THE SOLAR MAXIMUM MISSION

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I) INTRODUCTION

The Solar Maximum Mission (SMM), the most powerful package of instruments ever flown for the study of solar flares, was launched on 14 February 1980, near the peak of activity of the current 11-year sunspot cycle. It carried onboard seven instruments to observe solar flares over the entire spectrum from gamma rays to the visible. It also carried a sensitive radiometer to measure variations of the integrated light from the Sun. SMM had been designed for a minimum lifetime of one year, but it was expected that it could operate for a much longer period owing to the absence of consumables on board. After nine months of successful operations, a failure of the attitude control system interrupted operations of the fine pointed instruments. Although the full-disk experiments (GRE, HXRBS, ACRIM) could continue functioning successfully, and in spite of the large amount of excellent data which had already been gathered, it was felt that the premature interruption of the mission had somewhat compromised its scientific goals. In April 1984, a spectacular rescue mission by astronauts on board Space Shuttle allowed replacing of the attitude control system and of other malfunctioning parts. At present, the repaired Solar Maximum Mission (SMM-2) is fully operational and may even last until the next maximum of solar activity in 1991.

Some of the results obtained by the Solar Maximum Mission are reviewed in this volume by Principal Investigators and Co-Investigators of the experiments on board, as well as by Italian scientists which have been involved in mission operations, data analysis and/or theoretical interpretation. The present paper is intended as an Introduction to the following contributions. It describes the spacecraft, the experiments on board, mission operations and the subsequent phase of data analysis. Highlights of the results obtained so far are given and the level of participation by Italian scientists is outlined.
Fig. 1
II) THE SPACECRAFT

The SMM satellite consists of two sections: an upper part which houses the various solar experiments, and a lower part for attitude control, power, communication and data handling. Fig. 1 shows an exploded view of the satellite with the major components indicated. Fig. 2 shows the assembled satellite as it looks when in orbit. The entire observatory is approximately 4 m in length and fits into a circular envelope 2.3 m in diameter. The total weight is about 2360 kg. The satellite is orbiting the Earth on a circular orbit at an altitude of about 570 km, inclination of 28.5 degrees and period of 96 min.

The top 2.3 m of the satellite comprises the instrument module which houses the scientific payload as indicated in Fig. 2. The instruments with small fields of view are coaligned, although launch vibrations caused small, known offsets. Below the instrument module, and separated from it by a transition adapter, is the so-called Multi-mission Modular Spacecraft (MMS) which was conceived by NASA as a multipurpose spacecraft to be retrieved by the Space Shuttle for possible use in future missions. It was equipped with a grapple point which allowed the satellite to be grasped by the Shuttle arm during the repair mission in the spring of 1984.

The MMS is a triangular framework supporting three modules which house the essential components of the three spacecraft subsystems: attitude control, power, and communication and data handling. The atti-
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tude control subsystem (ACS) stabilizes the observatory, points it to the desired target on the solar disk, and performs slew maneuvers for repointing or generating scan patterns. The accuracy of the pointing is ~5 arcsec in each of two orthogonal axes in solar coordinates. It was a failure of fuses in this module which terminated operation of fine pointing instruments on November 23, 1980. The ACS module was re- placed in orbit by the Shuttle astronauts in April 1984.

The communication and data handling (C & DH) module receives commands uplinked from the ground, allows tracking, stores on-board data in tape recorders, transmits data to ground via telemetry, and provides the On-Board Computer (OBC) and its interfaces. The power module supplies the necessary electric power for operation of the satellite. The power is supplied by the solar array system during orbit days, and by three rechargeable batteries during orbit nights and eclipses. A high-gain antenna system is attached at the bottom of the observatory for radio linking with the ground.

III) THE EXPERIMENT PAYLOAD

The Solar Maximum Mission carries on board seven experiments (one, the XRP, actually made of two separate instruments) to observe the solar radiation over the entire range of wavelengths from gamma rays to the infrared. The only notable exception is the spectral range 20-1000 Å originally planned to be covered by an Extreme Ultraviolet Spectrometer of the Harvard College Observatory which later had to be cancelled. Table I gives a summary of the experiments, the wavelength ranges covered, the Institutions involved and the names of Principal Investigators.

Gamma Ray Experiment (GRE)

The Gamma Ray Experiment, developed jointly by the University of New Hampshire, Durham, N.H. (USA), the Max-Planck Institute for Physics and Astrophysics, Garching (FRG) and the Naval Research Laboratory, Washington, D.C. (USA), measures the hard X-ray continuum in the energy range 300-500 KeV and the gamma ray emission in the energy range 10-100 MeV, as well as detecting gamma ray lines above 0.3 MeV which result from prompt nuclear deexcitation, radiative capture and positron annihilation. The instrument is described by Forrest et al. (1980).

