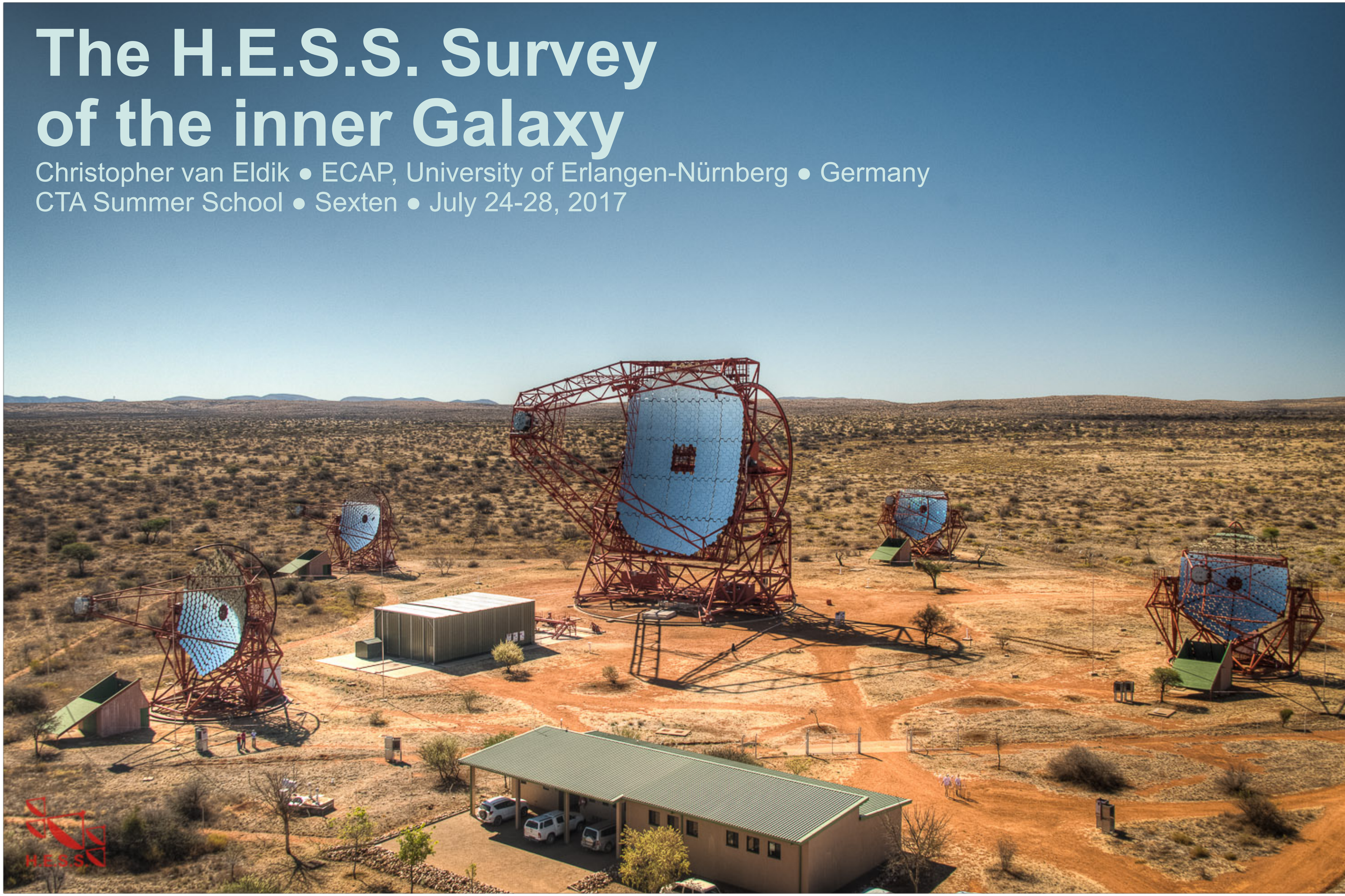
The H.E.S.S. Survey of the inner Galaxy

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

CTA Summer School • Sexten • July 24-28, 2017



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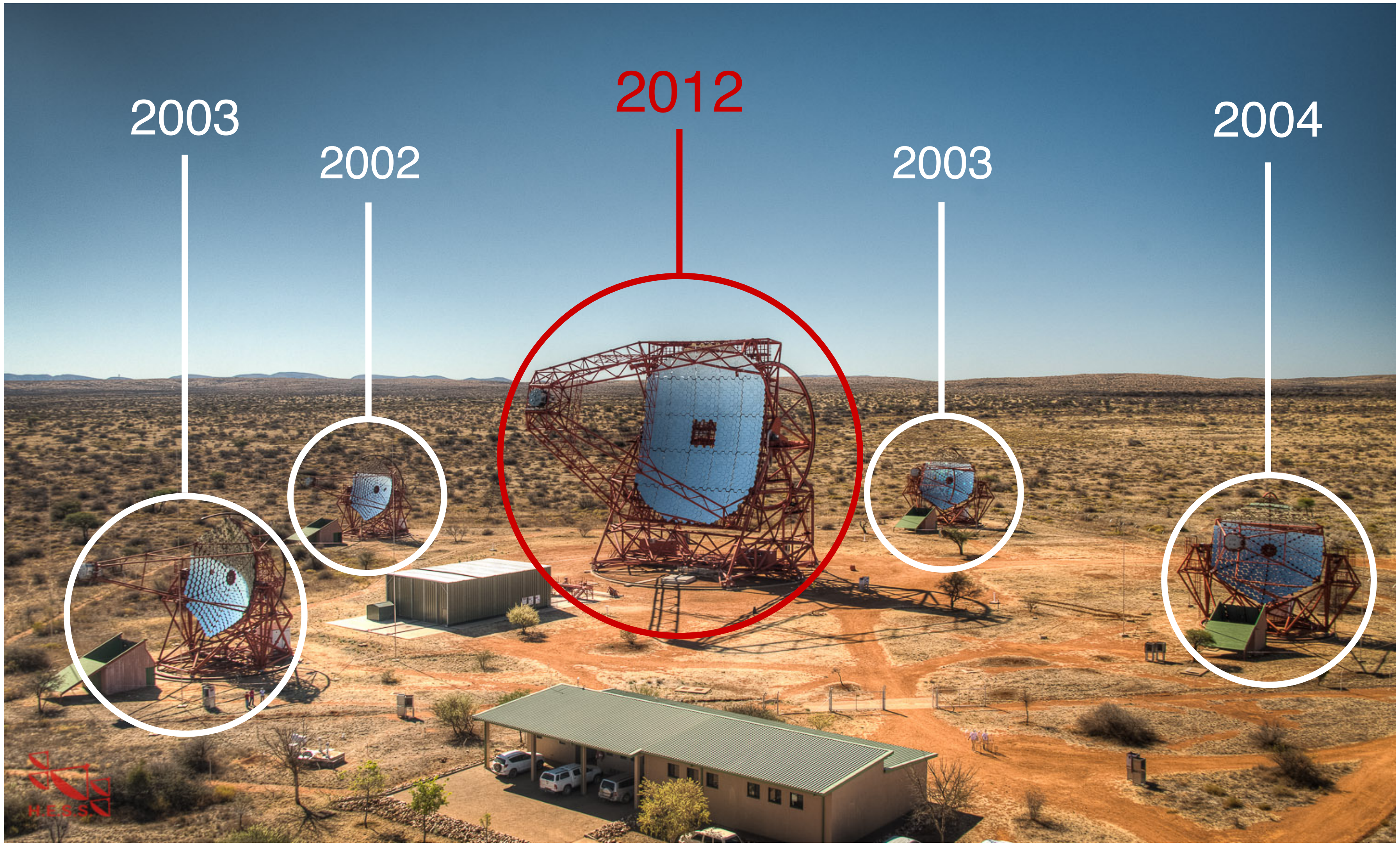
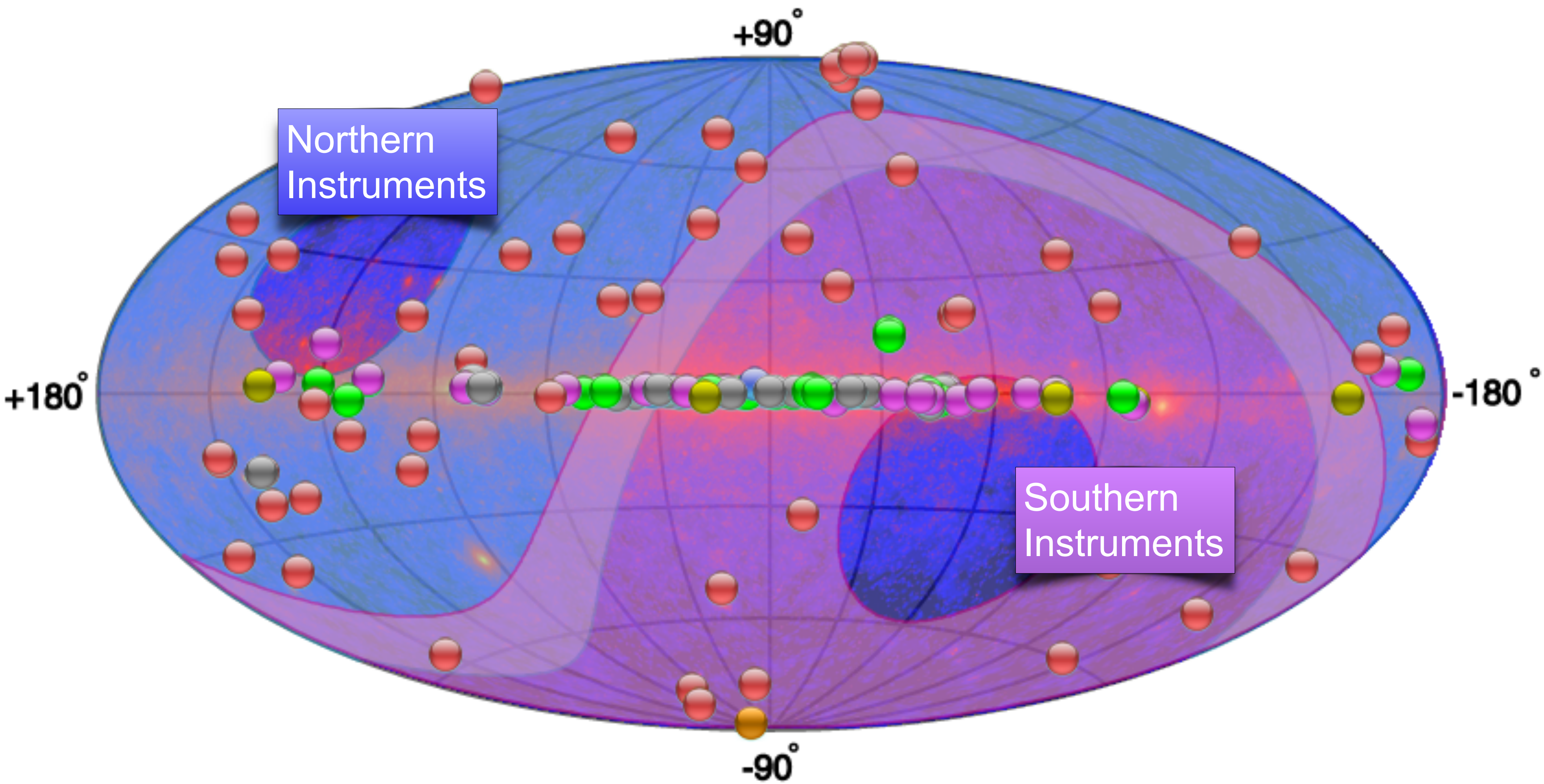
FOR ASTROPARTICLE
PHYSICS

The High Energy Stereoscopic System

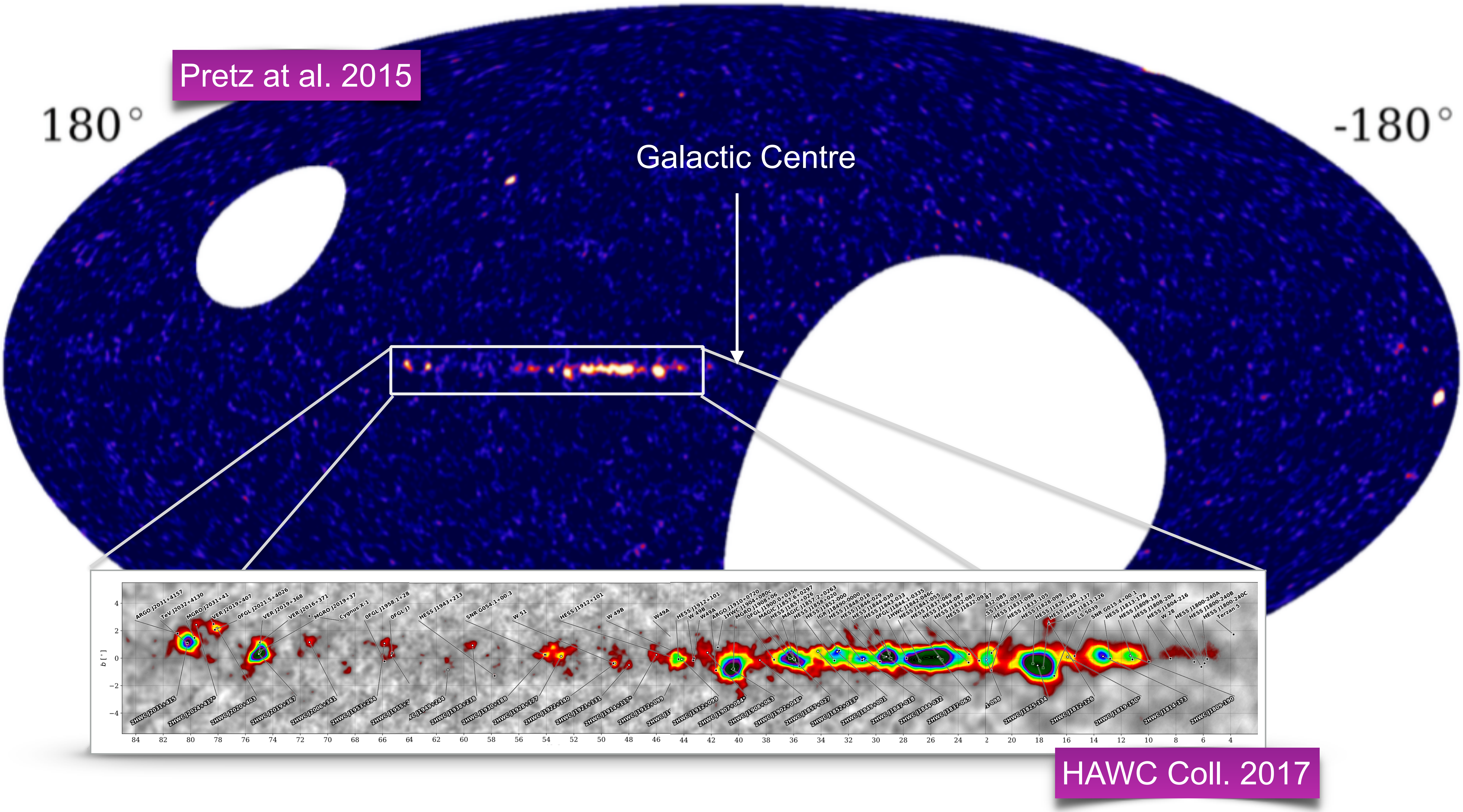
- H.E.S.S. Collaboration:
  250 scientists, ~40 institutes, 13 countries
- Operating since 2003, upgrade 2012
- Khomas Highlands, Namibia (1836 m)



Sky Coverage (Galactic Coordinates)



