MULTI SPACECRAFT OBSERVATIONS AND THICK-TARGET ELECTRON BEAM MODELS FOR THE 15-NOV-1991 FLARE

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Abstract

We present preliminary results from a comparison of thick-target electron beam models with data obtained from multiple spacecraft for the X 1.5 class flare observed on 15 November 1991 at 2237 UT. In particular, we compare the variation of the spectral index with observation angle with steady-state thick-target electron beam models, which include energy loss and pitch angle scattering due to Coulomb collisions. These calculations indicate that the results are consistent with an anisotropic electron injection.

1. observations

A large X-ray flare (GOES class X1.5) was observed by the hard X-ray spectrometers on board YOHKOH, ULYSSES and the Pioneer Venus Orbiter (PVO) at approximately 2237 UT on 15 November 1991. Yohkoh is an earth-orbiting satellite, Ulysses is undertaking an extended mission over the poles of the Sun, and PVO was in orbit about Venus. As it turned out, the three different spacecraft had widely varying view angles, which gives us the opportunity to test one of the major results of the thick-target electron beam model of hard X-ray flares. If the electrons responsible for the hard X-rays are beamed from an acceleration region up in the corona down into the footpoints of a flaring loop, then the spectral index of the emission should decrease as the view angle increases (i.e. spectral hardening towards the limb). There is still some controversy about whether this effect has been observed for flares; statistical studies of SMM-GRS results indicate that the effect exists for energies above 300 keV (Vestrand, *et al.* 1987) while stereoscopic observations using ISEE-3 and PVO do not show this effect (Kane, *et al.* 1988).

2. spectra and uncertainties

The view angles of the flare for each instrument are $\theta_y = 19°$, $\theta_p = 52°$, and $\theta_u = 82°$ for Yohkoh, PVO and Ulysses, respectively. We have obtained energy spectra observed by each instrument for the 20 second interval starting at 22:37:10 UT (the only interval for which we have PVO data). As can be seen from Table 1, the spectra do perform as expected; above 100 keV, where we expect to be able to observe spectral hardening, the spectral indices are $\gamma_y = 3.70 \pm 0.03$ for the Yohkoh Hard X-ray Spectrometer (HXS), $\gamma_p = 3.38 \pm 0.05$ for PVO and $\gamma_u = 2.72 \pm 0.07$ for Ulysses. The difference between the HXS and PVO spectral indices is $\Delta\gamma_{py} = \gamma_y - \gamma_p = 0.32 \pm 0.06$ and the difference between the Ulysses and Yohkoh indices is $\Delta\gamma_{uy} = \gamma_y - \gamma_u = 0.98 \pm 0.08$. At a 3 sigma level, the spectral indices are not consistent with anything expected from isotropic emission. The error bars are largest for the Ulysses spectrum due to the low excess count rates for the high channels. The uncertainties were calcluated for each spectrum using a Monte Carlo technique which takes into account the typically arbitrary method used to determine whether the count rate in a given channel is greater than that expected for the background. Another problem with the Ulysses spectrum is that it does not extend past 150 keV. The spectra for the other two instruments extend past 500 keV. Figure 1 is a plot of the HXS and Ulysses spectral indices for the entire flare; the HXS spectral index is larger for the entire event, wherever good spectra were obtained.

Table 1. Spectral parameters for the 15 Nov. 1991 flare at 22:37:10 UT.

	HXS	PVO	ULYSSES
θ	19°	52°	82°
γ	3.70 ± 0.03	3.37 ± 0.05	2.72 ± 0.07
J_{150}	0.17 ± 0.03	0.21 ± 0.04	0.39 ± 0.16
J_{350}	0.0085 ± 0.00006	0.012 ± 0.0001	0.040 ± 0.002

definitions:
θ = View Angle
γ = Photon Spectral Index
J_{150} = Photon Flux at 150 keV, in photons/(cm^2-sec-keV)
J_{350} = Photon Flux at 350 keV, in photons/(cm^2-sec-keV)

The absolute flux at a given energy may also be calculated and compared for the three instruments, Table 1 summarizes the results for emission at 150 keV and 350 keV along with the spectral index results. Note that the Ulysses results have been extrapolated out to 350 keV, and should not be taken too seriously. Also, since the spectrometers have not been calibrated against one another, the results for flux comparison should be considered to be less reliable than the spectral index comparison, which does not depend on the intercalibration of the instruments, or for that matter, corrections for dead time or distance from the Sun.

3. model results

The thick-target models used are simple; electrons are injected at the top of a loop and transported down into the chromosphere and photosphere. For energies greater than 100 keV and coronal densities $\lesssim 1.0 \times 10^{12} \mathrm{cm}^{-3}$ nearly all of the emission comes from the loop footpoints, where the magnetic field is assumed to be vertical with respect to the solar surface. These models have been described exhaustively by McTiernan and Petrosian, (1990a,b). The electron distribution is calculated using a steady-state Fokker-Planck equation which includes the effects of coulomb collisions, synchrotron radiation, bremsstrahlung radiation and magnetic

