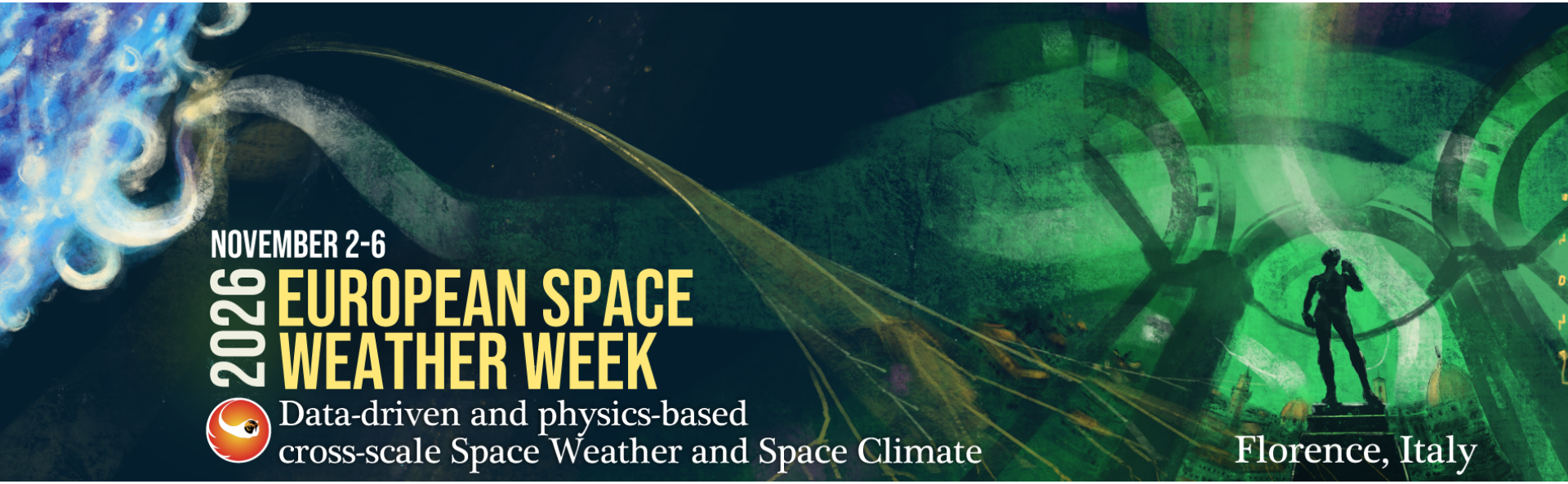
Space Weather Training Course



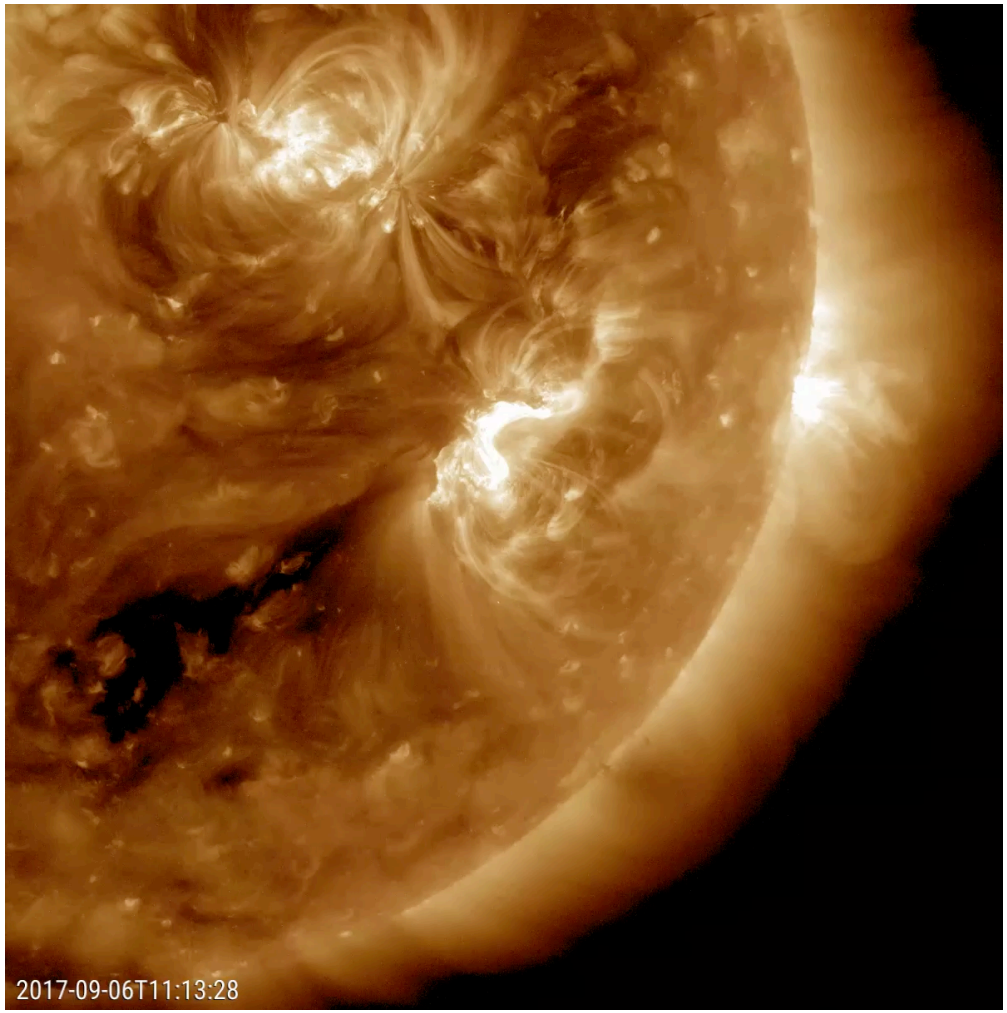
Collaboration of

e-swan

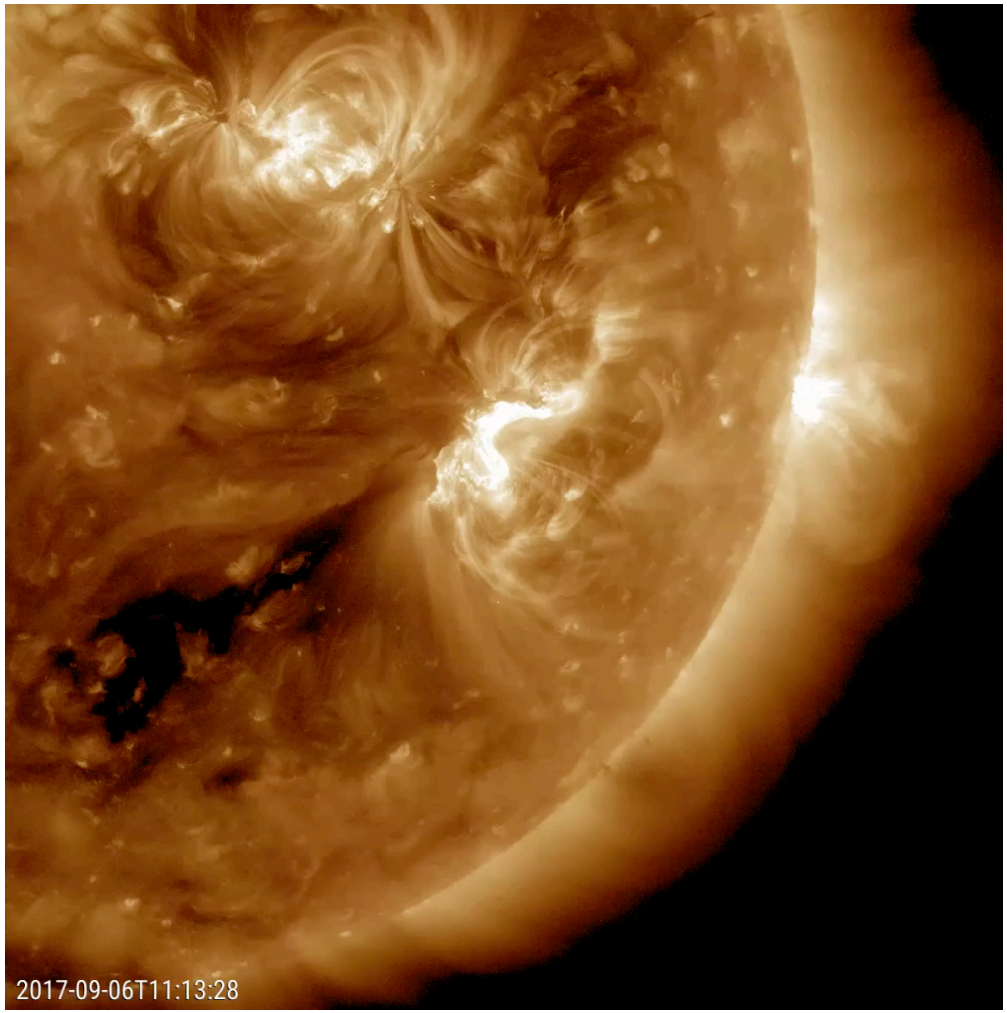
SWEC
Space Weather Education Centre

COMMUNITY COORDINATED MODELING CENTER

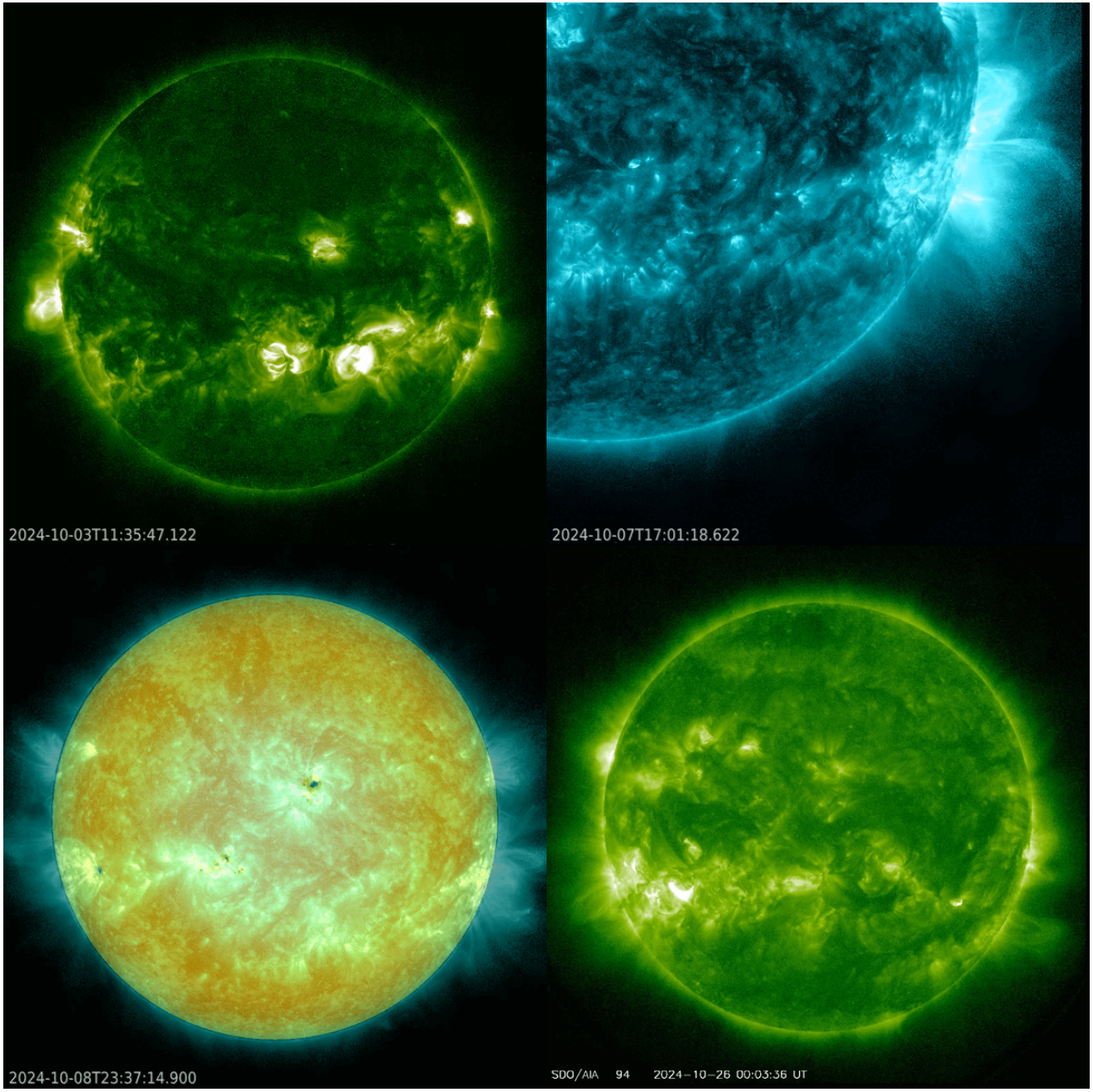
SOLAR FLARES



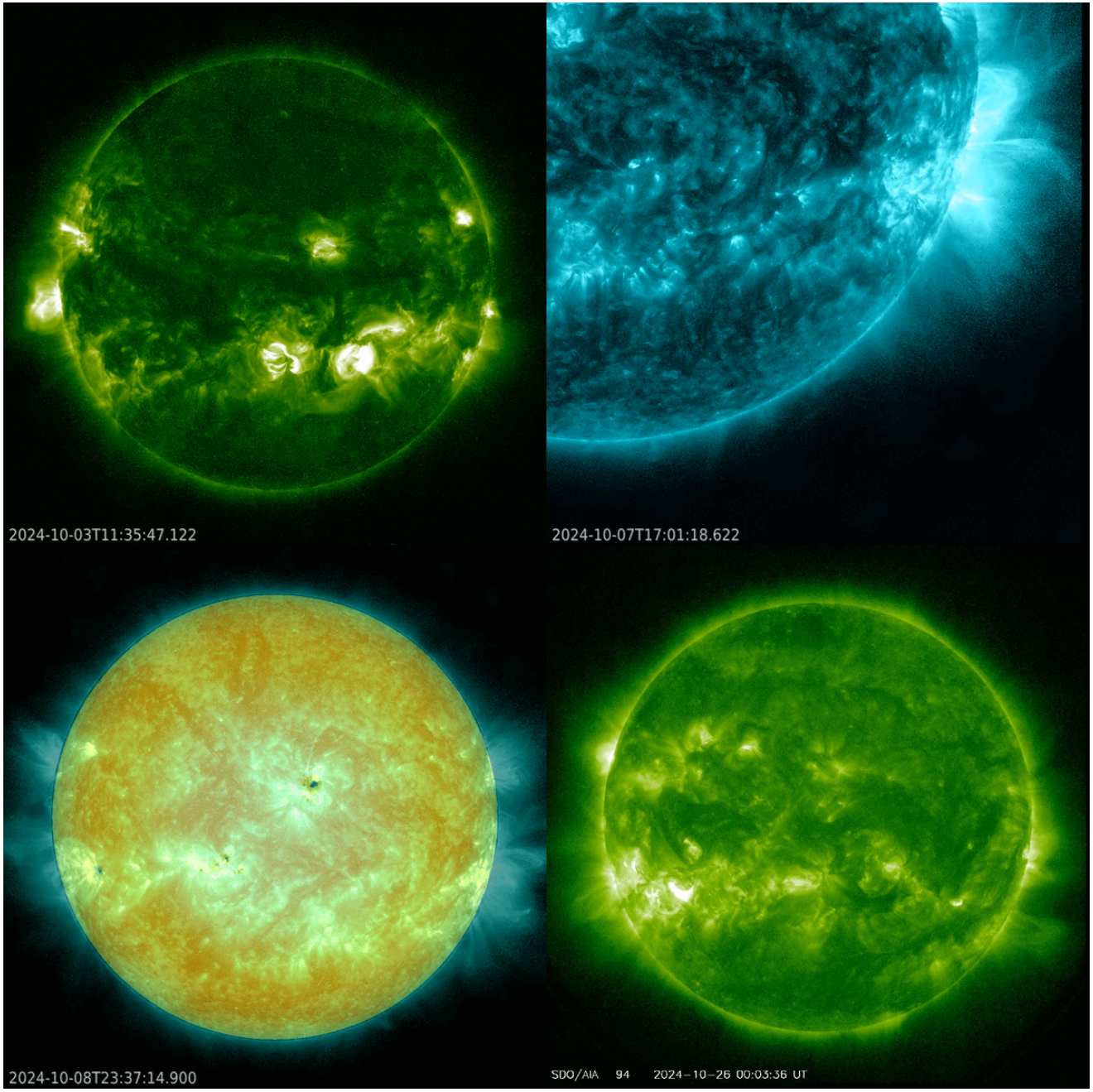
SOLAR FLARES



Introduction

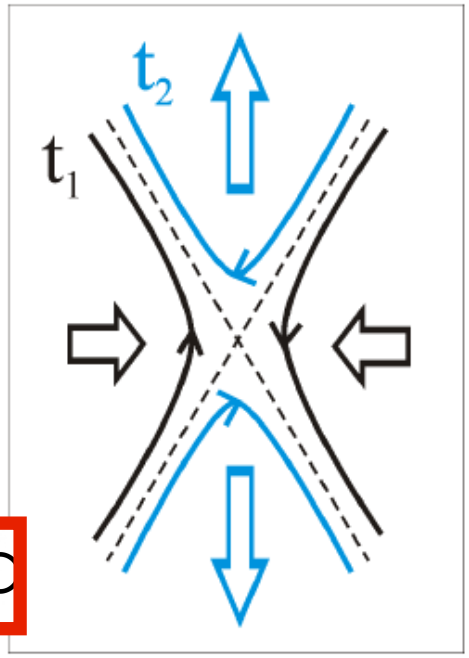


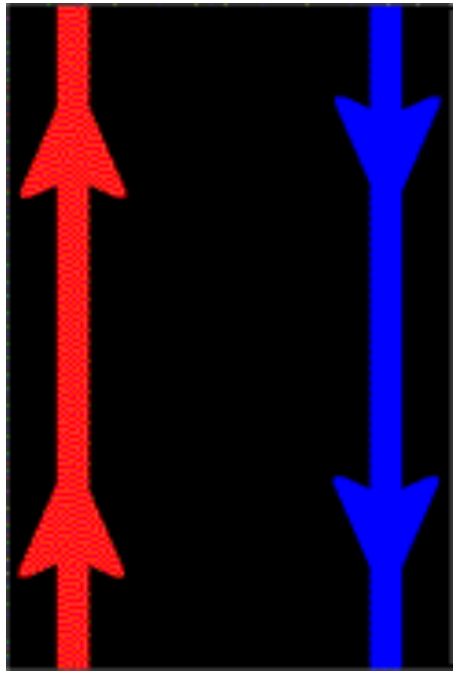
Introduction



Magnetic Reconnection

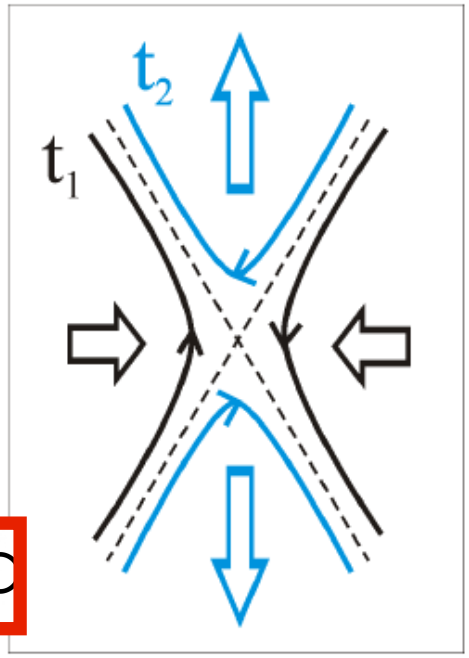
- Conversion of magnetic energy into kinetic energy and radiation
- Where
  - Solar flares
  - CME release from the Sun
  - Geomagnetic storms at Earth

