



The very high energy γ -ray view of our galaxy

Searching for the sources of Galactic cosmic rays
APC Paris, Dec. 11-14th 2018

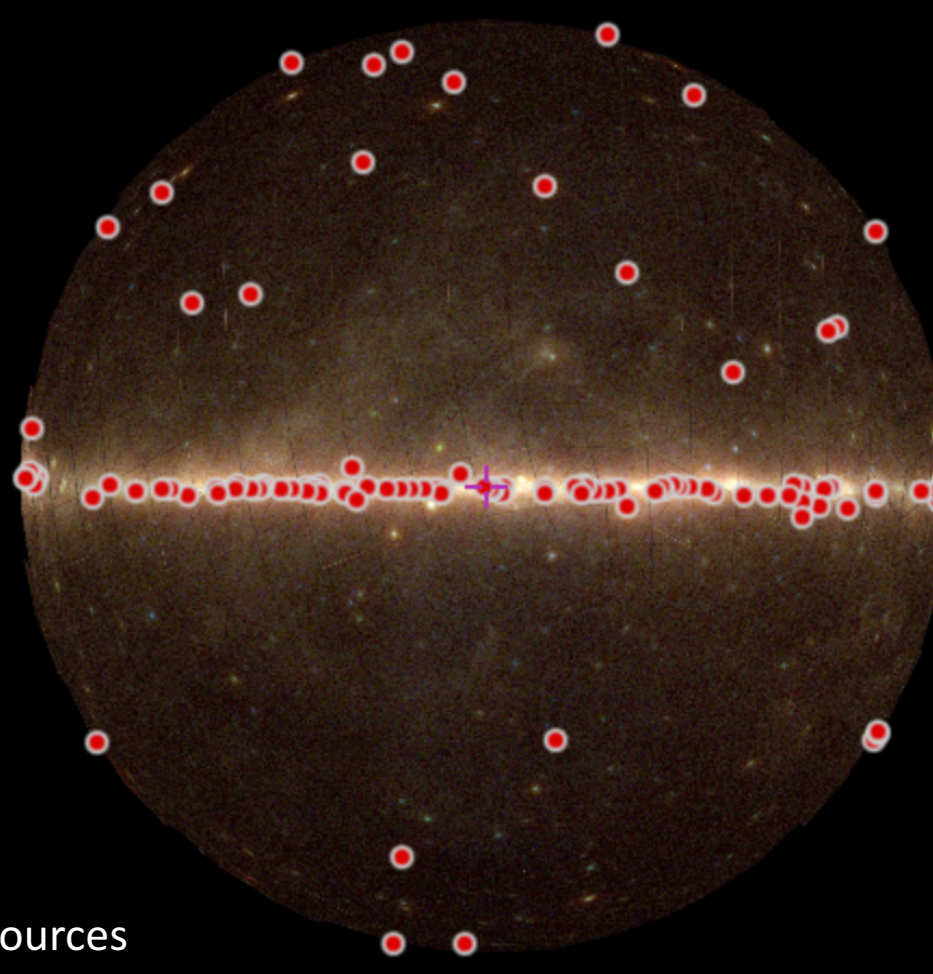
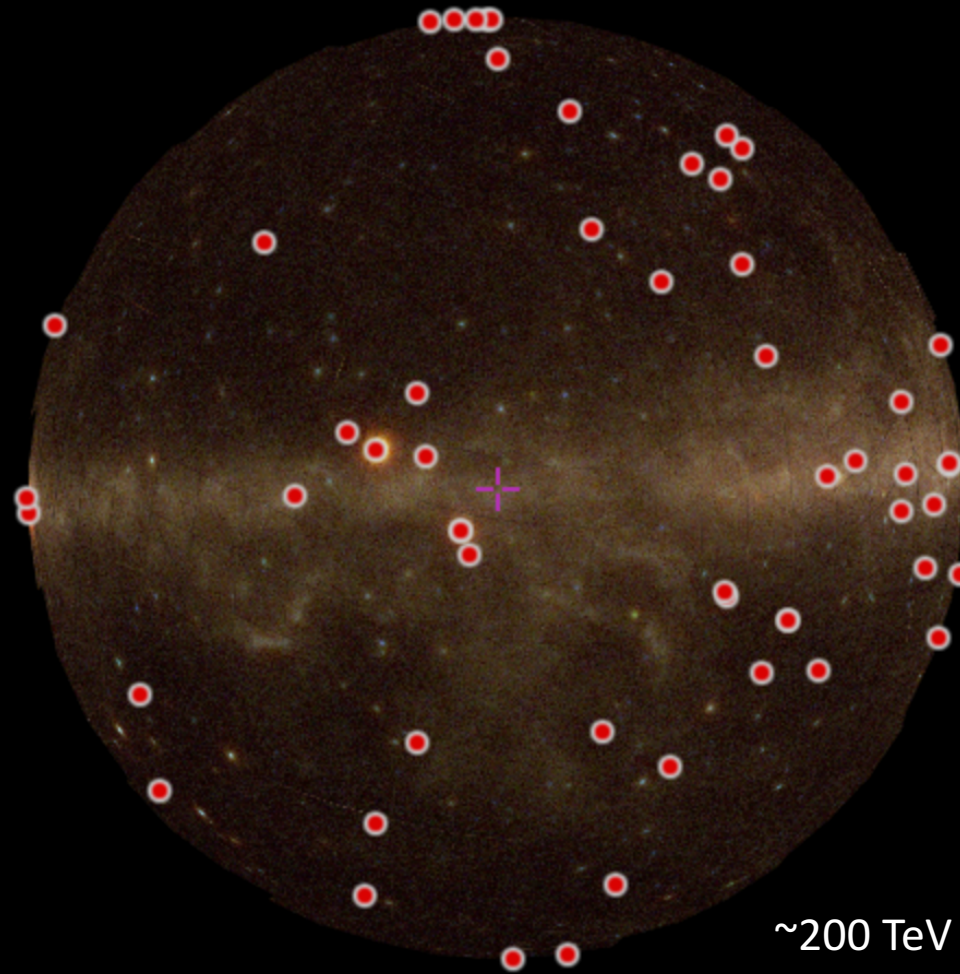
Jim Hinton - MPIK



