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# CAPABILITIES OF GRO/OSSE FOR OBSERVING SOLAR FLARES

J.D. Kurfess, W.N. Johnson, and G.H. Share
E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, DC 20375

S.M. Matz
Department of Physics and Astronomy
Northwestern University
Evanston, IL 60208

R.J. Murphy
Universities Space Research Association
Columbia, MD 21044

## ABSTRACT

The launch of GRO near solar maximum makes solar flare studies early in the mission particularly advantageous. The Oriented Scintillation Spectrometer Experiment (OSSE) on GRO, covering the energy range 0.05-150 MeV, has some significant advantages over the previous generation of satellite-borne gamma-ray detectors for solar observations. The OSSE detectors will have about 10 times the effective area of the Gamma-Ray Spectrometer (GRS) on SMM for both photons and high-energy neutrons. OSSE also has the added capability of distinguishing between high-energy neutrons and photons directly. The OSSE spectral accumulation time (~4s) is four times faster than that of the SMM/GRS; much better time resolution is available in selected energy ranges. These characteristics will allow the investigation of particle acceleration in flares based on the evolution of the continuum and nuclear line components of flare spectra, nuclear emission in small flares, the anisotropy of continuum emission is small flares, and the relative intensities of different nuclear lines. The OSSE observational program will be devoted primarily to non-solar sources. Therefore, solar observations require planning and special configurations. The instrumental and operational characteristics of OSSE will be discussed in the context of undertaking solar observations. The opportunities for Guest Investigators to participate in solar flare studies with OSSE will be presented.

## INTRODUCTION

Observations during the last solar maximum greatly increased our knowledge about solar flares. The Gamma-Ray Spectrometer (GRS) on the Solar Maximum Mission satellite, in particular, made a number of discoveries which relate directly to the process of particle acceleration in flares (for a review of GRS observations see Chupp 1984; for an overview of the current state of flare research and future prospects see the papers in volume 118 of Solar Physics as well as contributions in these proceedings). GRO will be able to observe the peak of the current solar cycle following its scheduled launch in June, 1990, and OSSE has the capabilities to extend the GRS observations to smaller flares and faster timescales, and to measure separately the high energy photon and neutron spectra. Thus, OSSE should help give a clearer picture of the flare process.

The Gamma-Ray Observatory (GRO) represents NASA's next major mission in high-energy astrophysics. GRO will carry four large instruments whose main objectives are to undertake comprehensive observations of astrophysical sources throughout the 20 keV to 30 GeV energy range. The general configuration of GRO is shown in Figure 1. GRO is a three-axis stabilized spacecraft. The solar panels can rotate ± 90 deg about the Y-axis, with the Sun restricted to the +X hemisphere relative to the S/C coordinate system. The movable solar panels enable the Z-axis of GRO (common axis of EGRET and COMPTEL) to be pointed to any position on the sky at any time, including the Sun. GRO will launched into a 450-km orbit with an inclination of 28.5 deg. The baseline mission duration is two years, although plans are being implemented for an extended mission.

