A remote Proposal System for VERITAS (VERPs) & Search for off-pulse emission from SNR CTA1 with Fermi

Outline:
- The VERITAS instrument
- VERPs
- Pulsars and their nebulae
- Search for off-pulse emission from SNR CTA1
The Cosmic Ray Mystery

Cosmic rays were discovered almost 100 years ago...

- Well measured composition
  - Mostly nuclei p, HE, ... Fe (99%)
  - Also e±
  - Few γ’s, ν’s

- Well measured spectrum
  - dN/dE ~ E^{-α}, Non-thermal

- Isotropic distribution

- What is their origin? Which sources produce them? From 100 GeV to 100 TeV are thought to be of Galactic origin

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Locating Cosmic Ray Sources

- Galactic CR sources located through study of γ ray photons

- Hadronic process: CR with ambient matter
  - $p + p \rightarrow \pi^0 + ... + \pi^\pm$
  - $\rightarrow \gamma + \gamma$ with $E_\gamma \sim 0.1 E_p$

- γ rays also produced by inverse Compton scattering of relativistic electrons
Potential Sources

- Sites in which particles are accelerated up to 100 TeV (10^{15} \text{ eV})
- Proposed sites include most extreme spots in our Galaxy, huge densities, law of physics probed under unprecedented conditions

- Supernova Remnants (SNRs)
- Pulsars & their nebulae (PWNe)
- Binary Systems
- Star Forming Regions
- Starburst Galaxies (extragalactic)
VERITAS: VHE photons (> 100 GeV)

**Design & Observations**
- Amado, Arizona
- Four 12-m IACTs, 3.5° FOV
- Fully operational since Fall 2007
- >1100 hrs/yr (>200 hrs/yr moon)

**Performance**
- Energy Range: 100 GeV - 30 TeV
- Energy Resolution: 15%-25%
- Angular Resolution: $\theta_{68} < 0.1°$

86 Scientists:
22 Institutions in 5 countries: US, Canada, UK, Ireland, Germany

Support from:
DOE, NSF, SAO (U.S.), STFC (U.K.), NSERC (Canada), SFI (Ireland)
The Imaging Air Cherenkov Technique

- Intensity
- Energy of coincident photon
- Image Axis
- Direction of shower
- Image Shape
- Hadron vs. Photon

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The Imaging Air Cherenkov Technique

Improvements

- Angular resolution
- Energy resolution
- Background rejection
- Sensitivity

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Technical work: VERPs

VERPS = VERITAS Remote Proposal System

- **Proposal Submission**: Every summer (around end of August) all VERITAS members submit proposals for observations to the Time Allocation Committee, who evaluates them and plans the observation for the next season.

  Motivation for building VERPs: Organizing the proposal submissions is time consuming and tedious.

- **Technical details**: I used PHP, JavaScript (jQuery), MySQL, HTML -more than 3000 lines of code.
Technical work: VERPs

The VERITAS
Remote Proposal System

Call for proposals 2011-2012

General Instructions

Deadline: 29 August 2011 at 4pm MST

If you have any comments, email me:
ajl2174 at columbia.edu

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Technical work: VERPs

The VERITAS Remote Proposal System

Call for proposals 2011-2012

General Instructions
Deadline: 29 August 2011 at 4pm MST

Cover
Target Form
Science Proposal
Technical work: VERPs

General Instructions
Deadline: 29 August 2011 at 4pm MST

Proposal id: 
PI last name: 

submit  Back
Technical work: VERPs

Science Working Group

Title: Origin of Cosmic Rays
Abstract: The final answer.

Principal Investigator

First Name: Andrew
Last Name: Please enter a valid last name
Email: Please enter a valid email
University: Please enter a valid university

No. of CoPIs:

Joint with Fermi?
- yes
- no

Who will analyze data & when:

Multiwavelength requirement:
- yes
- no

Thesis:
- yes
- no

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Technical work: VERPs

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<td>Minimum Exposure (hours)</td>
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Observation Mode

- Wobble

- 0.5 0.6 0.7 Other

- No. Tels ≥1 ≥2 ≥3 ≥4

- Moonlight Yes No

- Weather ≥A ≥B ≥C ≥D

Observable from: ___________________________ to ___________________________

Comments:

Please enter a when it is observable from to

TeVCat Visibility

Clear Validate

Add

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Technical work: VERPs

- The idea was presented in the Summer Collaboration Meeting in Montreal.

- Beta Test
  - For almost a week over 10 members of VERITAS tested VERPS and gave their comments and recommendations.
  - done! (Just finished Monday)

- approved for use this round of proposals.

- Final Step
  - update and finalize proposal.

- developed a useful tool for the VERITAS Collaboration, and in doing that I have learnt to write code in various languages, learnt to debug programs, etc.

