RECENT RESULTS FROM OSSE ON THE COMPTON OBSERVATORY

J. D. Kurfess

E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, DC 20375 USA

ABSTRACT

The Oriented Scintillation Spectrometer Experiment on the *COMPTON* Observatory was designed to undertake a broad range of high energy astronomical observations. Many of these have been realized during the first three years of the mission. In this paper we present several of the recent results from OSSE. We highlight recent OSSE results on the galactic center region and on transient galactic X-ray sources. In addition, we present OSSE results on the average spectrum of Seyfert galaxies, the search for ^{44}Ti emission from Cas A, and hard X-ray emission from SN1993j.

INTRODUCTION

The OSSE instrument on the *COMPTON* Observatory mission has been used to undertake observations of a variety of galactic and extragalactic sources. OSSE covers the energy range from 50 keV to 10 MeV (see Johnson et al. 1993 for a detailed description of the OSSE instrument). The field-of-view of the OSSE detectors is large: 3.8° x 11.4° FWHM. This is a compromise between a small field-of-view that is better suited for discrete source observations, and a large field-of-view that is preferred for study of the diffuse emission from the galactic plane. OSSE achieves high sensitivity by combining large detector effective areas and extended observation times. The OSSE limiting sensitivities are obtained through observations which normally consist of 2-3 week viewing periods (VP).

GALACTIC CENTER REGION

The galactic center region has been observed for a total of 30 weeks during the initial 2-1/2 years of the mission. These observations have several objectives, including mapping the distribution of the 0.511 MeV emission, mapping the diffuse galactic continuum emission which is primarily due to contributions from electron bremsstrahlung and inverse Compton scattering by cosmic ray electrons, searching for evidence of a variable point source(s) of 0.511 MeV emission, and the detection and study of other discrete sources. Purcell et al. (1993a, 1993b, 1994) discuss the galactic center observations in some detail and give the OSSE results on the 0.511 MeV emission. Briefly, the main results are as follows: The 0.511 MeV emission is adequately described by two components as shown by the model distribution in Fig. 1. The more intense component, with an intensity of 1.5×10^{-3} γ cm^{-2}s^{-1} in the inner radian is a spheroid centered on the galactic center and with scale size of about 1.2 kpc. There is also a narrow disk component that is observed out to ±60° galactic longitude, but whose intensity at the galactic center is only about 20% that of the spheroidal component. No point sources of 0.511 MeV emission are required. In particular, the upper limit for continuous 0.511 MeV line emission from 1E 1740.7-

<table>
<tr><td colspan="5">Report Documentation Page</td><td colspan="2">Form Approved
OMB No. 0704-0188</td></tr>
<tr><td colspan="7">Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</td></tr>
<tr><td colspan="2">1. REPORT DATE
1995</td><td colspan="3">2. REPORT TYPE</td><td colspan="2">3. DATES COVERED
00-00-1995 to 00-00-1995</td></tr>
<tr><td colspan="5" rowspan="3">4. TITLE AND SUBTITLE
Recent Results from OSSE on the Compton Observatory</td><td colspan="2">5a. CONTRACT NUMBER</td></tr>
<tr><td colspan="2">5b. GRANT NUMBER</td></tr>
<tr><td colspan="2">5c. PROGRAM ELEMENT NUMBER</td></tr>
<tr><td colspan="5" rowspan="3">6. AUTHOR(S)</td><td colspan="2">5d. PROJECT NUMBER</td></tr>
<tr><td colspan="2">5e. TASK NUMBER</td></tr>
<tr><td colspan="2">5f. WORK UNIT NUMBER</td></tr>
<tr><td colspan="5">7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory,Code 7650,4555 Overlook Avenue, SW,Washington,DC,20375</td><td colspan="2">8. PERFORMING ORGANIZATION REPORT NUMBER</td></tr>
<tr><td colspan="5" rowspan="2">9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</td><td colspan="2">10. SPONSOR/MONITOR’S ACRONYM(S)</td></tr>
<tr><td colspan="2">11. SPONSOR/MONITOR’S REPORT NUMBER(S)</td></tr>
<tr><td colspan="7">12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited</td></tr>
<tr><td colspan="7">13. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="7">14. ABSTRACT</td></tr>
<tr><td colspan="7">15. SUBJECT TERMS</td></tr>
<tr><td colspan="3">16. SECURITY CLASSIFICATION OF:</td><td rowspan="2">17. LIMITATION OF ABSTRACT</td><td rowspan="2" colspan="2">18. NUMBER OF PAGES
13</td><td rowspan="2">19a. NAME OF RESPONSIBLE PERSON</td></tr>
<tr><td>a. REPORT
unclassified</td><td>b. ABSTRACT
unclassified</td><td>c. THIS PAGE
unclassified</td></tr>
</table>

