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Investigation of the Relationship between Sunspots and Solar Flares

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Abstract: Solar flares tend to occur above sunspot groups. In this paper, four solar active regions are selected for observation, among which the AR13190 and AR13213 solar active regions are the main observation regions, and AR13182 and AR13184 are the brief observation regions. In this paper, the formation and evolution of sunspots and flares and the changes of solar structure before and after the eruption of flares are investigated, and the conclusion is that sunspots can affect the formation of the upper chromosphere atmosphere and flares, and solar flares can affect the structure of sunspots. Such research could also be applied to the prediction of solar flares.

1. Introduction

Solar activity refers to the activity of heating the Sun by various types of plasma caused by magnetic field changes in the solar atmosphere. There are mainly sunspots, facula, flocculus, flares, prominence and coronal transient events. Now we are in the rise period of 25th solar activity cycle, and soon will usher in a solar maximum year, during which solar activity will become more and more frequent, which will seriously affect short-wave communications, power systems, etc., and bring trouble to People's daily life. The study of sunspots and solar flares can better predict flares and make people better prepared to deal with them. This paper mainly explores the relationship between sunspots and solar flares by observing sunspot structure, magnetic field structure and chromosphere.

2. Research Tools and Observation Analysis

2.1 Research Tools

The solar image data used in this paper are all from professional Solar Dynamics Observatory (SDO) astronomical image website: https://www.helioviewer.org/

2.1.1 Helioviewer.org

Helioviewer.org is a popular astronomy site that offers near-real-time images of the Sun at different wavelengths taken by several space telescopes on different satellites. The experiment uses live images of the Sun sent back by SDO, which has two space telescopes on board: AIA and HMI. AIA can view the different levels of the Sun through 10 different wavelengths: 94, 131, 171, 193, 211, 304, 335, 1600, 1700 and 4500. The HMI provides a clearer view of sunspots and the sun's magnetic field(shown as in Figure 1 and in Figure 2).

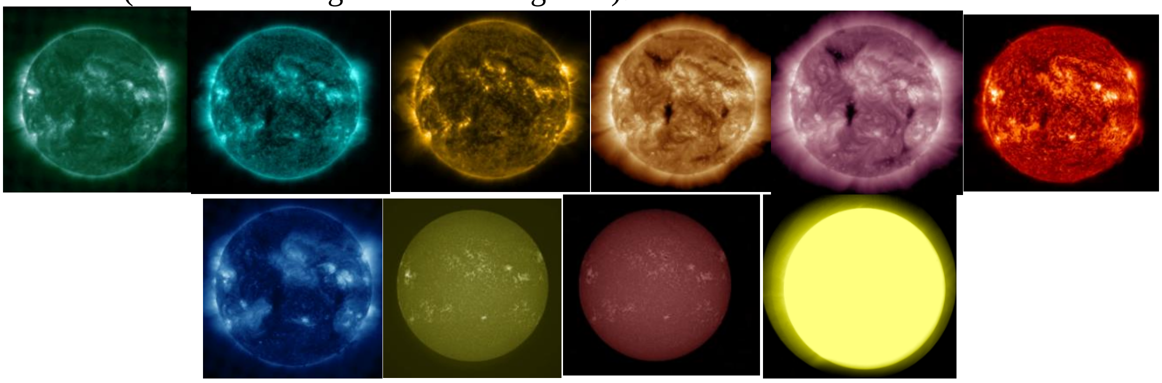

Figure 1: The ten images above show the Sun observed by the SDO satellites AIA at 15:25:12UTC in various wavelengths. The wavelength increases from left to right and from top to bottom

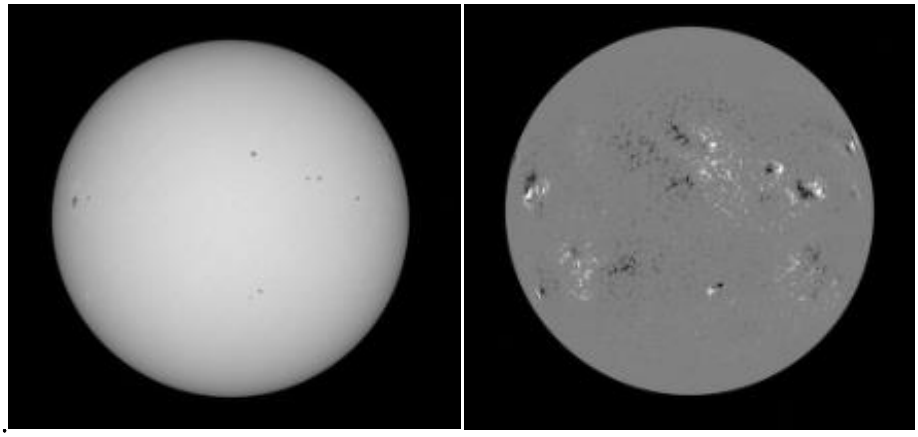

Figure 2: The two images above show the Sun observed by the SDO satellites HMI Continuum and Magnetogram at 15:25:12UTC. On the left is a sunspot image and on the right is a solar magnetic field image.

