The population of Pulsar Wind Nebulae seen by HESS and their Galactic environments
(work in progress)

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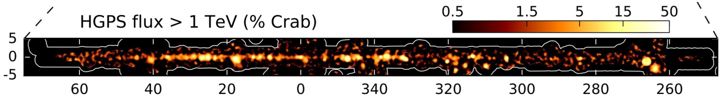
The HESS Cherenkov Telescope System

- **GeV** (High-Energy) γ-rays with satellites (e.g. *Fermi*-LAT)
- at high E_γ, limited by calorimeter depth and collecting area
- **TeV** : use Earth's atmosphere as detector, through Cherenkov light from electromagnetic shower (on dark, moonless nights)
- past decade(+) : current generation of *Imaging Atmospheric Cherenkov Telescope* (IACT) experiments

HESS-II IACT system (Namibia)

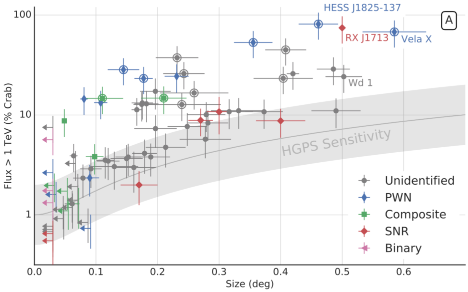
- HESS-I : 4 mirrors of 12 m diameter ; HESS-II : +28 m-diameter
- Southern hemisphere location ideal to observe inner Galaxy

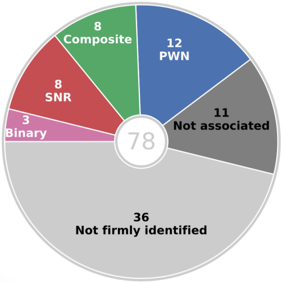
HESS Galactic Plane Survey (HGPS)



- $+75^\circ > \ell > -115^\circ$, exposure highly non-uniform (HESS Coll. 2018a)

- 78 sources in HGPS catalog, of which 40% identified
- identifications based on position, morphology and/or variability
- 90% of identifications are PWNe, shell-type or composite SNRs



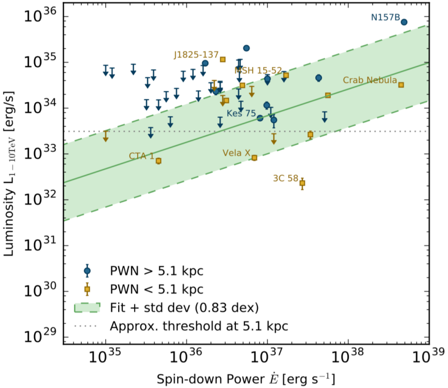


- flux sensitivity depends on source extension

TeV γ-ray luminosity distribution of PWNe

- PWN TeV luminosities $L_\gamma = 4\pi D^2 F_{1-10\,\mathrm{TeV}}$, plotted against (current) pulsar spin-down energy loss $\dot{E}$

(HESS Coll. 2018b; arXiv:1702.08280)

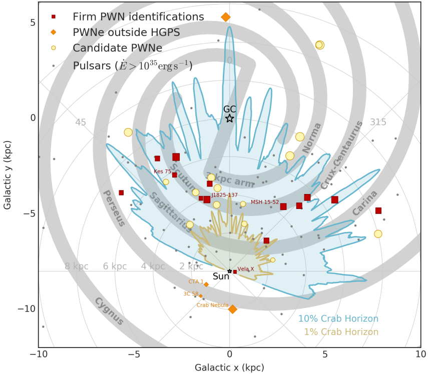


- relatively narrow range of L_γ ($\gtrsim$1 decade, with outliers)
- little correlation with $\dot{E}$, unlike L_X (Grenier 2009, Mattana+ 2009)
- add HESS GPS upper limits ⇒ weak but significant faintening

Galactic distribution of TeV PWNe

- PWNe trace recent massive star formation (spiral arms)

(Klepser et al. 2017, HESS)

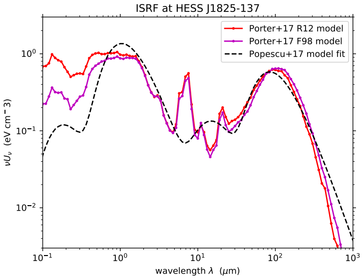


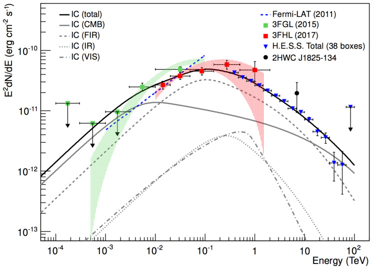
- HESS GPS detectability quite good to Scutum-Crux (Centaurus) arm
- deficit of TeV-emitting PWNe in Sagittarius-Carina arm ?
- PWNe in outer Galaxy (Vela X, 3C 58...) have low luminosities

- consequence of PWN parameters or of Galactic environment ?

