Resolving the kpc jet of Centaurus A in TeV gamma-rays

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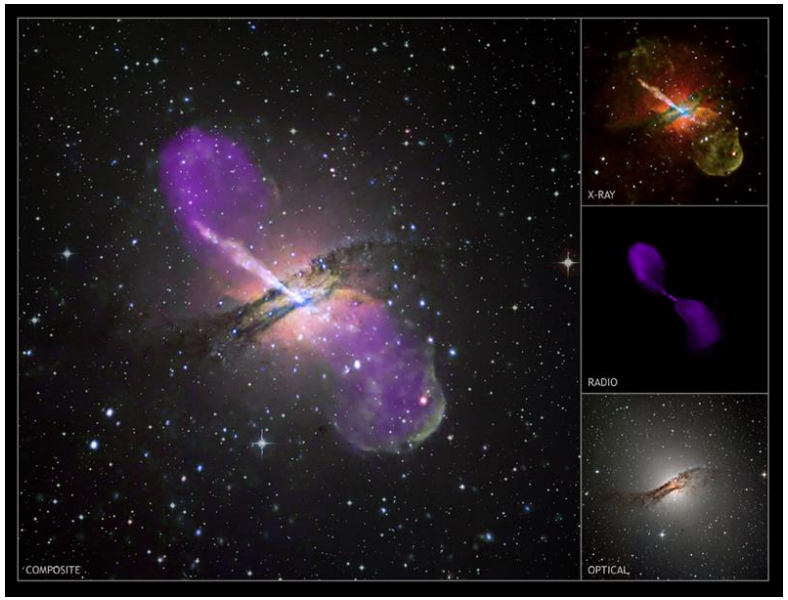
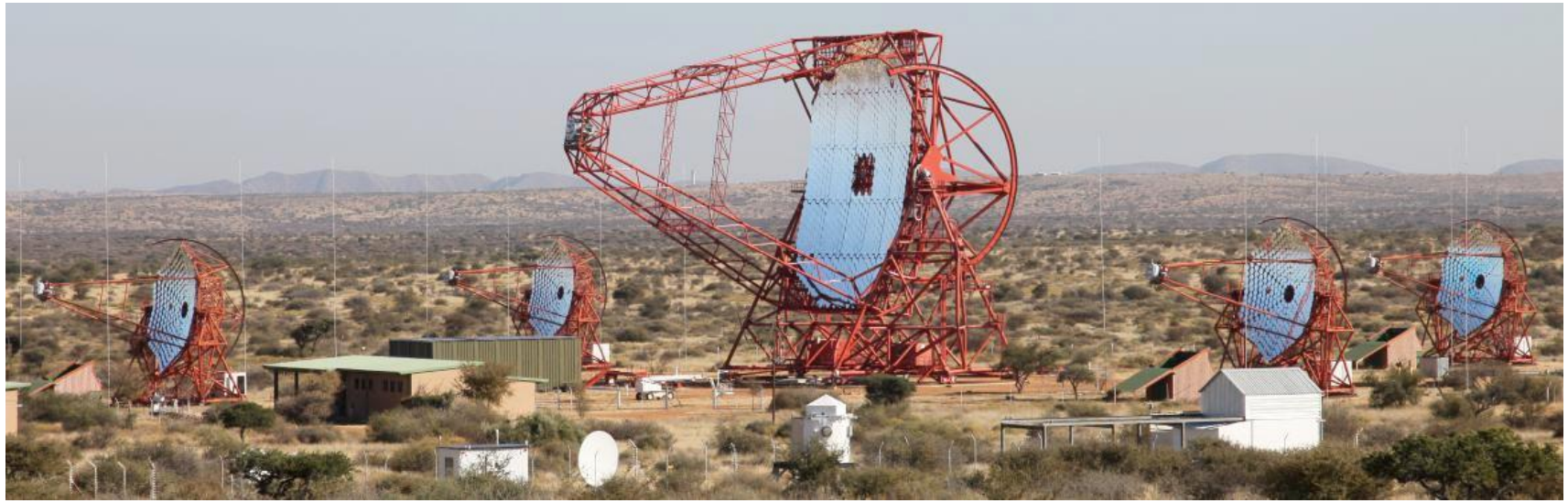
for the H.E.S.S. collaboration



High Energy Stereoscopic System (H.E.S.S.)



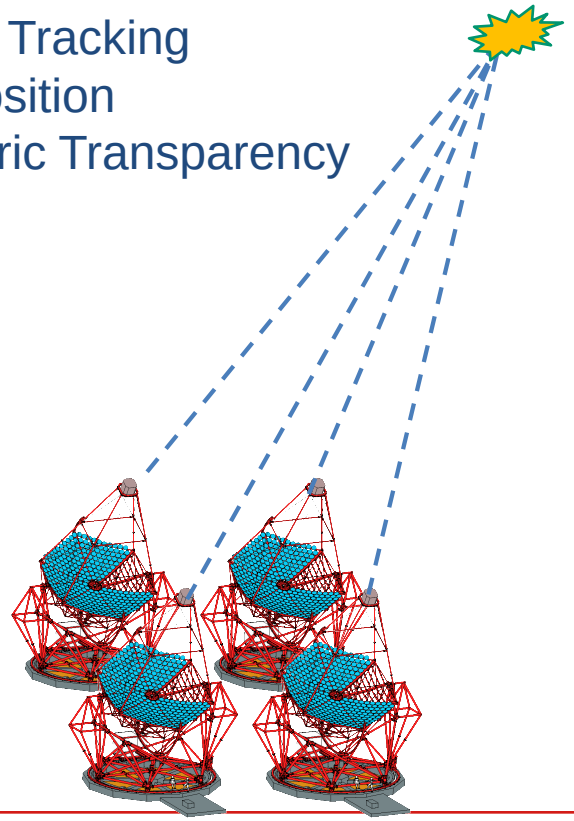
- Array of 4+1 Cherenkov telescopes located on Khomas Highland, Namibia (1800m asl, 23°16‘ S, 16°30‘E)
- H.E.S.S. phase 1 (09-2002):
  - 4 telescopes: Ø 12 m,107 m^2
  - Stereoscopic reconstruction
  - 960 PMTs/camera, Field of view : 5°
  - Observations : ~1000h/year
  - Source position : ~ 10’’
- H.E.S.S. phase 2 (09-2012):
  - a 5th telescope, Ø 28 m, 600 m^2 (largest IACT in the world)
  - 2048 PMTs, Field of view : 3.5°

