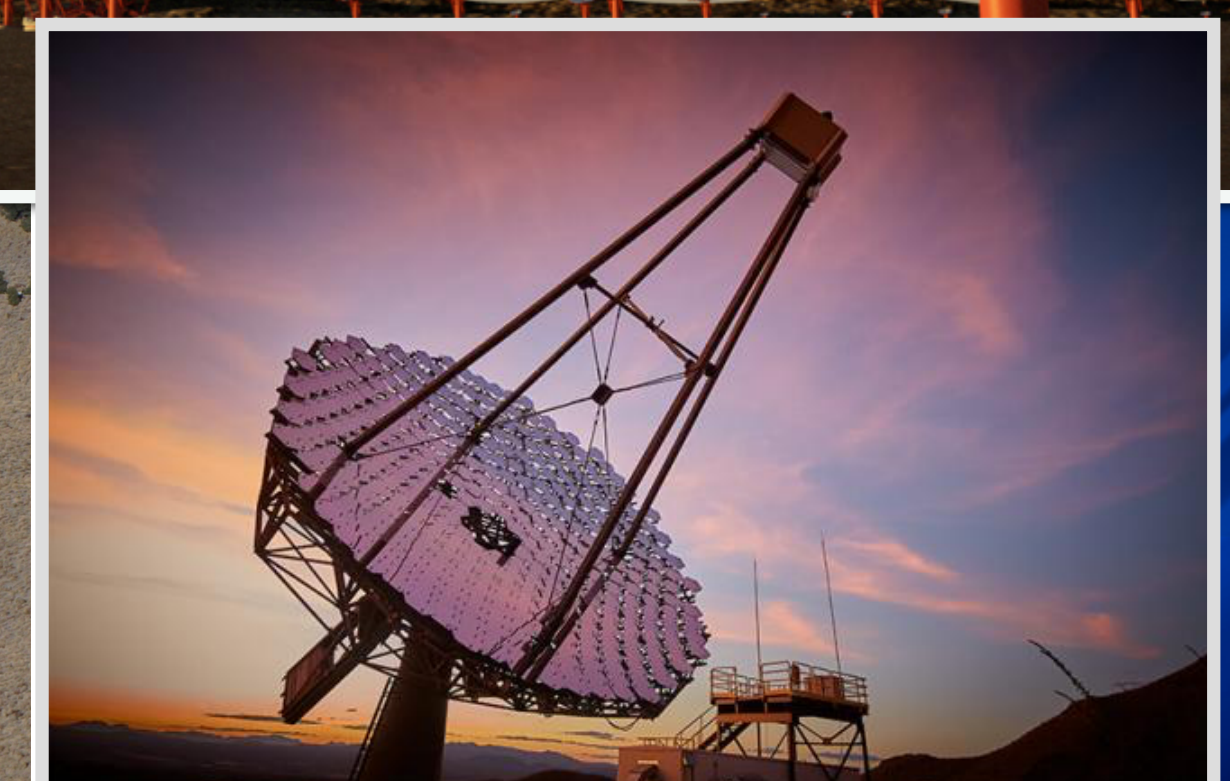
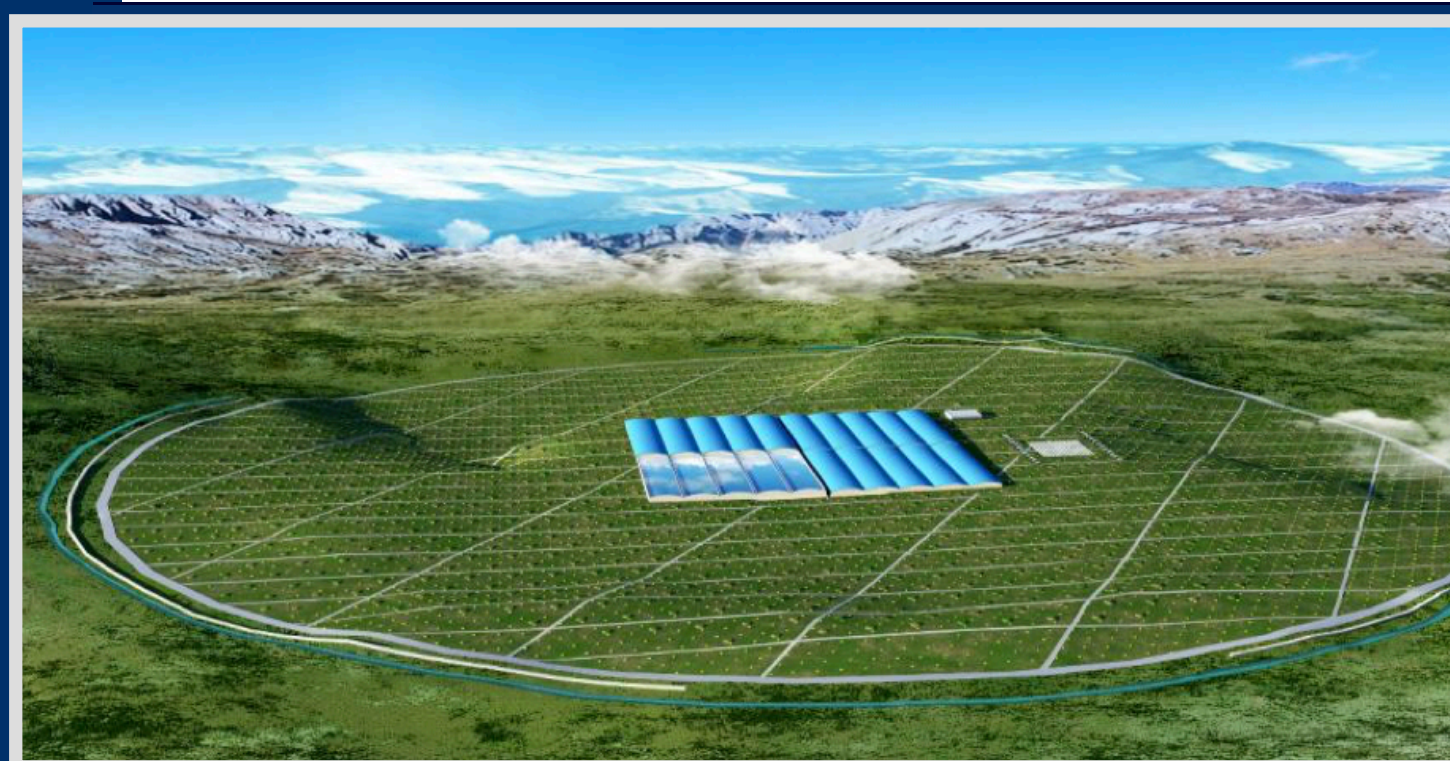


Status of gamma-ray astronomy

Stefan Funk - ECAP (Erlangen Centre for Astroparticle Physics)



Cosmic particle Acceleration

Extreme astrophysical conditions

The frontiers of physics

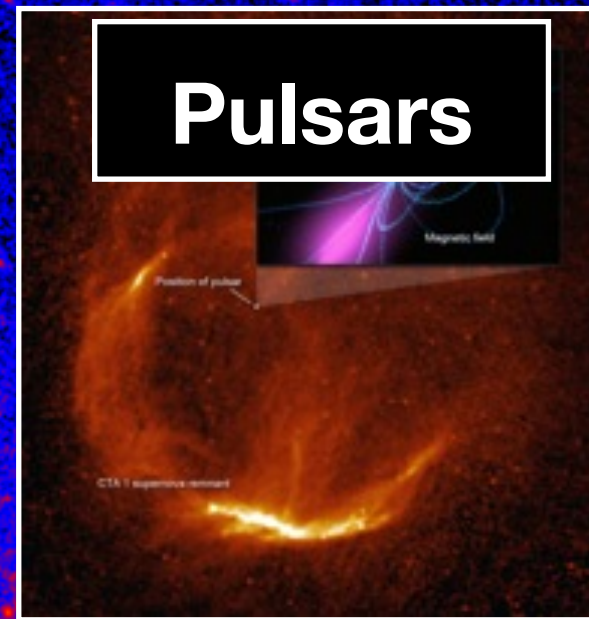
Cosmic rays



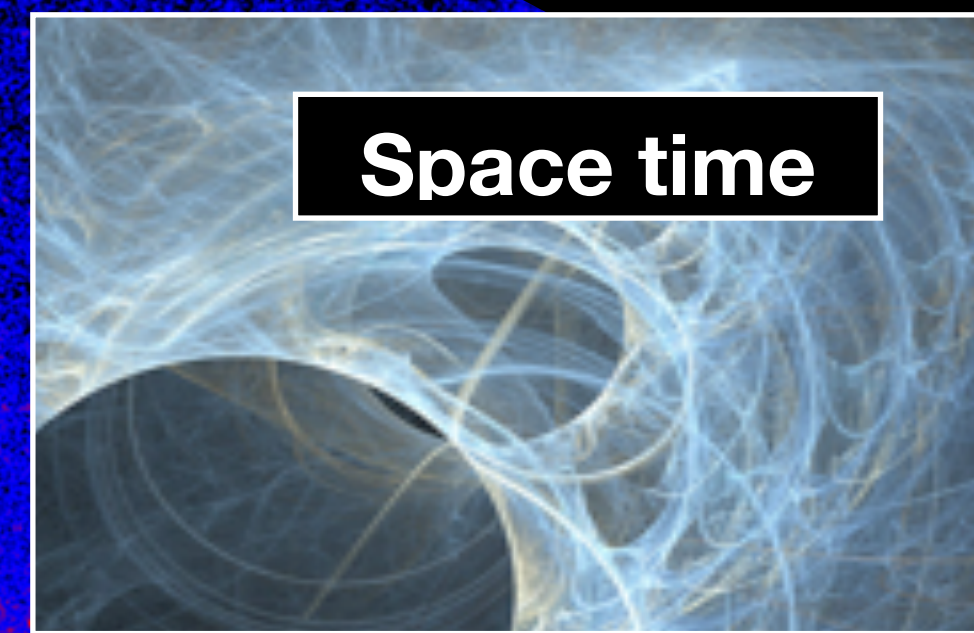
Supernova remnants



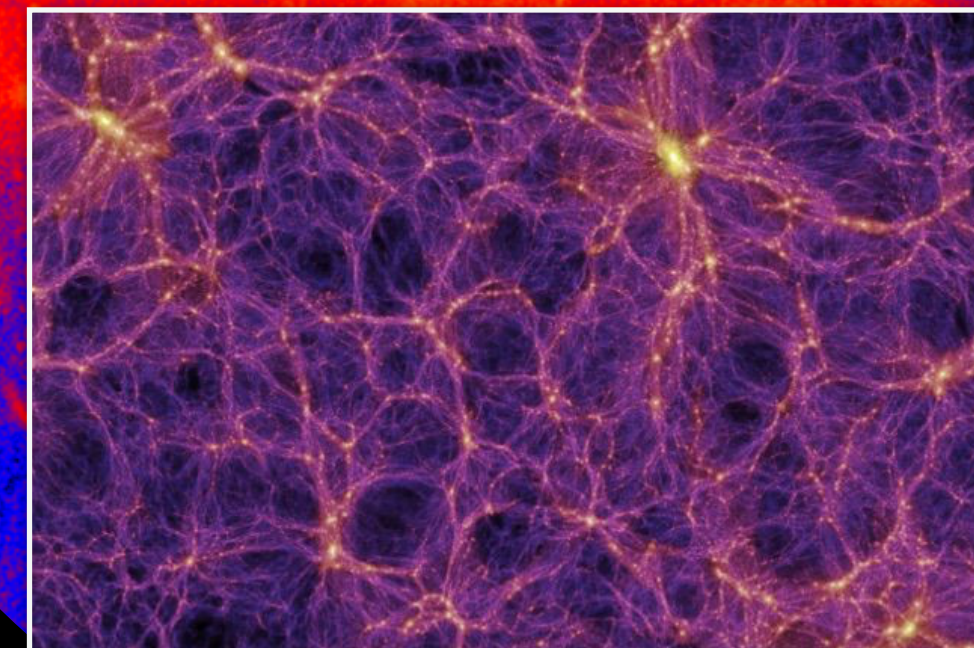
Pulsars



Space time



Propagation



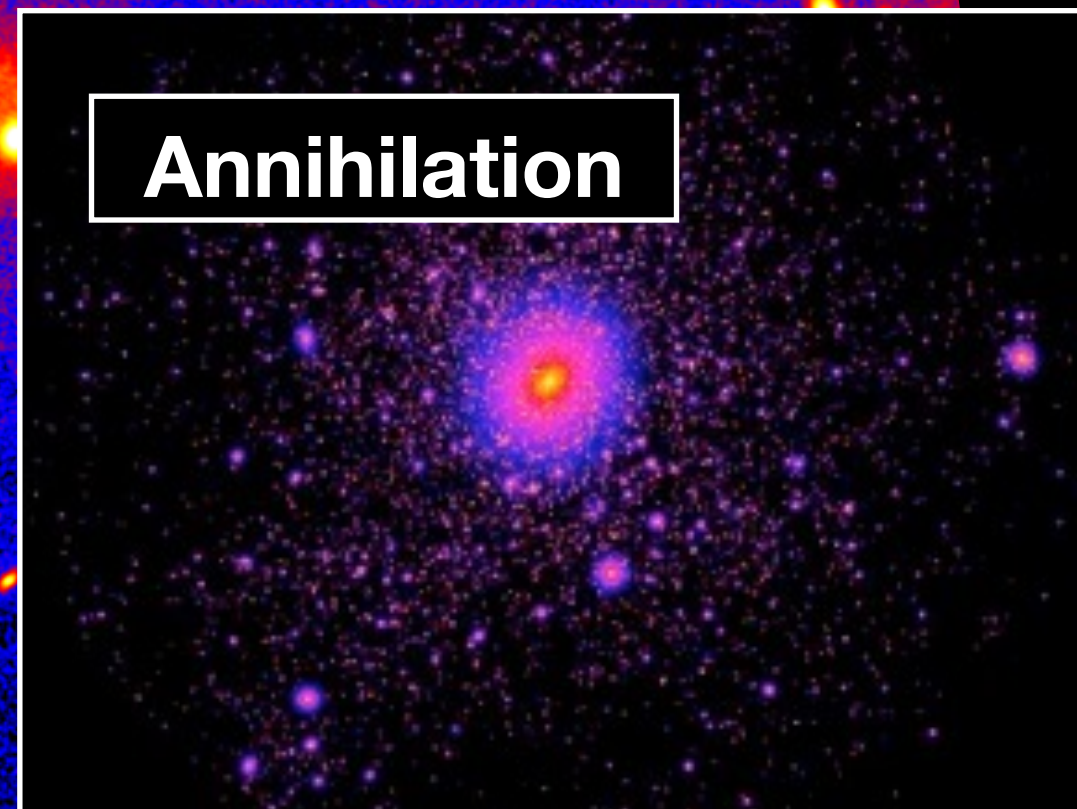
Binaries



AGN



Annihilation



Starburst Galaxies

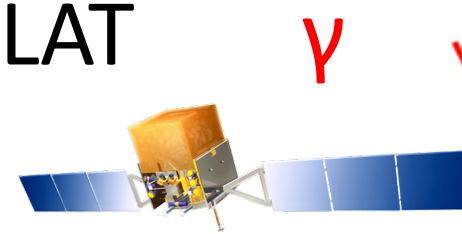


GRBs



DETECTION OF GAMMA RAYS

Fermi-LAT



Electro-
Magnetic
Cascade



HAWC



LHAASO

Cherenkov
Light



VERITAS

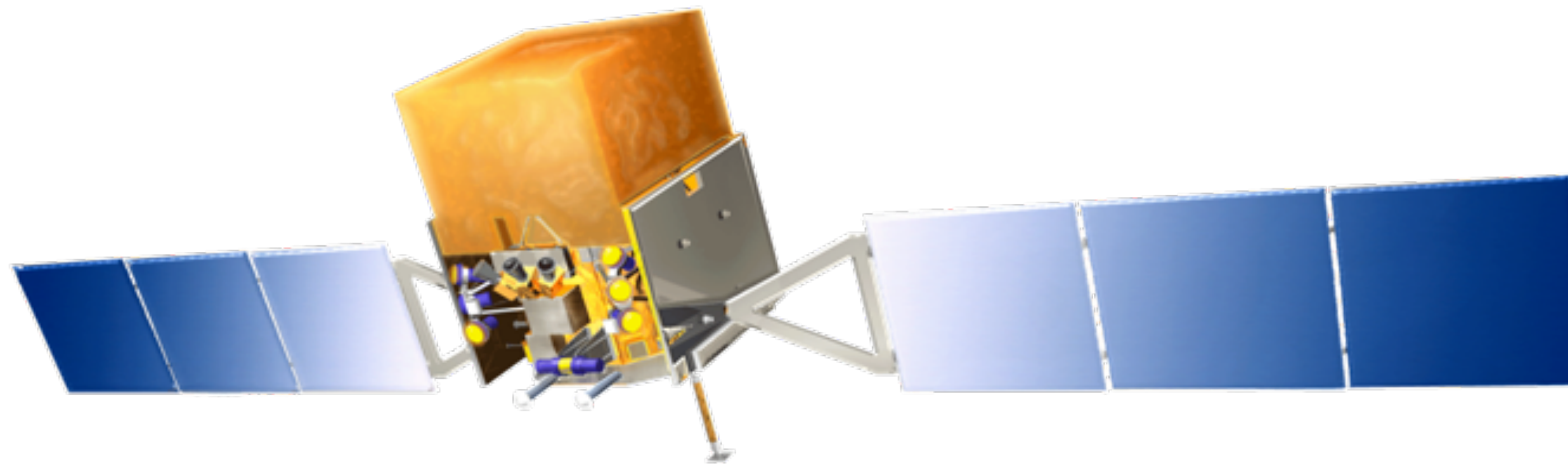


MAGIC

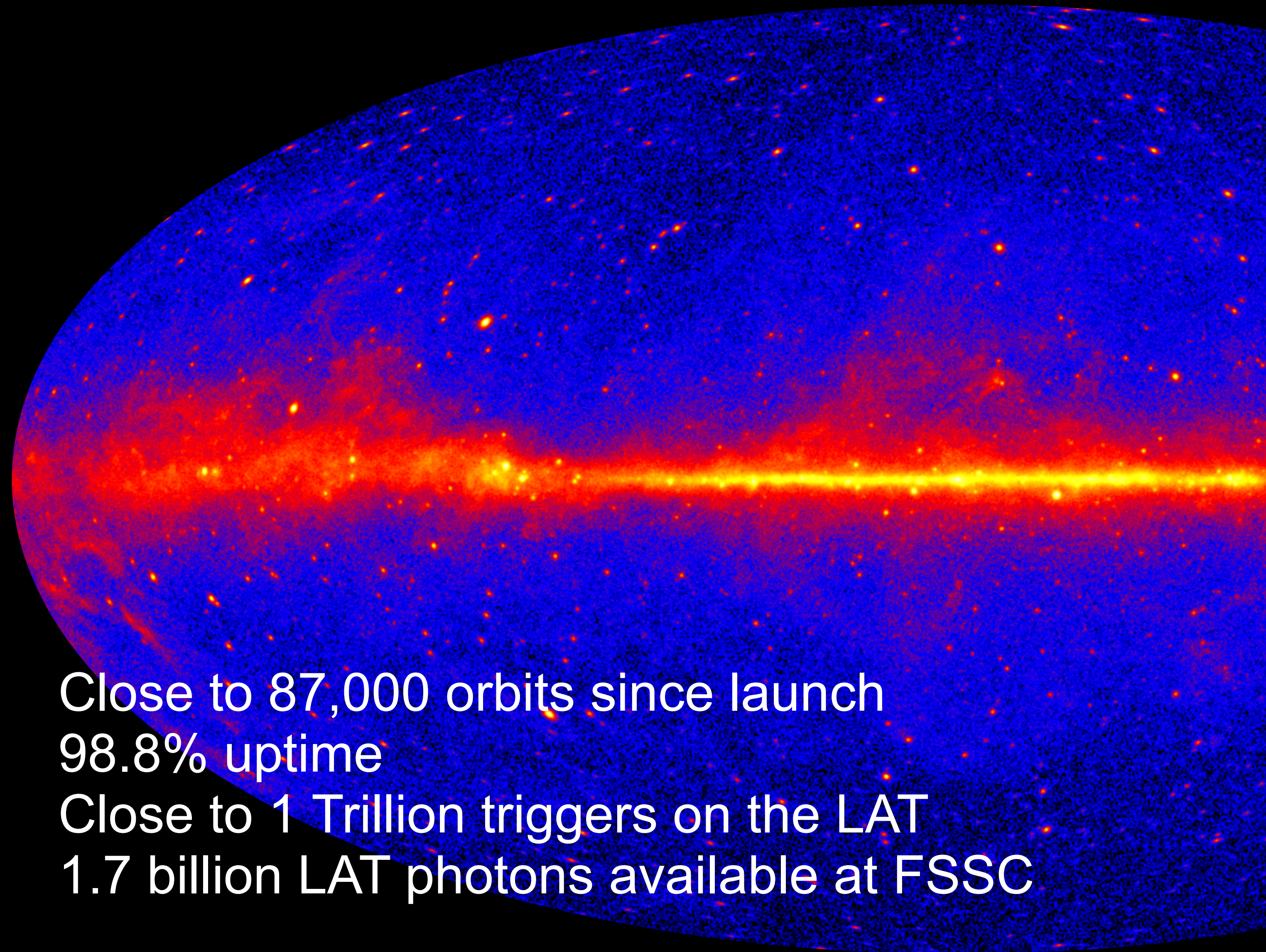


H.E.S.S.

Fermi-LAT



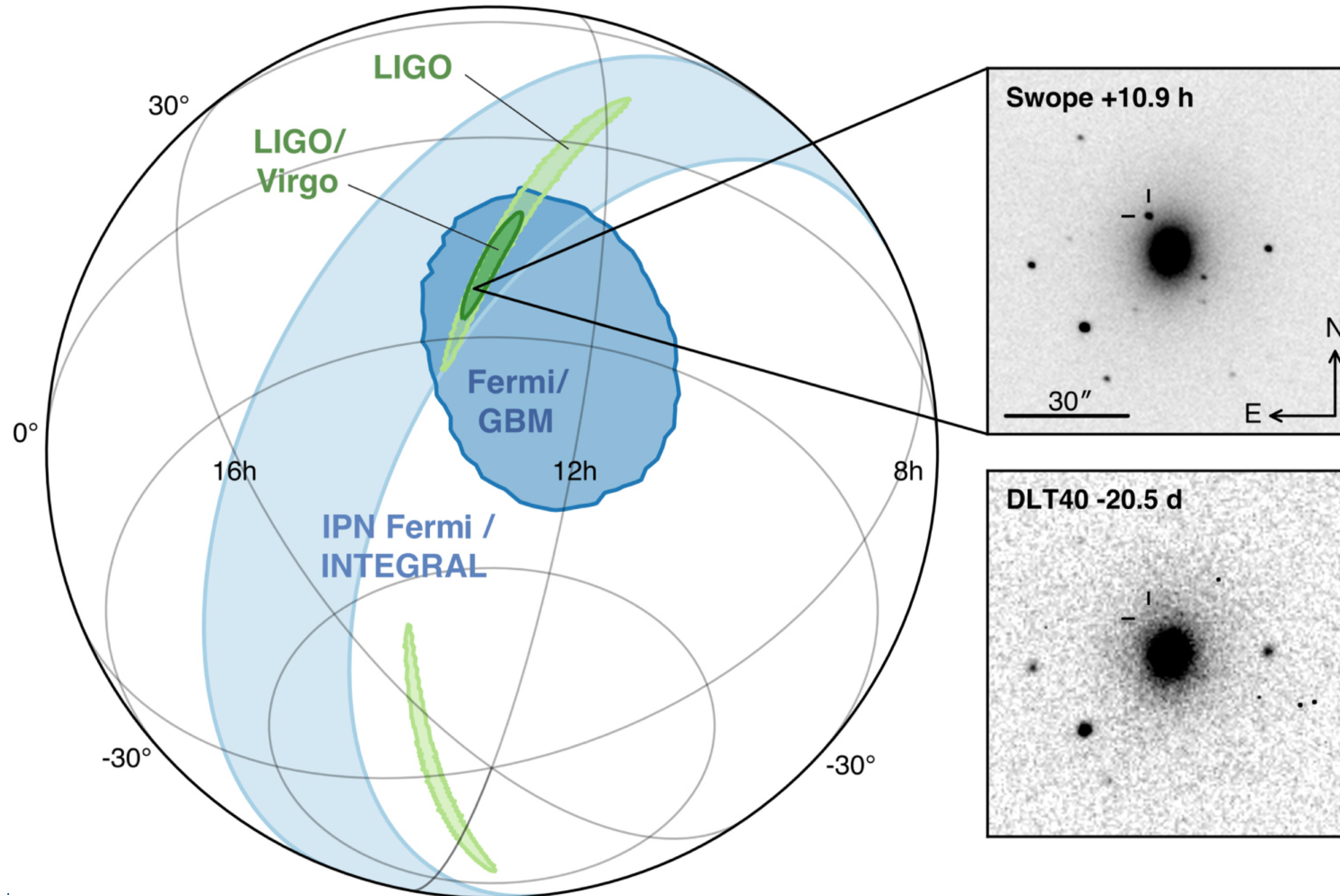
FERMI-LAT MAPPING THE SKY AT GEV ENERGIES



Close to 87,000 orbits since launch
98.8% uptime
Close to 1 Trillion triggers on the LAT
1.7 billion LAT photons available at FSSC

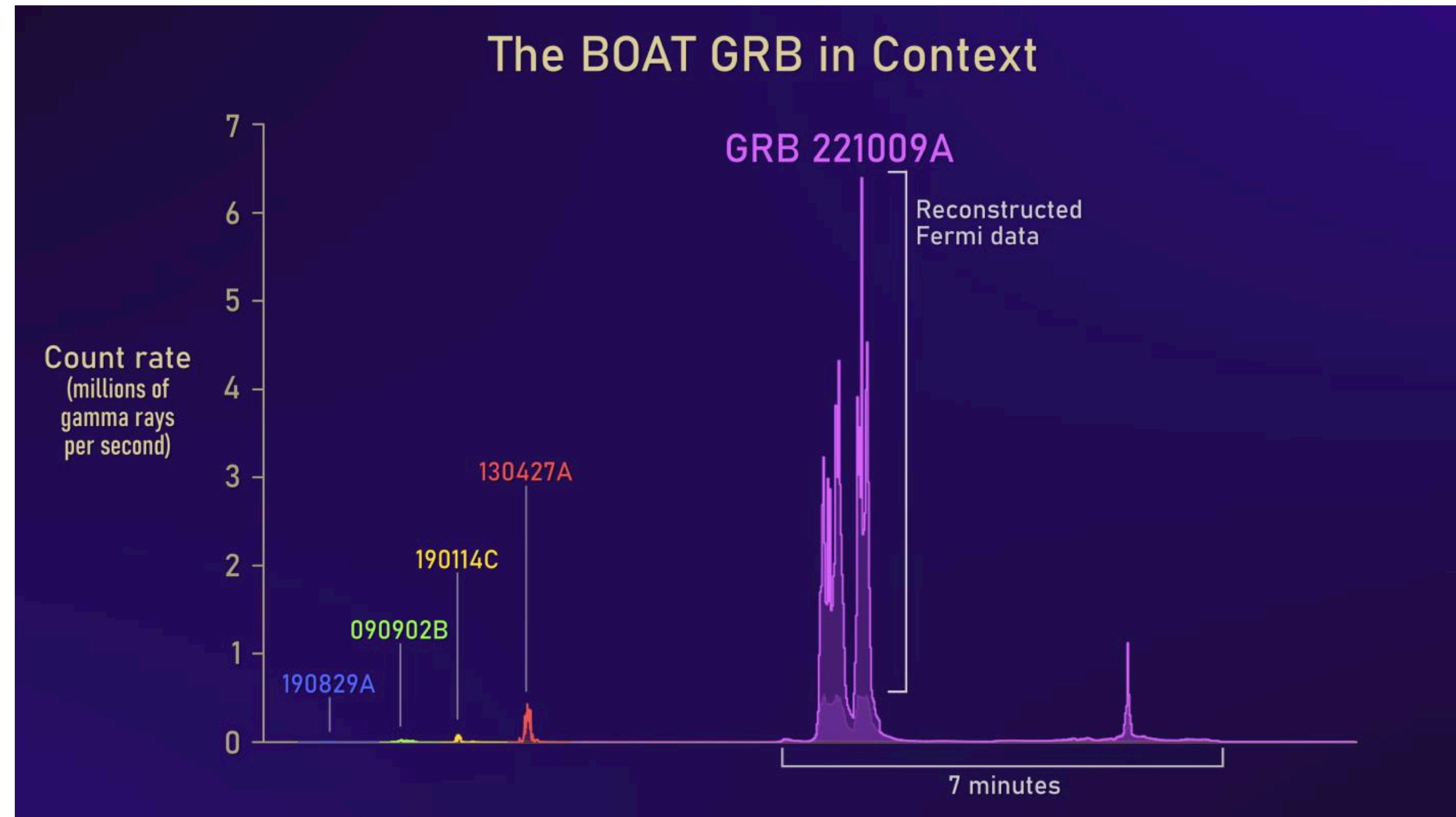


THE MULTI-MESSENGER EVENT GRB170817A, GW170817



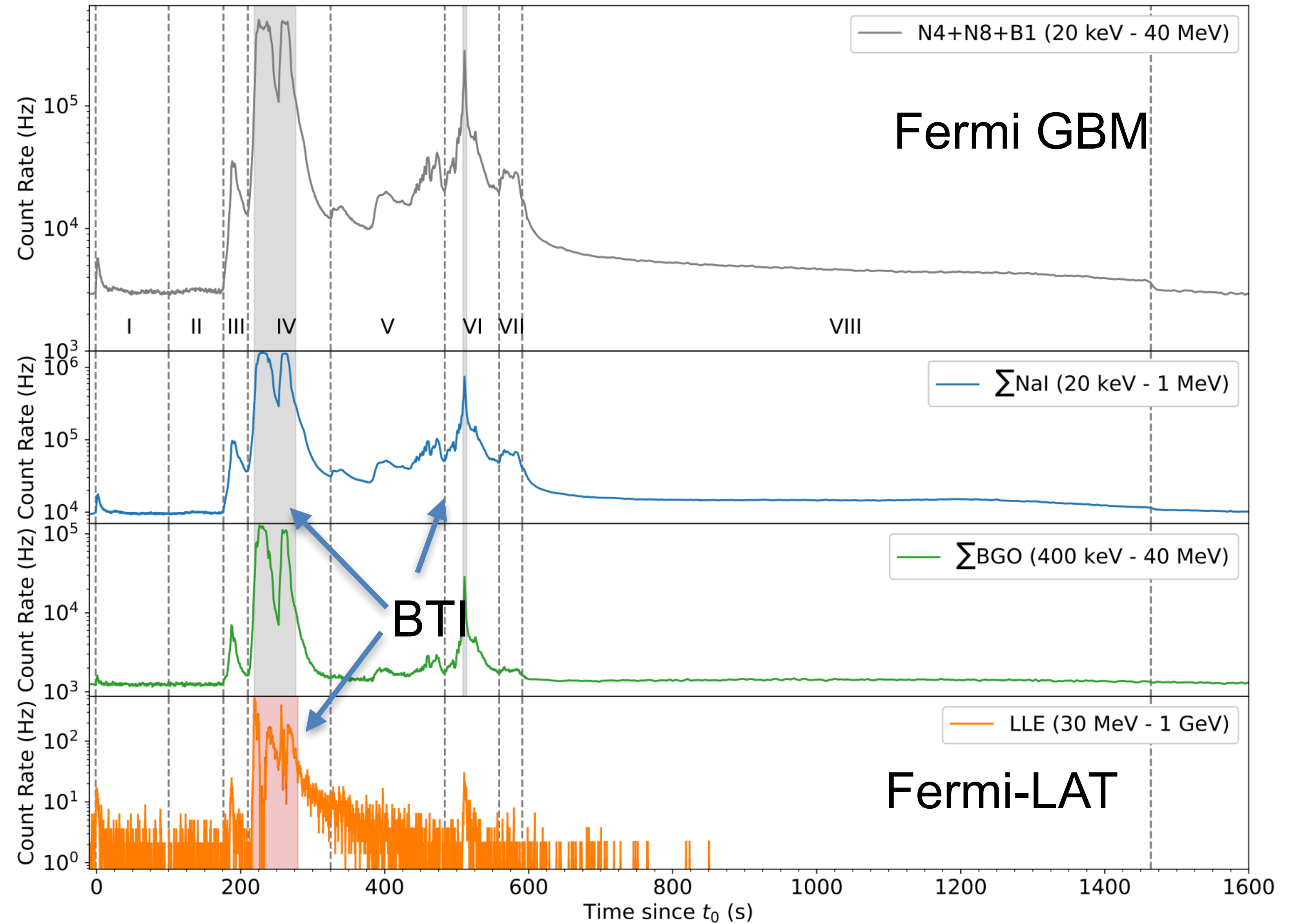
THE BOAT (BRIGHTEST OF ALL TIMES)

- 1-in-10000 year event
- Detected by Fermi GBM
- Severe saturation in GBM and LAT in main phase (Region IV)
- Detected by LHAASO and HAWC (IACTs: full moon)



