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Initial Results from OSSE on the Compton Observatory

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Abstract

The Oriented Scintillation Spectrometer Experiment (OSSE) was launched on NASA's Compton Observatory on 1991 April 5. OSSE uses large area scintillation detectors to undertake gamma-ray line and continuum observations in the 0.05 – 10 MeV energy range. During the first months of the mission, OSSE has obtained observations on a number of high priority sources including AGNs, SN1991T, the galactic center region, and several discrete galactic sources. The capabilities and performance of OSSE are discussed and initial results for several of the early observations are presented.

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[1]NAS/NRC Post Doc

1 Introduction

The Oriented Scintillation Spectrometer Experiment (OSSE) is one of four experiments on NASA's Arthur Holly Compton Gamma Ray Observatory (GRO) satellite. OSSE has been designed to undertake comprehensive gamma-ray observations of astrophysical sources in the 0.05 – 10 MeV energy range. The instrument also has secondary capabilities for gamma-ray and neutron observations above 10 MeV that are of particular value for solar flare studies.

OSSE consists of four identical detector systems with independent, single-axis orientation systems. The primary detecting element for each detector is a large area NaI(Tl) scintillation crystal (13-inch diameter by 4-inch thick) shielded in the rear by an optically coupled 3-inch thick CsI(Na) scintillation crystal in a "phoswich" configuration. The phoswich is actively shielded by an annulus of NaI(Tl) scintillation crystals and passively collimated by a tungsten slat collimator which defines the $3.8^\circ \times 11.4^\circ$ full width at half maximum (FWHM) gamma-ray aperture of the phoswich detector.

Each OSSE detector has an independent positioning system which provides 192 degrees of rotation. This pointing control system is used to perform offset-pointed background measurements on time scales which are fast, ~ 2 minutes, relative to the typical orbital background variations. The OSSE orientation systems also provide the capability of making observations well away from the nominal look direction (the spacecraft Z axis) of the GRO pointed instruments. In particular, finding a second target at an OSSE orientation near the X-axis, in addition to the primary target at the Z-axis, provides the possibility of a secondary target which OSSE can view at times in the orbit when the primary, Z-axis, target is occulted by the earth. Thus, OSSE can make good use of most of the orbit by viewing two targets per orbit.

The OSSE instrument was designed to address a broad range of scientific objectives which include gamma-ray and neutron emissions from solar flares, radioactivity in supernova remnants, gamma-ray emission from pulsars and binary systems with neutron stars or black holes, gamma-ray bursts, diffuse emissions from the galactic plane and the galactic center region, and gamma-ray emission from active galactic nuclei. These objectives are reflected in the OSSE targets in the GRO phase 1 viewing plan. Phase 1 consists of 33 two-week observations. During each viewing period OSSE observes two targets, obtaining $\sim 5 \times 10^5$ sec on each target. The preliminary results of some of these observations are discussed below.

2 Gamma-ray bursts

A number of different types of data are available for burst analysis. In response to BATSE triggers, OSSE dumps high time resolution data from its shields. As currently configured, we get 4096 16-ms samples, 256 before the BATSE trigger and the remainder after. The large shield area ($\sim$ 1000–1750 cm^2 per segment, depending on incident angle) gives us excellent statistics in events with favorable aspect. An example is shown in Fig. 1, for the event GB910503. Multiple sharp peaks are seen, with widths as narrow as $\sim$ 64 ms and rates as high as $\sim$ 6000 counts per 16 ms.

In addition to these triggered data, OSSE also obtains continuous rates from each of the 16 individual shield elements, with typical time resolution of 2.048 s. These rates as well as the central detector rates are examined for each BATSE trigger identified as a burst or solar flare. OSSE detects approximately 50% of the BATSE cosmic gamma-ray bursts in either the shields, central detectors, or both. Processing of the continuous shield rates permits independent searches for gamma-ray bursts.

Central detector response to bursts is usually low due to shielding and collimation. These limit the field-of-view to about 0.1% of the sky per detector within the FWHM at low energies. We expect to see only $\sim 2-5$ events in the FOV each year. To date, two events, GB910601 and GB910807, have been seen in or near the OSSE FOV. Fig. 2 shows a counts spectrum of GB910807 from two OSSE detectors; the other two detectors were pointed at different parts of the sky and show no response. Unfolding the spectrum will require an accurate source position.

For events with significant central detector response (even outside the FOV), there are a number of issues which can be addressed, even without a source position. These include spectral evolution during the burst, and the presence of spectral lines. For a burst in the center of the field of view of one detector, the 3σ sensitivity to a line at 511 keV is about 1×10^{-2} photons-cm^{-2}-s^{-1} (average flux over 16 s). There are no obvious lines in any of the burst spectra examined to date.

