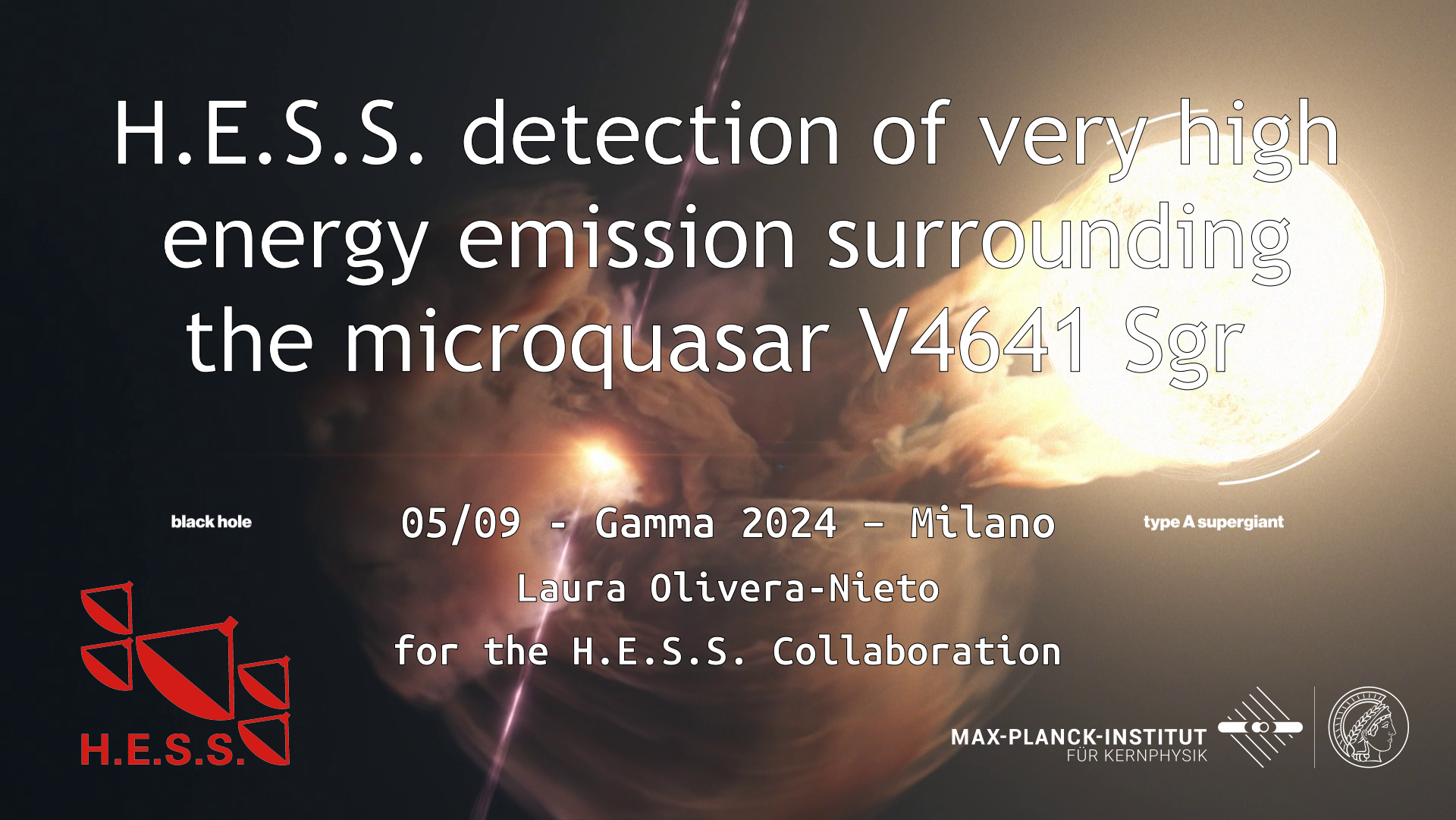
H.E.S.S. detection of very high energy emission surrounding the microquasar V4641 Sgr



05/09 - Gamma 2024 – Milano

Laura Olivera-Nieto

for the H.E.S.S. Collaboration

H.E.S.S.

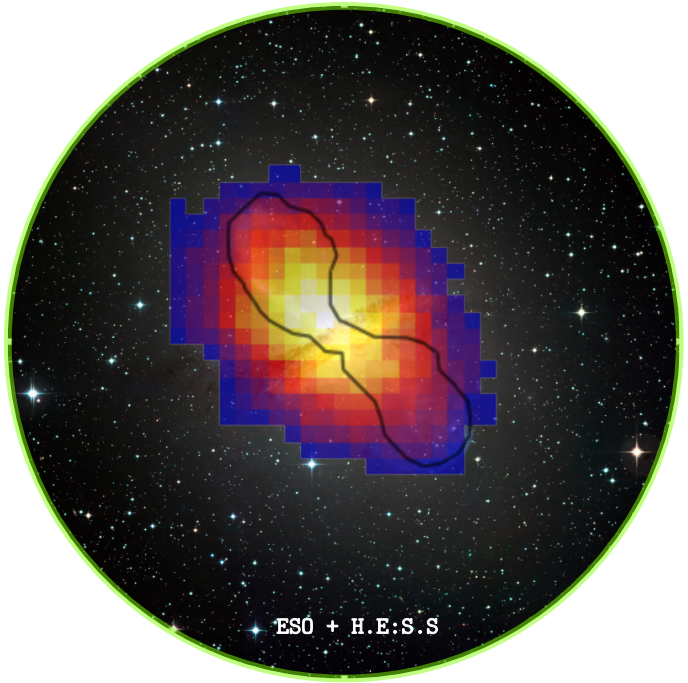
MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK

Astrophysical Jets

Centaurus A: the nearest active galactic nucleus

- Fast outflows of plasma moving at relativistic speeds.
- Originate due to accretion of matter onto a black hole.
- AGN jets: Perfect candidate for acceleration of particles to highest energies: powerful, large enough.
- **But how does this acceleration happen exactly?**

