Magnetic Properties of Solar Active Regions That Govern Large Solar Flares and Eruptions

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It is known that solar flares and coronal mass ejections (CMEs), especially the larger ones, emanate from active regions (ARs) holding sunspots. In order to understand the statistical properties of ARs that produce such strong flare events, we surveyed all flare events with GOES levels ≥ M5 within 45° from the Sun's disk center for 6 years from May 2010 [1]. Figure 1 shows a sample flare event that occurred in NOAA AR 12192, which exhibited the largest sunspots in about 24 years. From these observational data, we measured various parameters such as sunspot area, magnetic flux, field strength, area of flare ribbons (elongated intensity enhancements observed in the chromosphere), and flare duration, and conducted statistical analysis.

As a result, we found that more than 80 % of the 29 ARs that produced a total of 51 flare events exhibit "δ-sunspots," the most complex magnetic configuration in the sunspot classification. It is suggested that the δ-spots, in which positive and negative magnetic polarities are closely packed, store a high magnetic energy, which could be released in the form of solar flares. The above trend is consistent with previous observations [2].

We also found that the flare duration is linearly related with the size scales of flare ribbons (ribbon distance, ribbon area, and total flux inside the ribbon). These relations can be explained by the standard flare model based on the magnetic reconnection theory [3].

It has been known that some flares do not accompany any CME eruptions. Our statistical results show that the ratio of the ribbon area to the sunspot area is significantly smaller for the CME-less events compared to the CME-eruptive ones. This result may indicate that in the non-eruptive ARs, large over-lying arcade fields may inhibit the CME eruptions, which is well in line with preceding event studies [4].

Figure 2 displays the observation of perhaps the largest-ever-imaged sunspot-related flare ribbons. This great sunspot appeared in July 1946 and ranks 4th in size since the late 19th century. Comparison with the SDO statistics suggests that this AR might contain a total magnetic flux of 1.5×10^{23} Mx and that the magnetic energy contributing to the flare eruption (not the released energy) could amount to 8×10^{33} erg. If we suppose that the largest sunspot group in history (April 1947: total flux $\sim 2 \times 10^{23}$ Mx) causes a strong flare eruption, the estimated magnetic energy reaches 10^{34} erg, which is already in the category of "superflares."

2014-10-24 X3.1-class flare NOAA AR 12192

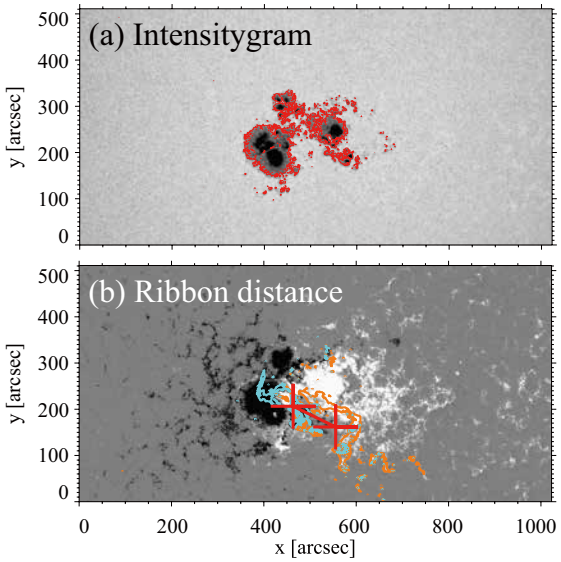

Figure 1: Sample flare data. (a) Continuum image showing the entire AR. (b) Magnetogram showing the magnetic fields (white: positive, black: negative), on which the flare ribbons observed by near UV band image are overplotted.

1946-07-25 Great flare RGO 14585

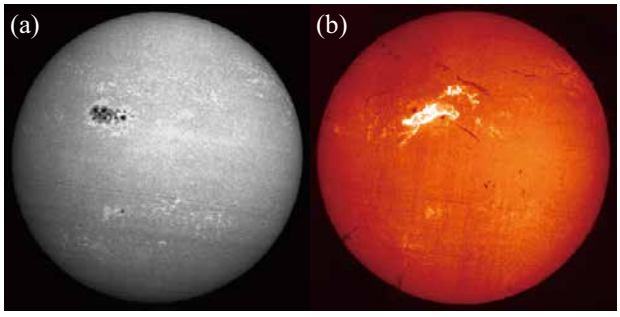

Figure 2: Great flare event in July 25, 1946, in RGO 14585. (Left) Sunspots observed in Ca II K1v. (Right) flare ribbons observed in H-alpha. Images courtesy of Paris Observatory.

References

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[4] Sun, X., et al.: 2015, *ApJL*, **804**, L28.