3 Galactic 511 keV Emission

OSSE has planned a sequence of observations of the Galactic center and Galactic plane designed to map the diffuse continuum and line emissions in addition to detection of point-source emissions. We summarize here the observations relevant to the 511 keV emission. Approximately 20 weeks of observations at various Galactic longitudes, latitudes and OSSE collimator orientations (position angles) relative to the Galactic plane have been performed.

The summed background-subtracted spectrum for two two-week observations of the Galactic center is shown in Fig. 3. This spectrum shows strong evidence for a 511 keV line and positronium continuum. The position of the line is consistent with an energy of 511 keV, and the line width is consistent with the instrumental resolution. For the spectral studies reported here, the spectral fits were performed in the count spectrum over the energy range 0.15 – 1.5 MeV. The fitting model consisted of a power law, a photopeak line fixed in energy at 511 keV and in width at the instrumental resolution, and a term approximating the positronium continuum. This model results in a fitted 511 keV line flux of $(2.4 \pm 0.4) \times 10^{-4}$ γ cm^{-2} s^{-1} and a positronium fraction of (0.95 ± 0.06). The spectral fit is shown in Fig. 3. Time variability of the 511 keV line flux was investigated by comparing averaged spectra for each day of the observation intervals separately. No significant time variability of the line flux is observed. The 3σ upper limit to daily variations from the mean is 3×10^{-4} γ cm^{-2} s^{-1} for the observations performed over the periods 1991 July 13 – 24 and 1991 December 12 – 27.

The results of fitting the summed background-subtracted spectra for the Galactic plane observations are shown in Fig. 4. Also shown in this figure are the expected OSSE responses for several Galactic distribution models, fitted simultaneously to all of the OSSE Galactic plane data. As can be seen, the data are sharply peaked in longitude near the Galactic center, consistent with the reported GRIS observations (Gehrels et al. 1991). The Galactic center latitude distribution suggests that the emission is centered near the plane and may be slightly broadened compared with the expected point source response.

If the observed 511 keV line emission is assumed to originate entirely from the X-ray source 1E 1740.7–2942, the corresponding flux would be $(3.2 \pm 0.6) \times 10^{-4}$ γ cm^{-2} s^{-1}. If all of the emission is assumed to originate from a diffuse Galactic source, the OSSE data are inconsistent ($> 3\sigma$) with a distribution following either the CO model of Leising and Clayton (1985) or the visual luminosity model of Bahcall and Soneira (1980). The addition of a time-independent point source at the position of 1E 1740.7–2942 to the diffuse models provides acceptable fits for all of the diffuse models. The fitted point source fluxes for these combined fits are in the range $\sim 1 - 3 \times 10^{-4}$ γ cm^{-2} s^{-1}, depending on the diffuse model. The Nova model fit is not significantly improved by the addition of a point source.

4 Pulsars

OSSE pulsar data modes permit acquisition of time-tagged gamma-ray energy losses for the study of fast pulsars. The entire event stream for the detectors cannot be accommodated on an event-by-event basis in telemetry; consequently, the pulsar processing includes event selection and compression for telemetry formatting. A typical OSSE sensitivity for the detection of fast pulsars in a two-week observation has been $\sim 0.1 - 0.05 \times$ Crab pulsars (3σ) in the $\sim 100 - 200$ keV region for a blind search. If we optimize our viewing for a Vela-like pulsar with a $\sim 5\%$ duty cycle, OSSE can detect $\sim 0.002 \times$ Crab pulsar (3σ) in the $100 - 600$ keV range for a known periodicity.

The Crab pulsar was observed during April and May of 1991. The average pulsed spectrum for the observation from 1991 May 17 – 30 is shown in Fig. 5. The OSSE results are in basic agreement with previous observations of Knight (1982) and Agrinier et al. (1990).

We cannot conclusively exclude the existence of the 440 keV line in the spectrum of the second peak reported by the FIGARO group (Agrinier et al. 1990, Massaro et al. 1991) of $0.86 \pm 0.33 \times 10^{-4}$ photons cm^{-2} s^{-1}. The FIGARO result is based on combining data from balloon flights made on 1986 July 11 and 1990 July 9. We find no features in the OSSE data at 440 keV or elsewhere. Our 2σ upper limit to a line that is intrinsically much narrower than OSSE's $\sim 8.5\%$ detector resolution at 440 keV is $\sim 0.8 \times 10^{-4}$ photons cm^{-2} s^{-1}. On average, between 200 and 500 keV, OSSE's 2σ sensitivity to a narrow line for this observation is $\sim 10^{-4}$ photons cm^{-2} s^{-1}.