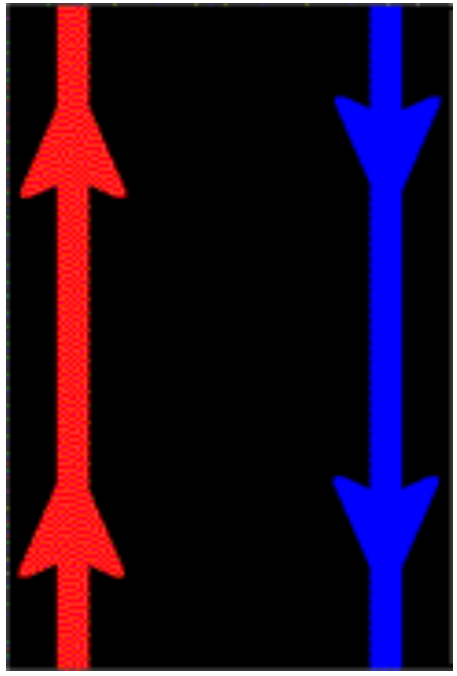




Magnetic Reconnection

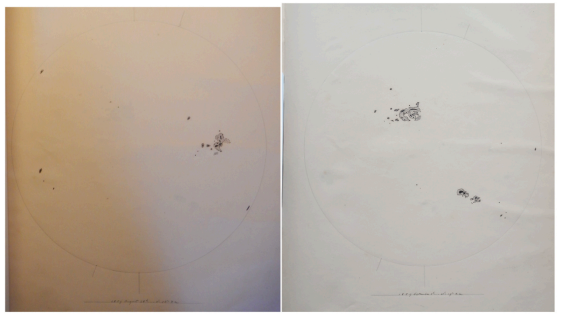
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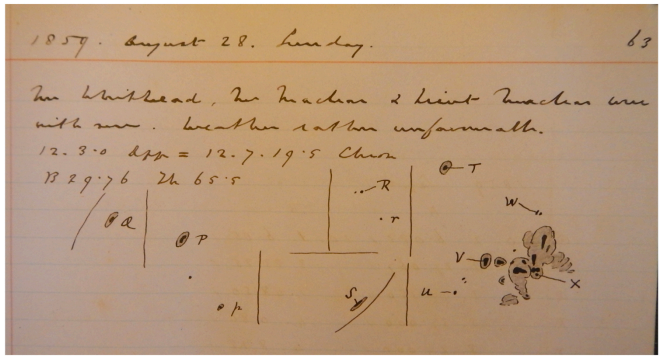


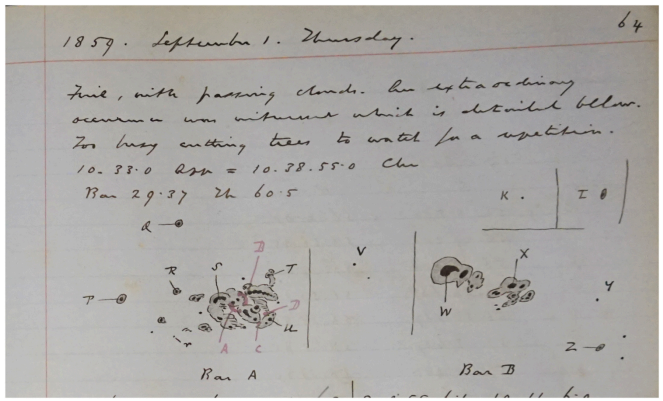


Solar Flares - WHAT?

