Prospects on a future Galactic plane survey with CTAO

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on behalf of CTAC

cherenkov telescope array

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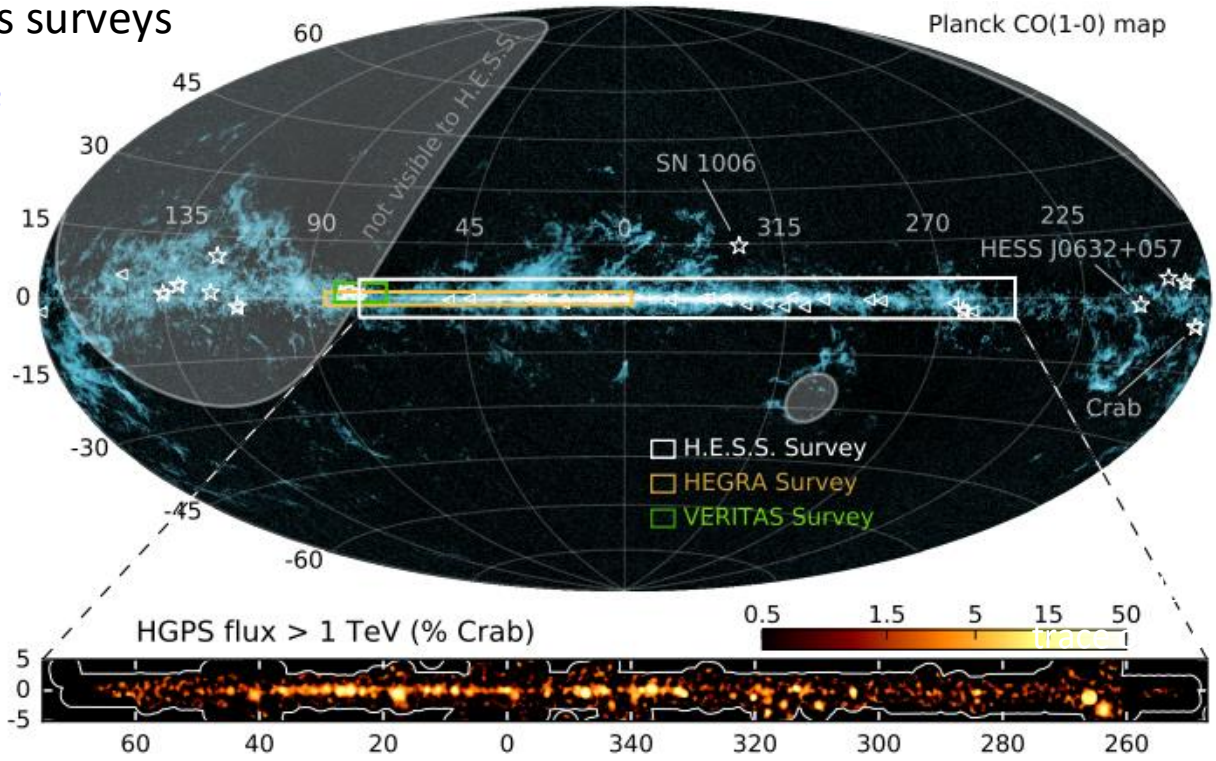
Very-high-energy γ-ray surveys from IACTs

- Previous IACTs surveys

  HESS-GPS 2018



- Galactic plane Survey proposed as Key Science Project for CTAO
  5-20x more sensitive than previous surveys

Goals : - unprecedented census of VHE emitters in the entire Galactic plane
- studying diffuse gamma-ray emission
- searching for new and unexpected phenomena

CTAO-GPS simulation and its analysis discussed in CTA Consortium 2023

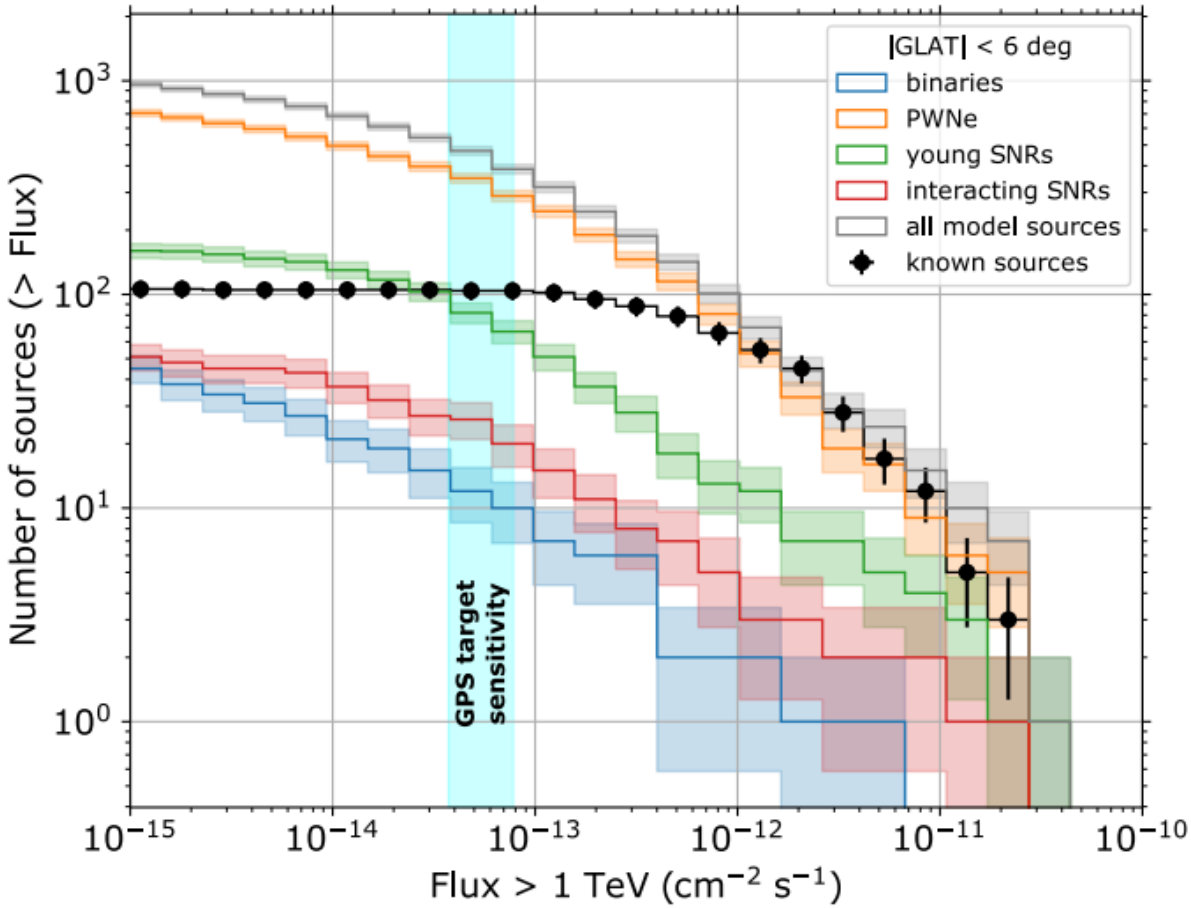
CTAO-GPS simulation : sky model

❖ Known sources
- IACTS sources compilation (gamma-cat.readthedocs.io)
- Fermi-LAT 3FHL
- 2HAWC

