Observation of the Giant Radio Galaxy M87 at TeV Energies with H.E.S.S.

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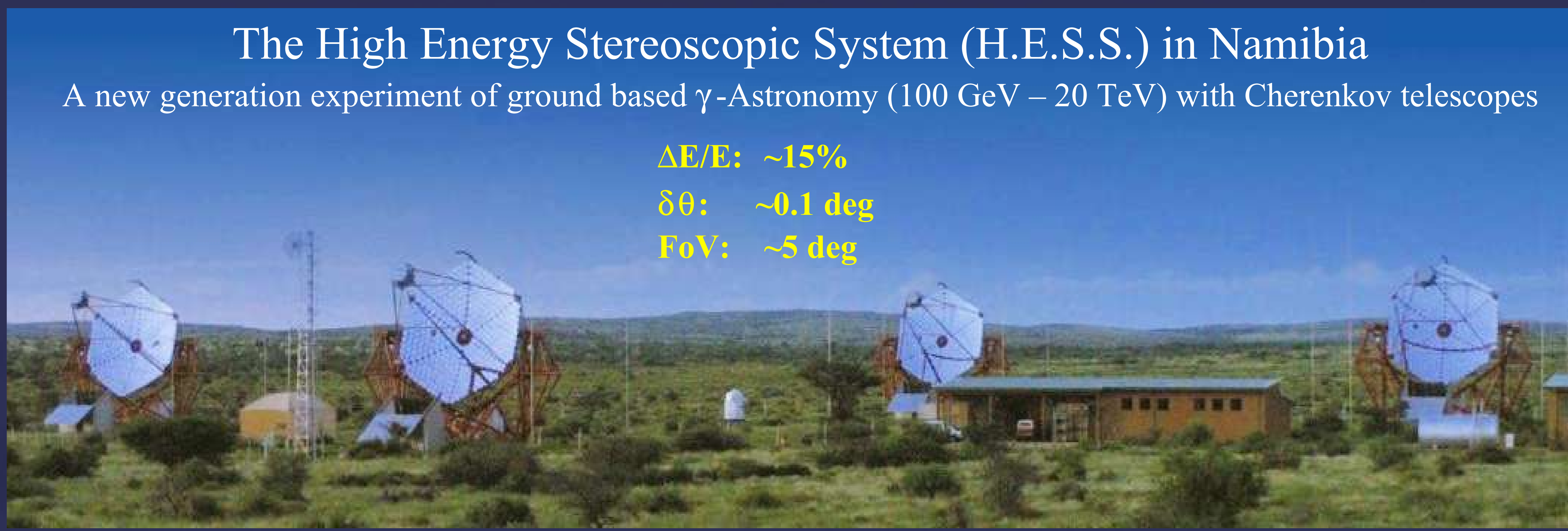
Abstract

The giant radio galaxy M 87 was observed at TeV energies with the Cherenkov telecopes of the H.E.S.S. collaboration (High Energy Stereoscopic System). The observations have been performed in the year 2003 during the comissioning phase and in 2004 with the full 4 telescope setup. The observations were motivated by the measurement of the HEGRA collaboration which reported a 4.7 sigma excess of TeV γ-rays from the direction of M87. The results of the H.E.S.S. observations indicating a possible variability of TeV γ-ray emission from M 87 (compared to the HEGRA result) are presented.



M 87

M 87 is a giant radio galaxy located in the Virgo cluster of galaxies. It has been intensively studied in different wavelengths (radio, optical, x-rays, see Fig. 1).

- Distance: ~16 Mpc (z = 0.0043)
- Supermassive central black hole (2.4 +- 0.7) 10^9 M_{solar}
- Jet angle to observer: 20-40 deg

M87 is of particular interest for observations at TeV energies: The large jet angle makes it different from the so far observed TeV emitting AGN which are of the Blazar type. Various models exist to describe emission of GeV/TeV photons from M87:

- Leptonic models (i.e. Inverse Compton), TeV γ-ray production in large scale jets
  [Bai & Lee, ApJ, 549, L173 (2001)],
  [Stawarz et al., Astrophys.J., 597, 186-201 (2003)]
- Hadronic models, i.e. Synchrotron proton blazar model, cosmic ray mechanisms, etc.
  [Protheroe et al., Astroparticle Physics, Vol.19, Issue 4, 559],
  [Reimer et al., A&A 419, 89-98 (2004)],
  [Pfrommer & Enslin, A&A, 407, L73 (2003)]
- M87 as a production site of ultra high energy cosmic rays (UHECR).
  [Ginzburg & Syrovatskii: "The origin of cosmic rays" (1964)],
  [Biermann et al., Nucl. Phys. B, Proc. Suppl., 87, 417 (2000)]
- Exotic particle (i.e. Neutralino) annihilation.
  [Baltz et al., Physical Reviews D, 61, 023514 (1999)]

