The sunspot observations by Samuel Heinrich Schwabe

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A long time-series of sunspot observations is preserved from Samuel Heinrich Schwabe who made notes and drawings of sunspots from 1825–1867. Schwabe's observing records are preserved in the manuscript archives of the Royal Astronomical Society, London. The drawings have now been digitized for future measurements of sunspot positions and sizes. The present work gives an inventory and evaluation of the images obtained from the log books of Schwabe. The total number of full-disk drawings of the sun with spots is 8486, the number of additional verbal reports on sunspots is 3699. There are also 31 reports about possible aurorae.

1 Introduction

Understanding the origin of the solar dynamo requires an extensive time series, since the cycle is not fully periodic, and only a large number of cycles can reveal the statistical properties produced by the dynamo mechanism. Solar activity is well covered by sunspot observations since 1874 when the Greenwich data start. Smaller sets are available from Gustav Spörer (Spörer 1874, 1878, 1880, 1886, 1894) and Richard Carrington (1863). A large series of several thousand observations was recorded by Samuel Heinrich Schwabe in the period of 1825–1867. Together with the observations by Spörer, a complete series of sunspot positions from 1825 to today can be constructed. Note however, that Spörer published only a few positions for sunspot groups instead of all individual spots. Tilt-angles of sunspot groups cannot be retrieved from his tables. He did publish drawings of the groups at some evolved stage, whence sunspot areas can potentially be determined. Schwabe provided full-disk drawings, however. It will thus be extremely interesting to measure the positions of the individual sunspots plotted in these drawings and determine the sunspot sizes as well.

Schwabe was born in Dessau on 1789 Oct 25 and started with his astronomical observations rather late in 1825, at an age of almost 36. While supposed to take over the pharmacy from his grandfather, he went to Berlin for the corresponding studies, and even joined university to listen to courses on experimental chemistry, botanics, and experimental physics. Schwabe did no finish the studies because he had to go back to Dessau in December 1811 and, being the eldest son, to take care of his family (Arendt 1925). He died in Dessau on 1875 Apr 11. Schwabe obtained the Gold Medal of the Royal Astronomical Society of 1857. Richard Carrington very likely handed the Medal over to Schwabe already when he visited him on 1856 Oct 15, according to Schwabe's notes, in which the latter did not mention the Medal though. According to a letter from Schwabe to Haase written in 1862, it was C.L. Harding (co-editor of "Kleine Ephemeriden") who initially motivated Schwabe to carry out sunspot observations with the aim to find a possible planet inside the orbit of Mercury (Arendt 1925).

Extended activities in botanics go back to Schwabe's childhood, and he published a seminal systematics of the flora in his region in the "Flora Anhaltina" in 1838.

2 The log books

The observing books of Schwabe are stored in the library of the Royal Astronomical Society in London and are in very good condition. In 1864, representatives of the RAS inquired to obtain the astronomical observations from Schwabe. He agreed under the condition that he can get them back whenever he wishes to carry out further analyses (being at an age of 75). He added: "After my death you may consider the whole of the Observations as the property of the Royal Astronomical Society" (Huggins 1876).

All observations were recorded in note books with a binding. There is no possibility of disordered lose sheets of papers. The total number of books is 39 with a few books containing the information of two years (Bennett 1978). The full period of time covered by solar observations spans from 1825 Oct 1 to 1867 Dec 31. The first drawing of the solar disk was made on 1825 Nov 05. In the beginning, until January 1826, several observations were combined in a full-disk drawing while it is always clearly mentioned which spots refer to which date. The last drawing was made on 1876 Dec 29, while the last verbal report is from 1867 Dec 31. The records stop without any mention of the reasons, but since several of the observations in the last years

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Fig. 1 The living house of Samuel Heinrich Schwabe and his family in Dessau, photographed on May 29, 2011. Most of the observations were made from the turret on top of the building.

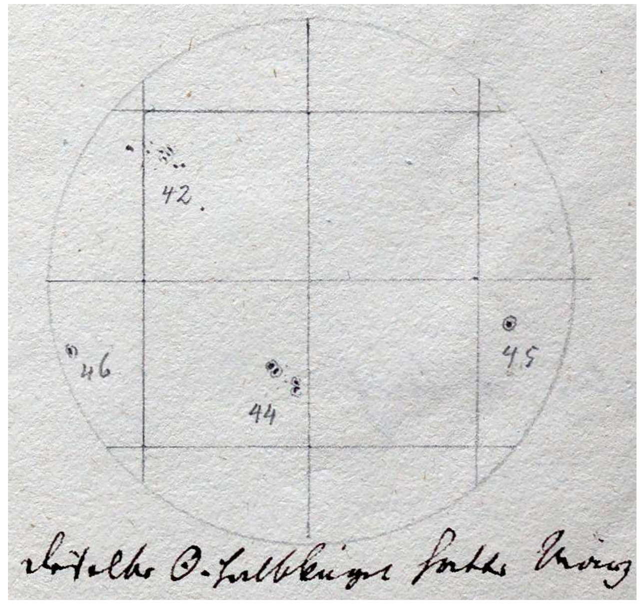

Fig. 2 Drawing of the sun of 1847 Apr 14.

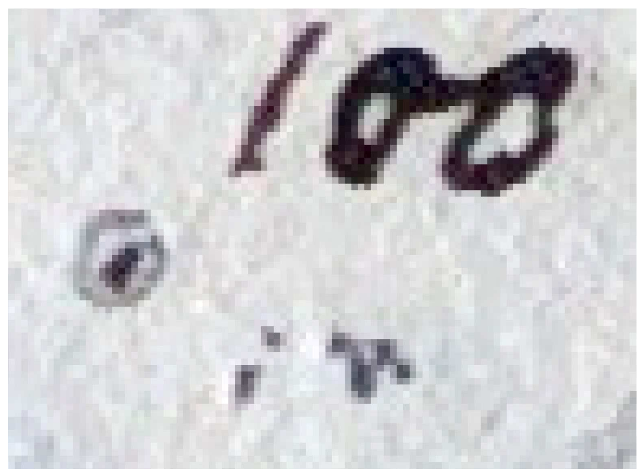

Fig. 3 Enlargement of a part of a full-disk drawing showing the pixel accuracy of the digitized images.

were actually recorded by people assisting Schwabe, we may assume that his health did not allow any further observations.

