WHY P/OF SHOULD LOOK FOR EVIDENCES OF OVER-DENSE STRUCTURES IN SOLAR FLARE HARD X-RAY SOURCES

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ABSTRACT

White-light and hard X-ray (HXR) observations of two white-light flares (WLFs) show that *if* the radiative losses in the optical continuum are powered by fast electrons directly heating the WLF source, then the column density constraints imposed by the finite range of the electrons requires that the WLF consist of an *over-dense region* in the chromosphere, with density exceeding 10^{14} cm^{-3}. Thus, we recommend that P/OF search for evidences of over-dense structures in HXR images obtained simultaneously with optical observations of flares.

I. SUMMARY OF CALCULATIONS

As a working hypothesis, we adopt a classical thick-target model, whereby nonthermal electrons are accelerated in a low-density coronal region and subsequently thermalized in the denser layers of the chromosphere. In the following steps we use optical and HXR data for two well-observed flares, 1 July 1980 and 24 April 1981; the calculated results are shown in Table 1.

a. The observed power (P_{WL}) in the optical continuum at the peak of the WLF was derived from measurements made with the Multiple-Band Polarimeter at Sacramento Peak (Neidig and Cliver, 1983; Kane et al., 1985).

b. The fast electron power loss spectrum (of the form $P(E) = AE^{-\delta}$, where E is the electron energy) was calculated from the associated HXR burst, assuming a thick-target model, at the time of the WLF peak power (Batchelor, 1984; Kane et al., 1985), and the electron energy E_0 above which the power in thick-target loss is equal to white-light power was then derived for both flares. Note that the values for E_0 obtained in this way are upper limits on the low-energy cutoff actually required under realistic conditions, as we assume (1) the electrons are depositing their energy only within the WLF area, and (2) all the energy in electrons with $E > E_0$ is converted into white-light emission.

c. The column density n_c that can be traversed by electrons of energy E_0 was calculated from the equations given by Bai (1982). Because the values for E_0 adopted in the previous step are upper limits, it follows that the column density n_c will be an upper limit on the range of the electrons that carry sufficient power to the WLF. If we take the electron trajectory to be normal to the sun's surface and with zero pitch angle, and denote the height (above $\tau_{5000} = 1$) of the acceleration site as z_1 and the height where the fast electrons are stopped as z_0, then

$$\int_{z_0}^{z_1} N(z)dz = n_c \quad ,$$

where N(z) represents the vertical density distribution in the solar atmosphere. If we assume that the density at the acceleration site is $\lesssim 10^{12}$ cm^{-3} and N(z) is similar to the density distribution in the quiet sun atmosphere, we can easily determine the electron stopping height z_0 (note that for the electron energies considered here, z_0 is not sensitive to the selection of z_1 as long as $N(z_1) \lesssim 10^{12}$ cm^{-3}).

d. Next, we considered the minimum amount of atmospheric material that could give rise to the WLF; i.e., we assumed H_{fb} emission at 10^4 K in an optically thin slab. In this way we obtained a lower limit on the linear emission measure, $N_e{}^2\Delta z$, required to produce the observed WLF intensity. A more realistic lower limit on $N_e{}^2\Delta z$ would actually be larger than the values listed in Table 1, as the observations of the peak WLF intensities were undoubtedly affected by seeing and finite spatial resolution of the telescope. Note that the adopted emission measures are considerably larger than the entire integrated atmospheric emission measures $\int_{z_0}^{\infty} N^2(z)dz$.

e. The minimum density, N_{WLF}, in the WLF source was then estimated from the quantities in steps (c) and (d), i.e., $N_{WLF} = N_e{}^2\Delta z/n_c$.

II. CONCLUSIONS AND DISCUSSION

The calculations summarized above show that it is not possible to obtain the required WLF emission measures within the column densities allowed by the finite range of the energetic electrons. Thus, we conclude that *if* WLFs are powered by fast electrons, in the sense of a classic thick-target model, then the solar atmospheric structure must be modified in such a way as to produce a steeper density gradient than is found in the quiet sun. This could imply (1) the existence of an *over-dense* region formed in the flare atmosphere, or (2) the partial *removal* of the atmospheric mass overlying the denser regions of the deep chromosphere (but probably not via evaporation, as the mass might still remain in a column between the WLF and the electron acceleration site). Further, we find that the density in the WLF, if heated directly by fast electrons, must exceed 10^{14} cm^{-3}.

These conclusions are based on several assumptions, each of which was chosen to give the fast electron heating model every chance of success. Furthermore, the calculations were made at the time of the peak white-light emission; if, on the other hand, we consider the maximum E_0 able to satisfy the power requirements at all times during the 24 April flare, we find that E_0 must be decreased from 85 keV to 25 to 40 keV! The result is that the conclusion reached above is even more strongly reinforced.

WLF structures are sometimes quite small and short-lived (see Figure 1) and, therefore, if they are associated with electron bombardment, high-spatial resolution observations in HXR are required in order to study them. A major goal of P/OF science should be to obtain HXR images of WLFs, simultaneous with optical observations, and to look for evidences of over-dense structures.

