Morphology of a radio galaxy
As seen with H.E.S.S. eyes
Friday 31. August

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for the H.E.S.S. collaboration
H.E.S.S.: Array of 4+1 Cherenkov telescopes located on Khomas Highland, Namibia (1800m asl, 23°16' S, 16°30'E)
H.E.S.S. phase 1:
- 4 telescopes CT1-4
- 12 m diameter
- Stereoscopic reconstruction
- 960 PMTs/camera
- FoV: 5 degrees
The H.E.S.S. array

H.E.S.S. phase 1:
- 4 telescopes CT1-4
- 12 m diameter
- Stereoscopic reconstruction
- 960 PMTs/camera
- FoV: 5 degrees

H.E.S.S. phase 2:
- Addition of CT5
- 28 m diameter
- 2048 PMTs/camera
- FoV: 3.5 degrees
- Mono or Hybrid
Morphology : Point-Like Sources

**PKS 2155-304**
- Detection significance: 125σ
- S/B ratio: 6.9
- Source appears point-like
- Extension upper limits (2D Gaussian width):
  - 13.7” (1σ)
  - 23” (3σ)

**Markarian 421**
- Detection significance: 196σ
- S/B ratio: 35
- No hints of systematics despite extremely large zenith angle
- Extension upper limits (2D Gaussian width):
  - 23.4” (1σ)
  - 33.5” (3σ)

Ref: Markus Holler for the H.E.S.S. Collaboration, Fermi Symposium, 2017
New capabilities in morphology studies

Extension of the Crab Nebula

Ref: Markus Holler for the H.E.S.S. Collaboration, Fermi Symposium, 2017

Preliminary
Advanced framework for simulations

More realistic simulation approach (ICRC 2017)
- Simulating each observation run of a data set
- Using actual observation and instrument conditions

Array-wise
- Telescope Tracking
- Source Position
- Transparency Coefficient

Telescope-wise
- Camera focus
- Trigger Settings
- Live-Time fraction

Pixel-wise
- Broken Pixels
- PMT Gain
- HI-Lo ratio
- Flatfield Coefficient
- NSB
Run wise simulations achievement

• Small source extensions
  – Good understanding of the Point Spread Function (PSF)
    --> Crab Nebula extension
    --> point-like AGNs

• H.E.S.S. PSF from MC
  – PSF asymmetry measurement
    --> Elliptic shape

Allowed by the use of the new simulation framework
Centaurus A

- Radio galaxy (NGC 5128) of FRI type
- Nearest active galaxy at a distance of 3.7 Mpc
- Detailed morphological analysis (1° ≈ 65 kpc).

Cen A @ gamma-ray

- H.E.S.S discovery at TeV energies
- Fermi-LAT: extended lobes
Re-analysis of the H.E.S.S. phase I data

Deep H.E.S.S. Observations from 2004 to 2013
• 202 hours of live time
• Change in hardware state, observation conditions

Detection significance: 13.1σ
S/B ratio: 0.5

Challenging data set
– Long exposure over several years
– Different hardware states
– Different obs. conditions
– Low S/B ratio
1D-projection of the event map

Projection along the radio jets
- Minor axis: no extension
- Major axis: PSF folded with the best-fit width from the 2D fit

Cen A VLA

H.E.S.S. Preliminary

Projection along Minor Axis

Projection along Major Axis
2D study of the Cen A data set

Morphological models

- Point-like
- Sym-Gauss.
- Elliptic-Gauss.

### Gaussian width of semi-major axis

- 0.044° ± 0.012°

### Alignments

- Point-Like in the transvers direction
- Aligned with radio jets

### Significance Levels

<table>
<thead>
<tr>
<th>Model Comparison</th>
<th>Significance</th>
</tr>
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<tbody>
<tr>
<td>Sym. Gauss. vs. Point- Like</td>
<td>3.54σ</td>
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<tr>
<td>Elliptic. Gauss. vs. Point- Like</td>
<td>5.15σ (5.47σ)</td>
</tr>
<tr>
<td>Elliptic. vs Symm. Gauss.</td>
<td>4.18σ (4.56σ)</td>
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Preliminary

VLA Map
Morphological models

Centaurus A emission is not point-like at TeV
First extragalactic extended source in the TeV range

- Systematic uncertainties still not evaluated
- X-check with former IRFs evaluation gives consistent results while less significant

<table>
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- Gaussian width of semi-major axis: 0.044 ° +/- 0.012°
- Point-Like in the transvers direction
- Aligned with radio jets

PRELIMINARY
Extended VHE emission along the kpc-scale jet in Cen A?

Chandra X-ray image of the first kpc of Cen A’s jet.

- VLA radio (8.4 GHz) emission (contours) correlates with X-rays.
- X-rays are continuously emitted throughout jet.
- If X-rays are due to synchrotron, electrons need to be accelerated everywhere (short cooling timescale for $\gamma \sim 10^8$)

(Credit: Schwartz 2010, Hardcastle et al. 2003)
Extended VHE emission along the kpc-scale jet in Cen A?

Source of soft photon fields

External soft photon fields

- **dust** (peaking @ $v_p \sim 3 \times 10^{12}$ Hz):
  
  \[ v_{VHE} \sim \gamma^2 v_p \, \text{(Thomson)} \Rightarrow \gamma \sim 10^7 \]

- **host starlight** ($v_p \sim 5 \times 10^{14}$ Hz):
  
  \[ v_{VHE} \sim \gamma m_e c^2 \, \text{(KN)} \Rightarrow \gamma \sim 10^6 \]

- CMB and SSC contribution negligible

(Credit: ESO/WFI)
New era for morphology studies in VHE astronomy

First extragalactic extended source at VHE

Centaurus A extended at VHE:
- Elliptical shape:
  - Gaussian width of semi-major axis: $0.044\degree \pm 0.012\degree$
  - Point-Like in the transvers direction
  - Aligned with radio jets

Thank you