The geographical coordinates of the observing location in Johannisstraße 18, Dessau (address still valid), are $\lambda = 12°14'32''$ E, $\phi = 51°50'19''$ N (WGS84) from where he started observing on 1830 May 17. A contemporary photo of the restored building is shown in Fig. 1. The observing tower on top of it may not be in the original style, and Schwabe actually changed the windows a few times to accommodate his telescopes and a transit instrument, as indicated by some of his notes, e.g. "In the evening, I had a hole broken into the wall and corrected the orientation of the cross hairs" (1840 Jun 20).

All full-disk drawings were made by pencil. On some pages, especially where the drawings are near the lower edge of the pages, the clarity of the pencil marks are somewhat washed out, but nowhere to the extent that information about sunspots would be lost. Schwabe assigned numbers to the sunspot groups which were added after the observation in ink or by pencil. An typical example of such a drawing is shown in Fig. 2 from the observation of 1847 Apr 14.

The logbooks were digitized photographically. Full pages were photographed with a Canon EOS 5D with a resolution of 2912×4378 pixels. The lens was a Sigma 50mm/2.8 EX DG Macro which provides an extremely low image distortion. The image scale is about 0.07–0.08 mm/pixel, depending on the sizes of the books. The images were taken with apertures of f/8–f/9 with ambient light from a near window, since the inclined infall of light preserves the paper structure and pencil engravings very well. This illumination will later help to distinguish the actual sunspots from paper defects and ink spots. All images were taken in the proprietary raw, 12-bit image format by Canon and processed automatically in RawTherapee 2.3 of February 2008[1]. Figure 3 shows an enlargement of an example image of 1838 May 02 without interpolation to show the pixel scale of the digitization. Even small spots are represented by several pixels to have enough accuracy for the positional measurements.

The images of the full pages were then cut into images for individual days as it was done for the drawings by Staudacher in Arlt (2008). Usually, a strip containing the drawing on one side and the description on the other side is cropped from the full-page image. Sometimes the descriptions are so lengthy that only an abridged version is visible in the final image. File names were constructed with the date and time in the format `YYYY_MM_DD_HHMM.JPG`. If there is no time in Schwabe's description which can be associated with the drawing, we set `HHMM` to `0000`.

[1] http://www.rawtherapee.com/

3 Types of information

The majority of sunspot observations consists of a circle with the distribution of sunspots. The circles have a diameter of about 4.5 cm. There is a considerable amount of detailed drawings of selected sunspot groups, but they are concentrated in the beginning of the entire observing period. Apart from observations with drawings, we find a lot of dates for which just the changes to the previous day was described verbally. These observations can be interesting for investigations of the life-time of sunspots, since Schwabe noted which sunspots had disappeared and if a new sunspot had appeared, mostly during the afternoon hours.

The last group of observations are about days on which no sunspots were seen. These were in fact the observations which led to the discovery of the solar cycle. Schwabe simply counted the days without sunspots per year and showed the variability of the (inverse) solar activity according to the 18 years of 1826–1843 (Schwabe 1844). He actually wrote the letter to Astronomische Nachrichten on Dec 31, 1843, immediately when he completed his set of data capable of proposing the cycle.

A total inventory of Schwabe's sunspot observations is given in Table 1. The numbers of drawings and the numbers of verbal reports without drawings are shown. We also list the numbers of drawings which show no "coordinate system" and the numbers of drawings which cannot be associated with a specific time of day (see Sect. 5). The inventory is also shown graphically by monthly totals in Fig. 4. One can see that there is actually a large number of months in which Schwabe managed to report on sunspots on *every* day. The annual variation comes from the fact that the winter months have fewer sunny days.

Schwabe very often reported on faculae for which he used the German word construction "Lichtgewölk" corresponding to "light clouds". Since he had to indicate these bright structures with a grey pencil, it is often not easy to distinguish faculae from sunspots in the drawings. The verbal information as well as the absence of group numbers (for faculae without spots) are helpful here.

The limb darkening was also noted on several occasions, specifically in 1841, 1846, 1847, and 1851, while in 1867 Schwabe noted that the limb was not darker than the rest of the disk. He also reported about the appearance of the granulation a few times and describes it as "the marbled surface of the Sun" (1841 Apr 05).

Many other astronomical observations accompany the sunspot drawings and descriptions, most notably of the Moon, Jupiter, and Saturn. Schwabe commented on meteors a few times, described a few fireballs, and gave descriptions of solar and lunar halos, rainbows and 31 occasions of aurorae. The latter are rather frequent given the relatively low latitude of his observing place. The descriptions resemble aurorae quite well, however, and they seem to cluster near or shortly after solar maxima. A list of Schwabe's aurorae sightings is given at the end of this paper in Table 4.

Table 1 Annual numbers of sunspot observations by Heinrich Schwabe. The total number of observations is 12185.

