Laboratoire d'Annecy de Physique des Particules

# Centaurus A, notre proche voisine

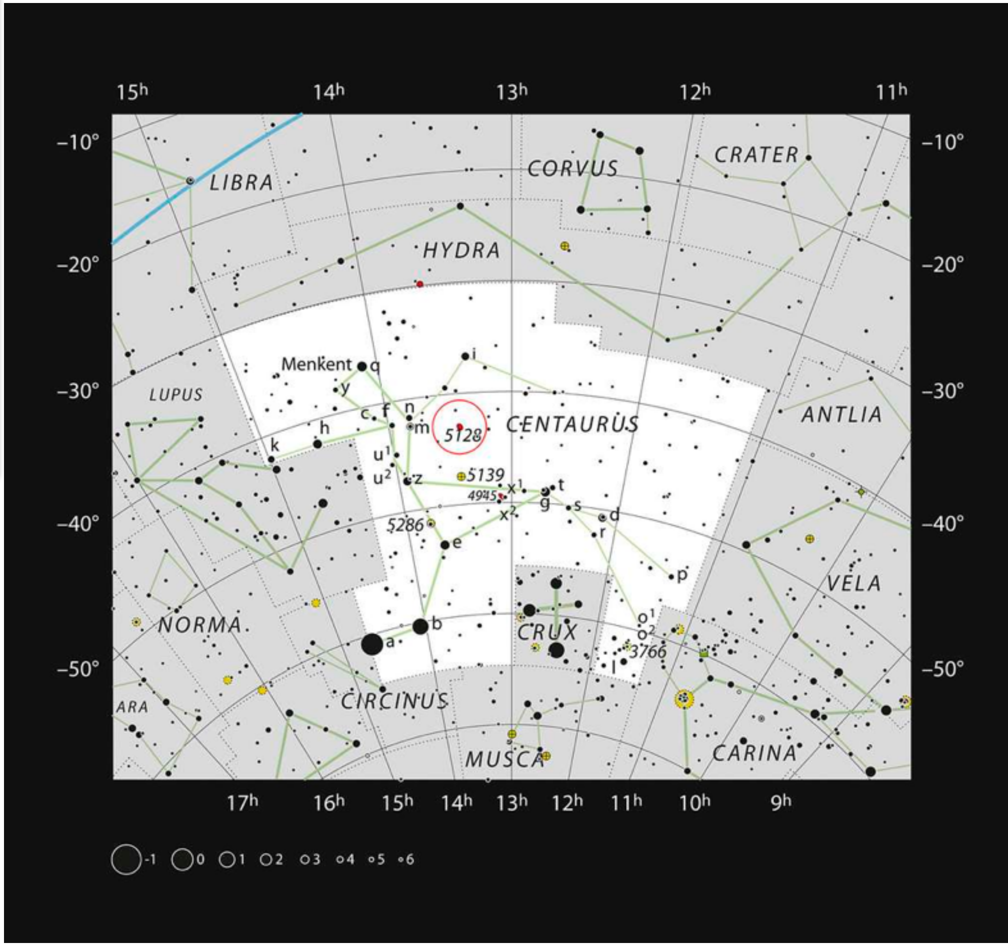
## H.E.S.S. view of the source

13/12/2021

Radio galaxy (NGC 5128) of FRI type

Nearest active galaxy at a distance of 3.7 Mpc

Detailed morphological analysis ($1^\circ \simeq 65$ kpc).



# The Many Faces of Centaurus A

Sydney, 28 June – 3 July 2009

**Content**

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- Rationale
- Programme
- Participants
- Venue
- Proceedings
- Contact

## Welcome

The international conference *The Many Faces of Centaurus A* aims at bringing together a broad range of astronomers and high-energy physicists that traditionally form separate research communities. The radio galaxy Centaurus A (NGC 5128) has attracted great interest from the international astrophysics and high energy physics communities since its discovery as a radio source 60 years ago. Yet this will be the first conference devoted to this intriguing source. Please see the Science Rationale for more information.


## Organising Committees

### SOC

- Ilana Feain (*chair, ATNF*)
- Phil Edwards (*ATNF*)
- Ken Freeman (*ANU*)
- Bill Harris (*McMaster University*)
- Frank Israel (*Leiden University*)
- Jun Kataoka (*Tokyo Institute of Technology*)
- Ken Kellermann (*NRAO*)
- Raffaella Morganti (*ASTRON*)
- Marina Rejkuba (*ESO*)
- Rob Sharp (*AAO*)
- Diana Worrall (*University of Bristol*)

### LOC

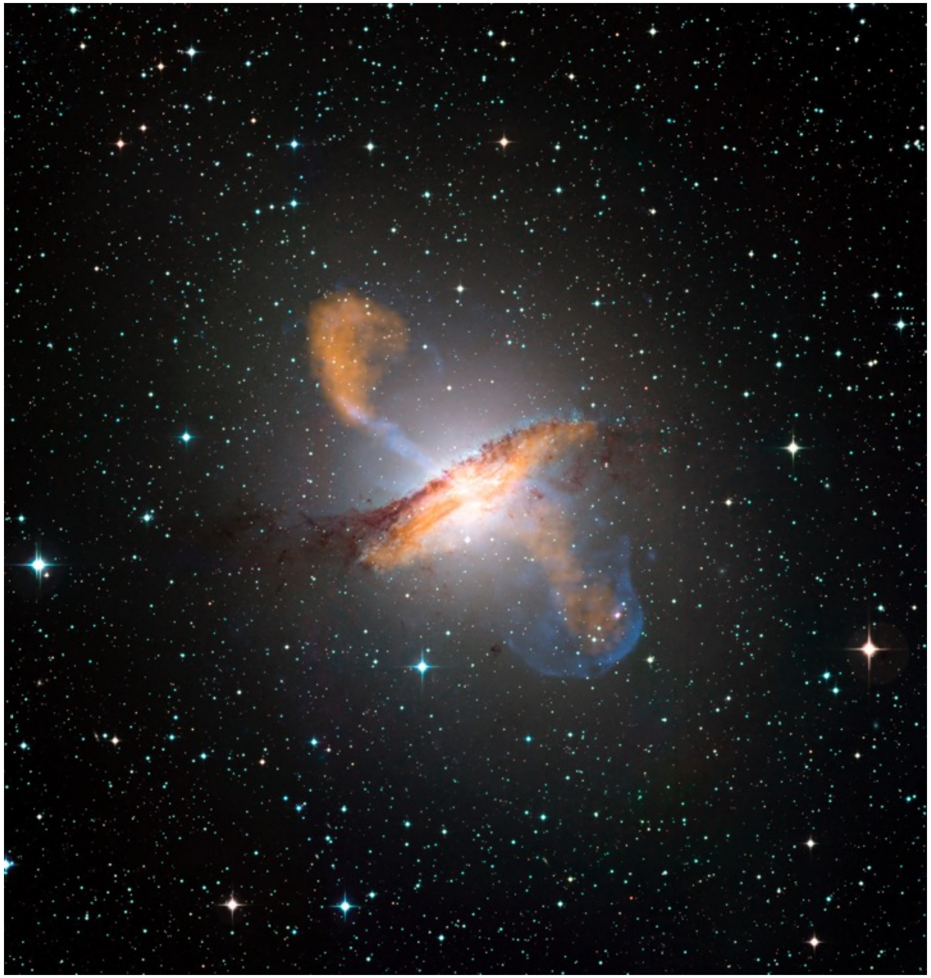
- Ilana Feain (*chair*)
- Bjorn Emonts
- Vicki Fraser
- Bärbel Koribalski
- Ángel López-Sánchez
- Tobias Westmeier

### E-mail

cena @ csiro.au

Discovered James Dunlop in 1826.

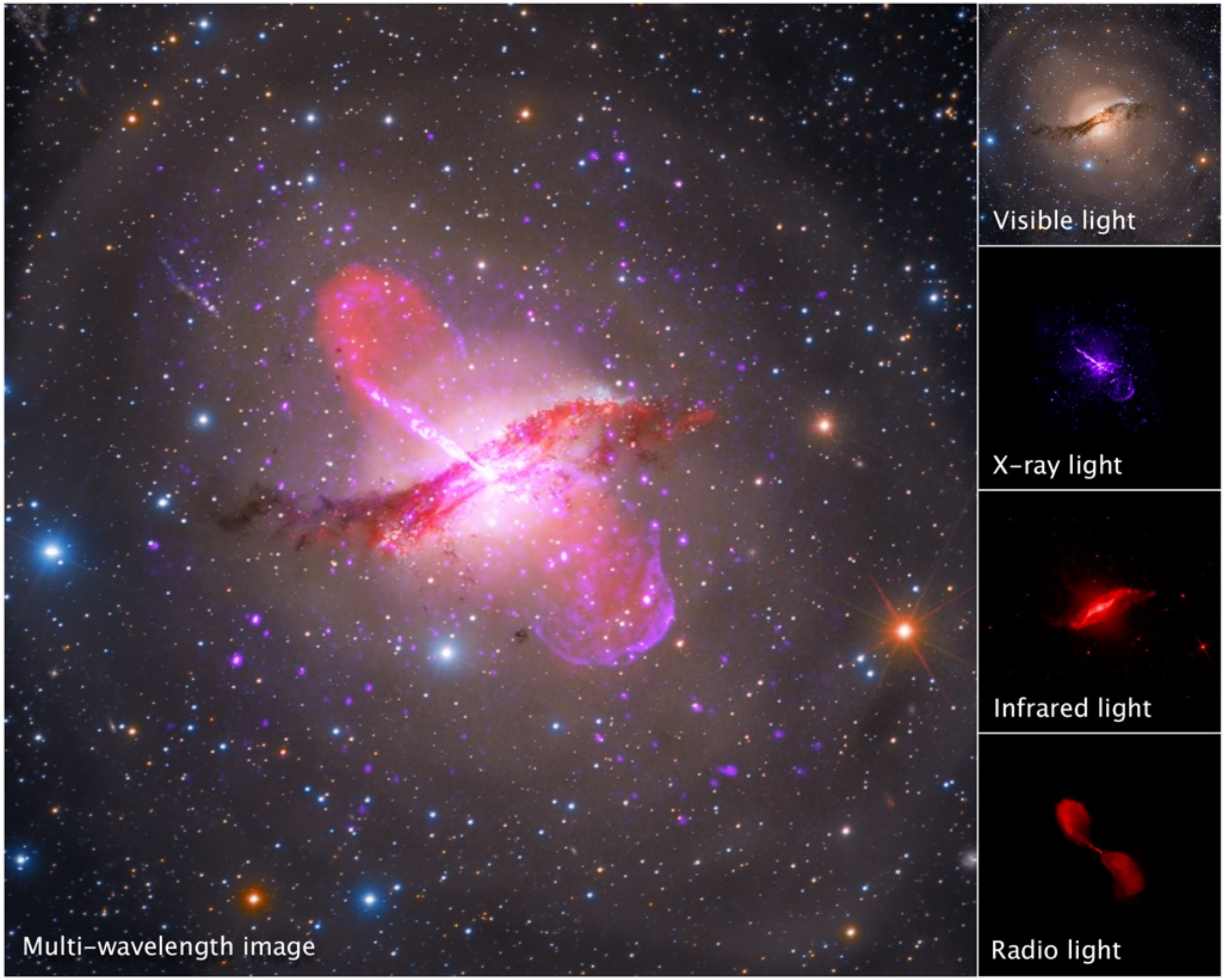
Thin dust layer noticed in 1847 by John Herschel



Elliptical galaxy collided with a relatively smaller spiral galaxy

Old star in the bulb

Layer is a star forming region




Centaurus A's dusty core is apparent in visible light…

… but its jets are best viewed in X-ray and radio light.

X-ray: NASA/CXC/SAO; optical: Rolf Olsen; infrared: NASA/JPL-Caltech; radio: NRAO/AUI/NSF/Univ.Hertfordshire/M.Hardcastle

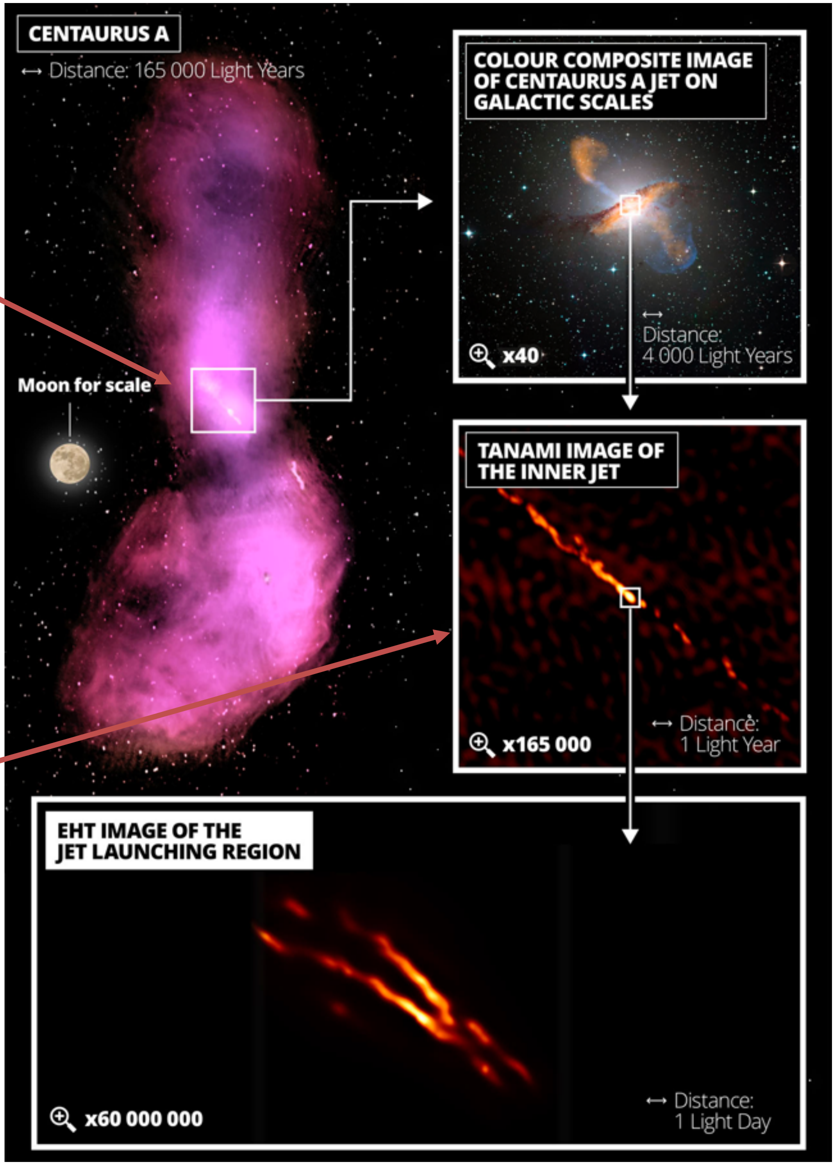
Detailed morphological analysis ($1^\circ \simeq 65$ kpc).

Core

Giant radio lobes

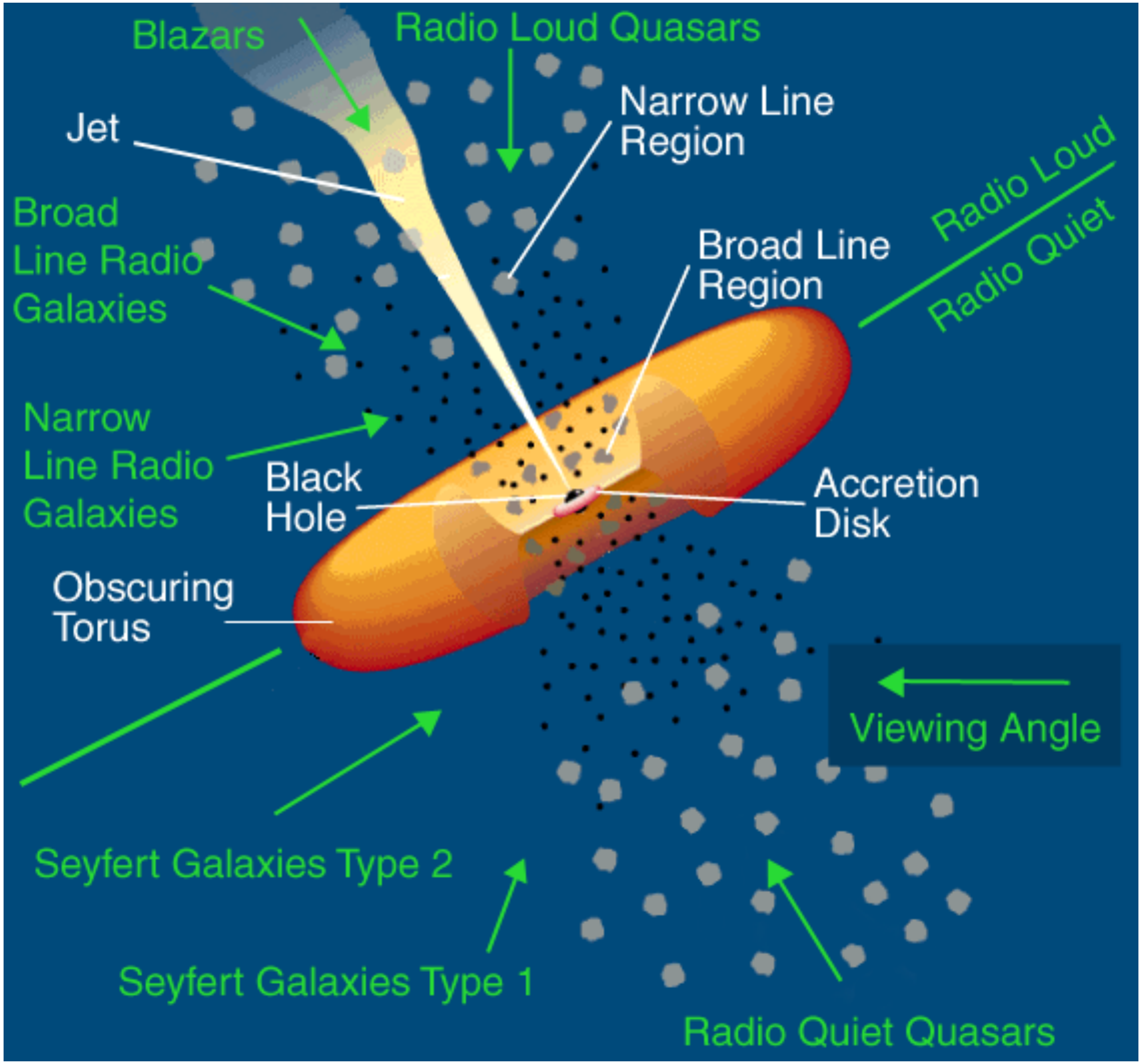
TANAMI Radio data
Müller *et al.*

EHT / Janssen *et al.*



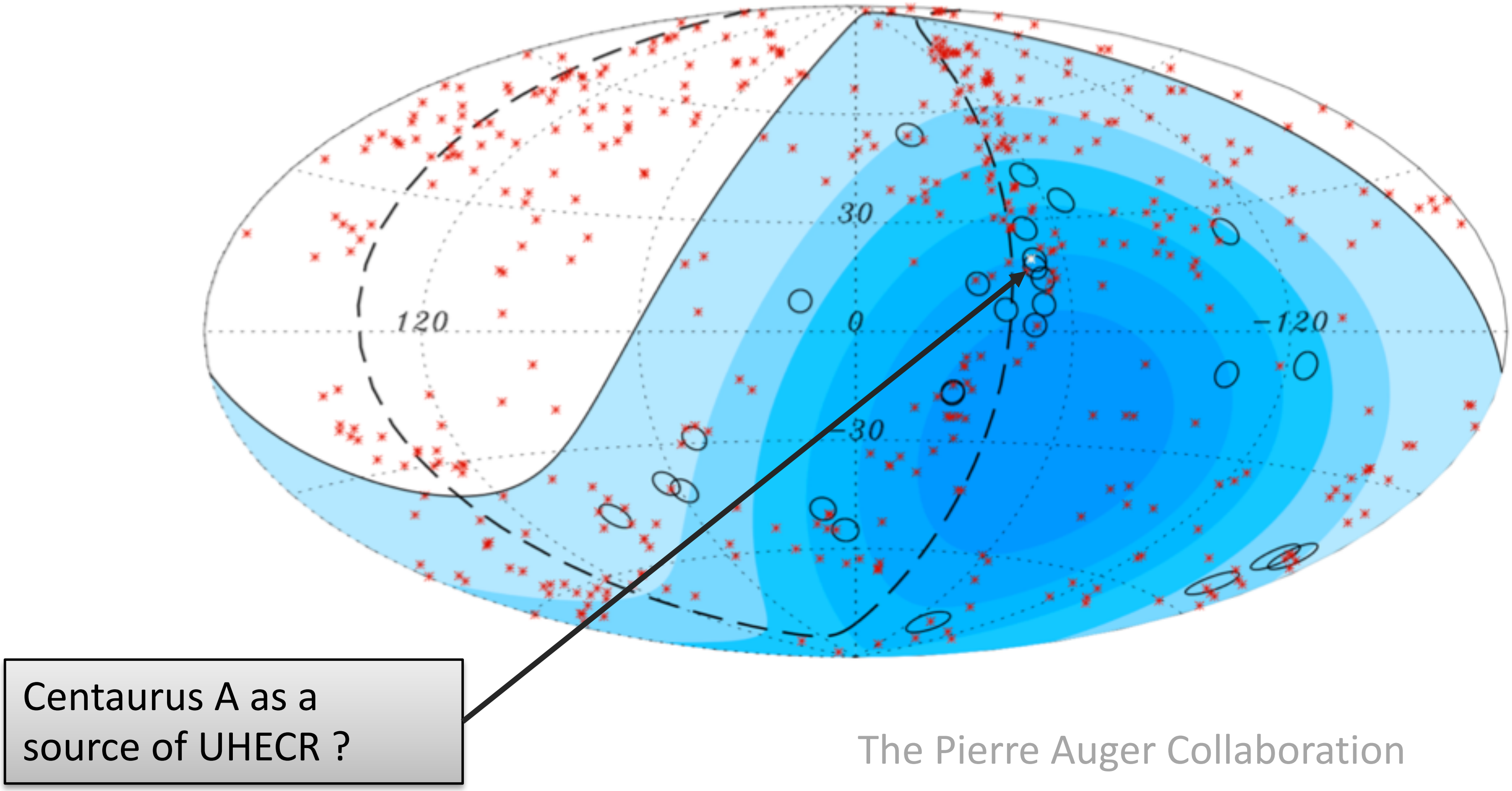
Black Hole

Torus, Cloud, Jet



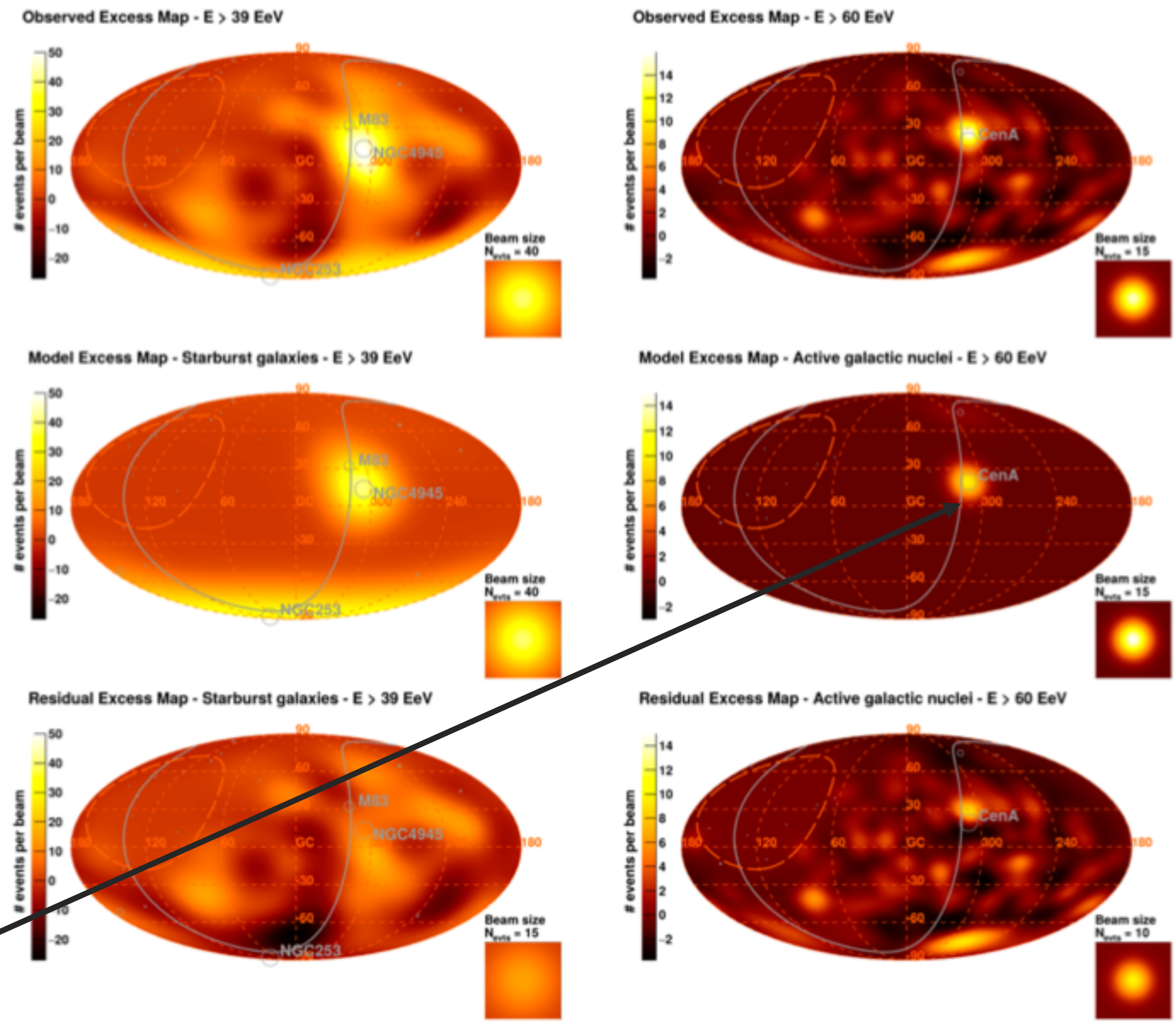
Correlation of UHECRs arrival with AGN?

