New TeV Supernova Remnant Shells in the Galactic Plane Discovered with H.E.S.S.

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for the H.E.S.S. collaboration

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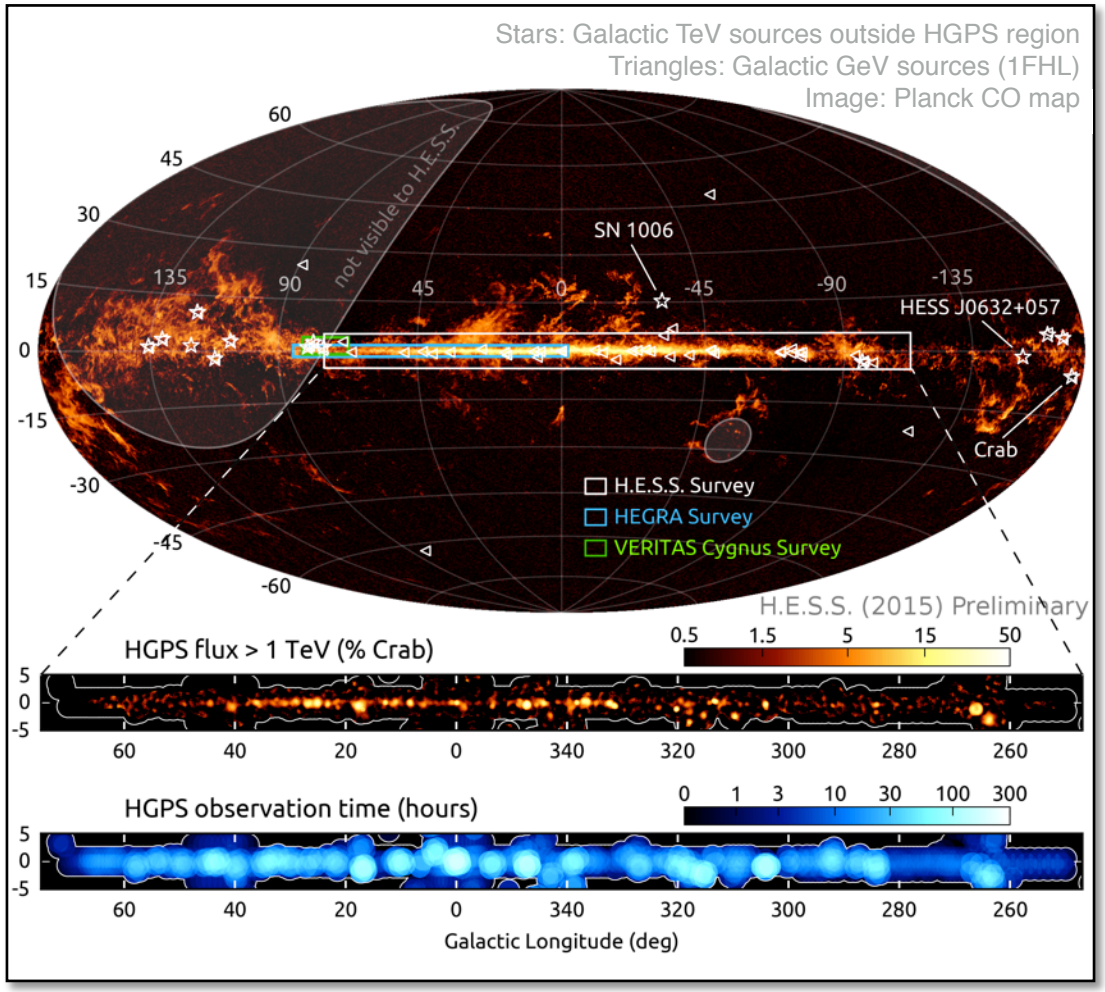
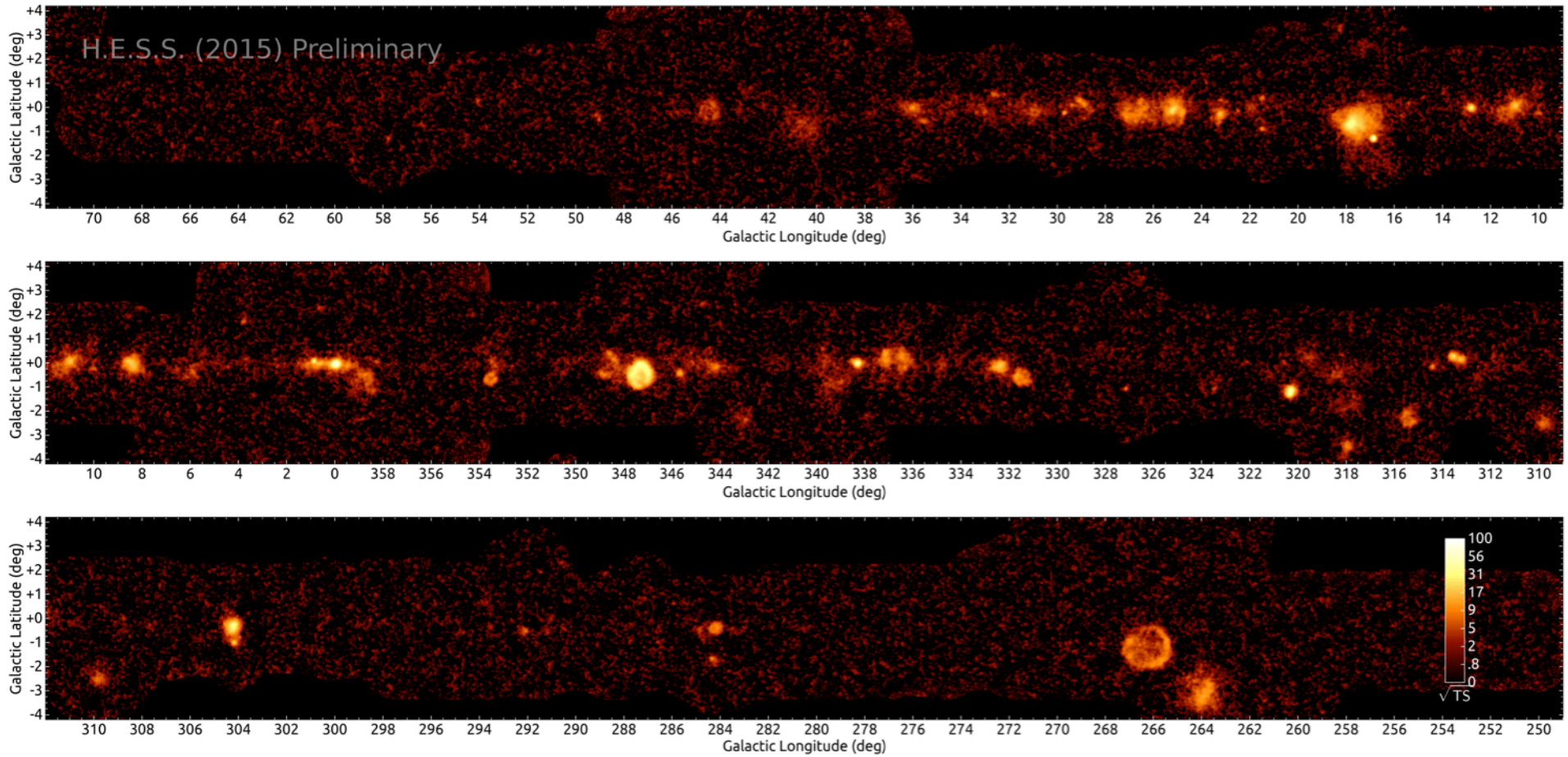
HGPS: The H.E.S.S. Galactic Plane Survey



- H.E.S.S. I telescope system (CT1 – CT4)
- ~3000 hours of observations, years 2004-2013
- $-110° < l < 65°$
  $-3.5° < b < 3.5°$
- 0.2-100 TeV, $R_{68\%} \sim 0.07°$

