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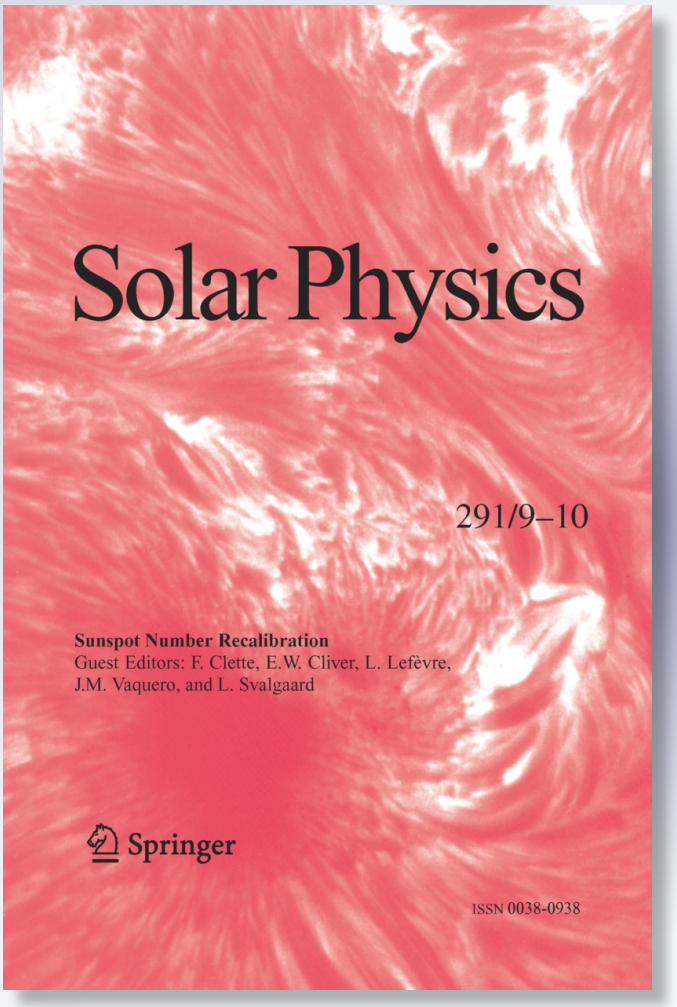

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Sunspot Observations of Rudolf Wolf from 1849 – 1893

Thomas K. Friedli[1]

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Abstract The sunspot observations of Rudolf Wolf form the core of the Wolf series of sunspot relative numbers, or Wolf numbers, since his observations define the original scale of the series and also the main course of solar activity from 1849 to 1893. Unfortunately, the raw data for the years 1856 to 1869 were never published in full detail. The heritage group of the Rudolf Wolf Society in Switzerland digitized parts of the hitherto unpublished original source book of the Wolf series and put it on its website www.wolfinstitute.ch. Now, the Wolf numbers from 1849 to 1876, as provided by the World Data Center for Solar Index and Long-term Solar Observations (WDC-SILSO), can be reconstructed in every detail, since the source book contains all the raw sunspot group and individual spot numbers as well as the implemented calibration and interpolation methods. Thus, the observations made by Rudolf Wolf with the 83/1320 mm Fraunhofer refractor and with the 40/700 mm Parisian refractor as well as those made by Heinrich Schwabe can be identified and separated now. In this article, we describe Wolf's instruments and methods of observation. An inspection of the source book and other published sources reveals that the calibration factor of the 40/700 mm Parisian refractor should probably be lowered. Since no appropriate comparison observations are available, the scale transfer from Heinrich Schwabe to Rudolf Wolf has to be analyzed further.

Keywords Solar cycle · Observations · Sunspots · Statistics

1. Introduction

The Wolf series of sunspot relative numbers, or Wolf numbers, as provided by the World Data Center for Solar Index and Long-term Solar Observations (WDC-SILSO), is the

Sunspot Number Recalibration
Guest Editors: F. Clette, E.W. Cliver, L. Lefèvre, J.M. Vaquero, and L. Svalgaard

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longest directly observed index series of solar activity. The daily Wolf number $[R]$ is calculated as

$$R = k(10g + f) \tag{1}$$

where g is the number of sunspot groups, f is the number of individual spots, and k is a data-reduction factor.

Homogeneity is considered as the most important property of the Wolf series since without a stable scale no valid conclusions about variations in the long-term course of the solar activity can be drawn. A homogenization of the Wolf series should be based on a fully transparent reconstruction of the daily Wolf numbers as provided by WDC-SILSO version 1.0 (Friedli, 2009). But since the original raw data and the data-reduction methods were never published, a thorough homogeneity testing and an appropriate correction of the Wolf series seems up to now nearly impossible (Clette *et al.*, 2015).

