# SPACE WEATHER INTRODUCTORY COURSE


Collaboration of

Solar-Terrestrial Centre of Excellence

Koninklijke luchtmacht

Koninklijk Nederlands
Meteorologisch Instituut
*Ministerie van Infrastructuur en Milieu*

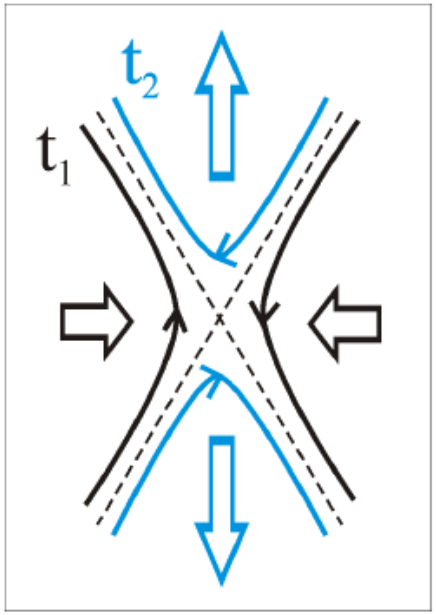
# SPACE WEATHER

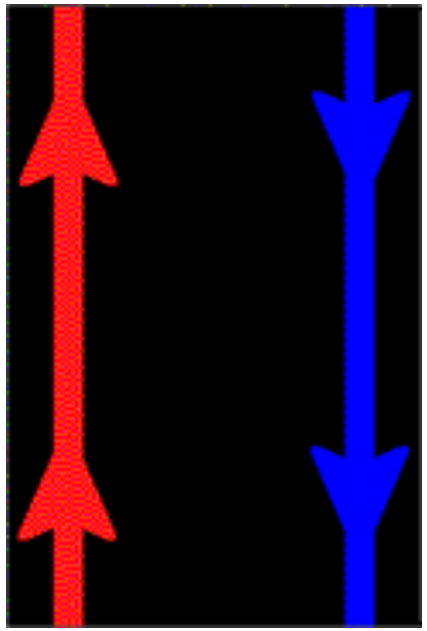
## Drivers

*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

Magnetic Reconnection

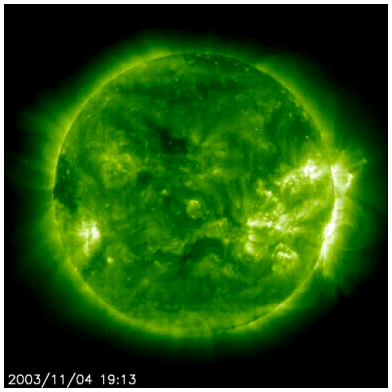
Radiation

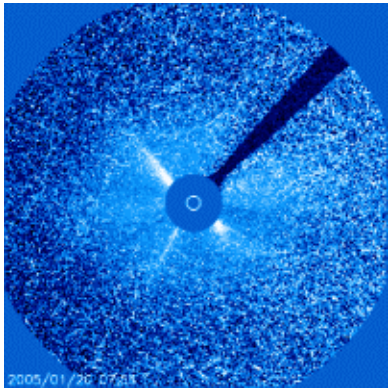
Particles

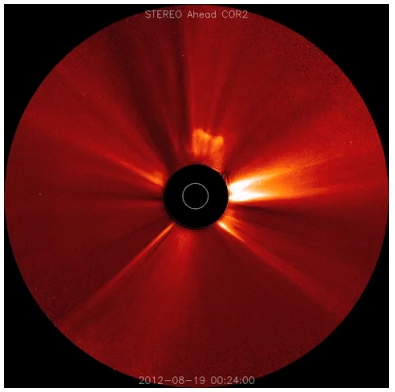
Solar flares

Proton events

Coronal Mass Ejections






SOHO/EIT

SOHO/LASCO

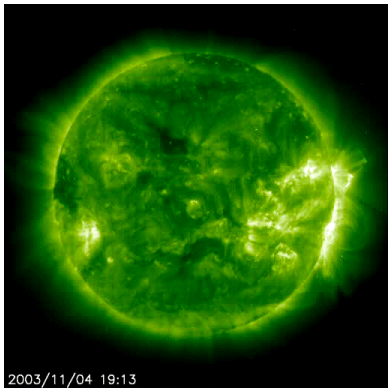
SOHO/LASCO

# SOLAR ERUPTIONS

Magnetic Reconnection

Radiation

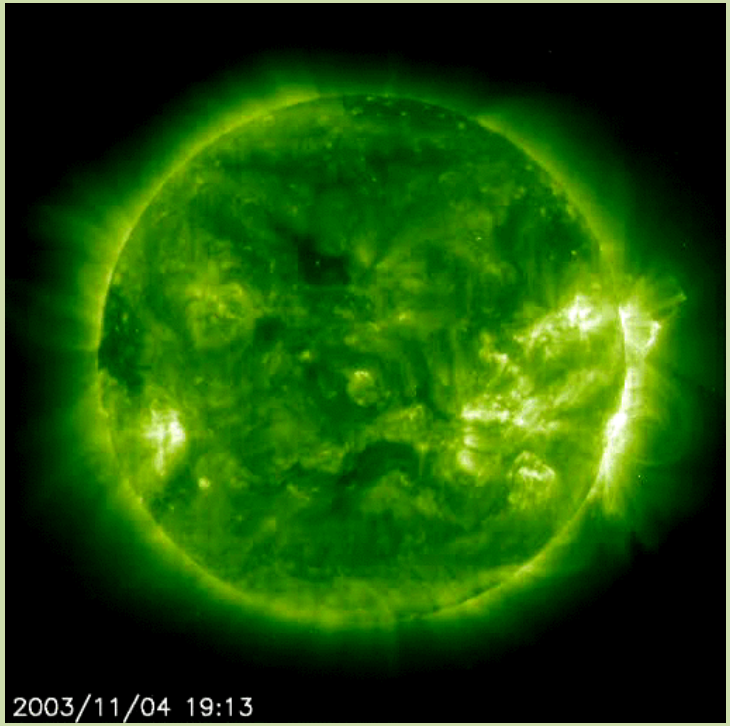
Solar flares




SOHO/EIT

# FLARES - OVERVIEW

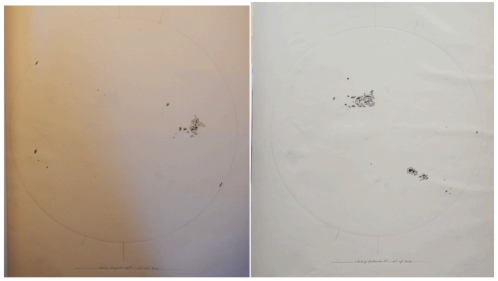
- **Flare Characteristics**
  - **Definition**
  - **Standard model**
  - **Flare triggers**
  - **Flare features**
- Flare Classification
- Flare Predictions

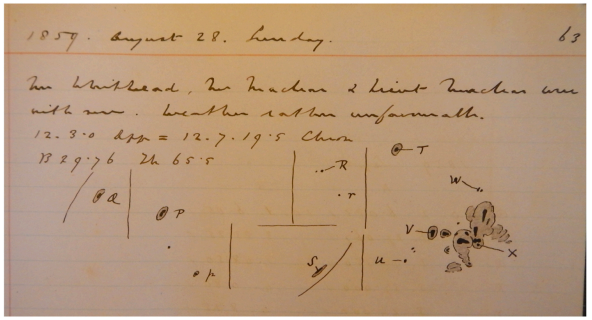


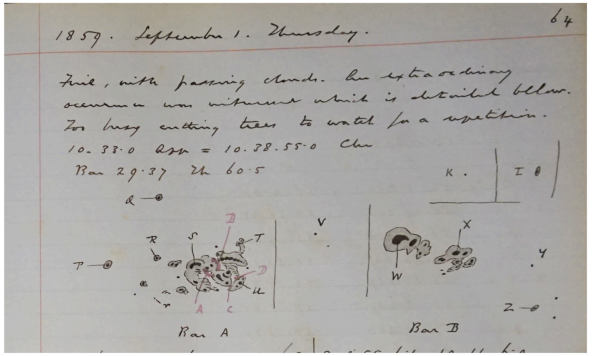

**SOHO/EIT**

# SOLAR FLARES - WHAT?

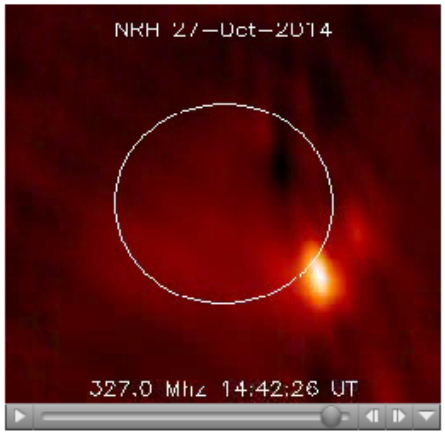
- Sudden burst of radiation
- First observation in 1859 (white light) by Carrington and Hodgson
- Large quantity of energy is released
  >10^20 Joule
- Required:
  A very rapid means of converting stored magnetic energy into particle energy and radiation – magnetic reconnection

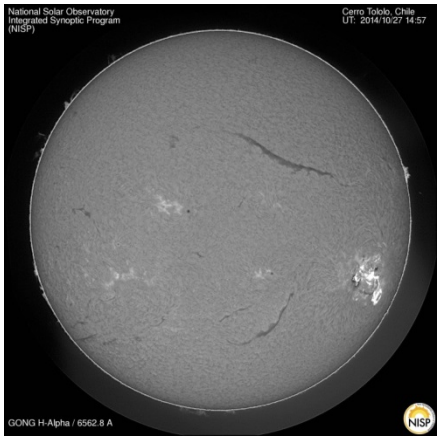


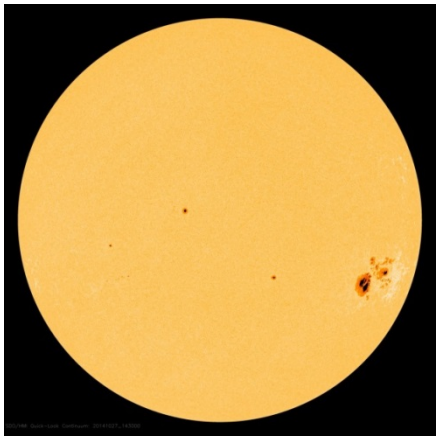


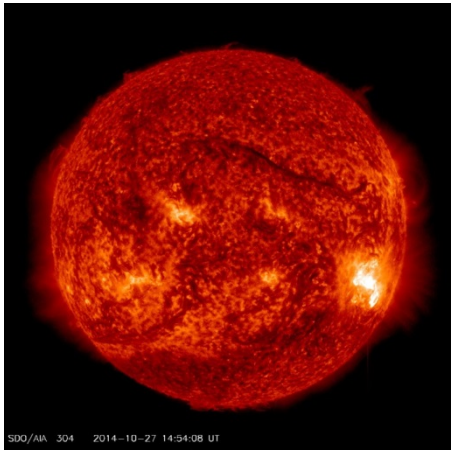
# SOLAR FLARES - OBSERVATIONS

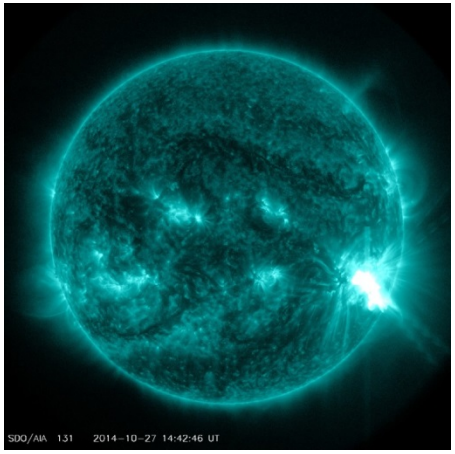


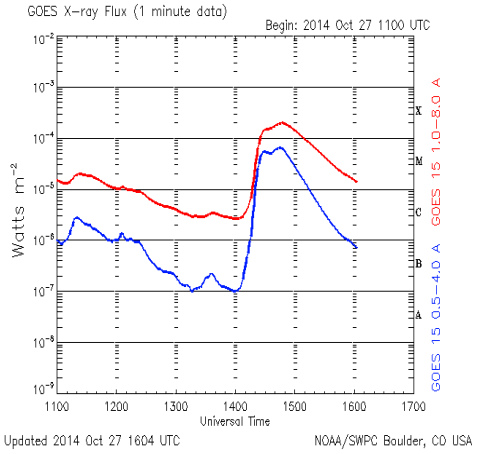



SDO/HMI



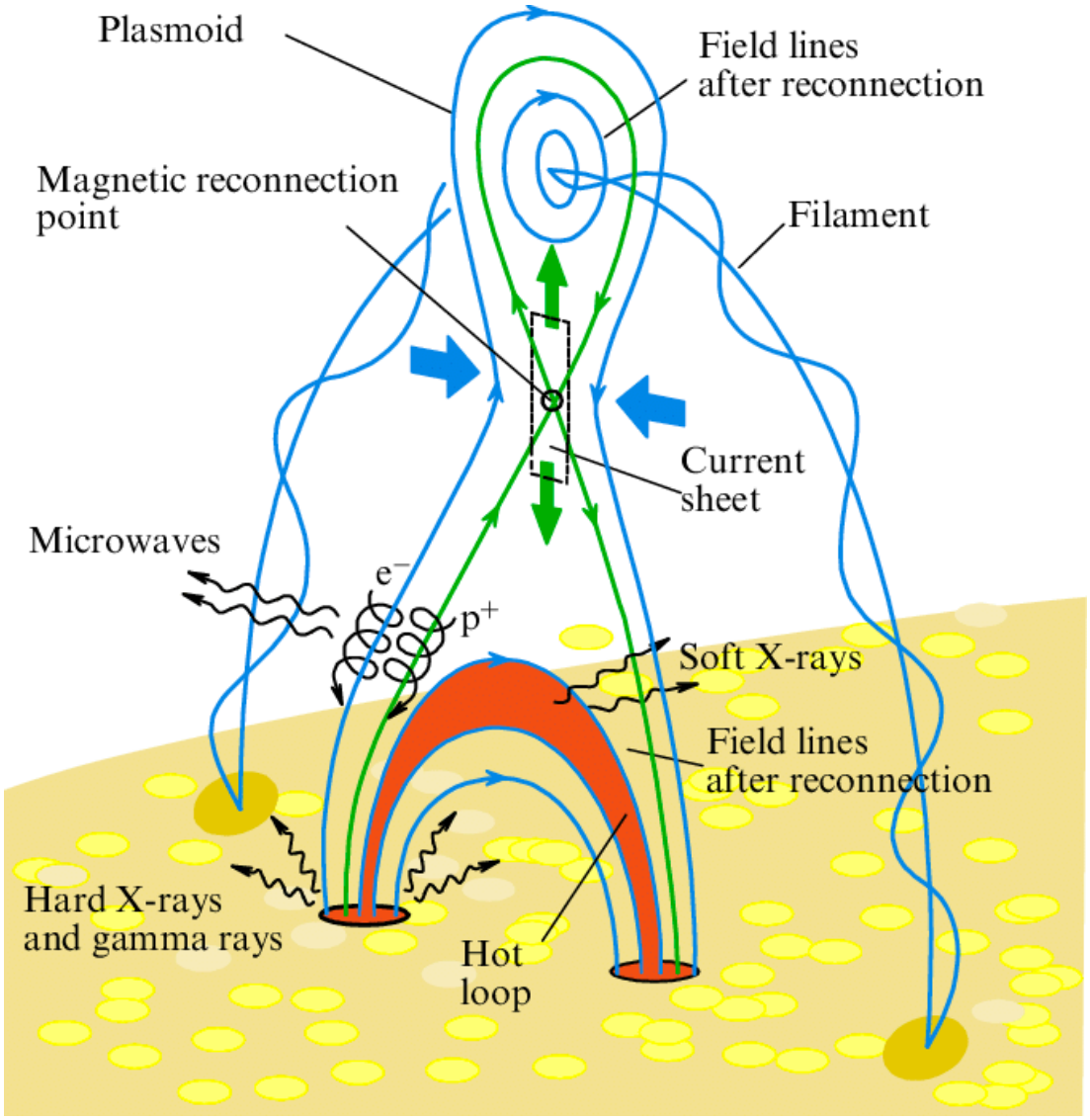




GOES

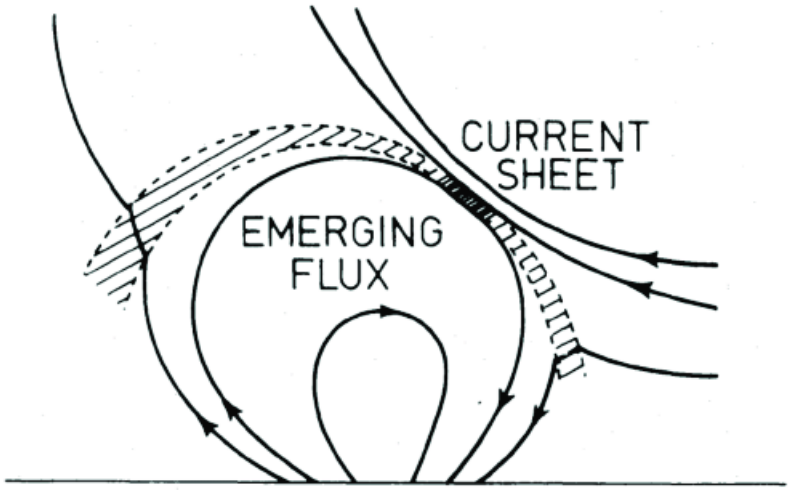
SDO/AIA

# STANDARD FLARE MODEL



# TRIGGERS OF SOLAR FLARES

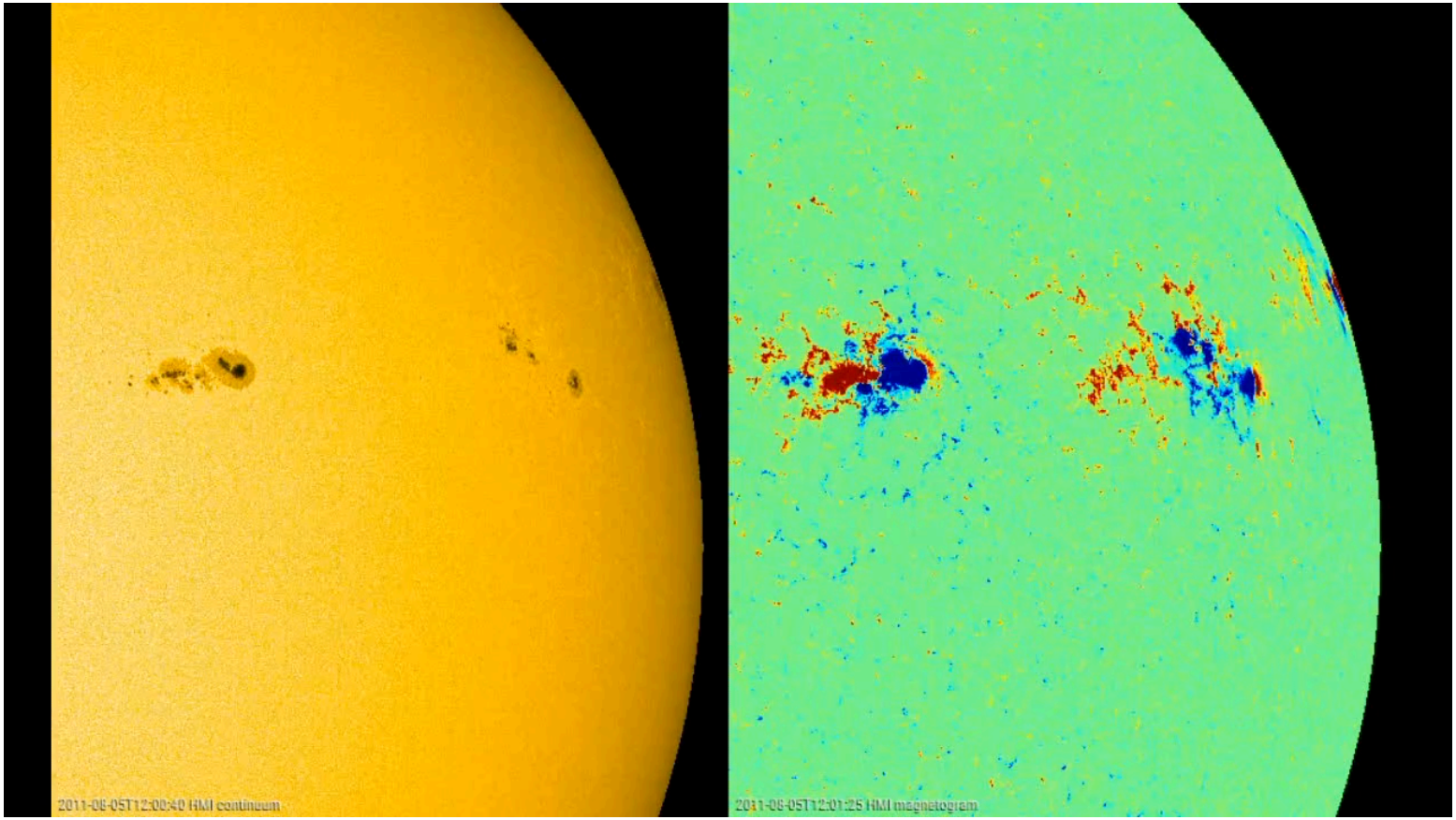
- Magnetic restructuring
- Magnetic flux emergence
- Helical energy storage
- Instability surrounding fields
- Interaction with nearby CH
- …



# TRIGGERS OF SOLAR FLARES

SDO/HMI

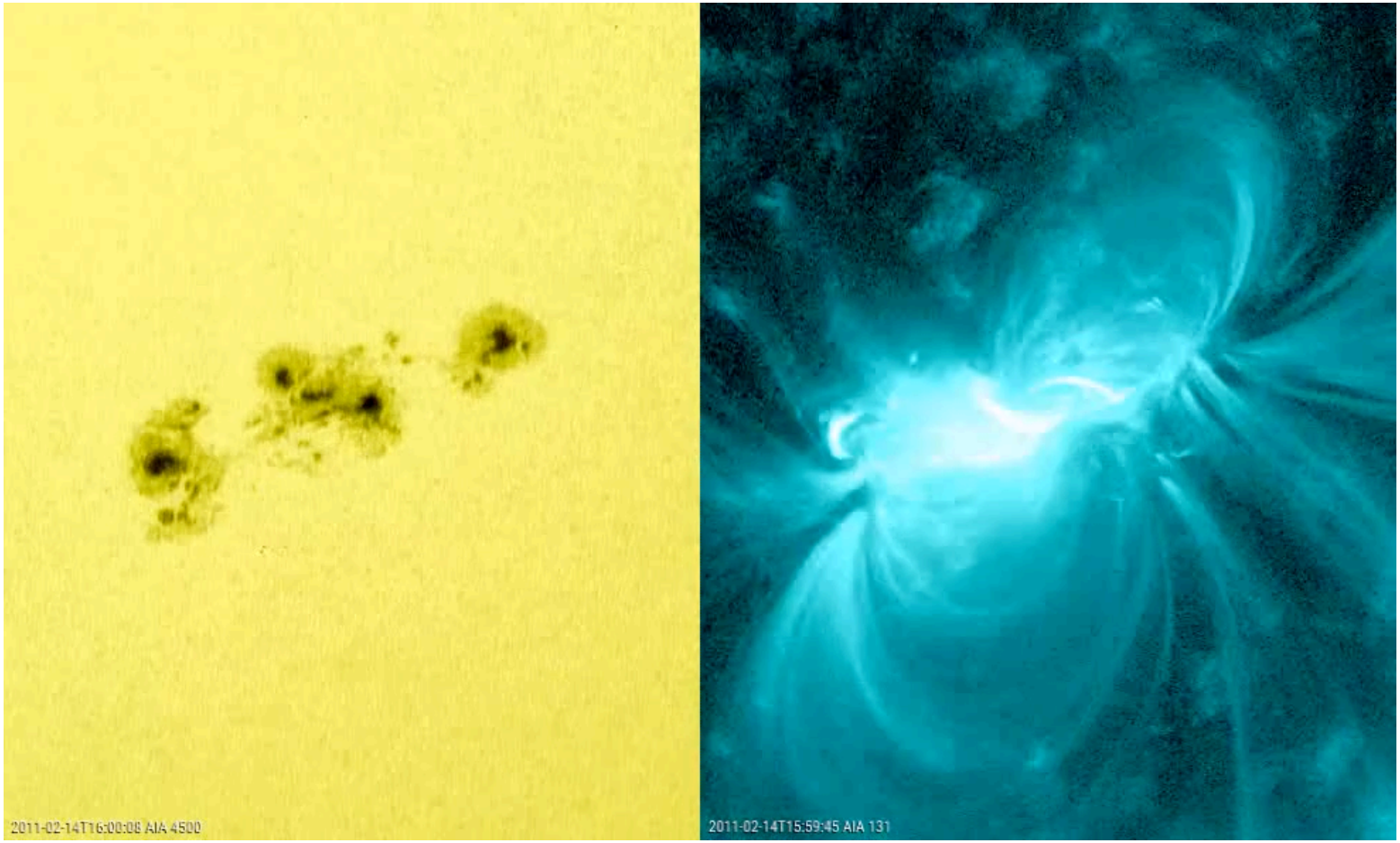
Magnetic flux emergence



# TRIGGERS OF SOLAR FLARES

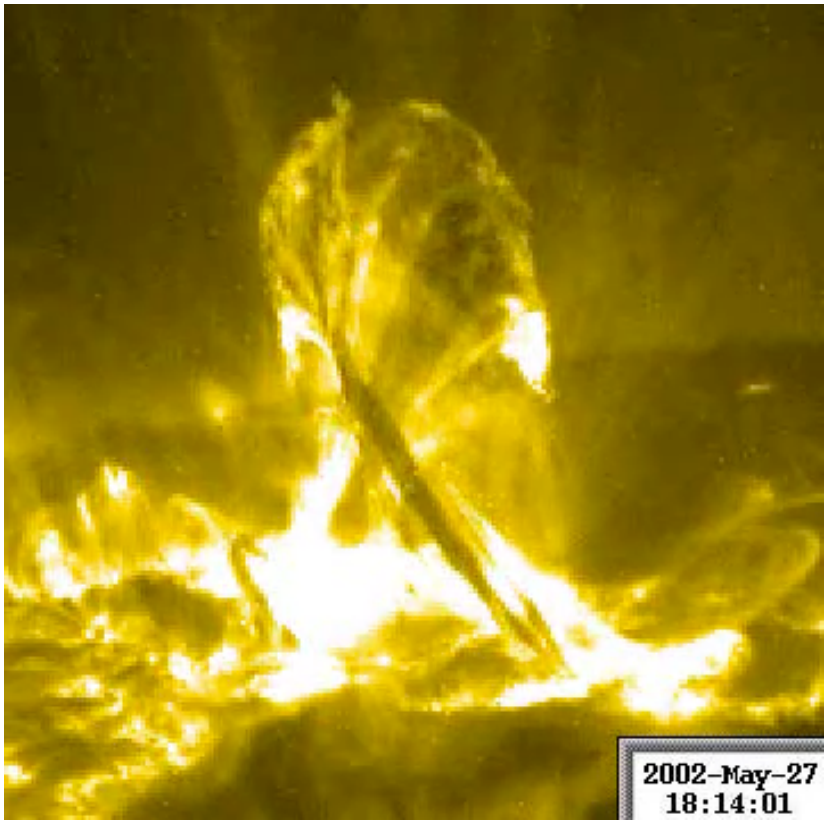
Helical energy storage

**SDO/AIA**

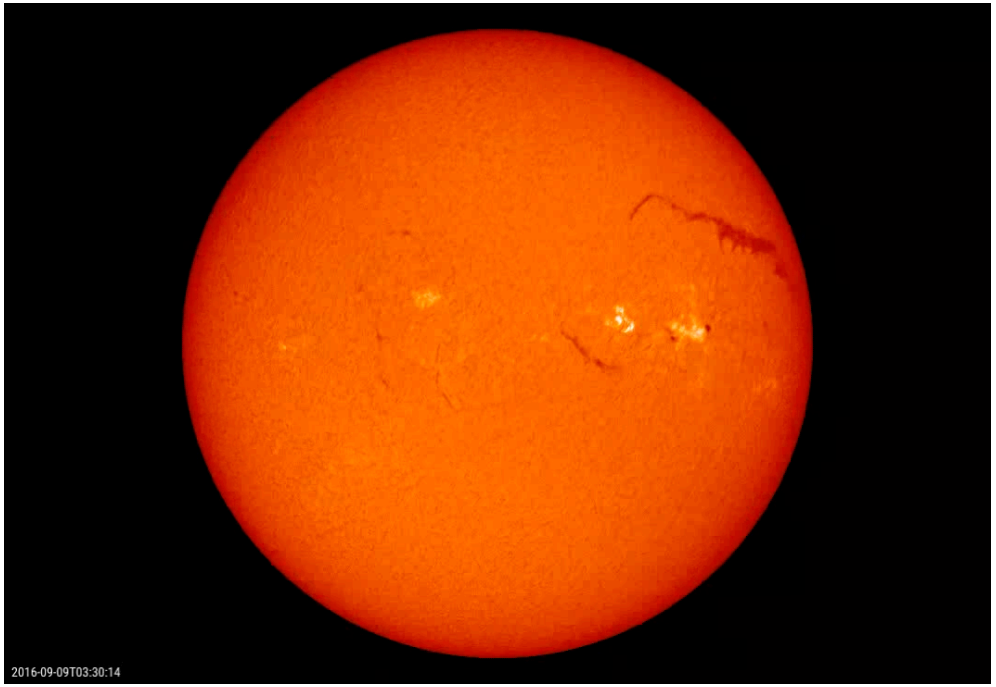


# TRIGGERS OF SOLAR FLARES

Kink instability




Unstable magnetic fields



: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


# Finding your way in the URSIgram

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 Mach 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.

