

Observations of the Microquasar SS 433 with H.E.S.S. and VERITAS

11th Meeting of the
Astroparticle Physics Committee (APC)

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DESY, Science Communication Lab

Contents

1. SS 433 as a strong particle accelerator
2. H.E.S.S. and VERITAS Observations of the Microquasar SS 433
3. Conclusion and continuing interest in SS 433



Probing the Universe's Extremes

- **Key Questions:**
 - Contribution to cosmic rays?
 - Mass transfer and accretion processes?
 - Jet dynamics and particle acceleration mechanisms?



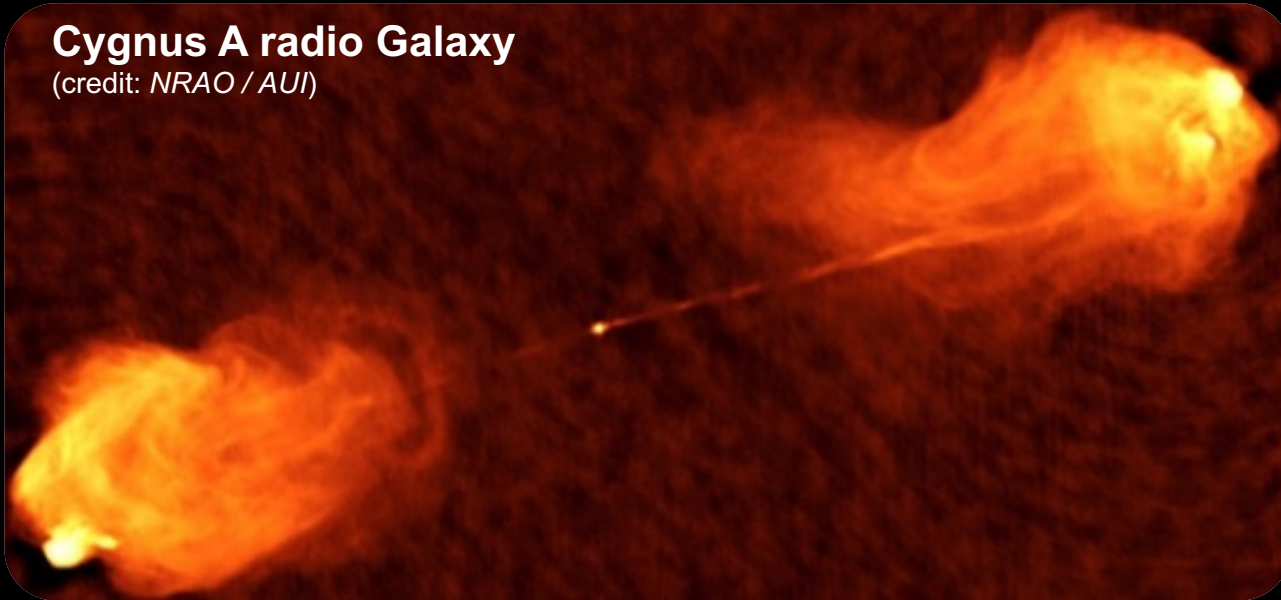
Quasars and Microquasars

Potential PeVatrons

- Accretion processes lead to the formation of jets
- Particle acceleration sites in jets

Cygnus A radio Galaxy

(credit: NRAO / AUI)



M87 with jet

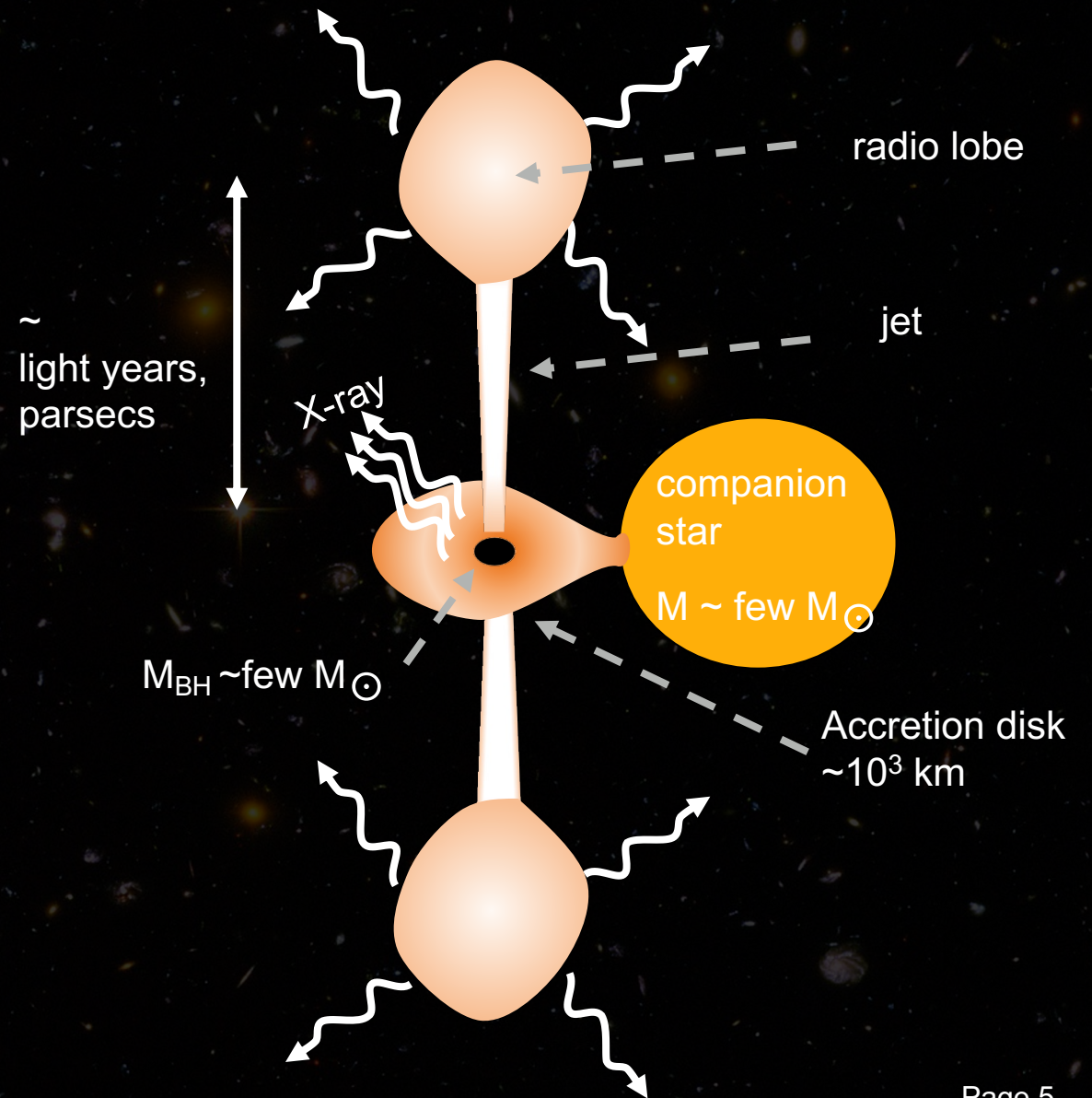
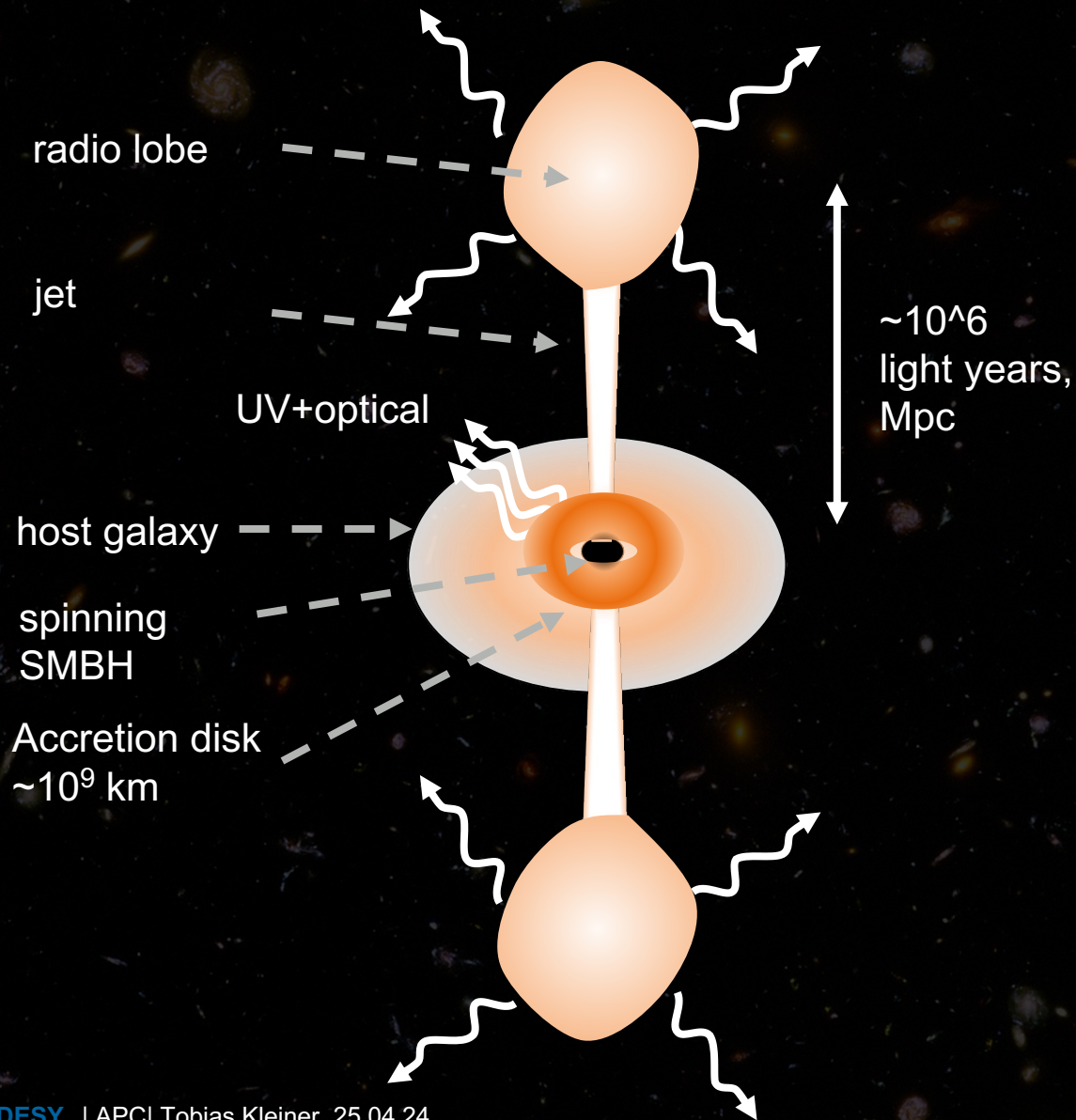
(Credit: Hubble Telescope)



