



Daniel Mögling’s Sunspot Observations in 1626–1629: A Manuscript Reference for the Solar Activity before the Maunder Minimum

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Abstract

The sunspots have been observed since 1610, and their group numbers have been used for evaluating the amplitude of solar activity. Daniel Mögling recorded his sunspot observations for more than 100 days in 1626–1629 and formed a significant data set of sunspot records before the Maunder Minimum. Here we have analyzed his original manuscripts in the Universitäts- und Landesbibliothek Darmstadt to review Mögling’s personal profile and observational instruments and derived the number and positions of the recorded sunspot groups. In his manuscript, we have identified 134 days with an exact sunspot group number and 3 days of additional descriptions. Our analyses have completely revised the observational dates and group numbers, added 19 days of hitherto overlooked observations, and removed 8 days of misinterpreted observations. We have also revisited the sunspot observations of Schickard and Hortensius and revised their data. These results have been compared with the contemporary observations. Moreover, we have derived the sunspot positions from his sunspot drawings and located them at 2° – 23° in heliographic latitude in both solar hemispheres. Contextualized with contemporary observations, these results indicate their temporal migration to lower heliographic latitudes and emphasize their location in the declining phase of solar cycle –12 in the 1620s. Mögling’s observations were probably conducted using a pinhole and camera obscura, which likely made him underestimate the sunspot group number by $\geq 33\%$ – 52% . This underestimation should be noted upon comparison with modern data sets.

Unified Astronomy Thesaurus concepts: Sunspot cycle (1650); Sunspot groups (1651); Sunspot number (1652); Solar cycle (1487); History of astronomy (1868); Solar-terrestrial interactions (1473); Maunder minimum (1015)

1. Introduction

Daily records of sunspot observations have formed an essential basis for evaluating long-term solar activity since 1610. This data series has often been considered one of the longest ongoing scientific experiments in modern science (Owens 2013; Vaquero et al. 2016; Arlt & Vaquero 2020). After the initial modern compilation of the comprehensive data set of sunspot group number in Hoyt & Schatten (1998a, 1998b, hereafter HS98), recent studies have continuously recalibrated and improved these data series to revise the overall long-term trends (e.g., Clette et al. 2014; Clette & Lefèvre 2018). Investigations of the original observational records have formed the basis for these analyses (Vaquero et al. 2011, 2016; Arlt et al. 2013; Usoskin et al. 2015; Carrasco et al. 2015; Svalgaard 2017). They have offered a ground truth for further recalibrations using sophisticated methods (Vaquero et al. 2016, hereafter V+16; Clette & Lefèvre 2018). However, as depicted in Figure 2 of Muñoz-Jaramillo & Vaquero (2019), it is challenging to extend these analyses beyond the mid-19th century, and their reconstructions remain somewhat controversial (Svalgaard & Schatten 2016; Usoskin et al. 2016, 2021; Chatzistergos et al. 2017; Willamo et al. 2017; Clette & Lefèvre 2018), especially toward and beyond the Maunder Minimum (e.g., Usoskin et al. 2015; Vaquero et al. 2015; Zolotova & Ponyavin 2015).

Even after the compilation of the revised database for historical sunspot observations (V+16), such reanalyses are ongoing efforts that have modified a number of historical observational data sets (e.g., Arlt 2018; Hayakawa et al. 2018a, 2018b; Carrasco et al. 2019c, 2019a; Karoff et al. 2019), including long-term observations around the Maunder Minimum (e.g., Carrasco et al. 2019b; Hayakawa et al. 2020b, 2021) and the Dalton Minimum (Hayakawa et al. 2020a). Sunspot drawings of the early 17th century are of particular interest, as they provide unique evidence for solar activity before the Maunder Minimum, and even moderate revisions or additions can update the existing understanding (e.g., Vaquero et al. 2011; Carrasco et al. 2019c). The major observers’ observational records before the Maunder Minimum have recently been analyzed to improve sunspot group numbers and derive sunspot positions (Arlt et al. 2016; Vokhmyanin & Zolotova 2018a, 2018b; Carrasco et al. 2019a, 2019c, 2020; Vokhmyanin et al. 2020, 2021). These results have characterized solar cycles before the Maunder Minimum (with both sunspot group number and butterfly diagrams), clarified their significant discontinuity with the Maunder Minimum, and formed a basis for improving solar dynamo models (e.g., Hotta et al. 2019; Charbonneau 2020). On the other hand, their sparse availability requires further data to improve their reconstructions (Muñoz-Jaramillo & Vaquero 2019).