- 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

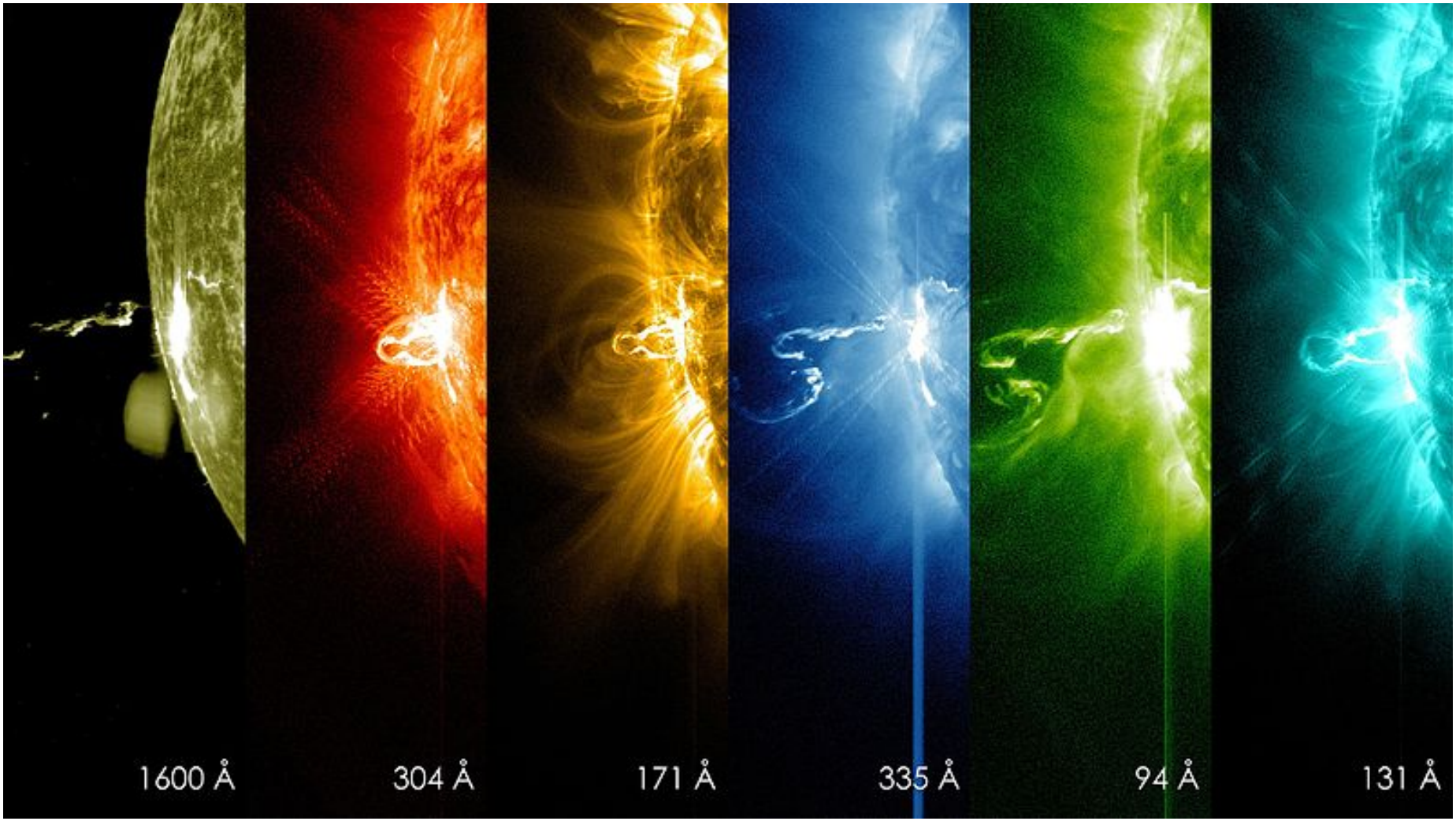




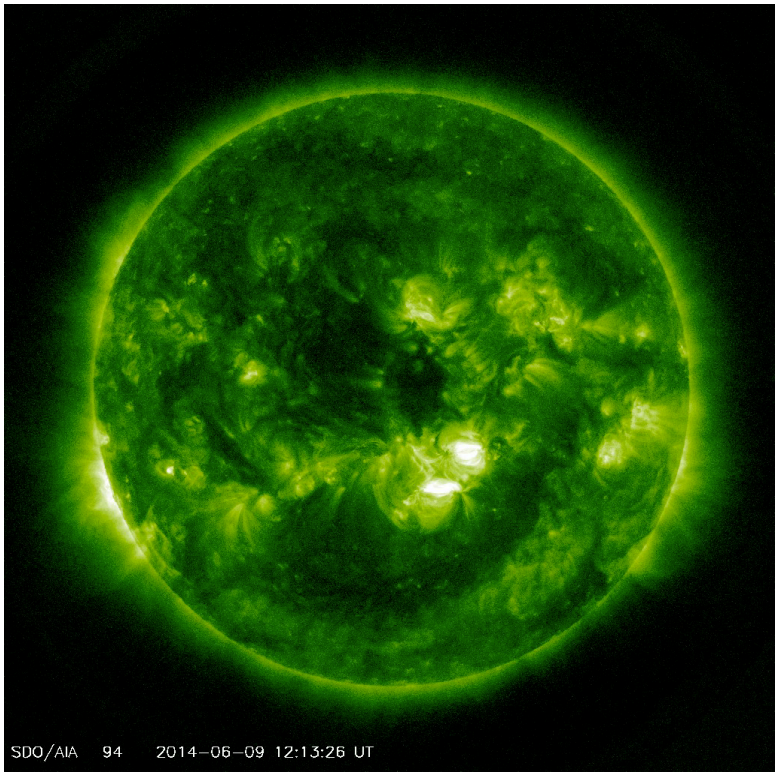


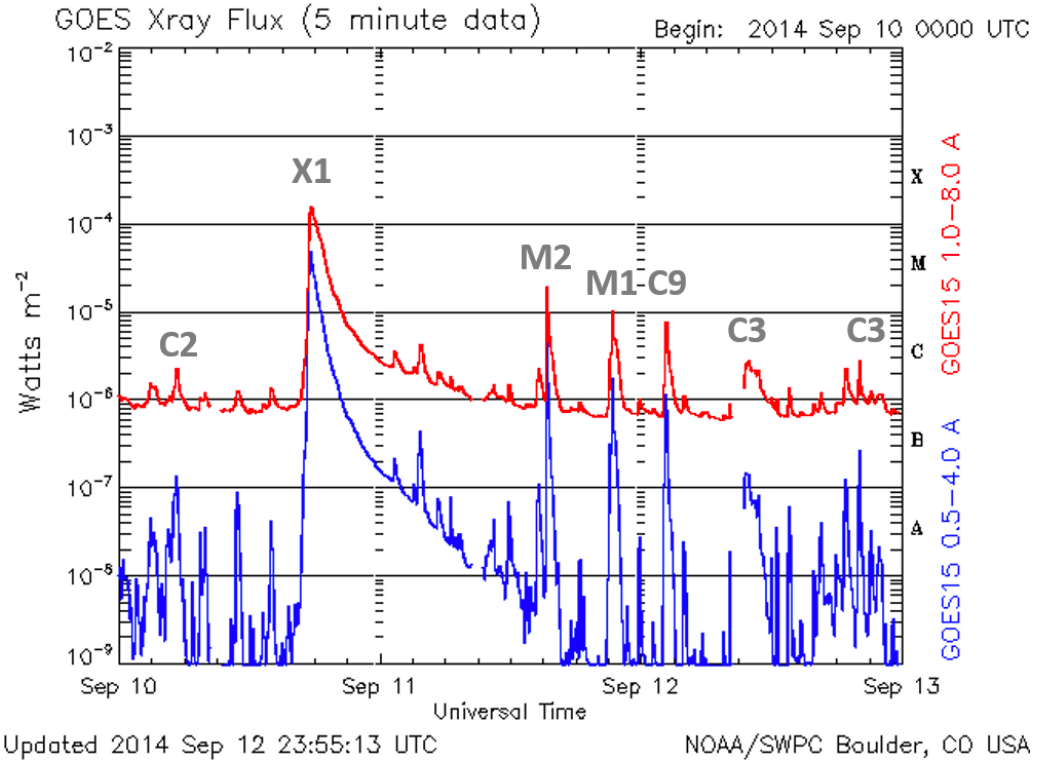
Solar Flares - Observations

SDO/AIA



Solar Flares - Observations

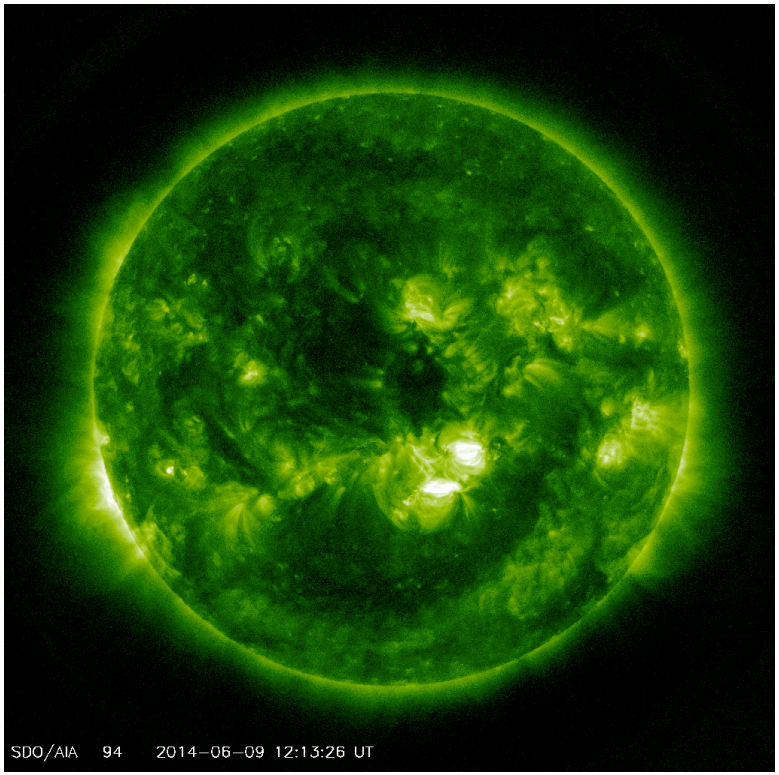


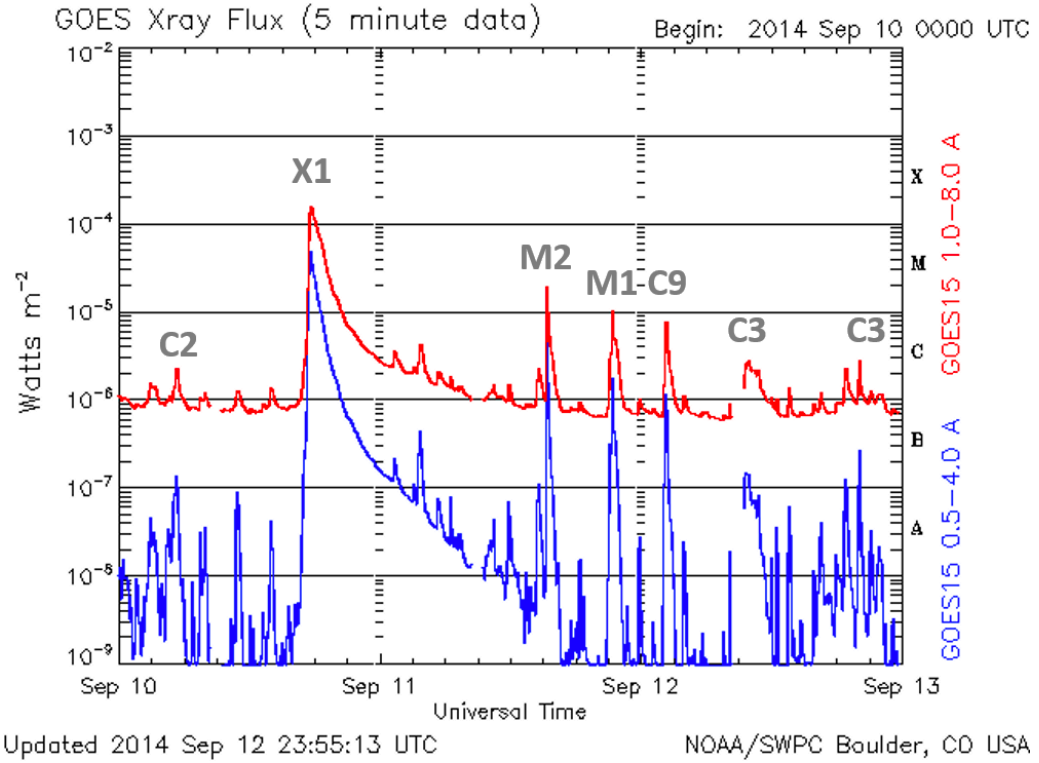


SDO/AIA

GOES

Solar Flares - Observations

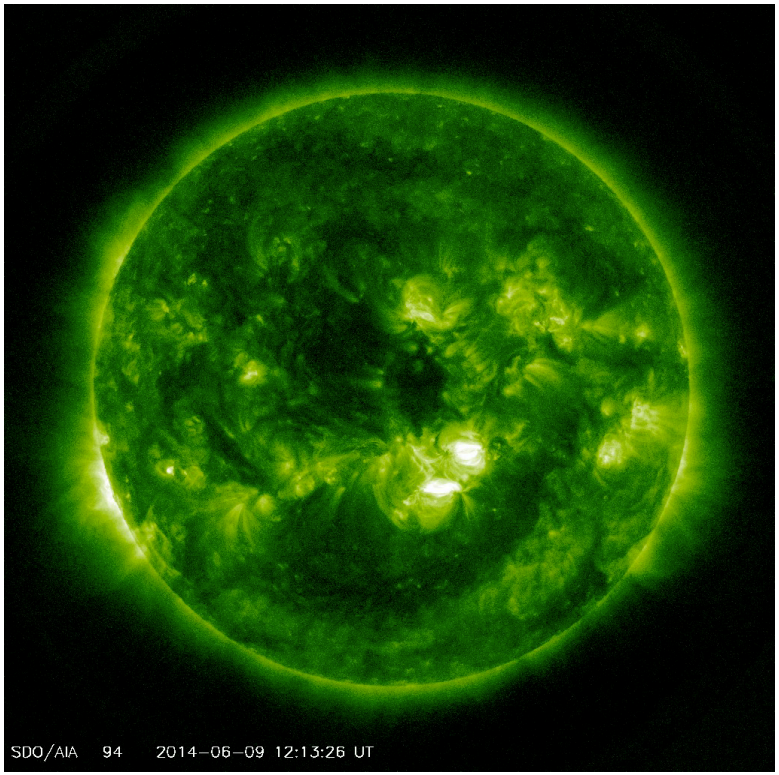


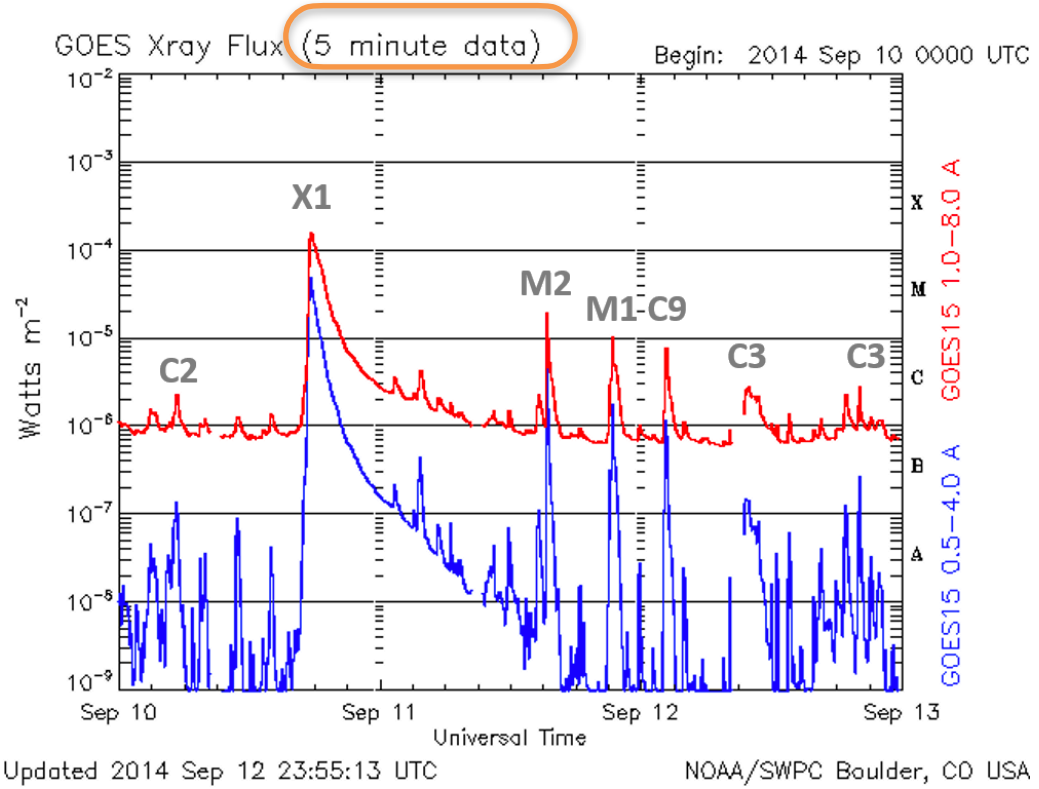


SDO/AIA

GOES

Solar Flares - Observations



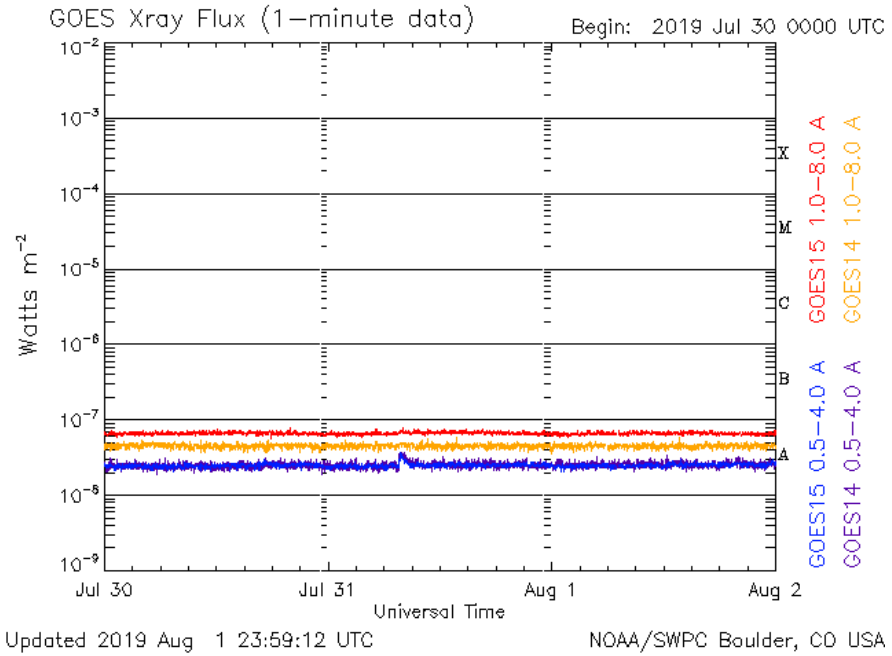


SDO/AIA

GOES

Solar Flares - Solar cycle

Solar minimum

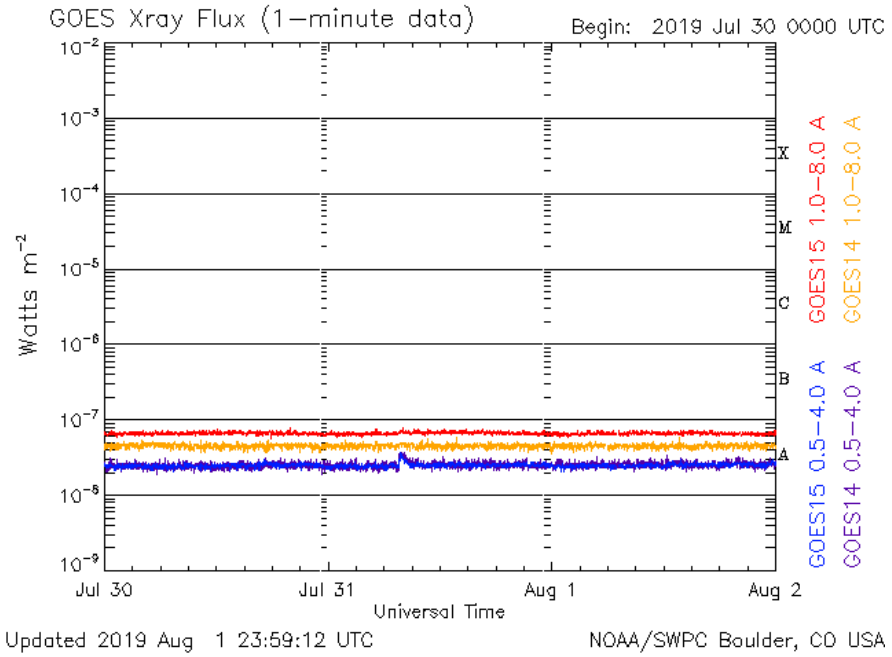


Solar maximum

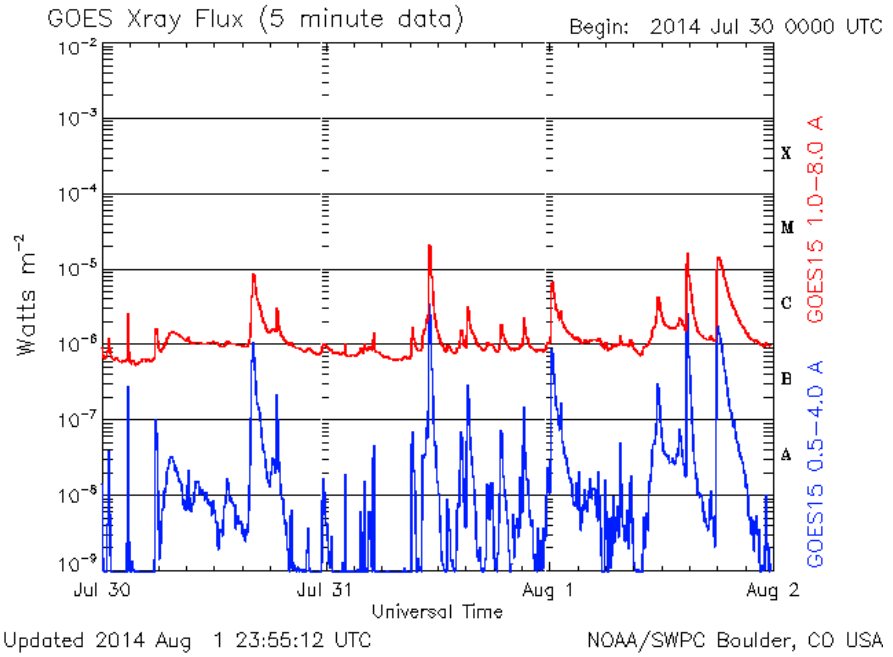
GOES

Solar Flares - Solar cycle

Solar minimum



Solar maximum



GOES

Solar Flares - Automated detection

https://www.sidc.be/solardemon/

Solar Demon Flare Detection (qlk)

Quick-look! running in real time on SDO/AIA 94 QKL data
3 minute cadence, typical delay 15 minutes
(detection version 1.00)
(view all Solar Demon detection tools)

Detector 24h operating status:

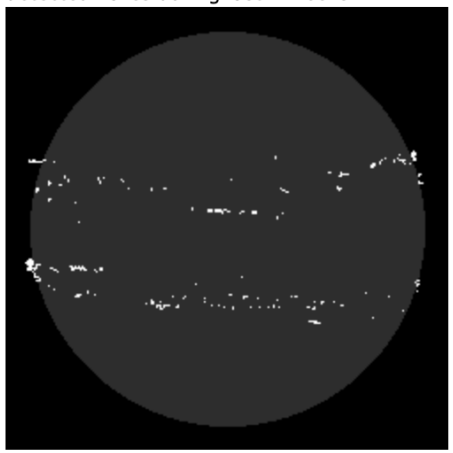
Last processed image:
0 hours and 34 minutes ago (2023-11-09 13:33 UTC)

Last detected flare:
2 hours and 46 minutes ago (2023-11-09 11:21 UTC)

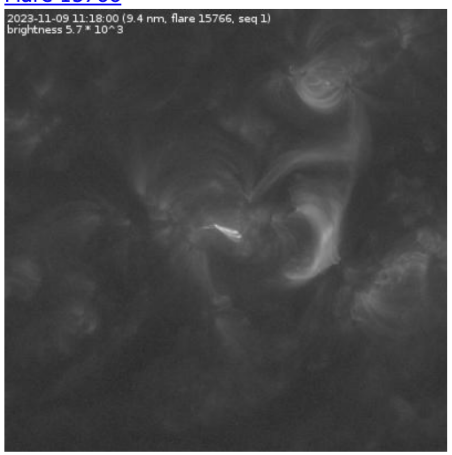
Filters (category)
-- *All classes*
Only C class flares and above
Only M class flares and above
Only X class flares and above

Filters (time)
Last 7 days
-- *Last 14 days*

detected flares during last 2 weeks



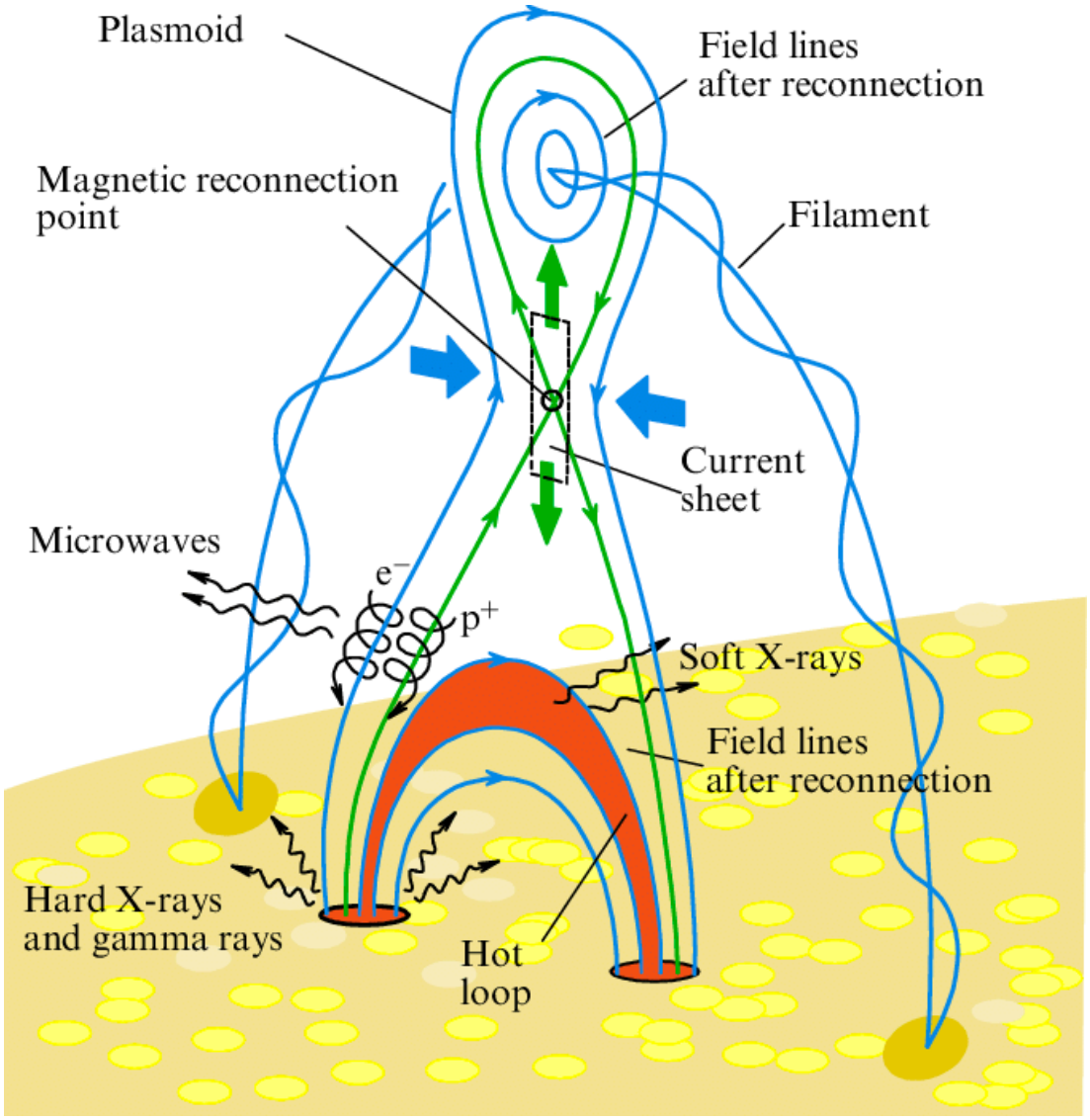
Flare 15766



Overview of flares

	est. class	start	peak	end	#	lat	lon	dist. R⊙	AR	est. flux	GOES flux	GOES peak time	COMESEP	# det.	dimming
November, 2023															
9	B3	11:18	11:21	11:21	15766	-10	4	0.25	AR 3480	2.6	**N/A**	N/A	0	2	-1,899
9	B1	10:48	10:51	10:51	15765	25	15	0.44		1.4	**N/A**	N/A	0	2	
9	A8	08:30	08:33	08:33	15764	8	16	0.29	AR 3483	0.8	**N/A**	N/A	0	2	
9	B2	01:15	01:15	01:21	15763	7	14	0.26	AR 3483	1.8	**N/A**	N/A	0	3	-19
9	B2	00:51	00:51	00:51	15762	23	70	0.95	AR 3479	1.6	**N/A**	N/A	0	1	
8	C2	20:09	20:18	21:00	15761	9	7	0.16	AR 3483	20.1	**N/A**	N/A	0	18	-44
8	B3	14:48	14:48	14:54	15760	8	4	0.11	AR 3483	2.8	**N/A**	N/A	0	3	-29
8	C3	08:30	08:51	09:36	15759	9	0	0.09	AR 3483	28.3	**N/A**	N/A	0	20	
8	B6	07:06	07:24	08:03	15756			1.01		5.8	**N/A**	N/A	0	19	-266
8	A7	07:24	07:24	07:24	15757	23	59	0.88	AR 3479	0.7	**N/A**	N/A	0	1	-266

