ISSN 0884-5913, Kinematics and Physics of Celestial Bodies, 2021, Vol. 37, No. 4, pp. 200–211. © Allerton Press, Inc., 2021.
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SOLAR PHYSICS

History of Sunspot Research and Forecast of the Maximum of Solar Cycle 25

I. E. Vasiljeva[a, *] **and M. I. Pishkalo**[a, **]

[a] *Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Kyiv, 03143 Ukraine*
**e-mail: vasil@mao.kiev.ua*
***e-mail: pish@mao.kiev.ua*

Received March 6, 2021; revised March 6, 2021; accepted April 19, 2021

Abstract—The paper provides a short historical overview of sunspot observations from their discovery until the present. The review goes beyond collecting all known historical information about the study of sunspots but highlights the research of five scientists of different epochs over five centuries since the 16th. Not as much attention is deliberately given to some well-known studies and discoveries. The focus is on the utmost long-term observations of sunspots, which provide information that expands the boundaries of classical Wolf numbers or the number of sunspots groups. Sunspots have been observed since ancient times and they were documented in ancient chronicles. Active observation of sunspots began after the invention of the telescope, probably by Hans Lippershey in the early 17th century. It is documented that Thomas Harriot was the first to observe sunspots with a telescope on December 8, 1610. It is probable that Galileo Galilei and Johann Fabricius observed sunspots almost simultaneously with him in December 1610 using a telescope, independently of each other and of Harriot. The first publication about sunspots was issued by Fabricius in June 1611. We dwell on the observations of Christoph Scheiner, Christian Horrebow, Heinrich Schwabe, and Hisako Koyama. Christoph Scheiner described his long-term observations and studies of sunspots from 1611 to 1630 in his book *Rosa Ursina sive Sol*, which became a model for the Sun observers for many years afterwards. Christian Horrebow was the first to speculate on the regularity of sunspots, and Heinrich Schwabe was the first in 1843 to discover the periodicity (with a period of approximately 10 years) of the number of groups of sunspots. In 1852 Rudolf Wolf, analyzing all available sources, clarified that solar activity has an 11-year periodicity. He introduced the concept of the relative sunspot number and organized regular observations and publication of their results. Hisako Koyama's 40-year observations have helped reconcile current sunspot counts with earlier ones. Wolf's system lasted until the beginning of the 21st century. In July 2015, a new version of the relative sunspot numbers was adopted (Version 2.0). In this paper, the ratio of "new" and "old" Wolf numbers is calculated and a table of characteristics of 11-year cycles according to Version 2.0 is proposed. Two forecasts of the maximum of solar cycle 25 are also calculated. In the case when the precursor of the maximum is the value of the relative sunspot number in the cycle minimum (correlation coefficient $r = 0.557$ and $P < 0.001$), the predicted maximum is 135.5 ± 33.8. In the second case, when the precursor is the duration of the previous cycle ($r = -0.686$ and $P < 0.001$), the predicted maximum is 179.4 ± 18.2. Both predictions indicate that solar cycle 25 will be stronger than solar cycle 24 and weaker than solar cycle 23.

Keywords: Sun, solar activity, solar cycle, prediction of solar activity

DOI: 10.3103/S0884591321040073

Solar activity is constantly changing, and this has a lot to do with modern life. The increase in solar activity implies an increase in extreme ultraviolet and X-ray radiation from the Sun, which leads to a sharp reduction in the lifetime of satellites in low Earth orbits, damage to instruments on spacecrafts, and it threatens the health of astronauts and aircraft passengers. Solar activity appears to have an effect on the Earth's climate as well, with temperatures increasing and decreasing as solar activity rises and falls. Centuries-old observations are the only direct evidence of what actually happened in the past of the Sun. Recovering this kind of information from various documentary records stored in libraries and historical archives around the world is essential for a better understanding of the evolution of our Sun.

It is difficult to say who was the first to notice spots on the Sun. They were almost certainly seen by prehistoric people looking at the Sun through the fog. Aristotle's student Theophrastus of Athens (4th century BC) mentioned spots on the Sun. They were described by Arab and Armenian chronicles, Russian chronicles, ancient Chinese chroniclers, and medieval historians as some kind of dark formations on the Sun (the word "spot" appeared later, in the 17th century, when it was possible to see sunspots through a telescope for the first time).

The earliest records of sunspots were made in China over 2000 years ago. Gan Do recorded sunspots in 364 BC. More systematic records are found in historical chronicles, for example, Hou Hanshu wrote, "on the day of bin-shen, second month of the fourth year of the Zhongping era of the reign of Emperor Xiaolin-di (March 5, AD 187) there was a melon-sized dark mass on the Sun;" Tongzhi wrote, "on the day of i-wei, 11th month of the fourth year of the Taishi era of the reign of Emperor Wu Jin (December 23, AD 268), there was a black spot on the Sun." Sunspots are described as black steam, plums, peaches, or eggs on the Sun. From 28 BC to AD 1638, large spots on the Sun have been described in the official Chinese chronicles at least 170 times [29, 34, 95].

