OSSE OBSERVATIONS OF GALACTIC SOURCES DURING PHASE 1

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ABSTRACT

The Oriented Scintillation Spectrometer Experiment (OSSE) on the COMPTON Gamma Ray Observatory has undertaken comprehensive observations of astrophysical sources during the eighteen-month Phase 1 of the mission. These include investigations of many galactic sources, including binary X-ray sources, pulsars, several transient X-ray sources observed as Targets-of-Opportunity, and Nova Cygni 1992. Multiple observations of the galactic center region were undertaken to map the diffuse galactic emission and search for point sources. An overview of the galactic source observations and some preliminary results are presented.

INTRODUCTION

During Phase 1 of the COMPTON Observatory mission, the OSSE instrument has been used to undertake observations of a variety of galactic sources. The OSSE instrument covers the energy range from 50 keV to 10 MeV when operated in nominal gain (see Johnson et al.[1] for a detailed description of the OSSE instrument). For several of the galactic source observations the instrument was operated at twice the nominal gain and covered an energy range from 40 keV to 5.0 MeV. The field-of-view of the OSSE detectors is large: 3.8^{o} x 11.4^{o} 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.

Phase 1 observations consisted of a sequence of 2-week viewing periods (VP) during which the observatory was maintained in a fixed orientation in inertial space. This strategy was implemented to enable the large field-of-view EGRET and COMPTEL instruments to carry out a complete sky survey. The plan was followed from the start of the science program in May 1991 through March 1992, at which

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time the effective failure of the observatory tape recorders forced a conversion to real time data acquisition though the TDRS system. To make up for the limited real-time coverage through TDRS, most viewing periods for the remainder of Phase 1 were extended to three weeks.

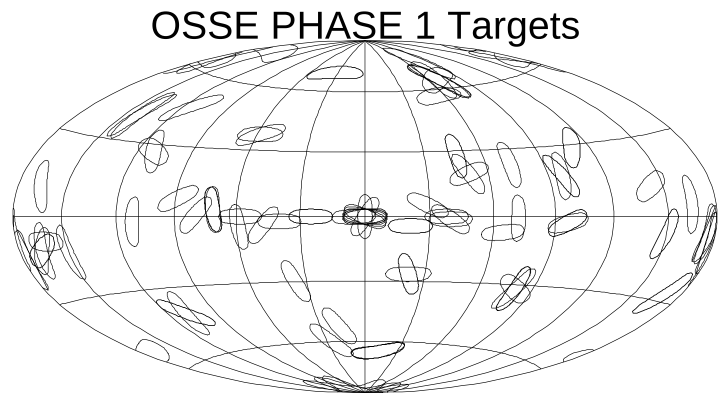

Figure 1. Target fields viewed by OSSE during Phase 1. Detector response is shown at the 90% level.

Table I provides a list of the discrete galactic sources observed during Phase 1. Each entry in the list provides source location, the period of time that the source was observed, the GRO viewing period number, and comments related to the observations. Only those sources which were specific OSSE objectives are listed. While there were often additional sources, e.g. soft X-ray sources, in the large OSSE field-of-view, such sources are unlikely to contribute in the OSSE energy range above 50 keV. Likewise, while known radio pulsars often populate these fields, Table I only lists those that are likely candidates for detection based on loss of rotational energy and distance[2]. Figure 1 shows a map of OSSE field-of-view locations during Phase 1. Background observations were typically acquired at offset angles of ±4.5 degrees from the locations shown in Fig. 1. In some regions, most notably the galactic center, scans were undertaken over an extended region. See Table 1 of Purcell et al.[3] for details.

