Training for SIDC Space Weather Forecasters

Royal Observatory of Belgium

Mini Workshop on Sunspot Classification

The Zurich, McIntosh and MtWilson classification schemes

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Royal Observatory of Belgium

Solar Influences Data analysis Centre
www.sidc.be

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- Aim
- Data sources
- Sunspot groups
  - What are they?
  - Basics
- Sunspot group classifications
  - The Zurich classification *(Waldmeier)*
  - The McIntosh classification
  - The Mount Wilson classification *(Hale)*
- Exercises

Aim of this (mini) Workshop

- To allow SWx forecasters to rule out obviously wrong classifications:
  - Zurich classification scheme
  - McIntosh classification scheme
  - MtWilson classification scheme
- To do this in a well-reasoned, structured manner

- *Sunspot groups come in a very wide variety of sizes and complexities*
  - *There will be debates and discussions…*

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Data sources: NOAA/USAF

```
:Product: 1002SRS.txt
:Issued: 2023 Oct 02 0030 UTC
# Prepared jointly by the U.S. Dept. of Commerce, NOAA,
# Space Weather Prediction Center and the U.S. Air Force.
#
Joint USAF/NOAA Solar Region Summary
SRS Number 275 Issued at 0030Z on 02 Oct 2023
Report compiled from data received at SWO on 01 Oct
I.  Regions with Sunspots.  Locations Valid at 01/2400Z
Nmbr Location  Lo  Area  Z   LL   NN Mag Type
3447 S23W72   059  0070 Hsx  02   01 Alpha
3448 N13W06   353  0080 Hsx  02   01 Alpha
3449 N15W22   009  0040 Cso  08   08 Beta
3450 S19E18   329  0180 Eai  12   20 Beta-Gamma
3451 N16E48   299  0050 Dri  06   07 Beta-Delta
3452 N11E47   300  0120 Dai  08   12 Beta
3453 N12E11   336  0020 Cro  04   06 Beta
3454 S12E64   283  0020 Hrx  01   01 Alpha
IA. H-alpha Plages without Spots.  Locations Valid at 01/2400Z Oct
Nmbr  Location  Lo
3446  N23W64   051
II. Regions Due to Return 02 Oct to 04 Oct
Nmbr Lat    Lo
3429 N12    229
```

USAF/NOAA SRS: https://www.swpc.noaa.gov/products/solar-region-summary

SWEC

Solar Influences
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Data sources: SolarMonitor

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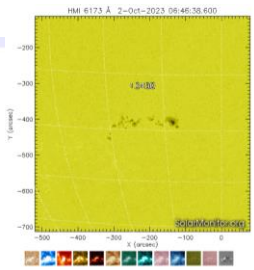
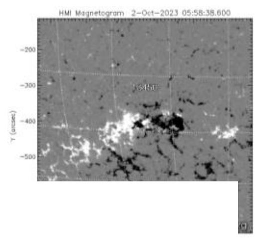
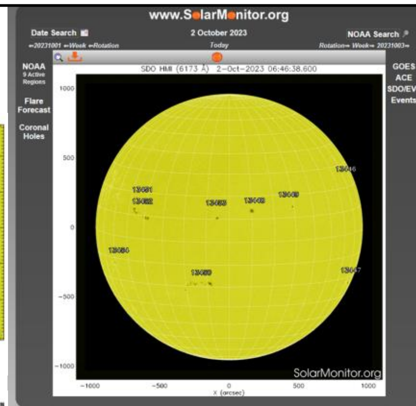






Today's/Yesterday's NOAA Active Regions

NOAA Number	Latest Position	Hale Class	McIntosh Class	Sunspot Area [millionths]	Number of Spots	Recent Flares
13447	S23W76 (856",-396")	α/β	Hsx/Cso	0070/0080	01/03	-
13448	N13W10 (162",107")	α/α	Hsx/Hsx	0080/0080	01/01	-
13449	N15W26 (407",150")	β/β	Cso/Csi	0040/0110	08/10	-
13450	S19E14 (-220",-413")	βγ/βγ	Eai/Eai	0180/0170	20/12	-
13451	N16E44 (-641",185")	βδ/βδ	Dri/Dai	0050/0080	07/08	-
13452	N11E43 (-643",101")	β/-	Dai/---	0120/----	12/--	-
13453	N12E07 (-114",90")	β/-	Cro/---	0020/----	06/--	-
13454	S12E60 (-813",-252")	α/-	Hrx/---	0020/----	01/--	-
13446	N23W68 (819",333")	/	/	/	/	-

Class (HH:MM) -Today
Class (HH:MM) -Yesterday

Events not associated with currently named NOAA regions: C2.0(01:16) C2.8(03:13) C3.2(04:00) C2.4(05:06) C1.6(05:39) C3.6(03:53) C4.0(04:00) C3.6(05:08) C3.6(05:10) C2.3(05:31) C2.6(09:08) C5.0(09:39) C3.6(11:06) C2.9(14:10) C3.4(14:41) C2.3(19:11) C2.1(20:08) C1.9(21:07) C2.5(22:30) C4.5(23:00)

Solar Monitor (1): https://www.solarmonitor.org/
Solar Monitor (2): https://solmon.dias.ie/
USAF/NOAA SRS: https://www.swpc.noaa.gov/products/solar-region-summary

Data sources: ASSA

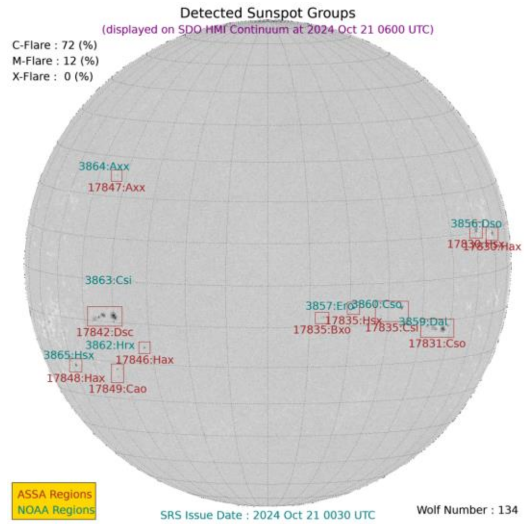
2024 Oct 21 0700 UTC
Sunspot Group Detection and Classification Results
(based on SDO HMI Continuum and Magnetogram Images)

Number of Detected Sunspot Groups : 12

ASSA Number	Num Spots	Num Spots (with penumbra)	Location	LE	Area	Area(pen)	McIntosh Class	Mag Class	fprob_C	fprob_M	fprob_X
17830	1	1	N09.2/W70.4	1.6	53	53	Hax	Alpha	5	1	0
17830	1	1	N10.8/W61.7	1.5	60	60	Hax	Alpha	5	1	0
17831	6	2	S11.4/W46.8	7.6	167	104	Cso	Beta-Gamma	20	2	0
17835	2	1	S06.1/W34.4	6.3	32	29	Csi	Beta-Gamma	10	1	0
17835	1	1	S05.5/W21.5	0.5	15	15	Hsx	Alpha	5	0	0
17835	1	0	S07.6/W14.0	0.1	3	0	Axx	Alpha	5	1	0
17846	1	1	S15.7/E31.3	0.7	10	10	Hax	Alpha	5	1	0
17849	2	1	S22.5/E41.4	1.6	11	7	Cao	Beta-Gamma	24	2	0
17847	1	0	N25.6/E42.9	0.1	5	0	Axx	Alpha	5	1	0
17842	6	2	S08.5/E41.6	8.3	260	212	Cai	Beta-Gamma	14	1	0
17848	1	1	S21.5/E57.5	1.6	35	35	Hsx	Alpha	5	0	0
17850	1	0	S11.6/E66.2	0.4	7	0	Axx	Alpha	5	1	0

Total Number of Spots : 24
Wolf Number : 144

< Flare Probability as a whole >
C-Flare : 69 (%)
M-Flare : 11 (%)
X-Flare : 0 (%)



ASSA - Automatic Solar Synoptic Analyzer
https://spaceweather.kasa.go.kr/assa

Solar Influences
Data analysis Centre
www.sidc.be

Data sources: SIDC/USET

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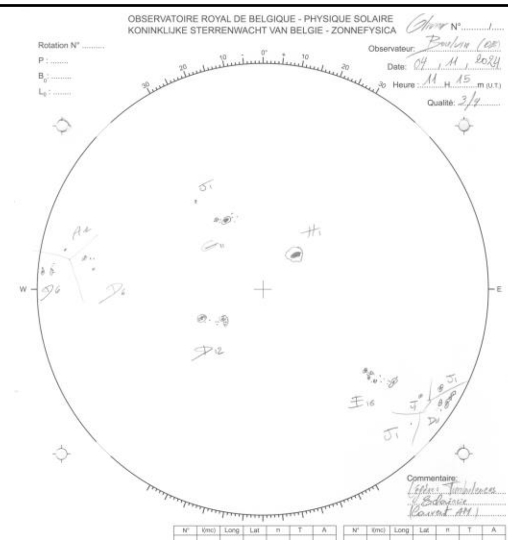
SIDC/USET Sunspot group characteristics archive

The operator of the SIDC local observing facilities (Uccle Solar Equatorial Table) produces every day a drawing of the w projected on paper sheet. The analysis of the drawing provides characteristics of the Sunspot groups visible on the disc combination of human interaction (grouping spots together and judging their classification) and automated routines (ca position).

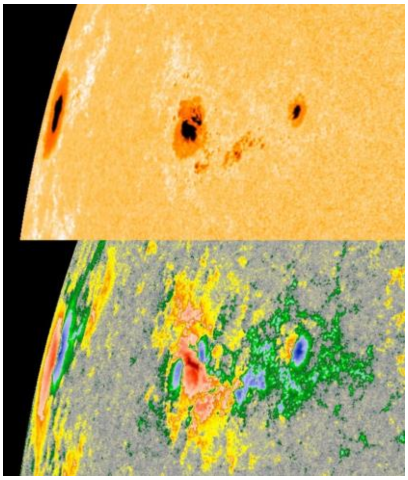
Sunspot group collection: [2024-11-04 11:15 UTC]

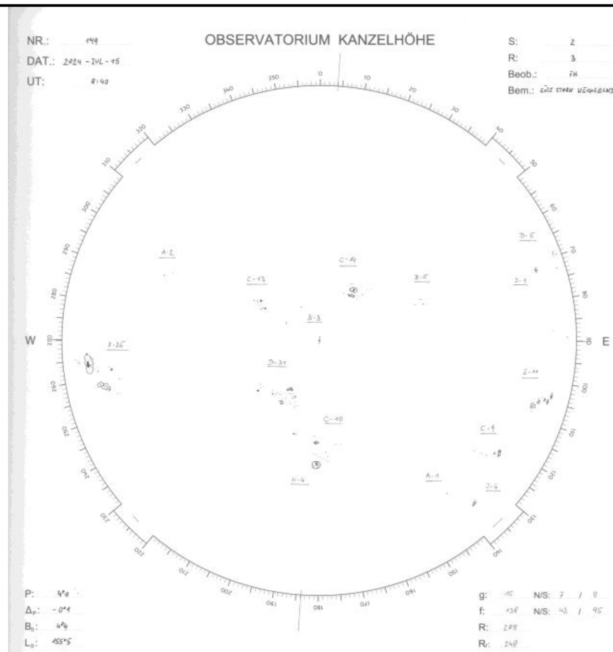
Location	# spots	Area	McIntosh	Leading spot
Longitude: -72.54 Latitude: -5.59	11	1068.65	Dko	Smallest
Longitude: -63.80 Latitude: -3.06	1	218.94	Hsx	/
Longitude: -60.27 Latitude: -14.31	1	16.76	Hsx	/
Longitude: -56.60 Latitude: -6.49	1	76.97	Hsx	/
Longitude: -39.53 Latitude: -5.56	16	519.08	Eki	Smallest
Longitude: -3.93 Latitude: 15.43	1	682.76	Hhx	/
Longitude: 8.62 Latitude: -8.44	12	450.08	Eki	Equal
Longitude: 16.78 Latitude: 16.07	11	271.89	Dhi	/



SIDC/USET sunspot groups: https://swe.ssa.esa.int/web/guest/sidc-S123b-federated
SIDC/USET sunspot groups: https://www.sidc.be/spaceweatherservices-private/applications/ESASSAproducts/stable/WEB/index.php?component=archive&pc=S123&psc=b
SIDC/USET drawings: https://www.sidc.be/uset/

Data sources: Other





SDO/HMI : https://sdo.gsfc.nasa.gov/data/
Kanzelhöhe Observatory - http://cesar.kso.ac.at/

The picture to the left are fromSDO/HMI and show a magnetogram and a white light image of NOAA 13878 on 29 October2024. It is recommended that instead of using the white/black SDO/HMI magnetograms, to use the line of sight magnetic field colored magnetograms. Around 236 Gauss, there's a sharp discontinuity in color change highlighting the location of sunspots and distinguishing them from the other local weak magnetic fields. These diagrams can be found at https://sdo.gsfc.nasa.gov/data/ , with an explanation at https://sdo.gsfc.nasa.gov/assets/docs/HMI_M.ColorTable.pdf

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What is a sunspot group?

Before the advent of magnetic measurements, a sunspot group was defined solely on the basis of its morphology and location relative to other groups. Sunspot groups were at first considered just to be spatially separate assemblies of sunspots. Schwabe's definition (1838) was: "Ich sehe diejenigen Fleckenhaufen als Gruppen an, die abgesondert dastehen und durch keine grösseren und kleineren Flecken und durch keinen Nebel miteinander verbunden sind." (I consider clusters of sunspots to be "groups" if they are isolated and not connected to other clusters by larger or smaller spots or by nebulous matter.) The observer Beck (1984) describes the Zürich tradition thus "Groups are spatially isolated collections of spots. An isolated single spot also counts as a group." Friedli (2009) reminds us that after the Waldmeier (1938) Classification was introduced, the evolution of a group became a determining factor in the very definition of a group which now, in addition to be a spatially isolated collection, also must evolve as an *independent* unit, going through (at least partly) the evolution sequence of the Waldmeier classification, Figure 32.

