H.E.S.S. observations of Active Galactic Nuclei

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Outline

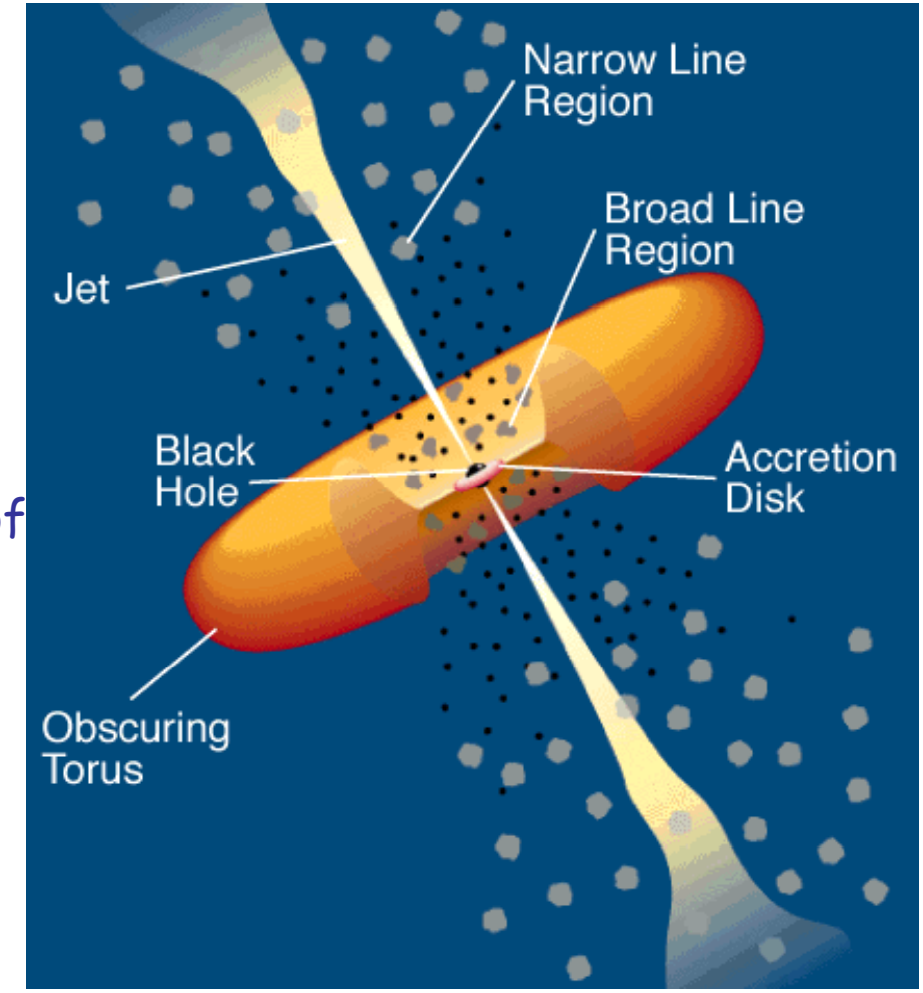
- Active Galactic Nuclei (AGN)
- PKS 2155-304 exceptional flare in July 2006
- HESS AGN campaign
- Discovery of two distant AGN in VHE range
- Conclusions

TeV γ-rays sources

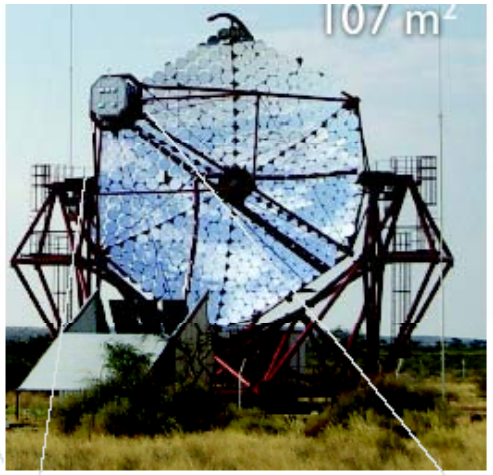
- Almost exclusively Blazars!

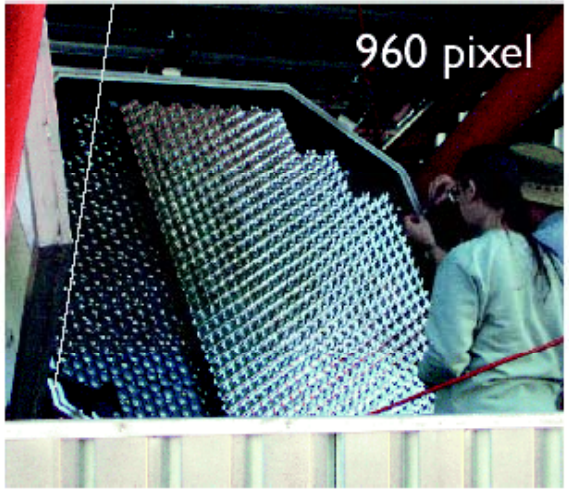
(up to now)

- Active Galactic Nuclei (AGN) standard model
  - Central black hole with accretion disk
  - Dust torus
  - Relativistic plasma jets
  - Different angles between jet and line of sight of observer give different object classes
  - Jet towards the observer: Blazars
- TeV photons from the jets
  - Leptonic (Inverse Compton)
  - Hadronic
  - Relativistic beaming
  - Extremely variable !!!



The H.E.S.S. array of Cherenkov Telescope





- 4 Cherenkov telescopes array located in Namibia stereoscopic observation mode
- 107 m^2 mirror area per telescope
- Photomultiplier camera:
- 960 PMTs, ~5 deg field of view
- Energy range: 100 GeV up to several 10 TeV
dE/E ~ 15%
- Angular resolution: ~0.1 deg per event

details in G. Puehlhofer's talk in this conference

PKS 2155-304 (z=0.116)

