TeV Gamma Ray Emission from Cen X-3

P.M. Chadwick, K. Lyons, T.J.L. McComb, K.J. Orford, J.L. Osborne, S.M. Rayner, S.E. Shaw, and K.E. Turver

Department of Physics, Rochester Building, Science Laboratories, University of Durham, Durham, DH1 3LE, U.K.

Abstract

Cen X-3 is a well-studied high-mass accreting X-ray binary and a variable source of high energy gamma rays from 100 MeV to 1 TeV. The object has been extensively monitored with the University of Durham Mark 6 telescope. Results of observations, including those taken in 1998 and 1999, are reported. There is no evidence for time variability in all the VHE data. There is also no evidence for correlation of the VHE flux with the X-ray flux detected by BATSE and *RXTE*/ASM. A search for periodic emission, at or close to the X-ray spin period, in the VHE data yielded a 3σ upper limit to the pulsed flux of $2.0 \times 10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

1 Introduction

Results of observations of the accreting X-ray binary Cen X-3 using ground based gamma ray telescopes have been reported which have included evidence for sporadic outbursts of strong pulsed emission in the > 1 TeV band (Carraminana at al. 1989, Raubenheimer et al. 1989) and a constant but weaker unpulsed emission at > 400 GeV (Chadwick et al. 1998). These results, together with the *CGRO* EGRET measurement of an outburst of pulsed GeV emission (Vestrand, Sreekumar & Mori 1997), indicate that Cen X-3, an accurately measured system containing a 4.8 s pulsar in a 2.1 d orbit around an O-type supergiant, is a sporadic source of high energy gamma rays.

The discovery of very high energy (VHE) gamma rays from X-ray selected BL Lacs has been a highlight of high energy astrophysics in recent years (Weekes et al. 1997). These objects have been shown to be sporadic and copious TeV gamma ray emitters. They exhibit extremely short term time variability in TeV emission and a correlation between the emission of X-rays and TeV gamma rays (Schubnell 1997). This short term TeV variability and the correlation with X-ray emission provide constraints on the possible production models for TeV gamma rays. Many models involve the jets which are a feature of such objects. There have been suggestions that some galactic objects may share the jet properties more usually associated with AGNs (Hjellming & Nan 1995) and jets have been suggested as sources of TeV emission from X-ray binaries (Vestrand & Eichler 1982, Hillas 1984, Kiraly & Meszaros 1988).

We present the results of a search for a possible correlation between > 400 GeV gamma rays recorded by the University of Durham Mark 6 telescope and X-ray emission according to measurements made with the *RXTE* and *CGRO*/BATSE experiments. We report the results of analysis of data taken during 1998 March and April and 1999 February. We also present the results of searches for variation of the emission at both the orbital and spin periods.

2 Recent Observations of VHE Gamma Rays

We report observations made with the University of Durham Mark 6 imaging gamma ray telescope operating at Narrabri NSW, Australia. The telescope has been described in Armstrong et al. (1999) and the results of initial observations of Cen X-3 have been reported (Chadwick et al. 1998). Our Cen X-3 dataset now comprises data from 31 hrs of observation during 23 exposures in 1997 March and June (JD 2450508 – JD 2450606), 1998 March and April (JD 2450899 – JD 2450932) and 1999 February (JD 2451220 – JD 2451230).

Our earlier report (Chadwick et al. 1998) was based on data recorded in 1997 March and June (JD 2450508 – JD 2450606) only. Assuming a collection area of $10^9\ \mathrm{cm}^2$ and that our selection procedure retained $\sim 50\%$ of the original gamma ray events, the time averaged flux was estimated to be $(2.0 \pm 0.3) \times 10^{-11}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

for > 400 GeV. We concluded that the measurements in these two months were consistent with a constant flux. Ongoing simulations suggest that our current selection procedure retains 20% of the gamma rays. On this basis, the flux for the 1997 March and June (JD2450508 – JD2450606) data would be $(5.0 \pm 0.9) \times 10^{-11}$ cm^{-2} s^{-1}. The additional data taken in 1998 and 1999 provide fewer gamma ray candidates suggesting weaker TeV emission. An analysis of the total data yields a time averaged flux of $(2.8 \pm 1.4_{sys} \pm 0.6_{stat}) \times 10^{-11}$ cm^{-2} s^{-1}; the significance of the detection based on the total dataset is 4.7σ.

