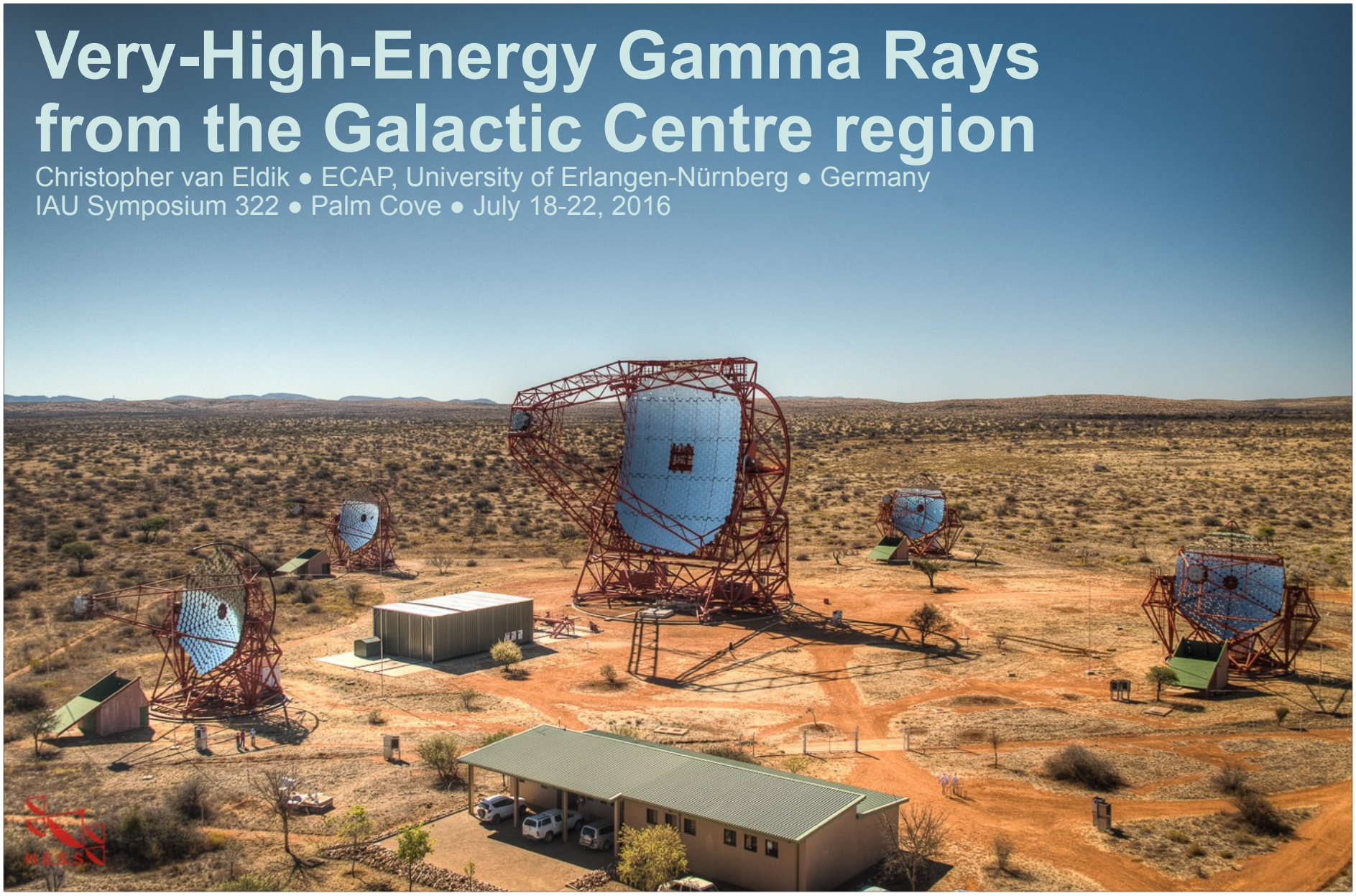
Very-High-Energy Gamma Rays from the Galactic Centre region

Christopher van Eldik • ECAP, University of Erlangen-Nürnberg • Germany

IAU Symposium 322 • Palm Cove • July 18-22, 2016



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Why Very High Energies?

VHE gamma rays

- carry photon energies E ≳ 50…100 GeV to few 10 TeV

Main production processes:

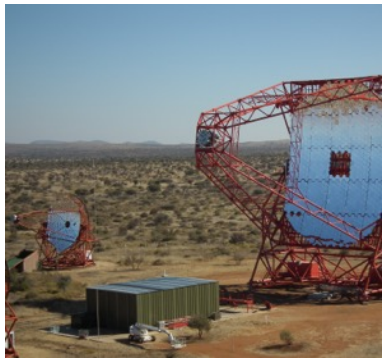
- inverse Compton of electrons/positrons off ambient photons
- inelastic collisions of protons/nuclei with gas
- (and dark matter annihilation)

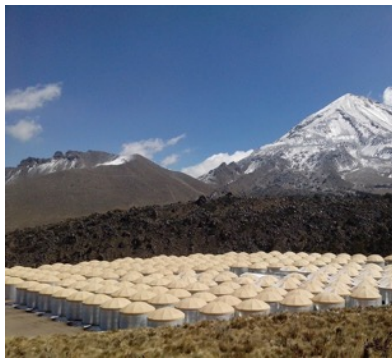
Detection

- photon-by-photon by ground-based instruments with > 10^5 m^2 effective detection area

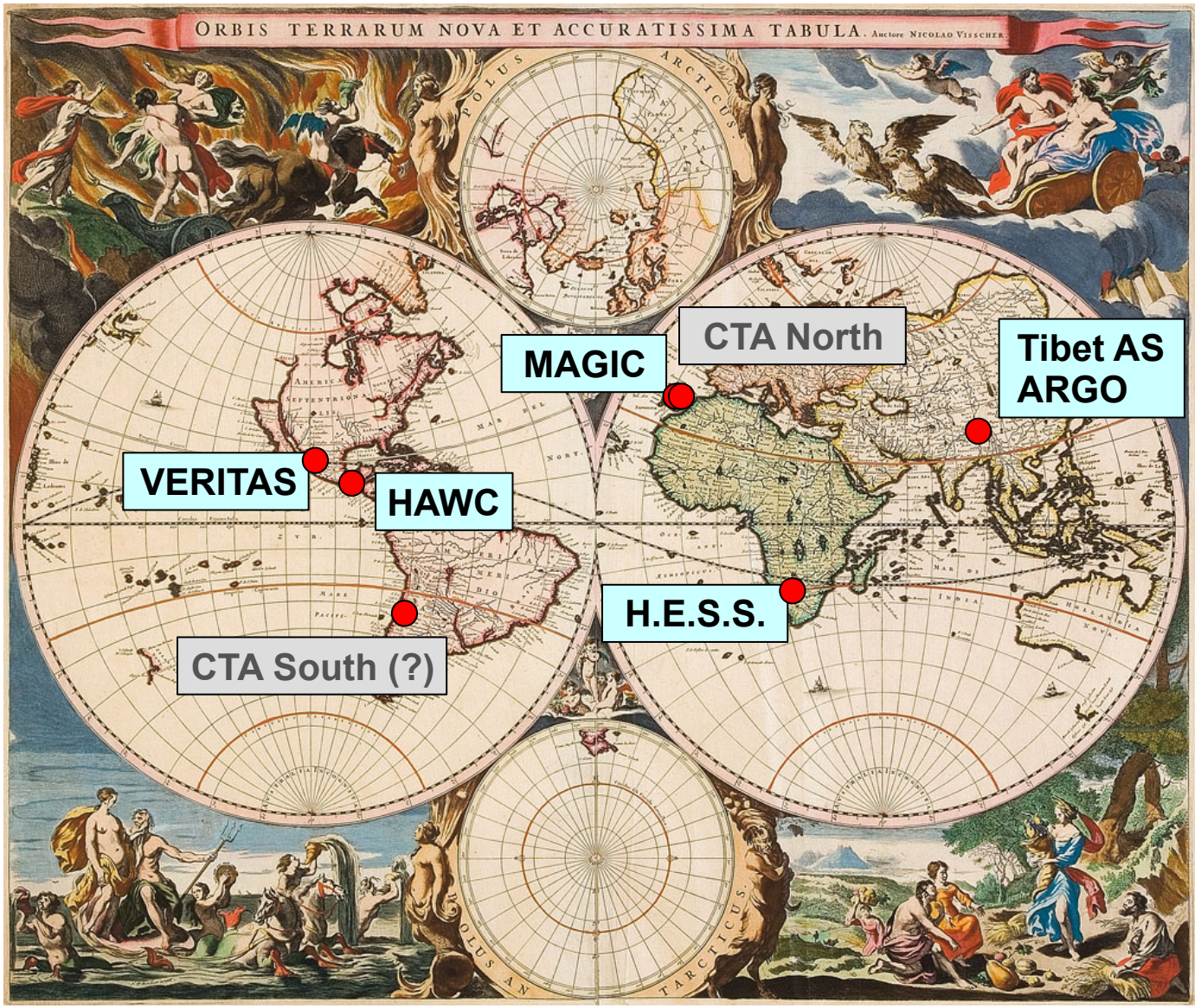
Why interesting?

- provide unambiguous proof of particle acceleration to and beyond TeV energies
- provide mapping of acceleration/propagation sites
- provide direct tracer of relativistic proton populations





The world of ground-based gamma-ray telescopes



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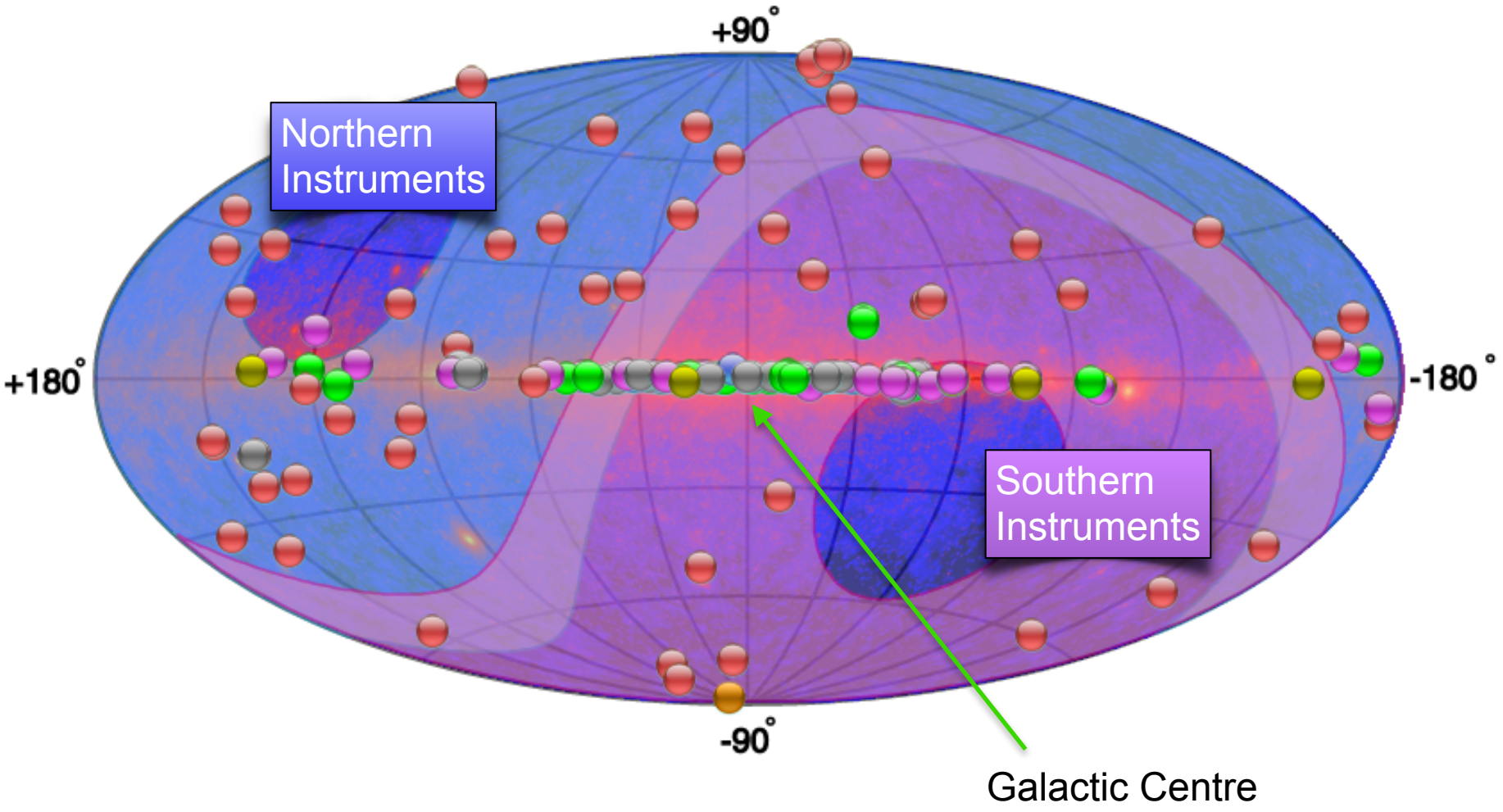
Sky Coverage



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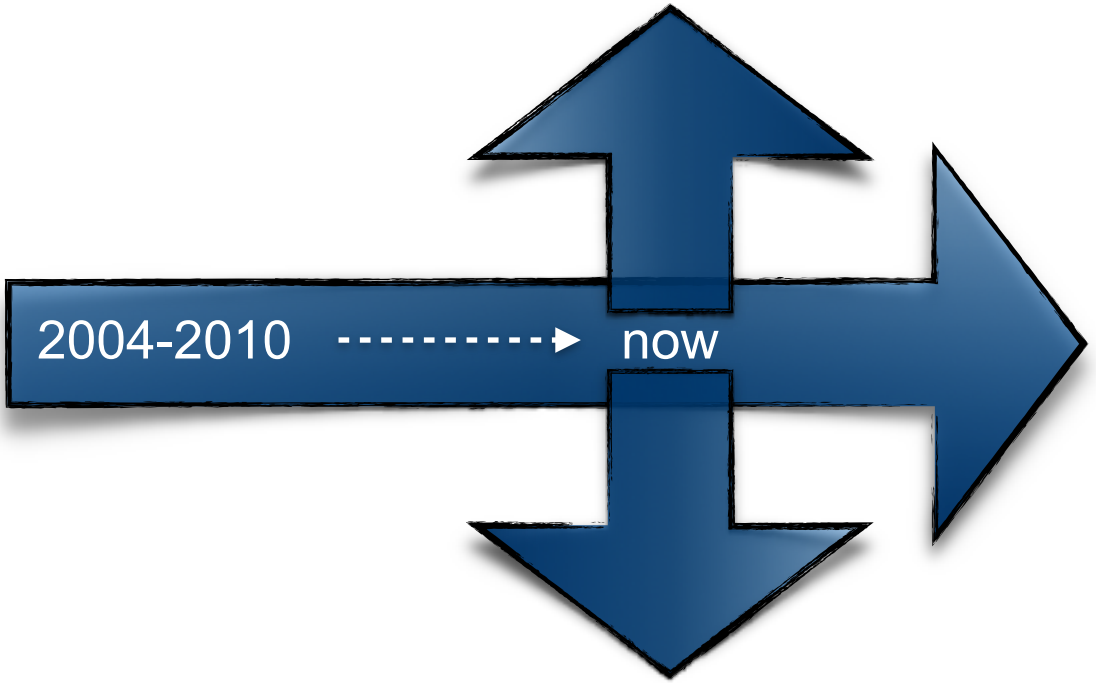
Evolution: from single source discoveries to key science and precision measurements

surveys & population studies

1 paper for each source



deep exposures of single sources

searching for the unknown:

