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A Crucial Window into the Sun: The Long and Arduous Road of Sunspots Observation and Study

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Abstract: Sunspot is a crucial "window" for humans to understand the complex activities inside the sun. The discovery, observation, and study of sunspots throughout history have been long and arduous. This paper traces and summarizes the history of observing and studying sunspots, dividing it into seven stages: germination, initial, revolution, development, spiral ascension, innovation breakthroughs, and modern research. It focuses on the important roles played by many scientists in this process and summarizes the overall research model of the development process. The goal is to gain a clearer and more comprehensive understanding of the sun through this window of sunspots and promote harmonious coexistence between humans and nature.

Keywords: Activity Laws; History; Scientists; Sunspots.

1. Overview of Sunspots

Sunspots, as the name implies, are black spots on the surface of the sun which can be discovered through direct observation. In fact, they are not black substances that appear in the solar atmosphere but rather areas on the surface of the sun that are relatively cooler than their surroundings [1]. Sunspots do not appear alone in various regions of the photosphere but often appear in pairs or groups with a certain periodicity. The average period is 11 years, known as the solar cycle [1].

As for the basic characteristics of sunspots, research has already gained a more comprehensive understanding of their features, distribution, periodicity rules, etc. Therefore, this paper will trace and summarize the history of observing and studying sunspots from their discovery to present days while interpreting important roles played by scientists in this process.

2. Germination Period: Differences between Eastern and Western Concepts

The discovery of sunspots can be traced back to ancient times when Western philosophy revered Aristotle's cosmology: that celestial bodies were eternal and perfect without flaws, which was later combined with Christian doctrine to become an inviolable dogma [1].

In contrast, the records of sunspots in East Asia are much more numerous [2]. The most recent addition by the Academy of Sciences' astronomical record compilation team has increased the number to 246 [4].

3. Initial Period: The Battle between Theology and Science

Astronomy is not like other natural sciences such as physics and biology, which can induce laws through experimental verification, but rather draws conclusions through observing celestial bodies.

In 1609, Galileo made a telescope that could magnify objects six times without distortion [6] and compiled his first observations into a book called The Sidereal Messenger, indirectly proving Copernicus's heliocentric theory. The sun, as the center of the earth's revolution, has received much attention.

In Letters on the Sunspots, Galileo scientifically demonstrated that sunspots are not planets but rather a substance that exists on the surface of the sun and has a certain periodicity [7]. As shown in Figure 1, the shapes of sunspots varied at different times, sometimes gathering and sometimes dispersing, accompanied by processes of generation and decomposition [8]. These findings directly proved that sunspots are part of the sun and broke through the stubborn cognition of "celestial perfectionism", freeing people from dogmatic constraints and enabling them to view celestial bodies with scientific eyes.

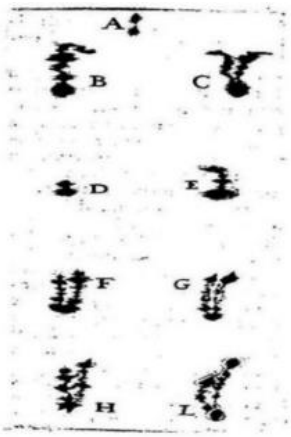


Figure 1. Galileo's Observations of Sunspots

In summary, the initial discovery and demonstration of sunspots were accompanied by many debates among various viewpoints and also represented a confrontation between theological and scientific spirits in the same era. In this conflict of ideas, a new revolution in astronomy was born.

4. Revolution Period: Transition from Positional Research to Regularity Research

However, as shown in Figure 2, after Galileo's significant discovery of sunspots in the 17th century, research on sunspots remained dormant for nearly 100 years due to the suppression of the church and low solar activity periods. It was not until the early 19th century that scientists gradually began to pay more attention to sunspots.