- High-frequency peaked BL-Lac object (HBL) – the first seen by HESS

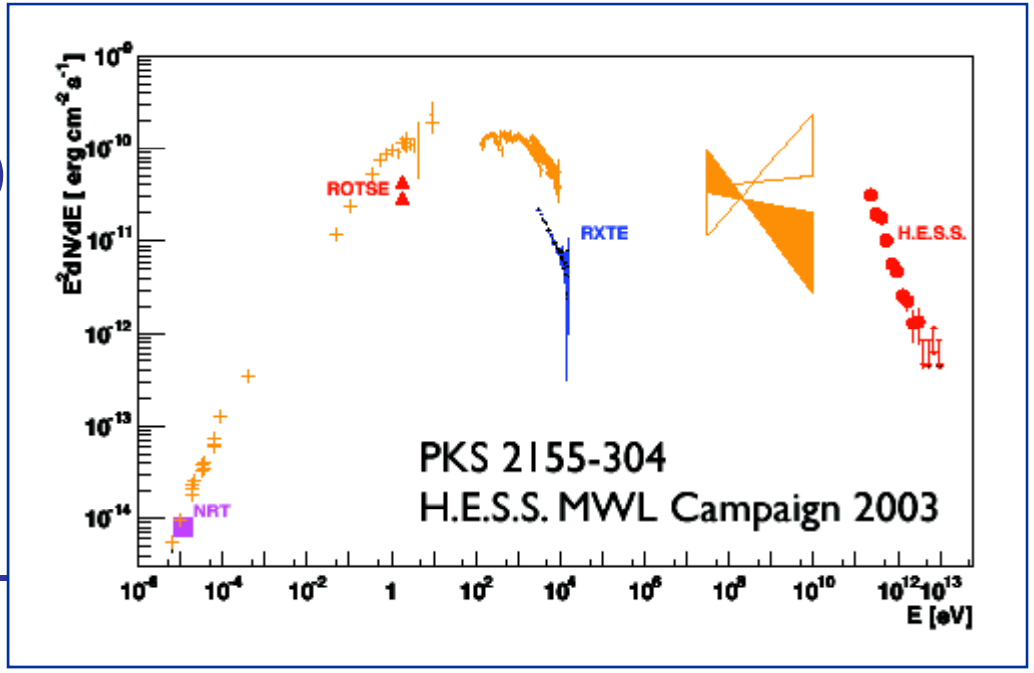
- Discovered in TeV in 1999 (Mark 6) / Confirmed by H.E.S.S.
Chadwick et al. (1999), Aharonian et al. , A&A, 430, 865 (2004)

- Extensive multi wavelength studies in 2003 and 2004
Simultaneous radio, optical ,x-ray & TeV observations
Aharonian et al. 2005, A&A, 442, 895 (2005),
Aharonian et al. in prep.

- Source always detected in TeV!
"quiescent state" (0.08-0.15 Crab)

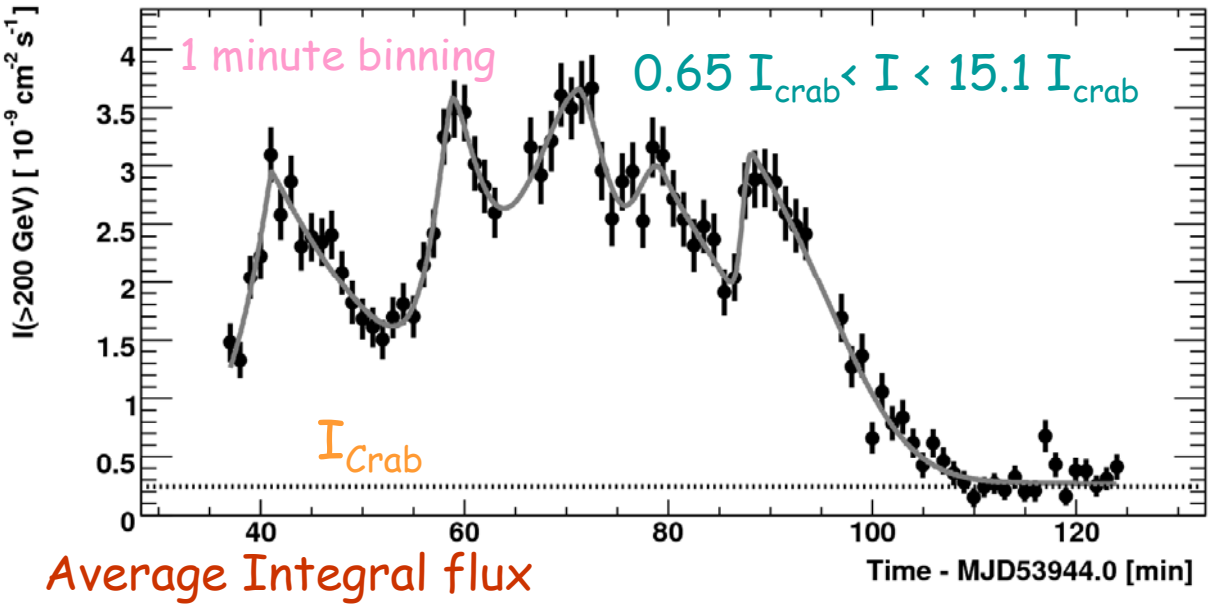
- Significant nightly HESS
detection systematic

LONG & RICH MWL HISTORY!!



Light Curve of the flare

Integral flux



Average Integral flux

$I(>200\ GeV) = (1.72 \pm 0.05_{stat} \pm 0.34_{syst}) \times 10^{-9}\ cm^{-2}\ s^{-1}$

~ 7 times the $I_{Crab}(>200\ GeV)$

July 28, 2006 (MJD 53944) exceptional VHE gamma-ray flare of this source

3 runs → 1.32h live time

standard analysis results:

γ-excess 11771

In the past VHE-flux variability on daily time scales. The most rapid flux variability measured is 25 min in X range

Fast variability in AGN provide a strong probe into the the physical process of their innermost regions

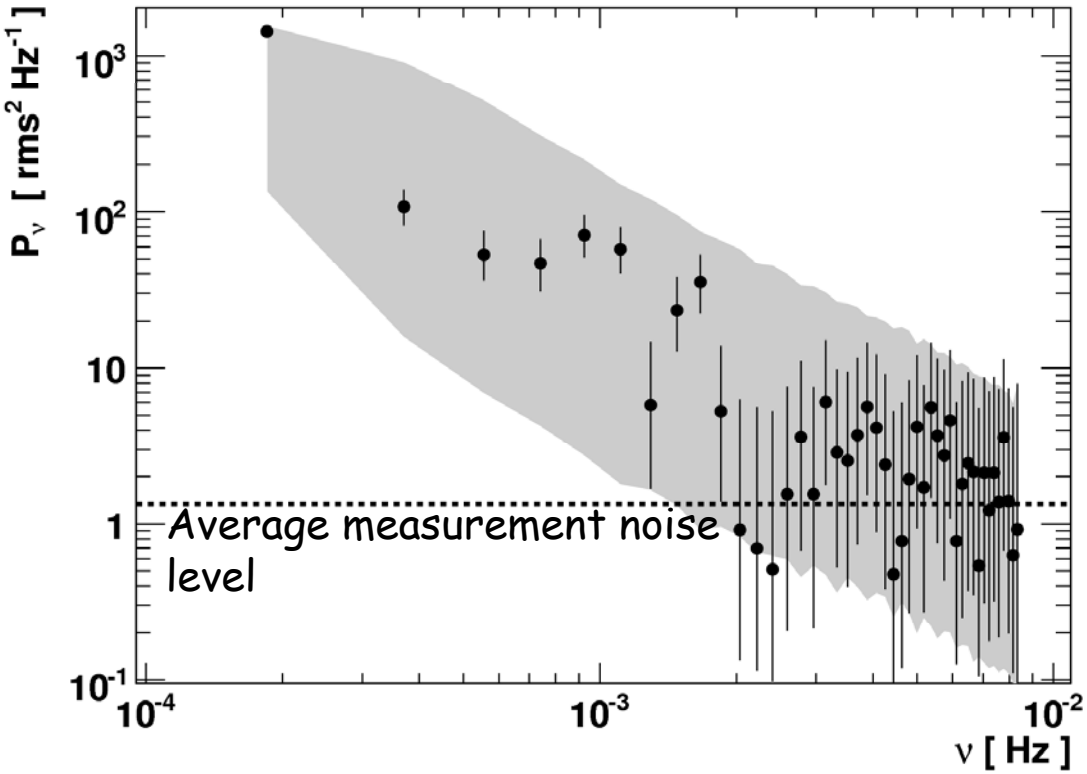
Fastest variations published for a blazar:

X-ray range: Mkn 501 varied ~30% in 800s (Xue&Cui 2005)

@VHE energies: Mkn 421 flux variability in ~15 min (Gaidos et al. 1996)

Fourier Analysis

Fourier Power Spectrum



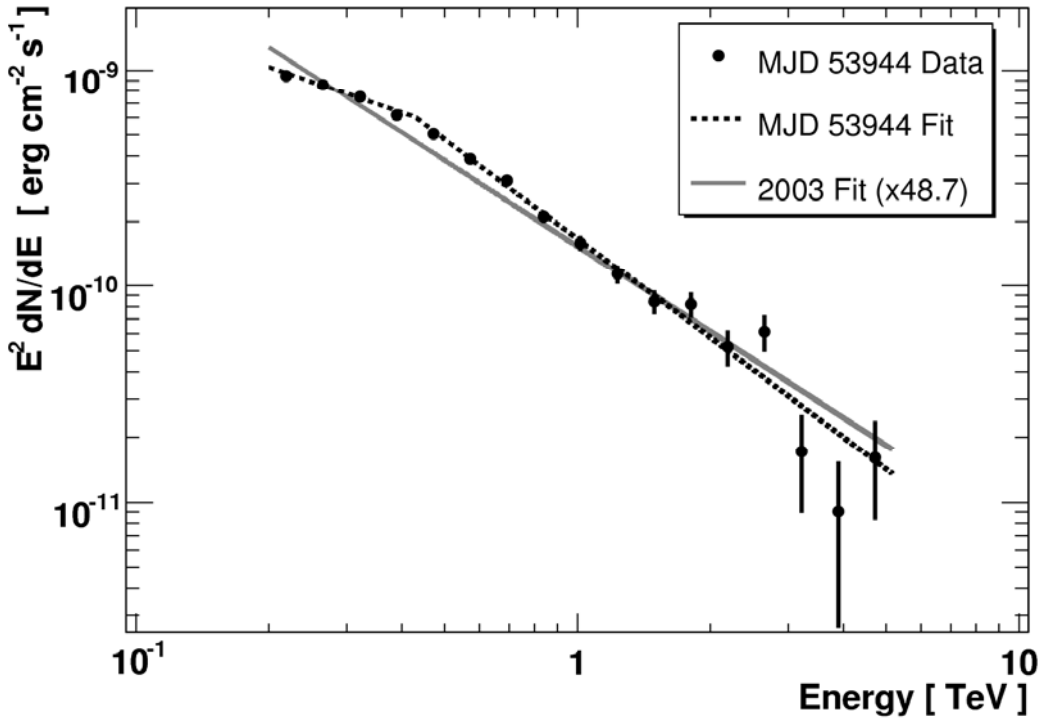
Error on the power spectrum: 90% confidence interval estimated from simulated lightcurves

90% confidence level obtained simulating lightcurves with a power-law Fourier Spectrum $P_\nu \propto \nu^{-2}$

- The most of the power is at low frequencies
- Power significantly above the noise level up to 1.6×10^{-3} Hz (600s)
- Power spectrum compatible with a light curve generated by a stochastic process with a power-law Fourier spectrum of index -2.
- Power spectra similar in X-rays.

PKS 2155-304 Spectral Analysis

Time-averaged spectrum



Except the factor, good agreement: E_B consistent if fitting the data with Γ_1&Γ_2 of 2003

NO EVIDENCE OF SPECTRAL VARIABILITY!

Steep spectrum probably due to EBL absorption

Broken power-law fit

χ^2/d.o.f. = 17.1/13

$$E < E_B : \frac{dN}{dE} = I_0 \left(\frac{E}{1TeV} \right)^{-\Gamma_1};$$

$$E > E_B : \frac{dN}{dE} = I_0 \left(\frac{E_B}{1TeV} \right)^{(\Gamma_2 - \Gamma_1)} \left(\frac{E}{1TeV} \right)^{-\Gamma_2}$$