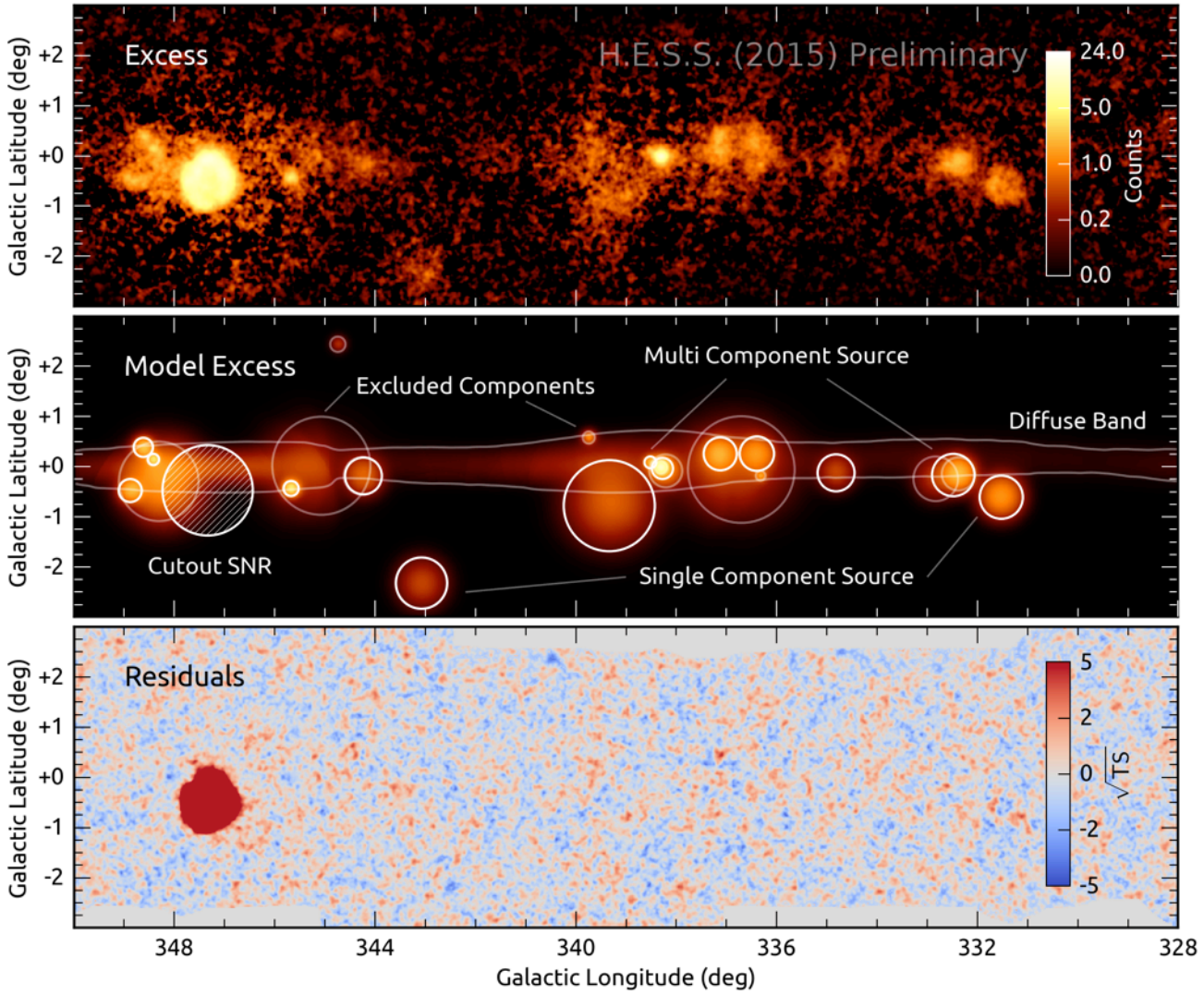
HGPS TS map



- In full detail for the first time shown at ICRC 2015

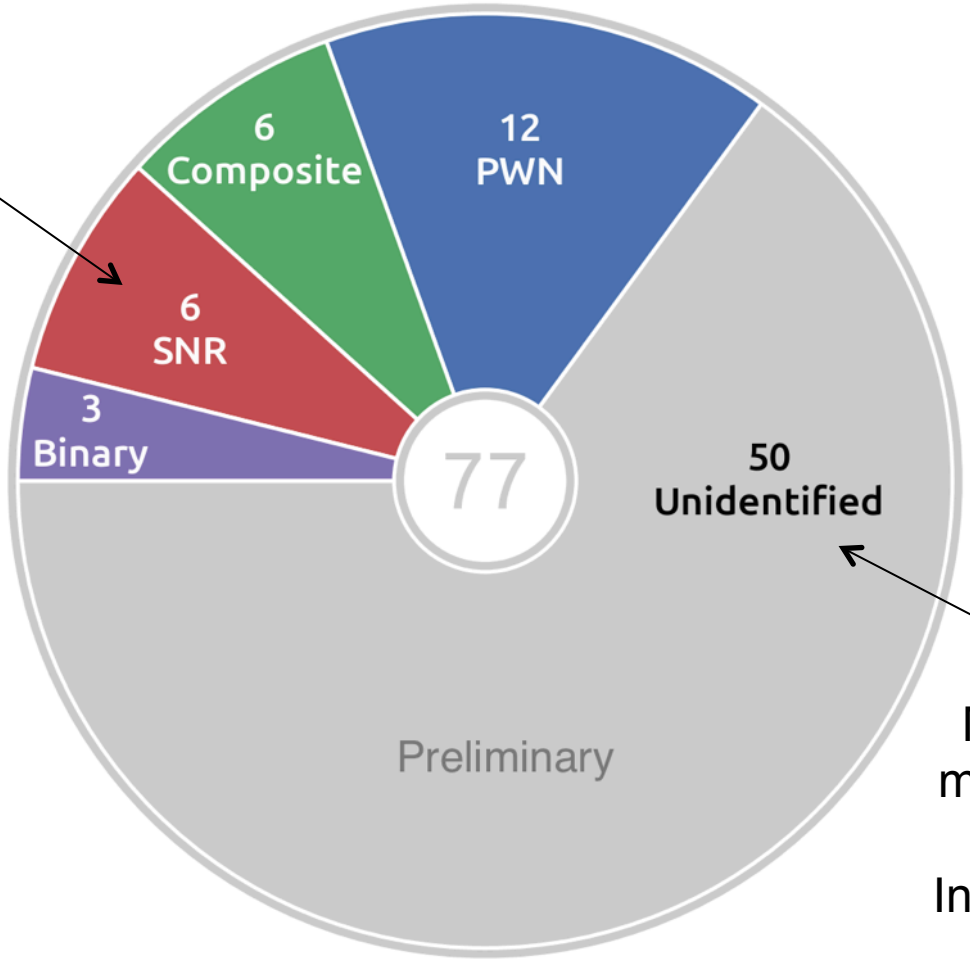
HGPS morphology model

- Cut out SNRs and Galactic center region (**13** sources)
- Large-scale diffuse Gaussian band model
- **100** significant Gaussian components with Poisson likelihood test statistic **TS > 30**
- **64** sources (re-)analysed
- HGPS catalog sources: **77** = 64 + 13



HGPS: Firm identifications

Known SNRs in the HGPS region



Mostly sources with multiple associations

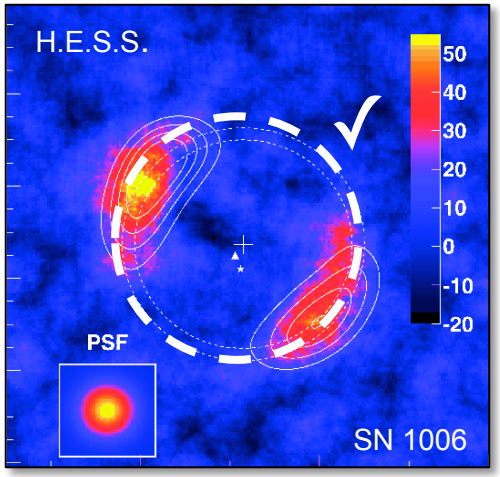
Including 2 new SNR candidates

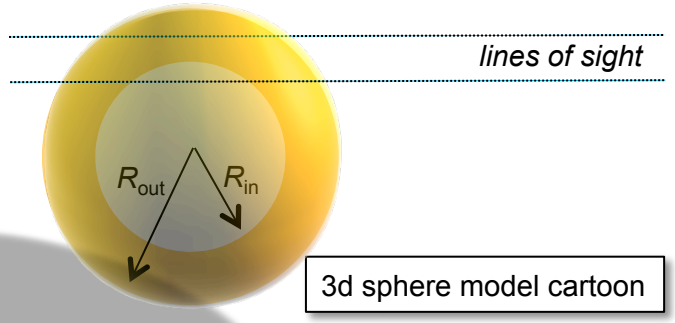
Shell search definition

Do not rely on HGPS definition of a source (Gaussian or composite Gaussian, cf. e.g. SN 1006)

