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The Magnetism of the Sun

Solar physics is the study of the physical nature of the Sun. Solar magnetism is a key component of solar physics and is relevant to many facets of the Sun's behavior. It has been deemed an extremely important aspect, leading to the study and understanding of most solar behavior. Many cycles and behaviors of the Sun are governed by its magnetic fields. These cycles include the sunspot cycle and the cycle of the magnetic fields in the Sun flipping. These cycles affect the general behavior of the Sun, which affects the bodies in the Solar System around it including other stars and the Earth. Other common solar phenomena are also affected by the magnetism of the Sun. Solar winds, solar flares, and the enigmatic corona of the Sun can all find some explanation within the study of the Sun magnetic fields. The magnetic fields of the Sun have had significant history in the study of solar and astrophysics. In the early 1600's, famous scientists such as Galileo and Christopher Scheiner were noticing the unique behavior of the Sun. Research and study has continued since then and is an ongoing project for many scientists at the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The enigma surrounding the magnetic fields of the Sun is still in the process of being researched, and new discoveries are constantly being made. The magnetism of the Sun contributes to many aspects of the basic behavior of the Sun, including its structure and intriguing phenomena. The study of magnetism is paramount to the growing knowledge of the Sun and it effect on other galactic bodies.

Magnetism is the behavior of magnetic fields. "Moving electric charges produce magnetic fields" [1]. In the Sun, the magnetic currents are produced within its hot gases. Many scientists believe that the magnetic fields that make up the Sun's magnetism are "generated by a magnetic dynamo within the Sun" [2] The assumption that the solar magnetic fields are generated within the Sun can be supported by the Sun's unique magnetic behaviors. The Sun's magnetic fields continually change in a cyclical manner, including the sunspot cycles and the reversal of polar magnetic fields. [2]

The Sun's magnetic fields encompass many aspects of its structure. Therefore, the structure of the Sun is instrumental in studying the magnetism of the Sun. The Sun is referred to as an oblate spheroid, meaning that the Sun is depressed or flattened at its poles. The Sun has a complex structure, consisting of inner, middle and outer layers and zones, many of which are dependent upon the Sun's magnetic fields and their behavior. [3]

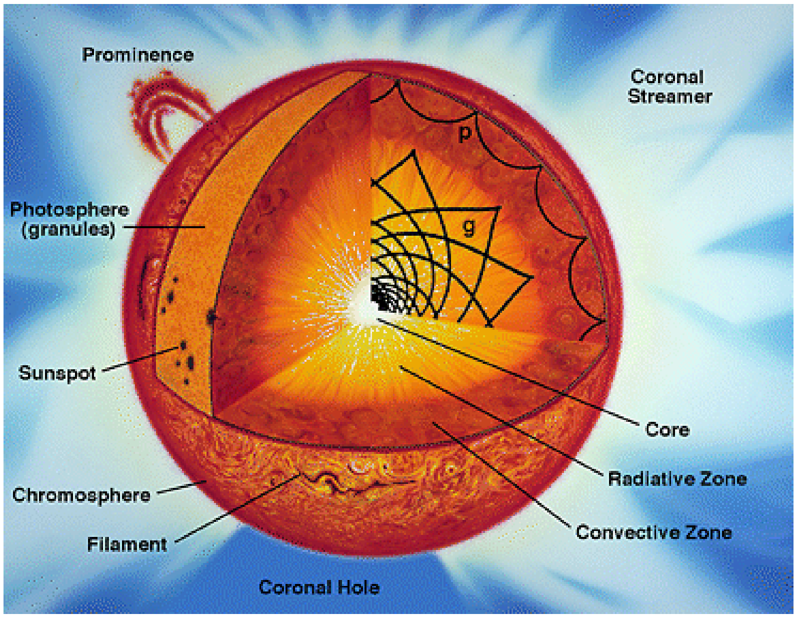

Image from “Solar Structure” [4]

The Sun’s interior consists of the core, the radiative zone, and the convective zone. The energy from the Solar interior is the basis for all of the Sun’s processes and behaviors. The core is the Sun’s internal source of energy. Because the Sun’s energy output is relatively constant, the change in brightness is unnoticeable. Due to the intense heat of about 15 million degrees Kelvin and dense plasma makeup of the core, it is the ideal environment for the Sun’s nuclear reactions. [2] The Sun’s radiative zone is the region outwardly adjacent to the core. The main function of the radiative zone is the “method of energy transport-radiation” [2] The energy generated in the core of the Sun is carried through the radiative zone in the form of light. The convective zone is the most outward of the solar interior regions. Due to the convective processes that occur in this region, radiation from the core and radiative zone is trapped. The convective motions allow heat to travel very quickly to the surface of the Sun. [2] The photosphere is the most familiar of the Sun’s structure. It is the visible layer of the Sun. When viewed, the Sun appears to be a disk. In the center of the disk is the hottest and brightest parts of the photosphere. The photosphere is the part of the Sun where sunspots occur and can be seen. [2] The chromospheres, also known as the color-sphere, is the layer directly above the photosphere. Temperatures in the chromosphere can reach up to 20,000 degress celsius. Due to these intense temperatures, hydrogen gives off a red color. This color is seen in the prominences of the Sun. The chromosphere is the region of the Sun where solar flares occur. [2]. In the visible region of red color are filaments, “dark, thread-like features” [2]. The filaments are dense “clouds of material that are suspended above the solar surface by loops of magnetic field” [2].