REFERENCES

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TABLE 1. CALCULATED PARAMETERS FOR TWO WLFs

	1 July 1980	24 April 1981
Observed power, P_{WL}, in the optical continuum (erg s^{-1})	4.5×10^{27}	7.0×10^{27}
Electron energy cut-off E_0 (keV)	37	85
Electron range $n_c(E_0)$ (cm^{-2})	2.7×10^{20}	1.4×10^{21}
Electron stopping height z_0 (km)	1100	875
Emission measure, $N_e^2 \Delta z$, in the white-light source (cm^{-5})	5.3×10^{34}	1.6×10^{35}
Integrated atmospheric emission measure above z_0 (cm^{-5})	1.1×10^{33}	3.5×10^{34}
Minimum density in the white-light source (cm^{-3})	2.0×10^{14}	1.1×10^{14}

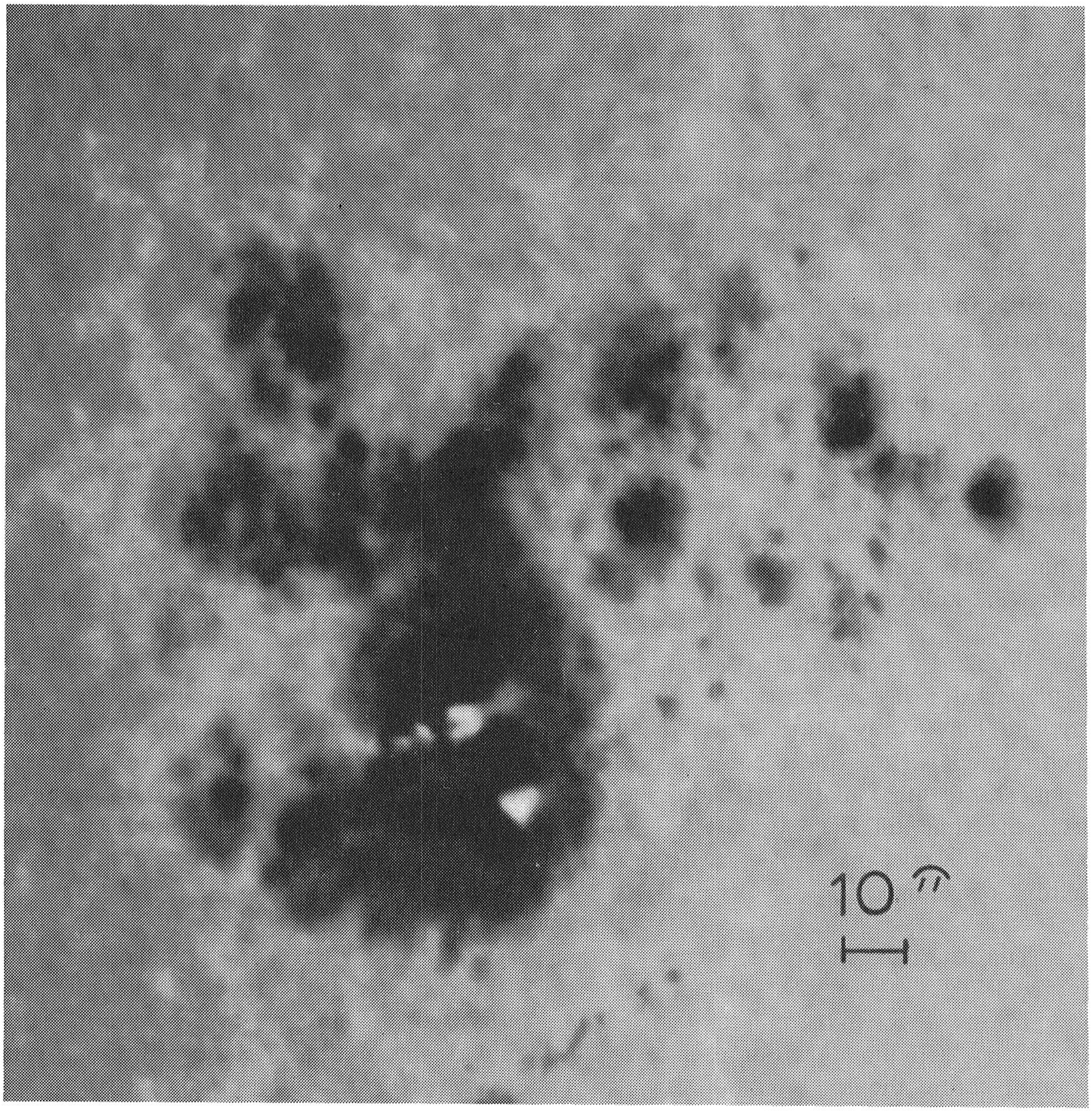

Figure 1. White-light flare of 4 June 1982, 1332 UT, photographed at 3610 Å. Small kernels show significant intensity variations in timescales of a few tens of seconds. (Photograph from National Solar Observatory, Association of Universities for Research in Astronomy, Inc.)