Finding Pulsar TeV Halos among VHE Sources

Zhongxiang Wang
Gamma24, Milan, 2024/09/03
(Yunnan University, China)
Collaborators: Dong Zheng, Yi Xing (SHAO)

Gemini
Canis Major
Orion
Taurus
Orion Nebula

Fermi Gamma-ray Space Telescope

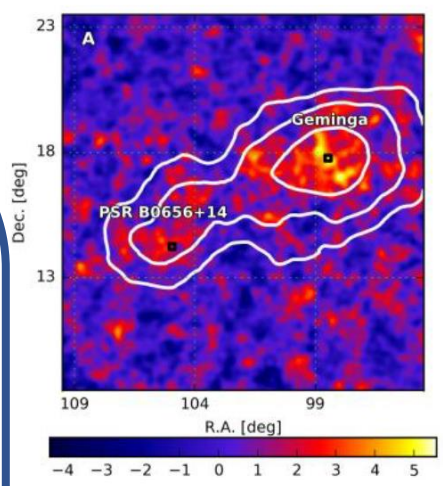
e Light | Gamma-rays | Gamma-ray Diffuse

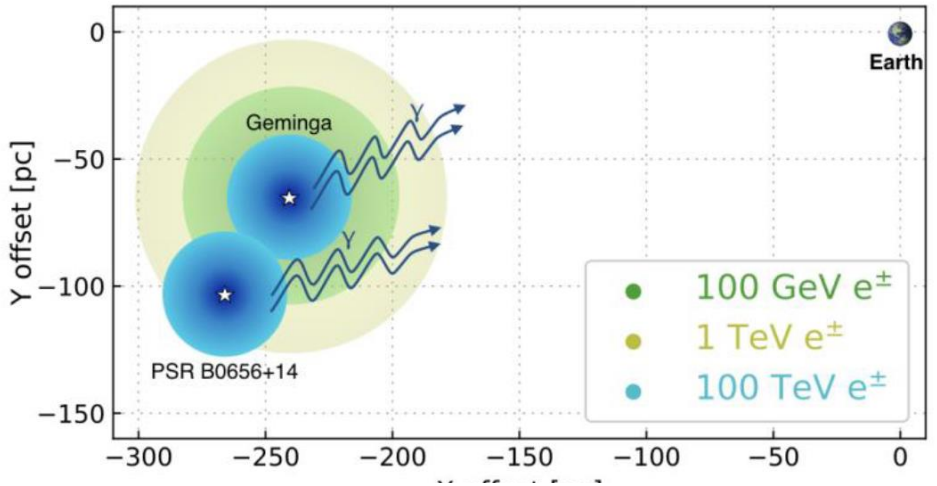
l Constellations | Gamma-ray Constellations

