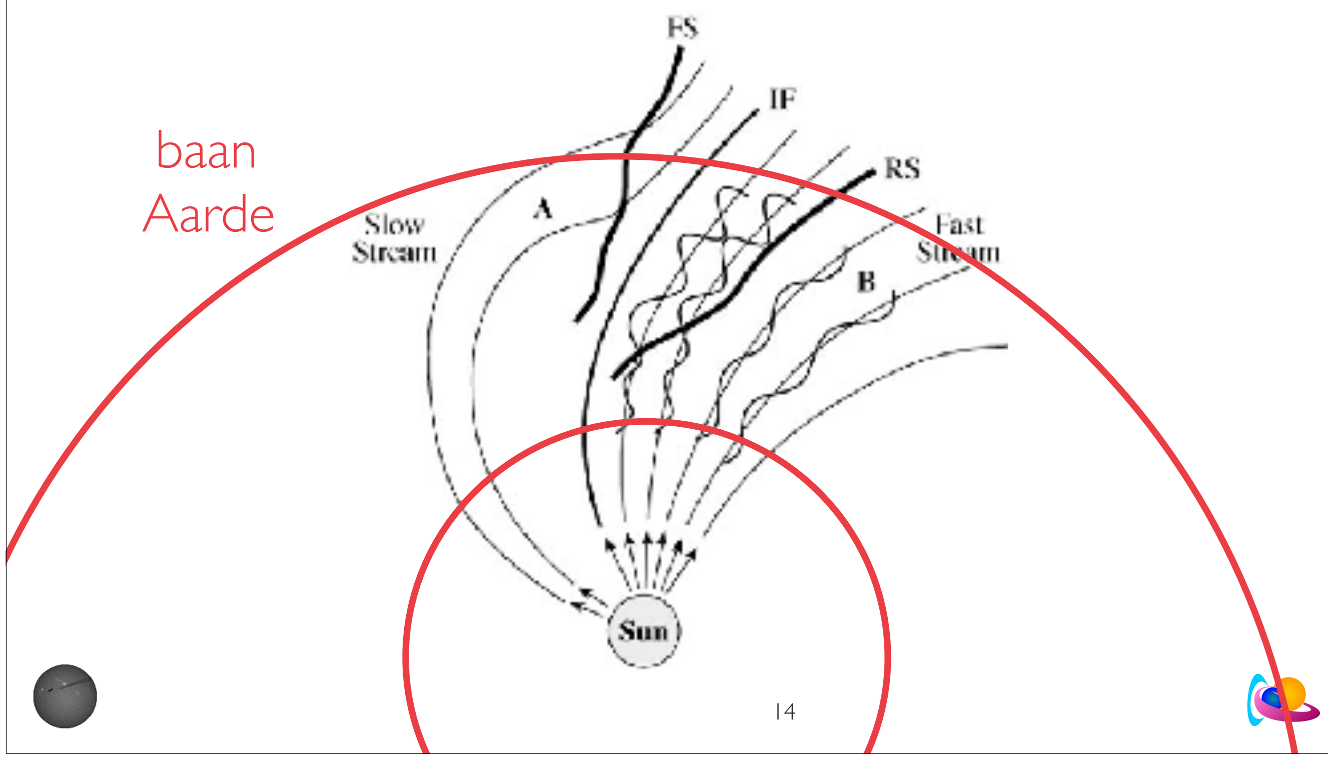
continue toevoer, oorzaak blijft aanwezig

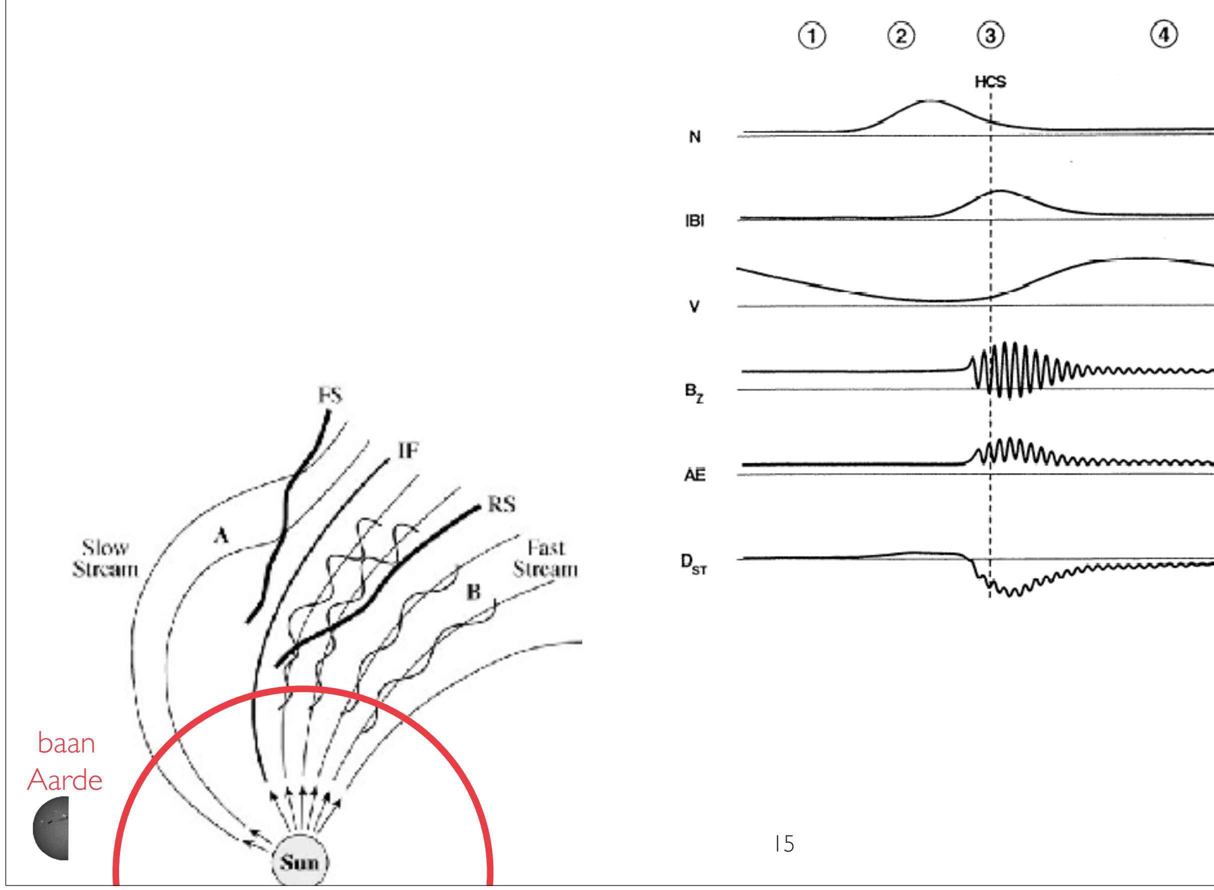
When fast solar-wind streams, emanating from coronal holes, interact with slow streams, they can produce Co-rotating Interaction Regions in interplanetary space. The magnetic fields of the slow streams in the solar wind are more curved due to the lower speeds, and the fields of the fast streams are more radial because of their higher speeds. Intense magnetic fields can be produced at the interface (IF) between the fast and slow streams in the solar wind. The Co-rotating Interaction Regions are bounded by a forward shock (FS) and a reverse shock (RS).

One reason why two shocks are eventually formed at a CIR is due to symmetry about the pressure enhancement caused by compression and entraining of the slow wind ahead of the fast stream (Figure 10.9 [Gosling, 1996]): **shocks are driven away from the pressure increase in both directions**, resulting in a so-called \Forward-Reverse shock pair" in which the forward shock propagates away from the Sun while the reverse shock propagates towards the Sun but is carried out with the solar wind flow.

