Stephan Prantner’s Sunspot Observations during the Dalton Minimum

Hisashi Hayakawa1,2,3,4, Shoma Uneme1, Bruno P. Besser5,6, Tomoya Iju7, and ShinSUke Imada1,4

1 Institute for Space-Earth Environmental Research, Nagoya University, 4648601, Nagoya, Japan
2 Institute for Advanced Researches, Nagoya University, 4648601, Nagoya, Japan
3 UK Solar System Data Centre, Space Physics and Operations Division, RAL Space, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Oxford, OX11 OQX, Didcot, Oxfordshire, UK
4 Institute of Physics, University of Graz, 8010 Graz, Austria
5 Space Research Institute, Austrian Academy of Sciences, 8042 Graz, Austria
6 Institute for Advanced Researches, Nagoya University, 4648601, Nagoya, Japan
7 National Astronomical Observatory of Japan, 1818588, Mitaka, Japan

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Abstract

In addition to regular Schwabe cycles (≃11 yr), solar variability also shows longer periods of enhanced or reduced activity. Of these, reconstructions of the Dalton Minimum provide controversial sunspot group numbers and limited sunspot positions, partially due to limited source record accessibility. In this context, we analyzed Stephan Prantner’s sunspot observations spanning from 1804 to 1844, the values of which had only been known through estimates despite their notable chronological coverage during the Dalton Minimum. We identified his original manuscript in Stiftarchiv Wilten, near Innsbruck (Austria). We reviewed his biography (1782–1873) and located his observational sites at Witten and Waidring, which housed the principal telescopes for his early and late observations: a 3.5 inch astronomical telescope and a Reichenbach 4 foot achromatic erecting telescope, respectively. We identified 215 days of datable sunspot observations, which is almost twice as much data as his estimated data in the existing databases (≈115 days). In Prantner’s records, we counted up to seven to nine sunspot groups per day and measured sunspot positions, which show their distributions in both solar hemispheres. These results strikingly emphasize the difference between the Dalton Minimum and the Maunder Minimum as well as the similarity between the Dalton Minimum and the weak solar cycles in the modern observations.

Unified Astronomy Thesaurus concepts: Sunspots (1653); Sunspot cycle (1650); Sunspot groups (1651); Solar-terrestrial interactions (1473); Maunder minimum (1015)

1. Introduction

The numbers of sunspot groups and individual sunspots—which have been monitored since 1610—form a direct basis for evaluating the magnitude of solar activity for ≃410 yr, as visual representations of solar magnetic fields (Vaquero & Vázquez 2009; Clette et al. 2014; Arlt & Vaquero 2020). These observations form one of the longest ongoing scientific experiments in human history (Owens 2013). These data have identified several cyclicities, such as the regular Schwabe cycles for each ≃11 years (Hathaway 2015). These data show fairly good correlations with other physical measurements such as sunspot area and solar-irradiance fluxes, and hence are used for their cross-comparisons, reconstructions, and recalibrations (Hathaway 2015; Tapping & Morgan 2017; Criscuoli et al. 2018; Chatzistergos et al. 2017,2019,2020; Clette 2020; Lean et al. 2020). This is also the case with the proxy data like cosmogetic isotopes, such as 14C in tree rings, 10Be in ice cores, and 44Ti in meteorites (Solanki et al. 2004; Beer et al. 2012; McCracken & Beer 2015; Usoskin et al. 2017; Asvestari et al. 2017). These correlations have often been used to chronologically extend the solar-irradiance fluxes beyond their observational onsets (e.g., Ermolli et al. 2013; Lean 2017; Berrilli et al. 2020).