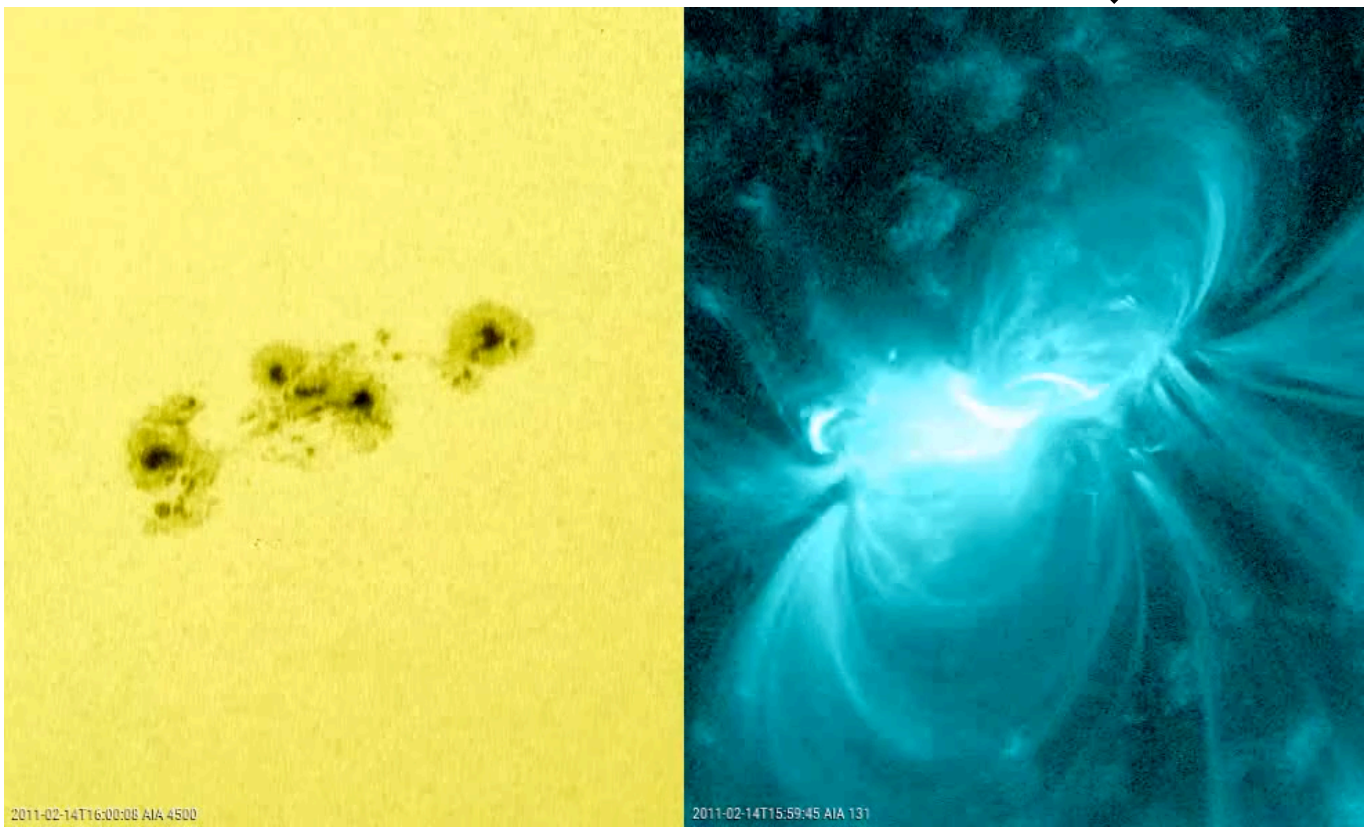
Solar Flares – Standard Model



Solar Flares - Triggers

Magnetic restructuring

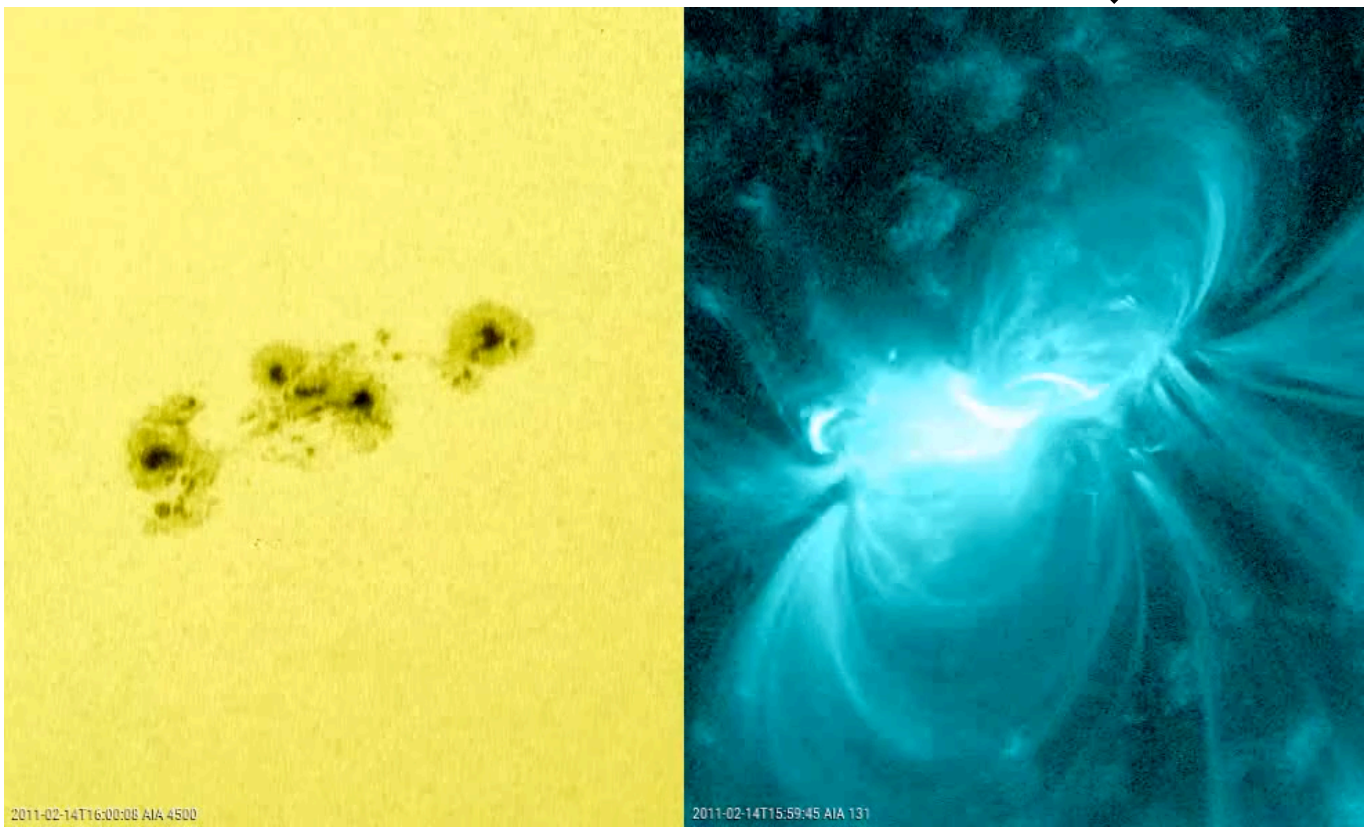
SDO/AIA



Solar Flares - Triggers

Magnetic restructuring

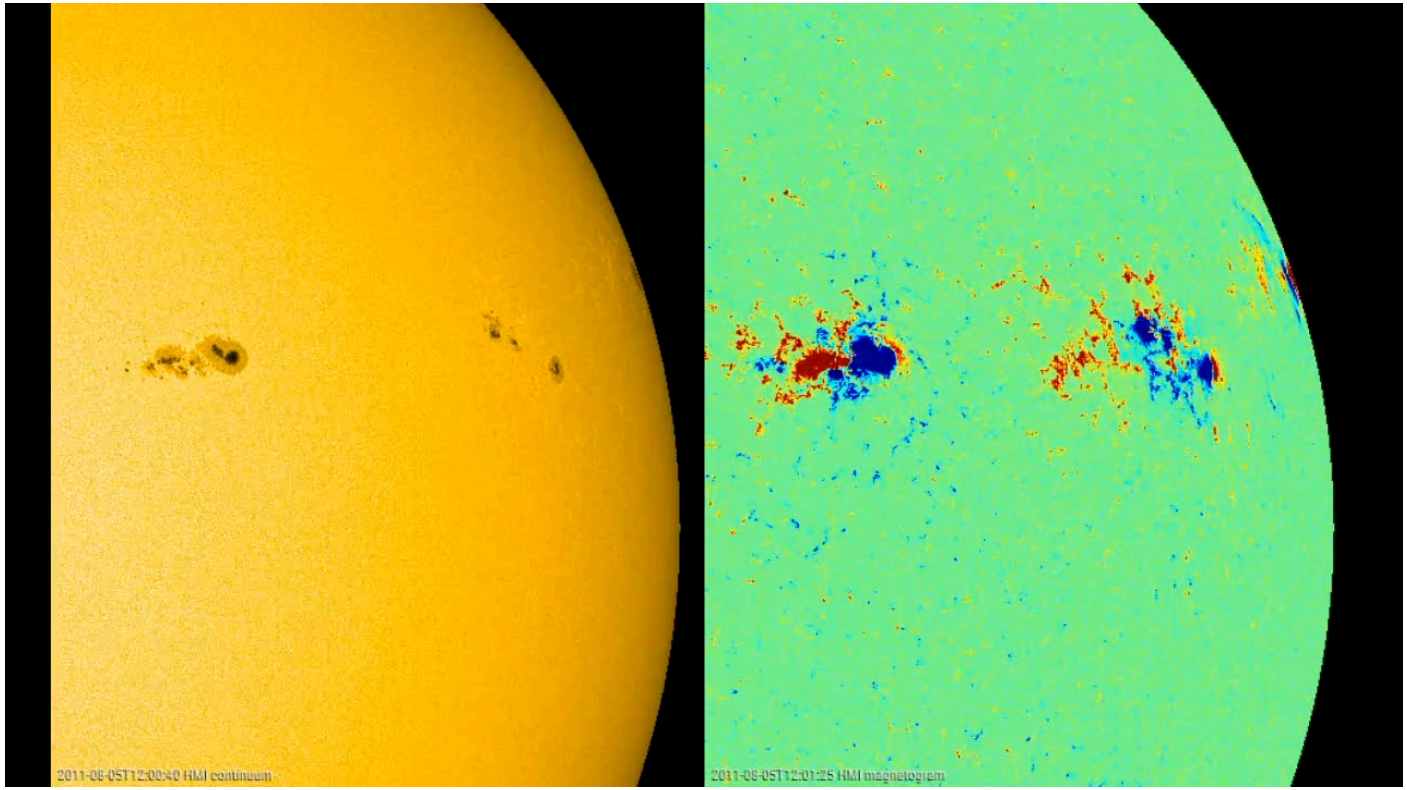
SDO/AIA



Solar Flares - Triggers

SDO/HMI

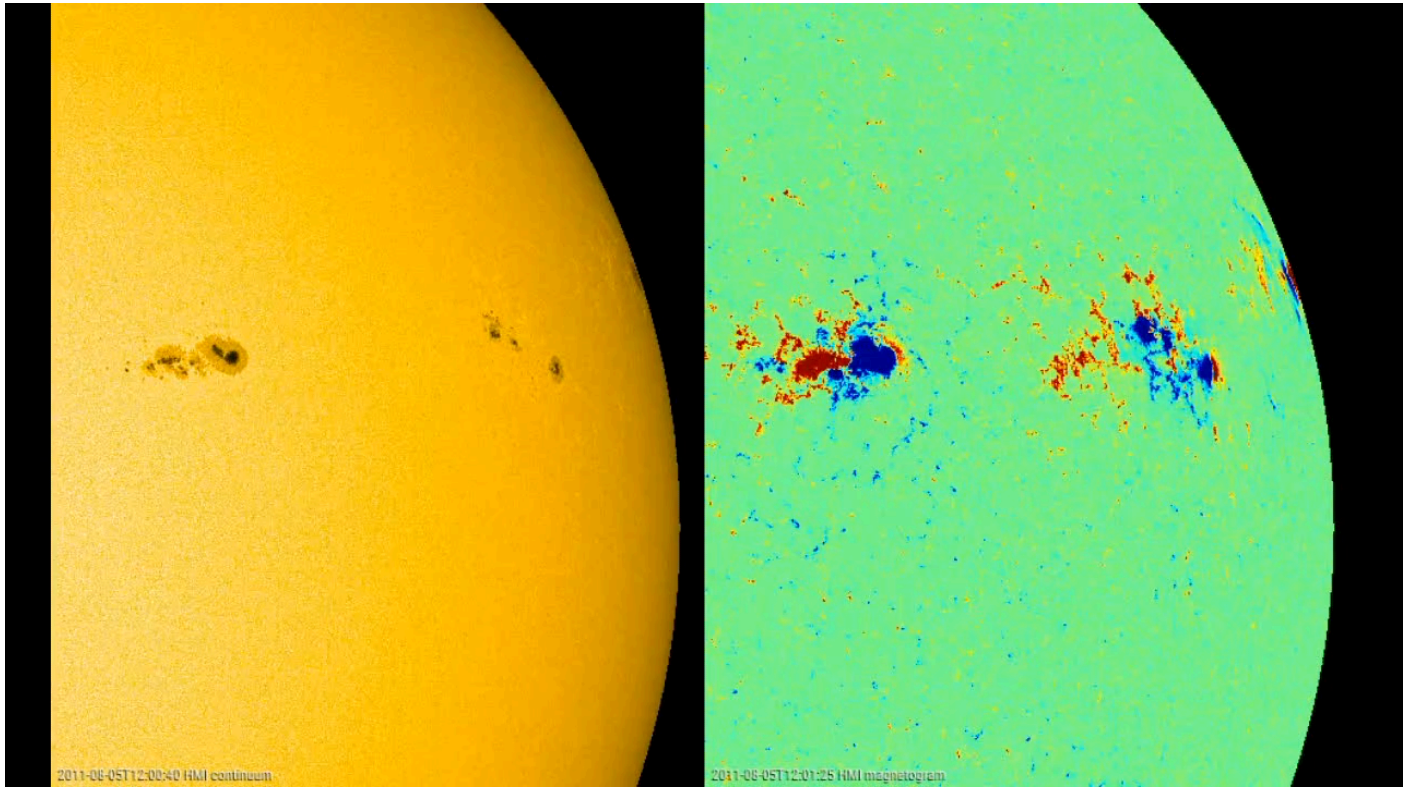
Magnetic flux emergence



Solar Flares - Triggers

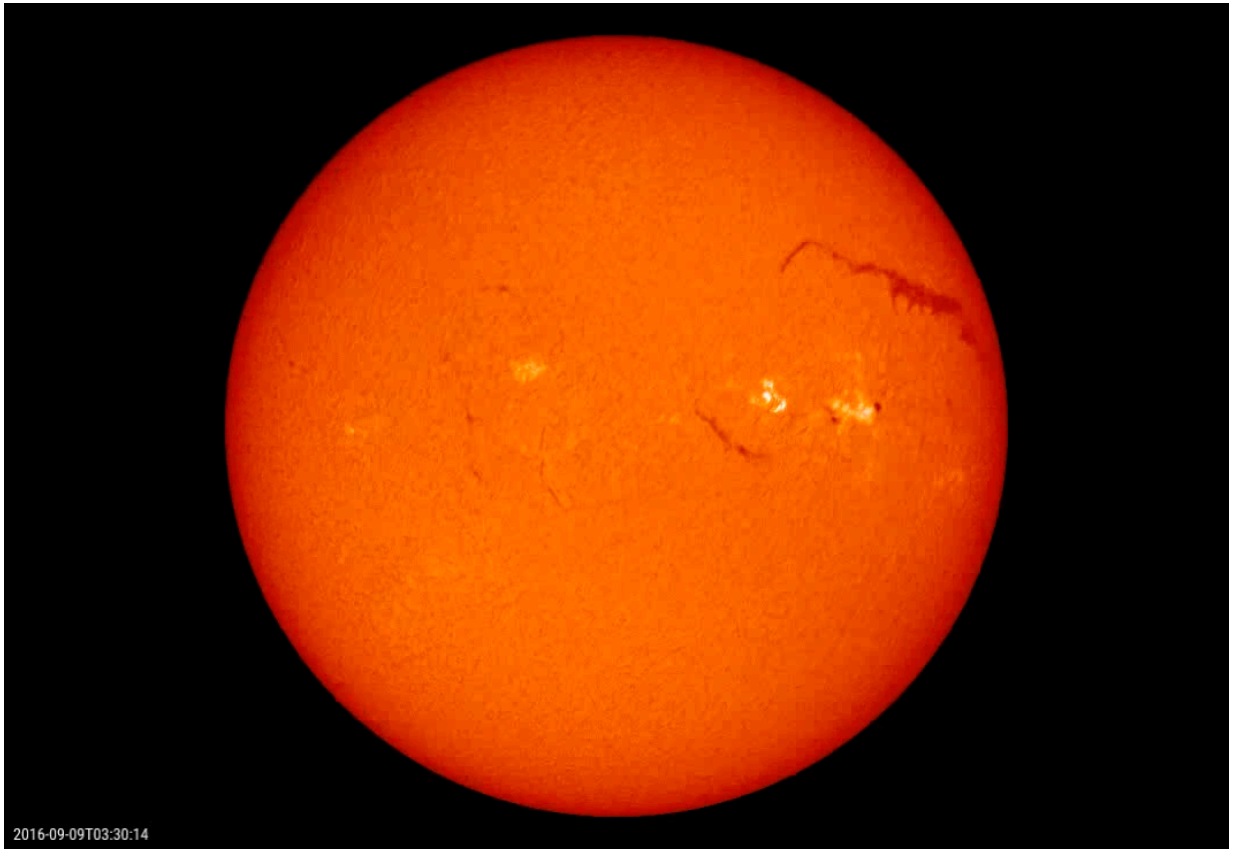
SDO/HMI

Magnetic flux emergence



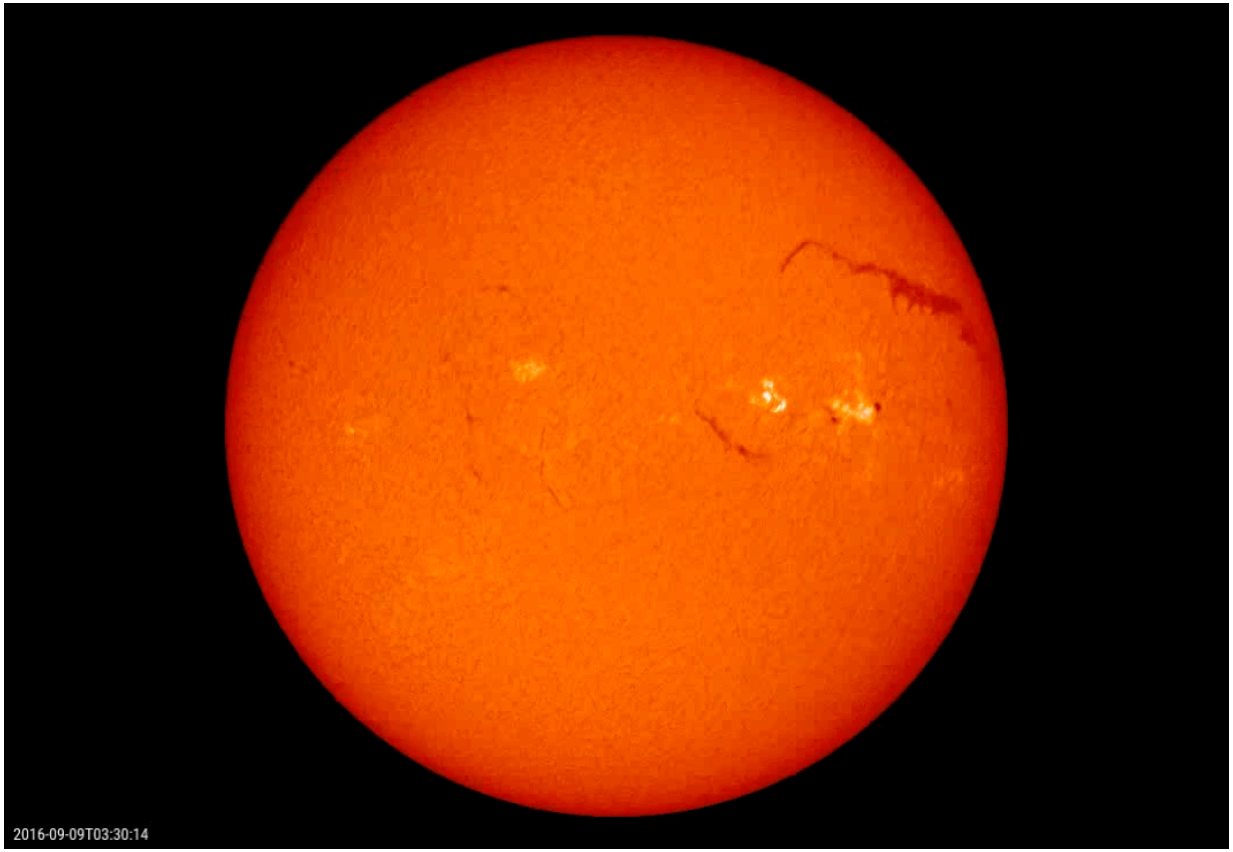
Interaction with other features

Instability elsewhere

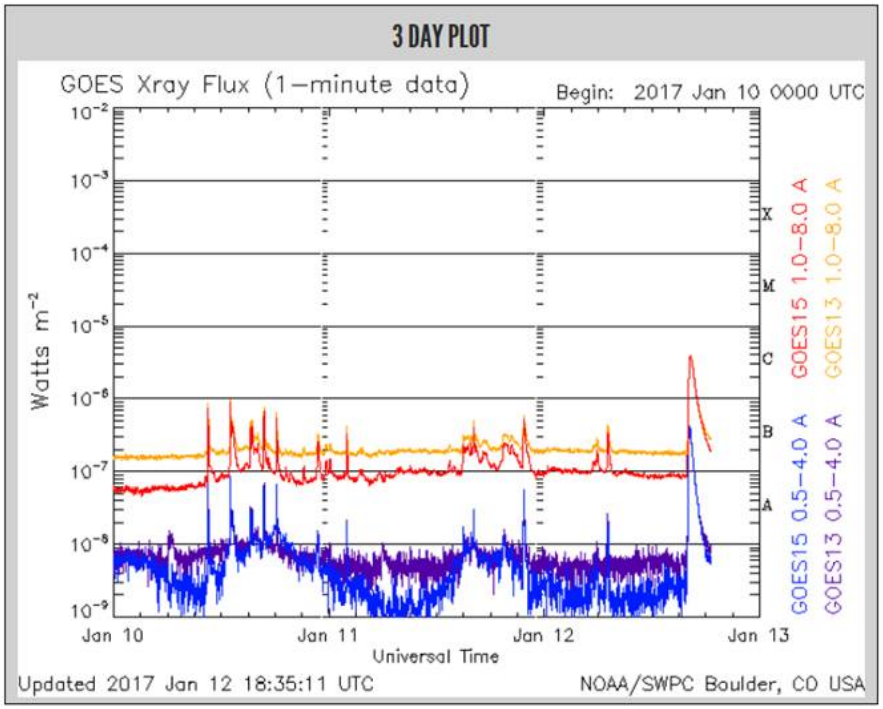


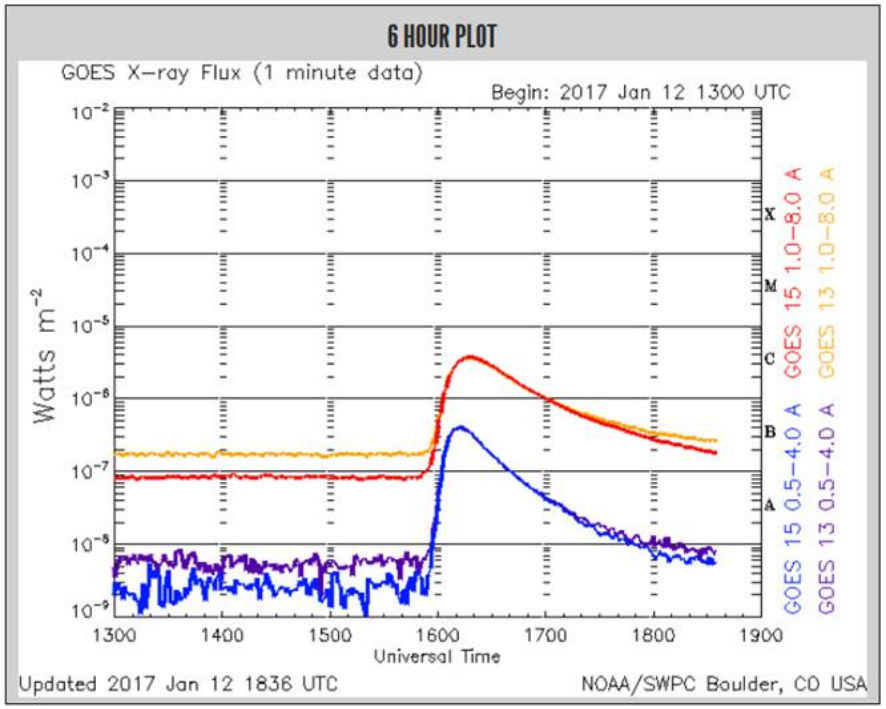
Interaction with other features

Instability elsewhere



Solar flares - Duration



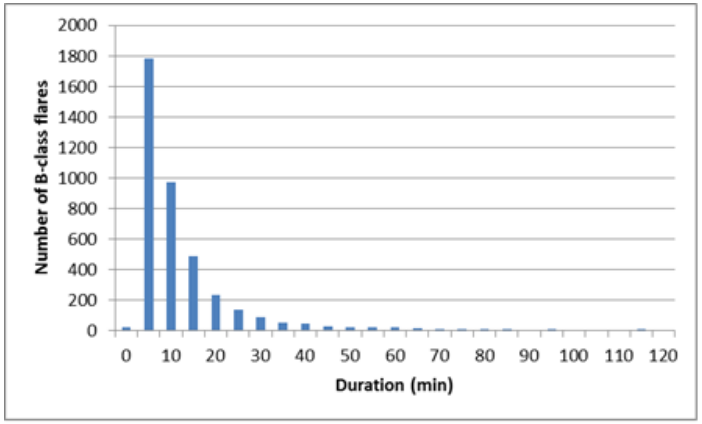


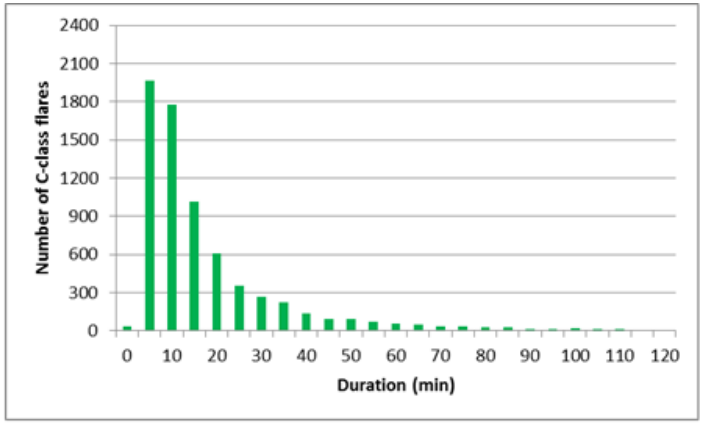


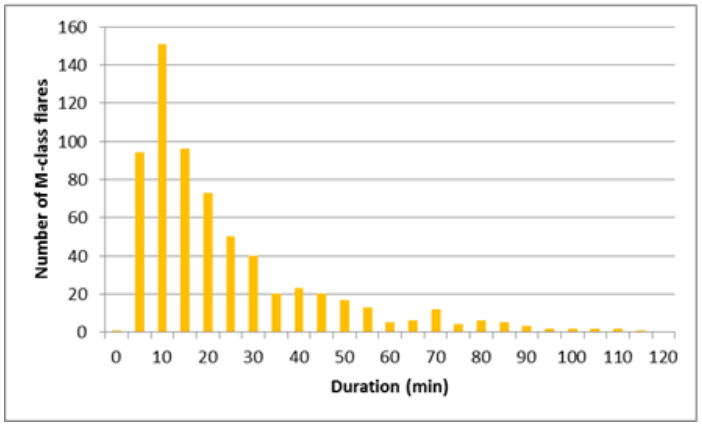
GOES

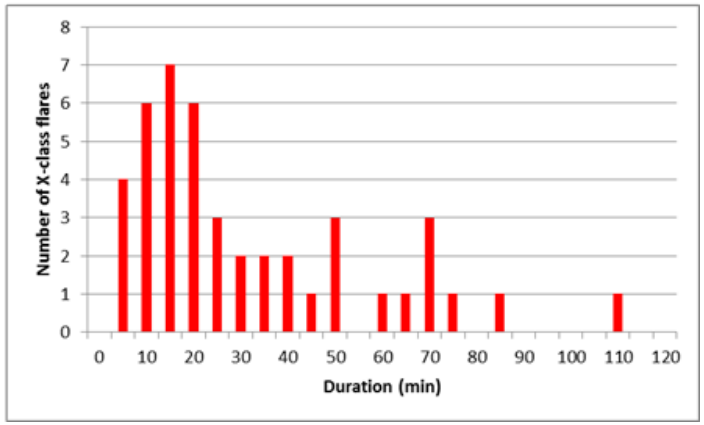
LATEST X-RAY EVENT (1-8Å)			
Current	2017-01-12 18:35:00 UTC	B1.8	Ratio: 0.031
Beginning	2017-01-12 15:54:00 UTC	B1.0	
