Edited Book

Green Frontiers

Emerging Technologies for a Sustainable Future

Editors

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Edu-LearningHub

A2Z

ISBN: 978-81-685803-8-1

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ISBN 978-81-685803-8-1

Mode of publication: Print | Non-Print

Month / Year: April, 2026

Published by:

A2Z EDULEARNINGHUB LLP

Door No. X/374, Kuthukallinkal

Udumbannoor, Cheenikuzhi P.O

Kerala, India - 685595

www.edulearninghub.com

editor@edulearninghub.com

Total pages:116

Price: INR 475 / USD 7

ISBN: 978-81-685803-8-1

 ISBN : 978-81-685803-8-1

Preface

In an age marked by rapid scientific progress and increasing global challenges, the integration of knowledge across disciplines has become essential for meaningful innovation and sustainable development. *Green Frontiers: Emerging Technologies for a Sustainable Future* is conceived as a comprehensive academic work that brings together diverse fields of study to present a unified perspective on contemporary scientific and technological advancements. The book seeks to highlight how evolving knowledge systems can address pressing environmental concerns, enhance technological capabilities, and contribute to the betterment of society.

The primary purpose of this volume is to provide a balanced understanding of both foundational concepts and emerging trends across multiple domains. It explores critical issues such as environmental degradation, renewable energy development, advanced materials, and intelligent systems, emphasizing their interconnected nature.

The scope of the book is intentionally broad, encompassing insights from environmental science, physics, engineering, biotechnology, and applied sciences. It reflects the growing need to move beyond isolated disciplinary frameworks and adopt integrated perspectives that foster innovation.

This volume is designed to serve as a valuable resource for students, researchers, and professionals alike. Students will find it particularly useful in building conceptual clarity and gaining exposure to emerging areas of study.

The relevance of *Green Frontiers: Emerging Technologies for a Sustainable Future* lies in its focus on the dynamic relationship between scientific advancement and societal needs. As the world faces challenges such as climate change, resource scarcity, and technological disruption, there is an increasing demand for knowledge that is both comprehensive and applicable. It is hoped that this work will encourage critical thinking, inspire innovation, and enable readers to contribute effectively to a sustainable and technologically advanced future.

— Editorial Board

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“Innovation and sustainability are not opposites—they are partners in shaping the future.”

— Paul Polman

Former CEO, Unilever; Sustainability Leader

CHAPTER 3

EFFECTS OF SUNSPOT ACTIVITY ON EARTH'S CONDITIONS

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Abstract:

We all know that the sun is the earth's closest star and sunlight is an essential component of our world's ability to sustain life. If you look at the surface of the sun through a telescope, you will see dark patches (sunspots) that appear as if they were formed from cold, dark matter on the sun's surface. These temporary formations have a lower temperature than the surrounding regions of the sun. In this article, we will cover all aspects of sunspots, including when they were discovered and their morphology, life cycle, and formation processes. We will also provide our readers with additional information to ensure that they have all the information necessary to have an understanding of sunspots. In doing so, we hope that you gain as much knowledge about sunspots as possible. We will also include topics related to sunspots, such as solar flares, the solar cycle, the Hale cycle, and the Wolf number, which will also help you develop an increased understanding of these topics. We encourage all readers to interact with us concerning this topic. If you learn anything new from this presentation, it will be successful considering all of the work we put forth.

Keywords:

Sunspot, Earth's circumstance, Solar activity, Solar Flare, Spörer's law.

Introduction:

The sun's exterior surface is a very dynamic and active area with electrically-charged gas (plasma) being constantly affected by vast and complex magnetic fields. The motion of plasma combined with the forces acting on it from the magnetic field produce an immense variety of energetic events that occur throughout the sun on a constant basis. Collectively, these energetic events are called solar activity. Solar activity fluctuates

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and occurs according to a periodical cycle referred to as the solar cycle that lasts for approximately 11 years.

One of the best-known indicators of solar activity are sunspots because they can be seen from the Earth as dark patches on the solar surface. Sunspots may appear colder than the area around them, but the temperature of sunspots is still quite hot (approx. 6,500°F) or (approx. 3,600°C). Sunspots are merely cooler than surrounding areas of the sun's photosphere and why they appear dark.