Astrophysical Jets



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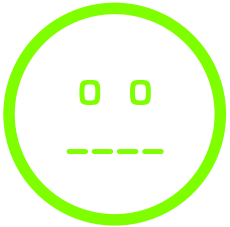
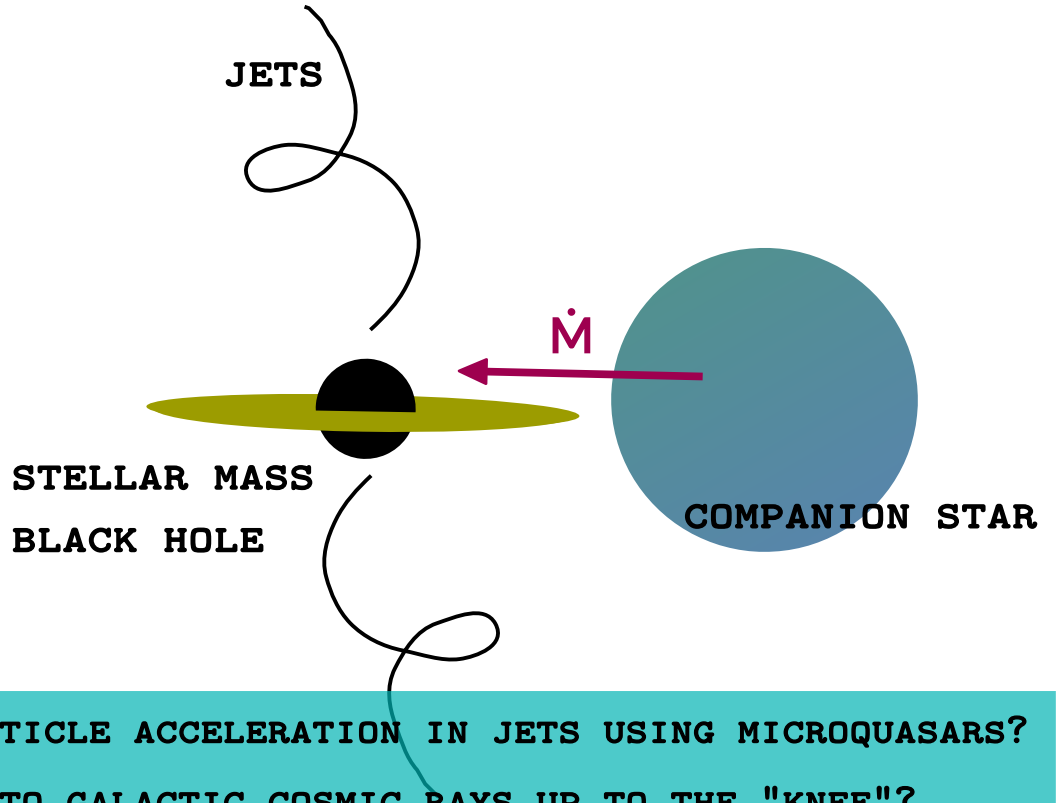


Meet Microquasars

- Inside our Galaxy: closer to Earth!
- Much less powerful than AGN: $L_{EDD} \sim 10^{39}$ erg/s
- Highly variable: short-lived phases of activity



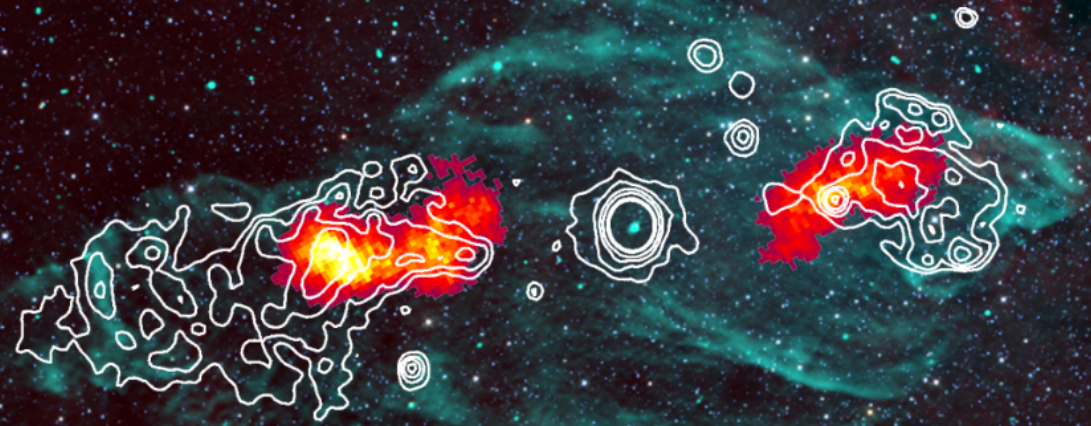
1. What can we learn about particle acceleration in jets using microquasars?
2. Do microquasars contribute to galactic cosmic rays up to the "knee"?

ACTUAL DATA

BLUE: RADIO EMISSION FROM NEBULA

WHITE: OUTLINE OF JETS IN X-RAY

RED/YELLOW: H.E.S.S. DATA



H.E.S.S. Collaboration Science 383 6681, 2024 (LON leading author)

Background: NRAO/AUI/NSF, K. Golap, M. Goss; NASA's Wide Field Survey Explorer (WISE); X-Ray (green contours): ROSAT/M. Brinkmann; TeV (red colors): H.E.S.S. collaboration.

1. What can we learn about particle acceleration in jets using microquasars?

- With SS 433 we could identify the mechanism by which particles are accelerated in an astrophysical jet for the first time
- But SS 433 might be a total outlier - **hard to make a statement with only one data point**

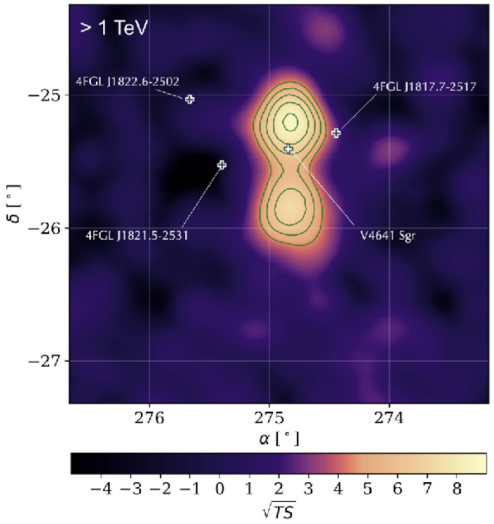
2. Do microquasars contribute to galactic cosmic rays up to the "knee"?

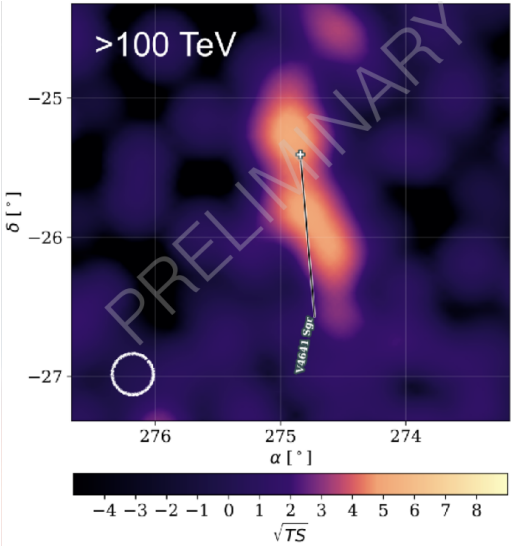
$$E_{\mathrm{Hillas}} \approx 10Z \left(\frac{B}{20\mu\mathrm{G}}\right)\left(\frac{u_1}{0.26c}\right)\left(\frac{R}{1.6\mathrm{pc}}\right)\mathrm{PeV},$$

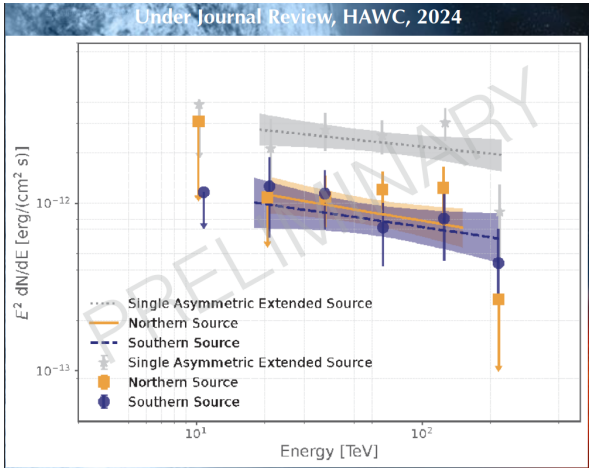
- In principle possible - but **very hard to make a statement when we only know one!**

