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The solar observations at Armagh Observatory in 1795–1797

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This article reports on solar observations by J.A. Hamilton and W. Gimingham at Armagh Observatory made in 1795–1797. A number of sunspot positions were obtained from the original observing notes, mostly from micrometer measurements. The period is particularly interesting for the understanding of the onset of the Dalton minimum and a possible minor cycle between the Cycles 4 and 5. For the same period, sunspot positions recorded by Staudacher were measured and published in an earlier paper.

1 Observational setup

The observatory in Armagh was founded and erected in 1790. The initially ordered instruments were countermanded by the heirs of the founding Archbishop, and the observatory started with meteorological observations. Later, from 1795 to 1797, casual observations of sunspots were carried out by James Archibald Hamilton and his assistant William Gimingham at the Armagh Observatory. They are of special interest for the understanding of the solar cycle, since the period may have seen a very weak, short cycle which is nearly invisible in sunspot counts (Usoskin, Mursula & Kovaltsov 2001, 2003). Even though the number of sunspots recorded at Armagh is small, the careful analysis of the data will provide helpful information about the solar activity between the Cycles 4 and 5.

The observers used both a wire micrometer and an object-glass micrometer for their measurements. The latter is also known as a heliometer which applies an objective split into two semi-circular glass elements to produce two images of the observed object which are offset against each other when the semi-circles are not concentric. One of the halves can be adjusted by a screw to let different features on the Sun coincide in the eyepiece, and the calibrated screw-scale tells the angular distance between the features. The purpose was mainly the measurement of the solar diameter and the comparison of the two instruments (Hamilton 1806). Both micrometers were attached to the same achromatic, Keplerian telescope with a focal length of 107 cm. Since the heliometer adds an optical element to the system, it lengthens the focal distance to 122 cm. In 1797, the new equatorial equipped with a telescope with 5 cm aperture and 91 cm focal length was used for the measurements. The equatorial gives declinations and hour angles directly on the setting circles of 1.22 m diameter and does not require the

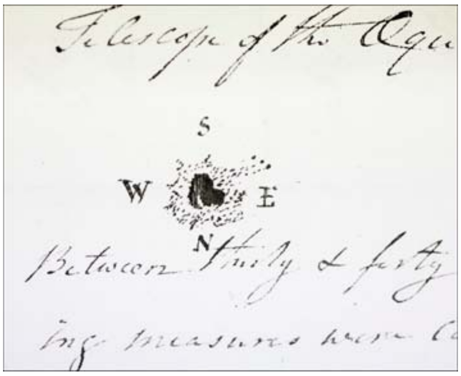

Fig. 1 Sunspot drawing of 1797 December 2 showing compass directions which are compatible with looking through a Keplerian telescope.

passage of the object through the southern meridian. The location of Armagh Observatory is $6°39'$ W, $54°21'$ N, the elevation is 65 m. Times are assumed to be local; noon corresponds to $12^{\rm h}27^{\rm m}$ UTC.

The sunspot measurements were occasionally given as additional objects for the tests. They are probably not complete, and it is likely that the observers used only very prominent spots for their measurements. Nevertheless, solar activity was very low in 1795–1797, and the few spots may already be a good indication for the overall activity. Note, however, that Wolf (1861) cites an observation by F. A. von Ende of 1795 November 5 who reported "an abundance of spots", while the Armagh drawings of November 2 and 3 show only a single, large spot.

We assume that the observations prior to the equatorial were also made with an equatorially mounted telescope, which was properly aligned with the Earth's rotation axis, and that the wire micrometer was aligned properly with the celestial equator. It is further reasonable to assume that all measurements were made by looking through the telescope

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rather than projecting the image onto paper. This is supported by the drawings, especially the one with compass directions shown in Fig. 1. An indication for looking through the eyepiece directly comes from Young (1881) who describes the development of solar telescopes in the 19th century and remarks "The old-fashioned way was to use an ordinary eyepiece, fitted with a dark glass next the eye." A general overview of the history of telescopic observations was compiled for example by King (1955).

The tip angles β between the solar equator and the celestial equator were determined with the "Planetary, Lunar, and Stellar Visibility 3" software by R. Lange (alcyone Software) and N.M. Swerdlow (Univ. Chicago)[1] in its version 3.1.0 of 2006 November 20. A positive β means a rotation of the Sun in mathematically positive direction (counterclockwise). The position angles of the Sun are accurate to $0\overset{\circ}{.}1$ for the period of 3000 BC to AD 6000, according to the description of the software.