The temperature of sunspots is relatively lower than surrounding areas because they have intense magnetic fields. The magnetic fields around sunspots are much stronger than the other areas of the solar surface and suppress the convection of heat from the interior to the surface. Because of this, thermal energy will be transferred into the sunspot region less often, causing the sunspot to appear darker than the surrounding areas, which are hotter.

Sunspots are associated with other energetic solar events. When the magnetic field lines around the sunspots become twisted, stressed, or suddenly changed from their usual configuration, they release a large amount of stored up energy. This rapid release of magnetic energy results in large scale solar flares. Solar flares produce a very large amount of radiation and charged particles and can greatly impact space weather and Earth's magnetic environment.

Review of Literature:

INVENTION:

Ancient Chinese society is where sunspots can be recorded for the very first time; references to their appearance could be found in the I Ching (China’s most revered divination tool) as early as 800 BC. These early records suggest that the human race was curious about what was happening on the sun for long before recorded history began, in this case, through direct visual observations of dark spots that appeared on it when the atmospheric conditions were just right.

Using a telescope, Thomas Harriot made the first scientific observation of sunspots in December 1610. His observations included several spots on the surface of the sun, but

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they did not appear to be published immediately. A few months later in March 1611, Johannes Fabricius and David Fabricius (his father) also made similar observations and published their results. Therefore, they too could be considered the first astronomers to [document sunspots] scientifically.

Galileo Galilei built on Johannes Fabricius' research to further develop systematic research on sunspots. Over 18 months, Galileo conducted a continuous examination of sunspots on the sun while keeping detailed notes on how they appeared, their characteristics, and how they changed as they moved across the face of the sun. The work he performed led to compelling evidence that sunspots were part of the sun and not simply some type of object passing in front of the sun. Galileo published his research under the title "Letters on Sunspots" in 1613 in Rome, which represented a significant advancement in the advancement of the study of our sun and formed the base of scientific knowledge for the sun to be treated as an active and ever-changing object as opposed to being considered an eternal and unchanging perfect sphere.

Later in the 19th century, interest in sunspot influence extended beyond just astronomers and entered the realm of earth scientists. The German / British scientist William Herschel was one of the first to recognize a correlation between sunspots and earth climate. His observations of no sunspots occurring between July 1795 to January 1800 coincided with an extraordinarily high wheat yield in England (Herschel). From these observations, he suggested that changes in solar activity could create changes in the atmosphere and thus create changes in the productivity of the crops growing on planet earth.

Several scientists attempted to confirm Herschel's theory after Herschel proposed his theory about solar and terrestrial events. Richard Carrington examined the correlation between sunspots and wheat prices in 1865, while John Henry Poynting examined the same correlation in 1884. However, neither study was able to confirm the presence of a reliable or conclusive correlation. Nevertheless, these investigations sparked further research into how solar activity influenced Earth's environment.

SOLAR FLARES:

The magnetic field surrounding sunspots has a very complicated structure and is

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extremely strong. Many magnetic field lines extend from the solar surface and return to it in the vicinity of sunspots. The constantly moving and electrically-charged plasma surrounding the sun causes the magnetic field lines to often become convoluted, intertwined and crossed.

When magnetic fields build up too much stress, the field lines can rapidly reorganize or reconnect and create a new, stable configuration. This rapid change is referred to as magnetic reconnection, and it releases a tremendous amount of magnetic energy that had been stored in the magnetic field.

When the energy is released all at once, it causes a massive explosion known as a solar flare. Solar flares are the most intense and energetic events in our solar system. When a solar flare occurs, it emits enormous quantities of electromagnetic radiation, including X-rays, ultraviolet radiation and radio waves in all directions into space.

A massive solar flare directed towards Earth can severely disturb the upper atmosphere of Earth, specifically the ionosphere, by releasing harmful radiation into the atmosphere. This disruption can disrupt how radio waves reach their destination, making it hard to use radio such as: communicating with a radio; navigation; using satellites. A huge solar flare can also disrupt the flow of electricity through electric grids and raise the amount of radiation exposure to astronauts and high-flying aircraft.

