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HIGH ENERGY FLARE PHYSICS GROUP SUMMARY

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Abstract

We review the contributions of the High Energy Flare Physics Special Session in the American Astronomical Society Solar Physics Division Meeting in Laurel, Maryland on 8, 9 June 1989. Oral and poster papers were presented on observatories and instruments available for the upcoming solar maximum. Among these are the space-based Gamma Ray Observatory, the Solar Flare and Cosmic Burst Gamma Ray Experiment on the Ulysses spacecraft, the Soft X-Ray Telescope on the spacecraft Solar-A and the balloon-based Gamma Ray Imaging Device. Ground based observatories with new capabilities include the new BIMA, Owens Valley Radio Observatory and the Very Large Array. The highlights of the various instrument performances are reported and potential data correlations and collaborations are suggested.

1. Max '91 Objectives

In the 1988 Kansas City Max '91 Workshop there was no specific session on High Energy Flare Physics; rather sessions were devoted to specific scientific questions such as particle acceleration and energy release. As the next maximum approaches we must be ready to design and implement real observing programs. It is appropriate then that special attention be paid to solar physics from the perspective of the type of measurements to be made. Toward this end the High Energy Flare Physics session in the 1989 Laurel Max '91 Workshop brought experimenters together who will be conducting such observations focussing on the high energy aspect of the flare problem.

As has been the situation for many years, gains in understanding flare physics often derives from the merging of complementary data sets and coordinated observations with common scientific goals. The upcoming solar maximum can be studied with new instrumentation starting from ideas based upon our accumulated knowledge of past solar cycles.

Effective coordinated observations are difficult to conduct. As pointed out by Rust (1988), the early success of such coordinated observations early in the Solar Maximum Mission serves as a warning that despite our best intentions our target data sets will not be easily obtained. This problem is most severe for the case of high energy flares, i.e. where X-rays, γ-rays and emissions typical of high energy particles are present. The occurrence rate of such events is significantly lower than that of flares in general and their predictability remains a problem. For example, no joint observation of a γ-ray flare between GRS on SMM and the VLA comes to mind despite numerous opportunities.

However, the payoff of a few such coordinated observations can be large thus motivating us to pursue them. Such observations during the last cycle include the simultaneous measurements of OV ultraviolet emission and hard X-rays (Woodgate et al. 1983), relating the OV excitation to the energetic electron population; the γ-ray/white light measurements of the 1 July 1980 and 24 April 1981 flares (Ryan et al. 1983; Kane et al. 1985; Zirin and Neidig 1981), constraining the role of energetic protons with respect to electrons in the production of the optical continuum emission; and the measurements of neutron-decay protons (Evenson et al. 1983) and direct energetic neutrons (Chupp et al. 1983) from the 3 June 1982 flare, yielding a neutron spectrum over a wide energy range and over a wide emission angle.

For studying high energy flares in this next maximum, the community will have new powerful instrumentation. This instrumentation includes the Gamma Ray Imaging Device (GRID), the Gamma Ray Observatory (GRO), the Solar Flare and Cosmic Gamma-Ray Experiment (HUS) on Ulysses, HIGRES and the Soft X-Ray Telescope (SXT) on Solar-A. Ground based observations will be possible with improved capabilities of the VLA and Owens Valley Radio Observatory (OVRO) and the construction of BIMA. Although our goals for studying high energy flares are similar to those in 1980, our starting point is well along. Our instrumentation is more sensitive and our questions are more directed. For example, in 1980 a major question was whether or not the electrons which produce the hard X-rays are the same ones which produce the microwave and radio emission. After observing many flares from which both emissions were measured, we now know that there is no simple answer which applies to all events. A better question today might be "Can we identify in frequency or space the emission best correlated with the X-radiation > 100 keV and associate this with the magnetic structure of the active region"? Answering such questions requires detailed and coordinated observations. The purpose of this special session was to gather together the experimentalists who will be responsible for obtaining these detailed data so as to spawn ideas on how to conduct such measurements. It was also hoped that theorists would contribute suggestions on new observations; however, the special session on theory conflicted in time and we enjoyed only one theory contribution to the session. This contribution by Batchelor (1989) did, in fact, directly, addressing the causative agent for impulsive bursts. Relating the physics of the flare process to observational signatures is a difficult task with certainly less than a 100% probability of success. The exercise, however, is a useful one. By observing in multiple wavelengths the progression or evolution of moving plasma and electron distributions, one should be able to eliminate some transport processes from the realm of potential flare producing agents. One most easily identified, and perhaps eliminated, is the propagating modes of magnetic reconnection due to the wide range of Alfven speeds within different coronal structures. By proposing such observations to the experimentalists, one must discuss the limitations of the measurements and alternatives which may be offered which address the same problem. The interplay between the theorists and the experimentalists is important in formulating a program for the upcoming maximum.