The HAWC's view: mapping the TeV sky



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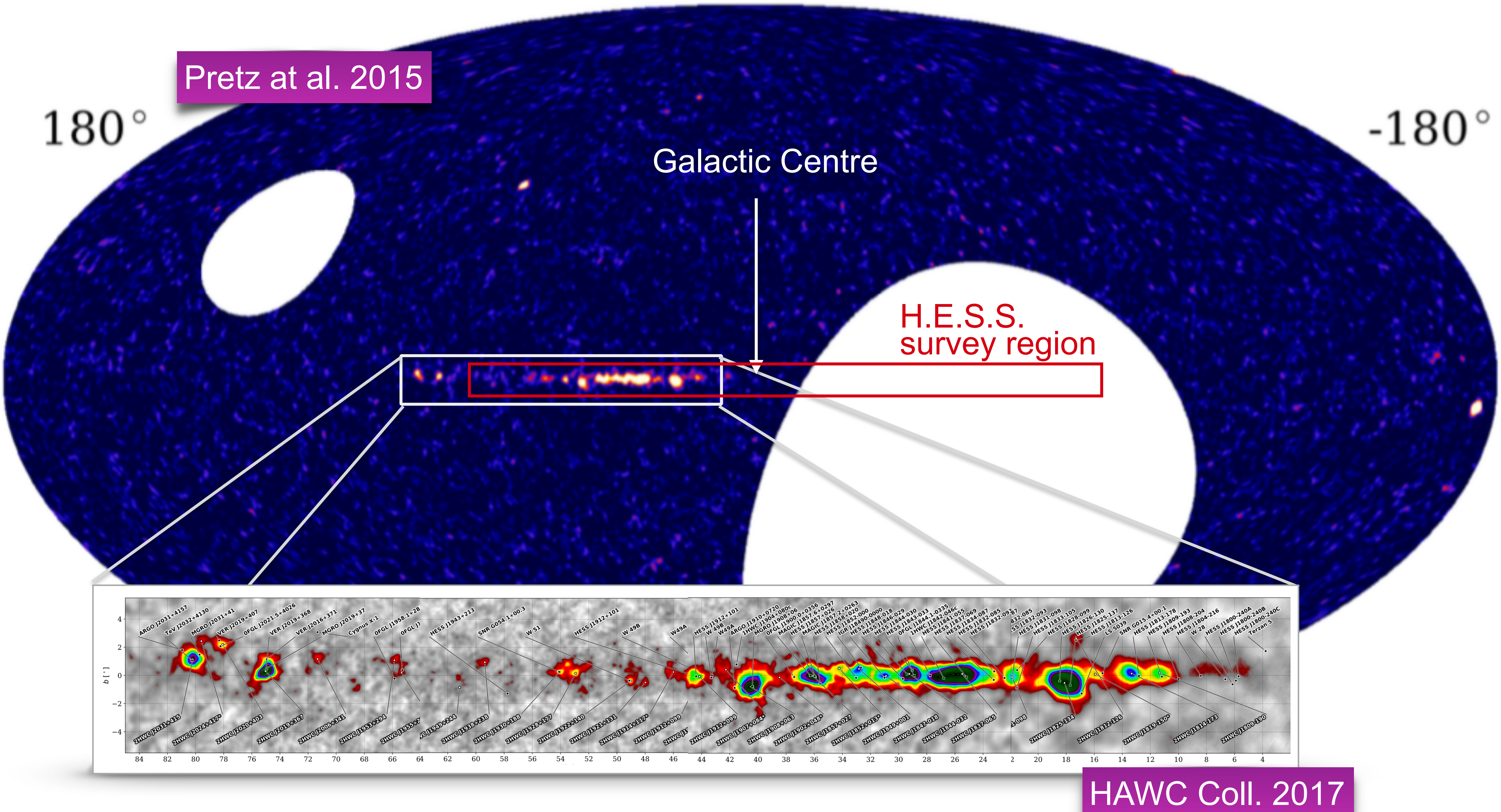
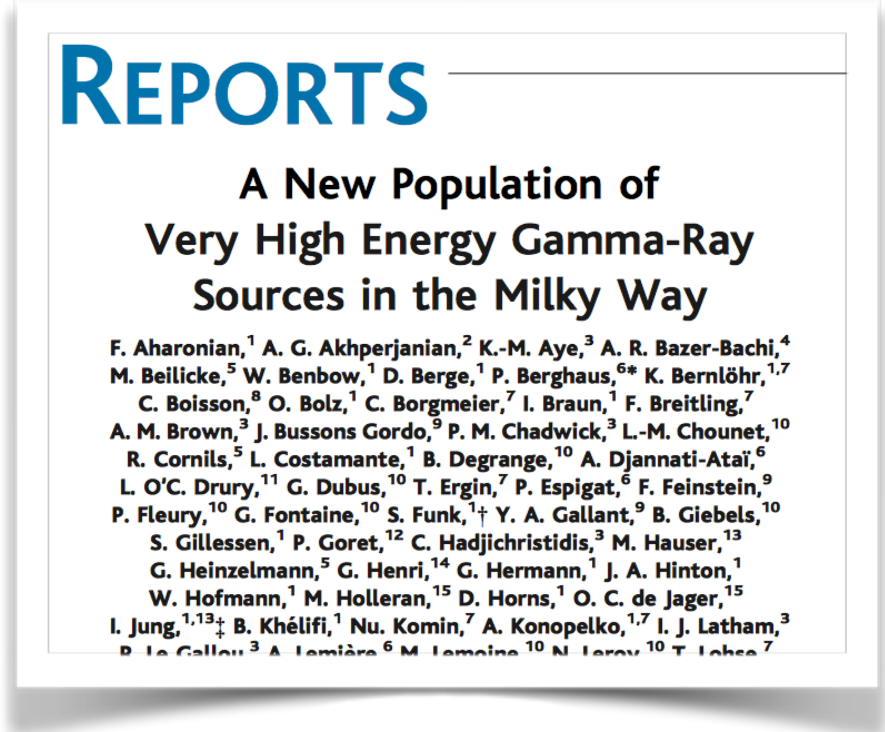


The first H.E.S.S. survey

- 05/2004 - 07/2004 (112 h of data)
- [-30°, 30°] in longitude, [-3°, 3°] in latitude
- additional deep exposures of specific sources

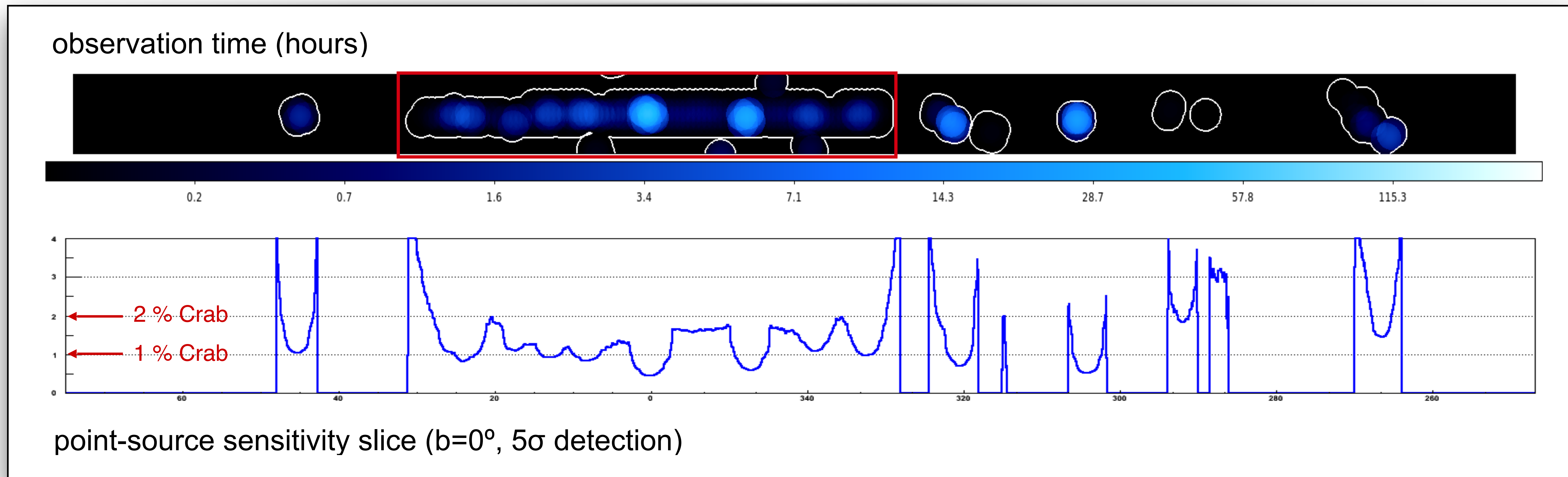


REPORTS

A New Population of Very High Energy Gamma-Ray Sources in the Milky Way

F. Aharonian,[1] A. G. Akhperjanian,[2] K.-M. Aye,[3] A. R. Bazer-Bachi,[4] M. Beilicke,[5] W. Benbow,[1] D. Berge,[1] P. Berghaus,[6*] K. Bernlöhr,[1,7] C. Boisson,[8] O. Bolz,[1] C. Borgmeier,[7] I. Braun,[1] F. Breitling,[7] A. M. Brown,[3] J. Bussons Gordo,[9] P. M. Chadwick,[3] L.-M. Chounet,[10] R. Cornils,[5] L. Costamante,[1] B. Degrange,[10] A. Djannati-Ataï,[6] L. O'C. Drury,[11] G. Dubus,[10] T. Ergin,[7] P. Espigat,[6] F. Feinstein,[9] P. Fleury,[10] G. Fontaine,[10] S. Funk,[1†] Y. A. Gallant,[9] B. Giebels,[10] S. Gillessen,[1] P. Goret,[12] C. Hadjichristidis,[3] M. Hauser,[13] G. Heinzelmann,[5] G. Henri,[14] G. Hermann,[1] J. A. Hinton,[1] W. Hofmann,[1] M. Holleran,[15] D. Horns,[1] O. C. de Jager,[15] I. Jung,[1,13‡] B. Khélifi,[1] Nu. Komin,[7] A. Konopelko,[1,7] I. J. Latham,[3]

2004-2005



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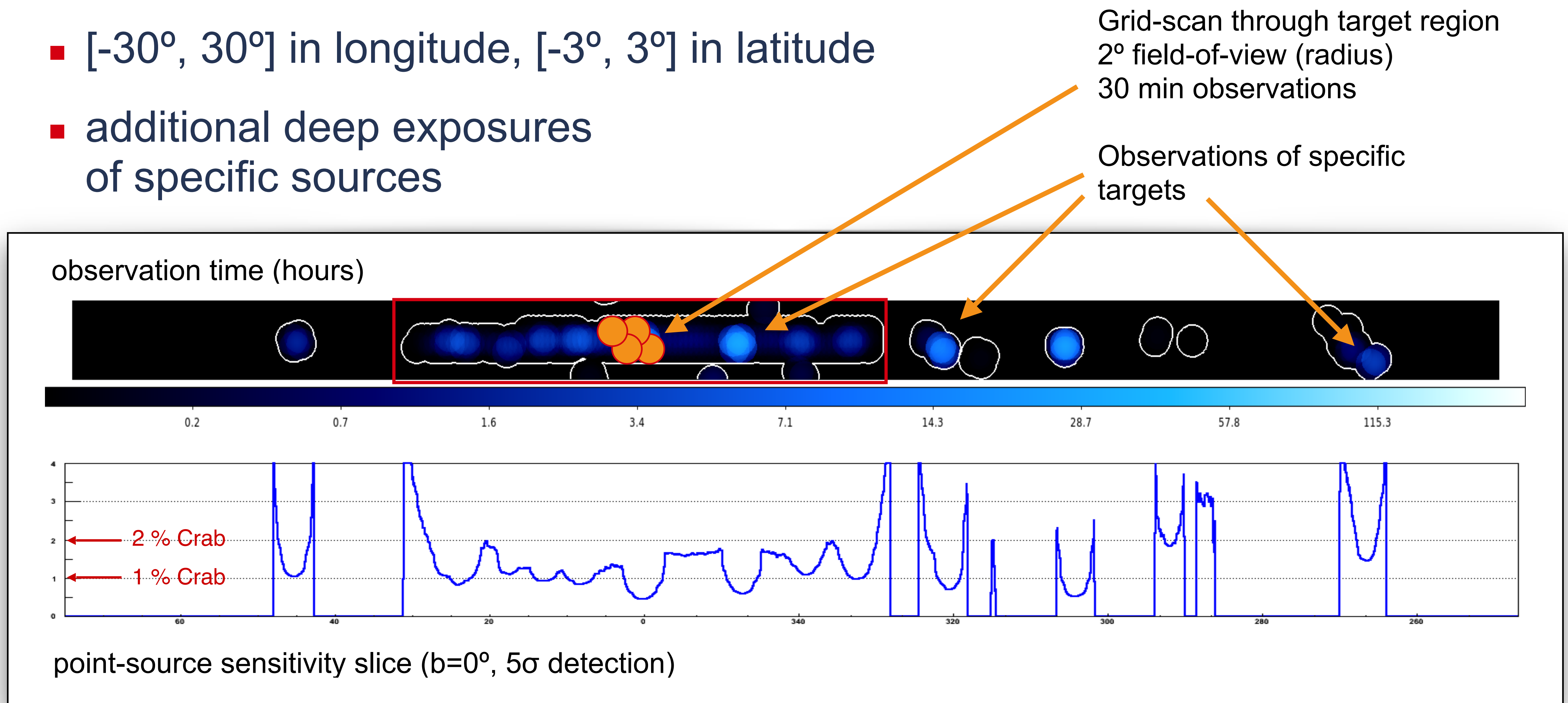

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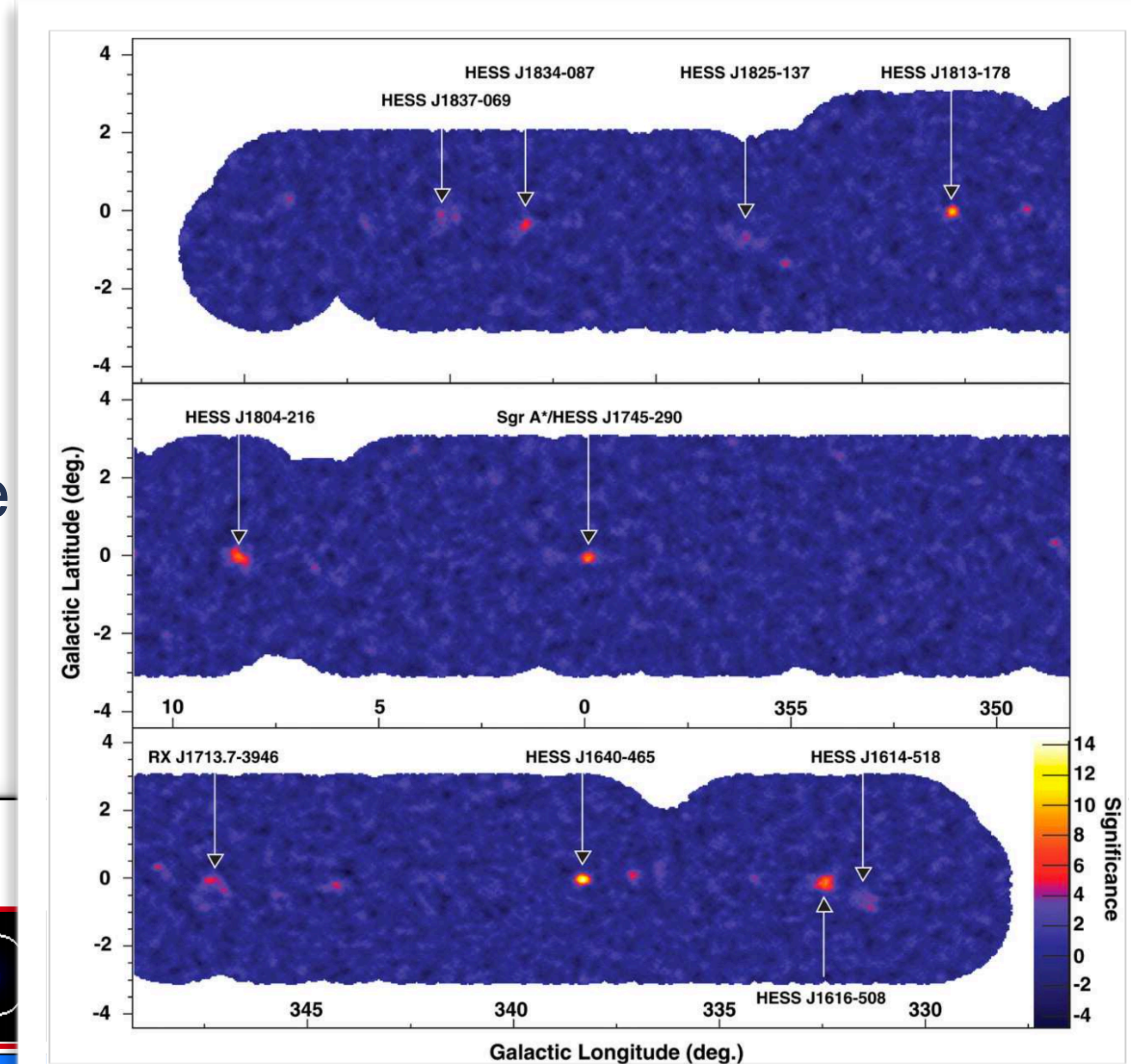
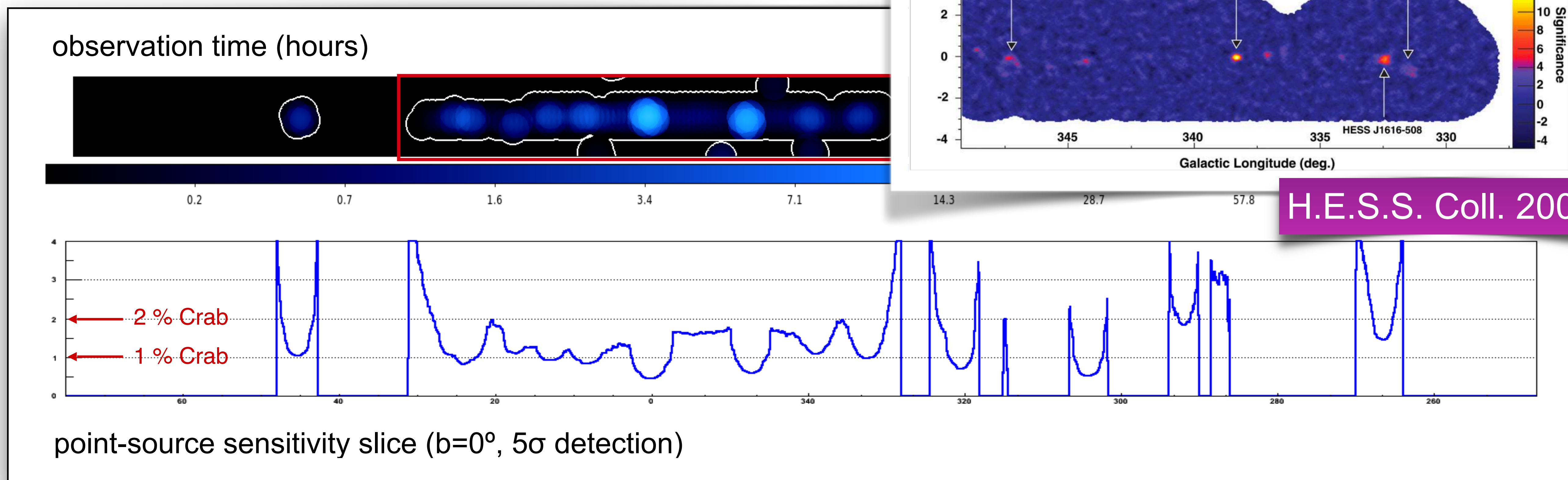


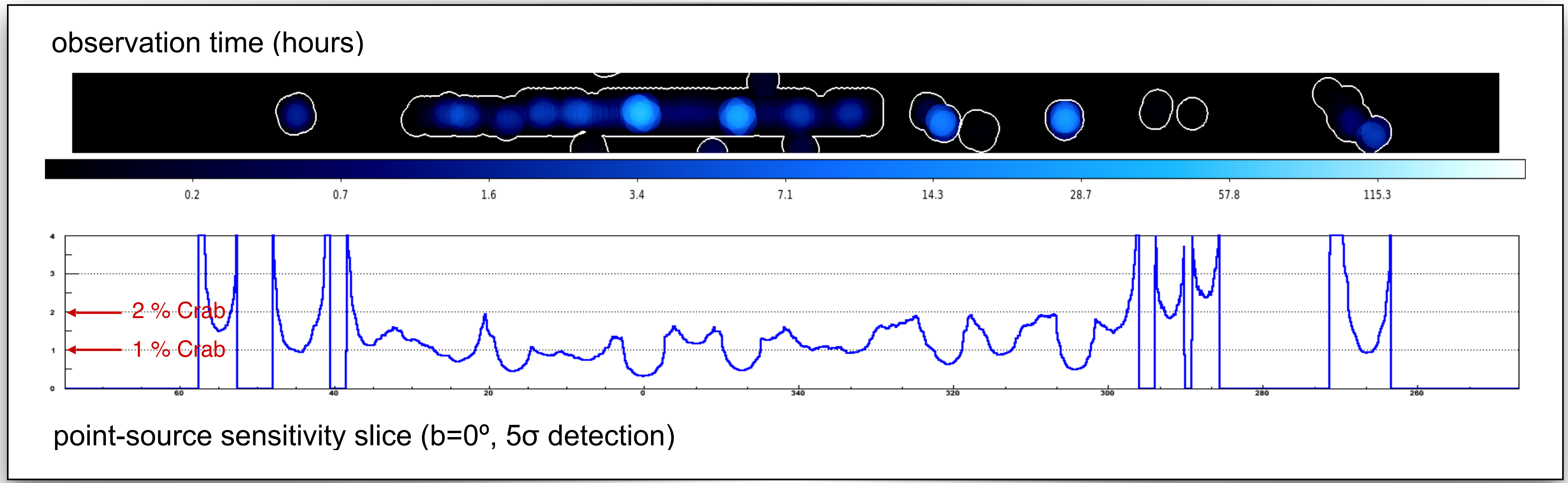
H.E.S.S. Coll. 2005



Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
- obtain homogeneous sensitivity
- follow-up source candidates,
  deep exposures of specific sources