The heart of the gamma ray experiment consists of 7 Na I(Tl) scin- tillation detectors which form the spectrometer operating between 0.3 and 9 MeV. The instrument provides a 476-channel pulse height spec- trum with energy resolution of 7% at 662 KeV. The temporal resolution is normally 16.38 sec, which, however, can be increased up to 2 sec in three windows between 3.5 and 6.5 MeV to study the prompt gamma ray lines at 4.4 and 6.1 MeV. A 50 KeV hard X-ray window centered at 330 KeV is read every 64 ms for fast time resolution studies of bursts.
The spectrometer is complemented by a CsI(Na) high energy detector to measure gamma rays in the range 10-100 MeV and neutrons 220 MeV, and by two X-ray detectors for the energy bands 10-80 KeV and 25-140 KeV. The time resolution of the high energy detector is 2.05 sec, that of the X-ray detectors is 1.0 sec. The purpose of the latter detectors is to provide correlated data for identification of the times when electron acceleration is occurring on the sun. It is expected that during the same time protons and other ions producing the nuclear excitation are also accelerated.

The objective of the Gamma Ray Experiment is to use the time and spectral information from both nuclear gamma ray lines and the photon continuum to study the acceleration of particles in solar flares. Prior to SMM our knowledge of nuclear acceleration in solar flares was extremely scanty, at least from an observational point of view. Most of the available data came from the observations of flares on August 4 and 7, 1972 by an instrument onboard OSO-7. These measurements showed gamma ray lines at 0.5 and 2.23 MeV as well as some features at 4.4 and 6.1 MeV (Chupp et al. 1973). Theoretical calculations (e.g. Ramaty et al. 1980) indicated that gamma ray line radiation associated with solar flares had to be expected as a consequence of the interaction of energetic nuclei with the solar atmosphere. The most prominent lines were expected to be at 0.511 MeV (due to electron-positron annihilation), at 2.23 MeV (due to neutron capture) as well as at 4.43 MeV and 6.13 MeV (due to prompt nuclear deexcitation of $^{12}$C and $^{16}$O, respectively). The GRE has confirmed these expectations and has increased enormously our understanding of particle acceleration in solar flares. As all other full disk instruments on SMM (HXRBS and ACRIM), the Gamma Ray Experiment continued to work after the failure of the spacecraft attitude system in November 1980.

**Hard X-Ray Burst Spectrometer (HXRBS)**

The Hard X-Ray Burst Spectrometer, developed by the Goddard Space Flight Center, Greenbelt, Md (USA), was designed to study the role of energetic electrons in the flare phenomenon. The instrument is described by Orwig et al. 1980. It consists of an actively-shielded CsI (Na) scintillation detector which operates in the spectral band 23-386 KeV. Pulse-height analysis provides spectral information in 15 energy channels within the above spectral range. The temporal resolution is 0.1 sec, but it can be as high as 10 msec for the photon flux integrated over all energy channels. The instrument views the entire solar disk and has no intrinsic spatial resolution.

The HXRBS is similar to hard X-Ray Spectrometers flown by the Goddard group on previous satellites, particularly on OSO-5 and OSO-8. Its major advantages with respect to previous experiments of the same type is the higher temporal resolution (0.1 sec instead of $\sim$1 sec as in most previous instruments) and the higher sensitivity, which has allowed detection of an extremely high number of bursts (several thousands) during the SMM mission. The time and spectral information pro-
vided by the HXRBS allows the study of the impulsive electron acceleration to energies ~20-100 keV, associated with microwave and Type III bursts, as well as of a possible secondary acceleration stage to energies greater than ~1 MeV, associated with radio bursts of Type II and IV. In addition, the HXRBS data has proved to be particularly useful for comparison with spatially resolved X-ray and UV observations obtained by other instruments on SMM.

**Hard X-Ray Imaging Spectrometer (HXIS)**

The Hard-Ray Imaging Spectrometer, developed jointly by the Space Research Laboratory at Utrecht, The Netherlands, and by the Department of Space Research of the University of Birmingham (U.K.), is a particularly valuable instrument on board SMM. For the first time it allowed imaging of the X-ray emitting flare plasma at higher energies (>3.5 keV) than attainable with grazing incident soft X-ray telescopes (Vaiana et al. 1977). The instrument is described by Van Beek et al. (1980). It consists of a mechanical collimator made by a two-dimensional array of subcollimators and coupled to a position sensitive detector system constituted by an array of mini-proportional counters. Collimation per subcollimators is obtained by means of grids equipped with holes glued to plates, placed at specific distances along the main axis of the collimator and precisely aligned relative to another in the plane perpendicular to that axis. The instrument has two different co-axial fields of view corresponding to two different spatial resolutions. The central Fine Field of View has a spatial resolution of 8''x8'' over an area of 2'40''x2'40''. The Coarse Field of View has a lower spatial resolution (32''x32'') over a larger area (6'24''x6'24''). The energy range imaged is from 3.5 to 30 keV and is subdivided into six energy channels for broad-band spectral information. Temporal resolution depends on the mode of operation but is typically of a few seconds. The instrument provided a flare flag (in time and position) for the other experiments on board SMM.

The main purpose of the HXIS instrument was to image the X-ray flare plasma in a region between the soft and the hard X-ray regimes. In particular it was aimed at determining the spatial distribution of the emission during the impulsive phase of flares with the intent of discriminating between thermal and non-thermal models of flares. It was also aimed at studying the spatial distribution of soft X-ray emission in the very late phases of large flares with the purpose of determining the distribution of high energy electrons in the regions which emit radio bursts of Type II and IV. Both these objectives were fulfilled during the mission as described by M. Machado and Z. Svestka later in this volume. Unfortunately, the HXIS experiment which had stopped operating in November 1980, malfunctioned in June 1981 and could not be repaired during the rescue mission in the spring of 1984.