The observers often refer to the "upper" limb of the Sun or spots. It is not easy to determine whether they refer to the northern or southern limbs. The observation of 1795 October 8 reports on a spot "first seen on October 7" which may be placed – according to their description – either on the eastern or on the western half of the solar disk (we will always refer to celestial directions and never to the directions in the solar rotational frame of reference). The heliographic grid resulting from the date is plotted over the Sun with the two possible spot locations in Fig. 2. If we assume that the spot was noted when it appeared on the eastern limb, the left spots in the upper and lower panel are the relevant locations. Since the non-rotated image implies a spot at very high latitude, we have to conclude that the "upper limb" is actually the southern limb of the Sun, i.e. we will rotate all images by $180°$.

The following section gives detailed descriptions of how the sunspot positions were determined. The subsection names contain the dates as they were given by Hamilton and Gimingham. Although angles were often given with $0\overset{\prime\prime}{.}01$ precision, we report figures rounded to the nearest arc second here, since the accuracy was technically $1''$ at best.

2 Analysis of the observations

2.1 1795 October 8, 3:30 P.M.

The observation of 1795 October 8 was carried out by Hamilton and Gimingham. It gives the distance of the lower limb of the spot from the "upper" solar limb in its own meridian, i.e. one that does not go through the center of the solar disk), of $5'51''$. And they notes the vertical distance of the declination of the spot's upper limb to the declination of the "upper" solar limb of $6'25''$. The distance from the lower spot limb was $7'41''$. It is reasonable to assume that the distances are measured from the southern solar limb. Because of the two measurements, we have two locations

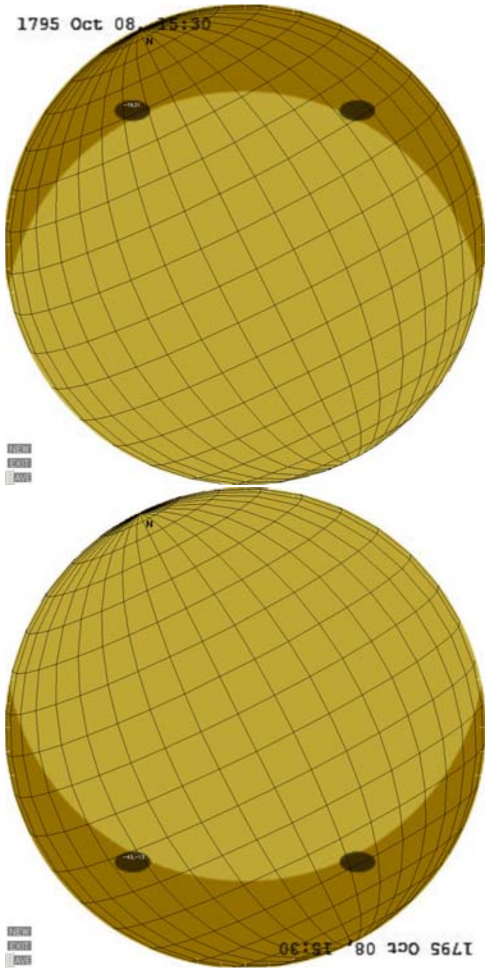

Fig. 2 (online colour at: www.an-journal.org) Reconstruction of the solar disk from the measurements on 1795 October 08. The two black dots in each panel are the two possible locations of the observed sunspot. The top image shows the grid over the construction assuming "upper limb" = "northern limb", and the lower image is the same construction but rotated about $180°$ before adding the grid.

on the solar disk in which the spot may have been located. However, since the appearance of the spot was somehow remarkable to Hamilton and Gimingham, we assume that the spot (which they first saw on 1795 October 7) appeared at the eastern limb and had progressed into the solar disk by October 8. The tip of the solar equator against the celestial one was $\beta = +26\overset{\circ}{.}3$. We adopt the lower panel of Fig. 2 as the correct representation of the observation.

The vertical extent of the "cluster of Macula" was given as $1'14''$ which agrees with the difference between upper an lower spot limbs mentioned above. The horizontal passage time was 9.5 s corresponding to a horizontal extent of $2'22''$.

2.2 1795 October 8, 20 P.M.