The magnetism of the Sun is produced by a flow of negatively charged ions and electrons. Magnetism on the Sun produce magnetic fields of about 0.15 Tesla or 1500 Gauss.

The enigmatic sunspot cycle is a byproduct of the recycling of magnetic fields by the material in the interior of the Sun. The magnetic fields of the Sun serve as supports for the prominences that seem to be floating above the surface of the Sun. At some points, these prominences are threaded through with magnetic fields, which aids in the support. The corona, most noticeable during a total eclipse of the Sun, is the Sun's outermost atmosphere. The structures visible in the Sun's corona are suggestive of magnetic properties. It is these observations that lead to the conclusion that the corona is shaped by magnetic fields. As seen in the image below, the arches are very similar to the field lines from an iron bar magnet. These arches are "short 'plumes' rising from the polar regions of the Sun" [5].

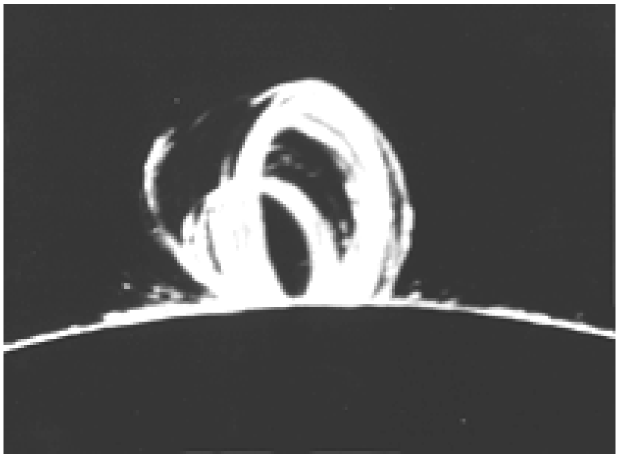

Image from Dr. David Stern and Dr. Mauricio Peredo's "The Sun's Corona" [5]

This observation suggests that the Sun has an intense magnetic field similar to that of the Earth's. From the top of the arches, long coronal streamers can extend to far distances, up to the distance of the Sun's diameter. It appears that the streamers are pulling material into space from the tops of the arches. This is actually the process of the solar winds. Cleverly, "[a]stronomers have named [the streamers] 'helmet streamers' because of their resemblance to spiked helmets worn by knights" [5]. These features are also shaped and affected by the magnetic fields on the Sun.

The shape of the Sun is sign of its rotation and interior flow. From the solar surface motion, the expected oblateness can be determined. However, recently, satellite images showed an unexpected large flattening, creating a larger solar radius. The larger radius values can be related to surface magnetism and magnetic elements. [3] Sunspots have been discovered to be particularly magnetic. This is evidence that the motion in the Sun's plasma generates electric currents, whose magnetic field aid in maintaining the same current. In addition to solar research, this discovery leads to scientists to believe that this "fluid dynamo" is similar to what may act in the Earth's core and may cause the Earth's magnetic field. [6] Similar to the Earth, the magnetic field of the Sun produces the Sun's north and south magnetic poles, which are crucial features of the Sun's magnetic behaviors. Similar to the Earth, the Sun also rotates on its axis which is tilted about 7.25 degrees from the Earth's. However, the Sun only rotates once about every 27 days. Therefore, the Sun's magnetic north pole is more visible in September every year, and the magnetic south pole is more visible in March.