Maximum	2017-01-12 16:18:00 UTC	C3.8	Integrated flux: 0.006896 J m^{-2}
End	2017-01-12 16:41:00 UTC	C1.9	

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 flares - Duration

Impulsive flare

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

Long Duration Event

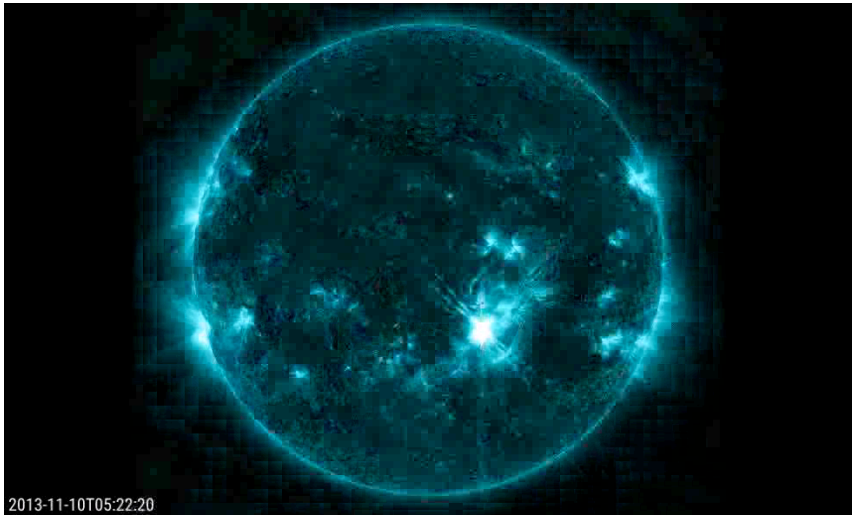
- All flare classes
- Duration
  - Total duration > 1 hour
  - Decay time > 30 minutes (SWPC)
- Association with CMEs increases with increased duration

Solar flare - Duration

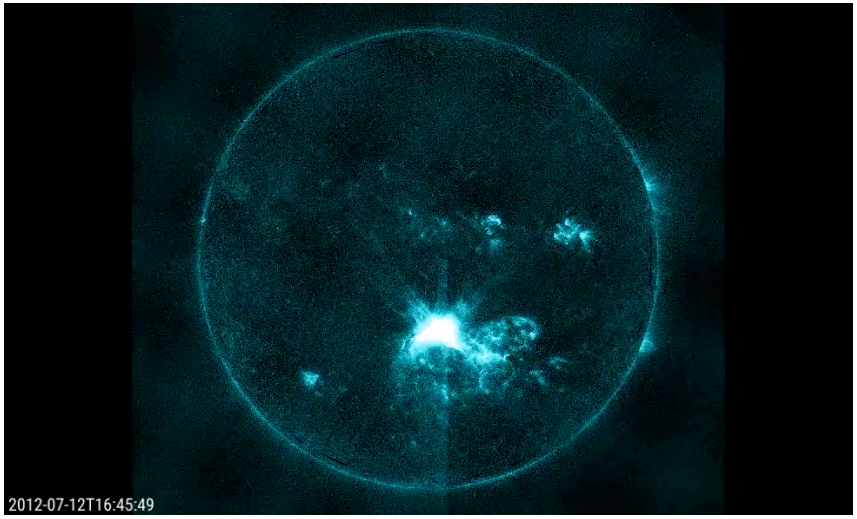
Impulsive flare

Long Duration Event

SDO/AIA



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



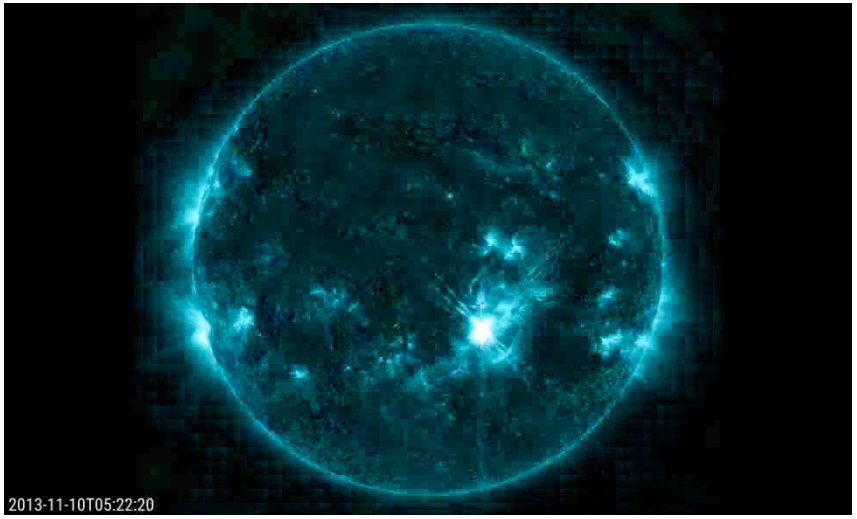
X1 - NOAA 1520 - 12 July 2012 (duration: 113 minutes)

Solar flare - Duration

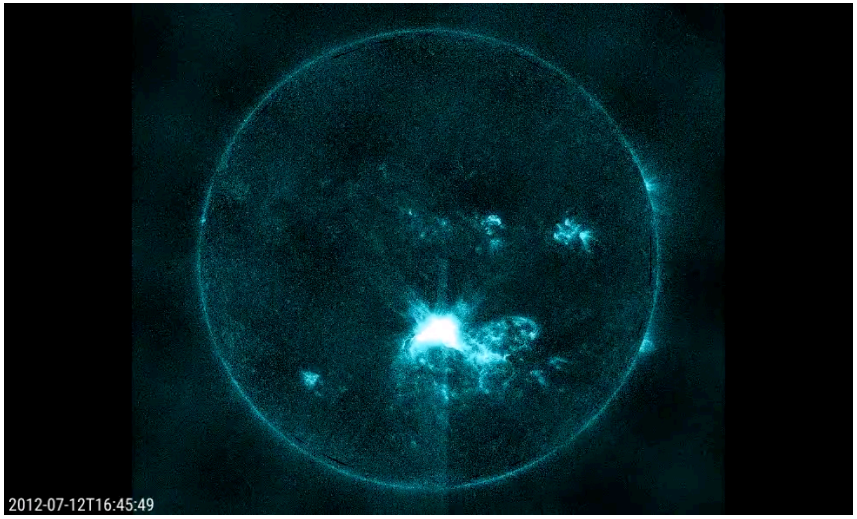
Impulsive flare

Long Duration Event

SDO/AIA



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



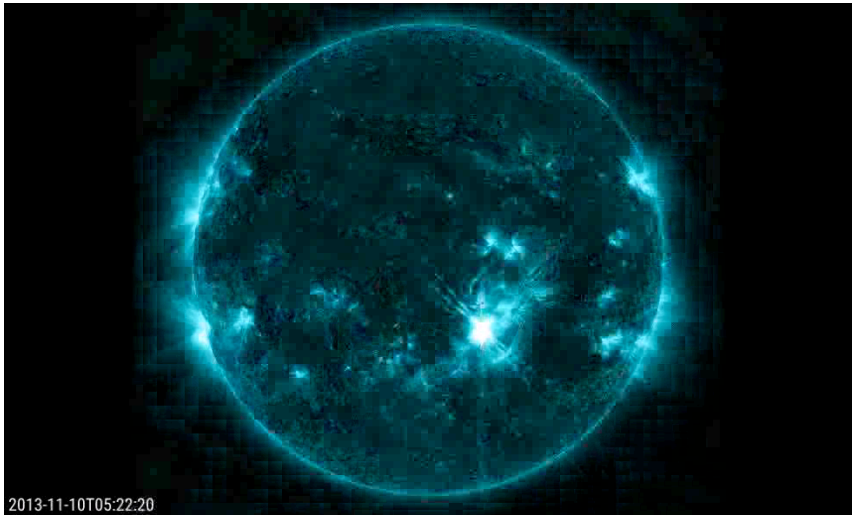
X1 - NOAA 1520 - 12 July 2012 (duration: 113 minutes)

