Search for TeV Counterparts of BATSE Gamma Ray Bursts with the HEGRA Air Shower Arrays

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Twenty nine gamma ray bursts recorded between 1993 and 1995 by the BATSE instrument were searched for an emission in the energy range above 13 TeV. The method used the data of the scintillator array and the wide angle Cherenkov counter array AIROBICC of the HEGRA experiment. As a novelty not only coincident emission but also short and long time emission in the hours before and after the BATSE detection were searched for. Weak evidence was found for coincident and for precursor short time emission.

I. INTRODUCTION

Despite the fact that Gamma Ray Bursts have been known for more than 25 years their distance scale, their energy scale and the underlying physical processes remain unknown. Counterparts at any wavelength would help to clarify the situation. There are reasons to believe that TeV counterparts can be observed:

- some models, especially galactic fireball models (2), predict or at least allow TeV emission

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- EGRET observed photons with energies up to 18 GeV (5)
- extrapolating some of the BATSE spectra (6) yields large TeV fluxes that could easily be registered by air shower experiments.

A positive observation of TeV counterparts would impose limits on the GRB distance scale, because the intergalactic radiation fields would absorb TeV photons from large distances ($z \gtrsim 0.005$). Moreover TeV detection would reduce the number of admissible emission mechanism models.

This study differs from previous searches for counterparts in the multi TeV energy region which did not reveal any positive evidence (see for example (3,4)) in that it combines the low energy threshold of the HEGRA EAS arrays ($E_{threshold}(\gamma) \approx 13$ TeV for vertically incident photons) with their good angular resolutions. Moreover, as motivated by the 75 min delay of the 18 GeV Photon measured by EGRET (5) relatively to the radiation registered by BATSE, not only coincident radiation is searched for but also short and long time emission before and after the BATSE signal. In section II the HEGRA experiment will be described. After depicting the searching method in section III the results of the search will be presented in section IV. In section V the results will be summarized and the future activities of the HEGRA group to search for TeV counterparts will be outlined.

II. THE HEGRA EXPERIMENT

HEGRA (**H**igh **E**nergy **G**amma **R**ay **A**stronomy) (1) is a multi component detector system for the registration of neutral and charged cosmic rays in the energy range of between 500 GeV and 10 PeV. It is located on the Canary Island La Palma (28.8°N, 17.9°W, 2200 m above sea level). The experiment covers at present a system of 3 Cherenkov telescopes (in future 6 telescopes), an array of 49 wide angle Cherenkov counters called "AIROBICC" (7), an array of 245 scintillation counters and an array of 17 Geiger towers on a surface of $4 \cdot 10^4 \mathrm{m}^2$.

This study is based upon the measurements taken with the two HEGRA extensive air shower arrays. With the matrix of scintillation counters the electromagnetic part of the extensive air shower (EAS) initiated by an energetic primary in the atmosphere is sampled at detection level. With the matrix of wide angle Cherenkov counters the Cherenkov light emitted by the EAS is measured. The field of view of each array is larger than one steradian. Both arrays are thus qualified for all sky surveys and allow a search for emission

TABLE 1. Facts about the HEGRA EAS arrays.

	Scintillation Matrix	AIROBICC
Effective Area	$4 \cdot 10^4$ m^2	$6 \cdot 10^4$ m^2
Grid Spacing	10 m - 15 m	30 m
Duty Cicle	$\approx 100\%$	$\approx 10\%$
$E_{threshold}(\gamma)$	18 TeV	13 TeV
Field of View	1.9 sr	1.5 sr
Trigger Rate	12 Hz	25 Hz
Pointing Error	$< 0.15°$	$< 0.20°$
$\sigma^{\theta}_{63\%}$	1°	0.4°
γ/h separation	only together, see (8) photon acceptance: 0.5 hadron rejection : 0.9	

not only after but also before a BATSE burst.

Table I shows the arrays features quantitatively.

III. THE SEARCHING METHOD

For each burst three searches are performed (see (9) for details):

- a search for **coincident emission**, i.e. for radiation in the time interval in which BATSE registered 90% of the burst counts
- a search for **short time emission** with 60 sec intervals, two successive intervals overlapping half a minute
- a search for **long time emission** with time intervals of a length of 2^i min for integer i, the shortest one being one minute.

The intervals of the second and third search cover the time in which the burst location is in the field of view of the HEGRA experiment ($\theta < 30°$).

For each time interval either the $2\,\sigma$ error region given by BATSE or the smaller ring segment given by the Compton/Ulysses Interplanetary Network of Satellites are searched for an emission. In order to exploit the better angular resolution of the HEGRA arrays in comparison to BATSE, grids of optimal search bins are used. Repeating the search with shifted grids ensures that a large fraction of about 90% of hypothetical source photons would fall into one of the bins.

With the trigger rate and the detector acceptance in horizontal coordinates the background is calculated (10) and Monte Carlo data are generated. The most significant excess is the burst candidate of a search. With the help of the Monte Carlo data the **chance probability** p for the background to yield a burst candidate equally or more significant than the observed one is calculated.