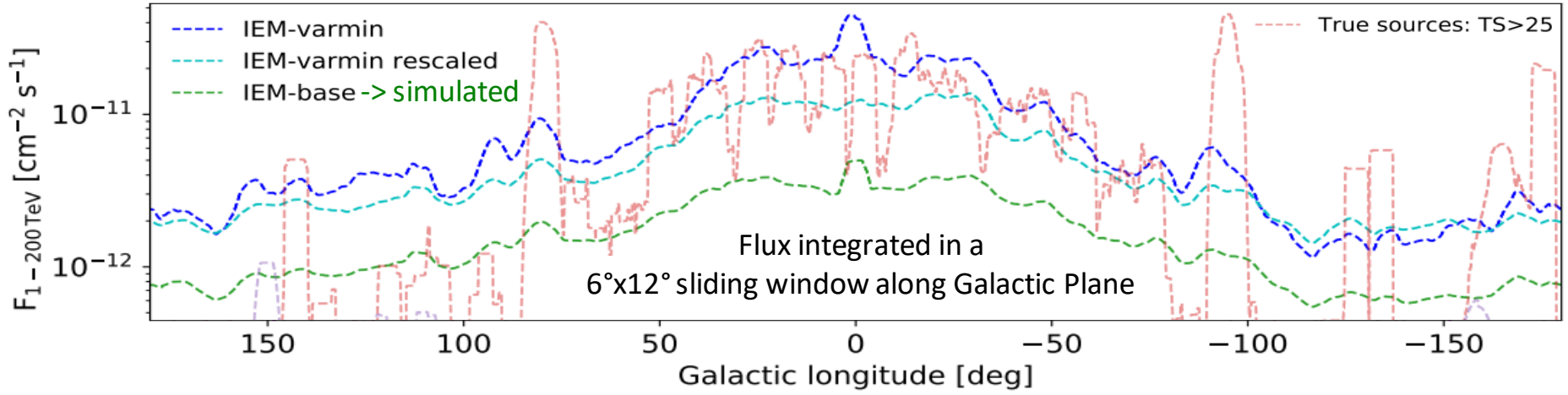
❖ Source population synthesis based on physical modelling
- supernova remnants: young and interacting with interstellar medium (Cristofari et al. 2017, Rice et al. 2016)
- pulsar wind nebulae (Fiori et al. 2022)
- binaries (Dubus et al. 2017)

❖ Interstellar emission
- Galactic Ridge
- Fermi-bubbles
- minimal model for gamma-ray emission from Galactic cosmic rays using DRAGON + HERMES cosmic-ray propagation code

❖ available at zenodo.org/record/8402589



Interstellar Emission Models



Largest contribution in intensity : Pi0-decay from CR interaction with gas

$$I_\gamma(l,b,E_\gamma) = \sum_i N_{\mathrm{H}}^i(l,b)\langle \epsilon_E(\mathbf{r},E_\gamma)\rangle^i,$$

Hydrogen column density divided in Galactocentric-rings

$$N_{\mathrm{H}}^i(l,b) = N_{\mathrm{HI}}^i(l,b) + 2X_{\mathrm{CO}}^i w_{\mathrm{CO}}^i(l,b),$$

- base :

$$X_{\mathrm{CO}} = 0.6\times 10^{0.4\left(\frac{R}{5\,\mathrm{kpc}}-1\right)}\times 10^{20}\ \mathrm{cm}^{-2}\,(\mathrm{K\,km\,s}^{-1})^{-1}$$

- varmin-rescaled : Xco from Fermi-LAT (compatible with base)

- varmin : Xco beyond the range suggested by current measurements

Emissivity from Cosmic Rays propagation code :

Diffusion coefficient :

$$D(\rho,\boldsymbol{x}) = D_0\cdot\beta\left(\frac{\rho}{\rho_0}\right)^{\delta(\boldsymbol{x})}$$

- base : constant index δ

- varmin :

$$\delta(R) = 0.04(\mathrm{kpc}^{-1})\cdot R(\mathrm{kpc}) + 0.17$$

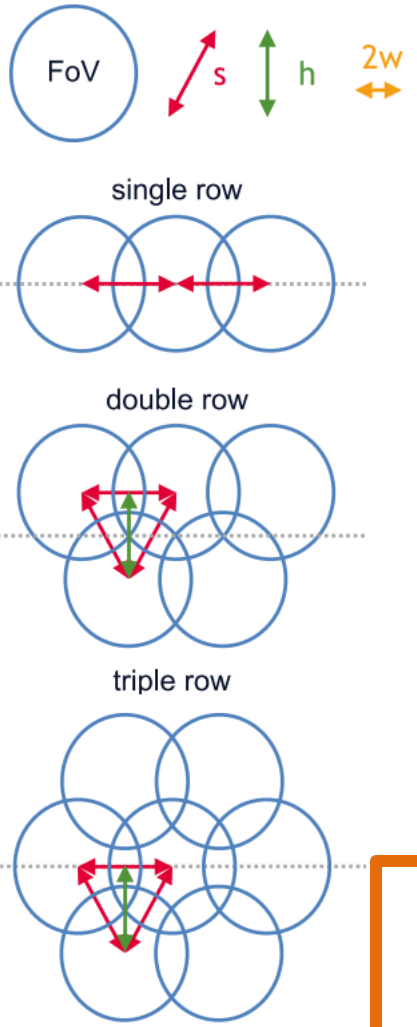
De La Torre Luque et al. 2022

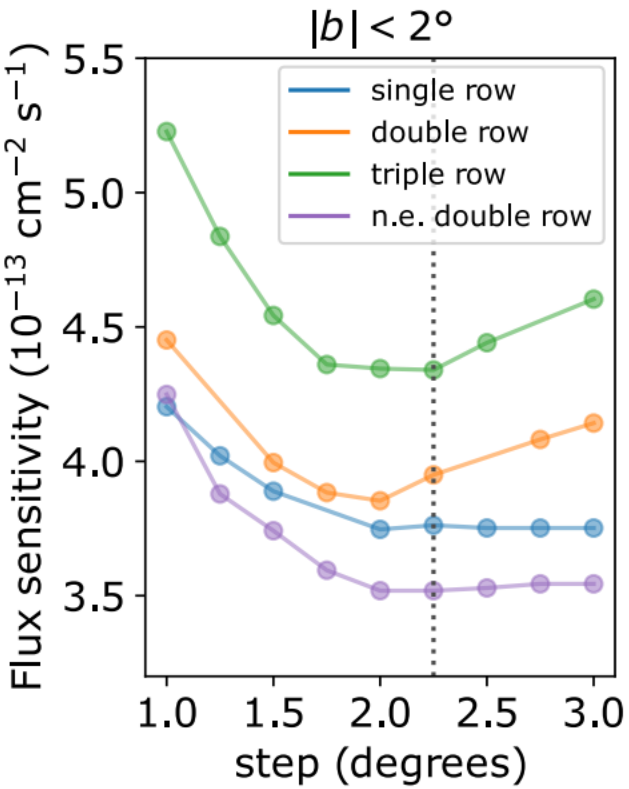
Radial gradient :

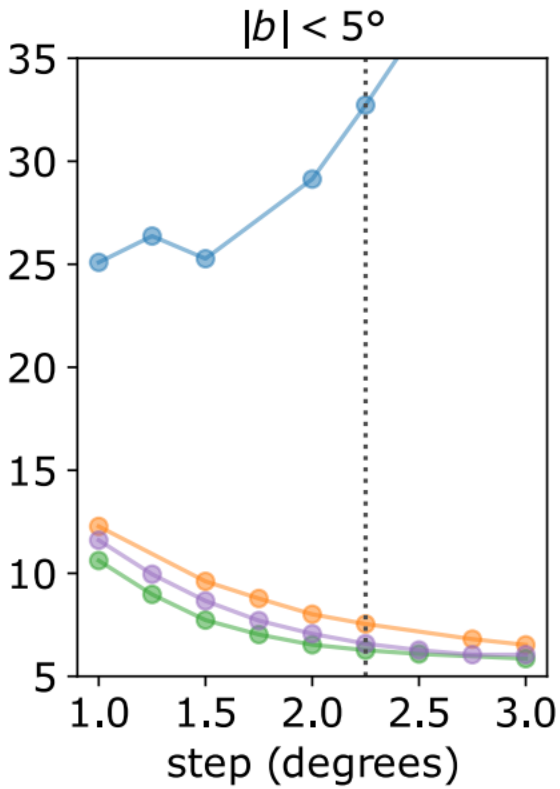
- base and varmin : smooth distribution of continuous sources

