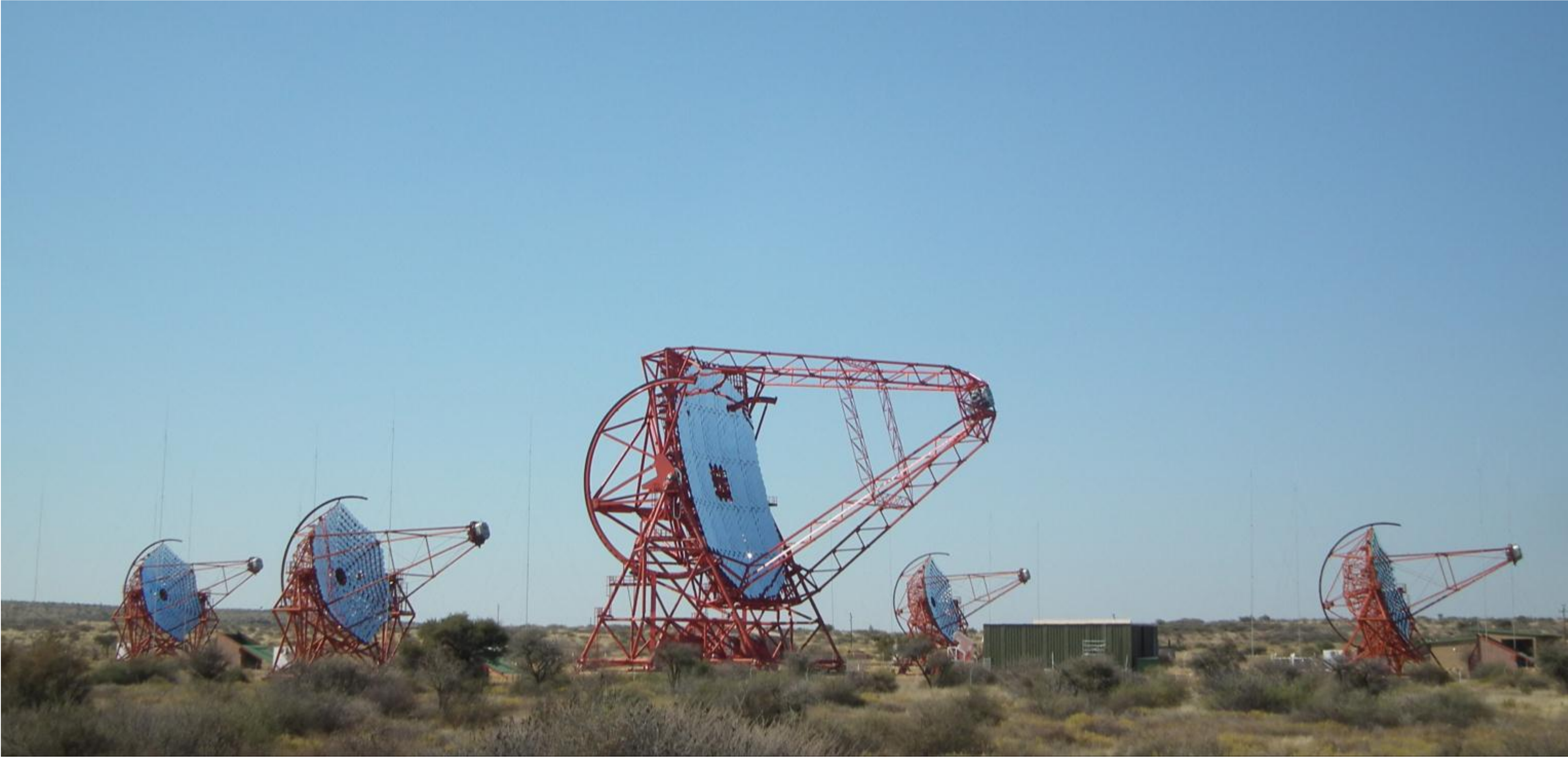


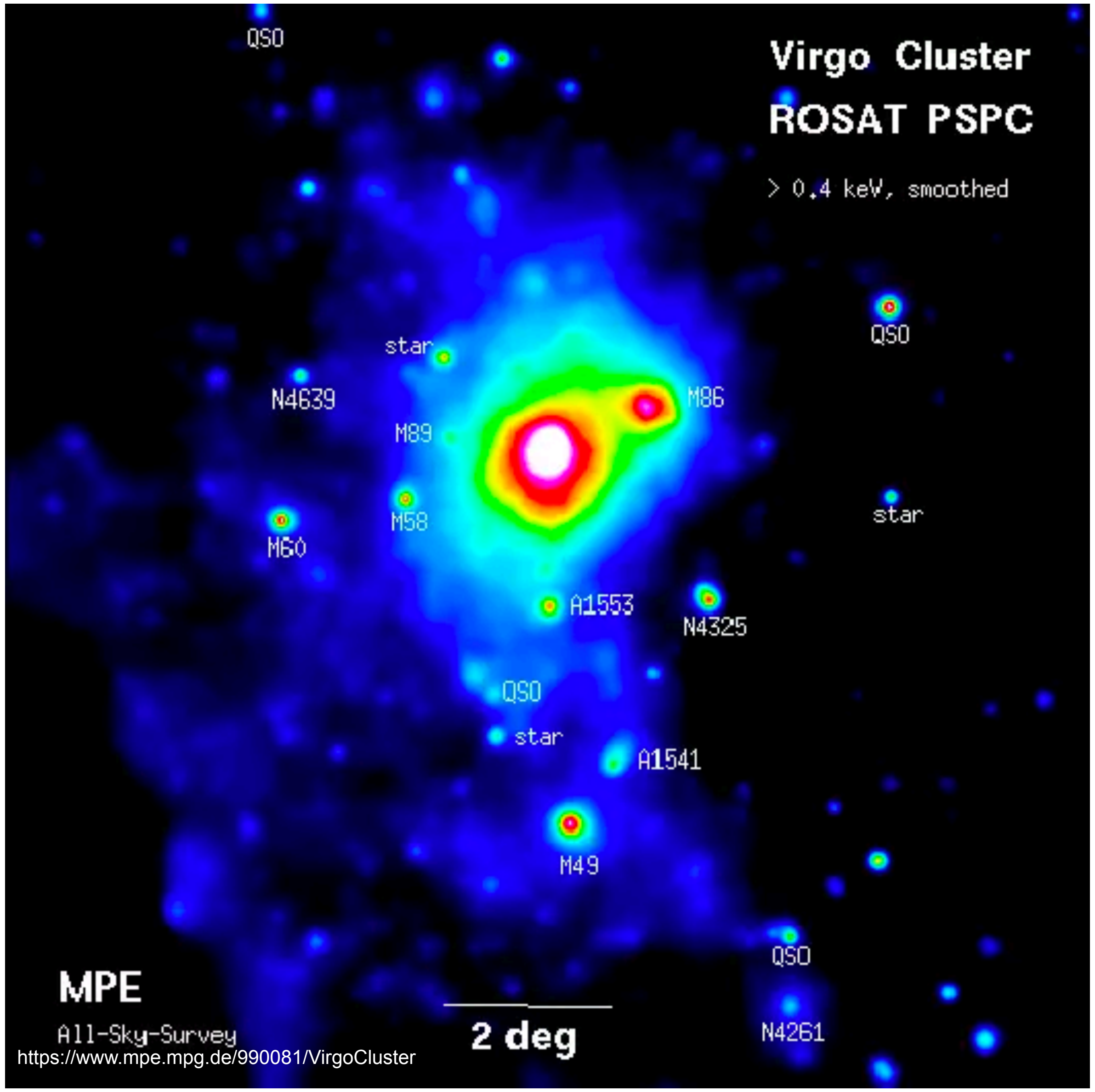
The gamma-ray morphology of M87 with H.E.S.S.

V. Barbosa Martins, C. Arcaro, N. Zywucka, S. Ohm, M. De Naurois, A. Taylor for the H.E.S.S. Collaboration

H.E.S.S.

Introduction

- The Virgo Cluster is a cool core cluster;



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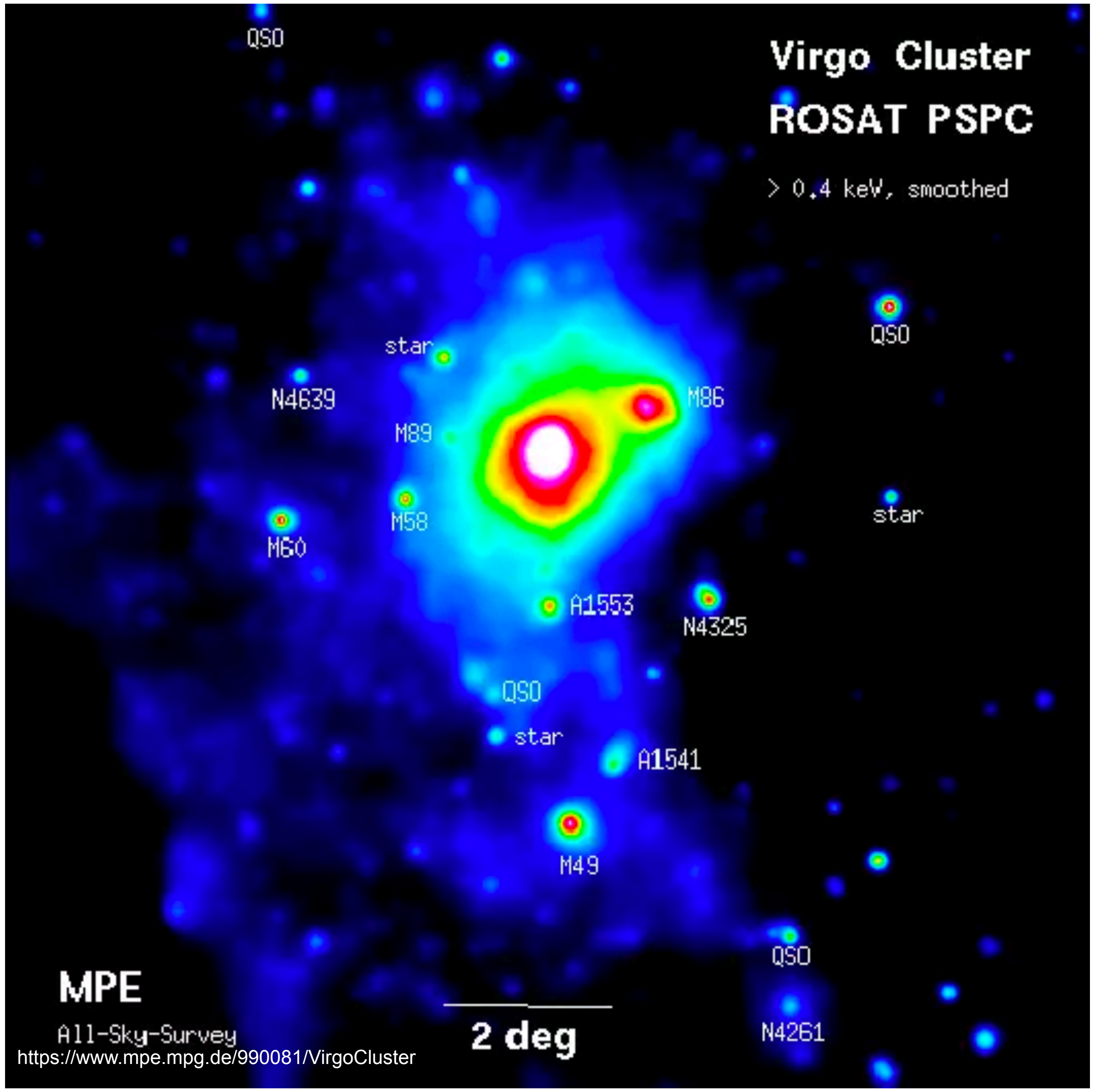