Based on some hitherto unpublished sources from the archives of the former Swiss Federal Observatory in Zurich we reconstruct in this article the daily raw observations of Rudolf Wolf, including the number of sunspot groups and the number of individual spots. His observations form the core of the Wolf series since they define the original scale of the series and the main course of solar activity from 1849 to 1893. But, unfortunately, it was widely neglected that Rudolf Wolf changed his standard instrument two times and that he suffered from an eyesight diminishment in his later years, although Wolf (1894) and Wolfer (1895) had claimed that the Wolf series had to be recalculated.

In Section 2 we give some historical background information on Wolf's sunspot observations and a description of his main instruments. In Section 3 we review the newly digitized raw observations of the Wolf series from 1849 to 1876. In Section 4 we give some historical background information concerning Wolf's method of counting sunspot groups and individual spots and on the eyesight diminishing in his later years. In Section 5 we review Wolf's estimates of the k-factor of his smaller instrument and of the observations of Heinrich Schwabe. In Section 6 the conclusions are summarized.

2. Historical Outline

2.1. First Attempts in Berne

On 25 March 1847, Johann Rudolf Wolf (1816 – 1893) (see Figure 1) was appointed director of the observatory in Berne (Wolf, 1866, 1879; Graf, 1896; Flury, 1929; Verdun, 2004). The observatory had been founded by Johann Friedrich Trechsel (1776 – 1849) in 1821 to secure the geodetic zero-point of Switzerland established in 1812 during the French occupation by the geodesists Maurice Henry (1763 – 1825) and François Delcros (1777 – 1865). In 1847, due to the complete lack of financial support by the Bernese authorities, the observatory was in such a bad condition that no useful measurements for daily geodetic or astronomical work could be taken any more. During the Summer vacation, Wolf made a journey to Germany to study the observatories in Bonn, Hamburg, Altona, Berlin, Leipzig, and Munich with the intent to look for a possible field of work (Graf, 1894). Back in Berne, Wolf almost accidentally observed sunspots on 4 December 1847, and he found them so fascinating that he decided to observe the Sun regularly (Wolf, 1848). During the year 1848 he made observations of the Sun on 201 days (Wolf, 1849a). Soon he realized that his poor equipment did not allow exact astrometrical measurements to study the rotation of the Sun. He then rather made observations of the physical nature of the spots, their number, extent, and evolution.

Figure 1 Johann Rudolf Wolf (1816 – 1893) as Professor of Astronomy at the University of Berne, Director of the Bernese observatory, and President of the Bernese Society of Natural Sciences in 1855 (Burckhardt, 1976).

In an article presented to the Bernese Society of Natural Sciences and published in its *Notices*, Wolf summarized his findings and concluded that there would be no quick progress in the exploration of the physical nature of the spots and that it would be better to collect more observations (Wolf, 1849b). In January 1849, Wolf started a systematic observing program with daily determinations of the number of sunspot groups and individual spots (Wolf, 1850). Only some years later, Wolf noticed that the frequency of sunspots had markedly diminished since his first observations in 1847 and 1848 and he introduced in 1850 a first version of so-called sunspot relative numbers, or Wolf numbers, to quantify this effect (Wolf, 1851; Friedli and Keller, 1993).

2.2. The Standard Refractor of the Wolf Series

Rudolf Wolf made most of his sunspot observations with a refractor fabricated by Utzschneider and Fraunhofer in Munich, which belonged to the Realschule (a private college focused on exact and natural sciences), where he worked as a teacher of mathematics and physics. The instrument had been acquired during the late 1820s by the well-known geologist Bernhard Studer (1794 – 1887), who became director of the Realschule during Wolf's stay in Berne. As indicated on page 170 of Wolf (1848) the refractor had an aperture of 37 Parisian lines, a focus length of 48 Parisian inches, and eyepieces for 64- and 144-fold magnification. These dimensions match perfectly with the entry number 10 in the catalog of Utzschneider (1829). If we assume the Parisian line to equal 2.2558 mm and the Parisian inch to equal 2.7070 cm, the refractor had an aperture of 83 mm and a focal length of

1300 mm. The latter is confirmed on page 5 of Wolf (1849a), where Wolf reports a focal length of 1313 mm. The instrument was equipped with a colored glass filter for solar observations. Nothing is known about the mounting of the telescope, but in 1854 Wolf put the refractor into the dome of the newly erected tower of the observatory, where the instrument was installed on an equatorial mount designed by himself (Wolf, 1854, 1879; Flury, 1929). After Wolf's departure to Zurich, this instrument remained in Berne and was further used by Wolf's former pupil Emil Jenzer for sunspot observations during the years 1861 to 1864 (Wolf, 1862, 1863, 1864, 1865). Later on, it was forgotten and Flury (1929), who visited the observatory in April 1925, found it completely corroded. Thus, the instrument indeed had a metallic tube, as described by Utzschneider (1829). Its further fate is unknown.

