MEASUREMENTS OF THE SPATIAL STRUCTURE AND DIRECTIVITY OF 100 KeV PHOTON SOURCES IN SOLAR FLARES USING PVO AND ISEE-3 SPACECRAFT

Grant NAG2-393

Kinsey A. Anderson, Principal Investigator

Space Sciences Laboratory
University of California
Berkeley, CA 94720

Final Report, April 1, 1986 - March 31, 1990

February 20, 1991

Prepared for:

NASA-Ames Research Center
Moffett Field, CA 94035

General Objectives

The objective of this grant was to measure the spatial structure and directivity of the hard X-ray and low energy gamma-ray (100 keV-2 MeV) continuum sources in solar flares using stereoscopic observations made with spectrometers aboard the Pioneer Venus Orbiter (PVO) and Third International Sun Earth Explorer (ISEE-3) spacecraft. Since the hard X-ray emission is produced by energetic electrons through the bremsstrahlung process, the observed directivity can be directly related to the "beaming" of electrons accelerated during the flare as they propagate from the acceleration region in the corona to the chromosphere/transition region. Some models (e.g., the thick-target model) predict that most of the impulsive hard X-ray/low energy gamma-ray source is located in the chromosphere, the effective height of the X-ray source above the photosphere increasing with the decrease in the photon energy. This can be verified by determining the height-dependence of the photon source through stereoscopic observations of those flares which are partially occulted from the view of one of the two spacecraft. Thus predictions about beaming of electrons as well as their spatial distributions could be tested through the analysis proposed under this grant.

Observation Technique and Instrument Calibration

The technique of stereoscopic observations and the instrument response and calibration procedure have been described by Kane *et al.* (publications 3 and 4 on the list below). The flare is observed "simultaneously" by similar instruments aboard the PVO and ISEE-3 spacecraft with corresponding view angles θ_P and θ_I, the view angles θ being defined as the angle between the line joining the flare site to the instrument and the outward solar radial direction at the flare site. The flares, for which both the view angles θ_P and θ_I were $\leq 90°$, were in full view of both the instruments and hence were used for studies of the directivity of the photon emission. The height-dependence of the photon source brightness was deduced from the observations of flares for which either θ_P or θ_I was $>90°$, so that part of the flare below the "occultation" height was occulted by the photosphere from the view of one of the instruments.

Accurate calibration of the two instruments is vital for the success of the stereoscopic observations. The procedure has been described by Kane *et al.* (publication 4, below). The photon spectra observed by the two instruments for flares with nearly the same view angle ($\theta_P \simeq \theta_I$) have been compared. The calibration of the two instruments has been found to be satisfactory.

Results

The results obtained so far from the analysis of the stereoscopic observations of hard X-ray flares made with the PVO and ISEE-3 instruments have been described in five papers. Copies of the papers are enclosed. The principal results can be summarized as follows:

1. Stereoscopic observations are a very useful and powerful technique for studies of the high energy (>100 keV) hard X-ray and gamma-ray sources in solar flares for which no imaging observations are available.

2. The hard X-ray source in impulsive solar flares extends from the chromosphere to the corona, the brightness of the source decreasing with increasing height. The brightness of the source above ~2500, 25,000 and 160,000 km is ~10%, 1% and 0.1%, respectively, of the total source brightness, with only weak dependence on the photon energy. On the other hand, the gradual soft X-ray (1-8Å) source seems to be confined to a height <25,000 km.

3. In the 100 keV-1 MeV range, the directivity of impulsive hard X-ray sources is relatively small for differences in view angles $\Delta\theta \lesssim 60°$.

4. The thick-target model, where electrons accelerated in the corona propagate down toward the chromosphere, is, in general, consistent with the stereoscopic observations. Details of the model, such as the strong energy dependence of the variation of the source brightness with height, does not seem to agree with the observations. Also the beaming of electrons appears to be much weaker than assumed in the basic thick-target model.

5. The thermal model with adiabatic compression, where the electrons are heated and confined to the corona during the impulsive phase, is not consistent with the stereoscopic observations.

Publications Resulting from This Grant

1. Kane, S. R., Propagation and confinement of energetic electrons in solar flares, in *Recent Advances in the Understanding of Solar Flares: Proc. of the U.S.-Japan Seminar, April 1987*, ed. by H. Hudson and K. Kai, *Solar Phys.* **113**, 145, 1987.
2. Kane, S. R., R. W. Klebesadel, E. E. Fenimore and J. G. Laros, X-ray and low energy gamma-ray observations of the 16 February 1984 solar flare, in *Solar-Geophysical Activity Report for STIP Interval XV, 12-21 February 1984 Ground Level Event, and STIP Interval XVI, 20 April - 4 May 1984 Forbush Decrease, Report* **UAG-96**, ed. by H. Coffey and J. Allen, p. 100, Nat'l. Oceanographic and Atmospheric Administration and Nat'l. Geophysical Data Center, Boulder, 1987.
3. Kane, S. R., E. E. Fenimore, R. W. Klebesadel and J. G. Laros, Directivity of 100 keV - 1 MeV photon sources in solar flares, *Astrophys. J.* **326**, 1017, 1988.
4. Kane, S. R., R. W. Klebesadel, E. E. Fenimore and J. G. Laros, Intercalibration of the hard X-ray spectrometers on the PVO and ICE (ISEE-3) spacecraft, *Adv. Space Res.* **8**, (11)241, 1988.
5. Kane, S. R. and H. W. Urbarz, A preliminary summary of the observations of the 16 February 1984 solar flare (STIP interval XV, 12-21 February 1984), in *STIP Symposium on Retrospective Analyses*, ed. by M. A. Shea and D. F. Smart, in press since 1986.