In medieval Europe, the first mention of sunspots is found in the chronicle of John of Worcester: "In the third year of Lothar, the Roman emperor, in the 28th year of the reign of King Henry of England (AD 1128), on the twenty-fifth moon on Saturday, the sixth id of December (8 December) from morning to evening, two black spheres appeared against the background of the Sun. The first was in the upper part and large, the second was in the lower part and small, and each was directly opposite the other" [6].

In 1608, an event occurred that radically changed the development of astronomy, including solar astronomy. A glass grinder from the Dutch city of Middelburg named Hans (Johann) Lippershey built a telescope with two lenses. On October 2, 1608, he provided the States General of the Netherlands with a "Distance Vision Tool." Soon, at the court of Count Maurits van Nassau in the Hague, Lippershey showed the operation of his invention, demonstrating that from the tower in the Hague one can see the clock on the tower of the church in Delft, at a distance of about 15 km. The demonstration was attended by envoys and statesmen who had gathered in connection with the negotiations for a 12-year truce in the Eighty Years War. Lippershey asked for financial support from the States General and received 900 guilders to improve technology and train specialists for the army. However, his patent request was rejected due to the fact that other masters, in particular Zachary (Zacharias) Jansen of Middelburg and Jacob Metius of Alkmaar, already possessed copies of telescopes, and the latter, shortly after Lippershey, filed a patent request with the States General [1, 18, 20, 49, 88, 93, 94, 97, 98]. On March 3, 1655, the Middelburg City Council investigated the priority of the invention of the telescope and found that the first telescopes began to be made in Middelburg around 1605, and soon many craftsmen were already making them [8]. Anthony Pannekoek in his *History of Astronomy* indicates that Zachary Jansen from Middelburg made a similar viewing pipe as early as 1604, in turn, copying it from a copy belonging to an unknown Italian [57].

The invention of the telescope was announced in a letter to the professor of the University of Padua, Galileo Galilei, by the Venetian envoy in Paris. Galileo built the described construction in his workroom in the summer of 1609. The name "telescope" (translated from Greek "looking into the distance") was invented by Ioannis Dimisianos, a member of the Accademia dei Lincei (Academy of Lynx Eyes), in which Galileo was included. The telescope, invented in Holland, soon became a popular instrument throughout Europe. Thus, it is natural that, among other celestial objects, sunspots were discovered independently in several places by different observers almost simultaneously [60].

Thomas Harriot is considered the first person to see sunspots at Sion House on December 8, 1610, observing the Sun directly through a telescope. Subsequently, Harriot captured images of sunspots in almost 200 drawings. But, like many other works, he did not publish images of sunspots [12, 27, 90].

The first message describing the spots was published in the book *De Maculis in Sole Observatis* (Spots Observed on the Sun) by Johann Fabricius, who observed the spots with a telescope at Ostila in East Friesland on February 27, 1611 (although there is information that Fabricius also observed sunspots in December 1610 for the first time). Fabricius reported that the Sun appears to be rotating on its axis. Following the motions of three spots on the surface of the Sun, he estimated the period of rotation of the Sun to be about 1 month [10, 54].

In a letter dated May 4, 1612, to Max Welser, a banker, philanthropist, politician and scientist, Galileo reported that he had been observing the spots for 18 months already, i.e., from the end of 1610, but did not give any evidence of this. It is known that in the spring of 1611, during his stay in Rome, Galileo showed sunspots to representatives of the nobility and clergy. In 1613, in a publication on sunspots, Galileo claimed to have observed this phenomenon in April 1611. He describes the observation technique in a letter to Welser dated August 14, 1612: "Point the telescope at the Sun, as if you were going to observe this body. Focusing and stabilizing it, place a flat white sheet of paper about a foot away from the concave lens; a circular image of the Sun's disk will fall on it with all the spots that are located on it and are located in the same symmetry as in the Sun. The more the paper moves away from the telescope, the larger this image becomes, and the better the spots will be depicted. So that all of them will be visible without damage