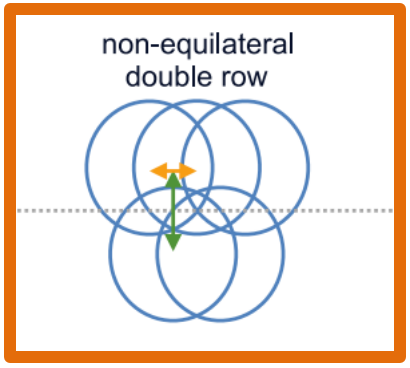
- varmin-rescaled : Radial gradient in emissivity rescaled on Fermi-LAT at 8 GeV

Pointing strategy optimization





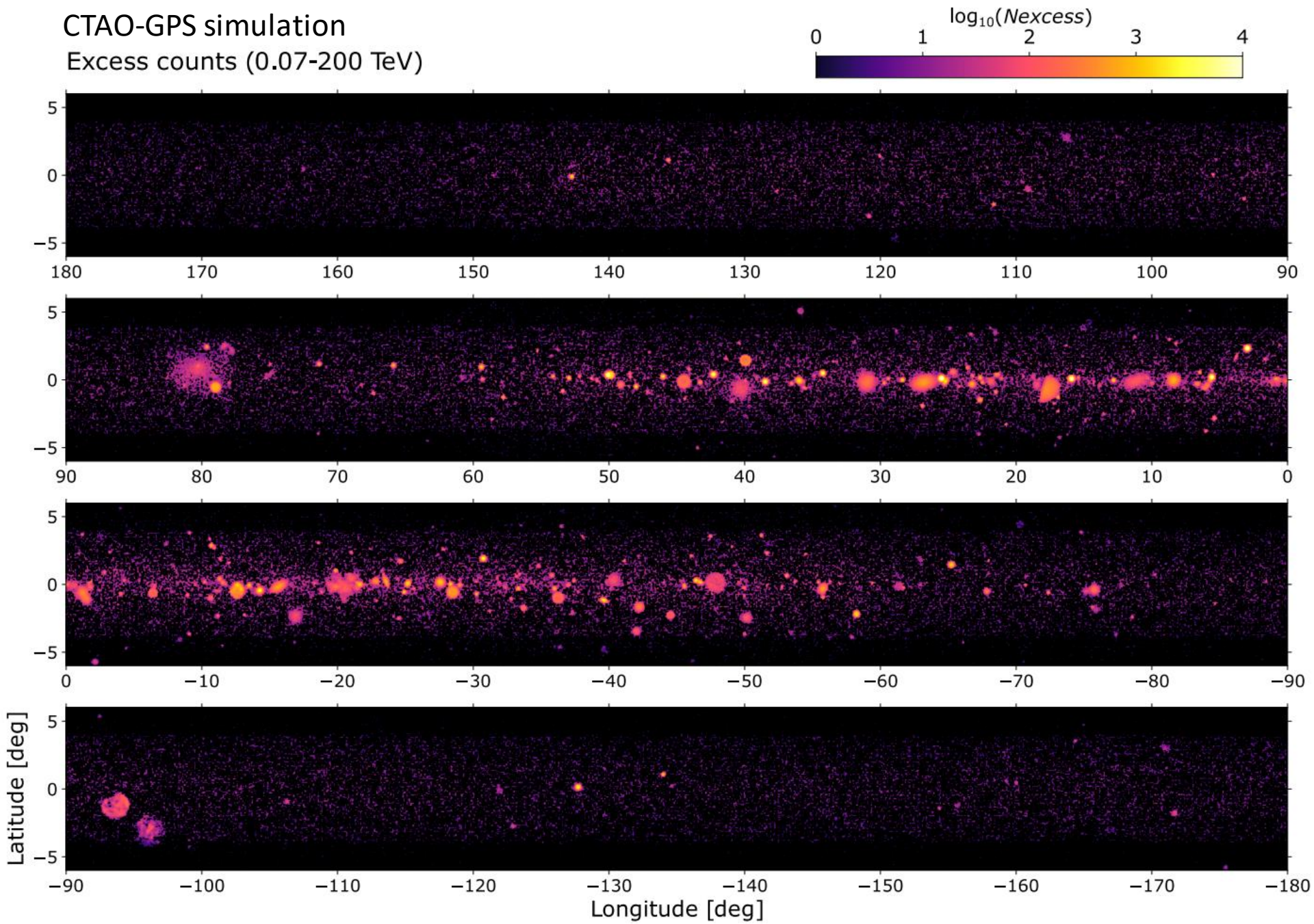




Selected : Non-equilateral double row
(h=1.95°, s=2.25°)

- best sensitivity in the Galactic plane
- as good as the triple-row pattern at higher latitudes
- Optimization in scheduling to allow detection of binaries

CTAO-GPS simulation

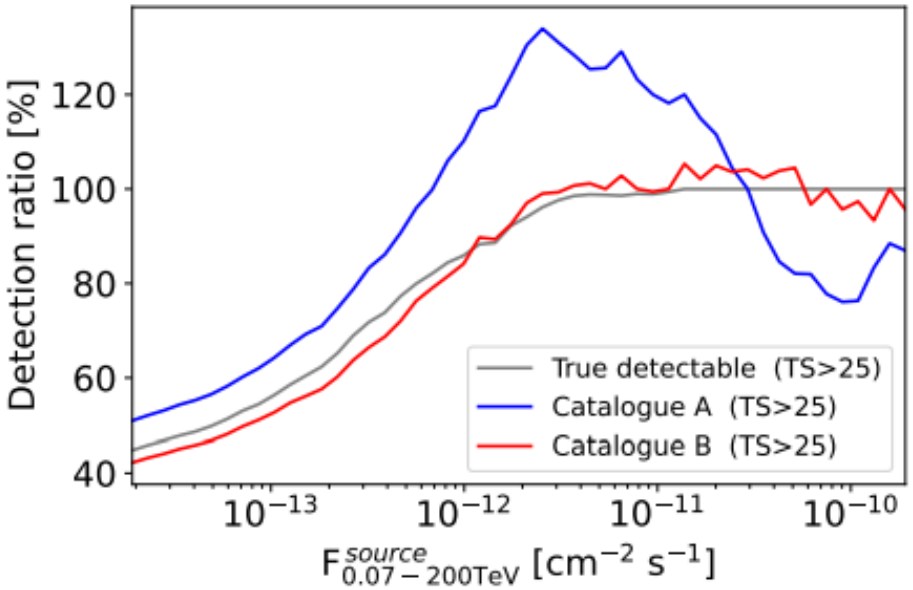


Catalogue : up to 500 sources detectables

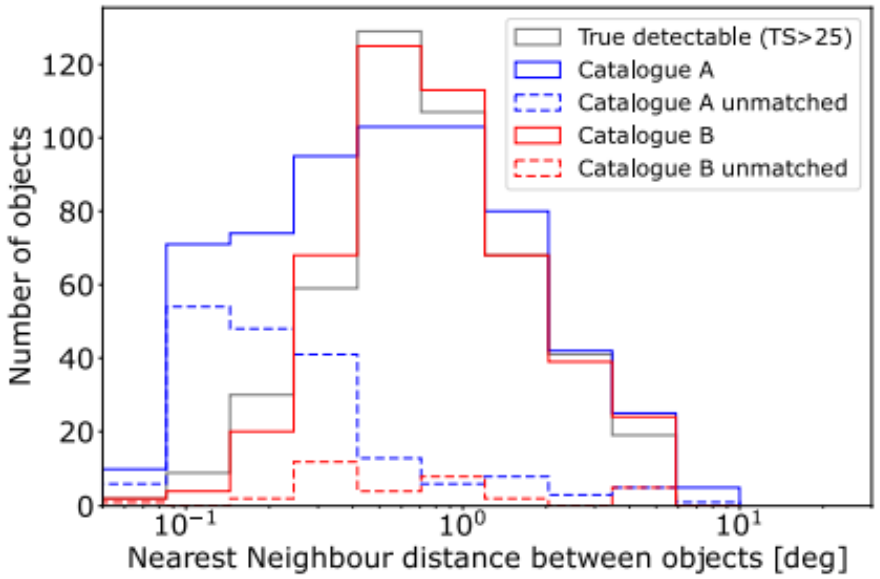
CTAO-GPS : Detections with TS >25 for E = 0.07-200 TeV :

