ALL SKY NORTHERN HEMISPHERE 10^{15} EV GAMMA RAY SURVEY

R.M. Baltrusaitis, G.L. Cassiday, R. Cooper, J.W. Elbert, P.R. Gerhardy, E.C. Loh, Y. Mizumoto, P. Sokolsky, P. Sommers, D. Steck and S. Wasserbaech.

Physics Department, University of Utah, Salt Lake City, UT 84112 USA

ABSTRACT

Flux limits in the range 10^{-13}-10^{-12}cm^{-2}s^{-1} have been obtained by observing Cerenkov flashes from small air showers. During 1983, a 3.5σ excess of showers was observed during the phase interval 0.2-0.3 of the 4.8h period of Cygnus X-3, but no excess was found in 1984 observations.

1. Introduction. A search for high flux PeV γ-ray sources has been performed using the University of Utah Fly's Eye cosmic ray air shower detector. There were 82,898 showers with >20,000 photoelectrons in 122 hours of operation during this survey. The data were divided into an array of overlapping bins to yield upper limits for the flux of PeV γ-rays from point sources for all right ascensions and for declinations from -10° to 75°. In addition, event rates from the direction of Cygnus X-3 have been studied as a function of the phase within the 4.8 hour period of that object. The observation of a signal from Hercules X-1 within this same data set is reported elsewhere (Baltrusaitis et al. 1985). Evidence for emission from the Crab is given in Boone et al., 1984.

2. Flux Upper Limits. The 67 mirrors of the Fly's Eye observe mutually exclusive sky regions at fixed elevation angles and azimuthal directions. The regions have negligible overlap and cover the sky at all elevation angles above about 3°. Each mirror focuses onto 12 or 14 pairs of hexagonal-faced aluminized Winston-type light collectors and EMI 9861B PMT's. Each light collector receives light from a separate 5.6° diameter sky region. In order to accept ~ 1 PeV Cerenkov flashes, a triggering condition was set up which accepted showers in which 6 or more PMT's in any mirror fired within 8 μs. This condition yielded a trigger rate of about 0.3 s^{-1} for the entire Fly's Eye and reduced accidental triggers to a negligible level. The observed Cerenkov flashes nearly always have a very large signal (equivalent to ~ 10,000 photoelectrons) in a single PMT, and much lower signals in neighboring PMT's.

For each declination band, the event rate was measured as a function of hour angle for each night's data. An expected number of showers in a specified target direction was calculated by summing the products of (a) the event rate at each hour angle by (b) the time interval during which the target region was observed at the particular hour angle. A small adjustment was made to take into account the variation of detector rate at different time intervals during the night. This adjustment was small, however, since the detector rate varied by <2% h^{-1} during each night. These expected numbers of showers were compared with the observed numbers in order to obtain the γ-ray intensity upper limits.

The observations during 1980 were made during 7.9 hours on 9 December. Other observation periods were 1981 February 1-7 (26.8 hours) 1983 July 9-13 (25.1 hours), 1984 August 26-29 (20.1 hours), and 1984 September 25-29 (42.4 hours). The 1980 and 1981 observations covered the R.A. intervals from about 1 to 17 hours and the 1983 and 1984 observations covered the R.A. intervals 16 to 24 and 0 to 7 hours. The sky survey for γ-ray sources was done in angular bins of declination interval 7.2° and in right ascension intervals of 0.48 cosδ hours, where δ is the declination. A grid of overlapping bins with centers separated by 3.6° in declination and 0.24 cos δ hours in right ascension was searched for excesses of observed counts above the background expectations. Of a total of ~2000 bins, no bins were found with excesses corresponding to chance probabilities less than 5 x 10^{-5}. No evidence of new point sources was found in this survey.

Figure 1 displays upper limits for steady fluxes of PeV γ-rays from point sources. The maximum signal to background ratio, S/B, was used to find the γ-ray flux limit, F, using the relation $F=I\Omega S/B$. I is the primary cosmic ray intensity (Linsley 1983) and Ω is the solid angle of the bins. Both F and I are determined for shower energies of E> 1 PeV. The expected and observed numbers of events in each bin were used together with a maximum likelihood method (Hearn 1969) to obtain the maximum value of the signal to background ratio at the 95% confidence level. It can be seen from Figure 1 that for most of the bins with declinations between 0° and 72°, the upper