The TeV Sky

Towards Anti-Centre

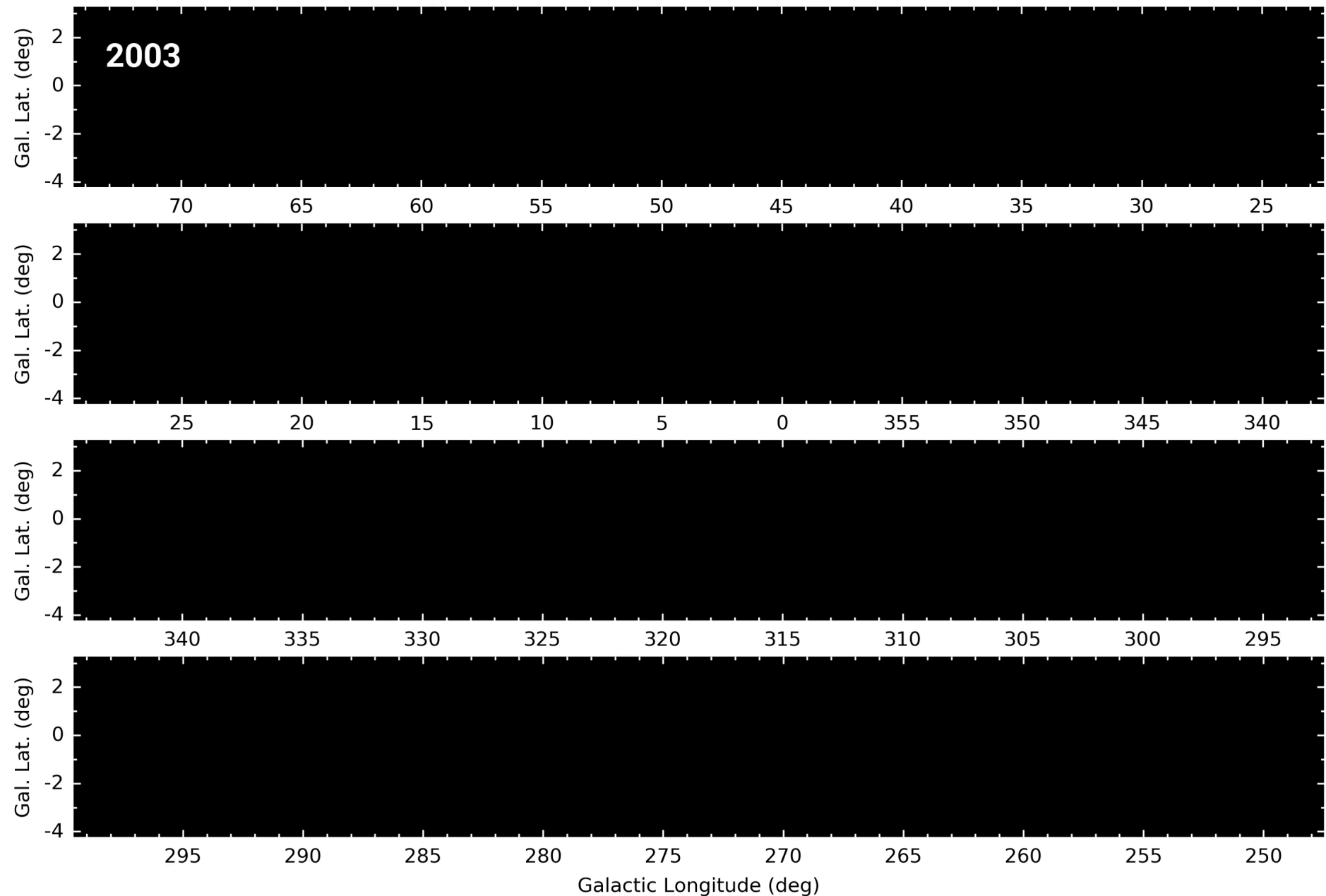
Towards GC



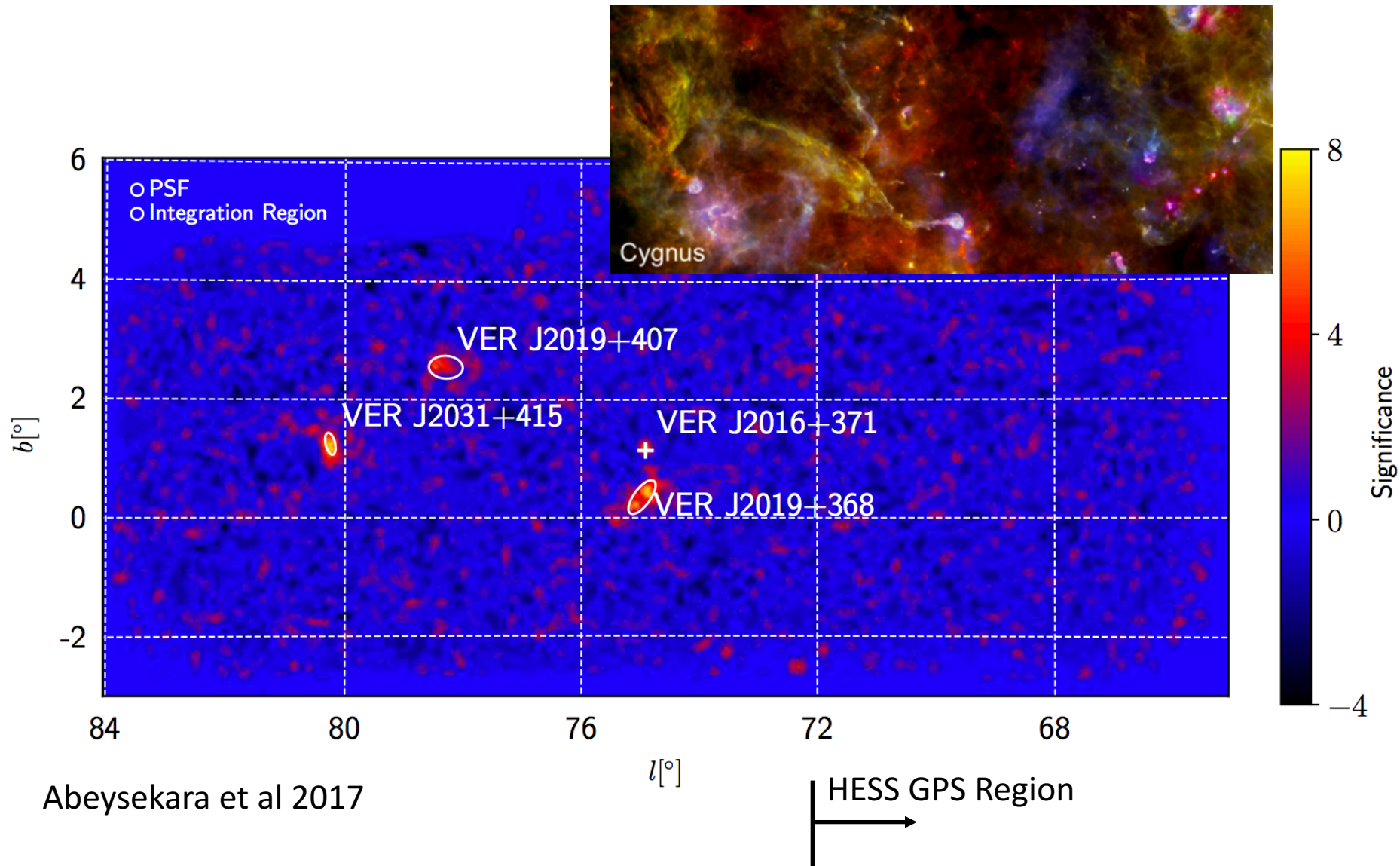
~200 TeV Sources

Background: Fermi-LAT

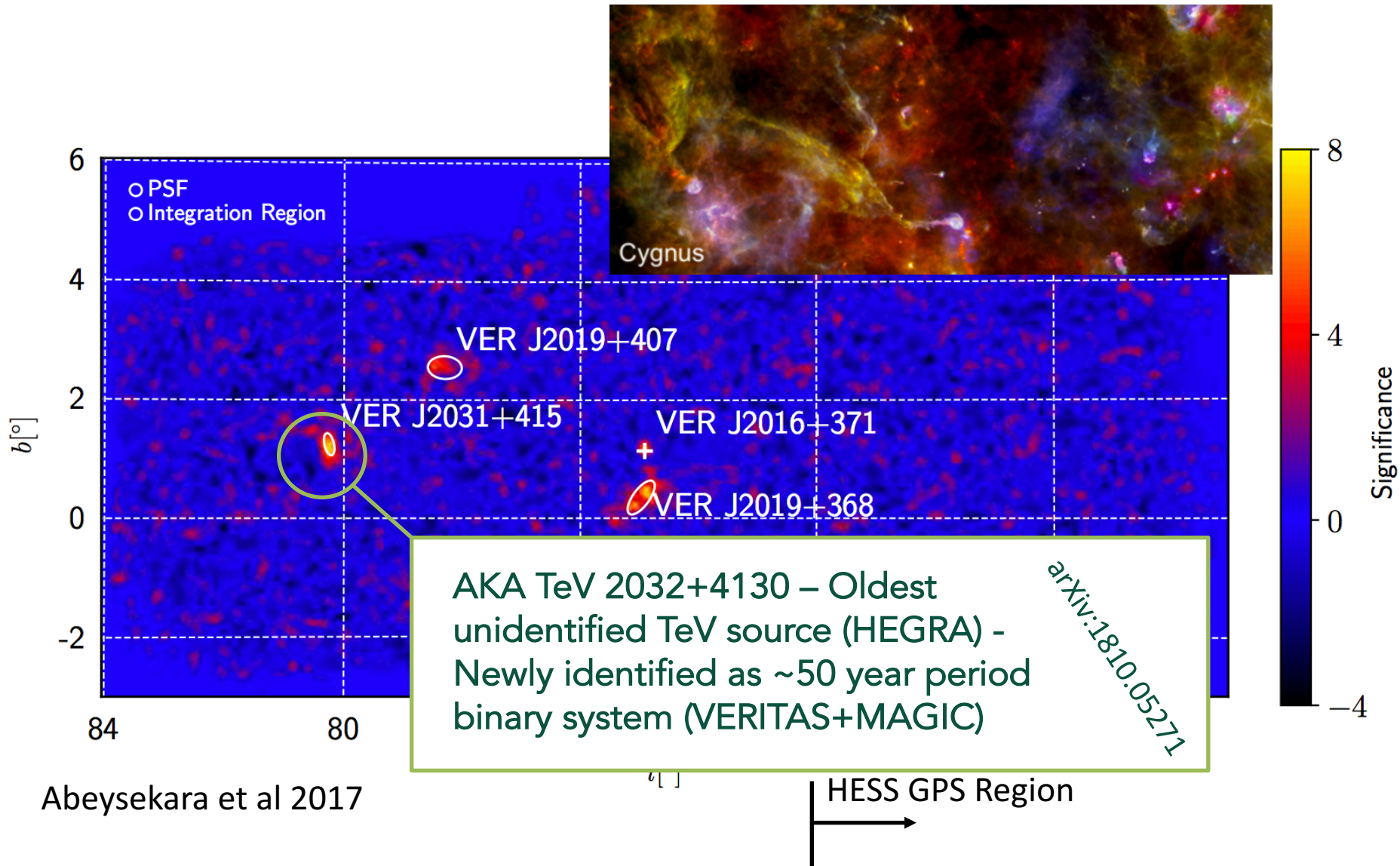


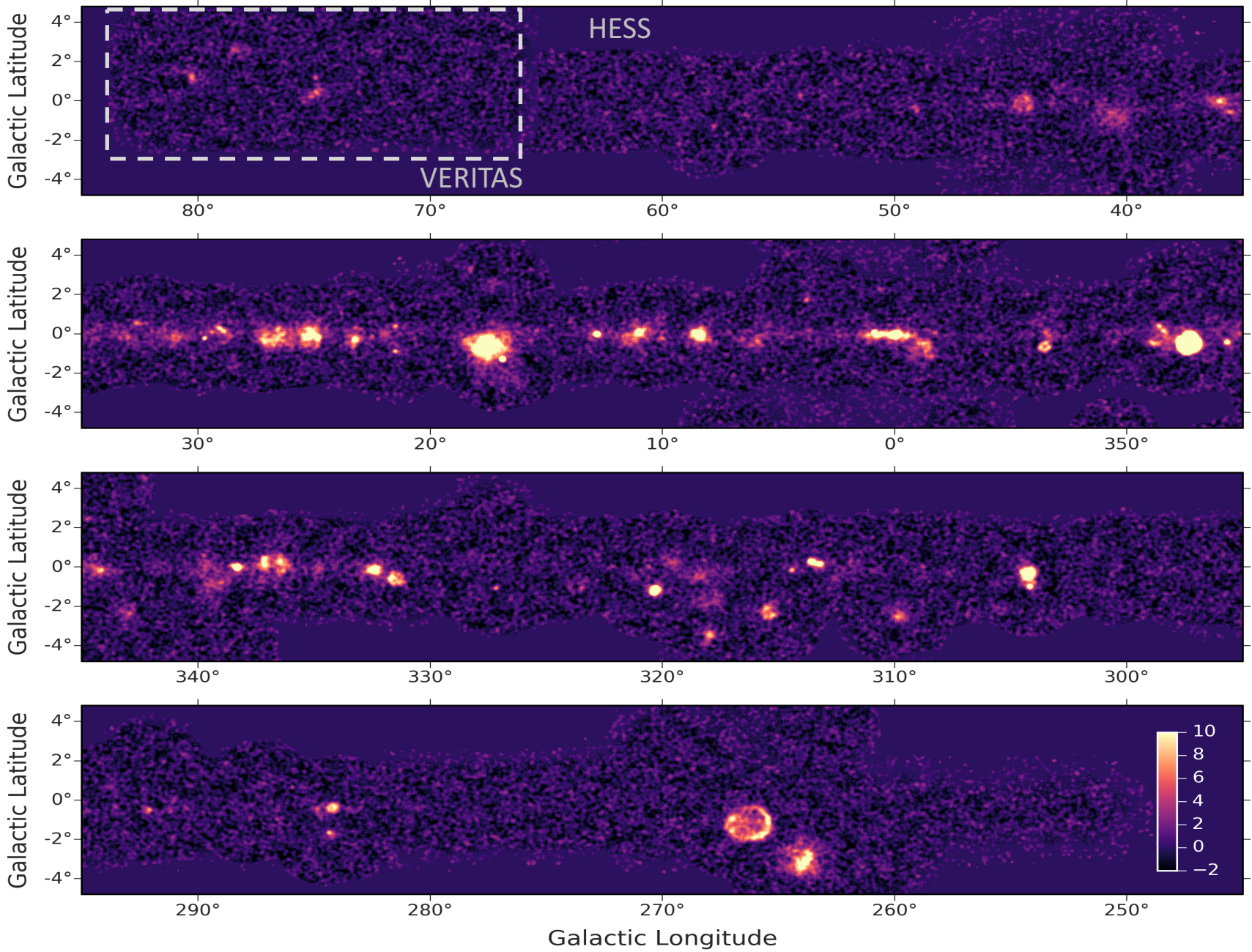


VERITAS - Cygnus Region



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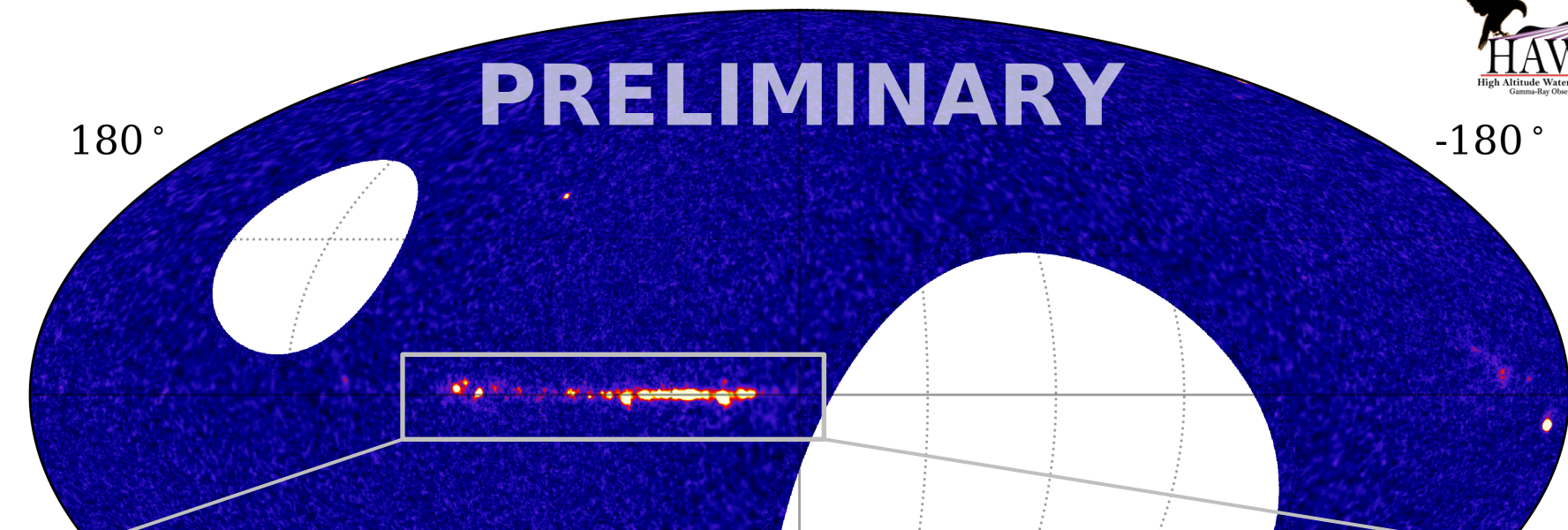


From Dan Parsons (MPIK)

