SOLAR X-RAY BRIGHT POINTS

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ABSTRACT

Preliminary analysis of photographs from the S-054 X-ray telescope aboard Skylab has shown that bright points have a statistical distribution of lifetimes with a mean of eight hours. The lifetime of a bright point is approximately proportional to its maximum area, which is typically $2 \times 10^8 \text{ km}^2$. A small bright core generally develops during the middle part of the bright-point lifetime with area $\sim 10^7 \text{ km}^2$. A small fraction of bright points are seen to increase their surface brightness by several orders of magnitude on a time scale of minutes. These "flares" occur at all latitudes from the equator to the poles. To first order, bright points are uniformly distributed across the solar surface. An estimated 1500 X-ray bright points emerge per day, possibly bringing more new magnetic flux to the surface than is contributed by the major active regions.

Subject headings: X-rays, solar

I. INTRODUCTION

Pointlike X-ray emitting features were first observed in rocket X-ray telescope images in 1969 (Vaiana et al. 1970). Typically they appear to be spots of 30" diameter with a 3"–10" bright core associated with small bipolar magnetic features and are found at essentially all solar latitudes (Krieger, Vaiana, and Van Speybroeck 1971; Vaiana et al. 1973a, b). The purpose of this Letter is to provide new quantitative and statistical data about bright points obtained by a preliminary examination of photographs from the X-ray spectrographic telescope aboard Skylab.

We have performed a statistical evaluation of bright-point lifetime, size, latitude, and temporal distributions. As a result of this investigation, we feel that a bright point represents a separate type of X-ray object, in many ways similar to an active region. We will show that bright points have a restricted range of sizes and lifetimes, separating them from other types of X-ray activity. In addition, we will give examples of bright-point behavior for which the word "flare" seems most appropriate. On the other hand, the uniform distribution of bright points across the solar surface indicates a production mechanism different from that of active regions.

II. STATISTICAL PROPERTIES

A preliminary lifetime distribution for bright points is shown in figure 1. An unbiased distribution was obtained by selecting a time-ordered set of photographs and tracing the history of only those points which appeared beginning with the second photo of the series. A method based on tracing all points visible on a single photograph backward to birth and forward to disappearance produces a distribution biased toward longer lifetimes. The mean lifetime for the points examined is 8 hours, and the distribution appears to be statistical. In the absence of a model for generation of bright points, we have chosen a single-class source function as a basis for comparison. We have therefore drawn the solid curve, which represents a Poisson distribution of lifetimes with a mean of 8 hours and a time resolution of 5 hours, normalized to the number of points examined. The data are seen to fit the curve reasonably well, with a $\chi^2$ per degree of freedom of 0.8, from which we

Fig. 1.—Histogram showing number versus lifetime for pointlike X-ray emitting features.

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conclude that bright points have a statistical distribution of lifetimes with a mean of approximately 8 hours and a variance consistent with the presently available time resolution. The similarity of the lifetime to that of supergranulation cells (Simon and Leighton 1964; Janssens 1970; Rogers 1970) and the statistical nature of both distributions is noteworthy.

The evolution of a typical X-ray bright point is shown in figure 2 (plate L2). The spot is first seen (fig. 2b) as a diffuse cloud 30" (21,000 km) in diameter and does not yet have a bright core. The core reaches a maximum diameter of 10" in figure 2c when the total diameter of the spot is 35". In figure 2e both the core and outer diffuse cloud have dimmed, and eventually the spot is no longer detectable above the grain noise. It is significant that in the nearly 100 points examined, the growth of a large diffuse cloud always precedes the growth of a bright core and that the core fades before complete disappearance of the point. We also note that the bright core is not always a true point, i.e., consistent with the resolution of the telescope, but very often is elongated to a roughly elliptical shape.

The maximum area attained by a bright point during its life is roughly correlated with its lifetime. This is demonstrated in figure 3, for which we have used the same points as in figure 1. The data show a large scatter which is due, in part, to the poor lifetime resolution, but may also be due to a real variation in bright point growth histories. It is clear, however, that small points have short lifetimes and that long-lived points are generally larger than average. At the mean lifetime value of 8 hours, the average maximum diameter a point attains is 20" ± 5", corresponding to an area of \((2.0 \pm 1.0) \times 10^8\) km². A linear proportionality may be written between the lifetime of a point and its maximum area,

\[
A_{\text{max}} = 2.5 \times 10^7 r,
\]

where \(r\) is measured in hours and \(A\) in km².

It is evident from the photographs that the solar activity represented by bright points is not concentrated in belts of activity as are the usual active regions. The distribution of points in coronal holes, or of the brightest points everywhere on the Sun appears to be uniform across the solar surface. This appearance is, in fact, a good first approximation to the distribution, as shown in figure 4. The figure shows the bright-point distribution as a function of latitude for points visible in short-exposure (4-s) pictures, in which overlying X-ray structures cannot be discerned. This is therefore a full-Sun plot of only the brightest points. The solid curve is a cosine and represents uniform surface area on the Sun. The curve generally fits the data, with the exception of the active-region latitudes in which bright points cannot be seen because of the brightness of the active regions. It is also possible that there are actually fewer bright points in the active-region latitudes, suggesting a possible complementary relation between the two types of activity.