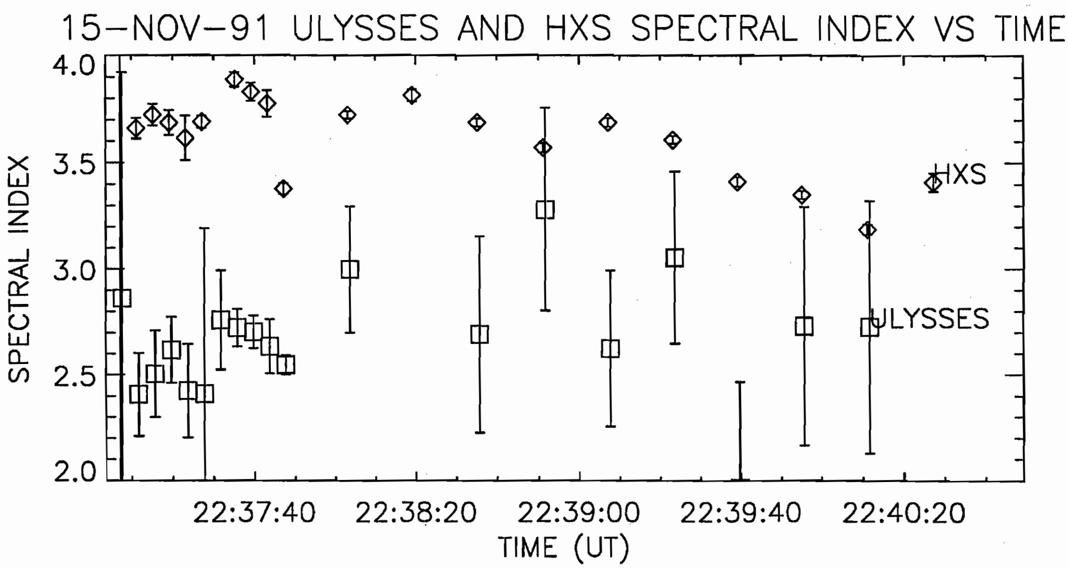

Fig. 1. HXS (diamonds) and Ulysses (squares) spectral index versus time.

mirroring. Both electron-ion and electron-electron bremsstrahlung radiation are accounted for. The injected electrons have a power law distribution in energy and an isotropic or gaussian pitch angle distribution.

$$F_{injected} = K\mathcal{E}^{-\delta} e^{\alpha^2/\alpha_o^2} , \tag{1}$$

where $\mathcal{E}$ is the electron kinetic energy, α is the pitch angle and α_o^2 is the dispersion of the pitch angle distribution.

Figure 2 shows the variation of the 100 keV to 500 keV spectral index for a model compared with the observed variation. The solid line shows the spectral index for a model with $\alpha_o^2 = 0.40$, i.e., a distribution that is beamed along the magnetic field, and no magnetic mirroring. The amount of directivity increases with energy, which is why the spectral index varies with angle. [As it turns out, increased beaming reduces the anisotropy of the radiation in the direction opposite to the beam direction. This is beacuse the emission for a beamed distribution is dominated by large angle emission from particles with small pitch angles; the bremsstrahlung cross-section does not vary much with angle for large angles, hence there is less anisotropy. (See McTiernan and Petrosian, 1990b.)]

The points with error bars on Figure 2 show the observed results for the variation of spectral index of the 15 November, 1991 flare. The HXS spectral index has been normalized to the curve, and the other indices are put in the appropriate position relative to the HXS index. As can be seen the observations fit the model rather well. It should be noted that models with magnetic mirroring and smaller pitch angle dispersion will also fit the observed results.

4. conclusions

We have been able to obtain photon spectra for the 15 November, 1991 flare from three different instruments. The spectra agree well with each other, and show the variation in spectral index above 100 keV with view angle that would be expected if the emission is due to a beam of non-thermal electons, with the spectral index decreasing for increasing view angles.

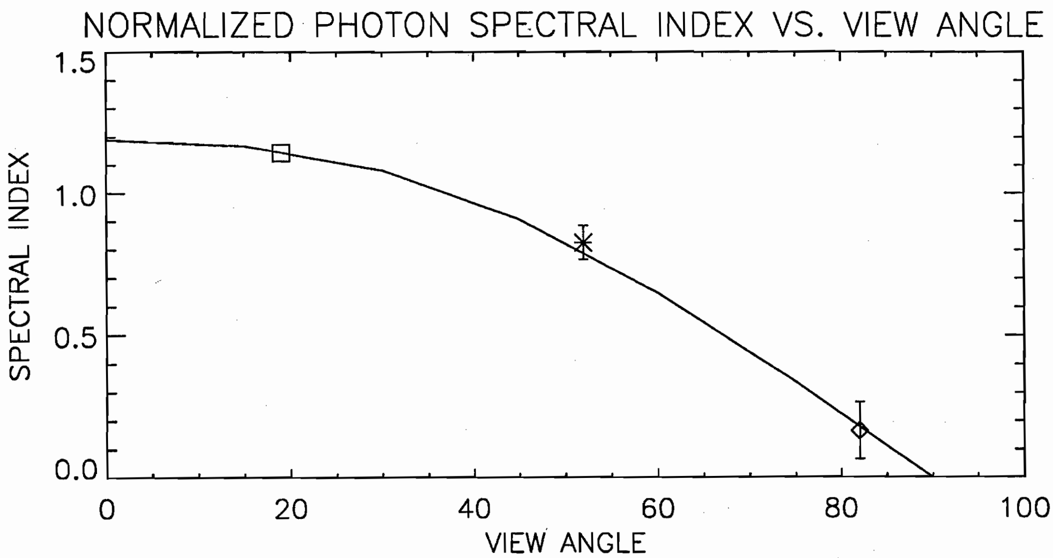

Fig. 2. The observed results for the variation of spectral index on a plot of the normalized photon spectral index versus angle for a model with a dispersion of $\alpha_o^2 = 0.40$ and a uniform magnetic field. The HXS spectral index (the square) has been normalized to the curve, the PVO index (star) and the Ulysses index (diamond) are put in the appropriate psoitions realtive to the HXS index.

Future work will include this sort of analysis for a large sample events common to Ulysses and Yohkoh, and a statistical analysis of the variation of the spectra with respect to view angle.

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