Morphology:

It has only two main structures:

Umbra: This is the darkest part of the sunspot area (the center of the sunspot) and can be as low as 3000 - 4500 K, while the average temperature is approximately 5780 K. The dark areas of the spot can easily be identified as dark spots (due to being black bodies). Although they're generally very much darker than the entire area of the sunspot, they can be brighter than the entire surface of the moon (the moon is quite red in color). The umbral dots form the structure of a sunspot and appear to be a series of round bright patches that last between 0.2 - 0.5 seconds each.

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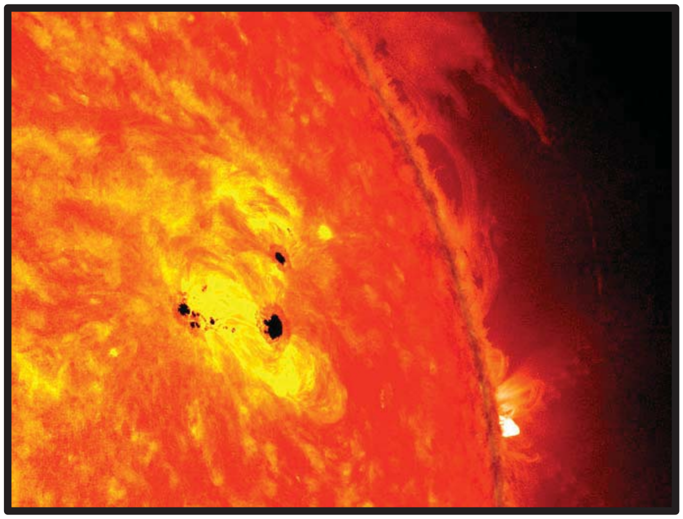

Figure 1: Chromospheric activity and Solar prominence [1]

Penumbra:

Sunspots are the product of the intersection of powerful magnetism and convective plasma motion in the sun's surface layers. The penumbra of a sunspot is due to a radially elongated arrangement of individual filament-like structures that characterize penumbra and contribute to energy transfer within the sunspot.

Penumbral filaments are generally characterized by dark central cores whose sides are surrounded by lighter (i.e., brighter) "halos" of material. This contrast occurs due to the different temperatures, strength of magnetic fields, and flow of plasma that exist between different regions of a filament.

Related to this complexity, in the case of groups of sunspots with complex structure, there may also be a single continuous penumbra surrounding two or more umbrae, indicating that the group shares a common magnetic framework as opposed to being comprised of independent magnetic entities.

Lifecircle: Sunspots are observable over periods of time ranging from weeks to months. There will only be specific amounts of activity in the sunspot's active region during the timeframe. The sunspot expands and contracts on the surface of the sun with a radius of 16 kilometers to 160,000 kilometers depending on whether it is expanding or contracting.

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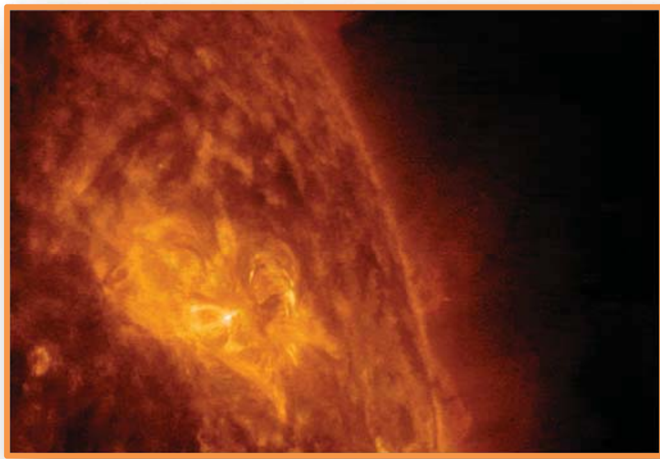

Figure 2: NASA's Solar Dynamics Observatory captured this imagery of a solar flare [2]

Formation: The specifics behind the development of sunspots are still being investigated, however, it is well-known that these sunspots are caused by magnetic flux tubes passing through the convective layer of the sun, and that sunspots create darker areas in the sun, since the strength of the magnetic field obstructs the convection of material from taking place in the area where the sunspot is located, giving the area of the sunspot a cooler temperature than surrounding areas.

