Results from VERITAS

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for the VERITAS Collaboration

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VERITAS Status: Complete!

- Smithsonian Astrophysical Observatory
- Purdue University
- Iowa State University
- Washington University in St. Louis
- University of Chicago
- University of Utah
- University of California, Los Angeles
- McGill University, Montreal
- University College Dublin
- University of Leeds
- Adler Planetarium
- Argonne National Laboratory
- Barnard College
- dePauw University
- Bartol Research Institute/ University of Delaware
- Grinnell College
- University of California, Santa Cruz
- University of Iowa
- University of Massachusetts
- Cork Institute of Technology
- Galway Mayo Institute of Technology
- National University of Ireland Galway

~25 Associate Members
Outline

Introduction to VERITAS
- Technique
- Instrument
  - Design
  - Performance, recent operations
- Science Overview

Highlight results
Summary and future prospects
Cherenkov Telescope Arrays

IACT, ~50GeV-50TeV

Core Reconstruction (< 15m)
Energy reconstruction

Stereoscopic viewing

Direction Reconstruction (<0.1°)
Telescope and Camera

- 3.5° FOV
- 499 PMT camera
- 0.15° pixel
- 500 MS/s FADCs
- 3-tier trigger system
**VERITAS at Whipple Observatory**

**Data, October 2007-June 2008:**
- Good weather, 4-telescopes
  ~700 hours
- Moonlight ~100hrs

**Fall 2006**
- FLWO, Mt. Hopkins, Az
  (1268 m asl)

**Specifications:**
- Angular resolution ~ 0.1°
- Energy resolution ~ 15-20 %

**Sensitivity:**
- 1% Crab @ 5 $\sigma$ ~ 47 hrs
- 5% Crab @ 5 $\sigma$ ~ 2.5 hrs

**Since March 2006**

April 2007

T2

T3

T4

T1

85 m

82 m

35 m

109 m
VERITAS Science Program

Supernova Remnants

Pulsars/PWN

SNR/PWN Key Science Project

Cygnus Region Sky Survey (forthcoming)

Dark accelerators…

HMXBs (microquasars)

(targeted observations)

Active Galactic Nuclei

Blazar Key Science Project

Non-blazar AGN

Extragalactic non-blazars (non-blazar AGN, Auger hotspots, galaxy clusters …)

Indirect Dark Matter Searches (KSP)

Gamma-Ray Bursts

A. Weinstein  14 Aug 2008– SSI
Discoveries (Mar 2008):
• 1ES0806+524 (blazar)
• W Comae (first IBL!)

Detections (Jan-Jul 2008):
• 1ES2344+514 (blazar, TeV flare correlated with X-ray)
• Supernova remnant Cas A
• MGRO J1908+06 (unidentified)

Updates:
• M87, Mrk 421 MWL campaigns
• 1ES1218+304 de-absorbed spectra
• IC443, measurement of source extension

Upper limits & constraints:
Auger hotspots, dark matter, AGILE 2021+4024

2007 observations:

Detections (Jul 2007):
• 1ES1218+304 (distant VHE blazar)
• M87 (non-blazar AGN)

First light! (April 2007)

Co-discovery (April 2007):
• SNR IC443

Comissioning period (2006-early 2007, 2 and 3-tel):
• XRB LSI+61 303: confirmed γ-ray variability

Blazars Mrk421, Mrk501

Crab Nebula
Extragalactic Science: AGN

- Acceleration mechanisms, source, mechanism of $\gamma$-ray emission
  - MWL Spectra, variability timescales
- Can be used to probe properties of universe at large distance scales (EBL)
- AGN observed in VHE $\gamma$-rays are mostly
  - Blazars (jets aligned with line of sight)
  - nearby ($z < 0.35$)
  - HBL

Variable emission

Accretion Disk

Active Galactic Nucleus

SSC

Catanese 1999

Mrk501

A. Weinstein 14 Aug 2008 – SSI
AGN and VERITAS

Recent discoveries
- **W Comae**
- **1ES 0806**

Non-blazars:
- **M87**

Multiwavelength studies
- **1ES 2344+514**
- **Mrk421**

EBL (distant blazars)
- **1ES 1218+304**
Highlight: W Comae

- First IBL detected at TeV energies
- 2 sources in one field!
- VERITAS discovery: (ref: ATeI #1422)
  - Triggered SWIFT follow-up observations
  - 4.9σ, ~40 hrs
  - ~6σ over 4 nights of flare

Later, stronger flare: (ref: ATeI #1565)
- Moonlight observations
- Analysis forthcoming
Highlight: W Comae

- Spectrum (2 peak nights):
  \[ \Gamma = 3.81 \pm 0.35\text{(stat)} \pm 0.34\text{(sys)} \]