Name	PWN	SNR	iSNR	Binaries	Known	Unmatched	Total	$\Delta F/F$	f_{match}	f_{reco}
True detectable	294	37	24	10	134	-	499	-	-	-
Catalogue A	241	16	20	10	111	169	567	-12.5%	0.70	0.80
Catalogue B	257	31	14	10	122	36	470	3.8%	0.92	0.87

Most of detectable sources are detected

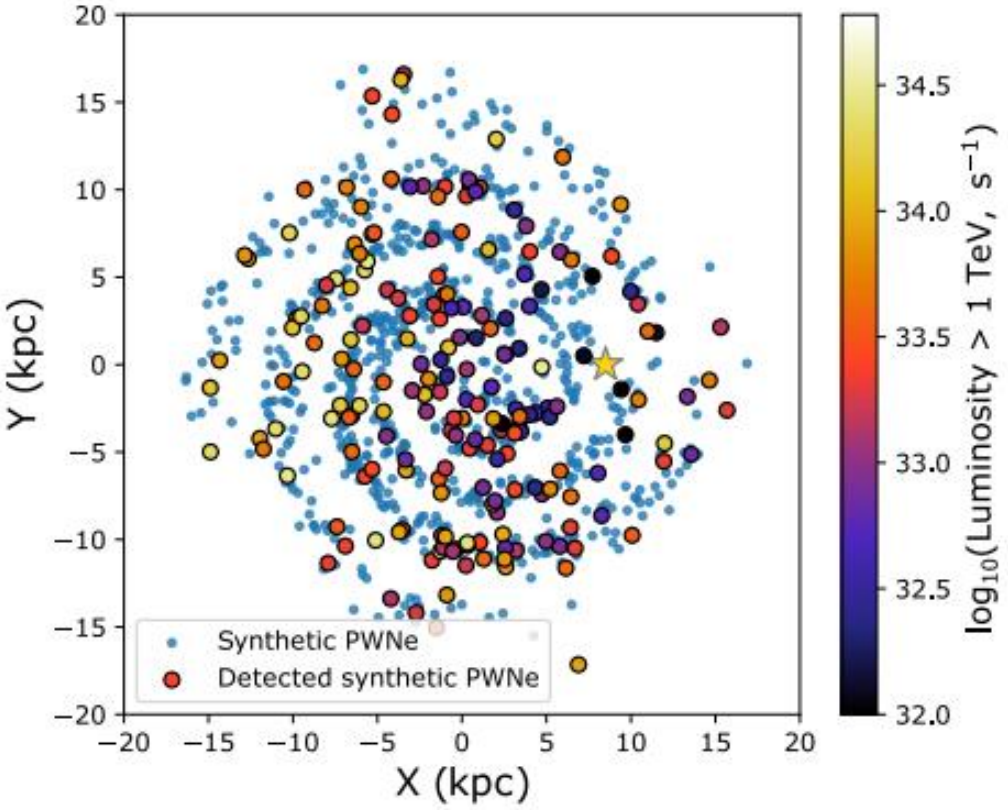


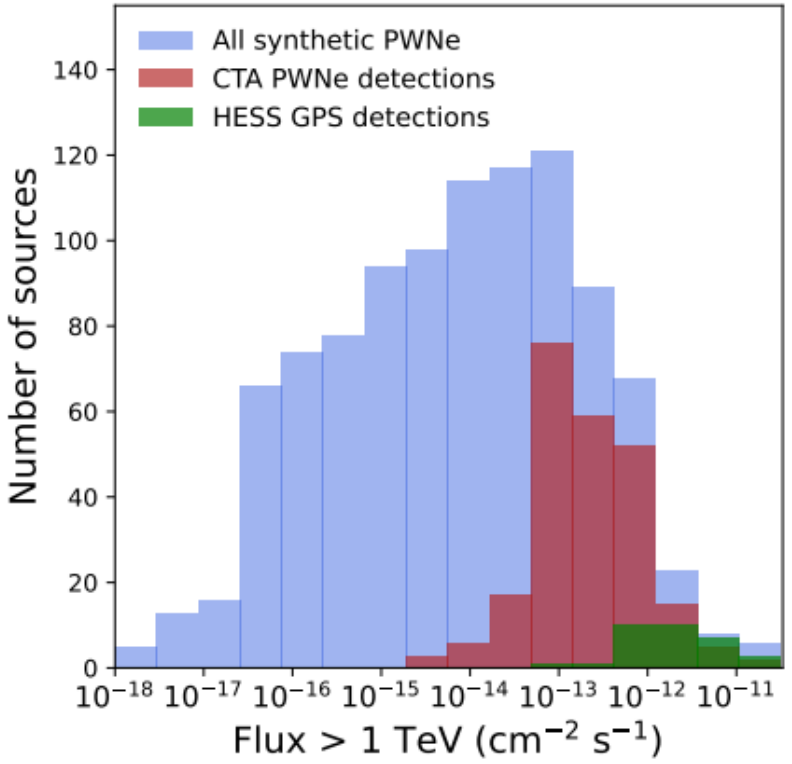
Few missed and spurious detections from source confusion or fragmentation effects



Population studies : PWNs

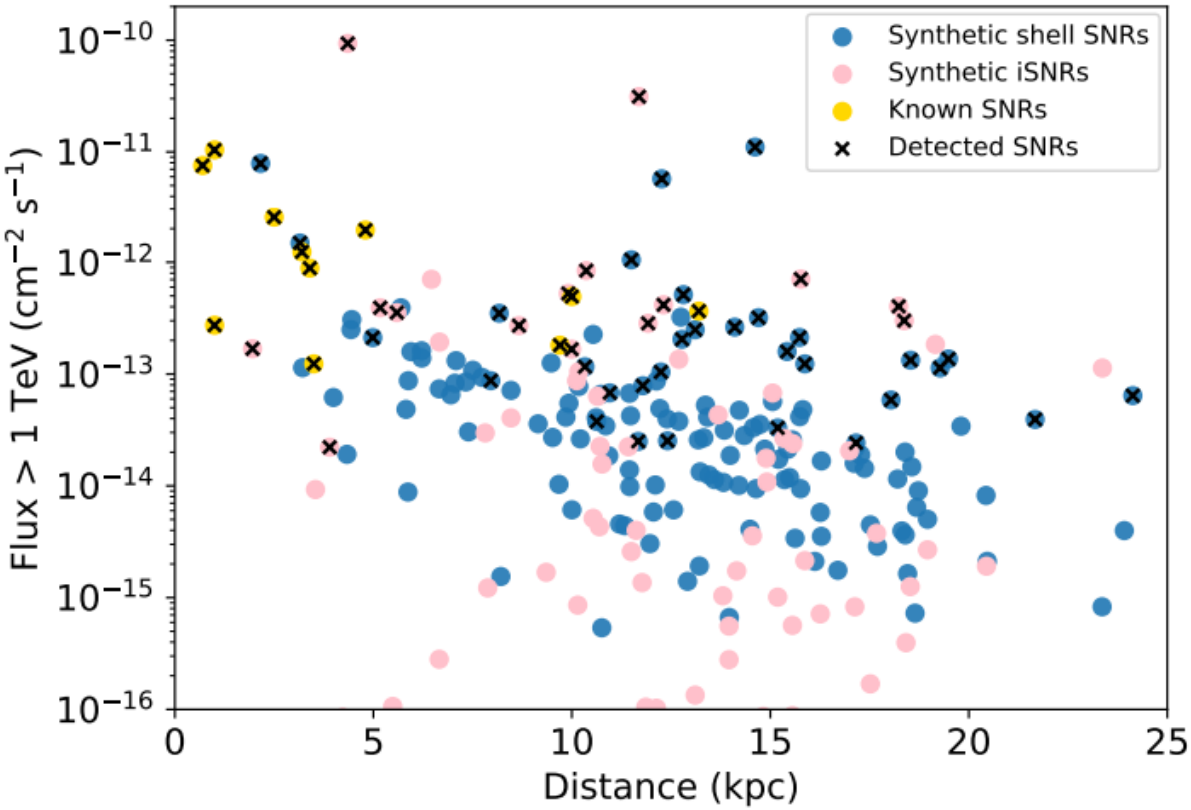
- Dominant population of the survey, about 250 new PWN detectable
  More than 7 times the current sample
- Detection across the whole Galaxy and wider range in flux





