DISTRIBUTION OF LIFETIMES FOR CORONAL SOFT X-RAY BRIGHT POINTS

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Abstract. We have measured the lifetimes of all compact emission features visible on three sets of high time resolution soft X-ray images. The spectrum of lifetimes is found to be heavily weighted toward short lifetimes. The number of features present on the disk which live 2–48 hours is at least ten times as great as the number living more than 48 hours. The distribution of lifetimes can be fit in all three cases by a four-parameter function \( N(t) = N_e \exp(-t/\tau_e) + N_L \exp(-t/\tau_L) \), with \( \tau_e = 8.7 \pm 0.2 \), \( \tau_L = 35 \pm 4 \) and \( N_e \approx 10N_L \). Features living two days or less have a very broad latitude distribution (Golub et al., 1974, 1975) whereas nearly all longer-lived features are found within 30° of the equator. The growth rates of long-lived vs short-lived points are the same to within \( \approx 20\% \), the major difference being that long-lived points continue to grow and generally reach larger sizes.

1. Introduction

This paper is part of a long-term study of emerging magnetic flux on the Sun. In the present study we will examine features visible in the low corona and having lifetimes ranging from two hours to two days. These are in general the objects which we have named ‘X-ray bright points’ (Krieger et al., 1971; Golub et al., 1974) and they are identified on high resolution magnetograms as small, short-lived and rapidly evolving bipolar features (Harvey et al., 1975).

The realization that the cycle of Solar Activity is related to magnetic flux emergence and the progression from Maunder’s butterfly diagram to modern migratory dynamo theories have been reviewed in several extensive articles (e.g., Parker, 1970). We will not attempt a summary of this work, except to point out that the emphasis has traditionally been placed at the high end of the magnetic flux spectrum, i.e., features containing large concentrations of magnetic flux. The solar cycle has usually been associated with the number and location of sunspots, with large active bipolar magnetic field regions living several days or longer and with large solar flares, particularly those involving energetic particles, radio bursts, etc. This emphasis is a natural consequence of the way in which observational techniques developed and to that extent it is an historical accident.

Several recent works have shown that small, short-lived bipolar regions are...
found in great numbers on the Sun and that the amount of magnetic flux contained in the many small regions is approximately equal to the amount contained in the few large regions (Harvey and Martin, 1973; Golub et al., 1974; and Harvey et al., 1975). These authors have begun the characterization of short-lived features as a basis for comparison with the more familiar forms of solar activity. The ultimate objective is a determination of the relative importance of small-scale emerging fields in solar cycle dynamics and a more complete definition of solar activity in general.

The heliocentric distribution of X-ray bright points (XBP) during one Solar rotation was examined in detail in Golub et al. (1975) (see also Harvey et al., 1975). The distribution of these short-lived regions is different from that of active regions, most notably in the wide latitude range over which XBP are found. In the present work we examine the lifetime spectrum of XBP. By 'spectrum' we mean a function $dN/dt$ describing the relative number of features having lifetime $t$ as a function of $t$. If this curve is known, then the number of features having lifetimes between $t_0$ and $t_0 + \Delta t$ is

$$n(t_0, \Delta t) = \int_{t_0}^{t_0 + \Delta t} \frac{dN(t)}{dt} \, dt.$$ 

From examination of soft X-ray images obtained with the S-054 X-ray spectrographic telescope aboard Skylab (Vaiana et al., 1973) we have measured the lifetime spectrum for a sample of 300 XBP, i.e., we have experimentally determined the function $dN/dt$. We find that it is a decreasing function of lifetime, approximately of the form $\exp(-t/\tau)$. However, a single parameter $\tau$ is insufficient to describe the entire histogram from 2–50 hours. It is necessary to use a two-parameter fit with a long and a short lifetime component, so that the slope of the curve becomes increasingly steep for shorter lifetimes.

These results may be put in the following way: The relative number of XBP having lifetime $t$ can be approximately characterized by $n(t) = n_0 \exp(-t/\tau)$, where $\tau = 8.7 \pm 0.2$ hours. However, it is found that the number of features living 20–30 hours, or longer, is greater than expected. The longer-lived features are described by adding to the above exponential a second term of smaller amplitude and longer lifetime $n_1 \exp(-t/\tau_1)$, with $n_1 \approx \frac{1}{10} n_0$ and $\tau_1 = 35$.

