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How Can We Create Flare-producing Sunspots?

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Solar flares, especially the energetic ones, are known to occur in sunspot regions. Observations have shown that such flare-producing sunspots are magnetically "complex". However, it is not clear how these spots are formed on the Sun.
To this end, we first surveyed all strong (GOES >M5-class) flares for 6 years from May 2010 and investigated the characteristics and evolution processes of these flare-producing sunspots [1]. The spots analyzed here was categorized into four types depending on their evolutionary history, as shown in the left column of Figure 1: (1) spot-spot, in which a long, sheared polarity inversion line (PIL: Bz=0 line) is formed between two major sunspots; (2) spot-satellite, where a newly-emerging minor bipole next to a pre-existing spot creates a compact PIL; (3) quadrupole, where two emerging bipoles produce a PIL in between; and (4) inter-AR, which produces flares not inside the spots but from between two separated regions. We found, for instance, that the average duration of the flares for the spot-spot group is 2512 s, which is four times longer than that for the spot-satellite group of 599 s. These results may indicate that the magnetic structures of flaring sunspots determine the characteristics of the flare eruptions. Therefore, it is critically important to understand how these sunspots are generated.
Then, we modeled these four types of sunspots by conducting MHD simulations [2]. In this work, we used the flux emergence simulations, in which we simulated the rising of magnetic flux tubes from the solar convection zone to the higher atmosphere and the eventual formation of sunspot regions. To model the four types, we applied the following initial conditions: (1) a strongly twisted flux tube emerges due to the kink instability; (2) the main tube emerges with a parasitic tube wrapping around it; (3) a single tube emerges at two locations [e.g. 3]; and (4) two separate tubes emerge independently. Middle column of Figure 1 shows the resultant layout of magnetic polarities on the solar surface. In types (1)-(3), positive and negative polarities lie next to each other, which is the typical characteristics of the flaring sunspots. We find that sheared PILs are created between the two polarities by spot motions, where the horizontal field (i.e. the (Bx, By) vector) is aligned along the PIL. Also, the non-potential magnetic fields are formed in the atmosphere above the PILs (Figure 1, right) and magnetic energies are stored in the current sheets. Therefore, we can conclude that, to create flaring sunspots, emerging magnetic fields in the convection zone need to have highly twisted configurations and/or interactions with other magnetic fields.
Together with detailed case studies [e.g. 4], the knowledge obtained here may link to the further understanding of flare eruptions not only of the Sun but also of many other stars.

References
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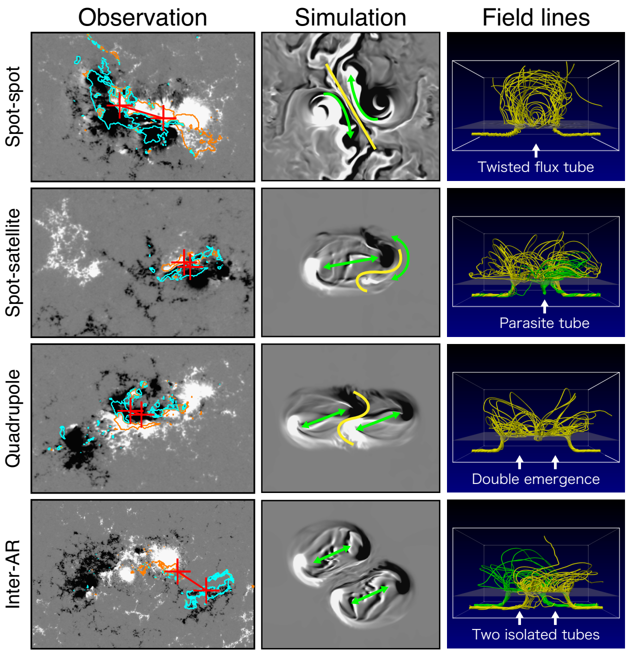

Figure 1. (Left) Four types of flare-producing sunspots. (Middle, Right) Results of numerical simulations.