- dark matter
- fundamental physics

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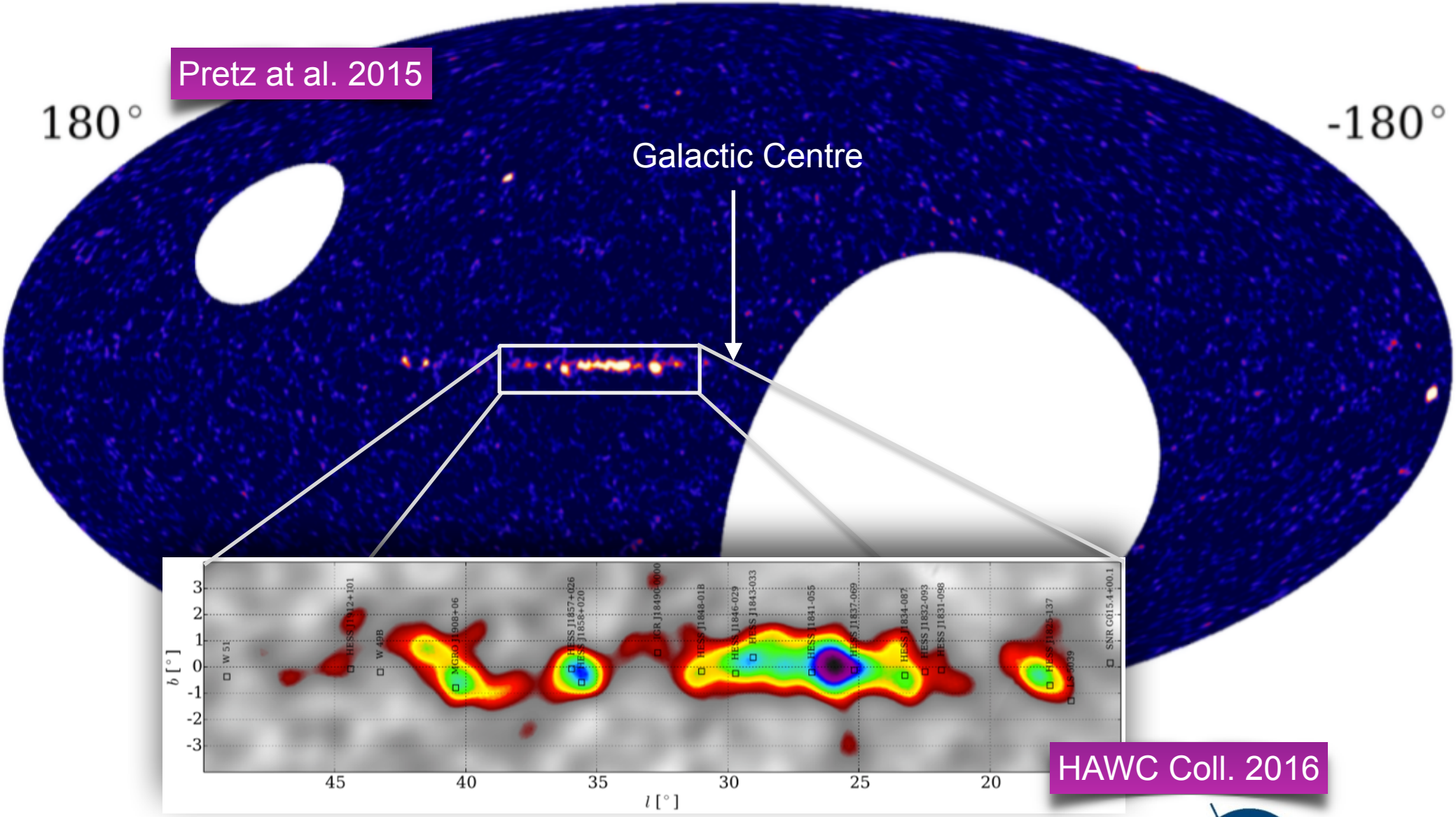
The HAWC's view: mapping the TeV sky

Pretz at al. 2015



HAWC Coll. 2016

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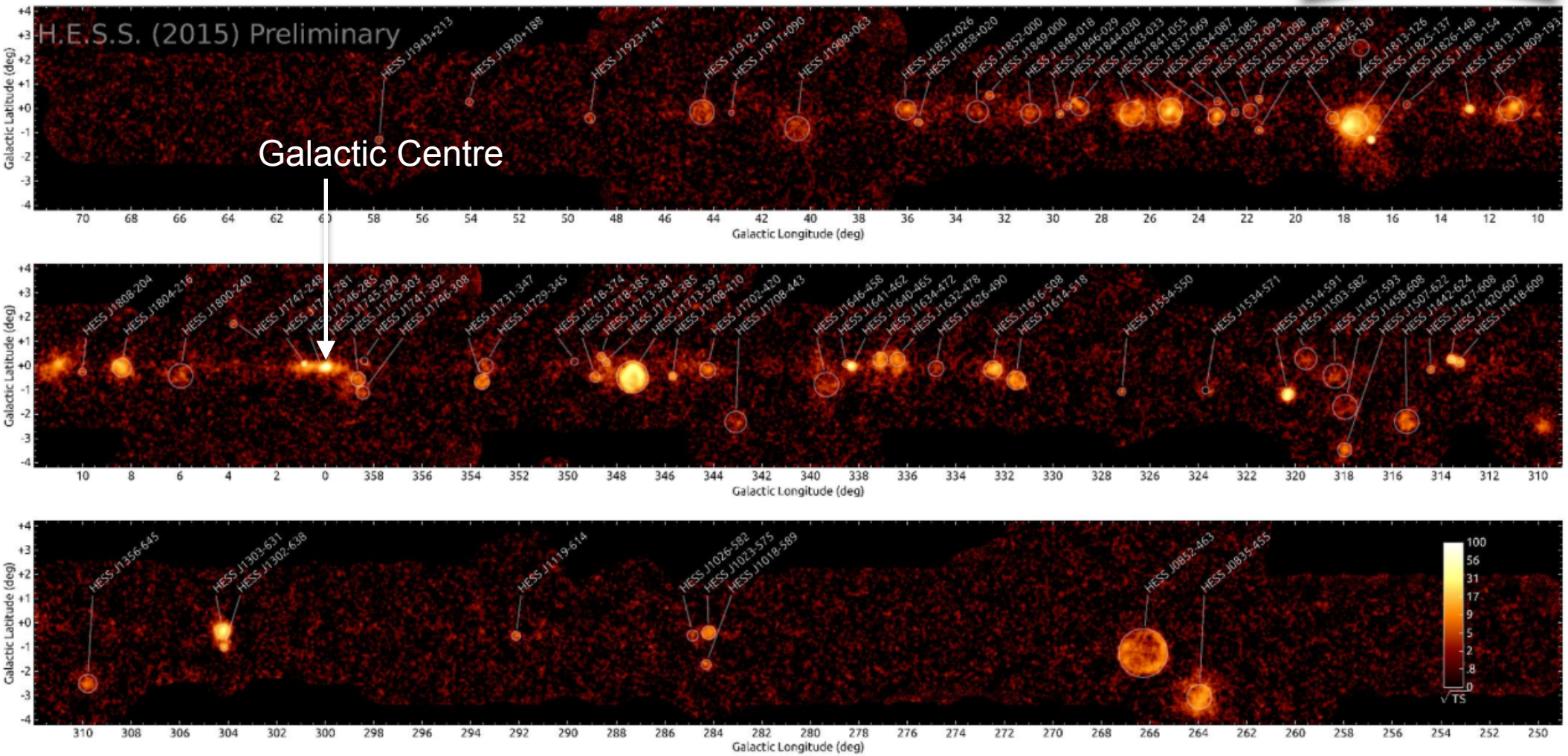
The H.E.S.S. Inner Galaxy Survey

Deil et al. 2015



- **mosaic:** 3000 h of pointed observations (2004-2013)
- **first systematic catalog** of Galactic TeV sources with $E\gamma$ > 200 GeV

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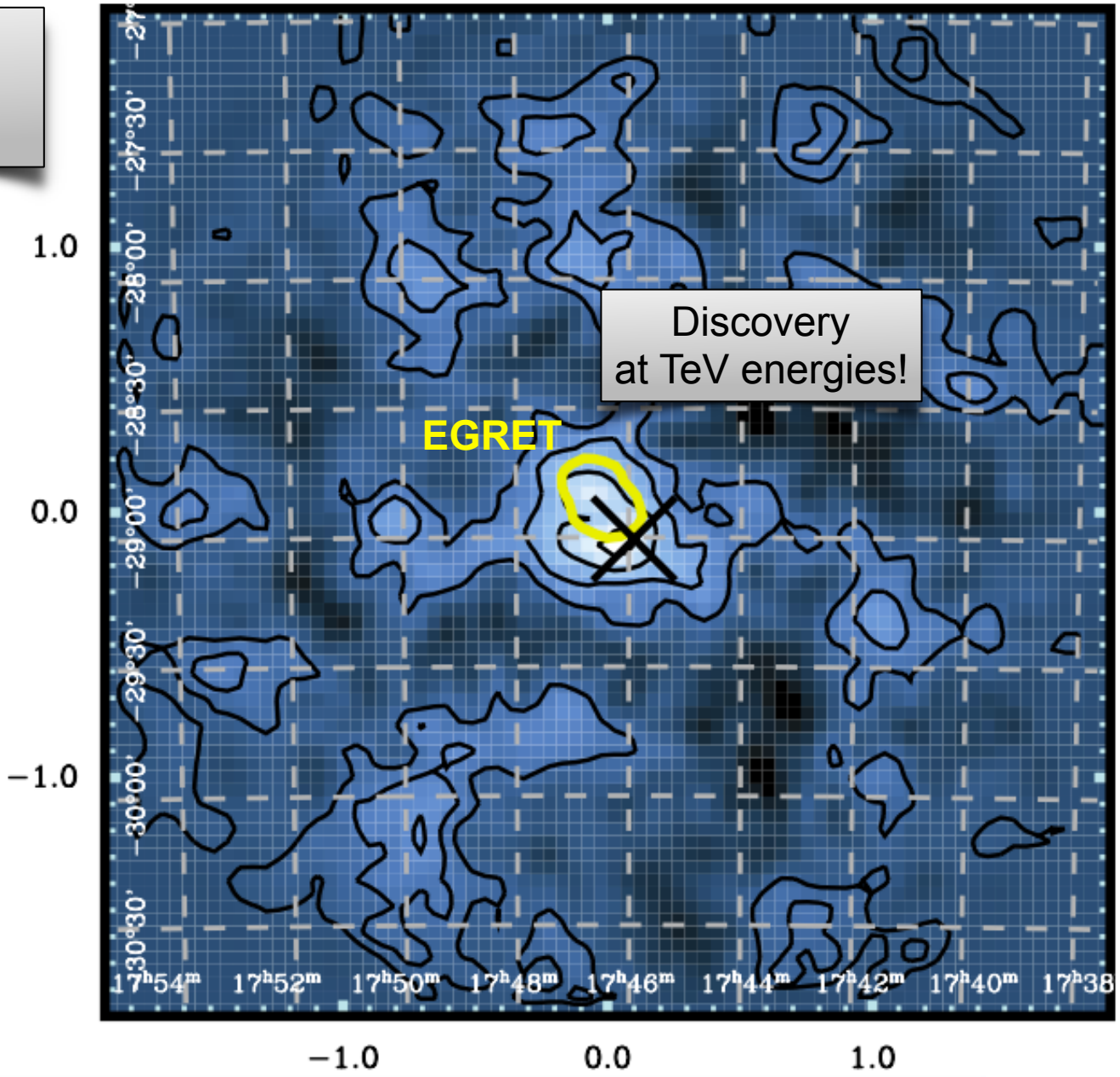
The GC at very high energies: 2004 vs. 2016

Whipple
2004
26 hours



The GC at very high energies: 2004 vs. 2016

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H.E.S.S.
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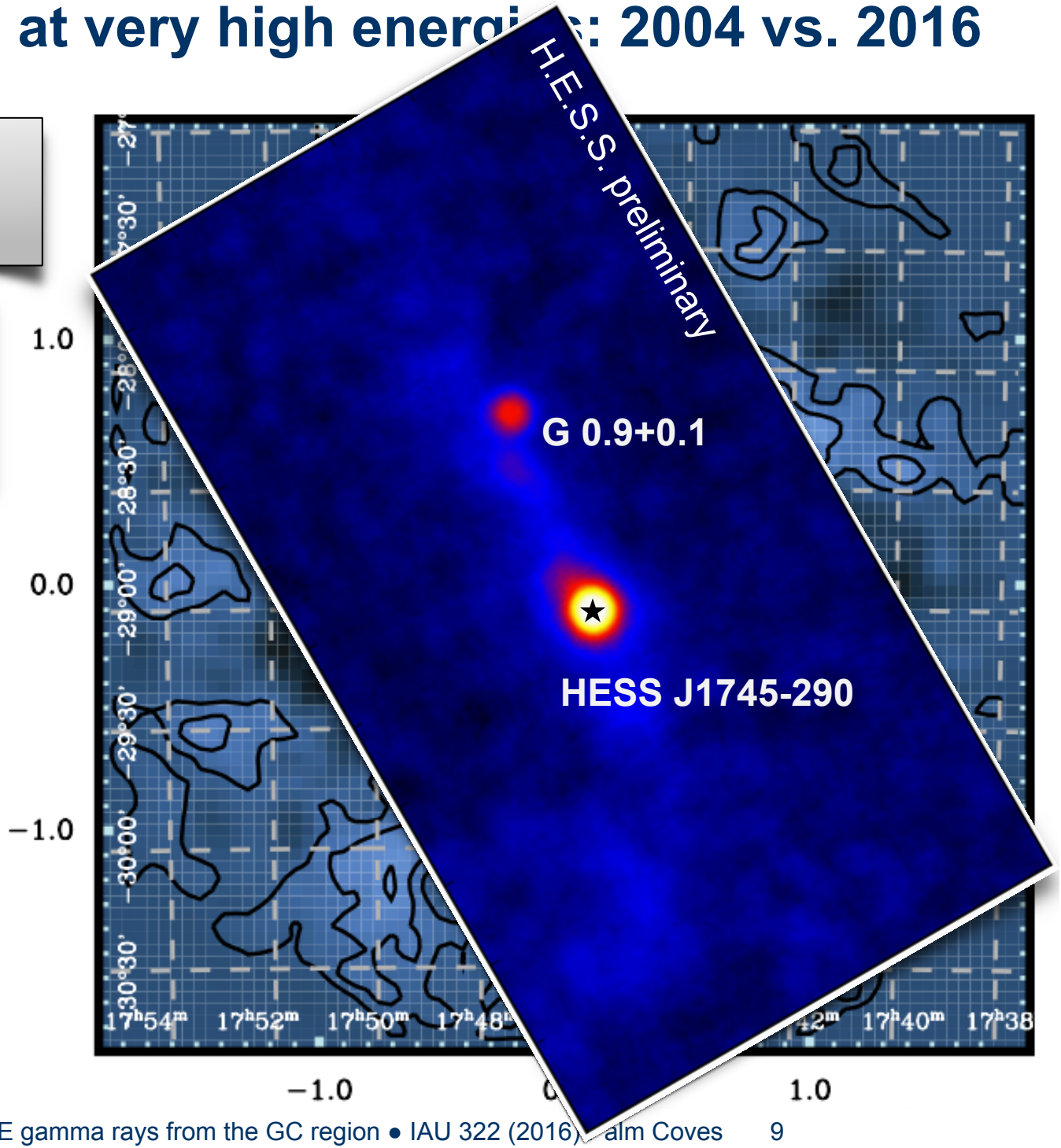
260 hours
$E\gamma$ > 350 GeV



