

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

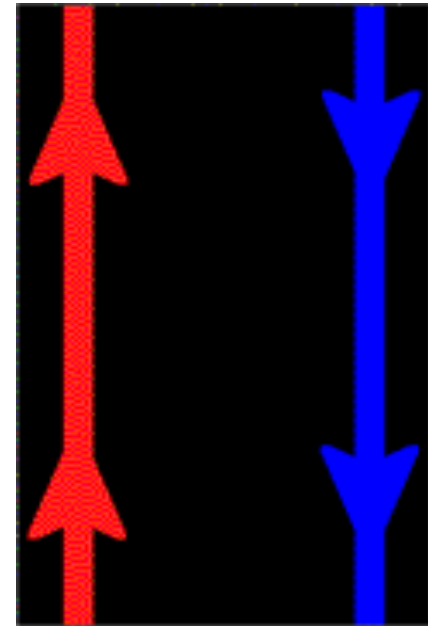
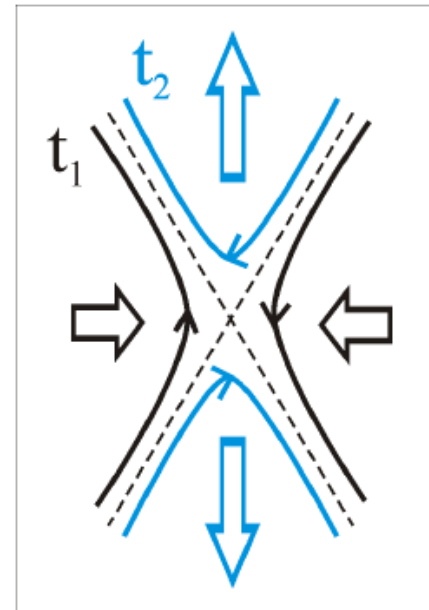
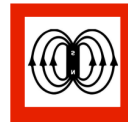
- Solar flares



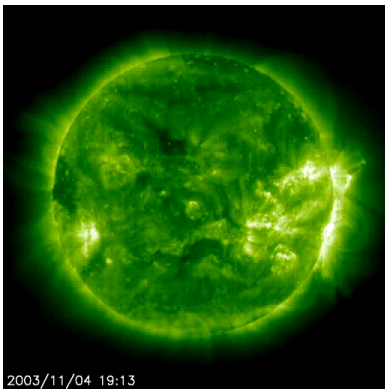
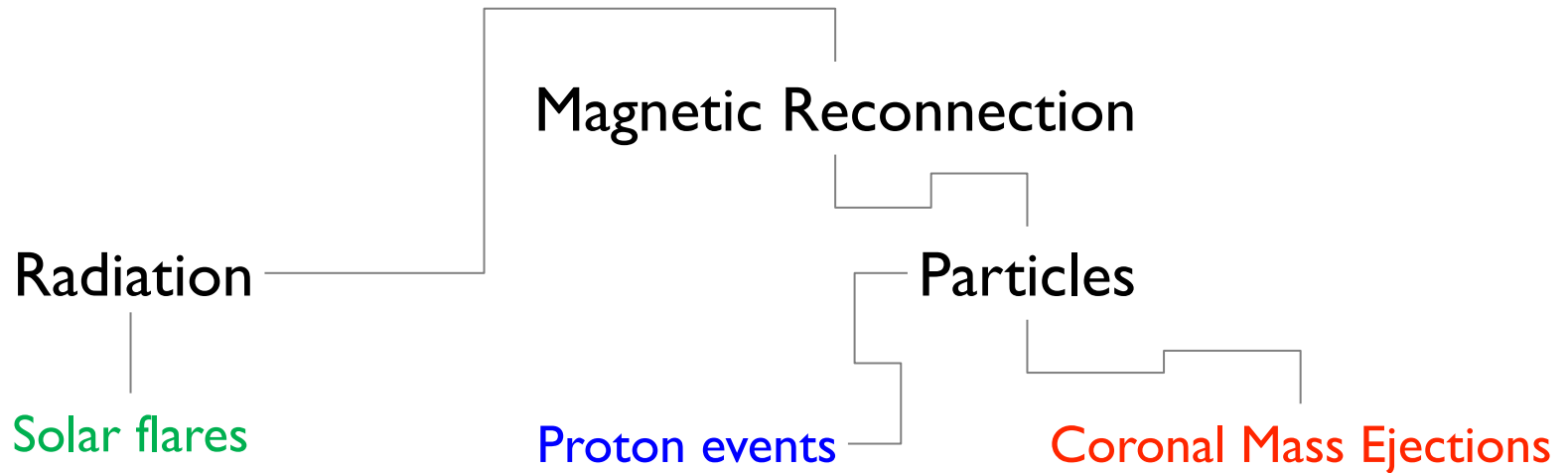
- CME release from the Sun



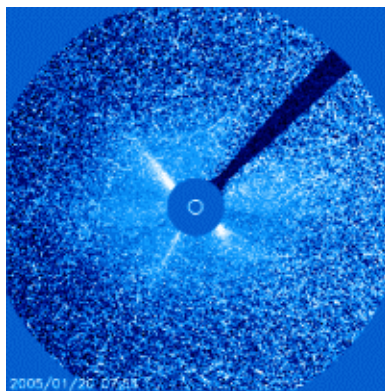
- Geomagnetic storms at Earth



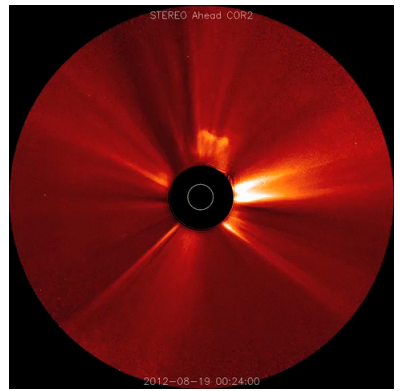
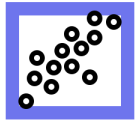
SOLAR ERUPTIONS



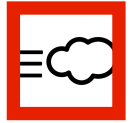
SOHO/EIT



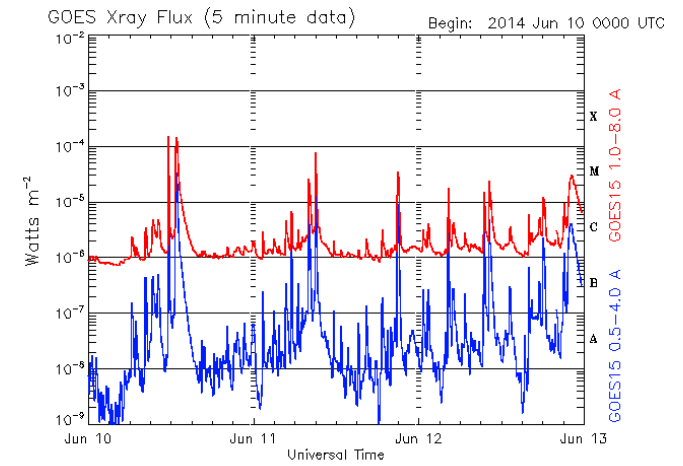
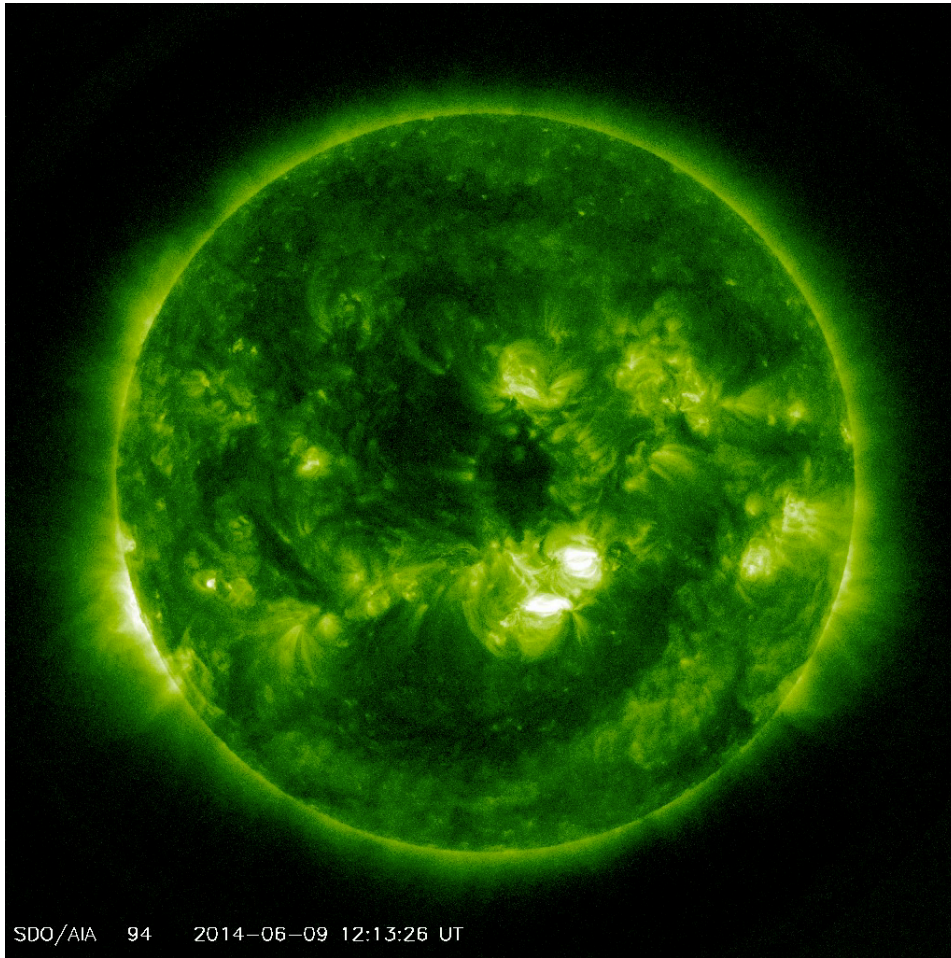
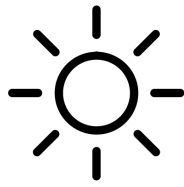
SOHO/LASCO



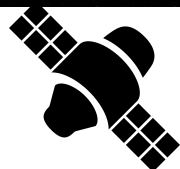
SOHO/LASCO



FLARE OBSERVATION



GOES



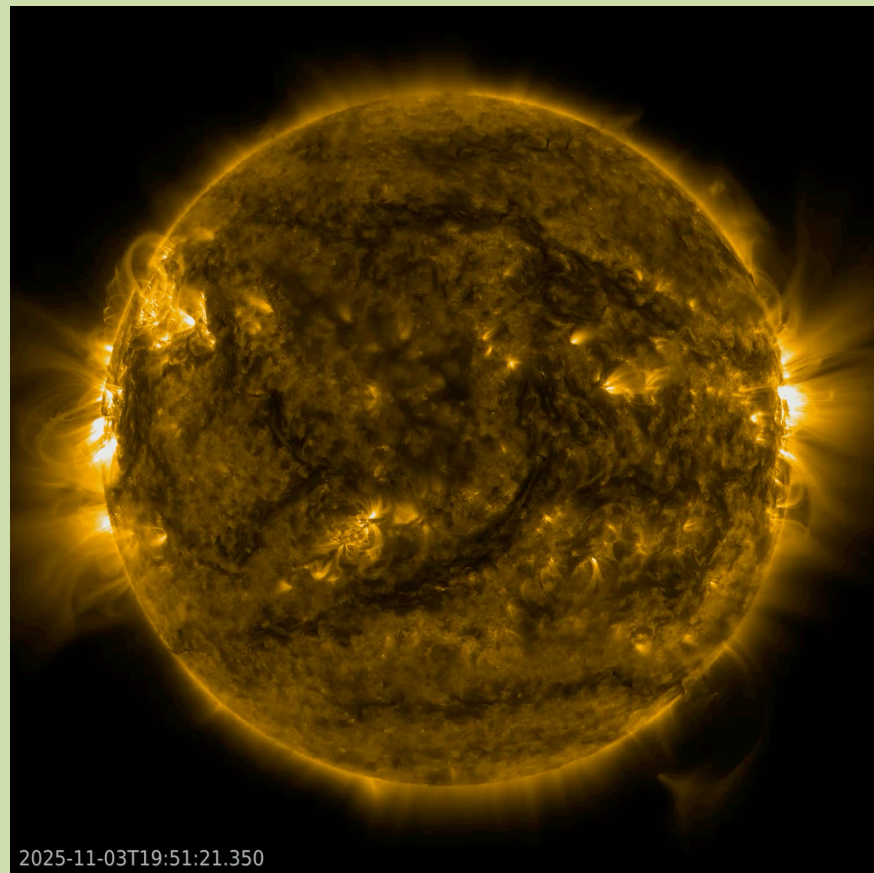
SDO/AIA





FLARES - OVERVIEW

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



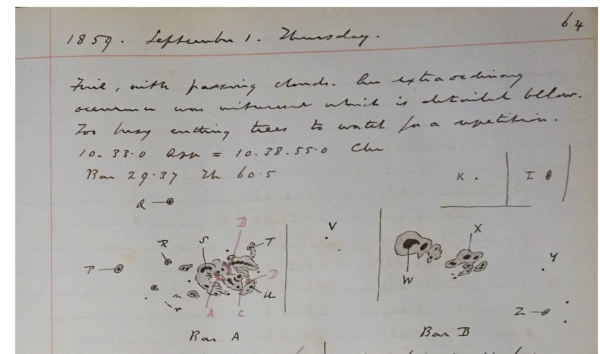
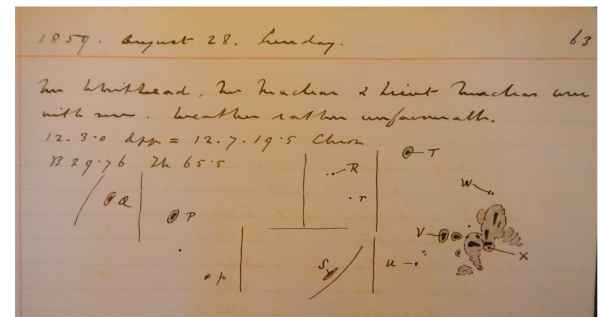
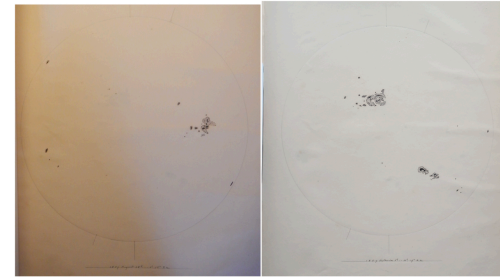
SDO/AIA





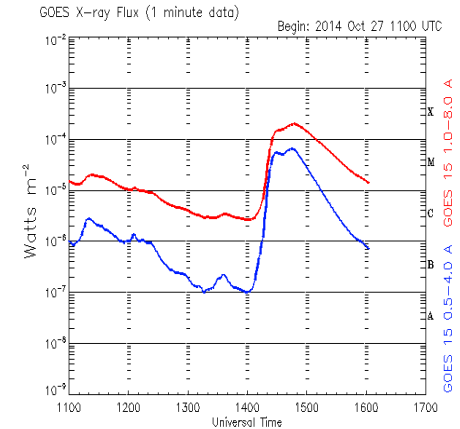
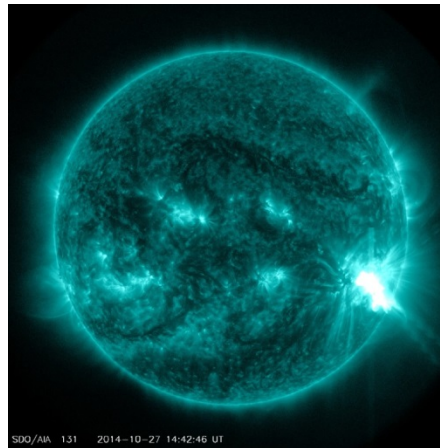
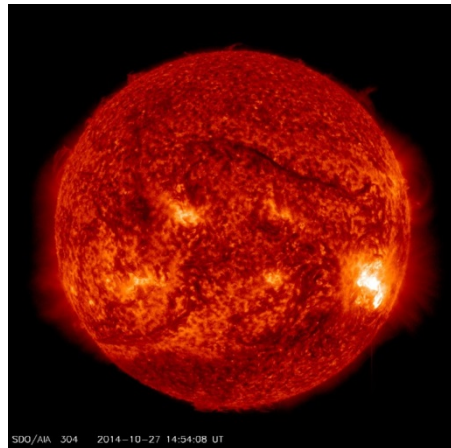
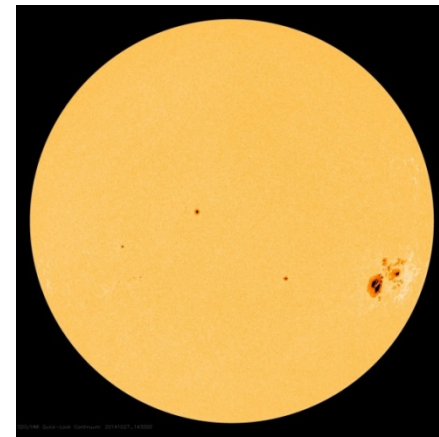
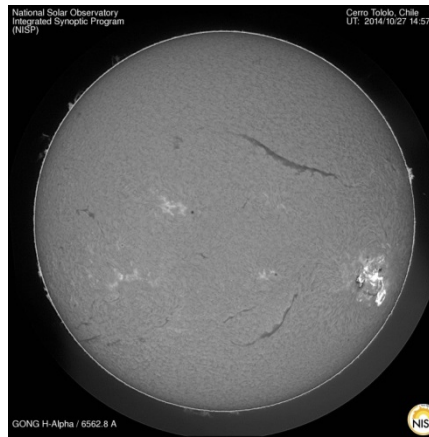
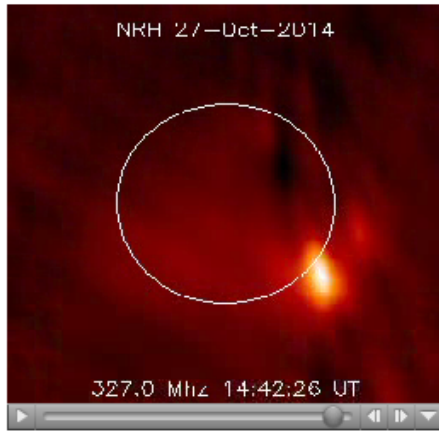
SOLAR FLARES - WHAT?