Svalgaard et al. 2016

From Svalgaard et al. 2016 - DOI 10.1007/s11207-015-0815-8

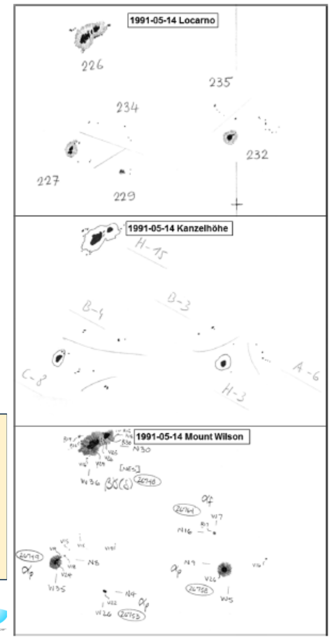
What is a sunspot group?

Most groups do not complete the full evolutionary sequence, and many (30 – 50 %) do not make it past the A or B stage, but the classification is a great help in resolving and determining the group structure at times of high activity where new groups emerge next to existing groups, generally leading to an increase of the group count.

As useful as the Group Classification is, its use creates an inhomogeneity in the group count (and therefore also in the sunspot number). When an observer begins to use the evolution aspect of the Waldmeier Classification, the group count generally increases as new groups that do not fit in the evolution of existing groups are accorded an independent existence even if they morphologically would belong to an existing group, Figure 33.

More examples of "extraneous" groups (as least from a morphological viewpoint) can be seen in Figure 34. Note that the observers differ on the determination of the groups.

- Rule of thumb *(NOT a law)*:
  - Separate groups if >5° in latitude or >10° in longitude
- McIntosh: difference unipolar/bipolar groups at 3° to 5°
- Change/modify following subsequent observations



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From Svalgaard et al. 2016 - DOI 10.1007/s11207-015-0815-8

There may be a discrepancy between

Solar observers

- Can only use white light observations in order to be consistent with old solar observations

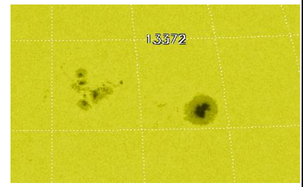
SWx forecasters

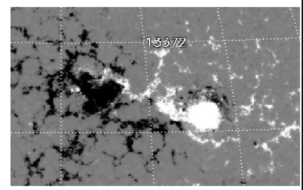
- Have to use both white light images and magnetograms in order to make accurate predictions of solar flares

There may be some difference in the splitting and classifications of sunspot groups between these two teams

Basics on sunspots and sunspot groups

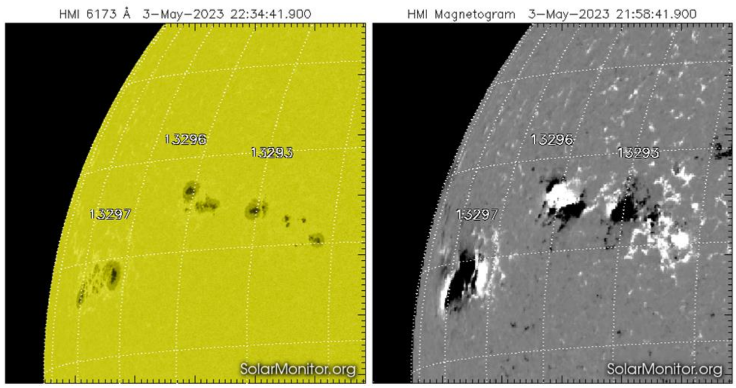
- The apparent solar rotation drags sunspots by +/- 13° / day to the west
  - Within a group, sunspots can "wander"
- Sunspots consist of a dark core ("umbra"), often surrounded by a somewhat greyish area("penumbra")
- "The" laws:
  - Most sunspot groups are bipolar
    - SC24-25: 33% unipolar ; 67% bipolar
  - Leading spots tend to have larger MF than trailing spots
    - Form earlier, are larger, last longer
  - Leading and trailing sunspots usually have opposite magnetic polarities
    - Opposite between solar hemispheres
    - Magnetic polarities reverse from one solar cycle to the next ("Hale's law")
  - The leading spot is usually more inclined towards the solar equator than the trailing one
    - Effect becomes more pronounced with increasing latitude ("Joy's law")





Hale et al. 1919: The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract
https://articles.adsabs.harvard.edu/pdf/1919ApJ....49..153H

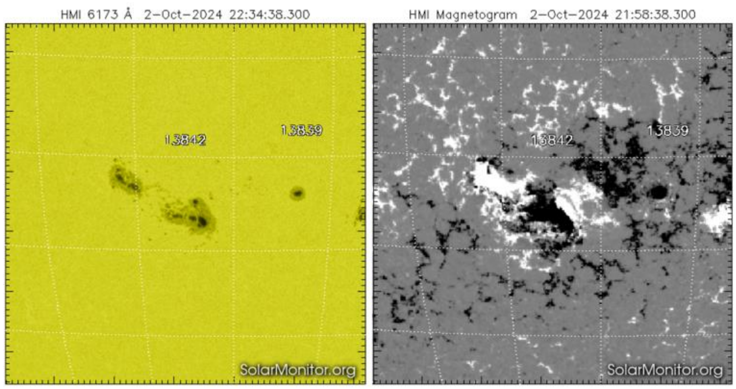
Anti-Hale



https://www.stce.be/news/644/welcome.html

Sunspot group NOAA 3296 then took over from NOAA 3293 in terms of flare production. NOAA 3296 had actually a reversed magnetic polarity, meaning that it had a magnetic configuration opposite to what can be expected for bipolar sunspot regions in the northern solar hemisphere this solar cycle. This can also be seen in the magnetogram above, where the leading sunspot of NOAA 3296 has a negative polarity (black colour) and the main trailing spot a positive polarity (white colour), opposite to the configuration in sunspot regions NOAA 3293 and 3297. Sunspot groups with such an inverted (also known as "anti-Hale") configuration are not too numerous, with only between about 3 to 10% of all sunspot groups during a solar cycle (see e.g. McClintock et al. 2014 ; https://iopscience.iop.org/article/10.1088/0004-637X/797/2/130) . It has been shown statistically that these groups have a higher likelihood on producing solar flares (Toriumi et al. 2019 ; https://link.springer.com/article/10.1007/s41116-019-0019-7) and NOAA 3296 supported this by producing 4 M-class flares over the next 4 days. The graph underneath (GOES) shows the first two (and strongest) flares from this region: an M3.9 flare on 4 May, and an M2.1 flare on 5 May. Both were long-duration events. The SDO/AIA 094 clips underneath show the two flares and other flaring activity in extreme ultraviolet on 4 and 5 May (still).

Anti-Joy



Kumar et al. 2024 - https://doi.org/10.1093/mnras/stae1052
Furthermore, observations show that about 8 per cent of BMRs in a solar cycle are anti-Hale (McClintock, Norton & Li 2014) while 25 to 30 per cent are anti-Joy. These anti-Hale and anti-Joy BMRs produce opposite polarity field and thus they disturb the regular polar field

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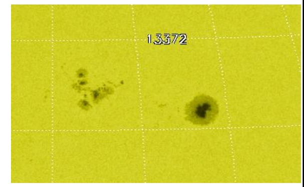
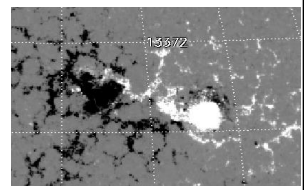
    - Effect becomes more pronounced with increasing latitude (“Joy’s law”)
  - Over the course of a solar cycle, sunspot groups emerge closer and closer to the solar equator (“Spörer’s law of sunspot zones”)
    - Butterfly diagram (Maunder, 1904)





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Hale et al. 1919: The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract
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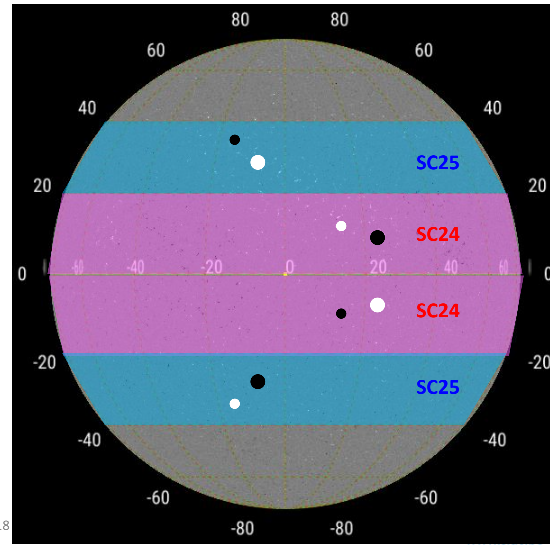

Hale et al. 1919: The magnetic polarity of sunspots
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Maunder 1904: Note on the Distribution of Sun-spots in Heliographic Latitude, 1874-1902
https://ui.adsabs.harvard.edu/abs/1904MNRAS..64..747M/abstract

STCE newsitems at https://www.stce.be/news/422/welcome.html ,
https://www.stce.be/news/429/welcome.html and https://www.stce.be/news/522/welcome.html

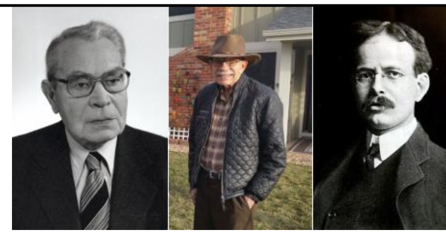
Unipolar and bipolar % were based on 16835 sunspot classifications by NOAA/SWPC & USAF between Jan 2010 and Sep 2023. Both in white light (A– and H– classes) as in the magnetograms (alpha), there were about 5560 or 33% unipolar, the rest (11275 or 67%) was bipolar or more complex. The numbers vary from solar cycle to solar cycle, generally by a few %.

The figure depicts the magnetic situation around the time of the previous solar cycle minimum in 2019. Old sunspot groups (SC24) are appearing close to the solar equator, while new groups(SC25) having the opposite magnetic polarity are emerging at high (around 30°) latitude. It illustrates Hale's laws, Joy's law, and Spörer's law of sunspot zones.

Groups that do not conform the Hale and Joy laws are called "anti-Hale" and "anti-Joy" groups respectively. The percentage of the anti-Joy regions is within the range of 10–30 per cent whereas the percentage of the anti-Hale regions is within the range of 3–7 per cent, keeping consistent with the observations (McClintock, Norton & Li 2014 - https://iopscience.iop.org/article/10.1088/0004-637X/797/2/130 ; Muñoz-Jaramillo, Navarrete & Campusano 2021 - https://iopscience.iop.org/article/10.3847/1538-4357/ac133b).

Contents

Sunspot group classification



Max Waldmeier *Patrick S. McIntosh* *George E. Hale*

- Three classification schemes
  - White light
    - Zurich classification *(Waldmeier)*
    - McIntosh classification
      - Based on the sunspot group morphology
  - Magnetogram
    - Mount Wilson classification *(Hale)*
      - Based on the magnetic structure of a sunspot group

- Detailed discussion and examples at STCE's SWx classification page
  https://www.stce.be/educational/classification

Patrick Siler McIntosh
George Ellory Hale

Kiepenheuer 1953 – Solar activity
https://ui.adsabs.harvard.edu/abs/1953sun..book..322K/abstract

McIntosh 1990 - The Classification of Sunspot Groups
https://ui.adsabs.harvard.edu/abs/1990SoPh..125..251M/abstract

Hale et al. 1919 - The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract

The Zurich classification

Max Waldmeier

- Developed by M. Waldmeier in the 1940s
  - Based on a scheme by Cortie (1901)
  - Published in 1947
    - Kiepenheuer 1953
- 9 classes only
  - Focus on evolutionary sequence of sunspot groups
    - Much simpler than Cortie's scheme
  - Poor correlation with solar flares

Kiepenheuer 1953: https://ui.adsabs.harvard.edu/abs/1953sun..book..322K/abstract

The Zurich classification

A. Composed of a small single spot or a very small group of spots, mostly of short duration, concentrated in a region of 2–3 square degrees. No systematic structure of the group; spots without penumbra.

B. Bipolar group of spots without penumbra, the long axis of which is directed roughly east-west. Concentration of spots on east and west ends.

C. Bipolar group like B, but at least one main spot with penumbra.

D. Bipolar group, the largest spots showing penumbrae.

E. Large bipolar group showing a complicated structure, the two major spots each having a penumbra. Numerous small spots between the major spots. Dimension of the group in longitude at least 10°.