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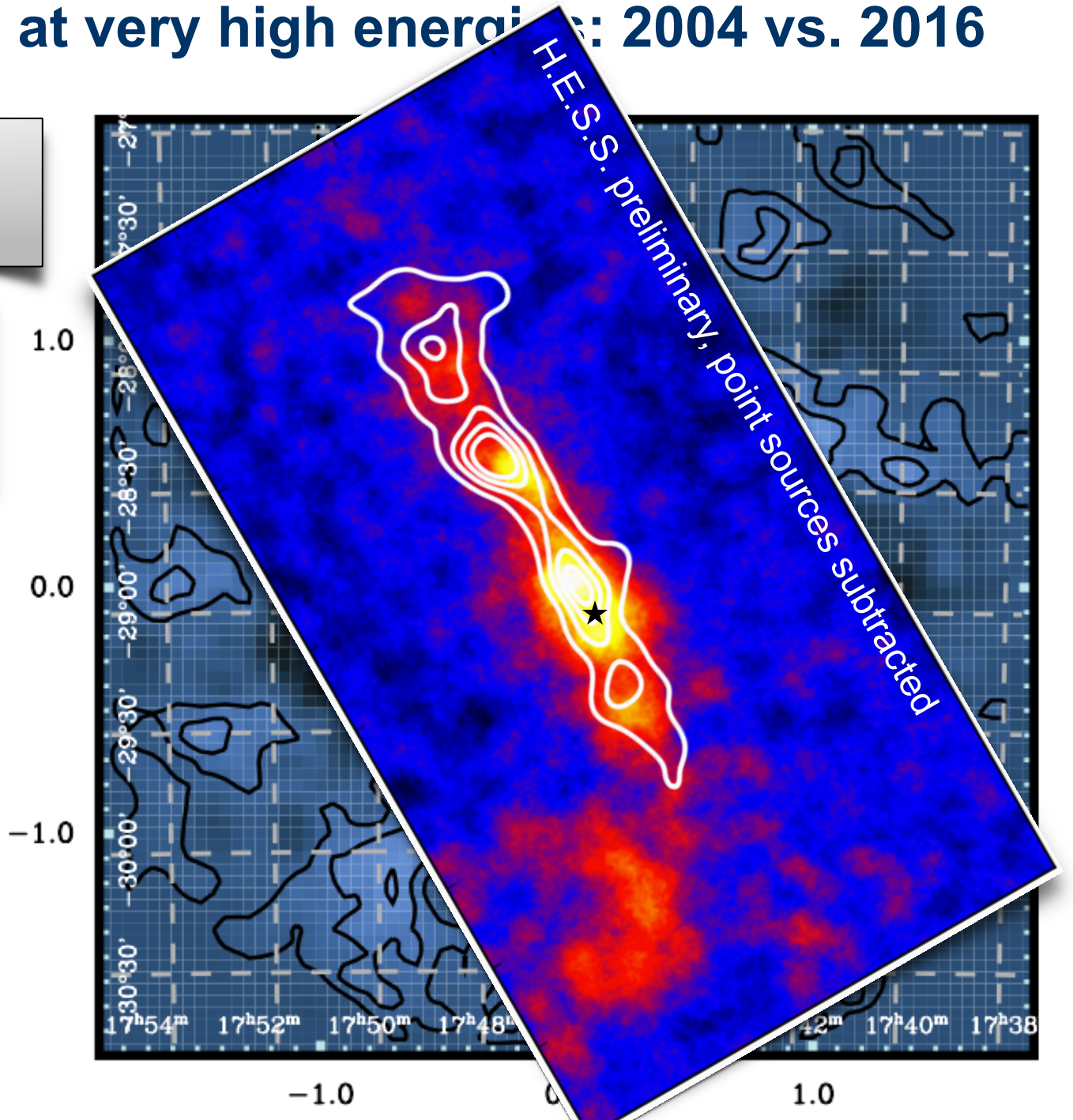

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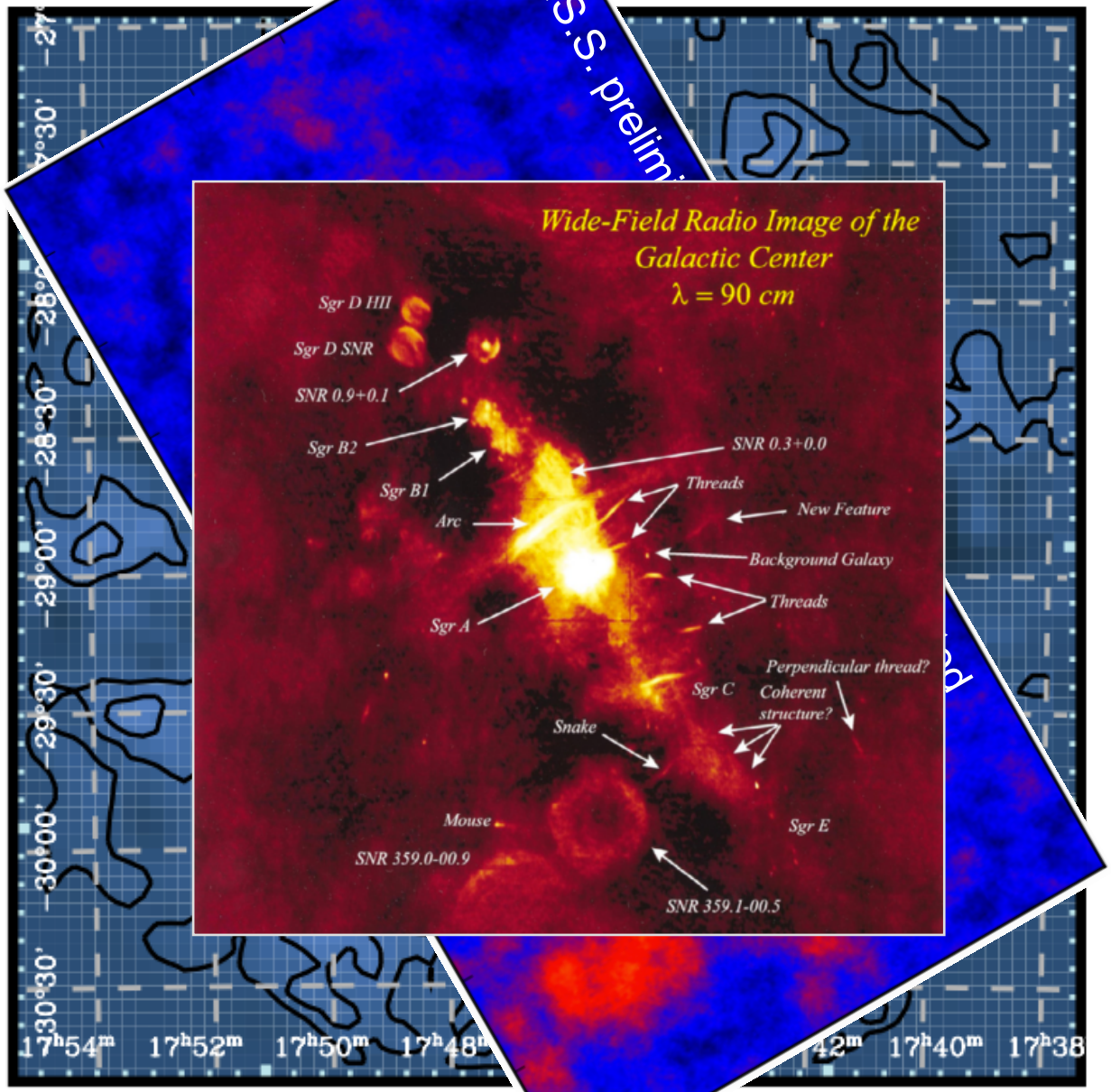
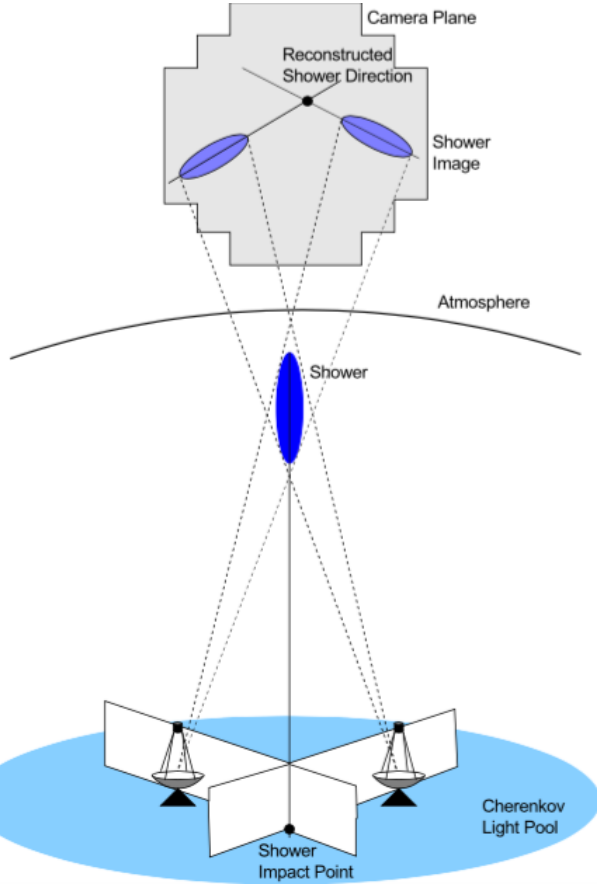
$E\gamma$ > 350 GeV

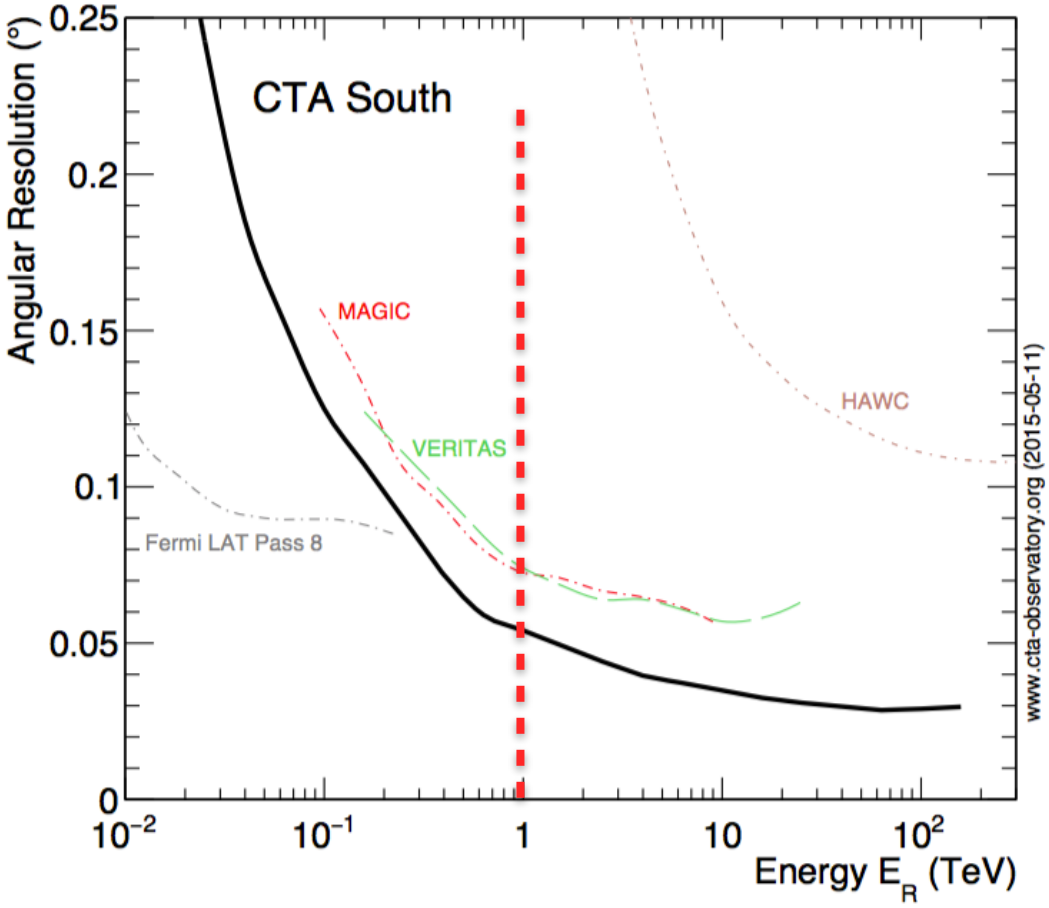
VLA 90 cm
2000
LaRosa et al.

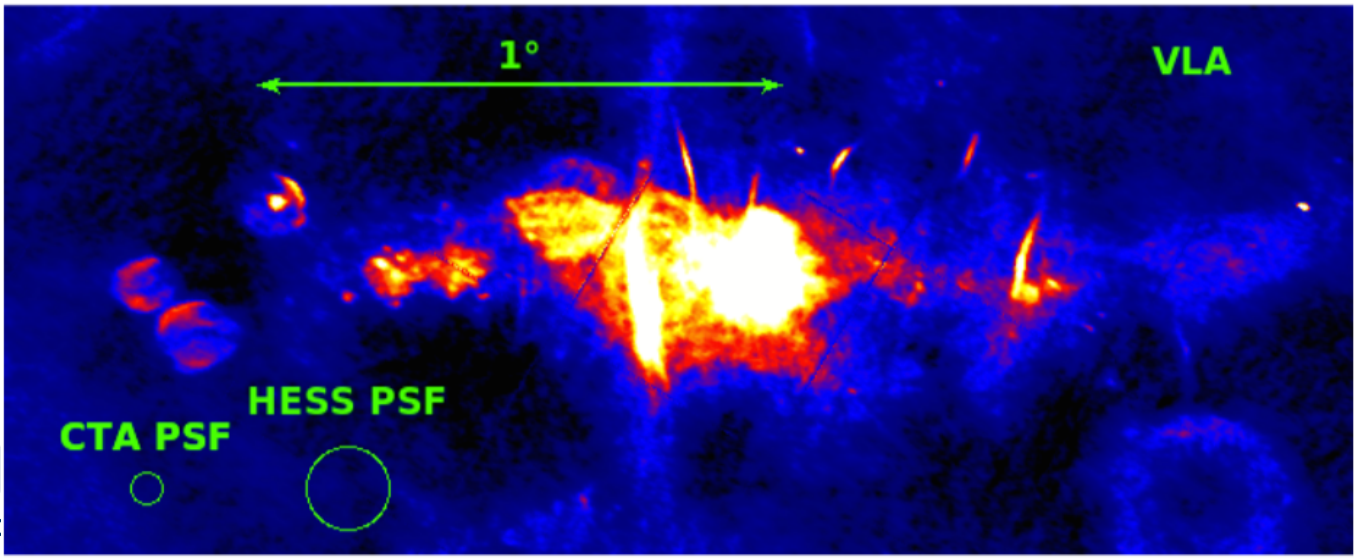


Angular Resolution

- strongly energy-dependent
- H.E.S.S. ~5’ @ 1 TeV
- CTA: ~3’ @ 1 TeV
- shower fluctuations: ultimate limit ~20’’ @ 1 TeV