BUT AGN trace latter and then sources




The Pierre Auger Collaboration

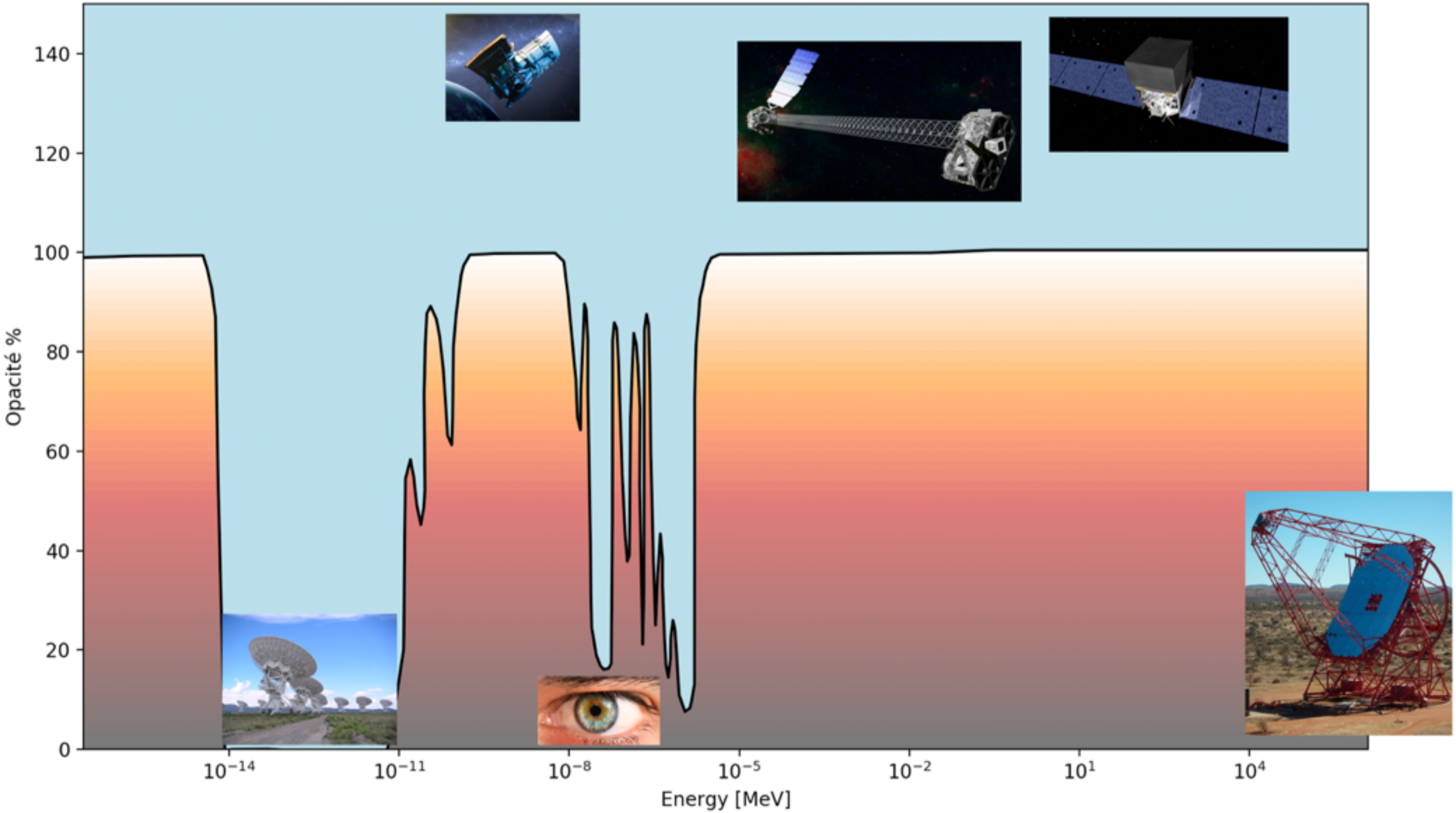
Starburst galaxies seems better counterpart




Centaurus A as a source of UHECR ?

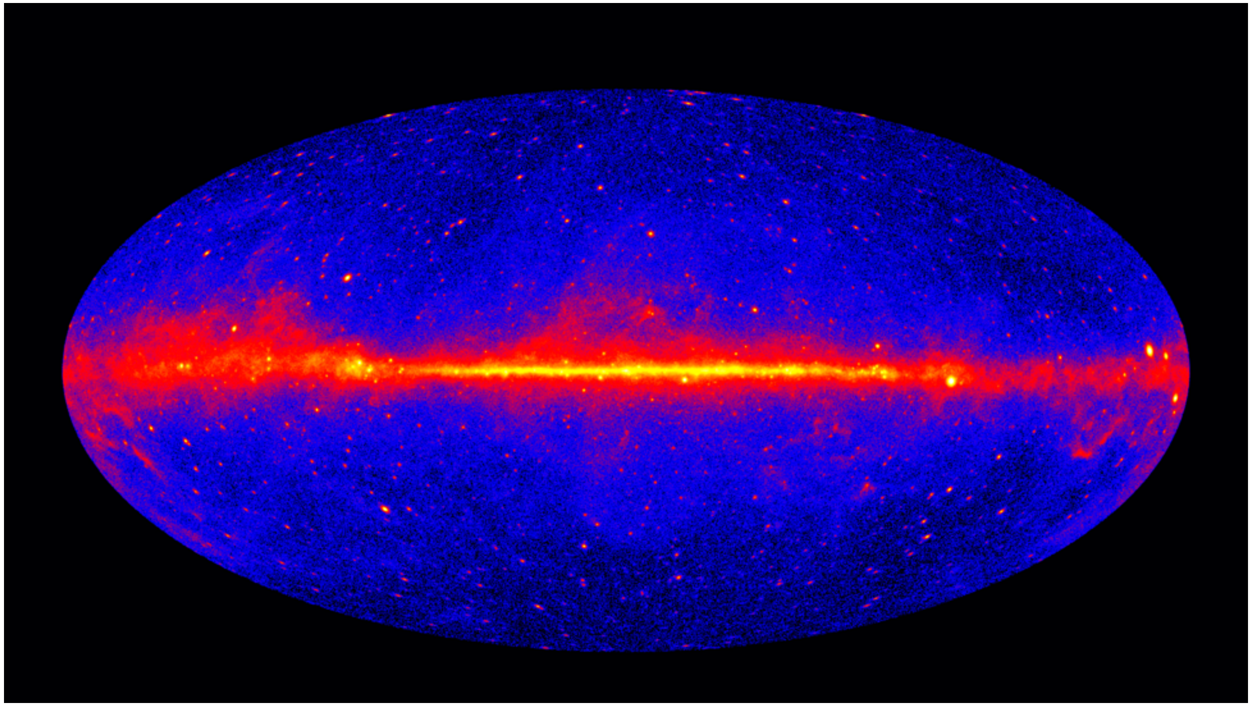
The Pierre Auger Collaboration, 2018

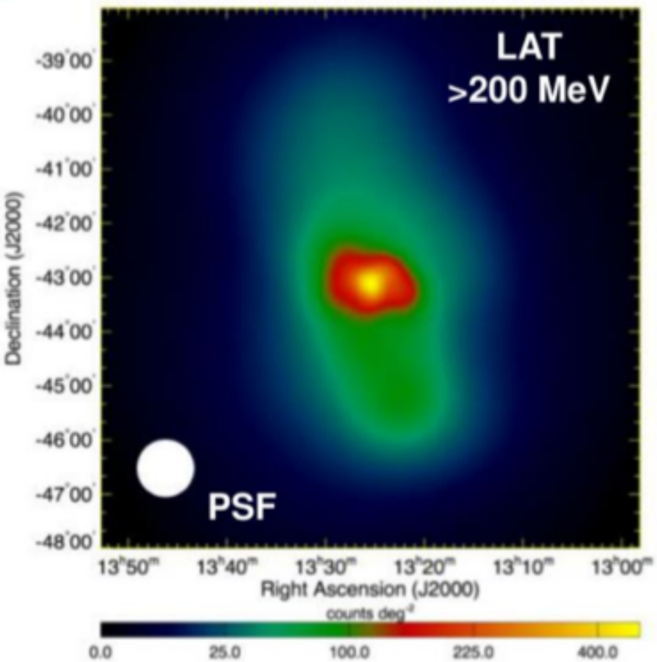
# Centaurus A at Gamma-ray energies



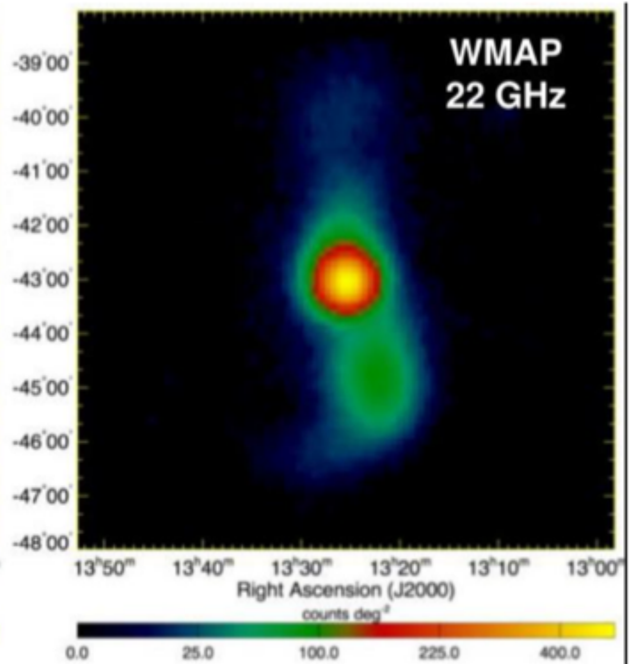
140
120
100
80
60
40
20
0
Opacité %
$10^{-14}$
$10^{-11}$
$10^{-8}$
$10^{-5}$
$10^{-2}$
$10^{1}$
$10^{4}$
Energy [MeV]

Characteristics
- Launched 11 June 2008
- All sky monitor
- 100 MeV- 300 GeV (Few TeV)
- Data and software publicly available




Background (isotropic and diffuse) and field point sources subtracted




WMAP images provided by Nils Odegard (GSFC)

Giant Lobes of Cen A

10 months of all-sky survey

Similar properties

Γ = 2.60 (+0.14/–0.15)

Γ = 2.52 (+0.16/–0.19)

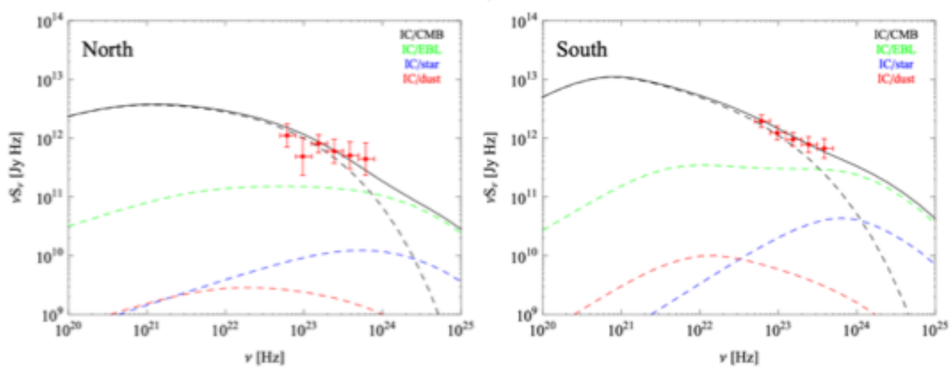
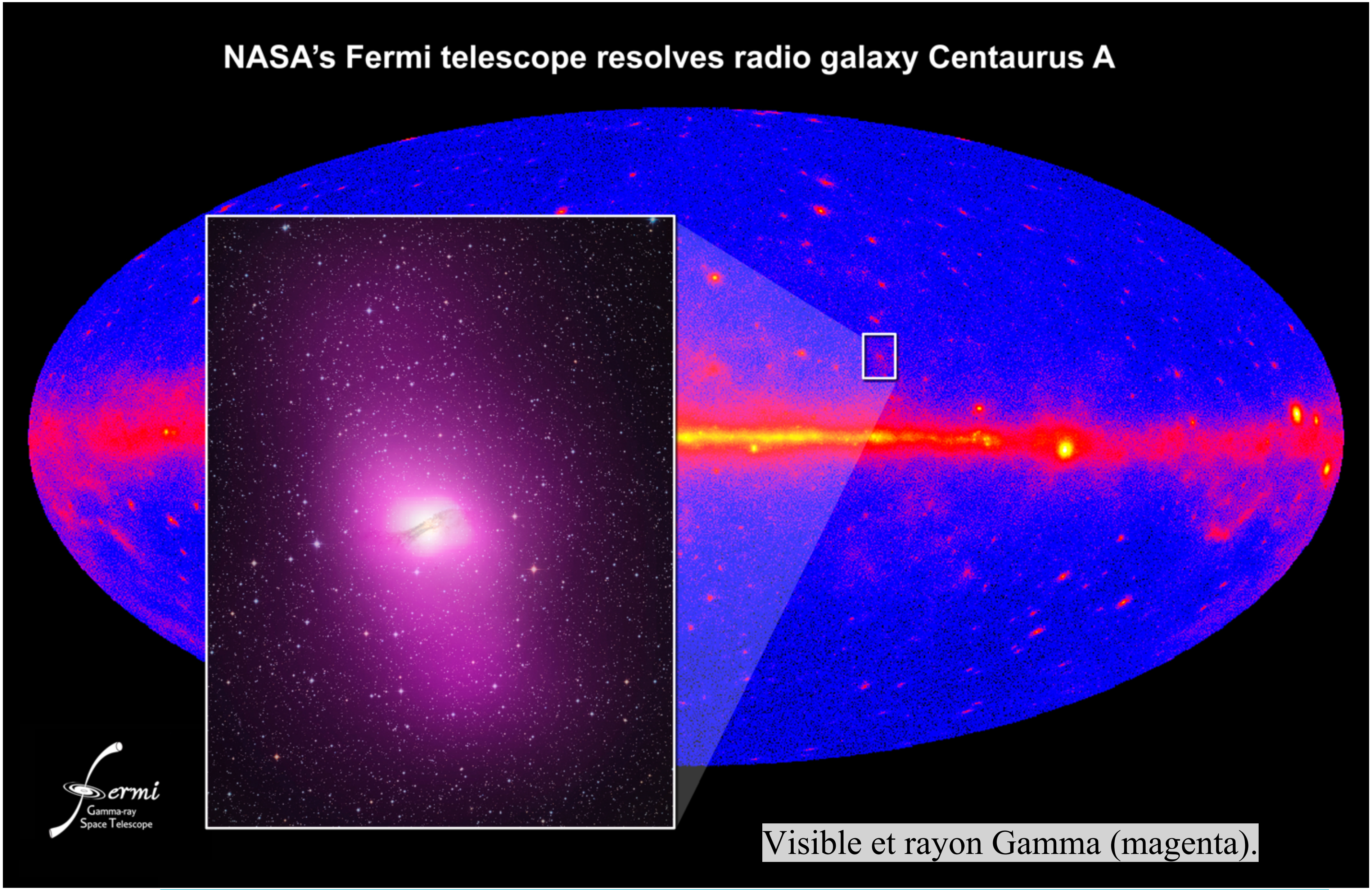



**Fig. 4.** Detail of the IC portion of the northern **(A)** and southern **(B)** giant lobes' SEDs (cf., Fig. 3). The separate contributions from the different photon seed sources are indicated with dashed lines while the total emission is the solid black line.

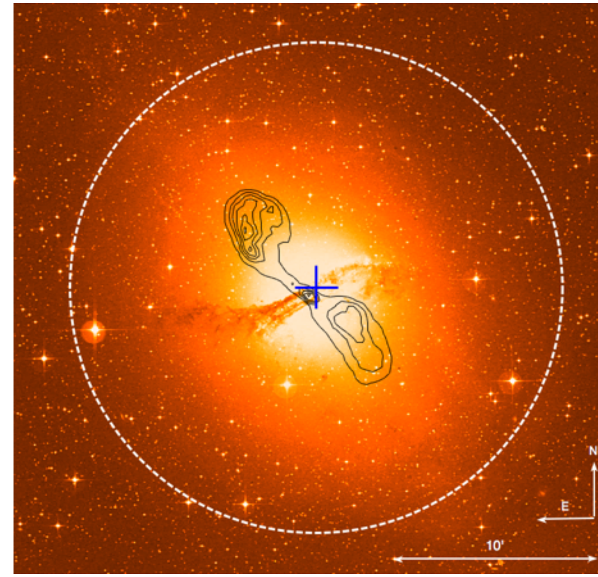



Visible et rayon Gamma (magenta).

