

## THE SOLAR MAXIMUM MISSION

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Received 1980 September 4; accepted 1980 December 1

### ABSTRACT

The *Solar Maximum Mission* spacecraft, launched on 1980 February 14, carries seven instruments for the study of solar flares and other aspects of solar activity. These instruments observe in spectral ranges from gamma-rays through the visible, using imaging, spectroscopy, and high-time-resolution light curves to study flare phenomena. In addition, one instrument incorporates an Active Cavity Radiometer for accurate measurement of the total solar radiant output. We review some of the most important current observational and theoretical questions of solar flare physics and indicate the ways in which the experiments on *SMM* will be able to attack these questions. The *SMM* observing program is described. The observing programs of the instruments for the study of flares are planned together, at a central location, to provide simultaneous observations of solar events by several instruments whenever possible. A Guest Investigator program has been initiated which allows broad use of these instruments by the scientific community and supports ground-based observations in conjunction with *SMM* observing programs.

*Subject headings:* Sun: activity — Sun: flares — Sun: general

### I. INTRODUCTION

Many different phenomena combine to make up the complex event which is a solar flare. A wealth of individual studies of the different manifestations of the flare event now exists, and these investigations have contributed significantly to the development of a general conceptual picture of the processes taking place. The *Skylab* Workshop on Solar Flares (Sturrock 1980) was a focal point for much of the recent work on analysis of flare observations, and several reviews have summarized developments in flare theory (Priest 1976; Van Hoven 1976; Spicer and Brown 1981).

It is generally agreed that the energy of flares is derived in some way from magnetic field energy, but observations are not at present able to distinguish among several different theories of how this energy is released. Data from *Skylab* and from ground-based telescopes have shown that the basic structure of a flare is a magnetically confined arch within the lower corona. After the impulsive phase, the arch is seen to be filled by hot thermal plasma, with the hottest plasma ( $>2 \times 10^7$  K) at the top of the arch. But we do not know what type of magnetic instability within or near such an arch can trigger a flare and release the flare energy, and we do not know how or where electrons and protons are accelerated to relativistic velocities in flares.

To get a complete picture of the energy release in a flare, we must first observe the flare buildup. The development of the active region in which a flare occurs should be followed up to the actual time of the flare. This should include  $H\alpha$  images and magnetograms from ground observatories, as well as soft X-ray and UV space data on the evolution of the structure, temperatures, and densities in the active region. Measurements of magnetic fields at chromospheric and

coronal heights are particularly valuable, since it is probably the nonpotential magnetic fields at these heights which are annihilated during the flare. Some past observations of preflare active-region development have shown some evidence of characteristic flare precursors in the form of increased soft X-ray or hard X-ray emission, and such effects should be searched for in the future as well.

The impulsive phase of flares is the most important phase from a theoretical point of view and is also the most difficult phase to study observationally. Events occur on time scales of seconds, and important emissions cover the whole electromagnetic spectrum. During this phase of the flare, we must observe both the changing configuration of the flare plasma, best seen by UV and soft X-ray imaging instruments, and also the time evolution of the spectrum of high-energy particles within the flare and emitted by the flare into space or into the solar atmosphere. These particles can be studied through their characteristic emissions in hard X-rays, gamma-rays, and microwaves. Detection of gamma-ray lines, caused by nuclear reactions such as positron annihilation and deuteron formation, can also give information on the abundances of the very highest energy particles accelerated in flares and on how these particles propagate after acceleration. Particularly valuable is an ability to image hard X-rays, since such data can give direct information on the location of accelerated particles or superheated plasma within a flare. Recent high-resolution observations of microwave bursts (Hurford, Marsh, and Zirin 1980) have shown that microwave emission originates at the tops of flaring loops, and many theories predict that the microwave and hard X-ray emission will originate in the same place.

There is also considerable evidence in favor of the

hypothesis that hard X-rays in flares are emitted from an extremely hot thermal plasma ( $\sim 200 \times 10^6$  K) rather than by interactions of beams of accelerated particles with the ambient plasma. One strong argument is that a thermal source for hard X-rays greatly reduces the total flare energy required to produce the observed X-ray intensities. Through observations of the locations and light curves of hard X-ray and microwave emission, it should be possible to make a definitive choice between thermal and nonthermal models for these types of radiation.