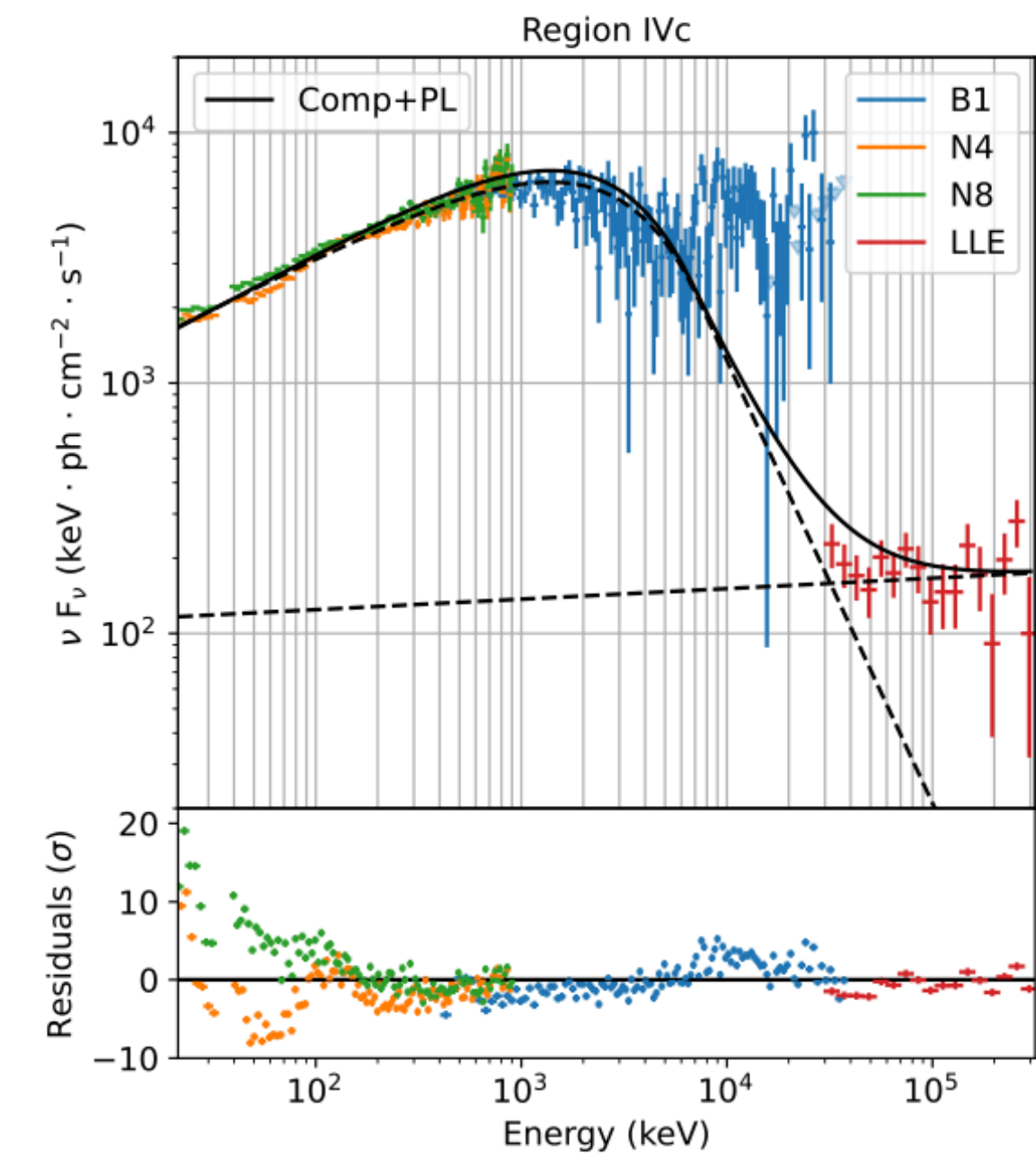
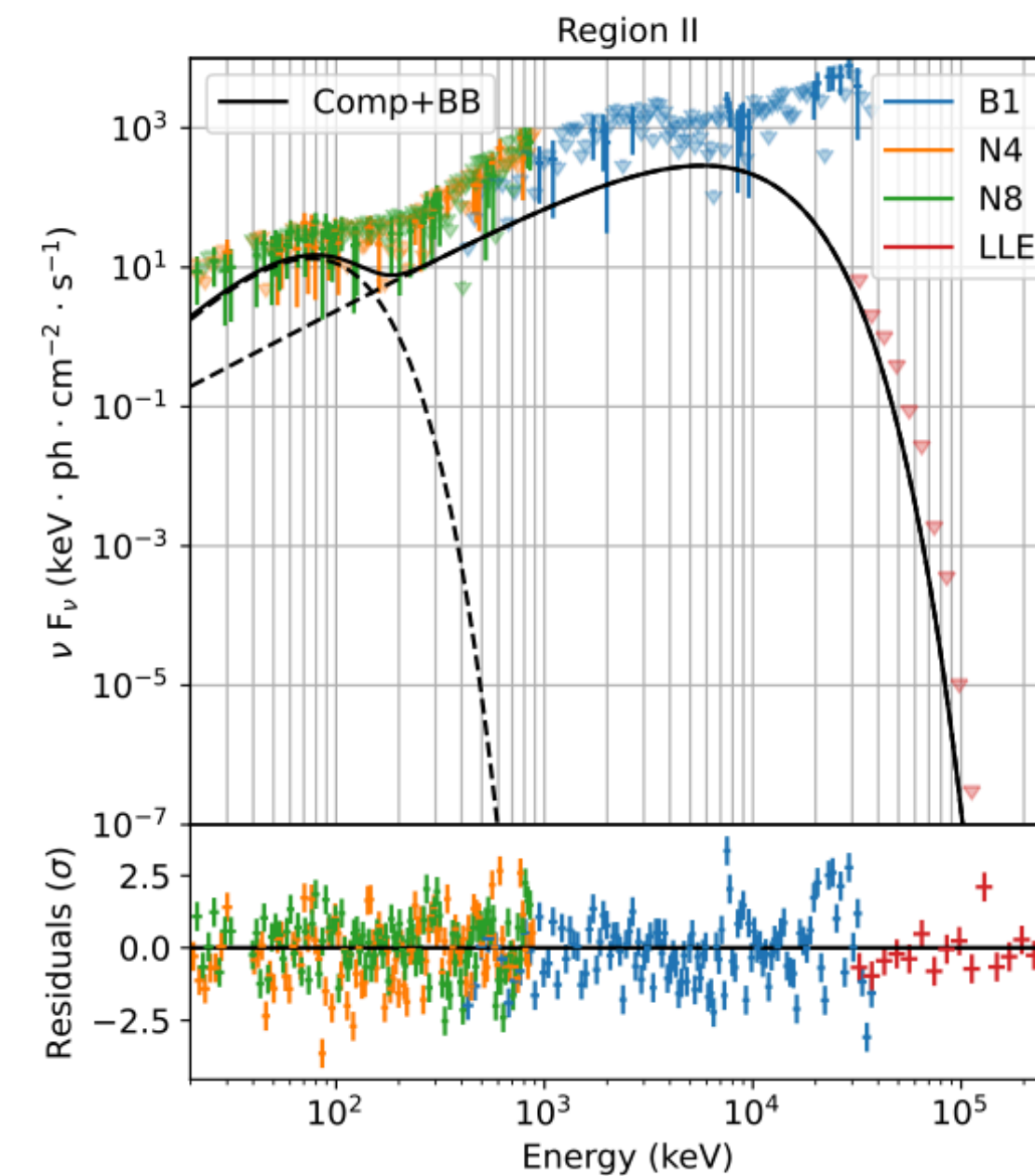
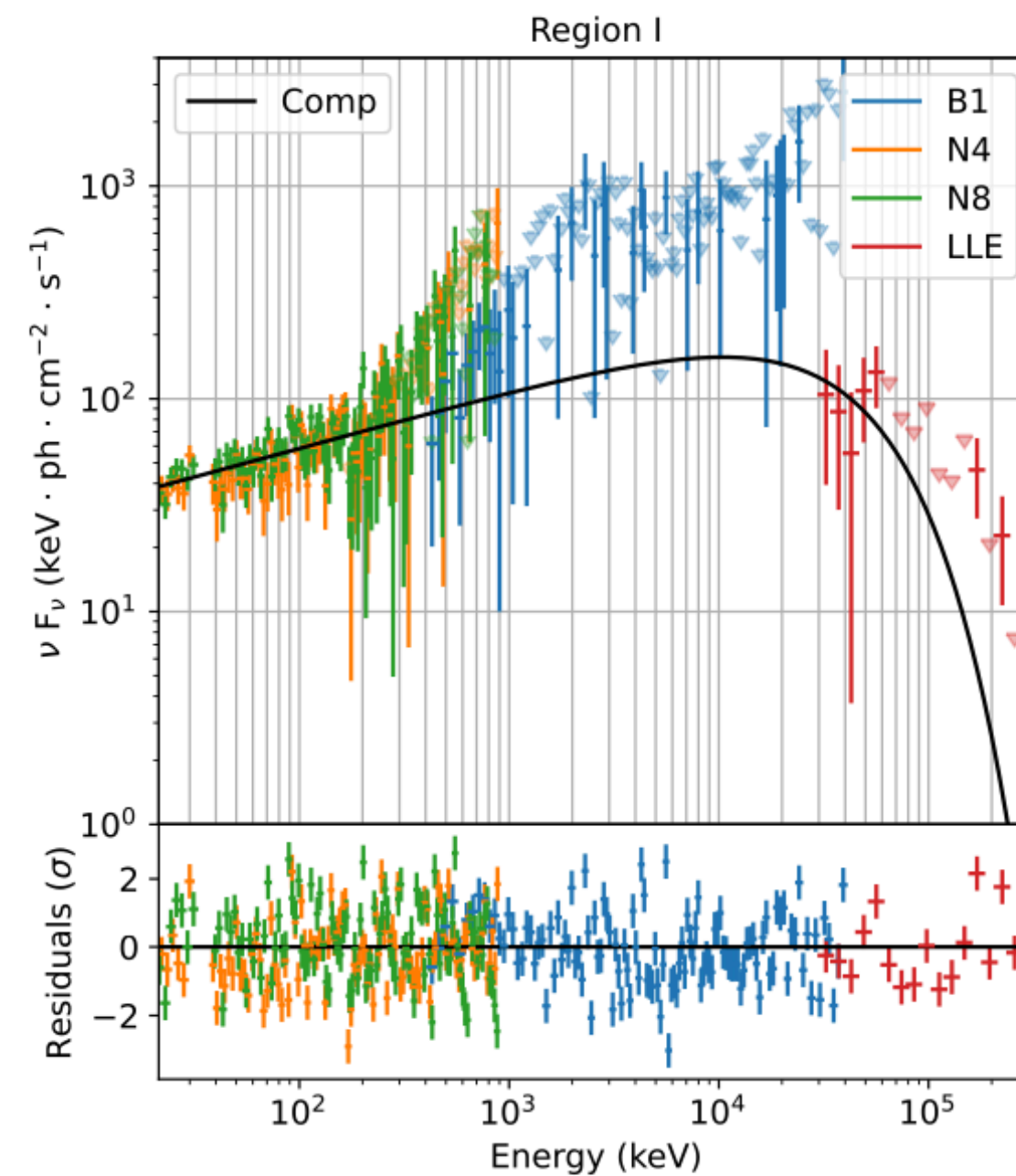
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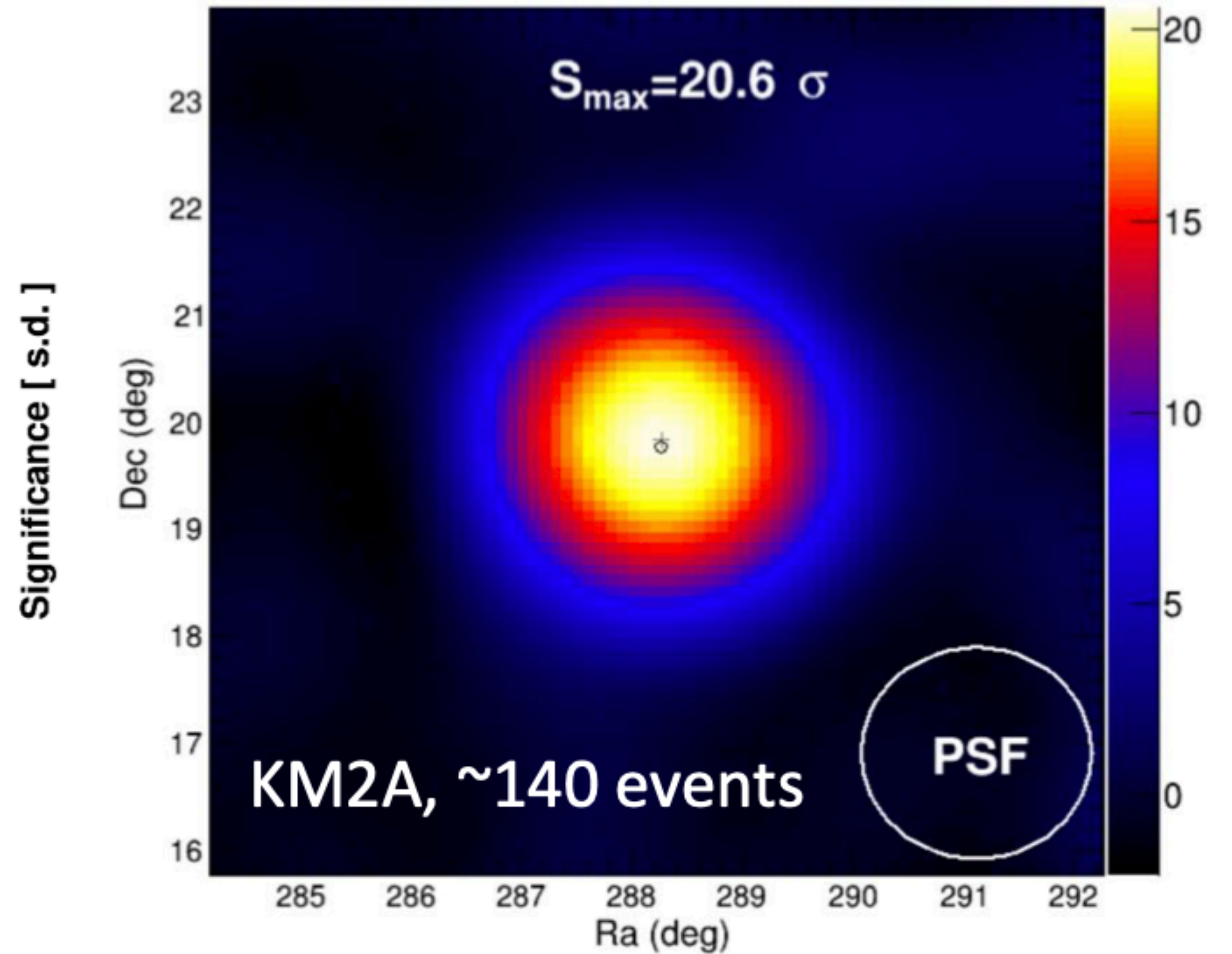
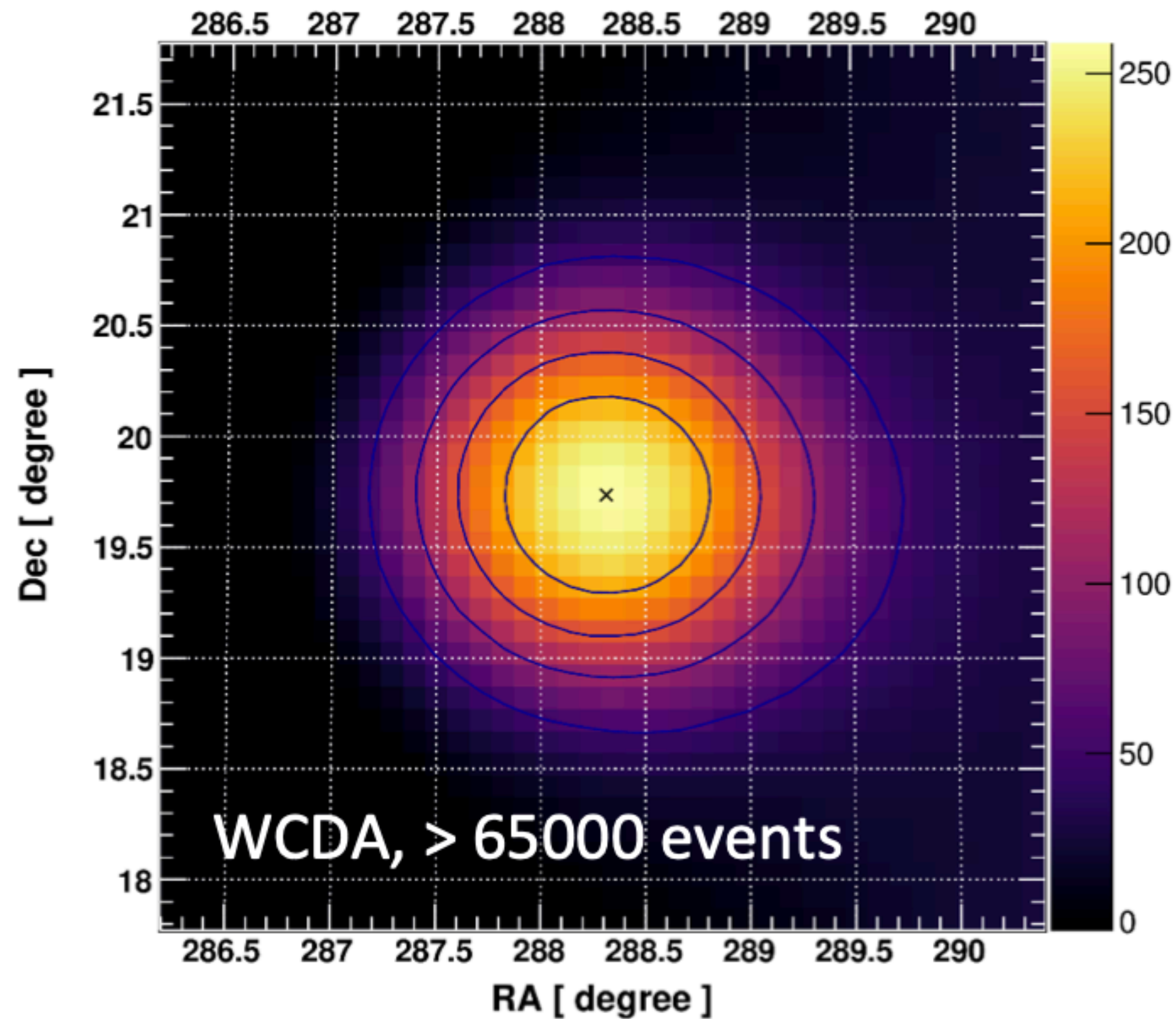
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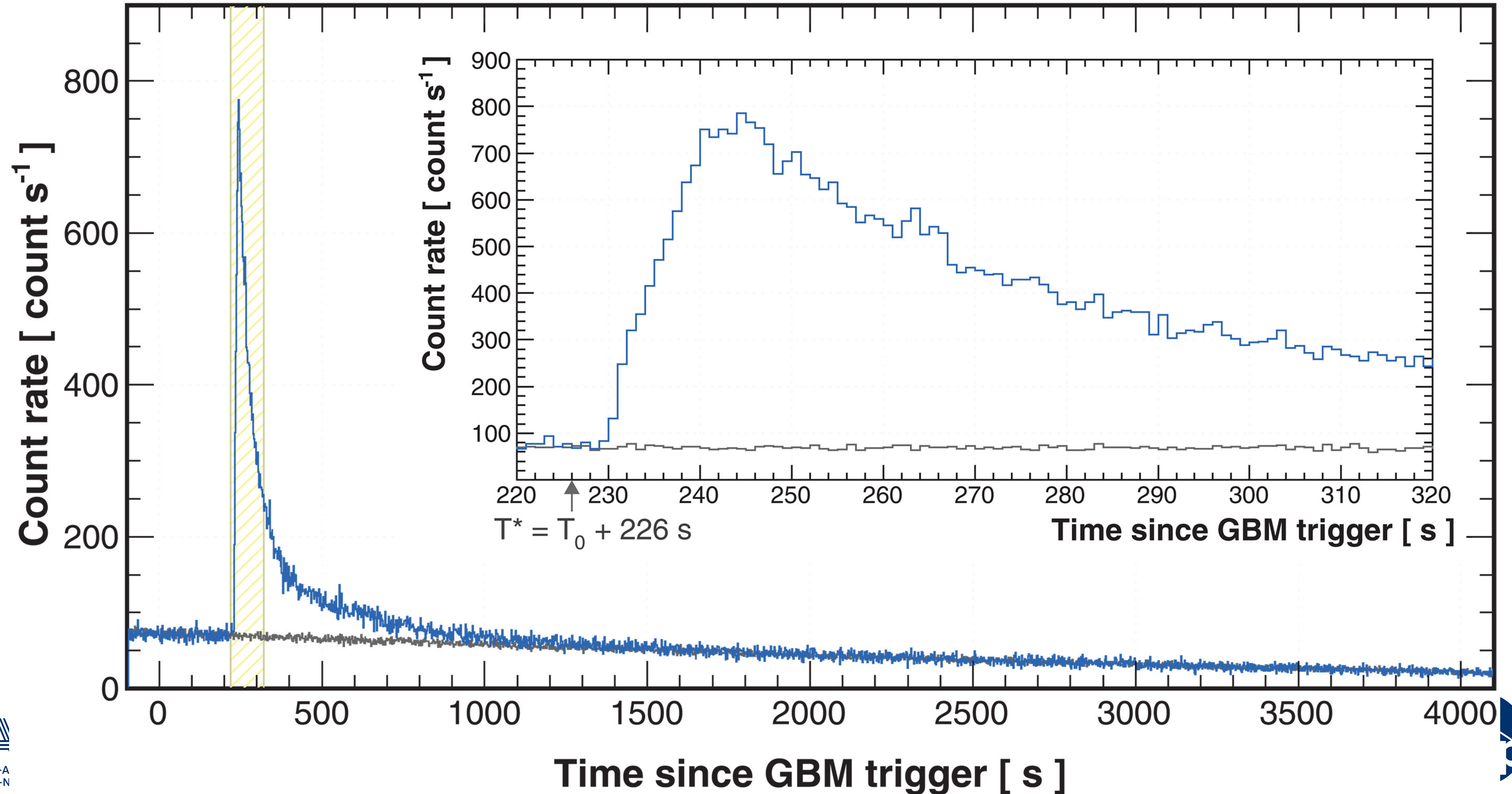


THE BOAT (BRIGHTEST OF ALL TIMES)

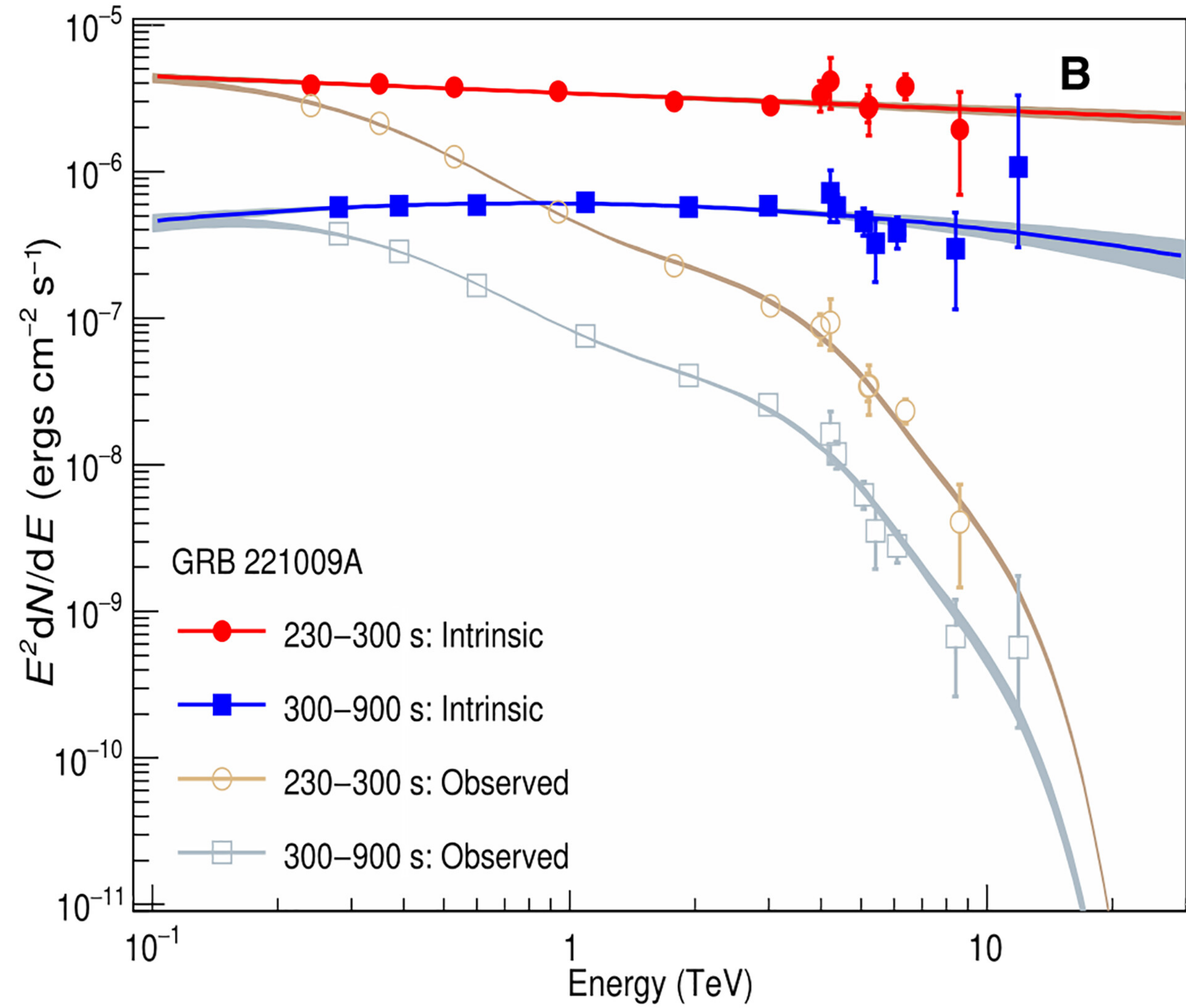
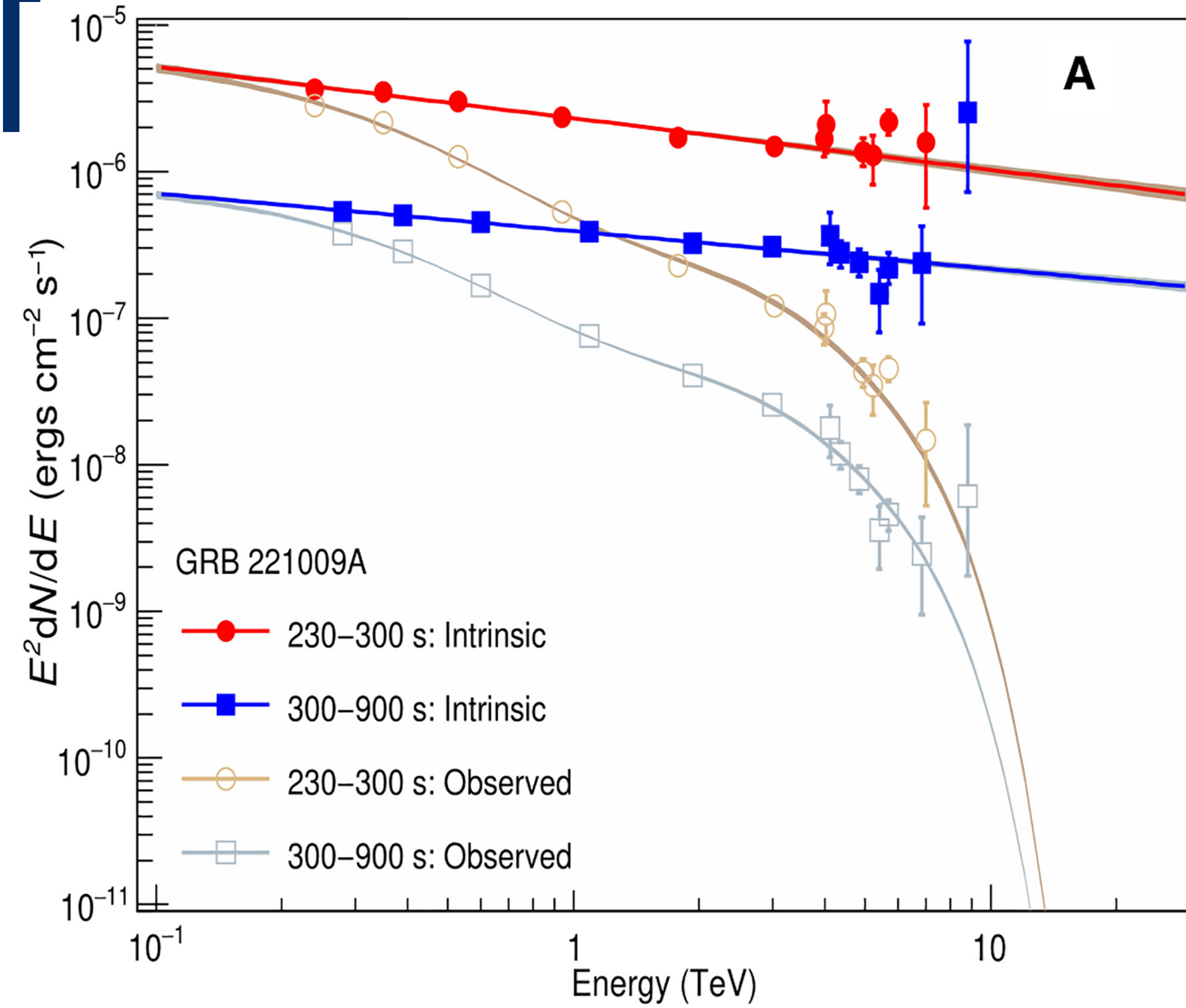
<https://www.science.org/doi/10.1126/sciadv.adj2778>



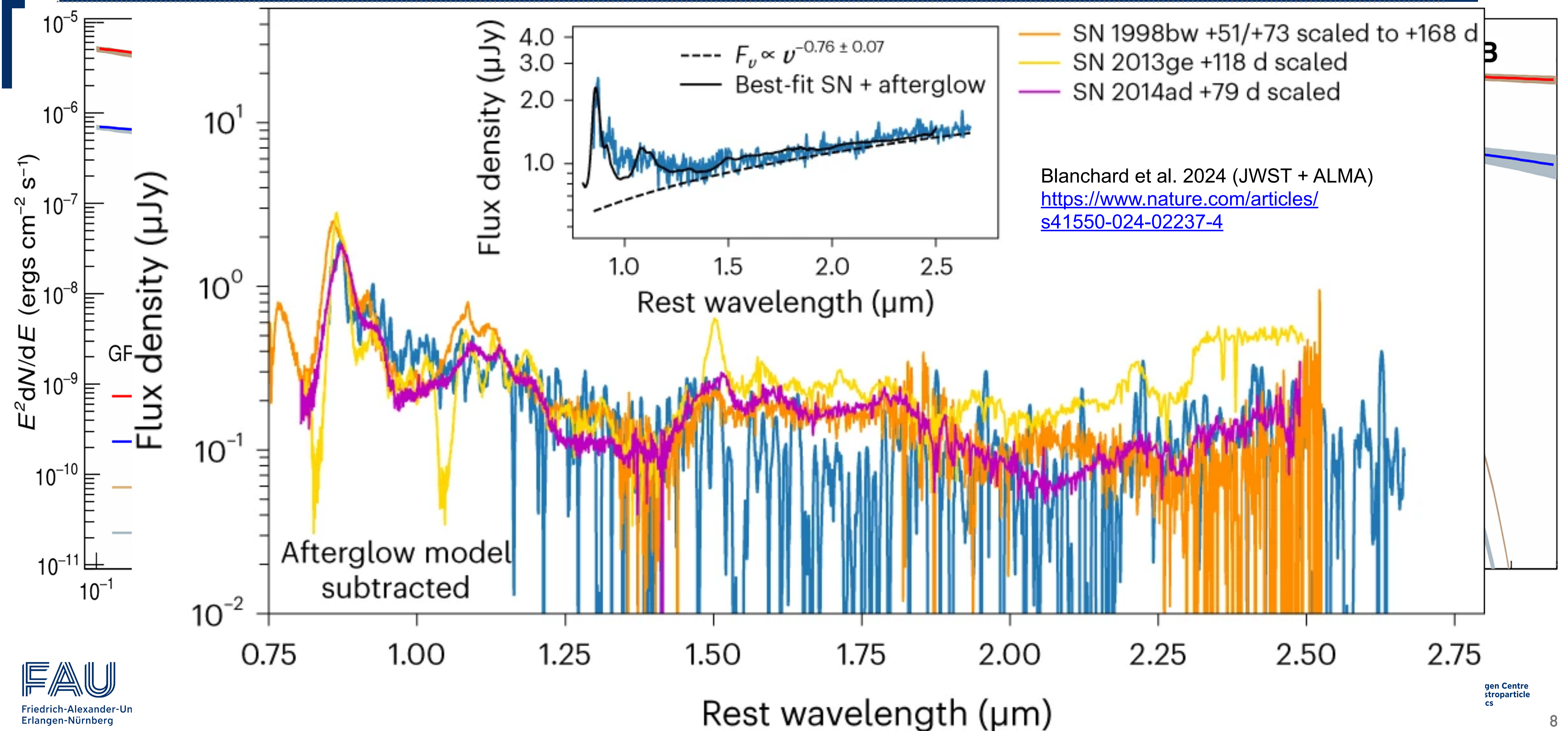
THE BOAT (BRIGHTEST OF ALL TIMES)



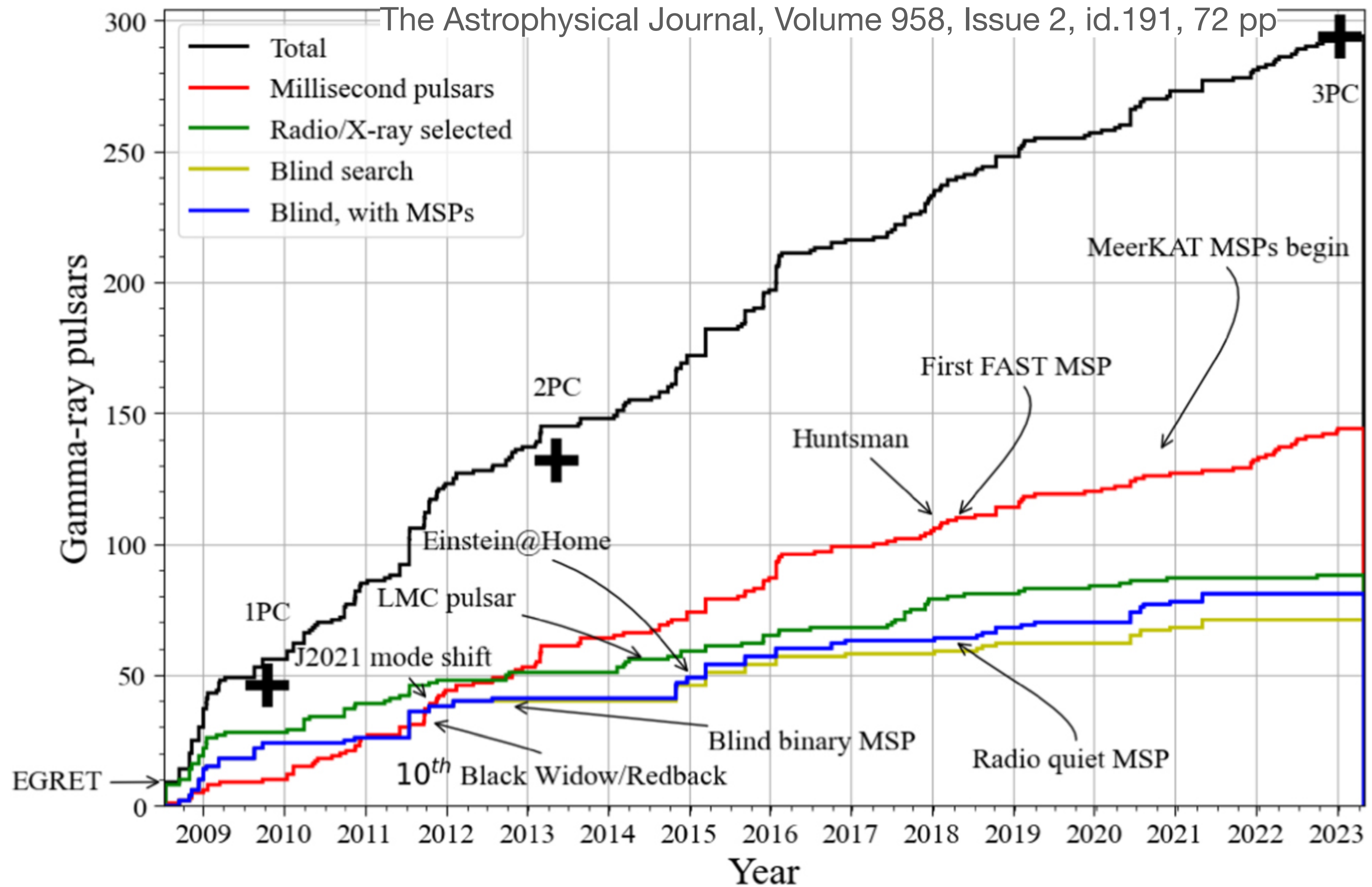
THE BOAT (BRIGHTEST OF ALL TIMES)



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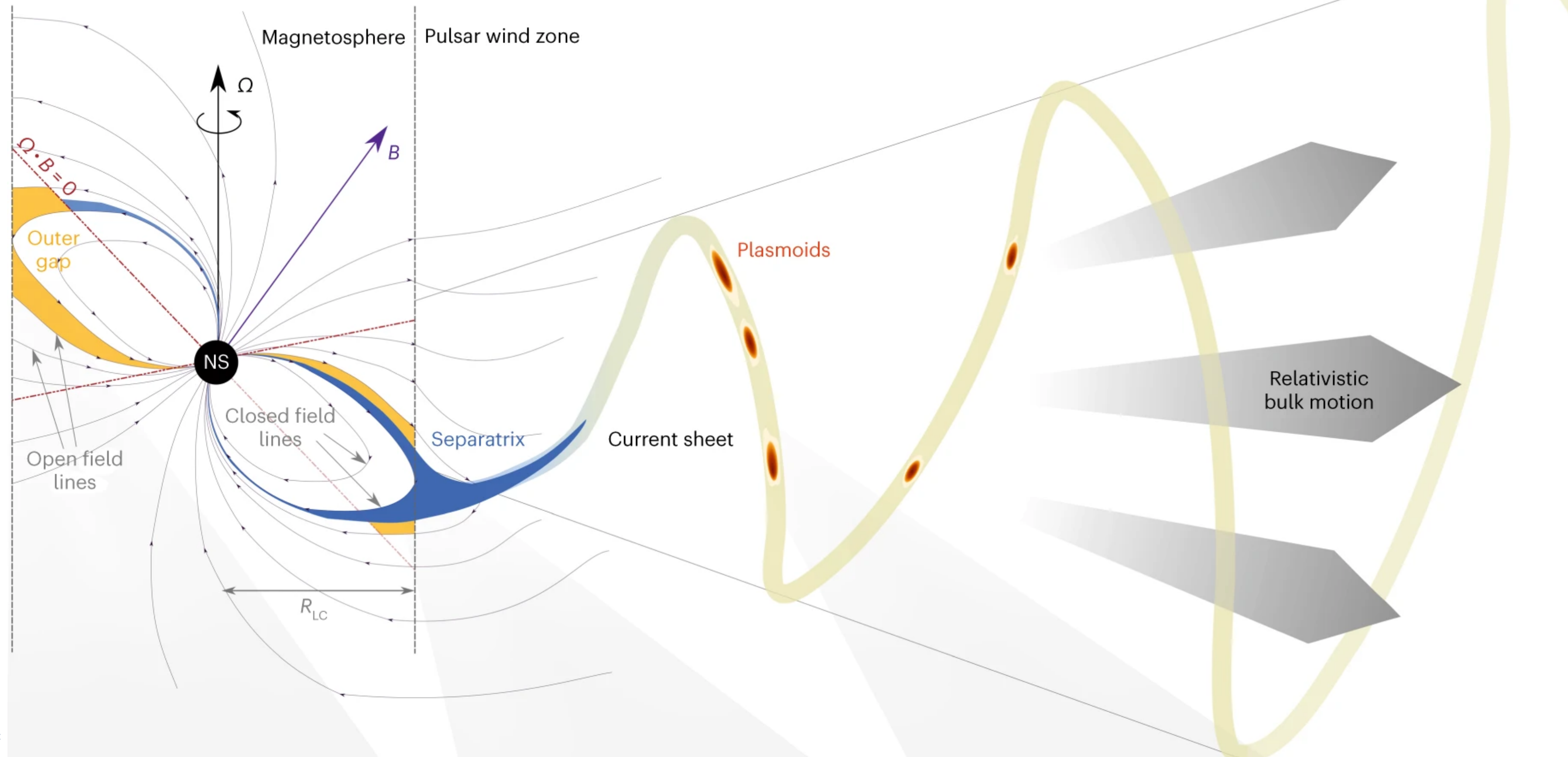


THE LAT AS A PULSAR FINDING MACHINE

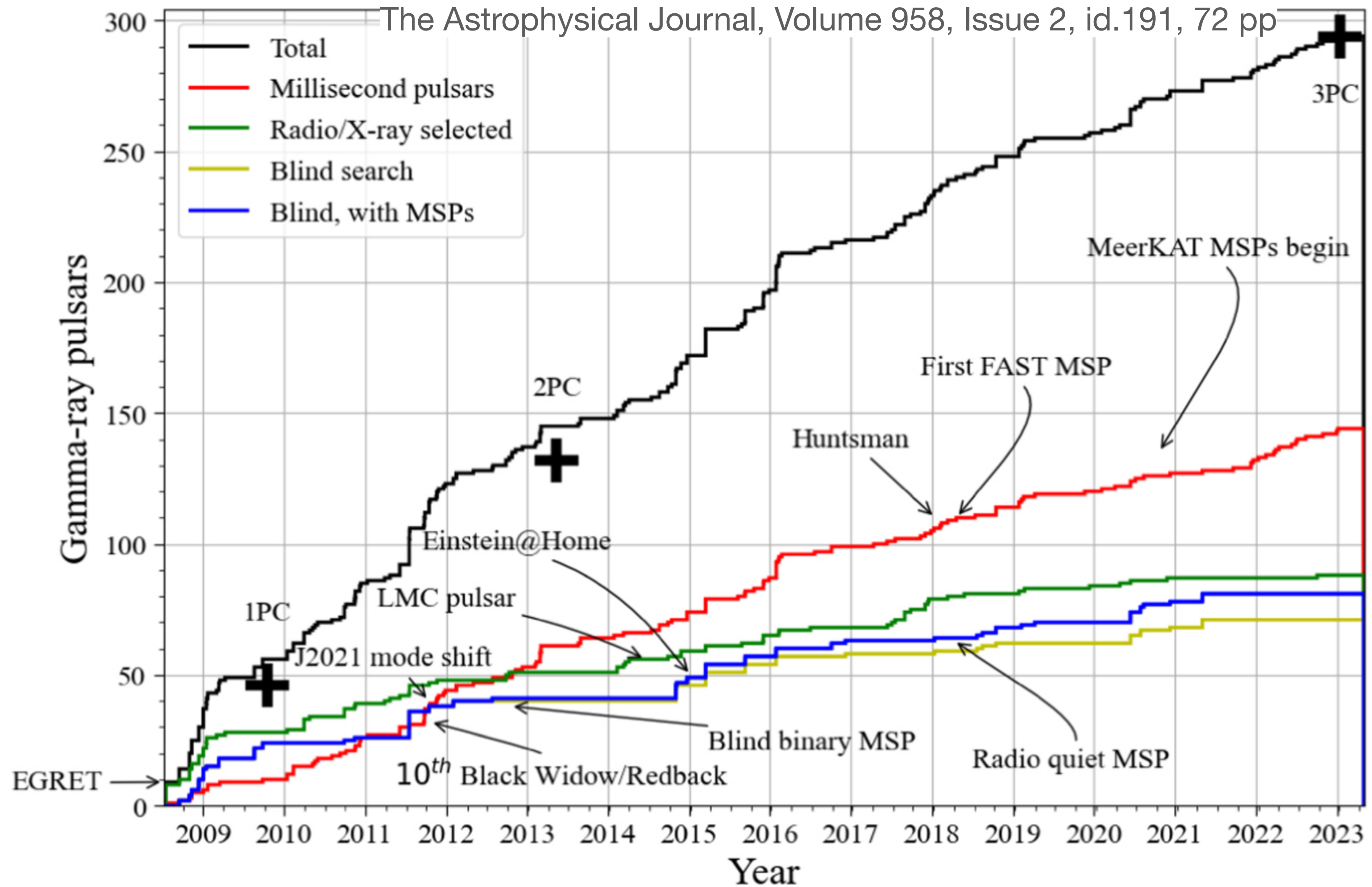


THE LAT AS A PULSAR FINDING MACHINE

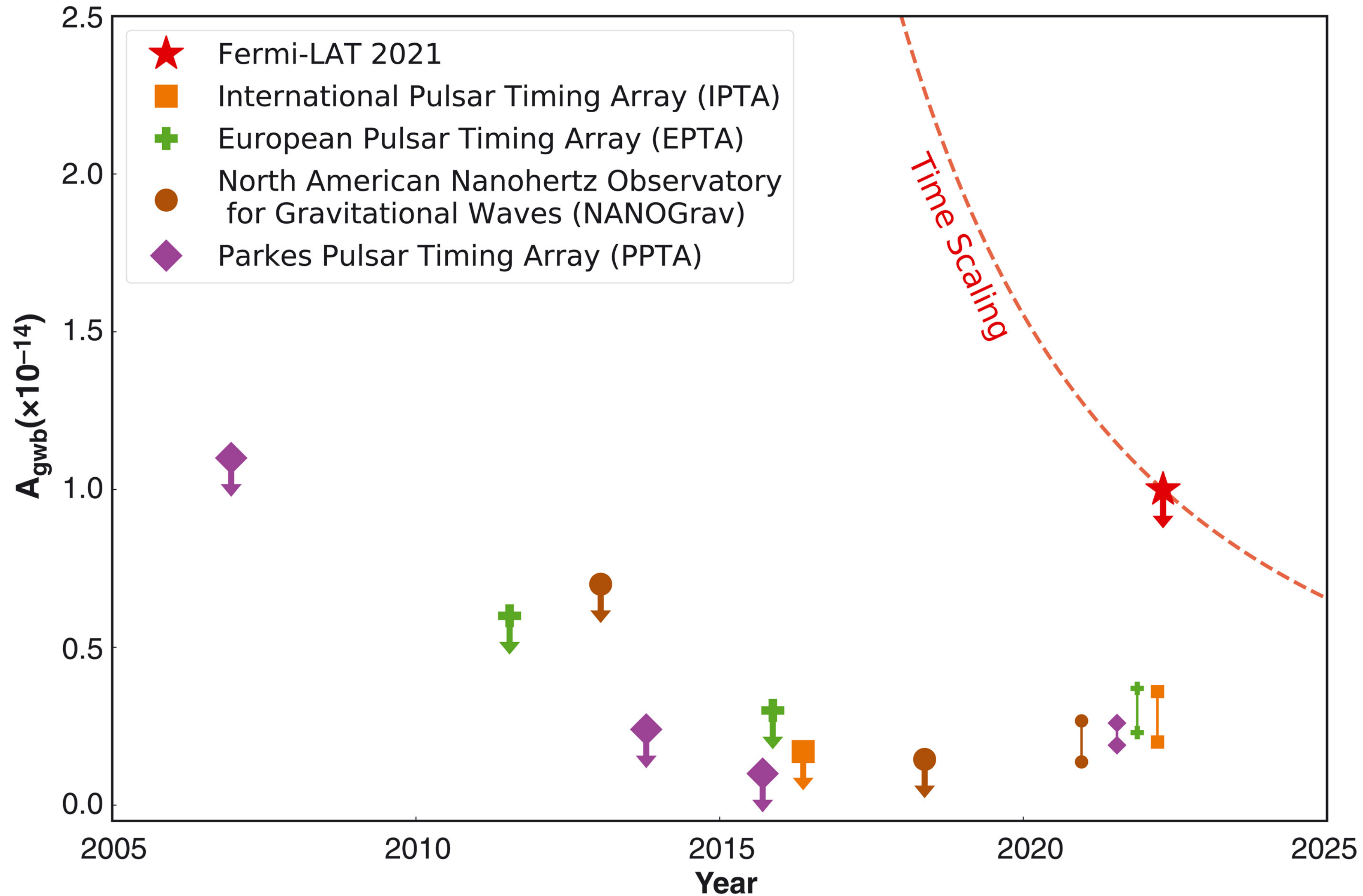
<https://www.nature.com/articles/s41550-023-02052-3/figures/4>