Two peculiar “prolonged solar minima”—the Maunder Minimum (1645–1715) and the Dalton Minimum (1797–1827)—have been identified within the multicentury sunspot observations (e.g., Usoskin et al. 2017). The Maunder Minimum was named after Edward W. Maunder (1851–1928), who noticed significantly reduced sunspot occurrences, reduced auroral frequency, and increased cosmogenic isotopes (Maunder 1922; Eddy 1976; Usoskin et al. 2015). This peculiar period has attracted significant scientific interest and has been characterized by extremely weakened solar cycles (Usoskin et al. 2015; Vaquero et al. 2015), hemispheric asymmetry of sunspot occurrences (Ribes & Nesme-Ribes 1993; Muñoz-Jaramillo & Vaquero 2019), and apparent loss of solar coronal streamers (Riley et al. 2015; Owens et al. 2017; Hayakawa et al. 2021). This period is generally considered a grand solar minimum and used as a standard reference for other grand minima identified in the proxy data of cosmogenic isotopes (Solanki et al. 2004; Usoskin et al. 2007, 2014; Inceoglu et al. 2015; Muscheler et al. 2016; Brehm et al. 2021). The other peculiar “prolonged solar minimum” in the chronological coverage of the direct sunspot observations has been named as the Dalton Minimum after John Dalton (Dalton 1834; Hayakawa et al. 2020b; Silverman & Hayakawa 2021). Its relationship with the Maunder Minimum has been somewhat controversial. Some have expected a similar physical mechanism (e.g., Zolotova & Ponyavin 2015), whereas others have considered them significantly different in physical mechanism (Vaquero et al. 2015; Usoskin et al. 2015; Charbonneau 2020; Petrovay 2020). Challengingly, as reviewed in Figure 2 of Muñoz-Jaramillo & Vaquero (2019), the composite data series of currently available sunspot group numbers significantly varied around the Dalton Minimum (e.g., Lockwood et al. 2014; Clette & Lefèvre 2016; Svalgaard & Schatten 2016; Usoskin et al. 2016; Chatzistergos et al. 2017), even after extensive revisions and recalibrations of sunspot group numbers (Clette et al. 2014; Vaquero et al. 2016) following the initial compilations in Hoyt & Schatten (1998a, 1998b) (=HS98). Even worse, little has been known about sunspot positions during the Dalton Minimum, whereas its peculiarity has significant indications to the long-term
solar variability and its background solar-dynamo activity (e.g., Usoskin 2017; Muñoz-Jaramillo & Vaquero 2019; Charbonneau 2020). As all the existing solar-irradiance reconstructions during the Maunder Minimum and the Dalton Minimum have relied on sunspot data or cosmogenic isotopes, their revisions and recalibrations potentially improve the reconstructions for solar-irradiance fluxes and their impact estimates for the terrestrial climate (e.g., Solanki et al. 2013; Anet et al. 2014; Kopp et al. 2016; Lean 2017; Berrilli et al. 2020).

The initial difficulties are partly originated from the limited accessibility to the original— and often unique—source documents. Considerable amounts of long-term observational records are preserved in the historical archives and hence are difficult to access, as partially documented in the bibliographic supplements in HS98. However, understanding of sunspot activity during the Dalton Minimum has gradually been improved with new observational evidence and efforts to recalibrate the sunspot group number (Clette et al. 2014). Short-term observations have been added to the existing data sets (Denig & McVaugh 2017; Hayakawa et al. 2018; Carrasco et al. 2018), and the original manuscripts of Derfflinger’s long-term observations from 1802 to 1824 have been reanalyzed to revise sunspot group numbers and derive sunspot positions to emphasize contrasts with the Maunder Minimum (Hayakawa et al. 2020a). Significant solar coronal streamers were confirmed in the Dalton Minimum (Hayakawa et al. 2020b), in contrast with the Maunder Minimum (Eddy 1976; Riley et al. 2015; Hayakawa et al. 2021). Still, these analyses require further additional evidence, especially because the Dalton Minimum allowed only Derfflinger’s data sets to be fully studied both in terms of the long-term sunspot group number and sunspot positions.