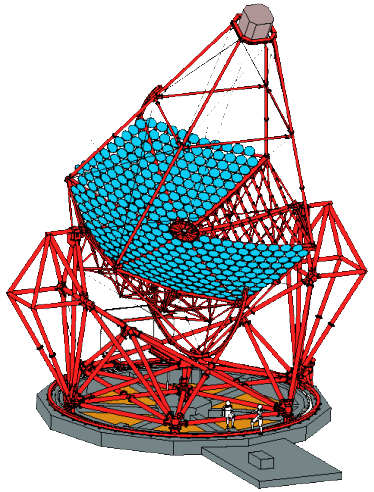
→ Energy threshold (zenith) ~ 30 GeV

Advanced framework for simulations

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

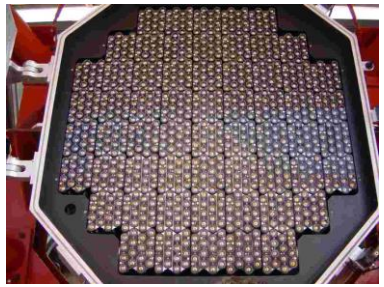
Array-wise
- Telescope Tracking
- Source Position
- Atmospheric Transparency



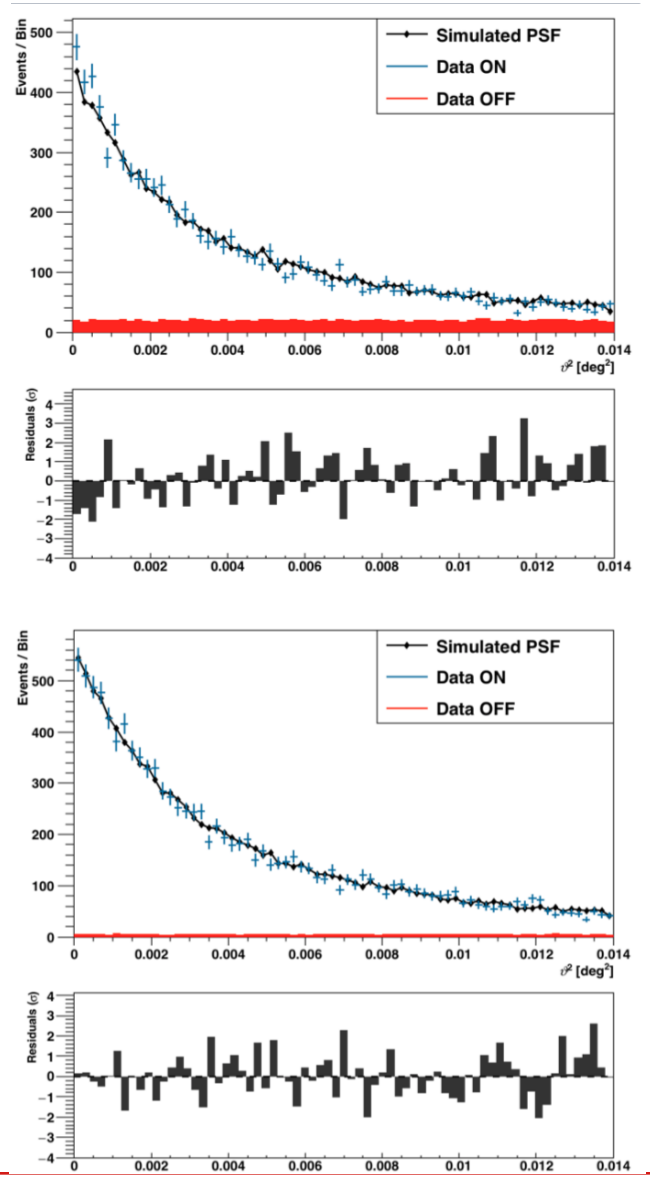


Telescope-wise
- Camera focus
- Trigger Settings
- Live-Time fraction
- Average reflectivity

Pixel-wise
- Broken Pixels
- PMT Gain
- HI-Lo ratio
- Flatfield Coeffient
- NSB (star field, …)