Sunspots were first discovered shortly after the first telescope was available, circa 1610. There were three scientists credited with the first observances, Galileo Galilei, Johann Fabricius, and Christopher Scheiner. These three men used the telescope to observe unusual dark spots on the Sun's surface. From repeated observations, the scientists could deduce that the Sun rotated. They deduced that the Sun's rotation had a period of about twenty-seven days relative to the moving Earth. However, since the Sun's surface is not completely solid, the period increases to about 29.5 days at higher latitudes. Galileo hypothesized that the sunspots were solar clouds floating above the surface, which blocked some sunlight from reaching the Earth's atmosphere. However, it has been discovered that the sunspots are indeed darker than the rest of the solar surface because the magnetic fields of the spots decrease the flow of heat from the interior of the

Sun, making them much cooler than the surrounding areas. Shortly after these scientists began observing the sunspots, they became a rarity for about seventy years. [6] This time when the sunspots were rarely observed is known as a period of solar inactivity. This time frame corresponds to a terrestrial climatic period when rivers unusually froze and snow remained for an unusual amount of time. This time period is referred to as the "Little Ice Age." [2] About 200 years after Galileo and Scheiner's observances, a German scientist noted their unique cycle. Heinrich Schwabe noticed that the number of sunspots increased and decreased on an irregular cyclical basis. He noted the cycle to last about eleven years. The specific nature of sunspots was not fully clarified until George Ellery Hale discovered that the light from sunspots was unique in ways that signified it was made in solar magnetic fields. [6]

The unique behavior of the sunspots during the cycle can be attributed to the magnetic fields. In most instances, the sunspots appear in pairs, with each member having an opposite polarity. Every other sunspot cycle differs in the way the leading spot behaves. The leading spot is the sunspot in the direction of the Sun's rotation. In half the solar cycles, the leading spot will always have a northern polarity. Therefore, the following spot will have an opposite, namely a southern, polarity. In the next cycle, the polarities of the sunspots are reversed. The general magnetic field of the Sun also reverses polarity during each cycle. Typically, the reversal of the solar magnetic field's polarities occurs about three years after the sunspot minimum.

During the course of a sunspot cycle, a sunspot number is assigned. The sunspot number is a calculation that takes the actual number of spots and the number of sunspot groups into account. The number is calculated by the sum of the individual spots and ten times the number of sunspot groups. Most groups have about ten spots. Knowing this average, the sunspot number is more reliable and easy to produce when the observation conditions are not ideal. The numbers are average monthly and doing this allows the eleven year cycle to be noticed. From this data, scientists can show that the number of visible sunspots "waxes and wanes with an approximate [eleven year] cycle" [2].

"Over the course of a solar cycle, the intensity and amount of magnetism generated by the Sun increases, like soup warming up on the stove, reaching a violent climax in which twisting, tangling magnetic fields break loose and release their energy in the form of solar flare explosions, coronal mass ejection, and tremendous heating the solar atmosphere" [7]. The number of sunspots observable and corresponding solar activity on the surface of the Sun reaches a maximum every eleven years. This period is known as the solar maximum. When the number of sunspot and their activity is at the lowest, the sun is at the aforementioned solar, or sunspot, minimum.

A solar flare is "a brightening of the chromosphere near a sunspot group, rising within minutes and typically lasting ten tot thirty minutes" [7]. The first observation of a solar flare was on September 1, 1859 by two scientists, Richard C. Carrington and Richard Hodgson. Most flares are observed in the red light of the heated hydrogen. However, in 1859, the first solar flare was observed as a rare white light flare. [6] Solar flares are caused by an explosion of discharged energy from the Sun's atmosphere. It is likely that the flare energy is stored in the Sun's magnetic fields in the atmosphere. [8] The flare occurs when the magnetic energy that builds up in the solar atmosphere is released. When the magnetic energy is released, particles are heated and accelerated in the atmosphere of the Sun.

Solar flares occur is three stages, the precursor stage, the impulsive stage, and the decay stage. The precursor stage signals the activation of the energy release. During the impulsive stage, the particles, consisting of protons and electrons, are accelerated. The decay stage is the build up and decay of soft x-ray emissions. Each stage can last between a few short seconds and an hour. While solar flares originate in the chromosphere, a solar flare extends out to the corona. The temperature inside a solar flare averages about ten to twenty million degrees Kelvin. However, a solar flare can reach temperatures of about one hundred million degrees Kelvin. In the corona, the arches, or bright loops, are located in areas of strong magnetic fields. Often, these arches connect the strong magnetic fields. These areas of strong magnetic fields are referred to as active regions. In these active regions, sunspots are located and solar flares occur. [9]

The occurrence of solar flares is directly related to its enigmatic eleven-year sunspot cycle. Solar flares are often few and far between during the period of the Sun's minimum. At these times, the active regions are smaller, hence the minimum of sunspots and solar flares. As the Sun approaches the maximum end of the cycle, the active regions begin to grow causing sunspots and solar flares to become more frequent. [2] NASA scientists have been observing the magnetic fields of the Sun that correlate with solar flare occurrences. Their findings show that "flares are likely to occur when the magnetic field lines linking two sunspots become sheared or twisted" [2]. During a solar flare, matter, often in the form of protons and electrons, are ejected into space at very high velocities. These ejections are called coronal mass ejections, as seen in the image below.

