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# THE MAUNDER MINIMUM IS NOT AS GRAND AS IT SEEMED TO BE

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## ABSTRACT

The Maunder Minimum (MM), which occurred between 1645 and 1715, is mainly known as an almost spotless period on the Sun. We analyze the nominal number of sunspot groups for each observer individually. Comparing the sunspot drawings and textual reports, we conclude that the latter underestimate the number of sunspots. We also argue that the different points of view of observers in the seventeenth century on the origin of sunspots resulted in the underestimation of sunspot groups or even gaps in observational reports. We demonstrate that Jean Picard and Giovanni Domenico Cassini of the Paris Observatory did not report any sunspots, while other observers reported on the occurrence of spots. Moreover, compared with other observers, La Hire underestimated the solar activity. The MM looks like an ordinary secular minimum with a depressed 11 yr solar cyclicity.

*Key words:* Sun: activity – sunspots

## 1. INTRODUCTION

One of the most enigmatic features of the solar history in the past is the Maunder Minimum (MM). Based on Spörer's studies of early records of sunspots, Maunder (1890, p. 252) summarized his conclusions: "For a period of about 70 yr, ending in 1716, there seems to have been a very remarkable interruption of the ordinary course of the spot cycle. In several years no spots appear to have been seen at all, and in 1705 it was recorded as a most remarkable event that two spots were seen on the Sun at the same time, for a similar circumstance had scarcely ever been seen during the 60 yr previous." (Maunder 1890).

Eddy (1976) reexamined Spörer's and Maunder's findings and concluded that the 70 yr period (1645–1715) was a time when solar activity all but stopped. The main objection to Eddy's claims regarding the anomaly in the behavior of the Sun was that the solar activity, though weak during this period, followed an 11 yr solar cycle. As a result, there was no prolonged sunspot minimum (Legrand et al. 1992, and references therein). Particularly, it was argued that according to the auroral data, the solar cycle was normal during the MM, though solar activity was low (Schröder 1992). Based on $^{10}$Be records from a Greenland ice core, Beer et al. (1998) showed that vigorous cycles persisted in these time series throughout the MM.

Kopecky & Kuklin (1987) analyzed the impact of the effective resolving power of the so-called visibility function on the sunspot observations in the seventeenth century. They suggested that the reduction in the sunspot activity was not dramatic, but could have been caused by a substantial qualitative change in the solar activity, strengthened by a minimum in the secular cycle and observational conditions in connection with the visibility function. Additionally, Ogurtsov et al. (2003) claimed that during the MM there were chaotic bursts of solar activity randomly distributed in time, but that this claim requires in-depth study and verification.

Using the unique collection of sunspot observations recorded at the Paris observatory, Ribes & Nesme-Ribes (1993) reconstructed the butterfly diagram from 1666 to 1719. They demonstrated that the butterfly symmetry was broken, and the sunspots were commonly observed in the southern hemisphere at low latitudes. Notice that Eddy (1976) indicated that this feature was previously reported by Spörer and Maunder (Maunder 1890). Vaquero et al. (2015) restored latitudinal coordinates of the sunspots from 1671 to 1719. Also, Casas et al. (2006) defined the positions of the sunspots observed by Galileo Galilei (Galilei et al. 1613). Soon & Yaskell (2003) mentioned that Elizabeth Nesme-Ribes also reconstructed the butterfly diagram from the sunspot drawings made by C. Scheiner, P. Gassendi, and J. Hevelius (Soon & Yaskell 2003, see Figure 48 therein).

Hoyt & Schatten (1998) introduced a time series known as the group sunspot number (GSN or $R_g$). It uses the number of sunspot groups (NSGs) observed, rather than groups and individual sunspots. Hoyt et al. (1994) argued that the $R_g$ series is more reliable and homogeneous than the Wolf sunspot number series before 1849. Starting from 1610 to 1720, the index is constructed from documentary sources provided by 135 observers. Kovaltsov et al. (2004) evaluated the upper limit of the annual GSN during the deep MM (1645–1700), which does not exceed 4. $R_g$ demonstrates the abrupt onset of the MM near the 1640s, which poses a challenge for the dynamo theories (Parker 1976; Sokoloff 2004; Charbonneau 2010).

Vaquero et al. (2011) recovered the sunspot observations by Georg Marcgraf in 1637 and revised the $R_g$ data for the period 1636–1642. They suggested that the magnitude of the sunspot cycle just before the MM is about three times lower than that in the paper by Hoyt & Schatten (1998). They also implied a possibly gradual onset of the minimum with the reduced activity that started two cycles before the MM. Recently, Vaquero & Trigo (2015) proposed a redefinition of the MM period with the core deep MM spanning from 1645 to 1700, as well as the wider extended MM for the period 1618–1723, which includes the transition periods.

Processing naked-eye sunspot observations and auroral sightings, Schove (1955) defined the minima and maxima of the solar cycles from 649 B.C. to A.D. 2000. Assuming exactly nine solar cycles per calendar century, he numbered the solar cycles using the Zürich numbering system. Therefore, from 1610 to 1723 Schove (1979) and Gleissberg et al. (1979) proposed 10 cycles with a duration of 8–15 yr (with reference to Wolf and his successors).

Livingston & Penn (2009) discovered that from 1992 to 2009 the nominal number of sunspots and the magnetic field strength in spots decreased in time. Further, the prolonged minimum between Cycles 23 and 24 is one of the longest solar minima. The Schwabe cycle period increases notably before each solar Grand minimum (Frick et al. 1997). The current cycle is characterized by small and short-lived sunspots. Whether the Sun is entering an era of global quiet conditions, similar to the MM, remains to be seen (Zolotova & Ponyavin 2014).

This paper is structured as follows. In Section 2, various styles of sunspot drawings before the MM are presented. Section 3 describes the underestimation of sunspot groups in textual sources. In the following sections, we compare the calendar date and the nominal NSGs reported by various observers. Special attention is given to the astronomers of the Paris observatory. In Section 8, we make our suggestions about the main features of the solar activity during the MM.

## 2. HISTORY

One of the first attempts to patent and sell a telescope was in 1608, when the Dutch lens grinder Hans Lipperhey (or Lippershey) presented his instrument to Maurice of Nassau, ruler of the Netherlands (Stefoff 2007). The lenses Lipperhey used would probably have restricted the magnification of his telescope to about three times (Watson 2004). Discovering the basic principles upon which the telescope worked, Galileo Galilei created instruments with magnifications of eight, twenty, and eventually thirty times. Along with the camera obscura, the telescopes became widespread among solar observers of the seventeenth century (Vaquero & Vázquez 2009).

At that time, Aristotelian geocentrism, or the Ptolemaic system, was the generally accepted scientific doctrine. In particular, according to Aristotle, the Sun was perfect and immaculate. The most popular point of view was that the sunspots (Sun's planets) are shadows from planetary transits (Vaquero & Vázquez 2009).

Figure 1 shows the sunspot drawings by Galileo Galilei (Galilei et al. 1613); Cristoph Scheiner (Scheiner 1630); Pierre Gassendi (Gassendi 1658), and Johannis Hevelii (Hevelii 1647). It is apparent that only the drawings by Galileo are similar to modern sunspot observations. Notice that during the seventeenth century most of the sunspots in the drawings tend to be circularized. This can be caused by an adherence to the planetary hypothesis of sunspot appearance on the Sun or just a psychological inclination to draw an unknown object as a circle (see drawings by Kircheri et al. 1678 or by John of Worcester 1140–1160).

The German Jesuit Athanasius Kircher (Athanasii Kircheri), collaborating with Scheiner, thought that sunspots result from a combination of solid and liquid bodies (Vaquero & Vázquez 2009). Thus, even though they had a different opinion of the sunspot origin, scientists tended to draw sunspots as circles (Kircheri et al. 1678, page 64). The origin of sunspots remained unknown for quite a long time. For instance, even after constructing the butterfly diagram Maunder (1922) claimed: "This diagram further suggests that the origin of the solar spots lies within the Sun, not without. They come from below the surface; they are not impressed upon the surface by some exterior influence; neither by planets, nor by meteors." With reference to Scheiner, Wolf (1861) also mentioned that rigorous observations of sunspot appearance on the solar surface indicate that spots are not the transit of a planet across the solar disk.

Cristoph Scheiner was a Jesuit priest and professor of mathematics. Vaquero & Vázquez (2009) cited Scheiner's letter, where, based on philosophy and his experience (Scheiner 1612), the author is sure that sunspots do not belong to the Sun. Over the years Scheiner (1630) agreed with Galileo that sunspots are either on the Sun's surface or in its atmosphere, and that the Sun is therefore not perfect (in contradiction to Aristotle). His book Rosa Ursina (Scheiner 1630) contains drawings in two styles: (1) sunspots tend to have a regular shape close to circles which resemble shadows from planetary transits and (2) complex sunspot groups are similar to Galilei et al. (1613).

The work Opera Omnia by the French philosopher, priest, and scientist Pierre Gassendi (1658) addresses the rigorous geocentric system and Tychonic system (a hybrid of geocentrism and heliocentrism, published by Tycho Brahe in the late sixteenth century). Several sunspot drawings cover the period 1633–1638. Gassendi sketched only big spot groups and schematically marked them as circularized texture objects (Figure 1(c)).

The mayor of Danzig (Poland), brewer, and astronomer Johannes Hevelius (Johannis Hevelii) was probably familiar with the works of Scheiner. The sunspot drawings from 1642 to 1644 published in Solenographia (Hevelii 1647) imitate the Scheiner (1630) style (Figures 1(b) and (d)). The sunspot groups tend to be similar to a set of circles. Solenographia also describes the geocentric, Tychonic, and heliocentric systems. Other sunspot observations up to 1684 are provided by Hevelius in a tabular format (Hoyt & Schatten 1995). Between 1653 and 1679, Hevelius only reported 19 sunspot groups, which is too few for the 26 yr period. This probably cannot be explained by low solar activity, because in the 1640s and 1650s Hevelius equally registered up to four to five sunspot groups per day, but in 1650s his interests shifted toward the Moon. In particular, a significant part of the second volume of Machina Coelestis (Hevelius 1679) is devoted to lunar observations ("Macula Lunaris," which means "spots on the Moon"). Also, in four cases, Hevelius quite consciously did not record sunspots reported by other European observers (Hoyt & Schatten 1995). The other possible explanation for the small number of sunspots reported from 1653 and 1679 is discussed in the next section.