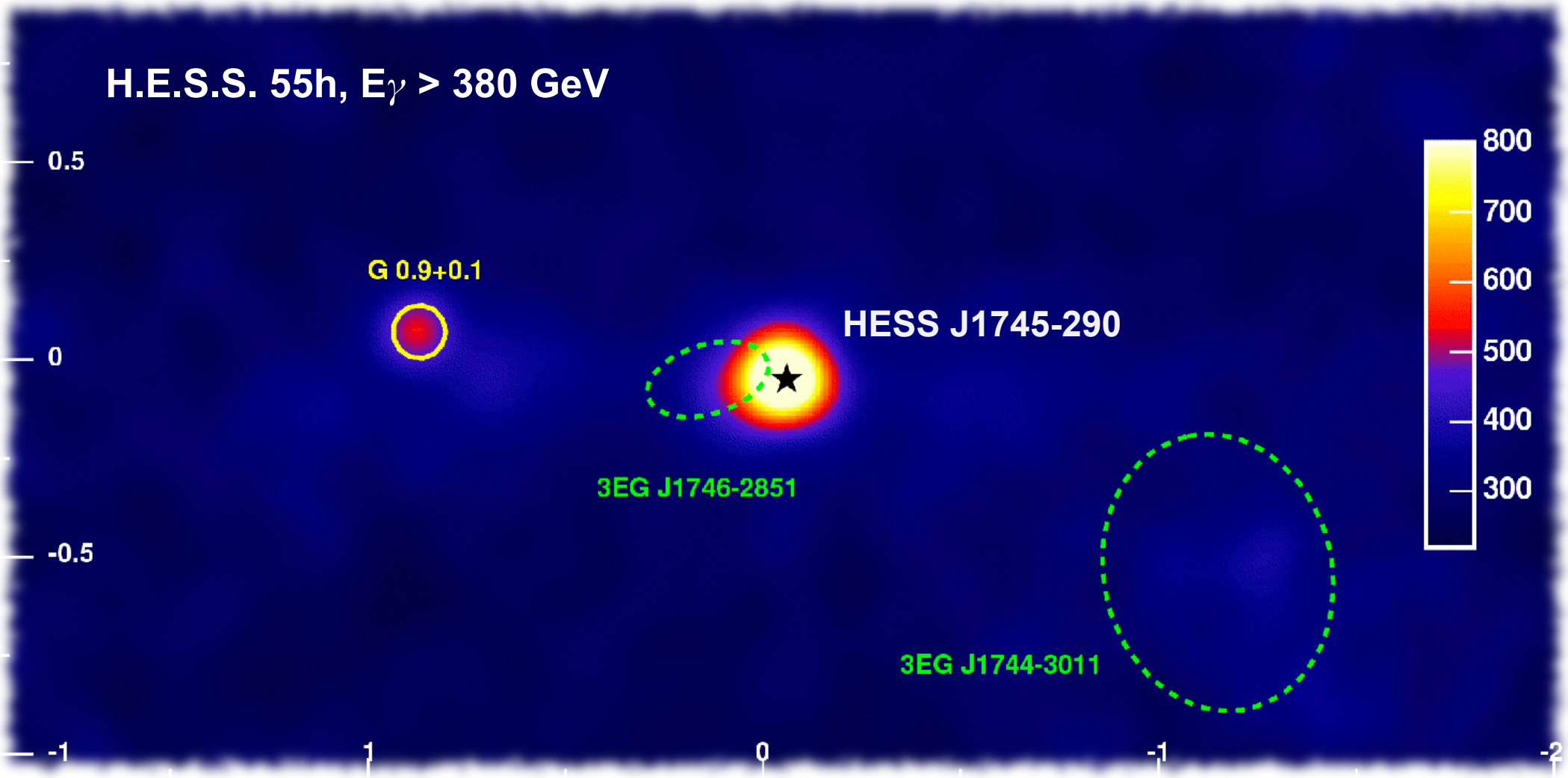






VHE Morphology of the Ridge

Aharonian et al. 2006



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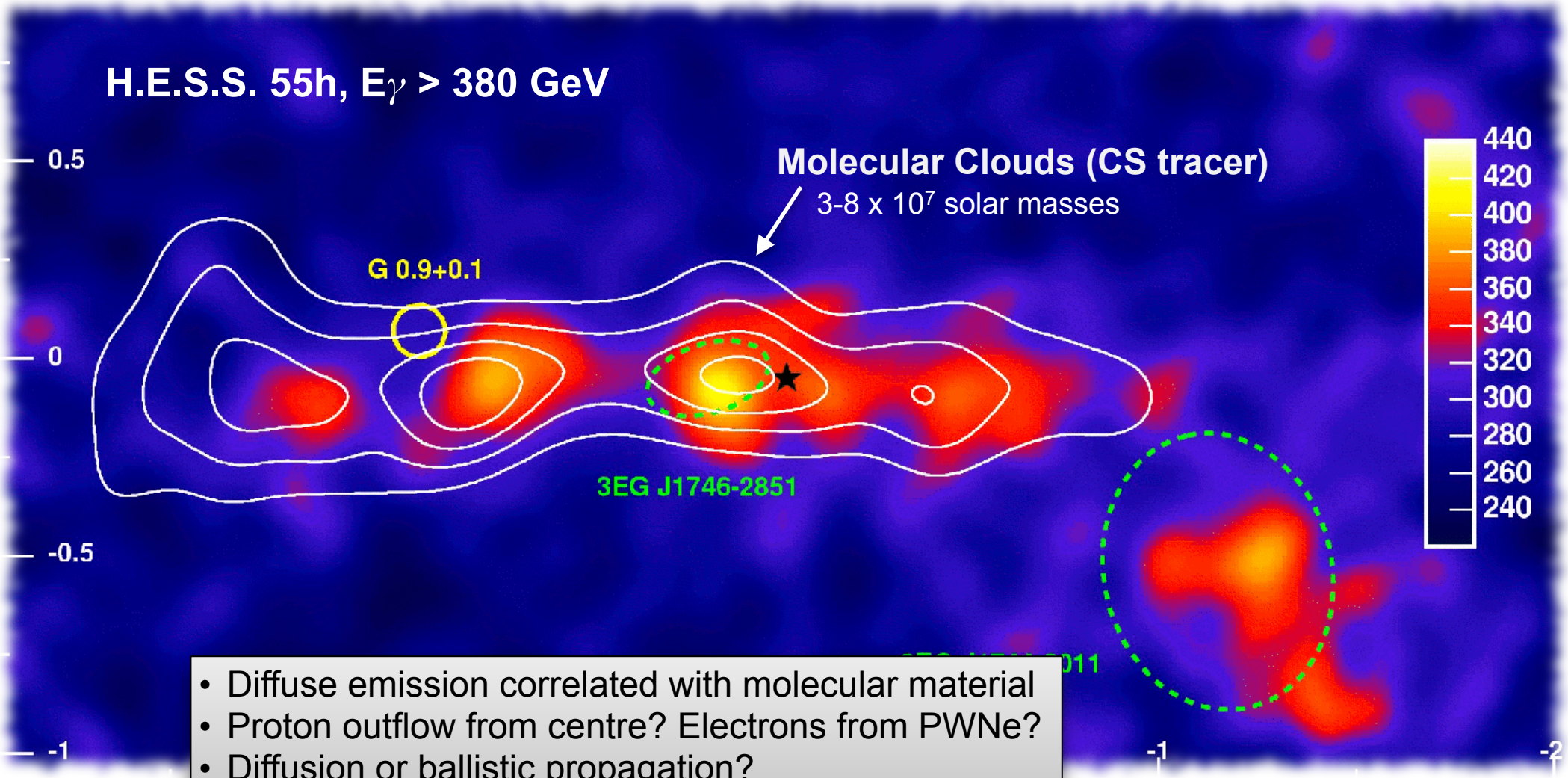

- Diffuse emission correlated with molecular material
- Proton outflow from centre? Electrons from PWNe?
- Diffusion or ballistic propagation?
- Impulsive injection or steady-state?

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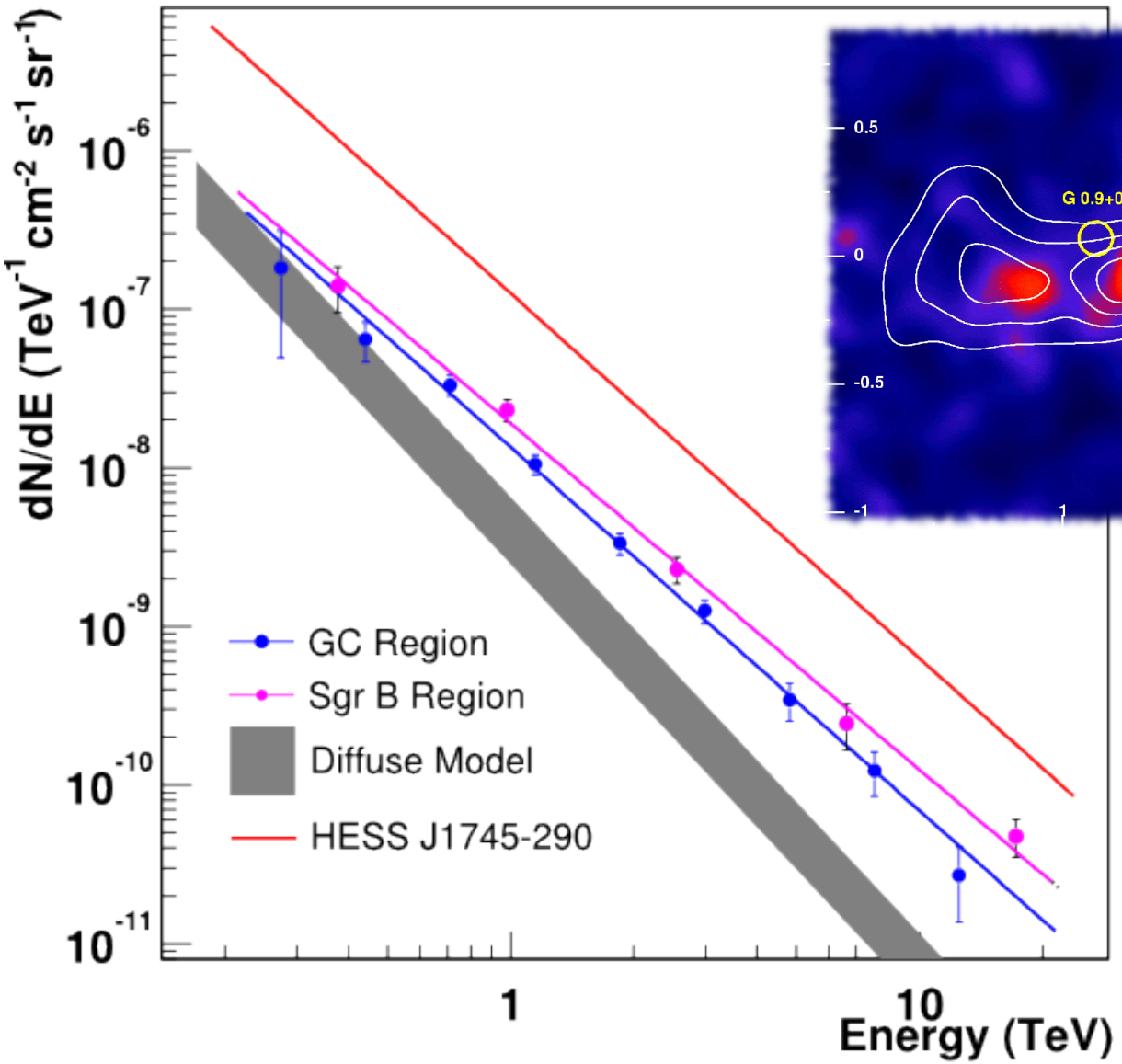

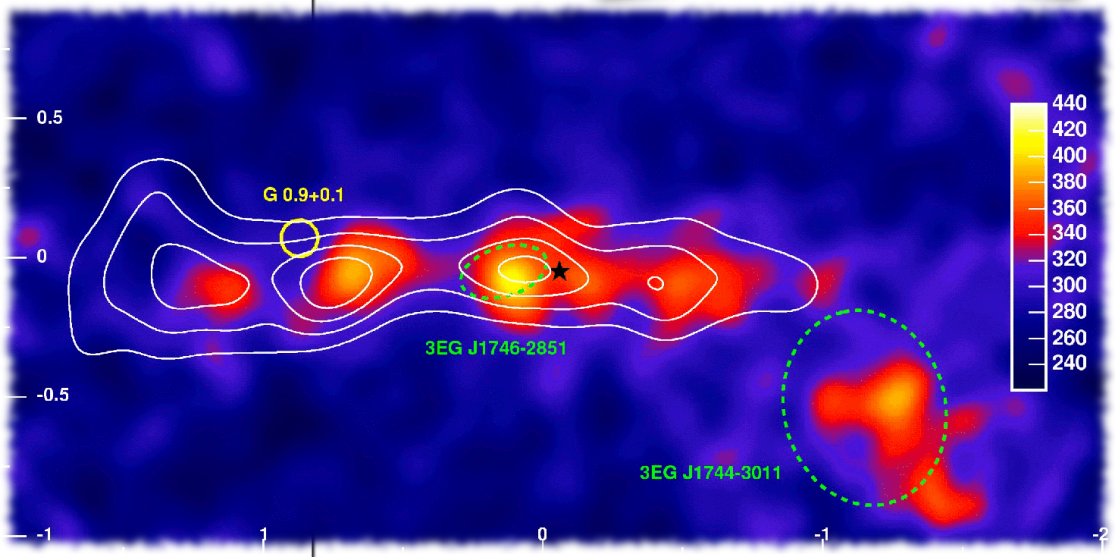

- Gamma rays up to 20 TeV
- Ridge flux exceeds model of passive CR illumination
- Enhanced CR density: total proton energy content ~10^{49} erg between 4-40 TeV
- Need local accelerator(s)

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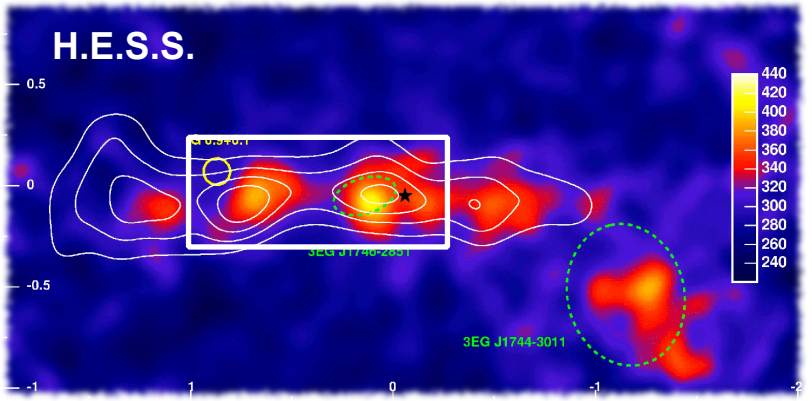
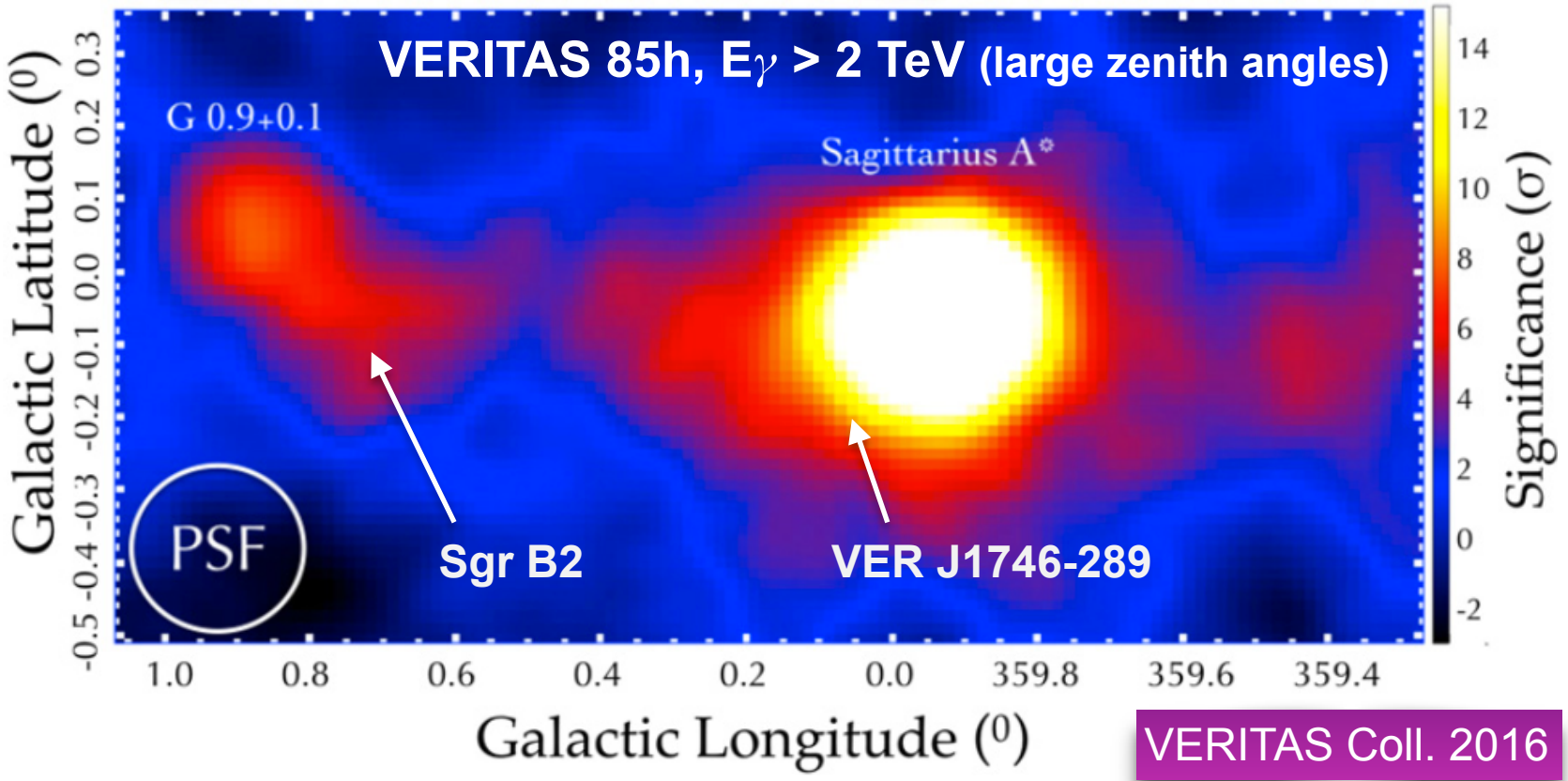
VHE Morphology of the Ridge