The statistical accuracy of the data does not justify the use of additional parameters in this analysis. However, we interpret the above findings to imply a continuous curve which is not properly fit by an exponential and whose true form we have not been able to guess. The transition from the shortest to the longest-lived bipolar features appears to be smooth with a change from the broad latitude distribution and small size of XBP to the distinctive narrow distribution of the large active regions occurring at $\approx$two-day lifetimes.
2. Bright Point Lifetimes

In Golub et al. (1974) we examined the lifetime distribution of a sample of 100 bright points, finding that the vast majority of emerging features had a mean lifetime of eight hours. The distribution was characterized by the observation of a large number of very short lived features and smaller numbers of features at longer lifetimes. Six features appeared to fall outside of the general distribution, leading to the suspicion that there was a second grouping with \( \approx 36 \) hours mean life. However, with the limited sample available we could not arrive at a firm conclusion concerning the reality of a longer-lived class of feature, and no mention was made in the paper of a possible second class of feature.

In order further to examine the lifetime spectrum of XBP we have analyzed several additional sets of high time resolution data. Employing the assumption that bright points behave independently of each other, as the photographs appear to indicate, we have used a method equivalent to the previous one but which is in practice easier to implement (Golub, 1976). For the present study we assembled the available sets of photographs and tagged all of the bright points visible on the first photo of each set. The total number of points in each set was \( \approx 100 \). Each point was then traced through the stack until it decayed, so that each photo in the stack was matched to those bright points which were last seen on that photo. We then proceeded through the stack subtracting the number of decays on each successive photo, resulting in a plot of the number of points remaining as a function of time, starting with the time of the first photo. (In those few cases (\( \approx 5\% \)) in which a point dimmed substantially and then ‘reemerged’, i.e., in which a second point might accidently have emerged very close to the first one, we always chose the shorter lifetime.)

If the number remaining as a function of time is plotted in semilogarithmic coordinates the result should be a straight line if the data all belong to a single lifetime class and the features are born at random times (Golub, 1976). The slope of the line is simply \(-1/\tau\), where \( \tau \) is the average lifetime and the intercept is \( N_0 \), the number of points at time \( t = 0 \). In linear coordinates the number remaining vs time is described by \( N(t) = N_0 e^{-t/\tau} \).

The available high time resolution data consisted of three sets, 1–2 June, 17–19 August and 20–23 August, all in 1973. Typical time resolution between photos was \( \frac{3}{4} \) to 2 hours, although the June study terminated in a 12 hour gap and some photos on 23 August were 6 hours apart. The three sets of observations are shown in Figure 1. We see that the number of points decreases with time in a uniform and approximately linear fashion, at least for the first 15–20 hours of observation. The solid lines on the figure show the best fit straight line (single lifetime) obtained by a least-squares method.

An estimate of the quality of the single-lifetime fit, we have calculated \( \chi^2 \) and \( P(\chi^2) \) for each data set, where

\[
\chi^2 = \sum_{i=1}^{n} \frac{[O(t_i) - E(t_i)]^2}{\sigma_i^2},
\]
Fig. 1. Number of points remaining as a function of time for three samples of X-ray bright points, total of 304 points. Dots with error bars show number of XBP surviving as a function of time, starting from the first picture of each set. Solid and dotted lines are theoretical fits, described in the text.

\[ O(t_i) = \text{observed number of points at time } t_i; \]
\[ E(t_i) = \text{expected number of points at time } t_i; \]
\[ \sigma_i = \text{calculated statistical uncertainty in } O(t_i); \]
\[ n = \text{number of data points} = \text{number of photographs in the data set.} \]

The value of \( \chi^2 \) is then combined with the number of degrees of freedom, i.e., \( n \) minus the number of free parameters in the fit to obtain \( P(\chi^2) \), the probability of exceeding the observed value of \( \chi^2 \) for real data having the assumed functional dependence given by \( E(t) \). The results are shown in Table I under the heading ‘one-lifetime fit’, ‘full disk’.