## 3. DIFFERENCE BETWEEN DRAWINGS AND TEXT REPORTS ABOUT SUNSPOTS

For analysis we use the database of the daily nominal NSGs extracted by Hoyt & Schatten (1998) from the historical archives. The backbone of our knowledge about the solar activity from 1610 to 1720 is based on continuous longstanding reports of several observers. Figure 2 shows the NSGs from 1611 to 1684 (inclusive) provided by three main observers of that period: Scheiner (1611–1640), pink; Gassendi (1631–1645), purple; and Hevelius (1642–1684), red. Blue (for Gassendi) and cyan (for Hevelius) denote periods in the NSGs tabulated by Hoyt & Schatten (1998), which are entirely filled with zeros over a period of several months or years. These "zero periods" are extracted from written sources where the observer notes that he did not see spots for several years or months, but it is unknown when and how many observations were done. Thus, we exclude these "zero periods" from analysis.

Gray bars (Figure 2) mark periods where there are drawings. Most likely, these periods correspond to active phases of the Sun. The leftmost gray bar refers to the sunspots drawing from 1611 October 21 to December 14 made by Scheiner and published in three letters to Mark Welser (Scheiner 1612). In these letters, the sizes of the solar disks are rather small (about the size of a coin), hence only those big spots are drawn whose shape in most cases tends to be circularized. The very fact that the Sun itself has spots was criticized, and Scheiner did not publish his observations until to 1630 (Vaquero & Vázquez 2009). The second gray bar in Figure 2 denotes Scheiner's drawings from 1624 December to 1627 June (see Section 2). We found the schematic sunspot drawings by Gassendi (1658) from 1633 to 1638 and drawings

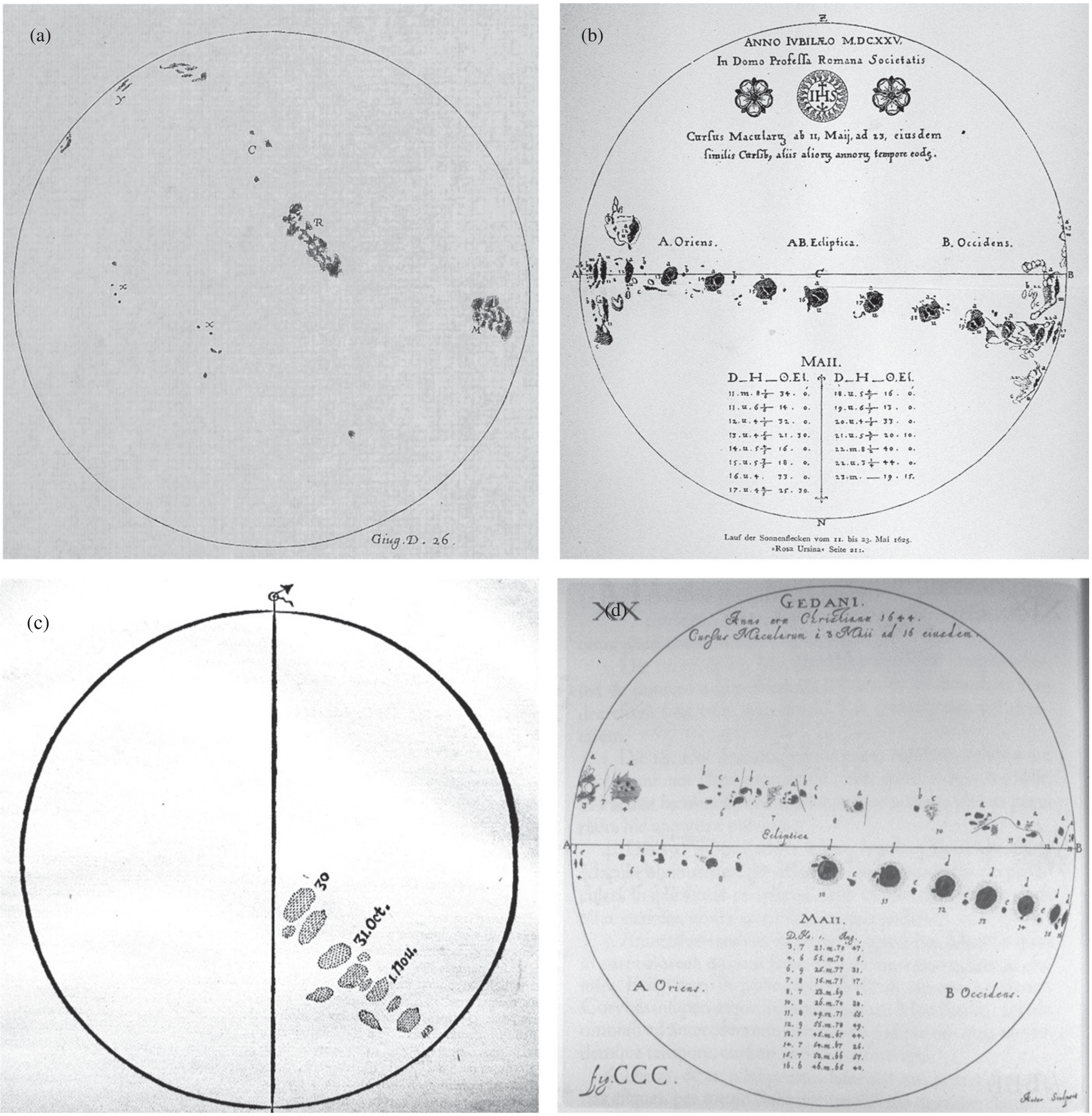


**Figure 1.** Sunspot drawings on (a) 1612 June 26 by Galileo Galilei, (b) 1625 May 11–23 by Cristoph Scheiner, (c) 1638 October 30 to November 1 by Pierre Gassendi, and (d) 1644 May 3–16 by Johannes Hevelius.

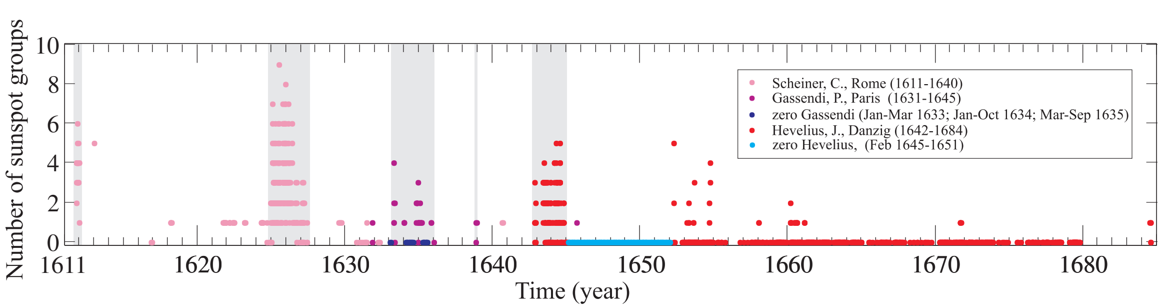


**Figure 2.** Nominal number of sunspot groups. Color defines the observer. Gray bars mark periods when the observers made drawings.

by Hevelii (1647) from October 1624 to October 1644 (the third and fourth gray bars in Figure 2). Reports about sunspots from 1653 to 1679 (Hevelius 1679) were found in tabular form by Hoyt & Schatten (1998).

From a comparison of the periods from the sunspot drawings and the periods from the information on sunspots extracted from the text reports, we emphasize a significant difference between them (Figure 2). The cumulative NSGs extracted from the drawings made from 1642–1644 by Hevelii (1647) is about 390, and that from the tables made from 1653–1679 by Hevelius (1679) is only 65. Figure 2 shows that the nominal NSGs per day in the 1640s and 1650s is comparable (up to four–five). Thus, the activity levels of these periods should be similar, but the difference in the NSGs from the drawings and text reports is evident. This discrepancy in NSG leads to significant variations in the amplitude of $R_g$. In particular, in the year 1642, $R_g$ is about 50, while in 1652, it is only 4. Scheiner's observations (Figure 2) also exhibit a large difference between the drawings and the text reports.

Since the text reports underestimate the NSGs, they automatically overestimate the number of spotless days. Here we would like to mention the illustrative and curious case noted by Vaquero & Vázquez (2009). A short text description made by the English astronomer, mathematician, ethnographer, and translator Thomas Harriot says that on 1610 December 8 the Sun was clear, but it is accompanied by a sketch of three spots. An apparent discrepancy between drawing and text can be explained as a consequence of the dominant point of view that the sunspots are shadows from a transit of an unknown planet. Therefore, a description of objects with irregular shape or consisting of a set of small spots could be withdrawn from a report because it was impossible to be sure that this object was a celestial body. All these findings suggest to us that the sunspot data during the seventeenth century should be significantly corrected.

Finally, we conclude that the reports about sunspot observations, especially those without drawings, contain reduced information on the NSGs. It was probably caused by the world view that a spot is an unknown celestial body. Let us do a thought experiment where an astronomer in the seventeenth century creates a text or tabular report on the solar observations. He sees objects of an irregular shape on the solar disk. How can he report about sunspots (Sun's planets) if he knows that the shadow of a celestial body must be round? Hence, irregular-shaped objects were probably skipped. That is why there is a crucial difference between the drawings and text reports. This point of view suggests to us that rare and short observations, which in the overwhelming majority of cases provide evidence of single sunspots, might also underestimate the nominal NSG because the observer could only be interested in the sunspot (Sun's planet) observation, but not in the accurate count of the spots. Small spots or those of irregular shapes could be skipped to avoid a mess in the reports.

## 4. FALSE SOLAR MINIMUM IN 1617–1618

According to Hoyt & Schatten (1998), the period 1617–1618 is densely covered by sunspot observations, mainly due to Simon Marius (Nuremberg, Germany) and Giovanni Battista Riccioli (Bonomia, Italy). In 1617 Marius's observations covered 208 days. In 1618 Marius and Riccioli synchronously observed the Sun for 333 days. Figure 3 shows $R_g$ from 1610 to 1650. According to this plot, the period 1617–1618 corresponds to a solar minimum. Notice that Marius observed sunspots in 1617–1618, and Riccioli in 1618, 1632, 1655–1657, and 1661. In those years, they only reported only a blank solar disk; in other words, they did not even register a single spot. Below we compare reports by Marius and Riccioli with those of other observers.

