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NONTHERMAL PROCESSES IN FLARING X-RAY–BRIGHT POINTS

M. R. KUNDU,[1,2] K. T. STRONG,[3] M. PICK,[2] S. M. WHITE,[1] H. S. HUDSON,[4] K. L. HARVEY,[5] AND S. R. KANE[6]
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ABSTRACT

X-ray–bright points (XBPs) are known to show variability on a number of timescales, including impulsive X-ray brightenings. The relationship between these XBP "flares" and normal solar flares is poorly known. A fundamental question is whether nonthermal acceleration of particles takes place in XBP flares. We address this issue by searching for nonthermal radio emission at metric wavelengths from flaring XBPs identified in *Yohkoh*/SXT data. Unequivocal evidence for type III–like radio bursts, usually attributed to beams of nonthermal electrons on open field lines, is found. This suggests that XBP flares are similar to normal flares and can indeed accelerate nonthermal populations of energetic particles.

Subject headings: Sun: activity — Sun: radio radiation — Sun: X-rays, γ-rays

1. INTRODUCTION

Solar X-ray–bright points (XBPs) are compact emitting regions associated with bipolar magnetic fields. Their properties as deduced from *Skylab* observations have been discussed by Golub et al. (1974, 1977). At any one time there appear to be dozens of XBPs present on the Sun. Their lifetimes range from a few hours to several days, although only a small number appear to last longer than 2 days. They may be associated with a large fraction of the magnetic flux that emerges to the solar surface. They are known to flare.

Between 1975 and 1991 there were no satellites capable of observing coronal bright points in soft X-rays, and their study has been possible only during brief rocket flights. The launch in 1991 of the Japanese satellite *Yohkoh* (Ogawara et al. 1991), carrying a soft X-ray telescope (SXT) of unprecedented resolution, now makes available excellent images of X-ray–bright points with high time resolution on a regular basis (Nitta et al. 1992; Strong et al. 1992), and joint studies of XBPs with observations at other wavelengths are timely.

From *Skylab* data it was known that about 10% of XBPs exhibit a type of sudden, substantial increase in surface brightness which in larger regions would be termed flaring. These flares appear to be impulsive in nature, lasting 2–3 minutes. One of the most important aspects of bright point flares, which has not been studied, is whether or not XBP flares produce nonthermal populations of energetic particles, as do ordinary flares (even in the case of very slow, long-duration flares there is evidence for nonthermal activity: Hudson et al. 1993). The two methods best suited for detecting the presence of nonthermal populations are hard X-ray observations and metric-wavelength radio observations. However, the current sensitivity of hard X-ray detectors limits searches for hard X-rays from flaring XBPs. On the other hand, the production of metric radio emission by nonthermal electron beams is very efficient due to the coherent nature of the emission mechanism, and thus such nonthermal electrons might be more easily detectable at radio wavelengths. In this *Letter* we discuss the results of such a search.

Kundu, Gergely, & Golub (1980) used the Clark Lake Radio Observatory interferometer data to look for short-lived type III bursts at the times of flaring bright points identified in the *Skylab* images. Temporal coincidence was used as the criterion for association of radio burst with X-ray–bright points; the spatial resolution of the radio data was low, and spatial location of the radio burst could only be used as a secondary criterion. They found only a 10% association between flaring XBPs and type III bursts. The sensitivity of both radio and soft X-ray detectors has improved since those observations. In this *Letter*, we present the results of a study of radio emission at meter wavelengths from flaring X-ray–bright points. We take advantage of the improved sensitivity in soft X-rays available with the *Yohkoh* SXT telescope (Tsuneta et al. 1991), and the excellent accuracy of source location at metric wavelengths available with the Nançay radioheliograph which can measure burst positions with an accuracy of better than 1′.