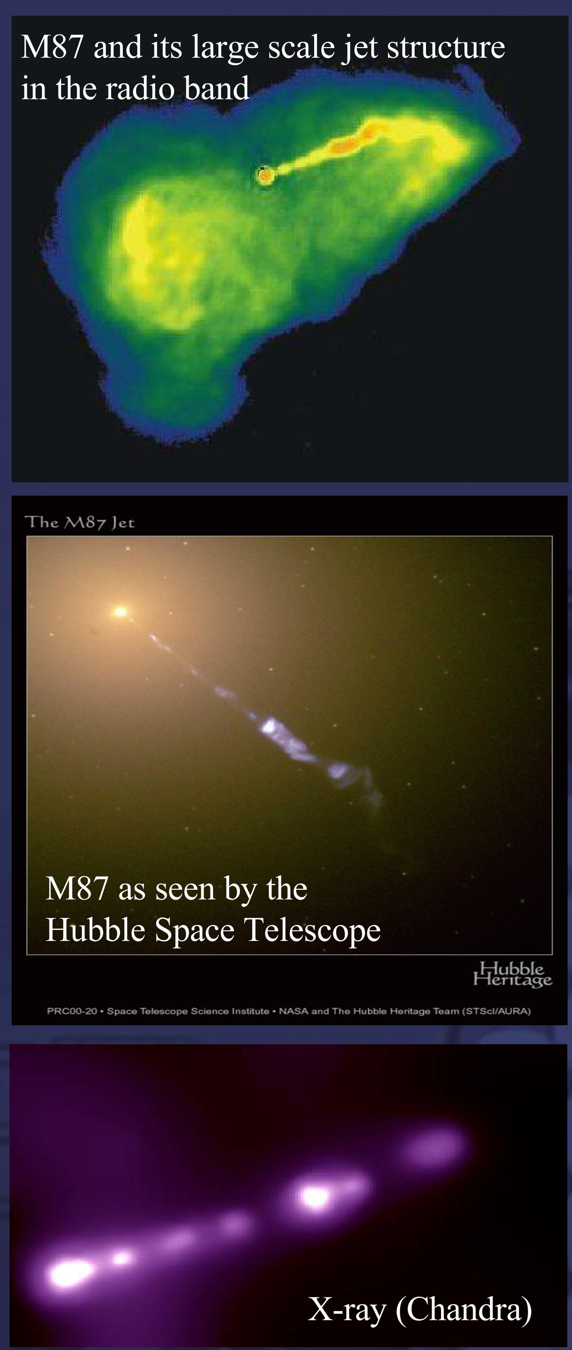


Fig. 1: M87 at different wavelength

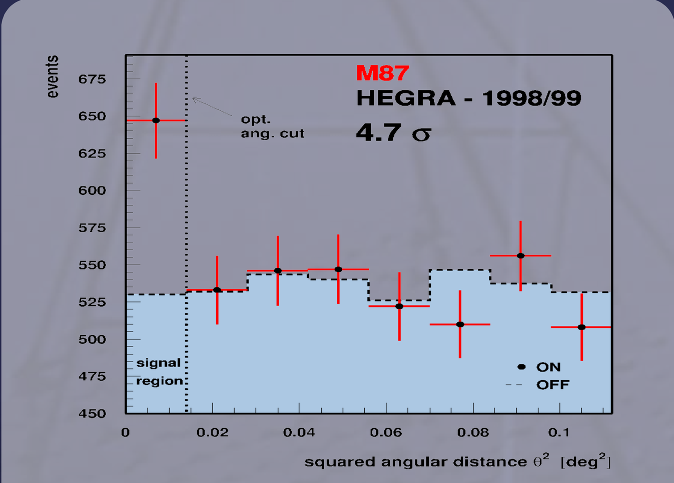


Fig. 2: The results reported by the HEGRA collaboration. Shown is the distribution of events vs. the squared angular distance $\Delta\theta^2$ measured between object and shower direction for the M87 position (red) and the off region (blue).