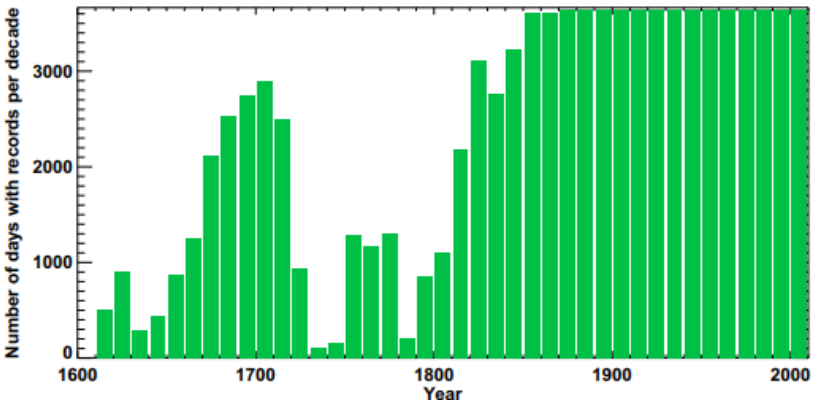


Figure 2. All Records of the Number of Sunspots Studies from 1600 to 2000 [2]

In 1795, Herschel discovered that there was periodic variation in the number of sunspots based on Galileo's observation of their shape, pointing out a new direction in this research field [9]. He compared two sets of data: the wheat prices and the records of sunspot occurrences, indirectly comparing the climate with the occurrences of sunspots. He found that the period when there were more sunspots coincided with peak wheat prices in England. Therefore, he believed that the number of sunspots must somehow affect our weather and agriculture.

5. Development Stage: In-depth Exploration and Induction of Activity Laws

Herschel's observation results opened a new chapter in the observation of sunspots, and people began to pay attention to the impact of changes in solar luminosity on the earth's environment.

5.1. Schwabe: Discoverer of the 10-Year Activity Cycle

German astronomer Schwabe collected 8,486 images and 3,699 observation records of sunspots between 1825 and 1867 [2]. He discovered that the variation of sunspots had an obvious rise and fall cycle, and then summarized the regularity of sunspot activity.

In 1844, Schwabe first explained his discovery about the cycle of sunspots in Astronomische Nachrichten: the rise and fall of sunspots have a period of about ten years, which is the time interval between two peaks. The probability of a group of sunspots appearing is small near the minimum value of sunspot numbers, while it is high near the maximum value [11].

5.2. Wolf: The Founder of Unified Observation Standards

In 1847, Swiss astronomer Wolf accidentally observed sunspots and introduced the concept of relative sunspot numbers in 1850 to quantify the activity level of sunspots. The definition of relative sunspot number is "R=K (10g+f)", where "R" refers to the relative number of sunspots, "g" is the number of sunspot groups observed on the solar surface, "f" is the total number of individual spots observed, and "K" is a calibration factor that can be adjusted according to observation location [12]. Wolf collected data on sunspot activity from observers around the world through network transmission and compiled historical observations into a detailed record. He concluded that the average period of change in sunspot numbers is 11.1 years, with a minimum of 9 years and a maximum of 14 years. The differences in the changes of the number of sunspots between different periods are also very significant.

6. Spiral Ascension Period: Longitudinal Study Combining Time and Space Dimensions

From Galileo's discovery of sunspots to Herschel's discovery of periodicity laws, and then to Schwabe and Wolf's summary of periodicity laws, people's understanding of sunspots has gradually deepened. But are there any laws governing the movement patterns between time and space dimensions?

6.1. Carrington: Explorer of Sunspot Latitude Variation Law

In 1859, Carrington discovered for the first time that there was a latitude variation in sunspot activity cycles [13]. He found that as solar cycles progressed, sunspots gradually moved towards the equator and contracted according to a certain law. He also summarized the deviation law for solar rotation, namely that rotation rates were higher at lower latitudes [14].

6.2. Spörer: Improver of Sunspot Latitude Variation Law and Proposer of Spörer's Law

German astronomer Spörer also reached the same conclusion as Carrington after long-term observation of sunspots [9]. He found that when a new cycle of sunspot activity began, the position of sunspot groups appeared at around latitude 30°. As solar activity continued, sunspot groups on both sides gradually moved towards the equator. New cycle sunspot groups appeared at high latitudes at the end of the active week, while old cycle sunspot groups had

moved to low latitudes. The two types of sunspot groups could coexist for about a year [1].