Quasars

and

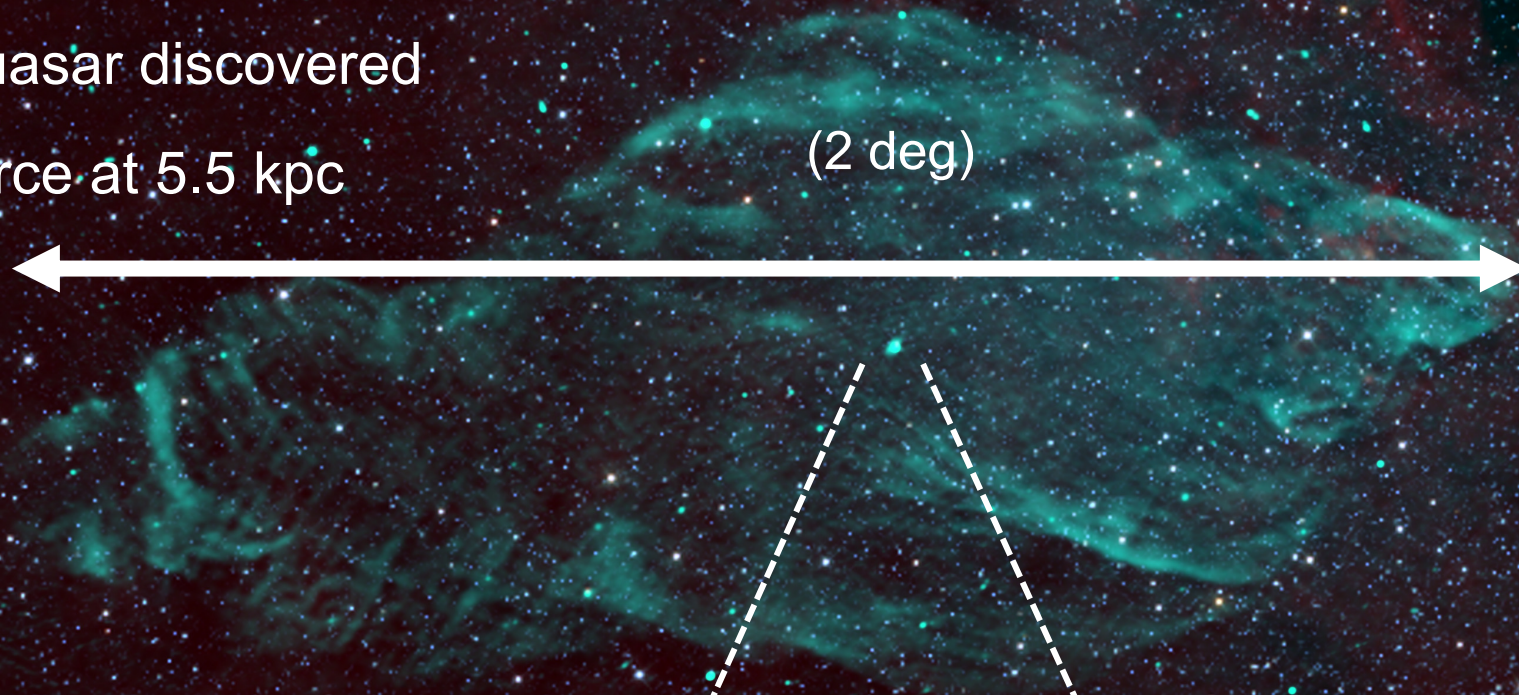
Microquasars (as SS 433)



*(The enigma of the century continued..)

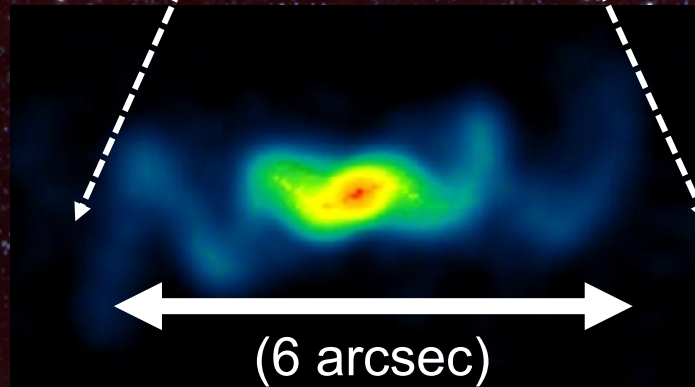
SS 433*

- First Microquasar discovered
- Galactic source at 5.5 kpc



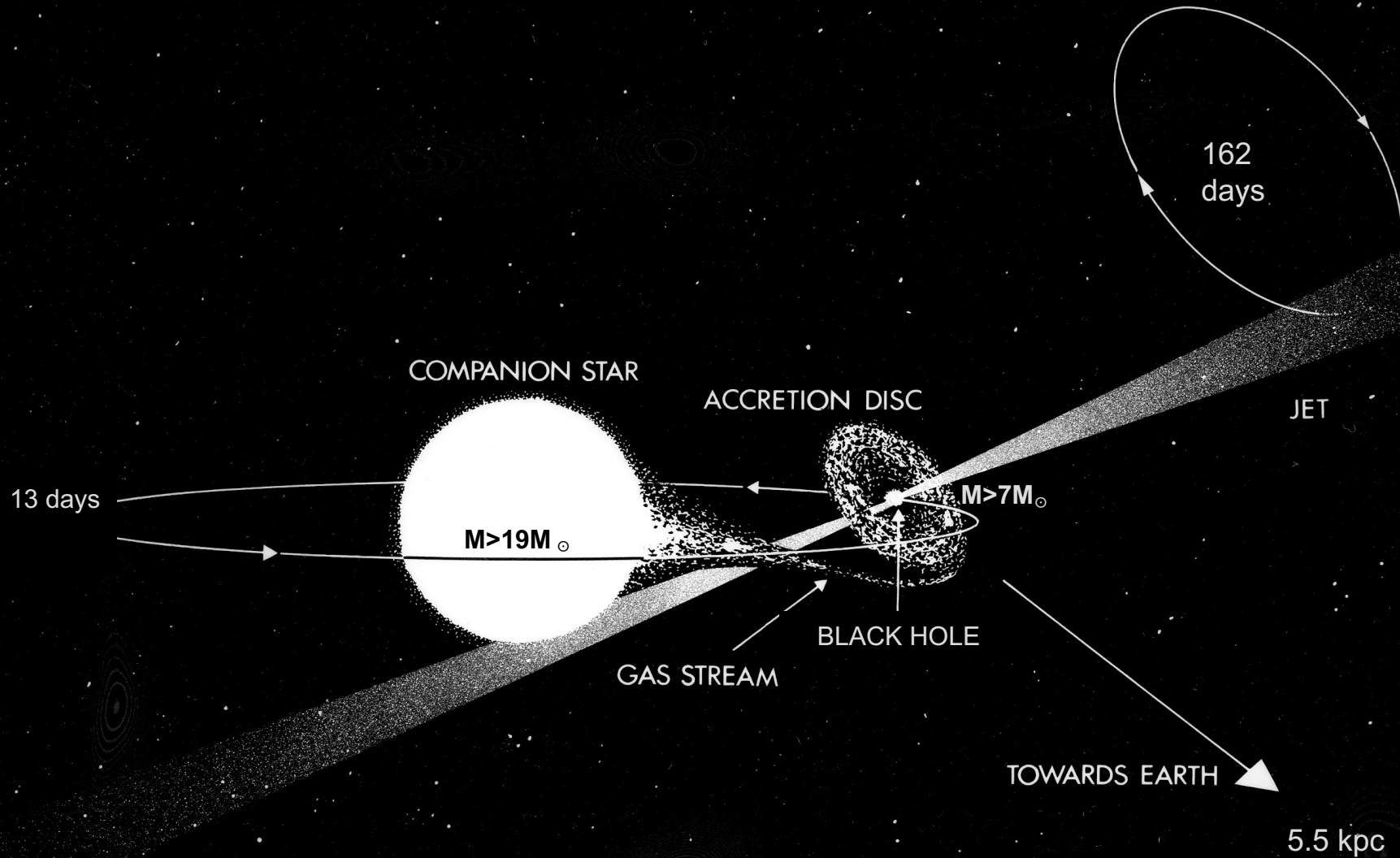
- Inside supernova remnant **W50**
- Powerful, precessing jets

~0.26c



*NRAO/AUI/NSF, K. Golap, M. Goss;
NASA's Wide Field Survey Explorer
(WISE).*

The SS 433 System (Illustration)



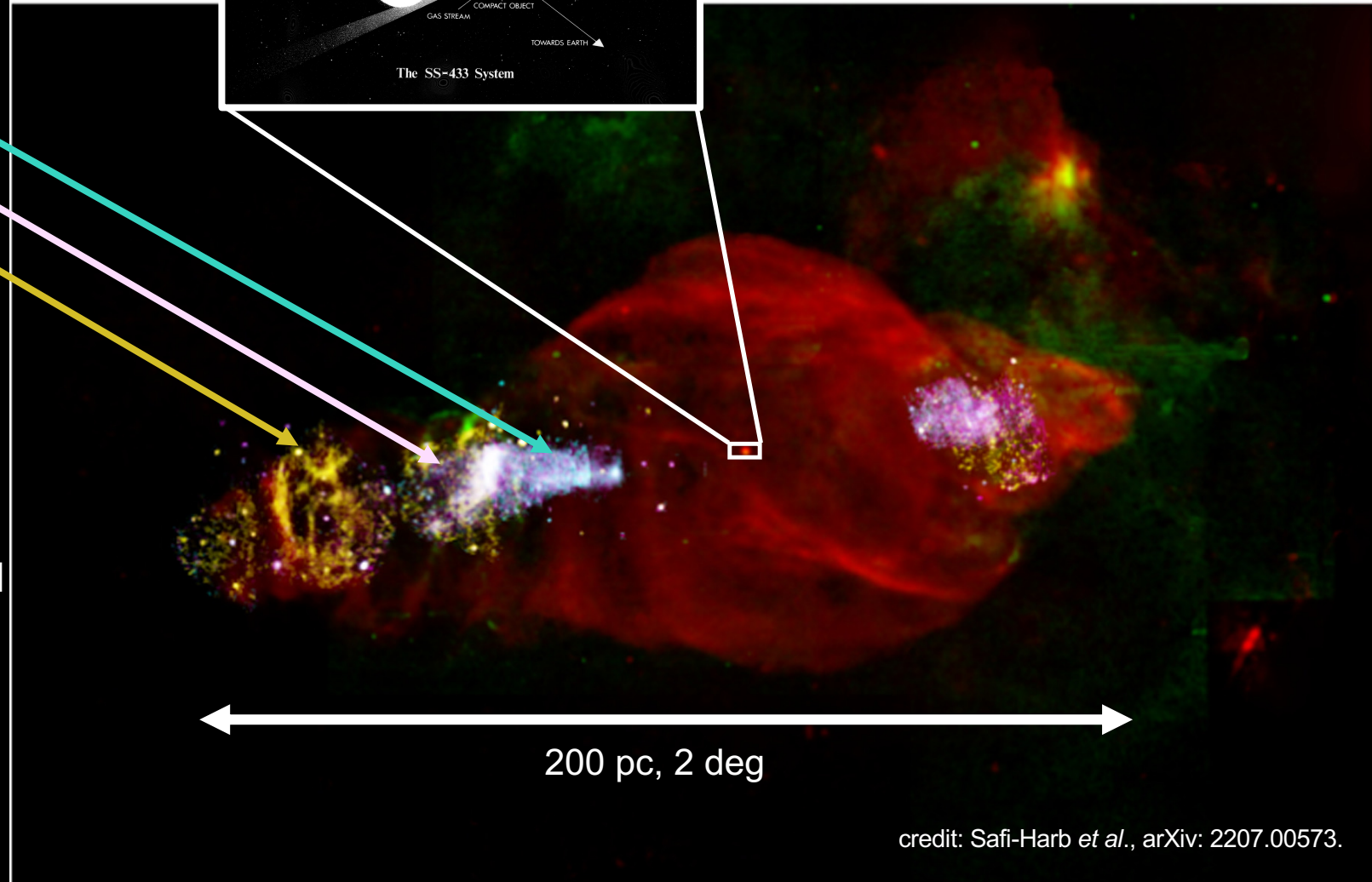
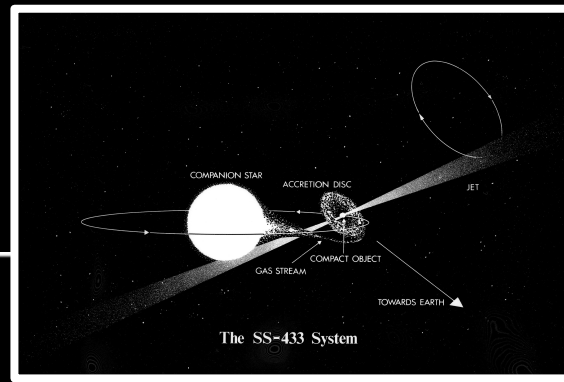
The SS-433 System