http://www.boulder.swri.edu/~deforest/Movies.html

Tijd - booglengte





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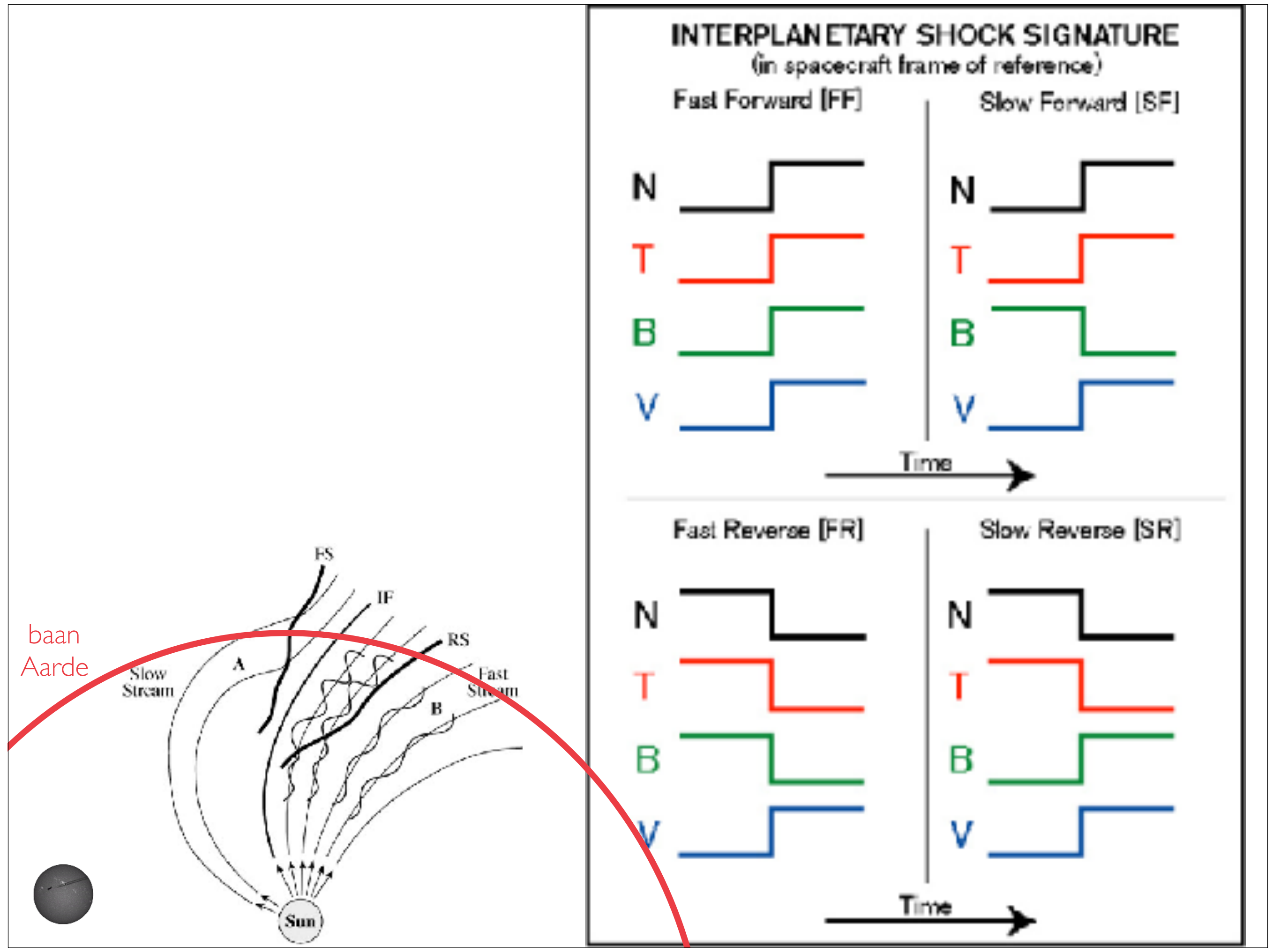
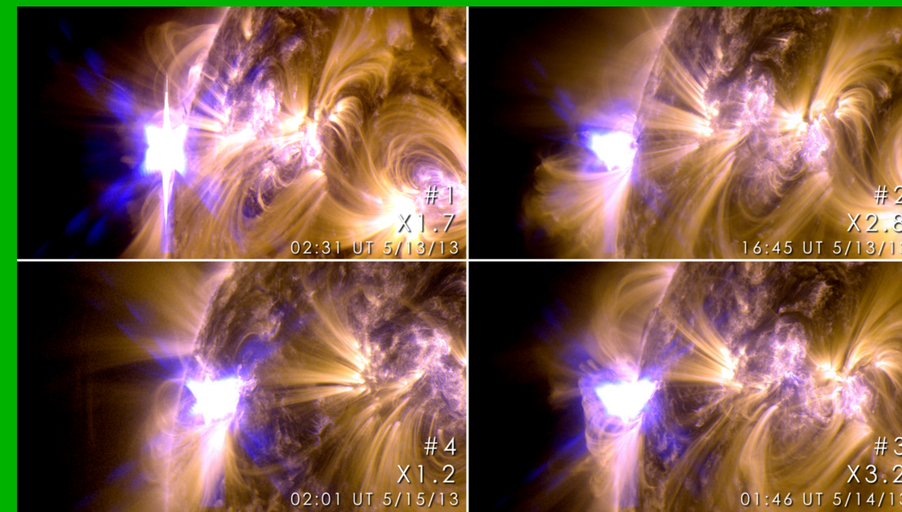


The front flank needs to move of course faster than the slow plasma in front of it. The shock in the front is called a forward shock, the shock trailing the high density region is called a reversed shock. For all shocks, it is the difference in speed between the slow and the fast solar wind that drives the whole system. When a forward shock driven by a CIR passes an instrument that makes in situ measurements, the speed, density and temperature suddenly increase. When a reversed shock passes, the speed increases, but density and temperature decrease.

Once passed the reversed shock, you end up in the fast stream emanating from the coronal hole with a typically low density and high speed such that the plasma flux is the same as in the part where you have a slow but dense plasma.



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.

From the CISM Summer School (Boulder, August 2013) - SW101_4_Flares
https://www.bu.edu/cism/SummerSchool/summerlist.html

Solar flares are sudden bursts of radiation lasting minutes - hours at wavelengths that can include:
Gamma-rays, HXR, SXR, EUV; H-alpha, radio

A large quantity of energy is released from a small volume in a short period of time. This requires:
Either a large amount of energy stored in that small volume that can be quickly transformed and released as energetic electrons and photons.
Or very efficient transport of energy into that volume where it is then converted into the observed forms.
The only viable energy source is intense solar magnetic fields.
Thus we need a very rapid means of converting stored magnetic energy into particle energy and heat - magnetic reconnection.

Magnetic energy is converted to thermal/radiative energy (flare, radio bursts) and kinetic energy (mass movement from CMEs and SEPs).

http://solarphysics.livingreviews.org/Articles/lrsp-2011-6/
Solar Flares: Magnetohydrodynamic Processes
Kazunari Shibata and Tetsuya Magara

SUNSPOTS

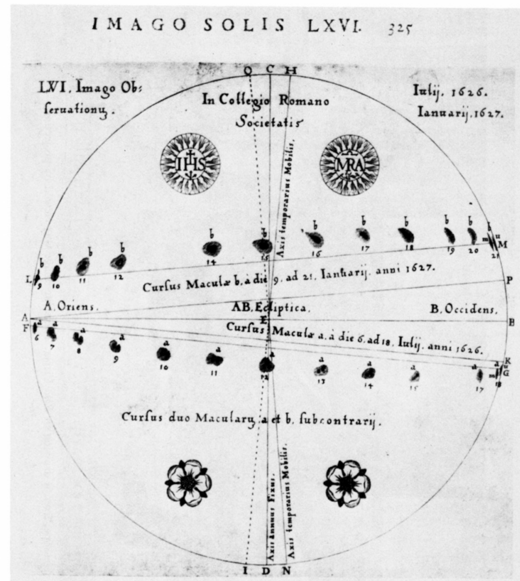
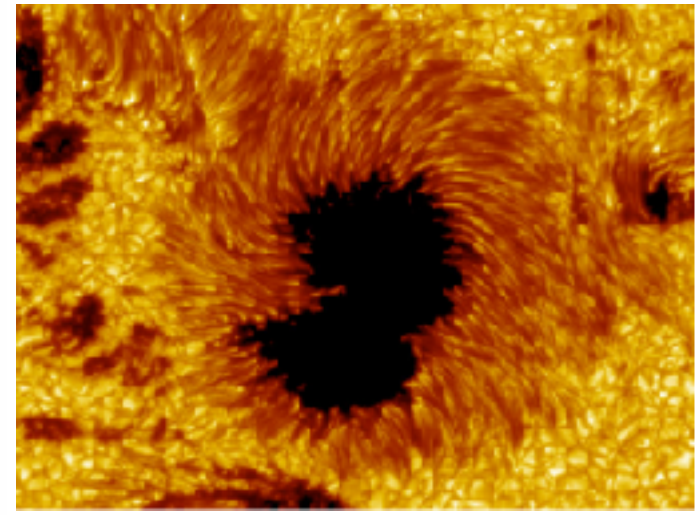


PLATE 1.1. Sunspot drawing from Scheiner's *Rosa Ursina*, showing the apparent paths of two spots across the solar disk at different times of the year. In both spots the umbra and penumbra are clearly distinguished.



rosa ursina: 1626–30

Zonnevlekken zijn de oudste en meest gekende uitingen van zonneactiviteit.

De zonneactiviteit is het geheel aan fenomenen waarbij energie op een impulsieve manier wordt vrijgegeven in de zonne-atmosfeer, en die gegenereerd wordt door de evolutie en brutale transformatie van magneetvelden die doorheen het zonneoppervlak lopen.