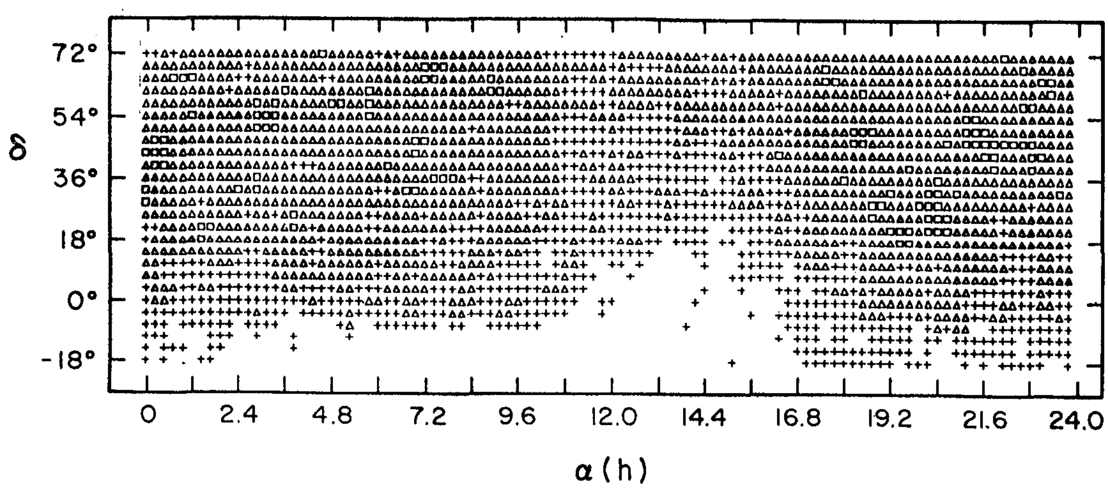

Figure 1. Flux upper limits at the 95% confidence level are represented by the following symbols: squares ($F<3x10^{-13}cm^{-2}s^{-1}$), triangles ($3x10^{-13}<F<10^{-12}cm^{-2}s^{-1}$), and plus signs ($10^{-12}<F<3x10^{-12}cm^{-2}s^{-1}$).

limits are less than 10^{-12} $cm^{-2}s^{-1}$ and some are less than 3 x $10^{-13}cm^{-2}s^{-1}$.

3. Cygnus X-3 Observations. The 1983 and 1984 data include the Cygnus X-3 vicinity. An angular bin was used of the same size as those in the survey described above, but centered on the Cygnus X-3 direction. The ephemeris (Van der Klis and Bonnet-Bidaud 1981) of Cygnus X-3 allows the data within a region centered on Cygnus X-3 to be plotted as a function of the phase within the 4.8 h period. An upper limit of the flux from Cygnus X-3 can be obtained using the data from 1984, only. The phase distribution for this data is shown in Figure 2a. In the third bin (the special significance of which is discussed below) there were 24 observed events, with 24.3 expected. The flux upper limit for phase 0.2-0.3 is 2.0 x $10^{-13}cm^{-2}s^{-1}$.

The 1983 data gave 256 events in the Cygnus X-3 direction, with 220.5 ± 15.8 expected. In bin 3 of Figure 2b, 32 events were observed, with 16.9 expected. Including the effect of uncertainty in the background, this is a 3.5σ excess. See Fig. 2c. A Monte Carlo calculation, allowing the numbers in the background and target regions to fluctuate, gave 1.4x10^{-3} as the probability that this peak occurred by chance. Since distributions were considered separately for the two years' data and the combined data, the probability is estimated to be 3 times larger or 4 x 10^{-3}. The time averaged

