Status of the high energy GRB counterpart search with the HEGRA experiment[1]

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Data taken with the HEGRA extensive airshower array at La Palma (Spain) are used to search for high energy emission from GRBs as detected by BATSE. By combining the four different detector components HEGRA covers an energy range from 1TeV to 10PeV and is thus well suited to search for TeV-counterparts. Furthermore burst information obtained from BACODINE and COMPTEL are used to study burst-like phenomena on longer time scales.

I. INTRODUCTION

The angular distribution as seen by BATSE in its four years of operation is consistent with a large scale isotropy. Even though this measurement can be reconciled with certain classes of Galactic halo models (2), it is widely believed that the origin of GRBs is cosmological. For a cosmological scenario following Norris (3) and several other authors BATSE samples the GRB distribution out to redshifts of $z_{\max} \sim 2$. It has been shown by Mannheim *et al.* (4,5) that even under these unfavourable conditions, which imply significant absorption of high energy photons ($E > 30\,\mathrm{GeV}$) by the diffuse background radiation field, GRBs should be detectable as a coincident phenomenon in the TeV energy range. Obviously, a prerequisite for such a TeV counterpart identification is that there is no intrinsic turnover between 20 GeV and 30 TeV as suggested by EGRET measurements and some recent theoretical models (6). Furthermore

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Waxman and Vietri (7,8) proposed that the virulent conditions in GRBs may be well suited to accelerate protons up to 10^{20} eV. By interacting with the diffuse background radiation these UHE protons produce pions which in return decay and lead to electromagnetic cascades (8). These cascades would show up in EAS data as delayed TeV γ-emission where due to the *rapid* energy loss of UHE protons the delay time is supposed to be on the order of days.

In this paper we focus on the HEGRA search for coincident (4,5) and long-term (8) emission of TeV photons from GRBs. In another contribution to this conference the search for GRB counterparts with the HEGRA scintillator array on coincident time scales is described in more detail (Krawczynski *et al.*). The experimental setup is described elsewhere (1).

II. LONG-TERM SEARCH

For the 3B catalogue 9 well localized bursts which occured in 1994 in the HEGRA declination band ($\delta_{\mathrm{HEGRA}} = 28.8^\circ \pm 30^\circ$) were selected for the long-term search. Whenever one of these bursts appeared in the field of view of HEGRA ($\theta < 35^\circ$) it was treated as a point source except for the size of the angular bin which in the first analysis was set to $\sigma_{\mathrm{bin}} = \sigma_{\mathrm{HEGRA}} + \sigma_{\mathrm{BATSE}}$, where σ_{BATSE} is the positional error stated in the 3B catalogue and σ_{HEGRA} is the angular resolution of the individual HEGRA detector components ($\sim 0.7^\circ$ at threshold energy). The data sets for each burst were divided in 1min chunks and thus could be finally grouped into intervals of almost arbitrary length ranging from 1 min to 4 hour. In a second step those intervals yielding a high probability for not being caused by a random fluctuation of the cosmic ray background were examined individually. Using a Kolmogorov-Smirnov hypothesis test it was checked whether the event distribution within the search bin were consistent with a single "point source" seen by HEGRA with its characteristic angular resolution.

For the long-term analysis two months of data recorded at the end of 1994 have been used. We found no statistically significant excess and thus calculated flux upper limits on different time scales (Tab. 1). Obviously, the integral flux limits depend on the number of examined time intervals. They are typically on the order of $5 \times 10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at an average threshold energy $< E_{\mathrm{th}} >$ of 40 TeV for the scintillator array and 25 TeV for AIROBICC (9). Fig. 1 shows the most significant excesses for GRB940830 on the 1 hour time scale and for GRB940717 on the 2 hour time scale. We applied a Kolmogorov-Smirnov test to the excess event distributions ("on-off-source") to determine wether these excesses were caused by a single point source smeared out by the angular resolution of the detector. We reject the point source hypothesis at a confidence level of 95% (99%) for GRB940830 (GRB940717). As already suggested by the low excess significance, it is therefore very unlikely that long-term counterparts for these GRBs have been identified.

