SPACE WEATHER INTRODUCTORY COURSE



Collaboration of



Solar-Terrestrial Centre of Excellence



Koninklijke luchtmacht



Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu





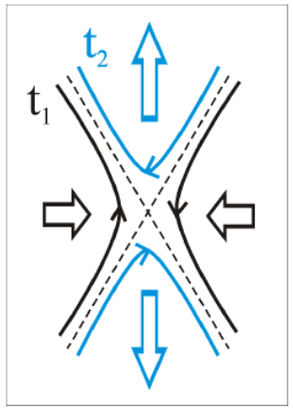
SPACE WEATHER

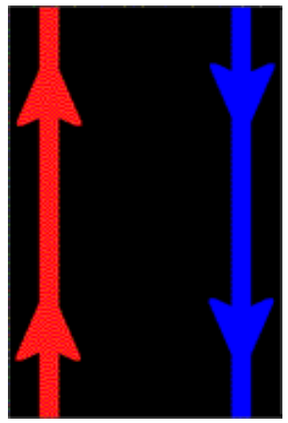
Drivers

Elke D'Huys, Jan Janssens & Petra Vanlommel

MAGNETIC RECONNECTION

- Conversion of magnetic energy into kinetic energy and radiation
- Where
  - Solar flares
  - CME release from the Sun
  - Geomagnetic storms at Earth





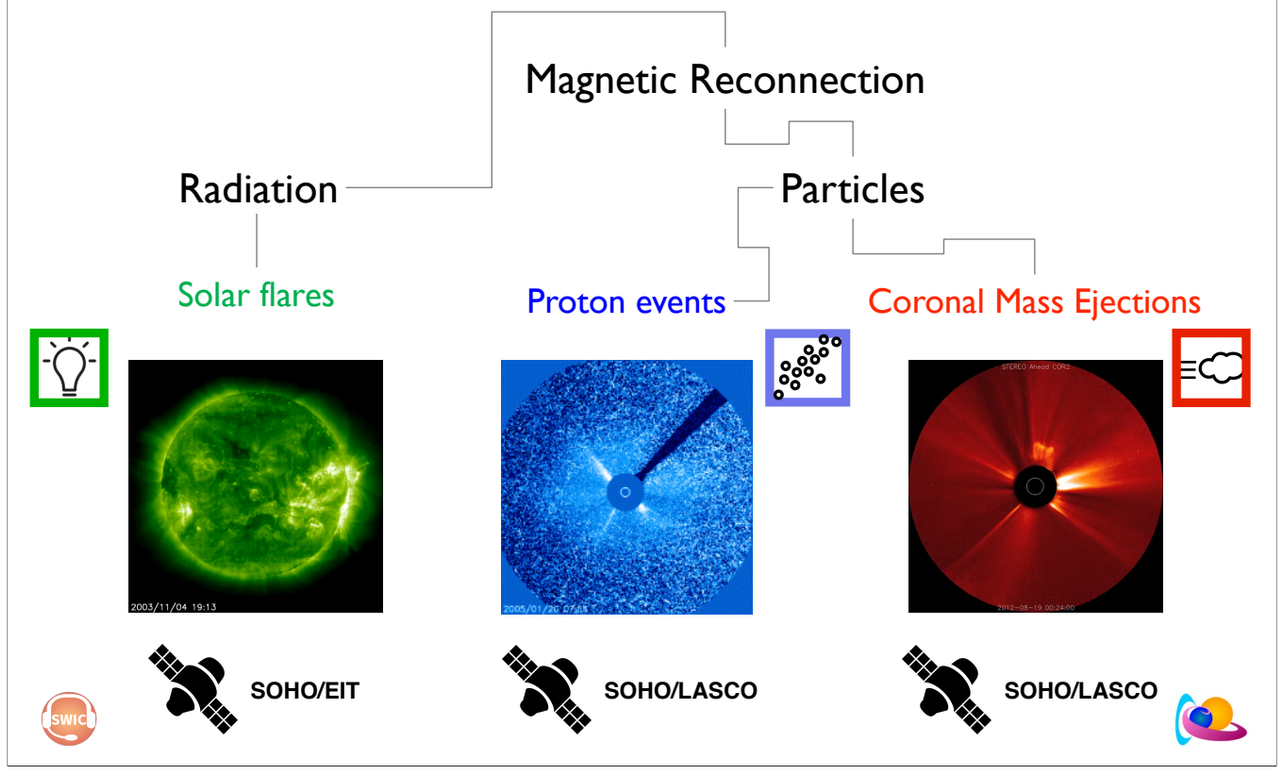
Magnetic reconnection occurs when antiparallel magnetic field lines are pushed towards each other and interact. The field lines disconnect at the X-point and form new connections, thus restructuring the magnetic field and creating new topological configurations.
During the process of magnetic reconnection (stored) magnetic energy is converted into kinetic energy and heat (radiation).

The first observational evidence for the reconnection process was found in solar flares.

Sources:
Text from the CISM Summer School (Boulder, August 2013) – SW101_4_Flares
https://www.bu.edu/cism/SummerSchool/summerlist.html

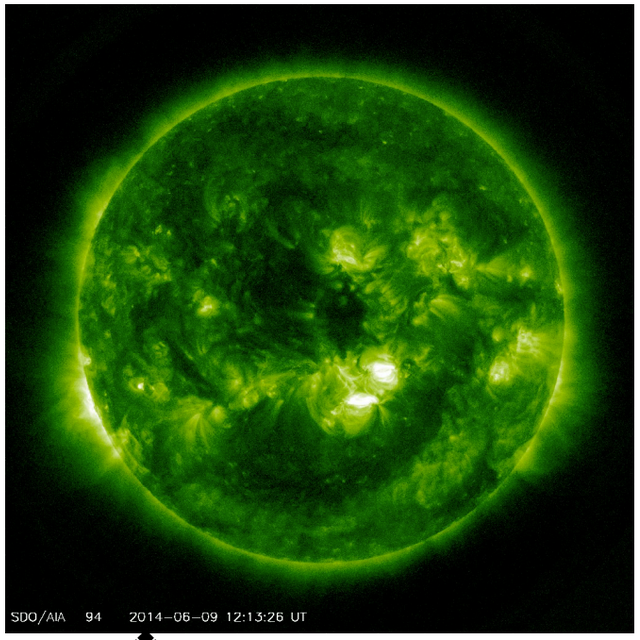
Animation from ESA: http://sci.esa.int/cluster/36447-direct-observation-of-3d-magnetic-reconnection/

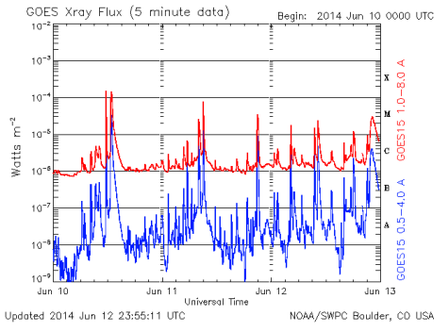
SOLAR ERUPTIONS



In this chapter we focus on eruptive solar events.
Magnetic reconnection is the physical principle at the base of the three types of space weather drivers: flares, proton events and coronal mass ejections.

FLARE OBSERVATION





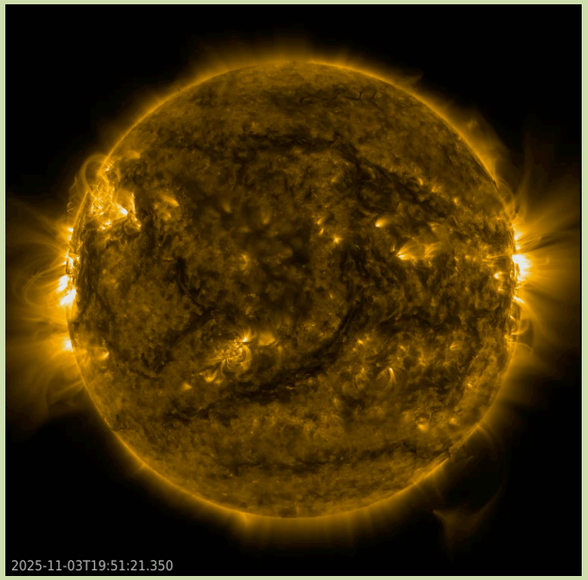
GOES

SDO/AIA

This movie shows a very active period with many M-class flares as measured by the GOES satellite. Remember that the solar flare radiation only takes 8 min to arrive at earth.

FLARES - OVERVIEW

- **Flare Characteristics**
  - **Definition**
  - **Standard model**
  - **Flare triggers**
  - **Flare features**
- Flare Classification
- Flare Predictions



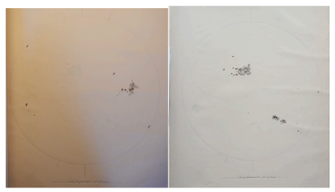
SDO/AIA

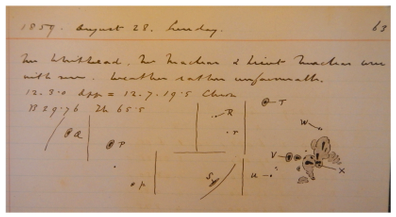
Period of November 3 to November 14, 2025
Six X-flares from same active region (NOAA AR 4274)

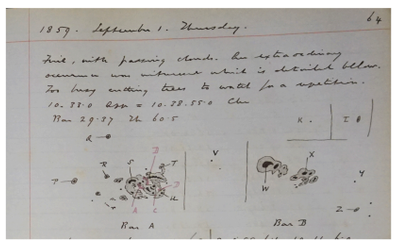
DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM	TYPE	Cat	NOAA	
03	0841	0925	0938		M1.6			VI/3		4274	
03	0938	1011	1037		M5.0					4274	
03	1219	1235	1237		M2.9			VI/2IV/1		4274	
03	1704	1708	1710	N26E69	M1.5	SF				4274	
04	0131	0148	0204		M3.5			III/2CTM/2	89	4274	
03	1237	1247	1251		M3.3					4274	
04	1715	1734	1751	N26E63	X1.8	1B		VI/2III/2IV/1	89	4274	
04	2145	2201	2211		X1.1			IV/1		4276	
04	2233	2244	2256	N22E36	M1.7	1		III/2	88	4272	
05	1036	1119	1143	N22E51	M7.4	2N			89	4274	
05	2152	2207	2216	N28E40	M8.6	2B		II/3	89	4274	
06	0417	0431	0439		M1.1					4276	
07	0631	0716	0753	N23E28	M1.7	1N		VI/2IV/3	89	4274	
09	0701	0735	0755	N23W3	X1.7	2		II/2IV/2IV/2	89	4274	
10	0855	0919	1019	N23W14	X1.2	2B	/	/	/	4274	III/3II/3IV/2
10	1946	1957	2003	N21W20	M1.5	2N	/	/	/	4274	VI/2
11	0802	0809	0813	N21W31	M1.4	SF	/	/	/	4274	
11	0949	1004	1017	//////	X5.1	/	/	/	4274	II/3VI/3III/2	
14	0744	0830	0840	//////	X4.0	/	/	/	////	III/2II/3IV/2	

SOLAR FLARES - WHAT?

- Sudden burst of radiation
- First observation in 1859 (white light) by Carrington and Hodgson
- Large quantity of energy is released
  >10^20 Joule
- Required:
  A very rapid means of converting stored magnetic energy into particle energy and radiation – magnetic reconnection







Solar flares are sudden bursts of radiation lasting minutes to hours. Flares are observed in a wide range of electromagnetic waves such as radio, visible light, X-rays, and gamma rays.

Solar flares occur in a power-law spectrum of magnitudes; an energy release of typically 10^20 joules of energy suffices to produce a clearly observable event, while a major event can emit up to 10^25 joules. (For comparison: atomic bombs release energies of the order of 10^12 J to 10^15 J.)
(Other comparison: **10^20 is the order of magnitude of the annual world energy consumption**)

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 Solar Energetic Particles).

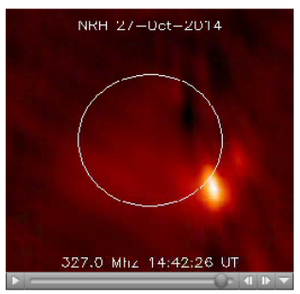
Flares in the visible continuum are particularly called white-light flares (WLFs), first observed by Carrington (1859). **Solar WLFs are usually rare** events compared to the Halpha and soft X-ray (SXR) flares because of the **short durations** (typically a few minutes; Hudson et al. 1992; Xu et al. 2006) and the **low contrast** (typically 5%–50%, at most 300%; Lin & Hudson 1976; Jess et al. 2008). (https://iopscience.iop.org/article/10.3847/1538-4357/aa9b34)

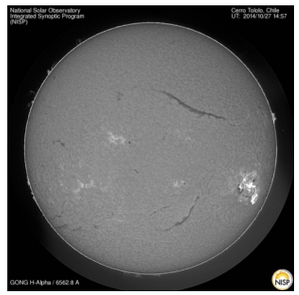
Sources:
From the CISM Summer School (Boulder, August 2013) – SW101_4_Flares
https://www.bu.edu/cism/SummerSchool/summerlist.html

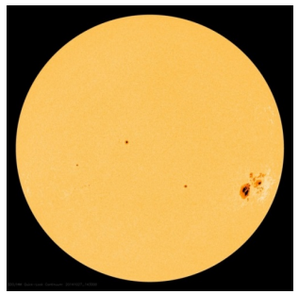
http://solarphysics.livingreviews.org/Articles/lrsp-2011-6/
Solar Flares: Magnetohydrodynamic Processes (Kazunari Shibata and Tetsuya Magara)

Images taken from https://iopscience.iop.org/article/10.3847/1538-4357/aae47c
Carrington's sunspot drawings on August 28 and September 1, shown in projected images. The whole disk drawings on August 28 and September 1 are shown above. The relevant parts of his logbook on August 28 and September 1 are shown below. These manuscripts are currently preserved in the archive of the Royal Astronomical Society.

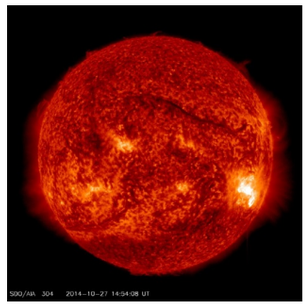
SOLAR FLARES - OBSERVATIONS

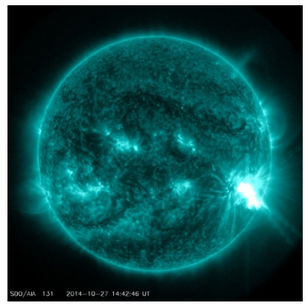


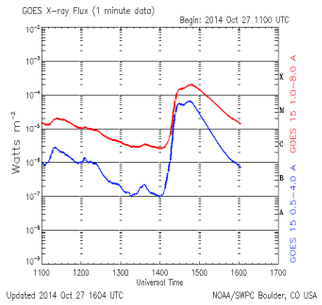




SDO/HMI







GOES

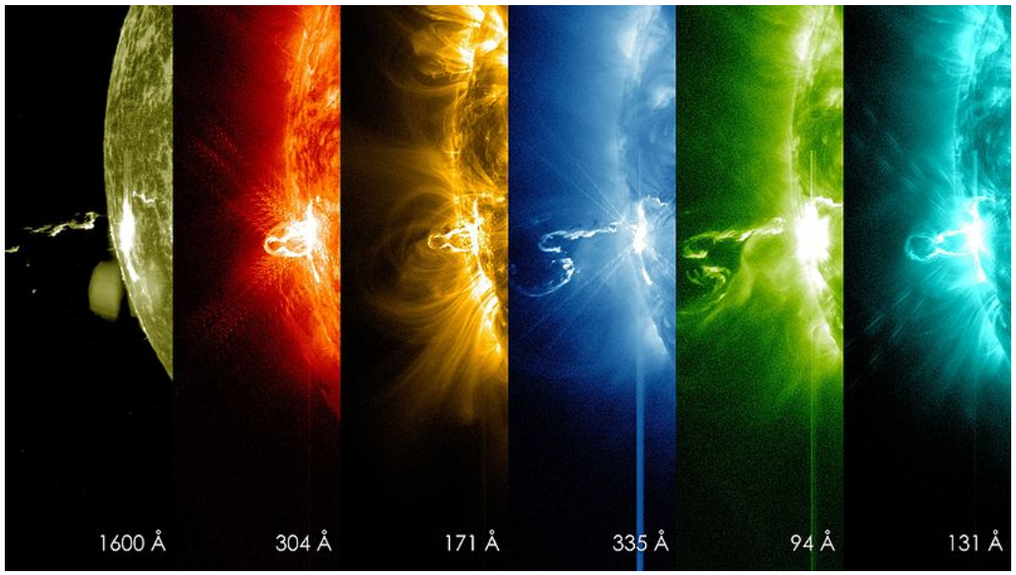
SDO/AIA

Solar flares are sudden bursts of radiation lasting minutes – hours at wavelengths over the entire electromagnetic spectrum: Gamma-rays, HXR, SXR, EUV; H-alpha, radio

The total irradiance enhancement is dominated by white light and infra-red emission (77%). UV and soft X-ray emissions <200 nm amount to 23%.
(Living Reviews in Solar Physics - Flare Observations (Benz, 2017), https://link.springer.com/article/10.1007/s41116-016-0004-3)

Sources:
http://bass2000.obspm.fr/home.php (Nançay Radio Heliograph)
http://www.stce.be/news/279/welcome.html

SOLAR FLARES - OBSERVATIONS



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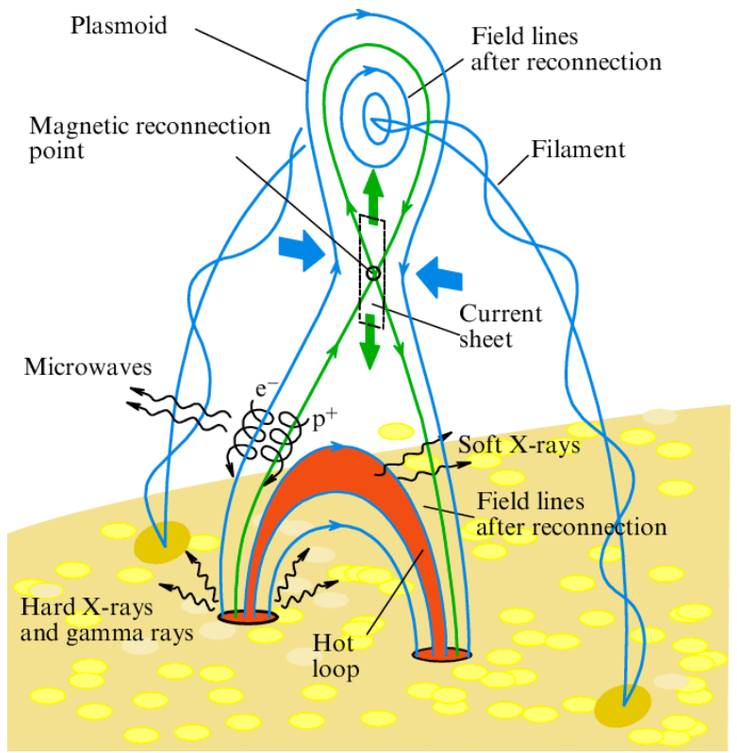
Sources:
http://bass2000.obspm.fr/home.php (Nançay Radio Heliograph)
http://www.stce.be/news/279/welcome.html

STANDARD FLARE MODEL



The CSHKP model is a model of solar flares that explains their observable features on the basis of magnetic reconnection. The basic idea of this model was proposed and developed by Carmichael, Sturrock, Hirayama, Kopp and Pneuman (Carmichael 1964; Sturrock 1966; Hirayama 1974; Kopp & Pneuman 1976), which is why this model is named CSHKP after these five scientists.

The model was originally proposed by Kopp and Pneuman and then refined. In broad lines it consists of the following phases:

0) Magnetic reconnection occurs
1) It requires a „transient“ that opens up the magnetic field lines.
2) As they close down and reconnect, energy is released that goes into accelerating electrons which travel down the magnetic field lines.
3) These highly energetic particles will heat the dense chromosphere at the footpoints
4) and this plasma is heated and conducted into the loops
5) Post-eruption loop arcade appears successively high, because of the reconnection site that rises with time
6) The ribbon separates with time because of the increasing distance between footpoints due to higher loop arcades

Polarity inversion line (PIL, also called neutral line): The line that separates solar magnetic fields of opposite polarity, typically determined from solar magnetograms.
From: https://www.swpc.noaa.gov/content/space-weather-glossary#n

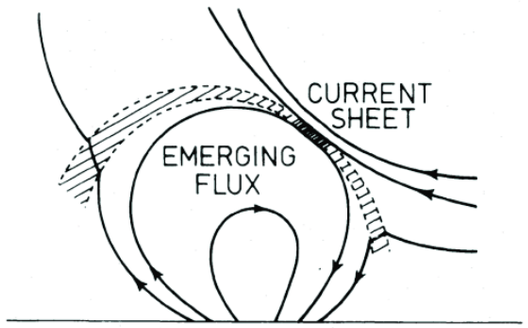
Sources:
From Maria Massi (What is a solar flare?)
http://www3.mpifr-bonn.mpg.de/staff/mmassi/#coronae1
Image:
https://www.researchgate.net/publication/341075910_X-ray_and_gamma-ray_emission_of_solar_flares

An animated model from a solar flare can be found at:
Cheung et al. (2018): A comprehensive three-dimensional radiative magnetohydrodynamic simulation of a solar flare
http://adsabs.harvard.edu/abs/2018NatAs...3..160C
YouTube movie at https://www.youtube.com/watch?v=kyhsBqB2x_Y&feature=youtu.be

TRIGGERS OF SOLAR FLARES

Magnetic restructuring

- Magnetic flux emergence
- Helical energy storage
- Instability surrounding fields
- Interaction with nearby CH
- …



There are various processes that can trigger a solar flare, but the underlying basic principle remains the same: magnetic reconnection transforms stored magnetic energy into kinetic and radiative energy.

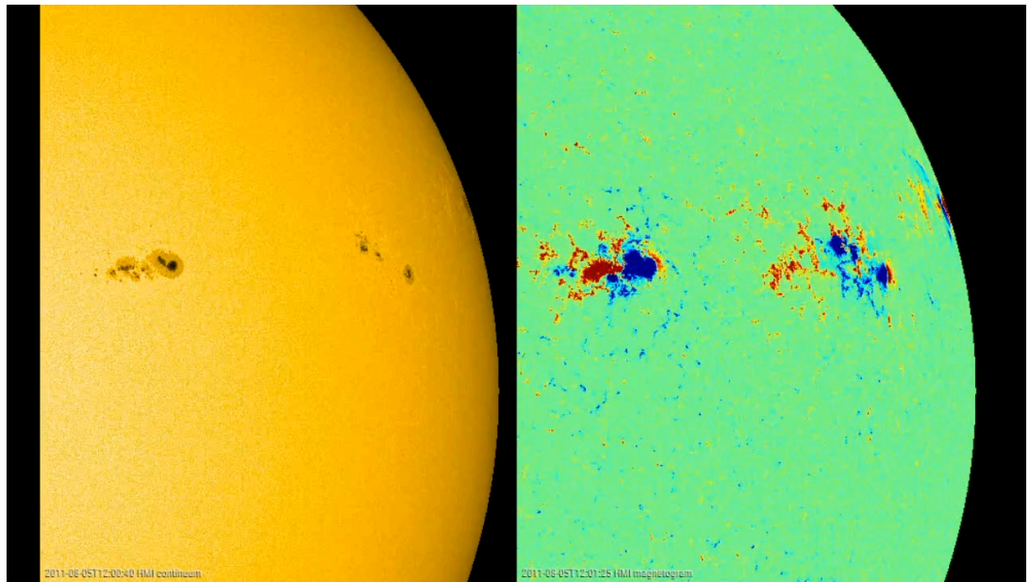
Sources:
Image from: https://www.researchgate.net/publication/274542590_Flux_Emergence_Theory

Other example: Solar flare mechanism: http://www.stce.be/news/265/welcome.html

TRIGGERS OF SOLAR FLARES

SDO/HMI

Magnetic flux emergence



This movie shows how magnetic flux is emerging in the trail of the sunspot regions. This emerging field interacts with the existing magnetic configuration. When it creates an instability, an X-flare is observed.