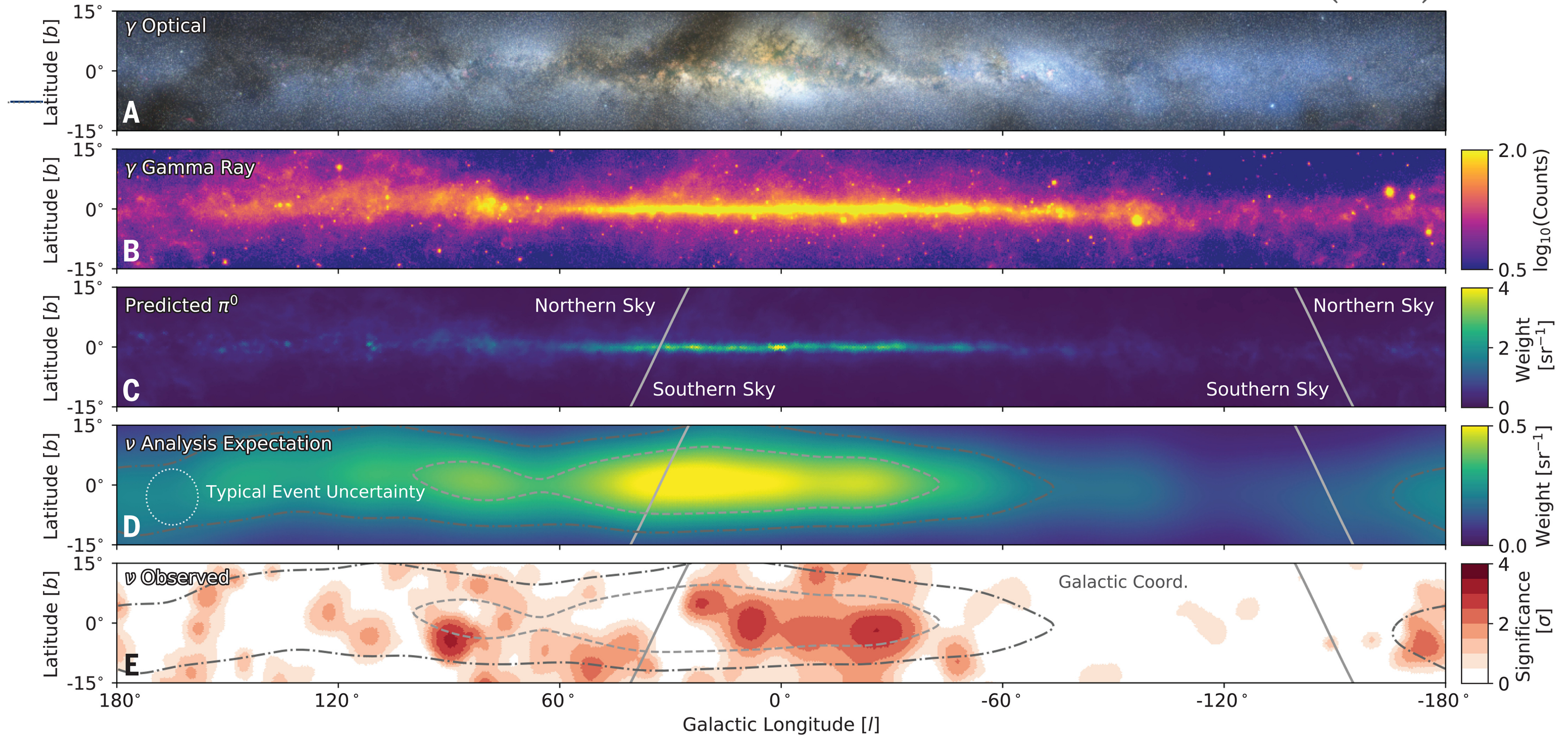


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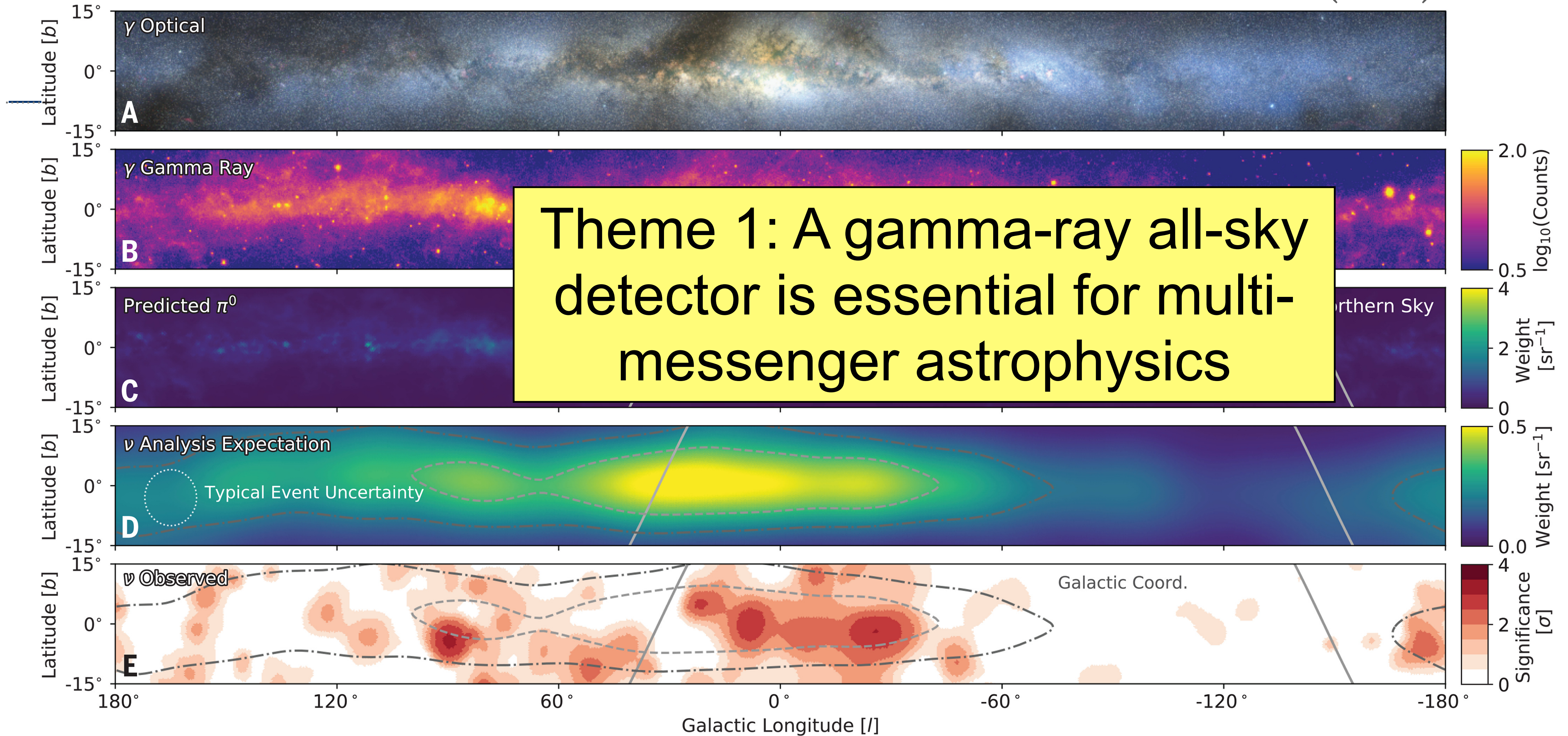


THE LAT AS A PULSAR FINDING MACHINE



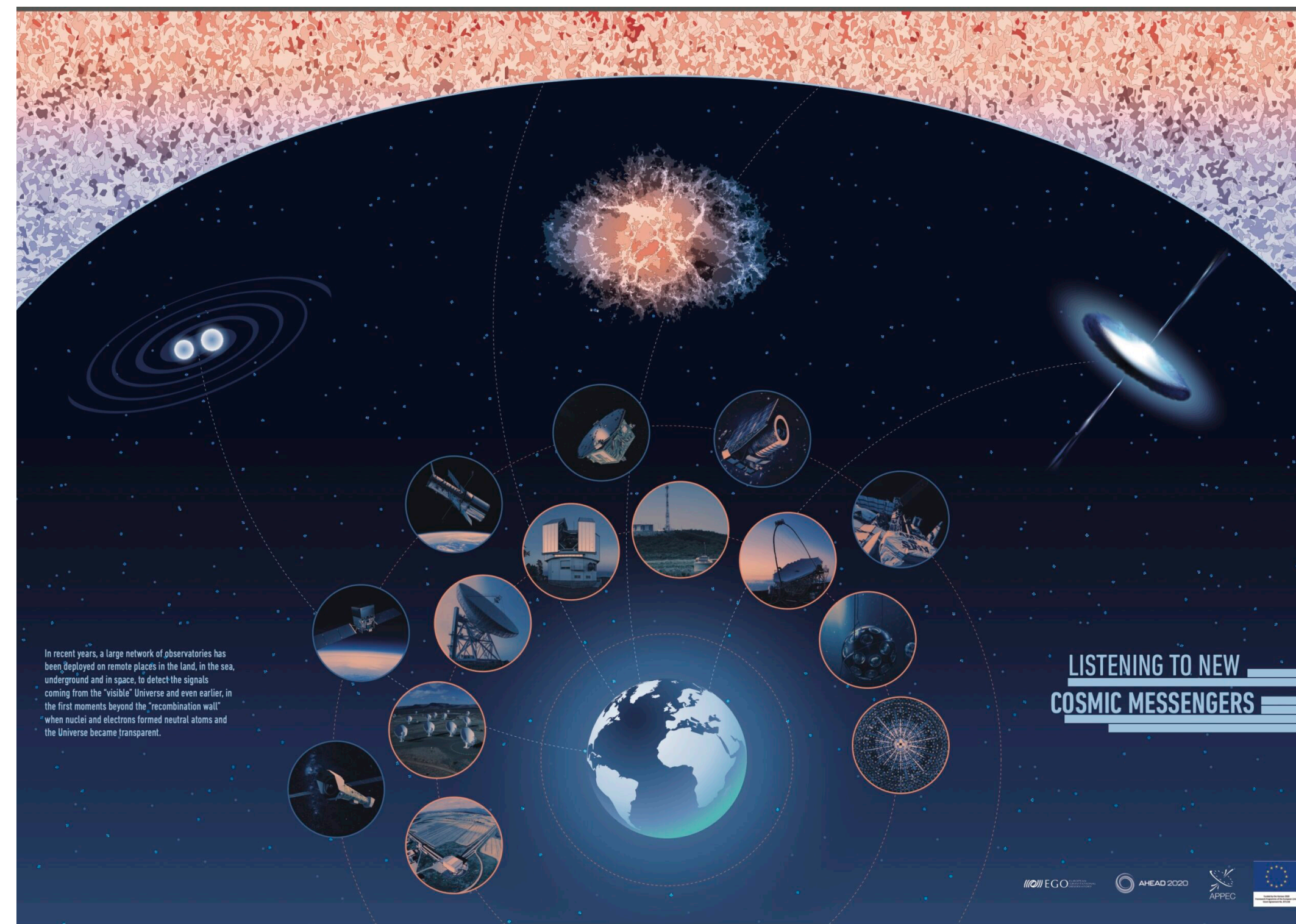


- Detection of the Galactic Plane in neutrinos – at 4.5σ in 10 years of IceCube data.
- No significant associations with known VHE gamma-ray sources (yet)

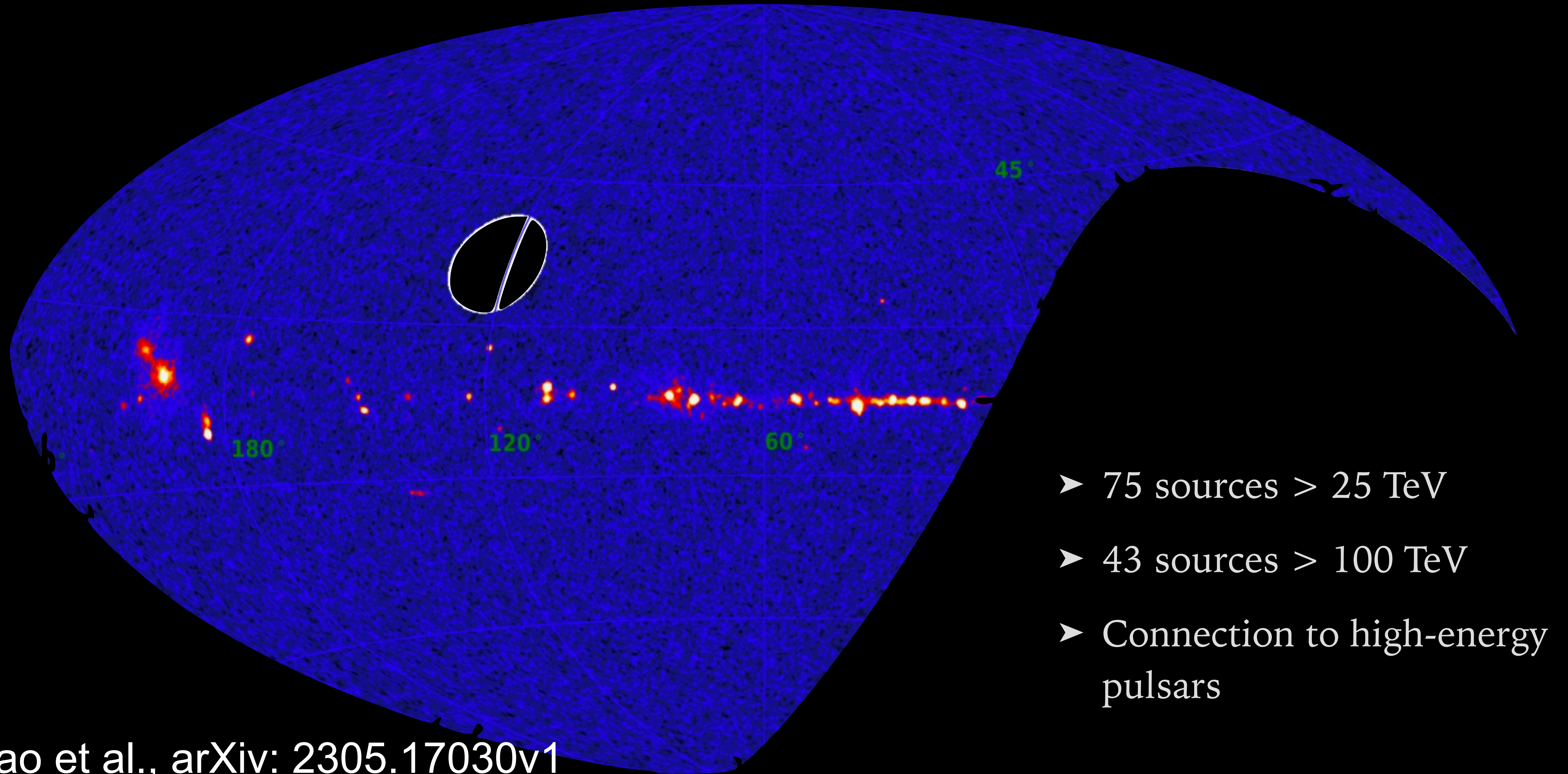


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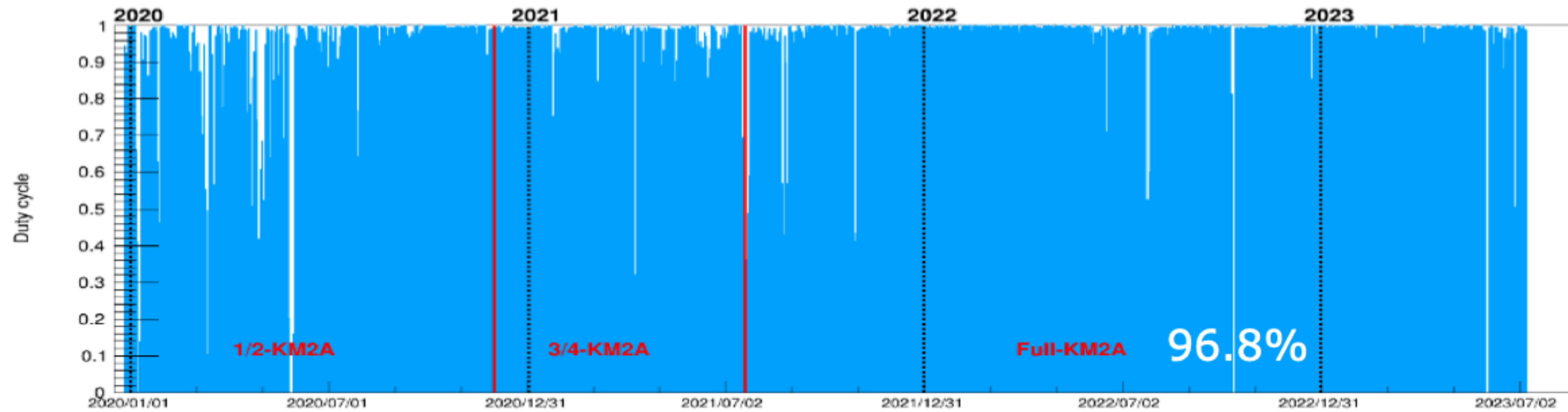
Multi-instrument synergies on the ground



LHAASO SKY AT >25 TEV ENERGIES

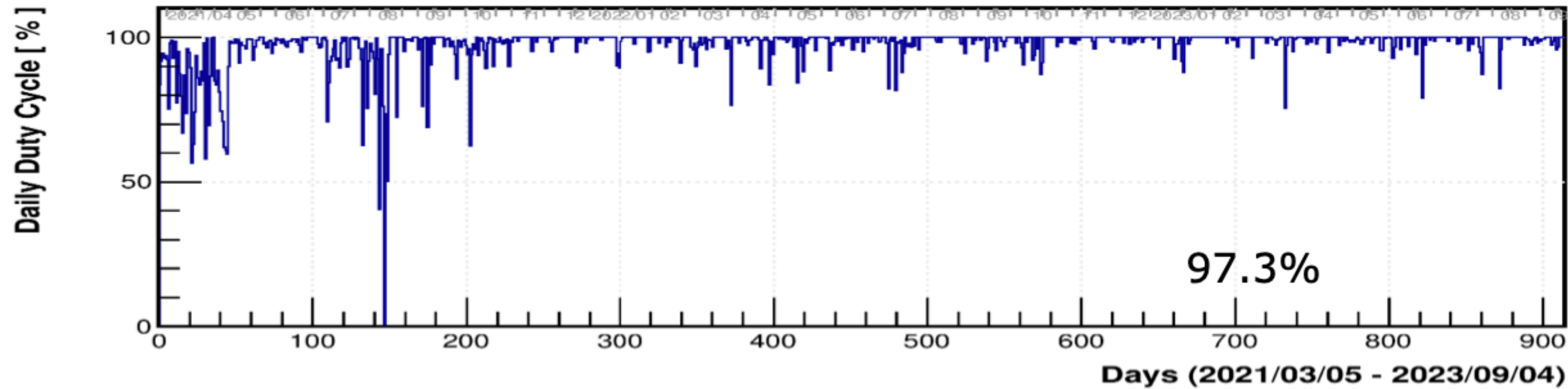


LHAASO PROPERTIES



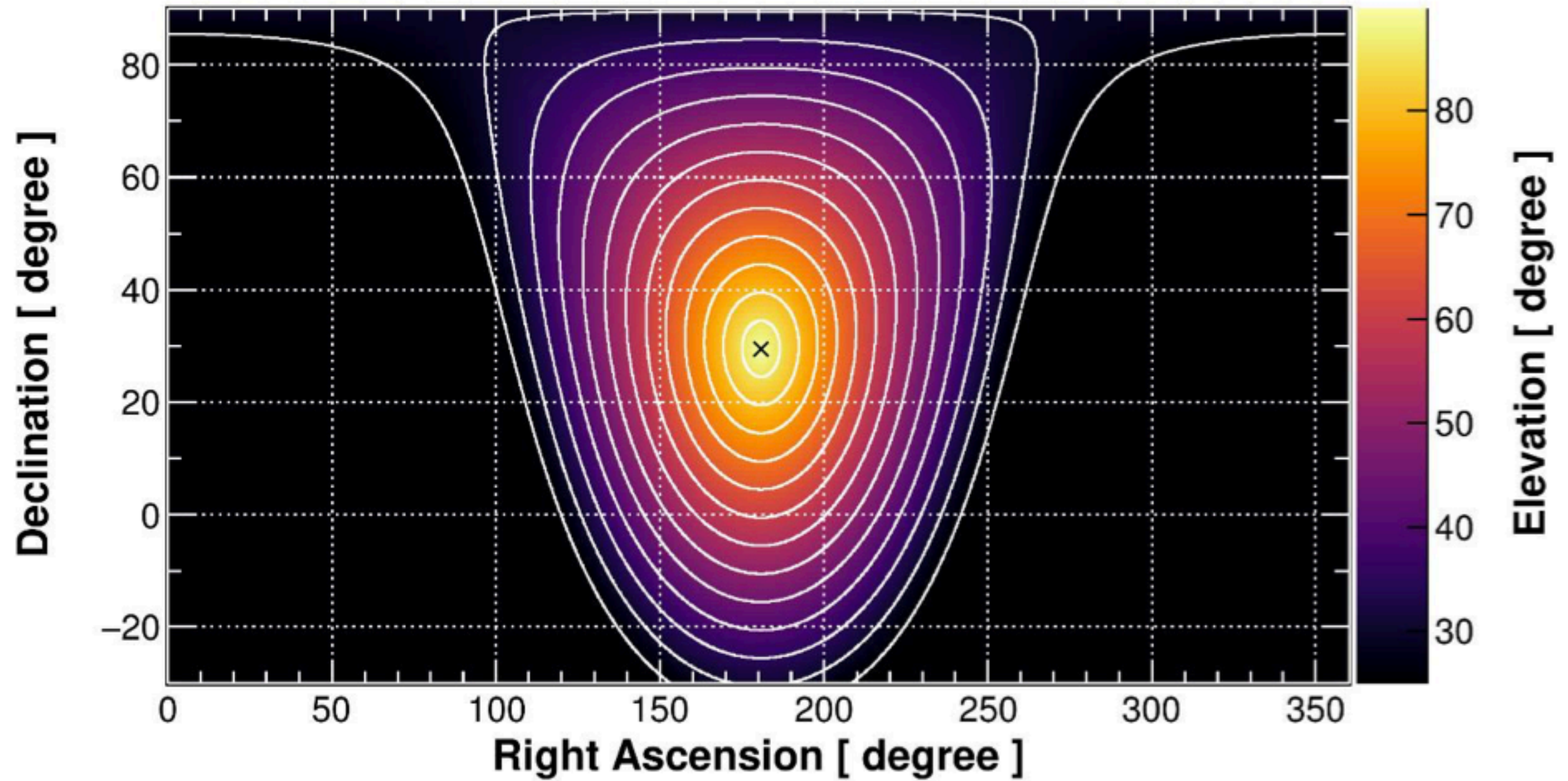
KM2A

Overall Duty Cycle = 97.37%



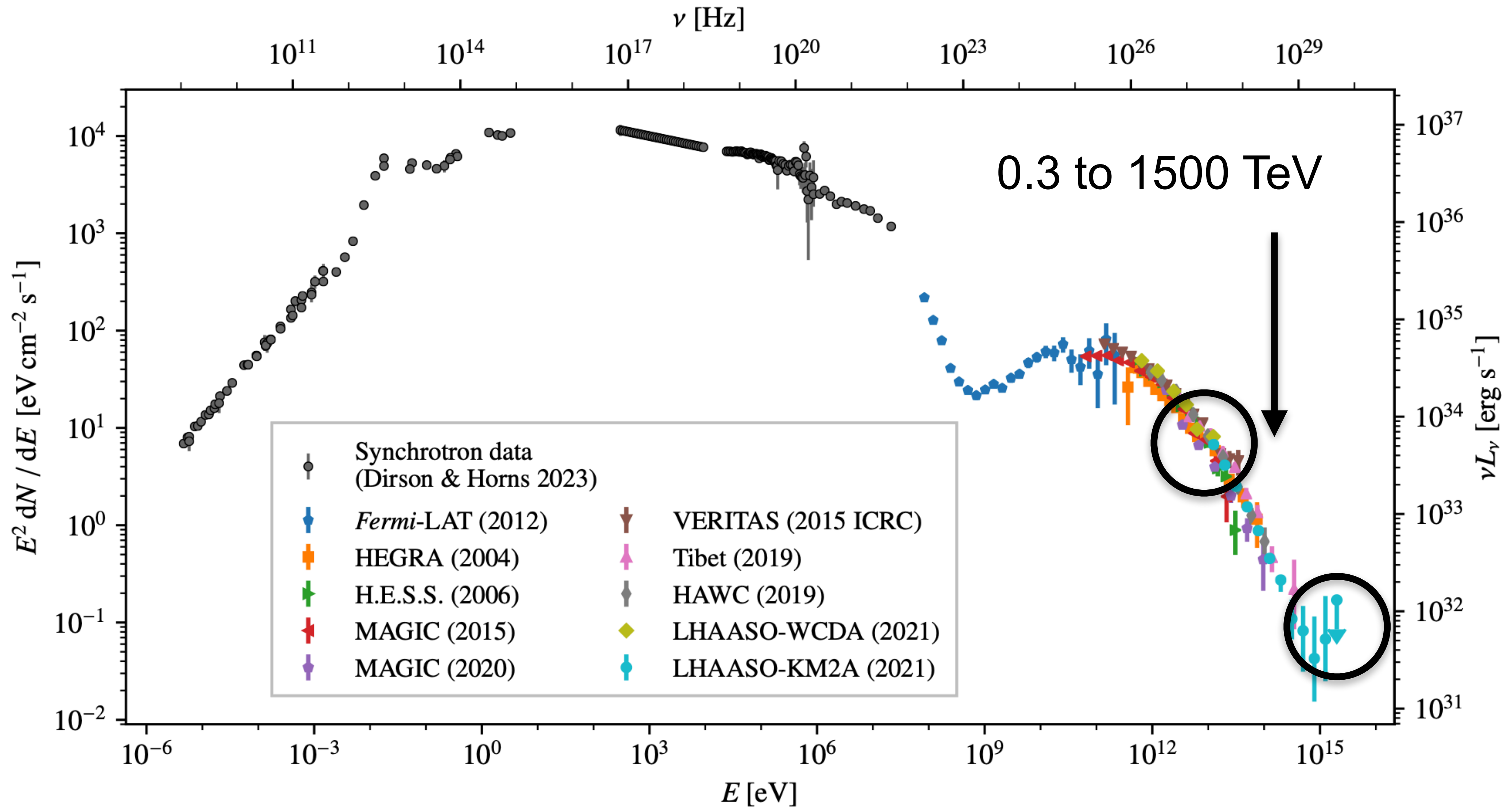
WCDA

LHAASO PROPERTIES



Instant FOV

LHAASO PROPERTIES

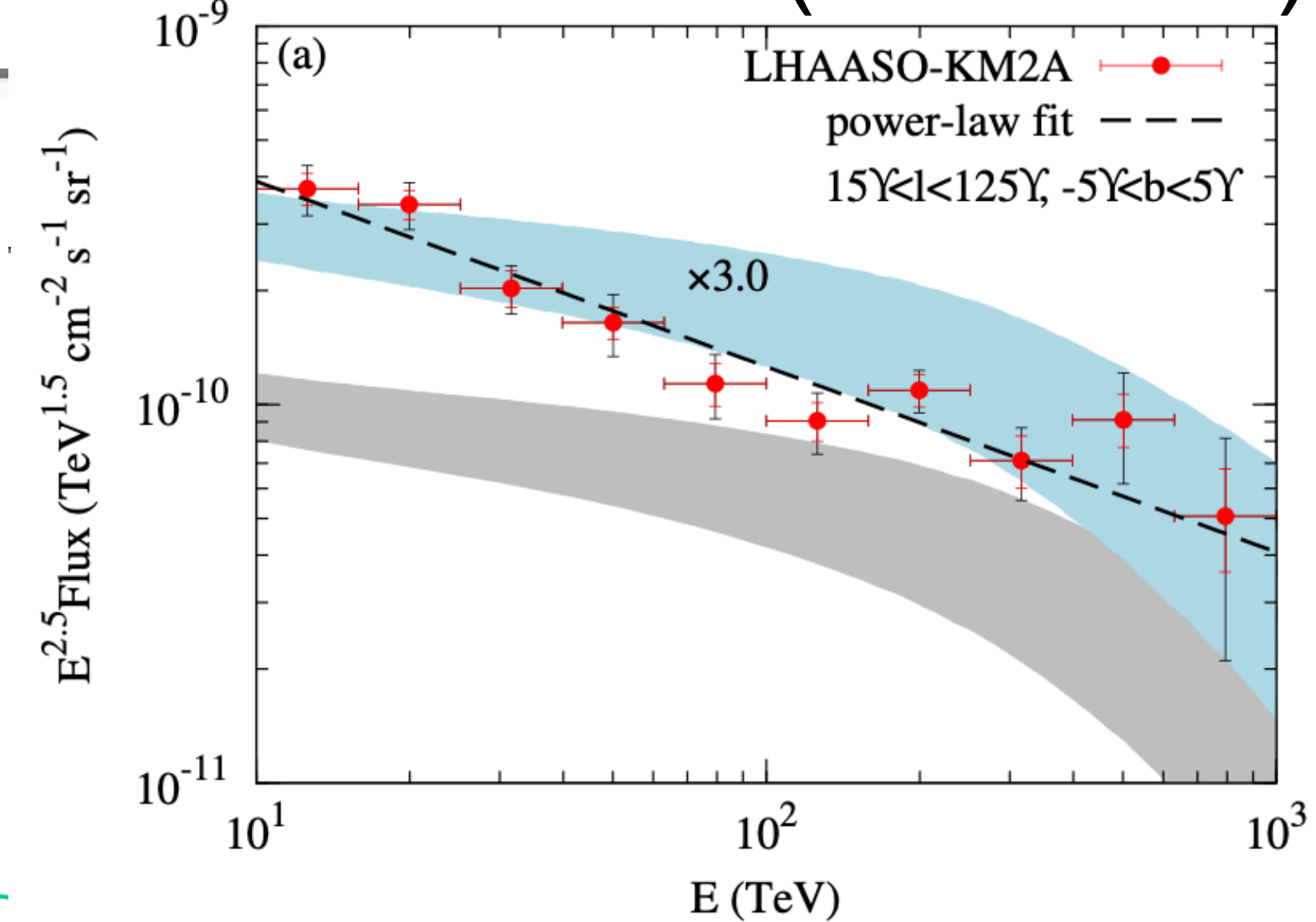
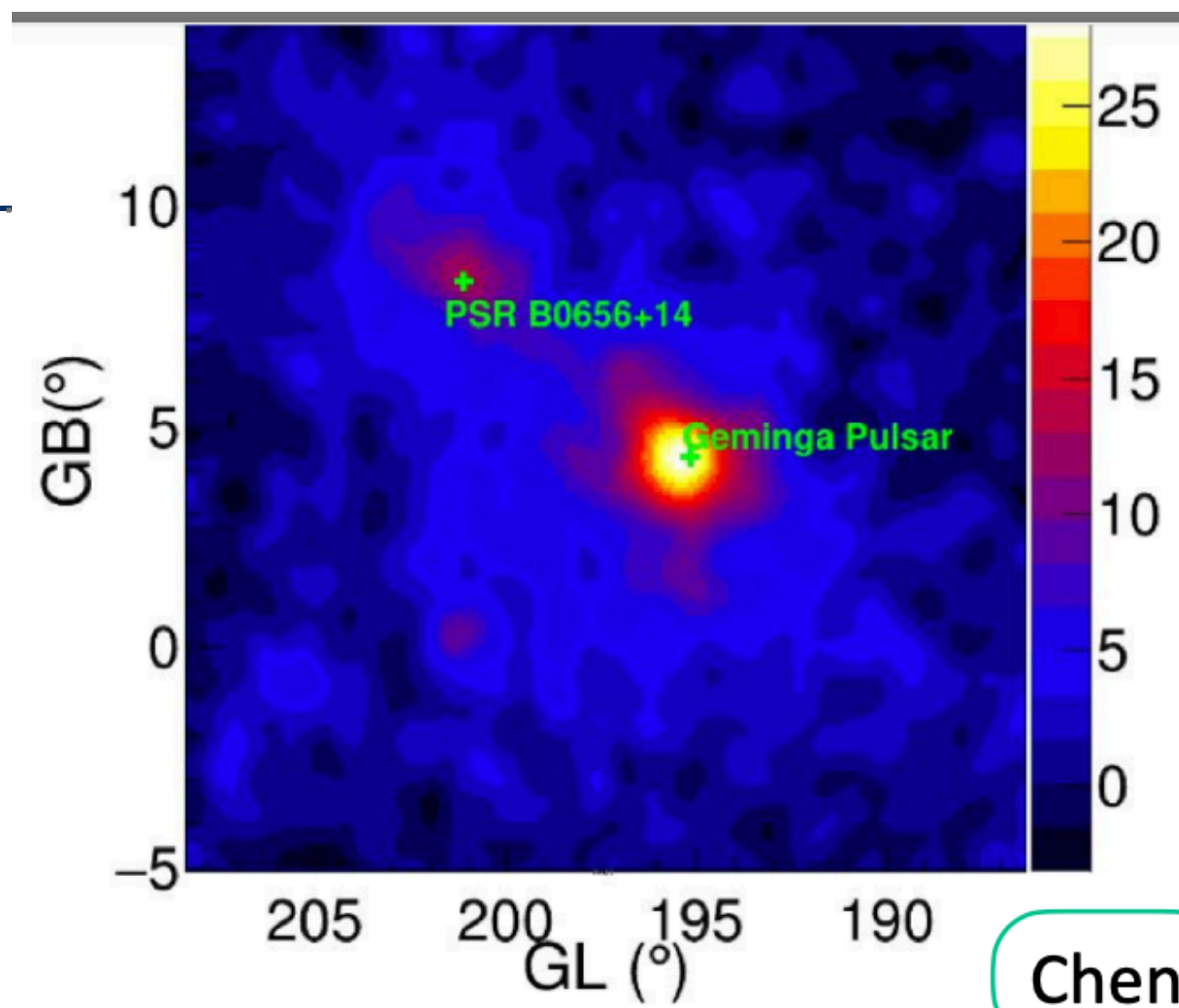
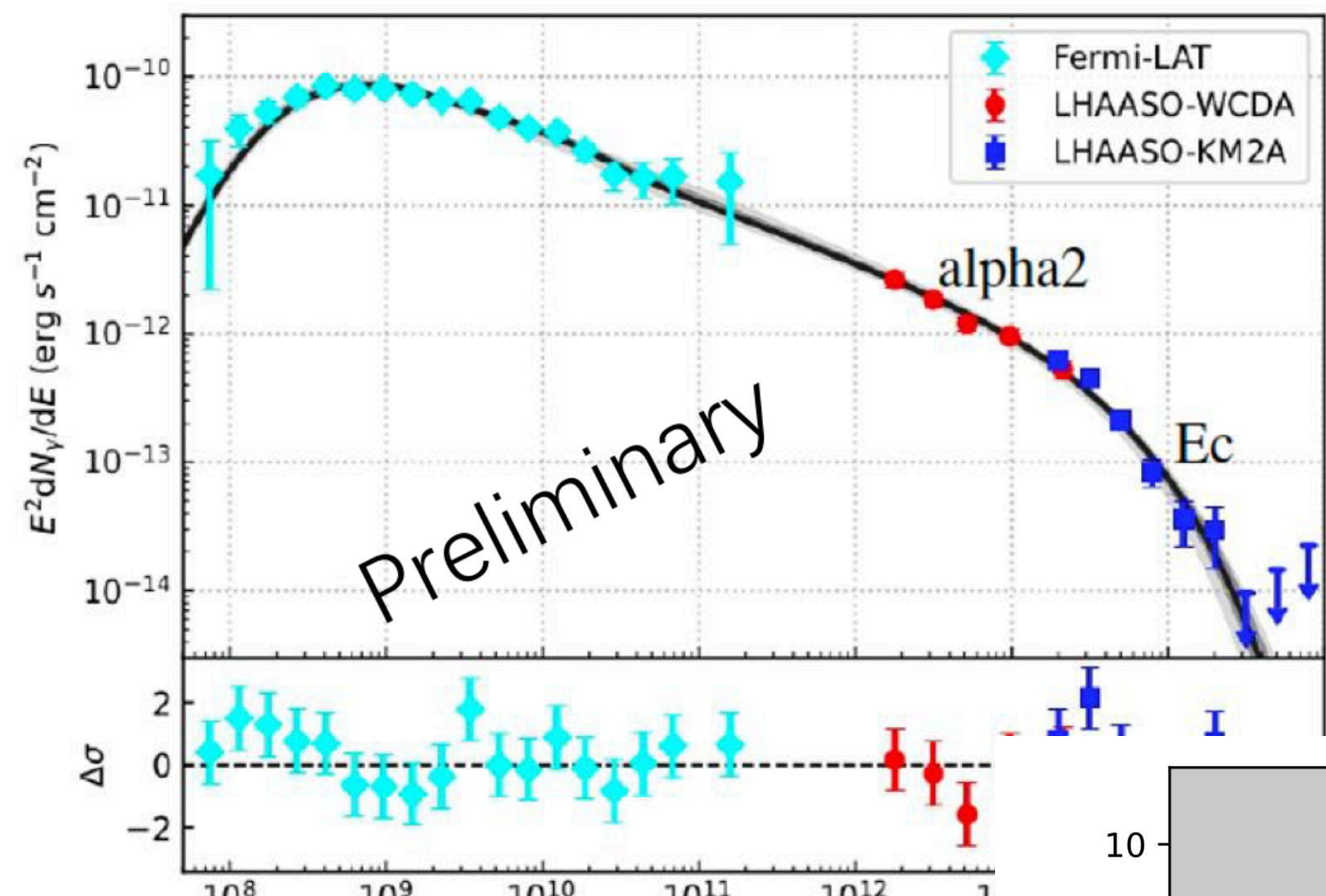