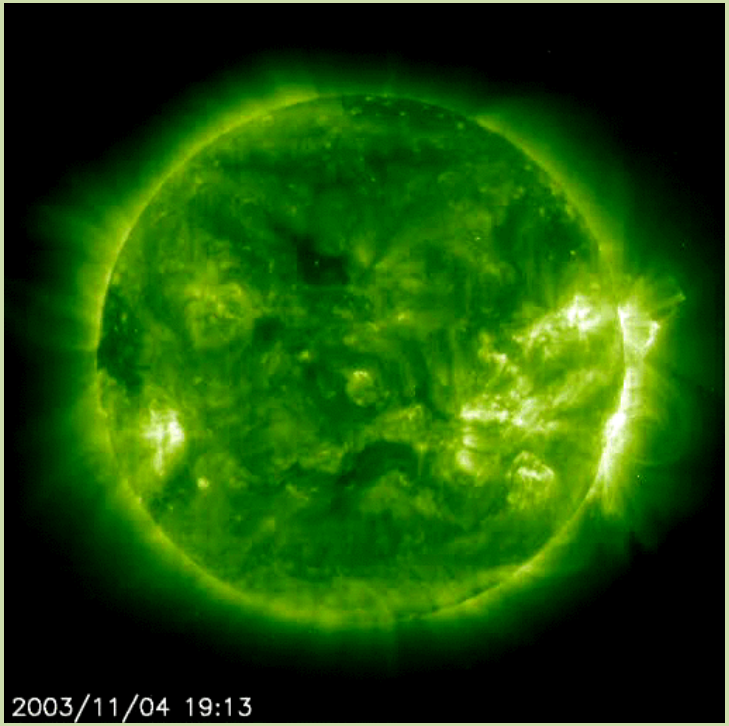
SOLAR INDICES FOR 17 Mar 2023
WOLF NUMBER CATANIA    : 110
10CM SOLAR FLUX        : 134
AK CHAMBON LA FORET    : 014
AK WINGST              : 007
ESTIMATED AP           : 007
ESTIMATED ISN          : 073, BASED ON 18 STATIONS.

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

## Flare features

# FLARES - OVERVIEW

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



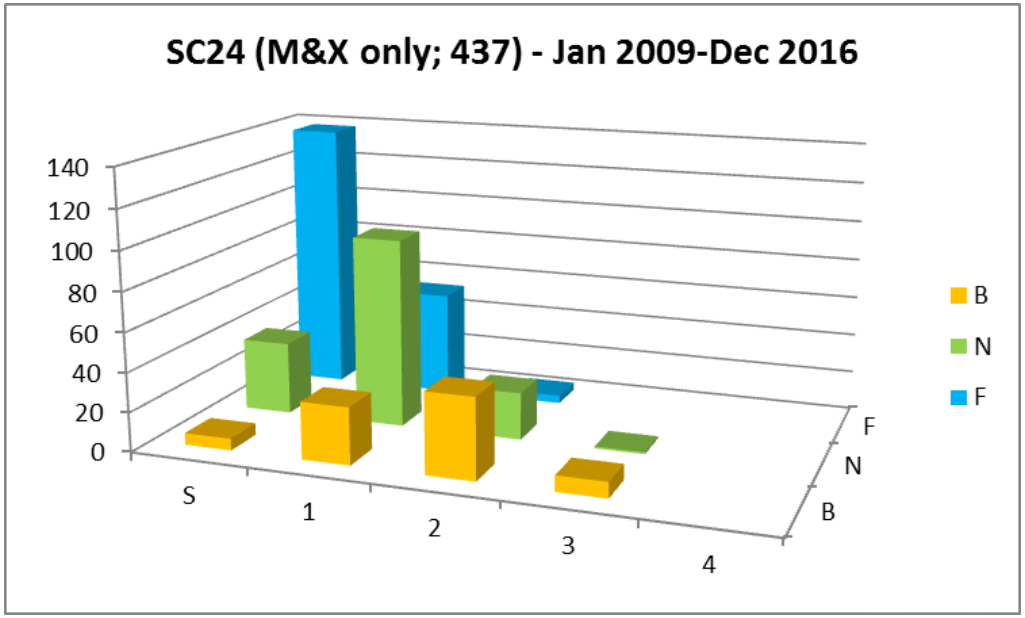

**SOHO/EIT**

# SOLAR FLARES CLASSIFICATION

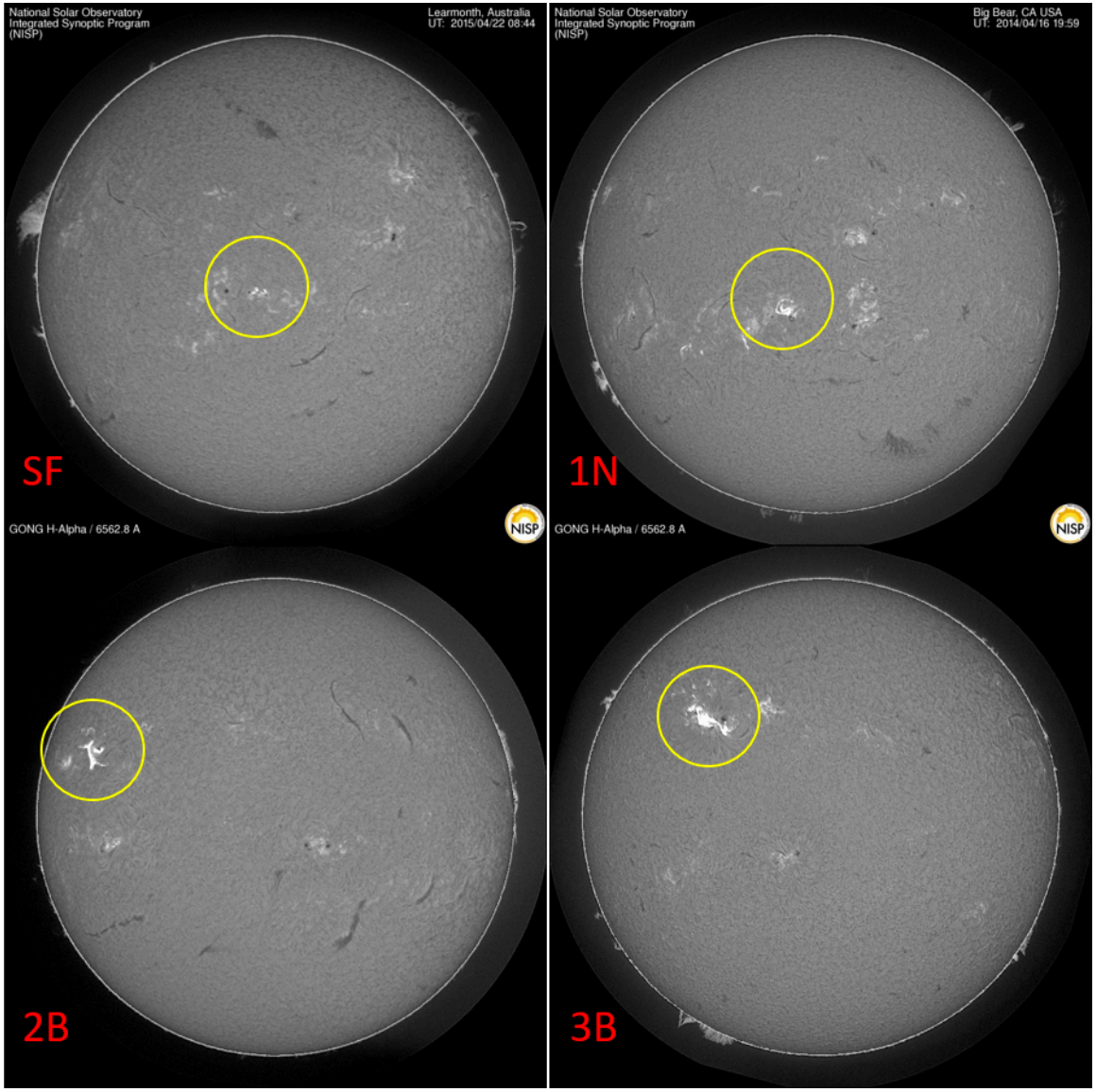
## H-alpha

- 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

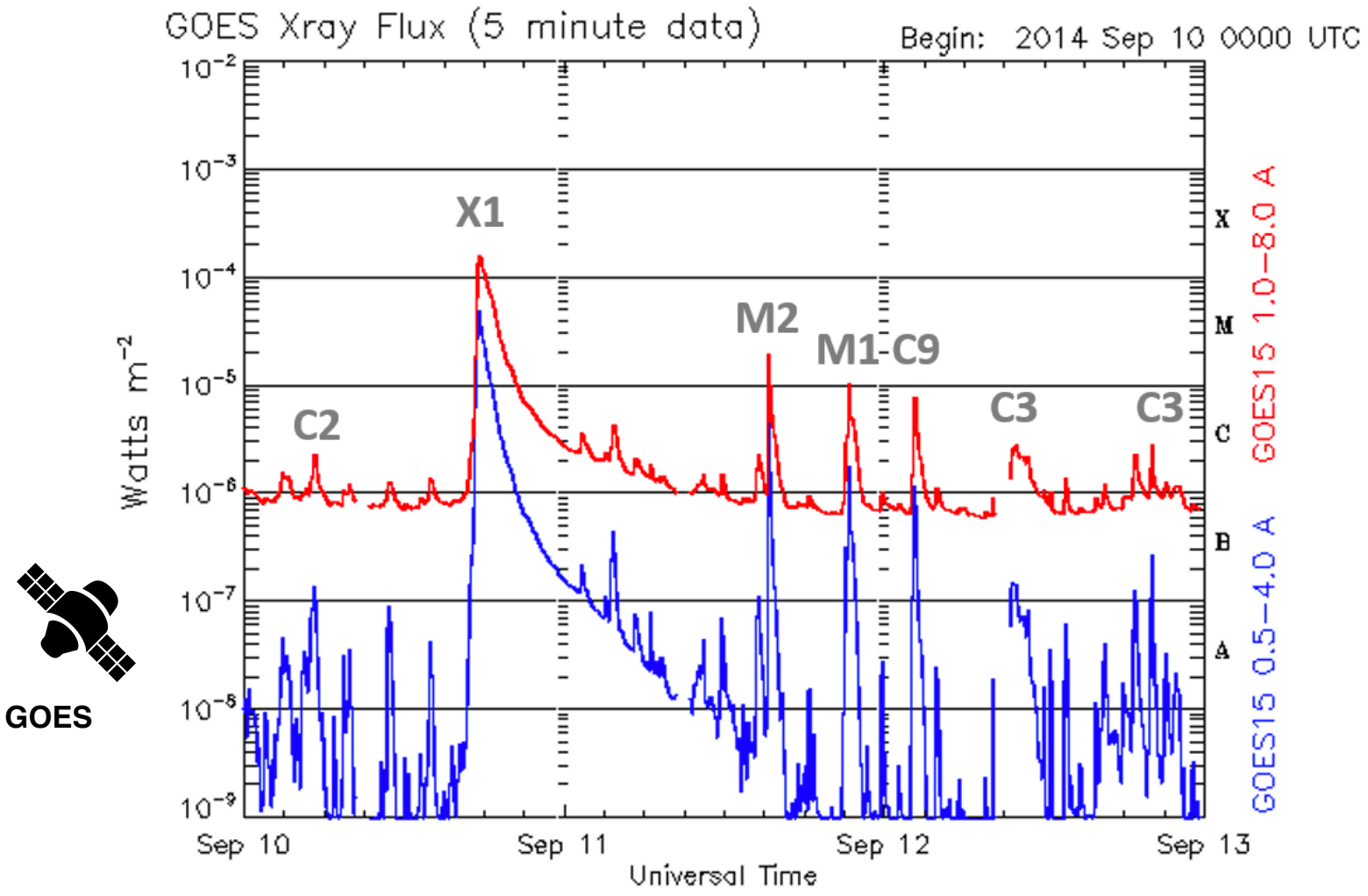
| Importance | $A_c$ (MH) | $A_c$ ($^{\circ 2}$) |
|---|---|---|
| S | $10 \leq A_c < 100$ | $0,2 \leq A_c < 2,1$ |
| 1 | $100 \leq A_c < 250$ | $2,1 \leq A_c < 5,2$ |
| 2 | $250 \leq A_c < 600$ | $5,2 \leq A_c < 12,4$ |
| 3 | $600 \leq A_c < 1200$ | $12,4 \leq A_c < 24,7$ |
| 4 | $1200 \leq A_c$ | $24,7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



# SOLAR FLARE CLASSIFICATION: H-ALPHA



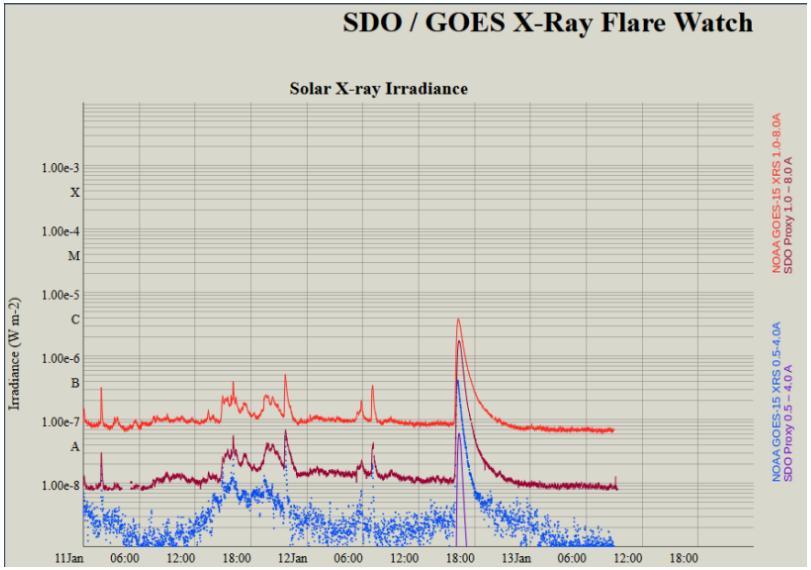
# SOLAR FLARE CLASSIFICATION: X-RAY



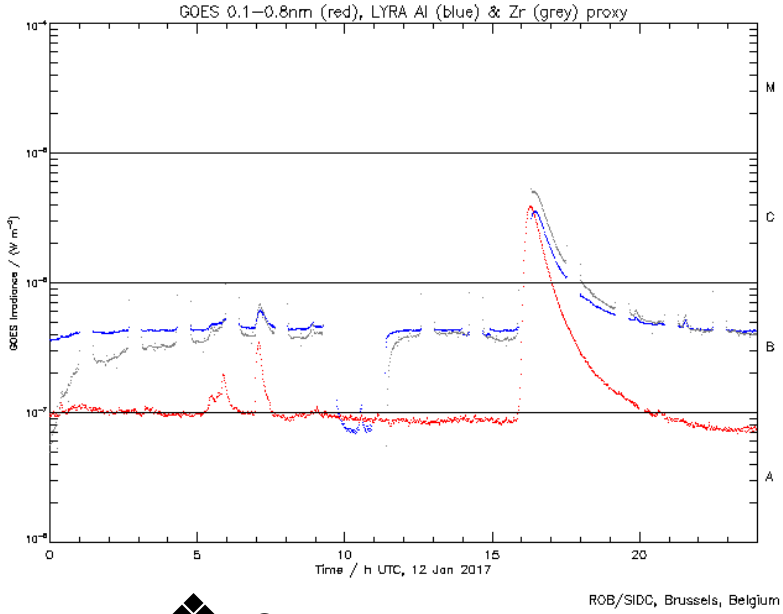

GOES

# SOLAR FLARE CLASSIFICATION: X-RAY

## Back-up for GOES x-ray




SDO/EVE

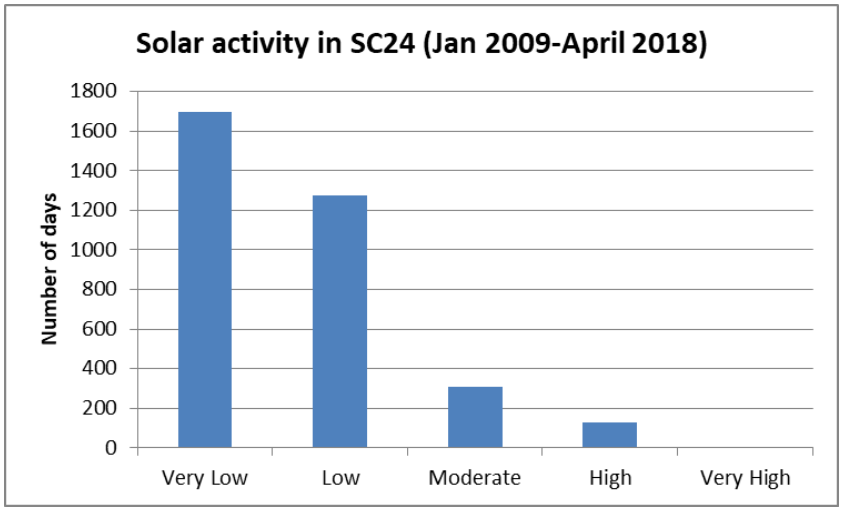



PROBA2/LYRA

# 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.

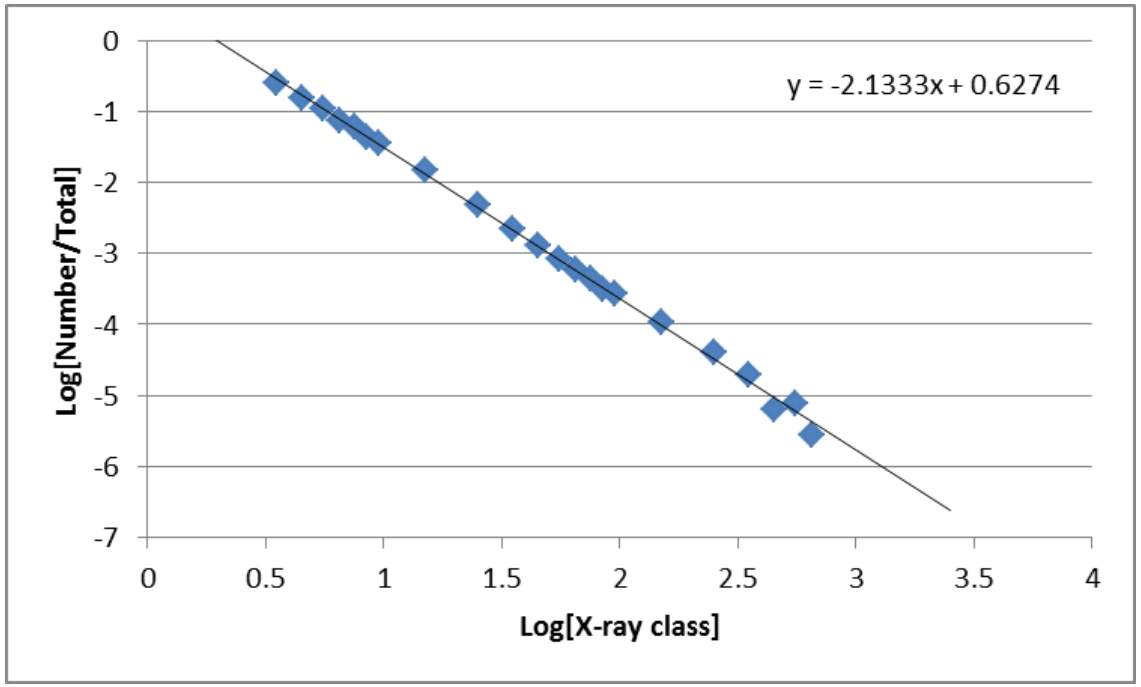
Low: C-class x-ray events.

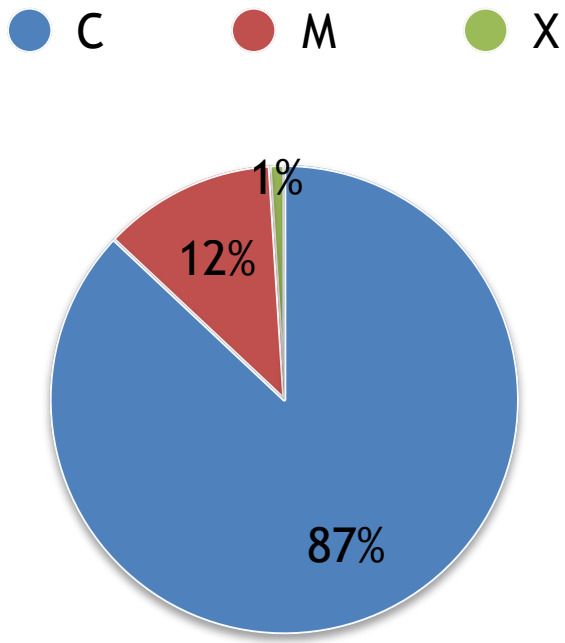
Moderate: isolated (one to four) M-class x-ray events.

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



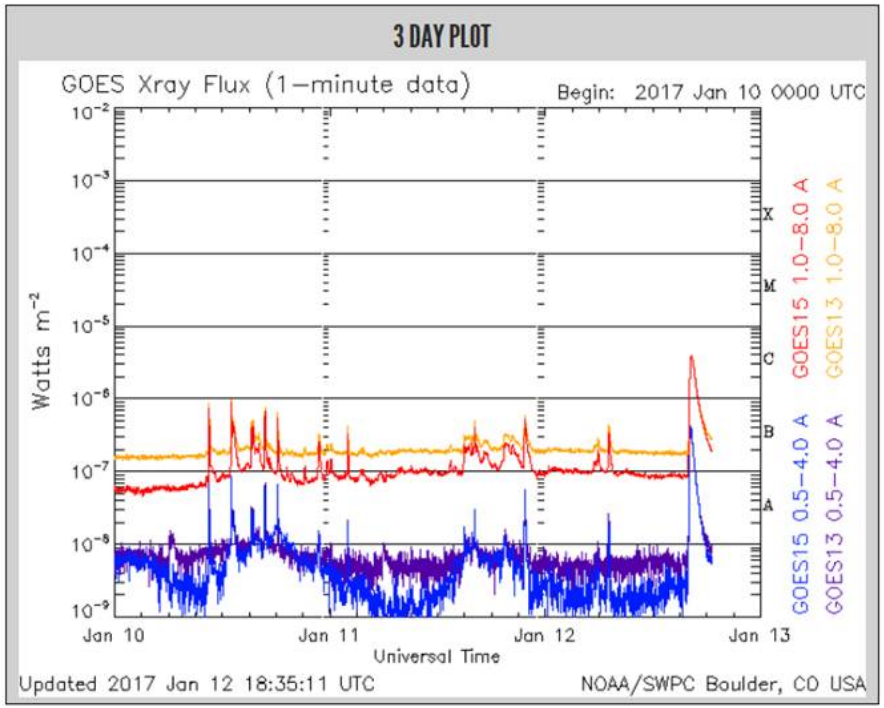



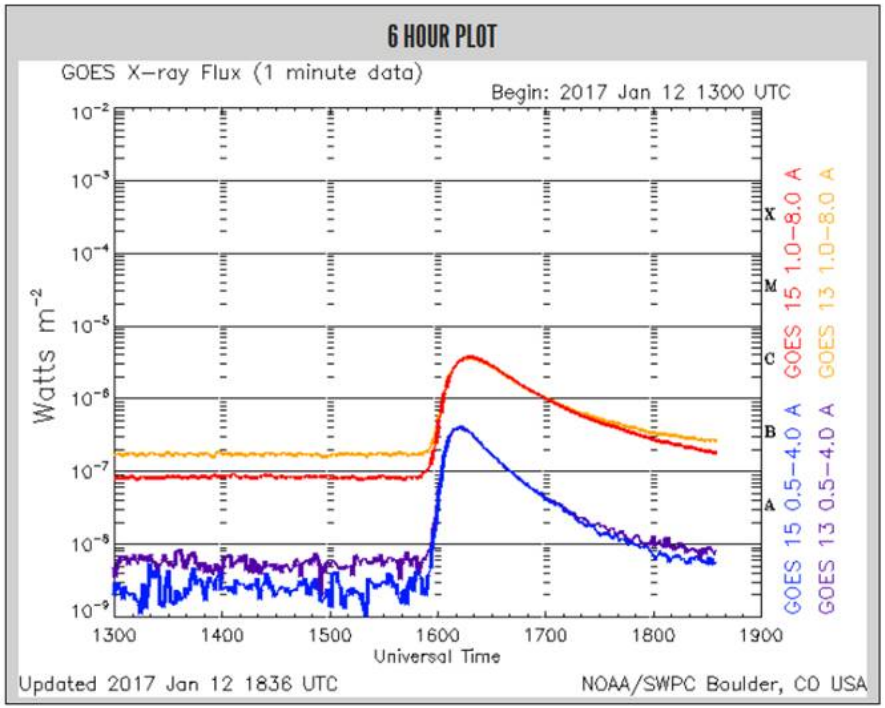
# SOLAR FLARE CLASSIFICATION: X-RAY

## NOAA-scales: R-scale

| Scale | Description | Effect | Physical measure | Average Frequency (1 cycle = 11 years) |
|---|---|---|---|---|
| R 5 | Extreme | | X20 ($2 \times 10^{-3}$) | 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 ($5 \times 10^{-5}$) | 350 per cycle (300 days per cycle) |
| R 1 | Minor | | M1 ($10^{-5}$) | 2000 per cycle (950 days per cycle) |