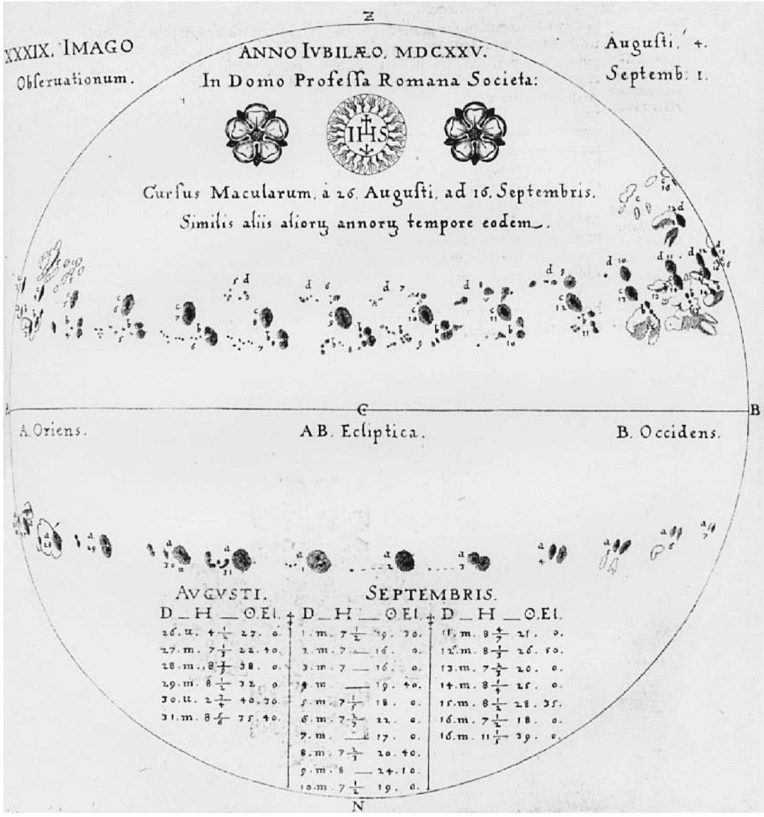

Fig. 1. Sketch of Scheiner's observations from August 26 to September 16, 1625.

to the eyes, even the smallest of them, which when viewed through a telescope is barely visible, and would only lead to eye fatigue and injury ..." [10, 22].

Another sunspot observer was Christopher Scheiner, a German Jesuit and professor at the University of Ingolstadt [48, 80, 91]. Church traditions, in principle, did not allow new discoveries, allowing only to quote and comment on the Holy Scriptures. The encroachment on the perfect purity of the Sun looked blasphemous. Churchman Scheiner was trying to save the Sun from imperfection. Therefore, he suggested that sunspots were caused by the Sun's satellites, whose shadows are projected onto the Sun's disk. His letters about this phenomenon, written to Mark Welser, were published in early 1612 under the pseudonym "Apelles latens post tabulam" ("Apelles hiding behind a painting"). Welser invited Galileo to comment on these letters, and Galileo replied with two letters to Welser in which he argued that sunspots are on or near the surface of the Sun, that they change their shape, and that they often appear on the Sun and die there, and therefore the Sun is imperfect [9, 21, 54].

However, Galileo did not make systematic observations of sunspots. Scheiner devoted himself entirely to these observations and continuously observed sunspots for more than 15 years [5, 6, 48, 86]. The first solar observations were made by Scheiner directly through a telescope in March–May 1611, when he discovered spots on the Sun. He continued regular observations after a few months, when he received and began to use blue and green glass filters. Figure 1 shows Scheiner's sketch of sunspots; he was the first to propose new ways of representing the motion of sunspots along the solar disk.

In the following years, Scheiner developed a "heliotropii telioscopici" (helioscope) for observing the Sun. The results of many years of observations were published in 1630 in his book *Rosa Ursina sive Sol* [17, 62, 87]. This book is divided into four parts. In the first part, Scheiner discusses the priority of sunspot discovery. The second part describes the helioscope, compares the optics of the telescope with the optics of the eye. In the third part, Scheiner presents a full account of his observations of sunspots. The fourth part deals with various solar phenomena, such as sunspots and solar flares, the 27-day period of the Sun's rotation, and the tilt of the rotation axis. At the end, Scheiner cites numerous fragments and quotations from the Bible and the writings of the church fathers.

In the second half of the 17th century–the beginning of the 18th century, sunspots were observed by Jan Hevelius in Danzig, Jean Picard in Paris, Martin Vogelius, and Heinrich Siverus in Hamburg, John Flam-

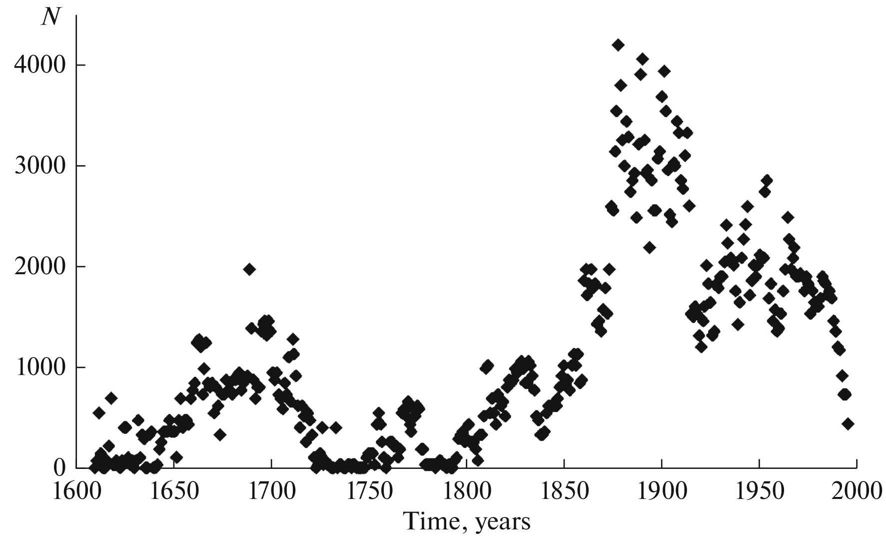

Fig. 2. Number of sunspot observations per year.

steed in Greenwich, Georg Christoph Eymmart in Nuremberg, Philippe de la Hir in Paris, and some their other contemporaries [86, 96]. For many years, they diligently took notes on the spots on the Sun. Gradually, the huge interest in observing sunspots, which existed soon after their discovery, was lost (see Fig. 2).