**Soft X-Ray Polychromator (XRP)**

The Soft X-Ray Polychromator is a joint experiment of the Rutherford-Appleton Laboratory at Chilton (U.K.), the Mullard Space Science
Laboratory of the University College at Holmbury St. Mary (U.K.) and the Lockheed Palo Alto Research Laboratory at Palo Alto, Ca. (USA). Co-principal investigators are L.W. Acton, J.L. Culhane and A.H. Gabriel. In order to cope with the conflicting demands of spatial, spectral, and temporal resolution, the XRP consists of two separate instruments, the Flat Crystal Spectrometer (FCS) and the Bent Crystal Spectrometer (BCS) which share a common control, data handling and power system. Both instruments operate on the principle of Bragg diffraction and use mechanical collimators to limit the field of view. A full description of the XRP instrumentation can be found in Acton et al. (1980). The FCS provides spectroheliograms simultaneously in seven spectral channels. The spatial resolution (FWHM) is 14" x 14", and the area to be observed is imaged by moving the axis of the entire system across the chosen region on the Sun in a raster pattern. The size of the area to be covered can vary on command from one resolution element (15" x 15") up to 7' x 7'. The temporal resolution depends on the size of the area to be rastered and on the sampling step size (which is usually 15''). In practice, the temporal resolution of most FCS observations range from 14 sec for the smallest areas rastered so far (30" x 30'') to more than 4 minutes for rastered areas of 4' x 4'. Higher time resolution (~1 sec) can be reached in the "sit and stare" mode, with the instrument imaging continuously the same pixel. Longer integration times (up to ~1/2 hour) are needed to perform full 7' x 7' rasters for active region studies.

Seven flat crystals, mounted on a common shaft, are used and the radiation diffracted by the crystals is collected by independent detectors. For a given angular position of the crystal shaft, the detectors record monochromatic radiation at seven wavelengths over the range 1.4-22.4 Å. In the spectroscopy mode, the FCS crystal shaft may be rotated under computer control to scan selected portions of the spectrum. Owing to the failure early in the mission of one of the redundant electronic units commanding the crystal rotation, the spectroscopy mode was used sparingly during SMM-1. Additional crystal scans, however, are being acquired during SMM-2.

In the standard position of the crystal shaft (the so-called "home position") the detectors are arranged in such a way as to record the resonance lines of O VIII at 18.97 Å, Ne IX at 13.45 Å, Mg XI at 9.17 Å, Si XIII at 6.65 Å, SXV at 5.04 Å and Fe XXV at 1.85 Å. These lines are emitted most strongly at temperatures of, respectively, 3x10⁶, 4x10⁶, 6.5x10⁶, 10x10⁶, 15.5x10⁶ and 50x10⁶ K, covering the range of coronal temperatures expected to occur in solar flares. An additional channel, originally aimed at recording the resonance line of Ca XIX at 2.85 Å (T_e = 30x10⁶ K), actually measured the continuum emission adjacent to the line.

Conceptually, the FCS instrument is similar to previous photoelectric mapping spectrographs which combine Bragg crystals and mechanical collimators. However it has a substantially higher spatial resolution in the mapping mode and a higher spectral resolution in the spectral mode. The latter varies over the available spectral range and is
10^{-9} \text{ Å} at the shorter wavelengths and 10^{-2} \text{ Å} at the longer wavelengths. The superior temperature discrimination of the FCS instrument with respect to broad-band X-ray observations allows the investigation of the multitemperature structure of the soft X-ray flaring plasma, and of its time evolution.

The Bent Crystal Spectrometer provides high resolution spectra in limited wavelength regions in the range 1.7-3.2 Å. In particular, it allows the exploration of the resonance, intercombination, and forbidden lines of the helium-like ions CaXIX and FeXXV as well as of their lithium-like satellite lines. It allowed also investigation of lines of FeXXVI (this channel only in the early phase of the mission) and of Fe K-\alpha emission. An important advantage of the BCS with respect to more traditional scanning instruments is the fact that its curved crystals allow a given spectral range to be recorded simultaneously at high resolution. This gives a better time resolution and a higher accuracy in the application of plasma diagnostic techniques. The temporal resolution is typically of a few seconds, although substantially longer integration times are usually required when applying diagnostic techniques, in order to reduce statistical fluctuations. The spatial resolution is coarse, with a field of view limited to a 6' x 6' FWHM area on the Sun.

The XRP has acquired many observations of flares and active regions during SMM-1, and is continuing to operate successfully during the repaired SMM. Some of the most important results obtained so far are summarized by L. Culhane, A. Gabriel and L. Acton elsewhere in this volume. The spectroscopy diagnostic techniques which can be applied to FCS and BCS observations are reviewed by F. Bely-Dubau and A. Gabriel. The high spectral resolution of the BCS allows measurements of line broadenings and shifts as summarized by E. Antonucci in this volume.