Galactic photon distribution and IC emission

- e.g. HESS J1825–137 in Scutum-Crux arm (talk by Sami Caroff)
- self-consistent models of Galactic (interstellar) radiation field (ISRF) by Porter et al. (2017) and Popescu et al. (2017) yield very similar results at HESS J1825–137 position (left panel)

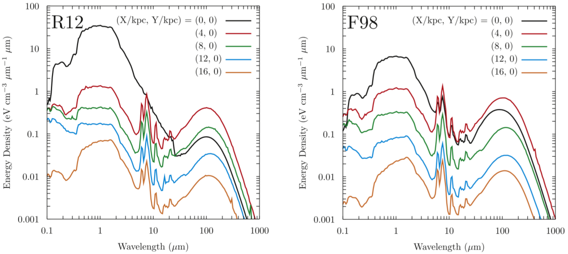




- inverse Compton γ-ray emission model (HESS Coll. 2019) shows that far-infrared (FIR) is dominant target photon component
- stellar photon contribution suppressed by Klein-Nishina effects at TeV energies (UV component even more so)

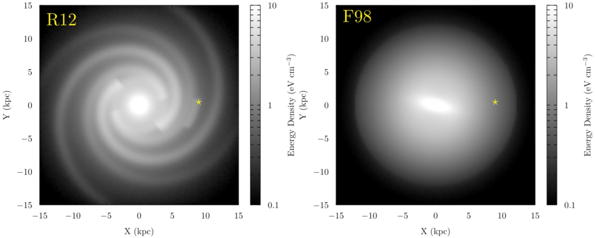
Radiative transfer models of the Galaxy

(e.g., Porter et al. 2017)



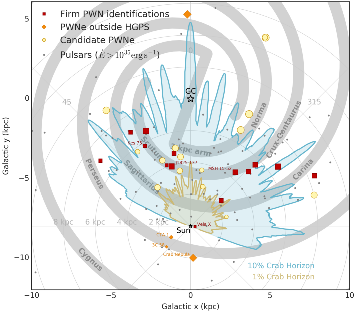
- self-consistent model : stellar radiation absorbed by dust, which re-emits in FIR according to its equilibrium temperature
- stellar emissivity and dust spatial distribution prescribed

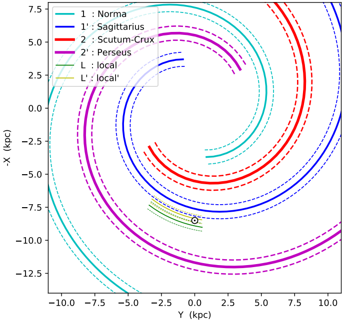
(Porter et al. 2017)



Spiral arm structure of the Galaxy

- Porter et al.'s R12 model includes the Galactic spiral arm model of Robitaille et al. (2012)
- 4 arms, but 2 dominant : 2 and 2′, i.e. **Scutum-Crux** and Perseus which have enhanced stellar emissivity (young, newly formed stars)

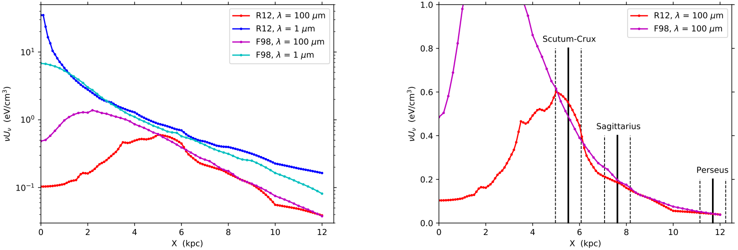




- also enhanced FIR density could explain more luminous PWNe
- in Porter et al.'s R12 model, dust is in an axisymmetric disk...