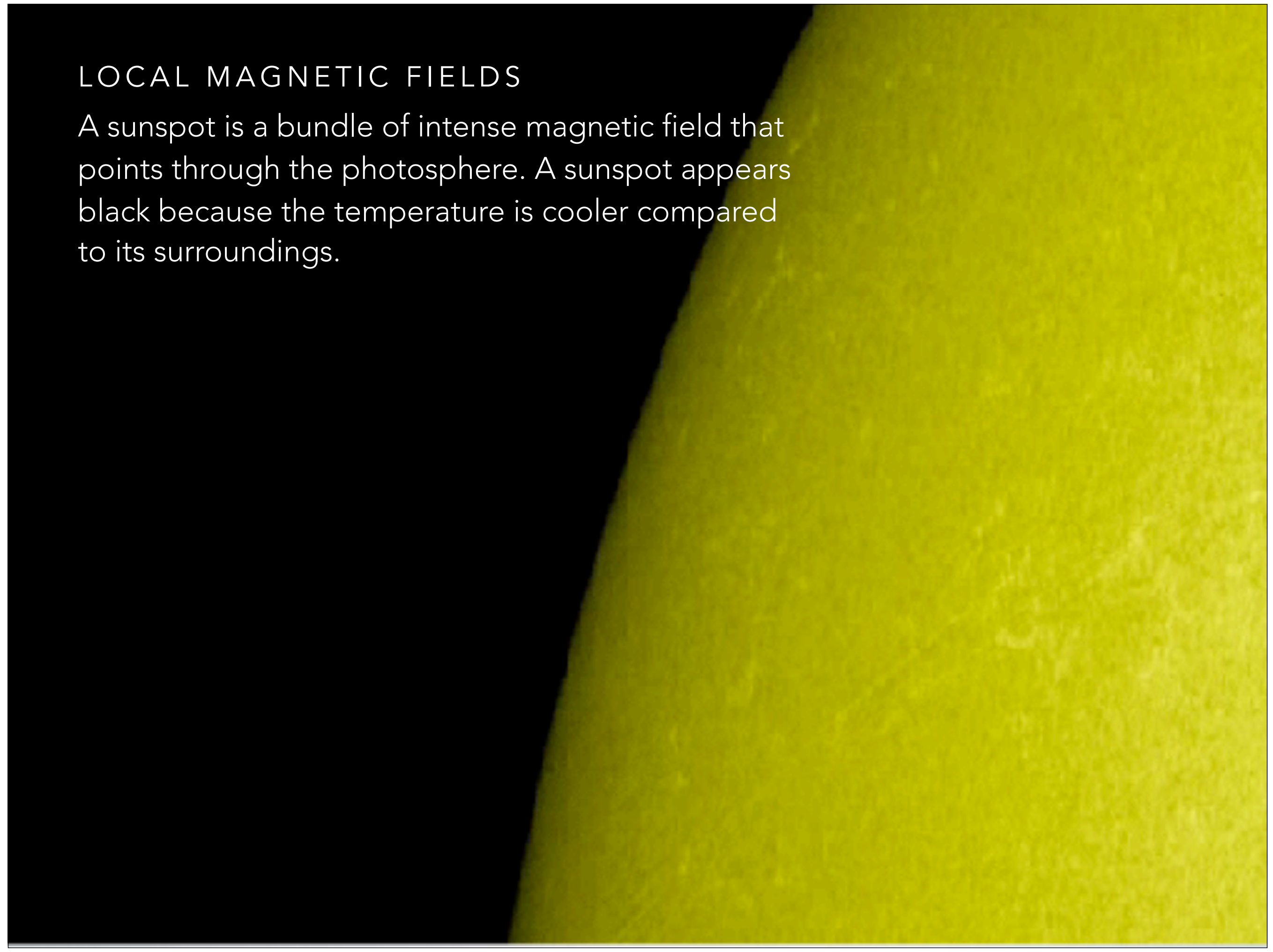
Zonnevlekken zijn donkere gebieden in de fotosfeer.
De kleinste vlekken hebben geen structuur (diameter D < 2 500km)
Voor D >2 500km, bestaan de vlekken uit 2 zones:
Centrale Schaduw:
Diameter =10 tot 15 000 km
Lichtsterkte = 5 tot 30% IFotosfeer
Halfschaduw:
Diameter : tot 50 000km
Lichtsterkte = 50 tot 70 % IFotosfeer

De vlekken leven enkele uren tot enkele maanden.

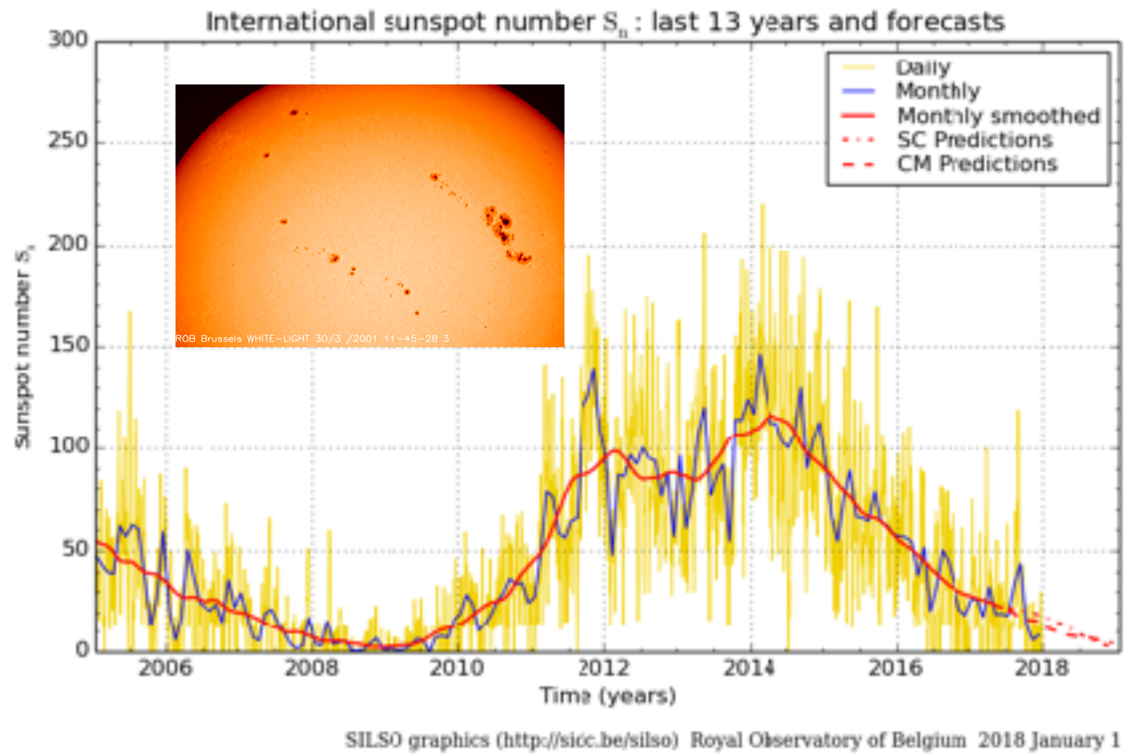
De temperatuur van de centrale schaduw is 4 000K, in plaats van 5 800K voor de normale fotosfeer.

Vlekken vormen langwerpige groepen, meestal uitgerokken in de oost-west richting. Ze kunnen tot 50 vlekken bevatten en zich uitsmeren over 20 lengtegraden.

Deze groepen spreiden zich uit over 2 strips tussen de 5e tot de 40e breedtegraad.



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.



$$R = k\,(10 \times Ng + Ns)$$

K - reduction coefficient, scaling factor, quality index — ingevoerd door Wolfer. Wolf, de vorige directeur heeft k = 1.

hangt af van hoe
goed een waarnemer kleine zonnevlekken kan waarnemen : persoonlijke ervaring, lokale zichtbaarheid, sterkte telescoop, zicht van de ogen, …

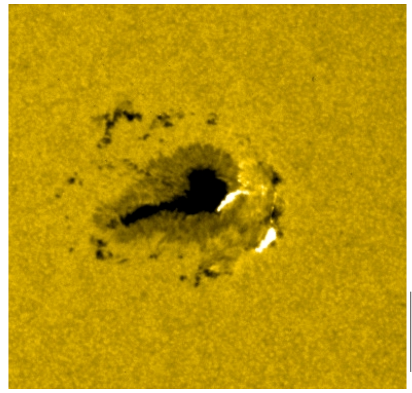
waarnemer groepen opsplitst

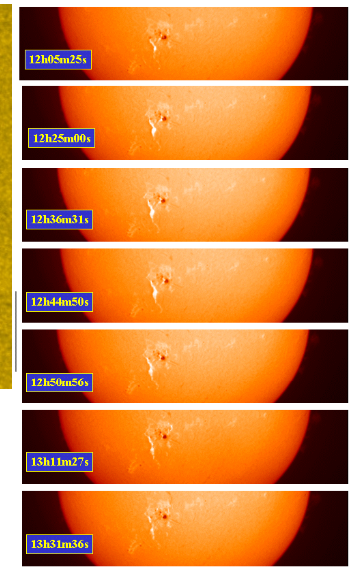
hierdoor kan het zonnevlekkengetal van 1 waarnemer verschillen van een geheel getal.

