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

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MODE–SNR–PWN 2019 Workshop
Hôtel Dupanloup, Orléans, April 9, 2019

HESS and its Galactic Plane Survey
PWN luminosities in (TeV) γ-rays
Galactic (far-infrared) interstellar radiation field
Offsets of TeV PWNe from their pulsar
The HESS Cherenkov Telescope System

- **GeV** (High-Energy) $\gamma$-rays with satellites (e.g. *Fermi*-LAT)
- at high $E_\gamma$, 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 $\gamma$-ray luminosity distribution of PWNe

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

  (HESS Coll. 2018b; arXiv:1702.08280)

- relatively narrow range of $L_\gamma$ ($\gtrsim 1$ decade, with outliers)

- little correlation with $\dot{E}$, unlike $L_X$ (Grenier 2009, Mattana+ 2009)

- add HESS GPS upper limits $\Rightarrow$ 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. . .

**Summary**

- Energy density vs. $R_{\text{Gal}}$ 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

- 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