Search for TeV Emission from Geminga by the VERITAS Observatory

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Abstract. During November/December 2007, we observed the region centered on the Geminga Pulsar for 10.4 hours using the VERITAS IACT Observatory. We find no evidence for either steady emission point source emission, or pulsed emission of a point source at the period of the Geminga pulsar (237 msec). The measured VHE γ-ray flux limits for the unpulsed search is $F_\gamma(> 300$ GeV , 99% c.l) $< 2 \times 10^{-8}$ m^{-2} s^{-1}. A search for overall pulsed emission as well as low energy emission ($E_\gamma < 200GeV$) found no statistically significant excess in any bin of the phase plot. The γ-ray flux upper limits from the pulsed search is $F_\gamma(E < 200$ GeV and $E > 300GeV$, 99%c.l.) $< 0.8 - 1.0 \times 10^{-8}$ m^{-2} s^{-1}.

Keywords: VHE Gamma Ray, Geminga pulsar, VERITAS Observatory, Supernova Remnant
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INTRODUCTION

The Geminga pulsar is a relatively old (3×10^5 yr) radio pulsar with an observed 237 msec modulated emission in soft X-ray[2], optical[3], and hard x-ray/γ-ray[4], [5]. The optical and soft emission shows evidence of a two component blackbody spectrum originating on the surface of the Geminga neutron star 1E 0630 +0178 , whereas the hard X-ray/γ-ray power-law emission is thought to arise in the magnetosphere around the neutron star [6]. If the hard X-ray/γ-ray radiations is created by a synchrotron process, Caraveo[7] estimates that Geminga must be accelerating electrons to energies approaching 100 TeV. The presence of such high energy electrons, combined with a relatively close distance to Geminga (160 pc), and its advanced pulsar age make Geminga a particularly interesting target for examining the evolution of the VHE emission processes in galactic pulsars.

Geminga is also positionally coincident with 630 mCrab (E > 20 TeV) extended ($2.8^\circ\phi$) VHE source C3 reported by the Milagro Observatory[8]. This extended emission has yet to be confirmed by other observatories in the TeV region, but it is interesting to note that Geminga was detected in the GeV energy range by EGRET[4] and more recently by the First public all-sky map of the FERMI GeV satellite observatory[9]. The FERMI all-sky plot shows a strong, diffuse emission region in GeV γ-ray about the position of the Geminga Pulsar. The source of the extended VHE emission from Geminga is therefore not yet understood. It could arise as a spectral continuation of GeV excess observed by EGRET/Fermi, potentially from the Pulsar Wind Nebula associated with the Geminga SNR remnant, or it could also include contributions from several individual point sources which are positionally coincident to (but potentially unrelated to) Geminga. Additional measurements of the Geminga region by higher angular resolution IACT observatories are therefore necessary to confirm and understand any potential VHE γ-ray emission from the Geminga region.

VERITAS OBSERVATORY

The VERITAS Observatory [10] is an array of four Imaging Air Cherenkov Telescopes (IACTs) located at the base camp of the F.L. Whipple Observatory, near Tucson, AZ, USA. The VERITAS Array detects Cherenkov light emitted by extensive air showers initiated by > 100 GeV energy γ-rays. Each telescope consists of an 12m diameter optical reflector using a Davies-Cotton design and Alt-Az positioner system. The optical images of Cherenkov light in each telescope are recorded by a 499 pixel PMT camera using a 500 Mhz Flash ADC readout system. The observations were analyzed by fitting the observed images to determine parameterizations of the Cherenkov image shapes and geometrical orientations. Based upon Monte Carlo simulations, cuts are applied to the image parameters to select γ-ray events and reject background cosmic ray events. Two different standard analysis packages were used to independently verify all results. VERITAS sensitivity allows a 5σ detection of a 50 milliCrab point source near zenith in 2.5 hours. The VERITAS Observatory has been in full operation since January 2007, and has successfully observed known VHE sources such as the Crab Nebula[11], Mrk 421[12], M87[13] and LSI 61+303[14] as well as several