Since the middle of the 18th century, the number of observations has increased. In particular, Johann Kaspar Staudacher in Nuremberg and Christian Horrebu in Copenhagen made notes and sketches for 50 (more than 1000 observation days) and 15 (more than 3000 observation days) years, respectively [19, 83]. At the same time, shorter series of observations were made by Ludovico Zucconi in Venice (almost 900 days of observations over 16 years) and Karl Schubert in Danzig (almost 500 days of observations over 4 years) [96].

Observations were carried out in Paris, Marseille, Lilienthal, Gottingen, Dresden, Berlin, Graz, Munich, Edinburgh, Venice, Milan, and Prague. But none of the observers even thought about how to generalize the observations. If this had happened, the periodicity of sunspots could have been known much earlier, but it was believed that the appearance of sunspots is an accidental phenomenon and, as the French astronomer Jean-Baptiste Joseph Delambre said: “The sunspots themselves are more funny than useful.” Here are some statements about the periodicity of sunspots by prominent astronomers of their time: “There is no regularity in the appearance and disappearance of [sunspots]" (John Keil, 1718, *Introductio ad veram astronomiam, seu lectiones astronomicæ habitæ in Schola Astronomica Academiæ Oxoniensis* [38]); "There are no rules in the formation, number, and shape [of spots]" (Jacques Cassini, 1740, *Elements d'astronomie*) [11]; “[Sunspots] do not follow any law in their appearance” (Pierre Charles Lemonnier, 1746, *Institutions astronomiques* [43]); “Sunspots are irregular in shape, power, number, or time of their appearance and life "(Roger Long, 1764, *Astronomy, in five books* [46]); and “The appearance of spots has nothing to do with regularity (Joseph Jérôme Lefrancois de Lalande, 1771, *Astronomie* [42]).

The first mention of the possible periodic behavior of sunspots was made by Christian Horrebu, who wrote in his diary in 1776: “Although our observations indicate that sunspot changes must be periodic, no one can find definite rules for the order in which this change occurs, and after how many years. This is mainly due to the fact that astronomers have so far made little effort to frequently observe sunspots, no doubt because they believed that nothing would come of it that would benefit astronomy” [28].

For his time, Christian Horrebu was a very productive scientist: he published at least seven monographs in Latin and 28 papers in Danish; 20 notebooks of his containing observations of sunspots, with tables, drawings, comments on observations in Latin have been preserved. [30, 35, 37, 50]. Thus, he was probably the first to suggest that solar activity has a periodicity [6].

At the end of the 18th century and the beginning of the 19th century, Pierre-Gilles-Antoine-Honore Flaugergue in Vivier, Augustine Stark in Augsburg, Johann Wilhelm Pastorff in Drossen, Frankvis Arago in Paris, and Johann Friedrich Julius Schmidt in Athens joined the Sun's observers [96]. And although Christian Horrebu mentions the possible periodicity of sunspots in 1776, the actual solar cycle was discovered 68 years later.

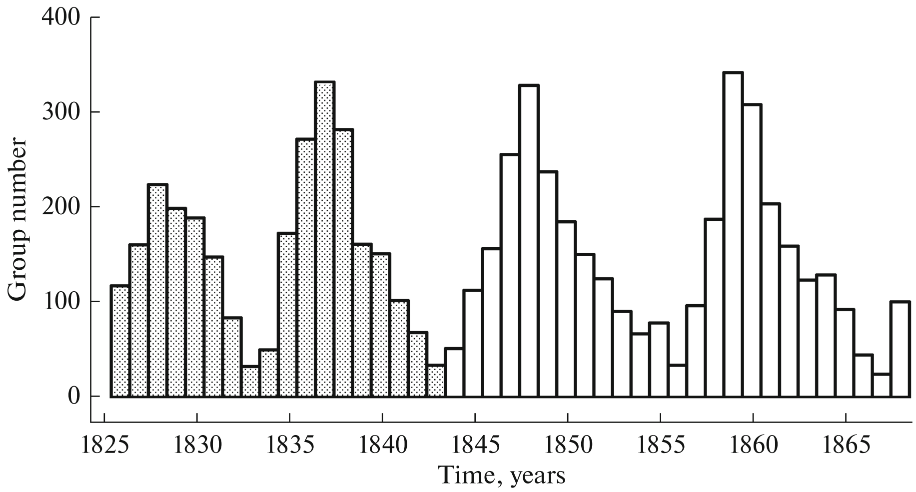

Fig. 3. Groups of sunspots observed by Heinrich Schwabe from 1826 to 1868. Shaded data are those on the basis of which Schwabe made his conclusion about the periodicity of solar activity.