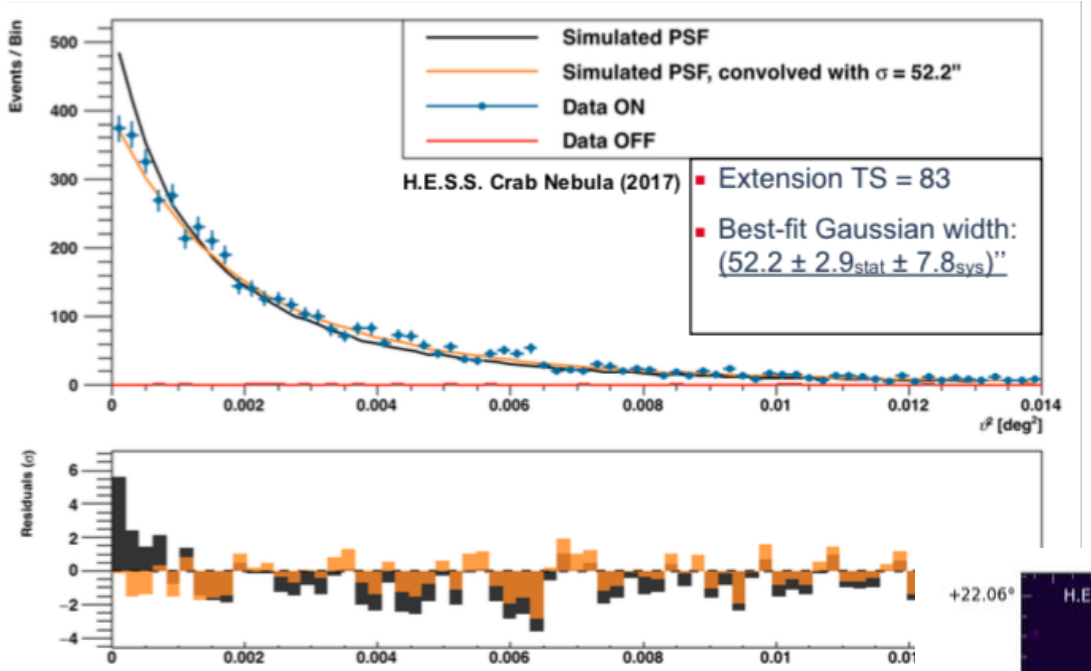


Outcome: Morphology of Point-Like Sources



- PKS 2155-304
  - Detection significance: 125σ
  - S/B ratio: 6.9
  - Consistent with 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)

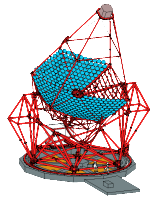
Outcome: New capabilities in morphology studies