LOTS OF INTERESTING PHYSICS

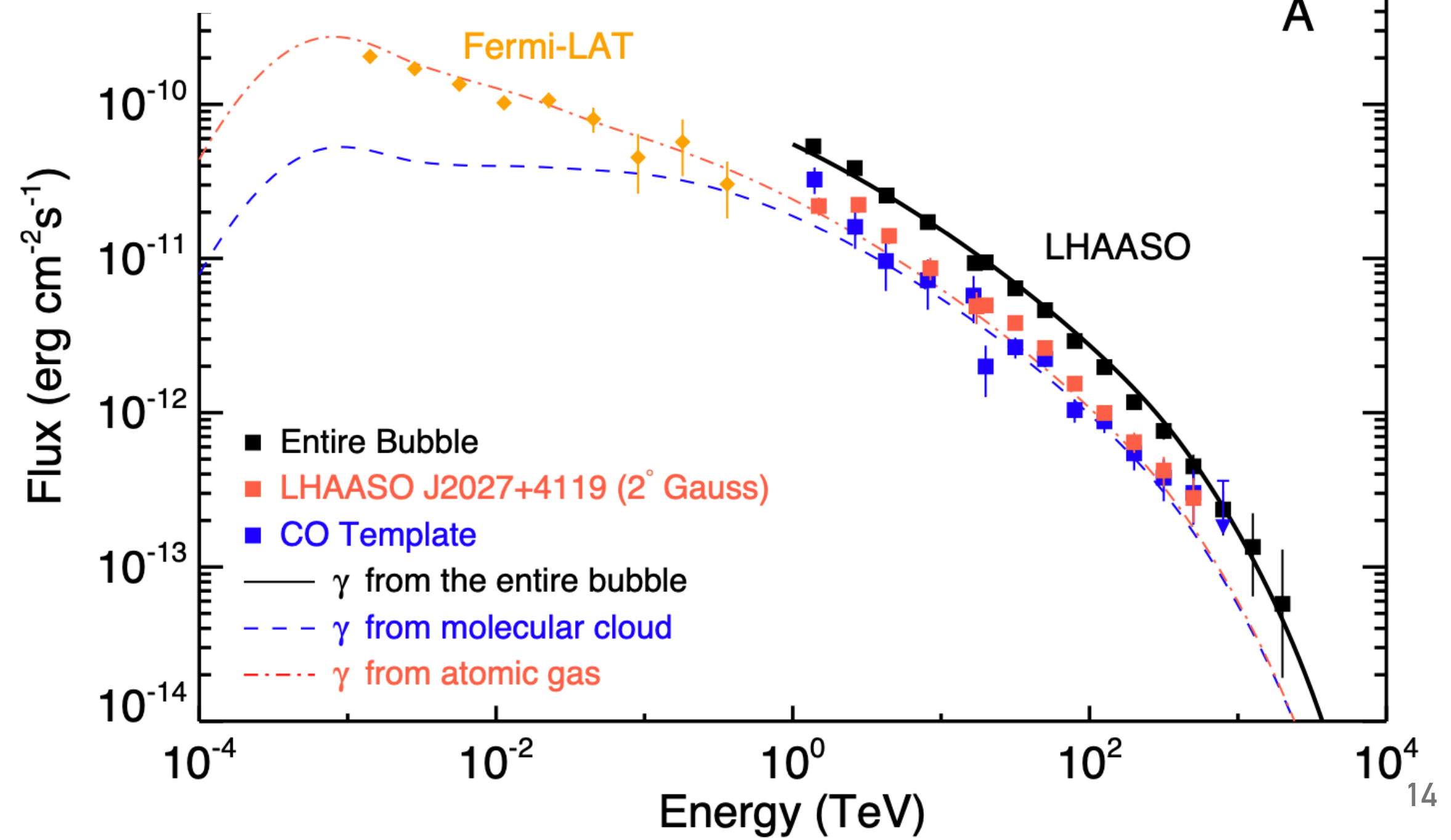
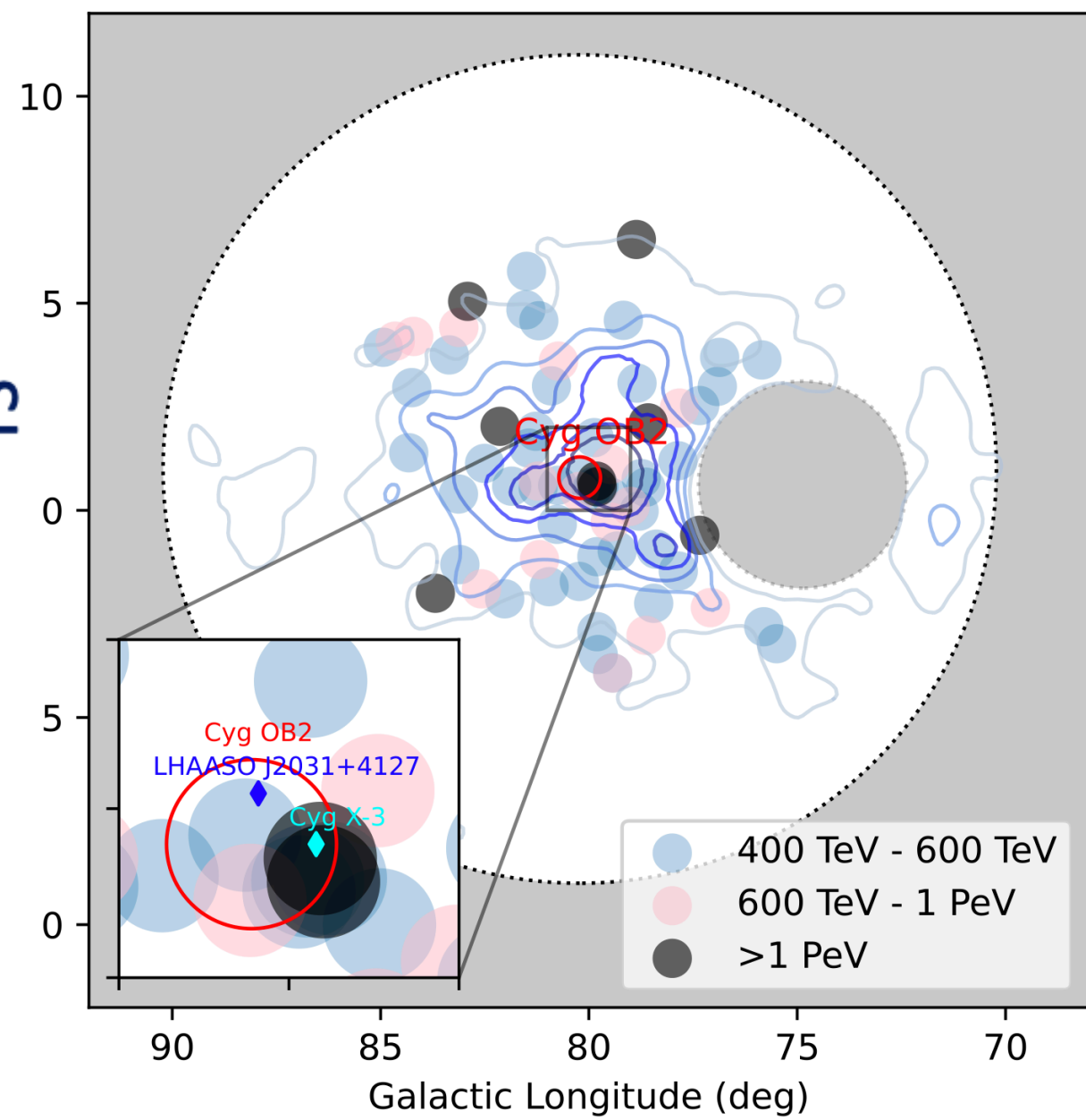
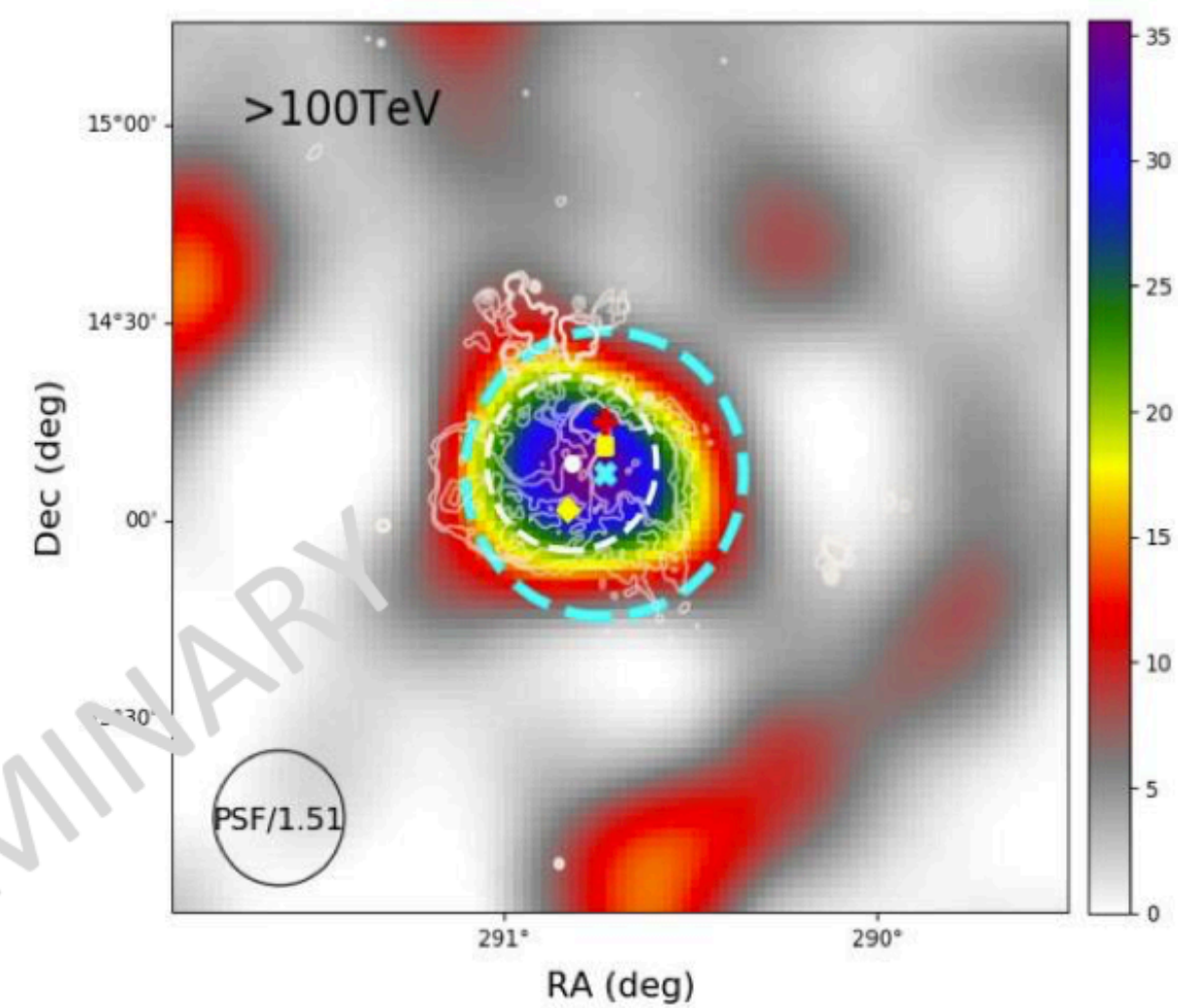
Geminga (Chen et al.)

Galactic diffuse (Cao et al.)

W 51C (Chen et al.)



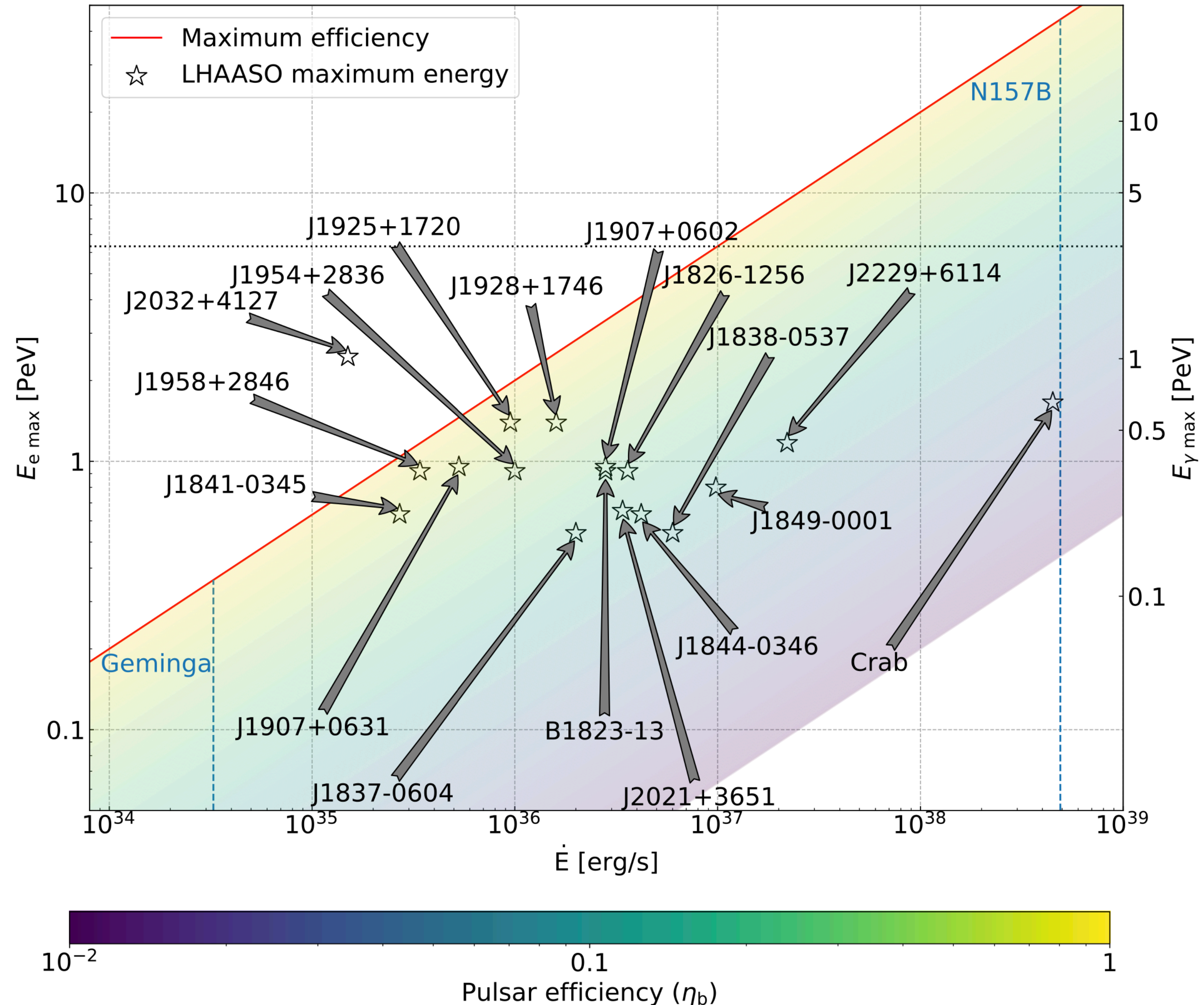
Cygnus cocoon (Cong Li et al.)



WHAT DOES THAT TELL US?

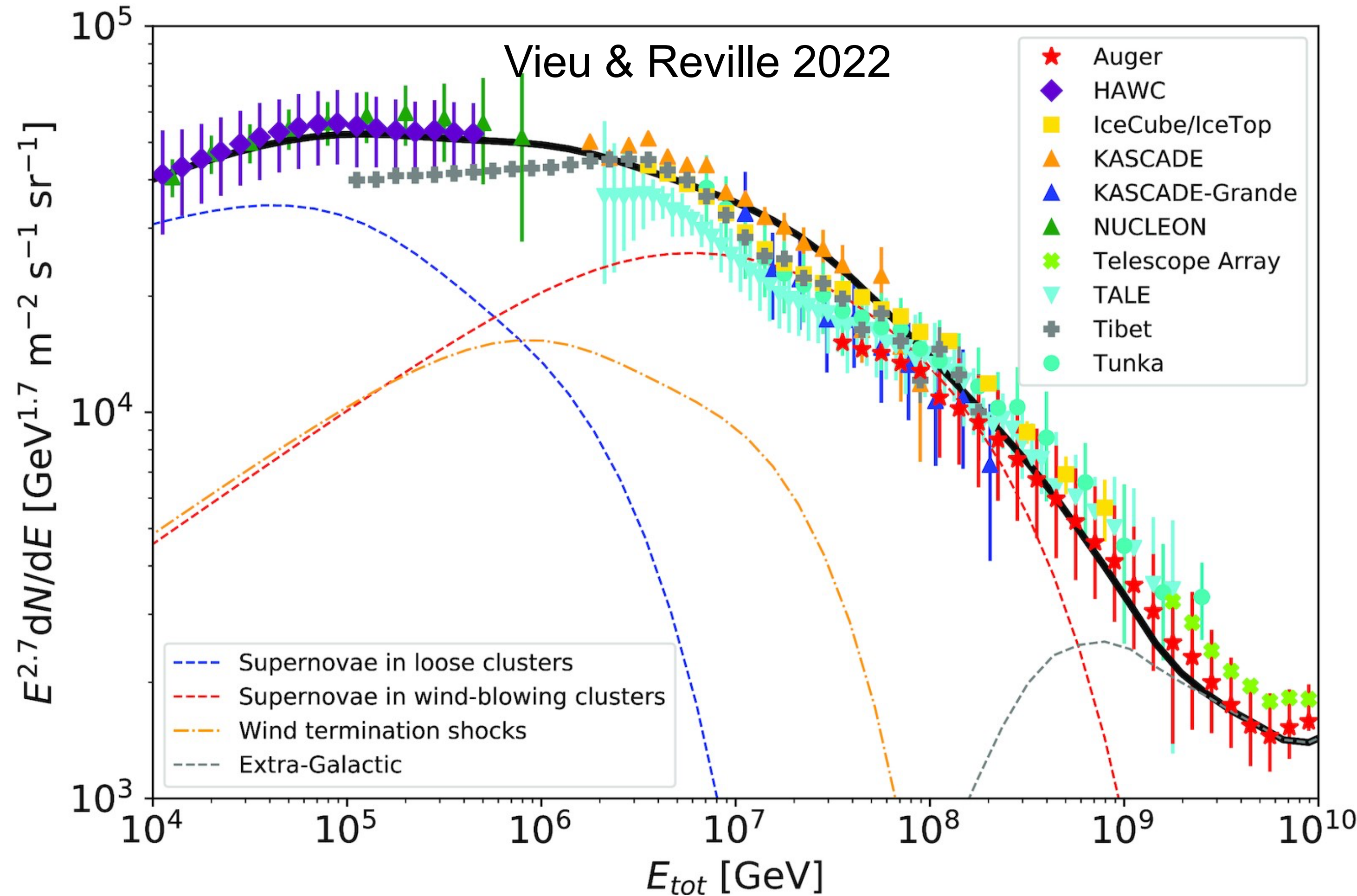
- Pulsar Wind Nebulae
 - Likely leptonic (IC > 100 TeV in radiation dominated environments possible (Breuhaus et al. 2021))
 - Acceleration to the maximum potential drop (de Oña Wilhelmi et al. 2022)
 - Hadronic component possible at the few % level (LHAASO)

de Oña Wilhelmi et al. 2022

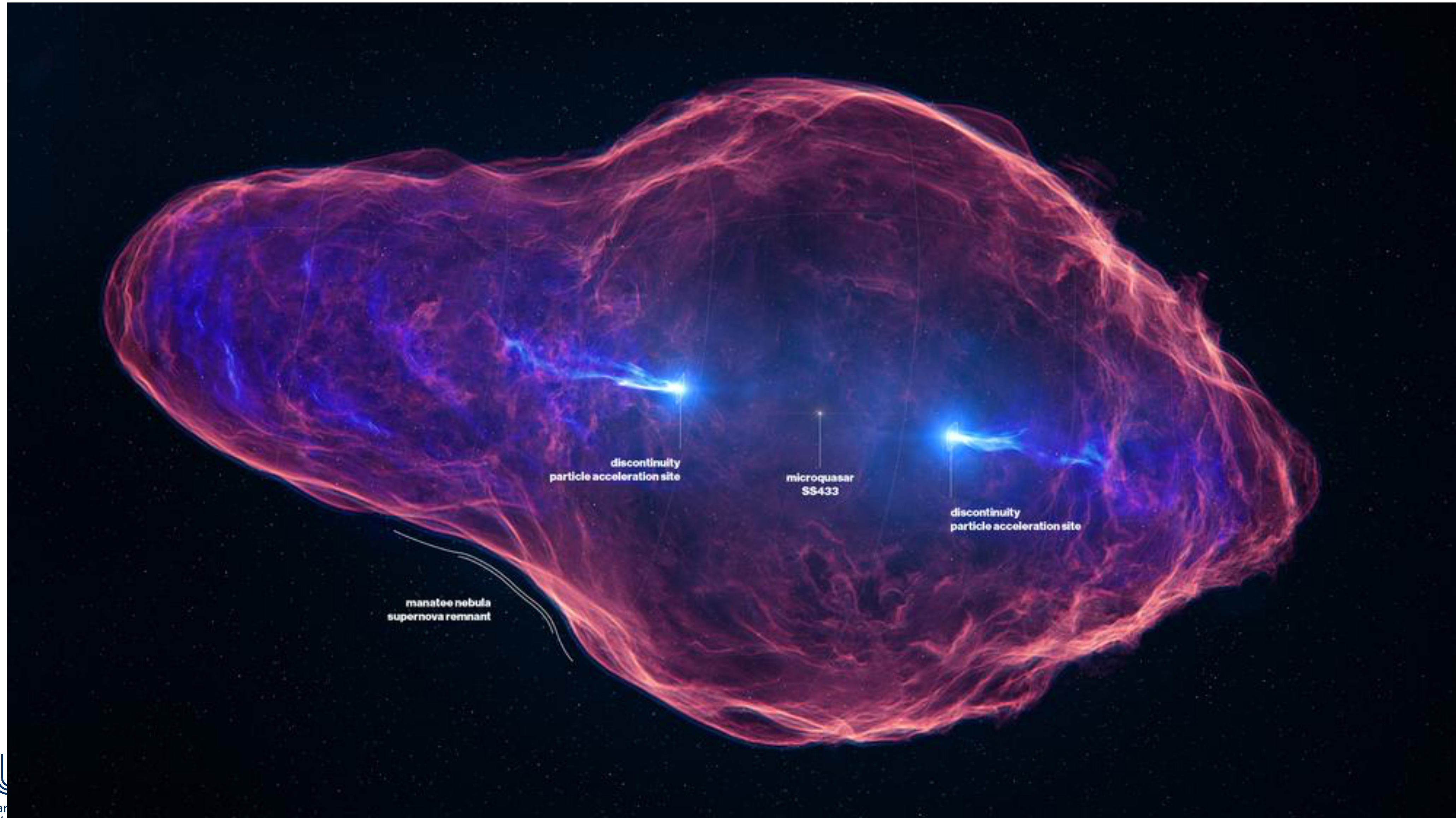


WHAT DOES THAT TELL US?

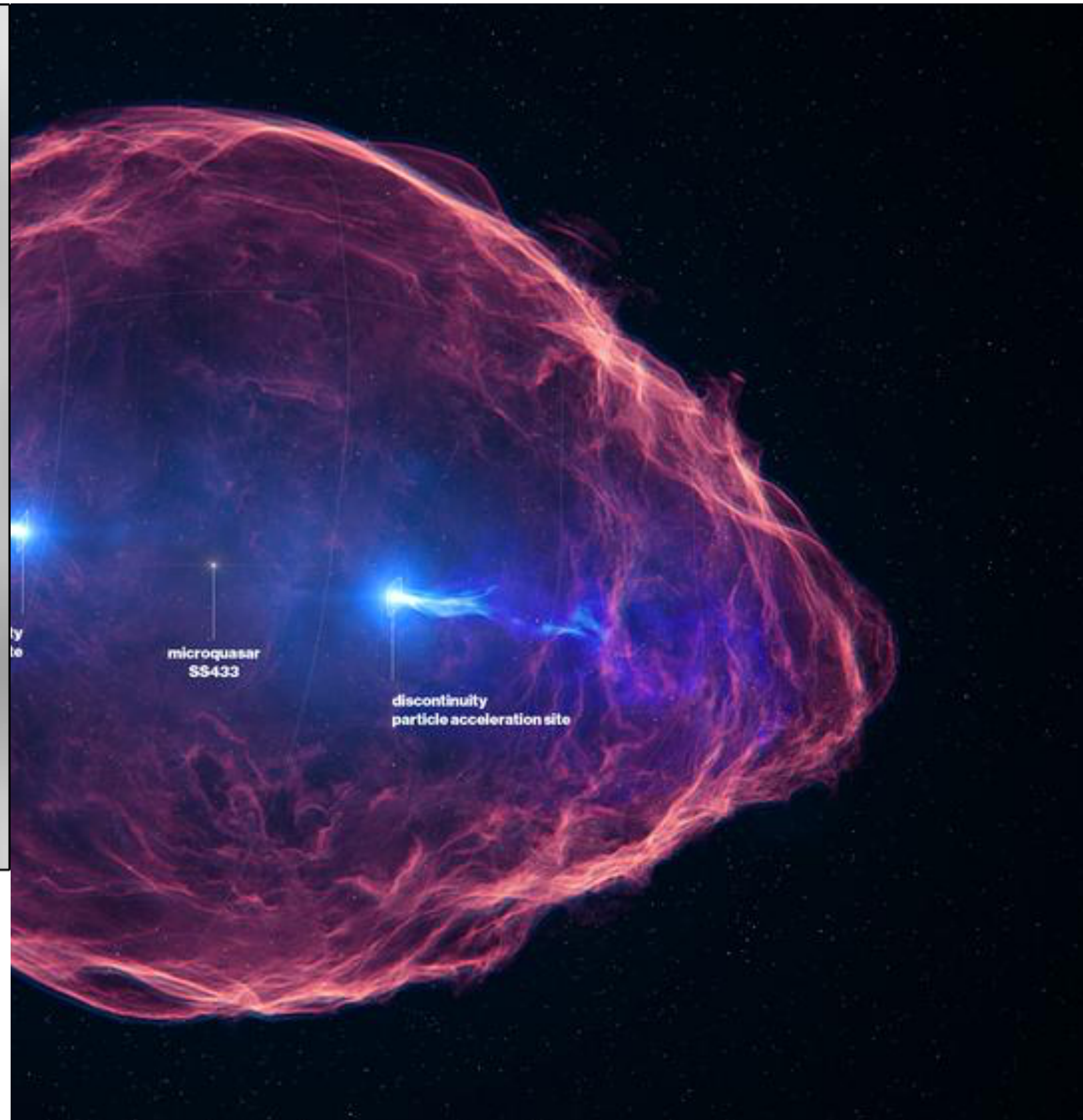
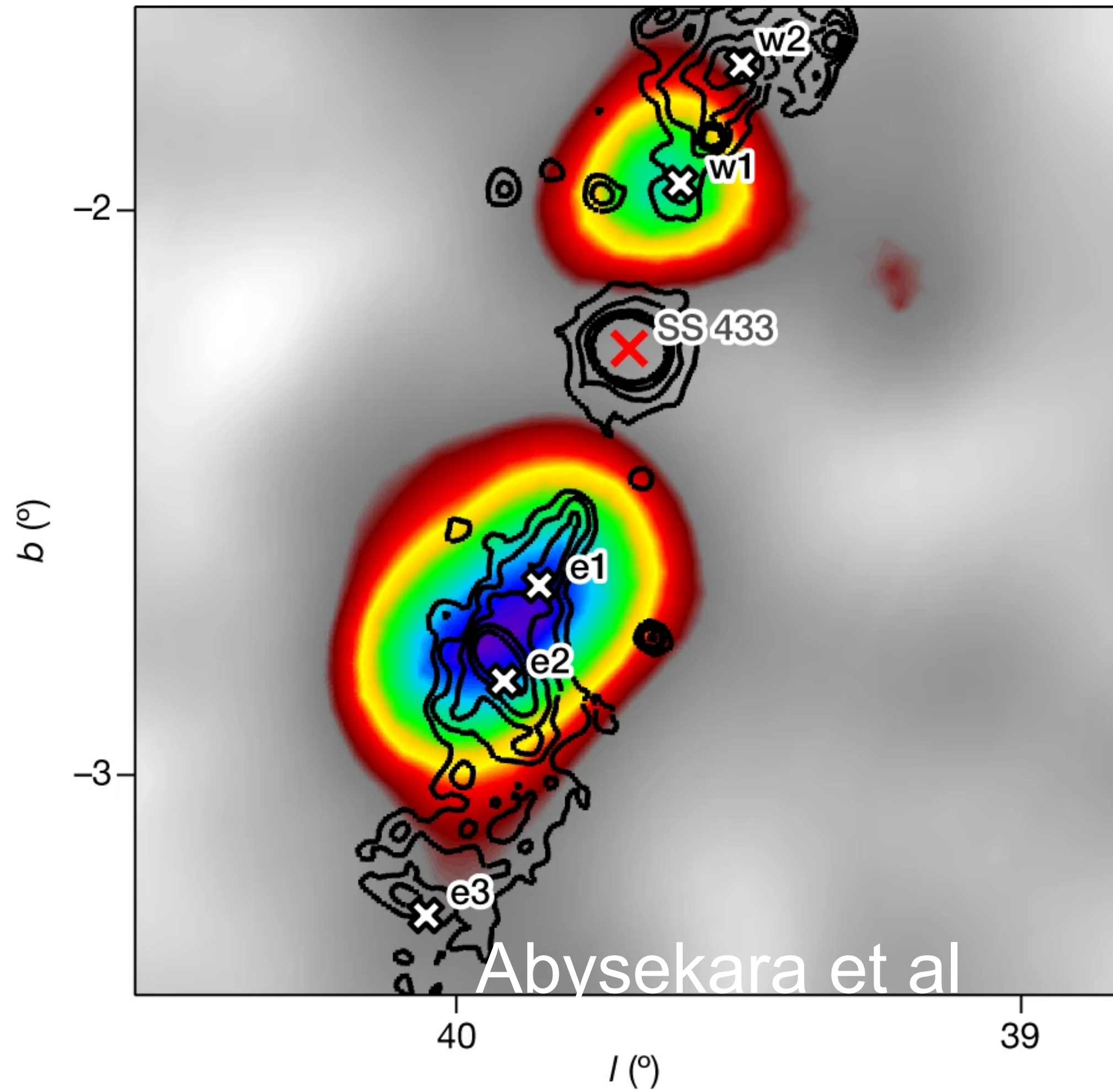
- CRs at the knee likely a mix
- H.E.S.S./LHAASO: several source classes
- DAMPE/CALET spectrum not featureless
- e.g. SNRs below the knee and then Stellar cluster with collective winds beyond the knee