3 The TeV Gamma Ray Signal Strength

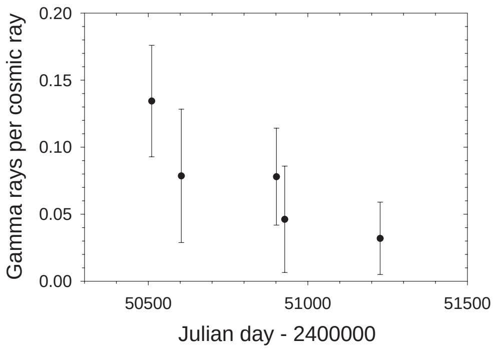

Figure 1: The VHE gamma ray flux from Cen X-3 averaged over observing periods.

Our recent work on PKS 2155–304 (Chadwick et al. 1999) has demonstrated a method of assessing the signal strength of gamma rays recorded by Cerenkov telescopes. It is suited to measurements made at different epochs and at different zenith angles when the telescope may have different sensitivities and consequently a varying background cosmic ray detection rate. We have estimated the signal strength of TeV gamma ray emission by expressing it as a fraction of the cosmic ray background remaining after image shape and orientation selection (Fegan 1997). In so doing we make allowance for variations in sensitivity, in first order, due to changes in efficiency of the telescope and variations in telescope performance with zenith angle. It is also assumed that the slopes of the gamma ray and cosmic ray spectra are similar.

In the present study, the average gamma ray signal strength from Cen X-3, expressed as a percentage of the cosmic ray background remaining after shape and orientation selection is (7.0 ± 1.5)%. The most straightforward, but not most powerful, test for constancy of emission is to repeat this process for the data recorded in each of the 5 dark periods as shown in Figure 1. On the basis of this test we find no internal evidence for monthly variability of the VHE signal; the data treated this way are consistent with a constant signal strength ($\chi^2 = 4.5$, 4 df).

4 X-ray Data

Cen X-3 is a strong but variable X-ray emitter. For example, the average daily rates for X-rays detected with the *RXTE*/ASM during 1997 and 1998 range from 0 to 32 counts s^{-1}; the data are variable on a time scale of days. The daily average for the *RXTE*/ASM count rates are available for 22 of the 23 days when TeV gamma ray observations were made[1].

The strength of pulsed X-ray emission was also available as a daily average from the BATSE archive for 1997[2]; during the 1998 and some of the 1999 VHE observations, the X-ray flux was low and less than the threshold for BATSE detection. The BATSE data provide a series of independent X-ray measurements, including a measurement on the single day of the TeV gamma ray observations for which there is no corresponding *RXTE*/ASM measurement.

[1]Available on the web at http://space.mit.edu/XTE/asmlc/srcs/cenx3.html

[2]Original data obtained from the web at http://www.batse.msfc.nasa.gov/data/pulsar

5 Correlations between X-rays and TeV Gamma Rays

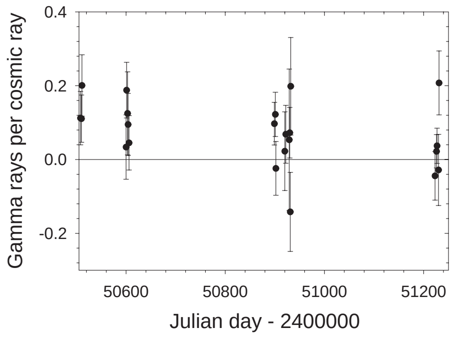

Figure 2: The VHE gamma ray flux from Cen X-3 plotted on a day-by-day basis.

The VHE gamma ray signal plotted on a day by day basis is shown in Figure 2. There is no evidence for outbursts of TeV gamma ray emission on a timescale of days and the data are consistent with a constant TeV gamma ray flux ($\chi^2 = 22.1$, 22 df).

In Figure 3(a) we show the relation between the count rate of the *RXTE*/ASM data and our gamma ray signals. In Figure 3(b) we show a similar plot between the individual BATSE pulsed X-ray fluxes and our gamma ray signals. We have no formal evidence for a correlation, although it is interesting to note that the day of highest detected gamma ray flux coincides with the day of most X-ray activity in the dataset (1997 Mar 4).