Second radio galaxy at TeV energies

115.0 h of data -> 5.0σ

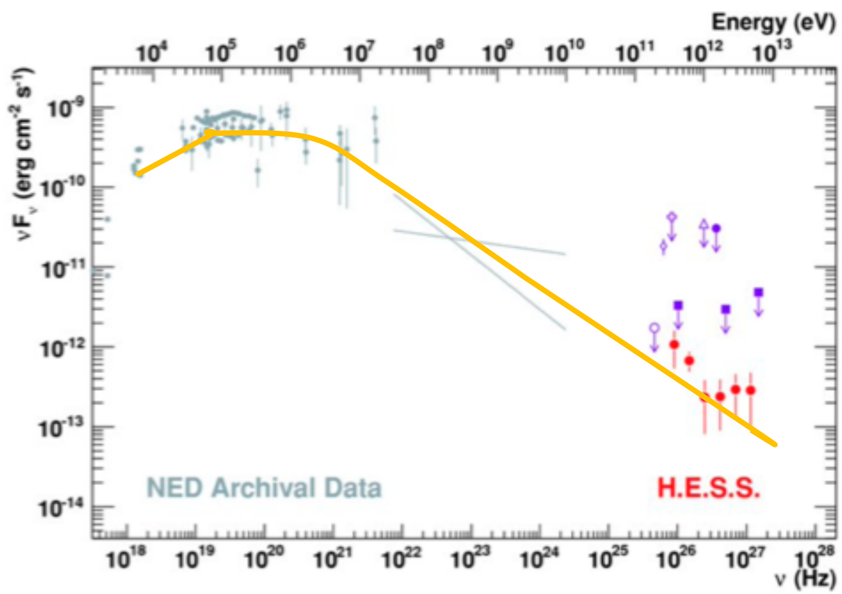
$\Gamma = 2.7 \pm 0.5_{stat} \pm 0.2_{sys}$




EGRET observations

$\Gamma = 2.90 \pm 0.11 \pm 0.07$

X-ray to High-energy peak

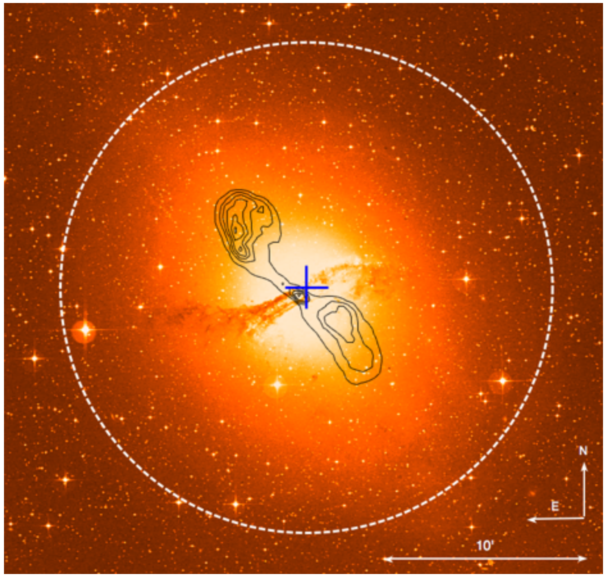



F. Aharonian, et al 2009

Second radio galaxy at TeV energies

115.0 h of data -> 5.0σ

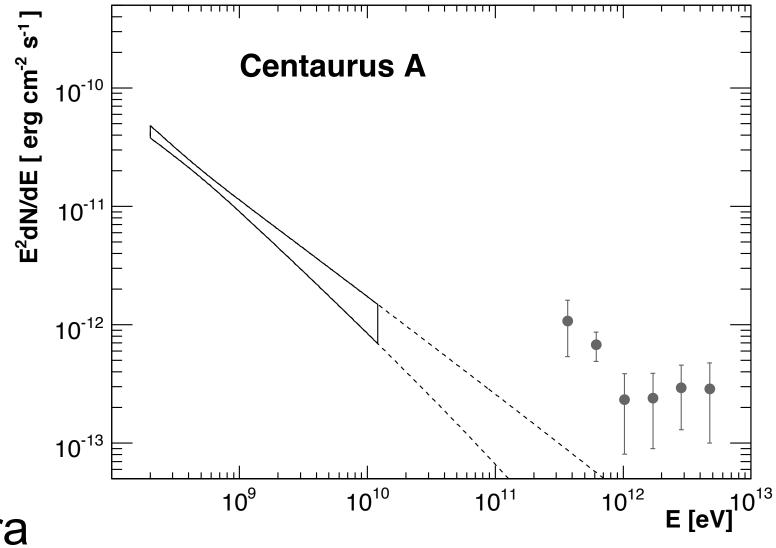
$\Gamma = 2.7 \pm 0.5stat \pm 0.2sys$




5.5 months of Fermi-LAT observations

TS = 308

$\Gamma = 2.90 \pm 0.11 \pm 0.07$

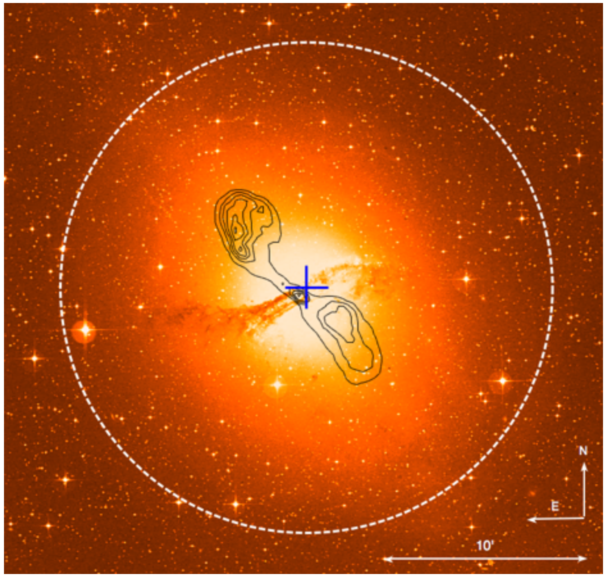



Mismatch of the spectra

Second radio galaxy at TeV energies

115.0 h  of data -> 5.0σ

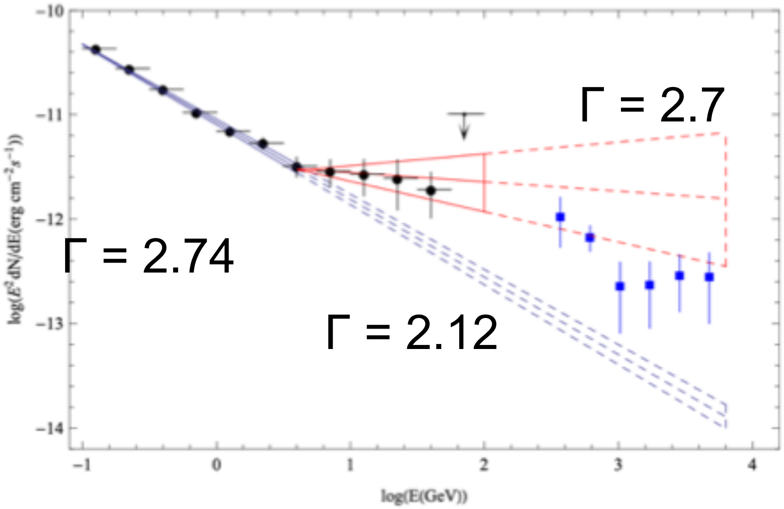
Γ = 2.7 ± 0.5stat ± 0.2sys




4 yr of  Fermi-LAT data

TS = 1978

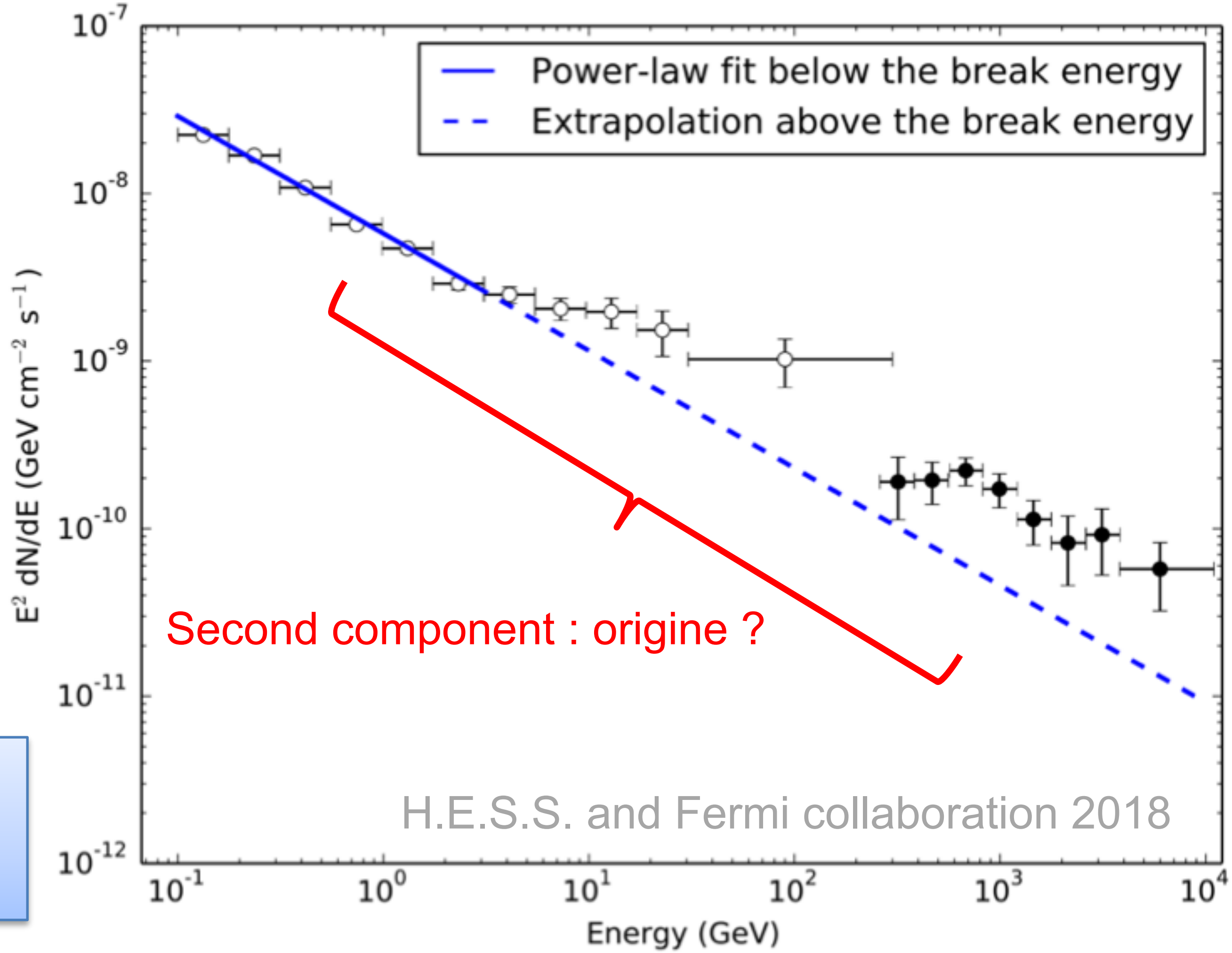
P(χ 2 ) < 2 × 10−5




Sahakyan et al; 2013

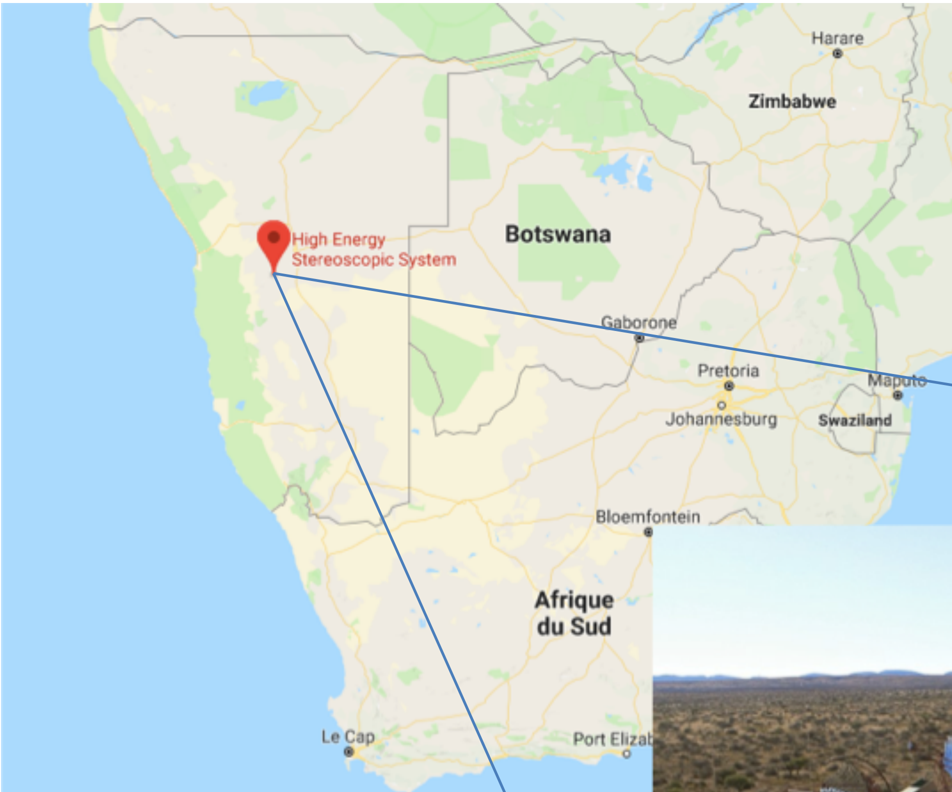
8 yr of Fermi-LAT data

H.E.S.S. 2004-2010

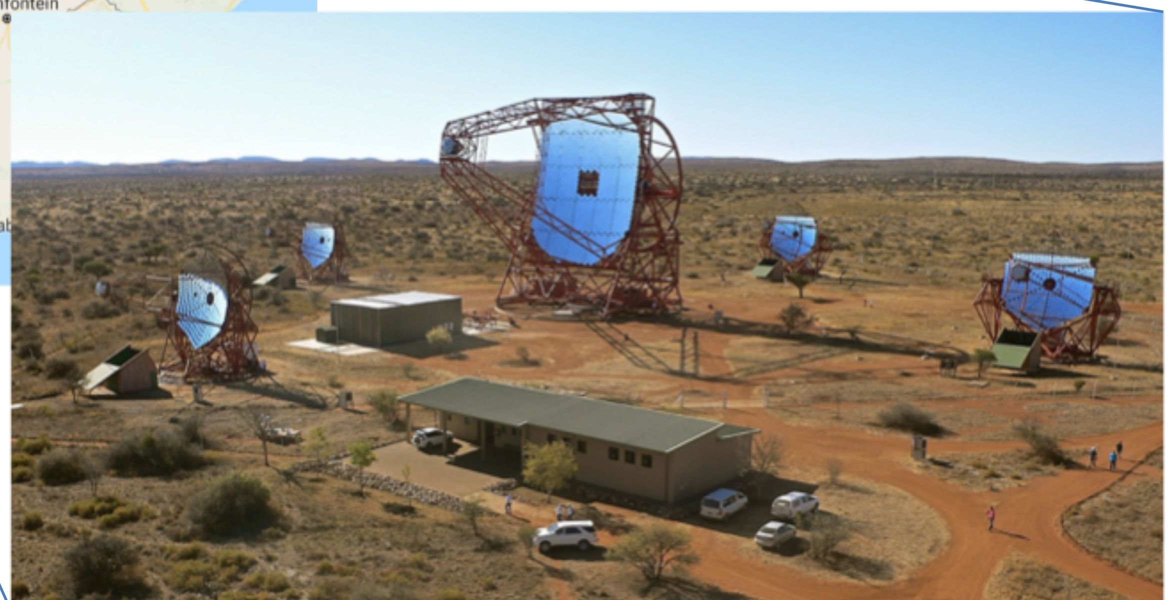


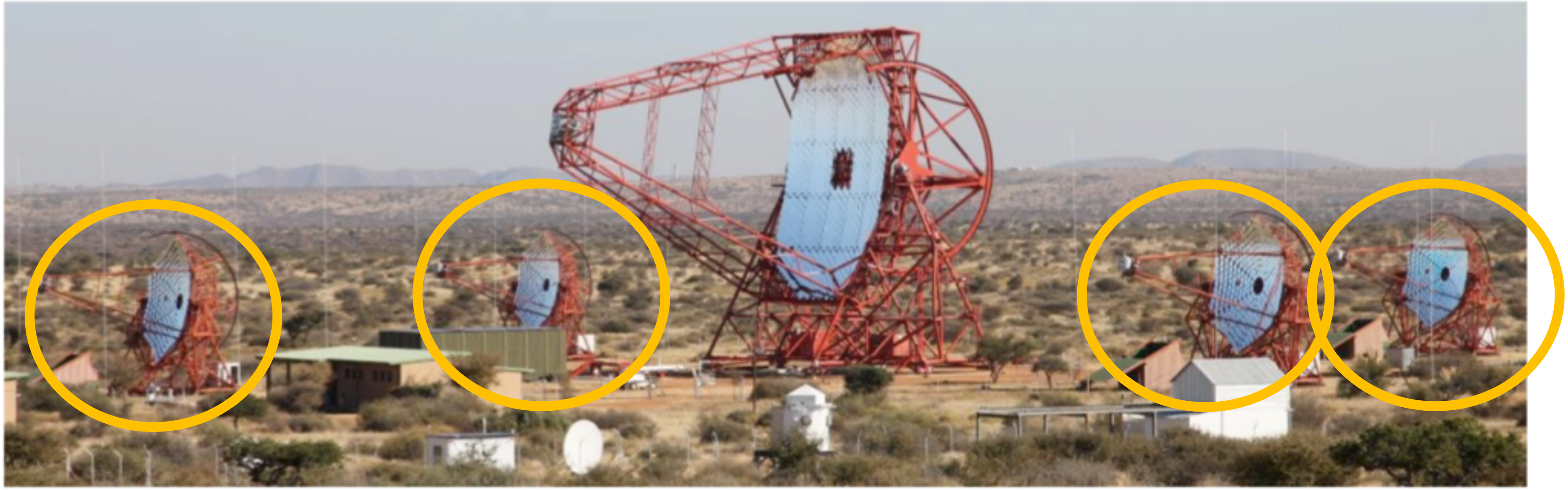

Inner jet model?
Extended emission ?
DM ?

# H.E.S.S. Instrument




**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

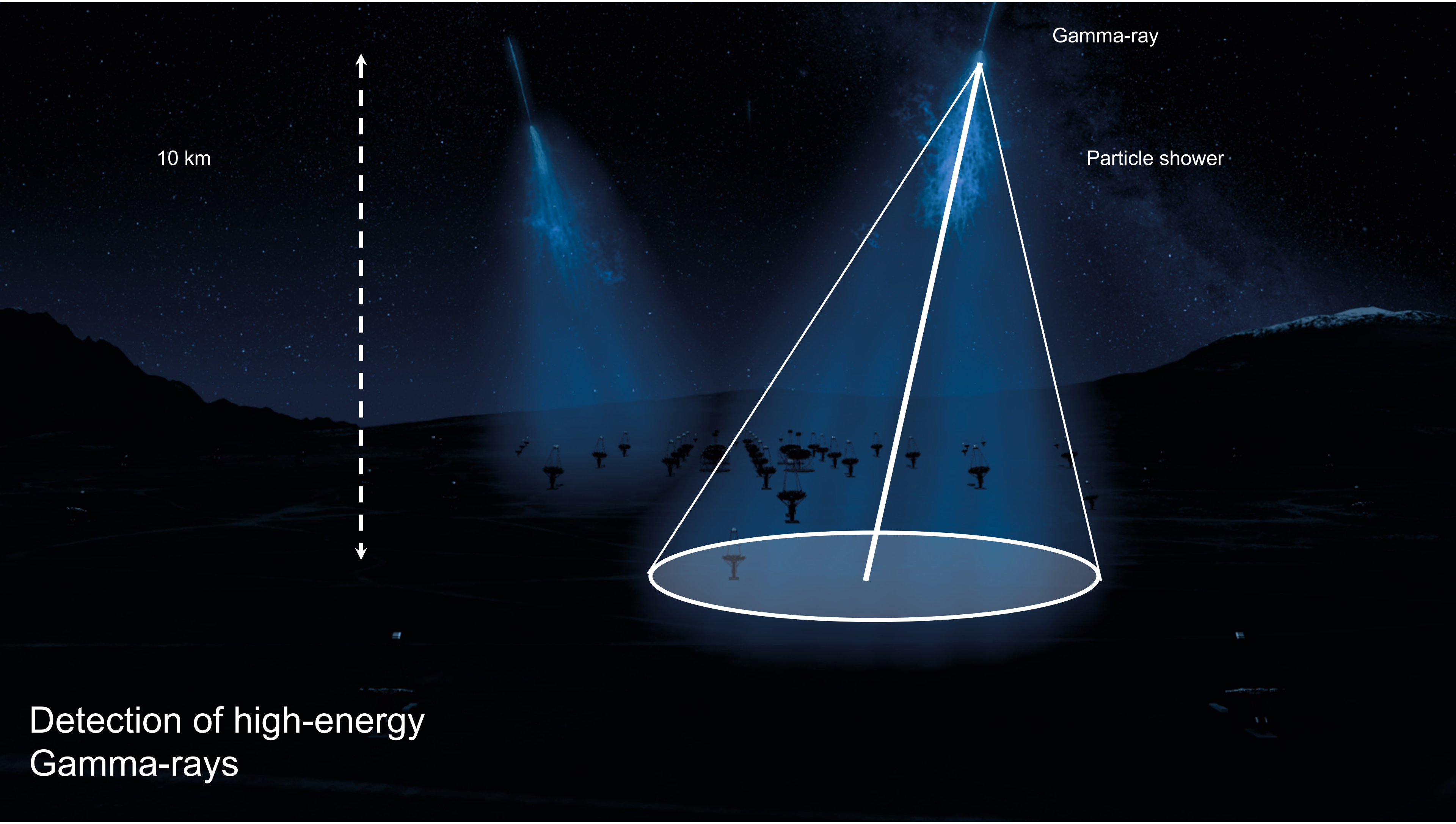
H.E.S.S. phase 1:

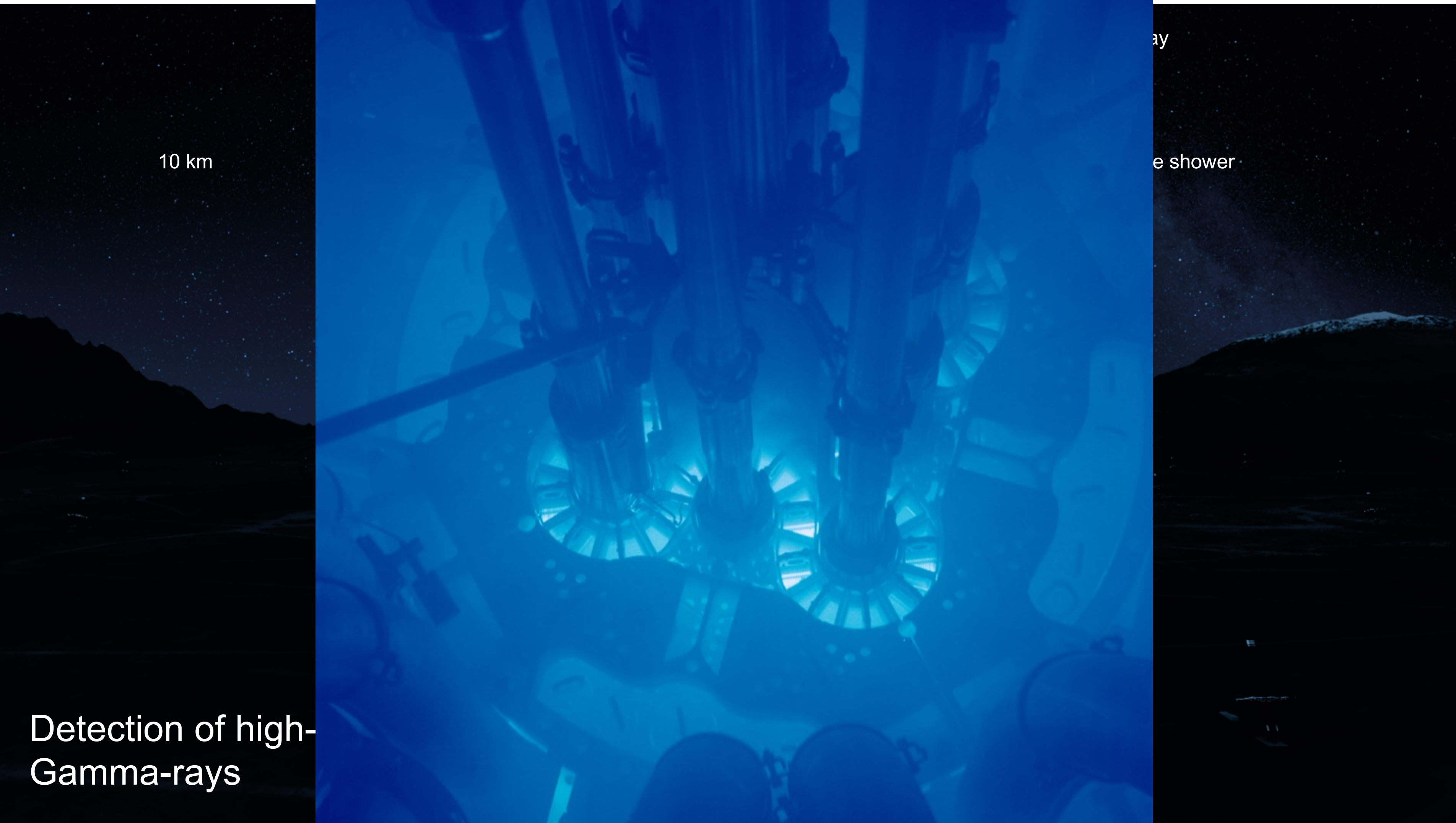
- 4 telescopes CT1-4
- 12 m diameter
- Stereoscopic reconstruction
- 960 PMTs/camera
- FoV:  5 degrees