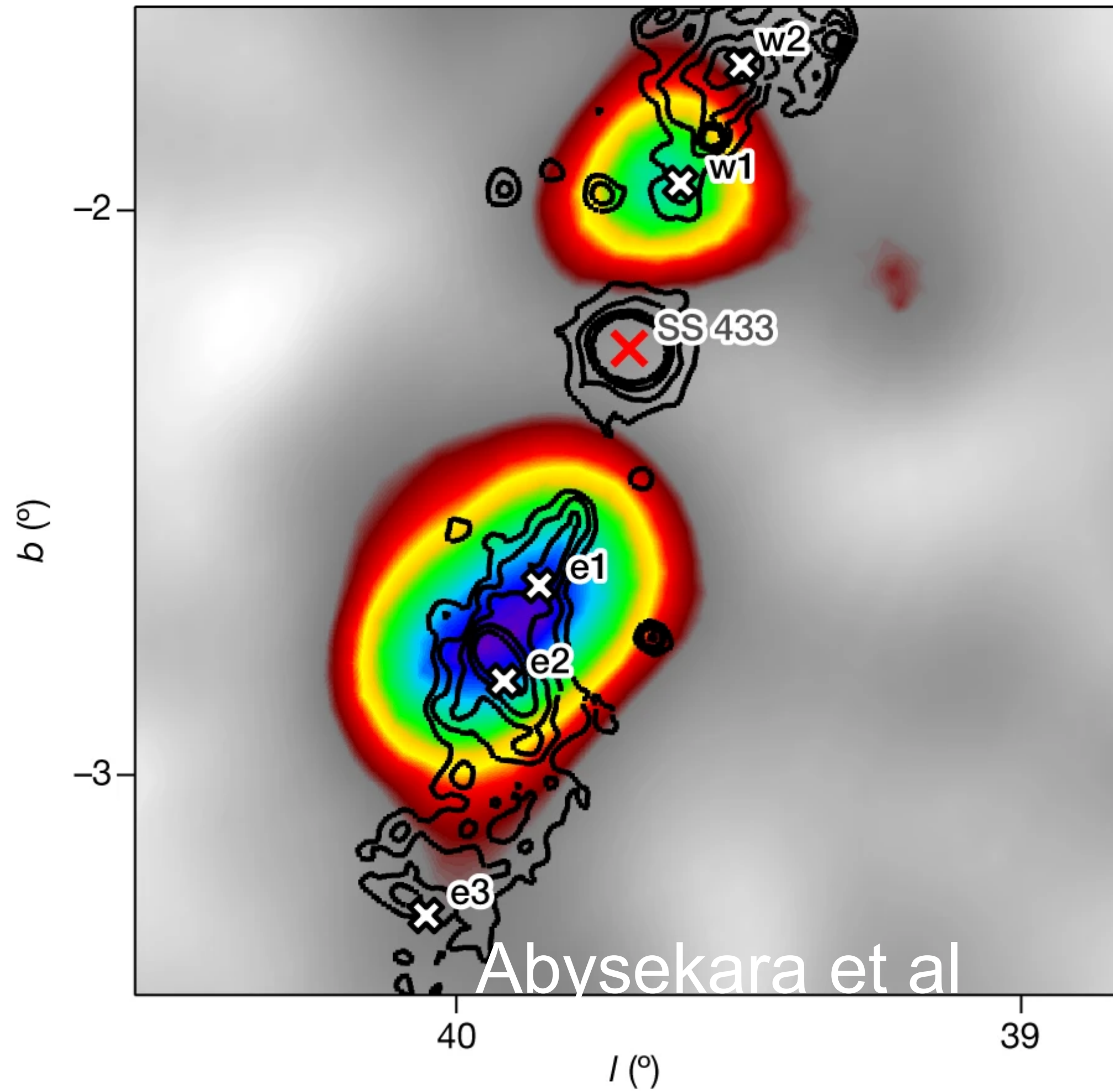
MICROQUASARS – SS 433



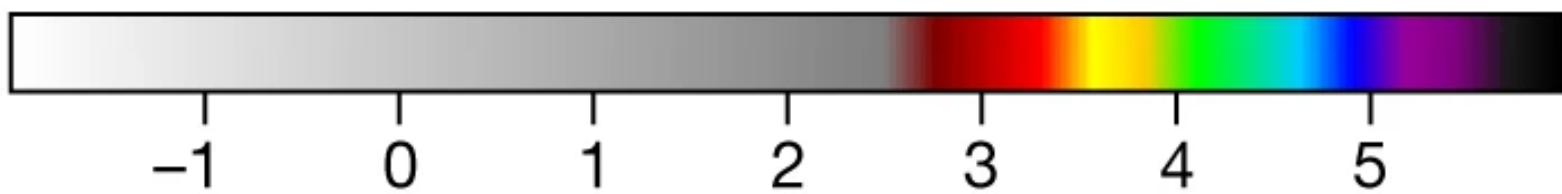
MICROQUASARS – SS 433



MICROQUASARS – SS 433

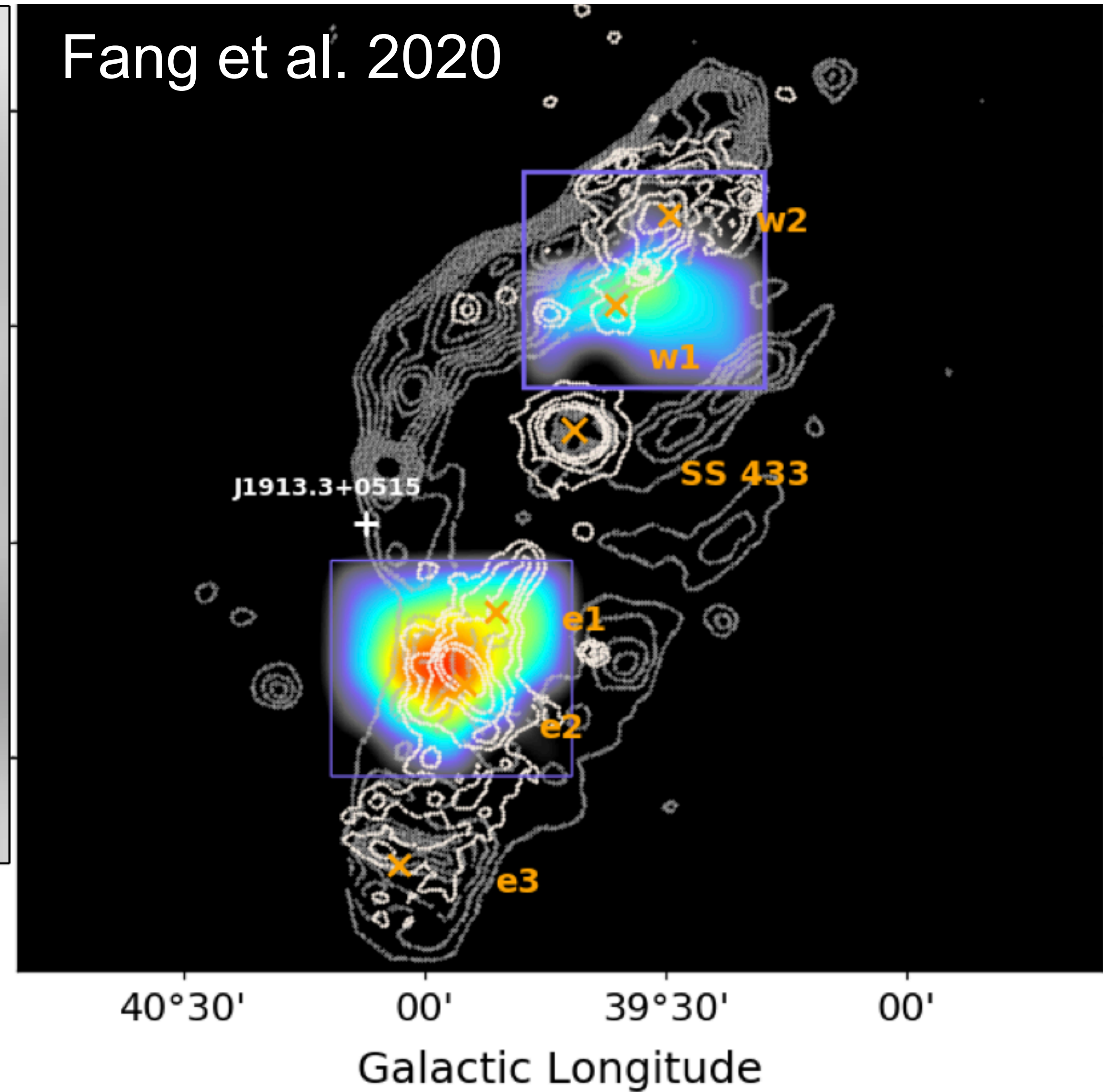


Abysekara et al



Pre-trial significance, σ

Fang et al. 2020



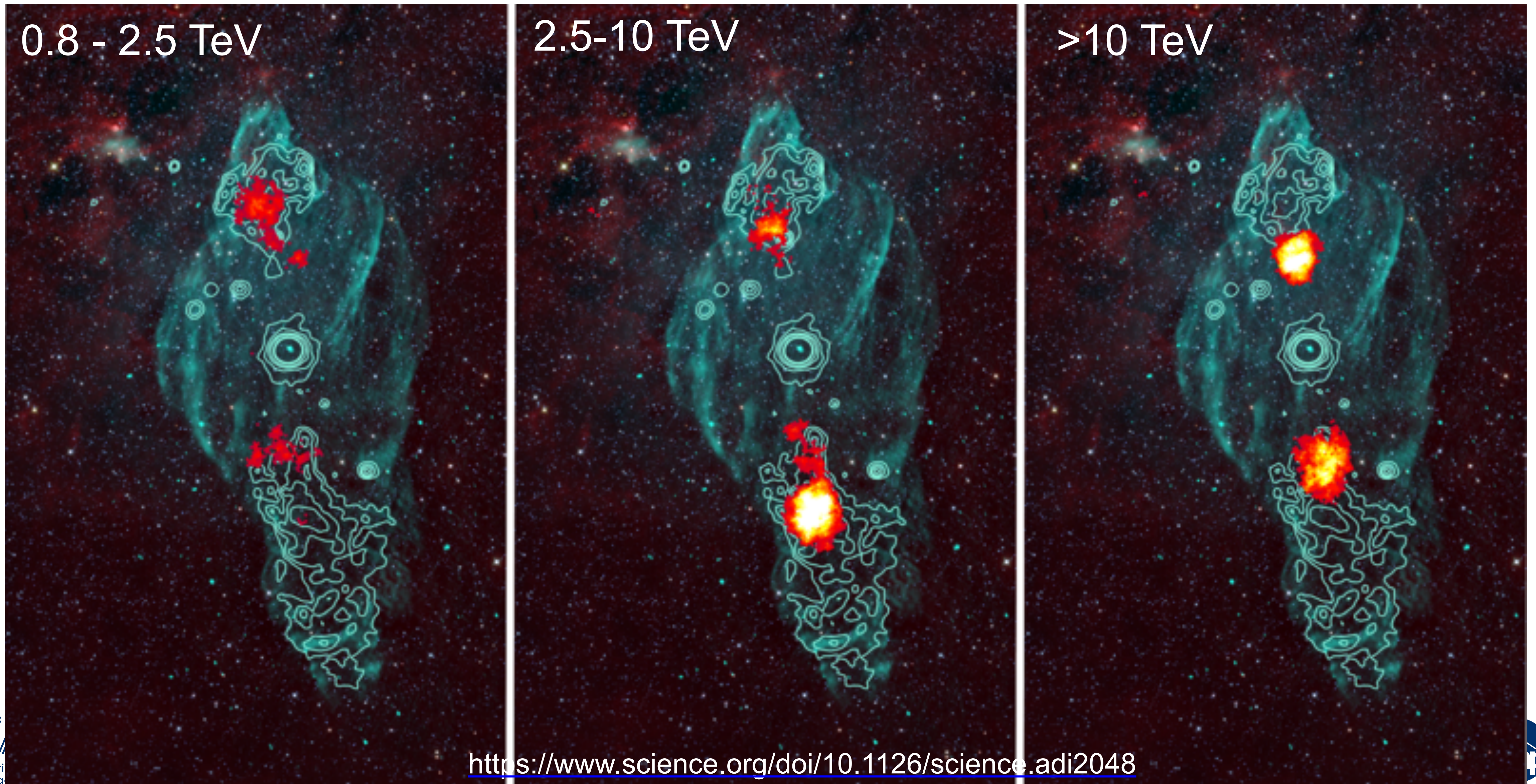
Galactic Longitude

MICROQUASARS – SS 433

0.8 - 2.5 TeV

2.5-10 TeV

>10 TeV

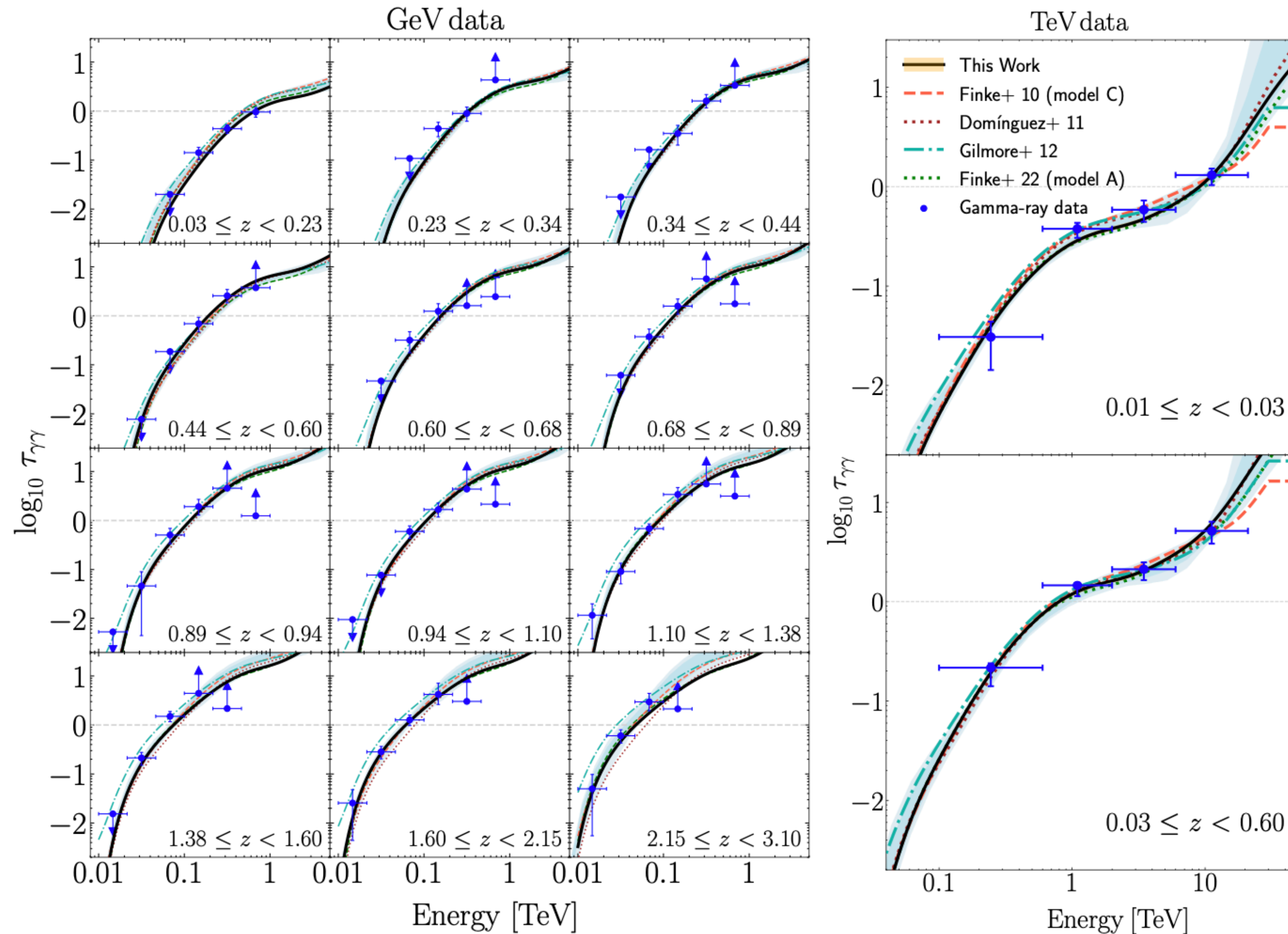


Pre-trial significance, σ

<https://www.science.org/doi/10.1126/science.adi2048>

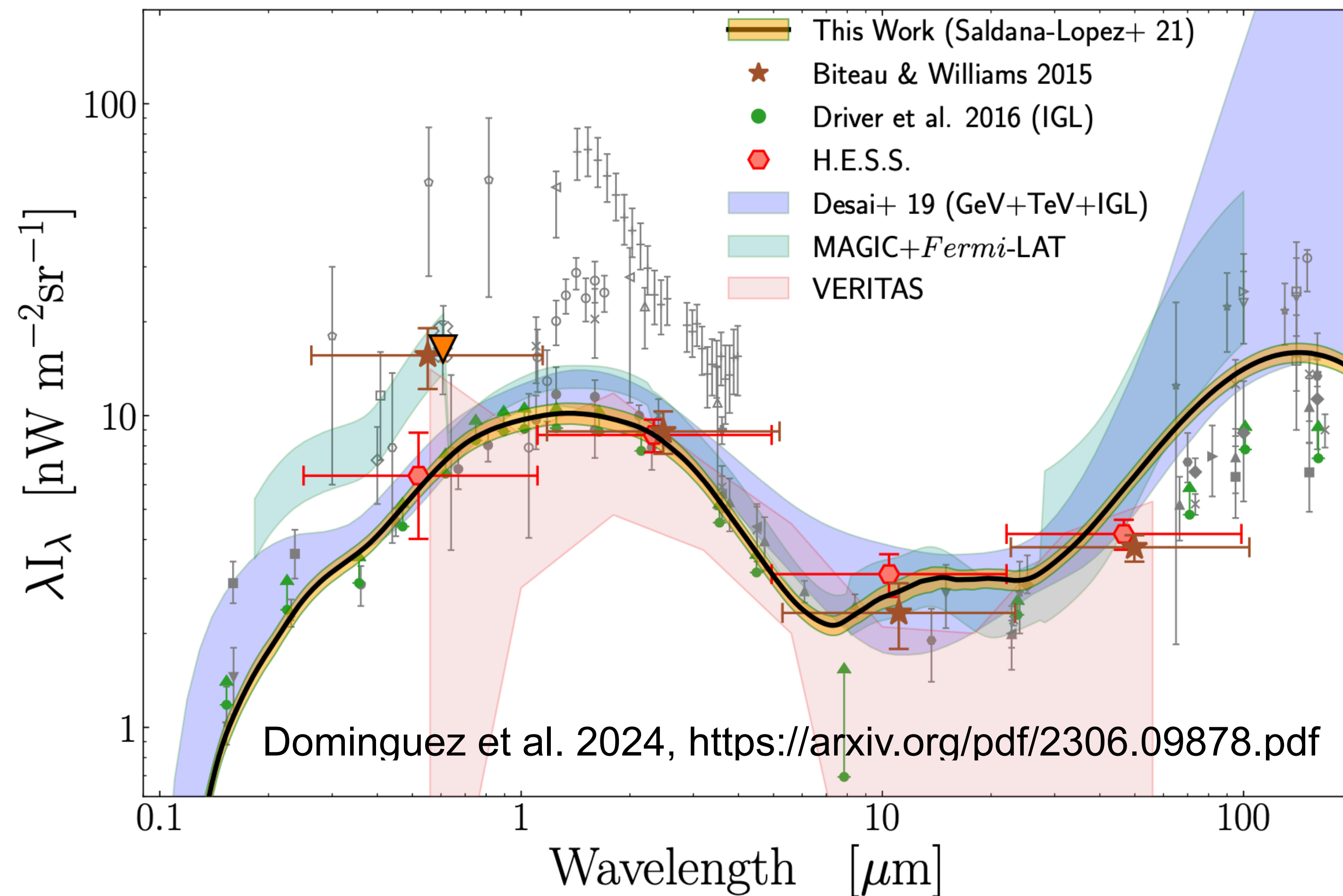
MEASURING THE EXTRAGALACTIC BACKGROUND LIGHT

- ▶ Optical depth as a function of redshift up to $z=3$ is sensitive to Hubble constant



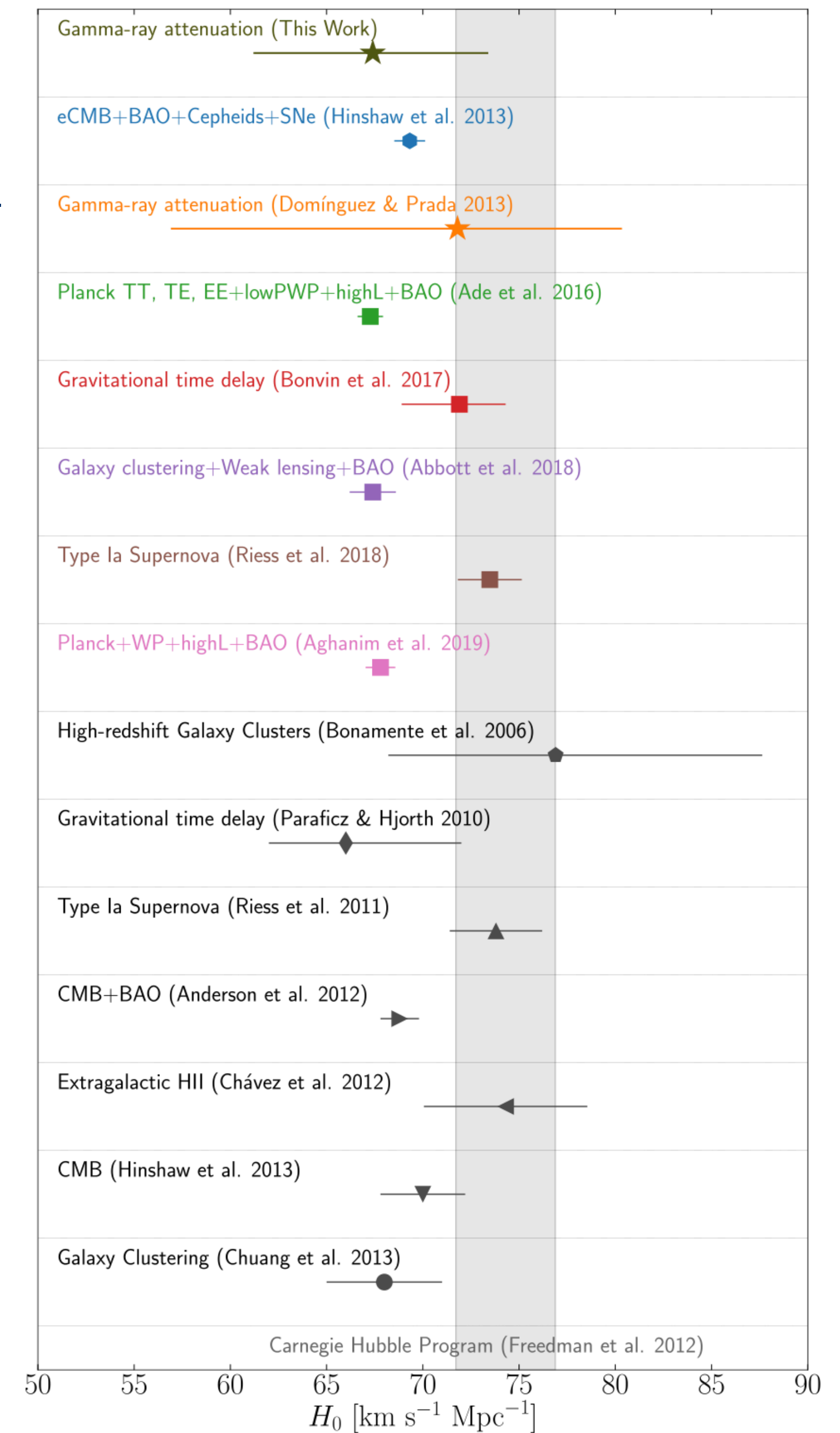
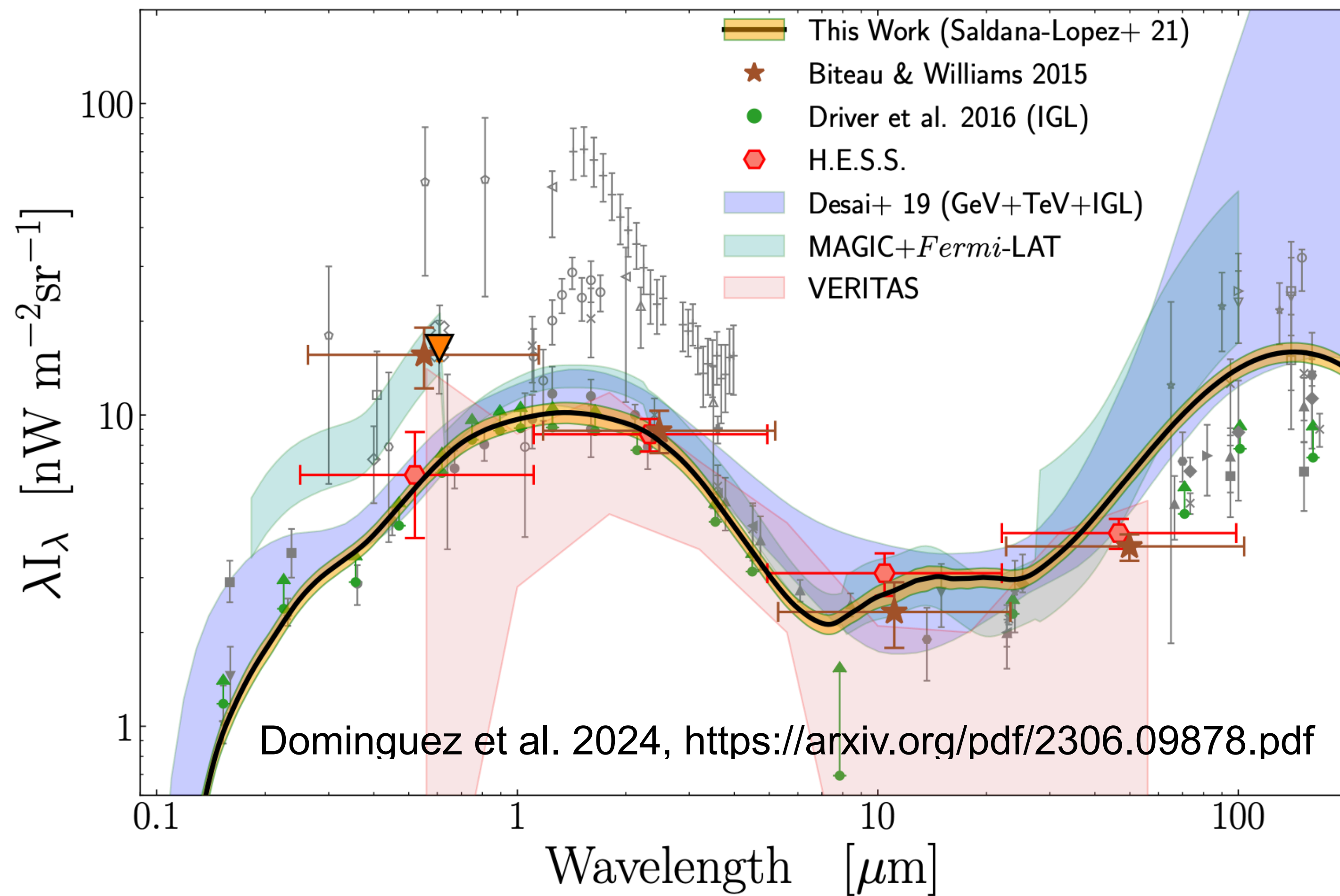
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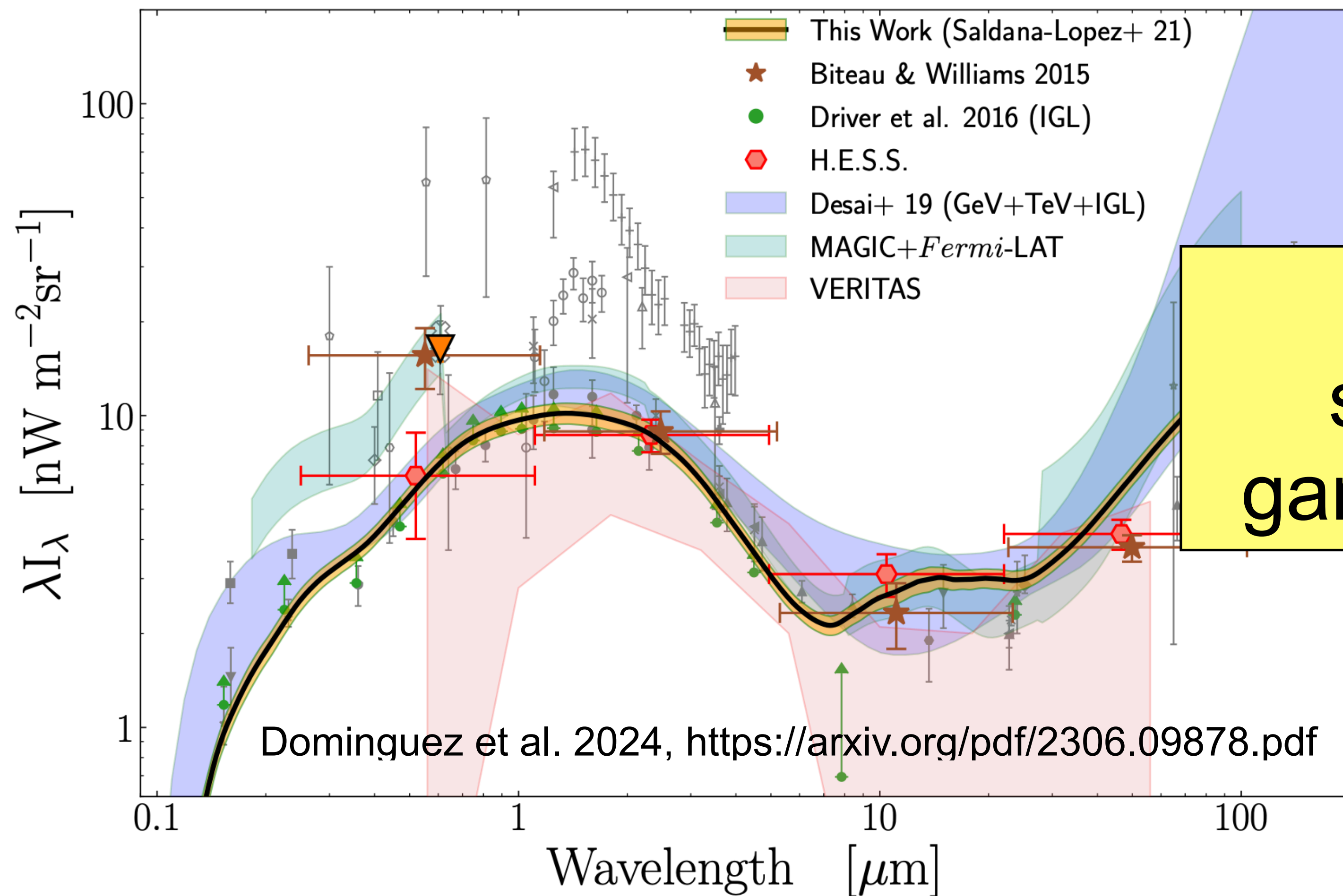
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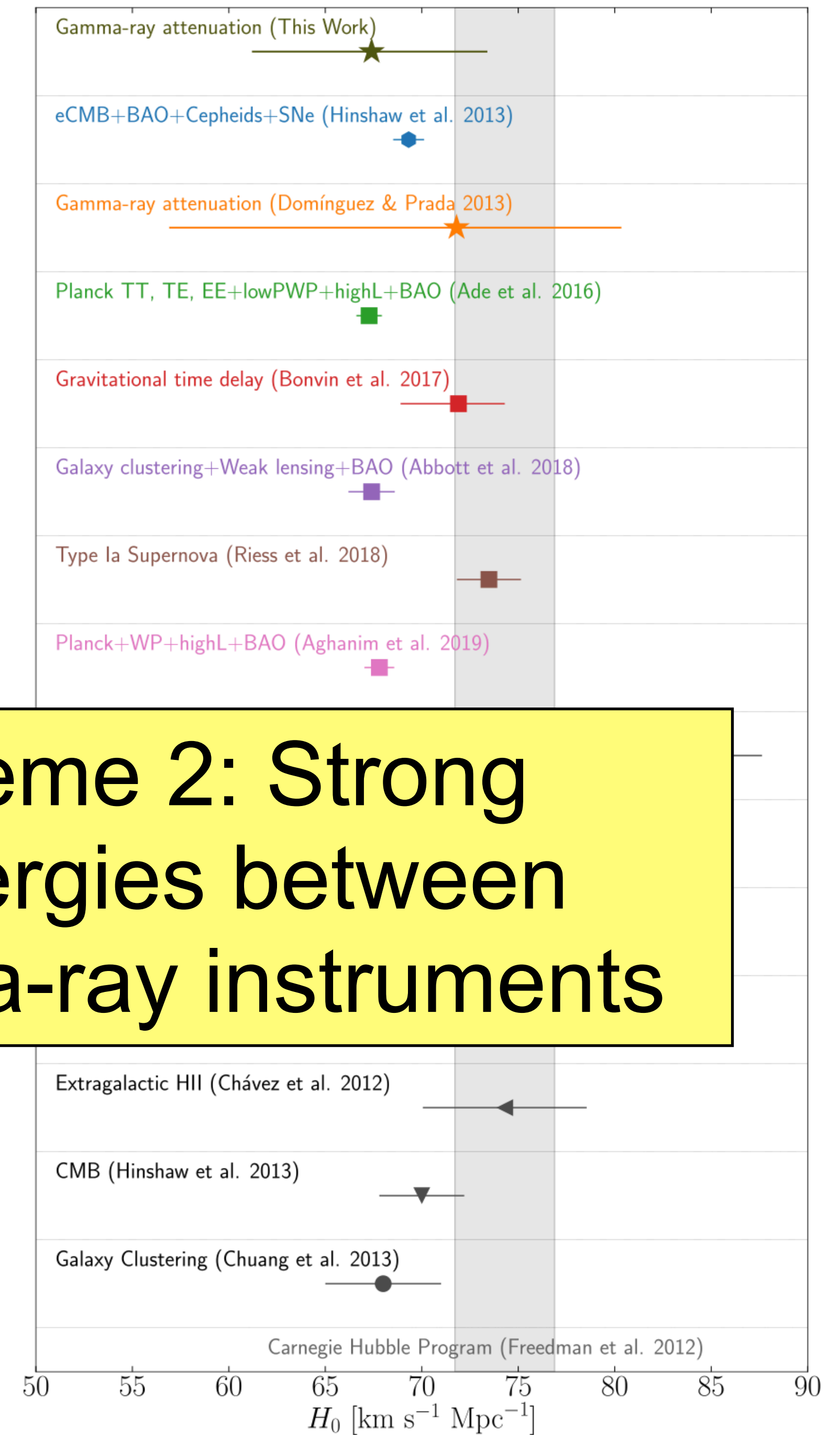


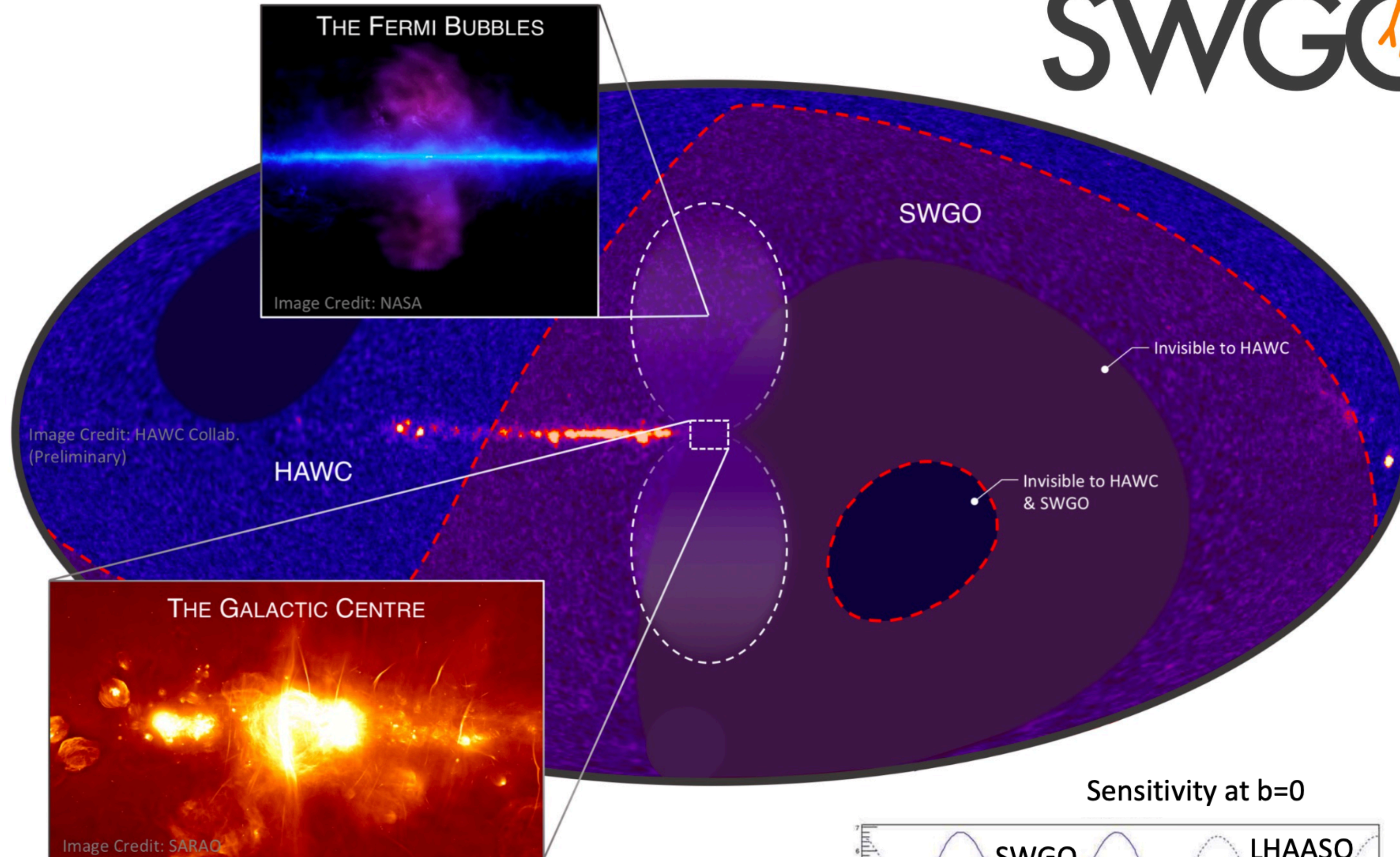
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Theme 2: Strong synergies between gamma-ray instruments





1 TeV – 1PeV gamma-sky

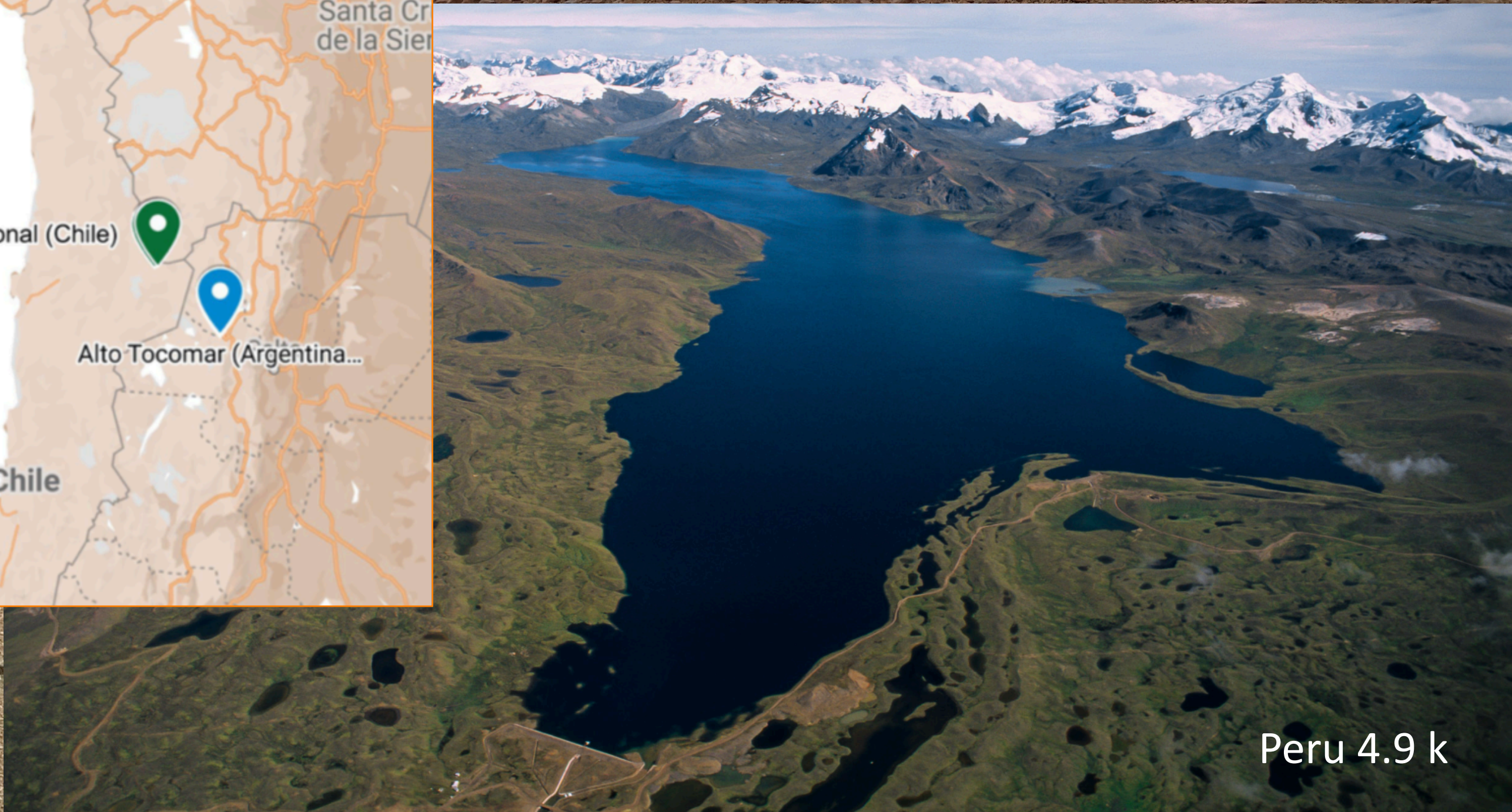
Bolivia 4.7k



Chile 4.8 k

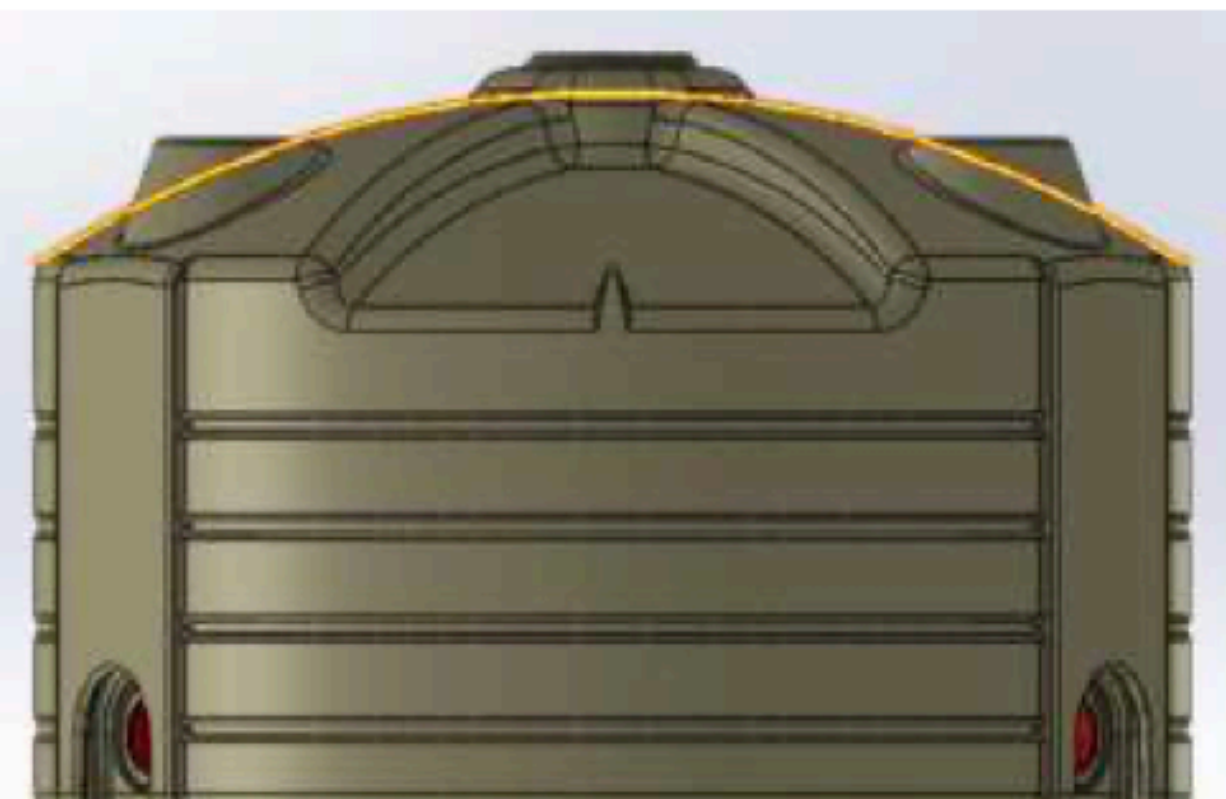
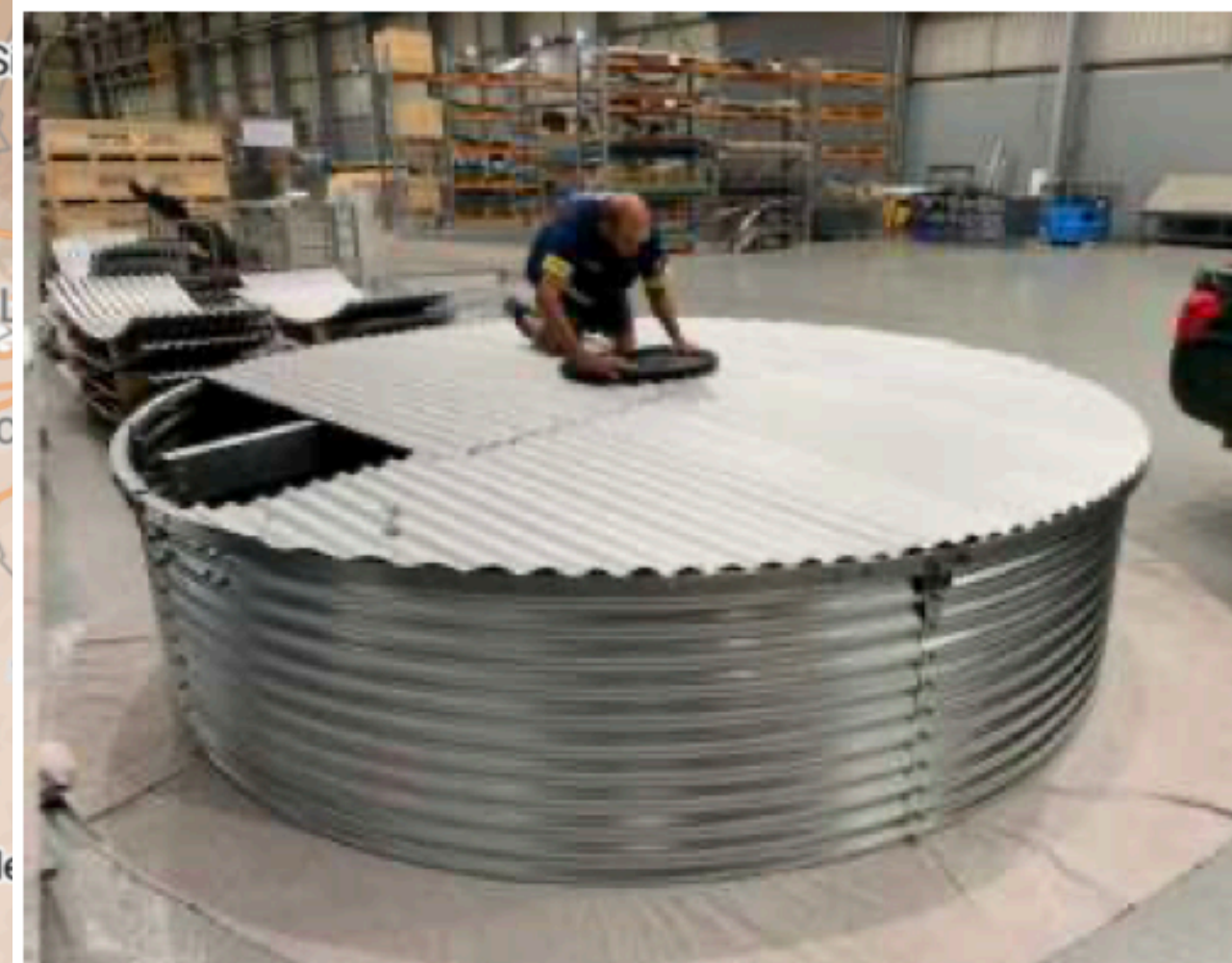
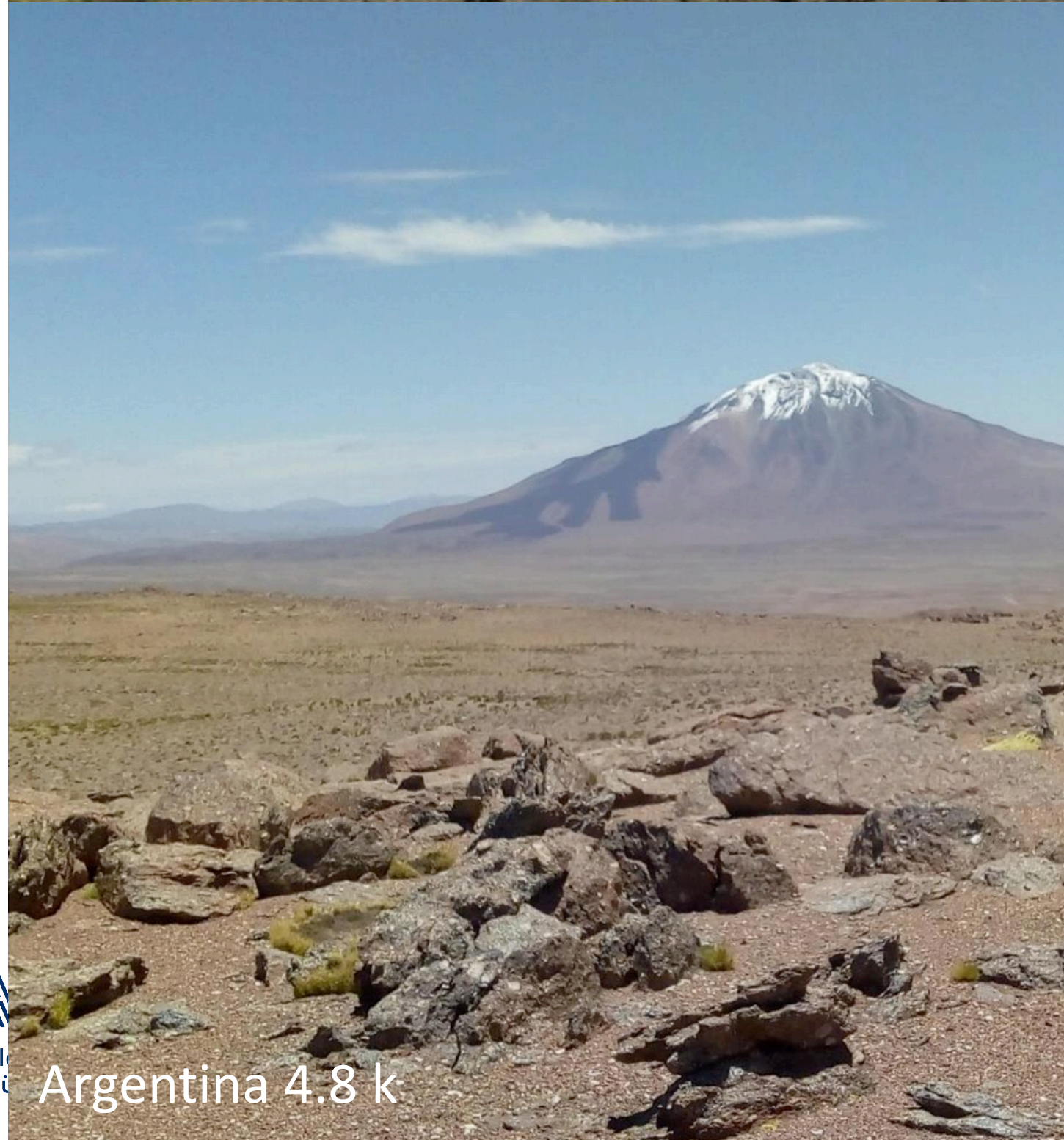