TABLE I: OSSE PHASE 1 GALACTIC SOURCE OBSERVATIONS

OBJECT	RA (J2000.0)	Dec	View Period	Observation Dates		Comments
CRAB PULSAR	83.52	22.02	1	16-MAY-1991	30-MAY-1991	
			32	25-JUN-1992	2-JUL-1992	
VELA PULSAR	128.92	45.18	8	22-AUG-1991	5-SEP-1991	first low-energy
			26	23-APR-1992	28-APR-1992	gamma-ray detection
			28	7-MAY-1992	14-MAY-1992	of Vela Pulsar
PSR 1509-58	228.48	59.14	23	19-MAR-1992	2-APR-1992	confirm BATSE obs.
			42	15-OCT-1992	29-OCT-1992	
GEMINGA	98.48	17.77	34	6-JUL-1992	6-AUG-1992	no detection
PSR 1957+20	299.84	20.81	1	16-MAY-1991	30-MAY-1991	no detection
PSR 1929+10	293.05	10.99	18	10-JAN-1992	23-JAN-1992	no detection

TABLE I (con't)

PSR 0950+08	86.03	-69.27	6	26-JUL-1991	8-AUG-1991	no detection
PSR 1706-44	257.25	-44.45	9	5-SEP-1991	12-SEP-1991	no detection
PSR 1951+32	297.21	32.89	15	28-NOV-1991	12-DEC-1991	no detection
PSR 1937+21	295.12	21.19	19	23-JAN-1992	6-FEB-1992	no detection
CYG X-1	299.59	35.21	2	30-MAY-1991	15-JUN-1991	low hard X-ray state
			7	8-AUG-1991	15-AUG-1991	low hard X-ray state
			15	28-NOV-1991	12-DEC-1991	low hard X-ray state
CYG X-3	308.10	40.96	2	30-MAY-1991	8-JUN-1991	before radio flare
			7	8-AUG-1991	8-AUG-1991	after radio flare
			15	28-NOV-1991	12-DEC-1991	
HER X-1	254.46	35.34	9	12-SEP-1991	19-SEP-1991	spans X-ray turn-on
			19	23-JAN-1992	6-FEB-1992	
SS 433	287.95	4.99	20	6-FEB-1992	20-FEB-1992	no detection
CIR X-1	230.23	-57.18	23	19-MAR-1992	2-APR-1992	no detection
GX 339-4	255.71	-48.79	9	5-SEP-1991	12-SEP-1991	high state
			13	7-NOV-1991	14-NOV-1991	low state
NOVA MUSCAE	171.61	-68.68	10	9-SEP-1991	3-OCT-1991	very weak
4U 1543-47	237.00	-47.80	27	28-APR-1992	7-MAY-1992	very weak
GRO J0422+32	65.43	32.91	36	11-AUG-1992	27-AUG-1992	intense transient
			38	1-SEP-1992	17-SEP-1992	
ETA CAR	161.95	-59.98	14	14-NOV-1991	28-NOV-1991	complex region
NOVA CYG 92	307.63	52.62	22	5-MAR-1992	19-MAR-1992	no detection
CAS A	350.87	58.81	34	16-JUL-1992	6-AUG-1992	no detection
G CENTER REGION	266.40	-28.94	5	12-JUL-1991	26-JUL-1991	sources obs. include:
			11	3-OCT-1991	17-OCT-1991	
			14	14-NOV-1991	28-NOV-1991	1E1740.7-2942
			16	12-DEC-1991	27-DEC-1991	GX1+4
			17	27-DEC-1991	10-JAN-1992	GX354+0
			21	20-FEB-1992	5-MAR-1992	GS1758-258
			24	2-APR-1992	9-APR--1992	
			25	16-APR-1992	23-APR-1992	coord. obs. with SIGMA
			40	17-SEP-1992	8-OCT-1992	Oct. '91 and Apr. '92
G PLANE 25	279.22	-7.05	7	15-AUG-1991	22-AUG-1991	
			12	31-OCT-1991	7-NOV-1991	
G PLANE 58.1	294.98	22.28	9	23-JAN-1992	6-FEB-1992	
G G PLANE 5+0	269.34	-24.53	24	9-APR-92	16-APR-1992	

PULSARS

OSSE has detected three radio pulsars in the low-energy gamma-ray band: the Crab Pulsar, the Vela Pulsar and PSR 1509-58. For pulsar observations, OSSE was operated in either an event-by-event mode or a rate mode to acquire high time resolution data. In the event-by-event mode the throughput is limited to about 200 counts/s and this restricts the energy range which can be investigated: the time resolution is either 1/8 ms or 1 ms. In the rate mode, broadband rates can be acquired in up to eight energy bands, with a best time resolution of 4 ms. For observations of the Crab pulsar and pulsars with comparable or shorter periods, the event-by-event mode is required. Preliminary results for the Crab pulsar were presented in Ulmer et al.[4] and spectral and temporal results are in preparation.[5]

OSSE observations of the Vela Pulsar have provided the first detection of low-energy gamma-ray emission from this object. Strickman et al.[6] discuss the results and implications of this detection.

