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Abstract. We present here the results of recent observations made with the Whipple 10m imaging Cherenkov telescope of the region of the supernova remnant IC443. No evidence for gamma-ray emission was found, and we obtain an upper limit above 500 GeV (99.9% confidence) of 0.6×10^{-7} ph m^{-2} s^{-1} (0.11 Crab) at the location of the recently identified X-ray plerion nebula and 0.8×10^{-7} ph m^{-2} s^{-1} (0.14 Crab) at the site of the OH maser at the densest part of the molecular cloud.

INTRODUCTION

The region of the shell-type supernova remnant IC443 (G189.1+3.0) has long been considered a good candidate for TeV emission via nuclear interactions of shock accelerated cosmic rays [1], in particular because of the presence of molecular clouds with densities as high as ~ 840 nucleons cm^{-3} and a total H_2 mass of $\sim 7900 M_\odot$[2]. These clouds provide an enhanced target density for accelerated cosmic ray nuclei and can thus greatly increase the neutral pion, and hence gamma-ray, production rate. The strongest case for an association with an EGRET unidentified source (3EG J0617+2238) has been made for this SNR [3]. Further interest has been triggered by the detection of a localised, non-thermal X-ray source situated on the southern edge of the radio shell, which Chandra [4] and XMM [5] observations have identified as a plerion nebula. Butt et al. [2] argue that

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the EGRET source, if associated with the SNR, is most likely to be the result of gamma-ray emission from cosmic ray interactions in the molecular cloud and not associated with the plerion nebula.

In an analysis of 38 hours of archival HEGRA data, Pühlhofer et al. [6] reported a possible TeV hot-spot, co-located with the site of the plerion, but statistically insignificant after accounting for the number of trials used in the analysis. The CAT experiment has also observed this region for 38 hours [7]. They provide 3σ upper limits above a threshold of 250 GeV of 0.9×10^{-7} ph m^{-2} s^{-1} at the site of the plerion nebula and 1.0×10^{-7} ph m^{-2} s^{-1} at the location of the EGRET source. Previous observations with the Whipple telescope based on 18 hours of observations resulted in an upper limit of 2.1×10^{-7} ph m^{-2} s^{-1} above 300 GeV, integrated over a circular aperture of radius 0.64° [8]. We report here on observations taken with the Whipple 10m atmospheric Cherenkov telescope during 2003-2004.

OBSERVATIONS

The Whipple 10m telescope is described in detail in Finley et al. [9]. Briefly, the telescope consists of a 10 m reflector and a 379 pixel photomultiplier tube (PMT) camera with 0.12° spacing, giving a total field-of-view of diameter 2.8°. Cherenkov images are recorded and parameterized according to Hillas [10] and gamma-ray like images are selected using criteria optimized on recent data from the Crab Nebula, the standard candle of TeV gamma-ray astronomy. In order to achieve optimal weak source sensitivity rather strict cuts have been applied, resulting in an energy threshold for this analysis of 500 GeV.

For the IC443 observations the camera was centred on the position of the plerion nebula. After selection for good weather the total dataset consists of 23.3 hours of ON source data, with the same amount of OFF source data, offset by 30 minutes in right ascension and used to provide a control background.

RESULTS

For a stand-alone imaging Cherenkov telescope, the greatest sensitivity is achieved when an *a priori* position for the gamma-ray source is known. We have chosen two such candidate positions: the first is the site of the plerion nebula at the centre of the field-of-view, the second is a region of intense OH maser emission, identified by Claussen et al. [11], and coincident with the densest part of the CO maps and the unidentified EGRET source. Figure 1 shows the distribution of the orientation angle, alpha, of the image in the camera, relative to the source position for both candidate emission sites. Gamma-ray images are expected to point to the location of the source, and so a signal would appear as an excess in the ON - OFF distributions at low alpha values. No significant excess is detected, and the upper limits are 0.6×10^{-7} ph m^{-2} s^{-1} (0.11 Crab) for emission from the plerion and 0.8×10^{-7} ph m^{-2} s^{-1} (0.14 Crab) for emission from the OH maser site, both at the 99.9% confidence level.