Ultraviolet Spectrometer and Polarimeter (UVSP)

The Ultraviolet Spectrometer and Polarimeter, developed by the Goddard Space Flight Center at Greenbelt, Md and the Marshall Space Flight Center at Huntsville, Ala., is a modification of the University of Colorado OSO-8 Ultraviolet Spectrometer flight spare unit. As such it uses much of the hardware and technology developed for the OSO-8 project. The Principal Investigator is E. Tandberg-Hanssen. The instrument, described by Woodgate et al. (1980), consists of a Gregorian Telescope and an Ebert-Fastie Spectrograph. By moving the telescope secondary mirror it is possible to make two-dimensional rasters of features of interest on the solar surface. The spectrometer grating can be rotated to allow selection of the wavelengths of interest. The grating is used in first and second order, which correspond to the spectral ranges 1750 to 3600 Å and 1150 to 1800 Å, respectively. A polarimeter is located behind the entrance slit to measure magnetic fields in the solar transition region. Five photoelectric detectors allow measurements of up to four spectral lines simultaneously.
The UVSP is probably the most versatile instrument on SMM and can be used in a variety of different modes. Its primary objective is to study the ultraviolet radiation from the solar atmosphere, in particular from active regions, flares and prominences. Contrary to most experiments on SMM, it allows also the study of the quiet sun. Another objective is to conduct an astronomy program to measure various constituents of the Earth’s atmosphere. In the raster mode, the instrument has a maximum field of view of 4' x 4' and a maximum spatial resolution of 3'' x 3''. Up to four emission lines can be recorded simultaneously, covering the temperature range \(10^6\) to \(2 \times 10^6\) K. The most commonly used UV lines are C IV at 1548 Å, Si IV at 1394 and 1403 Å, O V at 1371 Å and Lyα. Coronal emission from Fe XXI at 1354 Å (T \(\sim\) \(10^7\) K) may also be recorded during flares. Spectral scans can be made around the lines of interest by rotating the grating. This allows line profiles to be measured with a spectral resolution of 0.02 Å in second order and 0.04 Å in first order. By splitting a line profile into approximately equal halves by a beam splitter mirror leading to two separate detectors it is possible to determine velocities by measuring the difference in the signals from the two halves of the profile caused by Doppler shifts. Two-dimensional Dopplergrams can be constructed to study mass motions in the solar atmosphere. Finally, both linear and circular polarization can be measured. The temporal resolution of the instrument depends on the mode of operation and varies from \(\sim\)1 sec to several minutes.

The UVSP operated very successfully during SMM-1. A summary of the principal results obtained is given in this volume by E. Tandberg-Hanssen and W. Wenze (non-flaring Sun) and by C.C. Cheng (flares). After the repair of the mission in the spring 1984, the UVSP restarted operations. Some initial problems with the grating drive mechanism have been apparently solved and the instrument is again functioning well.

**Coronograph/Polarimeter (C/P)**

The Coronograph/Polarimeter, developed by the High Altitude Observatory at Boulder, Co., is the most recent version of an externally occulted Lyot coronograph previously flown on other missions such as Skylab. The SMM instrument, described in detail by MacQueen et al. (1980), differs most substantially from earlier instruments in: a) employing a double objective lens to improve the chromatic properties of the optical train; b) utilizing a Vidicon detector instead of photographic film; c) using spectral filters to discriminate between ejecta at high (coronal) and low (chromospheric) temperatures as well as to isolate the Fe XIV 5303 Å coronal emission line and to separate the K corona from F corona. It also features a polarimeter to measure linear polarization in the Fe XIV 5303 Å line.

The instrument images a solar quadrant from 1.6 \(R_\odot\) to \(\approx\) 6 \(R_\odot\), or a smaller part of it. The spatial resolution is 10''. Seven filters mounted on a rotating wheel are employed to isolate different spectral regions over the range 4448 to 6585 Å. In particular three filters
(blue, green and red) are used to separate the K corona and the F corona components, a narrow band filter is used to isolate the green Fe XIV 5303 line, and a 42 Å wide filter is used to isolate the Hx chromospheric emission. Three polaroids allow measurement of the linear polarization of the coronal radiance at 5303 Å, thus providing information on the orientation (not intensity) of coronal magnetic fields, through the process of coronal scattering of photospheric light by resonance fluorescence. The detector is a SEC Vidicon optimized for astronomical applications. The pointing of the C/P is independent of that of the spacecraft, so that the C/P can always look at the center of the solar disk irrespective of where the other instruments are pointed.

The C/P was intended to study coronal mass ejections associated with flares and erupting prominences, to determine the mechanism which drives the ejecta, to establish the relationship between coronal transients, prominences and metric Type II and Type IV radio bursts, and to map the global density and magnetic field structure of the corona. During SMM-1, operations of the Coronograph/Polarimeter had to be interrupted prematurely owing to a failure of the main electronics box. The box has been replaced by the astronauts of the Space Shuttle and the C/P is again in full operation.

**Active Cavity Radiometer Irradiance Monitor (ACRIM)**

This instrument, built by the Jet Propulsion Laboratory of Pasadena, California, is unique among the SMM instruments, since it was not designed for the study of solar flares. Rather, it measures the integrated solar irradiance from the ultraviolet to the infrared with high sensitivity to variations and high precision (better than ~0.1% over long time periods). The instrument is described by Willson (1979). It is an updated version of similar pyrheliometers flown previously on sounding rockets. In the instrument (which actually consists of three independent sensors) the heat produced in a black painted conical cavity by the absorption of solar radiation is compared with the heat produced on the same detector by the dissipation of a known amount of electric power. The main objective of ACRIM is to monitor short-term variations of the total solar irradiance, associated with activity on the sun, as well as long term variations of possible climatological significance. ACRIM has been extremely successful and has provided some of the most outstanding results of the mission.