PSR 1509-58, a radio pulsar with a period of 150 ms, was first detected by BATSE[7] in the low-energy gamma-ray region, and subsequently observed by OSSE during VP 23. The OSSE observations show a clear detection in the 60-570 keV region and are in general agreement with the BATSE results.

Geminga has recently been found to be both an X-ray pulsar[8] and a gamma-ray pulsar.[9] OSSE observed Geminga for a total of three weeks; however, we have not found clear evidence for a pulsed signal. The similarity between the X-ray and high-energy gamma-ray signatures of Geminga and the Vela pulsar indicates that additional observations of Geminga are warranted.

OSSE data have been used to search for gamma-ray emission from several millisecond pulsars with known periods, including PSR 1957+20 and PSR 1937+21. We find no evidence for gamma-ray emission from either object.

TRANSIENTS

OSSE was used to undertake extended observations of three transient sources as Targets-of-Opportunity following detections of outbursts by BATSE. These sources are GX339-4, 4U1543-47, and X-ray Nova Per = GRO J0422+32. GX339-4 is a well known transient X-ray source and black hole candidate which exhibits hard and soft spectral states similar to Cyg X-1, and QPO behavior. The OSSE observations of GX339-4 are discussed by Grabelsky et al.[10] OSSE obtained two observations of GX339-4. The first occurred near the end of the two-month "on" period when the source intensity was near the peak intensity observed during the outburst (300 mCrab). The second observation occurred after the intensity had rapidly decayed and was at a level of several mCrab. The spectrum observed during the first observation extends to several hundred keV and is similar to that of other black hole candidates. The GX339-4 spectrum is shown in Fig. 2 along with those of Cyg X-1 and GRO J0422+32.

The outburst of GRO J0422+32 was detected by BATSE on 1992 Aug 5[11] and a Target-of-Opportunity was implemented to enable OSSE to begin viewing the source within 24-hrs. of the BATSE report. At that time the source was already near its maximum intensity at about 3X Crab. OSSE undertook extensive observations of the source for 35 days of the next 40-day interval. The initial BATSE position, with a location uncertainty of about 1.5 degrees, was used to provide OSSE targeting for the first several days. During this period, OSSE performed observations at two scan angles to assist in obtaining a better location for the source. Using these data and additional BATSE occultation data, an improved location was obtained with an error radius of 0.2 degrees.[12] This assisted in the optical identification of the source with a low-mass X-ray binary system.[13,14]

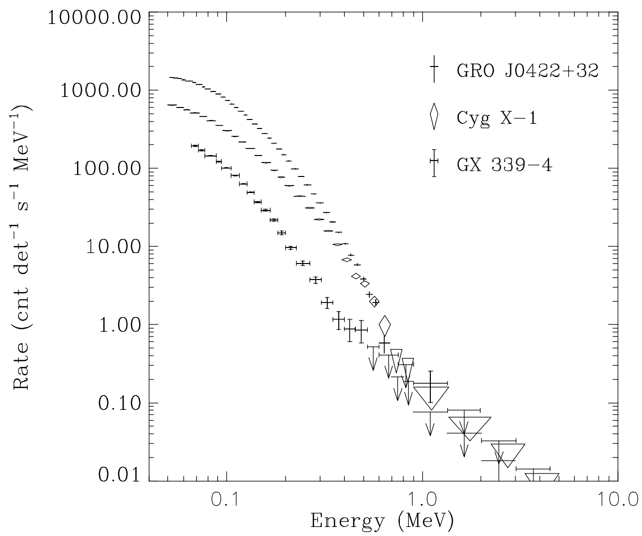

Figure 2. Energy spectra for three black hole candidates: Cyg X-1, GX 339-4, and X Nova Per.