2004-2006



Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
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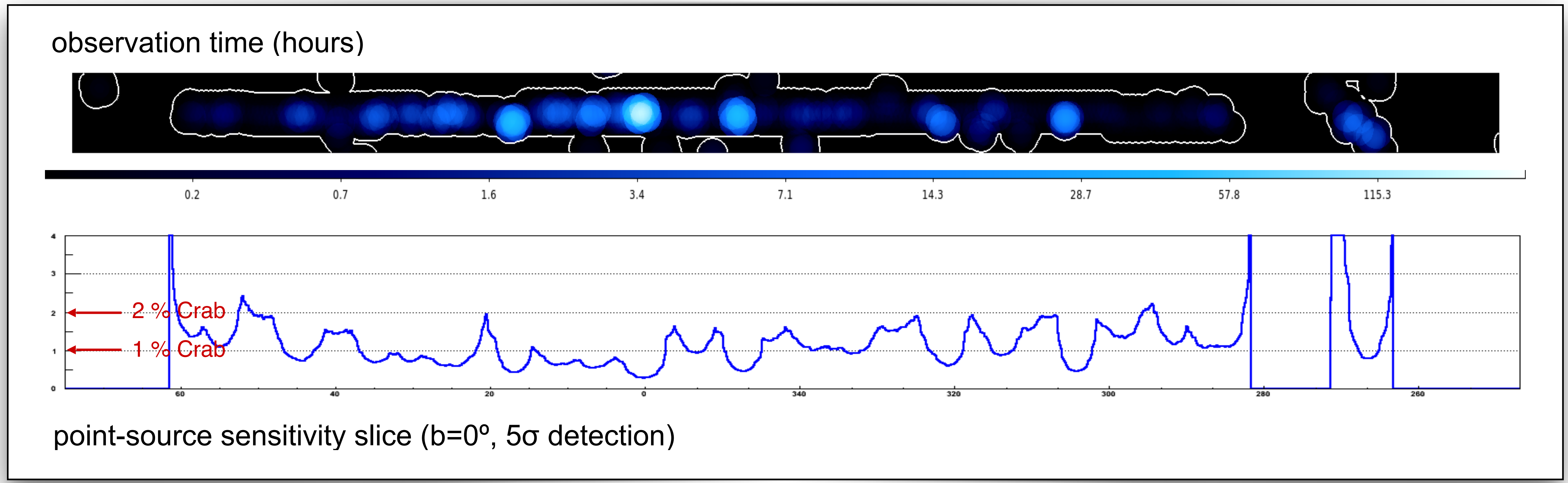
2004-2007

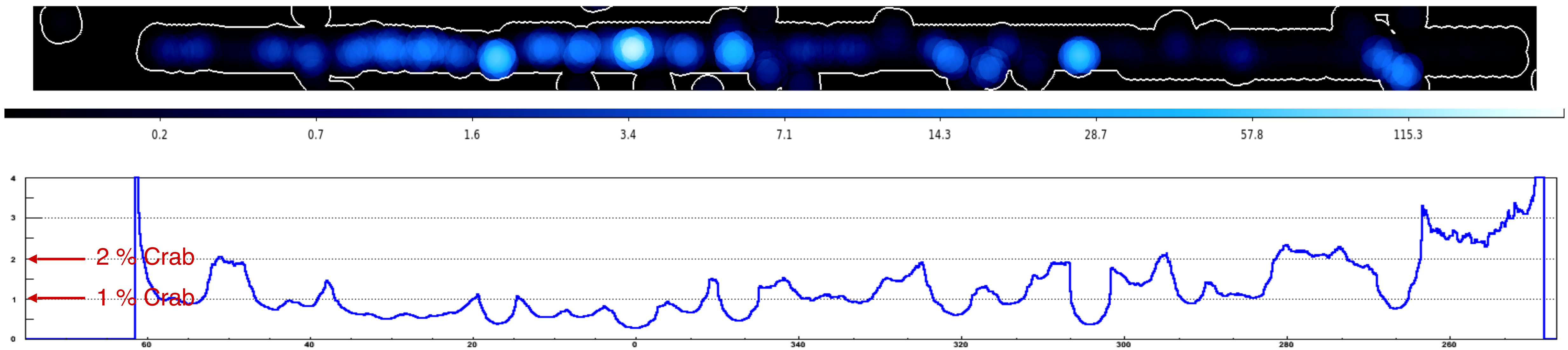


Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
- obtain homogeneous sensitivity
- follow-up source candidates,
  deep exposures of specific sources

2004-2008

observation time (hours)



point-source sensitivity slice (b=0°, 5σ detection)

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Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
- obtain homogeneous sensitivity
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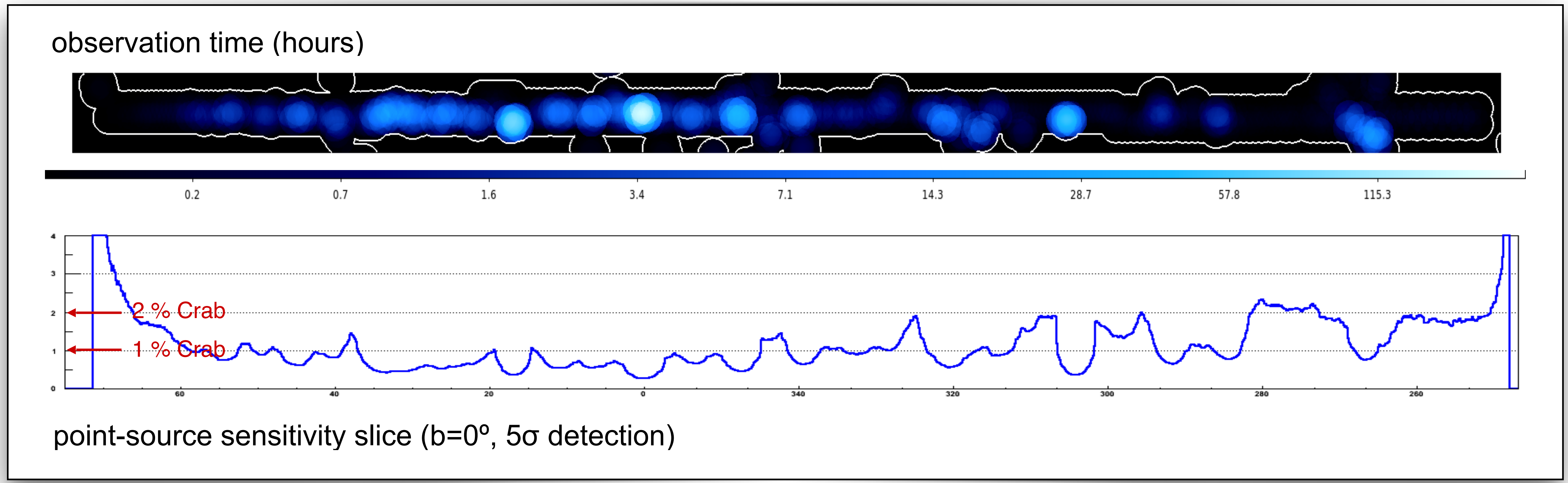
  deep exposures of specific sources

2004-2009



Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
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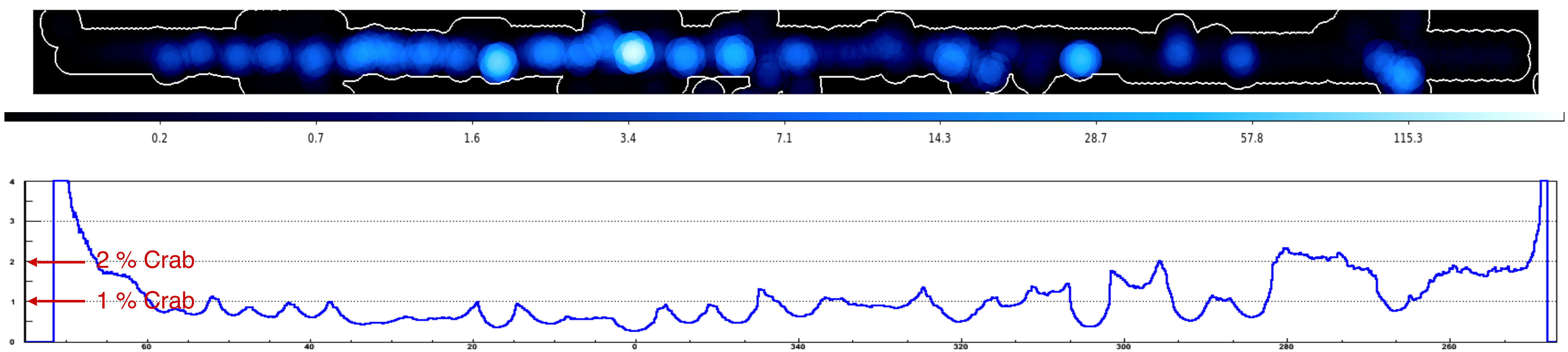
- follow-up source candidates,
  deep exposures of specific sources

2004-2010

observation time (hours)



point-source sensitivity slice (b=0°, 5σ detection)

Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
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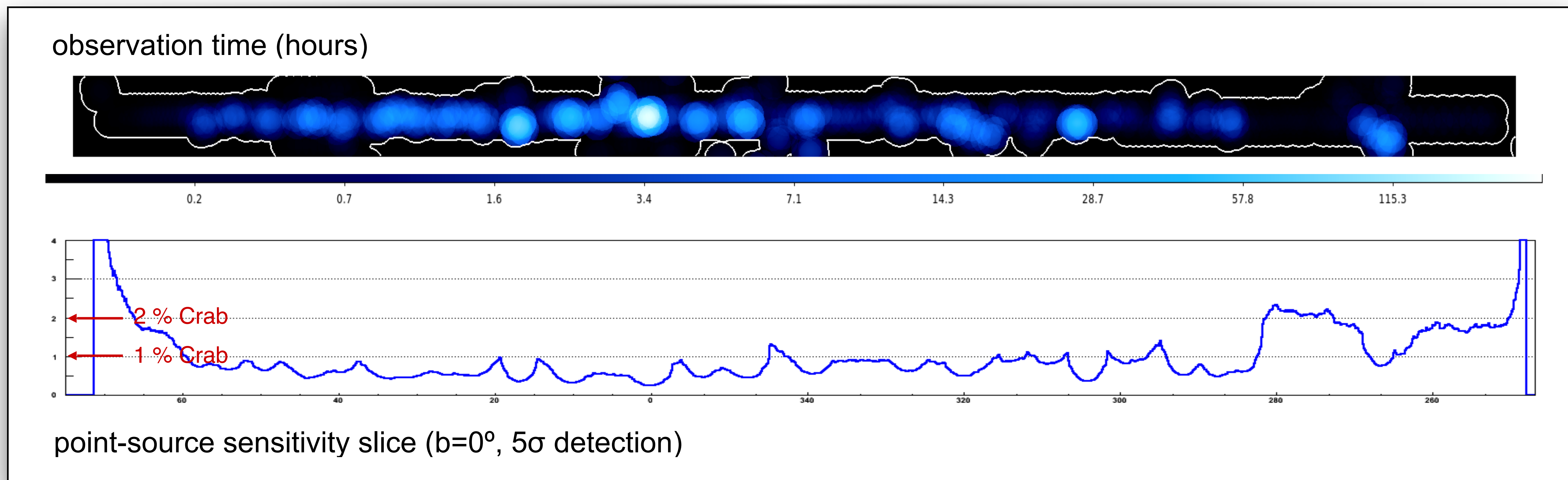
  deep exposures of specific sources

2004-2011

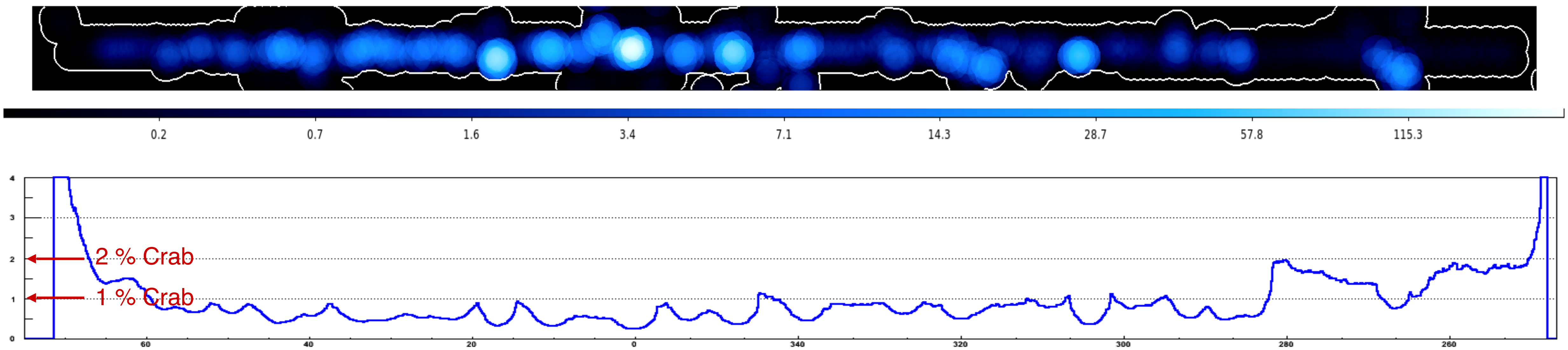


Survey Extension (2005-2013)

- extend scan region both in longitude and latitude
- obtain homogeneous sensitivity
- follow-up source candidates,
  deep exposures of specific sources

2004-2012

observation time (hours)



point-source sensitivity slice (b=0°, 5σ detection)

Survey Extension (2005-2013)

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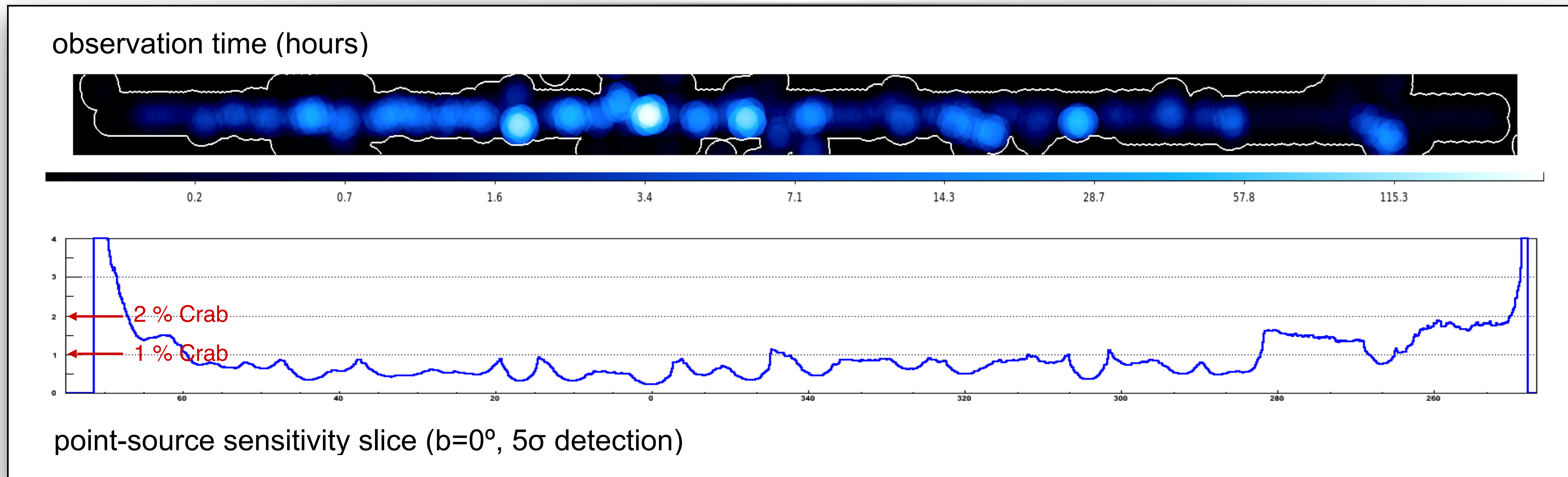
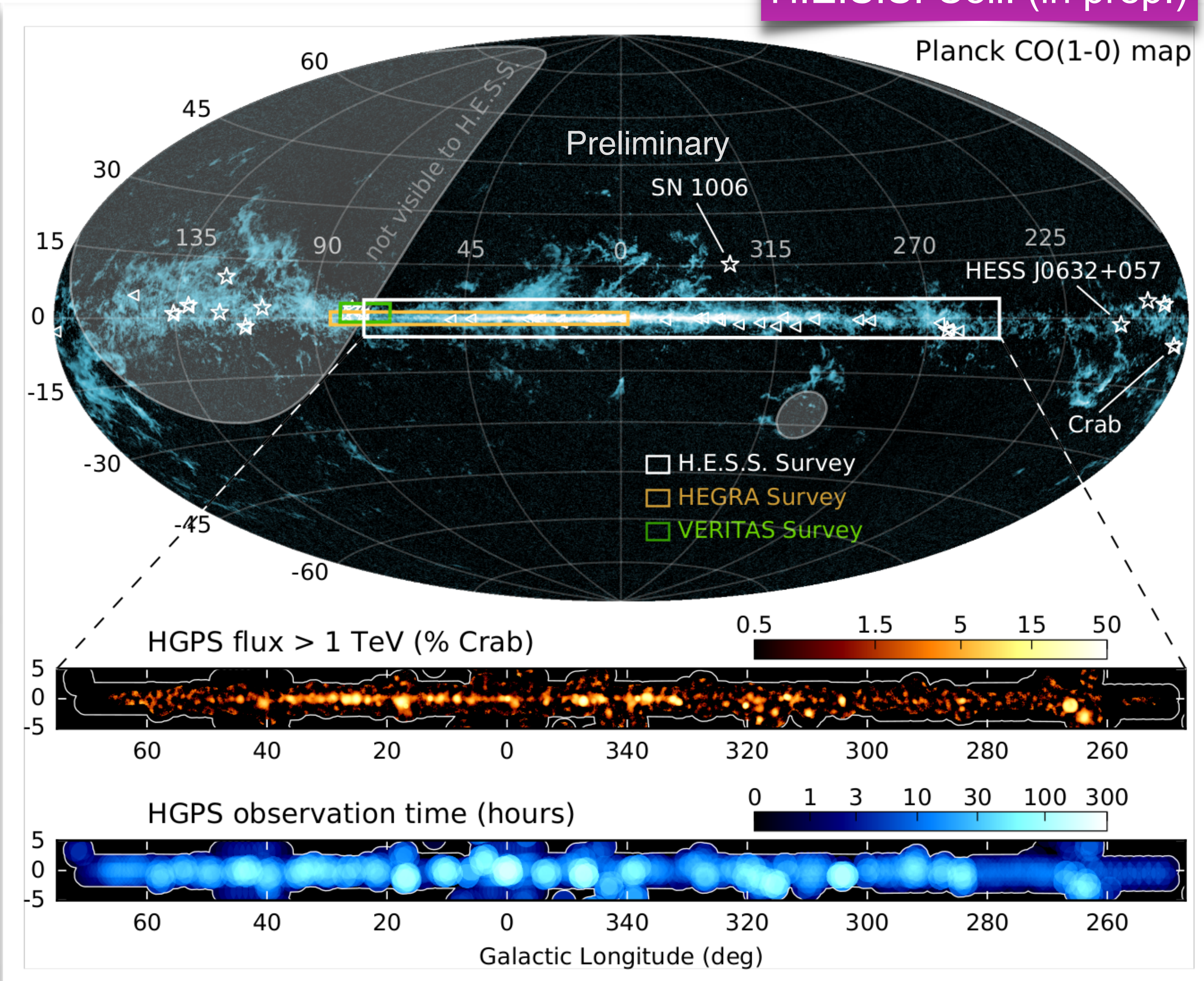
2004-2013



