

# Sunspot groups without active region numbers

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Using personal white-light disc drawings of the Sun, it is assessed that some 8% of all sunspot groups observed during the 10 years from 2009 to 2018 have not been assigned an NOAA active region number. This paper examines these groups to try to identify why this might be the case.



Figure 1. 80mm refractor projection box.

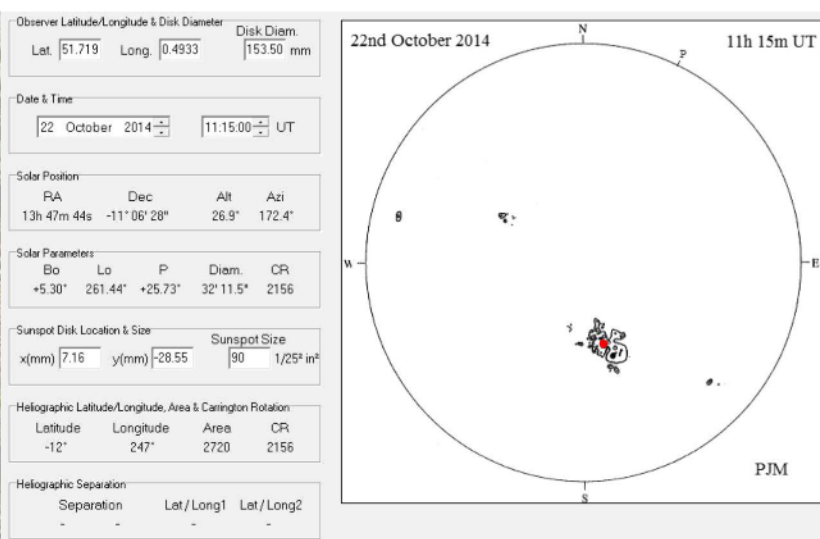


Figure 2. A disc drawing from 2014 Oct 22, displayed in *Helio Viewer*.

## Introduction

Most solar observers and organisations, whether they are amateur or professional, refer to sunspot groups by their active region (AR) numbers. This is the case for the BAA. The AR number is provided in the daily Solar Region Summary (SRS) from the National Oceanic and Atmospheric Administration (NOAA) and Space Weather Prediction Centre (SWPC). In particular, the SRS report compiled by SWPC is a joint product of NOAA and the US Air Force, issued daily at 00:30 UTC, providing a detailed description of sunspot active regions observed during the preceding day. It is created by SWPC after analysis and compilation of all individual reports from the USAF Solar Optical Observing Network (SOON).<sup>1</sup>

Personal white-light disc drawings for around ~180 days per year are analysed to determine parameters such as the number of groups,  $g$ , and the relative sunspot number  $R$ . As part of this analysis, all the groups visible are identified and then, based on their heliographic latitude and longitude as well as group type, assigned an NOAA AR number. This paper examines those groups identified from observations during the 10-year period of 2009 to 2018, *i.e.* for most of Solar Cycle 24, for which it has not been possible to assign an AR number. The author begins by explaining how the white-light disc drawings are made, before describing

how individual groups are identified. The main section of the paper presents those groups for which it has not been possible to assign an AR number (8% of all observed groups). Finally, the groups are analysed to determine why they might not have been included in the daily NOAA SRS reports.

### WARNING

**Never look at the Sun with the naked eye or with any optical instrument unless you are familiar with safe solar observing methods.**

## White-light observations

A Vixen 80mm  $f/11$  refractor on a driven equatorial mount is used to project the image of the Sun for daily observation whenever possible. A projection box is attached to the eyepiece holder as shown in Figure 1. A 20mm Plössl eyepiece is used to project the whole of the solar image on a sheet of paper, with a blank 6-inch (152mm) disc placed at the far end of the projection box. The north, east, south and west points are indicated on this disc. A backing sheet of paper is marked with a number of horizontal and vertical lines behind the blank disc. One of these horizontal lines is aligned along the east–west direction to aid in orientating the

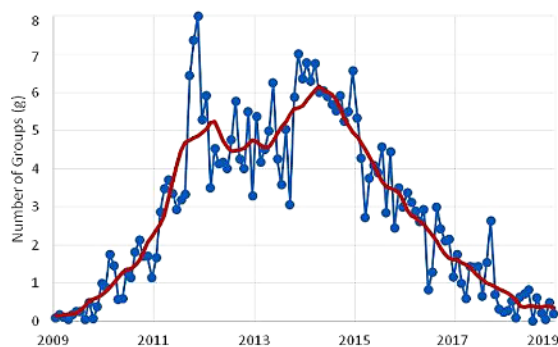


Figure 3. Solar Cycle 24, based on the MDF for the number of groups.

Solar Observations		October 2014							
Day	18	19	21	22	23	27	28	31	
Lat & Long	-18/15	-21/17							
Type	Hsx	Hsx	AR 12186						
Area	-	-							
Lat & Long	-7/318	-9/322	-9/323	-7/320	-7/322				
Type	Dso	Hax	Hax	Hsx	Hsx	AR 12187			
Area	200	180	130	-	-				
Lat & Long	-14/250	-12/253	-12/247	-12/247	-11/248	-11/246	-14/242		
Type	Fkc	Fkc	Fkc	Fkc	Fkc	Fkc	Fkc	AR 12192	
Area	-	2200	2770	2720	2780	2280	-		
Lat & Long		+5/285	+5/285	+7/285	+8/285				
Type		Cao	Cai	Dao	Cao	AR 12193			
Area		60	60	120	100				
Lat & Long			-13/207	-11/209	-11/209	-11/210	-11/208	-11/207	
Type			Hsx	Cso	Cso	Hsx	Hsx	Hsx	AR 12194
Area			-	100	110	60	60	-	
Lat & Long					+7/185	+7/184	+9/181	+8/184	
Type					Hsx	Hax	Cso	Hsx	AR 12195
Area					-	90	80	40	

Figure 4. Spreadsheet containing heliographic latitude and longitude, group type and area measurements for the passage of AR 12192.

projection box. The other lines are useful when making a sunspot drawing.

The steps to set up the telescope and make a disc drawing are as follows.

- Check that the telescope mounting is level and correctly aligned in azimuth; place an eyepiece in its holder and remove the telescope cap.
- Use the shadow of the Sun on the top of the projection box to ensure a solar image appears on the sheet of paper at the far end of the box (this avoids looking in the direction of the Sun).
- Focus the image and ensure it fits in the 6-inch circle. If it does not, the distance between the eyepiece and the sheet of paper will need adjusting.
- With the telescope drive switched off, place a small sunspot on one of the east–west lines of the sheet behind the blank disc and let it drift for a minute or so. If the sunspot moves above or below the line, rotate the projection box in the appropriate direction. Repeat until the sunspot moves along the east–west line before starting the drawing.
- Switch on the telescope drive and place the Sun within the disc circle. The drawing should then be made, first by marking the location of a sunspot in each group and checking they are correctly located within the disc. Then draw all the other sunspots, including the outline of penumbral spots. Draw any faculae present in yellow.
- Note the date and time (in UT) with the drawing, as well as the observing conditions.

Once the telescope and projection box have been set up, a drawing can take between five and 20 minutes to make, depending on the number and types of the sunspot groups visible. The drawing is then scanned and annotated, ready for various measurements to be made: the number of groups, sunspot number, quality

number, sunspot heliographic latitude and longitude, as well as sunspot area. An example drawing, displayed using the *Helio Viewer* software,<sup>2</sup> is shown in Figure 2. This shows the largest sunspot group of Cycle 24, AR 12192.<sup>3</sup>

Note that to ensure a consistent set of sunspot measurements over a long period of time such as a solar cycle, the same telescope and eyepiece are used (*i.e.*, no other eyepieces are used to obtain a higher magnification).

## Identification of sunspot groups

For a disc drawing such as that shown in Figure 2, it is straightforward to determine how many groups are present (four in this case) since there is a clear distinction in both latitude and longitude between the groups. However, for other observations, it can become difficult to distinguish one group from another. The approach taken by the BAA is to use the following guidance:<sup>4</sup>

‘Every sunspot, however small, counts as a separate sunspot group if it is at least 10° of latitude or longitude from its nearest neighbour. A large group, however, spread out in longitude, is still one group unless it has distinct separate centres of activity at least 10° apart.

‘From time to time, distinct groups do break out nearer than 10° from each other. This is mostly in latitude, which can be in the order of 5°. When such groups occur, they should be counted as two groups.’

Based on the above description, Figure 3 shows the monthly mean daily frequency (MDF) of the groups from 2009 to 2018. This is based on a total of 1,813 drawings. The red curve is a 13-month smoothed number of groups, which clearly shows the double peak of sunspot activity during Solar Cycle 24.

Once each group has been identified, the heliographic latitude and longitude is measured – as shown, for example, by the red dot in Figure 2 for AR 12192, which gives a latitude of 12°S and a longitude of 247° (*i.e.*, S12°/247°). Performing similar measurements for all groups and associating the latitude and longitude with previous observations

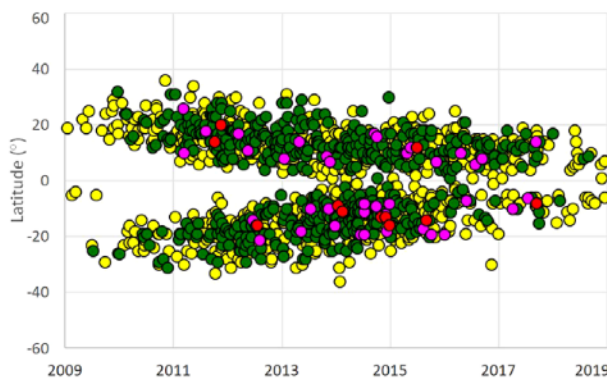


Figure 5. ‘Butterfly’ diagram for Solar Cycle 24.



gives a spreadsheet of measurements, as shown in Figure 4 for the passage of AR 12192 during 2014 October. The group type,<sup>5</sup> and area in millionths of the Sun's visible hemisphere (msh),<sup>6</sup> are added. Measurements of sunspot group location and area enable a 'butterfly' diagram to be plotted as shown in Figure 5 for Cycle 24. (The maximum measured size of a group is shown *via* the four colours: yellow for groups smaller than 100msh, green for groups between 100 and 500msh, purple for groups between 500 and 1,000msh and red for groups greater than 1,000msh.)