HAWC comes to the rescue

Gamma2022: Report of TeV emission surrounding a second microquasar

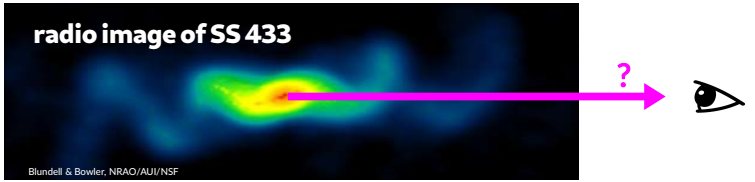






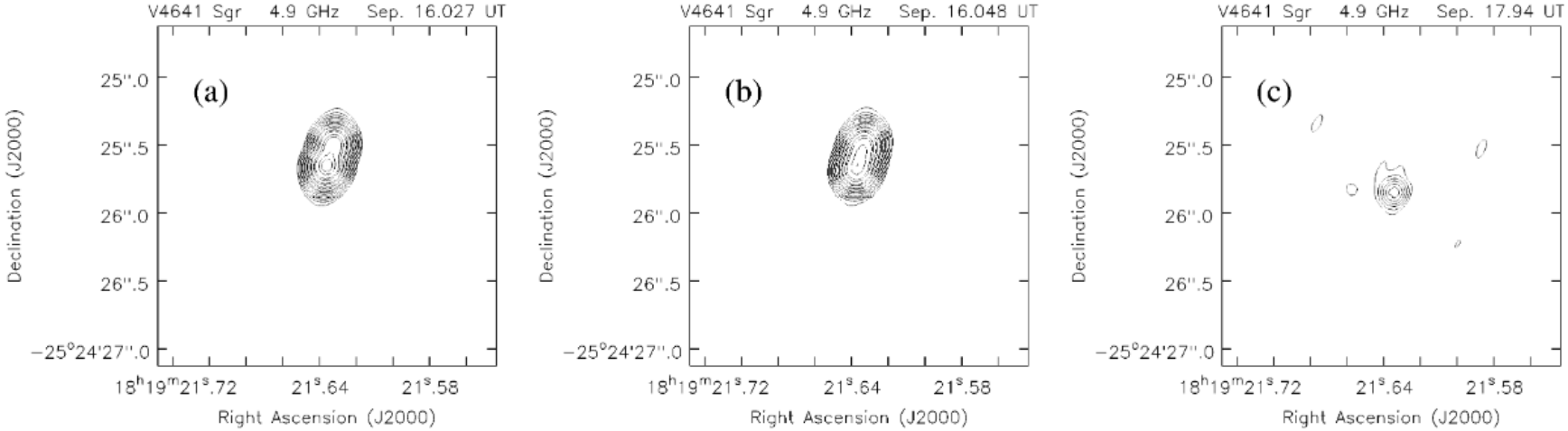
HAWC PRELIMINARY – XIAOJIE WANG TeVPA 2024

Meet V4641 Sgr



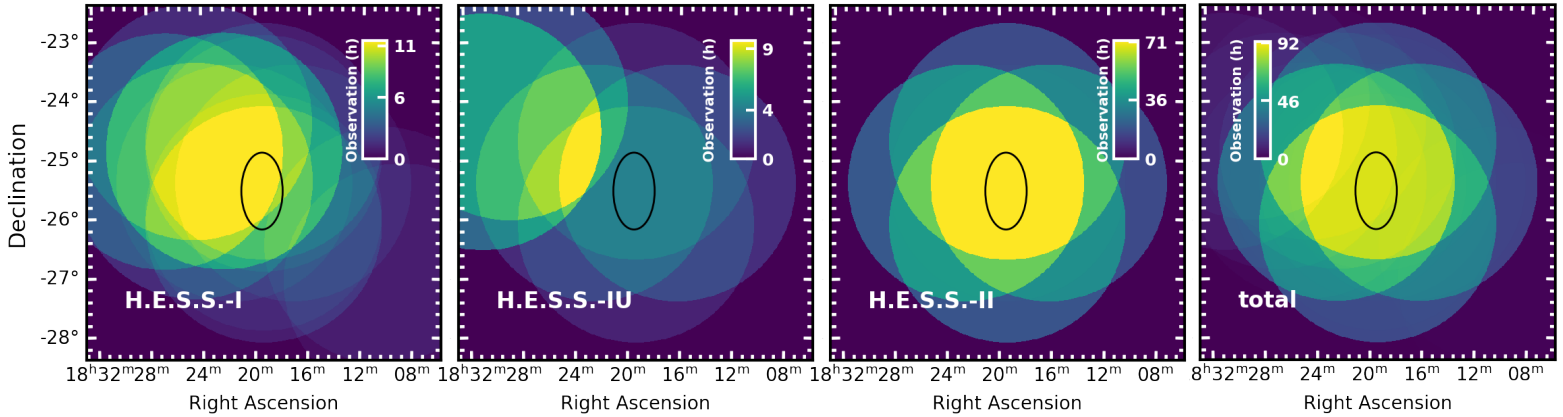
- LMXB with a B9III companion star (2.8 days period)
- Giant x-ray flare in 1999
- Radiio observations imply superluminal motion
- indication of relativistic motions at low inclination angle wrt to line of sight
- presence of a fast jet pointing towards us