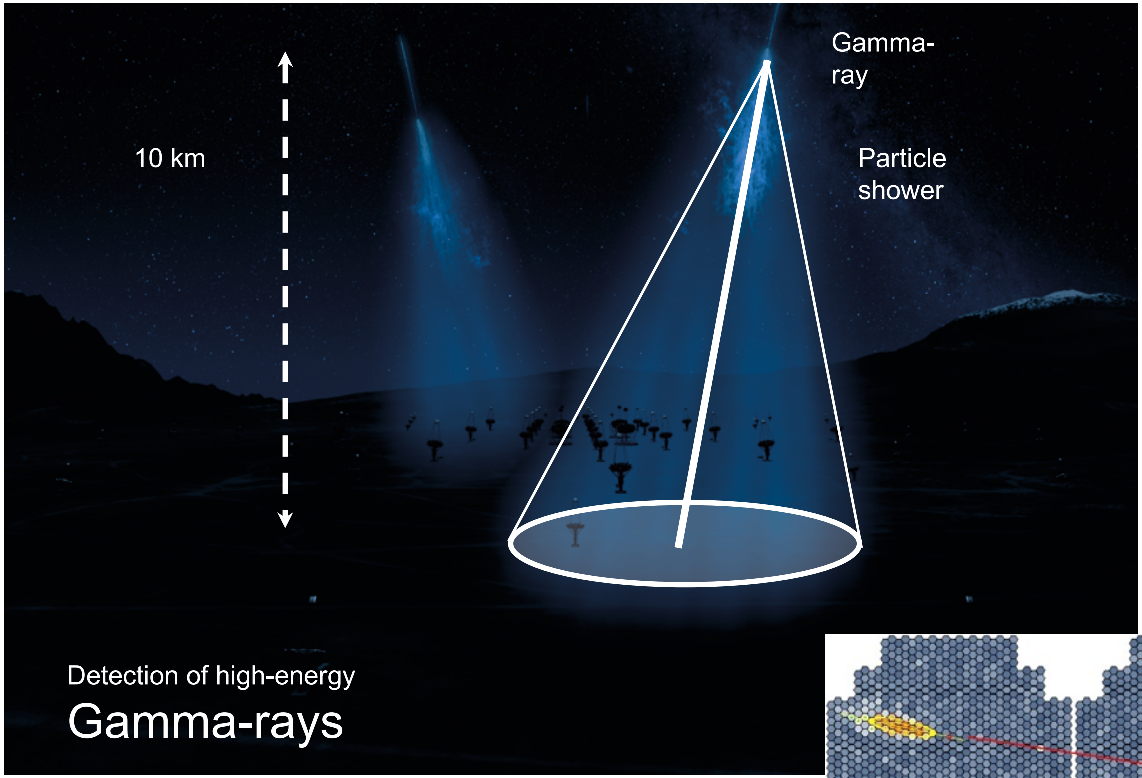
H.E.S.S. phase 2:

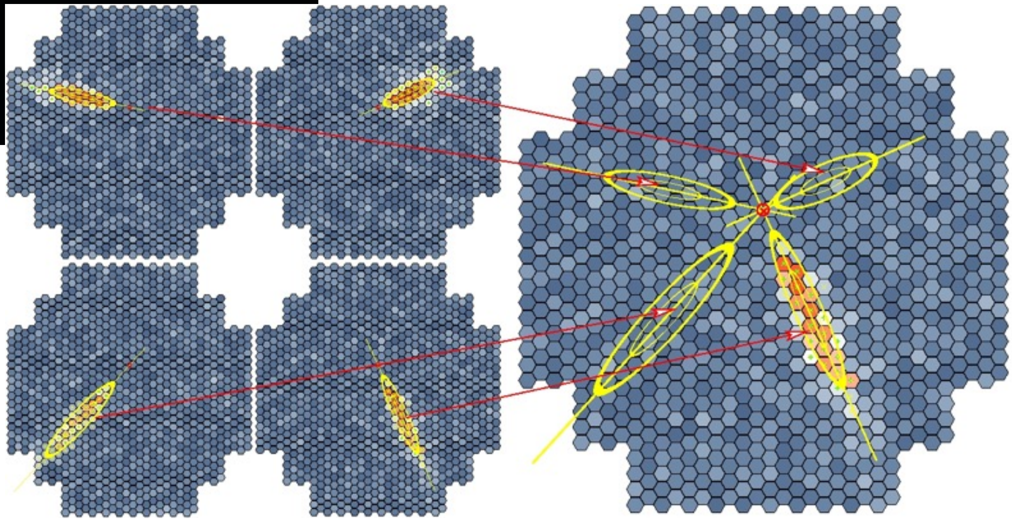
- Addition of CT5
- 28 m diameter
- 2048 PMTs/camera
- FoV:  3.5 degrees
- Mono or Hybrid

Credit : Bastien Foucher.
https://www.bastienfoucher.com/

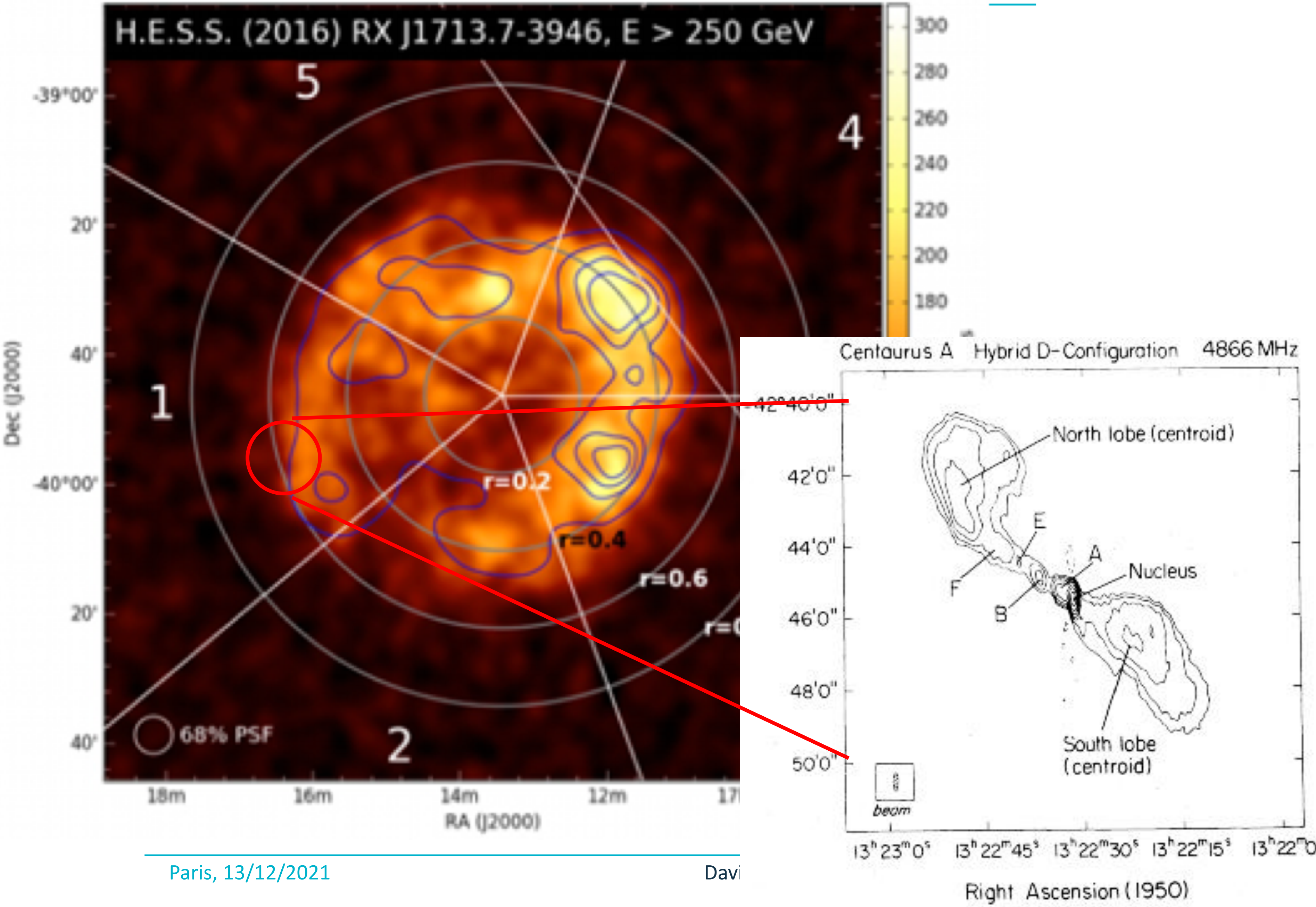

Gamma-ray
10 km
Particle shower
Detection of high-energy
Gamma-rays

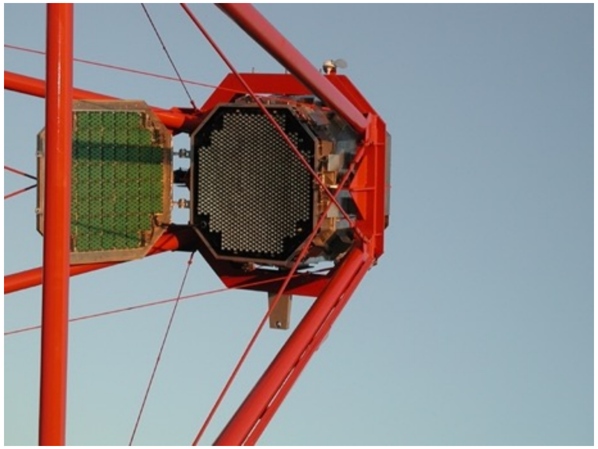

10 km
ay
e shower
Detection of high-
Gamma-rays



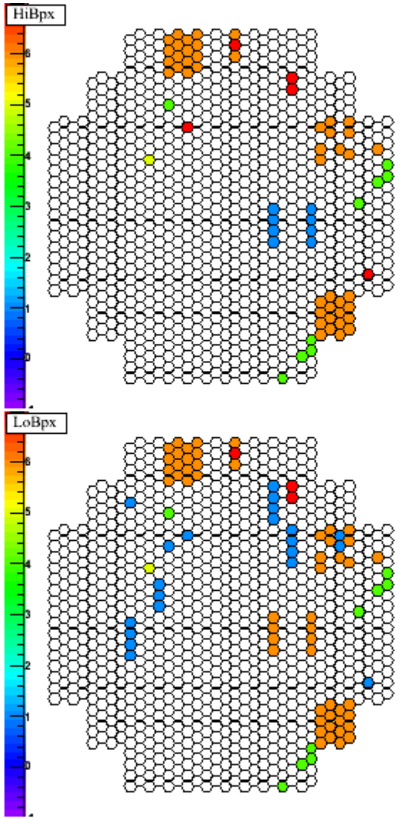



**Stereoscopy:**
- Better Gamma-Hadron separation
- Better Point Spread Function (PSF), energy resolution, etc...

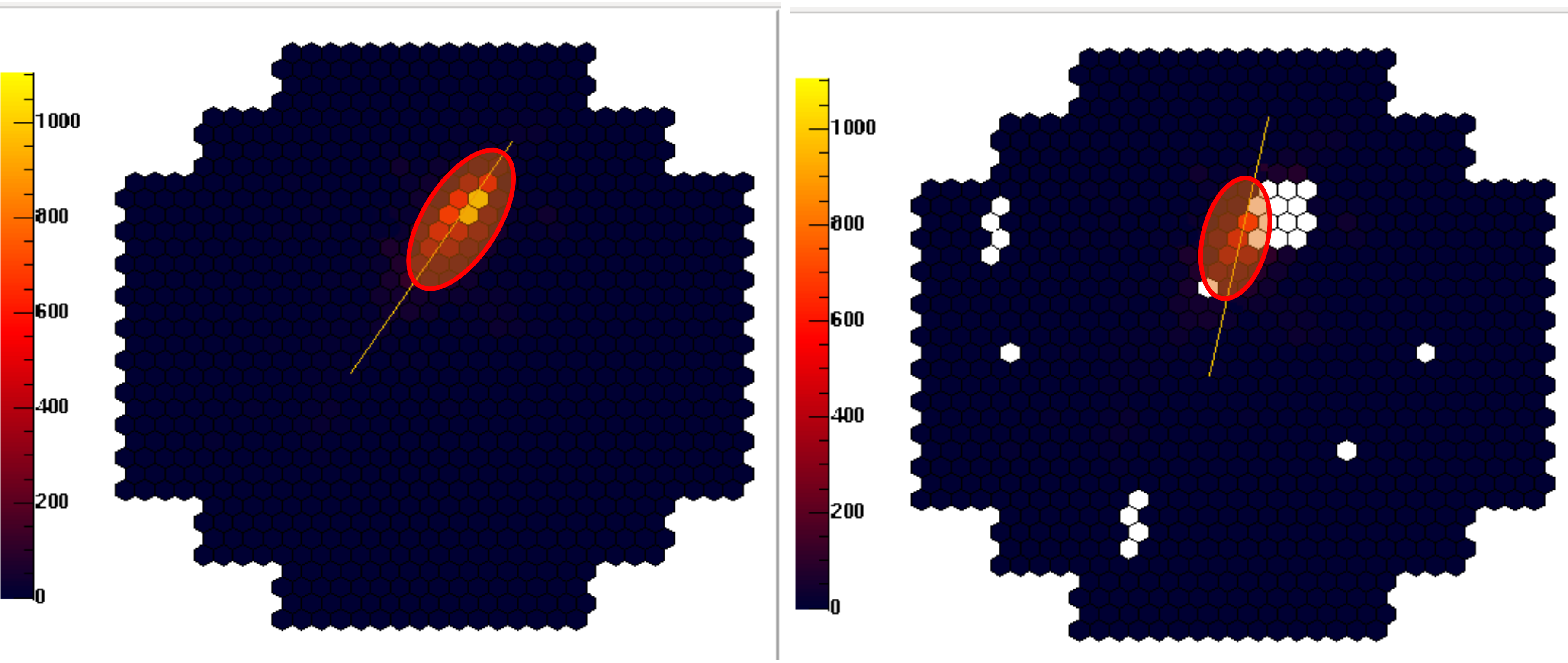

H.E.S.S. (2016) RX J1713.7-3946, E > 250 GeV
5
4
1
2
r=0.2
r=0.4
r=0.6
68% PSF
-39°00'
20'
40'
-40°00'
20'
40'
Dec (J2000)
18m
16m
14m
12m
RA (J2000)
300
280
260
240
220
200
180
Centaurus A Hybrid D-Configuration 4866 MHz
North lobe (centroid)
E
A
Nucleus
F
B
South lobe
(centroid)
beam
42'0"
44'0"
46'0"
48'0"
50'0"
13h23m0s
13h22m45s
13h22m30s
13h22m15s
Right Ascension (1950)



H.E.S.S I camera consist of 960 PMTs good image of the shower.




Simulations of an images using photoshop

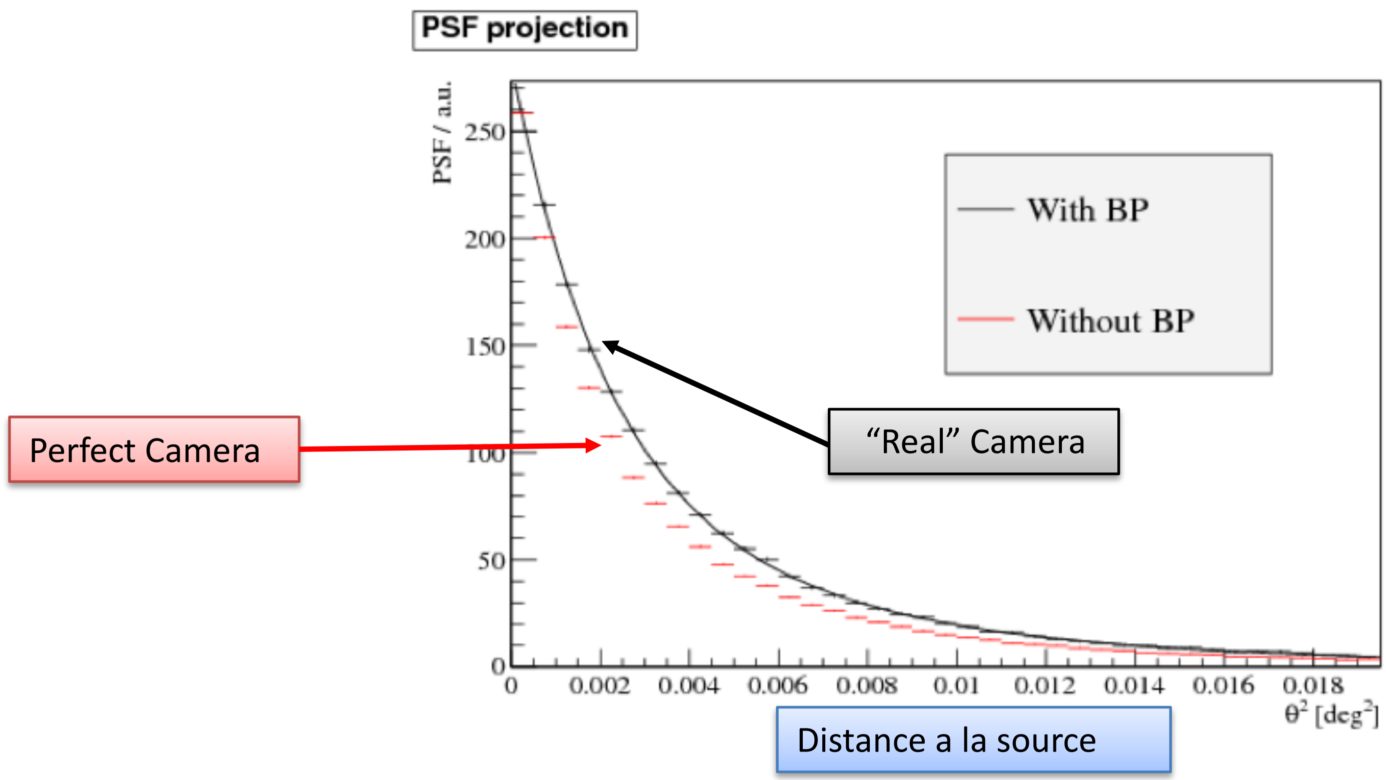



“Broken pixel” can change the direction of the reconstructed events

First attend to highlight this effect:

- Centaurus A data
- Simulate the true state of the camera for each run

- Compute for the perfect and the ‘real’ camera the reconstructed direction



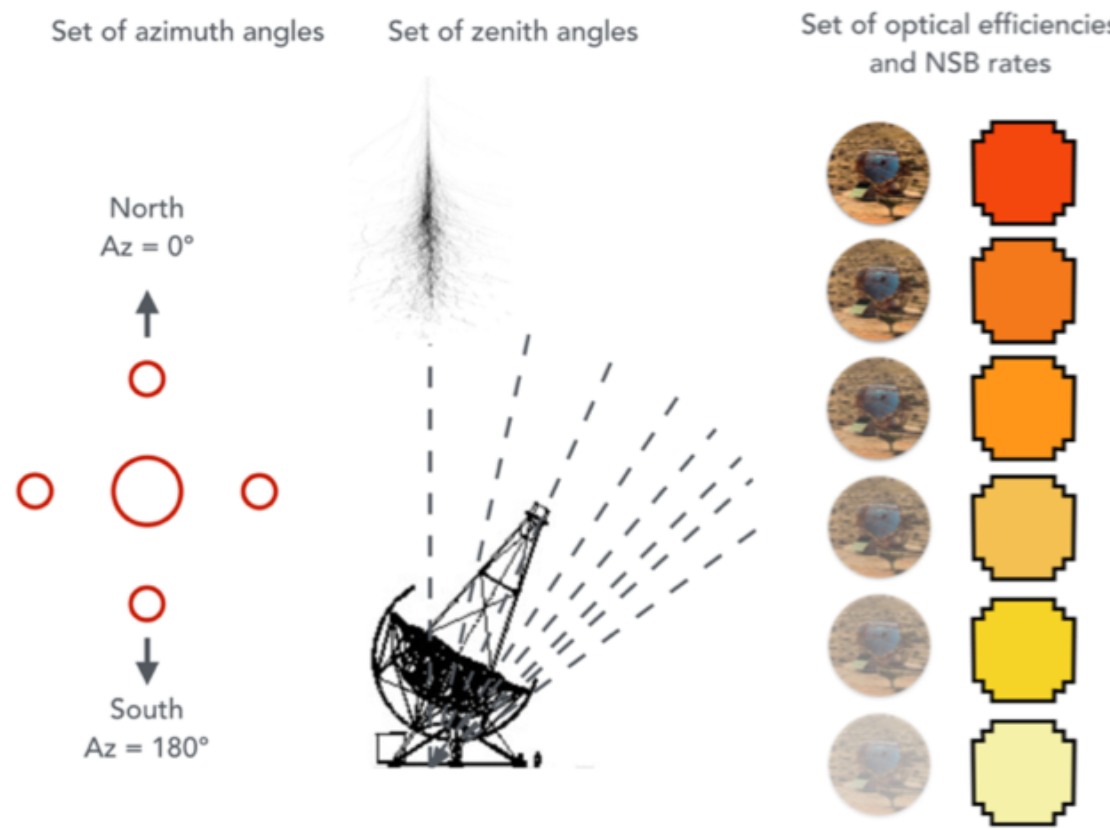
**M. Holler**, M. de Naurois, J-P Lenain, D. Sanchez