2.3. From Berne to Zurich

In 1855, Wolf was appointed professor of mathematics and physics at the college in Zurich, professor of astronomy and head librarian at the newly founded Federal Institute of Technology, and director of the observatory in Zurich as well. The exact date of the relocation is not known, but from the preserved letters we learn that it is almost certain that Wolf moved in the early days of August (Jaeggli, 1968; Gossweiler, 1996a, 1996b).

The observatory in Zurich had been founded by Johannes Feer (1763 – 1823) in 1811, and in 1855 it was in an even worse condition than the one in Berne, but luckily it was provided with a refractor by Utzschneider and Fraunhofer that was similar to the one Wolf had used in Berne, also equipped with a colored glass filter and an eyepiece giving magnification 64 (Wolf, 1879). This instrument originally belonged to Wolf's mentor Johann Caspar Horner (1774 – 1834) and is still used today (Figure 2). Unlike the Bernese instrument, it has a wooden lens tube, which was usually given only to the larger refractors at Utzschneider and Fraunhofer. The aperture measures 83 mm and the focal length is 1320 mm – virtually identical to the Bernese instrument. Since the instrument in Zurich was at Wolf's immediate disposal, no gap is found in the observation records due to the relocation. Wolf used this instrument from 1855 to 1863 for his daily solar observations.

In 1864, the instrument was relocated to the observation terrace of the newly founded Swiss Federal Observatory (Friedli *et al.*, 1998). Wolf never used it again. Henceforth, it was part of the daily duties of Wolf's assistants to count the groups and spots at the standard refractor. In the subsequent years, most probably in early 1870, a polarizing helioscope from G. and S. Merz was installed (Figure 3), which improved the quality of the image considerably and reduced the k-factor of the observing assistant Gustav Adolf Meyer by 15 % (Wolf, 1878a). Beginning in 1876, Alfred Wolfer revived the standard instrument and from 1894 on all group and spot counts of the Wolf series were again calibrated to the original scale of this instrument. In 1962 the telescope was moved on top of the roof of the Swiss Federal Observatory. After the closure of the observing station in December 1995, the instrument was relocated by the author to the Bernese outskirts where it is still used for the daily determination of the Wolf number (Friedli, 2012, 2014, 2015).

2.4. Portable Telescopes

During journeys, and also for observations from his apartment, Wolf used portable telescopes. The most prominent one is the so-called Parisian refractor with 40 mm aperture and 700 mm focal length, equipped with a colored glass filter and a terrestrial eyepiece giving magnification 20. This achromatic instrument was used from 1852 until the end of 1889 and served from 1861 on as the main telescope for Rudolf Wolf and thus set the scale of

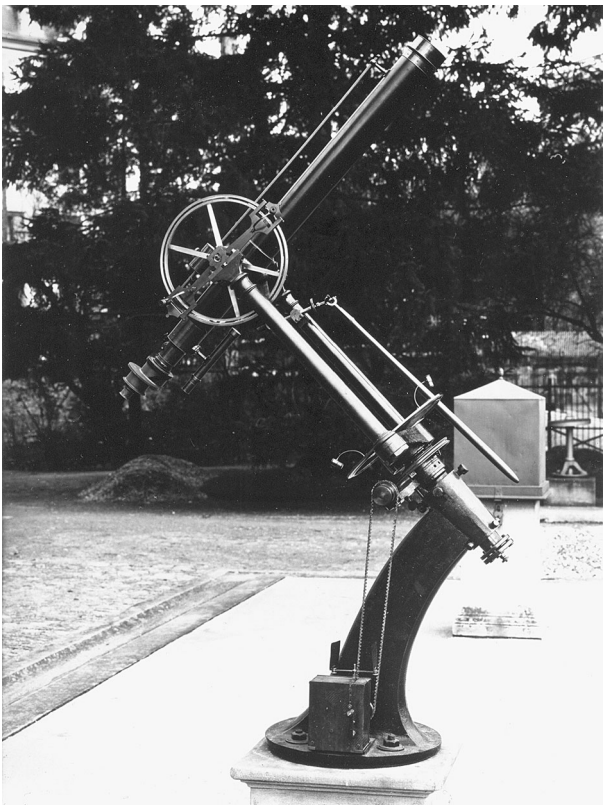

Figure 2 The 83/1320 mm Fraunhofer refractor, the standard instrument of the Wolf series, on the southern observation terrace of the Swiss Federal Observatory in Zurich around 1880. The instrument has an aperture of 83 mm and a focal length of 1320 mm, which also determine the dimensions of the wooden lens tube. It is equipped with a polarization helioscope made by G. and S. Merz in Munich and operated at a magnification of 64. The clockwork soon disappeared. In 1962 the instrument was put on top of the roof of the observatory and in 1996 it was moved to the Bernese outskirts, where it is still operated by the author for the daily determination of the Wolf number.

