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Research on the Property of Solar Flares in Active Region 12673

Qixiang Yin

The Frederick Gunn School, Washington, CT 06793, USA
Lucasqixiang@outlook.com

Abstract: *Solar active region NOAA 12673 produced numerous abnormally large solar flares including X9.3. The reason for how those solar flares were triggered, however, remains unclear. This letter, in specific, is intended to determine the underlying nature of how and why solar flares occurred by studying active region NOAA 12673. Having used several methods, we derived some shocking conclusions.*

Keywords: *Solar flares, Solar active region, Magnetic field*

1. Introduction

Solar active regions are places on the sun where the magnetic fields concentrated and magnetic fluxes are higher. Phenomena such as solar flares and sunspots normally occur in active regions due to the high magnetic flux. Sunspots are regions of reduced surface temperature caused by concentrations of magnetic flux that inhibit convection, and solar flares are a condensed release of energy caused by rapid magnetic change.

A prominent solar active region is NOAA 12673, as shown in Figure 1. It appears on about September 4th, 2017 and ends on September 10th, 2017. During this time, 4 X-class solar flares and 26 M-class solar flares were detected, which is abnormally flare-productive (X-class stands for the strongest solar flares, and M-class stands for those flares that are weaker than X-class but are stronger than other flares such as B-class or C-class). Some previous researchers refer to this active region as "unpredictable", for it presented contradictory results to previous conclusion. Many are also surprised about the rapidity of the built up of flares. What made this AR so strong and flare-productive? Though being mysterious, we still got some interesting clues from learning NOAA 12673 in detail. Therefore, this letter is intended to study how solar flares were triggered on NOAA 12673. [1][2][3]

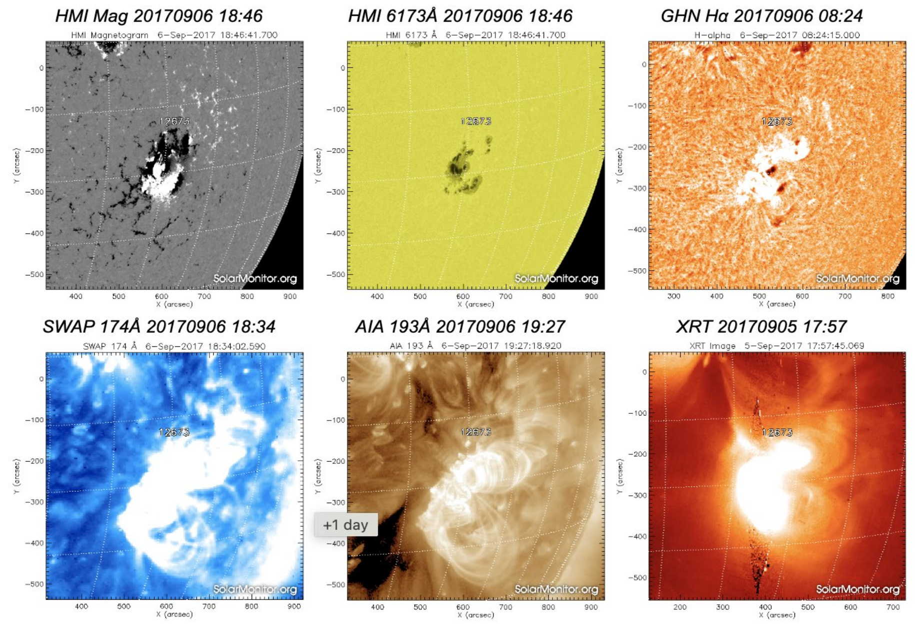

Figure 1: Representative pictures of the active region (AR) 12673 under different telescopes and frequencies.

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2. Observations and data analysis

The HMI and AIA telescope on Solar Dynamic Observatory offers a clear view of the full development of NOAA 12673. We first generated a video on NOAA 12673 using the HMI continuum from September 2nd, 2017, to September 9th, 2017. Then, We generated a video on this active region using an HMI magnetogram from the same period. Lastly, we generated a video on this active region using AIA with a frequency of 171 from the same time length. All these videos are for comparison purposes. The HMI continuum video can be used to see changes in sunspots; the HMI magnetogram is for research on the magnetic field, which is the most important in this specific topic; and the AIA telescope offers a clear view of how and when a solar flare would occur.