- 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





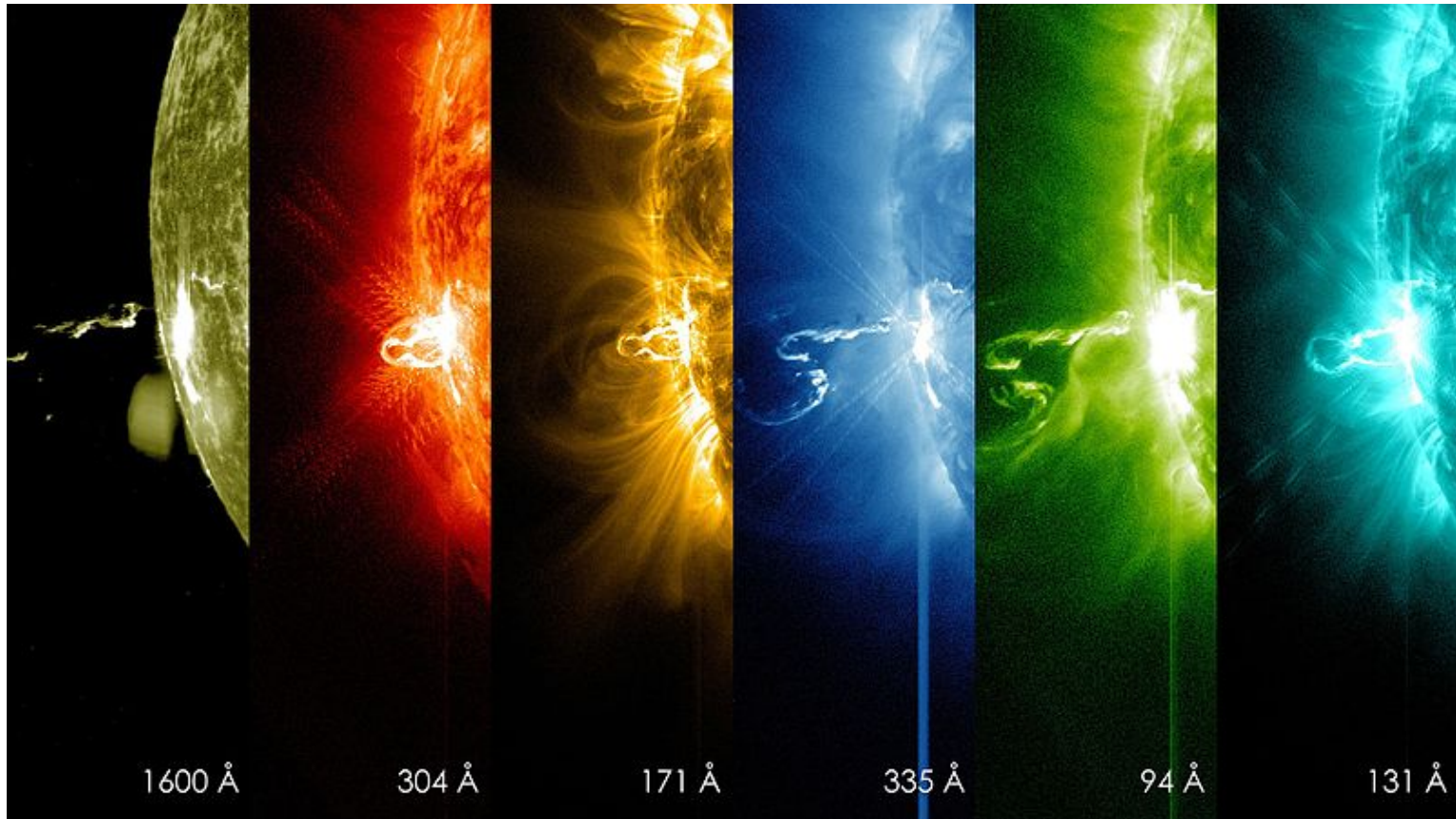
SOLAR FLARES - OBSERVATIONS



Updated 2014 Oct 27 1604 UTC NOAA/SWPC Boulder, CO USA



SOLAR FLARES - OBSERVATIONS

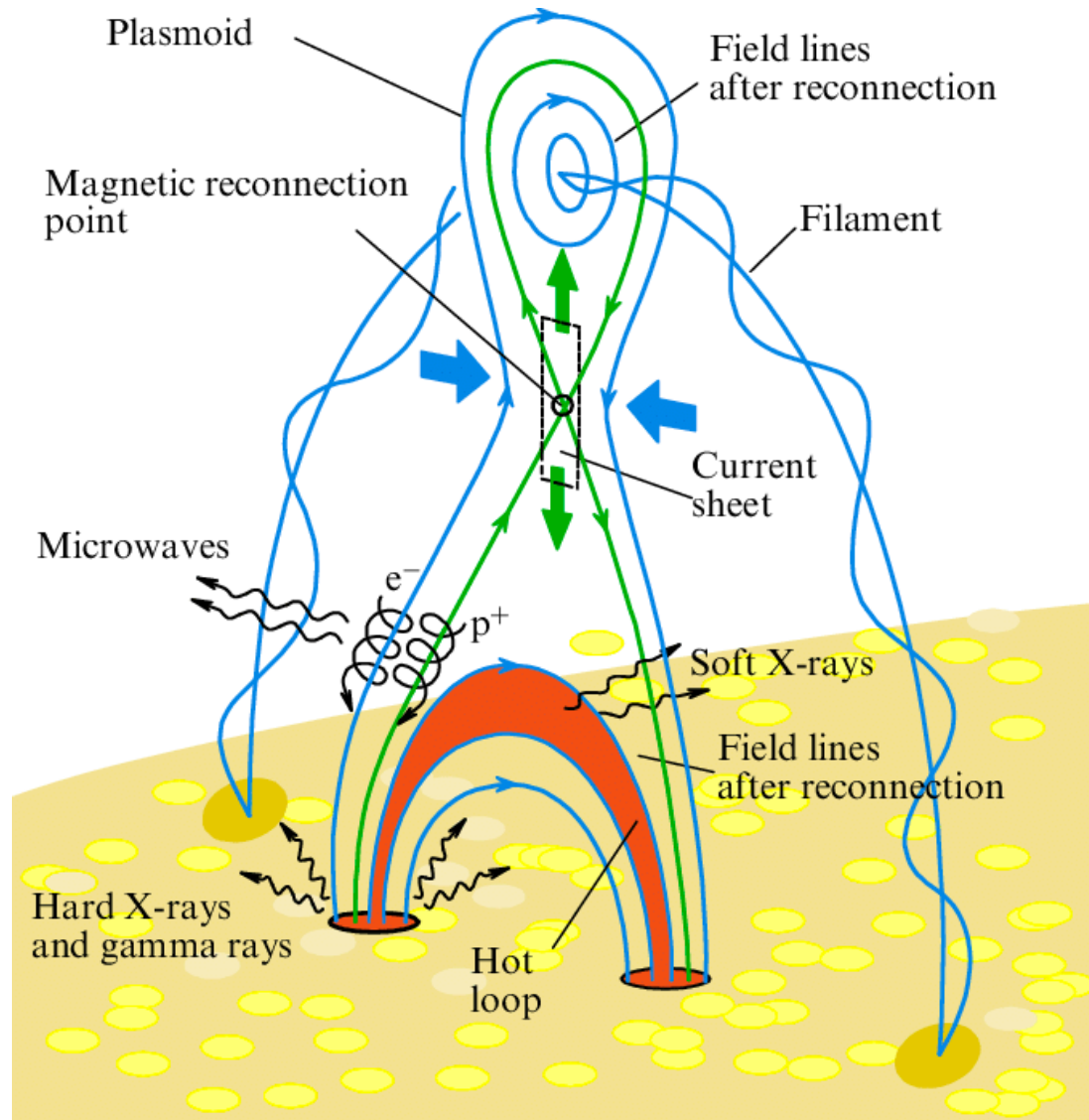


SDO/AIA





STANDARD FLARE MODEL

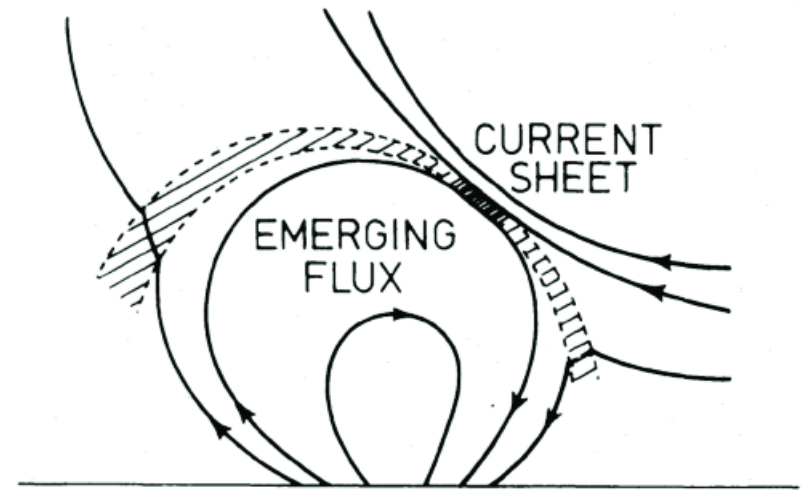




TRIGGERS OF SOLAR FLARES

Magnetic restructuring

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



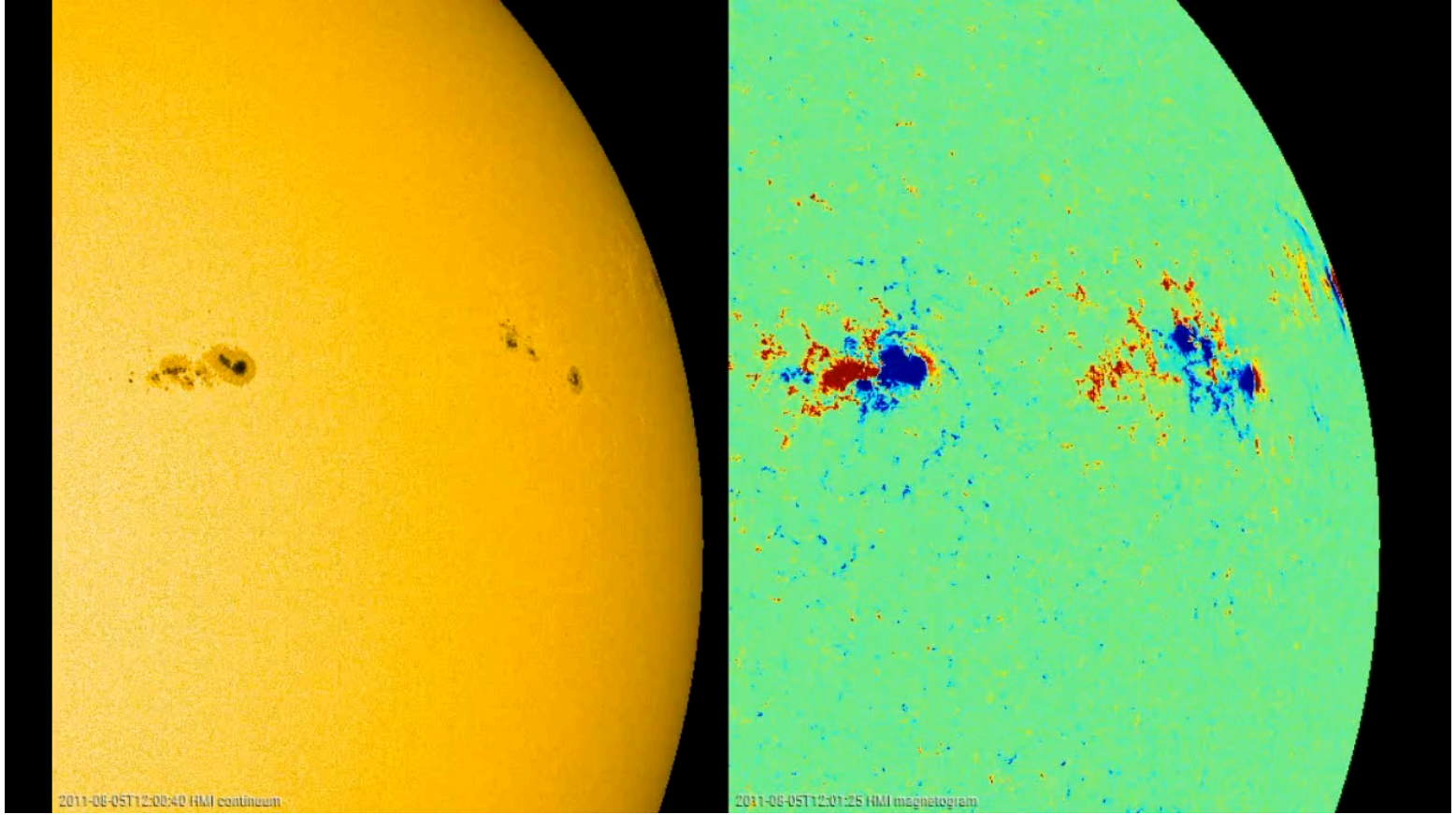


TRIGGERS OF SOLAR FLARES



SDO/HMI

Magnetic flux emergence



2011-06-05T12:00:40 HMI continuum

2011-06-05T12:01:25 HMI magnetogram



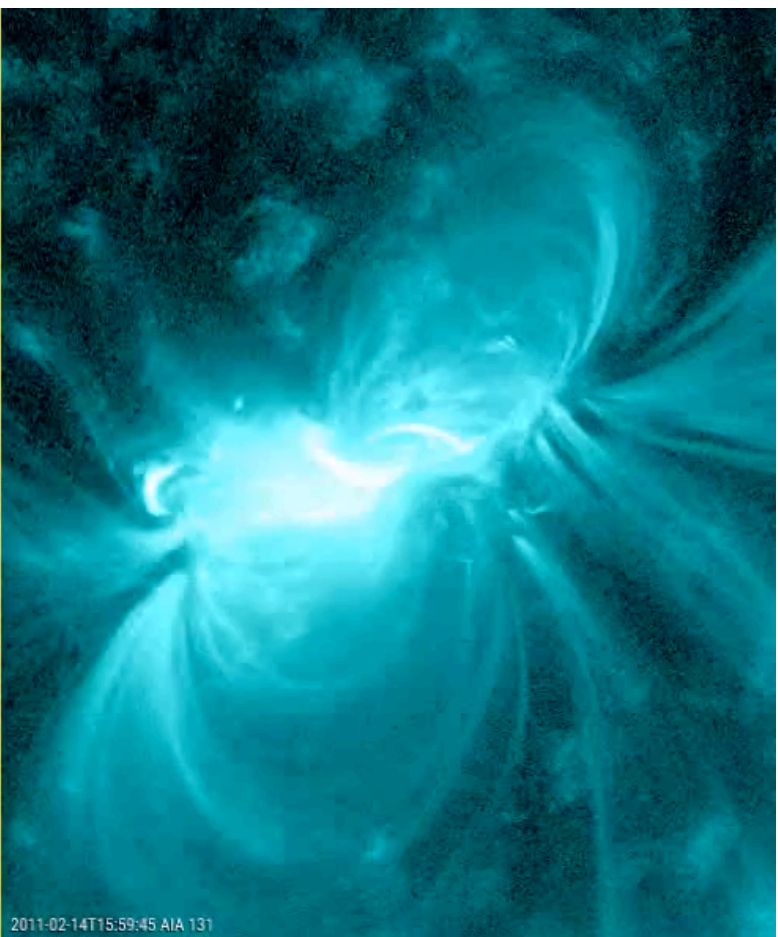
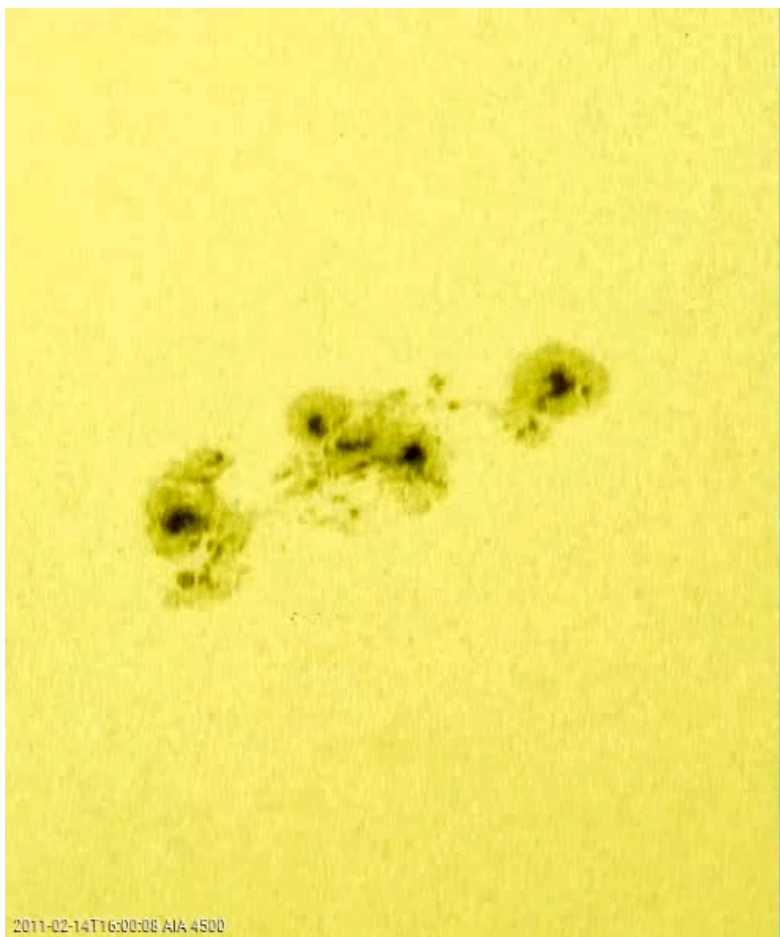