In this context, Stephan Prantner’s intermittent but long observations (1804–1844) provide a series of interesting contextual data sets during the Dalton Minimum and relatively rich observational data (115 days). However, Prantner’s data in the existing data sets (HS98; V+16) are not constructed from the original documents but estimated from his individual spot number (f) and other observers’ data at that time. HS98 themselves explicitly admitted that they could not access all of the data in their online bibliography: “We have seen some of these observations, but may not have all of them in our database.” This is further confirmed by Douglas Hoyt’s letter correspondence with Fritz Steinegger of the Stiftsarchiv Wilten on 1994 May 13, which is registered as MS 07 03 20 in this archive. Here, Douglas Hoyt confirmed to have received “the number of individual sunspots and not the number of sunspot groups” and “constructed estimates of the number of sunspot groups based on other observers,” whereas “copies of the sunspot drawings could not be made and sent to me [Douglas Hoyt].” This letter correspondence indicates that Prantner’s data in the existing data sets are not empirical data acquired from the original manuscript but estimates with his individual sunspot number (f) and contemporary observations. These estimates were acquired in the revised database (V+16) without revision. Therefore, we consulted Prantner’s original manuscript in the Stiftsarchiv Wilten and derived the sunspot group number and sunspot positions on their basis. Section 2 reviews Prantner’s personal profile and observational method. Section 3 derives his daily sunspot group number and compared them with contemporary observations both on daily and annual bases. Section 4 derives sunspot positions from his manuscript and constructed a butterfly diagram. Section 5 summarizes these results and compares them with the known data in the Maunder Minimum and the modern solar cycles.

2. Prantner’s Personal Profile and Observational Methods

Stephan Prantner was a clergyman and a teacher who worked in Tyrol. He was born on 1782 June 23 at Innsbruck and died on 1873 May 18 at Wilten. He studied at Innsbruck, particularly preferring mathematics and natural science. He joined a student legion against the French invasion in 1799. He later joined the Premonstratensians at Wilten Monastery (Figure 1) in 1800, took the vow in 1803, and was consecrated as a priest at Brixen in 1805. After its abolition by the Bavarian government in 1807, he settled as a vicar in the Tyrolian municipality Waidring near Kitzbühel in the archdiocese of Salzburg. He returned to Wilten in 1816. He became a professor of physics and mathematics and from 1836 a subprior of the Wilten Monastery. Throughout his career, Prantner worked on astronomy, meteorology, mineralogy, and botany, and conducted meteorological and astronomical observations for almost half a century (Anonymous 1873; Kosch 1937; Stift Wilten 1889).

His manuscripts are currently preserved in Stiftsarchiv Wilten (Figure 1). Of these, Prantner’s sunspot drawings are preserved as a small pamphlet in MS A07 03 07. This manuscript is entitled Zu den Heften der Tagebücher | Physisch-Astronomischer Beobachtungen und Ereignisse | Beobachtete Mittags Sonnen-Höhen im Stifte Wilten | von Stephan Prantner. Canonie. Wilten, which reads: “The journal diary of physical-astronomical observations and events. | Observations of midday solar altitudes in Stift Wilten | by Stephan Prantner canonicis at Wilten.” His pamphlet has two sections, as exemplified in Figure 2. The first section is entitled Abbildungen | beobachteter Sonnen-Flecken | vom Anfang des Jahres 1812 bis Ende | des Jahres 1815 | beobachtet und gezeichnet von Stephan Moritz Prantner, which reads “Drawings of observed sunspots from the beginning of 1812 to the end of 1815 observed and drawn by Stephan Moritz Prantner.” The second section is entitled Beobachtete und gezeichnete Abbildun gen der Sonnenflecken von Stephan Prantner Canonic Wilten, which reads “Observed and drafted images of sunspots by Stephan Prantner canonicus Wilten.”

The sunspot observations in these pamphlets were dated to 1804 and 1812–1815 (the first pamphlet); and 1816, 1826–1827, and 1844 (the second pamphlet). Prantner clarified his observational sites as Wilten (N47°15, E11°24) in 1804 (MS A07 03 07, f. 1), Waidring (N47°35, E12°34) in 1812–1815 (MS A07 03 07, ff. 2–13), and Wilten after 1816 (MS A07 03 07, f. 14). The described transition of his observational sites is broadly consistent with his career reviewed above (Anonymous 1873). Prantner explained the observational gap between 1804 and 1812 with time shortage and circumstantial difficulties as well as his residential movements in this interval (MS A07 03 07, f. 1).