HEGRA TeV observations

M 87 has been observed at TeV energies in 1998 and 1999 for ~83h with HEGRA:

- Energy threshold: 730 GeV
- Measured excess: 4.1 sigma (4.7 sigma with a refined analysis, see Fig. 2).
- Flux: 3.3% of the flux of the Crab nebula

[Aharonian et al, A&A, 403, L1 (2003)],
[Götting et al., The European Physical Journal C - Particles and Fields (2003)], see astro-ph/0310308

An upper limit on the 8% Crab level has been reported by the Whipple collaboration obtained from observations performed in 2000/01 with an energy threshold of 400 GeV. [LeBohec et al., ApJ, 610, 156-160 (2004)]

H.E.S.S. Observations & Analysis

H.E.S.S. observations in 2003 (construction phase) and 2004 (full setup). Standard cuts on run quality (stable weather and detector status):

Obs. Period	Livetime (h)	<zenith>	telescope setup
2003 (Mar-May)	13	39.6°	2 telescope setup offline event merging (GPS time)
2004 (Feb-May)	32	39.7°	4 telescope setup stereoscopic hardware trigger

Data analysed using standard H.E.S.S. calibration, image cleaning and Hillas parameterisation. Standard geometric shower reconstruction.
[Aharonian et al., A&A, submitted (2004) or astro-ph/0411582]

H.E.S.S. results

Combined 2003/2004 H.E.S.S. data: excess **>4 sigma** from the direction of M87.

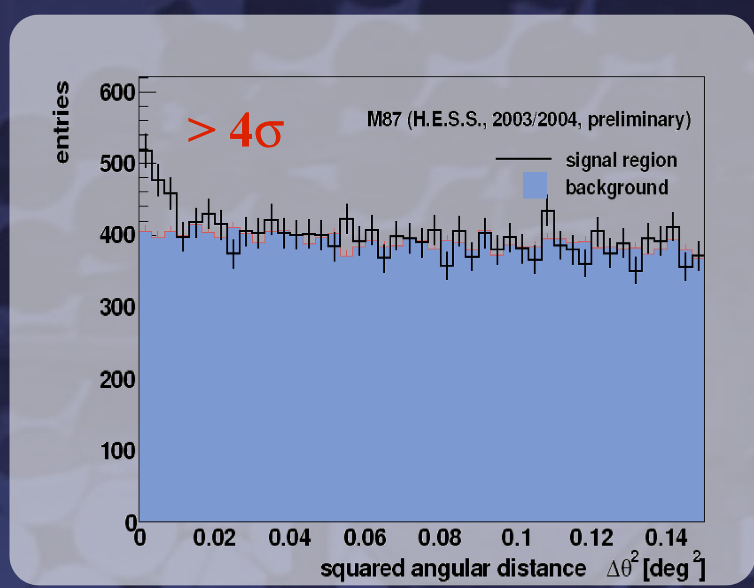


Fig. 3: Distribution of events vs. the squared angular distance $\Delta\theta^2$ (between shower direction and object position) for the M87 (signal) region and a background region (blue).

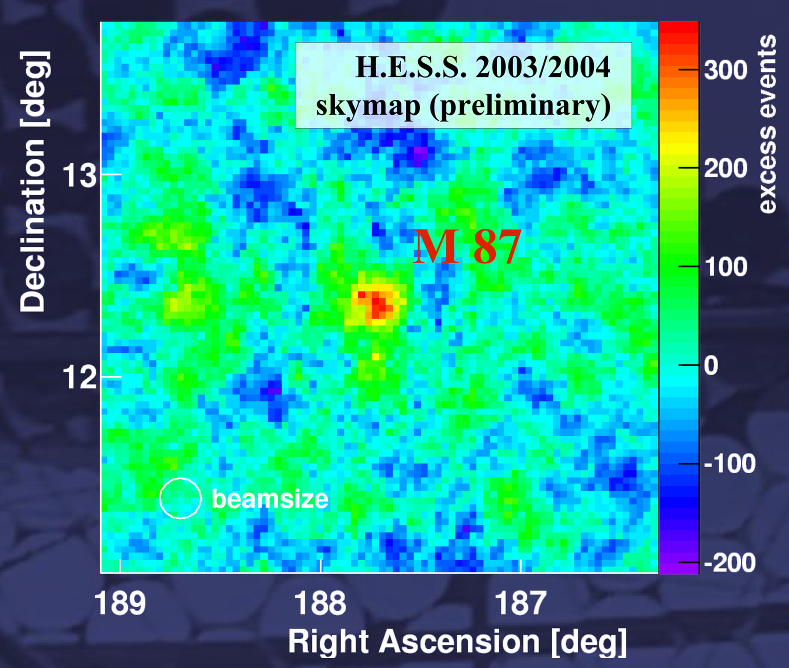


Fig. 4: Excess skymap (correlated bins) of the combined H.E.S.S. observations.