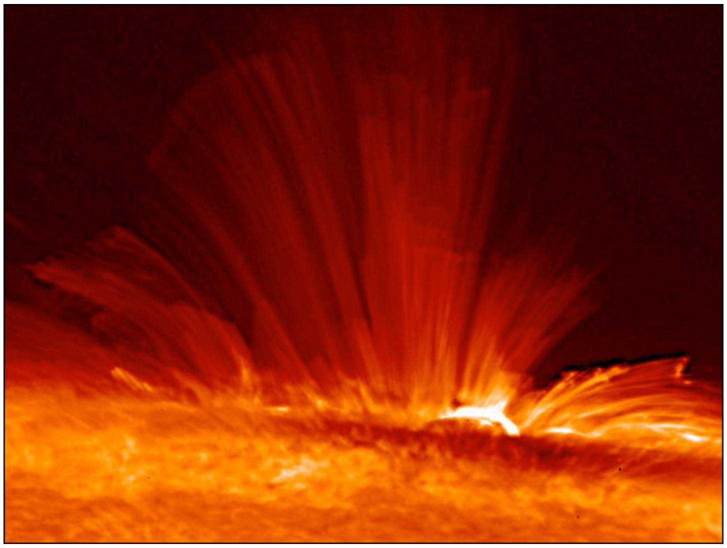

Image from NASA's Earth Observatory [10]

Solar weather is also impacted by the magnetism of the Sun. Solar winds flow off the Sun into space in various directions and extremely high speeds. These solar winds can reach speeds up to 400 kilometers per second. Solar winds originate in the Sun's corona. Solar winds have several variations. They are always moving off of the Sun, however they have constantly changing speeds. Solar winds carry with them magnetic clouds. These magnetic clouds are produced within the solar winds when solar flares and coronal mass ejections transport material off the Sun. Solar winds seem to originate in what are known as coronal holes. These coronal holes are characterized by dark spots in the Sun's corona. "Coronal holes are associated with 'open' magnetic field lines" [2]. These coronal holes are mostly found at the solar poles.

The Sun's magnetic fields often interact with the Earth and its atmosphere. These interactions have an impact on the Earth's weather and atmospheric conditions. One common way that the Sun's magnetism affects Earth is by the solar winds, which are directed outward from the Sun. There is a boundary between the Earth's field and the solar winds. This boundary is referred to as the magnetopause. The magnetopause has a "bullet-shaped front, gradually changing into a cylinder" [11], as seen below.

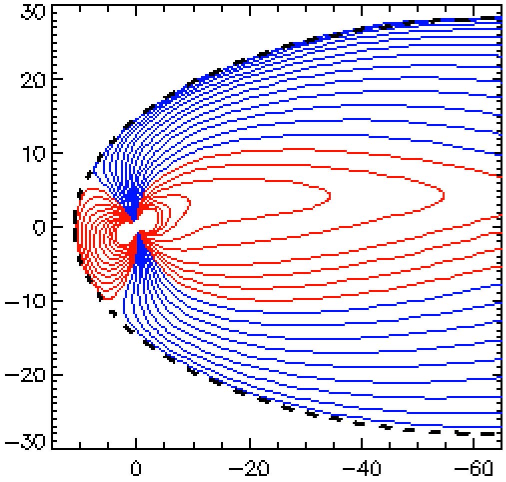

Image from "The Magnetopause" [11]

The magnetopause does not retain a constant size. As the parameters, including strength and pressure, of the solar wind shift, the magnetopause increases and decreases in size. Historically, the Sun and its behavior has been noted to affect the climate of the Earth. The aforementioned "Little Ice Age" is one important example of this phenomenon. NASA research has recently confirmed the theory that the Maunder Minimum of the Sun and the Little Ice Age of the Earth correlate. The Maunder Minimum was a period of about seventy years where there were very few sunspots observed. This resulted in lower solar activity. During this period of lower solar activity, the ultraviolet radiation emissions from the Sun. These changes in levels affect the stratosphere and upper atmosphere of the Earth. This period of low solar activity coincides with the Little Ice Age on Earth. The Little Ice Age was a period from 1645 to 1715 when the climate of the Earth was much colder than normal. The changes in ozone in the upper atmosphere saw its affects on the Earth's climate, explaining the cooler temperatures. [12]

In conclusion, the Sun's magnetism and its features are paramount to the functions of the Sun. The solar magnetic fields affect everything from solar structure to its normal processes and cycles to the climate of the Earth. The magnetic fields of the Sun have been researched for many years, since Galileo. Solar magnetic fields have the most prominent affects on the sunspot cycle, solar flares, and solar flares. The Sun has an eleven year cycle which corresponds to each of these magnetically influenced behaviors. Since the behaviors of the Sun affect the Earth and its climate, the magnetism of the Sun is important to the Earth as well. The magnetism of the Sun is still being researched, and the enigmatic nature of the Sun is still being solved.

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