Credit: ESO

SS 433

Multiwavelength view

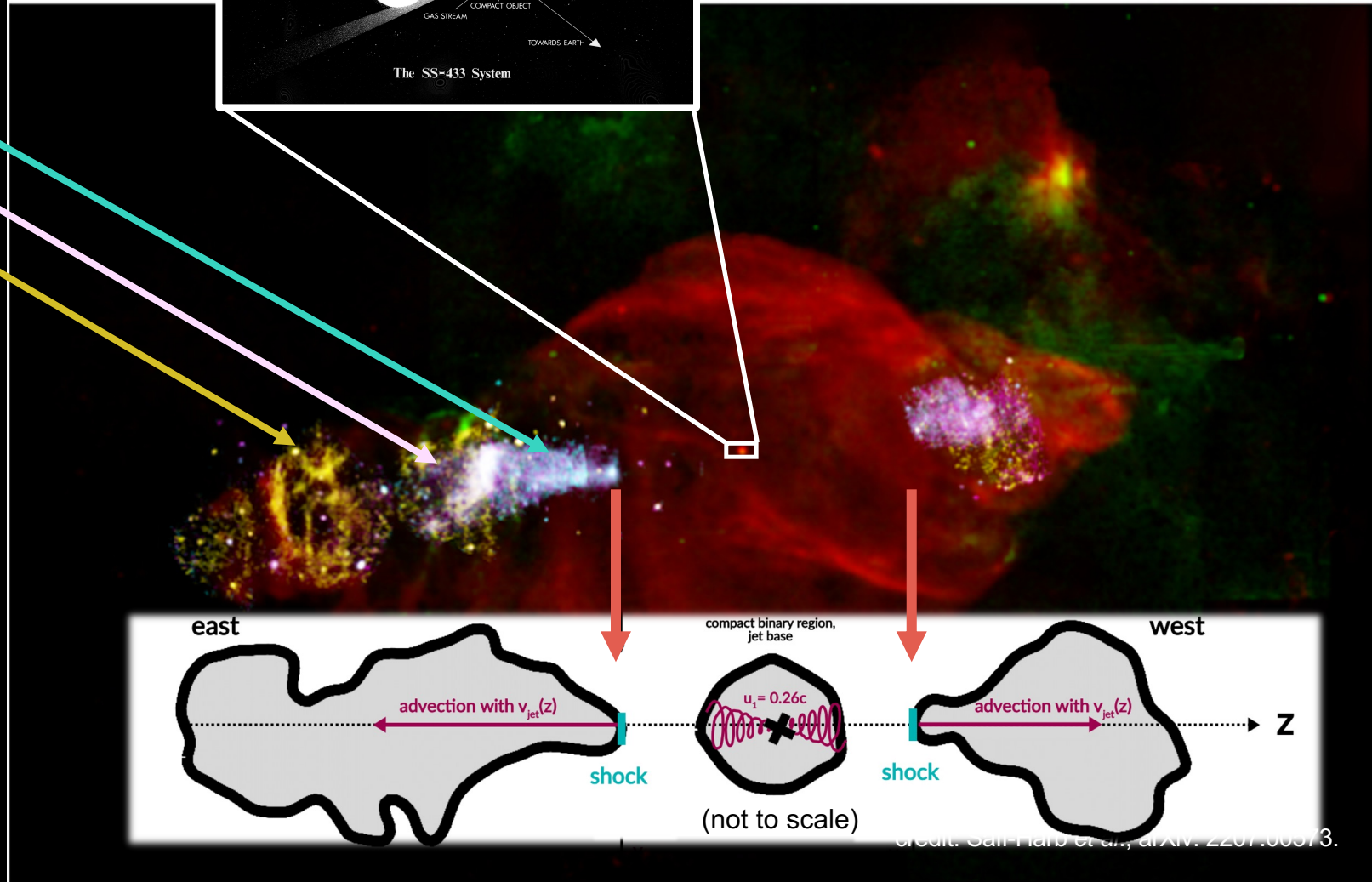
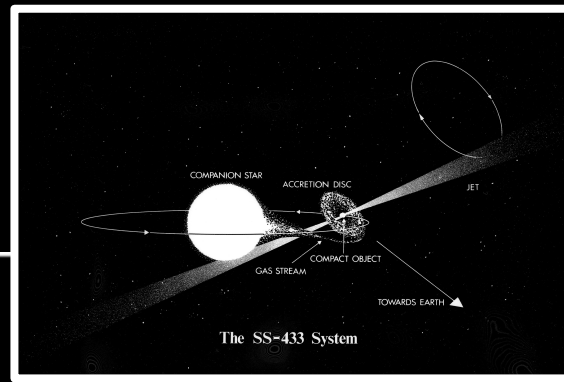
- Composite image **radio**, **optical**,
X-rays { **hard**,
medium,
soft
- X-ray observations reveal emission in the jet lobes with spectral softening along the jet
- X-ray emission reappears 25 pc from the binary, indicating collimated flows on larger scales.
- jets terminate about 100 pc from the black hole



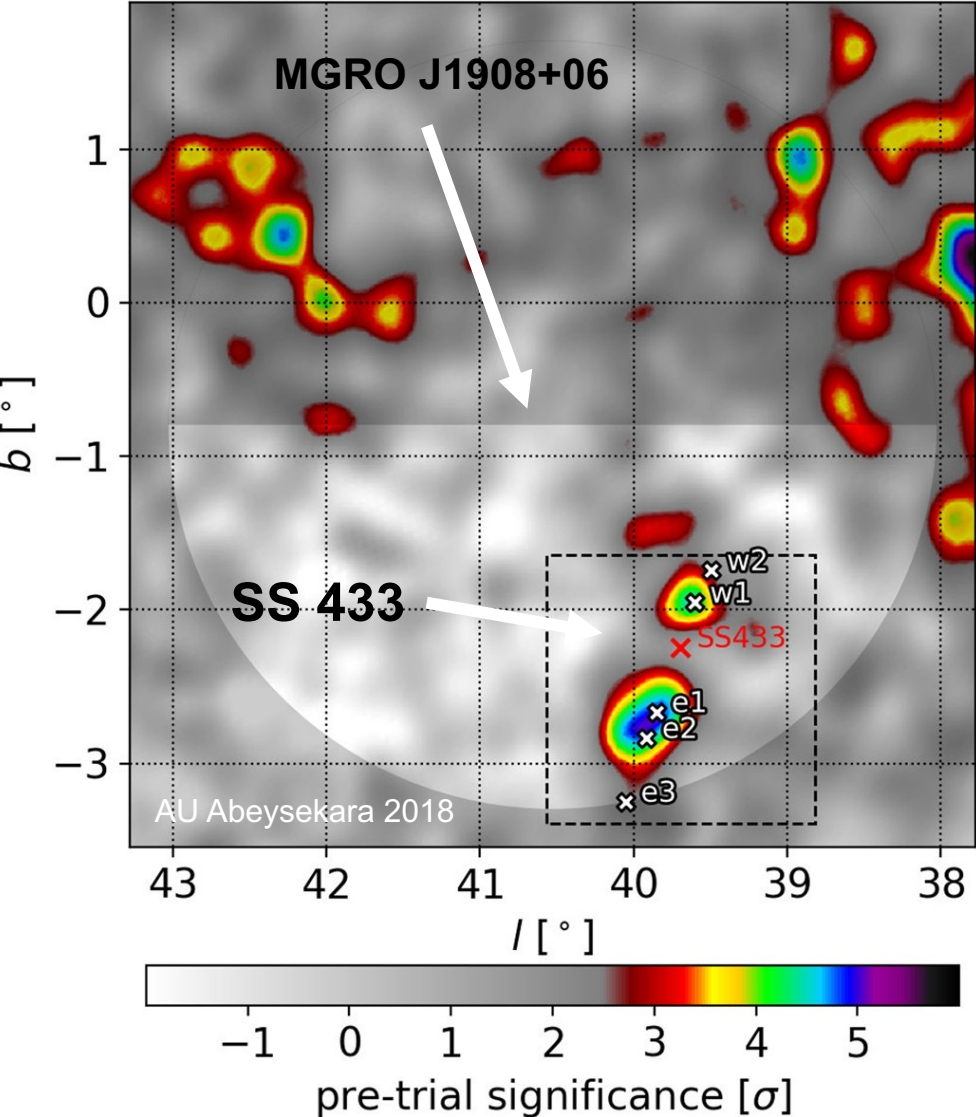
SS 433

Multiwavelength view

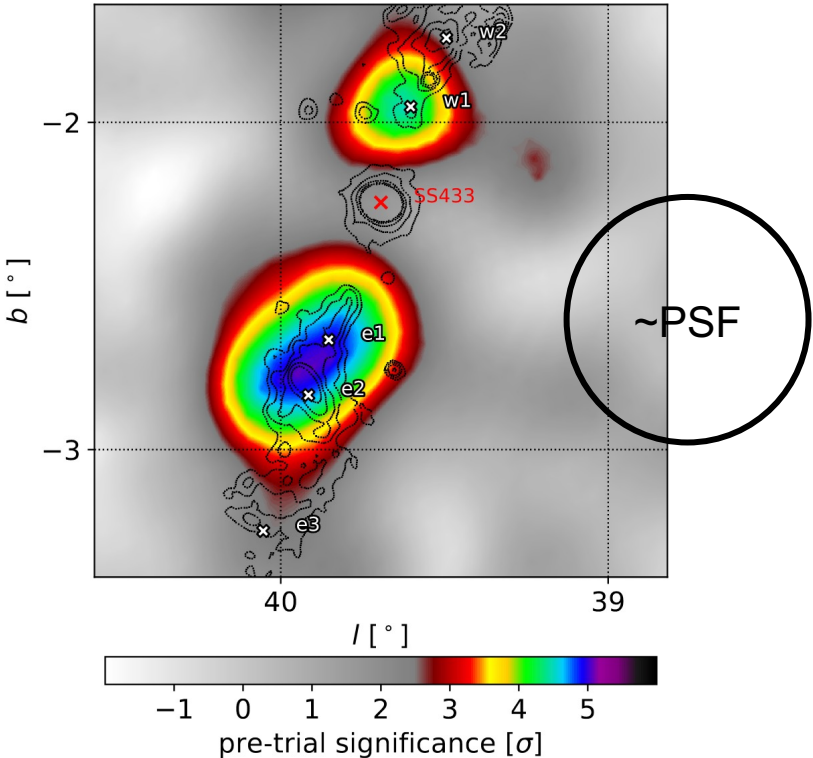
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SS 433: TeV Discovery by HAWC (High-Altitude Water Cherenkov Observatory)



- + In 2018, HAWC reported two **hot spots** at opposite sides of **SS 433**, spatially in coincidence with the X-ray contours
- Spatial resolution