Hjellming et al

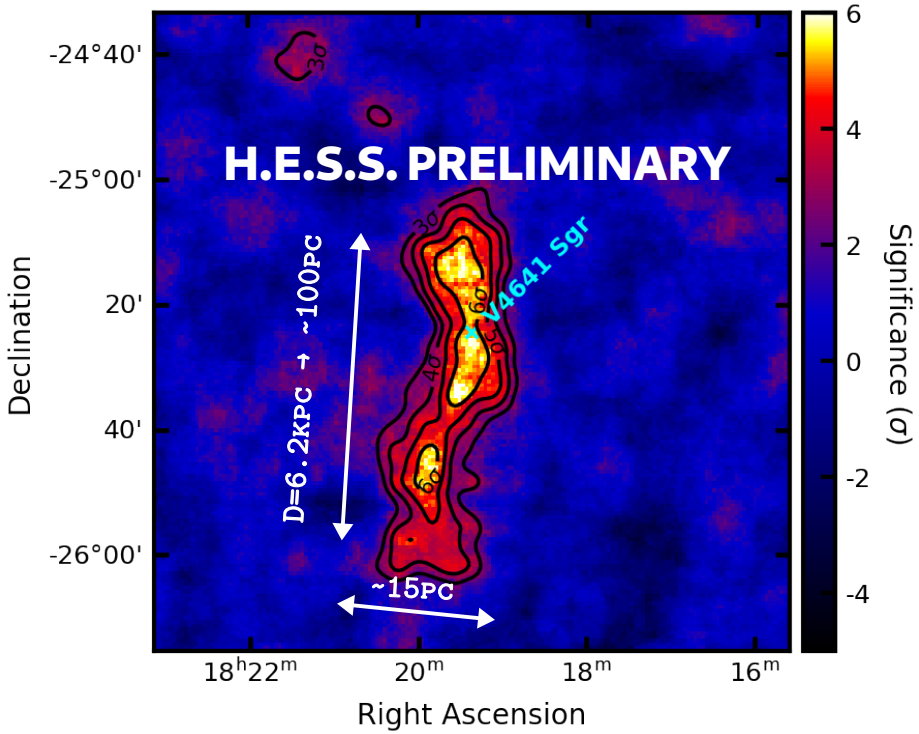


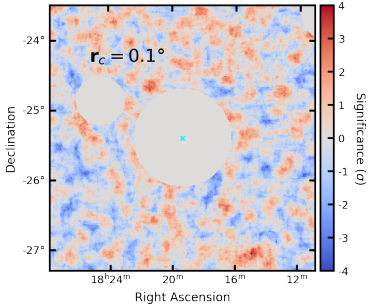
H.E.S.S. Observations

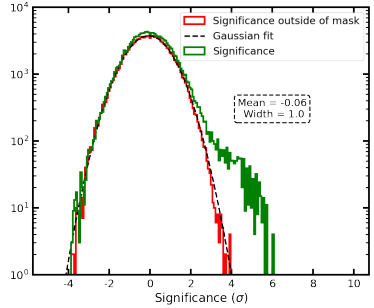
- 15h of archival data, around 100h of data taken between 2022 and 2023
- 3D analysis in Gammapy 1.2, hard (>200 p.e.) cuts, 2D background model
- Extra step of background rejection using CT5 data (ABRIR, Olivera-Nieto et al 2022)



H.E.S.S. DETECTION



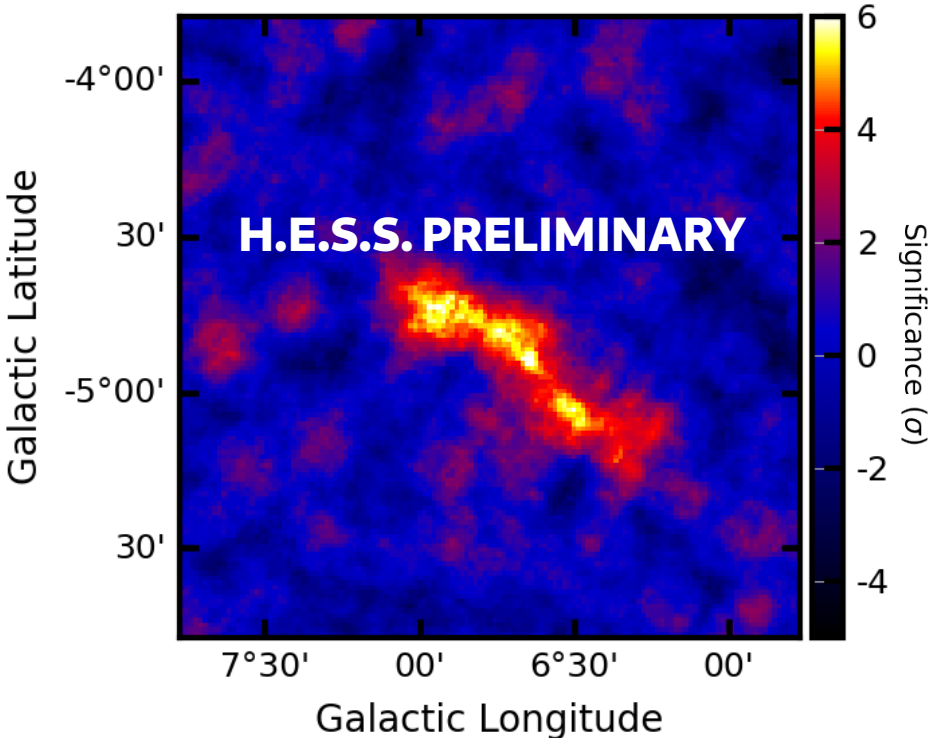


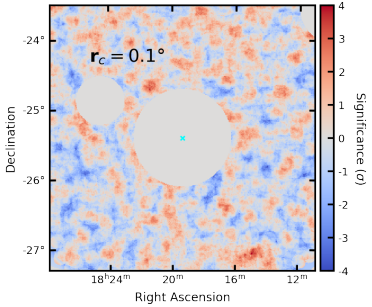


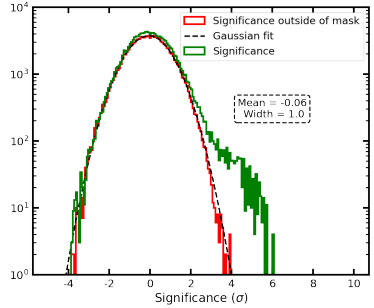
- Clearly detected, elongated and asymmetric
- Assuming d=6.2 kpc (MacDonalds et al) the emission is ~100 pc long (!)
- V4641 not at the centre of emission
- No better counterpart (5º below Gplane)

H.E.S.S. PRELIMINARY

H.E.S.S. DETECTION



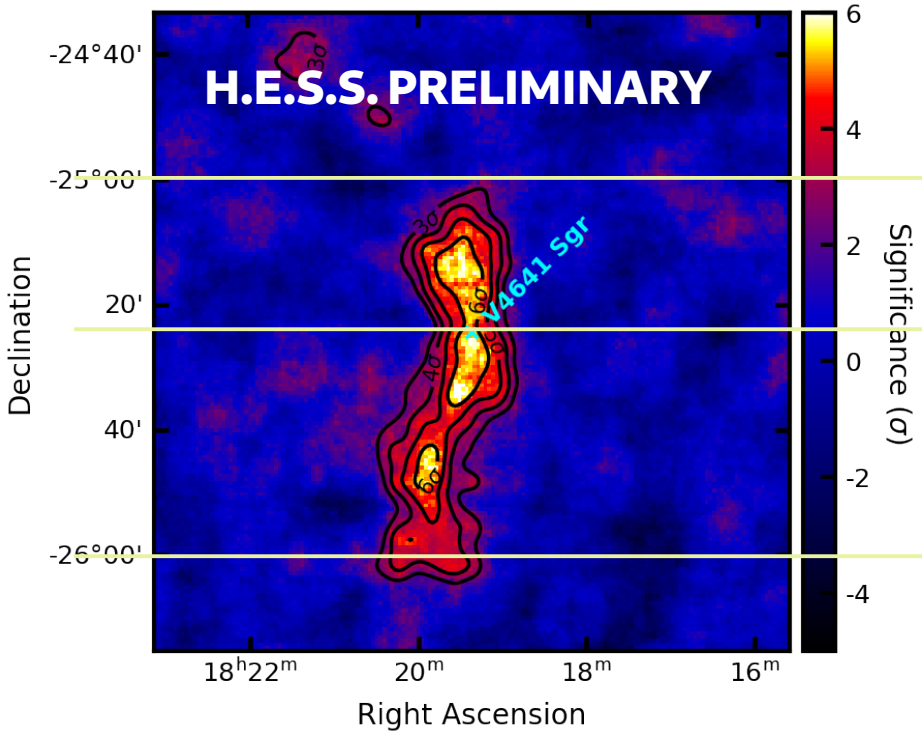


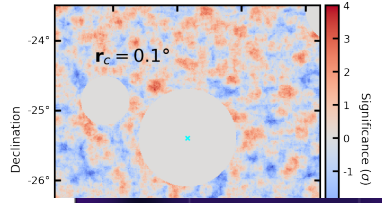


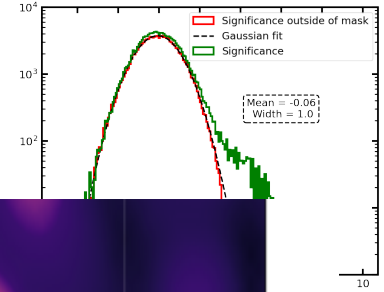
- CLEARLY DETECTED, ELONGATED AND ASYMMETRIC
- ASSUMING D=6.2 KPC (MACDONALDS ET AL) THE EMISSION IS ~100 PC LONG (!)
- V4641 NOT AT THE CENTRE OF EMISSION
- NO BETTER COUNTERPART (5º BELOW GPLANE)