Prantner used at least two telescopes. His early observations (1804–1815) were performed with a 3.5 inch astronomical telescope; the sunspots observed through this telescope were drafted with inverted images (MS A07 03 07, f. 0b). Prantner used a Reichenbach 4 foot achromatic erecting telescope for his latter observations and depicted sunspots in erect images, unless otherwise endorsed (MS A07 03 07, f. 15). Further details are difficult to locate, as some of his early instruments and books seemed to have been lost during the French invasions (Anonymous 1873).
3. Sunspot Group Number

We consulted Prantner’s manuscript (MS A07 03 07) and identified his sunspot observations for 215 days in 1804, 1812–1816, 1826–1827, and 1844. We have summarized these data in https://www.kwasan.kyoto-u.ac.jp/hayakawa/data/. In comparison with the existing data in V’s observations were most active in Solar Cycle 6 from 1812 to 1816. Thus, it is notable to identify a spotless day in 1816, immediately after the maximum in 1816 May. This spotless day is also confirmed in Tevel’s data on the same date (V+16).

We have computed the annual averages of Prantner’s sunspot group number and compared them with those of Derfflinger’s sunspot group number (Hayakawa et al. 2020a) and the yearly sunspot group number in Chatzistergos et al. (2017), which was evaluated as the “most recommendable version for further analysis” in Petrovay (2020). For the sunspot group number data, we have derived the error margins with standard deviations of individual data, following the procedures in the SISLO. Their results are summarized in Figure 4. On their basis, Prantner’s sunspot group number is almost comparable with or slightly larger than Derfflinger’s in his early observations (1804 and 1812–1815), whereas Prantner’s late observations are significantly larger than Derfflinger’s in 1816.

We have also compared their quasi-simultaneous observations on the same dates. Here, we have detected 24 days of their sunspot group number in Chatzistergos et al. (2017), following the use of different telescopes. Prantner recorded up to seven groups in the former half (1815 July 6) and nine groups in the latter half (1816 October 5–6). Prantner’s record on 1815 July 6 is consistent with von Lindener’s observations on 1815 July 5–6 (7 groups in V+16), whereas his data on 1816 October 5–6 significantly exceed von Lindener’s on 1816 October 5 (five groups in V+16). Prantner recorded only one spotless day (1816 August 24). Additionally, these data explicitly show the ascending phase of Solar Cycle 6 from 1812 to 1816. Thus, it is notable to identify a spotless day in 1816, immediately after the maximum in 1816 May. This spotless day is also confirmed in Tevel’s data on the same date (V+16).

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Figure 2. Examples of Prantner’s sunspot drawings. (a) The figure above shows his early sunspot drawings from 1813 September 23 to 24 (MS A07 03 07, f. 6). (b) The figure below shows his late drawings on 1816 April 9 and 1816 October 5 (MS A07 03 07, f. 16 and f. 27b). These images are reproduced with courtesy of the Stiftsarchiv Wilten.
overlapping observations on the same dates. On their basis, the annual averages of Prantner’s and Derfflinger’s turn out: 2.5 ± 0.5 versus 1.5 ± 0.5 in 1804, 1 versus 1 in 1812, 1.5 ± 0.2 versus 1.5 ± 0.2 in 1813, 1.5 ± 0.5 versus 2 in 1814, and 2.5 ± 0.2 versus 2.3 ± 0.3 in 1816. This result implies the Prantner’s sunspot group number agree with Derfflinger’s simultaneous observations within standard deviations. In this case, enhancements in Prantner’s sunspot group number in 1816 may be considered real rather than instrumental issues, as his observations were much richer in 1816 (for 83 days). In fact, Prantner reported the Sun with a significantly increased sunspot activity on the days in 1816 May, June, and early October, when Derfflinger did not conduct observations (see Hayakawa et al. 2020a). These intervals include 1816 October 5–6, when Prantner reported nine sunspot groups, for example. Considering the different reconstructions of sunspot group number series over that period (e.g., Figure 5 of Chatzistergos et al. 2017), these results seem more consistent with those of Usoskin et al. (2016) and Chatzistergos et al. (2017), in contrast to HS98 and Svalgaard & Schatten (2016). Therefore, it is possible that SC6 was slightly larger than SC5, as recorded in Prantner’s observations. This requires us to examine further long-term observers’ data during the Dalton Minimum on the basis of their original archival documents.

