VERITAS: Very Energetic Radiation Imaging Telescope Array System

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In this talk, I describe the VERITAS observatory, an array of seven 10m optical gamma ray Cerenkov telescopes to be constructed at the base of Mt. Hopkins, Arizona. We emphasize detection capabilities of the instrument and detail the science goals of the observatory. In particular, the small pixel size and multi-telescope event reconstruction provide substantial improvements in both gamma-ray astronomy and astro-particle physics capability.

1 Introduction

The field of high energy γ-ray astronomy has been made possible by the development of the ground-based atmospheric Cherenkov imaging and stereoscopic techniques. These techniques have provided discovery of radiation above 300 GeV from pulsar-powered nebulae, BL Lacertae-type active galactic nuclei (AGN), shell-type supernova remnants, and X-ray binary systems. The VERITAS observatory is a third-generation gamma-ray instrument, designed to provide a giant step forward in the study of extreme astrophysical environments and fundamental high energy physics phenomena.

2 Detector Description

The baseline VERITAS design[1] is a distributed array of seven air Cherenkov detectors arranged in a hexagonal layout, with 85m spacing between the telescopes (Figure 1). Each telescope uses a f/1.2 10 m diameter Cotton-Davies reflector and an optical camera of 499 photomultiplier tubes (PMTs) to view a 3.5 degree diameter of the night sky(Figure 2). Data from each PMT is readout using a 500 MHz Flash ADC (FADC) system of electronics located at the pedestal

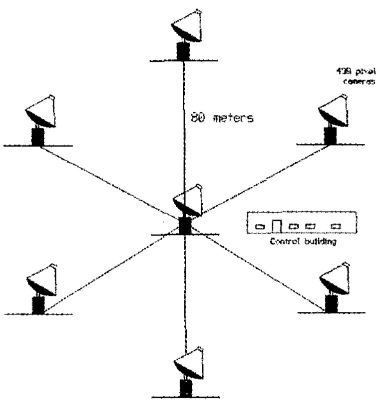

Figure 1: Layout of the array of Cerenkov Imaging Telescopes in VERITAS.

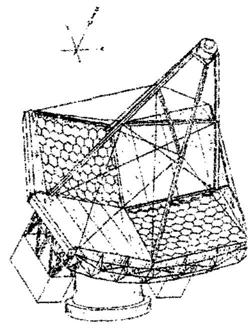

Figure 2: Engineering sketch of individual VERITAS telescope based upon conceptual design, with mirror covers retracted on upper left and lower right quadrants. (Sketch by T. Hoffman)

of each optical support structure. The VERITAS system will be built at the F.L. Whipple Observatory , near the base of Mt. Hopkins, Arizona, close to the site of the present Whipple Imaging Cerenkov Observatory. The VERITAS telescopes operate on dark, moonless nights, and can operate in a variety of observation modes.

2.1 Observation Modes

Independent (monocular) mode operation allows each telescope to track a different source in the sky, maximizing the celestial sky coverage. Array mode employs all seven telescopes to point to a single source in the sky, and triggers are formed by requiring coincident detection of the same gamma-ray induced Cherenkov image by two or more telescopes. Array mode has the advantage that multiple telescopes image the shower from different observation points, providing stereo or tri-ocular geometrical event reconstruction. Multiple telescopes can also provide multiple measurements of primary energy, and therefore allow measurements of joint distributions of the reconstructed energy. These distributions can be used to directly estimate the energy resolution of a single telescope. The array mode coincidence requirement also allows energy threshold of the telescopes to be reduced over what is achievable with a single (monocular) telescope, thereby improving the detection aperture at low energies.

Mixed mode consists of using some telescopes in an array mode with smaller numbers of telescopes in the arrays, and also some monocular (i.e., three telescopes observing one target and three observing another and a single monocular telescope observing a third source).

2.2 Detector Sensitivity

Table 1 details the expected VERITAS flux sensitivity, angular resolution, effective area, and energy resolution as a function of γ-ray energy. At 300 GeV, the minimum detectable flux sensitivity (assuming 50 hours of operation in array mode) is 5 millicrab, a factor of 20 improvement over the existing Whipple telescope. Figure 3 summarizes the point source integral sensitivities of the Whipple and VERITAS observatories, and several other ground based and satellite gamma-ray instruments. At the high energy end, VERITAS overlaps with the MILAGRO and Tibet AS air shower gamma-ray detectors. At the low energy range, VERITAS

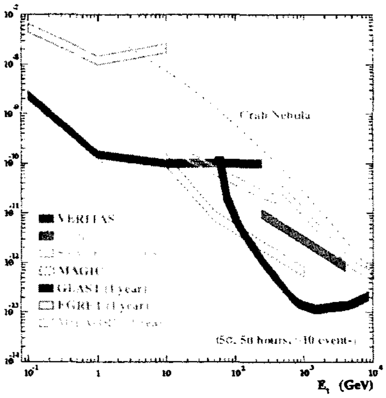

Figure 3: Comparison of the point source sensitivity of VERITAS to Whipple, CELESTE/STACEE, GLAST, EGRET and MILAGRO. The sensitivity of MAGIC is based upon the availibility of new technologies,e.g. high quantum efficiency PMTs, etc, that are not assumed in the other experiments. EGRET, GLAST and MILAGRO are wide field of view instruments and therefore ideally suited for all sky surveys.