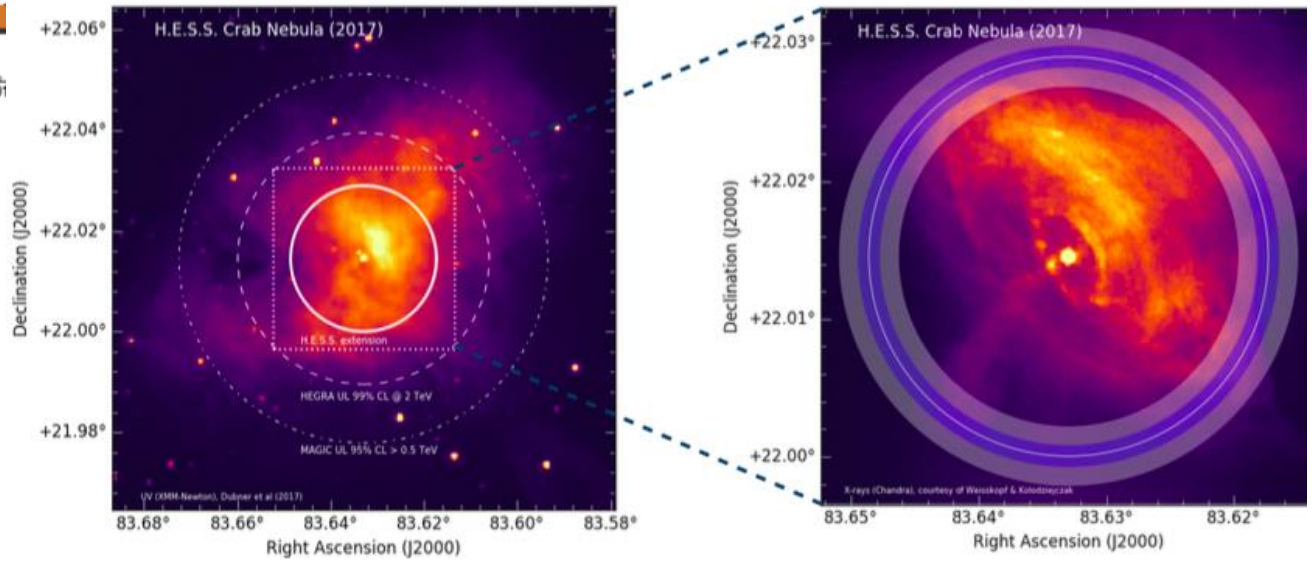


Extension of the Crab Nebula 52", comparable with X-ray Nebula

Fermi Symposium, 2017

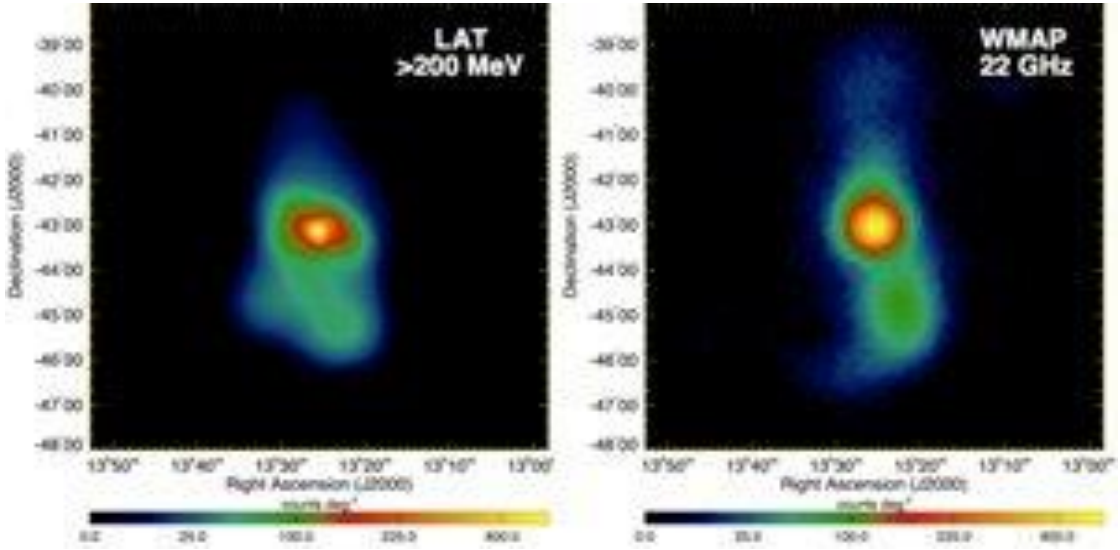
Nature Astronomy, in press

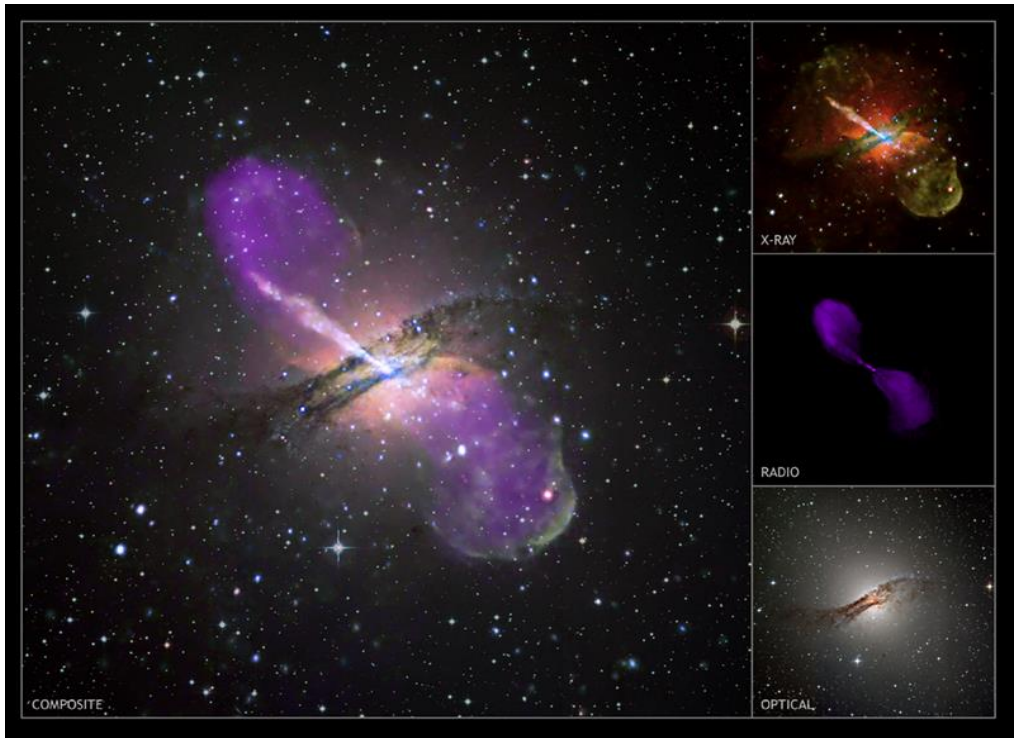




Centaurus A

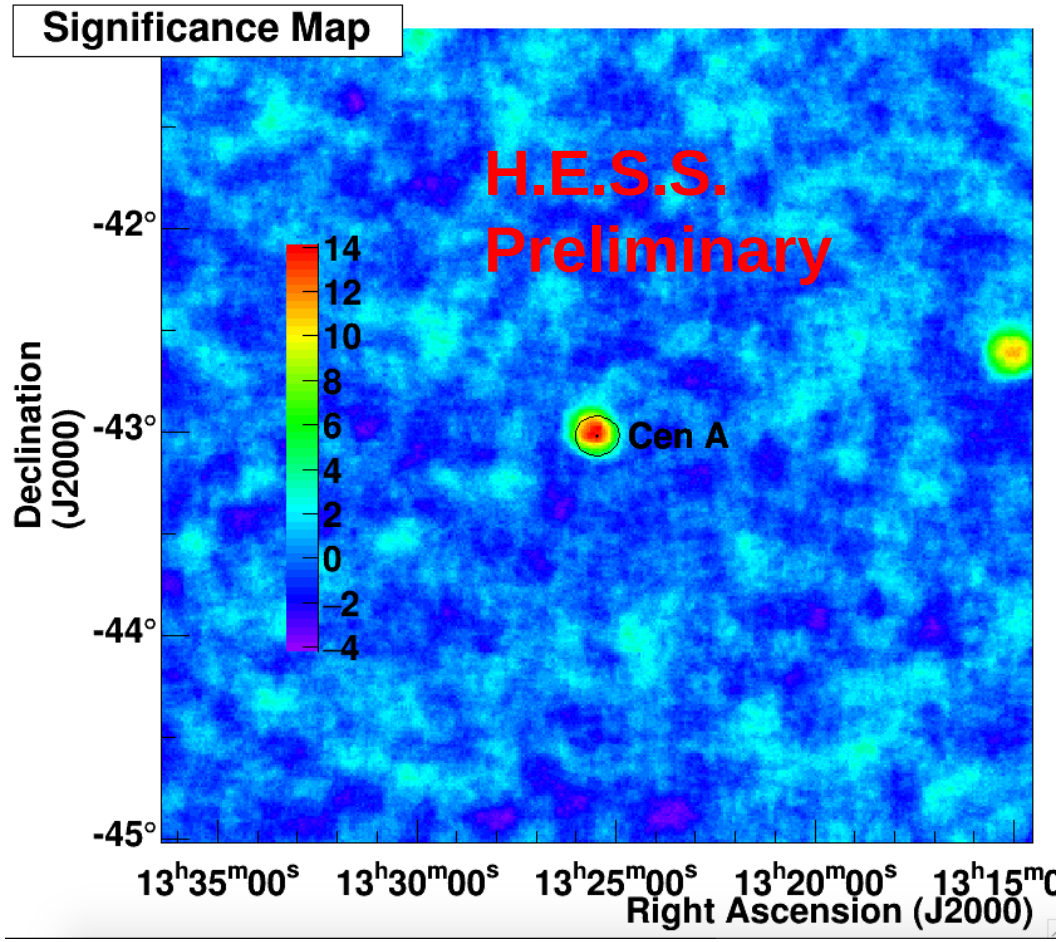
- Radio galaxy (NGC 5128) of FRI type
  - Nearest active galaxy at a distance of 3.7 Mpc
  - Giant lobes covering several degrees
  - Detailed morphological analysis possible (1° ≃ 65 kpc).
- Cen A @ gamma-ray
  - H.E.S.S discovery at TeV energies
  - Fermi-LAT : extended lobes (deg. Scale)