The remainder of this review paper addresses only the contents of the contributed talks and poster papers. The details of each presentation can be found elsewhere in this volume. We only address the global aspect of the session.

2. The Gamma Ray Observatory

The Gamma Ray Observatory (GRO) will carry four large instruments whose main objectives are to undertake comprehensive observations of astrophysical sources throughout the 15 keV to 30 GeV energy range. However, GRO will also provide significant capabilities for observations of energetic solar gamma rays and neutrons, and therefore be an integral part of the MAX '91 program. GRO is scheduled for launch in June 1990, near the peak of the current sunspot cycle. A 6-10 year mission lifetime is expected.

2.1 Solar Physics with GRO

The GRO instruments, briefly described below, provide enhanced capabilities for solar flare observations relative to previous high-energy instruments (Kurfess, 1988). Improved sensitivities and time resolutions will be available over a broad range of gamma ray energies. The capability to measure unambiguously the flux and spectrum of solar neutrons is also available. With these capabilities, GRO will provide dramatically improved measurements of the temporal histories for the acceleration and interaction of electrons and ions in the flare. Correlation of these measurements with X-ray, microwave and mm-wave observations, particularly new imaging instruments, will be particularly beneficial to our understanding of the flare acceleration mechanism.

The improved high-energy gamma-ray and neutron observations will provide, for the first time, high-quality spectra of the most energetic particles in the flare. When combined with spectral information derived from nuclear line ratios at lower energies, these will provide our best data on the nature of the acceleration processes producing these high-energy particles.

GRO will significantly extend the studies begun with SMM regarding the isotropy of the energetic ions. The shape of the $\sim$ 450 keV ^{7}Li and ^{7}Be feature from α–α fusion can be used to investigate the nature of the ion beam, whether isotopic, fan beam, or pencil beam by studying γ-ray spectra vs. heliospheric longitude (Murphy et al. 1990). Correlation of these observations with lower energy imaging detectors should yield information on the spatial extent of ions in the flare region.

Finally, we mention the unique capability for line γ-ray observations to determine elemental composition and compositional anomalies in the flare region. These studies, also initiated with SMM (Murphy et al. 1985a,b), can be greatly expanded, and with other MAX '91 observations, should provide improved insight into the sites of particle acceleration and interactions.