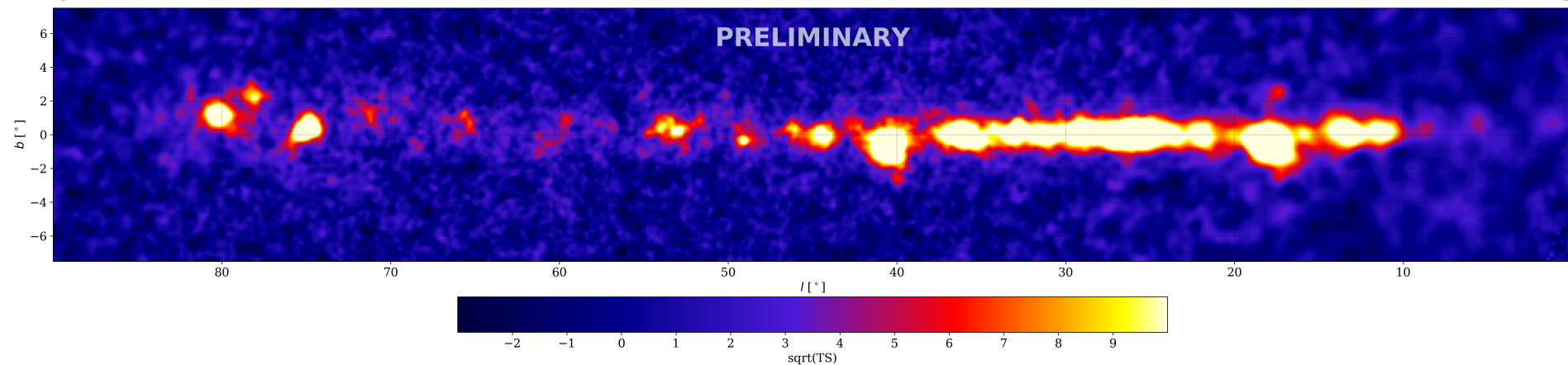
PRELIMINARY

180°

-180°



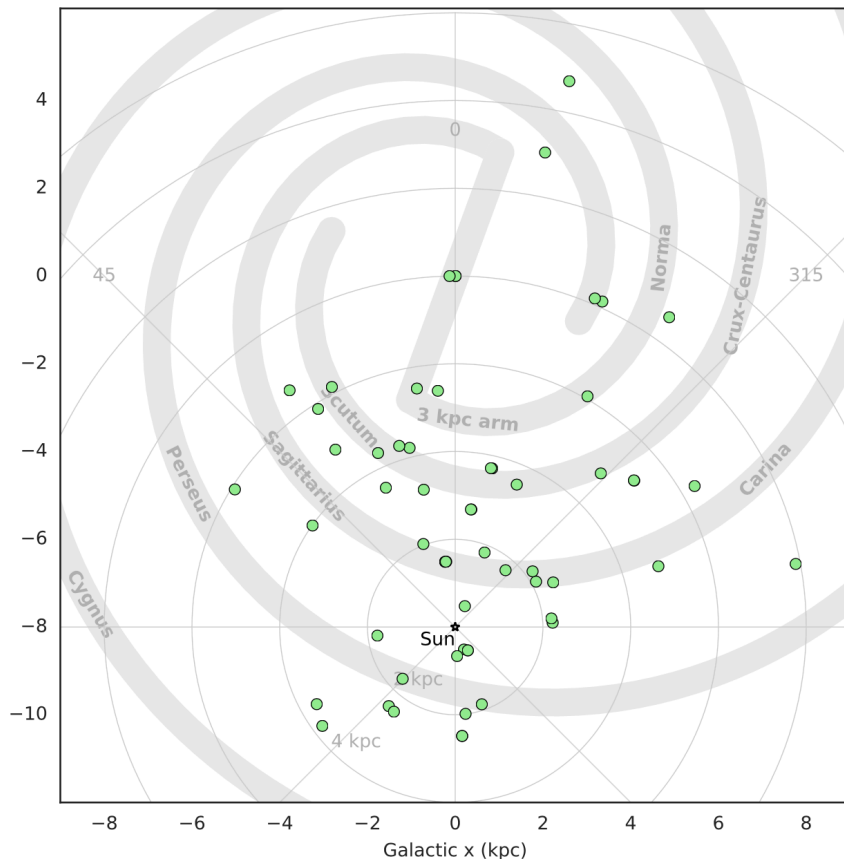
PRELIMINARY



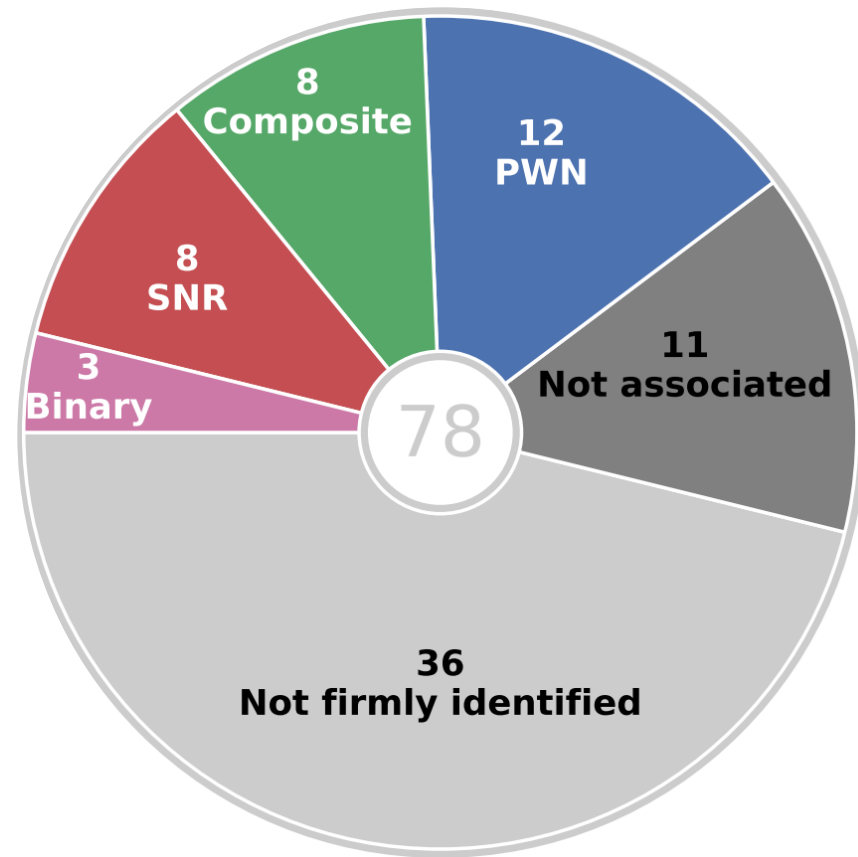
- ⊙ First HAWC catalogue: 39 sources, 16 new, 507 days
- + Dataset now doubled

Populations

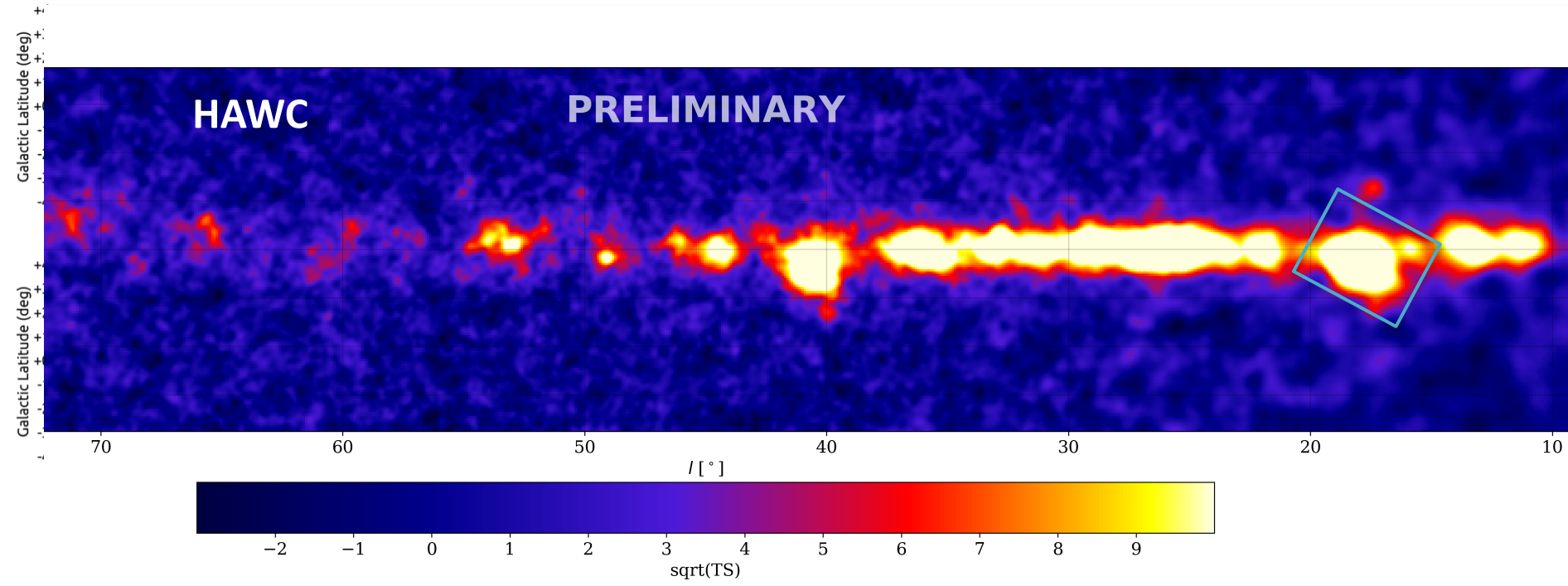
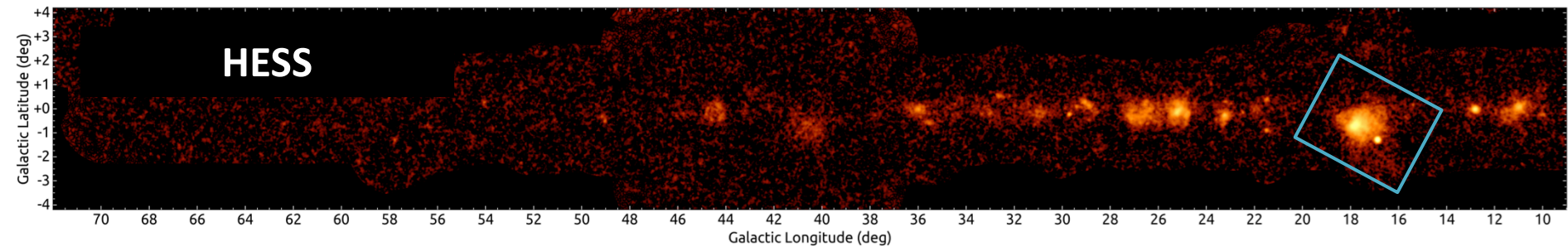
From Dan Parsons (MPIK)



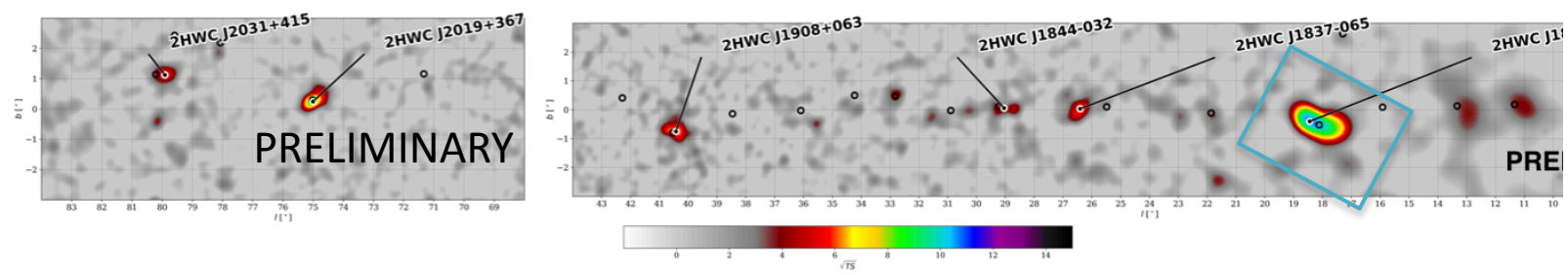
⊙ Typically probing few kpc distances



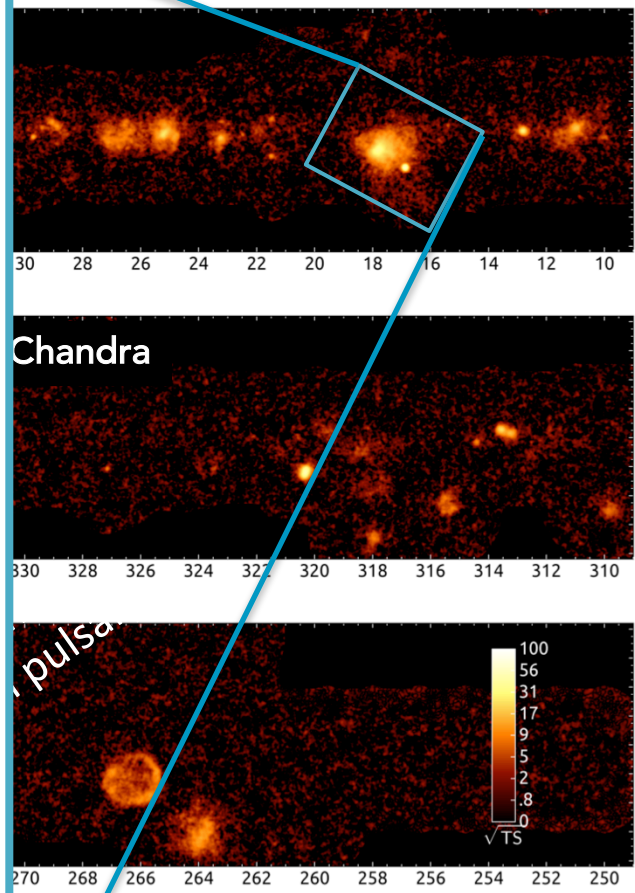
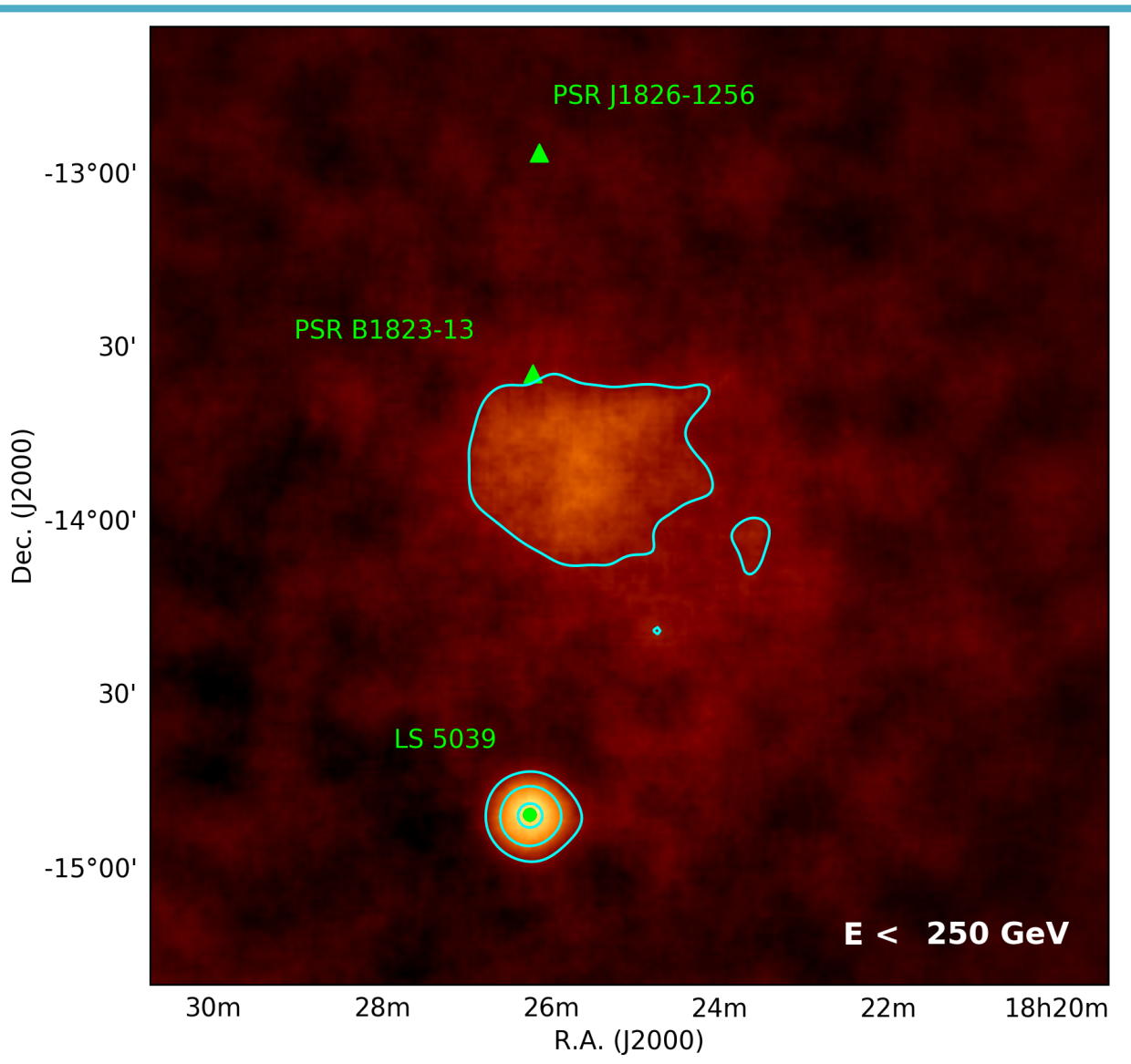
⊙ From HESS
GP Survey