Figure 1. Merian’s copper print of one of Mögling’s observatories at Butzbach, adopted from Zeiller & Merian (1646). His observatory was depicted on the right side of the castle, with the balustrade around the tower with a spherical top. In addition, he had placed a large telescope in the other observatory in the garden (Rösch 1975; Rößling 2010; Popplow 2013).

In this context, little is known about Daniel Mögling’s sunspot observations, whereas this observer, called “Mogling” in HS98 and V+16, has been considered the fifth most active sunspot observer before the onset of the Maunder Minimum, following Scheiner, Hevelius, Harriot, and Malapert (see HS98 and V+16), and even more active than Galilei and other contemporary observers (e.g., Vokhmyanin & Zolotova 2018a; Carrasco et al. 2020). His observations span 1626–1629 and form one of the important data sets during solar cycle –12 in the 1620s (e.g., Figure 27 of Arlt & Vaquero 2020). Locating his autographed manuscript at the Universitäts- und Landesbibliothek Darmstadt (ULBD), we analyzed his sunspot observations and clarified his data and metadata. Here we first profiled his biographical background, observational instruments, and the philological details of his observational records (Section 2). We then analyzed his observational records to derive sunspot group numbers in the Waldmeier classification, revise the existing data, and include forgotten data (Section 3). Using the revised data, we also derived the sunspot positions recorded in his sunspot drawings (Section 4). We have summarized and contextualized these results in comparison with contemporary sunspot observations, including those of Schickard and Hortensius, revised in this paper (Section 5).

2. Daniel Mögling and His Observations

Daniel Mögling (1596–1635) was born in Böblingen near Stuttgart and raised by his mother because his father, a physician, passed away soon after his birth in an epidemic. Members of his family had been professors at the University of Tübingen for several generations. Daniel entered the same university in 1611 April, where he received his bachelor’s and master’s degrees in philosophy in 1612 September and 1615 February, respectively. After a year of academic peregrination, he enrolled in medical studies at the University of Altdorf near Nürnberg. He then returned to the University of Tübingen at the end of 1618 and finished his studies in 1621. His interests also extended to physics and, in particular, astronomy. In 1621 May, he started his almost lifelong occupation as a court physician under Philipp III (1581–1643), Landgrave of Hessen-Butzbach. According to his employment contract, Mögling was also required to work on mathematics and astronomical observations (Rosen 2003).

During the course of his profession, he got in touch with several important contemporary astronomers, such as Wilhelm Schickard (1592–1635) and Johannes Kepler (1571–1630). In fact, Kepler visited his observatories at Butzbach ($N50^{\circ}26'$, $E8^{\circ}40'$; see also Figure 1) at least twice, in 1621 July and 1627 September (Rösch 1975). The contract between Mögling and Landgrave was canceled in 1635, probably because of the approach of the Thirty Years’ War to Butzbach. Landgrave Philipp recommended Mögling to his nephew Georg II of Hessen-Darmstadt for a position at the University of Marburg (today Marburg an der Lahn), but before its realization, Mögling died of plague in 1635 August in Butzbach (Neumann 1995).

Mögling had at least three instruments for solar observations, according to his inventory manuscript dated 1628 November (ULBD Hs¹⁰ 3020). Here we have located descriptions of a black wooden tube for observing the solar radii (No. 87 in ULBD Hs 3020, f.¹¹ 15a), a gilded sphere with an eye-tube for solar spots (No. 123 in ULBD Hs 3020, f. 15b), and a silver-style rod eye-tube, 4 feet long, for observing the Sun’s position (No. 151 in ULBD Hs 3020, f. 16a). Accordingly, we consider that Mögling measured the Sun’s position and radii with instruments Nos. 151 and 87 and monitored sunspots with instrument No. 123.

