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The Whipple Strip Sky Survey

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Abstract: As part of the normal operation of the Whipple 10m Gamma-Ray telescope, ten minute drift scan "zenith" runs are made each night of observation for use as calibration. Most of the events recorded during a zenith run are due to the background of cosmic-ray showers. However, it would be possible for a hitherto unknown source of gamma rays to drift through the field. From 2000-2004 nightly calibration runs were taken at an elevation of 89 º. A 2-D analysis of these drift-scan runs produces a strip of width ~ 3.5º in declination and spanning the full range of right ascension. In the 2004-05 observing season the calibration runs were taken at elevations of 86° and 83°. Beginning in the 2005-06 season, the nightly calibration runs were taken at an elevation of 80º. Collectively, these drift scans cover a strip approximately 12.5º wide in declination, centered at declination 37.18º, and spanning the full range of RA. This paper reports the results of a search for serendipitous high-energy gamma-ray sources in the Whipple 10m nightly calibration zenith data. The analysis procedures developed for drift-scan data, the sensitivity of the method, and the results will be presented.

Introduction

As part of the normal operation of the Whipple 10m Gamma-Ray telescope [1], ten minute zenith runs are made each night of observation for use in calibration. The telescope is brought up to an elevation of 88.99º (declination: 32.69º) and usually (but not always) at the stowed azimuth position of 359.98º. Data are then taken for 10 minutes in drift-scan mode. Most, if not all the events recorded during a zenith run are due to the background of cosmic-ray showers. However, it would be possible for a hitherto unknown source of gamma rays to drift through the field of view of the telescope. This paper reports the results of a search for serendipitous high-energy gamma-ray sources in the Whipple 10m nightly calibration zenith data.

From 2000 - 2004, nightly calibration runs were taken at an elevation of 89 º. Taken together, these runs span a strip of sky centered at declination 32.69º and covering the full cycle of right ascension. A 2-D analysis of these drift-scan runs produces a strip of width ~ 3.5º in declination with sensitivity going to zero at the edges of the strip. In the 2004-05 observing season, the calibration runs were taken at an elevation of 86°. An additional 24 hours of dedicated drift-scan observations were taken at an elevation of 83º. Beginning in the 2005-06 season, the nightly calibration runs were taken at an elevation of 80º. Collectively, these drift scans cover a strip approximately 12.5º wide in declination, centered at declination 37.18º, and spanning the full range of RA. Figure 1 shows the coverage of the survey in galactic coordinates.

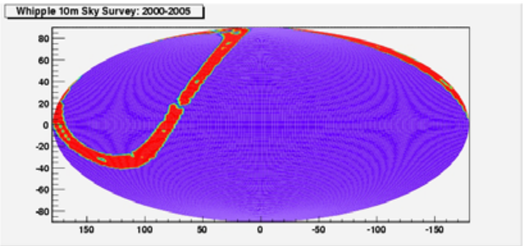

Figure 1: Whipple Strip Sky Survey coverage in galactic coordinates

Analysis

The standard Whipple tracking analysis would not detect an unknown source of gamma rays that happened to pass through the field of a zenith run. We developed an extension to the standard analysis procedure to search for possible sources of gamma rays in drift-scan data. First, the zenith runs were processed through the standard Whipple analysis [2] which does the gain corrections, determines pedestal variances, and then does an image moment analysis (the standard Hillas parameter analysis). Gamma-ray-like events were selected on the basis of the image shape parameters *width*, *length*, and *size*. The Whipple standard 2-D event reconstruction algorithm [3] was used to determine the likely point of origin of the image in the camera plane. We then mapped these locations from the camera coordinate system into RA and DEC coordinates by using the GPS event trigger time and the azimuth and elevation of the center of the camera field of view. This results in a map of events in the RA/DEC plane. Finally a map of events in relative RA/DEC coordinates was produced by subtracting off the RA and DEC of the center of the camera at the start of the run from the RA and DEC of each event. This relative RA/DEC map lets us easily combine fields, compare bin-by-bin to a background map, etc. Henceforth, we refer to these map coordinates as the "drift-field coordinates". It is these drift-field maps that are searched for serendipitous sources of gamma rays.