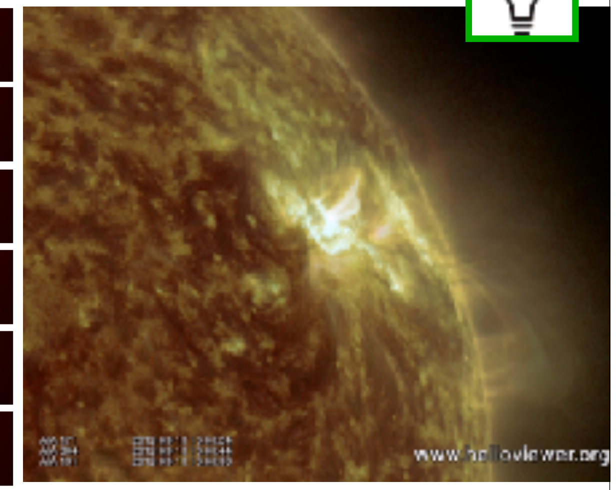
Het is een ‘synthetische’ index: gedefinieerd volgens een absolute maar arbitraire schaal - komt niet overeen met een fysische eenheid.

k<1 —-> neiging om meer vlekken te zien dan Wolf
k>1 —-> neiging om minder vlekken te zien dan Wolf

Flare







FLARES

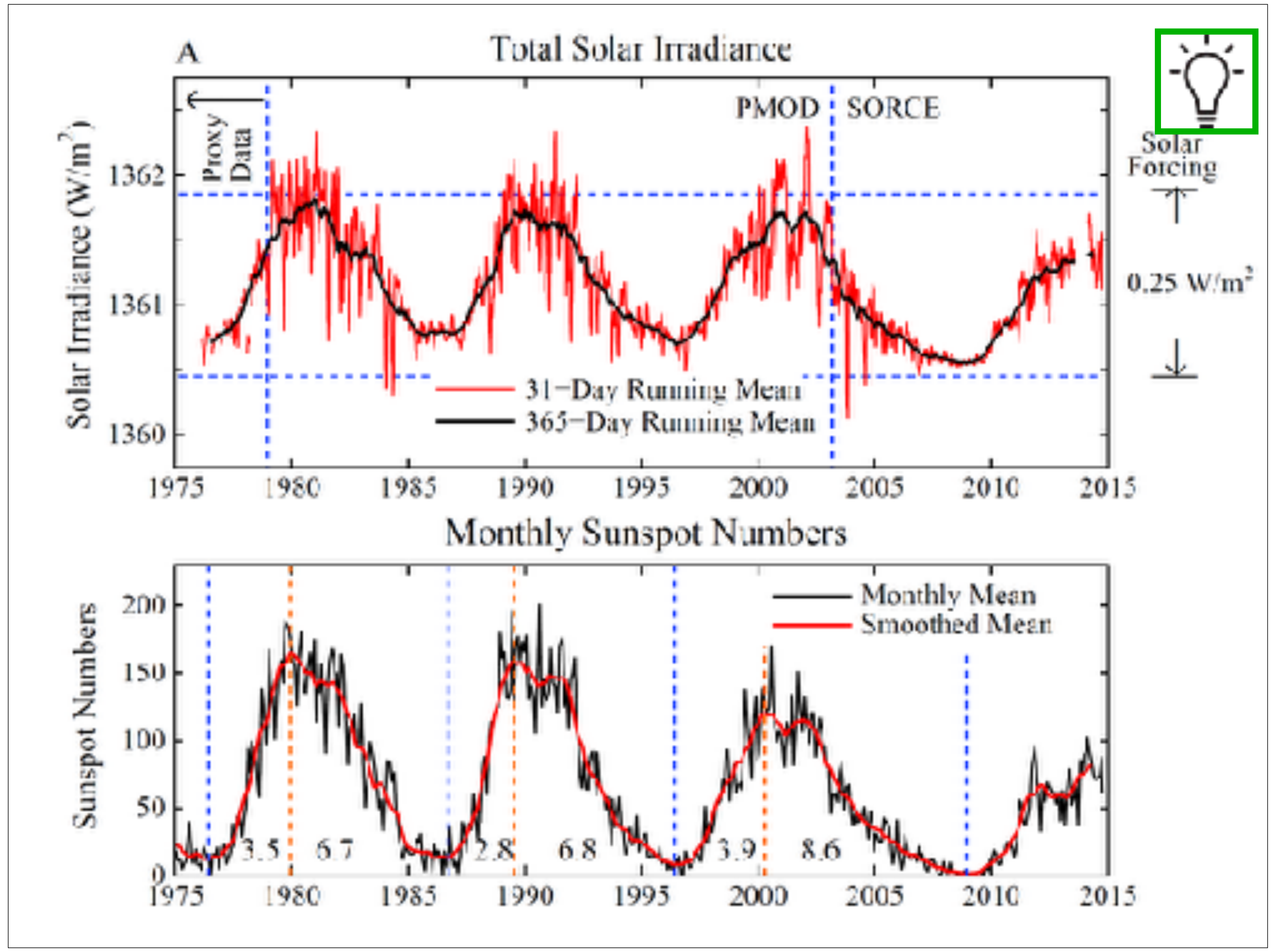
Visible in different layers
Photosphere - Chromosphere - Corona

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.

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.

How to classify flares?



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

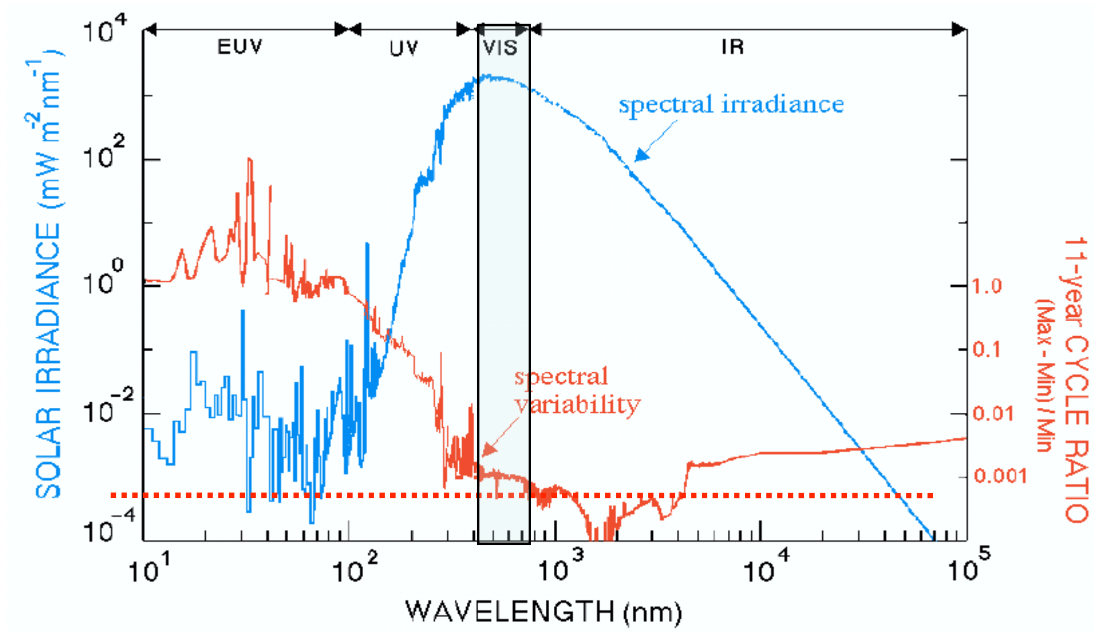
The solar constant, a measure of flux density, is the mean solar electromagnetic radiation (the solar irradiance) per unit area that would be incident on a plane perpendicular to the rays, at a distance of one astronomical unit (AU) from the Sun (roughly the mean distance from the Sun to the Earth). The solar constant includes all types of solar radiation, not just the visible light. It is measured by satellite as being 1.361 kilowatts per square meter (kW/m²) at solar minimum and approximately 0.1% greater (roughly 1.362 kW/m²) at solar maximum.

TSI: sunspots down
facula ?up

TSI geeft een indruk van globaal gedrag, maar niet van momentaan gedrag ?? zonnevlekkenindex

VARIATION LUMINOSITY

Solar light varies the strongest in the EUV part of the spectrum and the least the visible and infra red part.