$I_0 = (2.06 \pm 0.16 \pm 0.41) \times 10^{-10} cm^{-2} s^{-1} TeV^{-1}$

$E_B = 430 \pm 22 \pm 80 GeV$

$\Gamma_1 = 2.71 \pm 0.06 \pm 0.1; \Gamma_2 = 3.53 \pm 0.05 \pm 0.10$

Spectra determined @ time scales of 28/10/5 min are consistent

TeV γ-rays catalogue

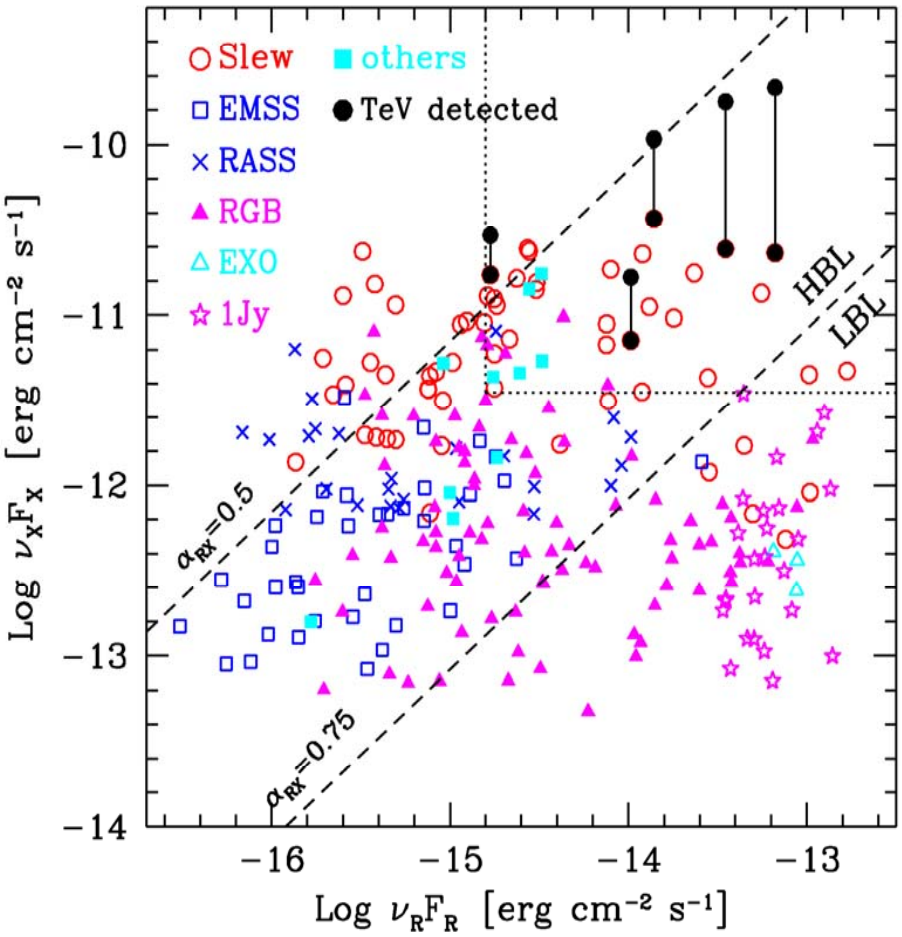
Source	Redshift	Experiment	Energy range (TeV)	Slope $\Gamma \pm \sigma_{st} \pm \sigma_{sy}$	Cut-off energy (TeV)	Reference
Mkn 421	0.030	MAGIC	0.10 – 3.0	2.20 ± 0.08 ± 0.20	1.44 ± 0.28	Albert et al. (2006c)
Mkn 421	0.030	HEGRA	0.70 – 18.0	2.19 ± 0.02 ± 0.20	3.6 + 0.4 – 0.3	Aharonian et al. (2002a)
Mkn 421	0.030	Whipple	0.35 – 0.90	2.31 ± 0.04 ± 0.05	——	Krennrich et al. (2002)
Mkn 501	0.034	HEGRA	0.50 – 22.0	1.92 ± 0.03 ± 0.20	6.2 ± 0.4	Aharonian et al. (1999)
1ES 2344+514	0.044	Whipple	0.80 – 11.0	3.32 ± 0.70 ± 0.70	——	Schroedter et al. (2005)
Mkn 180	0.045	MAGIC	0.14 – 1.5	2.20 ± 0.08 ± 0.20	——	Albert et al. (2006b)
1ES 1959+650	0.047	HEGRA	1.5 – 13.0	2.83 ± 0.14 ± 0.08	——	Aharonian et al. (2003a)
PKS 2005-489	0.071	H.E.S.S.	0.20 – 2.5	4.0 ± 0.4 (±0.2)	——	Aharonian et al. (2005a)
PKS 2155-304	0.116	H.E.S.S.	0.20 – 3.5	3.37 ± 0.07 ± 0.10	——	Aharonian et al. (2005b)
H 1426+428	0.129	HEGRA	0.70 – 12.0	2.6 ± 0.6 ± 0.1	——	Aharonian et al. (2003c)
H 2356-309	0.165	H.E.S.S.	0.16 – 1.0	3.06 ± 0.21 ± 0.10	——	Aharonian et al. (2006b)
1ES 1218+304	0.182	MAGIC	0.08 – 0.7	3.0 ± 0.4 ± 0.6	——	Albert et al. (2006a)
1ES 1101-232	0.186	H.E.S.S.	0.16 – 3.3	2.88 ± 0.14 ± 0.1	——	Aharonian et al. (2006a)
PG 1553+113	??	H.E.S.S.	0.2 - 5	4.0±0.6±0.1	-----	Aharonian et al. 2006

- ✓First detection in 1992
- ✓Current generation experiment (HESS/MAGIC) doubled number of sources
- ✓Source types: Blazars except for M87
- ✓M87 Radio Galaxy – AGN with jet not pointing directly towards observer

TeV detection by HESS of 3 additional blazars

1ES 0229+200	z=0.1396	HBL
1ES 0347-121	z=0.1888	HBL
PKS 0548-322	z=0.069	HBL

HESS AGN campaign



HESS selection of extragalactic observation targets relies strongly on this plot of X-ray intensity versus radio intensity for the BL Lac objects (Costamante & Ghisellini, 2002)

- Objects having their jet pointing towards us.
- Virtually all active galaxies detected previously at TeV energies (full black points) belong to this class and are characterized by high X-ray and radio flux, indicative of the presence of high-energy electrons in the source.
- Scattering off ambient or synchrotron photons, these electrons produce TeV gamma rays.

