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COMPTEL OBSERVATIONS OF CYGNUS X-1

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ABSTRACT

We report on the latest results from an analysis of data on Cygnus X-1 as collected by the COMPTEL experiment on the Compton Gamma-Ray Observatory (CGRO). COMPTEL detected the source around 1 MeV during two separate one-week observations in 1991. The measured flux levels indicate variability on a time scale of weeks. The results also indicate flux levels which are well below the levels reported by some investigators for an excess of emission in the energy range ≥ 1 MeV.

INTRODUCTION

The COMPTEL experiment on the Compton Gamma-Ray Observatory is designed to measure gamma-radiation in the energy range from 0.75-30 MeV. This is a particularly interesting energy range for the black-hole candidate Cygnus X-1. Various observers have reported detections of excess emission at energies around 1 MeV beyond that which would be expected based on an extrapolation of the hard x-ray spectrum[1,2,3]. 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. During the first year of CGRO orbital operations, Cygnus X-1 was within the COMPTEL field-of-view on two separate occasions. The first observation took place in early June of 1991. The second observation took place some 1-1/2 months later, in August, 1991. Cygnus X-1 is clearly seen in data collected during both observations, with a weaker signal detected during the first observation. Here we shall present the latest results from the analysis of these data along with a comparison between the COMPTEL data and earlier measurements at these energies.

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OBSERVATIONS

During the first year of orbital operations, the COMPTEL experiment 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. The net result was a total exposure which exceeded the standard 14-day observation. More importantly, these data provided an opportunity to study time variability during the intervening 1-1/2 month time interval.

During the early phases of the GRO mission, the COMPTEL instrument was not operating at full capacity. This was due primarily to out-gassing effects which were noted in certain detector modules. For this reason, the affected modules remained turned off for most of the early part of the mission. During V.P. 2.0, the instrument configuration changed frequently. For the purposes of the present anlysis, only eight days of data were used. Three of the 14 D2 modules were not active during this period; this amounts to a reduction in overall COMPTEL efficiency by 21%. During V.P. 7.0, one D1 and one D2 module were inactive; this is equivalent to a reduction of about 20% in the overall COMPTEL efficiency.

ANALYSIS

The analysis of the COMPTEL imaging data for these two observation periods has been performed using the maximum likelihood method.[5] This method provides quantitative 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.

For the present analysis, the response information comes from a COMPTEL simulation model. The simulation model is based on the CERN GEANT code and is used to simulate a large number of events which can then be used to define the PSF of the COMPTEL instrument. The present results are somewhat limited in terms of the number of simulated events which have been used to generate the PSFs. Therefore, it can be expected that the present results may be somewhat modified as the PSF statistics are improved with additional simulations.

It is also important to ensure that the PSF be defined for a spectrum which accurately represents the spectrum of the observed source. For the results described here, the PSFs were generated for an input Wien-type spectrum, which represents the high energy limit of the Sunyaev-Titarchuk inverse-Compton spectrum.[6] In addition to the normalization, this 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.

RESULTS

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 V.P. 7.0. Cygnus X-1 dominates the image. There is no apparent signature in the direction of Cygnus X-3; this is important to note, given that V.P. 7.0 was also the Cygnus X-3 target-of-opportunity. Upper limits for Cygnus X-3 have not yet been derived from these data.

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. The flux levels found 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 V.P. 2.0 than those in V.P. 7.0.

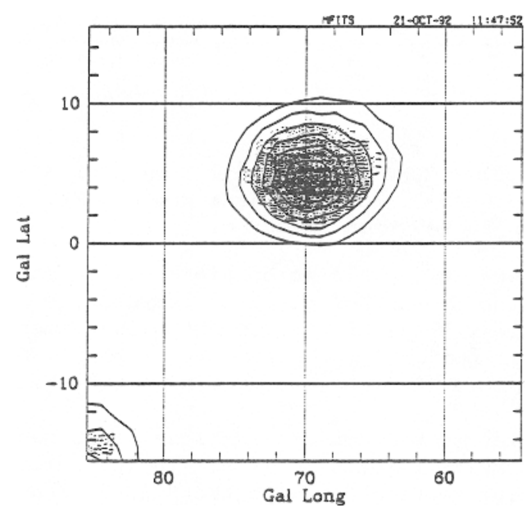

Fig. 1. Maximum likelihood image of the Cygnus region for the 0.75-1.0 MeV data collected during Viewing Period 7.0. The response from Cygnus X-1 (at l=71.3°, b=3.1°) stands out clearly whereas there appears to be no evidence for emission from Cygnus X-3 (at l=79.9°, b=0.7°).

