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Search for Cygnus Arm Diffuse TeV Gamma Ray Emission with the Whipple 10m Telescope

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The Whipple 10 meter atmospheric Cherenkov telescope has made observations of the region known as the Cygnus arm. This region has been recently reported by the Milagro experiment to contain a diffuse TeV γ-ray source centered at RA=308 and Dec=42. We report upper limits (using the Whipple 10 m telescope) obtained during the Fall 2004 observing season centered on RA=310 and Dec=42.65.

1. Introduction

The Milagro observatory[3] has made long term observations of the Cygnus Arm. They report an excess of over 5.5σ over a 5.9° square bin in RA and Dec.[13]. This excess is inconsistent with a point source and may be due to a giant molecular cloud(GMC) located in the same region as the excess. This cloud has been reported by Dame et. al.[4, 5] to be at a distance of 1.7 pc with a estimated mass of $5.1 \times 10^6 M_\odot$. The angular extent of the cloud is 44 square degrees.

Diffuse emission of γ rays at TeV energies have long been speculated to be the result of cosmic ray interactions with giant molecular clouds[7, 12]. In this scenario, galactic cosmic rays interact with hydrogen and produce neutral pions. These pions quickly decay and produce γ rays. Predictions by Aharonian and Atoyan [1, 2] have indicated that the flux from these GMC should follow the galactic cosmic ray flux (excluding enhancements by local sources) and would be proportional to the GMC Mass over the square of the distance to the GMC. The CygX cloud is a good target since it is close and very massive.

2. Analysis

The Whipple 10 meter atmospheric Cherenkov telescope utilizes the well proven imaging technique to reject cosmic ray background events and to determine source geometry[15, 11]. This method uses the shape of the shower image (fitted to an ellipse) to determine if the shower was initiated by a γ primary or a cosmic ray primary. Additionally, if the source is assumed to be at the center of the field of view (FOV), the angle between the major axis of the ellipse and the line formed by the centroid of the image and the center of the FOV(α angle), can be used to eliminate events not coming from the source location. The energy threshold for the Whipple 10 meter is 390 GeV for a Crab like spectrum[6]

Extensions of this method have been made to make observations for objects that may not be in the center of the FOV. This is often the case when searching for new sources, diffuse emission, or sources that have been identified by other experiments with relatively low angular resolution. In this two dimensional analysis [9], the source location is geometrically constrained to lie along the major axis of the shower image (as it the case with the one dimensional analysis), but no requirement is made of the α angle with respect to the center of the camera. The distance from the image centroid to the source location along the major axis is estimated using

$$d = \xi \left(1 - \frac{width}{length}\right) \tag{1}$$

where the *width* refers to the size of the minor axis, *length* refers to the size of the major axis, d is the distance along the major axis, and ξ is a scaling parameter that must be determined. To break the ambiguity as to which direction along the major axis the source lies, the skewness in the image is used.

The ξ parameter was determined by examining the crab supernova remnant [15, 14]. The two dimensional analysis was applied to on-source crab data. To optimize the ξ parameter, the value of ξ was varied in steps of $\delta\xi = 0.05°$. The optimal value was determined by the maximum signal at the source location The optimal value was determined to be $\xi = 1.35°$.

Once the ξ parameter has been determined the data can binned and the point spread function (PSF) for the method can be determined. Here we have used a $0.36° \times 0.36°$ square bin in RA and Dec. This bin size was found to optimize the significance of the on source crab observations. The binning of the data is shifted six times in RA and Dec. in steps of 0.06° in order to compensate for edge effects in the binning. Applying this analysis to the on source Crab data we get a maximum significance of 11.6σ from 5.6 hours of on source data ($4.9\sigma/\sqrt{hr}$). The PSF of the excess in RA and Dec. is fit to a Gaussian distribution with a $\sigma_{PSF} = 0.18°$

For points source off axis (that is to say, not in the center of the field) the PSF becomes broader as the source moves further away from the center of the FOV. While the radial spread to the PSF stays roughly the same, the azimuthal spread increases slightly from 0.18° to 0.21° at one degree offset. The behavior of the PSF as function off offset was determined by analyzing crab data taken at 0.3, 0.5, 0.8 and 1.0 degree offsets from the center of the field.