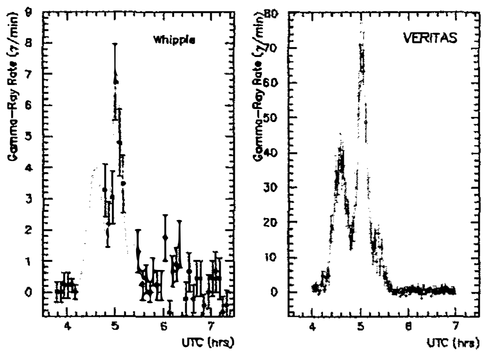

Figure 4: Left: Whipple Observations[1] of a rapid flare from Mkn 421 on 1996 May 15. The superimposed dashed curve is a possible intrinsic source variation that is consistent with the measured VHE gamma-ray flux. Right: Simulated reponse of VERITAS Array to such a flare above 200 GeV.

provides complementary information to the GLAST mission.

For example, the large VERITAS collection area enables measurements of extremely short variations in the γ-ray flux. This is illustrated by a comparison of measured[2] and simulated gamma-ray flares in Mkn 421 (Figure 4). While the flare is clearly seen by Whipple, the structure of the flare is not resolved. The dashed curve in the figure is a hypothetical flux variation that matches the Whipple data. The right part of Figure 4 shows a simulation of what VERITAS might detect above 200 GeV. All features of the flare are clearly resolved. Space-based telescopes do not have the collecting area to map out such low amplitude flares(GLAST would detect 3 photons above 1 GeV from a flare of this duration and power). The wide energy coverage of VERITAS will also allow spectral time variability to be resolved. Such detailed studies will provide conclusive information about the acceleration and flaring processes in the AGN jet, the location of the γ-ray emission, the jet characteristics, and even ambient photon levels and accretion rates for the central AGN.

3 Science Goals

It is anticipated that VERITAS will dramatically increase the catalog of very high energy (VHE, $E > 100$ GeV) sources, greatly improve measurements of already detected objects, and open up a vast range of physical and astrophysical problems for study. Among them are

- Physical mechanisms powering jets of active galactic nuclei
- Extragalactic background light (EBL) and nuclear synthesis in the Universe[3]
- Gamma-ray bursts energetic and origin
- Interaction of pulsars with plerionic nebulae and supernovae shells

Table 1: VERITAS Array Sensitivity. Flux sensitivity numbers assume 50 hours of observation.

Characteristic	Energy Range	Value
Flux Sensitivity	> 100 GeV	9.1×10^{-12} cm^{-2} s^{-1} = 15 mCrab
	> 300 GeV	8.0×10^{-13} cm^{-2} s^{-1} = 5 mCrab
	> 1 TeV	1.3×10^{-13} cm^{-2} s^{-1} = 7 mCrab
Angular resolution	50 GeV	0.14°
	100 GeV	0.09°
	300 GeV	0.05°
	1 TeV	0.03°
Effective Area	50 GeV	1.0×10^3 m^2
	100 GeV	1.0×10^4 m^2
	300 GeV	4.0×10^4 m^2
	1 TeV	1.0×10^5 m^2
Energy Resolution (ΔE/E)		< 15%

- Cosmic ray origin and propagation in the Galaxy
- Identification of the sources of γ-radiation detected by EGRET
- The nature of the dark matter
- Signatures of the quantum gravity effects on the propagation of VHE photons[4]
- Serendipitous discoveries of new phenomena in a new region of phase space (e.g. evaporation of black holes)[5].
- High Resolution charge measurements of PeV cosmic rays, and searches for trans-iron nuclei, magnetic monopoles and quark matter[6].

4 Status and Further Information

The VERITAS observatory was first proposed to Smithsonian in 1997, and DOE/NSF in 1999. Revised proposals, including detailed management plans and costs, were submitted to these agencies in January 2000. The VERITAS project has been thoroughly reviewed by the physics and astrophysics community, receiving strong endorsements from SAGENAP, the NAS Decadal survey, and from a DOE/NSF management review in April 2000. VERITAS has received initial funding from DOE and NSF in 2000, and full funding from PPARC and Enterprise Ireland. Additional details concerning the VERITAS science objectives, design parameters and capabilities can be found at the VERITAS website (http://veritas.sao.arizona.edu). The website also contains the full proposals submitted to DOE, NSF, and Smithsonian, as well as full listings of the collboration members and institutions.

References

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