Current framework

**Simulations**
- Nord-Sud
- Several fixed zenith angles
- Several set of efficiency and NSB<<

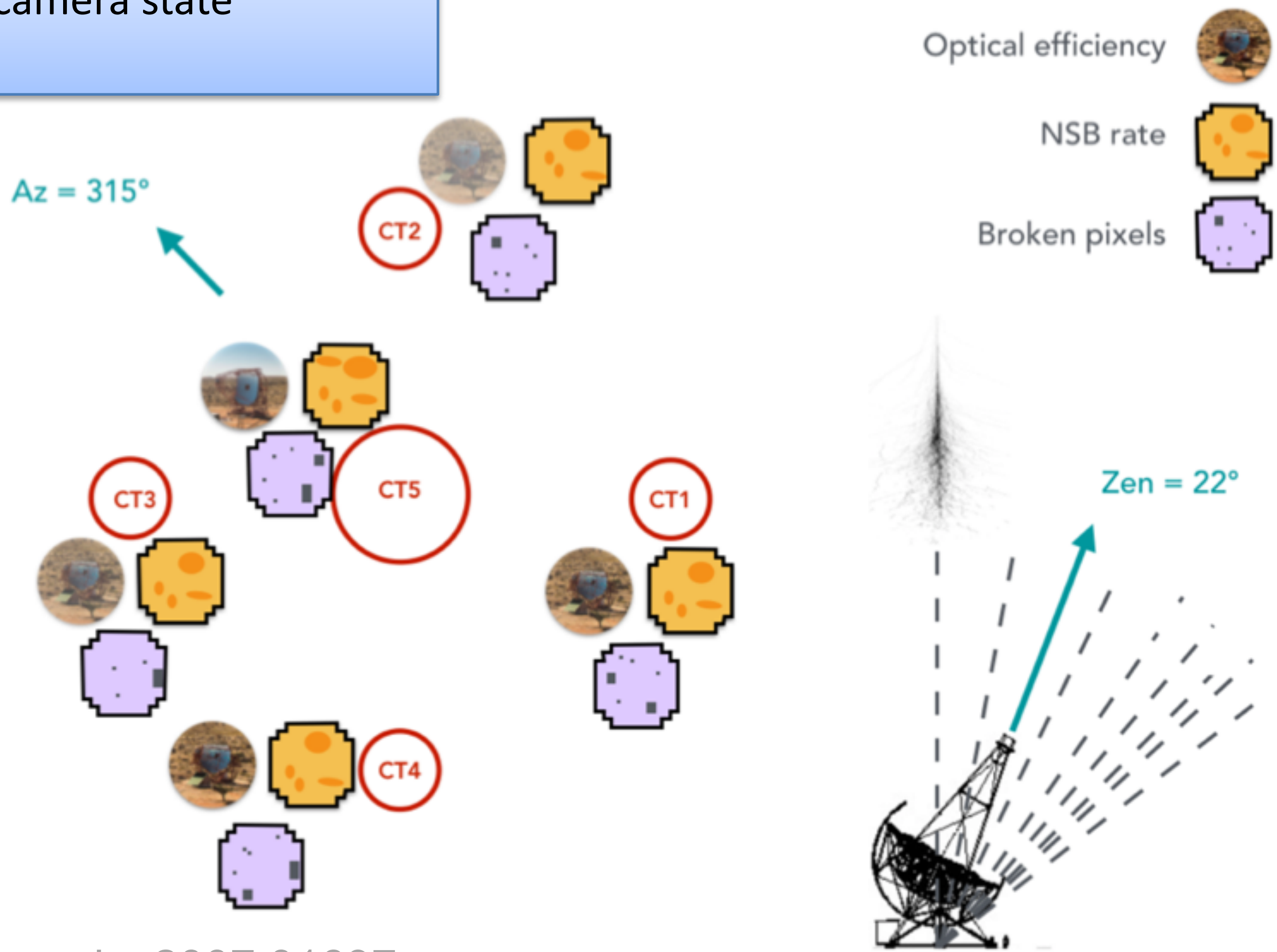
Interpolation

Instrumental responses




Holler M. et al, 2020. arxiv 2007.01697

- Actual tracking
- Actual telescope and camera state
- Actual sky

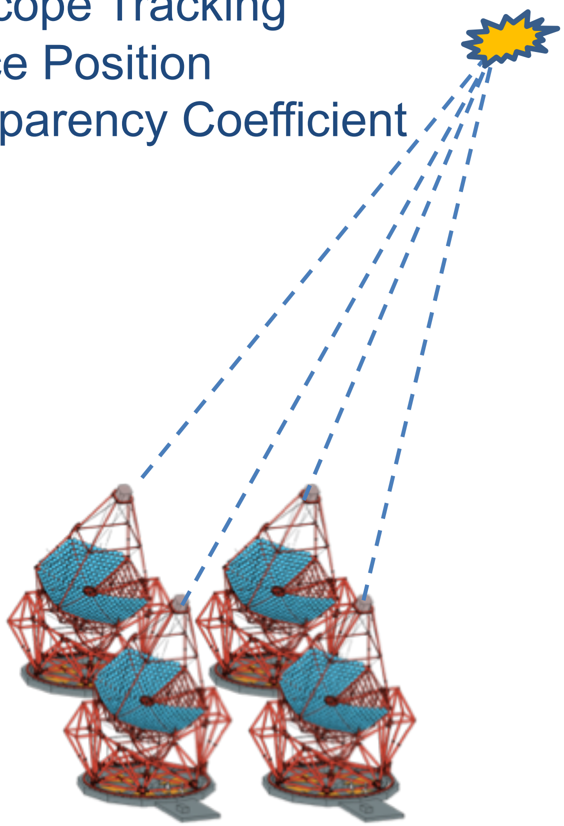


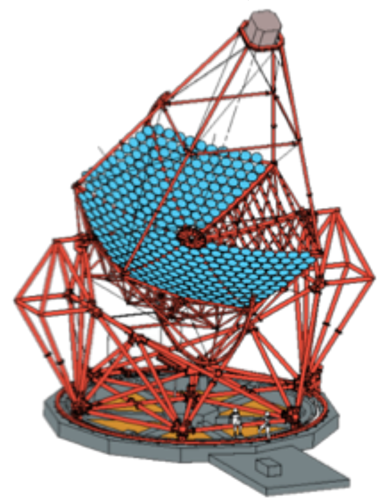

Holler M. et al, 2020. arxiv 2007.01697

**More realistic simulation approach**
- Simulating each observation run of a data set
- Using actual observation and instrument conditions

Holler M. et al, 2020. arxiv 2007.01697

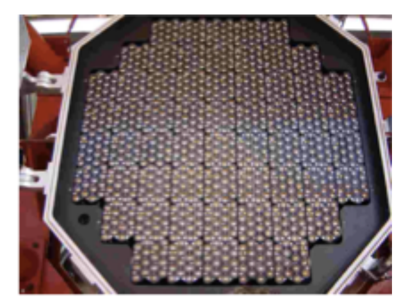
**Array-wise**
- Telescope Tracking
- Source Position
- Transparency Coefficient





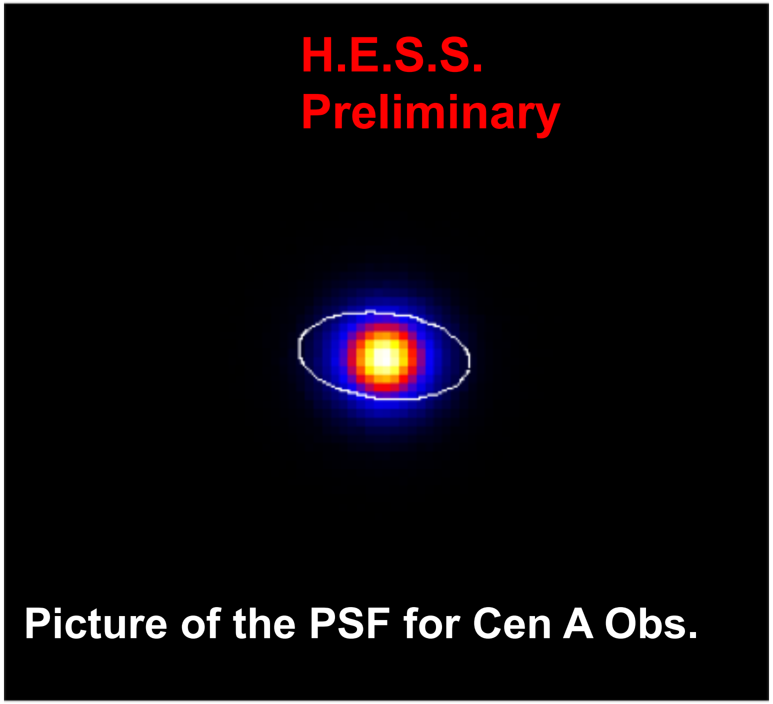
**Telescope-wise**
- Camera focus
- Trigger Settings
- Live-Time fraction

**Pixel-wise**
- Broken Pixels
- PMT Gain
- HI-Lo ratio
- Flatfield Coeffient
- NSB



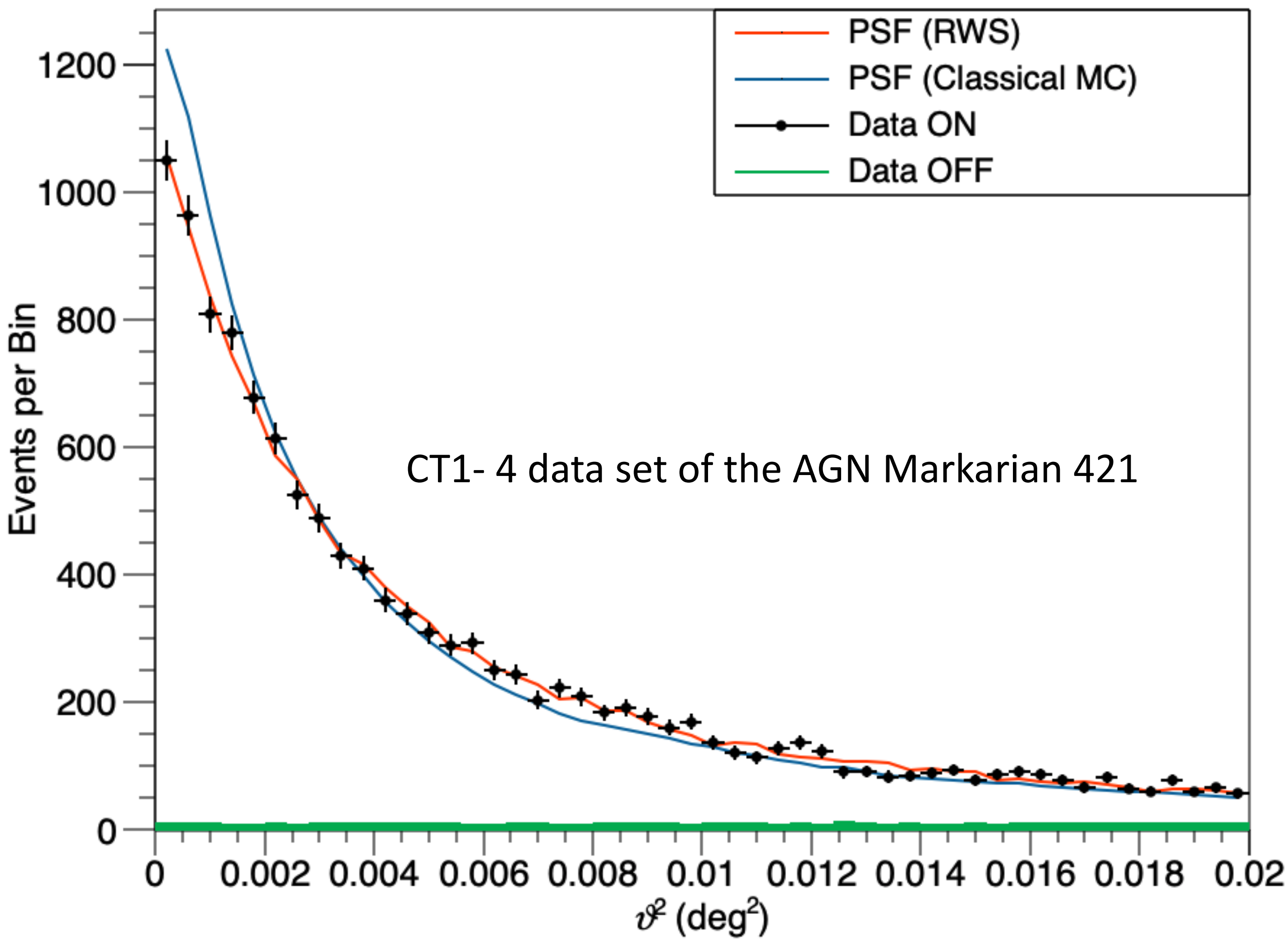
- **Small source extensions**
  - Good understanding of the Point Spread Function (PSF)
    - -> Crab Nebula extension
    - -> point-like AGNs

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




Picture of the PSF for Cen A Obs.

**Allowed by the use of the new simulation framework**




Holler M. et al, 2020. arxiv 2007.01697

# Morphology of Centaurus A with H.E.S.S. I telescopes

**Deep H.E.S.S. Observations from 2004 to 2013**

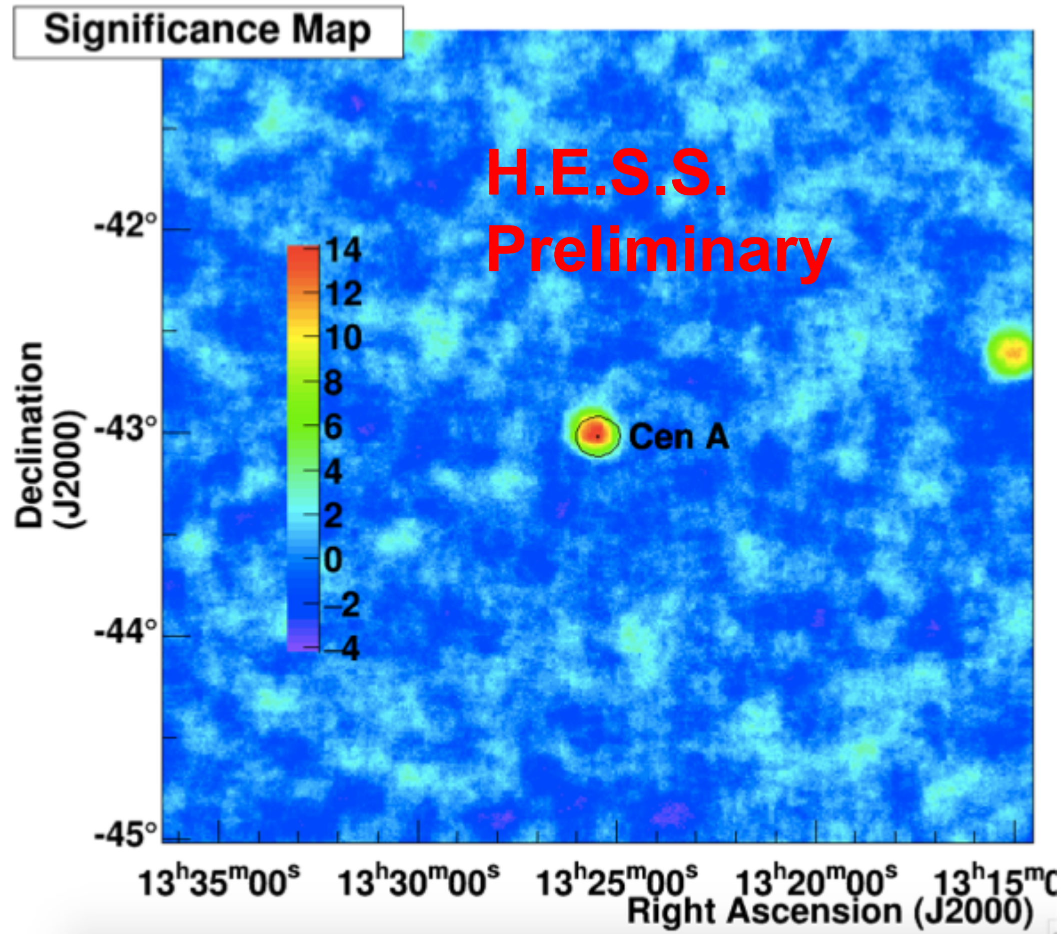
- 202 hours of live time
- Change in hardware state, observation conditions

Detection significance: 13.1σ

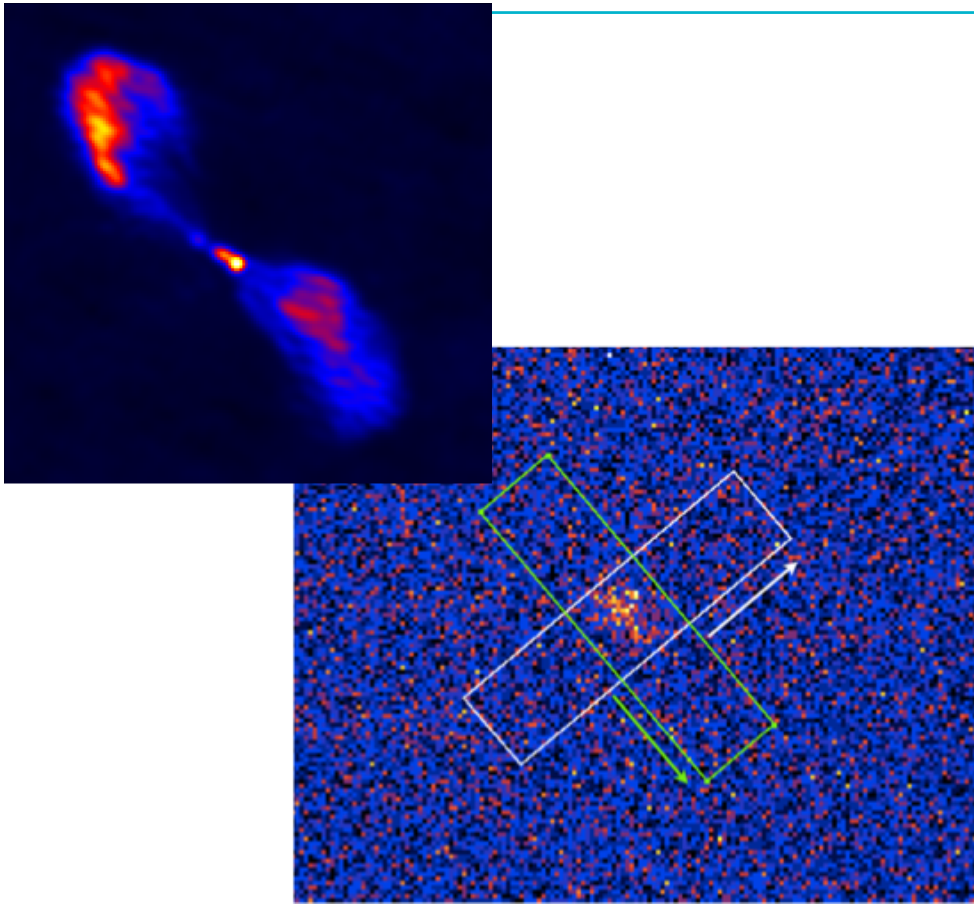
S/B ratio: 0.5

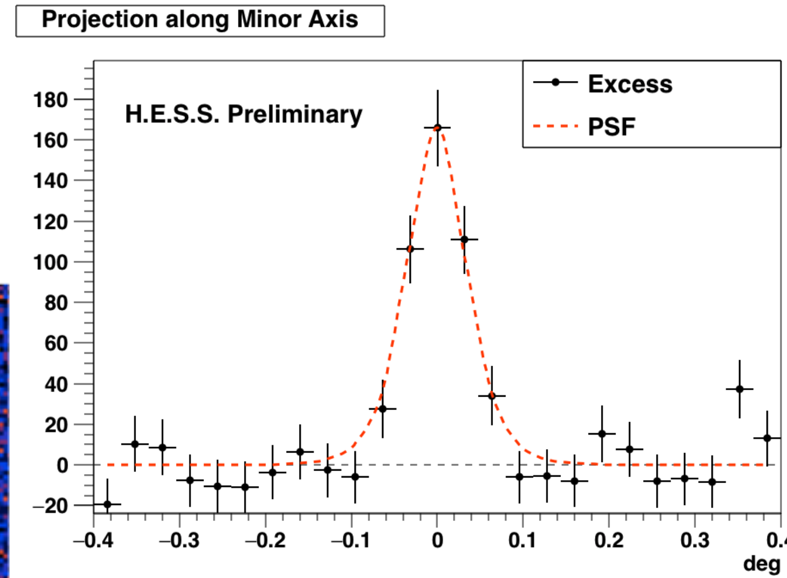
**Challenging data set**

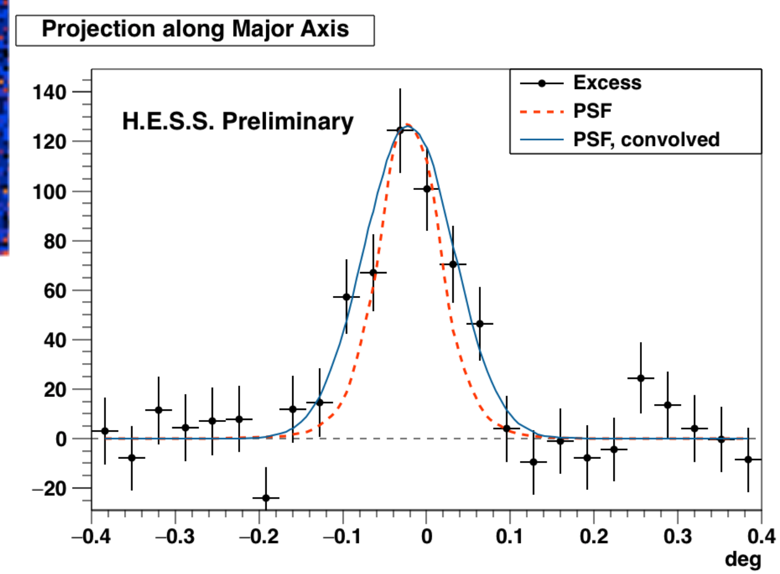
- Long exposure over several years
- Different hardware states
- Different obs. conditions
- Low S/B ratio



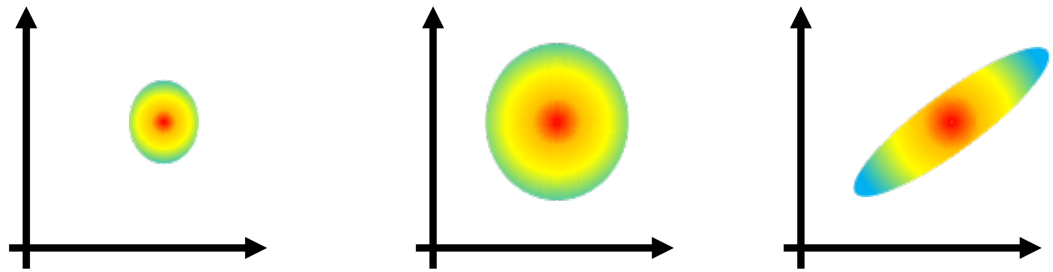
# 1D-projection of the event map





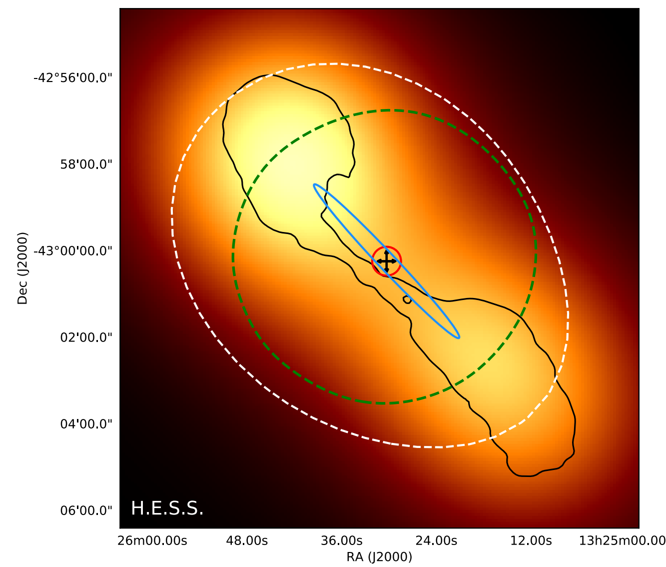




Projection along the radio jets
- Minor axis: no extension
- Major axis: PSF folded with the best-fit width from the 2D fit



Point-like Sym-Gauss. Elliptic-Gauss.

| Sym. Gauss. vs. Point-Like | Elliptic. Gauss. vs. Point-Like |
| --- | --- |
| TS : 6.1 | TS : 19.4 |