Kepler’s description allows us to confirm this supposition and even indicates Mögling’s records of sunspots shown in the projected images. Upon his visit to Butzbach in 1627, Kepler stated, “In an open and spacious place, a thirty-foot-high stake is fixed; at the top, a pulley is placed, through which a capstan cable is passed and it surrounds a fifty-foot-long tube, driven with great difficulty by six robust men from its ridge; this tube is raised to such a height that, through its hole, which is the size of a pea, a lens, or even a grain of millet, the Sun projects its rays onto an opposite white shelf, which terminates the cavity of the tube at its bottom. On the tablet, then, one can clearly distinguish the sunspots, which are formed by the simple hole, without the interposition of any convex glass” (Kepler 1629; Kepler 1983; see also Jeandillou & Mehl 2018, p. 68). Kepler further described Mögling’s interest in the motions of sunspots,

¹⁰ Here “Hs” is an abbreviation of “*Handschrift* (manuscript)” used as a part of the shelf mark.

¹¹ Here we describe a singular folio as “f.”

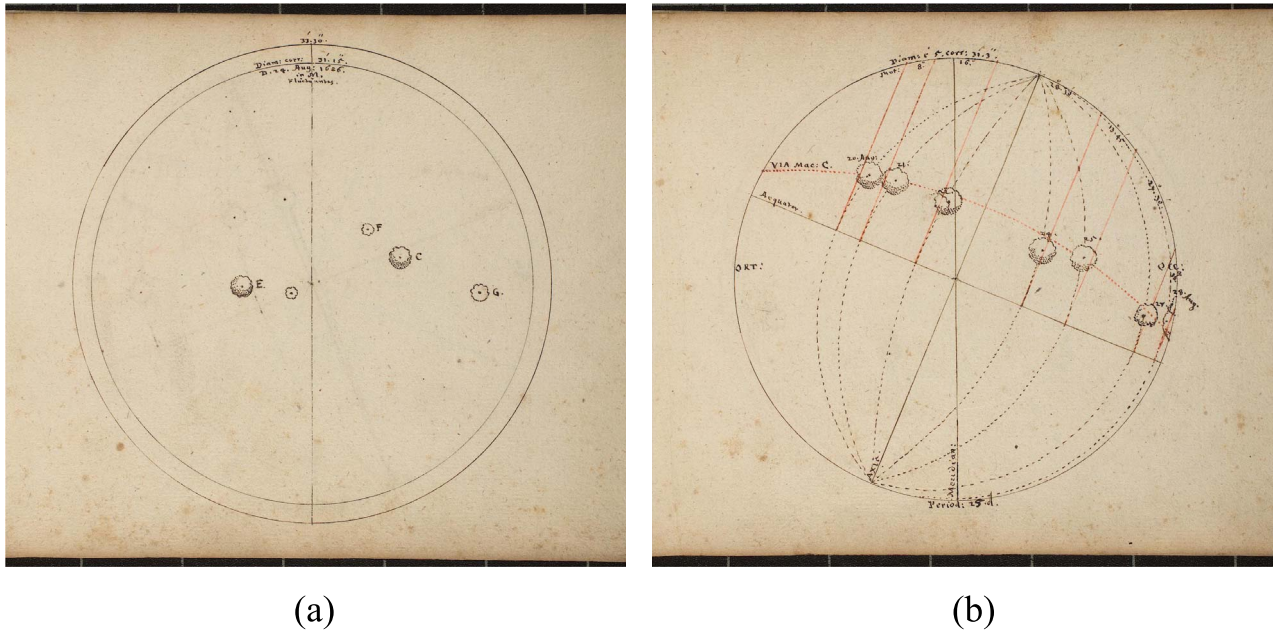


Figure 2. Examples of Mögling’s sunspot drawings for his daily observations and motion tracking of specific sunspot groups. (a) His whole-disk sunspot drawing on 1626 September 3 (ULBD Hs 228, f. 8a). (b) His motion tracking of sunspot group “C” on 1626 August 30–September 7 (ULBD Hs 228, f. 10a). ©Universitäts- und Landesbibliothek Darmstadt. It should be noted that the dates, shown according to the Julian calendar, have been converted to the Gregorian calendar in this paper.

their seasonal inclinations, and their existence on the solar surface. Kepler witnessed his sunspot drawings showing their motions.