HAWC
 $E_r > 56$ TeV

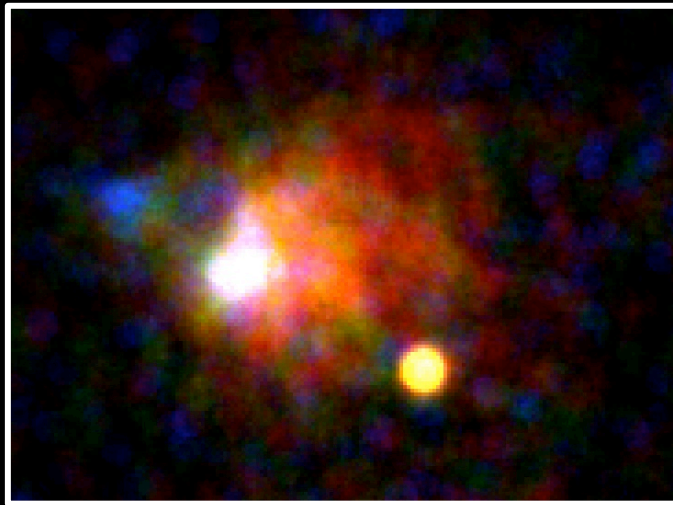


HESS Galactic Plane Survey

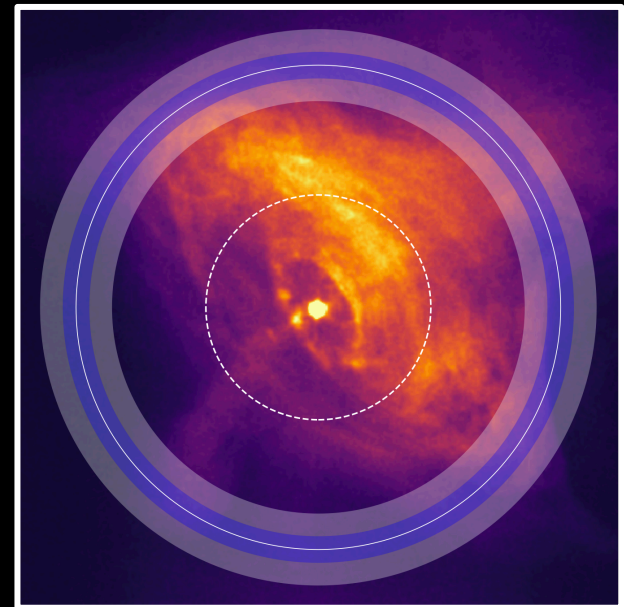


PWNe

Crab Nebula

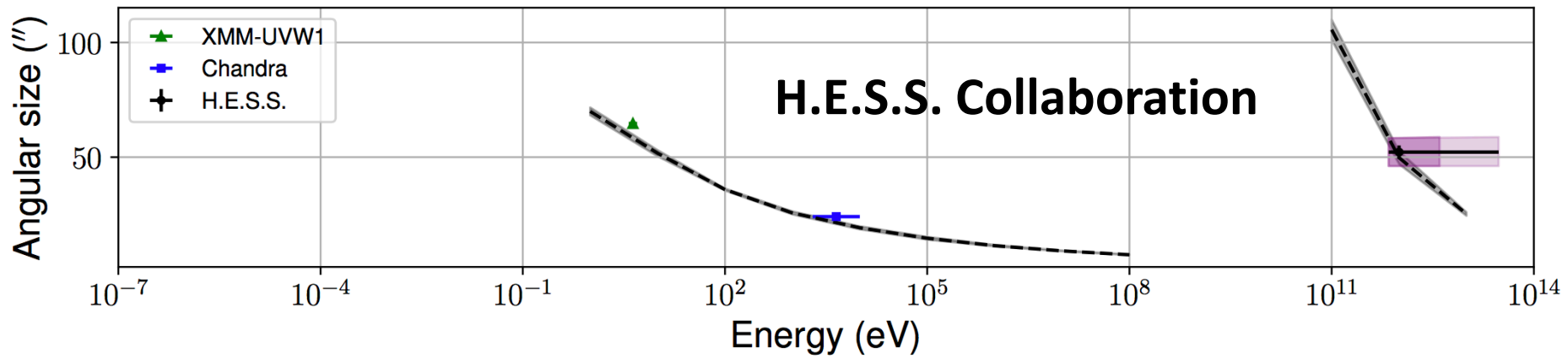
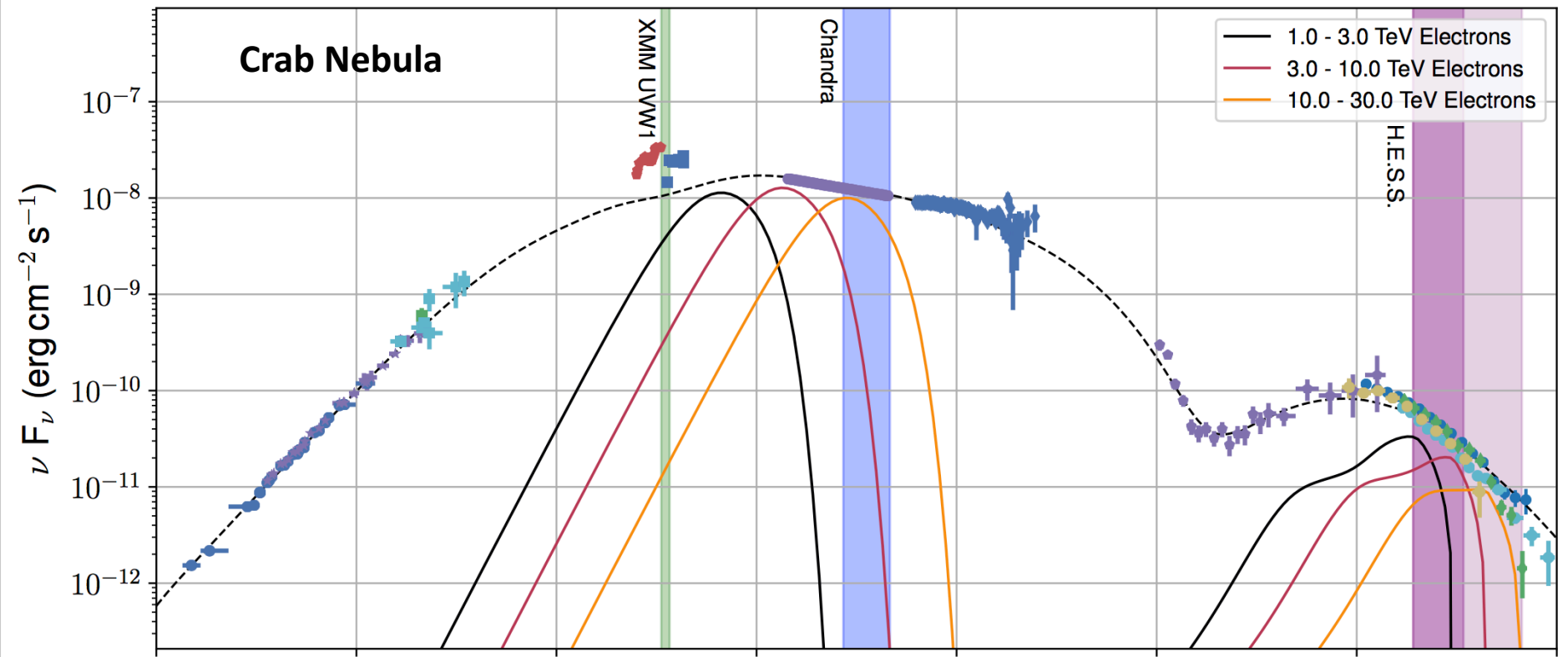


HESS J1825:
Anomalously bright/powerful



3C 58 : extremely
under-luminous
(MAGIC 2015)

