Chapter 7

The Search for a Modulated Signal from Cyg X-3

7.1 Introduction

If a signal varies with time in a known way, its signal-to-noise ratio can be improved. Looking for Cyg X-3 by searching for a signal modulated by its 4.8 hour orbital period was the method used by many of the experiments which have claimed detections of this source using muons in the past[1,2,3,4,5]. Such a search was based upon the hypothesis that whatever would produce a muon signal would be correlated with the mechanism producing the high energy, periodic X-ray emission in Cyg X-3.

7.2 Data

The data used for this search are the same data as used for the all-sky survey in Chapter 6 and described in Chapter 3. The backgrounds are also calculated the same way using the Monte Carlo method described previously. Each muon in a ½° half-angle cone from the position of Cyg X-3 is binned in the binary system's orbital phase according to the parabolic X-ray ephemeris obtained by the Ginga and ASCA satellites[6]. The phase was binned in tenths as was done in the searches by Soudan[3,4] and NUSEX[5], the experiments claiming positive detections of a modulated muon signal from the direction of Cyg X-3. The resulting muon count as a function of phase is shown in Figure 1. The error bars are $\sqrt{N}$ statistical errors. The background,

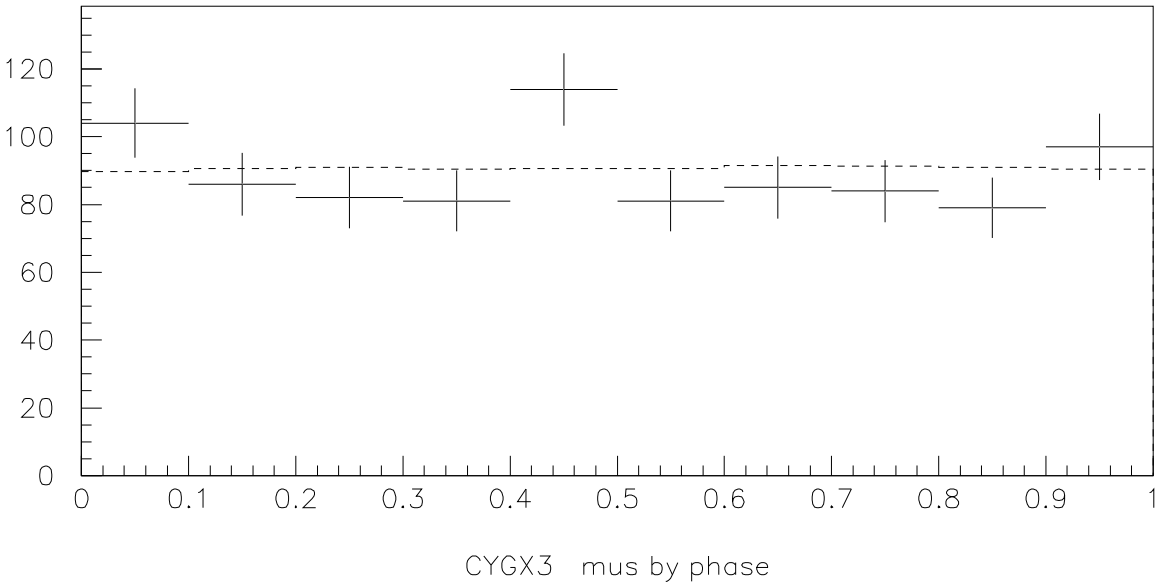

Figure 1: Muons from Cyg X-3 binned by orbital phase. The error bars are statistcal, and the expected background is the dashed line.

the dashed line in this figure, is the average of 271 Monte Carlo simulations.

7.3 Results

The phase bin containing the largest surplus of muons is the fifth. This bin contains 114 muons over an expected background of 90.6, or a deviation of 2.46σ. The probability of getting such a deviation given Gaussian statistics and ten phase bins is 13.8%, which is not statistically significant.

In the absence of a signal, the upper limit $J_{\mu}^{mod}(95\%)$ to the modulated muon flux coming from Cyg X-3 has been computed by evaluating

$$J_{\mu}^{\mathrm{mod}}(95\%) \leq \frac{n_{\mu}^{\mathrm{mod}}(95\%)}{0.41\bar{\epsilon}A_{eff}ft_{expos}}\ cm^{-2}s^{-1}\ , \qquad \textbf{(1)}$$

