CENTER FOR INTERDISCIPLINARY RESEARCH IN ASTROPHYSICS AND SPACE SCIENCES

Gamma-ray emission from Pulsar Wind Nebulae in the inner Galactic Center

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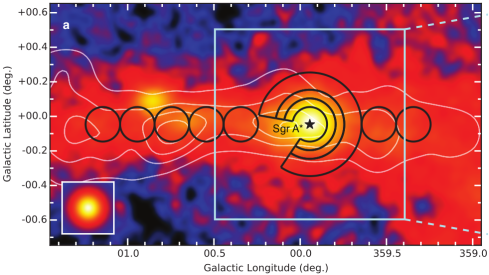
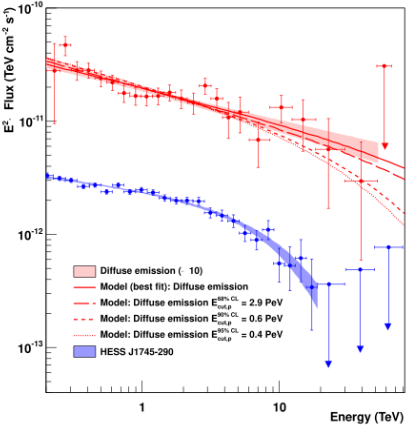
TeVPA, Valencia 2025

Gamma rays from the Galactic Center

A point-like TeV source (HESS J1745–290) coincident with Sgr A* has been detected at the Galactic Center (GC).



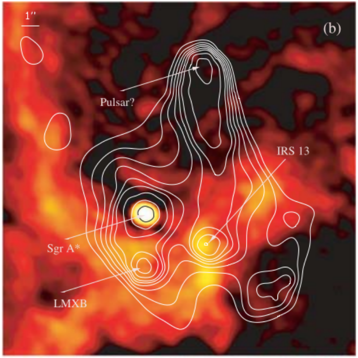


HESS Collaboration (2016)

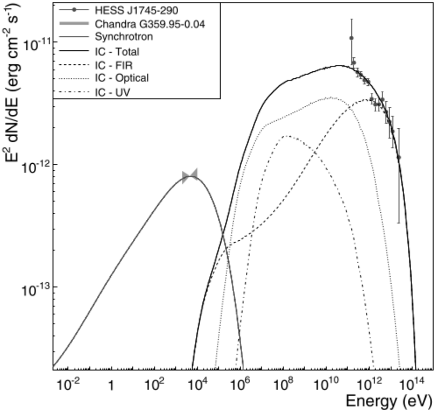
However, the quiescent state of Sgr A* challenges the idea that it powers the observed TeV emission.

Pulsar Wind Nebula along the line-of-sight

A synchrotron X-ray source near Sgr A* was identified as a PWN candidate. Spectral modeling showed that its predicted TeV emission reproduces the observed spectrum.



Wang (2006)

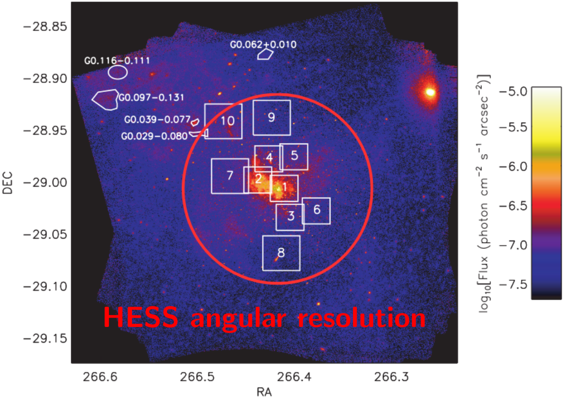


Hinton & Aharonian (2007)

In this scenario, the TeV emission originates from a single PWN

PWNe candiates within the HESS angular resolution

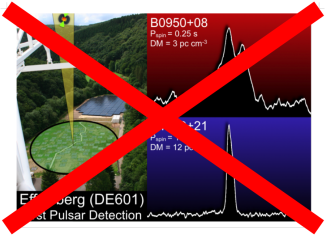
Chandra observations identified 18 PWN candidates within the HESS angular resolution (Radius$\approx 0.1^\circ \approx 15$ pc).



Muno et al. (2008)

Our aim is to test whether the TeV emission from the Sgr A* location can be explained by a population of PWNe.