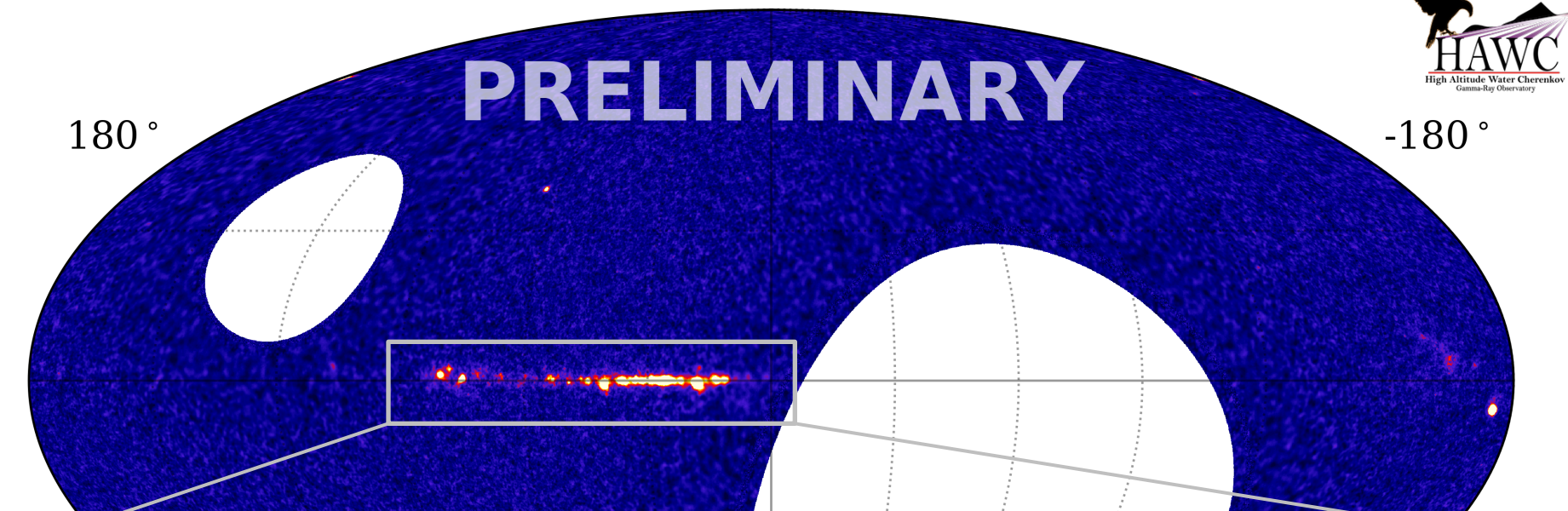




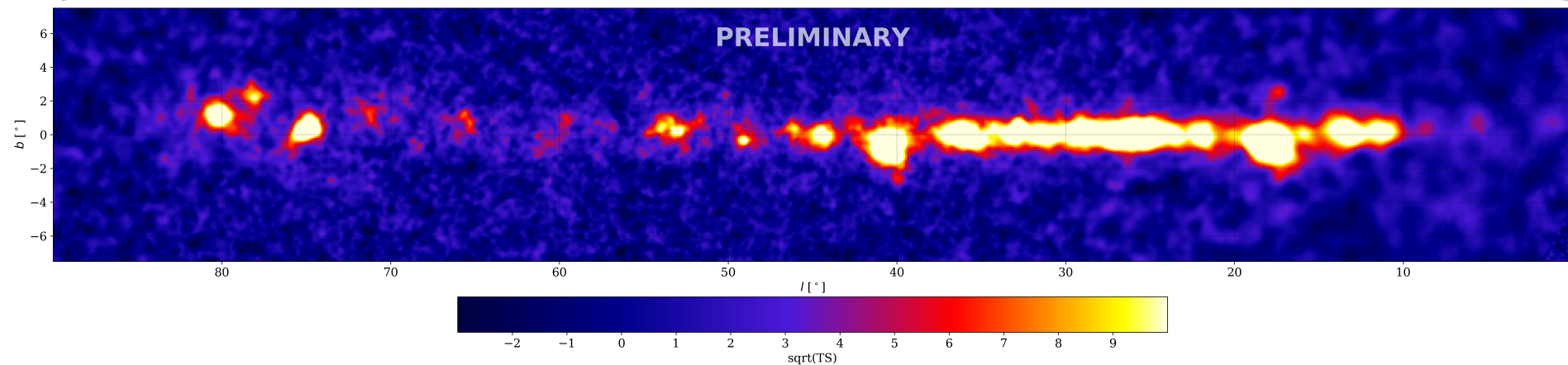
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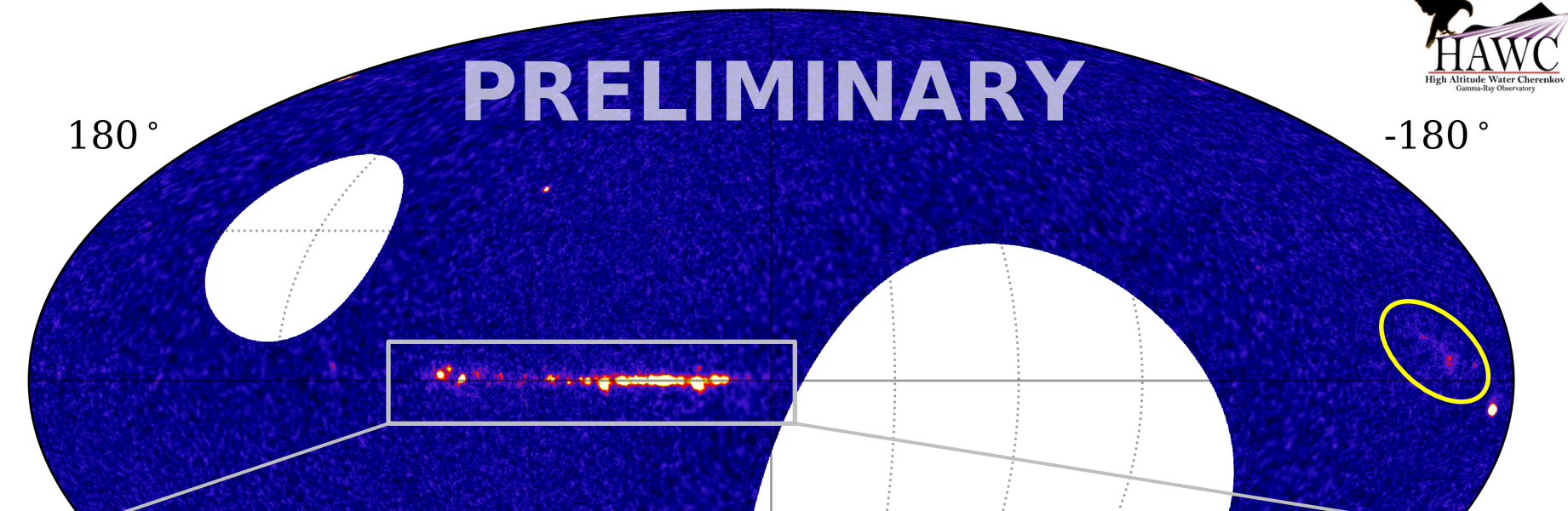


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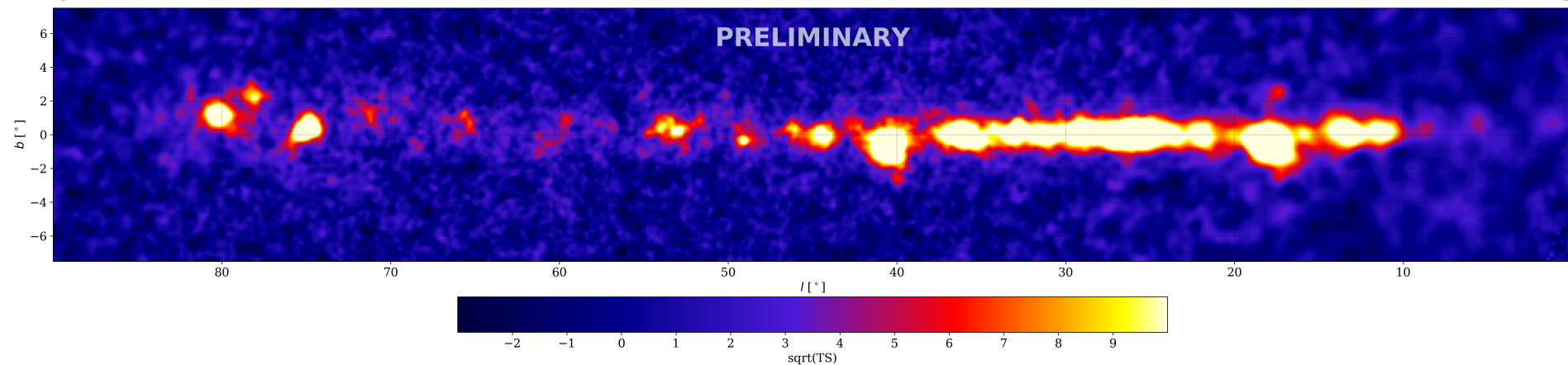
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The Moon (same scale)

Geminga

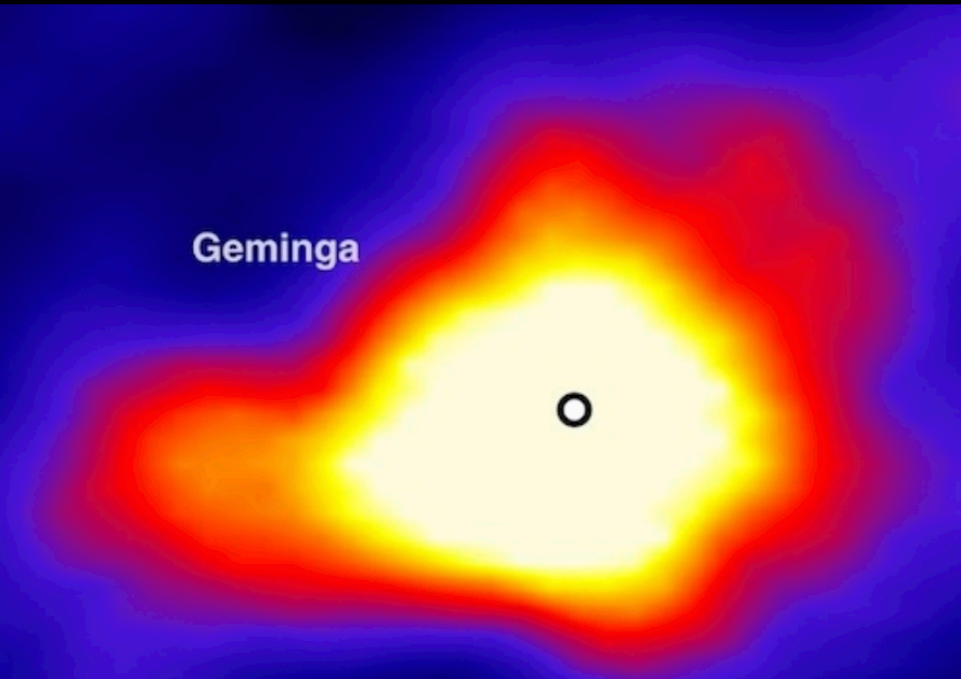
PSR B0656+14

(c) 2017 HAWC Collaboration
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Moon Image: (c) Gregory H. Revera



- Very old (10^5 y) low power systems – visible because they are very close – 200 pc
- Energy density inferred for electrons $< 1\%$ ISM \rightarrow Test particles (no longer inside PWN)

Geminga



PSR B0656+14

- Unexpectedly bright / compact \rightarrow (much) slower diffusion than classical expectation

Halos!

Geminga

PSR B0656+14

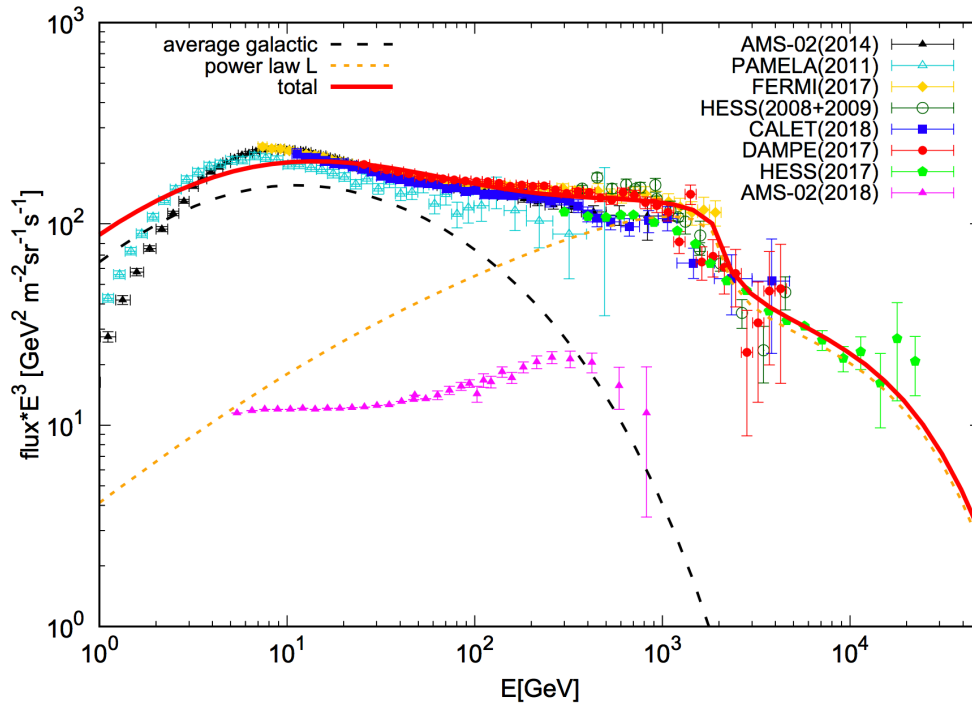
- NB – these are ‘Halos’ because the particle energy density is negligible compared to ISM pressure – particles have left the zone dominated by the pulsar (the PWN)
- NOT THE CASE FOR MOST EXTENDED TEV EMISSION ASSOCIATED WITH PWN

(c) 2017 HAWC Collaboration
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Moon Image: (c) Gregory H. Revera