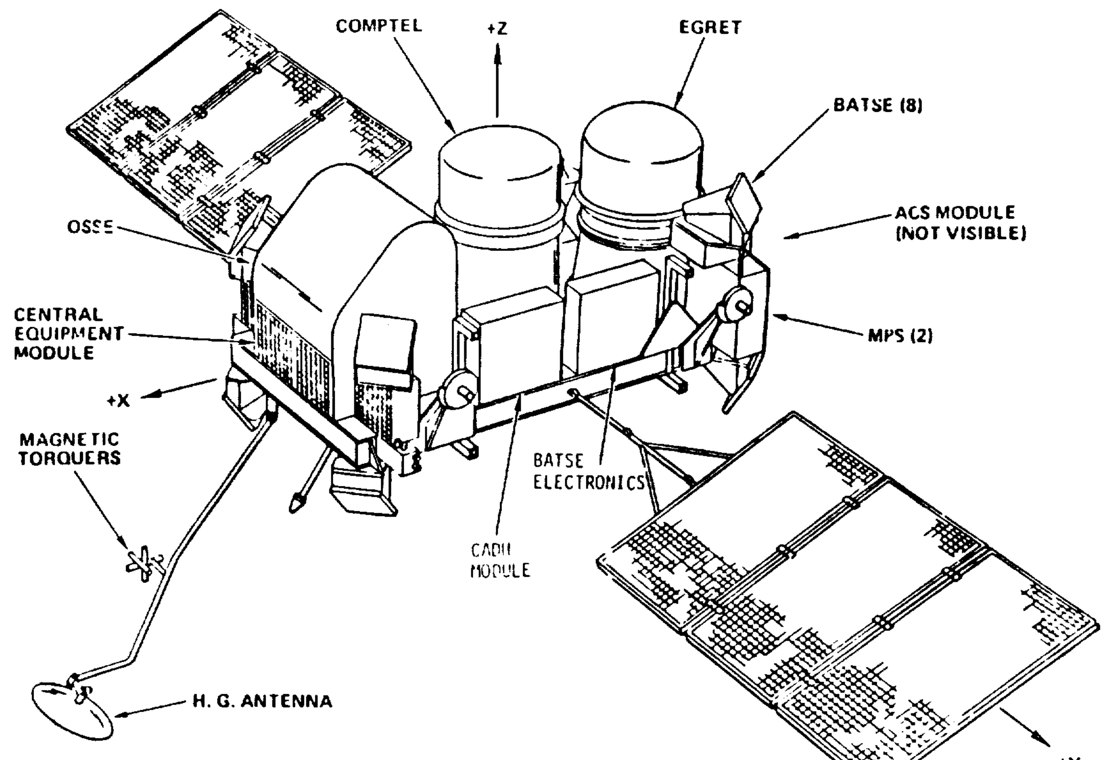


Figure 1. Illustration of the Gamma Ray Observatory and associated instruments. Three instruments (OSSE, COMPTEL, and EGRET) are mounted on the + Z side of the spacecraft. The eight BATSE modules are located on the corners of the S/C to provide full sky coverage. Other systems include the High Gain Antenna for communications with the TDRSS, Modular Power Systems (MPS), Command and Data Handling (CADH) system, and the Attitude Control System (ACS). The solar panels can rotate ± 90 deg about the Y-axis. The Sun is constrained to be located in the +X hemisphere and is further constrained to be not closer than about 50 deg to the Y-axis.

## II. THE OSSE INSTRUMENT

The OSSE instrument is described in detail elsewhere (Kurfess et al. 1983, Johnson et al. 1989), and the use of OSSE for solar observations has been discussed by Kurfess (1988). Figure 2 illustrates the overall OSSE instrument and Figure 3 is a diagram of an OSSE detector. Briefly, OSSE consists of four large NaI-CsI phoswich detectors, passively collimated, actively shielded on the sides with 3.35-inches of NaI and on the back by the CsI portion of the phoswich. Each detector can be independently rotated about an axis parallel to the spacecraft Y-axis, the axis of the solar panels (see Figure 1). This gives OSSE the ability to observe a number of different sources in a single GRO pointing. Normally, two or three celestial sources will be targets in a two-week interval; each target object will usually be observed by making measurements alternately with the source in and outside the detector field-of-view to obtain both source and background data.

Table 1: COMPARISON OF SMM/GRS AND GRO/OSSE CAPABILITIES

| | GRS | OSSE |
|---|---|---|
| Energy Range (main detectors) | 0.3-10 MeV | 0.05-10 MeV |
| Effective area at 511 keV | 150 $cm^2$ | 1950 $cm^2$ |
| Spectral time resolution | 16.384 s | 4.096 s |
| Field of view (FWHM, at 511) | $130^{\circ}$ | $3.8^{\circ} \times 11.4^{\circ}$ |
| Fast spectral windows | 300-350 keV<br>64 ms | 8 selectable<br>4-512 ms |

In Table 1 we have summarized some of the important characteristics of the OSSE instrument and compared them to those of the GRS (Forrest et al. 1980). Both instruments cover similar energy ranges and have similar energy resolutions. OSSE extends to a lower energy in its main spectral range; this range was covered by GRS with auxiliary X-ray detectors. Both instruments have the ability to measure high energy (>10 MeV) photons and neutrons. However, because of the pulse-shape discrimination employed on the OSSE phoswich detectors, OSSE has the additional capability of directly separating the neutron and photon signals. OSSE is much larger, with a total effective area (all four detectors) more than ten times that of the GRS at 511 keV. The normal spectral time resolution of OSSE is four times faster than that of the GRS. The fastest GRS time resolution was 64 ms in an energy window near 300 keV. In contrast, OSSE has eight programmable energy windows with time resolution of 4-512 ms.