2.1.2 SAOImageDS9 software

SAOImageDS9 is a very professional astronomical image visualization software, which can make detail analysis of astronomical images, so that the picture can be visualization.

2.2 Observation Analysis

2.2.1 Structure and evolution of sunspots

Sunspots are roughly composed of umbra, penumbra and bright bridge. Umbra is the darkest part of the center of a sunspot, and it is also the part with the strongest magnetic field and the vector direction is vertical. The penumbra is the fringed part around the umbra, and the magnetic field is relatively weak and the vector direction is biased; The bright bridge is the part of the umbra that protrudes inward.

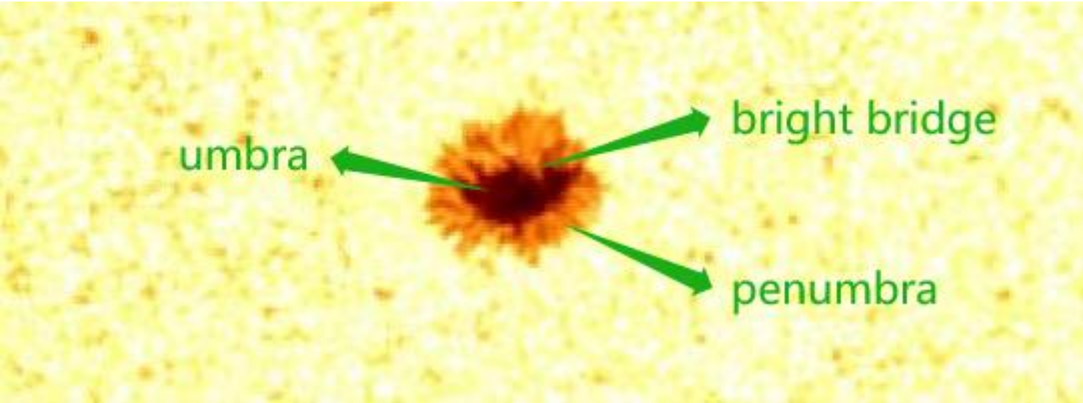

Figure 3: Above is the image sent back by SDO's HMI telescope at wavelength 6173 on 2014-09-26T 21:32:15.000.

The two stages of the Sun are connected by magnetic inductance lines, and because of the differential rotation, the middle magnetic inductance line rotates faster than the two stages, winding around and around, and eventually the large magnetic field rises to the surface, forming a sunspot. (shown as in Figure 3)

2.2.2 Solar Flares

A solar flare is an explosive solar activity occurring in the chromosphere, which is classified in a progressive order(A, B, C, M, and X) according to the magnitude of the eruption. It emits a lot of high-energy particles and rays, which can affect the Earth's space environment and sometimes cause health problems for astronauts. According to the research of S. Eren et al., flare bursts of class C, M, and x are most associated with large area sunspots, and the larger the sunspot, the more complex its magnetic field, the easier the flare is to form.[1] Moreover, fast spinning sunspots can also cause flares.[2] (shown as in Figure 4)

Class	Small	Medium	Large	End
C	0.33 ± 0.14	0.70 ±0.08	0.79 ± 0.05	0.65 ± 0.08
M	0.10 ± 0.13	0.46 ±0.11	0.74 ± 0.07	0.49 ± 0.11
X	0.04 ± 0.13	0.23 ±0.13	0.40 ± 0.12	0.24 ± 0.13
Total (C+M+X)	0.31 ± 0.12	0.68 ±0.08	0.81 ±0.05	0.65 ± 0.08

Figure 4: The image shows that the formation of major flares based on c, M, and x classes is more related to the number of large sunspots in the explosion, and has little relationship with the smaller ones. Image from an article by S. Eren et al