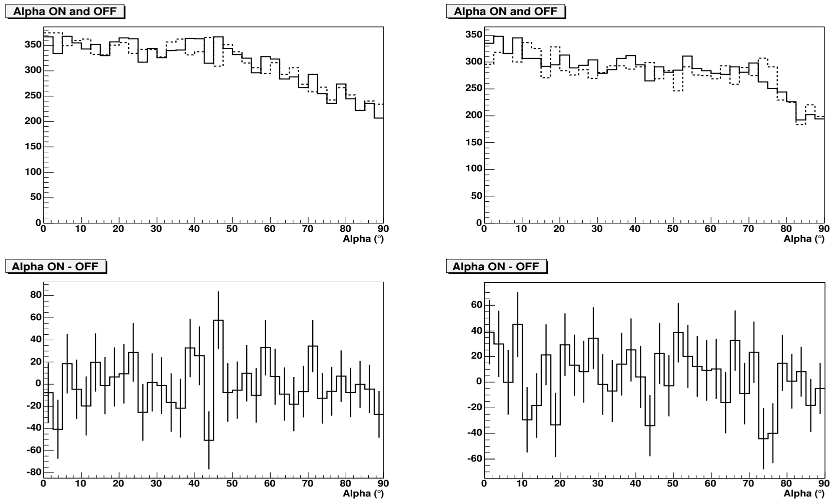

FIGURE 1. Distributions of the orientation angle alpha. The left-hand plots show alpha calculated with respect to the location of the plerion nebula; the right-hand plots correspond to the OH maser site.

Using the method of Lessard et al. [12], it is possible to reconstruct the arrival direction of gamma-rays in the camera. The sensitivity of this technique is improved by applying a Gaussian smoothing function of width $\sigma = 0.175^\circ$ (optimized on the Crab) to the reconstructed directions [13]. Figure 2 shows an example of this applied to the Crab Nebula taken during the same observing season as the IC443 observations, with the source offset from the centre of the camera. The two-dimensional significance map for the entire field-of-view for IC443 is shown in Figure 3. No significant excesses are detected, and there is no indication of regions of extended emission.

DISCUSSION

A number of authors have attempted to predict the emission spectrum due to cosmic ray acceleration in IC443 [14, 15]. In Figure 4 we show the model of Gaisser, Protheroe and Stanev [14] which uses the most realistic input parameters for the molecular cloud density, along with the EGRET flux and the various upper limits. The model assumes that the EGRET emission is produced by particle acceleration in the remnant, and includes the contributions from pion production, which dominates the emission at 500 GeV, bremsstrahlung, and inverse Compton scattering on the cosmic microwave, diffuse galactic, and locally produced radiation fields. Both the CAT upper limit and the upper limit calculated here lie below the predicted emission level, which may indicate that the assumption that the EGRET emission is due to cosmic ray acceleration is invalid.

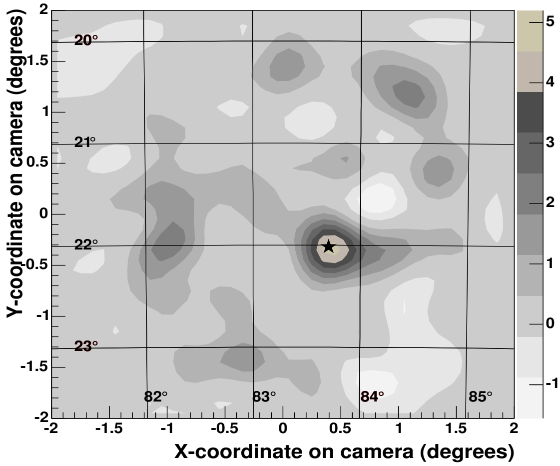

FIGURE 2. Two-dimensional significance map of 2.8 hours of offset Crab Nebula observations. The star indicates the true position of the Crab Nebula. The scale on the right is in standard deviations.