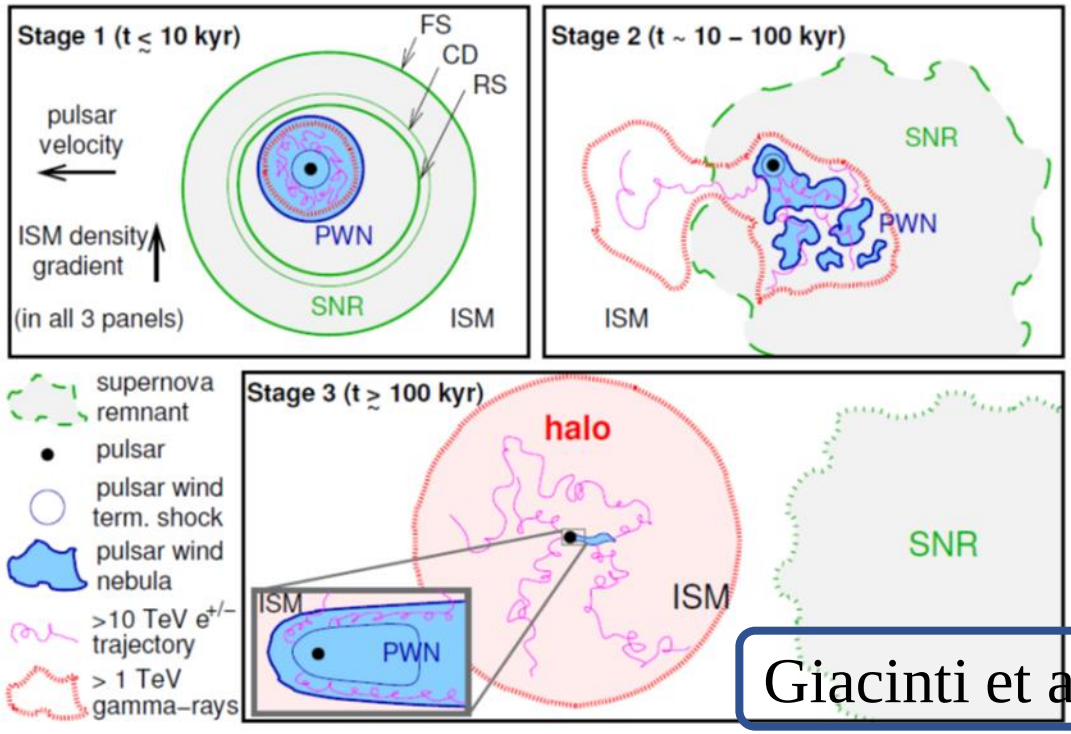
TeV Halos

- Discovered around the nearby Geminga and Monogem pulsar
- e-/e+ emitted by pulsars ICS background photons to TeV, forming the observed halos
- One challenge: slow diffusion of the particles
- Importance: if all pulsars have such a halo, their contribution to cosmic e-/e+ would be significant