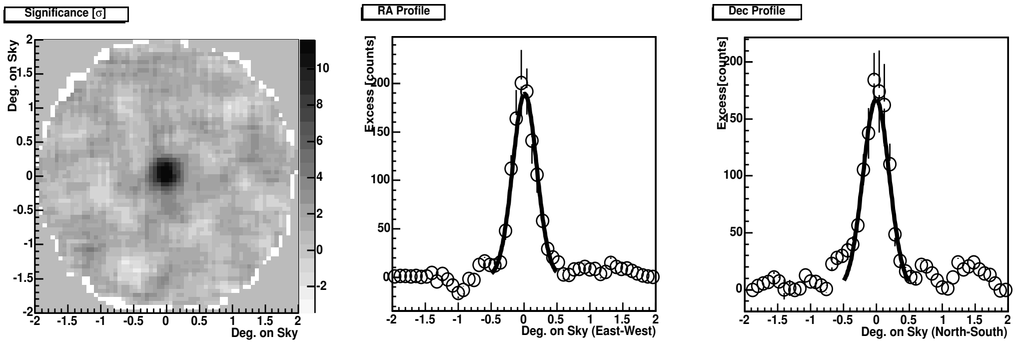

Figure 1. Application of the two dimensional analysis to the Crab supernova remnant. The maximum significance (pre trials) is $11.6\ \sigma$. The profiles in degrees on sky show a good fit to the center width of $\sigma_{PSF} = 0.18°$. and to the location of the source

3. Data

Data used in this work was taken during the months of August 2004 through November 2004. The observation window for this object is small as the Whipple 10 meter generally suspends observations in the summer months due to poor weather conditions in southern Arizona. In this analysis we have used 12 ON/OFF pairs of 28 minutes each. The total number of events in the ON/OFF field after shape cuts is 14406/14594 (ON/OFF). The coordinates of the observations are RA = 20:40:7.9 (310.03°) and Dec = 42:39:51.12 (42.66°) in J2000 coordinates. These coordinates were chosen to overlap with the morphology of the Milagro excess [13] as well as overlap with large values of neutral hydrogen column densities in the region [4].

4. Results and Discussion

The above analysis fails to find strong evidence for a point source of γ-rays within the 2-D FOV of the observations. Figure 2 shows the excess map and sigma map from the field. The significance was calculated using the standard Li and Ma method [10]. The most significant bin in the map (Figure 2) is located at RA=310.8° and Dec=41.3°. The pretrial significance is 3.8σ in this bin. To account for trials factors associated with the binning and the oversampling we simulated 30,000 data sets for this field. We find the chance probability of getting one bin with a sigma of 3.8 or higher is 12%