SS 433 as seen by Imaging Atmospheric Cherenkov Telescopes

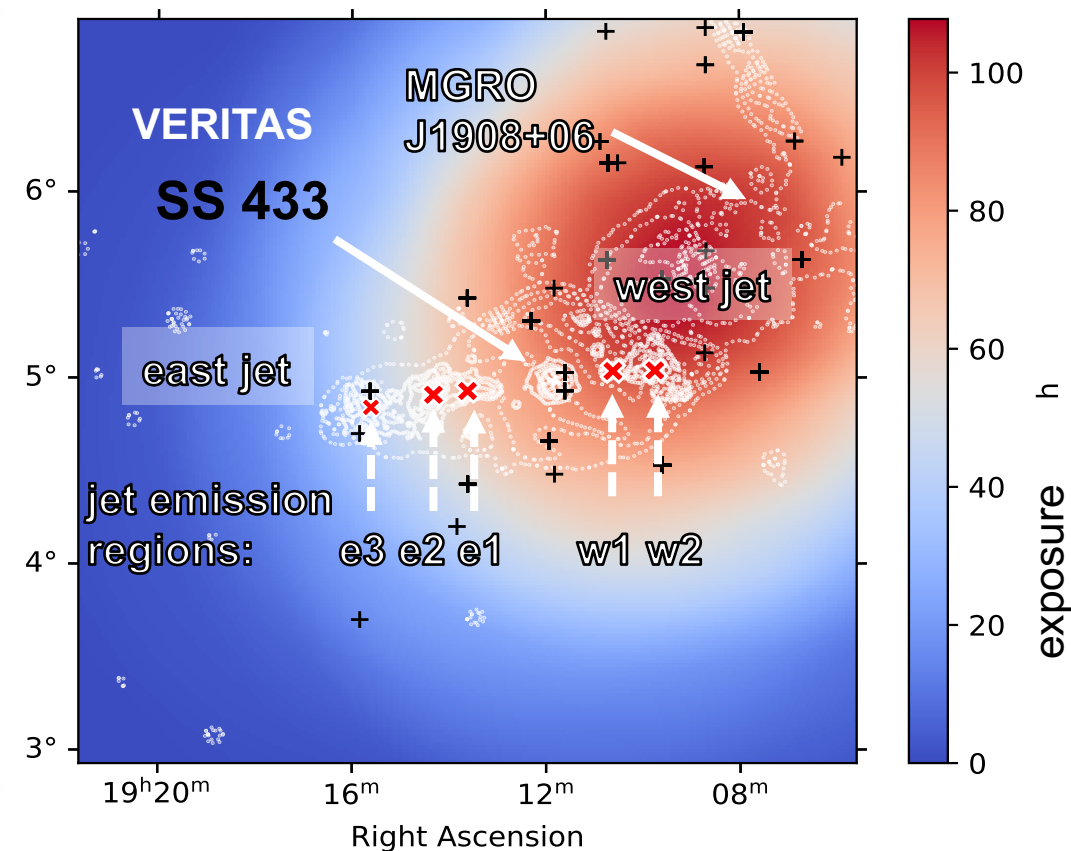
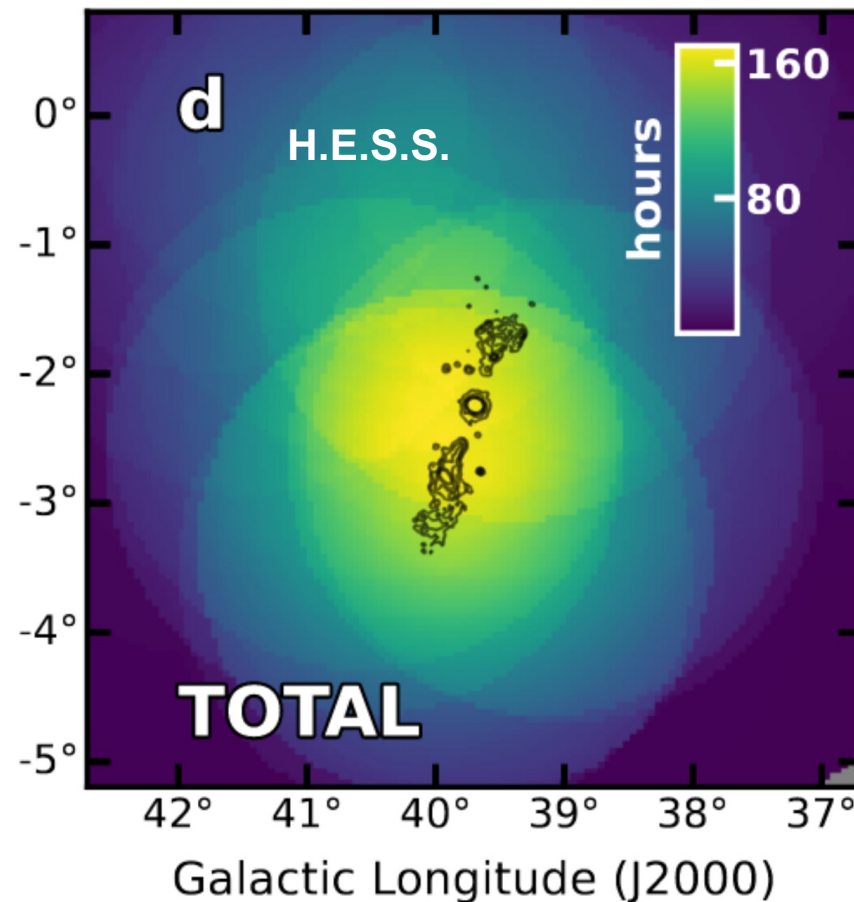
The Analysis of SS 433 with H.E.S.S. and VERITAS

Comparison of Datasets

Acceleration and transport of relativistic electrons in the jets of the microquasar SS 433

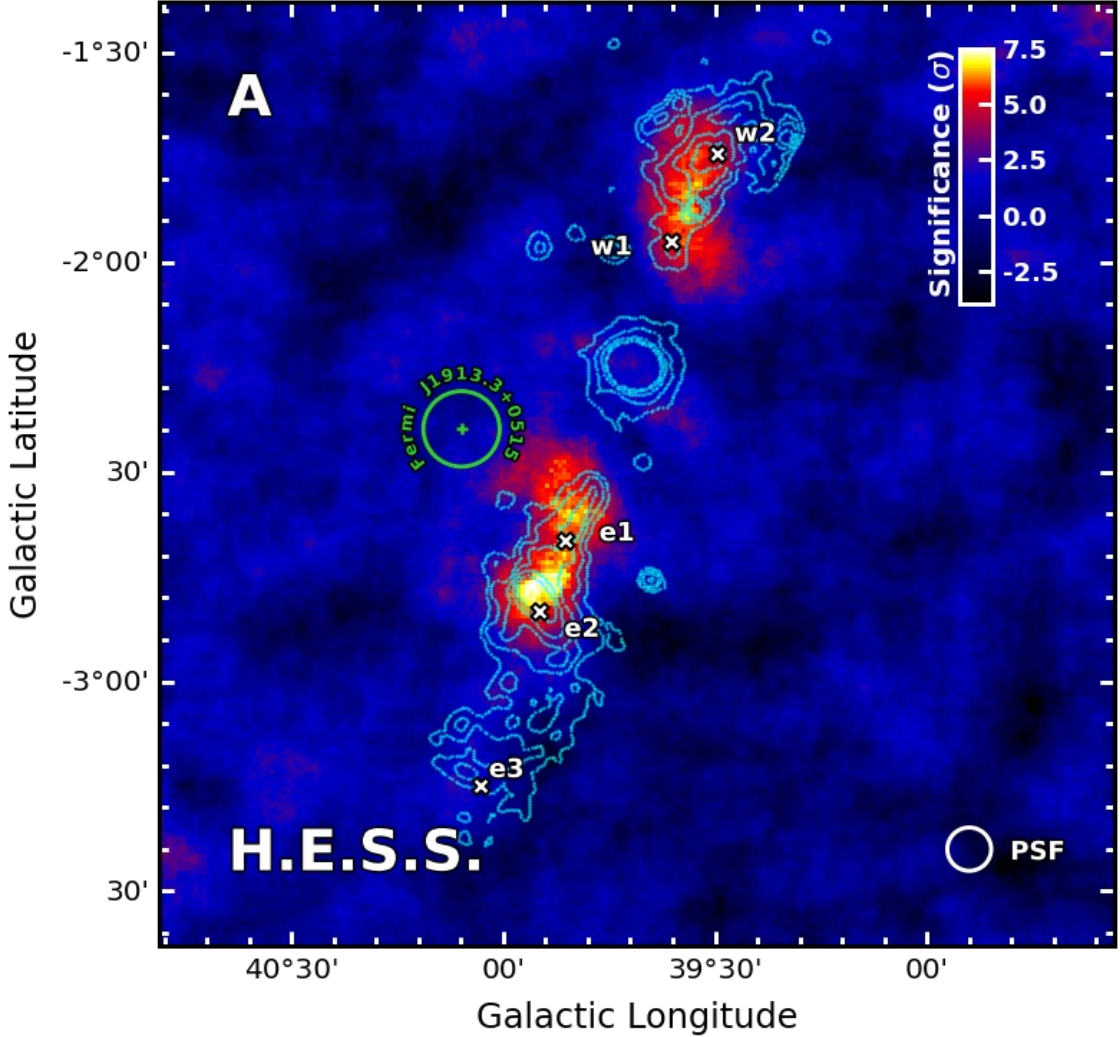
Published in: *Science* 383 (2024) 6681

DESY contribution:
Michelle Tsirou
et. al

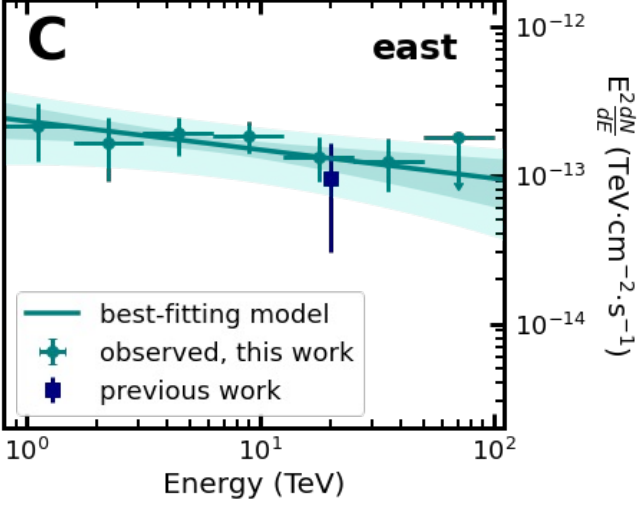
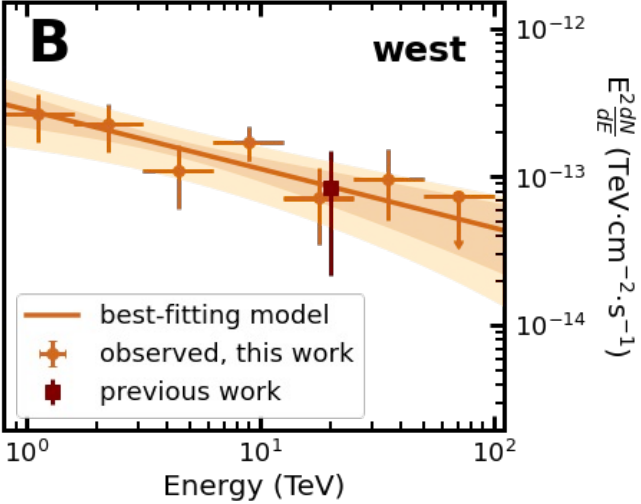


SS 433 Significance Map and Spectra

- Peak statistical significances of 7.8σ and 6.8σ for eastern and western jets
- hard spectral index