Local Electrons

e.g. arXiv 1811.07551

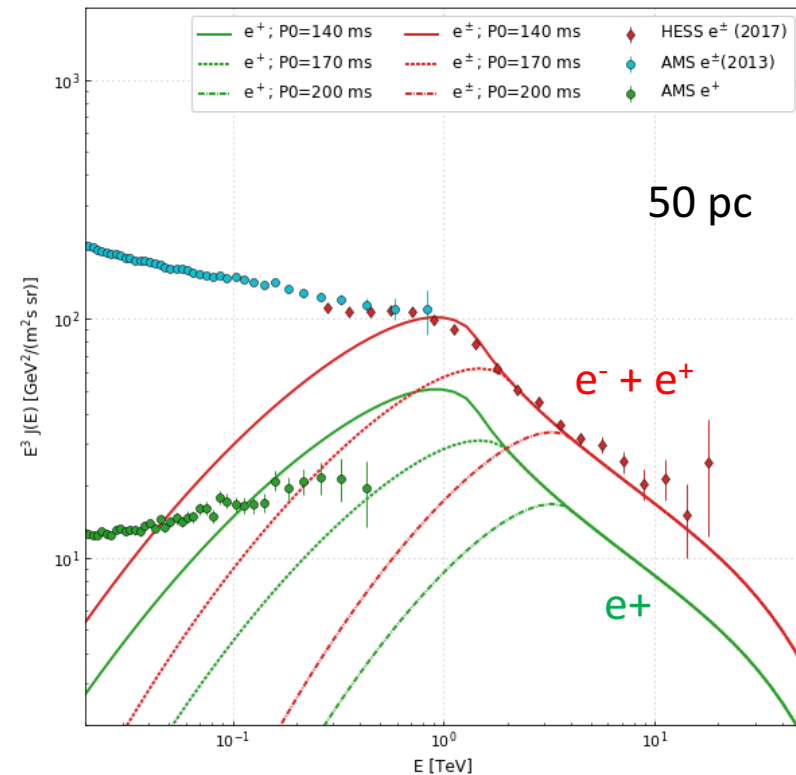


⊙ HESS Coll. New Spectrum

- + Implies a very local source – ‘fading’ to get the right spectrum

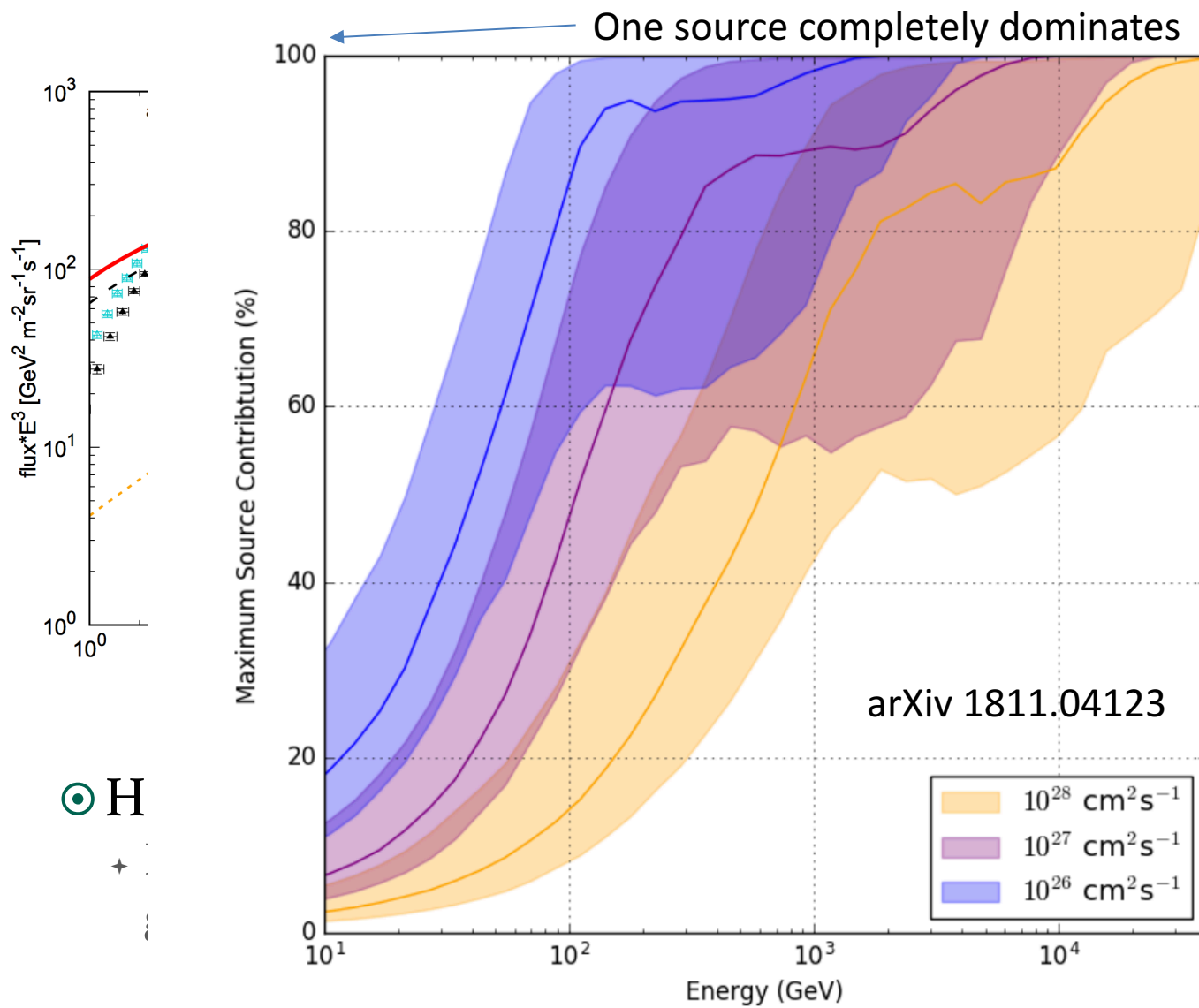
was planned talk by Daniel Kerszberg

e.g. arXiv 1811.04123



Local Electrons

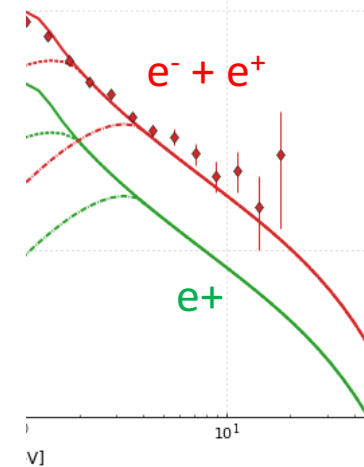
Daniel Kerszberg



/ 1811.04123

e[±]; P0=140 ms ♦ HESS e[±] (2017)
 e[±]; P0=170 ms ♦ AMS e[±](2013)
 e[±]; P0=200 ms ♦ AMS e[±]

50 pc



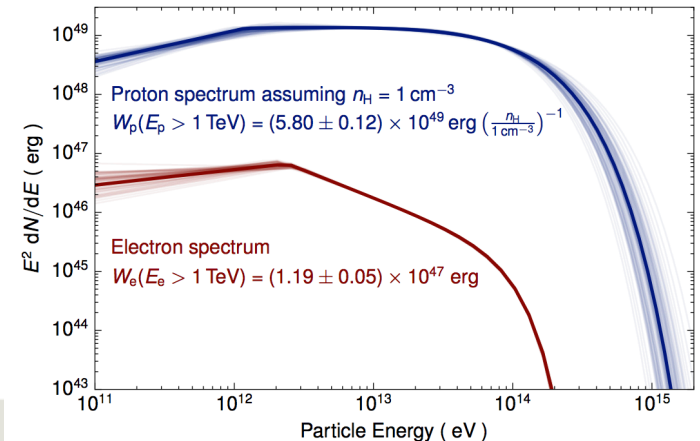
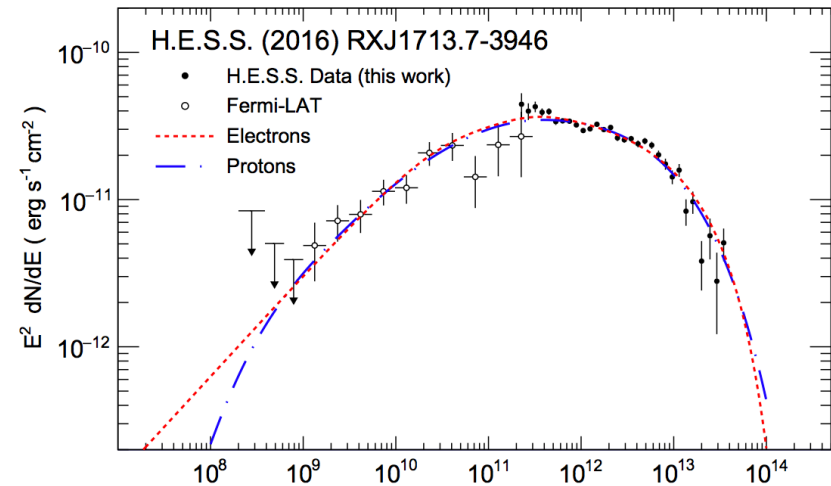
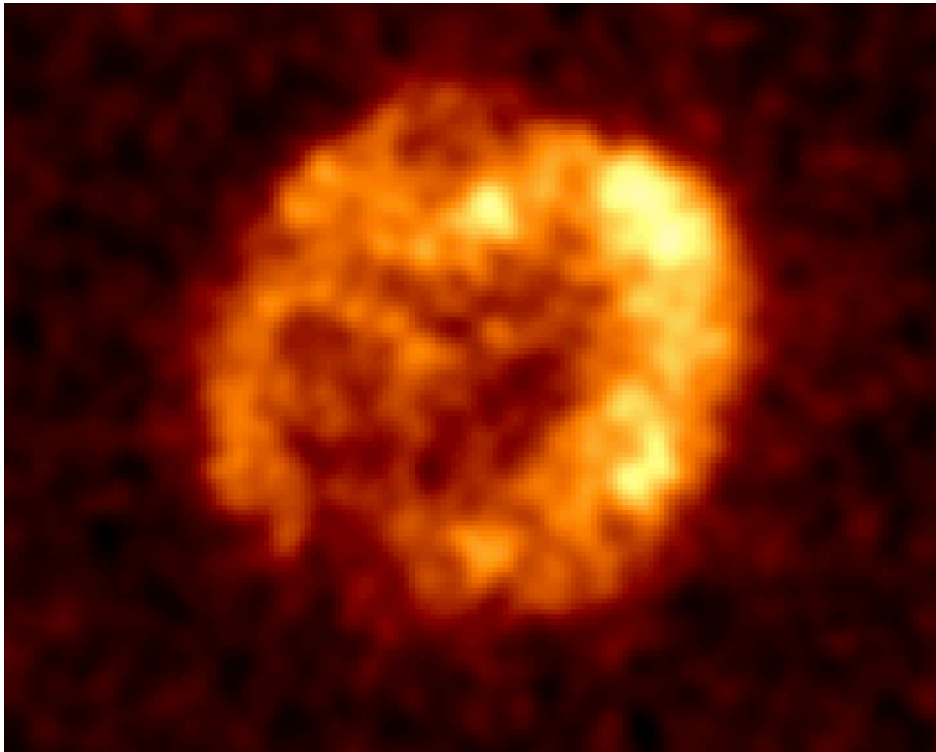
⊙ H

Supernova Remnants?

- ⊙ Brightest objects are ambiguous in terms of electron v. proton acceleration (e.g. RX J1713 + Vela Junior)