Year	Drawings	Drawings w/o time	Drawings w/o grid	Verbal reports
1825	24	0	1	14
1826	165	3	106	121
1827	274	38	274	25
1828	269	61	265	20
1829	233	45	233	26
1830	191	18	150	26
1831	225	64	27	34
1832	167	7	5	99
1833	74	1	14	169
1834	84	2	15	189
1835	131	4	22	108
1836	163	4	4	24
1837	153	41	0	3
1838	204	26	0	0
1839	199	30	3	4
1840	248	13	5	15
1841	241	14	0	40
1842	216	5	5	89
1843	131	4	3	177
1844	158	3	1	161
1845	222	3	12	109
1846	223	7	5	96
1847	227	22	5	49
1848	243	5	1	35
1849	227	4	1	58
1850	229	4	2	77
1851	231	4	0	79
1852	280	5	1	56
1853	231	3	1	69
1854	213	2	1	120
1855	97	0	0	216
1856	75	0	0	245
1857	203	3	0	120
1858	245	0	1	88
1859	263	1	0	79
1860	255	1	3	77
1861	243	0	1	76
1862	242	0	1	75
1863	244	0	0	87
1864	244	0	0	79
1865	221	0	0	86
1866	189	5	0	161
1867	88	0	0	224
Totals	8486		1168	3699

Schwabe observed several comets and asteroids after their discoveries, and he found Neptune on 1846 Sep 26, three days after its discovery. Le Verrier predicted another planet inside the orbit of Mercury on 1860 Jan 2 for which Schwabe also looked during his solar observations. There are many notes that nothing was seen except on 1862 Aug 06, he writes: "Is [group] 101 perhaps a planet between Mercury and the Sun, but at 12h there was no notable motion." He also mentioned the visibility of the zodiacal light several times in 1843–1855. Schwabe reported about the ca-

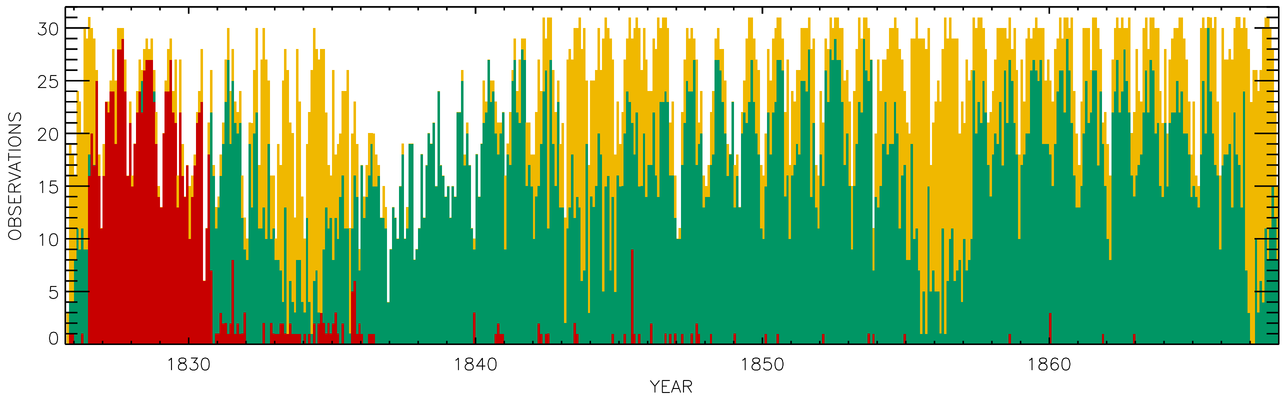

Fig. 4 Distribution of observations per month over time. The yellow (light) bars show the total number of observations per month, including verbal reports. The green (darker) bars depict the number of drawings with sunspots, while the red (darkest) bars show the number drawings which have no coordinate system.

pability of resolving a number of binary stars during the course of the years. These observations allow us to judge about the quality of his telescopes.

Schwabe also noted the temperatures for the morning, afternoon, and evening of each day since 1827 Jan 21. Barometric measurements were started on 1832 Jan 01. Information about the wind direction for the same three instances as for the temperature and the pressure starts on 1852 Oct 01.

4 Schwabe's instruments

The drawings are most likely aligned with the equatorial system, with north pointing downward and east pointing to the right. This is the view through a Keplerian telescope. For example, the description of 1840 Apr 18 says that new spots 'entered' the disk and these were drawn on the right side of the circle drawn. There are numerous of such verbal information all being consistent with east being on the left side of the image.

The images could still be mirrored as the result of a projection method, but the same description of 1840 Apr 18 also refers to another spot 'south' of the previous one, which is actually plotted above the previous one. On 1838 Apr 12, Schwabe mentions "spots only in the north" while the drawing shows spots only in the lower half. The image must thus be a rotated version of the solar disk as seen in a Keplerian telescope, and not a mirrored one.

Already in the very first observation of 1825 Oct 1, Schwabe noted that "the absorption glass appears to be too dark." Several other verbal comments deal with dimming glasses for observations through the telescope, as the following translated phrases illustrate:

– 1826 02 01: "During the observation the sun glass broke"
– 1826 02 02: "through a lava sun glass by Winkler"
– 1826 03 23: "with the brightest sun glass by F[raunhofer]"
– 1826 05 02: "with the sun glasses by Fraunhofer"
– 1826 11 29: "I could only use the sun glass by Utzfohl" – manufacturer not verified
– 1827 07 24: "with all my sun glasses"
– 1854 07 16: "with the old, usual sun glass"
– 1854 10 28: "the violet glass from Leipzig", "the pale-blue glass from Munich"

We therefore assume that he was looking through Keplerian telescopes with filters for the entire observing period.

Schwabe used several telescopes during his 43 years of astronomical observations. The first telescope mentioned is a "2-1/2-foot Ramsden" with an eyepiece magnifying 70 times (1825 Oct 01) and unknown aperture. The sizes refer to the focal lengths of the telescopes. In parallel, he used a "1-1/2-foot telescope by Harris" of which aperture and magnification are unknown (1825 Oct 07). The company Thomas Harris & Son, London, produced telescopes with diameters typically between 4 and 6 cm between 1806 and 1846. Schwabe obtained his third telescope on Nov 22, 1825, when he wrote "I observed with my 2-1/2-foot telescope by Winkler which I received from Leipzig today." This telescope was also mentioned by Arendt (1925).