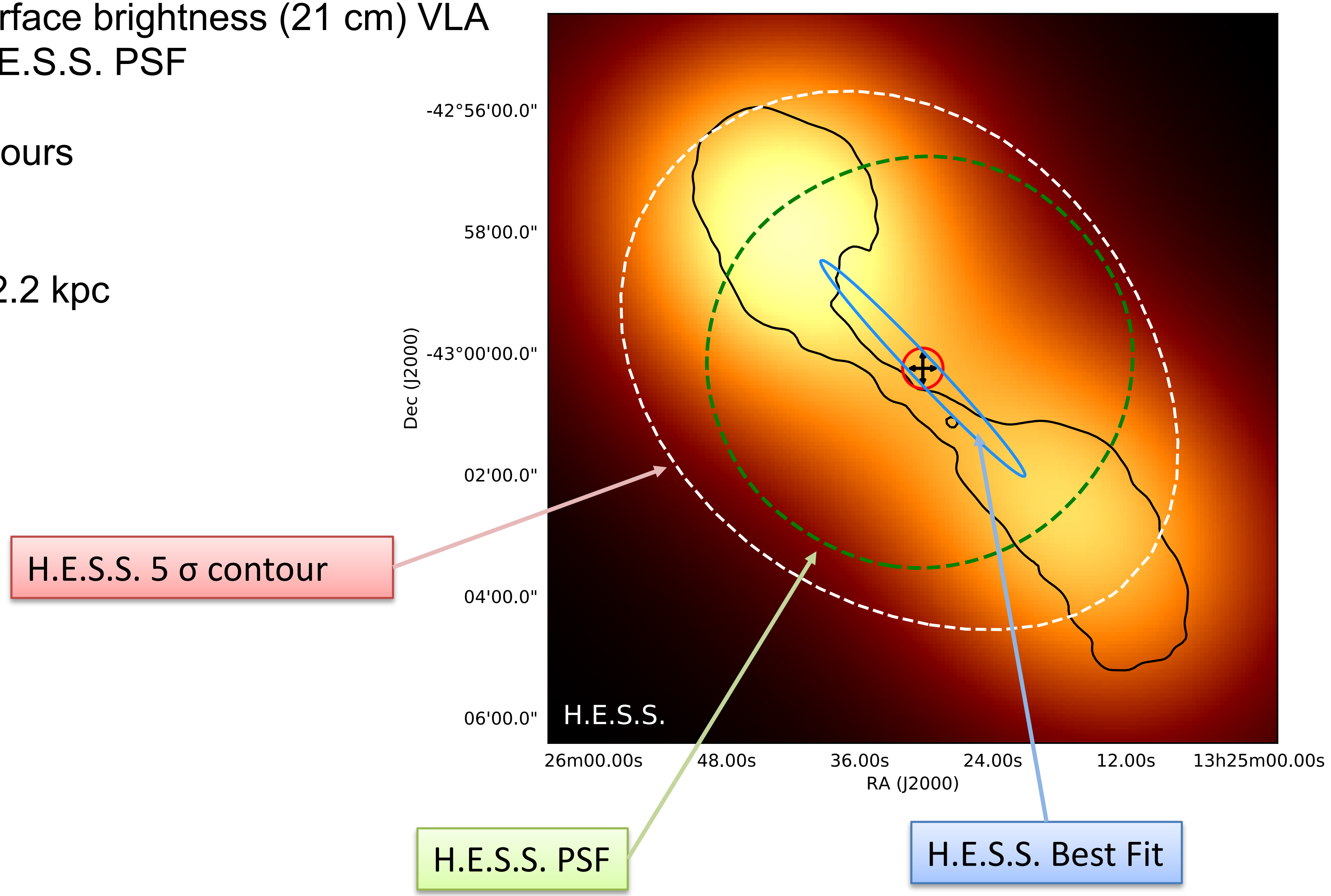



- Gaussian width of semi-major axis: 0.041 +/- 0.006°
- Point-Like in the transvers direction
- Aligned with radio jets

Radio surface brightness (21 cm) VLA map * H.E.S.S. PSF

VLA contours

Jet size 2.2 kpc



Article

# Resolving acceleration to very high energies along the jet of Centaurus A

https://doi.org/10.1038/s41586-020-2354-1

Received: 15 October 2019

Accepted: 17 March 2020

Check for updates

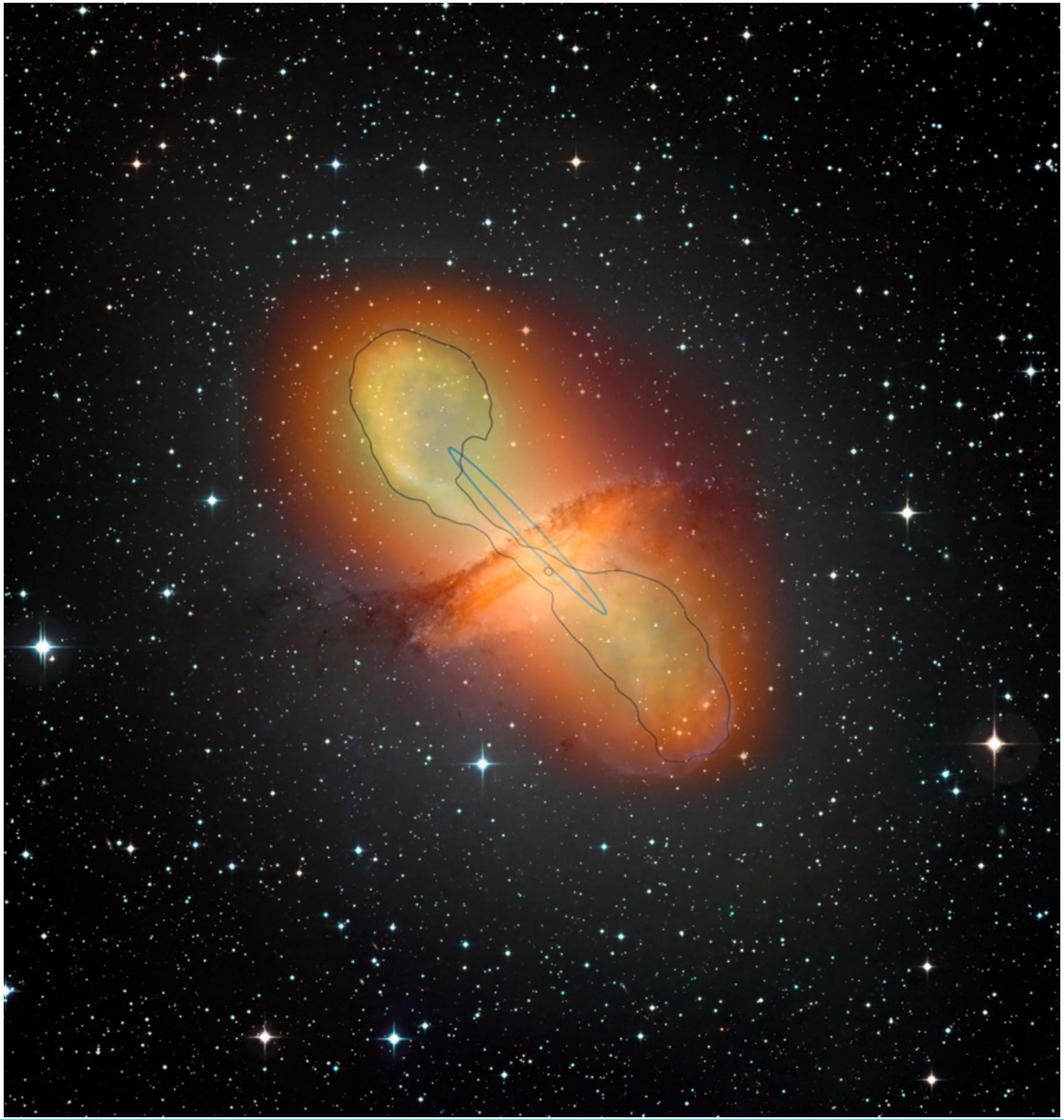
The H.E.S.S. Collaboration*

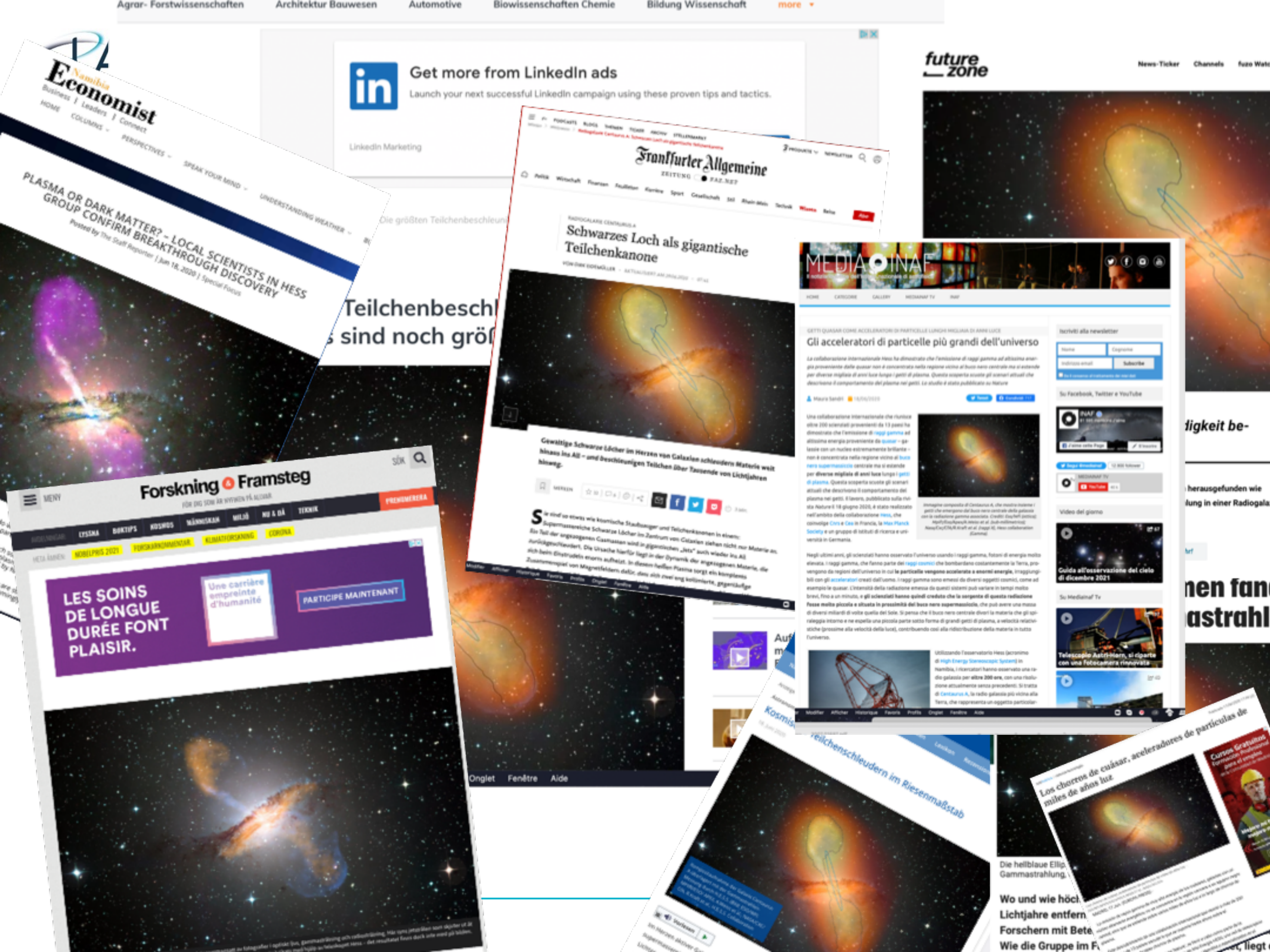
The nearby radio galaxy Centaurus A belongs to a class of active galaxies that are luminous at radio wavelengths. Most show collimated relativistic outflows known as jets, which extend over hundreds of thousands of parsecs for the most powerful sources. Accretion of matter onto the central supermassive black hole is believed to fuel these jets and power their emission[1]. Synchrotron radiation from relativistic electrons causes the radio emission, and it has been suggested that the X-ray emission from Centaurus A also originates in electron synchrotron processes[2–4]. Another possible explanation is inverse Compton scattering with cosmic microwave background (CMB) soft photons[5–7]. Synchrotron radiation needs ultrarelativistic electrons (about 50 teraelectronvolts) and, given their short cooling times, requires some continuous re-acceleration mechanism[8]. Inverse Compton scattering, on the other hand, does not require very energetic electrons, but the jets must stay highly relativistic on large scales (exceeding 1 megaparsec). Some recent evidence disfavours inverse Compton-CMB models[9–12], although other work seems to be compatible with them[13,14]. In principle, the detection of extended γ-ray emission, which directly probes the presence of ultrarelativistic electrons, could distinguish

Optical data

Radio surface brightness (21 cm wavelength) VLA map

HESS best fit





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Architektur Bauwesen
Automotive
Biowissenschaften Chemie
Bildung Wissenschaft
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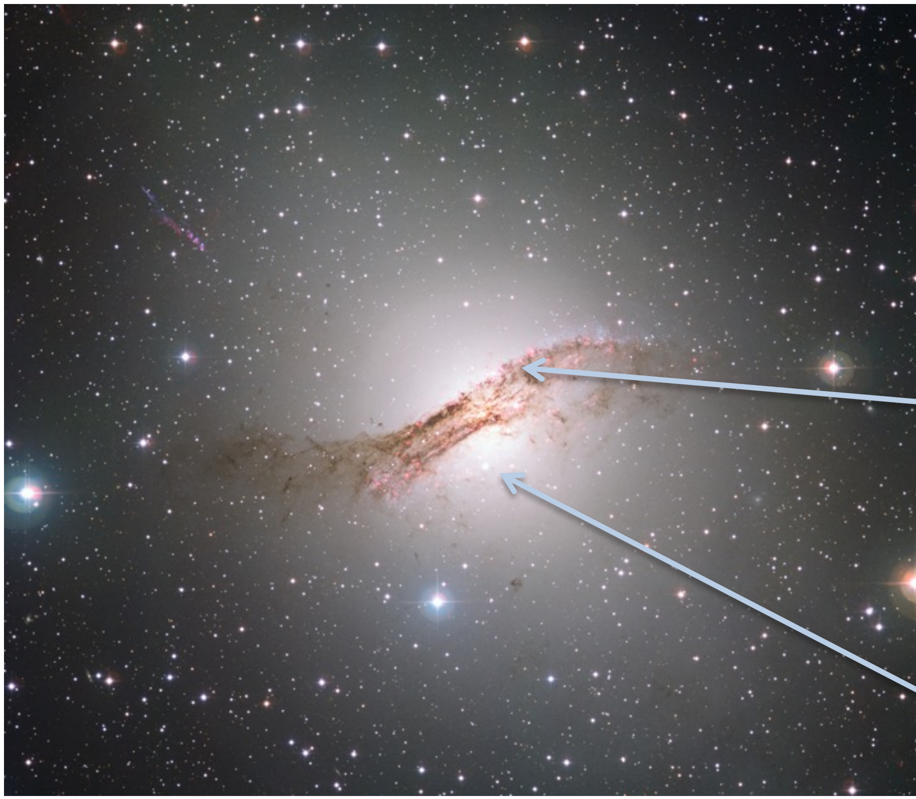
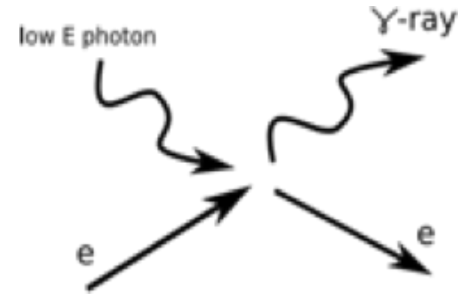
Launch your next successful LinkedIn campaign using these proven tips and tactics.
LinkedIn Marketing
Namibia Economist
PLASMA OR DARK MATTER? – LOCAL SCIENTISTS IN HESS GROUP CONFIRM BREAKTHROUGH DISCOVERY
Teilchenbeschl
sind noch grö
Frankfurter Allgemeine
Schwarzes Loch als gigantische Teilchenkanone
future zone
MEDIA INAF
Gli acceleratori di particelle più grandi dell'universo
Forskning & Framsteg
LES SOINS DE LONGUE DURÉE FONT PLAISIR.
Une carrière empreinte d'humanité
PARTICIPE MAINTENANT
Teilchenschleudern im Riesenmaßstab
Los chorros de cuásar, aceleradores de partículas de miles de años luz
Die hellblaue Ellip
Gammastrahlung
Wo und wie höc
Lichtjahre entfern
Forschern mit Bete
Wie die Gruppe im F

# Implications

- First VHE extragalactic extended source
- Size of the jet : 2.2 kpc
- Most of the VHE emission arise far  from the black hole
- VHE emission probably due to IC of electrons accelerate along the jet
- Target photons ?

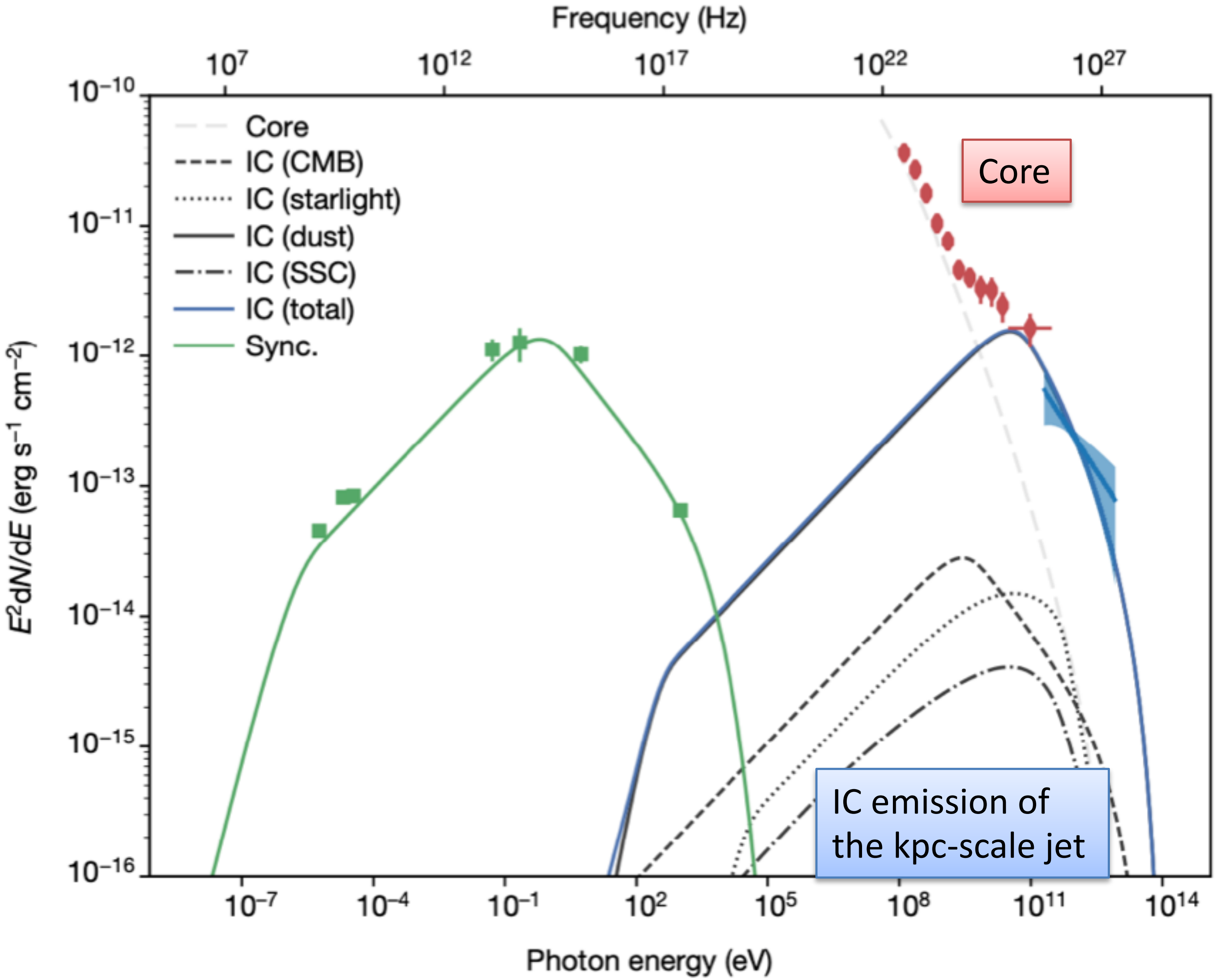


(Credit : ESO/WFI)




External soft photon fields

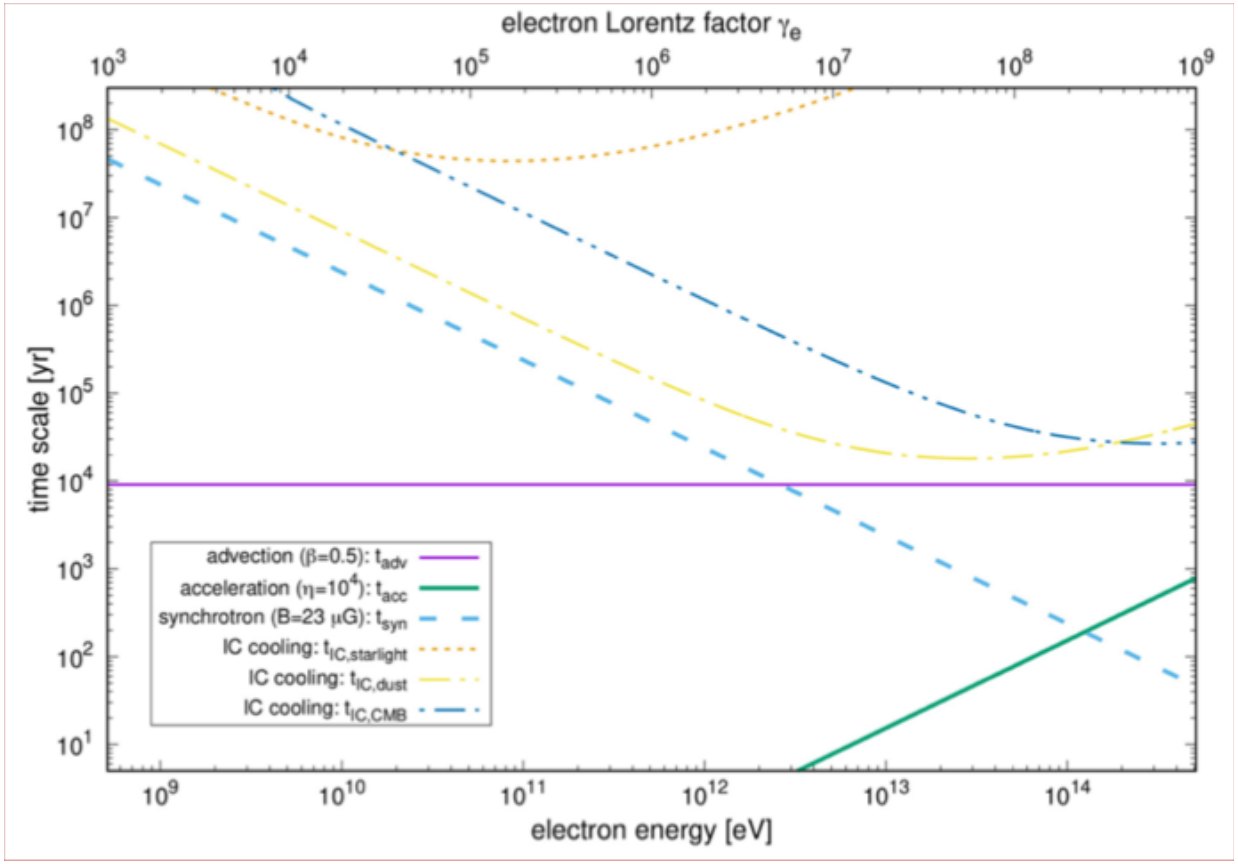
- **dust** (peaking @ $\nu_p \sim 3 \times 10^{12}$ Hz):
  $\nu_{VHE} \sim \gamma^2 \nu_p$ (Thomson) $\Rightarrow \gamma \sim 10^7$
- **host starlight** ($\nu_p \sim 5 \times 10^{14}$ Hz):
  $\nu_{VHE} \sim \gamma m_e c^2$ (KN) $\Rightarrow \gamma \sim 10^6$
- CMB and SSC contribution negligible