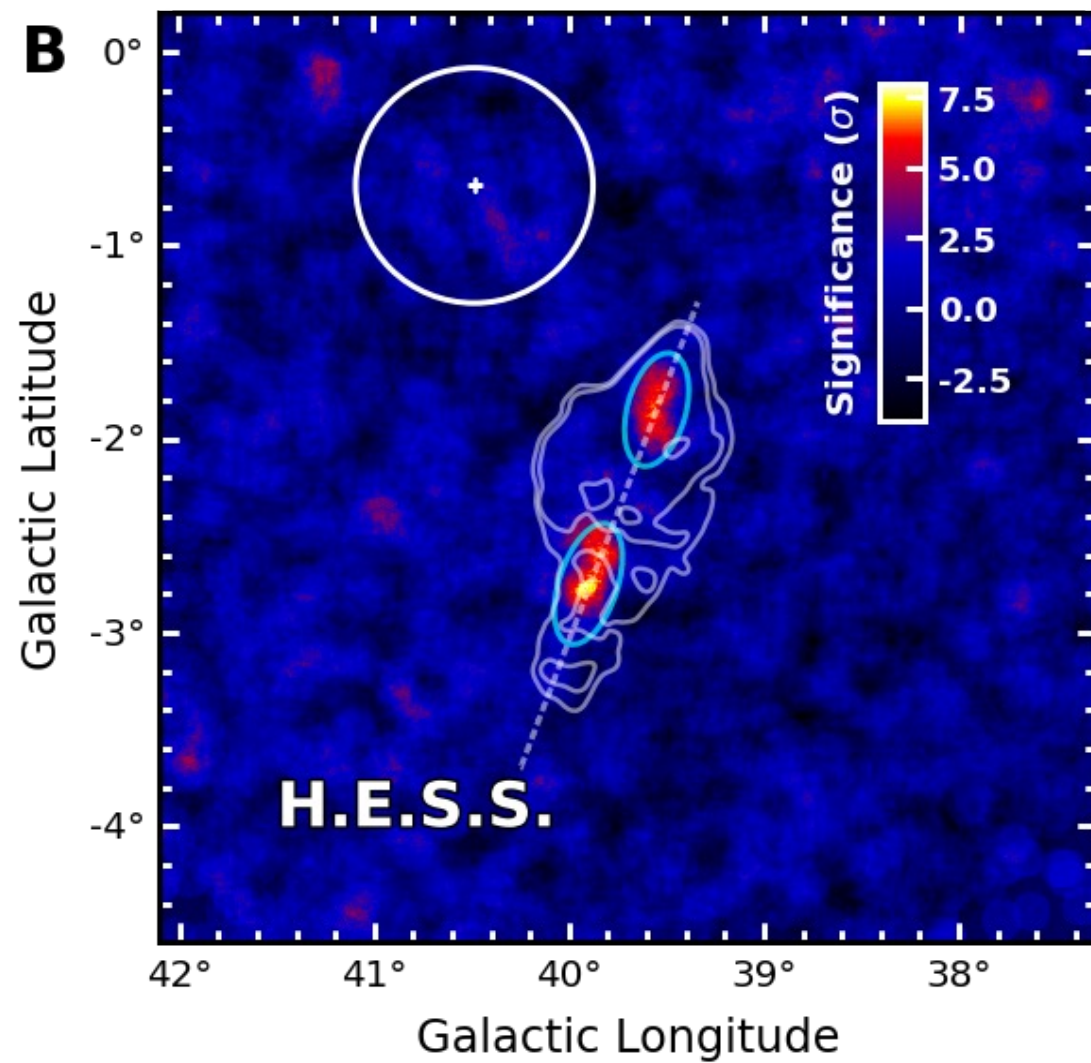
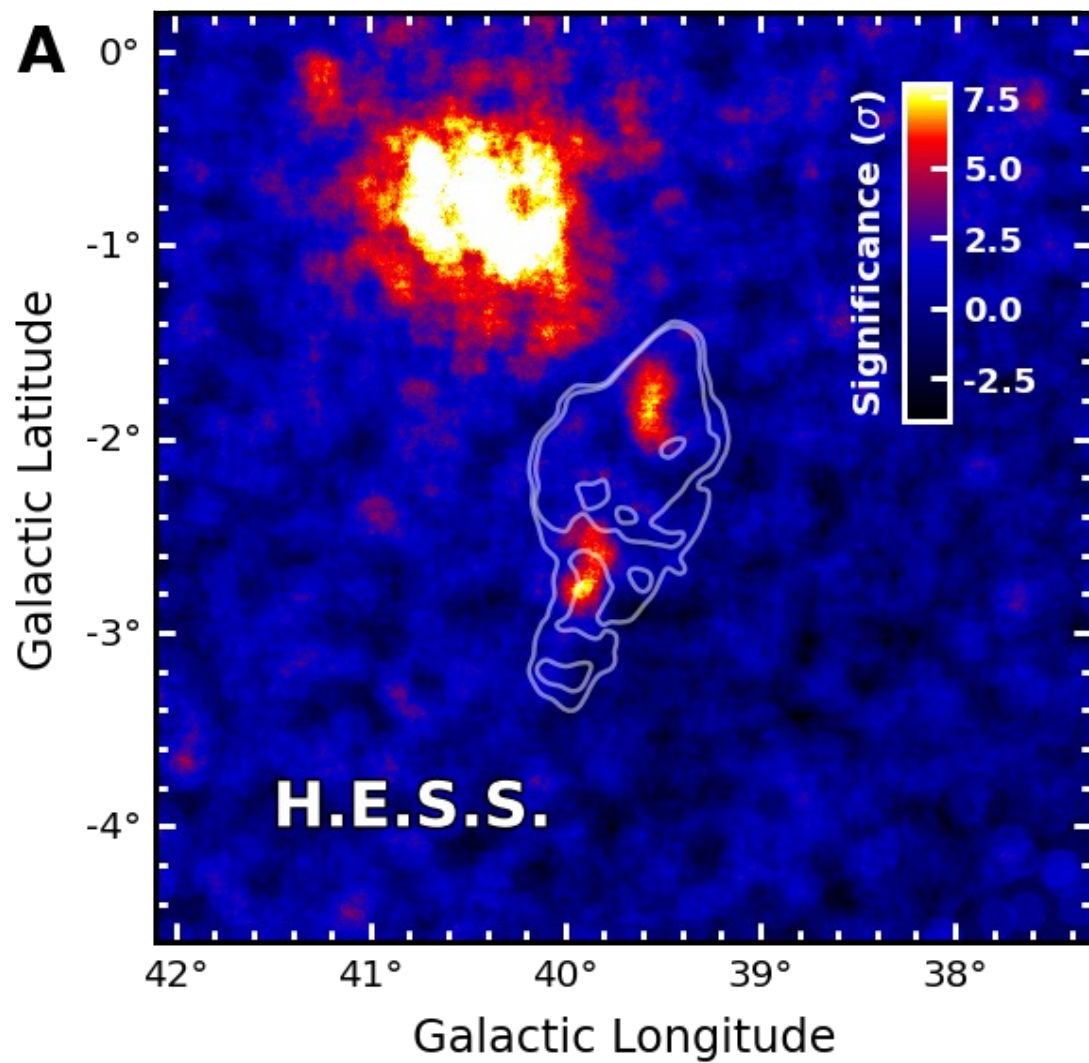
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SS 433 Modelling

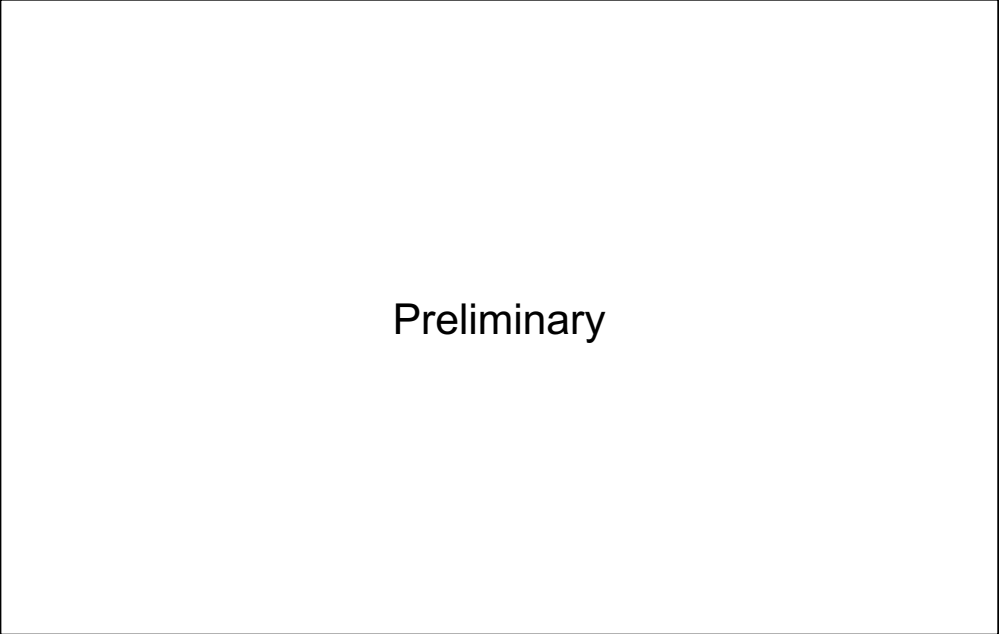
Background and Morphology Estimation

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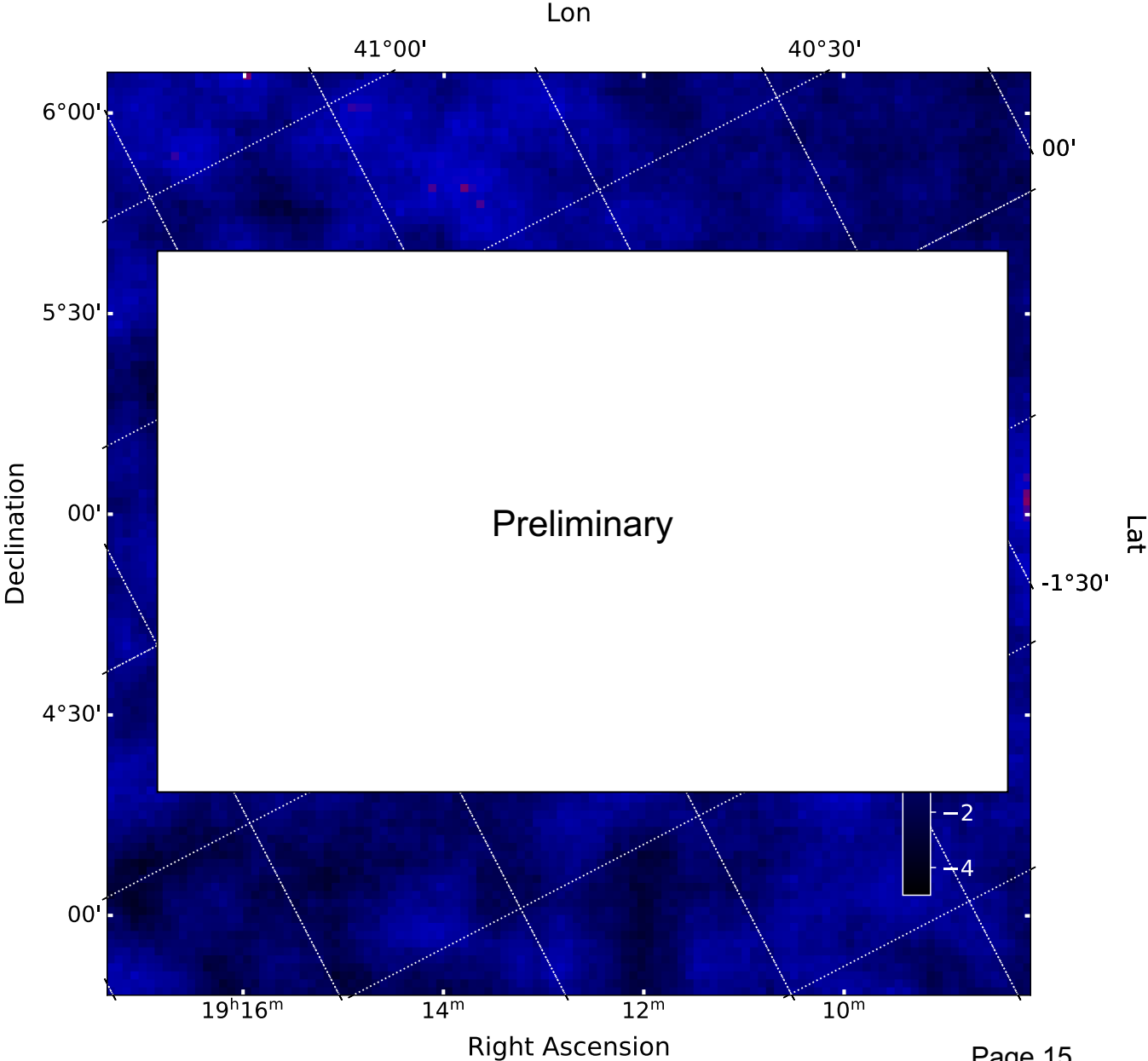