# SOLAR FLARE DURATION

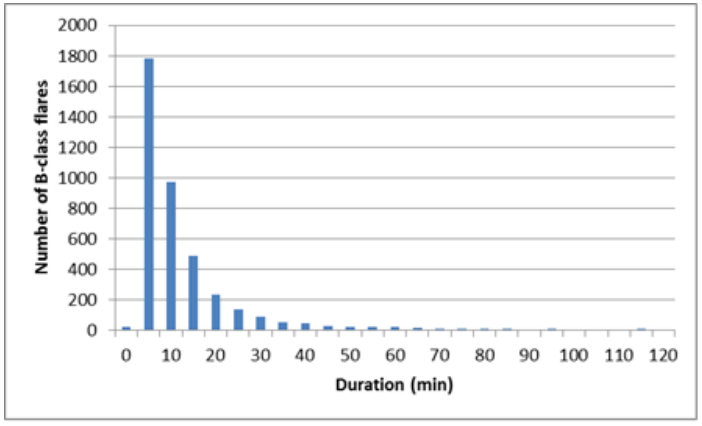


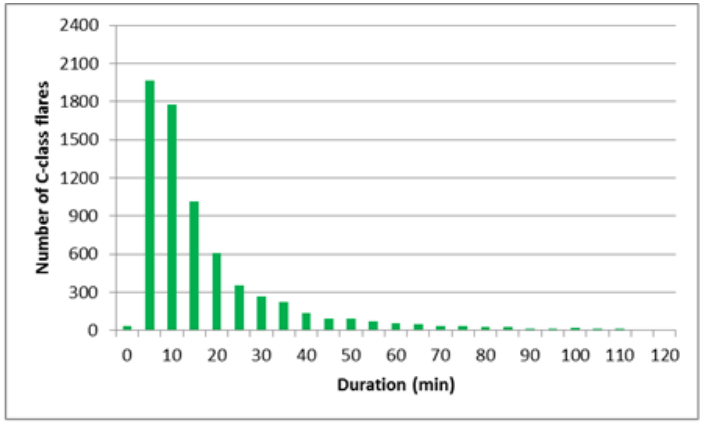



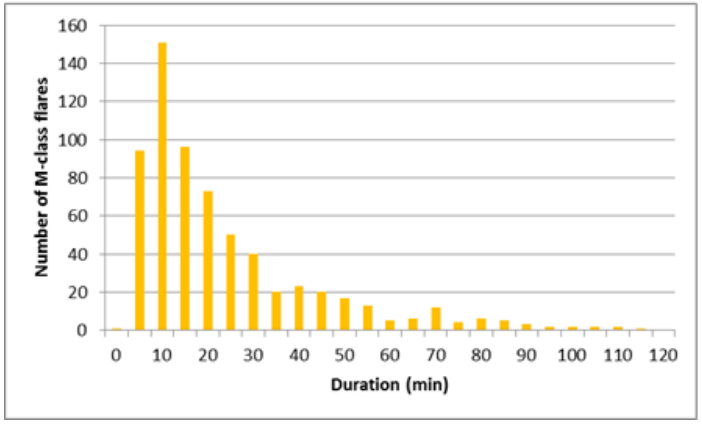

GOES

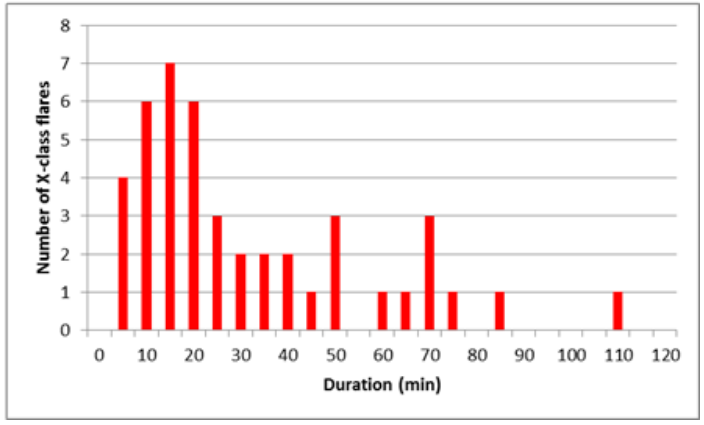
| LATEST X-RAY EVENT (1-8Å) | | | |
|---|---|---|---|
| **Current** | 2017-01-12 18:35:00 UTC | B1.8 | Ratio: 0.031 |
| **Beginning** | 2017-01-12 15:54:00 UTC | B1.0 | |
| **Maximum** | 2017-01-12 16:18:00 UTC | C3.8 | Integrated flux: 0.006896 J m$^{-2}$ |
| **End** | 2017-01-12 16:41:00 UTC | C1.9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

# 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**

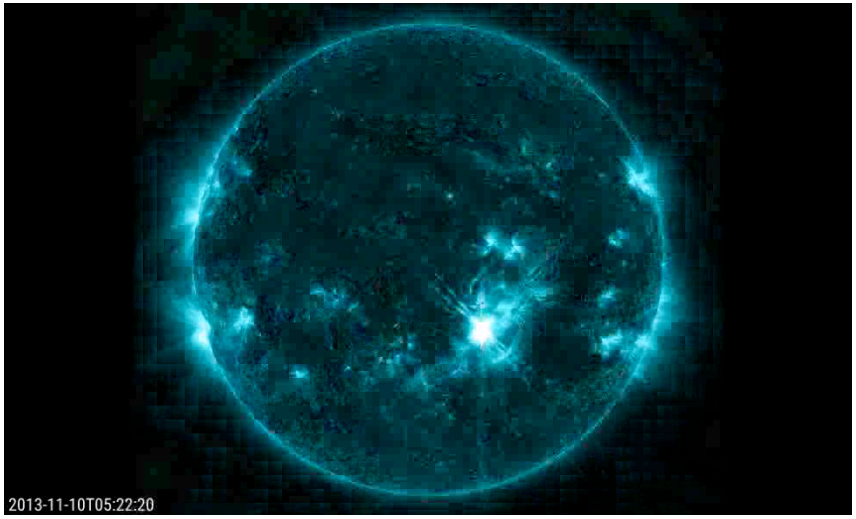
- All flare classes
- Duration
  - Total duration > 1 hour
  - Decay time > 30 minutes (SWPC)
- Association with CMEs increases with increased duration

# SOLAR FLARE DURATION

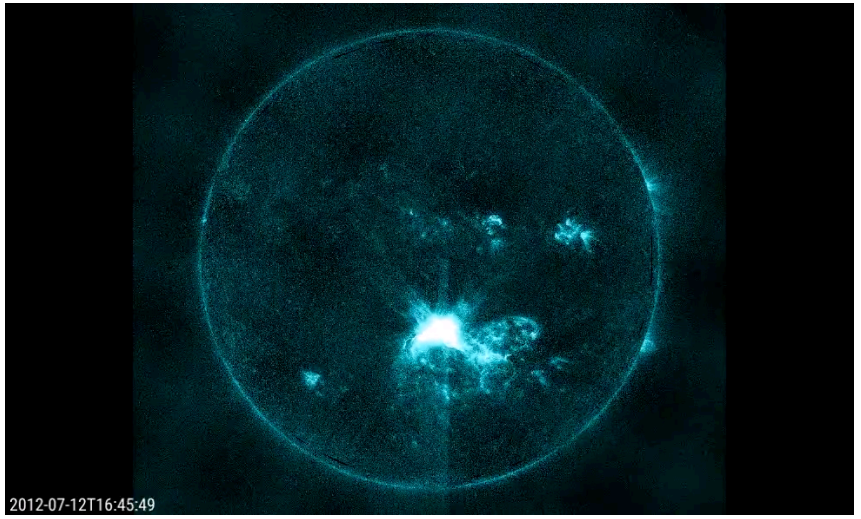
## Impulsive flare

## Long Duration Event

**SDO/AIA**




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

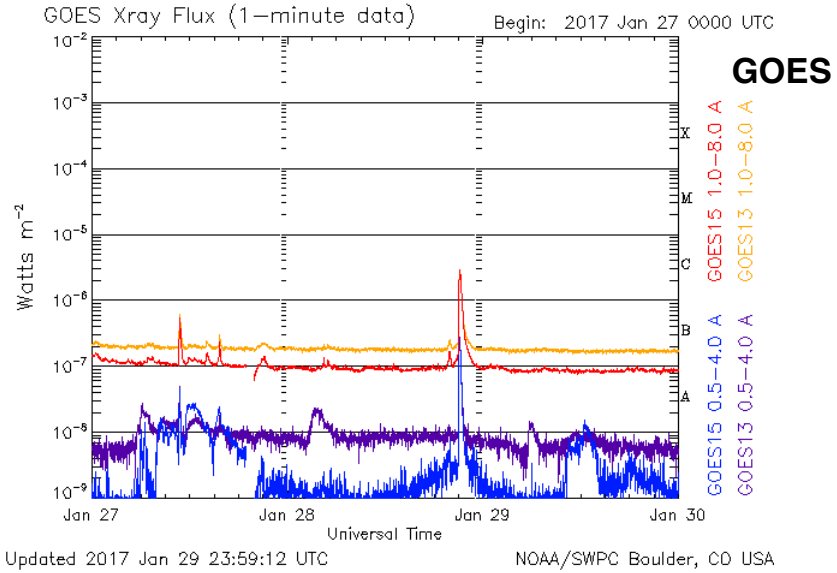


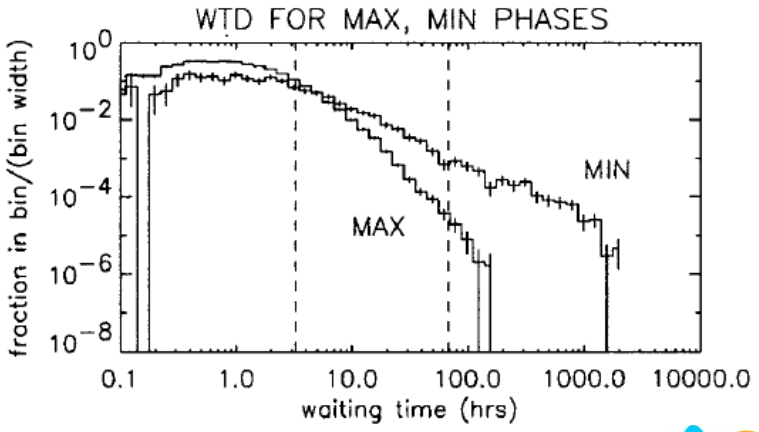

X1 - NOAA 1520 - 12 July 2012 (duration: 113 minutes)

# 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 (≥ C1)
  - SCmax: 3 hours
  - SCmin: 3 days




# 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 Mach 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.

NOTICEABLE EVENTS SUMMARY

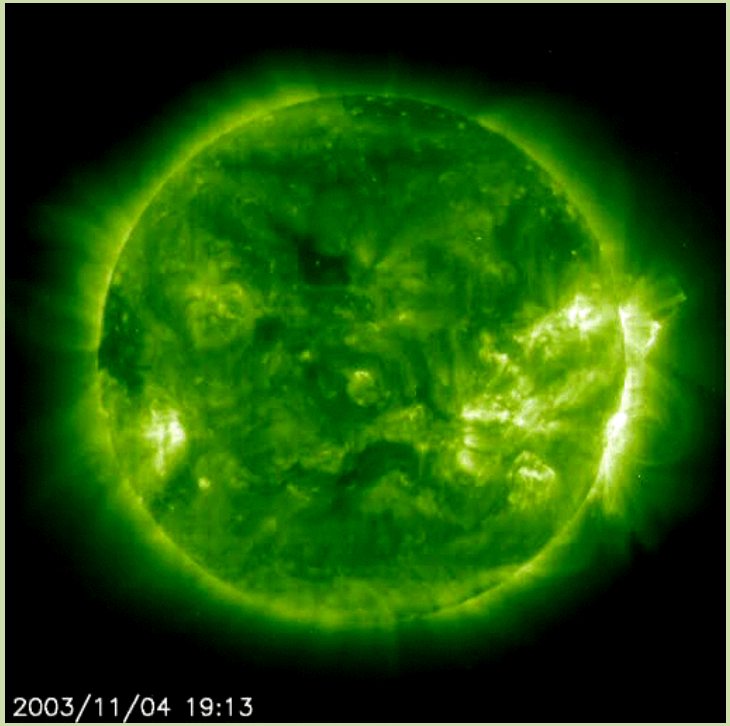
| DAY | BEGIN | MAX | END | LOC | XRAY | OP | 10CM | Catania/NOAA | RADIO_BURST_TYPES |
|---|---|---|---|---|---|---|---|---|---|
| 17 | 1504 | 1507 | 1511 | S22W65 | M1.0 | SN | | 12/3247 | |

END

## Flare classification

# FLARES - OVERVIEW

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

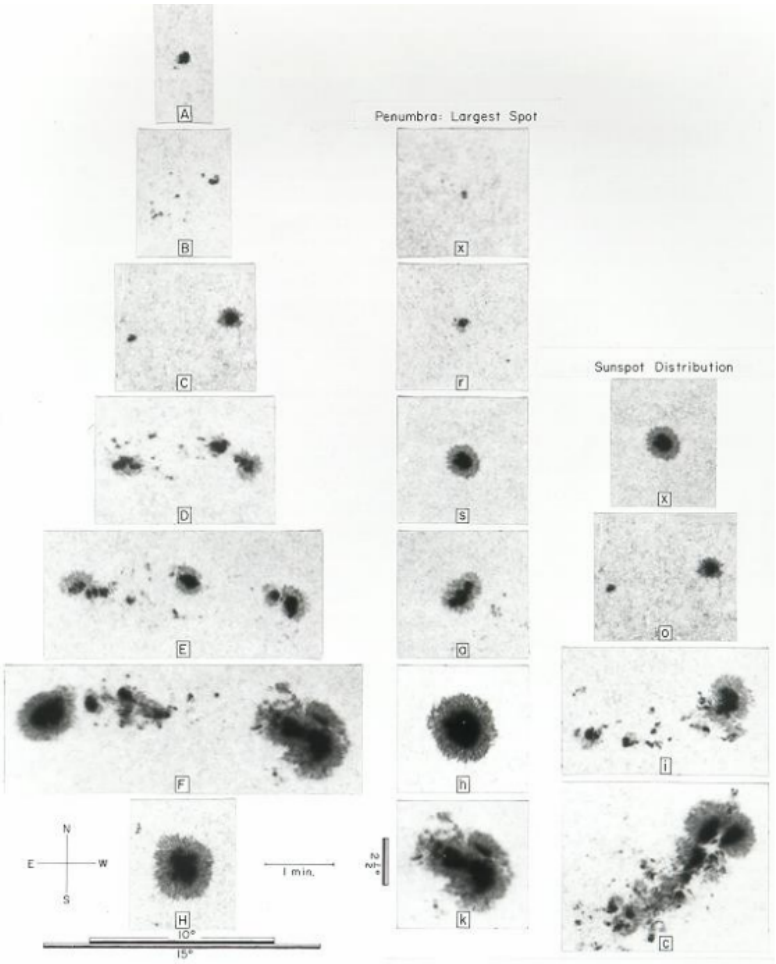



**SOHO/EIT**

# FLARE PREDICTIONS

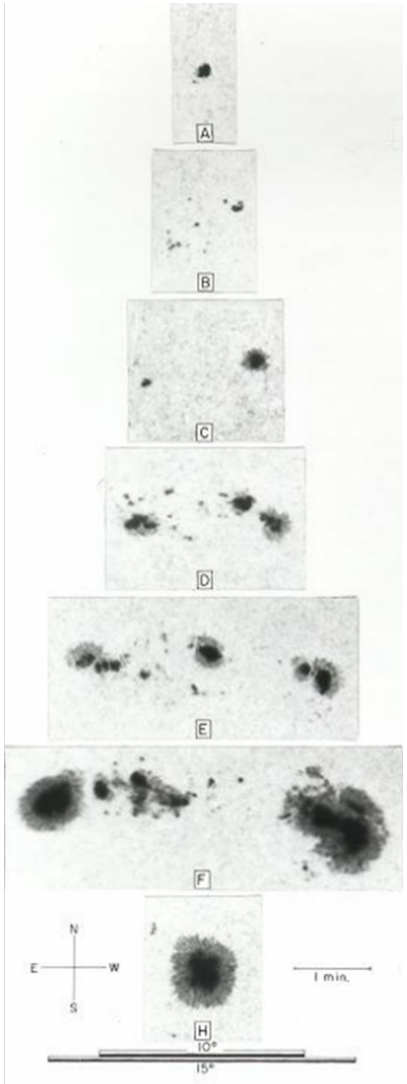
McIntosh classification

- 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
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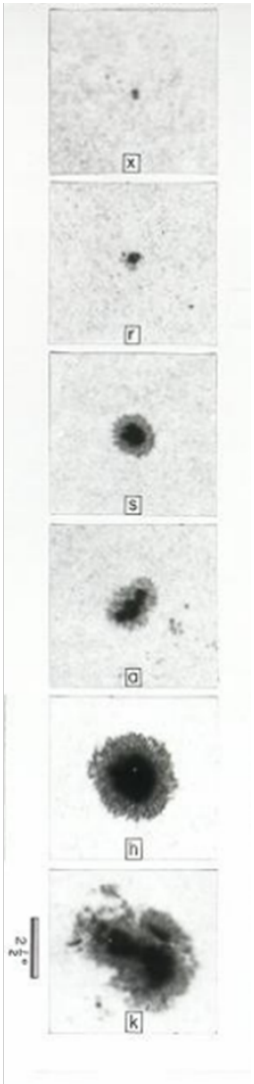


x
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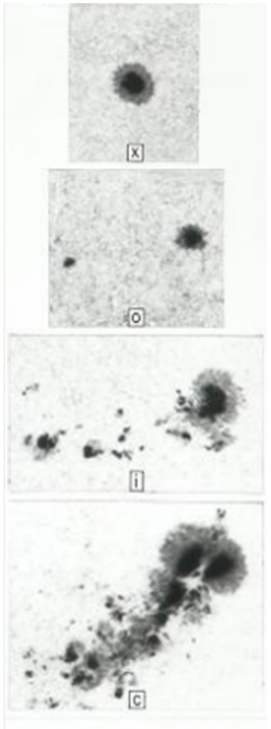


# FLARE PREDICTIONS



**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."

# FLARE PREDICTIONS

## Likelihood (terminology)

**RWC Belgium: Decision on use of scales and wording**

**Flare forecast**

| ISES |
|---|
| 0 = Quiet (<50% probability of C-class flares)<br>1 = Eruptive (C-class flares expected, probability >=50%)<br>2 = Active (M-class flares expected, probability >=50%)<br>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<br>C-class flaring activity/conditions expected<br>we expect solar active conditions ([C,M,X]-class flares)<br>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

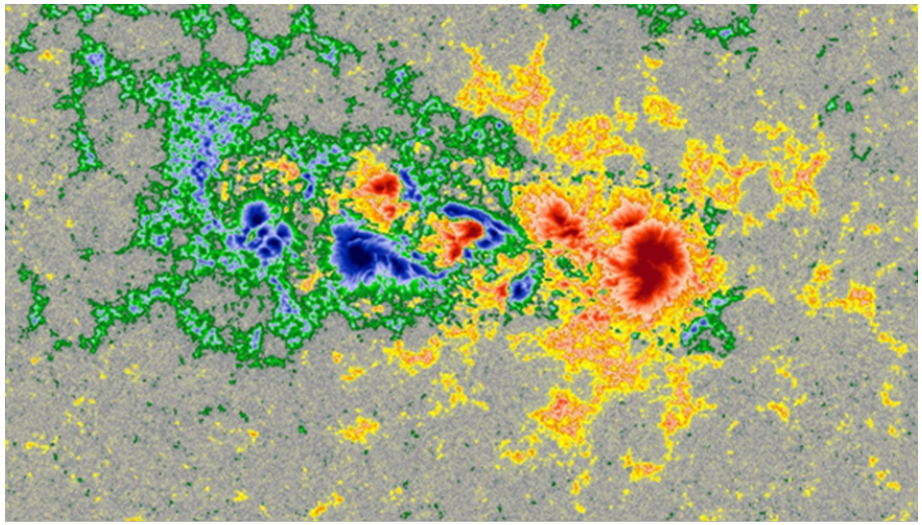
| Probability (%) | Terminology |
|---|---|
| 0-10 | Unlikely |
| 10-25 | Small chance |
| 25-50 | A chance; Possible |
| 50-75 | Likely |
| 75-100 | Very likely; Expected |

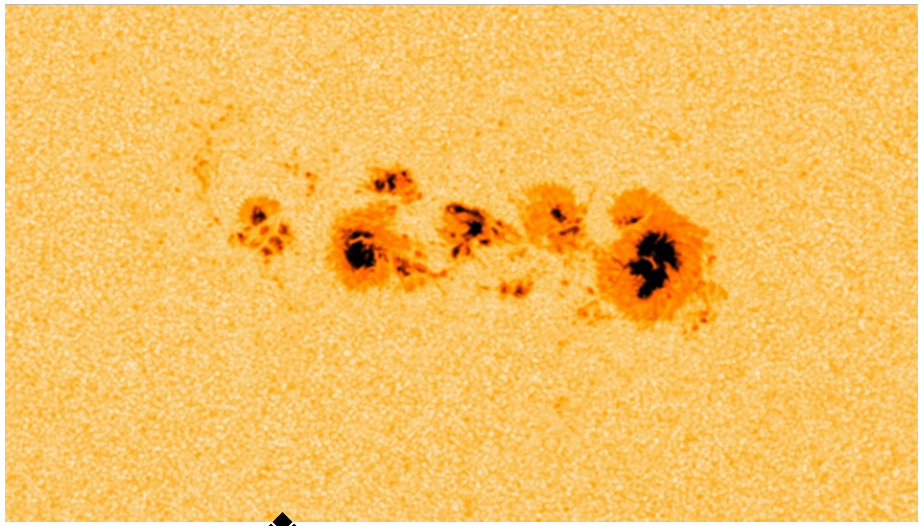
This is a topic under continued improvement / discussion….

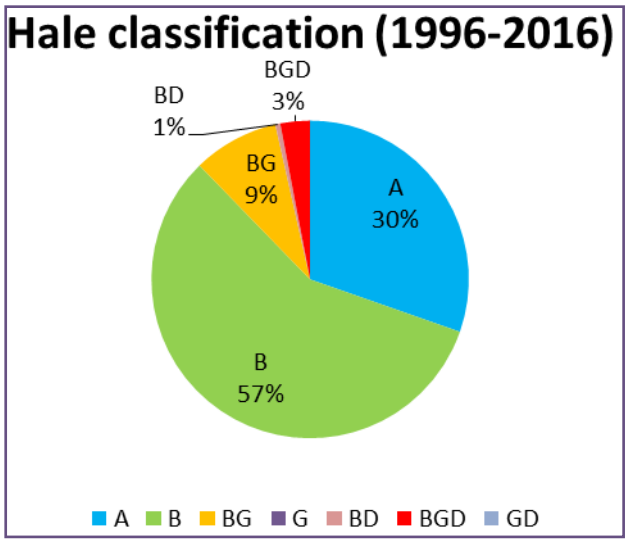
# FLARE PREDICTIONS

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)