Frequency (Hz)
$10^{7}$ $10^{12}$ $10^{17}$ $10^{22}$ $10^{27}$
$10^{-10}$ $10^{-11}$ $10^{-12}$ $10^{-13}$ $10^{-14}$ $10^{-15}$ $10^{-16}$
Core
IC (CMB)
IC (starlight)
IC (dust)
IC (SSC)
IC (total)
Sync.
Core
IC emission of the kpc-scale jet
$E^2$dN/d$E$ (erg s$^{-1}$ cm$^{-2}$)
$10^{-7}$ $10^{-4}$ $10^{-1}$ $10^{2}$ $10^{5}$ $10^{8}$ $10^{11}$ $10^{14}$
Photon energy (eV)

# Relevant timescales in the jet

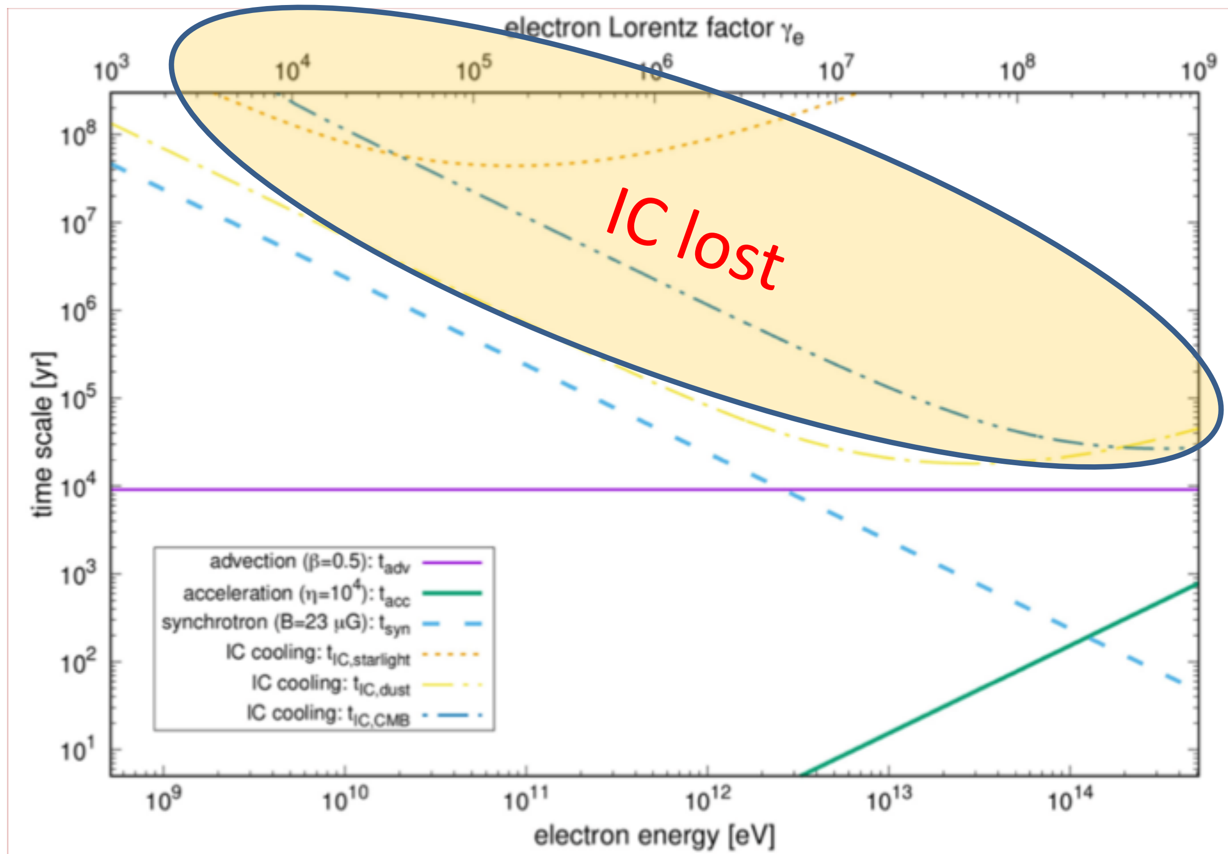
Increasing energy

Faster cooling



Increasing energy

Faster cooling

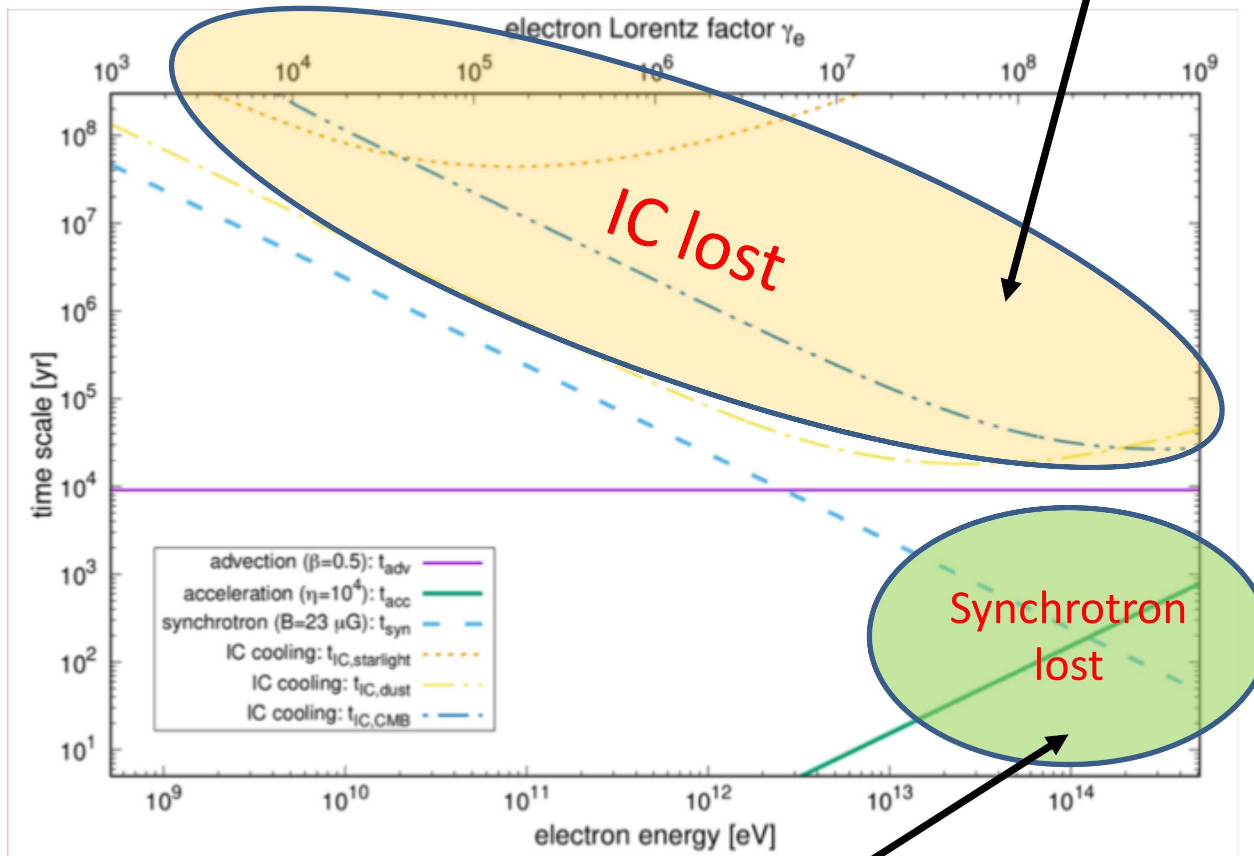


# Relevant timescales in the jet

Increasing energy

TeV Photons

Faster cooling

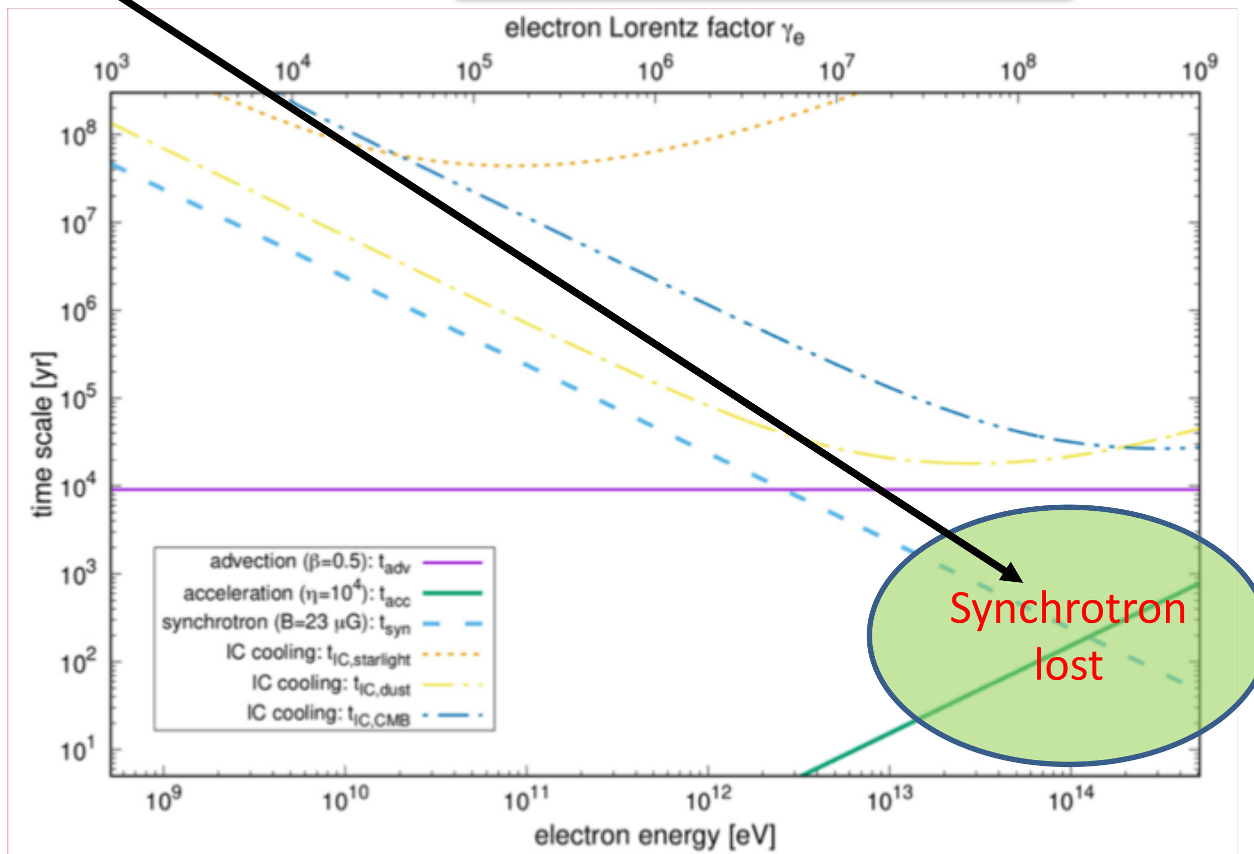



X-ray Photons

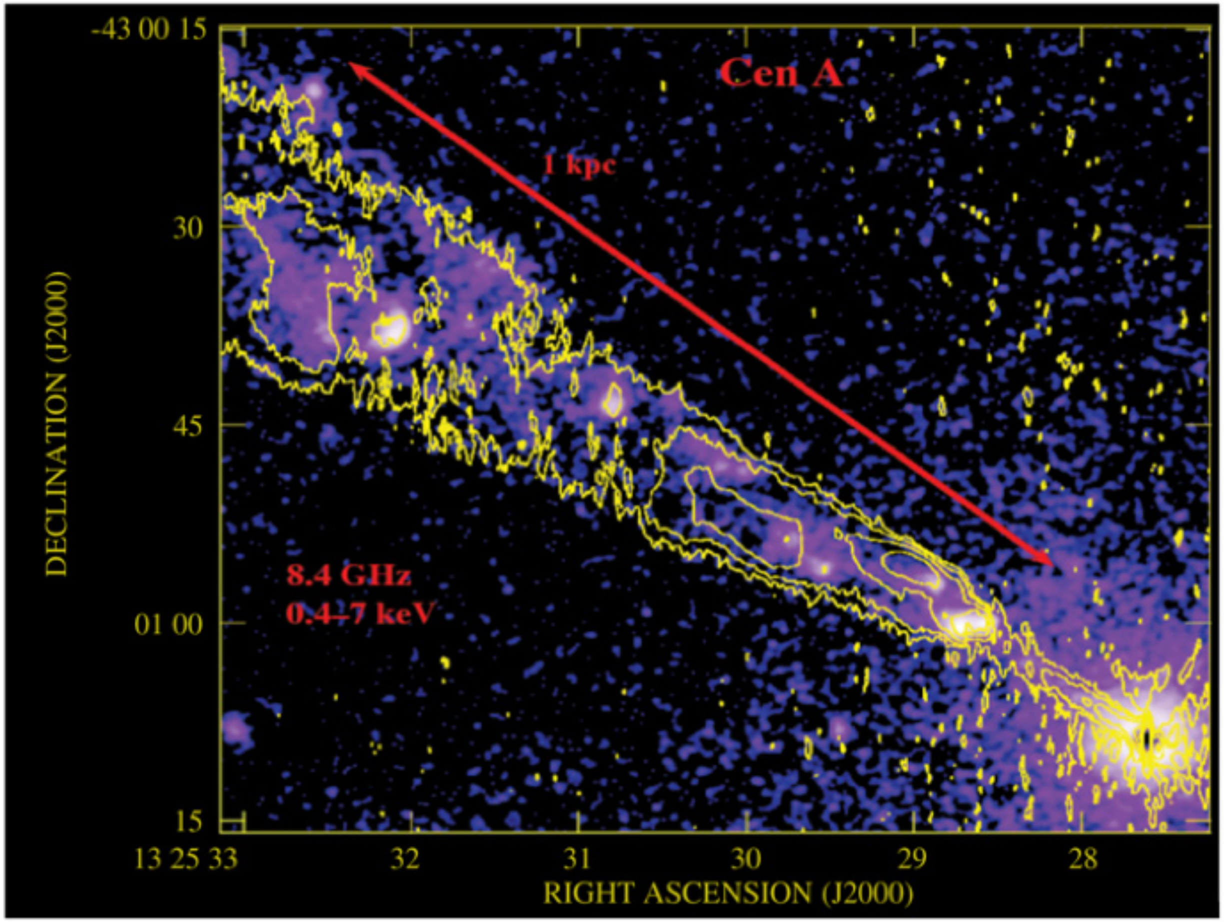
This correspond to < 100 pc

The acceleration mechanism as to be distributed along the kpc x-ray jet

Faster cooling



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

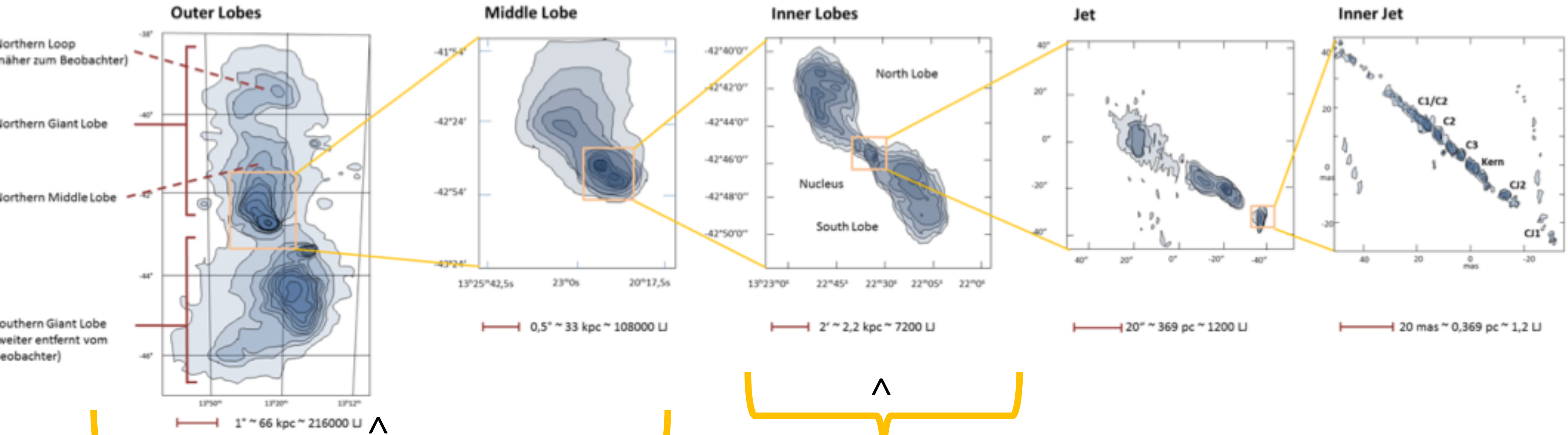


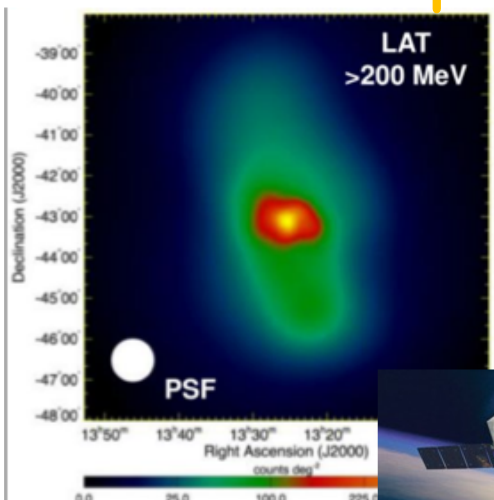

(Credit: Schwartz 2010, Hardcastle et al. 2003)

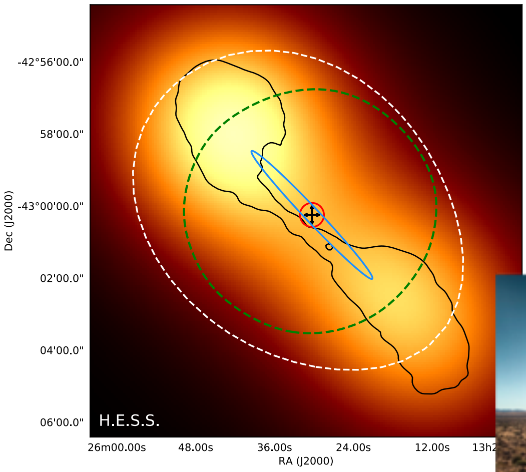
- VLA radio (8.4 GHz) emission (contours) correlates with X-rays.
- X-rays are continuously emitted throughout jet.
- X-rays due to synchrotron (?), electrons need to be accelerated everywhere (short cooling timescale for $\gamma \sim 10^8$)