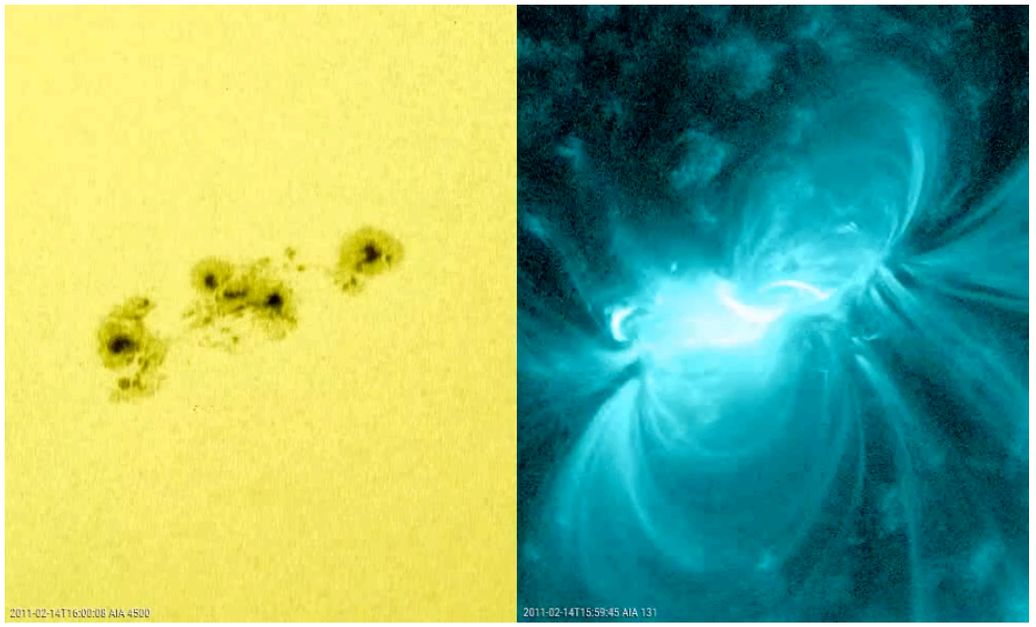
X6.9 flare on 9 August 2011: http://www.stce.be/news/353/welcome.html

Blue/black is negative (inward) magnetic polarity, red/white is positive (outward) polarity.

TRIGGERS OF SOLAR FLARES

Helical energy storage

SDO/AIA



This movie shows rotating sunspots that cause a solar flare.
Rotating sunspots are an extremely efficient way to inject energy into the magnetic field of the Sun's atmosphere. Twisting the Sun's magnetic field is like twisting an **elastic band**. At first you store energy in the elastic, but if you twist too much the elastic band snaps, releasing the stored energy. Similarly, rotating sunspots store energy in the Sun's atmospheric magnetic field. If they twist too much, the magnetic field breaks releasing energy in a flare.

X2.2 flare on 15 February 2011

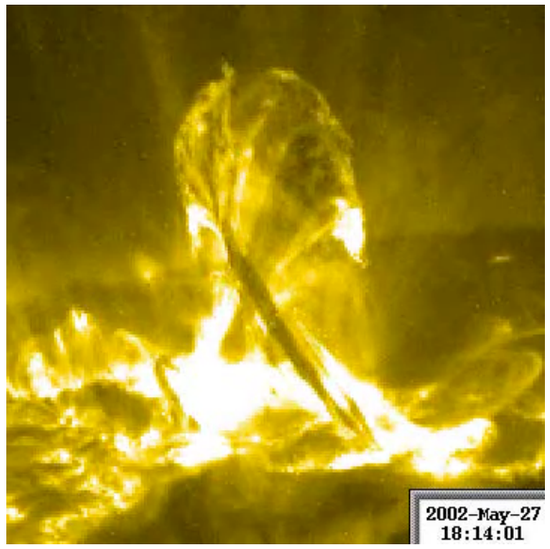
Sources:
Velareddi et al. (2012): On the role of rotating sunspots in the activity of solar active region NOAA 11158
http://iopscience.iop.org/article/10.1088/0004-637X/761/1/60/pdf

Jiang et al. (2011): Rapid sunspot rotation associated with the X2.2 flare on 2011 February 15
http://iopscience.iop.org/article/10.1088/0004-637X/744/1/50

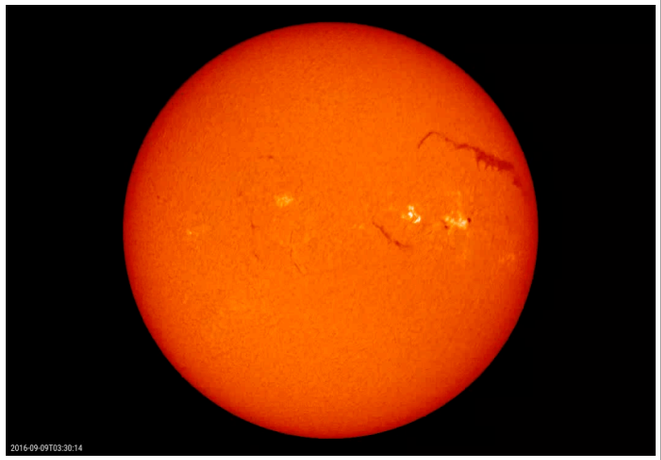
Also at PhysOrg: https://phys.org/news/2011-04-rotating-sunspots-super-solar-flare.html

TRIGGERS OF SOLAR FLARES

Kink instability



Unstable magnetic fields



The left movies shows a kink magnetic flux tube, this is a bunch of magnetic strands that are intertwined. If it twist too much, it breaks.
The movie on the right is taken in H-Alpha and shows a B7 flare that did not only produce electromagnetic radiation. It apparently also created an imbalance in the magnetic fields. As a result, about an hour after the B7 flare, first the middle portion and then the western portion of the nearby filament disappeared entirely from view in H-alpha. The 40-degrees long filament to the upper right remained unchanged.

Sources:
Kink instability
Török et al. (2010): The writhe of helical structures in the solar corona
https://www.aanda.org/articles/aa/full_html/2010/08/aa13578-09/aa13578-09.html
http://www.lmsal.com/TRACE/POD/TRACEpodarchive14.html#movie61 (27 May 2002; M2 ; NOAA 9957)
Unstable if twist ~2.5pi (Török et al., 2003: https://www.aanda.org/articles/aa/pdf/2003/30/aah4206.pdf).

Unstable magnetic fields
Collateral damage: http://www.stce.be/news/361/welcome.html

Shen et al. (2014): A Chain of Winking (Oscillating) Filaments Triggered by an Invisible Extreme-ultraviolet Wave
http://adsabs.harvard.edu/abs/2014ApJ...786..151S

:Issued: 2026 Oct 09 1254 UTC
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 61009
SIDC SOLAR BULLETIN 09 Oct 2026, 1253UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Minor storm expected (A>=30 or K=5)
SOLAR PROTONS : Warning condition (activity levels expected to increase, but no numeric forecast given)
PREDICTIONS FOR 09 Oct 2026 10CM FLUX: 122 / AP: 021
PREDICTIONS FOR 10 Oct 2026 10CM FLUX: 124 / AP: 022
PREDICTIONS FOR 11 Oct 2026 10CM FLUX: 126 / AP: 015



Finding your way in the URSIgram

Solar Active Regions and flaring: The solar flaring activity over the past 24 hours reached high levels with background C-class flaring and one registered M-flare. The strongest recorded activity was a M6.7 flare (SIDC Flare 8685) with peak time at 15:48 UTC on October 08. The flare was produced within SIDC Sunspot Group 976 (NOAA Active Region 4549) currently located at N10W31. A total of 5 numbered sunspot groups were identified on the visible solar disk with SIDC Sunspot Group 976 remaining the largest and most complex region. It continues to be classified as magnetic type beta-gamma-delta and was the main contributor to the observed flaring activity over the past 24 hours. SIDC Sunspot Group 973 (NOAA Active Region 4545), currently located at N18W37, has exhibited some decay. It is classified as magnetic type beta and remained quiet. A new region has emerged on disc SIDC Sunspot Group 979, currently located at N22W11, and another one, SIDC Sunspot Group 980, is rotating from behind the south-east limb. Both are classified as magnetic type beta and the latter one has exhibited some low flaring activity while behind the east limb. The solar flaring activity is expected to be at moderate over the next 24 hours with likely M-class flaring and chances for an X-class flare.

Coronal mass ejections: A wide coronal mass ejection (SIDC CME 727) was observed by LASCO/C2 to lift off the solar surface around 16:12 UTC on October 08 with a white-light shock and an estimated projected speed of around 500 km/s. The eruption is likely linked to the M6.7 flaring from SIDC Sunspot Group 976 (NOAA Active Region 4549) with an associated EUV dimming and a coronal wave detected in the SDO/AIA data around 16:33 UTC on October 08. Related type II and type IV solar radio emissions were detected at 15:42 UTC and 16:12 UTC on October 08 respectively. SIDC CME 727 is estimated to have an Earth-directed component and current analysis suggests a possible arrival time late UTC on October 11 to early UTC on October 12. Another EUV dimming and a small coronal wave were observed in the SDO/AIA imagery starting at 17:36 UTC on October 08, seemingly related to a filament eruption in the south-eastern quadrant triggered by the same event chain. A faint eastward eruption is visible in the LASCO/C2 around 17:00 UTC, but is expected to travel off the Sun-Earth line.

Coronal holes: SIDC Coronal Hole 149 (a recurrent mid-latitude coronal hole with a negative polarity) continues to reside on the central meridian. A high-speed stream related to it might be expected at Earth on October 09, possibly mixed with anticipated ICME arrival signatures related to SIDC CME 725.

Solar wind: Over the past 24 hours the solar wind parameters (as measured by ACE at L1) registered some enhancements, possibly the precursor of a high-speed stream arrival related to SIDC Coronal Hole 149. The solar wind speed remained slow, varying in the range of 333 to 390 km/s. The interplanetary magnetic field (B) registered a maximum value of 12.7 nT with a north-south (Bz) component down to - 7 nT. The B field phi angle switched from the positive to the negative sector (directed towards the Sun). The solar wind parameters are expected to be perturbed over the next 24 hours with an anticipated arrival of a high-speed stream possibly mixed with an ICME arrival related to SIDC CME 725. Perturbed solar wind conditions are expected to continue on October 10 with anticipated high- speed stream influence and possible waning ICME influence. A mild glancing blow arrival related to SIDC CME 726 could be expected on October 11 with the possibility of another ICME arrival late UTC on October 11 or early UTC on October 12 related to SIDC CME 727.

Geomagnetism: The geomagnetic conditions over the past 24 hours were locally (over Belgium) quiet to unsettled and globally quiet to active with NOAA Kp reaching 4 in the period 9-12 UTC on October 09. Unsettled conditions to minor storm levels are expected over the next 24 hours with chances for isolated moderate storms. Unsettled to active conditions with chances for more minor storm levels can continue on October 10, October 11 and October 12.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux remained at close to nominal levels, while exhibiting some further enhancements related to activity from SIDC Sunspot Group 976 (NOAA Active Region 4549). The greater than 10 MeV GOES proton flux is expected to further increase over the next 24 hours with chances of reaching the 10 pfu proton event threshold.

Electron fluxes at GEO: The greater than 2 MeV electron flux as measured by GOES 18 and GOES 19 has exceeded the 1000 pfu threshold over the past 24 hours and is expected to be predominantly below the 1000 pfu threshold over the next 24 hours. The 24-hour electron fluence was at moderate levels and is expected to decrease to nominal levels over the next 24 hours.

TODAY'S ESTIMATED ISN : 086, BASED ON 07 STATIONS.

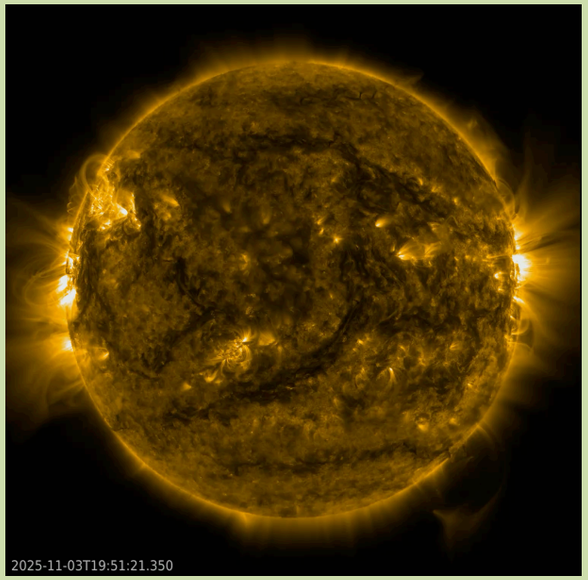
SOLAR INDICES FOR 08 Oct 2026
WOLF NUMBER CATANIA : 089
10CM SOLAR FLUX : ///
AK CHAMBON LA FORET : 017
AK WINGST : 006
ESTIMATED AP : 006
ESTIMATED ISN : 075, BASED ON 18 STATIONS.

Flare features

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
08 1529 1548 1558 N12W20 M6.7 2B 57/4549 I/3
END

FLARES - OVERVIEW

- Flare Characteristics
- **Flare Classification**
  - **H-alpha**
  - **X-ray**
- Flare predictions



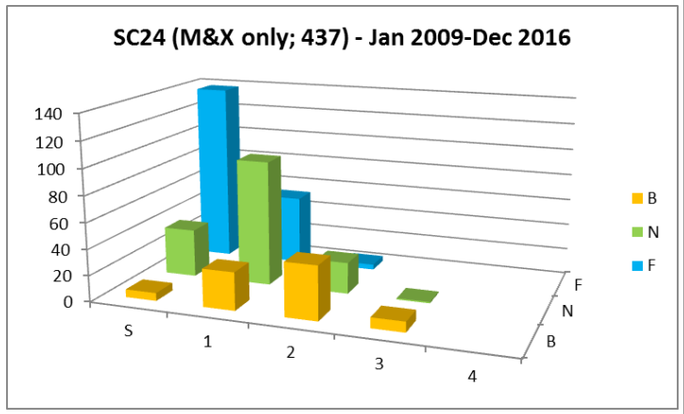
SDO/AIA

SOLAR FLARES CLASSIFICATION

H-alpha

- Visual classification
- Importance
  - Area at max. brightness
- Brightness
  - Faint, Normal, Brilliant
- Optical class
  - E.g. SF, 3B,…
- Limited correlation with geophysical effects
- Depends strongly on seeing conditions

Importance	A_c (MH)	A_c ($^{\circ 2}$)
S	$10 \leq A_c < 100$	$0,2 \leq A_c < 2,1$
1	$100 \leq A_c < 250$	$2,1 \leq A_c < 5,2$
2	$250 \leq A_c < 600$	$5,2 \leq A_c < 12,4$
3	$600 \leq A_c < 1200$	$12,4 \leq A_c < 24,7$
4	$1200 \leq A_c$	$24,7 \leq A_c$



Optical Information (Op): The optical classification and location of an associated flare, observed in Hα. It contains an importance and a Brightness parameter:
* Importance is the corrected area of the flare in heliospheric square degrees at maximum brightness, observed in the Hα line (656.3 nm).
S – Subflare (area ≤ 2.0 deg.2)
1 – Importance 1 (2.1 ≤ area ≤ 5.1 deg. 2)
2 – Importance 2 (5.2 ≤ area ≤ 12.4 deg. 2)
3 – Importance 3 (12.5 ≤ area ≤ 24.7 deg. 2)
4 – Importance 4 (area ≥ 24.8 deg. 2)
* Brightness is the relative maximum brightness of flare in Hα.
F – faint ; N – normal ; B – brilliant
In photometric observations: **If a flaring region reaches a brightness of 1.6 times (160%) the surrounding quiet sun background brightness, then it is considered a faint (F) flare**. If the flaring region reaches a brightness **between 160% and 360%** the background brightness, it is catalogued as a flare of **normal** intensity (N). Finally, in order to be considered a "brilliant" flare (B), the flaring region should reach an intensity of 360% the background brightness and its are should cover at least 10 millionths of the solar hemisphere.

* Location (°Lat. °CMD) gives the spherical, heliographic coordinates of the solar flare in Hα. The field is blank for x-ray events with no optical correlation (no optical flare observed or no optical patrol at the time) and for flares that occasionally occur in unassigned regions).

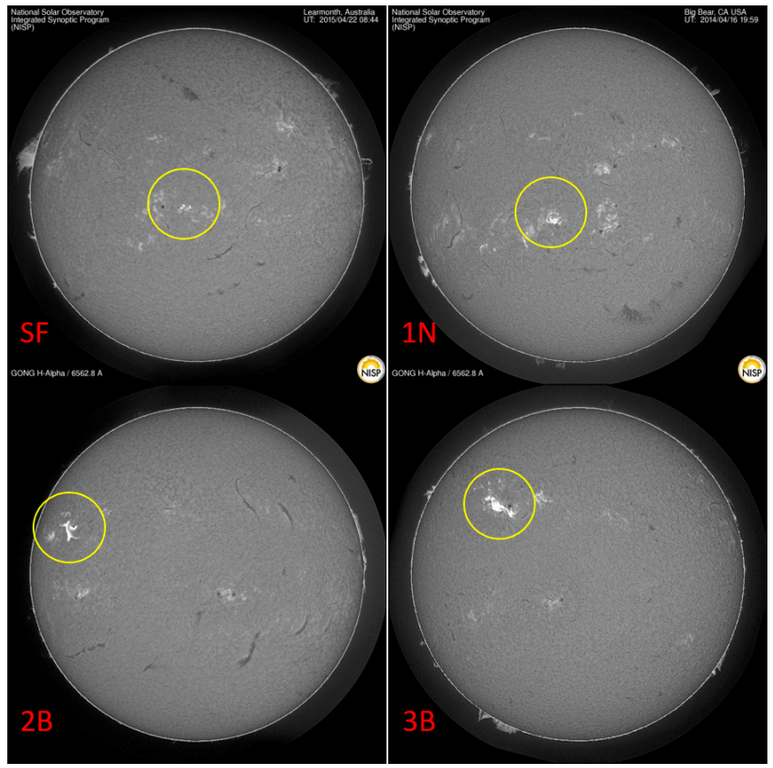
Note however, that the observed intensity is **strongly dependent on the seeing conditions**, and only a slight amount of atmospheric pollution can drastically alter the measured intensity.

This classification is still **widely used**, e.g. in the daily SWPC (event) reports, The Weekly, the SIDC's Ursigrams and weekly bulletins,…

Sources:
H-alpha flare classification: Australian SWS: http://www.sws.bom.gov.au/Educational/2/4/2
H-alpha observing: http://users.telenet.be/j.janssens/Halpha/Halfaeng.html#Flares
From SWPC 's « The Weekly » User guide (https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf ; page 4)
A detailed analysis of H-alpha flare properties is by Temmer et al. (2001): Statistical analysis of solar H flares
https://www.aanda.org/articles/aa/pdf/2001/33/aa1413.pdf

See also: https://www.stce.be/educational/classification

SOLAR FLARE CLASSIFICATION: H-ALPHA

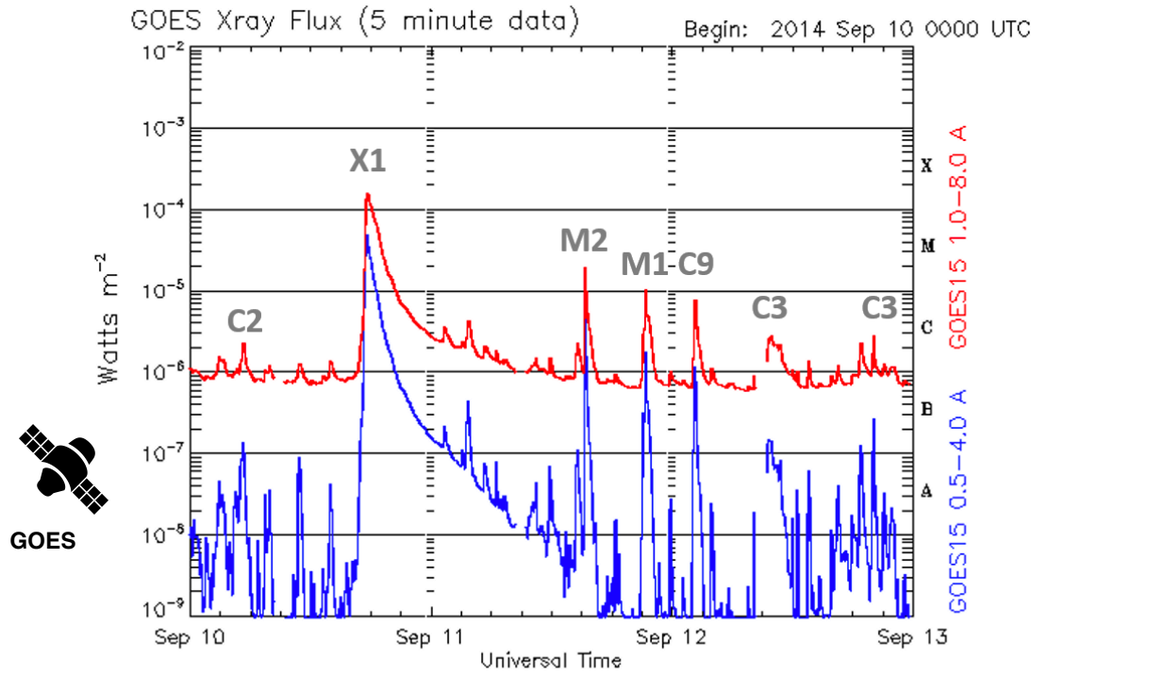


NOTICABLE EVENTS SUMMARY

	DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM	Catania/NOAA	RADIO_BURST_TYPES
SF:	22 Apr 2015	- 0830	0844	0858	S09E05	**M1.1**	SF			
1N:	16 Apr 2014	-1954	1959	2004	S14E09	**M1.0**	1N		24/2035	II/2
2B:	02 Apr 2014	- 1318	1405	1428	N14E53	**M6.5**	2B	3700	09/2027	II/1IV/2
3B:	07 Mar 2012	- 0002	0024	0040	N17E27	**X5.4**	3B	7200		IV/1,II/2,V/2

Data are from the SIDC / Daily Ursigrams (http://www.sidc.be/archive)
Images are from GONG/NSO H-alpha Network (ftp://gong2.nso.edu/HA/hag/)

SOLAR FLARE CLASSIFICATION: X-RAY



GOES

Source: http://iopscience.iop.org/article/10.1086/304521/fulltext/36016.text.html

From SWPC 's « The Weekly » User guide (https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf ; page 2)
The letter classification of solar flares was initiated on 01 January 1969. This classification ranks solar activity by its peak x-ray intensity in the 0.1-0.8 nm band as measured by the Geostationary Operational Environmental Satellites (GOES). This x-ray classification offers at least two distinct advantages compared with the standard optical classifications: it gives a **better measure of the geophysical significance** of a solar event, and it provides an objective means of classifying geophysically significant activity **regardless of its location** on the solar disk.

Table 1. The SWPC x-ray flare classification

Peak Flux Range (0.1-0.8 nm) Classification	mks system (W m-2)	cgs system (erg cm-2s-1)
A	Φ <10-7	Φ <10-4
B	10-7 ≤ Φ <10-6	10-4 ≤ Φ <10-3
C	10-6 ≤ Φ <10-5	10-3 ≤ Φ <10-2
M	10-5 ≤ Φ <10-4	10-2 ≤ Φ <10-1
X	10-4 ≤ Φ	10-1 ≤ Φ

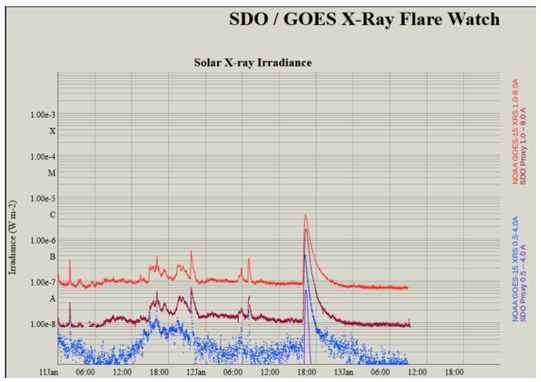
The letter designates the order of magnitude of the peak value and the number following the letter is the multiplicative factor. A C3.2 event for example, indicates an x-ray burst with 3.2x10-6Wm-2 peak flux. Solar flare forecasts are usually issued only in terms of the broad C, M, and X categories. Since x-ray bursts are observed as a full-Sun value, bursts below the x-ray background level are not discernible. The **background** drops to class A level during solar minimum; only bursts that exceed B1.0 are classified as x-ray events. During solar maximum the background is often at the class M level, therefore class A, B, or C x-ray bursts cannot be discerned. Data are measured by the NOAA GOES satellites, monitored in real time in Boulder (Grubb 1975).

The C is often referred to as « Common » , M as « Medium (or moderate) », and X as « eXtreme

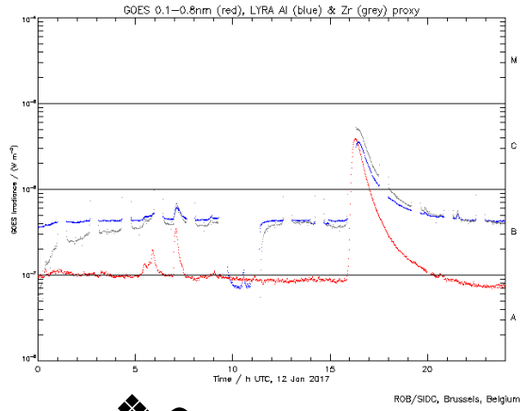
See also: https://www.stce.be/educational/classification
Note the peak intensity of a flare is based on the 1-minute averages by GOES, not on the **5-minute averages** which are often used for the graphs. Also, the peak intensity may not be rounded up, as the true flux never reached that level (e.g. a C5.8 is a C5 flare, not a C6 event).