The time history of the OSSE data is shown in Fig 3. The intensity of the source decreases rather monotonically over the period of the OSSE observations. Excellent spectral and timing information have been obtained by OSSE. The spectrum is hard and is well fit by a 100-keV thermal bremsstrahlung model. The spectrum for days 91/225-232 is shown in Fig 2. There may be a hint of an excess above this fit in the region above about 400 keV. However, this appears to be a hardening of the continuum rather than evidence for broad line emission such as has been reported for several other galactic sources. The spectrum hardened further as the intensity decreased toward the end of the OSSE observations. The limit on narrow line emission near 0.5

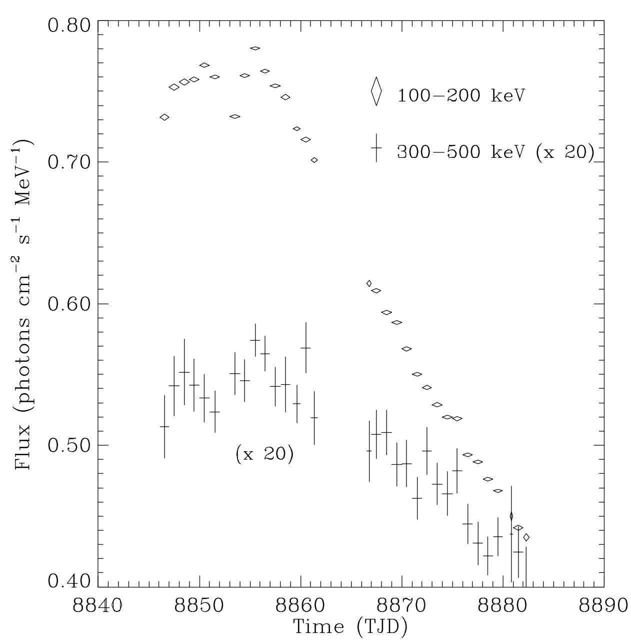

Figure 3. Time history for gamma-ray flux from X Nova Per.

MeV on a daily basis is < 0.1 times that reported by the SIGMA experiment for X-ray Nova Muscae on 1991 Jan 20.[15] Also, GRO J0422+32 reached an intensity of about six times that of Nova Muscae, so the limit for 0.5 MeV emission relative to the hard X-ray continuum flux is about 100 times lower in GRO J0422+32 than that observed for Nova Muscae on Jan 20, 1991.[15] OSSE has also detected QPO behavior in GRO J0422+32.

The third transient observed by OSSE is the source 4U1543-47. This source was reported by BATSE to be in outburst in April 1992[16], and re-orientation of GRO was undertaken to permit OSSE observations starting 1992 April 28. Unlike the other two transients discussed above, 4U1543-47 decayed rapidly and was nearly undetectable by BATSE at the time of the OSSE observation. Nevertheless, OSSE was able to observe the source for about one additional week and acquired temporal and spectral data during this period.

X-RAY BINARY SOURCES

In addition to the transient sources observed as Targets-of Opportunity, OSSE has also obtained observations of several other discrete galactic sources, most of which fall into the category of X-ray binary systems. These include the several XRB sources listed in Table I and several additional sources for which OSSE obtained significant exposure during the several viewing periods devoted to the galactic center region. Because of the large OSSE field-of-view, many other galactic sources were observed in the course of the Phase 1 observations for which the exposure was limited. These are not included in the table.

Cygnus X-1 had significant exposure for viewing periods 2 and 15 and a more limited exposure during VP 7. VP 7 was a Target-of-Opportunity following a reported radio flare in Cyg X-3, and Cyg X-1 was observed for a limited period of time with an effective exposure of only about 25%. All of the Cyg X-1 observations occurred when the source was near its lower intensity levels by historical standards. The energy spectrum observed during VP 2 is shown in Fig 2. The spectrum is observed up to energies of about 800 keV and is well represented by a two-temperature Sunyaev-Titarchuk spectrum.[10] Similar fits are also found for the other Cyg X-1 observations. We have seen no evidence for the gamma-1 state with excess MeV emission as reported by Ling et al.[17] If the low intensity of the hard X-ray emission is taken as evidence for the gamma-1 state with an accompanying MeV emission, the MeV component should have been present at levels ten times above the OSSE limits.