Population studies : SNRs

- about 40 new SNRs detectable, half are significantly extended
- Detection of SNR up to 20 kpc, with ages up to 100 kyear
- 5-10 times better flux sensitivity than the current TeV SNR sample

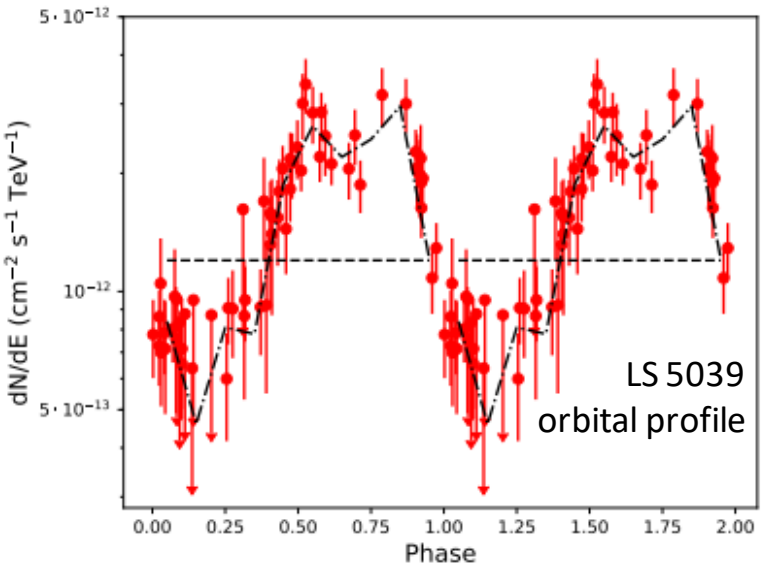


Dedicated analyses

Binaries

-Known bright binaries clearly detected in 30 min observation during phases with
dN/dE(100 GeV) > 2.5 ×10^{-19} cm^{-2} s^{-1} MeV^{-1}

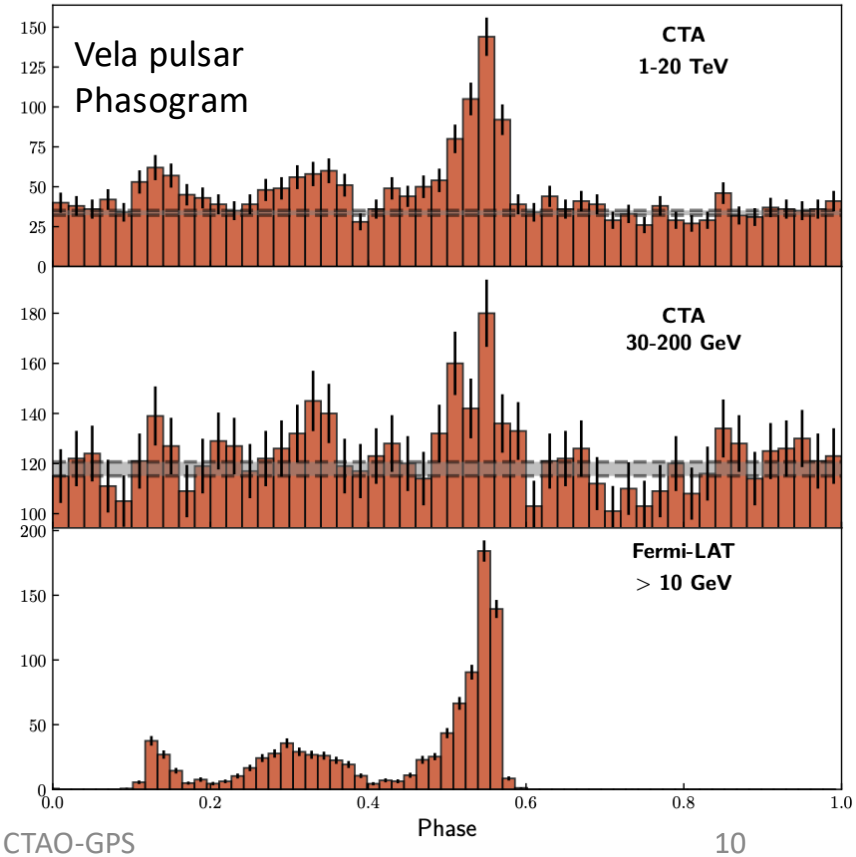
- 9 detections from blind search on different time scales



Pulsars

- Hypothetical pulsars with Vela-like TeV component could be confirmed by CTA

- Potential marginal detection of γ-ray pulsars with extrapolation of GeV spectrum