Observer Heinrich Schwabe was looking for an unknown planet inside the orbit of Mercury, which, he believed, could be detected as a dark spot when passing in front of the Sun but soon focused on observing sunspots [24, 47]. Year after year, beginning in 1826, Schwabe observed and sketched sunspots every clear day. In 1843, based on the records of daily observations between 1826 and 1843, he discovered the frequency of occurrence of spots with a cycle of approximately 10 years. He published this discovery in a small paper "Solar Observations in 1843" in *Astronomische Nachrichten* [64]. Figure 3 shows his data on the number of sunspot groups observed annually from 1826 to 1855 [63, 65–79]. In 1857, the Royal Astronomical Society awarded Schwabe its gold medal (it was presented to him in Dessau by Carrington), and he was elected a Fellow of the Royal Society in 1868 [2–4, 7, 16, 23, 33].

At first, Schwabe's report on the periodicity of sunspots received little attention. It became widely known and generally recognized only in 1851, when the famous naturalist Alexander Humboldt, in the third volume of his book *Cosmos*, notified the whole world about this discovery [92].

In 1852, astronomer Rudolph Wolff redefined the duration of the solar cycle. According to his calculations, it turned out that the maximum number of spots is repeated every 11.1 years (and not once every 10 years, as Schwabe believed). As director of the Zurich Observatory, Wolf was the first to organize permanent systematic observations of sunspots. He also introduced the concept of the daily "relative" sunspot number (Wolf number, international sunspot number, Zurich number)

$$W = k(f + 10g),$$

where g is the number of groups of spots, f is the number of individual spots, and k is the weight factor for the observer. Wolf introduced a system based on the use of a main observer. The number of sunspots per day was determined by the main observer. If the main observer was unable to count, then the definition from the secondary or tertiary observer with different weights was used instead [96]. From 1849 to 1893, Wolf himself was the main observer, Alfred Wolfer (Zurich) from 1894 to 1926, William Otto Brunner (Zurich) 1926–1944, Max Waldmeier (Arosa) 1945–1979, and the International Sunspot Number has been provided since 1981 by the Royal Observatory of Belgium with Sergio Cortesi (Locarno) as main observer. Wolf expanded the records 100 years ago, using Johann Kaspar Staudacher (Nuremberg) as the main observer from 1749 to 1787, Honore Flogerga (Vivier) from 1788 to 1825, and Samuel Heinrich Schwabe (Dessau) from 1826 to 1847. It should be noted that scientists made very detailed sketches of the structure of sunspots, which are not inferior in detail to even the best modern images, even in the 19th century (Figs. 4, 5).

Already in the 20th century, Hisako Koyama, a Japanese observer, created one of the most significant collections of sunspot observations in the last 400 years. In 1944, she presented her first sketch of a sunspot to Issei Yamamoto, professor of astronomy at Kyoto University. Under Yamamoto's guidance, Koyama began sketching sunspots by projecting images from a 20-cm refractor telescope onto a sheet of paper. In the spring of 1946, Koyama began working as a professional staff observer at the Tokyo Science Museum (now the National Museum of Nature and Science) [55, 85]. From 1947 to 1984, Koyama documented over 8000 sunspot groups, which she published in a monograph in 1985. Her observations have made a

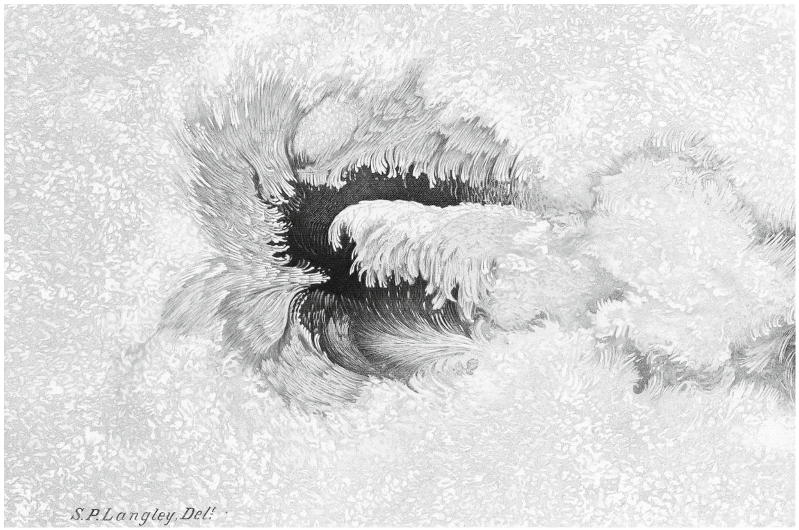

Fig. 4. Image of a sunspot made by Samuel Pierpon Langley on December 24, 1873. The sunspot was observed using a 13-inch Fitz-Clark refractor at the Allegheny Observatory (Pittsburgh, Pennsylvania). Presented in *The New Astronomy*, 1888.