Spörer found that there were very few visible black spots on the surface of the sun. As shown in Figure 3, from 1650 to 1720, sunspots almost did not appear, and during half a century from 1800 to 1850, there were relatively few average numbers of sunspots. Therefore, there are not only eleven-year cycles in the regularity of sunspot cycles but also longer ones.

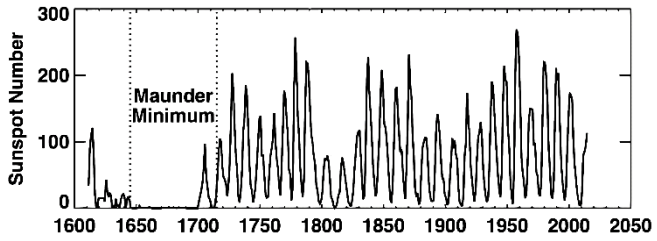


Figure 3. Diagram of Sunspot Number Changing with the year

Therefore, after Spörer's discovery, research trends changed again. Astronomers' research on sunspots can be roughly divided into two categories: one is to study the position regularity of sunspots; another is to study deeper time regularities.

6.3. Maunder: The aggregator of research and the discoverer of the Maunder Minimum Period

Through a survey of past literature, maunder found that observations of sunspots were difficult between 1671 and 1675, and some astronomers did not observe a sunspot for several years. This suggests that there may be differences between solar activity at that time and current solar activity.

After observing sunspots for twenty years, maunder published Long-term Sunspot Contraction, which detailed the details of the sunspot's silence from the mid-seventeenth century to the early eighteenth century, and concluded that the sun entered a dormant period [16]. In addition, he combined observation data in time and space dimensions to draw a chart with time as the horizontal axis and latitude of the sunspot group as the vertical axis, which can more vividly reflect Spörer's law. As shown in Figure 4, two major laws of periodicity of sunspots can be clearly seen: one is an 11-year cycle represented by each butterfly; the other is a minimum period represented by the smaller butterflies.