Argentina 4.8 k



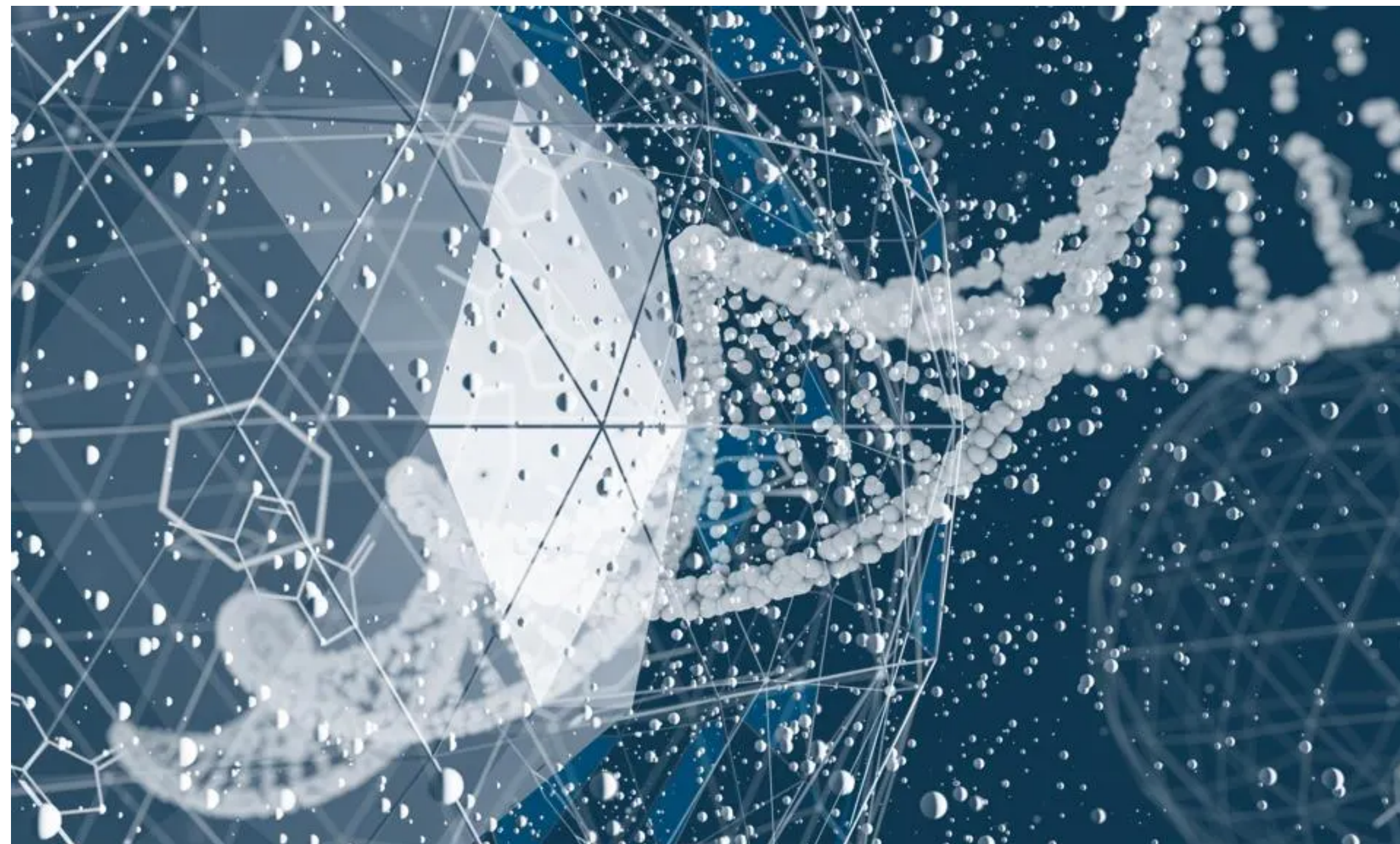
Peru 4.9 k

Bolivia 4.7k



Argentina 4.8 k

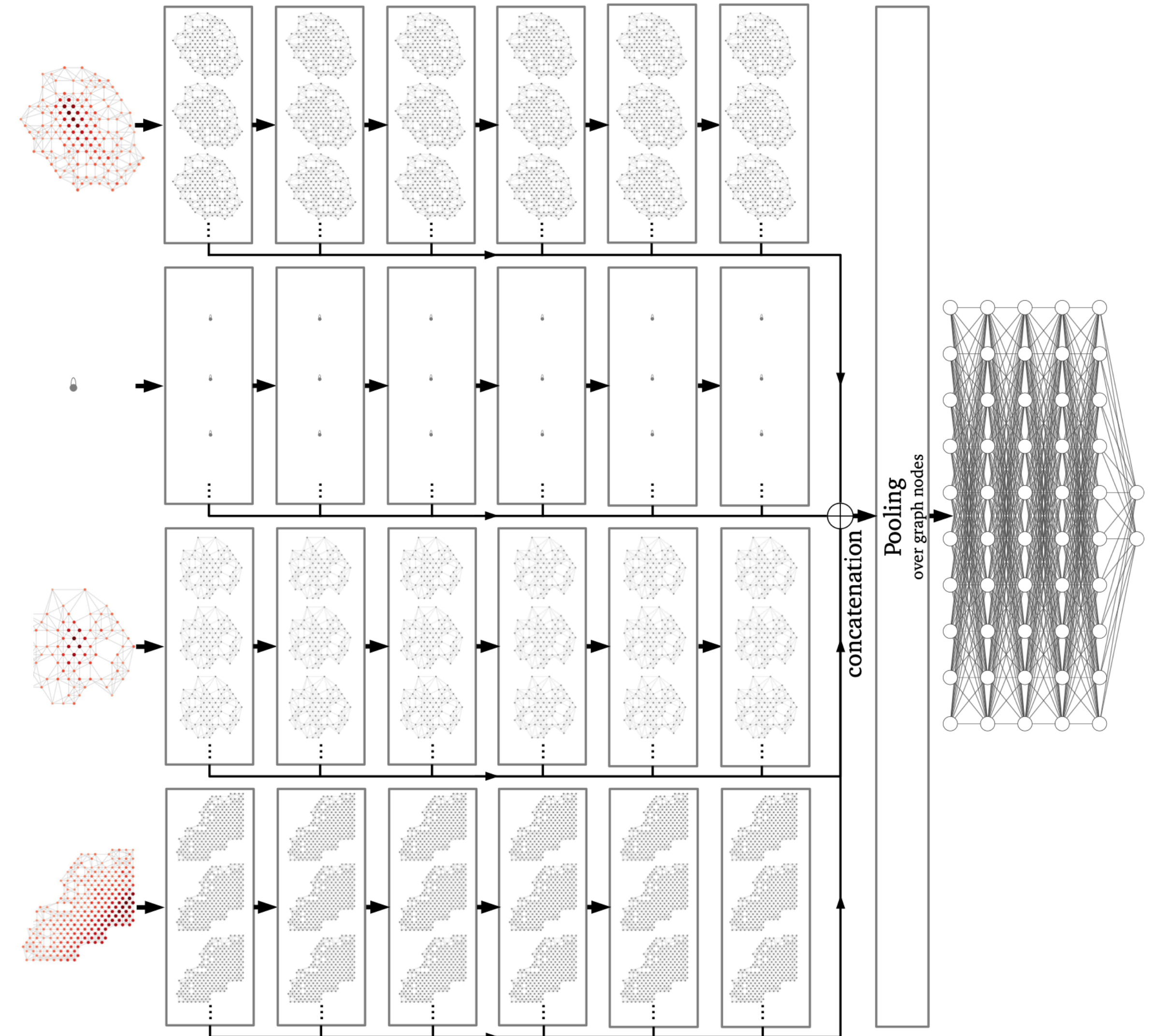
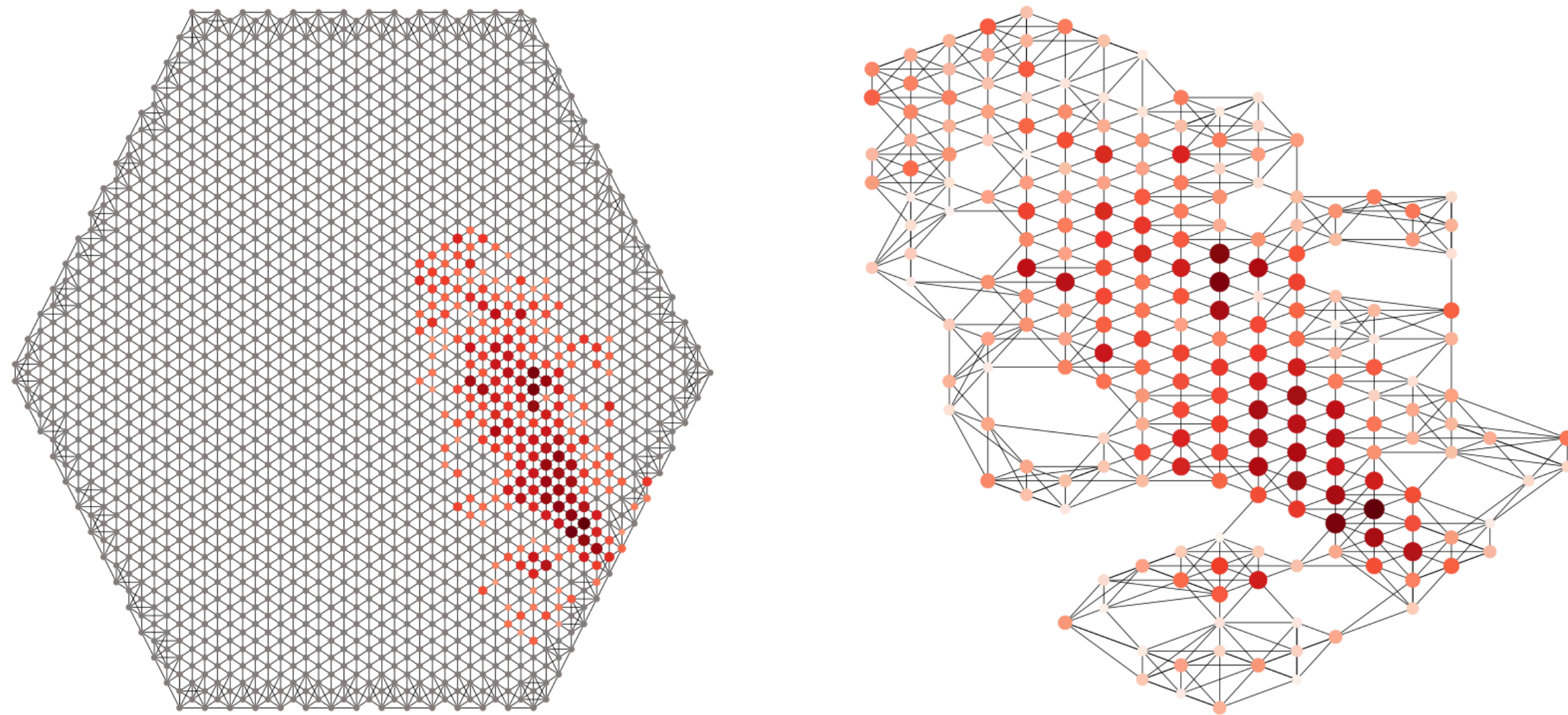
Technical developments



Getty images

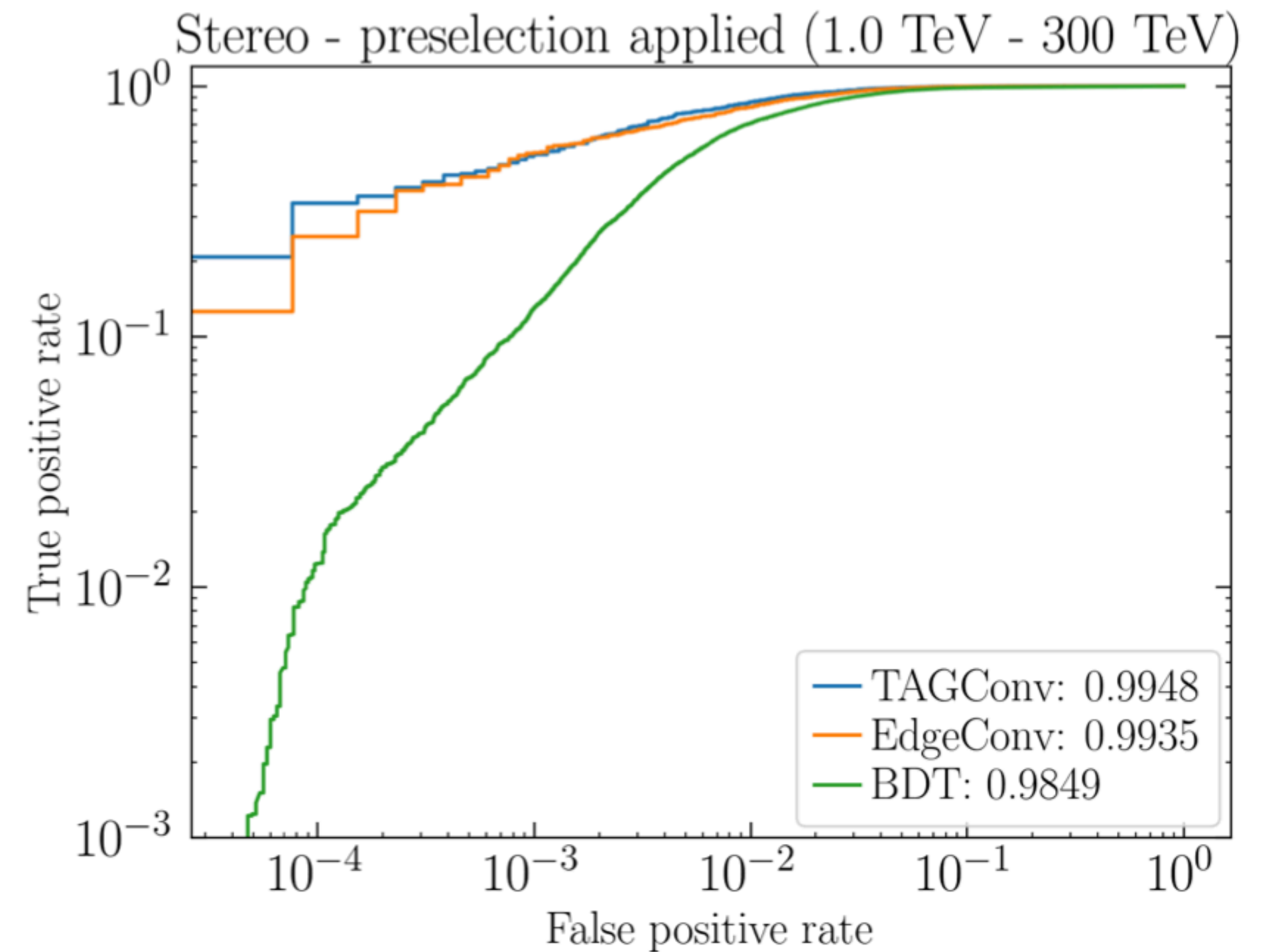
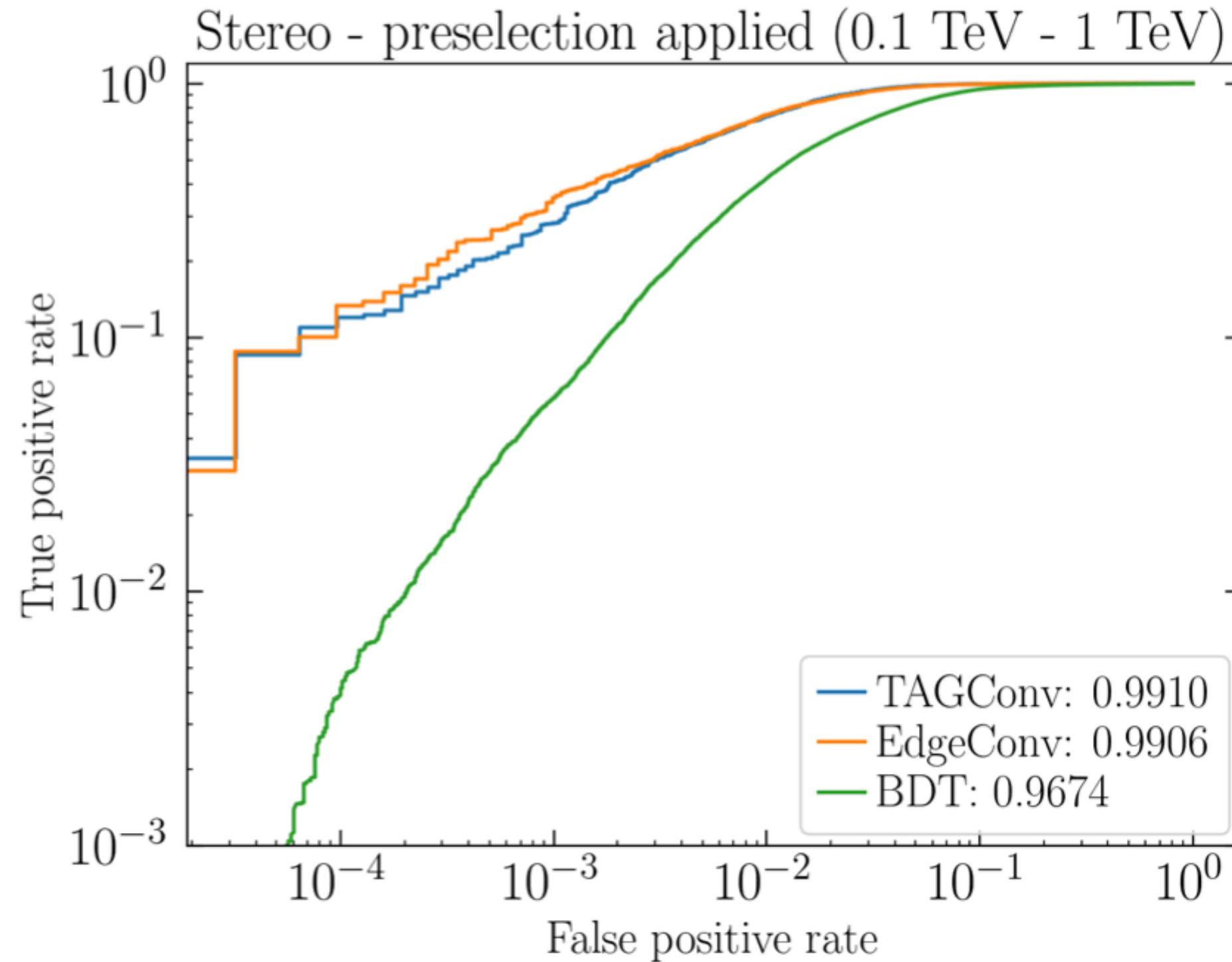
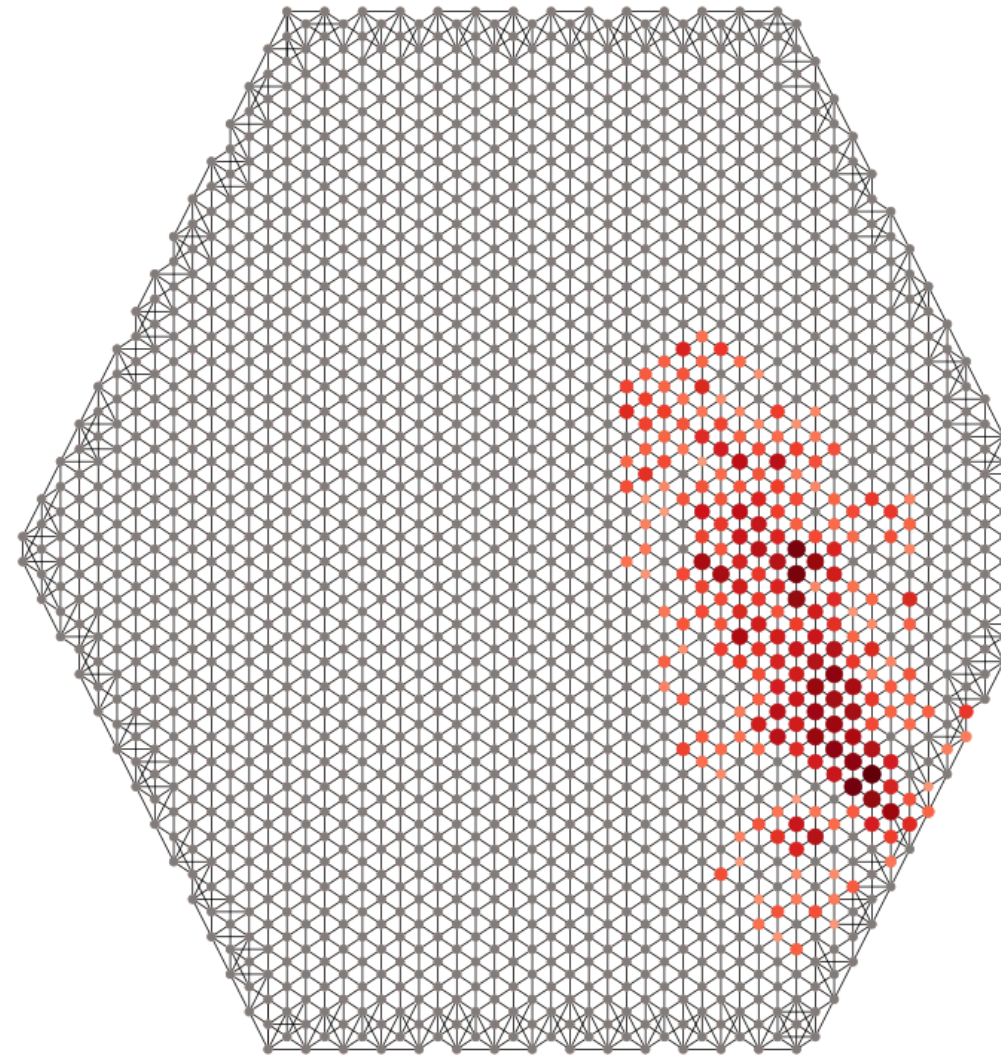
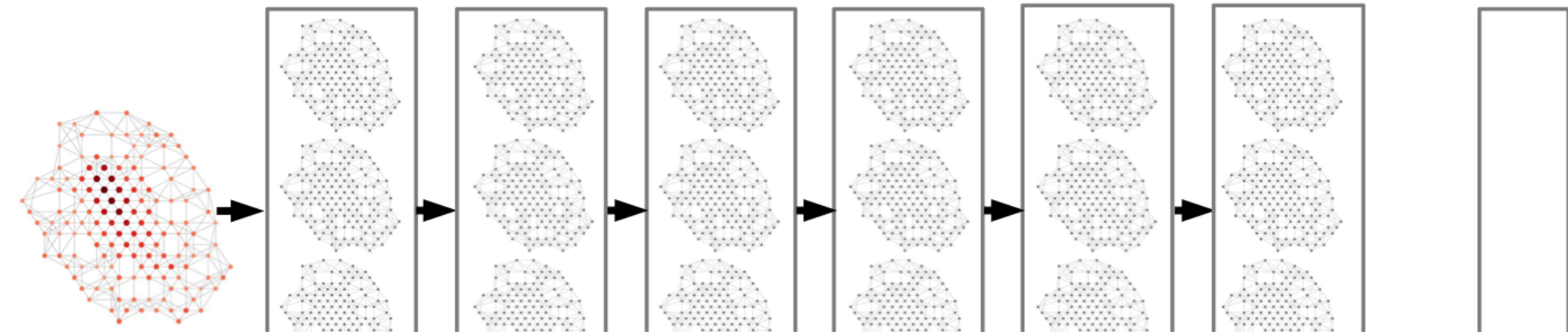
GAMMA-HADRON SEPARATION AND RECONSTRUCTION USING DNNs

- For gamma-ray astronomy with varying telescope/station participation graph neural networks (GNNs) particular appropriate

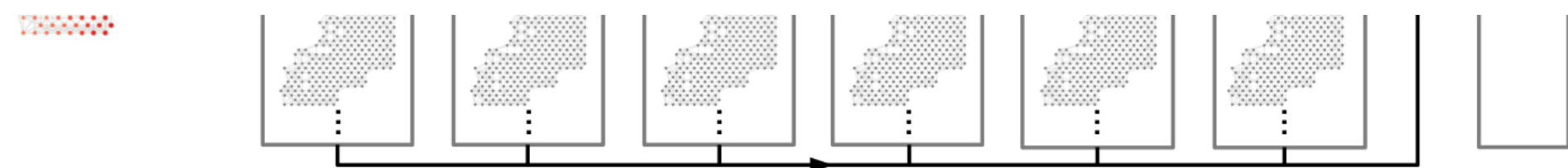


GAMMA-HADRON SEPARATION AND RECONSTRUCTION USING DNNs

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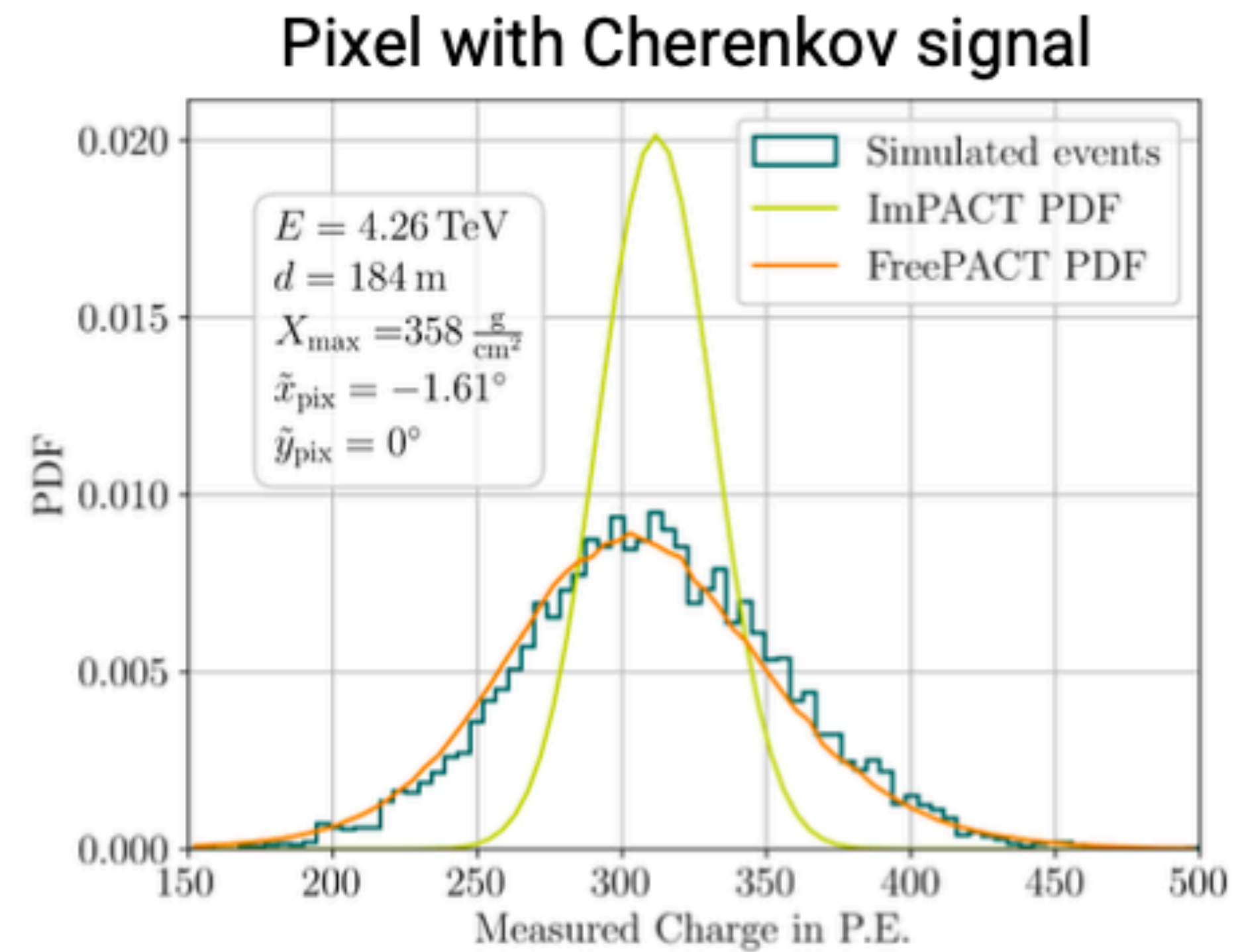
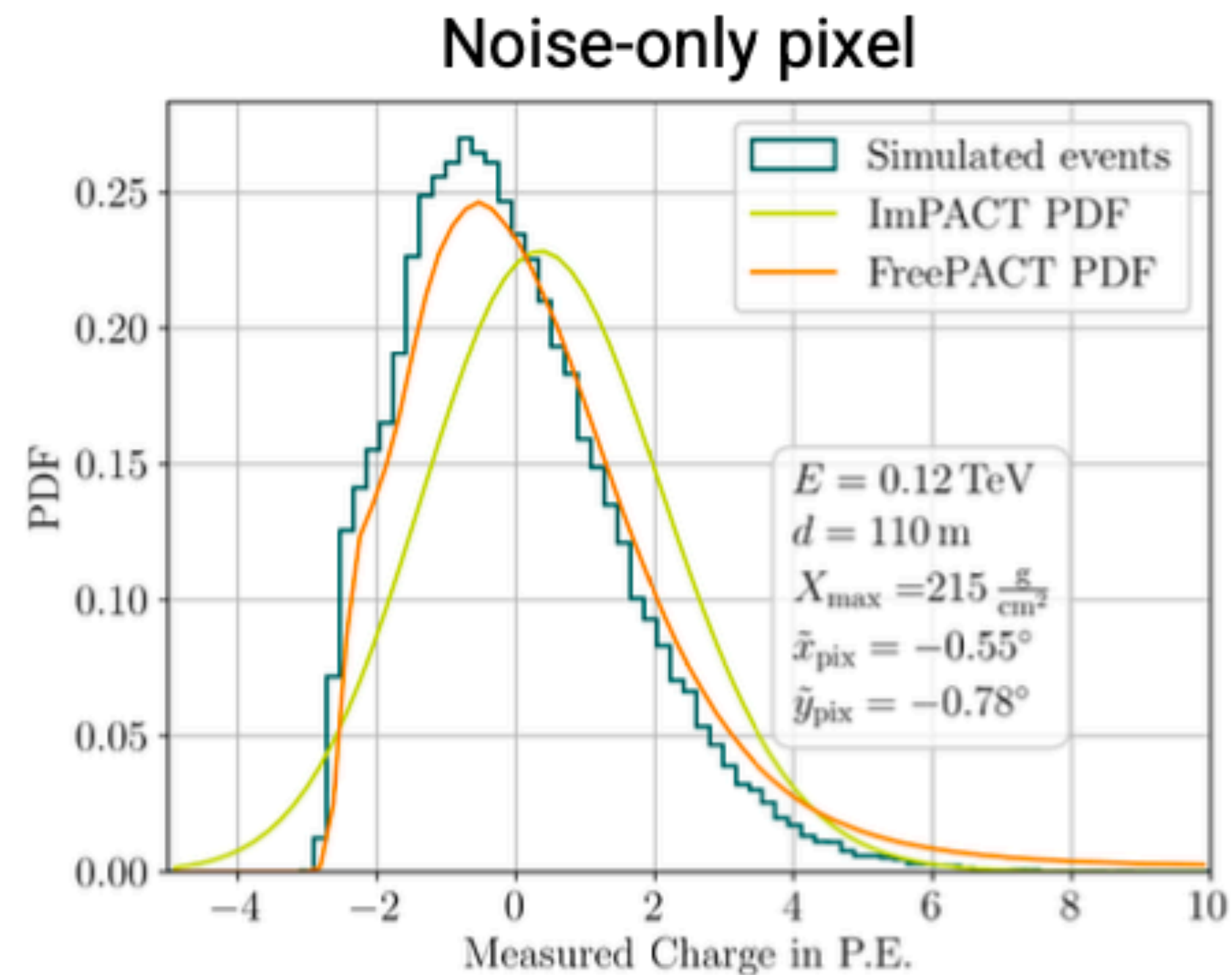


e.g. Glombitza et al. 2024



HYBRID MACHINE LEARNING-LIKELIHOOD EVENT RECONSTRUCTION

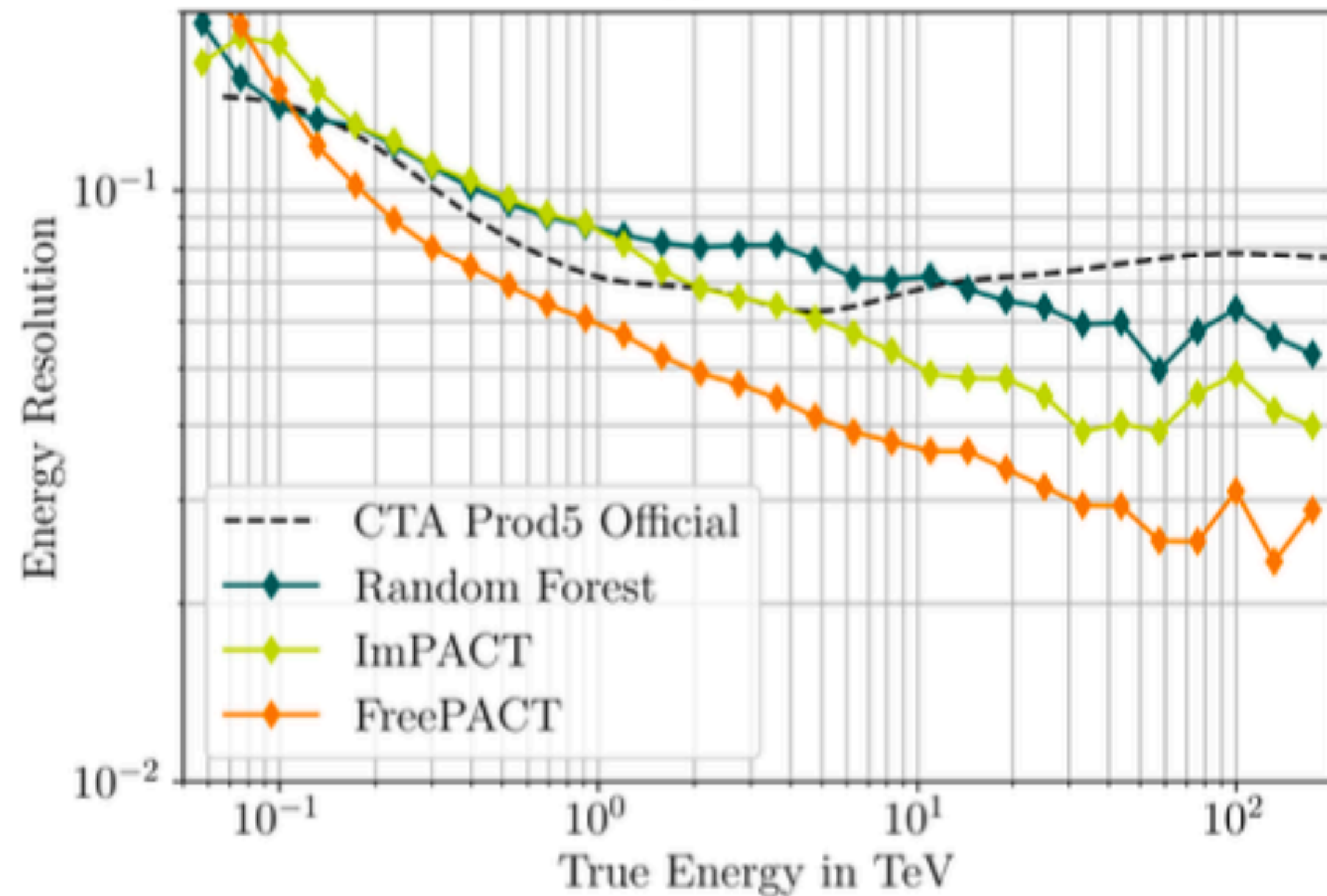
- Improve per-pixel likelihood using machine learning (Schwefer et al. 2024)



