The UMC Extensive Air Shower Array: Results and Prospects

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ABSTRACT

The Utah-Michigan-Chicago array addresses the need for greater measurement sensitivity in searches for ultra-high energy gamma rays. Results from the Utah-Michigan experiment demonstrate the power of muon rejection. Even if photons interact in unconventional ways, the combination of CASA and the large muon array will measure these effects.

There have been many attempts to observe UHE ($> 10^{14}$eV) gamma rays from celestial sources since the reported observation of Cyg X-3 by the Kiel group in 1983[1]. However, results so far have been inconclusive with most positive reports having weak statistical significance[2]. Those experiments which have attempted to distinguish gamma-ray induced showers from the plentiful hadronic cosmic ray background have reported the surprising observation that the gamma showers have a muon content similar to ordinary cosmic rays.

The Utah-Michigan-Chicago (UMC) Air Shower Array is designed to provide a definitive answer to the question of whether UHE sources exist. The technique increases the size and improves the resolution of the ground array method and rejects hadron showers using large-scale muon detection.

The UMC experiment (Figure 1) consists of the Chicago Air Shower Array (CASA) and a large buried array for muon detection located around the Fly's Eye II detector at Dugway, Utah. CASA will involve 1089 scintillator stations spread uniformly over a 500m×500m grid. Fast timing will provide angular resolution of $\approx 0.5°$; a sophisticated triggering scheme will record EAS above 10^{14} eV at 20 Hz. The muon array components[3] are 2.5 m^2 plastic scintillator sheets arranged in banks of 64 adjacent counters, buried at a depth of 3m. The total coverage of 16 banks (1024 counters with 2560 m^2 total area) far exceeds that of any other operating array and provides a hadron rejection factor of $10^2 - 10^3$, depending upon energy. Shower calculations indicate that electromagnetic punch-through to the muon counters is negligible when they are buried to this depth. We have made measurements with a test arrangement of buried counters at two depths to confirm the simulations.

The size, resolution, and hadron rejection abilities will result in 15 γ-showers day^{-1} from Cyg X-3 (with a signal to noise factor of 33) if the source intensity is like that reported by the Kiel experiment. Put another way, a 5σ excess over background would emerge if the source intensity was only 10^{-2} the Kiel report.

The current Utah-Michigan array (Figure 1) is the first stage of the UMC experiment and has been in operation since late 1987. There are 33 surface stations, each with four plastic scintillators, arranged over an area of radius 100m. The present configuration of 8 banks (512 counters totalling 1280 m^2) is the largest muon detector of any air shower array now operating. Triggering and resolution are more fully described elsewhere[4].

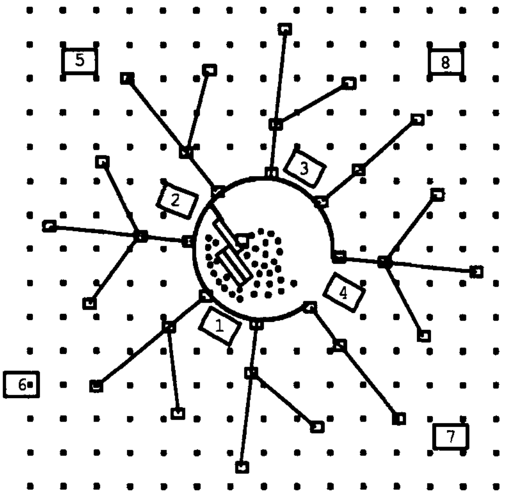

Figure 1. Layout of the central region of the UMC experiment showing the currently operating Utah-Michigan array. Grid marks are 15 m spacings and represent the location of CASA detectors under installation. The numbered rectangles indicate 64-counter muon banks. The smaller connected rectangles indicate positions of the present 33 unit surface array. The Fly's Eye II and electronics trailers are at the center. The full UMC array extends beyond that shown in the diagram and will include a total of sixteen muon banks and 1089 CASA stations.

The location and direction of the shower axis are found by fitting the pulse heights and arrival times of the surface counter hits. The electron and muon sizes N_e and N_μ are computed from maximum likelihood fits of surface data to an NKG function[5] and muon counter hits to a Greisen muon density function.[6]

The directional resolution $\delta\theta$ is defined such that 72% of events from a point source will reconstruct within $\delta\theta$ of the source direction. This definition maximizes $S/\sqrt{B}$ for a signal S in the presence of a uniform background B. The resolution is estimated by dividing the array into two parts, fitting each half separately, and comparing the results. For cores within 100m of the center of the array and $N_e > 10^4$, $\delta\theta = 3°$. Systematic pointing error is negligible, determined by comparison to data obtained by a tracking air-Cerenkov telescope operated in coincidence with the arrays.

Calculations predict 98% of gamma ray induced showers will have less than one-tenth the mean number of muons in hadron showers with similar N_e and zenith angle. We accept showers meeting this μ-poor criterion as γ-ray candidates.

