First Results from VERITAS

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Outline of Presentation

- collaboration
- description of the detector
telescopes
readout
trigger
construction timeline
- 2006-2007 observations
  Crab
  Mrk431, Mrk501
  LSI+61 303
  1ES 1218
  M87
- near-term plans
  key science projects
VERITAS Collaboration
Four Countries, Six Funding Agencies,
Twenty Institutions, Eighty members

- Smithsonian Astrophysical Observatory *
- Adler Planetarium
- Purdue University *
- Barnard College, NY
- Iowa State University *
- DePauw University, IN
- Washington University, St. Louis *
- Grinnell College, IA
- University of Chicago *
- University of California, Santa Cruz

- University of Utah *
- University of Massachusetts
- University of California, Los Angeles *
- Cork Institute of Technology
- McGill University, Montreal *
- Galway-Mayo Institute of Technology
- National University of Ireland, Dublin *
- National University of Ireland, Galway
- University of Leeds *
- Argonne National Lab
- Associate Members

Project office: F.L. Whipple Observatory, SAO

Funding from
NSF/DOE/Smithsonian/PPARC/SFI/NSERC
VERITAS
Very Energetic Radiation Imaging Telescope Array System

four 12 m telescopes located at
Whipple Observatory Base Camp

Amado, Arizona

31° 40’ N, 110° 57’ W, 1268 masl
Each Telescope

Reflector
- 349 hexagonal facets
- spherical - 24 m radius
- Davies-Cotton mounting
- 12 m diameter
- 12 m focal length
- 110 m² area

Camera
- 499 29mm PMTs
- 0.15° separation
- 3.5° field-of-view
Trigger and Readout

- three-level trigger

1. constant fraction discriminator on each PMT

2. pattern trigger on every telescope
   (require hits on adjacent PMTs – typically 3)

3. array trigger (require 2 or more telescopes)

- 500 Mega-sample/s Flash ADC on every channel
VERITAS Construction History

Observations done with various combinations as they became possible
shower direction and shower core reconstruction

reconstructed shower direction

reconstructed shower core position

85 m
Four-telescope event inside the array
Four-telescope event outside the array
Core Reconstruction - 3 telescopes
Core Resolution: 68% Containment

The diagram shows the core resolution over distance for different configurations:
- 2-tel array (black dots)
- 3-tel array, 2-tel trigger (red squares)
- 3-tel array, 3-tel trigger (green triangles)
reflected region model

stay away from potential source region

fill all events from the three background regions into this bin

background region have same radial distance to camera center as source region

Crab run 31965, wobble offset 0.30
ring background model

fill all events from this ring into the bin (acceptance correction!)

Crab run 31965, wobble offset 0.30
Crab Nebula (test pattern)

January 2007
three-telescope data
wobble
76° elevation
28.1 σ
$\theta^2$ distributions:

measure the arrival direction of the candidate gamma ray

subtract the coordinates of the source being tracked

square the result $\rightarrow \theta^2$

cut and subtract background from the background regions to get signal

Crab data
Pointing Accuracy from Crab Nebula runs

scatter to be reduced with pointing monitors being installed on all telescopes

accuracy degrades as off-axis distance increases
Crab Nebula

30 $\sigma/\sqrt{\text{hour}}$
Growth of Crab Signal
VERITAS Performance

effective area: $10^4 - 10^5$ m$^2$

energy range: 80 GeV - 30 TeV

sensitivity: 10% of Crab Nebula Flux in under one hour (5σ)

angular resolution: $\sim 0.1^\circ - 0.2^\circ$ (68% containment - E dependent)

energy resolution: $\sim 15\%$
**AGN Observations:**

Markarian 421 and Markarian 501

Two telescopes: Spring, 2006

Mrk421: 7.2 hours
5.6 $\gamma$/minute

active state

Mrk501: 11.4 hours
0.8 $\gamma$/minute

good sensitivity to MrK501 in its quiescent state
1ES1218+30.4

2nd furthest VHE blazar (z = 0.182) detected by MAGIC

$E > 120$ GeV

8.2 hours

$6.4 \sigma$

VERITAS detection:

observations Dec 06 - Mar 07

2 or 3 telescopes

0.5° wobble

17.4 hours after quality cuts

$10.2 \sigma$

$0.3 +/- 0.05 \gamma/\text{minute}$
VERITAS light curve: no evidence for time variability but statistics are limited

counts per minute averaged over the run (not corrected for elevation angle)

counts per minute daily average

statistical errors only
M87

- giant (elliptical) radio galaxy
- only non-blazar extragalactic VHE source
- 16 Mpc distant - near centre of Virgo cluster
  - also called Virgo A
  - powerful radio source
- core has an AGN with $3.2 \times 10^9 M_\odot$ black hole
- like a BL Lac, but jet does not point at us
  - jet seen in radio, optical and X-rays with similar morphologies
  - probably synchrotron radiation $\rightarrow$ IC can give VHE $\gamma$
  - HST says jet angle is $<19^\circ$ (superluminal motion)
- previous detections:
  HEGRA 4.1 $\sigma$ (1998-1999)
  HESS 13 $\sigma$ (2003-2006) variable on different time scales
VERITAS observations of M87

51 hours, Feb - Apr 2007
(90% pass quality cuts)
55° - 71° elevation
wobble mode 0.5°
3 telescopes

263 events above background → 5.1 σ
threshold energy = 250 GeV
point-like: < 2.3 arc-min radius (ie PSF)
M87 light curve

no statistically significant variability observed

NB: HESS detected day-scale variability during M87 high state in 2005
LSI+61 303

- high mass X-ray binary (HMXB)
- one of three detected in TeV γ rays (HESS detected PSR B1259-63 and LS5039)
- massive Be star with dense circumstellar disk
- orbiting a neutron star or black hole
- period = 26.5 days (very similar to lunar cycle - see later)
- close orbit only a few stellar radii separation
- phases (radio defines phase = 0)
  - periastron 0.23
  - apastron 0.73
  - inferior conjunction 0.26
  - superior conjunction 0.16
- phase-dependent variable emission seen at all wavelengths

**MAGIC detection**: 54 h, 9.0σ, E>200 GeV
particle acceleration in both models - VHE $\gamma$ rays produced by
- inverse-Compton scattering with electrons and stellar photons and/or
- hadronic production of $\pi^0$s from proton collisions
VERITAS observations of LSI +61 303

Sep - Nov 2006  2 telescopes  32 hours  0.3° wobble
  sensitivity: 5 σ in 3.3 h for 10% of a Crab-like source at 70°

Jan - Feb 2007  3 telescopes  12 hours  0.5° wobble
  sensitivity: 5 σ in 1.2 h for 10% of a Crab-like source at 70°

raw rates vs phase

no data while moon is up

no detection in February but limited observing/statistics
Flux < 3% of Crab in low-flux phase bins,
Flux > 10% of Crab in high-flux phase bin

Period of 26.49 days has 99.94% probability
Can we resolve the source?

$\theta^2$ distribution for high-flux phase bin (0.6 - 0.7) is well fit by Monte Carlo assuming a point source.

2D sky maps are consistent with point-spread function.

2-telescope data

$0.5 < \psi < 0.8$ (25 h)

$0.8 < \psi < 0.5$ (19 h)
preliminary energy spectrum
Crab-like but 10%
consistent with MAGIC
More Results

results on other topics/sources will be given at the
International Cosmic Ray Conference

Merida, Mexico

July 3 – 11, 2007
Future Plans

near term (first two years):
  4 key science projects (50%)
    - sky survey (Cygnus) 130 hours/year
    - active galactic nuclei 110
    - supernova remnants 100
    - dark matter 60

  proposed observations (40%)
    - time allocation committee

director's discretionary time (10%)
  - targets of opportunity
  - engineering

longer term:
  stay at present site to at least end of 2010