2.2 The GRO Mission

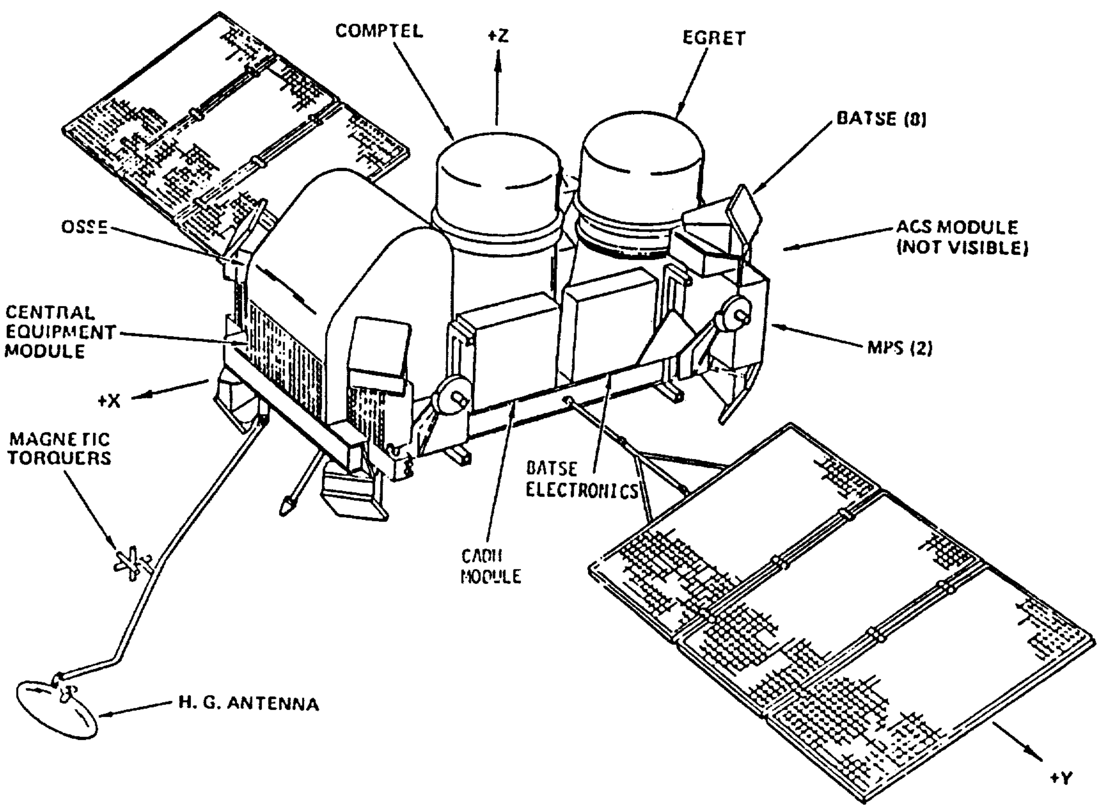

Figure 1. Illustration of the Gamma Ray Observatory and associated instruments. Three instruments (OSSE, COMPTEL, and EGRET) are mounted on the +Z side of the spacecraft. The Eight BATSE modules are located on the corners of the S/C to provide full sky coverage. The solar panels can rotate + 90 degrees about the Y-axis. The Sun is constrained to be located in the +X hemisphere and is further constrained to be not closer than 48 degrees to the Y axis.

The general configuration of the GRO is shown in Figure 1. Three of the instruments (OSSE, COMPTEL and EGRET) are located on the +Z side of the spacecraft. GRO is a three-axis stabilized spacecraft with solar panels that can rotate ± 90 degrees about the Y-axis, and with the Sun generally restricted to the +X hemisphere in the S/C coordinate system. This enables the +Z instruments to be pointed to any position on the sky at any time, including the Sun. The fourth instrument, BATSE, is designed to provide a full sky monitor for transient sources and consists of eight modules located on the corners of the spacecraft.

Following the initial on-orbit check-out of the GRO spacecraft and instruments, a 15-month phase will be conducted during which a complete sky survey will be obtained by the wide field-of-view EGRET and COMPTEL instruments. This will be accomplished using a sequence of about 30 two-week viewing periods during which the Z-axis of the spacecraft (see Figure 1) is held fixed at pre-selected positions on the sky. The viewing program is currently under development, and is subjected to a number of constraints (Bertsch, 1989). Solar observations can be incorporated during this period by selecting a viewing program that achieves a uniform sky survey while also placing the Z-axis near the Sun for selected viewing periods. If the periodicity and phase of the 155-day cycle observed during the last solar cycle (Rieger et al. 1984) can be determined, this can be used to optimize solar observations within the overall sky survey. It is also possible to consider "targets of opportunity" wherein the GRO viewing program is interrupted by a high- priority event, which could include a period when solar activity is expected to be high. Reorientation of GRO in response to a target-of-opportunity can be accomplished in less than 1 day (Kniffen, 1989).

2.3 GRO Instruments

A brief description of the four GRO instruments is given in the following sections. Characteristics of the instruments are listed in Table I.

2.3.1 BURST AND TRANSIENT SOURCE EXPERIMENT (BATSE)

The Burst and Transient Source Experiment (BATSE) consists of eight detector modules positioned on the GRO spacecraft to provide full coverage of the sky for cosmic gamma-ray bursts and transients (Fishman et al. 1985). Each module contains two uncollimated NaI scintillation detectors; a large area detector (2025 cm2), to provide high sensitivity and directional capability and a 125 cm^2 by 3.0"-thick NaI crystal which provides better energy resolution. The energy range covered is 15 keV to 100 MeV.

