Search for MeV Emission from the X-Ray Binary Cyg X-3

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ABSTRACT

A comprehensive search for emission of the X-ray binary system Cyg X-3 in the soft γ-ray range (0.75 - 30 MeV) is currently in progress. For this search all the available COMPTEL data on the Cygnus region collected between the launch of the Compton Gamma-Ray Observatory (CGRO) in April 1991 and the end of Phase III of the CGRO-mission in October 1994 are used. MeV-emission from Cyg X-3 was neither detected during individual CGRO viewing periods (VPs), nor during individual CGRO viewing phases, nor in the sum of all available data. These non-detections prove the absence of strong MeV-flares within individual VPs and result in the most stringent upper limits derived to date on the phase-averaged MeV-flux of Cyg X-3. A first order phase dependent analysis (5 phase bins with respect to the 4.8 hour periodicty) was carried out, which has also resulted in upper limits only.

1. INTRODUCTION

Cyg X-3 was discovered as an X-ray source by a rocket flight in 1966 [1]. It is one of the brightest X-ray sources in the sky and shows a roughly sinusoidal 4.8 hour modulation of its X-ray flux. Due to the high stability of this periodicity this is interpreted as the orbital period of a binary system. At hard X-rays ($\geq$20 keV) Cyg X-3 shows a steep spectrum $\sim E^{-3}$ (e.g. [2], [3]) which makes the source undetectable for X-ray instruments above $\sim$200 keV.

After reports on the the detection of γ-ray emission from Cyg X-3 at TeV energies [4] and at medium γ-ray energies (40-100 MeV) [5], the source gained much attention in the γ-ray community. At soft γ-rays (around 1 MeV) observations of Cyg X-3 are sparse. There has been one report of emission from Cyg X-3 up to about 600 keV [6], however subsequent observations at these energies have not yielded any positive measurement [7].

In this paper we present results of COMPTEL observations (0.75 - 30 MeV) of Cyg X-3 in the soft γ-ray range. Imaging is possible within the COMPTEL 1 steradian field of view with a location accuracy of better than 1° for strong sources. Different sources of equal intensity can be resolved if they are separated by more than $\sim 5^\circ$. For a detailed description of the COMPTEL instrument see [8]. Preliminary COMPTEL upper limits on the MeV flux from Cyg X-3 have been reported [9] using a subset (7 days) of the data analysed for this paper.

2. OBSERVATIONS

From the beginning of the CGRO mission in April 1991 up to the end of Phase III in October 1994, Cyg X-3 was in the COMPTEL field of view (within 30° of the pointing direction) many times. Overall the Cyg X-3 region was viewed for 116 days (more than 16 weeks). This time is roughly equally divided between the different Phases of the CGRO-mission. The data of the pointings are given in Table 1.

VP #	Obs. Time yy/mm/dd - yy/mm/dd	Dur. [days]	Sep. [°]	Phase	Dur. [days]
2	91/05/31 - 91/06/08	8	6.9	I	38
7	91/08/08 - 91/05/30	7	13.1		
34	91/07/16 - 91/08/06	21	29.0		
203.0	92/12/01 - 92/12/08	7	2.1	II	37
203.3	92/12/08 - 92/12/15	7	2.1		
203.6	92/12/15 - 92/12/22	7	2.1		
212	93/03/09 - 93/03/23	14	11.6		
302	93/09/07 - 93/09/09	2	11.7	III	41
303.2	93/09/22 - 93/10/01	9	11.7		
303.7	93/10/17 - 93/10/19	2	11.7		
318	94/02/01 - 94/02/08	7	11.5		
328	94/05/24 - 92/05/31	7	15.1		
331.0	94/06/07 - 94/06/10	3	15.1		
331.5	94/06/14 - 94/06/18	4	15.1		
333	94/07/05 - 94/07/12	7	15.1		

Table 1: COMPTEL observations of the Cygnus region between May 1991 and July 1994. The fourth column gives the angular separation between the position of Cyg X-3 and the COMPTEL pointing direction.