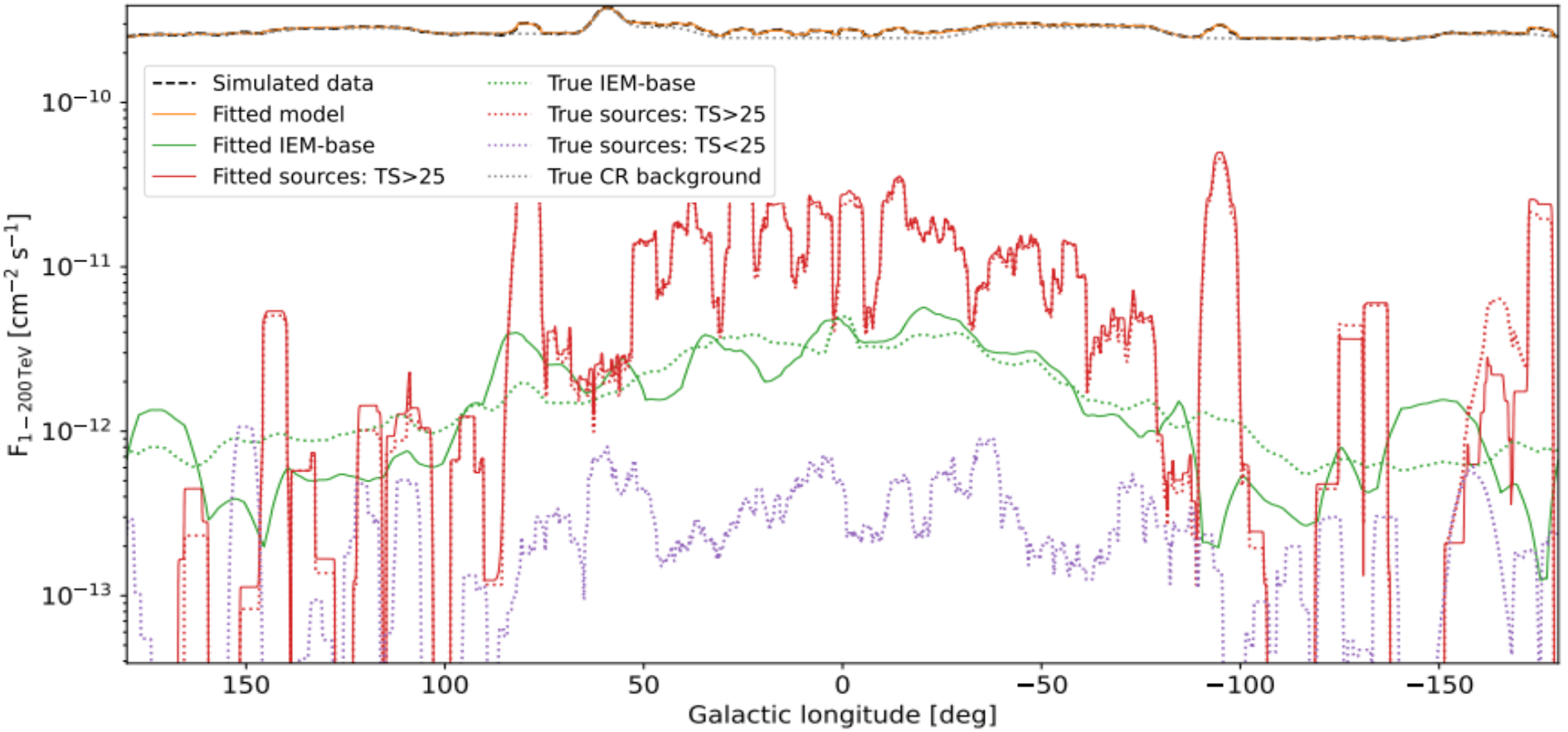
PeVatrons

- 32 candidates and 3 detections out of 470 objects in the general catalog using methods from CTAC 2023

GPS as a pathfinder for deeper observations and more detailed studies

Diffuse emission : interstellar emission

Flux integrated in a 6°x12° sliding window along Galactic Plane (E=1-200 TeV)



- Good agreement between fitted and simulated model in the inner Galaxy ($|l| < 90°$).
- Lower significance and larger flux deviation in the outer Galaxy and at lower energies as the signal-to-background decreases
- Possible to distinguish between the alternative models tested

Diffuse emission : unresolved sources

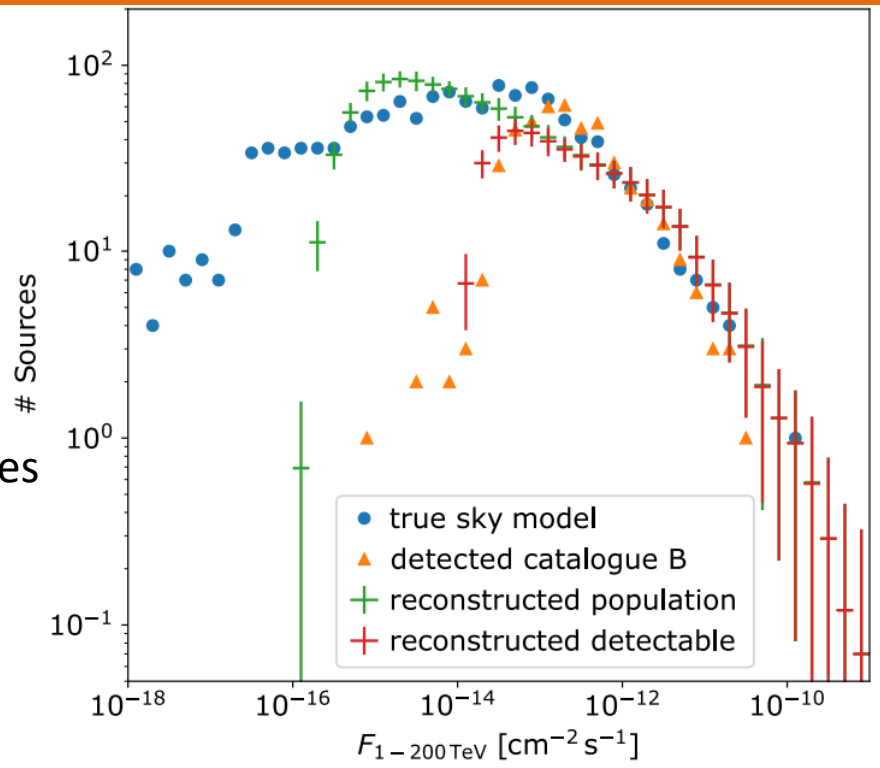
Data-driven approach to build generic gamma-ray source population model
[Steppa & Egberts 2020]

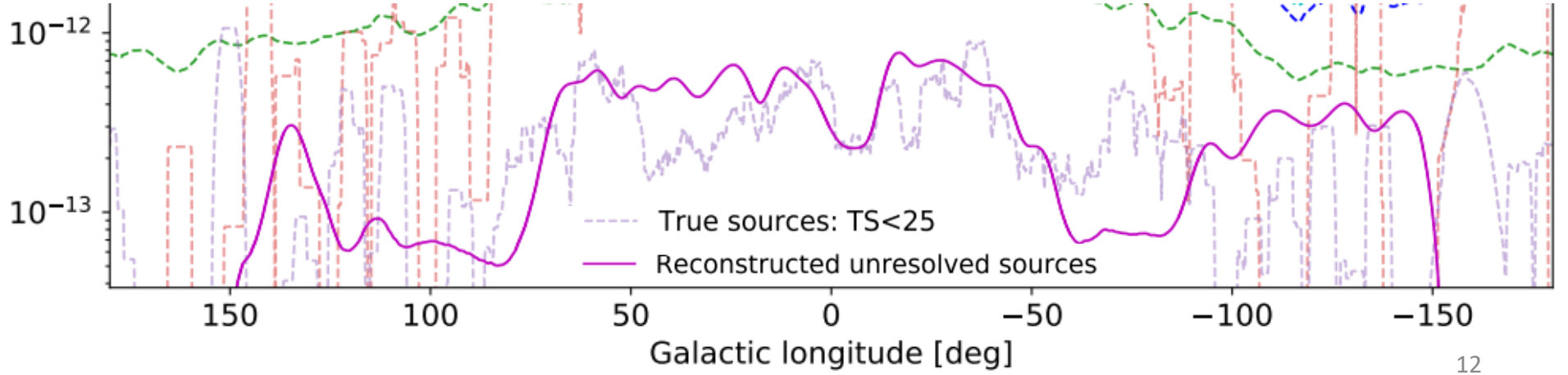
Application to the GPS:

- Reasonable agreement with simulated sources fluxes

- Mean template can't match a single observed sky so large fluctuations are expected

- less than 10% contribution to diffuse emission



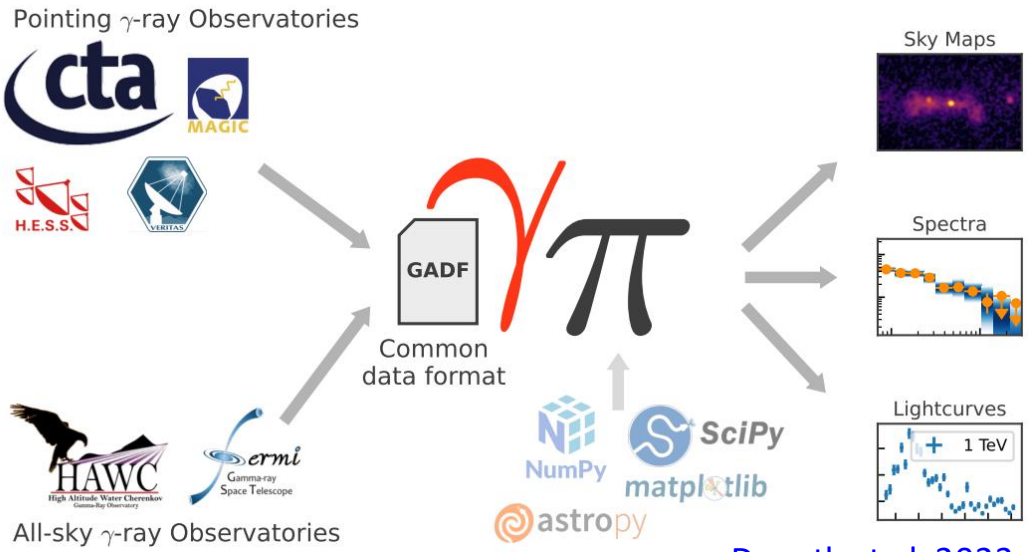


Developments for CTAO already in application

- New science tools offer new possibilities
  multi-instrument joint analyses,
  3D modeling…