The final step is to associate each group with an NOAA AR number given in the daily SRS reports.<sup>1</sup> This is based on the measured latitude and longitude, and in most cases the group type information in the SRS report. It is from this step that an observed group without an AR number is identified.

## Groups without AR numbers

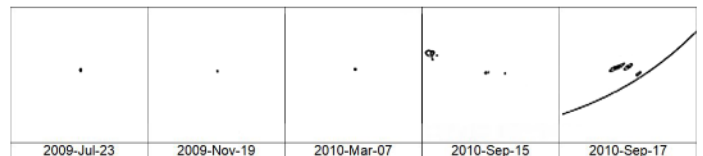
Table 1 indicates that 8% of all sunspot groups observed during 2009 to 2018 have not been assigned an AR number. These groups are examined to understand why this is the case. Note that there are likely to be more groups without an AR number, since disc drawings have only been possible for an average of 181 days per year.

The observed groups without AR numbers are shown in Figures 6, 9, 13, 15, 18, 22, 26 & 27, with details provided in Tables 2 to 9. The extracts from the author's disc drawings in these figures are orientated with north at the top and east to the right (*i.e.*, as for the projected disc). In this paper the decision as to whether nearby sunspots belong to the same group or to separate groups is based on the magnetic field strength and polarity, as shown in SOHO Michelson Doppler Imager (MDI) images up to the end of 2010,<sup>7</sup> and subsequently by the Solar Dynamics Observatory (SDO) Helioseismic and Magnetic Imager (HMI) magnetogram images,<sup>8</sup> acquired at a time as close as possible to the disc drawing. The tables include information on the duration of unassigned AR groups based on either SOHO MDI or SDO HMI continuum images,<sup>8,9</sup> the latter usually being available every 15 minutes.

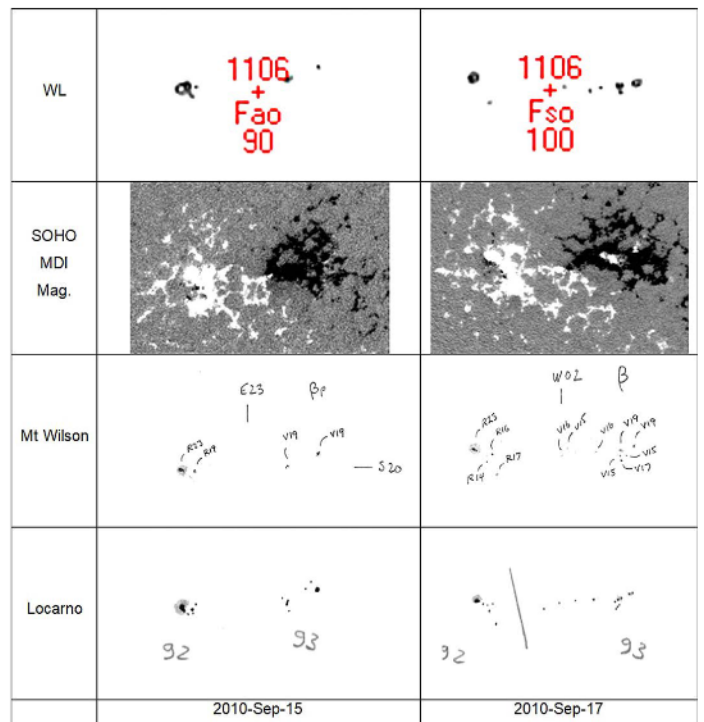
In addition, full-disc drawings from Mt Wilson Solar Observatory,<sup>10</sup> California, USA and the Specola Solare Ticinese,<sup>11,12,13</sup> in Locarno, Switzerland are used to supplement the author's own drawings. The annotation on these drawings is also used to infer, in the case of nearby sunspots, whether they have been assigned as one or more groups. For the Mt Wilson drawings,<sup>14</sup> this is done by assuming that pairs of latitude and longitude values are given

**Table 1. Number of observed sunspot groups & those without AR number**

Year	Total no. of observed groups	No. of groups without AR number	Percentage of groups without AR number
2009	22	2	9.1
2010	68	3	4.4
2011	207	12	5.8
2012	221	11	5.0
2013	244	15	6.1
2014	306	31	10.1
2015	205	26	12.7
2016	125	10	8.0
2017	64	7	10.9
2018	26	2	7.7
<b>Total</b>	<b>1,488</b>	<b>119</b>	<b>8.0</b>



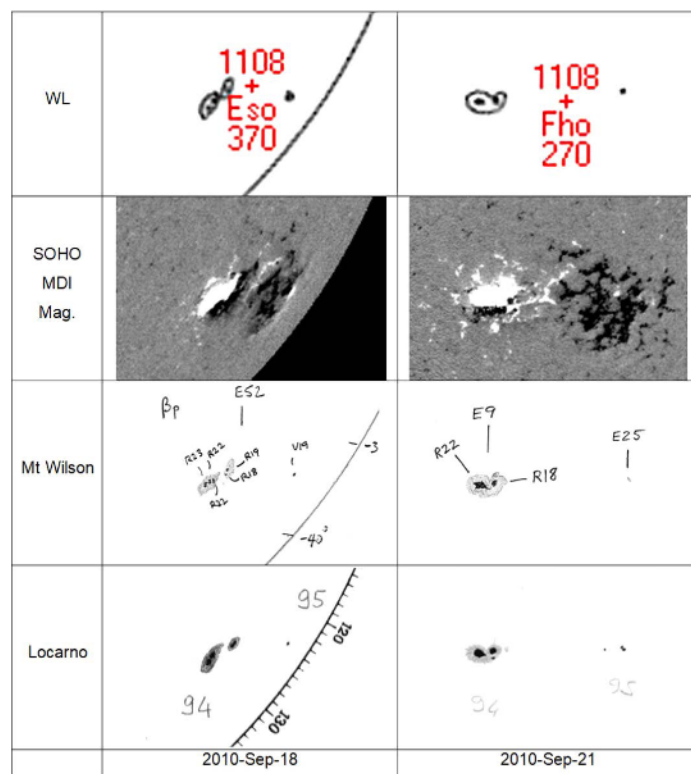
**Figure 6. Drawings of sunspot groups without AR numbers during 2009 and 2010.**



**Figure 7. White-light drawing and SOHO MDI magnetogram image comparisons for 2010 Sep 15 & 17.**

**Table 2. Details of sunspot groups without AR numbers during 2009 & 2010**

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2009 Jul 23	S05°/005°	Axx	0.5	Y	N	An isolated group.
2009 Nov 19	N27°/236°	Axx	0.2	Y	N	An isolated group.
2010 Mar 7	N23°/238°	Axx	1.4	ND	Y	An isolated group.
2010 Sep 15	S18°/204°	Bxo	—	Y	Y	Magnetically combined with AR 11106 at S19°/216° (Hax) although more than 10° apart. Also seen up to Sep 18. Mt Wilson: seen as one group. Locarno: seen as two separate groups. <b>Figure 7.</b>
2010 Sep 17	S30°/131°	Hsx	—	Y	Y	Magnetically combined with AR 11108 (Dao) at S29°/144°, although more than 10° apart. Also seen on Sep 18 & 21. Mt Wilson: seen initially as one group and then two groups. Locarno: seen as two separate groups. <b>Figure 8.</b>



**Figure 8.** White-light drawing and SOHO MDI magnetogram image comparisons for 2010 Sep 18 & 21.

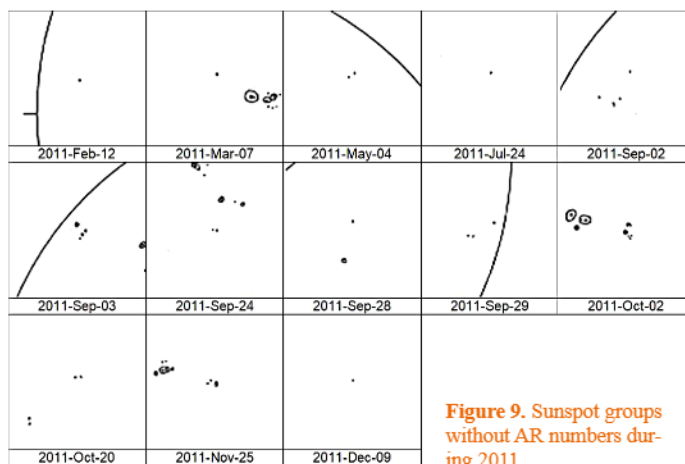
for each group (the magnetic class is also included). For the Locarno drawings a number is used to label each group, with a table of latitude and longitude provided in the upper right of the drawing. For isolated groups, the Mt Wilson and Locarno drawings are used to ascertain whether another observer has recorded the same group as the author.

Information on groups without AR numbers is separated into different time periods below. Particularly interesting examples of these groups are examined in further detail. (These drawings and images are orientated with the solar rotation axis top to bottom, and east towards the right, *i.e.*, the same orientation as the SOHO and SDO images as well as the Mt Wilson and Locarno drawings.)