The standard single telescope ON/OFF analysis [4] is not applicable to the drift-scan data, as there is no corresponding OFF field from which to determine an excess and its significance. Instead, to search for a possible source of gamma rays in our data set, we used a maximum-likelihood method to test the hypothesis that our data is best fit by background alone versus the hypothesis that it is best fit by background plus signal. This method requires models of the background and of the point-spread functions of gamma-ray events centered on each bin in the drift field map. The background model is generated from real data. We selected runs taken at high elevation in good weather which showed no evidence of gamma-ray sources. The camera plane source location was determined for those events which passed the gamma-ray image shape cuts[2]. We chose enough data runs to have on the order of 100,000 events in the camera plane after cuts. This set of real event locations in the camera plane was used to generate a background map for the maximum-likelihood method. Random event times in a ten minute interval were assigned to these events. The assigned event time was combined with the telescope altitude and azimuth to form a simulated drift scan background. Each real event was used about 5 times in the final map. However, each time an event was used, it was assigned a different random event time and thus reconstructs to a different point in the drift field coordinates. By basing the background map on real data, we naturally incorporate any camera biases into the background drift field map. We did indeed observe variations in the camera response map from one observing season to another. Thus, we constructed a separate background model for each observing season in our data set. Figure 2 shows the background drift field map for the 2000-2001season.

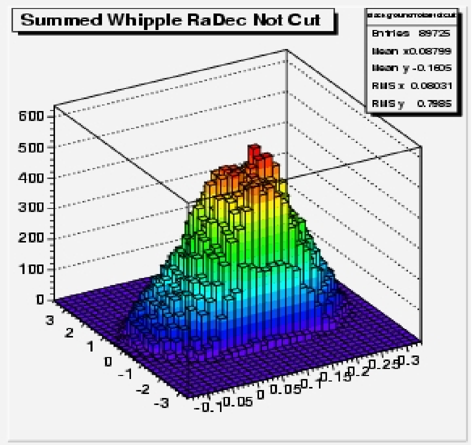

Figure 2: Background model for 2000-2001 observing season.

The point-spread function for gamma-ray events was determined from the KASCADE simulation package. Figure 3 shows the gamma-ray point-spread function for a source offset from the center of the camera. The details of the maximum-likelihood method are described in a separate paper in these proceedings [5].

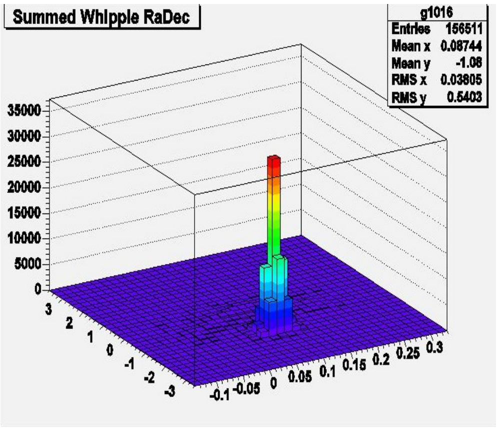

Figure 3: Gamma Ray PSF in drift field coordinates for a source offset from the camera center.

Calibration

We used 10 minute drift scans of the Crab Nebula and of Mrk421 to test and calibrate our methods. We obtained a 10 minute drift scan of Mrk421 in April 2004. Four normal tracking runs [4] taken on the previous night yielded a fairly steady rate of 8 γ/min with a tracking analysis significance of 14σ. A tracking run immediately after the drift scan yielded 10 γ/min at 16σ. This run was followed by an ON/OFF pair which gave 9 γ/min at 11σ. The ON/OFF pair was followed by three more tracking runs with rates of 8.0, 8.0, and 4.2 γ/min respectively. The maximum-likelihood significance plot is shown in figure 4. The shape of the Mrk 421 signal agrees with the shape of a simulated gamma-ray signal. The location of Mrk 421 determined by the drift scan analysis was RA=11.083h Dec = 38.18° compared to the actual coordinates of RA= 11.074h Dec = 38.21°. The maximum-likelihood analysis yielded a rate of 6.6 γ/min and a probability of 4 x 10-9 of being due to background alone. This corresponds to a significance of 5.9σ. In order to compare the gamma-ray rate obtained with the drift-scan analysis to that in the standard tracking analysis, we used a simulated Crab Nebula signal to compare the relative efficiency of the two methods. The simulated Crab signal was subjected to the normal tracking analysis, yielding 2.6±.04 γ/min. The same simulated Crab signal was subjected to the drift scan analysis yielding a rate of 2.2±.04 γ/min, or about 86% of the tracking analysis.