F. Very large bipolar or complex group. Dimension in longtiude at least 15°.

G. Large bipolar group, without small spots between the two major spots. Dimension in longitude at least 10°.

H. Unipolar spot with penumbrae, sometimes with complicated structure. Diameter >2°5.

J. Unipolar spot with penumbra. Round shape, diameter <2°5.

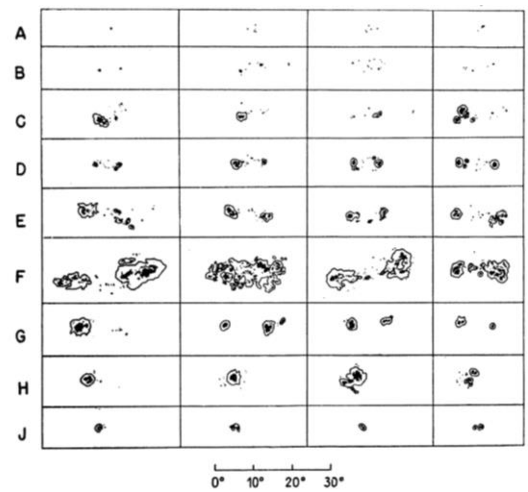
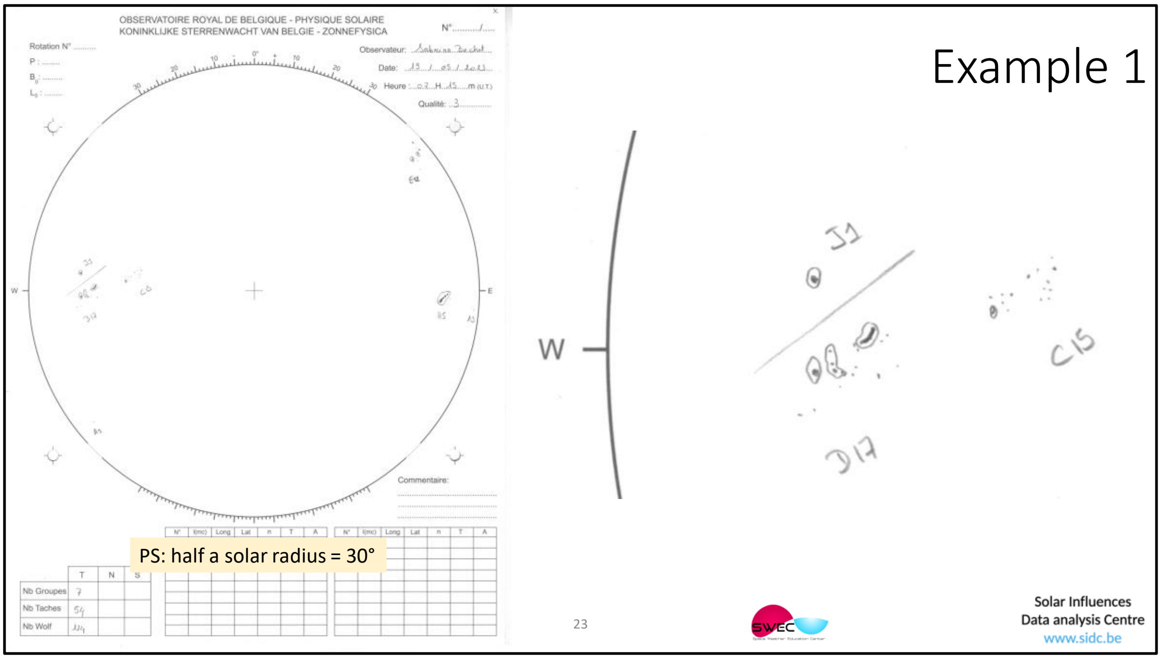


FIG. 15.—Zurich classification of sunspots; W is left on spot pictures. Four examples are given of each class (Waldmeier, 1947).

Royal Observatory of Belgium


OBSERVATOIRE ROYAL DE BELGIQUE - PHYSIQUE SOLAIRE
KONINKLIJKE STERRENWACHT VAN BELGIE - ZONNEFYSICA
Rotation N°
Observateur:
Date:
Heure
Qualité:
Commentaire:
Nb Groupes
Nb Taches
Nb Wolf
PS: half a solar radius = 30°
Example 1
W
J1
C15
D17
23
SWEC
Solar Influences
Data analysis Centre
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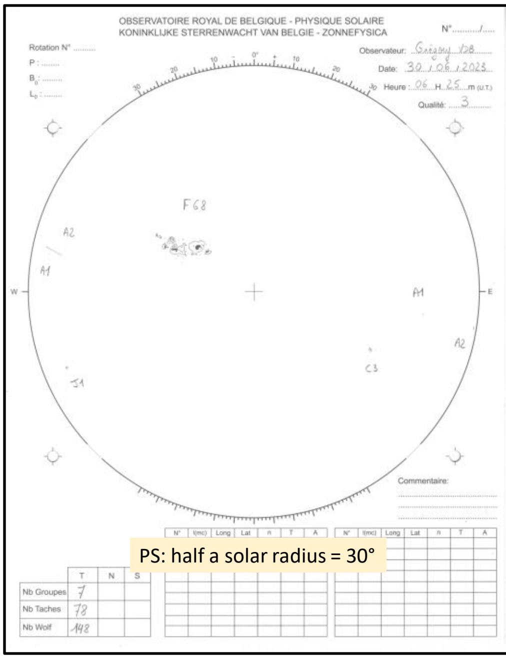
Example 2



PS: half a solar radius = 30°

Solar Influences
Data analysis Centre
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The McIntosh classification

- Developed by P. McIntosh in the mid-1960s, published in 1990
- 3 components: Zpc
  - Z – Zurich modified : general outlook of the sunspot group
    - 7 possibilities
  - p – Penumbra: outlook and size of the penumbra of the main spot
    - 6 possibilities
  - c – Compactness: describes the sunspot distribution in the interior of the sunspot group
    - 4 possibilities
- In total not 168 classes, but “only” 60 classes
- Based on a full-disk view of the Sun

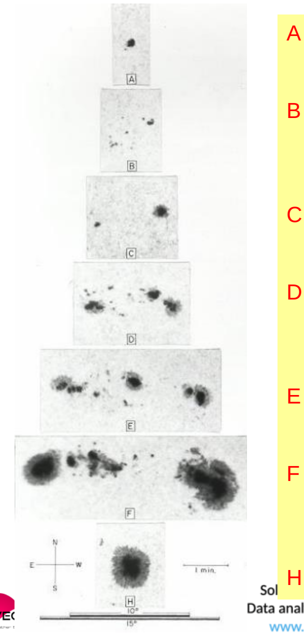
Patrick S. McIntosh

McIntosh 1990 - The Classification of Sunspot Groups
https://ui.adsabs.harvard.edu/abs/1990SoPh..125..251M/abstract

The full disk view is to avoid zooming in with the current satellite imagery to irrelevant detail, thus avoiding too complex classes than what really is, thus e.g. rudimentary penumbra instead of asymmetric penumbra ; intermediate sunspot distribution instead of compact distribution.

The McIntosh classification - Z

- General outlook of the group
  - Unipolar or bipolar group?
    - Unipolar: distance between spots < 3°
    - Bipolar: distance between main spots > 3°
      - If large spots: distance > 5°
  - Penumbra or no penumbra?
  - Penumbra on one or both sides of the sunspot group?
  - Length of the group (>10°? >15°?)
    - Between the *outer extremities of the main spots*
      - As is, NOT projected

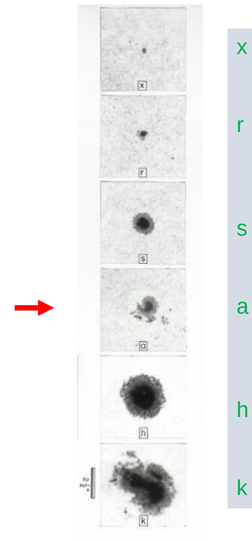


The McIntosh classification - Z

- **A** unipolar group with no penumbra, representing either the formative or final stage of evolution in a spot group.
- **B** bipolar group without penumbra on any spots.
- **C** bipolar group with penumbra on one end of the group, in most cases surrounding the largest of the leader umbrae.
- **D** bipolar group with penumbra on spots at both ends of the group, and with length $\leq 10°$.
- **E** bipolar group with penumbra on spots at both ends of the group, and with length defined as: $10° < \text{length} \leq 15°$.
- **F** bipolar group with penumbra on spots at both ends of the group, and length $> 15°$.
- **H** unipolar group with penumbra. The principal spot is usually the leader spot remaining from a pre-existing bipolar group.

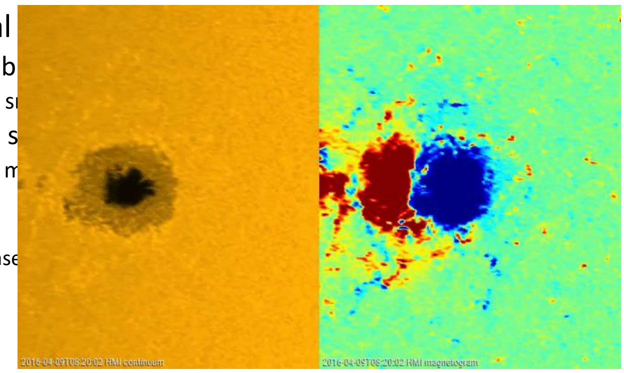
The McIntosh classification - p

- Penumbra and size of principal sunspot
  - Rudimentary or mature penumbra?
    - Rudimentary: incomplete and/or small penumbra
  - Symmetric or asymmetric main spot?
    - Symmetric means also: elliptical, multiple umbrae, slight irregularity of the edge
    - Light bridges!
      - Usually herald the decaying phase of the spot



The McIntosh classification - p

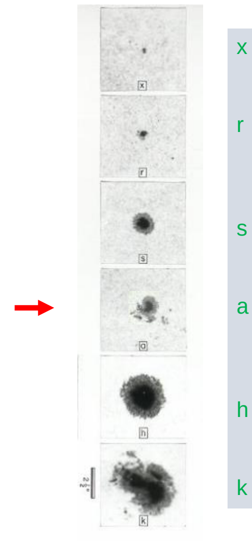
- Penumbra and size of principal
  - Rudimentary or mature penumb
    - Rudimentary: incomplete and/or s
  - Symmetric or asymmetric main s
    - Symmetric means also: elliptical, m irregularity of the edge
    - Light bridges!
      - Usually herald the decaying phase



STCE newsitem at https://www.stce.be/news/344/welcome.html (NOAA 12529 from 9 until 18 April 2016)

The McIntosh classification - p

- Penumbra and size of principal sunspot
  - Rudimentary or mature penumbra?
    - Rudimentary: incomplete and/or small penumbra
  - Symmetric or asymmetric main spot?
    - Symmetric means also: elliptical, multiple umbrae, slight irregularity of the edge
    - Light bridges!
      - Usually herald the decaying phase of the spot
  - North-South diameter of main spot >2,5°?
    - To avoid misleading effect from sunspot stretching by differential solar rotation
    - “h” and “k” are the big brothers/sisters of resp. “s” and “a”



The McIntosh classification - p

x no penumbra (group is class A or B).

r rudimentary penumbra partially surrounds the largest spot. This penumbra is incomplete, granular rather than filamentary, brighter than mature penumbra, and extends as little as 3 arc sec (2200 km) from the spot umbra. Rudimentary penumbra may be either in a stage of formation or dissolution (McIntosh, 1981, Section 2.3; Bray and Loughhead, 1964, Plate 3.7).

s small, symmetric (like Zurich class J). Largest spot has mature, dark, filamentary penumbra of circular or elliptical shape with little irregularity to the border. There is either a single umbra, or a compact cluster of umbrae, mimicking the symmetry of the penumbra. The north–south diameter across the penumbra is $\leq 2.5°$.

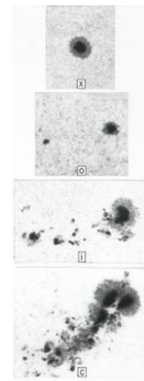
a small, asymmetric. Penumbra of the largest spot is irregular in outline and the multiple umbrae within it are separated. North–south diameter of penumbra $\leq 2.5°$.

h large, symmetric (like Zurich class H). Same structure as type '*s*', but north–south diameter of penumbra $> 2.5°$. Area, therefore, must be ≥ 250 millionths solar hemisphere.

k large, asymmetric. Same structure as type '*a*', but north–south diameter $> 2.5°$, and area ≥ 250 millionths. This type of spot sometimes contains spots of opposite polarity, the Potsdam ∂-configuration (Kunzel, 1960), and may indicate potential for proton flares (Warwick, 1966).

The McIntosh classification - c

- Internal sunspot distribution
  - Sunspots between leading and trailing main spots?
    - Open: No or a few small spots
    - Intermediate: *<u>Numerous</u>* small spots, but no mature
  - Is there internally at least 1 spot with a mature penumbra?
    - Compact: many strong spots with at least 1 containing a mature penumbra
    - Extreme case: entire sunspot group enveloped by a continuous penumbra



x

o

i

c

The McIntosh classification - c

- *x* undefined for unipolar groups (class A and H).
- *o* open. Few, if any, spots between leader and follower. Interior spots of very small size. Class E and F groups of *open* category are equivalent to Zurich class G.
- *i* intermediate. Numerous spots lie between the leading and following portions of the group, but none of them possesses mature penumbra.
- *c* compact. The area between the leading and following ends of the spot group is populated with many strong spots, with at least one interior spot possessing mature penumbra. The extreme case of compact distribution has the entire spot group enveloped in one continuous penumbral area.