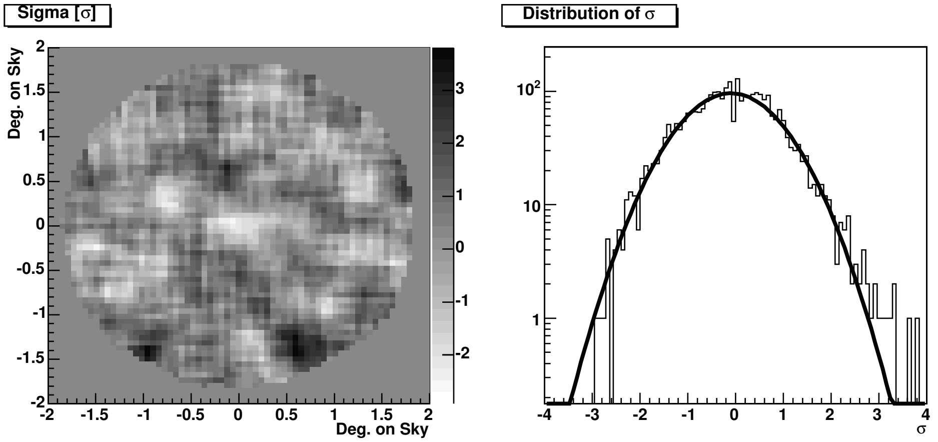

Figure 2. (Left) Sigma map of the Cygnus Arm FOV in degrees on sky. relative to the center of the field (RA = 20:40:7.9 (310.03°) and Dec = 42:39:51.12 (42.66°)) (where north is up and east is to the right). (Right) Distribution of significance. The most significant bin (located at RA = 310.8°, Dec = 41.3°) has a pre-trials significance of 3.8σ with a post-trial probability of being a chance fluctuation of 12%

As no compelling point source was found within this field of view, we must conclude that the Milagro source[13] must be rather diffuse in this region, or must be at a flux level below the sensitivity of this analysis. Diffuse sources are rather difficult with the Whipple 10 meter, particularly if size of the regions of emission is extends beyond the FOV. Such emission would be difficult to detect with this technique, which is optimized for point-source detection.

Upper limits have been calculated in the manner prescribed by Helene[8]. Once the upper limit is known, the values are adjusted to correct for the changing sensitivity across the FOV. This changing sensitivity has been determined by the analysis of offset Crab data. Figure 3 shows the upper limits for each bin in RA and Dec. The field has been limited to the inner 1° of the FOV. Beyond this the sensitivity decreases such that it is difficult to set meaningful upper limits. We find no point source within in the inner half degree of the FOV above 3.0%, 3.3%, and 4.0% of the Crab at the 90%, 95% and 99% confidence level. In the outer half degree we find no point source above 15.0%,16.7% and 20% of the Crab at the 90%, 95%, 99% confidence level. These upper limits are obtained by comparing the total number of excess counts at a given offset (within the 2σ ellipse of the PSF) with the expected excess counts from the Crab at the same offset. This method assumes a crab like spectrum and point source distribution.

Further work is being done to convolute the PSF with the expected source distribution, obtained from neutral

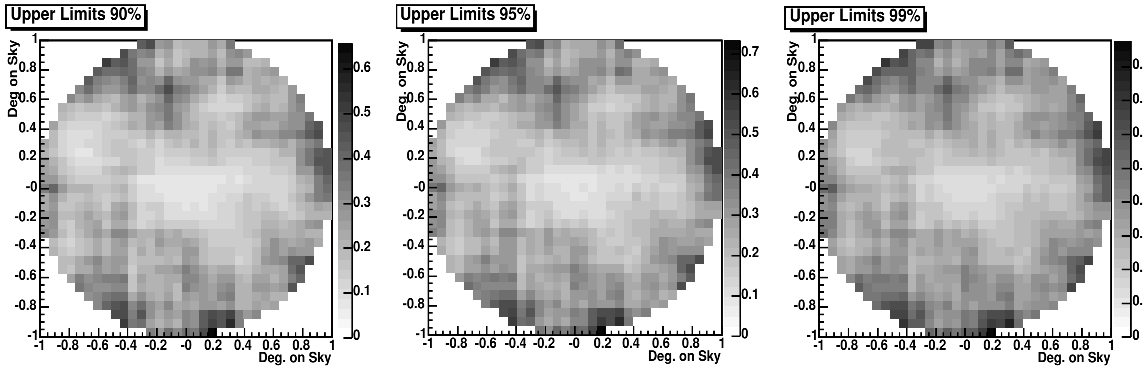

Figure 3. 90%, 95%, and 99% upper limits, in γ /minute for the inner 1° FOV of the field.

hydrogen column density maps of the region. This will allow us to set stronger upper limits for the region and may reveal a sources that the point source analysis failed to detect. We are also continuing to collect data on this target and are also observing other fields within the region of the Milagro excess.

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