TRIGGERS OF SOLAR FLARES

Helical energy storage



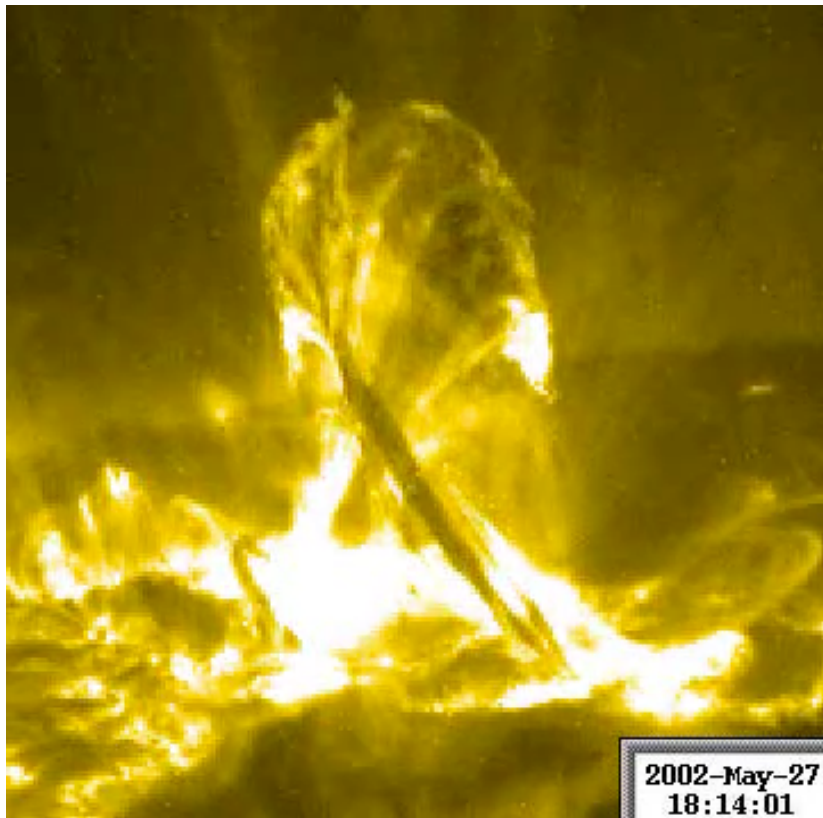
SDO/AIA



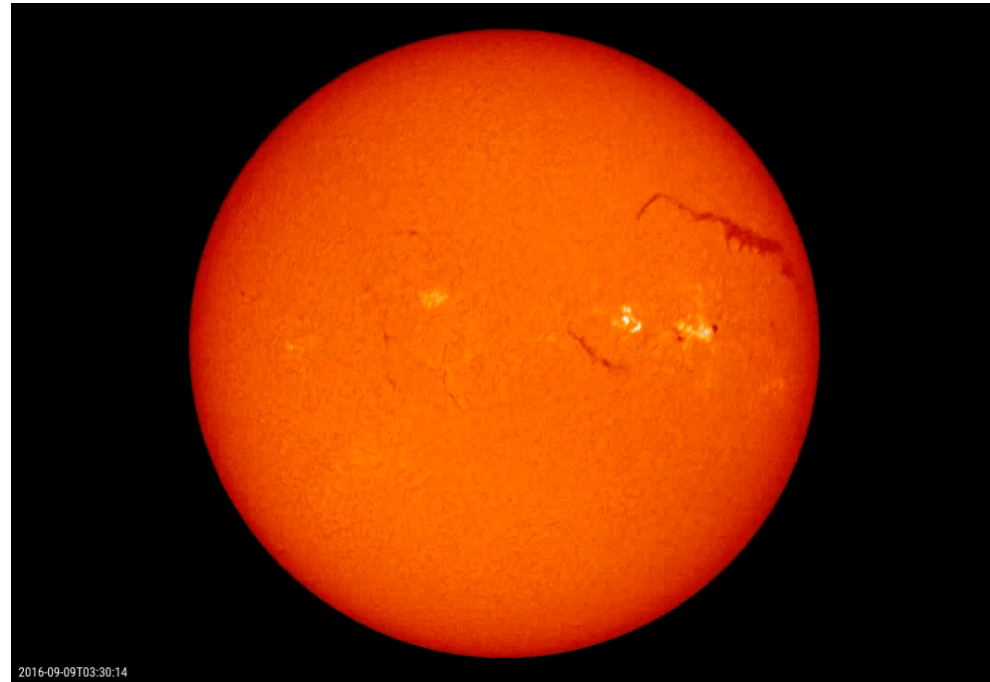


TRIGGERS OF SOLAR FLARES

Kink instability



Unstable magnetic fields





Finding your way in the URSIgram

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:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#
SIDC URSIGRAM 30318
SIDC SOLAR BULLETIN 18 Mar 2023, 1230UT
SIDC FORECAST (valid from 1230UT, 18 Mar 2023 until 20 Mar 2023)
SOLAR FLARES : C-class flares expected, (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 18 Mar 2023 10CM FLUX: 138 / AP: 007
PREDICTIONS FOR 19 Mar 2023 10CM FLUX: 140 / AP: 019
PREDICTIONS FOR 20 Mar 2023 10CM FLUX: 138 / AP: 029

```

COMMENT: The solar flaring activity was at moderate levels during the last 24 hours with one M-class flare and several C-class flares detected, with the most frequent sources being NOAA active regions 3254 and 3256. The largest flare was a M1.1 flare, peaking at 15:07 UTC on March 17, associated with active region NOAA 3254 (beta class). NOAA active region 3256 produced an impulsive C9.4 flare at 07:10 UTC on March 18. This event was also associated with Type IV radio emission. Other regions on the disc did not show any significant flaring activity. Further M-class flare activity is possible but not probable, while frequently C-class activity is expected in the next 24 hours.

A filament eruption in the southwestern quadrant was observed on March 17 from around 09:20UTC. The associated CME appears in SoHO/LASCO C2 coronagraph data from 10:23UTC onwards. The CME is directed to the south-west and the bulk of the CME is not expected to be Earth directed. However, a glancing blow of the shock may impact Earth at around 19:00 UTC on March 19. Another small filament eruptions occurred in the northwestern quadrant from around 17:09UTC and 20:09UTC on March 17. We are awaiting corresponding coronagraph data for further analysis. During the last 24 hours there were no other potentially Earth-directed CMEs detected in the available coronagraph observations.

The greater than 10 MeV proton flux was at almost nominal levels over the past 24 hours and is expected to remain so for the next 24 hours. The greater than 2 MeV electron flux remained below the 1000 pfu alert threshold and is expected to remain below this threshold during the next 24 hours. The 24h electron fluence was at normal levels and is expected to remain so.

Over the past 24 hours the solar wind parameters (ACE and DSCOVR) have been indicative of slow solar wind conditions. The solar wind speed ranged between 400 km/s and 450 km/s. The interplanetary magnetic field magnitude was about 6 nT. The magnetic field orientation was predominantly in the positive sector (field directed away from the Sun). Similar slow solar wind regime is expected on March 18 with a slight wind speed enhancement possible for late on March 19, due to expected influence of the small equatorial coronal hole of positive polarity with a chance of being mixed with glancing blow from a CME which left the solar surface around 10 UTC on March 17th.

The geomagnetic conditions over the past 24 hours were globally and locally quiet to unsettled (NOAA Kp and K Bel 1-3). Quiet conditions are expected for March 18 with active to minor storm conditions possible for late on March 19 and March 20, due to expected arrival of the high speed stream and a possible glancing blow from a CME.

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TODAY'S ESTIMATED ISN : 044, BASED ON 14 STATIONS.

SOLAR INDICES FOR 17 Mar 2023
WOLF NUMBER CATANIA : 110
10CM SOLAR FLUX : 134
AK CHAMBON LA FORET : 014
AK WINGST : 007
ESTIMATED AP : 007
ESTIMATED ISN : 073, BASED ON 18 STATIONS.

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Flare features

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NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
17 1504 1507 1511 S22W65 M1.0 SN 12/3247
END

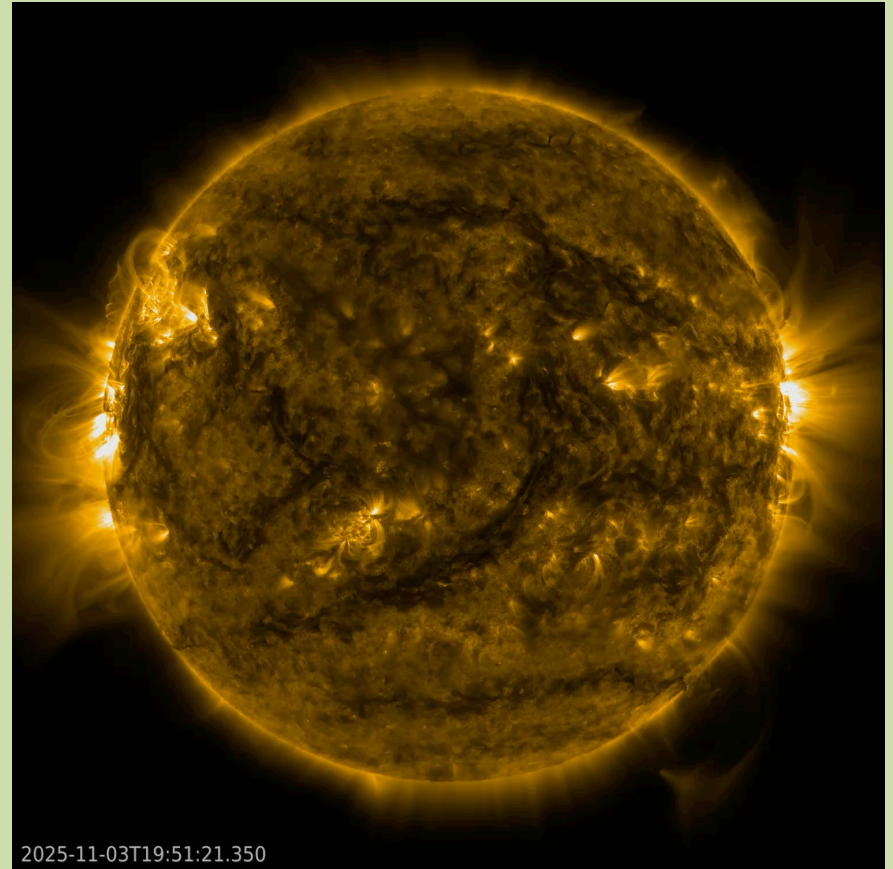
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FLARES - OVERVIEW

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



SDO/AIA



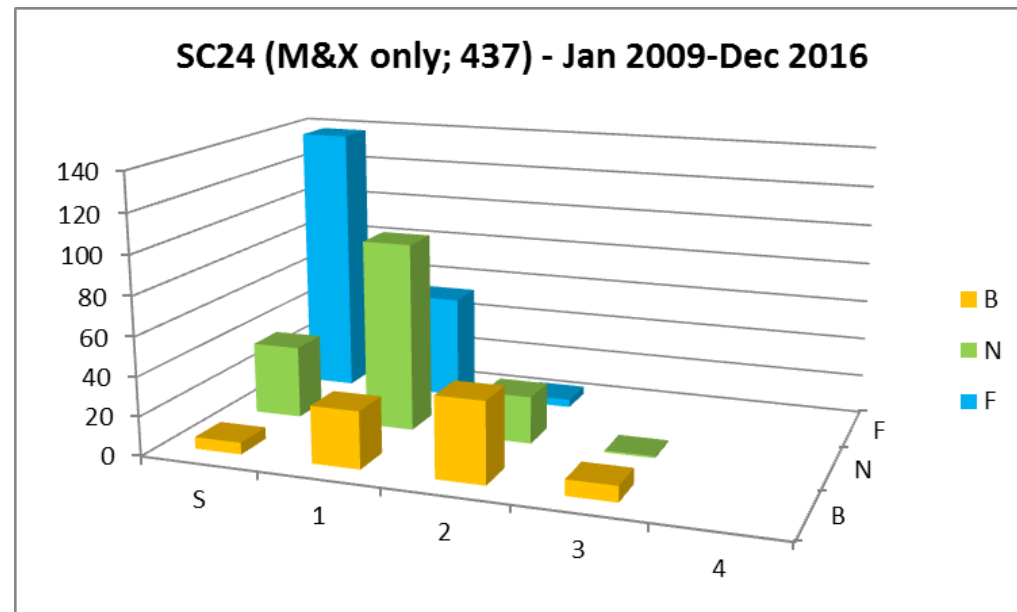


SOLAR FLARES CLASSIFICATION

H-alpha

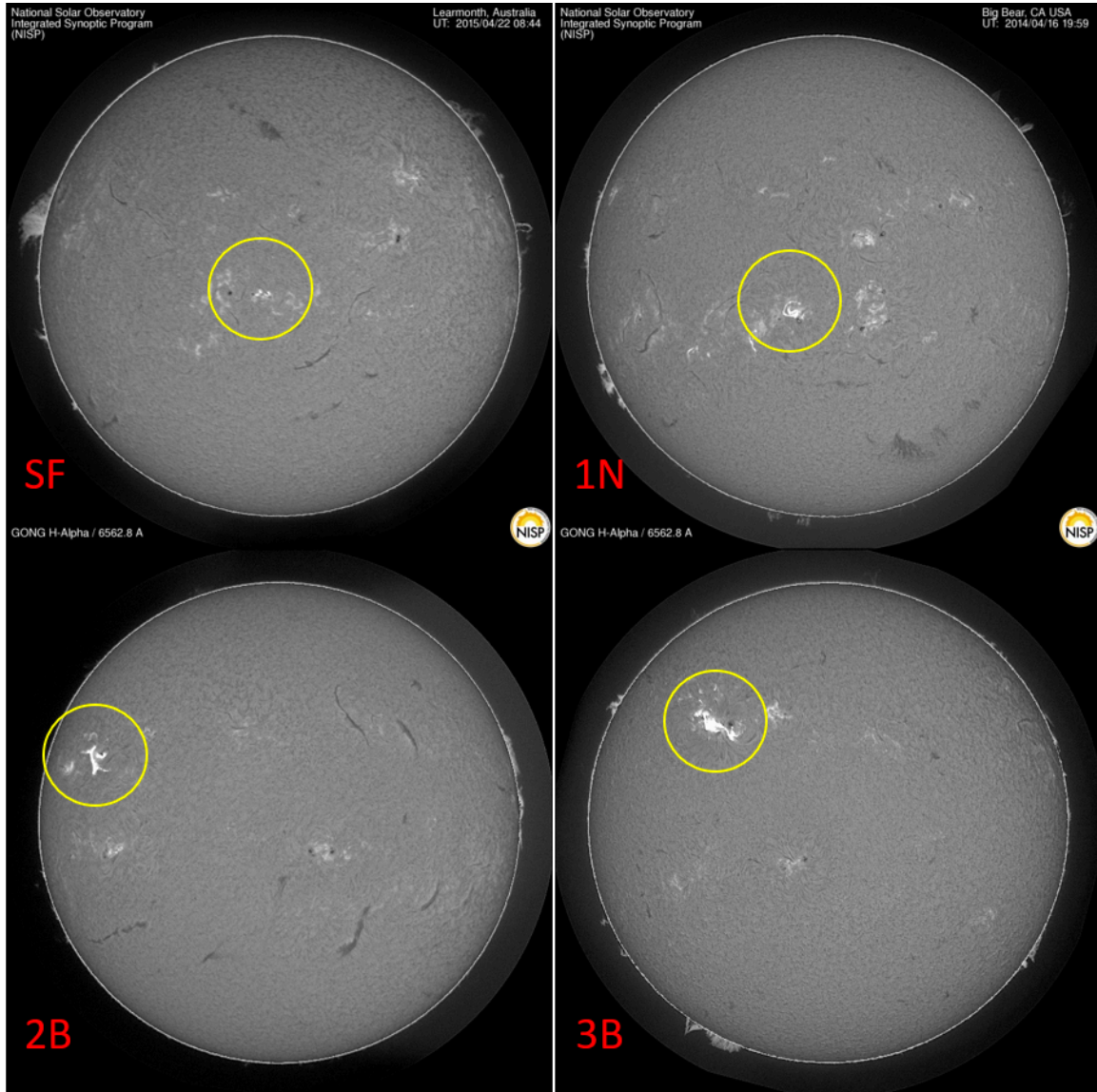
- Visual classification
- Importance
 - Area at max. brightness
- Brightness
 - Faint, Normal, Brilliant
- Optical class
 - E.g. SF, 3B,...
- Limited correlation with geophysical effects
- Depends strongly on seeing conditions

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	$1200 \leq A_c$	$24,7 \leq A_c$



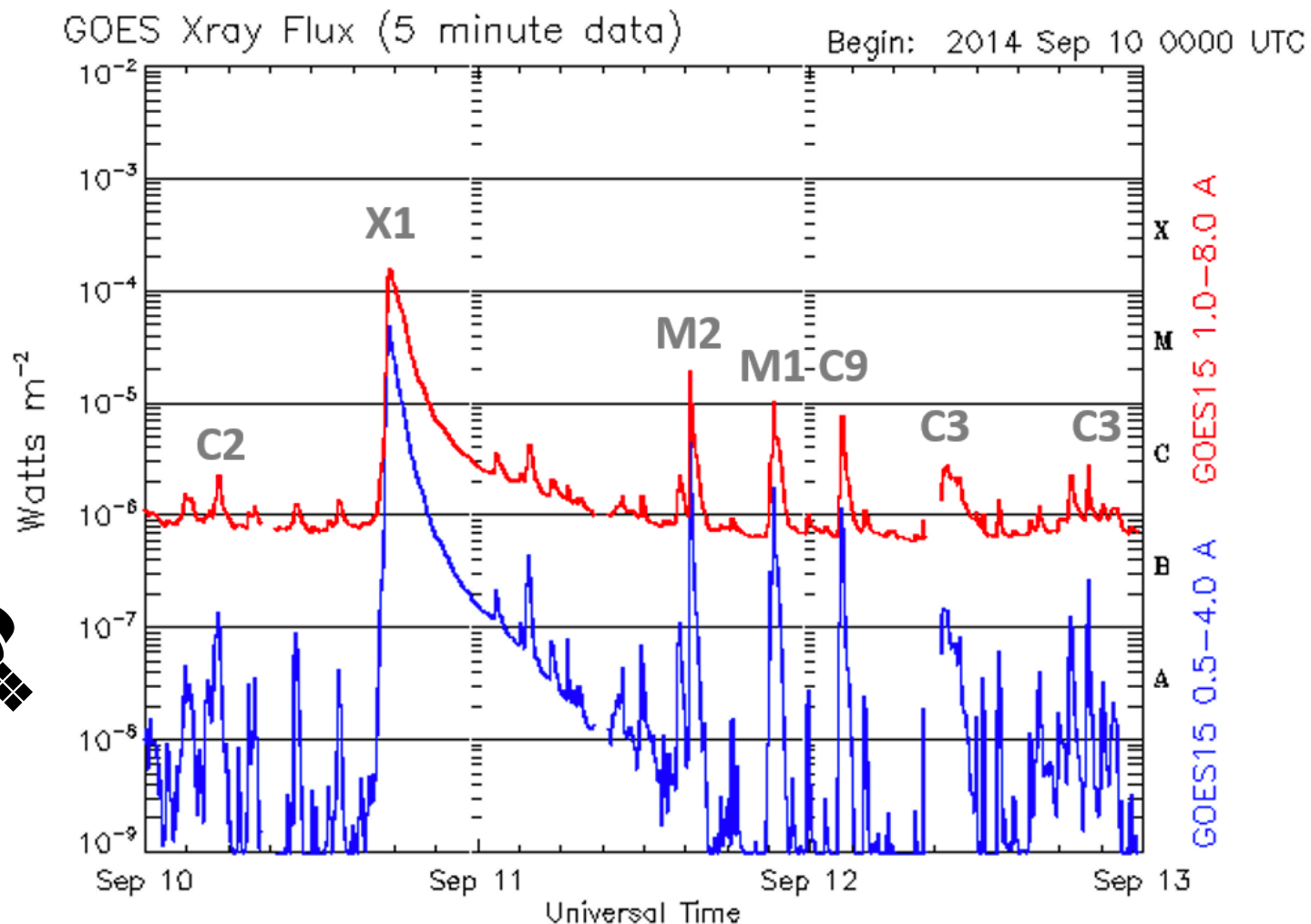


SOLAR FLARE CLASSIFICATION: H-ALPHA





SOLAR FLARE CLASSIFICATION: X-RAY



Updated 2014 Sep 12 23:55:13 UTC

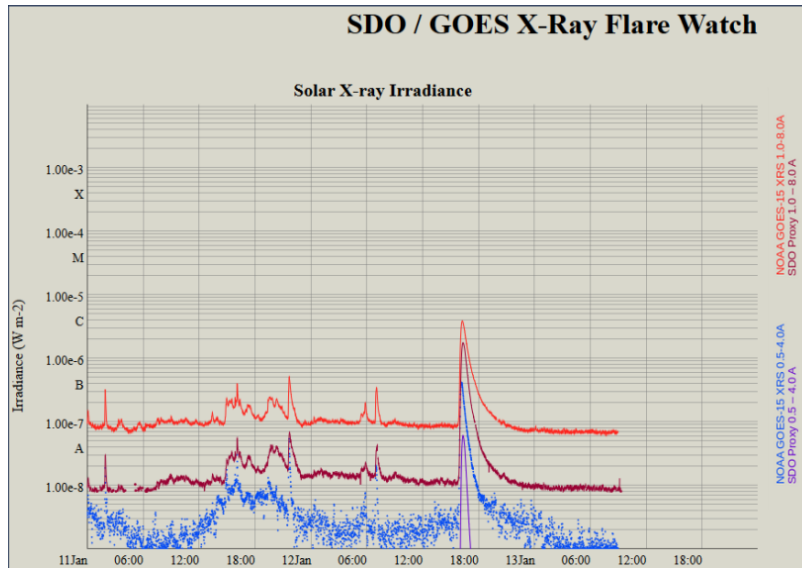
NOAA/SWPC Boulder, CO USA



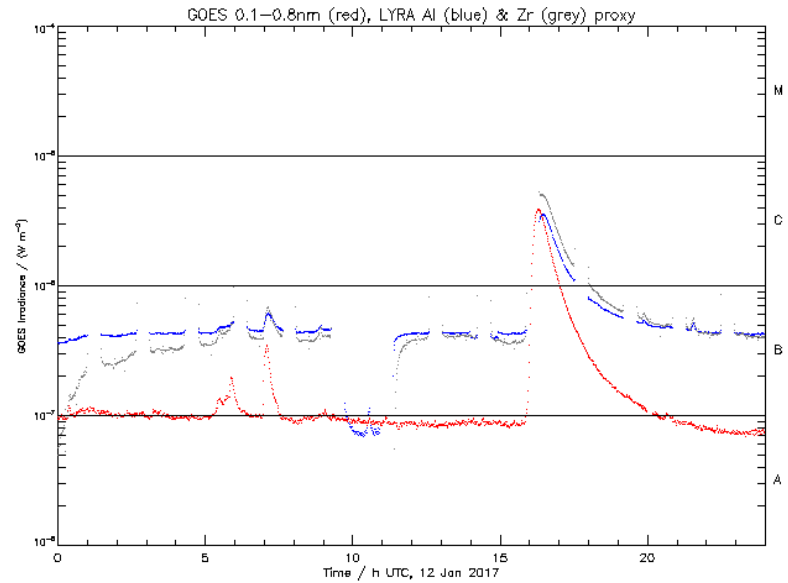


SOLAR FLARE CLASSIFICATION: X-RAY

Back-up for GOES x-ray



SDO/EVE



PROBA2/LYRA

ROB/SIDC, Brussels, Belgium





SOLAR FLARE CLASSIFICATION: X-RAY

Frequency terminology

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

Terms Used to Describe Solar Activity

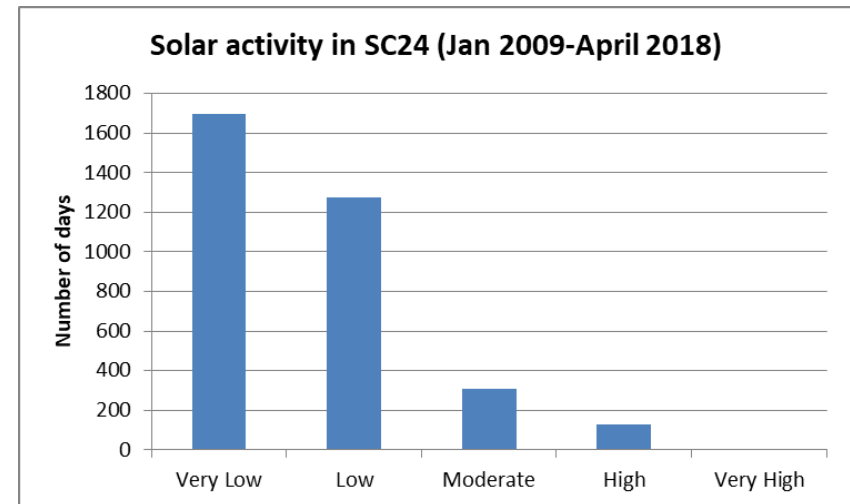
Very Low: x-ray events less than C-class.

Low: C-class x-ray events.

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

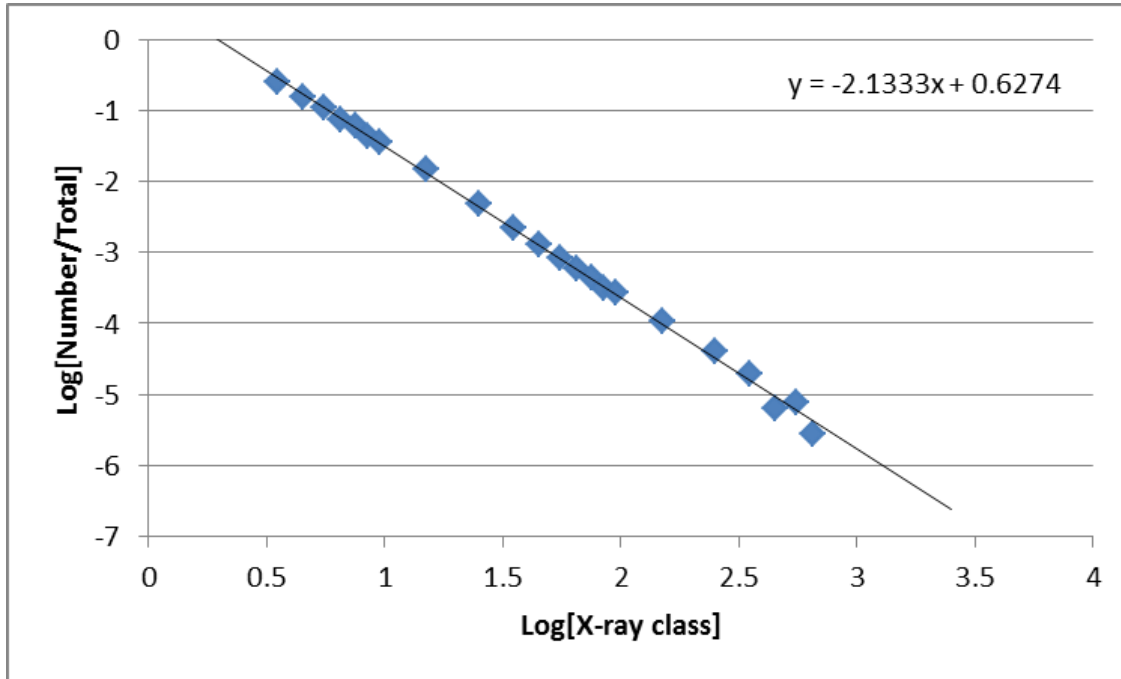
High: several (5 or more) M-class x-ray events, or isolated (one to four) M5 or greater x-ray events.

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

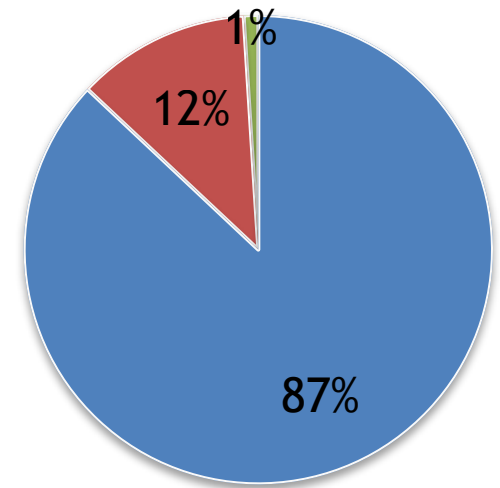




SOLAR FLARE STATISTICS: X-RAY



● C ● M ● X





SOLAR FLARE CLASSIFICATION: X-RAY

NOAA-scales: R-scale

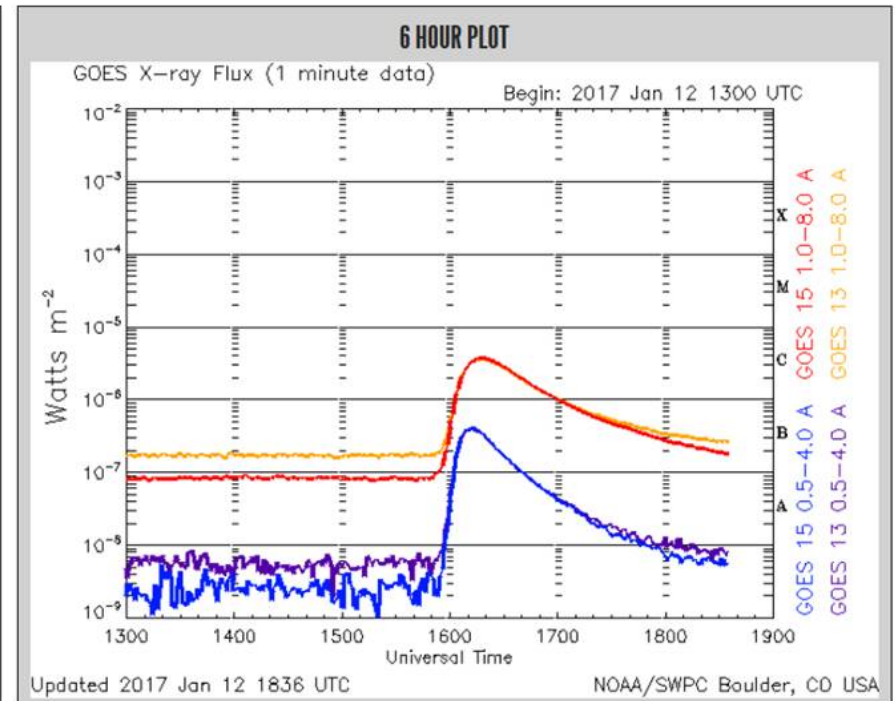
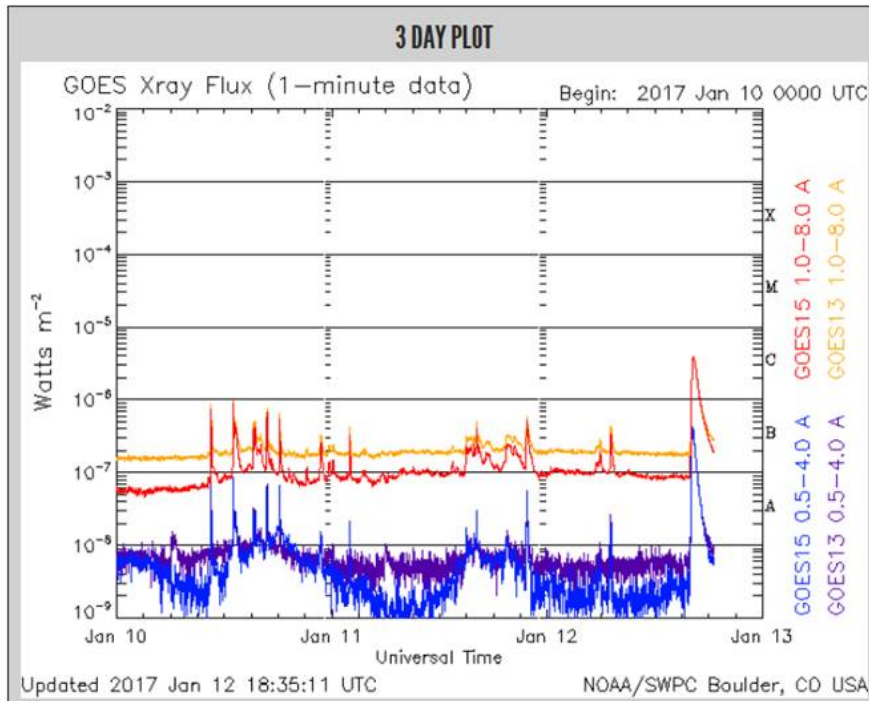
Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
R 5	Extreme		X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe		X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong		X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate		M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor		M1 (10^{-5})	2000 per cycle (950 days per cycle)

