A Deep Observation of Gamma-ray Emission from Cassiopeia A using VERITAS

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For The VERITAS Collaboration
In this talk

• A brief survey of Cassiopeia A
• The VERITAS experiment
• Current Cassiopeia A results with VERITAS
A brief survey of Cas A

• Young Supernova Remnant: ~350 years*

• Located in our galaxy at a distance of ~3.4 kpc from us**

• Type IIb supernova, 15-25 M☉. Helium core-collapse red supergiant that lost its hydrogen envelope before exploding***

A brief survey of Cas A

One of the brightest radio sources* **

- Main fraction of the radio emission comes from reverse-shock
- Due to synchrotron radiation in which electrons are trapped and accelerated by the magnetic field

A brief survey of Cas A

Somewhat faint optical source

- Dominated by thermal emission due to reverse-ejecta and fast moving knots*

- Spitzer space telescope discovered a broadening of CO emission lines in the northern region of Cas A, indicating interaction between the shock front and molecular clouds**

***

A brief survey of Cas A

Extensively studied in X-rays by XMM-Newton, Chandra (0.1 to 10 keV) and NuSTAR (3 to 79 keV)

- Thermal X-ray emission is originated in the reverse-shocked ejecta, rich in highly ionized atoms* **

- Non-thermal (synchrotron) emission at both forward and reverse shock*** †

- NuSTAR observations (above 15 keV) also include interior knots as source for non-thermal X-ray emission‡

A brief survey of Cas A

• Very high energy (VHE) gamma-rays were first detected by HEGRA† (2001), and later confirmed by MAGIC†† and VERITAS ‡

• High energy (HE) gamma-rays (MeV to GeV) were first detected by Fermi-LAT in 2010*

• Subsequent Fermi-LAT data indicated a broken spectrum at around 1.72 GeV, favoring a hadronic emission model over a leptonic one** ***

A digression on the origin of cosmic rays


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The VERITAS experiment

- The Very Energetic Radiation Imaging Telescope Array System consists of 4 ground-based telescopes located in southern Arizona (31 40N, 110 57W, 1.3km a.s.l.)
The VERITAS experiment
499 PMTs
3.5° field of view
0.15° spacing

Four 12 meter diameter telescopes
(106 m² total mirror area each)
The VERITAS experiment

- From 2007 to 2012, two major updates: 1) in 2009 a telescope was moved to make the array more symmetric; 2) 2011-12 installation of FPGA-based L2 trigger system and higher efficiency PMTs* **

- Currently, a source with a flux level of 1% of the Crab Nebula can be detected in 25h. The angular resolution for gamma-rays at 1 TeV is 0.08° and the sensitivity range spans from 85 GeV to 30 TeV.

The VERITAS experiment

- There are currently 54 sources detected by VERITAS
The VERITAS experiment

• The data analysis is performed in the following steps:

1. Image is calibrated and cleansed, selecting pixels with Cherenkov light and removing the ones with night sky background*
2. Hillas parameters are calculated (length, width and size of the image), allowing us to differentiate showers originated by gamma-rays from those originated by cosmic rays.**
3. The intersection of major axes of the shower images in the camera plane provides a geometric technique to locate the origin of the gamma-ray.

The VERITAS experiment
Current Cas A results with VERITAS

Cassiopeia A data were taken using all four telescopes under very dark and clear sky conditions.

Summary of our Cas A data

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Date</th>
<th>N_{tels}</th>
<th>θZ range (deg)</th>
<th>Average θZ (deg)</th>
<th>Wobble (deg)</th>
<th>Live Time (Hours)</th>
<th>Mean trigger rate (Hz)</th>
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<td>0.5</td>
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<tr>
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<td>4</td>
<td>40-64</td>
<td>56</td>
<td>0.5</td>
<td>25</td>
<td>300</td>
</tr>
</tbody>
</table>
Current Cas A results with VERITAS

Left: - Skymap from 18h of post-upgrades observations and at small zenith angles, significance of 11 $\sigma$.
- PSF in white. Cas A is a point source!
- Centroid (blue cross) at RA=$23^{h}23^{m}20.4^{s}$ ±0°.006stat ±0°.014sys and Dec= 58.817±0°.006stat ±0°.014sys

Right: Comparison of centroid positions from Fermi (yellow, *), VERITAS (green, **) and MAGIC (red, †) with the new VERITAS (white)

Current Cas A results with VERITAS

The spectral points are fitted with a power-law in the energy range from 300 GeV to 7 TeV, giving a $\chi^2$ of 2.22 for 5 degrees of freedom, resulting in a good fit probability of 81%.

The differential energy spectrum for the whole data set is in agreement with previous results by HEGRA*, MAGIC**, and VERITAS.***

$$\frac{dN}{dE} = (1.45 \pm 0.11) \times 10^{-12} (E/1\text{TeV})^{-2.75 \pm 0.10_{\text{stat}} \pm 0.20_{\text{sys}}} \text{cm}^{-2} \text{s}^{-1} \text{TeV}^{-1}$$

Current Cas A results with VERITAS

VERITAS new data points combined with *Fermi*-LAT most recent results*


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Current Cas A results with VERITAS

Power-law fits to the data. *Fermi*-LAT index: $-2.17 \pm 0.09_{\text{stat.}} +0.10/-0.05_{\text{syst.}}$. VERITAS index: $-2.75 \pm 0.10_{\text{stat.}} +/-0.20_{\text{syst}}$


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Current Cas A results with VERITAS

Probability of PL/BPL = 0.010 (~2.5 sigma)
Probability of PL/CPL = 0.0045 (~2.8 sigma)

Current Cas A results with VERITAS

Hadronic model preferred for the GeV range; uncertain at the TeV range.

Conclusions and Prospects

• We were able to refine the VHE spectrum, both at lower and higher energy;

• We reduced statistical errors in the index and in the centroid location below the current systematic uncertainties. We will work on improving our systematics;

• There are prospects for a better analysis process for the large zenith angle data, important for the TeV-range spectrum.
Thank you!

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