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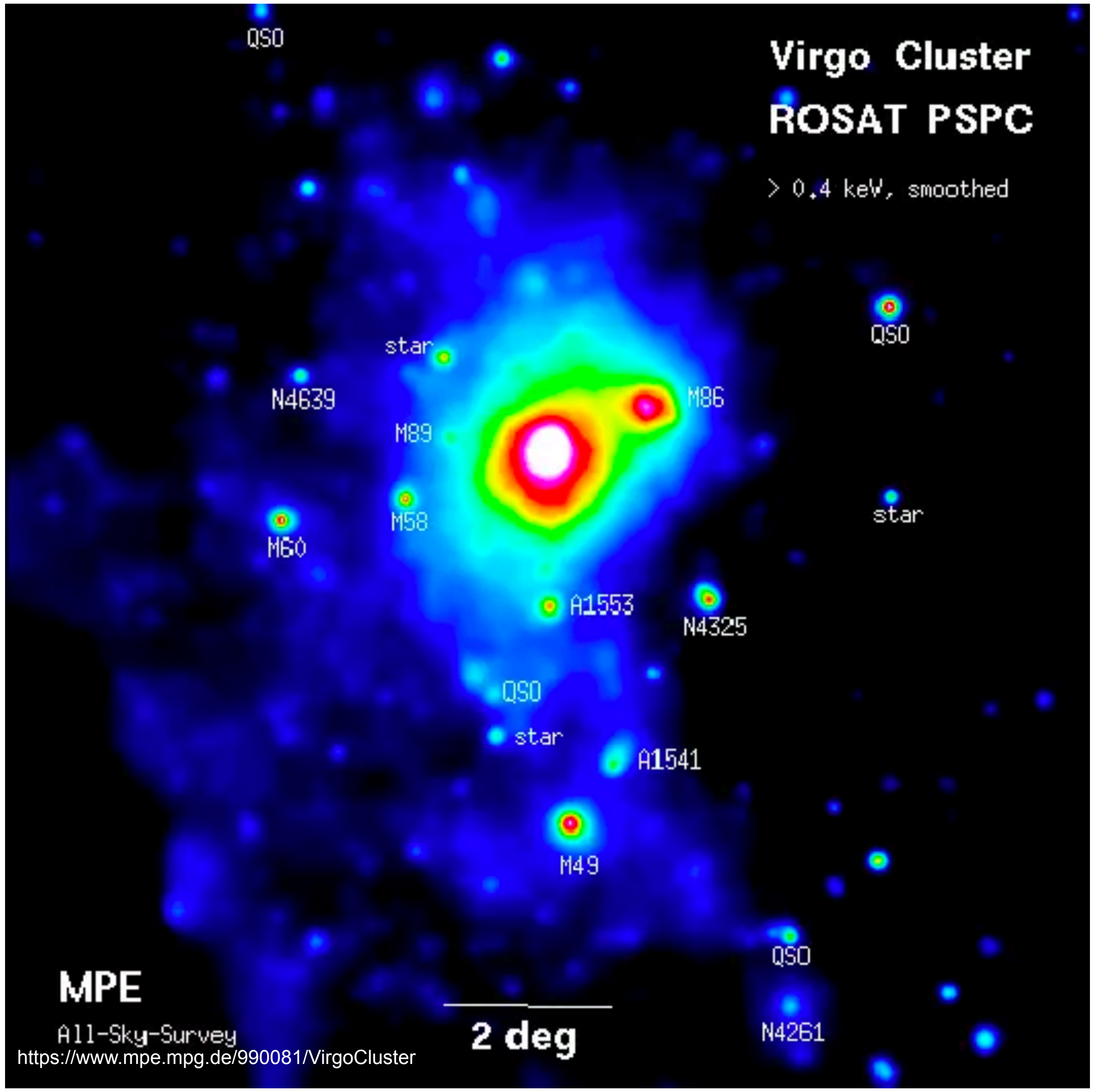

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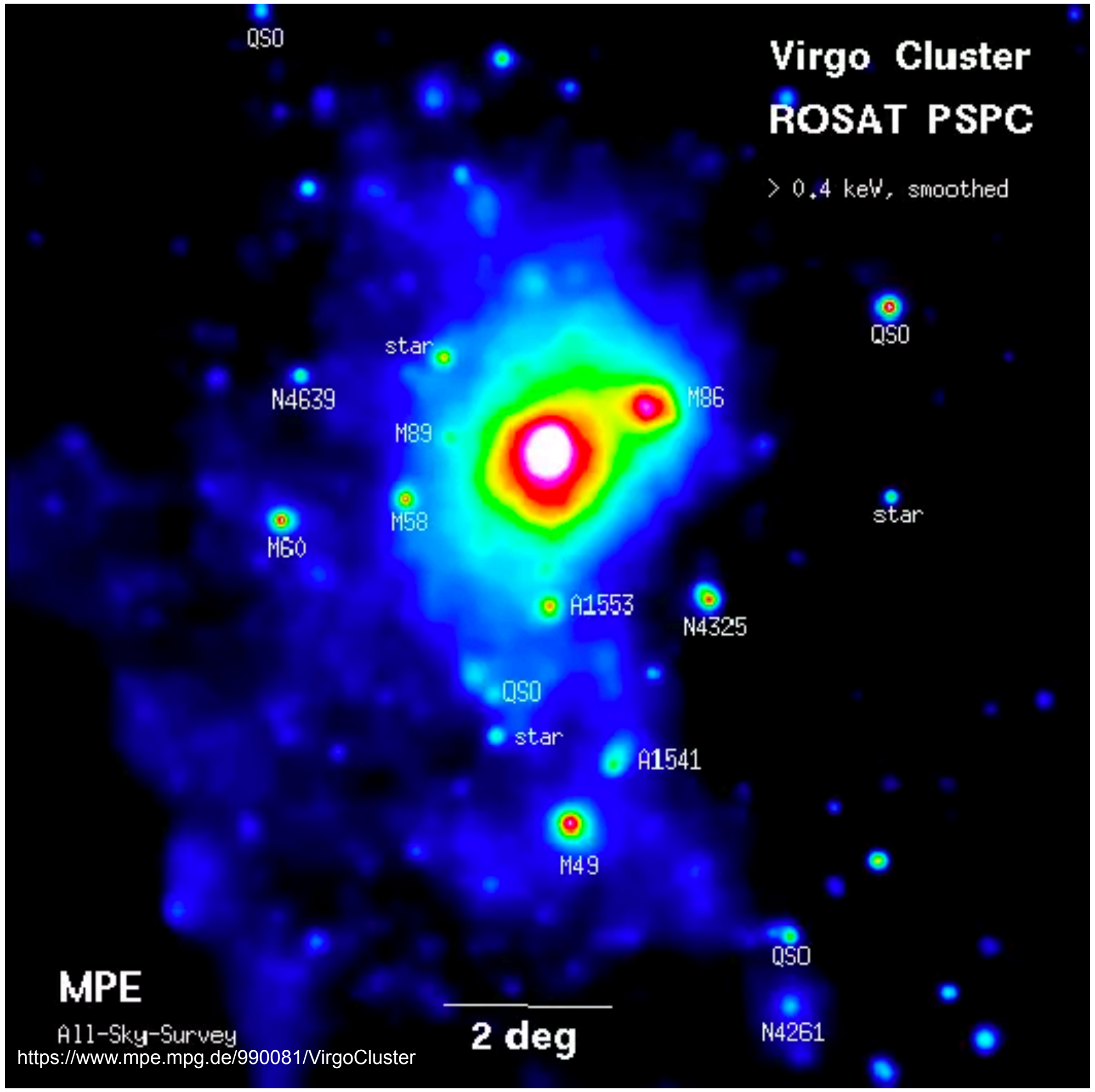