the Wolf series for these years. In 1890, it was replaced by a portable 42/800 mm refractor by Utzschneider and Fraunhofer in Munich with magnification 29. Short descriptions of both instruments were published by Wolf (1889). In 1894 Wolfer started a systematic observation campaign to study the performance of three of Wolf's smaller refractors including the two instruments mentioned above (Wolfer, 1895) which he conducted up to his retirement in 1926. The archives of the former Swiss Federal Observatory keep an unpublished manuscript with the main results from this study (Wolfer, 1926). In 1993 the author started a new observation campaign with the same three refractors. Currently, only the 40/700 mm Parisian refractor is in regular daily use (Figure 4). As for the Wolf numbers determined with the 83/1320 mm Fraunhofer refractor, those determined with the 40/700 mm Parisian refractor are entering the WDC-SILSO database.

3. Reconstruction of the Original Observations

At first glance, virtually all of Wolf's original observations seem to have already been published in one of the many articles in the periodicals of which he was the editor. However, if we compare the published observations with the benchmark publication of Waldmeier (1961), which for the first time contained also the daily values of the Wolf series, we find that the tables of Wolf (1856) containing the observations from 1849 to 1855 make no distinction between Wolf's observations and those by Schwabe, and those made at the standard

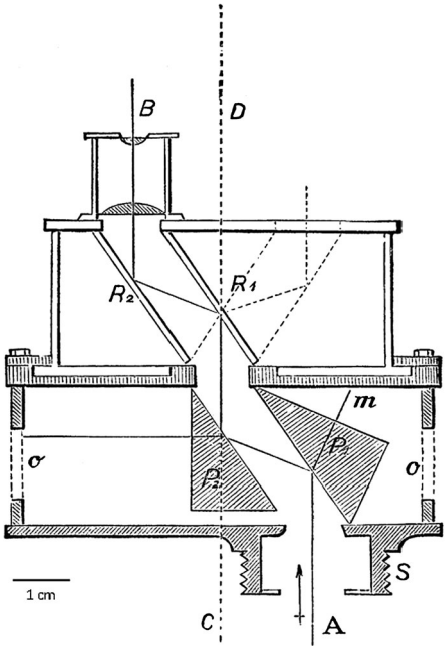

Figure 3 Little is known about the polarization helioscope made by G. and S. Merz in Munich. The above cut is from Young (1896), but it shows not exactly the same optical configuration as the device mounted at the 83/1320 mm Fraunhofer refractor of Rudolf Wolf. According to Young (1896), the mode of operation is quite simple: "The light entering at A first encounters the surface of a prism, P_1, set at the polarizing angle; about 6.25 % of the light is reflected and polarized. The reflected ray next strikes the surface of a second prism, P_2. That which is left is reflected into the upper portion of the eyepiece parallel to its original direction, through an opening in the top of the circular case in which the two prisms are mounted. The upper case is attached to the lower in such a manner that it can be turned around the line CD as an axis. It contains two plane mirrors of black glass, placed as shown in the figure. With things in the position indicated, a beam of considerable strength would reach the eye at B – so strong in fact, as to be painful. But, by turning the upper piece one quarter of a revolution, the issuing ray can be almost extinguished, and, by turning it less or more than 90 degrees, the intensity of the light can be controlled at pleasure". In the device mounted at the 83/1320 mm Fraunhofer refractor of Rudolf Wolf, the second prism [P_2] is replaced by a plane mirror of black glass.

refractor and the Parisian refractor, either. Furthermore, no daily values of the Wolf number are given and no k-factors for reducing them to the standard scale, either. Obviously, the tables of Wolf (1856) are missing several values, whereas the year 1849 of Waldmeier (1961) is complete.