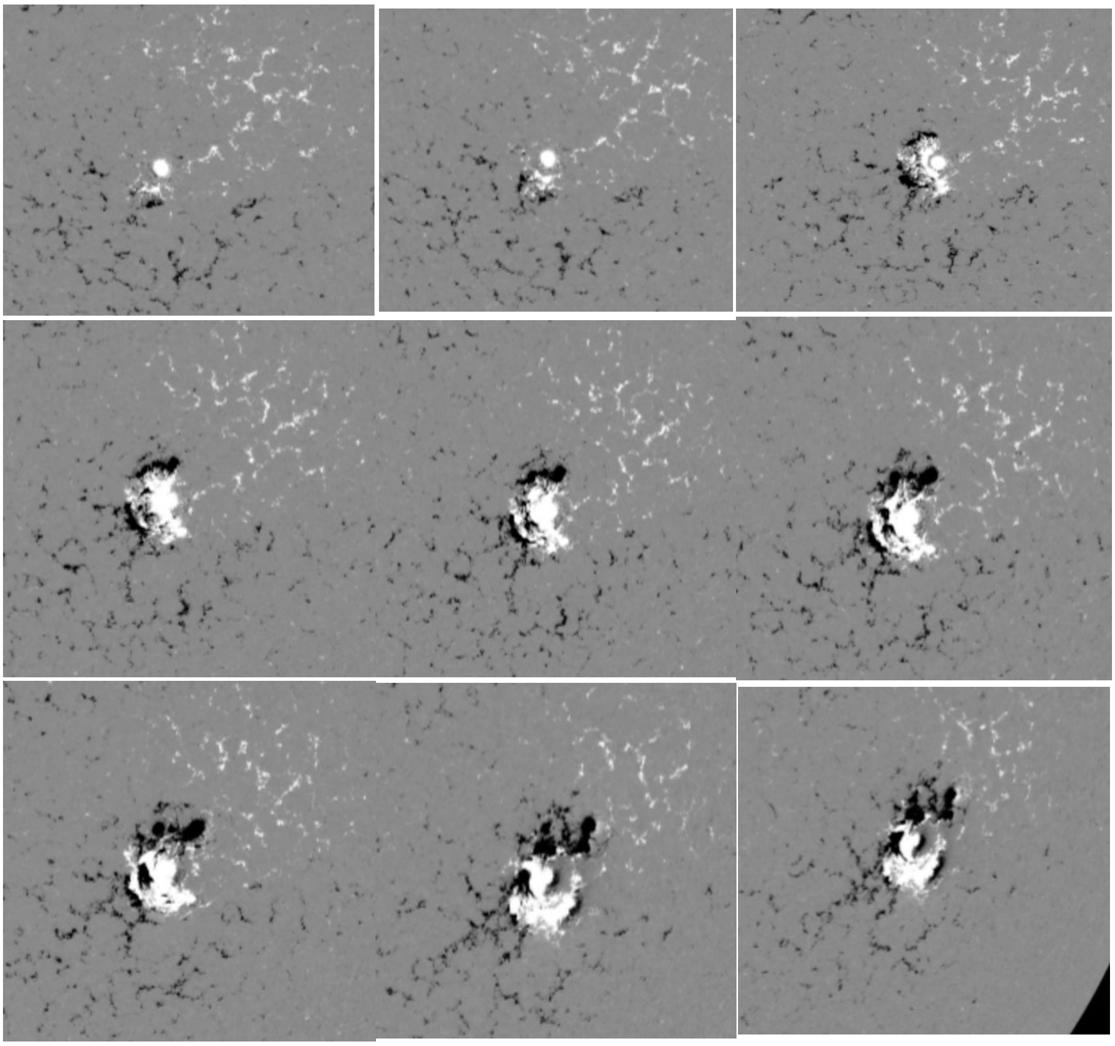

Figure 2: Sequence of images detected from the HMI magnetogram from September 2nd, 2017, to September 9th, 2017. The bright portion is the positive pole, and the dark portion is the negative pole.