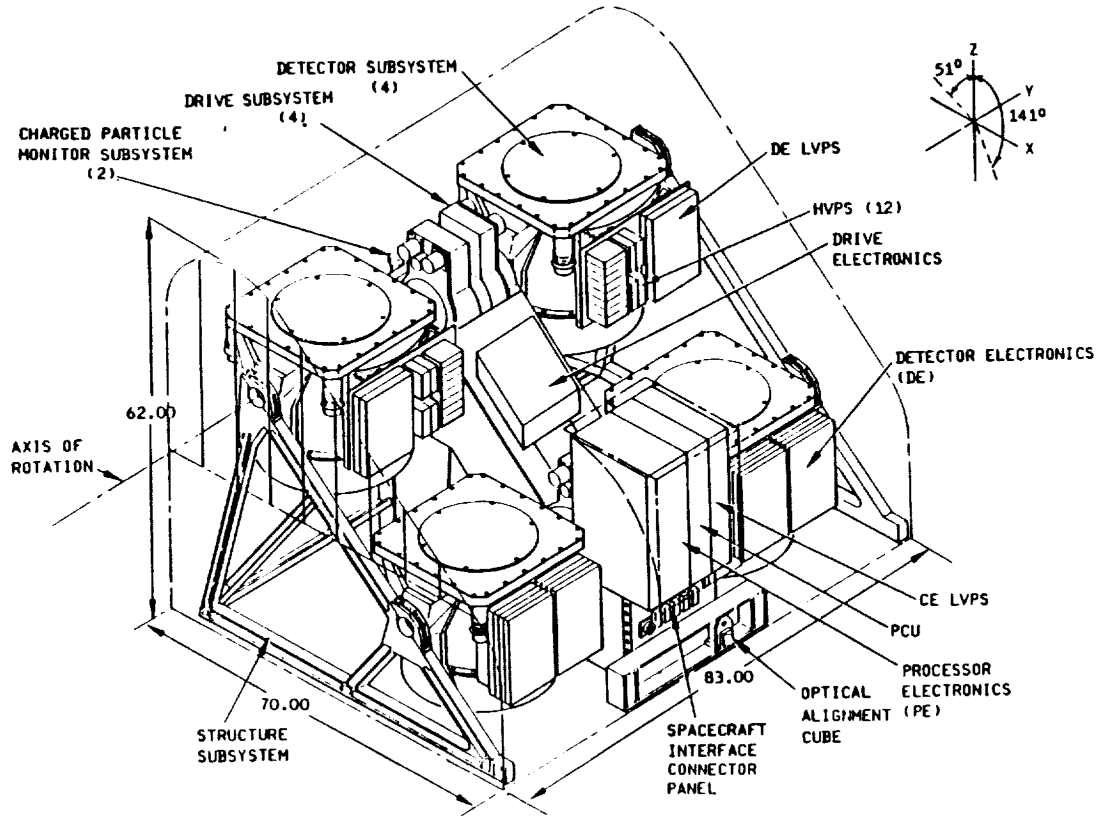


Figure 2. OSSE instrument for GRO. OSSE includes four identical scintillation detector assemblies. Each detector has an independent single-axis pointing system which has a 192° range of motion in the X-Z plane.