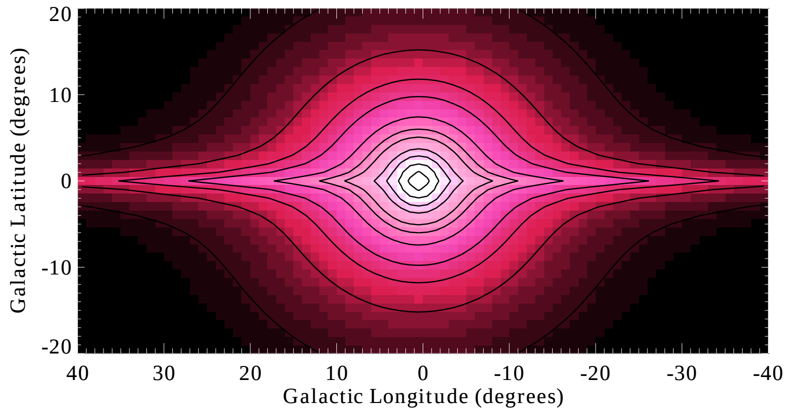

Figure 1. Model distribution for the 0.511 MeV emission from the galactic center region. The distribution consists of two components: a spheroidal component and a disk component. Contour levels are 1,2,3,4,6,8,10,15,20,30 and 50 in units of 10^{-3} photons $cm^{-2} s^{-1} str^{-1}$.

2942 is ~10^{-4} γ $cm^{-2} s^{-1}$. Other results on OSSE observations of 1E1740.7-2942 will be presented in the next section. In addition, no evidence for variability in the narrow 0.511 MeV emission has been observed in the OSSE observations. The positronium fraction is found to be 0.96± 0.04, in general agreement with earlier measurements. Future work is aimed at producing maps of the galactic center region using the OSSE data, and extending the coverage in longitude. This will provide maps of the central radian of the Galaxy and facilitate improved modeling of the origin of the positrons though correlations with the several candidate sources (novae, supernovae, pulsars, black holes).

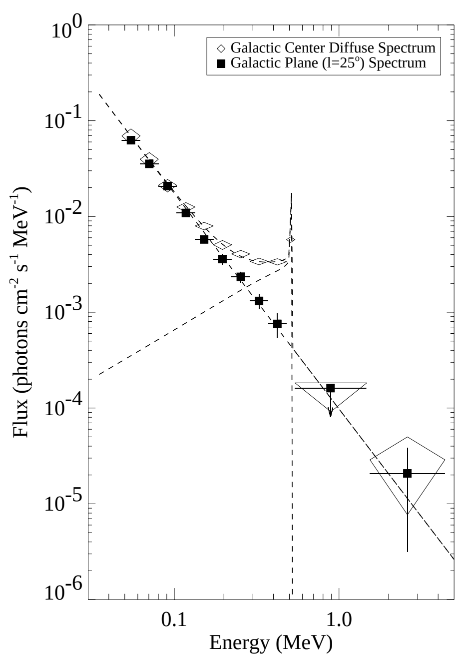

Figure 2. The diffuse continuum emission from the galactic center region obtained by subtracting from OSSE observations the discrete source contributions from simultaneous SIGMA observations. The spectrum of the galactic plane at +25° longitude is shown for comparison.

At low energies, the challenge for the OSSE team is to extract the diffuse and discrete components in a region where there is considerable source confusion. The approach for doing this is to undertake scans of the region at several position angles. Analysis of the data is complicated by the transient nature of many of the hard X-ray sources in the region. To assist in this task, we have undertaken several correlative observations with the GRANAT/SIGMA experiment (Cordier et al. 1994). SIGMA can obtain hard

X-ray and low-energy gamma-ray images, but at a somewhat reduced sensitivity relative to OSSE. Undertaking joint analysis of these data is proving very beneficial. We have, for the first time, obtained the continuum spectrum of the central region of our Galaxy from which the contributions of the stronger discrete sources have been removed. A preliminary spectrum of the diffuse emission is shown in Fig. 2. This represents the diffuse galactic continuum flux seen by OSSE with the detector pointed at the galactic center and the long axis of the collimator parallel to the galactic plane. For comparison, the spectrum at galactic longitude +25° is also shown. Note that the continuum emission at the two positions is very similar. The main difference in the two spectra is the increased flux of 0.51 MeV and associated positronium continuum emission from the galactic center region. This indicates that the continuum emission is extended in galactic longitude, perhaps similar to that seen in high-energy gamma rays. Combining these results with X-ray, COMPTEL, and EGRET data will, for the first time, provide a spectrum of the diffuse emission from the galactic center region from several keV to several GeV. This will enable an improved understanding of the electronic and nucleonic contributions to the diffuse gamma ray flux and the energy input of the interactions of these components to the interstellar medium. Of particular interest will be the ionization of the interstellar medium by low-energy cosmic ray electrons (Skibo et al. 1993).

TRANSIENTS

OSSE has observed several transient sources as Targets-of-Opportunity. These were often the result of the detection by BATSE of a galactic source which had gone into outburst. A list of the transient galactic sources which have been observed as OSSE Targets-of-Opportunity are given in Table 1. In this paper, we discuss the OSSE observations of A0535+26, GRO J0422+32, 1E1740.7-2942, and review the OSSE observations of Cyg X-1.