10 years of surveying the Galaxy

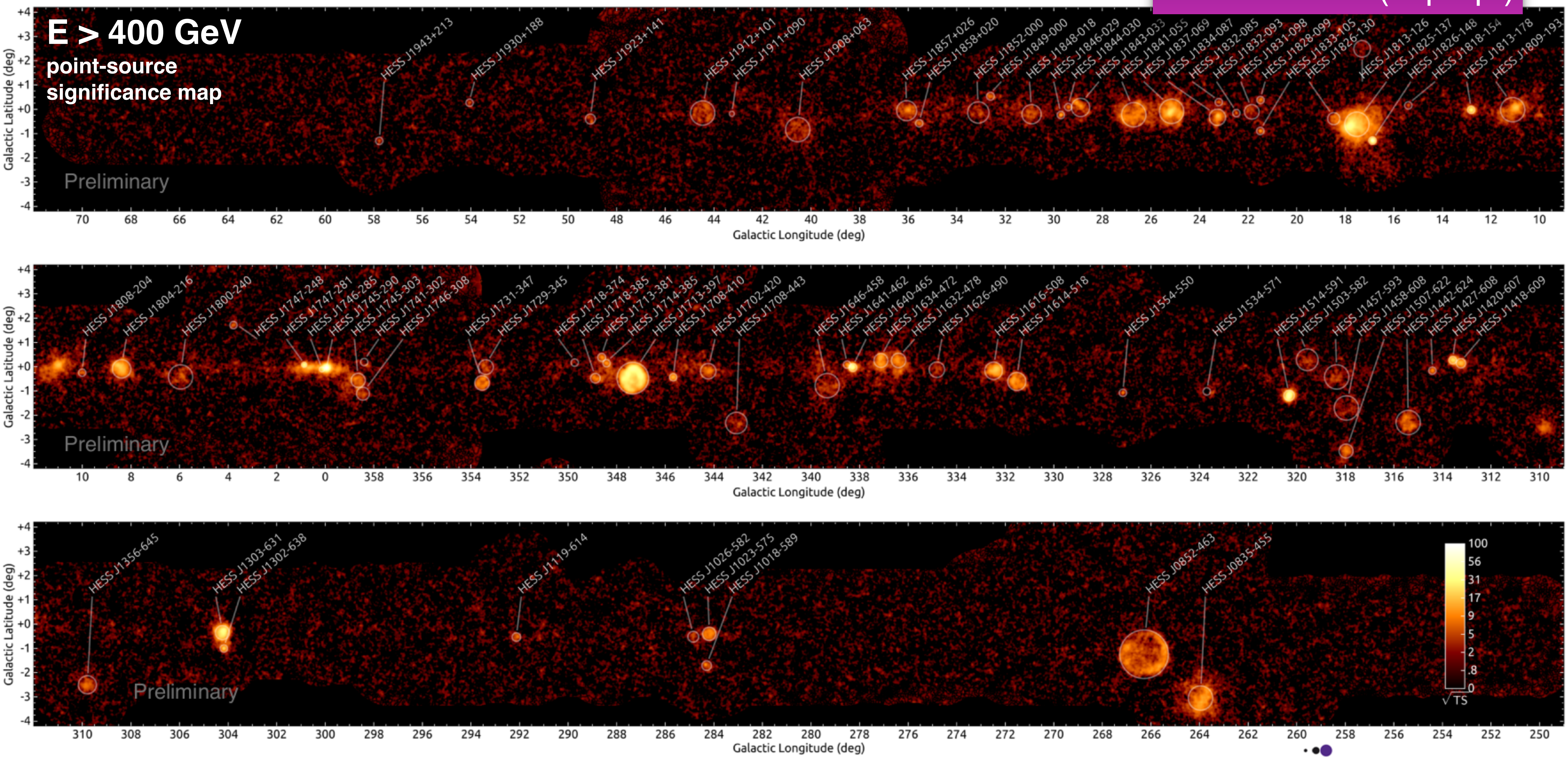
- 2004-2013
- [65º, 250º] in longitude
  [-3.5º, 3.5º] in latitude
- 3000 hours exposure
- Energy > 200 GeV
- Angular resolution 0.08º
- Point source sensitivity < 1.5% Crab
- 78 sources (16 unpublished)

H.E.S.S. Coll. (in prep.)



10 years of surveying the Galaxy

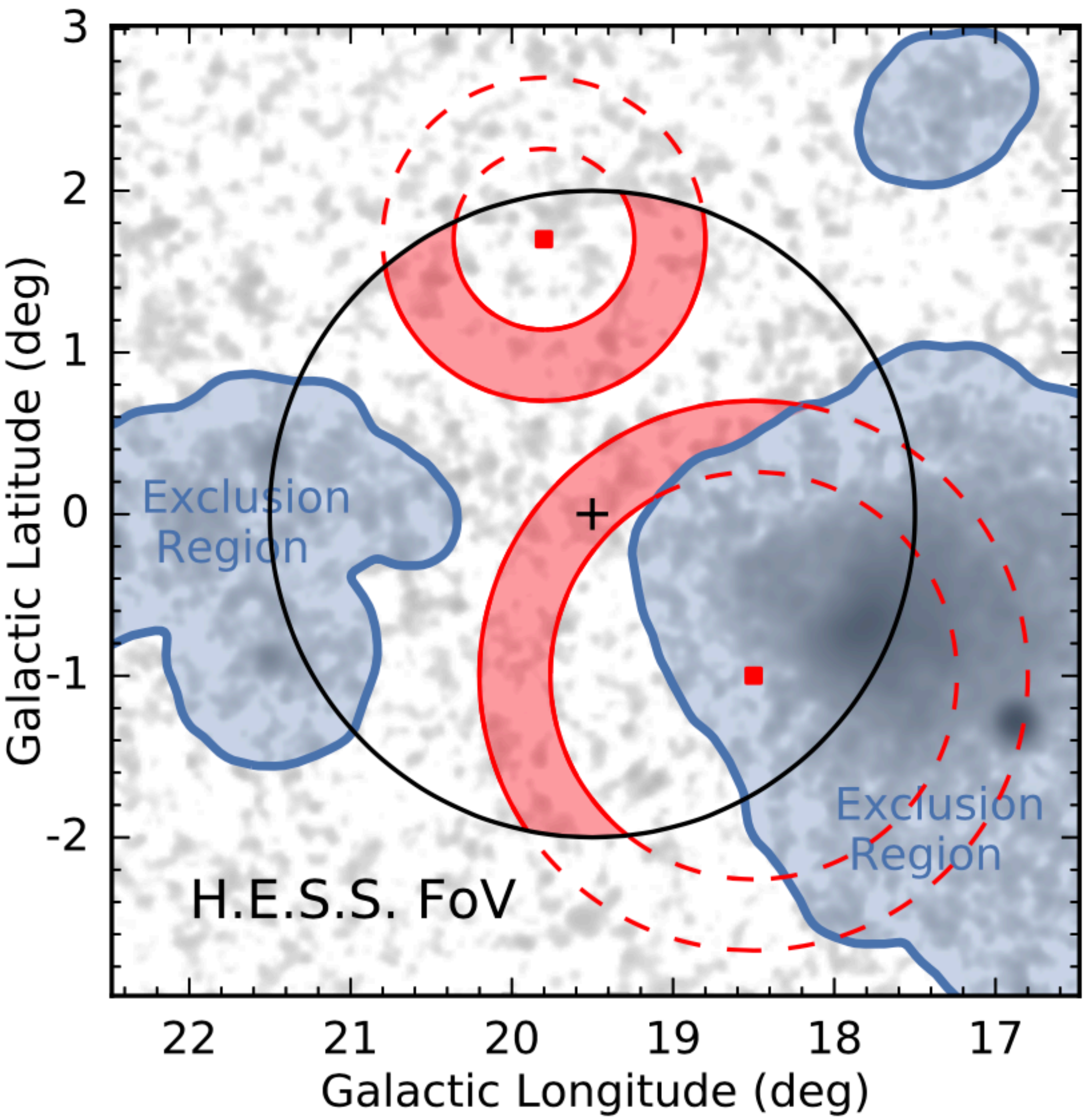
H.E.S.S. Coll. (in prep.)



First comprehensive survey at TeV energies

Map construction

- Gamma-ray instruments are counting experiments
  → basic product is count map
- Largest background: residual cosmic ray events, must be subtracted or properly modelled
- here: estimate background of any position by ring around that position
- intermediate products:
  - original event map
  - background map
  - excess map
  - exposure map
  - significance map (Li+Ma)



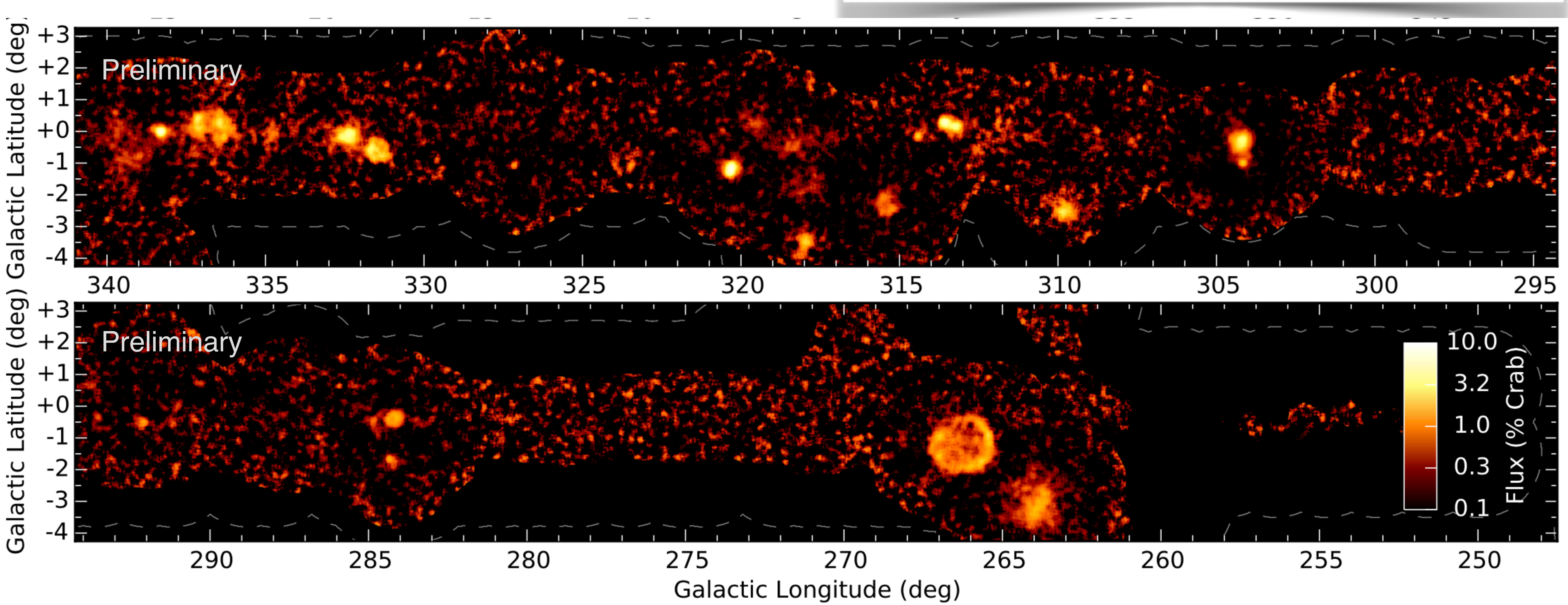
High-level maps

- Flux maps (integrated >1 TeV)
  - 0.1° and 0.4° correlation radii
- Flux upper limit maps
- Sensitivity maps

$$\phi_{\mathrm{ref}}(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-2.3}$$

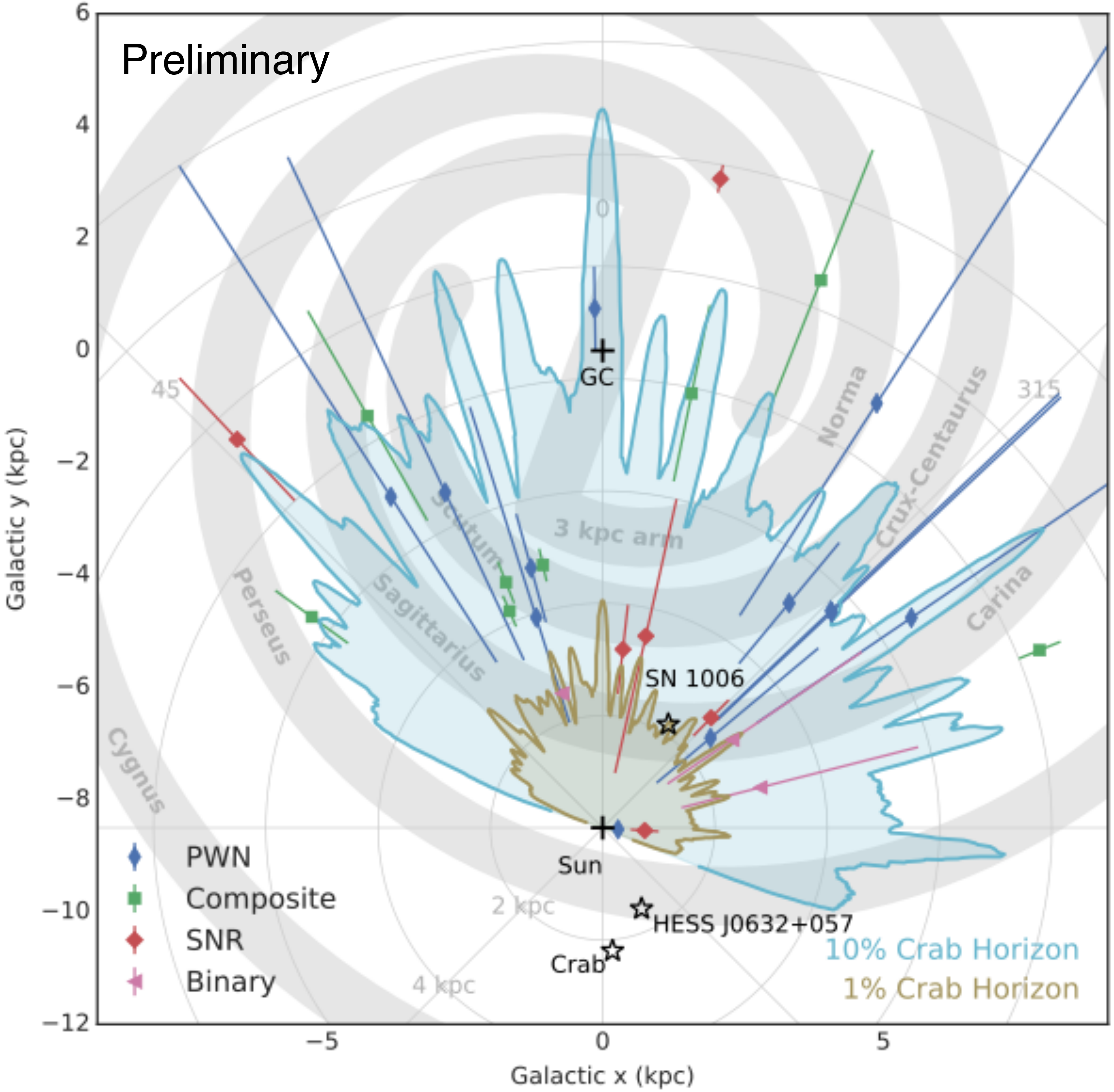
$$N_{\mathrm{ref}} = T \cdot \int_{1\ \mathrm{TeV}}^{\infty} \phi_{\mathrm{ref}}(E_{\mathrm{r}})\ A_{\mathrm{eff}}(E_{\mathrm{r}})\ dE_{\mathrm{r}}$$

$$F(>1\ \mathrm{TeV}) = \frac{N_\gamma}{N_{\mathrm{ref}}} \int_{1\ \mathrm{TeV}}^{\infty} \phi_{\mathrm{ref}}(E) dE$$



Sensitivity

- Out to which distance is a point source of certain flux detected?
- does not account for source overlap
- CTA prospects: will extend sensitivity to entire Galaxy