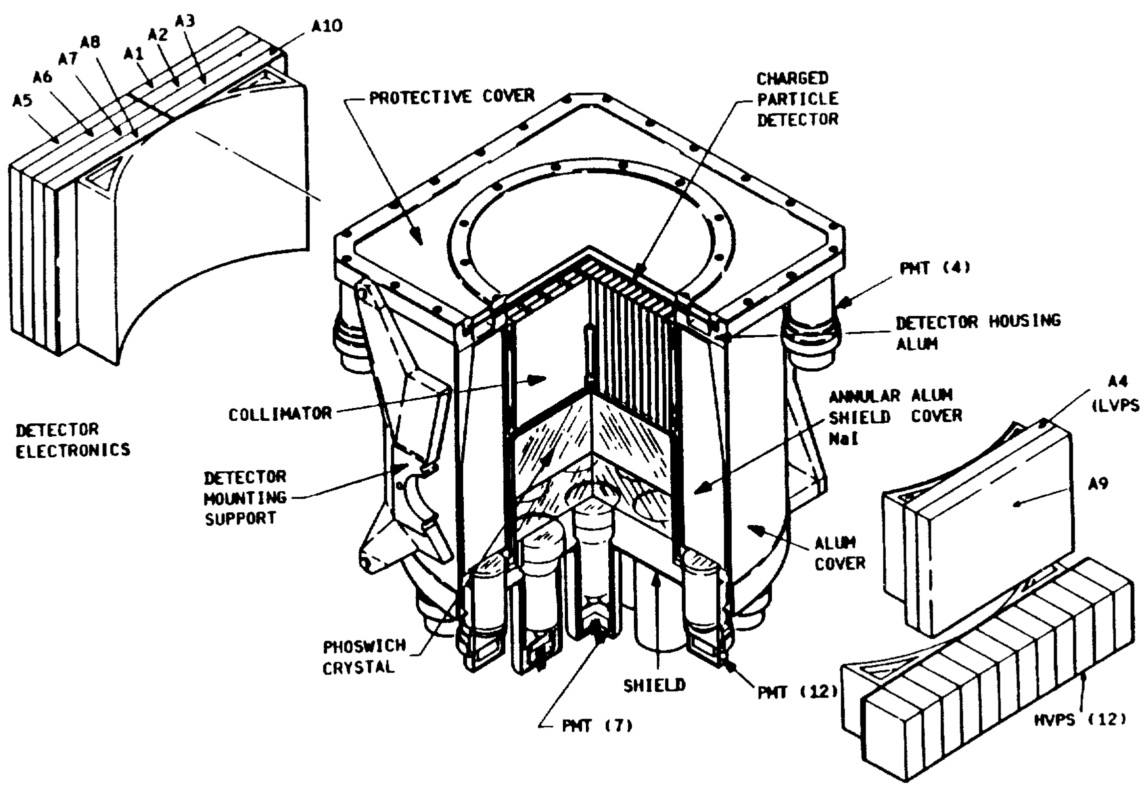


Figure 3. Cut-away view of an OSSE detector assembly.

Figures 4 and 5 compare the sensitivities of OSSE and SMM for the detection of $\gamma$-rays and neutrons respectively.

## III. SOLAR OBSERVING MODES

As described above, OSSE has a number of characteristics which make it valuable for solar observations: large effective area, fast time resolution, good spectral range, and the ability to distinguish between high energy photons and neutrons. This gives it the promise of significantly extending the work done with the GRS. However, unlike the GRS, it has a small field-of-view (defined by its collimator) and it is not a dedicated solar-pointing instrument. It is necessary therefore to plan observations specifically to acquire solar data with the main detectors.

There are three principal modes which can be used to observe solar flares. In the first case, the Sun may be selected as one of the OSSE sources for a GRO pointing. This implies that (typically) 50% of the time during a two-week viewing period would be dedicated to solar observation, with the Sun in the field-of-view of one or more of the OSSE detectors. The GRS discovered (Rieger et al. 1984) a 154-day period in the occurrence of gamma-ray flares, with 35% of such flares occurring in the 15.4 days at the peak of the cycle. If the coming solar maximum is as active as the last, and the 154-day cycle is present, we can choose our dedicated solar observations at the peak of the flare cycle. We would then expect to observe approximately 5 GRS-class flares in a two-week observation. We would also detect (presumably) a large number of flares which would have been too weak to be classified as gamma-ray flares by the GRS.

In addition to the pre-planned observations, solar activity may cause the Sun to be considered a target of opportunity. For example, a period of solar observing could be initiated by predictions of flare activity. Since the Sun can often be placed in the OSSE field-of-view simply by a detector rotation about the Y-axis, such observations will often be possible without requiring any re-orientation of the GRO spacecraft.