BATSE will have extensive capabilities for solar flare observations (Fishman et al. 1989) due to its large sensitive areas, versatile data system for handling transient phenomena, and continual observation of the Sun during daylight portions of the orbit. During

TABLE I. GRO INSTRUMENT SUMMARY

Instrument	BATSE	OSSE	COMPTEL	EGRET
Energy Range (MeV)	0.15–1.0(LAD) 0.15–100 (spect.)	0.05–10.0 10–150 (solar)	1–30	20–30000
Energy Resolution	30% (LAD) 8.0% (spect.)	8.0% (.6 MeV) 3.2% (6.1 MeV)	5–8%	15%
Time Resolution				
Broad-Band Spectroscopy	10μsec 1 sec	125μsec 4 sec	125μsec	100μsec
Effective Area (cm2) (maximum) (per module)	1800 (LAD) 125 (spect.)	1950 (0.5 MeV)	30	1000
Field-of-View (degrees)	Full Sky	3.8x11.4	45 FWHM	45x51

normal operations, BATSE will accumulate 16-channel spectra with 2-second resolution from all detector systems. Full 256-channel resolution spectra are acquired from each detector every one minute. Upon detection of a transient event, as defined by a programmable burst trigger algorithm, up to 4Mb of dedicated data can be stored for subsequent transmission to the ground. These data will provide the best time-resolved solar flare spectra available at high energies. This can include, for example, 192 high-resolution spectra from the spectroscopy detectors with time resolutions as short as 64 msec based on a time-to-spill algorithm. Higher time resolution can be obtained in an event-by-event mode which can store up to 64k events with a time resolution of 128 microseconds.

The burst trigger algorithm can determine the start of a transient event with a minimum timescale of 64 msec, clearly adequate for most solar phenomena. BATSE provides a burst trigger signal to the other three instruments on GRO which can use this signal to reconfigure operating modes for acquisition of burst data. Comparative rates in the four LAD's viewing the Sun can be used to determine the solar origin of an event. This information is also provided as part of the burst trigger signal to OSSE and COMPTEL which can establish operating modes specifically dedicated to solar phenomena.

2.3.2 ORIENTED SCINTILLATION SPECTROMETER EXPERIMENT (OSSE)

The Oriented Scintillation Spectrometer Experiment is designed to provide high sensitivity in the nuclear line region of the spectrum (Kurfess et al. 1989). Each of the four identical OSSE detectors is mounted in a single-axis pointing system which provides rotational freedom of 192 degrees about the spacecraft Y-axis. The OSSE is located on the +X (solar) end of the spacecraft, which will enable the drive capability to be used to point the OSSE detectors at the Sun without disturbing the Z-axis objectives of the COMPTEL and EGRET instruments.

The total OSSE detector area is 2685 cm^2, about 10 times that of the SMM gamma ray detector. A tungsten alloy passive collimator provides a 3.8° by 11.4° field-of-view for the study of localized sources. This requires OSSE detectors to be pointed at the Sun for primary solar flare observations. Pulse-shape discrimination is used distinguish gamma-ray and neutron interactions in the NaI and to provide a positive detection of solar flare neutrons in the energy range above about 20 MeV.

Spectra in the 0.1-10 MeV energy range are processed by two 256-channel PHA's; individual spectra are accumulated every four seconds. Above 10 MeV, 16-channel gamma-ray and neutron energy-loss spectra are accumulated, also with typical 4-second time resolutions. An event-by-event data mode for selected energy ranges (e.g. the 4.4 MeV and/or 6.1 MeV lines for ^{12}C or ^{16}O) with a time resolution of 0.125 milliseconds is available for high time resolution observations. Thus, solar flare spectra in the nuclear line region will be acquired with much improved sensitivity and time resolution when compared with SMM.

The operation of the OSSE instrument is controlled by redundant on-board micro-processors. In response to a BATSE burst signal indicating detection of a solar flare, the four detectors can automatically re-orient to the Sun if the Sun is located near the X-Y plane, (see Figure 1), which due to solar panel attitude constraints, will often be the case.

2.3.3 IMAGING COMPTON TELESCOPE (COMPTEL)

COMPTEL is designed to observe gamma rays in the 1-30 MeV energy range in a broad (approx. 1 sr) field-of-view centered on the spacecraft Z-axis. COMPTEL also provides and excellent neutron detection capability in the 20-200 MeV energy range. The instrument consists of two detector arrays; and upper array, D1, comprised of seven 28-cm diameter NE213A liquid scintillation detectors, and a lower array, D2, which consists of fourteen 28-cm diameter x 3" thick NaI scintillation detectors. The basic properties of the instrument are described in Schoenfelder et al. (1981). Solar capabilities are discussed by Ryan and Lockwood (1989). Operationally, an incoming gamma ray or neutron scatters in detector array D1, and the scattered particle is detected in array D2. See Figure 2. In those events where the scattered gamma ray is totally absorbed in D2, the energy of the incident gamma ray is the sum of the energy losses in the upper and lower detectors, and the arrival direction is confined to a cone whose axis is determined by the locations of the interactions in D1 and D2 and the Compton scattering angle derived from the scattering kinematics. For events of solar origin, the requirement that the Sun lie on the angular acceptance cone results in a gamma-ray spectrum with non-photopeak events strongly suppressed.