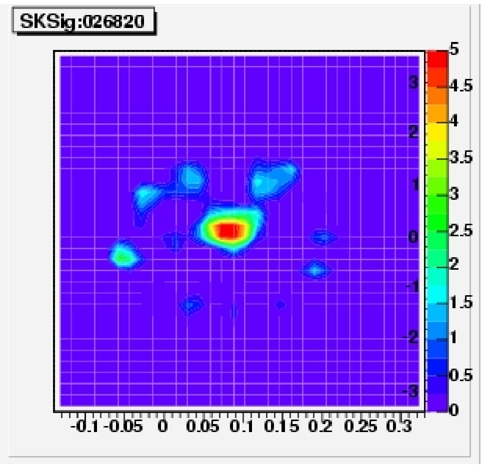

Figure 4: Significance plot for 10 minutes Mrk 421 drift scan in camera coordinates

Correcting the Mrk421 drift scan rate of 6.6 γ/min by this factor, we estimate an equivalent tracking rate of 7.8 γ/min. This is consistent with the observed rate in the adjacent runs.

Sensitivity

The Mrk 421 drift-scan analysis clearly demonstrates that a three Crab source drifting near the center of the field would be detected by this method. We used the Monte Carlo simulations to further characterize the detection limits of this method. We used the set of 500,000 background events to build a background with numbers of events appropriate for seasons 2, 4 and/or 5. Into this we injected simulated gamma-ray events at the center of the drift field. We analyzed this set of simulated data with the maximum-likelihood method, obtaining a probability of best fit to the background alone. We then increased the number of events in the simulated gamma-ray signal and repeated the analysis. We continued in this manner until the resulting maximum-likelihood probability that the data was consistent with background alone was less than 3 x 10^{-5} (approximately a 4σ result). We repeated this procedure 100 times. The result was a histogram of the number of gamma-ray events in the signal needed to obtain a probability of less than 3 x 10^{-5}. For a background of 330 counts (reasonable for seasons 2, 4, and 5) the mean of this distribution was ~48 gamma rays in 10 minutes. This corresponds to approximately 2.2 times the Crab Nebula flux.

Results

The bin-by-bin probabilities for each run in a season were stored in a summary file, which was scanned for low probability runs. There were 10 runs with a probability less than 10^{-4} of being best fit by background alone. These runs were then scanned by eye. All but one run showed the event excess occurred in a single bin, which is not consistent with the PSF of a gamma-ray signal. Only one run in this set of the ten least probable runs had evidence of a cluster of elevated bins. The significance map for this run is shown in figure 5. The probability that this run was due to background alone is 1 x 10^{-4} (approximately a 3.4σ result).

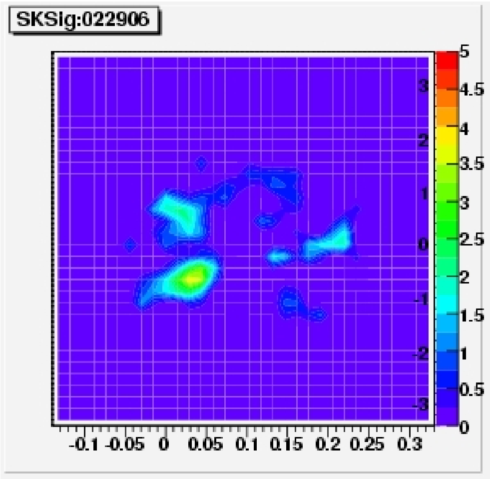

Figure 5: Significance map in camera relative drift field coordinates most likely source

Conclusions

We have analyzed 110 hours of data from the Whipple 10m gamma-ray telescope taken in the drift scan mode. The data set spans all values of RA and covers declinations from 31.2° to 40.2°. Based on the maximum likelihood analysis of these data, there is no compelling evidence for any gamma-ray sources with a flux greater than 2.2 times the Crab flux in this strip.

Acknowledgments

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