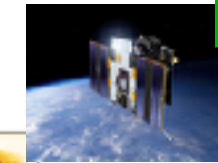
Het zichtbare en infrarode spectrum, voortgebracht ter hoogte van de fotosfeer, varieert bijzonder weinig (<1%).
De variaties zijn veel hoger (een factor 10 tot 1000), bij golflengtes onder de 320 nm, in het ultraviolet. Deze straling, die echter van de andere lagen komt (chromosfeer, corona) komt slechts overeen met 2% van de totale straling. Ze heeft niettemin een belangrijk effect op de hogere aardatmosfeer

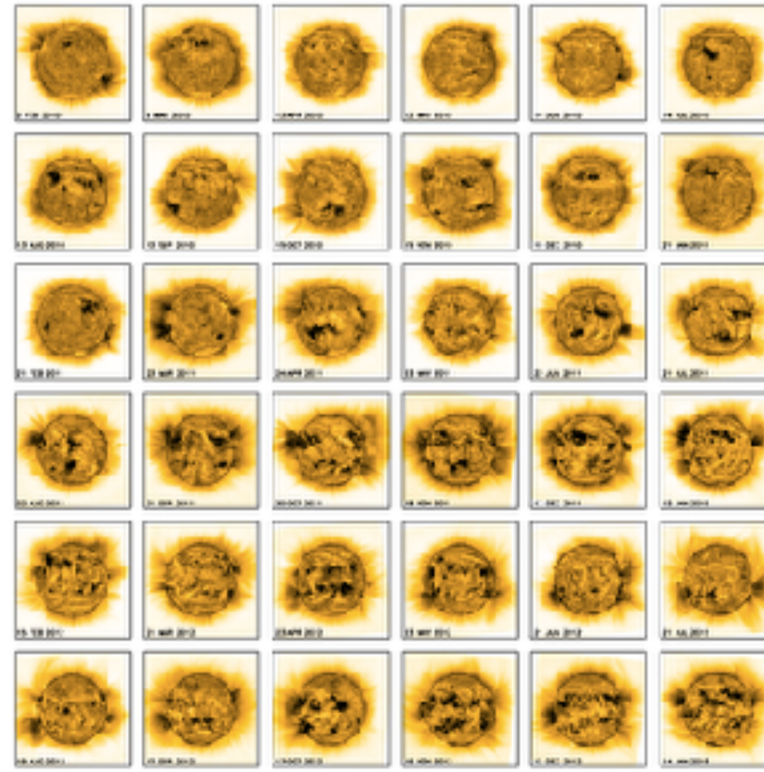
als je alles integreert onder de blauwe curve, bekom je de TSI

als je de TSI vermenigvuldigd met het oppervlak van een bol met straal 1AU,
4*Pi*R^2*1367 met R=1,496 10^8 km dan bekom je de lichtkracht van de zon, 3,839 10^26 Watt

waarom volgt ons klimaat niet de 11-jarige cyclus: de bijdrage tot de TSI van het stuk van het spectrum dat het meest varieert over een zonnecyclus is het kleinst

EUV variation over 5 year

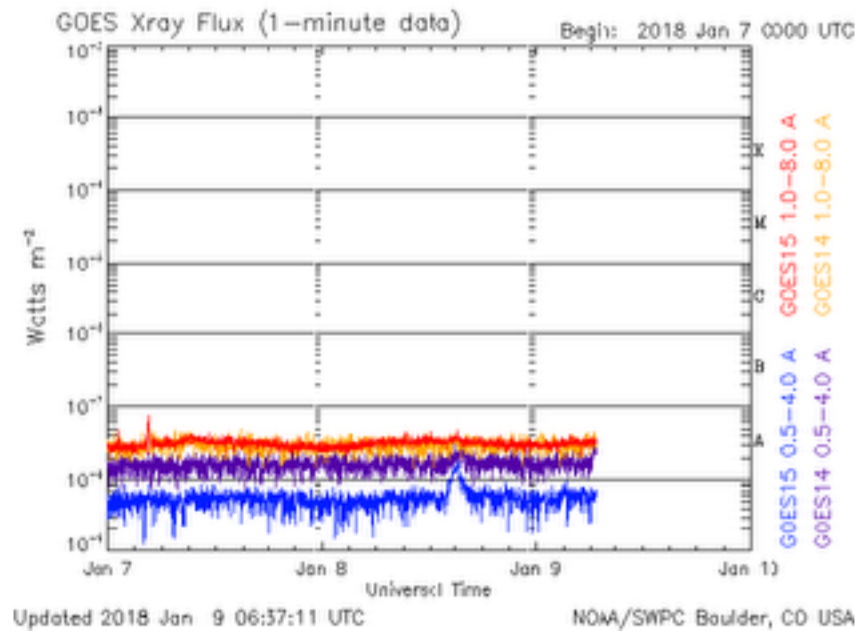




Flare

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

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.

A flare can be a simple peak in the X-ray curve or a long duration event.

NOAA SPACE WEATHER SCALES

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)

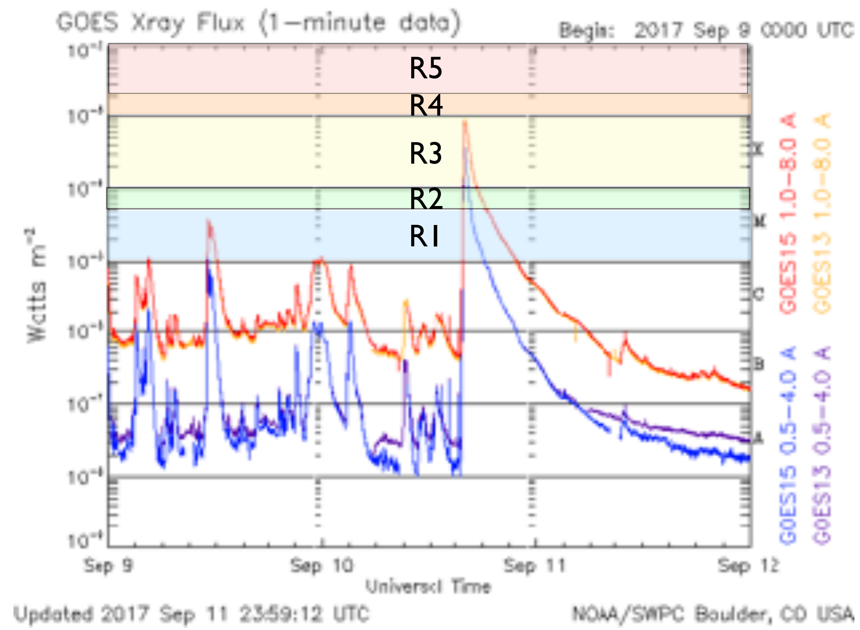
* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on this measure, but other physical measures are also considered.

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

URL: www.swpc.noaa.gov/NOAAscales

April 7, 2011

FLARE CATEGORIES & SW SCALES



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

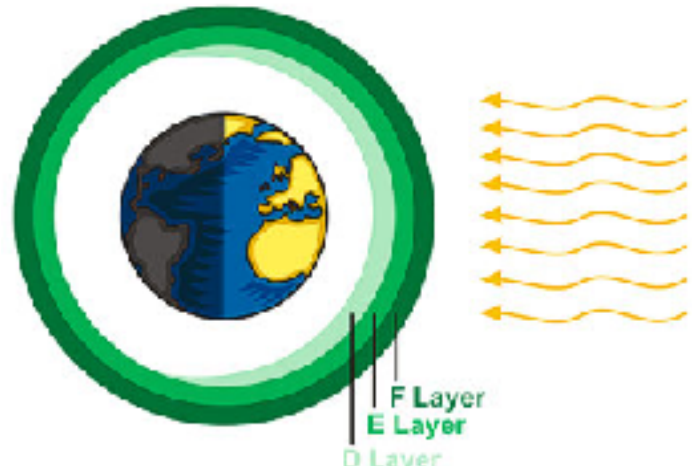
During a flare, magnetic energy is transformed into e.m. waves.

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.

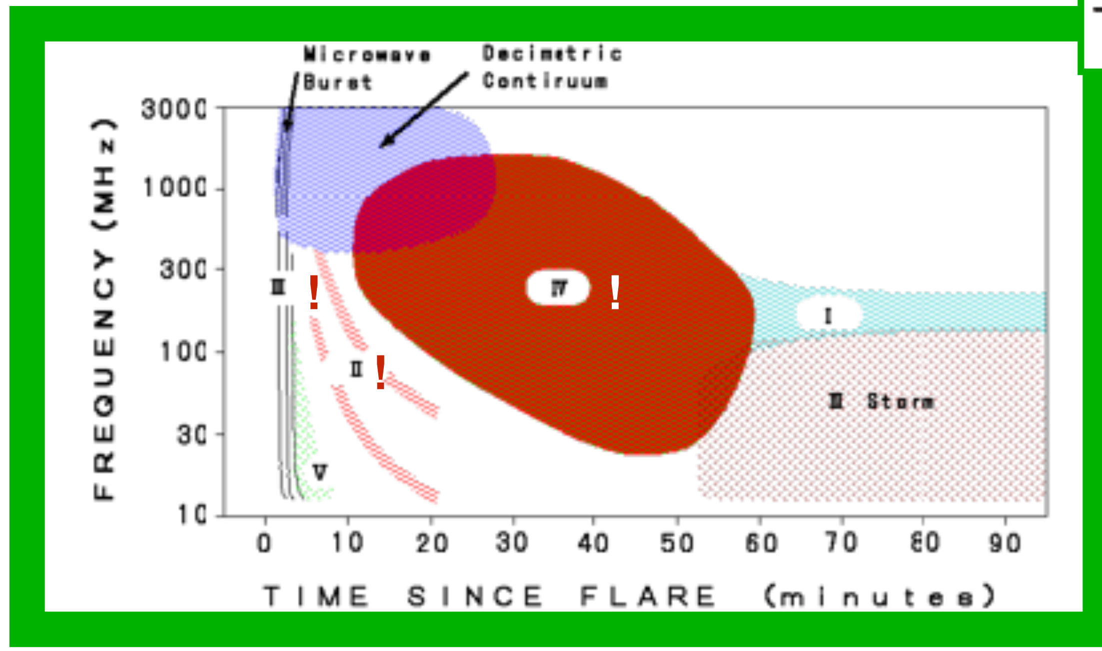
Flares are put into X-ray flux categories. The X-ray flux is measured by GOES (meteo-satellites of NOAA). The classes are based on the enlargement factor of the X-flux in the spectral range 1 to 8 Å - logarithmic. This enlargement factor can go up to 10 000, typically between 10 and 100.