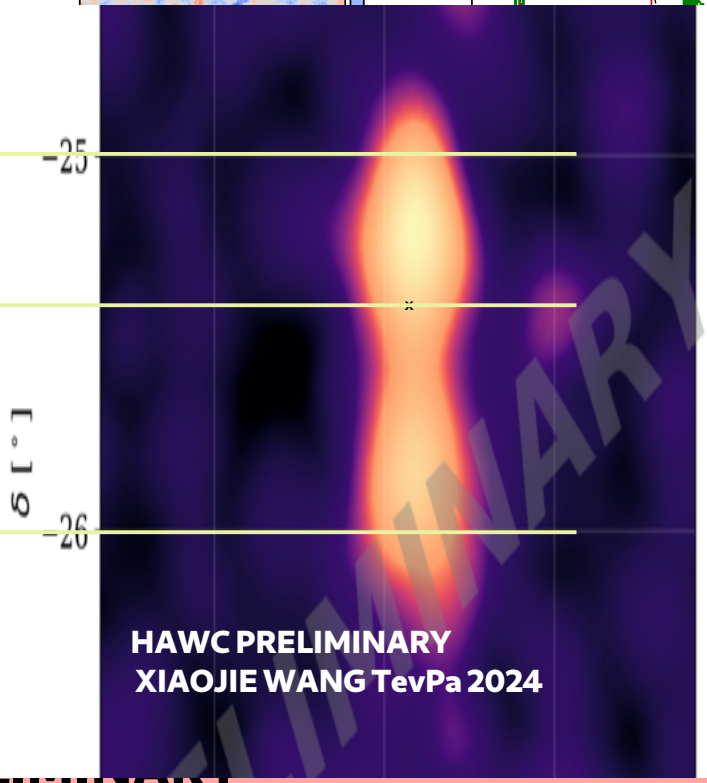
H.E.S.S. PRELIMINARY

H.E.S.S. DETECTION







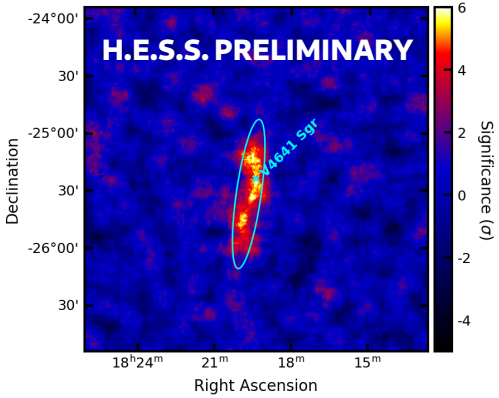


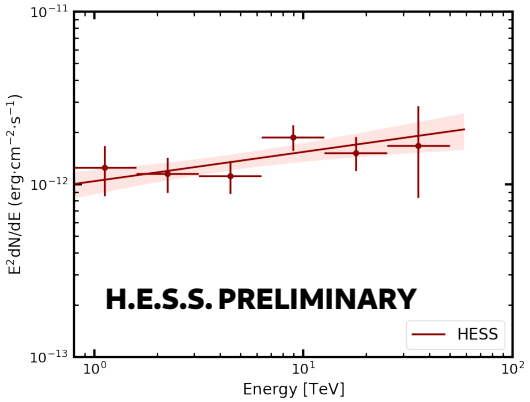
H.E.S.S. PRELIMINARY

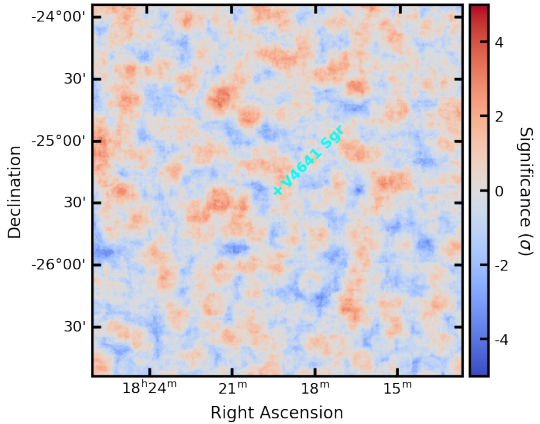
Modeling – 1 component

type	name	value	unit	error	min	max	frozen	is_norm	link	prior
	index	1.8304e+00		8.300e-02	nan	nan	False	False		
	amplitude	1.8234e-13	TeV-1 s-1 cm-2	2.275e-14	nan	nan	False	True		
	reference	2.0000e+00	TeV	0.000e+00	nan	nan	True	False		

- Simultaneous spectral+spatial (3D) fit using gammapy
- best-fit single component is elongated and has a hard (index <2) spectrum
- Correcting for number of free parameters (7), the significance is 12.9σ
- best fit position incompatible (>>3σ) with V4641 Sgr location







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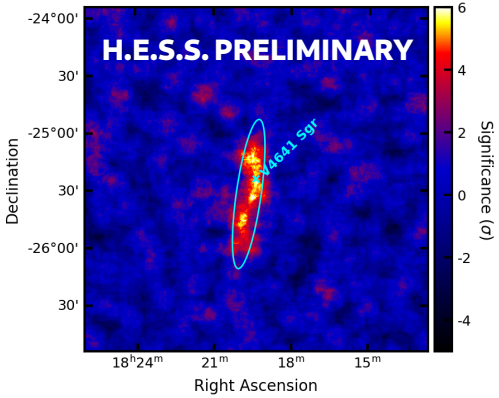
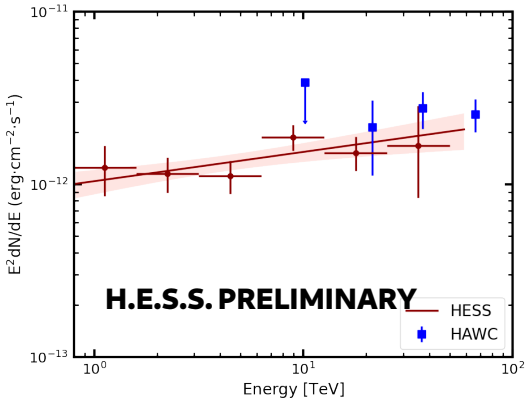
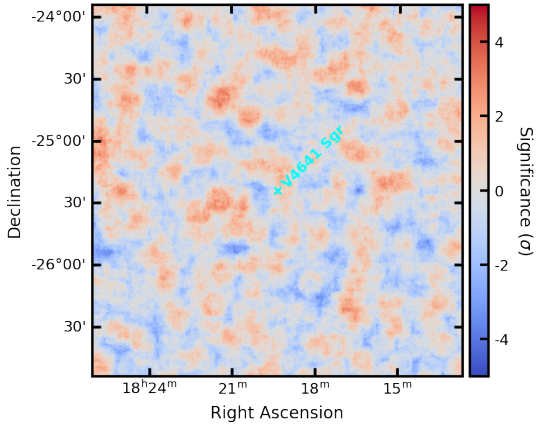


