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III. Solar Maximum Mission Results

(M.E. Machado)

The ongoing research carried out by the solar community has been reported in the proceedings of several recent symposia, seminars and workshops, as well as in scientific journals (Kane et al. 1983, Švestka et al. 1982a, Shea et al. 1984, Kundu & Woodgate 1984, Simon 1984). We summarize here some of the novel results with reference to flare research as far as SMM data analysis is concerned. Understanding of impulsive phase phenomena was one of the primary goals of the SMM. The early reports from the analysis of the first ever obtained high-resolution images in the <30 keV energy range stressed the fact that some flares showed hard x-ray (HXR) bright sources at the feet of coronal loops (Hoyng et al. 1981a,b, Machado et al. 1982, Duijveman et al. 1982), the so-called HXR "footpoints," favoring the thick-target beam mechanism for the production of HXRs, and indicating acceleration efficiencies >20% during the early impulsive phase. This phenomenon was shown to be accompanied by soft x-ray (SXR) line broadening, indicative of strong turbulence, and the immediate appearance of blue shifted spectral lines, which shows that plasma heated to $>10^7$ K rises from the footpoints of loops with velocities to 300 km s^{-1} (Antonucci et al. 1982, Antonucci et al. 1984a). This result provides a strong indication of the chromospheric evaporation phenomenon, which has been confirmed in analyses of combined SXR and Hα observations (Acton et al. 1982, Gunkler et al. 1984).

High temporal resolution HXR observations (E < 300 keV) have revealed the existence of millisecond time variations (FWHM ≈ 45 ms)during the impulsive bursts. These place new constraints on the physical nature of the HXR source. Particularly, in a non-thermal scenario the observed time scales are upper limits to the temporal scale of the acceleration process itself, while within the context of thermal HXR models, it follows that they lose their energetic advantage over the non-thermal hypotheses (Kiplinger et al. 1983). Along the same lines, the combined analysis of HXR and UV impulsive bursts, particularly those observed in the OV line at 1371 Å, formed at $T \simeq 2.5 \times 10^5$ K, has shown a simultaneity in the burst structures to within <1 s, limited by the UV temporal resolution (Woodgate et al. 1983). There is also very good correlation between the appearance of HXR and UV spikes, and the density of the UV burst region as determined from the Si IV/O IV line ratio (Cheng et al. 1981) yields a range $5 \times 10^{12} < n < 10^{13}$ cm^{-3}, confirming that UV burst emission originates below the height of the preflare transition region. An important aspect stemming from this comparison arises from the fact that hydrodynamic simulations have established that the response of the transition region should be different in conductively heated and particle heated models. Only the latter predicts a strong temporal correlation of UV intensity with energy input, as measured by the HXR flux (Emslie & Nagai 1984). It is thus obvious that the HXR/UV correlation seems to favor the beam model, a fact supported by the spatial coincidence of HXR and UV footpoints in cases where common data sets have been analyzed (Machado et al. 1982, Duijveman et al. 1982, Poland et al. 1982).

Important information concerning the acceleration of ions has been provided by the gamma-ray observations. Simultaneous peaking of <100 keV and >10 MeV photons has been observed, accompanied by direct evidence of ion acceleration revealed by line emission (<10 MeV), meaning that all energetic particles were injected into and interacted with the target medium at the same time (≤1 s), or they were produced (accelerated) simultaneously (Forrest & Chupp 1983, Chupp 1983, 1984), in contradiction with widely accepted concepts before the SMM launch. High-energy neutrons were also observed for the first time by the SMM, indicating the rapid acceleration (<<60 s) of GeV protons during the impulsive phase. The limb flare observations require densities $\leq 5 \times 10^{15}$ cm^{-3} in the interaction region, so that the flux is not greatly attenuated. On the other hand, prompt gamma-ray lines have to be produced in a region with density $>10^{11}$ cm^{-3}. The SMM events with significant emission above 10 MeV show a concentration towards the limb (Chupp et al. 1982), a fact that provides evidence for downward beaming in agreement with previous statements. Although the evidence for particle beaming is strong, the imaging observations have also indicated that a substantial fraction of the HXR output may be thermal in nature (Rieger et al. 1983). The presence of hot ($\geq 4 \times 10^7$ K) sources embedded within the flaring loops or at the boundary between field structures has been detected (Hoyng et al. 1981b, Machado et al. 1982, Duijveman 1983, Machado 1983, Machado & Lerner 1984). In the case of a two ribbon flare observations, these have been interpreted as the heating byproduct of the reconnection of field lines blown open during the filament eruption. The same x-ray imaging observations have also provided some observational evidence for thermal wave fronts, whose flux may comprise a large fraction of the released flare energy (Rust 1984, Rust et al. 1984, Švestka & Poletto 1984).