Table 1 displays results of a search for excess showers from within 3° of Cyg X-3. The data is divided into subsets of increasing energy based on cuts on electron size N_e. The γ-ray energy threshold E_0 is defined as the energy at which our acceptance of γ showers has attained 25% of its maximum value. The background is determined by using the measured rate of all off-source events in local coordinates to predict the rate of ordinary events from the source direction as it moves across the sky. The data are shown with and without cuts on the muon content.

We find no excess activity from the source, with or without a μ-poor cut. The power of muon rejection is evident in Table 1. The sample is reduced by factors of $10^{-2} - 10^{-3}$ and flux limits are improved by a factor of ten. The flux limits obtained for μ-poor showers are approximately ten times lower than previously reported observations[2] at these energies (see Figure 2).

Table 1. Cygnus X-3 Observations from 4 April 1988 to 3 August 1989

$\log_{10}N_e$	E_0(eV)	Observed Events	Expected Background	Flux(90%CL) ($cm^{-2}sec^{-1}$)
4.5–6.0	2.1×10^{14}	25890	26277	$< 1.3 \times 10^{-13}$
	(μ-poor)	129	141	$< 1.3 \times 10^{-14}$
5.0–6.0	4.7×10^{14}	5214	5378	$< 6.9 \times 10^{-14}$
	(μ-poor)	6	6.38	$< 4.9 \times 10^{-15}$
5.5–6.0	1.1×10^{15}	662	715	$< 3.6 \times 10^{-14}$
	(μ-poor)	0	0.22	$< 3.5 \times 10^{-15}$

We have searched in a similar manner data taken during the large radio outbursts from Cyg X-3 in June and July 1989[7]. We find no evidence for any enhanced emission from the source on timescales from 15 minutes to 1 day during this period. Flux limits are a factor of ten below those reported during similar radio flares in October 1985 by the Baksan collaboration[8].

Similarly negative results have been obtained in searches for emission from Her X-1[9] and a whole sky survey for sources[10]. We have also analyzed data from the Crab Nebula[11]. This object is perhaps emerging as the leading candidate as a standard candle in VHE gamma rays. The persistent emission reported by two groups[12] has an apparently softer spectrum than that presumed from Cyg X-3. Consequently, our flux limits are about twenty times higher than the VHE flux levels extrapolated to 200 TeV.

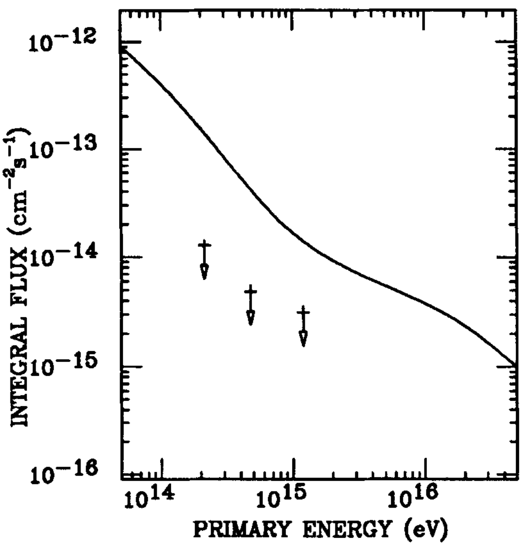

Figure 2. Upper limits (90% C.L.) on the γ-ray flux of Cygnus X-3 from the Utah-Michigan array using muon-poor showers (from Table 1). The solid line is the γ flux expected from the source based an extrapolation of x-ray and VHE results. This line also approximates results and limits obtained above 10^{14} eV (see reference 2). The dip in the spectrum corresponds to the expected loss of UHE γ rays which interact with the 3° cosmic background radiation.

The Chicago Air Shower Array (CASA) will permit flux sensitivity substantially below previous reports of Cyg X-3, Her X-1, and similar to that expected from the Crab Nebula. CASA offers eight times the target area and improves the angular resolution by a factor of six over the existing apparatus. The energy threshold will be somewhat lower due to the higher density of counters. Using $S/\sqrt{B}$ as a figure of merit, we anticipate more than a factor of ten improvement.

The first 500 units of CASA are now in place with data taking to begin in November, 1989. The remaining elements of this array are scheduled for installation in 1990 along with the final eight muon patches.

In summary, large scale muon detection and surface measurements will offer a definitive resolution of the current puzzle regarding UHE gamma ray emission from astrophysical objects. Flux limits for Cyg X-3 using Utah-Michigan array data are at levels comparable to previous experiments; use of μ-rejection improves these tenfold. Thus, if photons interact conventionally, muon rejection provides demonstrated sensitivity to fluxes well below those previously reported. Should there be new physics and/or anomolous interactions, the CASA array will be more sensitive to such activity than prior attempts and the muon structure will be examined in detail.

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