6 Modulation at the orbital period

We have looked for modulation of the gamma ray signal at the orbital period of the binary system. The orbital phase of each of our observations has been calculated using the ephemeris of Kelley et al. (1983). The results are shown in Figure 4. From this evidence we conclude that there is no modulation of the VHE gamma ray emission at the orbital period.

7 Modulation at the pulsar period

The data have been subjected to a Rayleigh test for periodicity at a small range of periods around the BATSE period. Phase coherence between observations was not assumed. No significant periodicity was detected, leading to a 3σ upper limit to the pulsed flux of $2.0 \times 10^{-12}\ \mathrm{cm^{-2}\ s^{-1}}$ in the total dataset.

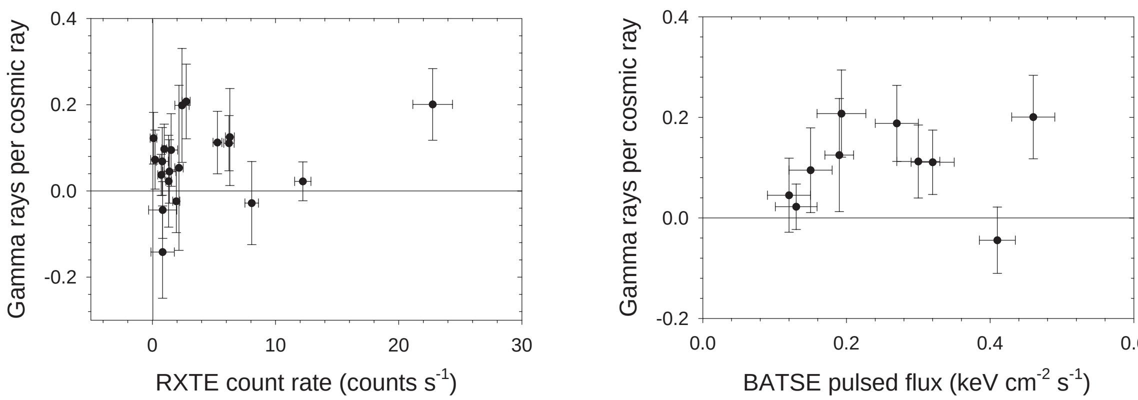

Figure 3: The relation between the daily VHE gamma ray flux from Cen X-3 and (a) the X-ray flux detected by ASM/*RXTE* and (b) the X-ray pulsed flux detected by BATSE.

8 Discussion

We have detected VHE gamma ray emission from Cen X-3 during each dark moon period that we have observed this object. The data are consistent with a weak but persistent emission, both when the VHE data is averaged over dark moon periods or when considered observation by observation. Although the observation that yields the strongest gamma ray flux occurs on the day when the daily averaged RXTE X-ray flux was the highest of any day on which we observed Cen X-3, there is no evidence for a formal correlation between the VHE gamma-ray and X-ray fluxes.

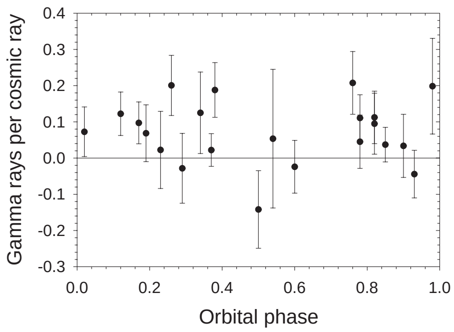

Figure 4: The measured VHE gamma ray rate during each observation of Cen X-3 plotted as a function of orbital phase.

We have also tested for modulation of the VHE gamma ray flux at the orbital period of the binary system and at the pulsar period. We have no evidence for modulation of the VHE gamma ray emission at either period.

The processes considered for the production of TeV gamma rays in X-ray binaries have included beam dump models with both electrons and protons as the accelerated particles (Vestrand & Eichler (1982) for protons and Cheng, Ho & Ruderman (1985) for electrons). In addition, a co-rotating jet model has been suggested by Kiraly & Meszaros (1988).

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