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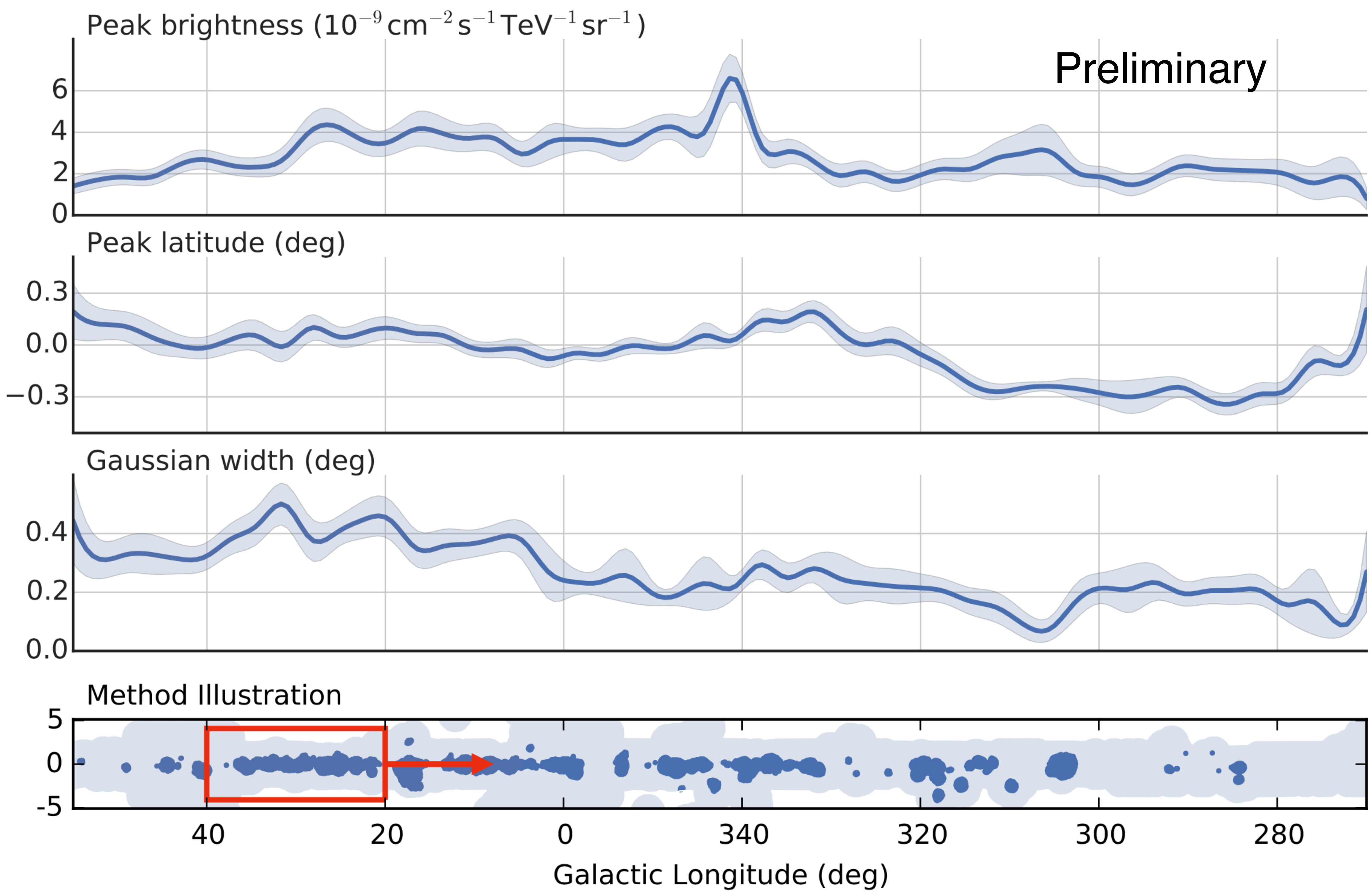
Large scale emission

- truly diffuse emission plus unresolved sources
- estimated from regions outside of sources



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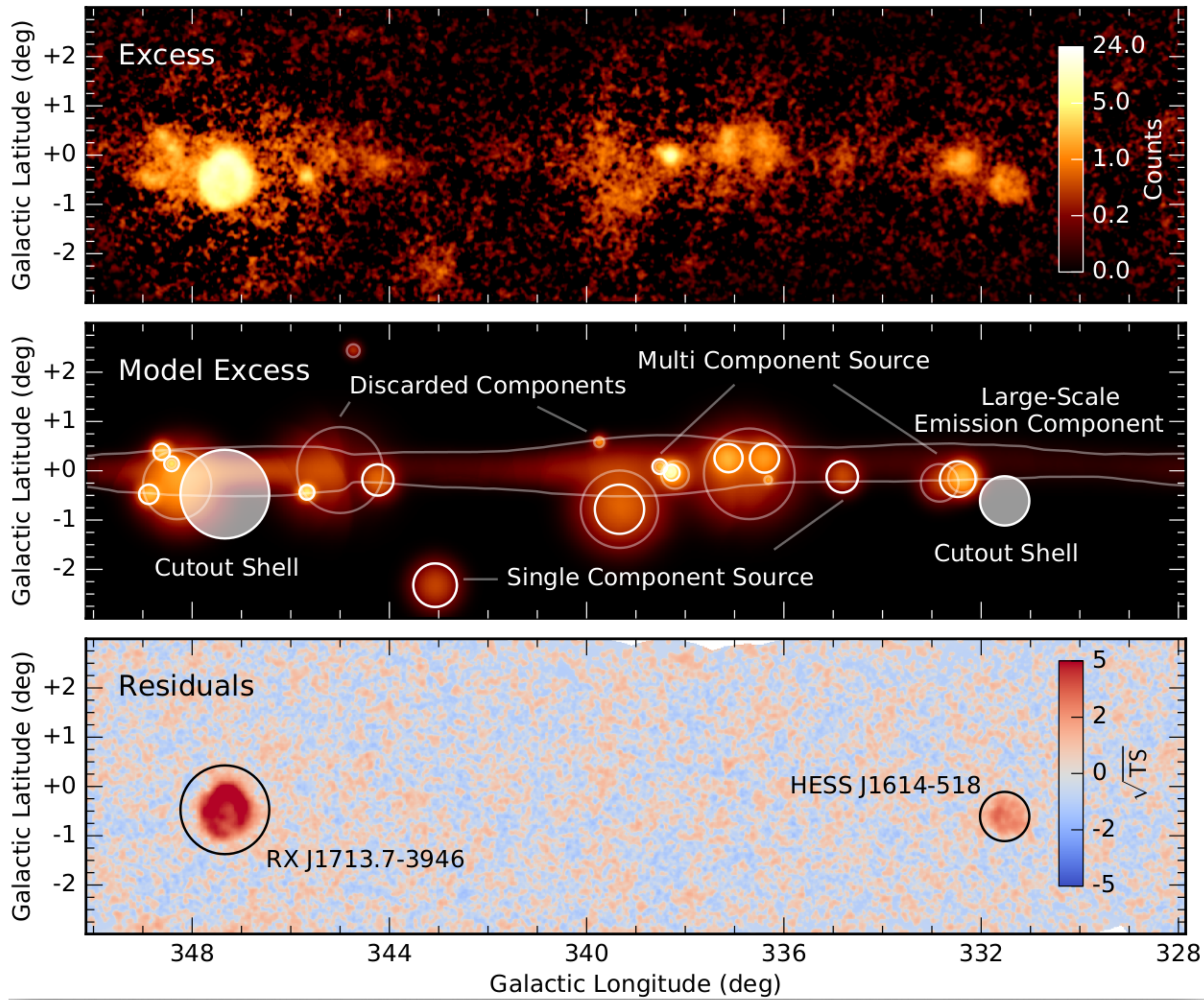
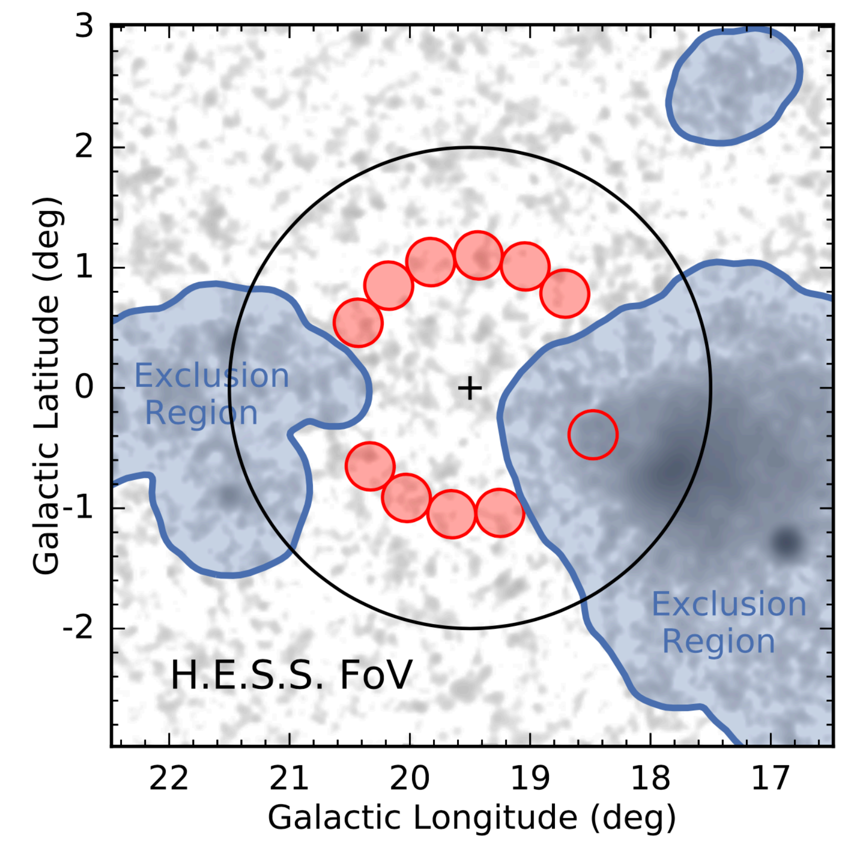
Catalog Construction

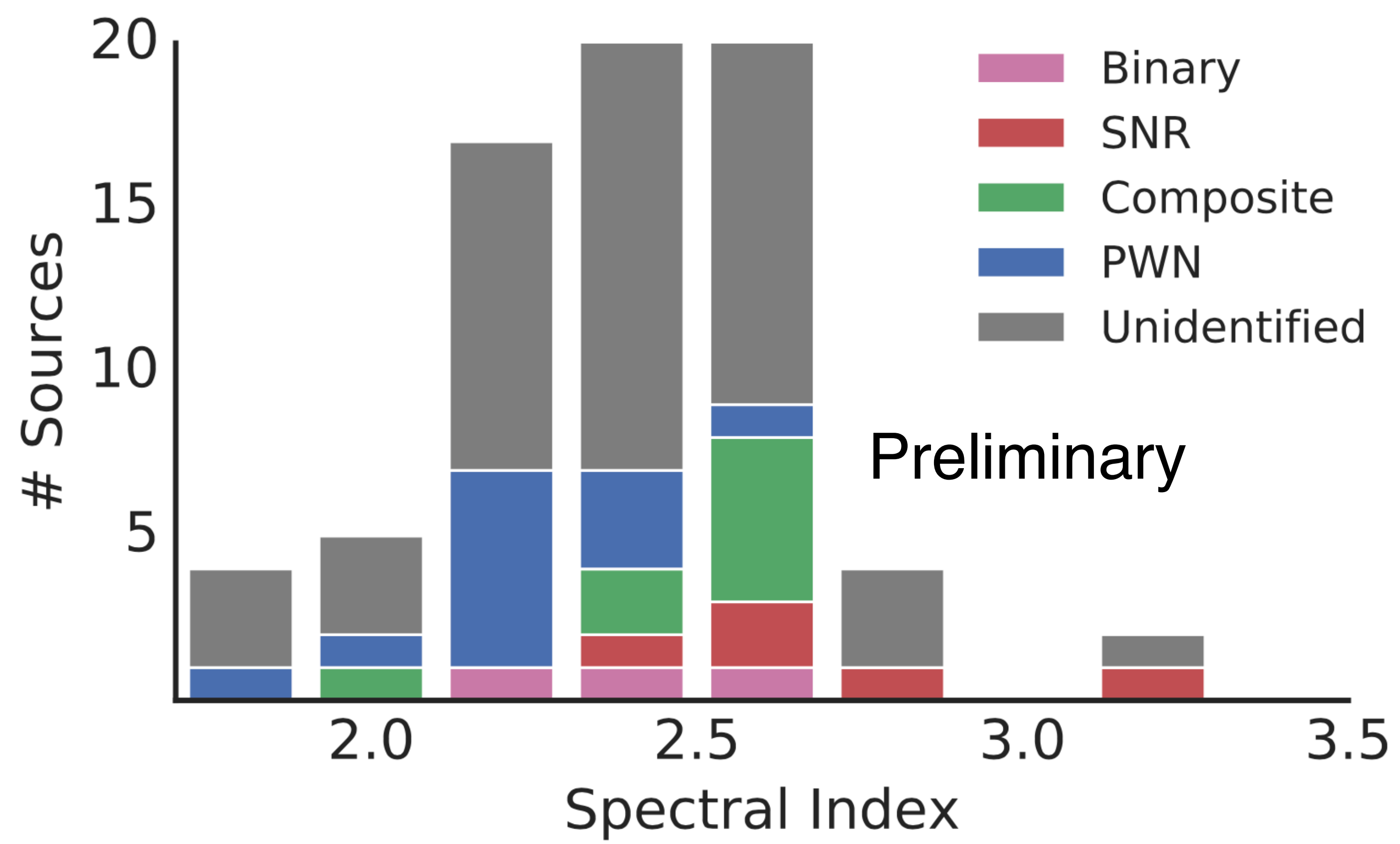
- model gamma-ray excess as
  - sum of Gaussian components
  - large scale emission
  - cut out known sources w/ complicated morphology
- add components until no TS improvement and flat residuals
  - chose TS such as to expect one false detection in entire survey
- merge components into physical sources



Differential flux measurement

- based on standard methods ("aperture photometry")
- Power-law flux model (w/ and w/o exponential cut-off)
- background from same field-of-view
- correction for modelled source morphology
- full spectral information in the catalog





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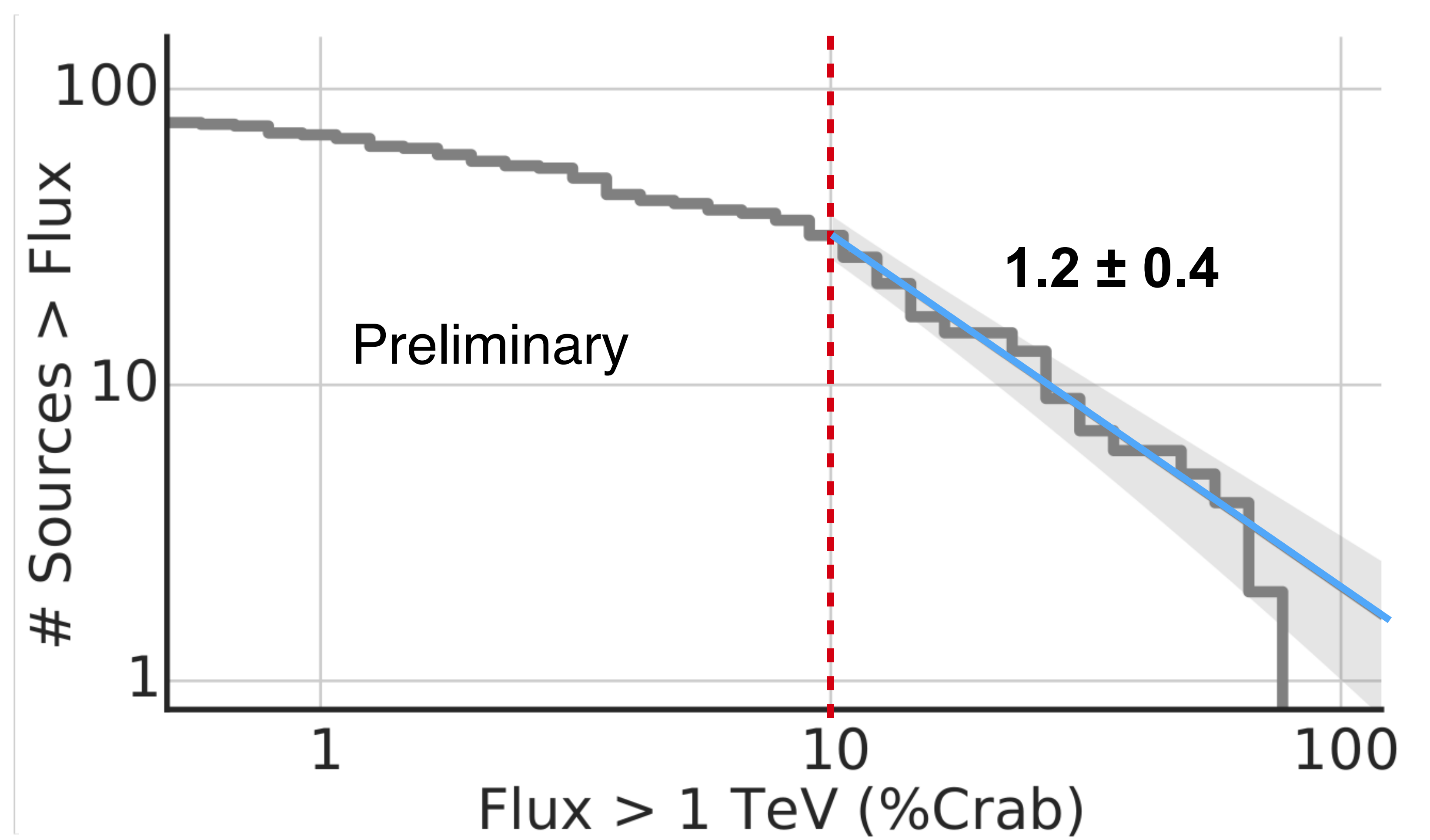
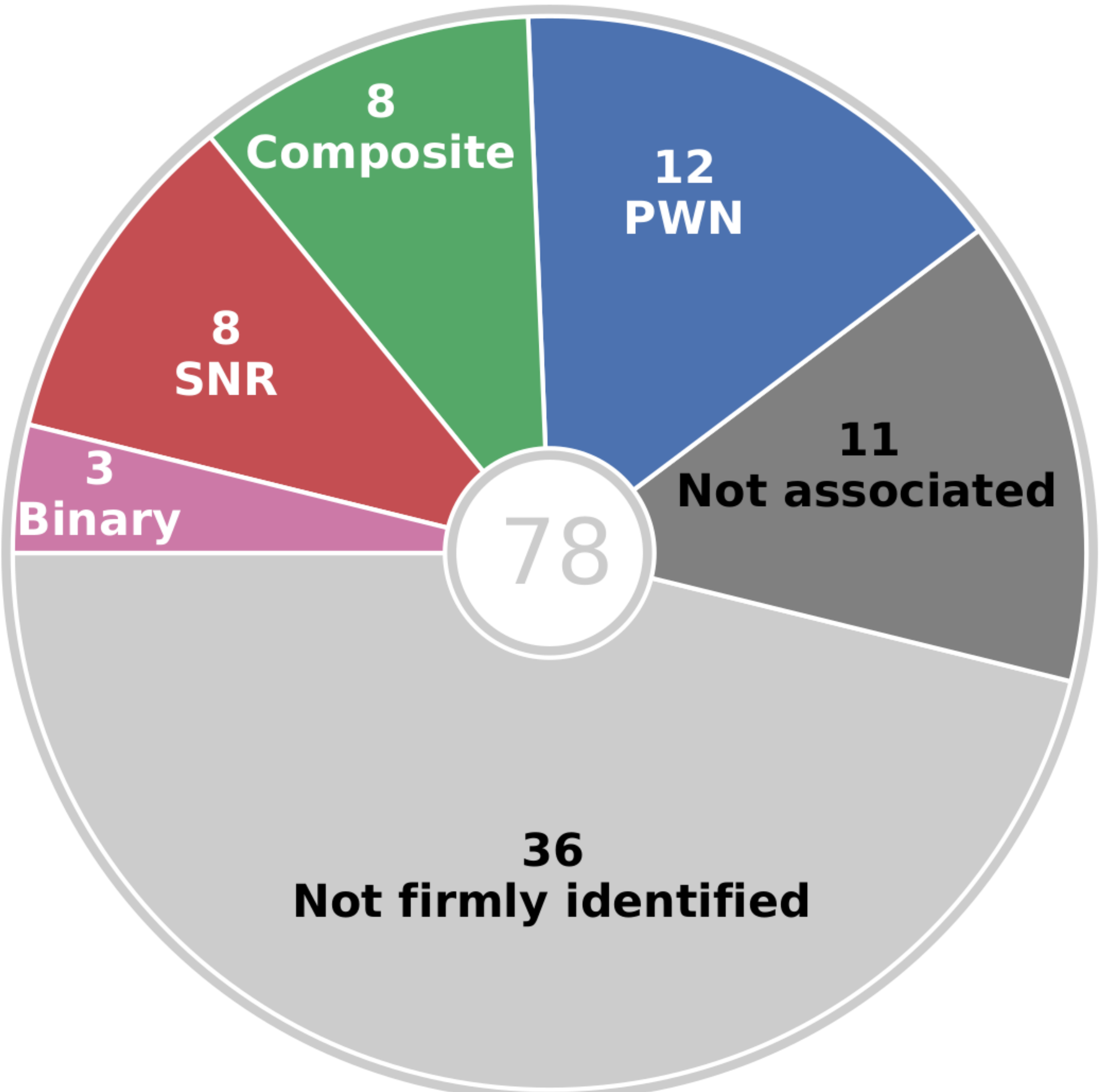
Catalog Completeness