5 Galactic Black Holes

OSSE has observed several galactic black-hole candidates during the first nine months of the mission. These include Cyg X-1, GX 339-4, Nova Muscae, and 1E1740.7-2942. Each of these sources is characterized by variability on long time scales, with the low energy flux varying by an order of magnitude of more. Emission from Cyg X-1 and GX 339-4 exhibit a well-established anticorrelation between the intensities of low-energy X-ray emission and low-energy gamma rays. For Cyg X-1, Ling et al. (1987) identified three distinct gamma ray states in the HEAO-C1 data: continuum emission in the region from 30 to several hundred keV which is anticorrelated with the x-ray flux, and a state characterized by a broad feature above 0.5 MeV which may reflect production of a hot electron – positron pair cloud expected under certain accretion conditions onto a black hole. The hard X-ray emission from these sources has been best characterized by Sunyaev-Titarchuck emission models which would result from the compton up-scattering of a low-energy X-ray component by such a hot electron gas.

OSSE observed Cyg X-1 during three two-week periods: 1991 May 30 – June 15, 1991 Nov 27 – Dec 12, and also 1991 Aug 8 – Aug 15. Figure 6 indicates the average spectrum observed during May – June period. A single temperature Sunyaev-Titarchuck does not provide an acceptable fit to this spectrum; however the spectrum is adequately characterized by a two-temperature model as indicated in the figure. It must be noted that some variability of the source is detected during the observation, and that the spectrum shown is a time-averaged spectrum. No evidence for the MeV state observed by HEAO-C has been obtained yet.

BATSE detected the transient GX 339-4 in outburst in July 1991 (Fishman et al. 1991). The OSSE observation program was modified to include two one-week observations of this source (1991 Sep 5 – 12 and Nov 7 – 14). The average spectrum observed during the first period is also shown in Fig. 6. As with Cyg X-1, a two-temperature S-T model is required to fit the data, suggesting that this might be a characteristic of galactic black-hole candidates.

6 Active Galactic Nuclei (AGN)

OSSE has observed $\sim$ 13 AGNs in the first year of the mission. The strategy is to observe "known" hard x-ray/γ-ray emitting AGN with the purpose of extending good spectroscopy into the MeV range and correlating spectral and temporal variability with observations at other wavelengths. Here we present preliminary results of an observation of the radio galaxy Centaurus A (NGC 5128) during the period 1991 Oct 17 – 31.

During the two week observation of Cen A, a significant variation in the emission was detected (Fig. 7). By averaging the observed flux for the first 6 days of the observation and the last 9 days, the two spectra shown in Fig. 8 were obtained. As is seen in the figure, the OSSE data is well represented by a broken power law spectrum. Both OSSE spectra have a power law number index $\gamma \sim 1.8$ below the break energy (E_b) and an index $\gamma \sim 2.5$ above the break. As the source flux diminishes from the higher intensity during the first 6 days, the observed break energy moves from $E_\mathrm{b} \sim 0.17$ MeV to ~ 0.14 MeV.

7 Summary

The OSSE instrument is performing as designed and providing data at the anticipated sensitivity. The OSSE team is looking forward to working with the guest investigators in phase 2 of the GRO observation plan. The OSSE science team has placed high priority on continuing in phase 2 the mapping of the Galactic center and plane and the monitoring of black hole and AGN targets.

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Figure 1: A section of the time history of GB910503 observed in the OSSE shields. The BATSE trigger occurred at approximately 7:04:15 UT.

Figure 2: OSSE count rate spectrum for GB910807, accumulated for about 50 s around the peak of the burst. This event occurred within the FOV of two OSSE detectors. The data from those two detectors were summed to produce this spectrum.

Figure 3: The OSSE Galactic center and Galactic plane spectra. Each spectrum represents the summed spectra from all four detectors. The long direction of the OSSE collimator was parallel to the Galactic plane for each of these observations. The Galactic center spectrum was accumulated over the periods 1991 July 13 – 24 and 1991 December 12 – 27. The solid curve represents a fit to the Galactic center spectrum and consists of a power law, a photopeak line and a term approximating the positronium continuum. See text for details.