- Data format standardization in progress

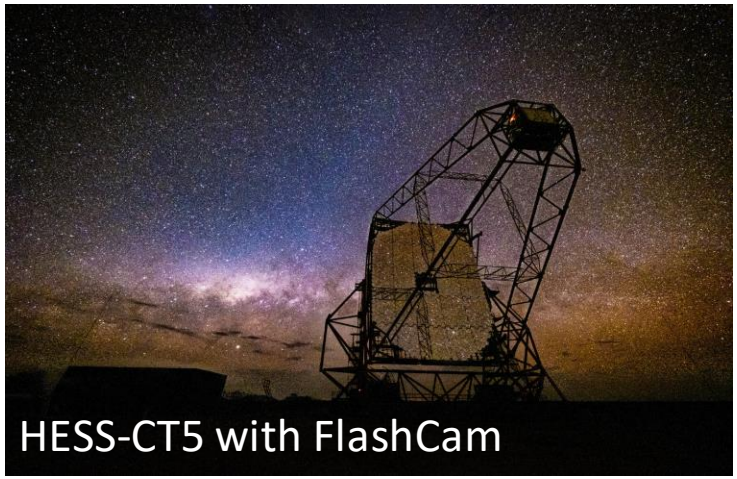
- Improvements of IRFs production
  (event classes, machine-learning…)



Donath et al. 2023

- New camera prototypes already in service

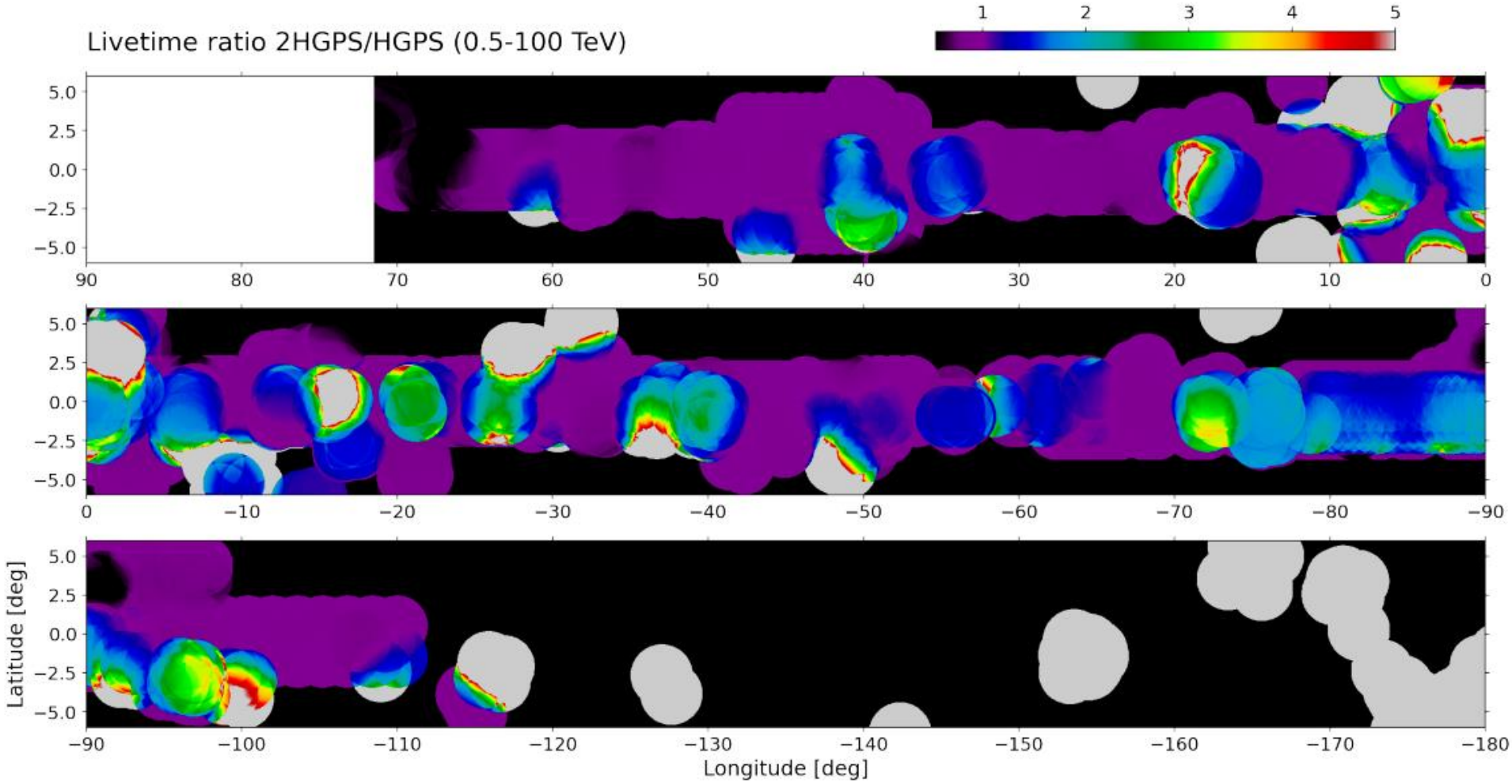
- Current generation of instruments still operating
  Lot of data to be (re)-analyzed


HESS-CT5 with FlashCam

Toward a second H.E.S.S Galactic plane catalogue

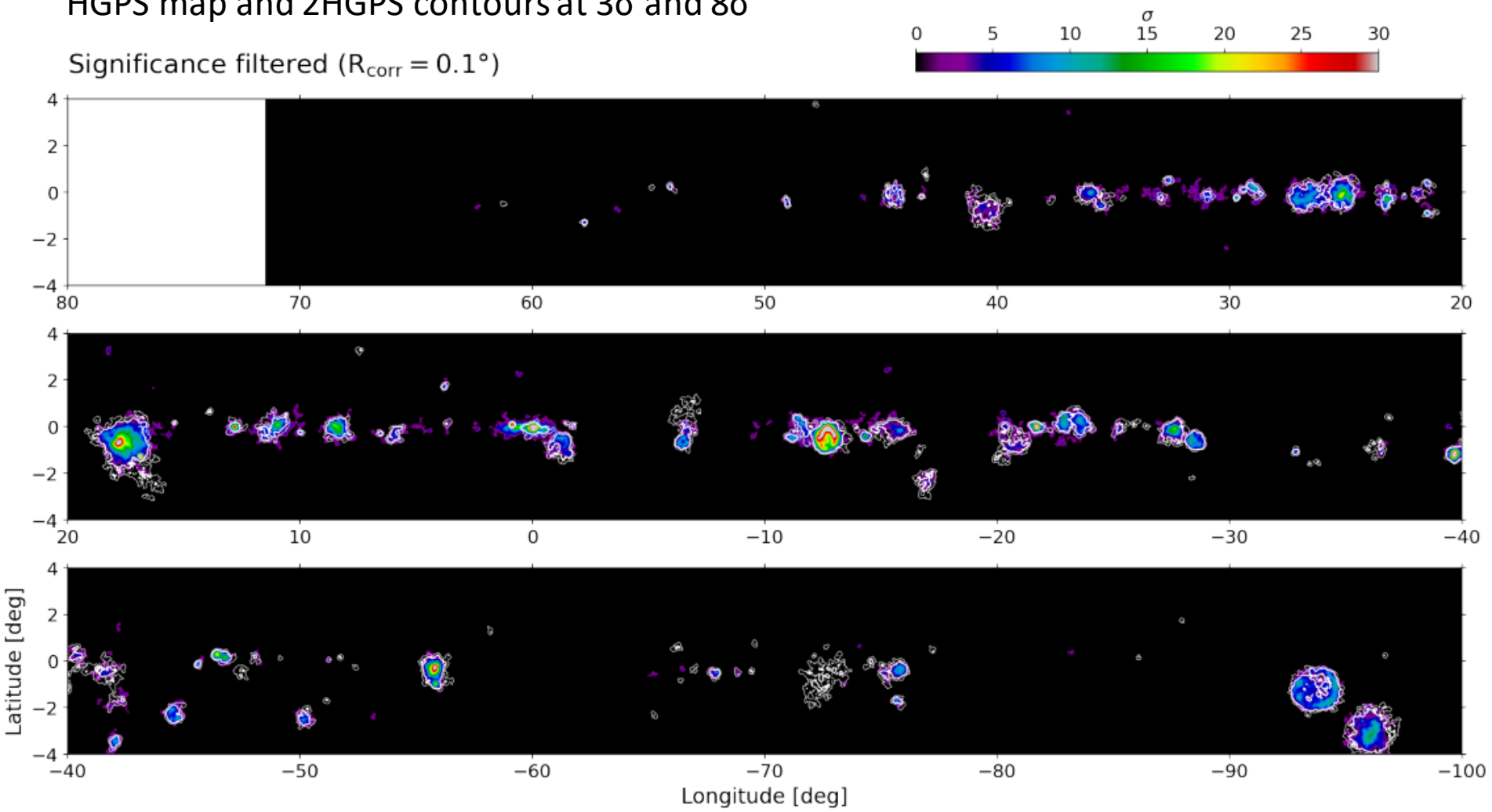
- 6 more years of data compared to HGPS
- improved IRFs and background model
- new catalogue workflow tested on CTAO-GPS simulations