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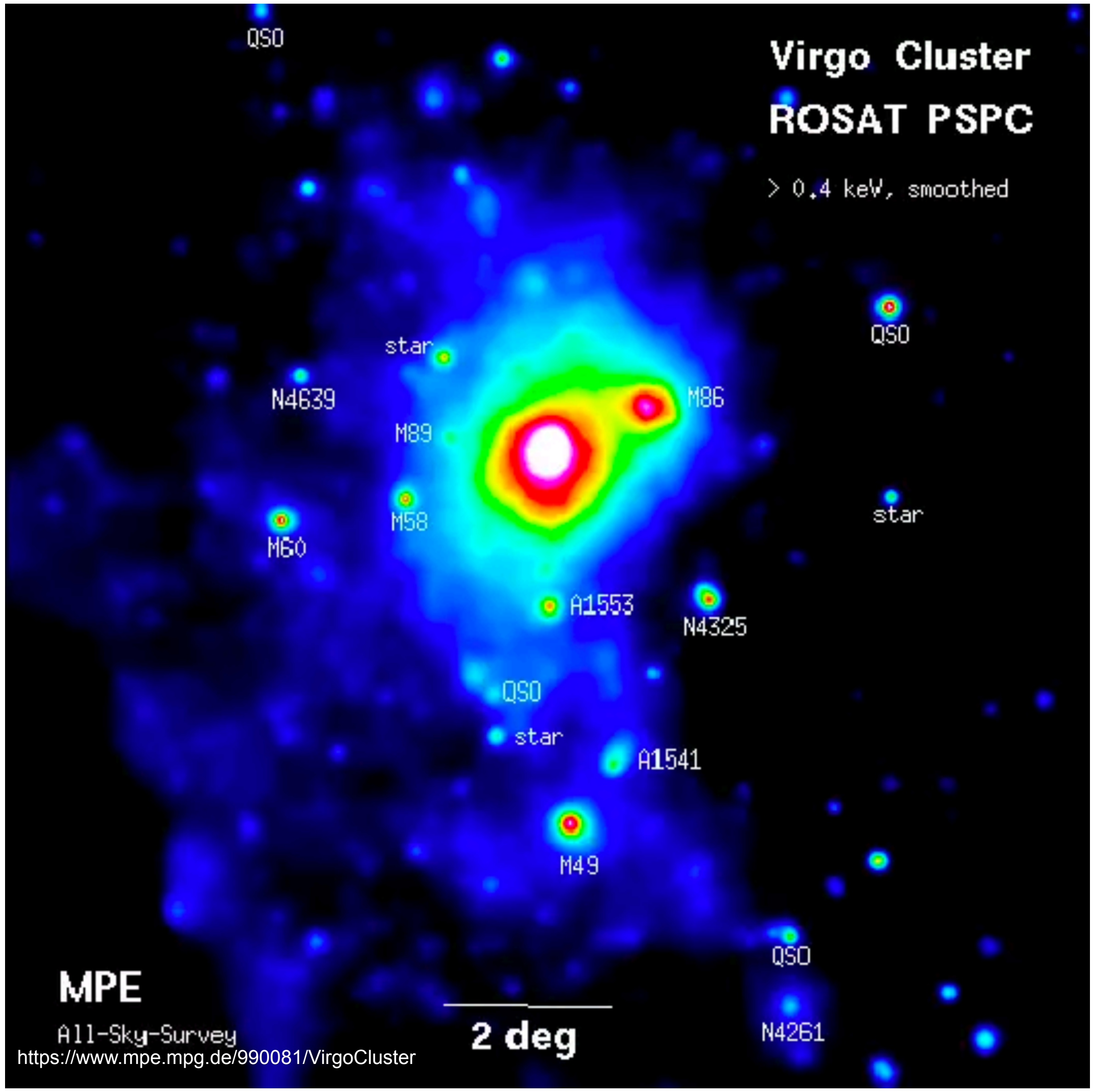

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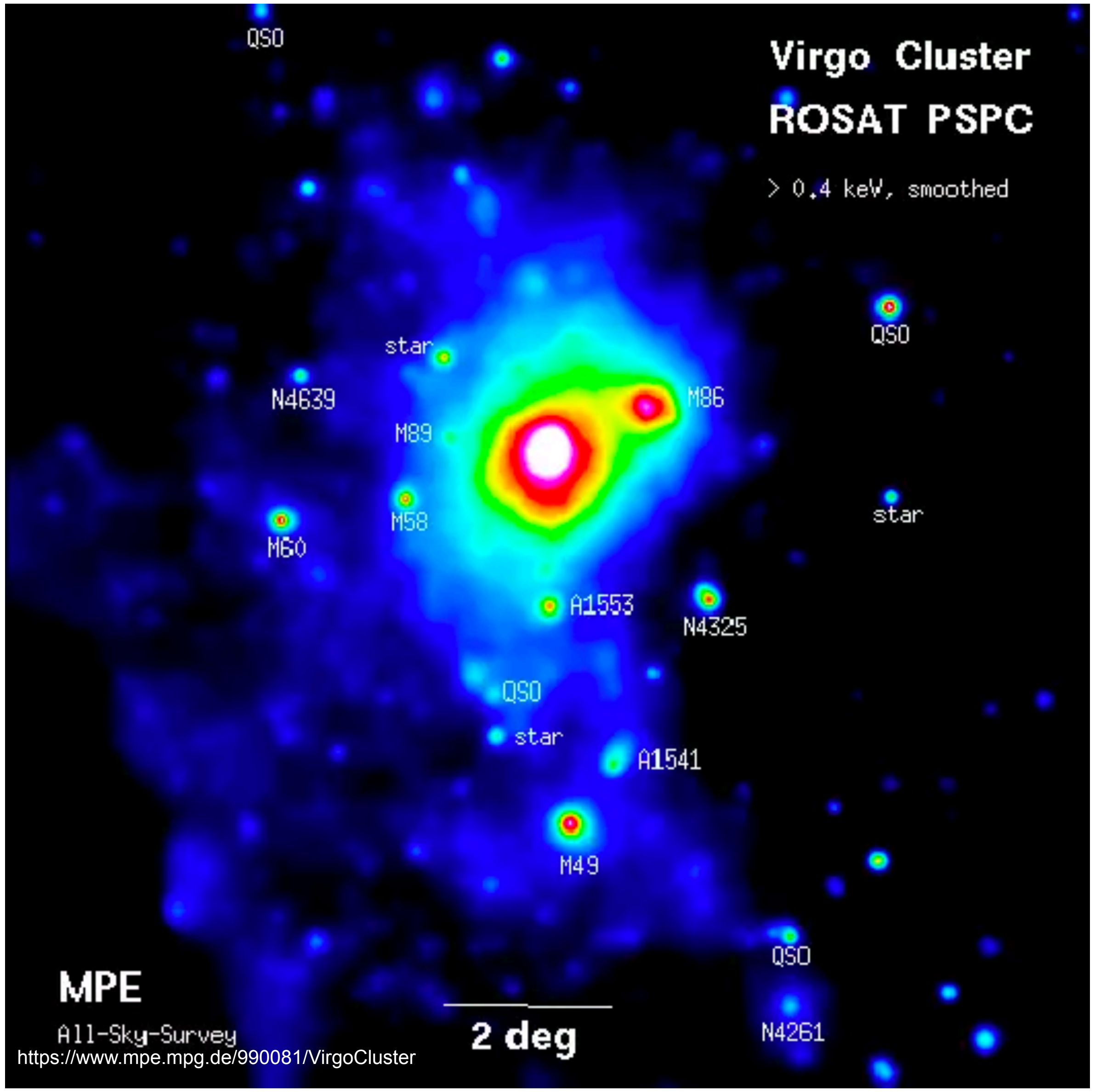
- In a dense environment such as a cluster core: $pp \rightarrow pp\pi^0$ $\pi^0 \rightarrow \gamma\gamma$ (Extended and non-variable)



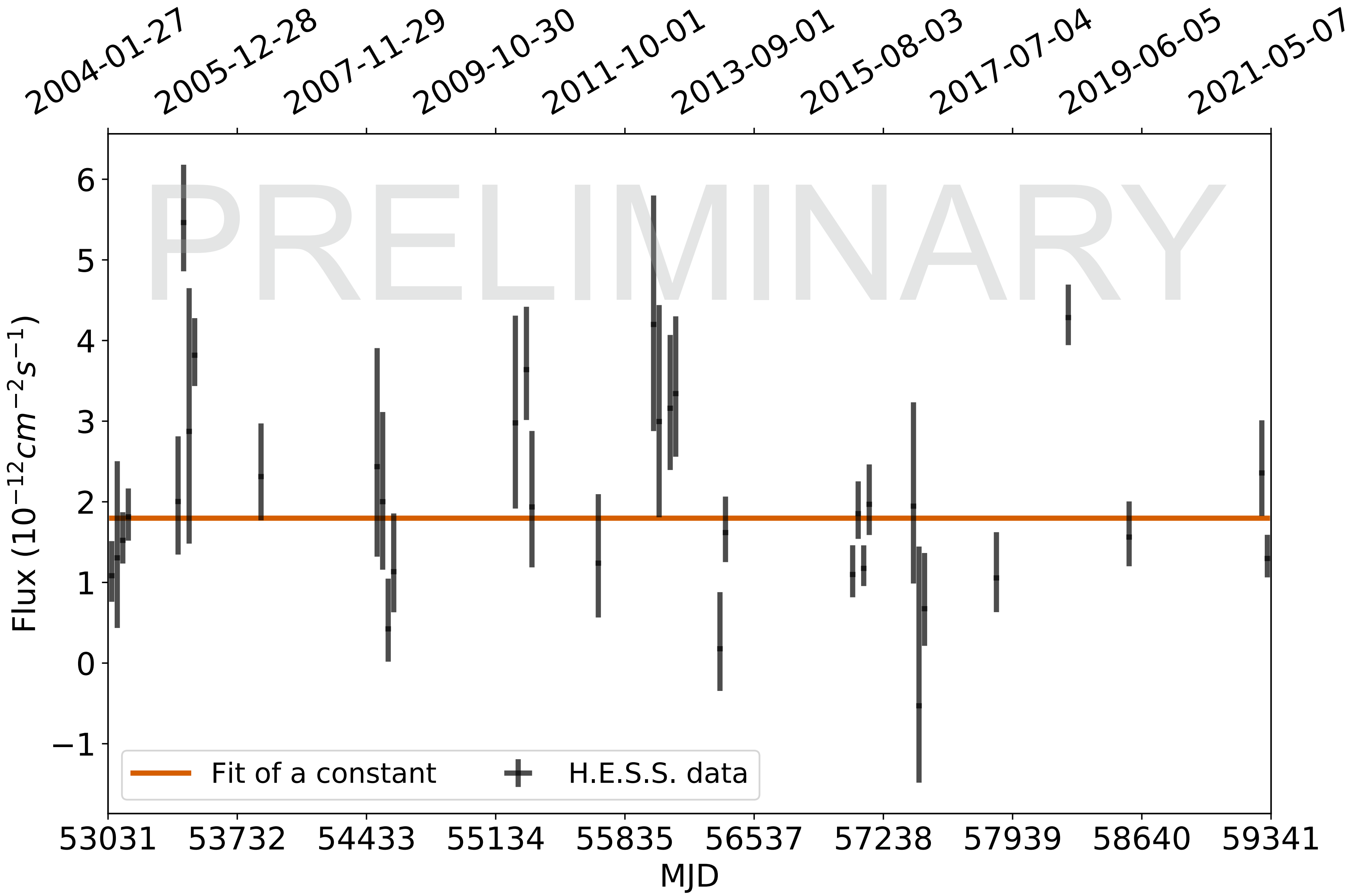
M87 morphology in VHE gamma-rays with H.E.S.S.