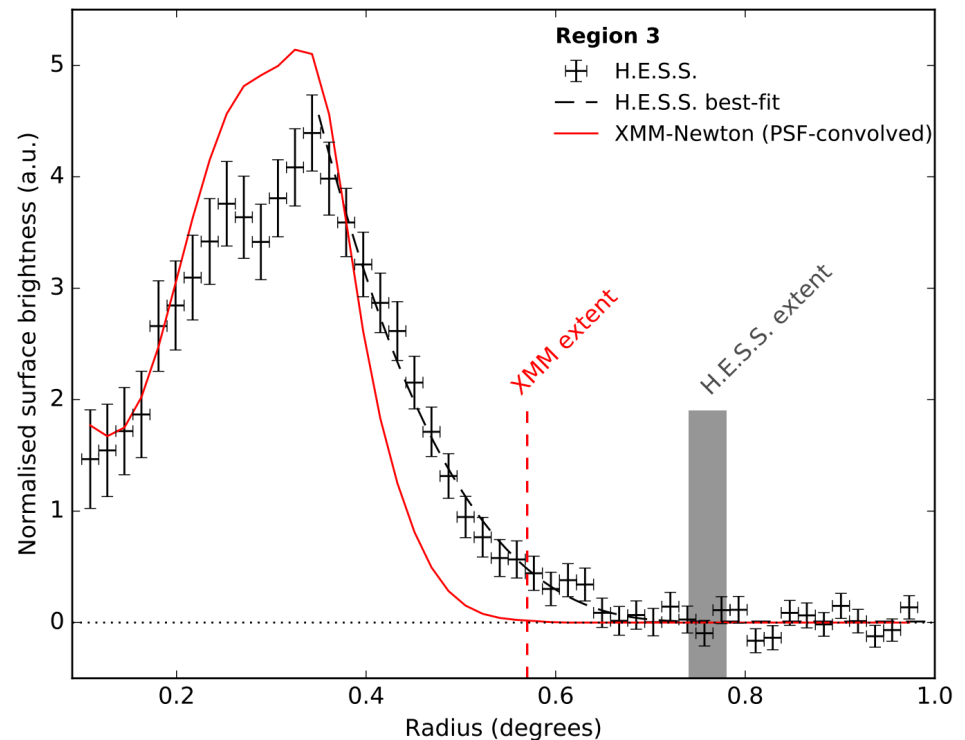
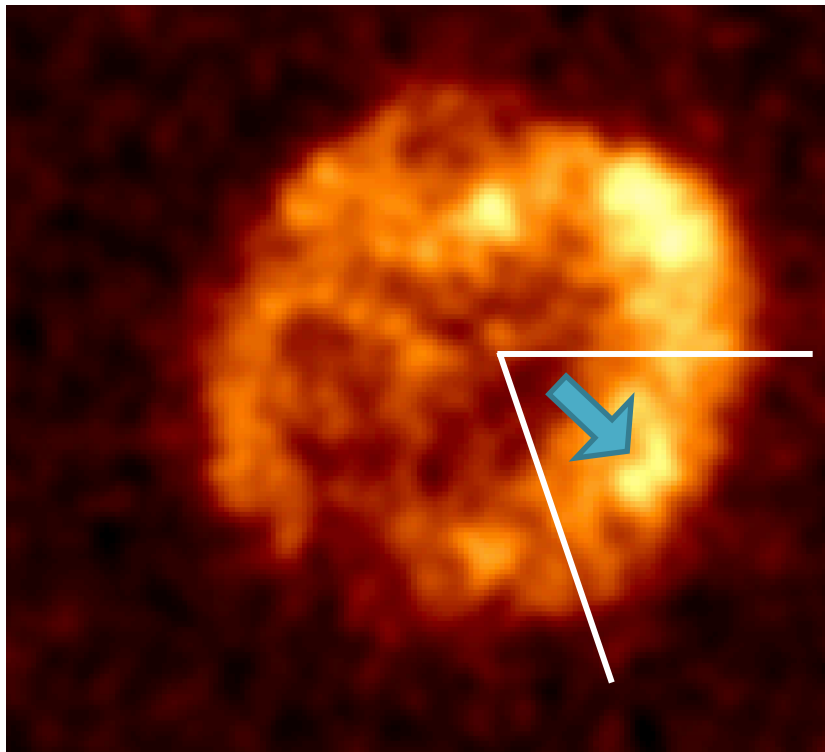
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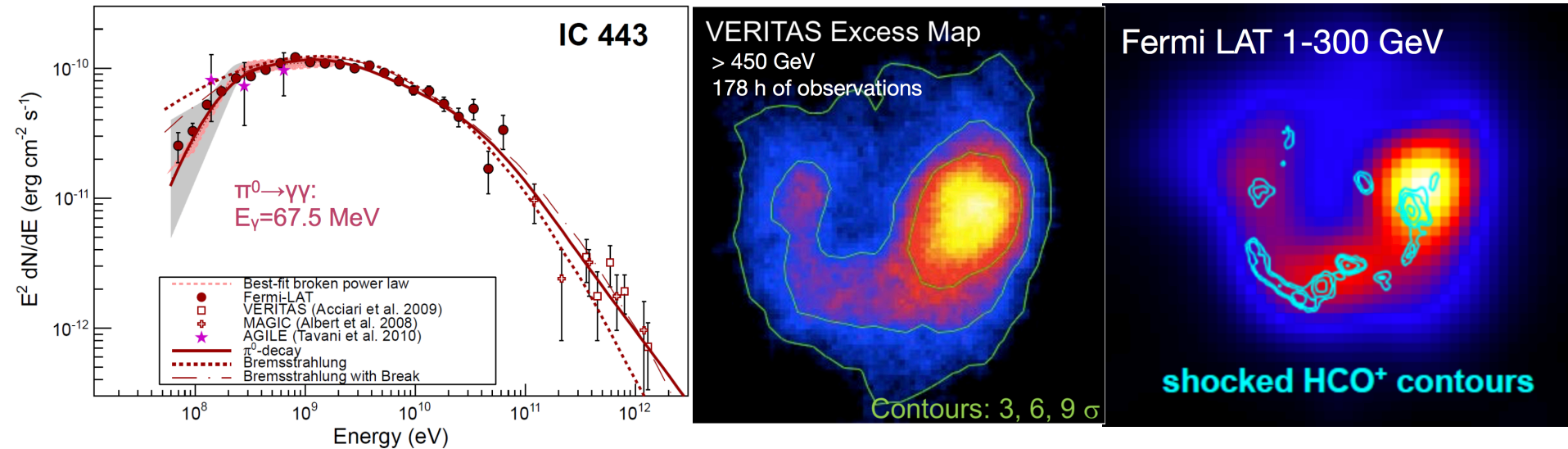


Supernova Remnants?

- ⊙ Brightest objects are ambiguous in terms of electron v. proton acceleration (e.g. RX J1713 + Vela Junior)
- ⊙ Several clear cases of interacting SNRs
 - + At GeV & TeV : e.g. W 28 and IC 443
- ⊙ Emission correlated with molecular clouds
- ⊙ Spectral feature consistent with 'pi-zero bump'

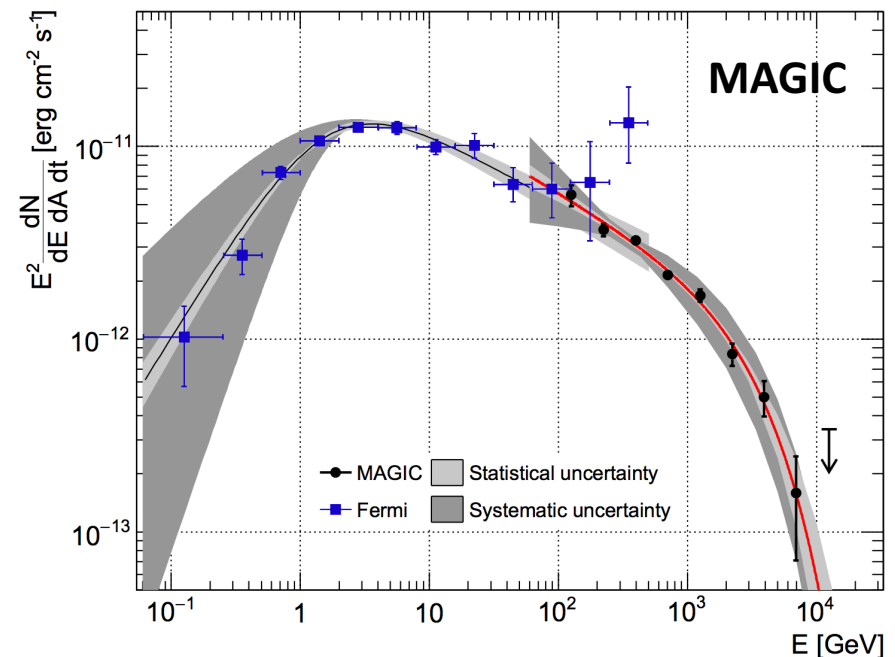
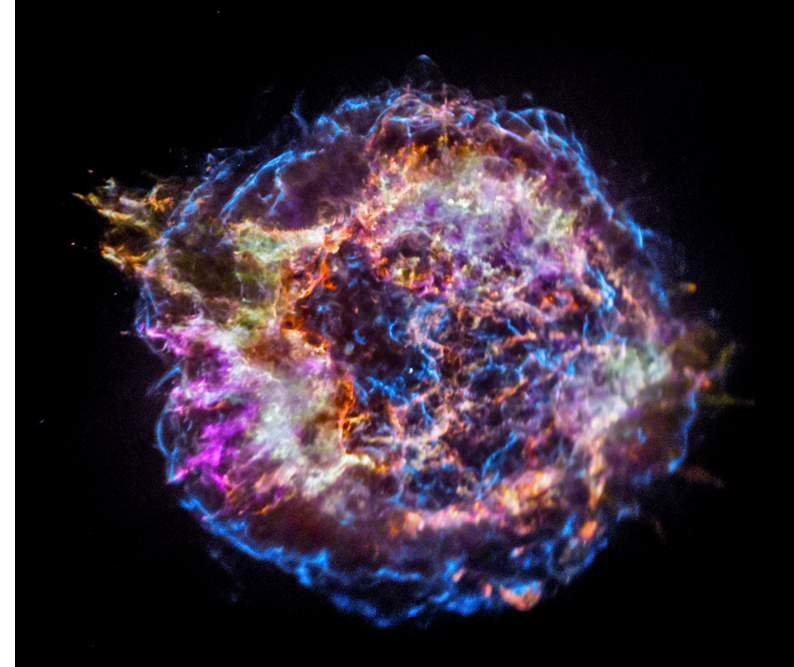
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To the Knee?

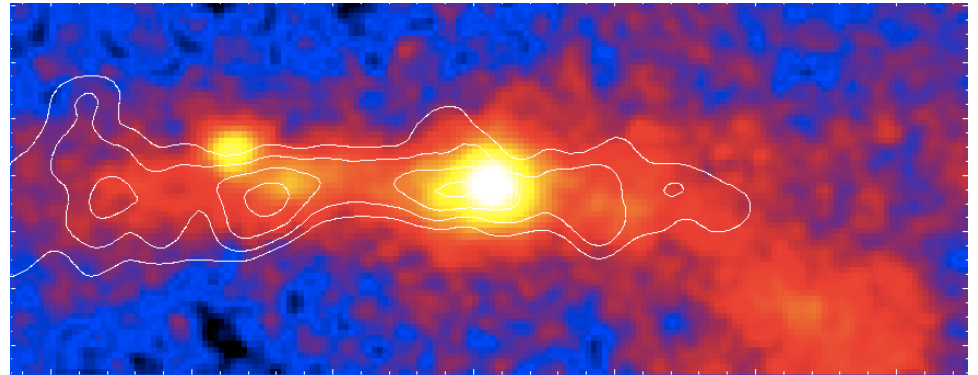
- ⊙ Steepening in spectra of all known TeV SNR at ≤ 10 TeV
 - + Lack of protons/nuclei > 100 TeV
- ⊙ e.g. Cassiopeia A
 - + Young SNR (~ 300 years), dense environment – looked like best chance for PeV acceleration...
 - + Second component?
- ⊙ SNRs not the main contributor at/beyond the knee?



Other Accelerators?

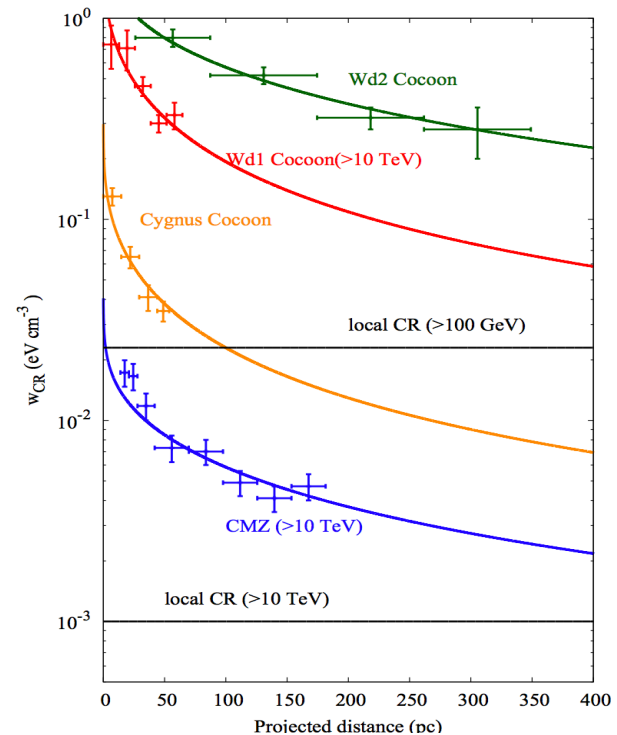
⊙ Galactic Centre

- + Central molecular zone 'lit up' by cosmic rays
- + Hard excess above the 'sea'
- + Extending to at least 0.5 PeV
- + Sgr A* is injector?

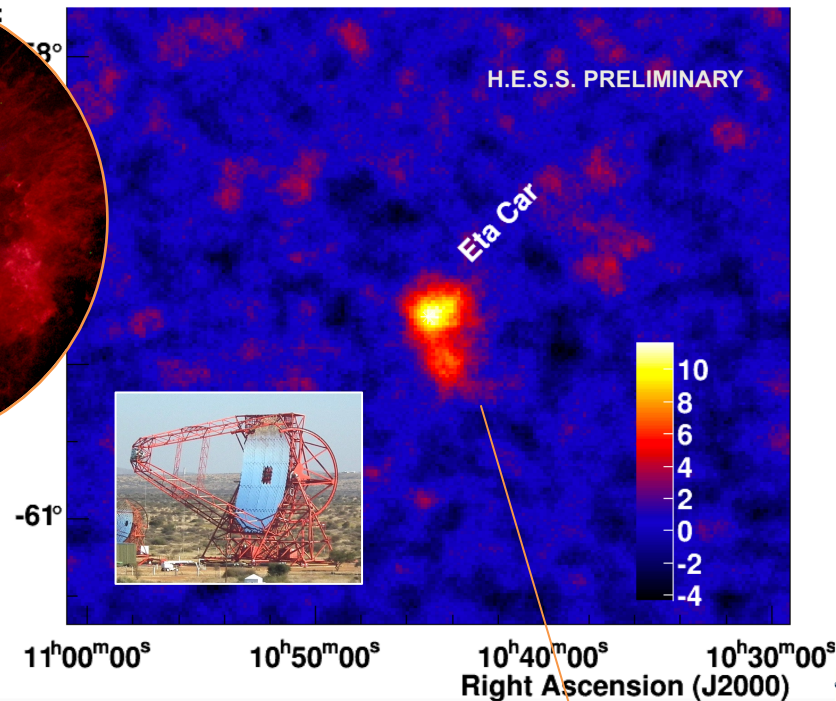
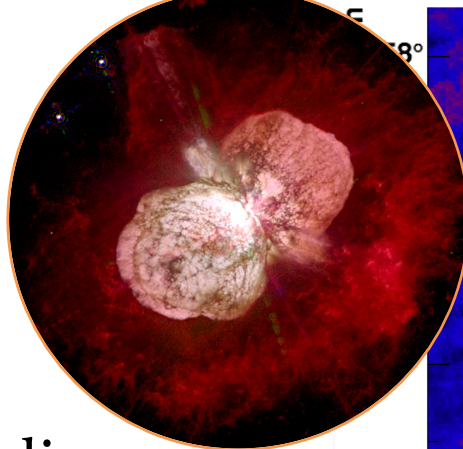


⊙ Stellar Clusters?