For V.P. 7.0, we have crudely estimated the electron plasma temperature (kT) 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

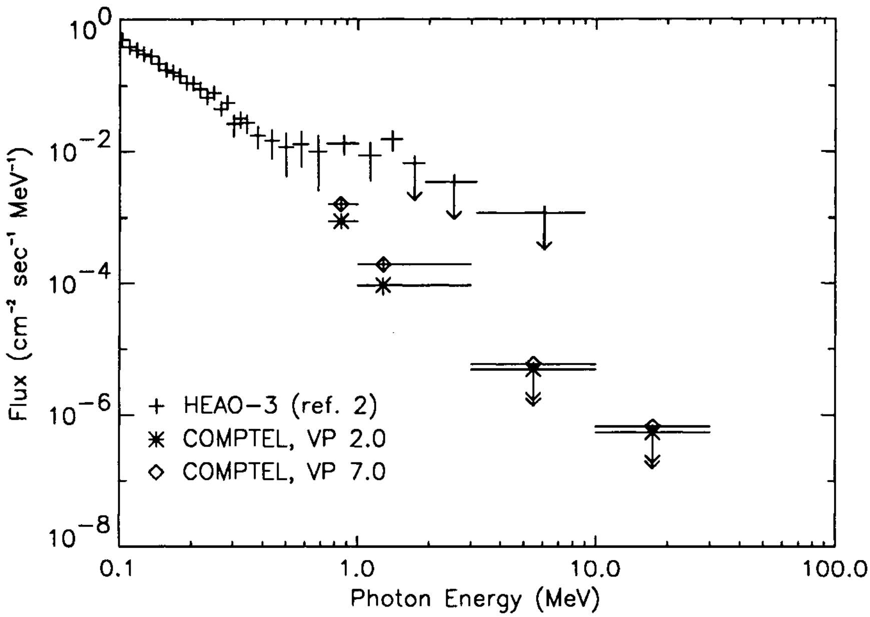

Fig. 2. The COMPTEL spectra compared with the γ_1 spectrum of HEAO-3. COMPTEL data below 3 MeV are plotted based on an 80 keV Wien spectrum.

the range of 80-100 keV. This is consistent with many previous measurements of the Cygnus X-1 electron temperature at hard x-ray energies.[7] Figure 2 shows the two COMPTEL measurements relative to the γ_1 spectrum as measured by Ling et al. (1987). The COMPTEL measurements are more than one order of magnitude below the HEAO-3 data.

Several relevant balloon observations are shown in Figure 3 along with the COMPTEL results for V.P. 7.0 (the higher of the two COMPTEL flux measurements). As with the HEAO-3 data, the COMPTEL data points fall far below some of these data. The UCR Compton telescope upper limits are, however, compatible with the COMPTEL results.

DISCUSSION AND SUMMARY

The present COMPTEL results are interesting in that they permit a high-sensitivity measurement of the Cygnus X-1 spectrum to energies

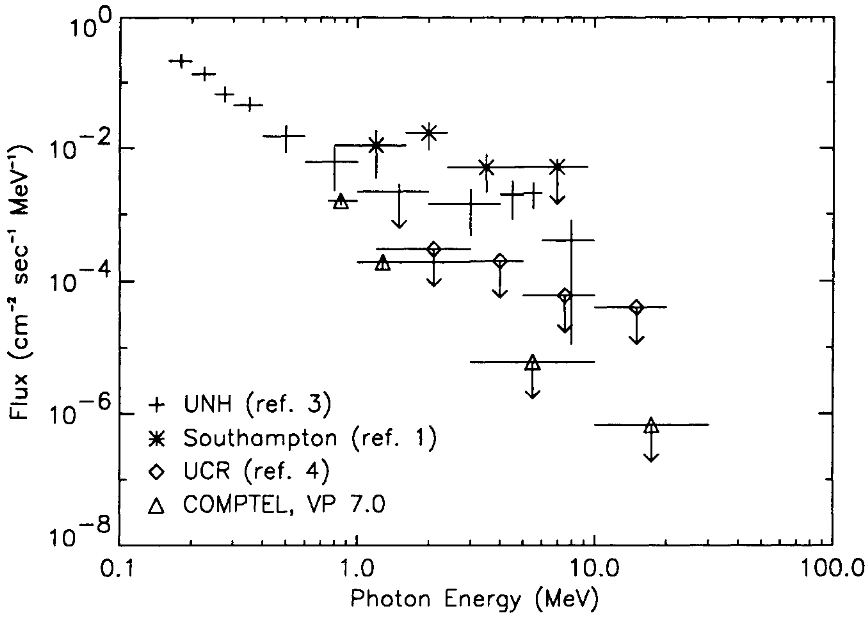

Fig. 3. The COMPTEL spectra compared with various balloon measurements. COMPTEL data below 3 MeV are plotted based on an 80 keV Wien spectrum.

above 1 MeV. These data show no evidence for any excess emission near 1 MeV as has often been reported in the past. It is interesting to note that during Viewing Period 2.0, the OSSE spectral data indicate that the hard x-ray flux was in a relatively low state.[8] More specifically, it was in a level comparable to that of the γ_1 state as defined by the HEAO-3 measurements[2]. The excess of emission near 1 MeV observed by HEAO-3 was found during a correspondingly low level of hard x-ray flux. The fact that the COMPTEL results show no evidence for any excess emission suggests that the low hard x-ray flux may be a necessary condition for MeV emission, but it is certainly not a sufficient condition.

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