Table 1 OSSE Galactic Transient Observations During GRO Mission

Source	Observation Dates	Comments	Reference
Cyg X-3	8-15 Aug 1991	after radio flare	Matz et al. 1994
GX 339-4	5-12 Sept 1991		Grabelsky et al. 1993
	7-14 Nov 1991		
Nova Cyg 1992	5-19 Mar 1992	Limit on ^{22}Na	Leising et al. 1993
4U 1543-47	28 Apr-7 May 1992	power-law spectrum	
GRO J0422+32	11-27 Aug 1992	Thermal brems. spectrum	Grove et al. 1994a
	1-17 Sept 1992	"peaked noise" timing component	
GRO J1008-57	27 Jul- 3 Aug 1993	93 s pulsar	
GX 1+4	9-21 Sept 1992	Guest Investigation	
GRS 1009-45	21-22 Sept 1993	hard power-law	
GRS 1716-249	25-27 Oct 1992	hard thermal bremsstrahlung spectrum	
	30-31 Oct 1992		
A0535+26	8-17 Feb 1994	110 keV cyclotron line	Grove et al. 1994b

A0535+26 A0535+26 is a high mass X-ray binary which has a recurrent, transient pulsar with a pulse period of 103 s and a recurrence period of about 111 days. The companion star is a Be star at a distance of 1.8±0.3 kpc. Kendziorra et al. (1992, 1994), reporting on results obtained with the HEXE instrument on MIR, suggested evidence for cyclotron absorption features at 50 and 100 keV.

Infrequently, A0353+26 undergoes unusually intense outbursts during which it becomes the brightest hard X-ray source in the sky. The most recent such outburst occurred in February 1994. Initial BATSE observations suggested a spectral deficit above 100 keV, so a Target-of-Opportunity was used to enable OSSE observations during the period 8-17 Feb 1994.

Fig. 3a shows the phase-averaged spectrum summed over the entire OSSE observation. The spectrum is soft, consistent with previous hard X-ray observations. However, no simple model can adequately characterize the spectrum. There is a clear deficit in the spectrum near 100 keV which demands spectral features or multicomponent spectra to adequately characterize the emission. Grove et al. (1994b) find that the best fit the spectrum is obtained with an absorption feature at 110 keV. Based on the suggestion (Kendziorra et al. 1992, 1994) that the source may have features near 50 and 100 keV, Grove et al. (1994b) fit the OSSE data with a power-law times exponential function and one or two absorption lines. This model has been found to provide adequate fits to Ginga spectra of several galactic X-ray sources with cyclotron features at lower energies (e.g. Nagase et al. 1991; Tamura et al. 1992).

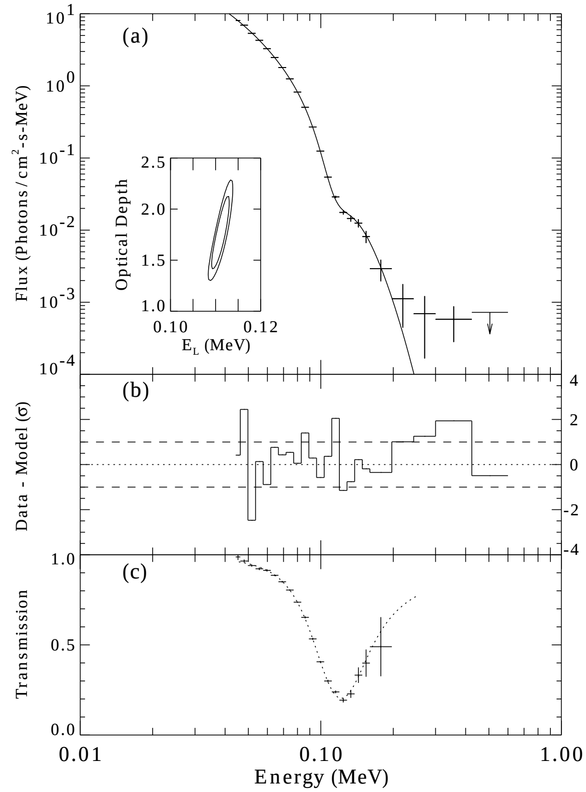

Figure 3. (a) Energy spectrum for A0535+26. The best fit model is a power law times exponential with an absorption feature at 110 keV. (b) residuals from the best fit model. (c) Transmission function for the absorption line feature.

The best fit parameters for the absorption features are given in Table 2. The energy of the second harmonic has been constrained to be twice that of the first harmonic. Note that the optical depth of the feature at 110 keV is large (τ=1.8) as can be seen from Fig. 3c. The OSSE data for the phase-averaged spectrum is consistent with no absorption feature required at 55 keV. However it should be indicated that the lower limit of the OSSE energy range (45 keV) makes a definitive statement about the necessity for a 55 keV line difficult. In any case, it is clear that the optical depth of a feature at 55 keV is substantially less than that required at 110 keV. This is in contrast with the situation for lower energy cyclotron features for other sources observed by Ginga (Tamura et al. 1992), and also is rather unexpected theoretically. The most plausible interpretation is that the fundamental cyclotron absorption feature in A0535+26 is at 110 keV. This would imply a surface magnetic field of about 1.1 x 10^{13} gauss, and make it the most intense magnetic field determined for any accreting pulsar.