### 2009 & 2010

As shown in Figure 3, the years 2009 and 2010 were at the end of solar minimum and at the start of the rise towards solar maximum for Cycle 24. During 2009, two of the 22 individual groups observed were without AR numbers. As shown in Table 2 and Figure 6, both groups were single Axx sunspots, *i.e.*, isolated groups where the SDO HMI images indicate they were short-lived, lasting half a day or less. They were observed at Mt Wilson Observatory, but not at Locarno Observatory.

For 2010, three out of 68 groups observed did not have an assigned AR number. The first of these was another isolated group, but with a longer duration of 1.4 days – no drawings (denoted in the tables by ‘ND’) were available at Mt Wilson and the group was visible at Locarno. The second unassigned group was of type Bxo (2010 Sep 15) – as described in the ‘Comments’ column of Table 2 and shown in Figure 7, the group identified by the author is in fact, as determined by the SDO HMI magnetogram, part of the same group as nearby sunspots. This is despite the fact that they were more than  $10^\circ$  apart and hence assigned as two groups



**Figure 9.** Sunspot groups without AR numbers during 2011.

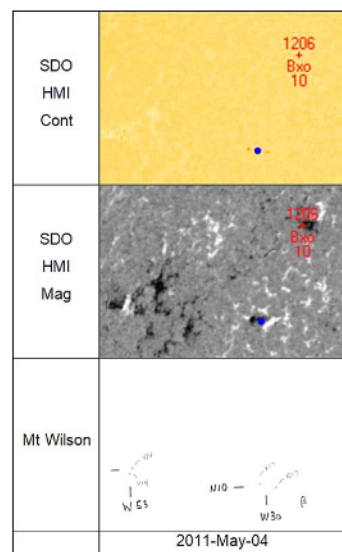
based purely on their visual appearance and the BAA method of identifying groups. Mt Wilson identified just one group, again based on the magnetic polarity, whereas Locarno assigned these sunspots as two groups, based only on their visual appearance. Figure 7 (top row) has the NOAA SRS AR number (the four-digit version), group type and area in msh superimposed on the white-light drawing – this also indicates a single combined group. This example illustrates how the number of assigned groups can be different based on visual or magnetic information.

The third example of 2010, Figure 8, also indicates that sunspots visually assigned to two groups were magnetically the same group, although in this case a few days later (on 2010 Sep 21); Mt Wilson also assigned two separate groups.

### 2011

During 2011 the number of observed groups increased significantly over the previous two years (207 compared with 68 in 2010). The end of 2011 also saw high solar activity, with an MDF of eight groups in 2011 November; the first of the two peaks of Solar Cycle 24 occurred during the beginning of the following year (Figure 3). Some 12 (6%) of the observed groups were recorded as not having an AR number. This is described in Table 3 and shown in Figure 9.

Many of the groups without AR numbers were isolated and short-lived, usually of type Axx. Figure 10 shows an example of an isolated Bxo group from 2011 May 4, which can be seen in SDO HMI continuum images for just over two days. In the SRS reports for 2011 May 4 & 5 there should be a nearby group, AR 11206, also of type Bxo; this is not actually visible in the HMI continuum images nor the Mt Wilson and Locarno drawings, but it is indicated in the HMI magnetogram images as shown in Figure 10. Perhaps the latitude given in the SRS reports is incorrect.



**Figure 10.** SDO HMI continuum and magnetogram images with white-light image for 2011 May 4.



An isolated Axx sunspot was seen near the western limb on 2011 Sep 2 as was a magnetically separate group, AR 11280, to the south as shown in Figure 11. On the following day, the Axx sunspot had developed into type Dsc, still with a reduced AR 11280 to the south. Given this development it is perhaps surprising that it was not included in the SRS reports. Mt Wilson and Locarno also recorded the development of the northern group and the decay of the southern group.

On 2011 Nov 25 three groups were recorded, exactly  $10^\circ$  apart at longitudes of 212, 222 and  $232^\circ$ . As the HMI magnetogram in Figure 12 shows, the leading (left) Hsx sunspots appear to have

been separate from the other sunspots. Mt Wilson indicates that there were two groups, as does the NOAA in the SRS reports, whereas Locarno indicates there were three (*i.e.* the same as the author). This example illustrates that a different number of groups can be recorded by different observers.

## 2012

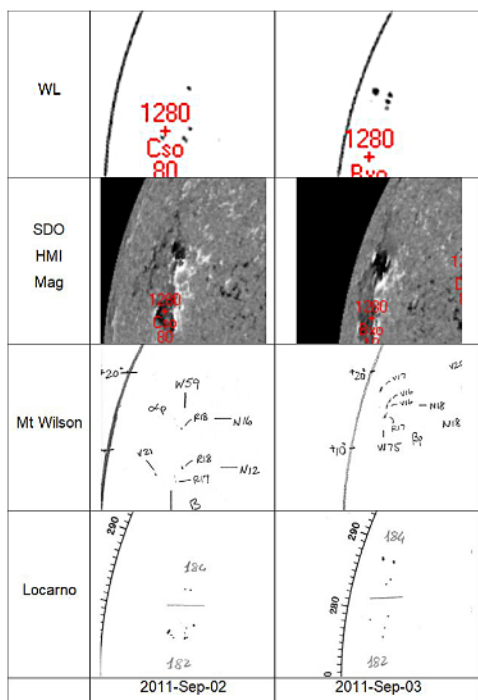
Although at solar maximum, activity during 2012 (in terms of the monthly group MDFs) was slightly reduced compared to the end of the previous year. The total number of groups observed was

**Table 3. Details of sunspot groups without AR numbers during 2011**

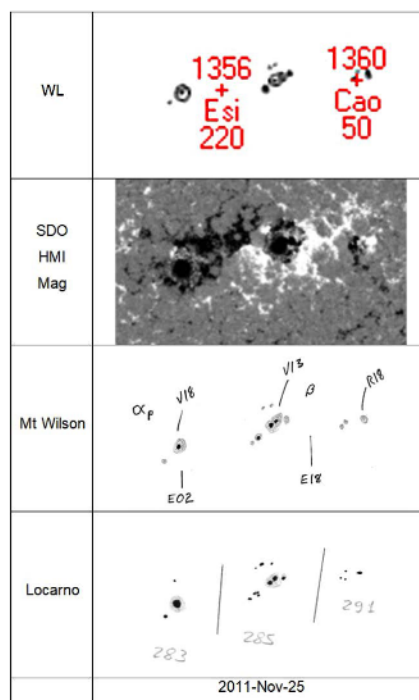
Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2011 Feb 12	N16°/111°	Axx	0.8	N	N	An isolated group.
2011 Mar 7	N18°/099°	Axx	3.0	Y	Y	An isolated group – magnetically separate from nearby AR 11166 (Ekc) at N10°/091°. Also seen on Mar 8.
2011 May 4	N09°/094°	Bxo	2.2	Y	Y	An isolated group. AR 11206 at N22°/093°, type Bxo, is not seen in images/drawings except the HMI magnetogram – a possible mis-identification? <b>Figure 10.</b>
2011 Jul 24	N28°/058°	Axx	1.0	Y	Y	An isolated group.
2011 Sep 2	N17°/322°	Axx	2.7	Y	Y	Magnetically separate from AR 11280 at N11°/323°. Also seen on Sep 3 as type Dsc at N20°/326° and near to the W limb. Mt Wilson and Locarno: seen as separate group. <b>Figure 11.</b>
2011 Sep 24	N13°/325°	Bxo	–	Y	Y	Magnetically the same group as AR 11301 (Dac) to the north at N20°/328°. Also seen on Sep 25. Mt Wilson & Locarno: seen as separate group.
2011 Sep 28	N24°/331°	Axx	–	Y	Y	Same group magnetically as AR 11301 (Hsx) to the south at N18°/327°. In HMI images some small sunspots between this sunspot and AR 11301 are seen – these decayed to give the appearance of two groups. Mt Wilson: seen as separate group from AR 11301. Locarno: seen as combined group with AR 11301.
2011 Sep 29	N15°/194°	Axx	–	Y	Y	Magnetically combined with AR 11307 (Bxo) at N12°/204°, although the separation was $10^\circ$ in longitude. Also seen on Sep 30 and Oct 2. Mt Wilson: seen as a combined group with AR 11307. Locarno: seen as separate group.
2011 Oct 2	N15°/272°	Dso	–	Y	Y	These sunspots were the following part of AR 11302 at N12°/284°, before the decay of intermediate sunspots. Magnetically combined with AR 11302. Mt Wilson and Locarno: seen as combined group.
2011 Oct 20	S06°/001°	Axx	0.7	Y	Y	An isolated group – magnetically separate from AR 11321 at S17°/006°.
2011 Nov 25	N17°/212°	Hsx	–	Y	Y	The following of three nearby groups – others at N15°/232° (Hax) and N17°/222° (Dac). Assigned as two different groups by NOAA and Mt Wilson, but three groups by Locarno. The Hsx group appears to have been magnetically separate from the others. <b>Figure 12.</b>
2011 Dec 9	N12°/023°	Axx	0.9	Y	ND	An isolated group.