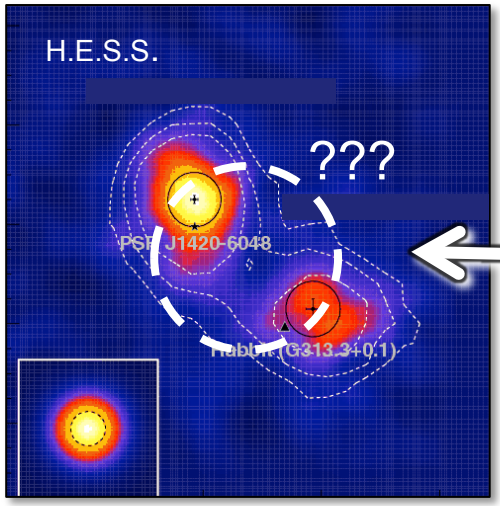
→ Two-step approach:

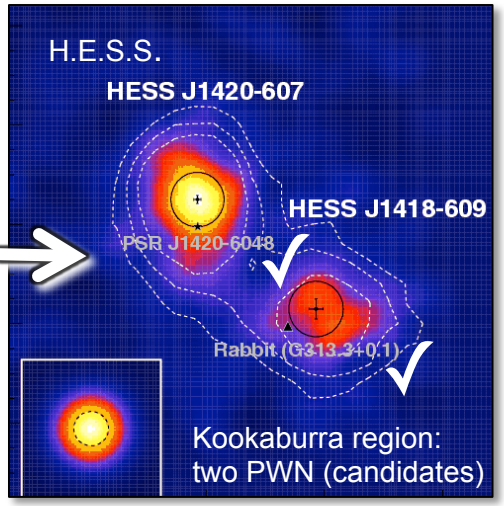
1. Grid search in H.E.S.S. GPS data
   - Search setup: grid 0.02° × 0.02°, test null hypothesis (no shell) vs. shell-like appearance at each position
   - Null hypothesis: 2d Gaussian
   - Shell hypothesis: projected 3d sphere, homogeneously emitting between R_{min} and R_{max}
2. Evaluation of good candidates on an individual „source-by-source“ basis





3d sphere model cartoon





Search on a grid in the HGPS data

- All known TeV SNR *shells* within the HGPS boundaries are (re-)identified with high significance:
  - RX J1713.7-3946, Vela Jr., HESS J1731-347, RCW 86

→ What follows are the three SNR (candidates) that survive the 2nd step assessment on individual source maps

all numbers preliminary

	Discovery status	**Lifetime**	**Source detection** excess inside $R_{out,shell}$	**Null hypothesis probability** unconstrained 2d-Gaussian vs. projected 3d-sphere	**Circular shell model parameters**	
					R_{in}	R_{out}
HESS J1534-571	New in HGPS (TS_{diff} = 39)	57.4 hrs	9.3 σ	6.4×10^{-3}	$0.28^{\circ}\ ^{+0.06^{\circ}}_{-0.03^{\circ}}$	$0.40^{\circ}\ ^{+0.04^{\circ}}_{-0.12^{\circ}}$
HESS J1912+101	Published 2008 (6 x less exposure)	121.6 hrs	17.3 σ	1.7×10^{-6}	$0.32^{\circ}\ ^{+0.02^{\circ}}_{-0.03^{\circ}}$	$0.49^{\circ}\ ^{+0.04^{\circ}}_{-0.03^{\circ}}$
HESS J1614-518	Published 2006 (3.5 x less exposure)	34.2 hrs	34.2 σ	3.1×10^{-6}	$0.18^{\circ}\ ^{+0.02^{\circ}}_{-0.02^{\circ}}$	$0.42^{\circ}\ ^{+0.01^{\circ}}_{-0.01^{\circ}}$

HESS J1534-571: a new HGPS source

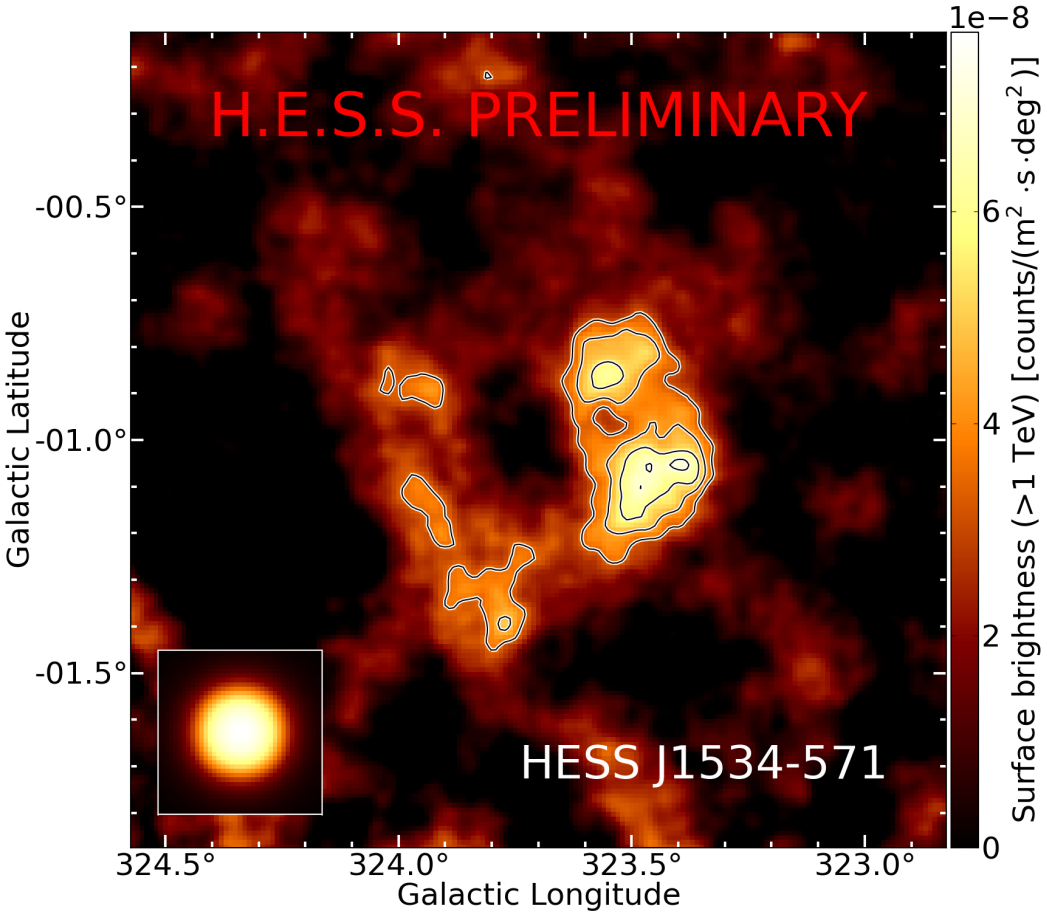
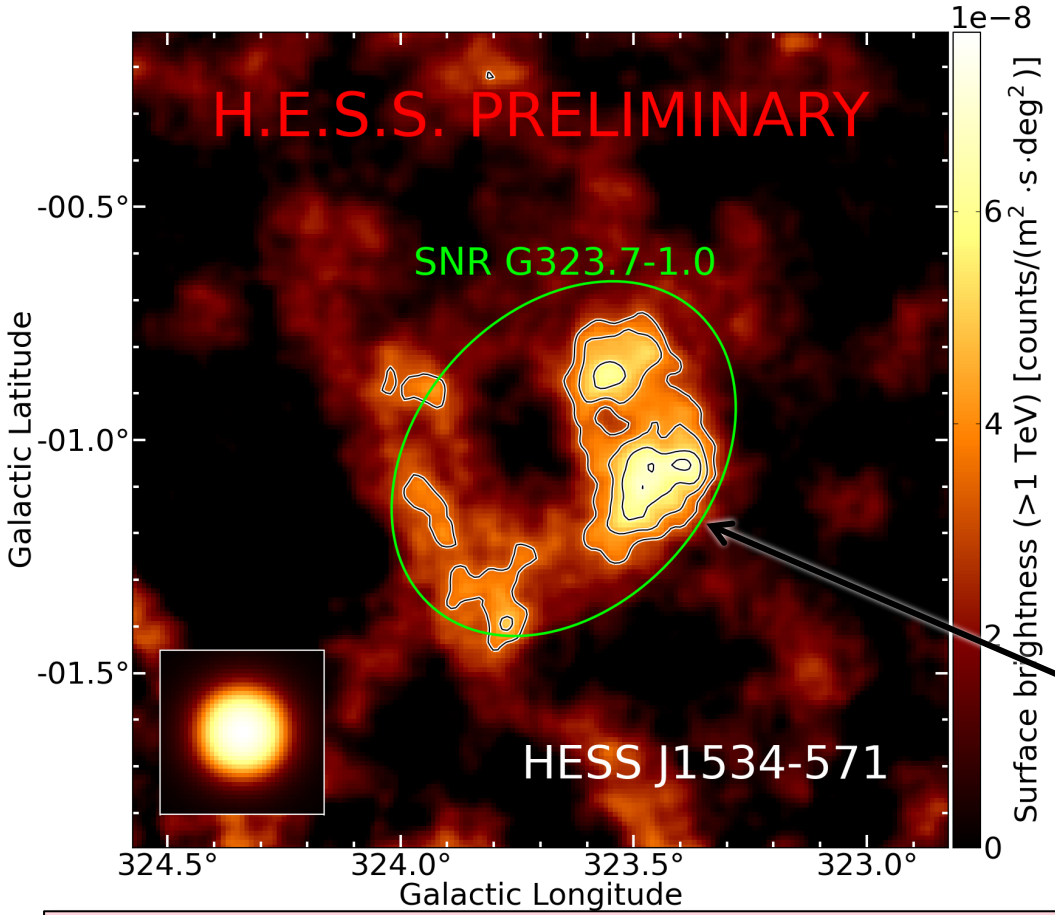


