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Search for UHE Point-Source Emission Over Various Time Scales

The CYGNUS Collaboration

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Abstract

A method has been developed to search for pulsed and/or unpulsed ultra high energy (UHE) emission from point sources over a range of time scales. This method has been applied to data accumulated with the CYGNUS extensive air-shower array for events associated with the directions of Cyg X-3, Her X-1, the Crab nebula, and a collection of 48 secondary source candidates. An examination of time scales ranging from minutes to years has yielded results consistent with background fluctuations.

1. Introduction

The initial report of ultra high energy (UHE) radiation associated with the x-ray binary Cyg X-3 (Samorski and Stamm 1983) launched the field of UHE astronomy with the promise of large, steady source fluxes. Since that time, other experiments have failed to demonstrate the existence of such steady sources. However, several groups have reported possible UHE emission on time scales ranging from several days to several years, while other observations indicate short-duration bursts, lasting from 10 to 60 minutes (for example, see the review of Fegan, 1990). Source variability is well known to occur at lower energies. For example, the EGRET detector on board the Compton Observatory has noted day-to-day variations in flux from active galactic nuclei (Fichtel *et al.* 1992), while other experiments have recorded numerous gamma-ray bursts with typical time scales ranging from tens of milliseconds to minutes. In the absence of more specific theoretical models of UHE emission, a large range of possible time scales should therefore be considered.

2. Outline of Episodic Search Technique

The method that has been employed to search for episodic emission over various time scales is as follows:

> 1) For a given interval of data, a range of time scales to be tested is chosen.
>
> 2) The data interval is then spanned with a series of consecutive time *windows* corresponding to the smallest time scale that is of interest.
>
> 3) Within each time window, the probability for emission (based either on event excess, periodicity, or the combination of the two) is assessed.
>
> 4) Steps 2 and 3 are then repeated with time-window boundaries offset by 50% with respect to the initial choice to account for emission that may not be centered in a given window.
>
> 5) The chance probability of the most significant window for this time scale, given the effective number of independent windows searched, is then determined.
>
> 6) Steps 2 through 5 are then repeated for time windows of increasing length, each a factor of 3 longer than the previous length, until the entire range of time scales has been investigated.
>
> 7) Finally, the time scale corresponding to the most significant result is chosen and the chance probability of that result, given the number of time scales searched, is calculated.

This method (conceptually illustrated in figure 1) has been designed to insure that sensitivity to emission is proportional to the duration of the signal. The technique returns the chance probability for the single most significant burst occuring within a given interval of data (taken here to be 1 source transit in tests for short-term emission, and the entire data set in tests of long-term emission). Simulated data sets were used to estimate the trials factors relevant for the search, and to streamline the procedure so as to minimize computation time while maintaining a high efficiency for observing a wide variety of signal types. For further details, see Biller, 1992.

3. Search for Short-Term and Long-Term Emission

The method described above has been applied to data acquired with the CYGNUS-I array between April, 1986 and Jan., 1993. We have performed a search for short-term, UHE emission from each of our 3 primary source candidates (Cyg X-3, Her X-1, and the Crab nebula), and from any of our 48, collectively treated, secondary source candidates (see Alexandreas *et al.*, 1993). Time scales of 3.3 minutes, 10 minutes, 30 minutes, 90 minutes and 1 source transit (~5 hours) were examined for event excess. No significant deviation from background expectation was found in the distribution of burst probabilities for any of these source hypotheses.

A search has also been conducted to look for unpulsed emission on time scales greater than 1 source transit. Specifically, the significance of event excesses were examined for time scales of 2, 6, 18, 54, 164, 486, and 1458 days. The post-trial chance probabilities of the most significant, multi day episodes for each source hypothesis are found, once more, to be consistent with background fluctuations.

4. Search for Short-Term, Pulsed Emission from Her X-1

For Her X-1, 4 different periodicity hypotheses were tested for each interval: 1) pulsed emission precisely at the interpolated X-ray period; 2) pulsed emission at a frequency within 1 Doppler shift of the interpolated X-ray period; 3) pulsed emission at a blue-shifted period lying within the uncertainty range of the contemporaneous UHE/VHE results of 1986 (Dingus *et al.* 1988, Lamb *et al.* 1988, Resvanis *et al.* 1988); and 4) pulsed emission that may occur over a wide range of frequencies, arbitrarily chosen to encompass $\pm 0.5\%$ of the pulsar period. The significance of each periodicity hypothesis was assessed using the Protheroe statistic, with corrections for the number of independent periods and the oversampling relevant to each case. The most significant result was then taken, and a trials factor of 4 was assessed for the different periodicity hypotheses. The resulting chance probability for periodicity was then combined with that for the observed event excess in the data interval. The distribution of burst probabilities was found to be consistent with fluctuations from a background distribution, with no single burst of comparable significance to the previously published observation of 1986 (Dingus *et al.* 1988).