SOLAR FLARE CLASSIFICATION: X-RAY

Back-up for GOES x-ray



SDO/EVE



PROBA2/LYRA

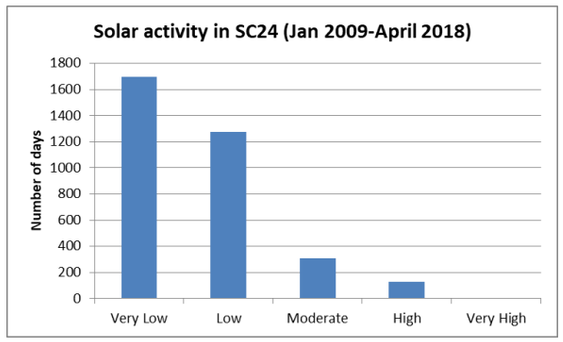
SDO/EVE: http://lasp.colorado.edu/eve/data_access/sdo-goes-eve-flare-watch/index.html
PROBA2/LYRA: http://proba2.oma.be/ssa

These instruments measure the solar EUV output which is then scaled to GOES so that they can be reliably compared and substituted. In that sense, the scaled EUV measurements are proxies for the GOES x-ray measurements.

SOLAR FLARE CLASSIFICATION: X-RAY

Frequency terminology

- Solar (flaring) activity
- For a 24 hour period



Terms Used to Describe Solar Activity

Very Low: x-ray events less than C-class.

Low: C-class x-ray events.

Moderate: isolated (one to four) M-class x-ray events.

High: several (5 or more) M-class x-ray events, or isolated (one to four) M5 or greater x-ray events.

Very High: several (5 or more) M5 or greater x-ray events.

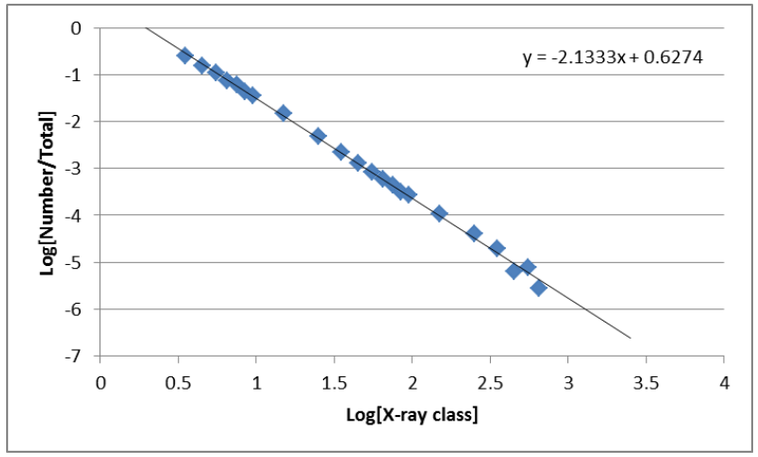
PRF User Guide – August 2012

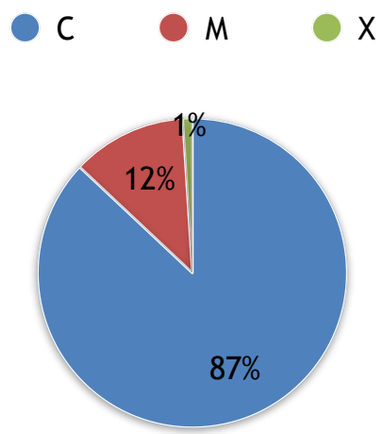
Source: https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf

Solar Activity in SC24 (Jan 2009 - Dec 2016)
Very Low 1691 days
Low 1214 days
Moderate 299 days
High 118 days
Very High 0 days

See also: https://www.stce.be/educational/classification

SOLAR FLARE STATISTICS: X-RAY





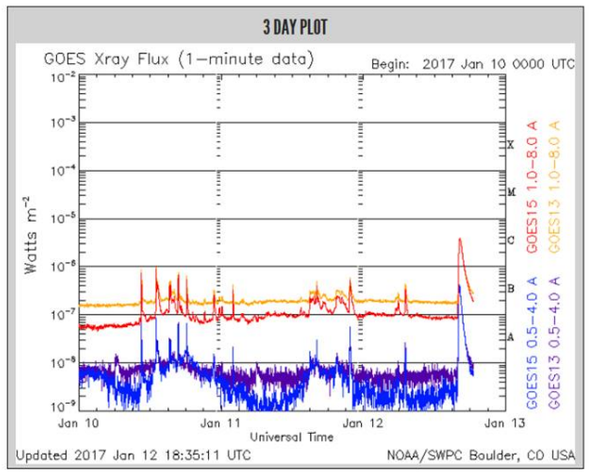
The above chart shows for each bin of solar flare intensity (C3-X6) the ratio of the number of flares for that bin vs. the total number of flares (25031 flares; January 1976 – May 2016). Both axes are logarithmic in nature. The C2 and lower classes were omitted as these numbers are affected during high solar activity (high x-ray background). The X7 and higher intensities were omitted for not sufficient data.

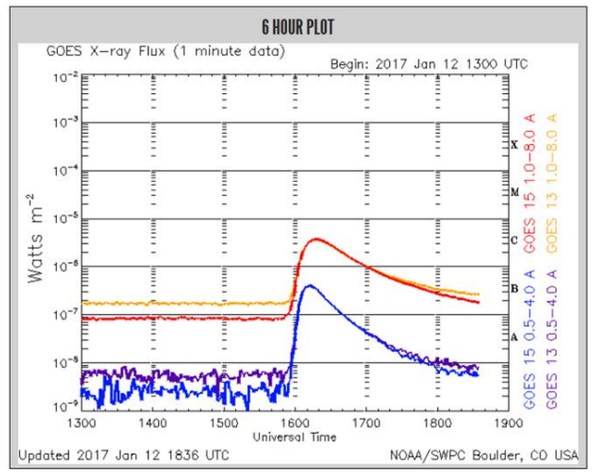
The linear expression between these two quantities is y=0.6274-2.1333x
This means that **the number of flares N for a bin can be calculated from a power law equation**: N = 25031. delta . 4.24 ^I-2.13 , with delta equalling 1, 10 or 100 for the resp. class C, M or X.

Another rule of thumb: Since 1976, there have been a total of 55000 x-ray flares. About 48000 were C-class flares, 6500 were M-class flares, and 500 were X-class flares.
Or in percentages: **For every 100 solar flares, there are 87 C-class flares, 12 M-class flares, and 1 X-class flare.**

More on this (for the period 1976-1993) is at the Australian SWS: http://www.sws.bom.gov.au/Educational/2/4/5

SOLAR FLARE DURATION





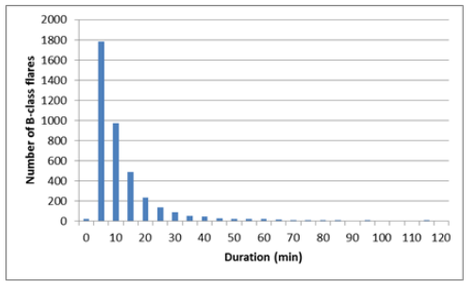
GOES

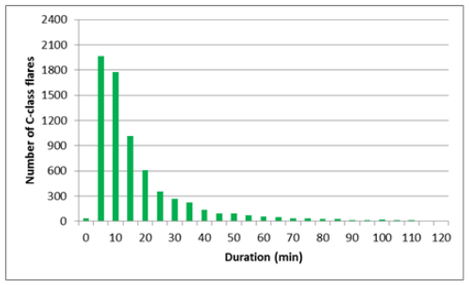
LATEST X-RAY EVENT (1-8Å)			
Current	2017-01-12 18:35:00 UTC	B1.8	Ratio: 0.031
Beginning	2017-01-12 15:54:00 UTC	B1.0	
Maximum	2017-01-12 16:18:00 UTC	C3.8	Integrated flux: 0.006896 J m^{-2}
End	2017-01-12 16:41:00 UTC	C1.9	

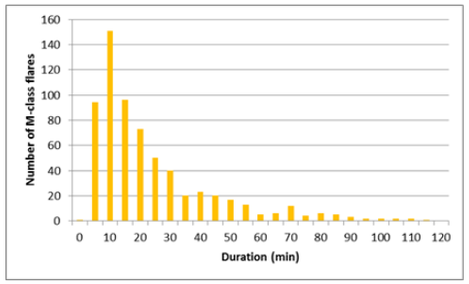
From SWPC 's « The Weekly » User guide (https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf ; page 15)

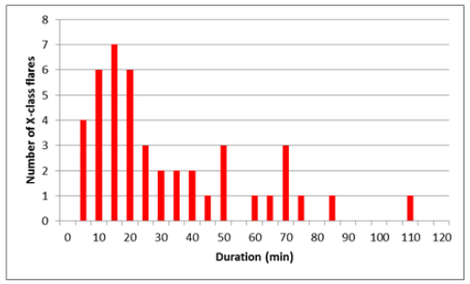
The **start** of an x-ray event is defined as the **first minute in a sequence of 4 minutes** of steep monotonic increase in 0.1-0.8 nm flux. The time of x-ray maximum is defined as the time tag of the peak 1-minute averaged value x-ray flux. The **end time** is the time when the flux level **decays to a point halfway** (1/2 peak) **between the maximum flux and the pre-flare background level.**

SOLAR FLARE DURATION









Jan 1976 - Dec 2000			Jan 2009 - Nov 2015		
Class	Number	Median	Class	Number	Median
B	8844	10	B	4041	10
C	16507	12	C	7015	14
M	1331	24	M	659	19
X	63	30	X	45	24
T	*26745*	*12*	*T*	*11760*	*13*

These graphs show the distribution of the duration (in minutes) of flares in the different categories. It is clear that stronger flares tend to last longer.

Sources:
From SWPC 's « The Weekly » User guide (https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf ; page 15)
From **Temporal aspects and frequency distributions of solar soft X-ray flares**
Veronig et al. (2002): https://www.aanda.org/articles/aa/pdf/2002/06/aa1910.pdf
And from **The duration of solar flares**
http://www.stce.be/news/332/welcome.html

SOLAR FLARE DURATION

Impulsive flare

- M- and X-class only
- Duration
  - Total duration < 10 minutes
- Usually NOT associated with CMEs
- Compact

Long Duration Event

- All flare classes
- Duration
  - Total duration > 1 hour
  - Decay time > 30 minutes (SWPC)
- Association with CMEs increases with increased duration

From the SWPC glossary at https://www.swpc.noaa.gov/content/space-weather-glossary#longduration (operational definition)

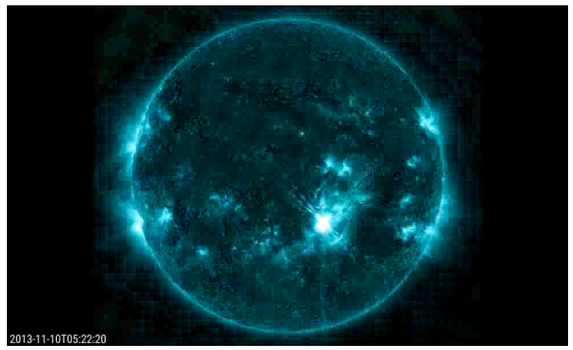
Long duration X-ray events (LDE) are not impulsive in appearance. The exact time threshold separating impulsive from long-duration events is not well defined, but **operationally**, any event requiring 30 minutes or more to decay to one-half peak flux is regarded as an LDE. It has been shown that the likelihood of a coronal mass ejection increases with the duration of an x-ray event, and becomes **virtually certain for durations of 6 hours or more**.

SOLAR FLARE DURATION

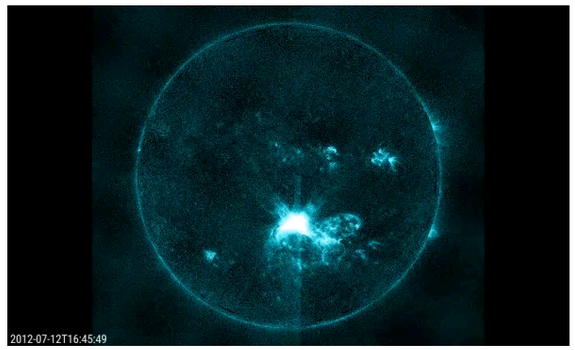
Impulsive flare

Long Duration Event

SDO/AIA



X1 - NOAA 1890 - 10 Nov 2013 (duration: 10 minutes)



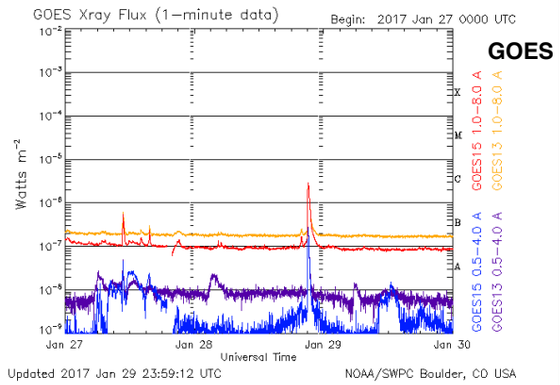
X1 - NOAA 1520 - 12 July 2012 (duration: 113 minutes)

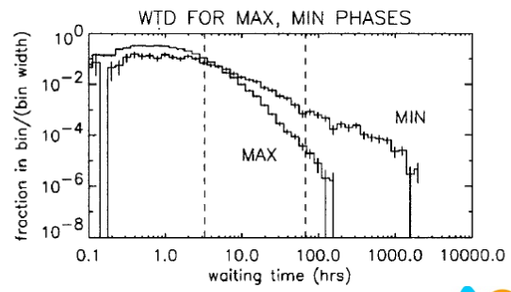
Imagery from STCE: http://www.stce.be/news/332/welcome.html
A short and a long duration X1 flaring event. These took place resp. in NOAA 11890 on 10 November 2013 (duration: 10 minutes) and in NOAA 11520 on 12 July 2012 (duration: 113 minutes or nearly 2 hours). The latter was accompanied by a full halo CME (no surprise), but also the 2013 X1 flare was associated with a partial halo CME.

SOLAR FLARE FREQUENCY

Isolated flare

- Usually specified per class (B, C, M, X)
- From entire Sun
  1-4 per day
- In practice
  1 event in 24 hours
- Average waiting time
  - 6.5 hours (≥ C1)
  - SCmax: 3 hours
  - SCmin: 3 days





Wheatland et al. (2002): Understanding solar flare waiting-time distributions
http://www.physics.usyd.edu.au/wheat/papers/pdfs/understanding_WTD.pdf

The bottom figure shows the Waiting Time Distribution for all years 1975–2001, and reproduces the power-law tail reported by Boffeta et al. (1999). The distribution for the maximum phase of the solar cycle has a steeper distribution, because the rate of flaring is higher around solar maximum, and so the average waiting time is less. The average waiting times for the two phases are indicated by the dashed vertical lines (average waiting time for all flares regardless the phase of the cycle is 6,5 hours). The maximum and minimum distributions both exhibit approximate power-law tails.

From http://users.telenet.be/j.janssens/Archives/Archives.html#021109
The longest stretch without C-class flares was from 3 April till 3 November 2008, that's 214 consecutive days of very low activity.
Since the start of systematic GOES observations, there have been only 9 periods with more than 60 consecutive days with no C-class flares, 6 of those happened during the most recent SC23-SC24 minimum… The longest stretch without M-class flares was from 25 March 2008 till 19 January 2010 (665 days). … The longest stretch without X-class flares was from 14 Dec 2006 till 15 February 2011 (1524 days).

From SWPC 's « The Weekly » User guide (https://www.swpc.noaa.gov/sites/default/files/images/u2/Usr_guide.pdf ; page 1)

Terms Used to Describe Solar Activity
Very Low: x-ray events less than C-class.
Low: C-class x-ray events.
Moderate: isolated (one to four) M-class x-ray events.
High: several (5 or more) M-class x-ray events, or isolated (one to four) M5 or greater x-ray events.
Very High: several (5 or more) M5 or greater x-ray events.

:Issued: 2026 Oct 09 1254 UTC
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 61009
SIDC SOLAR BULLETIN 09 Oct 2026, 1253UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Minor storm expected (A>=30 or K=5)
SOLAR PROTONS : Warning condition (activity levels expected to increase, but no numeric forecast given)
PREDICTIONS FOR 09 Oct 2026 10CM FLUX: 122 / AP: 021
PREDICTIONS FOR 10 Oct 2026 10CM FLUX: 124 / AP: 022
PREDICTIONS FOR 11 Oct 2026 10CM FLUX: 126 / AP: 015



Finding your way in the URSIgram

Solar Active Regions and flaring: The solar flaring activity over the past 24 hours reached high levels with background C-class flaring and one registered M-flare. The strongest recorded activity was a M6.7 flare (SIDC Flare 8685) with peak time at 15:48 UTC on October 08. The flare was produced within SIDC Sunspot Group 976 (NOAA Active Region 4549) currently located at N10W31. A total of 5 numbered sunspot groups were identified on the visible solar disk with SIDC Sunspot Group 976 remaining the largest and most complex region. It continues to be classified as magnetic type beta-gamma-delta and was the main contributor to the observed flaring activity over the past 24 hours. SIDC Sunspot Group 973 (NOAA Active Region 4545), currently located at N18W37, has exhibited some decay. It is classified as magnetic type beta and remained quiet. A new region has emerged on disc SIDC Sunspot Group 979, currently located at N22W11, and another one, SIDC Sunspot Group 980, is rotating from behind the south-east limb. Both are classified as magnetic type beta and the latter one has exhibited some low flaring activity while behind the east limb. The solar flaring activity is expected to be at moderate over the next 24 hours with likely M-class flaring and chances for an X-class flare.

Coronal mass ejections: A wide coronal mass ejection (SIDC CME 727) was observed by LASCO/C2 to lift off the solar surface around 16:12 UTC on October 08 with a white-light shock and an estimated projected speed of around 500 km/s. The eruption is likely linked to the M6.7 flaring from SIDC Sunspot Group 976 (NOAA Active Region 4549) with an associated EUV dimming and a coronal wave detected in the SDO/AIA data around 16:33 UTC on October 08. Related type II and type IV solar radio emissions were detected at 15:42 UTC and 16:12 UTC on October 08 respectively. SIDC CME 727 is estimated to have an Earth-directed component and current analysis suggests a possible arrival time late UTC on October 11 to early UTC on October 12. Another EUV dimming and a small coronal wave were observed in the SDO/AIA imagery starting at 17:36 UTC on October 08, seemingly related to a filament eruption in the south-eastern quadrant triggered by the same event chain. A faint eastward eruption is visible in the LASCO/C2 around 17:00 UTC, but is expected to travel off the Sun-Earth line.

Coronal holes: SIDC Coronal Hole 149 (a recurrent mid-latitude coronal hole with a negative polarity) continues to reside on the central meridian. A high-speed stream related to it might be expected at Earth on October 09, possibly mixed with anticipated ICME arrival signatures related to SIDC CME 725.

Solar wind: Over the past 24 hours the solar wind parameters (as measured by ACE at L1) registered some enhancements, possibly the precursor of a high-speed stream arrival related to SIDC Coronal Hole 149. The solar wind speed remained slow, varying in the range of 333 to 390 km/s. The interplanetary magnetic field (B) registered a maximum value of 12.7 nT with a north-south (Bz) component down to - 7 nT. The B field phi angle switched from the positive to the negative sector (directed towards the Sun). The solar wind parameters are expected to be perturbed over the next 24 hours with an anticipated arrival of a high-speed stream possibly mixed with an ICME arrival related to SIDC CME 725. Perturbed solar wind conditions are expected to continue on October 10 with anticipated high- speed stream influence and possible waning ICME influence. A mild glancing blow arrival related to SIDC CME 726 could be expected on October 11 with the possibility of another ICME arrival late UTC on October 11 or early UTC on October 12 related to SIDC CME 727.

Geomagnetism: The geomagnetic conditions over the past 24 hours were locally (over Belgium) quiet to unsettled and globally quiet to active with NOAA Kp reaching 4 in the period 9-12 UTC on October 09. Unsettled conditions to minor storm levels are expected over the next 24 hours with chances for isolated moderate storms. Unsettled to active conditions with chances for more minor storm levels can continue on October 10, October 11 and October 12.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux remained at close to nominal levels, while exhibiting some further enhancements related to activity from SIDC Sunspot Group 976 (NOAA Active Region 4549). The greater than 10 MeV GOES proton flux is expected to further increase over the next 24 hours with chances of reaching the 10 pfu proton event threshold.

Electron fluxes at GEO: The greater than 2 MeV electron flux as measured by GOES 18 and GOES 19 has exceeded the 1000 pfu threshold over the past 24 hours and is expected to be predominantly below the 1000 pfu threshold over the next 24 hours. The 24-hour electron fluence was at moderate levels and is expected to decrease to nominal levels over the next 24 hours.

TODAY'S ESTIMATED ISN : 086, BASED ON 07 STATIONS.

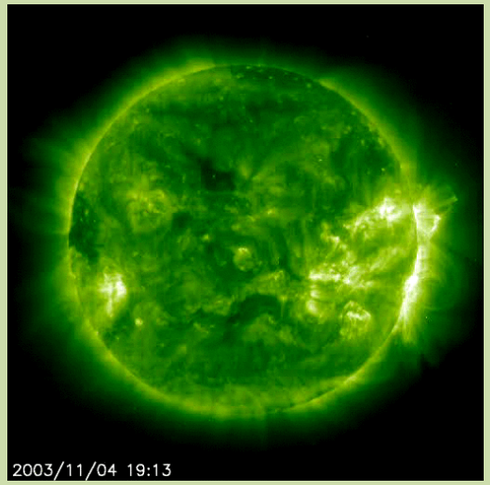
SOLAR INDICES FOR 08 Oct 2026
WOLF NUMBER CATANIA : 089
10CM SOLAR FLUX : ///
AK CHAMBON LA FORET : 017
AK WINGST : 006
ESTIMATED AP : 006
ESTIMATED ISN : 075, BASED ON 18 STATIONS.

Flare classification

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
08 1529 1548 1558 N12W20 M6.7 2B 57/4549 I/3
END

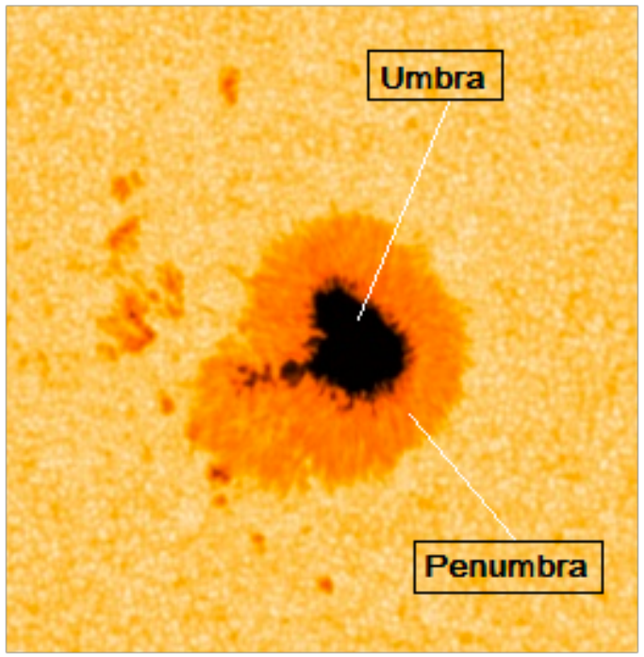
FLARES - OVERVIEW

- Flare Characteristics
- Flare Classification
- **Flare predictions**
  - **McIntosh**
  - **Hale**



SOHO/EIT

SUNSPOT NOMENCLATURE

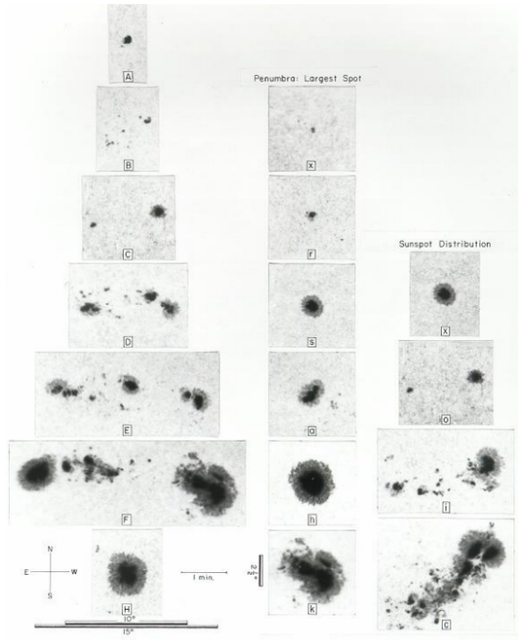


Often two distinct regions can be seen in a sunspot: the dark core called the umbra (shadow in Latin) and the slightly less dark surroundings, called the penumbra.