COMPTEL is sensitive to solar flares in three different operating modes. In the normal operating mode, COMPTEL provides high sensitivity to flares when the Sun is within the instrument field-of-view. This mode will provide excellent sensitivity for line and continuum gamma-ray emissions in the 1-30 MeV region. In addition, COMPTEL has the capability to observe transient phenomena, including solar flares, in a "single detector mode". In this mode, two of the fourteen NaI detectors are used to accumulate 256-channel pulse-height spectra in the 0.1 to 20 MeV region on programmable time scales of 0.1 to 25 seconds. The BATSE burst trigger signal is used initiate the acquisition of these spectra.

In the neutron detection mode a neutron elastically scatters on a hydrogen nucleus in a D1 detector and then interacts in a D2 detector. The energy loss in D1 and the time of flight between the upper and lower detector arrays is used to determine the neutron energy. The TOF information and pulse-shape discrimination in the D1 array are used to distinguish neutrons from gamma rays. The neutron mode is entered in response to a solar trigger signal from BATSE and will provide excellent neutron spectroscopy with a large signal-to- noise ratio for large flares.

2.3.4 ENERGETIC GAMMA RAY EXPERIMENT TELESCOPE (EGRET)

EGRET covers the high-energy portion of the spectrum from 20 MeV to 30 GeV (Fichtel et al. 1983). The instrument consists of two spark chamber modules which convert incoming gamma rays to positron-electron pairs. The arrival directions of incident gamma rays can be determined to several degrees at 100 MeV and to less than one degree at 1 GeV. EGRET's field-of-view is centered on the +Z axis and has a full-width-at-half- maximum of about 45° x 51°. A total absorption calorimeter below the spark chambers provides $\sim$ 15% energy resolution for gamma rays extending into the several GeV region.

EGRET provides solar flare capability in two modes. First, when the +Z axis of GRO is pointed to within 45 degrees of the Sun, EGRET provides high sensitivity to gamma radiation in the primary spectral region of the instrument. This will represent the first experiment to have good sensitivity in this spectral region for solar flares and will provide the opportunity to investigate the most energetic phenomena on the Sun through the gamma rays associated with neutral pion decay and the production of bremsstrahlung from the highest energy electrons in the flare region. In the second mode, the NaI crystal assembly is used to monitor transient events in the energy range from 0.6 MeV to 167 MeV. Upon receiving a BATSE burst trigger signal, 256-channel spectra will be acquired every 65.5 seconds during the flare or burst.