**Table 4. Details of sunspot groups without AR numbers during 2012**

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2012 Jan 16	S31°/336°	Axx	2.2	ND	Y	An isolated group approaching the W limb.
2012 Feb 1	N16°/128°	Axx	1.4	Y	Y	An isolated group approaching the W limb.
2012 Feb 1	S19°/087°	Bxo	1.6	Y	Y	An isolated group.
2012 Feb 19	S16°/212°	Bxo	1.4	ND	Y	An isolated group and the only one in the southern hemisphere.
2012 Feb 25	S15°/105°	Bxo	1.9	Y	Y	An isolated group near the CM in the southern hemisphere.
2012 Jun 14	N15°/072°	Axx	–	N	Y	Associated magnetically with nearby AR 11506 (Dso) at N10°/076°. Locarno: Axx sunspot seen, but not as separate group.
2012 Jun 16	N10°/085°	Axx	–	Y	Y	Magnetically same group as AR 11506 (Bxo) at N12°/075°, although $10^\circ$ apart. Locarno: on Jun 16 seen as two sunspots marked ‘pp’, but not separate from AR 11506; seen on Jun 17 as one sunspot in a separate group. Mt Wilson: seen to be same group as AR 11506.
2012 Jul 7	S24°/088°	Axx	–	Y	Y	Near to AR 11520 at S16°/083° – most likely part of same group (magnetically). Locarno: seen as separate group. Mt Wilson: single sunspot seen, but not as separate from AR 11520. <b>Figure 14.</b>
2012 Aug 31	N14°/180°	Axx	2.5	Y	ND	An isolated group in NE quadrant.
2012 Nov 11	S16°/247°	Bxo	0.8	N	ND	An isolated group.
2012 Nov 25	S19°/045°	Axx	1.7	Y	Y	Magnetically isolated from AR 11622 at S24°/052°.



**Figure 11.** White-light drawings and SDO HMI magnetogram images for 2011 Sep 2 & 3.



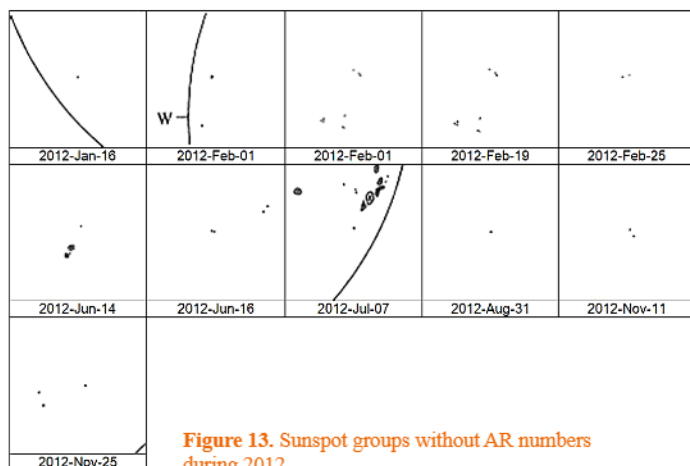
**Figure 12.** White-light drawings and SDO HMI magnetogram image for 2011 Nov 25.

221 of which 11 (5.0%) had no AR number, as given in Table 4 and Figure 13.

Of particular note amongst the many isolated groups was a single Axx sunspot to the south of an Fkc group (AR 11520) near the eastern limb on 2012 Jul 7. The Fkc group was at S16°/83° while the Axx sunspot was at S24°/88° (*i.e.*, separated by 5° in latitude). As shown in Figure 14, the Fkc and Axx sunspots are likely to have been from the same group, as seen in the magnetogram image. The Mt Wilson drawing shows all the sunspots belonging to the same group while that of Locarno shows the Axx sunspot separately (this drawing assigns the sunspots to four groups).

## 2013

For most of 2013 activity was similar to that of 2012, except towards the end of the year when there was an increase towards the second peak of Cycle 24 in 2014. A total of 244 individual groups were observed, of which 15 (6.1%) were not assigned an



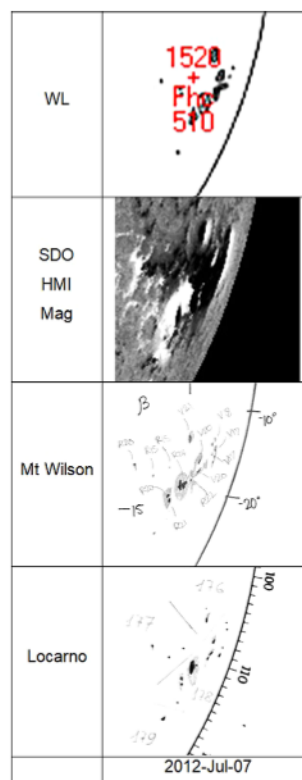
**Figure 13.** Sunspot groups without AR numbers during 2012.

AR number. Table 5 and Figure 15 describe and show these unassigned groups.

On 2013 Aug 13 an Axx group comprising two sunspots at S14°/183° was seen to the west of AR 11820, which was of type Axx at S12°/173° (*i.e.*, a separation in longitude of exactly 10°). As shown in Figure 16 the SRS report indicates a combined group of type Cso, which also appears to be the case for the magnetogram and the Mt Wilson drawing. Locarno indicates that there were three groups. This is another example of differences when determining groups magnetically or purely visually, based on sunspot heliographic latitude and longitude.

On 2013 Nov 16 an Hkx sunspot, AR 11899, was seen at N07°/038°. To its north and west was an Axx group at N11°/049°, comprising three sunspots. As Figure 17 (left column) shows, this was magnetically separate from the Hkx sunspot but had no AR number. Mt Wilson and Locarno also indicate that the Hkx and Axx sunspots were from separate groups (the Mt Wilson drawing in Figure 17 is from Nov 17). The observation on Nov 19 showed another Axx group near to AR 11899,

this time to the north and just to the east at N14°/036°. Again this appeared to be magnetically distinct from the Hkx sunspot and it was seen at Mt Wilson as a separate group, as shown in Figure 17 (middle column) – there was no Locarno drawing. However, on Nov 23 the Axx group was given as AR 11904, although it had been on the disc for several days. It was now of type Dai and close to the western limb, as shown in Figure 17 (right column).



**Figure 14.** White-light drawings and SDO HMI magnetogram image for 2012 Jul 7.

## 2014

The second and highest peak of Cycle 24 occurred during 2014. The highest number of individual groups was observed during the year, 306, of which 31 were not assigned an AR number (10.1%), as described in Table 6 and shown in Figure 18.

As AR 11967, the second largest group of Cycle 24, approached the western limb on 2014 Feb 8;<sup>3</sup> it was much smaller than a few days earlier. In particular, no sunspots were observed between the former leading and following parts of the group. Now AR 11967 comprised an Hsx sunspot at S08°/121°, close to the limb, and an Hkx sunspot at S11°/108°, as shown in Figure 19 (right column). Given that the now two parts of the previously more impressive group (shown in Figure 19 (left column) from Feb 5)

were separated by  $13^\circ$  in longitude and no sunspots were seen in-between, the Hsx sunspot close to the limb was assigned as a separate group from the Hkx sunspot for which there was no AR number. The magnetogram from Feb 8 shows a complex magnetic field whereby the Hsx and Hkx sunspots were magnetically the same group. This is the case for the Mt Wilson drawing, but not for the Locarno drawing. The interpretation is the same from Feb 5 (the Locarno drawing is from Feb 6).

Between 2014 Apr 19 & 21, several sunspots developed on the disc at  $S09^\circ/226^\circ$ , to the north of AR 12035 at  $S15^\circ/222^\circ$  (type Dsc). Although both groups had similar longitudes, the latitude separation was more than the  $5^\circ$  limit suggested by the BAA guidance for the identification of groups,<sup>4</sup> and thus the northern

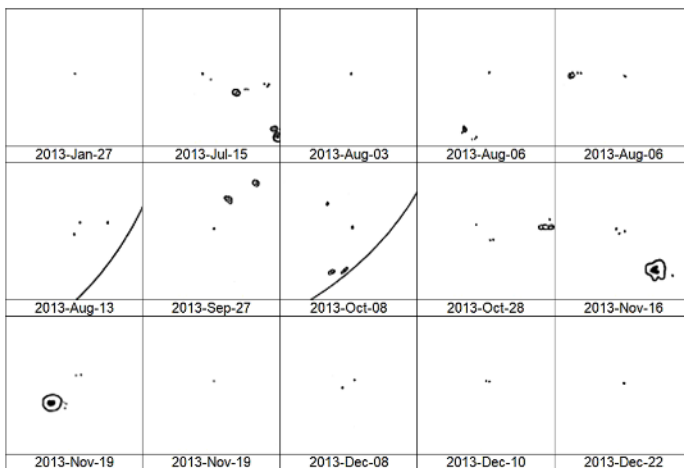


Figure 15. Sunspot groups without AR numbers during 2013.

sunspots were identified by the author as a separate group (type Cso) which had no AR number. Figure 20 shows a complex magnetic field around both groups, which probably means that the sunspots from the Dsc and Cso groups were actually from the same group (rather than two). This appears to be the case for the Mt Wilson drawing, where only one group is indicated. However, for the Locarno drawing three groups separated in latitude are shown.

On 2014 Dec 19, an isolated Axx sunspot was seen near the western limb (at  $S07^\circ/279^\circ$ ). Figure 21 shows that it was visible in SDO HMI continuum images from Dec 16 (12:00 UT) to Dec 20 (03:00 UT). On Dec 18 & 19, small penumbral sunspots were visible. At Mt Wilson it was seen on Dec 19 only (no drawing on Dec 20), while at Locarno it was observed on Dec 18 & 19 (no drawing on Dec 17). Given that it was visible for almost four days and it comprised small penumbral sunspots, it is surprising this group was not given an AR number.