2. OBSERVATIONS

A search was made for meter-wavelength radio emission from more than a dozen coronal bright points observed in soft X-rays by the *Yohkoh*/SXT experiment. The radio observations were carried out with the Nançay (France) radioheliograph (NRH) at five frequencies in the range 150–450 MHz (Radioheliograph Group 1989), and we chose to concentrate on the 1992 June period since the spatial resolution and hour-angle coverage of NRH are optimal in June. Approximately 20 XBP brightenings were identified in the SXT data for 1992 June 20 and 21, and we then searched the corresponding time periods in the Nançay data. When time profiles showed that there was a radio burst at the right time, we then made images of the burst to check for positional coincidence. The high spatial resolution of the radio data guarantees that we are not subject to the possibility of spurious associations being found, which is always possible for data sets which do not have spatial resolution in both wavelength ranges as good as that used for this study (SXT has a full resolution of $\sim 5''$, although here we can only use quarter-resolution images with a resolution of

[1] Department of Astronomy, University of Maryland, College Park, MD 20742.
[2] Observatoire de Meudon, Place Jules Janssen, F-92195 Meudon, Cedex, France.
[3] Lockheed Palo Alto Research Laboratory, Department 91-30, Building 252, 3251 Hanover Street, Palo Alto, CA 94304.
[4] University of Hawaii, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822.
[5] Solar Physics Research Corporation, 4720 Calle Desecada, Tucson, AZ 85718,
[6] University of California-Berkeley, Space Sciences Laboratory, Berkeley, CA 94720.

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20″; NRH has a resolution of 1′). In all, six of the 20 XBP X-ray brightenings showed evidence for an associated radio burst: in this *Letter*, we discuss one example representative of this association in detail. More detailed statistical results will be deferred to a subsequent study.

The metric radio emissions appear to be type III bursts, which are produced by nonthermal beams of electrons: this represents strong evidence that the XBP-flare mechanism is capable of accelerating particles to nonthermal energies, as well as producing the heated material detected in soft X-rays. The radio emission comes from a significant height in the corona (0.3 $R_\odot$ at 164 MHz), i.e., well above the height of the soft X-ray (SXR) emission, and so projection effects must be taken into account when making associations. The example we discuss here is an isolated bright point, well away from any active region which might lead to ambiguity in the source of the radio emission.

3. THE XBP X-RAY FLARE

Figure 1 (Plate L4) shows SXT quarter-resolution images prior to (*upper panel*, 08:32 UT, 1992 June 21) and during (*lower panel*, 08:41 UT) the XBP flare we discuss. The XBP is away from the primary target on this day, and consequently full-resolution images are not available. The intensity display in Figure 1 has been chosen to show very faint emission within the coronal hole, and specifically the weak SXR emission from the XBP in the upper panel; the low spatial resolution and intensity display mean that other features are poorly represented in these images.

The quiescent soft X-ray emission from this XBP is actually very weak, and it is barely visible in the top image. It lies at the eastern edge (at −360″, +120″ in the lower panel of Fig. 1, where the origin of the axes is at apparent disk center) of a prominent low-latitude "guitar"-shaped coronal hole which dominates the region around disk center on this day. There is also a region of closed field lines in the middle of the coronal hole. The XBP discussed here existed from at least 22 UT on June 20, and it exhibited fluctuations in brightness from time to time, sometimes approaching levels which would be called XBP flaring. A time profile of the SXR flux from the XBP over one *Yohkoh* orbit is shown in Figure 2. Two brightenings are seen: the first, at 08:10 UT, is very weak. The second, at 08:37, is the subject of this *Letter*. The XBP is visible only in the quarter-resolution (10″ pixels) full-disk frames taken every 256 s, so the time resolution available is poor. The X-ray flare appears to last about 10 minutes: the time of the peak is poorly determined but appears to be close to 08:37 UT. These soft X-ray flares from this XBP typically have temperatures of order 5 MK and peak emission measures of order 10^{46-47} cm^{-5}.