The distribution of solar flares is not as evenly distributed as sunspots. Take a rare and violent flare as an example, which is called white light flares. In the article published by J. -René Roy, he summarized the research of Bell et al., and explained the north-south distribution asymmetry of white light flares and power flares. From the figure 2-3, it is obvious that the distribution of flares in the north is significantly higher than that in the south, highlighting the asymmetry of flare distribution. This is because of geomagnetic disturbances, and the greater the disturbance, the higher the asymmetry. [3] (shown as in Figure 5)

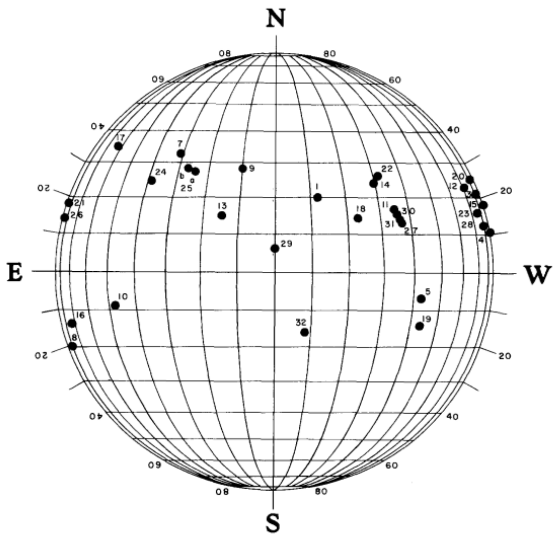

Figure 5: The image shows that the distribution of white-light flares, which occur more frequently in the north than in the south Image from an article by J. -René Roy

2.2.3 Influence of Sunspots on the Chromosphere

By selecting sunspots in multiple active regions (including AR13182, AR13184, AR13190, and AR13213), the changes in the atmosphere above the sunspot, known as the chromosphere, were observed during sunspot formation. The authors found that during the formation and evolution of the penumbra of the sunspot, the corresponding region of the chromosphere atmosphere directly above it also has a similar striped structure, which has a wider range than the penumbra, and constantly evolves and emits light, and this light is partly connected with the light emitted by the flare. Dr Xu's research suggests that this pattern changes the direction of the sunspot's magnetic field, which is not perpendicular, like the umbra's vector direction, but tilts, resulting in the formation of a penumbra. [4] (shown as in Figure 6)

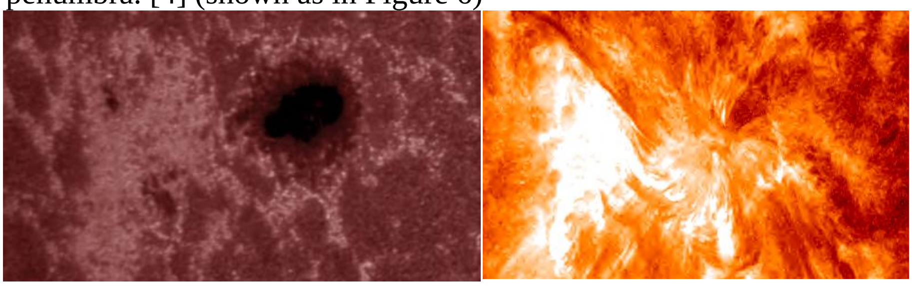

Figure 6: The two images above show the Sun at 2023-1-1514:28:05UTC observed by the AIA telescope on the SDO satellite at wavelengths 1700 and 304. Left is the sunspot on photospheric, right is the fringe structure on chromospheric above to the sunspot penumbra.

2.3 Effects of Solar Flare eruptions on sunspot structure

An M4.8 flare erupted in the solar active region AR3190 and an M1.6 flare erupted in AR13213. By comparing the changes of sunspots before and after the flare in AR13190, it is found that the size of the umbra of the sunspots has changed. The original umbra area is larger, but after the solar flare erupts, the penumbra will rapidly spread to the umbra, and the area of the umbra can be observed to shrink. (shown as in Figure 7)

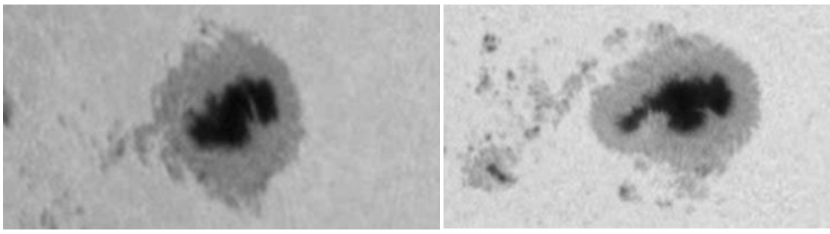

Figure 7: The two images above show the Sun at 2023-1-1507:43:53 UTC and 2023-1-1619:48:22 as observed by the SDO satellite HMI continuum. On the left is the sunspot before the flare, and on the right is the sunspot after the flare, where the umbra structure area can be seen shrinking.