R = Radio Blackout





SOLAR FLARE DURATION



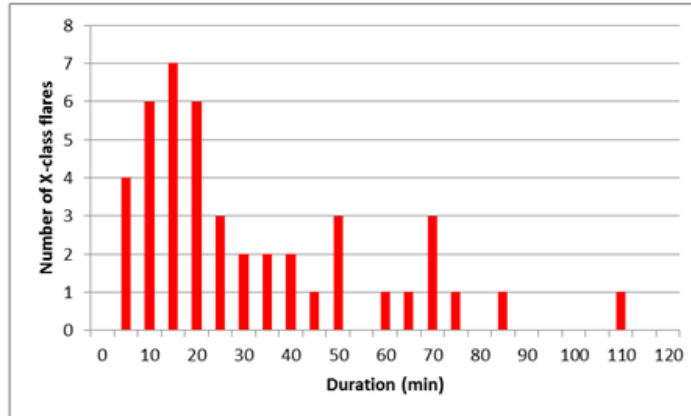
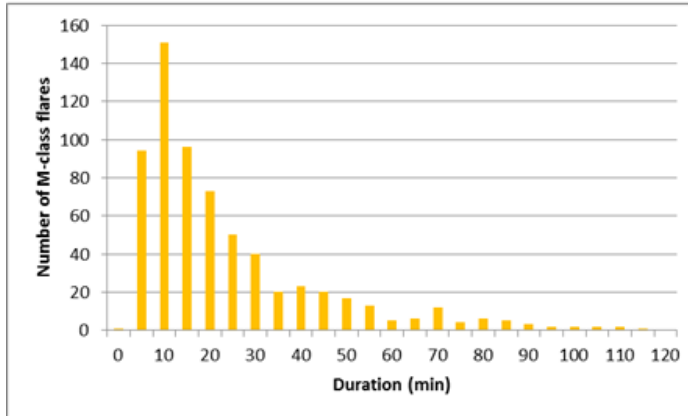
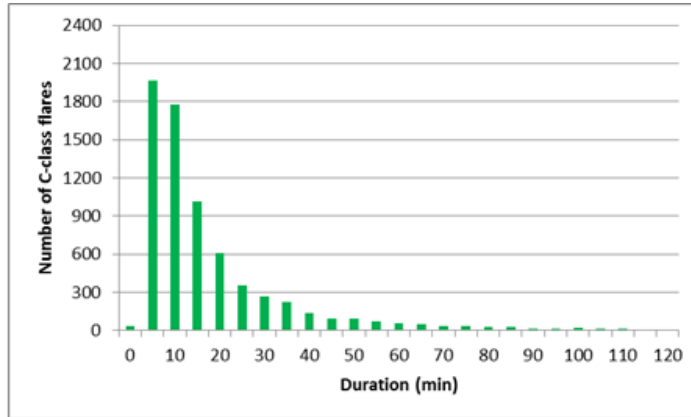
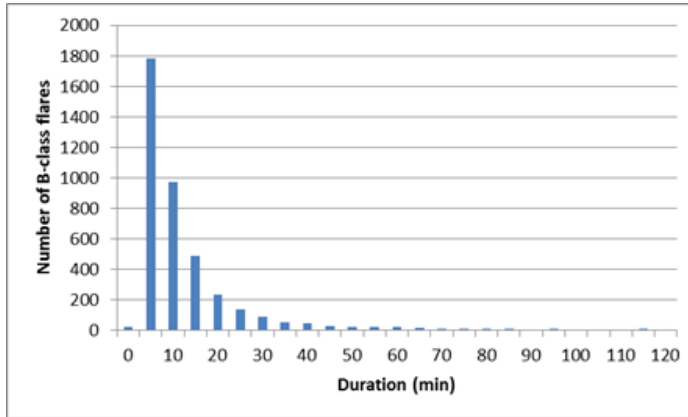
GOES

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	





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





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



SOLAR FLARE DURATION

Impulsive flare

Long Duration Event

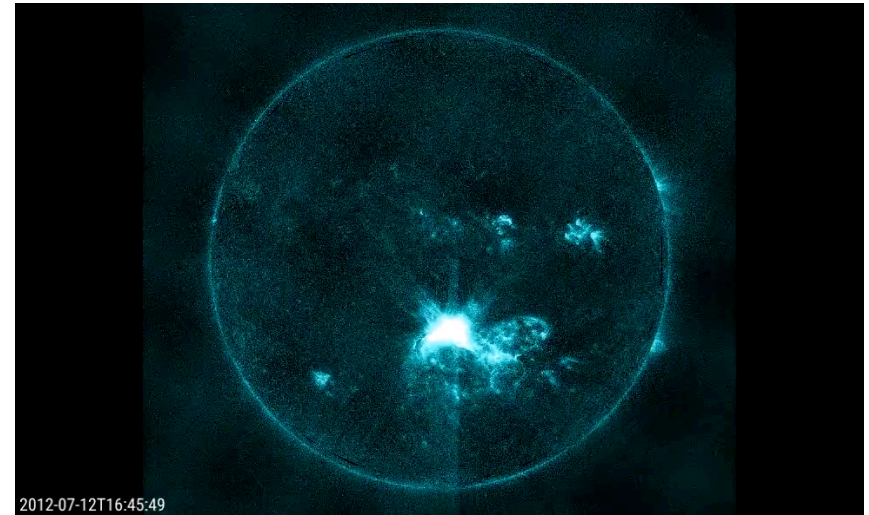


SDO/AIA



2013-11-10T05:22:20

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



2012-07-12T16:45:49

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



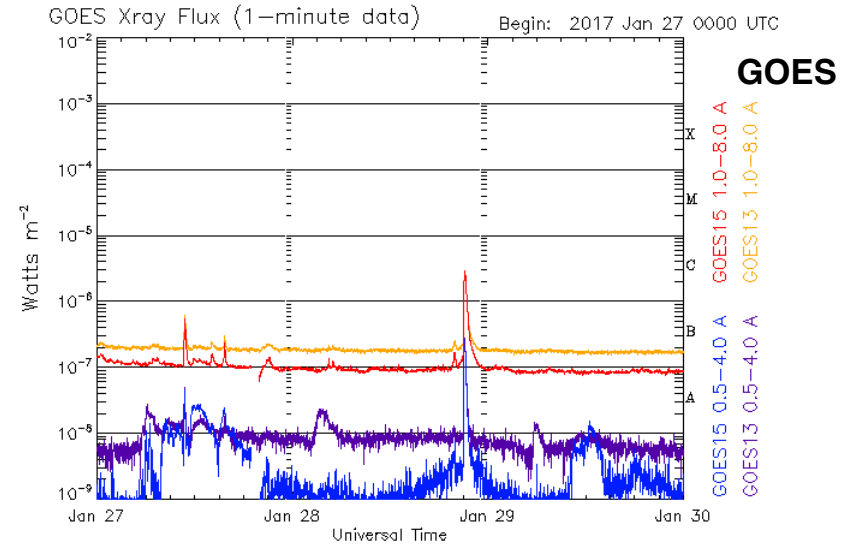


SOLAR FLARE FREQUENCY



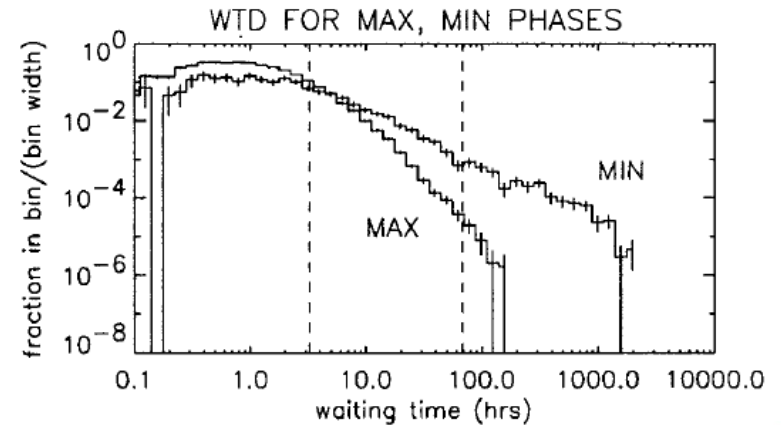
Isolated flare

- 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 ($\geq C1$)
 - SCmax: 3 hours
 - SCmin: 3 days



Updated 2017 Jan 29 23:59:12 UTC

NOAA/SWPC Boulder, CO USA





Finding your way in the URSIgram

:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at <http://www.sidc.be/products/meu>
#-----#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
(RWC Belgium) #
#-----#

SIDC URSIGRAM 30318
SIDC SOLAR BULLETIN 18 Mar 2023, 1230UT
SIDC FORECAST (valid from 1230UT, 18 Mar 2023 until 20 Mar 2023)

SOLAR FLARES : C-class flares expected, (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 18 Mar 2023 10CM FLUX: 138 / AP: 007
PREDICTIONS FOR 19 Mar 2023 10CM FLUX: 140 / AP: 019
PREDICTIONS FOR 20 Mar 2023 10CM FLUX: 138 / AP: 029

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10CM SOLAR FLUX : 134
AK CHAMBON LA FORET : 014
AK WINGST : 007
ESTIMATED AP : 007
ESTIMATED ISN : 073, BASED ON 18 STATIONS.

Flare classification

NOTICEABLE EVENTS SUMMARY

DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM Catania/NOAA	RADIO_BURST_TYPES
17	1504	1507	1511	S22W65	M1.0	SN	12/3247	

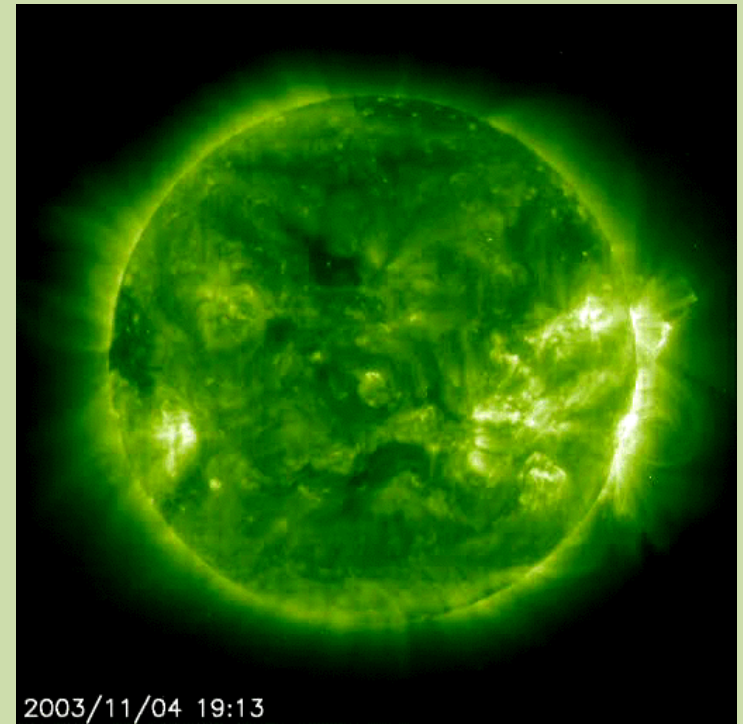
END





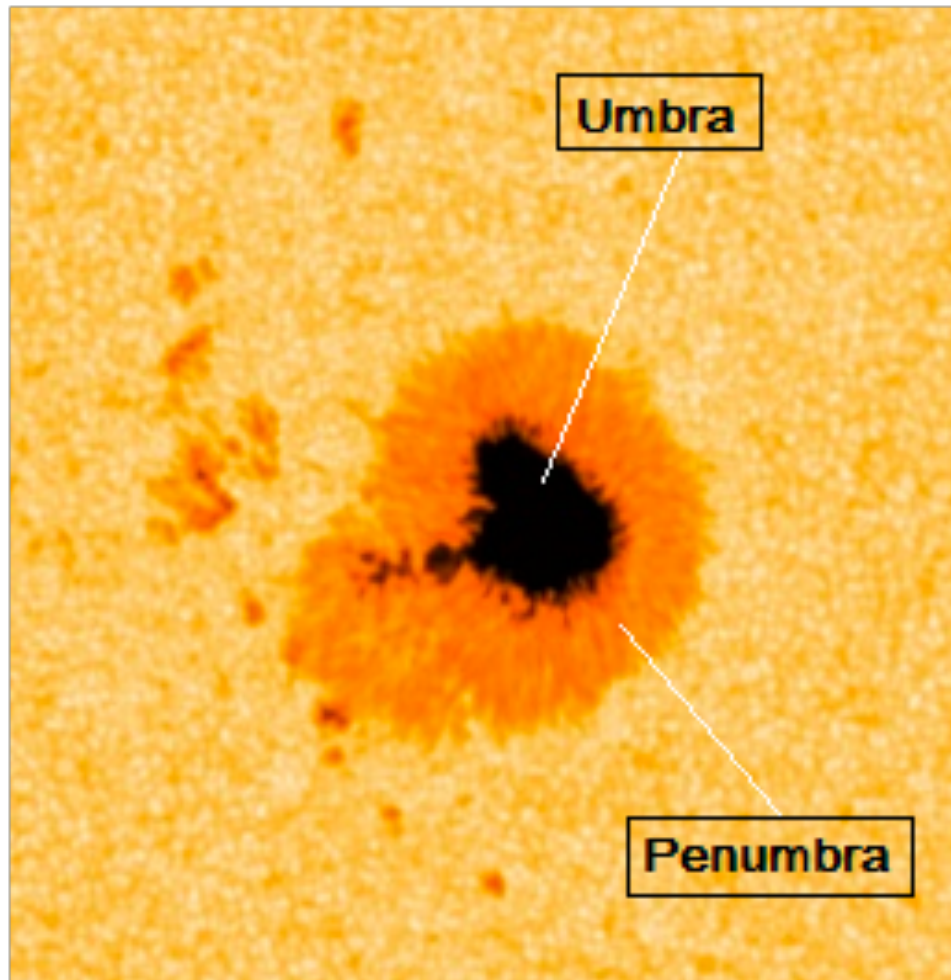
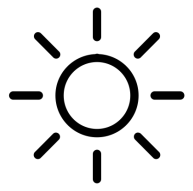
FLARES - OVERVIEW

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



SOHO/EIT

SUNSPOT NOMENCLATURE

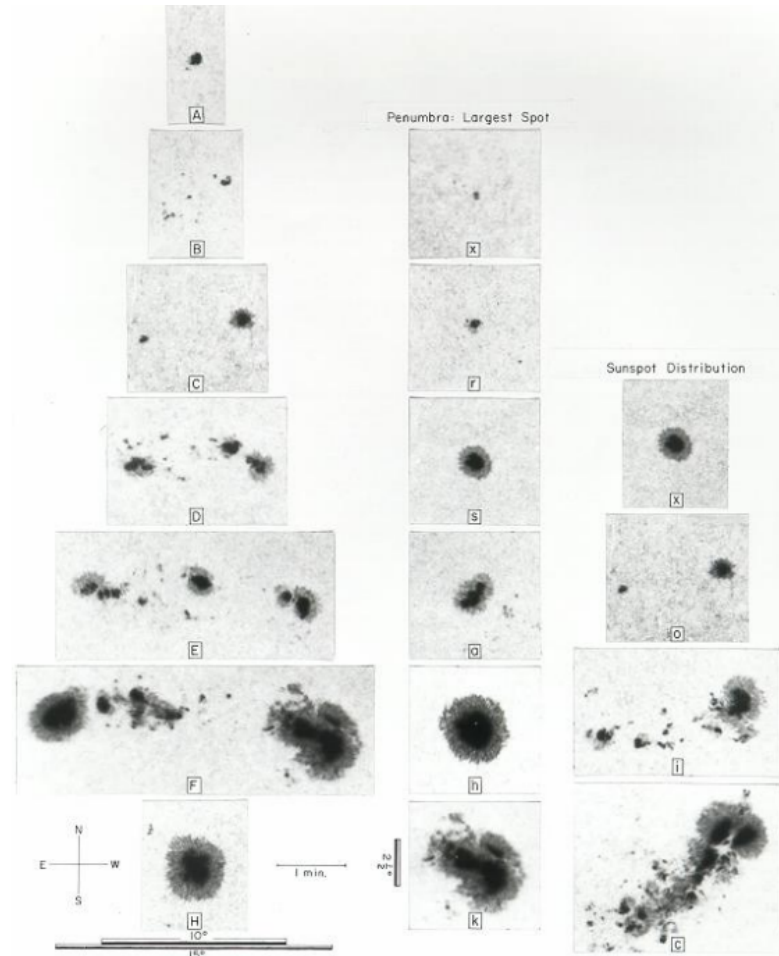




FLARE PREDICTIONS

McIntosh classification

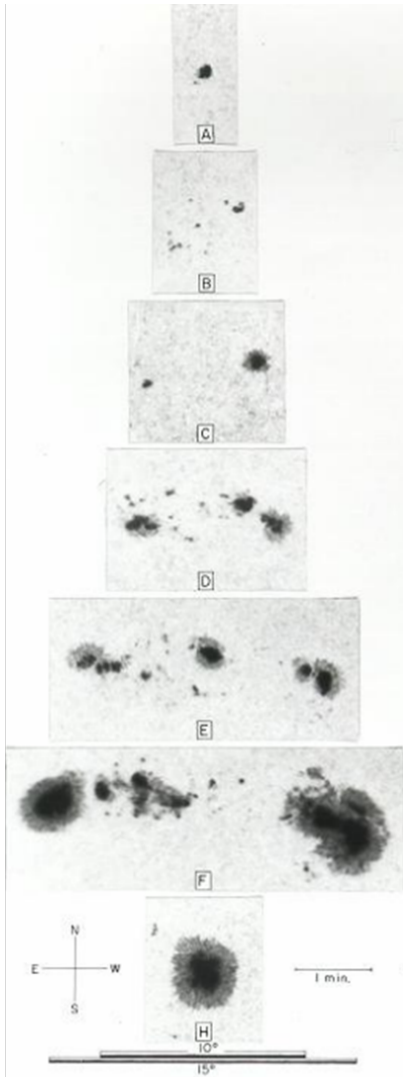
- Zpc (*3-letter code*)
 - Z - Modified Zürich classification
 - p - Penumbra largest spot
 - c - Interior sunspot distribution
- 60 possible combinations
 - Linked to flare intensity
 - Rather large uncertainties
- Used worldwide



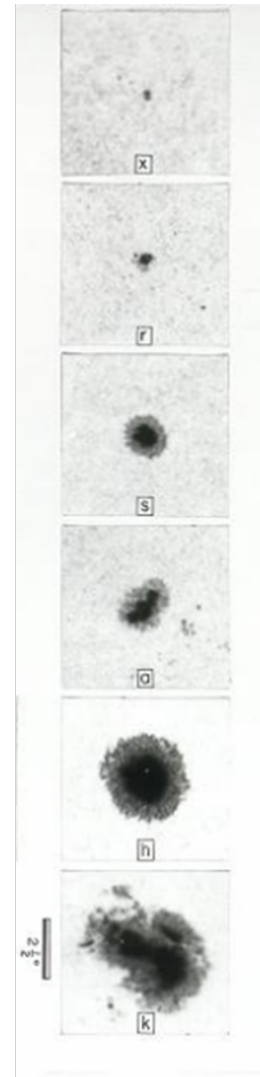


FLARE PREDICTIONS

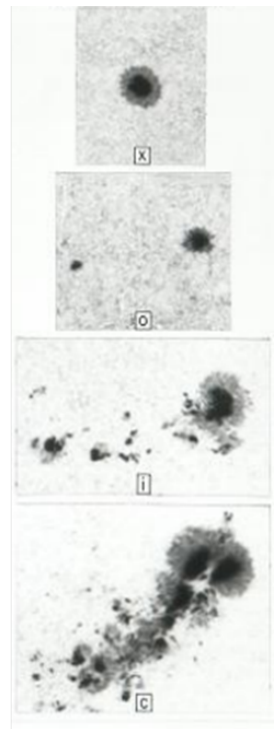
A
B
C
D
E
F
H



x
r
s
a
h
k



X
O
i
C





FLARE PREDICTIONS

THE ASTROPHYSICAL JOURNAL LETTERS, 747:L41 (7pp), 2012 March 10

BLOOMFIELD ET AL.

Table 2
McIntosh Classification Flare Statistics

McIntosh Region Classes ^a	SWPC (1988–1996)			Kildahl (1969–1976) ^b			Combined Flare Rate (24 hr ⁻¹)				Poisson Flare Probability (%)						
	Region Count	Total Flares			Region Count	Total Flares			In GOES Class				In GOES Class			Above GOES ^d	
		C	M	X		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 ≥ 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."





FLARE PREDICTIONS

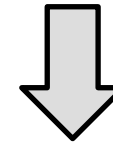
Likelihood (terminology)

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 $\geq 50\%$)	
2 = Active (M-class flares expected, probability $\geq 50\%$)	
3 = Major flares expected (X-class flares expected, probability $\geq 50\%$)	
Activity level	wording for bulletin
<50% probability of C-class flares	Quiet solar conditions
C-class flares expected, probability $\geq 50\%$	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 $\geq 50\%$	M-class flares expected / idem as above
X-class flares expected, probability $\geq 50\%$	X-class flares expected / idem as above

Unofficial terminology deduced from various SWx reports/services



Probability (%)

0-10
10-25
25-50
50-75
75-100

Terminology

Unlikely
Small chance
A chance; Possible
Likely
Very likely; Expected

This is a topic under continued improvement / discussion....

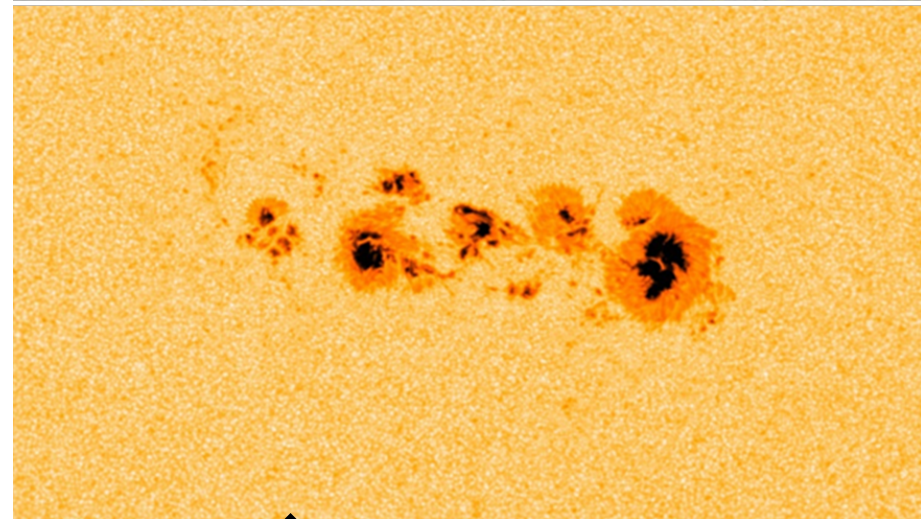
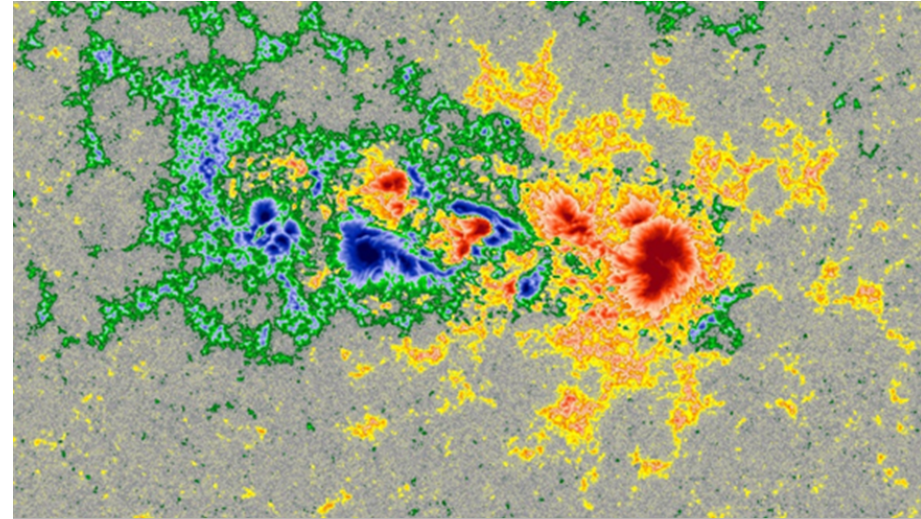




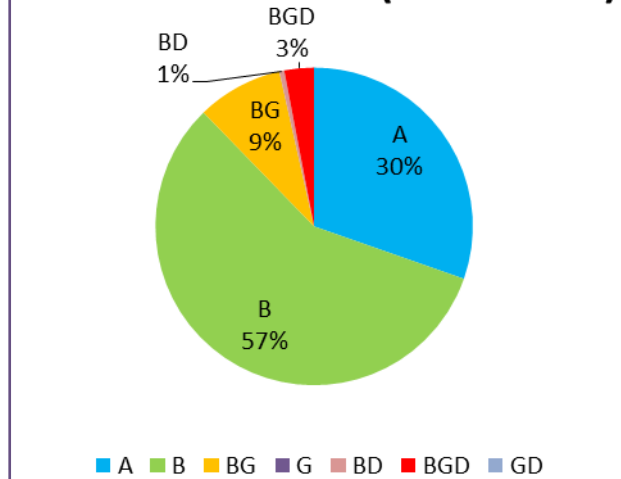
FLARE PREDICTIONS

Mount Wilson (Hale) classification

- Based on the magnetic properties of a sunspot group
- 7 options:
 - A (α)
 - B (β), BG ($\beta\gamma$), G (γ)
 - BD ($\beta\delta$), BGD ($\beta\gamma\delta$), GD ($\gamma\delta$)



Hale classification (1996-2016)



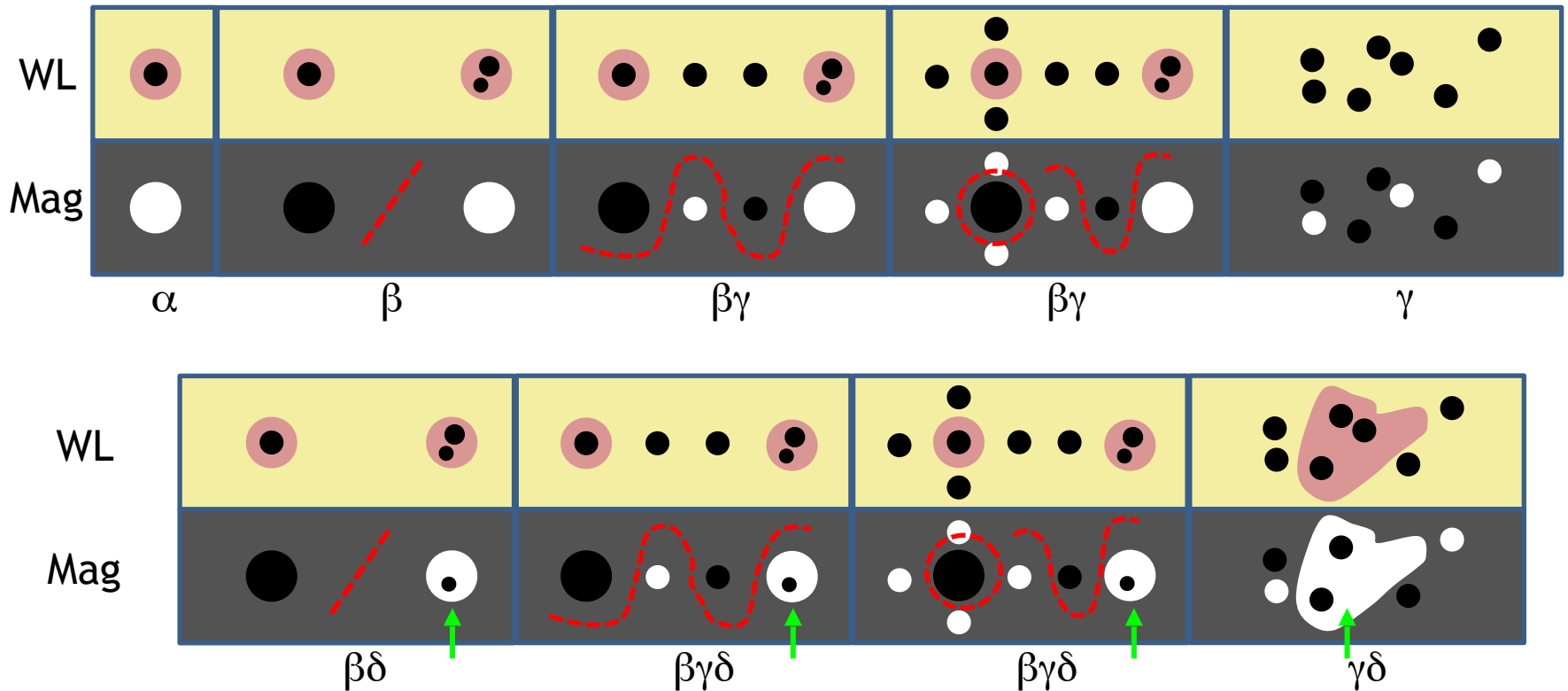
SDO/HMI





FLARE PREDICTIONS

Mount Wilson (Hale) classification - Sketches





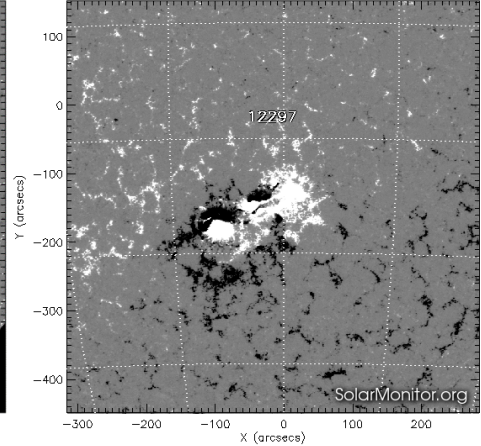
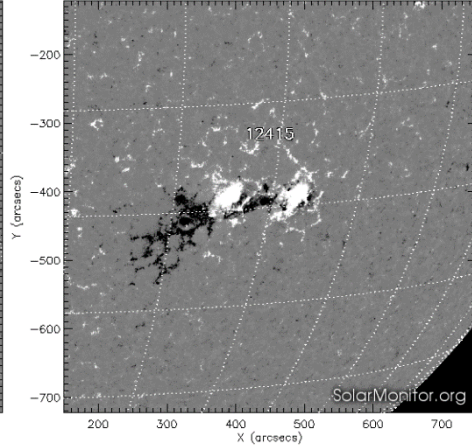
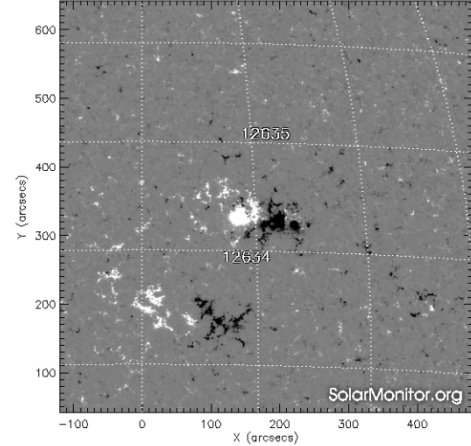
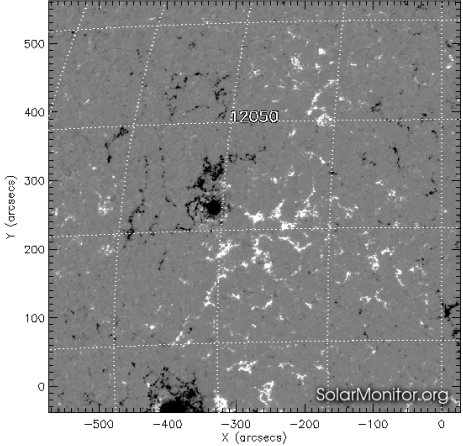
EXAMPLES OF HALE CLASSIFICATION

HMI Magnetogram 1-May-2014 22:46:21.300

HMI Magnetogram 11-Feb-2017 19:34:31.400

HMI Magnetogram 18-Sep-2015 23:10:18.800

HMI Magnetogram 12-Mar-2015 21:58:14.300

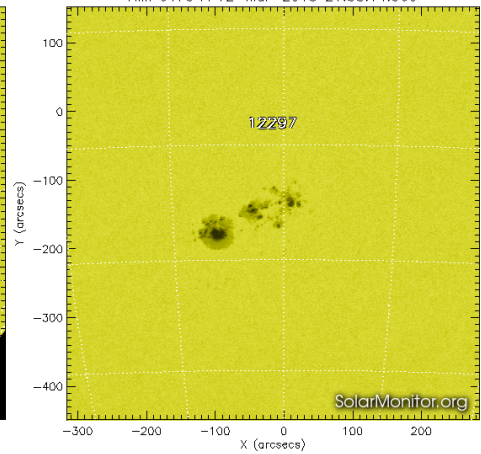
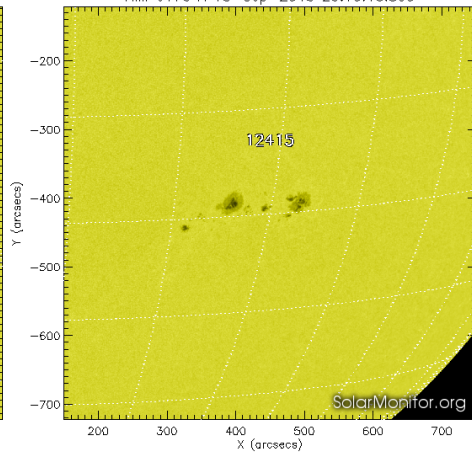
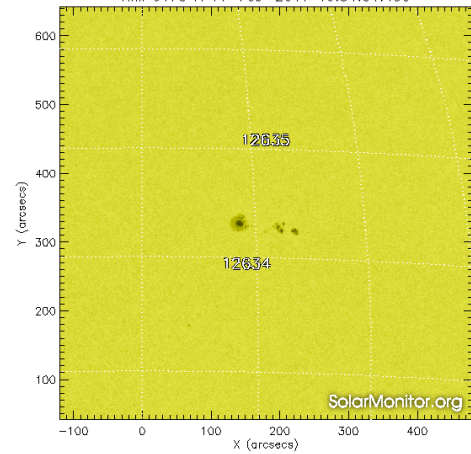
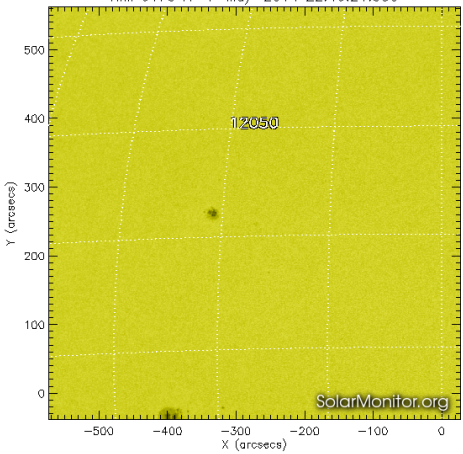


HMI 6173 Å 1-May-2014 22:46:21.300

HMI 6173 Å 11-Feb-2017 19:34:31.400

HMI 6173 Å 18-Sep-2015 23:10:18.800

HMI 6173 Å 12-Mar-2015 21:58:14.300



α

β

$\beta\gamma$

$\beta\gamma\delta$



SDO/HMI

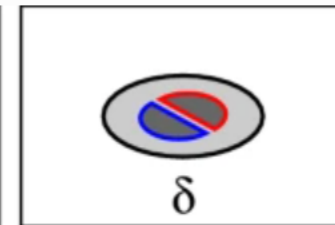
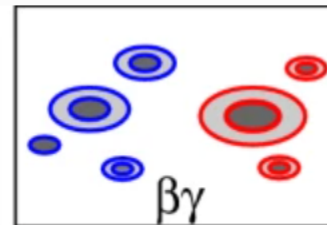
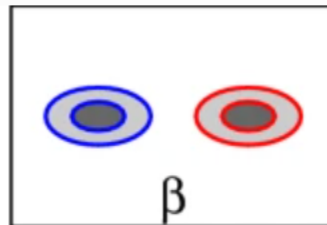
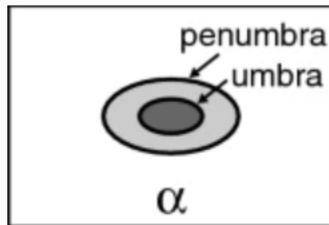
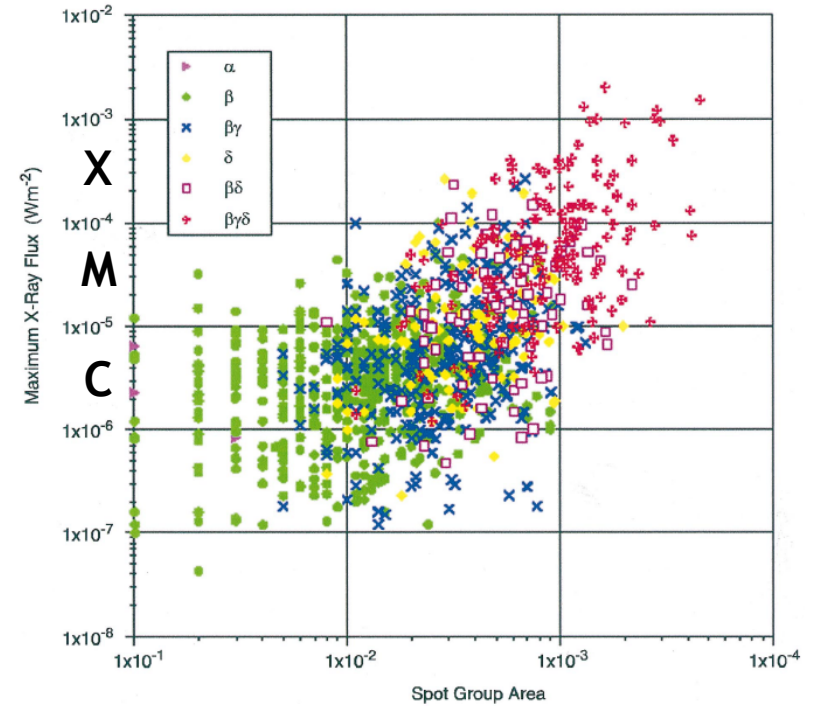
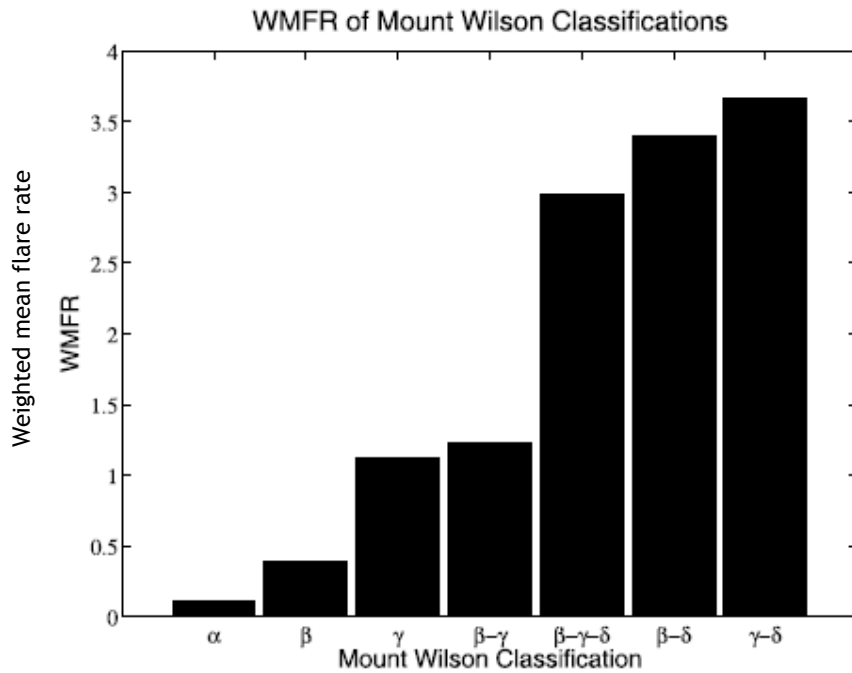




FLARE PREDICTIONS

2000

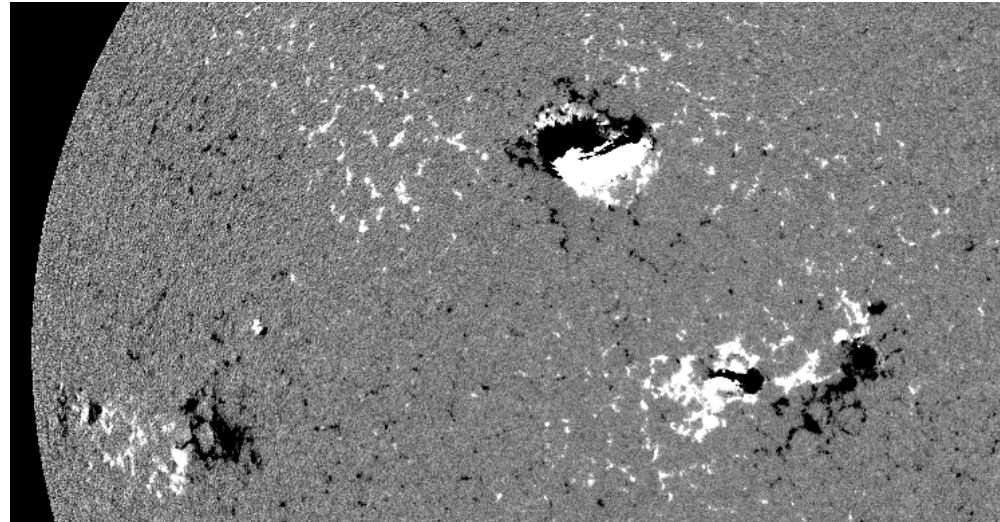
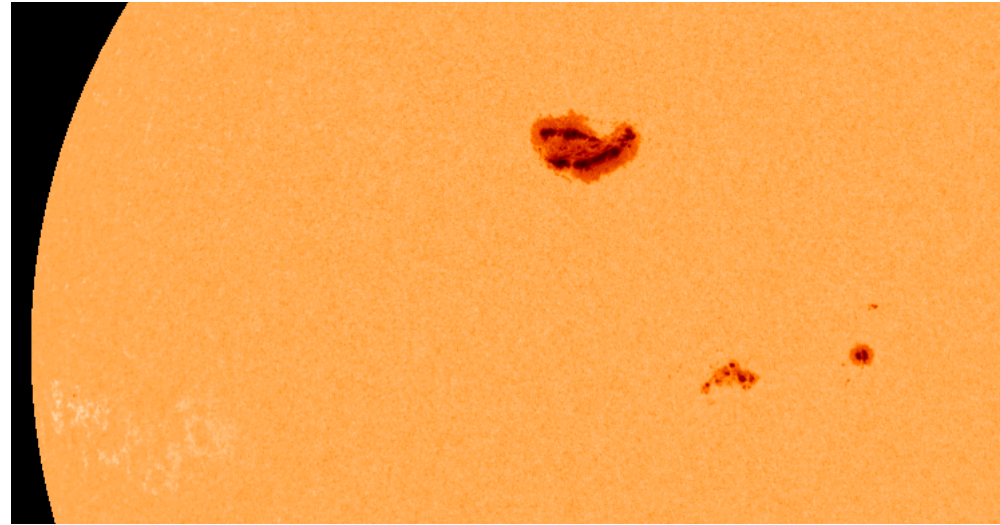
RELATION BETWEEN δ SPOTS AND LARGE FLARES





FLARE PREDICTIONS

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





Finding your way in the URSIgram

