Observations of the Galactic Plane at Energies above 0.6 TeV

S.LeBohec[1], I.H.Bond [2], S.M. Bradbury [2], J.H.Buckley[3], A.M.Burdett[2,4], D.A.Carter-Lewis[1], M.Catanese[1], F.Krennrich[1], M.F.Cawley[5], S.Dunlea[6], M. D'Vali[2], D.J.Fegan[6], S.J.Fegan[4], J.P.Finley[7], J.A.Gaidos[7], T.A.Hall[7], A.M.Hillas[2], J.Knapp[2], R.W.Lessard[7], C.Masterson[6], J.Quinn[6], H.J.Rose[2], F.W.Samuelson[1], G.H.Sembroski[7], V.V.Vassiliev[4], T.C.Weekes[4]

[1]*Department of Physics and Astronomy, Iowa State University, Ames, IA 50011-3160, USA*
[2]*Department of Physics, Leeds University, Leeds, LS2 9JT, UK*
[3]*Department of Physics, Washington University,St. Louis, MO 63130, USA*
[4]*Fred Lawrence Whipple Observatory, Harvard-Smithsonian CfA, P.O. Box 97, Amado, AZ 85645-0097, USA*
[1]*Department of Physics and Astronomy, Iowa State University, Ames, IA 50011-3160, USA*
[5]*Physics Department, St. Patrick's College, Maynooth, County Kildare, Ireland*
[6]*Experimental Physics Department, University College, Belfield, Dublin 4, Ireland*
[7]*Department of Physics, Purdue University, West Lafayette, IN 47907, USA*

Abstract

In 1998 the Whipple Observatory 10 m telescope was used to observe the Galactic Plane at TeV energies. At this time, the telescope was equipped with a large ($4.8^{\rm o}$) field of view camera well suited to detect diffuse emission. We report here a preliminary analysis of these data. Assuming the TeV emission profile matches that found by EGRET above 1 GeV, we find an upper limit of $4.9 \cdot 10^{-8} {\rm s}^{-1} {\rm cm}^{-2} {\rm sr}^{-1}$ average diffuse emission at galactic longitude $40^{\rm o}$ and energies above $0.6 {\rm TeV}$. Further observations and analysis are in progress.

1 Introduction:

The diffuse emission from the galactic plane is the main feature of the high energy γ-ray sky. The general spatial and spectral properties of the diffuse emission indicate that it is primarily due to the interactions of cosmic rays with the interstellar medium. Models of the diffuse emission accurately reproduce the angular and energetic distributions above $100{\rm MeV}$ (Hunter et al. 1997). However, the same models underestimate the diffuse emission above $1{\rm GeV}$ by 40% as measured by EGRET. A simple extrapolation of the recorded spectrum indicates that diffuse emision maybe within reach of the sensitivity of atmospheric Cherenkov detectors.

In addition, it has been suggested (Porter and Protheroe 1997) that leptonic cosmic rays could be the dominant source of TeV diffuse emission from the galactic plane. The X-ray observations of synchrotron photons for several supernova remnants indicate that electrons are accelerated up to 100 TeV energies. When such particles escape their acceleration site, diffusing in the galaxy, they would cool by synchrotron radiation and inverse Compton scattering producing TeV γ-rays.

2 The 1998 Whipple Telescope Galactic Plane Observations

In 1998, the Whipple Imaging Cherenkov Telescope (Quinn et al. 1999) was used to carry out observations of the galactic plane at a galactic longitude of $40^{\rm o}$. This field was selected for being relatively free of background stars, for culminating high enough in the sky above Whipple observatory and for being in the diffuse γ-ray bright part of the milky-way. The wide field of view ($4.8^{\rm o}$) covered by the 331 photomultipliers on a $0.25^{\rm o}$ hexagonal matrix is particularly well suited for observing extended objects. Observations were made in the standard "ON-OFF" mode in which the direction $({\rm l} = 40^{\rm o}, {\rm b} = 0^{\rm o})$ is observed for 28 minutes after which the telescope tracked a background region of the sky covering the same path in elevation and azimuth for another 28 minutes. There are 7 pairs of 28 minute runs measured in this way. The corresponding elevations ranged from $49^{\rm o}$ to $64^{\rm o}$ above the horizon.