Time histories of the impulsive emissions are also extremely important. The fine temporal structure of hard X-ray and microwave bursts must reflect conditions of the acceleration process, and correlations of X-ray and microwave light curves can give independent evidence on the similarity of origin of these two emissions. Soft X-ray and UV line intensity light curves are important indicators of temperature and density evolution during the impulsive phase of the flare. The evolution of the hard X-ray spectrum of flares shows the changes in the populations of accelerated electrons, either due to time variations in the source of these particles or to energy-dependent loss mechanisms.

Another important aspect of the energy release in flares is the fraction of energy released in the various forms of radiative and mechanical fluxes. *Skylab* data showed that as much as half of the total flare energy can appear in the form of kinetic energy associated with a coronal transient. The relative amounts of energy in

the various forms can vary greatly between flares, so it is important in analyzing any given flare to consider all of the major energy-loss mechanisms. A coronagraph instrument is needed in order to detect flare-associated coronal transients and to study the relationship between the initiation of the transient and the initiation of the flare itself.

Following the impulsive phase, a flare enters a thermal, or decay, phase when the hot plasma cools by conduction and/or radiation back down to a normal active-region state. At this time almost all of the flare-associated high-energy particles have disappeared. The time development of temperature and density in the thermal plasma can be followed by a soft X-ray or a UV spectrometer, and a high-resolution UV spectrometer can provide Doppler shift information about the motions of chromospheric, transition region, or coronal material along the magnetic structures which dominate the flare.

Answers to the theoretical and observational questions just described will require observations from a dedicated set of space experiments with capabilities specifically adapted to the study of solar flares. The *Solar Maximum Mission* provides such a package of dedicated experiments for the study of flares and other aspects of solar activity during the current maximum of the solar cycle. An overview of the *SMM* has been given by Bohlin *et al.* (1980); the investigations on the mission are summarized in Table 1. Six of these investigations will study solar flares and other aspects of

TABLE 1  
SMM EXPERIMENTS

| Experiment                                | Principal Investigator(s)                     | Organization(s)                                                 | Spectral Range                       | Spectral Resolution          | Spatial Resolution             |
|-------------------------------------------|-----------------------------------------------|-----------------------------------------------------------------|--------------------------------------|------------------------------|--------------------------------|
| Gamma-Ray Spectrometer . . . . .          | E. L. Chupp                                   | University of New Hampshire; Max Plank Institute; NRL           | 0.3–17 MeV<br>10–160 MeV             | 7.5%                         | full Sun                       |
| Hard X-Ray Burst Spectrometer . . . . .   | K. J. Frost                                   | Goddard Space Flight Center                                     | 20–300 keV                           | 16 channel                   | full Sun                       |
| Hard X-Ray Imaging Spectrometer . . . . . | C. de Jager                                   | Astronomical Institute at Utrecht; University of Birmingham     | 3.5–30 keV                           | 6 channel                    | 8"×8"                          |
| Soft X-Ray Polychromator . . . . .        | L. W. Acton<br>J. L. Culhane<br>A. H. Gabriel | Lockheed; Mullard Space Science Laboratory; Appleton Laboratory | 1.4–22.4 Å (FCS)<br>1.7–3.23 Å (BCS) | 1000 at 20 Å<br>25000 at 2 Å | 12"×12"<br>6'×6'               |
| UV Spectrometer and Polarimeter . . . . . | E. Tandberg-Hanssen                           | Marshall Space Flight Center; Goddard Space Flight Center       | 1100–3000 Å                          | 0.02 Å                       | 3"×3"                          |
| Coronagraph/Polarimeter . . . . .         | L. L. House                                   | High Altitude Observatory                                       | 4435–6583 Å<br>H $\alpha$<br>5303 Å  | 200 Å<br>±20 Å<br>±2 Å       | 6.4"×6.4"<br>or<br>12.8"×12.8" |
| Active Cavity Radiometer . . . . .        | R. C. Willson                                 | Jet Propulsion Laboratory                                       | UV-IR                                | ...                          | full Sun                       |

solar activity, while the seventh, the Active Cavity Radiometer, is designed to measure the total radiant output of the visible hemisphere of the Sun, on time scales of minutes to months, with an accuracy of better than 0.1%. The radiometer investigation is part of a long-term NASA program of solar constant monitoring and is primarily aimed at applications in solar interior structure studies, aeronomy, and meteorology.