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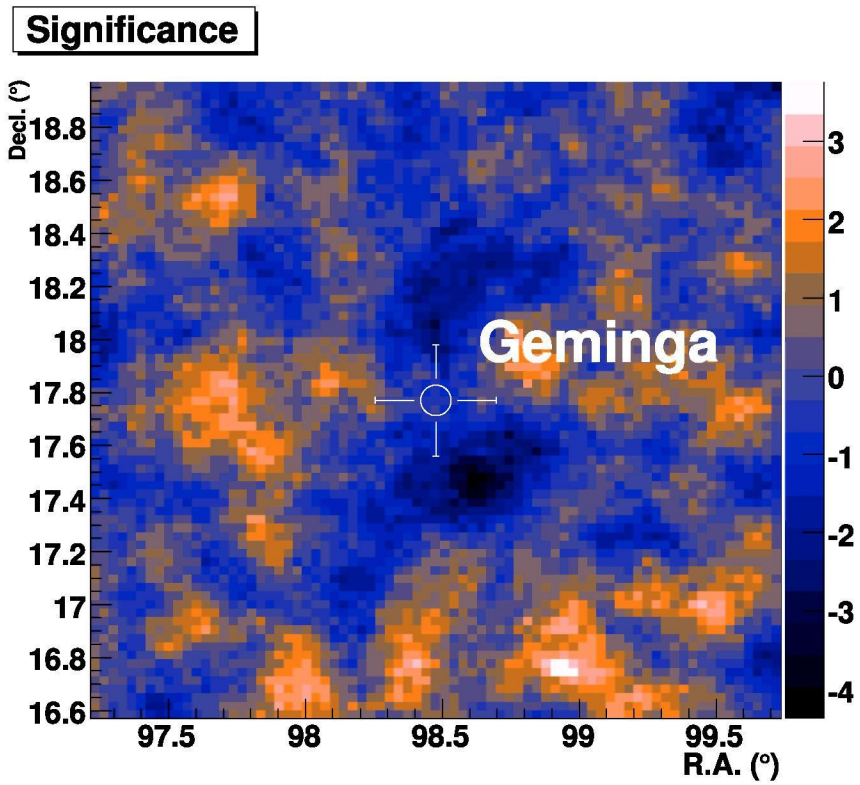

FIGURE 1. 2D significance plot about the direction of Geminga.Horzontal Axis: Right Ascension (°). Vertical Axis: Declination(°)

