H.E.S.S. Observations of AGN

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Properties of VHE AGN

- Several AGN are known VHE (>100 GeV) $\gamma$-ray emitters
  - 5 in Northern Hemisphere:
    - Mkn 421 ($z=0.030$)
    - Mkn 501 ($z=0.033$)
    - 1ES 2344+514 ($z=0.044$)
    - 1ES 1959+650 ($z=0.048$)
    - 1ES 1426+428 ($z=0.129$)
  - 1 in Southern Hemisphere:
    - PKS 2155-304 ($z=0.116$)
- All are relatively nearby ($z<0.13$) "Blazars"
- Highly variable in all wavelengths

- Characterized by double-humped spectral energy distribution (SED)
  - 1 peak in soft to hard x-ray
  - 1 peak in VHE region
  - SED is emitted power vs energy
H.E.S.S. Performance

- Located in Namibia (1800 m asl)
- 4 imaging Cherenkov telescopes
  - D = 13 m, f = 15 m, 120 m separation
  - Tesselated mirror (~107 m$^2$)
  - Fast camera (960 pixels, 5° F.o.V.)
  - Central trigger system (STEREO)
- Good angular resolution
  - <0.1°/event, comparable to ASCA
- Strong background rejection (>99%)
- Low Energy Threshold:
  - 100 GeV at Zenith (150 GeV post-cuts)
  - Remains below 1 TeV up to ~60 degrees
- Excellent Sensitivity!

For comparison: HEGRA needed ~100 hrs to detect 5σ from a 5% Crab source

### Time Required for a 5σ Detection at 20°

<table>
<thead>
<tr>
<th>Flux (Crab Units)</th>
<th>Obs. Time (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 Crab</td>
<td>~25 hrs</td>
</tr>
<tr>
<td>0.05 Crab</td>
<td>~1 hr</td>
</tr>
<tr>
<td>0.10 Crab</td>
<td>~20 min</td>
</tr>
<tr>
<td>0.50 Crab</td>
<td>~1.5 min</td>
</tr>
<tr>
<td>1.00 Crab</td>
<td>~30 sec</td>
</tr>
</tbody>
</table>
Goals of H.E.S.S. AGN Observations

- **Identify new VHE AGN**
  - Only HBLs?
  - How far can we see?
    - TeV photons absorbed by EBL
    - Energy dependent horizon

- **Measure flux**
  - Variability time-scales?

- **Measure energy spectrum**
  - Features?
  - Variability?
  - Hardening with increased flux?

- **MWL campaigns**
  - Correlated variability?
  - SED modelling

- **AGN physical properties**
  - Acceleration mechanisms
  - Hadrons or leptons?
  - B-field, doppler factors, size of the emission region

- **Understand EBL**
  - Cosmologial implications
H.E.S.S. Detection of PKS 2155-304

VHE (>160 GeV) emission is clearly detected (>4500 γ-rays; ~45 σ)
- 63 hrs (live time) of observations made during detector construction
- Aharonian et al., 2005, *A&A*, 430, 865

Confirms previous detection of 2nd furthest known VHE AGN (z=0.116)

Time-average spectrum is soft:
\[ \Gamma = 3.32 \pm 0.06 \pm 0.1 \]

Fits of curved spectra show improved \( \chi^2 \), but the improvement is marginal (\~2 σ)
Variability of PKS 2155-304

VHE flux is clearly variable on monthly time-scales.

$I(>300 \text{ GeV})$ ranges from 0.1 Crab to 0.6 Crab.

No evidence for variability of photon index or spectral hardening with increased flux, but it is not ruled out either.
Nightly VHE Flux Variability

August 2003

Clear evidence for VHE flux variability on nightly time-scales in some dark periods

June 2003

However, the flux is also stable in some dark periods
Intra-Nightly Flux Variability

Fit a constant to the VHE flux (~30 min intervals) within each night

- Dashed line is for >1 d.o.f.