The three single exponential fits have confidence levels of 0.02, 0.30 and \( 10^{-3} \). It is usual in \( \chi^2 \) tests to consider a \( P(\chi^2) \) acceptable if it is within the limits
TABLE I
One and two-lifetime fits to bright point lifetime curves

<table>
<thead>
<tr>
<th>Date and type</th>
<th>One-lifetime fit</th>
<th>Two-lifetime fit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\tau$</td>
<td>$P(\chi^2)$</td>
</tr>
<tr>
<td>1–2 June</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full disk</td>
<td>11.9 ± 0.5</td>
<td>0.02</td>
</tr>
<tr>
<td>coronal holes</td>
<td>11 ± 1</td>
<td>0.75</td>
</tr>
<tr>
<td>$</td>
<td>\text{lat.}</td>
<td>&lt; 30^\circ$</td>
</tr>
<tr>
<td>17–19 August:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full disk</td>
<td>10.5 ± 0.3</td>
<td>0.30</td>
</tr>
<tr>
<td>CH</td>
<td>10.4 ± 0.6</td>
<td>0.69</td>
</tr>
<tr>
<td>$&lt; 30^\circ$</td>
<td>9.9 ± 0.4</td>
<td>0.12</td>
</tr>
<tr>
<td>20–23 August:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full disk</td>
<td>11.2 ± 0.3</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>CH</td>
<td>11.3 ± 0.5</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>$&lt; 30^\circ$</td>
<td>11.5 ± 0.4</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>Averages:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full disk</td>
<td>11.0 ± 0.2</td>
<td>8.7 ± 0.2</td>
</tr>
<tr>
<td>CH</td>
<td>10.9 ± 0.4</td>
<td>7.9 ± 0.3</td>
</tr>
<tr>
<td>$&lt; 30^\circ$</td>
<td>11.0 ± 0.3</td>
<td>9.3 ± 0.3</td>
</tr>
</tbody>
</table>

Values of the parameters obtained in one- and two-lifetime fits to the data of Figure 1 for each of three data sets. Each full disk set has been further divided into subsets, consisting of only those XBP found in coronal holes and only those XBP found at latitudes within 30° of the equator. Average values of the three observations for each of the subsets and for the full disk sets are also listed.

$0.10 \leq P(\chi^2) \leq 0.90$. We find therefore that the single lifetime fit is acceptable in only one of the three data sets examined. The average lifetime value is determined to be $11.0 \pm 0.2$ hours and all three measurements are consistent with this average. Thus, even though the bright point decay curves cannot in general be fit by a single exponential, the measure of mean lifetime provided by the fit is consistent in all three cases.

The same type of analysis has also been applied to two subsets of the full data sets. We have first selected only those points in coronal holes on each of the three starting photographs, typically 30–40 points out of the $\approx 100$ in each data set. The statistical significance of the analysis is somewhat reduced and the $P(\chi^2)$ is acceptable in two of the three cases. However, the mean lifetime values determined in these subsets are again consistent with each other in all three cases and more significantly, are consistent with the full disk data sets values. The mean lifetime of XBP in coronal holes is found to be consistent with that of the XBP observed on the entire solar disk.

We also chose another subset of the full disk data for analysis. In Golub et al. (1975) we noted that the latitude distribution of bright points could be interpreted.
as having two components, one uniformly distributed over the entire solar surface and another superposed distribution confined mostly to within 30° of the equator. One possible explanation for the larger number of points observed near the equator is simply that the low latitude points live longer. If an equal number emerge per unit time at high and low latitudes but the low latitude points have longer lifetime then we would observe more points at low latitudes. A difference of a factor of two in lifetime would be necessary to explain the number density differences which we observed.

The results listed in the ‘one-lifetime’ column of Table I show that the lifetime explanation is untenable. Bright points within 30° of the equator are found to have a mean lifetime of 11.0±0.3 hours, whereas the full disk data shows 11.0±0.2 hours. If the high latitude points are separated out of the full disk data their mean lifetime is found to be exactly the same as those at low latitudes, since the full disk and low latitude values are equal. We conclude that the mean lifetimes of bright points found at low latitudes and at high latitudes are equal.