5. Flux Limits

Scaling from the direct measurement of the cosmic flux in the energy range of $\sim 10^4$GeV/nucleon (Burnett *et al.*, 1990), we have derived upper limits to source fluxes according to the prescription given by Alexandreas *et al.*, 1993. Figure 2 shows the predicted median gamma-ray energy as a function of zenith angle for the current CYGNUS-I array. Figure 3 shows the upper limit (90% CL) on source flux above the corresponding median gamma-ray energy as a function of zenith angle, for the case of zero observed excess events (*i.e.* typical limits). Calculated limits for time scales of 3.3, 10, 30 and 90 minutes are given for the current CYGNUS-I array configuration. Also shown are the corresponding flux levels that would yield a 1% *post-trial* chance probability.

6. Conclusion

A method has been designed to search for UHE emission over a range of time scales. This method has been applied to the CYGNUS data set to search for both short-term (minutes to hours) and long-term (days to years) emission from Cyg X-3, Her X-1, the Crab nebula, and a collective treatment of 48 secondary sources. Results from all tests are consistent with fluctuations from the cosmic-ray background.

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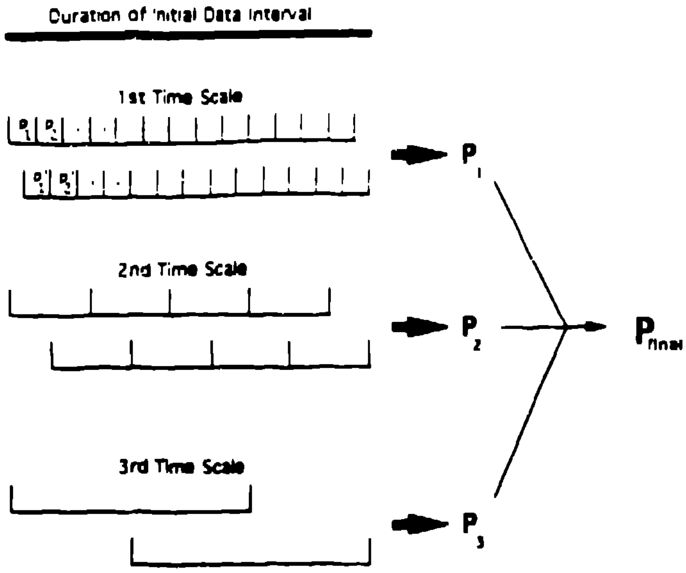

Figure 1 : Schematic illustration of episodic search technique. Each arrow indicates where trials factors are assessed for

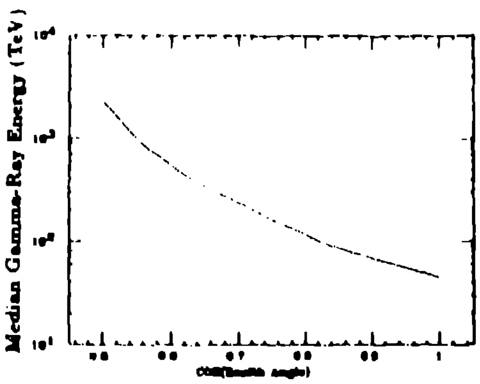

Figure 2 : Median energy of simulated gamma-ray energy triggers vs. zenith angle.

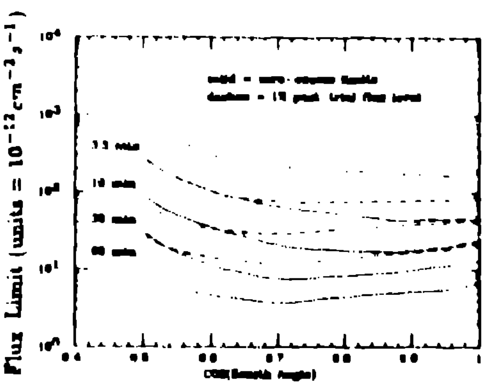

Figure 3 : Zero-excess flux limits (90% C.L.) above the median gamma-ray energy for various time scales (solid line). The dashes show the flux necessary to achieve a 1% post-trial chance probability.