Implementation of a Time Dependent Analysis Technique for Use in Gamma Ray Astronomy

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VERITAS
Columbia University
Overview

- Gamma ray astronomy
- VERITAS
- Statistical analysis techniques
- Swift J164449.3+573451
- Results
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**Cosmic Rays**

- High energy charged particles
- Scattered by magnetic fields in space
Cosmic Ray and Gamma Ray Sources

- **Non-thermal sources:**
  - Supernova remnants (SNR)
  - Active galactic nuclei (AGN)
  - Gamma ray bursts (GRB)
  - Dark matter searches
  - Unidentified sources

- **Production techniques:**
  - Hadronic collisions
  - Inverse Compton scattering
  - Synchrotron
Tidal Disruption Event

- Star orbiting black hole pulled apart by gravity
- Accretion disk forms from stellar matter
- Relativistic jet might produce gamma rays
Orbital Observation

- Detects gamma rays using pair production
- Detect sources in High Energy range (HE), 30MeV-100GeV
- Wide field of view, small effective area (1m²)

Fermi Large Area Telescope (LAT)
Ground Observation: Particle Showers

- Gamma rays interact in upper atmosphere
- Causes more interactions and decays
- Charged particles emit Cherenkov light
- Light pool ~250m diameter on ground
Ground Observation

- Imaging Air Cherenkov Telescopes (IACT)
- 3.5° field of view
- Large effective area (100,000 m²)
- Detects in very high energy range (VHE), >100GeV

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VERITAS Telescopes

- 3rd generation IACT
- Array of 4 telescopes- stereo imaging
- 350 hexagonal mirrors- array of 499 circular PMTs
- Sensitive from 100 GeV to >30TeV (complementing Fermi LAT)
Muon Ring

Cosmic Ray

Gamma Ray
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Signal Significance

• Large background flux in observations
• Increases as energy threshold is lowered (increase sensitivity)
• Take data in source and background (on and off) regions
Li & Ma

- Method published in 1983
- Maximum likelihood ratio (hypotheses test)
  - Null hypothesis- conditional maximized parameters
  - Alternative hypothesis- maximized parameters
- Wilks theorem

\[ \lambda = \frac{L(X|E_0, \hat{T}_c)}{L(X|\hat{E}, \hat{T})} \]

\[ -2 \ln \lambda \sim \chi^2(r) \]
Li & Ma – Likelihood Ratio

• Background and source counts have Poisson distribution
• Null hypothesis: no source exists ($\bar{s} = 0$)
• Alternative hypothesis: source exists ($\bar{s} \neq 0$)

$$P(N) = \frac{\mu^N}{N!} e^{-\mu}$$

$$\lambda = \frac{\bar{b}_0^{(N_{on}+N_{off})}}{\bar{b}^{N_{off}} (\bar{b} + \bar{s})^{N_{on}}}$$

$$-2 \ln \lambda \sim \chi^2(1)$$

$$S = \sqrt{-2 \ln \lambda}$$
Time Dependent Significance

- Same hypotheses as Li & Ma
- Change signal rate to be time dependent \((s = s(t))\)
- New parameter in alternative hypothesis
  - Must have unknown parameter in Wilks theorem solution- amplitude
Interpolation Methods

Linear Method
• Save time by not searching
• Apply constant $\Delta t$ time bins to all data
• Vectors became 3 orders of magnitude larger
• 45s initialization
• .13s interpolation (10$^6$ points)

Binary search method
• Recursive search algorithm
• Splits data each iteration
• $O(\log n)$
• .15s initialization
• .45s interpolation (10$^6$ points)
Tests of New Analysis

- Program to insert one count into analysis file
- Create fake light curve with spike in flux
- Should show large increase in significance at that point
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**Swift J164449.3+573451**

- Detected by radio, optical, and X-ray observations
- Could cause VHE emission- no detection so far
- Highly energetic signal- unlike other signals
  - Signal doesn’t fade like typical GRB
  - Signal too variable for typical AGN
  - Signal too luminous for typical supernova
- Tidal disruption event
- High signal variability- good candidate for time dependent analysis
Swift J164449.3+573451: Swift XRT Count Rate and VERITAS Temporal Coverage

VERITAS coverage indicated by blue and red dashes.
VERITAS Observation of Swift J1644+57

- VERTIAS observed swift for several days
- Only had observations during low X-ray signal times
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Previous VERITAS Results

Significance Map (smoothed)

1.34σ
Results

- Hard cuts analysis:
  - No detection at source
  - Low number of counts
  - Error in analysis
  - Large data set
  - Source significance: 3.75σ
Results

- **Medium cuts analysis:**
  - No detection at source
  - Slightly above expected significance values
  - Similar to hard cuts error
  - Source significance: $1.57\sigma$
Results

- **Soft cuts analysis:**
  - No detection at source
  - Pronounced hole at star location
  - Good mean significance
  - Source significance: $0.063\sigma$
Conclusion

• No detection in Swift J1644+57
• Large data set errors
• VEGAS is operational with time dependent analysis
• New sources with transient VERITAS signal
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Questions?
Image Credits

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