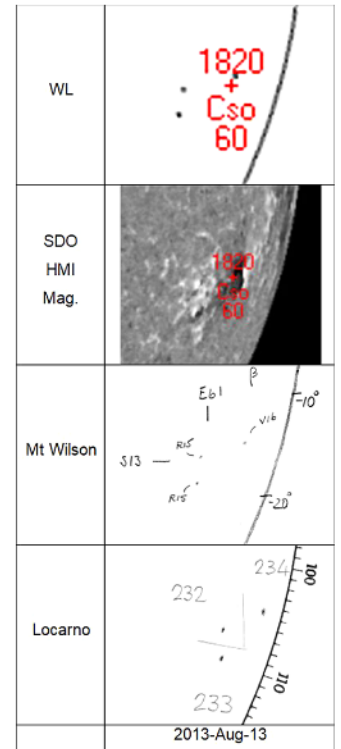
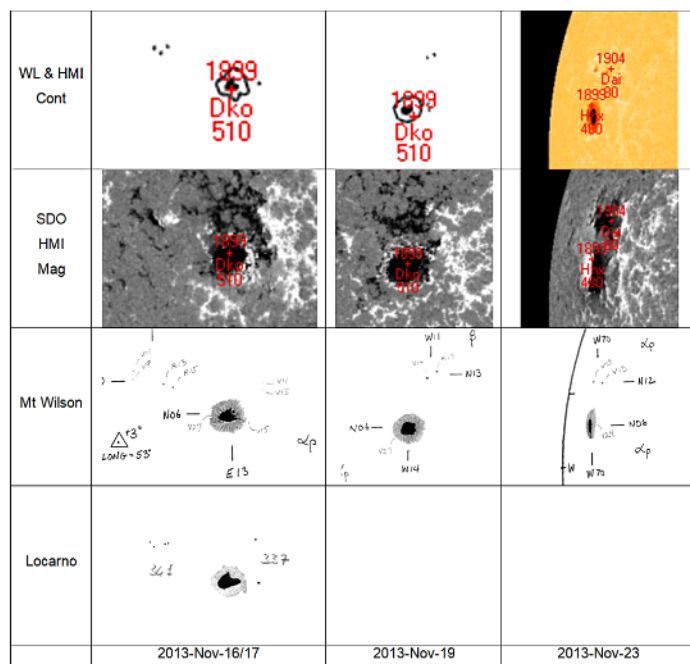


Figure 16. White-light drawings and SDO HMI magnetogram image for 2013 Aug 13.

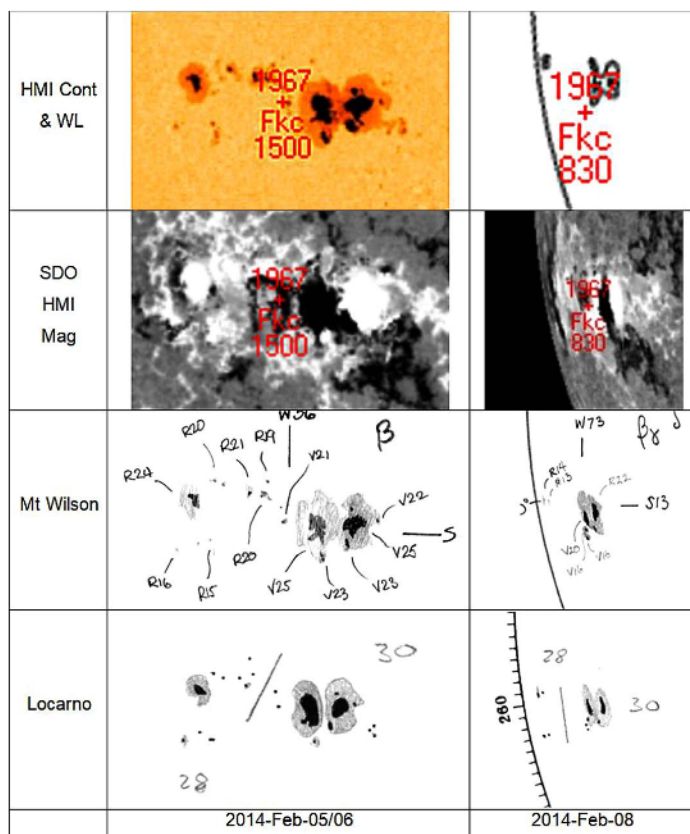
Table 5. Details of sunspot groups without AR numbers during 2013

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2013 Jan 27	N08°/314°	Axx	2.3	N	Y	An isolated group.
2013 May 15	S14°/346°	Axx	1.2	Y	N	An isolated group. Also seen on May 16 (Hsx). Separate magnetically from nearby AR 11747 at $S19^\circ/337^\circ$ .
2013 Jul 6	S12°/025°	Bxo	1.3	Y	N	An isolated group – only group in northern hemisphere.
2013 Aug 3	S13°/015°	Axx	3.4	Y	Y	An isolated group. Also seen on Aug 5 but not Aug 4.
2013 Aug 6	S11°/334°	Axx	0.6	Y	Y	An isolated group.
2013 Aug 6	N14°/333°	Axx	–	Y	Y	AR 11809 nearby at $N13^\circ/342^\circ$ – magnetically same group as Axx sunspot. Mt Wilson: seen on Aug 6 as a combined group. Locarno: seen as separate group.
2013 Aug 13	S14°/183°	Axx	–	Y	Y	Magnetically the same group as nearby AR 11820 at $S12^\circ/173^\circ$ . Mt Wilson: seen as a combined group. Locarno: on Aug 13 & 14, Axx sunspot and AR 11820 seen as three groups, on Aug 15 as two groups and then as one group on Aug 16 & 17. <b>Figure 16.</b>
2013 Sep 27	N07°/025°	Axx	–	Y	Y	Same group as AR 11850 at $N11^\circ/033^\circ$ as seen in magnetogram. Mt Wilson: seen as one group on Sep 26, but two groups on Sep 27. Locarno: seen on Sep 27 as two groups.
2013 Oct 8	S13°/163°	Hsx	–	Y	Y	Magnetically the same group as Hsx at $S10^\circ/175^\circ$ (although $12^\circ$ separation). Mt Wilson: both Hsx sunspots seen as one group. Locarno: seen as two groups.
2013 Oct 28	S14°/305°	Bxo	1.9	N	ND	An isolated group – magnetically separate from nearby AR 11882 (Dko) at $S07^\circ/293^\circ$ . Curiously, a small Bxo group (AR 11881 at $S22^\circ/332^\circ$ ) was recorded by NOAA, but not this larger Bxo group.
2013 Nov 16	N11°/049°	Axx	2.0	Y	Y	Appears to be magnetically separate from AR 11899 (Hkx) at $N07^\circ/038^\circ$ . Mt Wilson and Locarno: seen as separate group.
2013 Nov 19	N14°/036°	Axx	6+	Y	ND	Magnetically a separate group, especially near limb. North of AR 11899 (Hkx) at $N07^\circ/038^\circ$ . Assigned AR 11904 on Nov 23 when close to W limb. Mt Wilson: seen on Nov 19, 20, 23 & 24 as separate group (no drawings on Nov 21 & 22). <b>Figure 17.</b>
2013 Nov 19	S09°/012°	Axx	0.7	N	ND	An isolated group.
2013 Dec 8	S15°/108°	Bxo	3.2	Y	Y	An isolated group. Also seen on Dec 10 at $S17^\circ/113^\circ$ .
2013 Dec 22	N17°/327°	Axx	2.8	Y	ND	An isolated group near the CM.





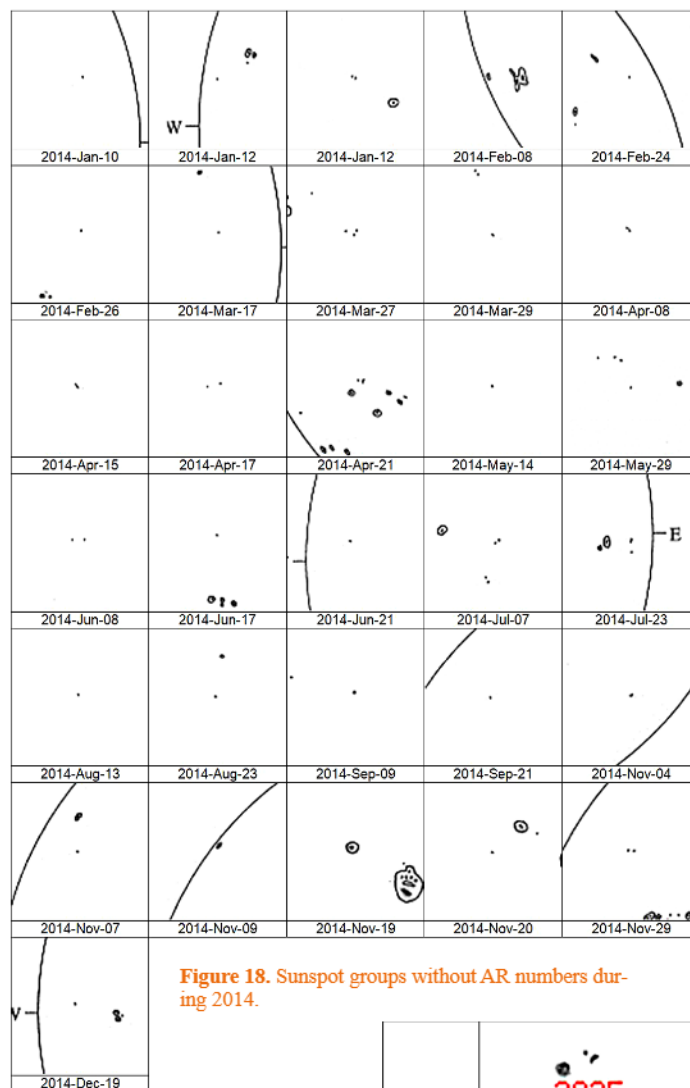
**Figure 17.** White-light drawings with SDO HMI continuum and magnetogram images for 2013 Nov 16/17, 19 & 23.