TABLE 2 A0535+26 Spectral Parameters
(power-law times exponential and two absorption lines)

Continuum Parameters		Line Parameters	
70 keV Flux (γ cm^{-2}s^{-1} MeV^{-1})	$2.35^{+4.32}_{-0.35}$	Line Energy (2nd Harm.,keV)	$110.0^{+2.2}_{-3.8}$
Power-Law Index	$-0.13^{+0.65}_{-1.67}$	Line HWHM (2nd Harm.,keV)	$28.4^{+16.2}_{-9.0}$
Folding Energy (keV)	$17.8^{+5.4}_{-3.8}$	Optical Depth (55 keV)	$0.10^{+0.48}_{-0.10}$
		Optical Depth (110 keV)	$1.8^{+1.1}_{-0.5}$

GRO J0422+32 GRO J0422+32 (X-ray Nova Persei) was discovered by BATSE in August, 1992 (Paciesas et al. 1992) and is the strongest galactic source observed by OSSE at 100 keV. OSSE viewed the source for 34 days spanning the period 11 Aug 1992 - 17 Sep 1992. The source reached a maximum intensity of about 3x Crab shortly after the start of the OSSE observations, and then decreased in intensity with an ~40-day e-folding time. The energy spectra obtained by OSSE are well described by optically thin thermal bremsstrahlung spectra with a kT of ~100 keV. Of special interest is any evidence for persistent or time-variable annihilation radiation such as has been reported by the GRANAT/SIGMA experiment for Nova Muscae (Sunyaev et al. 1992; Goldwurm et al 1992) and 1E 1740.7-2942 (Bouchet et al. 1991). The OSSE data do not show any clear evidence for such features, with a limit relative to the continuum emission that is ~100 times less than the Nova Muscae line feature.

Grove et al. (1994a) have presented preliminary timing analysis of the OSSE data on GRO J0422+32. High time resolution data were collected with 8-ms samples in five energy bands between ~35 and ~600 keV. They have modeled the power spectra as being composed of two classes of randomly occurring shots with characteristic e-folding times of ~50 ms and ~2.2 seconds and an additional component which produces a "peaked noise" feature at 0.23 Hz. The profile of the noise peak is rather broad compared to QPO phenomena observed in LMXRB's and this component accounts for an RMS variation of the source flux of about 10%. Preliminary analyses of these data indicate that the fractional RMS power from the source increases as the source strength decreases. However, the frequencies of the "peaked noise" component and the breaks in the power spectra near 2 Hz and 0.04 Hz do not change with the varying intensity of the source. More detailed modeling of the OSSE data are in progress.

Cyg X-1 Cygnus X-1 has been observed frequently by OSSE during the *COMPTON* mission. All of the Cyg X-1 observations occurred when the source was near low intensity levels by historical standards. The spectrum summed over all observations during 1991-1993 (see Fig. 4) is observed up to energies of about 1 MeV and is well represented by an exponentially cut-off power law with corrections for Compton reflection from a cold gas. The best fit spectral model has a characteristic temperature of 118 keV and a reflection coefficient of 1.5 (Phlips et al. 1994).

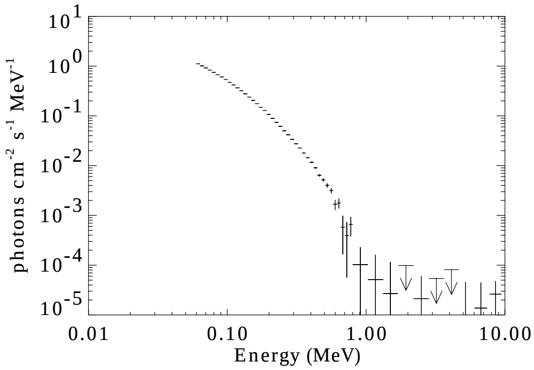

Figure 4. Energy spectrum for all OSSE data for Cyg X-1 obtained during 1991-1993.

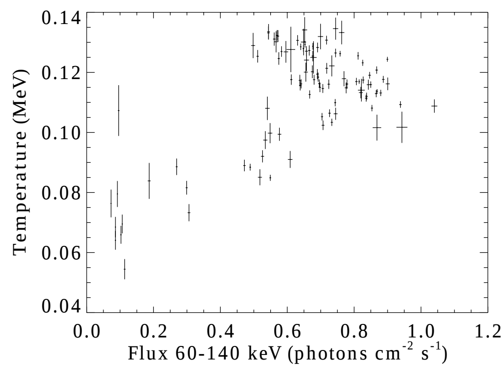

Figure 5. Temperature-Intensity correlation for Cyg X-1 observations.

In June, 1993 BATSE reported (Harmon et al. 1993) a decrease in the intensity of Cyg X-1 which corresponded to a transition from the γ_2 state to the γ_1 state. These states were defined by Ling et al. (1987) who had reported a strong, broad MeV emission associated with the low intensity γ_1 state observed by the HEAO C1 spectrometer in 1979-1980. Such emission would be evidence for copious production of e^+e^- pairs in certain states of accretion onto galactic black hole candidates. The OSSE data in the 45-140 keV energy range show gradual intensity changes but no clear bipolar intensity levels, similar to those suggested by HEAO, which would clearly be attributed to different states. However, Cyg X-1 does appear to exhibit temperature-intensity correlations, wherein episodes of lower effective temperature of the emission are observed as the overall X-ray luminosity is reduced. This correlation is shown in Fig. 5. In the lowest intensity state, which was observed recently in January, 1994, the spectrum is better fit with a power law than with the exponentially-truncated power-law which characterizes the higher-intensity source spectra.