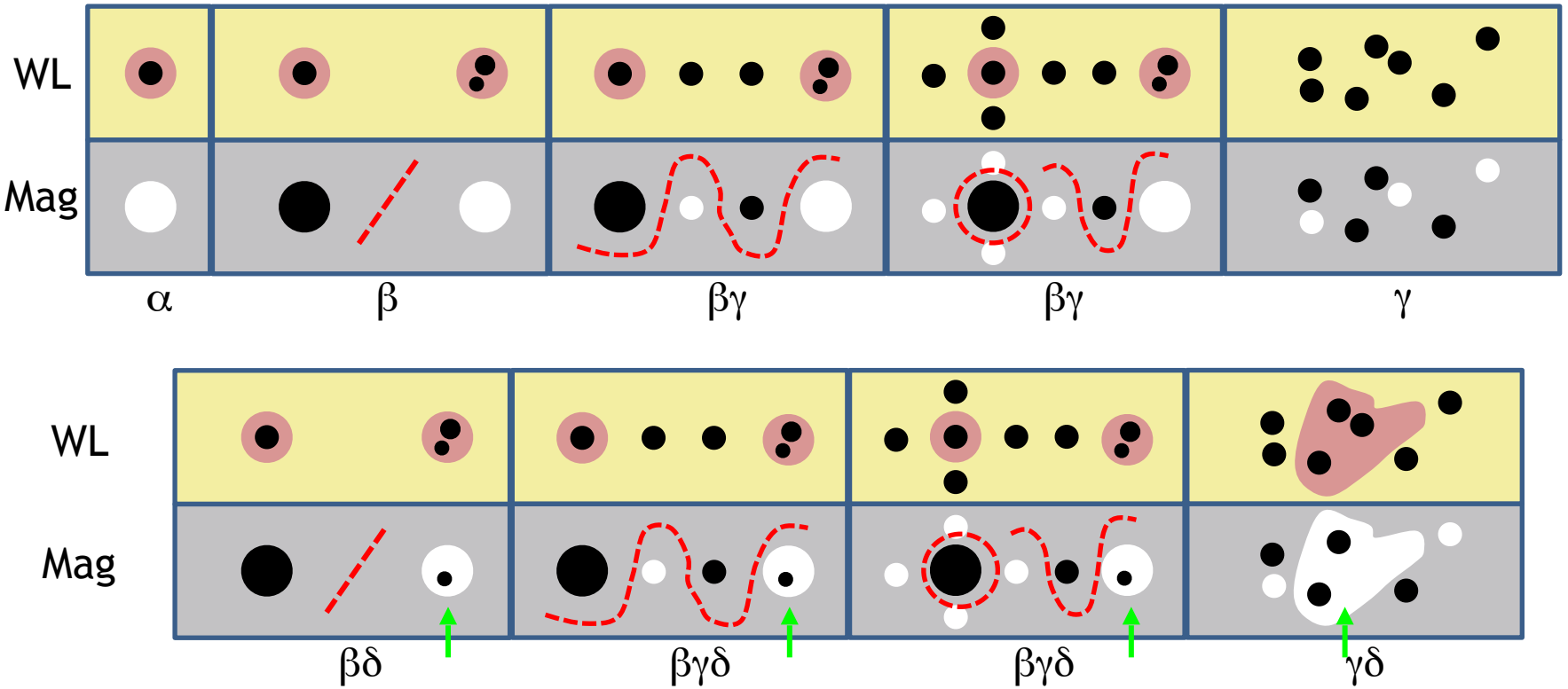




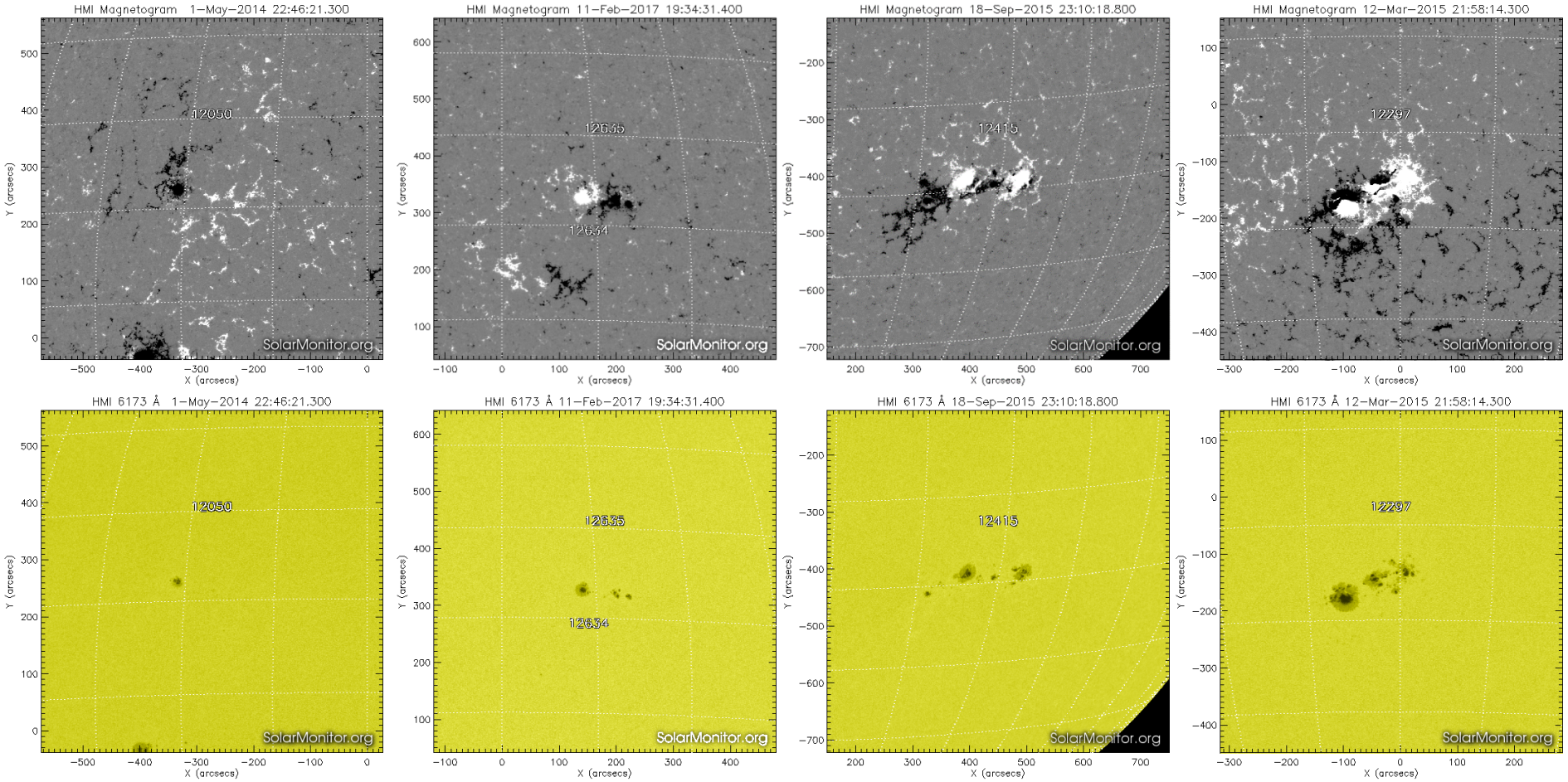

SDO/HMI

# FLARE PREDICTIONS

## Mount Wilson (Hale) classification - Sketches



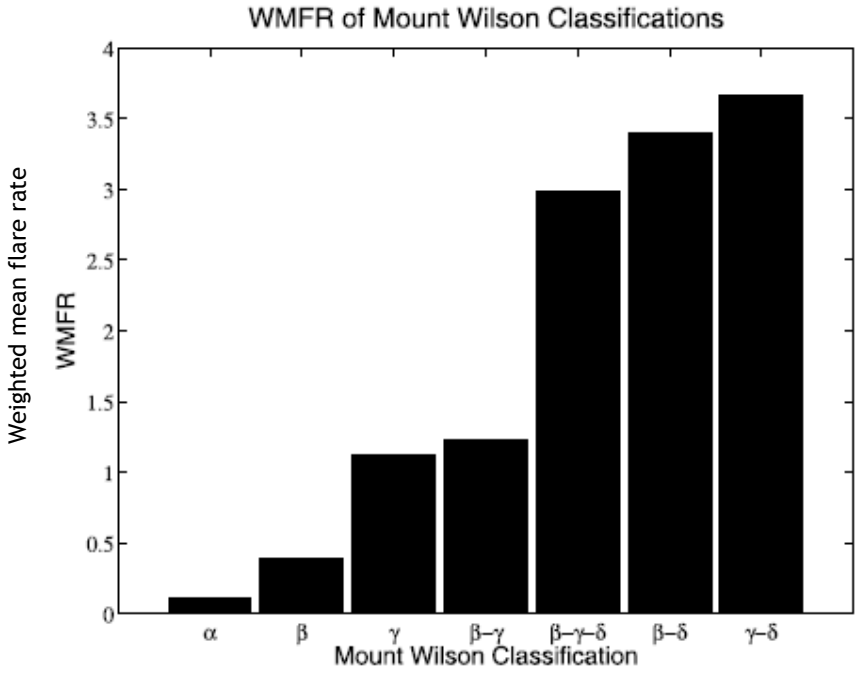
# EXAMPLES OF HALE CLASSIFICATION

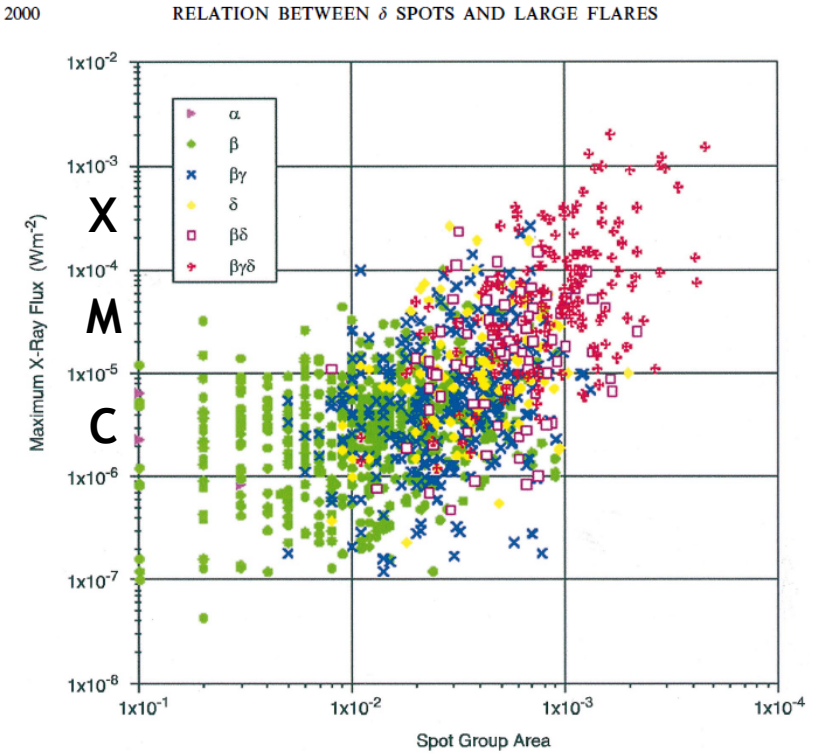


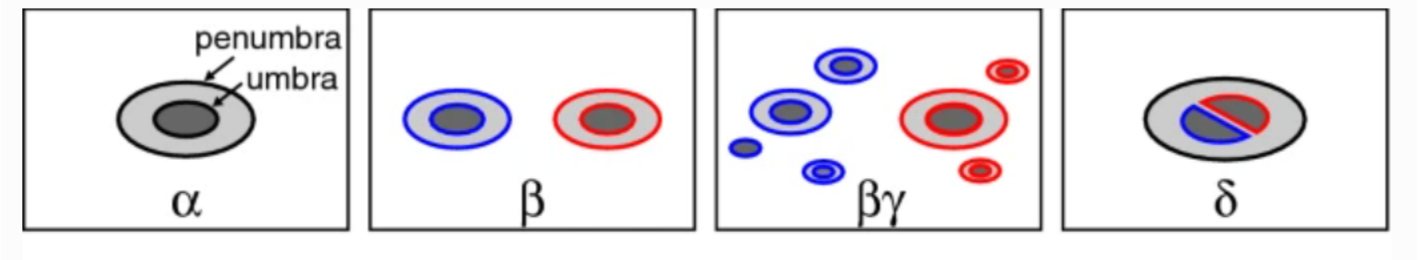

α β βγ βγδ

**SDO/HMI**

# FLARE PREDICTIONS

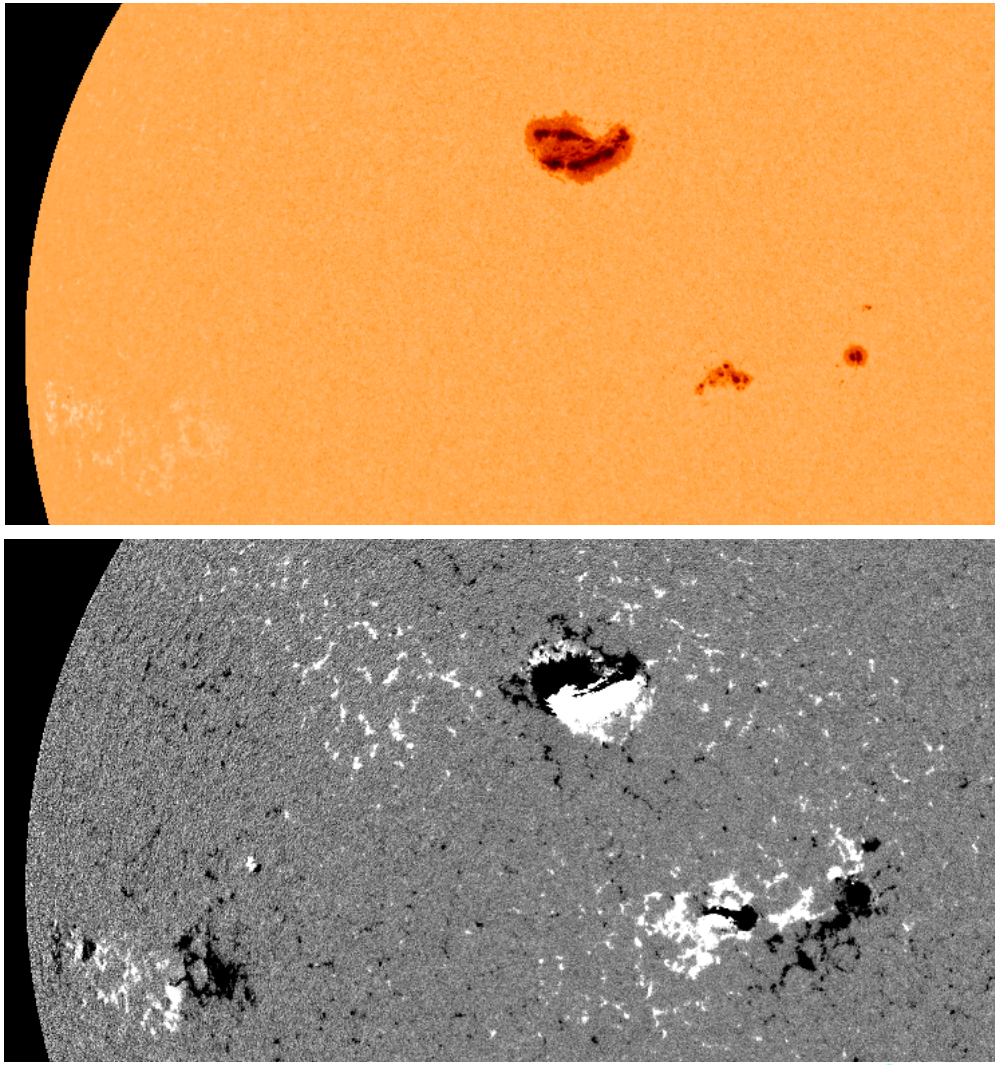


# FLARE PREDICTIONS

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



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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.

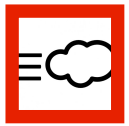
NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX  END  LOC    XRAY OP  10CM Catania/NOAA RADIO_BURST_TYPES
17  1504  1507 1511 S22W65 M1.0 SN       12/3247
END

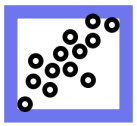

Finding your way in the URSIgram

Flare prediction

# SPACE WEATHER DRIVERS: EXERCISE

 Solar flares

 Coronal Mass Ejections

 Proton events

What does a forecaster look for?
What does a forecaster look at?

# SOLAR ERUPTIONS

Magnetic Reconnection

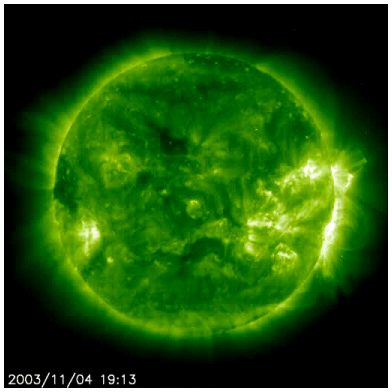
Radiation

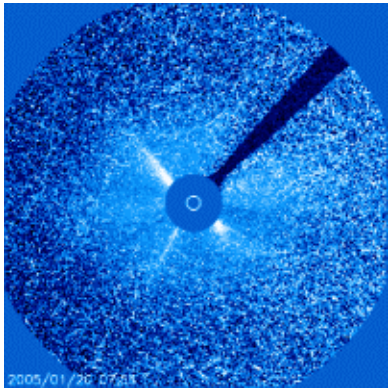
Particles

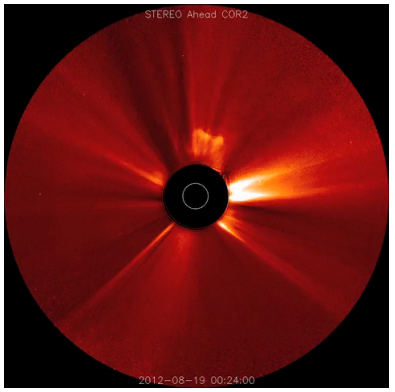
Solar flares

Proton events

Coronal Mass Ejections






SOHO/EIT

SOHO/LASCO

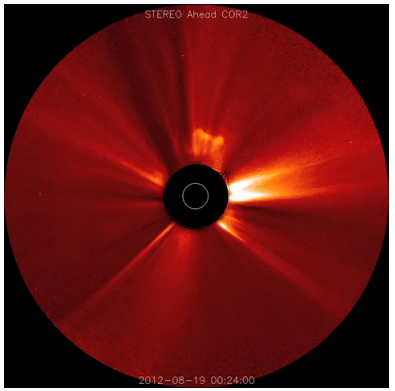
SOHO/LASCO

# SOLAR ERUPTIONS

Magnetic Reconnection

Particles

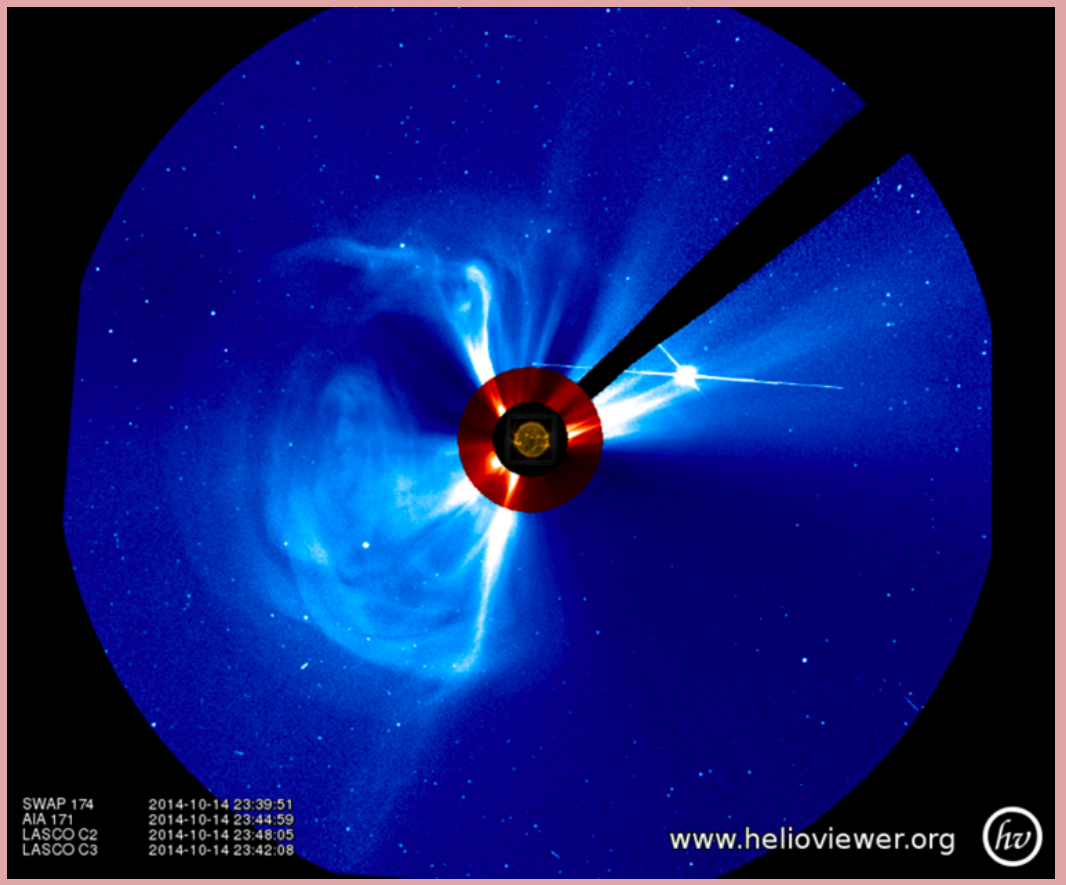
Coronal Mass Ejections




SOHO/LASCO

# CME - OVERVIEW

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




**PROBA2/SWAP**
**SDO/AIA**
**SOHO/LASCO**

# CORONAL MASS EJECTION

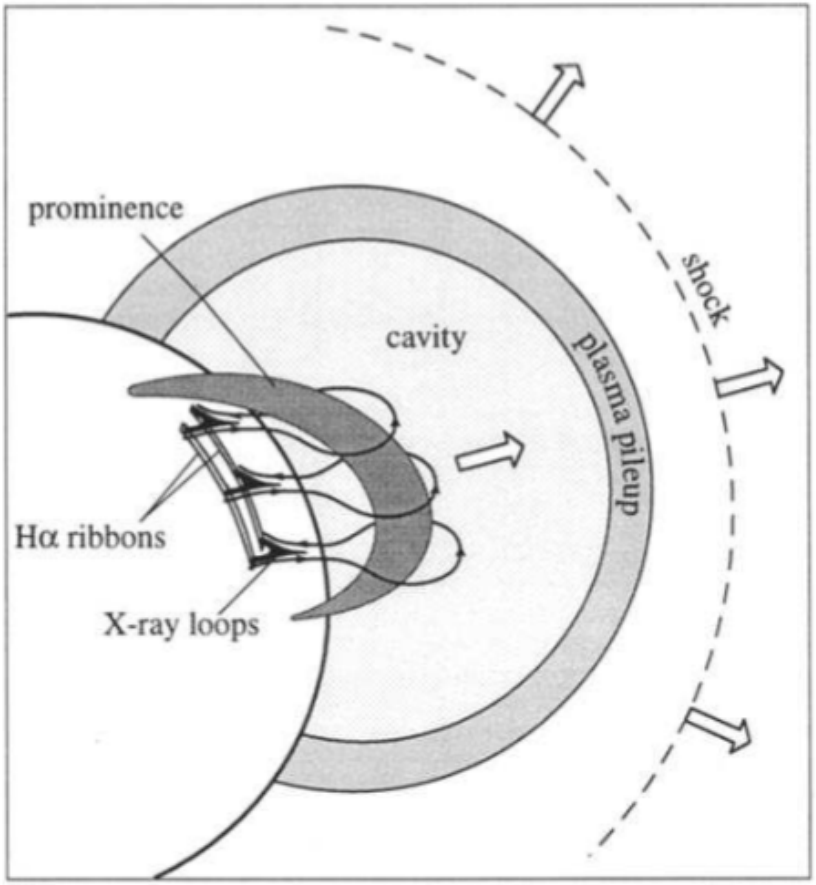
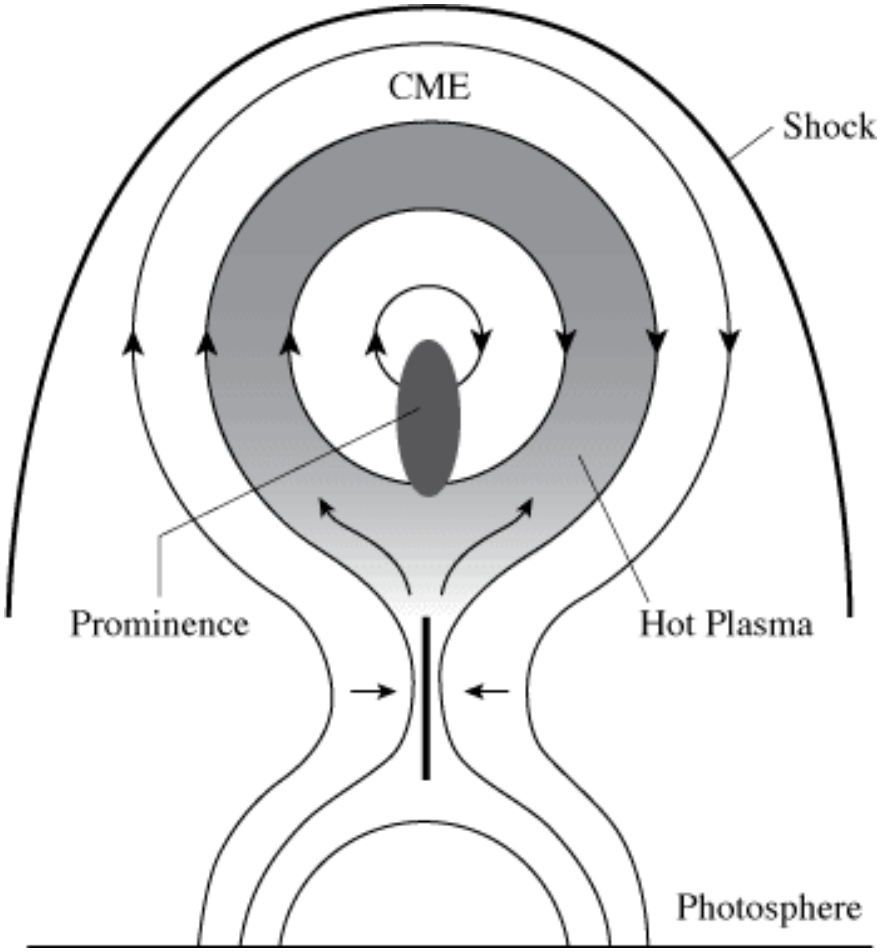



**Figure 3.** Schematic diagram showing the relationship between various features associated with a CME. The shaded region labeled "plasma pileup" refers to the outer circular arc seen in coronagraphs.