Solar flare - Duration

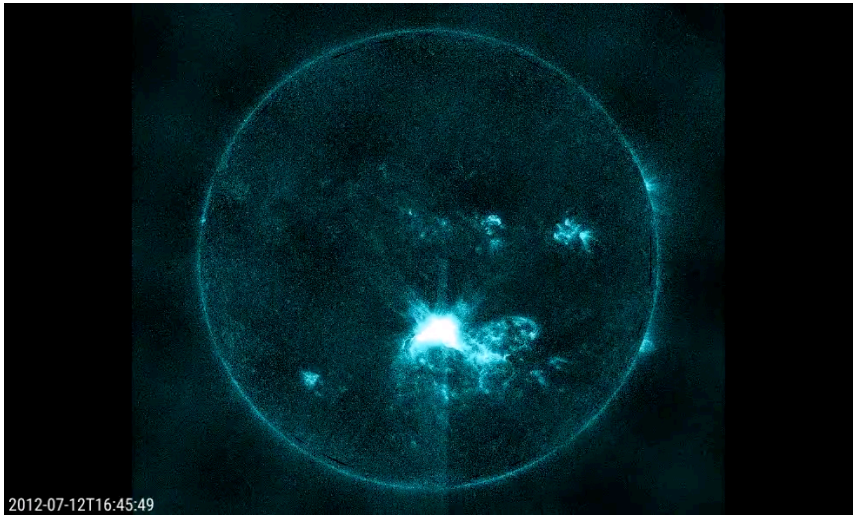
Impulsive flare

Long Duration Event

SDO/AIA



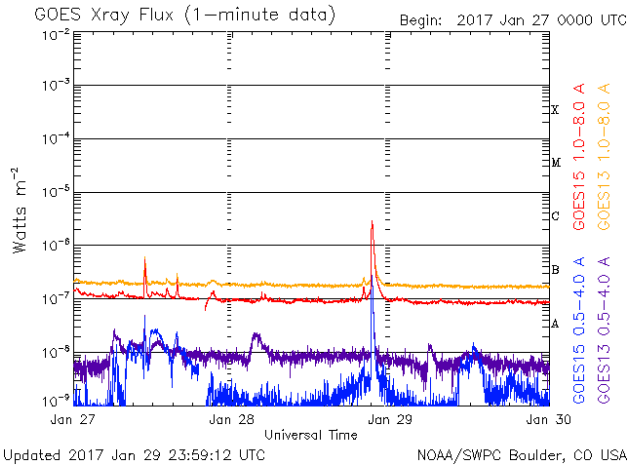
X1 - NOAA 1890 - 10 Nov 2013 (duration: 10 minutes)



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

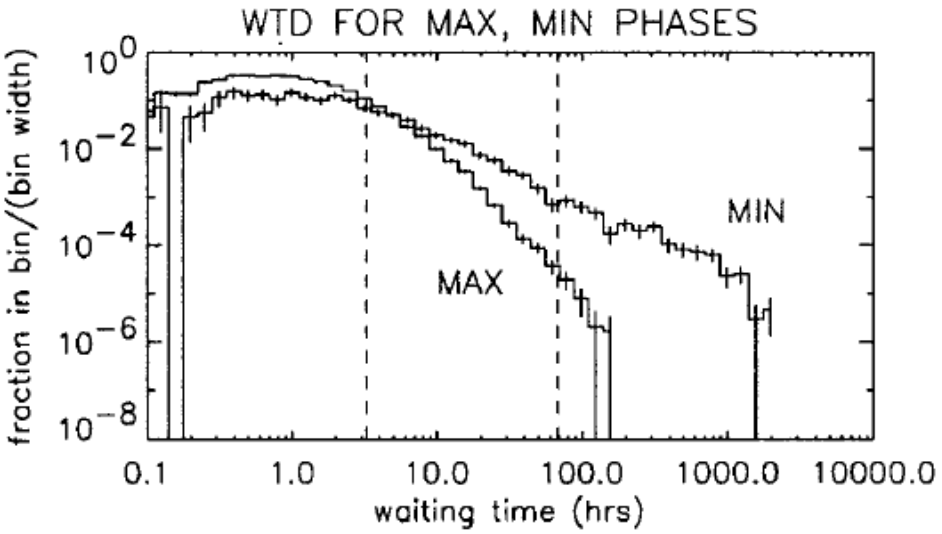
Solar flares - Frequency

- 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

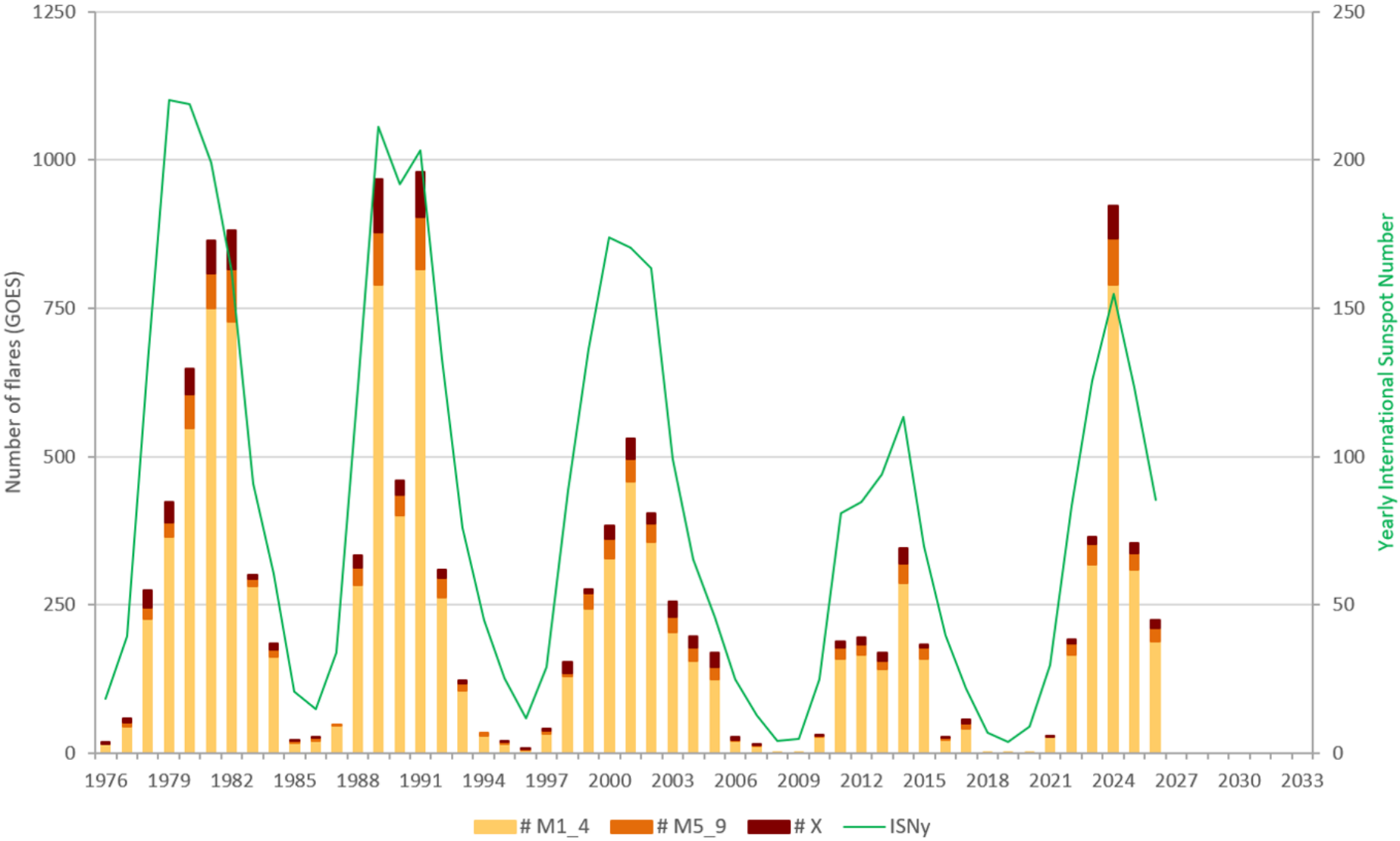




GOES

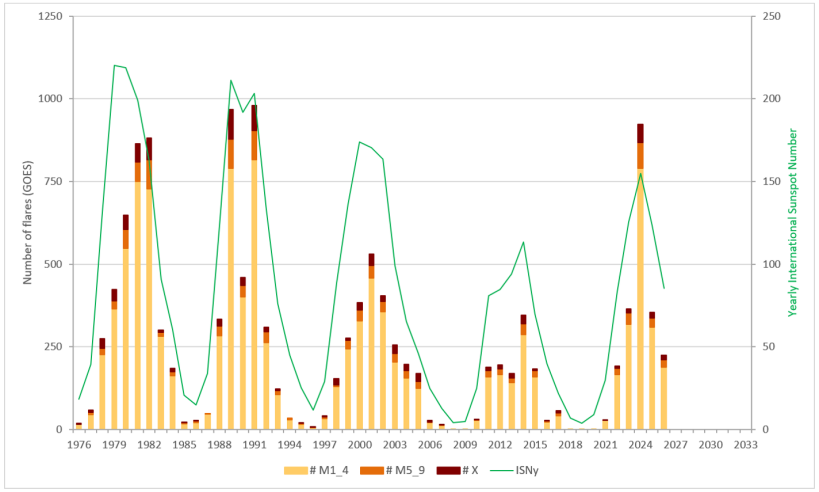


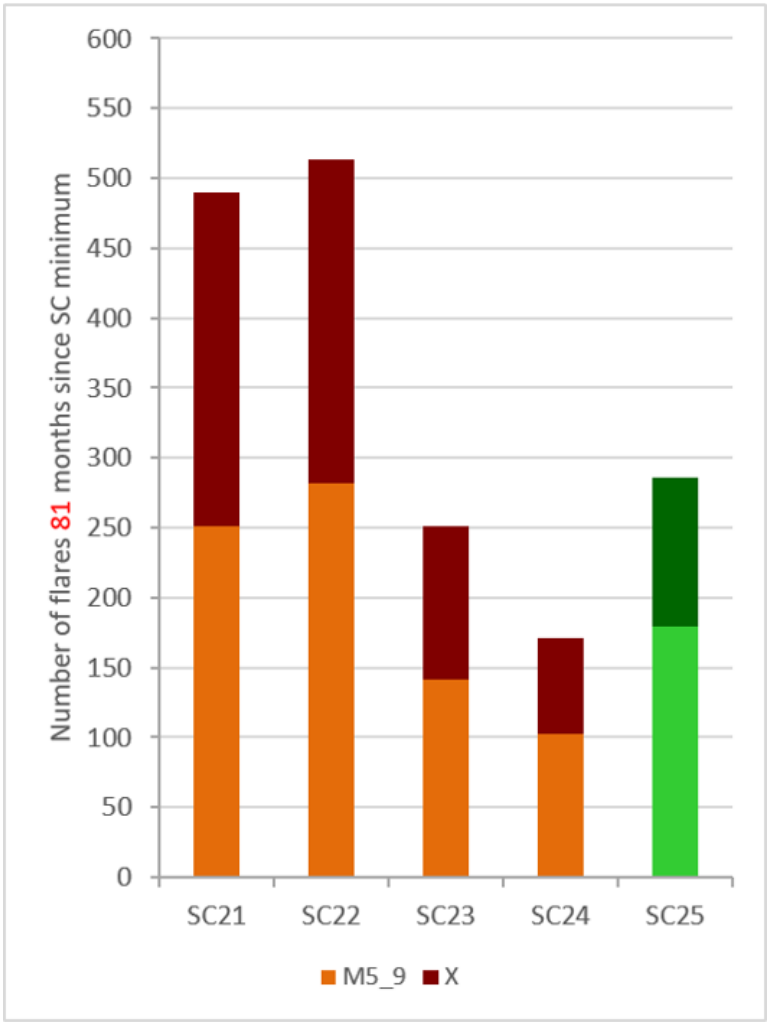
Solar Flares - Solar cycle



https://www.stce.be/content/sc25-tracking#flares

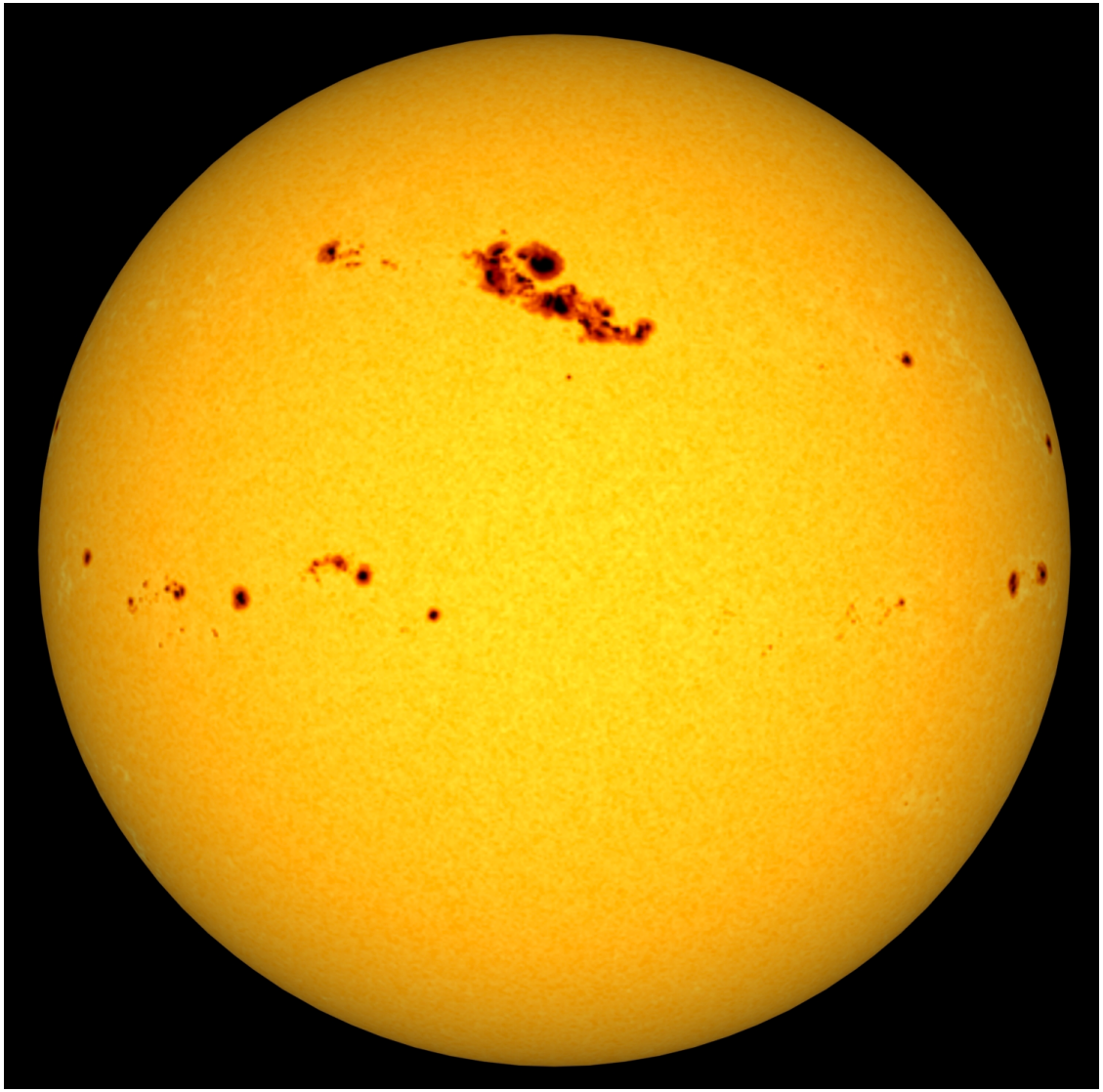
Solar Flares - Solar cycle





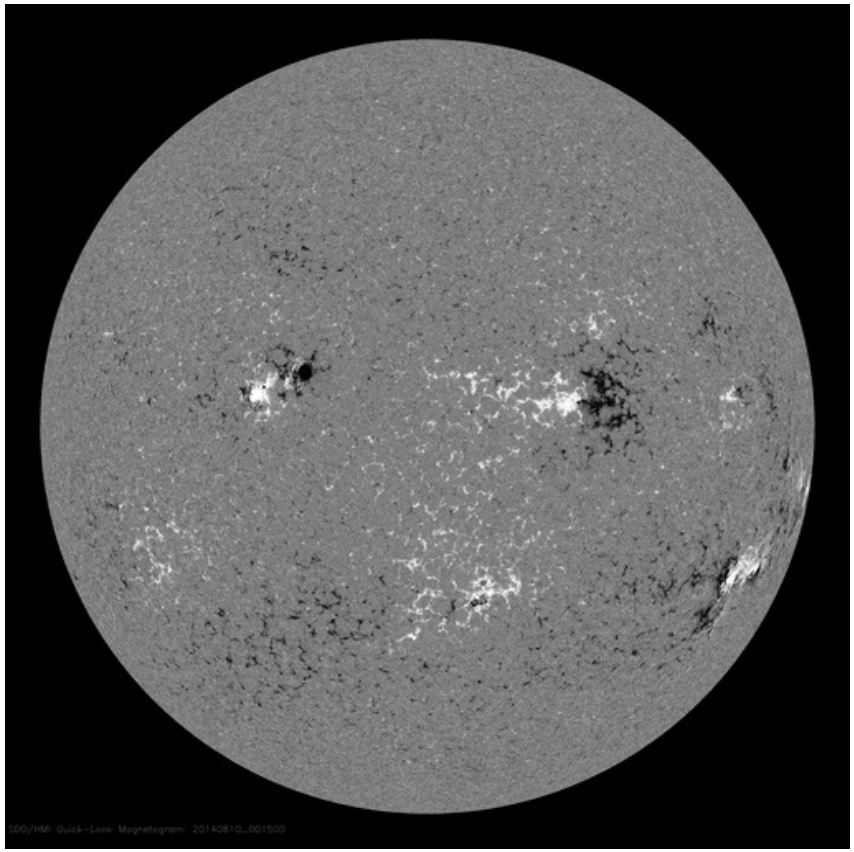
https://www.stce.be/content/sc25-tracking#flares