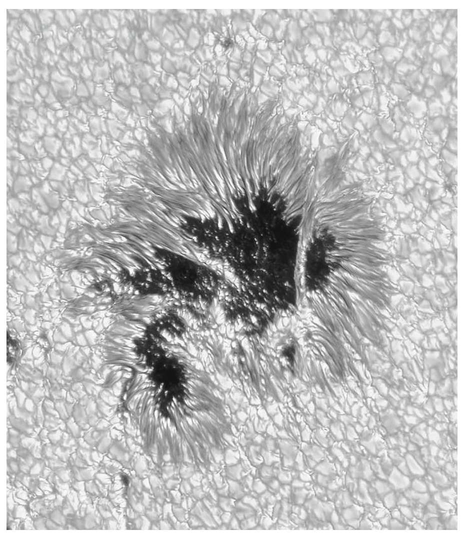

Fig. 5. Active region AR NOAA 11109 September 27, 2011, NST telescope at Big Bear Solar Observatory in California. One of the most detailed sunspot images to date.

significant contribution to the establishment of continuous registration of sunspots over the past four centuries. In 1986, she was the recipient of the Eastern Astronomical Association (OAA) Prize [55, 85]. Over 40 years of research, she made more than 10000 drawings of the Sun [41]. All of Koyama's sketches were created using the same telescope and observation method [25, 40]. Because of this, her observations were used as a basis for calibrating sunspot counts, to bridge the important gap between the early twentieth century and modern records.

A significant step in improving the sunspot series was made in 1998, when Douglas W. Hoyt and Ken Schatten [31, 32] published a revised sunspot series from 1610. The new series was based on an analysis of 455242 records of 463 observers. However, not all the problems in the comparison of sunspot records, which are often indistinct and were made in conditions of different visibility, were solved [36, 52, 53].

Since 2011, an international team of researchers led by Leif Svalgaard has been trying to reconstruct an almost 400-year history of sunspot activity from 1610 to the 2000s [13, 45, 81, 82]. The project is based on

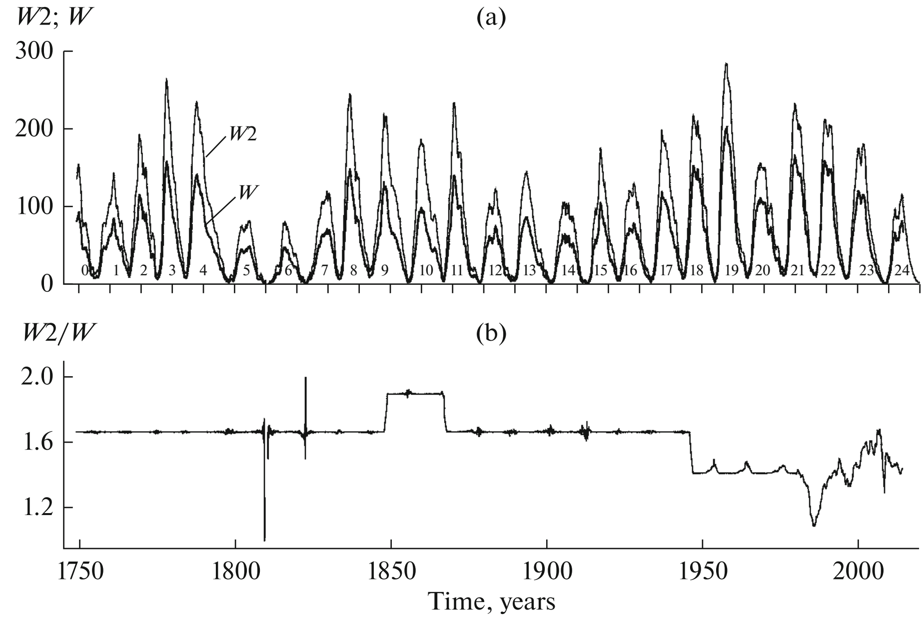

Fig. 6. Change over time of the monthly smoothed relative sunspot number ("new," Version 2.0—*W*2, *thin line*, "old"—*W*, bold line; upper panel) and the relationship between "new" and "old" values (lower panel).

sketches by Christoph Scheiner, Johann Kaspar Staudacher, Heinrich Schwabe, Rudolf Wolf, and Hisako Koyama [9, 26].

Since July 2015, the SILSO International Data Center (*Sunspot Index and Long-term Solar Observations*) at the Royal Observatory of Belgium maintains a new, revised series of relative sunspot numbers (Version 2.0). New sunspot data have been fairly reliable since 1750. They also agree well with other measurements of solar variability [14, 15, 44, 84]. Detailed information about the need for such a revision and how it was done can be found, for example, in [14].