The generally poor quality of the one-lifetime fit combined with the suspicion of a second lifetime grouping as discussed above led us to attempt a two-component fit to the data. The deviations from exponential behavior in Figure 1 took the form of a long-lived tail. That is, most of the bright points decayed along a nearly linear short-lifetime decay curve, but a small number in each of the three data sets took longer than expected to decay. The observed decay curve therefore climbed above the straight line fit after 15–20 hours of observation. In the context of exponential decay analysis the logical next step is to attempt a two-lifetime fit to the data. A detailed statistical analysis will then show whether the use of an extra parameter is justified.

We describe the number remaining vs time as the sum of a short and a long lifetime component:

\[ N(t) = N_s e^{-\tau_s} + N_L e^{-\tau_L}. \]

The major change introduced by the second component is that the decay curve is no longer linear on a semilogarithmic plot, but first dips below, then crosses over and remains above the linear fit. It approaches linear behavior in the limits \( t \to 0 \) and \( t \to \infty \) (Golub, 1976).

The remainder of Table I shows the best values of the parameters \( \tau_s \) and \( \tau_L \), obtained by minimizing \( \chi^2 \) in an iterative fashion. Maps of \( \chi^2 \) at different portions of the parameter space were examined to check that the minima obtained were true rather than local minima.

The table shows that the two-lifetime fits are consistently favored. In eight of the nine cases the two-lifetime fit shows a higher confidence level than the single exponential and all of the full disk and coronal hole fits are within acceptable limits. We consistently find a short-lived component with average lifetime of about 8 hours and a long-lived 1.5 day component. The results for features in coronal holes show no significant difference from the full disk results. Note that
$P(\chi^2)$ takes into account the increased number of parameters used in the two-lifetime fit, so that a direct comparison with the linear fit is valid. The higher confidence levels for the two-lifetime show that the use of the extra parameter is justified. Furthermore, since 7 of the 9 cases have acceptable $\chi^2$ values with the two-lifetime fit, there is no valid statistical reason with the data available for trying a three-lifetime fit.

The observed fraction $N_f/N_s$ of long to short lived points is highly variable, as shown by the column labelled 'f'. For this ratio it appears that the average value shown at the bottom of the table is not meaningful. In June, the fraction of long-lived points is significantly higher than the fraction seen in August, by about a factor of three. For each data set the fraction of long-lived points found in coronal holes is consistent with the value found for the full data set. Moreover, the low latitude data set shows a fraction of long-lived points consistent with the full disk and coronal hole data. Thus XBP in coronal holes and those found within 30° of the equator show the same two component lifetime fit and the same fraction of long-lived points as are found in the full disk data. This fraction appears however to vary considerably between June and August.

We note also that the previous lifetime study (Golub et al., 1974) found the same fraction of long-lived points as determined here. The earlier study examined all emerging features and found six of the 100 points to be in the $1\frac{1}{2}$ day tail. The present study examined features present on the disk at a particular time. The relative probability of observing a feature on a single 'snap-shot' is proportional to its lifetime, so that the $1\frac{1}{2}$ day class would be about four times as prevalent in the present study as they were in the earlier one. Comparing the June data from Table I we find exactly the expected result, $f = 24\%$.

We have shown above that a two-lifetime exponential can be fit to the decay curves of X-ray bright points. A test of the validity of this fit would be the prediction of bright point properties which were not used to obtain the fit. We have performed two such checks and both confirm the need for a two-lifetime fit.

The decay curves in Figure 1 were obtained by examining the time behavior in one direction of bright points, starting with a given photo and examining successive photos. We can now use the values of $N_s$, $N_L$, $\tau_s$ and $\tau_L$ to predict the behavior of bright points when the time-reversed side of the decay curve is examined. The procedure is to start with a given photo and go forward and backward in time to obtain the total lifetime of each bright point on the photo. After all of the lifetimes are determined, they are sorted into finite intervals, resulting in a histogram showing number of points vs total lifetime, which can then be compared with the predicted behavior for that data sample from the fit listed in Table I.

