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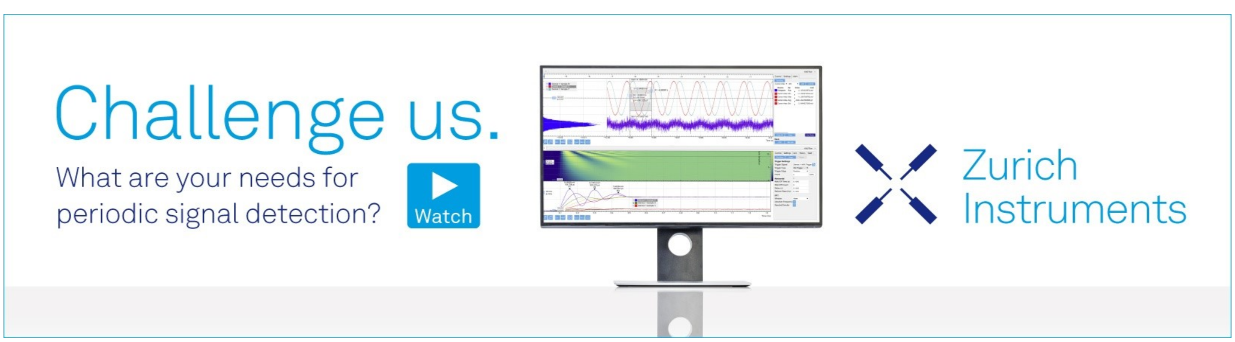

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VERITAS Observations of Pulsars

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Abstract. The EGRET detector on board the Compton Gamma-Ray Observatory detected pulsed emission from seven pulsars up to energies around 10 GeV. Despite numerous attempts, no pulsed emission has been observed by ground-based gamma-ray telescopes operating above $\sim$100 GeV. A pulsed emission cut-off necessarily lies between. Any detection of this cut-off has important implications for the models that attempt to explain pulsar emission. With the current generation of ground-based gamma-ray telescopes extending in energy below 100 GeV and with GLAST promising observations above 10 GeV, pulsars are promising targets for future gamma-ray observation. We discuss here the VERITAS program for pulsar observations, its progress to date, and methods to improve the sensitivity of VERITAS for gamma rays below 100 GeV.

Keywords: Pulsars, VERITAS, EGRET, GLAST, TeV, Cherenkov, Polar Cap, Outer Gap
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INTRODUCTION

Periodic emission from seven pulsars was observed by EGRET up to energies of about 10 GeV [1]. Despite numerous observations, no confirmed detections of these or any other pulsars have been reported in the TeV regime (>100 GeV).

The lack of observed pulsed emission from gamma-ray pulsars above 10 GeV can be attributed to two causes: (1) a cut-off in the pulsed emission spectra, between 10 GeV and 100 GeV and (2) poor detector sensitivity in the 1–100 GeV regime. While (1) is intrinsic to the pulsar emission mechanism, (2) will ultimately be overcome by GLAST and possibly by the sensitive ground-based stereoscopic imaging atmospheric Cherenkov telescopes, such as VERITAS.

Pulsar Emission Models

Non-thermal photon emission from pulsars is believed to arise in the conversion of the pulsar's rotational energy into photons. The rapidly rotating, magnetized neutron star can produce electric fields strong enough to pull charged particles from the stellar surface into the magnetosphere [2]. It is these charged particles that give rise to the observed non-thermal photons. Two main model types attempt to explain gamma-ray emission: the *Polar Cap* [3] and *Outer Gap* [4] models.

The Polar Cap models localize the emission site to a region close to the magnetic poles of the neutron star, where the magnetic field is strong. The Outer Gap models, on the other hand, contend that gamma-ray production occurs far from the neutron star surface in a region of relatively weak magnetic field, in so called "outer gaps" near the null surface of the outer magnetosphere.

The emission sites dictate the energy of the expected spectral cut-off, insofar as the maximum energy of the curvature-radiated photons escaping the magnetosphere is limited by pair-production in the pulsar's magnetic field. Since the magnetic field is stronger near the polar cap, Polar Cap models anticipate a lower-energy cut-off than Outer Gap models.

Any detection of TeV emission would clearly favor the Outer Gap model and would thereby significantly contribute to our understanding of pulsar emission processes. Thus far, no pulsed TeV emission has been detected from any pulsar, although ever-lower upper limits are now constraining Outer Gap models [5].