Cyg X-3 was also observed during the three viewing periods VP 2, VP 7 and VP 15. The VP 7 observation was undertaken as a Target-of-Opportunity following a major radio flare,[18] peaking at 17 Jy, which occurred in July 1991. This major flare was preceded by a smaller (5 Jy) flare in late June 1991. The VP 2 OSSE observation ended about one week prior to the precurser flare and the VP 7 observations occurred during the decay phase of the major flare when the radio emission had declined to below 2 Jy. The OSSE data provide the opportunity to investigate any potential correlation between the radio flaring and the high-energy gamma-ray emission. Analysis of these data is in progress. Figure 4 shows the time history of the hard X-ray flux during the period of time covering the three OSSE observations. It is seen that a dramatic decrease in the gamma-ray emission was observed during the VP 2 observation (prior to the precursor radio flare), dropping by a factor of three or more in a period of two days. The intensities during each of the latter observations, which occurred during the decay phase of the radio flare and during a radio quiet period resp., were higher and relatively constant. It is not clear whether there is any connection between the gamma-ray variability observed and the radio flaring. It is most plausible that radio flaring would be delayed from the higher energy activity, which is presumably indicative of processes much nearer to the central compact object.

Her X-1 was observed 1991 Sept 12-19, a period of time which included the X-ray turn-on during the 35-day period. OSSE detected the 1.24 sec. pulsar period at energies up to about 100 keV. 1.7-day eclipses are also seen in the data. The OSSE energy threshold (40-50 keV) is not low enough to see the previously reported cyclotron feature in the Her X-1 spectrum.[19] The OSSE data will be carefully analyzed for higher energy harmonics and phase-dependent spectral characteristics. However no information is available on these yet.

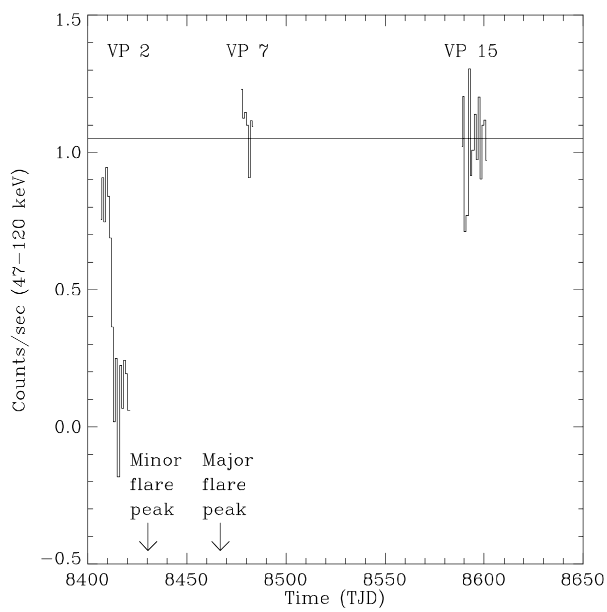

Figure 4. Time history of the gamma-ray emission from Cyg X-3. The OSSE observations during VP 7 were a Target-of-Opportunity following radio activity in June and July 1991.

GALACTIC CENTER SOURCES

The galactic center region has been observed for a total of 17 weeks during Phase 1 of the mission. The times of these observations are listed in Table 1. These observations have several objectives, including mapping the distribution of the 0.511 and 1.809 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 variable point source(s) of 0.51 MeV emission, and the detection and study of other discrete low-energy sources in the region. Purcell et al.[3] discuss the galactic center observations in some detail and give the OSSE results on the 0.511 MeV emission. In this article, we comment on the status of discrete sources in the region.