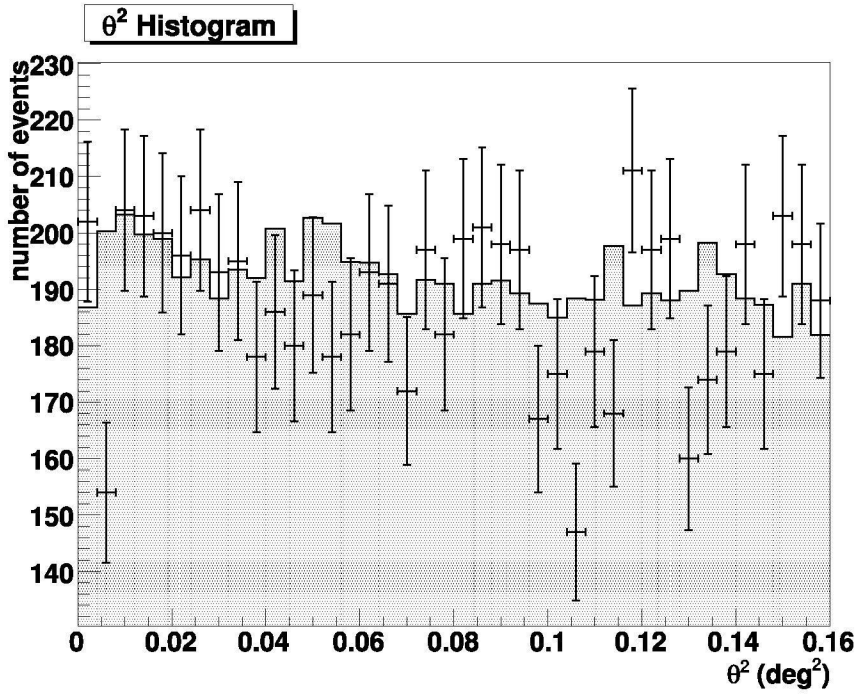

FIGURE 2. Comparison of ON and OFF source θ^2 distributions. Horizontal axis : θ^2 (deg). Vertical Axis: Number of Events per θ^2 bin.

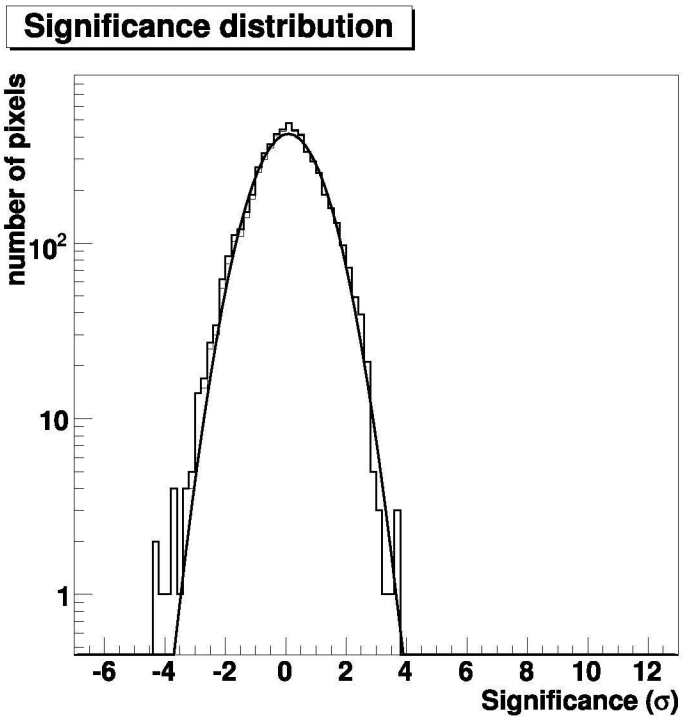

FIGURE 3. Histogram of the 2D plot (Figure 1) significance distributions. Horizontal Axis: Statistical Significance. Vertical Axis: Number of events. Solid Line : Simulated distribution for background events (no signal).

new VHE sources[1].

OBSERVATIONS AND DATA SELECTION

Between November and December 2007, the VERITAS Observatory performed multiple observations of the target region centered on the Geminga pulsar. After applying run quality selection criteria, which includes observing in high quality observing conditions (A or A-weather), a total of 10.4 hours of data was available for analysis. The average observation was performed at an elevation of 71.4°. All data was observed in wobble mode, with the direction to Geminga offset 0.5° from center of the field of view.

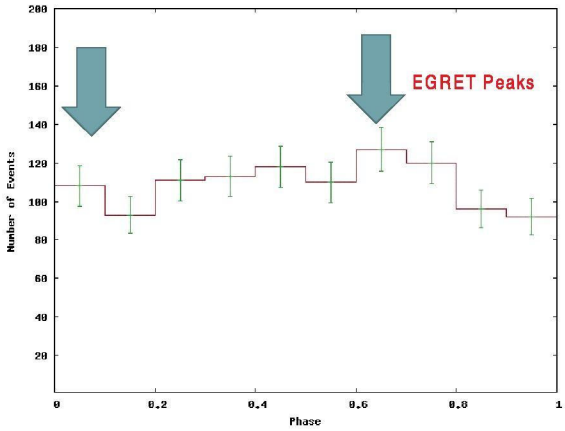

FIGURE 4. Histogram of the phase distributions of all the ON data. Horizontal Axis: Phase bin. Vertical Axis: Number of events. Blue Arrows: Peaks in the EGRET phase plot[4].