Mögling’s drawings were later compiled in a manuscript, “*Observationes macularum Solis* (Observations of Sunspots),” which is currently preserved in the ULBD as Hs 228, compiled probably between 1629 and 1635. This manuscript consists of 38 *folia* (hereafter, *ff.*) and involves sunspot drawings dated from 1626 June 23 to 1629 June 16. Mögling depicted two kinds of sunspot drawings: individual drawings for his daily observations and summarized drawings for motion tracking of specific sunspot groups (Figure 2), probably owing to his interest in the solar rotation period (e.g., Hoyt & Schatten 1997, p. 20). Initially, he used small sunspot drawings ($\phi^{12} \approx 3.4$ cm) for his early daily observations (ULBD Hs 228, *ff.* 1a–1b) and medium sunspot drawings ($\phi \approx 7.0$ cm) for tracking the motion of specific sunspot groups (ULBD Hs 228, f. 2a). After 1626 August, he regularly depicted a large sunspot drawing ($\phi \approx 12.6$ cm) on each folio until the end of his observations.

3. Sunspot Group Number

Consulting ULBD Hs 228, we acquired 137 days of Mögling’s sunspot observations, applied the Waldmeier classification, and summarized the results in Figure 3.¹³ His sunspot observations are found not only in his sunspot drawings (covering 103 days) but also in his textual descriptions for 34 days. Although they mostly describe spotless days, he reported several spots in three of these descriptions (1626 October 16 and 20 and 1627 March 3). As these descriptions are only small text pieces like “several sunspots (*cum maculis* or *aliquibus maculis*),” we were able to use them just for calculations of active-day fractions (ADFs). These textual records hindered us from deriving their sunspot

group number. Thus, our summary includes 134 of Mögling’s datable sunspot observations, excluding these active-day reports.

Comparing our results with the existing databases (HS98 and V+16), we have realized that Mögling’s observations in these data sets were interpreted according to the Gregorian calendar and incorporated as described in his manuscript, whereas Darmstadt was under Lutheran confession and using the Julian calendar at the time of Mögling’s observations (e.g., Gingerich 1983). In fact, his correspondence with Schickard followed the Julian calendar, dating 1626 July 23 as Sunday, 1626 September 27 as Wednesday, and 1629 February 26 as Thursday, for example (Seck 2002). Therefore, the dates of these observations should be converted from the Julian calendar to the Gregorian calendar for scientific comparison with other contemporary sunspot observations. Apart from this overall calendar issue, we have included 19 days of hitherto overlooked observations, revised three of the Julian dates, and removed 8 days of misinterpreted observations.

Mögling’s sunspot group number has been revised throughout and shows lower values than the existing databases (HS98 and V+16), where the individual sunspots in the same group had occasionally been split. Still, Mögling recorded multiple sunspot groups up to five in his observations and was probably free from the arbitrary selection of the observed sunspots, which was often the case with contemporary sunspot observers (see Carrasco et al. 2019c). Mögling actively recorded spotless days in 1626–1627. His reports of the spotless days may further benefit future analyses in ADFs in combination with other contemporary observations.

Mögling’s data compare well with contemporary observations (e.g., Vaquero et al. 2016; Carrasco et al. 2019a), as shown in Figure 3. Here we have also consulted the records of Hortensius and Schickard, who were based in the Protestant cities of Leiden and Tübingen that used the Julian calendar at that time. We have revised their observational data as well. This is confirmed from the dating in Schickard’s

¹² Here we abbreviate “diameter” as ϕ .