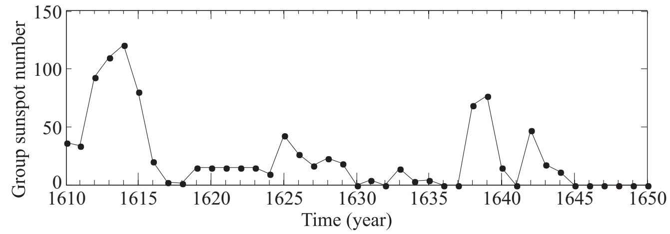


**Figure 3.** Group sunspot number from 1610 to 1650, according to Hoyt & Schatten (1998).

Figure 4(a) depicts the daily NSG extracted by Hoyt & Schatten (1998). The period from 1615 to the end of 1623 is covered by reports of eight observers. Red and purple denote observers (Tarde and Saxonius) who registered more than one sunspot group per day; blue and cyan mark Marius and Riccioli; green and dark green correspond to those observers who reported a single sunspot group from 1615 to 1623 (Scheiner, Malapert, Smogulecz, and Schickard), and green spots demonstrate those from the middle of 1616 to the end of 1623, when there were only rare observations of single sunspot groups. We think that the reports of that period reflect a sunspot (celestial body) transit, but not the exact number of spots. For instance, 1626 is covered in Scheiner's drawings, which contain up to seven sunspot groups per day, while according to Malapert, the solar activity was weak (one or two sunspot groups per day). This finding supports our idea that NSGs extracted from the text sources without drawings (see Section 3) are underestimated.

Figure 4(b) shows a histogram of the sunspot observations from 1617 until the end of 1619. The lower part of the histogram shows the time periods when Marius (blue) and Riccioli (cyan) reported a blank solar disk (zero NSG); the upper part shows those periods when other observers reported one sunspot group. In March 1618 Scheiner and Malapert synchronously observed a sunspot group. It is noteworthy that when the Sun became active, Marius and Riccioli immediately stopped observations. This nonuniformity of the sunspot observations leads to dramatic changes in $R_g$. For instance, in November 1615, the Hoyt and Schatten database contains observations done only by Tarde, who reported one sunspot group, hence $R_g = 15$. 1617 June is covered by several observations made by Tarde, and is mainly filled by Marius with zeros, hence $R_g = 3$.

Figure 4(c) shows $R_g$ (blue) from 1615 to 1624. Green stems depict the annual number of naked-eye sunspots (Vaquero et al. 2002). The period of 1617–1618 is characterized by several large spots. It is very atypical for a solar minimum and corresponds better to a declining phase of a cycle, as large sunspots tend to occur in the second half of the solar cycle (Gnevyshev 1967). In addition, one should bear in mind the style of Marius's and Riccioli's reports, who never registered even a single spot and have gaps in their reports when other observers noticed sunspots. So, we think that the solar minimum in $R_g$ in 1617–1618 is artificial.

## 5. OBSERVATIONS BY PICARD FROM 1653 TO 1659

Knowledge about the number and heliographic positions of the sunspots during the MM mainly comes from observations recorded by Jean Picard and Philippe de La Hire (Ribes & Nesme-Ribes 1993) at the Paris observatory (Observatoire de

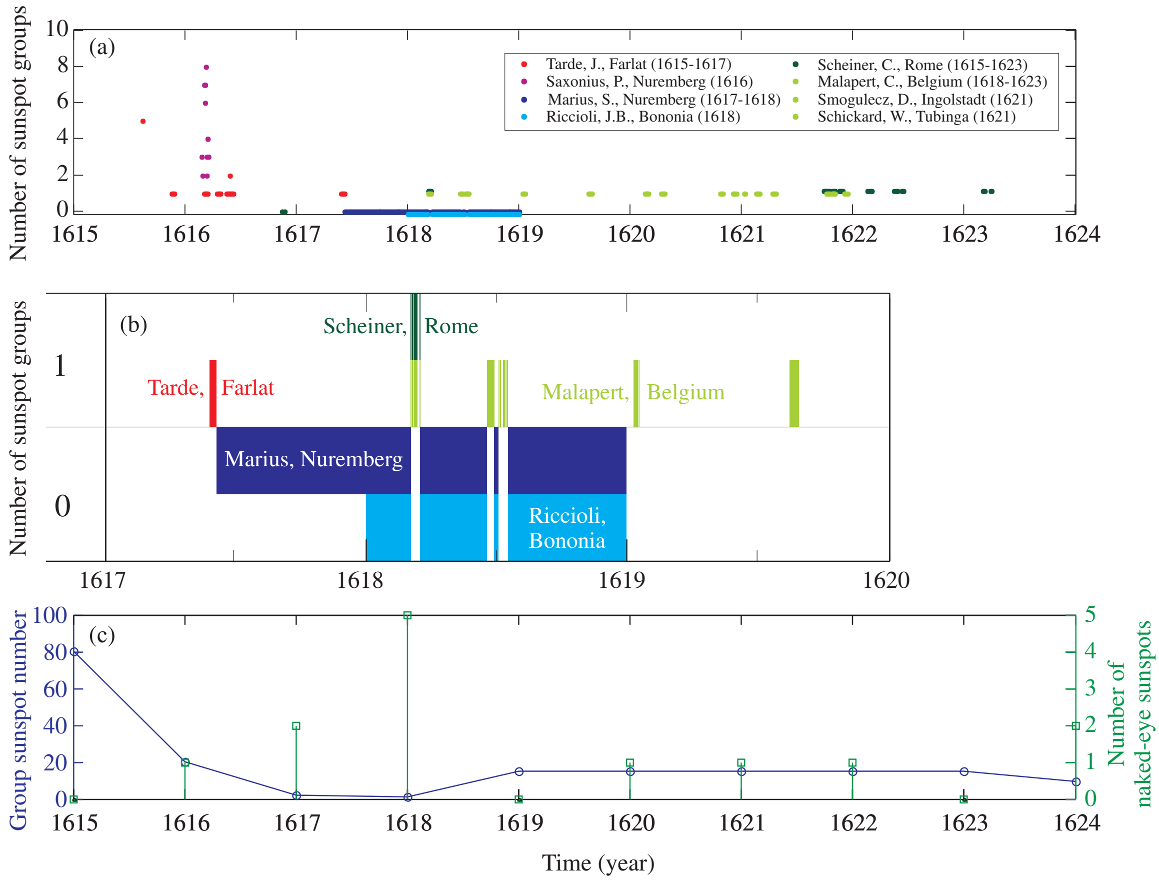


**Figure 4.** Sunspot group observations. (a) Nominal number of sunspot groups from 1615 to the end of 1623. Color defines the observer. (b) The diagram shows the date and daily nominal number of sunspot groups reported by each observer from 1617 to the end of 1619. (c) Blue denotes $R_g$ and green the number of naked-eye spots from 1615 to 1624.

Paris or Observatoire de Paris-Meudon). In 1645 Picard assisted Pierre Gassendi in observing a solar eclipse, and he remained with Gassendi for 10 yr (Hoyt & Schatten 1997). Gassendi sketched only big spot groups, and schematically marked them as circularized texture objects (Section 2). It is natural to expect that the scientific preferences of Picard must have been affected by Gassendi.

Hoyt & Schatten (1996, 1998) claimed that Picard's manuscripts written before 1665 were lost. John Keill (a disciple of Isaac Newton) in 1745 was the last person to see those early notebooks by Picard. It was Keill who copied Picard's manuscripts. But there is some uncertainty as to the accuracy of these copies and the authorship of Picard's archives. Hoyt & Schatten (1996) wrote about the sunspot observations from 1653 February to 1660 January and from 1660 August 11 to 1665 December 31, copied by Keill. However, in the GSN database, the label "Picard/Keill" only refers to the period from 1653 to 1659 with 2352 observational days, and from 1660 the observations are marked as being reported directly by Picard. Ribes & Nesme-Ribes (1993) processed Picard's notebooks, which were stored in the Paris observatory, starting 1666 March 27.

The histogram in Figure 5(a) compares the calendar dates when individual observers reported one or several sunspot groups or a blank solar disk (zero NSG) from 1653 to the end of 1659. Only Petitus from the GSN database is not shown in Figure 5(a), as from 1653 to 1659 he reported a spotless solar disk only once, in 1659 November 14. In Figure 5(a), the blue gradation denotes observers (Giovanni Battista Riccioli, Giovanni Domenico Cassini, Giacomo Francesco Maraldi, and Gabriel Mouton) who only reported a blank Sun from 1653 to the end of 1659. The green gradation marks those observers who reported not only a spotless Sun, but also observed at least one sunspot group (Johann Andreas Bose, Unknown1/Maunder/JBAA, Unknown2/Maunder/JBAA. The latter two are unknown observers according to Maunder.). Red defines observations by Johannes Hevelius, who registered up to four sunspot groups per day.

During the period analyzed only Hevelius made more or less regular observations, while Bose and the two unknown observers (Unknown1 and Unknown2 in the database of Hoyt and Schatten) were probably interested in the actual sunspot observations themselves. Their reports are short and are unique in nature (green stripes in Figure 5(a)). The GSN database for the observer Unknown1 is successively filled with zeros from 1654 January 1 to August 12, and then from 1654 August 13–15 he reports a sunspot. Similar intervals of "continuous zeros" are not rare, according to other observers. We suggest that these long periods of successive zeros signify "I did not see sunspots for several months/years." This type of information is usually extracted from letters (Vaquero & Vázquez 2009; Soon & Yaskell 2003). However, from those notes it is unknown how often the Sun was observed by the astronomer during the period mentioned. Finally, the proportion of spotless days becomes overvalued in the estimated $R_g$.