3. DATA ANALYSIS

The data collected by COMPTEL on the Cyg X-3 region during Phase I, II and III of the CGRO-mission are currently being analysed. So far, the analysis has proceeded along the COMPTEL standard analysis procedures. Significance, flux- and flux error maps in the four standard COMPTEL energy bands (0.75-1 MeV, 1-3 MeV, 3-10 MeV, and 10-30 MeV) have been generated by applying a maximum-likelihood method [10] and a background modelling technique as described by [11]. These maps have been (visually) inspected for evidence of Cyg X-3 (see Fig. 1).

For the derivation of quantitative flux (upper limit) values of Cyg X-3, the nearby strong source Cyg X-1 ($\sim 9^\circ$away) was taken into account. Source models (known or assumed source parameters are folded with the COMPTEL response at a given source position) of Cyg X-1 and Cyg X-3 have been generated and included in the likelihood fitting process. This approach leads to a simultaneous determination of the Cyg X-1 and Cyg X-3 fluxes. The flux results for Cyg X-3 have been derived with point spread functions (PSFs) assuming an $E^{-2.0}$-power law spectral shape. Though this might not correspond to the true spectral slope of Cyg X-3, the impact of this specific choice on the flux results is small.

The analysis described above has been applied to each individual VP (parts of VPs have not been analysed separately because of their short observation times), to the mosaic of data in individual CGRO phases, and to the mosaic of all data, which leads to results on the phase-averaged MeV-flux of Cyg X-3. In a second step, a first order phase dependent analysis with respect to the 4.8 hour X-ray modulation was carried out. Using the ephemeris of [12], the complete dataset (116 days of data) has been subdivided into 5 phase intervals (0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, 0.9-1.1). To each phase interval, the analysis method described above has been applied.

In the analysis presented here no diffuse emission model of the Cygnus region has been included. This will be done in further analyses.

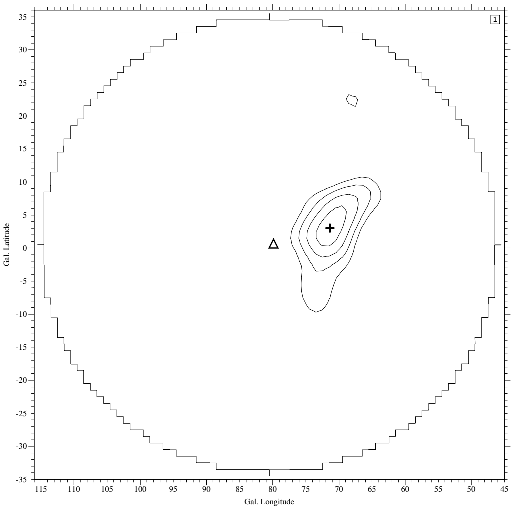

Figure 1: COMPTEL 0.75-1 MeV skymap of the Cygnus region for the sum of all data (CGRO Phase I-III). The contour lines start at a detection significance level of 3σ with a step of 1σ assuming known sources (the maximum-likelihood ratio is interpreted in terms of a χ^2-distribution with 1 degree of freedom). The locations of Cyg X-1 (+) and Cyg X-3 (Δ) are indicated. Cyg X-1 is clearly detected ($>6\sigma$) while at the position of Cyg X-3 no emission is obvious.

CGRO Phase	0.75 - 1 [MeV]	1 - 3 [MeV]	3 - 10 [MeV]	10 - 30 [MeV]
I+II+III	<7.05	<11.2	<2.17	<1.68
I	<10.8	<18.2	<4.96	<3.01
II	<10.4	<15.7	<2.99	<2.04
III	<8.92	<13.1	<6.06	<2.03

Table 2: COMPTEL upper limits (10^{-5}cm^{-2}s^{-1}) on the MeV flux of Cyg X-3 for different energy bands and different observational periods. The upper limits are 2σ and are statistical only. No assumptions about systematic errors ($\sim$30%) are included.