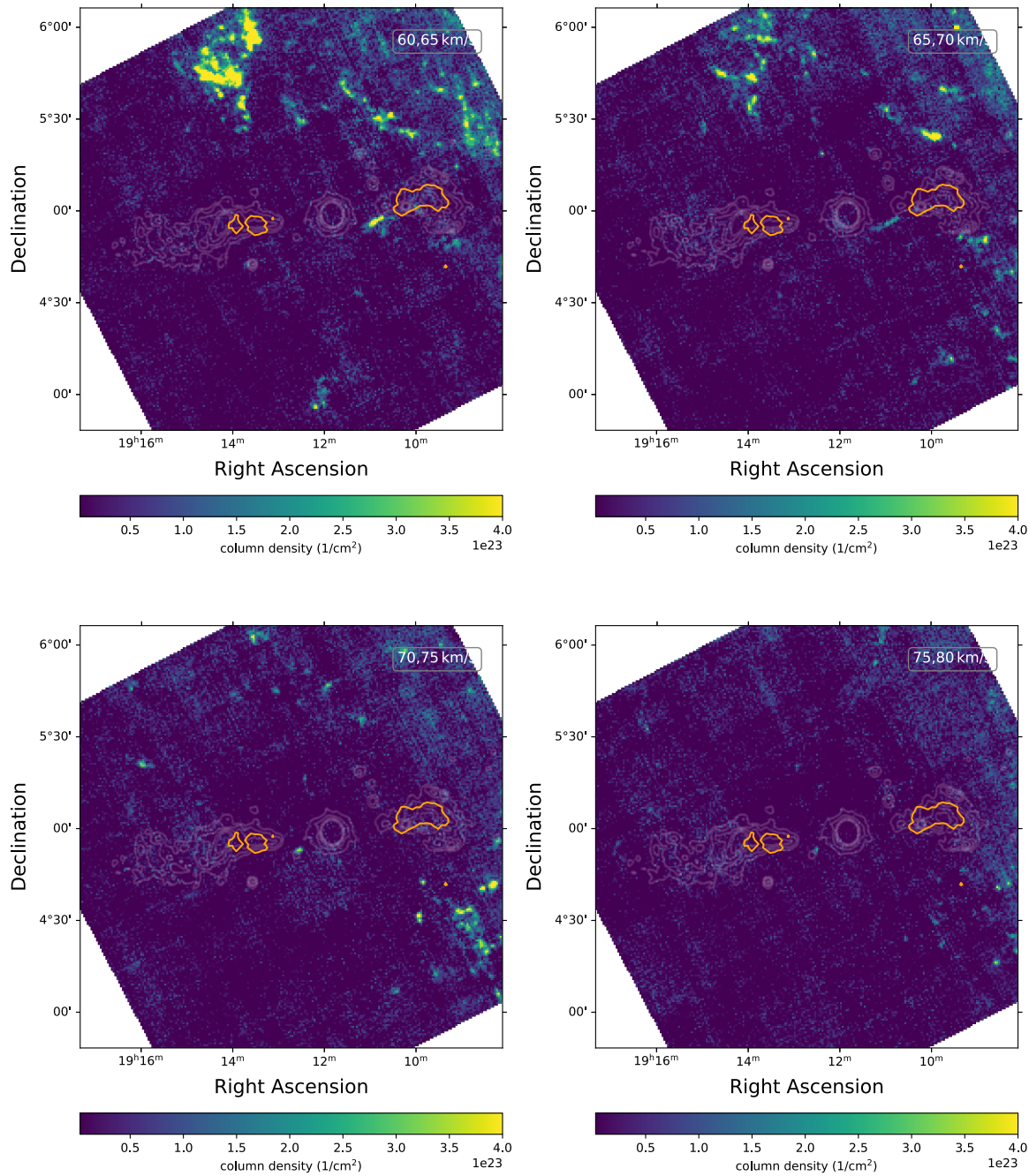
Detection of SS 433 with VERITAS

- **Significant** detection in the eastern and western jets



(in prep.)

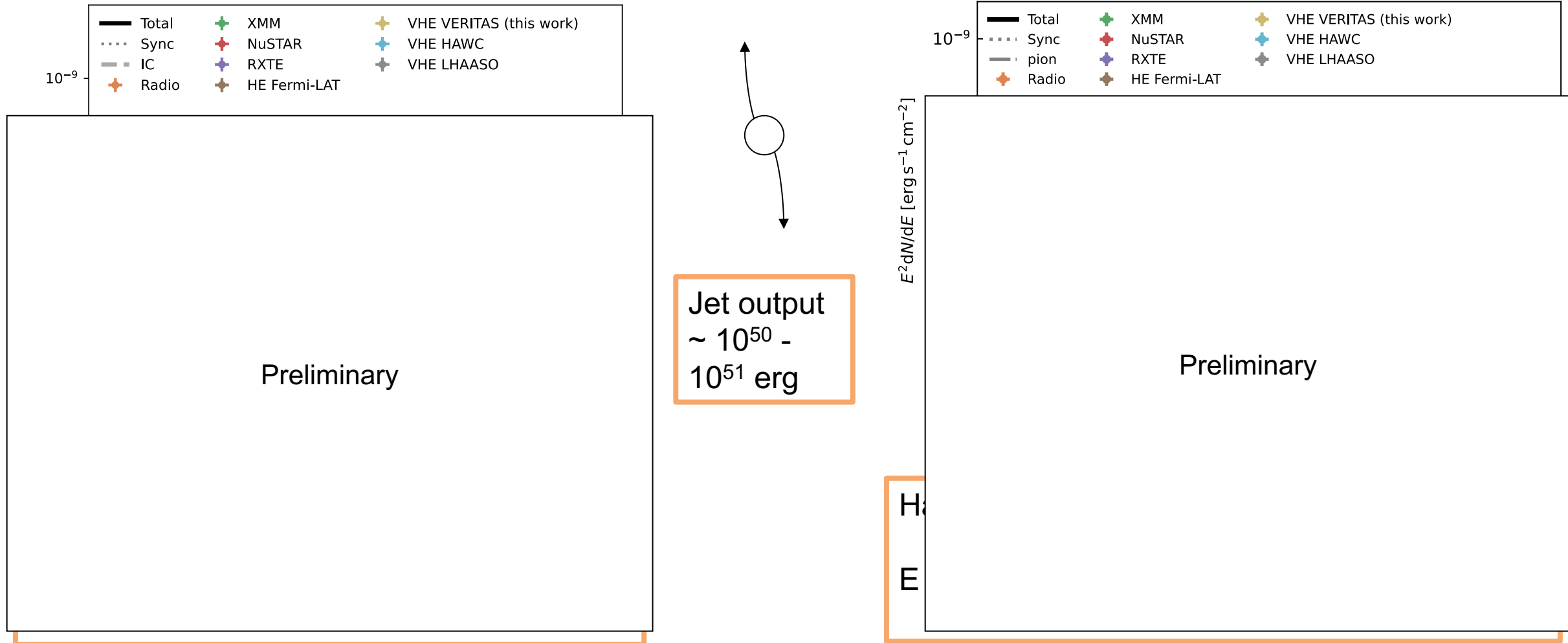




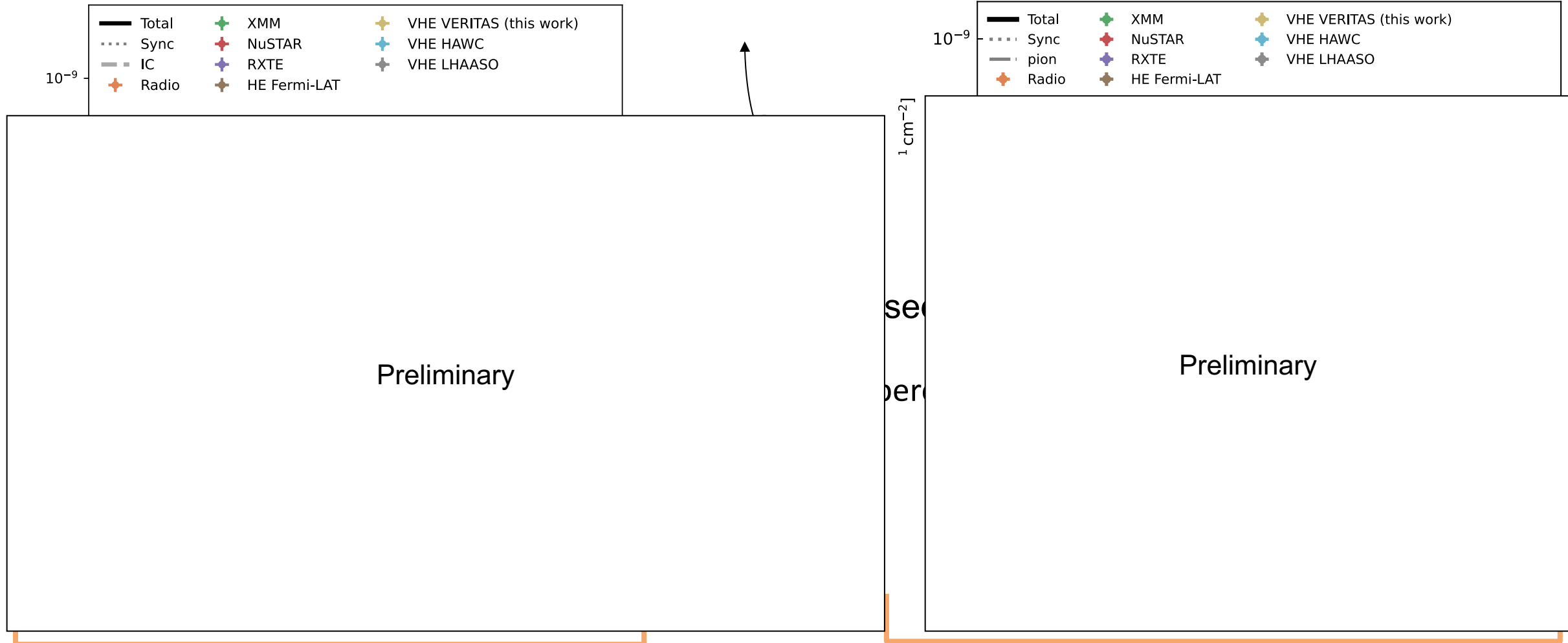
- ^{12}CO analysis: Milky way image scroll painting data line survey. 13.7 m millimeter wave telescope of the Purple Mountain Observatory.
- 3.5σ VERITAS orange and ROSAT contours in grey
- Derive lower and upper limits of expected proton densities in the eastern and western jet lobes

n_p east	n_p west
0.15-1.2	0.88-2.1

Spectral Properties of SS 433 (Jet Interaction Region)