```

:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#

```

```

SIDC URSIGRAM 30318
SIDC SOLAR BULLETIN 18 Mar 2023, 1230UT
SIDC FORECAST (valid from 1230UT, 18 Mar 2023 until 20 Mar 2023)

```

SOLAR FLARES : C-class flares expected, (probability >=50%)

GEOMAGNETISM : Quiet (A<20 and K<4)

SOLAR PROTONS : Quiet

PREDICTIONS FOR 18 Mar 2023 10CM FLUX: 138 / AP: 007

PREDICTIONS FOR 19 Mar 2023 10CM FLUX: 140 / AP: 019

PREDICTIONS FOR 20 Mar 2023 10CM FLUX: 138 / AP: 029

COMMENT: The solar flaring activity was at moderate levels during the last 24 hours with one M-class flare and several C-class flares detected, with the most frequent sources being NOAA active regions 3254 and 3256. The largest flare was a M1.1 flare, peaking at 15:07 UTC on March 17, associated with active region NOAA 3254 (beta class). NOAA active region 3256 produced an impulsive C9.4 flare at 07:10 UTC on March 18. This event was also associated with Type IV radio emission. Other regions on the disc did not show any significant flaring activity. Further M-class flare activity is possible but not probable, while frequently C-class activity is expected in the next 24 hours.

A filament eruption in the southwestern quadrant was observed on March 17 from around 09:20UTC. The associated CME appears in SoHO/LASCO C2 coronagraph data from 10:23UTC onwards. The CME is directed to the south-west and the bulk of the CME is not expected to be Earth directed. However, a glancing blow of the shock may impact Earth at around 19:00 UTC on March 19. Another small filament eruptions occurred in the northwestern quadrant from around 17:09UTC and 20:09UTC on March 17. We are awaiting corresponding coronagraph data for further analysis. During the last 24 hours there were no other potentially Earth-directed CMEs detected in the available coronagraph observations.

The greater than 10 MeV proton flux was at almost nominal levels over the past 24 hours and is expected to remain so for the next 24 hours. The greater than 2 MeV electron flux remained below the 1000 pfu alert threshold and is expected to remain below this threshold during the next 24 hours. The 24h electron fluence was at normal levels and is expected to remain so.

Over the past 24 hours the solar wind parameters (ACE and DSCOVR) have been indicative of slow solar wind conditions. The solar wind speed ranged between 400 km/s and 450 km/s. The interplanetary magnetic field magnitude was about 6 nT. The magnetic field orientation was predominantly in the positive sector (field directed away from the Sun). Similar slow solar wind regime is expected on March 18 with a slight wind speed enhancement possible for late on March 19, due to expected influence of the small equatorial coronal hole of positive polarity with a chance of being mixed with glancing blow from a CME which left the solar surface around 10 UTC on March 17th.

The geomagnetic conditions over the past 24 hours were globally and locally quiet to unsettled (NOAA Kp and K Bel 1-3). Quiet conditions are expected for March 18 with active to minor storm conditions possible for late on March 19 and March 20, due to expected arrival of the high speed stream and a possible glancing blow from a CME.

TODAY'S ESTIMATED ISN : 044, BASED ON 14 STATIONS.

SOLAR INDICES FOR 17 Mar 2023

- WOLF NUMBER CATANIA : 110
- 10CM SOLAR FLUX : 134
- AK CHAMBON LA FORET : 014
- AK WINGST : 007
- ESTIMATED AP : 007
- ESTIMATED ISN : 073, BASED ON 18 STATIONS.

Flare prediction

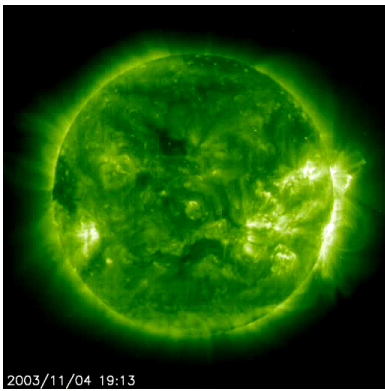
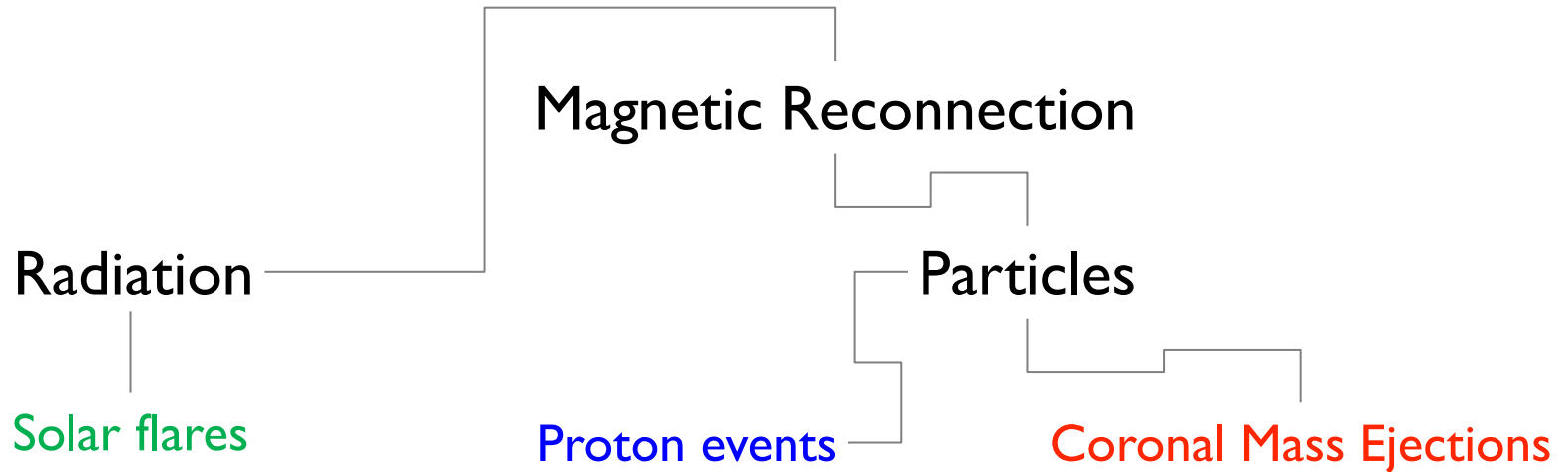
NOTICEABLE EVENTS SUMMARY

DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM	Catania/NOAA	RADIO_BURST_TYPES
17	1504	1507	1511	S22W65	M1.0	SN			12/3247

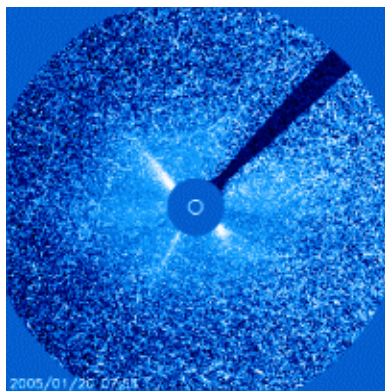
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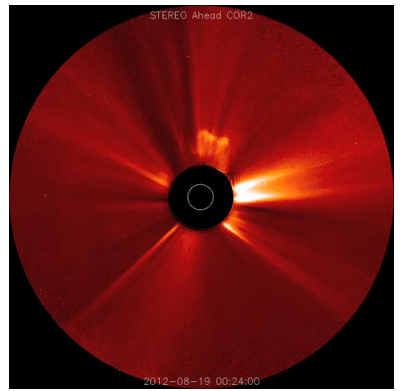
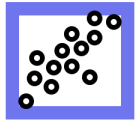
SOLAR ERUPTIONS



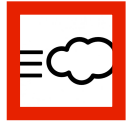
SOHO/EIT



SOHO/LASCO



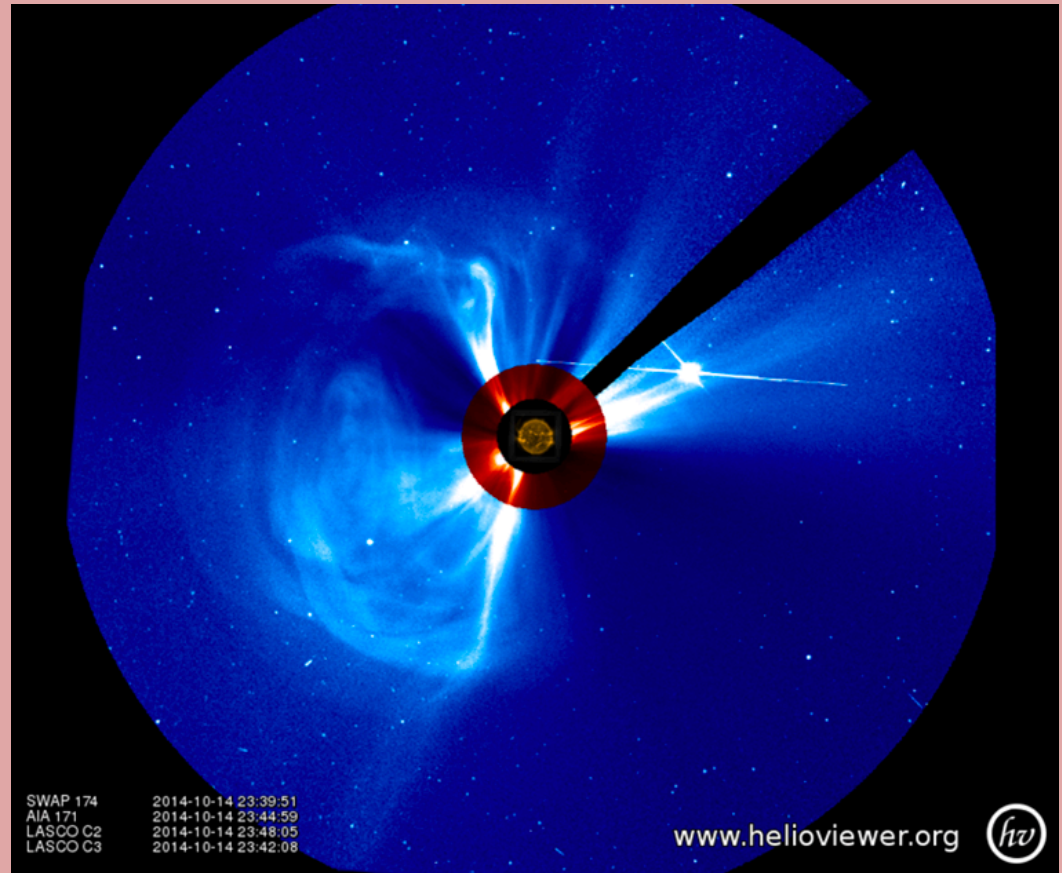
SOHO/LASCO





CME - OVERVIEW

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



PROBA2/SWAP
SDO/AIA
SOHO/LASCO





CORONAL MASS EJECTION

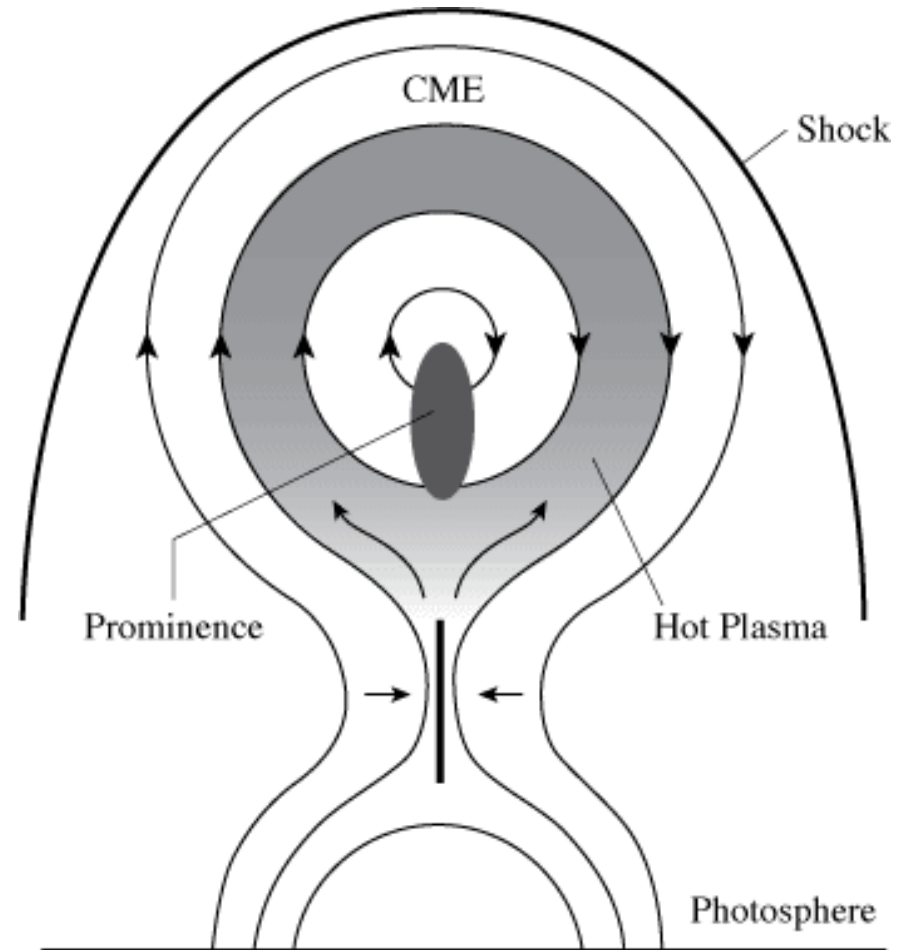
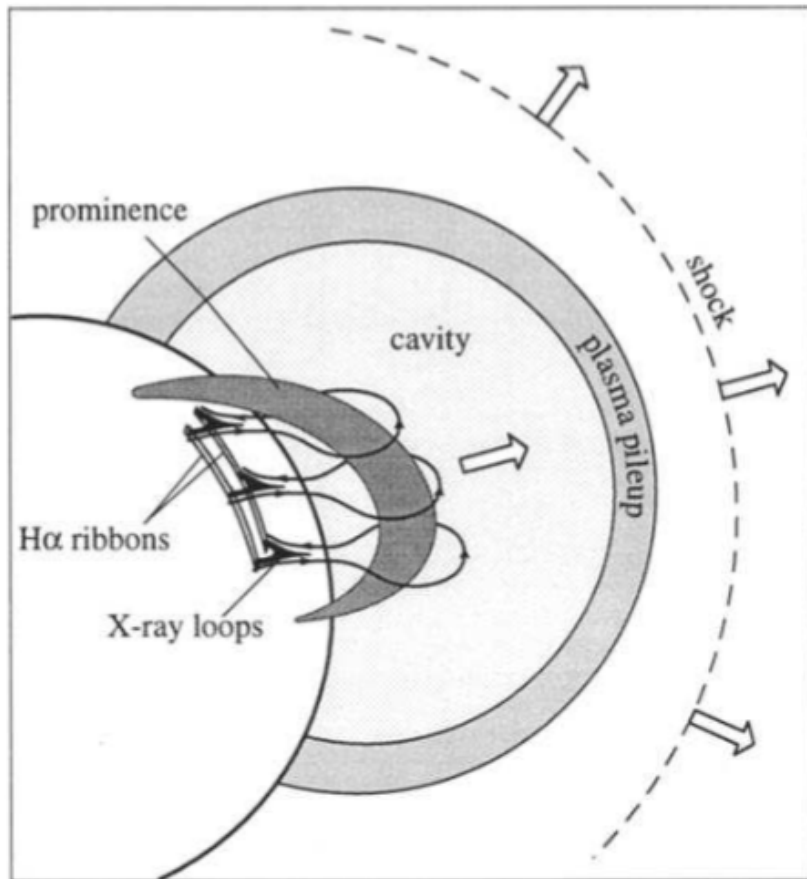


Figure 3. Schematic diagram showing the relationship between various features associated with a CME. The shaded region labeled “plasma pileup” refers to the outer circular arc seen in coronagraphs.



CME SKETCH

Step 2: Expanding flux rope evolving into a CME

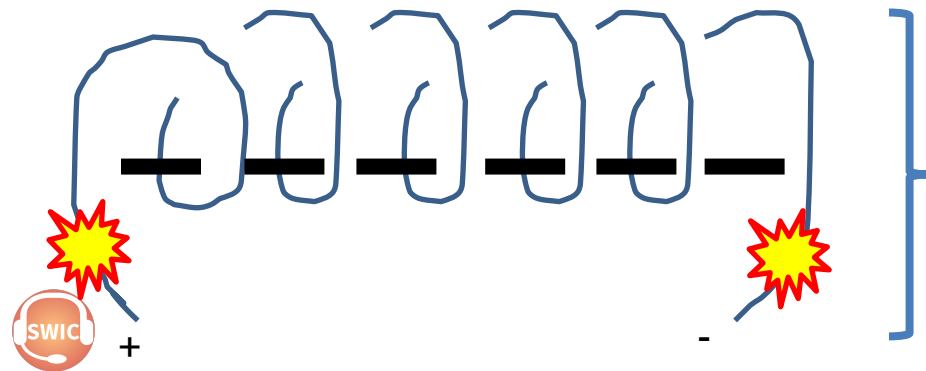
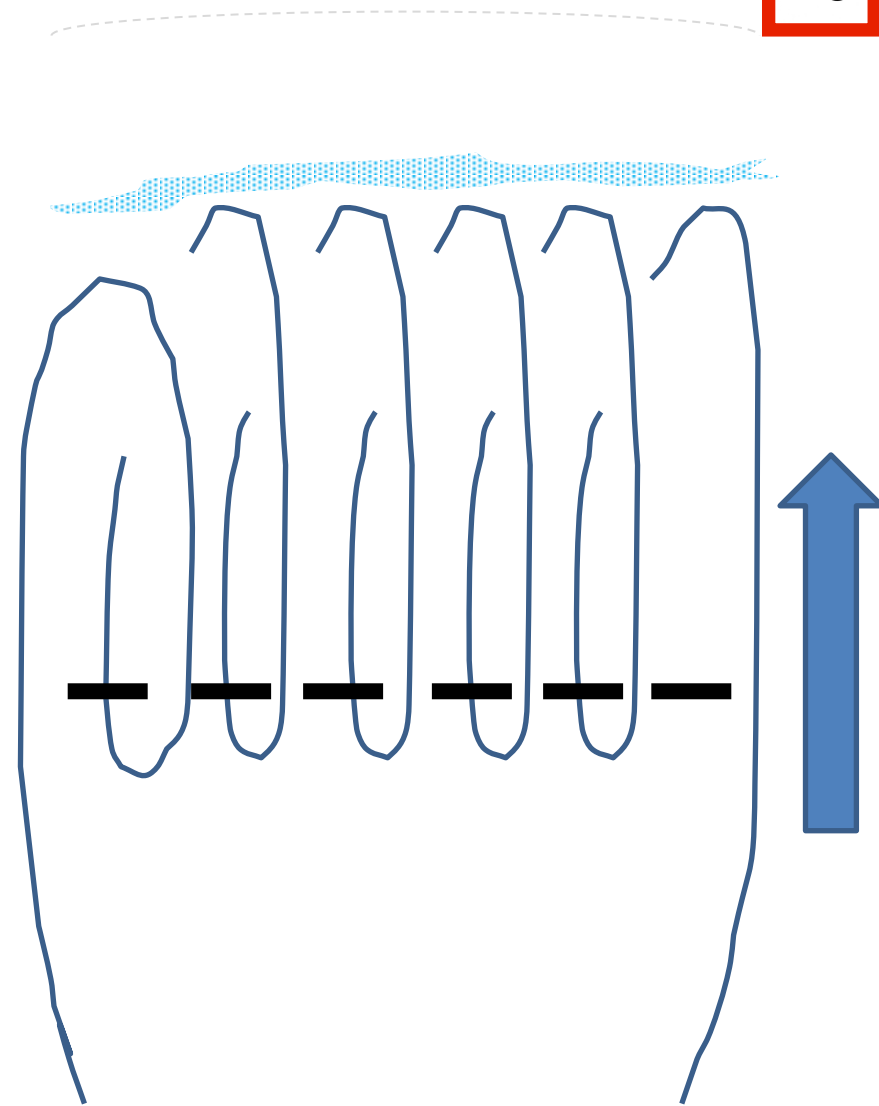
Shock

Plasma pile-up

Cavity

Core filament

Flanks



Step 1: Magnetic flux rope at magnetic reconnection

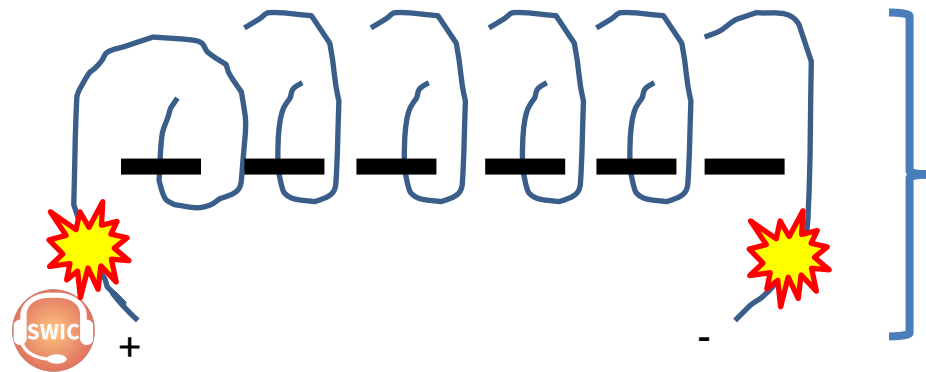
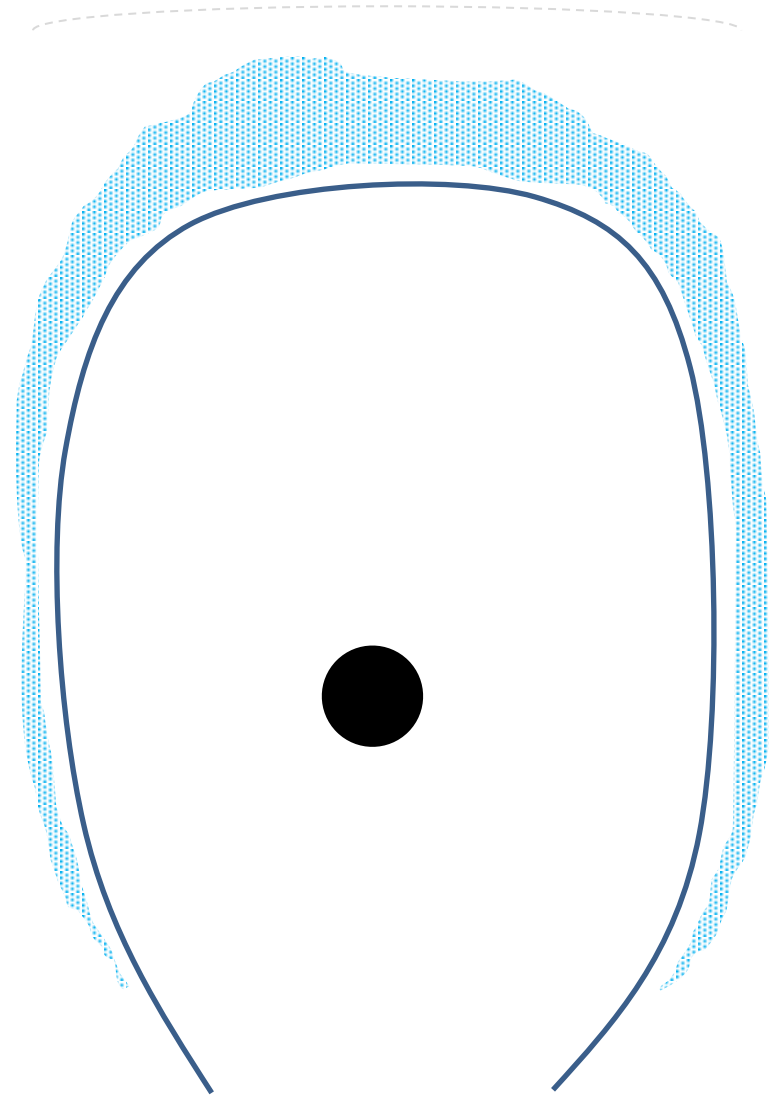




CME SKETCH

Step 2: Expanding flux rope evolving into a CME

Shock
Plasma pile-up
Cavity
Core filament
Flanks

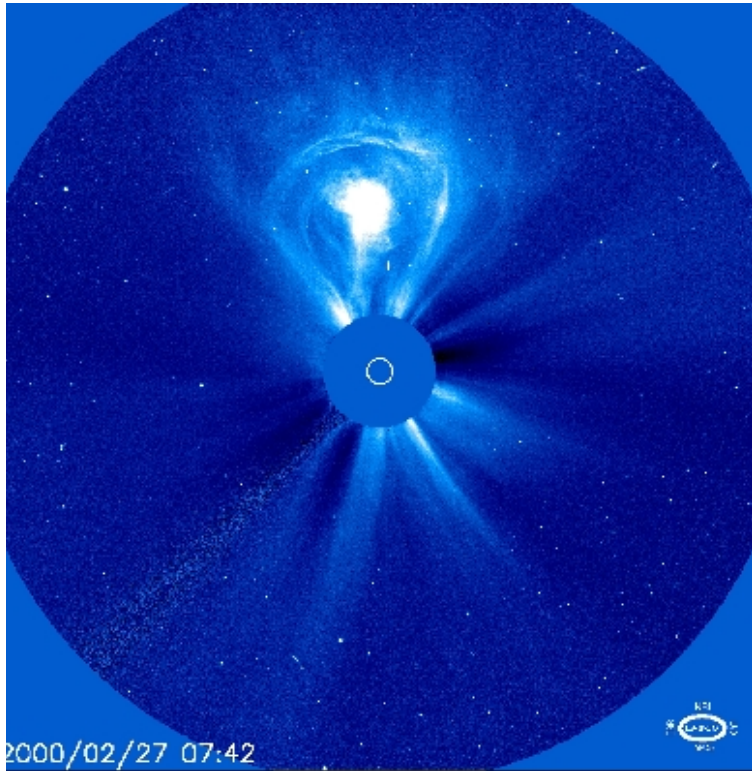


Step 1: Magnetic flux rope at magnetic reconnection

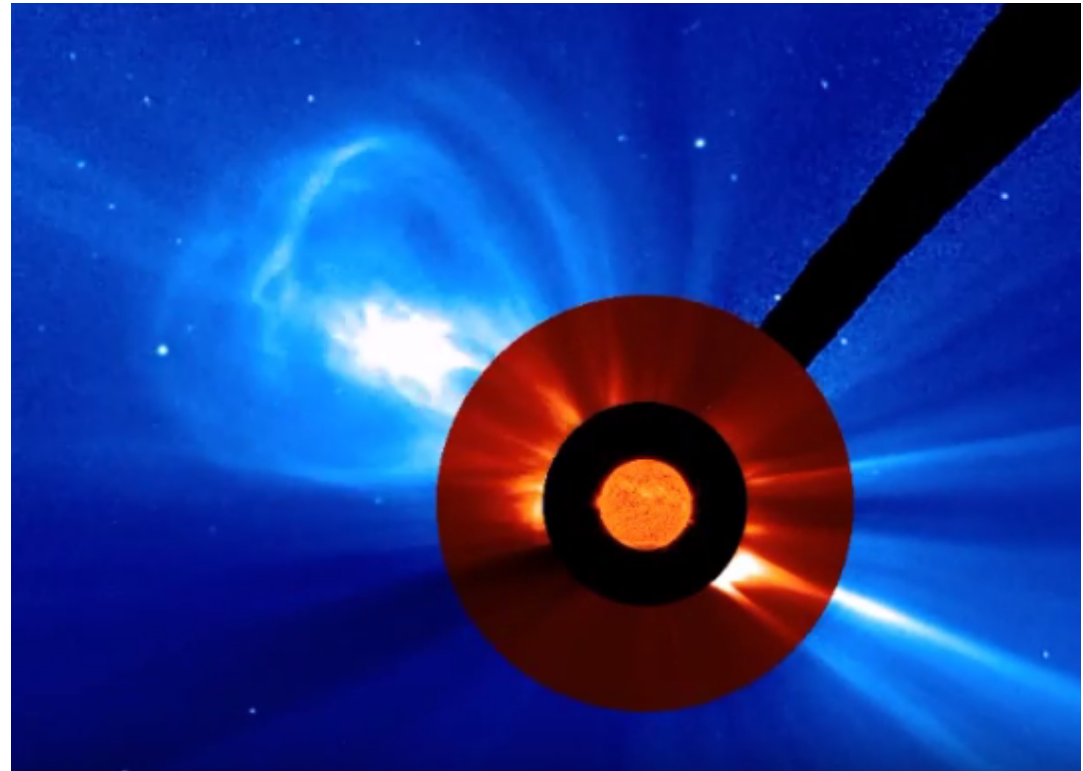




CORONAL MASS EJECTION

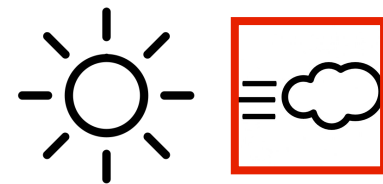


SOHO/LASCO



SDO/AIA
SOHO/LASCO

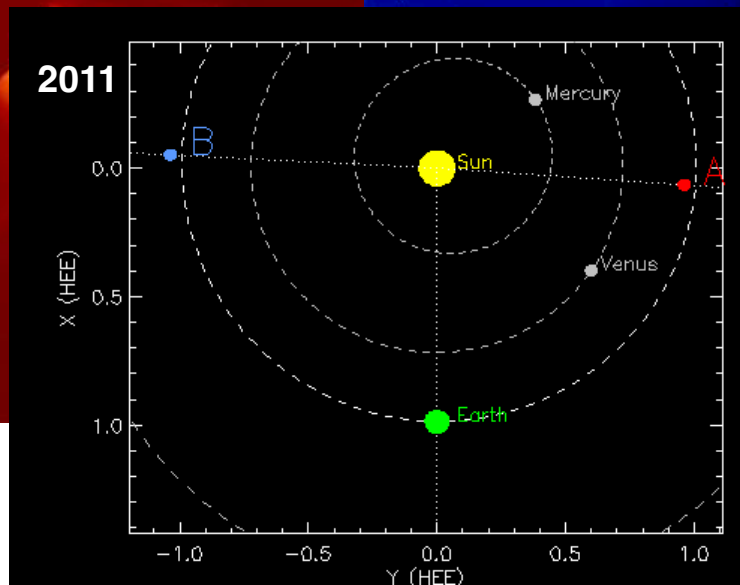
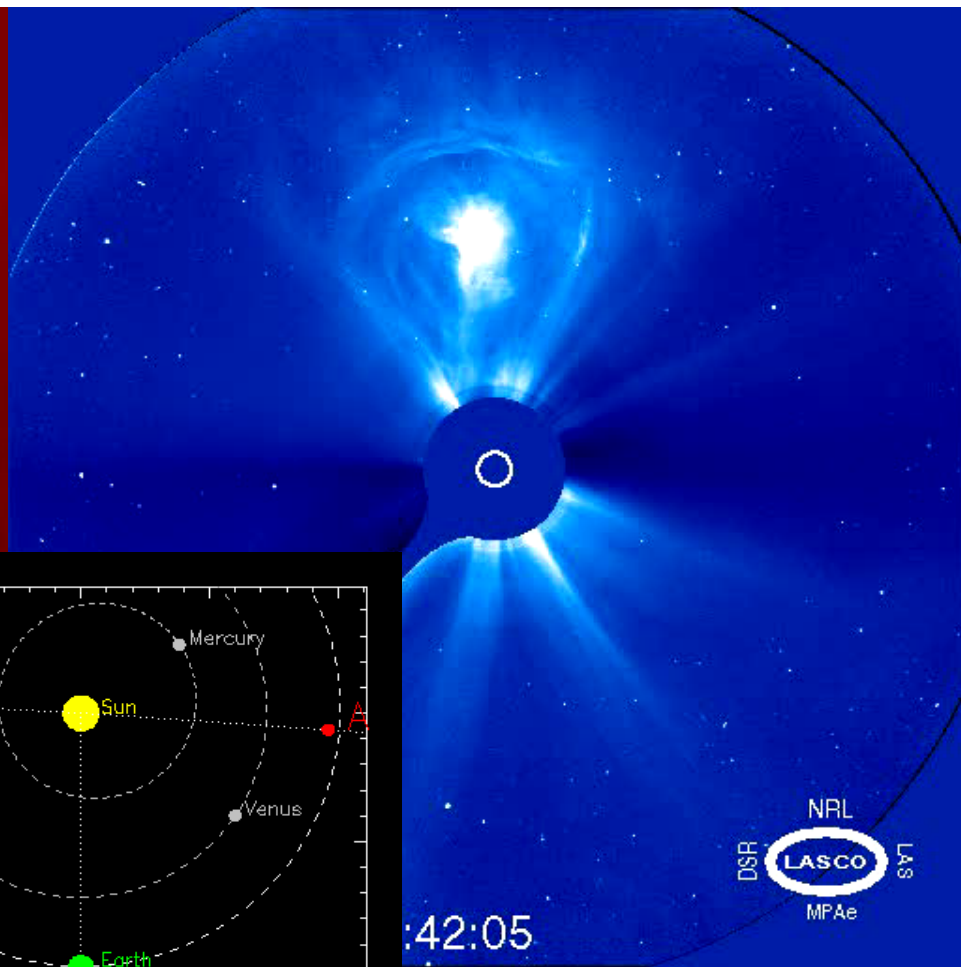
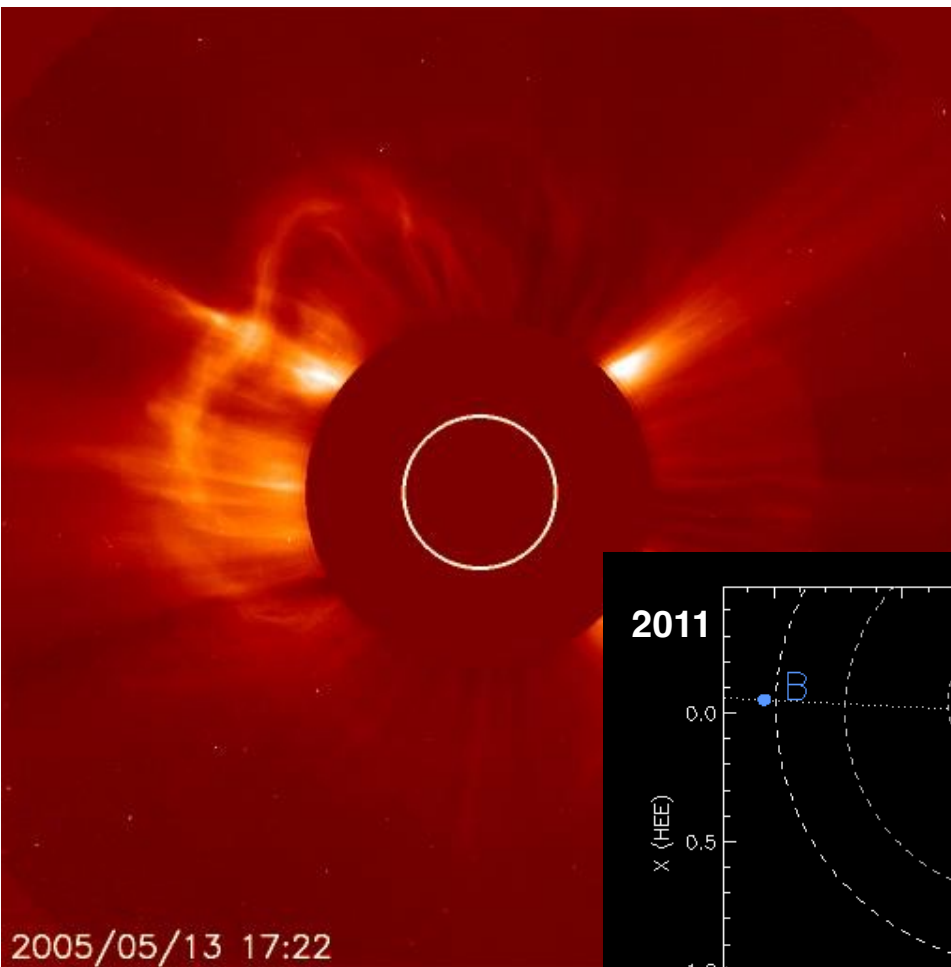




PLASMA CLOUDS

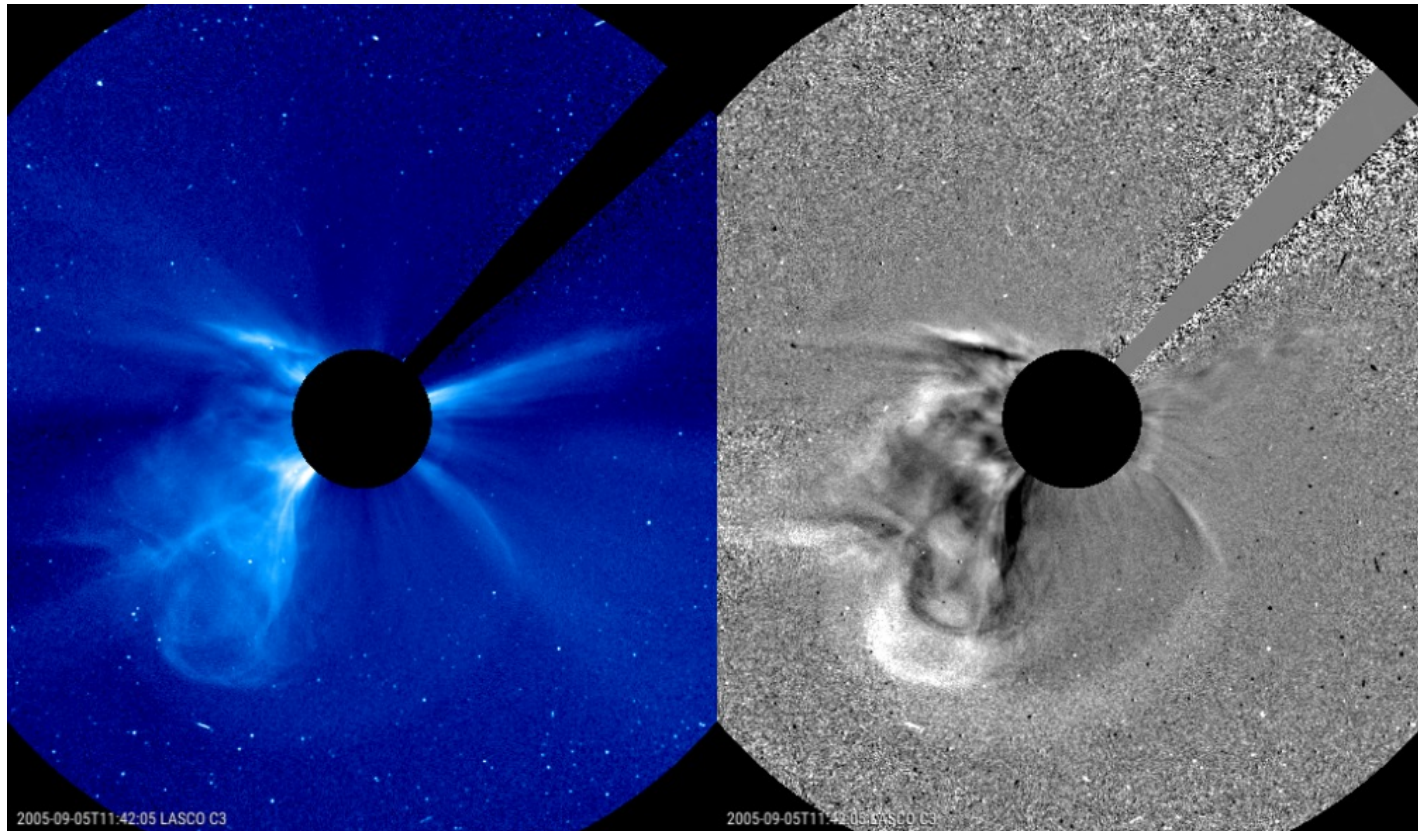
SOHO/LASCO C2

SOHO/LASCO C3





DIFFERENCE IMAGES



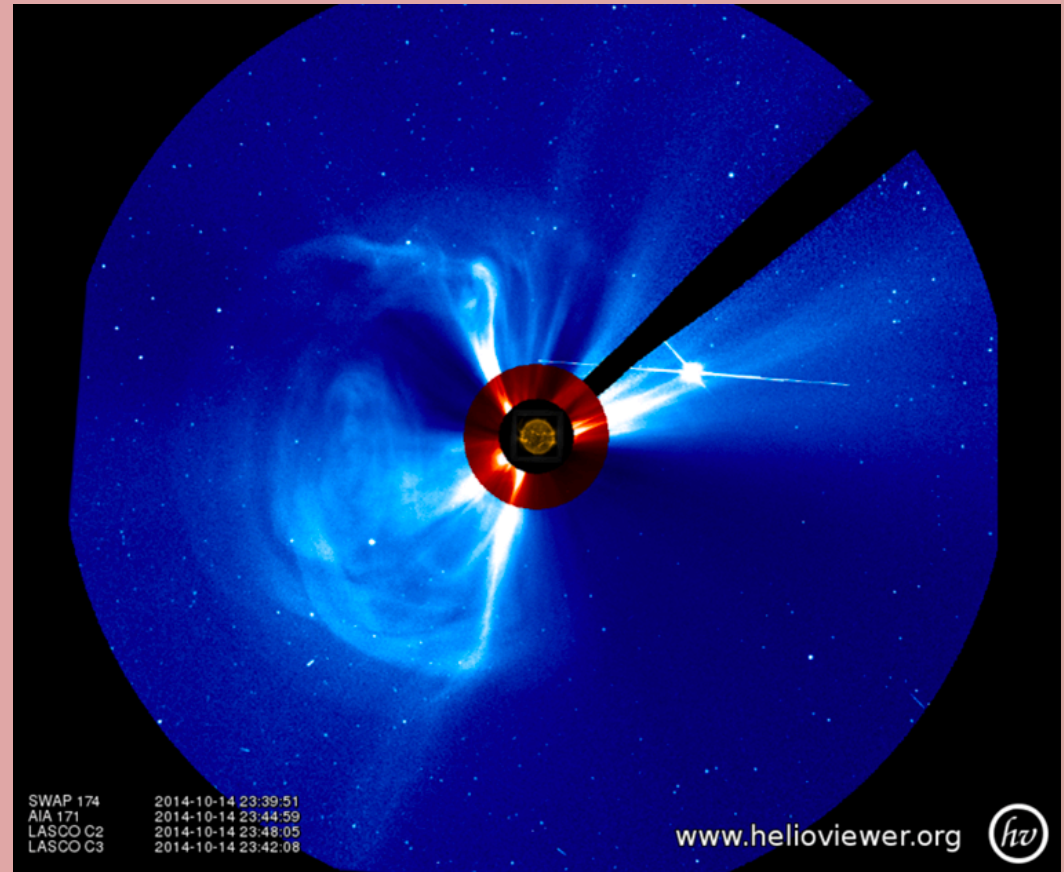
SOHO/LASCO





CME - OVERVIEW

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



PROBA2/SWAP
SDO/AIA
SOHO/LASCO





FILAMENTS & PROMINENCES

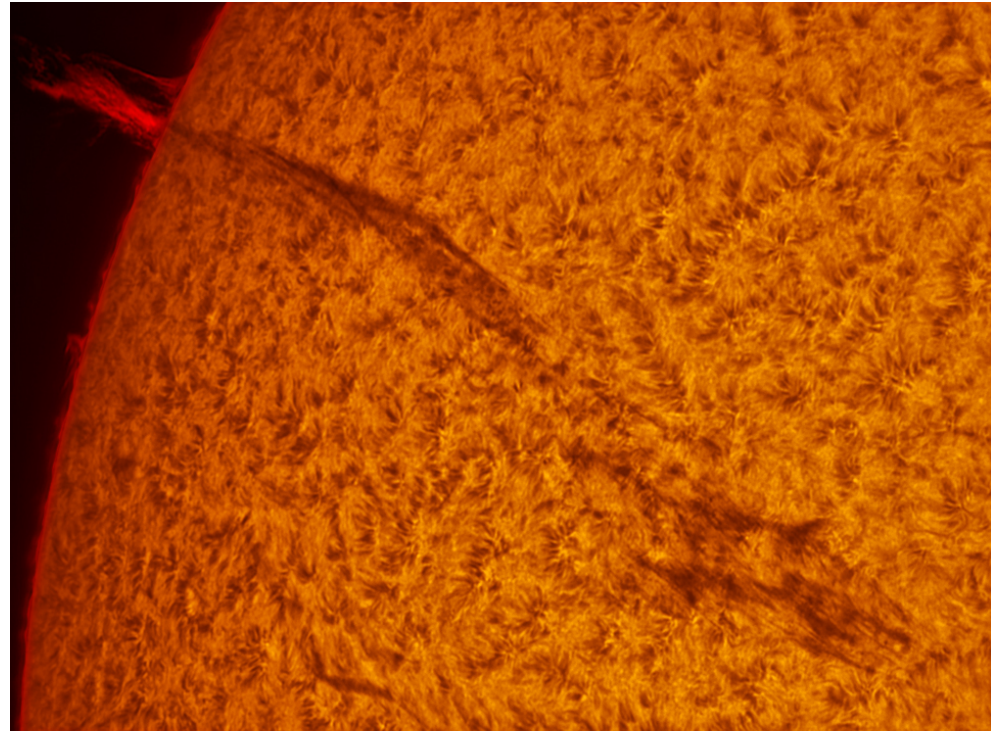
Chromospheric features

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

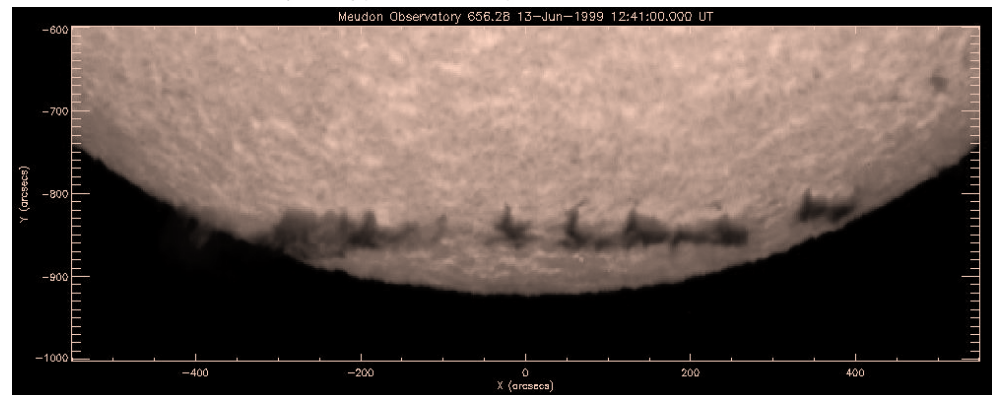
Mark the transition between positive and negative magnetic areas
Appear all over solar disk

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





FILAMENTS & PROMINENCES

1120

A.G. Tlatov *et al.*

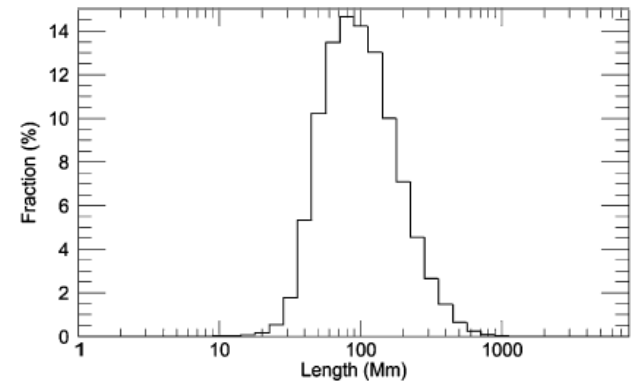
Quiescent

- Not associated to AR
- Weeks to months

Length

- Long filaments ($> 15^\circ$)
- 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 : CI-MI

Figure 4 Distribution of the filament length in a logarithmic scale. The relative number of filaments is given as a function of their length in Mm.



R. Mawad et al. / Advances in Space Research 55 (2015) 696–704

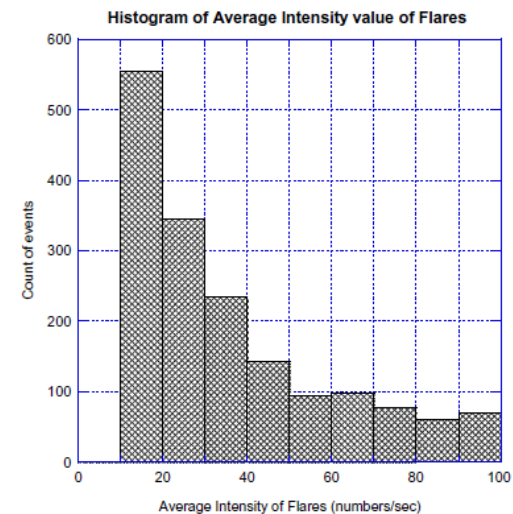


Fig. 6. Histogram of intensity of solar flares which are occurred during duration time of filament disappearance event during 1996–2010.





FILAMENT/PROMINENCE ERUPTIONS

Height

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

Other signs

- Darkening filament
- Change in tilt or length

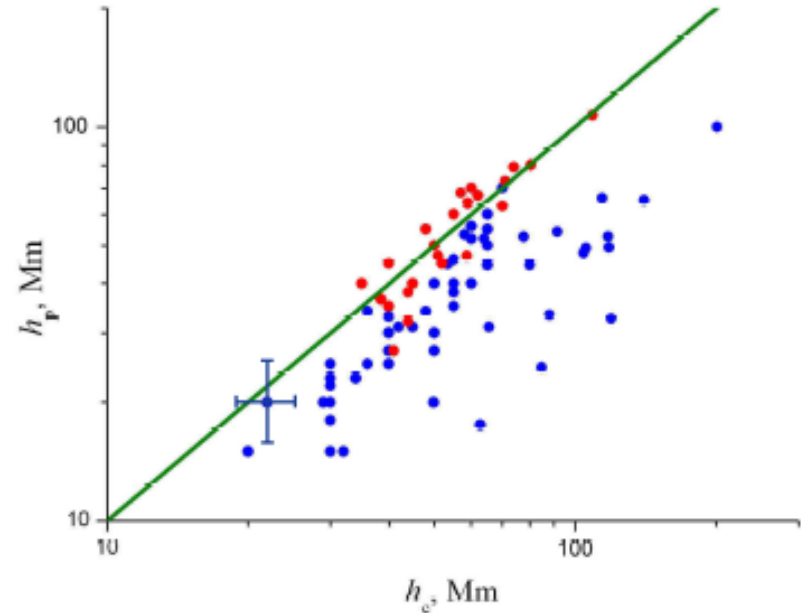
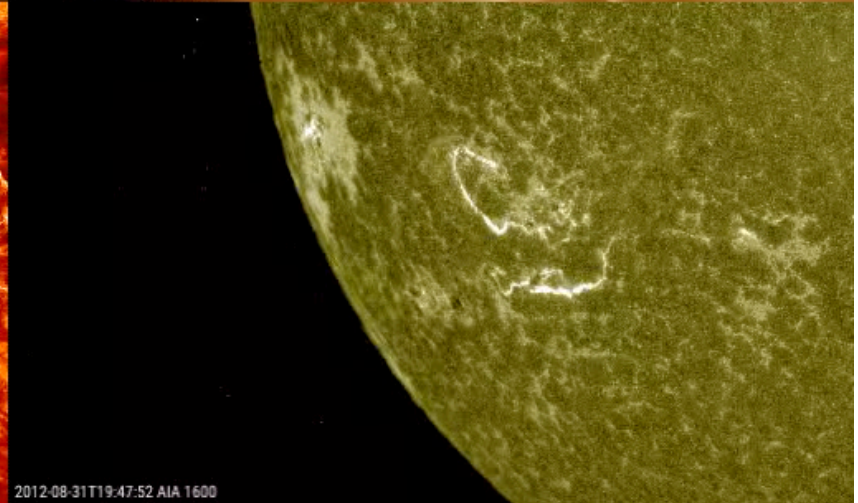
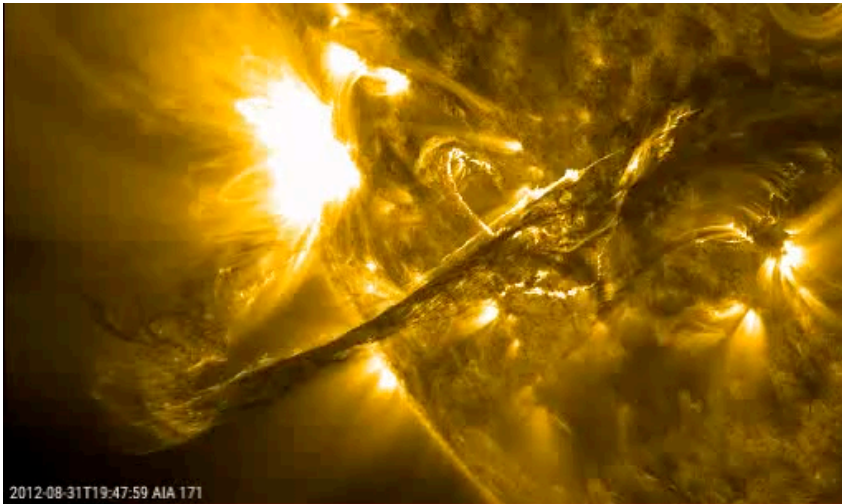


Fig. 7. The observed filament height above the chromosphere h_p versus the critical height of stable filament equilibrium h_c . The blue circles correspond to the filaments which safely passed the west limb. The red circles correspond to the filaments which disappeared from the disk. The straight green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



FILAMENT ERUPTION



SDO/AIA