- Catalog seems complete for sources < 1º down to 10% Crab flux
- Power-law index of 1.2 ± 0.4 compatible with Galactic sources distributed in thin disk
- How many sources would CTA see?
  - my (naive) extrapolation to 1% Crab: ~300-400
  - but difficult because of large uncertainties



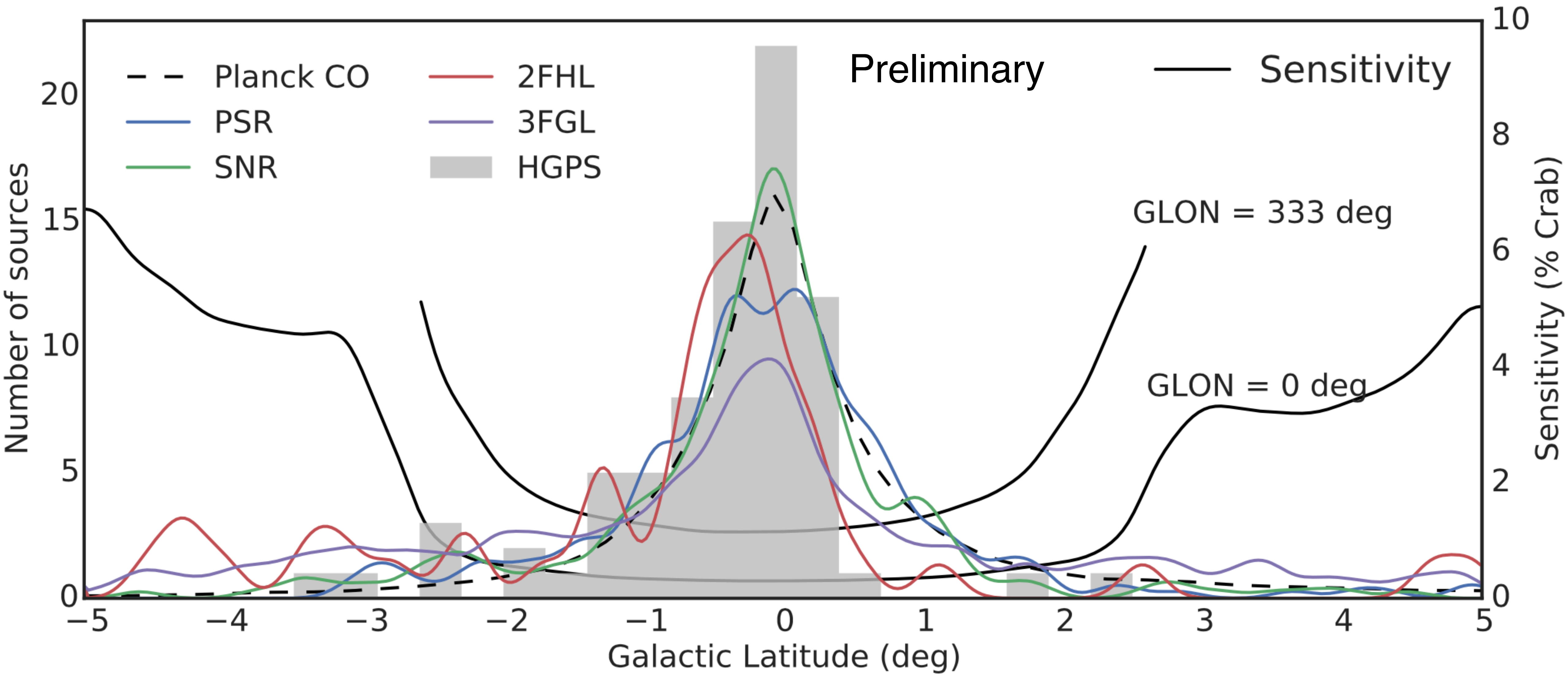


Identifications and Associations

- 78 sources detected in the survey
- 16 newly discovered sources
- only 31 firmly connected to known (shock-accelerating) objects
- 11 sources without counterpart (dark sources?)
- 36 sources confused (too many counterparts)

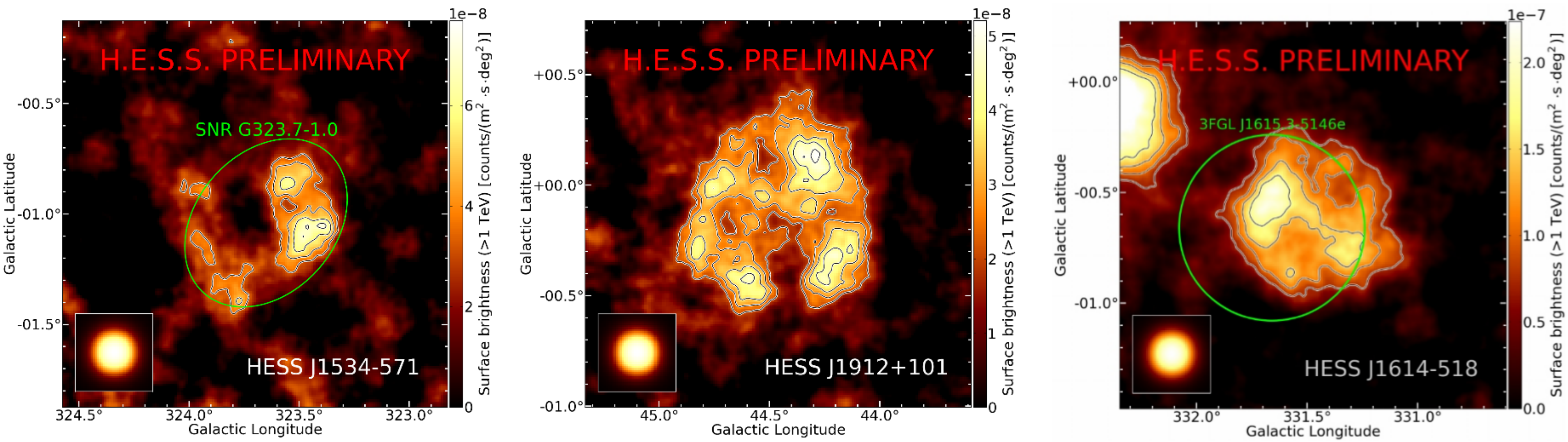
Sources concentrate on low latitudes

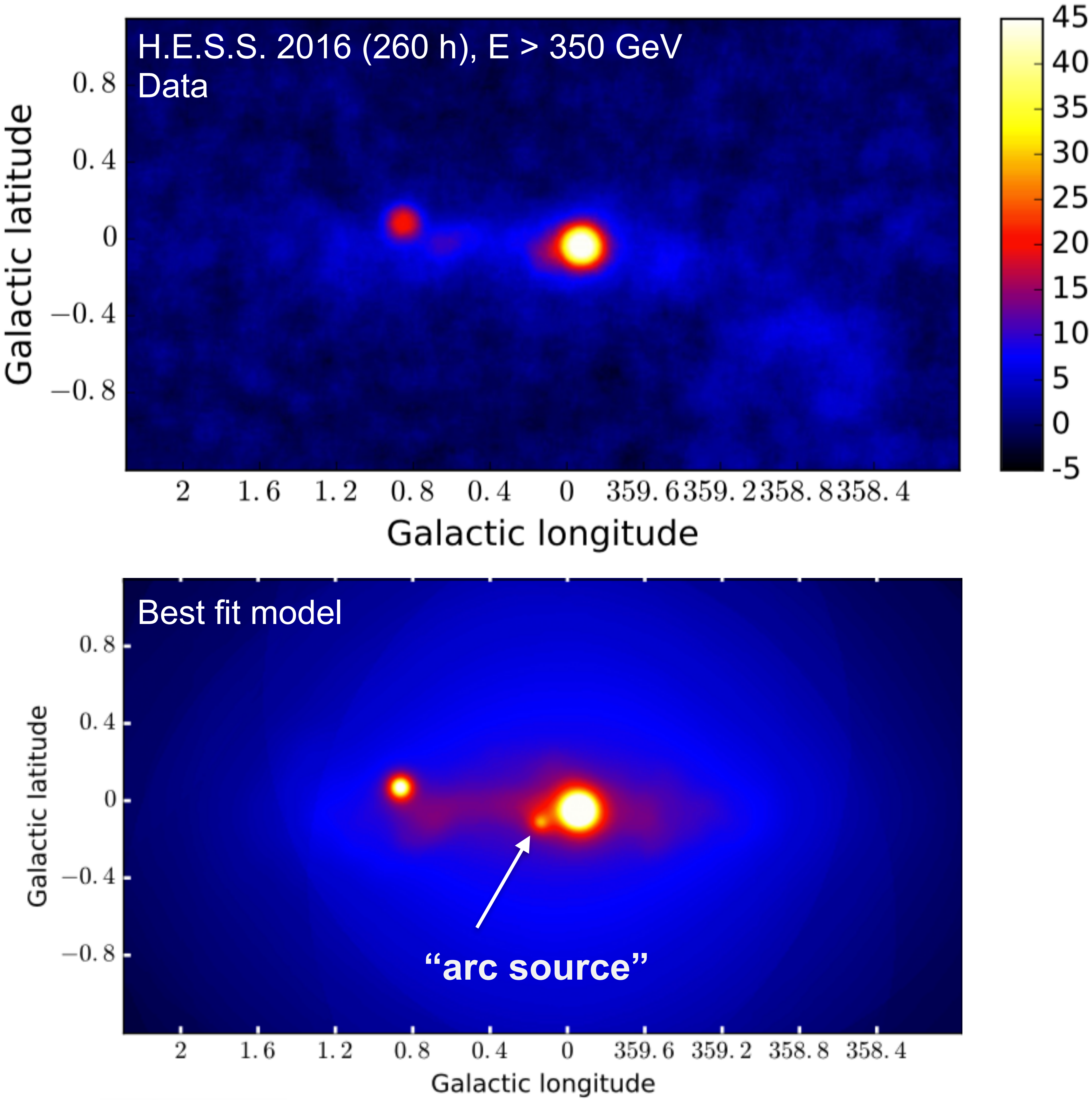
- in agreement with gas, SNR and pulsar distributions
- in agreement with distribution of LAT sources



Discovery of new SNR shells

- dedicated search for shell-like morphology in survey maps
- one new confirmed shell, two new shell candidates





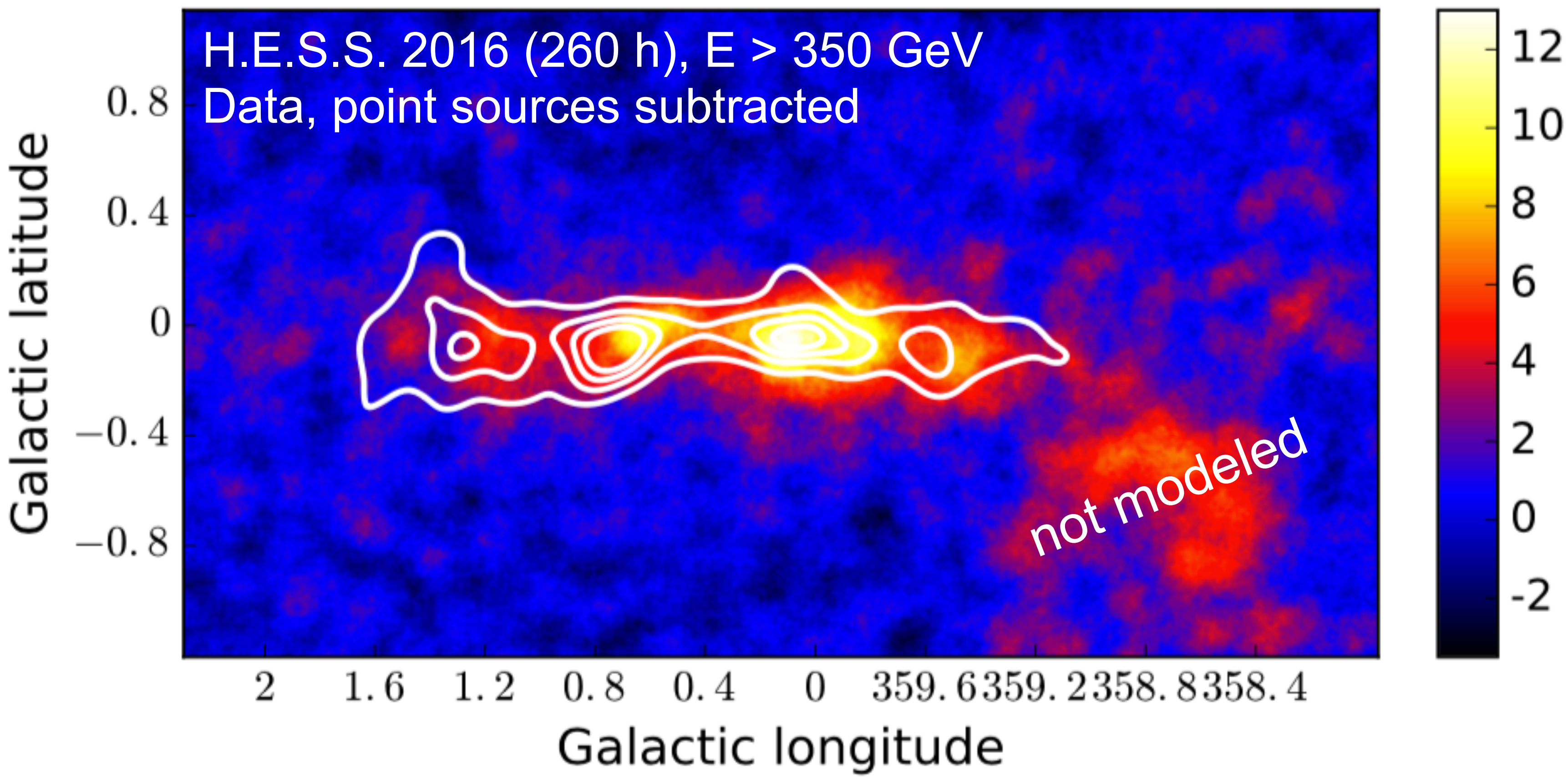
A closer look at the GC ridge

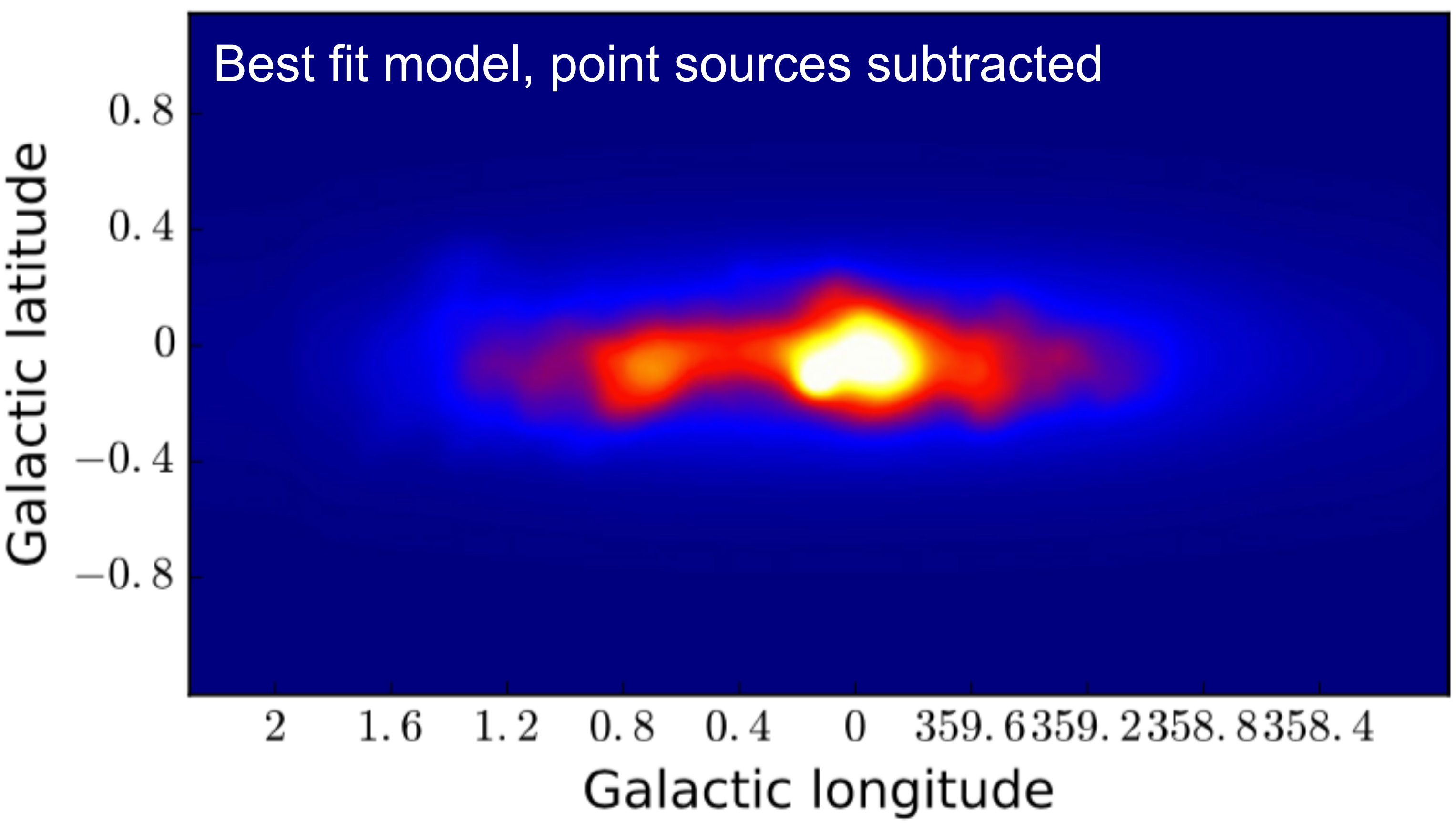
- full H.E.S.S. I data set
- improved data analysis techniques: better angular resolution, sensitivity

full 2D morphology fitting:

- 2 point sources
- 2 gaussian components
- galactic diffuse emission
- molecular cloud template (CS tracer)
- new point-like "arc source": G0.13-0.11, a PWN candidate

H.E.S.S. Coll. 2017
arXiv:1706.04535





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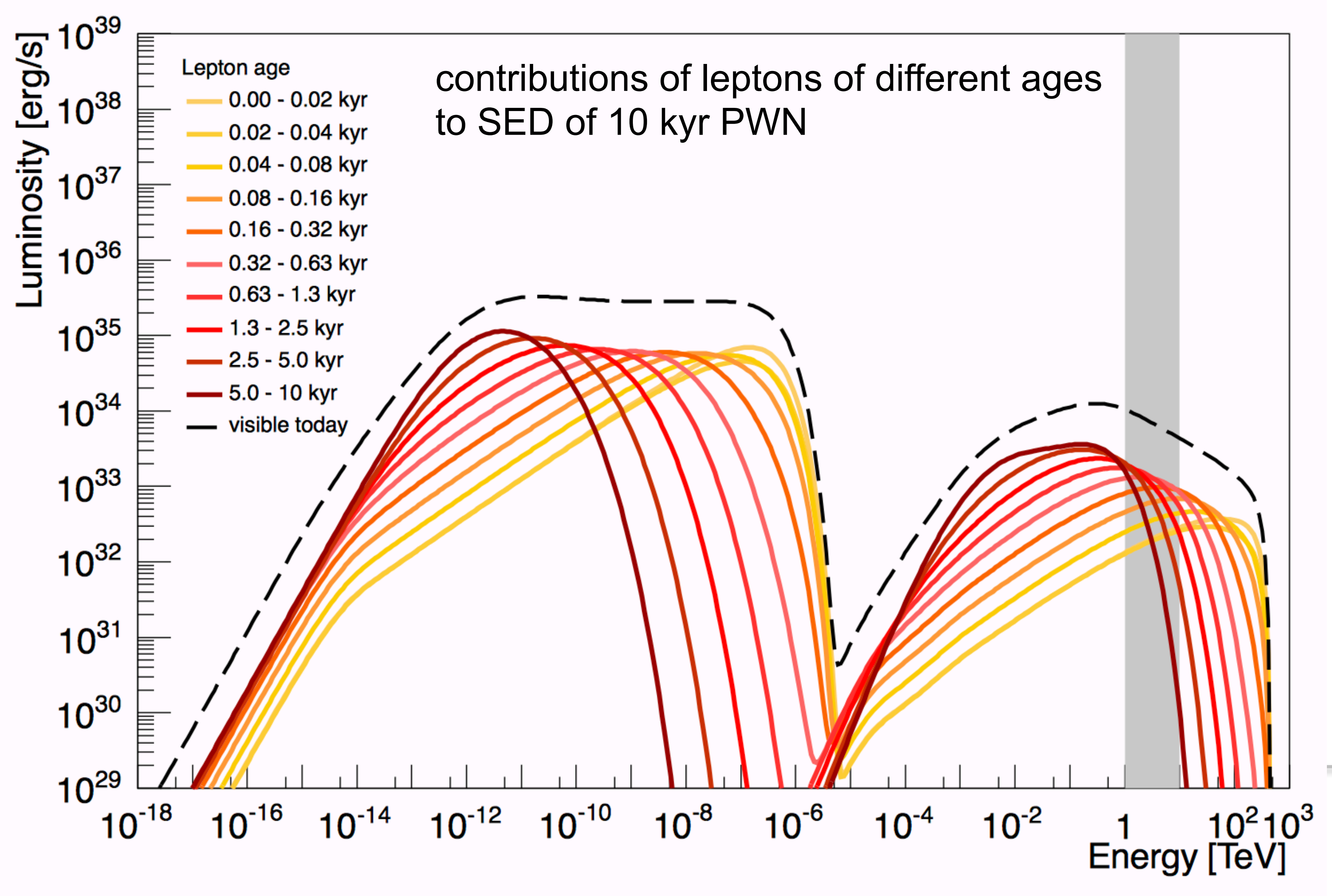
H.E.S.S. Coll. 2017
arXiv:1706.04535

H.E.S.S.

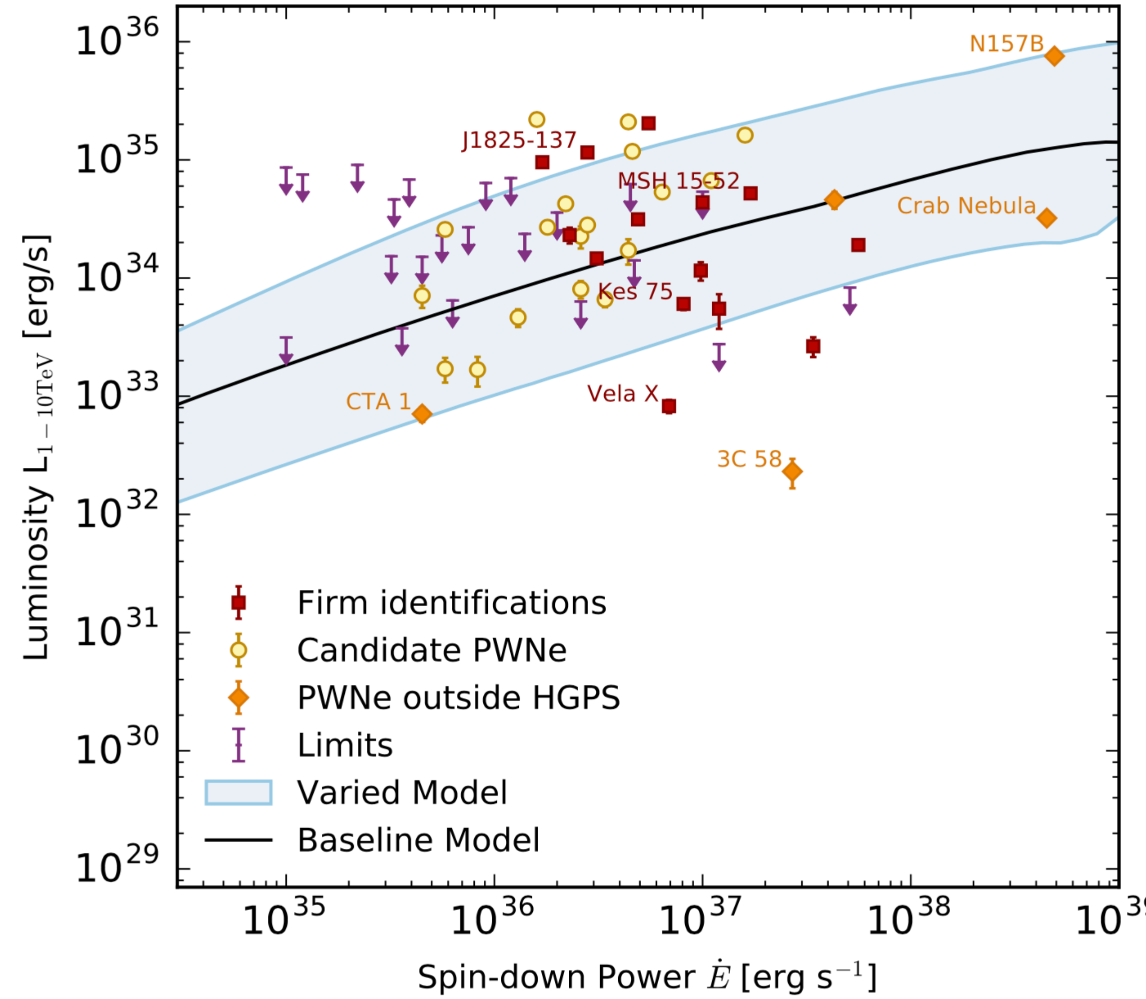
Population Studies: Pulsar Wind Nebulae

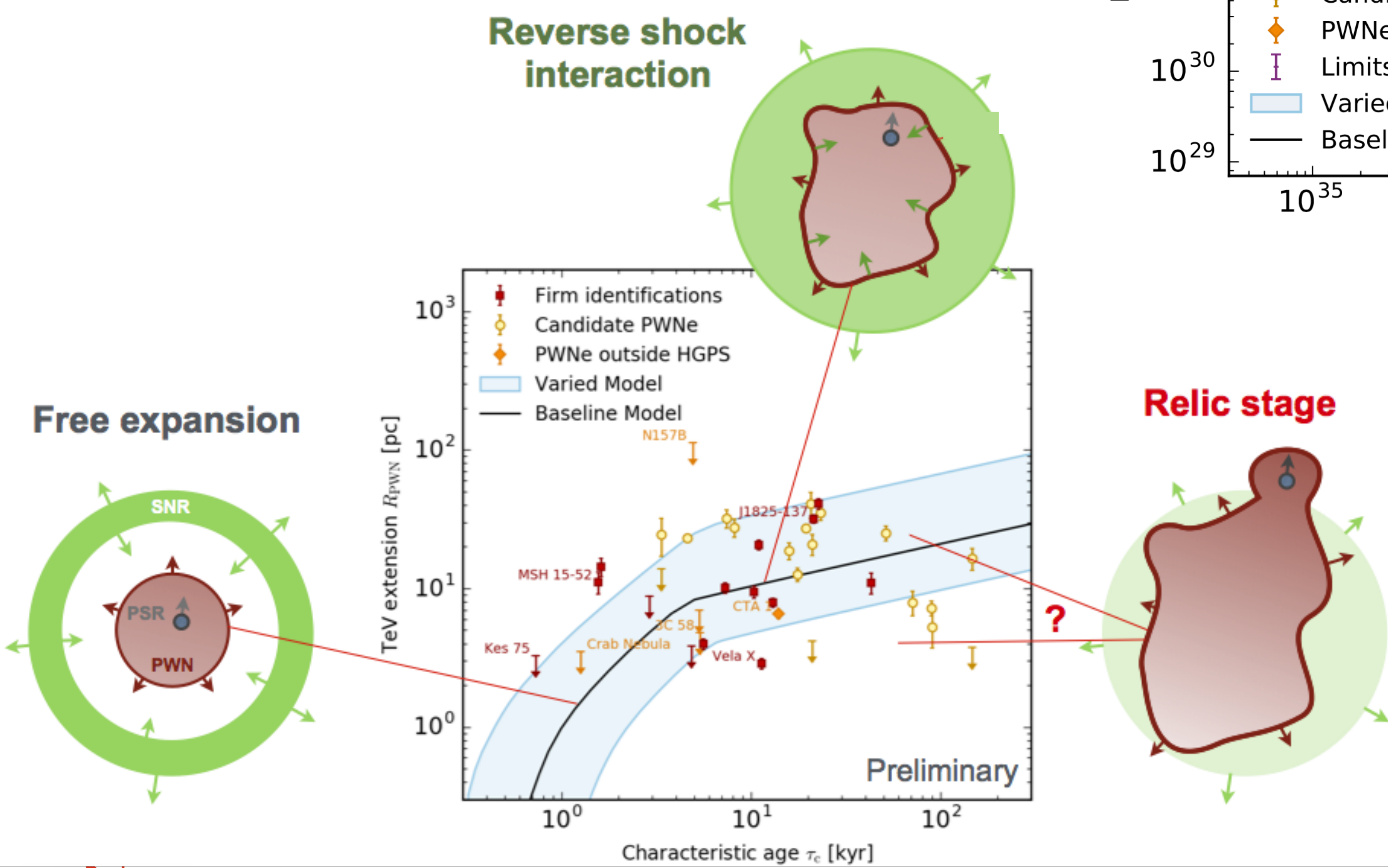
- Sample: 14 Survey PWN, 5 outside survey, 10 PWN candidates
- Goal: Get understanding about population behaviour, not about individual objects
- Simplistic baseline model:
  - PWN powered by $\dot{E}$ of pulsar (time-dependent injection)
  - PWN cooled by synchrotron, IC, adiabatic expansion and escape losses
- For details, see arXiv:1702.08280



Population Studies: Pulsar Wind Nebulae

- PWNe grow and fade away as their age increases
  → prevents detection of old
  (> 10 kyr, < 10^{35} erg/s) PWNe





for details, see arXiv:1702.08280

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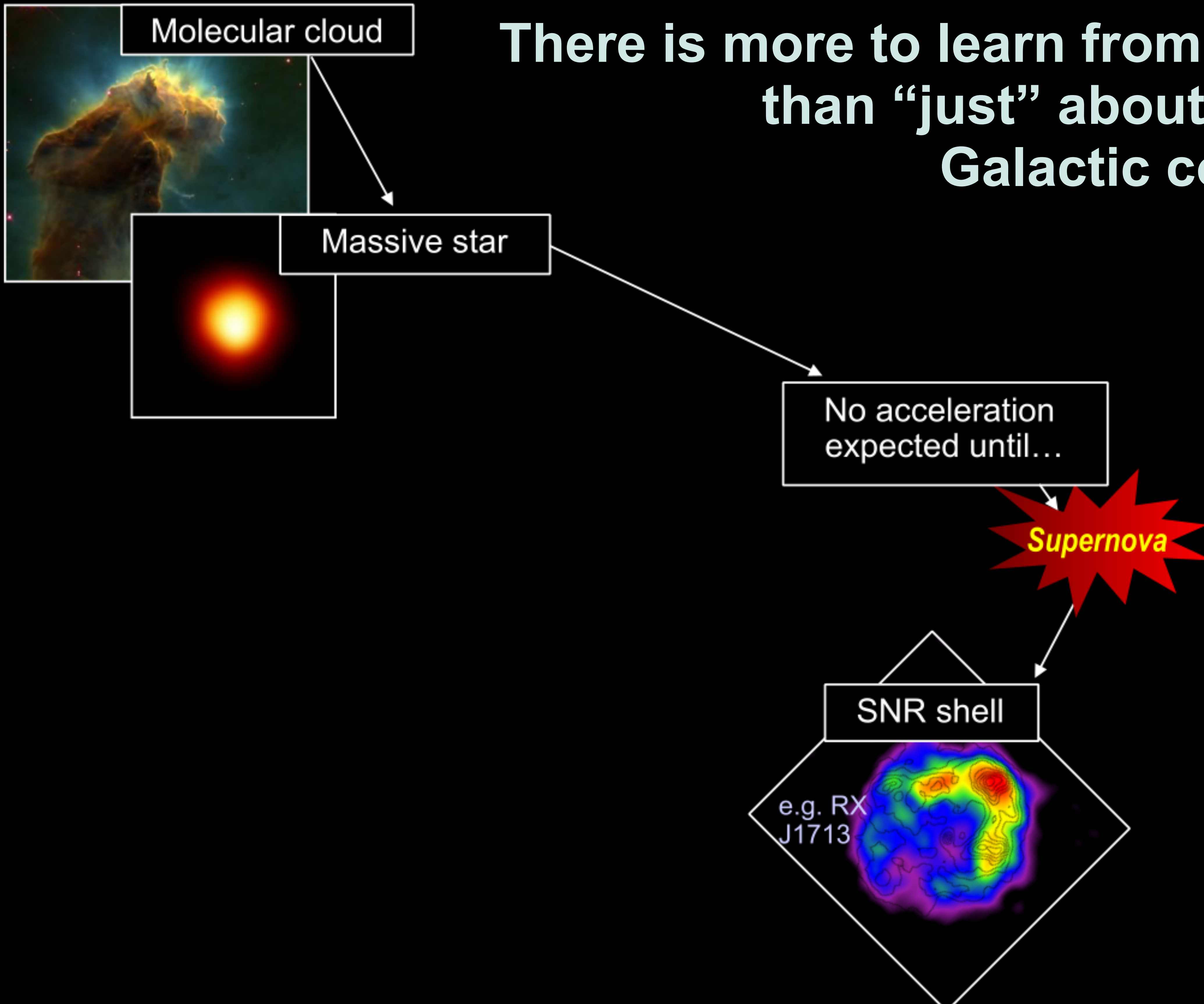
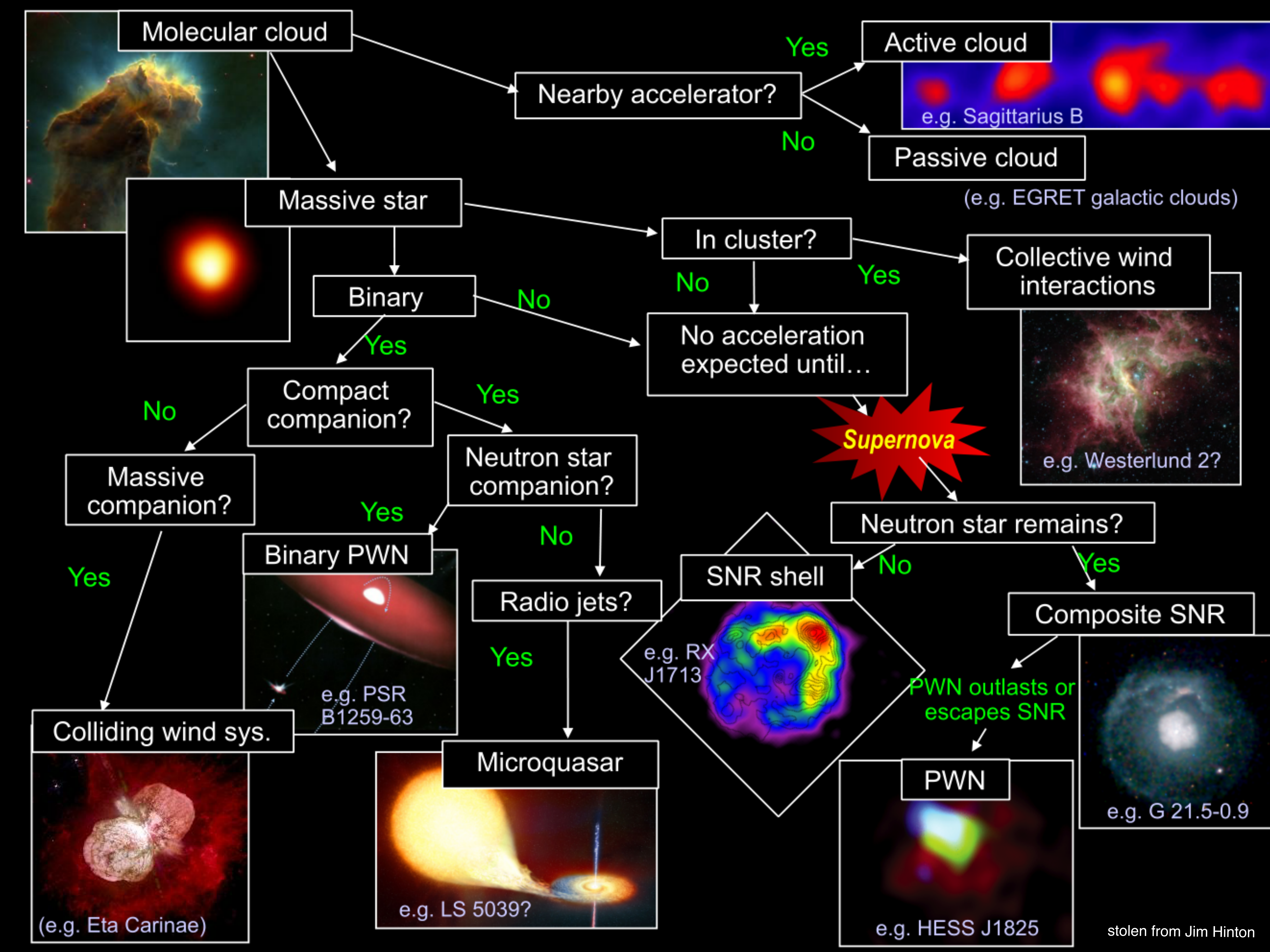
There is more to learn from gamma rays than “just” about the origin of Galactic cosmic rays…