Two other aspects of SXR line spectroscopy during impulsive and gradual flare phases have been considered. The spectral analysis leads to densities of the order of 10^{12} cm^{-3} in the 10^7 K emitting region (Phillips et al. 1982, Wolfson et al. 1983). At the same time it has been determined that, due to the high densities of flaring loops, ionization balance is very close to steady state over almost all phases of flares for which statistically good data are available (Antonucci et al. 1984b). Finally, the behavior of the Fe Kα emission near 1.94 Å has been shown to be consistent with photoionization by x-rays with energy >7.11 keV (fluorescence). In a limited number of cases, the Kα light curve showed impulsive behavior coincident with HXRs, which could be indicative of electron impact ionization, but these results are rare (Culhane et al. 1981, Parmar et al. 1984) perhaps because they are masked by the overwhelming effect of fluorescence. With respect to the origin of all these energy release by-products, the SMM observations have pointed out that a very large fraction of the x-ray flares are composed of two or more loop structures which intersect at a common point (Machado et al. 1983, Rust & Somov 1984, Acton et al. 1983). Only in few cases (Tandberg-Hanssen et al. 1984), flaring may occur spontaneously within a simple nonpotential arch. This fact has thus stressed the importance of flux emergence and evolution in the production of flares through magnetic reconnection. Magnetic shear (Hagyard et al. 1984) is also well correlated, and defines which of the possible flaring structures may possess the strongest high-energy phenomena. The association of Type III/V radio events, whose components may appear at widely different locations with strong HXR bursts, also suggests that accelerated particles have immediate access to various field structures. Thus, the acceleration/injection site may comprise a rather large volume of interacting field lines (Pick & Raoult 1984, and Chapter 2 of Kundu & Woodgate 1984). In the high corona, broad expansions of the SXR emitting regions have been detected right at the maximum of the flares, a newly discovered phenomenon which has been called "coronal explosion" (de Jager & Boelee 1984, de Jager et al. 1984). Another discovery was that of the gigantic post flare arches which appear after strong two ribbon flares (Švestka et al. 1982b,c). These seem to be related to Type I noise storms observed for many years in the radio records, and sometimes undergo in situ variations in SXR high in the corona, without an obvious chromospheric counterpart (Švestka et al. 1983). They demonstrate the importance of large-scale magnetic fields in relation to flaring activity. Regions of high temperature plasma ($>10^7$ K) in non-flaring active regions have also been detected in the imaging data (Schadee et al. 1983), while spectra show line widths broader than the Doppler width corresponding to the local electron temperature (Acton et al. 1981).

Finally, the SMM data have provided new information on coronal mass ejections (CMEs) (Wagner 1982, 1984), which are a clearly important manifestation of activity, with mass and energy content which may exceed other flaring manifestations (Wagner et al. 1981). The CMEs may be related either to the flare explosions or eruptive prominences and, surprisingly, their frequency did not change by more than 20% as compared with the Skylab (1973-74) period (Wagner 1984, Hundhausen et al. 1984). This seems to be related to a similar phenomenon in eruptive prominences, and its explanation is still controversial. The observations have also shown that the shape of these transients favors in many cases a three-dimensional bubble geometry over the commonly accepted planar loop. Comparison of CME observations with radio data (Stewart et al. 1982, Gary et al. 1984), as well as extrapolated estimates of starting times, casts strong doubts on the physical association of this phenomenon with flare blast shocks. The observations have also revealed (House et al. 1981) frequent Hα emission from insulated cool remnants of eruptive prominences seen in the outer corona. There is a type of CMEs, those most commonly observed, which appears to be unassociated with flares and eruptive prominences (Wagner 1984). These are of great interest in themselves, not only because they represent a distinct physical class, but also due to the fact that they may be indicators of the evolution of large-scale fields related to dynamo processes internal to the Sun (Wagner 1984).

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IV. Results from Hinotori and P78-1

(K. Tanaka)

Hinotori observed 720 flares through its operation February 1981-October 1981. General discussions of the results were given in two symposia: the Hinotori Symposium (ISAS 1982) and the U.S.-Japan Seminar (de Jager & Švestka 1983). The hard x-ray imaging made at the effective energy 20-35 keV showed a wide variety of morphology. Many flares (22 out of 30 events) showed single source structure, either compact (12) or extended (10) in the spatial resolution of 15 arc sec (Takakura et al. 1983a, Ohki et al. 1983, Takakura 1984). Evidences are given in some limb events that the main source is located in the high corona (1-4 x 10^4 km) (Takakura et al. 1983b). The extended single source could be the whole coronal loops which may include footpoints, but the maximum brightness is near the loop top. In some events (8 out of 30), weak subsource(s) which sould be identified with the footpoint(s) appear intermittently (Tsuneta et al. 1983). Takakura et al. (1984) found that the extended single source becomes compact and slightly shifts to higher altitudes in later phases of the impulsive burst (5 out of 10 events). Tanaka (1984), Takakura (1984), and Tanaka & Zirin (1984) argued that the hard x-ray morphology of the impulsive burst is consistent with the non-thermal electron beam model in high density corona. Sakurai (1983) investigated magnetic field structures of the hard x-ray sources based on the potential field calculations. Timing between the hard x-ray and microwave in the impulsive bursts was examined by Takakura et al. (1983c), who found correlated subsecond time structures and also by Takakura et al. (1983d), who found a long (5-10 s) delay of the peaks at 17 GHz and E > 300 keV to the peak at E < 100 keV. Kurokawa (1983) showed detailed coincidence between the hard x-ray spikes and Hα brightenings.

The flares observed from Hinotori were classified into three types (Types A, B, and C) according to combined characteristics of the morphology, spectrum, and time profile (Tanaka 1984, Tanaka et al. 1983). With contrast to the impulsive burst (Type B), the gradual hard burst (Type C) shows an extended duration without impulsive spike component, and a spectral hardening is observed with a large delay (30 s-1 min) of the gamma-ray peak to the hard x-ray peak (Yoshimori et al. 1983). Tsuneta et al. (1984a) showed that its hard x-ray image is an extended, stationary source located high in the corona. Microwave interferometric (one-dimensional) observations by Kawabata et al. (1983) showed the microwave structure co-spatial with the hard x-ray source suggesting that the high-energy electrons in the MeV range are trapped due to magnetic mirroring. Kai et al. (1985) found a larger microwave to hard x-ray flux ratio for this type