**IV. DATA ACQUISITION AND ANALYSIS**

From the very beginning, the Solar Maximum Mission was conceived as an array of complementary instruments to be operated simultaneously as to provide a multiwavelength description of the flare phenomenon. To this purpose, it was necessary to ensure a high degree of coordination between the different experiments. This was done by establishing an Experiment Operation Facility (EOF) at the NASA Goddard Space Flight Center at Greenbelt, Md (USA). All hardware groups had their teams at
the EOF for running the experiments, quick look data analysis and rapid reaction to changing conditions on the Sun. Most of the in depth data analysis during SMM-1 was carried out at the EOF, which was also the meeting point of guest investigators and external collaborators.

During the mission, the telemetry data were available within a few hours to the experiment groups at the EOF and were rapidly reduced for a first evaluation of the results. Each morning a planning meeting was held between representatives of the various SMM experiment teams and personnel from NOAA, who reported on the activity status of the Sun and on the forecast for the following 24 hours. In this way, it was possible to acquire a large number of coordinated data sets, as well as optimizing the operation of the various instruments on the basis of the data already acquired. This coordinated operation of the experiments makes SMM distinctly different from previous space missions.

In the period between the end of SMM-1 and the renewal of operations in 1984, the EOF has remained the center for dissemination of the data and for preliminary data reduction, although most of the experiment teams had moved back to their home Institutions. With the start of SMM-2, the EOF has reacquired its essential role in the planning, coordination and quick look analysis of the data, although on a somewhat reduced scale. At present, each experiment team keeps only a small number of people at the EOF, while most of the in depth data analysis is carried out at the home Institutions. In fact, the 3½ years elapsed between SMM-1 and SMM-2, have witnessed an intense analysis of the data which has made it much easier to plan future observations.

Although SMM was not conceived as an Observatory-type mission for use by the general astronomical community, a Guest Investigator Program was established early by NASA to allow access to the mission by a larger number of people. Accepted Guest Investigators could propose their own observing programs, generally upon agreement with the relevant P.I.'s. Other Guest Investigator Programs were related to coordinated ground-based observations as well as to theoretical efforts aimed at a better interpretation of the data. Further collaborations could also be established by direct agreement with the various P.I.'s.

The early results from the Solar Maximum Mission were published in 1981 as a special issue of the Astrophysical Journal Letters (Vol. 244). Subsequent analysis greatly benefitted from various meetings organized in connection with the Solar Maximum Year (in Crimea, at Annecy etc.). A joint HINOTORI-SMM Symposium was held in Tokyo in October 1982 with a purpose of comparing flare research from SMM and the Japanese satellite HINOTORI. A special Meeting devoted to SMM data analysis has been organized recently in connection with the Cospar Meeting (Graz, July 1984). However, the greatest impetus to SMM data analysis came by the SMM Workshops which were organized in 1983/84 both in the U.S. and in England.

The US-SMM Workshop series, directed by M. Kundu and B. Woodgate,
was held at the Goddard Space Flight Center. Three meetings took place in January and June 1983 and in February 1984. The participants were almost 200. This was the largest series of Workshops which covered all aspects of SMM flare research. The Proceedings of the Workshop are being published by NASA as a Special Monograph on Solar Flares.

The U.K.-SMM Workshops were organized by P. McWhirter and were held in Oxford in April and September 1983 and in March 1984. They were attended by about 60 people and covered a more limited list of topics. No publication of Proceedings was foreseen, the main purpose of the Workshop being to stimulate collaborative studies to be published in the open literature. A summary report of the U.K.-SMM Workshops has been prepared by P. McWhirter for inclusion in the present volume.

V. HIGHLIGHTS OF RESULTS

The Solar Maximum Mission has provided many new important results and has contributed substantially to our understanding of the flare process as well as of other activity phenomena on the Sun. Many new findings are reviewed in the various papers which constitute this volume. Other results, not mentioned in the following contributions, are briefly summarized in this section.

Results from the Gamma Ray Experiment have been reviewed recently by Chupp (1984). More than 150 flares with photon energies greater than 270 keV have been detected in the first four years of operations. The observed emission consists of a continuum due to relativistic electron bremsstrahlung, plus an excess emission between ~1 and 8 MeV due to narrow and broad gamma-ray lines. In about 30 events, lines are strong enough to be individually detected. In a few cases, high energy neutrons (with energies up to 1 GeV) have been observed. Gamma-ray emission is believed to be produced by the interaction of energetic charged particles (ions and electrons), accelerated at the time of the optical flare, with the dense atmospheric layers, likely the footpoints of coronal loops. From the observed gamma radiation and neutrons it is possible to infer the charged particle distribution at the flare site. This provides important clues about the acceleration mechanism.