Many of the OSSE observations have been at intensity levels which are similar to the HEAO γ_1 level, including the observations in June, 1993. We have seen no evidence for excess MeV emission similar to that reported by Ling et al. (1987) in any of the OSSE observations. Figure 6 shows the best fit MeV intensity levels (modeled as a broad Gaussian) above a thermal bremsstrahlung continuum. This distribution is also compared with the MeV flux reported by Ling et al. (1987). If the low intensity of the hard X-ray emission is taken as evidence for the γ_1 state with an accompanying MeV emission, the MeV component should have been present at levels ten times above the OSSE limits.

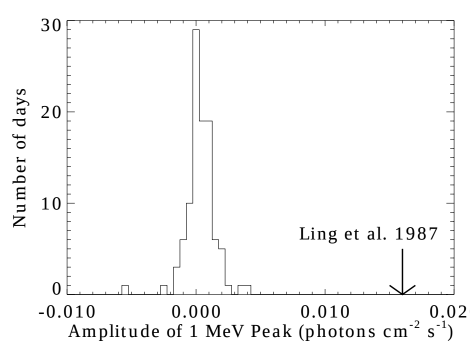

Figure 6. Distribution of the best fit MeV emission amplitudes in the OSSE Cyg X-1 data. The fits were performed for each individual day of Cyg X-1 observations.

<u>1E 1740.7-2942</u> 1E 1740.7-2942 is a variable hard X-ray source about 1° from the galactic center. In its higher intensity states, it is the strongest hard X-ray source in the galactic center region. SIGMA has reported several episodes of enhanced emission above 200 keV which have

been interpreted as red-shifted positron annihilation radiation. The most compelling evidence occurred on 13-14 Oct 1990 (Bouchet et al. 1991). The intensity of the observed feature was ~10^{-2} γ $cm^{-2}s^{-1}$. This outburst was similar to a feature SIGMA observed from Nova Muscae in Jan 1990 about 10 days after the beginning of an outburst in that source. A similar 1-day transient of 1E 1740.7-2942, but of lower significance, occurred on 20 Sept 1992 (Cordier et al. 1993), and enhanced emission in the 0.2-0.5 MeV region also was reported during a 2-week period in 1991 October (Churazov et al. 1993). This unusual character led to speculation that it may be the source of variable 0.511 MeV positron annihilation radiation which has been reported from the galactic center region (Riegler et al. 1985; Leventhal et al. 1989). VLA observations by Mirabel et al. (1991) detected opposing radio jets emanating from the location of 1E 1740.7-2942. The combination of these observations have been incorporated into a model (Ramaty et al. 1992) wherein outbursts in 1E 1740.7-2942 produce copious electron-positron pairs near a central black hole. A fraction of the positrons annihilate on nearby material (presumably the inner portion of the accretion disk) and produce the broadened and gravitationally red-shifted radiation observed by SIGMA. The remainder of the positrons form part of the jet and eventually slow down in a nearby molecular cloud (Bally and Leventhal 1991) and annihilate on much longer time scales (months to years). The positrons annihilating in the cloud produce a narrow 0.511 MeV line feature. The infrequent nature of the 1E1740.7-2942 outbursts contributing to this narrow line feature might explain the variable 0.511 MeV emission reported by Riegler et al. (1985) and Leventhal et al. (1989).

This scenario may be questioned, however, because of the low statistical significance of both the reported feature in the SIGMA observations from 13-14 Oct 1990 and the reported variability of the narrow line emission, and from other observations which have not observed these phenomena. The gamma ray instrument on SMM observed the galactic center region for several months each year from 1981-1989, and observed no evidence for either long term variability of the 0.511 MeV emission or for transient features such as SIGMA observed in Oct. 1990 (Harris et al. 1994). The more sensitive OSSE instrument on GRO has acquired over 100 days of observations of the galactic center region, including 1E1740.7-2942, and has observed no evidence for variability of the 0.511 MeV emission or for short term transient features. The OSSE limit on continuous emission from 1E 1740 is ~1.0×10^{-4} γ $cm^{-2}s^{-1}$, which is below the sensitivity of the instruments reporting the previous variability. Clearly, confirmation of these phenomena is required, preferably by simultaneous observations with two or more independent instruments.

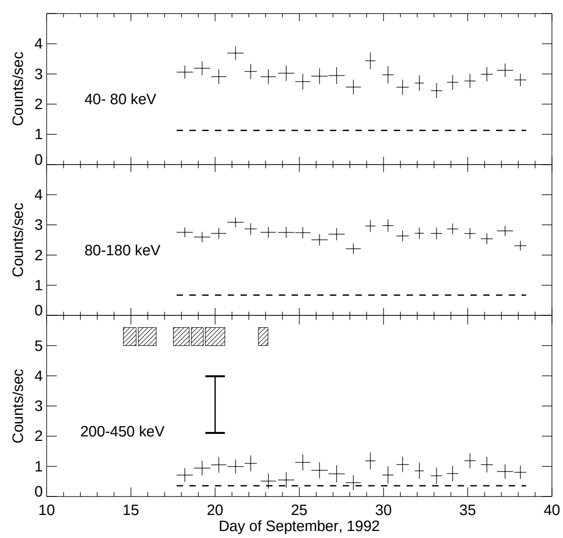

Figure 7. Time history of OSSE observations of 1E 1740.7-2942 for Sept-Oct 1992. No increase is seen during the 20-21 Sept 1992 session when SIGMA reported increased 0.2-0.5 MeV emission. The SIGMA observation sessions are indicated by the hashed regions in the lower panel. The expected OSSE response to the reported SIGMA increase in the 200-450 keV region is indicated by the thick error bar in the bottom panel.