¹³ <https://www.kwasan.kyoto-u.ac.jp/~hayakawa/data>

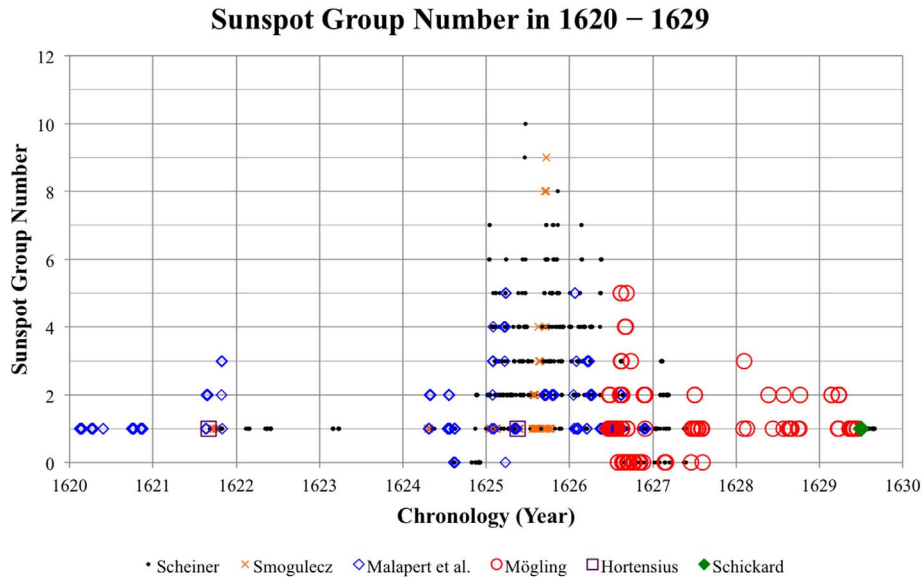


Figure 3. Sunspot group number in 1620–1629, based on contemporary sunspot observations. Among them, those of Mögling, Hortensius, and Schickard are revised in our study, whereas those of Malapert et al. are derived from Carrasco et al. (2019a) and those of Scheiner and Smogulecz are derived from Vaquero et al. (2016).

correspondence, such as the identification of 1626 July 29 as Saturday and 1626 October 1 as Sunday. In the case of Hortensius, we have revised his observation to 1625 May 25 and added another observation on 1621 September 20 (Hortensius 1633, p. 65). For Schickard, we have revised one observation to 1629 July 16 (Schickard 1632, p. 10) and removed his observations on 1621 January 9–11, as they were not recorded in either of HS98’s alleged sources: Schickard (1632) or Wolf (1850, p. 119). Figure 3 depicts Mögling’s sunspot observations in the declining phase of solar cycle –12, in comparison with other contemporary observations including Schickard and Hortensius, which have been revised in this paper.

4. Sunspot Positions

On the basis of ULBD Hs 228, we also analyzed the sunspot positions in Mögling’s sunspot drawings to construct a butterfly diagram. As shown in Figure 2, Mögling recorded not only the daily whole-disk drawings but also drawings for the motions of specific sunspot groups. We have combined them to derive the sunspot positions. On their basis, we consider that these sunspot drawings are upside down. Despite his controversial annotations of the disk orientations around some of his sunspot drawings, the recorded sunspot groups generally move from left to right (see Figure 2(b)). This indicates the E–W orientations in his drawings set as E on the left and W on the right. Their N–S directions are inferred from the comparisons of the recorded inclinations of the sunspot motions and the B0 angles for their observational dates. For instance, in early 1626 September (Figure 2(b)), the B0 angles are calculated as $\approx 7^\circ$. This matches best with the recorded inclination of the sunspot motion when this drawing is shown upside down. This trend has been universally confirmed throughout Mögling’s sunspot drawings, as long as their sunspot motions can be tracked in chronological sequence. Therefore, it is considered that Mögling depicted sunspot drawings upside down, with the E–W directions shown from left to right. This interpretation is consistent with Kepler’s

description of Mögling’s instrument that projected sunspot images on a sheet of paper.

We derived the sunspot positions on this basis. We used the scanned images of Hs 228. We fitted depicted disk limbs to the circle, adjusting their disk centers. When they were geometrically distorted and either vertically or horizontally too large to be a circle, we have modified the larger diameter to fit the limbs to the circle, following the procedure of Fujiyama et al. (2019). We have derived the sunspot positions for the drawings that depict sunspot motion tracking of specific groups (e.g., Figure 2(b)), minimizing the latitudinal deviations of each sunspot group. After deriving the sunspot positions for specific groups, we applied their estimated positions to the whole-disk drawings for the daily observations to constrain the disk orientations (e.g., Figure 2(a)). This enabled us to derive the minor sunspot groups whose motions were not tracked by Mögling himself in his manuscript ULBD Hs 228.

Our results are summarized in Figure 4, which shows a comparison with the existing sunspot positions derived from Scheiner’s and Malapert’s observational accounts (Arlt et al. 2016; Carrasco et al. 2019a). Mögling’s sunspot positions fill the chronological gaps in these existing data sets. In 1626, they are located at 2° – 23° in both solar hemispheres. Afterward, their distributions shift more equatorward, still showing sunspots in both solar hemispheres. As such, especially in 1627–1629, Mögling’s sunspot distributions were biased slightly more in the northern solar hemisphere and seemed to show a trend similar to Scheiner’s sunspot positions in 1629 (Arlt et al. 2016). Their overall distributions are consistently contextualized in the declining phase of solar cycle –12, as confirmed by Scheiner’s and Malapert’s accounts (Figure 4). This result contrasts this cycle with the Maunder Minimum, where most of the sunspot positions were reported only in the southern solar hemisphere (Ribes & Nesme-Ribes 1993). In turn, this trend is consistent with the positions of the reported sunspots in Gassendi’s and Hevelius’s accounts (Vokhmyanin & Zolotova 2018b; Carrasco et al. 2019b).