During the Bernese period, Wolf published his results regularly in the *Notices of the Bernese Society of Natural Sciences* (Graf, 1894). After 1855, Wolf completed his own series with counts from other observers, but in the published tables, he did not always specify the observer. Under these circumstances, a thorough reconstruction of the combined series is not possible. In 1873, Wolf realized the importance of an explicit publication of all raw data (Wolf, 1873). But although most of the original observations included in the Wolf series were published later, his own observations between July 1855 and December 1869 remained partially unknown. A further exception concerns Heinrich Schwabe, from whom he never received all of the available raw data. It seems that Wolf had to ask Schwabe at the end of each year for those observations falling within the gaps of his own series. Thus, typically no observations were available for comparison and Wolf had some difficulties in calculating a

Figure 4 The 40/700 mm Parisian refractor mounted on a modern tripod in the backyard of the author in Belp, Switzerland. The brass lens tube has a length of 710 mm and an outer diameter of 45 mm. First, Wolf used this telescope only during journeys and excursions, but beginning with 1861 this instrument became his main instrument for the daily counting of the sunspot groups and individual spots. Wolfer (1895) measured the focal length to be 480 mm but did not include the terrestrial eyepiece which extends the focal length considerably. According to Wolf (1860, 1871) the magnification is 20, according to Wolfer (1895, 1926) it is 21. Since the diameter of the aperture is slightly smaller than 40 mm, we adopt a magnification of 20.

reliable calibration factor for Schwabe's observations. During the years 1874 to 1876, Wolf recalculated the whole series backwards to 1749 and included observations from additional observers. Unfortunately, this final compilation was never published.

Among the treasures preserved in the archives of the Swiss Federal Observatory a manuscript was found containing the daily raw data for the whole Wolf series from 1610 up to 1876 (Wolf, 1878a). Since Wolf considered himself as the standard observer of the series, we find all of his observations with the 83/1320 mm Fraunhofer refractor in the source book. Others, among them all of the comparison observations between the standard refractor and the Parisian instrument during the years 1860 and 1862, are irretrievably lost.

The Rudolf Wolf Society (RWG) in Switzerland, founded in 1992, aims to promote the homogeneous continuation of the Wolf series based on the original instruments used by Rudolf Wolf and his successors and to explore the archives of the former Swiss Federal Observatory at Zurich. The heritage group of the Rudolf Wolf Society digitized parts of this source book and placed it on the site www.wolfinstitute.ch. Now we are able to reconstruct the Wolf numbers up to 1876 as given by Waldmeier (1961) in every detail. In Figures 5 and 6 facsimiles from the original source book and the tables given by Wolf (1856) are provided. As may be seen in Figure 6, the missing days in Figure 5 are filled with observations, some, surprisingly, even by Wolf himself, *e.g.* during the first half of December 1849. These gaps were all numerically interpolated, which can be visually explored by consulting the dynamic graph on the web site. The observer labels for the interpolated days are simply placeholders.

Figure 5 Facsimile of page 5 from Wolf (1856) containing the daily counts of sunspot groups [g] (first number) and of individual spots [f] (second number) as observed by Rudolf Wolf and Heinrich Schwabe. Incomplete observations obtained with smaller instruments or under bad weather conditions are printed in smaller type. Missing observations are indicated by $-$. The last line contains the monthly averages of the Wolf number calculated as $R = 10g + f$.