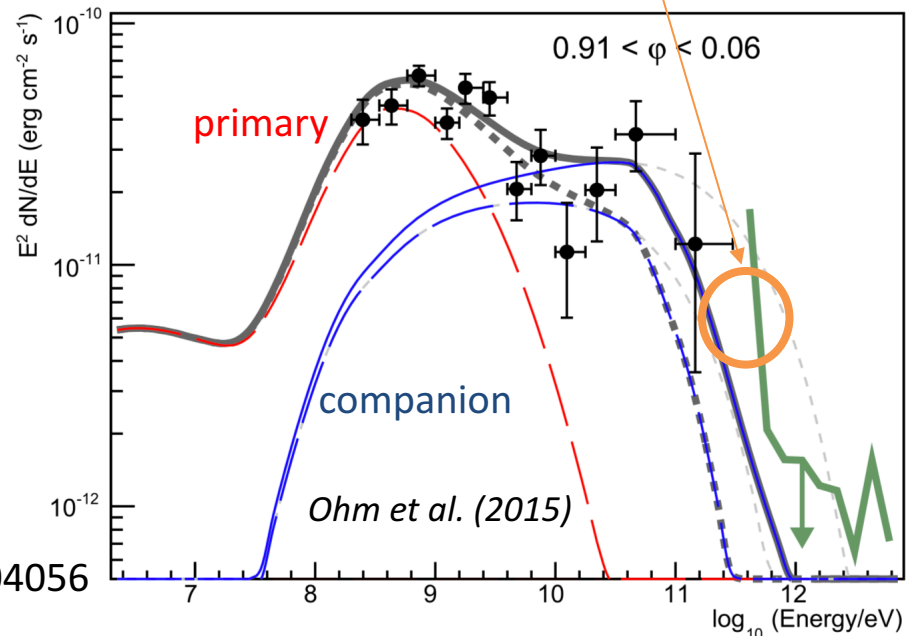
- + *see arXiv:1804.02331*
- + GC cluster
- + Westerlund 1 & 2
- + Cygnus Cocoon
- + But no clear correlation yet with target material in cases other than CMZ



Eta Carina



- ⊙ Most prominent colliding wind binary
 - + Strong winds+shocks
 - + Dense environment
 - + Looks like calorimetric conditions for $pp \rightarrow \text{pions} \rightarrow \text{gammas}$ in shock of primary stellar wind
 - + Electrons disfavoured by energetics and rapid cooling (problem with E_{max})
- ⊙ Acceleration of hadrons up to at least $\sim \text{TeV}$

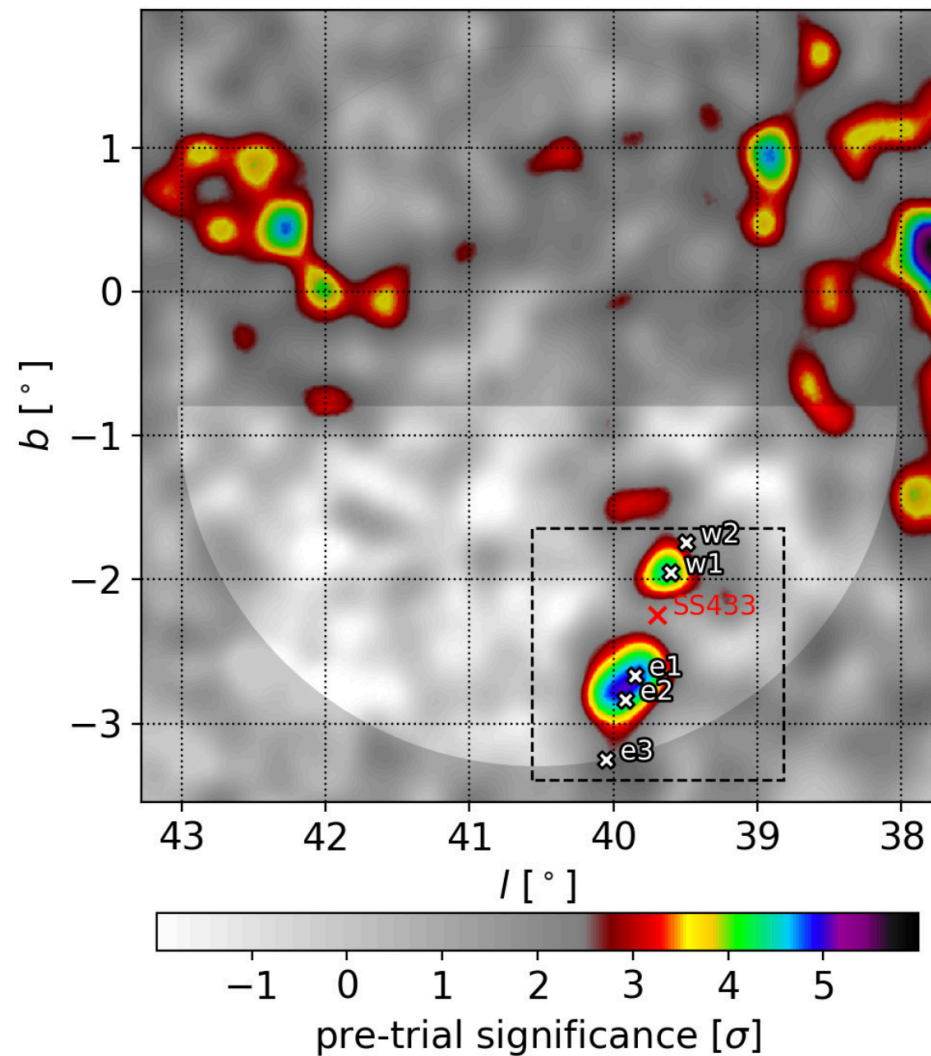
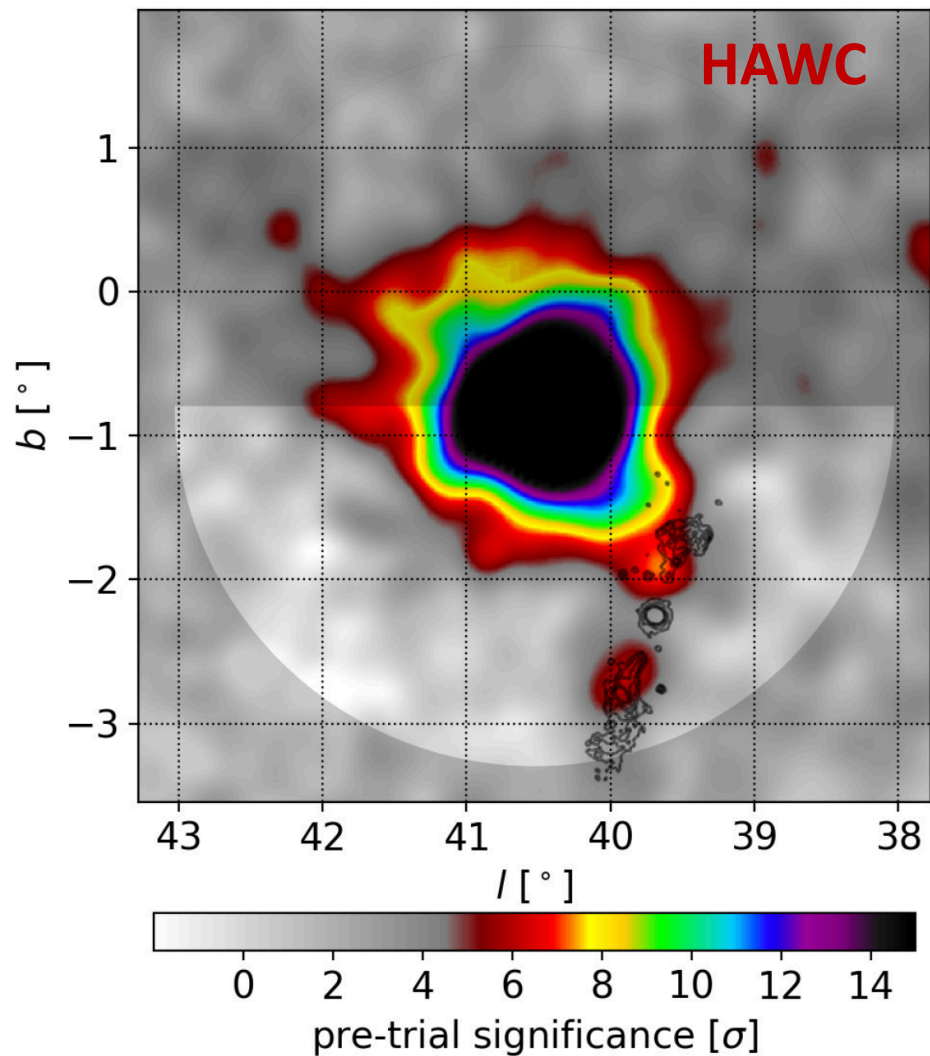


arXiv 1502.04056

SS 433

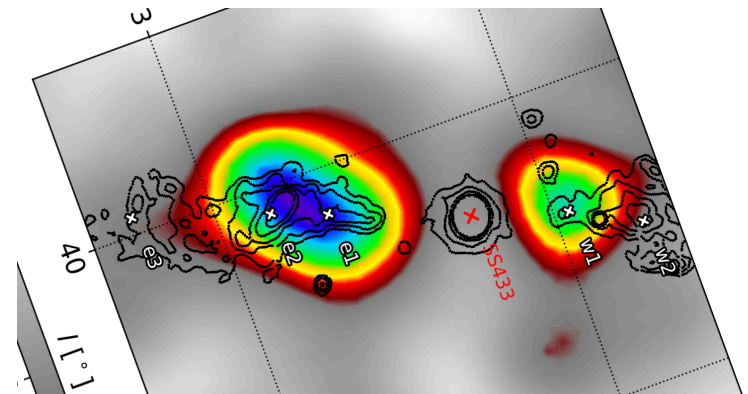
[Nature 562 \(2018\), 82-85.](#)

After subtracting MGRO J1908+06

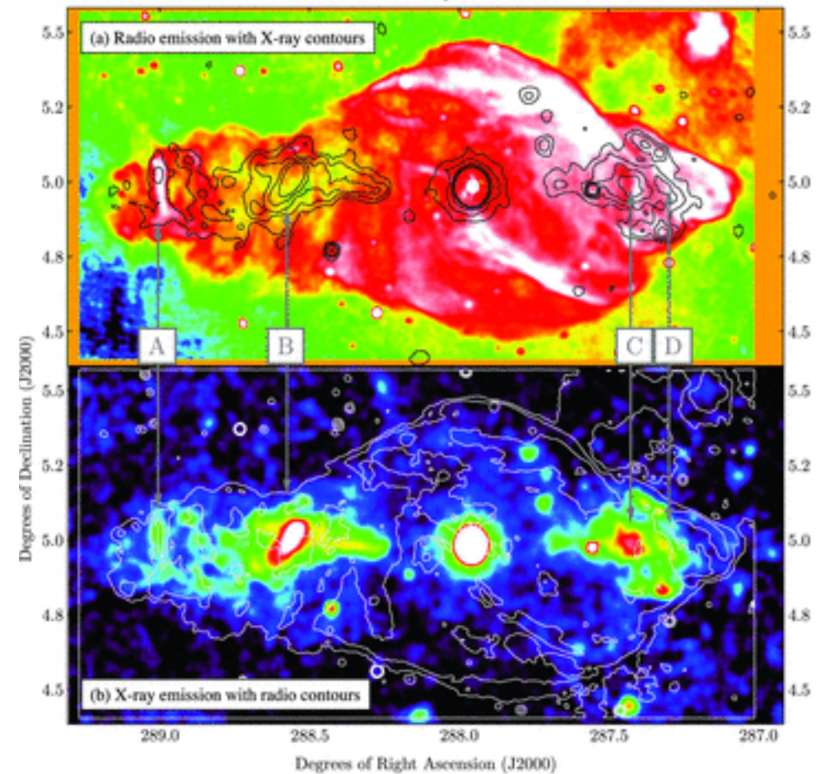


SS 433

- ⊙ 20 TeV gamma-ray emission with hard spectrum
 - + From zones where jets are thought to decelerate
- ⊙ A very high energy accelerator
- ⊙ IC origin seems likely
 - + cf X-ray synchrotron
 - + density likely low in these regions
- ⊙ BUT
 - + Very plausible (unavoidable?) that protons are co-accelerated to at least the same energies!
 - + Plenty of power and $v=0.3$ c shock !



The Radio-X-ray correlation



Conclusions

- ⊙ Many clues from VHE gamma-ray astronomy on the origin and transport of Galactic cosmic rays
- ⊙ Lacking
 - + Sufficient detected objects to reach strong conclusions on populations (possible exception: PWN)
 - + Sufficient resolved detail in gamma-ray + gas tracers to remove ambiguities on hadronic origin and CR distribution
 - + Good enough sensitivity at high energy to resolve steepening versus cut-offs (and/or check for second components)
- ⊙ See Werner's talk for solutions!