Galactic photon density distribution

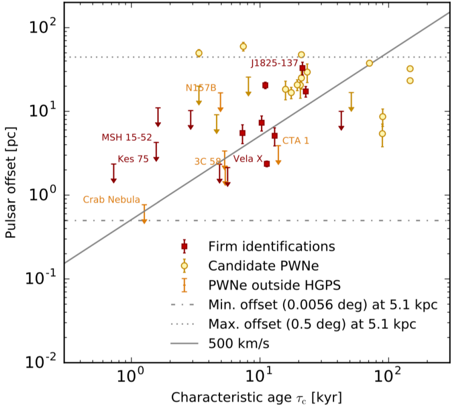
- Porter et al.'s calculations show low arm-interarm contrast
- but large decrease in FIR density (factor $\gtrsim 4$) between $R \approx 5$ kpc (Scutum-Crux) and $R \gtrsim 8.5$ kpc (outer Galaxy)
- enough to explain PWN luminosity contrast ? To be continued. . .



energy density vs. R_{Gal} at $Y = Z = 0$

- large discrepancy between models for FIR at $R \lesssim 4$ kpc (and in central bulge for stellar photons)
- a sufficiently large and deep TeV PWN sample (as should be obtained by CTA) would likely help resolve the FIR discrepancy

TeV PWN offsets vs. age



(H.E.S.S. Coll. 2018 ; `arXiv:1702.08280`)

- older TeV PWNe have **large** offsets from their pulsar
- cannot be explained solely by typical pulsar proper motions (observed distribution implies $v_\perp < 500$ km/s for most)
- alternative/complementary effect of asymmetric environment ?

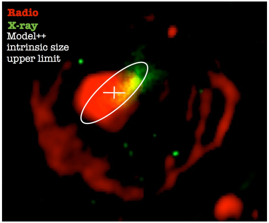
Offsets from asymmetric medium around SNR

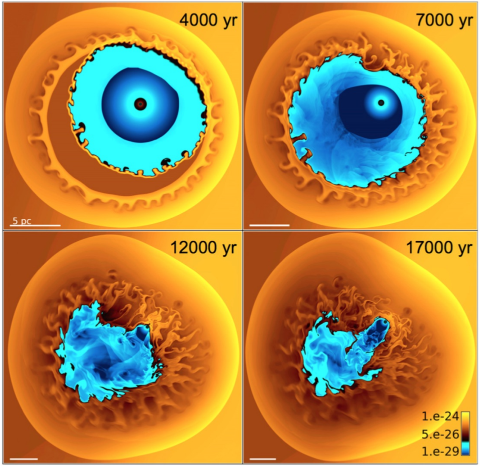
- proposed to explain offset of **Vela X** (Blondin et al. 2001)

G327.1–1.1

simulations →
(Temim et al. 2015)

multiwavelength image
(Acero et al. 2011) ↓





- Temim et al. simulations have pulsar moving 400 km/s toward top (N), higher density to the right (W)
- asymmetric reverse shock interaction "crushes", displaces PWN

Issues and prospects on TeV PWN offsets

Issues

- what evidence supports asymmetric medium surrounding SNR ?
- consistent with SNR shell vs PWN geometry ; but only 2–3 composite SNRs with large TeV offsets (G327.1–1.1, Vela X and maybe MSH 15–52)
- SNR no longer visible around older offset PWNe…

Prospects

- (2D) relativistic MHD simulations in progress (with Z. Meliani, AMR-VAC shock-capturing simulation code)
- address question for population : how to reproduce large offsets
- search MWL evidence for density contrasts of magnitude needed : molecular clouds in CO, diffuse clouds in HI…

Summary

H.E.S.S. Galactic Plane Survey

- 78 sources, 40% identified (mostly as PWNe and SNRs)
- $\gtrsim$ 30% of detected sources are PWNe or candidates

PWN TeV luminosities

- weak trend of decreasing TeV luminosity with pulsar $\dot{E}$
- higher luminosities in inner Galaxy : FIR main IC target
- modelled FIR photon density contrast could explain trend
- deeper PWN sample (with CTA) could sample FIR in Galaxy ?

TeV PWN offsets

- older TeV PWNe have large offsets from their pulsar
- larger than can be explained by pulsar proper motion alone
- density inhomogeneities around SNR can also contribute
- relativistic MHD simulations in progress
- limited MWL evidence for required density contrasts