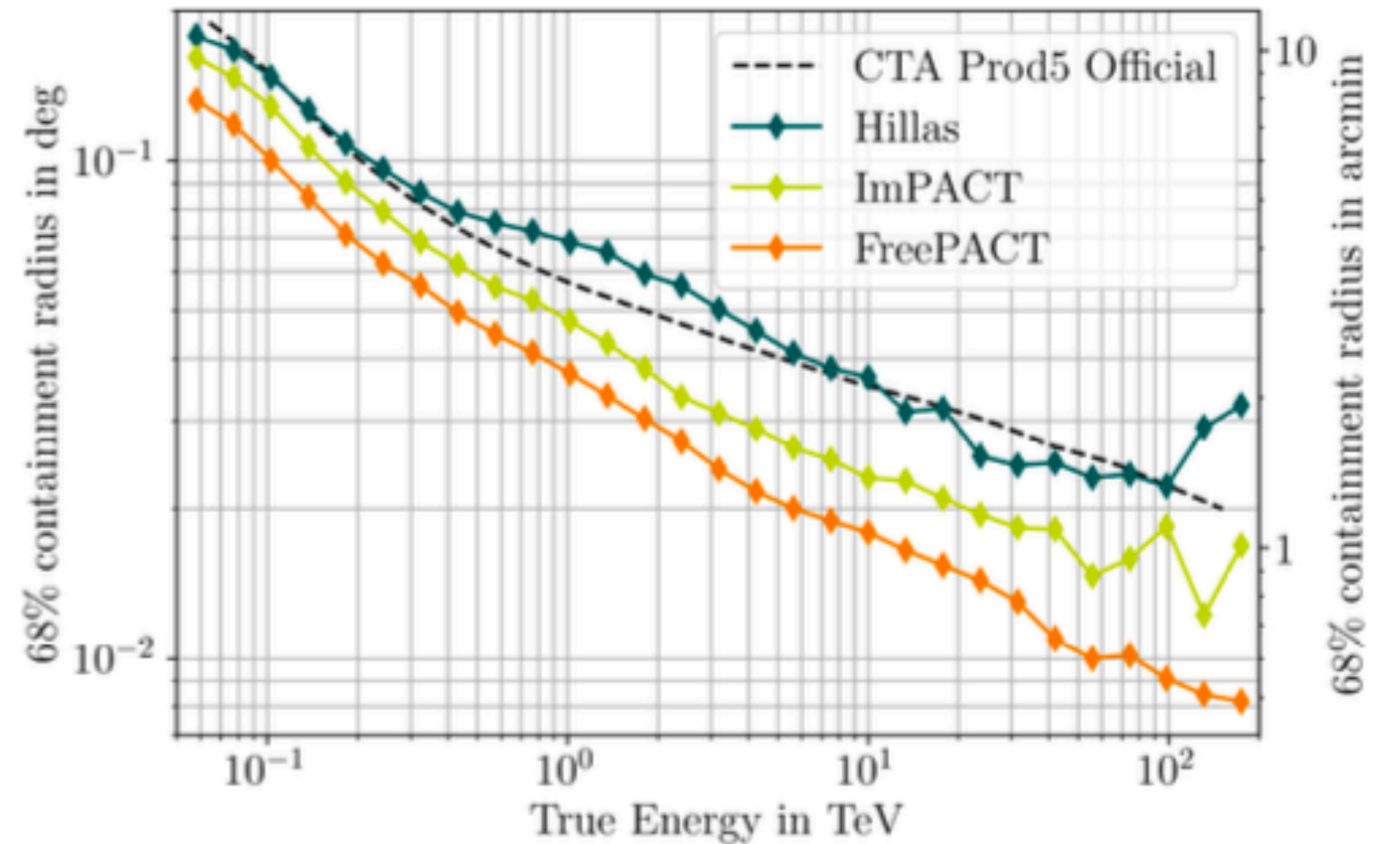
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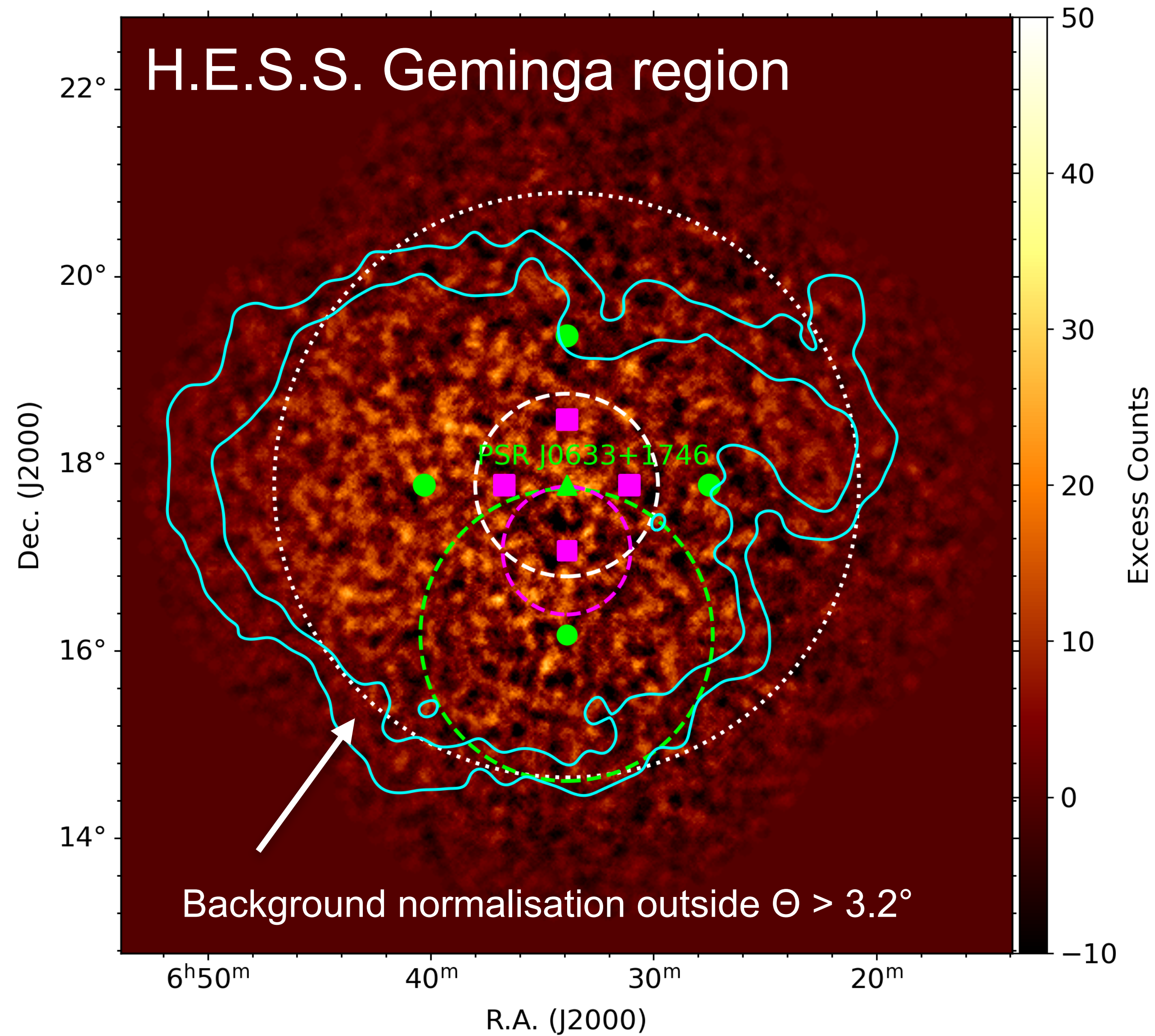
Energy Resolution



Angular Resolution

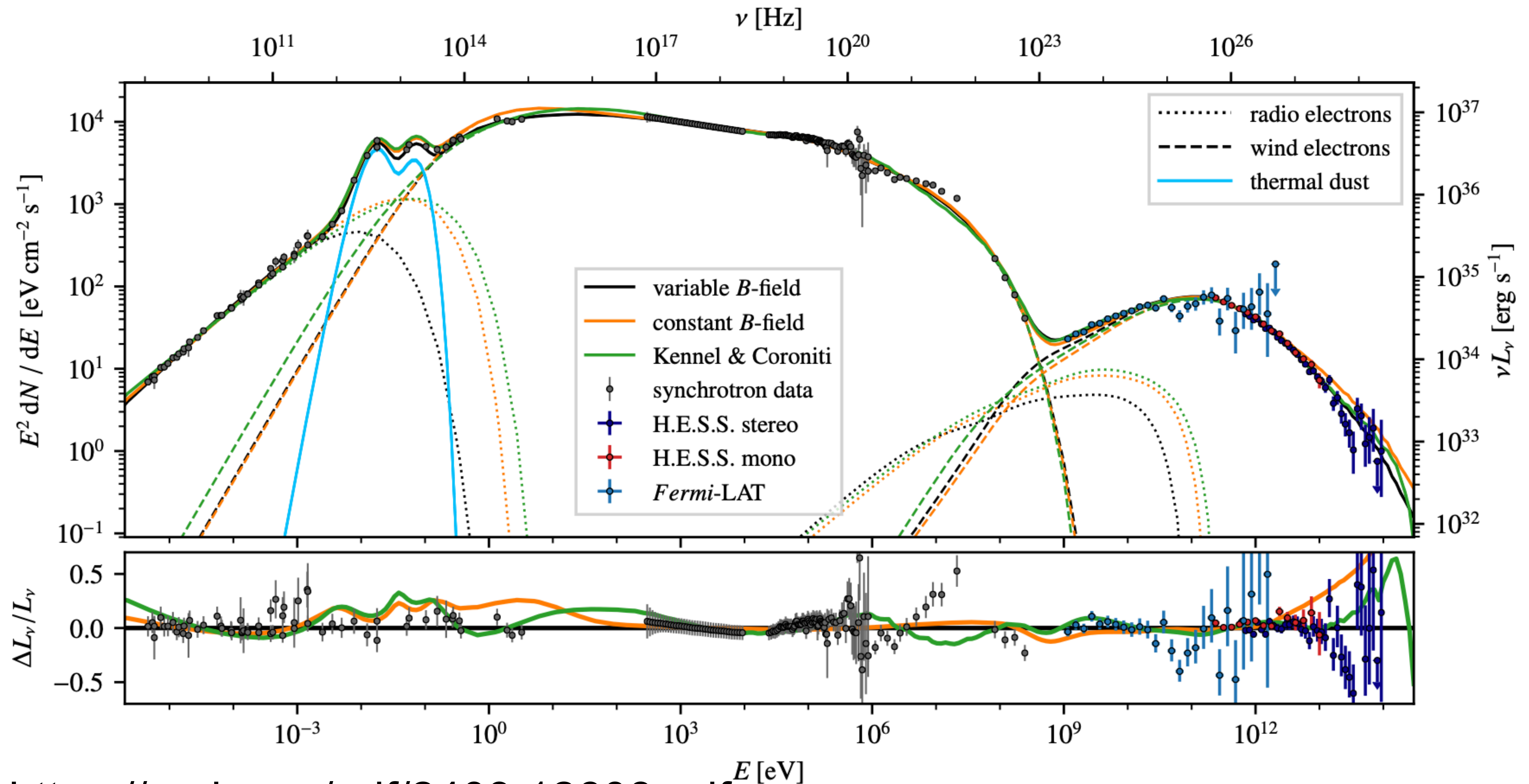


ANALYSIS OF COMPLEX AND LARGE-SCALE EMISSION REGIONS

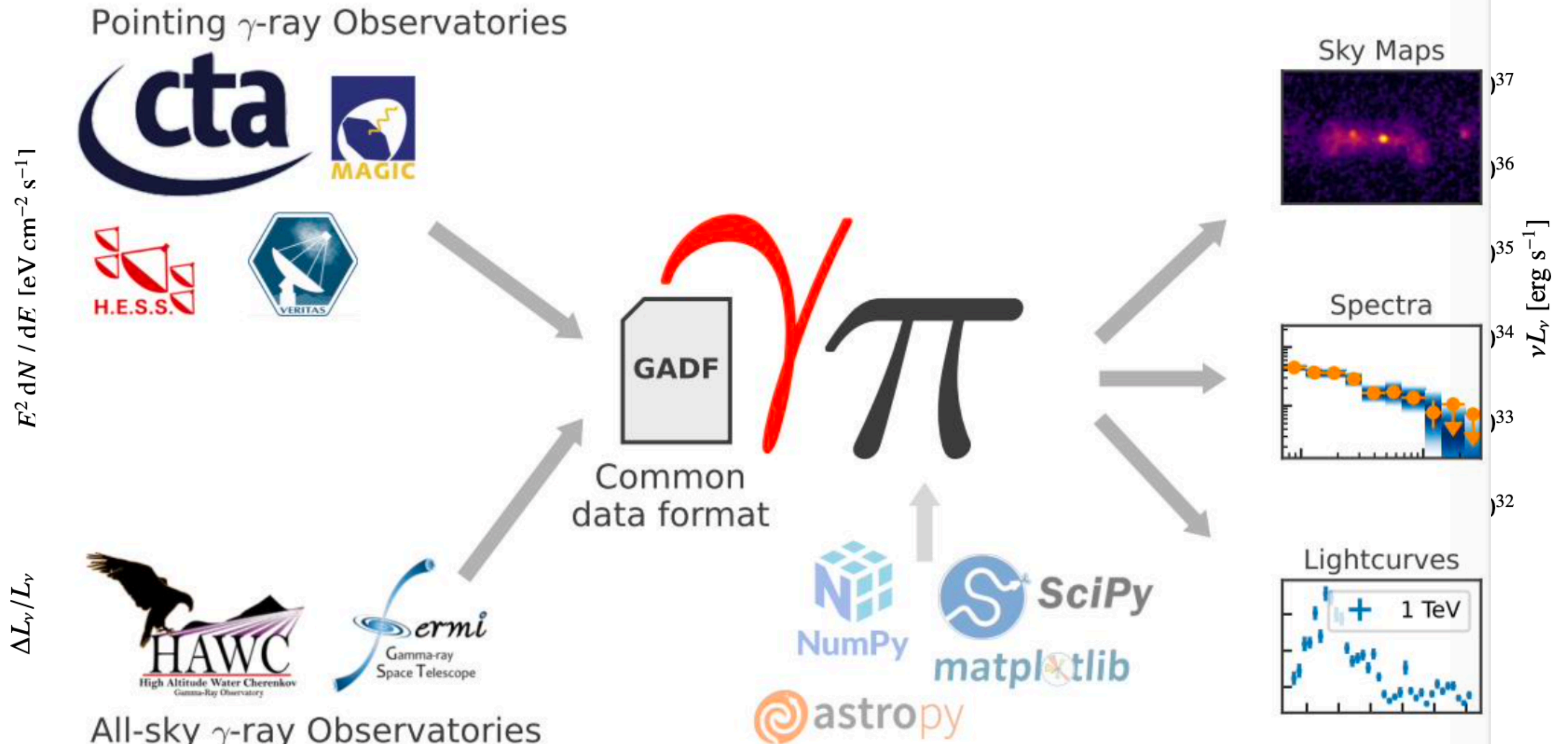


<https://arxiv.org/pdf/2304.02631.pdf>

MULTI-INSTRUMENT 3D MODEL-FITTING AT THE EVENT LEVEL WITH GAMMAPY



MULTI-INSTRUMENT 3D MODEL-FITTING AT THE EVENT LEVEL WITH GAMMAPY

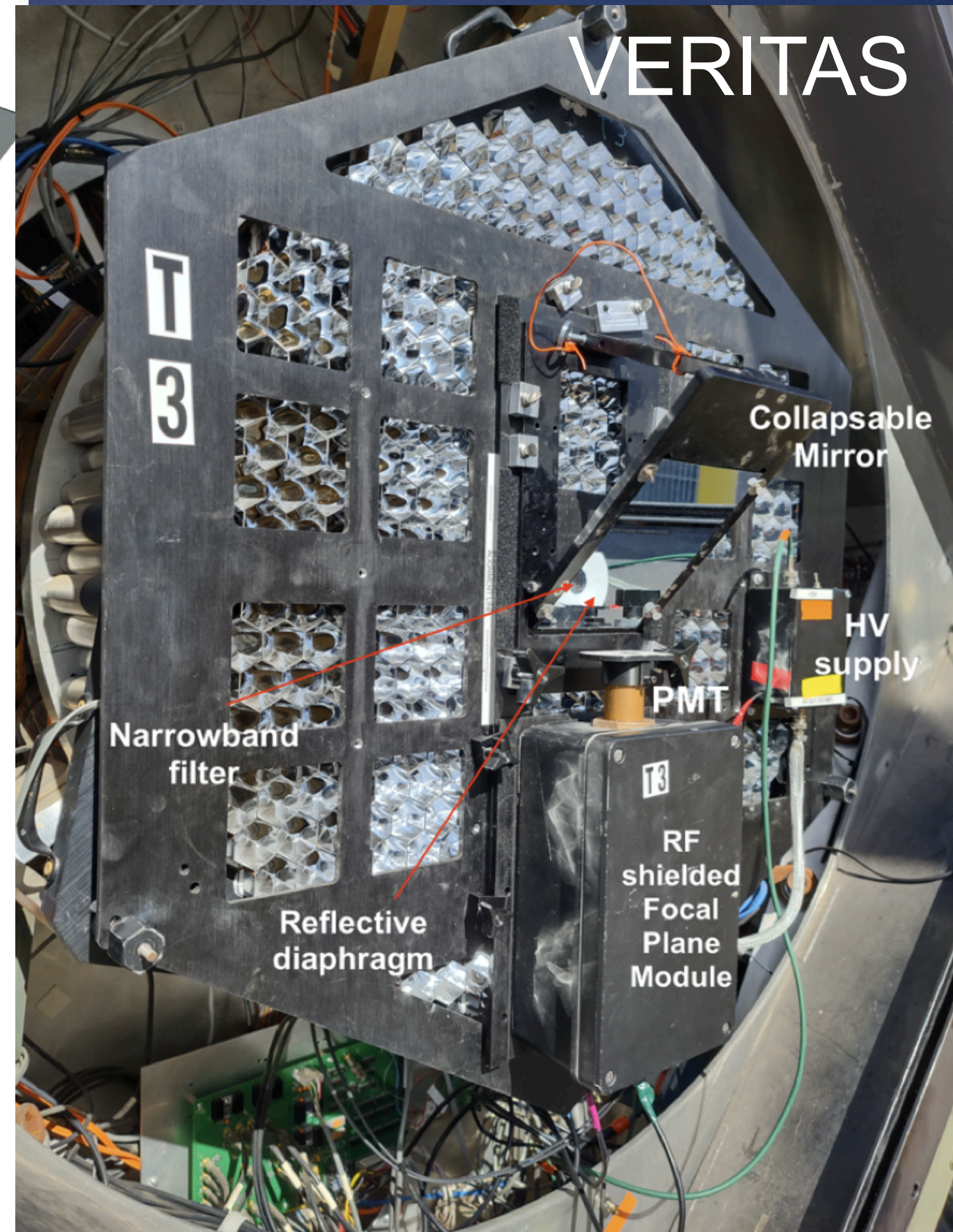
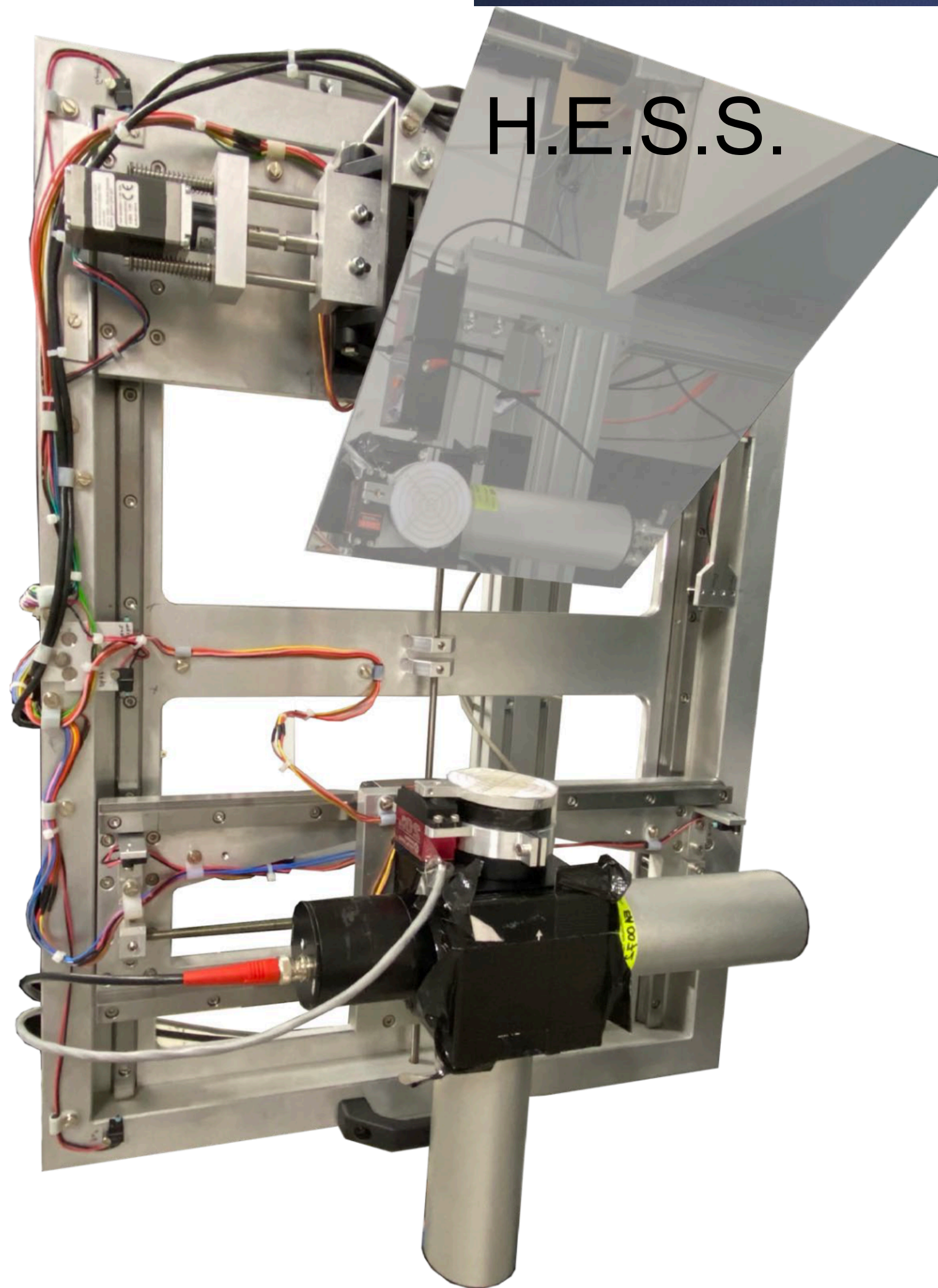


[Donath et al. 2023](#)

INTENSITY INTERFEROMETRY WITH H.E.S.S., VERITAS, AND MAGIC



INTENSITY INTERFEROMETRY WITH H.E.S.S., VERITAS, AND MAGIC

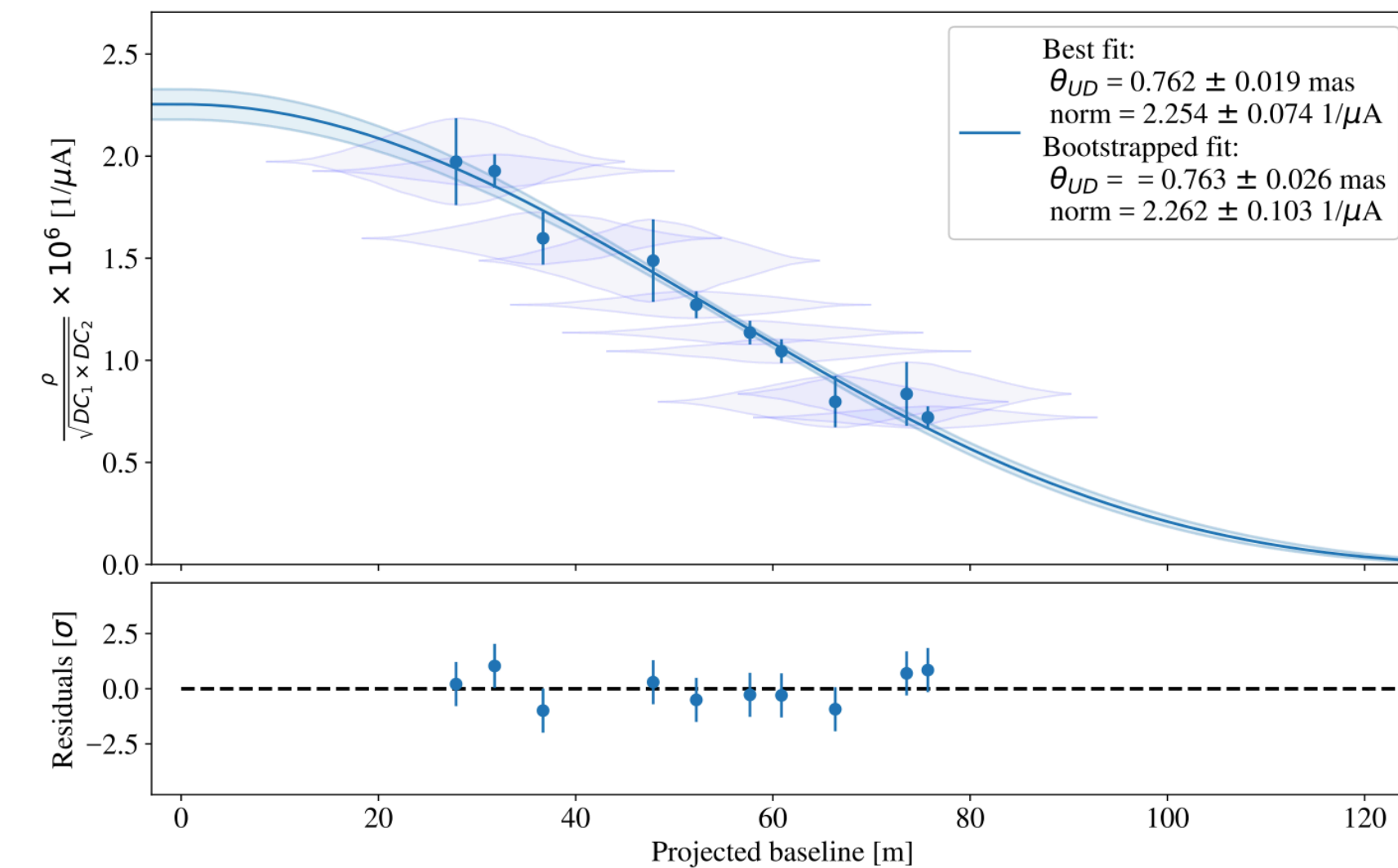
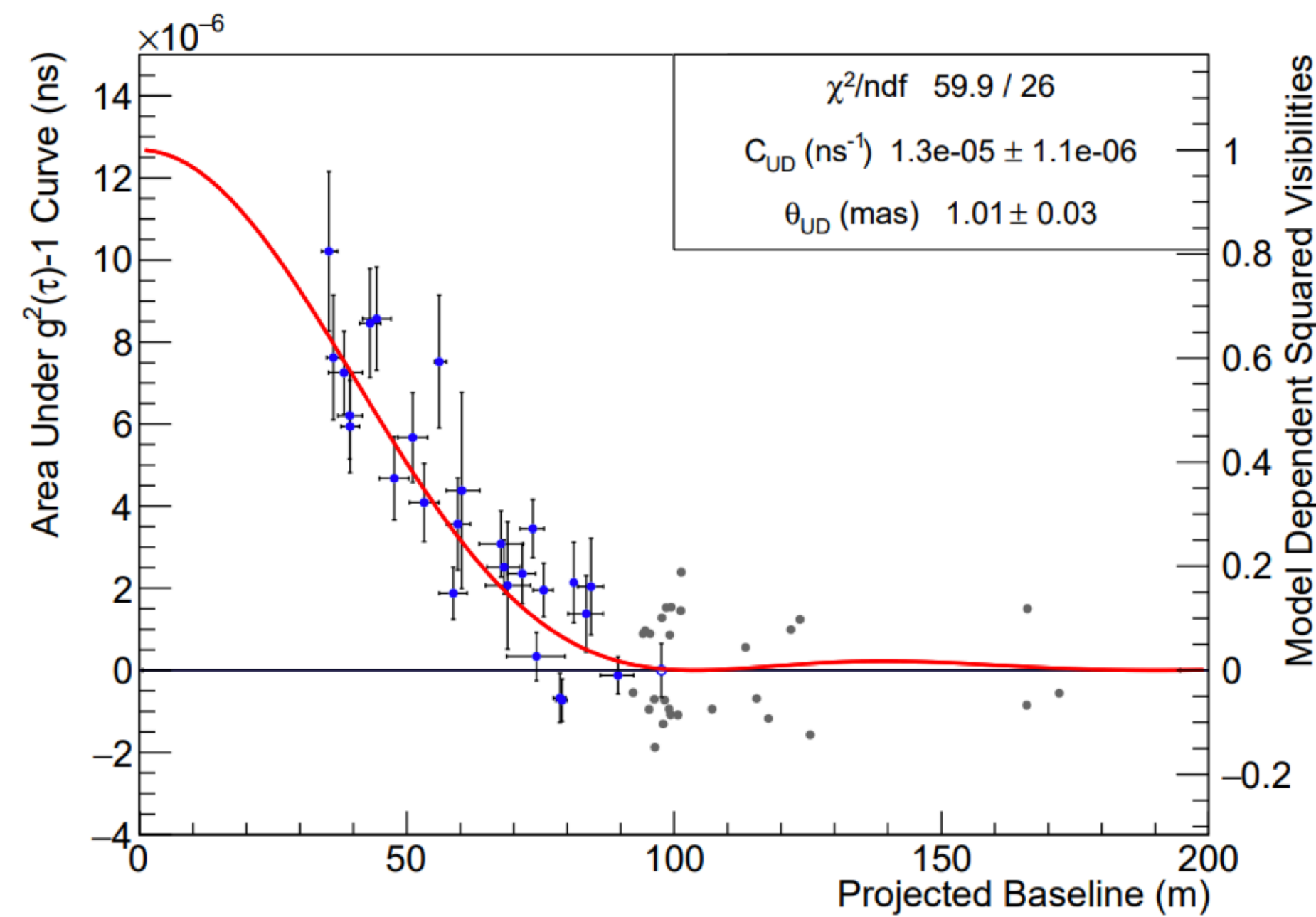
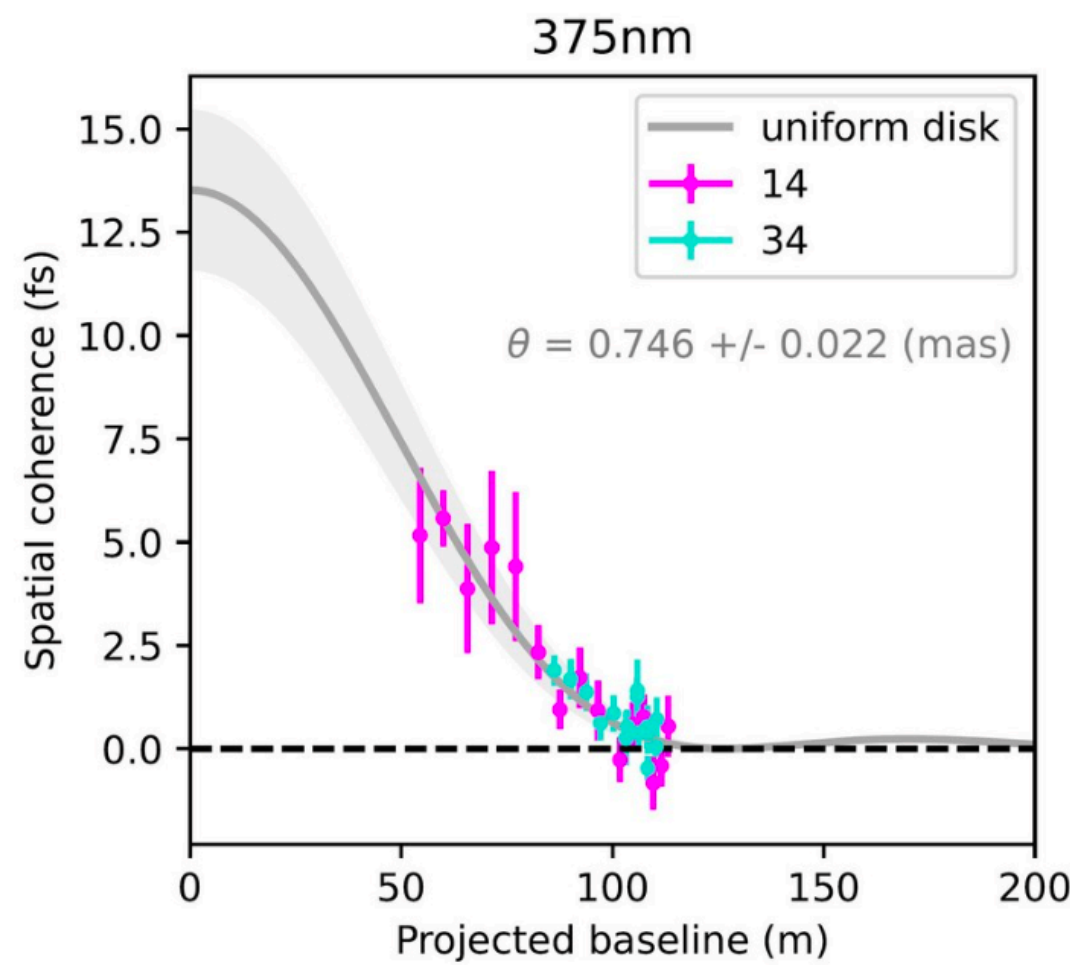
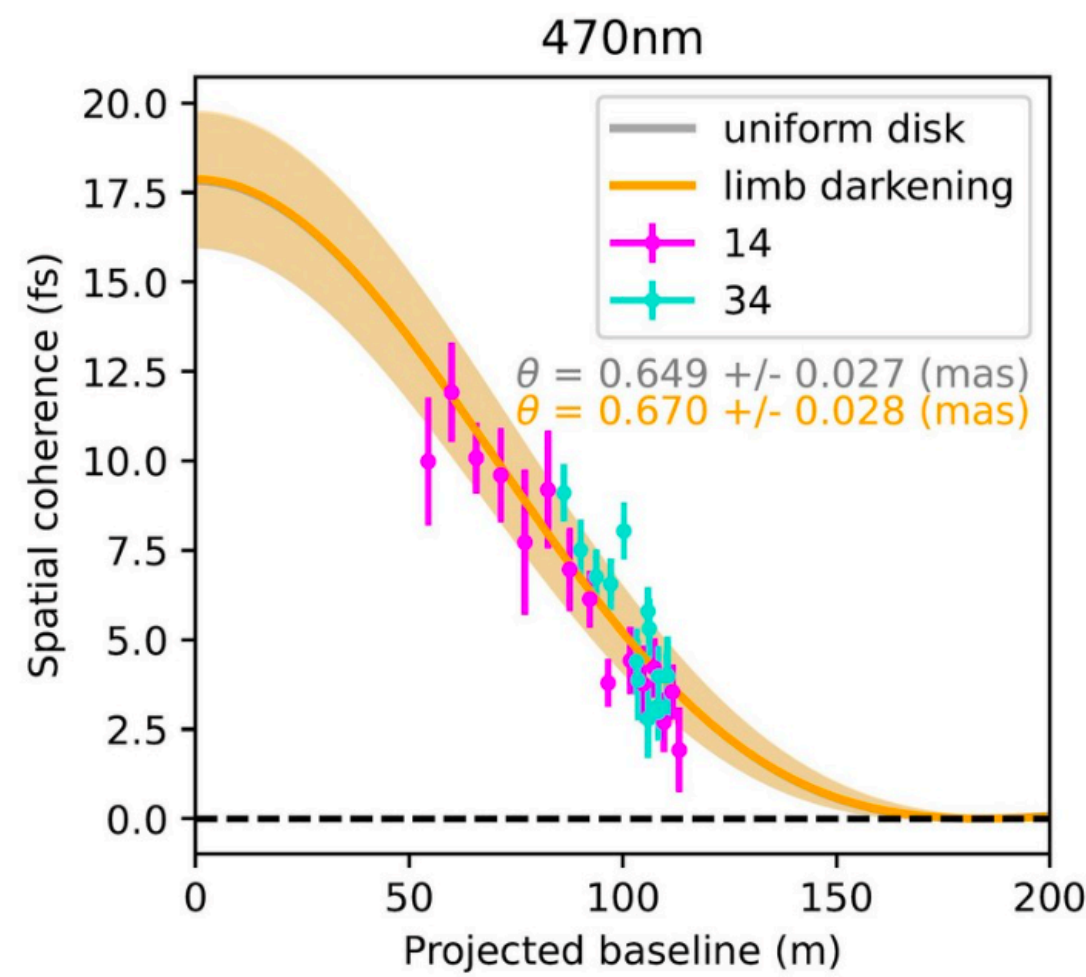


INTENSITY INTERFEROMETRY WITH H.E.S.S., VERITAS, AND MAGIC

H.E.S.S.

VERITAS

MAGIC

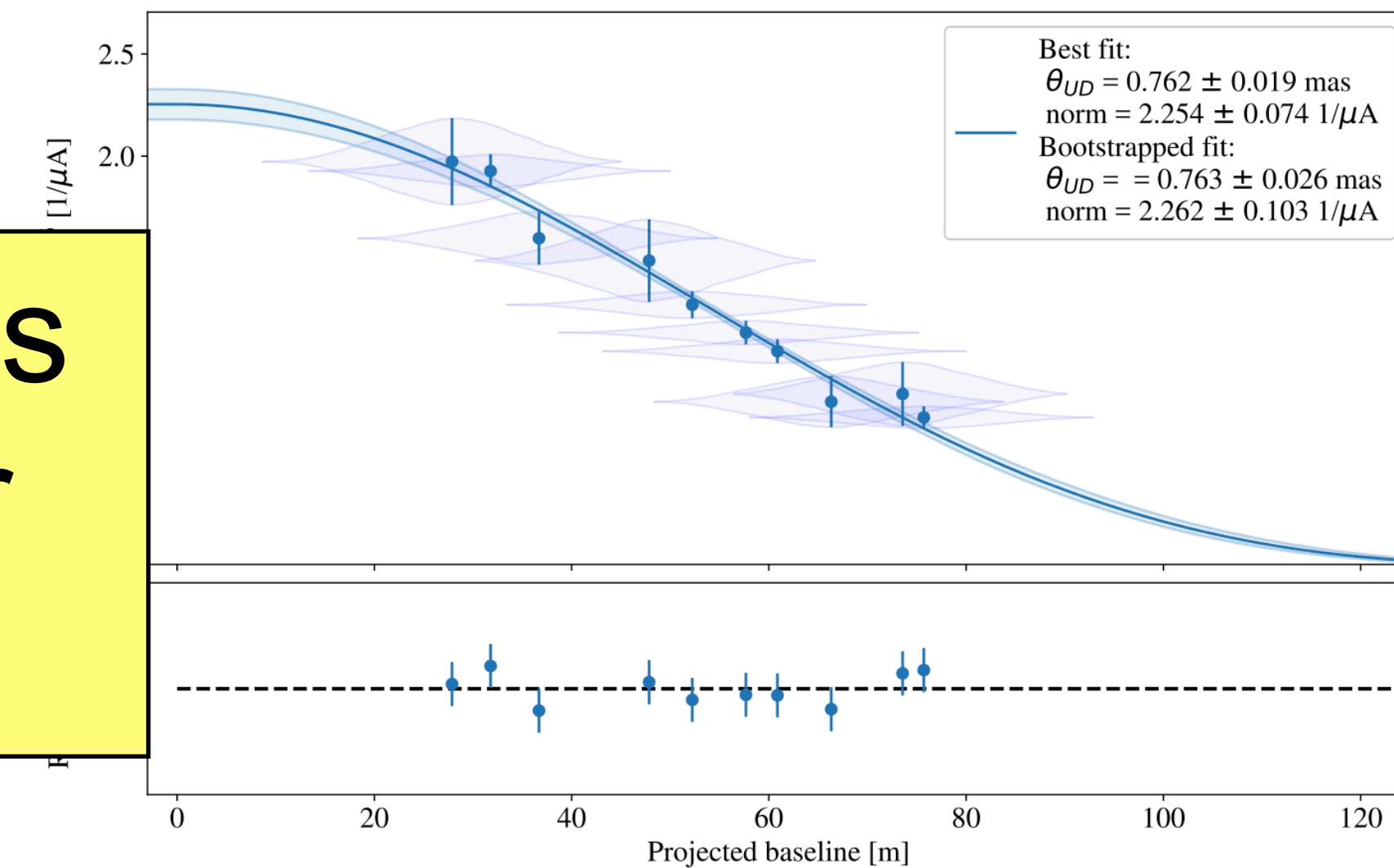
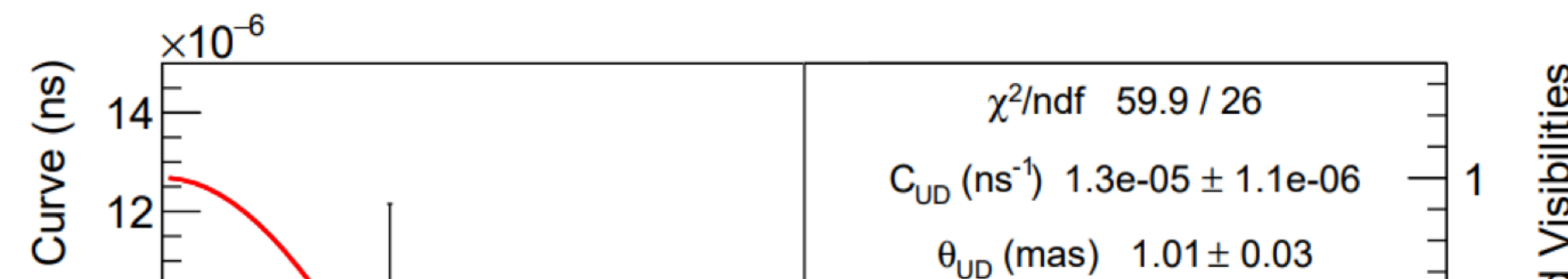
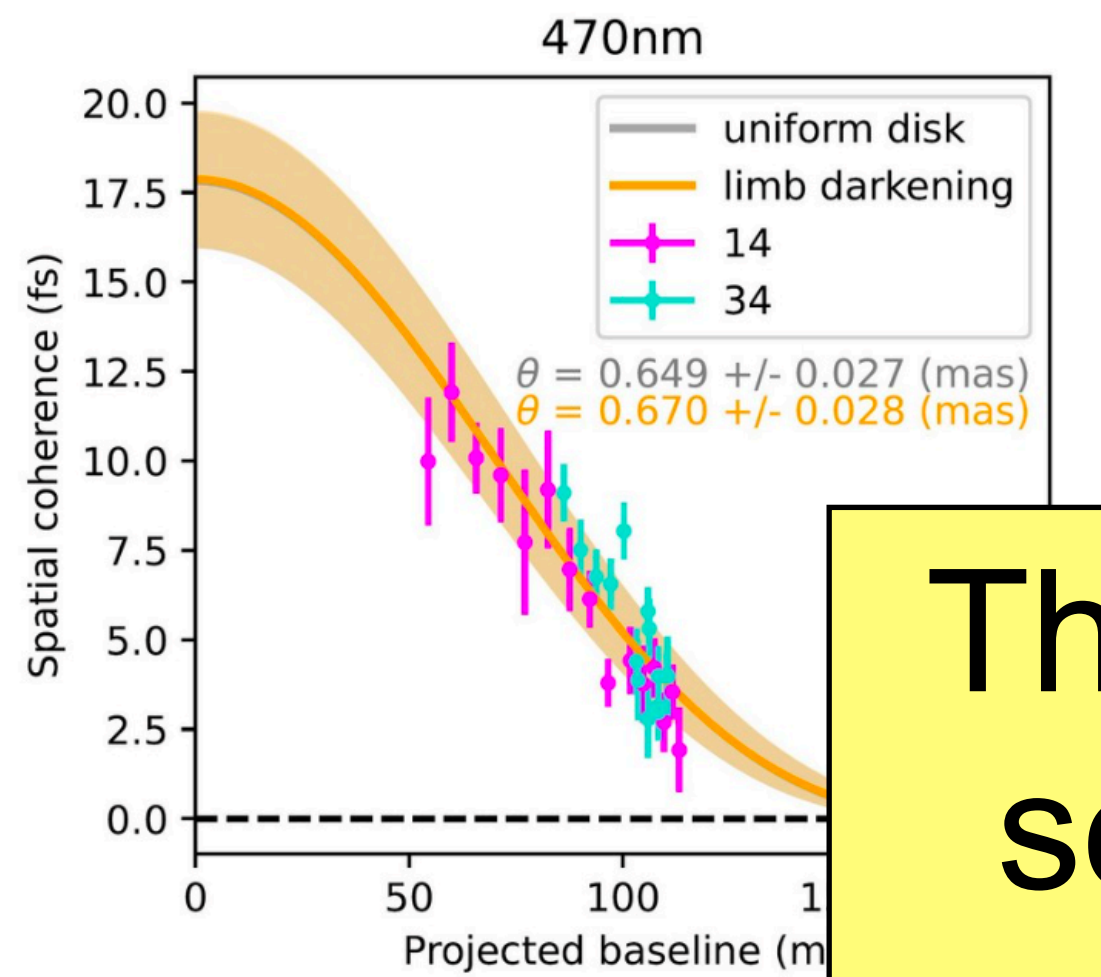