- Data from 2004 to 2021;
- Largest data-set ever analysed in VHE gamma rays for this source;
- Best-quality events selected;
- Improved angular resolution ($\sim 0.05^{\circ}$);
- Template analysis.

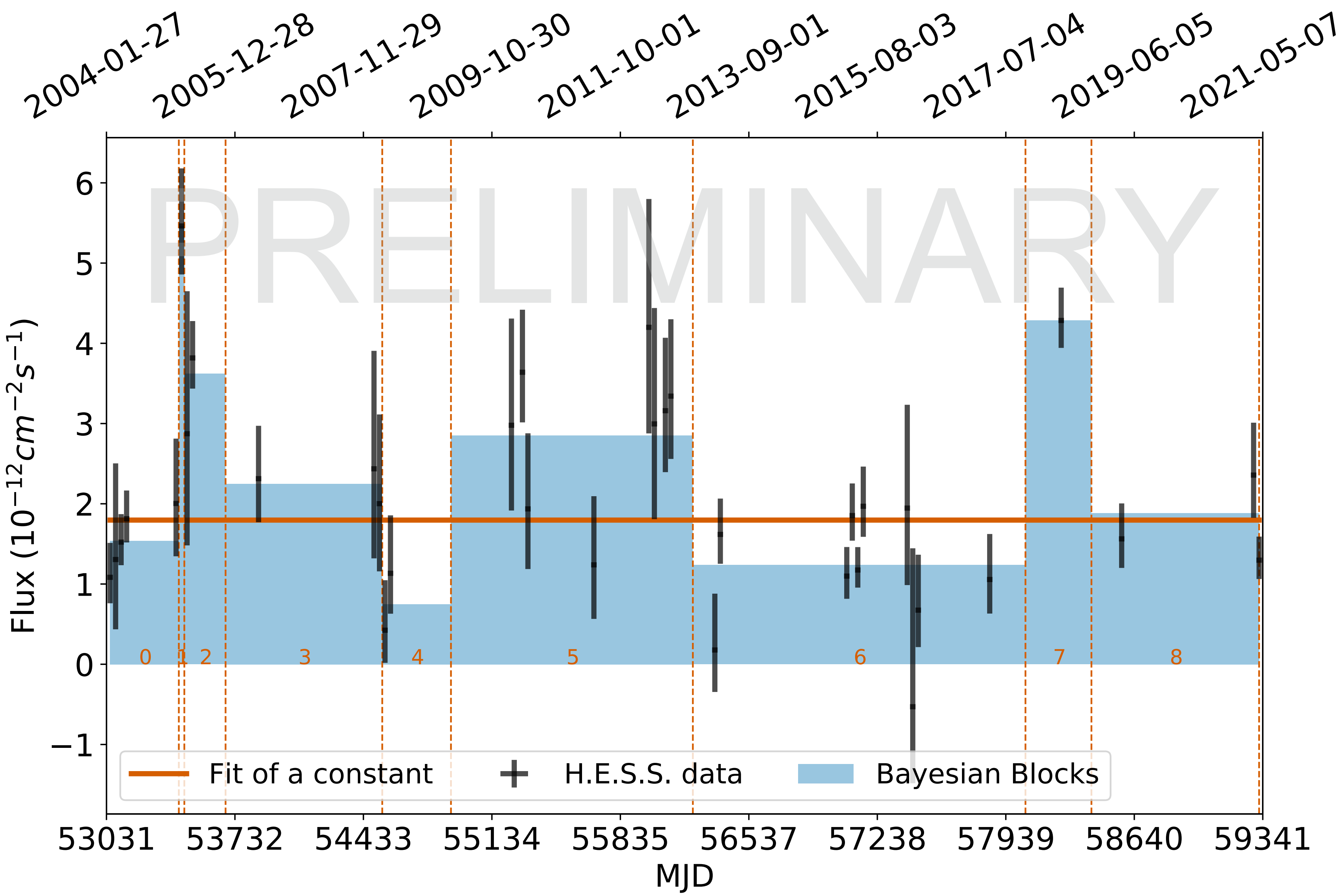
↓

livetime: 194 hours

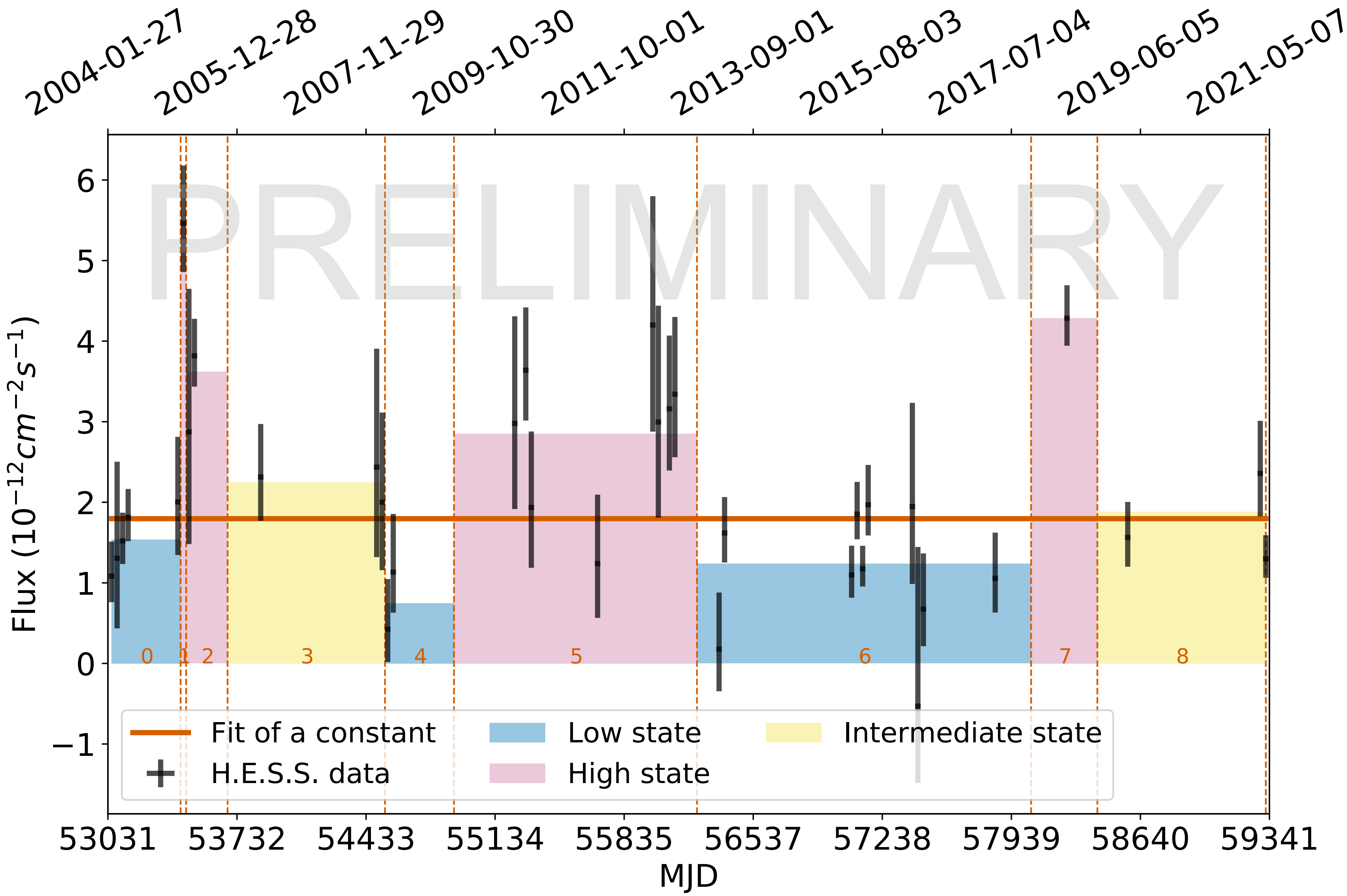
- The monthly-binned Light-curve;