In Figure 5(a), Picard's reports restored by Keill are shown in black. This archive is successively filled with zeros (see the database by Hoyt & Schatten 1998) and has seven gaps which are marked by gray bars. It is remarkable that Picard would

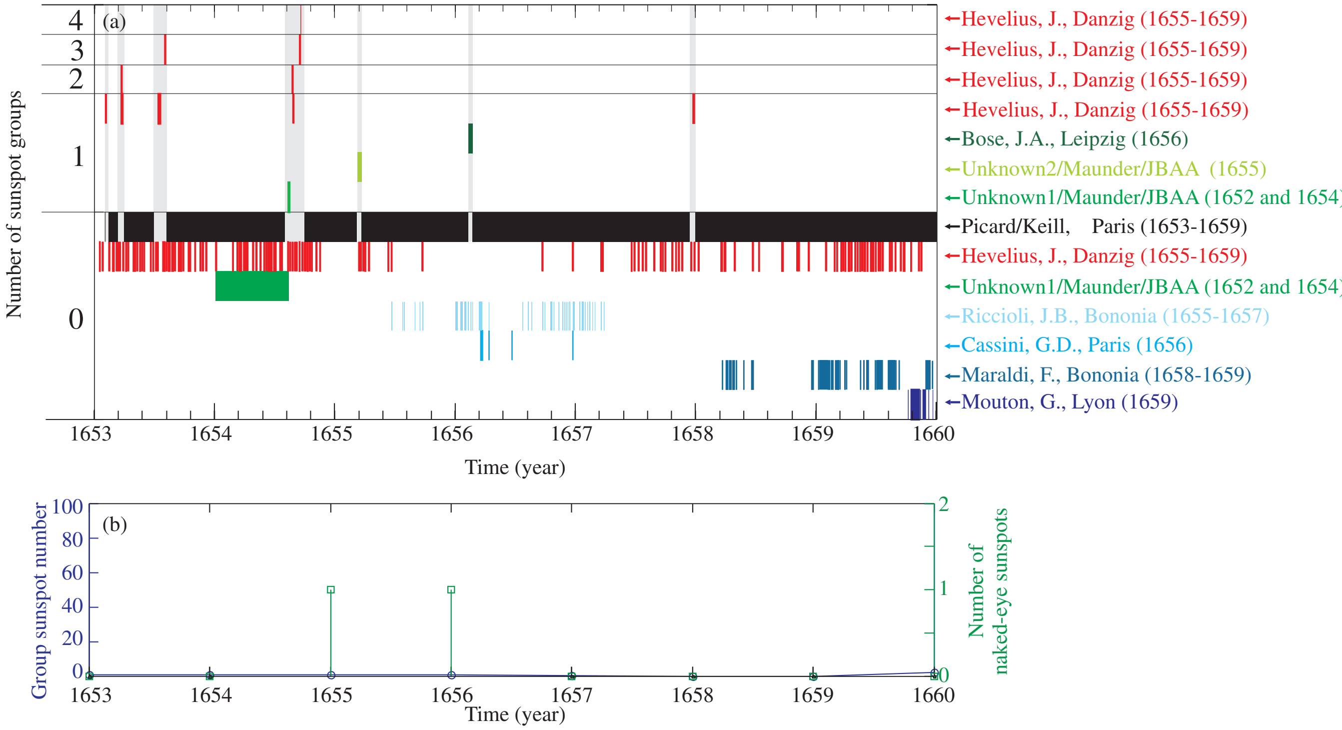


**Figure 5.** Sunspot observations. (a) The diagram shows the date and daily nominal number of the sunspot groups reported by each individual observer from 1653 to the end of 1659. (b) Blue denotes $R_g$ and green the number of naked-eye spots from 1653 to 1660.

stop recording as soon as other observers reported solar activity. From 1653 to the end of 1659, there are only textual and tabular archives on sunspot records. Thus, Figure 5(a) suggests that the NSGs is underestimated (see Section 3). The excessive number of zeros in the database by Hoyt & Schatten (1998) leads to a reduction of $R_g$ (Figure 5(b)).

Finally, our findings for the period 1653–1659 lead us to think that the priest Jean Picard considered the Sun to be in accordance with the canons of Aristotle.

## 6. OBSERVATIONS BY PICARD AND SIVERUS FROM 1660 UNTIL 1682

Similar to Figures 4(b) and 5(a), Figure 6(a) compares the calendar dates when observers reported either one or several sunspot groups or a blank solar disk (zero NSG) from 1660 to the end of 1682. Because the histogram covers more than 20 yr, we organized the observers in groups.

The "blue observers" include Erhard Weigel, Christop Weickmann, and Martin Fogel (or Vogel or Fogelius or Vogelius). In the bibliography of the sunspot observers, with comments, Hoyt and Schatten indicate that Weigel reported no sunspots for the years 1662–1664, and Weickmann, for 1666–1667. To these we have added the period from 1661 October 15 to 1671 July 31 when the database of the daily nominal NSGs for Fogel is filled with zeros without gaps. Also, Hoyt and Schatten mention that it is unknown on which days Weigel, Weickmann, and Fogel were observing. Notice that at the boundaries of the 10 yr period (1661–1671), Fogel observed single-spot groups three times (according to the information from a letter by Fogel to Oldenburg). Thus, these three observations by Fogel are moved into the green list of observers (see below).

The "cyan observers" include those who reported only a blank solar disk, but we know exactly on which days they were observing. These are Christiaan Huygens, Antoine-Francois Payen, Francis Willoughby, Giovanni Battista Riccioli, Camillo Mezzavacca, Pietro Mengoli, Fabrius, Jean Richer, Manzius, Julio Cæfare Calcina, Varin, Deshayes, Gulielmini, and Francesco Maraldi. For all of them, information on their observations is very scant, and for most of them this information was extracted from tables in the book by Manfredi (1736). Revising this book, Clette et al. (2015) however concluded that Manfredi's tables (Manfredi 1736) only contained solar meridian observations, but never included information on sunspots. They pointed out that if no sunspots were mentioned in the meridian observations, it did not necessarily mean that spots were absent.

The "green observers" include observers who reported not only a blank Sun, but also at least one sunspot during the period (Figure 6(a)). These are Gabriel Mouton, Robert Boyle, Athanasius Kircher, Robert Hook, Stetin, Petitus, Edmund Halley, Haynes, Nicolas Hartsoeker, "Macula in Sole" (anonymous, but written by Cassini), Michael Ernst Ettmüller, "Memories" by Joseph-Jerome Lefrancais de Lalande in which he reports of various unidentified earlier observers, Gian Domenico Cassini, Geminiano Montanari, Georg Christoph Eimmart, Gottfried Kirch, and three observations by Martin Fogel in 1661 and 1671. Excluding Eimmart, who observed unsystematically from 1677 to 1702, and only twice reported a sunspot group, all other observations in the green list are rare or singular.

The "red list" comprises observers who made regular observations (Johannes Hevelius and John Flamsteed) or reported more than one sunspot group per day (Johann Abraham Ihle and Jonas Moore).

Similar to Figure 5(a), in Figure 6(a), Picard's observations are shown in black. In 1660 and 1661, he mainly reported a blank Sun, but in the middle of 1660 he registered two sunspot groups (one in May, one in June). Up to the end of 1661, in several instances he stopped reporting immediately as soon as

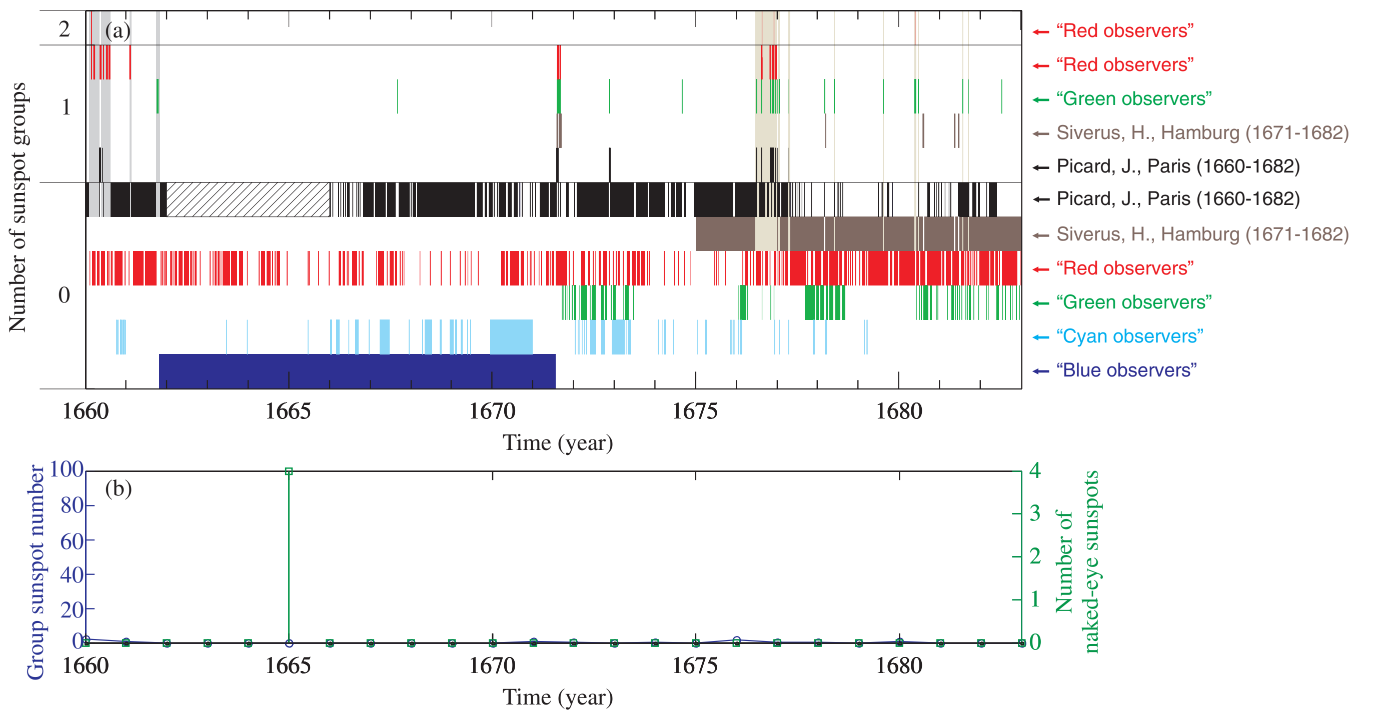


**Figure 6.** Sunspot observations. (a) The diagram shows the date and daily nominal number of the sunspot groups reported by an individual observer or a group of observers from 1660 to the end of 1682. (b) Blue denotes $R_g$ and green the number of naked-eye spots from 1660 to 1683.

sunspot groups appeared on the solar surface (these periods are marked by gray bars). The period of four years (1662–1665) is continuously filled with zeros. In Figure 6(a) we marked this period by a hatched region, because it is unknown how often Picard carried out observations. Later, from 1666 to 1677, he observed more or less regularly; the exact dates of observations are known, and Picard also recorded most of the sunspot groups reported by other observers. However, he never reported two or more sunspot groups simultaneously visible on the solar disk.