SIGMA has reported two other periods of enhanced hard emission from 1E1740-2942 which have been interpreted as red-shifted e^+e^- emission. During a two week period in Oct 1991 (Churazov et al. 1993) and during a 1 day event in Sept 1992 (Cordier et al. 1993). OSSE has coordinated observations with both of these SIGMA observations. For the 1-day event of 20-21 Sept 1992, which was similar to the Oct 1990 event (feature flux about 4 x 10^{-3} γ $cm^{-2}s^{-1}$), Jung et al. (1994) do not confirm this event with the OSSE data. The time history of the OSSE data are shown in Figure 7, where it is seen that the flux from 1E1740.7-2942 during the period of the SIGMA outburst was not significantly different than that during the remainder of the three week OSSE observation. The 3σ upper limit obtained by OSSE is 2.4 x 10^{-3} γ $cm^{-2}s^{-1}$. For the reported SIGMA flux, OSSE should have seen a 5-13σ increase, but did not. The spectrum observed by OSSE in the region above 250 keV during this period is consistent with other OSSE observations of the galactic center region. The OSSE data do not confirm the reported SIGMA feature for 20-21 September 1992. Coupled with the lack of observed variability in the 0.5 MeV region in over 200 days of observations of the galactic center region, and the lack of evidence for similar events in the SMM data, this suggests that the requirement for pair plasma emission models in galactic black hole candidates, and for the possible transient production of positrons in these sources, is far from compelling.

OTHER RESULTS

Average Spectrum of Seyfert Galaxies An important and surprising result from early OSSE observations was the detection of a thermal-like spectrum from the nearby Seyfert galaxy NGC 4151 (Maisack et al. 1992). Balloon-borne observations by Perotti et al. (1981) had indicated that the power-law spectra for NGC 4151 extended up to the MeV region. Assuming that this was typical of most Seyferts had two important implications. First, this limited the contribution of Seyfert galaxies to the diffuse γ-ray background because extrapolating the hard X-ray spectra overproduced the γ-ray background in the several hundred keV region. Also, it indicated that the Seyfert luminosities were dominated by MeV γ-ray emission and this led to the development of models for AGN which invoked pair plasmas around the massive black holes. (e.g. Zdziarski et al. 1990).

Johnson et al. (1994) have measured the average spectrum for Seyfert galaxies by summing the spectra of weak Seyferts observed by OSSE during the first 2+ years of the mission. This spectrum is shown in Figure 8. The average Seyfert spectrum is also best modeled as a thermal rather than a power-law spectrum by the OSSE data, and a clear spectral break is required between the X-ray data and the low-energy γ-ray data obtained by OSSE. This general result appears to support the AGN paradigm wherein all AGN are assumed to be powered by accretion onto massive black holes and many observational characteristics are determined by the observer's line of

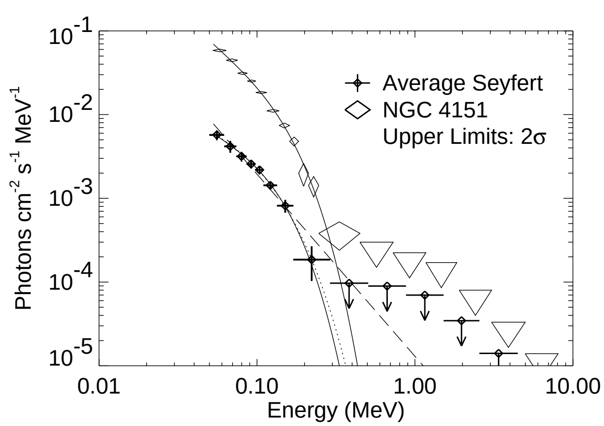

Figure 8. Average spectrum of weak Seyfert galaxies observed by OSSE. The spectrum of NGC 4151 is shown for comparison.

sight relative to a thick torus which envelopes the central object. This is reflected in the gamma ray energy range, in part, by the distinction between blazars in which the line of sight is nearly aligned with a jet which is oriented perpendicular to the accretion disk, and Seyferts in which the line of sight is outside of this jet, or perhaps no jet is formed. In this paradigm, the distinction between Type 1 and Type 2 Seyfert galaxies is determined by whether the line of sight is obstructed by the torus (Type 2) or not. Future observations and analysis of OSSE data can test this model by looking for evidence of increased absorption in the low-energy γ-ray spectra of Type 2 Seyfert galaxies.

Cassiopeia A Iyudin et al. (1994) have recently reported the COMPTEL detection of ^{44}Ti in the supernova remnant Cassiopeia A. This was achieved with the observation of 1.156 MeV gamma rays, at a flux of 7.0 ± 1.7 x 10^{-5} γ $cm^{-2}s^{-1}$, which are associated with the decay of radioactive ^{44}Ti ($\tau_{1/2}$= 46.4 - 66.6 yrs). This remarkable observation is the first detection of ^{44}Ti gamma rays from an astrophysical source and establishes the capability for gamma ray astronomy to discover recent galactic supernovae which have been obscured optically.