# CME SKETCH

Shock

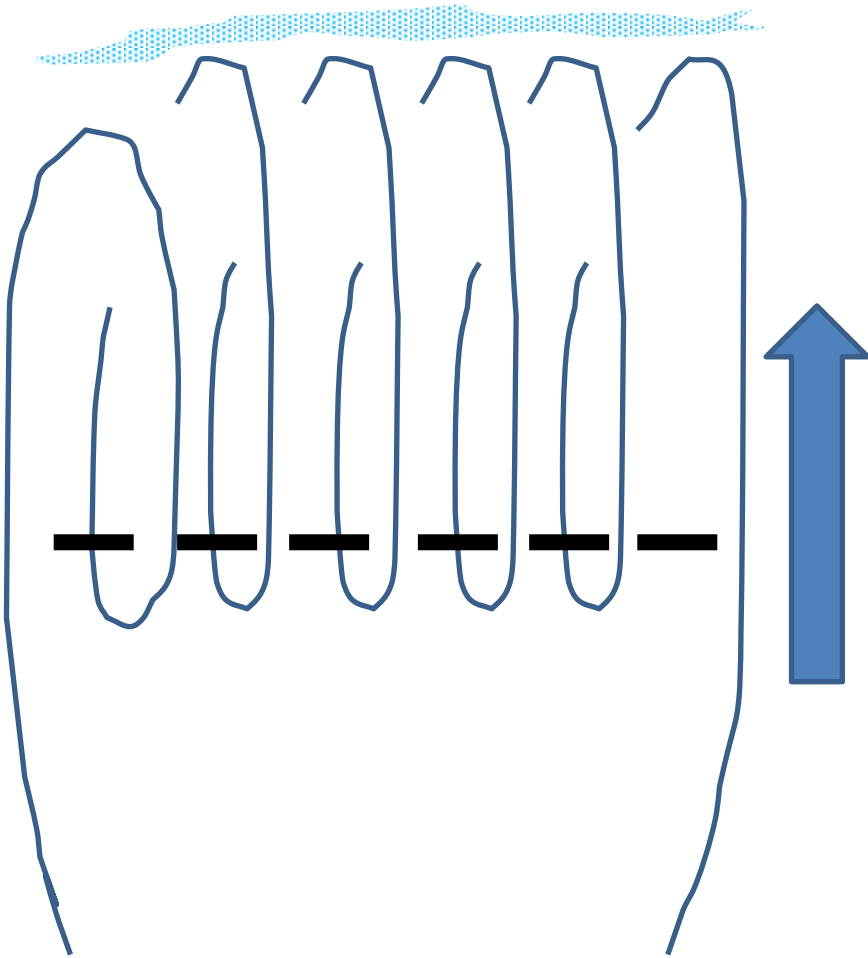
Plasma pile-up

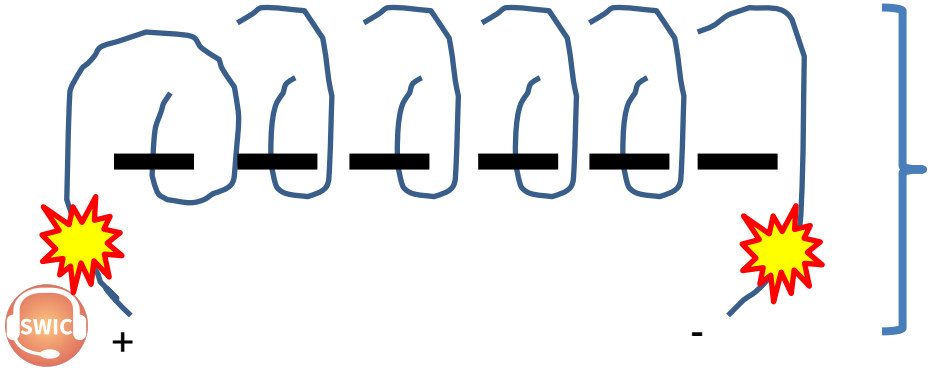
Cavity

Core filament

Flanks

Step 2: Expanding flux rope evolving into a CME






Step 1: Magnetic flux rope at magnetic reconnection

# CME SKETCH

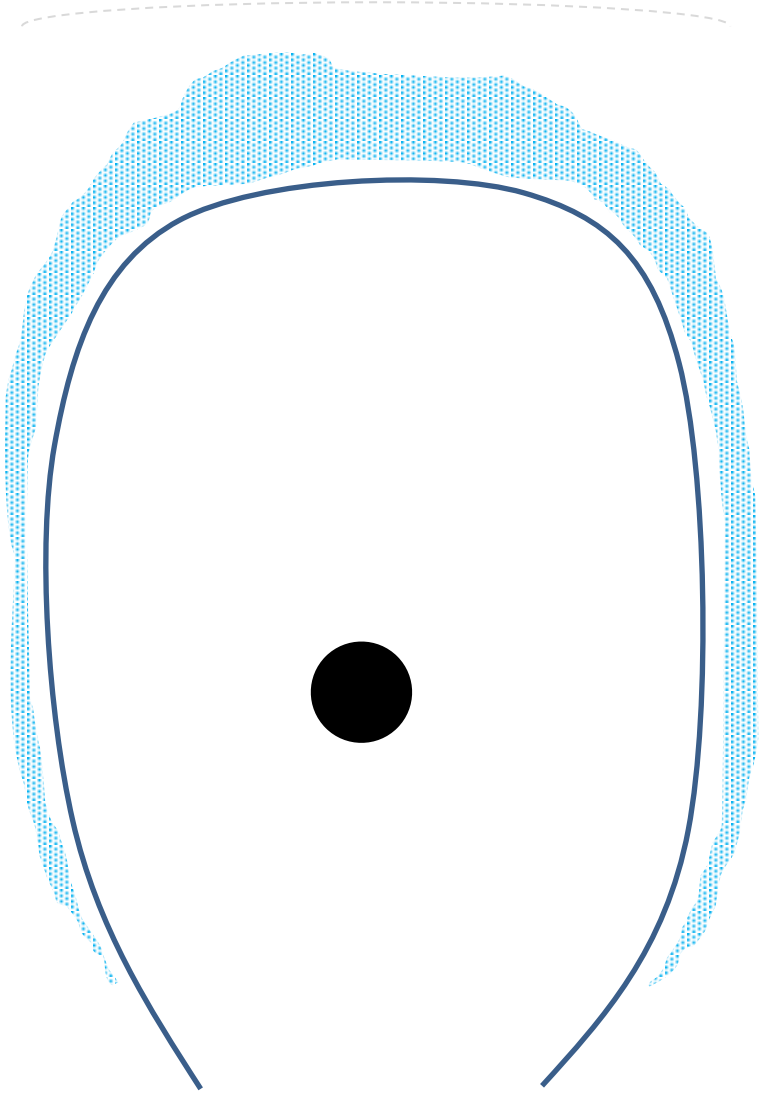
Shock

Plasma pile-up

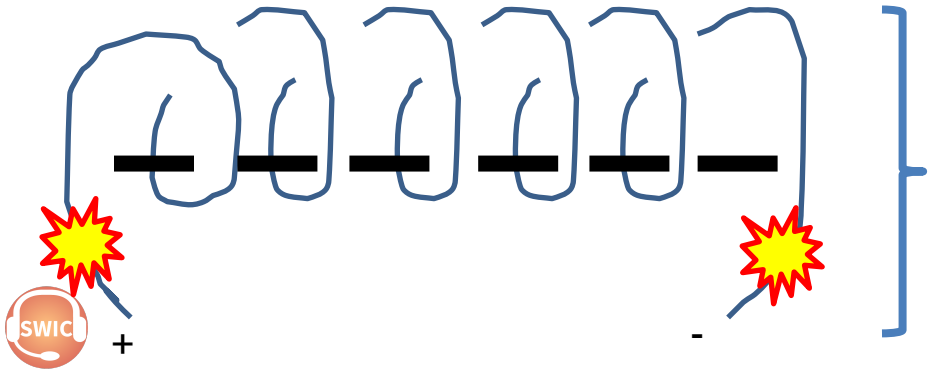
Cavity

Core filament

Flanks

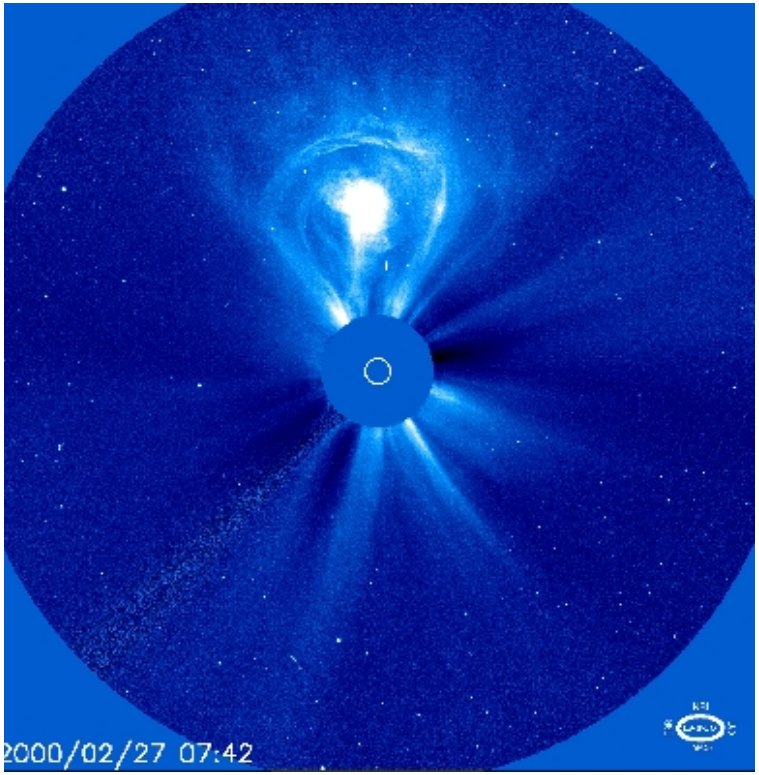


Step 2: Expanding flux rope evolving into a CME

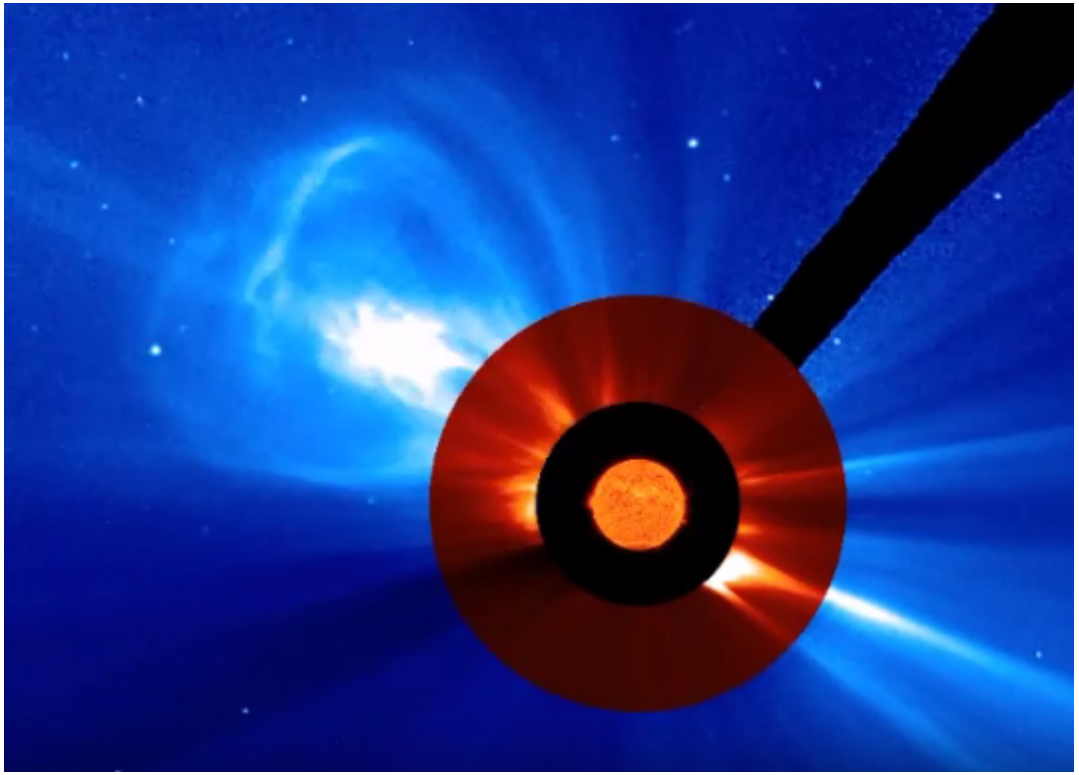



Step 1: Magnetic flux rope at magnetic reconnection

# CORONAL MASS EJECTION

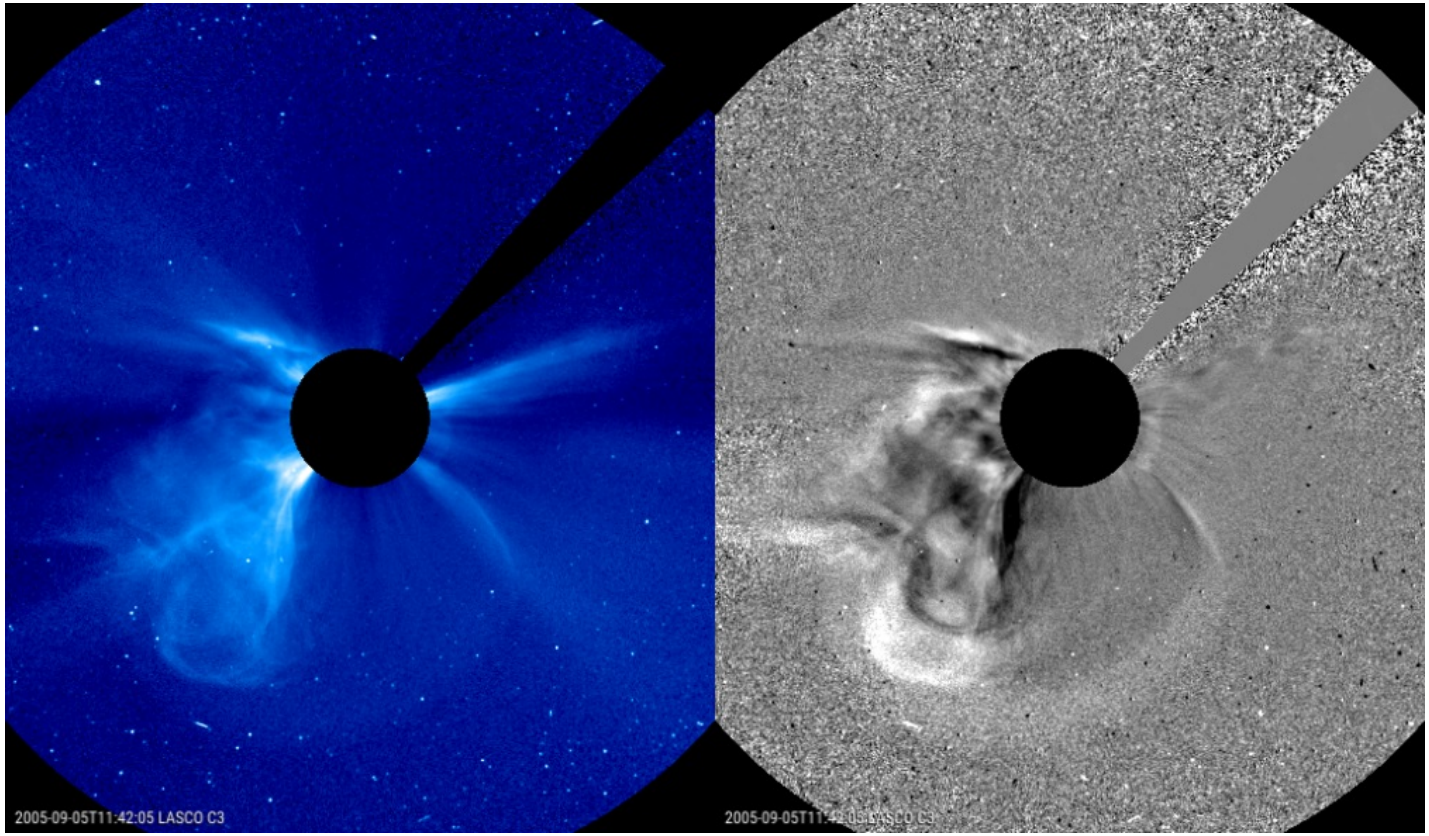



SOHO/LASCO



SDO/AIA
SOHO/LASCO

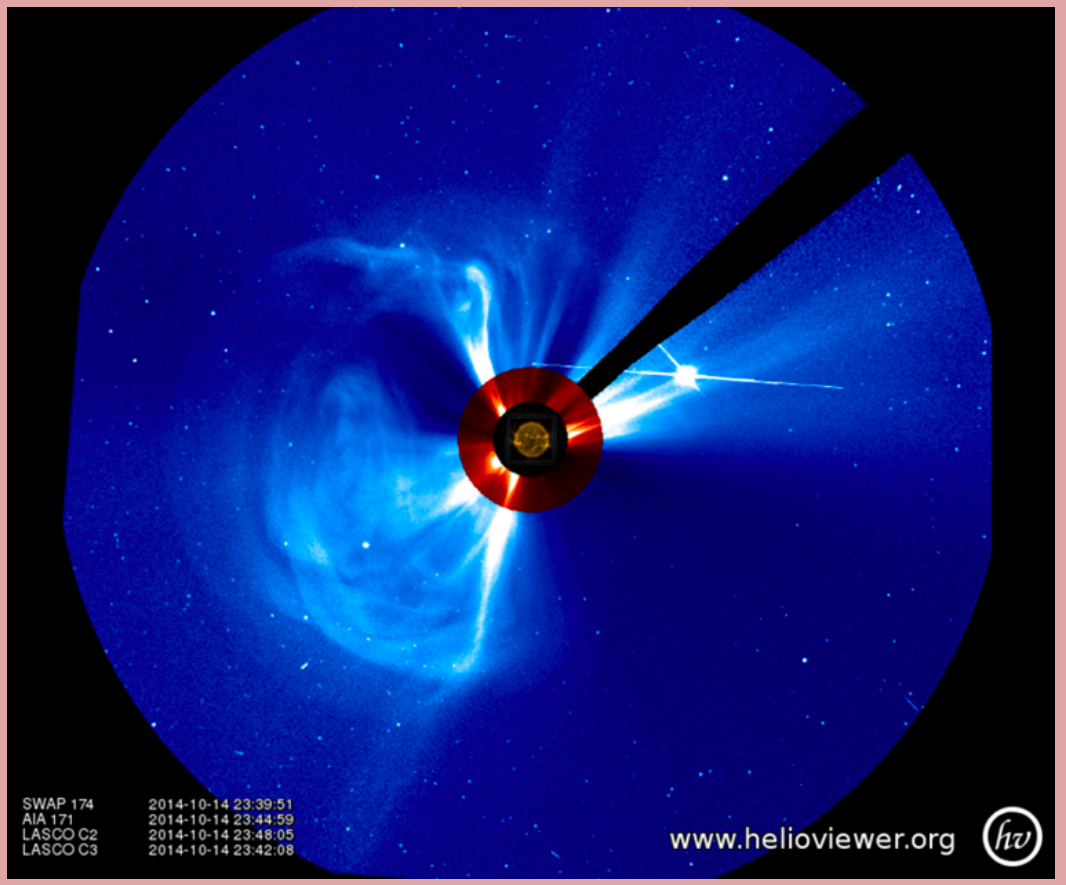
# DIFFERENCE IMAGES




**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)

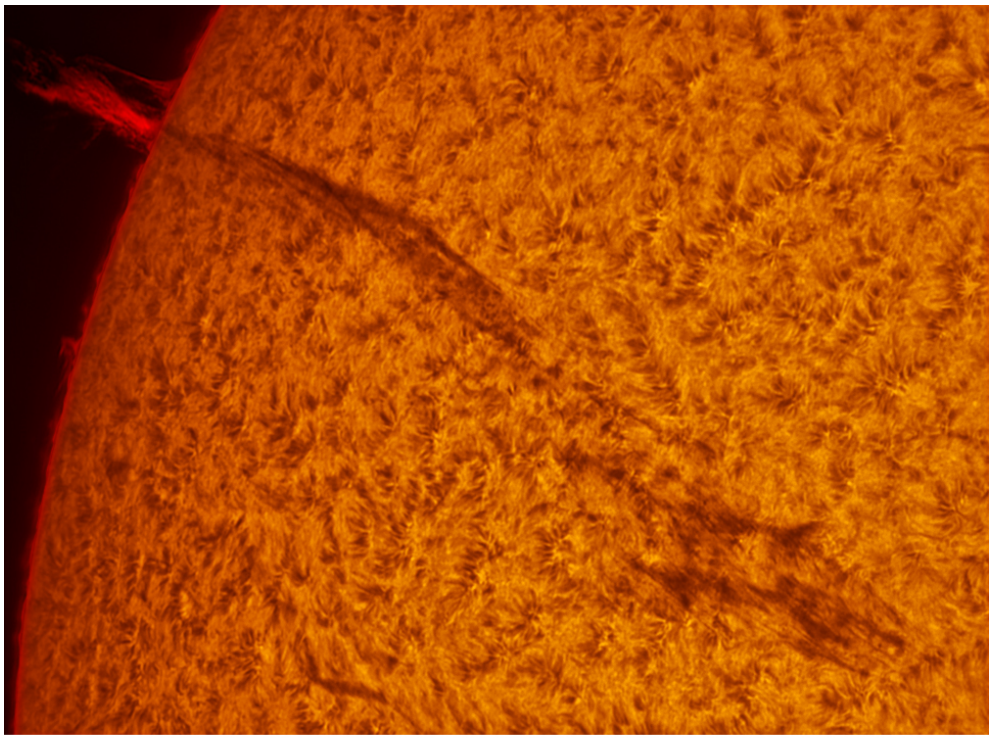
Mark the transition between positive and negative magnetic areas

Appear all over solar disk

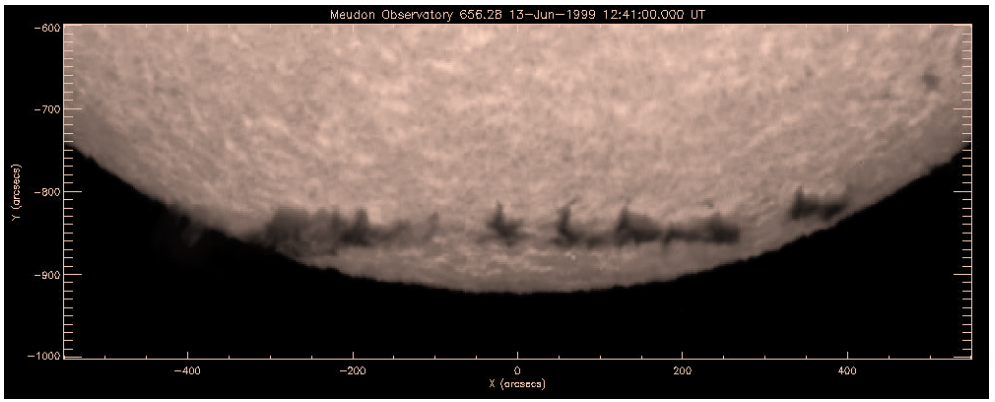
Location
- In active region

  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

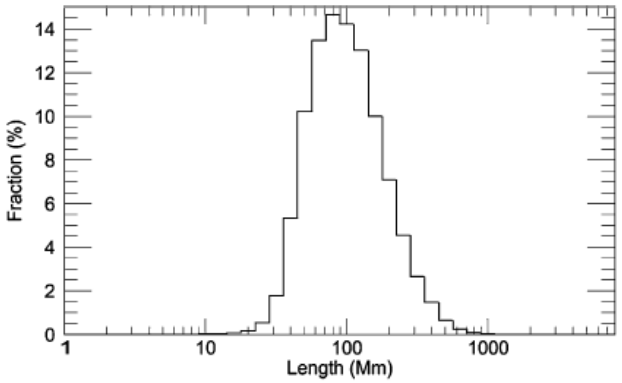


# FILAMENTS & PROMINENCES

- 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



**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*

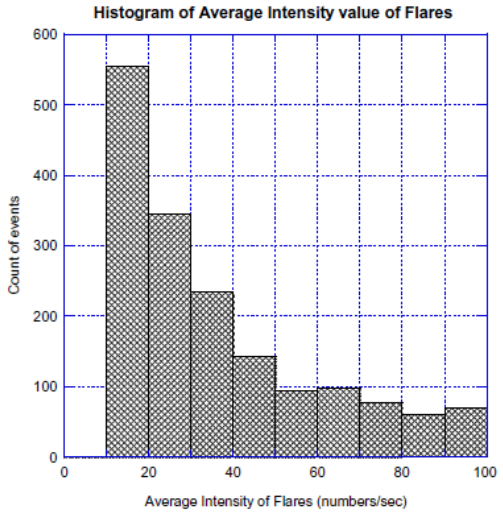



Fig. 6. Histogram of intensity of solar flares which are occurred during duration time of filament disappearance event during 1996–2010.

# FILAMENT/PROMINENCE ERUPTIONS

Height

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

Other signs

- Darkening filament
- Change in tilt or length

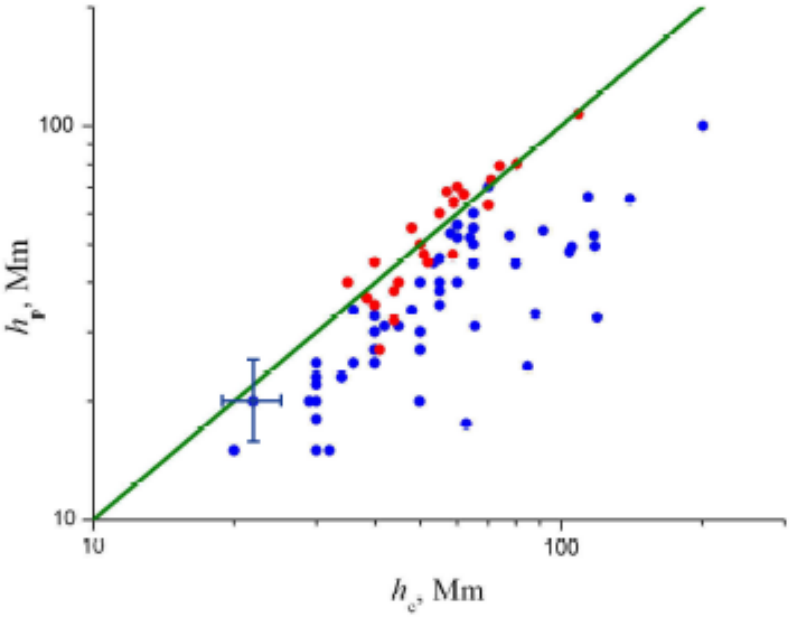
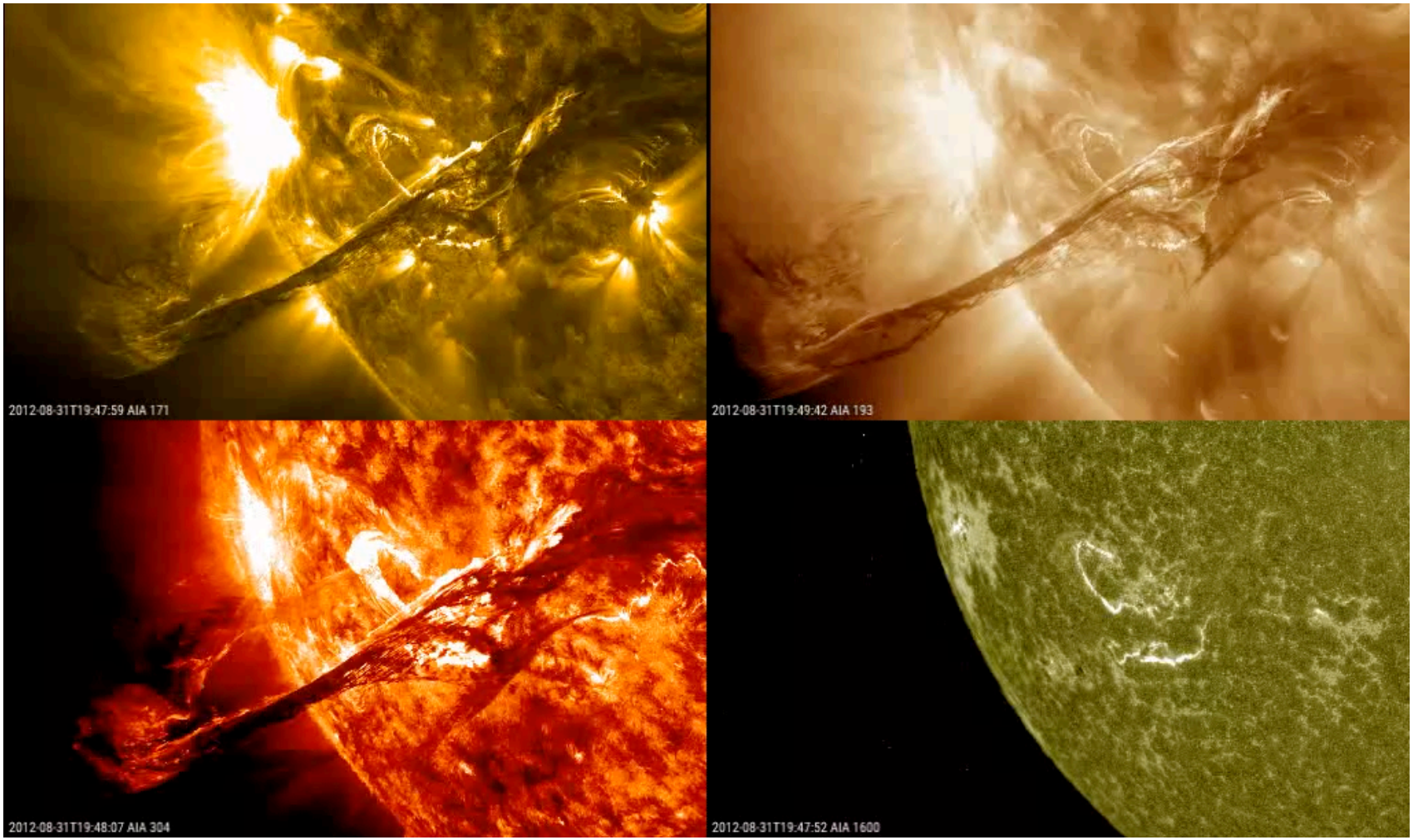



**Fig. 7.** The observed filament height above the chromosphere $h_p$ versus the critical height of stable filament equilibrium $h_c$. The blue circles correspond to the filaments which safely passed the west limb. The red circles correspond to the filaments which disappeared from the disk. The straight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

# 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


Finding your way in the URSIgram

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 Mach 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.

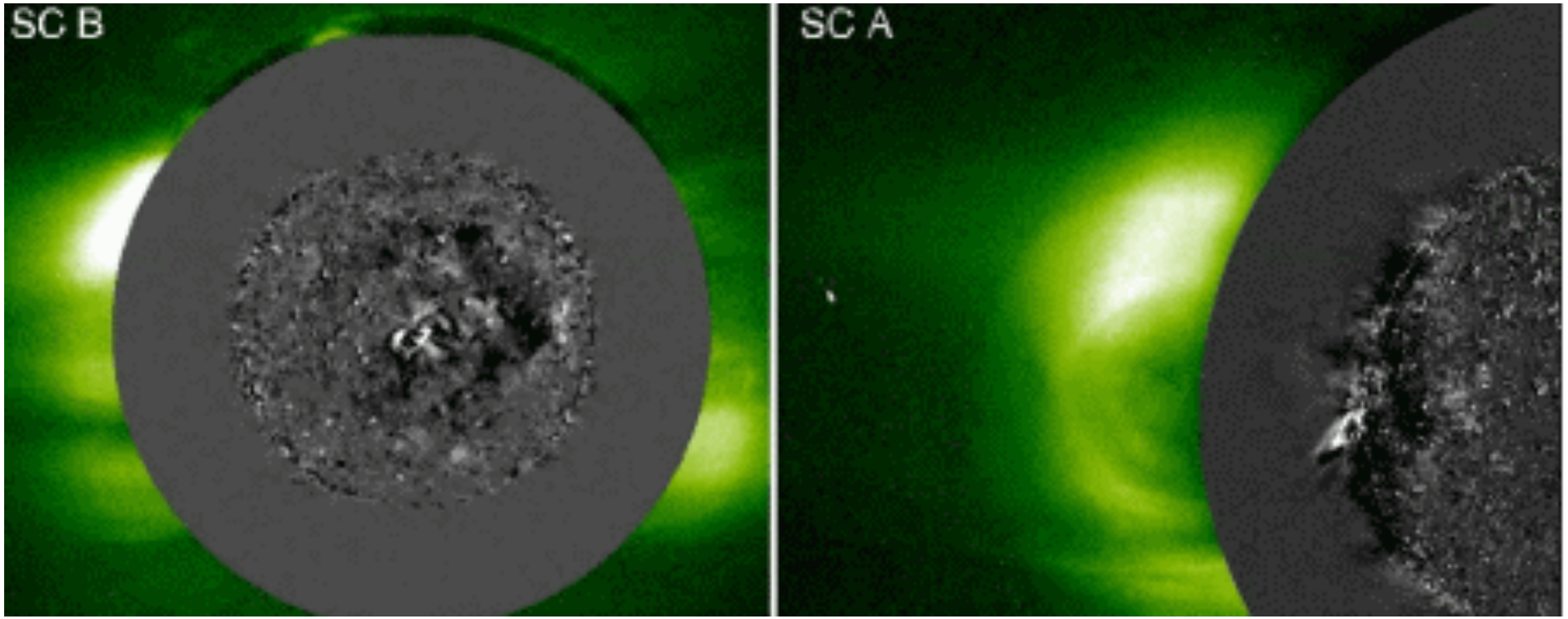
TODAY'S ESTIMATED ISN : 044, BASED ON 14 STATIONS.