IV. RESULTS

The method was applied to twenty nine GRB's that were registered by BATSE between 1993 and 1995. The burst locations and durations of eighteen burst were taken from the 3B catalog and the data of eleven bursts has been transmitted to us by the BACODINE facility. The search for coincident emission was applied to 27, the search for short time emission to 25 and the search for long time emission to 20 out of the 29 bursts, depending on the position of a GRB in the local sky and on interruptions of the detector exposure due to calibration runs.

Results:

- **Coincident emission:** In figure 1 (left side) the chance probabilities p of the searches are shown. If there are no TeV counterparts the p are

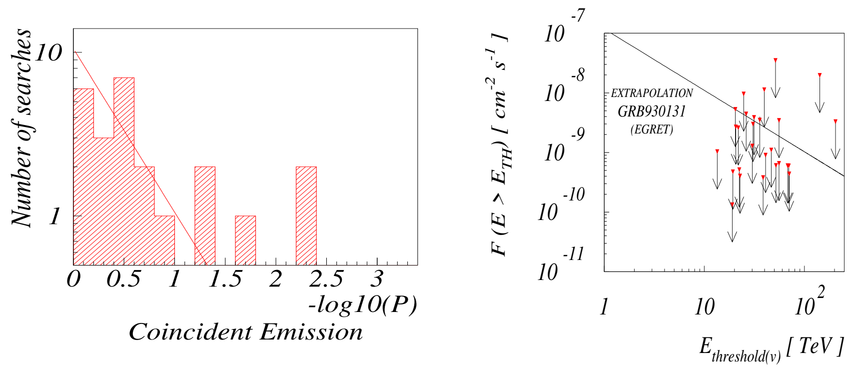

FIG. 1. Results of the searches for coincident emission of 27 bursts. On the left side the distribution of the chance probabilities p is shown. The line depicts the distribution expected for the case that there are no counterparts in the data. On the right side the upper limits on the coincident flux (90% CL) against the threshold energy for inducing photons are shown. The threshold energy is a function of the zenith angle of the location of a burst. To guide the eye an extrapolated GRB spectrum (11) is displayed.

equipartitioned between zero and one. The two excesses with $p < 1\%$ were found in the study of GRB 3B 940321 and of GRB 950401 (20:43 UTC). *The chance probability of finding two excesses with $p < 1\%$ after 27 searches is* 0.03 *($\approx 3\,\sigma$).* In figure 1 (right side) the upper limits on the observed flux (90% CL) are shown. The upper limits lie well within the region of extrapolated GRB spectra.

- **Short time emission:** A remarkable excess (fig. 2, left side) was found for GRB 950701 (06:35 UTC). During one minute, 86 minutes before the burst triggered the BATSE detector, 12 events were observed from the burst direction where 1.7 were expected.
- **Long time emission:** The most significant excess (fig. 2, right side) was found for GRB 3B 931112. In the 16 minutes interval centered at the time when the burst was observed by BATSE the scintillation matrix recorded 19 events whereas only 6 were expected.

All together the seventy two searches yielded four times a p smaller than 1%, corresponding to a chance probability of 0.006 ($\approx 3.4\,\sigma$). The results are preliminary.

V. SUMMARY AND FUTURE ACTIVITIES

A new method for the search for TeV counterparts of GRB's with EAS arrays has been presented. In this method not only coincident emission is searched for but also short and long time emission in the hours preceding and following the bursts.

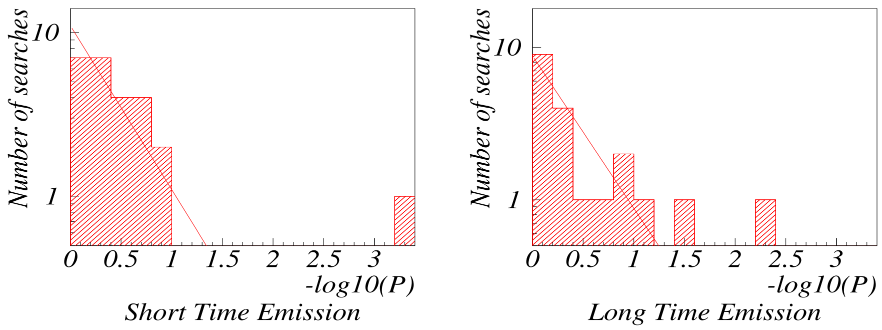

FIG. 2. Distributions of the chance probabilities p for the searches for short and long time emission. The lines show the distributions expected if there are no counterparts.

The method has been applied to 29 bursts. The results are promising:

1. In 27 searches two coincident excesses were found with chance probabilities smaller than 1%.
2. For one burst a large short time excess was registered in a one minute interval, 86 min. before the BATSE observation.

The searching method presented here will be further applied to all known bursts in the field of view of the HEGRA experiment. Moreover it is intended to extend the search towards lower energies. An "angle sensitive trigger" for the scintillator array will allow to accept after a BACODINE warning only showers from the burst direction. By this means the energy threshold of the scintillator array can be lowered without increasing the trigger rate. The search for counterparts with the Cherenkov Telescopes with a photon energy threshold of 0.5 TeV (see Funk et al. elsewhere in this proceedings) will be continued.

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