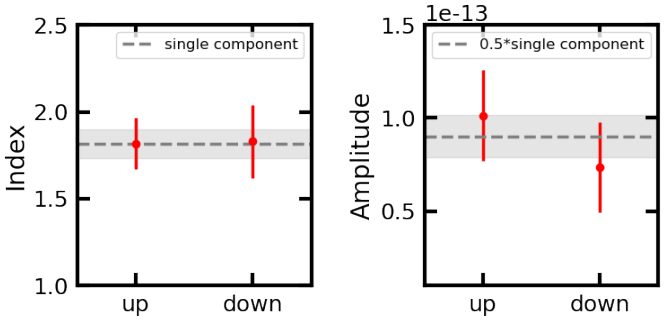




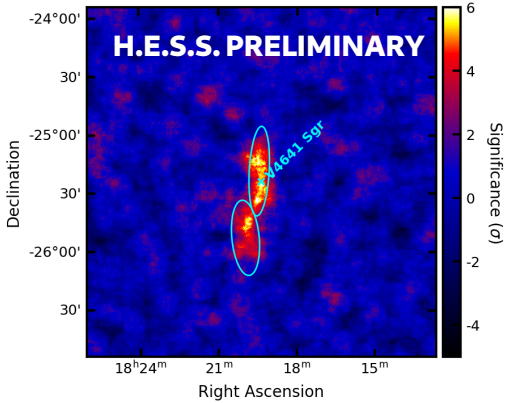
H.E.S.S. PRELIMINARY

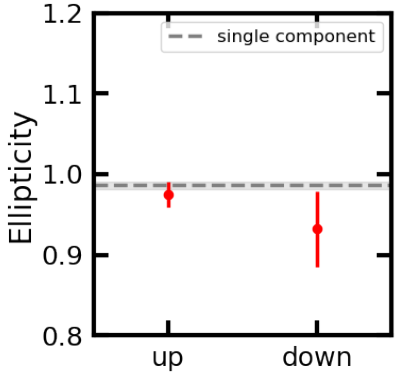
Modeling – 2 components

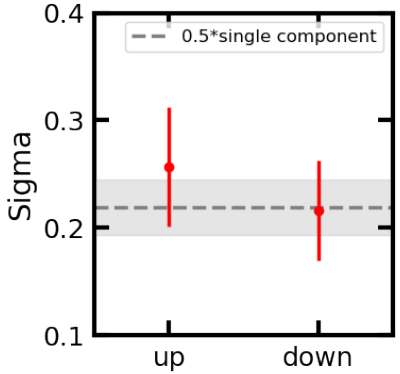
- Simultaneous spectral+spatial (3D) fit using gammapy
- ΔTS = 6.6 **without taking into account extra parameters!** → 0.73σ
- Parameters consistent with single component
- top best fit position compatible (~2σ away) with V4641 Sgr location, <u>not the gap</u>!