To conclude, before 1666 Picard saw spots, but did not think that these were sunspots; from 1666 onward, he saw spots and wrote in his notebooks that he observed sunspots. Thus, we think that it is Picard's scientific view on the nature of sunspots that was transformed, not the observing methods, because telescopes were sufficiently good from the middle of the seventeenth century, and their field of view was much larger than that in Galilean telescopes (Vaquero & Vázquez 2009).

Another observer who deserves attention is Heinrich Siverus (brown in Figure 6(a)). In 1671, he reported two sunspot groups (one per observation). His regular observations began in 1675. In the bibliography, Hoyt and Shatten noticed that the original observations of Siverus are now lost and it is unknown on which days he was observing. However, similarly to Marius, Riccioli, and Picard/Keil, Siverus immediately discontinued monitoring when other observers reported sunspots (these periods are marked by beige bars), and vice versa. He registered a few sunspot groups in 1680 and 1681 (one per day) which were not mentioned by other observers (Figure 6). We can speculate that Siverus and Picard had definite criteria for a sunspot, probably in accordance with Aristotle, hence they could reject those objects on the solar surface which did not satisfy their prescriptions. In case of irregularly shaped, or small and not-deserving-of-attention objects, they also might not have marked the day as spotless; thus, gaps appeared in reports.

Finally, the period from 1660 to 1682 is poorly covered by regular observations. A significant part of the reports was extracted from the book by Manfredi (1736), which does not contain information on sunspots (Clette et al. 2014). An excessive number of zeros (spotless days) also originates from historical archives that do not provide the exact dates of the observations. Hence, $R_g$ from 1660 to 1683 is about zero (Figure 6(b)). According to the database of the naked-eye spots (Vaquero et al. 2002), in 1665 there were four large spots, none of which was registered in the historical archives from the GSN database. These findings suggest to us that $R_g$ is significantly underestimated from 1660 to 1682.

## 7. OBSERVATIONS BY FATHER AND SON LA HIRE

From 1682 June to 1718 April, solar observations in the Paris observatory were carried out by Picard's student Philippe de La Hire, and then from 1718 April to 1719 May by his son Gabriel-Philippe de La Hire. Ribes & Nesme-Ribes (1993) noticed that after Picard's death, the elder La Hire worked independently.

Figure 7 compares the calendar dates and the nominal NSGs registered by the astronomers in the Paris observatory and by other observers. Figure 7(a) shows the calendar dates when the father and son La Hire made regular observations and reported sunspots.

Figure 7(b) shows in green the dates and NSG for the list of observers who reported a blank solar disk or one sunspot group per day during the period from 1680 to the end of 1720. These are Giovanni Domenico Cassini, Johannes Hevelius, Christianus Agerholm (excluding the time period from 1695 May 31 to 1700 October 31, which is entirely filled with zeros in the GSN database), Gulielmini (from 1675 to 1679 he only reported a spotless Sun, because according to Figure 6(a) he is from the cyan list), Georg Christoph Eimmart (observed regularly, but registered only a few spots in 1682 July, 1684 June, 1703 May–July), Michael Ernst Ettmüller, Caswell, Clausen, Jesuit father Petrus Jartoux in Peking, Johann Heinrich Hoffmann, Stephen Gray, Ole Christensen Roemer, Salvago,

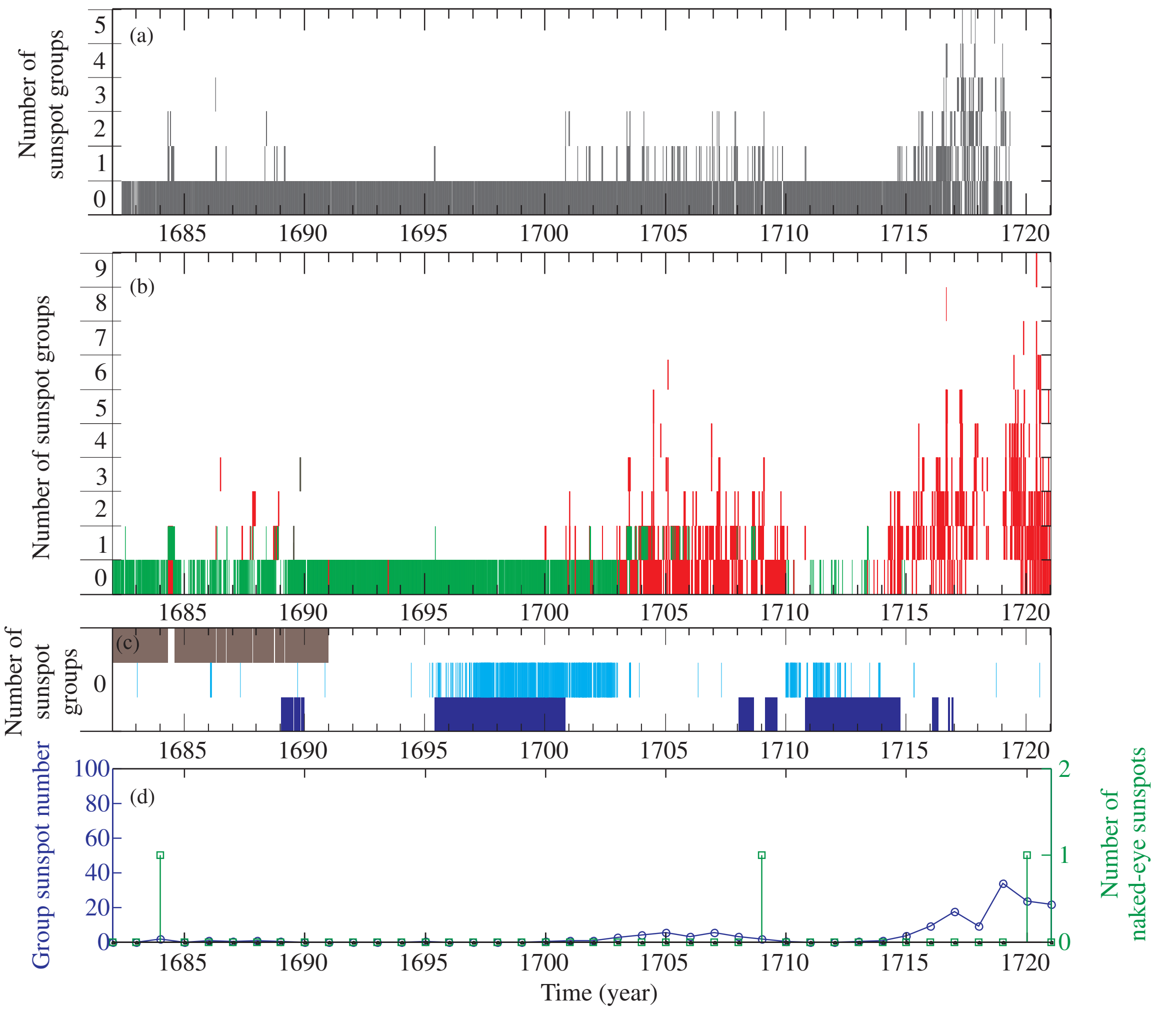

**Figure 7.** Sunspot observations. (a) The diagram shows the date and daily nominal number of the sunspot groups reported by Philippe de La Hire and Gabriel-Philippe de La Hire. (b) The same information but for a group of observers who reported at least one (green) or several (red) sunspot groups per day. Brown defines observations by Siverous. (c) The same information but for a group of observers who reported a spotless Sun. Brown marks days when Siverous reported a blank solar disk. (d) Blue denotes $R_g$ and green the number of naked-eye spots from 1682 to 1721.

De La Val, De Clapier, Fulchiron, Thyoli, Unknown/Lalande (unidentified observer from "Memories" by Joseph-Jerome Lefrancais de Lalande), John Flamsteed (observed regularly up to 1700, reported few spots in 1684 and 1703), and Johann Abraham Ihle.

Further, Figure 7(b) illustrates the dates and NSG for the red list of the observers who reported more than one sunspot group per day from 1682 to the end of 1720. These are Jacques Cassini, Johann Philipp Wurzelbaur (excluding the time period from 1710 October 29 to 1713 May 17 which is entirely filled with zeros in the GSN database), Johann Bernhard Wiedenburg (excluding the time period from 1708 January 16 to 1708 August 10, due to the same reason), M. Maraldi (excluding 1689, February, March, October, and December in 1716. Also, according to the GSN database, M. Maraldi is actually Giacomo Filippo Maraldi who is a son of Francesco Maraldi), Gottfried Kirch, Christoph or Christfried Kirch, Maria Margarethe Winkelmann Kirch, Christof Arnold, Eustachio Manfredi, Francesco Blanchini, Stannyan, Plantade, J. H. Muller, Johann Christop Muller, Johann Jakob Scheuchzer, Christian Theoph. Hertel, L. C. Sturm, Louis Feuillee, Christopher Wolf, Joseph-Nicolas De L'Isle, Joh. Wilhelmo Wagner, Alischer, Schutz, Antoine François Laval, and William Derham (excluding the time period from 1710 October 19 to 1714 September 9, which is filled with zeros in the GSN database).