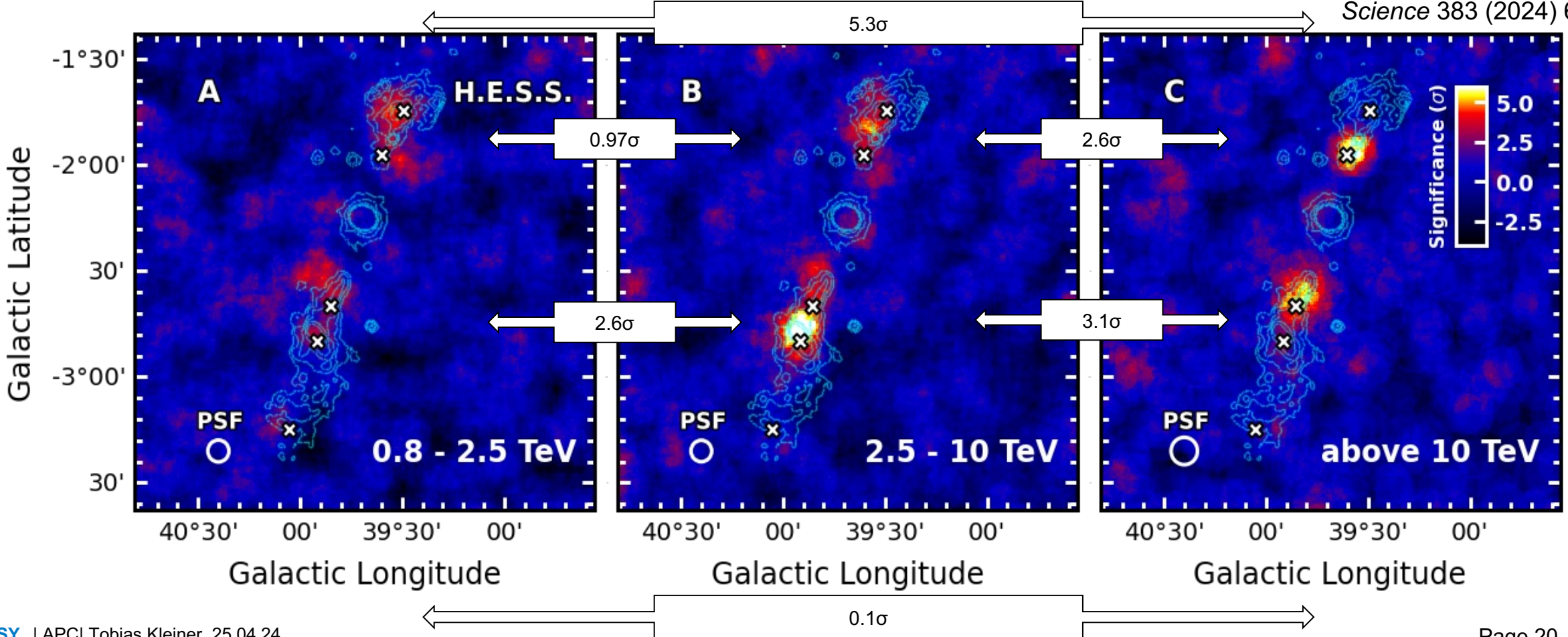


Spectral properties of SS 433 (Jet Interaction Region)



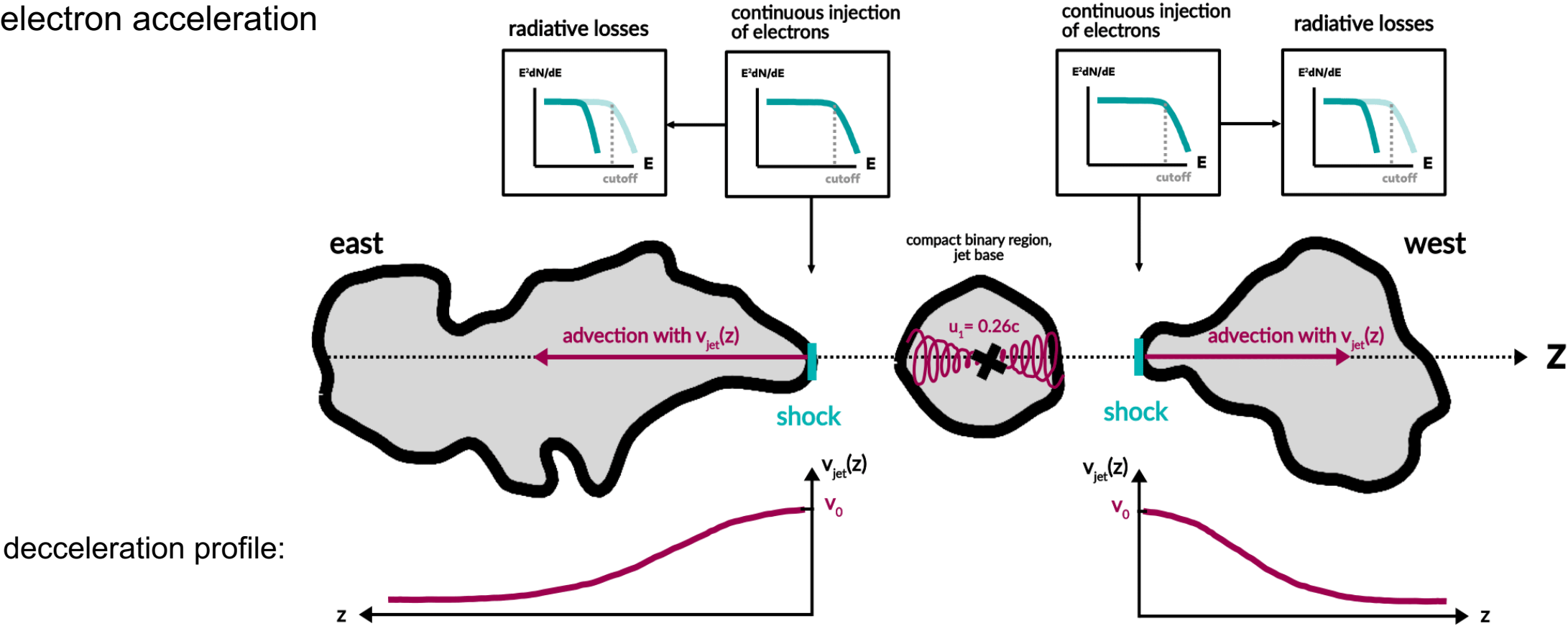
Particle Acceleration and Energy Dependence

- Energy-dependent morphology suggests advection dominates particle transport in the outer jets.
- Gamma-ray emission likely originates from particle acceleration at the base of the outer jets.

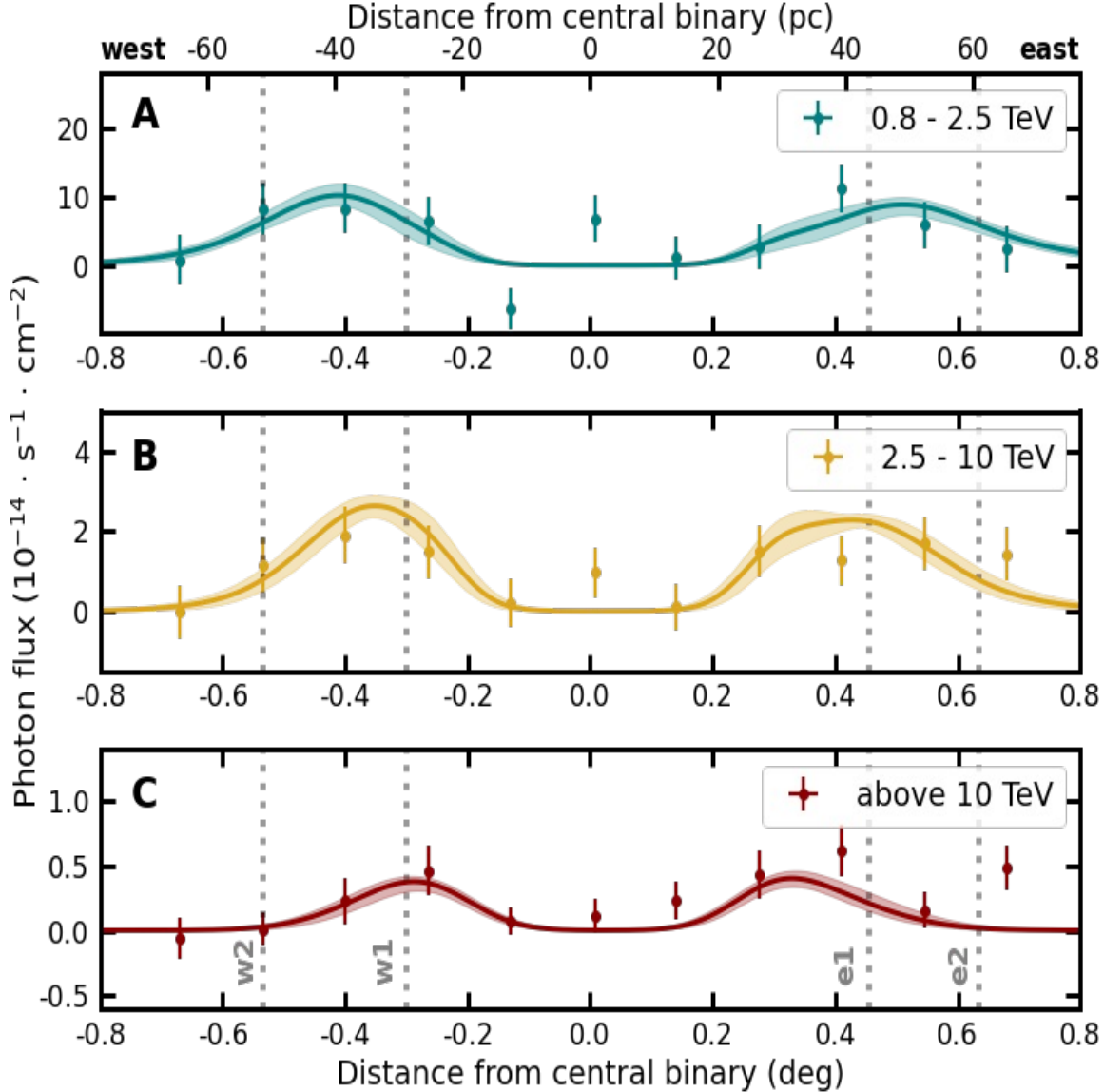


H.E.S.S. Modelling and Interpretation

- Model combines distances between gamma-ray regions and electron cooling timescales to infer jet velocity.
- Presence of a shock at the base of outer jets
- Site for electron acceleration