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Pulsar: What are they?

- First observed on November 28, 1967 by Jocelyn Bell Burnell and Antony Hewish
- CP1919 emits radio wavelengths
- Others emit visible light, X-rays, and/or gamma ray
- Contraction of "pulsating star"
- Rapidly rotating magnetized neutron star
- "Lighthouse" beam
- Periods vary between milliseconds (millisecond pulsars) and has much as eight seconds (normal pulsars)
Unipolar Induction: Faraday disk
- Disk perpendicular to magnetic field
- One electrical contact on axle, one on rim of disk
- $\mathbf{v \times B}$ => magnetic force outwards
- Therefore electric circuit complete

• Pulsar Model
Pulsar: P and Pdot

With P and Pdot can estimate: pulsar age, magnetic field strength, spin-down power.

\[ E_{\text{rot}} = \frac{1}{2}I\dot{\Omega}^2 = \frac{2\pi^2 I}{P^2} \]

\[ \frac{dE_{\text{rot}}}{dt} = \frac{d}{dt} \left( \frac{1}{2}I\dot{\Omega}^2 \right) = I\dot{\Omega} \dot{\Omega} \]

\[ \Omega = \frac{2\pi}{P} \quad \text{so} \quad \dot{\Omega} = 2\pi(-P^{-2}\dot{P}) \]

\[ \frac{dE_{\text{rot}}}{dt} = I\dot{\Omega} \dot{\Omega} = \frac{2\pi}{P} 2\pi(-\dot{P}) = -\frac{4\pi^2 IP}{P^3} \]

\[ \dot{E} = I\omega \dot{\omega} = 4\pi^2 IP / P^3 \]

\[ \tau \equiv \frac{P}{2\dot{P}} \]

\[ p^2 - p_0^2 = \dot{P} \tau \]

Pulsar age:

\[ B^2 = \frac{3c^3 I P \dot{P}}{8\pi^2 R^6 \sin^2 \alpha} \]

Magnetic field strength:

\[ P_{\text{rad}} = -\frac{dE_{\text{rot}}}{dt} \]

\[ \frac{2}{3c^3} (BR^3 \sin \alpha)^2 \left( \frac{4\pi^2 I}{P^2} \right)^2 = \frac{4\pi^2 IP}{P^3} \]

\[ B = \left( \frac{3c^3 I P \dot{P}}{8\pi^2 R^6} \right)^{1/2} (\dot{P})^{1/2} \]

\[ \left( \frac{B}{\text{Gauss}} \right) > 3.2 \times 10^{19} \left( \frac{PP}{s} \right)^{1/2} \]

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Pulsar: P and Pdot

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small fraction (<10% for young Pulsar) of $E_{\text{dot}}$ converted into observable pulsed emission
- most energy leaves in form of magnetized winds (electrons & positrons)
- A shock is formed when the ground pressure of the wind is balanced by the internal pressure of the nebula being formed
- particles accelerated in the shock and their pitch angles randomized
- nebula produces synchrotron and IC radiation seen in all wavelengths
Measuring the IC Component in PWNe

• Objective:
  - Measure IC component of VERITAS-detected PWNe

• Method:
  - upper end: VHE instruments (IACTs)
  - lower end: HE instruments (e.g. Fermi)

• Drawback:
  - Pulsar component of spectrum stronger than PWNe (with Fermi)

• We measure the off-pulse emissions

• How?
• Use Fermi analysis data and tools
  1. Timing analysis
  2. Calculate phase by barycentering photons
  3. Determine where is the off-pulse emission
  4. By eye
  5. More sophisticated methods
  6. Calculate how significant is the off-pulse emission
  7. If the spectrum has a large slope, this implies that the emission is from the magnetosphere (i.e. the Pulsar) and not the PWNe.
What is Fermi?

- Space observatory
- low-orbit (period = 95 min)
- “rocking zenith”
- covers whole night sky every three hours
- Two parts
  - LAT.
  - GBM
- HE gamma-rays (100 MeV – 100 GeV)
- Continues research from EGRET
- launched in 11 June 2008
- joint venture of NASA, US, France
  Germany, Italy, Japan, Sweden
chose to work with CTA 1
Recently discovered so Ester and Reshmi currently working on it
First look at CTA 1: Light Curves

Crab

Eh...maybe?

CTA 1

Something went wrong...
Obstacles and Summary

- Urgency and amount of time needed on the VERPs (Plan to use in August)
- Beta Test => fix lots of code
- Update in Fermi software during this past week
- Lesson Learned: don’t do make updates last minute/don’t do things last minute period!
- Hopefully continue search for off-pulse emission!
Acknowledgements

- Reshmi Mukherjee
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- Ester Aliu