**Figure 19.** White-light drawings with SDO HMI continuum and magnetogram images for 2014 Feb 5/6 & 8.

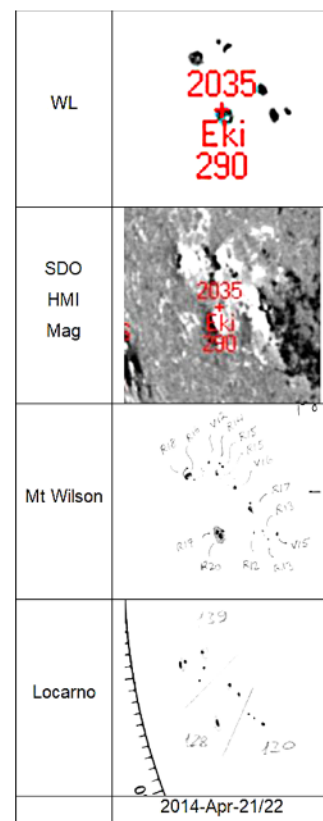
## 2015

Although activity began to reduce during the latter part of 2014, activity was lower during 2015. This was the start of the declining phase of Cycle 24. Unsurprisingly the number of groups observed was lower, at 205, of which 26 did not have an AR number (12.7%) as described in Table 7 and Figure 22.



**Figure 18.** Sunspot groups without AR numbers during 2014.

On 2015 Feb 9 an Hsx group at N07°/182° was observed to the south and east of another Hsx group, AR 12282, at N13°/191°. As shown in Figure 23 (left column), these two groups appeared to be magnetically separate as is also indicated by the Mt Wilson drawing. The SRS report gives just one group, of type Dso. Over subsequent days, the longitude difference between the northern and southern Hsx sunspots reduced such that by Feb 17 the southern sunspot was just to the east of the northern sunspot, as shown in Figure 23 (middle and right). Figure 24 shows the large relative motion in longitude between the two groups. The SRS reports continued to indicate one group, even though the sunspots would form a highly tilted bipolar group.<sup>15</sup>



**Figure 20.** White-light drawings and SDO HMI magnetogram image for 2014 Apr 21/22.



Locarno also separated the northern and southern sunspots into two groups.

The first observation of a Dso group at N13°/098° and an Hax sunspot at N09°/109° was on 2015 Sep 24, when both groups were midway between the eastern limb and the central meridian (CM). The SRS report indicates that all the sunspots were in one group, AR 12420, even though the author observed that the main sunspots were more than 10° apart with no visible intermediate sunspots. However, as shown in Figure 25, there were a few small intermediate sunspots visible in the SDO HMI continuum image. Figure 25 also clearly shows that magnetically all the sunspots were from the same group. The Locarno drawing reveals two separate groups, again illustrating differences in the number of groups recorded based purely on visual or magnetic information.

## 2016

As shown in Figure 3, the decline of Cycle 24 continued in 2016, with 125 groups identified out of which 10 had no AR number (8.0%). Table 8 and Figure 26 show that these were all isolated and short-lived sunspots.

## 2017 & 2018

As the cycle declined further towards solar minimum the number of observed groups reduced further, such that in 2017 there were 64 and in 2018 just 26. Out of these, seven had no AR number in 2017 (10.9%) and two in 2018 (7.7%).

One of the more complex groups given in Table 9 (and shown in Figure 27) was seen as type Fac on 2017 Aug 20, with many

**Table 6. Details of sunspot groups without AR numbers during 2014**

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2014 Jan 10	N07°/006°	Axx	2.3	Y	Y	An isolated group near the E limb.
2014 Jan 12	N09°/109°	Axx	–	Y	Y	Magnetically the same group as nearby AR 11946 (Dao) at N12°/97°. Mt Wilson: a combined group. Locarno: also a combined group, but with a sunspot between Axx and Dao groups.
2014 Jan 12	N11°/051°	Axx	2.5	ND	Y	An isolated group – appears to have been magnetically separate from nearby AR 11948 at N06°/44°.
2014 Feb 8	S08°/121°	Hsx	–	Y	Y	Possibly magnetically the same as AR 11967 (Hkx) at S11°/108°. Mt Wilson: a combined group. Locarno: two groups. <b>Figure 19.</b>
2014 Feb 24	N04°/124°	Axx	4.3	Y	Y	An isolated group near the E limb.
2014 Feb 26	S11°/127°	Axx	1.2	N	ND	An isolated group.
2014 Mar 17	S22°/220°	Axx	1.4	Y	Y	An isolated group.
2014 Mar 27	S21°/163°	Bxo	1.3	Y	Y	An isolated group.
2014 Mar 29	S06°/139°	Axx	0.7	Y	Y	An isolated group.
2014 Apr 8	S02°/317°	Axx	2.1	Y	Y	An isolated group.
2014 Apr 15	N16°/219°	Axx	1.8	Y	Y	An isolated group. Could be recorded due to incorrect location of AR 12040.
2014 Apr 17	N25°/235°	Bxo	–	Y	Y	An isolated group – became correctly identified as AR 12039 on Apr 18.
2014 Apr 21	S09°/226°	Cso	–	Y	Y	Within the same magnetic region as AR 12035 (Dso) at S15°/222°. Mt Wilson: one combined group. Locarno: three separate groups. <b>Figure 20.</b>
2014 May 14	S01°/213°	Axx	1.6	Y	N	An isolated group.
2014 May 29	S17°/063°	Axx	–	Y	N	Magnetically, probably the same as AR 12070 (Cso) at S19°/50°. Mt Wilson: two groups.
2014 Jun 8	S16°/234°	Bxo	0.8	N	Y	An isolated group.
2014 Jun 17	S05°/151°	Axx	0.5	N	N	An isolated group.
2014 Jun 21	N10°/148°	Axx	0.8	Y	Y	An isolated group near the W limb.
2014 Jul 7	N08°/250°	Bxo	–	Y	ND	Likely to be the same group magnetically as AR 12106 (Hax), but 12° between Hax and Bxo sunspot. Mt Wilson: two separate groups.
2014 Jul 23	N06°/310°	Axx	–	Y	Y	Same group magnetically as nearby AR 12121 (Dso) at N07°/322°. Mt Wilson: one group. Locarno: two groups.
2014 Aug 13	N08°/106°	Axx	0.8	Y	ND	An isolated group near the middle of the disc.
2014 Aug 23	S16°/332°	Axx	0.6	Y	ND	Unclear magnetically, but probably separate from AR 12147 (Hsx) at S09°/333°. Mt Wilson: two groups.
2014 Sep 9	N12°/134°	Hsx	2.1	Y	Y	An isolated group seen as type Bxo at Locarno.
2014 Sep 21	N16°/008°	Axx	–	Y	Y	An isolated group, but assigned as AR 12174 on Sep 22 by NOAA.
2014 Nov 4	S15°/030°	Axx	–	Y	Y	An isolated group, but assigned as AR 12206 on Nov 5 by NOAA.
2014 Nov 7	N07°/111°	Axx	1.5	Y	Y	Magnetically separate from AR 12203 at N13°/117°. Mt Wilson and Locarno: seen as separate from AR 12203.
2014 Nov 9	N16°/103°	Hsx	1.6	Y	Y	An isolated group very close to the W limb.
2014 Nov 19	S11°/253°	Hsx	–	Y	Y	Although >10° apart, the Hsx sunspot and AR 12209 at S14°/241° (Hkx) were the same group magnetically. Mt Wilson and Locarno: one group. NOAA gives AR 12209 as type Fko (leader much smaller than follower).
2014 Nov 20	S17°/256°	Axx	–	Y	Y	Magnetically the same group as AR 12209. Mt Wilson: one group. Locarno: two groups.
2014 Nov 29	N14°/174°	Bxo	2.3	Y	Y	An isolated group.
2014 Dec 19	S07°/279°	Axx	3.6	Y	Y	An isolated group near the W limb. <b>Figure 21.</b>

sunspots visible throughout the length of the group (20°) when it straddled the CM.

Over the next few days the number of intermediate sunspots reduced, such that on Aug 24 there was a gap of 12° between the

former leader and follower sunspots. Thus, the two parts of the Fac group were now counted as separate groups. The Locarno drawings show two separate groups on Aug 20 & 24, as shown in Figure 28.