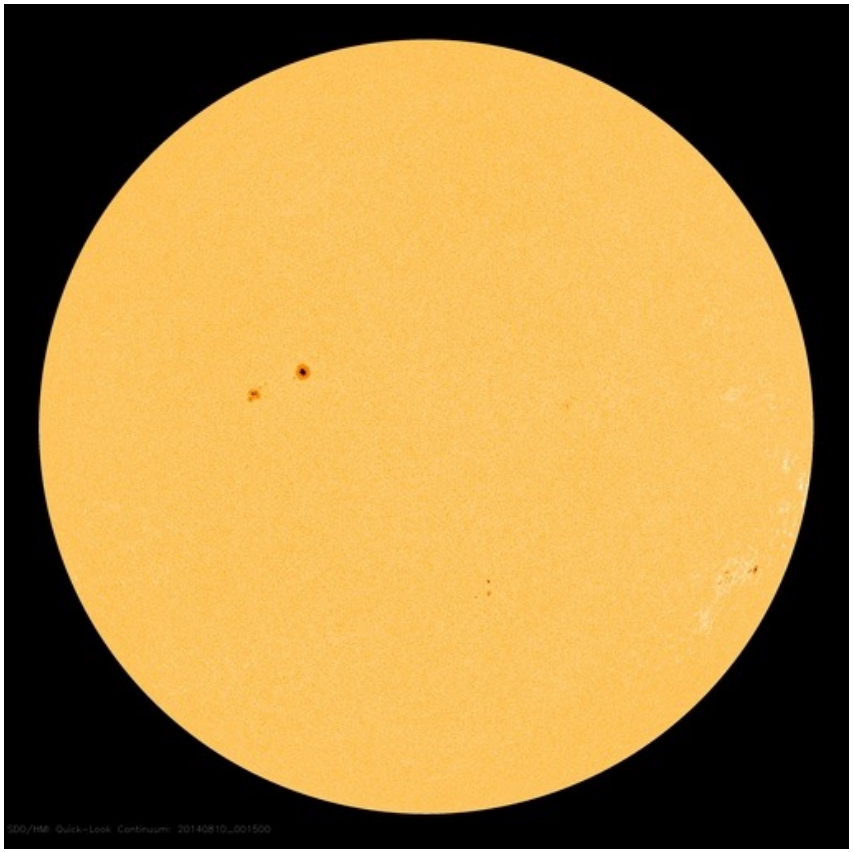
Flare Prediction - Sunspots



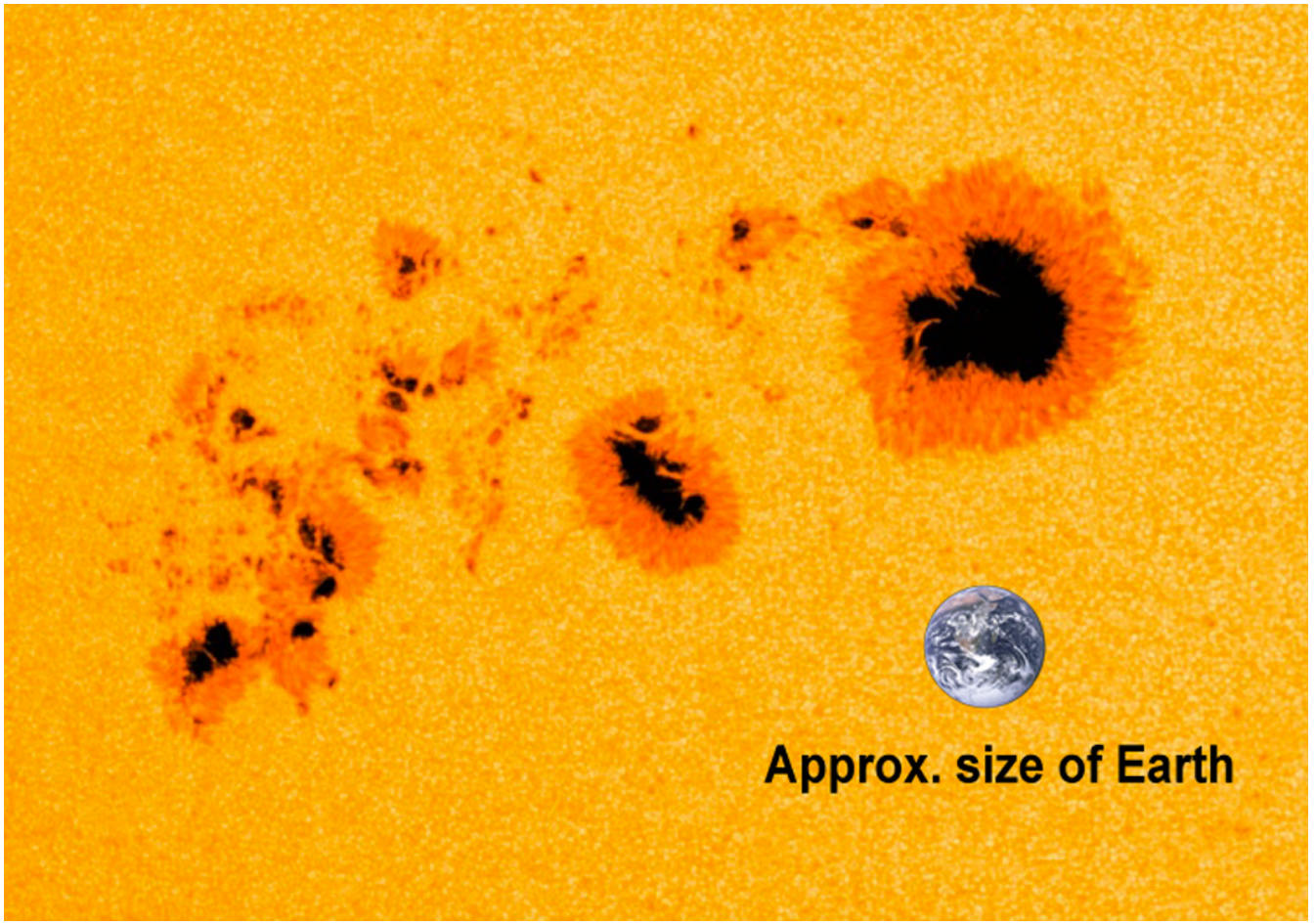
Magnetogram

SDO/HMI

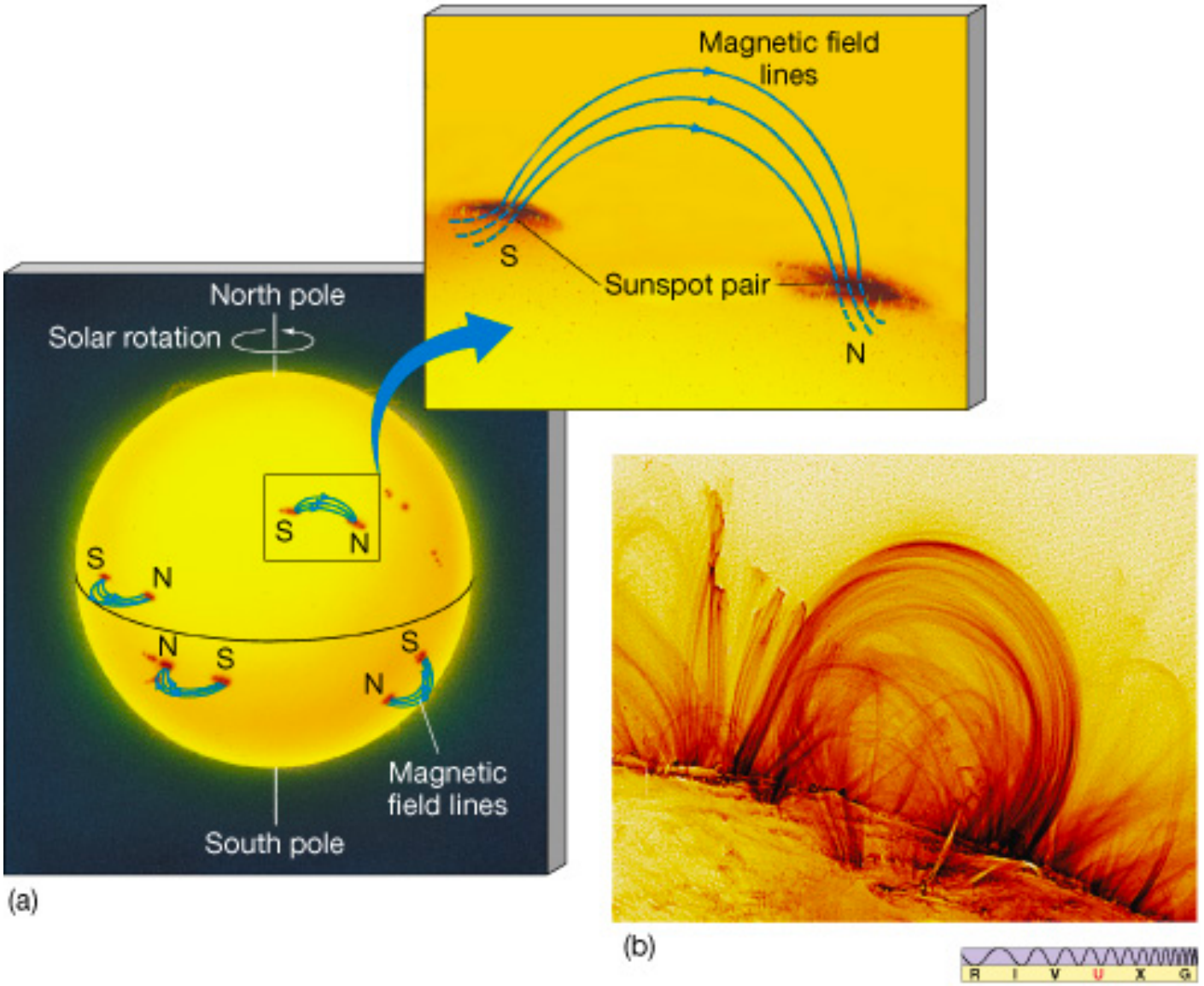




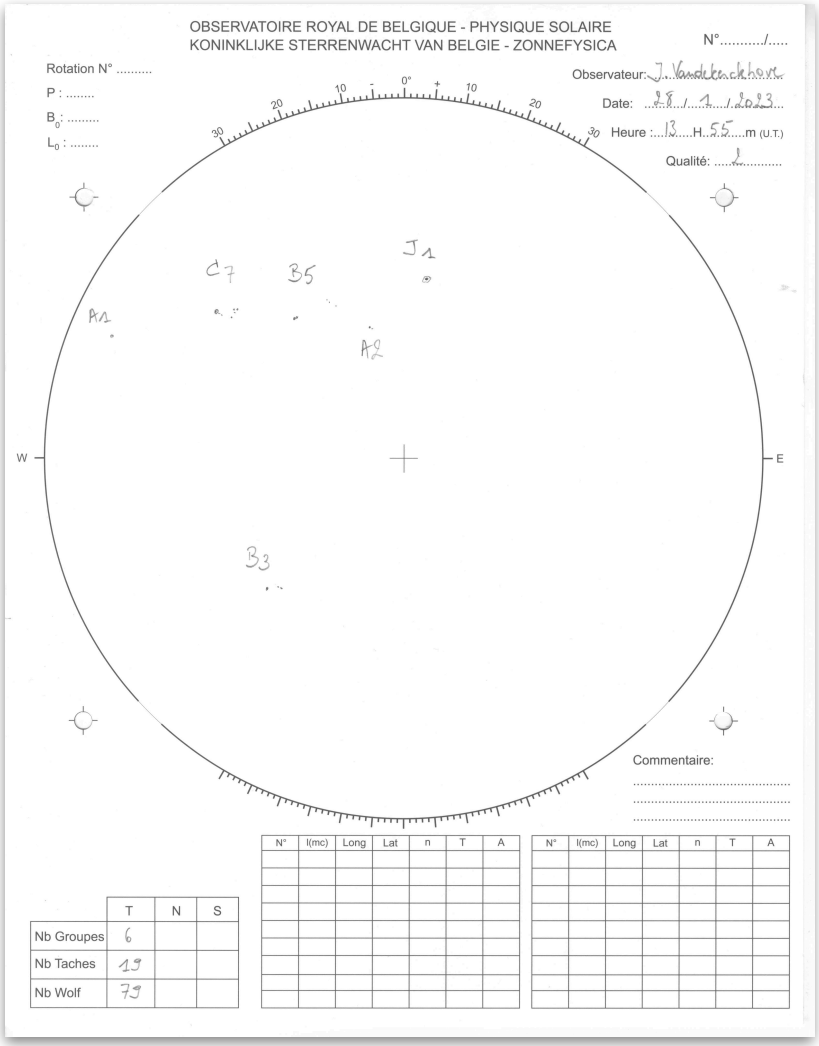
Sunspot size



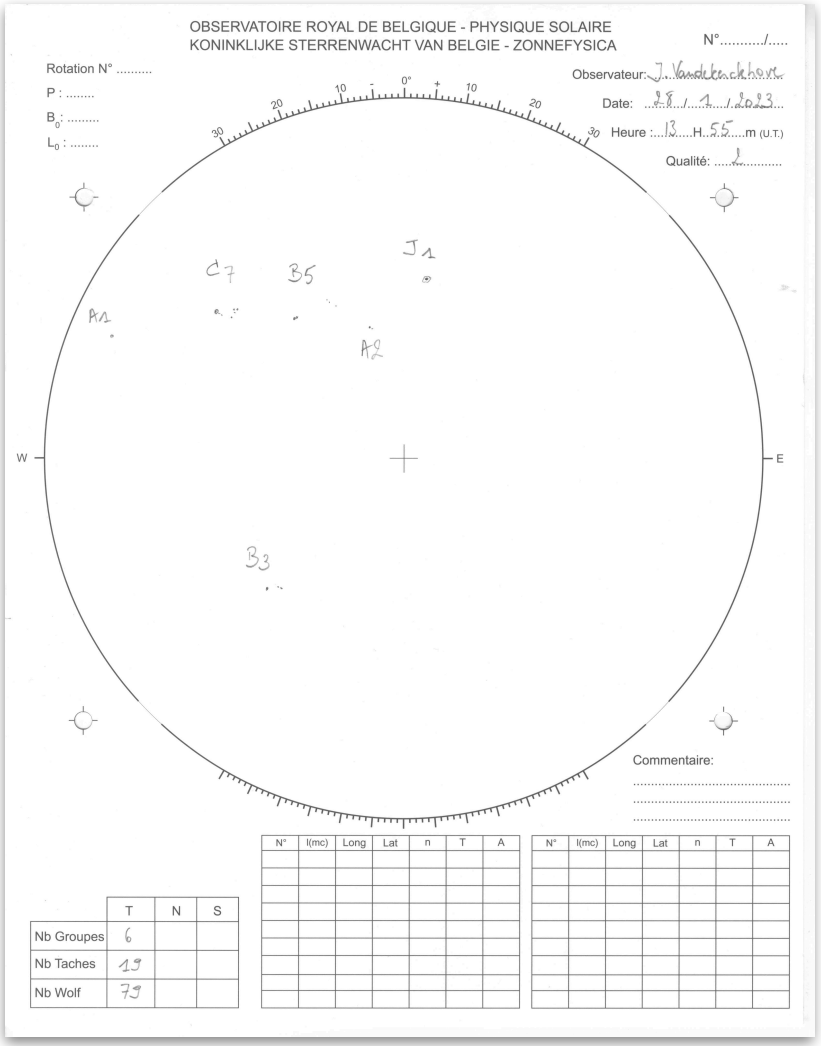
Magnetic field



Sunspot drawings



Sunspot drawings


OBSERVATOIRE ROYAL DE BELGIQUE - PHYSIQUE SOLAIRE
KONINKLIJKE STERRENWACHT VAN BELGIE - ZONNEFYSICA

N°...../.....

Rotation N° .....
P : .....
B_0 : .....
L_0 : .....

Observateur: J. Vandenchhove
Date: 18 / 1 / 2023
Heure : 13 H 55 m (U.T.)
Qualité: 2

W E

C7 B5 J1 A1 A2 B3

Commentaire:
.....
.....
.....