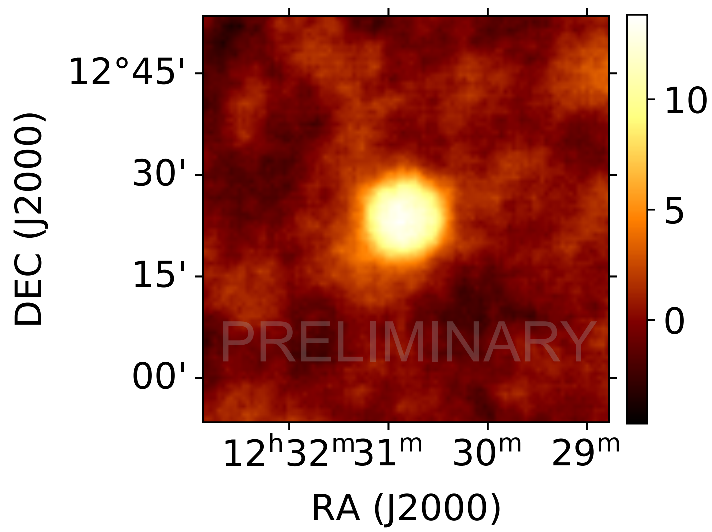
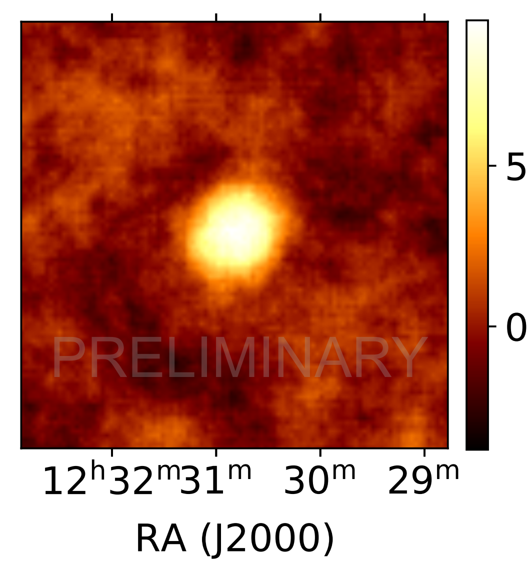
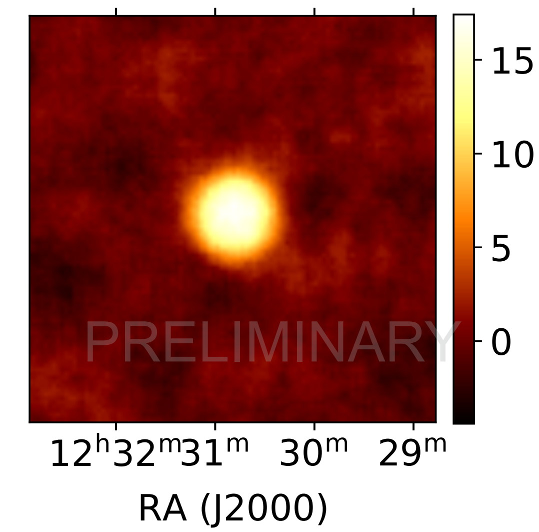
- The monthly-binned Light-curve;
- Bayesian blocks;



- The monthly-binned Light-curve;
- Bayesian blocks;
- Source states: low (below the average), intermediate (<30% above the average), high state (>30% above the average).



Source states

	Low	Intermediate	High
Livetime	$120\,h$	$28\,h$	$29\,h$
Significance	15.6σ	10.5σ	19.4σ
			
Flux (> 0.3 TeV)	$1.48 \pm 0.14 \times 10^{-12}\,cm^{-2}\,s^{-1}$	$1.58 \pm 0.22 \times 10^{-12}\,cm^{-2}\,s^{-1}$	$3.75 \pm 0.43 \times 10^{-12}\,cm^{-2}\,s^{-1}$
Spectral index α*	2.63 ± 0.09	2.40 ± 0.10	2.25 ± 0.05

$^*\Phi = \Phi_0(E/E_0)^{-\alpha}$

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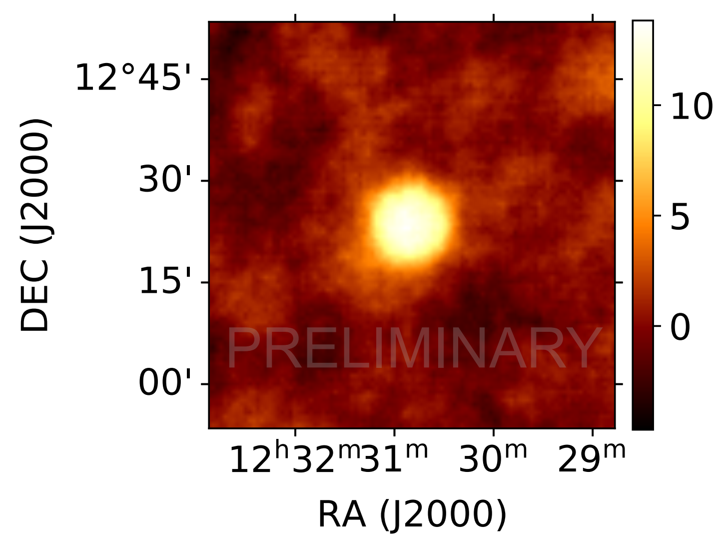

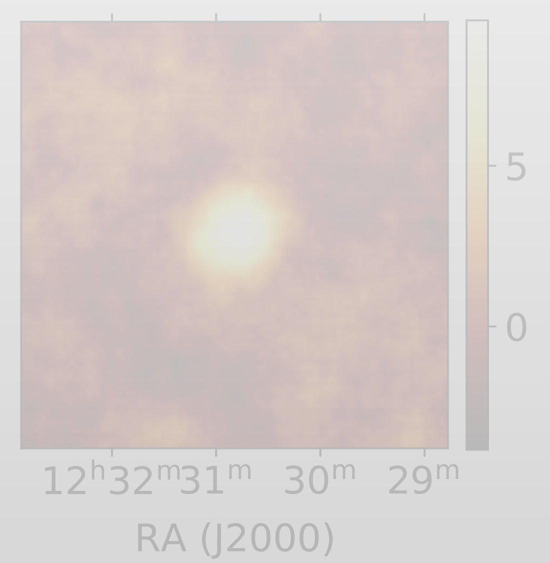

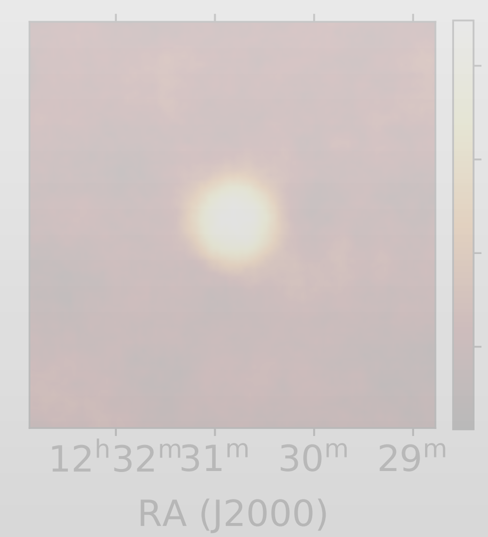

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- Morphology fit

Point-like model

X

2D Symmetrical Gaussian

- Morphology fit

Point-like model X 2D Symmetrical Gaussian

- Fit statistics

Low

$\Delta TS \approx 0$

0σ

No extension detected!

- Morphology fit

Point-like model X 2D Symmetrical Gaussian

- Fit statistics

Sanity check:

Low	Intermediate	High
$\Delta TS \approx 0$	$\Delta TS \approx 2.7$	$\Delta TS \approx 0.4$
0σ	1.6σ	0.6σ

No extension detected!

- Gamma-ray localisation

99.7% c.l. σ Gaussian extension UL

Low
16.2 mdeg
4.6 kpc*

Intermediate
36.0 mdeg
10.3 kpc

High
22.3 mdeg
6.4 kpc

* distance to M 87 = 16.5 Mpc

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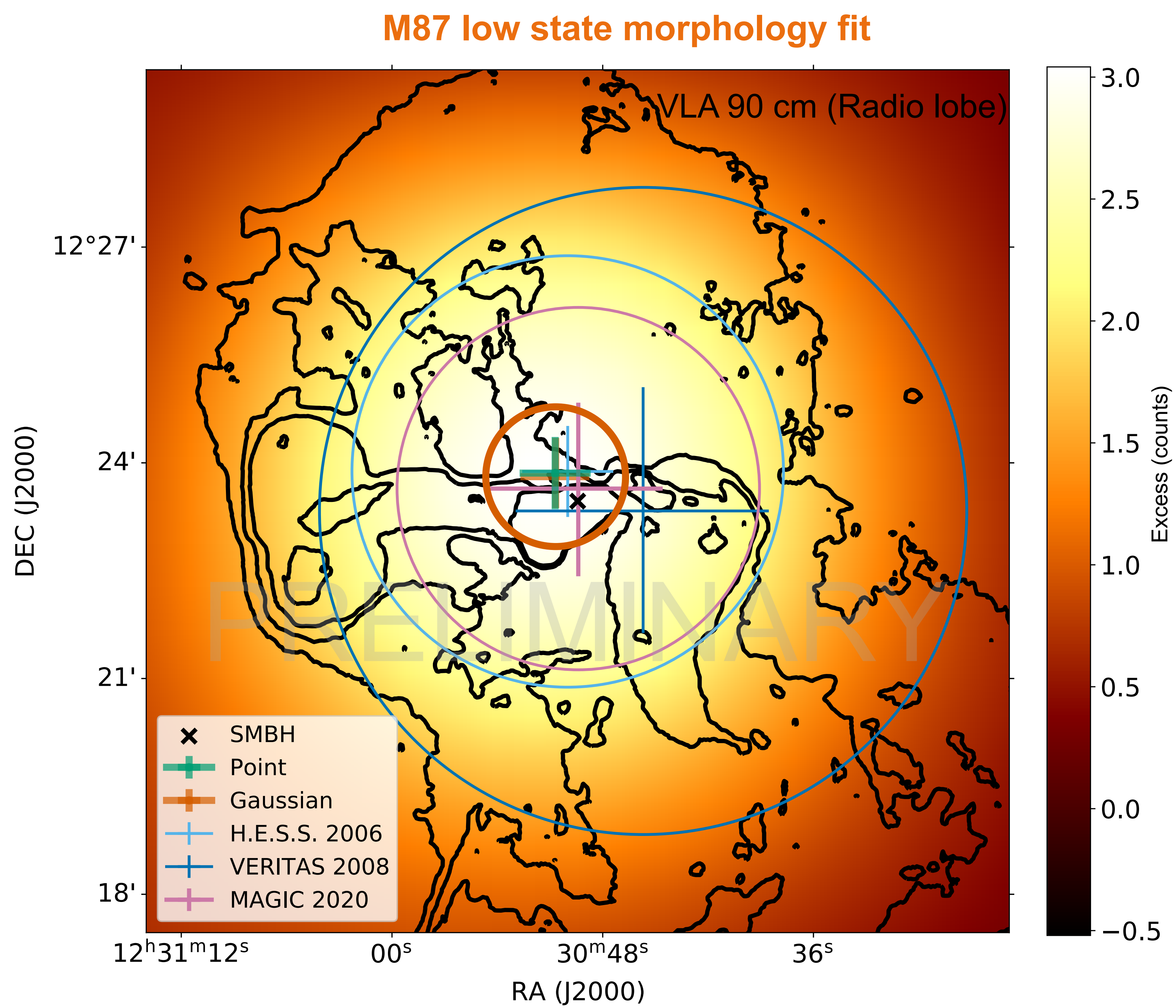

