COMPTEL Observations of X-Ray Binaries

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ABSTRACT

Over the past several years, there have been sporadic reports of emission at energies > 1 MeV from several X-ray binary (XRB) sources. This includes not only observations in the 1-10 MeV range, but several reports at TeV and PeV energies. These observations suggest that very energetic processes may be taking place in these systems. The COMPTEL experiment provides the most sensitive measurements to date in the critical 0.75-30 MeV energy range which bridges the region between thermal and non-thermal emission processes. We have therefore initiated a search for XRB sources in the COMPTEL database. To date, only two such sources have been detected - Cygnus X-1 and the transient X-ray nova GRO J0422+32 (Nova Persei 1992). Here we summarize the latest results from these two sources along with upper limits for Cygnus X-3.

1. INTRODUCTION

The COMPTEL experiment on the *Compton Gamma-Ray Observatory* (CGRO) is designed to image gamma-radiation in the energy range from 0.75-30 MeV. This is a particularly interesting energy range for several XRB sources, including the black-hole candidate Cygnus X-1. Various observers have reported detections of excess emission from Cygnus X-1 at energies around 1 MeV beyond that which would be expected based on an extrapolation of the hard X-ray spectrum (e.g., Baker *et al.* 1973, Ling *et al.* 1987 and McConnell *et al.* 1989). The reported flux levels are more than two orders of magnitude above the COMPTEL detection threshold, suggesting that COMPTEL is capable of studying such emission in detail. Such emission has also been reported from the galactic center source 1E1740.7-2842 (e.g., Ling and Wheaton 1989; Sunyaev *et al.* 1991). This suggests that a complete survey of the sky at these energies may be useful for studying XRB sources. Here we shall present the latest results from the first such survey being conducted with data collected by COMPTEL.

2. OBSERVATIONS AND ANALYSIS

During the first 18 months of orbital operations, COMPTEL has performed the first-ever sky survey in the 0.75-30 MeV energy range. This sky survey was completed in November, 1992. A second phase of the CGRO mission, which will be completed by August, 1993, will provide additional coverage for selected regions of the sky. These data provide an unprecedented opportunity to perform a systematic search for MeV emission from XRBs.

The analysis of COMPTEL data relies on having accurate response information for the COMPTEL experiment. The instrumental response information comes from a Monte Carlo simulation model which is based on the CERN GEANT code. This simulation has been verified by comparisons with pre-flight calibration data. An instrumental point-spread-function (PSF) is defined by simulating a large number of events and binning those events into the appropriate dataspace. For COMPTEL, this is a three-dimensional dataspace which is defined by the projected

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direction of the scattered photon (based on the interaction locations in the upper, D1, and lower, D2, detectors) and the derived Compton scatter angle (based on the energy loss measurements in D1 and D2). The various analysis techniques which are employed for COMPTEL data analysis all depend on a comparison of the PSF and the measured data within this three-dimensional dataspace. (See also Schönfelder *et al.* 1993.)

The PSF is defined for a given source location within the field-of-view and a given source spectrum. In the search for emission from XRBs, we generally employ a PSF based on a Wien spectrum, which represents the high energy limit of the Sunyaev-Titarchuk inverse-Compton spectrum (Sunyaev and Titarchuk 1992). This spectrum is typically used to describe the hard X-ray spectrum of XRB sources. In addition to the normalization, the Wien spectrum has only a single parameter - the electron temperature (kT) of the accreting plasma. Given the relatively high energy threshold of the COMPTEL data, the resulting observations are relatively insensitive to the Compton scattering optical depth in the standard inverse-Compton model.

Images can be produced from COMPTEL data using a maximum entropy technique (Strong *et al.* 1992), which seeks to determine the 'flattest' intensity distribution consistent with both the given data and the instrumental response. A more quantitative analysis is performed using a maximum likelihood method (de Boer *et al.* 1992), which provides information regarding the source location and flux. For the present analysis, no independent estimate of the background (predominantly instrumental in origin) was available for the maximum likelihood analysis. Therefore, an estimate of the background was derived directly from the source data by an averaging technique which suppresses point-source signals, but preserves the general background structure.