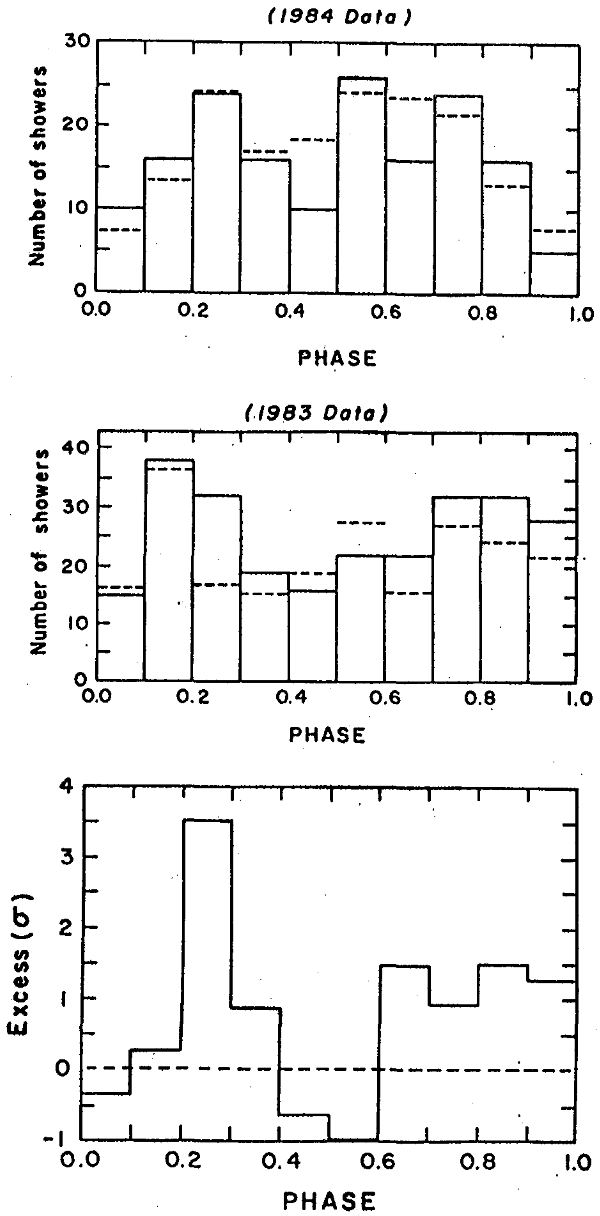

Figure 2. Parts a and b show the light curves within the 4.8h Cygnus X-3 period for (a) the 1984 data, and (b) the 1983 data. Expected background levels are shown by the dashed lines. In part c, the statistical significances of deviations are plotted for the 1983 data.

flux in 1983 due to the excess in bin 3 was $3.2 \pm 1.2 \times 10^{-13} cm^{-2} s^{-1}$.

Lloyd-Evans et al. found a peak in the phase interval 0.225-0.25. Samorski and Stamm saw an excess in the bin 0.3-0.4. An adjustment of -0.11 in phase is needed to adjust the Samorski and Stamm results to the ephermeris used here and by Lloyd-Evans et al. Consequently, the two data sets predict that a signal should be found in the phase bin 0.2-0.3 the same bin in which our signal appears.

The phase bin widths were chosen to be 0.1, following Samorski and Stamm. However, a bin centered on 0.27 but 0.04 wide gave 16 observed, 4.2 expected. It appears that most of the possible signal is concentrated within a more narrow phase interval than 0.1, in agreement with Samorski and Stamm and Lloyd-Evans et al.

4. Discussion. At flux levels near those at which Cygnus X-3 is detectable, no previously unknown sources were found in this survey. Except for Cygnus X-3, none of the possible sources reported by Samorski and Stamm (1984) were detected. The periodic nature of Cygnus X-3 was of great assistance in its detection, however, and it would have been missed in the survey if its detailed properties were not known. The discrepancy between the 1983 and the 1984 results is suggestive of variability in the PeV γ-ray emission from Cygnus X-3. The flux error given above is from statistics, only. Systematic effects could give rise to a factor of two error in the stated fluxes or flux limits.

5. Acknowledgement. This research was sponsored by the United States National Science Foundation under grant number PHY8201089.

References.

Baltrusaitis, R.M., Cassiday, G.L., Cooper, R., Elbert, J.W., Gerhardy, P.R., Loh, E.C., Mizumoto, Y., Sokolsky, P., Sommers, P. & Steck, D. 1985, Ap. J. (Letters) accepted and Paper OG 2.2-7 in these proceedings.

Boone, J., Cady, R., Cassiday, G.L., Elbert, J.W., Loh, E.C., Sokolsky, P., Steck, D., Wasserbaech, S. 1984, Ap. J., 285, 264.

Chanmugam, G., and Brecher, K. 1984, preprint.

Hearn, D. 1969, Nucl. Instr. Methods, 70, 200.

Linsley, J. 1983, Proc. 18th Int. Cosmic Ray Conf., (Bangalore) 12 , 135.

Lloyd-Evans, J., Coy, R.N., Lambert, J., Lapikens, J., Patel, M., Reid, R.J.O., and Watson, A.A. 1983, Nature, 305, 784.

Samorski, M., and Stamm, W. 1983, Ap. J. (Letters), 268, L17.

Samorski, M., and Stamm, W. 1984, Ap. J. 277, 897.

Van der Klis, M., and Bonnet-Bidaud, J.M. 1981 Astr. Ap. 95, L5.