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

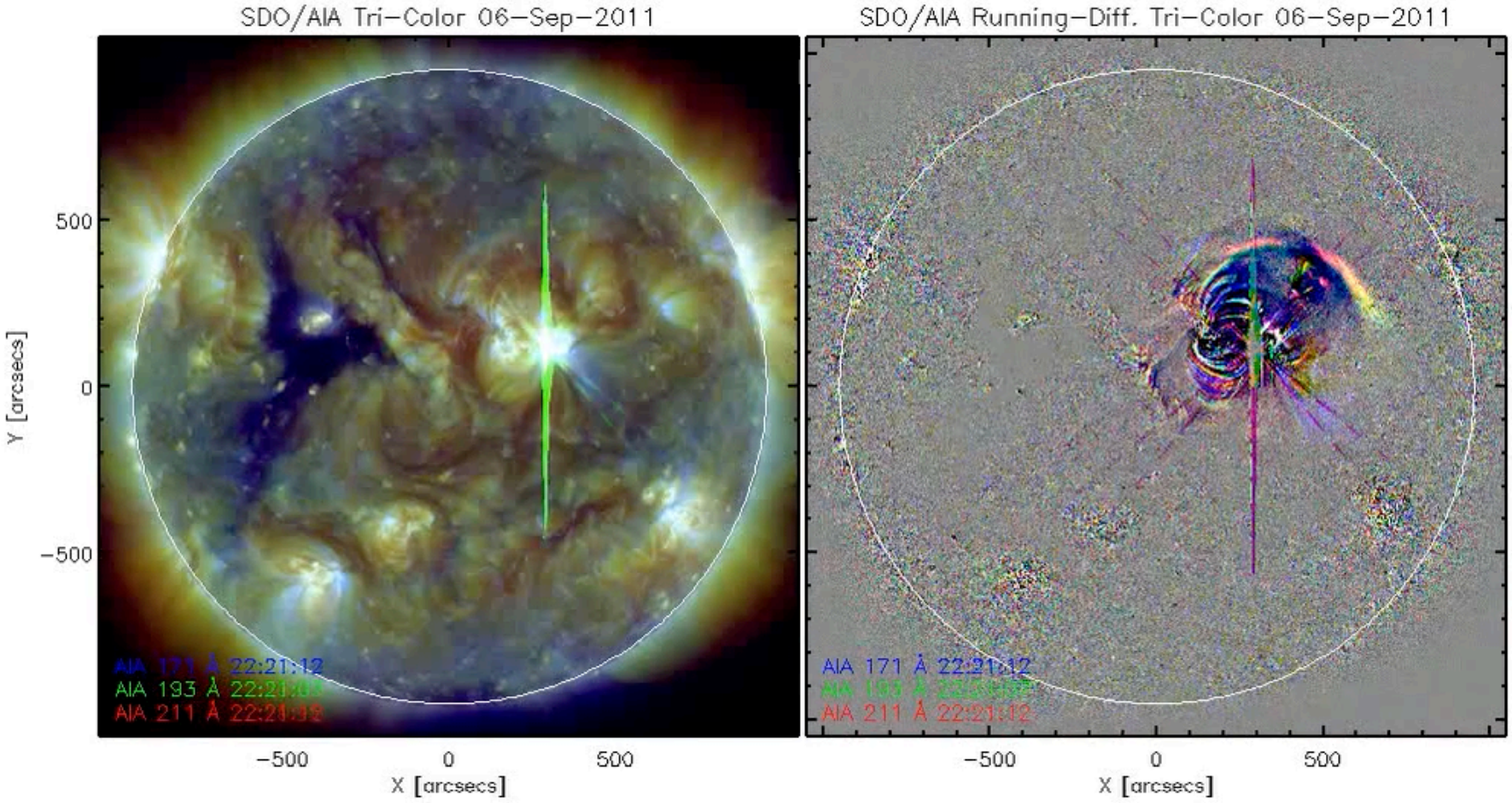
NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
17 1504 1507 1511 S22W65 M1.0 SN 12/3247
END

# EIT WAVE




STEREO/EUVI & COR1

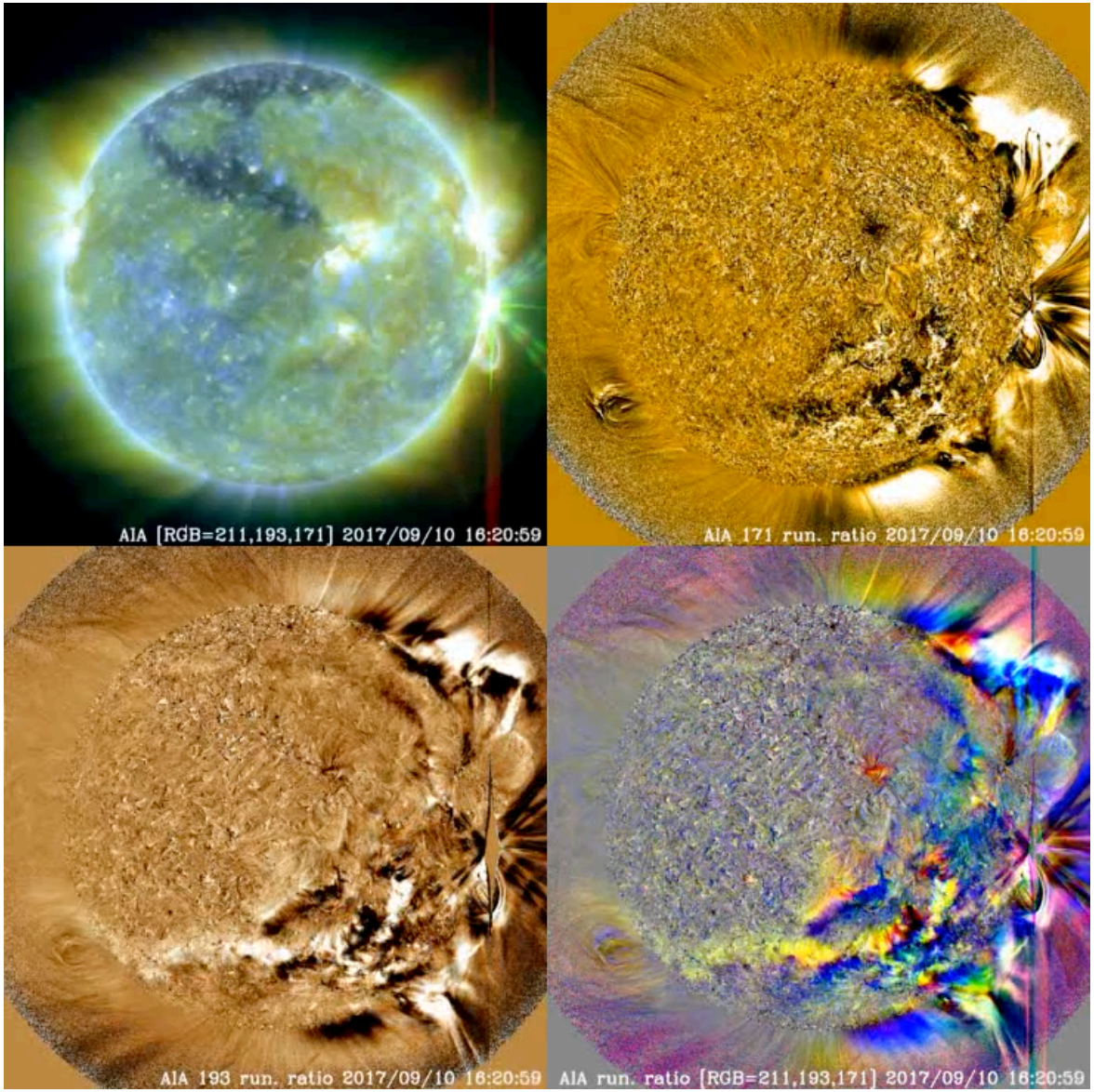
# EUV WAVE



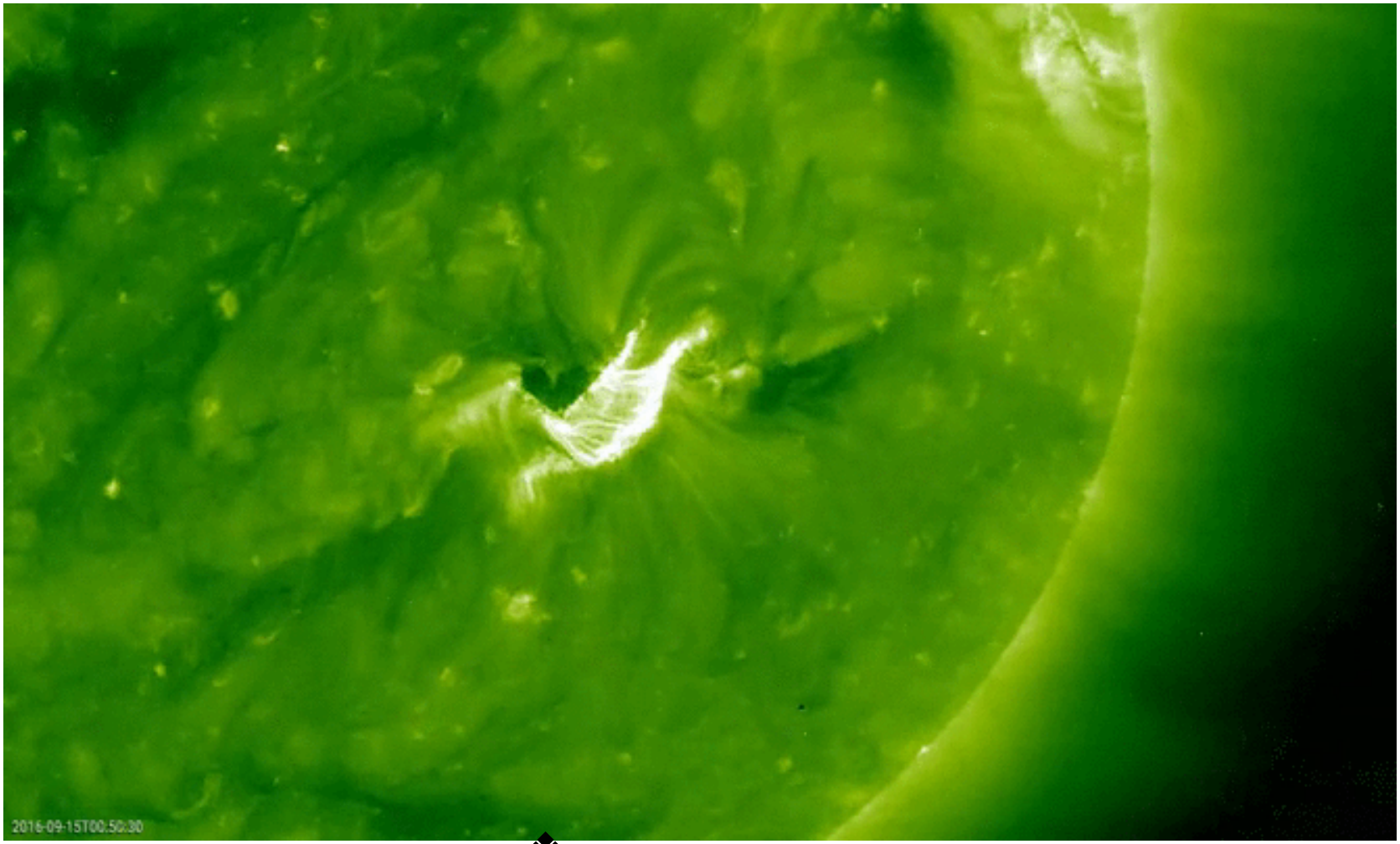

SDO/AIA

# GLOBAL EUV WAVE

**SDO/AIA**

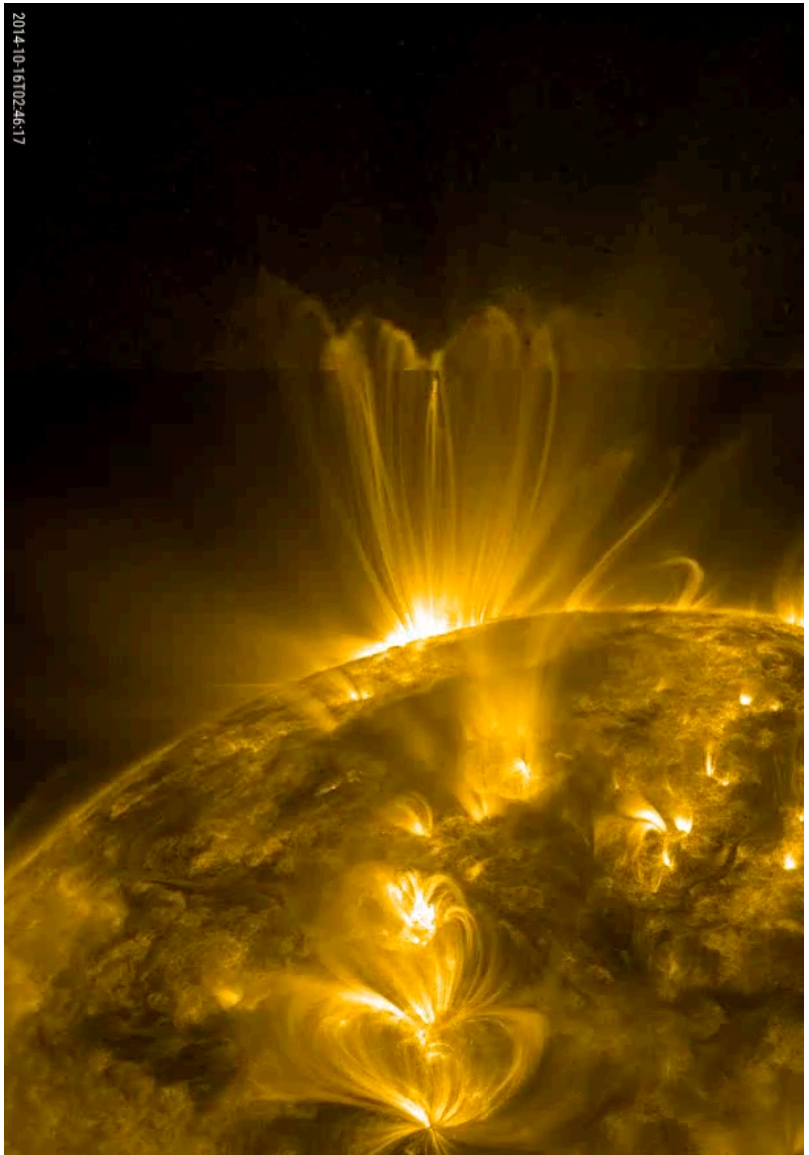


# CORONAL DIMMING
# ~~(TRANSIENT CORONAL HOLE)~~




STEREO/EUVI

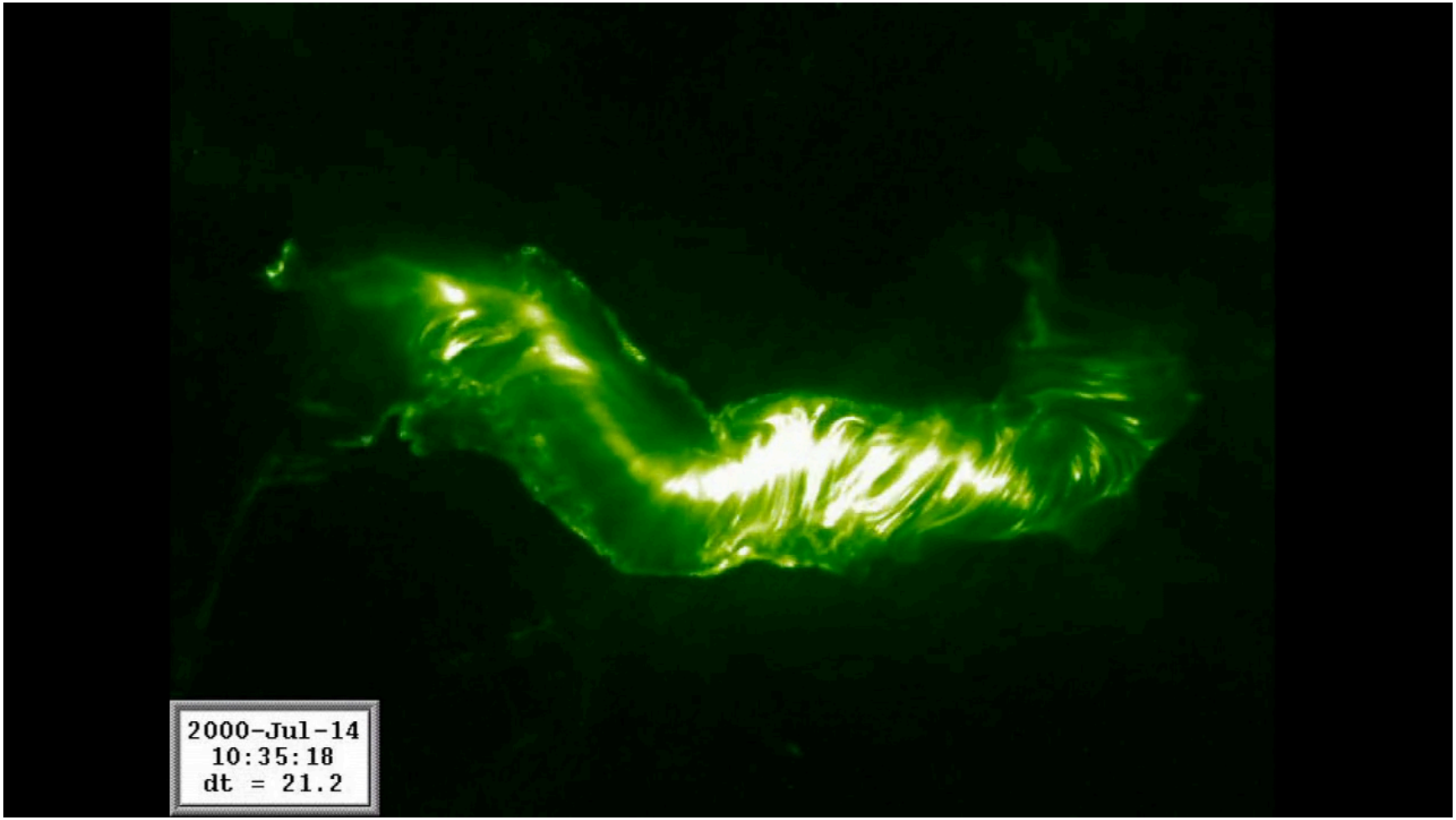
# POST-ERUPTION CORONAL LOOPS




PROBA2/SWAP

SDO/AIA

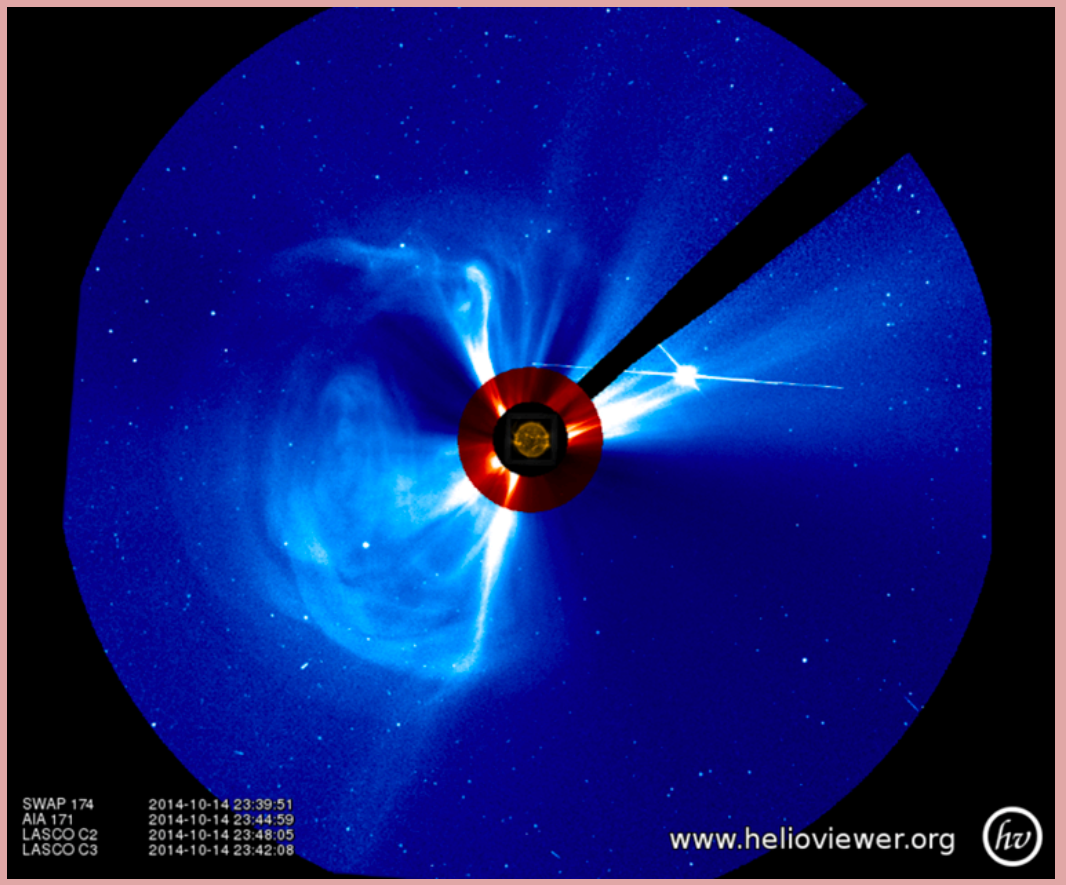
# POST-ERUPTION CORONAL LOOPS ARCADE




SOHO/EIT

# CME - OVERVIEW

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




**PROBA2/SWAP**
**SDO/AIA**
**SOHO/LASCO**

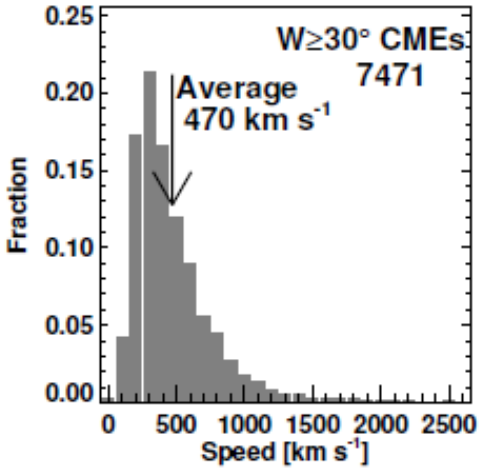
# CORONAL MASS EJECTION

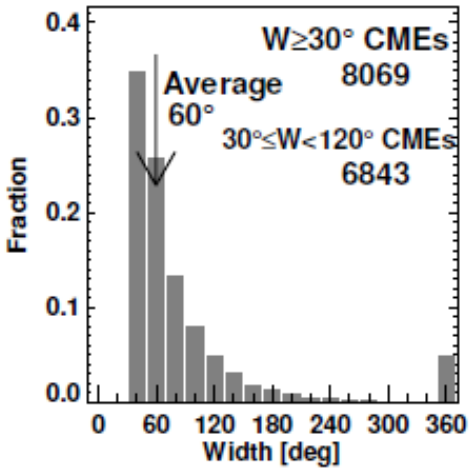
## Characteristics

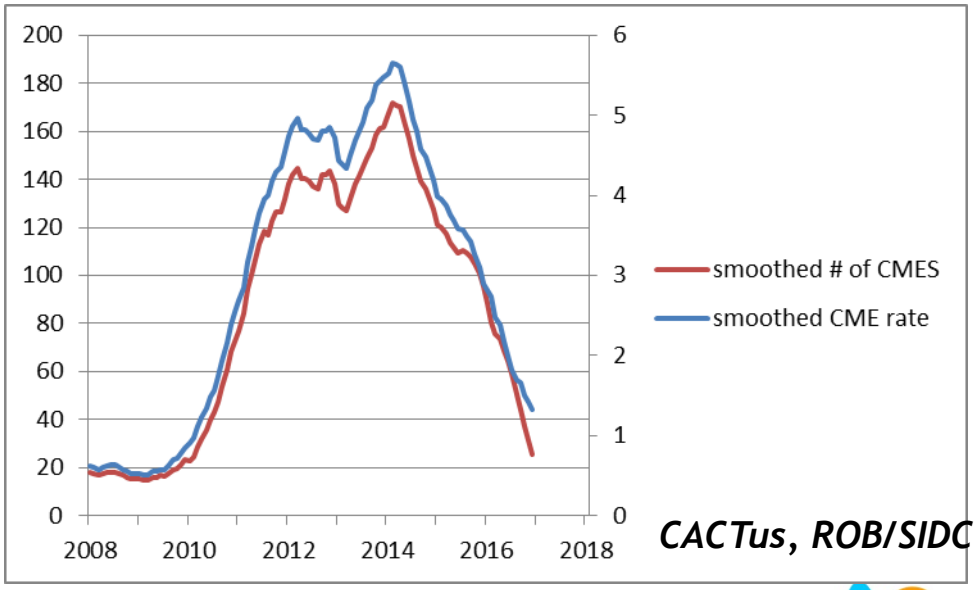
- Average speed
  - 470 km/s
  - Fast transit event (<24h)
- Average width

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

  1-6 / day



# CORONAL MASS EJECTION

## Terminology

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

  Frontside/Farside
- De- & acceleration

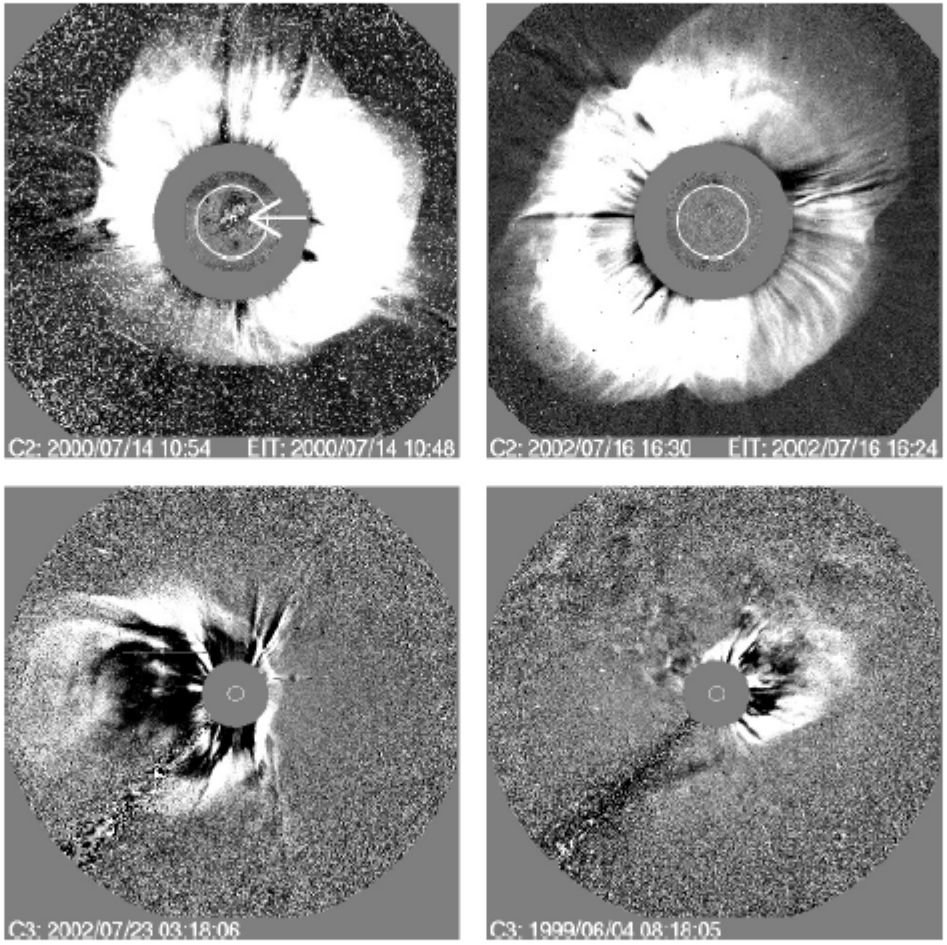
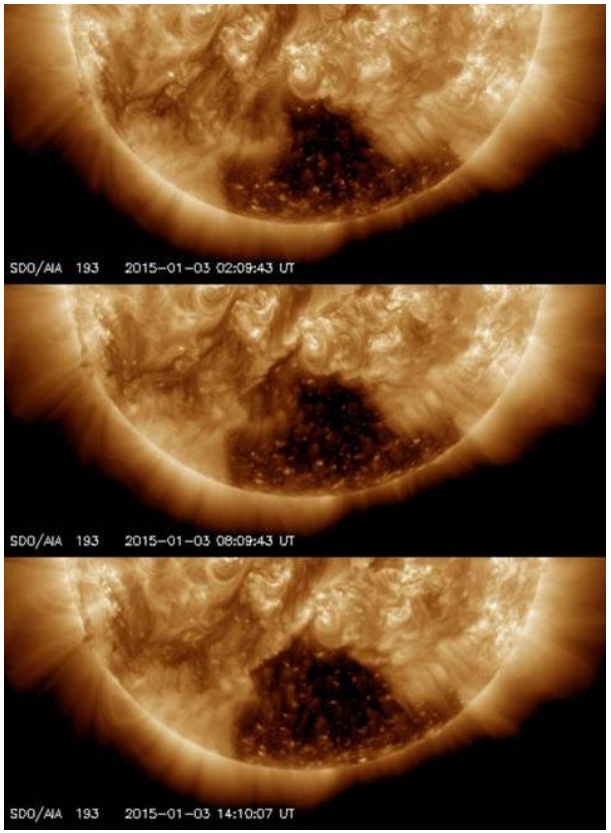



**Figure 4:** Examples of a variety of halo CME observations, clockwise: a frontside full halo (arrow shows likely source near Sun center); a backside full halo; a partial halo; and an asymmetric full halo. Image reproduced with permission from Gopalswamy *et al.* (2003a).