The galactic center observations were undertaken with several different position angles of the OSSE 3.8^o x 11.4^o collimators with respect to the galactic plane (see Purcell et al.[3] for details). 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. SIGMA can obtain hard X-ray and low-energy gamma-ray images, but at a sensitivity which is about 5 times poorer that the OSSE limiting sensitivity. Nevertheless, undertaking joint analysis of these data is proving very beneficial.

OSSE has detected several sources in the galactic center region, including GX1+4, 1E1740.7-2942, and GX354+0. These have all been confirmed as SIGMA sources during several of the joint observations.[20] For the OSSE data, preliminary spectra of the individual sources can be obtained. The quality of these results will continue to improve as the mapping studies provide an improved distribution of the diffuse hard X-ray continuum, thereby permitting extraction of the discrete source contributions. Two examples illustrate the capabilities for OSSE to detect and study discrete sources in this complex region. These observations were typically undertaken at several scan angle positions separated by 1 or 2 degrees. Background observations were usually acquired at scan positions of 10 to 12 degrees from the center of the scan region. See Purcell et al.[3] for details. Figure 5 shows the time history of the 80-150 keV emission during the first eight galactic center observations in Phase 1. Shown is the flux in the OSSE field-of-view for the scan position which was centered on the galactic center. The position angle for each of the viewing periods is shown. A position angle of $\pm 90^o$ corresponds to the long axis of the OSSE collimators being aligned parallel to the galactic plane. Note that the collimator was aligned along the galactic plane or close to it, with the

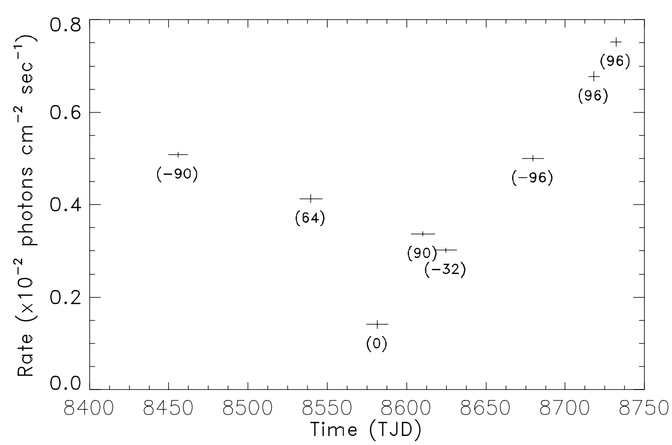

Figure 5. Time History of the 50-100 keV flux from the galactic center region. Observations were during VP 5, 11, 14, 16, 17, 21, 24 and 25. The position angle of the OSSE collimators is shown.

exception of VP 14, when the long axis of the collimator was perpendicular to the plane, and VP 17 at a position angle of 32^{o}. This results in a reduced exposure to a galactic plane component during VP 14. The lowest flux observed in these galactic center views was in VP 14, suggesting that the overall emission is dominated by a diffuse component or multiple discrete sources along the galactic plane, although it should be noted that the background observations for the VP 14 datum were also positioned on the galactic plane at galactic longitudes of $\pm 12^{o}$. Note, also, that viewing periods 5, 16, 21, 24, and 25 all have collimator position angles of 80-90 degrees. The dramatic decrease between viewing periods 5 and 16 and subsequent increase in viewing periods 21 and 24 indicate that one or more sources are highly variable. Correlative SIGMA observations in VP 24 indicate that 1E1740.7-2942 was in a higher intensity state at that time.[20]