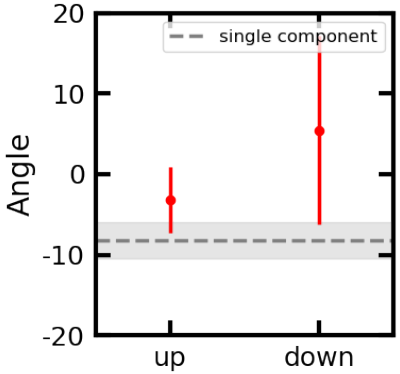


H.E.S.S. PRELIMINARY





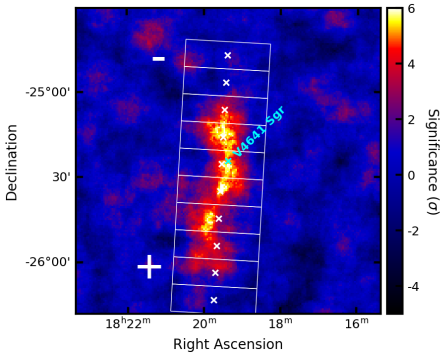


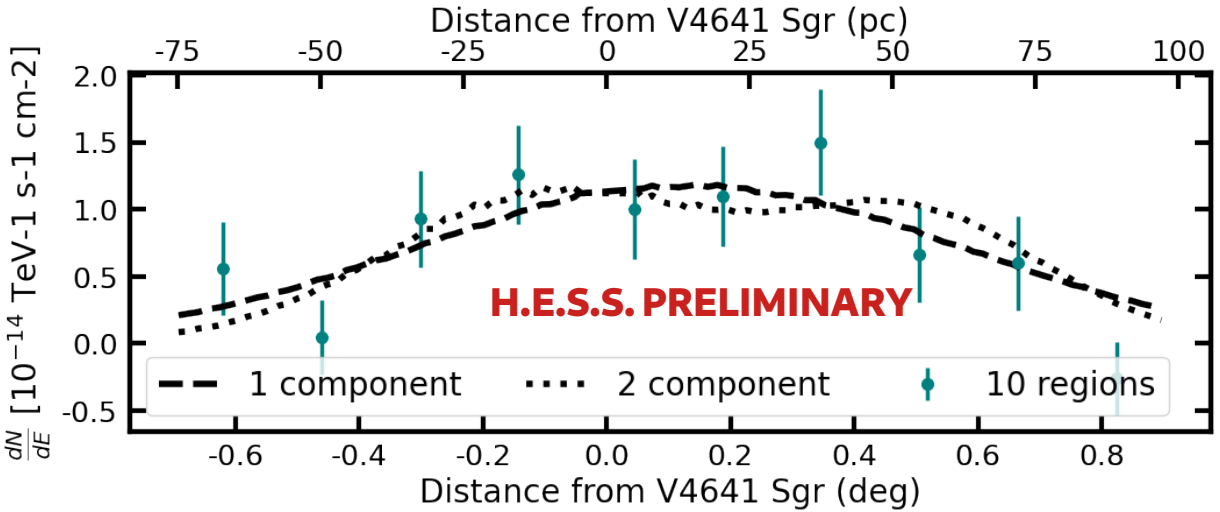


H.E.S.S. PRELIMINARY

Spatial profiles - ALONG

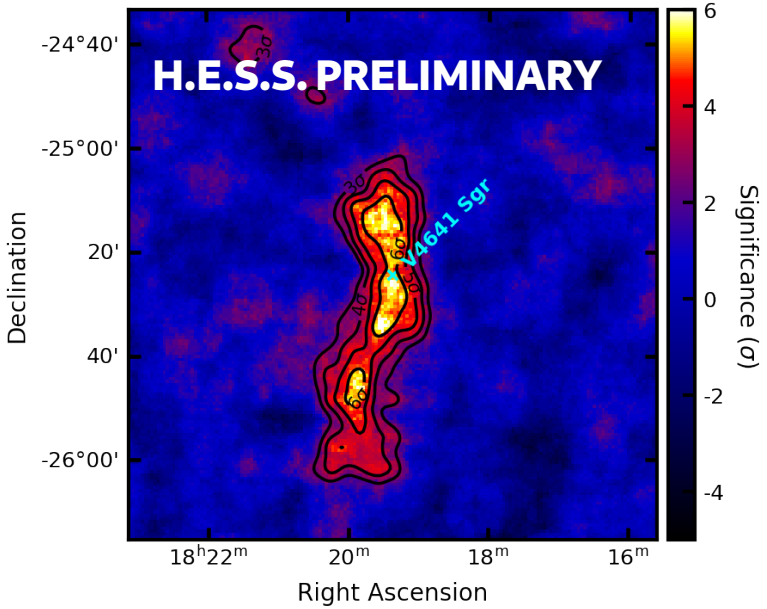
- Flux profiles along the excess
- Assuming d=6.2 kpc
- V4641 Sgr clearly not at peak/gap between models

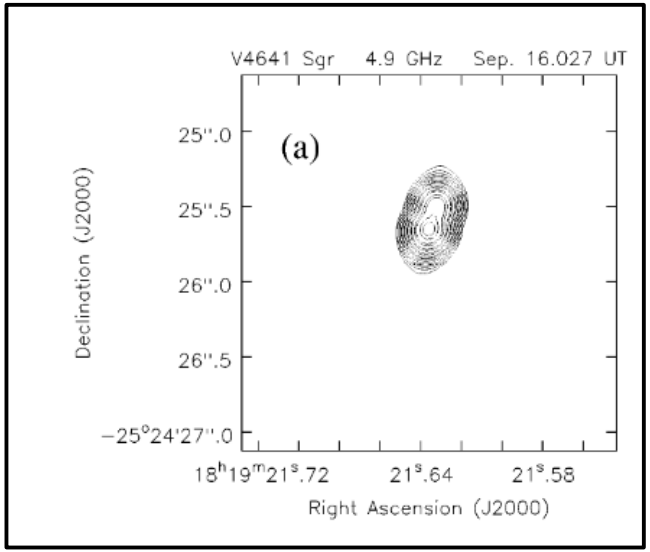




H.E.S.S. PRELIMINARY

What is this thing?





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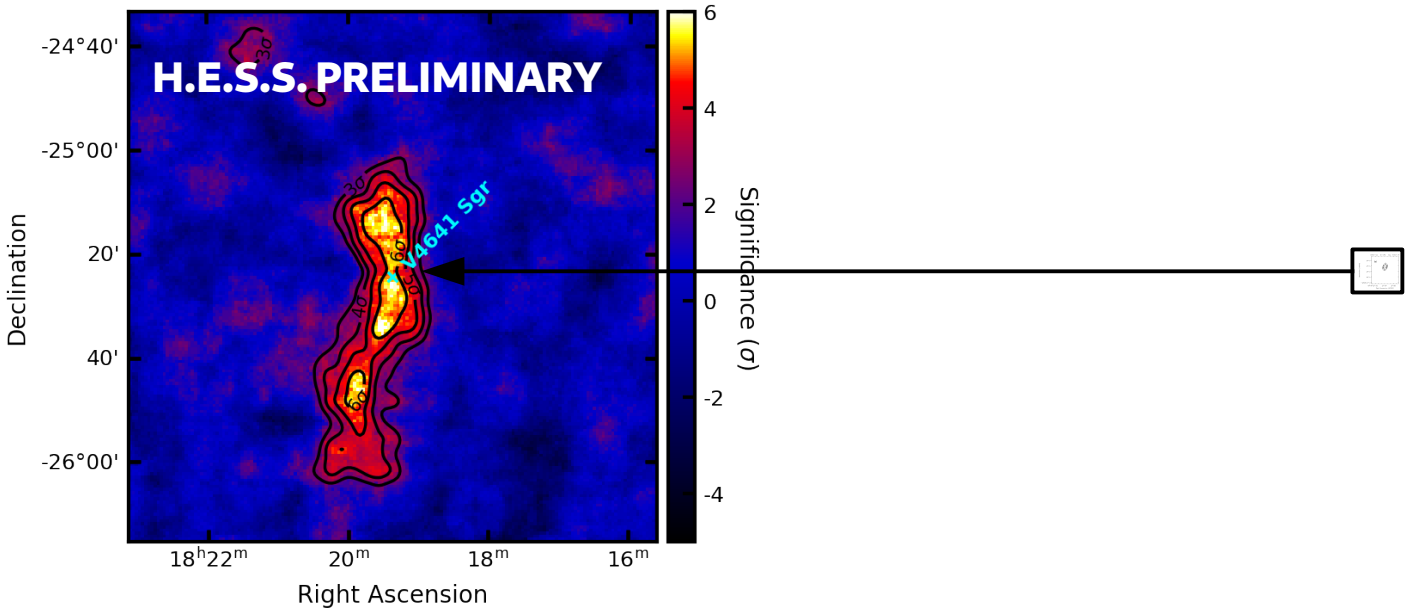
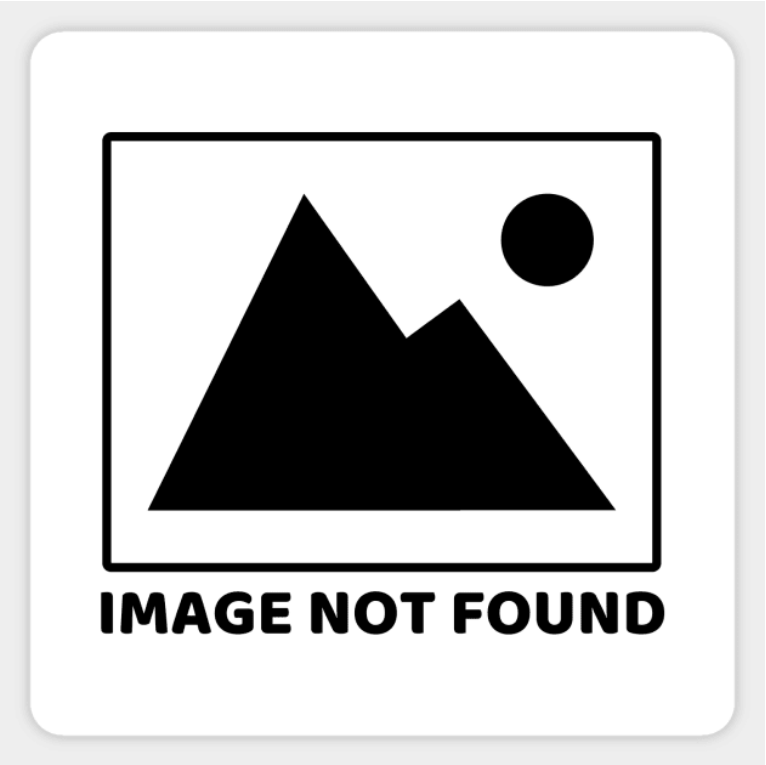


H.E.S.S. PRELIMINARY

Any help from other wavelengths?