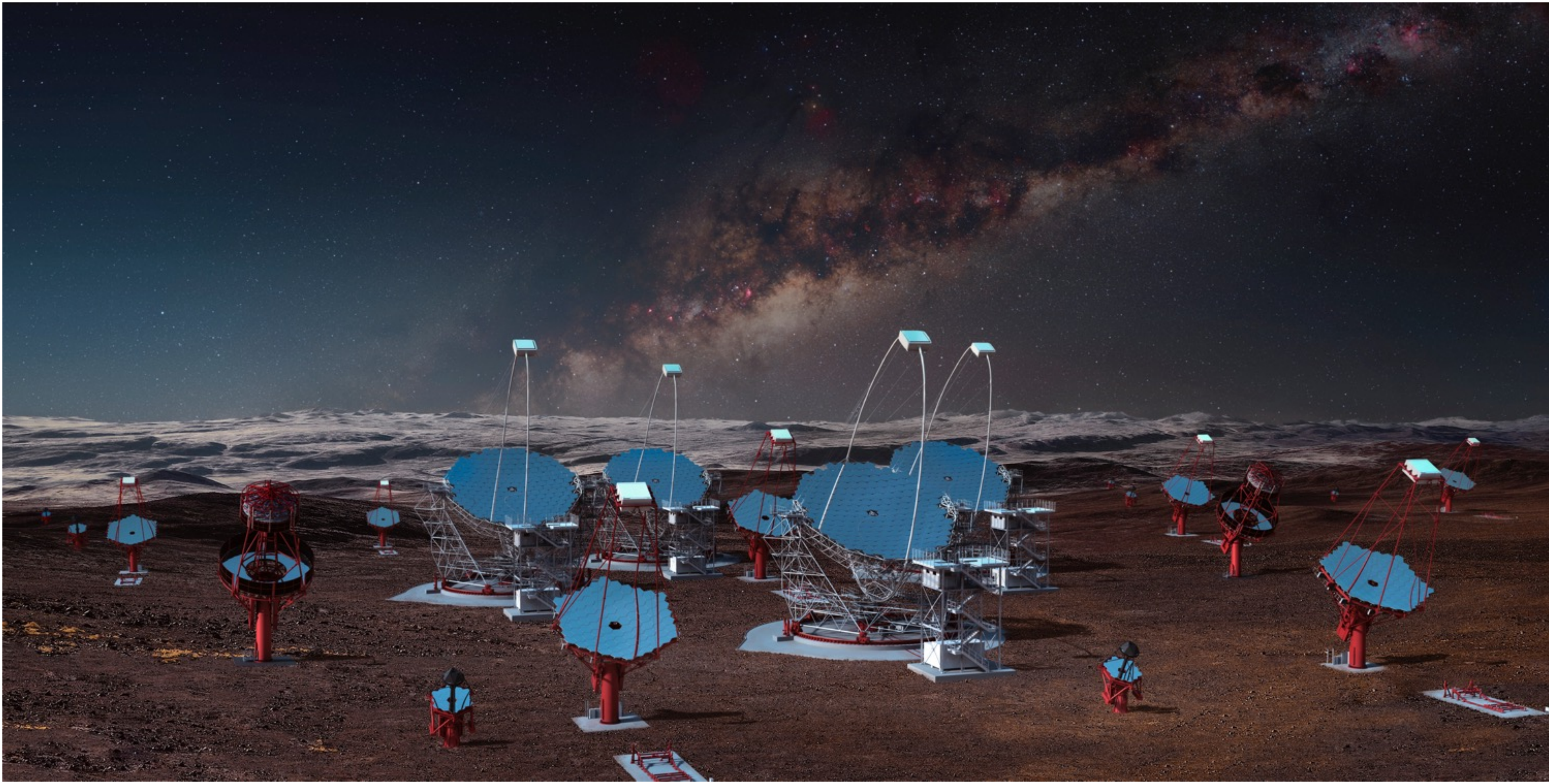
# Conclusions

# Conclusion : echelles

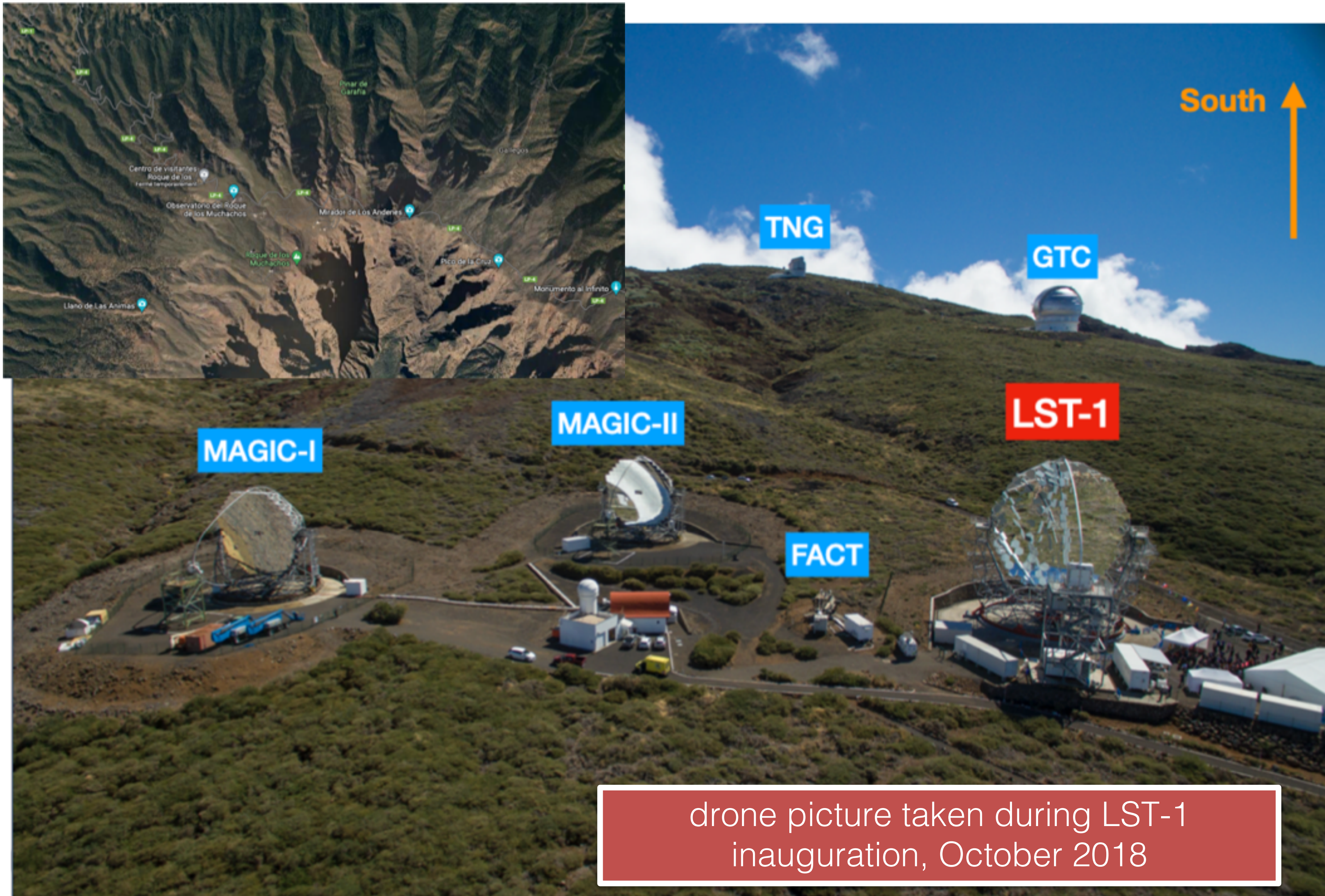


More information on Cen A morphology
RWS ?

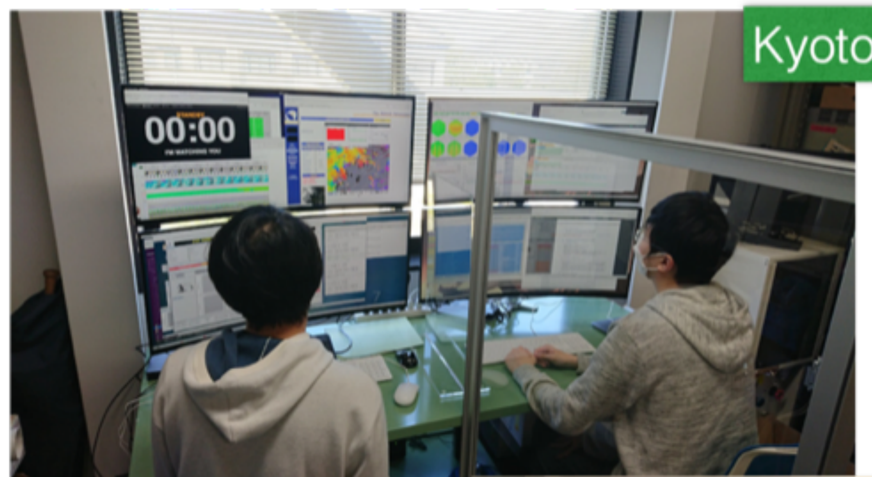



drone picture taken during LST-1
inauguration, October 2018

# Semi-remote operation

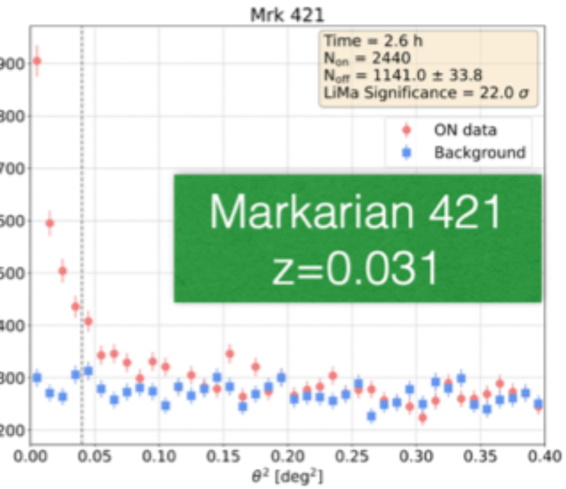
Implementation of semi-remote operations

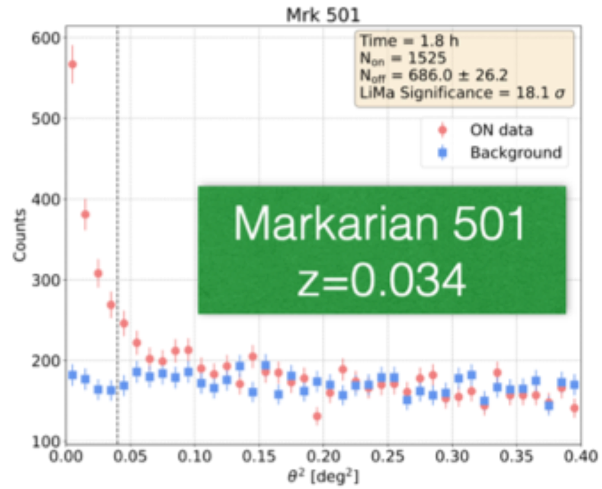
- Always people at ORM
- Japan and Europe allow full coverage of a night

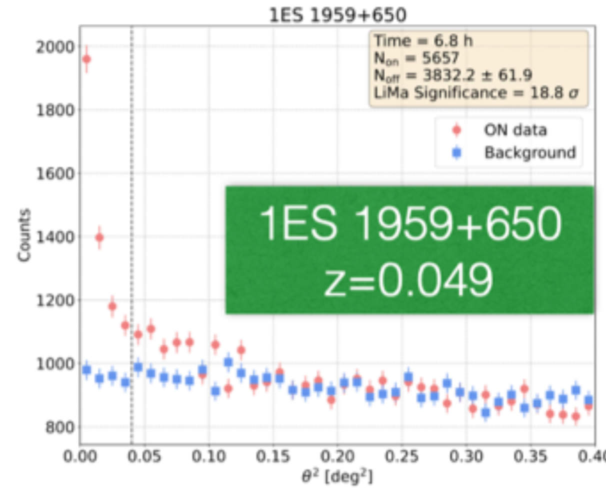



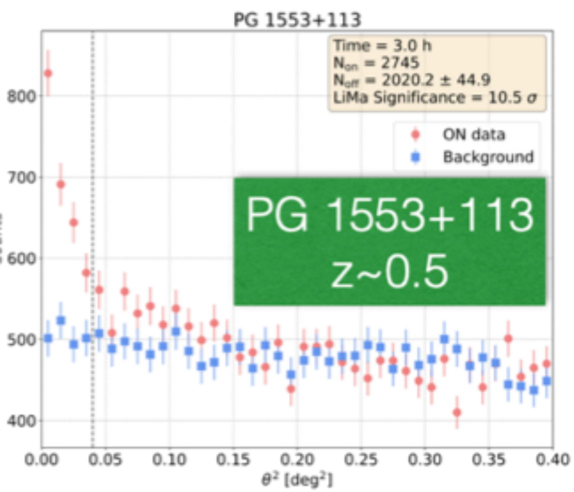


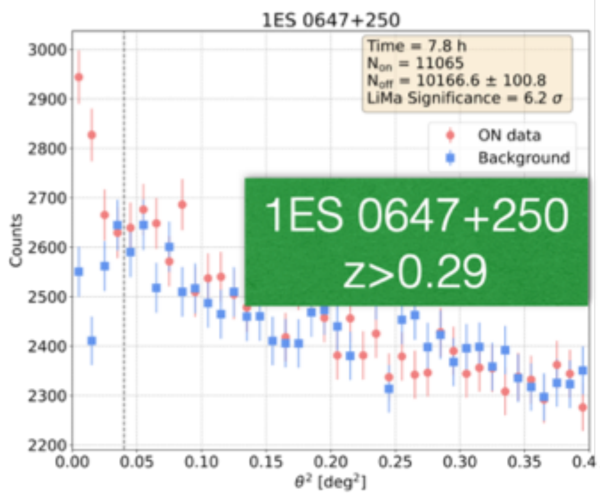

# Detection of several blazars and Crab pulsar

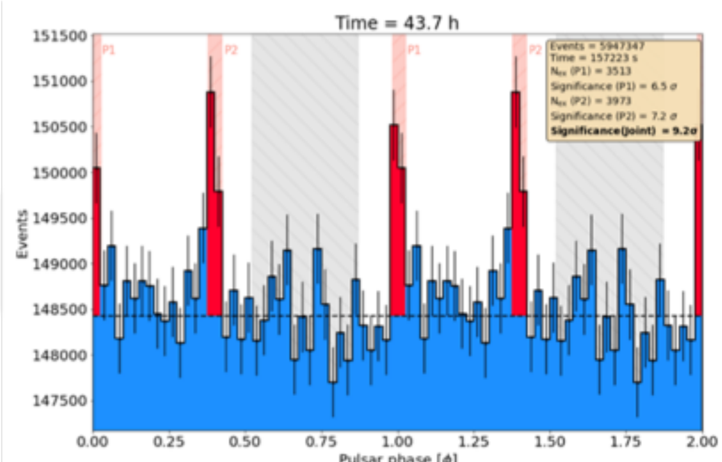


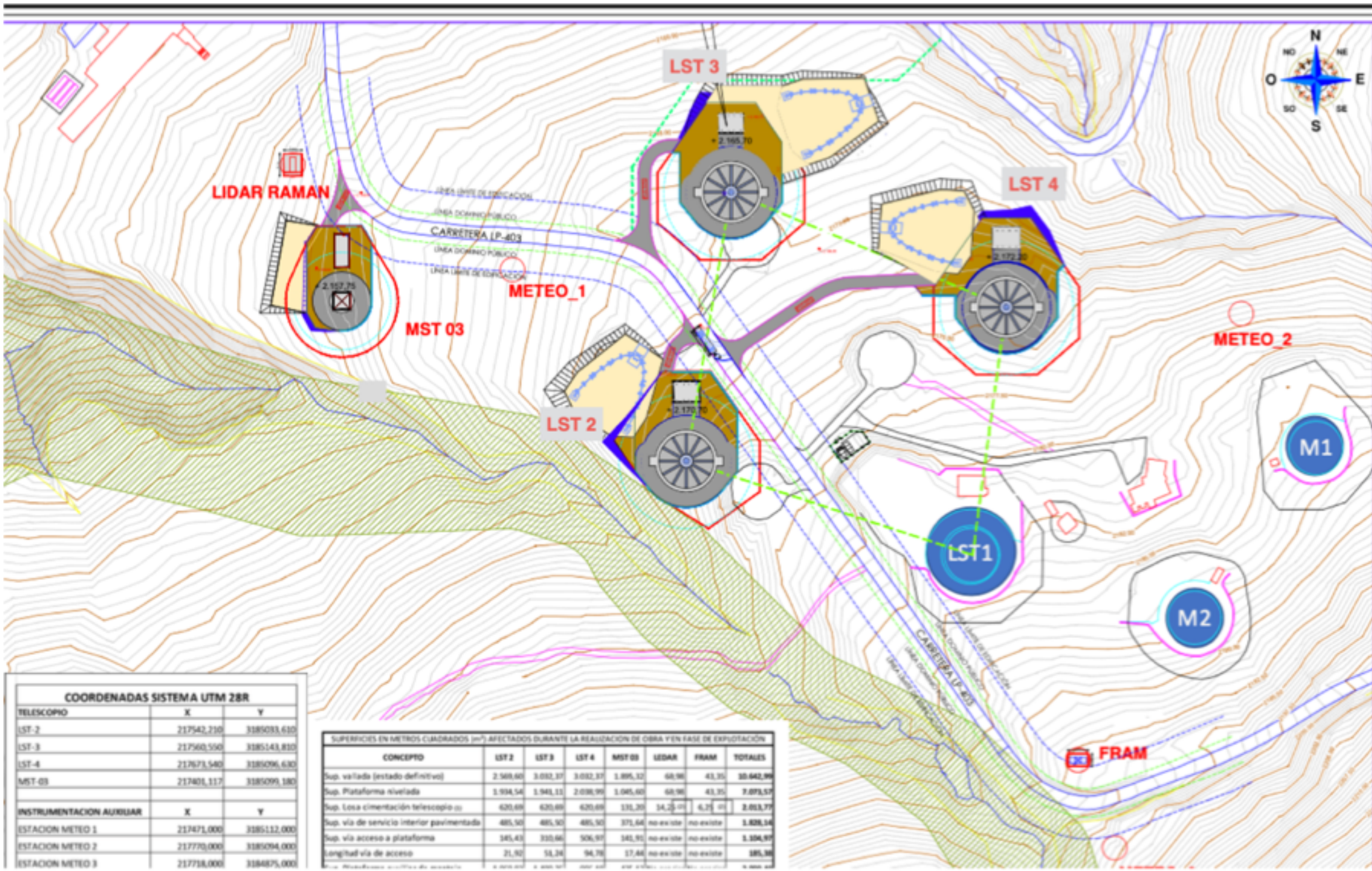




Crab pulsar

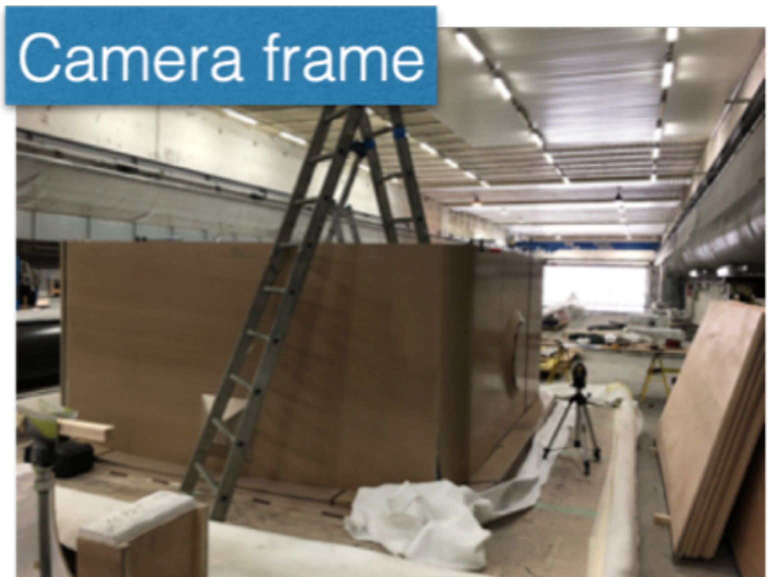
https://pos.sissa.it/395/872/

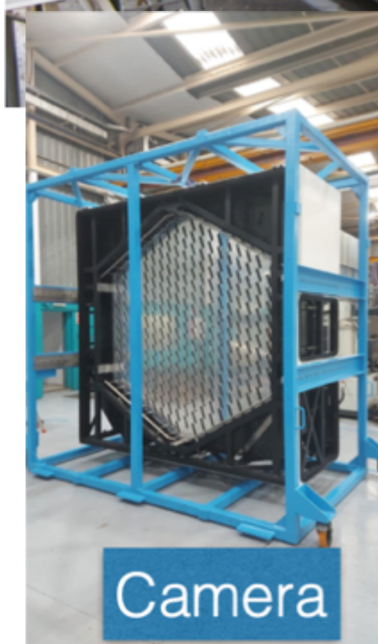
LST2 -> End of 2021- early 2022
LST3-4 -> completed end of 2023



# Future LST 2-4





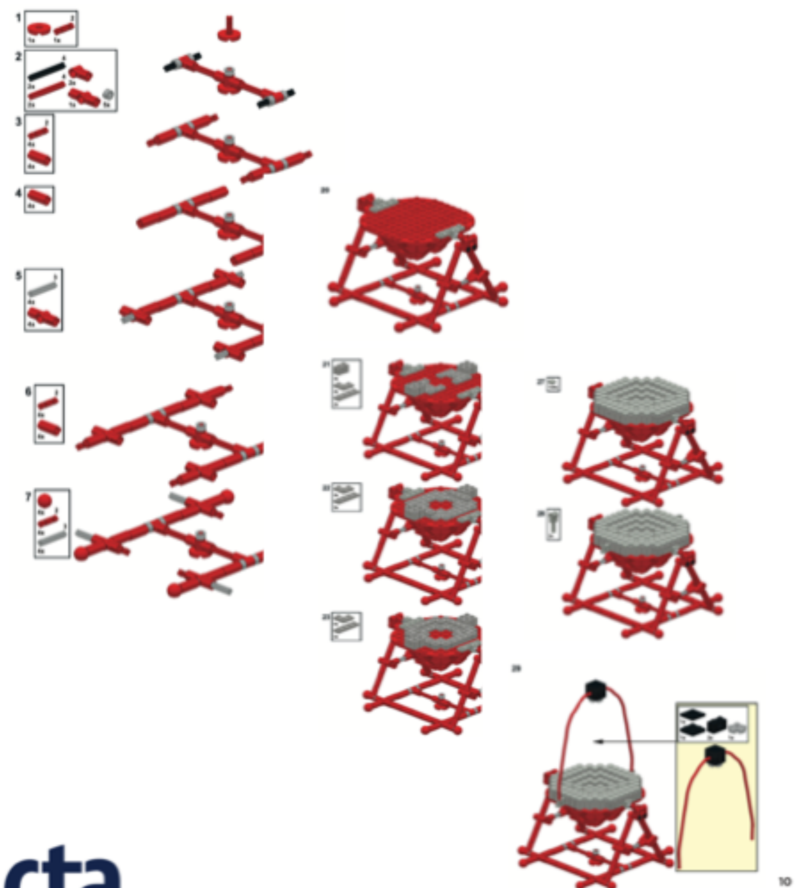



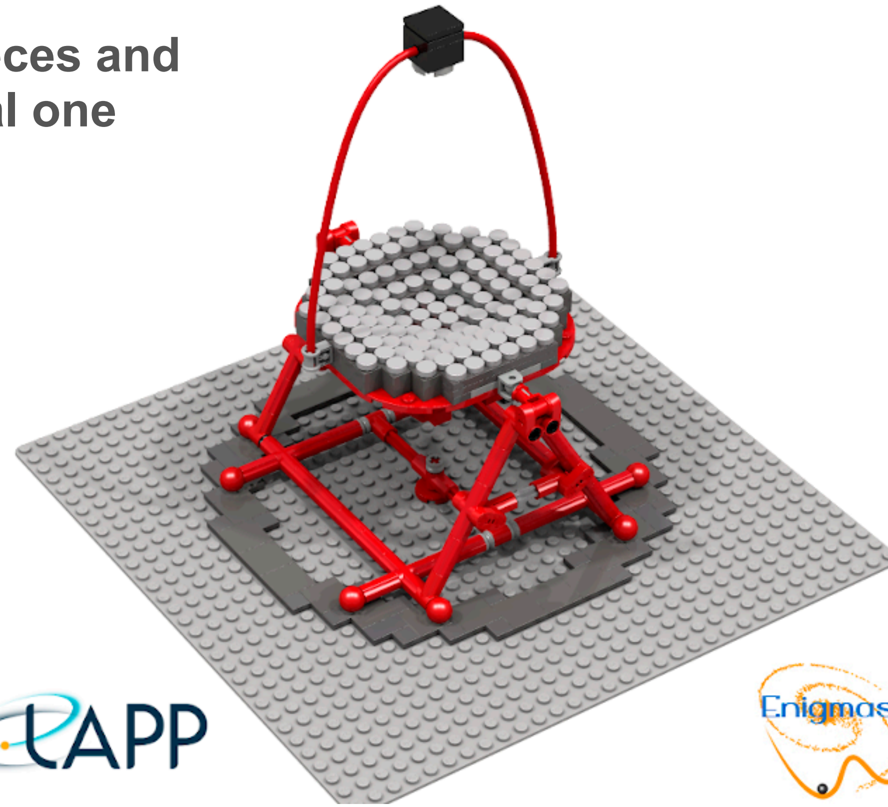


Activities currently stopped

Peoples and Telescopes are safe at ORM

**The LEGO model is made of 423 pieces and can rotate around its axis as the real one**





https://www.youtube.com/watch?v=Xun9GZQ3BN4