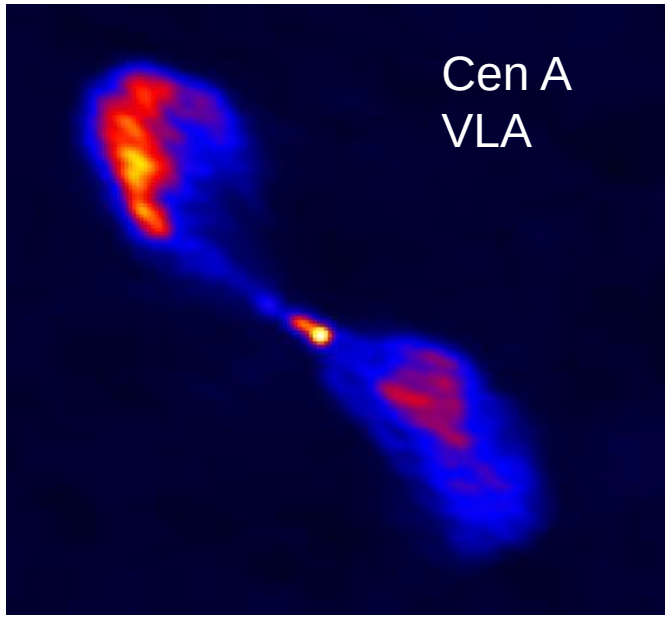


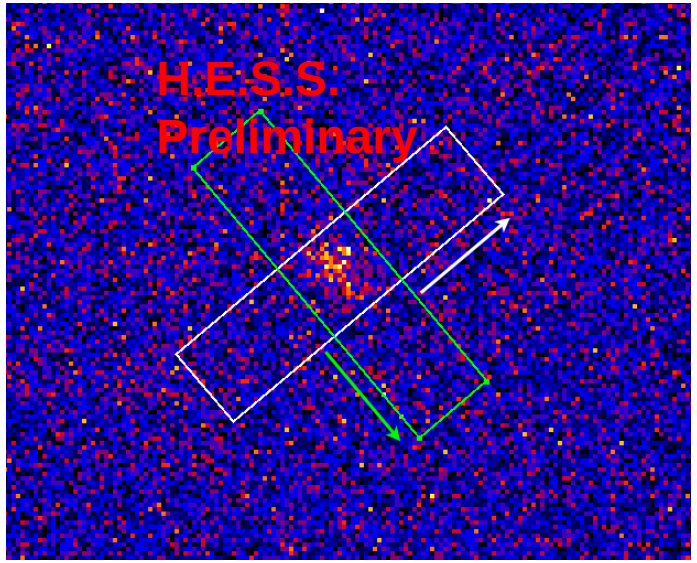
H.E.S.S. Re-analysis of the H.E.S.S. phase I data

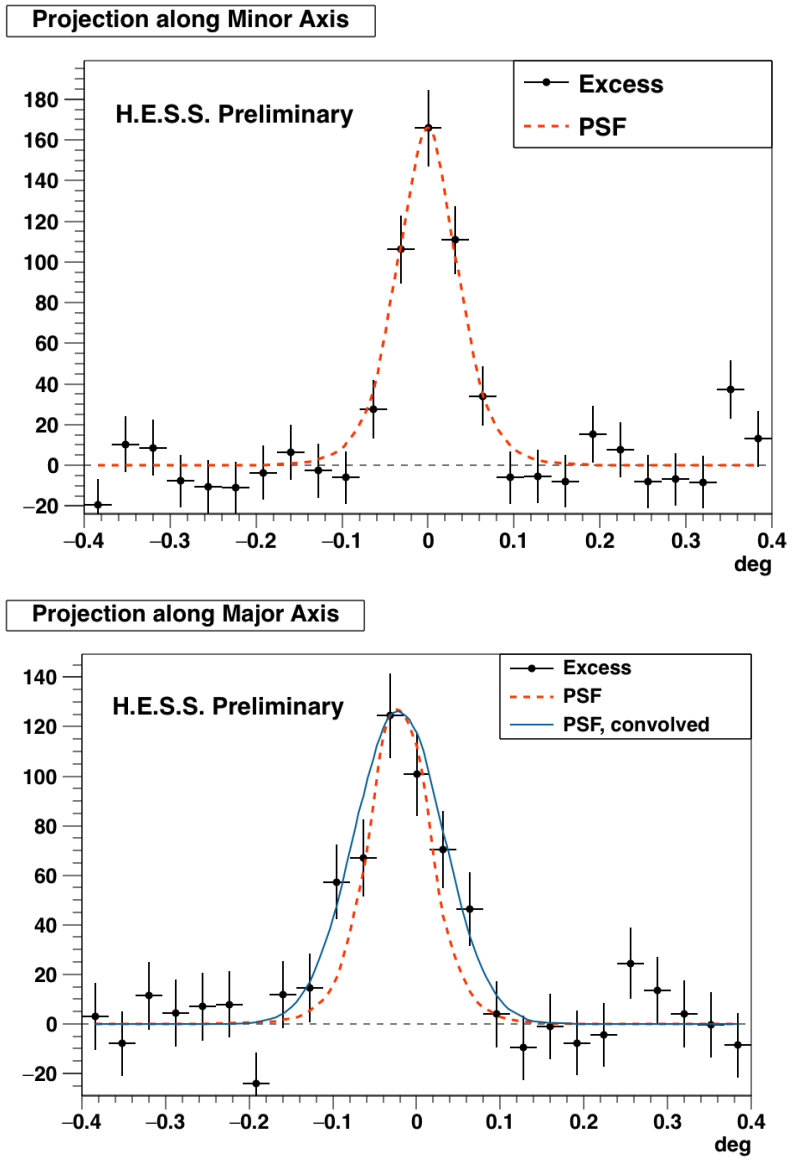
- Deep H.E.S.S. Observations from 2004 to 2013
  - 202 hours of live time
  - Change in hardware state, observation conditions
- Detection significance: 13.1σ
- S/B ratio: 0.5
- Challenging data set
  - Long exposure over several years
  - Different hardware states
  - Different obs. conditions
  - Low S/B ratio