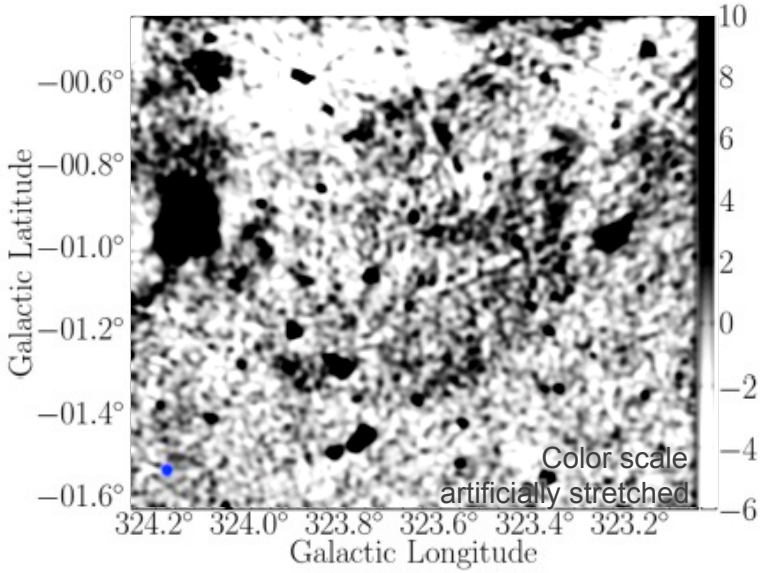
Image details:

- Surface brightness map, spectral assumption power-law with $\Gamma = 2.3$
- 0.1° integration radius per image pixel; smoothed with Gaussian filter ($\sigma = 0.01°$)
- Significance contours (0.1° integration): 3,4,5,6 σ

HESS J1534-571: a new HGPS source



Green et al. 2014, PASA 31, 42



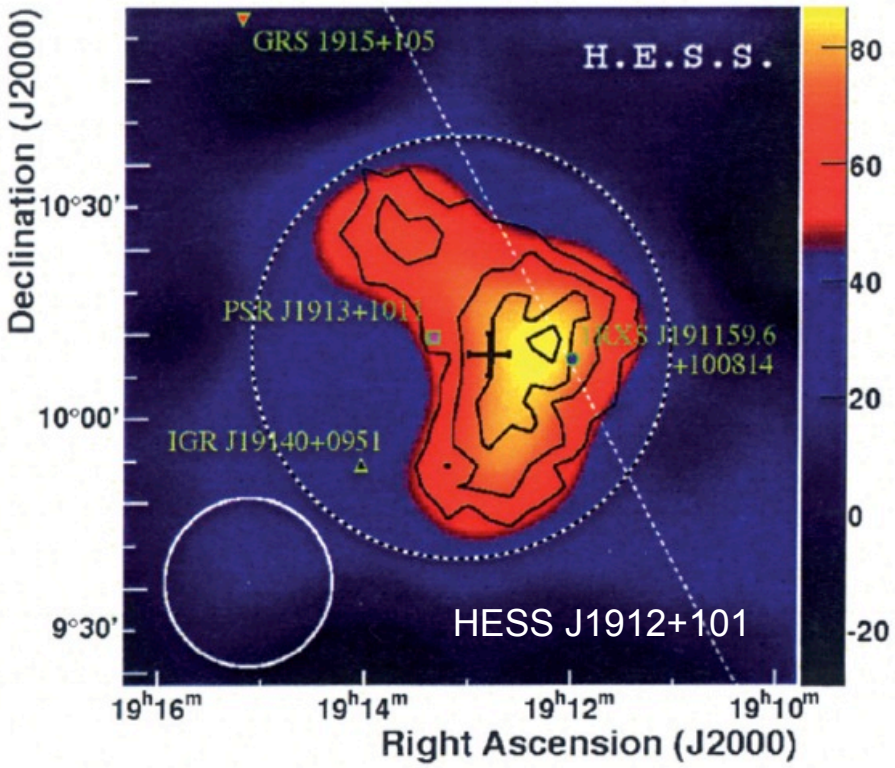
→ radio SNR candidate counterpart in 2nd Molonglo GPS

Source classification:

- TeV shell morphology (though marginal significance)
- Clear morphological association with radio SNR candidate
- No alternative known counterpart

→ New SNR

HESS J1912+101: a 2008 HESS source



- Source discovery published in 2008
- No identification, but possible association with PSR J1913+1011 in PWN scenario discussed
- PWN scenario challenging (spin-down age $\tau_c \approx 1.7 \times 10^5$ years)
- No known radio SNR counterpart

Aharonian et al. (H.E.S.S. collaboration), A&A 2008

HESS J1912+101: a 2008 HESS source

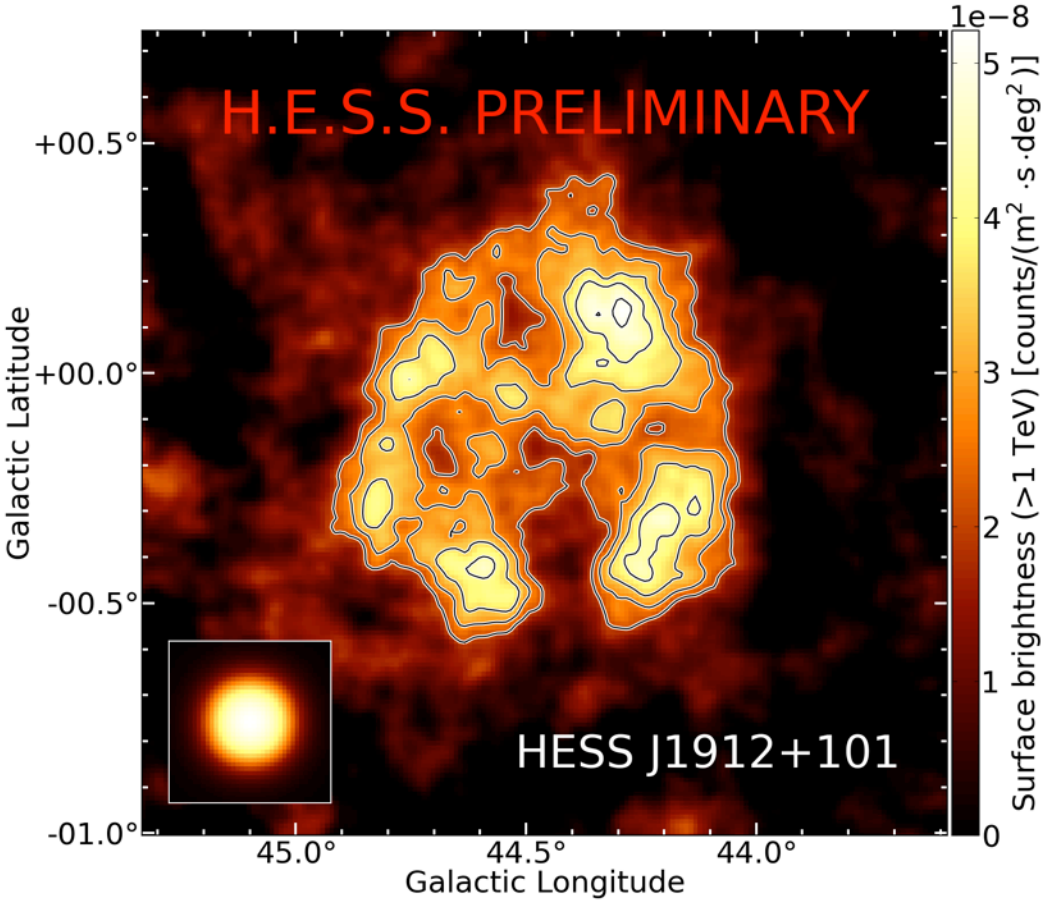


Image details:

- Surface brightness map, spectral assumption power-law with Γ = 2.7 *(from H.E.S.S. coll. A&A 2008)*
- 0.1° integration radius per image pixel; smoothed with Gaussian filter (σ = 0.01°)
- Significance contours (0.1° integration): 3,4,5,6,7 σ

Source classification:

- Very significant TeV shell morphology
- No reliable known counterpart

→ TeV SNR candidate

→ Likely the first TeV SNR w/o counterpart in other wavebands

HESS J1614-518: a 2006 HESS source

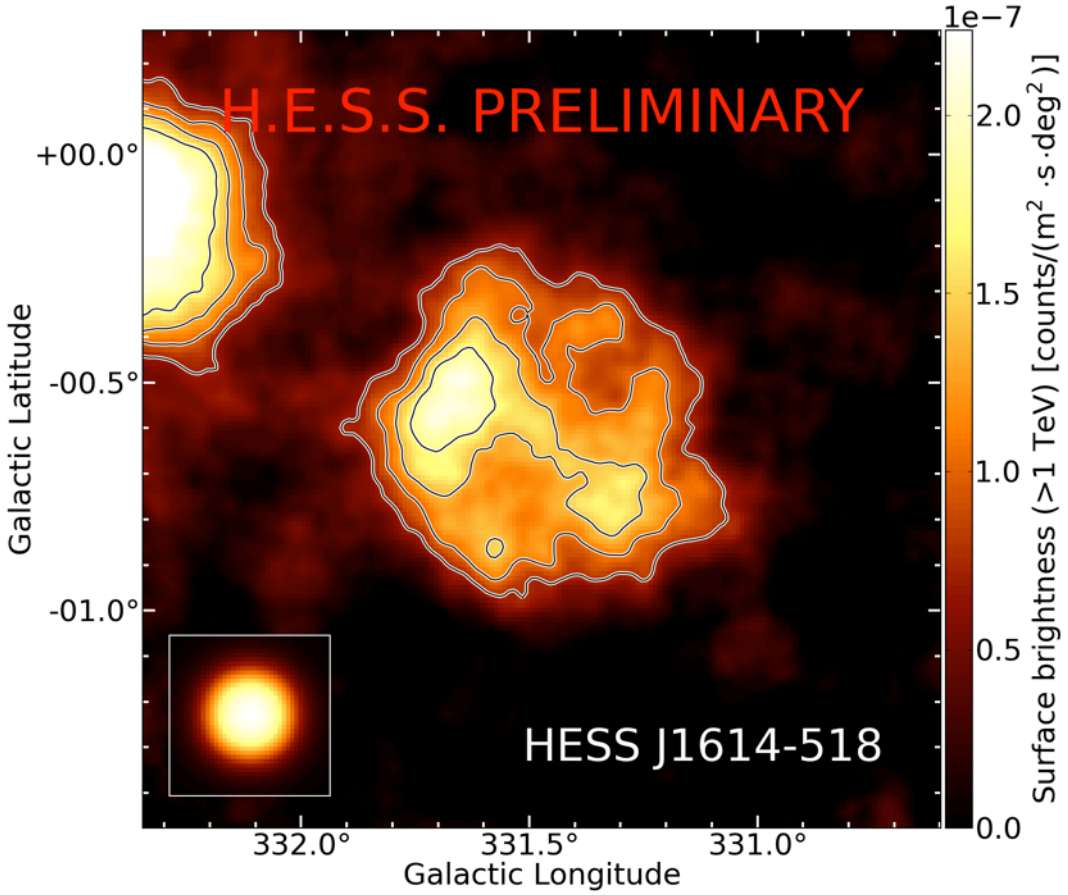
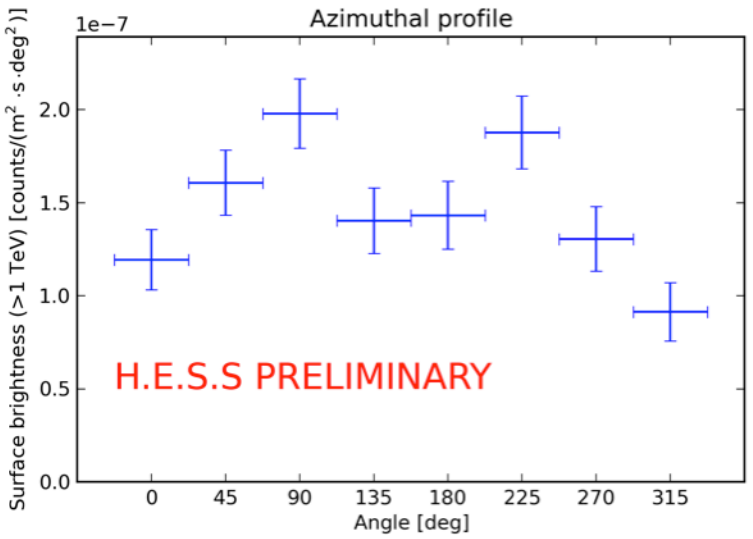


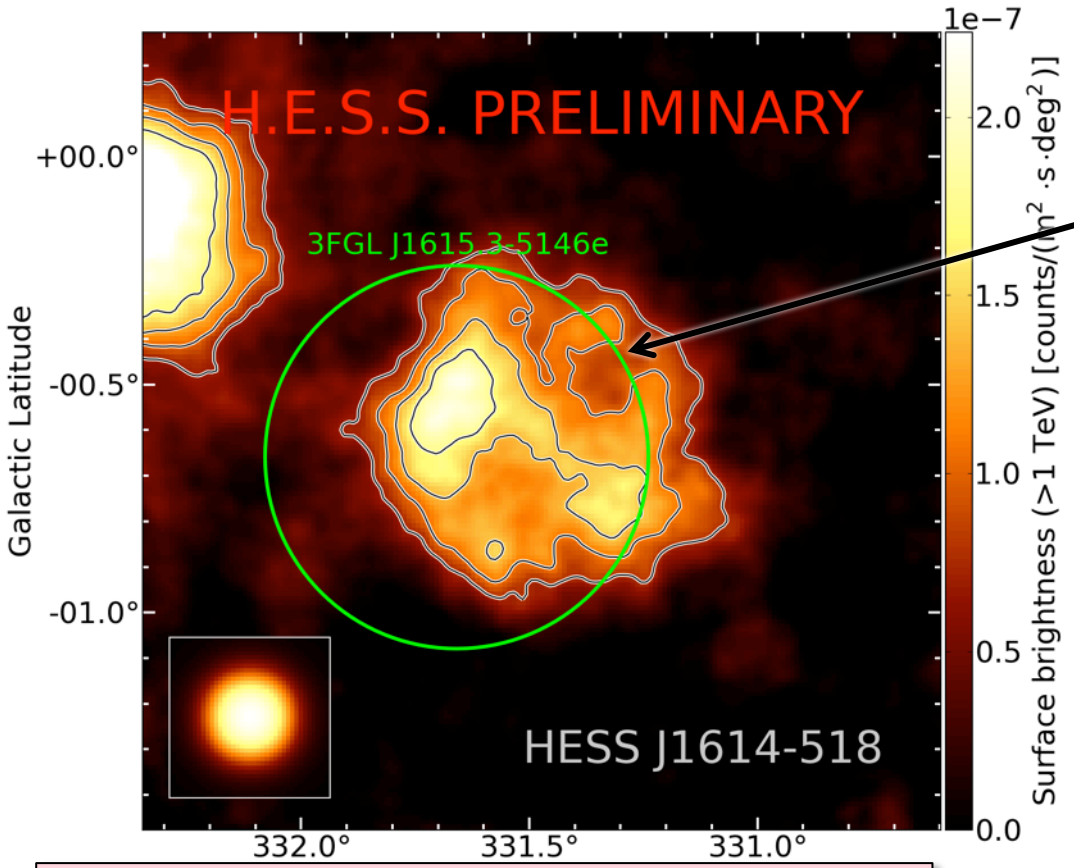
Image details:

- Surface brightness map, spectral assumption power-law with Γ = 2.5 *(from H.E.S.S. coll. ApJ 2006)*
- 0.1° integration radius per image pixel; smoothed with Gaussian filter (σ = 0.01°)
- Significance contours (0.1° integration): 5,7,9,11 σ



- Resolved shell, with significant deviation from a flat azimuthal profile
- Adding additional (Gaussian) components to the model not stable (likely due to diffuse surrounding component)