McIntosh classification scheme

Unipolar			
No penumbra	Penumbra		
Axx			
North-south diameter main spot	Shape penumbra main spot		
	rudimentary	symmetric	asymmetric
≤ 2,5°	Hrx	Hsx	Hax
> 2,5°		Hhx	Hkx

Bipolar													
Sunspot distribution	No penumbra	Penumbra											
open	Bxo	Penumbra on 1 end			Penumbra on both ends								
intermediate	Bxi	Length of sunspot group			Length ≤ 10°			10° < Length ≤ 15°			Length > 15°		
Sunspot distribution	North-south diameter main spot	Shape penumbra main spot											
		rudim.	symm.	asymm.	rudim.	symm.	asymm.	rudim.	symm.	asymm.	rudim.	symm.	asymm.
open	≤ 2,5°	Cro	Cso	Cao	Dro	Dso	Dao	Ero	Eso	Eao	Fro	Fso	Fao
intermediate		Cri	Csi	Cao	Dri	Dsi	Dai	Eri	Esi	Eai	Fri	Fsi	Fai
compact						Dsc	Dac		Esc	Eac		Fsc	Fac
open	> 2,5°		Cho	Cko		Dho	Dko		Eho	Eko		Fho	Fko
intermediate			Chi	Cki		Dhi	Dki		Ehi	Eki		Fhi	Fki
compact						Dhc	Dkc		Ehc	Ekc		Fhc	Fkc

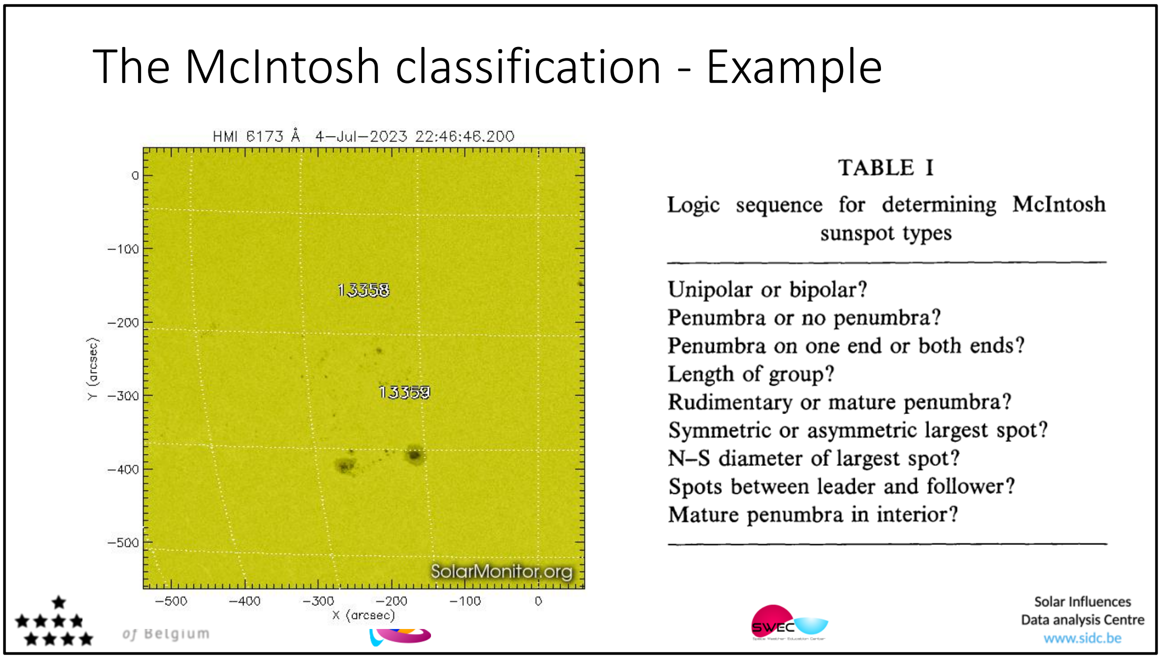


TABLE I

Logic sequence for determining McIntosh sunspot types (NOAA 3359)

Unipolar or bipolar? BIPOLAR => B, C, D, E, F

Penumbra or no penumbra? PENUMBRA => C, D, E, F

Penumbra on one end or both ends? BOTH ENDS => D, E, F

Length of group? ~9° => **D**

Rudimentary or mature penumbra? MATURE => s, a, h, k

Symmetric or asymmetric largest spot? SYMMETRIC => s, h

N-S diameter of largest spot? < 2.5° => **s**

Spots between leader and follower? YES => i , c

Mature penumbra in interior? => NO => **i**

Dsi

The McIntosh classification - Example

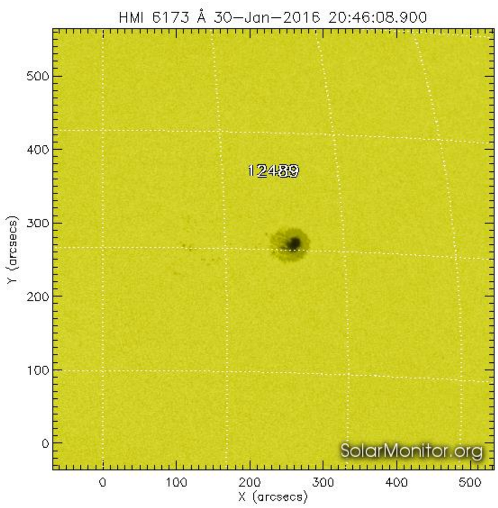


TABLE I

Logic sequence for determining McIntosh sunspot types

Unipolar or bipolar?
Penumbra or no penumbra?
Penumbra on one end or both ends?
Length of group?
Rudimentary or mature penumbra?
Symmetric or asymmetric largest spot?
N–S diameter of largest spot?
Spots between leader and follower?
Mature penumbra in interior?

of Belgium

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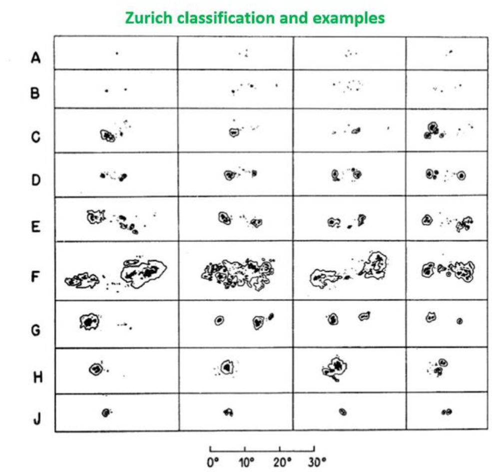
TABLE I
Logic sequence for determining McIntosh sunspot types
Unipolar or bipolar? BIPOLAR => B, C, D, E, F
Penumbra or no penumbra? PENUMBRA => C, D, E, F
Penumbra on one end or both ends? ONE END => C
Length of group? (~13°) irrelevant => **C**
Rudimentary or mature penumbra? MATURE => s, a, h, k
Symmetric or asymmetric largest spot? SYMMETRIC => s, h
N-S diameter of largest spot? > 2.5° => **h**
Spots between leader and follower? NO => o
Mature penumbra in interior? => NO => **o**

Chi

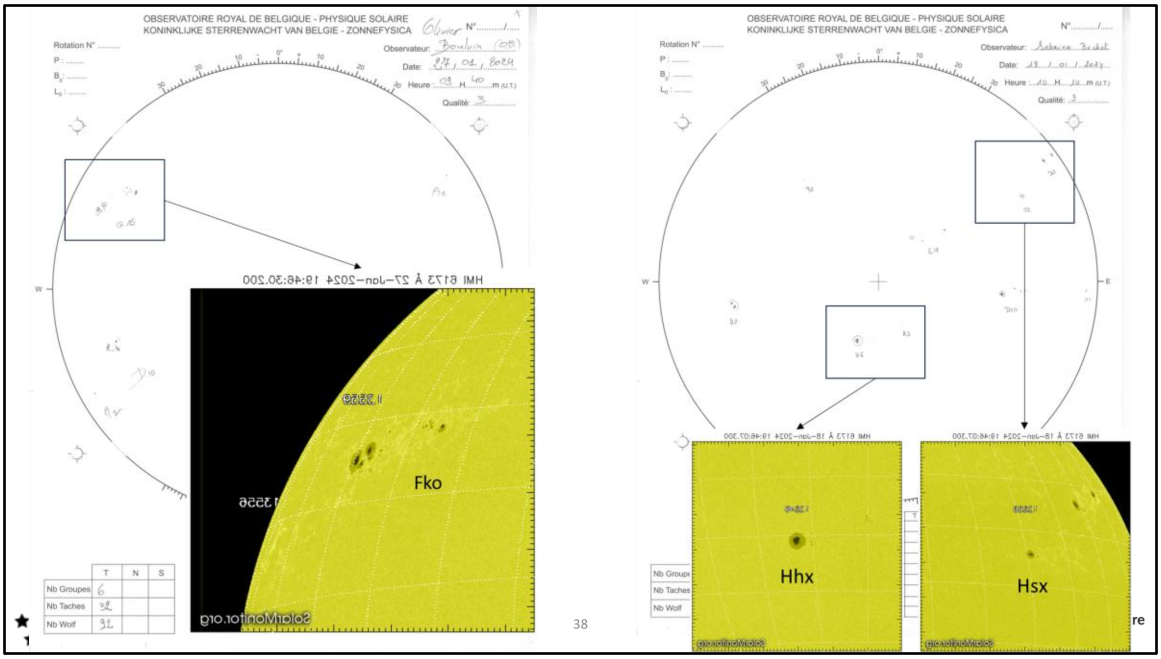
Zurich classification: G

Conversion between Zurich and McIntosh



Zurich	McIntosh (Zpc)
A	Axx
B	Bxo, Bxi
C	C . i , small C . o
D	D . .
E	E . i , E . c
F	F . i , F . c
G	E . o , F . o , wide C . o
H	Hhx, Hkx
J	Hrx, Hax, Hsx

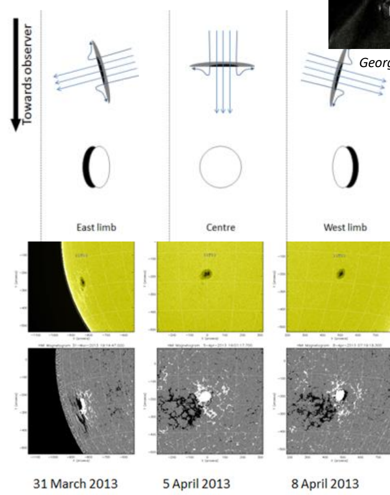
FIG. 15.—Zurich classification of sunspots; *W* is left on spot pictures. Four examples are given of each class (Waldmeier, 1947).


OBSERVATOIRE ROYAL DE BELGIQUE - PHYSIQUE SOLAIRE
KONINKLIJKE STERRENWACHT VAN BELGIE - ZONNEFYSICA
Rotation N°
Observateur:
Date:
Heure
Qualité:
Fko
Nb Groupes 6
Nb Taches 32
Nb Wolf 92
OBSERVATOIRE ROYAL DE BELGIQUE - PHYSIQUE SOLAIRE
KONINKLIJKE STERRENWACHT VAN BELGIE - ZONNEFYSICA
Hhx
Hsx
38

The Mount Wilson classification

- Developed by Hale in the early 20th century
  - Supplemented by Künzel (1960)
    - “Mount Wilson” classification
- Based on magnetic structure of sunspot groups
  - Sunspots, not ephemeral magnetic structures
  - Attention for line-of-sight effects!
    - Near solar limb
- Only 7 classes
  - A (α)
  - B (β), BG ($\beta\gamma$), G (γ)
  - BD ($\beta\delta$), BGD ($\beta\gamma\delta$), GD ($\gamma\delta$)


George E. Hale



Hale et al. 1919: The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract
https://articles.adsabs.harvard.edu/pdf/1919ApJ....49..153H

Künzel (1965): Zur Klassifikation von Sonnenfleckengruppen
https://ui.adsabs.harvard.edu/abs/1965AN....288..177K/abstract

Figures from this STCE newsitem: https://www.stce.be/news/188/welcome.html

George Ellery Hale

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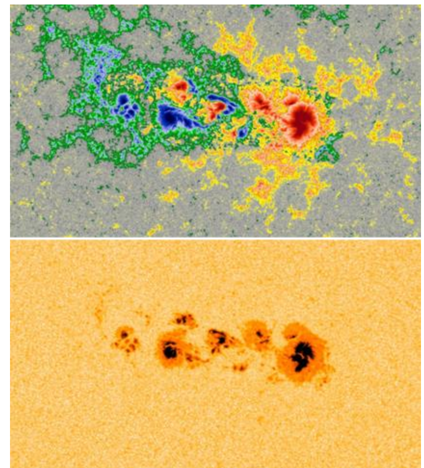
  - BD ($\beta\delta$), BGD ($\beta\gamma\delta$), GD ($\gamma\delta$)



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

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

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

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

The pictures to the right are from SDO/HMI and show a magnetogram and a white light image of NOAA 1875 on 23 October 2013. It is recommended that instead of using the white/black SDO/HMI magnetograms, to use the line of sight magnetic field colored magnetograms. Around 236 Gauss, there's a sharp discontinuity in color change highlighting the location of sunspots and distinguishing them from the other local weak magnetic fields. These diagrams can be found at https://sdo.gsfc.nasa.gov/data/ , with an explanation at https://sdo.gsfc.nasa.gov/assets/docs/HMI_M.ColorTable.pdf

An alternative for the black/white magnetograms is the much lower resolution imagery at GONG
https://gong2.nso.edu/products/mainView/table.php?configFile=configs/mainView.cfg

The Mount Wilson 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

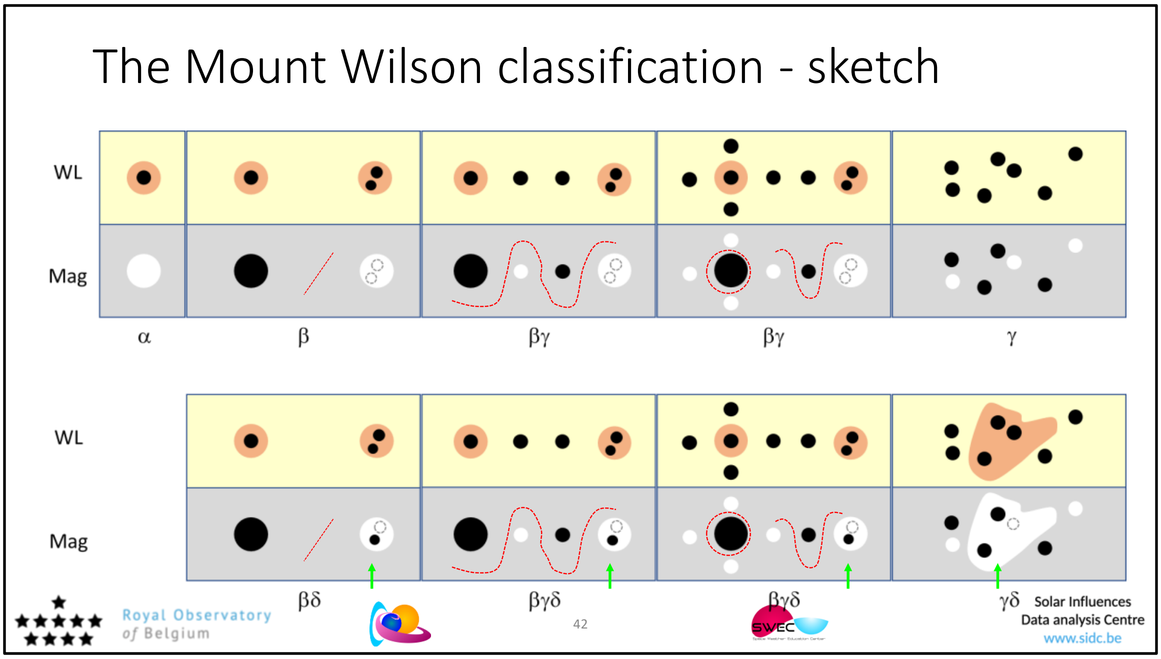
Hale et al. 1919: The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract
https://articles.adsabs.harvard.edu/pdf/1919ApJ....49..153H

Künzel (1965): Zur Klassifikation von Sonnenfleckengruppen
https://ui.adsabs.harvard.edu/abs/1965AN....288..177K/abstract

Table 3.1 is from McCloskey 2019 - http://www.tara.tcd.ie/handle/2262/86182

Jaeggli and Norton (2016): The Magnetic Classification of Solar Active Regions 1992-2015
http://iopscience.iop.org/article/10.3847/2041-8205/820/1/L11/pdf

… For the period 1992-2015, the beta groups are the most numerous (64%) followed by the alpha regions (20%), beta-gamma (11%), beta-gamma-delta (4%), and beta-delta (1%).