1D-projection of the event map





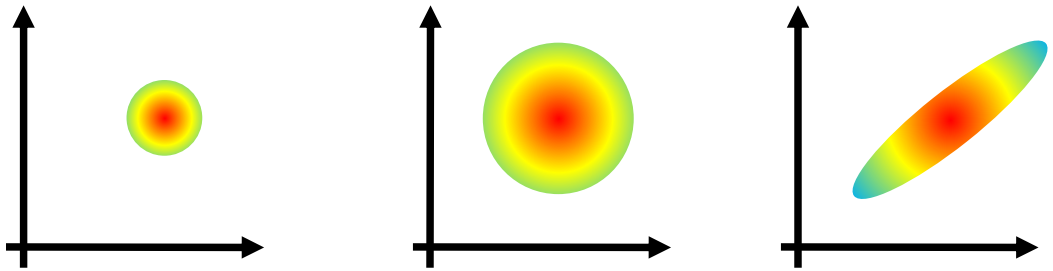


Projection along the radio jets

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

2D study of the Cen A data set

- Morphological models



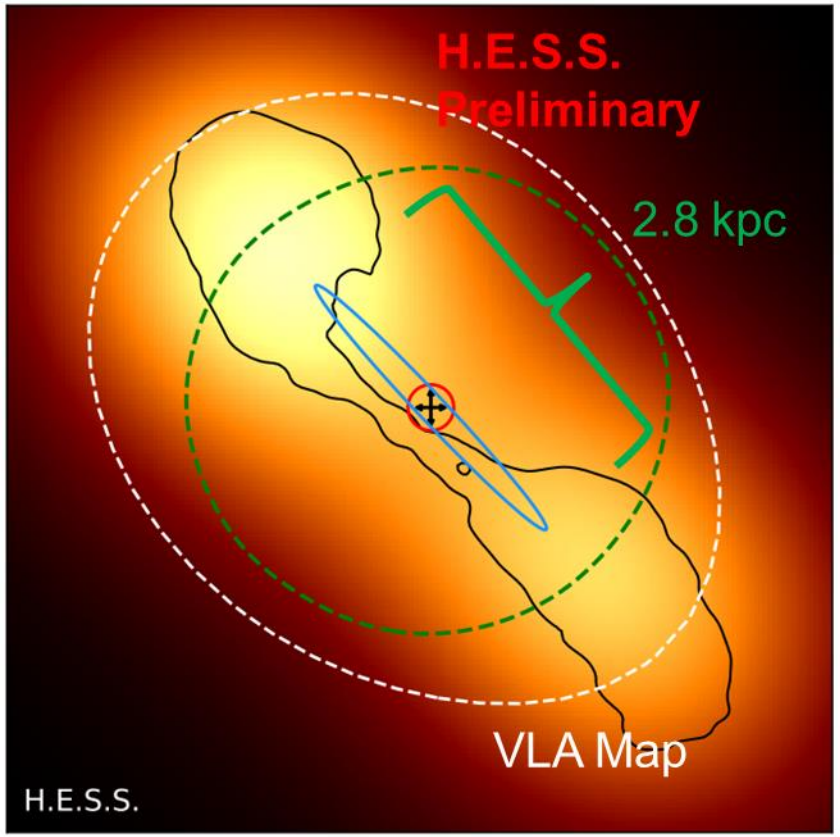
Point-like | Sym-Gauss. | Elliptic-Gauss.

Sym. Gauss. vs. Point-Like	Elliptic. Gauss. vs. Point-Like	Elliptic. vs. Symm. Gauss.
3.54σ	5.15σ *(5.47σ)*	4.18σ *(4.56σ)*

PRELIMINARY

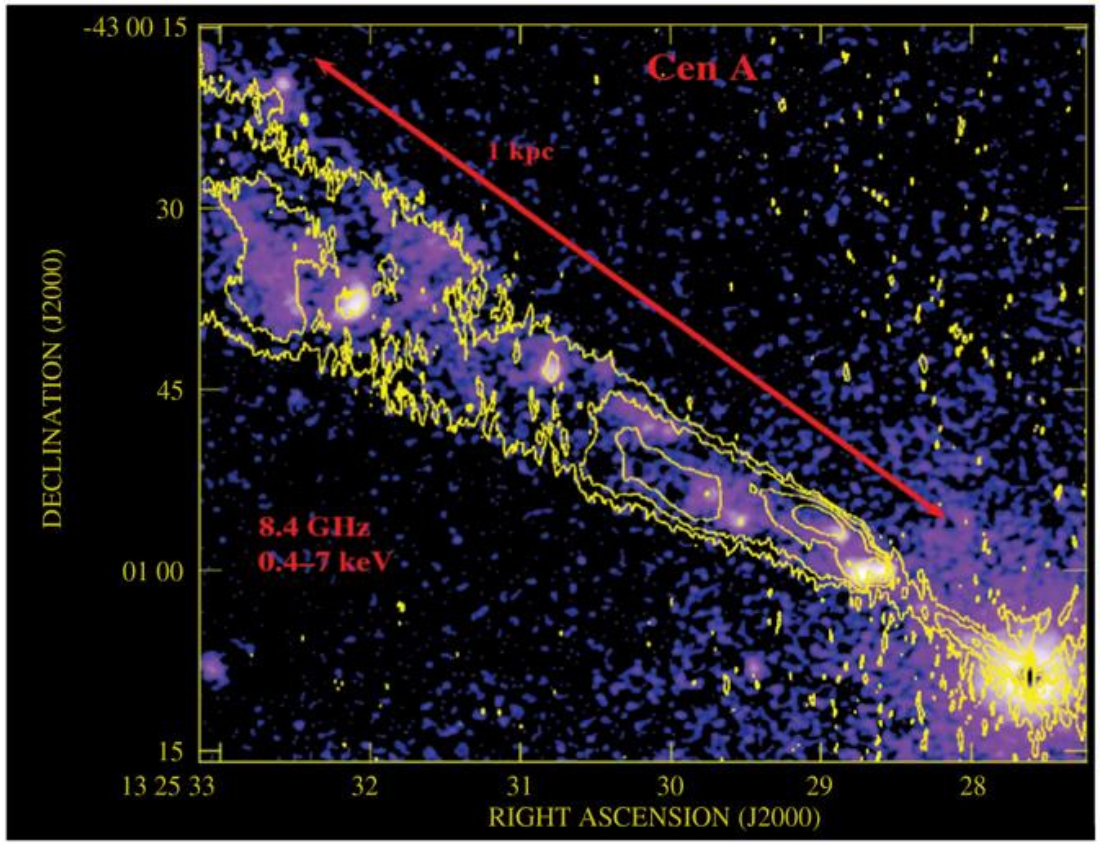
- Gaussian width of semi-major axis: 0.044 ° +/- 0.012°
- ~ Point-Like in the transverse direction
- Aligned with inner radio jets