Preliminary 2HGPS
Remy 2023



Toward a second H.E.S.S Galactic plane catalogue

HGPS map and 2HGPS contours at 3σ and 8σ



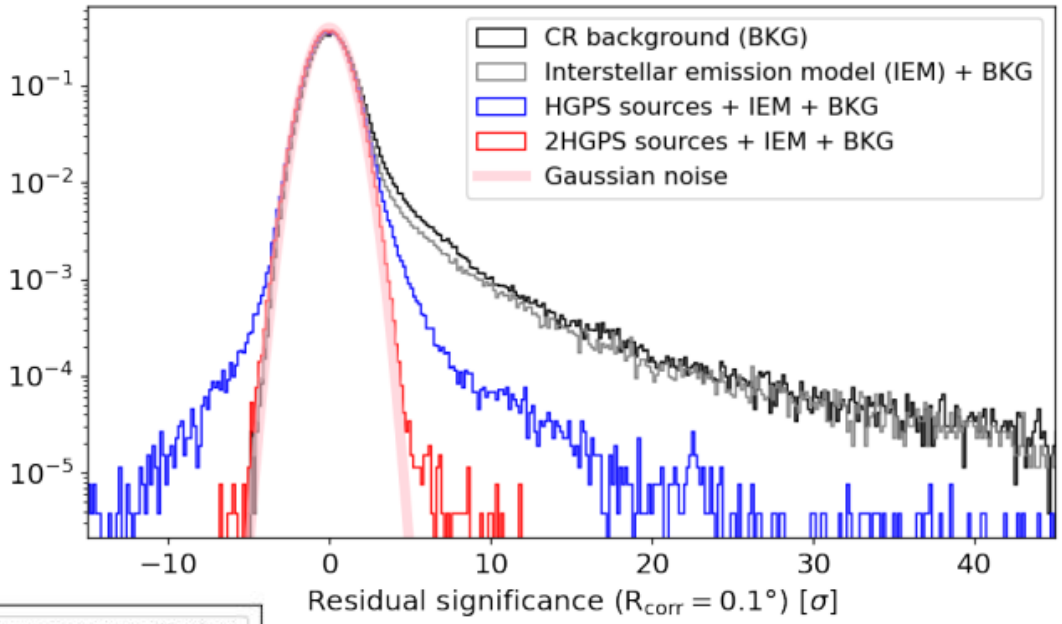
Significance filtered by hysteresis : keep pixels above 2σ only if they continuously connect to a pixel above 4σ

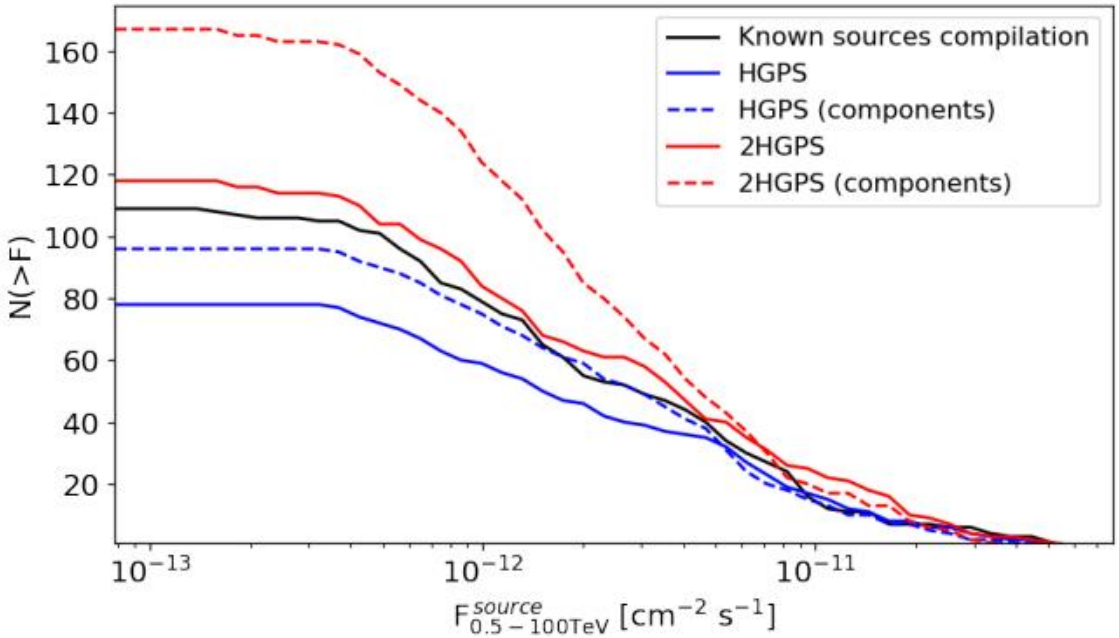
Preliminary 2HGPS catalogue

- Consistent detection and fitting strategies for all the survey

- Refined modeling (point-like, shell, generalized gaussian, ellipticity)

- Few alternative models considered for interstellar emission





- better description of complex sources (more components)

- several new detections

- associations to the latest catalogues

Summary

- Galactic plane Survey proposed as Key Science Project for CTAO
  1620 hours of observations in 10 years
  5-20 more sensitive than previous surveys

- Sky model based physical models of the different source populations, known sources from catalogues, and diffuse emission models. Available to the community.

- CTAO-GPS up to 500 sources detectable with TS>25 in the 0.07-200 TeV energy range, about 6 times more sources detectable than in the HESS-GPS or HAWC catalogues

- Detection of PWNe and SNRs across the whole Galaxy,
  wider range in properties (age, luminosity…) scanned with CTAO

- Survey as pathfinder for candidates PeVatrons, binaries, pulsars
  to follow-up with deeper observations using CTAO.

- Survey necessary to study diffuse emission at Galactic scale and distinguish alternative models

- 2HGPS and 4HWC catalogues in preparation
  new detections and improved sources modeling using techniques tested on CTA-GPS simulations