Search for TeV Emission from Geminga by VERITAS

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Abstract. **The Geminga gamma ray source was first detected by SAS-2 and COS-B, and has been identified as a radio-quiet pulsar associated with a 300,000 year old supernova remnant. Geminga is one of the brightest GeV sources and was also detected by Milagro at energies greater than 20 TeV. During 2007 VERITAS performed observations to search for TeV gamma ray emission from the Geminga pulsar and the region near Geminga. In this paper, we describe these measurements and new analysis of these observations.**

I. Introduction

Geminga is a relatively close pulsar approximately 170pc away. It is considered to be an older pulsar at an age of 3×10^5 years. It was first detected in high-energy (MeV-GeV) gamma rays by the SAS-2 satellite [1]. The Geminga gamma ray pulsar was detected by the EGRET telescope aboard the Compton Gamma Ray Observatory satellite [11]. More recently the Fermi gamma-ray telescope has also detected high energy gamma rays from Geminga [2]. Very high energy gamma rays (TeV) have been detected by Milagro that are positionally coincident with Geminga at energies greater than 20 TeV [3]. This leaves a gap in the energy spectrum of Geminga from the GeV range to 20 TeV, see figure 1. Imaging atmospheric Cherenkov telescopes (IACTs) such as VERITAS have a sensitivity from 100 GeV to greater than 30 TeV that will cover the energy gap between space-based detectors and the ground-based water Cherenkov detector Milagro.

Caraveo [4] estimated that Geminga is accelerating electrons to energies greater than 100 TeV with a bow-shock like structure. Milagro has detected an excess of TeV gamma rays with a significance greater than 6σ with an extension of $2.6^{+0.7^\circ}_{-0.9}$ that is positionally coincident with Geminga [3]. This makes the diffuse size of Geminga extension approximately 5 to 10pc which is in agreement with XMM-Newton observations [5].

II. VERITAS Observations

VERITAS is an array of four imaging atmospheric Cherenkov telescopes (IACTs) located south of Tucson, Arizona, USA, at the Fred Lawrence Whipple Observatory (FLWO). Each telescope has a camera with 499 photomultiplier tubes with a 500 mega-samples per second flash ADC readout system. The optical reflector of each telescope is 12m in diameter and uses a Davies-Cotton design. VERITAS sensitivity allows for a greater than 5σ detection of a source at a 1% Crab Flux level in 50 hours.

During November and December of 2007 VERITAS collected 15 hours of data. After quality weather selection 10.4 hours of observations were selected to analyze. All observations were taken in wobble mode, where the source is offset 0.5° from the camera center. The average observation was performed at an elevation of 71.4°.

III. Analysis and Results

VERITAS detects the Cherenkov light emitted by extensive air showers that are created when a particle enters the atmosphere. The image parameters are then compared with shape parameters that are derived from Monte Carlo simulations and specific cuts are made to separate gamma-ray showers from hadronic showers. Geometric parameters are applied to each event to calculate the arrival direction of the shower.

The observations taken in wobble mode were analyzed using a reflected region background method. The signal region and the background regions (0.15° disk in the field of view) are taken around a radius 0.5° from the camera center but in different directions. Wobble mode allows for the background signal to be estimated in the same field of view as the source. This is an excellent method for the search of point-source objects.

A steady-source analysis was first done on the data. Figure 2 shows a histogram of the squared angular distribution of the events recorded around the Geminga source location. The ON source data (points) of figure 2 are consistent with the OFF region (shaded), and therefore no significant excess was found. Figure 3 shows a 2-D map of the significance for the region and figure 4 is a 1-D histogram of significance of each pixel in the 2-D map of the significance. The 1-D histogram of significance is well fit by a Gaussian distribution corresponding to the expected background signal. The observations were analyzed using a point-source analysis. The 99% confidence level [9] limit of the steady-source analysis for energies above 300 GeV is $< 2 \times 10^{-12} cm^{-2} s^{-1}$ and for a pulsed search with energies greater than 200 GeV is $0.8 - 1.0 \times 10^{-12} cm^{-2} s^{-1}$. An extended-source analysis is ongoing.