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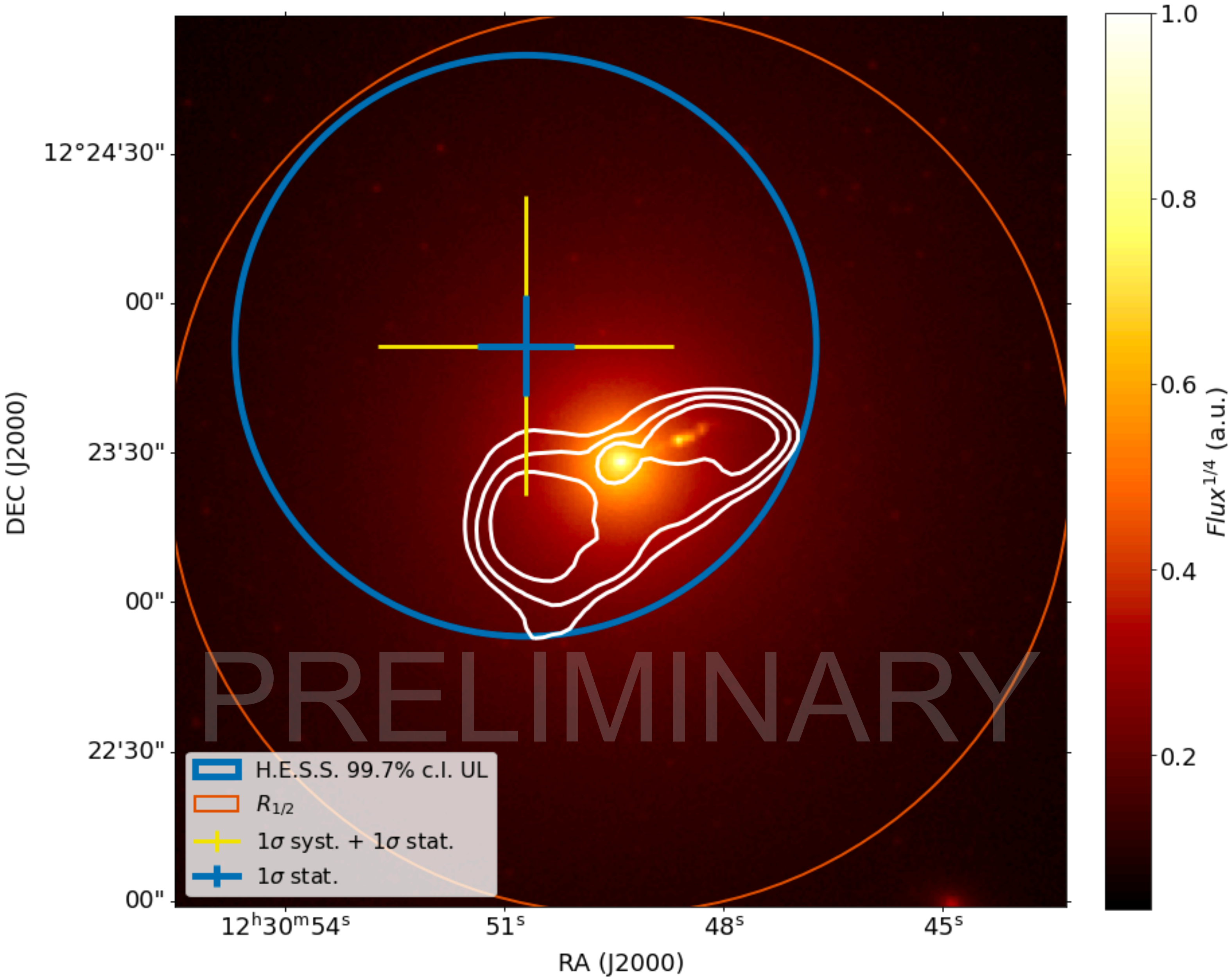
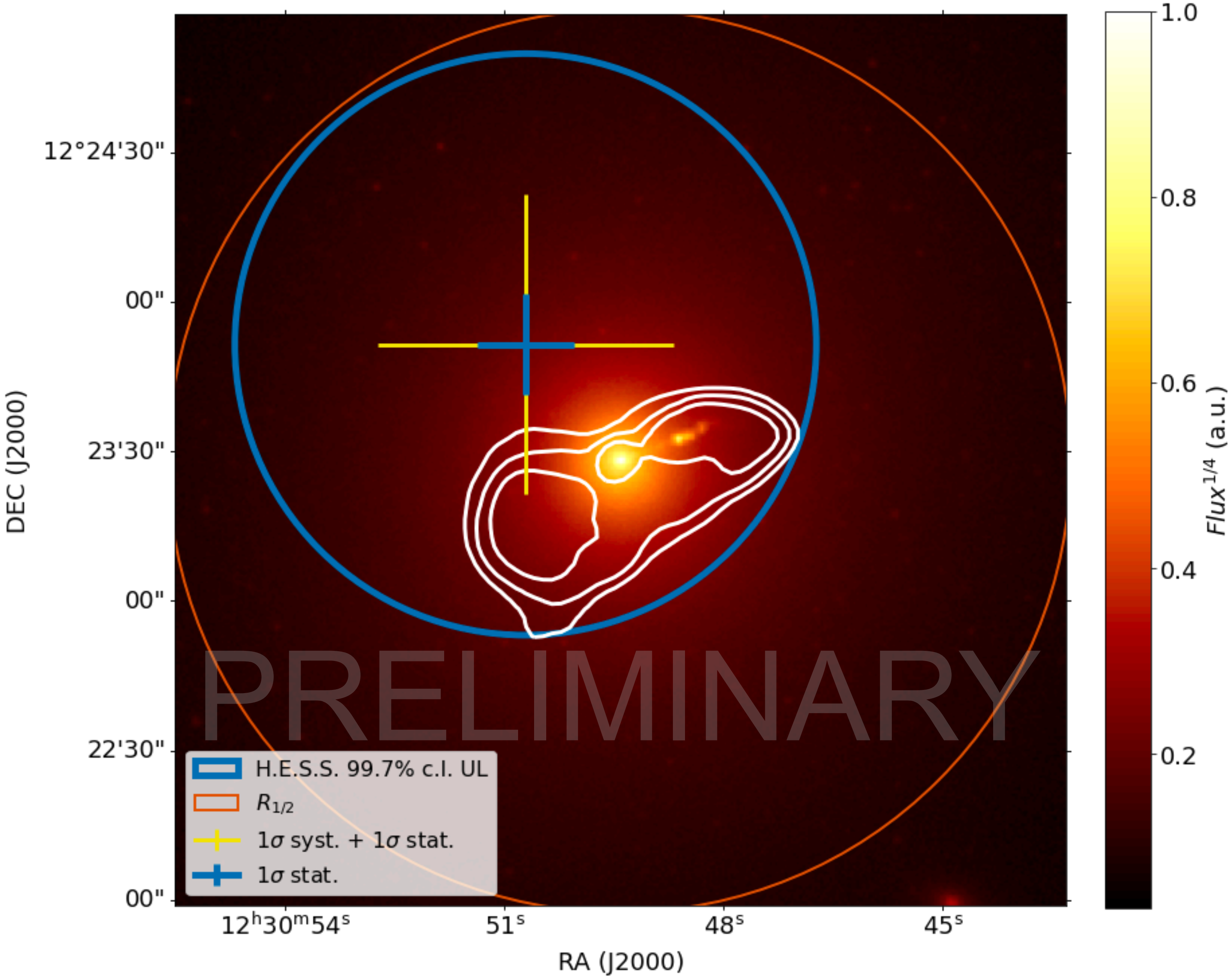
M87 low state extension UL



Radio VLA 21 cm (white)

Optical SDSSg (color-scale)