The initial formed appearance of a sunspot is that of a small dark region in the photosphere without any penumbra and is referred to as a solar pore. As the two (2) pores grow in size, they get closer together, when one of the pores reaches a diameter of approximately 3,500km, the penumbra will develop.

Solar Cycle: The solar magnetic activity cycle is known as a cycle of solar activity based on changes in the number of sunspots. As the number of sunspots on the sun progresses through an "eleven year" solar magnetic activity cycle as defined by the number of observed sunspots and therefore the amount of solar radiation and solar material in the sun's atmosphere and solar flares and coronal loops from each solar to the next. There is a steady increase through each part of the cycle thus each solar activity cycle has a solar minimum followed by a solar maximum and then back to a solar minimum again thus resulting in an overall solar activity cycle.

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Through cycles of twelve, the sun's magnetic field returns to an originally determined original magnetic field thus completing what we know as a Hale cycle.

Sunspot formation starts at higher latitudes and progresses to equatorial latitudes as the solar cycle nears its maximum (**Spörer's law**). Two associated solar cycles can co-exist at the same time, but due to differences in magnetic orientation and latitude, they can be easily distinguished from one another.

In 1908, GEORGE ELLERY HALE first connected magnetic fields and sunspots and proposed that the sunspot cycle had a period of 22 years. According to him, there are two cycles of increased and decreased numbers of sunspots.

The Wolf Number: The Wolf sunspot number indicates the average number of sunspots and sunspot groups for a specific interval of time (typically one year). The 11-year Solar Cycle is numbered sequentially from the time that records first began to be created in the late 1750s.

The relative sunspot number, R, is derived using the following equation:

$R = k(10g + s)$

Where,

- s = number of individual sunspots
- g = number of sunspot groups
- k = a factor (called the observer factor, k), which varies by observer and location.

Babcock Model: The American Astronomer HORACE W. BABCOCK proposed a quantitative model for understanding the dynamics that govern the outer layers of our Solar System. The Babcock Model describes how the changes in magnetic fields of a star affect the behavior of the spots that are found on its surface. The sun exhibits an oscillating magnetic field on a very large scale. This oscillation is referred to as the Babcock-Leighton Dynamo Cycle. A half dynamo cycle corresponds to each entire solar cycle of sunspots. At this time, the external poloidal dipole magnetic field is at its minimum strength during the Dynamo Cycle; however, at the same time, the internal toroidal quadrupole magnetic field, produced by the differential rotation of the sun, is

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at its maximum strength.

Modern Observation: Solar telescopes are used to observe sunspots both from the ground and from orbit around the Earth. Most of the time, the light detected will be in or close to the range of wavelengths described by the electromagnetic spectrum (i.e., some light found outside of the visible spectrum). When observing sunspots, filters are typically used and images are projected onto a surface as opposed to viewing the sun directly.

Spectroscopes and spectrohelioscopes allow for the examination of sunspots as well as the areas surrounding them.

Spectroscopes measure the properties of light at specific positions along the electromagnetic spectrum of sunspots. Often used in the analysis of materials, spectroscopes provide the information about how much energy is being emitted at each discrete wavelength of light.

Spectrohelioscopes are solar telescopes which provide an image of the sun at a specific wavelength of light. These telescopes were invented in 1924 by George Ellery Hale. They consist of an Optogematic system that forms an image through the optics and with the spectroscope. The lens creates an image at the slit, which is covered and allows for the observation of only a small area of the surface of the sun in this instance.

Due to the ability for observation on the sun to cause permanent damage to human eyesight, it is standard practice to observe sunspots either through projection of filtered images or with the use of at least a protective filter to view the sun through.