Isolated Pulsars

Seven rotation-powered isolated pulsars were detected by EGRET at high significance (Crab, Geminga, Vela, PSR B1951+32, PSR B1706-44, PSR B1055-52 and PSR B1509-58). Another four are considered possible detections, at low-significance (B0656+14, B0355+54, B0631+10 and B0144+59). The spectral energy distributions of the seven firmly-detected objects indicate that most power is emitted at X-ray and gamma-ray energies, with spectral turnovers observed in all but PSR B1951+32 and PSR B1055-52. Due to the lack of EGRET data above $\sim$10 GeV, the steepness of the spectral turnovers are undetermined—an important motivation for higher-energy observations.

Spun-up Millisecond Pulsars

Pulsed emission from two millisecond pulsars was marginally detected by EGRET (PSR J0218+4232, PSR B1821-24). Millisecond pulsars are believed to be old neutron stars in binary systems that are "spun-up" by

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FIGURE 1. The VERITAS telescope array at the basecamp of the Whipple Observatory, Arizona. Each telescope is 12 m in diameter and employs a 499-PMT camera. The telescopes are used to detect atmospheric Cherenkov light from gamma-ray air showers on clear moonless nights.

accreting matter from their companion stars. At TeV energies, millisecond pulsars are particularly interesting, in that their weak magnetic fields may allow photons of higher energy to escape than are possible from young pulsars with strong magnetic fields.

Nearby High-Spindown-Luminosity Pulsars

The H.E.S.S. collaboration have demonstrated that a large fraction of high-spindown-flux pulsars correlate with sources of unpulsed VHE gamma rays [6]. Using the catalog of VHE gamma-ray sources discovered in the H.E.S.S. Galactic plane survey, they have shown that 70% of the pulsars discovered by the Parkes Multibeam Pulsar Survey, with $\dot{E}/d^2 > 10^{35}$ erg s^{-1} kpc^{-2} and within the H.E.S.S. survey region, are coincident with H.E.S.S. sources. In the northern hemisphere, at least nine similar sources are visible to VERITAS, and are accordingly very interesting targets for observation.

VERITAS

The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is an array of sensitive Imaging Atmospheric Cherenkov (IAC) telescopes for the study of astrophysical gamma rays in the energy range 50 GeV to 50 TeV [7]. The VERITAS telescopes are located at the basecamp of the Whipple Observatory, near Mt. Hopkins in Southern Arizona (Figure 1).

The Imaging Atmospheric Cherenkov Technique

Using an IAC telescope, the Cherenkov light emitted by the secondary charged particles in gamma-ray and cosmic-ray initiated air showers may be imaged using a PMT-camera to obtain spatial, temporal, and calorimetric information regarding the instigating photon or particle (Figure 2).

Employing an array of IAC telescopes allows for improved background rejection (mainly muons and cosmic-ray air showers), provides for a lowering and extension of the detectable energy range, and yields superior energy and angular resolution when compared to a single telescope.

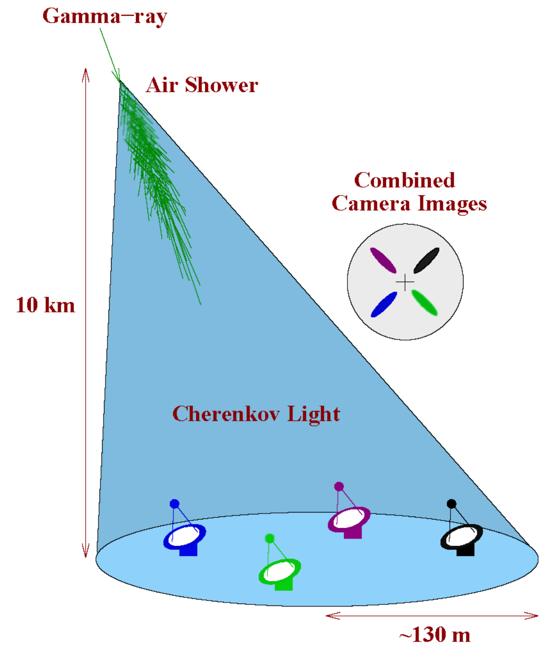

FIGURE 2. The Imaging Atmospheric Cherenkov Technique. When a gamma-ray is absorbed by the Earth's atmosphere it produces an electromagnetic particle cascade. This shower of relativistic particles is detectable from the ground by imaging the blue Cherenkov light emitted as the charged particles traverse the atmosphere.

PULSAR OBSERVATIONS AND ANALYSIS

Candidate pulsars for future observation by VERITAS include all those detected at high and low significance by EGRET, nearby high-spindown-luminosity pulsars, and any radio or X-ray pulsars that fall within the region of the VERITAS sky survey (52 $\leq$ l $\leq$ 82, -1 $\leq$ b $\leq$4).