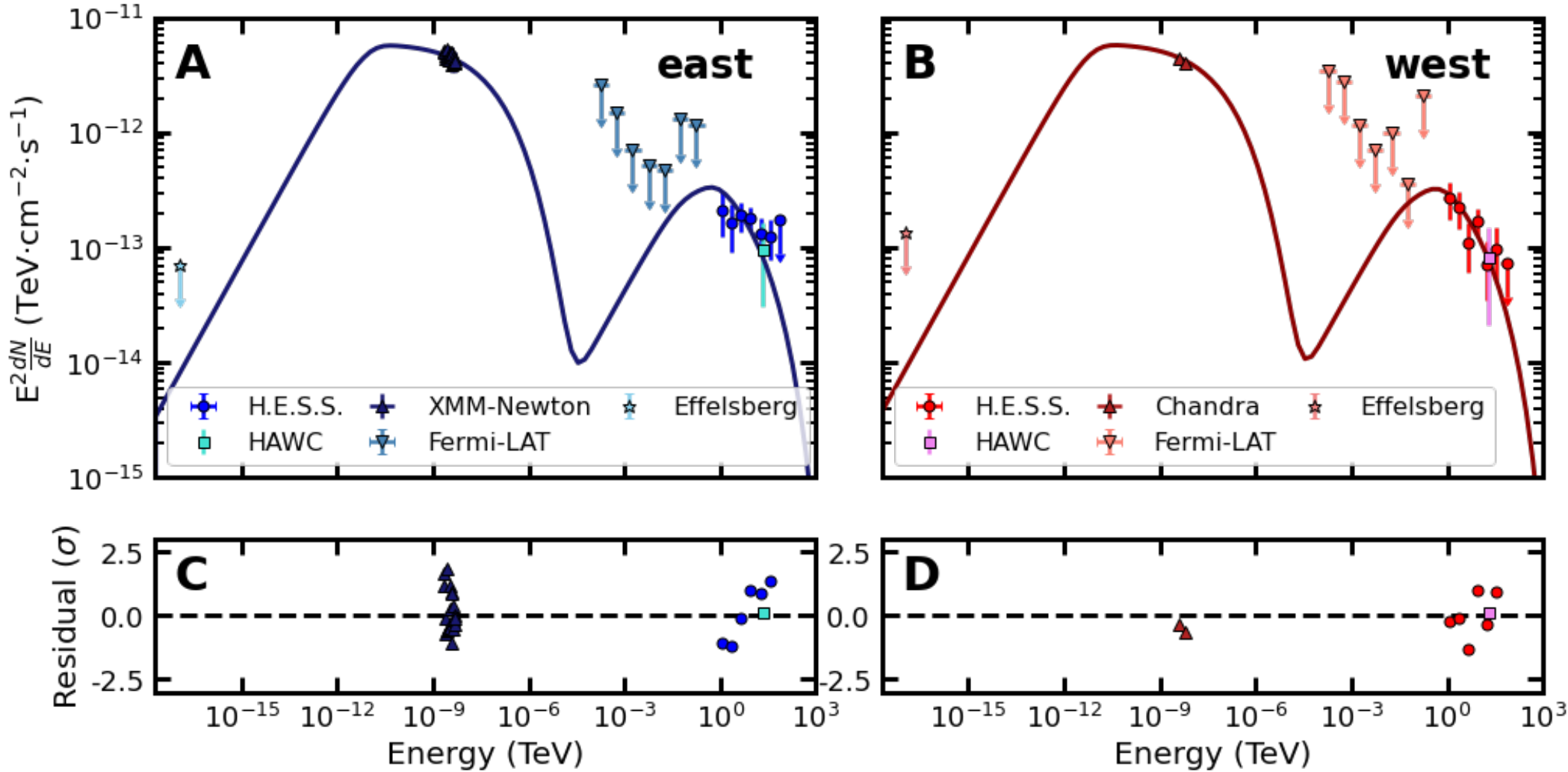
Gamma-ray flux profiles along the jets compared with the model prediction



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Multi-wavelength SED

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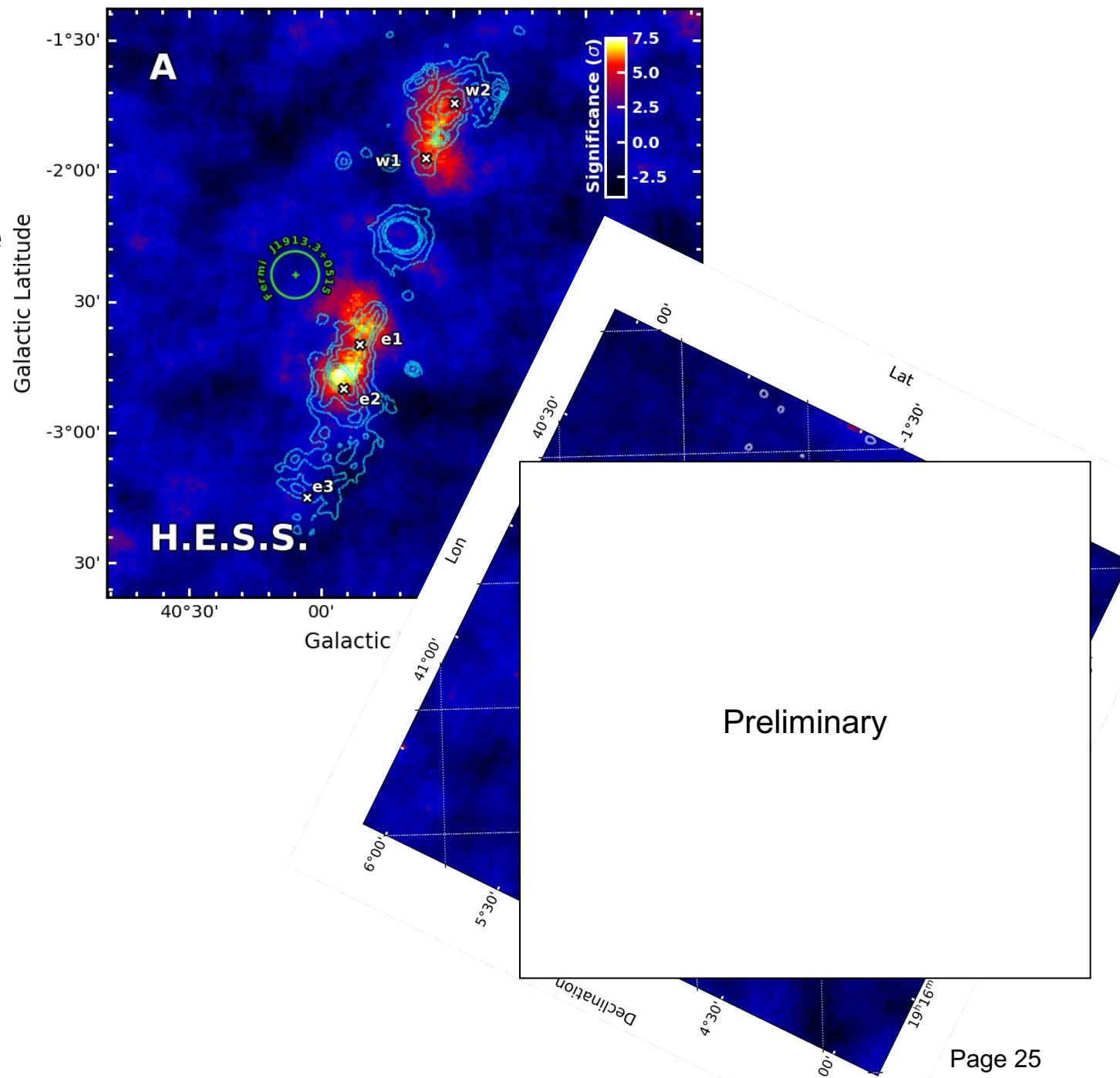


SUMMARY

FUTURE: CTA

Summary

- Gamma-ray observations provide insights into particle acceleration mechanisms of SS 433's complex jets.
- Presence of shocks at the base of outer jets inferred from modelling and observations.
- Implications for understanding microquasars and extragalactic jets, contributing to cosmic-ray flux understanding.

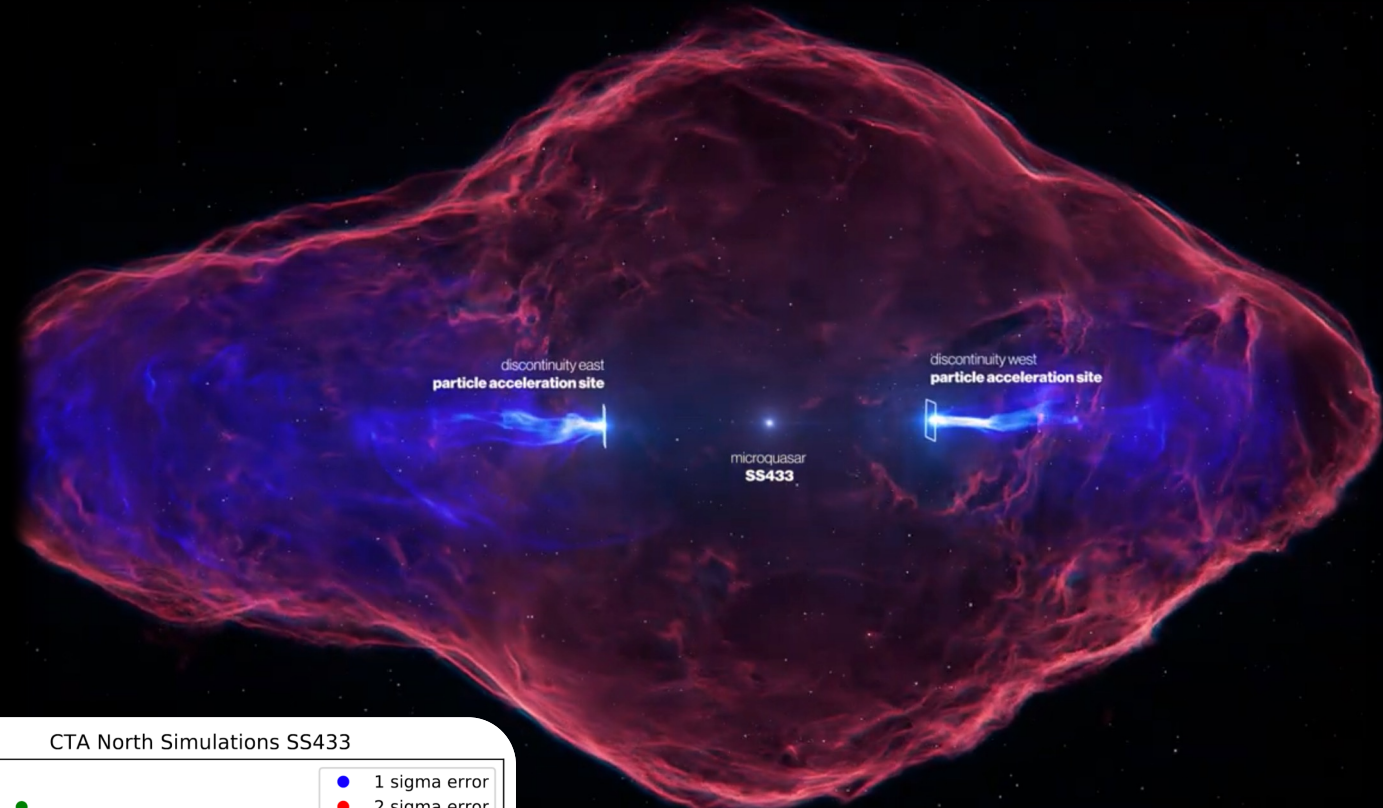


CTAO

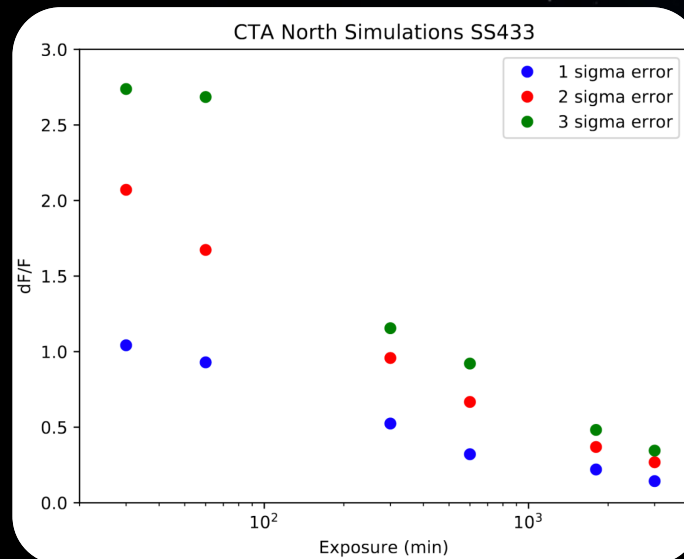
~10x more sensitive than current IACTs

Angular resolution improved by factor 2

- CTAO Observation of SS 433:
 - more details on jet development
 - upper limits black hole region
 - variability?



Model	TS_{10h}^{West}	TS_{10h}^{East}	TS_{30h}^{West}	TS_{30h}^{East}	TS_{50h}^{West}	TS_{50h}^{East}
1	137.4	184.6	738.8	821.9	886.3	1261.4
2	59.2	73.6	178.4	384.2	273.1	401.0
3	11.1	31.3	76.3	104.3	79.5	226.7
4	2.6	7.2	44.4	60.3	34.7	115.9



Galactic transient sources with the Cherenkov Telescope Array (preprint)

**Acceleration and transport of relativistic electrons in the jets
of the microquasar SS 433**

Thank you.