
Whipple Telescope Observations of Potential TeV Gamma-Ray Sources Found by the Tibet Air Shower Array

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Abstract

An all-sky survey performed with the Tibet Air Shower Array (Tibet AS) has found a number of potential point sources of TeV gamma rays. If they are steady sources, the implied Tibet AS fluxes should be visible with strong significance to the Whipple 10-m gamma-ray telescope ($E > 400$ GeV) with only a short (5 hour) exposure. We have observed four candidate directions from the Tibet-II HD dataset for ~ 5 hours each with the Whipple telescope. In addition, we observed a new candidate direction from the Tibet-III Phase 1 dataset for 7.5 hours. We have found no corresponding excesses at the flux levels implied, and we have set upper limits for each candidate.

1. Introduction

The Tibet AS is an array of particle detectors located in Tibet at an elevation of 4300 m and operated by the TibetAS γ collaboration. The Tibet-II HD array operated from 1996 to 1999 with an energy threshold of 3 TeV and an angular resolution of 0.9° . The Tibet-III array has operated since 1999 with the same threshold and resolution [1,2]. The ability of these arrays to detect gamma-ray sources has been demonstrated through detection of the Crab Nebula [3] and Mrk 501 [4].

A wide angle survey conducted with the Tibet-II HD array found 19 direc-

Table 1. Tibet gamma-ray source candidates

Name	Tibet Dataset	RA	Dec	Tibet Excess	Whipple Observations	Exposure (hours)
*Crab	Tibet-II HD	5h 33.2m	22.2°	4.8 σ		
Tibet1	Tibet-II HD	3h 47.2m	34.2°	4.9 σ	Oct01 - Feb02	6.0
Tibet9	Tibet-II HD	13h 38.4m	24.2°	4.2 σ	Feb02 - Jun02	4.7
Tibet14	Tibet-II HD	20h 21.6m	37.9°	4.2 σ	May02 - Jul02	4.2
Tibet16	Tibet-II HD	21h 29.6m	45.3°	4.8 σ	Oct01 - Jun02	4.7
*Crab	Tibet-II HD + III	5h 34.4m	22.0°	5.4 σ		
Tibet0554	Tibet-II HD + III	5h 54.8m	30.1°	4.8 σ	Dec02-Feb03	7.5

*Crab included for reference

tions with excesses greater than 4σ over the average background. The TibetAS γ collaboration noted that these may be explained as statistical fluctuations, but one direction corresponded to the Crab Nebula [1]. We searched radio, optical, x-ray, and gamma-ray catalogues for corresponding objects within 1° of each of the Tibet directions, and we selected four promising candidate directions for observation with the Whipple telescope during the 2001-2002 season. After receiving an update from the Tibet-III all-sky survey, we selected one more candidate for observation during the 2002-2003 season. Table 1 gives a summary of the targets and observations. The candidates were selected as follows:

- Tibet1 had a high significance and showed steady increase through Tibet-II HD data.
- Tibet9 is 0.3° from a Seyfert 1 galaxy (RGB J1337+243).
- Tibet14 is 0.7° from an EGRET unidentified (3EG J2021+3716).
- Tibet16 had a high significance and is in the Cygnus star field.
- Tibet0554 showed steady increase through Tibet-II HD and Tibet-III and was second in significance to the Crab.

2. Observations and Analysis

Observations were made with the Whipple 10 m gamma-ray telescope with the 490 pixel camera [5]. Only the inner 379 pixels (2.4°) were used in the analysis, and because of the large uncertainty in the Tibet AS source coordinates, 2-dimensional (2-D) analysis was required. In the analysis, potential gamma rays were selected by applying standard supercuts shape cuts. Then the *distance* and *alpha* cuts ($\alpha < 10^\circ$) were applied across a grid of points, with *alpha* and *distance* calculated with respect to each point. The background was estimated using either