VERITAS > 2 TeV:
- Morphology generally confirmed
- Evidence for emission from Sgr B2
- New source J1746-289



VERITAS Coll. 2016

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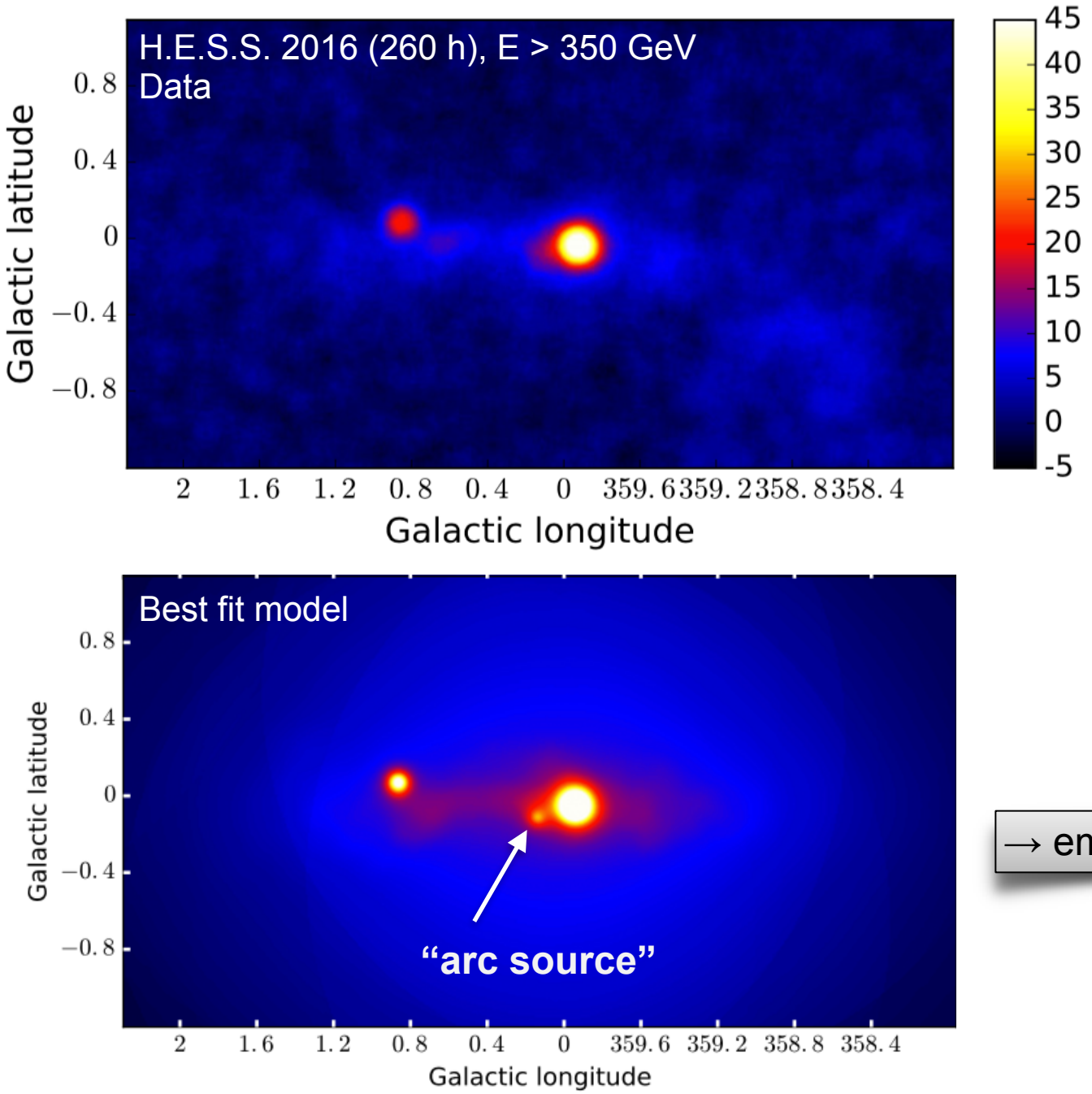
A Closer Look at the Ridge



- full H.E.S.S. I data set
- improved data analysis techniques: better angular resolution, sensitivity

full 2D morphology fitting:
- 2 point sources
- 2 gaussian components
- galactic diffuse emission
- molecular cloud template (CS tracer)
- new point-like “arc source”

→ empirical model of ridge emission

Lemiere et al. 2015
Parsons et al. 2016

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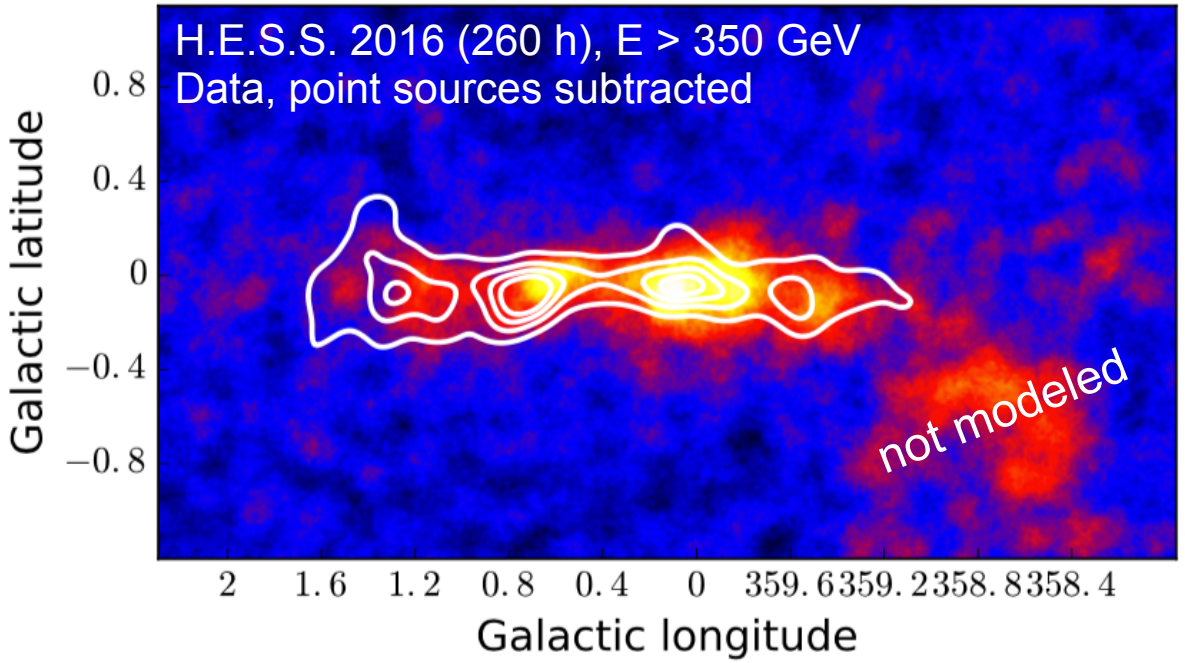

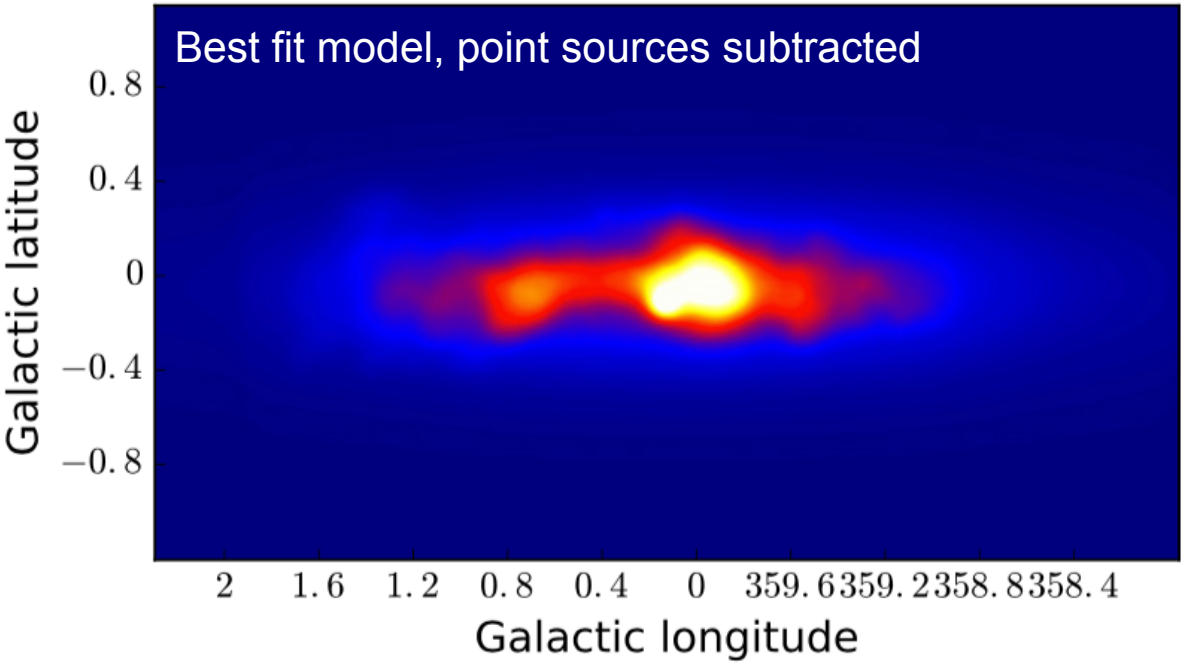

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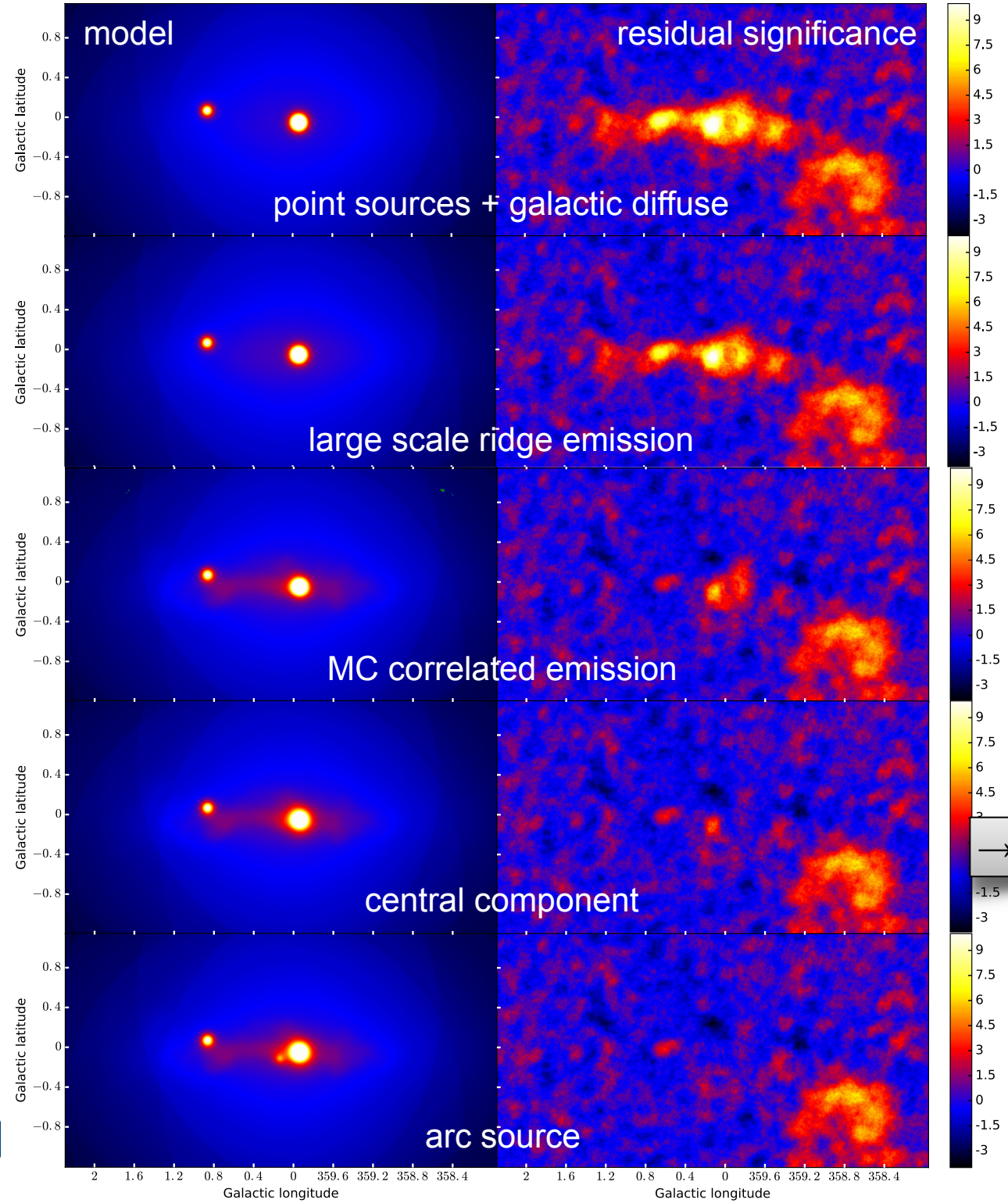