HESS J1614-518: a 2006 HESS source



→ MeV-GeV counterpart: 3FGL J1615.3-5146e (Acero et al., Fermi-LAT collaboration, ApJS 2015)

Source classification:

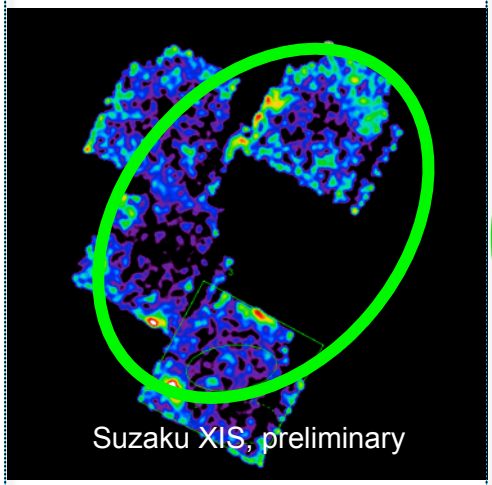
- Very significant TeV shell morphology
- 3FGL/2FHL morphological (and spectral) counterpart

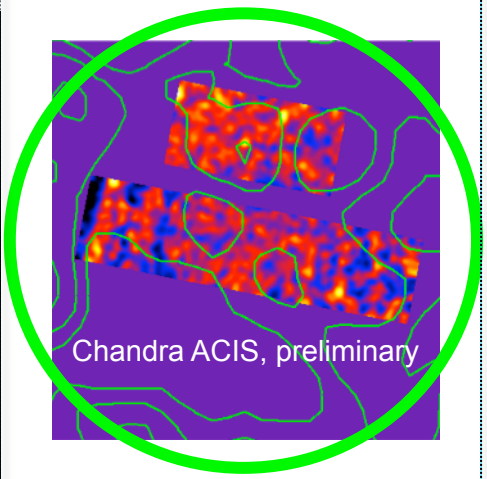
→ GeV counterpart, but counterpart nature not identified

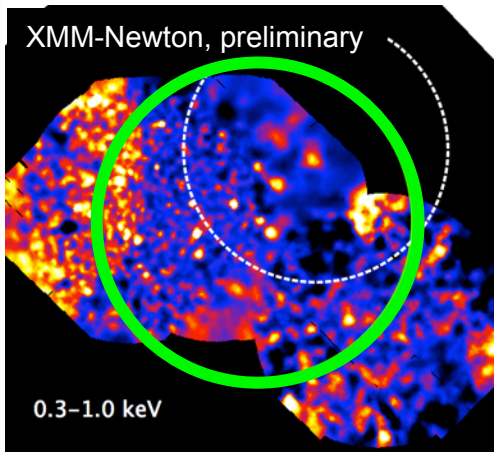
→ TeV SNR candidate

Multiwavelength overview (very briefly)

	HESS J1534-571	HESS J1912+101	HESS J1614-518
Radio synchrotron	SNR candidate in MGPS2	---	---
X-rays	no ROSAT counterpart sensitive limit with Suzaku	no ROSAT counterpart no sensitive coverage yet	no ROSAT counterpart XMM-Newton coverage inconclusive due to straylight
Fermi-LAT	no published counterpart	no published counterpart	3FGL/2FHL disclike counterpart
Sub-mm (CO/CS)	inconclusive (so far)	inconclusive (so far)	inconclusive (so far)







Discussion and Conclusion

- HESS Galactic Plane Survey completed:
  - paper and legacy data release (including source catalog + FITS maps) soon
- TeV SNR shell search in HGPS data:
  - Source confusion, necessarily limited choice of tested source morphologies
    → no claim for completeness of presented search to any sensitivity level at this point
  - No search for unresolved sources, biased to nearby, largely extended sources
    → cf. to SNR population studies and CTA predictions with focus on typical Galactic distances and thus smaller angular source scales
  - HESS J1534-571:
    → new TeV SNR (radio SNR candidate counterpart)
    → lack of non-thermal X-ray emission at current satellite sensitivity level
    → good prospects for TeV emission by proton-induced interaction
  - HESS J1912+101:
    → possible PWN interpretation invalidated
    → likely the first TeV SNR w/o counterpart in other wavebands
  - HESS J1614-518
    → disclike 3FGL/2FHL counterpart
    → TeV SNR candidate

Backups

Motivation for SNR shell search in HGPS

Physics motivation: What to expect from search for TeV-selected SNRs?

- Either intrinsically bright X-ray synchrotron emitters (so far missed e.g. due to absorption)
  → Extend small population of known TeV shells
- Or intrinsically X-ray dim
  → low level of HE electrons, potentially TeV view on HE protons
  → Shell morphology → particles still confined (being accelerated?) in shells, but no hard $\propto E^{-2}$ spectra expected due to potential particle escape

Observational motivation:

- If TeV shell, identification as SNR *candidate* possible even w/o MWL counterpart
  → cf. MC association ambiguities / PWN ambiguities
  → cf. dark TeV sources as old SNRs

The known TeV SNRs

TeV shells

Cas A (unresolved)

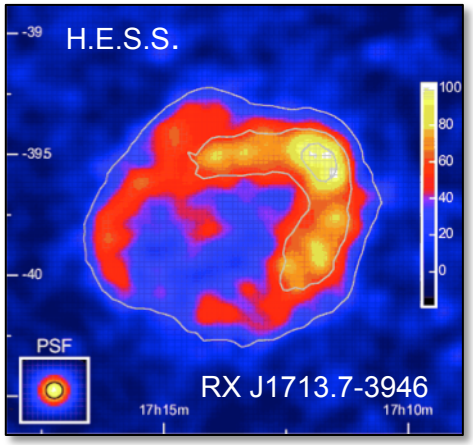
SN 1006

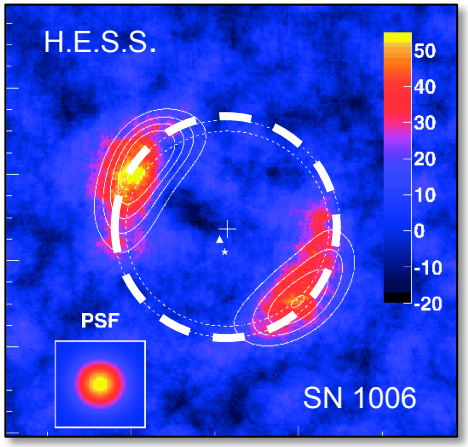
RCW 86

Vela Jr.

RX J1713.7-3946

HESS J1731-347





??

Shock-MC interaction

e.g. γ-ray sources @

MC@ CTB 37A

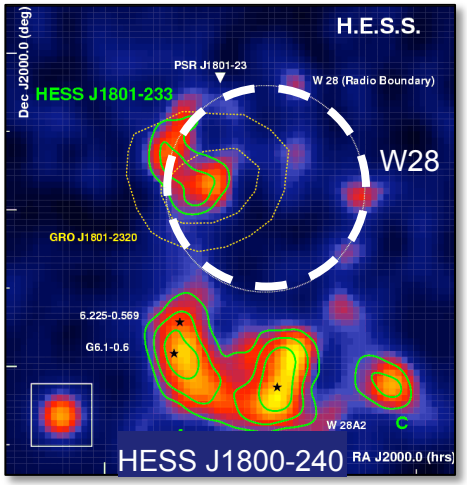
MC@ Tycho's SNR

MC@ IC 443

MC@ W51C

MC

HESS J1800-240 near W28



The known TeV SNRs

TeV shells

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Shock-MC interaction

e.g. γ-ray sources @

MC@ CTB 37A

MC@ Tycho's SNR

MC@ IC 443

MC@ W51C

MC

HESS J1800-240 near W28

Radio selected

X-ray selected

TeV selected

GeV selected

TeV

The known TeV SNRs

TeV shells

Cas A (unresolved)

SN 1006

RCW 86

Vela Jr.

RX J1713.7-3946

HESS J1731-347

??