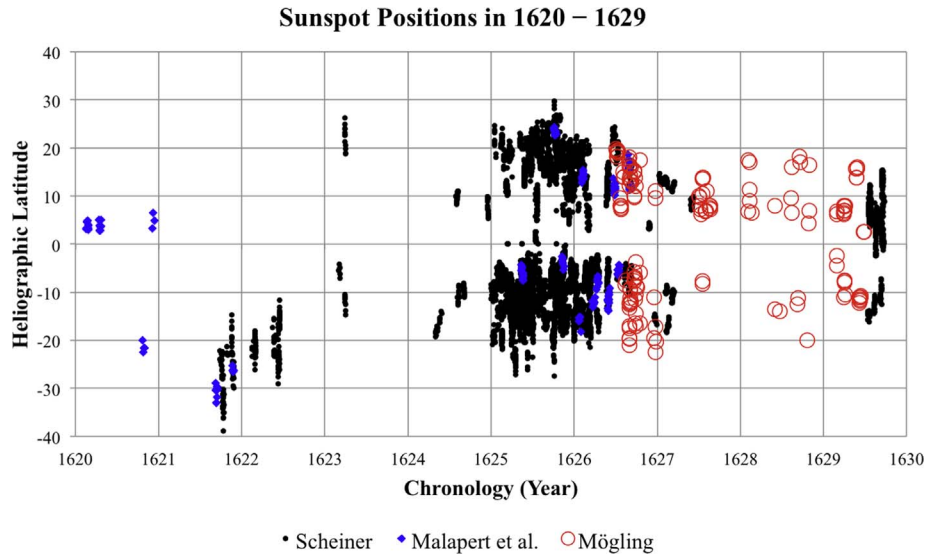


Figure 4. Sunspot positions in 1620–1629, consisting of the sunspot observations of Scheiner (Arlt et al. 2016), Malapert et al. (Carrasco et al. 2019a), and Mögling (this study).

5. Discussions

Mögling’s manuscripts (ULBD Hs 228 and Hs 3020) and Kepler’s contemporary records indicate that his small and large drawings were the observational results of different instruments: the gilded sphere with the eye-tube (No. 123 in ULDB Hs 3020) and the black wooden tube (No. 87 in ULDB Hs 3020). The small drawings show sunspots with various time stamps without their solar diameter. This indicates that his observational instrument was likely compact and capable of tight turns. The large drawings show sunspots and solar diameters, indicating the usage of the black wooden tube for “observation of the solar radii.” This is consistent with the large tube(s) documented in Kepler’s report. The size of the aperture was probably ≤ 1 cm, as it was compared with “the size of a pea, a lens, or even a grain of millet,” while six example sizes of tube aperture were noted in Mögling’s manuscript (ULBD Hs 228, *f.* 2b; see also Jeandillou & Mehl 2018, p. 71). Their time stamps were mostly around noon, indicating observations on a meridian line and consistent with the heavy tube documented in Kepler’s report.

Mögling’s instruments for solar observations were probably not telescopes but sighting tubes without any convex lens; one of them had an aperture ≤ 1 cm in diameter on the Sun-facing side of a long tube (50 feet ≈ 12.5 m; see von Bauernfeind 1862) and projected the solar disk onto a white shelf placed on the other side of the tube. As such, he appears to have observed sunspots with an instrument that functioned like a camera obscura. This supposition is consistent with the upside-down orientation of the solar disk (see, e.g., Figure 2 of Vaquero 2007) and the somewhat blurred depiction and uneven areas of sunspots in Mögling’s sunspot drawings (Figure 2). We estimate the focal lengths of his instruments as 3.9 and 14.4 m, using the depicted aperture sizes and diameters of depicted sunspot drawings (3.4 and 12.6 cm). Thus, the solar images should have been projected on sheets ≈ 1.9 m away from the end of the tube for the large drawings. Our estimates are consistent with how Mögling observed the solar disk: using the gilded sphere with eye-tube for the small drawings and the black wooden tube for the large drawings. Contemporary sunspot observations through pinholes have been documented

in Malapert’s records, whereas Malapert himself considered telescopes more suitable for sunspot observations (Carrasco et al. 2019a).