In the second mode OSSE would not have the Sun as one of the selected sources for a two-week observation. However, BATSE will provide, in addition to the normal transient event triggers, a flag signaling an event of solar origin, based on count ratios in the four BATSE detectors viewing the Sun. OSSE can be configured so that one or more of its detectors will be repositioned to point at the Sun after receiving a flare trigger from BATSE. Since the OSSE detectors can move at a rate of $2^{\circ}$ per second over a maximum angular range of $192^{\circ}$, solar pointing can be achieved within 45-90 s after the trigger.

Finally, when it is not possible or desirable to re-orient the detectors to put the Sun in the field-of-view, photon spectra can still be taken from the detector shield elements. In this mode we would choose to analyze the shield elements with the best solar exposure. This would allow dedicated monitoring of the Sun with large effective areas, ~ 600 $cm^2$ at 511 keV for each shield element. A small number of shield spectra that cover 0.1-8 MeV in 256 channels can be acquired at 4 s time resolution.

In any of these modes OSSE can be set up to change configuration electronically after a flare trigger to enhance observations. For example, the detectors could be commanded to stop chopping, or to transmit more detailed neutron data.

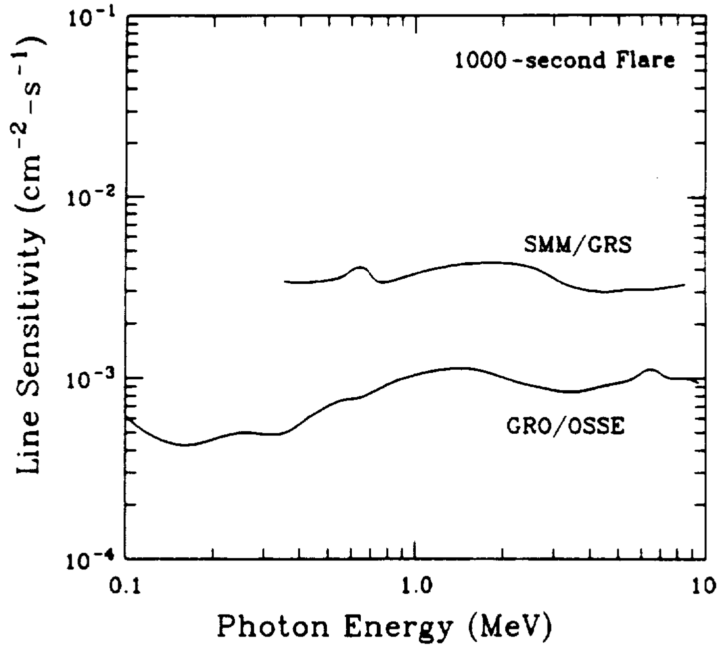


Figure 4. Comparison of the line gamma-ray sensitivities of the OSSE instrument on the Gamma-Ray Observatory with the SMM Gamma-Ray and Neutron Monitor. A flare duration of 1000 s was assumed, and the limiting sensitivities utilize nominal detector background but do not include any consideration of underlying solar continuum.