The date is interpreted to be 1795 October 9, 8h local time. The observation was carried out by Hamilton and Gimingham. The tip angle is $\beta = +26\overset{\circ}{.}3$. The non-rotated and ro-

[1] http://www.alcyone.de/PVis/english/

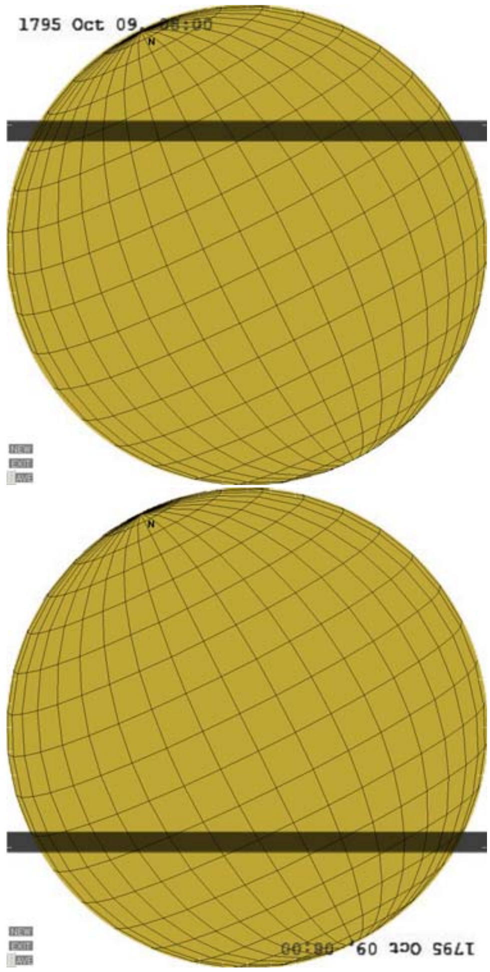

Fig. 3 (online colour at: www.an-journal.org) Reconstructions of the solar disk for 1795 October 9, based on a non-rotated (*top*) and rotated (*bottom*) image.

tated reconstructions are again combined with the grid resulting from the tip β of the solar equator against the celestial one. Only the vertical (declination) distance from the lower spot limb to the upper solar limb of $9'09''$ and the vertical diameter of the spot of $1'20''$ are given. The possible bands where the spot may have been located are shown in Fig. 3. The rotated image (lower panel) obviously matches the idea of a spot moving from east to west fairly well.

If the same latitude as the spot of October 8 is used for the middle of the strip of possible spot locations in the October 9 image, the resulting longitude difference between the two observations is $15\overset{\circ}{.}1$. The expected synodic rotation over these 16.5 h is $9\overset{\circ}{.}2$ from modern observations (Balthasar, Vazquez & Wöhl 1986). The disagreement may stem from the fact that Hamilton and Gimingham measured the full size including penumbrae of what may have been a rather complex spot or even group. It may well be that the centers of these areas we assumed for the positions, are not exactly the same spots.

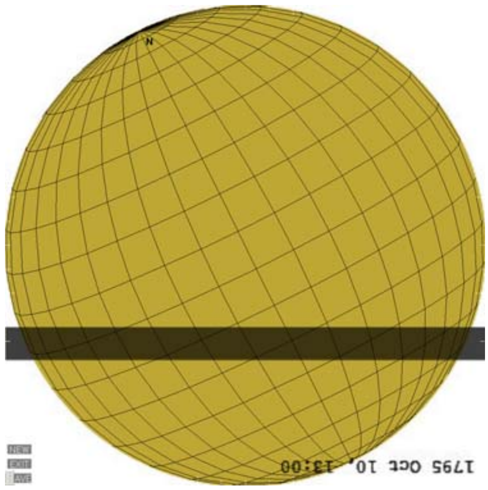

Fig. 4 (online colour at: www.an-journal.org) Reconstruction of the solar disk for 1795 October 10, based on a rotated image.

2.3 1795 October 10, 12:30–13:00 P.M.

The observation was carried out by Gimingham. The only measurements which are given are again the vertical diameter of the spot of $2'8\overset{\prime\prime}{.}26$ and the distance of the southern limb of the spot to the northern limb of the Sun of $10'34''$. The tip of the solar equator against the celestial one was still $\beta = +26\overset{\circ}{.}3$. The reconstruction is given in Fig. 4 and matches nicely the assumption that the spot further moved west. The longitude difference to the October 8 spot is $25\overset{\circ}{.}4$ while the differential rotation profile known from Balthasar et al. (1986) gives $25\overset{\circ}{.}3$.