During the "zero period" 1710–1714, Derham's archives have the only gap on 1713 May 18–30. It is exactly the time when Wurzelbaur, Kirch, De l'Isle, Unknown/Lalande, and Gray reported a sunspot group. Hence, Derham probably saw this group, but preferred to be silent. Since this sunspot group was registered by observers from Nuremberg, Berlin, Paris, and Canterbury (England), it must not have been small. However, Ph. La Hire was the only one who observed the Sun for several days in 1713 May 18–30 but reported a spotless Sun. Here we can conclude that not all sunspot groups were registered by the astronomers from the Paris observatory.

In the red list of observers, we do not include observations done by Johann Leonhard Rost, because in 1719 and 1720 he systematically reported a very large NSGs, up to 36. However, according to the Royal Greenwich Observatory, the maximum nominal NSGs in Cycle 19 is only 25.

Figure 7(b) also contains two brown stems which mark one and three sunspot groups, respectively, registered by Siverus in 1689. With the exception of these two observations, Siverus reported of a blank Sun daily (brown in Figure 7(c)). His records on spotless days contain gaps as soon as other observers

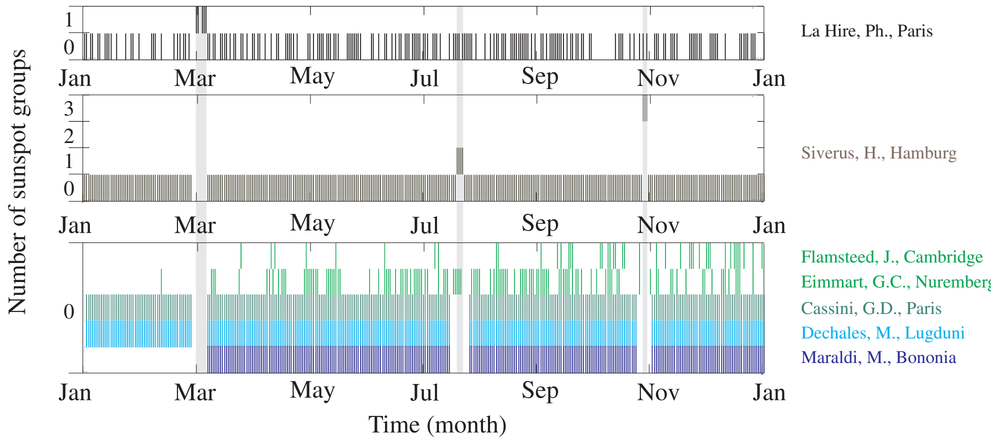


**Figure 8.** Date and daily nominal number of the sunspot groups reported by Ph. de La Hire, H. Siverus, J. Flamsteed, G. C. Eimmart, G. D. Cassini, M. Dechales, and M. Maraldi during 1689.

wrote about solar activity. In other words, we divided Siverus's observations into two groups. Two of his reports on sunspots in 1689 are shown in Figure 7(b), and all notices about the blank solar disk, in Figure 7(c).

Figure 7(c) includes the observers who announced only a blank solar disk from 1682 to 1720. The cyan color depicts observations with known dates. These are Christiaan Huygens, Camillo Mezzavacca, Jesuits in China, D. G. Schultz, Balthasar Mentzer, Thomas Brattle, I. Uccelli, J. T. Moeren, Johannes Meyer, Abraham Sharp, F. Torre, J. Poleni, P. A. B. Gesu, P. B. G. Fontana, Augustinum Hallerstein, Johann Friedrich Weidler, J. C. Parisius, and Vittorio Francesco Stancarius (or Stancari). Regular observations were only done by the last two, but the source of these reports, Manfredi (1736), contains solar meridian observations, not the sunspot ones (Clette et al. 2014).

Blue denotes periods in the tabulated NSG by Hoyt & Schatten (1998) entirely filled with zeros over a period of several months or years, when it is unknown on which days the observations were done. These observers are Johann Philipp Wurzelbaur (from 1710 October 29 to 1713 May 17), William Derham (from 1710 October 19 to 1714 September 9), Christianus Agerholm (from 1695 May 31 to 1700 October 31), Johann Bernhard Wiedenburg (from 1708 January 16 to 1708 August 10), Claude-François Milliet Dechales (or de Chales) in 1689, Unknown3/Maunder/JBAA in 1709, M. Maraldi on 1689 February, March, and October, and 1716 December.

Analysis of Figure 7 shows that a large number of zeros in the GSN database leads to $R_g$ vanishing (Figure 7(d)). However, the information on the naked-eye spots from 1682 to 1721 is also poor (Vaquero et al. 2002). Figure 7(b) demonstrates that before 1705, the observers from the green list dominate, but after 1705, those from the red list dominate. Philippe de La Hire reported a fewer NSGs, in comparison with that reported by the observers from red list, especially from 1700 to 1710. Notice also that in 1712 the director of the Paris observatory Giovanni Domenico Cassini died. In 1715, at the age of 77, "Sun King" Louis XIV died. In 1715, reports on the great suppression of solar activity known as the MM were replaced by reports of "normal activity level." It is unknown whether those administrative and political events had an impact on the scientific worldview.

We think that the scientific school the observer belonged to significantly influenced the style of his reports. We know nothing about Heinrich Siverus, who systematically created gaps in his reports from 1675 to March 1689, when the Sun was not spotless. From 1653 to 1661, Jean Picard also became inactive on spotted days. Year 1689 is remarkable, as it illustrates a different style of historical records.

Figure 8 compares the calendar dates when individual observers report of sunspot groups or a blank solar disk (zero NSG) during 1689. Ph. de La Hire registered a sunspot group on March 1–6. H. Siverus reported a sunspot group on July 19–22 and three groups, on October 27–29. Historical archives by G. D. Cassini, M. Dechales, and M. Maraldi have gaps in March, July, and October. It is most likely that these gaps are not accidental. An object on the solar disk in March is defined by La Hire as a sunspot group, while his chief, Cassini, as well as Dechales, Maraldi, and Siverus did not mark these days as spotted, but it is evident that they saw an object or objects on the solar disk. A similar situation happened in July and October. While Cassini, Dechales, and Maraldi preferred to be silent, La Hire marked July 19, 20, as well as 22 and October 27 and 29 as spotless days. This finding suggests to us that each observer was guided by a set of definite criteria for sunspots. Despite the fact that telescopes were good enough to resolve even small spots, not all objects on the solar disk were included into the historical archives during the seventeenth century (see also Section 3). If so, then the information about the MM is significantly distorted. Also notice that Philippe de La Hire, Giovanni Domenico Cassini, Claude Francois Milliet Dechales, and Christiaan Huygens were taught by the Jesuit Honore Fabri. It is probably in accordance with Aristotle that they were looking for celestial objects, hence not all spots were documented. Similar asynchronicity in reports of the observers can be found in 1713 and other years.

## 8. DISCUSSION

In Figure 9(a), the red stems depict the number of observations per year for individual observers, while blue ones depict the cumulative number of observations per year over all observers. For instance, in 1611 Harriot observed the Sun for 16 days, and Scheiner, for 33. Hence, in Figure 9(a) there are two red stems in 1611 and their cumulative sum, 49, is shown in blue. Some observers were not included. These are Rost (because he reported a very large NSGs) and the list of the observers who reported a blank Sun, but the exact dates of observations remain unknown (Table 1). For instance, according to the GSN database, Zahn reported a spotless Sun during the whole of the year 1632, but it is unknown how many observations were

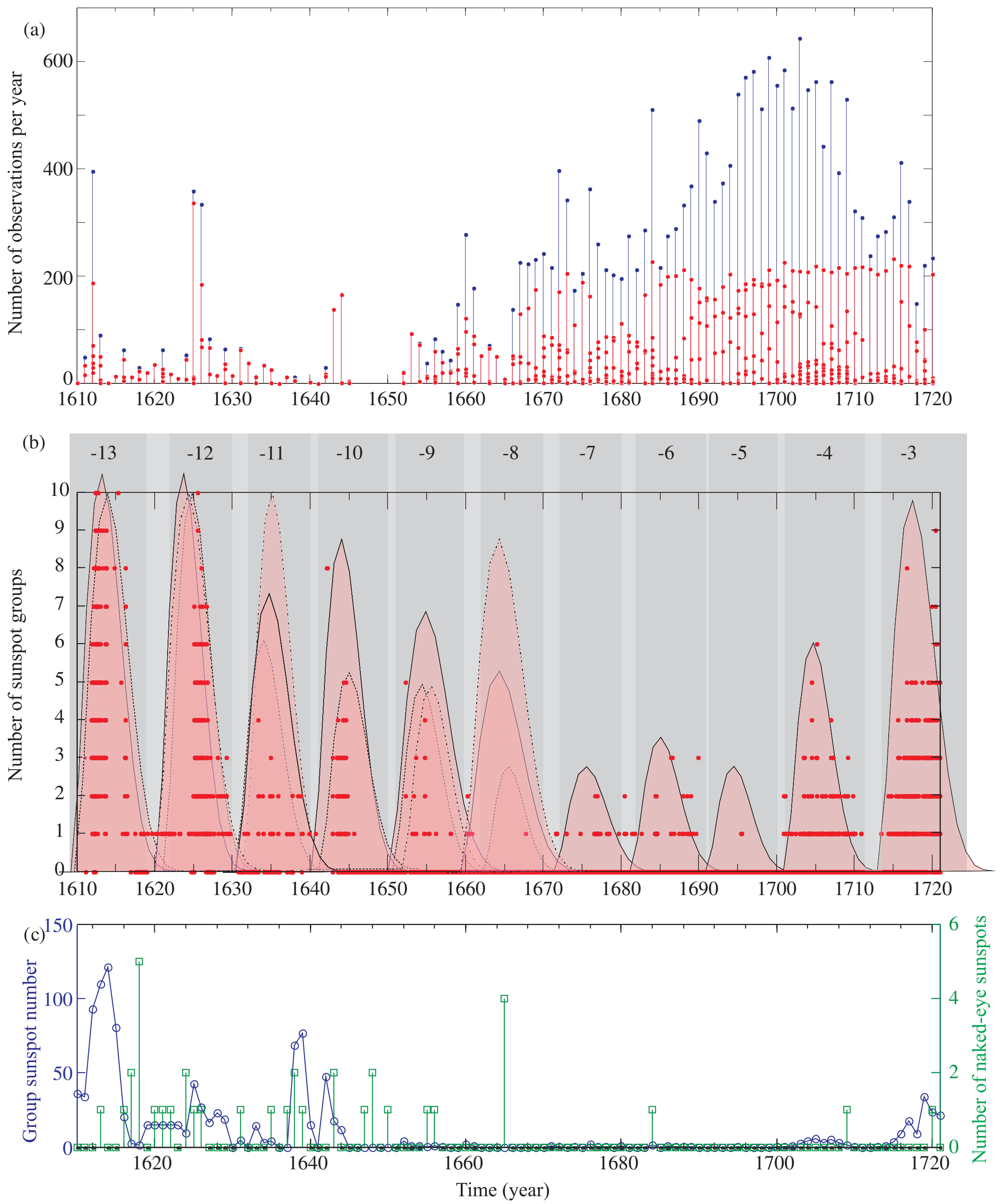


**Figure 9.** (a) Red stems depict the number of observations per year for individual observers, blue the cumulative number of observations per year over all observers. (b) Red points are the daily nominal number of sunspot groups for each observer, according to the GSN database by Hoyt & Schatten (1998). Light red defines the supposed amplitude of solar cycles. Light gray bars mark the assumed solar minima. Numbers from −13 to −3 define the cycle number, according to the Zürich numbering. (c) Blue denotes $R_g$ and green the number of naked-eye spots from 1610 to 1721.

actually done. Thus, Figure 9(a) does not contain a stem in 1632 with the value 366.