GRB (3B)		900s	1800s	3600s	7200s	σ_{BATSE} [deg]	$< E_{\mathrm{th}} >$ [TeV]
		$[10^{-11}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$					
940129	max. excess(σ)	3.18	3.25	2.9	2.6	0.82	34
	UL (CL. 90%)	15.9	9.9	33.8	30.1		
940217	max. excess(σ)	3.1	2.8	2.4	2.1	0.4	49
	UL (CL. 90%)	6.5	5.3	4.9	1.2		
940410	max. excess(σ)	2.6	3.3	2.9	1.8	0.93	35
	UL (CL. 90%)	16.8	7.9	5.3	3.6		
940503	max. excess(σ)	2.7	2.6	2.8	2.4	0.60	40
	UL (CL. 90%)	57.7	20.2	10.0	9.1		
940704	max. excess(σ)	2.9	3.0	2.6	2.5	0.64	48
	UL (CL. 90%)	8.4	5.2	11.2	14		
940717	max. excess(σ)	3.4	2.8	3.3	2.8	0.71	37
	UL (CL. 90%)	16.2	14.1	4.4	3.9		
940717A	max. excess(σ)	3.4	3.6	2.1	2.7	0.75	49
	UL (CL. 90%)	16.4	8.9	2.1	1.6		
940830	max. excess(σ)	3.4	2.7	3.2	2.6	0.74	34
	UL (CL. 90%)	30.5	9.4	8.5	7.2		

TABLE 1. Scintillator flux limits for different time scales. Taking into account the number of examined time intervals the most significant excesses are consistent with a gaussian distribution **(preliminary).**

III. SHORT-TERM SEARCH

To account for the much better angular resolution of AIROBICC compared to BATSE the well-known grid search method described for example in (10,11) is applied. For this purpose either the BATSE 2-σ error box or the IPN annulus (whenever it is available) is overlaid by a grid of rectangular bins of size 1.8°. The grid is then shifted three times (once for an IPN annulus) by half a bin size in order to be sensitive to GRBs which are located close to the border of the initial grid. By generating identical Monte Carlo data sets we calculate the final burst probabilities P_{fin} which is the probability that the most significant excess is due to a fluctuation of the cosmic ray background. Hence, the smaller P_{fin} the more likely it is that the excess is caused by a burst-like phenomenon. The time scale for the short-term search is dictated by the time T_{FOV} during which a given GRB remains in the field of view of AIROBICC. The length of the overlapping temporal search bins which cover the full time interval T_{FOV} are set to $2^{\mathrm{n}}T_{90}$ where n is an integer number taking all values between 0 and $log_2 \frac{T_{\mathrm{FOV}}}{T_{90}}$. The time interval coincident with BATSE's T_{90} is obviously included in the $n = 0$ search cycle.

Since September 1994 four GRBs have occured during the ontime of AIROBICC. For these GRBs the results are consistent with no TeV γ-ray emission on coincident time scales. Flux upper limits at 90% confidence level are listed in Tab. 2 for time intervals from T_{90} to $8 \times T_{90}$. Since the T_{90} coincident temporal bins for GRB940909 and GRB950403 were interrupted by a detector