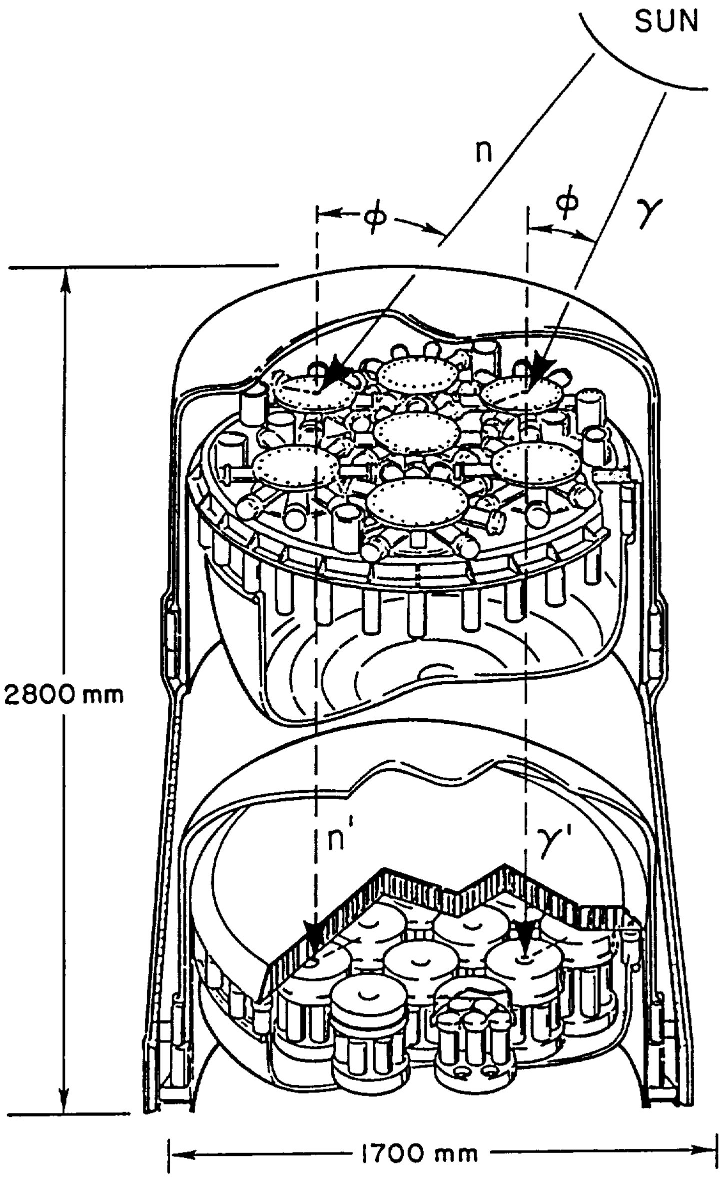

Figure 2. Imaging Compton Telescope (COMPTEL). Imaging is accomplished by reconstruction of event cones from incident gamma rays which scatter in a liquid scintillator array (D1) followed by detection of the scattered photon in detector array D2.

2.4 GRO Guest Investigator Program

A vigorous Guest Investigator program will be implemented on GRO. The GI program will be initiated during the 15-month sky survey phase and will reach full level about three years into the mission. During the sky survey phase about 50% of the BATSE data on flares will be made available for Guest Investigator studies. Also, a selected rate history from the BATSE detectors will be provided to the solar physics community, through the HXRBS/SMM analysis center at GSFC. OSSE opportunities will include OSSE data on selected flares (probably those same flares available from BATSE) and opportunities to participate on an OSSE Solar Flare team. These opportunities will be available through GRO a NASA Research Announcement.

To support GRO investigators, a GRO Science Support Center (GROSSC) is being established at GSFC (Kniffen, 1989). This Center will be the central point of contact between the GI and the GRO data, and will assist GI's and prospective GI's by providing access to selected GRO data, past and planned GRO observations, data analysis software, etc. A Center employee for each GRO instrument (Instrument Specialist) will be located at a PI institution to assist GI's with the detailed aspects of their investigations.

3. Hard X-ray and Gamma-Ray Imaging - GRID

To date, imaging solar flares above soft X-ray energies has been accomplished with limited sensitivity and with angular resolutions barely adequate to detect flare morphology. No gamma-ray imaging has been attempted. Such observations are critically needed to determine the precise locations of particle acceleration and interaction in the flare region for comparison with observations at lower energies. One of the three instruments selected for the MAX '91 Balloon Program, GRID, is designed to provide such observations.

GRID, Gamma Ray Imaging Device, is currently under development by a consortium led by Dr. C.J. Crannell of GSFC (Orwig et al. 1989). The instrument uses the technique of Fourier transform imaging and employs a 22-set scanning modulation grid collimator optical system and NaI non-position sensing detectors. Full Sun imaging in the 20-700 keV spectral region will be obtained with a limiting spatial resolution of 1.9 arc-seconds and time resolutions down to 100 ms.

The first flight of GRID is scheduled for a 8-14 day long-duration balloon flight to be launched from Antarctica in January, 1992. During a two-week balloon flight, it is estimated that $\sim$ 40 flares can be imaged at energies above 100 keV. These images, in conjunction with microwave imaging and high-energy observations provided by GRO, should provide critically needed information on the location and mechanisms for particle acceleration in solar flares.

4. The Soft X-Ray Telescope (SXT) on Solar-A

In studying the effects of high energy particles it is necessary that measurements be made at other wavelengths where manifestations of these particles may be found. The importance of soft X-ray measurements cannot be underestimated. The interplay between the thermal and non-thermal processes is not fully understood, so measuring the thermal plasma temperature in space and time is critical to constraining the role of particles in heating the solar atmosphere. As a rule soft X-rays always precede the impulsive phase of the flare, but only by a few seconds in many cases. The Soft X-Ray Telescope (SXT) on Solar-A should be capable of improving our coverage in this wavelength domain (Brown et al. 1989).