Schwabe eventually received a 3-1/2-foot telescope from Fraunhofer on 1826 Jan 22, and the first drawing made with this is probably from 1826 Jan 29. This telescope was used for the vast majority of full-disk drawings made from 1826–1867. A second Keplerian telescope with 6 feet focal length and 12.2 cm aperture from Wilhelm Gotthelf Lohrmann in Dresden, Germany, was received on 1829 Feb 13 and used for solar observations since 1829 Feb 26. The lenses of the telescope were also manufactured by Fraunhofer while the construction and parallactic mount was made by Rudolf Sigismund Blochmann (Arendt 1925; Weichold 1985). These and additional telescopes, which have little relevance for the sunspot observations, are listed in Table 2.

Table 2 The telescopes of Samuel Heinrich Schwabe sorted by the order in which they appear in the logbooks.

Focal length	Manufacturer or Schwabe's designation if unknown	First mention	Remarks
2 1/2 foot	Ramsden	1825 10 01	
1 1/2 foot	Thomas Harris & Son	1825 10 07	
2 1/2 foot	Winkler	1825 11 22	more precisely 29 inch
3 1/2 foot	Fraunhofer	1826 01 22	
Sternsucher		1826 10 23	
18 inch	Cometensucher	1827 07 05	
7 inch	Taschenperspectiv	1827 07 05	possibly identical to "Sternsucher"
5 inch	Cometensucher	1828 09 04	
16 inch	Cometensucher	1828 09 04	
17 inch		1828 10 15	16, 17, 18 inch possibly identical
6 foot	Fraunhofer	1829 02 13	obtained from Lohrmann, Dresden
20 inch	Bobbe	1840 06 20	also called "Mittagsfernrohr"
2 1/2 inch		1853 08 16	most likely identical with Winkler's

A final proof for the interpretation of the orientation as being the view through a Keplerian telescope comes from the drawings of the solar eclipses. Figure 5 shows the eclipse of 1845 May 06 with the Moon moving from left to right. The path of the Moon was actually north of the solar disk center. The eclipse of 1847 Oct 09 is shown in Fig. 6 with a direct comparison with an ephemeris software.

It may perhaps be useful to use the observations of binary stars to evaluate the quality of the telescopes. The following examples demonstrate the capabilities of the two main telescopes; first the 3-1/2-foot Fraunhofer:

– The observation of σ Ori shows stars in a field of about $5'$ of which the two stars TYC 4771-1205-1 and TYC 4771-1204-1 are clearly separated. Their today's separation is $8.5''$.
– Schwabe separated the two components of γ Vir with his 3-1/2-foot telescope and a magnification of 168 times on 1827 Apr 29 which at the time had a distance of $2.1''$ and was actually measured by a few observers (Mädler 1838).

The 6-foot Fraunhofer telescope was of similar quality, and it was actually used to draw a lunar atlas of highest resolution by Lohrmann before. We just give two examples here:

– On 1829 Sep 04, Schwabe writes "Uranus disk-like with 6-foot, 144 times magnification." Uranus had a diameter of $3.7''$ at the time.
– Schwabe separated the binary Castor with the 6-foot Fraunhofer on 1836 Jan 19 (magnification probably 216 times) and 1863 May 08 (magnification 144 times); the distance was about $5.4''$ then.

It is strange though that Schwabe claims to have found a companion of Vega which does not exist. He writes on 1840 Aug 29 "Vega in Lyra fluttering strongly but the faint companion was visible" and on 1841 Nov 16 "I see the faint companion very clearly". However, there is no star brighter than magnitude 12 in the $5'$ vicinity of Vega.

The diffraction limits of the telescopes must have been between $1''$ and $1.5''$ while the seeing in such a low-elevation city place is at least as large. Visually, the seeing is not that harmful since very short clear moments can deliver information on scales smaller than the seeing indicates. Small sunspots have angular (celestial) diameters of about $2''$ and are resolvable by Schwabe's telescopes. Since he occasionally describes the granulation, we can assume that the optical quality of his telescopes was very high and resolving $2''$ structures was often possible.

Schwabe also made a large number of measurements on sunspots. In 1836, he started reporting on transit times and thus size measurements of the sun and sunspots with the threads in the 3-1/2-foot Fraunhofer and continued occasionally until November 1840. He obtained a transit telescope made by Bobbe on 1840 Jun 20, but it was not until 1840 Nov 05 when he actually measured the transit times of a sunspot with this instrument. On 1840 Dec 21, he reports about a "Schraubenmicrometer" (screw micrometer) which must be a device different from the micrometer with the transit telescope, since Schwabe reported on both in parallel on 1840 Dec 28. He gave calibrations of screw turns of the screw micrometer on the first pages of his observing books of 1840, 1842, 1843, 1844, 1845, 1846, 1847, and 1849. There are many measurements of transit times of sunspots until 1842 which may be used to estimate the quality of the actual drawings. The measurements ceased as the solar activity minimum in 1843 approached.

5 The times of day

5.1 Time offset to UTC

Which time reference was used? There was no common reference time in Germany yet. Prussia started to use the Berlin time as a reference in the middle of the 19th century, after telegraphic lines had been installed. It is not clear whether the duchy of Anhalt-Dessau used the same system. On 1830 Dec 23, the observation was marked with "12h mittl. Z." and later on, the abbreviation "m.Z." appears until 1831 Feb 07, which translates into mean time. The abbreviation was omitted later, but we may assume that Schwabe used the mean