The observational parameters listed in Table 1 for the *SMM* instruments represent typical values and do not necessarily summarize all possible operating modes of the instruments or the best possible resolutions. The individual instruments are described in some detail in a group of papers (Forrest *et al.* 1980, and following papers in that issue). It should be noted that within the X-Ray Polychromator investigation there are two separate instruments, the Bent Crystal Spectrometer and the Flat Crystal Spectrometer. A comparison of the instruments listed in Table 1 with the requirements for solar flare studies as discussed above shows that this payload can make almost all of the desired observations. This set of instruments can observe material at all of the temperature regimes found in flares, as well as those emissions arising from nuclear reactions and from relativistic particles.

The *SMM* spacecraft was launched into Earth orbit on 1980 February 14. The orbit is close to circular with an altitude of 574 km and an inclination of 28° to the equator. Spacecraft functions for this mission are provided by the Multimission Modular Spacecraft, which contains modules that house systems for attitude control, power, and communications and data handling. Pointing stability is approximately  $\pm 1''$ . The solar arrays supply between 1500 and 3000 watts of power. The total observatory weight is 2360 kg, with an overall length of 4 m and a diameter of 2.3 m exclusive of the solar arrays. The *SMM* is fitted with an attachment mechanism which would enable it to be retrieved by the Space Shuttle. The spacecraft and instruments have a minimum design lifetime of 1 yr, but since the spacecraft systems contain no consumables, an operating lifetime of several years is possible.

## II. THE OBSERVING PROGRAM

Each of the instruments on *SMM* has certain capabilities exceeding those of any instruments previously flown for the study of the Sun. Equally important, however, is the fact that these instruments can work together to do joint science by simultaneous observations of solar flares and other solar events. Five of the instruments on *SMM* have limited fields of view. These instruments have been mounted in such a way as to permit useful concurrent and cospatial observations by all instruments at all times.

To allow for close coordination of the observing

programs, all of the flare instruments on *SMM* are operated from the same Experiment Operations Facility (EOF) at Goddard Space Flight Center. Daily planning meetings are held to identify the most favorable target on the Sun for the next day's observations and to select an advantageous observing program in light of current solar activity and mission priorities. Target selections can be updated at any time before the observations are made, if changes on the Sun make this desirable. The daily observing plans of the *SMM* are coordinated with other programs for the study of solar activity, such as the Solar Maximum Year (SMY), and with occasional rocket and balloon flights which observe solar flares.

For both the planning and data reduction and interpretation phases of the *SMM* investigations, the presence of all of the experiment teams in the EOF is an essential element in the science of this mission. Close interaction on a daily basis is important in order to coordinate the observing modes of all of the instruments in response to day-to-day changes in solar activity. Equally important is the ability to compare data from different instruments in as close to real time as possible. Such comparisons allow a response of the observing program to the results of previous observations. The collocation of the experiment teams also allows a better forum for the detailed analysis of observational data in terms of flare physics than would otherwise be possible.

Plans for a Guest Investigator program for the *Solar Maximum Mission* were developed concurrently with other mission planning, and an initial group of Guest Investigations was selected in 1978. At the present time, 31 investigations from US institutions and 28 from foreign institutions have been selected. The intent of this program has been to broaden the use of the *SMM* facilities within the interested science community and to incorporate a wide variety of ground-based and other non-*SMM* observing facilities, and theoretical ideas and expertise, into the *SMM* program as a complement to the investigations of the *SMM* experiment teams.

Initial observations from the *SMM* experiments are presented in the following *Letters*. The analyses of flares jointly observed by several *SMM* instruments, especially the 1980 April 30 event, clearly merit combined analysis in greater depth. Such work is currently underway by the *SMM* teams. The presentations here are preliminary and may contain internal inconsistencies and uncertainties which will be reconciled in more mature analysis. This early publication is for the purpose of giving the scientific community access to these results as quickly as possible in the hope of stimulating further interpretations that may influence the observing program of the *SMM* later in the mission.

## REFERENCES

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