Shock-MC interaction

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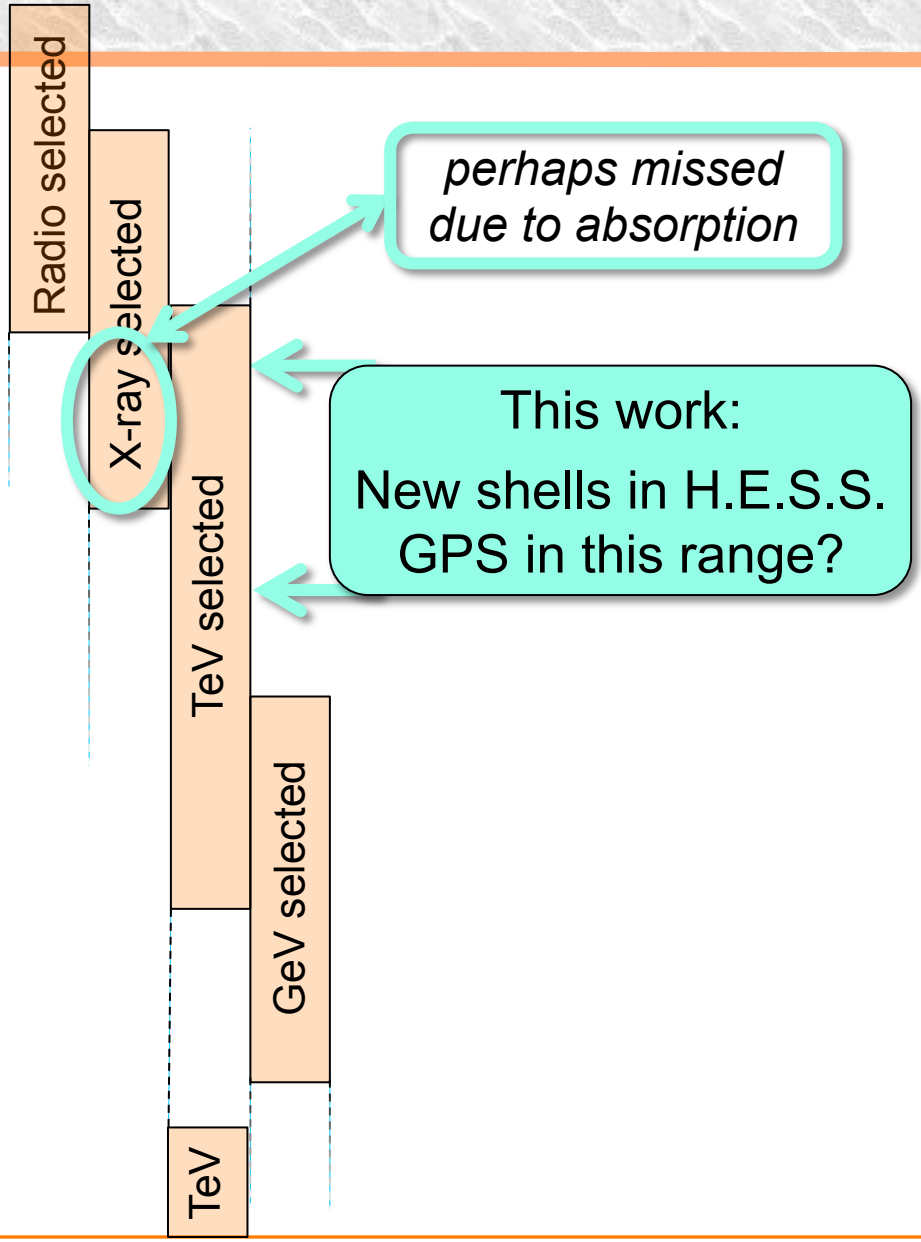


SNR shells analysis details

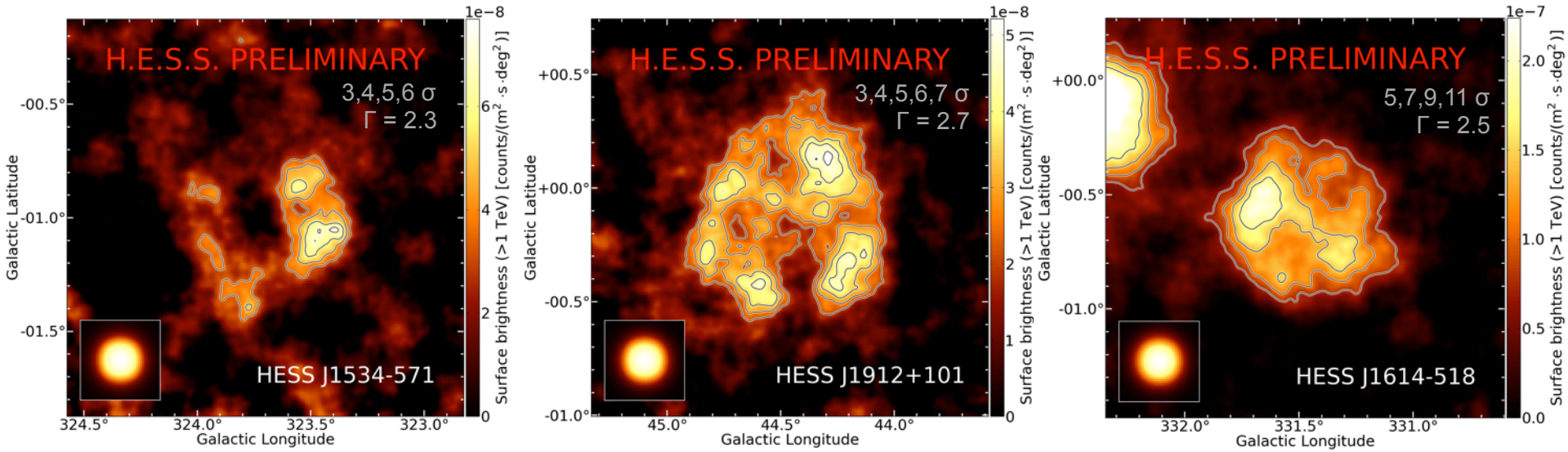


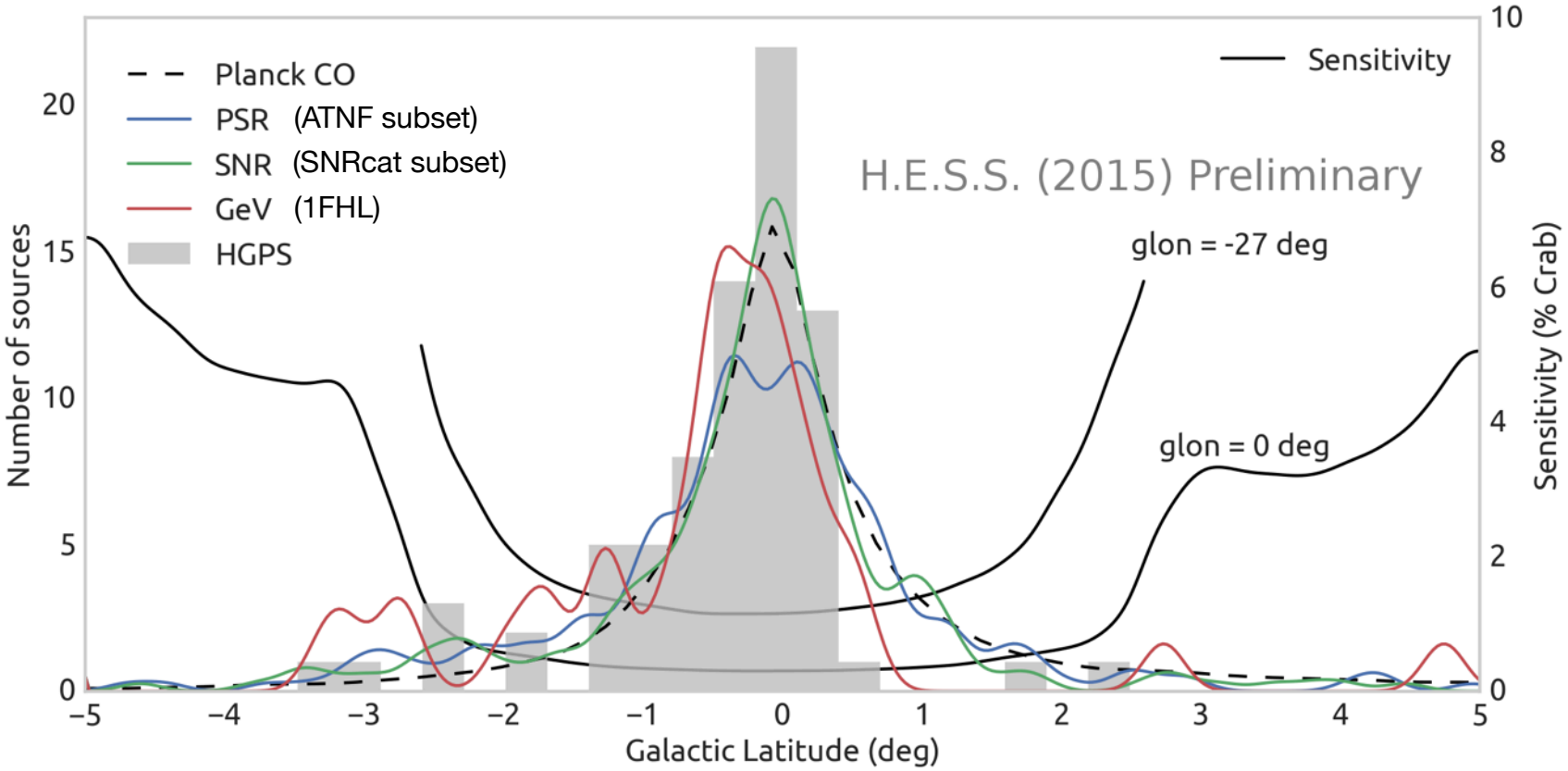
Image analysis details:

- Hillas-based analysis, TMVA-based background rejection
- Surface brightness map, power-law with index Γ as spectral assumption
- 0.1° integration radius per image pixel; additionally slightly smoothed with Gaussian filter (σ = 0.01°)
- Significance contours (0.1° integration)

Shell significance:

- Unconstrained (compared to initial grid search) morphology fit of 2d-Gaussian (= null hypothesis) vs. projected 3d-shell
- Null hypothesis probability computed using the Akaike Information Criterion (AIC, *Akaike, IEEE Transactions on Automatic Control, 1974, 716*)

HGPS sources and sensitivity: Galactic latitude distribution

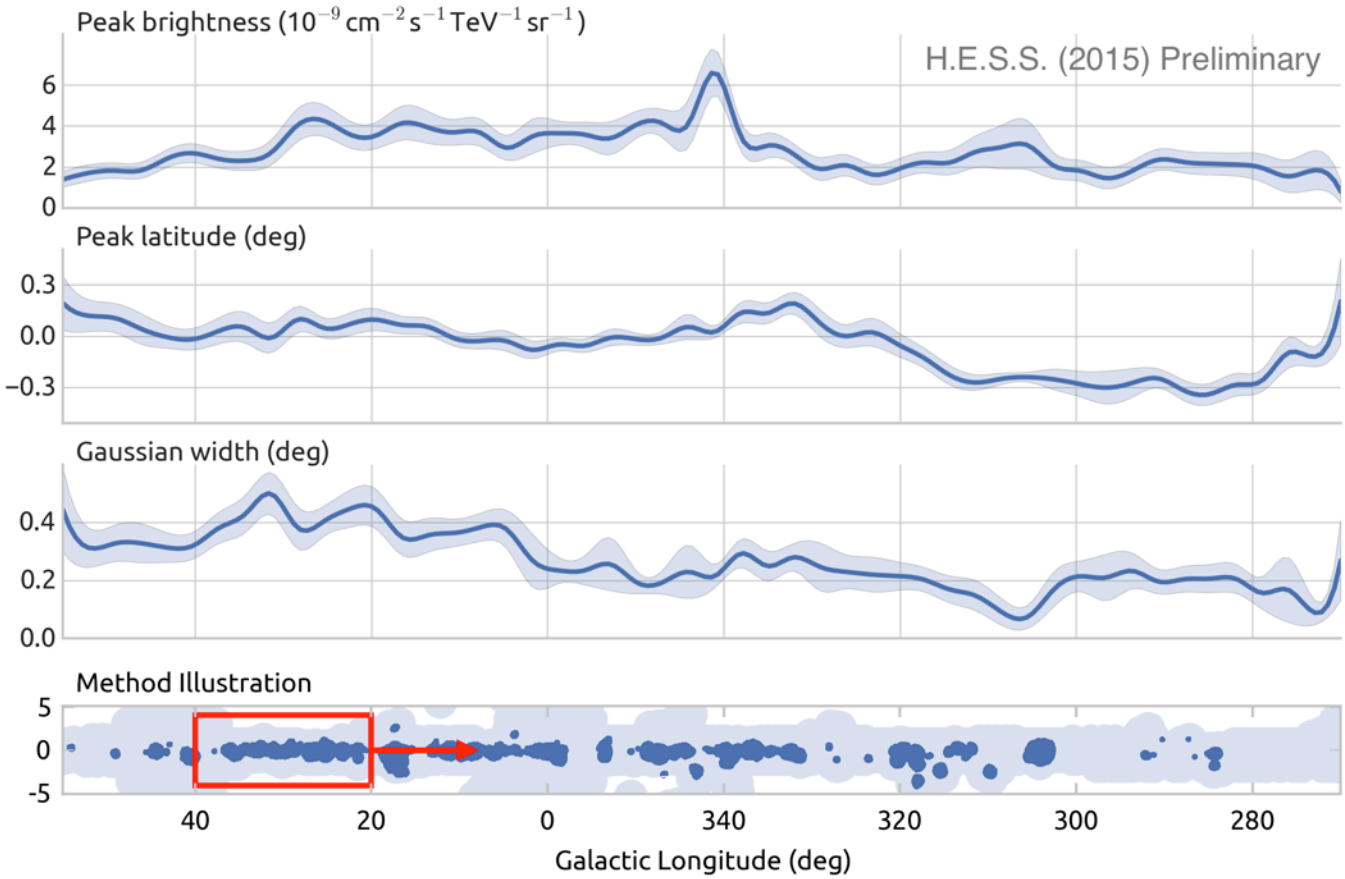


Caveat: these are observed distributions, not taking survey coverage and selection effects into account!

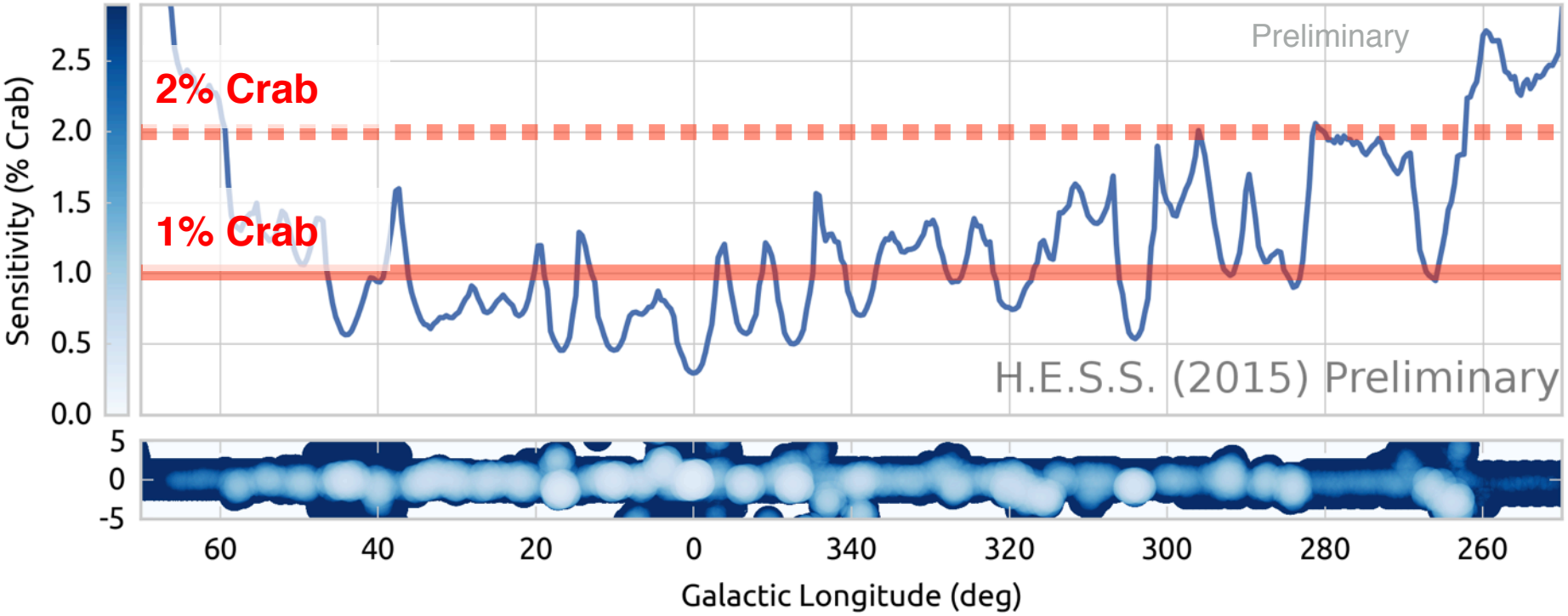
See H.E.S.S. PWN and SNR population studies.
PWN – Klepser et al. ICRC 2015
SNR – Hahn et al. ICRC 2015

Gaussian band large-scale emission model

- Gaussian shape in GLAT
- Parameters vary with GLON:
  - Peak Brightness
  - Peak latitude
  - Gaussian width
- Fitted outside exclusion regions, using sliding window with 20 deg width



HGPS point source sensitivity



HGPS energy threshold