M87 low state extension UL

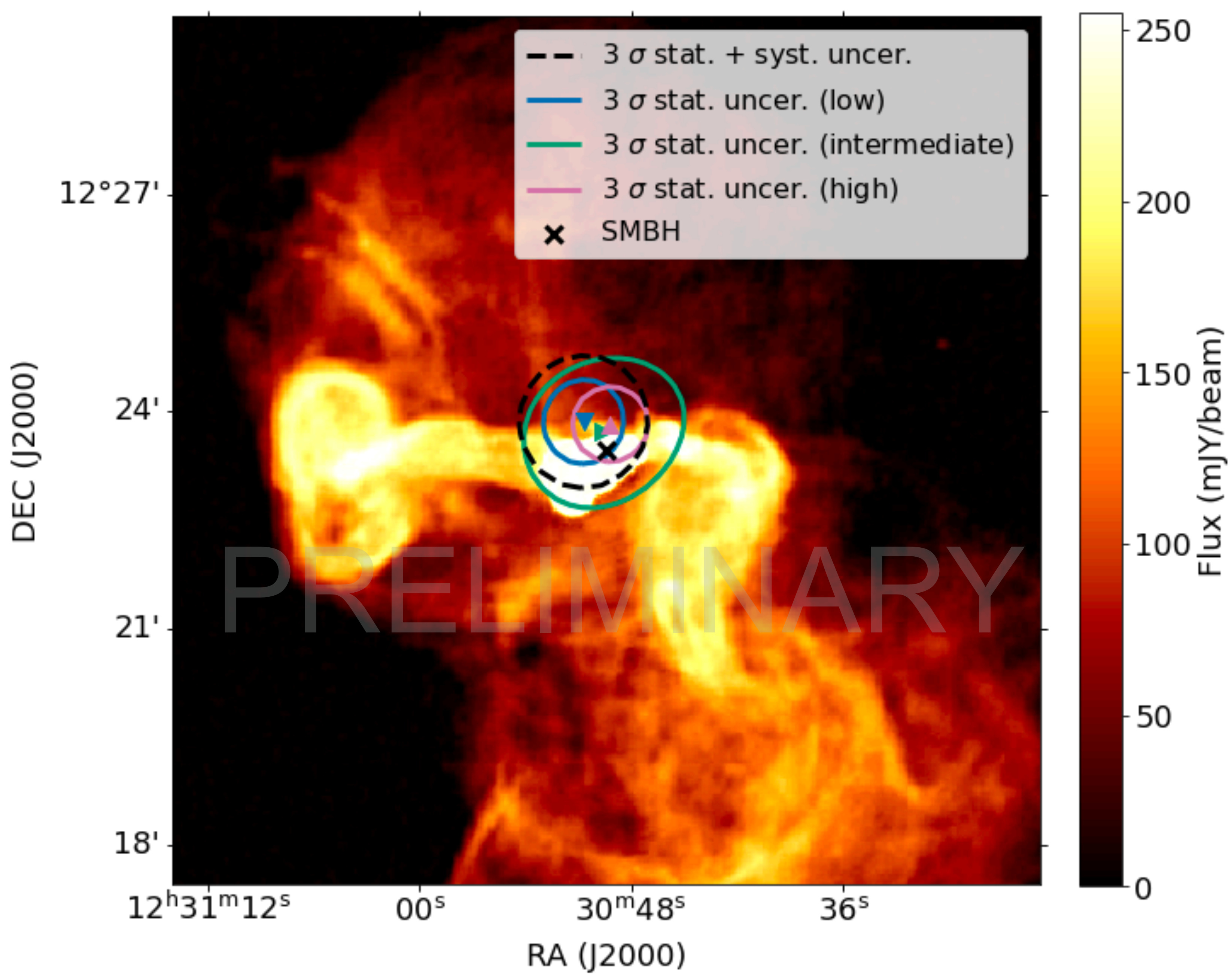


Radio VLA 21 cm (white)

Optical SDSSg (color-scale)

- The extension UL:
  - does not constrain the inner radio cocoon;
  - Does not constrain the emission from the large-scale jet;
  - Lies already inside M87's optical galaxy

M87 source states with the 3σ statistical uncertainties in the position



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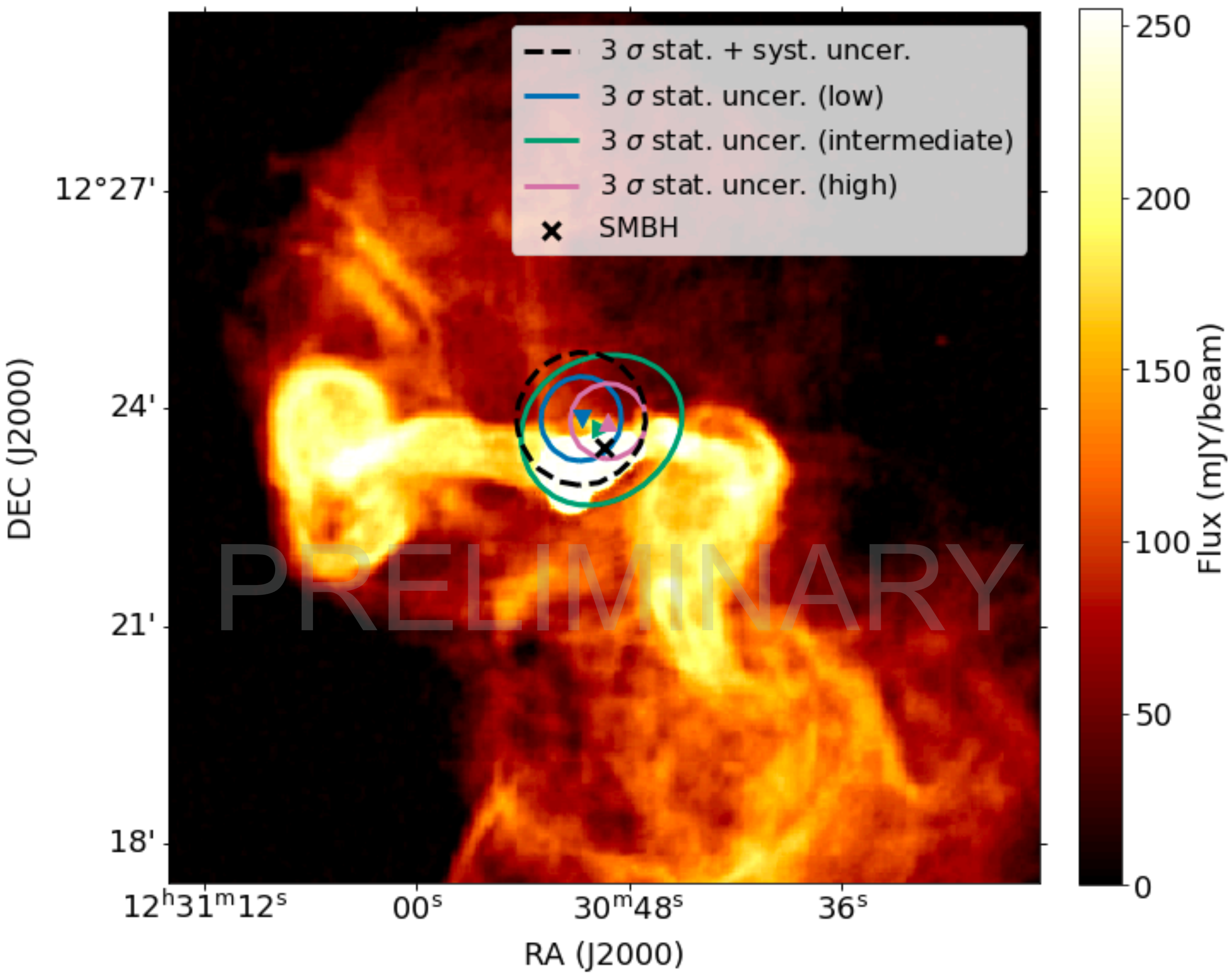

- Best fit position of the source states consistent with each other;
- All states consistent within 3σ with the SMBH position;
- Systematic checks assures the stability of the results.

The cosmic-ray pressure in the inner Virgo Cluster

- We used the limits on the extension of M87's VHE low state emission to derive an estimate of the cosmic-ray pressure from the AGN in the inner ($\lesssim 20$ kpc) Virgo Cluster;
- We adopted two approaches:

Steady state model
(AGN feedback)
Jacob & Pfrommer 2016

AGN feedback:

- **Steady state model**: heating by the AGN and thermal radiation counterbalances the cooling of the ICM

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LOFAR*-based emission

AGN feedback:

- **Steady state model**: heating by the AGN and thermal radiation counterbalances the cooling of the ICM

LOFAR-based:

- The extension of a gamma-ray signal from a hadronic scenario is assumed to have the same shape as the LOFAR emission

*image provided by de Gasperin

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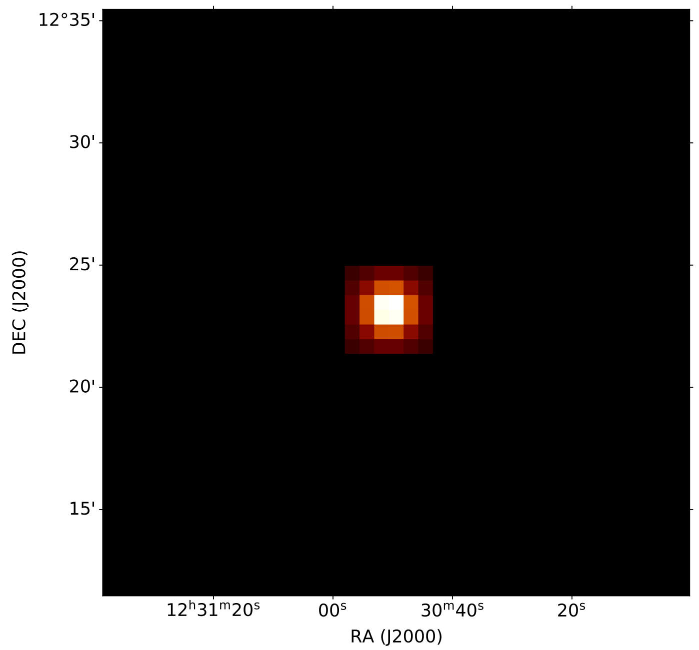
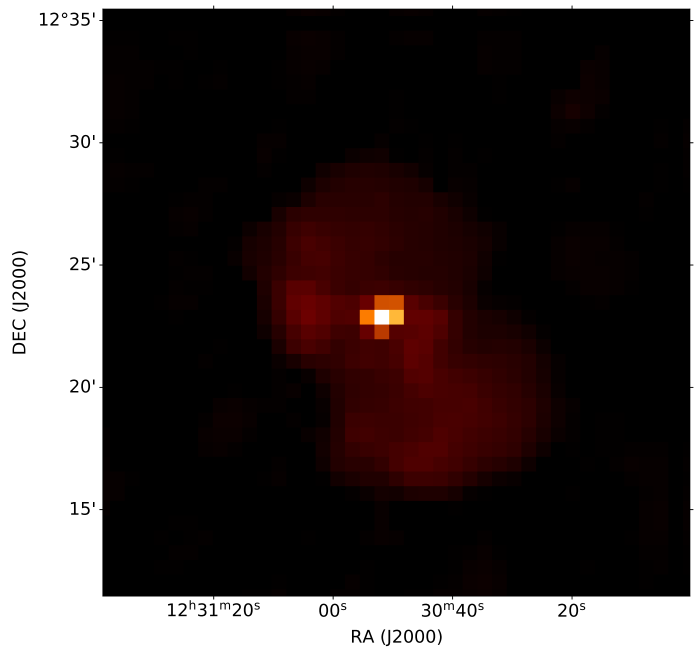