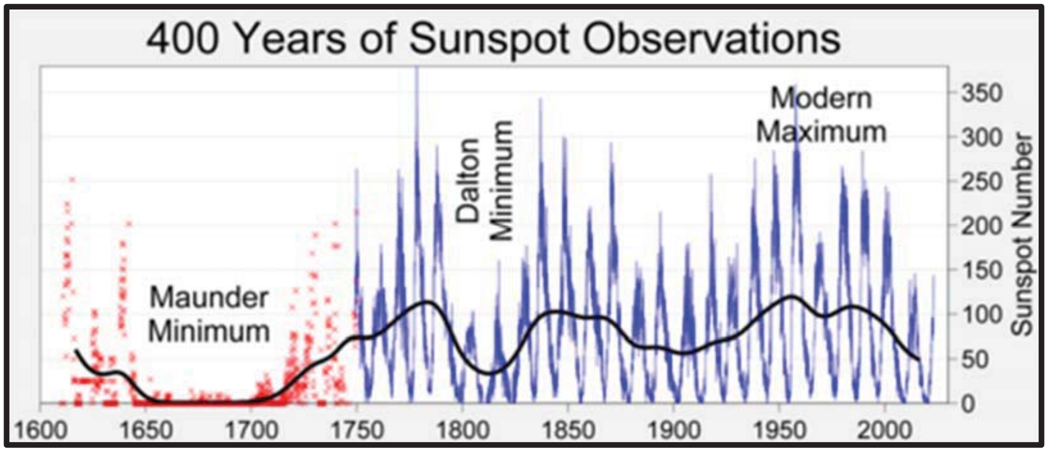

Figure 3: 400-year history of sunspot numbers, showing Maunder and Dalton minima, and the Modern Maximum (left) and 11,000-year sunspot reconstruction showing a downward trend over 2000 BC - 1600 AD followed by the recent 400-year uptrend [3]

Conclusion:

Because of the sun's surface being filled with charged particles and containing many magnetic forces, we can say that the sun is an active environment. The activities that take place on the surface of the sun create what is called solar activity which is related to the solar cycle. The primary component of solar activity is sunspots. Although the sunspots are actually over 65000 degrees Fahrenheit, they appear as dark spots on the top of the sun's surface because the intense magnetic field lines do not allow the heat from inside the sun to the surface of the sun. The magnetic field lines burst with energy causing a solar flare when they are disrupted. To understand the sun's activities, we must also understand the processes that create and sustain the sun's activities.

References:

1. The Astrophysical Journal, "Observations of Large-Scale Prominence Eruptions and Their Impact on Space Weather," Vol. 945, Art. ID 112, 2023.

2. NASA/SDO/Goddard. (2016). *Solar Dynamics Observatory imagery of a solar flare* [Image]. NASA. https://www.nasa.gov/missions/sdo/nasas-solar-dynamics-observatory-captured-trio-of-solar-flares-april-2-3.

3. *Sunspot – Wikipedia*. (n.d.). **400-year history of sunspot numbers and 11,000-year sunspot reconstruction** [Graph]. In *Wikipedia, The Free Encyclopedia*. Retrieved

 ISBN : 978-81-685803-8-1

February 10, 2026, from https://en.wikipedia.org/wiki/Sunspot.

4. **Lean, J., & Rind, D.** (2009). *Solar activity, sunspots, and climate.* **Reviews of Geophysics, 47**, RG4001.

5. **Vaquero, J. M., Gallego, M. C., & Aparicio, H.** (2007). *Sunspots: An overview*. **Living Reviews in Solar Physics, 4**, 1.

6. **Hanslmeier, A.** (2008). *The solar activity cycle: Physical causes and consequences.* Springer.

7. **NASA Space Place.** (n.d.). *Sunspots and solar flares* (Solar Activity). NASA. Retrieved February 10, 2026, from https://spaceplace.nasa.gov/solar-activity/en/

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Dr. Tanay Pramanik

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Publisher:

Department of Research and Publications
A2Z EduLearningHub
Kerala, India

editor@edulearninghub.com www.edulearninghub.com

9 788168 580381

Publication Month: **April 2026**