5. Solar Research from Space, 1982-1984 (Some Highlights)

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I. INTRODUCTION

During this reporting period, the satellites ISEE 3 (now ICE), IMP 8, Helios 1, Hinotori, Nimbus 7 (ERB), P78-1, Pioneer Venus Orbiter (PVO), Spacelab 1 and Solar Maximum Mission (SMM) continue to provide solar observations. We review briefly some recent developments, selected by the author as most significant, concerning: coronal mass ejecta, high-energy neutral emissions, X-ray and microwave bursts, the solar constant, and solar flare periodicity. While the emphasis is on new work, some significant results, obtained in earlier spacecraft experiments and only recently reported, are also mentioned. The repair, in space, of SMM in 1984 April, resulting in reactivation of three of the four pointed experiments is briefly described and a status report of the SMM 2 mission is given. We conclude with a summary of important future programs.

II. RECENT PROGRAMS

1. Coronal Mass Ejecta (CME)

Observations of CME are still being carried out by the SOLWIND coronagraph on the P78-1 satellite (Doschek 1983). The SMM Coronagraph Polarimeter (C/P) was nonoperational from 1980 October until it resumed observing the Sun in 1984 April. Thus, a large CME data base now exists for studying this phenomenon over a large part of the solar cycle.

The SOLWIND data base has led to several correlation studies. CME and type II correlation studies by Sheely et al. (1984) have revealed that "type II bursts without CMEs were associated with short lived soft X-ray events but not with interplanetary shocks at the Helios 1 spacecraft." They also note that "type II bursts with CMEs were associated with longer lived X-ray events (3 h on the average), and interplanetary shocks with CME speeds >400 km s^{-1}." For faster CME (>455 km s^{-1}) without metric type II bursts there was usually an associated interplanetary shock. Sheely et al. (1984) conclude that "shocks without CME, have a relatively impulsive origin, and may die out sooner than many shocks with CME which are piston driven," and that the lack of type II emission is due to formation of the faster CME above the lower corona where metric emission originates or, alternately, that the CME form shocks which (for some reason) cannot excite type II emission.

Kahler et al. (1984a) have also studied flares producing metric type II bursts and CME, and find that both compact and large mass ejection flares are associated with type II bursts and that "CME accompany about 60% of all flares with type II bursts for solar longitudes >30°." On the other hand, for events "with no CME," they suggest that "many of the apparent type II shocks are not piston driven and that there is strong indication that type II shocks are not necessarily produced by large energy releases in the flare's impulsive phase," since small 3 cm impulsive bursts are poorly correlated with occurrence of type II bursts.

The Skylab observations showed that "long duration" ($\sim$ h) "X-ray events were almost always accompanied by mass ejections through the outer corona" (Sheeley et al. 1983). This suggested that the soft "X-ray events fall into two distinct classes," that is, long-duration events with CME and short-duration events without CME. A statistical study of CME observed from 1979-1981 on P78-1 has shed further light on this correlation. In particular, Sheeley et al. (1983) find that there is "no duration that separates X-ray events into two distinct classes depending on whether or not they have associated CMEs." Instead, the X-ray CME association is due to different differential distributions for events with and without CME. Also,

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a study of associations of CME, Hα flares and solar energetic particle events (SEP) has shown "in 26 of these 27 cases an associated CME was found indicating a high but not perfect association" (Kahler et al. 1984b).

The structure of the solar corona is known to be characteristically different between solar maximum and minimum. This was beautifully demonstrated by C/P observations made in 1980 and in 1984 respectively (Hundhausen et al. 1984a). Other post-repair results are still being analyzed; however, the 1980 C/P data has confirmed the Skylab result "that the type of surface activity most likely to be associated with a CME is an event near the limb with Hα material ejection, such as a prominence erruption" (Sawyer et al. 1984). The CME association with activity in the chromosphere or the low corona is tenuous. An interesting observation by Hundhausen et al. (1984b) is that the occurrence rate for CME at solar maximum as seen by C/P is slightly higher than during the declining phase of cycle 20 as seen by Skylab i.e. 0.9 ± 0.15 and 0.75 per 24 hour day, respectively.

2. High Energy Neutral Emissions

Uninterrupted observations (1980-1984) by the SMM High-Energy X-Ray Burst Spectrometer (HXBRS) and the Gamma-Ray Spectrometer (GRS) and by the Gamma-Ray Detector (GRD) on Hinotori (1981-1982) have made it possible to routinely detect several energetic solar flare neutral emissions. These include: hard X-rays, γ-ray lines and continuum, and direct neutrons at the Earth. Of importance is the strong indication that impulsive ion and electron acceleration occur simultaneously in flares (Chupp 1984 and references therein). Traditionally, the time relation between electron and ion acceleration had been presumed to be determined by the different peak times of X-ray and γ-ray emissions (Ramaty 1980). Such differences have been observed for some flares with time profiles of 4-8 MeV nuclear γ-rays, which are delayed relative to hard X-rays >100 keV (Bai 1982). The inference is that ions are accelerated later than relativistic electrons; however, the time of the peak fluxes in X-ray and γ-ray channels can be simultaneous within instrumental resolution in some events. The starting times of the 4.1-6.4 MeV and the 40-65 keV fluxes were essentially the same ($\lesssim 2$ s), even though these two fluxes show a delay in the times of maximum emission (Forrest and Chupp 1983). It is therefore highly probable, that if a single primary accelerator is operable, any apparent delay between X-ray and γ-ray emissions is due to other factors, such as "energy-dependent Coulomb losses in a trap model" (Kundu et al. 1985 and references therein). The GRD on Hinotori sees the same general time relations (Yoshimori et al. 1983a,b).