FLARE PREDICTIONS

McIntosh classification

- Zpc ***(3-letter code)***
  - Z - Modified Zürich classification
  - p - Penumbra largest spot
  - c - Interior sunspot distribution
- 60 possible combinations
  - Linked to flare intensity
  - Rather large uncertainties
- Used worldwide



See: https://www.stce.be/educational/classification

The McIntosh classification for sunspot groups was developed by Patrick McIntosh (McIntosh, 1990) based on an earlier scheme devised by Max Waldmeier in 1947, called the Zürich classification. The general form of the McIntosh classification is Zpc (overview image above), where Z is the modified Zurich class, p is the type of principal spot, primarily describing the penumbra, and c is the degree of **compactness** in the interior of the group.

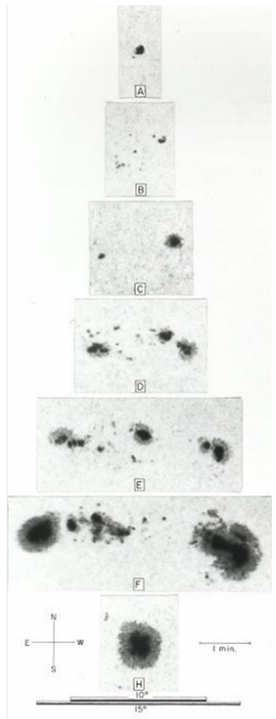
The modified **Zurich classes** are defined on the basis of whether **penumbra** is present, how the penumbra is distributed, and by the **length** of the group.

McIntosh, P.S. (1990): The classification of sunspot groups
http://adsabs.harvard.edu/abs/1990SoPh..125..251M

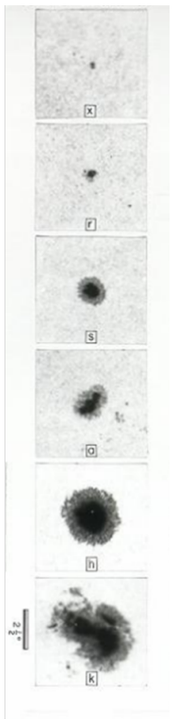
https://wwwbis.sidc.be/educational/classification.php#:~:text=The%203%20component%20McIntosh%20classification,the%20interior%20of%20the%20group.

FLARE PREDICTIONS

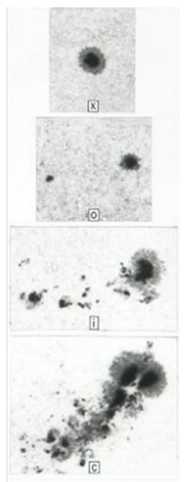
A B C D E F H



x r s a h k



x o i c



McIntosh, P.S. (1990): The classification of sunspot groups
http://adsabs.harvard.edu/abs/1990SoPh..125..251M

Questions to ask (Table 1 from McIntosh paper)
Z – **General outlook of the sunspot group:**
=> Unipolar or bipolar group?
=> Penumbra or no penumbra?
=> Penumbra on one or both sides of the group?
=> Length of the group (>10°? >15°?)
* 7 options: A, B, C, D, E, F, H

p – Penumbra largest spot
=> Rudimentary or mature penumbra?
=> Symmetric or asymmetric penumbra main spot?
=> N–S–diameter of the largest spot (>2,5°?)
* 6 options: x, r, s, a, h, k

c – Sunspot distribution interior (“compactness”)
=> Several spots between leading and trailing main spot?
=> Internally, is there at least one spot with a mature penumbra?
* 4 options: x, o, i, c (open, intermediate, compact)

FLARE PREDICTIONS

Table 2
McIntosh Classification Flare Statistics

McIntosh	SWPC (1988–1996)				Kildahl (1969–1976)[b]				Combined Flare Rate (24 hr^{-1})				Poisson Flare Probability (%)				
Region	Region	Total Flares			Region	Total Flares			In *GOES* Class				In *GOES* Class			Above *GOES*[d]	
Classes[a]	Count	C	M	X	Count	C[c]	M	X	C	M	X	$\pm\sigma$	C	M	X	M1.0	C1.0
ESO	95	37	6	0	82	31.9	14	0	0.39	0.11	0.00	0.08	32	11	0	11	39
ESI	18	33	1	0	78	143.0	22	2	1.83	0.24	0.02	0.10	84	21	2	23	88
EAO	459	267	61	0	47	27.3	10	4	0.58	0.14	0.01	0.04	44	13	1	14	52
EAI	295	370	83	2	82	102.8	48	1	1.25	0.35	0.01	0.05	71	29	1	30	80
EAC	3	5	1	0	17	28.3	6	3	1.67	0.35	0.15	0.22	81	30	14	39	89
EHO	42	31	6	0	39	28.8	6	0	0.74	0.15	0.00	0.11	52	14	0	14	59
EHI	15	24	6	0	45	72.0	28	4	1.60	0.57	0.07	0.13	80	43	6	47	89
EHC	2	9	0	0	4	18.0	8	0	4.50	1.33	0.00	0.41	99	74	0	74	100
EKO	185	173	35	3	52	48.6	20	1	0.94	0.23	0.02	0.06	61	21	2	22	69
EKI	423	703	173	23	81	134.6	103	11	1.66	0.55	0.07	0.04	81	42	7	46	90
EKC	103	278	132	17	63	170.0	149	21	2.70	1.69	0.23	0.08	93	82	20	85	99
FRI	0	0	0	0	2	0.0	1	0	0.00	0.50	0.00	0.71	0	39	0	39	39
FSO	14	9	3	0	13	8.4	6	1	0.64	0.33	0.04	0.19	47	28	4	31	64
FSI	6	12	0	0	8	16.0	15	0	2.00	1.07	0.00	0.27	86	66	0	66	95
FAO	73	63	16	0	3	2.6	0	0	0.86	0.21	0.00	0.11	58	19	0	19	66
FAI	91	106	35	3	12	14.0	8	0	1.16	0.42	0.03	0.10	69	34	3	36	80
FHO	9	5	1	0	10	5.6	0	0	0.56	0.05	0.00	0.23	43	5	0	5	46
FHI	10	17	9	0	18	30.6	15	0	1.70	0.86	0.00	0.19	82	58	0	58	92
FHC	0	0	0	0	5	0.0	4	0	0.00	0.80	0.00	0.45	0	55	0	55	55
FKO	97	165	29	1	19	32.3	6	0	1.70	0.30	0.01	0.09	82	26	1	27	87
FKI	235	517	161	17	47	103.4	106	17	2.20	0.95	0.12	0.06	89	61	11	66	96
FKC	93	233	146	24	27	67.6	39	13	2.51	1.54	0.31	0.09	92	79	27	84	99

Notes.
[a] Only includes classifications producing $\geqslant$1 C-, M-, or X-class flare in either time range.
[b] From Kildahl (1980).
[c] Non-integer flare numbers result from use of observed C-class rates from SWPC (1988–1996).
[d] "Above *GOES* X1.0" is equivalent to "In *GOES* Class X."

For space weather forecasting it is important to know how this classification relates to the probability of producing a flare.

Bloomfield S. et al. (2012): Toward Reliable Benchmarking of Solar Flare Forecasting Methods
http://adsabs.harvard.edu/abs/2012ApJ...747L..41B

FLARE PREDICTIONS

Likelihood (terminology)

RWC Belgium: Decision on use of scales and wording

Flare forecast

ISES
0 = Quiet (<50% probability of C-class flares) 1 = Eruptive (C-class flares expected, probability >=50%) 2 = Active (M-class flares expected, probability >=50%) 3 = Major flares expected (X-class flares expected, probability >=50%)

Activity level	wording for bulletin
<50% probability of C-class flares	Quiet solar conditions
C-class flares expected, probability >=50%	C-class flares expected C-class flaring activity/conditions expected we expect solar active conditions ([C,M,X]-class flares) with a high/small probability for a [C, M, X]-flare
M-class flares expected, probability >=50%	M-class flares expected / idem as above
X-class flares expected, probability >=50%	X-class flares expected / idem as above

Unofficial terminology deduced from various SWx reports/services

Probability (%)	Terminology
0-10	Unlikely
10-25	Small chance
25-50	A chance; Possible
50-75	Likely
75-100	Very likely; Expected

This is a topic under continued improvement / discussion….

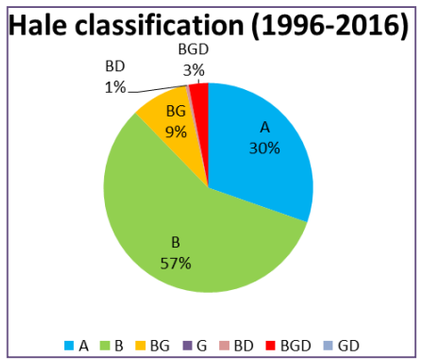
Nearly equivalent terms are used by the different space weather service providers (SWPC, SIDC,…)

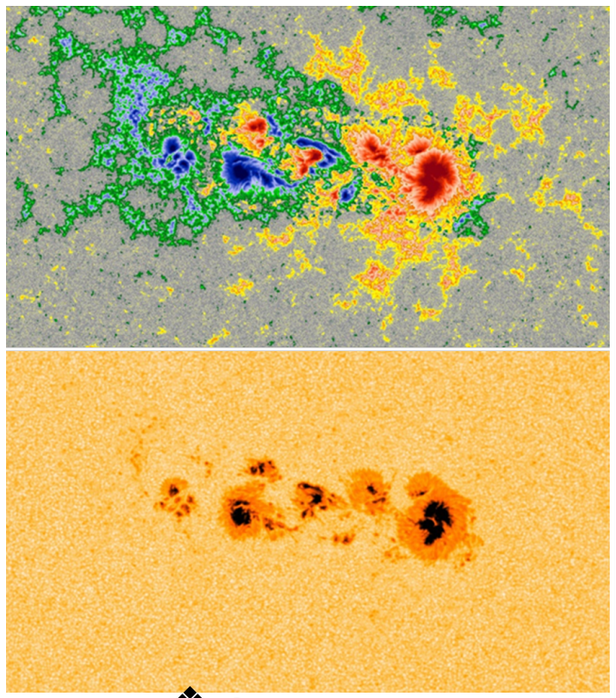
As far as we know, there’s no clear terminology consistently applied internally or between the space weather prediction services.

FLARE PREDICTIONS

Mount Wilson (Hale) classification

- Based on the magnetic properties of a sunspot group
- 7 options:
  - A (α)
  - B (β), BG (βγ), G (γ)
  - BD (βδ), BGD (βγδ), GD (γδ)





SDO/HMI

Jaeggli and Norton (2016): The Magnetic Classification of Solar Active Regions 1992–2015
http://adsabs.harvard.edu/abs/2016ApJ...820L..11J
http://iopscience.iop.org/article/10.3847/2041-8205/820/1/L11/pdf

Magnetic classifications provide a simple way to describe the configuration of the magnetic flux and sunspots in a solar active region (AR). The Mount Wilson (or Hale) classification system for sunspot groups put forward by Hale et al. (1919) has been used for nearly a century. In the original Hale classification scheme, the designation (**alpha**) is given to regions that contain a single sunspot or sunspot group all having the same polarity. Generally, these also have a weaker opposite polarity counterpart that is not strong or concentrated enough to produce sunspots. (**beta**) is assigned to regions that have two sunspots or sunspot groups of opposite polarity. The classification (**gamma**) is appended to the above classes to indicate the AR has a complex region of sunspots with **intermixed polarity**. This classification can also be used individually to describe an AR that has no organized magnetic behavior. As an addendum to the original scheme, Kunzel (1965) proposed an additional classification to modify the existing three. (**delta**) indicates that at least one sunspot in the region **contains opposite magnetic polarities inside of a common penumbra** separated by no more than 2° in heliographic distance (24 Mm or 33″ at disk center).

Also at STCE: http://www.stce.be/news/222/welcome.html

Make sure to avoid classifying too quickly a sunspot group as a delta or a gamma type when this sunspot group is still very close to the **limb**. Indeed, line-of-sight may come into play that show an unipolar spot as if it would have a delta structure.
See STCE: http://www.stce.be/news/188/welcome.html

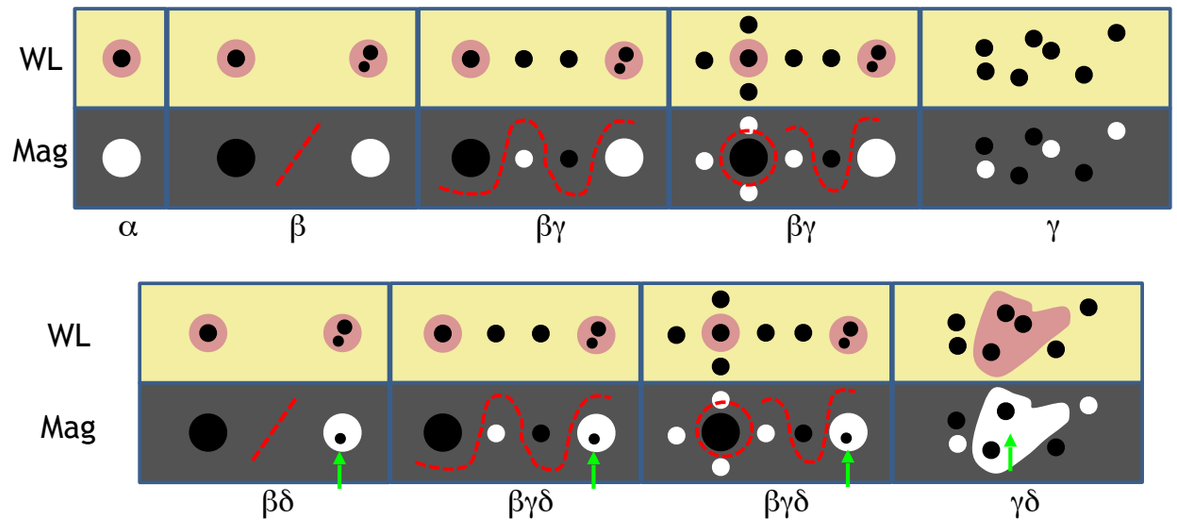
The pictures to the right are from SDO/HMI and show a magnetogram and a white light image of NOAA 1875 on 23 October 2013.

The chart with the % of Hale classification was based on the NOAA reports at https://solarscience.msfc.nasa.gov/greenwch.shtml for the period Jan 1996-September 2016. A total of 32965 classifications were made. The percentage of reported delta's in the sunspot groups is 3.5%.

See also: https://www.stce.be/educational/classification

FLARE PREDICTIONS

Mount Wilson (Hale) classification - Sketches

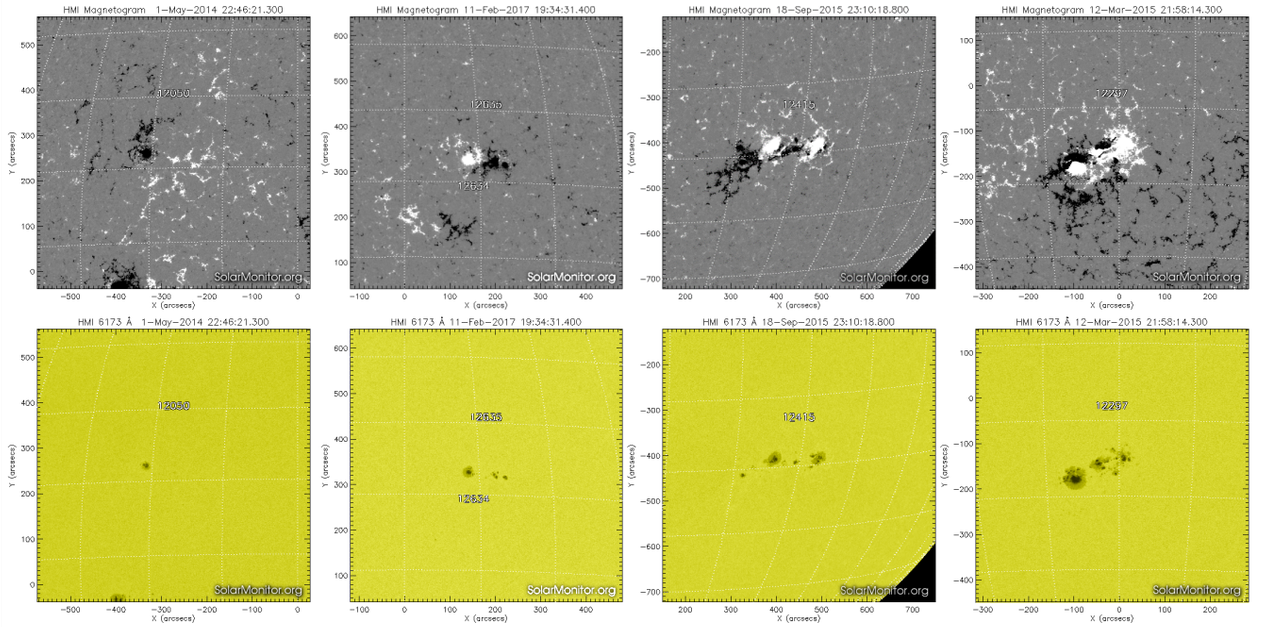


Text underneath based on SWPC User Guide, SWPC Glossary (https://www.swpc.noaa.gov/content/space-weather-glossary#m), Mount Wilson (http://obs.astro.ucla.edu/spotlgnd.html) and SIDC old webpages (http://sidc.oma.be/educational/classification.php#magnetic).

Alpha – Unipolar group; that is, all plus or all minus magnetic field
Beta – A bipolar group; that is a mix of plus and minus magnetic polarities exist, with the plus well divided from the minus with one polarity in each end (E-W) of the group, i.e. “easily divided by a simple line”.
Beta-Gamma – A group which is generally bipolar but which is lacking a well marked dividing line between the opposite polarity regions (“you need to lift your pencil to divide the polarities” or “no single, continuous line can be drawn between spots of opposite polarities”).
Gamma – a group in which the polarities are so completely mixed that **no bipolar structure** can obviously be recognized.
Delta – This is a sub-classification for non-unipolar regions. It means at least two opposing polarity umbrae are **within two heliographic degrees** of each other and share the same penumbra.

[The determination of the Hale class is done on the (magnetic polarity of the) sunspots, NOT the magnetograms!]

EXAMPLES OF HALE CLASSIFICATION



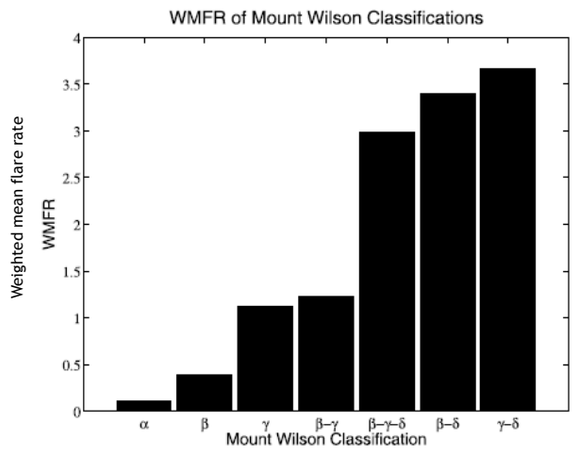
α β βγ βγδ

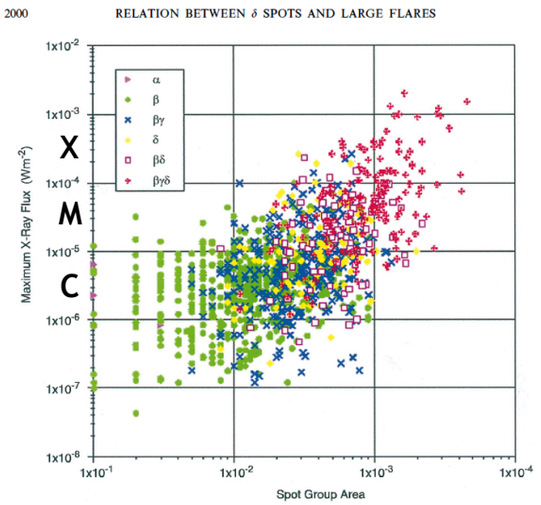
SDO/HMI

Examples from https://www.solarmonitor.org/index.php

Delta means we have opposite polarities very close together, increasing the chances of a flare significantly.

FLARE PREDICTIONS





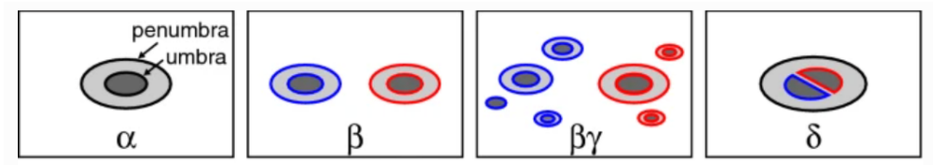


Figure left: Shin et al. (2016): Development of Daily Maximum Flare-Flux Forecast Models for Strong Solar Flares - http://adsabs.harvard.edu/abs/2016SoPh..291..897S

Most of the complex sunspots of the Mount Wilson magnetic classification that are characterized by gamma and/or delta show higher WMFR values (WMFR: weighted mean flare rate).

Figure right: Sammis et al. (2000): The Dependence of Large Flare Occurrence on the Magnetic Structure of Sunspots
http://adsabs.harvard.edu/abs/2000ApJ...540..583S
http://iopscience.iop.org/article/10.1086/309303/pdf

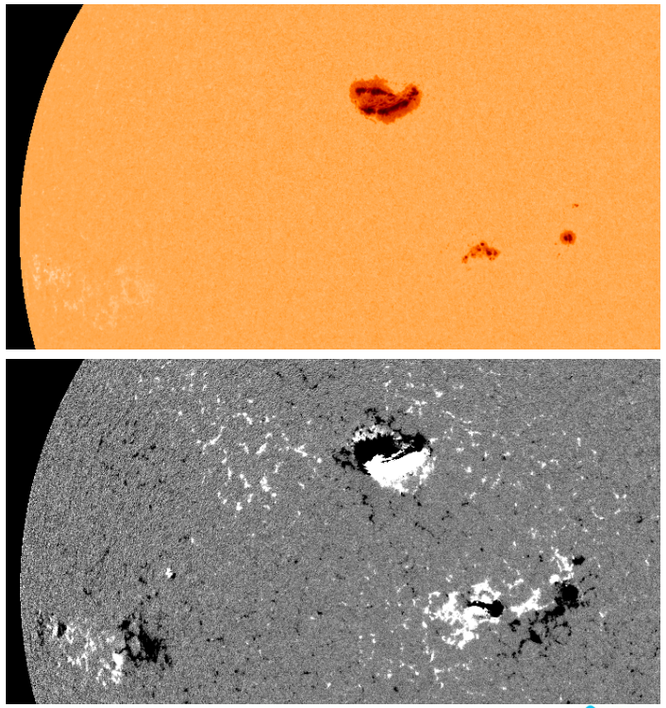
In Figure 2, we plot the largest flare from each active region against the largest reported area from that region, for each magnetic class. This shows a roughly linear connection between the logs of SXR flux and active region maximum areas. The general slope of Figure 2, upward and to the right, confirms the well-known fact that large active regions have more large flares than small ones and also tend to be more complex.

The increase in flare size with spot size shows that although the sharp gradient and currents of the delta configuration provide the appropriate situation for flare occurrence, the scale offered by a large spot is important in producing great flares. All large flares (X4 or higher) occur in spot groups of area greater than 1000 MH (micro hemispheres, **disk fraction**) classified bgd. Predictions that X1 flares will occur for such a class will enjoy a 41% probability of success with no other considerations. Adding some of the considerations mentioned by Zirin & Liggett (1987) and Zirin & Marquette (1991), particularly H-alpha brightness and flux emergence, should improve these predictions considerably.

Bottom figure from https://link.springer.com/article/10.1007/s41116-019-0019-7

FLARE PREDICTIONS

- Magnetic shear
- Magnetic helicity
- Flaring history
- Evolution of group
- Size of the spots
- …



Massi et al.: http://www3.mpifr-bonn.mpg.de/staff/mmassi/c4-Model.pdf
⇒Magnetic shear: the vector magnetic field is oriented more parallel to the neutral line than perpendicular to it.
(Shear: laterally shifted in relation to each other.)