stolen from Jim Hinton


Molecular cloud
Nearby accelerator?
Yes
Active cloud
e.g. Sagittarius B
No
Passive cloud
(e.g. EGRET galactic clouds)
Massive star
In cluster?
Yes
Collective wind interactions
e.g. Westerlund 2?
No
No acceleration expected until…
Supernova
Binary
No
Yes
Compact companion?
No
Yes
Massive companion?
Yes
Colliding wind sys.
(e.g. Eta Carinae)
Neutron star companion?
Yes
Binary PWN
e.g. PSR B1259-63
No
Radio jets?
Yes
Microquasar
e.g. LS 5039?
Neutron star remains?
No
SNR shell
e.g. RX J1713
Yes
Composite SNR
e.g. G 21.5-0.9
PWN outlasts or escapes SNR
PWN
e.g. HESS J1825
stolen from Jim Hinton

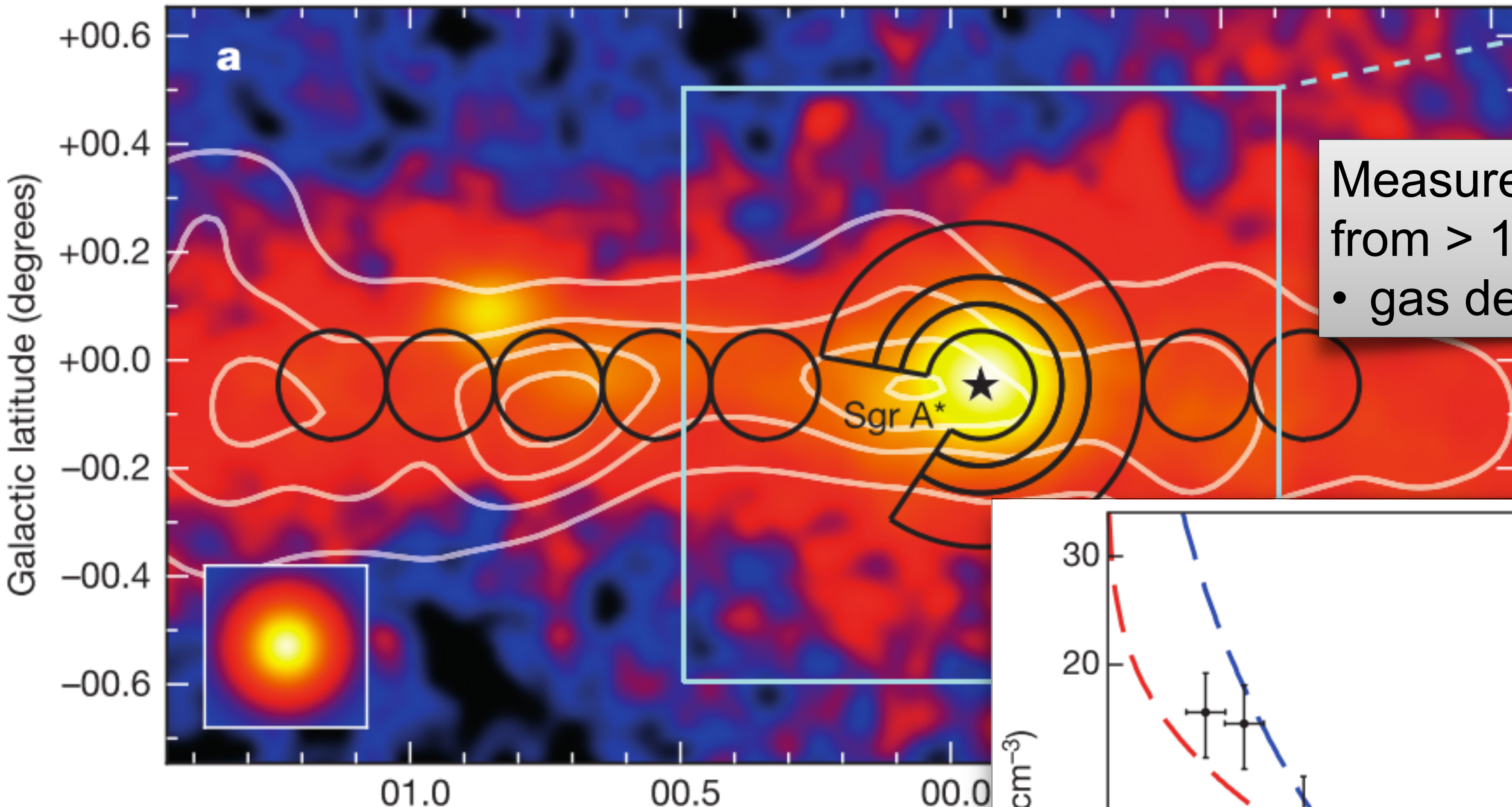
Upcoming Special Issue of
Astronomy & Astrophysics

with 13 papers on H.E.S.S. I Galactic Science.
Does include the Survey paper.

Will be available soon.

Thanks for your patience.

Testing Cosmic Ray Transport in the GC



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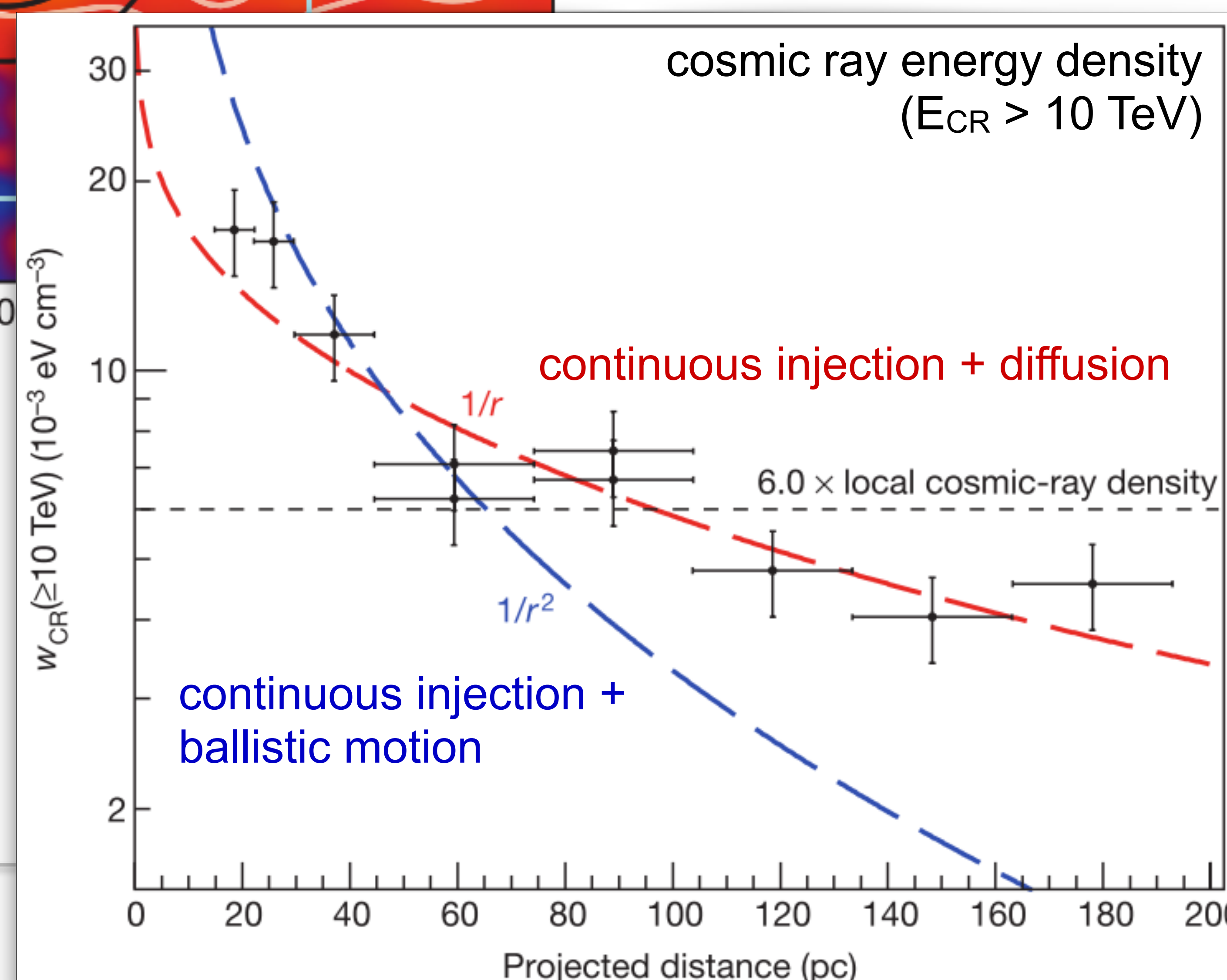
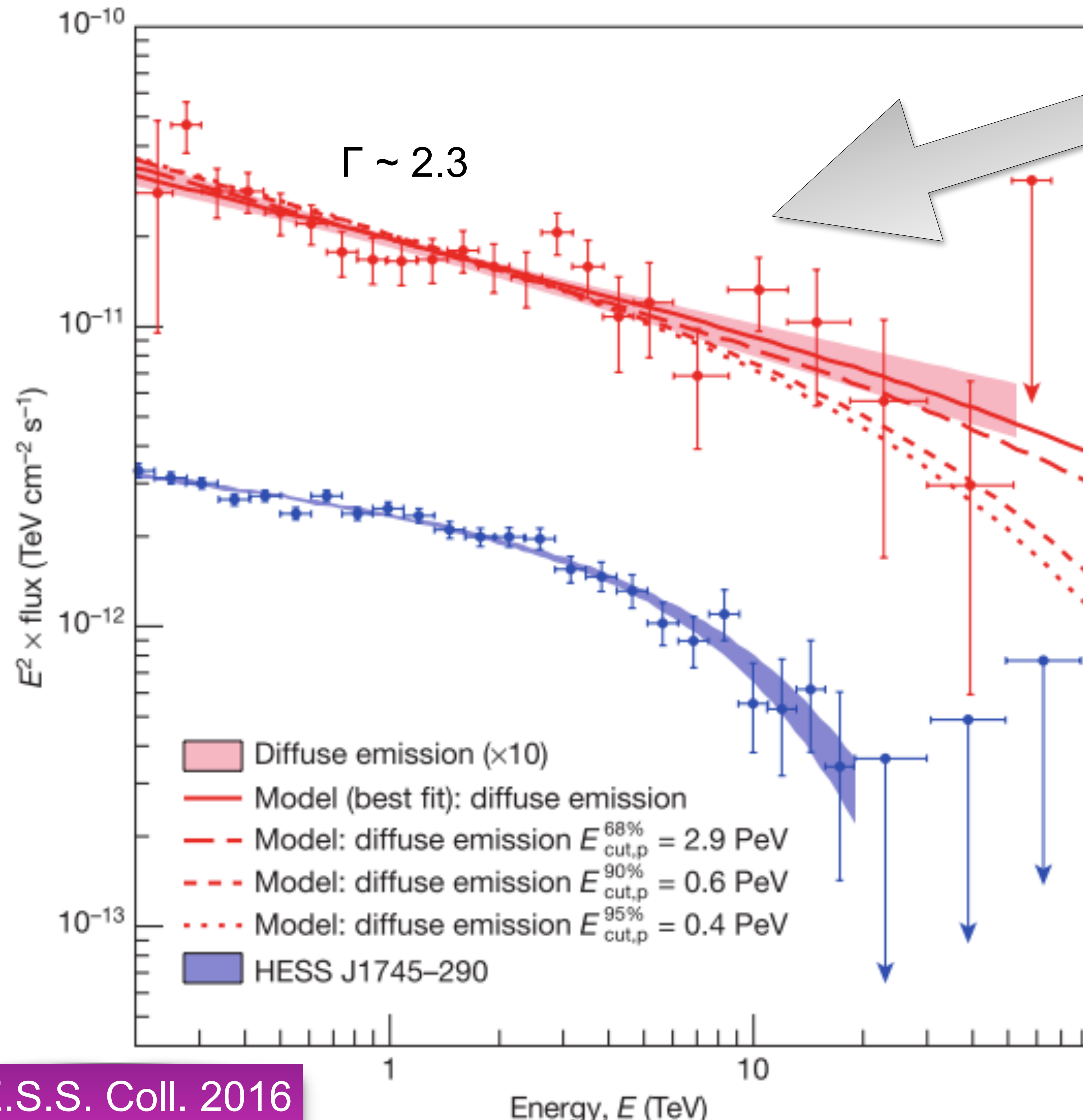
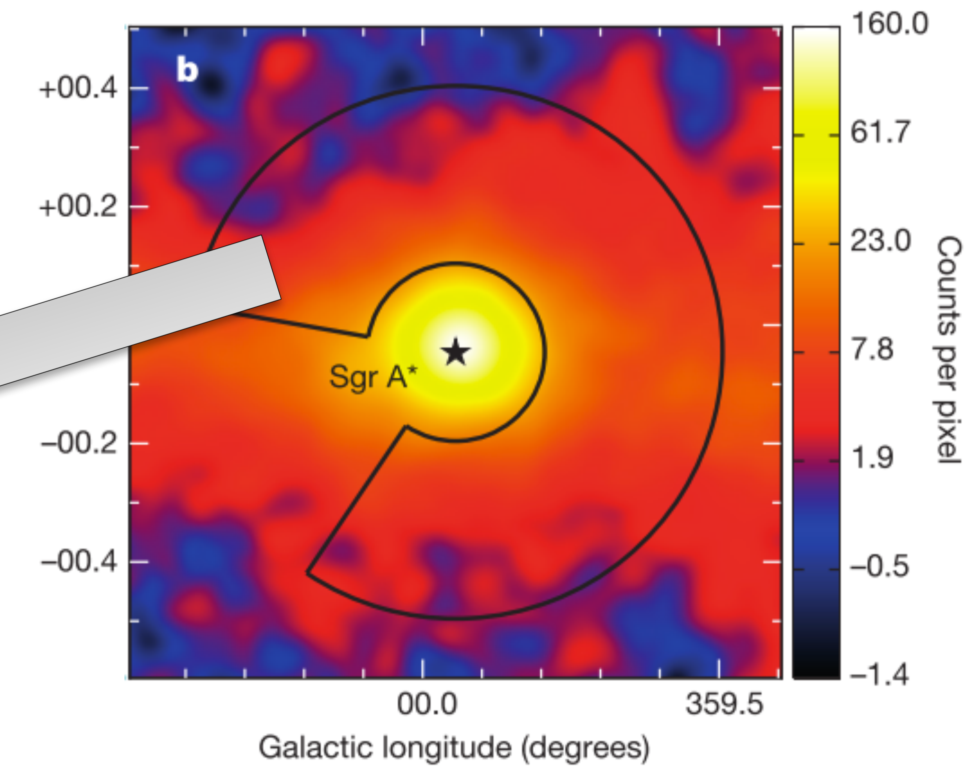
Measurement of CR energy density from > 10 TeV gamma rays
- gas density from CS (CO, HCN)



- 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





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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