```

:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#

```

```

SIDC URSIGRAM 30318
SIDC SOLAR BULLETIN 18 Mar 2023, 1230UT
SIDC FORECAST (valid from 1230UT, 18 Mar 2023 until 20 Mar 2023)
SOLAR FLARES : C-class flares expected, (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 18 Mar 2023 10CM FLUX: 138 / AP: 007
PREDICTIONS FOR 19 Mar 2023 10CM FLUX: 140 / AP: 019
PREDICTIONS FOR 20 Mar 2023 10CM FLUX: 138 / AP: 029

```

COMMENT: The solar flaring activity was at moderate levels during the last 24 hours with one M-class flare and several C-class flares detected, with the most frequent sources being NOAA active regions 3254 and 3256. The largest flare was a M1.1 flare, peaking at 15:07 UTC on March 17, associated with active region NOAA 3254 (beta class). NOAA active region 3256 produced an impulsive C9.4 flare at 07:10 UTC on March 18. This event was also associated with Type IV radio emission. Other regions on the disc did not show any significant flaring activity. Further M-class flare activity is possible but not probable, while frequently C-class activity is expected in the next 24 hours.

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The geomagnetic conditions over the past 24 hours were globally and locally quiet to unsettled (NOAA Kp and K Bel 1-3). Quiet conditions are expected for March 18 with active to minor storm conditions possible for late on March 19 and March 20, due to expected arrival of the high speed stream and a possible glancing blow from a CME.

```

TODAY'S ESTIMATED ISN : 044, BASED ON 14 STATIONS.

SOLAR INDICES FOR 17 Mar 2023
WOLF NUMBER CATANIA : 110
10CM SOLAR FLUX : 134
AK CHAMBON LA FORET : 014
AK WINGST : 007
ESTIMATED AP : 007
ESTIMATED ISN : 073, BASED ON 18 STATIONS.

```

filaments / prominences

```

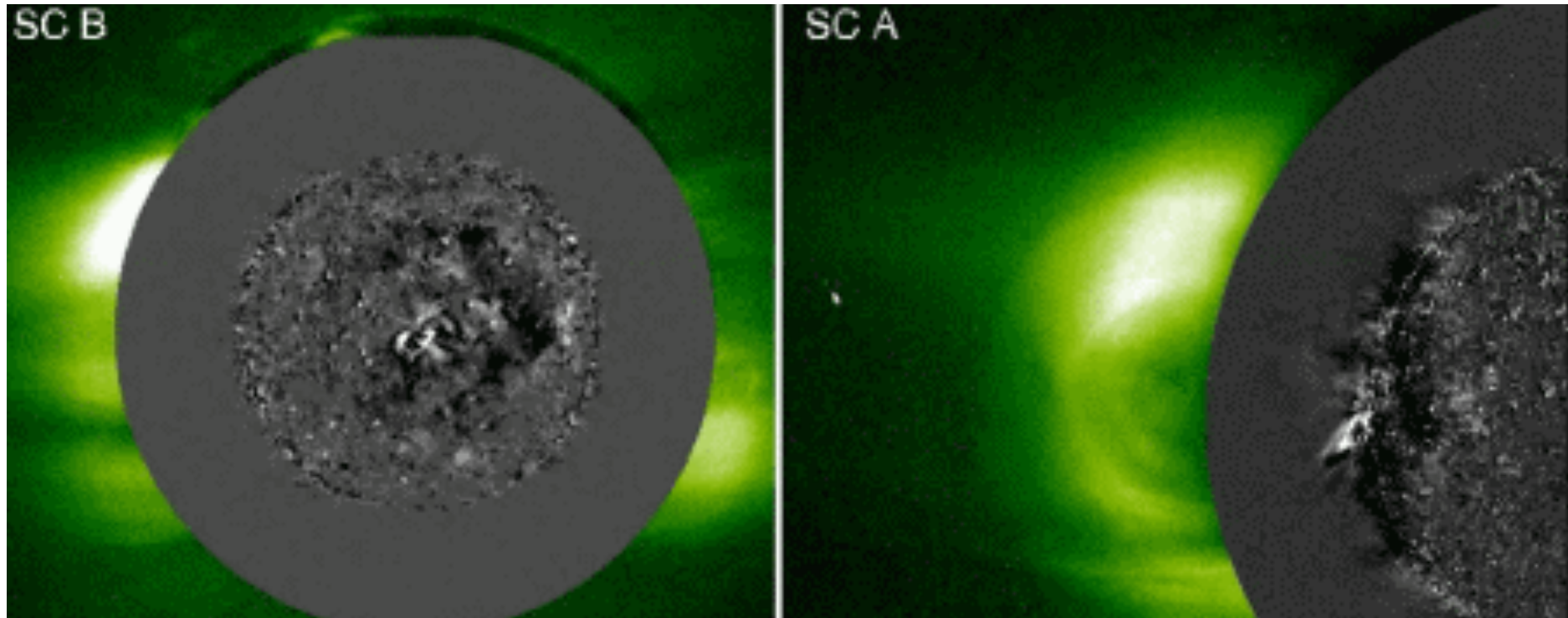
NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
17 1504 1507 1511 S22W65 M1.0 SN 12/3247
END

```





EIT WAVE



STEREO/EUVI & COR1

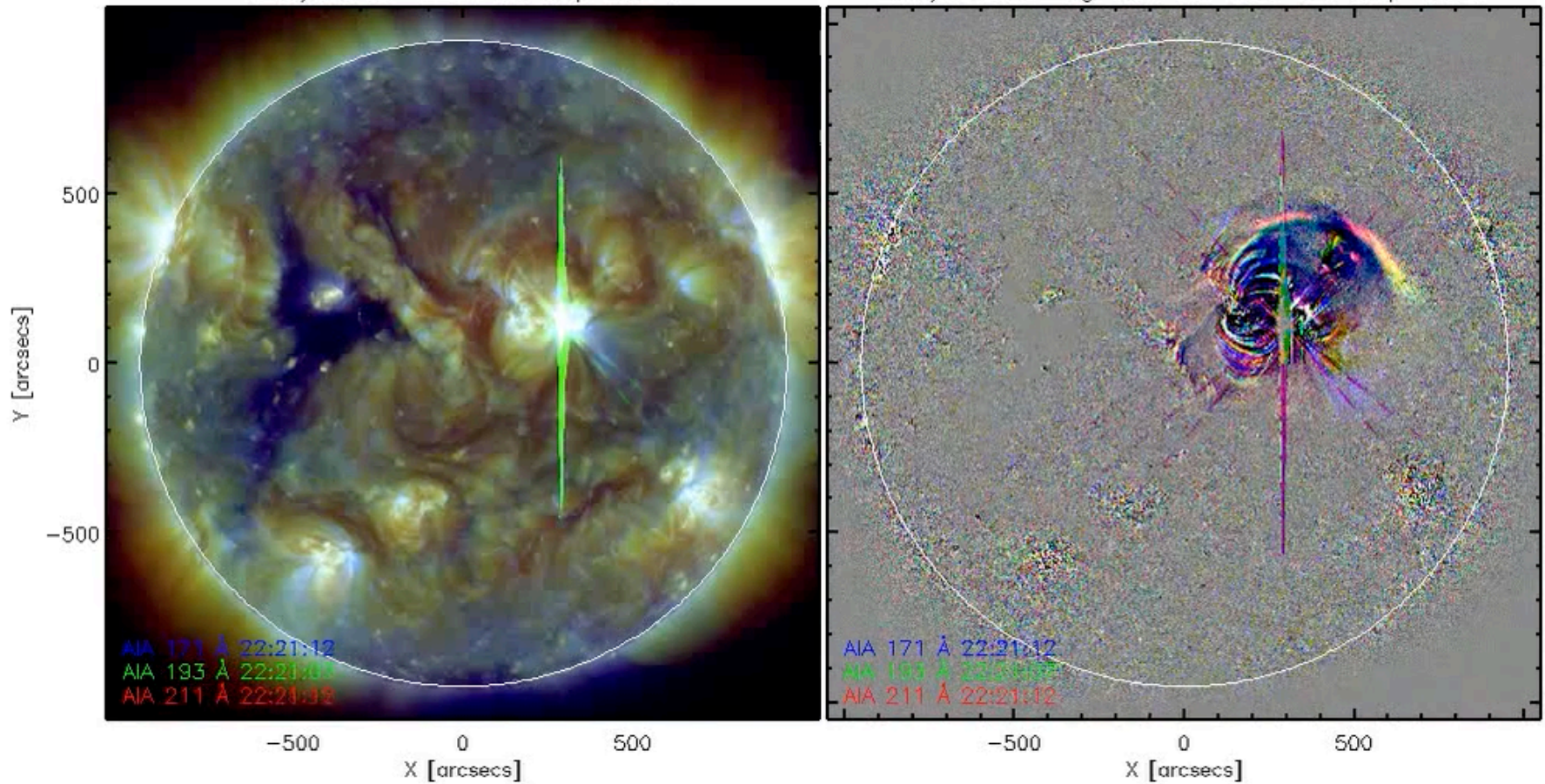




EUV WAVE

SDO/AIA Tri-Color 06-Sep-2011

SDO/AIA Running-Diff. Tri-Color 06-Sep-2011

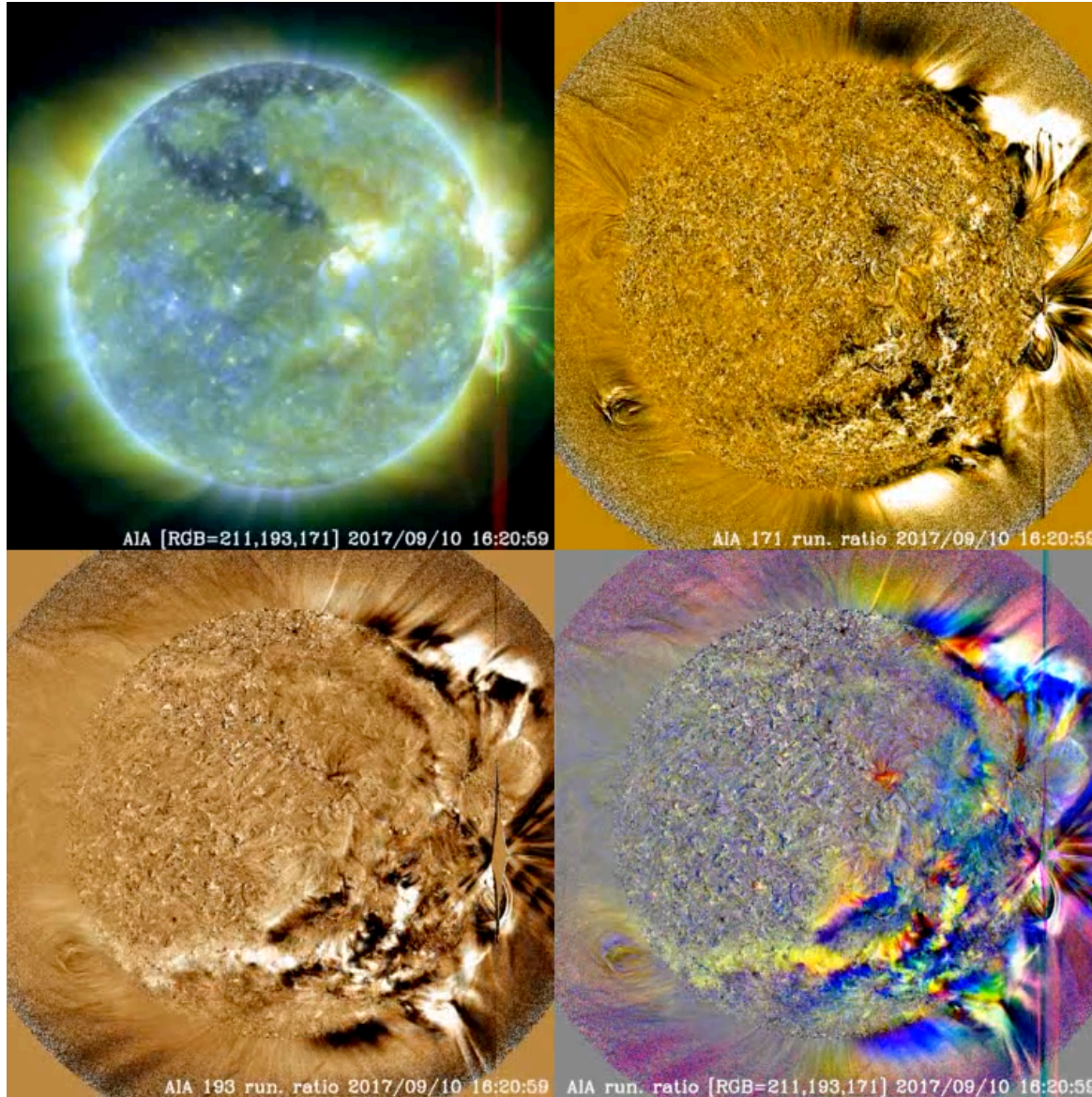


SDO/AIA





GLOBAL EUV WAVE

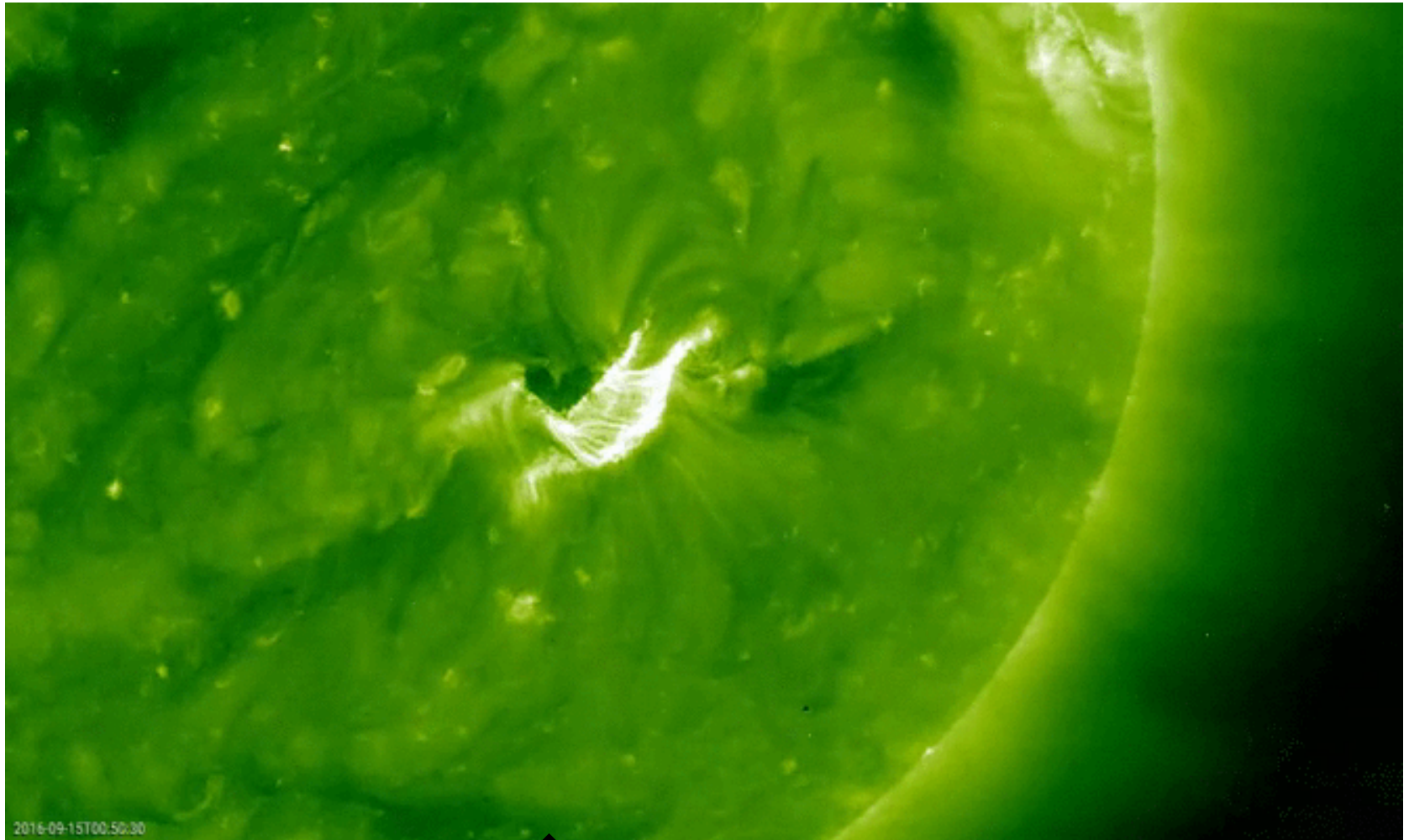


SDO/AIA





CORONAL DIMMING ~~(TRANSIENT CORONAL HOLE)~~



STEREO/EUVI





POST-ERUPTION CORONAL LOOPS



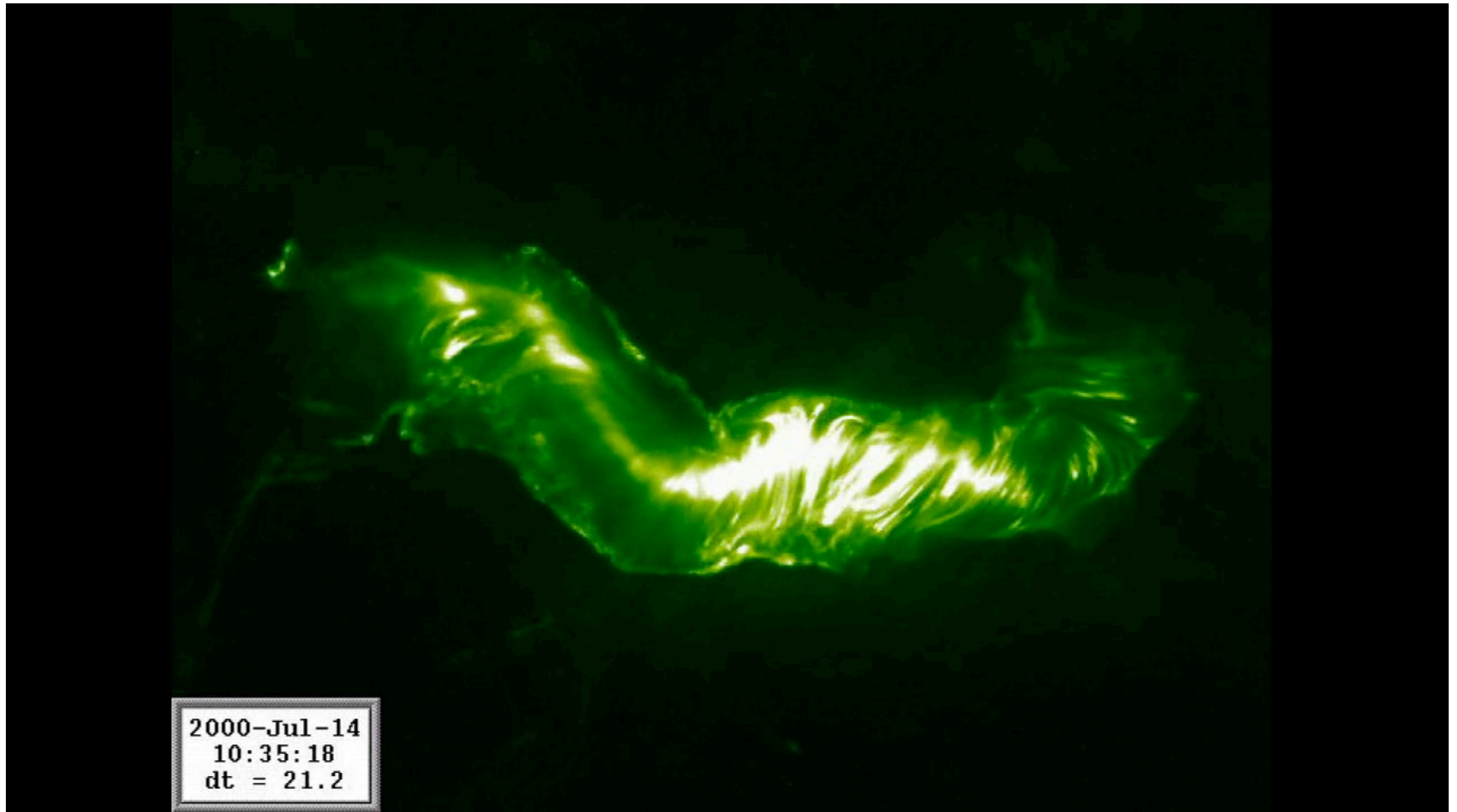
PROBA2/SWAP



SDO/AIA



POST-ERUPTION CORONAL LOOPS POST-ERUPTION ARCADE



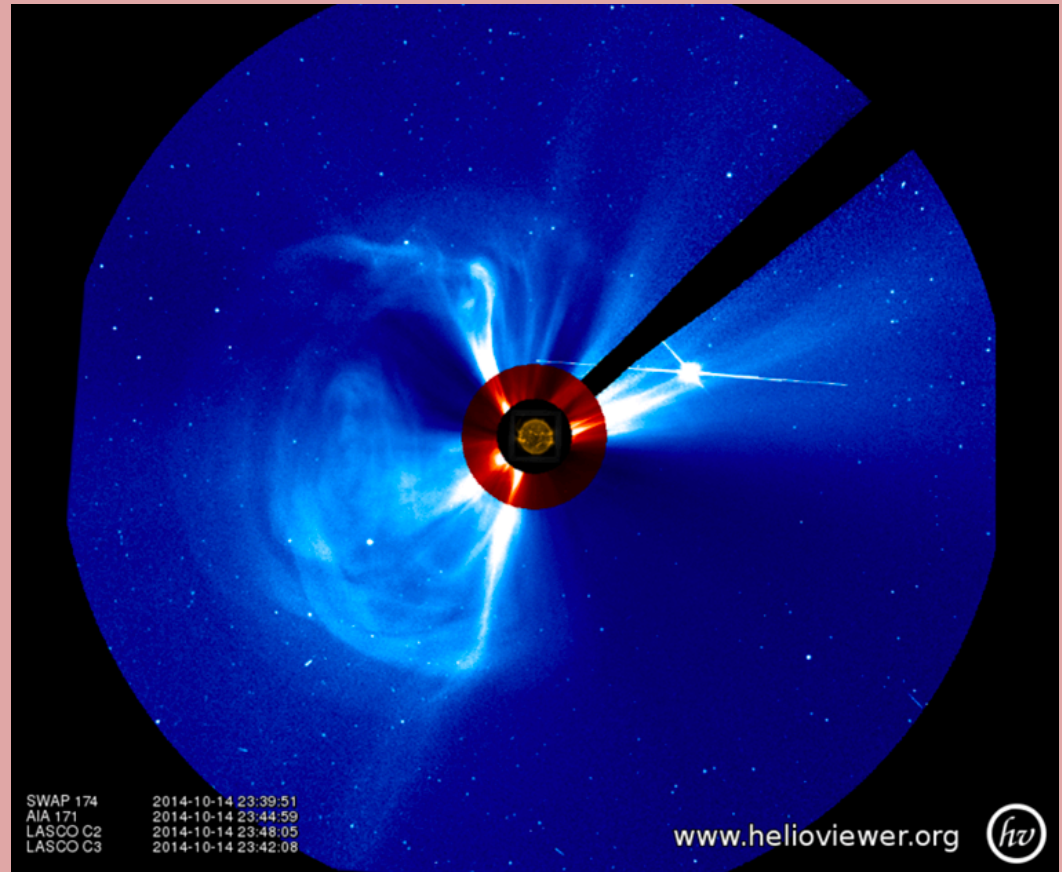
SOHO/EIT





CME - OVERVIEW

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



PROBA2/SWAP
SDO/AIA
SOHO/LASCO

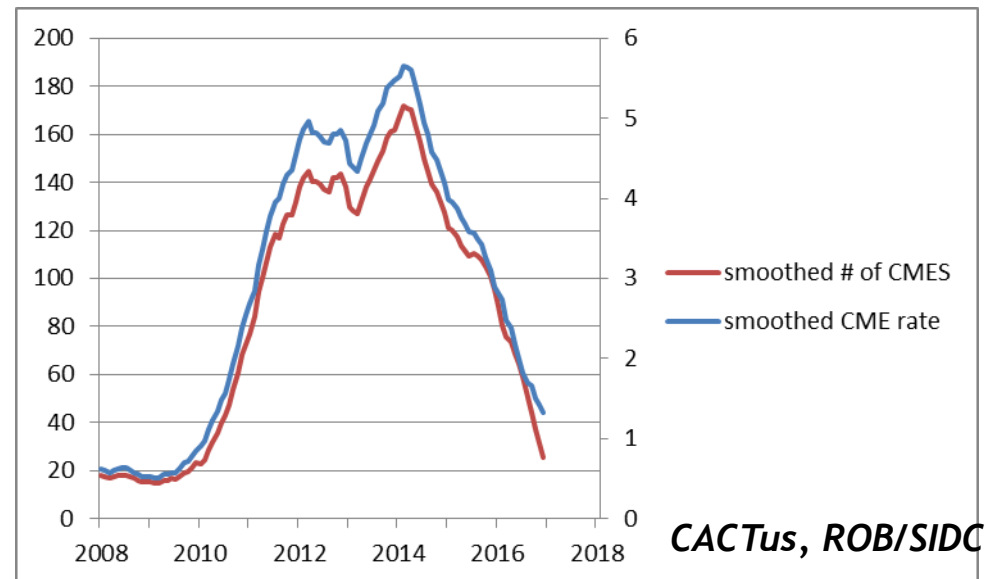
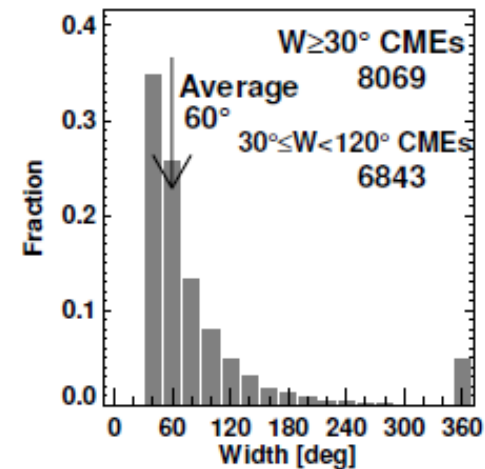
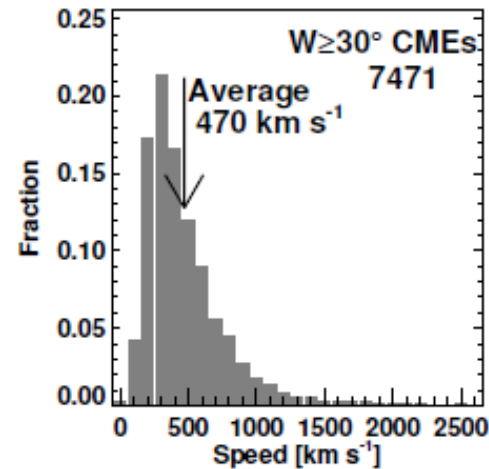




CORONAL MASS EJECTION

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





CORONAL MASS EJECTION

Terminology

- Width
 - Narrow: $< 20^\circ$
 - Partial halo: $> 120^\circ$
 - (Full) halo: 360°
- Shape halo
 - Symmetric
 - Asymmetric
- Origin
 - Frontside/Farside
- De- & acceleration

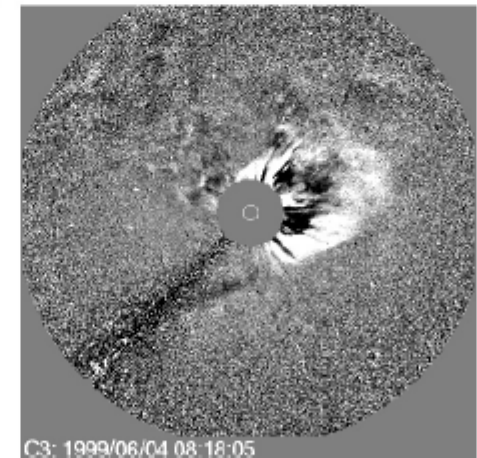
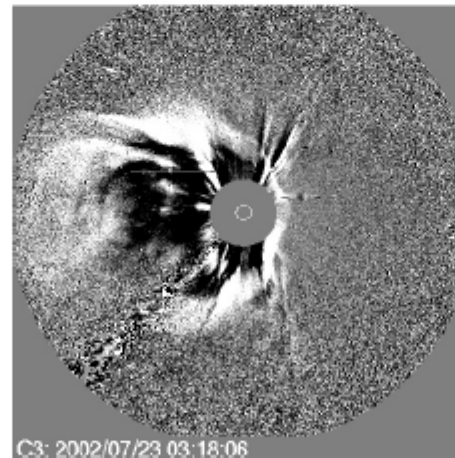
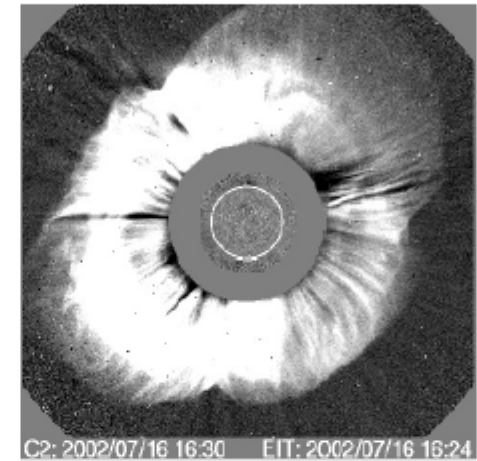
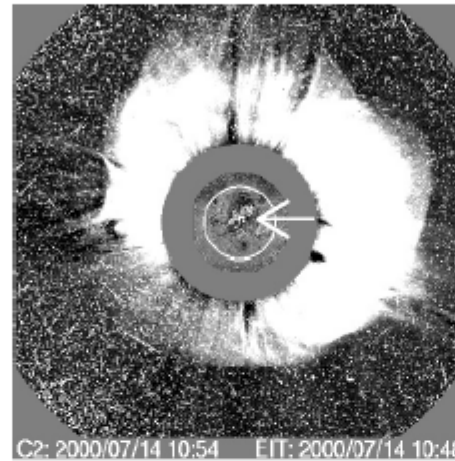


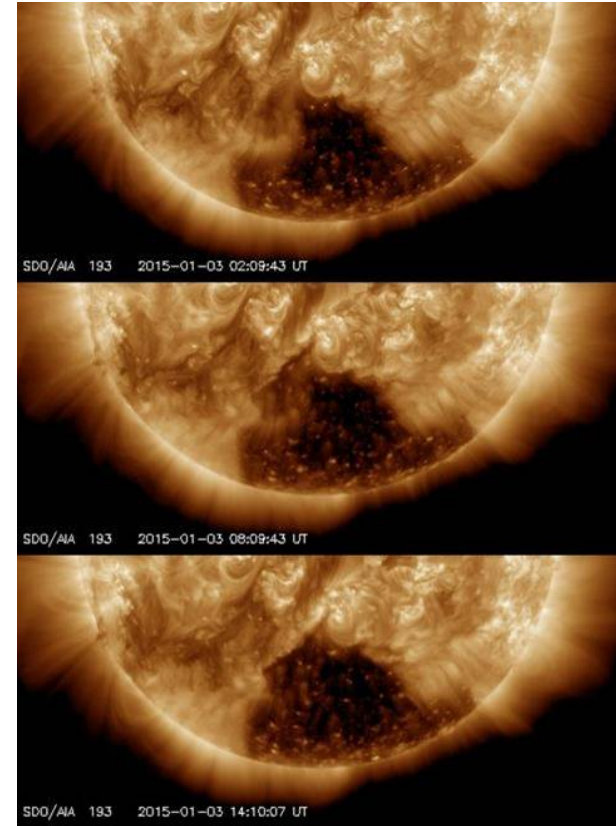
Figure 4: Examples of a variety of halo CME observations, clockwise: a frontside full halo (arrow shows likely source near Sun center); a backside full halo; a partial halo; and an asymmetric full halo. Image reproduced with permission from *Gopalswamy et al. (2003a)*.



CORONAL MASS EJECTION

Terminology

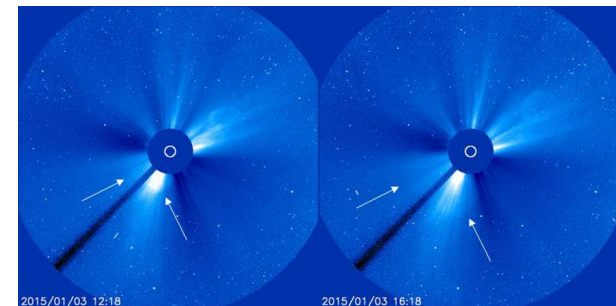
- Stealth CME
 - No obvious surface signature
 - Rather slow (<300 km/s)
 - Rather faint
- CME cannibalism
 - 2nd CME overtakes 1st
 - Enhanced geomagnetic storms
- Deflection
 - By corona holes, CME,...



SDO/AIA



SOHO/LASCO



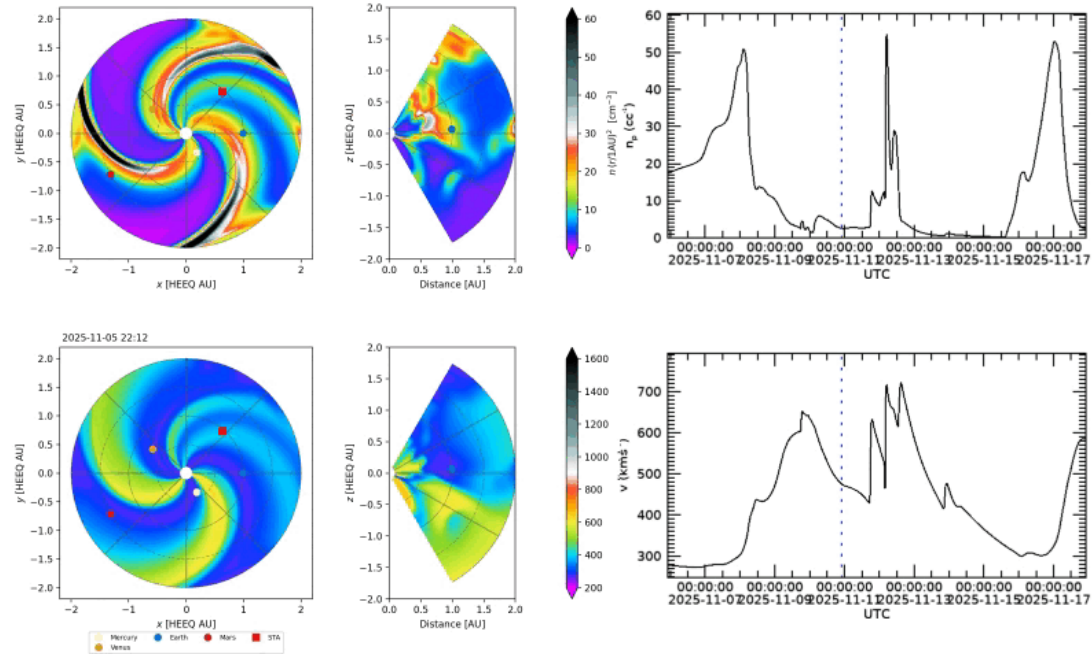


CORONAL MASS EJECTION

Terminology

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

EUHFORIA (Earth) - 2025-11-05T22:12:50

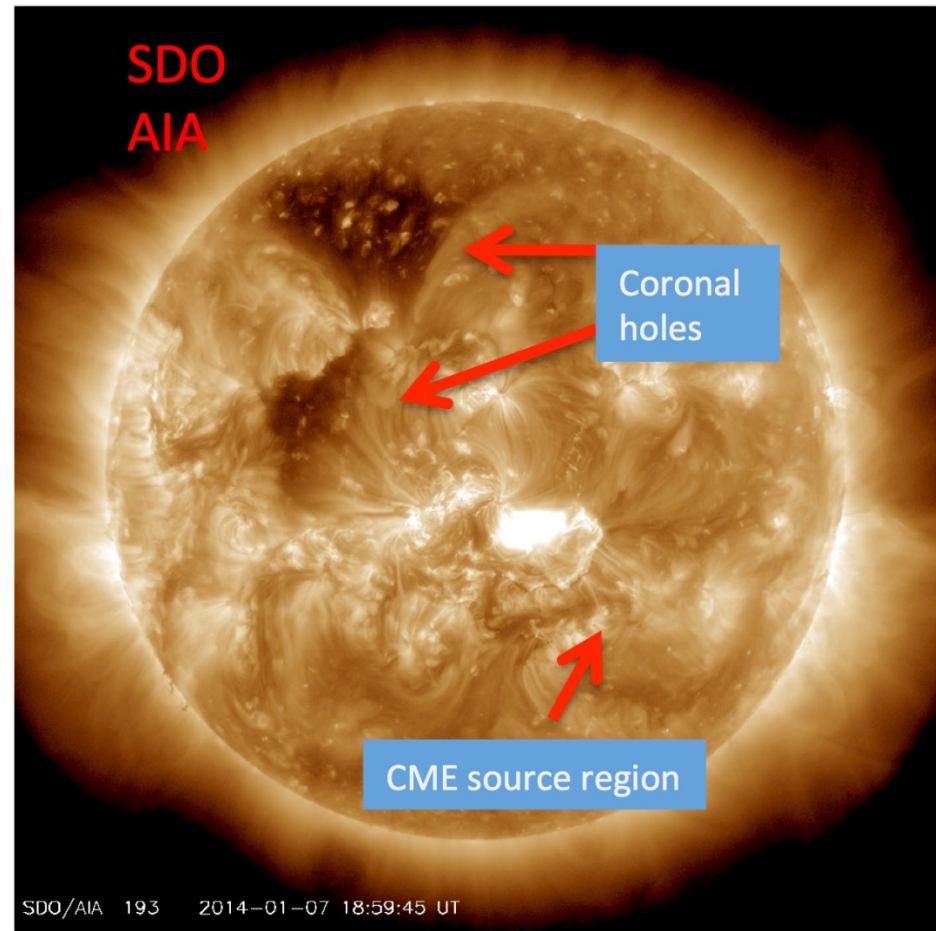




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 - By coronal holes, CME,...



SDO/AIA

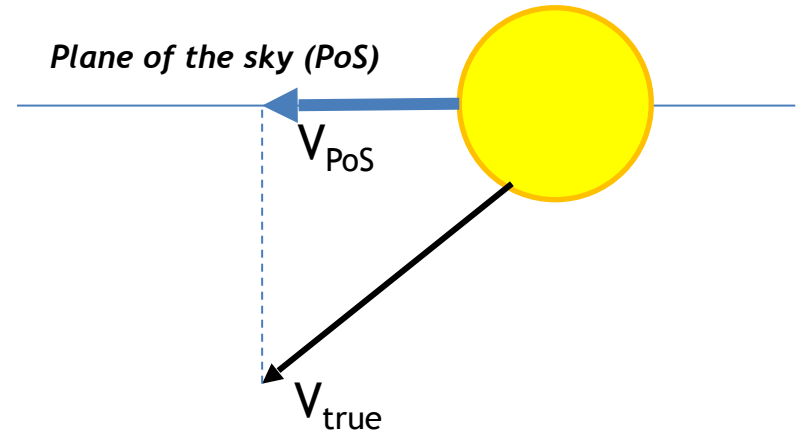




CORONAL MASS EJECTION

Speed

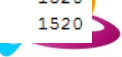
- We see the projected speed
 - Plane of the sky (PoS)
- We use the true speed
 - = Corrected PoS speed
$$V_{\text{true}} \geq V_{\text{PoS}}$$
 - From Type II radio bursts
 - = shock speed