From https://solarscience.msfc.nasa.gov/flares.shtml
Stable sunspots tend to be fairly symmetrical unless there is extensive magnetic shear nearby from emerging magnetic flux or the passing of an area of opposite magnetic polarity. Magnetic shearing can cause large portions of sunspot penumbras to distort or vanish.

Lee et al. (2012): Solar Flare Occurrence Rate and Probability in Terms of the Sunspot Classification Supplemented with Sunspot Area and Its Changes
http://adsabs.harvard.edu/abs/2012SoPh..281..639L
We used sunspot data from 1996 to 2010. We noted that sunspot area and its changes can be a proxy of magnetic flux and its emergence/cancellation, respectively.
When the sunspot area increases, the flare occurrence rates and probabilities noticeably increase, especially for major flares.This is statistical evidence that magnetic flux emergence is an important mechanism for triggering solar flares, because sunspot area can be a good proxy of magnetic flux.

Filament: e..g 7 June 2011:
STCE: http://www.stce.be/news/353/welcome.html
STCE: http://www.stce.be/news/x137x/welcome.html
Science at NASA: https://science.nasa.gov/science-news/science-at-nasa/2011/11jul_darkfireworks

:Issued: 2026 Oct 09 1254 UTC
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 61009
SIDC SOLAR BULLETIN 09 Oct 2026, 1253UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Minor storm expected (A>=30 or K=5)
SOLAR PROTONS : Warning condition (activity levels expected to increase, but no numeric forecast given)
PREDICTIONS FOR 09 Oct 2026 10CM FLUX: 122 / AP: 021
PREDICTIONS FOR 10 Oct 2026 10CM FLUX: 124 / AP: 022
PREDICTIONS FOR 11 Oct 2026 10CM FLUX: 126 / AP: 015



Solar Active Regions and flaring: The solar flaring activity over the past 24 hours reached high levels with background C-class flaring and one registered M-flare. The strongest recorded activity was a M6.7 flare (SIDC Flare 8685) with peak time at 15:48 UTC on October 08. The flare was produced within SIDC Sunspot Group 976 (NOAA Active Region 4549) currently located at N10W31. A total of 5 numbered sunspot groups were identified on the visible solar disk with SIDC Sunspot Group 976 remaining the largest and most complex region. It continues to be classified as magnetic type beta-gamma-delta and was the main contributor to the observed flaring activity over the past 24 hours. SIDC Sunspot Group 973 (NOAA Active Region 4545), currently located at N18W37, has exhibited some decay. It is classified as magnetic type beta and remained quiet. A new region has emerged on disc SIDC Sunspot Group 979, currently located at N22W11, and another one, SIDC Sunspot Group 980, is rotating from behind the south-east limb. Both are classified as magnetic type beta and the latter one has exhibited some low flaring activity while behind the east limb. The solar flaring activity is expected to be at moderate over the next 24 hours with likely M-class flaring and chances for an X-class flare.

Coronal mass ejections: A wide coronal mass ejection (SIDC CME 727) was observed by LASCO/C2 to lift off the solar surface around 16:12 UTC on October 08 with a white-light shock and an estimated projected speed of around 500 km/s. The eruption is likely linked to the M6.7 flaring from SIDC Sunspot Group 976 (NOAA Active Region 4549) with an associated EUV dimming and a coronal wave detected in the SDO/AIA data around 16:33 UTC on October 08. Related type II and type IV solar radio emissions were detected at 15:42 UTC and 16:12 UTC on October 08 respectively. SIDC CME 727 is estimated to have an Earth-directed component and current analysis suggests a possible arrival time late UTC on October 11 to early UTC on October 12. Another EUV dimming and a small coronal wave were observed in the SDO/AIA imagery starting at 17:36 UTC on October 08, seemingly related to a filament eruption in the south-eastern quadrant triggered by the same event chain. A faint eastward eruption is visible in the LASCO/C2 around 17:00 UTC, but is expected to travel off the Sun-Earth line.

Coronal holes: SIDC Coronal Hole 149 (a recurrent mid-latitude coronal hole with a negative polarity) continues to reside on the central meridian. A high-speed stream related to it might be expected at Earth on October 09, possibly mixed with anticipated ICME arrival signatures related to SIDC CME 725.

Solar wind: Over the past 24 hours the solar wind parameters (as measured by ACE at L1) registered some enhancements, possibly the precursor of a high-speed stream arrival related to SIDC Coronal Hole 149. The solar wind speed remained slow, varying in the range of 333 to 390 km/s. The interplanetary magnetic field (B) registered a maximum value of 12.7 nT with a north-south (Bz) component down to - 7 nT. The B field phi angle switched from the positive to the negative sector (directed towards the Sun). The solar wind parameters are expected to be perturbed over the next 24 hours with an anticipated arrival of a high-speed stream possibly mixed with an ICME arrival related to SIDC CME 725. Perturbed solar wind conditions are expected to continue on October 10 with anticipated high- speed stream influence and possible waning ICME influence. A mild glancing blow arrival related to SIDC CME 726 could be expected on October 11 with the possibility of another ICME arrival late UTC on October 11 or early UTC on October 12 related to SIDC CME 727.

Geomagnetism: The geomagnetic conditions over the past 24 hours were locally (over Belgium) quiet to unsettled and globally quiet to active with NOAA Kp reaching 4 in the period 9-12 UTC on October 09. Unsettled conditions to minor storm levels are expected over the next 24 hours with chances for isolated moderate storms. Unsettled to active conditions with chances for more minor storm levels can continue on October 10, October 11 and October 12.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux remained at close to nominal levels, while exhibiting some further enhancements related to activity from SIDC Sunspot Group 976 (NOAA Active Region 4549). The greater than 10 MeV GOES proton flux is expected to further increase over the next 24 hours with chances of reaching the 10 pfu proton event threshold.

Electron fluxes at GEO: The greater than 2 MeV electron flux as measured by GOES 18 and GOES 19 has exceeded the 1000 pfu threshold over the past 24 hours and is expected to be predominantly below the 1000 pfu threshold over the next 24 hours. The 24-hour electron fluence was at moderate levels and is expected to decrease to nominal levels over the next 24 hours.

TODAY'S ESTIMATED ISN : 086, BASED ON 07 STATIONS.

SOLAR INDICES FOR 08 Oct 2026
WOLF NUMBER CATANIA : 089
10CM SOLAR FLUX : ///
AK CHAMBON LA FORET : 017
AK WINGST : 006
ESTIMATED AP : 006
ESTIMATED ISN : 075, BASED ON 18 STATIONS.

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
08 1529 1548 1558 N12W20 M6.7 2B 57/4549 I/3
END

Flare prediction

SOLAR ERUPTIONS

Magnetic Reconnection

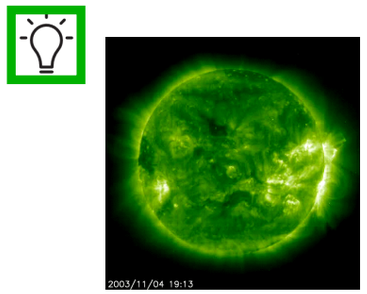
Radiation

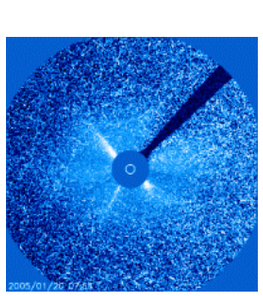
Particles

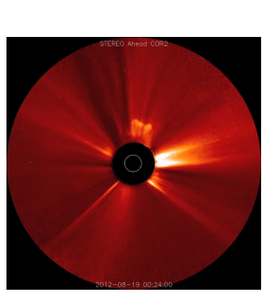
Solar flares

Proton events

Coronal Mass Ejections







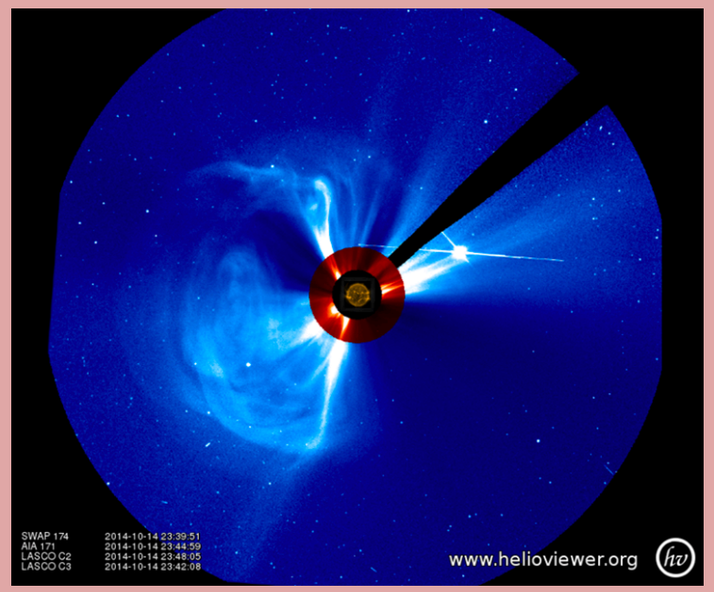
SOHO/EIT

SOHO/LASCO

SOHO/LASCO

CME - OVERVIEW

- **Model**
- On-disk signatures
  - Filaments
  - Waves
  - Dimming
  - Post-eruption arcade
- Characteristics



PROBA2/SWAP
SDO/AIA
SOHO/LASCO

CORONAL MASS EJECTION

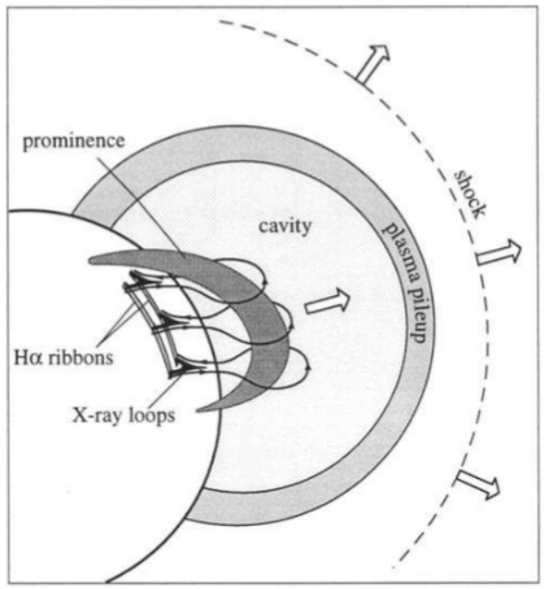


Figure 3. Schematic diagram showing the relationship between various features associated with a CME. The shaded region labeled "plasma pileup" refers to the outer circular arc seen in coronagraphs.

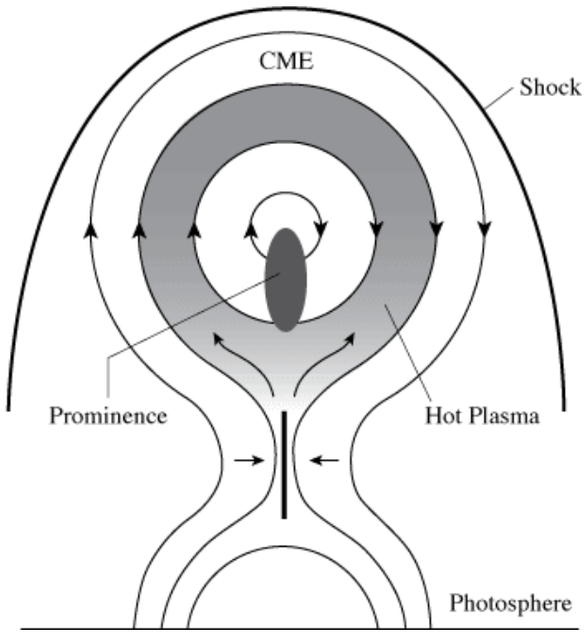
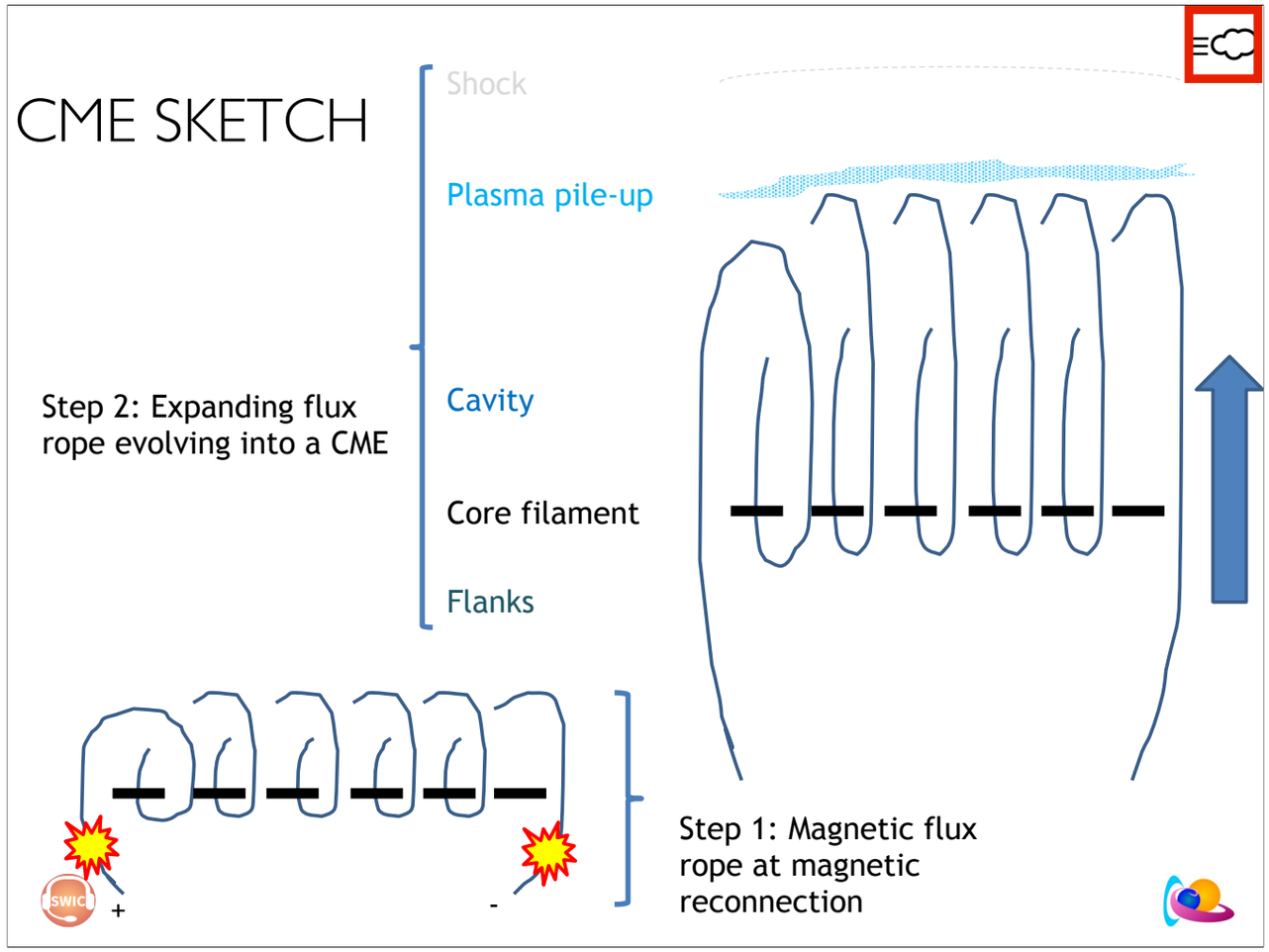


Figure to the right taken from https://ase.tufts.edu/cosmos/print_images.asp?id=27
A magnetic reconnection takes place at a current sheet (dark vertical line) beneath a prominence and above closed magnetic field lines. The coronal mass ejection (CME) traps hot plasma below it (hatched region). The solid curve at the top is the bow shock driven by the CME. The closed field region above the prominence (center) is supposed to become a flux rope in the interplanetary medium.

Left: In this model of a three-part coronal mass ejection, portrayed by Terry Forbes (2000), swept-up, compressed mass and a bow shock have been added to the eruptive-flare portrayal of Tadashi Hirayama (1974). The combined representation includes compressed material at the leading edge of a low-density, magnetic bubble or cavity, and dense prominence gas. The prominence and its surrounding cavity rise through the lower corona, followed by sequential magnetic reconnection and the formation of flare ribbons at the footpoints of a loop arcade. [Adapted from Hugh S. Hudson, Jean-Louis Bougeret and Joan Burkepile (2006).]

Figure to the left taken from Forbes (2000): A review on the genesis of coronal mass ejection
http://adsabs.harvard.edu/abs/2000JGR...10523153F
http://onlinelibrary.wiley.com/doi/10.1029/2000JA000005/epdf

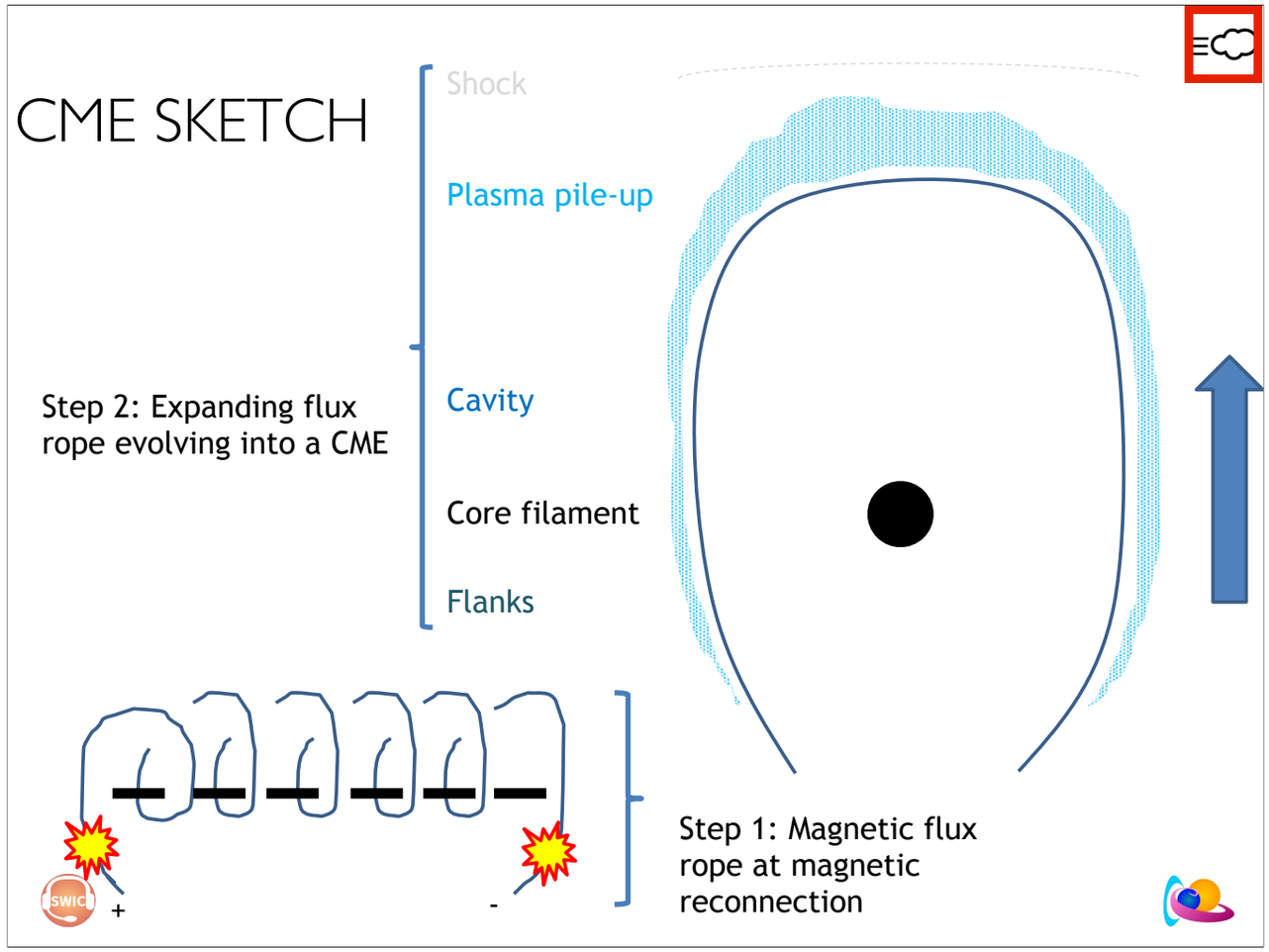
When CMEs were first clearly identified by Skylab in 1973, many researchers assumed that they were caused by the outward expansion of hot plasma produced by a large flare. We now know that this is not the case, for several reasons. First, less than 20% of all CMEs are associated with large flares [Gosling, 1993]. Second, CMEs that are associated with flares often appear to start before the onset of the flare [Wagner et al., 1981; Simnett and Harrison, 1985]. Finally, the thermal pressure produced by a flare is too small to blow open the strong magnetic field of the corona.



Expanding flux rope consisting of magnetic field lines and filament at bottom (left sketch) evolves into a CME with leading edge (pushed up by top of magnetic field lines from flux rope), cavity and core filament (right sketch). The shock is usually not visible, but measurable by e.g. Type II radio bursts or by observing the deflection of nearby streamers.

Source file: Webb et al. (2012): Coronal Mass Ejections: Observations
http://link.springer.com/article/10.12942/lrsp-2012-3
However, with the larger dynamic range of LASCO rims of material detected ahead of fast LASCO CMEs are now considered evidence of shock waves, and emission can be detected ahead of slower speed CMEs as low-level brightness enhancements due to the expanding streamer.

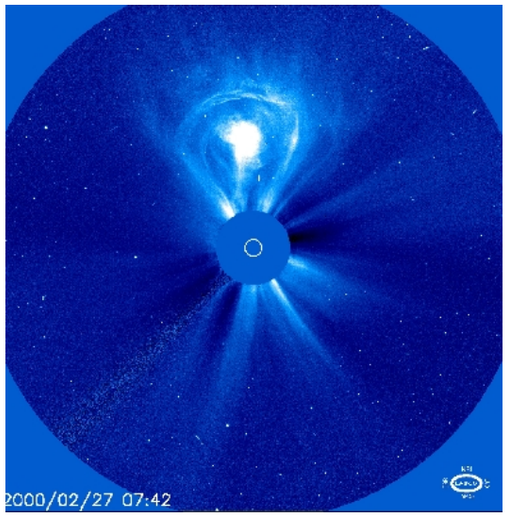
It should be kept in mind that these features are not necessarily present in all CMEs. Not all CMEs contain a prominence, nor do all CMEs have detectable chromospheric ribbons and shock waves

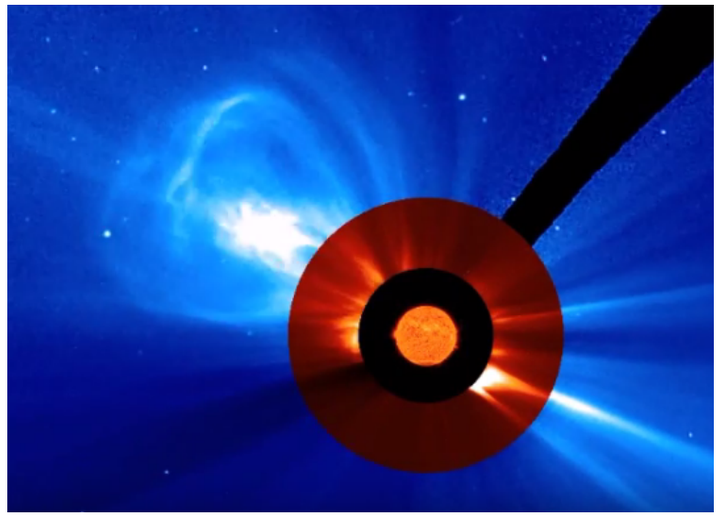


Expanding flux rope consisting of magnetic field lines and filament at bottom evolves into a CME with leading edge (pushed up by top of magnetic field lines from flux rope), cavity and core filament.