Several gamma ray lines have been detected over the energy range ~0.5-8 MeV. These include prompt lines due to nuclear deexcitation (of \(^{16}\)O at 6.13 MeV, \(^{12}\)C at 4.44 MeV, \(^{14}\)N at 2.31 MeV, \(^{20}\)Ne at 1.63 MeV, \(^{24}\)Mg at 1.37 MeV, \(^{56}\)Fe at 1.24 MeV), as well as delayed lines at 2.23 MeV (due to neutron capture) and at 0.511 MeV (due to electron-positron annihilation). The observed events last from ~10 sec up to ~20 min, with individual pulses which can be as short as 10 sec in events of ~1 min duration, and as long as 2 min in events of 20 min duration. There is only a poor correlation between the detection of gamma-ray events and the importance of the associated optical flare. A gamma ray event may be associated with optical flares of any H\(\alpha\) class. Most events
with photon energies >270 KeV are associated with optical flares of class B; however, only a small fraction (20%) of flares of class >2B show an excess 4-8 MeV emission due to gamma-ray lines. For instance, the large two-ribbon flare of 21 May 1980 did not produce gamma-ray emission. Even more significantly, there is no correlation between the gamma-ray events seen by GRE and the flux of cosmic rays observed at Earth. This may indicate that the energetic particles responsible for GRE events are accelerated by a different mechanism and/or at different sites than those responsible for proton flares observed from the ground.

Probably the most important result obtained by the Gamma Ray Experiment has been the finding that at least in some flares particle acceleration occurs within ~1 sec over an extremely broad range of energies, from less than 100 KeV to more than 10 MeV. This is opposite to the early concept that relativistic electrons and ions were accelerated by a "second stage" process which is delayed by several minutes with respect to the initial acceleration of electrons to energies less than 100 KeV. The GRE data are consistent with rapid acceleration of ions to energies >50 MeV and of electrons to >10 MeV, all within ~1 sec. These requirements pose severe constraints on the acceleration mechanisms and are not easily satisfied by the acceleration mechanisms proposed so far.

Probably, the largest number of flares detected from SMM has been observed by the Hard X-ray Burst Spectrometer. More than 7000 events have been detected by this instrument with good sensitivity and high time resolution. This has provided us with an unprecedented sample of temporally and spectrally resolved observations of hard X-ray flares, to be used for statistical purposes. A substantial degree of fine structuring has been observed in many flares with quasi-periodic fluctuations over time scales of ~1 sec.

As discussed by C.C. Cheng in this volume, there is a good temporal correlation between individual peaks seen in hard X-rays and localized brightenings in ultraviolet emission lines (OIV, OV, SiIV). This indicates that energetic electrons, released during the impulsive phase of flares, deposit their energy in the dense atmospheric layers. The hard X-ray burst is usually accompanied by localized UV brightenings in many different points, indicating that energy release and/or deposition occur in different parts of the flaring area. There is only a poor correlation between the intensity of hard X-ray peaks and the intensity of the corresponding UV brightenings, which suggests that the relationship between the two emissions is far more complicated than it may be expected. An important question is whether the energetic electrons responsible for hard X-ray bursts carry enough energy to explain the subsequent gradual phase of flares. Unfortunately, the estimates of the energy carried by electrons depend critically on the assumed low-energy cutoff of the electron energy spectrum, and the answer to the above question remains largely controversial.

Results from the Hard X-ray Imaging Spectrometer are reviewed in this volume by M. Machado. One of the most significant results has been
the finding that during the impulsive phase hard X-ray emission origi-
nates from loop footpoints, rather than from the loop apex. This can
be taken as evidence in favor of a non-thermal thick target model of
hard X-ray emission, as opposite to a thermal interpretation. Whether
this result applies to all flares, and whether the energy deposited at
the loop footpoints is sufficient to explain the radiative output du-
dring the subsequent thermal phase remains to be determined. Another
interesting result found by HXIS has been the discovery of large-scale,
long-lasting high temperature arches associated with two-ribbon flares
and with Type I radio noise storms. This topic is reviewed in this
volume by Z. Svestka, who interpretes such phenomena in the framework
of the Kopp and Pneuman (1976) model of post-flare loops. For a de-
vlopment of this model for two-ribbon flares see also the contribution
by R. Kopp and G. Poletto in this volume.

Additional information on the impulsive phase of flares have been
provided by high resolution spectra obtained with the Bent Crystal
Spectrometer. During the impulsive phase, large non-thermal broadenings
are observed in high temperature lines such as CaXIX and Fe XXV. This
indicates the presence of a high level of turbulence in the flare pla-
sma at the onset of the transient event. The broadenings decay rapi-
dly towards the flare peak and are not observed during the gradual pha-
se. Blue-shifted components corresponding to upward velocities of se-
veral hundred kilometers per seconds are also observed at the onset of
the impulsive phase, as reviewed in this volume by E. Antonucci. The
blue-shifted component is usually interpreted as indicating evaporation
of chromospheric material driven either by non-thermal energy deposi-
tion or by heat conduction. Simple order of magnitude estimates indi-
cate that the blue shifted components may carry enough energy to ex-
plain the subsequent gradual phase of flares. However, it remains un-
clear whether the blue shifted components describe the real dynamic
process of mass and energy transfer to the thermal flare phase, or ra-
ther if they represent only an insignificant aspect of the entire fla-
re energy budget. The smallness of the blue shifted component (~20%)
with respect to the stationary component remains puzzling and it is at
variance with the predictions of model calculations assuming simple
loop geometries.