A periodicity analysis which is similar to the steady source analysis was done on the same data. The arrival times of each event, after barycentric corrections were applied, were compared to the ephemeris of Geminga based on recent XMM-Newton observations as well as

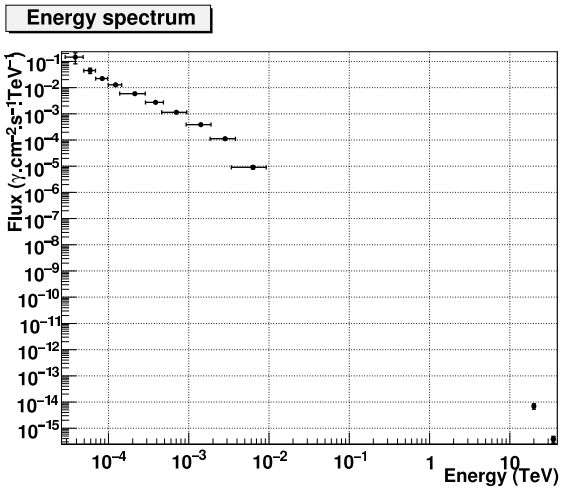

Fig. 1. The differential energy flux of the Geminga pulsar from EGRET [12] (top left hand points) and the differential energy flux of Geminga from Milagro (lower right hand corner) [3] [13] shows the energy gap between the two measurements.

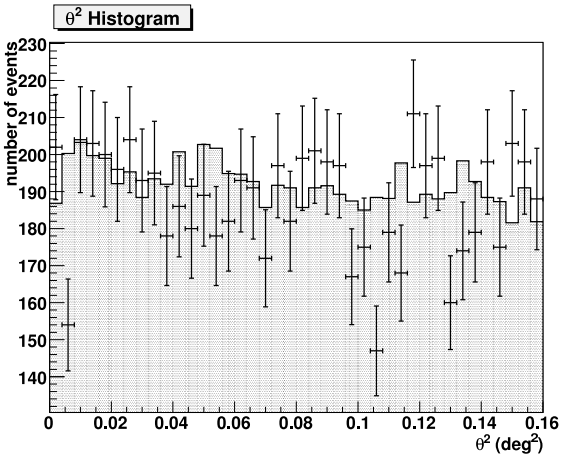

Fig. 2. Comparison of ON (points) and OFF source (shaded) as function of the distance from the source center measured in degrees squared (θ^2). Horizontal Axis: (θ^2), Vertical Axis: Number of Events.

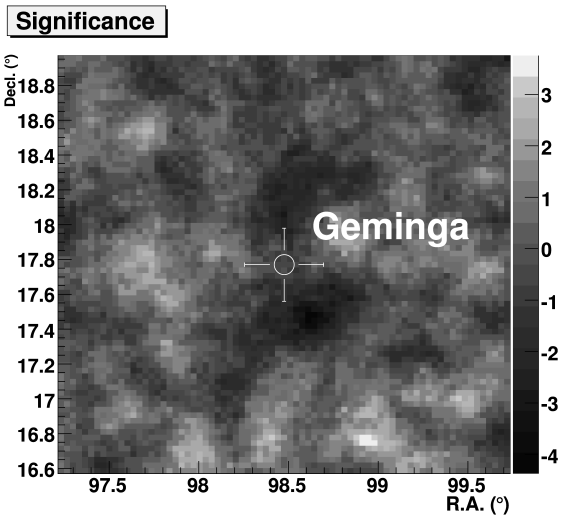

Fig. 3. 2D significance plot about the direction of Geminga. Horizontal Axis: Right Ascension (°). Vertical Axis: Declination(°)

archival ASCA and EGRET data [10]. Figure 5 shows a histogram of the phase distribution for all of the ON data. Figure 6 is a similar plot but for energies less than 200 GeV. The arrows point out the peaks in the EGRET phase plot [11]. No correlation was found with the VERITAS data and the pulsar phase distribution of Geminga.