Vourlidas et al. (2013): How Many CMEs Have Flux Ropes? Deciphering the Signatures of Shocks, Flux Ropes, and Prominences in Coronagraph Observations of CMEs – http://adsabs.harvard.edu/abs/2013SoPh..284..179V
"… the brightness of the front originates from the pile-up of the overlying streamer material. … the cavity, while not completely devoid of plasma, does contain less electrons (it is less bright) than its surroundings. … 'three-part'-CMEs are indeed systems of ejected FRs, where the cavity is the actual FR. …"

CORONAL MASS EJECTION





SOHO/LASCO

SDO/AIA
SOHO/LASCO

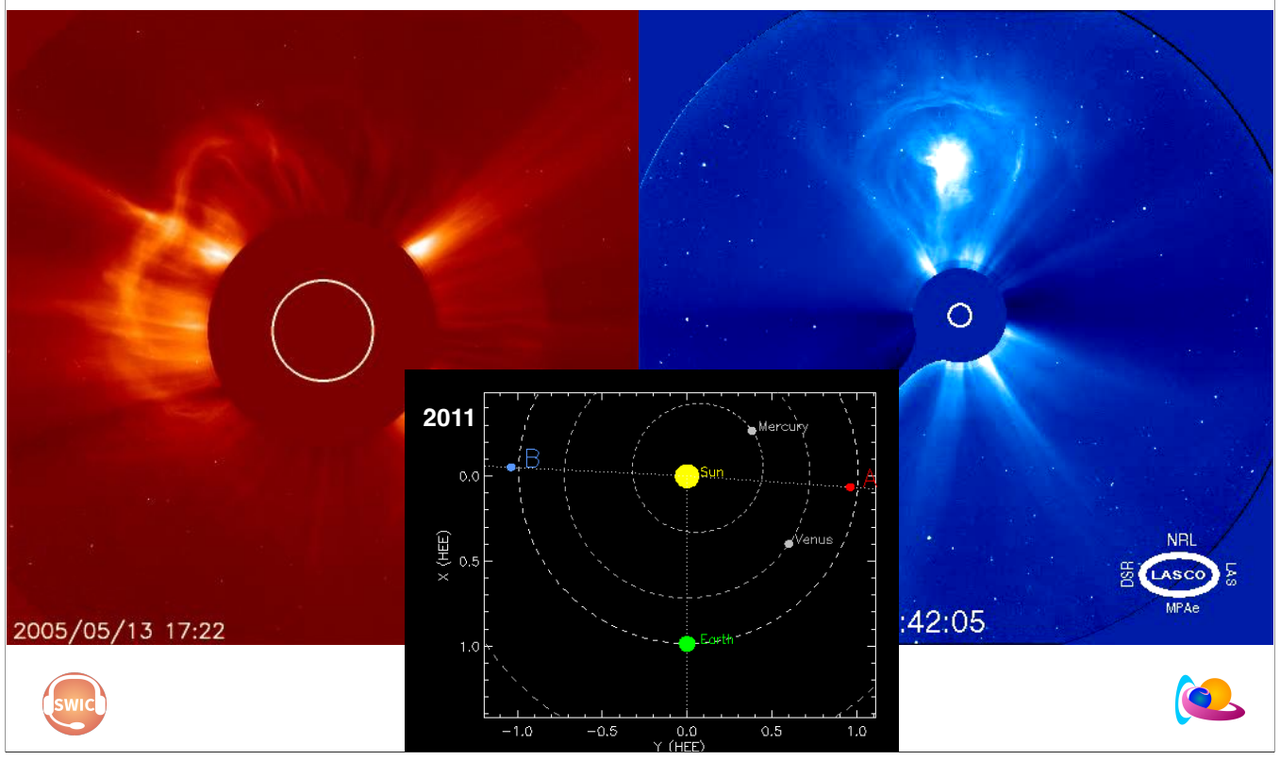
Left picture: SOHO Gallery: https://sohowww.nascom.nasa.gov/gallery/images/las02.html
Right picture: STCE: http://www.stce.be/news/342/welcome.html

Coronagraph LASCO: https://lasco-www.nrl.navy.mil/index.php?p=content/handbook/hndbk_5
CMEs are mostly observed in white light by coronagraphs from space (SOHO, STEREO).
In order to make the faint CMEs better visible, **difference images** are used (one image subtracted from the other).

Ground-based observatories can observe CMEs very close to the Sun: MLSO (K-Cor):
http://download.hao.ucar.edu/d5/www/fullres/latest/latest.kcor.gif

How can we know the direction these clouds are travelling in? Look at the shape in the picture and think of a balloon that is being blown up. When you look straight at it, you see it expand in all directions, as in the picture on the left. When you look from the side, and the balloon is thus not expanding towards you, it looks more like the picture on the right.

PLASMA CLOUDS



These coronagraph images show coronal mass ejections (CMEs) which are huge clouds of highly energised plasma that are hurled away into space. When these are directed towards Earth, they may have all kinds of space weather effects.

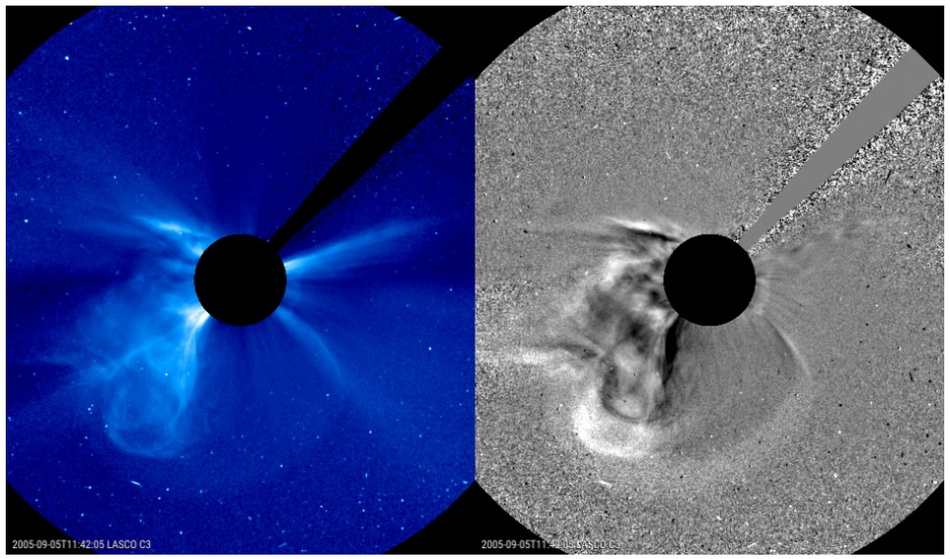
A coronagraph is a telescope with a plate that covers the Sun to block the overpowering light of the solar disk. This allows us to image the solar surroundings, it's corona. The white circle in the middle indicates the position and size of the Sun. A coronagraph creates an artificial eclipse, allowing us to study the far corona without having to wait and travel for an eclipse that can be observed from ground.

How can we know the direction these clouds are travelling in? Look at the shape in the picture and think of a balloon that is being blown up. When you look straight at it, you see it expand in all directions, as in the picture on the left. When you look from the side, and the balloon is thus not expanding towards you, it looks more like the picture on the right.

To really be able to estimate the direction and speed of CMEs we need observations from two different view points. This is where the STEREO A and STEREO B spacecraft come in. These spacecraft are in the same orbit as Earth, but one is lagging behind, while the other is ahead of Earth. This is how we can get a side view of plasma clouds. Unfortunately, contact with STEREO B was lost on October 1, 2014.

Very fast plasma clouds may bridge the distance from Sun to Earth in less than a day. These are exceptional, fortunately. Most often plasma clouds take around 3 days to reach us, the slow ones up to 5 days.

DIFFERENCE IMAGES



SOHO/LASCO

Left picture: SOHO Gallery: https://sohowww.nascom.nasa.gov/gallery/images/las02.html
Right picture: STCE: http://www.stce.be/news/342/welcome.html

Coronagraph LASCO: https://lasco-www.nrl.navy.mil/index.php?p=content/handbook/hndbk_5
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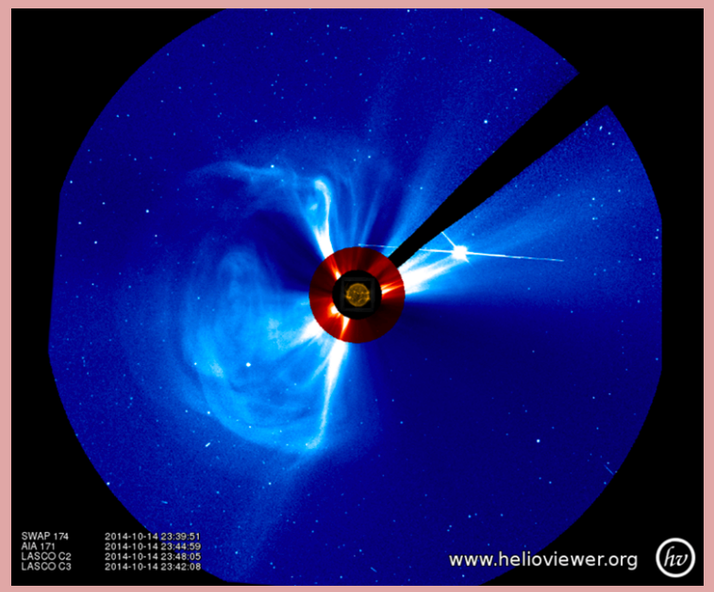
http://download.hao.ucar.edu/d5/www/fullres/latest/latest.kcor.gif

CME - OVERVIEW

- Model
- On-disk signatures
  - Filaments
  - Waves
  - Dimming
  - Post-eruption arcade
- Characteristics



PROBA2/SWAP
SDO/AIA
SOHO/LASCO

FILAMENTS & PROMINENCES

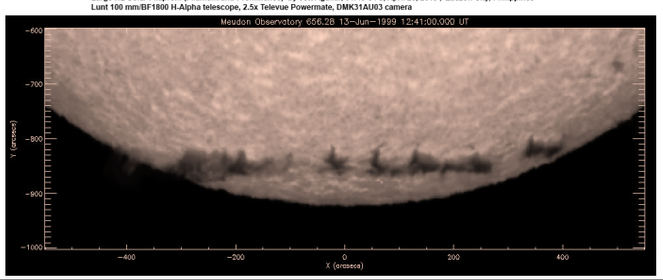
Chromospheric features
- Protruding into corona
- H-alpha and EUV
- Relatively cool (10.000K)

Mark the transition between positive and negative magnetic areas
Appear all over solar disk

Location
- In active region
  Group filament
- Outside active region
  Quiescent filament
- Polar crown filament



Large NE Solar Filaprom (Filament and Prominence) by Jett Aguilar, 01:45 UTC, April 28, 2015 , Quezon City, Philippines
Lunt 100 mm/BF1800 H-Alpha telescope, 2.5x Televue Powermate, DMK31AU03 camera



Prominences are observed at the limb, filaments on the solar disk, but these are in fact the same features.

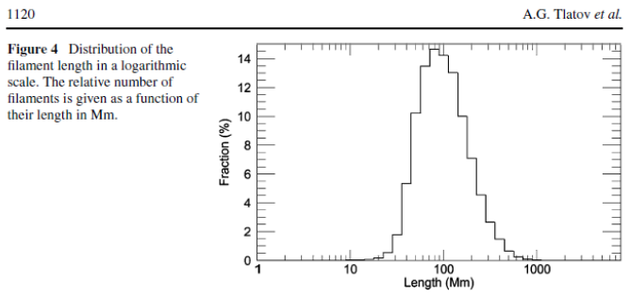
More info on filaments at http://www.stce.be/news/219/welcome.html

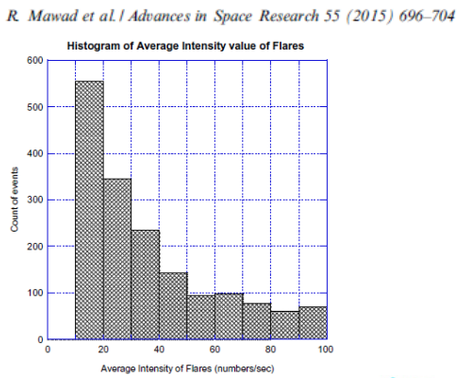
Polar crown filaments form above the polarity inversion line between the old magnetic flux of the previous cycle and the new magnetic flux of the current cycle. Studying their appearance and their properties can lead to a better understanding of the solar cycle.

More info on polar crown filaments at:
- http://solar.physics.montana.edu/wood/99Prom.html
- https://science.nasa.gov/science-news/science-at-nasa/2008/17sep_polarcrown

FILAMENTS & PROMINENCES

- Quiescent
  - Not associated to AR
  - Weeks to months
- Length
  - Long filaments (> 15°)
  - More prone to instabilities
    - Near (emerging) active regions
    - From chromospheric or coronal waves
    - Near coronal holes
  - Flaring
    - 38% result in at least 1 flare
    - Intensity : C1-M1





Tlatov et al. (2016): Tilt Angles of Solar Filaments over the Period of 1919 – 2014
http://adsabs.harvard.edu/abs/2016SoPh..291.1115T

Mawad et al. (2014): Filaments disappearances in relation to solar flares during the solar cycle 23
http://adsabs.harvard.edu/abs/2015AdSpR..55..696M

Hao et al. (2015): Statistical Analysis of Filament Features Based on the Hα Solar Images from 1988 to 2013 by Computer Automated Detection Method
http://adsabs.harvard.edu/abs/2015ApJS..221...33H

FILAMENT/PROMINENCE ERUPTIONS

Height
- Zirin (1988)
  - If > 50.000 km, eruption likely within next 48 hours
- Filippov (2008)
  - Height cannot exceed ciritical height
  - Related to strength of and change in magnetic field

Other signs
- Darkening filament
- Change in tilt or length

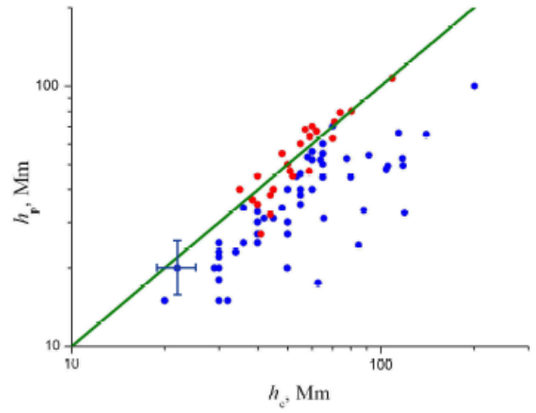


Fig. 7. The observed filament height above the chromosphere h_p versus the critical height of stable filament equilibrium h_c. The blue circles correspond to the filaments which safely passed the west limb. The red circles correspond to the filaments which disappeared from the disk. The straight green line corresponding to an equality of these quantities is the stability boundary.

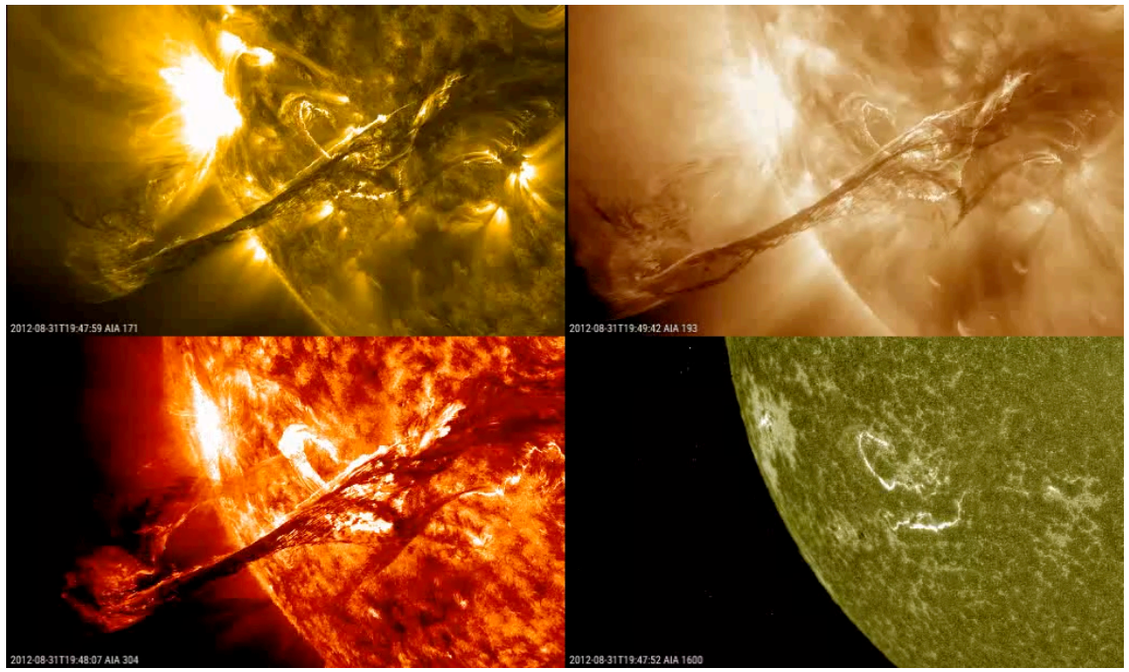
Data taken from:
Filippov et al. (2008): Causal relationships between eruptive prominences and coronal mass ejections
http://adsabs.harvard.edu/abs/2008AnGeo..26.3025F
http://www.ann-geophys.net/26/3025/2008/angeo-26-3025-2008.pdf

Zirin (1988): Astrophysics of the Sun

The critical height is a model based parameter depending on the strength of the magnetic field and describing how the equilibrium of a prominence will be unstable when it reaches a certain height (See Filippov & Den (2000)).

Most disrupted prominences become unstable at a height of 0.06–0.14 R⊙ from the solar surface, and there are two most probable critical heights at which a prominence is very likely to become unstable, the first one is 0.13 R⊙ and the second one is 0.19 R⊙. (https://iopscience.iop.org/article/10.1088/0004-637X/744/2/168)

FILAMENT ERUPTION



SDO/AIA

This movie shows a spectacular filament eruption, where a very long-living filament (that was already seen at the previous solar rotation) came back around the solar limb. Only, now the filament was not stable anymore and erupted causing a coronal mass ejection. Due to the location of the filament on the east limb, only a glancing blow (flank) of this relatively slow moving particle cloud (+/- 520 km/s) struck Earth, sparking a minor geomagnetic storm. Aurorae were visible in Scandinavia, Scotland, Canada and Alaska.

In the lower right panel, the **flare ribbons** are clearly seen to move apart.

Sources:
http://www.stce.be/news/157/welcome.html
http://www.stce.be/news/218/welcome.html

:Issued: 2026 Oct 09 1254 UTC
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 61009
SIDC SOLAR BULLETIN 09 Oct 2026, 1253UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Minor storm expected (A>=30 or K=5)
SOLAR PROTONS : Warning condition (activity levels expected to increase, but no numeric forecast given)
PREDICTIONS FOR 09 Oct 2026 10CM FLUX: 122 / AP: 021
PREDICTIONS FOR 10 Oct 2026 10CM FLUX: 124 / AP: 022
PREDICTIONS FOR 11 Oct 2026 10CM FLUX: 126 / AP: 015



Solar Active Regions and flaring: The solar flaring activity over the past 24 hours reached high levels with background C-class flaring and one registered M-flare. The strongest recorded activity was a M6.7 flare (SIDC Flare 8685) with peak time at 15:48 UTC on October 08. The flare was produced within SIDC Sunspot Group 976 (NOAA Active Region 4549) currently located at N10W31. A total of 5 numbered sunspot groups were identified on the visible solar disk with SIDC Sunspot Group 976 remaining the largest and most complex region. It continues to be classified as magnetic type beta-gamma-delta and was the main contributor to the observed flaring activity over the past 24 hours. SIDC Sunspot Group 973 (NOAA Active Region 4545), currently located at N18W37, has exhibited some decay. It is classified as magnetic type beta and remained quiet. A new region has emerged on disc SIDC Sunspot Group 979, currently located at N22W11, and another one, SIDC Sunspot Group 980, is rotating from behind the south-east limb. Both are classified as magnetic type beta and the latter one has exhibited some low flaring activity while behind the east limb. The solar flaring activity is expected to be at moderate over the next 24 hours with likely M-class flaring and chances for an X-class flare.

Coronal mass ejections: A wide coronal mass ejection (SIDC CME 727) was observed by LASCO/C2 to lift off the solar surface around 16:12 UTC on October 08 with a white-light shock and an estimated projected speed of around 500 km/s. The eruption is likely linked to the M6.7 flaring from SIDC Sunspot Group 976 (NOAA Active Region 4549) with an associated EUV dimming and a coronal wave detected in the SDO/AIA data around 16:33 UTC on October 08. Related type II and type IV solar radio emissions were detected at 15:42 UTC and 16:12 UTC on October 08 respectively. SIDC CME 727 is estimated to have an Earth-directed component and current analysis suggests a possible arrival time late UTC on October 11 to early UTC on October 12. Another EUV dimming and a small coronal wave were observed in the SDO/AIA imagery starting at 17:36 UTC on October 08, seemingly related to a filament eruption in the south-eastern quadrant triggered by the same event chain. A faint eastward eruption is visible in the LASCO/C2 around 17:00 UTC, but is expected to travel off the Sun-Earth line.

Coronal holes: SIDC Coronal Hole 149 (a recurrent mid-latitude coronal hole with a negative polarity) continues to reside on the central meridian. A high-speed stream related to it might be expected at Earth on October 09, possibly mixed with anticipated ICME arrival signatures related to SIDC CME 725.

Solar wind: Over the past 24 hours the solar wind parameters (as measured by ACE at L1) registered some enhancements, possibly the precursor of a high-speed stream arrival related to SIDC Coronal Hole 149. The solar wind speed remained slow, varying in the range of 333 to 390 km/s. The interplanetary magnetic field (B) registered a maximum value of 12.7 nT with a north-south (Bz) component down to - 7 nT. The B field phi angle switched from the positive to the negative sector (directed towards the Sun). The solar wind parameters are expected to be perturbed over the next 24 hours with an anticipated arrival of a high-speed stream possibly mixed with an ICME arrival related to SIDC CME 725. Perturbed solar wind conditions are expected to continue on October 10 with anticipated high- speed stream influence and possible waning ICME influence. A mild glancing blow arrival related to SIDC CME 726 could be expected on October 11 with the possibility of another ICME arrival late UTC on October 11 or early UTC on October 12 related to SIDC CME 727.

Geomagnetism: The geomagnetic conditions over the past 24 hours were locally (over Belgium) quiet to unsettled and globally quiet to active with NOAA Kp reaching 4 in the period 9-12 UTC on October 09. Unsettled conditions to minor storm levels are expected over the next 24 hours with chances for isolated moderate storms. Unsettled to active conditions with chances for more minor storm levels can continue on October 10, October 11 and October 12.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux remained at close to nominal levels, while exhibiting some further enhancements related to activity from SIDC Sunspot Group 976 (NOAA Active Region 4549). The greater than 10 MeV GOES proton flux is expected to further increase over the next 24 hours with chances of reaching the 10 pfu proton event threshold.

Electron fluxes at GEO: The greater than 2 MeV electron flux as measured by GOES 18 and GOES 19 has exceeded the 1000 pfu threshold over the past 24 hours and is expected to be predominantly below the 1000 pfu threshold over the next 24 hours. The 24-hour electron fluence was at moderate levels and is expected to decrease to nominal levels over the next 24 hours.

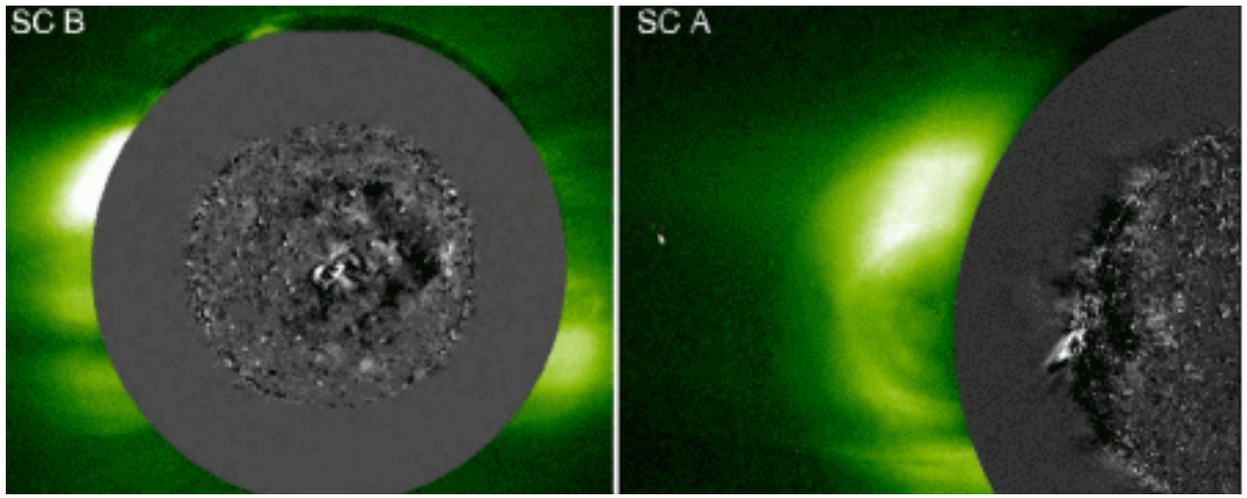
TODAY'S ESTIMATED ISN : 086, BASED ON 07 STATIONS.

SOLAR INDICES FOR 08 Oct 2026
WOLF NUMBER CATANIA : 089
10CM SOLAR FLUX : ///
AK CHAMBON LA FORET : 017
AK WINGST : 006
ESTIMATED AP : 006
ESTIMATED ISN : 075, BASED ON 18 STATIONS.