LOFAR*-based emission



*HR image provided by de Gasperin

- Morphology fit of a **hybrid model** composed of a **diffuse template** and a **point-like component** (jet emission) yield a 99.7% c.l. UL on the diffuse component:

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Jacob & Pfrommer 2016

$\approx 55\%$ of M87's low state VHE flux

LOFAR-based emission

$\approx 45\%$ of M87's low state VHE flux

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- Cosmic-ray pressure ratio:

$$< X_{CR} > = < P_{CR} > / < P_{th} > \quad \text{for } r < 20 \text{ kpc.}$$

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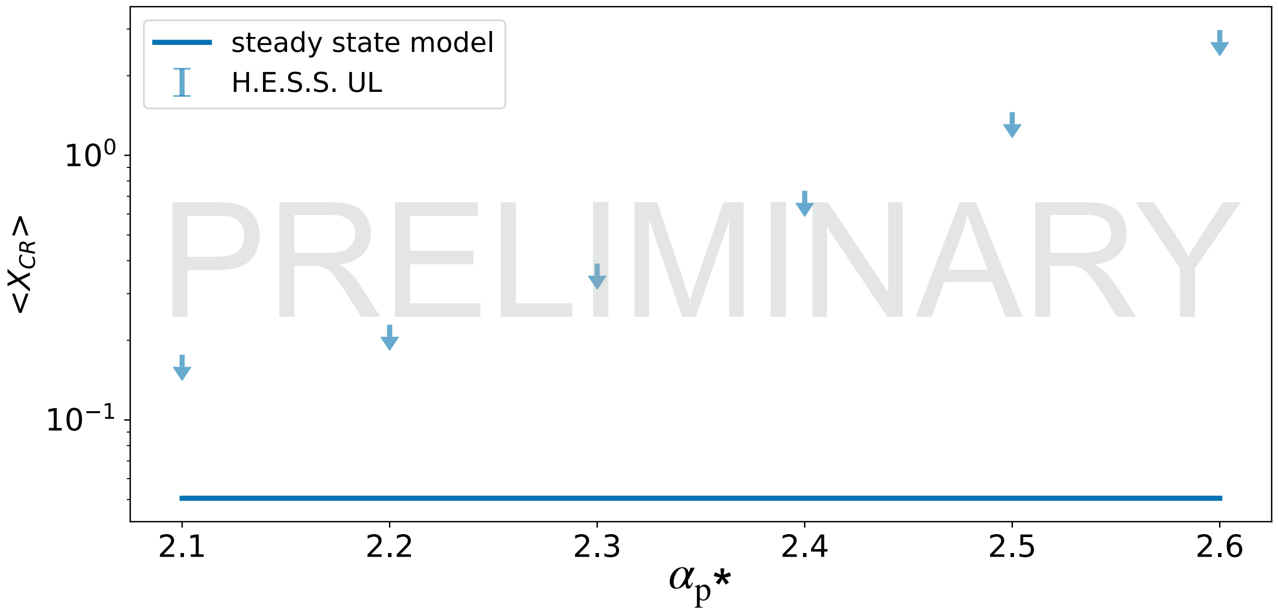
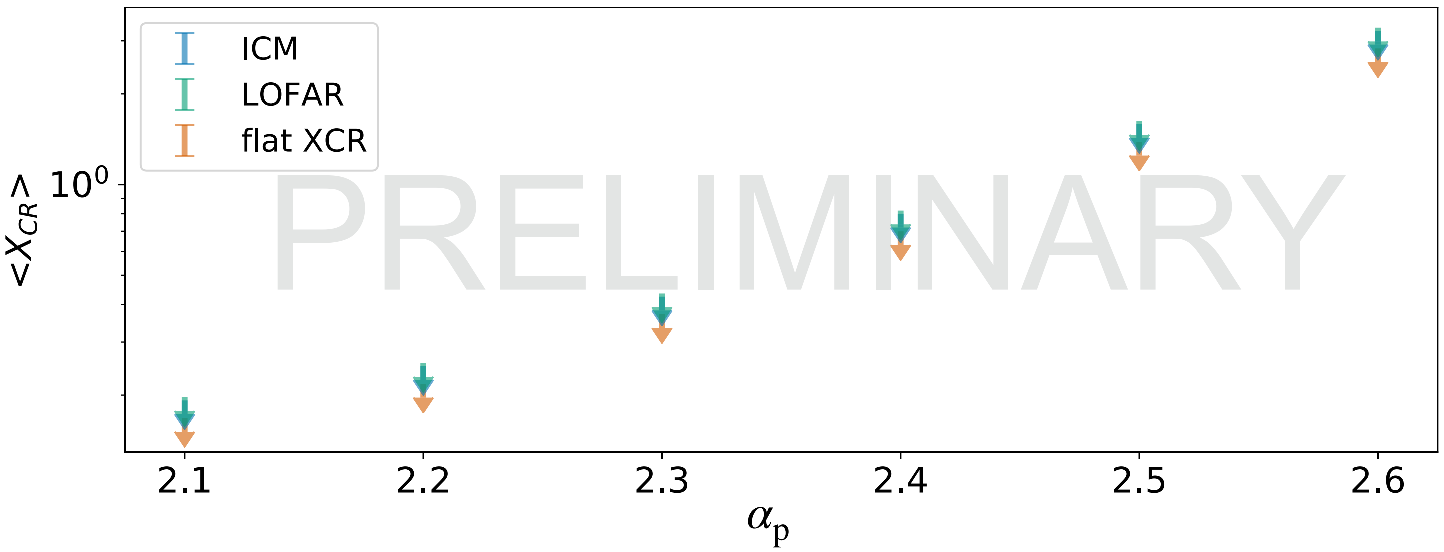
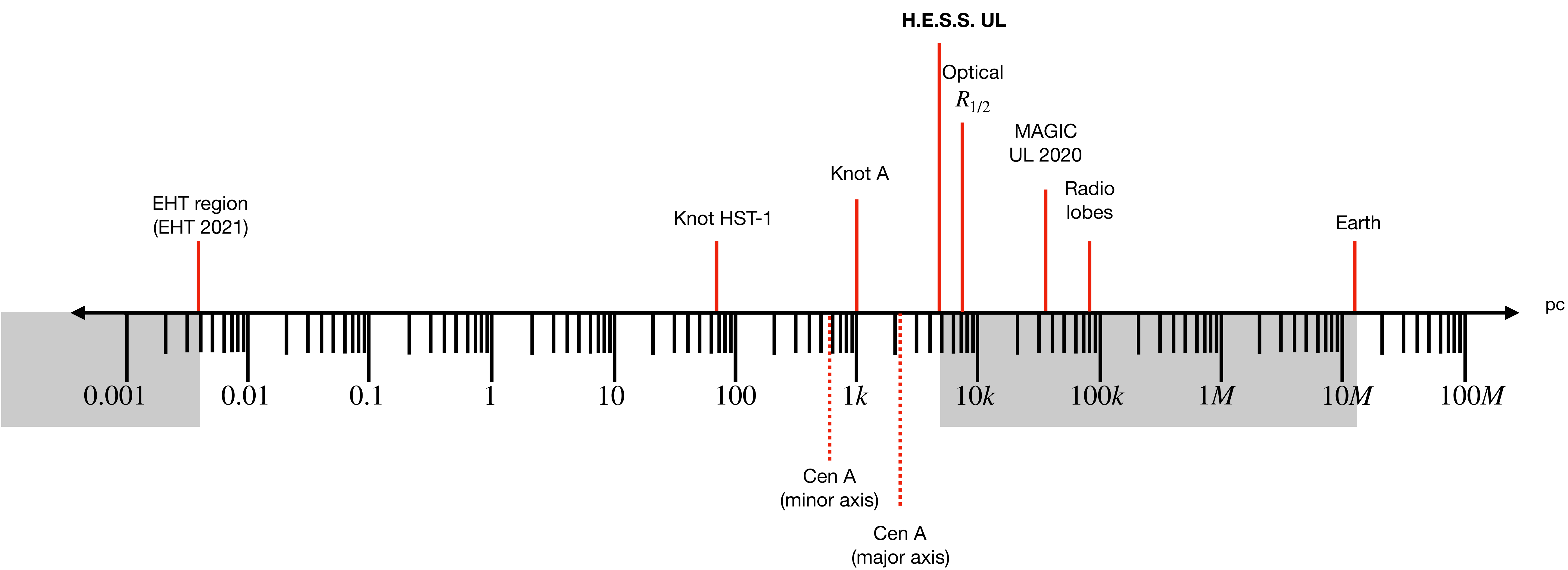




*cosmic-ray proton distr.: $N = N_0(p/p_0)^{-\alpha_p}$

Summary and prospects

- We exclude the **radio lobes** (~ 40 kpc) as the main contributor to the VHE low state emission of M87;
- We constrain the size of the emission to a region inside the **optical galaxy**;
- We do not rule out the **inner radio cocoon** as a main contributor;
- We do not rule out the **outer jet** (~ 2 kpc) and the **X-ray knots** as main contributors to the VHE low state emission of M87.



- We constrained the cosmic-ray pressure ratio to $< X_{\mathrm{CR}} > \leq 20\,\%$ to in the inner 20 kpc for a hard proton distribution ($\alpha_p = 2.1$) considering two different approaches;
- The limit lies above the expected pressure from a steady state model, hence, the model is not probed by our morphology fit;
- Our results do not collide with the Fermi-LAT limit, which constrains the cosmic-ray pressure up to the cluster viral radius (~1.1 Mpc) to be $< X_{\mathrm{CR}} > \leq 6\,\%$;
- An analysis of the Fermi-LAT data in the 50 - 100 GeV band for the low state as defined in VHE regime could be promising;
- The Cherenkov Telescope Array (CTA) with a better angular resolution and sensitivity will potentially be able to unravel an extended VHE gamma-ray emission from M87.

Thank you!

H.E.S.S.