HESS AGN campaign

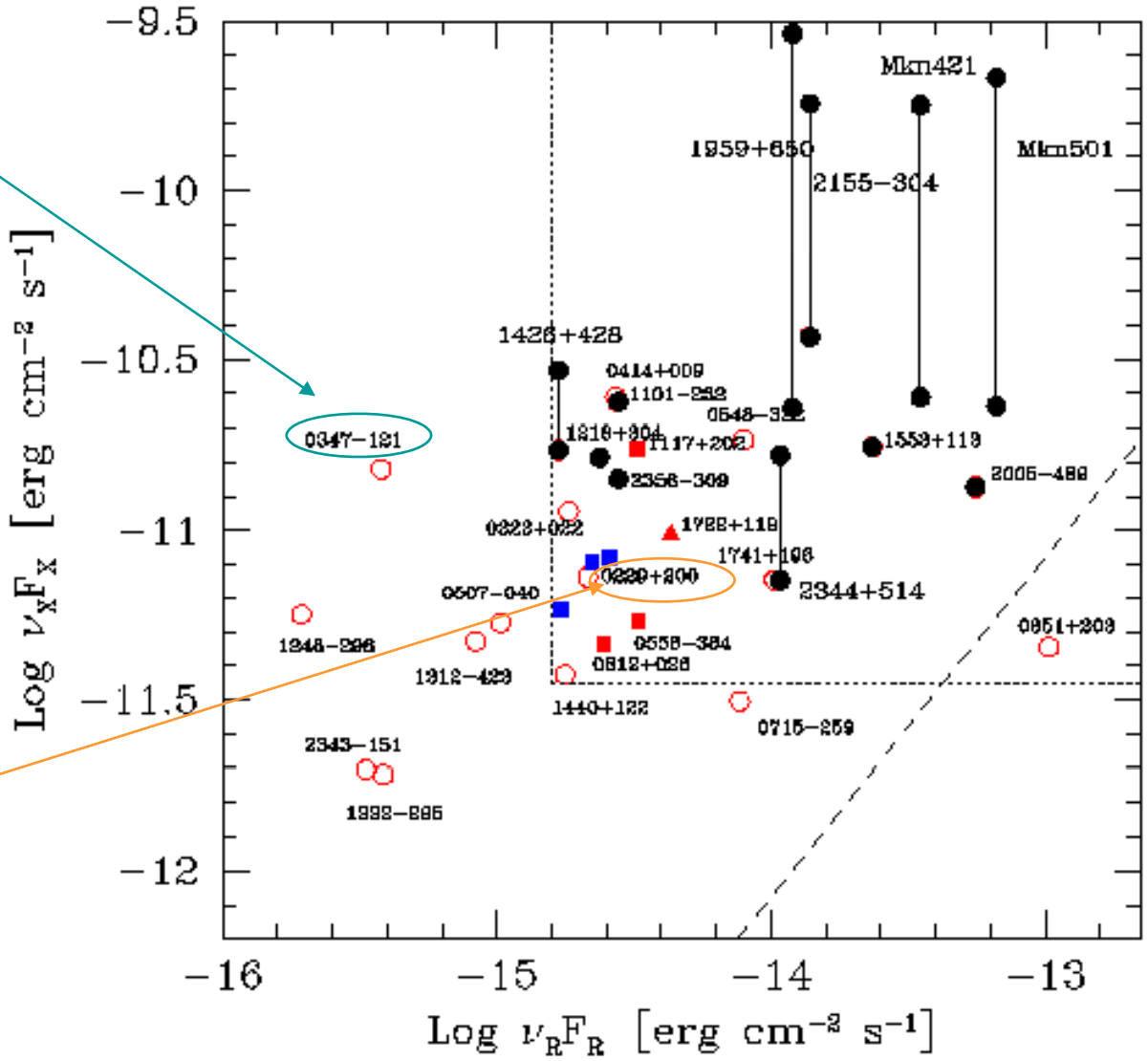
1ES 0347-121

Same redshift of 1ES 1101-232 (z=0.186) and comparable X-ray flux

1ES 0229+200

Same redshift of 1ES 1426+428 (z=0.129) whose spectrum has been measured up to ~ 10 TeV

⇒disentangle intrinsic spectra from EBL features



Analysis Methods: 3D Model & Standard analysis

1. 3D Model

- Shower model: 3D gaussian photosphere, with anisotropic angular distribution
- Path integral along line-of-sight $\Rightarrow$ light in each pixel
- Log-likelihood fit of observed images to model-images

$\rightarrow$ 8 parameters: altitude, direction, width, length, # of photons

high performance for 3 & 4 telescopes events

see Lemoine-Goumard et al. - Astro. Phy. (2006)

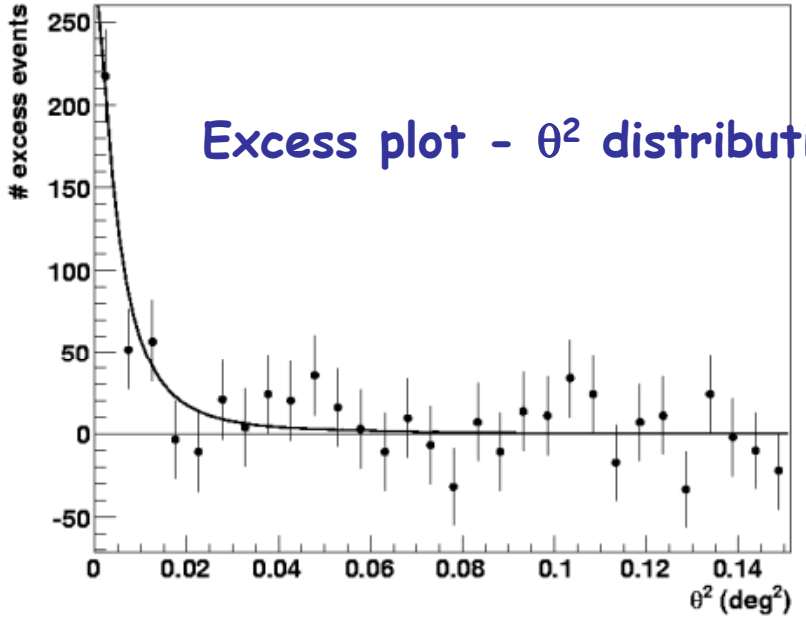
2. Standard Analysis

Moment analysis, Hillas parameters

see Aharonian et al. – A&A (2006)

Based on 2 different data calibrations

HESS detection of 1ES 0347-121



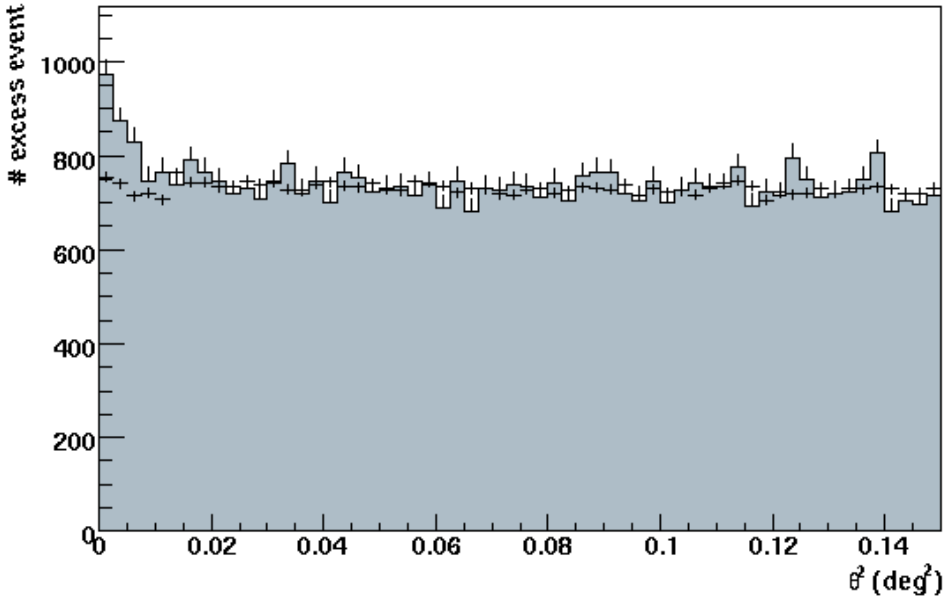
25.1 h live time – data taken in 2006

mean zenith angle ~19⁰

➢Moment analysis results with hard cuts:

327 γ

Significance 10.1 (Li&Ma)



