Outline of Presentation

- introduction to VERITAS
  science motivations
  historical and technical developments
- present status and recent results
- near-term future
- longer-term opportunities
Science Topics

Galactic sources
- Supernova Remnants (SNRs)
  - source of cosmic rays (with E < 10^{15} \text{ eV})?
- Pulsar Wind Nebulae (PWNe)
- Binary Systems
- Primordial Black Holes (PBH)
- Cosmic-ray electrons (dark matter or pulsars?)

Dwarf Spheroidal Galaxies
- clean targets for WIMP annihilation searches
- more candidates being discovered thanks to SDSS

Active Galactic Nuclei (AGNs)
- how do they work?
  - what is accelerated? protons or electrons?
  (implications for Auger, IceCube, Antares)
- located at cosmological distances
  - fast flares probe quantum gravity
  - spectral distortions probe extragalactic radiation
VERITAS

four 12-m atmospheric Cherenkov telescopes
1.3 km altitude in southern Arizona
Construction 2003-2007
Full operation from September 2007
~ 100 collaborators at 22 institutions
   15 - USA
   4 - Ireland
   2 - Germany
   1 - Canada
Nominal cost - $20M
VERITAS: some details

the array comprises four 12 m diameter telescopes

each has 350 mirror facets
made from glass surfaced with anodized aluminum

they are mounted on a steel frame to make a Davies-Cotton reflector with a 12 m focal length and a point-spread function with a width of 0.07°

A 'camera' at the focal point is made from 499 30-mm PMTs which are read out by 500 MHz FADCs
McGill Contributions to VERITAS

Mirror Mounts

Trigger Electronics

UV-LED Calibration System
McGill Contributions to VERITAS

Mirror Alignment Tool
McGill Contributions to VERITAS

Mirror Reflectivity Measurement

- T2 Red Filter: $\chi^2 / n \approx 1147 / 7$
  - $p_0 = 75.29 \pm 0.0688$
  - $p_1 = -0.02731 \pm 0.000303$

- T2 Green Filter: $\chi^2 / n \approx 1407 / 7$
  - $p_0 = 82.71 \pm 0.0381$
  - $p_1 = -0.03103 \pm 0.000382$

- T2 Blue Filter: $\chi^2 / n \approx 1257 / 7$
  - $p_0 = 85.39 \pm 0.0589$
  - $p_1 = -0.03369 \pm 0.000893$
McGill Contributions to VERITAS

People!

VERITAS is ~2x smaller collaboration than HESS or MAGIC

McGill is one of the larger teams

Excellent opportunities for HQP training

- no lack of good students

- healthy flow into and out of traditional HEP

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## NSERC Support

### Project Grants

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### Equipment Grants

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Recent Developments

2012 Upgrade

- replaced all PMTs with Hamamatsu Super-Bialkali (QE ~ 35%)
- factor 1.5 in effective mirror area
- installed flexible, faster FPGA-based second-level trigger

VERITAS is the most sensitive VHE detector in the world
Evolution of TeV catalog

(see tevcat.uchicago.edu
Scott Wakely, Deirdre Horan)

1996
3 sources

2002
12 sources
(galactic continuum sky map from EGRET)

2008
72 sources
(galactic continuum sky map from Fermi)
Evolution of TeV catalog
(see tevcat.uchicago.edu
Scott Wakely, Deirdre Horan)

2015 (February)
156 sources
Kifune Plot - VERITAS

Andy Smith (Utah)
Detection of Crab Pulsar above 100 GeV

Crab Pulsar

remnant of supernova in 1054

seen at all wavelengths

most energetic pulsar

$4.6 \times 10^{38}$ erg s$^{-1}$

one of the brightest in gamma rays

Fermi-LAT energy spectrum suggests that there are few gamma rays above $\sim 10$ GeV

(all Fermi-detected pulsars exhibit this feature)
VERITAS

Detection of Crab Pulsar above 100 GeV

VERITAS data:

- 2007-2009: 45 hours
- 2010: 62 hours
- 4 telescopes
- Zenith angle < 25°

VERITAS analysis:

- Two independent analysis packages
- Analysis optimized for weak, soft source
  - Few-percent Crab flux
  - Power-law with index -4
- Analysis threshold: 120 GeV

Significance ~ 6σ
energy spectrum (combine P1 and P2)

- no exponential cutoff - power law with $\Gamma = -3.8 \pm 0.5 \pm 0.3$
- non-zero flux above 100 GeV (1% of Nebula at 150 GeV)
- curvature radiation cannot be the dominant mechanism
- the paradigm is shifting - stay tuned
The Competition

**MAGIC-II (Canaries)**
- two 17-m reflectors

**HESS-II (Namibia)**
- four 12-m reflectors
- 30 m reflector now in operation
- Lower threshold to 20 GeV?
Fermi Space Telescope

- on orbit since 2008
- still running perfectly (lifetime is dollar limited)
- great signal-to-noise (anti-coincidence detector to veto charged particles)
- excellent duty factor - always on
- superb acceptance - Fermi scans the entire sky in 3 orbits

But

- limited collection area (order 1 m²) - need long integration times for faint sources (poor sensitivity to transients)
- limited angular resolution (especially at low energies) due to multiple scattering of e⁺e⁻
- useful to VERITAS as a pathfinder
  - flares
  - hard-spectrum sources
HAWC (High Altitude Water Cherenkov observatory) - a new pathfinder at TeV energies

new detector in Mexico (Sierra Negra 4100 m)

signal comes from shower particles generating Cherenkov light in 300 large water tanks

large field-of-view (15% of sky)

no pointing

100% duty cycle

recently (2015) completed and now fully operational

less sensitivity than VERITAS but good for unbiased surveys and as a pathfinder
CTA - the far future

- VHE gamma-ray astronomy has a well-defined and promising near-term future with VERITAS, MAGIC and H.E.S.S.

- the next-generation instrument is already in the design phase

- Cherenkov Telescope Array (CTA)

see www.cta-observatory.org for details
Future Plans

- application to NSERC for three-year project grant 2016-19
- continued exploitation of VERITAS for the next three years
  - Fermi and HAWC will strengthen search and measurement programs
  - VERITAS is mature and understood - more difficult and longer-term studies can be carried out
    - CR electrons
    - LIV with Crab pulsar
- ramp-down after three years
  - migration of groups and funding to CTA
    (DOE already leaving gamma-rays, NSF and SAO still on board but resources need to be shifted)
- McGill group has no plans to join CTA
Summary:

- VERITAS is going strong
  - a good investment of time and resources
  - excellent HQP opportunities

- Canadian contributions are significant and recognized

- near-term future (3 years): continued success

- longer term prospects
  - ramp-down VERITAS and engage in new projects
  - finish in-progress analyses and theses