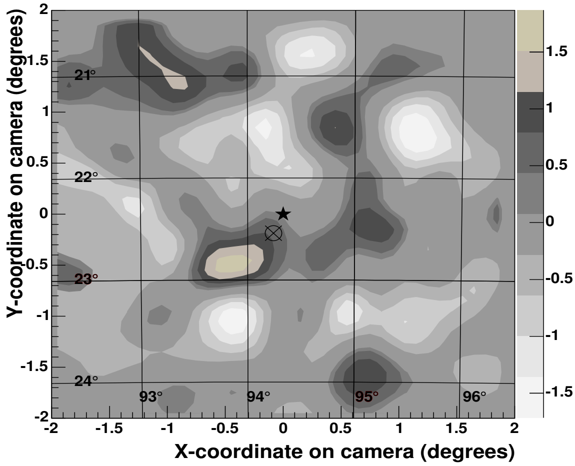

FIGURE 3. Two-dimensional significance map of the IC443 observations. The star indicates the position of plerion nebula at the centre of the camera. The crossed circle indicates the OH maser site. The scale on the right is in standard deviations.

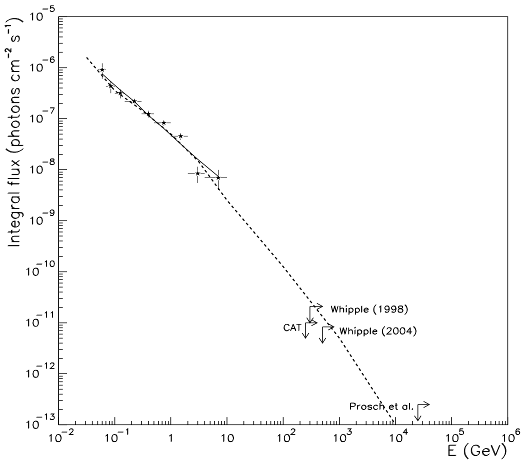

FIGURE 4. The spectrum of IC443. Stars are the EGRET points [16]. The upper limits are from Buckley [8] (Whipple 1998), assuming diffuse emission integrated over a circular aperture of radius 0.64°; Khelifi [7] (CAT) assuming a point source at the location of 3EG J0617+2238, and this work (Whipple 2004), assuming a point source at the location of the OH maser. The dashed line is "fit 3" from Gaisser, Protheroe and Stanev [14], which uses the most realistic input parameters for the molecular cloud density [2].

Khelifi [7] has attempted to estimate the emission due to inverse Compton scattering of ambient photon fields by an electron population accelerated by the plerion. The input electron spectrum is adjusted, assuming a magnetic field strength at equipartion of 16 μG, so as to produce a match to the measured synchrotron spectrum. The target photons are comprised of the cosmic microwave background and infrared emission produced by heated dust grains. The results of their model are shown in Figure 5 along with the CAT and Whipple upper limits.The upper limits presented here do not yet constrain models of emission due to electron acceleration in the plerion nebula.

IC443 remains a strong candidate for TeV emission and further observations are planned with the Whipple 10m during the coming year. The recent detection of the SNR RXJ1713.7-3946 by the HESS experiment [17] highlights the capabilities of imaging Cherenkov telescope arrays for SNR studies. Observations of IC443 with the VERITAS array in the future will provide much greater sensitivity than those presented here[18].

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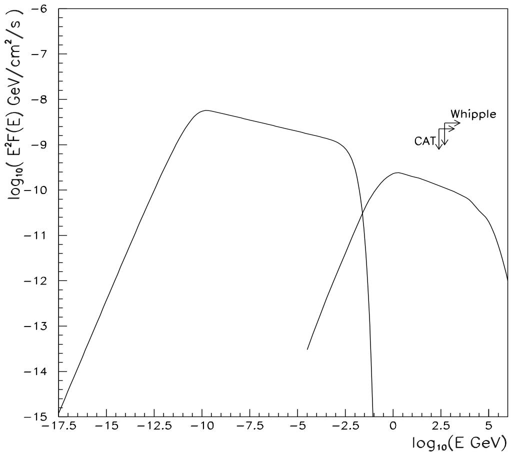

FIGURE 5. The spectrum of the plerion nebula in IC443 (in an E^2 representation). The upper limits both assume a point source at the location of the plerion. The lines show the model of Khelifi [7]

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