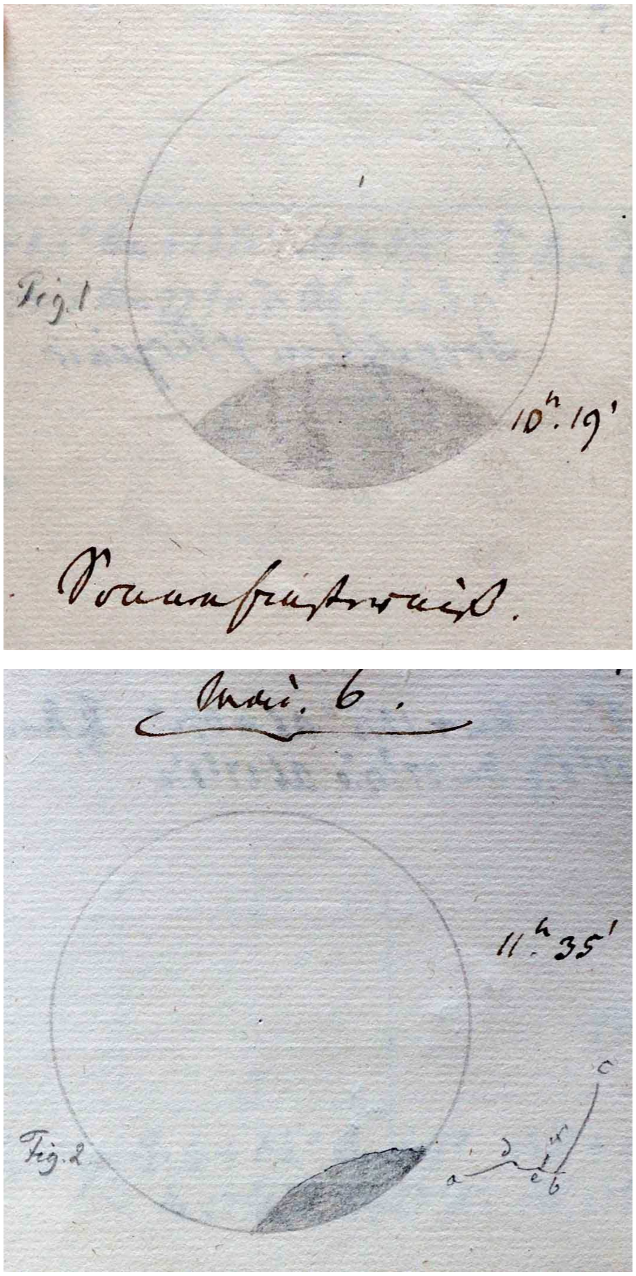

Fig. 5 Drawings of the solar eclipse of 1845 May 06 at $10^{\rm h}19^{\rm m}$ and $11^{\rm h}35^{\rm m}$ local time.

local time for his observations. He obtained a sextant on 1830 Apr 29 with which he determined the time of noon from "corresponding solar elevations." It can be assumed that the remaining deviations from the mean local time of his geographical longitude are not more than a few minutes and will be negligible for future analyses, given the limitations in plotting accuracy. Observations from before 1830 may have larger timing errors though. Some observations cannot be associated with any time of the day. These are also listed in the inventory in Table 1 and are particularly frequent until 1831.

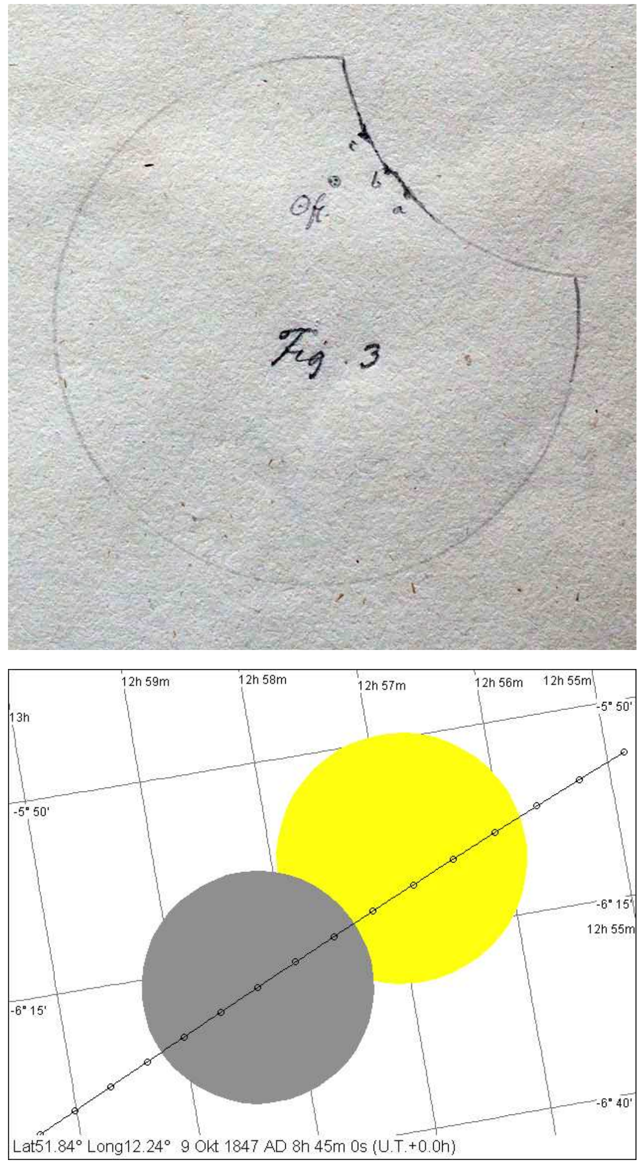

Fig. 6 Drawing of the solar eclipse of 1847 Oct 09. Bottom: reconstruction of the lunar path with StarCalc by Alexander E. Zavalishin, http://homes.relex.ru/˜zalex/.

We are now listing all the eclipses mentioned by Schwabe and try to deduce the reference time used in the observations he made, at least after 1830. The eclipse times for Dessau were obtained from the NASA eclipse web site by the Javascript Solar Eclipse Explorer [2].