The main differences between Version 2.0 and the previous one are as follows:

(1) the observational series of Alfred Wolfer was taken as a basis and not the observational series of Rudolf Wolf, which increases the earlier values by approximately 1.67 times, making them comparable with modern definitions;

(2) the value after 1947, when Max Waldmeier, when determining the relative sunspot number, introduced "weights" in accordance with the size of the sunspots, corrected;

(3) a trend found and eliminated in observations of the Locarno Observatory, which was a reference observatory after 1980.

Figure 6 shows the plots of "new," revised, and "old," up to 2015, monthly smoothed Wolf numbers and their ratio, and Table 1 presents solar cycle characteristics according to Version 2.0. The maximum number of sunspots was observed in the 19th cycle (285.0) and the minimum number of sunspots was observed in the sixth cycle (81.2). The shortest and longest cycles were respectively the second and fourth cycles with the duration of 9.0 and 13.58 years.

The future forecast of solar activity is of great interest for heliophysics and space weather, both at the maximum of the current 25th solar activity cycle, the minimum of which was observed a little over a year ago, in December 2019, and in the long term. There are many methods of forecasting the maximum of the cycle (see, for example, [59]); there are new forecasts of the maximum of the 25th cycle almost every day. We will also estimate what the maximum number of sunspots can be in the 25th cycle.

Figure 7 shows the dependences of the maximum smoothed monthly sunspot number W_{max} on the value of W_{min} at the minimum of the cycle and on the duration of the previous cycle T_{cp}. These dependences in the linear approximation are described by the expressions

$$W_{max} = (125.3 \pm 18.9) + (5.7 \pm 1.7)W_{min},$$

$$W_{max} = (557.9 \pm 86.1) + (-34.4 \pm 7.8)T_{cp}.$$

The correlation in both cases is statistically significant. The correlation coefficient between W_{max} and W_{min} is 0.557 ($P < 0.001$), and between W_{max} and T_{cp} is 0.686 ($P < 0.001$).

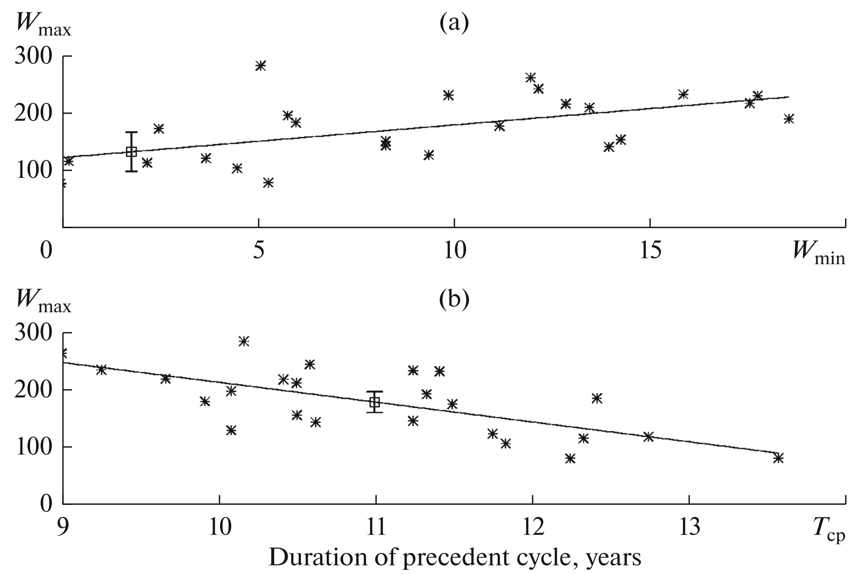

Fig. 7. Forecast of the maximum number of sunspots W_{max} in the 25th cycle by the value of W_{min} at the minimum of the cycle (above) and by the duration of the previous cycle T_{cp} (below). Straight lines are regression lines. The predicted values for the 25th cycle with a confidence interval of 2σ are shown by squares.

Table 1. Solar cycles (monthly smoothed values, Version 2.0)