Recall that the decay curve is of the form

$$N(t) = N_s \exp \left(-t/\tau_s\right) + N_L \exp \left(-t/\tau_L\right).$$

The number of points decaying per unit time at time $t$ is the derivative of this
function
\[-\frac{dN(t)}{dt} = \frac{N_s}{\tau_s} \exp (-t/\tau_s) + \frac{N_L}{\tau_L} \exp (-t/\tau_L). \tag{2}\]

Equation (2) describes the number of points which disappear on a photo at time \(t\) after the first photo of the set. The behavior should be symmetric about \(t = 0\), so that
\[-\frac{dN(-t)}{dt} = \frac{dN(t)}{dt}.\]

Points with lifetime \(t_0\) will on the average, live \(\pm t_0/2\) from time \(t = 0\). The number living between \(t_0\) and \(t_0 + \Delta t\) is therefore
\[n(t_0, \Delta t) = -\int_{t_0}^{t_0 + \Delta t} \frac{dN(t/2)}{dt} dt = \frac{dN_T(t)}{dt} \Delta t.\]

The histogram of total lifetime will thus follow a two-component exponential shape given by
\[\frac{dN_T(t)}{dt} = \frac{N_s}{2\tau_s} \exp (-t/2\tau_s) + \frac{N_L}{2\tau_L} \exp (-t/2\tau_L). \tag{3}\]

Of the three data sets considered, high time resolution photos in both directions from \(t = 0\) were available in only one case, that of 20 August. Using the lifetime values for that data set from Table I and the values of \(N_s\) and \(N_L\) predicted total lifetime distribution from Equation (3) is:
\[\frac{dN_T(t)}{dt} = 5.4 \exp (-t/17.2) + 0.10 \exp (-t/86). \tag{4}\]

This prediction together with the actual values found are illustrated in Figure 2. Note that the curve has been raised a factor of two to coincide with the two-hour binning used here, i.e., \(\Delta t = 2\). The agreement appears quite good, as is confirmed by a \(\chi^2\) test in which the observed number of points in each lifetime bin is compared to the expected number given by Equation (4). With 20 degrees of freedom we find a \(\chi^2\) per degree of freedom of \(\chi^2 = 0.99\) for a \(P(\chi^2)\) of 0.49. Thus, the first test of the two-lifetime fit shows a positive result.

The above test can be extended for a second prediction. The length of our data base was such that several of the points which lived longer than 50 hours extended out of the high time resolution photo sequence into a 12 hour data gap. The accuracy of lifetime determination for these points was therefore inconsistent with the two-hour binning used in Figure 2. In all, we found 11 points which lived longer than 50 hours, or 12 points if the one active region present at the time is included. This ‘overflow’ can be used as another independent check on the fit,
because the expected number of overflow points is given by
\[ n_0 = \int_{50}^{\infty} \frac{dN_T(t)}{dt} \, dt. \]

Integrating Equation (4) and taking into account the uncertainties in the parameters \( \tau_s, \tau_L, N_s, N_L \) we find that \( n_0 = 9.6 \pm 1.5 \). The number is in good agreement with the value \( n_0 = 11 \) actually observed. Note that the contribution to \( n_0 \) comes from both the 8.6 hour and the 43 hour exponentials in about equal parts. Splitting Equation (4) into its two parts we have
\[ 5.4 \int_{50}^{\infty} \exp \left( -\frac{t}{17.2} \right) dt = 5.1, \]
\[ 0.10 \int_{50}^{\infty} \exp \left( -\frac{t}{86} \right) dt = 4.5. \]

Thus, the points which live longer than two days come as much from the \( 8\frac{1}{2} \) hour group as from the \( 1\frac{1}{2} \) day group, primarily because of the extreme difference in normalization between the two exponentials.

3. Discussion

The preceding analysis leads to the question, how are the long-lived points different from the short-lived ones? Examination of the photographs shows that both similarities and differences in appearance, development and location of the features can be found. First, we have been able to locate to first order the
transition from a broad latitude distribution to the equatorial type of distribution found for active regions.

Because the relative number of long-lived regions is quite small we have not been able to produce a detailed latitude map. Instead, Table II shows the fraction of XBP found within 30° of the equator for the entire sample of 304 points, for the 94 points visible on 20 August and then for long-lived subsamples of this latter data set. We notice that only the 12 points living longer than two days show a concentration near the equator, with 11 of 12 points falling in the equatorial band. Such a concentration is not evident in the sample of XBP living 30–50 hours. Of the 12 long-lived points, only one is an active region and the remaining live less than three days and do not reach an X-ray size larger than =1 arcmin. The chance probability of finding such a skewed distribution in a sample of 12 points is =10⁻³.