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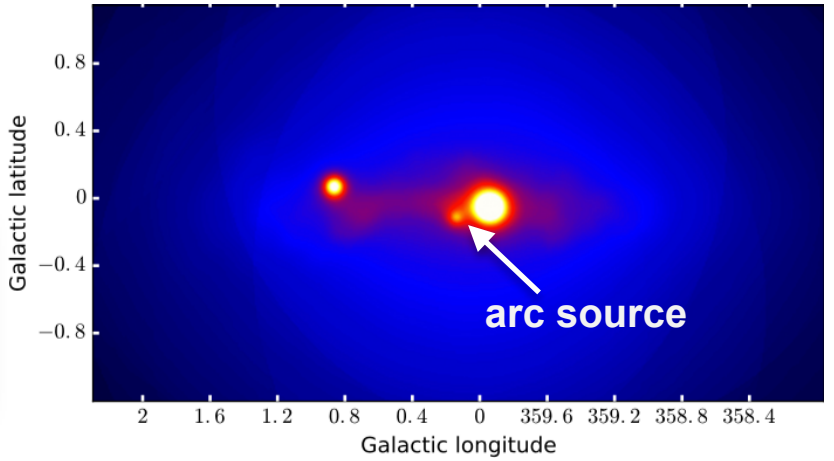
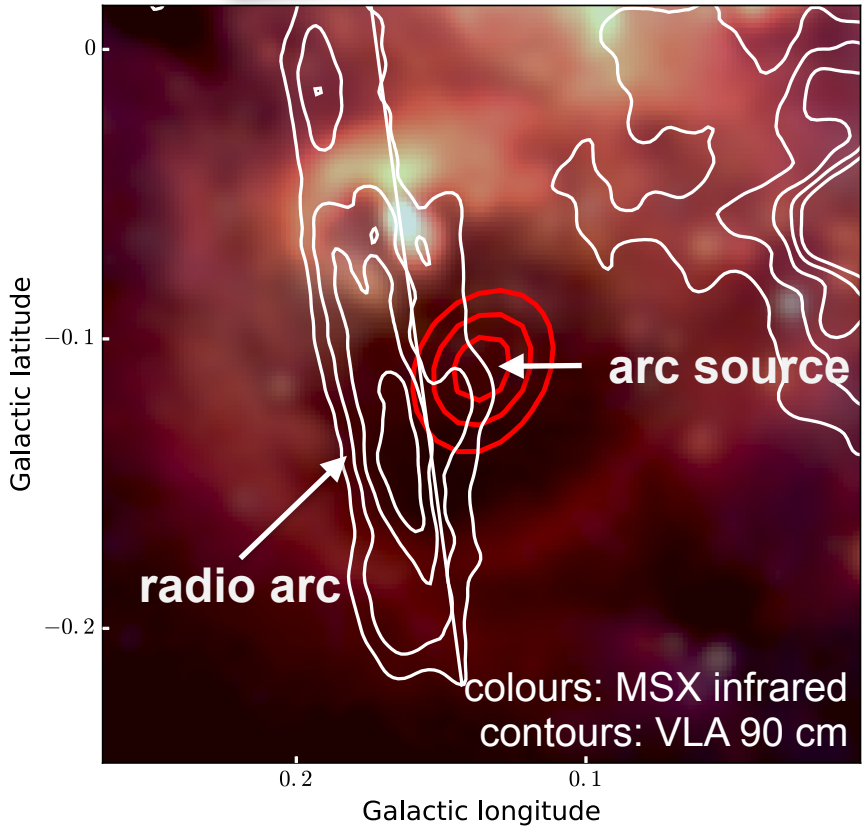
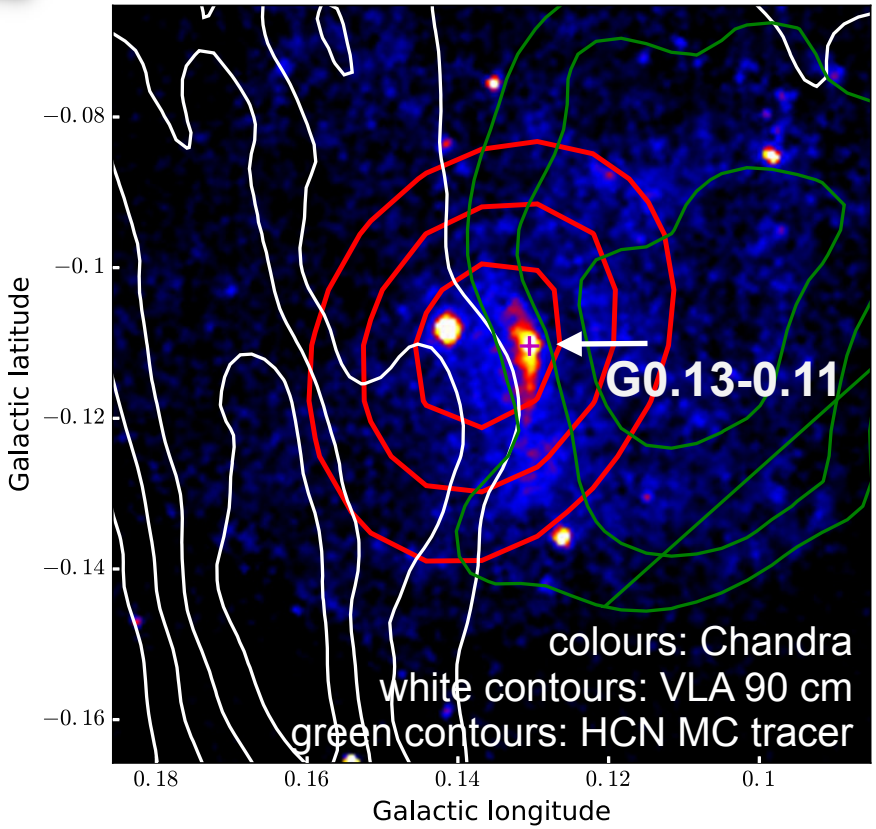
The Arc Source

- point-like emission
- hard spectrum source: Γ ~ 2.2
- VHE luminosity ~ 7 x 10^{33} erg/s > 350 GeV

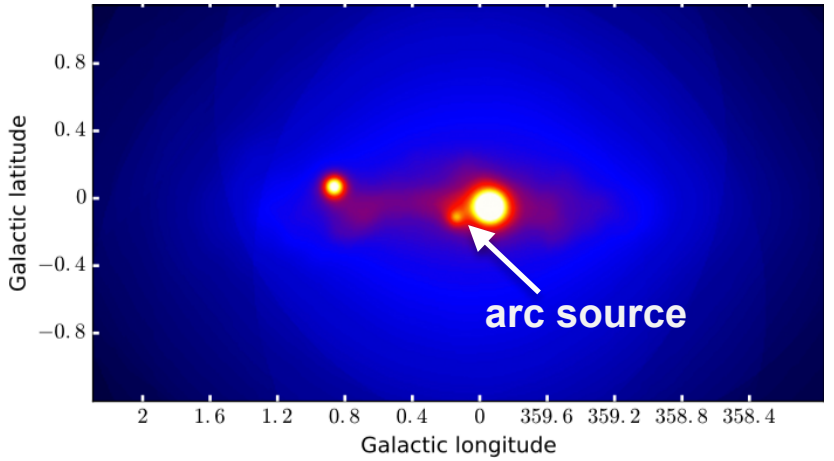
Association?
- likely candidate PWN G0.13-0.11 w/ spin-down power ~10^{35} erg/s



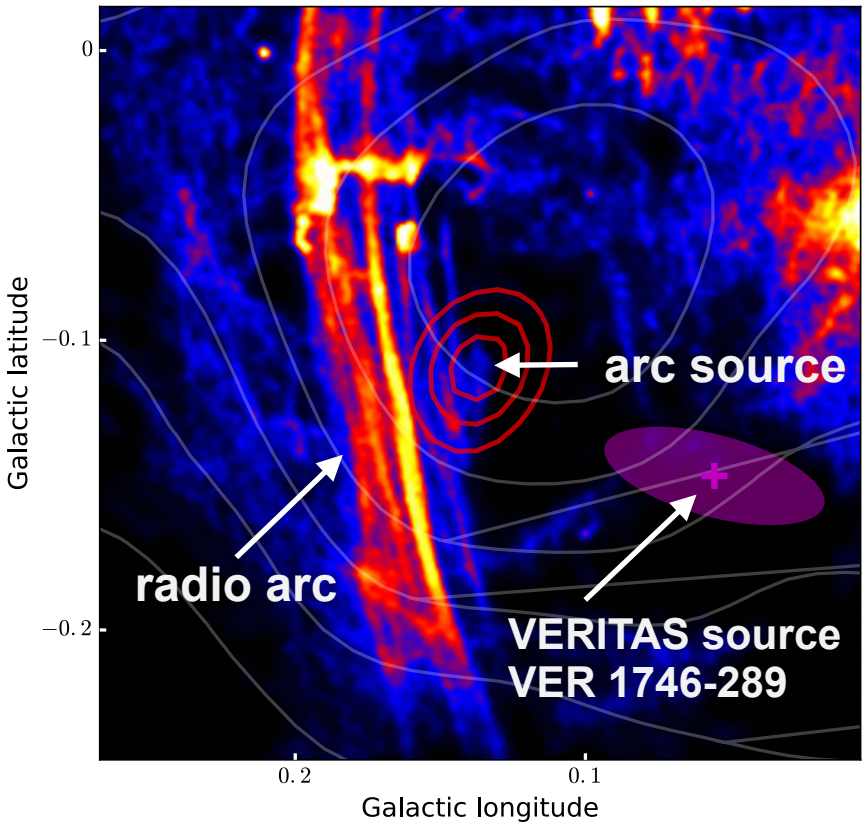


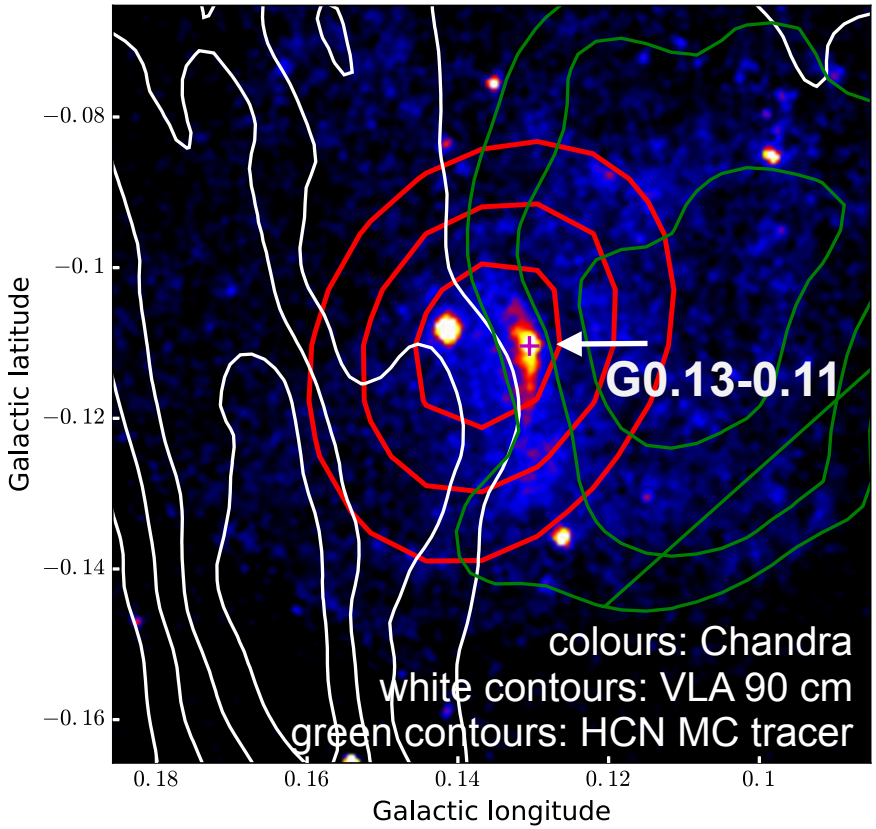


The Arc Source

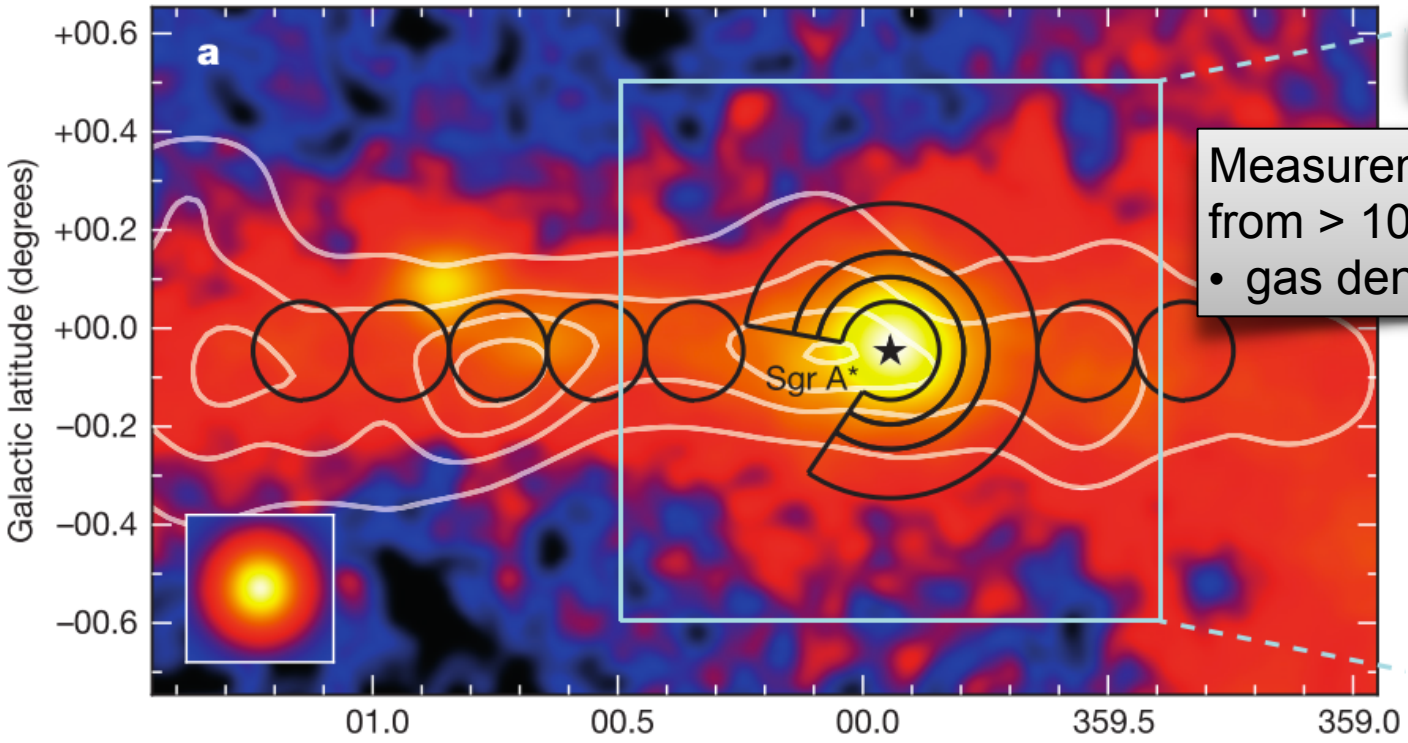


Association with VER 1746-289?
- neither clear case nor excluded
- but: not as detailed modeling of diffuse component by VERITAS





Testing Cosmic Ray Transport in the GC



H.E.S.S. Coll. 2016

Measurement of CR energy density from > 10 TeV gamma rays

- gas density from CS (CO, HCN)

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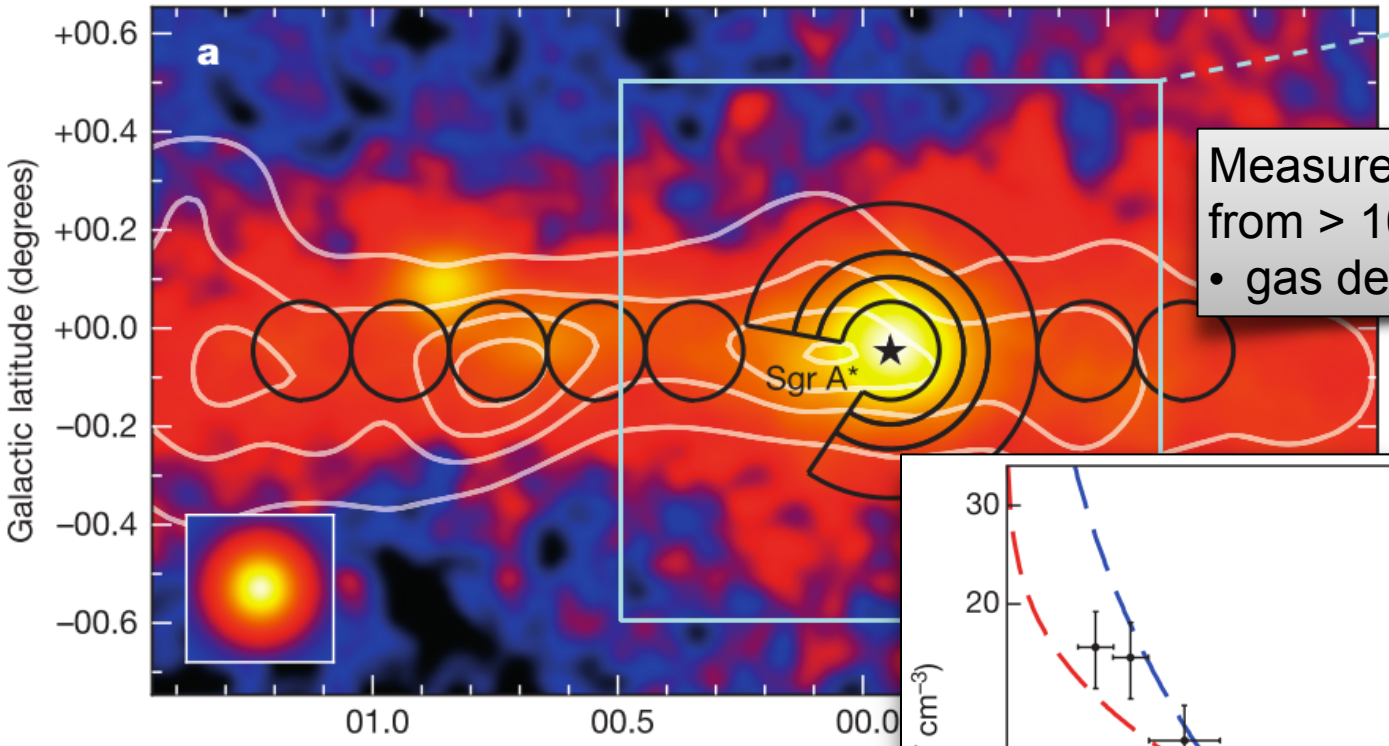

