X-RAY BRIGHT POINTS AND THE SOLAR CYCLE

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Abstract

Soft X-ray filtergrams show the presence on the Sun of numerous small, closed regions of coronal emission. These features, called "X-ray bright points" correspond to topologically closed short-lived regions of emerging magnetic flux. As a function of size or lifetime they form a broad spectrum of activity which is continuous with the active regions. The shape of the Sun's activity spectrum is such that the majority of all magnetic flux emerging at the surface comes in the form of bright points, i.e., regions living less than two days.

Examination of soft X-ray data obtained from 1970 to 1978 shows that the number of bright points appears to be anticorrelated with traditional activity indices, such as sunspot number; the anticorrelation persists after corrections are made for obscuration by active regions. Comparison of X-ray data with KPNO magnetograms shows that to within a factor of two, the average total amount of magnetic flux emerging over the full Sun is constant through the entire period of observation. The Solar cycle therefore appears to be more an oscillation in the wavenumber distribution of emerging flux than of the total quantity of magnetic flux produced.

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1. **Introduction**

High spatial resolution observations of the Solar corona in its characteristic radiation, soft X-rays, have proven to be a valuable new tool in the study of Solar activity and active regions. For a number of reasons (cf. Vaiana et al., 1973), soft X-ray instruments provide extremely high contrast between closed and open magnetic field regions in the Solar atmosphere, so that the X-ray emitting plasma observed by imaging instruments belong primarily to the closed corona. The corona is observed to be highly structured and recent theoretical work has shown the advantage of considering the corona to be fundamentally inhomogeneous, with loops forming the relatively isolated building blocks (cf. Vaiana and Rosner, 1978).

The sharp division in X-ray brightness between open and closed regions is particularly advantageous in studying the small-scale end of the active region distribution, i.e., the X-ray bright points or XBP. This name was given to the numerous small regions of bright X-ray emission which were seen on early high-resolution images (Vaiana et al., 1970). Now what is significant about these small features is that most of the magnetic flux emerging through the Solar photosphere comes up in regions living two days or less. Moreover, detailed study reveals major variations in magnetic flux emergence at locations on the Sun for which flux emergence had not heretofore been considered and with spatial and temporal scales which have not until now been observed. Finally, there is evidence from observations over most of a Solar cycle that the total amount of magnetic flux integrated over all emerging scale sizes may vary little, if at all, through the Solar cycle.

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Over the past decade we have begun to form a comprehensive picture of the small-scale end of the Solar magnetic flux emergence spectrum, with profound implications for Solar cycle and dynamo theories. We will first present the results from Skylab in §2, more recent findings in §3 and discuss the implications and directions for further research in §4.

2. Results from Skylab

Bright points had been observed in several rocket flights before the launch of Skylab and many of their basic properties had been established. Physical parameters such as size, electron temperature and density were known and we were reasonably certain that they represented magnetically bipolar features.

However, the availability of continued observations over many hours and days in the Skylab data provided a new dimension for the analysis. We were able to study the lifetimes and evolution of activity on all time scales and to look for large-scale patterns in emergence on the Solar surface. The motivation, of course, was to find out whether XBP represented emerging magnetic flux and if so, how much of it and what new information could be gained about Solar magnetic activity from studying these objects.

By comparing the X-ray data with high-resolution KPNO magnetograms we were able to establish that (Golub et al. 1977):

i) XBP represent emerging magnetic flux and they are bipolar;

ii) the lifetime in X-rays of XBP is (to first order) linearly correlated with the total magnetic flux in the region;

iii) the relation between lifetime and $\Phi_{\text{Tot}}$ extends over three orders of magnitude, the proportionality constant being $\sim 10^{20}$ Mx/day.
For the Skylab observing period the relative contribution of bright points to that of active regions, using two-day lifetime as a demarcation between the two classes, has an average value of 4 to 1. In other words, features living less than two days (but more than two hours) contributed about 80% of the total emerging Solar magnetic flux.

Because bright points in a sense represent the "whole story" of magnetic flux emergence on the Sun, we need to examine the global properties of their emergence. Theoretical models of the Solar dynamo and of the cycle could potentially contain enormous systematic errors if the short lifetime end of the activity distribution, which we have shown to contain the vast majority of all magnetic flux, emerges with substantially different properties from those of the large, long-lived active regions. In this regard we have at present only partial answers; these pages may be viewed as a progress report on work which is now being performed.

X-ray bright points have a broader latitude distribution than do longer-lived active regions (Golub et al. 1974), which is consistent with magnetograph and CaK observations of ephemeral regions (Harvey and Martin 1973). These results are in turn consistent with the well-known observation that pores (small sunspots lacking penumbrae) are more broadly distributed in latitude at a given phase in the cycle than are sunspots (Bray and Loughead 1964). It is apparent that emerging flux regions with pores represent intermediate cases between the shortest-lived bright points and the active regions. Born (1974) has identified such regions as living from 10 to 60 hours; shorter-lived regions do not develop pores and longer-lived ones develop penumbral spots. An association between lifetime and total magnetic flux, similar to the one we discussed above, was inferred.
More recently, we have found that there appear to be large-scale variations in bright point emergence. The variation appears to consist of a single event over the full Sun, correlated with an emergence of active regions. The total number of XBPs emerging per unit time varies globally by a factor of two over a time scale of 2 to 3 Solar rotations, and there is a local, temporary depletion of XBP near the large active regions. We are looking into the possibility that the observed variation is connected with the deep-rooted dynamo action in the Sun.