These facts lead us to consider that Mögling probably missed all of the small sunspots (A- and B-type groups in the Waldmeier classification) and arguably the J-type sunspot groups as well, but likely detected the larger ones (E-, F-, G-, and H-type groups). Within the modern observations, the A-, B-, and J-type sunspot groups account for $\approx 19\%$, $\approx 14\%$, and $\approx 19\%$, respectively, of all observed sunspot groups in the data set of the Uccle Solar Equatorial Table (USET) from 1940 to 2014 (Carrasco et al. 2015). He was also unable to resolve the umbrae from the penumbrae. Therefore, it is assumed that Mögling underestimated the sunspot group number, overlooking $\geq 33\%$ – 52% of the total sunspot groups on the solar disk. Despite this probable underestimation, Mögling’s sunspot records seem to depict the decay of the sunspot group number (Figure 3) and the migration of their positions to lower heliographic latitudes (Figure 4) from 1626 to 1629. This is typical of the declining phases of the modern solar cycles (Hathaway 2015; Muñoz-Jaramillo & Vaquero 2019) and agrees with the existing data for the other contemporary observations (Figures 3 and 4).

6. Conclusion

In this paper, we have analyzed the sunspot observations of Daniel Mögling. His autograph has been identified with Hs 228 at the ULBD. We have extended and detailed information on his life (1596–1635) and personal profile. He worked as a court physician/astronomer under Landgrave Philipp III of Hessen-Butzbach and recorded his astronomical observations at Butzbach (N50°26′, E8°40′) using at least three instruments for his solar observations. Mögling’s autograph manuscript (ULBD Hs 228) contains sunspot drawings from 1626 June 23 to 1629 June 16 according to the Julian calendar. These drawings are classified into two categories. One category features whole-disk drawings for each date, while the other tracks the motion of each specific sunspot group for successive dates.

Consulting this manuscript, we have derived the sunspot group number for each observational date using the Waldmeier classification. We have acquired 103 days of sunspot observations in his drawings and 34 days in his textual descriptions. The latter mostly describe spotless days, whereas three of them report multiple sunspots without exact numerical values. On this basis, we have identified 134 days with an exact sunspot group number in his manuscript. His background and correspondence show that his observational dates were recorded in the Julian calendar, while the existing data sets misinterpreted them as the Gregorian calendar. Therefore, we have revised all the dates of Mögling's sunspot observations. Apart from this calendar issue, we have added 19 days of hitherto overlooked observations, revised three dates (even in the Julian calendar), and excluded 8 days of misinterpreted observations. We compared our result with contemporary observations, thereby revising the contemporary observational records of Schickard and Hortensius. Overall, Mögling's revised sunspot group number visualizes the declining phase of solar cycle -12 and fills the gaps of other contemporary observations. As Mögling probably used a pinhole with a camera obscura, he probably missed all of the A- and B-type sunspot groups, and, arguably, the J-type sunspot groups as well. Therefore, his sunspot group number is probably underestimated, overlooking $\geq 33\%$ – 52% of the total groups (see, e.g., Carrasco et al. 2015).

We have also derived the sunspot positions from Mögling's manuscript. The E–W orientation was set left to right based on the motion of each sunspot group. The N–S orientation was set upside down based on a comparison of the inclination of the depicted sunspot motions and their calculated B0 angles. On this basis, we derived sunspot positions by combining sunspot-motion drawings for successive days and whole-disk drawings for a specific date. The sunspot groups in 1626 were located at 2° – 23° in heliographic latitude in both solar hemispheres. Temporal variations in their latitudinal distributions show their migration to lower heliographic latitudes toward 1629. This result, which agrees fairly well with the existing distributions of contemporary sunspot observations by Scheiner (Arlt et al. 2016) and Malapert et al. (Carrasco et al. 2019a), visualizes sunspot migration during the declining phase of solar cycle -12 . This confirms the hypothesis of the continuity of solar cycle -12 from 1621 to somewhere in 1631/1632 (Vokhmyanin & Zolotova 2018b; Carrasco et al. 2019a).





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Data Availability

Mögling's manuscripts are preserved in the manuscript archives of the Universitäts- und Landesbibliothek Darmstadt as Hs 228 and Hs 3020.

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