High-energy neutrons (>50 MeV) which arrive at the Earth after an intense solar flare on 1980 June 21 have been reported by Chupp et al. (1982); also, for a flare on 1982 June 3 (Chupp et al. 1983; Debrunner et al. 1983; Evenson et al. 1983). In the later event, a ground-level response of neutron monitors in Switzerland, Czechoslovakia, and Italy recorded the highest energy neutrons (>500 MeV) through an atmospheric nucleon cascade (Debrunner et al. 1983; Efimov et al. 1983) also, the neutron decay protons (20-100 MeV) were observed in space by detectors on ICE (Evenson et al. 1983). Neutral π^0 mesons were also produced, as expected in the above two events as evidenced by detection of the characteristic γ-ray spectrum (Forrest et al. 1984, Vestrand et al. 1984a). These results can be related to the spectrum of ions at energies up to ∿ 1 GeV.

Evidence for directivity of relativistic electrons has come from a recent study with SMM GRS data of the longitude distribution of the number of solar flares with photons >300 keV. Vestrand et al. (1984b) have shown that the number of such flares is enhanced (>3σ) near the limb (heliocentric angle >65°) relative to the number expected if photon bremsstrahlung emission is isotropic. This observation can be expected if the relativistic electrons are beamed downward toward the photosphere. This interpretation is supported by the observation that the limb enhancement of GRS events with photon emission (>10 MeV) is even stronger (>6σ) as expected since the higher energy bremsstrahlung (>10 MeV) is more anisotropic than for photons <1 MeV (Rieger et al. 1983).

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SMM HXRBS has observed more than 7000 flares (1980-1984). Temporal studies have revealed that hundreds of flares have statistically significant hard X-ray spikes of less than 1 s. Further, "rise and decay times as fast as $\sim$20 ms" (Kiplinger et al. 1984) have been seen in X-rays for the first time. These observations, as well as earlier HXRBS data, are consistent with production of hard X-rays ($\sim$100 keV) as due to thick target interaction of electrons in the lower chromosphere. A likely model (Kiplinger 1984) is the "instantaneous injection of electrons into the top of a coronal loop" of height $10^8 < h < 3 \times 10^9$ cm above the interaction region.

ICE and PVO spectroscopic data (Kane 1983) give further information on the spatial structure of the sources of high-energy (>100 keV) photons. Some interesting conclusions are "that (1) the thermal model with adiabatic compression and expansion is not consistent with the observations of a magnetically-confined plasma and the thin target (non-thermal) model; (2) the thick target (non-thermal) model and the dissapative thermal model are partially in agreement with the observations; (3) the emission probably originates in many individual nonthermal sources distributed in altitude," where those at the lowest altitudes are brighter (Kane 1983). In the case of "gradual" or slowly increasing X-ray emissions, the explanation does not seem to be a purely coronal source model, but rather "a partial precipitation model with trapped as well as precipitating electrons." A white light flare on 1981 April 24, observed by the X-ray spectrometer on ICE, has shown a good temporal relationship between these two emissions. Kane et al. (1984) have concluded that the white light emission in this flare "is produced nonthermally in the upper chromoshpere, by the energy provided, by energetic ($\geq$25 keV) electrons if the source in the impulsive phase consists of an over-dense region above the altitude where the density is normally 10^{14} cm^{-3}." Earlier, Ryan et al. (1983) showed that ions (>30 MeV nucleon^{-1}) could not produce the white light emission in a flare on 1980 July 7.

3. Solar Constant

Solar constant observations on Nimbus 7 (Hickey et al. 1980) and SMM Active Cavity Radiometer Intensity Measurement (ACRIM) (Willson 1980) have continued to date. The data from both show a decrease of (0.03-0.05)% per year over the time period 1980-1982. This pattern is similar to that observed form Nimbus 6 over a 10 year period from 1968-1978. Earlier balloon observations apparently showed an increase of $\sim$0.04% per year. On the shorter time scale of days and weeks, both Nimbus 7 and ACRIM observe correlated variations of a few tenths of 1%. Also, it appears that sunspots on the solar disc cause a decrease in the solar constant. A new series of solar constant measurements was initiated on Spacelab 1 (Crommelynck et al. 1984).