- Flaring flux \(\sim 9\%\) Crab Nebula above 200 GeV

**Models**

- **Single-Zone**
  - Requires very small magnetic field (0.007 G) due to wide separation of peaks

- **External Compton**
  - Allows more natural parameters
  - Magnetic field 0.3 G

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EGRET spectrum hard (up to 25 GeV with no cutoff)

GLAST coverage important here
Highlight: 1ES1218+304

- EBL
  - IR photons, trace history of star formation
- 1ES1218:
  - Distant blazar (z=0.182)
- VERITAS:
  - ~17hrs, 10.4σ
  - I(E>200 GeV): ~6% Crab Nebula flux
- Use EBL lower limits (galaxy counts), variety of EBL scenarios → deabsorbed spectra
  - Considered alone: softest Γ=2.32±0.37
  - Combined with other distant blazars:
    - Range of values still consistent with shock acceleration
Highlight: M87

- Giant radio galaxy
  - 16 Mpc away (center of Virgo Cluster)
  - jet misaligned
  - jet resolved in radio, optical and X-rays (similar morphologies)
    - Unique laboratory
- only extragalactic non-blazar object seen in VHE γ-rays
  - HEGRA 4.1 σ (1998-1999)
  - confirmed by HESS, VERITAS, MAGIC
    - Day-scale variability
    - Subject of joint campaign in 2008 (VERITAS, MAGIC, HESS)
Light Curves

- TeV
- Core
- HST-1

Elevated over long period
Light Curves

2 flares within 1 week (MAGIC trigger, then VERITAS)

Further observations/campaigns required
**VERITAS: Indirect Dark Matter**

- **Component 1: Self-annihilating WIMP**
  - $\chi\chi \rightarrow \gamma\gamma$ (or $\chi\chi \rightarrow \gamma Z$)

- **Component 2: Clumpy dark matter**
  - Monoenergetic

- **VERITAS Strategy**
  - **e.g.** SUSY Neutralino ($\chi$)
    - TeV instruments sensitive above 100 GeV
  - **Observe galaxies with**
    - Favorable DM distributions
    - Absence of conventional TeV emission
    - Large mass-to-light ratio
  - Dwarf galaxies, galaxies with enhanced central DM content

Simulated gamma-ray signature in galaxy

Taylor & Babul (2005)
VERITAS: Dark Matter KSP

\[ \langle \sigma v \rangle : \]
Thermal average of product
\( \sigma \): WIMP self annihilation x-sec
\( v \): WIMP velocity

Recent VERITAS observations:
Draco, Ursa Minor, Willman I

Minimal Supersymmetric extensions to Standard Model (MSSM) allowed by WMAP
Galactic Science

MGRO J1908+06

IC443

Galactic sources under discussion…
IC 443

- SNR/molecular cloud interaction, PWN
- Co-discovered (MAGIC/VERITAS) in TeV in 2007
- Observed (wobble, 0.5° offset) during two epochs, for 37.1 hrs total livetime:
  - Feb / Mar 2007 with 3 telescopes, PWN location
  - Oct / Nov 2007 with 4 telescopes
    - Center of Feb/Mar hot spot:
      - 06 16.9 +22 33
- 8.2σ peak significance pre-trials
- 2-D Gaussian profile fit
  - Centroid: 06 16.9 +22 32.4 ± 0.03°(stat) ± 0.07°(syst)
  - Extension: σ ~ 0.17° ± 0.02°(stat) ± 0.04°(syst)
IC 443

- Centroid located at $06\ 16.9 + 22\ 32.4$ consistent with MAGIC
- Overlap with CO indicating molecular cloud along line of sight
- Maser emission suggests SNR shock interacting with cloud
- TeV emission could be
  - CR-induced pion production in cloud\(^{(1,2)}\)
  - associated with the pulsar wind nebula to the south\(^{(3)}\)

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\(3\) Bartko, H. and Bednarek, W. arXiv:0712.2964.
Partial survey of Cygnus region

-1 < b < 4 and 67 < l < 82

2 year program

- Started late April 2007
- 3 and 4-telescope data
- Final pointings will be completed this fall
- High probability of extended sources

MGRO J1908+06/HESS J1908+063

- Under aegis of sky survey
- ~22h of 4-telescope data
- 4.85σ detection
- ~0.2° extension
- position in agreement with HESS J1908+063
Summary

- Excellent first full year of VERITAS observations
- Some highlights:
  - **Blazar KSP**
    - Discovery of two new blazars including the first IBL
    - Detailed multi-wavelength observations, long-term light curves contribute to understanding of emission mechanisms
    - EBL upper limits to calculate deabsorbed Blazar spectra
  - **Extragalactic non-blazars: M87**
  - **SNR/PWN KSP: IC443, Cas A**
  - **LSI+61 303**
  - **Sky Survey KSP**
    - Much learned from studies of MGRO J1908+06
    - Full results to come
- More to come!