Figure 2 are presentative pictures from the video of how the magnetic field has changed using the HMI magnetogram. It shows an interesting fact that this active region (AR) has formed in a relatively quick time, which is less than 5 days. The time an AR forms might be an important factor to determine how flare-active an AR is. [4]

The negative pole, which is represented by dark color in the picture, usually appears on the left of the positive pole (bright color) in the southern hemisphere of the sun. And it is the reverse condition in the northern hemisphere of the sun. It can be seen from the first 3 pictures (in Figure 2) that the negative pole was, indeed, overall on the left side of the positive pole, with a smaller portion of the negative pole on the top of the positive pole, but as this active region keeps growing, more and more negative pole appears on the top of the positive pole, which cannot be explained by norms. It seems that the magnetic gradients are steeper than other active regions. This "horizontal" field might be the key to answering why so many strong solar flares occur in this region. Therefore, to know what exactly has happened, we need to

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compare the HMI magnetogram images with the AIA images to see under what magnetic conditions can a strong solar flare occur.

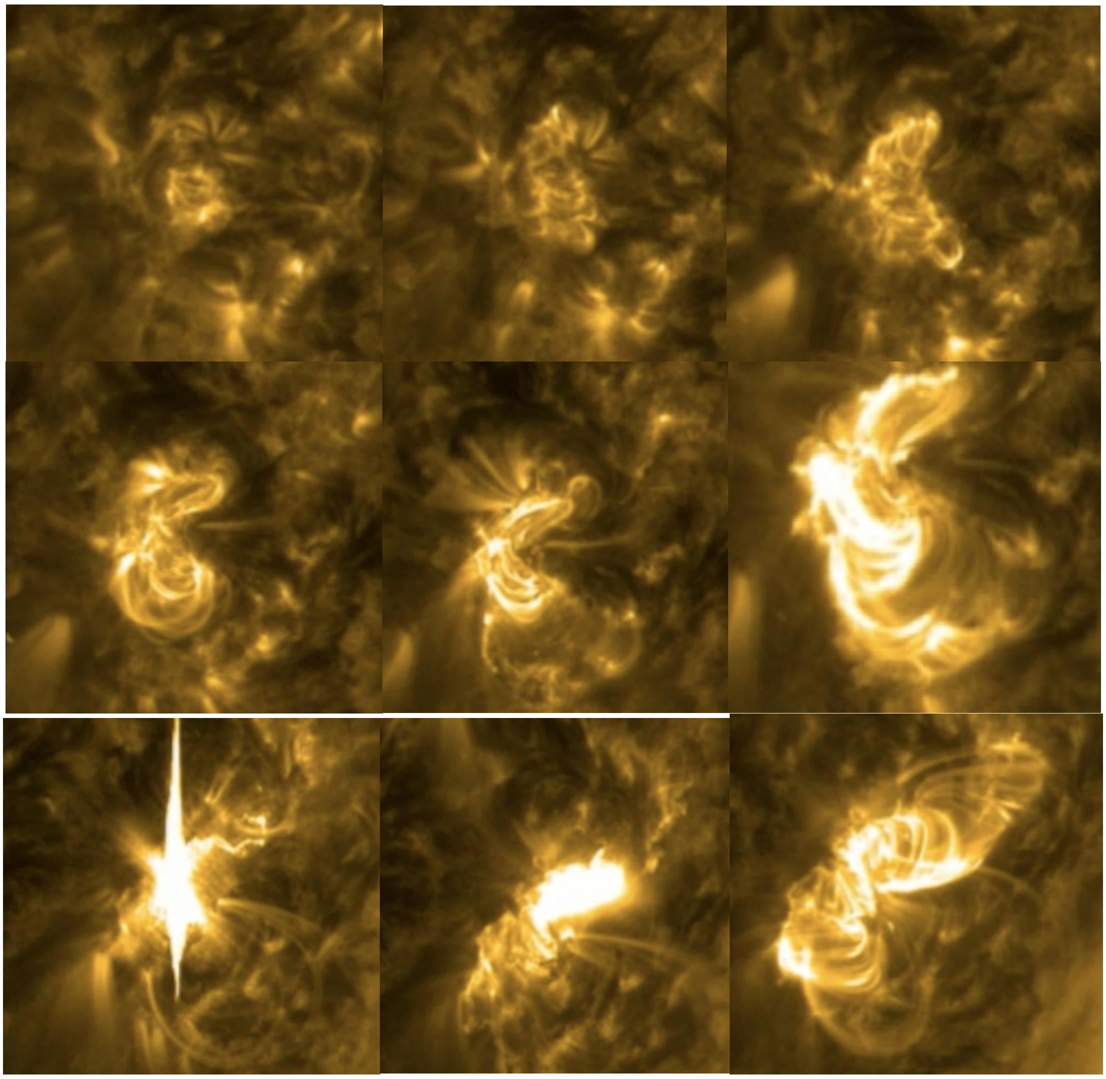

Figure 3: Sequence of images detected from the AIA 171 from September 2nd, 2017, to September 9th, 2017.

These sequence of pictures in Figure 3 demonstrate the development of this active region virtually. Countless solar flares occurred during this period. One of the strongest solar flares, X9.3, started at 11:53 on September 6th, 2017, and ended at 12:10 on the same day. This solar flare is shown in the seventh picture (Figure 3), where you can see a huge increase in brightness in the middle of AR 12673.

3. Results

By comparing the AIA 171 images with the HMI magnetogram images, we realized that the magnetic field of AR 12673 might be the main cause of those strong solar flares including X9.3. So what is special about the magnetic field in AR 12673 that allows it to stimulate so many solar flares? We find the answer by comparing AR 12673 with other active regions that didn't stimulate any solar flares.

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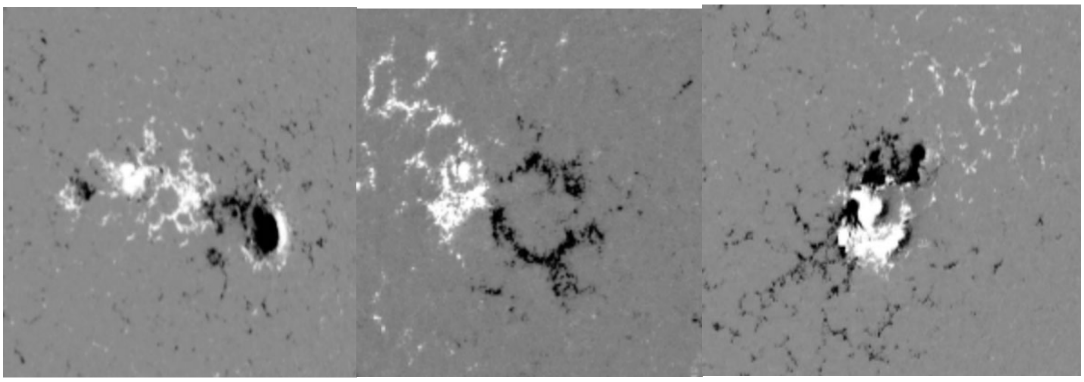


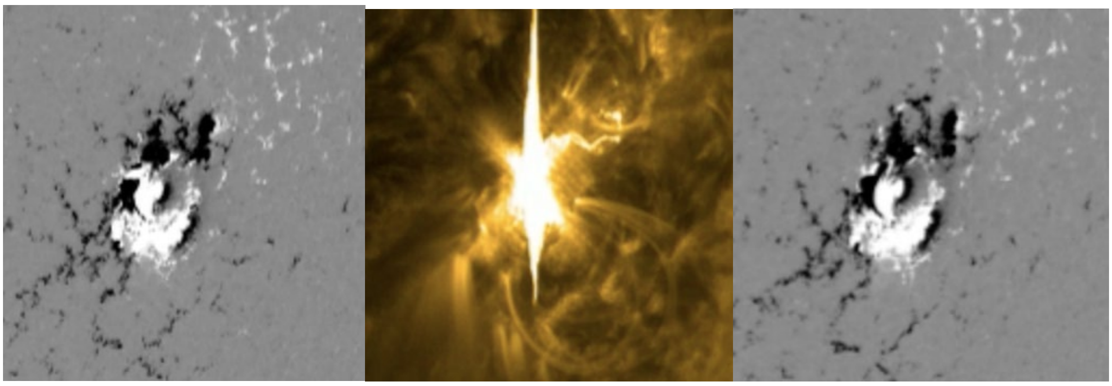
(NOAA 12674) (NOAA12677) (NOAA12673)