H.E.S.S. Coll. 2016

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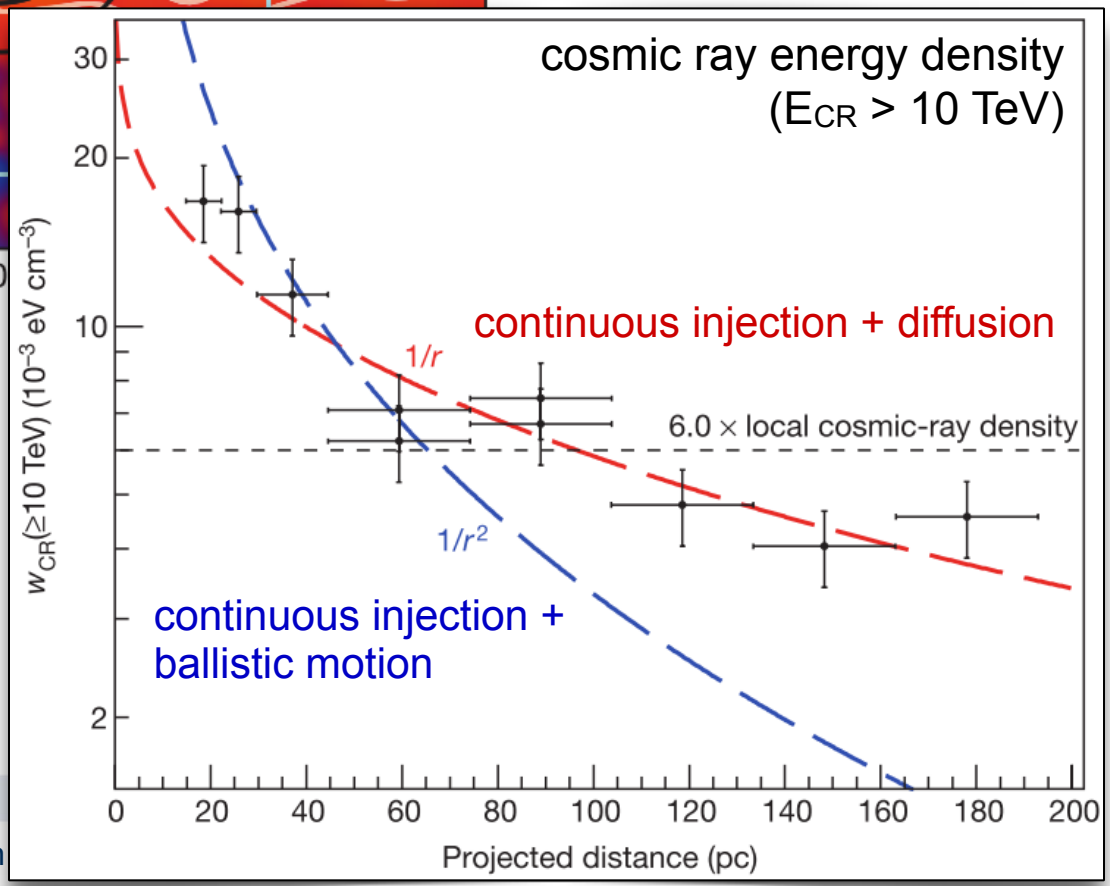
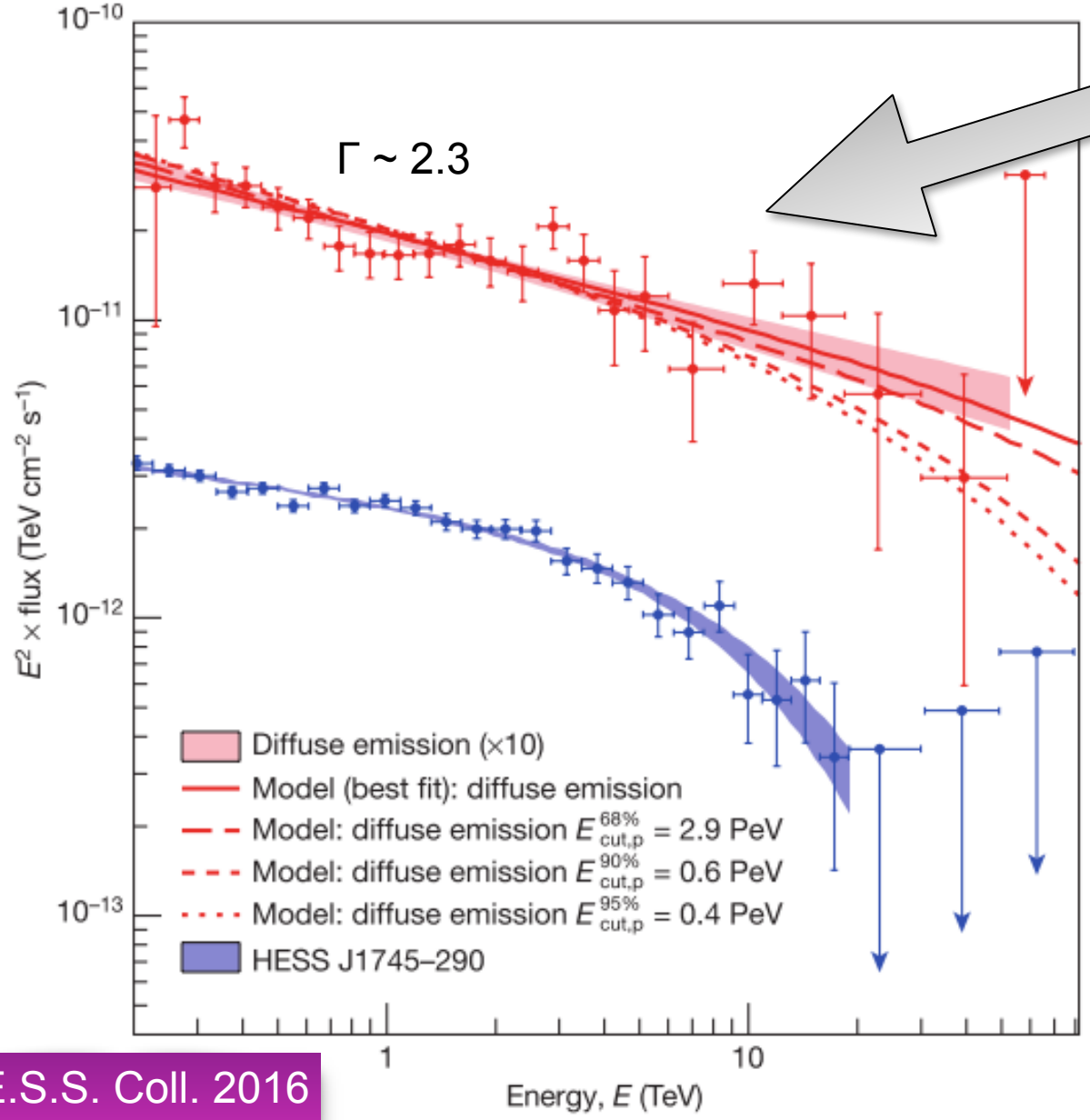
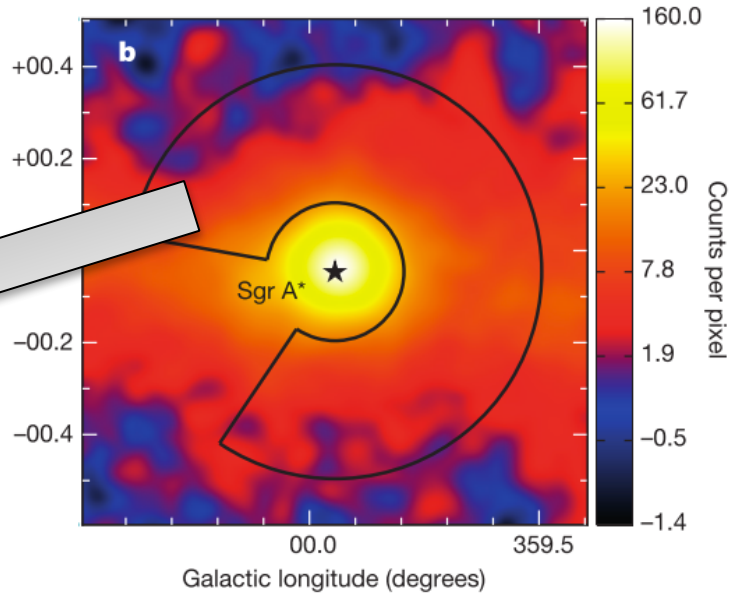


- again: density of multi-TeV CRs much larger than galactic average → local accelerator required
- density compatible with 1/r projection → favours quasi-continuous injection (> 10^3 yr) + CR diffusion
- total injected power << 10^{38} erg/s

A PeVatron in the GC



H.E.S.S. Coll. 2016



Gamma-ray spectrum extends to 50 TeV w/o cutoff
→ proton energies exceeding 1 PeV

First solid detection of a Galactic PeVatron!
- CR acceleration up to the knee!

Detection ≠ Identification:
What's the accelerator?

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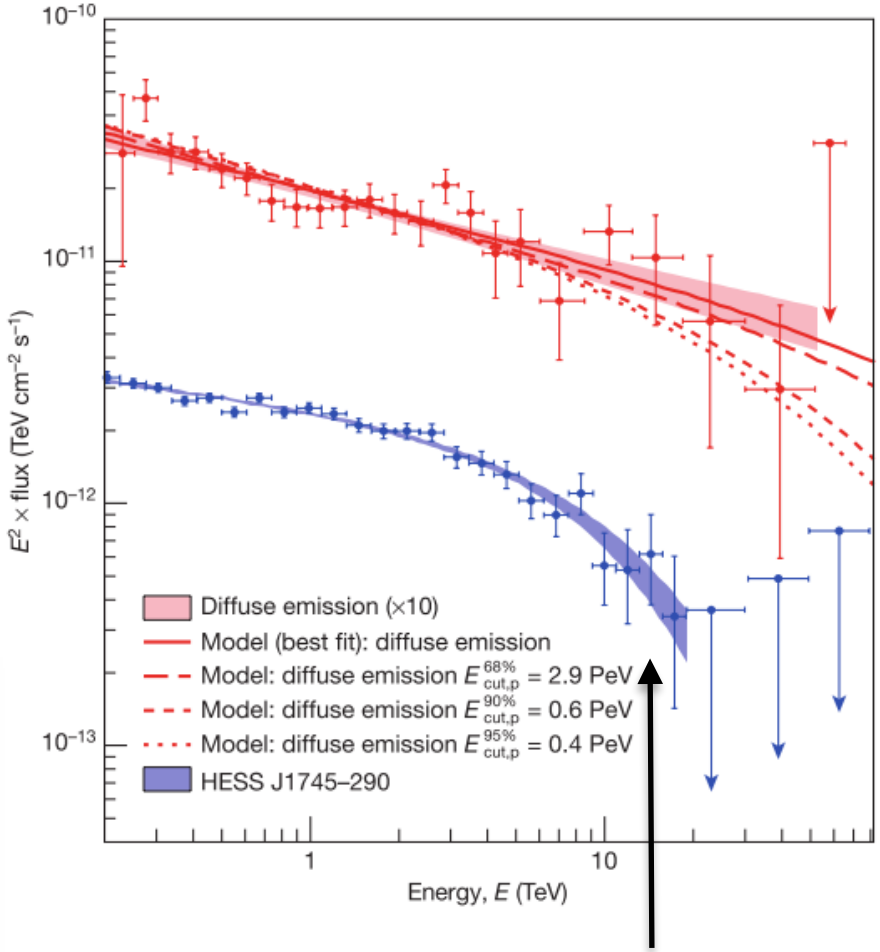
The nature of the PeVatron

Requirements:
- located within central 10 pc
- particle acceleration to 1 PeV
- continuous injection of $< 10^{38}$ erg/s during $> 10^3$ yrs into CMZ

Potential sources:
- one/several SNRs (e.g. Sgr A East)?
  - PeVatrons during first ~100 yr → need >1 SNR/100 yr in inner 10 pc region (unlikely)
- stellar winds in central star cluster?
  - need >10.000 km/s shock speeds, only realised in SNRs
- SMBH?
  - energetically at least viable, several acceleration mechanisms proposed
- How to get protons out of the inner 10 pc region?



cutoff due to IR absortion?

PeVatron = GC VHE source?
association likely, but neither clear case nor required for PeVatron discussion

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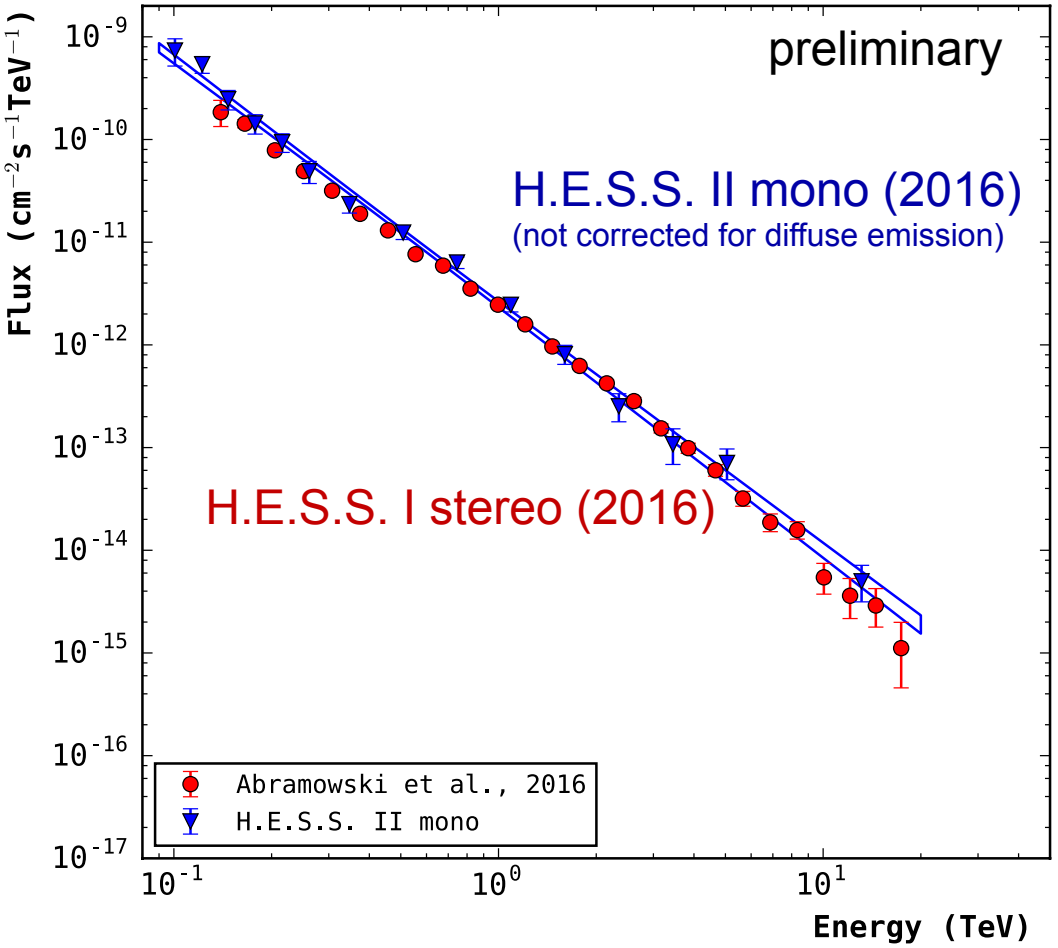
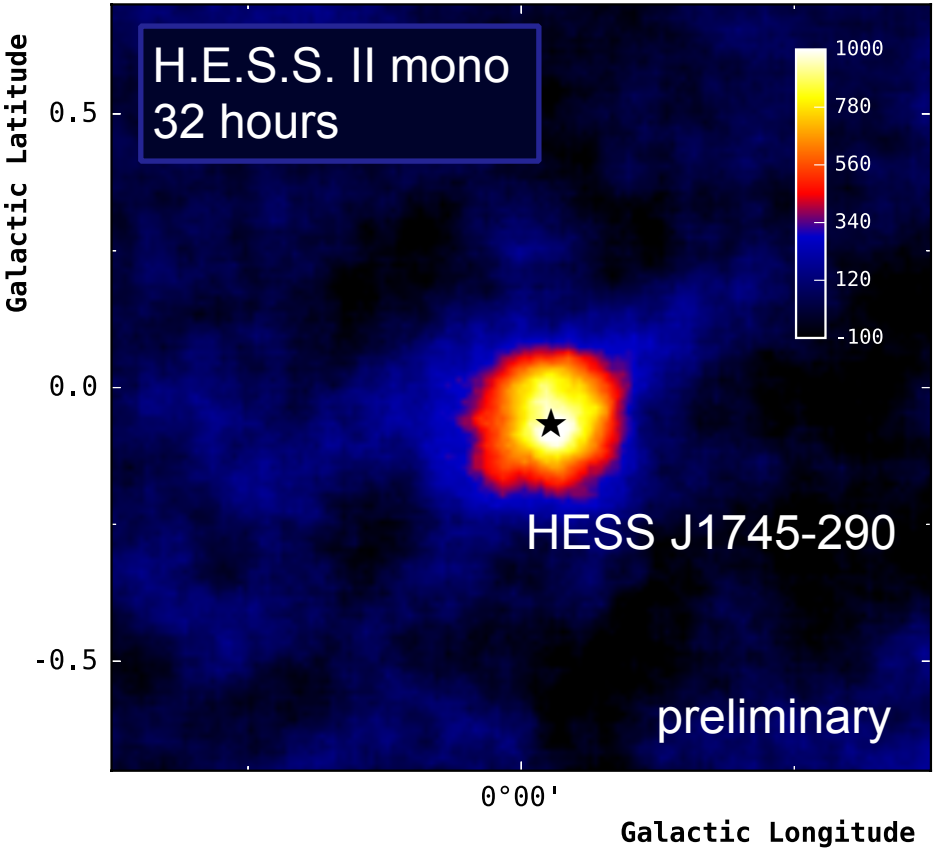
The GC with H.E.S.S. II