The total number of bright points on the Sun at any one time is at least 200, since we see 100 points in a typical photo and we assume that the far side of the
Fig. 2.—The evolution of a typical X-ray bright point. (a) 1973:162:13:41.—Point is not visible. (b) 162:18:10.—Point has appeared as a diffuse cloud ~21,000 km in diameter with no bright core. (c) 162:21:16.—Cloud has grown slightly, and a bright core has developed. (d) 162:23:08.—The core reaches its maximum size. (e) 163:03:29.—The point has become very dim and the core is greatly reduced in size. (f) 163:05:04.—The point can no longer be distinguished.

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Sun does not change significantly when we are not observing it. However, we have found no reason to believe that bright points in coronal holes are different from those anywhere else on the Sun. In regions where X-ray emitting structures overlie bright points, the number density appears to be a factor of 3 less than in coronal holes. The uniformity of the distribution of the brightest bright points implies that this is an observational effect attributable to the difficulty of distinguishing faint pointlike features against the background provided by the overlying large-scale coronal structures. Accordingly, we believe the greater density of bright points observed in coronal holes to be representative, implying a total number of approximately 500 points on the Sun, roughly one point per 10° X 10° heliocentric.

We have selected several long-lived bright points near the equator and have measured their synodic rotation rates. The measurements are necessarily crude at this stage in the analysis and will be substantially improved when good pointing information becomes available. The measured value of 13°6 ± 0°3 per day is consistent with the low-latitude sunspot and photospheric magnetic field rotation rates (Newton and Nunn 1951; Howard and Harvey 1970; Wilcox and Howard 1970). The location of bright points at a very low height above the photosphere is evident from photos in which points are visible near the limb.

III. PHYSICAL PROPERTIES

By comparing the relative brightness of an X-ray emitting feature through two or more of the filters available in our telescope, we are able to estimate the effective electron temperature and density (Vaiana et al. 1973b). The ratio of the intensity passed by two filters, the “spectral hardness index,” is a measure of the effective temperature of a region along the line of sight. An estimate of the spectral hardness index was obtained by noting that the same points are generally visible in a 256-s exposure through a 13-μ Be filter (3–17 Å) as are visible in a 4-s exposure through the 1-μ polypropylene (3–32; 43–54 Å). Allowing for a 50 percent error in this estimate, the average temperature of the brightest points falls in the range (1.3–1.7) X 10^6 K. This is a typical temperature range for large-scale coronal structures and implies that bright points have densities which are at least a factor of 2 to 4 higher than the coronal average.

Examination of all of the synoptic sequences from the first Skylab mission has revealed 14 examples of bright points which are substantially increased in brightness compared to the thousands of other points which are seen. Such a point is shown in figure 5 (plate L3), which indicates the very rapid rise time of the brightening. The figure shows the two longest exposures (64 and 256 s) from two sequences taken 1½ hours apart. In the first sequence, one of the bright points has increased in brightness from the 64-s to the 256-s exposure by at least a factor of 10, estimated from photographic density. The time between the end of the 64-s exposure and the beginning of the 256-s exposure is less than 1 s, so that the rise is most likely to have occurred during the 256-s exposure. The estimate of a factor of 10 increase in surface brightness is modified upward if the brightening took place late in the exposure. The later pair of photographs shows that the point which flared has decreased in brightness to a very low level of visibility.

Of the 12 examples we have seen, 10 of them are not visible in the next sequence taken, whereas the statistical treatment described earlier predicts that more than
The number of flares observed together with the "shutter open" time of observation imply that 5-10 percent of all X-ray bright points exhibit this flaring behavior. The interesting question of the typical rise and decay times of these flares will have to await the better-time-resolution data expected from the second and third Skylab missions.

The bipolar magnetic nature of bright points is seen in figures 6a and 6b (plate L4). The longitudinal field strength of bright points is near the lower limit of sensitivity of the magnetogram, so that many of the points visible in X-rays are not seen in the magnetogram. Pointlike brightenings corresponding to the X-ray features are seen in H Alpha and Ca K filtergrams.

The evolution of a typical X-ray bright point shown in figure 2, implies a growth and dispersal process for bright points, with a rapid growth and slower decay. We point out that the term "size" in this study refers to measurable photographic density, which is a function of both plasma temperature and density. Therefore, a decrease in size during the latter part of a bright-point lifetime may mean that the temperature is decreasing or the density is decreasing, or both. From the points used in figures 1 and 3 we can arrive at an estimate of the growth rate of X-ray bright points, which averages 20 km s^{-1} per hour, or 1 km s^{-1}, for some points. The average growth velocity of 1 km s^{-1} is comparable to the measured horizontal velocity of 0.5 km s^{-1} in supergranulation cells (Leighton et al. 1962).