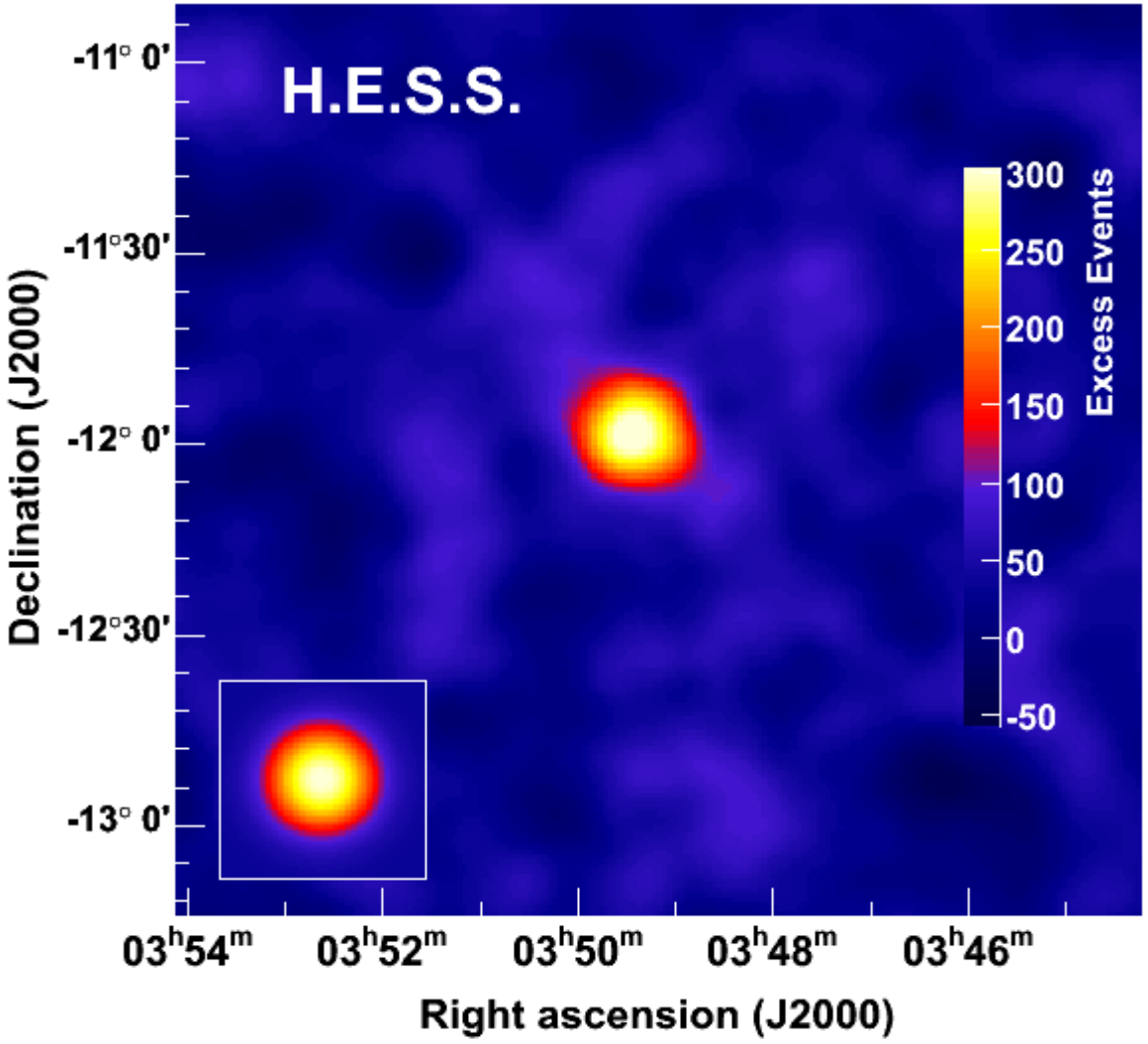
➢3DModel analysis results with standard cuts:

590 γ

Significance 7.1 (Li&Ma)

SOURCE DETECTED WITH 2 ANALYSIS CHAINS

HESS detection of 1ES 0347-121



Excess Sky Map

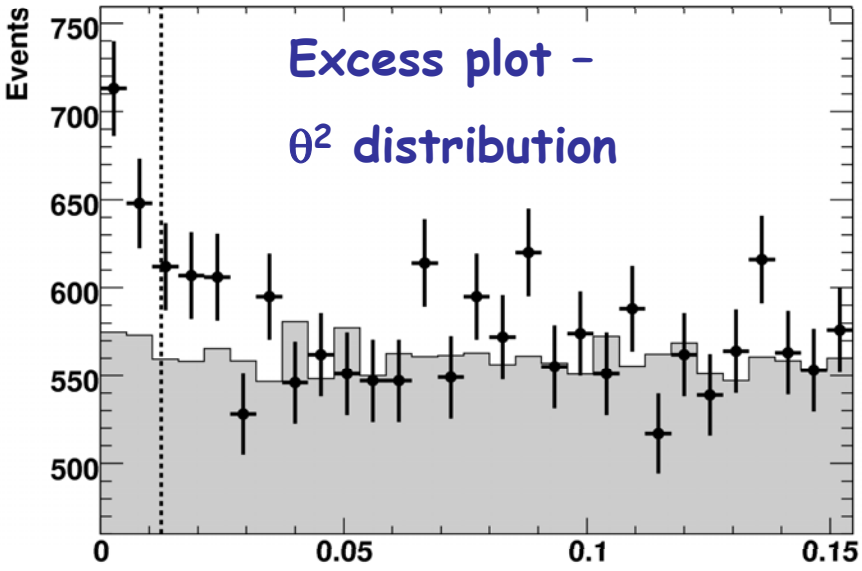
Fit Position:

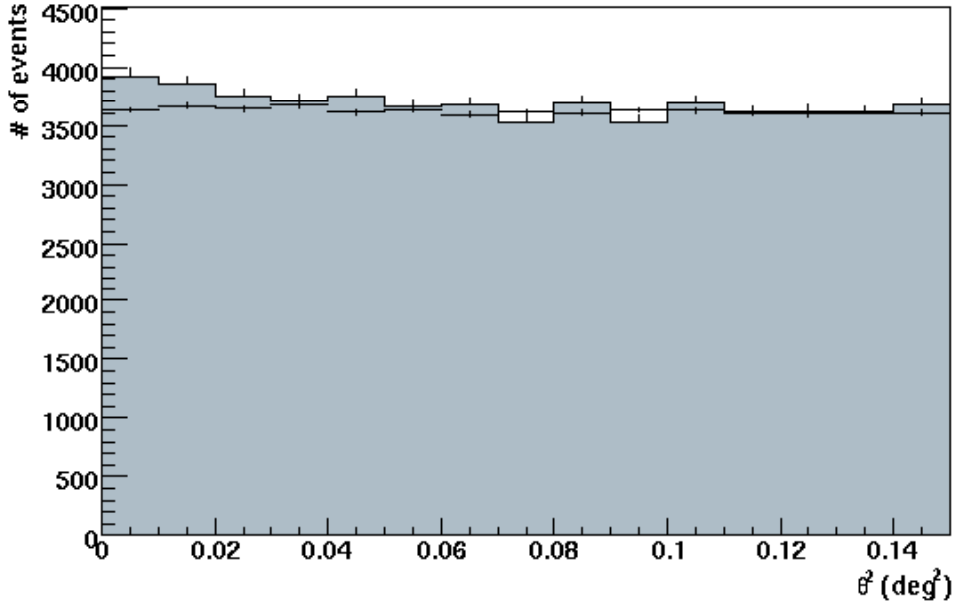
3h 49m 24.6s, -11d 58′49″

ΔRA=24″±23″,
Δdec=38″±27″

Point-like source

HESS detection of 1ES 0229+200





data taken in 2005-2006

mean zenith angle ~46^0

➢Moment analysis results with hard cuts on 41.8h livetime :

261 γ

Significance 6.6 (Li&Ma)