Solar-A is scheduled to be launched in September 1991 and thus is well timed with respect to the availability of GRID, GRO and Ulysses. SXT, a grazing incidence telescope with an intrinsic resolution of better than 4 arc-sec, will image in 64 $\times$ 64 pixels the field-of-view (6.25 arc-min^2) in several wavelengths. The five wavelength windows have been chosen to be most sensitive to variations in plasma temperature. Thus, a temperature image can be constructed in the limit with a angle resolution approaching that of GRID.

The telemetry of Solar-A is limited, so that the 64 x 64 image budget is restricted to 8000 per day coming from 5 accessible orbits per day. SXT will also construct up to 5 large images (1024 x 1024 pixels) of almost the full Sun at these same wavelengths.

5. The Solar Flare and Cosmic Gamma-Ray Experiment on Ulysses

For the experimental gamma-ray astronomer, solar flares are much like cosmic gamma-ray bursts. Both are emitters of transient gamma-ray fluxes with solar flares generally lasting somewhat longer. With the measurement techniques being identical, cosmic gamma ray burst detectors such as BATSE on GRO and the Solar Flare and Cosmic Gamma-Ray Experiment (HUS) on Ulysses can provide excellent high-energy photon data on flares. The HUS on Ulysses will provide the opportunity to measure gamma-ray fluxes from flares at large aspect angles with respect to the earth direction with virtually a 100% duty cycle. The trajectory of Ulysses takes the spacecraft first past Jupiter and then over the south and then the north solar pole. With such a configuration of Ulysses, GRO and perhaps GRID, we will have a situation similar to that of PVO and ISSE-3. That is, spacecraft at different heliographic latitudes will be making observations of the same solar flare, measuring the differential gamma ray flux from different aspect angles (e.g. Kane et al., 1979). These stereoscopic observations can provide data on the altitude dependence of the flux and the emission measure as a function of heliographic latitude.

HUS consists of two detectors, a Si surface barrier detector and a CsI omnidirectional scintillator (Boer et al. 1989). The CsI detector is probably most adaptable to solar flare studies. It has an area of 20 cm^2 operating in the range of 30 to 200 keV. This instrument on Ulysses is small, but has the advantage of spending a long period within 1 A.U. and observing the Sun almost continuously. In the burst mode, the mode in which flare data will be obtained, the detector accumulates 16-channel spectra at different accumulation times beginning with 1 s and progressing to 16 s for a total period of 496 s. The beginning of the burst (for 16 s) has the detector transmitting the total counting rate at an 8 ms cadence. At the end of this 496 s period the telemetry buffer is full and readout begins with continued monitoring of the total count rate every 0.5 s. But for the small area factor, the HUS instrument characteristics match well with BATSE. The period for which the spacecraft will be at high latitudes (> 70 degrees) is roughly 230 days.

The launch of Ulysses is to take place in October 1990. From there the trajectory takes it out to the orbit of Jupiter (5 AU), after which it begins its path over the south solar pole. The passage over the south pole takes place in 1994 with a similar passage over the north pole in 1995. The sensitivity of the HUS will, of course, be reduced at large solar radii, but the exposure towards the Sun will be well coordinated with the GRO and Solar- A. The prospect for obtaining complementary data sets is good.

6. Radio and Microwave Observations

6.1 Millimeter-Wave Imaging - BIMA

Millimeter wave observations provide information on the highest energy electrons in solar flares, and enable observations of this component into the chromosphere. Operating in an atmospheric window from 70 - 115 GHz, a consortium consisting of the Univ. of California (Berkeley), Univ. of Illinois and the Univ. of Maryland have established the BIMA mm-wave interferometer (Kundu et al. 1989) and plan to devote extended observing periods to solar flare observations.

BIMA will provide (by late 1990 or early 1991) a 6-element array. With 15 baselines, BIMA will be able to generate maps of solar flares with a temporal resolution of 0.1 sec and spatial resolution of $\sim$ 1 arc sec. Thus, BIMA will provide detailed maps indicting the electron acceleration and emission region with high-time resolution. Correlating these images with the maps obtained with GRID, Solar A, or with other high energy observations obtained, e.g. by GRO instruments will provide much greater insight into the acceleration region and mechanism.