Sonnenfleckenbeobachtungen im Jahre 1849.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
1	9.31	3. 6	4.–	10.70	9.30	8.48	4.13	4 15	7.64	8.10	5.16	–
2	9.34	7.40	5.–	7.–	9.40	9.64	3. 3	6.18	5.35	7.10	7.41	8. 9
3	15.–	2.–	6.12	10.38	5.12	8.50	3. 6	6.15	4.27	3. 4	3.10	8.17
4	9.31	7.37	7.15	12.58	7.45	10.50	3 10	4.12	5.41	2. 3	4.31	–
5	9.–	9.22	2.–	8.20	8 50	8.45	7.–	5.20	1. 1	1. 2	–	9.47
6	8.–	10 34	7.24	10.60	7.38	7.45	4. 8	4.18	6.25	4. 6	–	2. 2
7	–	3.–	3.–	8.24	1.–	5.–	5.10	3.20	7.48	–	6.22	–
8	8.28	10.21	4.–	6.20	6.20	5.12	6 15	3.15	5.38	5.16	7.35	–
9	8.30	10.35	3.→	9.45	6.25	5.–	7.20	4 14	7.50	5.26	6.20	–
10	–	–	2.–	2.–	2.–	3.–	3. 6	5.37	9.26	–	–	–
11	–	8 20	5.20	6.24	4.10	1.–	3. 4	5.32	7.35	2. 5	–	–
12	7.28	9.56	7.30	–	1. 2	5.12	3. 8	7.25	6.–	–	–	–
13	–	11.64	–	5.14	0. 0	5.14	4.10	7.24	4.40	4.26	5.41	3.22
14	–	7.–	7.22	5 16	5.16	6.14	3.12	6.45	5.15	–	6.22	3.12
15	4.–	2. 2	6.23	5.10	4.–	4. 8	3.12	6 14	9.59	–	5.20	4.19
16	5.–	6.–	–	2. 2	4.25	3. 4	7.45	7.21	7.54	3. 5	–	3. 5
17	9.25	15.40	4.14	2.–	–	4. 8	8.40	6.–	6.32	4.21	–	5.22
18	11.60	8.–	7.30	3.–	4.30	5.35	9.30	6.30	5.19	4.25	2.22	7.37
19	10.25	11.36	4.–	6.35	2. 2	5.35	7.22	5.26	3. 9	6.56	5.25	6.10
20	11.74	13.60	5.30	6.11	3.42	2. 5	7.22	3. 5	4.26	6.41	7.47	4. 5
21	12.75	12.–	5 30	–	3.22	4.42	7.15	5.10	6.24	8.36	6.16	2. 2
22	9.46	10.21	6.35	6 36	3.28	6.56	6. 8	4. 4	7.28	–	–	–
23	10.–	11.58	–	3.12	4.25	5.38	5.12	4. 7	7.34	7.49	–	–
24	10.–	11.40	–	2.10	3. 8	2.–	5. 9	3. 4	7.23	5. 8	–	–
25	11.65	10.68	3.–	5.30	6.25	5.30	7.14	3.10	5.32	4. 4	–	11.43
26	10.76	10.35	–	4.10	5.12	4.25	4. 8	5.20	5.15	–	–	6.13
27	10.95	2.–	4.–	6.44	6.20	2.15	5. 7	5.21	8.15	–	9.68	–
28	9.63	7.36	12.50	3.–	8.30	2.10	7.20	3.15	9.16	3. 4	11.72	5.–7
29	9.62		2.–	3.20	6.10	4. 6	7.24	4.24	8.17	5.11	13.74	8.52
30	9.–		9.31	3.20	7.40	1. 1	8.20	5.36	8.17	7.48	11.52	4.11
31	–		11.58		6.10		5.16	6.45		5.16		–
Mittel.	144,0	128,1	100,7	87,9	83,3	88,1	80,4	67,5	92,6	82,0	96,4	92,1

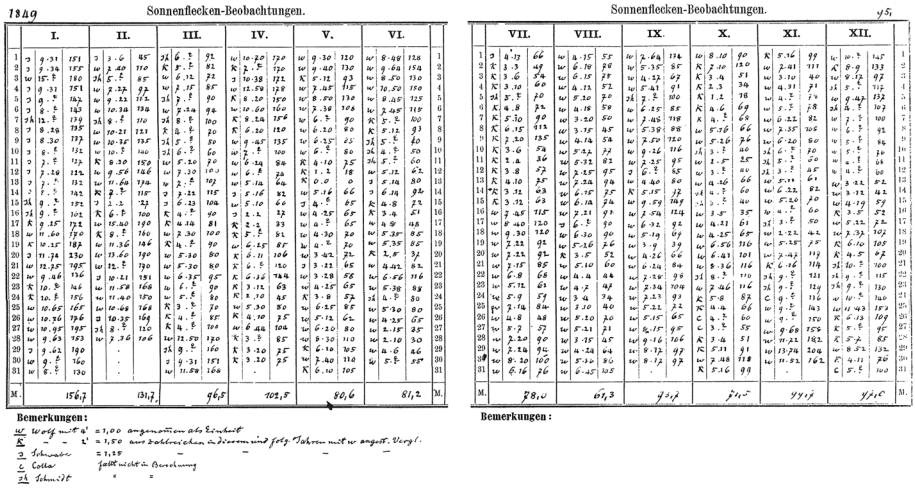

Figure 6 Facsimile of a page from the source book (Wolf, 1878a) containing data from the same year as in Figure 5. Additionally, the observer and the daily Wolf number are indicated, calculated as $R = k(10g + f)$. The k-factors may be found in the bottom part of the table. Note that the daily and monthly mean Wolf numbers are identical to those of Waldmeier (1961).

Note that the source book mentions additional observers for this year – Schmidt and Colla – who were not known in 1856 (see Figure 6).

The source book ends in 1877, since Wolf changed the data, reduction procedure (Wolf, 1878b). Now, the Wolf series no longer consisted of one single observation per day, as before, but contained the average Wolf number of several observers for some days without group numbers and individual spot numbers of the standard observer, which could no longer be handled in the form of a diary. So, Wolf published all of the raw data *in extenso* in the *Astronomische Mittheilungen*. The heritage group of the Rudolf Wolf Society digitized from these sources Wolf's remaining observations up to 1893 and placed them on the site www.wolfinstitute.ch. Thus, all surviving daily group numbers and individual spot numbers

of Rudolf Wolf as used in the published Wolf series from 1849 to 1893 are now explicitly known.