Caveats must be noted here. Except for his core observations in 1812–1816, his observations (those in 1804, 1826–1827, and 1844) involve only ≤ 5 days for each year and cannot fully represent their annual averages. As also shown here, both Prantner and Derfflinger show their annual sunspot group number ≥ 1. This is because spotless days were reported only once in Prantner’s observations and not in Derfflinger’s. Therefore, Prantner’s report for a spotless day in 1816 is extremely important and his annual averages have been slightly exaggerated than reality due to his general omissions of the spotless days. These caveats require us to be cautious for the exaggeration of the solar-cycle amplitudes around the Dalton Minimum, whereas their daily data still form ground truth in contrast with their annual averages.

4. Sunspot Positions

We measured sunspot positions in Prantner’s sunspot drawings and constructed a butterfly diagram. The orientations of the sunspot drawings in the early (1804–1815) and late (from 1816 to 1844) observations vary significantly. Prantner’s
manuscript explains his telescopes showing inverted images in the early observations and erect images in the late observations (MS A07 03 07, f. 0b and f. 15). This description is confirmed with the sunspot motions from right to left and from left to right in the early and late drawings, respectively. Therefore, the early drawings must be inverted both vertically and horizontally, and the late drawings should be compared with the solar disk as seen in the sky in terms of their orientations. Prantner also described the raw disk orientations as viewed through his telescopes in the folio margins of his manuscript for his early drawings and at the first sunspot drawing for his late observations.

We inferred Prantner’s disk orientations with the recorded local time and sequential motion of individual sunspot groups. Prantner recorded time stamps for each sunspot drawing with local time (MS A07 03 07, f. 0b) and recorded the sequential motion of the same sunspot groups, probably due to his interest in solar rotation. We used two methods to fix the position angle of the solar disks in Prantner’s manuscript. For sunspot drawings recorded in a chronological sequence, we tracked the same sunspot groups and minimized their latitudinal variations with rotational matching (see, e.g., Arlt et al. 2013). For chronologically isolated sunspot drawings, we assumed the position angle from the described local time using the ephemeris of JPL DE430 (Folkner et al. 2014).

Fixing the position angle of Prantner’s sunspot drawings, we measured the heliographic coordinates of the depicted sunspot groups. Note that Prantner also made position measurements for some of the observed sunspots and solar radius on some dates, whereas they do not cover all his sunspot observations (Figure 2). In particular, in his late observations, Prantner’s position measurements are limited for specific groups. Therefore, as a matter of consistency, we measured the sunspot positions from Prantner’s drawings for the entire period. Here, we have used our own photographs, in order not to damage the original manuscript (see also MS 07 03 20). In order to minimize their geometrical distortion, we have manually detected the described disk limbs and geometrically fitted the depicted disk limbs to circles following the procedures in Fujiyama et al. (2019). Thus, we have derived the apparent sunspot positions in the sunspot drawings with circle fitting and modified their disk orientations following the position angle for each drawing.

We measured the heliographic coordinates of each sunspot group, constructed butterfly diagrams (Figure 5), and showed the sunspot population of each bin for 6 month periods in chronological order and for 1° heliographic latitude increments, and marked their concentrations in blue to red. The populations of sunspot groups in significantly high heliographic latitudes (≈50°) are notably small within the entire data set and could be attributed to lower accuracy. In fact, the majority of sunspots remain within |30°| and provide insights on Solar Cycles 5, 6, 7, and 9.