Hale et al. 1919: The magnetic polarity of sunspots
https://ui.adsabs.harvard.edu/abs/1919ApJ....49..153H/abstract
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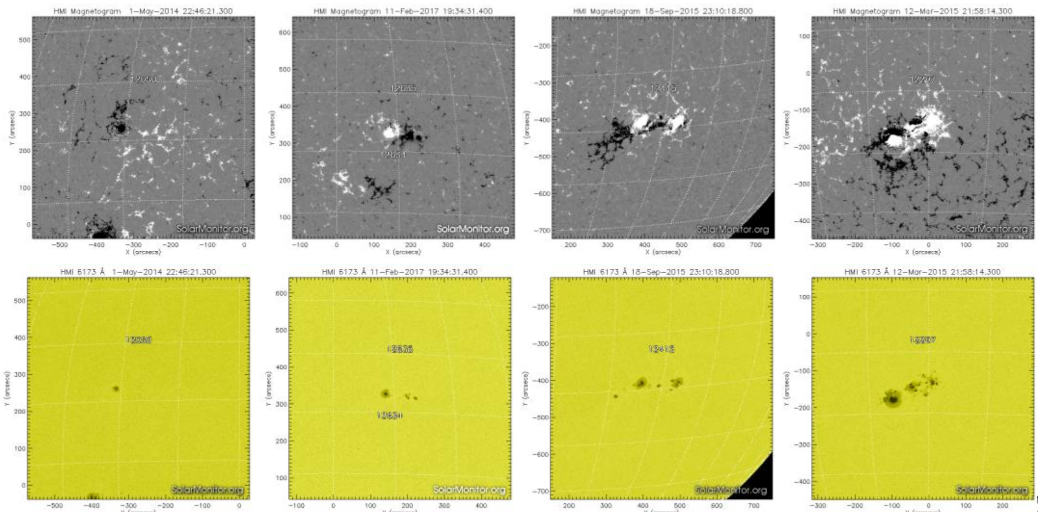
https://ui.adsabs.harvard.edu/abs/1965AN....288..177K/abstract

Figures from this STCE newsitem: https://www.stce.be/news/188/welcome.html

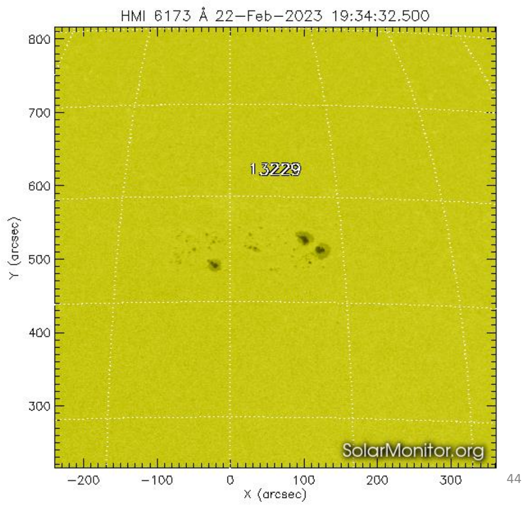
WL: white light ; Mag: Magnetogram

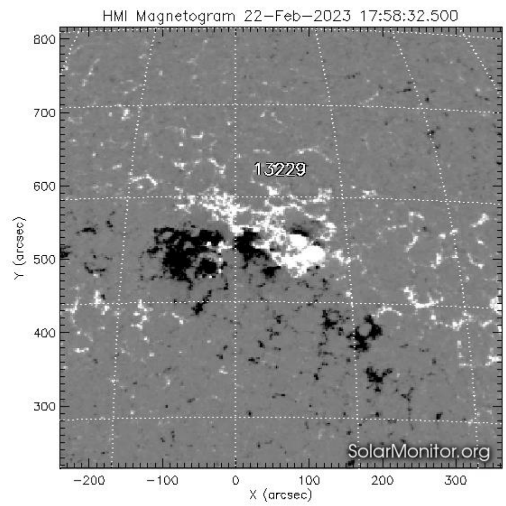
The Mount Wilson classification - Example



α β βγ βγδ

The Mount Wilson classification - Example





Note the time difference (2 hours)!

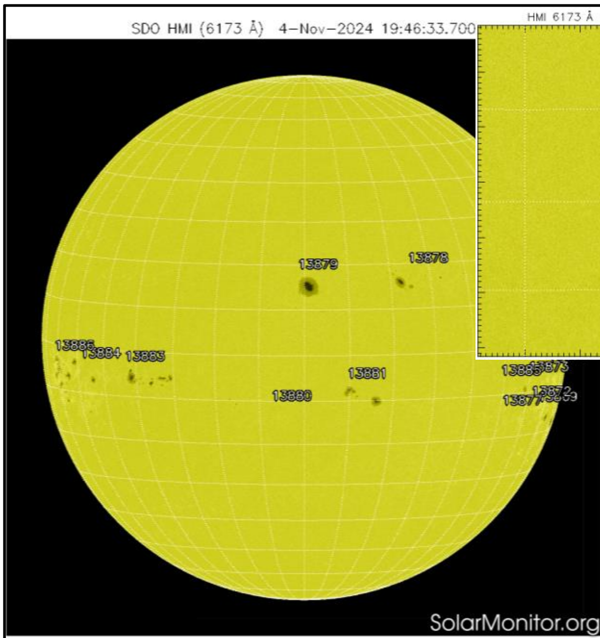
Unipolar sunspot group? NO => B, BG, G, BD, BGD, GD
Bipolar or Complex sunspot group? Bipolar => B, BG, BD, BGD
Can a distinction between the two polarity portions easily be made? NO => BG or BGD
Are 1 or more delta spots present? NO => BG

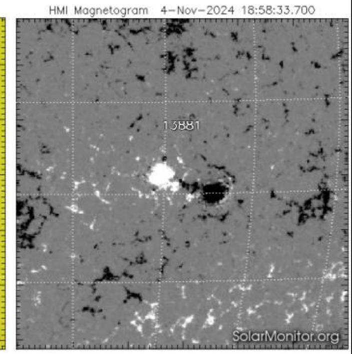
The McIntosh classification of NOAA 3229 is Eri (remember: the images above are highly magnified)

Contents

- Aim
- Data sources
- Sunspot groups
  - What are they?
  - Basics
- Sunspot group classifications
  - The Zurich classification *(Waldmeier)*
  - The McIntosh classification
  - The Mount Wilson classification *(Hale)*
- Exercises

Remember: *Different institutions may have done their observations at different times (several hours of difference), which may explain some of the differences in the various classifications.*





NOAA 13881	McIntosh	MtWilson
ASSA	Dsc	-
NOAA	Dao	BG
SWx WS	Dso	B

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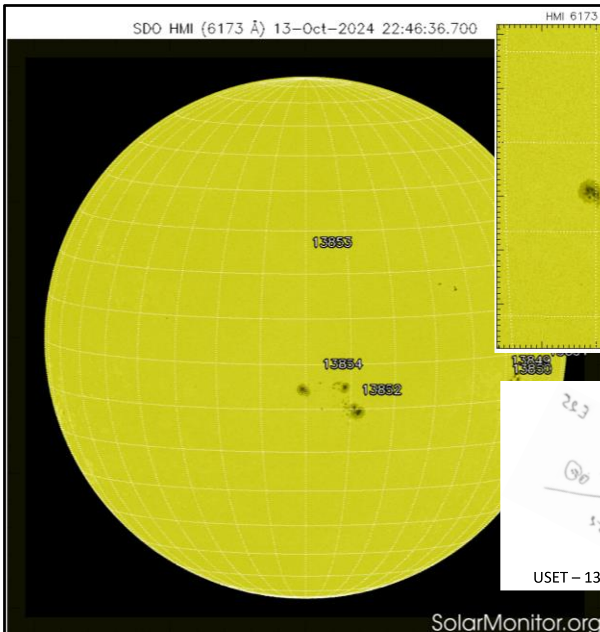
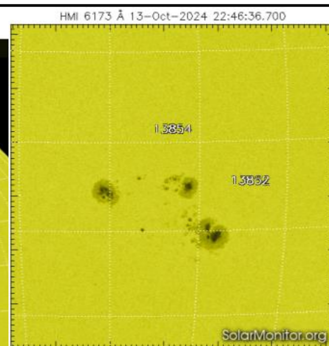
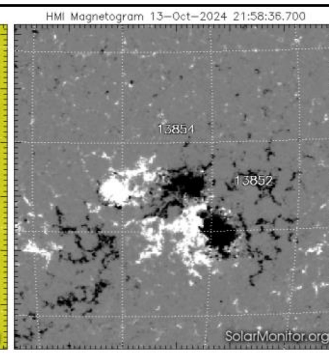
www.sidc.be





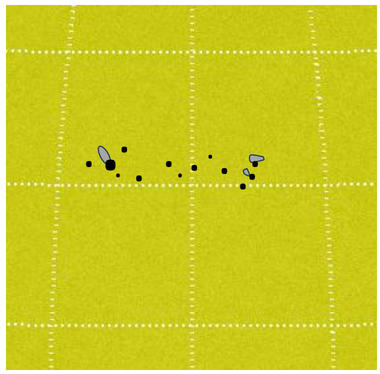



USET – 13 Oct / 09:10UTC

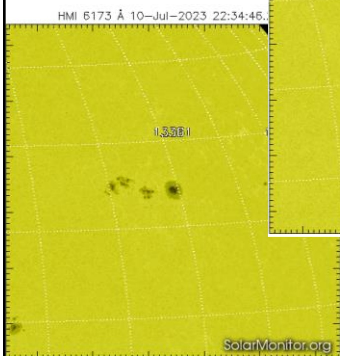
	NOAA 13854		NOAA 13852	
	McI	MtW	McI	MtW
NOAA	Eki	BG	Dki	BG
USET	E	-	H+J	-
SWx WS	Ehi	B	Cko	BG

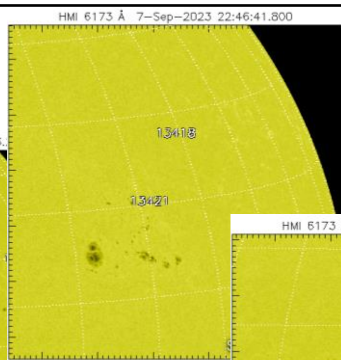
Only low-level C-class flares observed

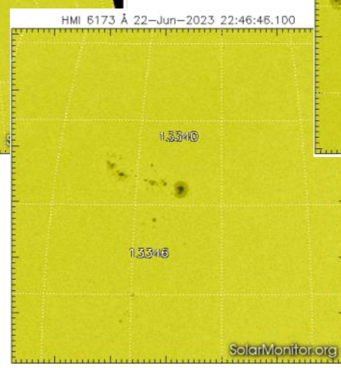
Sketch an Eri sunspot group

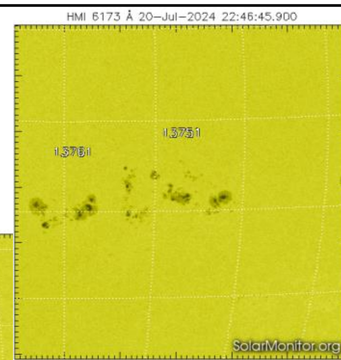


E a/s i/c?