**Table 7. Details of sunspot groups without AR numbers during 2015**

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2015 Jan 10	N17°/250°	Axx	–	ND	Y	Magnetically linked with nearby sunspots to form AR 12258 (Cro), even though 11° apart. At Locarno classified as a combined group.
2015 Jan 11	S16°/315°	Dao	–	Y	Y	Magnetically it appears that these sunspots and the nearby Hrx at S11°/322° were one group (AR 12255). Also for Mt Wilson (Jan 12) and Locarno.
2015 Jan 11	S14°/262°	Bxo	0.8	ND	Y	An isolated group near the CM.
2015 Jan 11	S09°/240°	Axx	–	Y	Y	Magnetically the same group as nearby AR 12259 (Eao) at S15°/242°. Also for Mt Wilson (Jan 12) and Locarno. Again seen on Jan 12.
2015 Jan 14	S06°/272°	Axx	1.2	Y	ND	An isolated group seen as Bxo in HMI images and at Mt Wilson.
2015 Jan 19	S13°/183°	Cso	1.2	Y	Y	An isolated penumbral group.
2015 Feb 6	S02°/303°	Bxo	1.5	N	ND	An isolated group.
2015 Feb 6	S15°/293°	Axx	0.8	ND	ND	An isolated group.
2015 Feb 9	N07°/182°	Hsx	13.0	Y	ND	Assigned in SRS report with nearby Hsx group at N13°/191° as one group, AR 12282, but magnetically separate. Mt Wilson likewise assigns as two groups. Also up to Feb 18. <b>Figure 23.</b>
2015 Feb 15	S19°/162°	Hsx	1.2	Y	ND	An isolated group.
2015 Mar 2	S06°/309°	Axx	4.5	Y	Y	An isolated group, but not seen in HMI images continuously between Mar 2 & 6.
2015 Mar 8	S22°/330°	Axx	1.2	ND	Y	An isolated group approaching the W limb.
2015 Apr 22	S27°/009°	Hsx	1.5	ND	Y	An isolated group just past the CM.
2015 Apr 27	S21°/352°	Axx	2.0	N	ND	An isolated group.
2015 May 3	S11°/223°	Bxo	2.3	ND	ND	An isolated group.
2015 May 13	N14°/044°	Bxo	3.2	Y	Y	An isolated group near the E limb.
2015 Jun 10	N10°/125°	Bxo	–	Y	Y	Magnetically the same group as nearby AR 12360 at N16°/128°. Identified as one group at Mt Wilson and Locarno.
2015 Jul 1	N16°/155°	Axx	–	ND	Y	Magnetically the same group as nearby AR 12373 at N16°/142°, although more than 10° apart. Seen as two groups at Locarno.
2015 Jul 5	N19°/125°	Bxo	–	ND	Y	Probably the same group magnetically as AR 12376 (Cao) to the south at N10°/125°. Noted at Locarno as a pore on Jul 5 and as a separate group on Jul 6.
2015 Jul 8	S15°/135°	Axx	0.8	ND	N	An isolated group approaching the SW limb.
2015 Jul 30	N14°/103°	Axx	–	Y	Y	Probably same group as AR 12393 (Dao) to the north, at N18°/098°. Mt Wilson: this Axx sunspot was seen before subsequent development of northern sunspots. Locarno: seen as separate group from AR 12393.
2015 Aug 6	N23°/020°	Axx	0.7	ND	Y	An isolated group.
2015 Sep 24	N13°/098°	Dso	–	Y	Y	Same group magnetically as nearby AR 12420 (Hax), at N09°/109°. Small sunspots in HMI images between Dso and Hax sunspots. Seen up to Oct 1. Mt Wilson: one combined group. Locarno: two separate groups. <b>Figure 25.</b>
2015 Oct 8	S11°/317°	Axx	2.8	ND	Y	An isolated group.
2015 Nov 13	S07°/211°	Axx	–	Y	Y	Magnetically the same group as AR 12449 (Axx) at S12°/205°.
2015 Dec 7	N07°/243°	Axx	0.5	N	N	An isolated group.

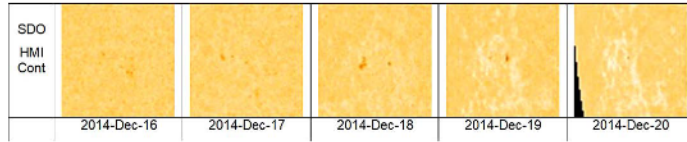
**Table 8. Details of sunspot groups without AR numbers during 2016**

Observation date	Lat./long.	Group type	HMI duration (days)	Mt Wilson	Locarno	Comments
2016 Jan 10	S07°/181°	Axx	1.4	ND	ND	An isolated group.
2016 Feb 7	N05°/131°	Axx	1.4	ND	ND	An isolated group.
2016 Apr 30	N17°/133°	Axx	1.4	ND	Y	An isolated group.
2016 Jul 3	N01°/009°	Axx	0.4	N	Y	An isolated group and only group on the disc.
2016 Jul 16	N13°/201°	Axx	0.9	N	Y	An isolated group.
2016 Oct 15	S15°/102°	Axx	0.4	N	ND	An isolated group.
2016 Oct 17	N06°/023°	Hrx	0.4	ND	ND	An isolated group.
2016 Nov 11	N10°/052°	Axx	0.7	Y	N	An isolated group.
2016 Nov 26	N10°/295°	Axx	0.8	N	ND	An isolated group near the W limb.
2016 Dec 27	N13°/185°	Axx	0.9	N	N	An isolated group near the CM.

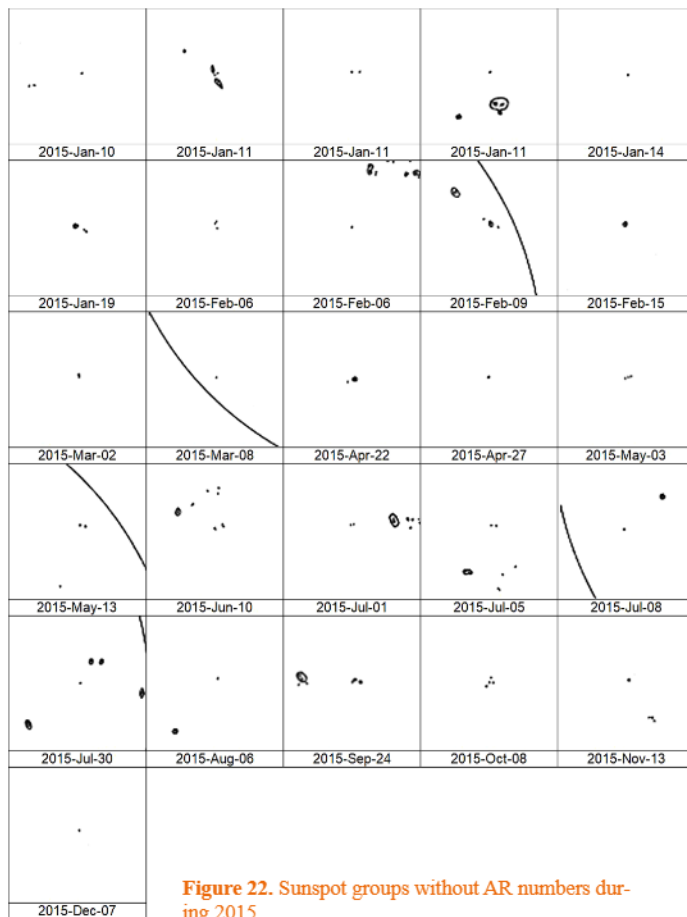


## Analysis

As given in Table 10, the majority of the groups without AR numbers are short-lived isolated groups, mostly of types Axx and Bxo. The duration of these isolated groups is plotted in Figure 29, where it can be seen that although there is a peak in the



**Figure 21.** SDO HMI continuum images for 2014 Dec 16 to 20.

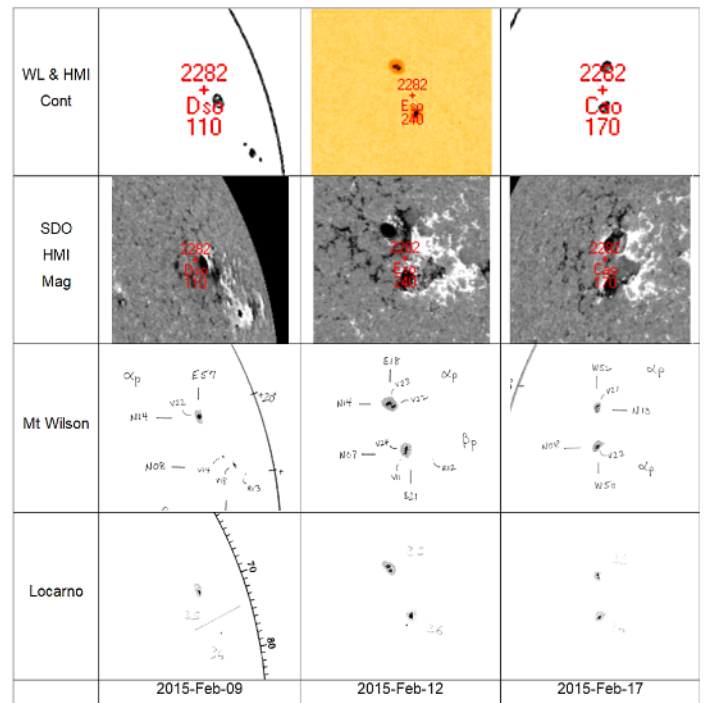


**Figure 22.** Sunspot groups without AR numbers during 2015.

distribution at 0.8 days (based on SDO HMI continuum images), there are many examples of up to three days and beyond. It is particularly surprising that the longer-duration sunspot groups have not been observed for inclusion in the NOAA SRS reports.

Table 10 also shows that where two groups are visually identified as being separate (one with an AR number and the other without), they are actually just one group based on the magnetic field structure (usually bipolar). These are roughly equally divided between cases where the sunspots are less than  $10^\circ$  apart (usually in latitude) and more than  $10^\circ$  apart (usually in longitude). Of course, amateur and in many cases professional visual observers are only basing the identification of individual groups on their visual observation, without knowledge of the magnetic field structure. An exception is for Mt Wilson disc drawings, where the magnetic field appears to influence the identification of individual sunspot groups.