Cas A exploded in the second half of the 17th century at a distance of 2.8 ± 0.2 kpc. At this distance, the COMPTEL observation implies the production of 1.5-3 x 10^{-4} M_o of ^{44}Ti in the explosion which is believed to have been a Type II (core collapse) supernova. Models for Type II supernovae place this production of ^{44}Ti at the upper end of the expected range, and these large production amounts are believed to result from explosions of massive stars (initial mass ~35 M_o)

OSSE observed Cas A for a period of three weeks during 1992. We have searched these data for evidence of the 1.156 MeV line from ^{44}Ti as well as the 68 and 78 keV lines that would also accompany this emission. We cannot positively confirm the COMPTEL result. Analysis of the OSSE data has been undertaken (The et al. 1994) by jointly fitting the OSSE spectrum (Fig. 9) for the 3 gamma-ray lines. We find a 3σ upper limit for each of these lines of ~6 x 10^{-5} γ $cm^{-2}s^{-1}$. This result is in marginal disagreement with the COMPTEL result. Combining the results from the two observations suggest a likely flux of 3-5 x 10^{-5} γ $cm^{-2}s^{-1}$ which would be marginally compatible with the two separate results (2% probability). Additional observations have been proposed for cycle 4 of the GRO mission during which time it is expected that the combined OSSE-COMPTEL observations will achieve a sensitivity (3σ) of ~2 x 10^{-5} γ $cm^{-2}s^{-1}$. This sensitivity will be adequate to detect ~1 x 10^{-4} M_o of ^{44}Ti in Cas A with high confidence.

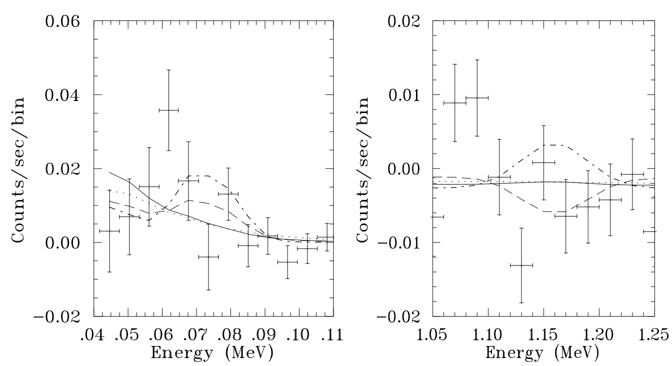

Figure 9. Energy spectra for Cas A in the regions containing the 68 and 78 keV lines and the 1.156 MeV line emission associated with the decay of ^{44}Ti.

TABLE 3 Production of ^{44}Ti and ^{56}Ni in Type II Supernovae (from Hoffman et al. 1994)

Stellar Mass	12 M_o	15 M_o	18 M_o	20 M_o	25 M_o	35 M_o
^{44}Ti (10^{-4} M_o)	0.79	0.63	0.083	0.14	0.32	2.0
^{56}Ni (10^{-2} M_o)	4.2	1.1	6.5	9.5	13	60

The COMPTEL observation, if confirmed, will place important constraints on models for nucleosynthesis of heavy elements in supernovae. Hoffman et al. (1994) have reported on recent calculations for the production of heavy elements in Type II supernovae. The production of ^{44}Ti and ^{56}Ni for supernovae ranging from 12-35 M_o is shown in Table 3. As is seen, production of 10^{-4} M_o ^{44}Ti is expected for core collapse explosions in the more massive stars. Note that these large production fractions of ^{44}Ti are always accompanied by large production fractions of ^{56}Ni. The decay of ^{56}Ni drives the luminosity of the supernova. For a supernova which produces ≥ 0.1 M_o of ^{56}Ni, one would expect that the optical object would be brighter than -2 mag at a distance of 3 kpc. Since Cas A is a high latitude object, which would have been visible from many northern European sites throughout the year, it seems highly unlikely that it would not have been observed optically. Flamsteed may have observed a 6th magnitude object at this site in 1680 (Ashworth 1980), but if this report is near maximum brightness, the production of ^{56}Ni and ^{44}Ti would be expected to be much lower than implied by the COMPTEL observations and our current understanding of supernovae. This result has far-reaching implications and requires more observations.

SN1993j In addition to Cas A, OSSE has observed three other supernovae: SN1987a from which the first detection of ^{57}Co gamma radiation was obtained (Kurfess et al. 1992), SN1991t (a Type Ia supernovae in NGC 4527) and SN1993j, a Type IIb in M81 at a distance of 3.6 Mpc.

Gamma radiation from a Type II supernova at the distance of M81 would not be expected to be detectable by GRO. However, OSSE did observe hard X-radiation from SN1993j following the explosion in March 1993. The light curve of OSSE 50-150 keV emission for 5 observations of the M81 region, as reported by Leising et al. (1994) is shown in Fig. 10. It is seen that enhanced emission is observed in the periods 10-15 and 24-37 days after the explosion. It is not believed that this emission is due to scattered nuclear line gamma radiation. Such emission would be expected to have a very hard spectrum below 100 keV due to scattering of the radiation in the expanding envelope. Optimistic estimates of the scattered radiation of nuclear origin suggest that it would have been marginally detectable only if more that 0.15 M_o of ^{56}Ni were produced, whereas the models for the optical light curve indicate that 0.06-0.09 M_o was produced. The radiation observed by OSSE is believed to arise from matter in the pre-supernova stellar wind which is heated by the supernova shock to temperatures of ~10^9 °K. This result is