We have examined in detail the growth curves of a sample of 26 selected bright points, with lifetimes ranging from 4 hours to >52 hours. Seven of these points had lifetimes of two days or longer. As a measure of the growth rate we have taken the number of hours needed for each point to reach maximum area on the X-ray images and compared the average slope of this growth curve for the seven long-lived points to the average slope for the remaining points. The values obtained are (4.8±0.5)×10⁷ km² hr⁻¹ for the long-lived points and (5.9±1.1)×10⁷ for the remaining points. The error bars were determined from the data by using the dispersion formula \( \sigma^2 = \overline{X}^2 - \overline{X}^2 \). Within the accuracy of the measurement the growth rates of the two groups are identical.

The relationship between maximum area and total lifetime which we found earlier (Golub et al., 1974) is reconfirmed in the present set of measurements. For the XBP sample having lifetimes shorter than two days we find A_{max} = (2.4±1.0)×10⁷ \( \tau \) km² hr⁻¹ and for long-lived points we find (1.5±0.6) km² hr⁻¹. The dispersion in the data is large compared with the difference between the two groups. That is, points in each group having similar lifetimes were observed to reach maximum sizes different by up to a factor of three, whereas the difference between the averages for the two groups is ≈40%. A similar large dispersion is

| Type          | Full disk | |lat|<30° | Fraction |
|---------------|-----------|-----------------|------|
| All data      | 304       | 167             | 0.55 |
| 20 August     | 94        | 56              | 0.59 |
| 30 h<\(\tau\)<50 h | 15      | 8               | 0.53 |
| \(\tau\)>50 h | 12        | 11              | 0.92 |

Number of XBP on full disk images and occurring within 30° of the equator relative to total number observed. Also same ratio calculated for the points seen on 20 August and subsets consisting of points having long lifetimes.
found in the growth rates discussed above, the variations within each group being much larger than the difference in the mean values.

A straightforward extrapolation to zero lifetime of the distribution function we have found (Equation (3), Section 2) for the relative number of short- to long-lived points would imply that the number of emerging features having zero lifetime is infinite. We arrive at this inference by noting that Equation (3) describes the distribution of lifetimes for features present on the disk at one particular time. This distribution is biased toward longer lifetimes and against shorter lifetimes. Simply put, emerging features which live a long time have a greater chance of being observed on a random photo than do features which live a short time. The relative probability is just proportional to the lifetime of the feature so that a distribution for the number of features emerging per unit time is obtained by dividing Equation (3) by $t$. Therefore since Equation (3) extrapolates to a finite value at $t = 0$, the extrapolated number of features emerging with zero lifetime becomes infinite. The integral is the well-known ‘exponential integral’, which is logarithmically divergent as the lower limit of integration approaches zero.

This situation does not necessarily imply that an infinite amount of magnetic flux is emerging in zero lifetime regions. For instance, the observed lifetime of a region may be proportional to the amount of flux it brings up to the photosphere. Then the shortest lifetime regions will contain the smallest amounts of flux and the integral over the entire flux spectrum can still be finite, as is the case for the photon energy distribution in a thin target bremsstrahlung spectrum. A correlation between magnetic flux and lifetime for arch filament systems (AFS) living from several hours to several days has been deduced by Born (1974), who also found short-lived AFS to be more numerous than long-lived ones. Although Born assumed a minimum flux for production of an arch filament of $10^{19}$ Mx, our X-ray observations appear to be observing smaller features. XBP are generally seen in Hα as emerging flux regions which are not associated with AFS (H. Zirin, private communication). A detailed comparison between simultaneous soft X-ray images and high resolution Kitt Peak magnetograms is presently under way.

The above remarks are not intended to imply that the number of short lifetime bipolar features emerging on the Sun is truly divergent. There could for instance be a mechanism which increasingly hinders the appearance of smaller regions, or the actual generation mechanism of the magnetic fields might produce a roll-off at small flux values. Our aim has been to demonstrate the potential impact of our formulation on the concept of solar activity which may result from continued study of the very smallest forms of activity.

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References