6.2 Microwave Imaging and Spectroscopy - OVRO

The Owens Valley radio interferometer (OVRO) is currently undergoing an expansion which will provide a 5 antenna array (10 baselines) dedicated to solar observations. This system, to be operational in October 1990 (Hurford and Gary, 1989), will include two existing 27m antennae and three 2m antennae. Each antenna will be equipped with frequency agile receivers which can be tuned to 86 discrete frequencies in the 1-18 GHz band in rapid succession (10-30 frequencies/second).

With this expansion, the Owens Valley solar array will provide simultaneous imaging and spectroscopy. Two-dimensional microwave images with $\sim$ 2 arc-second resolution will be acquired in the 1-18 GHz band. This combination of spectroscopy and imaging will enable the acquisition of magnetograms at the base of the corona. The microwave spectrum is sensitive to the nature of the energetic electrons (thermal vs. non-thermal) and also provides information on the plasma properties in the flare region. This dedicated data set will be an integral part of many MAX '91 correlative studies.

6.3 The Very Large Array (VLA)

During the Solar Maximum Mission, the coincidence of positive VLA and GRS observations of a gamma ray flare did not occur (Kundu, priv. comm., 1989; Lang, priv. comm., 1989). For the purpose of coordinating radio/microwave telescope data with those from a gamma ray instrument, the VLA is in effect an unexploited instrument. Its imaging capability offers a real chance to relate the electron bremsstrahlung emission above 1 MeV to the optically thin microwave emission perhaps originating from the same original electron population. The populations responsible for these emissions could, in principle, be the same; but, more likely derive from the same population, fractionating by some unknown process. Recent work by Lang and Willson (1989) indicates that different parts or phases of a flare exhibit radio emissions from different sites. Until recently (GRID), all hard X-ray ($>$ 200 keV) and gamma ray instruments integrated over the entire solar disk. It has thus been difficult to identify the elements of the flare's temporal structure with physical processes or structures on the Sun. Spatial information has always been lacking. The new feature of the VLA which was not present in the last solar maximum is the ability to observe the full Sun at both 20 and 90 cm. The two wavelengths probe different depths of the corona and view different coronal structures.

To a high degree the emission of nuclear gamma rays is well correlated to the emission of electron bremsstrahlung $>$ 300 keV. We can use this fact with the spatial information provided by the VLA to locate the sites of electron activity in a flare, and thus the sites of energetic proton activity. What is required is dedicated and coordinated observing. Max '91 can provide the environment for such observing. The small field-of-view in earlier configurations of the VLA made the observation of a gamma ray flare an improbable event. With full Sun coverage, the likelihood of obtaining coordinated data sets is dramatically increased.

7. Conclusion

As compared to the last solar maximum, there will be new and different instrumental power being trained on the Sun. These instruments require different observing plans and goals to study the elusive high-energy solar flare. It is imperative that an organized effort be initiated to refine these goals and to devise the appropriate observing plan. The Max '91 Workshop is one of the first steps in that direction. Further work is necessary, before the maximum and before the first of the balloon-based and space-based instruments described above becomes operational.

What potential collaborations and data correlations may be possible with the instruments described above? The following are a few suggestions.

1) BIMA, OVRO and VLA with GRID

These radio and microwave telescopes each will offer better than 2 arcsec spatial resolution over a wide range of frequencies. Any of these data can be correlated with the images produced by GRID. All are sensitive to energetic electrons giving rise to gyrosynchrotron radiation and bremsstrahlung.

2) BIMA, OVRO and VLA with any or all of the GRO instruments

The GRO provides unprecedented sensitivity to electron bremsstrahlung radiation above 5 MeV. At these energies there is no confusion between thermal and non-thermal origins of the radiation. These energetic electrons in reasonable solar magnetic fields will radiate at optically thin frequencies observable to all the radio telescopes. The bremsstrahlung gamma-ray flux over a wide range of energies can be directly compared or contrasted with the radio and microwave images over a wide range of frequencies.

3) HUS with BATSE

The continuous coverage of the Sun by HUS at large solar aspect angles combined with the sensitivity of BATSE offer considerable prospects for a new set of stereoscopic observations of flares from different heliographic latitudes.

4) SXT with any or all of the GRO instruments

The role of energetic particles in heating the lower solar corona is still in question. If rapid images could be obtained by SXT, they could be compared to the gamma ray (electronic or nuclear) light curves to search for and study any correlations.

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