PSF
Best fit
Pointing uncertainties
Stat. uncertainties



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

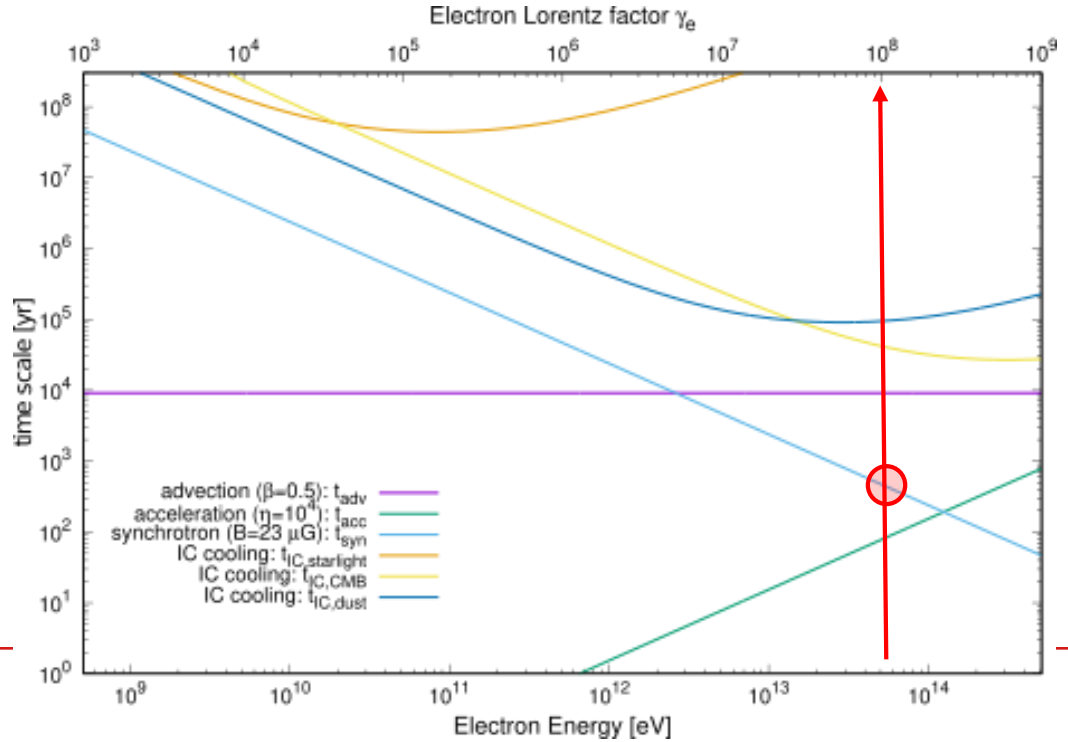
Chandra X-ray image of the first kpc of Cen A's jet.



(Credit: Schwartz 2010, Hardcastle et al. 2003)

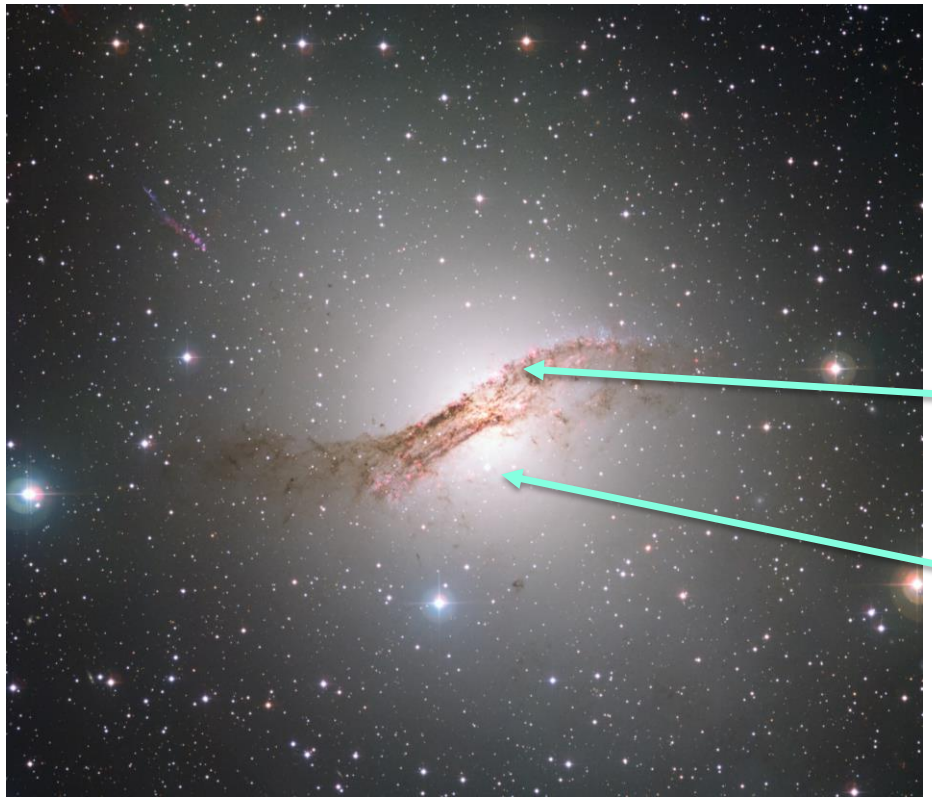
Emitting particles ?