2.4 1795 October 12, 20:30 A.M. and 22:00 A.M.

The observation was carried out by Gimingham. It is assumed that the time refers to 8:30 h and 10 h local time on October 15. The observational data are passage times between solar and spot limbs. The passage time from the western solar limb and the western limb of the sunspot group was 30 s corresponding to $7'30''$; while the time between the eastern limbs was 85.5 s corresponding to $21'22''$. The horizontal size of the group was $3'38''$, while the vertical extent was $2'54''$. Finally, the distance between the spot's lower limb and the upper (southern) solar limb was $16'02''$. A smaller spot was reported whose lower limb was $16'25''$ from the upper solar limb and whose eastern limb was $14'34''$ from the eastern solar limb. The horizontal size was $1'30''$.

Figure 5 shows the reconstruction of the solar disk from these measurements. The heliographic grid was added again under the assumption that the image is rotated, with north being at the bottom and west to the left, and that the wires of the micrometer were parallel/perpendicular to the celestial equator. The tip of the solar equator against the celestial one was $\beta = +26\overset{\circ}{.}2$.

The large spot (group) is apparently still the same which had been observed since October 7, although the latitude of

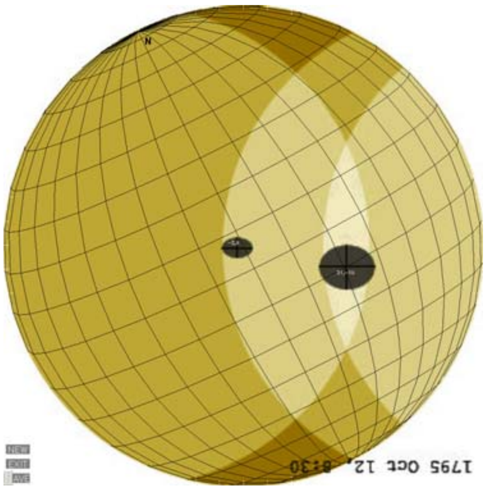

Fig. 5 (online colour at: www.an-journal.org) Reconstruction of the solar disk from the measurements on 1795 October 12; the grid was imposed to the resulting image, which was again rotated about 180°.

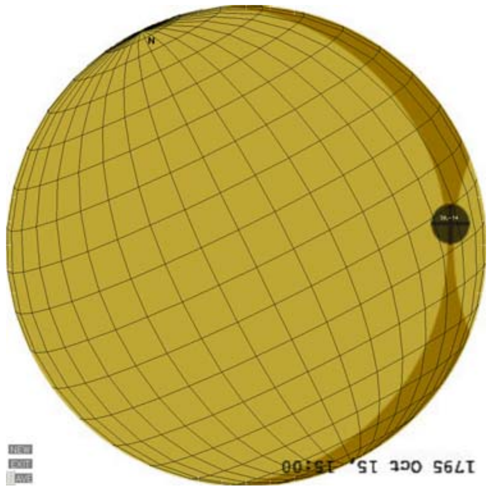

Fig. 6 (online colour at: www.an-journal.org) Reconstruction of the solar disk from the measurements on 1795 October 15; the grid was imposed to the resulting image, rotated about 180°.

$B = -9\overset{\circ}{.}9$ is somewhat closer to the solar equator and the longitude difference to October 8 is 59° although the expected longitude shift would be 50° according to the rotation profile by Balthasar et al. (1986) for the average heliographic latitude of the spot on October 8 and 12.

2.5 1795 October 15, 3:00 P.M.

The following notes do not say anything about the observer. The tip of the solar equator against the celestial one was $\beta = +26\overset{\circ}{.}0$. We find the vertical distance of the lower spot limb from the upper (southern) limb of $18'49''$ as well as crossing times resulting in an eastern-limbs' distance of $29'45''$ and a western-limbs' distance of $2'38''$. Also the size of the sunspot (group) is given as $2'30''$ horizontally and $2'38''$ vertically. It is interesting that the passage times from the eastern and western limbs do not allow for any extension of the spot. The sum of the passage times should be smaller than the passage time of the whole solar disk, since the passage of the spot itself adds another 10 seconds or so. The sum of the distances to the eastern and western limbs is 129.5 s, very close to the passage time of the entire solar disk on that date. As is shown in Fig. 6, we placed the spot in the most probable position, although the distances from the passage times do not allow for any positive spot size. Perhaps the times erroneously referred to the *same* spot limb rather than to the two opposite ones.