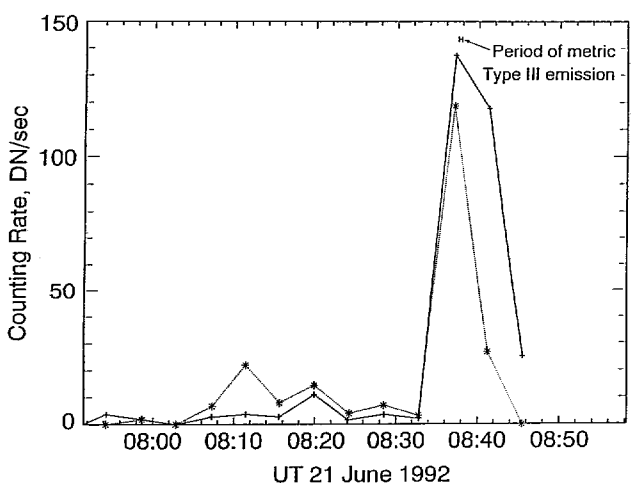

FIG. 2.—The time profile of X-ray emission from the XBP measured by SXT, seen through the thin aluminum filter (peak response at about 1 keV). The observations were made at 256 s intervals with exposure times alternating at 17 and 668 ms, and a pixel size of 9.″84. The two light curves correspond to adjacent pixels.

4. RADIO EMISSION FROM THE FLARING XBP

Coincident with the XBP X-ray flare, the Nançay radioheliograph observed type III–like radio emission at metric wavelengths. Figure 3 shows the time profiles of radio emission at

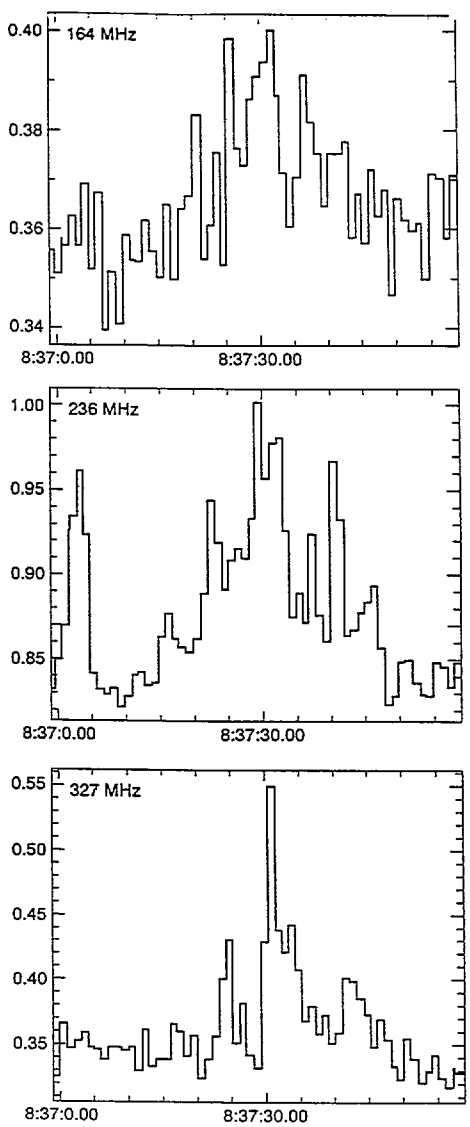

FIG. 3.—The time profiles of radio emission measured by the Nançay radioheliograph on 1992 June 21 at 08:37 UT, at 1 s time resolution. Three frequencies are shown: 164 MHz (*upper panel*), 236 MHz (*middle panel*), and 327 MHz (*lower panel*). The amplitude scales are arbitrary; the peak fluxes were ~20 sfu at 164 and 236 MHz.

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164, 236, and 327 MHz at 08:37–08:38 UT. The radio emission peaks at 08:37:30 at all three frequencies; at 236 MHz there is an additional peak at the earlier time of 08:37:00–08:37:05 UT. The radio emission lasts only about 10 s at 164 MHz; at 236 MHz the radio emission has a longer duration (~20 s centered on 08:37:30) and an additional type III of 5 s duration with a peak at 08:37:02. The brief duration of individual peaks within the profile, their coincidence in time at all frequencies, and the fact that they are seen across a wide frequency range strongly suggest that these bursts are type III–like radio emission due to beams of nonthermal electrons propagating out through the corona along open magnetic field lines (e.g., Kundu 1965).