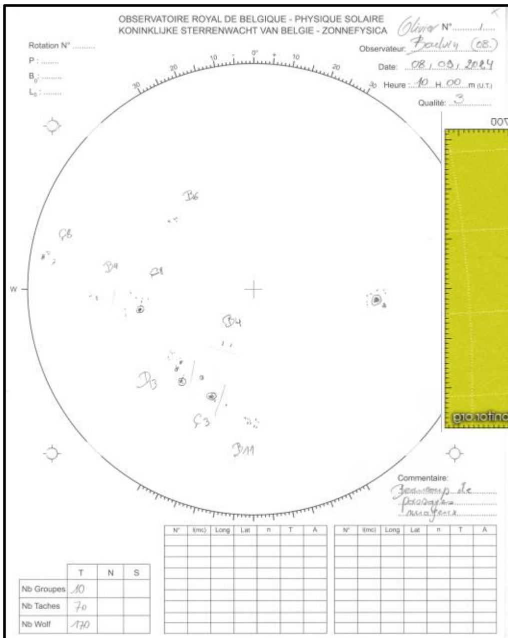


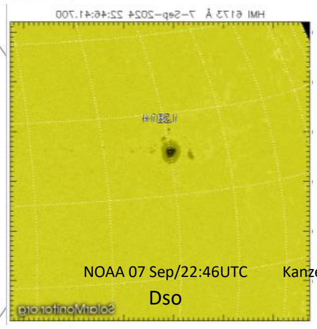






	NOAA	SWx WS
13361	Ehc	Esc
13421	Eai	Eai
13340	Dsi	Esi
13751	Ekc	Eac





NOAA 07 Sep/22:46UTC

Dso

Kanzelhöhe 08 Sep/06:10UTC

C

USET 08 Sep/10:00UTC

G

Dho

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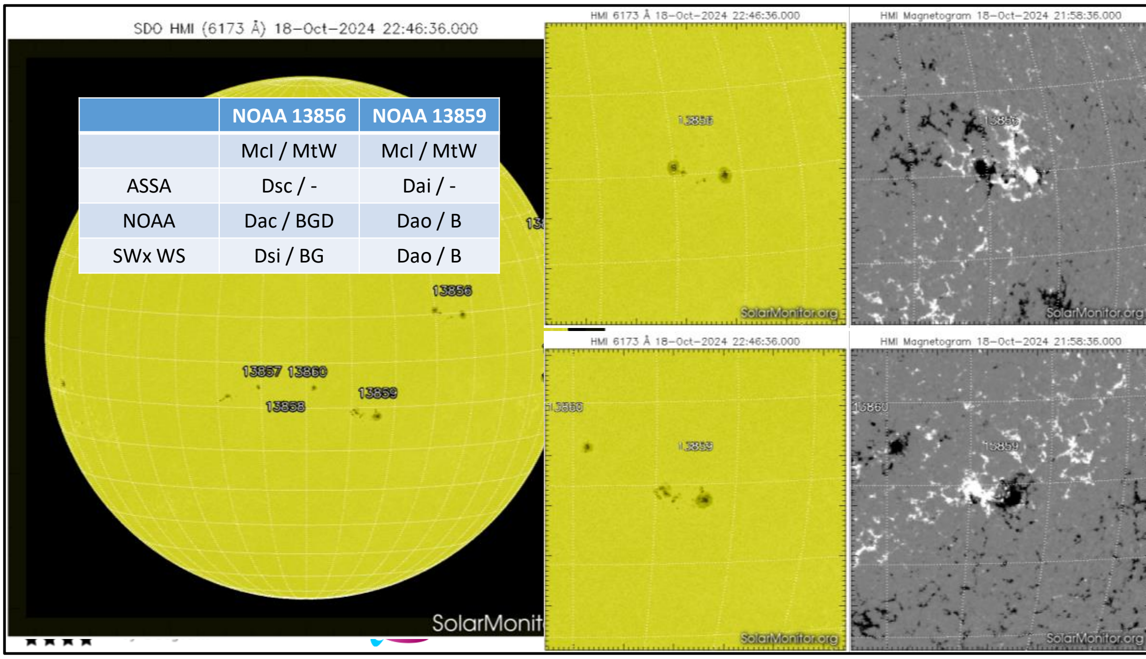
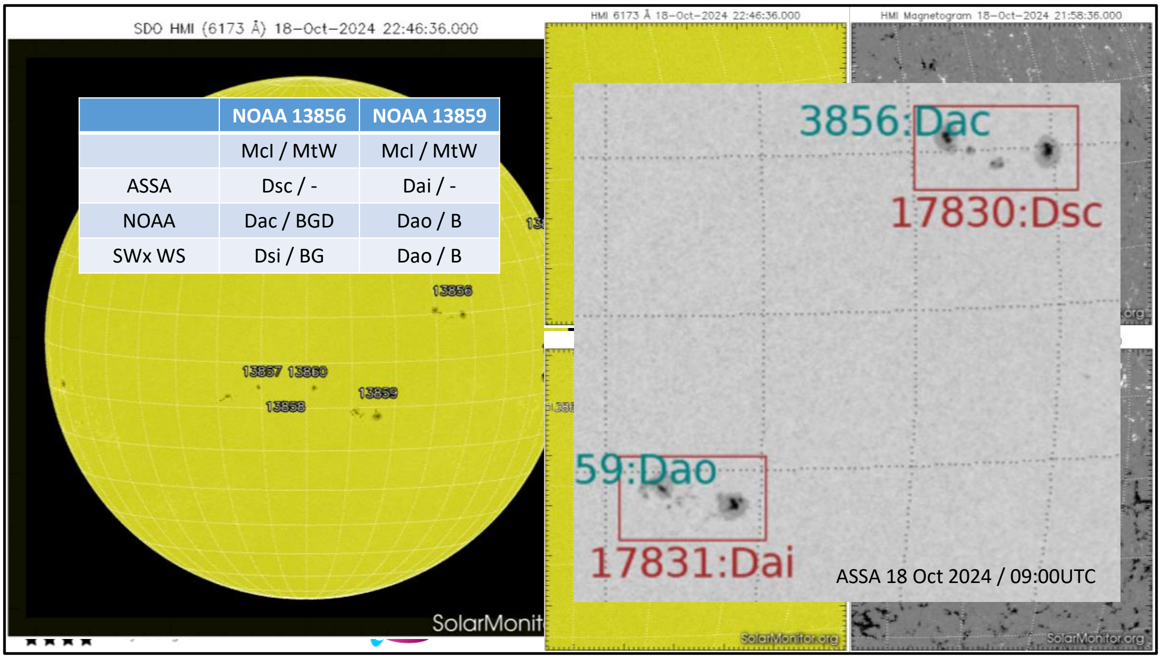
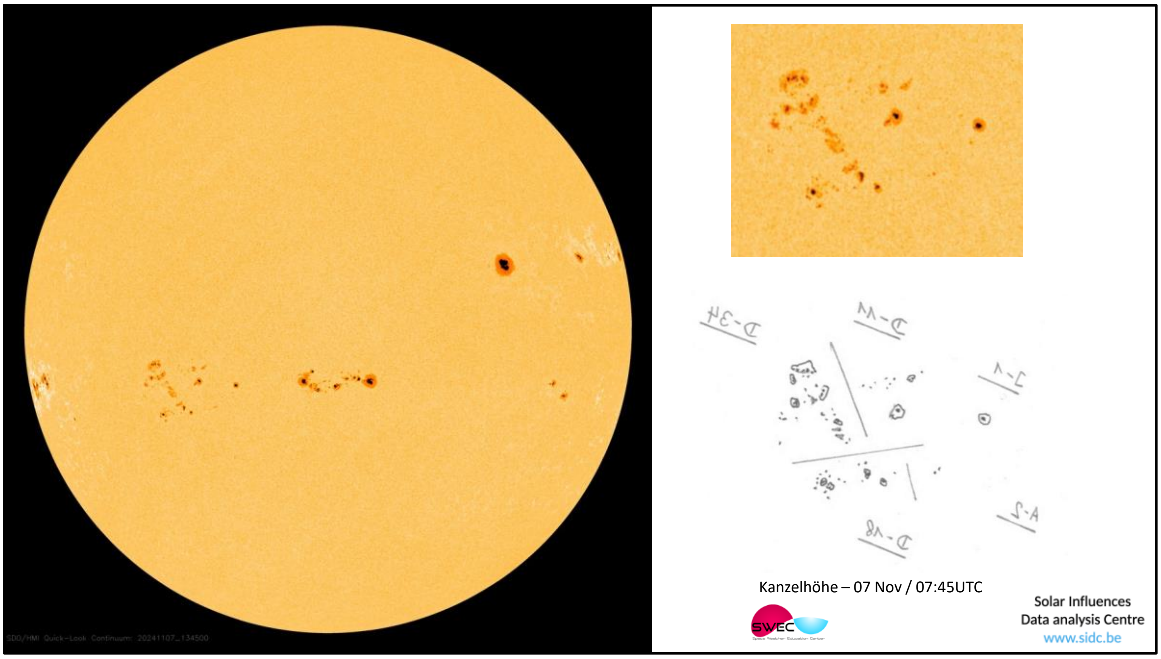


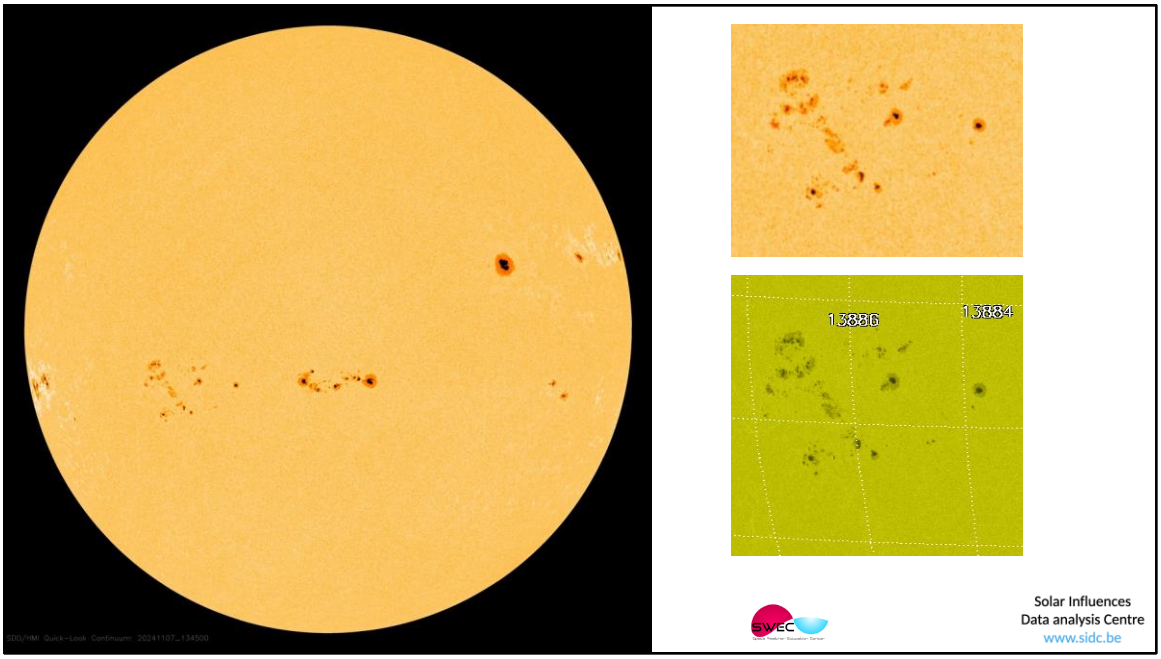
	NOAA 13856	NOAA 13859
	McI / MtW	McI / MtW
ASSA	Dsc / -	Dai / -
NOAA	Dac / BGD	Dao / B
SWx WS	Dsi / BG	Dao / B

	NOAA 13856	NOAA 13859
	McI / MtW	McI / MtW
ASSA	Dsc / -	Dai / -
NOAA	Dac / BGD	Dao / B
SWx WS	Dsi / BG	Dao / B





Kanzelhohe 07:45UTC ; SDO/HMI 13:45UTC on 07 November 2024



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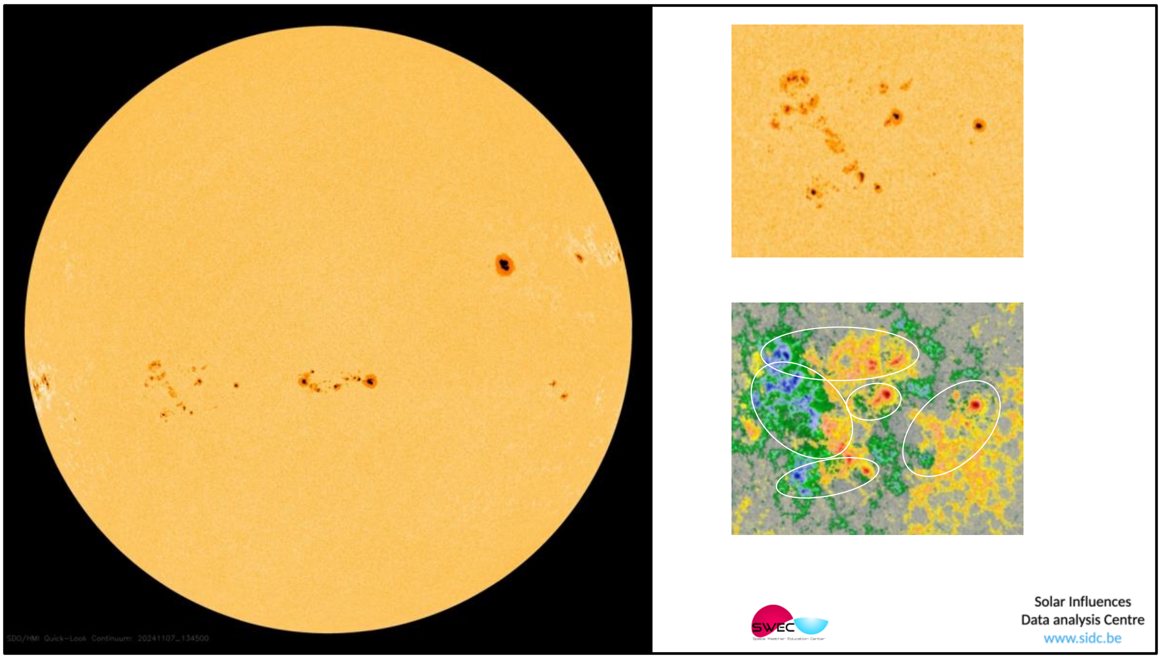

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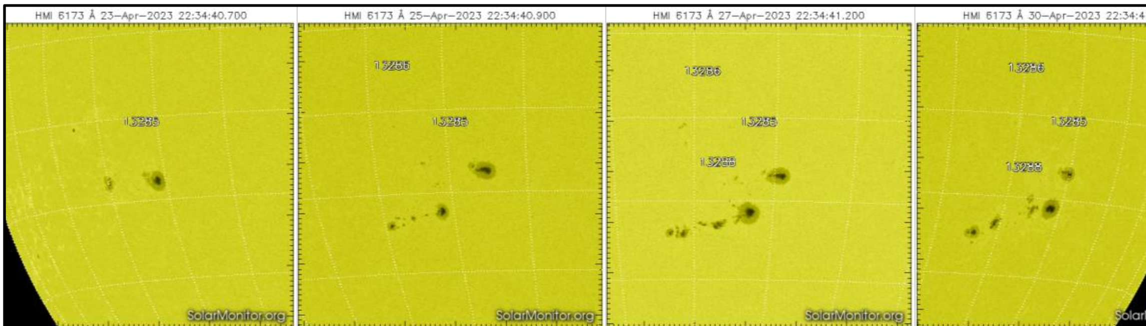

	23 April 2023			25 April 2023			27 April 2023			30 April 2023		
	SWx WS	NOAA	USET	SWx WS	NOAA	USET	SWx WS	NOAA	USET	SWx WS	NOAA	USET
13286	*Axx*	-	A	*Axx*	Axx	A	*Axx*	Bxo	A	*Axx*	Axx	J
13285	*Eao*	Dao	E	*Cso*	Dao	G	*Cso*	Cao	C	*Cso*	Cao	C
13288	-	-	-	*Dsi*	Dso	D	*Ekc*	Eki	E	*Fhc*	Ehc	E

Only M-class flares are by NOAA 13288 on 27 Apr, 01 May (2) and 03 May

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Kanzelhohe 07:45UTC ; SDO/HMI 13:45UTC on 07 November 2024

What’s wrong?