In Figure 9(b), the red points are the daily nominal NSGs, according to the GSN database from 1610 to the end of 1720 for all individual observers, excluding only Rost. As an example, on 1611 December 13 Harriot reported three sunspot groups, and Scheiner, four. Hence, in Figure 9(b) both of these observations are shown for the corresponding calendar date. We excluded the data for Crabtree in 1638–1639 because the database for this observer is filled with the Greenwich data in order to give four to five groups per day. This was done by Hoyt & Schatten (1998) on the basis of a letter by Crabtree that during those years, the average NSGs was four to five per day. We see no reason not to trust that letter, but we do not use the Greenwich data in Figure 9(b). We also add observations by Marcgraf in 1637 recovered by Vaquero et al. (2011).

Based on the descriptions and drawings of the Sun from 1818 to 1848, Wolf reconstructed the daily sunspot numbers. Since 1848, sunspots had been recorded on a regular basis. Eddy (1976) qualified the sunspot number index as good since 1818.

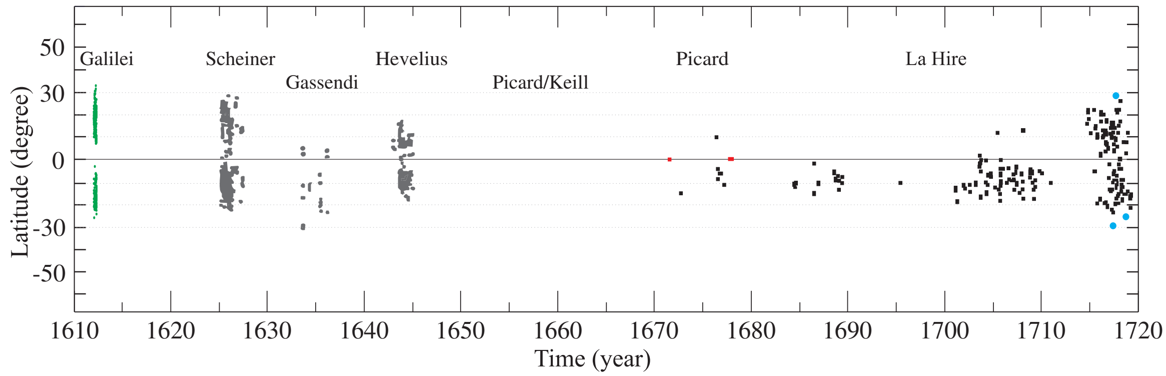


**Figure 10.** Butterfly diagram reconstructed from the sunspot drawings by Galilei, Scheiner, Gassendi, Hevelius, Picard, father and son La Hire. Sources: Ribes & Nesme-Ribes (1993), Soon & Yaskell (2003), and Casas et al. (2006).

**Table 1**
List of Observers and Periods of Their Reports of a Blank Sun, When the Exact Dates of Observations are Unknown

| No. | Observer | Date |
|---|---|---|
| 1 | Marius, S., Nuremberg | 1617–1618 |
| 2 | Riccioli, J. B., Bononia | 1618, 1632 |
| 3 | Zahn, J., Nuremberg | 1632 |
| 4 | Gassendi, P., Paris | 1633 Jan–Mar, 1634 Jan 1–Oct 23 |
| 5 | Crabtree, W., England | 1638–1639 |
| 6 | Hevelius, J., Danzig | 1645–1651 Feb |
| 7 | Unknown/Kraft | 1648 May 1–Aug 21 |
| 8 | Unknown1/Maunder/JBAA | 1652, 1654 Jan 1–Aug 12 |
| 9 | Picard/Keill, Paris | 1653–1659 |
| 10 | Picard, J., Paris | 1660 Jan, 1660 Aug 11–1665 Dec 31 |
| 11 | Fogel, M., Hamburg | 1661 Oct 15–1671 Jul 31 |
| 12 | Weigel, E., Jena | 1662–1664 |
| 13 | Weickmann, C., Germany | 1666–1667 |
| 14 | Siverus, H., Hamburg | 1675–1690, excluding several days in 1678, 1680, 1681, 1689 |
| 15 | Cassini, G. D., Paris | 1689 |
| 16 | Dechales, M., Lugduni | 1689 |
| 17 | Meraldi, M., Bononia | 1689, 1716 Feb, Mar, Oct, and Dec |
| 18 | Agerholm, C., Copenhagen | 1695 May 31–1700 Oct 31 |
| 19 | Wiedenburg, J. B., Helmstadt | 1708 Jan 16–Aug 10 |
| 20 | Unknown3/Maunder/JBAA | 1709 Feb 18–Aug 18 |
| 21 | Derham, W., Upminster | 1710 Oct 19 – 1714 Sep 9 |
| 22 | Wurzelbaur, J. P., Nuremberg | 1710 Oct 29–1713 May 17 |

According to NOAA/NGDC data, the duration of the solar cycles from 1823 to 2008 varied from 9.6 to 12.5 yr. We assume that similar criteria can be applied to duration of the solar cycles in the seventeenth century. Light gray bars (Figure 9(b)) show expected solar minima. We suggest that there were 11 cycles from 1609 to 1725. Note that Schove (1979) and Gleissberg et al. (1979) proposed 10 cycles with a duration of 8–15 yr. The numbers from −13 to −3 define the cycle number (Figure 9(b)) according to Zürich numbering. Light red schematic cycles show our speculation as to the amplitude and duration of the solar cycles.

Our second assumption is that the daily nominal NSGs is an estimate of the amplitude of a cycle. However, most of the time (see the previous sections) the number of sunspots is underestimated, which leads to uncertainties. Specifically, from 1630 to 1640, the information on sunspots is very limited (Figure 9(a)). It was mainly extracted from Opera Omnia. Note that Gassendi (1658) sketched only big sunspot groups, schematically marked as circularized texture objects (Section 2). Hence, the amplitude of Cycle −11 is questionable (Figure 9(b)). Observations from 1640 to 1650 are also poor. In February 1642, Rheita reported eight sunspot groups, but all other observers registered a fewer number of groups. Thus, Cycle 10 can be high or in the middle. In February 1660 Hevelius reported two sunspot groups. We cannot say whether these groups belong to the descending phase of Cycle −9 or the ascending one of Cycle −8, which leads to uncertainty in the duration of these cycles. From 1645 to 1671, the information on sunspots was only extracted from textual or tabular sources. In Section 3, we demonstrate that reports of sunspot observations without drawings provide an underestimated number of spots. Hence, the amplitude and duration of the solar cycles from 1645 to 1670 are especially questionable. The proposed maxima of Cycle −8 was poorly observed (Figure 9(a)), hence the amplitude of this cycle is unknown (Figure 9(b)), but in 1665 four naked-eye sunspots were registered (green stem in Figure 9(c)), though the number of naked-eye sunspots implies that Cycle −8 was not very low. Note that similarly to Figures 4–7, Figure 9(c) shows the annual GSN (Hoyt & Schatten 1998) and the number of naked-eye sunspots (Vaquero et al. 2002). Notice also that the Schwabe cycle period before each solar Grand minimum increases notably (Frick et al. 1997), hence on the eve of the Grand minima

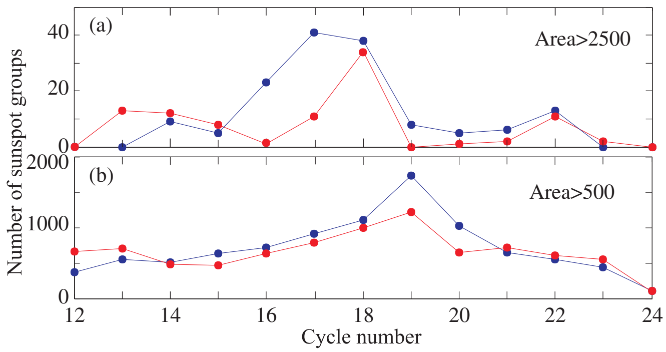


**Figure 11.** Number of sunspot groups in the northern hemisphere (blue) and the southern hemisphere (red): (a) with an area larger than 2500 msh and (b) with an area larger than 500 msh.

we can expect a cycle similar to Cycles 4, 11, or 23 (Zolotova & Ponyavin 2014). Due to the large number of zeros in the GSN database, $R_g$ has been vanishing since 1645 (blue line in Figure 9(c)). Also, few sunspot groups were registered from 1670 to 1710 (red points in Figure 9(b)). We suggest that Cycles −7 to −5 correspond to the minimum of the secular cycle.