On the bottom panel of Figure 1 (during the XBP flare) the positions of the type III bursts observed at Nançay at 164, 236, and 327 MHz at 08:37 are marked. The size of the beam at 327 MHz, which is approximately the positional uncertainty for the radio bursts, is also shown (~1.'1 FWHM; 1.'6 at 237 MHz and 2.'2 at 164 MHz). There appears to be a small dispersion of position with frequency; the highest frequency (327 MHz) is closest to disk center and the XBP, and the lower frequencies are farther away from the center. The dispersion in position with frequency is consistent with the plasma emission process of type III bursts. The radio source centroid locations are consistent with projection effects for a source at E22, for typical heights of the plasma level of 0.1 $R_\odot$ at 327 MHz and 0.3 $R_\odot$ at 164 MHz, which should produce an apparent separation of ~70″ on the sky, as observed.

The type III bursts observed in conjunction with the XBP flare were rather weak, ~20 sfu at both 164 and 236 MHz. They were not observed on the Nançay dynamic spectrum records in the frequency range 30–450 MHz with 1 s time constant; they were also observed but barely detected at 408 MHz. They were not polarized at 164 MHz, the polarization being <5%; at the other frequencies the polarization was not measurable. This weak flux is roughly consistent with the weak SXR emission from these events, although there is a great range in the ratio of type III flux to the associated SXR flux of a flare, and so this is not a strong result. The angular sizes of the radio bursts were ~2′ E-W at 164 MHz; the size was very small (unresolved) in the N-S dimension. The peak times of type III emission at the three frequencies coincided well within 10 s and at the two lower frequencies within 1 s. The positions of type III's coincided well within the error bars, which gives credence to the belief that they originated from the same cause, namely the XBP flare. The small offset between the location of the 327 MHz source and the position one expects purely due to projection effects for a source directly above the XBP location can be explained by refraction in the solar corona (e.g., Duncan 1979), which shifts source locations.

From the positional data at the three frequencies one can infer that the type III–producing electron beam propagated from the XBP toward the northeast (in projection). All this activity pertains to the XBP flare on the eastern edge of the low-latitude extended coronal hole; there is no other feature in the vicinity of the radio burst locations which could plausibly produce a type III burst. The important point to note about the 08:37 UT type III bursts is that they are coincident in time and space (at all three frequencies) with the XBP flare. From the measured source size (~2′) and flux (21 sfu), we estimate that the brightness temperature of the type III emission reaches 7×10^8 K at 164 MHz (somewhat lower at the higher frequencies): as is well established, such a brightness temperature requires the presence of a nonthermal population of electrons in the corona.

Another important implication of the association is that electrons accelerated to nonthermal energies in XBP flares have access to open field lines. In addition, the XBP showed a "jet"-like feature extending to the northeast in earlier SXT images (e.g., at 22:29 UT on June 20), similar to those discussed by Shibata et al. (1992), which also suggests the presence of open field lines connected to the XBP. As in normal flares, this raises the question of whether open field lines are intrinsic to the flare process, or whether accelerated electrons can obtain access to open field lines by drifting across closed field lines. It is also known that flares which have associated type III emission in the rise phase tend to be impulsive, rather than long-duration, events (Cane & Reames 1988). Impulsive flares are also thought to be associated with compact loops, and such loops are expected in the compact bipole magnetic geometries which underlie X-ray–bright points.

5. CONCLUSIONS

We have demonstrated that the XBP flares can give rise to nonthermal emission in the form of type III–like radio emission from electron beams, in addition to thermal soft X-ray emission from the heated plasma. The radio bursts associated with XBP flares are very weak and not spectacular in appearance, and are observed to be of restricted bandwidth. As in normal solar flares, the electron beams appear to be produced preferentially near the onset of impulsive emission. The X-ray flare emission lasts longer than the radio burst, as in normal flares. The simple detection of type IIIs from flaring XBPs is interesting because it strengthens the association between XBP flares and normal flares, implying that the same physical process is involved in each. The simple nature of the bipolar regions underlying XBPs offers the possibility that XBP flares may be simpler to study than flares occurring in the more complex geometries of active regions, and their continued study may prove fruitful for understanding the solar flare mechanism itself. Clearly further work must be done to fully characterize the nature of XBP flares and their relationship to solar flares.

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