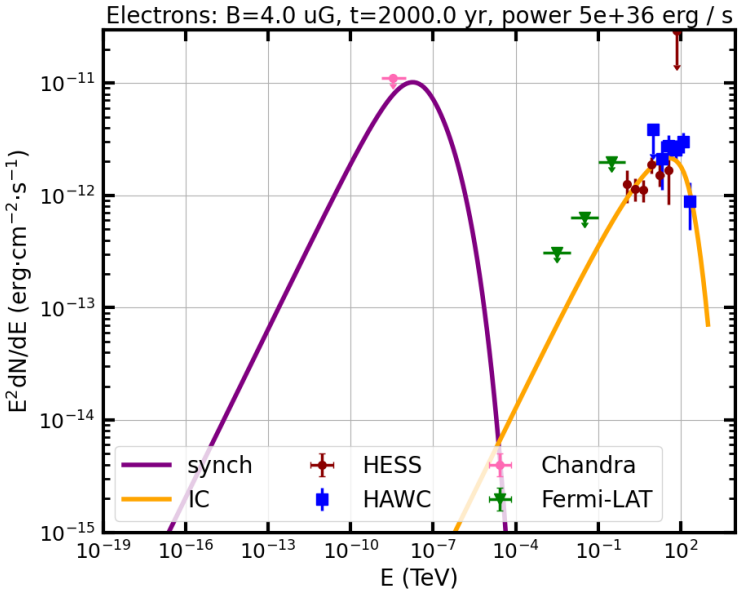


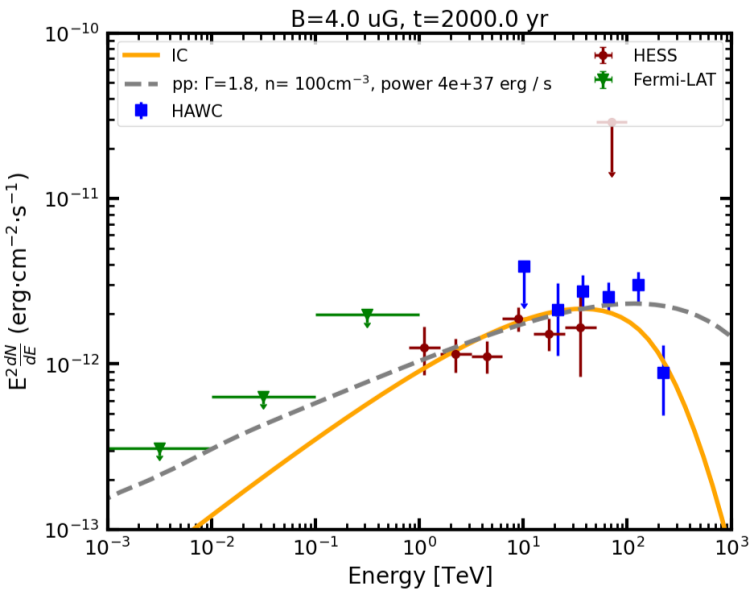
- Previous observations focused on the narrow field around the binary.
- No known X-ray emission on large scales, Chandra UL derived by Naomi Tsuji
- No comparable known radio structure

Some simple modeling using Gamera

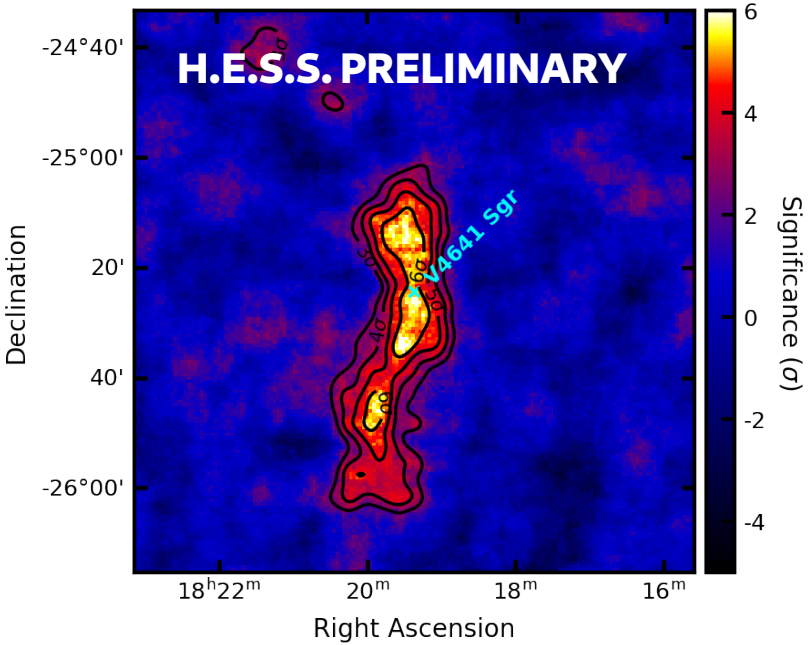
Fermi-LAT analysis: M. Lemoine-Goumard
x-ray analysis: N. Tsuji

- Assuming Popescu et al radiation model, t=2000 yr (total guess)
- With short time protons need too high density - but time could be longer
- B field has to be relatively low (<5 μG), (SS 433 → 20 μG)





What can this be?



1) The structure we see is the jets

- **Geometry?**

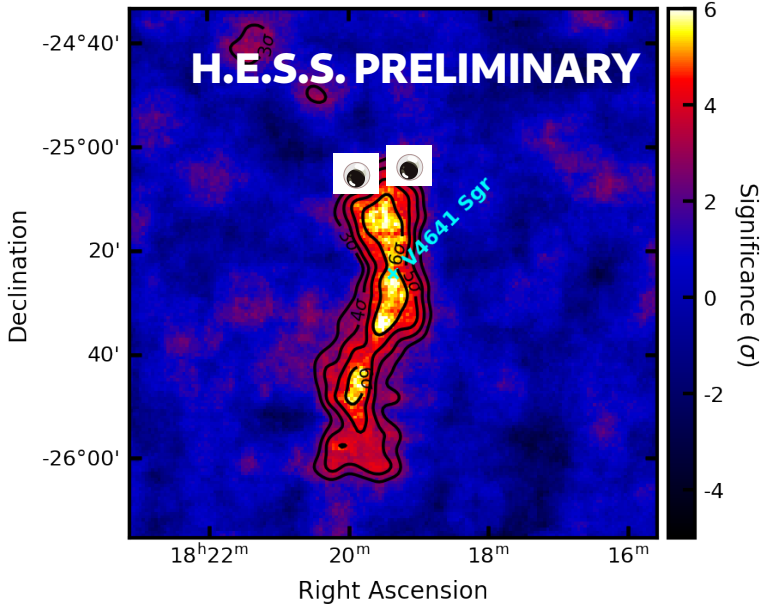
2) The structure we see is created by particles accelerated by the jets which escaped

- **Why does it have that shape?**

Summary

- Elongated structure around V4641 Sgr
- Bright, hard (<2) spectrum
- Best described as a single component
- Asymmetric: ~0.9º major vs ~0.14º minor axis
- Unclear interpretation: jets vs ISM structure?

Paper soon: stay tuned!



BACK UP SLIDES