where $n_{\mu}^{mod}(95\%)$ is the 95% confidence limit for the undetected muon signal in the phase bin containing the largest surplus of muons, 0.41 is the fraction of muons falling in a ½° half-angle cone centered on Cyg X-3 given MACRO's PSF, $\overline{\epsilon}$ is the average detector efficiency for events in this bin, A_{eff} is the average effective area for these events, f is the fractional live time seen by this bin, and t_{expos} is the total live time in this analysis. These numbers are calculated in the same way as they were for the DC flux upper limits $J_{\mu}^{stdy}(95\%)$ in the all-sky survey of Chapter 6. This produces an upper limit on the modulated muon flux coming from Cyg X-3 of $J_{\mu}^{mod}(95\%) = 1.44 \times 10^{-13}$ cm^{-2}s^{-1}, which improves upon the DC flux from Cyg X-3's bin in the all-sky survey of $J_{\mu}^{stdy}(95\%) = 2.27 \times 10^{-13}$ cm^{-2}s^{-1}.

7.4 Conclusions

No significant excess of muons has been found in any bin in the orbital phase distribution of muons from the direction of Cyg X-3. The 95% confidence limit on the flux observable by MACRO using this technique is $J_{\mu}^{mod}(95\%) = 1.44 \times 10^{-13}$ cm^{-2}s^{-1}. This flux is shown compared to flux detections and limits other experiments in Figure 2. These experiments are those referenced in Chapter 1 and are plotted versus depth in meters of water equivalent.

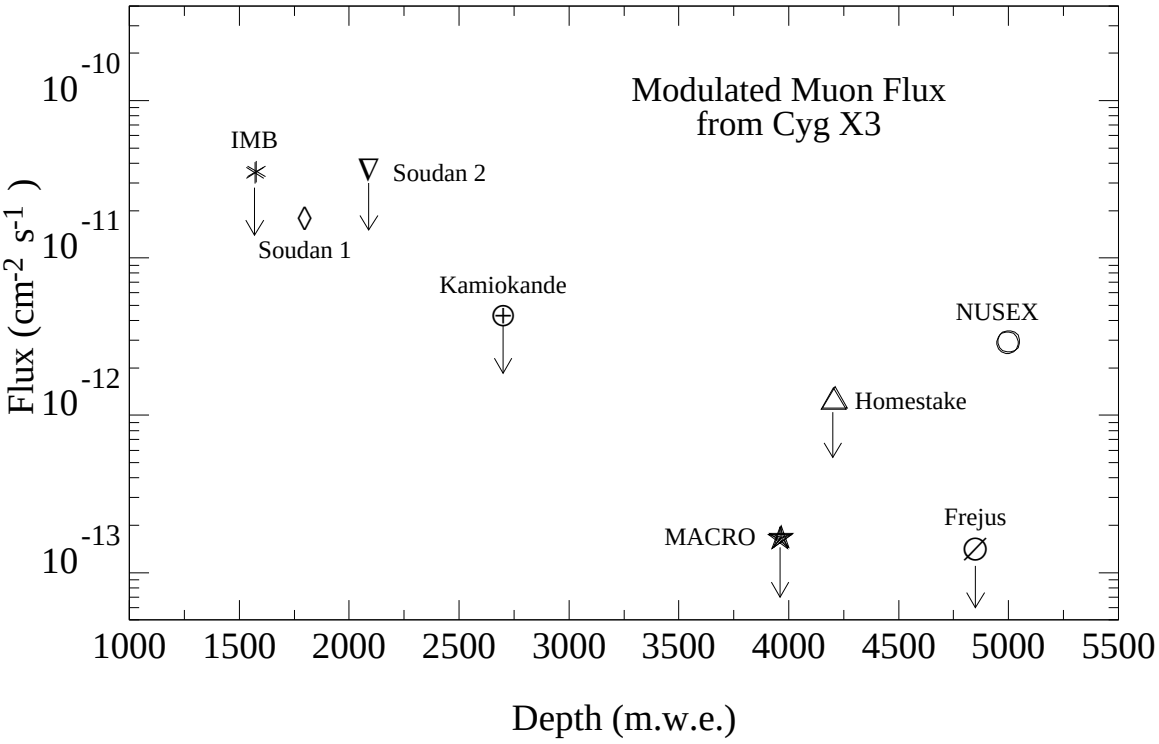

Figure 2: Observations of Cyg X-3 with muons from various experiments. Soudan 1 and NUSEX are detections, the rest are upper limits. The X-axis is the depth of each experiment in m.w.e.

References

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2. Lloyd-Evans, J., Coy, R.N., Lambert, T., Lapikens, J., Patel, N., Reid, R.J.O., Watson, A.A., 1983, "Observations of γ-rays $>10^{15}$ eV from Cygnus X-3", *Nature* **305**, 784.

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