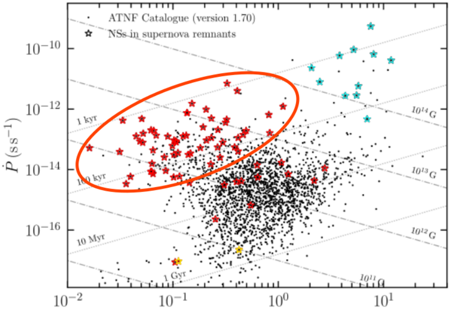
Pulsar population

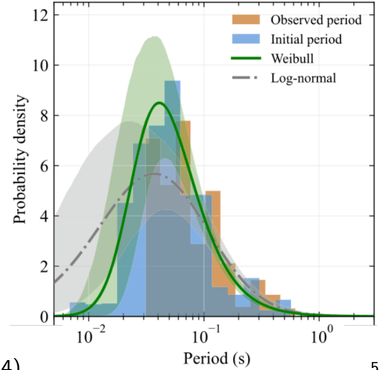


The dense and turbulent environment prevents pulse detection (p and $\dot{p}$ are unknown).

Consequently, ages, and magnetic fields remain uncertain.

We therefore build synthetic populations of pulsars.





Du et al. (2024)

Synthetic pulsar sample

We generate a synthetic sample of 18 pulsars, statistically consistent with Galactic pulsar distributions.

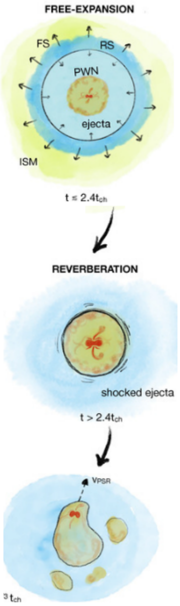
ID	B_{ns} [G]	p_0 [s]	$\dot{E}_0$ [erg/s]	τ_{sd} [yr]
PSR-1	1×10^{12}	0.023	9.17×10^{37}	17177
PSR-2	1×10^{12}	0.050	4.10×10^{36}	81177
PSR-3	1×10^{12}	0.077	7.30×10^{35}	192520
PSR-4	3×10^{12}	0.017	2.76×10^{39}	1043
PSR-5	3×10^{12}	0.023	8.25×10^{38}	1909
PSR-6	3×10^{12}	0.048	4.35×10^{37}	8313
PSR-7	3×10^{12}	0.065	1.29×10^{37}	15243
PSR-8	3×10^{12}	0.083	4.87×10^{36}	24855
PSR-9	3×10^{12}	0.130	8.08×10^{35}	60973
PSR-10	1×10^{13}	0.017	3.07×10^{40}	94
PSR-11	1×10^{13}	0.023	9.17×10^{39}	172
PSR-12	1×10^{13}	0.048	4.83×10^{38}	748
PSR-13	1×10^{13}	0.065	1.44×10^{38}	1372
PSR-14	1×10^{13}	0.083	5.41×10^{37}	2237
PSR-15	1×10^{13}	0.130	8.98×10^{36}	5488
PSR-16	3×10^{13}	0.023	8.25×10^{40}	19
PSR-17	3×10^{13}	0.050	3.69×10^{39}	90
PSR-18	3×10^{13}	0.077	6.57×10^{38}	214

Preliminary results

Each pulsar is characterized by its p_0 and B_{ns}.

$\dot{E}_0$ and τ_0 are obtained to compute each pulsar evolution.

PWN evolution



Olmi (2023)

Modeled evolution:
(Gelfand et al. 2009 and Bucciantini et al. 2011)
→ Free expansion
→ Reverberation (thin-shell approximation)
→ Pulsar escape from structure

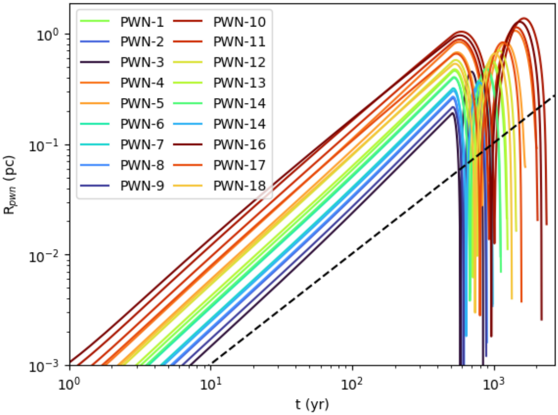
Each system evolves under typical GC conditions:
→ Gas density ≈200 cm^{-3} (Ferrière et al. 2012)
→ Intense photon fields (Davidson et al. 1992)

Photon Field	ϵ_{ph} [eV]	U_1 [eV cm^{-3}] (<1 pc)	U_2 [eV cm^{-3}]	U_3 [eV cm^{-3}] (10 pc)
St	3	5000	500	50
NIR	0.3	5000	500	50
FIR	0.006	500	50	5
CMB	0.00023	0.26	0.26	0.26

For each pulsar, we track $\dot{E}$, R_{pwn}, B_{pwn}, and radiation via synchrotron and IC losses.