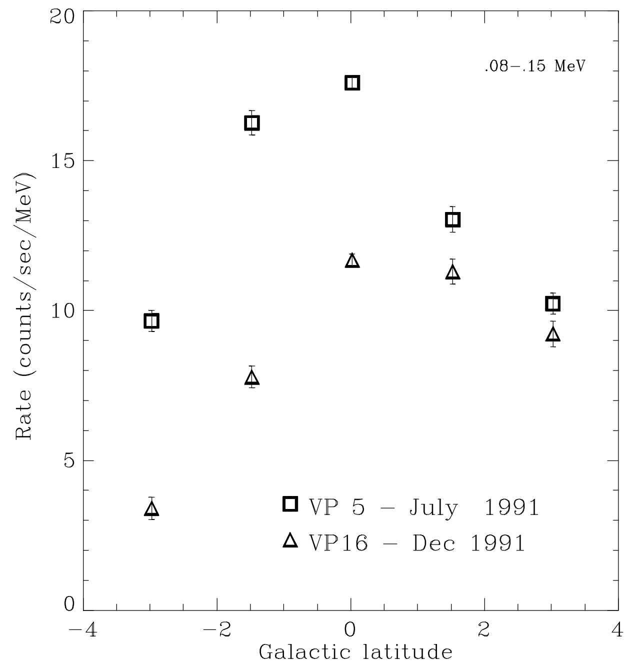

Figure 6. Comparison of the galactic latitude scan data at galactic longitude 0 degrees for VP 5 and VP 16. The observation strategies were identical for these viewing periods.

Figure 6 compares the flux vs. scan angle for viewing periods 5 and 16. These observations had identical exposures to the galactic center regions so any differences are due to variability of discrete sources in the region. The difference between the VP 16 data and the VP 5 data is shown in Figure 7. It is clear that there is a variable source near a galactic latitude of -1.5 to -2.0 degrees. Candidates for this object may be GS 1758-258[21] or 1H1743-32.[22]

OTHER GALACTIC SOURCES

Several other galactic sources that OSSE has observed in Phase 1 include Nova Cygni 1992, Cas A and the Eta Carina region. Leising et al.[23] present upper limits to the OSSE search for ^{22}Na emission from Nova Cygni. Additional observations of this source may be warranted due to the long half life of ^{22}Na and the possibility that Nova Cygni 92 was still optically thick to gamma rays at that time of the OSSE observation.[24] The Eta Carina region is interesting from several viewpoints. In addition to Eta Carina, it is a region of considerable current star formation and includes several Wolf-Rayet stars. Enhanced continuum emission is also likely from the galactic arm, thereby complicating the analysis for this confusing region. OSSE Phase 1 and Phase 2 data will be analyzed together to determine the emission, if any, from this region.

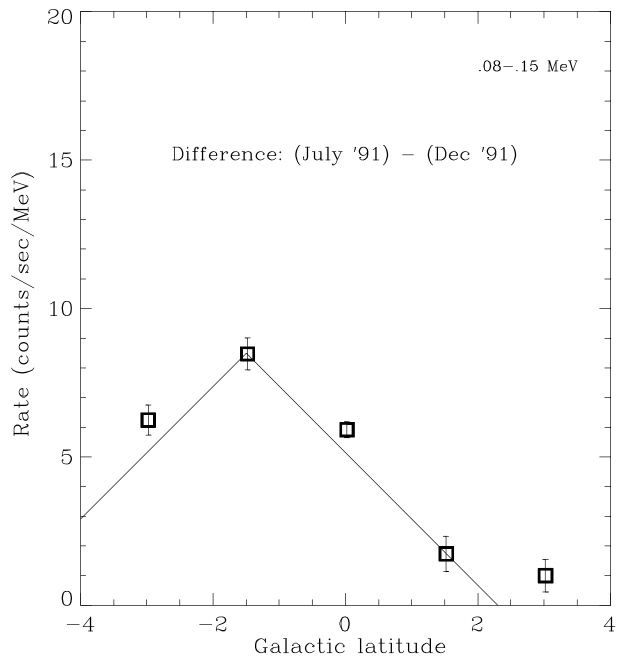

Figure 7. The difference between the VP 5 and VP 16 scans indicates a discrete source at galactic latitude -2 degrees was on during VP 5 but off, or at a lower intensity, during VP 16.

SUMMARY

OSSE has undertaken dedicated observations of about 20 galactic sources during Phase 1. Several of these have been Targets-of-Opportunity following initial discovery by BATSE, demonstrating the complementary nature of the GRO instruments. During Phase 1, multiple observations were devoted to the galactic center region in support of a number of scientific objectives and several sources in the galactic center region have been observed. Understanding the spectral and temporal characteristics of these sources will continue to improve as the spatial distribution of the diffuse component is better determined.

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