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
08 1529 1548 1558 N12W20 M6.7 2B 57/4549 I/3
END

filaments / prominences

EIT WAVE



STEREO/EUVI & COR1

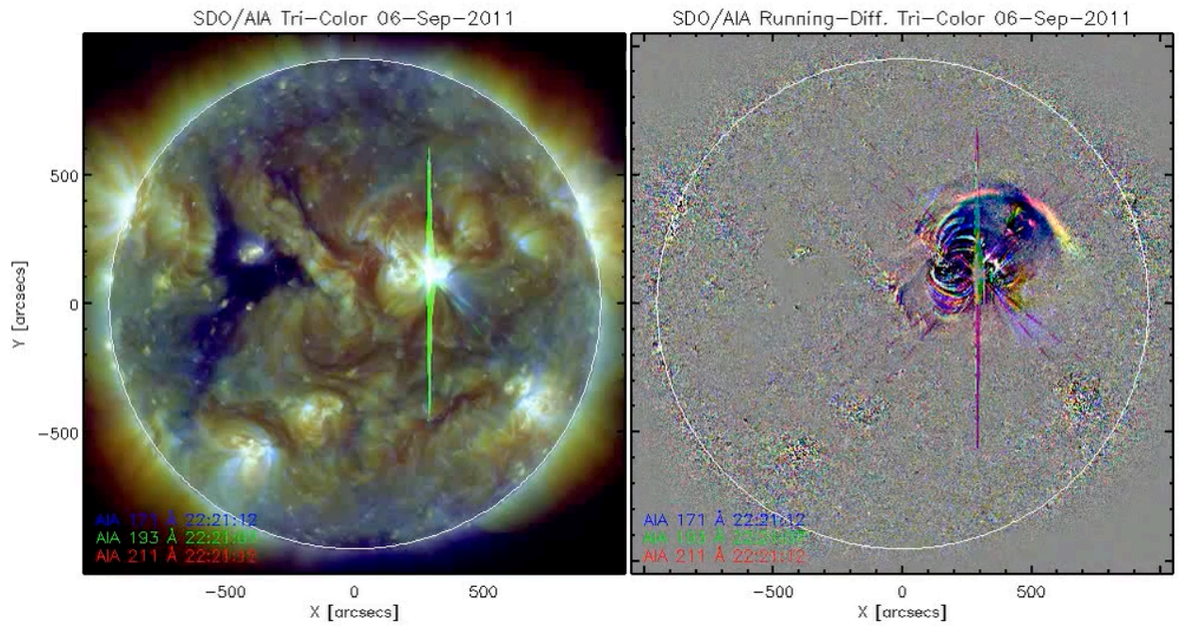
Another name for this kind of feature is "solar tsunami".

EIT waves are named after the SOHO/EIT instrument with which they were first discovered. They are coronal waves with rather low speeds **(200-600 km/s)** and are typically related to CMEs. Since all EUV imagers have observed these events, we now call them EUV waves as well.

Example above on EIT wave from: https://cor1.gsfc.nasa.gov/
The twin STEREO spacecraft confirmed the existence of EIT waves in February 2009 when sunspot 11012 unexpectedly erupted. The blast hurled a billion-ton cloud of gas (a "CME") into space and sent a tsunami racing along the sun's surface. STEREO recorded the wave from two positions separated by 90 degrees,

More examples:
Moreton waves: http://www.stce.be/news/222/welcome.html
EIT waves: http://www.stce.be/news/222/welcome.html and http://www.stce.be/news/241/welcome.html

EUV WAVE

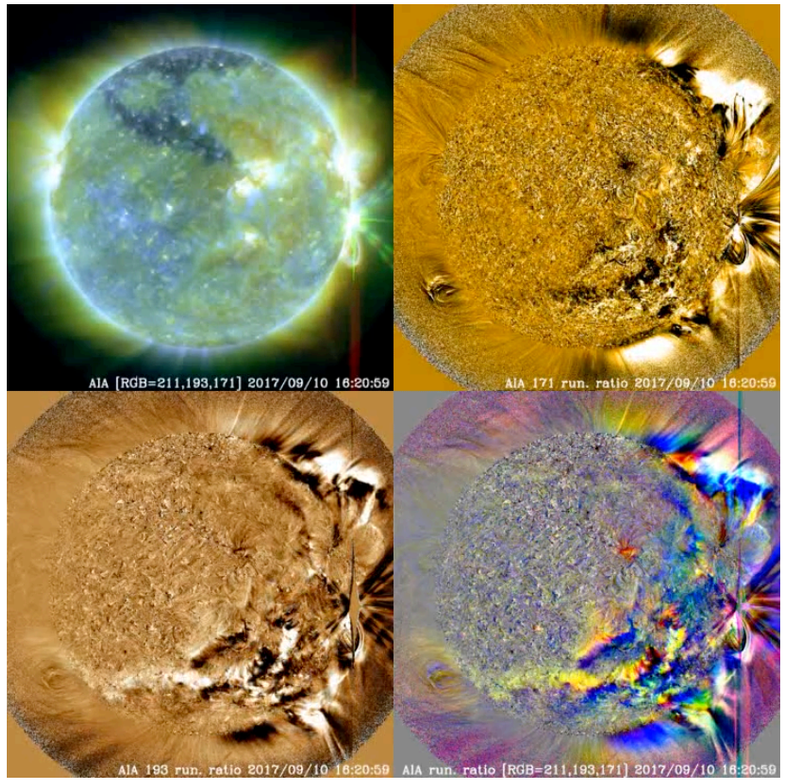


SDO/AIA

Shen et al. (2014): A Chain of Winking (Oscillating) Filaments Triggered by an Invisible Extreme-ultraviolet Wave
http://adsabs.harvard.edu/abs/2014ApJ...786..151S
In this paper, we present an interesting observational study of a chain of winking filaments that was in association with a GOES **X2.1** flare in the NOAA active region AR11283 (N13W18) on 2011 September 6. The flare was produced with a remarkable EUV wave propagating mainly in the northwest direction, which not only triggered the **oscillation** of three filaments in the northwest of AR11283, but also launched the oscillation of a long filament and the occurrence of a small jet in the eastern hemisphere, where the wave signature is very weak or even invisible.
Based on our analysis results, we conclude that the EUV wave is a **good agent for triggering and connecting successive but separated solar activities** in the solar atmosphere.

GLOBAL EUV WAVE

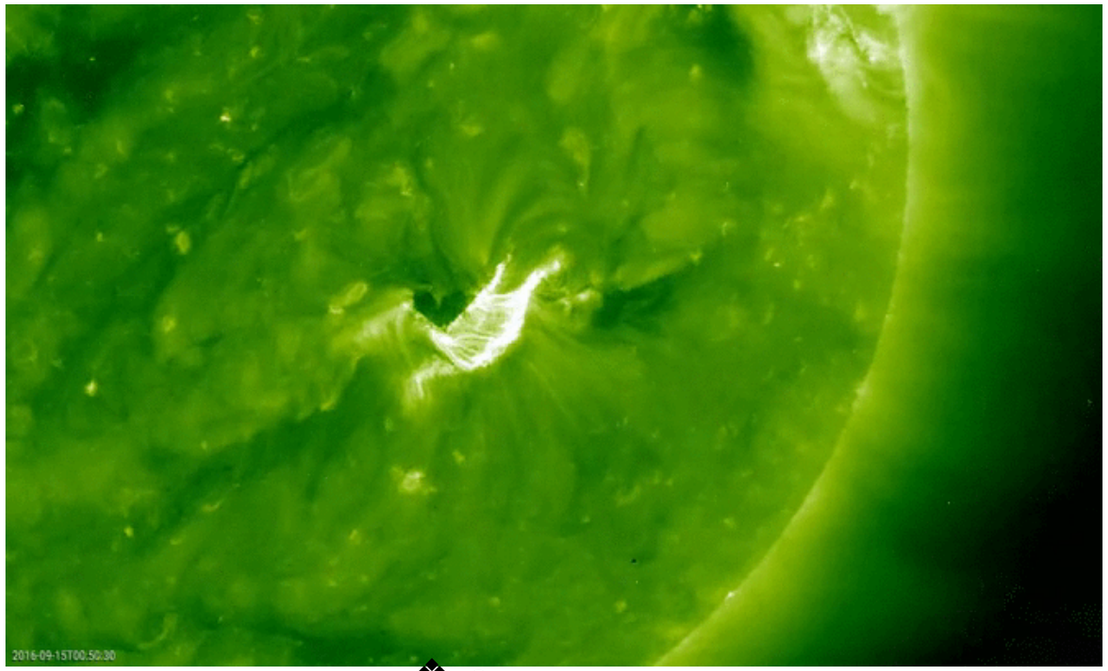
SDO/AIA



EUV-waves can be **stopped**, **reflected** and **refracted** at the boundary of coronal holes or near active regions.

Liu et al. (2018): A Truly Global Extreme Ultraviolet Wave from the SOL2017-09-10 X8.2+ Solar Flare-Coronal Mass Ejection
http://adsabs.harvard.edu/abs/2018ApJ...864L..24L
from X8 flare

CORONAL DIMMING
~~(TRANSIENT CORONAL HOLE)~~



STEREO/EUVI

A coronal dimming occurs in the wake of coronal mass ejection and is usually interpreted as mass depletions due to the loss or rapid expansion of the overlying corona (the plasma is hurled away in the coronal mass ejection). This darkening is temporary as the plasma is supplemented again. That is why they are also called transient coronal holes. However, this is a confusing name as a coronal hole is a completely different type of structure.

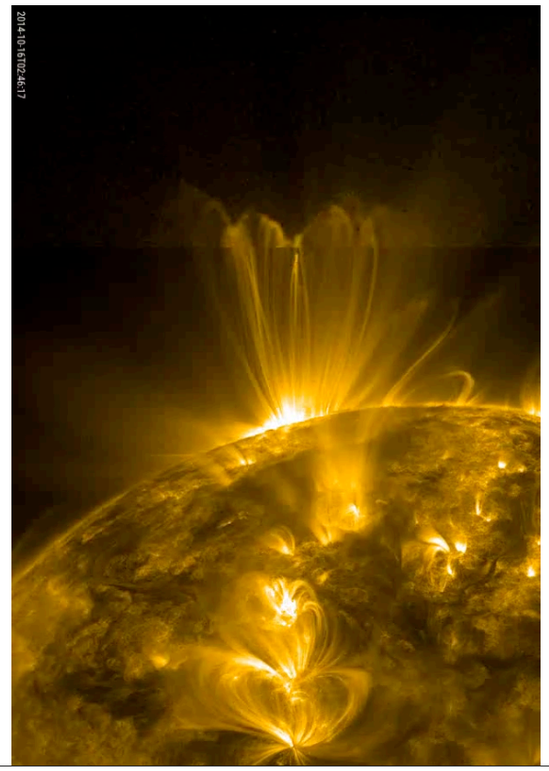
Sources:
http://www.stce.be/news/362/welcome.html

Mason et al. (2016): Relationship of EUV Irradiance Coronal Dimming Slope and Depth to Coronal Mass Ejection Speed and Mass
http://adsabs.harvard.edu/abs/2016ApJ...830...20M

http://www.stce.be/news/362/welcome.html

Cheng et al. (2016): The Nature of CME-flare-Associated Coronal Dimming
http://adsabs.harvard.edu/abs/2016ApJ...825...37C

POST-ERUPTION CORONAL LOOPS



PROBA2/SWAP

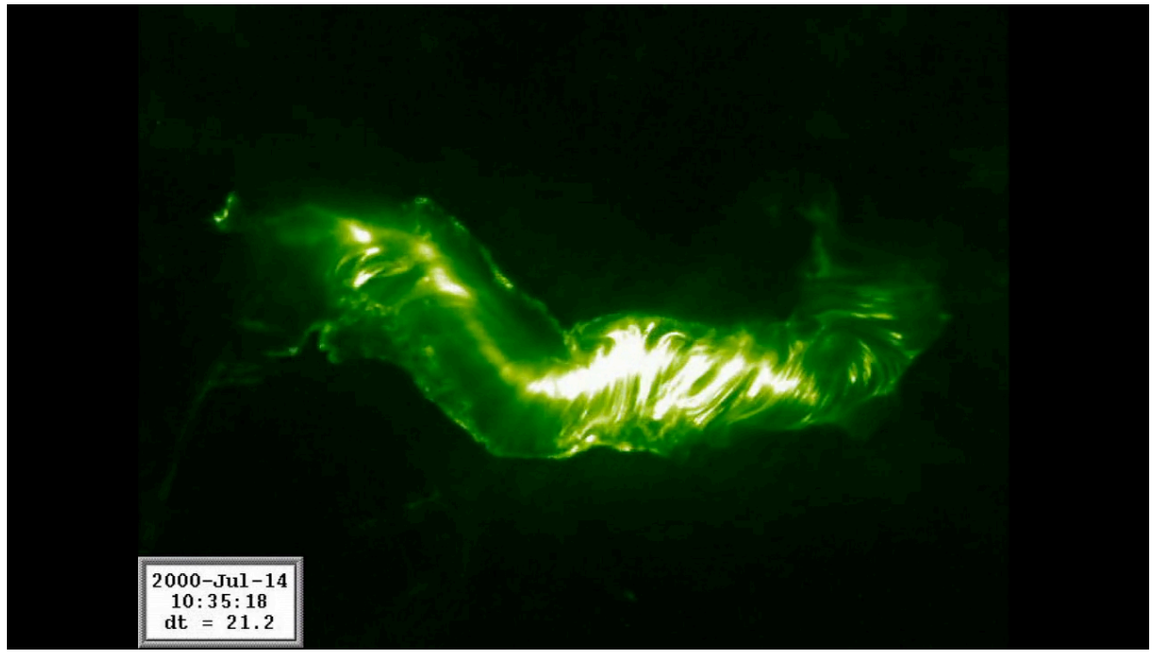
SDO/AIA

Post-flare loops indicate a long duration event and thus the presence of a CME.

This M2-event finished with an **arcade**, which is the technical term for a series of post-flare coronal loops. Interestingly, these post-flare loops continued to grow, first reaching the limit of AIA's Field-Of-View (FOV), and then continuing to grow even beyond AIA's FOV. Fortunately, PROBA2's wider-field SWAP telescope was able to monitor this arcade in its full glory till its disappearance.
The loops of this long duration arcade were **visible for about 2.5 days** (60 hours!), and at their maximum height, they were towering at least 340.000 km above the solar surface. That's not far from the average Earth-Moon distance!

Sources:
STCE: http://www.stce.be/news/316/welcome.html
STCE: http://www.stce.be/news/331/welcome.html
STCE: http://www.stce.be/news/274/welcome.html

POST-ERUPTION CORONAL LOOPS
POST-ERUPTION ARCADE



SOHO/EIT

Also the **Bastille** day event showed a nice arcade, a series of post-eruption coronal loops. (X5.7 event)

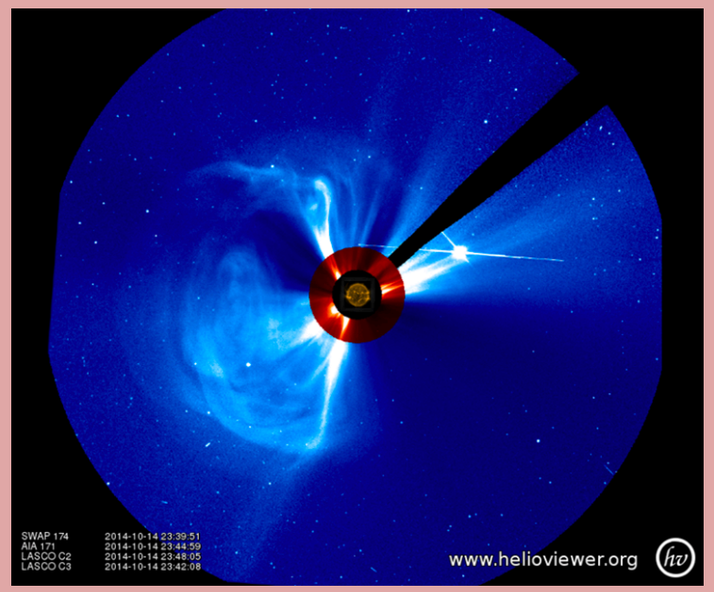
Two-ribbon flares are characterized by a pair of bright ribbons observed in H-alpha and ultraviolet (UV) images. The ribbons are located on either side of a magnetic polarity inversion line and they separate from each other as the flare progresses. Two-ribbon flares are often associated with filament eruptions and coronal mass ejections (CMEs). After the launch of the filament, long-lived arcades are formed connecting the two ribbons across the polarity inversion line. The emerged assembly of arches is called a post-eruption arcade (PEA). The PEAs are observed at multiple wavelengths and are known also as long-duration (or decay) events (LDEs; Pallavicini, Serio, and Vaiana, 1977) in X-ray observations. The erupting filament becomes the core of the associated CME (Webb and Hundhausen, 1987; Gopalswamy et al., 2003), thus PEAs are considered as surface signatures of CMEs (Tripathi, Bothmer, and Cremades, 2004).

Sources:
SOHO: https://soho.nascom.nasa.gov/gallery/Movies/flares.html
TRACE: http://soi.stanford.edu/results/SolPhys200/Schrijver/TRACEpodarchive3.html

Yashiro et al. (2013): Post-Eruption Arcades and Interplanetary Coronal Mass Ejections
http://adsabs.harvard.edu/abs/2013SoPh..284....5Y
https://cdaw.gsfc.nasa.gov/publications/yashiro/yashiro2013SolPhys.pdf

CME - OVERVIEW

- Model
- On-disk signatures
  - Filaments
  - Waves
  - Dimming
  - Post-eruption arcade
- **Characteristics**



PROBA2/SWAP
SDO/AIA
SOHO/LASCO

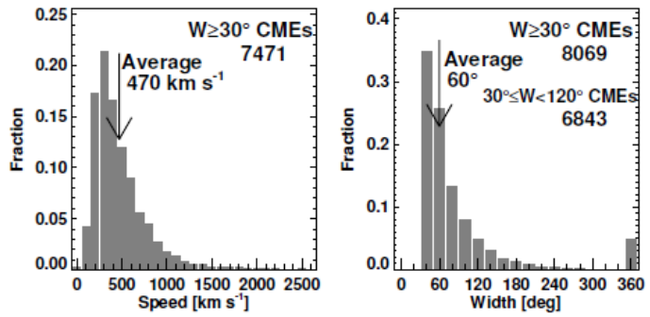
CORONAL MASS EJECTION

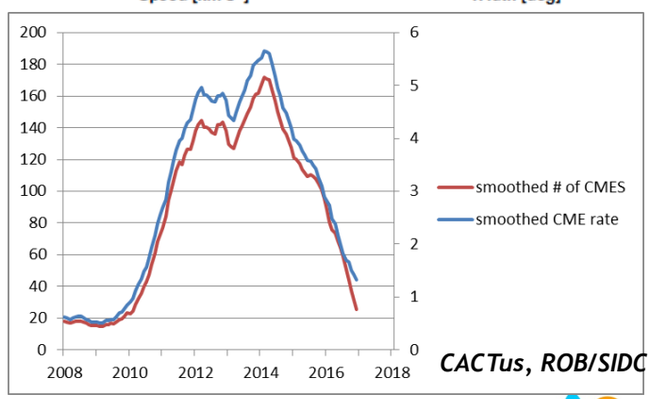
Characteristics

- Average speed
  - 470 km/s
  - Fast transit event (<24h)
- Average width

  60 degrees
- Average Mass
  - 10^{12} kg
  - ~ medium sized mountain
- Number per day

  1-6 / day





Source file: Webb et al. (2012): Coronal Mass Ejections: Observations
http://link.springer.com/article/10.12942/lrsp-2012-3

A nice example a fairly recent (2012) Fast Transit Event can be found in the STCE News item: A CME with an Olympic Speed
http://www.stce.be/news/152/welcome.html
This CME had a transit time of about 19 hours, but was directed towards ST-A, not Earth.
It is believed that, if the CME had been earth-directed, the space weather consequences would have been similar to the Carrington event.

CORONAL MASS EJECTION

Terminology

- Width
  - Narrow: <20°
  - Partial halo: >120°
  - (Full) halo: 360°
- Shape halo
  - Symmetric
  - Asymmetric
- Origin

  Frontside/Farside
- De- & acceleration

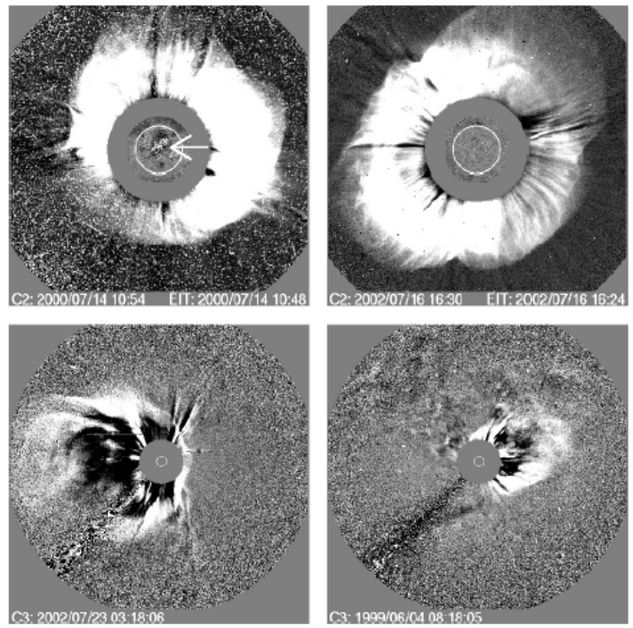


Figure 4: Examples of a variety of halo CME observations, clockwise: a frontside full halo (arrow shows likely source near Sun center); a backside full halo; a partial halo; and an asymmetric full halo. Image reproduced with permission from Gopalswamy *et al.* (2003a).

Source file: Webb et al. (2012): Coronal Mass Ejections: Observations
http://link.springer.com/article/10.12942/lrsp-2012-3

Some CMEs appear as narrow jets, some arise from pre-existing coronal streamers (the so-called streamer blowouts), while others appear as wide almost global eruptions. CMEs spanning very large angular ranges are probably not really global, but rather have a large component along the Sun-observer line and so appear large by perspective. These include the so-called halo CMEs. The CDAW CME catalog defines a “partial halo” as a CME with an apparent position angle range > 120°. Hence, again, the definition of a CME is restricted by its viewing perspective.

Partial and full halo CMEs occur at a rate of about 10% that of all CMEs, but 360° halo CMEs are only detected at a rate of ~ 4% of all CMEs.

CMEs that are aligned near the relative disk center tend to be more geoeffective while those nearer the relative solar limb are less so. The vast majority of the most intense geomagnetic storms of Cycle 23, for example, were caused by halo CMEs (Gopalswamy, 2010a).

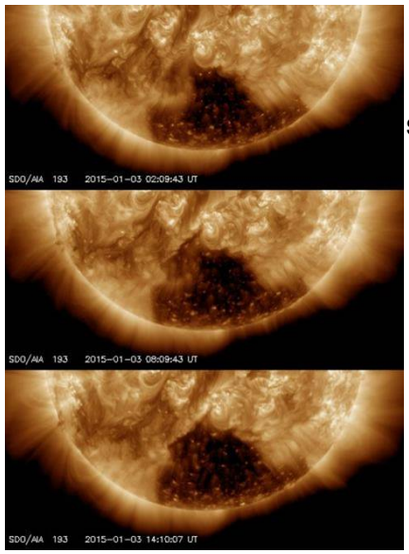
Because of their increased sensitivity, field of view and dynamic range, the SOHO/LASCO and STEREO/COR coronagraphs now frequently observe halo CMEs, which appear as expanding, circular brightenings that completely surround the coronagraphs’ occulting disks (Figure 4). Observations of associated activity on the solar disk are necessary to help distinguish whether a halo CME was launched from the front or backside of the Sun relative to the observer. This has had limited success, as frontsided CMEs that do not have a solar surface association can be mistaken for backsided events. In recent years several CMEs have been observed by the “three eyes” of STEREO-B, LASCO and STEREO-A by a variety of viewing points, thus reducing this latter problem.

Yashiro et al. (2004) found that slow CMEs tend to accelerate and fast CMEs decelerated through the LASCO field of view, with those around the solar wind speed having constant speeds. Thus, CMEs attain fast acceleration low in the corona until gravity and other drag forces slow them further out. This process continues into the interplanetary medium.