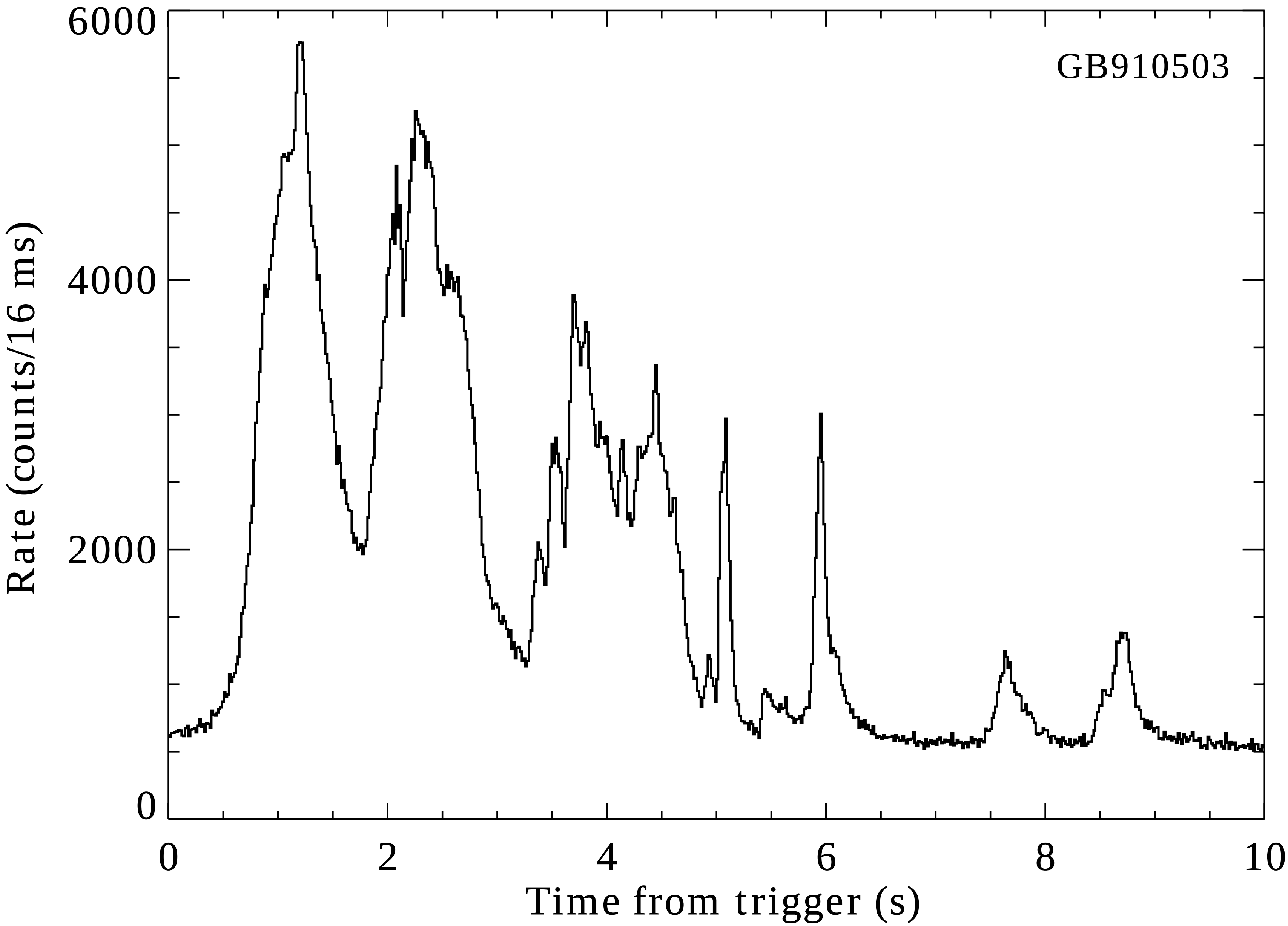
Figure 4: The fitted 511 keV line flux for the Galactic plane observations. The curves represent the expected OSSE responses for several Galactic distribution models, fitted simultaneously to all of the OSSE Galactic plane data. The thin and thick solid lines represent the CO and Nova models of Leising and Clayton (1985), respectively, the thin dashed line represents the observed CO distribution (Dame et al. 1987), the thick dashed line represents a model following the Galactic visual luminosity (Bahcall & Soneira 1980), and the dotted line represents the response for a point-source located at the position of 1E1740.7-2942.

Figure 5: The average OSSE Crab pulsar spectrum. The inset displays the average Crab pulsar light curve in the 60 – 250 keV range.

Figure 6: The observed spectra from Cyg X-1 and GX 339-4.

Figure 7: The daily average event rate from Cen A in the 0.06 – 0.15 MeV energy range.

Figure 8: The observed spectra from Cen A measured by OSSE during the first 6 days of the observing period and the last 9 days. For comparison previous measurements by balloon experiments are displayed.


GB910503
Rate (counts/16 ms)
6000
4000
2000
0
0
2
4
6
8
10
Time from trigger (s)