The actual result for October 15 is a spot location at almost the same latitude as on October 8 indicating that still the same sunspot group was observed, now near the western limb already. Also the longitude difference to the October 8 spot of $94\overset{\circ}{.}2$ is very close to the expected value of $93\overset{\circ}{.}6$ according to Balthasar et al. (1986).

2.6 1795 November 2, 12:00, and November 3, 11:00

These observations were noted as being on November 2, "some few minutes from the mean noon" and on "November 3, 23 H.P.M." which were translated into November 3, 11:00, especially since Hamilton refers to the spot "noted yesterday", i.e. on November 2. The first image was annotated as being "inverted"; we thus assume again that they represent the rotated view in a Keplerian telescope just as in Fig. 1. The word "inverted" may as well describe a mirrored image, but we have no indication of the Sun being projected onto a screen in the original notes.

The heliographic grid was obtained by a rotational match (cf. Arlt 2009, Sect. 3.2) of the two representations of the same spot. The procedure searches for the optimum position angles of both drawings so that the heliographic latitudes for the spot on the two days are the same and the rotation matches the profile obtained by Balthasar et al. (1986). Figure 7 shows a very plausible result of this fit. A second attempt uses the fact that the horizontal lines are most likely aligned with the celestial equator and the vertical lines point to the celestial pole, since these lines very likely represent the micrometer wires seen in the eyepiece. The tips of solar equator against the celestial one on November 2 and 3 were $\beta = +23\overset{\circ}{.}7$ and $\beta = +23\overset{\circ}{.}5$, respectively. Figure 8 shows the result, which does not make use of the spots themselves and is fully independent of the method used for Fig. 7. Firstly, the agreement with the rotational fit is fairly good, with latitude differences of $6\overset{\circ}{.}1$ and $5\overset{\circ}{.}8$ for November 2 and 3 respectively. Even more amazing is the agreement of the latitudes among the two grids obtained from the alignment with the celestial equator shown in Fig. 8, given that these drawings are mere sketches to illustrate the meaning of the symbols used: the latitude difference is $1\overset{\circ}{.}1$ between November 2 and 3. The results from the second method will be used for the final positions.

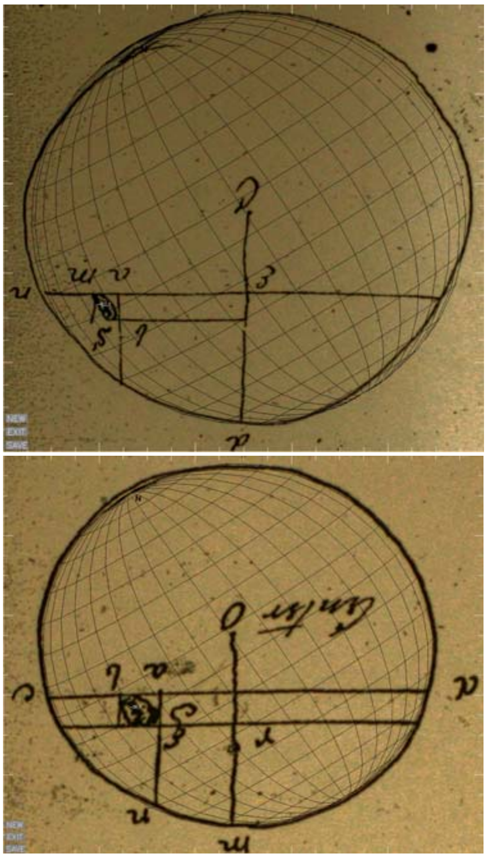

Fig. 7 (online colour at: www.an-journal.org) Drawings of the solar disk for 1795 November 2 (*top*) and November 3 (*bottom*). The grid was reconstructed from a rotational match.