4. RESULTS

Applying a detection threshold of 3σ, Cyg X-3 was not detected in any of the four energy ranges neither in individual VPs, nor in the mosaic of data in individual CGRO phases, nor in the mosaic of all data. As an example, Figure 1 shows a skymap of the Cygnus region in the 0.75-1 MeV energy range for the sum of all data. Evidence for Cyg X-1 is clearly visible while at the position of Cyg X-3 the map is empty. This skymap demonstrates that even at its lowest energies where the angular resolution is at worst, COMPTEL is able to clearly distinguish between Cyg X-3 and any emission from Cyg X-1. The derived upper limits on the flux of Cyg X-3 for the different energy intervals and observational periods are given in Table 2. In Figure 2 the COMPTEL upper limits for the sum of all data are compared to previous observations of Cyg X-3 at MeV energies, and to the average (CGRO Phase I-III) spectral shape measured at hard X-rays by OSSE [13]. This shape was determined between 50 keV and roughly 200 keV and is extrapolated throughout the COMPTEL energy range. The COMPTEL upper limits are consistent with the extrapolation of the OSSE spectral shape and provide the most stringent upper limits on the phase-averaged, quiesent MeV emission of Cyg X-3. The non-detections of Cyg X-3 in individual VPs and CGRO observational phases shows that during 16 weeks of COMPTEL observations no strong MeV flare has occured.

The phase dependent analysis has resulted also in upper limits only. In none of the four energy ranges of the five phase intervals could significant MeV emission from Cyg X-3 be detected.

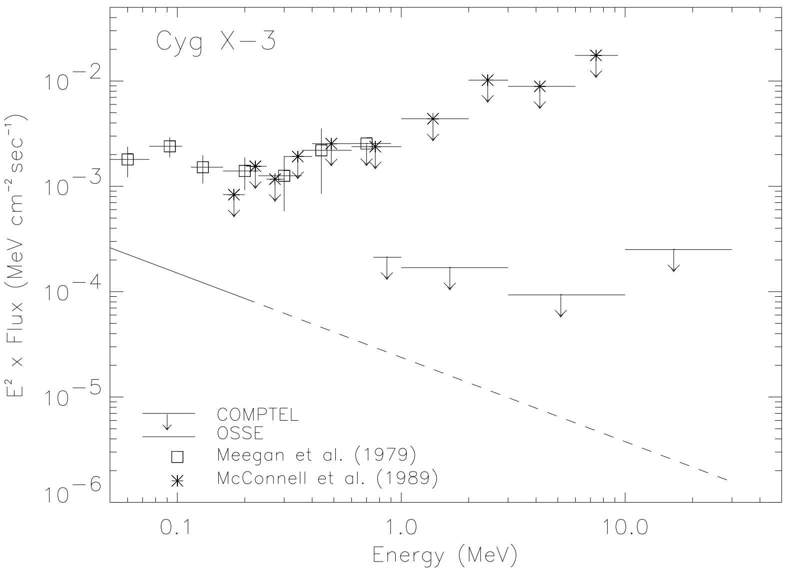

Figure 2: COMPTEL upper limits (2σ) derived in the four energy bands for the mosaic of all data compared to previous observations around MeV energies, and to the measured spectral shape at hard X-rays (solid line) by OSSE [13]. This shape is extrapolated into the COMPTEL energy range (dashed line). The McConnell et al. results are upper limits (1σ) as well.

5. SUMMARY

A comprehensive search for MeV emission of Cyg X-3 using the complete COMPTEL database on Cyg X-3 (in total 116 days of observation time) up to the end of Phase III of the CGRO mission (October 1994) is in progress. Neither in the phase-averaged nor in the phase dependent analysis (covering 5 phase bins of the 4.8 hour periodicity) carried out so far, significant MeV emission from Cyg X-3 could be detected. The derived upper limits on the phase-averaged flux, provide the most stringent constraints on the quiescent MeV emission of Cyg X-3 to date.

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