In Figure 7 we display the number of observing days of Rudolf Wolf for each instrument. During the first years Wolf made the bulk of observations with the standard refractor, reaching a remarkably high maximum of 335 observing days in 1856. Starting with 1860, the number of observing days with the standard refractor decreased and on 5 October 1863 Wolf made the last observation with this instrument. First, he used the smaller telescope only occasionally during journeys and excursions. During the years 1858 and 1859 no observing days with this instrument are recorded. However, from 1860 on the Parisian refractor was revived and from 1861 to 1889 served as principal instrument of the Wolf series. During 1864 and 1869, the number of observing days was well below the average since Switzerland took part in the European triangulation initiated by the General Baeyer from Prussia during these years and Wolf – as president of the geodetic commission and main observer at one of the fiducial sites – was working mainly during the night-time to measure the latitude and longitude of the newly established Swiss Federal Observatory and the curvature of the geoid over the Alps (Wolf, 1879). Thus, from the second semester of 1864 to the end of 1868, the major part of the observations included in the Wolf series was provided by the new assistants of the Swiss Federal Observatory at the 83/1320 mm Fraunhofer refractor. An unknown number of additional observations a year by Rudolf Wolf with the 40/700 mm Parisian refractor was used for calculating the yearly k-factors of the assistants and the other secondary observers, but they did not enter the series and were never published (Wolf, 1878a).

4. Methods of Observation

The original raw observations of Rudolf Wolf are lost, but it may easily be concluded from his articles that Wolf logged his observations in a diary – at least at the beginning. In his first report on sunspot observations, he mentioned such a notebook (Wolf, 1848). Furthermore he gave observational details that could not have been provided from memory. It seems that Wolf made also some sort of sketch, since he mentioned where on the solar disk new sunspot groups appeared. The notebooks were also mentioned later on (Wolf, 1849a, 1852, 1857). However, it seems that Wolf had a somehow different observation technique than the following standard observers: Wolfer, Brunner, Waldmeier, Zelenka, and Keller. He first counted the groups and then all individual spots within the groups. This technique allowed Wolf to work fast and to use days with bad weather conditions, where only the group number could be determined. But such an approach leads to counting errors in the number of individual spots, because during maximum activity it is quite probable that the observer loses track and counts the same spots or even the same groups several times or never. To avoid such errors, the subsequent standard observers wrote the number of individual spots for each group on their approximate position within a circle drawn on a piece of scrap paper. Therefore, the number of spots could be summarized later. Since 1996, the author's daily observation record at the 83/1320 mm Fraunhofer refractor contains a sketch of each sunspot group and several indices including the number of individual spots and the modified McIntosh classification (Friedli, 2013).

Wolf was a very talented observer with a long measuring experience in geodesy, meteorology, and astronomy. However, he was nearsighted, especially in his right eye. Although there exists no portrait of Wolf wearing glasses, we learn from his diary that Wolf got a prescription during his stay in Vienna in 1838 and bought a pair of glasses from Ploessl (Larcher, 1993). Also, it seems that Wolf did not see the smallest spots since his pupil and

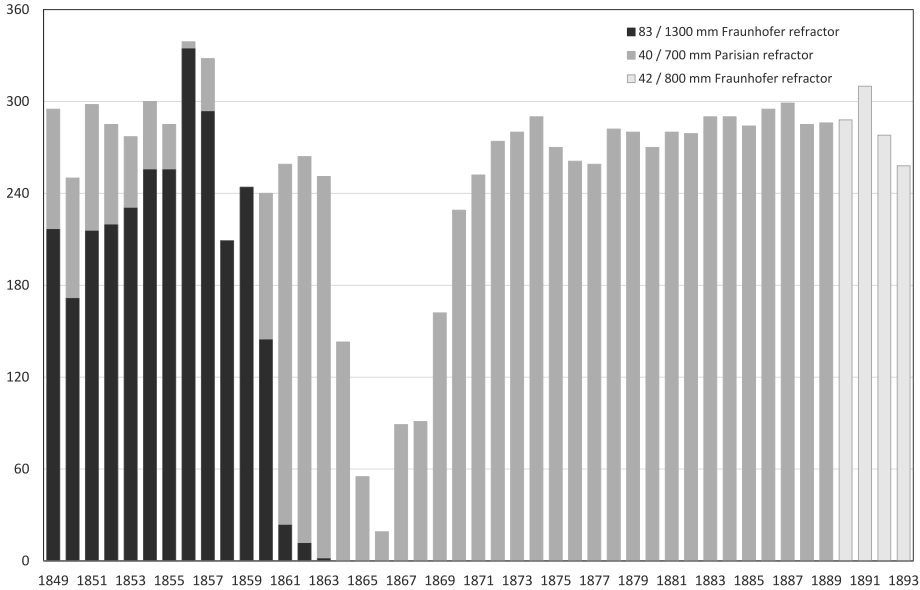

Figure 7 Number of complete observing days of Rudolf Wolf from 1849 to 1893. The 83/1320 mm standard refractor with a colored glass filter was mainly used during the first decade. From 1861 on Wolf reduced all observations to the scale of the 40/700 mm Parisian refractor. In his later years, Wolf's eyesight diminished and he changed in 1890 to a more powerful instrument.