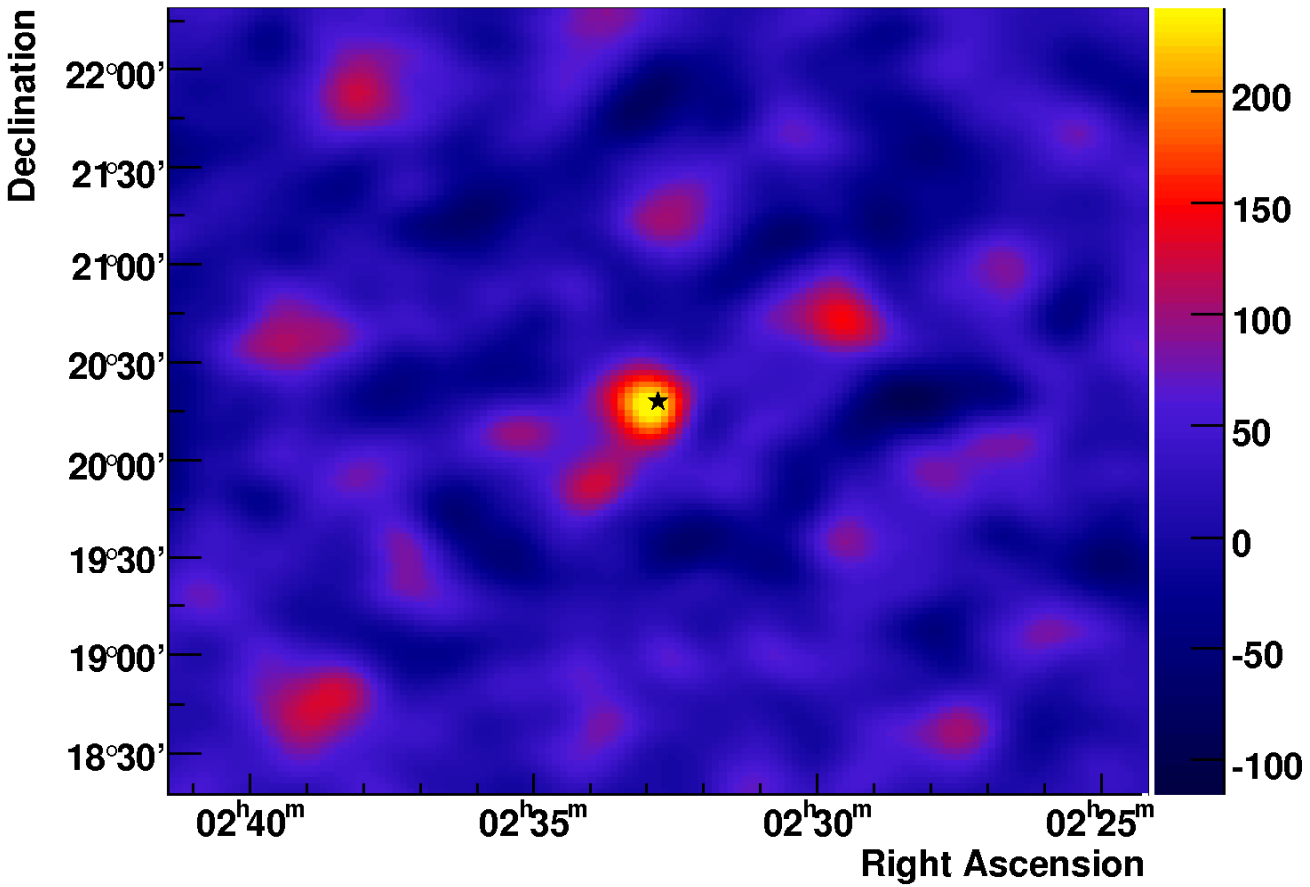
➢3DModel analysis results with standard cuts on 44.1 h livetime:

505 γ

Significance 5.5 (Li&Ma)

SOURCE DETECTED WITH 2 ANALYSIS CHAINS

HESS detection 1ES 0229+200



Excess Sky Map

Fit Position:

2h 32m 53.2s, 20d 16′21″

ΔRA=69″±46″,
Δdec=-57″±44″

Point-like source

Conclusions

❑PKS 2155-304

- First blazar ever to show such high luminosity
- TeV short time variability (even shorter than for Mkn 421)
- No spectral variability compared to the low state
- Huge MWL dataset

(HESS, CHANDRA, RXTE, optical.....)

❑Discovery of blazars 1ES 0347-321 & 1ES 0229+200

with significance above 5σ

- Results with standard analysis soon published
- The spectral analyses will give further constraints on the intensity of the extragalactic background light

H.E.S.S. II increase the sensitivity and reduce the threshold

Drawing some conclusions....

Assuming that the electromagnetic emission in blazars is generated in jets that are beamed and Doppler-boosted toward the observer (causality arguments)

$\Rightarrow$ γ-ray variability on a time scale t_{var} with a Doppler factor (δ) is related to the radius (R) of the emission zone by $R \leq c\, t_{var}\, \delta/(1+z)$

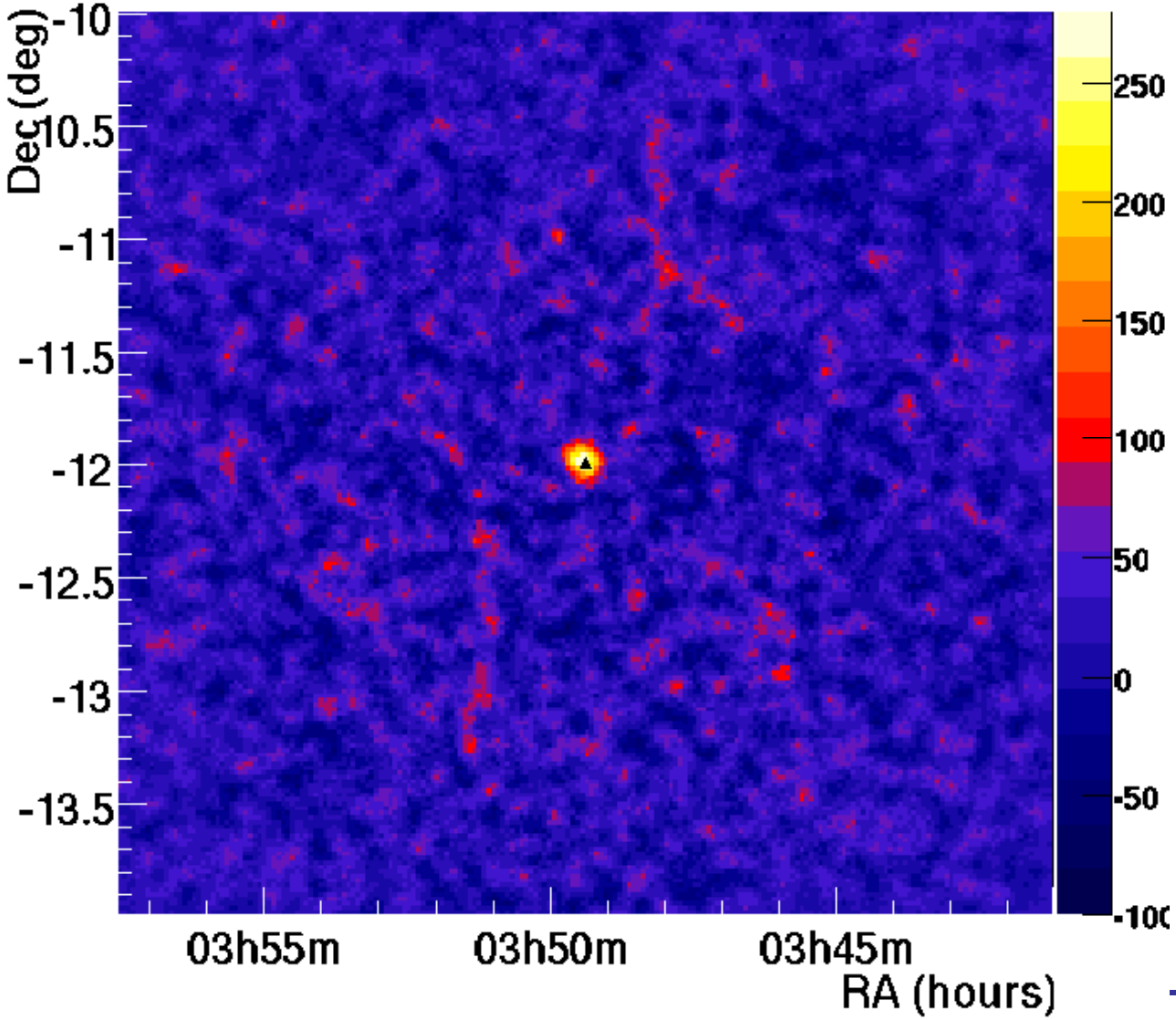
where $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$; Γ is Bulk Lorentz factor of the plasma in the jet; $\beta=v/c$; and θ is the angle to the line of sight.