3 Analysis

Following the standard procedure used for analysis of Whipple telescope data (Reynolds 1993), each shower image is characterized by parameters derived from the 1^{st}, 2^{nd} and 3^{rd} moments of the Cherenkov light distribution on the focal plane of the camera. (Software padding is used to compensate the noise level difference between the two members of a pair before moments are calculated.) These parameters are required to fulfill the standard supercut set of criteria for the event to be classified as a γ-ray candidate.

For each selected event, the most likely arrival direction of the primary γ-ray is estimated by assuming the source to lie on the image major axis on the side indicated by the asymmetry parameter at a distance from the image center of $1.85^{o}(1 - Width/Length)$(Lessard 1997). The position in the sky is then corrected for field rotation due the use of an alt-azimuth mount. Two dimensional histograms of arrival directions are constructed for both "on" and "off" source members of a pair, and the difference histogram is an estimator of the signal. The analysis method has been tested on Crab Nebula data taken with the same camera in which the telescope was pointed directly at the object and pointed at a region offset by 1.0 and 1.5 degrees from the Nebula.

4 Signal Simulation

In order to estimate how the galactic plane should appear in our data, we have assumed that the TeV emission pattern from the plane is the same as found by EGRET at energies greater that 1 GeV (Hunter et al. 1997). This flux as a function of galactic latitude, x, at longitude 40^{o} (our observation point) was parameterized as $\frac{1}{\sqrt{2\pi}}\left[\frac{\epsilon}{\sigma_1}e^{\frac{-x^2}{2\sigma_1^2}} + \frac{1-\epsilon}{\sigma_2}e^{\frac{-x^2}{2\sigma_2^2}}\right]$ where $\sigma_1 = 4.15^{o}$, $\sigma_2 = 1^{o}$ and $\epsilon = 0.703$. We have simulated 111,196 γ-rays according to this distribution on a patch of sky covering 5^{o} in longitude and 5^{o} in latitude. For simulation convenience, the diffuse emission distribution was truncated in galactic latitude at 2.5^{o} from field center. This region contains 61.18 percent of the emission. The γ-rays were generated by ISUSIM (Mohanty et al. 1998) with energies chosen from a power-law spectrum starting at 0.1 TeV with a differential spectral index of 2.4. The γ-rays fell onto a disk $300\mathrm{m}$ in radius centered on the telescope and the zenith angle was set at 20^{o}. (We will change the zenith angle to a more appropriate value $\sim 35^{o}$ in a more detailed analysis in progress.) For each event passing the selection criteria described above, the angular origin was estimated. The energy threshold is defined as the energy at which the rate per interval of energy is highest for a spectrum with an integral spectral index of 1.4. From the simulations, this is estimated to be 0.6 TeV. This unusually high value reflects the fact that the telescope was not operated under the usual set up. The discriminators were set conservatively because of the brightness of the galactic plane, there were no light cones and the outer ring of mirrors was removed. It also reflects, to a lesser extent, the very extended nature of the source.

In the context of this picture, a signal should appear as an excess number of events with a maximum at the center of the camera, i.e., the $\mathrm{b} = 0$ direction. As one moves across the camera face in the direction of in galactic longitude, the number of γ-rays detected should remain constant for an ideal camera. However, because of the finite field of view, the detection efficiency falls off with distance from the optic axis. Consequently, we have restricted the data to directions corresponding to longitude $\mathrm{l} = 40^{o} \pm 1.5^{o}$. At 1.5^{o} from the center of the field of view, the efficiency has dropped to 1/2 of the central value. A total of 417 of the 111,196 simulated γ-rays passed all cuts, including the restriction on longitude.