Figure 4: Comparison of other AR with AR 12673

From this comparative study shown in Figure 4, we found that the specialty of active region 12673 comes from its special magnetic field. NOAA 12674 and NOAA 12677 (these two ARs are all from the northern hemisphere) are two other active regions that didn't produce many solar flares. We can see that NOAA 12674 and 12677's north and south poles follow strictly the Joy's law that the leading spots are closer to the equator than the trailing spots. From the magnetograms, we can see that the negative polarities (dark portion) are closer to the equator than the positive polarities (bright portion). However, NOAA 12673's magnetic field, is more vertical to the equator, meanings that the negative pole rides on the top of the positive pole instead of placing it on the left of the positive pole. As a result, we believe that this abnormal Joy's law caused the magnetic field of this AR to be extremely unstable. Just like those unstable particles want to release energy (release electrons), unstable AR caused by its unusual magnetic field wants to release energy to make the field stable again as well, and human named this process of releasing energy to make it more stable as "solar flare". [5]

The reason of this abnormal arrangement of magnetic field to form, we assume, is the merging of two separate magnetic field. Figure 2 shows, though not obvious, that there were two magnetic field at start, but merged when they get closer. Former research also proved this hypothesis, as Professor Li from Chinese Academic of Science states "The evolution of sunspots in the three regions was involved in the interaction of two magnetic field systems". As the later-emerging magnetic field comes near to the pre-existing one, the stability of this whole magnetic field be disturbed, and the horizontal arrangement will occur due to the balance of force. [6]

We also want to know something about X9.3. How did a strong solar flare X9.3 occur and what had it changed on the magnetic field? Therefore, we collected the magnetic field 3 hours before and after the explosion of X9.3 to see if there was anything worth noticing.



(3 hours before X9.3) (X9.3) (3 hours after X9.3)

Figure 5: Image of HMI magnetogram 3 hours before and after X9.3

The change is minimal, as presented in Figure 5, but we still see some clues. When X9.3 and some lower-energy solar flares occur, in 6 hours, the negative pole on the left is moving closer to the negative pole on the top and they join at last. So, we guess that X9.3 is stimulated by the two negative pole's tendency to fuse. The two negative pole, as stated, comes from two magnetic field system. The form of the horizontal arrangement of magnetic poles is caused by the merging of two magnetic field system, but again they are not stable. Therefore, energy, or solar flares, is released for the magnetic field to become

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more stable. we are concluding that combining two negative poles into one is a necessary step to make this magnetic field stable and to turn this abnormal Joy's law into normal organization again.

4. Conclusions

By interpreting and comparing the HMI and AIA images from the SDO observatory, we studied active region NOAA 12673. We collected data from September 2nd to September 6th to study how NOAA 12673 has developed and how NOAA 12673 produces so many strong solar flares, including X9.3, the biggest solar flare detected.

By comparing the magnetic field of 12673 with other active regions, we concluded that it is because of the abnormal nature of the magnetic field of this active region that made it so flare productive. Caused by the merging of two magnetic field system, NOAA 12673 balanced two systems by moving all the positive poles into the bottom side, resulting in an arrangement that contradicts to the Joy's law. Since this horizontal polarization is extremely unstable, the solar flares function as a way to trade stability with energy, just like particles release energy to transform it into a low-energy stable state. Moreover, by comparing the magnetic field before and after the strongest solar flare X9.3, we found that perhaps the process of two poles combining into one is a first step to make an active region more stable, and as a result, it would for sure stimulate a strong solar flare, because again, it trades stability with energy.

We believe that these conclusions can be also used for solar flares from other active regions. The next question is, where do these magnetic fields come from and what would affect them? These questions can only be answered by future research. [7]

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