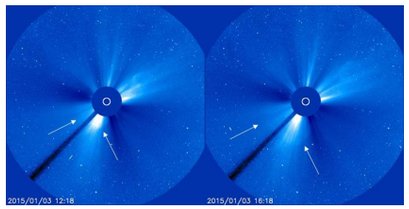
CORONAL MASS EJECTION

Terminology

- Stealth CME
  - No obvious surface signature
  - Rather slow (<300 km/s)
  - Rather faint
- CME cannibalism
  - 2nd CME overtakes 1st
  - Enhanced geomagnetic storms
- Deflection
  - By corona holes, CME,…



SDO/AIA



SOHO/LASCO

Stealth CME
Source file: Webb et al. (2012): Coronal Mass Ejections: Observations
http://link.springer.com/article/10.12942/lrsp-2012-3

The absence of solar surface activity with observed CME activity is not a new observation (Howard and Harrison, 2012). The launch of STEREO in 2006, however, afforded us the opportunity to study the origins of CMEs simultaneously from multiple lines of sight. Robbrecht et al. (2009a) presented a study of a streamer blowout CME without a clear source region. The STEREO spacecraft were sufficiently widely separated (53°) that the CME and its source region could be viewed edge-on in STEREO A and face-on in STEREO B. STEREO B saw the CME as a faint halo and it was detected in-situ as a magnetic cloud 5 days later. Robbrecht et al. suggested that the CME originated high enough up in the corona such that no surface signatures were evident. Subsequently, Ma et al. (2010) performed a statistical study of all CMEs observed during the first 8 months of 2009 when the STEREO lines of sight were nearly perpendicular to each other. They found that about a third of the CMEs were “stealth”, having no distinct surface association, and tending to be slow, i.e., < 300 km s-1. Faint coronal changes could be detected in about half of the stealth CMEs, again suggesting a higher launch site. It is noted that this period was during the recent unusual extended solar minimum, so the fraction of such CMEs may be different at other times.

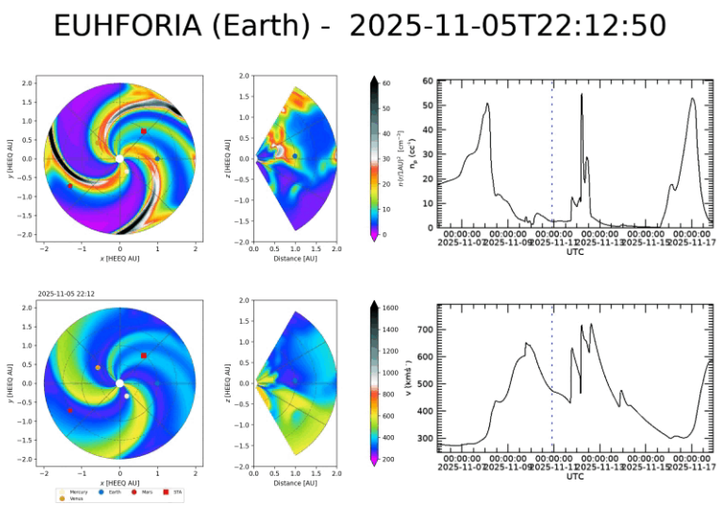
A good example is in this STCE Newsitem: The curious case of a strong storm
http://www.stce.be/news/290/welcome.html

More info at Howard et al. (2012): Stealth Coronal Mass Ejections: A Perspective
http://adsabs.harvard.edu/abs/2013SoPh..285..269H

CORONAL MASS EJECTION

Terminology

- Stealth CME
- CME cannibalism
  - 2nd CME overtakes 1st
  - Enhanced geomagnetic storms
- Deflection



Animation from https://stce.be/news/789/welcome.html

In this EUHFORIA model run, the Sun has launched three coronal mass ejections (CMEs) which may merge into a single front as it expands into the solar system. These events are sometimes called 'cannibal' CMEs.

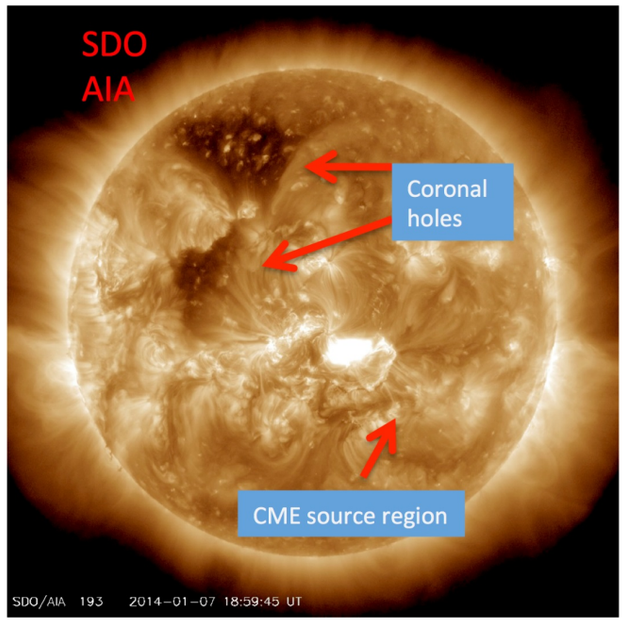
This model run is based on estimated parameters from solar events of November 2025.
Top panel: solar wind density
Bottom panel: solar wind velocity

Also at https://science.nasa.gov/science-news/science-at-nasa/2001/ast27mar_1

CORONAL MASS EJECTION

Terminology

- Stealth CME
  - No obvious surface signature
  - Rather slow (<300 km/s)
  - Rather faint
- CME cannibalism
  - 2nd CME overtakes 1st
  - Enhanced geomagnetic storms
- Deflection
  - By coronal holes, CME,…



SDO/AIA

A good example of deflections is at https://science.gsfc.nasa.gov/674/swl_research.html
Extreme Solar Wind Deflects CMEs
A very fast CME was observed on January 7, 2014. Preliminary data analysis and all 8 community forecasts reported in GSFC's Space Weather Scoreboard indicated rapid arrival at Earth and a major geo-magnetic storm. However, the CME arrived at Earth ~19 hr after the predicted time, and the geomagnetic storm was weak (Kp < 3). What happened? Detailed analysis by the CCMC/SWRC team identified possible causes for the gap between predicted vs. actual outcome. The solar wind coming from the nearby coronal holes was extremely fast – 950 km/s at Earth (very rare!) and deflected the CME away from the Earth. However, the solar wind speed assumed at the lower boundary of the CME transport model (WSA-ENLIL) was too low – 750 km/s (maximum allowed value). Therefore the model CME propagated to Earth much too slowly. Previously the same coronal hole did not produce such high speed wind, so the strong deflection was a surprise. We know that CMEs can be deflected by a coronal hole, so a CME that seems to be Earth-directed can be deflected from the Earth-Sun line. The simulations did not predict that the deflection would be so large that the CME only hit a glancing blow to the Earth.

Deflections
Kay et al. (2015): Global Trends of CME Deflections Based on CME and Solar Parameters
http://adsabs.harvard.edu/abs/2015ApJ...805..168K
Forecasting space weather effects relies on knowledge of the path of a CME. Observations commonly show significant non-radial deviations in the CME trajectories. Understanding these deflections will allow for more accurate space weather predictions. Coronal observations show that CMEs can undergo significant deflection close to the Sun, but it is often hard to disentangle the effects of deflection, rotation, and non-uniform expansion in the lower corona (Nieves-Chinchilla et al. 2012). Byrne et al. (2010) measure a latitudinal deflection of 30° below 7 ⊙ R for the 2008 December 12 CME. Kilpua et al. (2009) suggest that CMEs may not be able to penetrate the open magnetic field emanating from coronal holes (CHs). The CH magnetic field then guides CMEs toward the Heliospheric Current Sheet (HCS). Shen et al. (2011) and Gui et al. (2011) attribute the deflection to gradients in the background magnetic energy density, which would also cause CMEs to tend to deflect toward the HCS. As with the observed CMEs, the MHD CMEs tend toward regions of lower magnetic energy. In some cases, magnetic reconnection creates an imbalance in the magnetic energy, which causes a CME to deflect early in the eruption (Zuccarello et al. 2012; Lynch & Edmondson 2013). MHD simulations also show that CMEs can deflect due to interactions with other CMEs (Lugaz et al. 2012). Finally, there are also effects of CME rotation due to a torque created by differential forces along the CME's toroidal axis.

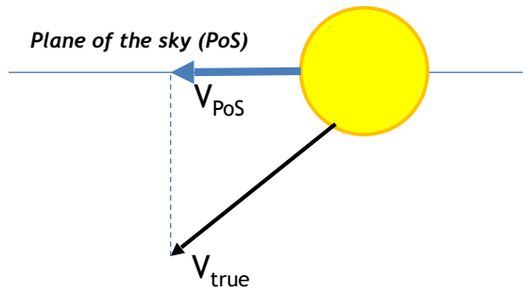
CORONAL MASS EJECTION

Speed

- We see the projected speed
  - Plane of the sky (PoS)
- We use the true speed
  - = Corrected PoS speed

    $V_{true} \geq V_{PoS}$
  - From Type II radio bursts

    = shock speed

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:Created: 2012 Jul 15 0332 UT
:Date: 2012 07 12
# Prepared by the U.S. Dept. of Commerce, NOAA, Space Weather Prediction Center
# Please send comments and suggestions to SWPC.Webmaster@noaa.gov
#
# Missing data: ////
# Updated every 30 minutes.
#                          Edited Events for 2012 Jul 12
#
#Event    Begin    Max       End  Obs  Q  Type  Loc/Frq   Particulars       Reg#
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9900 +     1614   1649      1732  SAG  G   RBR  410         6600              1520
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9900 +     1614   1653      1714  SAG  G   RBR  4995        480               1520
9900 +     1615   1653      1824  SAG  G   RBR  8800        430               1520
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9900 +     1621   1654      1815  SAG  G   RBR  15400       270               1520
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9900 +     1638   ////      2359  PAL  C   RSP  025-180    IV/2              1520
```

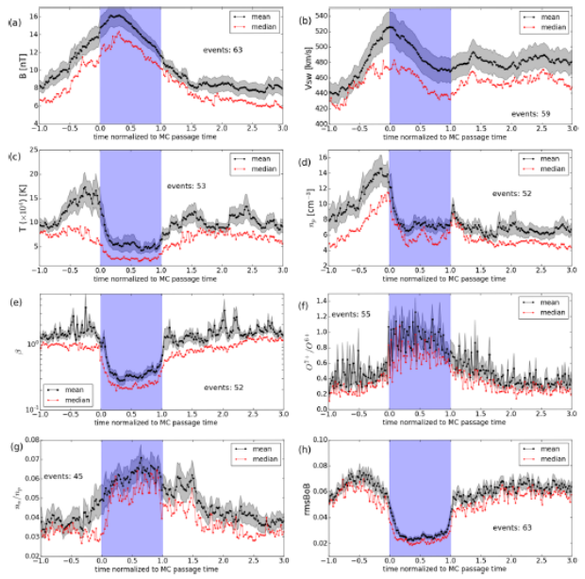
Source file: Webb et al. (2012): Coronal Mass Ejections: Observations
http://link.springer.com/article/10.12942/lrsp-2012-3

Some additional information on the relation between CMEs, CME shocks and Type II radio bursts can be found at http://www.ovsa.njit.edu/fasr/Chapter_15.pdf (Gopalswamy: Interplanetary Radio bursts, in Solar and Space Weather Radiophysics – Chapter 15).
As well as in Gopalswamy et al. (2008): Coronal mass ejections, type II radio bursts, and solar energetic particle events in the SOHO era
http://adsabs.harvard.edu/abs/2008AnGeo..26.3033G
http://www.ann-geophys.net/26/3033/2008/angeo-26-3033-2008.pdf

Some good examples on how to calculate/deduce the CME speed:
- NASA: http://rodshome.com/TLA/sunspots/CMEveloctiry%20calc.pdf
- Pohjolainen et al. (2007): CME Propagation Characteristics from Radio Observations
http://adsabs.harvard.edu/abs/2007SoPh..244..167P

Data of Type II bursts with derived shock speeds:
NOAA: https://www.swpc.noaa.gov/products/solar-and-geophysical-event-reports
SWS: http://www.sws.bom.gov.au/Solar/2/3
Attention: The shock speed is usually (a bit / a lot) higher than the (corrected) CME speed.

INTERPLANETARY CORONAL MASS EJECTION



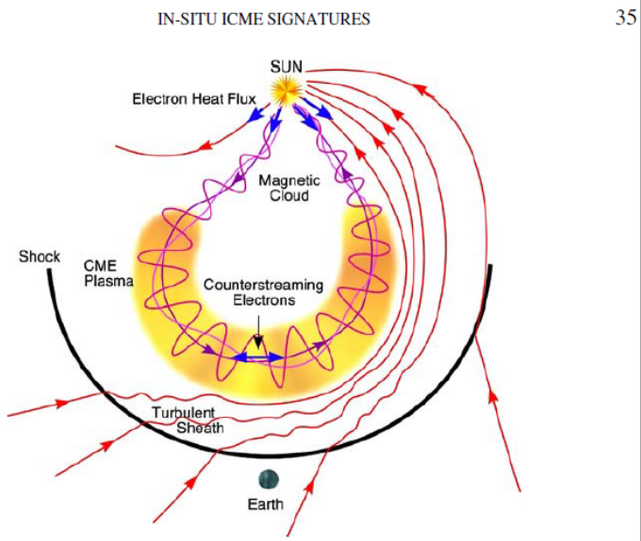


Figure 2. Schematic of the three-dimensional structure of an ICME and upstream shock, relating magnetic field, plasma, and BDE signatures.

Figure right: Zurbuchen et al. (2006): In-Situ Solar Wind and Magnetic Field Signatures of Interplanetary Coronal Mass Ejections http://adsabs.harvard.edu/abs/2006SSRv..123...31Z

An interplanetary CME (ICME) is a CME of which the solar wind features are measured in situ by spacecraft at Earth or in the solar system.

Pending the mutual positions of the Earth and the CME, Earth may experience the following impacts from this (I)CMEs:
1.Nothing
2.Shock + Sheath
3.Shock + Sheath + Magnetic Cloud leg (long)
4.Shock + Sheath + Magnetic Cloud (head-on) + rarefied region
5.No shock, still magnetic cloud
These all give different signatures in the various solar wind parameters.

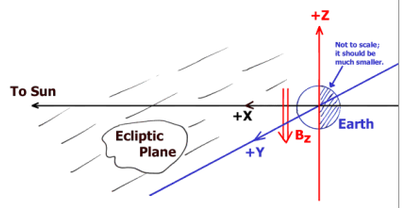
Rodriguez et al. (2016): Typical Profiles and Distributions of Plasma and Magnetic Field Parameters in Magnetic Clouds at 1 AU
http://adsabs.harvard.edu/abs/2016SoPh..291.2145R

Figure to the left: Rodriguez et al. (2016): Typical Profiles and Distributions of Plasma and Magnetic Field Parameters in Magnetic Clouds at 1 AU
http://adsabs.harvard.edu/abs/2016SoPh..291.2145R

Coronal mass ejections (CMEs) are large-scale solar eruptive events in which large amounts of plasma carrying magnetic flux and helicity (see e.g. Démoulin, Janvier, and Dasso, 2016, and references therein) are expelled into the interplanetary space. When sampled in situ by a spacecraft in the interplanetary medium, they are called interplanetary CMEs (ICMEs). Magnetic clouds (MCs) are an important subset of ICMEs that exhibit a particular internal magnetic field configuration resembling that of a flux rope. This is characterized by an enhanced magnetic field intensity, smooth rotation of its magnetic field vector, and low temperature (e.g. Burlaga, 1991).
The classical three-part structure of a CME (bright front, dark cavity, and dense core) is commonly also interpreted in terms of a magnetic flux rope propagating in the corona (see e.g. Illing and Hundhausen, 1986; Vourlidas et al., 2013). The bright front corresponds to the plasma pile-up in front of the flux rope, the cavity represents the bulk of the flux rope, and the dense core is the erupting prominence that is located in the bottom (concave-out) parts of the flux rope field lines. However, it is very difficult to identify the corresponding three-part morphology in ICMEs detected in situ (e.g. Kilpua et al., 2013a).

The plasma β (the ratio of the plasma pressure to the magnetic pressure) and the level of fluctuations in the magnetic field vector are the best parameters to define the boundaries of MCs. We find that one third of the events shows a peak in plasma density close to the trailing edge of the flux ropes.

CORONAL MASS EJECTION



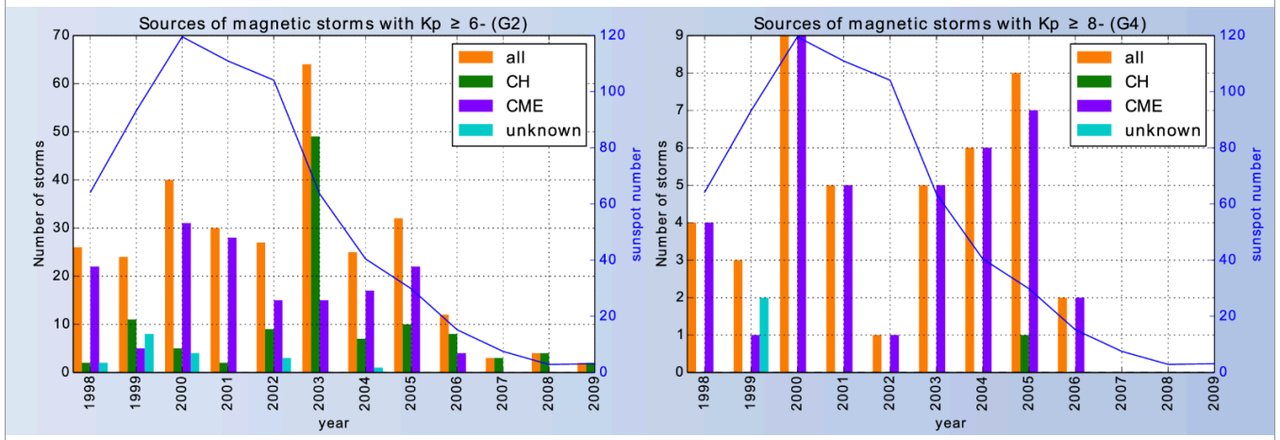
Bz

- North-South component of magnetic field (nT) perpendicular to the ecliptic
- Intensity varies much more than CME speed
- **Negative (south), strong and long-lasting Bz is necessary to get a strong geomagnetic storm**
- Need to predict both orientation and intensity

  Not easy and potentially changing during Sun-Earth transit!

Zhukov (2017): Predicting Geomagnetic Storms on the Base of Solar Observations
https://events.oma.be/indico/event/21/
The solar wind–magnetosphere coupling is governed by the duskward electric field Ey ~ vBz. However, v varies only by a factor of 2 (maybe 5 in extreme events). Bz varies by a factor of 10 and is thus a parameter more important for predictions. To be geoeffective, the CME-associated disturbance should have a suitable magnetic field configuration: the interplanetary magnetic field (IMF) Bz component should be negative (southward), strong enough and long-lasting.

CME STATISTICS - SOURCE



From: https://nora.nerc.ac.uk/id/eprint/507308/1/MIST_Kelly_CMEs.pdf
Statistics of Coronal Mass Ejections for use in Space weather Forecasting, Gemma S Kelly

The plots show the number of days when the maximum Kp reached 6- (left) or 8- (right) and over, the blue line indicates the solar cycle. In this data set the highest number of storms (Kp > 6-) occurs in 2003, during the descending phase of the solar cycle, mostly caused by coronal hole effects. Larger storms (Kp > 8-) are almost exclusively caused by CMEs with the highest number at solar maximum, although the number of CME related storms during the descending phase is also significant.

:Issued: 2026 Oct 09 1254 UTC
:Product: documentation at http://www.sidc.be/products/meu
#---#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC
(RWC Belgium)
#---#
SIDC URSIGRAM 61009
SIDC SOLAR BULLETIN 09 Oct 2026, 1253UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Minor storm expected (A>=30 or K=5)
SOLAR PROTONS : Warning condition (activity levels expected to increase, but no numeric forecast given)
PREDICTIONS FOR 09 Oct 2026 10CM FLUX: 122 / AP: 021
PREDICTIONS FOR 10 Oct 2026 10CM FLUX: 124 / AP: 022
PREDICTIONS FOR 11 Oct 2026 10CM FLUX: 126 / AP: 015



Solar Active Regions and flaring: The solar flaring activity over the past 24 hours reached high levels with background C-class flaring and one registered M-flare. The strongest recorded activity was a M6.7 flare (SIDC Flare 8685) with peak time at 15:48 UTC on October 08. The flare was produced within SIDC Sunspot Group 976 (NOAA Active Region 4549) currently located at N10W31. A total of 5 numbered sunspot groups were identified on the visible solar disk with SIDC Sunspot Group 976 remaining the largest and most complex region. It continues to be classified as magnetic type beta-gamma-delta and was the main contributor to the observed flaring activity over the past 24 hours. SIDC Sunspot Group 973 (NOAA Active Region 4545), currently located at N18W37, has exhibited some decay. It is classified as magnetic type beta and remained quiet. A new region has emerged on disc SIDC Sunspot Group 979, currently located at N22W11, and another one, SIDC Sunspot Group 980, is rotating from behind the south-east limb. Both are classified as magnetic type beta and the latter one has exhibited some low flaring activity while behind the east limb. The solar flaring activity is expected to be at moderate over the next 24 hours with likely M-class flaring and chances for an X-class flare.

Coronal mass ejections: A wide coronal mass ejection (SIDC CME 727) was observed by LASCO/C2 to lift off the solar surface around 16:12 UTC on October 08 with a white-light shock and an estimated projected speed of around 500 km/s. The eruption is likely linked to the M6.7 flaring from SIDC Sunspot Group 976 (NOAA Active Region 4549) with an associated EUV dimming and a coronal wave detected in the SDO/AIA data around 16:33 UTC on October 08. Related type II and type IV solar radio emissions were detected at 15:42 UTC and 16:12 UTC on October 08 respectively. SIDC CME 727 is estimated to have an Earth-directed component and current analysis suggests a possible arrival time late UTC on October 11 to early UTC on October 12. Another EUV dimming and a small coronal wave were observed in the SDO/AIA imagery starting at 17:36 UTC on October 08, seemingly related to a filament eruption in the south-eastern quadrant triggered by the same event chain. A faint eastward eruption is visible in the LASCO/C2 around 17:00 UTC, but is expected to travel off the Sun-Earth line.

Coronal holes: SIDC Coronal Hole 149 (a recurrent mid-latitude coronal hole with a negative polarity) continues to reside on the central meridian. A high-speed stream related to it might be expected at Earth on October 09, possibly mixed with anticipated ICME arrival signatures related to SIDC CME 725.

Solar wind: Over the past 24 hours the solar wind parameters (as measured by ACE at L1) registered some enhancements, possibly the precursor of a high-speed stream arrival related to SIDC Coronal Hole 149. The solar wind speed remained slow, varying in the range of 333 to 390 km/s. The interplanetary magnetic field (B) registered a maximum value of 12.7 nT with a north-south (Bz) component down to - 7 nT. The B field phi angle switched from the positive to the negative sector (directed towards the Sun). The solar wind parameters are expected to be perturbed over the next 24 hours with an anticipated arrival of a high-speed stream possibly mixed with an ICME arrival related to SIDC CME 725. Perturbed solar wind conditions are expected to continue on October 10 with anticipated high- speed stream influence and possible waning ICME influence. A mild glancing blow arrival related to SIDC CME 726 could be expected on October 11 with the possibility of another ICME arrival late UTC on October 11 or early UTC on October 12 related to SIDC CME 727.

Geomagnetism: The geomagnetic conditions over the past 24 hours were locally (over Belgium) quiet to unsettled and globally quiet to active with NOAA Kp reaching 4 in the period 9-12 UTC on October 09. Unsettled conditions to minor storm levels are expected over the next 24 hours with chances for isolated moderate storms. Unsettled to active conditions with chances for more minor storm levels can continue on October 10, October 11 and October 12.

Proton flux levels: Over the past 24 hours the greater than 10 MeV GOES proton flux remained at close to nominal levels, while exhibiting some further enhancements related to activity from SIDC Sunspot Group 976 (NOAA Active Region 4549). The greater than 10 MeV GOES proton flux is expected to further increase over the next 24 hours with chances of reaching the 10 pfu proton event threshold.

Electron fluxes at GEO: The greater than 2 MeV electron flux as measured by GOES 18 and GOES 19 has exceeded the 1000 pfu threshold over the past 24 hours and is expected to be predominantly below the 1000 pfu threshold over the next 24 hours. The 24-hour electron fluence was at moderate levels and is expected to decrease to nominal levels over the next 24 hours.

TODAY'S ESTIMATED ISN : 086, BASED ON 07 STATIONS.

SOLAR INDICES FOR 08 Oct 2026
WOLF NUMBER CATANIA : 089
10CM SOLAR FLUX : ///
AK CHAMBON LA FORET : 017
AK WINGST : 006
ESTIMATED AP : 006
ESTIMATED ISN : 075, BASED ON 18 STATIONS.

CME/ICME

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
08 1529 1548 1558 N12W20 M6.7 2B 57/4549 I/3
END