2024 Oct 05 0600 UTC
Sunspot Group Detection and Classification Results
(based on SDO HMI Continuum and Magnetogram Images)

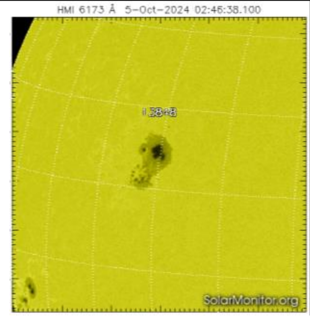
Number of Detected Sunspot Groups : 6

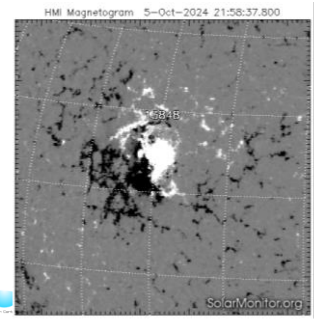
ASSA Number	Num Spots	Num Spots (with penumbra)	Location	LE	Area	Area(pen)	McIntosh Class	Mag Class			
17732	4	3	S09.3/W55.2	11.5	138	133	Esc	Beta-Gamma	33	3	0
17732	9	7	S14.8/W44.8	13.7	520	512	Eko	Beta-Gamma	51	8	1
17737	5	4	N11.7/W34.7	9.2	38	32	Dao	Beta-Gamma	30	3	0
17732	12	6	S15.3/W23.5	9.8	631	604	Dko	Beta-Gamma-Delta	46	8	0
17763	7	3	N13.5/E40.0	5.1	699	658	~~Ckc~~	Beta-Gamma	49	12	2
17768	5	4	S07.8/E59.3	13.1	209	203	Eac	Beta-Gamma	49	7	0

Total Number of Spots : 42
Wolf Number : 102

< Flare Probability as a whole >
C-Flare : 97 (%)
M-Flare : 35 (%)
X-Flare : 3 (%)

05 Oct 2024	NOAA 13848	MtWilson
ASSA	~~Ckc~~	BG
NOAA	Dkc	BD
USET	H	-
SWx WS	Dkc	BD





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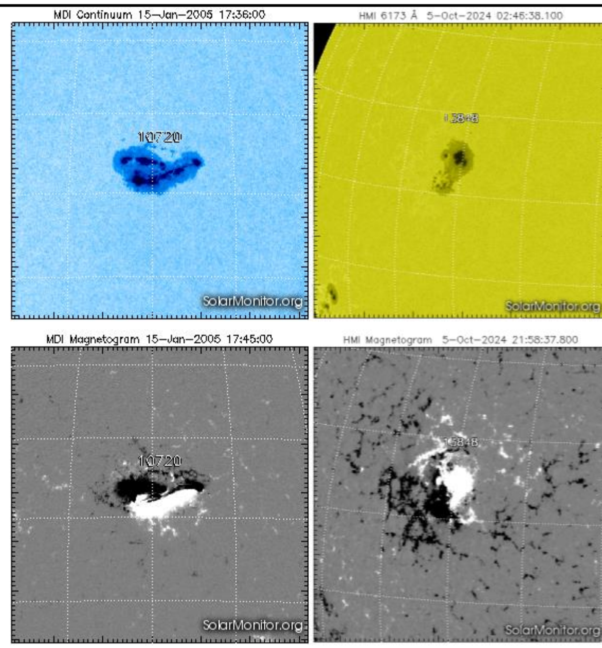
Compact groups

	NOAA 10720	NOAA 13848
NOAA	Dkc / BD	Dkc / BD
USET	E	H
SWx WS	Ekc / BD	Dkc / BD
M/X-class	5 / 2	0 / 0
Total M/X	16 / 5	1 / 1



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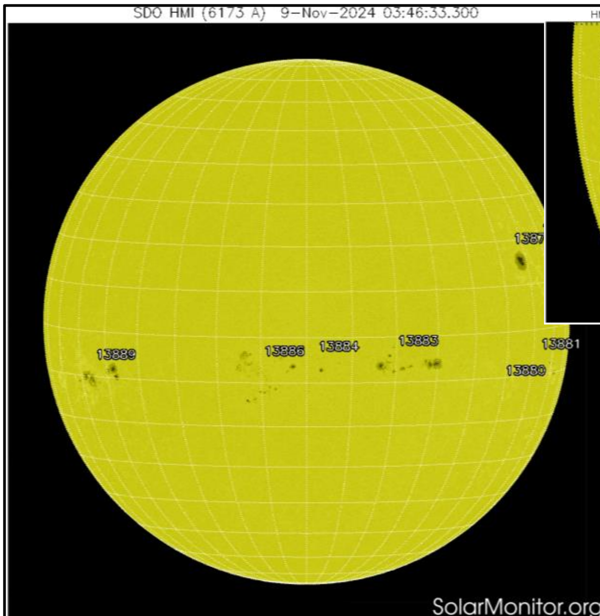

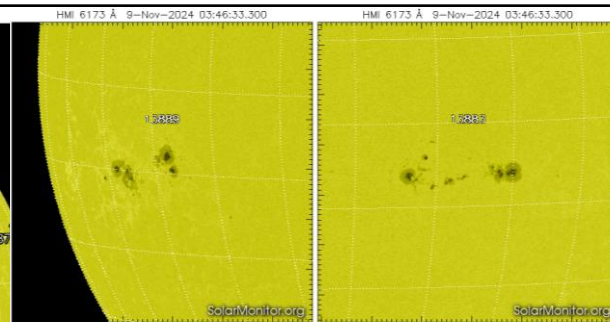

	NOAA 13889	NOAA 13883
	McI / MtW	McI / MtW
ASSA	Fkc /	Fao /
NOAA	Eko /	Fki /
SWx WS	Eko /	Fhi /

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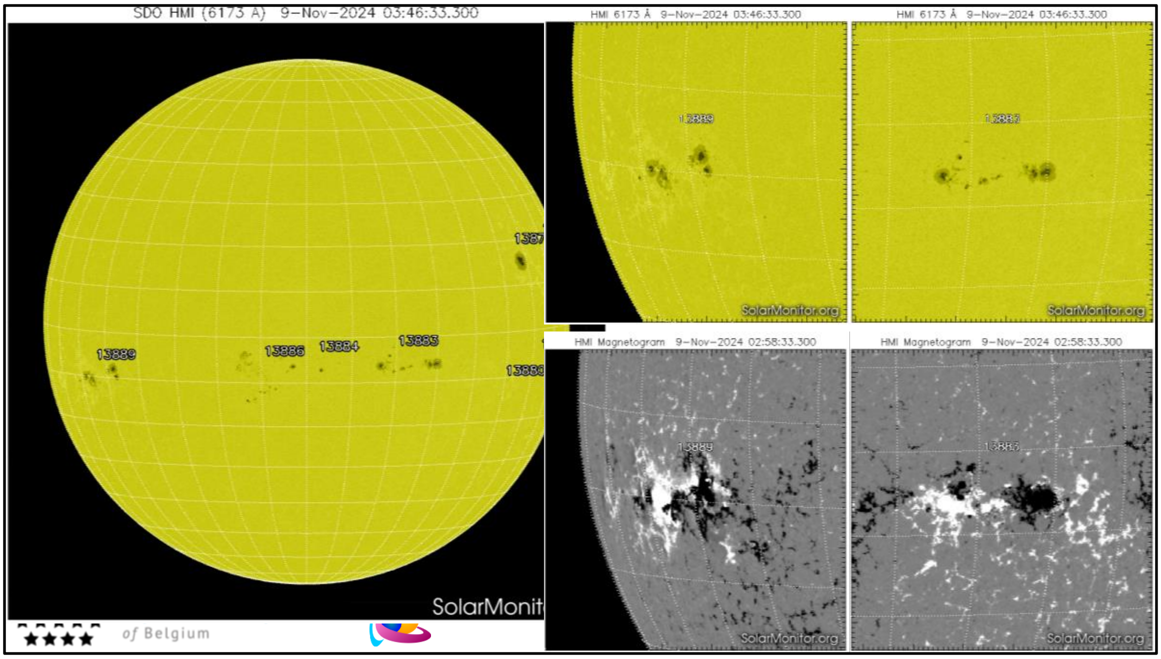
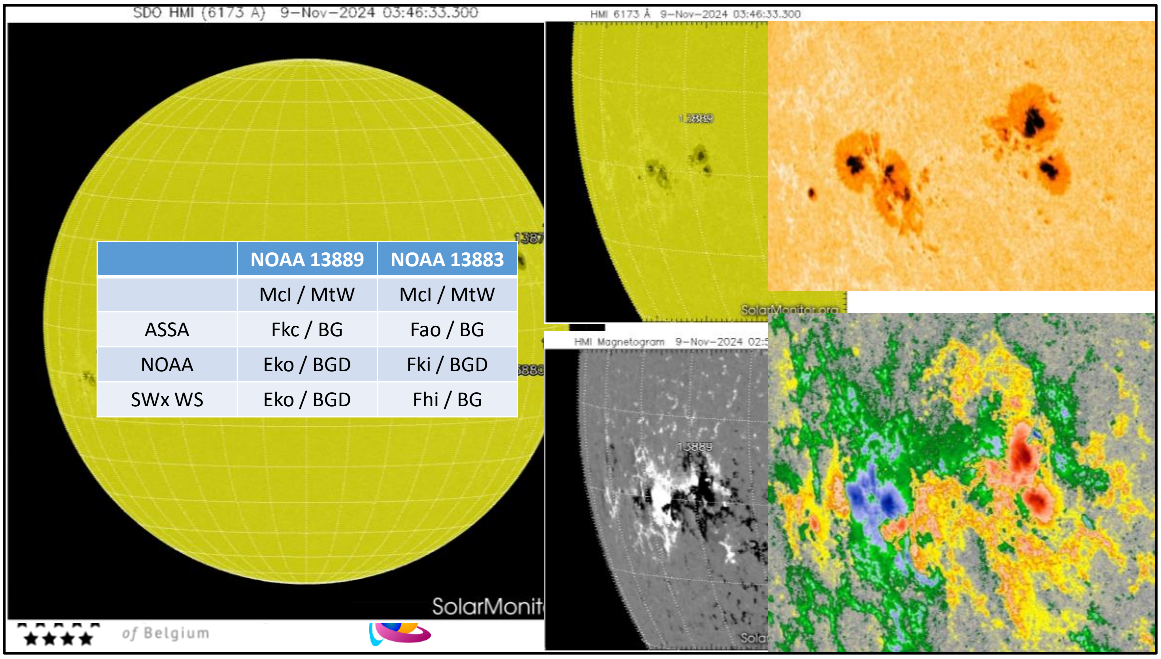
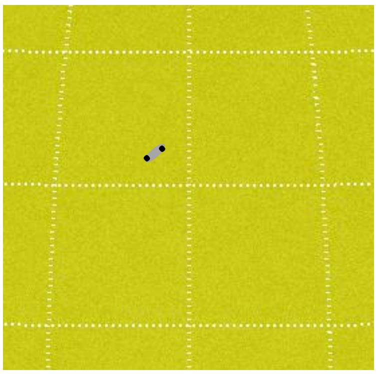
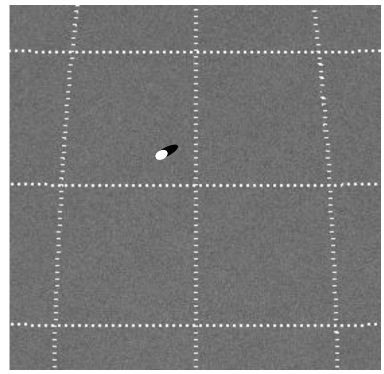

SDO HMI (6173 Å) 9-Nov-2024 03:46:33.300
13889
13886
13884
13883
SolarMonit
of Belgium
HMI 6173 Å 9-Nov-2024 03:46:33.300
13889
SolarMonitor.org
HMI 6173 Å 9-Nov-2024 03:46:33.300
SolarMonitor.org
HMI Magnetogram 9-Nov-2024 02:58:33.300
13889
SolarMonitor.org
HMI Magnetogram 9-Nov-2024 02:58:33.300
SolarMonitor.org