- 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 $\gamma \sim 10^8$)

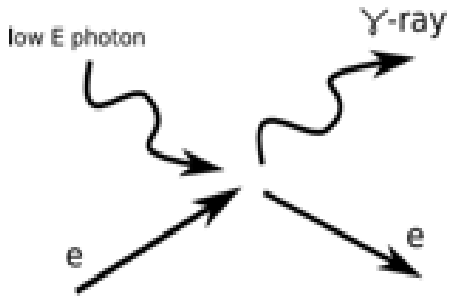


Extended VHE emission along the kpc-scale jet in Cen A?

Source of soft photon fields



(Credit : ESO/WFI)

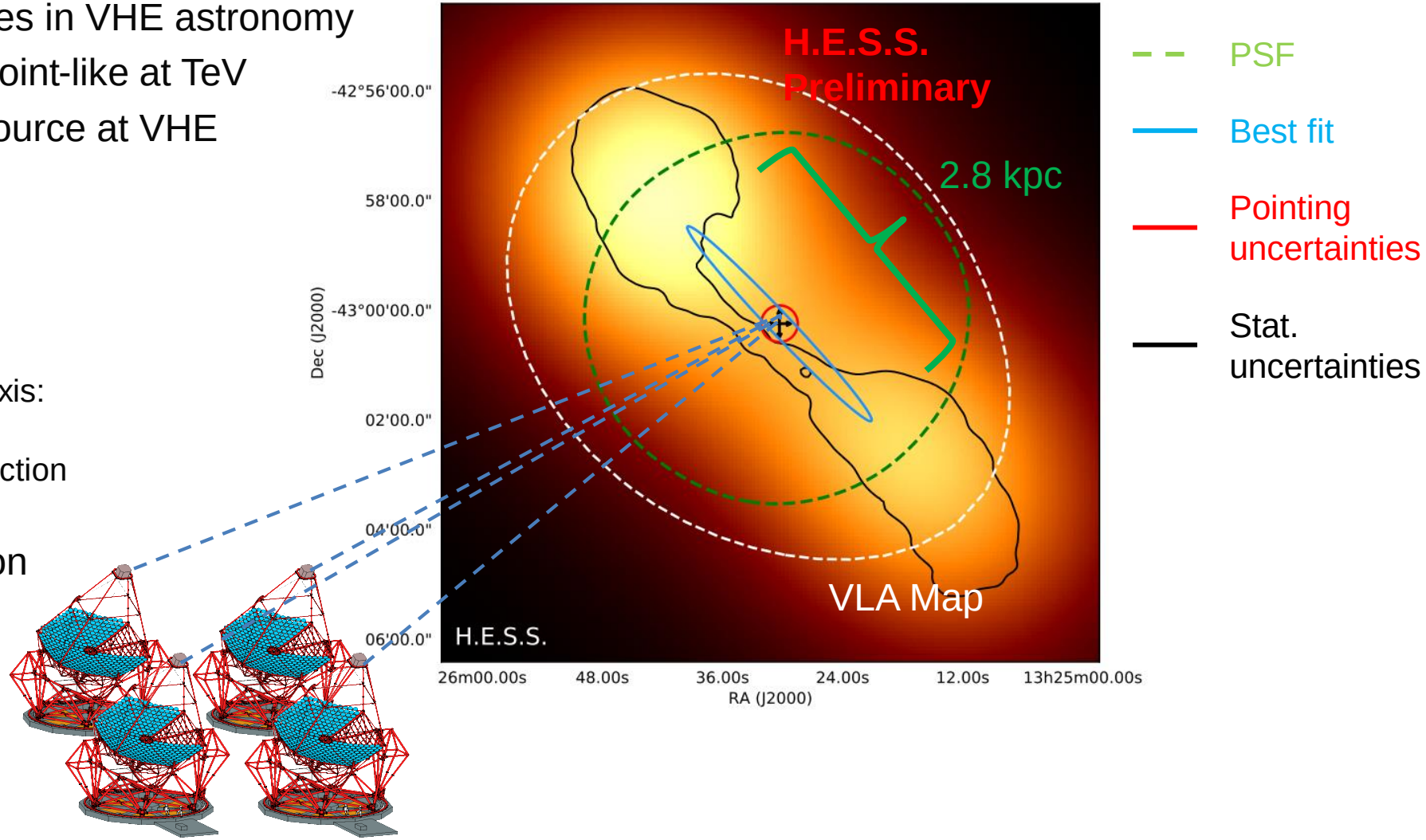


- External soft photon fields
  - **dust** (peaking @ $\nu_p \sim 3 \times 10^{12}$ Hz): $\nu_{VHE} \sim \gamma^2 \nu_p$ (Thomson) $\Rightarrow \gamma \sim 10^7$
  - **host starlight** ($\nu_p \sim 5 \times 10^{14}$ Hz): $\nu_{VHE} \sim \gamma m_e c^2$ (KN) $\Rightarrow \gamma \sim 10^6$
  - CMB and SSC contribution negligible

Conclusions

- New era for morphology studies in VHE astronomy
- Centaurus A emission is not point-like at TeV
- First extragalactic extended source at VHE

- Morphology of Cen A:
  - Elliptical shape :
  - Gaussian width of semi-major axis: 0.044 ° +/- 0.012° (2.8 kpc)
  - Point-Like in the transverse direction
  - Aligned with radio jets
- Implies continuous acceleration along the jets
- Paper to appear soon



Thank you