Low-Energy Data

Due to the expected cut-off in the pulsed-emission spectra of pulsars in the 10-100 GeV range, the observation and analysis of VERITAS pulsar data must be optimized for low-energy gamma-ray showers. During the fall of 2007, various operating conditions for the observation of low-energy showers will be tested. Optimization of the standard VERITAS analysis tools for low-energy events is ongoing, making extensive use of the FADC data provided by each of the 499 pixels in the four VERITAS cameras [8].

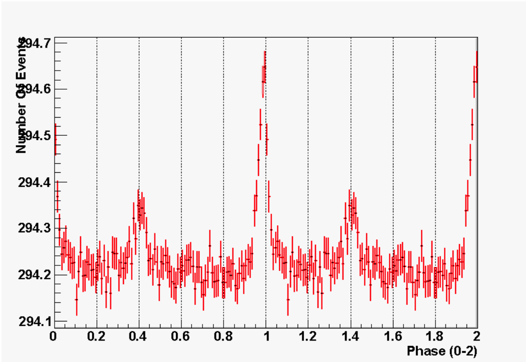

FIGURE 3. Phaseogram of the Crab optical pulsar as observed using the central PMT of a single VERITAS telescope.

Temporal Analysis

VERITAS employs five GPS clocks to stamp the arrival times of air-shower events recorded by the array. One clock is employed by each telescope and one by the central array trigger system. The clocks are accurate to 100 ns. To search for a periodic signal in a gamma-ray-selected data set, the registered time of each event is transformed to the solar system barycenter and folded using the pulsar's radio ephemeris.

The Crab Optical Pulsar

To test both the barycentering algorithm and the fidelity of the VERITAS timing electronics, an optical signal of the Crab pulsar, as seen using the central PMT of one telescope, operated in a single-photoelectron counting mode, was analyzed [9] . The resulting phaseogram (Figure 3) shows clear evidence for a pulsed optical signal phase-aligned with the Crab pulsar radio pulsations [10].

Search for the Crab Gamma-Ray Pulsar

Using 3.7 hours of Crab pulsar observations recorded by three VERITAS telescopes during the commissioning phase of the array in early 2007, an upper limit, F_{UL} (>200 GeV) = 8.17×10^{-12} photons cm^{-2} s^{-1}, was determined for the pulsed emission flux [9]. This result is presented in Figure 4, together with the EGRET data points and upper limits from other experiments.

FUTURE PLANS

VERITAS is complete and operational. Pulsars form a class of interesting objects for observation with VERITAS and efforts are underway to optimize the sensitivity of the array for energies below 100 GeV. Upper limits on the pulsed emission of the Crab pulsar have already been determined and are expected to be improved upon

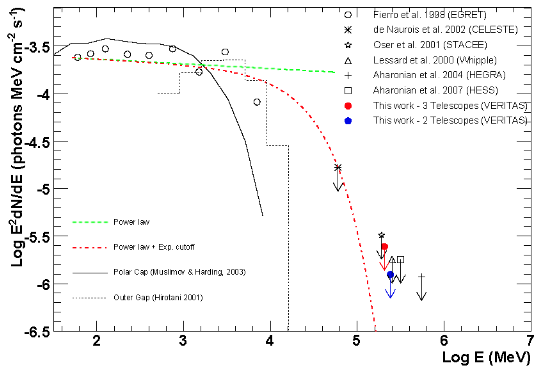

FIGURE 4. Pulsed photon spectrum of the Crab pulsar, showing the EGRET data points, recent VERITAS upper limits and upper limits from other experiments [9].

as more data is recorded and the array is optimized for pulsar observations.

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REFERENCES

1. Thompson, D. J., 2001, AIP Conference Series, 558, 103.
2. Goldreich, P., & Julian, W. H. 1969, ApJ, 157, 869.
3. Muslimov, A.G and Harding A.K., 2003, ApJ, 588, 430.
4. Hirotani, K. and Shibata S., 2001, MNRAS, 325, 1228.
5. Aharonian, F., et al., 2007, A&A, 466, 543
6. Carrigan et al., 2007 Proceedings of the 30th ICRC, Merida.
7. Weekes et al., 2002, Astroparticle Physics 17, 221-243.
8. Holder, J., et al., 2006, Astroparticle Physics, 25, 391
9. Celik et al., 2007, Proceedings of the 30th ICRC, Merida.
10. Lyne, Jordan and Roberts, http://www.jb.man.ac.uk/pulsar/crab.html.