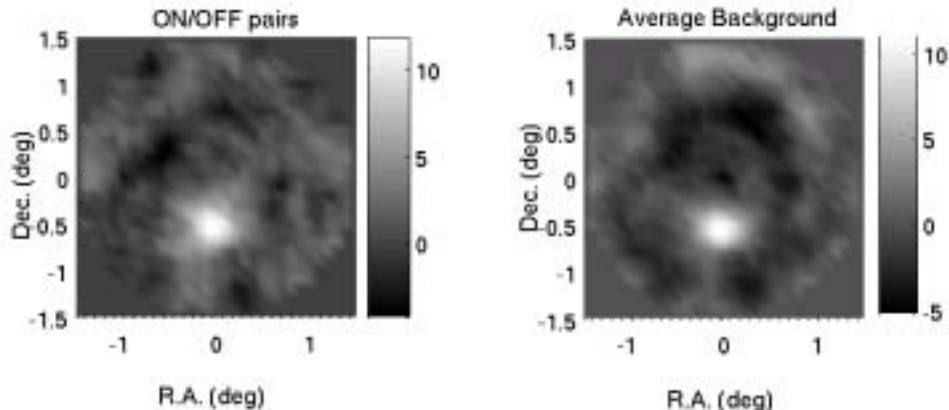


Fig. 1. Significance maps for the Crab at 0.5° offset and 5.1 hour exposure. Both figures were created using the same ON-source dataset, but in the left, the corresponding OFF-source data was used, while in the right an average background was used. The scale represents pre-trials significance in σ .

OFF-source data, or an average background comprised of many OFF runs. We applied this technique to data with the Crab off-axis and found it to be effective, as seen in Figure 1.

3. Results

The 2-D analysis of the 2001-2003 Whipple data has failed to detect a source in any of the target regions. A 2-D significance plot for Tibet0554 is shown in Figure 2 as an example. Assuming that each candidate is point-like and has a spectral shape similar to the Crab, we are able to set upper limits on the TeV gamma-ray flux from each candidate region. These flux limits are summarized in Table 2.

Table 2. Results of Analysis

Candidate	Expected Significance (pre-trials)	Measured Significance (pre-trials)	Expected Flux Ratio To Crab Based On Tibet Data*	Measured 2σ Upper Limit From Whipple Data*
Tibet1	10σ	3σ	1.0	0.5 Crab
Tibet9	8σ	2.5σ	0.9	0.5 Crab
Tibet14	7σ	2σ	0.9	0.5 Crab
Tibet16	9σ	3σ	1.0	0.6 Crab
Tibet0554	9σ	2σ	0.9	0.4 Crab

*Assuming a Crab-like spectrum

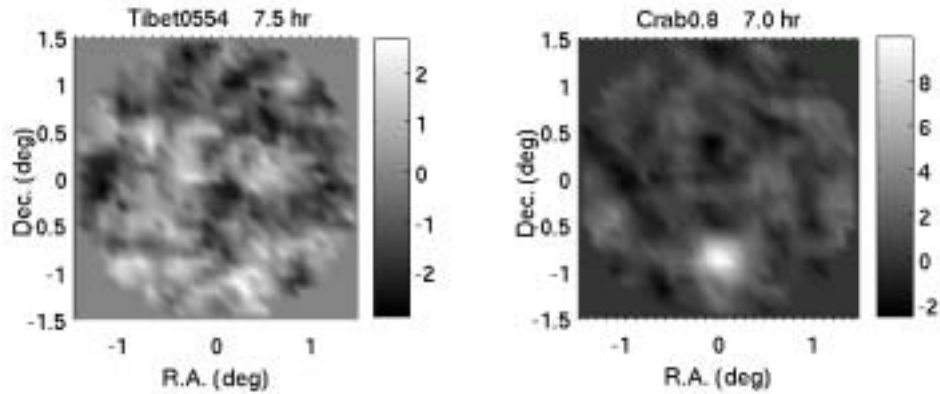


Fig. 2. Significance map for Tibet0554. The Crab at 0.8° offset is included for comparison. The scale represents pre-trials significance in σ .

It should be noted that this analysis cannot rule out the possibility that the Tibet AS had observed an extended source ($size > 0.2^\circ$) or a line source with $Energy > 3$ TeV. However, assuming the candidates are point-like with power-law energy spectra, we conclude that the five Tibet AS excess regions we studied were either statistical fluctuations in the Tibet AS data, or due to the non-contemporaneous observation periods, the emissions were episodic.

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