3. RESULTS

Although our survey is far from complete, our studies have found positive evidence for emission from at least two XRBs - Cygnus X-1 and GRO J0422+32 (Nova Persei 1992). Both of these sources are considered to be strong black hole candidates. Here, we shall review our results for both of these sources along with some upper limits which have been derived for Cygnus X-3.

3.1 Cygnus X-1

During the sky survey period, COMPTEL observed the Cygnus region on two separate occasions. The first observation, which was part of the planned 15-month sky survey, took place from May 30 to June 8, 1991 (Viewing Period 2.0). Although planned as a full two-week exposure, this observation was interrupted after only nine days due to the declaration of a solar target-of-opportunity for CGRO. A second opportunity to observe the Cygnus region came only 1-1/2 months later, when another target-of-opportunity was declared to observe Cygnus X-3 (which had recently exhibited an intense outburst of radio emission). This observation (Viewing Period 7.0) lasted from August 8 to August 15, 1991. In addition to these phase 1 observations, a total of five additional weeks of observation time is being allotted to the Cygnus region for the second phase of the CGRO program.

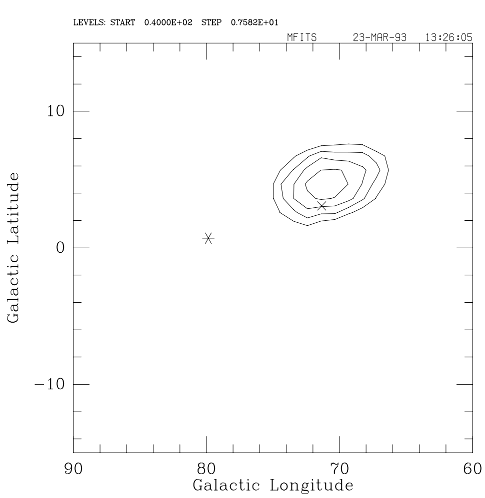

Fig. 1: Maximum likelihood map produced from the 0.75-1.0 MeV data of VP 7.0. An 'x' marks the location of Cygnus X-1. An asterisk marks the location of Cygnus X-3.

To date, only the phase 1 data has been analyzed. Positive flux measurements are found for both observation periods in the range of 0.75-3.0 MeV. Only upper limits are available at higher energies. In Figure 1 we show a maximum likelihood map of the Cygnus region as derived from the 0.75-1.0 MeV data collected during VP 7.0. The strong feature which dominates the image is consistent with a point source at the location of Cygnus X-1. The COMPTEL spectra derived from both observation periods are shown in Figure 2, along with the OSSE spectrum derived from data collected during VP 2.0 (Johnson *et al.* 1993). The flux levels found by COMPTEL in both the 0.75-1.0 MeV band and the 1.0-3.0 MeV band are about a factor of two lower during VP 2.0 than those in VP 7.0. This is consistent with the fact that OSSE also observed a more intense spectrum during VP 7.0.

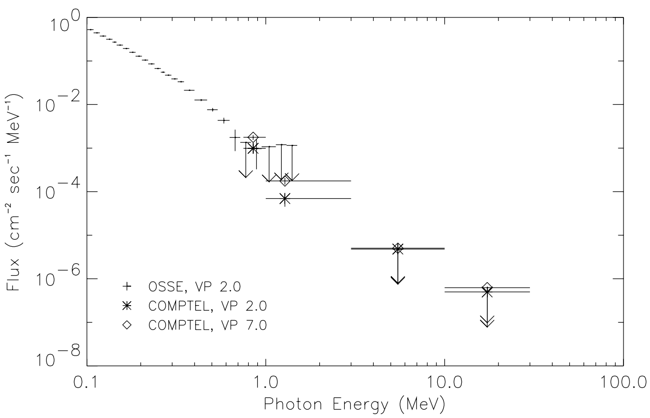

Fig. 2: COMPTEL spectra of Cygnus X-1 produced from data collected during VP 2.0 and VP 7.0. The OSSE spectrum from VP 2.0 is also shown.

