Solar Flares

Solar flares are thought to occur due to self-organised criticality (SOC; see Lu & Hamilton [1]; Aschwanden [2]). The events draw upon a reservoir of energy much greater than that of the events themselves and are not characterized by a specific physical length-, time- or energy-scale. This results in power law number distributions, Lin et al. [3], Hudson et al. [4]. This means that solar flares should follow scale-free distributions for parameters such as solar flare energy.

Number Distributions

Plotting a histogram of number of flares against the energy of the solar flares results in a power law, where $N(E) \propto E^{-\alpha}$ where N is number of flares, and E is the energy of the flares.

Evolution of Active Regions

We tracked the evolution of active regions with time. We flagged flares depending on whether they occurred before or after the peak area of the active region.

Slicing of Flare Parameters

We looked at how various parameters of the flares affected the flare distributions. We selected the characteristics of:
- Duration of the Flare
- Evolutionary status of active region - Before or after peak sunspot area
- Area of the sunspot at the time of flare
- Ratio of the area at the time of peak
- Ratio of the 131Å to the 193Å wavelength flux

We compared the value of $\alpha$ for different slices of each of these characteristics. Flares with shorter durations tend to have steeper distributions, with fewer higher energy flares.

Data

NOAA Daily solar weather report [6]
We extracted the sunspot area and magnetic classification.

GOES, AIA 131Å & 193Å Flare Detective [7], XRT Flare Catalog [8]
We gathered properties of flares, such as flare duration, peak luminosity, the active region number of the flare, and the start, peak, and end times of the flare.

Before and after the peak

When we compared the number of flares which occurred before the peak of the active region, to the number which occurred afterwards, we found a significant difference. We found far more flares occur before the peak of the active region than after.

Flares vs Active Region

We looked at the energy of solar flares which occurred in an active region, and compared it to the maximum area of the active region achieved.

Solar vs Stellar Superflares

We compared our solar flare dataset to the stellar superflares found in the Kepler data (Maehara et al. [9]). We found that $\text{Duration} \propto \text{Energy}^{1.36(0.01)}$. This is close to the relationship for stellar superflares which is, $\text{Duration} \propto \text{Energy}^{0.4}$.

Conclusions

- The energy released in an active region, duration of the active region and number of flares in an active region are correlated with the maximal active region size.
- Energy of flares $\propto \text{Area}^{1.36(0.01)}$
- Flare durations $\propto \text{Energy}^{0.36(0.001)}$
- Solar flares have no discernible effect on active region evolution.
- There is a tendency for more high energy flares to occur later in the evolution of the active region.
- The number distributions of the before peak and after peak flares are statistically indistinguishable.

References

[6] NOAA daily solar weather report
[7] Flare Detective
[8] XRT Flare Catalog

Distributions over time

We normalized the timing of the flares to when they occurred in the active region, with the start of the active region being at time 0, the peak at time 0.5, and the end being a time of 1.

We then investigated how the value of $\alpha$ changed as we went further along the normalized time.

We found the value of a decreased as we included flares from later in the normalized time, and that the distribution tended to fill out at higher energies as the active region ages.

This meant comparatively more high energy flares were occurring later in the active regions, implying that there is a deviation from the simple SOC process. This is consistent with there being a winding up effect whereby longer lasting ARs have the time to store excess energy that can be released in larger flares.

Building Big Flares

Constraining Generating Processes of Solar Flare Distributions

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