4. X-Ray and μ-Wave Correlations

Recent precision comparisons of time histories of 10.6 GHz microwave and <100 keV hard X-ray emission (Cornell et al. 1984) indicate that "microwave emissions are delayed with respect to the X-rays by $\sim$0.2 s." Earlier observations (Takakura 1975; Crannell 1978) with time resolution of $\gtrsim$1 s showed a good correlation; the improved timing accuracy of the recent data now permits a study of the effects of geometry and acceleration time scale of electrons. It is too early to give a definite conclusion on this observation. The results could hold the key to understanding one of the important questions concerning electron acceleration.

At higher microwave frequencies (30 and 90 GHz) correlated observations (Kaufmann et al. 1984) were made with the HXRBS hard X-ray observations (>25 keV) during an impulsive burst on 1984 May 21. In this case the "hard X-ray time structures at energies >25 keV were almost identical to the 90 GHz time structures to <1 s." It is important to note that "The onset of the major 90 GHz burst structure was coincident (with) the hard X-ray structure to better than 128 ms." This observation taken with those mentioned above might well indicate that both

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the electrons producing the X-rays and microwaves are accelerated much closer in time than previously thought; that is to <128 ms. Thus onset time, rather than peak time is a more significant indicator of the accelerator or injector time scale.

5. Solar Flare Periodicity

From 1980 through 1984 the GRS has recorded 140 events with emission above 300 keV. A time series analysis of the GRS data base has shown that 1/3 of the events recur with a period of 155 days (Rieger et al. 1984). These authors further note that such behavior is also exhibited by GOES X-ray events of class M >2.5 and by the most intense HXRBS (>25 keV) events. It has been shown (Dennis et al. 1984) that the full HXRBS data base of 7000 flares, obtained over 4 years, also exhibits this behavior. Therefore, it appears that this phenomenon is not specific to γ-ray flares but is related to all flares, (i.e. at least X-ray flares). Studies are in progress by several groups to see if other solar phenomena show a similar behavior. It is possible that a connection of solar flares with the internal dynamics of the Sun has been discovered.

III. SPECIAL NOTE ON POST-SMM REPAIR CAPABILITIES

In 1984 April, the SMM satellite was retrieved by the Space Shuttle, repairs were effected in space and the satellite was relaunched. SMM was first launched in 1980 (see previous IAU Report). After 9 1/2 months of operation the precision pointing system and electronics systems for two experiments failed. Subsequently, the satellite attitude was approximately stablized by magnetic torquing, allowing excellent data to be accumulated for the next 3 1/2 years by 3 wide field instruments in X-rays, γ-rays and total solar irradiance. Since the repair, the original instruments with the exception of the Hard X-ray Imaging Spectrometer (HXIS), continue observing the Sun. It is noteworthy that within two weeks of the repair a major solar flare occurred on 1984 April 24. The pointed and wide field instruments obtained joint data of unprecedented quality. A summary of the prospects for the renewed mission has been given by Woodgate (1985) and by Suess et al. (1984).

The results of the first observations on SMM in 1980, the Solar Maximum Year (SMY), have been studied intensively in 1982 and 1983 at a series of NASA sponsored workshops (Kundu and Woodgate 1985).

IV. FUTURE PROGRAMS

The next major set of solar observations from space will take place on Spacelab 2, currently planned for launch in 1985 July. On this mission, payload specialists L.W. Acton and J.D. Bartoe will operate several solar telescopes:

NRL **Solar Ultra Violet Spectral Irradiance Monitor** - Fullsun - 1200-4000 A^{o}

NRL **High Resolution Telescope/Spectrograph-** (1176-1700) A^{o} $\Delta\lambda$ = 0.05 A^{o}, spatial resolution 1"

Mullard Space Science Laboratory and Appleton Laboratory **Coronal He Abundance Experiment** - EUV (150-1300) A^{o}, 15"

Lockheed Scientific Laboratory **Solar Magnetic Velocity Field - Measurement in the form of an Optical Universal Polarimeter & Telescope** (4000-7000) A^{o} $\Delta\lambda$ =0.030 A^{o} spatial resolution 0.5"

A detailed description of this second U.S. manned solar mission since Skylab is described by Clifton (1982).

Development of a major solar instrument, the Solar Optical Telescope (SOT) is planned to start in 1985. This instrument will study the Sun on the spatial scale of 73 km or 0.1" of angular resolution using a primary mirror of 0.3 m diameter with diffraction limited operation in the UV, and overall wave length coverage

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from 1200-10,000 A°.

A European mission known as SOHO is also under development. This spacecraft is a part of a wider international program involving Europe, Japan and the US, which is known as the International Solar-Terrestrial Physics Program (ISTP). The SOHO is a three axis stablized spacecraft which will direct a variety of telescopes to within 10" of the solar center and will study the spectral and total luminosity of the sun, solar oscillations, the chromosphere, transition region and corona at high spectral resolution, outflow velocities in the inner corona and the solar wind shock. The overall wave length coverage is from (66-7000) A°.

The USSR is also planning solar observations from dedicated spacecraft, but no detailed information is available to the author at this time.

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