Building Big Flares

Constraining Generating Processes of Solar Flare Distributions

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12th August 2015
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Solar Flares

What are we answering?

Winding up the solar magnetic fields

Flare distributions for different environments

Looking for deviations from $\alpha = 1.8$ for our $E^{-\alpha}$ power law

Deviations mean unanticipated physics

Flare Distribution for Year 2013 - (2035 flares)
dN/dE = E^-1.8
Number of Flares
100
10
1
26
27
28
29
30
31
Log10Energy of Flare [ergs]

Why does it matter?

Self organised criticality (SOC)

Limitations of SOC when applied to flares

Why does it matter?

Why does it matter?

Self organised criticality (SOC)

Limitations of SOC when applied to flares

Searching for the solar flare trigger

What causes our solar "avalanches"?

Where/What is the trigger?

What data did we use?

Active Regions

Flares can be linked to their active regions

Active Region 11875 in 1600Å and 131Å wavelengths

The most active active region in 2013 – 75 flares

What data did we use?

Active Regions

Flares can be linked to their active regions

NOAA

Sunspot area & magnetic classification

GOES

Flare duration, peak luminosity.
Start, peak, and end times of the flare.

AIA 131Å & 193Å

Extend to AIA using HEK & Flare Detective

Flare Distributions 101

$E^{-\alpha}$

- α
  Usually 1.8

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- *Smaller α:*
  Flatter distribution

Flare Distributions 101

$E^{-\alpha}$

- α
  Usually 1.8
- *Smaller α:*
  Flatter distribution
- *Larger α:*
  Steeper distribution

Estimating α

Estimated α using unbinned data

{"Crawford et al. 1972, ApJ 162, 405"}

Bias Correction

Due to finite sample size

Bootstrapping

To get error bars

Slicing

Evolution of an Active Region

Plot of flares per day before peak against after peak
Flares per day after peak
Flares per day before peak
0
2
4
6
8
10

Slicing

Duration

< 10, 10 – 18, > 18, [minutes]

Area of active region

$< 3.5 \times 10^{18}$, $3.5 - 8.5 \times 10^{18}$, $> 8.5 \times 10^{18}$ [cm^2]

Before or after the peak

median = 0.6 (before) 0.715 (after)

Ratio of 131Å and 193Å flux

median = 0.1

Cumulative distribution of duration of flares
2000
1500
1000
500
0
10
100
1000
Duration [mins]
Upper third is
< 18 minutes
Lower third is
> 10 minutes

Cumulative distribution of area of active region at time of flares
Upper third is
< 1.1x10^19 cm^2
Lower third is
> 3.5x10^18 cm^2
1500
1000
500
10^17
10^18
10^19
Active region area at time of re [cm^2]
Surface Area of the Earth

Cumulative distribution of before peak activity values
Ratio of area at time of flare to peak area
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
Before peak median
= 0.6
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
After peak median
= 0.715

Cumulative distribution of ratio of 131 and 193 flux
600
500
400
300
200
100
Median of flux
= 0.11
0.1
1.0
Ratio of the 131 to 193 flux

Larger Active Regions

Last longer, have more flares, release more energy

Flare Effect on Active Regions

Flares are energetically unimportant to active regions

Despite different numbers of, and energy lost to, flares

Max Area of active region against number of flares
Max Area of active Region [cm^2]
4×10^{19}
3×10^{19}
2×10^{19}
1×10^{19}
0
0
20
40
60
80
Number of flares

Comparison with Stellar Superflares

$$\textit{Flare durations} \propto \textit{Energy}^{0.36\pm0.01}$$

Consistent with Kepler superflares

{Maehara et al. 2015, EPS 67, 59}

Energy of flare against duration
Duration = Energy^0.4 line
Line of best fit
Duration = Energy^0.36
Duration of Flare [sec]
1000
100
10
1
10^26
10^27
10^28
10^29
10^30
10^31
Energy [ergs]

Comparison with Stellar Superflares

Flare durations $\propto$ *Energy*$^{0.36\pm0.01}$

Consistent with Kepler superflares

{Maehara et al. 2015, EPS 67, 59}

Flare energy $\propto$ *Area*$^{0.3}$

Inconsistent with Kepler superflares

Expected flare energy $\propto$ Area$^{1.5}$

{Maehara et al.}

Energy of flare against area
Area of active region [cm^2]
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
10^{26}
10^{27}
10^{28}
10^{29}
10^{30}
10^{31}
Energy [ergs]
Line of best fit
Energy ∝ Area$^{0.3}$
Energy ∝ Area$^{1.5}$

Short Duration Flares

Shorter duration flares

$\alpha = 2.2$

Much steeper flare distribution

Flare Distribution for Short Flares
100
10
1
Number of Flares
alpha = 1.8
alpha = 2.2
27
28
29
30
Log10Energy of Flares [ergs]
alpha = 2.2876837

Before vs. after peak flares

Indistinguishable flare distributions

α tends towards the same value for before and after peak flare distributions

Flare Distribution for Before Peak
Number of Flares
100
10
1
27
28
29
30
Log10Energy of Flares [ergs]
alpha = 1.7787462
Flare Distribution for After Peak
Number of Flares
100
10
1
27
28
29
30
Log10Energy of Flares [ergs]
alpha = 1.7772719

Flare distributions with time

Flare Distribution for Year 2013 - (2035 flares)
dN/dE = E^-1.8
Number of Flares
100
10
1
26
27
28
29
30
31
Log10Energy of Flare [ergs]

Flare distributions with time

Investigate the normalised active region time

The value of α decreases over the duration of the active region

This points towards there being a 'wind up' of higher energy solar flares

dN/dE
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
27
28
29
30
Log_{10}Energy [ergs]

Conclusions

- Energy of flares $\propto$ Area$^{0.3}$
- Flare durations $\propto$ Energy$^{0.36}$
- Solar flares have no effect on active region development
- Active region size is related to energy release, duration and number of flares
- α can vary for various groupings
- Before and after peak flares distributions are indistinguishable

- There is a tendency for more higher energy flares to occur with time

More study needed but this is a good start

Thank you for listening

- *Thank you to my mentors, Vinay and Sean*
- *Thank you to Kathy and Trae for coordinating this REU program*
- *Thank you to Kathy, Trae and Nicole for Hinode and AIA data*

This work was supported by the NSF-REU Solar Physics Program at SAO, grant number AGS 1263241, NASA contract NAS8-03060 to the Chandra X-ray Center and by Hinode/XRT grant NNM07AB07C to SAO

[durations]
short
medium
long
1000
100
flares
1.4
1.6
1.8
2.0
2.2
2.4
alpha
* error bars are not independent

Area Vs Alpha for each AR
Alpha
Area
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10^{18}
10^{19}
1731
1640
1659
1657
1723
1704
1700
1678
1652
1653
1710
1646
1727
1675
1665
1717
1719
1715
1667
1639
1718
1703
1695
1641
1696
1698
1643
1658
1684
1683
1692
1661
1669
1660
1711
1663
1687
1638
1645
1686
1644
1714
1680
1726
1690
1708
1681
1730
1724
1721
1654

Timespan of AR vs Max Area of AR
Correlation: 0.41977739
alog10(max area) vs alog10(timespan)
timespan [mins]
Max Area
10^5
10^4
10^3
10^2
10^1
10^{17}
10^{18}
10^{19}
10^{20}