successor at the observatory of Berne, Emil Jenzer, had a k-factor of 0.85 with the same instrument and the same magnification (Wolf, 1878a). During his later years Wolf's eyesight obviously diminished (Wolfer, 1895). To compensate for the loss, Wolf changed his main instrument to a more powerful instrument in 1890 (Wolf, 1889).

5. Scale Transfer

The observations of Rudolf Wolf made with the 83/1320 mm Fraunhofer refractor in Berne and Zurich from 1849 to 1863 form the core of the Wolf series and define its scale. Wolf transferred this scale to his 40/700 mm Parisian refractor and continued the series up to 1893. Backwards in time the scale was transferred to Heinrich Schwabe. The implementation of both transfers is closely related with the invention of the k-factor. During the Bernese period Wolf published his own observations only. However, after the movement to Zurich, Wolf began to complete his series with observations from Heinrich Schwabe. Based on the experiences that Wolf gained during his educational visit to several observatories in Germany in Autumn 1851, Wolf first considered the observations by Schwabe as equivalent with his own (Wolf, 1852). In 1859, Wolf discovered, based on observations by Schwabe from the years 1835 to 1850, a linear relationship between the Wolf numbers and the diurnal variations in arcminutes of the magnetic-needle (Wolf, 1859). In the following year Wolf noticed that the observed values of the magnetic needle variations were different from the predicted ones and thus, the scale of the combined Wolf number series had changed since 1850 (Wolf, 1860). As a quick fix, Wolf added a calibration factor [k] in the formula of the Wolf number (Wolf, 1861). To estimate the k-factor values, he made in 1860 with

the Parisian refractor 109 comparison observations and deduced a k-factor of 1.5 (Wolf, 1861). In 1861 and 1862 Wolf made some additional 26 and 120 comparison observations and found values for k of 1.43 and 1.45, respectively, slightly lower than before (Wolf, 1862, 1863). Finally, he adopted 1.5 (Wolf, 1878a). If we calculate a weighted average of the above values, excluding some 49 less-reliable indirect comparisons with other observers during the year 1860, we find $k = 1.44$. Thus, it seems that the k-factor for the 40/700 mm Parisian refractor as fixed by Wolf (1878a) is probably too high and should be lowered. But this has to be analyzed further.

Interestingly, Wolf did not adapt his k-factor when he replaced his beloved 40/700 mm Parisian refractor with the 42/800 mm Fraunhofer refractor in 1890.

The reconstruction of the transfer from Wolf to Schwabe is more complicated since it seems that Wolf received from Schwabe only counts from those observations lying in the gaps of his own series. Thus, the value of $k = 1.25$ as given by Wolf (1878a), is quite unreliable, since no comparison observations were available and Wolf had to calculate Schwabe's k-factor via secondary observers (Wolf, 1861, 1862). Furthermore, it remains questionable if the same value should also be applied to the years before 1849 since the Wolf numbers during the years 1826 and 1848 were reconstructed by Wolf (1859) himself from the original diaries of Schwabe, and from the values provided for the years 1849 to 1867 it is not known if they were calculated by the same principles. Thus, this scale transfer has to be analyzed further.

6. Conclusions

In the archives of the former Swiss Federal Observatory, a manuscript was found containing the raw data of the entire Wolf series from 1610 to 1876 (Wolf, 1878a). Now, the Wolf numbers as provided by WDC-SILSO version 1.0 can be reconstructed in every detail, since the source book contains all the raw sunspot group and individual spot numbers as well as the implemented calibration and interpolation methods. In this article we digitized and published the hitherto unknown daily numbers of sunspot groups and individual spots Rudolf Wolf observed from 1849 to 1893 with his three main instruments on the site www.wolfinstitute.ch. Thus, a thorough homogeneity testing of the Wolfian period, acting in fact as the core part of the Wolf series, has become possible, including the widely disregarded scale transfer from the 83/1320 mm Fraunhofer refractor – the standard instrument of the Wolf series – to the 40/700 mm Parisian refractor. Furthermore, a detailed reanalysis and correction of the effects of Wolf's eyesight diminishment on the homogeneity of the Wolf series can now be done.

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