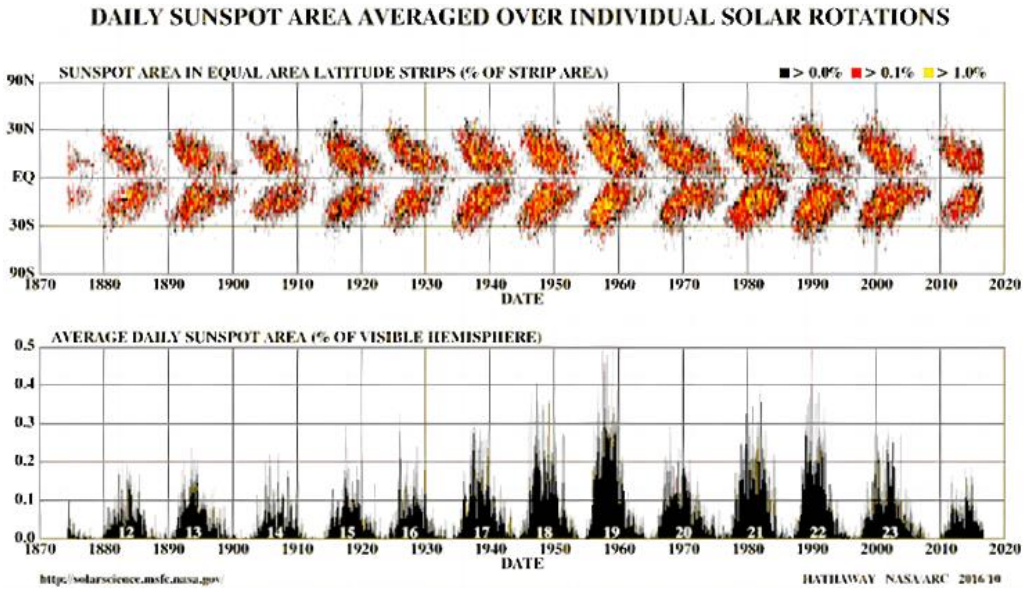


Figure 4. Maunder Butterfly Diagram

In 1976, American astronomer Eddie determined the activity cycle of sunspots by measuring the content of radioactive isotope 14C in plants during years with very few or very many sunspots. He concluded that when there are fewer sunspots, solar activity is low, and pointed out that there are indeed longer-term changes in sunspot activity with durations ranging from 50 to 200 years each time [17]. People compared and summarized Maunder Minimum Period with the coldest stage of Little Ice Age, realizing that solar spot activity cycles may affect earth's climate. Some periods of maximum or minimum were named after their discoverers (Table 1).

Astronomers' discoveries at this stage provided valuable observational facts and made important contributions to modern astronomy. From meteorology and other perspectives, they made long-term weather forecasts for future years possible, enabling humans to arrange production and life rationally and promoting the realization of harmonious relations between the sun and earth.

Table 1. The acticity of sunspots

Year (AD)	Name
1010-1050	Oort Minimum
1100-1250	Medieval Maximum
1280-1340	Wolf Minimum
1420-1530	Spörer Minimum
1645-1715	Maunder Minimum
1790-1820	Dalton Minimum
1950-Now	Modern Maximum

7. The Period of Innovation and Breakthroughs: The Discovery and Exploration of Sunspot Magnetic Fields

In 1852, German astronomer Lamont observed earth's magnetic field for 12 years and found that its strength varied over time with a period of about 10 years [17]. That same year,

Edward Sabine discovered that the sunspot cycle varied in sync with earth's magnetic field strength [16]. These findings proved that there was some connection between solar activity and earth's magnetic field, but what exactly caused sunspots to affect earth's magnetic field remained a mystery.

In 1904, American astronomer Hale captured the world's first sunspot spectrum using a homemade large spectroscope and solar telescope, indirectly confirming his hypothesis that sunspots had lower temperatures than the surface of the sun [19]. Two years later, he used a large solar tower he built himself to capture photos using Hα rays that showed clear vortex structures in the region centered on the sunspot, leading him to conclude that sunspots had magnetic fields with strengths reaching several thousand gausses [20].

Combined with the Maunder Butterfly Diagram, this meant that high-latitude bipolar groups appearing at the start of a new cycle had opposite polarities to those of the last bipolar group in the old cycle. A complete cycle of sunspot changes takes about 22 years [20]. This enriched our understanding of periodicity in sunspot activity and continued previous research while opening up new branches in research on sunspots' magnetic field laws and their effects on the earth.

8. Modern Research Progress: Exploring Relationships Between the Sun, the Earth, and Humans

Solar activity has a huge impact on climate change, the environment of the sun and the earth, and natural disasters [21]. The number and period of sunspots represent changes in solar activity to some extent and have become a primary basis for observing solar activity levels [22]. If we have a deeper understanding of the nature and activity laws of sunspots, we can use natural laws to explore the past and predict the future, thereby avoiding risks and achieving better development.

Reviewing the exploration of sunspots, we now have a certain understanding of the fine structure, activity laws, strong magnetic fields and other aspects of sunspots. The research scope of sunspots is also becoming broader and more comprehensive. As astronomers gradually unveil the mysterious veil of sunspots, they are also gradually correcting their erroneous understanding of the sun, reasoning and summarizing the objective laws of the sun, and constructing a systematic and scientific theoretical system of solar astronomy with more precise observation techniques and means.

In short, such fruitful achievements are inseparable from the theoretical accumulation of scientists. Through reflection, correction and practice, they have further improved, breakthroughs and innovations to form a spiral development model. However, there is still much for humanity to explore in order to gain a deeper understanding of sunspots. More precious than money is an endless curiosity and the starry sky above our heads. We believe that in the future, with constantly improving observation techniques, scientists will be able to discover more objective laws about changes in sunspots and gain a clearer and more comprehensive understanding of the sun through this "window".

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