```

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: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 + 1537 1649 1730 G15 5 XRA 1-8A X1.4 4.6E-01 1520
9900 1610 //// 1638 PAL C RSP 108-180 C1M/1 1520
9900 + 1614 1649 1732 SAG G RBR 410 6600 1520
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9900 1620 1655 1814 SAG G RBR 610 2400 1520
9900 + 1621 1654 1815 SAG G RBR 15400 270 1520
9900 + 1625 //// 1653 SAG C RSP 025-082 II/2 1268 1520
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INTERPLANETARY CORONAL MASS EJECTION

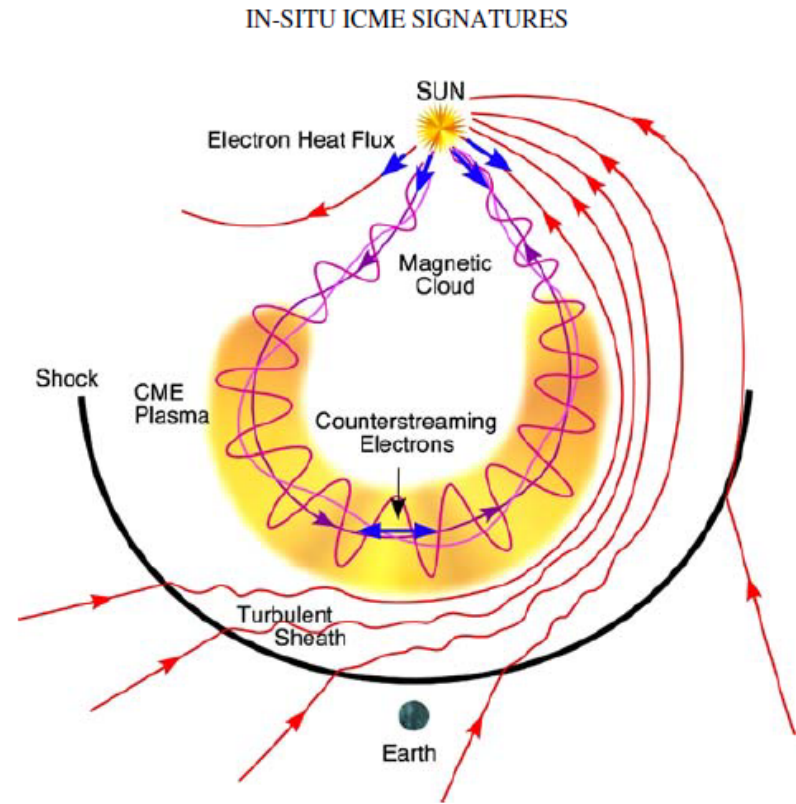
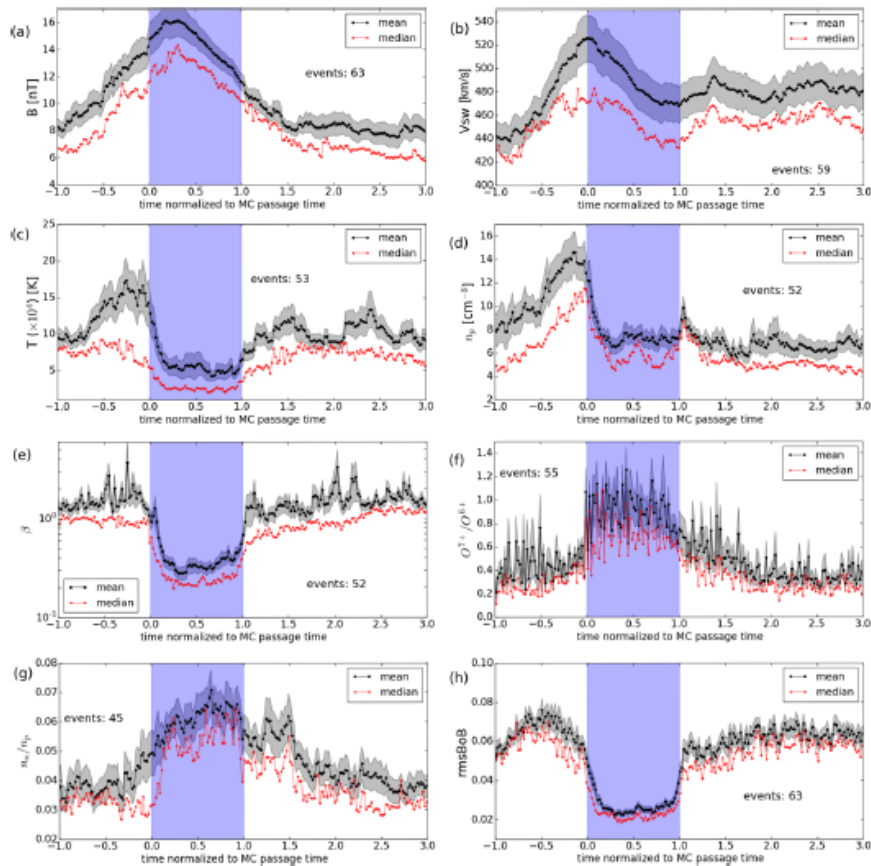
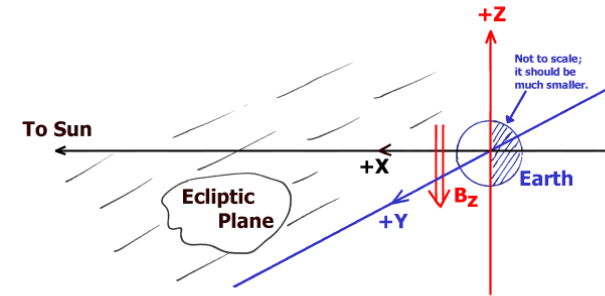


Figure 2. Schematic of the three-dimensional structure of an ICME and upstream shock, relating magnetic field, plasma, and BDE signatures.



CORONAL MASS EJECTION

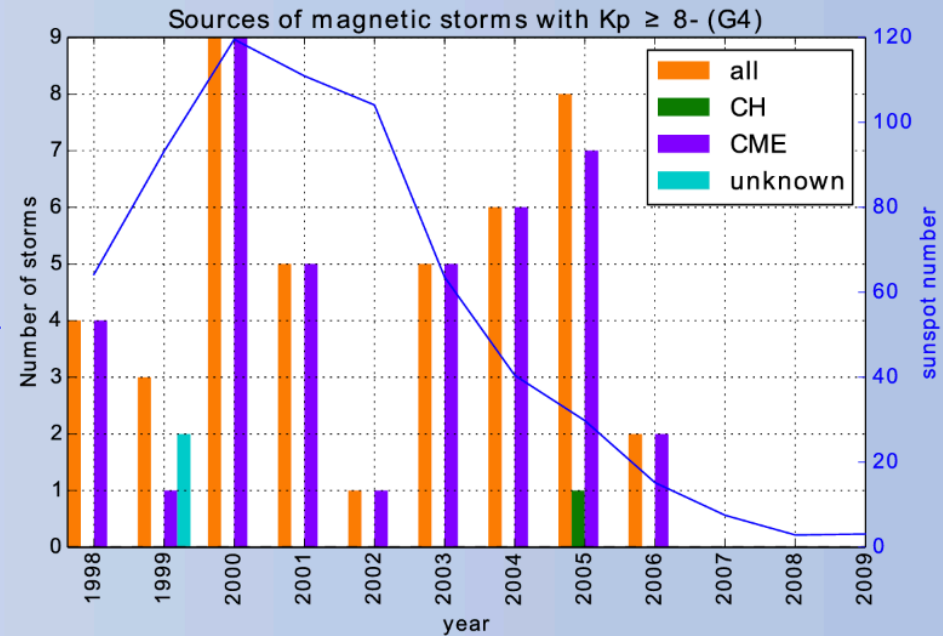
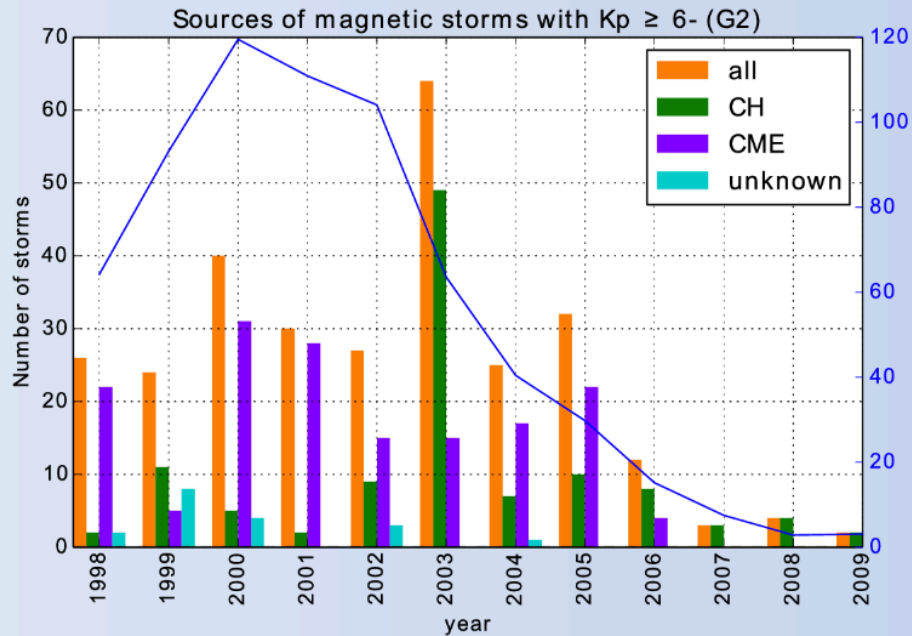
Bz



- 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!



CME STATISTICS - SOURCE





Finding your way in the URSIgram

```

:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
#-----#
# DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
# (RWC Belgium) #
#-----#

```

```

SIDC URSIGRAM 30318
SIDC SOLAR BULLETIN 18 Mar 2023, 1230UT
SIDC FORECAST (valid from 1230UT, 18 Mar 2023 until 20 Mar 2023)
SOLAR FLARES : C-class flares expected, (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 18 Mar 2023 10CM FLUX: 138 / AP: 007
PREDICTIONS FOR 19 Mar 2023 10CM FLUX: 140 / AP: 019
PREDICTIONS FOR 20 Mar 2023 10CM FLUX: 138 / AP: 029

```

COMMENT: The solar flaring activity was at moderate levels during the last 24 hours with one M-class flare and several C-class flares detected, with the most frequent sources being NOAA active regions 3254 and 3256. The largest flare was a M1.1 flare, peaking at 15:07 UTC on March 17, associated with active region NOAA 3254 (beta class). NOAA active region 3256 produced an impulsive C9.4 flare at 07:10 UTC on March 18. This event was also associated with Type IV radio emission. Other regions on the disc did not show any significant flaring activity. Further M-class flare activity is possible but not probable, while frequently C-class activity is expected in the next 24 hours.

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```

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10CM SOLAR FLUX : 134
AK CHAMBON LA FORET : 014
AK WINGST : 007
ESTIMATED AP : 007
ESTIMATED ISN : 073, BASED ON 18 STATIONS.

```

CME/ICME

```

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
17 1504 1507 1511 S22W65 M1.0 SN 12/3247
END

```