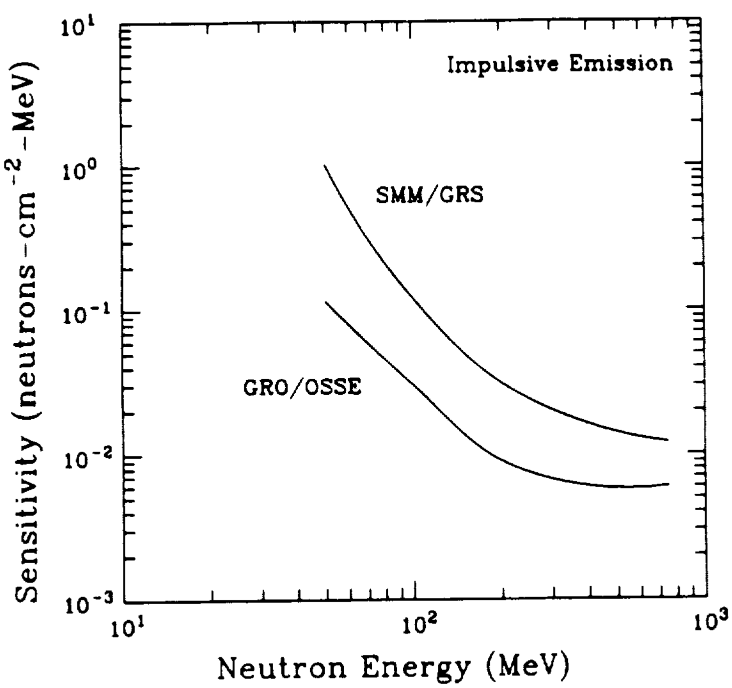


Figure 5. Comparison of neutron detection capabilities of the OSSE instrument on the Gamma-Ray Observatory with the SMM Gamma-Ray and Neutron Monitor. An impulsive neutron emission at the Sun is assumed, with no continuing high-energy solar gamma flux at the time of arrival of neutrons at the Earth.

# IV. OSSE SOLAR PHYSICS CAPABILITIES

Although OSSE is not optimized for viewing transient sources such as solar flares, its design characteristics nevertheless offer significant advantages over the previous generation of solar-flare-dedicated detectors. The increased sensitivity due to the large effective area of OSSE will provide substantial advancements in several areas in solar research. For example, it will allow the extension of the study of the electron and nuclear emission correlation discovered by the SMM/GRS (Forrest 1983) to much smaller flare sizes. This will help determine whether a threshold for ion acceleration exists.

The study of solar abundances, begun with the analysis (Murphy et al. 1985a,b) of the SMM/GRS data from the 27 April 1981 solar flare, can be extended to include a large number of flares. Data exists from several flares in the SMM data base, but the usefulness of these data is limited by its statistical quality. The high sensitivity of OSSE will improve this situation. The increased sensitivity will also allow for a search for ion acceleration by the quiet Sun, evidenced by the detection of the 2.223 MeV neutron-capture line or nuclear de-excitation lines such as the 4.44 MeV line from $^{12}C$.

Finally, the larger area could help resolve the issue of accelerated-ion anisotropy addressed by the analysis (Murphy et al. 1990) of the ~450 keV $^{7}Li$ and $^{7}Be$ lines from $\alpha$-$\alpha$ fusion observed by SMM from the 27 April 1981 limb flare. Observations of a disc-centered flare with sufficient statistical quality could distinguish an isotropic distribution from a fan-beam distribution; this is impossible for a limb flare except with a high-resolution detector. Associated with this analysis would be a determination of the fraction of flare-generated positrons which decay via positronium, as evidenced by the positronium continuum below the 511 keV annihilation line. This positronium fraction can provide information on the density and temperature at the annihilation site. The positronium continuum makes a contribution to the $<$511 keV emission comparable to that from the $\alpha$-$\alpha$ lines and the improved statistical quality of OSSE data will help distinguish between these two sources.

Another advantage of OSSE is improved time resolution. In some SMM/GRS events, electron and ion emissions were observed (Forrest and Chupp 1983, Kane et al. 1986) to have rapid fluctuations which were simultaneous to within the GRS temporal resolution (~2 seconds). Shorter timescales have been observed (e.g., Kiplinger et al. 1983) in hard X-ray electron emission but there are no corresponding measurements for nuclear emission. The high time resolution modes and large area of OSSE can be used to constrain relative electron and ion acceleration timescales to within several milliseconds.

The energy of the protons responsible for the production of nuclear line emission is 10 to 30 MeV while that of the protons responsible for producing the pions which yield the 100 MeV pion-decay emission is ~1 GeV. In the 3 June 1982 flare, these two emissions were observed (Ramaty and Murphy 1987) to be simultaneous to within the SMM/GRS temporal resolution of 16 seconds implying the simultaneous acceleration of the associated protons. The increased temporal resolution of OSSE will improve the constraint to within 4 seconds. This constraint is important for understanding the energy dependence of ion acceleration in solar flares.