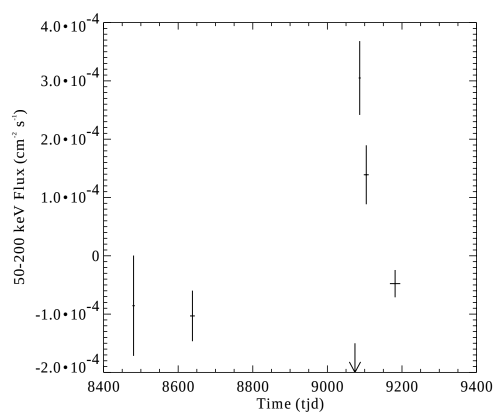

Figure 10. Time history of OSSE observations of the M81 region. Note the increase following the outburst of SN 1993j indicated by the arrow.

surprising, for models (Chevalier 1982) of the interaction of the shock with the surrounding medium had suggested that the luminosity would be dominated by emission from the expanding nebula which is heated by a reverse shock to a temperature of ~ few x 10^7 °K.

SUMMARY

Many important objectives have been met by OSSE during the first three years of the *COMPTON* Observatory mission. However, many other key objectives remain, and these should be realized with the good prospects for a mission lasting at least another five years. These objectives include the detailed mapping of the Galaxy in low-energy gamma rays, observations of nearby supernovae and novae, and the first sensitive sky survey observations in the low-energy gamma-ray region.

ACKNOWLEDGMENTS

The author wishes to thank the members of the OSSE team for their assistance. Special thanks to W. Purcell, M. Bell, G. Jung, J. E. Grove, N. Johnson, K. McNaron-Brown, B. Phlips, L-S The, and M. Leising. This work was supported under NASA DPR S-10987C.

REFERENCES

Ashworth, W.B., 1980, Journal of the History of Astronomy, **11**, 1.
Bally, J., and Leventhal, M., 1991, Nature, **353**, 234.
Bouchet, L., et al., 1991, ApJ. Lett., **383**, L45.
Chevalier, R., 1982, ApJ, **259**, 302.
Churazov, E., et al., 1993, ApJ, **407**, 752.
Cordier, B. et al., 1993, Astron. & Astrophys., **275**, L1.
Cordier, B., et al., 1994, AIP Conference Proceedings, **304, 446.**
Goldwurm, A., et al., 1992, Ap J. Lett., **389**, L79
Grabelsky, D. A., et al., 1993, AIP Conference Proceedings, **280**, 345
Grove J.E., et al., 1994a, AIP Conference Proceedings, **304**, 192.
Grove, J.E. et al., 1994b, accepted for publication in ApJ (Letters).
Harmon, B.A., et al., 1993, IAUC 5813.
Harris,, M.J., Share, G.H., and Leising, M.D. 1994, submitted to ApJ.
Hoffman, R., et al. 1994, Proc. of Les Houches Conf. "The Gamma Ray Sky with COMPTON GRO and SIGMA"
Iyudin, A.F., et al., 1994, AIP Conference Proceedings, **304**, 156.
Johnson, W.N., et al., 1993. ApJ. Supp., **86**,693.
Jung, G.V., et al. 1994, submitted to A&A
Kendziorra, E., et al., 1992, in Frontiers of X-Ray Astronomy (Proc. 28th Yamada Conf.), ed. Y. Tanaka, and K. Koyama, (Univ. Acad. Press, Tokyo), p.51.
Kendziorra, E., et al., 1994, submitted to A&A.
Kurfess, J. D., et al., 1992, ApJ (Letters) **399**, L137.
Leising, M.D., et al. 1994, ApJ. (Letters) **431, L95.**
Leising, M.D., et al., 1993 AIP Conference Proceedings, **280**, 137.
Leventhal, M, et al. 1989, Nature, **339**, 36.
Ling, J.C., et al., 1987, Ap.J., **321**, L117.
Maisack, M., et al., 1992, ApJ (Letters), **407**, 167.
Matz S.M., et al., 1994, submitted to ApJ.

Mirabel, I.F., et al., 1991, Nature, **358**, 215.
Nagase, F., et al. 1991, ApJ, **375**, L49.
Paciesas, W.S., et al., 1992, IAUC 5580
Perotti, F., 1981, ApJ (Letters), **247**, L63.
Phlips, B. et al., 1994, submitted to ApJ.
Purcell, W.R., et al., 1993a, AIP Conference Proceedings, **280**, 107.
Purcell, W.R., et al., 1993b, ApJ (Letters), **413**, L85.
Purcell, W.R., et al., 1994, AIP Conference Proceedings, **304**, 403.
Ramaty R., et al., 1992, ApJ (Letters), **392**, L63.
Riegler, G.R., et al., 1985, ApJ, **294**, L13.
Skibo, J. and Ramaty, R., 1993, AIP Conference Proceedings, **280**, **70.**
Sunyaev, R., et al., 1992, ApJ**, 389**, l75.
Tamura, K., et al. ApJ., **389**, 67
The, L.-S., et al., 1994, submitted to ApJ.
Zdziarski, A.A., et al., 1990, ApJ, **363**, L1.