Through many of this paper's examples of sunspot group identification (by the author, observers contributing to the SRS



**Figure 23.** White-light drawings with SDO HMI continuum and magnetogram images for 2015 Feb 9, 12 & 17.

### Table 9. Details of sunspot groups without AR numbers during 2017 & 2018

<i>Observation date</i>	<i>Lat./long.</i>	<i>Group type</i>	<i>HMI duration (days)</i>	<i>Mt Wilson</i>	<i>Locarno</i>	<i>Comments</i>
2017 May 20	N06°/107°	Axx	0.4	ND	Y	An isolated group. Assigned AR 12657 in SRS as ‘H $\alpha$ plage without spots’ between May 17 & 23 inclusive.
2017 May 25	N14°/090°	Axx	1.1	N	Y	An isolated group near the W limb.
2017 Jun 5	N19°/305°	Axx	0.8	N	ND	An isolated group near the W limb.
2017 Aug 23	N09°/277°	Axx	1.5	ND	Y	An isolated group near the CM. Seen in HMI images and at Locarno as type Bxo.
2017 Aug 24	N14°/294°	Dso	–	Y	Y	Part of AR 12671, which was of type Fac, but intermediate sunspots decayed so leading and following parts appear to have been separate (>10° apart). <b>Figure 27.</b>
2017 Sep 7	S09°/075°	Bxo	0.6	N	N	An isolated group near the CM.
2017 Sep 9	S08°/046°	Bxo	0.5	ND	ND	An isolated group near the CM.
2018 Apr 18	S14°/002°	Axx	0.8	Y	N	An isolated group near the CM.
2018 Jun 6	N10°/109°	Hrx	1.1	Y	Y	An isolated group.

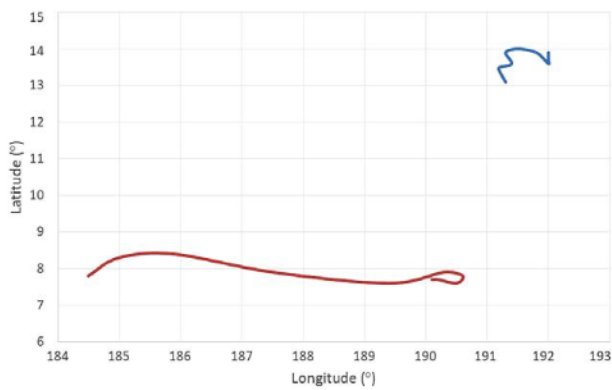


Figure 24. Positions of the two groups in Figure 23 between 2015 Feb 9 & 17.

reports, Mt Wilson Observatory and the Specola Solare Ticinese, Locarno), it can be seen that the recorded number of groups can differ. This appears to indicate that the separation of sunspots into groups can be subjective or that different criteria are being used.<sup>16</sup> This is particularly true around solar maximum when there are more sunspots visible, even for the relatively modest Cycle 24.

Summary

This paper shows that 8% of all groups identified from 6-inch (152mm) disc drawings using an 80mm refractor during the majority of Cycle 24 have not been assigned an NOAA AR number. Most of these (71%) were small, isolated groups and were short-lived, lasting around one day. The remainder are cases where two groups appeared distinct based on

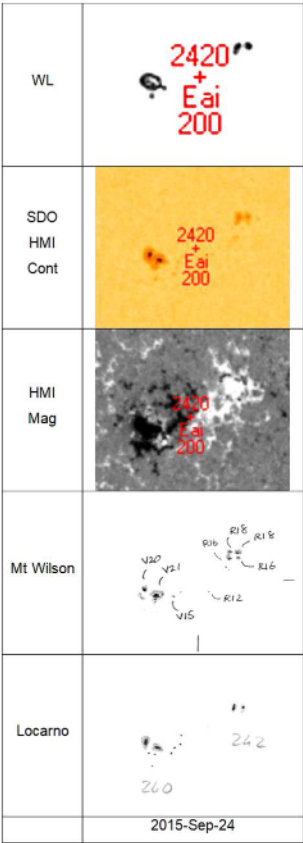


Figure 25. White-light drawings with SDO HMI continuum and magnetogram images for 2015 Sep 24.

Table 10. Types of the groups without AR numbers

Year	Isolated group	Magnetically assoc. with nearby spots (<10° apart)	Magnetically assoc. with nearby spots (≥10° apart)
2009	2	0	0
2010	1	0	2
2011	7	2	3
2012	7	3	1
2013	11	2	2
2014	23	1	7
2015	16	7	3
2016	10	0	0
2017	6	0	1
2018	2	0	0
Total	85 (71%)	15 (13%)	19 (16%)

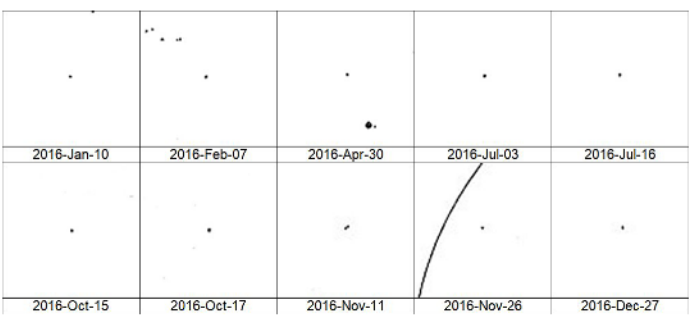


Figure 26. Sunspot groups without AR numbers during 2016.

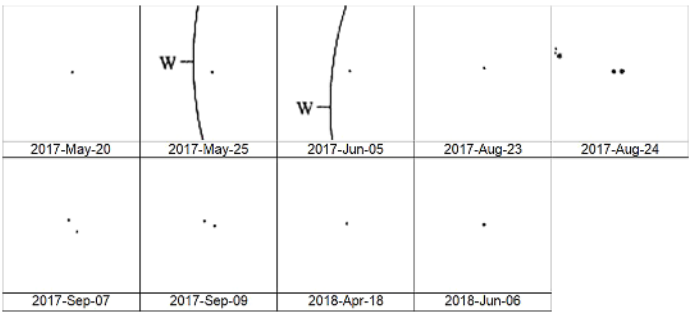


Figure 27. Sunspot groups without AR numbers during 2017 and 2018.

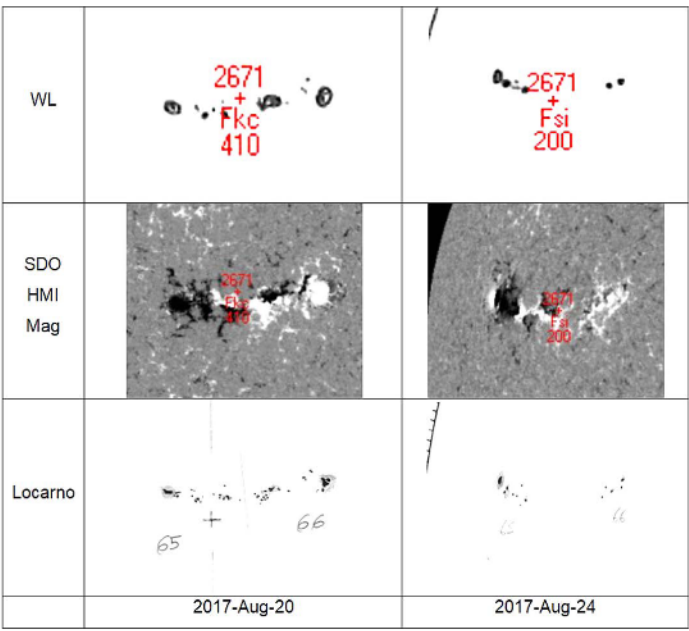


Figure 28. White-light drawings and SDO HMI magnetogram images for 2017 Aug 20 & 24.

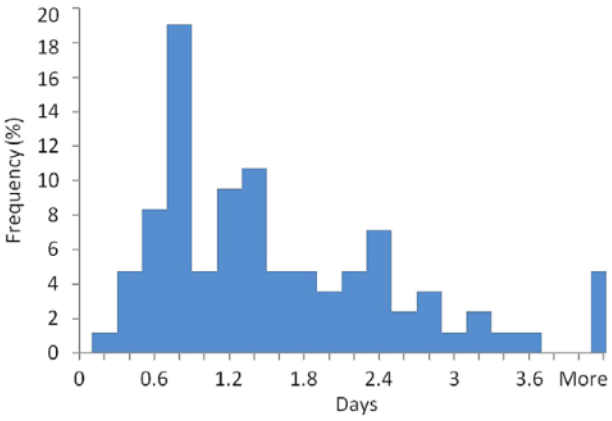


Figure 29. Duration of isolated groups without AR numbers.



their visual separation from nearby sunspots but were magnetically one group. Differences have been found in the number of groups identified by professional observers that contribute to the NOAA SRS reports, at Mt Wilson Observatory and the Specola Solare Ticinese, Locarno. In particular, the identification of sunspot groups at Locarno is based on how groups were identified in the past.<sup>16</sup>

Based on the results presented in this paper, it is felt that no changes should be made to the approach used by the BAA Solar Section for the identification of sunspot groups.

## Acknowledgements

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- 14 For each group, the Mt Wilson drawings include the heliographic latitude and longitude as well as the Mt Wilson magnetic class. There are three classes: unipolar ( $\alpha$ ) groups composed of one or more sunspots, bipolar ( $\beta$ ) groups comprising two sunspots of opposite polarity, and complex ( $\gamma$ ) groups where the polarities of the sunspots are so irregularly distributed that the group cannot be classed as bipolar. There are sub-classes for the unipolar and bipolar groups – see Section 6.2.6 of Bray R. J. & Loughhead R. E., *Sunspots*, Dover Publications Inc., New York, USA, 1976.
- 15 Meadows P., 'AR 12536: An unusual bipolar sunspot group', *J. Brit. Astron. Assoc.*, **127**(1), 23–24 (2017)

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- 16 Marco Cagnotti, Director of the Specola Solare Ticinese in Locarno, has indicated that their group identification is based on how groups were identified in the past. This is to ensure consistency to the present. In particular, they ask the questions: 'What would Wolf have done? How would he have counted? How would he have separated the groups?'. (Pers. comm., 2019 October.) Note that R. Wolf introduced the sunspot number  $R$  in 1848.

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