The distribution of the 417 simulated signal events along the direction on the camera corresponding to b, the galactic latitude, is well reproduced by: $\frac{\mathrm{dn_0}}{\mathrm{db}}(\mathrm{b}) = \frac{\mathrm{A_0}}{\sqrt{(2\pi\sigma_0^2)}}\exp(-\frac{\mathrm{b}^2}{2\sigma_0^2})$ with $\sigma_0 = 0.843^{o}$. This shape reflects both the emission pattern from the plane and the response of the camera. The signal should manifest itself as an excess of events distributed across the camera face in the direction of b with a Gaussian shape.

5 Results

The distribution of events in galactic latitude for the observations is shown in Figure 1. It was fitted with the function $\frac{dn_0}{db}$ with only the normalization factor A_0 as a free parameter yielding a detection rate from diffuse emission: $A_0 = (1.37 \pm 0.58)/\text{minute}$ at a very marginal (2.4σ) significance. The fit and limits are also shown in the figure. Given the low statistical significance of this result, it is best used to derive an upper limit of $3.39/\text{minute}$ at the 99.9 percent confidence level.Thus, using a camera efficiency derived from simulations as confirmed by observations of the Crab Nebula, and assuming the TeV diffuse emission profile to be the same as observed by EGRET, we get the 99.9 percent confidence level upper limit of $4.9 \cdot 10^{-8} \text{s}^{-1}\text{cm}^{-2}\text{sr}^{-1}$ on the average flux between $b = -2^o$ and $b = 2^o$ above 600GeV.

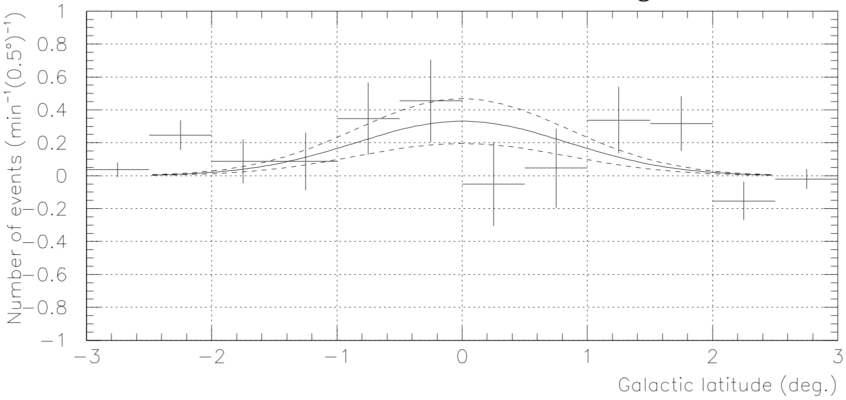

Figure 1: Distribution of excess events in galactic latitude .

6 Discussion

In this analysis, the upper limit on diffuse emission from the galactic plane was derived under the assumption that the TeV emission would have the same pattern in the sky at $l = 40^o$ as the EGRET data above 1 GeV. This upper limit is not sufficiently low to constrain simple extrapolations of the EGRET spectrum. It is emphasized that these results are very preliminary, e.g., no corrections were made for inhomogeneities in the camera sensitivity across the field of view. Observations are now in progress (Spring 1999) with a camera with lower energy threshold due to light cones and a hardware pattern trigger which will expand the statistically limited data set. When these observations are complete, a detailed analysis will be made for both data sets.

References

Hunter, S.D., et al. 1997, ApJ, 481, 205.
Porter, T.A., Protheroe, R.J., 1997, J.Phys.G, 23, 1765.
Reynolds, P.T., et al., 1993, ApJ, 404, 206.
Quinn, J., et al., 1999, ApJ, in press.
Lessard, R.W., et al., 1997, Proceed. of “Toward a Major Atmospheric detector V”, 356, ed. O.C. De Jager
Mohanty, G., et al. 1998, Astrop. Phys., 9, 15