- The solar eclipse of 1826 Nov 29 does not help much, since no precise times were reported for the two drawings given.
- The eclipse of 1833 Jul 17 was not observed.
- On the eclipse of 1836 May 15, Schwabe reports that his clock still had some irregularities. He observed the first contact at about $14^{\rm h}56^{\rm m}$ "mean time". The last contact was seen at $17^{\rm h}32^{\rm m}16^{\rm s}$. In reality, the first contact

[2] http://eclipse.gsfc.nasa.gov/JSEX/JSEX-index.html

was at $14^{\rm h}8^{\rm m}28^{\rm s}$ UTC while the last contact was at $16^{\rm h}44^{\rm m}29^{\rm s}$ UTC corresponding to time differences of 48 min in both cases.
- The eclipse of 1841 Jul 18 was reported to show its first contact at $15^{\rm h}25^{\rm m}27^{\rm s}$ including a time correction of 15 seconds. The drawing – which is a few seconds after the first contact – corresponds to the situation at 14h37m UTC giving a time offset of 48 minutes.
- There are no times given for the eclipse of 1842 Jul 18 because of clouds.
- There are two drawings for the eclipse of 1845 May 06. The constellation of the lower panel of Fig. 5 was reached at $10^{\rm h}45.5^{\rm m} \pm 1$ min UTC. Schwabe gave $11^{\rm h}35^{\rm m}$ for his drawing. The time offset is thus 49.5 minutes. The drawing in the upper panel of Fig. 5 is not suitable because it shows the eclipse rather near the maximum phase ($9^{\rm h}55^{\rm m}$ UTC) when the distance between Sun and Moon changes very slowly.
- For another eclipse on 1847 Oct 09, Schwabe determined the last contact at $9^{\rm h}51^{\rm m}31^{\rm s}$ while the actual time was $9^{\rm h}3^{\rm m}$ UTC indicating an offset of about 47.5 minutes.
- There are also no exact times given for the eclipse of 1851 Jul 28.
- The fourth contact of the eclipse of 1858 Mar 15 was observed at $15^{\rm h}17^{\rm m}20.3^{\rm s}$, the time obtained by the Solar Eclipse Explorer is $14^{\rm h}27^{\rm m}24^{\rm s}$ UTC corresponding to a time offset of a bit more than 49 minutes.
- The observation of the eclipse of 1860 Jul 18 delivered a first contact at $14^{\rm h}43^{\rm m}$, whereas the Solar Eclipse Explorer obtains $13^{\rm h}53^{\rm m}51^{\rm s}$ UTC, leading to a time offset of 49 minutes.
- The eclipse of 1863 May 17 was not observed because of clouds.
- There is a drawing of the eclipse of 1867 Mar 06, but no precise times were given.

The times are consistent with a mean local time for Dessau which has an offset of 48.8 minutes to UTC, $t_{\rm UTC} = t_{\rm Schwabe} - 48.8$ min. We recommend to use this offset for future analyses.

5.2 Time referring to full-disk drawings

In many cases, the observation consisted of several parts at different times of the day. While the precise knowledge of the time is not essential for constructing the butterfly diagram, it is important for measuring the differential rotation of the Sun. We need to associate the full-disk drawings with one of the multiple observing times during the day. The verbal information often does not say to which time the full-disk drawing refers.

Most of the observations starting with 1831 Sep 02 refer to 12h of each day (after a one-week trip to Halle and Sandersleben, by the way). This is supported by many occasions when Schwabe either directly said the spots were plotted at noon, or verbal information which indicates that the full-disk drawing refers to 12h. A number of examples of these indications are given below.

- 1832 May 17: “new spot 46 with penumbra not yet visible at 8:30 am.” The full-disk drawing contained this spot and indicates that it was made clearly after $8^{\rm h}30^{\rm m}$ am to when the rest of the description refers.
- 1848 Aug 14: “12h [...] Because of haze I could indicate only the general positions of the spot groups.” The drawing does indeed show only little spots as positions, no penumbrae or details, although a detailed observation was reported for 6:30, when no drawing was obviously made.
- 1853 May 26: “7h pm [...] I saw a newly formed group.” The new group was not plotted in the full-disk drawing which is consistent with an observation made at noon.
- 1860 Jul 10: “12h [...] 97 obtained five new subsidiary spots.” These spots are actually plotted in the drawing indicating it was made at noon rather than at $5^{\rm h}25^{\rm m}$ in the morning when he saw a single spot with penumbra.
- 1861 Mar 30: While in the morning, Schwabe writes “6 3/4 h [...] 42 a fine dot and close to exiting”, he write at noon “42 exited” and does not plot the spot in the full-disk drawing. This is a good indication that he did not compile all the spots he saw during the course of the day, but in fact drew what was visible at noon.
- 1861 Dec 24: “At noon I could see [...] the spots 201, 202 and the entering spot 203.” He writes at 2 pm that he saw “199 not significantly changed and 202 as two fine dots” As these were not included in the full-disk drawing, we may assume that Schwabe referred strictly to noon for these drawings, at least during the last years of his observations.
- 1863 Jun 21: “12 1/2 h [...] only 62 visible.” Again, he did see another group early in the morning but excluded it from the drawing made at (or very near) noon.
- 1864 Aug 13: “7h am [...] 78 increased in size but close to exiting. 12h [...] 78 exited definitively.” This is yet another indication for the full-disk drawings referring to noon, since group 78 was not plotted.
- 1865 Jun 04: “9 1/2h am [...] 51, 52, 54 not changed significantly. 12h [...] the spots could not be drawn. Weather cloudy during day.” Indeed, the drawing is empty, most likely because of the weather.

Direct or indirect indications continue to suggest that drawings were made preferably at noon until the end of 1867, if $12^{\rm h}$ is mentioned among the various observing times Schwabe mentioned during the course of each day. When the drawing was made at another time, it is usually mentioned clearly in the description.

We can also take the numerous disks without sunspots into account. These were typically made when no $12^{\rm h}$ observation is reported, so that means there was bad weather at noon, and no drawing could be made later. Schwabe drew the circle already in the morning but clouds precluded the actual observation at noon.

6 Coordinate system

The majority of drawings show a cross of two diameter lines or a net of six lines consisting of the two diameter lines and a square with an edge length of about 64% of the diameter. An example of such a grid is shown in Fig. 2. It is not likely to be meant as a golden ratio within the diameter, since it is clearly different from the 61.8% and the construction would not be any easier than other constructions. The lines must have corresponded to hairs in the eye-piece, since Schwabe writes on 1855 Jun 12: "In the cross hairs of the 3-1/2-foot [telescope], one hair was broken." (This is a footnote in which he also noted the time when his wife Ernestine Amalie 'Malchen', née Moldenhauer, passed away.)