	T	N	S
Nb Groupes	6		
Nb Taches	19		
Nb Wolf	79		

N°	l(mc)	Long	Lat	n	T	A

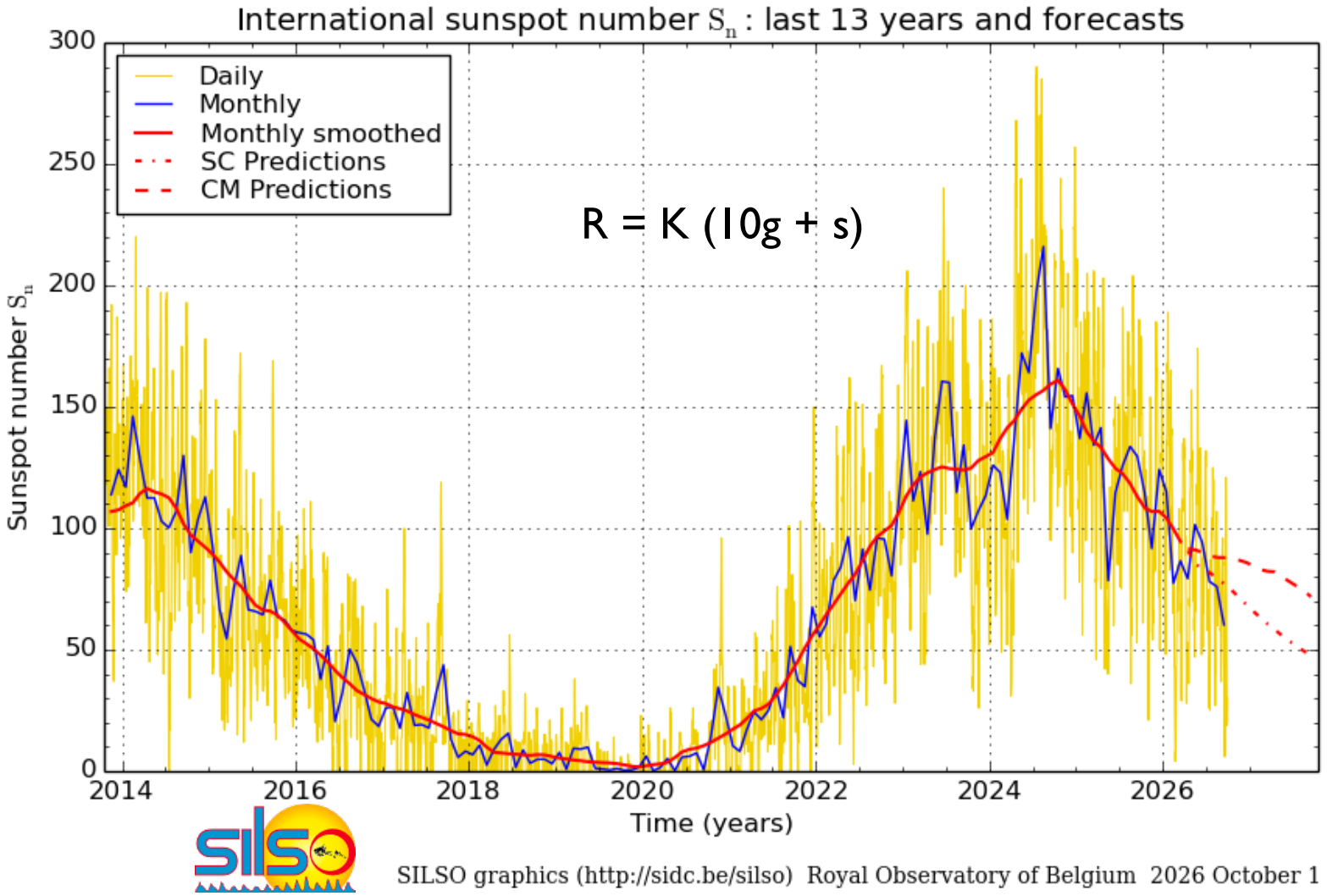
N°	l(mc)	Long	Lat	n	T	A



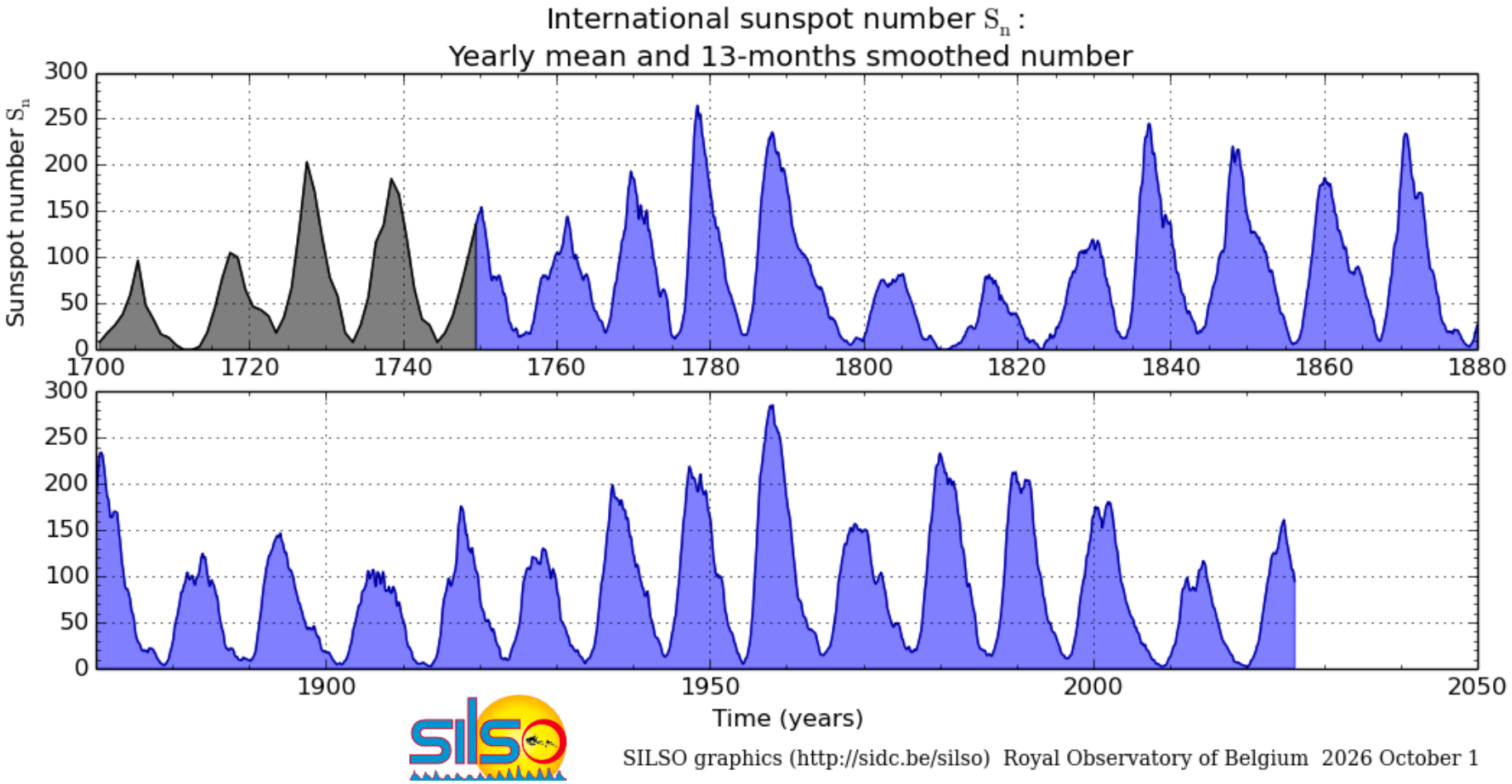


USET

Sunspot number and solar cycle



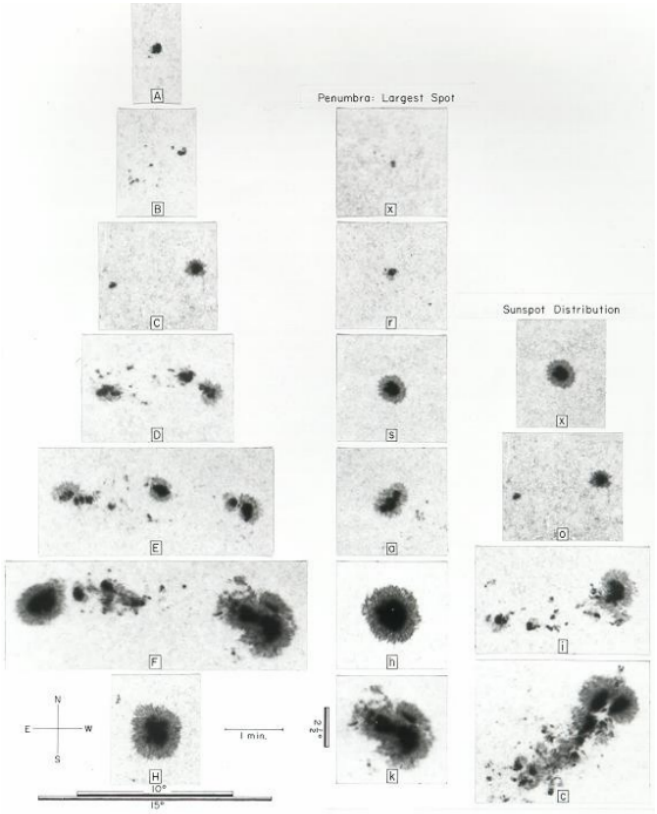
Long term solar activity
Solar seasons



Solar Flares - Classification

McIntosh classification

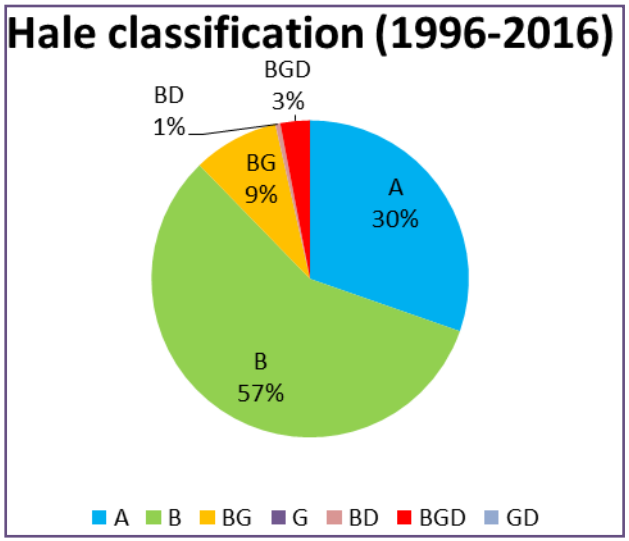
- Zpc (3-letter code)
  - Z - Modified Zürich classification
  - p - Penumbra largest spot
  - c - Interior sunspot distribution
- 60 possible combinations
  - Linked to flare intensity
  - Rather large uncertainties
- Used worldwide

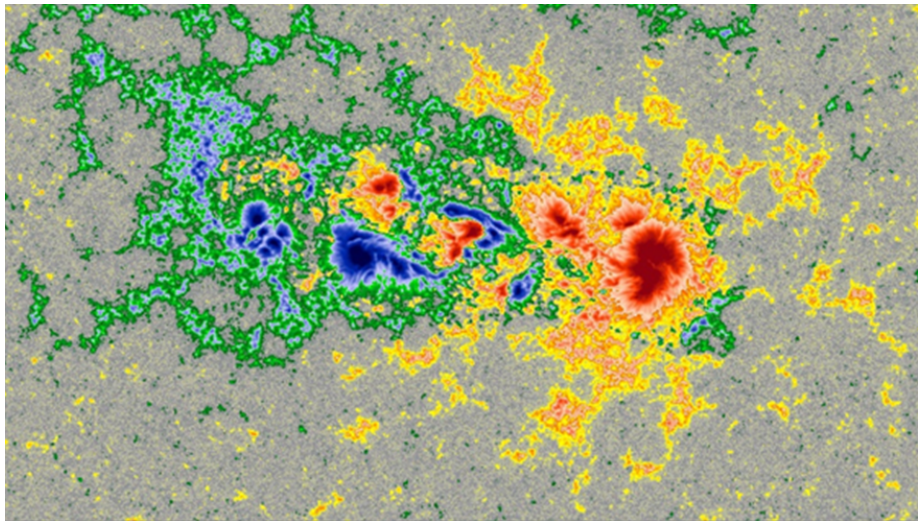


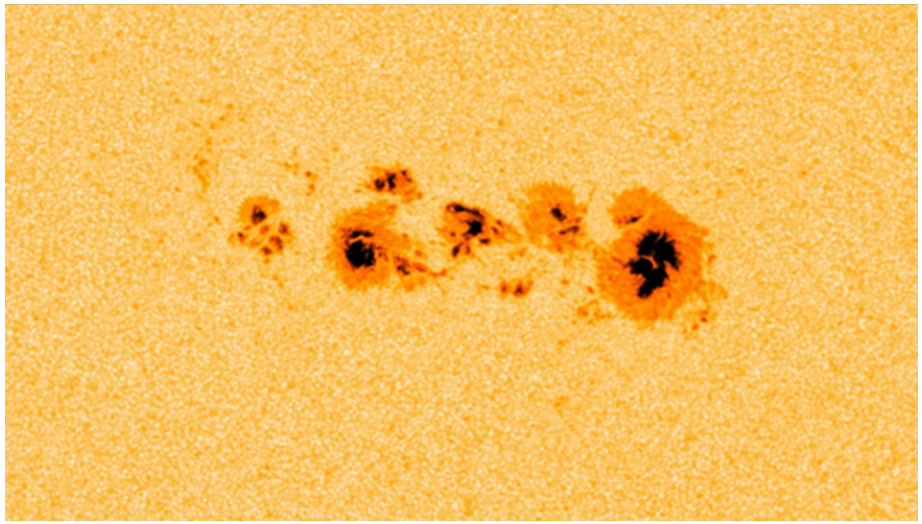
Solar Flares - Classification

Mount Wilson (Hale) classification

- Based on the magnetic properties of a sunspot group
- 7 options: α, β, βγ, γ, βδ, βγδ, γδ





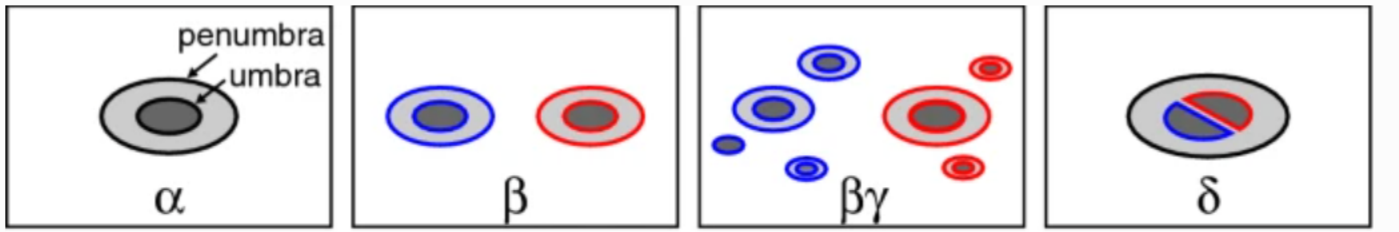


SDO/HMI

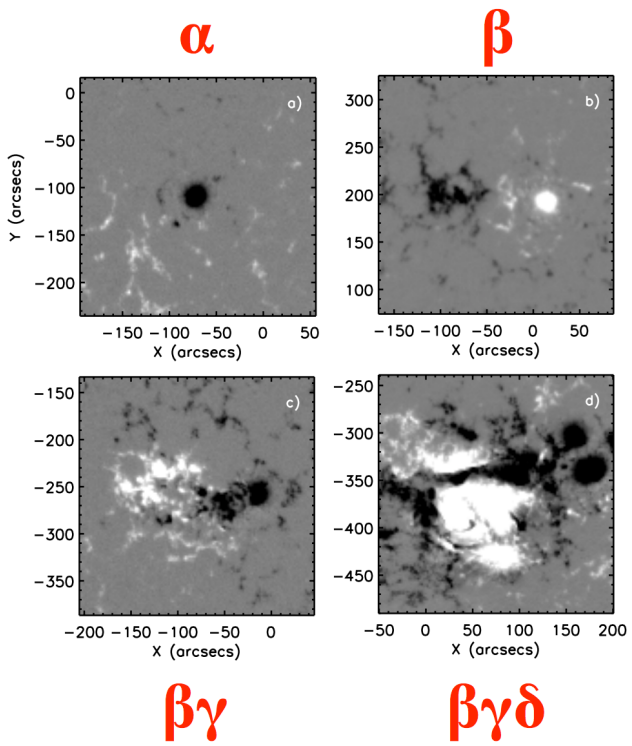
Solar Flares - Classification

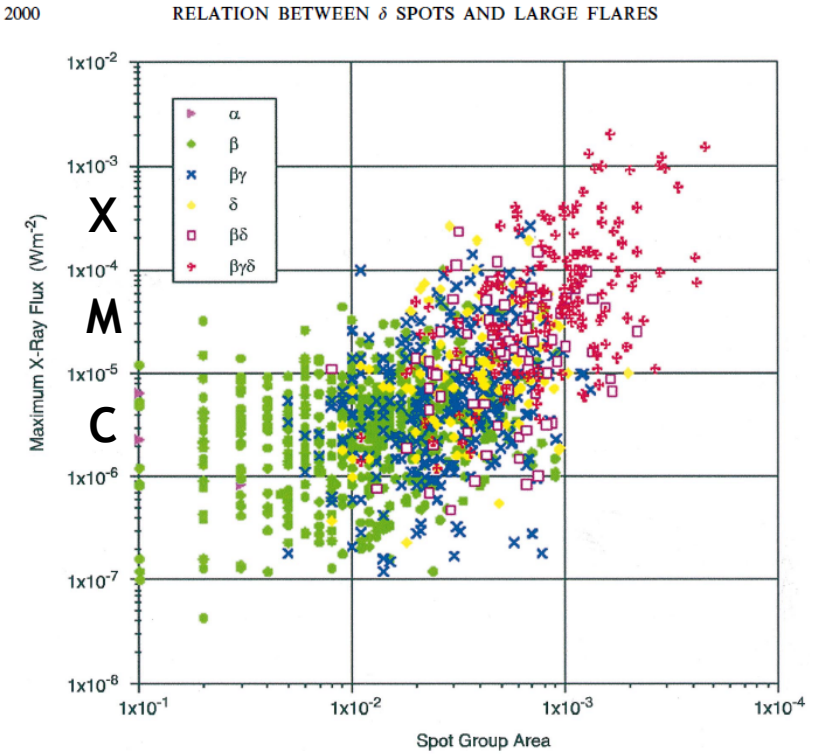
Table 3.1: Mount Wilson Scheme

Magnetic Class	Description
α	Unipolar sunspot
β	Bipolar sunspot group
γ	Atypical mixing of polarities
$\beta\gamma$	Mixture of polarities within a predominantly bipolar group
δ	Opposite polarity umbrae ($< 2^\circ$ separation) surrounded by a single penumbra
$\beta\delta$	Bipolar with delta configuration
$\beta\gamma\delta$	Bipolar, mixed & delta configuration



Solar Flares - Prediction





Solar Flares - Prediction

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