Population of nights with a low $\chi^2$ probability

Sub-hourly changes on the night with the most significant flux variability:

- Increase by a factor of 2.7 +/- 0.7 in 30 minutes
- Decrease by a factor of 2.3 +/- 0.9 in the next 30 minutes
PKS 2155-304 MWL Campaign

Simultaneous observations in October & November 2003
- VHE: H.E.S.S. (2-tels.)
- X-ray: RXTE
- Optical: ROTSE
- Radio: NRT

Clear detection by H.E.S.S
- ~1800 $\gamma$-rays, ~34 $\sigma$ in 32.4 hrs
- VHE flux & spectrum ~same as in detection paper
- Detected every night

• Clear flux variability
  • VHE, X-ray, optical

No evidence for correlated flux variability
  Smaller data set (~11 hrs)
Leptonic (dashed & dotted lines) & Hadronic (solid line) models

PKS 2155-304 in a "low" state
3 different EBL models show different intrinsic spectrum

Need sample of AGN at different redshifts to determine which is "correct"
H.E.S.S. Observations of Mkn 421

9 nights in April & May 2004; Zenith angle range 60-65°; \( E_{th} \sim 1.5 \) TeV

\[
\frac{dN}{dE} \sim E^{-\Gamma} \exp(E/E_{cut})
\]

\( \Gamma = 2.1 \pm 0.1 \pm 0.3 \)
\( E_{cut} = 3.1 (+0.5 / -0.4) \pm 0.9 \) TeV

7000 photons in \( \sim 15 \) hrs; \( 8 \gamma/\text{min} \); \( >100 \sigma \)
Spectrum clearly curved!
Flux (>2 TeV) varies by factor of 4.3; Average value ~3 Crab
Doubling time-scale less than 1 hour
Mkn 421 Spectral Hardening

From fit spectrum for each night (fixed $\Gamma=2.1$)

Clear evidence for spectral hardening with increased flux!
H.E.S.S. Observations of PKS 2005-489

- **General characteristics:**
  - Discovered as bright (>0.5 Jy) radio source in 9th Parkes 2.7-GHz survey
  - A relatively nearby (z = 0.071) HBL
    - Low energy component of SED peaks in the UV
  - Well studied from the radio to the X-ray regime
    - Target of many multi-wavelength campaigns
  - Marginal EGRET source (>100 MeV & GeV regime)
  - Several papers predict detectable levels of VHE γ-rays

- **Not previously detected in VHE observations:**
  - University of Durham Mark 6 Telescope (1996-2000)

- **H.E.S.S observed PKS 2005-489 in 2003 & 2004**
  - 2003: 27.3 hrs live time, <θ> ~28°, Construction phase (< 4 tels.)
  - 2004: 24.3 hrs live time, <θ> ~38°, Full H.E.S.S. array
H.E.S.S. Detection of PKS 2005-489

2004 Result: Significant excess of 288 γ-rays, 6.7 σ
2003 Result: No Significant excess, 1.4 σ
Combined significance is: 6.3 σ

First AGN independently discovered as VHE emitter by H.E.S.S.
Only the second known VHE AGN in the Southern Hemisphere
PKS 2005-489 Spectrum & Flux

- **2004 data:** $dN/dE \sim E^{-\Gamma}$
  - $\Gamma = 4.0 \pm 0.4$
  - $\chi^2/\nu = 0.8 (5.6/7)$, $P(\chi^2) = 0.6$
  - $I(>200 \text{ GeV}) = (6.9 \pm 1.0) \text{ e}-12 \text{ cm}^{-2} \text{s}^{-1}$
    - \sim 2.5\% of Crab Nebula Flux

- **2003 data (non-detection):**
  - 99\% Flux upper limit (assume $\Gamma = 4.0$
    - Feldman & Cousins 1998
    - $I(>200 \text{ GeV}) < 5.2 \text{ e}-12 \text{ cm}^{-2} \text{s}^{-1}$

- **No evidence for flux variability on monthly, nightly, or intra-nightly time scales**

**Lowest flux & steepest spectrum ever detected from a VHE AGN!**
H.E.S.S. has detected several AGN!

**PKS 2155-304 (z=0.116):**
- Soft spectrum ($\Gamma=3.32$)
- VHE flux variable
- Successful MWL campaign

**PKS 2005-489 (z=0.071):**
- 1st AGN "discovered" by H.E.S.S
- 2nd "Southern" VHE AGN
- Softest spectrum ($\Gamma=4.0$) & lowest flux ever for a VHE AGN

**Mkn 421 (z=0.030) at LZA:**
- Curved spectrum
- High flux & large variability
- Spectrum hardens with increased flux

~20 other AGN have been observed
- Analysis ongoing

Much exciting physics in the queue