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RELATIVE MUON CONTENT OF UHE SHOWERS ASSOCIATED WITH HERCULES X-1

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Abstract

A further analysis is presented of the muon content associated with the July, 1986 UHE observation of the Hercules X-1 system, previously reported by the CYGNUS collaboration. The probability for observing comparable muon content in a set of "background" showers similar to those of the Hercules burst is given.

Introduction The CYGNUS EAS array consists of 200 scintillation detectors spread over an area of 6×10^4 m^2 at an atmosperic depth of 800 gm/cm^2 at Los Alamos National Laboratory in northern New Mexico. The area of each detector is approximately 1 m^2 and the angular resolution of the entire array is about 1 degree. The array is graded from an average spacing of 14 to 25 meters between detectors to enhance its sensitivity at higher energies. The denser section of the array (CYGNUS I) surrounds a muon detector consisting of 44 m^2 of multi-wire proportional chambers (MWPCs) shielded with an average overburden of 1.8 meters of steel.

In 1986, the array consisted of only 50 scintillation modules covering 1×10^4 m^2 and surrounding the muon detector of the CYGNUS I region. On July 24 of that year, a burst of 17 events with an expected background of 6 was observed from the direction of Hercules X-1 (Dingus *et. al.*, 1988). This burst can be further divided into two smaller bursts ("**A**" and "**B**"), each approximately half an hour in duration, occurring at average zenith angles of 35 and 5 degrees respectively. These events were found to be modulated by a 1.23568 s perodicity, shifted from the well-known x-ray orbital period of 1.2378 s. This same shifted period had previously been observed by Resvanis *et.al.*, and by Lamb *et.al.* in May and June of that same year. The probability that such a burst might be explained by a fluctuation of the background was estimated to be 2×10^{-5}.

The muon content of these events was substantial, particularly when compared to that expected from photon-induced showers. The purpose of this paper is to compare the muon content of showers from the Hercules burst with that of background showers, which are presumably dominated by proton-induced interactions.

Analysis Of the 17 burst events, 11 that occurred within the main phase peak of the 1.23568 s periodicity were chosen for this analysis. In this "purified" sample, only 0.3 events are expected to be background. 235 hours of data taken close to the time of the burst were used to extract background showers with similar characteristics to each of the 11 burst events. Specifically, the criteria for these background events were as follows: **1)** Each event must have a zenith angle which matches that of its corresponding burst event to within 5 degrees, and have an azimuthal angle that matches within 15 degrees; **2)** The distance of the shower core from the muon detector (as measured in the shower plane) must agree to within 5 meters ; **3)** The shower size, as derived from a fit to a NKG lateral distribution, must agree with that of the corresonding burst event to within the estimated errors of the fit. These cuts resulted in 100 to 300 background events per burst event. The one exception was the last event in our sample which, due to its extremely large shower size ($\sim 6 \times 10^5$), limited the available background to 34 events.

Under the assumption that the muon lateral distribution for the burst events is similar to that of the background showers, the probability for an event drawn from each background set to have a muon content equal to or greater than that of the corresponding burst event was then determined. The ability to count individual muons in our detector saturates when the number reaches 12 or more. This number is thus used to imply a lower bound. Table 1 shows the results. The first 6 events belong to burst **A**, and the last 5 are from burst **B**. Any slight differences in the shower size estimate as presented here when compared with our earlier publication are due to the use of different fitting algorithms. In addition, the muon numbers presented here were determined by a computerized algorithm rather than by scanning MWPC hits by eye, as was done in our earlier publication. This was done for ease of background analysis.

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Table 1

Event	Size in units of 10^4	Radius (m) from core (in shower plane)	Muons * observed	Prob. to match or exceed burst value
1	9±7	13	11	6%
2	7±4	36	6	20%
3	16±9	21	≥12	4%
4	11±7	12	7	22%
5	4±3	10	9	7%
6	21±16	46	4	41%
7	7±3	3	≥12	3%
8	11±10	48	0	100%
9	21±13	63	0	100%
10	8±4	22	1	76%
11	65±30	39	8	33%

The combined probability that the muon content of a similar set of 11 background events will match or exceed that of the burst events is found to be 3%.

Effect of Energy Spectra The range of shower sizes which fit the burst events indicates that the source energy spectrum may be much flatter than that of the background. One must therefore assess how the average energy of a shower as inferred from a given shower size differs for events originating from each of these two spectra. This difference emerges from the fact that, with a steep spectrum, a large shower size is more likely to be a fluctuation from a lower energy event than it is with a flatter spectrum. To determine how this will change the significance of the previous calculation, the selected shower size of background events can be increased with respect to those of the burst events, and the procedure can be repeated. Table 2 shows the results when the average shower size of background events is increased by 25%, 50%, and 100% with respect to the corresponding burst events. Computer simulations indicate that the effect of different spectra can cause the energies of the background to be overestimated with respect to the burst events by approximately 40%.

Table 2

n × shower size observed for burst events	1.00	1.25	1.50	2.00
Prob. for background to match or exceed burst muon content	3%	12%	29%	68%

* see preceeding text.

Conclusion The muon content of UHE air-showers associated with the July, 1986 burst from Hercules X-1, which is anomolous for gamma-induced interactions, has been studied relative to hadronic, background showers. If one assumes that the muon lateral distribution and the primary energy spectrum of the burst source is similar to that of the background, then the probability that the muon content in a set of similar background showers matches or exceeds that of the burst events is found to be 3%. When the possible difference in energy spectra is taken into account, this probablilty increases to about 25%.

References

Dingus *et. al.*, 1988, Phys. Rev. Letters 61, No.17
Resvanis *et. al.*, 1988, Astrophys. J. 328, L13
Lamb *et. al.*, 1988, Astrophys. J. 328, L9