INTENSITY INTERFEROMETRY WITH H.E.S.S., VERITAS, AND MAGIC

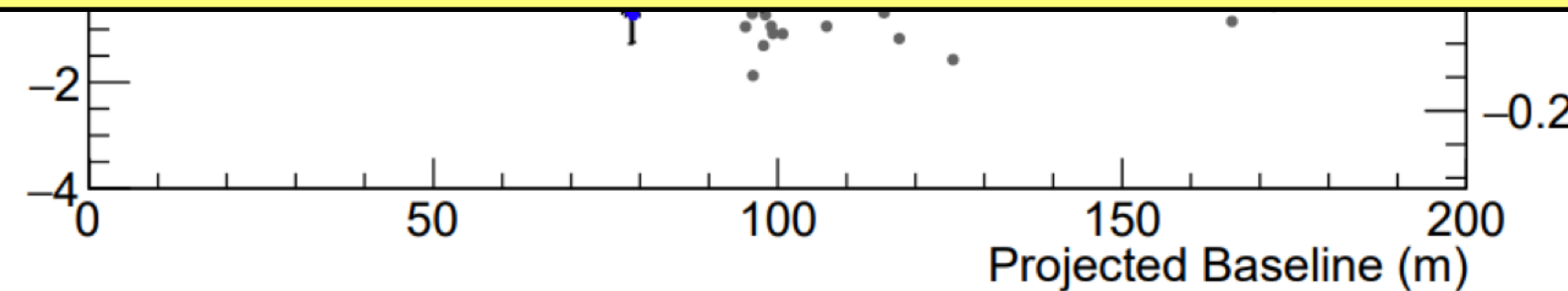
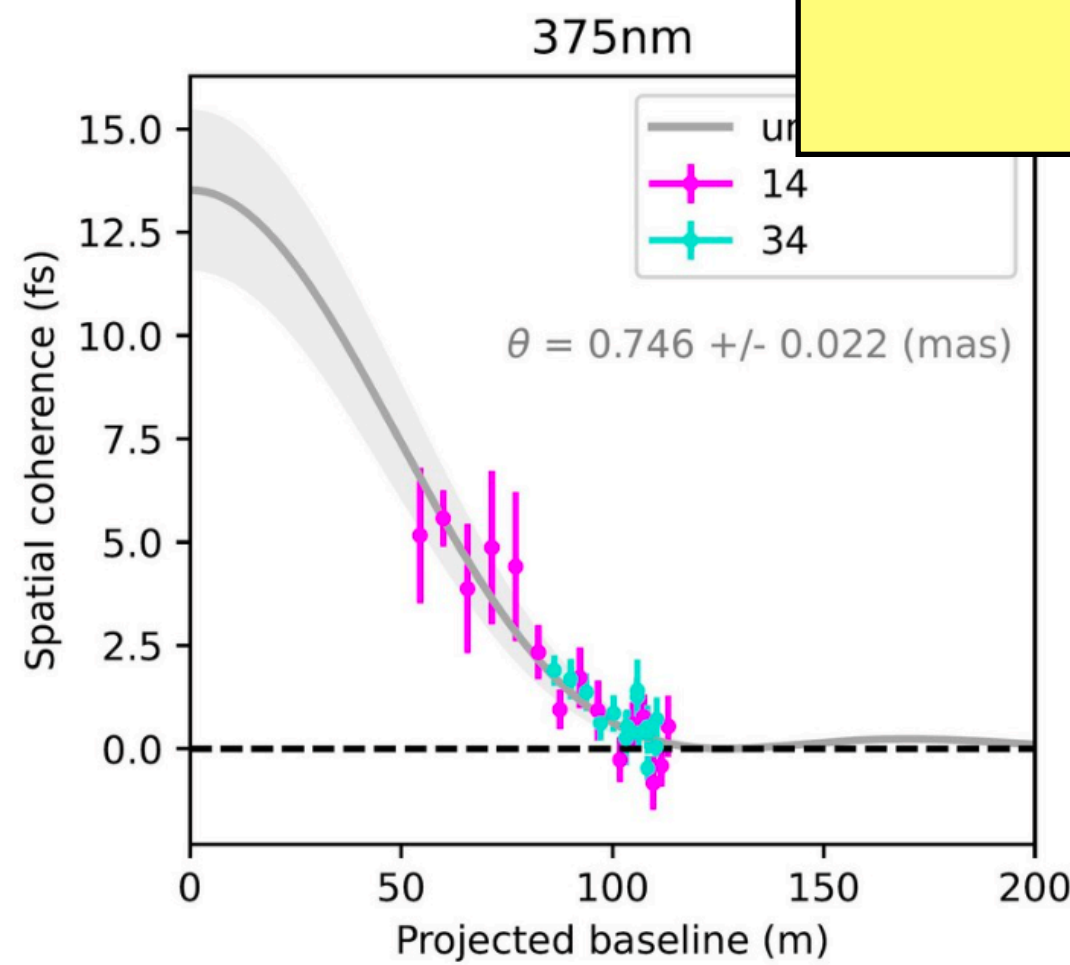
H.E.S.S.

VERITAS

MAGIC



Theme 3: Current instruments serve as crucial testbeds for technical developments.



CTA IS COMING: CAMERA FOR MSTs (FLASHCAM) IN OPERATION SINCE OCTOBER 2019



CTA IS COMING: SST-LIKE DESIGN IN ASTRI MINI ARRAY IN TENERIFE



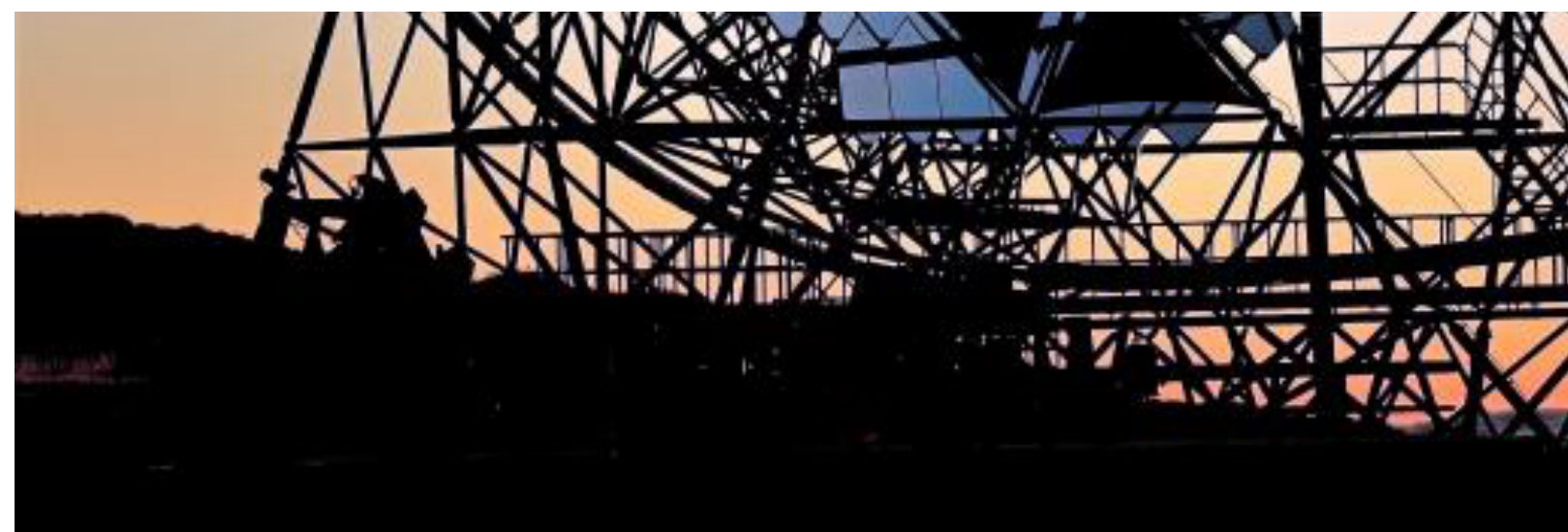
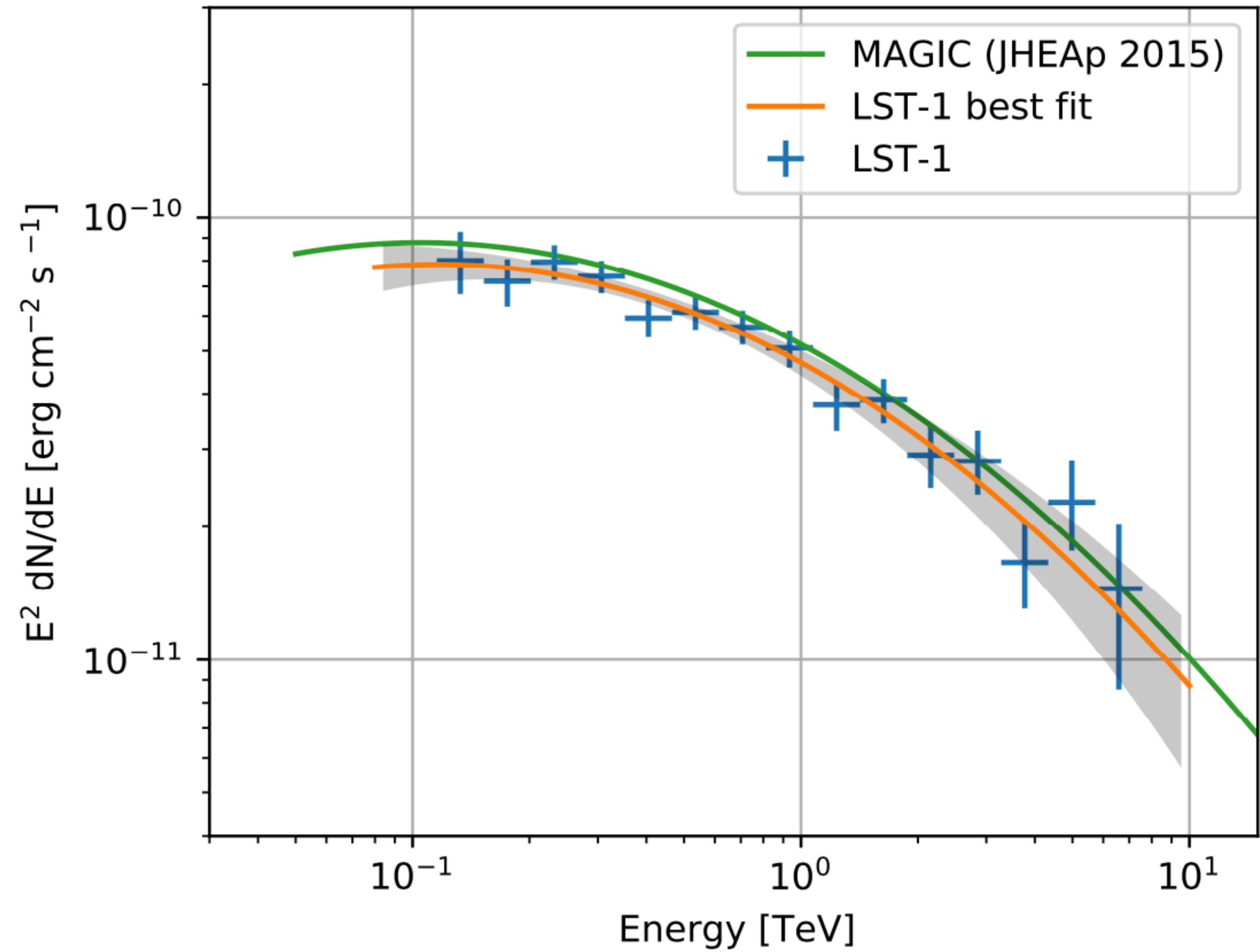
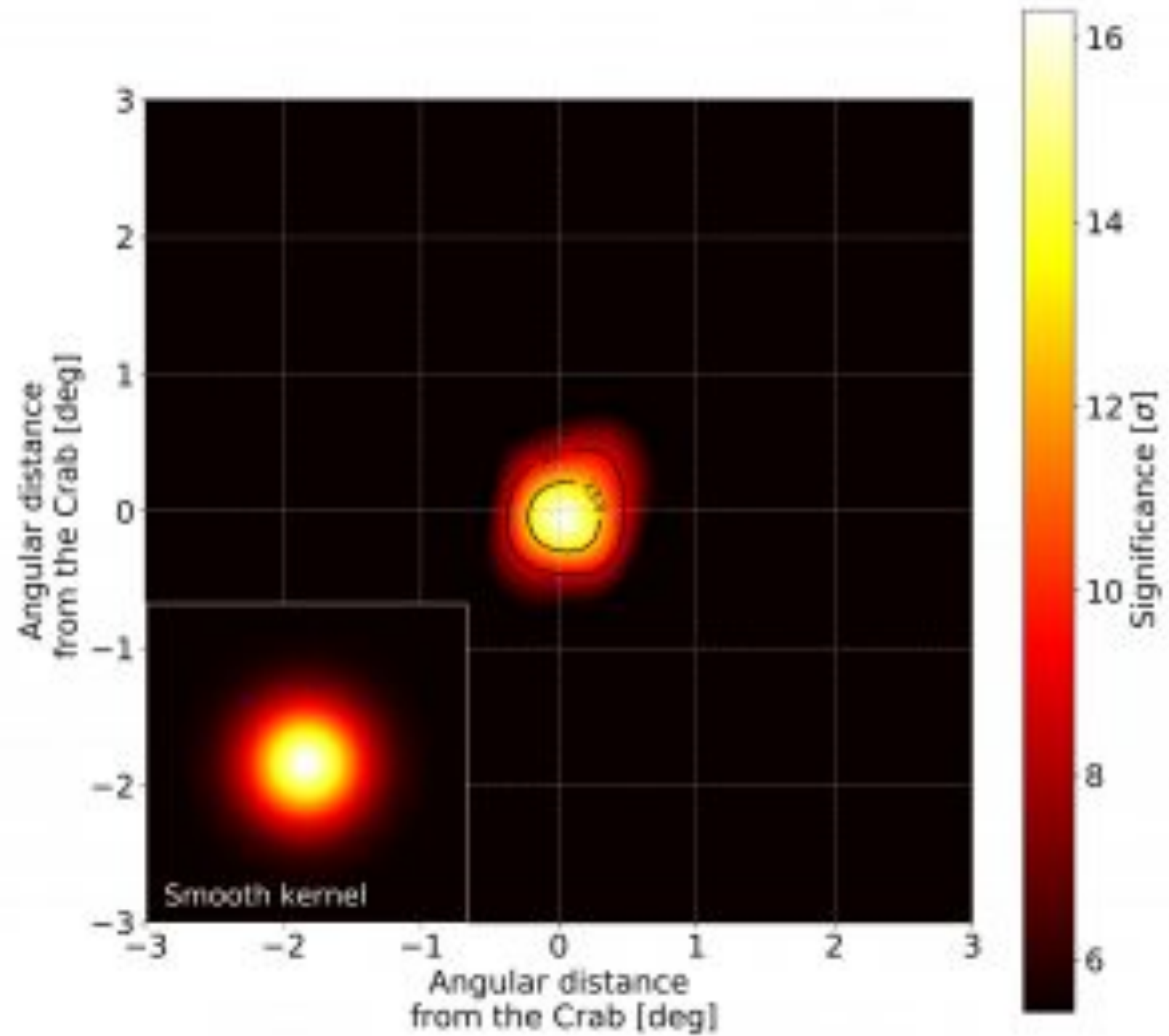
CTA IS COMING: SST-LIKE DESIGN IN ASTRI MINI ARRAY IN TENERIFE



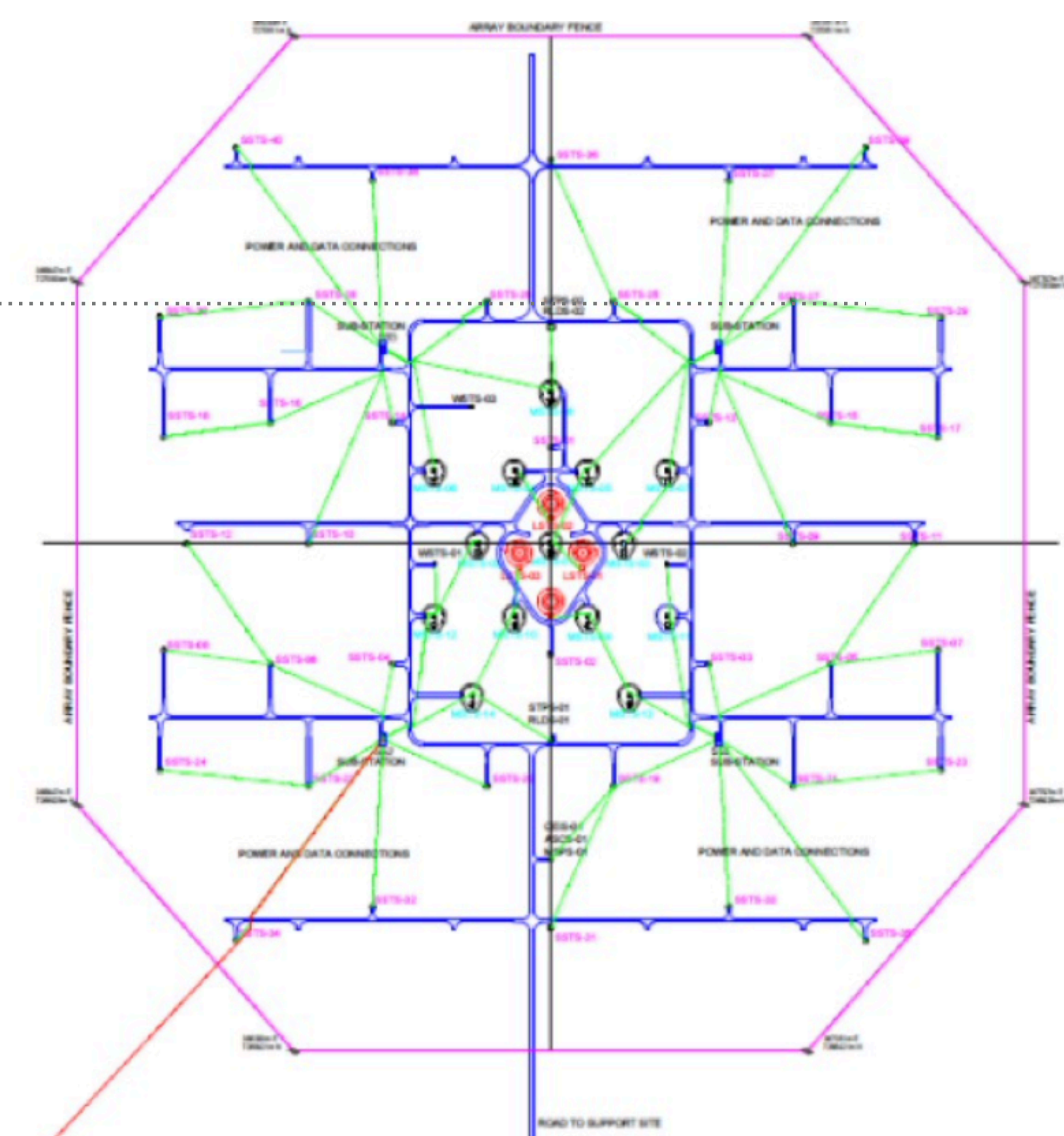
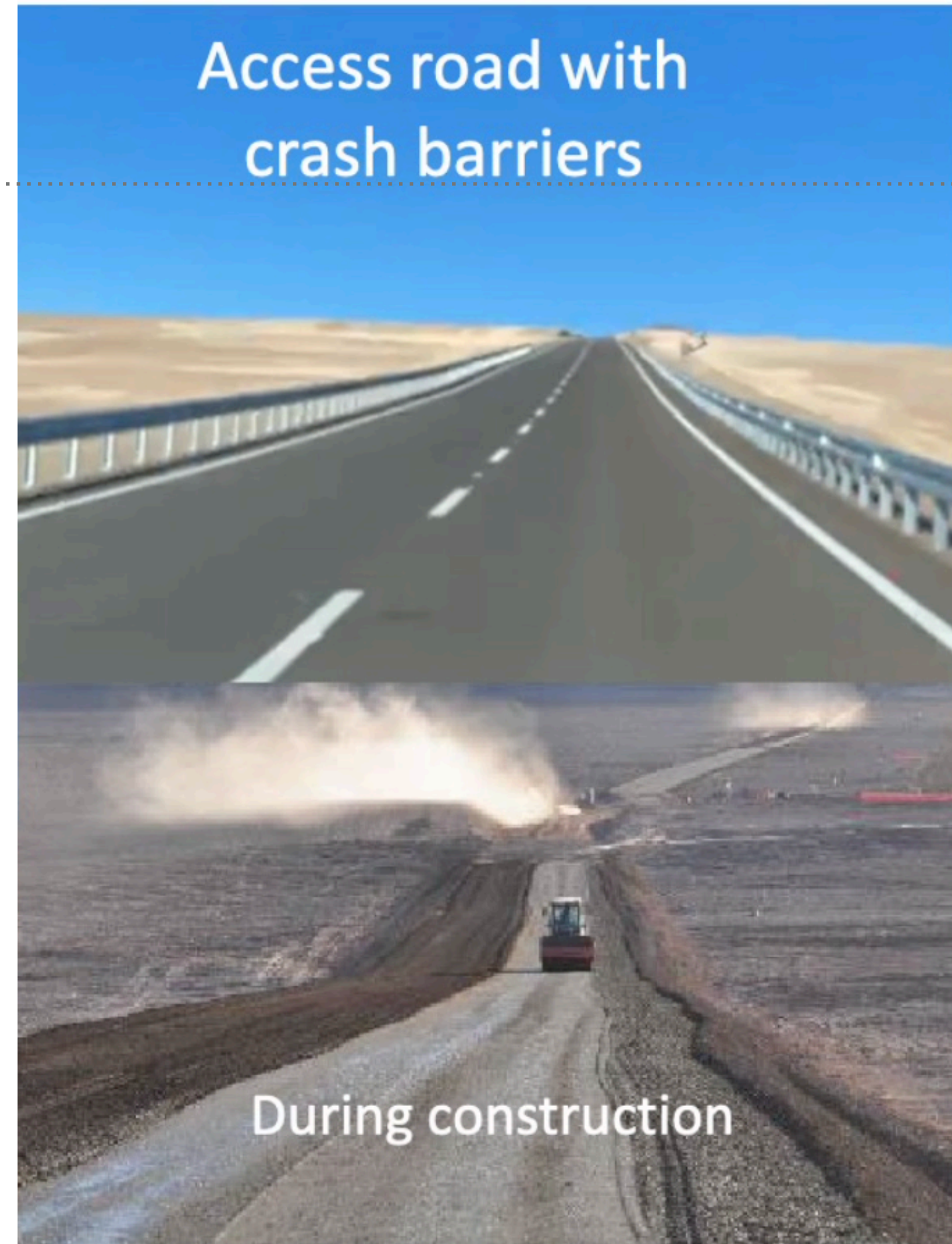
CTA IS COMING: THE LST1!



CTA IS COMING: THE LST1!

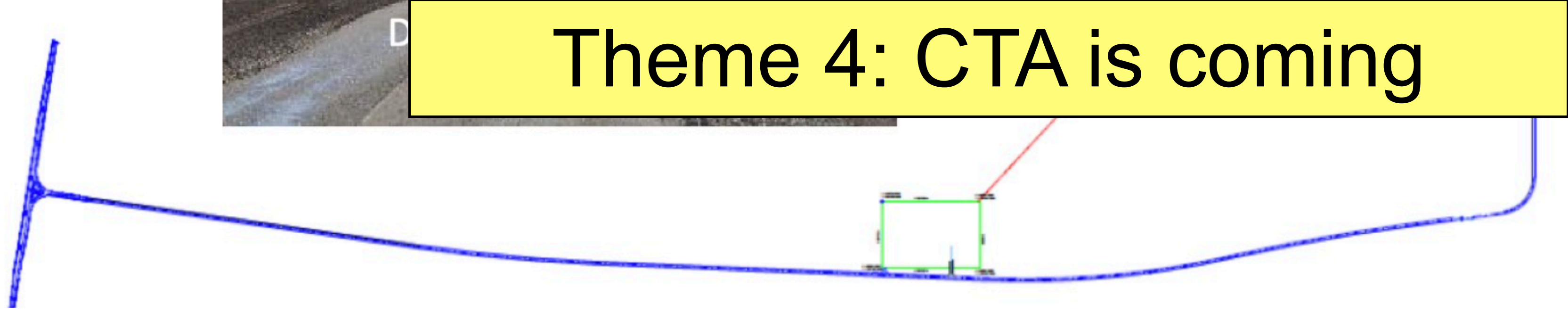
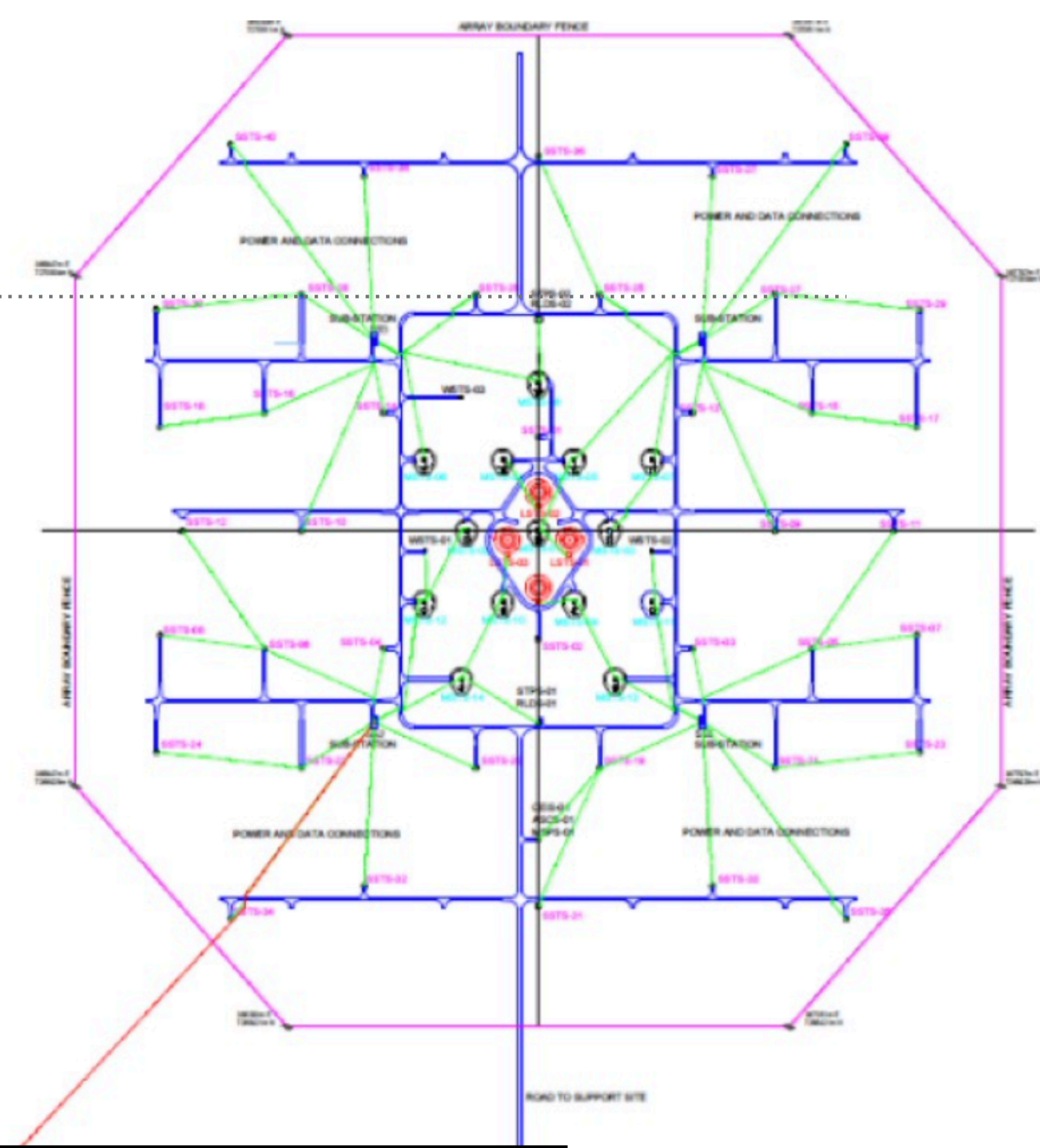
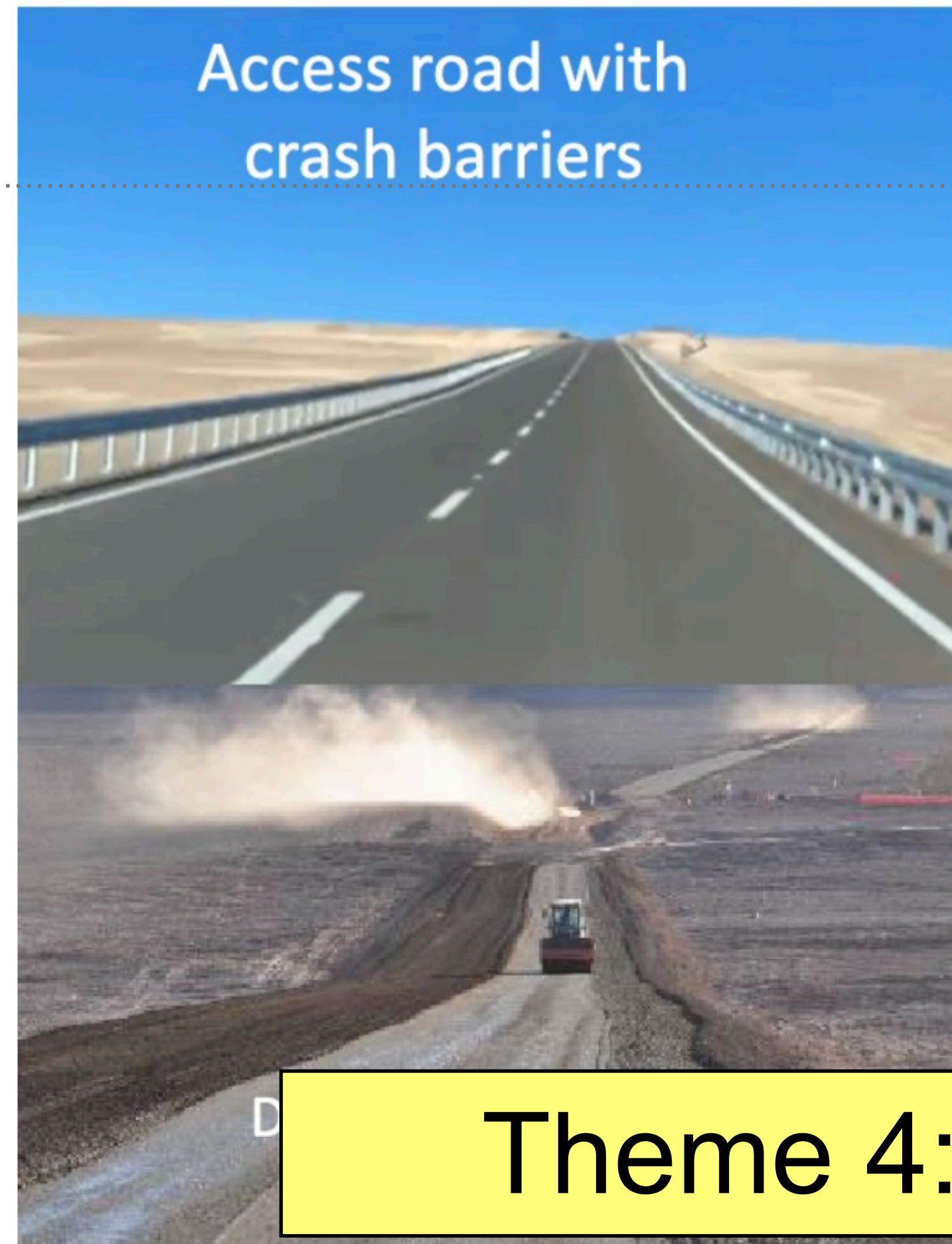


LATEST STATUS

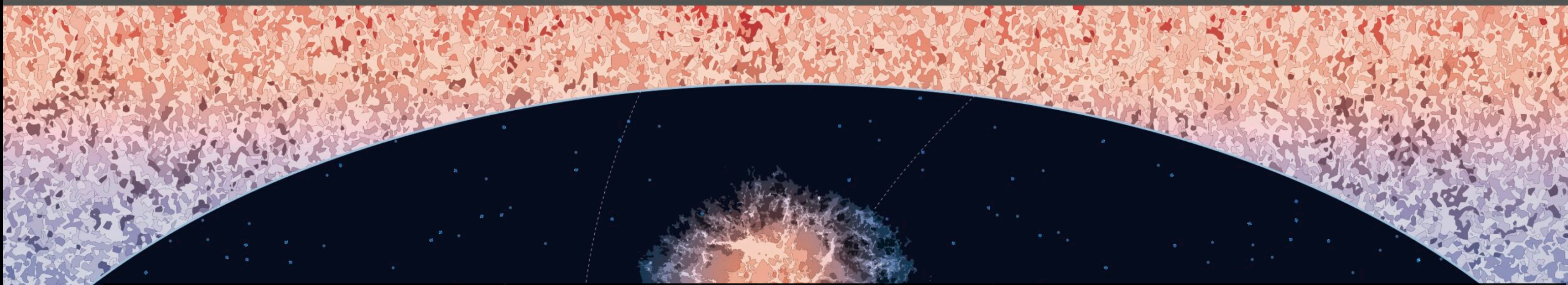



Pre-Construction Current Phase	Pre-Production 2022-2023	Production 2023-2027
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LATEST STATUS



Pre-Construction Current Phase	Pre-Production 2022-2023	Production 2023-2027
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- Theme 1: A gamma-ray all-sky detector is essential for multi-messenger astrophysics.
- Theme 2: Strong synergies between gamma-ray telescopes
- Theme 3: Current instruments serve as crucial testbeds for technical developments.
- Theme 4: CTA is coming!



In recent years, a large network of observatories has been deployed on remote places in the land, in the sea, underground and in space, to detect the signals coming from the "visible" Universe and even earlier, in the first moments beyond the "recombination wall" when nuclei and electrons formed neutral atoms and the Universe became transparent.

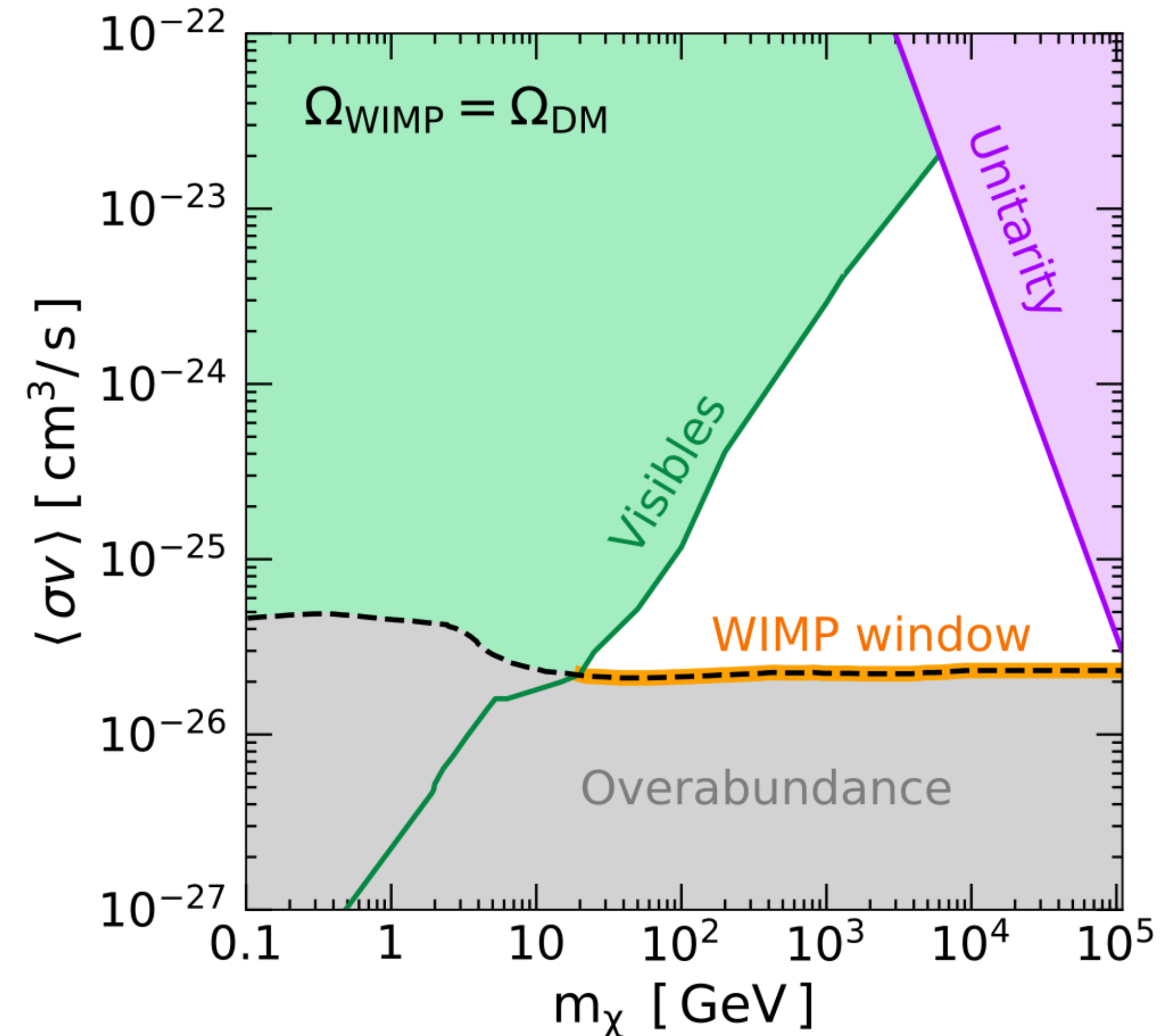
LISTENING TO NEW
COSMIC MESSENGERS

DARK MATTER: WIMPS ARE NOT DEAD

- WIMP window at 100-10000 GeV.
- See e.g. paper <https://arxiv.org/pdf/1805.10305.pdf>
- Neutrinos not included!
- Neutrinos least constraining at the moment but likely decisive in testing WIMP hypothesis

1805.10305

Leane, Slatyer, Beacom, Ng



WHY A 1-IN-10000 YEAR EVENT?