The lightcurve indicates flux variability at TeV energies: The H.E.S.S. estimated flux correspond to ~40% (2003 data) resp. ~20% (2004 data) of the reported HEGRA flux of M 87 (see Fig. 5).

Excess position: The mean position of the H.E.S.S. excess is compatible with the center of M87 (see Fig. 6).

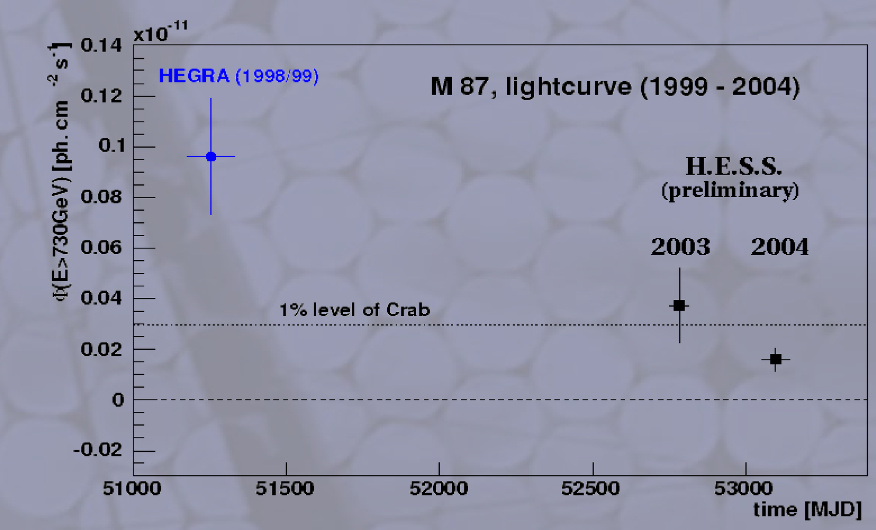


Fig. 5: Lightcurve showing the integral flux above 730 GeV (HEGRA threshold) assuming a power-law with photon index of Γ = 2.9. Systematic flux errors: ~20%. Indication of variability when comparing the H.E.S.S. and HEGRA results.

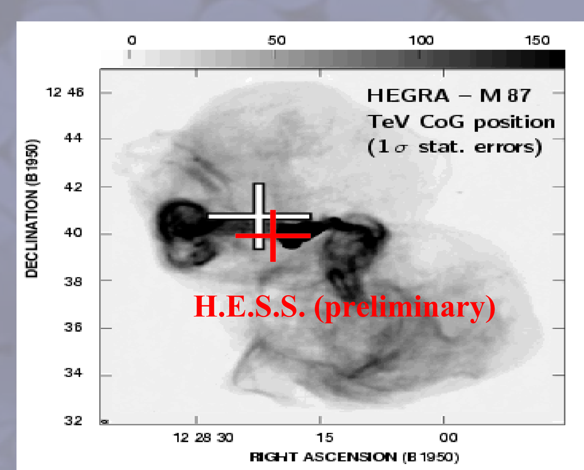


Fig. 6: The H.E.S.S. (red) and HEGRA (white) TeV positions in the M87 radio map. The H.E.S.S. position is compatible with the center of M87.

Conclusions

Indication for TeV emission on the >4σ level from M87 in the 2003/2004 H.E.S.S. data.

Indication for flux variability when comparing the H.E.S.S. and HEGRA results.

Physics interpretation: Flux variability would rule out an exclusive origin of TeV γ-ray production:...

- ... in outer jet regions
- ... correlated with cosmic rays (CR)
- ... originating from exotic particle annihilation processes (i.e. Neutralinos)

Still possible would be TeV γ-ray production in:...

- ... the central object, inner jet regions
- ... in compact knots in the jet (i.e. The HST-1 knot)

Acknowledgements

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