3. **Solar Cycle Variation**

Data obtained from two rocket flights in 1976 revealed a dramatic and unexpected change in the spectrum of Solar activity (Davis, Golub and Krieger, 1977). Whereas the number of large active regions had decreased substantially from 1973 to 1976, the number of bright points observed had increased significantly.

This result prompted a reexamination of other available data from two flights in 1970 and one in 1974; an additional flight in 1978 provided a further data point. Analysis of the six rocket flights plus the ATM data shows a consistent pattern of anticorrelation between the relative number of bright points and the level of activity as measured by the sunspot index.

With the above considerations, using the relative numbers of XBPs and active regions observed from 1970 to 1978 and taking the 1973 fraction of 80% as a base, we estimate that 40% of the total magnetic flux in 1970 emerged in the form of XBPs, and a peak of ~ 95% in 1976. Early in 1978
the fraction was ~ 70%, much the same as in 1973. We see that XBPs represent a substantial contribution to the total emerging flux spectrum throughout the entire solar cycle and are the dominant contributors through the declining, minimum, and rising phases.

During the Skylab period there were typically $1.5 \times 10^3$ XBPs emerging per day,† each with $3 \times 10^{19}$ Mx of flux and active regions added another 20%. The typical value for magnetic flux emergence on the Sun is, therefore, $\gtrsim 5 \times 10^{22}$ Mx per day.

If we assume that the XBPs observed in all rocket flights are the same, then the total amount of magnetic flux emerging at solar minimum is twice as great as in 1973; the total in 1970, near maximum, is nearly identical to that in 1973. However, the shift toward smaller regions at minimum could extend down to features as small as XBPs, so that the larger number observed does not necessarily imply more total magnetic flux emerging. The possibility of a factor of 2 decrease in the average flux per XBP exists in the 1976 magnetogram data (J. Harvey, private communication) so that within the factor of 2 the average total amount of magnetic flux emerging on the Sun throughout the solar cycle is constant.

IV. Discussion

In this paper we have presented the results in decreasing order of certainty. A schematic outline of our knowledge may be portrayed as shown in table 1. It appears that the least certain results are those with the greatest potential significance.

The question of the Solar cycle variation is the one which we

† The number $1.5 \times 10^3$ per day is equivalent to 500 XBPs on the full Sun at any one time, or 250 on the visible disk; this number is clearly greater than the average of 38 quoted in the text. The smaller numbers, such as those quoted in table 1, are relative counts and are obtained from short exposure images, in order to minimize obscuration and visibility effects from overlying coronal structures. The larger numbers, used for obtaining flux estimates, are based on the scaling of XBP counts in coronal holes on long-exposure images (cf. Golub et al. 1974, figure 7).
presently feel to be the most important. Based on the behavior of the familiar large active regions, one would presumably expect that the short-lived regions and the bright points would have a similar Solar cycle variation. That is, the number of regions emerging per unit time or the integrated total quantity of emerging magnetic flux would be expected to vary roughly in phase with other activity indices, such as the sunspot index R. Another possibility which might have been observed would be no average variation in the number of bright points. One could then have argued that these features have no relation to the Solar cycle and represent some unrelated surface effect. The observed anticorrelation described in §III therefore argues not only for a close association between XBP and the Solar cycle, but for a possible major revision in Solar dynamo calculations.

Although the Solar cycle variability is the major unresolved question in bright point research, there are a number of other significant areas still to be explored. For example, there are no simultaneous magnetograph and soft X-ray observations having good time resolution. With such data one could determine unequivocally whether all bright points represent emerging magnetic flux and whether all detectable emerging flux shows up in X-ray emission. Such data could also be of use in answering far broader questions concerning the physical structure of the corona and its relation to the magnetic field.

Other areas of research which have been suggested and which are presently under study include: the relationship between bright point flares and macrospicules (and spicules), analysis of flare energy storage and release mechanisms using bright point flare data, and bright points as sources of the solar wind. Clearly, there is a great deal of work yet to be done.
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<thead>
<tr>
<th>Property</th>
<th>Level of Certainty</th>
<th>Significance</th>
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<tbody>
<tr>
<td>1. Bright points are magnetically bipolar closed regions.</td>
<td>Certain</td>
<td>They appear to be a little-explored form of Solar activity.</td>
</tr>
<tr>
<td>2. Bright points form the short lifetime end of a continuous distribution of activity.</td>
<td>Well established</td>
<td>There are no &quot;characteristic&quot; parameters for active regions on the Sun.</td>
</tr>
<tr>
<td>3. Bright points represent emerging magnetic flux.</td>
<td>Fairly well established</td>
<td>Magnetic flux is produced in a large range of scale sizes in the Sun.</td>
</tr>
<tr>
<td>4. During the Skylab period most of the magnetic flux on the Sun emerged in the form of bright points.</td>
<td>Highly probable</td>
<td>The basic method of magnetic flux generation may be small, rather than large, concentrations.</td>
</tr>
<tr>
<td>5. During most of the past Solar cycle, bright points dominated the emergence of magnetic flux on the Sun.</td>
<td>Appears likely</td>
<td>Dynamo theories for large active centers may be missing much of the true picture.</td>
</tr>
<tr>
<td>6. Bright points vary in anticorrelation with long lived active regions throughout the Solar cycle.</td>
<td>Appears likely</td>
<td>The Solar cycle may be an oscillation in wavenumber of flux production rather than in total quantity of magnetic flux emerging.</td>
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<td>7. The total average rate of magnetic flux emergence on the Sun may not vary with the cycle.</td>
<td>Suggested by results to date</td>
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References