IMPACT

- GNSS
- Radio communication
- Drag on satellites



Global Navigation Satellite System



SOLAR RADIO BURSTS

We can measure the **solar e.m. radio output and put it into a spectrogram.**
At low frequencies, **5 types** of radio wave bursts are seen, **each with a unique signature in frequency and time.**

These bursts are triggered by a solar event.

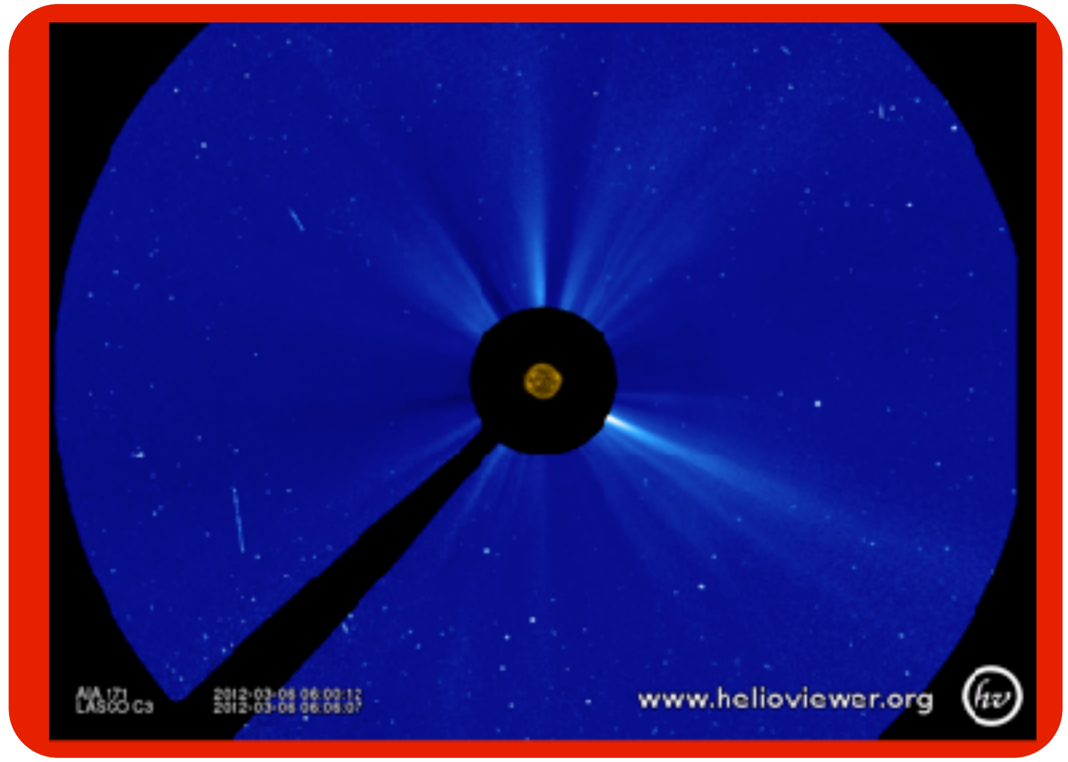
Mind the orientation of the vertical axis! Other figures may have a reversed direction. As the frequency is proportional to the square root of the density, and the density decreases with increasing distance from the Sun, a decreasing frequency means locations higher up in the solar atmosphere.

The ionospheric cut-off frequency is around 15MHz (due to too low frequency and so reflected by ionosphere). In order to observe radio disturbances below this frequency, one has to use satellites (above the earth atmosphere) such as STEREO/SWAVES or WIND. Radio bursts at low frequencies (< 15 MHz) are of particular interest because they are associated with energetic CMEs that travel far into the interplanetary (IP) medium and affect Earth's space environment if Earth-directed. Low frequency radio emission needs to be observed from space because of the ionospheric cutoff.
Example: https://stereo-ssc.nascom.nasa.gov/browse/2017/01/16/insitu.shtml

Coronal Mass Ejections and solar radio emissions, N. Gopalswamy
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.708.626&rep=rep1&type=pdf
Gopalswamy: The three most relevant to space weather radio burst types are type II, III, and IV. Three types of low-frequency non-thermal radio bursts are associated with coronal mass ejections (CMEs): Type III bursts due to accelerated electrons propagating along open magnetic field lines, type II bursts due to electrons accelerated in shocks, and type IV bursts due to electrons trapped in post-eruption arcades behind CMEs.

[Radio burst type II, III, and IV are also the only ones that ever get mentioned in the Ursigrams.]

PROTON STORM

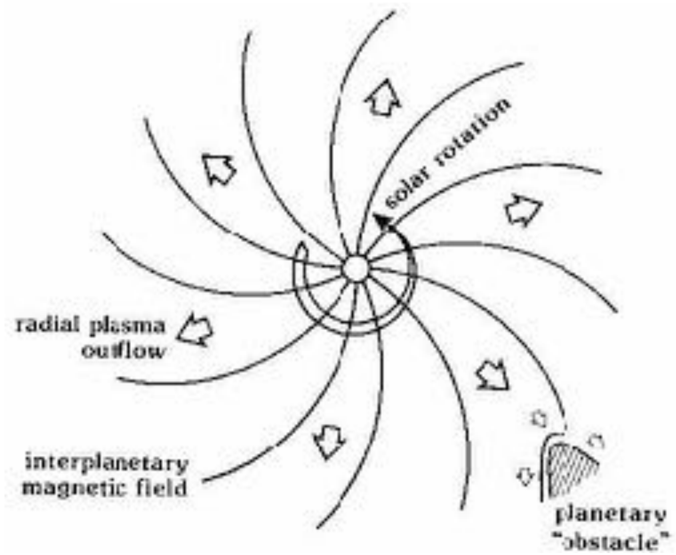


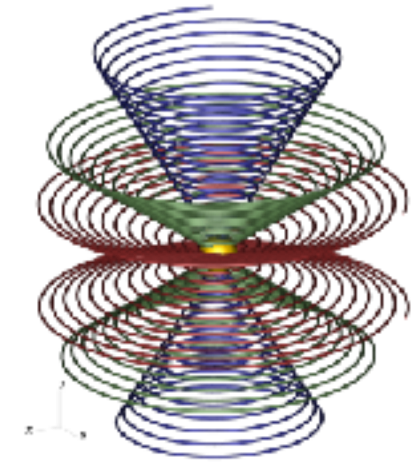
Electrically charged particles that are ejected by the Sun. They spiral around magnetic field lines.
They are ejected during an flare or CME event. The solar event accelerates the particles.

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.

INTERPLANETARY MAGNETIC FIELD

The interplanetary space is filled with the magnetic field of the dipolar Sun. If these fields pass along the Earth, we say that the Earth is magnetically connected.





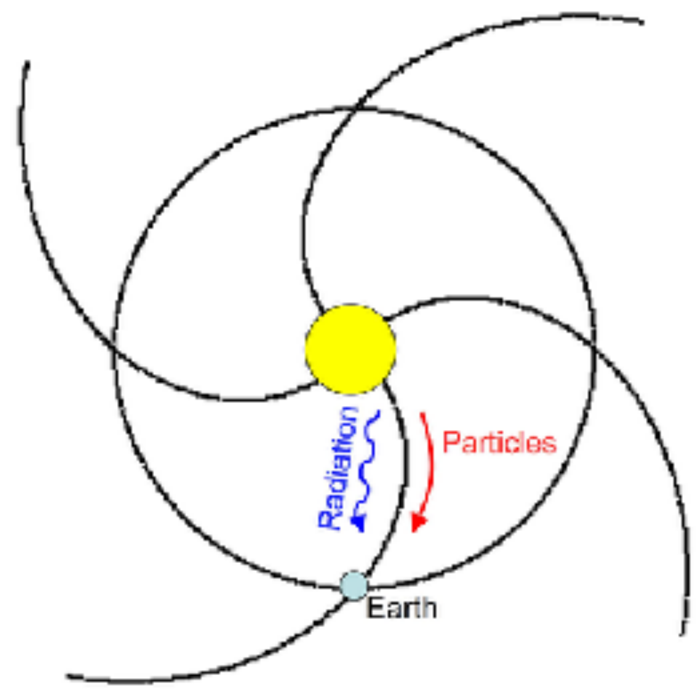
Left: This is a view of the global IMF in the solar equatorial plane.
Right: The IMF and our space is 3D. You have at a particular latitude also IMF lines coming out. Also these lines bend because of the solar rotation. All IMF lines at a particular latitude form a magnetic coin. The solar equatorial plane is a flat cone :)

This is the ideal IMF.
left: It has no component perpendicular on the solar equatorial plane.
right: it has no component perpendicular to the surface of the magnetic cone.