When we observe the change of sunspots in AR13213, we not only see penumbra spreading to umbra, but also observe that the lower half of the sunspots disappear and become darker. This is because the penumbra rapidly declines and transforms into umbra after the eruption of solar flare. (shown as in Figure 8)

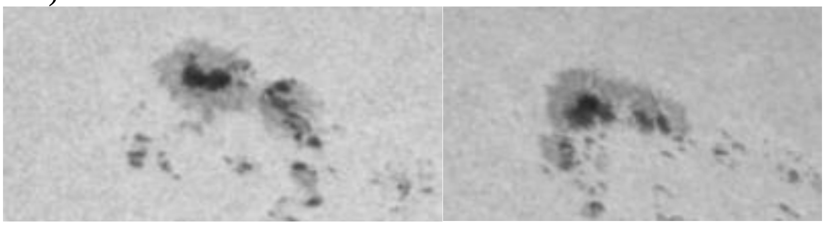

Figure 8: The two images above show the Sun at 2023-02-0811:43:05UTC and 2023-02-09 23:34:05UTC as observed by the SDO satellite HMI continuum. On the left is the sunspot before the flare and on the tight is the sunspot after the flare, the lower half of the penumbra can be seen darkening and converting to the umbra.

2.4 Effects of Solar flares on Magnetic Field Structure

The magnetic field structure of the Sun is very complex, and it is different in the northern and southern hemispheres. A solar active region consists of positive and negative poles connected by magnetic field lines. White is positive, the vector is going outward; And black is the negative, and the vector is going inward. The region outside the active solar region, called the “quiet zone”, has a weaker magnetic field, but some smaller solar activity is also associated with magnetic changes in the quiet zone. (shown as in Figure 9)

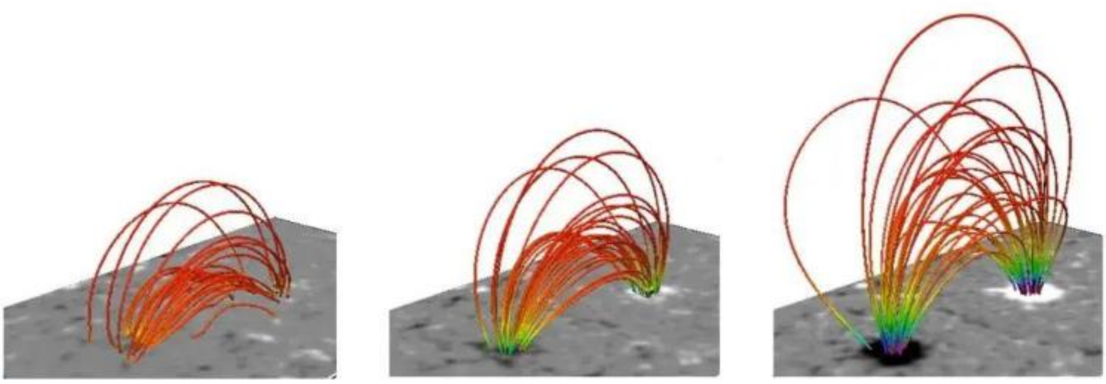

Figure 9: This diagram shows the magnetic field lines connecting the two stages of the magnetic field gradually emerging from the sun's interior and passing through the solar atmosphere. The picture is taken from an online article by Chen Jie, Deng Yuanyong, Su Jiangtao and others.[5]

A solar active region has leading polarity and backward polarity. During the same solar activity cycle, the leading polarity in the northern hemisphere is the same; The leading polarity of the southern hemisphere is also the same, but the magnetism is opposite to that of the northern hemisphere. During the next solar activity cycle, the magnetic fields of the northern and southern hemispheres are reversed, that is, the leading polarity of the northern hemisphere in this activity cycle is equal to the leading polarity of the southern hemisphere in the previous activity cycle, and vice versa.