All tests with a superimposed heliographic grid delivered a satisfactory spot distributions. The superposition includes the inclination of the ecliptic against the celestial equator and the tilt of the solar rotation axis against the ecliptic. We therefore assume, that whenever a net or two axes are present in the drawing, we can be sure these were aligned with the celestial equator and the direction to the celestial pole, as was the telescope itself. This is also compatible with the description of Lohrmann's refractor which clearly indicates a parallactic mount (Weichold 1985).

Some grids are rather skew, examples are 1840 Mar 23 and 1840 Oct 31. The maximum deviation from 90° of the vertical axis against the horizontal one is about 2.5°. In case of a net, only the middle vertical is considerably skew while the auxiliary lines near the limbs are better aligned. There is no indication that the skewness was drawn on purpose.

A considerable number of drawings show no grid. These drawings will pose problems to the measuring of the sunspots. We also list the numbers of drawings without grid in Table 1. Before 1831, the majority of drawings have no grid. Since the observer has no reference lines except the solar limb, one could think that these drawings are less accurate. Since the drift of the sunspots over the solar surface shows a very consistent manifestation of the solar rotation, however, we may assume that the accuracy was yet fairly high. It may actually be that a draft drawing with reference lines was first made, before the observation was copied into the actual logbook. But there are no hints on how the observation was actually conducted. An evaluation of the evolution of the accuracy of the observing technique will be performed in the follow-up paper on the positional measurements.

7 Drawings by other persons

Schwabe fell ill several times during his record of sunspot observations, until 1831 because of fever attacks, and later on due to podagra, a gout attack in the big toe. A number of journeys also prevented Schwabe from observing occasionally. A fracture of his leg prevented him from observing (Arendt 1925) probably for several months in the 1860s to which the notes do not directly refer. Several people then helped with observations. We do not know the full names of a few of them and in which relation they were to Schwabe.

Table 4 Dates on which Schwabe claimed to have seen aurorae. The one in 1852 is a report about a sighting from Berlin. The uncertain ones are descriptions of atmospheric phenomena which are fairly reminiscent of aurorae.

Date	Date
1827 09 26	1847 12 17
1831 01 07	1848 10 23
1831 08 10	1848 11 17
1833 09 17	1849 02 22
1834 11 03	1849 02 27
1837 02 18	1851 09 30
1837 11 12	1852 02 19 (not seen by Schwabe)
1838 09 15	1853 09 01 (uncertain)
1838 09 16	1859 08 28
1838 11 13	1859 09 03
1839 09 20 (deleted)	1859 10 12
1840 12 21	1861 05 03 (uncertain)
1844 01 13	1861 12 02
1846 10 17	1862 12 14
1847 03 19	1863 10 08 (uncertain)
1847 10 13	1863 10 10 (uncertain)
1847 10 24	

A total of 329 drawings were made by other people which is 3.9% of the total number of drawings available. In all cases, Schwabe added the group numbers afterwards, since the style of writing them appears to be the same all the time. We can therefore assume that Schwabe 'approved' these drawings to some extent. He comments "Marie seems to have plotted the spots incorrectly" on 1860 Jan 14, although the drawing does not look too bad, compared with the adjacent days. His critique underlines the precision he wished to achieve with his observations.

All observations made by other persons are listen in Table 3. We do not know the background of most of them. An exception is Wilhelm Jahn who joined Schwabe's observations often over the last years, first as a student and later as a teacher of mathematics and physics (Arendt 1925).

8 Conclusions

The solar observations by Samuel Heinrich Schwabe of 1825–1867 were digitized. A total of 8486 full-disk drawings with sunspots are available from 43 years. The drawings are precise enough to be exploited for individual sunspot positions and areas. Times are given as local times with an approximate offset of 49 min to UTC. All drawings are upside-down as seen through a Keplerian telescope. According to this preliminary evaluation, the accuracy of the drawings will be particularly high for the periods of 1831–1867.

The measurements will be published in a follow-up paper. The positions and spot sizes may not only be useful for the butterfly diagram, but will also serve as a suitable

Table 3 Solar drawings made by other people in assistance to Schwabe.

