AN EXTENDED "SUPERHOT" SOLAR FLARE X-RAY SOURCE

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ABSTRACT

The *Hinotori* hard X-ray imaging instrument observed a "superhot" ($T > 3 \times 10^7$ K) source during a solar flare occurring beyond the W limb of the Sun on March 28, 1981. Because of the circumstance of occultation by the limb, we determine a height of $(3.1 \pm 0.8) \times 10^4$ km. The source extended 4×10^4 km along the limb and was smaller than the instrumental resolution perpendicular to the limb. After the disappearance of the X-ray source, weak Hα emission occurred at the position if the X-ray sources, suggesting the formation of a loop prominence system. The cooling time estimated for thermal conduction appears to be considerably shorter than the observed time scale of the event, even including a factor of ten to represent suppression of conduction due to possible field-line convergence. We conclude that either stronger forms of suppression, or else extended energy deposition, will be required to explain events of this type.

1. Introduction. The hard X-ray spectrum of a solar flare may give us the key information regarding the basic release of energy. Kane[1] showed that the hard X-rays above about 20 keV[2-3] (the "impulsive" component) have a strikingly different time history from the softer X-rays[4] (the "gradual" component). Recent observations[5] have shown that the spectral evolution exhibits more complexity than had previously been supposed, and that an intermediate spectral component also exists. This new feature, often referred to as the "superhot" component, appears to be thermal but has temperatures considerably above the mean temperature of the bulk of the flare emission measure, typically in the vicinity of 2×10^7 K.

The Solar Maximum Mission obtained images of a superhot source in the May 21, 1980 flare; its temperature was initially estimated[6] at 7×10^7 K, but later revised downwards to 4×10^7K (for a full discussion, see Duijveman[7]). At the present time there appears to have been no systematic study of the HXIS superhot sources, although Duijveman carried out a complete analysis of the 1980 May 21 event. In the meanwhile the *Hinotori* observed many such events including images of five of them[8]. Of the five, three were compact at the *Hinotori* resolution, but two were extended[8].

This paper describes a single superhot source imaged by *Hinotori* in special circumstances: occultation by the solar limb. In this configuration we obtain a clear altitude separation and can make definite statements about the source geometry. The characterization of this source as "superhot" is vague, mainly because of the lack of good spectral data, but the analysis here does not depend upon the classification.

2. Flares in Late April, 1981. In late April, 1981, the *Hinotori* spacecraft observed a sequence of energetic solar flares, including a major one on April 27 (onset about 08:00 UT) that produced γ-ray line emission[9]. The flare to be discussed in this paper occurred on April 28, with an onset in the *Hinotori* data at about 21:10 U.T. Although the April 28 event had a smaller soft X-ray flux than the April 27 event, both had the "long duration event" characteristics described by Kahler[10]. Each produced type II, III, and IV meter-wave radio bursts.

At the time of the April 28 event, the active region responsible for this activity (Hale Region 17590, central meridian passage April 21.1) was already well beyond the limb. From a plot of flare longitudes, we extrapolate to a position 18.8 ± 2.3 degrees beyond the limb. This position corresponds to an occultation height of 31000(±8000) km. An examination of Hα data from Big Bear Solar Observatory (S. Martin, private communication) suggests that the faint flare-like brightenings represented late-brightening components of a classical loop prominence system. They initially appeared in the Big Bear films at 21:57 (at disk intensity) and ended at 23:54, with the N component preceding the S component by about ten minutes.

Several other characteristics of these two events are worth mentioning. From the time profiles of hard X-ray emission, little evidence exists for impulsive hard X-ray emission. We believe that the impulsive phase of the April 28 flare occurred while *Hinotori* was in sunlight because of the timing of the meter-wave radio events reported in Solar-Geophysical Data. If so, the April 28 event had a striking deficiency of impulsive hard X-ray emission, consistent with earlier OSO-7[11] and ISEE-3[12] observations of limb-occultation events.

3. The *Hinotori* Hard X-ray Images. A representative hard X-ray image from the SXT instrument on board *Hinotori* appears in Figure 1; many images from different times during the evolution of the event show approximately the same shape and location. The energy range of the the image was nominally 17-40 keV. The smoothness of the time profile and the spectral steepness indicate that this was a "superhot" source, probably with a temperature exceeding 3 x 10^7 K. The great elongation of the source along the limb suggests that we are viewing the topmost structures of the usual arcade of post-flare loops, a conclusion confirmed by the presence of the Hα brightening at the same position later on.

4. Analysis. We analyze these data using the simplest approximation of conductive energy transport, assuming a constant flux-tube cross-section. This gives a cooling time

$$\tau = 1.25^{-10} n_e \ell^2 T^{-2.5}$$

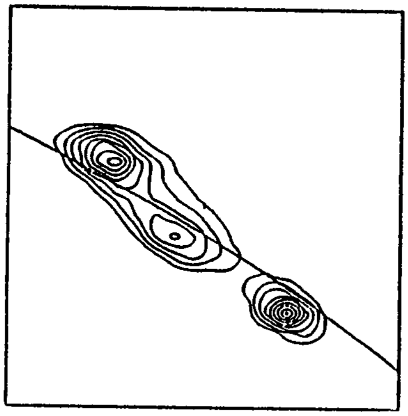

Fig. 1. Image from the *Hinotori* hard X-ray imaging instrument in a nominally 17-40 keV spectral band, taken at 2114 UT, using the ART (algebraic reconstruction technique) method A smooth time profile, plus the softness of the hard X-ray spectrum, shows that this image comes from a "superhot" source The appearance of the S component inside the limb may be an artifact.

from the Culhane *et al.*[13] estimate. In the absence of accurate parameters for physical conditions in the source, we can evaluate this time constant for the parameter values that would give the fastest and slowest plausible rates as shown in Table 1. To lengthen the "slow" time maximally, we have included a factor of 10 to account for suppression due to field-line convergence[14].

The results of these simple estimates range from 6.8 msec (probably unphysically small) to about 100 sec. The long-limit time does not agree well with the observed event lifetime, although the cooling time properly refers to the decay of source temperature, for which we have no good observational limit. We conclude that the extended lifetime of the event probably requires either (a) a more effective mechanism of suppressing thermal conduction through new physics, or (b) a continued supply of energy to the source.

5. <u>Conclusions</u>. We have identified a "superhot" hard X-ray source in a solar flare occulted by the solar limb, and find its hard X-ray image to show great horizontal extent but little vertical extent. An Hα brightening at the same limb position about an hour later suggests a multi-component loop prominence system, so that it appears that a superhot source can evolve in the same manner as a normal solar soft X-ray source. The assignment of plausible values to physical parameters in the source suggests (from the simplest form of classical thermal-conduction theory) that either new physics will be required to suppress conduction, or else that gradual energy release well after the impulsive phase of the flare must occur. In this respect too, the superhot source appears to resemble ordinary soft X-ray sources, except of course that its temperature is higher.

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TABLE 1

Parameters for Conductive Cooling Estimates

	Fast	Slow	
Density	10^8	10^{10}	cm^{-3}
Temperature	5×10^7	3×10^7	K
Length scale	3.1×10^9	6.2×10^9	cm
Convergence suppression	none	10	
Conductive cooling time	6.8×10^{-3}	98	sec

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