For example, during the 24th solar activity cycle, the leading polarity of the northern hemisphere was negative and the backward polarity was positive; The leading polarity of the southern hemisphere is positive, and the backward polarity is negative. During the 25th solar week, conditions in the northern and southern hemispheres were reversed from the previous solar week. (shown as in Figure 10)

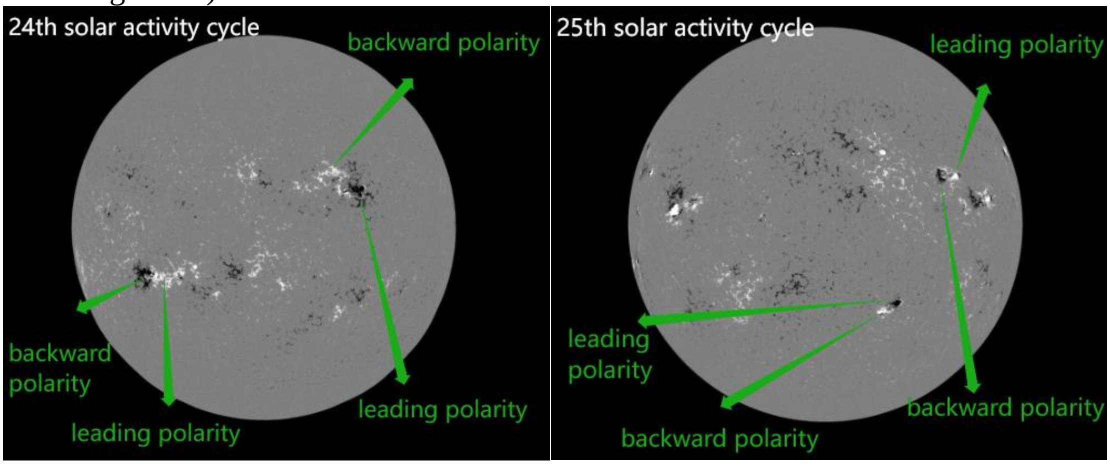

Figure 10: The two images above are images of the Sun at 2014-11-12 12:23:37UTC and 2023-9-1912:23:37UTC as observed by the SDO satellite HMI Magnetogram. You can see that the magnetic fields of solar cycles 24 and 25 are completely reversed.

This experiment also observed the change of the magnetic field in the solar active region AR13190 (Northern Hemisphere) before and after the eruption of the solar flare, and found that after the eruption of the solar flare, the leading polarity region of the magnetic field, that is, the negative region, gradually spread like the sunspot to the backward polarity region, and swallowed it. (shown as in Figure 11)

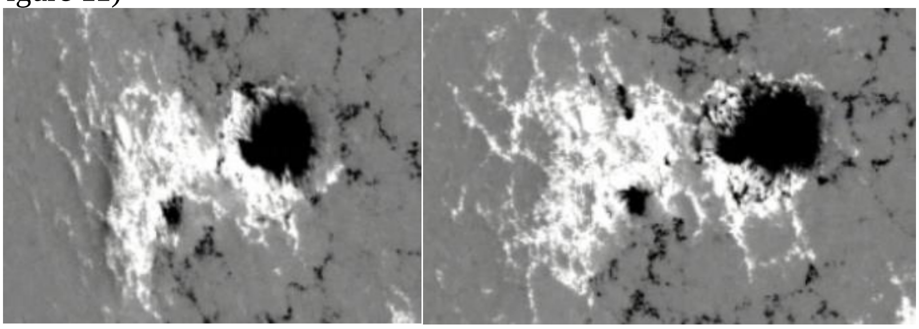

Figure 11: The two images above show the Sun at 2023-01-15 14:10:07UTC and 2023-01-15 15:47:03UTC as observed by the SDO satellite HMI Magnetogram. On the left is the magnetic field before the flare, and on the right is the magnetic field after the flare.

3. Conclusion

In this study, the author observed and explored how sunspots affect solar flares, and what impact the eruption of solar flares will have on sunspots, and made the following conclusions :

1) Sunspots are closely connected with the atmosphere of the chromosphere above them, and sunspots will lead to changes in the structure of the chromosphere, and the specific structure of the chromosphere will affect the magnetic field, resulting in penumbra and more complex sunspots.

2) Solar flares erupt in the chromosphere, and changes in the structure of the chromosphere and the formation of more complex sunspots will affect the formation and eruption of solar flares.

3) Solar flares can affect the structure of sunspots, causing the penumbra to spread to the umbra and the umbra to be decayed.

4) Solar flares will also affect the structure of the solar magnetic field, resulting the leading polarity region to spread to the backward polarity region.

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