PWNe evolution in a high-density environment

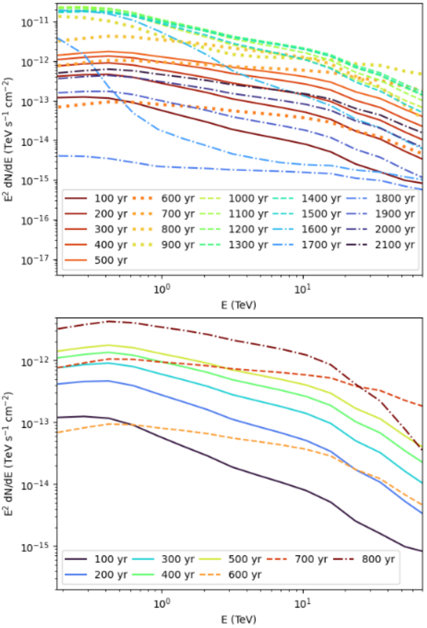
In the dense GC environment, PWNe evolve ≈100 times faster than in the Galactic disk. Typical lifetimes $\approx 10^3$ yr.



Preliminary results

Combining this with star formation and MSP statistics → ≤2 active PWNe expected within 30 pc

Gamma-rays from PWNe synthetic populations



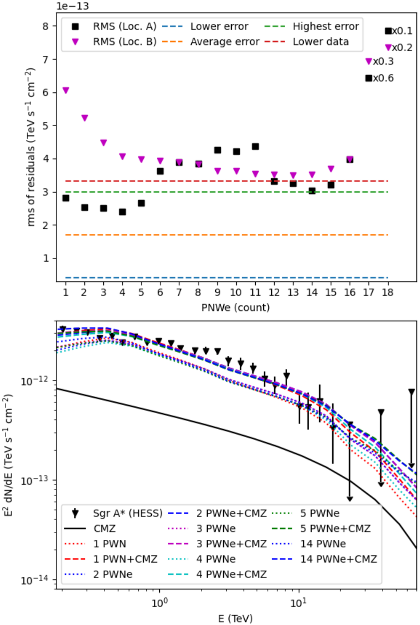
We combined spectra from evolved PWNe (excluding those exceeding the observed flux).

We considered pulsars of different ages and locations, and PWN populations sizes,

Finally, we obtained over 5×10^7 gamma-ray spectra from synthetic PWN populations.

Preliminary results

Comparing with HESS data



We compared the RMS residuals with the observational spectral errors.

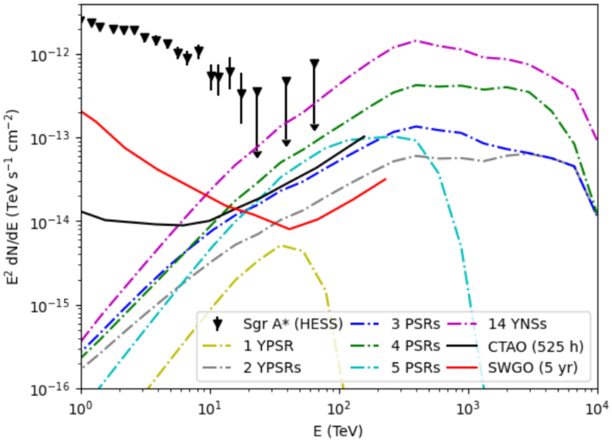
Only populations with $\leq$5 PWNe have RMS values lower than the spectral uncertainties.

The dominant source is typically in the reverberation phase, embedded in an intense photon field.

Preliminary results

Protons from young pulsars

The expected gamma-ray flux from proton–proton interactions of young pulsars (YPSRs) is faint but detectable by CTA and SWGO.



Detection would confirm the presence of young pulsars in the inner GC.

Conclusions and next step

Conclusions:

- PWNe in the Galactic Center evolve $\approx$100 times faster than in the Galactic disk.
- These short lifetimes imply $\leq$2 active PWNe within 30 pc.
- The dominant sources are in the reverberation phase, embedded in intense photon fields.
- The hadronic component could be detected by CTA and SWGO.

Next step:

- Model the reverberation phase of PWNe with a more accurate external pressure evolution following Bandiera et al. (2023).

Thank you for your attention!