2014 single telescope (mono) observations
- much reduced energy threshold
- much enhanced background systematics





Parsons et al. 2016

- safe detection at 26σ
- measurement down to 90 GeV
- energy spectrum consistent with previous publications

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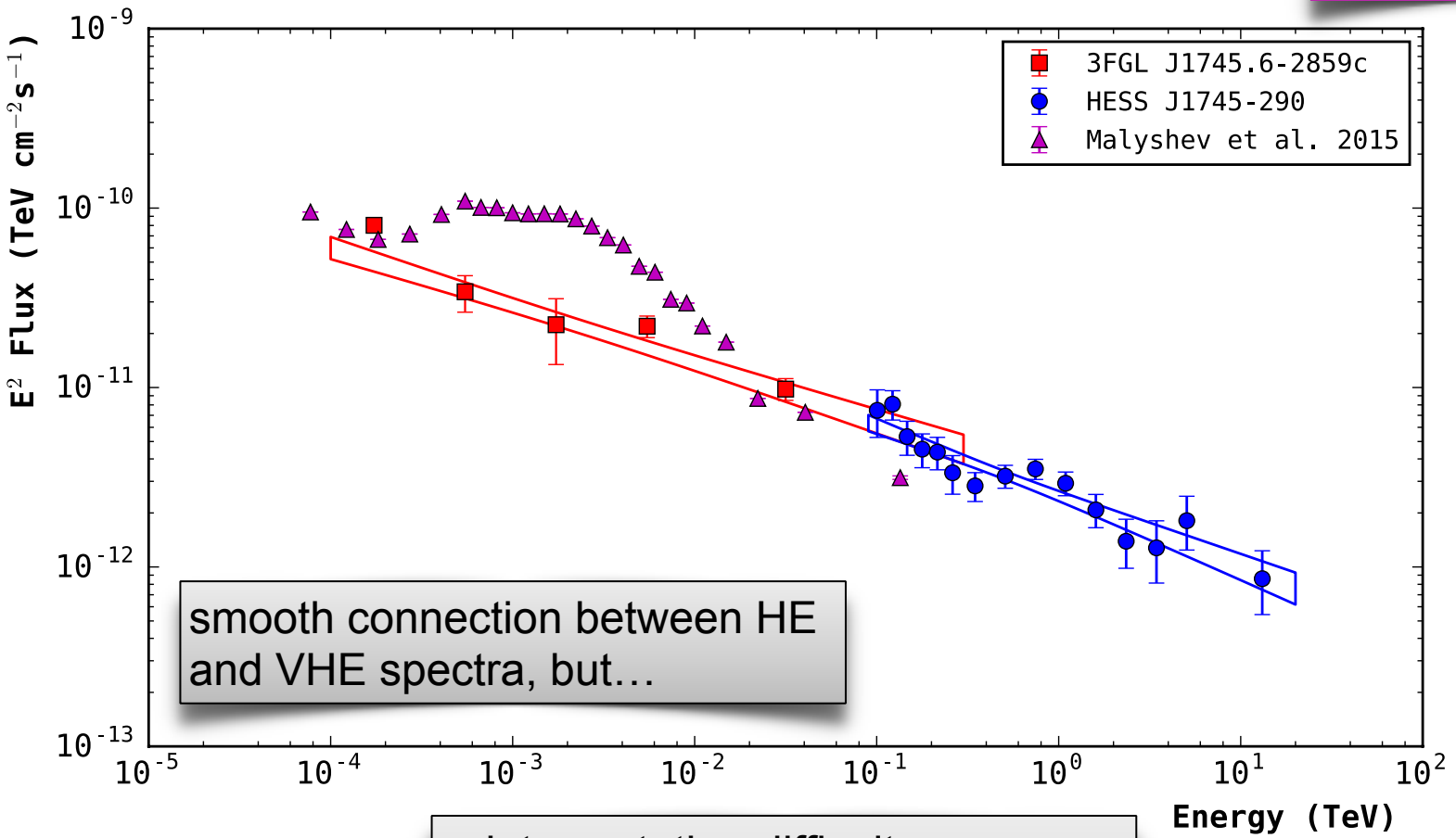
The GeV/TeV connection

Parsons et al. 2016



smooth connection between HE and VHE spectra, but…

…interpretation difficult:

- very dependent on spectral extraction region
- very dependent on assumed HE diffuse emission model

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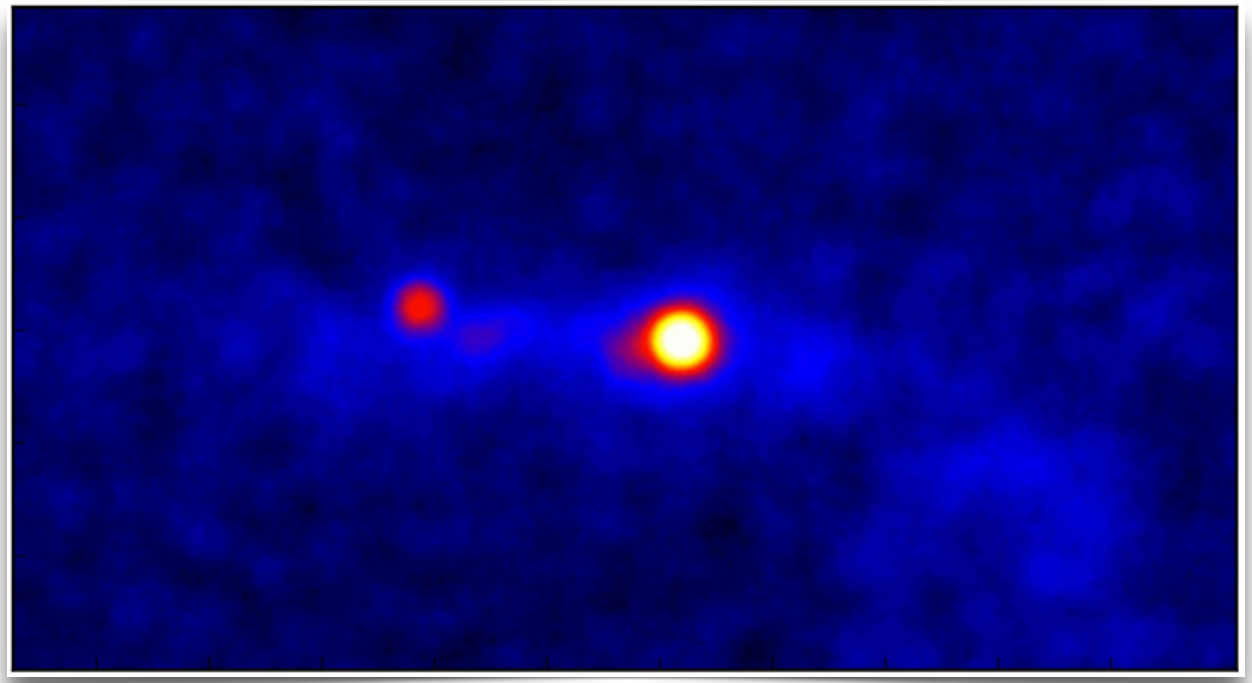
Summary



VHE gamma rays are important messengers to study high-energy astrophysics of the GC:

- Search for multi-TeV CR accelerators provides first detection of Galactic PeVatron
- Diffuse emission along CMZ is unique region to study particle transport close to a local CR accelerator
- Can the SMBH accelerate particles to multi-TeV or even PeV energies?

GC is key science project of CTA, which will further improve angular resolution and sensitivity.

see talk by Sera Markoff

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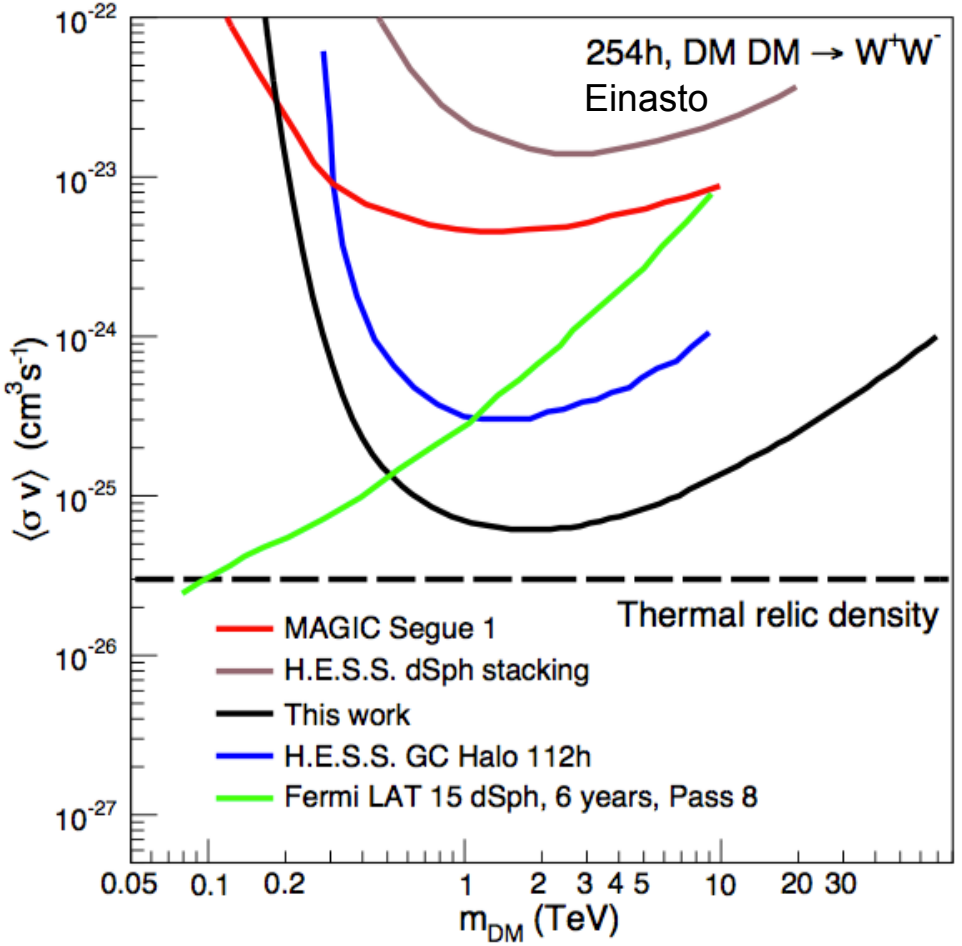
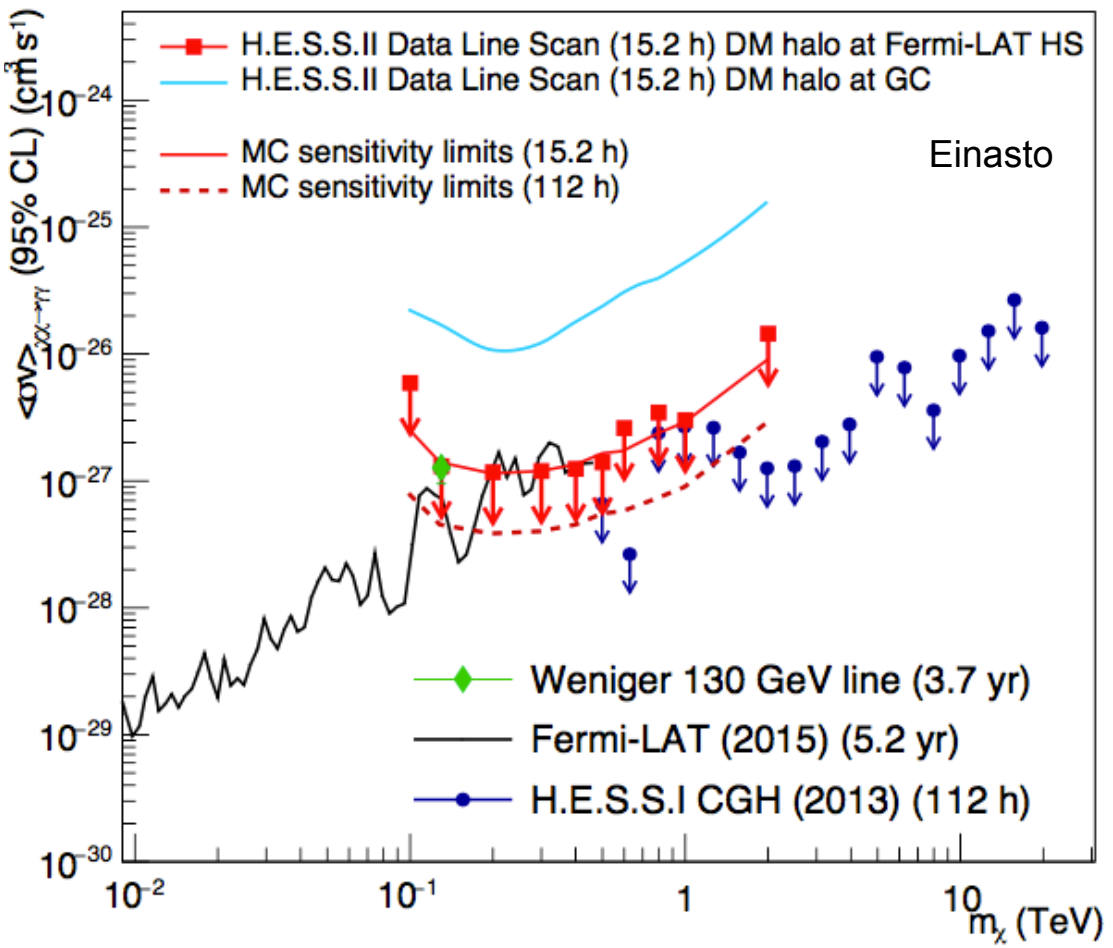
Addendum: GC Dark Matter Searches

Emanuel Moulin (cancelled)





- H.E.S.S. I: increased data sample, improved analysis techniques
- H.E.S.S. II stereo: demonstration of access to $E\gamma$ ~ 100 GeV, complementing Fermi-LAT searches

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Thanks for your patience.

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung
HELMHOLTZ ASSOCIATION
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