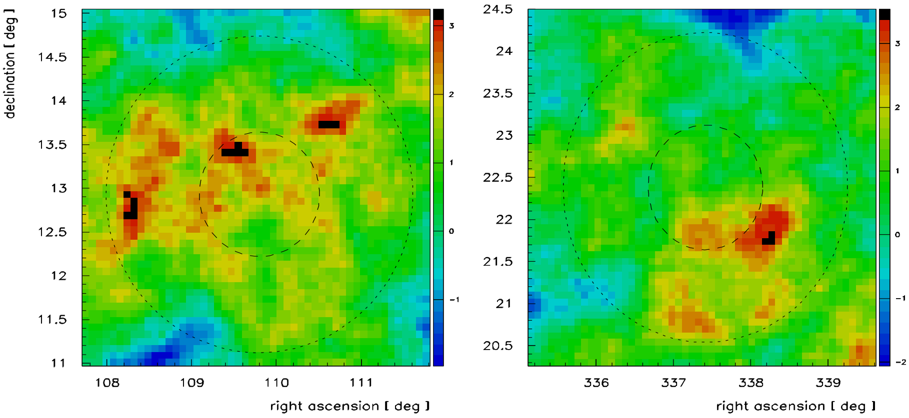

FIG. 1. The left (right) plot shows the most significant excess (z-axis) for GRB940717 (GRB940830) on the 2 hour (1 hour) time scale. *Dashed line:* BATSE (3B) error box, *dotted line:* search bin of radius $\sigma_{\rm bin} = \sigma_{\rm SCI} + \sigma_{\rm BATSE}$.

calibration they are not included in the table.

By now three of the final six Air Čerenkov Telescopes[4] are exploited to search for prompt emission at the low energy threshold ($E_{\rm th,\gamma}$ = 0.7 TeV). They can be pointed at the burst location transmitted by BACODINE within $\sim$ 10 min after the burst onset. Taking into account the large effective area of AČTs which is on the order of 10^4m^2 and making realistic assumptions about spectral indices of GRBs as inferred from the sub-GeV energy range, the burst sensitivity compared with EGRET's high energy GRB measurements is roughly an order of magnitude higher. So far two follow-up observations have been carried out using the AČTs. The final positions of these GRBs as indicated by the IPN error box were both more than 15° off from the positions stated in the BACODINE notifications and thereby clearly out of our field of view.

IV. THE FUTURE

For the long-term counterpart search we are currently implementing a γ/hadron seperation method (12) which will enhance the flux sensitivity by a factor of 3. In future well localized strong GRBs will immediately be followed by using the AČTs in a medium-term observation campaign ($\sim$ 2-3days). This is of great interest since thereby HEGRA should be capable of detecting the TeV-γ-flux induced by a possible GRB-UHECR correlation (8). For immediate AČT follow-up observations of BACODINE bursts the procedure has been changed to take fully advantage of the unique HEGRA feature of having more the one AČT. The new strategy allows to cover a significant fraction

[4]All six AČTs will be operational by the end of 1996.

GRB		UL $[10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ for				E_{th}	T_{90}	Comments
		T_{90}	$2 \times T_{90}$	$4 \times T_{90}$	$8 \times T_{90}$	[TeV]	[s]	
940909 (3B)	$P_{\mathrm{fin}}[\%]$	91.7	98.0	63.8	63.2	19.7	3.0	"$T_{90} \equiv 48\mathrm{s}$"
	UL	4.8	1.8	1.1	0.7			
	$P_{\mathrm{fin}}[\%]$	55.2	44.2	20.7	29.9			coincident
	UL	2.3	1.4	0.5	0.2			coincident
950403	$P_{\mathrm{fin}}[\%]$	27.2	18.7	34.4	57.4	20.6	55.0	IPN
	UL	0.8	0.5	0.3	0.2			
950624	$P_{\mathrm{fin}}[\%]$	16.4	11.7	61.9	52.8	13.4	50.0	IPN
	UL	3.9	2.3	1.1	0.8			
	$P_{\mathrm{fin}}[\%]$	64.8	2.0	8.7	52.8			coincident
	UL	2.1	1.7	0.9	0.6			coincident
950806	$P_{\mathrm{fin}}[\%]$	23.7	75.5	72.8	61.3	64.7	60.0	BACODINE
	UL	1.0	0.5	0.3	0.3			

TABLE 2. Final burst probabilities and flux limits for the 4 bursts seen by AIROBICC. For GRB940909 T_{90} was only 3 s, due to the low expected rate within the temporal search bin the smallest temporal bin was set to 48s (**preliminary**).

of the GRB error box by pointing each AČT at a slightly different position. Hence, the chance to provide a coincident measurement will be much higher than it was before.

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