IV. DISCUSSION

A graph which indicates that we are now seeing essentially all of the X-ray bright points consistent with the present level of resolution is shown in figure 7.

This is a plot of the number of points visible versus exposure time, in regions of the Sun where no detectable X-ray emitting structure obscures the bright points (i.e., in coronal holes). We have taken 4-, 16-, 64-, and 256-s exposure photographs from several sequences during the mission and counted the number of points visible, going from short to long exposure to prevent bias. It is clear from the figure that initially the number of points increases in proportion to the exposure time, but does not increase substantially in going from the 64-s to the 256-s exposure. This indicates that we are seeing an entire class of X-ray emitting feature, rather than the top of a larger distribution.

A summary of properties of X-ray bright points is shown in table 1, which also shows properties of two other classes of solar activity: active regions and "ephemeral active regions" (Harvey and Martin 1974). We have made a distinction between bright points and ephemeral active regions which is based primarily on the lifetime and size distributions of corresponding X-ray features shown in figures 1 and 3. From figure 3 it is apparent that most of the features that emerged during the time of our study are clustered at times and sizes appropriate to the X-ray bright points. However, there are some X-ray features which are well separated from the general distribution. These may be the beginning of a separate distribution for ephemeral active regions, centered at ~2 days and ~7 X 10^{8} km². Using the numbers presented in this paper and in that of Harvey and Martin, we find that per unit time there are 15 times as many X-ray bright points emerging on the Sun as there are ephemeral active regions. This figure agrees well with our assumption of two separate classes of activity, and with the number of each type found. This separation may also exist in the magnetogram data of Harvey and Martin, who found that 96 percent of the points examined were seen on one day only with the remainder lasting two days or more.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bright Points</th>
<th>Ephemeral Active Regions</th>
<th>Active Regions</th>
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<tbody>
<tr>
<td>Lifetime (days)</td>
<td>½</td>
<td>2 (1)</td>
<td>50 (4)</td>
</tr>
<tr>
<td>Size (km²)</td>
<td>10⁶</td>
<td>5 X 10⁴ (1)</td>
<td>10¹⁵ (4)</td>
</tr>
<tr>
<td>Size/lifetime (km² hr⁻¹)</td>
<td>10⁷</td>
<td>10⁷</td>
<td>10⁷</td>
</tr>
<tr>
<td>Growth rate (km s⁻¹)</td>
<td>1</td>
<td>0.2 (2)</td>
<td></td>
</tr>
<tr>
<td>Distribution</td>
<td>Full Sun</td>
<td>Active-region belts</td>
<td></td>
</tr>
<tr>
<td>Mag. flux (Mx)</td>
<td>&gt;10¹⁰</td>
<td>10¹⁰ (1)</td>
<td>10¹⁵ (3)</td>
</tr>
<tr>
<td>No. emerging per day</td>
<td>1500</td>
<td>100 (1)</td>
<td>¼</td>
</tr>
<tr>
<td>New flux per day</td>
<td>&gt;1.5 X 10²²</td>
<td>10²²</td>
<td>5 X 10²¹</td>
</tr>
</tbody>
</table>

References.—(1) Harvey and Martin 1974; (2) Bumba and Howard 1965a; (3) Sheeley 1966; (4) Bumba and Howard 1965b.
Fig. 6.—Appearance of bright points: X-ray versus magnetogram. (a) Portion of X-ray photograph taken at 165:1319 UT, 1973 June 14, with several bright points indicated. (b) Corresponding magnetogram showing bipolar magnetic features corresponding to X-ray bright points (courtesy of Kitt Peak National Observatory).

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From preliminary measurements of temperature and density, we estimate from the equipartition argument that the average magnetic field of these points is $\sim 10$ gauss. This agrees with estimates of the longitudinal field in bright points obtained by comparison with Kitt Peak magnetograms (J. Harvey, private communication; also Harvey and Martin 1974). With an average area of $10^{18}$ cm$^2$ and 1500 points emerging per day, the magnetic flux brought to the surface would be $\sim 10^{22}$ Mx per day. This estimate leads us to the surprising conclusion that X-ray bright points contribute more emerging flux than do active regions at this time in the solar cycle. If this flux is dispersed over the solar surface, e.g., by a process similar to that for major active regions (Leighton 1964), then bright points not only are major contributors to the solar magnetic field, but may be the dominant contributors. Thus, an explanation of X-ray bright points may be of fundamental importance to our understanding of solar dynamo theories and of the solar cycle.

The flaring behavior, the similarity in structure of the bright points to active regions, and the association with bipolar magnetic field regions suggest that the X-ray bright points may be miniature active regions. On the other hand, their uniform distribution across the solar surface indicates that they are not produced in exactly the same way as active regions. The association with the supergranulation cells is probably the key to their origin. As a working hypothesis we are suggesting that while active regions are produced as an amplification of subsurface magnetic field by the differential rotation of the Sun, bright points are due to the amplification of subsurface field by turbulence in the convection zone.

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REFERENCES

———. 1965b, ibid., p. 1502.