Cycle number	T_{min}	W_{min}	T_{max}	W_{max}	T_{rise}	T_{fall}	T_{cycle}
0	1744.500	8.3	1750.288	154.3	5.788	4.835	10.623
1	1755.123	14.0	1761.455	144.1	6.332	5.000	11.332
2	1766.455	18.6	1769.707	193.0	3.252	5.748	9.000
3	1775.455	12.0	1778.371	264.3	2.916	6.337	9.253
4	1784.708	15.9	1788.124	235.3	3.416	10.164	13.580
5	1798.288	5.3	1805.123	82.0	6.835	5.415	12.250
6	1810.538	0.0	1816.373	81.2	5.835	6.915	12.750
7	1823.288	0.2	1829.874	119.2	6.586	4.000	10.586
8	1833.874	12.2	1837.204	244.9	3.330	6.334	9.664
9	1843.538	17.6	1848.124	219.9	4.586	7.834	12.420
10	1855.958	6.0	1860.124	186.2	4.166	7.080	11.246
11	1867.204	9.9	1870.623	234.0	3.419	8.335	11.754
12	1878.958	3.7	1883.958	124.4	5.000	6.246	11.246
13	1890.204	8.3	1894.042	146.5	3.838	8.000	11.838
14	1902.042	4.5	1906.123	107.1	4.081	7.415	11.496
15	1913.538	2.5	1917.623	175.7	4.085	6.000	10.085
16	1923.623	9.4	1928.290	130.2	4.667	5.417	10.084
17	1933.707	5.8	1937.288	198.6	3.581	6.836	10.417
18	1944.124	12.9	1947.371	218.7	3.247	6.917	10.164
19	1954.288	5.1	1958.204	285.0	3.916	6.587	10.503
20	1964.791	14.3	1968.874	156.6	4.083	7.332	11.415
21	1976.206	17.8	1979.958	232.9	3.752	6.749	10.501
22	1986.707	13.5	1989.874	212.5	3.167	6.750	9.917
23	1996.624	11.2	2001.874	180.3	5.250	7.084	12.334
24	2008.958	2.2	2014.288	116.4	5.330	5.670	11.0
25	2019.958	1.8					
Average		9.0		177.7	4.418	6.601	11.018

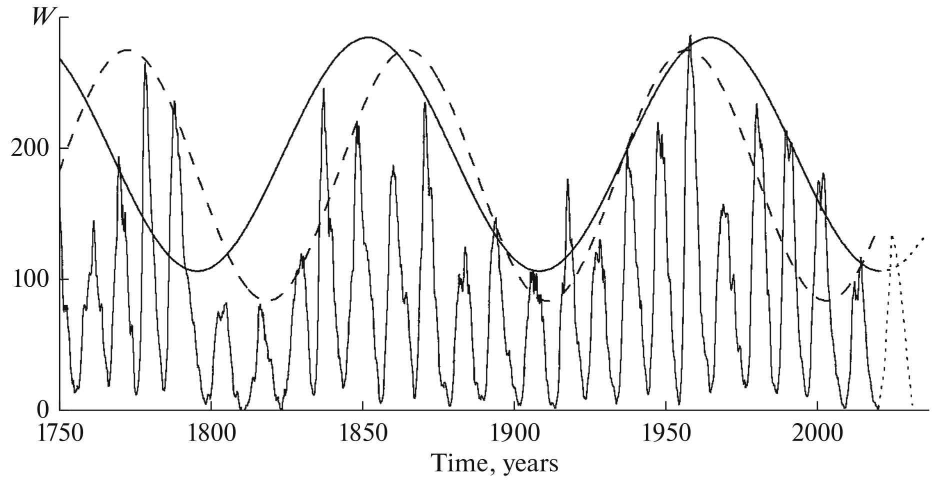

Fig. 8. Monthly smoothed sunspot number *W* and graphs of sinusoids with periods of 92.193 and 112.727 years (dashed and solid lines, respectively). The dotted line shows the predicted sunspot number in the 25th cycle.

The above dependences make it possible to obtain the predicted values of the maximum of the 25th cycle. Taking into account that $W_{min}(25) = 1.8$ and $T_{cp}(24) = 11.0$ (see Table 1), we obtain, respectively, two forecasts of the maximum of the 25th cycle: 135.5 ± 33.8 and 179.4 ± 18.2 (confidence intervals correspond to 2σ). Comparing the obtained forecast values for the 25th cycle with the highs of the previous cycles, it can be seen that the 25th cycle is expected to be higher than the 24th but below the 23rd cycle.

Our forecasts for the 25th cycle are consistent with the forecasts in [39, 56, 58, 61], where the predicted value is 135 ± 25, 122.1 ± 18.2, 154 ± 12, 147 ± 30, respectively; it is also predicted that the 25th cycle will be more active than the previous one and weaker than the 23rd cycle.

The time dependence of the number of sunspots also shows the so-called "secular" cycle with a period of seven to ten 11-year cycles (*Gleisberg cycle*, Fig. 8). For 1750–2020, the average secular cycle is approximately 92.2 years and that for 1910–2020 is approximately 112.7 years. The amplitude of the secular cycle is likely to go up in the coming years. This also indicates that a further drop in solar activity to the level of some new minimum, such as the Maunder minimum, is not expected.

Thus, the relative sunspot number, the main index of solar activity, is by far the longest continuous observational index characterizing the Sun. It allows one to study not only the dynamics of solar activity over a long time but also its influence on the climate or other processes on Earth.

New data show that solar activity has been relatively constant since the 1750s, with no significant trends (other than secular cycle variations). And this, in turn, indicates the need to adjust or revise climatological models of the influence of solar activity on global warming. The work of observers and researchers of sunspots of past centuries allows not only to better understand solar activity and processes on the Sun but also to predict the impact of solar activity on our life in the future.

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Translated by E. Seifina