X-RAY AND RADIO EMISSION IN SOLAR ^{3}HE-RICH EVENTS

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Abstract

We have examined radio and X-ray properties of solar flares associated with a new sample of individually-identified ^{3}He-rich solar-particle events. Given the association between kilometric type III bursts and ^{3}He-rich events, the timing of the radio events is used to identify the related X-ray increases. Examination of these events shows correlations among the radio, X-ray and particle parameters. The sense of these correlations is that larger ^{3}He/^{4}He ratios occur in smaller flares suggesting that waves required for ^{3}He enhancment are damped in large, energetic flares.

1. Introduction. For many years the properties of the small and elusive ^{3}He-rich solar particle events could only be observed by integrating particle intensities for periods of many hours (see e.g. Ramaty, 1980; Kocharov and Kocharov, 1984). Therefore, these early "events" frequently combined the output of several solar flares with differing intensites and composition.

Using more sensitive instrumentation on ISEE-3, Reames, von Rosenvinge and Lin (1985, hereafter RvL) were able to resolve ^{3}He-rich periods into sequences of individual events, each accompanied by an electron increase. The precise timing of the electron increases could be used to determine the time of the parent flare with an accuracy of a few minutes. The kilometric type III radio emission produced by these same electrons was used by Reames and Stone (1986) to extend the list of well-identified ^{3}He-rich solar flares and to study the relationship of flares within a group.

In the present paper we examine, for the first time, the source properties of this new list of individual ^{3}He-rich solar flares. The same type III radio emission used to identify the events provides the timing required to select the associated hard and soft X-ray increases.

2. Observations. Particle and radio observations were made aboard the ISEE-3 spacecraft and have been described extensively in RvL and in Reames and Stone (1986). Both soft and hard X-rays were also measured aboard ISEE-3 by the Berkeley X-ray Spectrometer that covered the energy region above about 5 keV. In addition, hard X-ray measurements were made with the Hard X-ray Burst Experiment (HXRBS) on SMM. A recent summary of measurements from this instrument are given by Dennis (1986).

Of the 31 ^{3}He-rich events, 5 could not be studied completely because of data gaps or other ambiguities. For the remaining 26 events, plots like that shown in Figure 1 were prepared to study the event timing. The example in Figure 1 shows the time histories of the hard X-rays in the center panel with the radio and soft X-ray data in the upper and lower panels, respectively. Extrapolation of the radio data back (2 MHz corresponds to about 6 solar radii) to the hard X-ray peak is clear in this figure. In more complex events the timing of the dominant radio peak was used to select the correct X-ray increase or to provide timing in cases were hard X-ray data were absent.

Of the 26 events, all showed radio increases, 20 showed soft X-ray increases and 15 showed hard X-ray increases. The X-ray profiles, like the ones in Figure 1, were extremely impulsive; soft X-ray durations (at 10% of maximum) were in the range 5-10 mins.

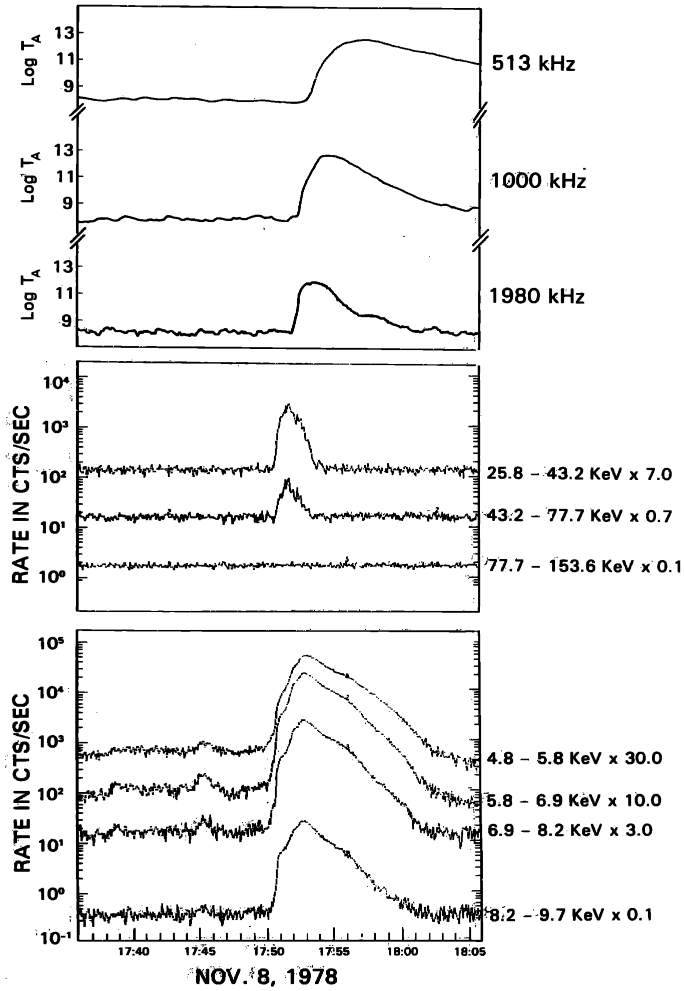

Figure 1. Radio X-ray and radio timing in the Nov 8, 1978 ^{3}He-rich event

If one assumes that the hard X-ray time profile in Figure 1 describes the profile of particle acceleration, then the delay to the peak of the 2 MHz radio data would represent the time required for electrons to propagate out to ~6 solar radii, and the delay to the soft X-ray peak represents the time required for the accelerated particles to heat the low corona. Based on this simplistic picture, we chose the time of hard X-ray maximum to determine soft X-ray properties that might be most representative of the ambient conditions seen by the particles being accelerated.