Figure 10 shows the spatio-temporal sunspot distribution from 1610 to 1719. Sunspot positions (green points) from Galilei's drawings are provided by Casas et al. (2006). Gray circles mark drawings by Scheiner, Gassendi, and Hevelius. This part of the figure was taken from the book by Soon & Yaskell (2003), where the authors referred to Elizabeth Nesme-Ribes. Notice that Opera Omnia by Gassendi (1658) contains drawings from 1633 to 1638; however, the asymmetric butterfly diagram only covers 1634–1636. The small black squares from 1671 to 1719, originally published by Ribes & Nesme-Ribes (1993), are taken from Sokoloff & Nesme-Ribes (1994). The butterfly diagram for the MM can also be found in Soon & Yaskell (2003). Also notice that the red squares in Figure 10 are present in Ribes & Nesme-Ribes (1993), but they are absent in Soon & Yaskell (2003), while the blue ones are present in Soon & Yaskell (2003) and absent in Ribes & Nesme-Ribes (1993).

According to reports by Gassendi, Picard, and La Hire, the butterfly diagram was asymmetric (Figure 10) for several cycles (Eddy 1976; Ribes & Nesme-Ribes 1993). In Section 2, we argue that Gassendi (1658) drew only large sunspot groups. In Section 7, we demonstrate that La Hire also reported a fewer number of spots compared to other observers. We suggest that these facts can be explained by the scientific point of view of the observers, according to which sunspots are shadows cast by unknown celestial bodies. Hence, only sufficiently large sunspots with circularized shapes were reported. Small spots and spots of irregular shapes were probably not mentioned, in order to avoid a controversy.

Figure 11 shows the NSGs from the RGO/USAF/NOAA database. Figure 11(a) illustrates the NSGs in the northern hemisphere (in blue) and in the southern one (in red), with an area larger than 2500 msh. In Cycles 16 and 17, there was a significant asymmetry in the number of large sunspot groups. In Cycle 16 in the northern hemisphere there were 23 large groups, in the southern one, only 1. In Cycle 17, there were 41 big groups in the north, and 11, in the South. As to the NSGs with an area of more than 500 msh (Figure 11(b)), this asymmetry is reduced. We conclude that the asymmetric butterfly diagram in the seventeenth century and at the beginning of the eighteenth century can be the result of the asymmetry in the appearance of big spots. Notice also that the weak Cycles 12 and 24 even do not have sunspot groups with an area more than 2500 msh. These cycles of the secular minima can be similar in amplitude to Cycles −7, −6, and −5.

Waldmeier (1941), Becker (1954), and Vitinsky et al. (1986) showed that during weak cycles, sunspots more often appear at lower altitudes than during strong ones. It means that during the MM the sunspot zone shifted to lower latitudes. Moreover, according to Gnevyshev (1967), there is a tendency for the large spots to appear at the middle–low latitudes ($(10°–15°) \pm 5°$). These findings can explain the location of the spots at low latitudes during the mm.

Finally, we combine the hypothetical cycles from Figure 9(b) with modern sunspot indexes. Figure 12 illustrates Cycles 12 and 19. The blue points are the nominal NSGs for Greenwich, according to the Hoyt and Schatten database. The green line shows the monthly sunspot area. The points coincide with the lines, thus we use the same assumption that the nominal NSGs is an estimate of the amplitude of a cycle. The average nominal NSGs for Cycles 12 and 19 is about 6 and 15, respectively. Returning to Figure 9(b), we chose the cycle with the most realistic nominal NSGs. This is Cycle −13, when Galileo Galilei made drawings. The maximum value of the nominal NSGs of Cycle −13 is 10. We compare this value with the average amplitude of the nominal NSGs for Cycles 12 and 19. Thus, for

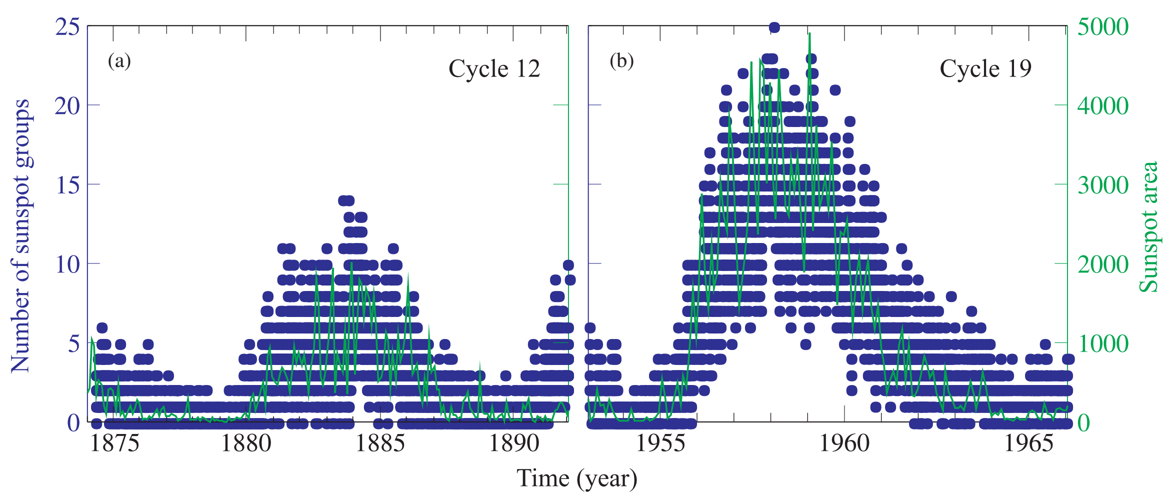


**Figure 12.** Blue shows the daily nominal number of sunspot groups, and green the monthly sunspot area for Cycle 12 (a) and Cycle 19 (b).

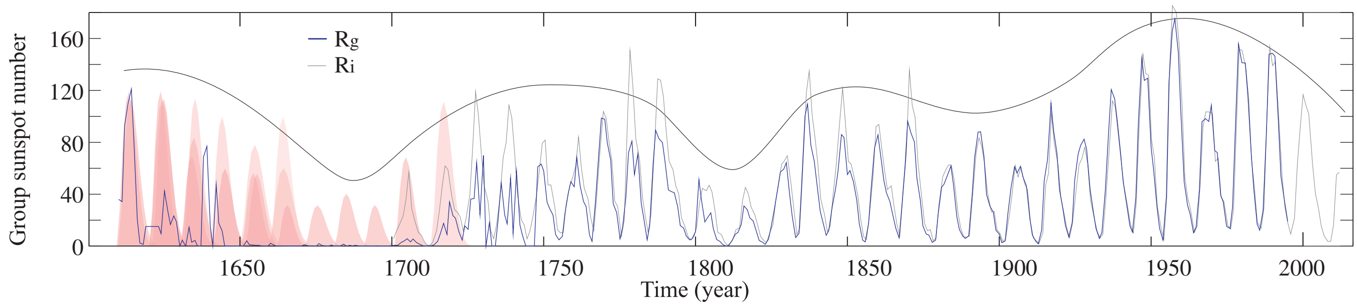


**Figure 13.** Group sunspot number $R_g$ is shown in blue, the international sunspot number $R_i$ in gray. Light red defines the supposed amplitude of solar cycles. The black line is the secular cycle.

Cycle −13 we use the maximum value instead of the average one, because Galilei's reports did not provide pores (small short-lived sunspots without a penumbra). They have been included into sunspot statistics by Alfred Wolfer (Clette et al. 2014) only since 1877. Certainly, this trick only roughly smoothes over disparity in the nominal number of sunspots due to the increase in the resolving power of telescopes from the seventeenth to the twentieth centuries.

Thus, the nominal NSGs for Cycles −13, 12, and 19 are 10, 6, and 15, respectively, and the amplitudes of $R_g$ for Cycles 12 and 19 are 60 and 180. Using a simple proportion, we evaluate $R_g$ for Cycle −13 as equal to 120. Also notice that the time span from 1610 to 1616 is free from observational reports continuously filled with zeros; hence $R_g$, according to Hoyt & Schatten (1998) for Cycle −13, is also about 120.

Figure 13 depicts the GSN $R_g$ (in blue), along with the international sunspot number $R_i$ (in gray). Light red cycles show our speculation regarding the amplitude and duration of solar cycles. The black line is a secular cycle that assumes the solar activity during the seventeenth century was not dramatically different from that over the past 300 yr.

## 9. CONCLUSIONS

In our work, we analyze the database of the nominal NSGs by Hoyt & Schatten (1998) from 1610 to 1720. Comparing the sunspot drawings by Galilei, Scheiner, Gassendi, and Hevelius, we conclude that only Galilei's drawings are similar to the modern sunspot observations. There was a tendency to draw sunspots as objects of a circularized form. Sunspot drawings provide a significantly larger number of sunspots, compared to textual or tabular sources. We suggest that this can be caused by the dominant worldview of the seventeenth century that spots (Sun's planets) are shadows from a transit of unknown celestial bodies. Hence, an object on the solar surface with an irregular shape or consisting of a set of small spots could have been omitted in a textual report because it was impossible to recognize that this object is a celestial body.

We also note that rare and short observations usually contain information only about one sunspot group. This suggests to us that an observer can be interested exactly in the Sun's planet transit, but not in the exact number of spots.

We demonstrate that some observers (among them Jean Picard and Giovanni Domenico Cassini, both from the Paris observatory) systematically created gaps in observations when other observers reported sunspots. This allows us to assume that in spite of the fact that telescopes were good enough to resolve even small spots, not all objects on the solar disk were included in historical archives. Hence, information about the solar activity over the seventeenth century is underestimated.

Analyzing the daily nominal NSGs for all individual observers, we suggest that the 11 yr solar sunspot cycle occurred non-stop throughout the seventeenth century. We assume that the solar activity from 1609 to 1723 was not dramatically different from that over the past 300 yr. Our findings suggest that the MM can be an ordinary secular minimum.

We use data from the Historical Archive of Sunspot Observations (http://haso.unex.es), Solar Influences Data Analysis Center (SIDC: http://sidc.oma.be/), Royal Greenwich Observatory, United States Air Force, National Aeronautics and Space Administration (RGO/USAF/NOAA: http://solarscience.msfc.nasa.gov/greenwch.shtml), the database by Hoyt & Schatten (1998) provided by the National Geophysical Data Center (NOAA/NGDS: http://www.ngdc.noaa.gov/stp/SOLAR/), and the Galileo Project (http://galileo.rice.edu/).

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