# CORONAL MASS EJECTION

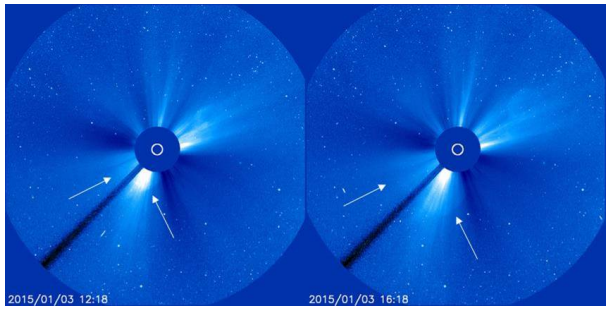
Terminology

- 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



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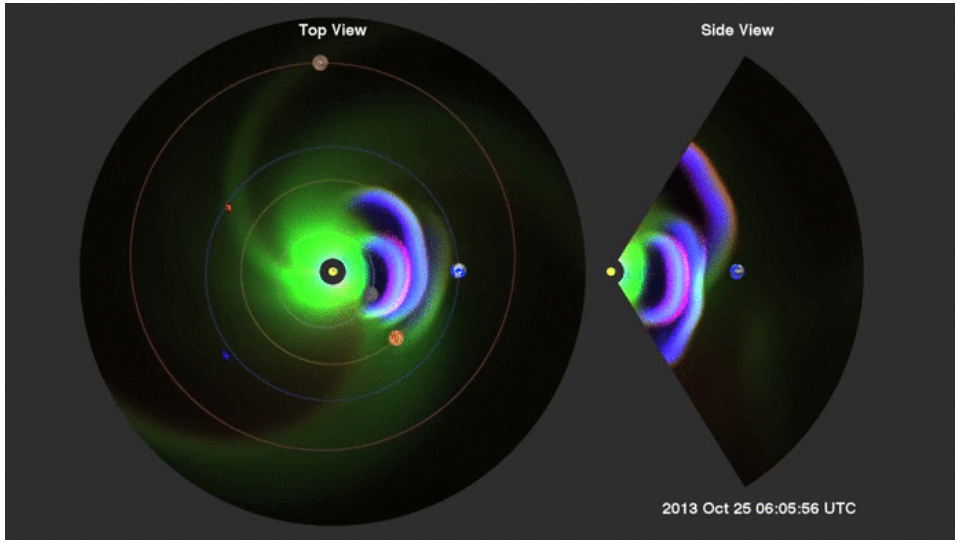

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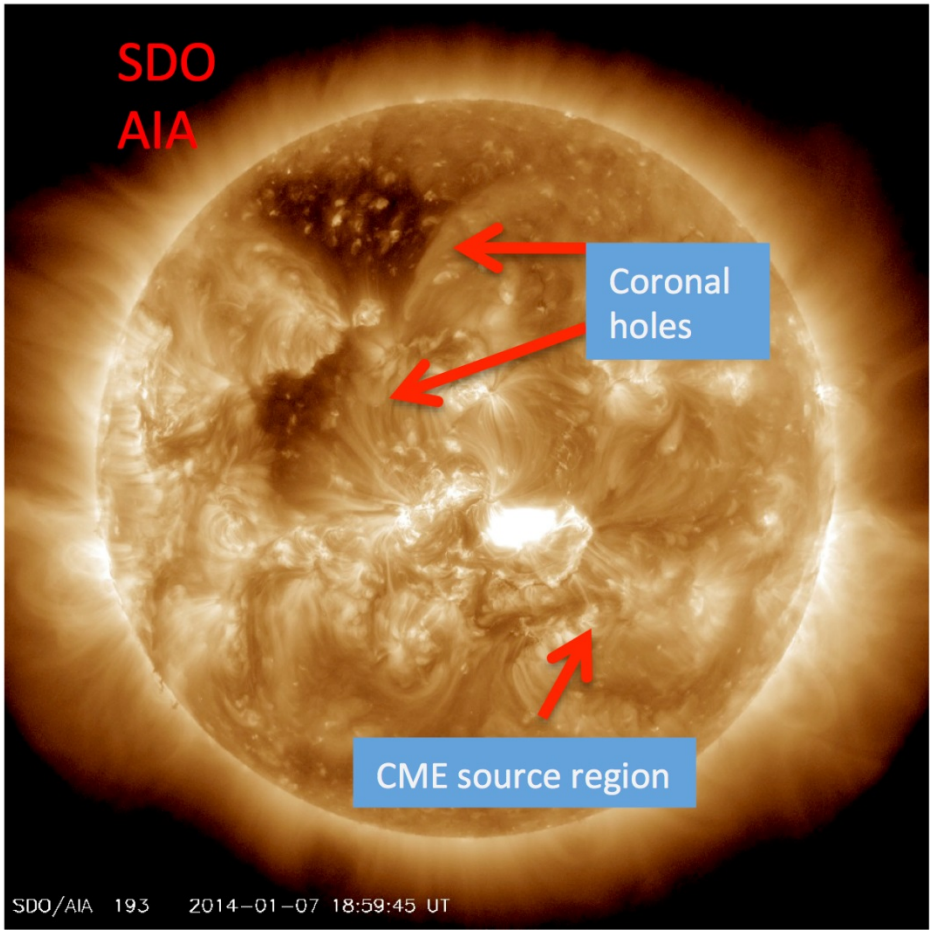



SDO/AIA

# CORONAL MASS EJECTION

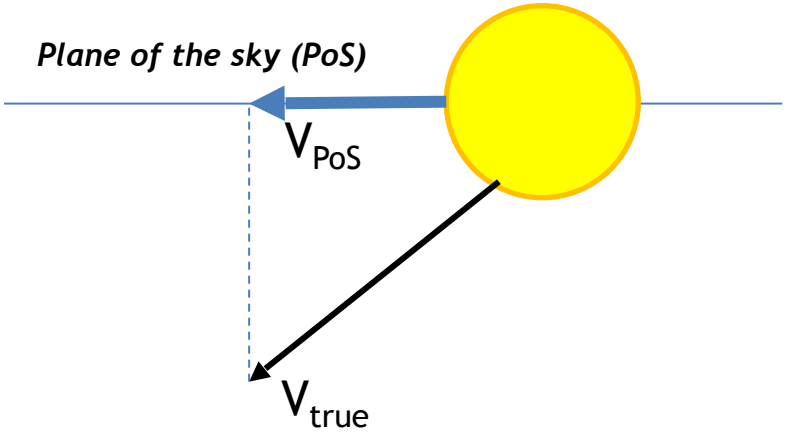
## Speed

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

$$V_{true} \geq V_{PoS}$$

  - 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       1610   ////      1638  PAL  C   RSP  108-180   CTM/1               1520
9900 +     1614   1649      1732  SAG  G   RBR  410       6600                1520
9900 +     1614   1652      1706  SAG  G   RBR  1415      1100                1520
9900 +     1614   1653      1705  SAG  G   RBR  2695      800                 1520
9900 +     1614   1653      1714  SAG  G   RBR  4995      480                 1520
9900 +     1615   1653      1824  SAG  G   RBR  8800      430                 1520
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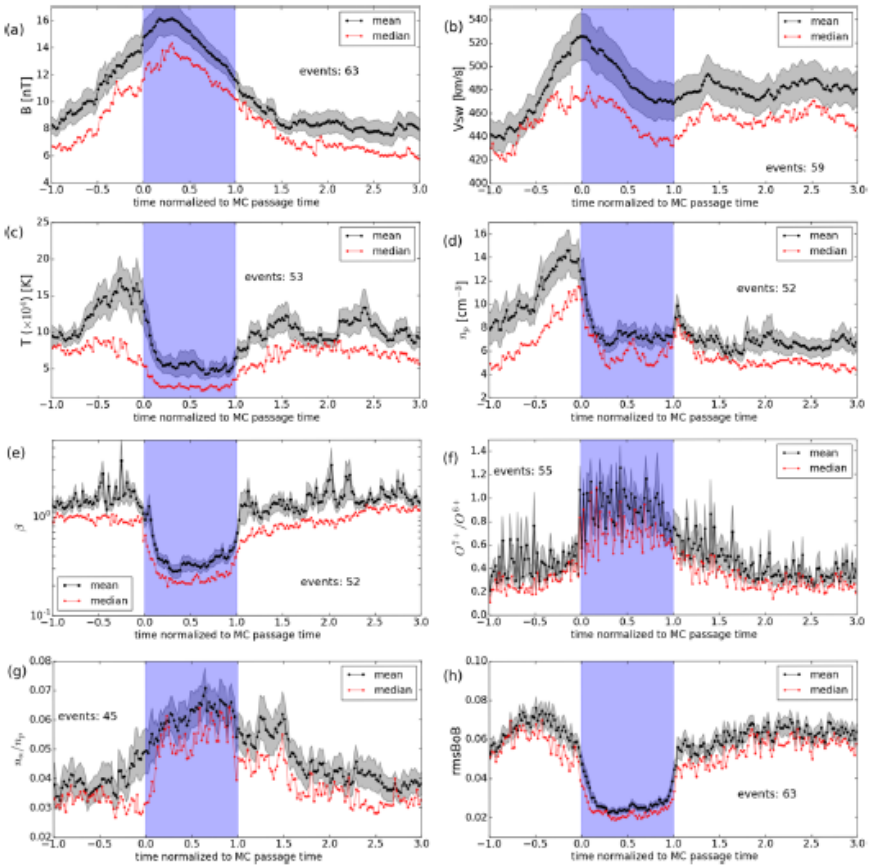
# INTERPLANETARY CORONAL MASS EJECTION



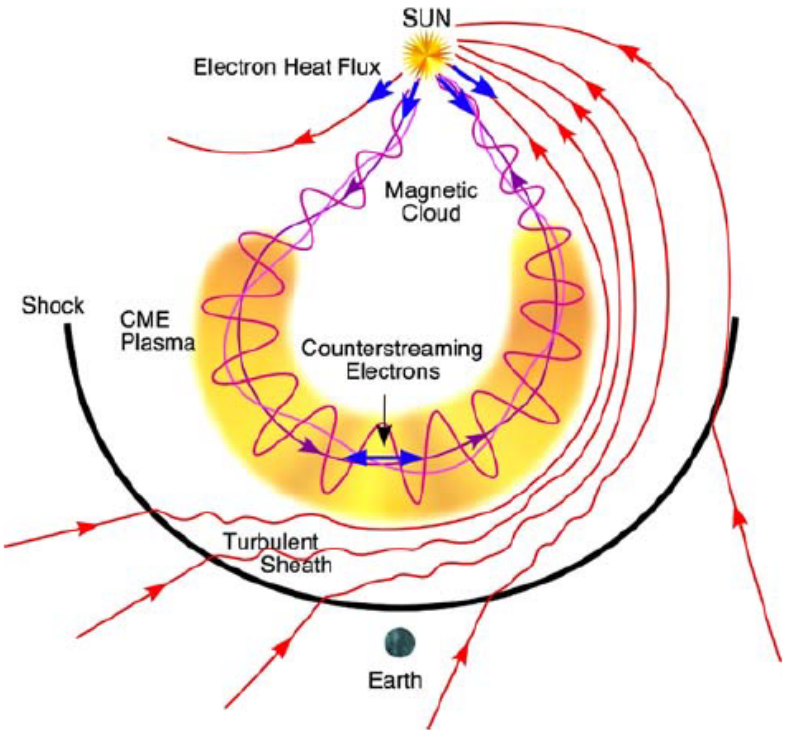
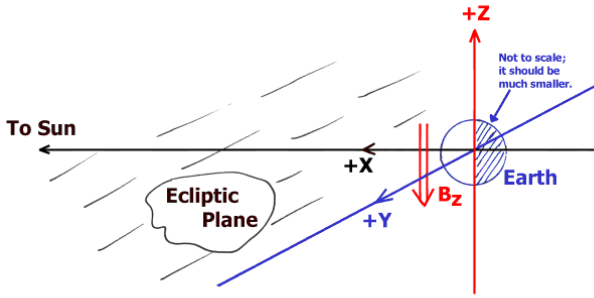




*Figure 2.* Schematic of the three-dimensional structure of an ICME and upstream shock, relating magnetic field, plasma, and BDE signatures.

# CORONAL MASS EJECTION



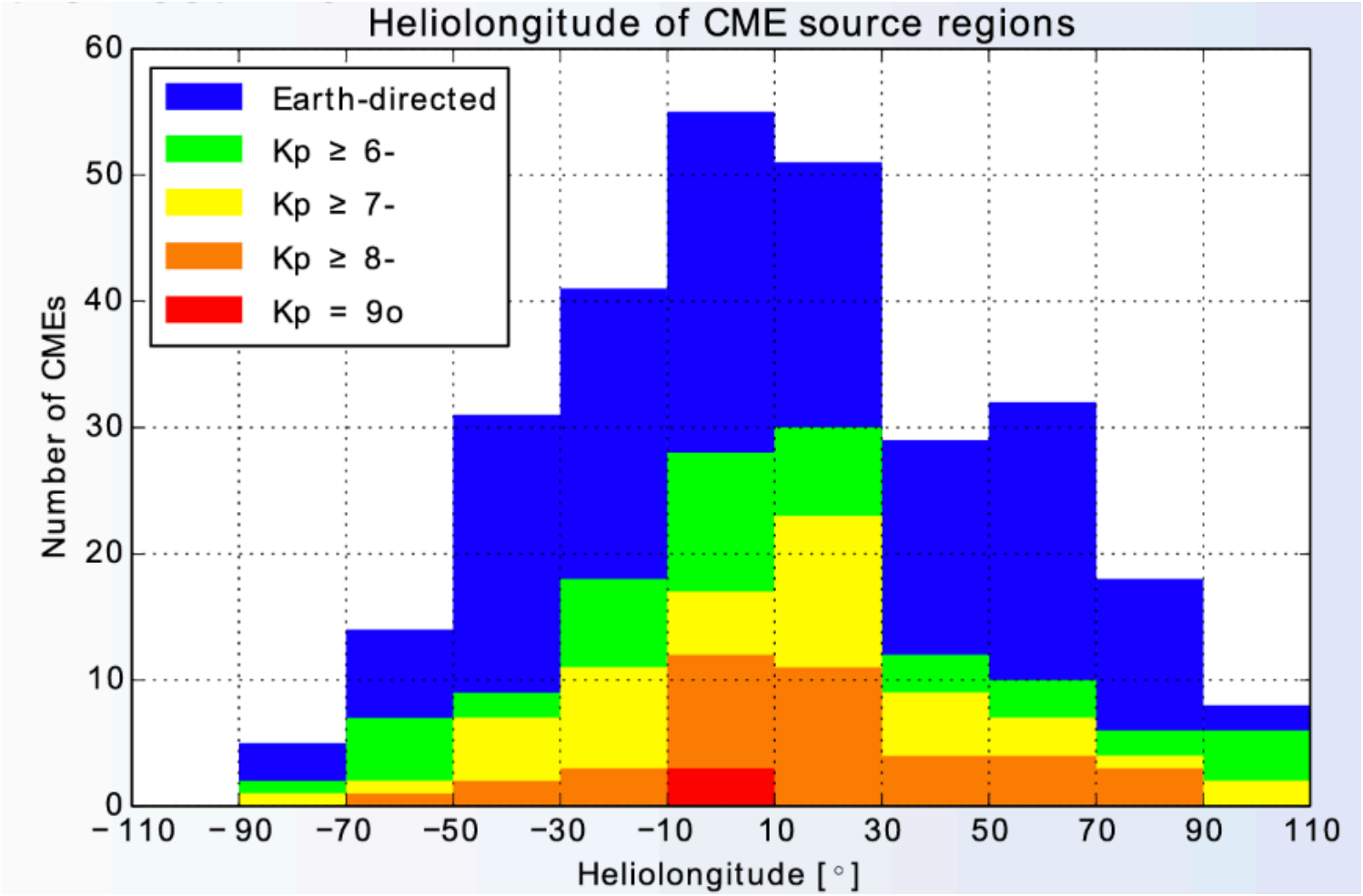

+Z is perpendicular to the Ecliptic Plane.

Bz

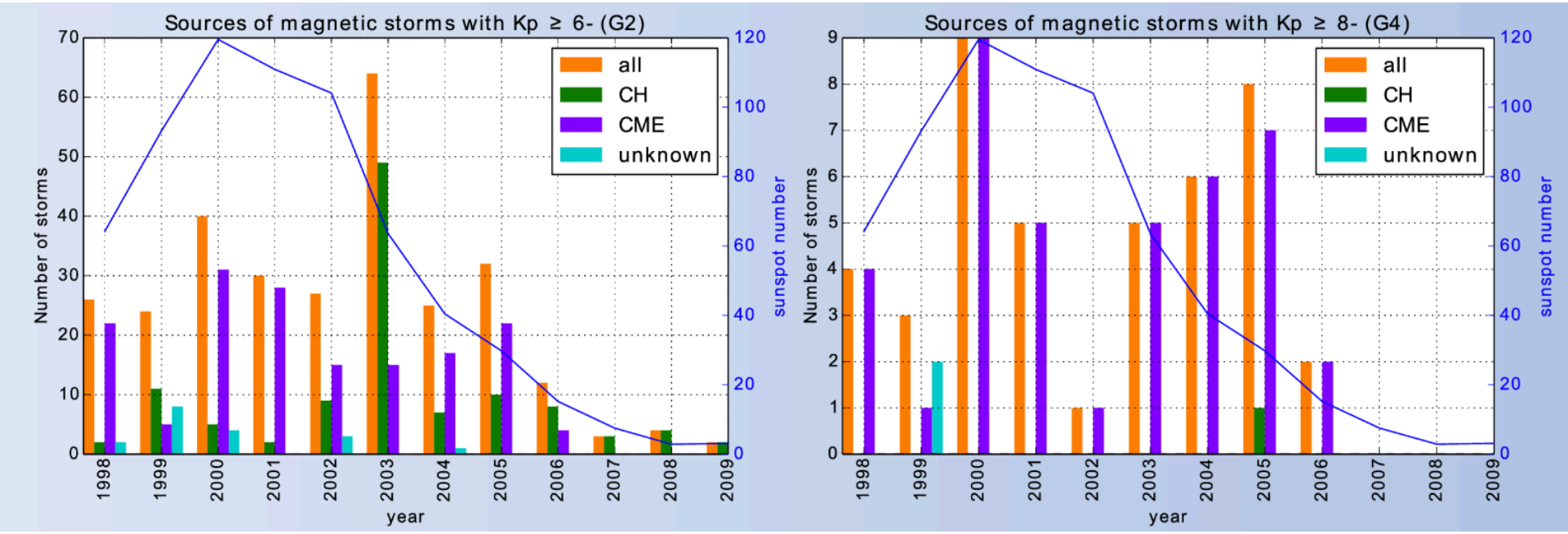
- North-South component of magnetic field (nT) perpendicular to the ecliptic
- Intensity varies much more than speed
- **Negative (south), strong and long-lasting Bz is necessary to get a strong geomagnetic storm**
- Need to predict both orientation and intensity

  Not easy and potentially changing during Sun-Earth transit!

# CME STATISTICS - LONGITUDE



# CME STATISTICS - SOURCE



:Issued: 2023 Mar 18 1231 UTC
:Product: documentation at http://www.sidc.be/products/meu
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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 Mach 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.

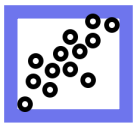
CME/ICME

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

# SPACE WEATHER DRIVERS: EXERCISE

 Solar flares

 Coronal Mass Ejections

 Proton events

What does a forecaster look for?
What does a forecaster look at?

# SOLAR ERUPTIONS

Magnetic Reconnection

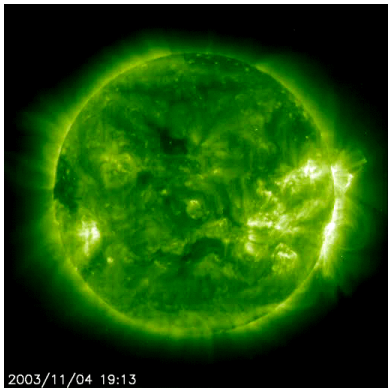
Radiation

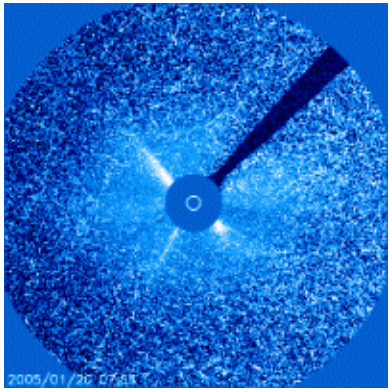
Particles

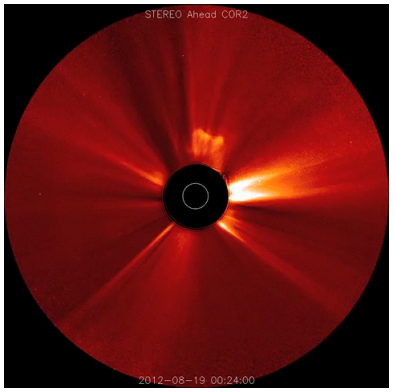
Solar flares

Proton events

Coronal Mass Ejections






SOHO/EIT

SOHO/LASCO

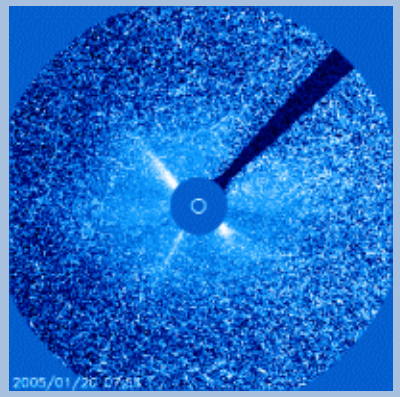
SOHO/LASCO

# SOLAR ERUPTIONS

Magnetic Reconnection

Particles

Proton events



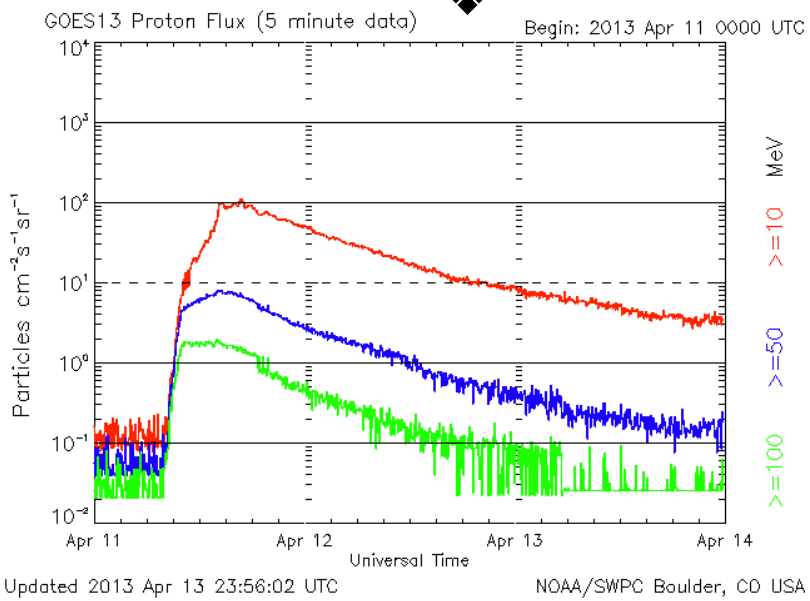
SOHO/LASCO

# PROTON EVENTS

Proton event

- > 10MeV proton flux
  5 min. average
- Start: ≥ 10 pfu
  Need at least 3 data points
- Peak: maximum value
  May take hours to days
- End: < 10 pfu
  NO new events as long as flux > 10 pfu

**GOES**




Proton enhancement

Increased flux, but below 10 pfu

Solar Energetic Particles

High energy (keV to GeV) protons, electrons and ions which come from the Sun

# PROTON EVENTS

## Impulsive

Associated with impulsive solar **flares** (electron rich)

The onsets are not necessarily fast, but the events are of rather **short** duration (1 to 20 hours)