Prantner’s butterfly diagram immediately visualizes sunspot distributions in both solar hemispheres. These results are consistent with Derfflinger’s sunspot drawings during 1802–1824 (Hayakawa et al. 2020a) and contrasted with those of the Maunder Minimum, when sunspot groups were mostly concentrated in the southern solar hemisphere (Ribes & Nesme-Ribes 1993; Muñoz-Jaramillo & Vaquero 2019). Prantner’s core observations from 1812 to 1816 show slight equatorial migrations of recorded sunspots and agree with the chronological context of the ascending phase from 1810 August and the maximum in 1816 May (Tables 1–2 of Hathaway 2015). Prantner’s observations in 1804, 1826–1827, and 1844 are situated shortly before the maximum of Solar Cycle 5 (1805 February), in the ascending phase of Solar Cycle 7 (1829 November), and immediately after the minimum of Solar Cycle.
8/9 (1843 July), respectively (Tables 1–2 of Hathaway 2015). These chronological contexts are consistent with the relatively large latitudinal scattering of the observed sunspot groups in these years.

5. Summary and Discussions

In this article, we analyzed Stephan Prantner’s sunspot observations. We first reviewed his life from 1782 to 1873. Prantner worked in the Premonstratensians at Wilten Monastery beginning in 1800, received formal education in mathematics and astronomy, and became a professor of physics and mathematics and a subprior of Wilten Monastery in 1836.

Prantner’s sunspot observations are currently preserved in the MS A07 03 07 of the Stiftsarchiv Wilten and are dated to 1804, 1811–1816, 1826–1827, and 1844. We located his observational sites as Wilten (N47°15, E11°24) in 1804, Waidring (N47°35, E12°34) in 1812–1815, and Wilten from 1816 onward, and clarified that Prantner primarily used a 3.5 inch astronomical telescope in his early observations (1804–1815) and a Reichenbach 4 foot achromatic erecting telescope in his later observations to show inverted and erect solar images, respectively.

We consulted his manuscripts, identified 215 days of datable sunspot observations, and doubled the data in comparison with his previous group number in HS98 and V+16 (=115 days), which were estimated from Prantner’s individual spot number (f) and contemporary observers’ group number in HS98. We applied the Waldmeier classification and derived the sunspot group number (Figure 3). Prantner recorded up to seven and nine groups in his early and late observations, respectively, and reported only one spotless day in 1816, immediately after the maximum of Solar Cycle 6. We also confirmed that Prantner’s observations are generally consistent with contemporary observations.

We measured Prantner’s sunspot positions and constructed a butterfly diagram (Figure 5), which shows sunspot groups in both solar hemispheres like Derflinger’s (Hayakawa et al. 2020a). Prantner’s core sunspot position observations show possible equatorial migration in Solar Cycle 6. Additionally, Prantner’s sunspot groups are shown near the maximum of Solar Cycle 5, in the ascending phase of Solar Cycle 7, and immediately after the minimum of Solar Cycles 8/9.

These results strikingly contrast the Dalton Minimum with the Maunder Minimum, in which the few reported sunspot groups (Usoskin et al. 2015; Vaquero et al. 2015) were mostly confined to the southern solar hemisphere (Ribes & Nesme-Ribes 1993). These observations during the Dalton Minimum appear much more consistent with low-amplitude solar cycles, such as Solar Cycle 24. Prantner’s sunspot observations show up to seven to nine sunspot groups and distributions in both solar hemispheres.

Our analyses of Prantner’s sunspot observations significantly improve the data for sunspot group number and sunspot positions during the Dalton Minimum. These results robustly confirm its difference with the Maunder Minimum and similarities with low-amplitude solar cycles in secular minima. Therefore, the Dalton Minimum is not similar to the Maunder Minimum (e.g., Zolotova & Ponyavin 2015) but is likely to have a different physical background against the Maunder Minimum (e.g., Usoskin et al. 2015). This conclusion agrees with the significant differences in solar coronal streamers during the Maunder Minimum and the Dalton Minimum (Riley et al. 2015; Hayakawa et al. 2020b, 2021).

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Data Availability

Prantner’s original manuscript is preserved as MS A07 03 07 in the Manuscript Department of the Stiftsarchiv Wilten.
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