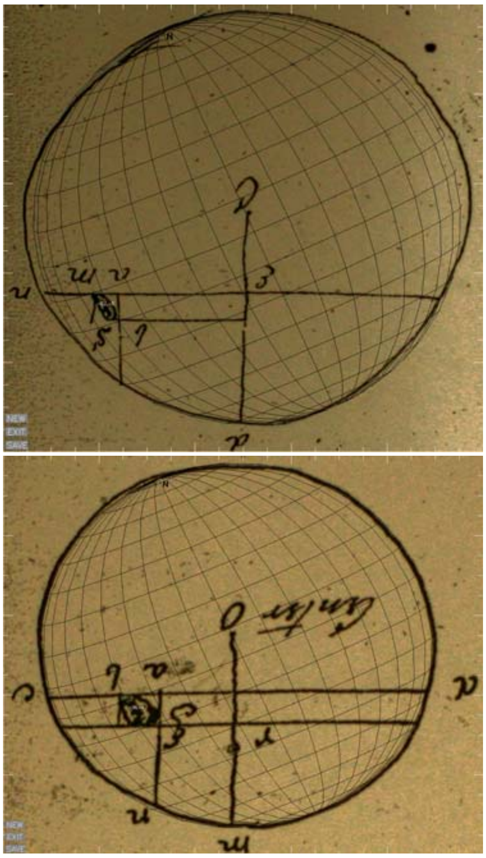

Fig. 8 (online colour at: www.an-journal.org) The same drawings as in Fig. 7 but with a heliographic grid determined from the tip of the solar equator, assuming the horizontal lines are aligned with the celestial equator.

2.7 1797 December 2, 12:30-12:40

The observation was carried out with the new equatorial delivered by Troughton. The instrument shows north-pole distances (or declinations) directly on the setting circle with 1.22 m diameter. The north-pole distances of two spots were reported to be $111^\circ 59' 58''$ and $112^\circ 01' 30''$. The second spot was described to be "very near the western Limb." The positions were combined with the location of the Sun in the sky at the epoch of the observation. The topocentric positions of the Sun for the location of Armagh Observatory were taken from StarCalc 5.72[2] by Alexander Zavalishin. The Sun was at an elevation of only $12\fdg9$ in the sky, and a refraction correction of $4\farcm35$ was added to the north-pole distances to obtain the unrefracted positions (assuming a pressure of 760 mm Hg and a temperature of 0°C; Blanco & McCuskey 1961). The tip of the solar equator against the celestial one was $\beta = +14\fdg2$; the reconstruction is shown in Fig. 9. The larger spot is the one depicted in Fig. 1.

2.8 1797 December 5, 16:20 sidereal time

The time corresponds to about 11:20 local time. The original measurements are the north-pole distance of the spot center of $112^\circ 26' 25''$ and the passage time between the solar western limb and the spot of 6 s, corresponding to a distance of $1' 30''$. The size of the spot "nucleus" was given with about $0\farcm5$ in both directions but is not relevant here.

The tip of the solar equator against the celestial one was $\beta = +12\fdg9$. The elevation of the Sun above the horizon was again $12\fdg9$ resulting in a refraction angle of $4\farcm35$ which was added to the measured north-pole distances. Figure 10 shows the reconstruction of the solar disk and spot. The heliographic latitude of $3\fdg8$ was derived for the spot. We can now go back to December 2 and pick the heliographic longitude for which the band of possible spot positions crosses the latitude of $+3\fdg8$. One can now go back to December 2 and fix the longitude. The resulting heliographic longitudes of December 2 and 5 show a shift of $39\fdg5$ which agrees very well with the $40\fdg0$ following from the rotation profile of Balthasar et al. (1986).

3 Summary

The sunspot positions obtained from the observations by Hamilton and Gimingham at Armagh Observatory are summarized in Table 1. The heliographic longitudes are in the Carrington rotation frame. Note that we have only given the

[2] http://www.relex.ru/~zalex

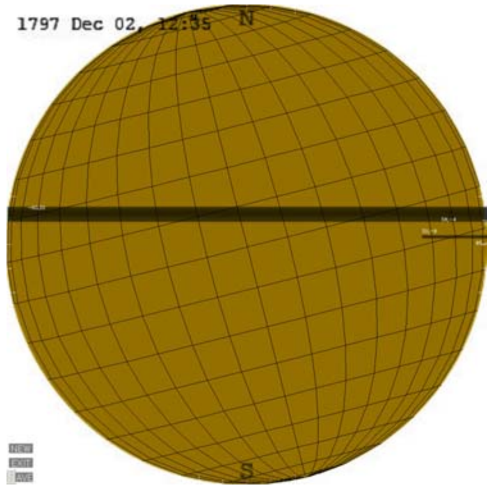

Fig. 9 (online colour at: www.an-journal.org) Reconstruction of the solar disk for 1797 December 2. Since the longitudes of the spots are not known, maximum and minimum heliographic longitudes were determined.