An extremely wide range of X-ray sizes are found for the events, ranging from very large events to events with little or no detectible increase in even the softest X-rays. X-ray temperatures range from 8 to 19 x10^6 °K.

3. Results and Discussion. In Figure 2 we show cross plots of the particle, X-ray, and radio parameters for all flares in which the required measurements are available. Figure 2(a) shows $^3He/^4He$ versus the 2 MHz

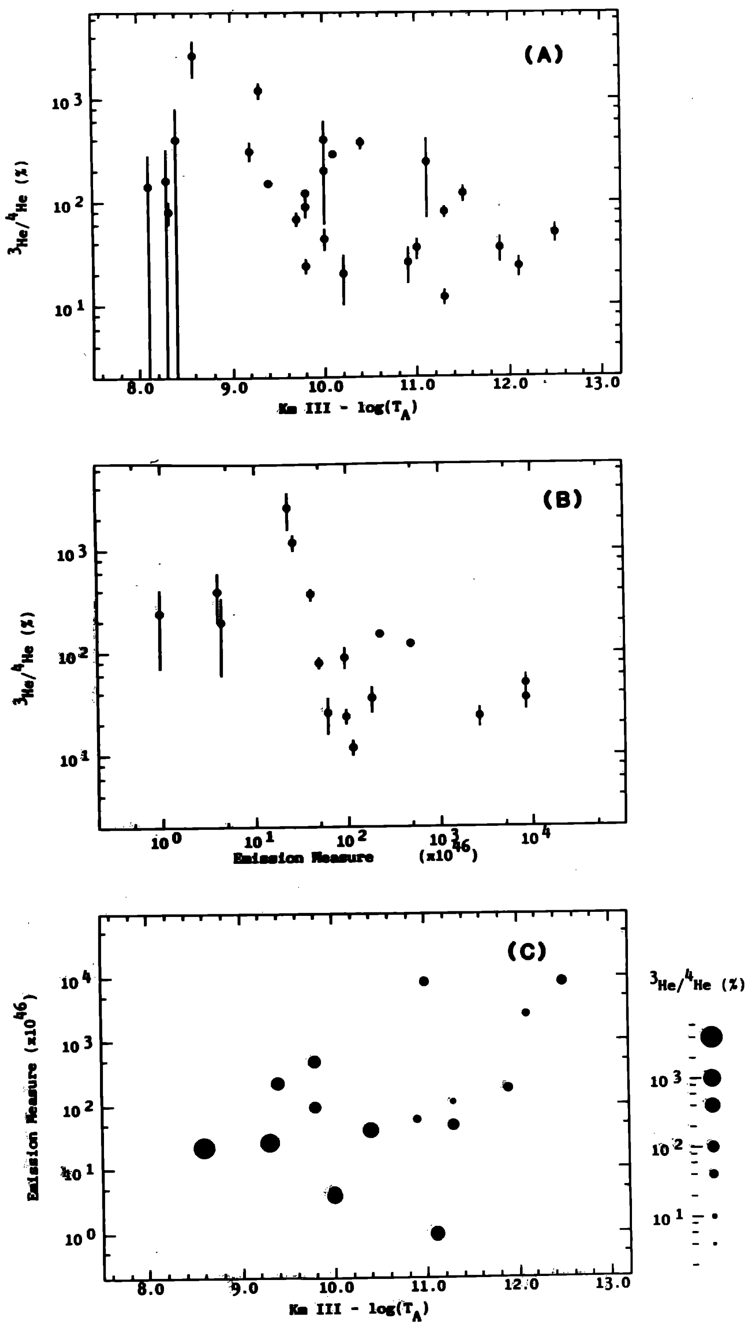

Figure 2. Cross plots of particle, radio and X-ray parameters

intensity (log of antenna temperature) for 27 events, Figure 2(b) shows the $^3He/^4He$ ratio as a function of the soft X-ray emission measure for 17 events, and Figure 2(c) shows a cross plot of the X-ray and radio parameters with the symbol size proportional to $\log(^3He/^4He)$.

The linear correlation coefficients for the data as plotted in Figure 2 are (a) -0.520, (b) -0.533, and (c) 0.449. The corresponding probability that the variables are correlated in each case is (a) 99%, (b) 98%, and (c) 93%. However, we would not necessarily expect the underlying correlation to be either linear or simple. The figure does seem to show a tendency for higher values of $^3He/^4He$ to occur in the smaller events.

Table 1 shows correlation coefficients for several available parameters taken pairwise. The number of events contributing to each coefficient is shown in the table as is the correlation probability when it is greater than 90%. ^3He intensity was omitted from the table since it is strongly affected by the degree of magnetic connection between the event and Earth and is therefore poorly correlated.

Table 1. Correlation with $\log(^3He/^4He)$

	Coef.	Events	Prob.
Soft X-ray Temp.	0.096	17	-
log (Soft X-ray E. M.)	-0.533	17	97%
log (Soft X-ray Peak)	-0.568	18	98%
log (SMM Hard X-ray Peak)	-0.611	11	95%
Km III log(TA)	-0.520	27	99%

The data in Table 1 show a persistent negative correlation of the $^3He/^4He$ ratio with nearly all measures of the parent event size including the hard and soft X-ray peak fluxes in addition to the parameters mentioned above. The mechanism leading to ^3He enhancment appears to operate preferentially in small events.

The existence of a correlation among event parameters seems to argue in favor of a single acceleration event rather than the decoupled pre-heating and acceleration phases suggested by Fisk (1978). Evidently the waves required for ^3He enhancement are damped in larger, more energetic events.

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