Taking as t_{var} the best determined time rise (173±28 s) in the fit of the lightcurve, the limits to the size of the emission region is: $R\delta^{-1} \leq 4.65\times10^{12}$

Accretion/ejection properties presumed to scale with the Schwarzschild radius R_S of the SMBH (smallest size of the system)

Assuming the size of the emission region ~ R_S, the t_{var} limits the SMBH mass to ~1-2 M_O and so a Doppler factor $\delta > 100$ to accommodate this variability time scales.

HESS observation 1ES 0347-121



Excess Map

Fit Position:

3h 49m 24.6s, -11d 58′49″

ΔRA=24″±23″,
Δdec=38″±27″

Point-like source

Summary of the analysis

1ES 0229+200

➢ Standard analysis

- theta2cut=0.015
- 41.8h livetime :
- 1590 ON events
- 14542 OFF events
- 261 γ
- Significance 6.6

➢ 3DModel

- 44.1 h livetime
- Theta2 cut = 0.02
- 7786 ON events
- 53491 OFF events
- 504 γ
- Significance 5.5

1ES 0347-321

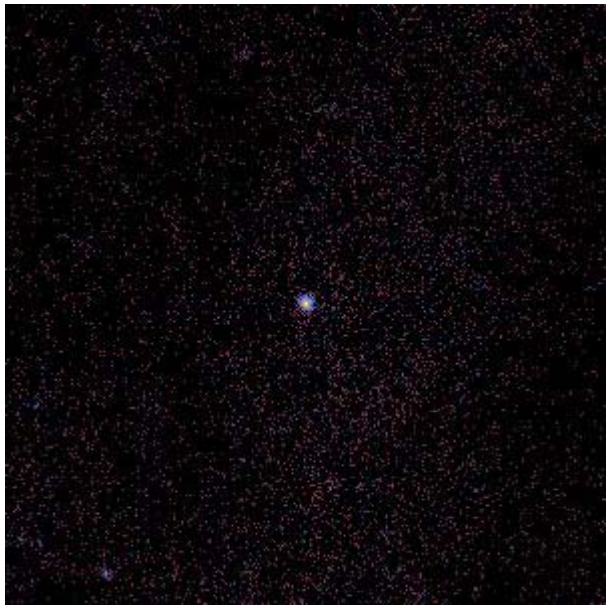
➢ Standard analysis

- Theta2cut = 0.01
- 25.4 h livetime
- 1167 ON events
- 9241 OFF events
- 327 γ
- Significance 10.1

➢ 3DModel

- 25.4 h livetime
- Theta2 cut = 0.02
- 6479 ON events
- 46408 OFF events
- 590 γ
- Significance 7.1

1ES 0347-121 z=0.188



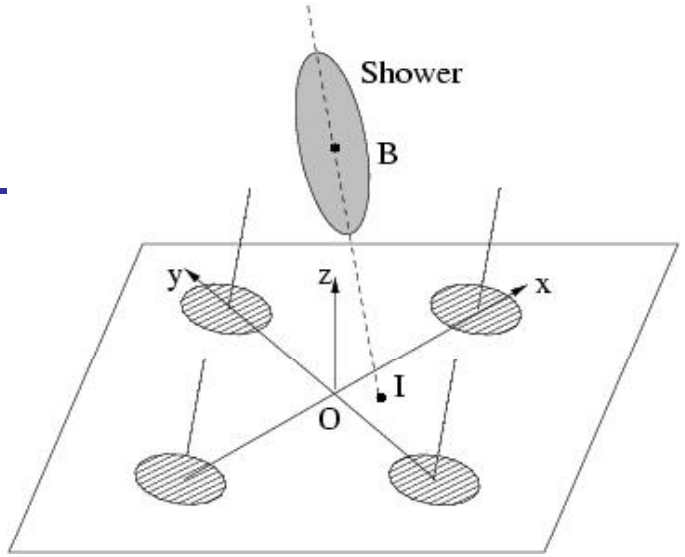
Discovered in the Einstein Slew Survey (Elvis et al. 1992)

It harbors a super massive black hole of mass $\log(M_{BH}/M_{sun}) = 8.02 \pm 0.11$

Stecker et al. (1996) predicted a flux above 0.3 TeV of 3.8×10^{-12} cm^{-2} s^{-1}

Upper limit on the integral flux above 1.46 TeV of 5.14×10^{-12} cm^{-2} s^{-1} (0.56% Crab

Stereoscopic analysis in HESS



- Simple modelization in 3-dimensions of the Cherenkov « photosphere »:
  - Origins of the photons:
    3D gaussian distribution with
    revolution symmetry (electromagnetic shower)
  - Directions of the photons: anisotropic distribution
- Max. Of the Likelihood to reproduce the contents of the pixels in the different views→ 3D shower:
  - Altitude of the shower maximum
  - Typical width of the emitting zone at the maximim of the shower or « 3D WIDTH »
  - Incident direction, impact position, energy etc.
- The 3D width is the discriminating variable between γ and hadrons characterizing the shape independently from the direction.