One additional advantage of OSSE is the ability to directly distinguish between >10 MeV photons and neutrons. The SMM/GRS was able to do this to some degree either by arrival-time considerations or by appealing to the statistical nature of the detection process (Chupp et al. 1987). The former is inadequate when the gamma-ray and neutron production is extended in time and the latter has uncertainties inherent in the statistical approach. In addition, OSSE can directly determine the neutron energy spectrum which was accomplished by SMM through time-of-flight measurements, again inadequate when the emission is extended.

An important aspect of any effective observing program is correlation with observations made by other detectors at both similar and different wavelengths. Such correlated observations can directly address important issues of solar-flare research. For example, evidence for the anisotropy of relativistic electron bremsstrahlung, and therefore of the relativistic electrons themselves, has been obtained through statistical studies (Rieger et al. 1983, Vestrand et al. 1987, Rieger 1989, Dermer and Ramaty 1986) of flare locations on the solar disc. This anisotropy can be tested directly in individual flares through simultaneous observations by two spacecraft viewing the Sun from significantly-different directions; e.g. by GRO/OSSE and the proposed Ulysses mission (Cotin et al. 1983) which will view the Sun from out of the ecliptic plane.

Whether the hard X-ray emission from solar flares arises from thermal or non-thermal processes is a continuing controversy. Evidence for a non-thermal origin would be the unambiguous detection of footpoint emission from a flaring magnetic loop. Correlating OSSE observations with an imaging detector like the proposed GRID instrument (Crannell et al. 1988) would help resolve this issue.

Another question concerning particle acceleration is the relationship between flare protons observed in interplanetary space and the protons responsible for the gamma-ray emission. Proton kinetic-energy spectra deduced from gamma-ray observations by OSSE can be compared to direct spectral measurements of the protons escaping from the flare by spacecraft such as IMP-8 (assuming it continues to operate during some fraction of the OSSE mission) or the proposed CRRES mission (Gussenhoven, Mullen and Sagalyn 1985).

The upper energy limit for the detection of neutrons by OSSE is about several hundred MeV. This limit can be extended for large flares by correlating OSSE observations with those of ground-based neutron monitors. These monitors generally do not have energy resolution but can provide upper limits to the neutron energy spectrum (e.g., Murphy, Dermer and Ramaty 1987) and thus to the proton spectrum responsible for neutron production.

The relativistic electrons responsible for the hard X-ray and gamma-ray emission via bremsstrahlung also can produce microwave emission via the synchrotron process. Electron kinetic-energy spectra deduced from the hard X-ray and from the microwave measurements can be compared with OSSE data to provide insight into the physical properties of the common (if any) regions of emission. Observations with the VLA or from VLBI can also provide imaging of the microwave emission region.

## V. GRO GUEST INVESTIGATOR PROGRAM

A Guest Investigator program for GRO will be implemented with release of an initial NASA Research Announcement (NRA) planned for later this year. GI opportunities for the 15-month phase I (sky-survey) period of the mission will be limited primarily to opportunities on OSSE and BATSE. Increasing GI opportunities will be available during the second and third years of the mission, and beyond.

Since GRO will be launched at the peak of solar activity, interest in using GRO data for solar flare work is expected to be high. In order to accommodate representation from the solar physics community, both in terms of planning and implementing solar observations with OSSE, and in analysis and interpretation of solar data, GI representation on an OSSE Solar Physics Science Team will be solicited as part of the NRA. Questions relating to solar opportunities with OSSE should be directed to J. Kurfess, OSSE Principal Investigator, or R. Murphy, Team Leader for the OSSE Solar Physics Science Team.

## VI. CONCLUSIONS

OSSE can make significant observations of transient sources, but these observations require planning. This planning is in progress, although a number of issues are unresolved. Attempts to synchronize solar observations with peaks of solar activity depend on the presence and phase of the 154-day period. These have not been determined for the current solar cycle. In addition, we need to examine other predictors of flare activity which could be used to define target of opportunity criteria for the Sun. There may be difficulties in observing large flares, where the intense low-energy flux could swamp the detector (pulse pile-up, gain changes, etc.). Most importantly, we need to look at what are the most interesting solar and burst questions we can address, and what observing modes (physical and electronic) are optimum to test them.

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