Rather narrow propagation cones

Events from eastern hemisphere may not be observed

## Gradual

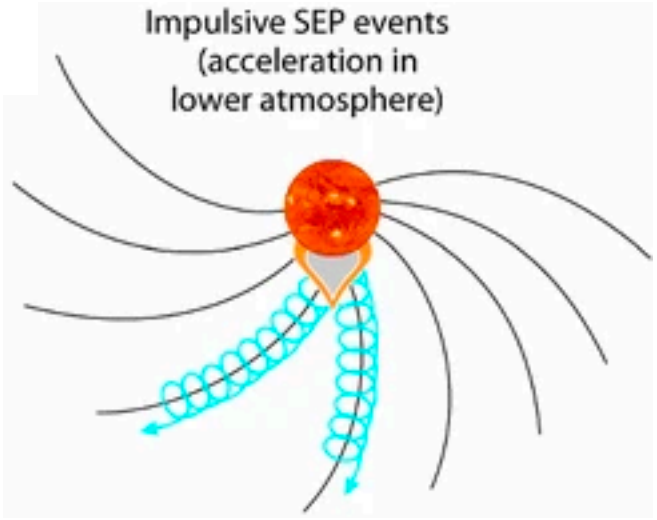
Associated with **CME**-driven shocks

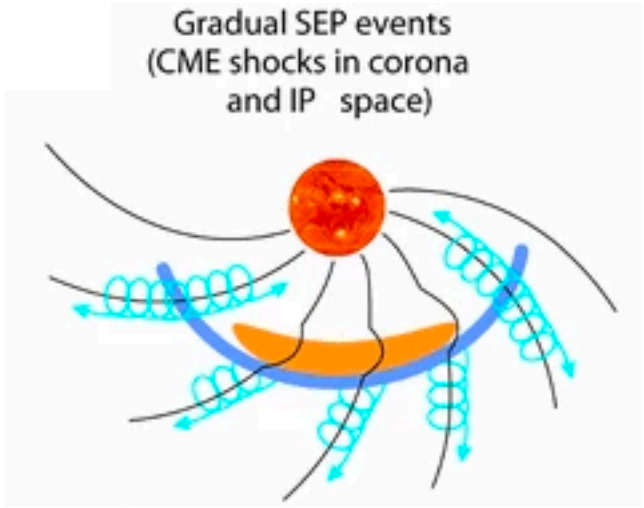
- Gradual solar flares (LDE)
- Wide and fast shocks
- Type II and IV radio bursts
- Usually proton rich

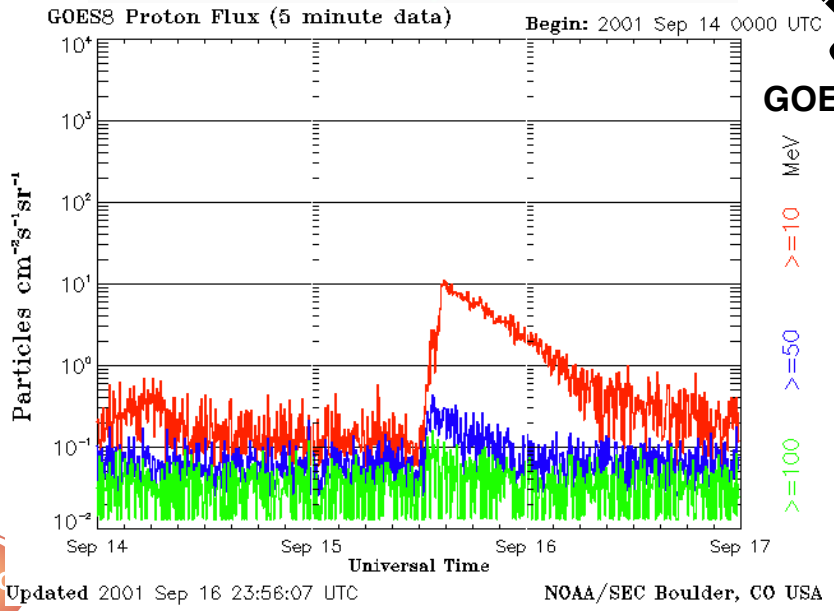
The onsets are not necessarily gradual, but the events are of **long** duration

- 1 to 3 days
- Partly due to continuing acceleration of shock

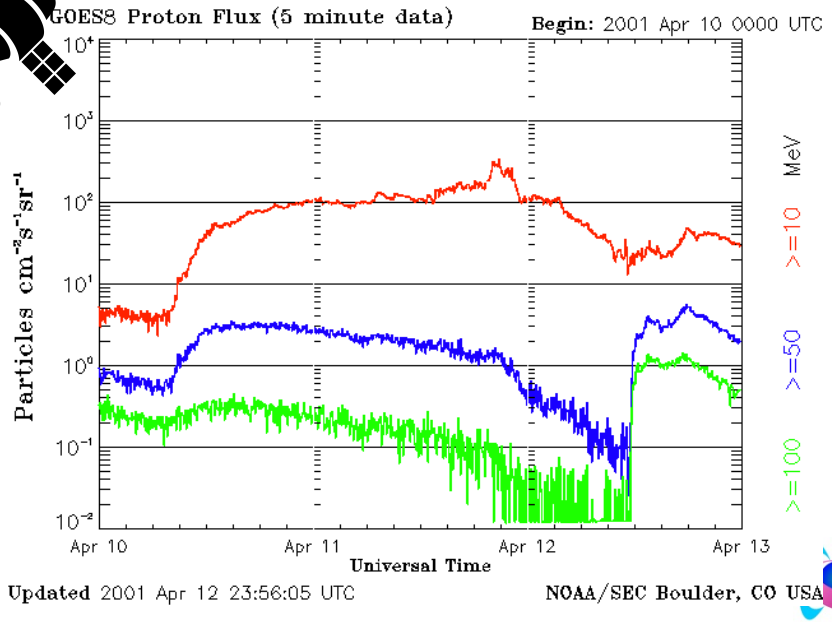
# PROTON EVENTS



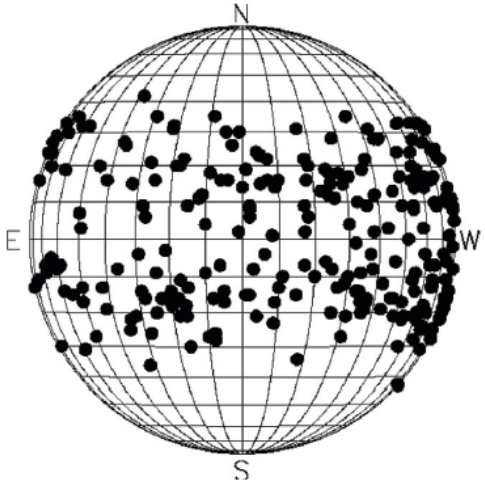

GOES

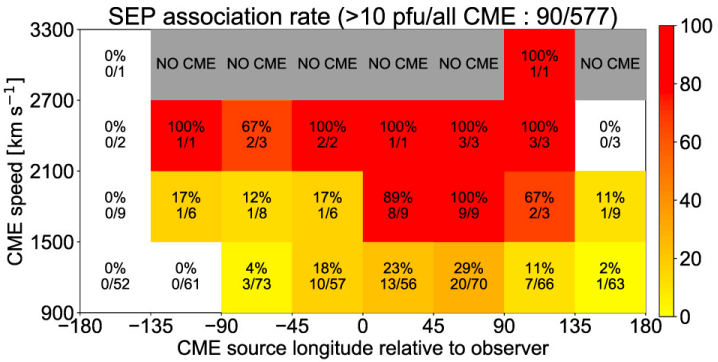


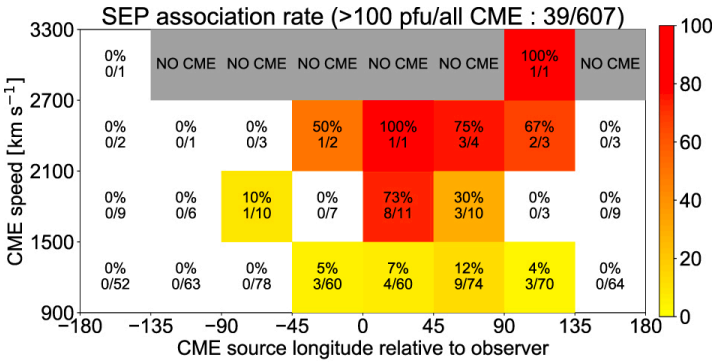
# EFFECTS FROM LOCATION SEP SOURCE

There's a higher likelihood for SEP events from the western hemisphere

- Does not exclude SEPs from the eastern hemisphere or even from the Sun's backside!
  - E.g. Major flare on 23 July 2012
  - Mechanism?
- Eastern SEPs: slower rise



# PROTON EVENT CLASSIFICATION

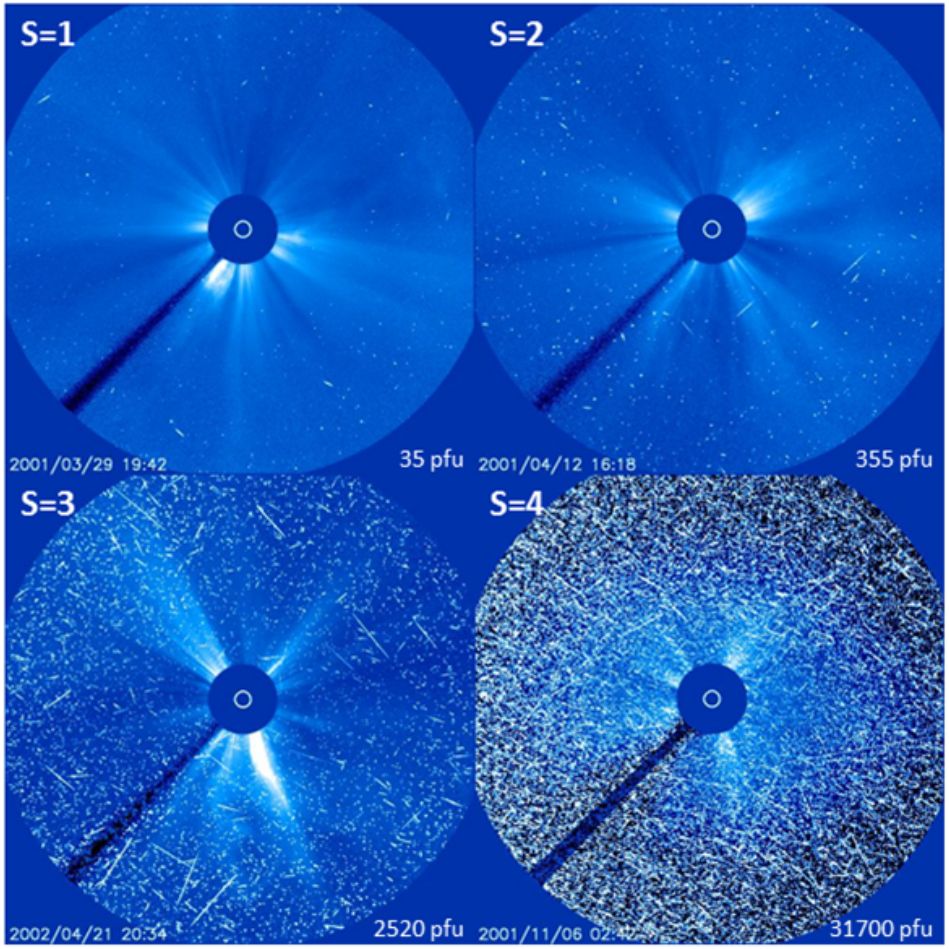
## NOAA-scales: S-scale

| Scale | Description | Effect | **Physical measure** (Flux level of >= 10 MeV particles) | **Average Frequency** (1 cycle = 11 years) |
|---|---|---|---|---|
| S 5 | **Extreme** | | $10^5$ | Fewer than 1 per cycle |
| S 4 | **Severe** | | $10^4$ | 3 per cycle |
| S 3 | **Strong** | | $10^3$ | 10 per cycle |
| S 2 | **Moderate** | | $10^2$ | 25 per cycle |
| S 1 | **Minor** | | 10 | 50 per cycle |

# PROTON EVENT CLASSIFICATION

## NOAA-scales: S-scale

SOHO/LASCO



# FORECASTING PROTON EVENTS

A. Papaioannou et al.: SEP events and their parent solar sources

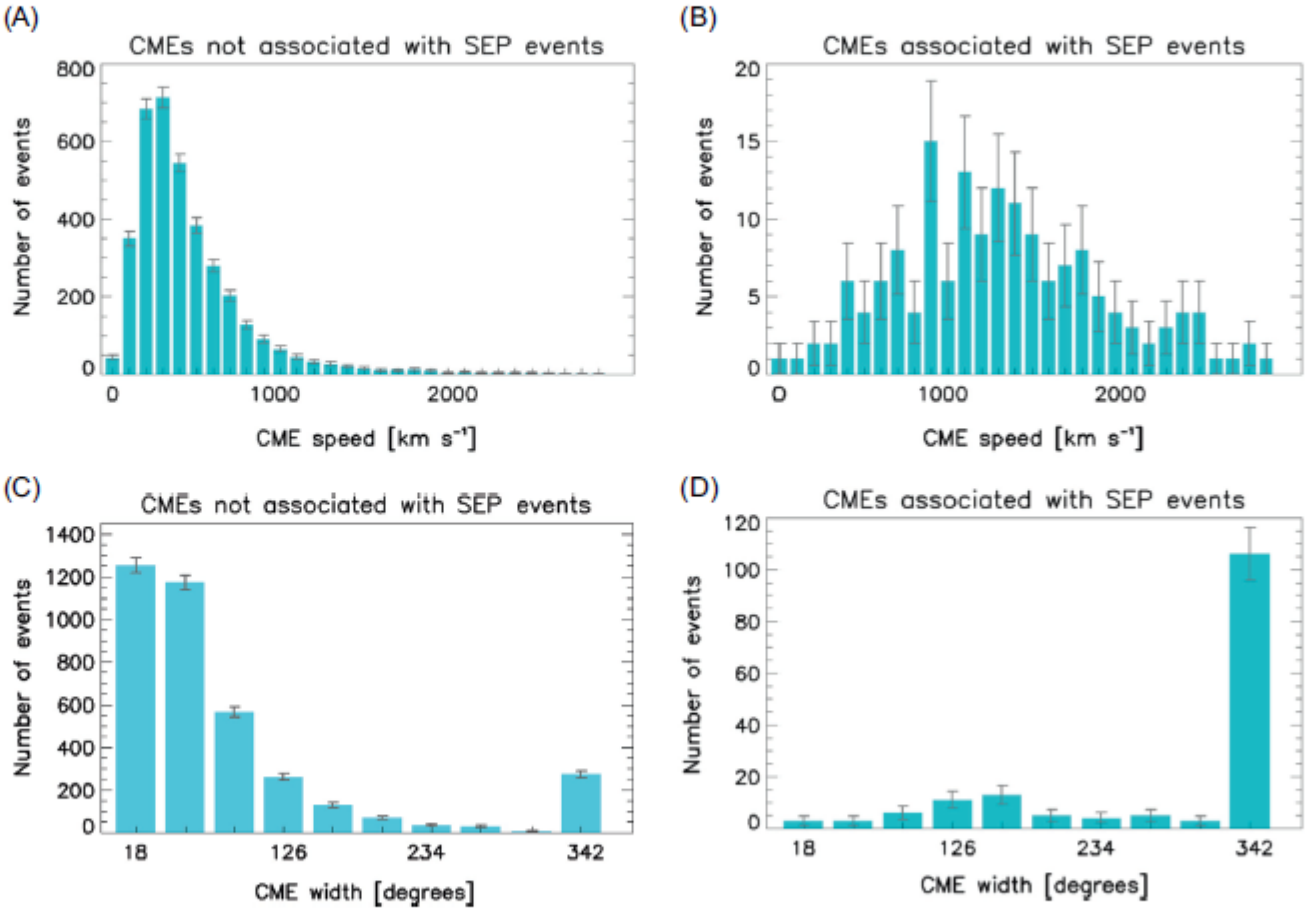
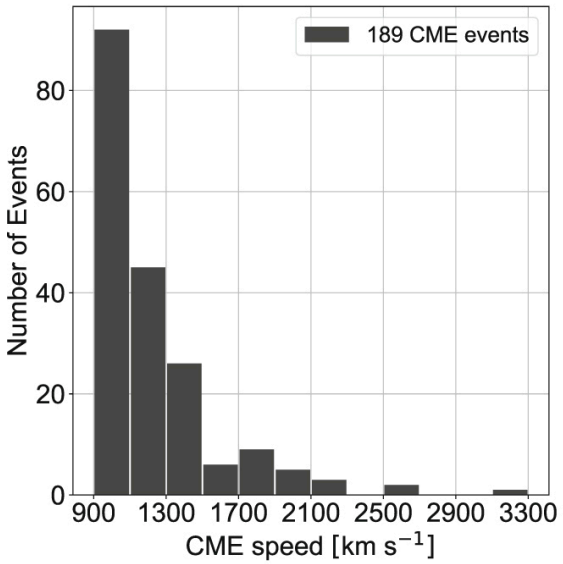
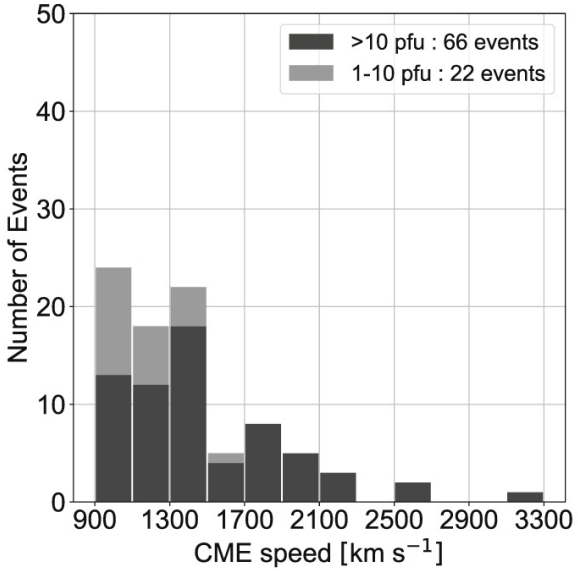



**Fig. 6.** Distribution of the CME velocity (in km $s^{-1}$) for all 3535 CMEs not associated with SEP events in our sample from 1997–2013 (A) and for the 158 SEP events, within the same time period (B). Distribution of the CME width (in degrees) for all 3535 CMEs not associated with SEP events in our sample from 1997–2013 (C) and for the 158 SEP events, within the same time period (D). The error bars denote the statistical error.

# FORECASTING PROTON EVENTS




(a)

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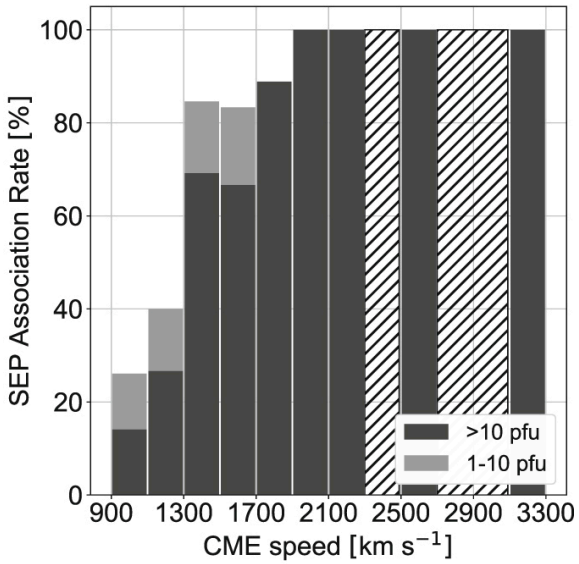


(c)

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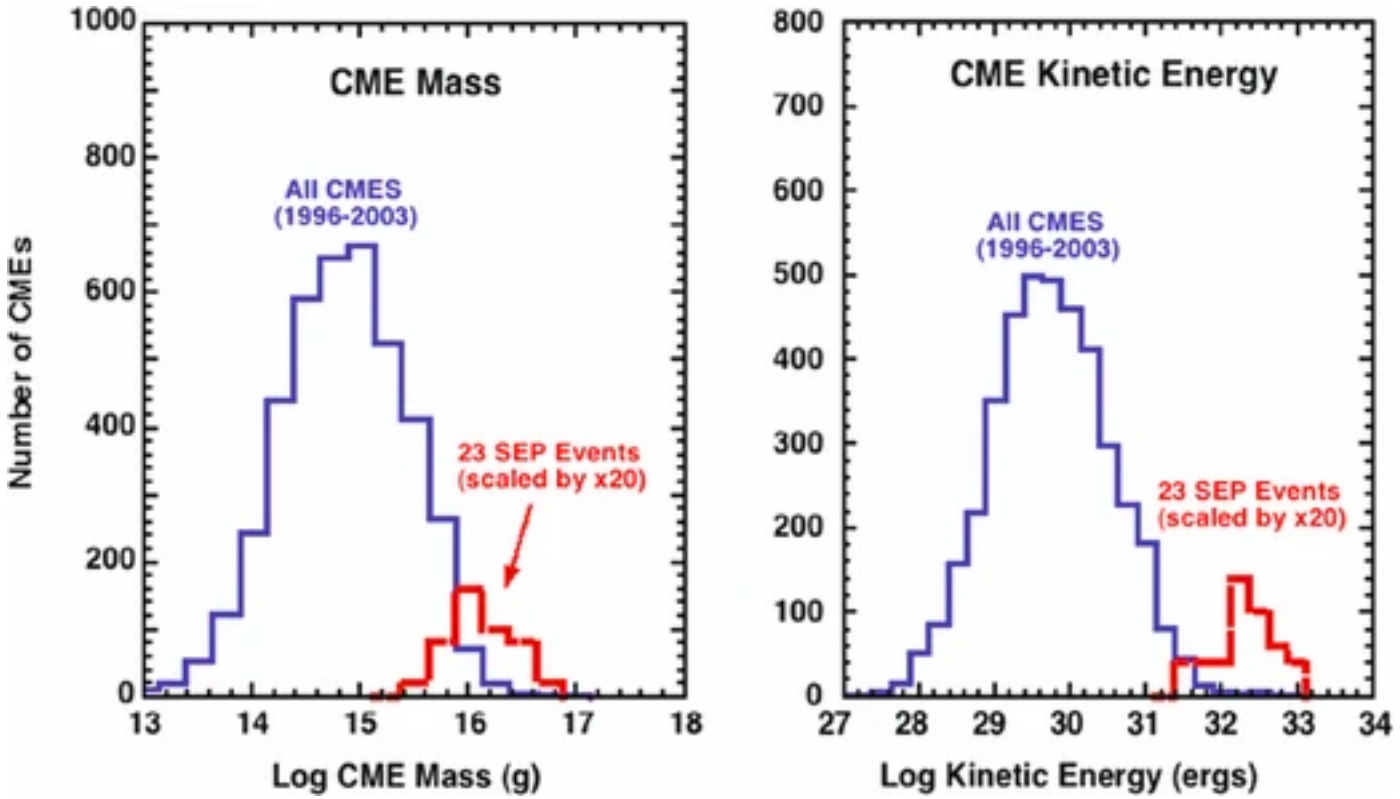


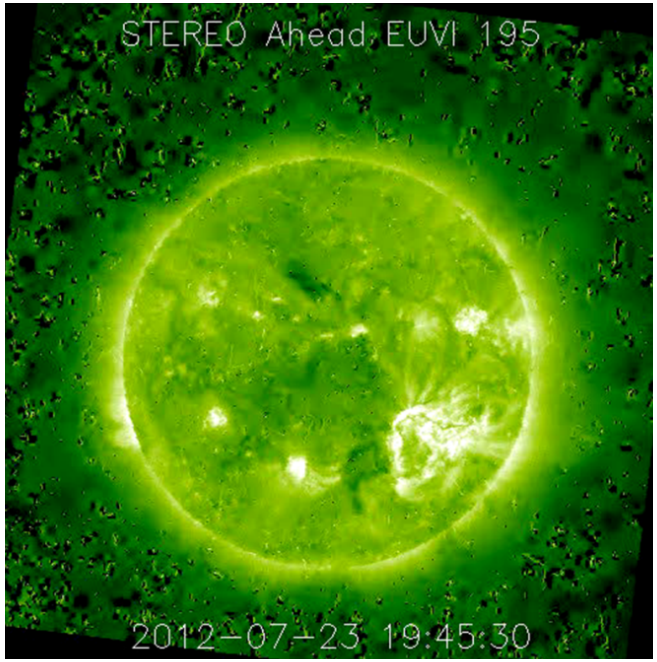
# FORECASTING PROTON EVENTS

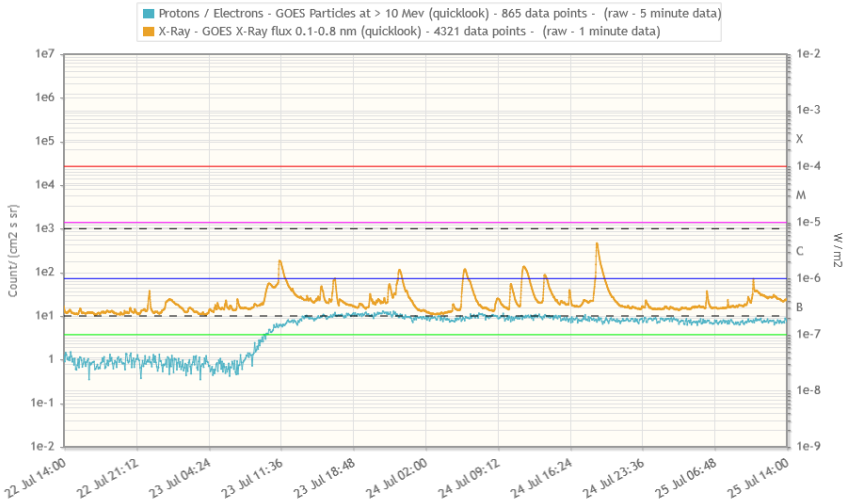
Look for active regions & filaments that can:

- Produce strong x-ray flares
- Fast CMEs (~1000 km/s or more)
- Wide CMEs (partial or full halo CMEs)
- Preferably on the western solar hemisphere

Finetune from history on farside/ eastern hemisphere

- Proton flux enhancements,…
- Observations by STEREO spacecraft



: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.

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END

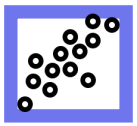

Finding your way in the URSIgram

Proton flux / events

# SPACE WEATHER DRIVERS: EXERCISE

Solar flares
Radio Bursts

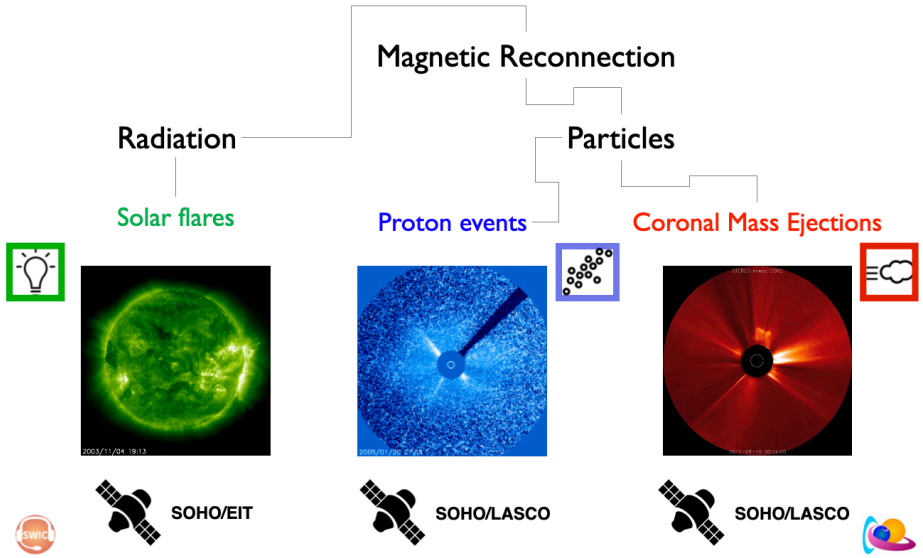
Coronal Mass Ejections



Proton events

What does a forecaster look for?
What does a forecaster look at?

# SUMMARY 1/2




## Solar flares

- Standard model
- Classification
  - Hα, x-ray, NOAA scale (R)
- Flare predictions
  - McIntosh, Hale

# SUMMARY 2/2

## Proton events

- ≥10 MeV proton flux ≥ 10 pfu
- Classification
  - Impulsive vs. Gradual
  - NOAA Scale (S)
- Forecasting
  - Strong flare
  - Wide and fast CME
  - Western solar hemisphere

## Coronal Mass Ejection

- Model
- On-disk signatures
- Classification & Terminology
  - Stealth, Cannibalism, Deflection
- True vs. Plane-of-the-Sky speed
- Interplanetary CME & Bz