IV. Summary

Geminga is a very interesting source to observe due to its proximity and age. Observations of Geminga will help explain how a pulsar changes with time. Since Geminga is a nearby powerful galactic source of high energy gamma-rays, a TeV detection can help confirm that Geminga is a cosmic-ray accelerator.No significant excess was observed with VERITAS using a point-source analysis. We report an upper limit of $F_\gamma(>= 300$ GeV, 99% c.l.)$2 \times 10^{-12} cm^{-2} s^{-1}$ and for a pulsed search an upper limit of $F_\gamma(>= 200$ GeV 99% c.l.) $< 0.8 - 1.0 \times 10^{-12} cm^{-2} s^{-1}$. Extended-source analysis is on going.

V. Acknowledgments

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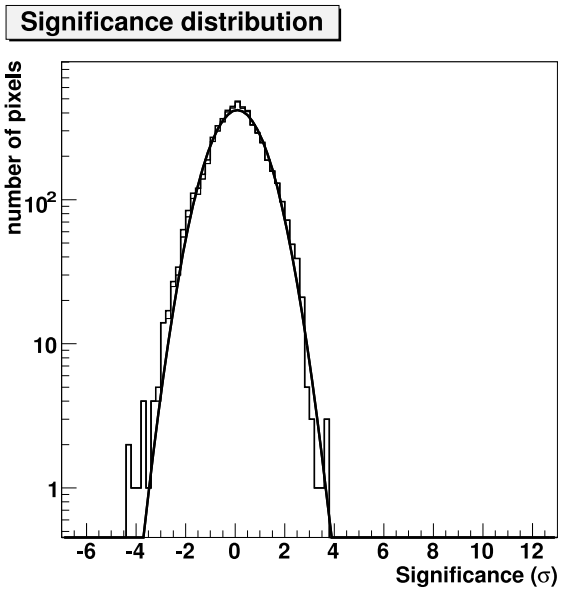

Fig. 4. Histogram of the 2D plot (Figure 3) significance distributions. Horizontal Axis: Statistical Significance. Vertical Axis: Number of pixels. Solid Line : Simulated distribution for background events (no signal).

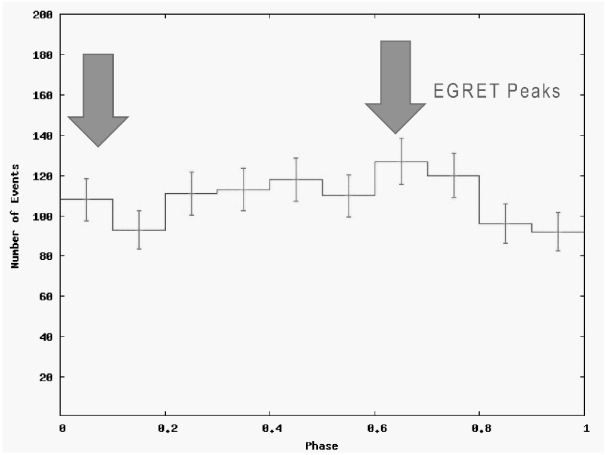

Fig. 5. Histogram of the phase distributions of all the ON data. Horizontal Axis: Phase bin. Vertical Axis: Number of events. Arrows: Peaks in the EGRET phase plot [10].

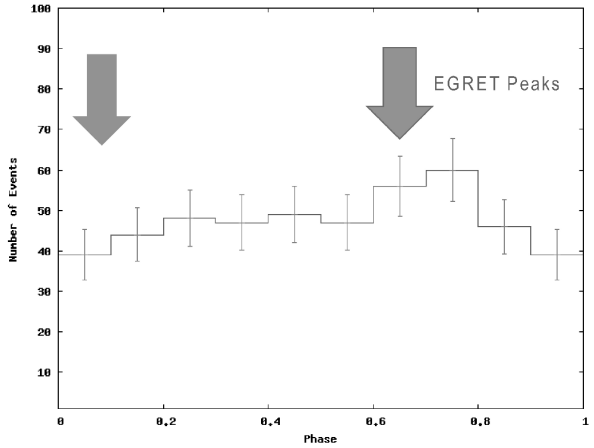

Fig. 6. Histogram of the phase distributions of the events with an energy $<$ 200 GeV Horizontal Axis: Phase bin. Vertical Axis: Number of events. Arrows: Peaks in the EGRET phase plot [10].