The observations from SMM have stimulated the development of time
dependent hydrodynamic calculations which describe the energy and mass
transfer during transient events. The characteristics of different co-
des and how they compare with each other are discussed by R. Kopp in
this volume. One of the code is described in somewhat more detail by
G. Peres and S. Serio, who show that hydrodynamic flare simulations
are capable of reproducing quite satisfactorily the observed general
properties of flares, especially the light curves observed by the X-
Ray Polychromator on SMM. Work remains to be done to establish whether
the models are also able to reproduce detailed line profiles as those
observed by the XRP and UVSP. Preliminary investigations indicate
that simple loop models predict larger blue-shifted components than ob-
erved (e.g. Cheng et al. 1983, Doschek et al. 1983). Whether this
is due to some fundamental limitation of the models, or rather to geo-
metry effects remains to be established. R. Mewe discusses in this volume the spectroscopic signatures of out of ionization equilibrium effects by combining time-dependent ionization equilibrium calculations with the results of numerical simulations of flare dynamics in a loop structure. The expected effects are found to be too small to be detectable at the sensitivity level of the SMM instruments.

The high spectral resolution of the BCS and FCS instruments (the latter when used in the spectral scanning mode) has allowed the application of sophisticated plasma diagnostic techniques, to derive temperature, density, velocity and ionization ratio in the flaring plasma. This is discussed in this volume by L. Culhane, L. Acton and A. Gabriel in their review of XRF results. The atomic energy calculations and the plasma diagnostic techniques are discussed in more detail in the contribution by F. Bely-Dubau and A. Gabriel.

Results from the Ultraviolet Spectrometer and Polarimeter are reviewed in this volume by E. Tandberg-Hanssen and W. Henze (non-flaring sun) and by C.C. Cheng (flare studies). For the first time, it has been possible to measure the intensity of the magnetic field in the transition region using the Zeeman effect. Longitudinal magnetic fields of ~1000 gauss were measured above sunspot umbras using the C IV line at 1548 Å. Unfortunately, it is not possible to determine precisely the height above the photosphere of the C IV emitting region and hence the field gradient. Oscillations in the C IV line were observed above sunspots with periods ranging from ~130 to 170 sec. The observed oscillations are interpreted as due to acoustic waves trapped in the umbral atmosphere.

Use of the UVSP in the Dopplergram mode has allowed the study of mass motions in the transition region. Steady flows have been observed with velocities of the order of ~5 km sec\(^{-1}\). The flows tend to be downward over bright C IV areas and upwards above quiescent areas. A variety of flows have also been observed in loop structures and prominences. Preliminary models for interpreting loop flow observations are discussed in this volume by G. Poletto and R. Kopp. SMM has also confirmed early results from OSO-8 implying that the energy flux carried by acoustic waves is insufficient to provide for coronal heating.

As discussed by C.C. Cheng in this volume, transition region densities in flares can be derived from the ratio of the Si IV allowed line at 1402.8 Å and the O IV intersystem line at 1401.2 Å. Derived densities during flares are of the order of ~10\(^{13}\) cm\(^{-3}\), about one order of magnitude larger than the preflare value. The ultraviolet emission in the O V line (at T ~ 2.5 \times 10^5 K) usually peaks early during the impulsive phase and is strongly correlated with hard X-ray emission observed by HXRBS. On the contrary the coronal line of Fe XXI (T ~ 10^7 K) peaks later during the flare gradual phase. Observations of flares with the UVSP have demonstrated the importance of loop interactions in the flare energy release process. A similar conclusion has also been reached on the basis of HXIS observations, as discussed by M. Machado in this volume.
Results from the Coronograph/Polarimeter have been reviewed recently by Wagner (1984). The most interesting of them refer to observations of coronal mass ejections, i.e. sudden expulsions of dense clouds of plasma out of the gravitational potential well of the Sun. Coronal mass ejections, or more generally white-light coronal transients, were discovered by Skylab near the minimum of the sunspot cycle. Subsequent observations by the P78-1 satellite and the C/P on SMM have greatly increased our knowledge of this type of phenomena, and have allowed a comparison to be made between the occurrence of coronal transients at the sunspot maximum and minimum. A surprising result is that the frequency of occurrence of coronal transients remains virtually constant from the minimum to the maximum, in spite of the fact that, for instance, the flare frequency has increased by a factor of 6. The explanation is that only a small fraction (10 to 20%) of coronal mass ejections are, indeed associated with flares. A larger fraction is associated with erupting prominences, whose rate of occurrence did not change appreciably from the minimum to the maximum. Even more interesting, a very large fraction of coronal mass ejections (30 to 50%) appear unassociated with any activity phenomena on the solar surface, and may result from neutralization of large-scale magnetic fields away from active regions.

The mechanism responsible for the onset of coronal mass ejections remains unclear. It may be a pressure pulse that consists of increased temperature, magnetic energy or mass, such as occurs in erupting prominences or flares; or, alternatively, the mass ejection may be driven primarily by magnetic forces. Contrary to the early picture based on Skylab observations, there is now a large body of evidence which suggests that coronal mass ejections are three-dimensional in shape and more similar to blobs rather than loops. The mass injected into the solar wind by a coronal ejection may be up to $10^{18}$ gr and the total energy may exceed $10^{32}$ erg. As already found by Skylab, the energy released in the form of mass motions may be a large fraction (probably the dominant one) of the total energy released in a solar flare.