	NOAA 13889	NOAA 13883
	McI / MtW	McI / MtW
ASSA	Fkc / BG	Fao / BG
NOAA	Eko / BGD	Fki / BGD
SWx WS	Eko / BGD	Fhi / BG

Sketch a delta configuration (magn) with rudimentary penumbra (white light)





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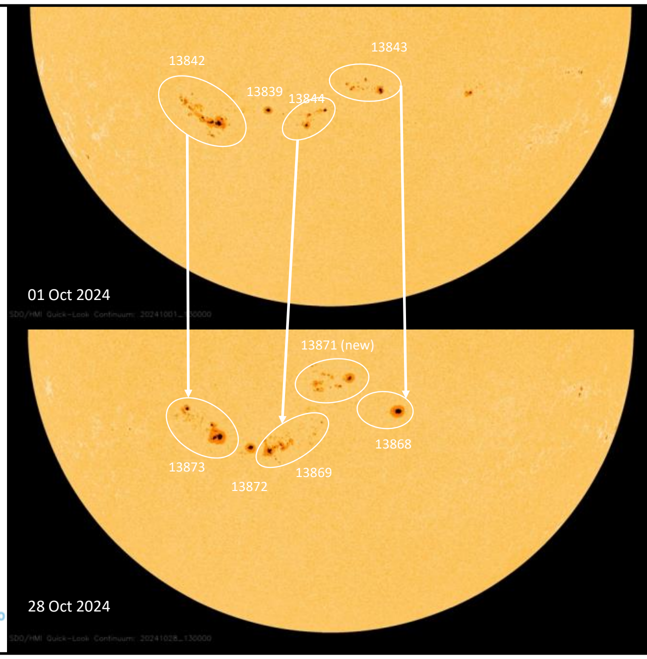

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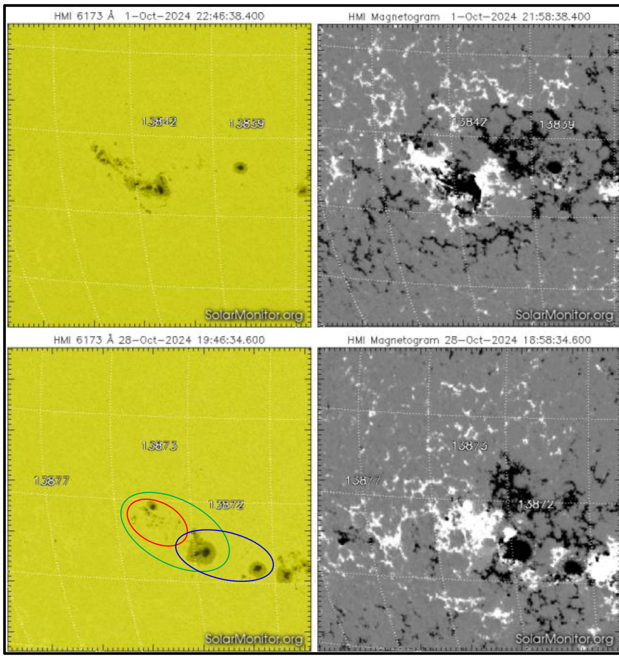

	NOAA 13842	NOAA 13873
	McI / MtW	McI / MtW
NOAA	Ekc / BGD	Cai+Eko / B+BGD
SWx WS	Ekc / BGD	Eki / BD

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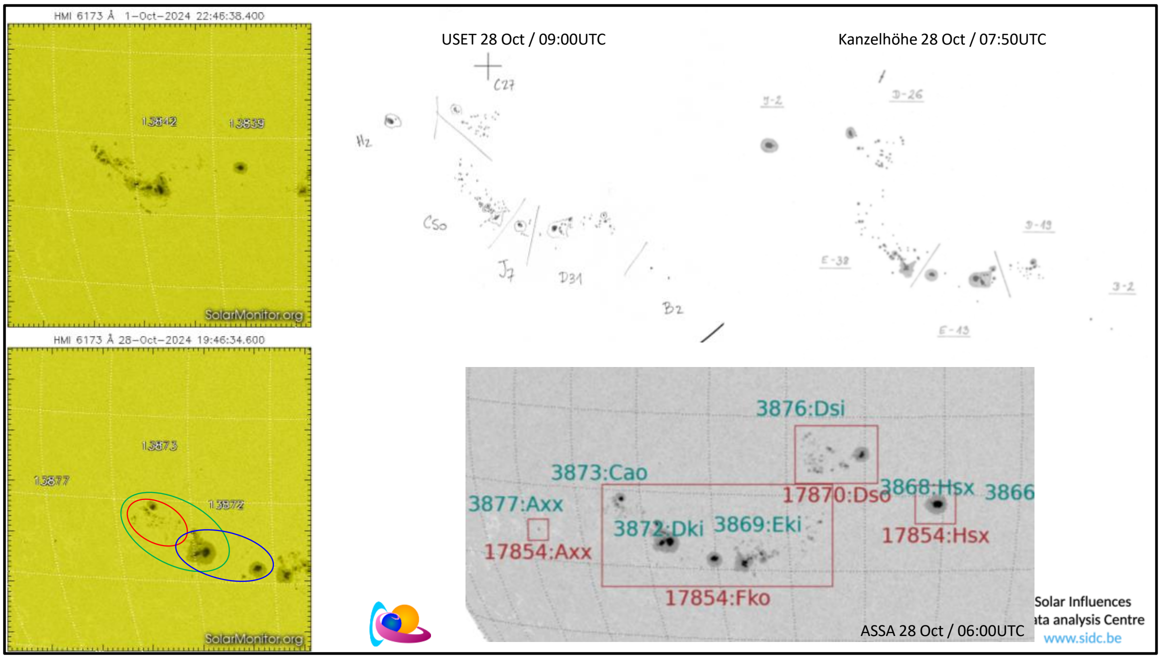
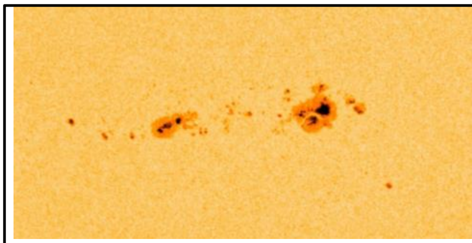
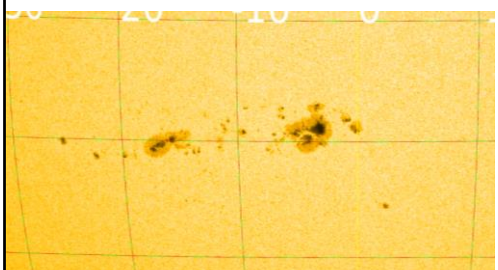

HMI 6173 Å 1-Oct-2024 22:46:38.400
13842
13839
SolarMonitor.org
HMI 6173 Å 28-Oct-2024 19:46:34.600
13873
13877
13872
SolarMonitor.org
USET 28 Oct / 09:00UTC
Kanzelhöhe 28 Oct / 07:50UTC
3876:Dsi
3873:Cao
17870:Dso
3868:Hsx
3866
3877:Axx
3872:Dki
3869:Eki
17854:Axx
17854:Hsx
17854:Fko
ASSA 28 Oct / 06:00UTC
Solar Influences
ata analysis Centre
www.sidc.be





SDO/HMI – 12 Nov / 08:15UTC

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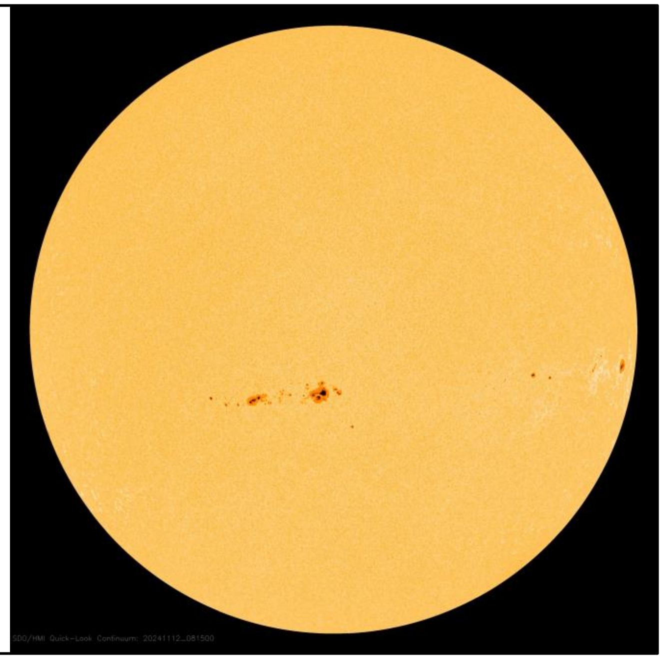
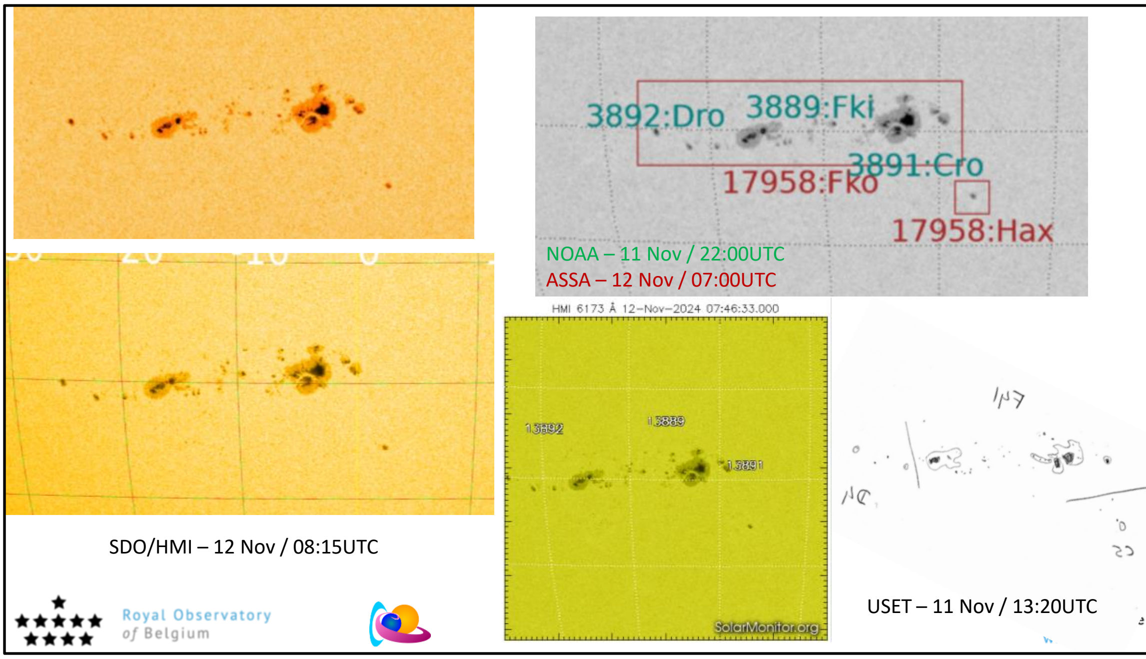
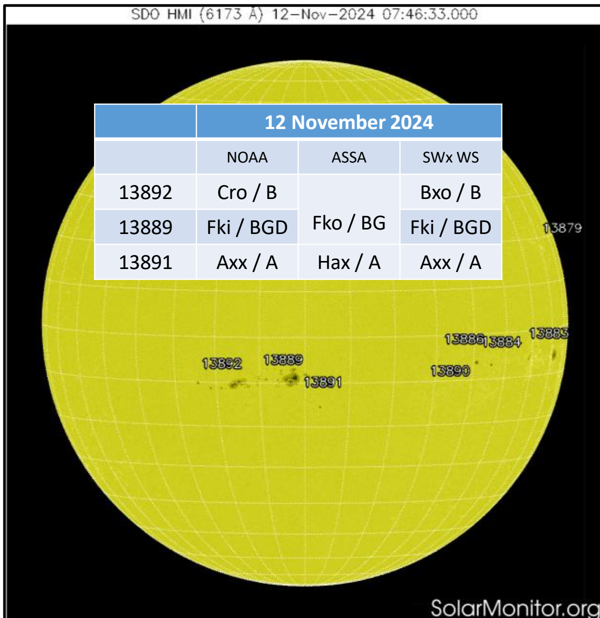
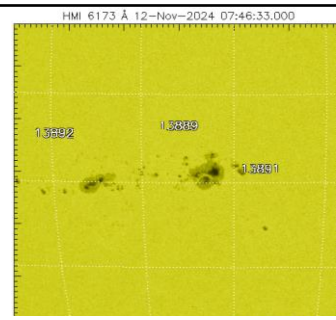
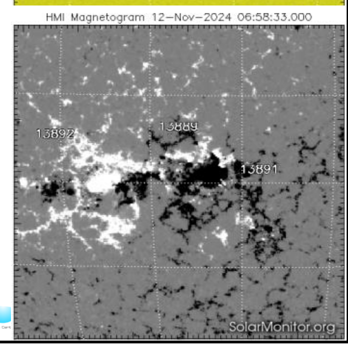



3892:Dro
3889:Fki
3891:Cro
17958:Fko
17958:Hax
NOAA – 11 Nov / 22:00UTC
ASSA – 12 Nov / 07:00UTC
HMI 6173 Å 12–Nov–2024 07:46:33.000
SolarMonitor.org
SDO/HMI – 12 Nov / 08:15UTC
USET – 11 Nov / 13:20UTC
Royal Observatory of Belgium



	12 November 2024		
	NOAA	ASSA	SWx WS
13892	Cro / B		Bxo / B
13889	Fki / BGD	Fko / BG	Fki / BGD
13891	Axx / A	Hax / A	Axx / A





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