Year	Observer	Number	Dates of drawings
1831	Alexander	0	only seven verbal reports
1834	Moldhauer	0	only one verbal report
1837	Götz	10	1837 06 07, 1837 06 08, 1837 06 09, 1837 06 12, 1837 06 13, 1837 06 15, 1837 06 17, 1837 06 18, 1837 06 19, 1837 06 20
1837	unknown 1	17	1837 09 15, 1837 09 16, 1837 09 20, 1837 09 21, 1837 09 22, 1837 09 23, 1837 09 24, 1837 09 25, 1837 09 26, 1837 09 28, 1837 10 01, 1837 10 04, 1837 10 05, 1837 10 08, 1837 10 10, 1837 10 11, 1837 10 12
1837–1838	unknown 2, possibly Krause	8	1837 12 29, 1837 12 30, 1837 12 31, 1838 01 01, 1838 01 02, 1838 01 03, 1838 01 04, 1838 01 08
1838	Krause	1	1838 01 18
1838	Krause and Fritz	1	1838 01 21
1838	Krause, Fritz and Grube	1	1838 01 22
1838	Krause	8	1838 01 23, 1838 01 28, 1838 02 05, 1838 02 13, 1838 02 17, 1838 02 18, 1838 02 20, 1838 02 22
1838–1839	unknown 3	30	1838 05 06, 1838 08 12, 1838 08 14, 1838 08 15, 1838 09 02, 1838 09 03, 1838 09 04, 1838 09 05, 1838 09 06, 1838 09 07, 1838 09 08, 1839 06 07, 1839 06 08, 1839 06 09, 1839 06 11, 1839 06 12, 1838 06 14, 1839 06 15, 1839 06 16, 1839 06 17, 1839 06 18, 1839 06 20, 1839 06 21, 1839 06 22, 1839 06 23, 1839 06 26, 1839 08 18, 1839 08 19, 1839 08 20, 1839 08 24
1846–1847	unknown 4	23	1846 12 26, 1846 12 30, 1847 01 03, 1847 01 05, 1847 01 11, 1847 01 12, 1847 01 15, 1847 01 20, 1847 01 24, 1847 01 26, 1847 01 27, 1847 01 29, 1847 02 10, 1847 02 11, 1847 02 12, 1847 02 14, 1847 02 19, 1847 02 22, 1847 02 23, 1847 02 24, 1847 02 25, 1847 02 28, 1847 03 01
1860	Marie	41	1860 01 05, 1860 01 06, 1860 01 08, 1860 01 09, 1860 01 09, 1860 01 10, 1860 01 12, 1860 01 13, 1860 01 14, 1860 01 19, 1860 01 20, 1860 01 21, 1860 01 25, 1860 01 27, 1860 01 28, 1860 01 30, 1860 01 31, 1860 02 01, 1860 02 02, 1860 02 03, 1860 02 09, 1860 02 11, 1860 02 14, 1860 02 20, 1860 02 21, 1860 02 28, 1860 02 29, 1860 03 01, 1860 03 02, 1860 03 08, 1860 03 10, 1860 03 11, 1860 03 12, 1860 03 13, 1860 03 14, 1860 03 15, 1860 03 17, 1860 03 18, 1860 03 19, 1860 03 21, 1860 03 27
1860	Ferdinand	1	1860 01 07
1860	Wilhelm Jahn	14	1860 02 26, 1860 04 02, 1860 04 03, 1860 04 04, 1860 04 05, 1860 04 06, 1860 04 07, 1860 04 10, 1860 04 11, 1860 04 13, 1860 04 15, 1860 04 15, 1860 04 16, 1860 07 28
1860	Emilie Würzler	5	1860 03 24, 1860 03 26, 1860 03 28, 1860 03 31, 1860 04 01
1863–1866	Wilhelm Jahn	163	1863 04 09, 1863 04 10, 1863 04 11, 1863 09 20, 1864 01 31, 1864 03 21, 1864 03 22, 1863 03 26, 1864 04 01, 1864 08 15, 1864 08 21, 1864 09 27, 1864 09 28, 1864 09 30, 1864 10 06, 1864 10 07, 1864 10 09, 1864 10 10, 1864 10 14, 1864 10 15, 1864 01 17, 1864 10 18, 1864 10 19, 1864 10 22, 1864 10 23, 1864 10 24, 1864 10 25, 1864 10 26, 1864 10 27, 1864 10 31, 1864 11 01, 1864 11 02, 1864 11 03, 1864 11 06, 1864 11 07, 1864 11 08, 1864 11 09, 1864 11 10, 1864 11 11, 1864 11 13, 1864 11 14, 1864 11 15, 1864 11 19, 1864 11 20, 1864 11 23, 1864 11 24, 1864 11 28, 1864 11 30, 1864 12 01, 1864 12 04, 1864 11 05, 1864 12 07, 1864 12 08, 1864 12 11, 1864 12 12, 1864 12 15, 1864 12 17, 1864 12 18, 1864 12 23, 1864 12 27, 1864 12 30, 1865 01 01, 1865 01 07, 1865 01 08, 1864 01 12, 1865 01 13, 1865 01 16, 1865 01 17, 1865 01 19, 1865 01 20, 1865 01 21, 1865 01 22, 1865 01 27, 1865 01 30, 1865 02 01, 1865 02 05, 1865 02 06, 1865 02 07, 1865 02 10, 1865 02 12, 1865 02 14, 1865 02 16, 1865 02 20, 1865 02 22, 1865 02 23, 1865 02 25, 1865 02 27, 1865 03 01, 1865 03 04, 1865 03 05, 1865 03 06, 1865 03 09, 1865 03 10, 1865 03 11, 1865 03 19, 1865 03 20, 1865 03 21, 1865 03 22, 1865 03 25, 1865 03 27, 1865 04 01, 1865 04 02, 1865 04 03, 1865 04 04, 1865 04 05, 1865 04 08, 1865 04 09, 1865 04 10, 1865 04 11, 1865 04 12, 1865 04 16, 1865 04 17, 1865 04 21, 1865 40 22, 1865 04 23, 1865 04 24, 1865 05 02, 1865 05 03, 1865 05 04, 1865 05 06, 1865 05 07, 1865 05 08, 1865 05 09, 1865 05 10, 1865 05 13, 1865 05 20, 1865 05 21, 1865 05 24, 1865 05 26, 1865 06 03, 1865 06 08, 1865 06 09, 1865 06 16, 1865 06 18, 1865 06 20, 1865 07 01, 1865 07 04, 1865 07 08, 1865 07 23, 1865 08 07, 1865 08 19, 1865 08 23, 1865 08 26, 1865 09 05, 1865 09 26, 1865 09 27, 1865 09 28, 1865 10 01, 1865 10 02, 1865 10 08, 1865 10 16, 1865 10 29, 1866 04 16, 1866 04 17, 1866 07 25, 1866 07 26, 1866 09 02, 1866 09 19, 1866 09 23, 1866 10 04, 1866 10 06, 1866 12 28, 1866 12 31
1866	Hartmann	7	1866 07 15, 1866 07 16, 1866 07 17, 1866 07 18, 1866 07 22, 1866 08 06, 1866 08 09

record for the analysis of group tilt angles, differential rotation, possible hemispheric asynchrony, and possible active longitudes. Besides the drawings, there are verbal reports on 3699 additional days with which fairly precise lifetimes of spots can be obtained. The accuracy could also be enough for sunspot tracking and the derivation of meridional drifts as well as the evolution of the polarity separation.

Additionally, the possible sightings of aurorae can be compared with other observational records of the time. The dates for which Schwabe mentioned aurorae are listed in Table 4.

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