Important new results have been obtained by means of simultaneous radioheliograms from Culgoora and C/P observations from space. Prior to SMM, there was a general consensus that metric Type II bursts were produced by the action of the shock wave travelling in front of the coronal mass ejection. Observations by the C/P has definitely disproved this concept. On the contrary, coronal mass ejections are intimately related to moving type IV bursts. The sources of type IV bursts appear to be hot plasmoids at coronal temperature, cospatial with the top of coronal mass ejections.

Results from the Active Cavity Radiometer Irradiance Monitor have been reviewed recently by Willson (1984). For the first time, the ACRIM observations from space have allowed detection of variations of the total radiative output of the sun (the so called "solar constant"). The largest variations - at a level of 0.3% - are associated with the presence of large sunspots on the solar disk and correspond approximately to the fraction of the solar disk covered by spots. These variations last typically from days to week. More subtle variations are
associated with the presence of faculae on the solar disk. The observation of these variations indicate that the energy flux which is missed in sunspots - likely by the inhibiting effect of magnetic fields - is not redistributed elsewhere on the solar surface on time scales much shorter than the lifetime of active regions. The ACRIM results, on the contrary, are consistent with temporary storage of the energy on time scales at least as long as the lifetime of active regions. The relevance of these observations for our understanding of energy transport in the subphotospheric convection zone and in the presence of strong magnetic fields is at present the subject of intense debate.

The high precision of ACRIM has allowed detection of the 5-min oscillations in the integrated solar radiation, with amplitudes of a few parts per million and coherence lifetimes of at least one week. As is now recognized, the five-minute oscillation is a signature of global solar oscillations. The ACRIM results therefore are of an extreme importance, since they have opened up an entire new field of space research aiming at studying the internal constitution of the sun by monitoring the variations of solar luminosity (helioseismology). These researches will be pursued by future space missions such as the planned European Solar and Heliospheric Observatory (SOHO).

Finally, analysis of the data gathered so far has shown a constant decline of the total solar irradiance since 1980 at a rate of 0.04% per year. This may indicate a possible variation of the solar constant along the sunspot cycle. If SMM can last past the solar minimum, we can have an unique opportunity to see whether this trend continues (as it appears unlikely) or whether it will change sign, following the activity cycle. Long term monitoring of variations of the solar irradiance is important for understanding climate changes on the Earth. The variations observed so far are too small to have any significant effect on Earth's climate. However, only future observations extended over much longer time periods may allow ascertaining the possible climatological significance of the observed variations.

VI. THE ITALIAN PARTICIPATION

Italian scientists have participated at all phases of SMM data acquisition, analysis and interpretation as official, and unofficial, co-investigators, guest-investigators and collaborators. In most cases it was not necessary to go through formal NASA Guest Investigator proposals, which in any case were not financially supported by NASA for non-US participants and which were usually limited to specific programs. More often, direct agreement with the P.I.'s proved to be more effective allowing Italian scientists to join the various experiment teams and to work in tight collaboration with the hardware groups. An early hardware effort by the Laboratory for UV Spectroscopy of the Arcetri Observatory in connection with the planned Harvard experiment on SMM, although successfully completed in due time, suffered from the cancellation of this experiment shortly before launch.
The Italian participation has been financially supported by the National Research Council (Consiglio Nazionale delle Ricerche) through the National Space Program (Piano Spaziale Nazionale) which is here gratefully acknowledged. Several groups in Italy have taken part in the Solar Maximum Mission and related activities, particularly scientists from the Osservatorio Astrofisico di Arcetri/University of Florence, the Institute of Physics at the University of Turin, the Osservatorio Astronomico di Capodimonte/University of Naples, and the Osservatorio Astronomico di Palermo/University of Palermo. E. Antonucci, R. Pallavicini and G. Poletto spent long periods at the Goddard Space Flight Center in mission operations and data analysis. F. Chiuderi-Drago and R. Falciani were involved in ground-based radio and optical observations coordinated with SMM; G. Noci, G. Peres and S. Serio contributed theoretical expertise and models to be used in the interpretation of the observations. Many others, working in collaboration with the above people, have contributed to the analysis and interpretation of SMM data and coordinated ground-based observations. Their names, too numerous to be listed individually, can be found in the papers referenced throughout this volume.

Italian scientists were mainly involved in two experiments on SMM, i.e. the X-Ray Polychromator (XRP) and the Ultraviolet Spectrometer and Polarimeterer (UVSP). Data from other SMM experiments (particularly the HXRBS and HXIS) were also used. This explains why in this volume the emphasis is on the results obtained by the above mentioned experiments, with very little or no mention of the equally important results obtained by other instruments such as GRE, C/P and ACRIM. For a detailed summary of the results of the latter experiments we refer the reader to the Proceedings of the US-SMM Workshops as well as to the papers quoted in the previous section.

On behalf of the Italian solar physics community I would like to conclude this introduction by expressing our warmest thanks to the P.I.'s and experiment teams which gave us the opportunity to join them in this exciting venture and which were always extremely cooperative and friendly both in the U.S. and during their visits to Italian Institutions. Their spirit of collaboration is demonstrated also by their prompt response to the invitation of the Italian Astronomical Society which has allowed the publication of this special issue of the Memorie.

REFERENCES