STEADY SOURCE ANALYSIS

After data selection cuts, we search for evidence of a steady source at or near the position of Geminga by comparing the number of counts in the putative source direction with the estimated background count rate. The background is estimated using a reflected region model. Figure 1 shows the resulting 2 dimensional significance plot about the direction of Geminga. Figure 2 compares the θ^2 distribution between the Geminga source direction and estimated background. Figure 3 compares a histogram of the significance distribution from the entire 2-D significance plot compared to the same distribution with the Geminga direction events removed. In all three plots it is clear that there is no evidence for a point source of >100 GeV γ-rays from the direction of Geminga.

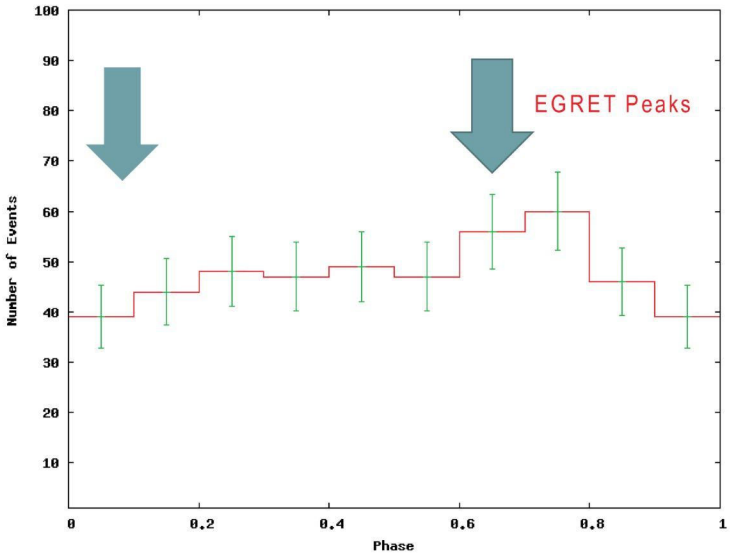

FIGURE 5. Histogram of the phase distributions of the events with an energy < 200 GeV Horizontal Axis: Phase bin. Vertical Axis: Number of events. Blue Arrows: Peaks in the EGRET phase plot[4].

PERIODICITY ANALYSIS

We search for evidence of periodically modulated emission with the 237 msec period by calculating the phase of emission for each event in the direction of Geminga using a recently updated Geminga X-ray ephemeris[17]. This ephemeris is based upon recent XMM observations as well as archival ASCA and EGRET data[6]. Figure 4 shows a histogram of the phase distribution for all events in the direction of Geminga; Figure 5 shows the subset of these events with energy < 200 GeV. There is no statistically significant evidence of pulsed emission in either analysis.

SUMMARY

During November/December 2007, the VERITAS Observatory has searched for evidence of unpulsed and pulsed emission from the direction of the Geminga pulsar. We do not observe any statistically significant evidence for either steady emission point source emission in the Geminga field of view, or for pulsed emission from a point source at the period of the Geminga pulsar (237 msec). The measured VHE γ-ray flux limits for the unpulsed search is $F_\gamma(> 300$ GeV , 99% c.l) $< 2 \times 10^{-8}$ m^{-2} s^{-1} $\simeq 9$ milliCrab. The searches for overall pulsed emission and also for low energy emission ($E_\gamma < 200GeV$) found no statistically significant excess in any bin of the phase plot. The γ-ray flux upper limits from the pulsed search is $F_\gamma(E < 200$ GeV and $E > 300GeV$, 99%c.l.) $< 0.8 - 1.0 \times 10^{-8}$ m^{-2} s^{-1} $\simeq$ 3-5 milliCrab.

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