For VP 7.0, we have crudely estimated the electron plasma temperature (kT) from the COMPTEL data by comparing the measured flux ratio in the two lowest energy bands with that expected for the Wien spectrum used in the corresponding PSFs. It is found that the derived flux ratio agrees fairly well with that predicted for an electron temperature in the range of 80-100 keV. This is generally consistent with previous hard X-ray measurements of Cygnus X-1. The COMPTEL data, however, show no evidence for any excess emission in the region around 1 MeV beyond that which is expected from an extrapolation of the hard X-ray spectrum. For example, the COMPTEL measurements are more than an order of magnitude below the HEAO-3 results of Ling *et al.* (1987). (See also McConnell *et al.* 1993.)

3.2 Cygnus X-3

As can be seen in Figure 1, there is no evidence for a source at the location of Cygnus X-3; this is important to note, given that VP 7.0 took place shortly after a major radio outburst from Cygnus X-3. We have derived (time-averaged) upper limits for this source during VP 7.0, which are given in Table 1. These upper limits provide the most stringent constraints to date on the MeV emission from Cygnus X-3.

Table 1: Upper Limits for Cygnus X-3 (VP 7.0)

Energy (MeV)	2σ Flux Limit (cm^{-2} sec^{-1} MeV^{-1})
0.75-1.0	6.0×10^{-4}
1.0-3.0	8.1×10^{-5}
3.0-10.0	6.7×10^{-6}
10.0-30.0	6.0×10^{-7}

3.3 GRO J0422+32 - Nova Persei

This X-ray nova was discovered by the BATSE experiment on CGRO on August 5, 1992 (Paciesas *et al.* 1992). Within a few days, the intensity increased to ~3 Crab in the 20-300 keV energy range. After the initial outburst, the source intensity decreased exponentially with an e-folding decay time of ~41 days.

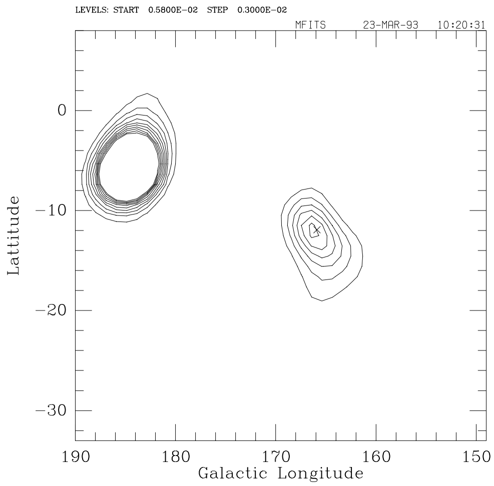

Fig. 3: Maximum entropy image of the anticenter region obtained using 1-2 MeV data collected during VP 36.5. The Crab is clearly seen at upper left. An ‘x’ marks the location of Nova Persei.

A target-of-opportunity was soon declared for CGRO and the spacecraft was repointed on August 11. This first observation (consisting of two consecutive CGRO viewing periods - VP 36.0 and 36.5) lasted a total of 9 days. A second observation, which began on September 1, lasted 16 days (VP 39.0). A detailed analysis of these data is complicated, in part, by the presence of the very strong Crab signal. Spectral results are not yet available, but there is evidence that COMPTEL has measured Nova Persei up to 2 MeV during August and up to 1 MeV during September. Figure 3 shows the image obtained for the 1-2 MeV energy range from part of the August observation.

The OSSE results for this source indicate a spectrum very similar to that of Cygnus X-1 (Cameron *et al.* 1992). In addition, the decay of the hard X-ray flux was observed to be very similar to that of pevious X-ray novae (Harmon, Fishman, and Paciesas 1992), which are now associated with black hole candidates. These data, along with dynamical evidence derived directly from optical observations of Nova Persei (Kato, Mineshiga and Hirata 1993) also suggests the presence of a black hole. This would make Nova Persei the second black hole candidate detected by COMPTEL.

4.0 SUMMARY AND FUTURE WORK

The COMPTEL database affords an unprecedented opportunity to obtain high-sensitivity measurements of XRB sources to energies beyond 1 MeV. This has already provided some interesting results on Cygnus X-1. These results show no evidence for any excess emission near 1 MeV as has often been reported in the past. We plan to continue our present survey efforts, looking at several other XRB sources in an effort to determine the level to which XRB sources may be visible in the MeV energy range.

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