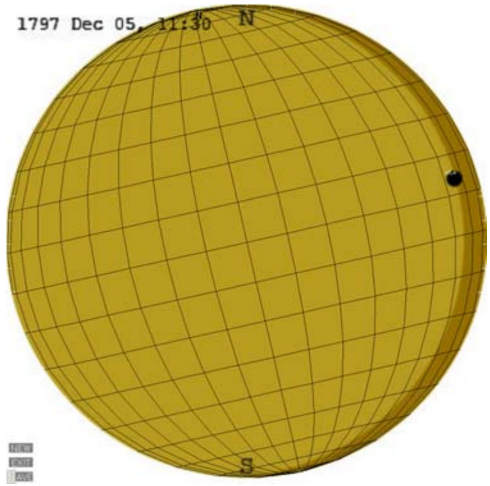

Fig. 10 (online colour at: www.an-journal.org) Reconstruction of the solar disk for 1797 December 5.

most probable position for each date. The first four lines of the Table and the October 15 position are measurements of the same sunspot group, although we have to bear in mind that it was certainly no single individual spot measured over that period of time. The positions of November 2 and 3 refer to the center of a very large spot which may have a structure with a few smaller spots as indicated by Figs. 7 and 8. The observations of December 2 and 5 contain one spot seen on both days and a second spot for which the right ascension could not be determined, whence the uncertainties in heliographic longitude and latitude. In general, the accuracy of the spot positions should be around 2° in heliographic coordinates, given the fuzziness of the sunspot groups and the remaining inconsistencies mentioned above, although the observed values in the log book suggest a high accuracy of sub-arcminutes in the sky ($1''$ in celestial coordinates corresponds to $0\overset{\circ}{.}06$ in heliographic coordinates in the center of the solar disk, increasing towards the limbs).

Table 1 Heliographic longitudes L and latitudes B of sunspots derived from observations at Armagh Observatory in the period of 1795–1797.

Date	L	B
1795 Oct 08, 15:30	$264\overset{\circ}{.}8$	$-12\overset{\circ}{.}8$
1795 Oct 09, 08:00	$272\overset{\circ}{.}6$	$-12\overset{\circ}{.}8$
1795 Oct 10, 12:30	$267\overset{\circ}{.}2$	$-12\overset{\circ}{.}8$
1795 Oct 12, 08:30	$280\overset{\circ}{.}5$	$-9\overset{\circ}{.}9$
	$258\overset{\circ}{.}2$	$+6\overset{\circ}{.}0$
1795 Oct 15, 15:00	$272\overset{\circ}{.}4$	$-13\overset{\circ}{.}8$
1795 Nov 02, 12:00	$288\overset{\circ}{.}9$	$-5\overset{\circ}{.}5$
1795 Nov 03, 11:00	$290\overset{\circ}{.}1$	$-4\overset{\circ}{.}4$
1797 Dec 02, 12:35	$42\overset{\circ}{.}0$	$+3\overset{\circ}{.}8$
	$66^\circ \ldots 101^\circ$	$-12\overset{\circ}{.}2 \ldots -8\overset{\circ}{.}7$
1797 Dec 05, 11:30	$43\overset{\circ}{.}1$	$+3\overset{\circ}{.}8$

It has to be noted that the archives of the Armagh Observatory have not yet been entirely searched for casual reports of sunspot positions, since they may appear among other measurements. There was no dedicated solar observing program at Armagh. Since the knowledge about the 1795–1797 positions is essential for the investigation of the cycles near the Dalton minimum, we started with the data presented here and postpone the full record of sunspot positions measured in Armagh to a future paper. The data provided here will be combined with the sunspot positions derived from drawings by Johann Staudacher (Arlt 2009) to clarify the question whether there was a weak cycle between Cycles 4 and 5. The publication of these results is currently under preparation. The appearance of a few spots with latitudes of $\pm 10^\circ$ may be an indication for a weak cycle superimposed to the very low latitude spots from the old Cycle 4.

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