The frozen-flux theorem: IMF and plasma are glued.
The food points of the magnetic field lines are attached to the sun. At the same time, the plasma of the solar wind on the further distance is glued to that same magnetic field line. When the sun rotates, the IMF is forced to bend.

INTERPLANETARY MAGNETIC FIELD

The interplanetary space is filled with the magnetic field of the dipolar Sun. If these fields pass along the Earth, we say that the Earth is magnetically connected.

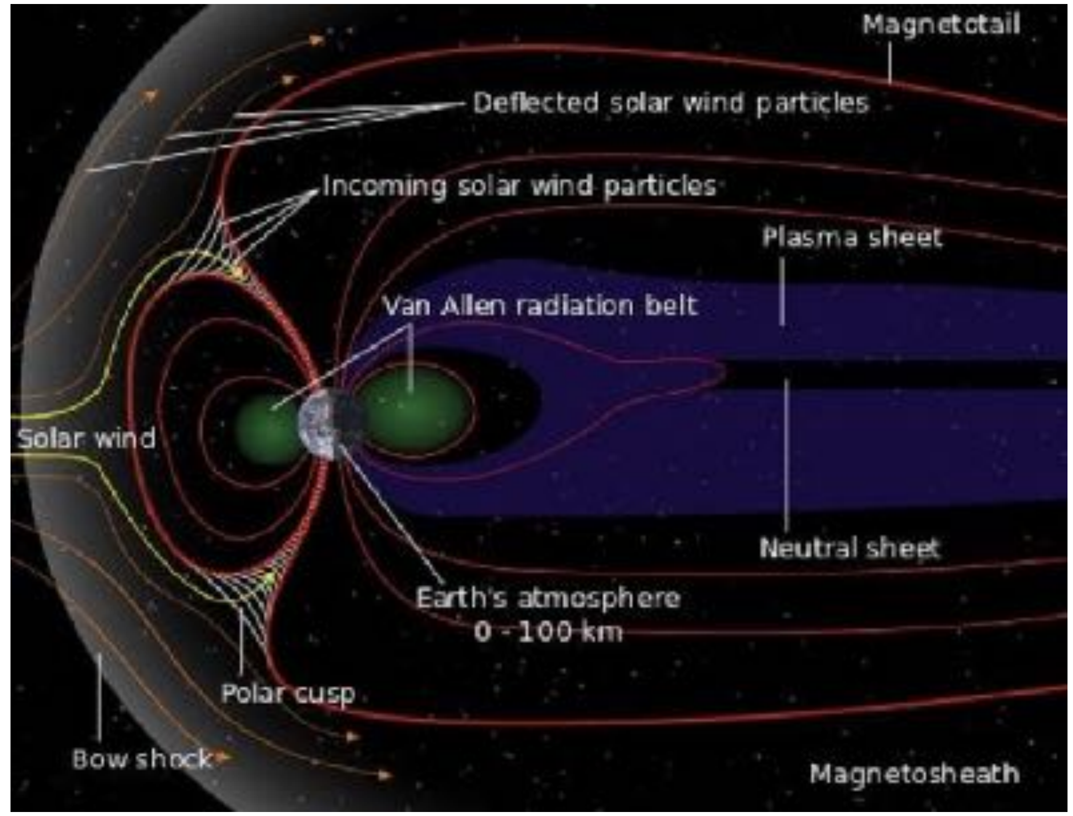


Electrically charged particles that are ejected by the Sun. They spiral around magnetic field lines.
They are ejected during an flare or CME event. The solar event accelerates the particles.

The field lines extending into the interplanetary space remain rooted in the Sun, and rotate with it. The radial outflow of the solar wind resembles the outflow of water from a rotating sprinkler in the garden. An observer on the Sun following a parcel of solar wind would see just the same. And the magnetic field is aligned with this trajectory. This is why magnetic field lines in the interplanetary medium are curved. When one looks on them from above the Sun's northern pole, they have the shape of an Archimedean spiral, which is also called a Parker spiral, after Eugene Parker who in 1958 developed the first hydrodynamical model of the solar wind with its embedded magnetic field. As seen in the Figure, the Parker spiral magnetic field line connects the Earth with a point to the right of the centre of the solar disk, in the Sun's western hemisphere.

CME: shock front has large extension and can intercept with some magnetic field line connected with earth
→even backsided CME can give rise to protons arriving at earth (UNCERTAIN)

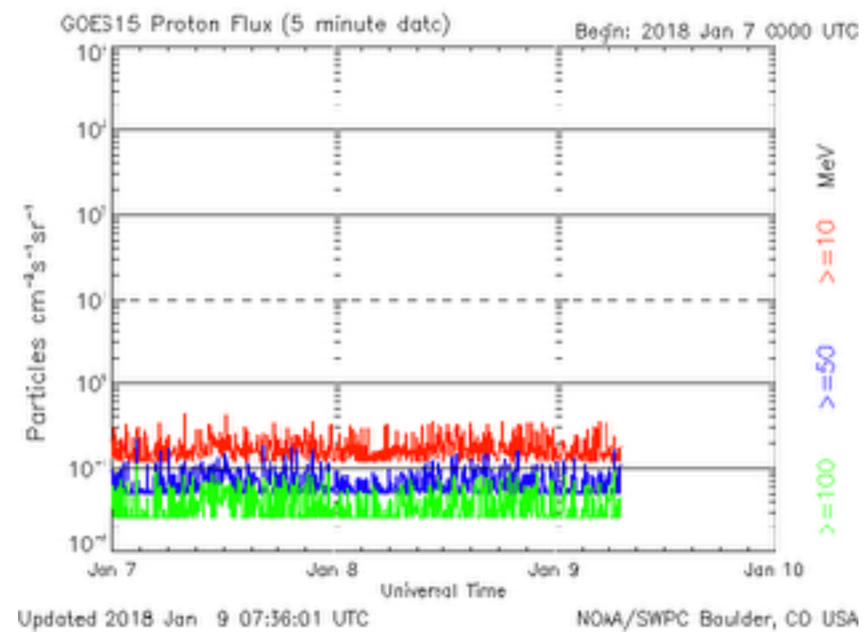
Flares on the Westlimb: source on a magnetic field line going to earth



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.

Particles

PROTON FLUX NOW



Particles

NOAA SPACE WEATHER SCALES

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

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

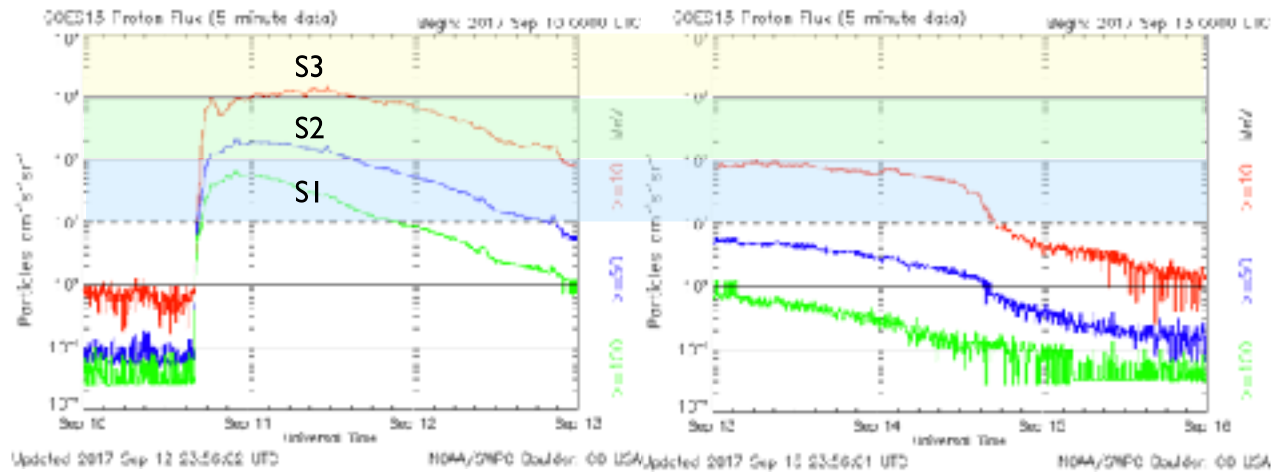
NOAA categorizes Solar Radiation Storms using the NOAA Space Weather Scale on a scale from S1 - S5.

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.

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.

Particles

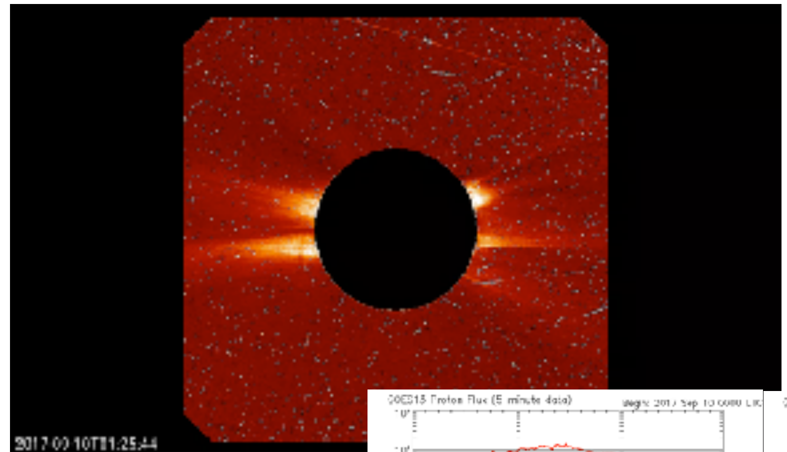
PROTON FLUX BY GOES

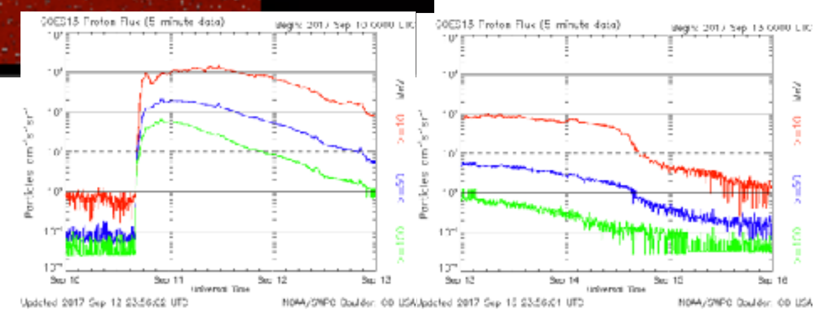


This definition allows multiple injections from flares and interplanetary shocks to be encompassed by a single Solar Radiation Storm.

A Solar Radiation Storm can persist for time periods ranging from hours to days.

PROTON FLUX BY SOHO/LASCO

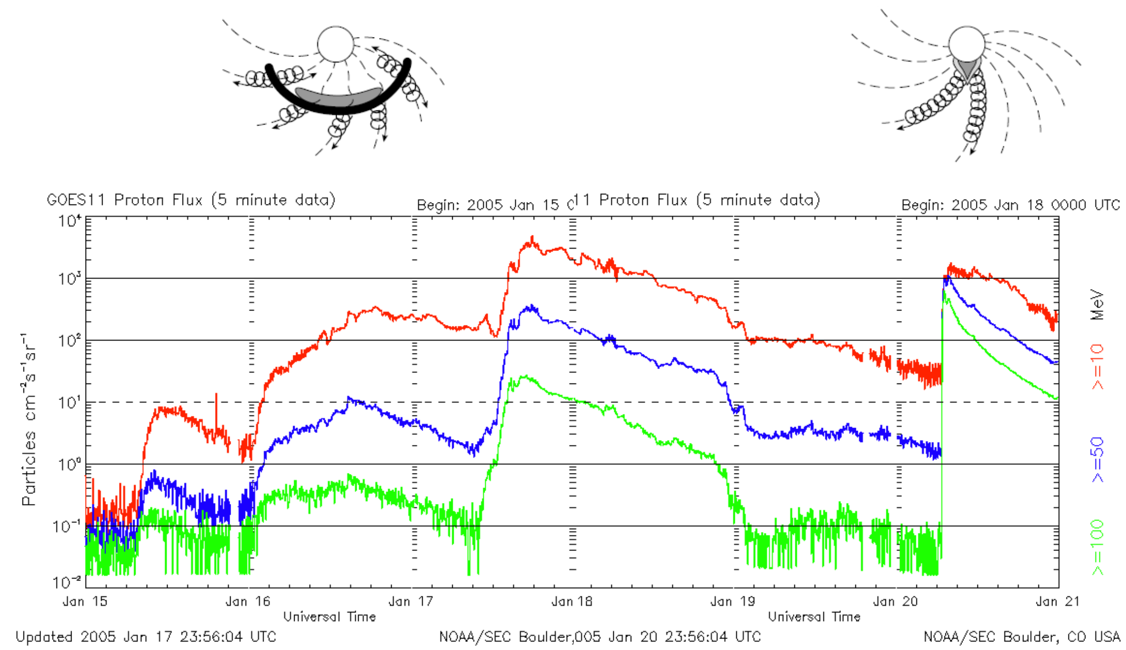




Particles

CME/FLARE DRIVEN PROTON EVENT

In a CME driven proton event, the measured proton flux increases more gradual, while in a flare drive proton event, the measured proton flux increases in a impulsive or prompt way.



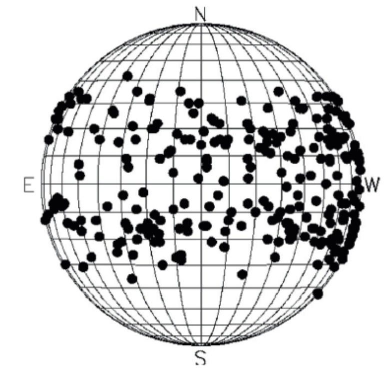
Impulsive
•Associated with impulsive solar flares
–Electron rich
•The onsets are not necessarily fast, but the events are rather of short duration
–Hours
•Rather narrow propagation cones
–Events from eastern hemisphere may not be observed

Gradual
•Associated with CME–driven shocks
–Gradual solar flares (LDE)
–Wide and fast shocks
–Type II and IV radio bursts
–Usually proton rich
•The onsets are not necessarily gradual, but the events are of long duration
–Days
–Partly due to continuing acceleration of shock

A very good site on the characteristics between gradual and impulsive events is at SEPEM: http://dev.sepem.oma.be/help/sep_intro.html

LOCATION OF SEP SOURCE

Even when the solar event is back-sided, energetic particles can arrive at Earth.



SEP=Solar Energetic particle

There’s a higher likelihood for SEP events from the western hemisphere. Does not exclude SEPs from the eastern hemisphere or even from the Sun’s backside!

Impulsive
•Associated with impulsive solar flares
–Electron rich
•The onsets are not necessarily fast, but the events are rather of short duration
–Hours
•Rather narrow propagation cones
–Events from eastern hemisphere may not be observed
–Flares on the Westlimb: source on a magnetic field line going to earth

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•Associated with CME–driven shocks
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–Type II and IV radio bursts
–Usually proton rich
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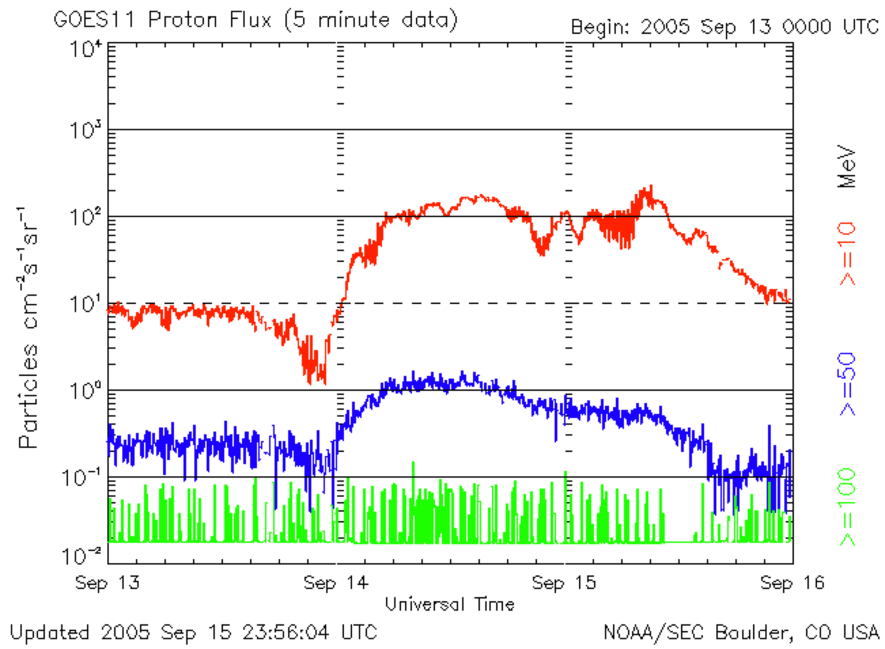
–Days
–Partly due to continuing acceleration of shock

CME: shock front has large extension and can intercept with some magnetic field line connected with earth

ARRIVAL OF ICME

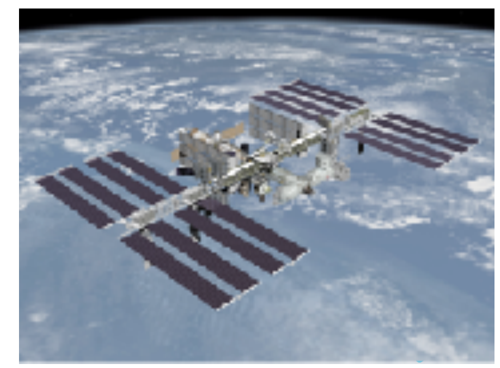
Some SEP events have two peaks - a prompt one arriving 10s of minutes after the solar activity, and a second, arriving with the ICME shock.



Particles

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.

Visit to the STCE Radio group

Visit of the STCE Solar Dome