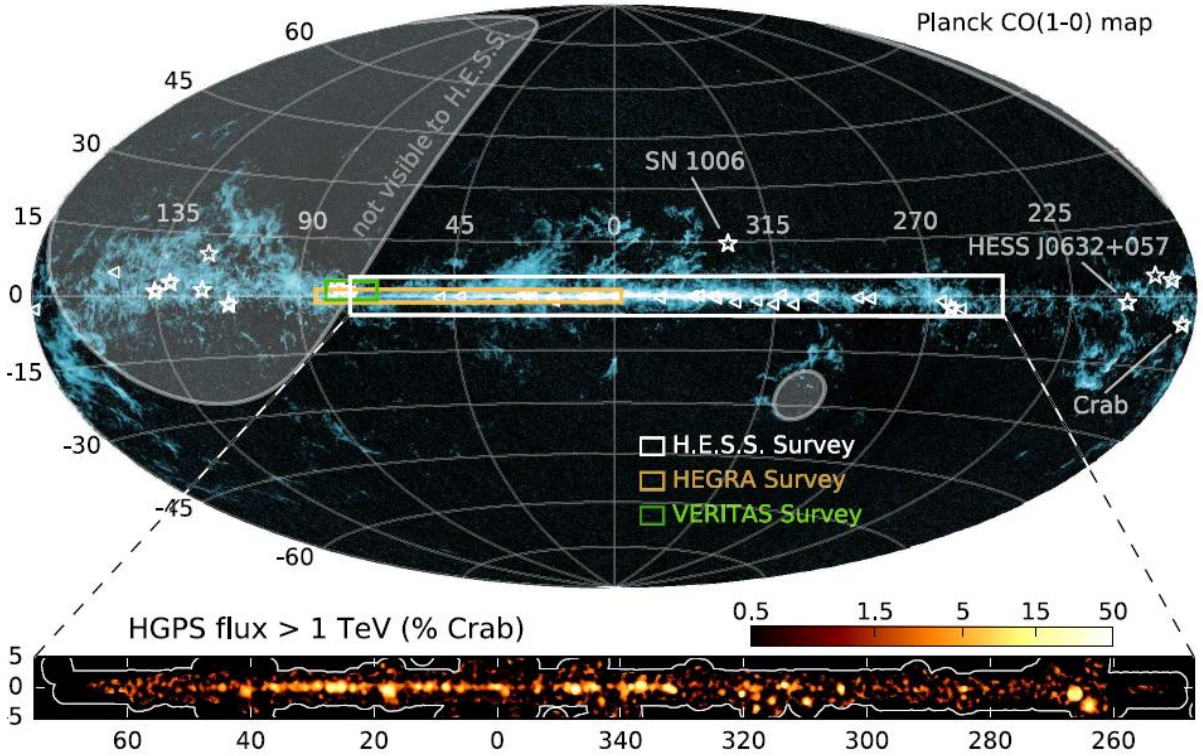
Abeysekara et al. 2017



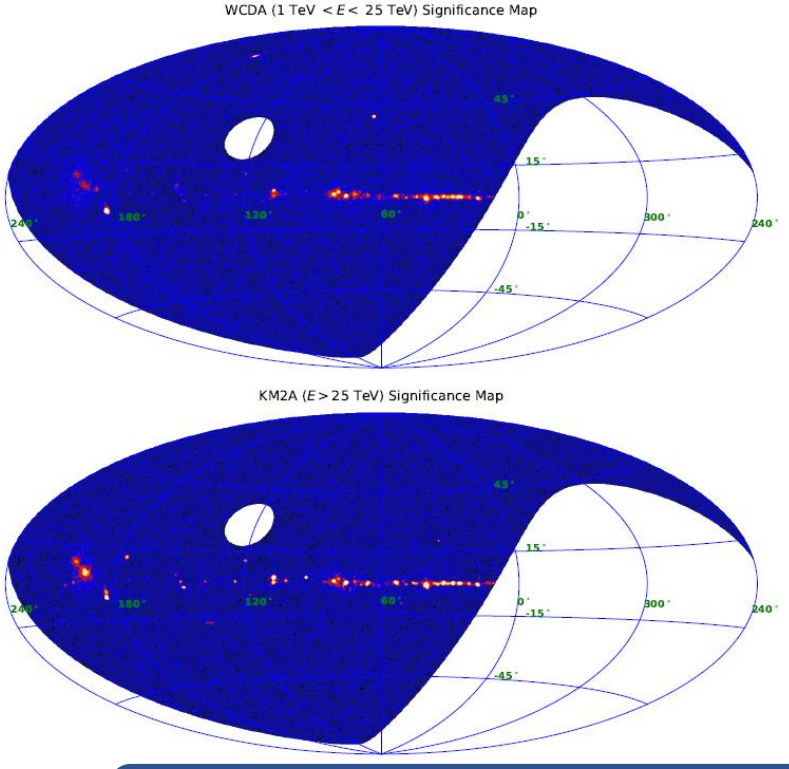




Giacinti et al. 2020



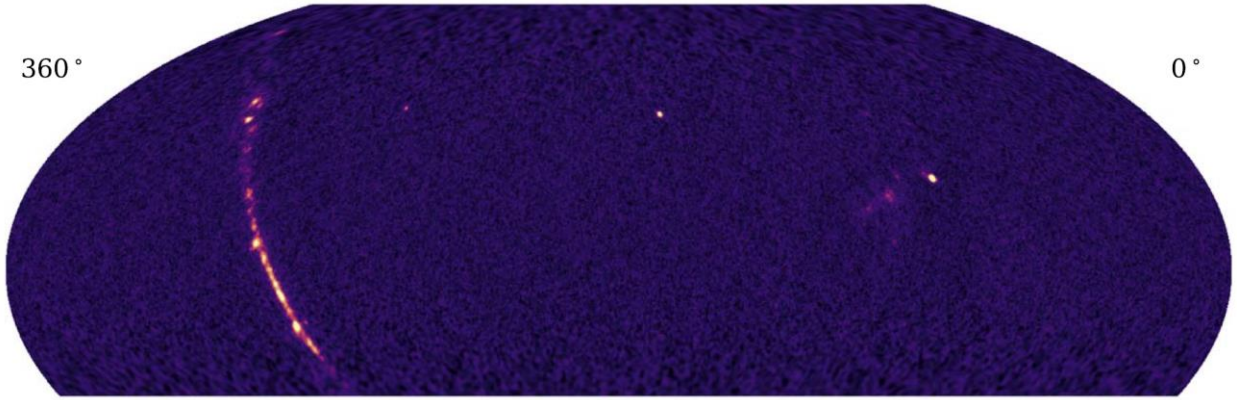
HESS Galactic Plane Survey (HESS Collaboration, 2018)



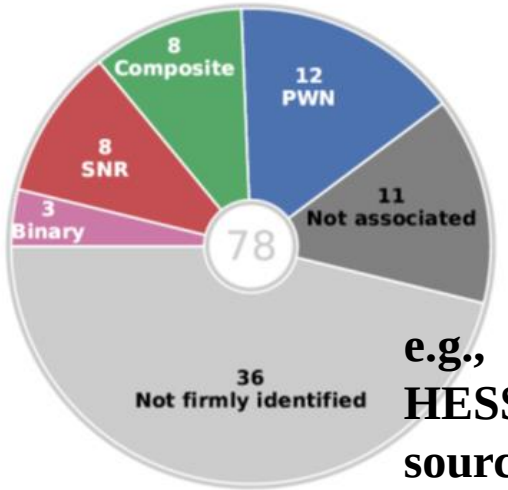
WCDA: 1-25 TeV

KM2A: >25 TeV

1LHAASO catalog (Cao et al. 2023)



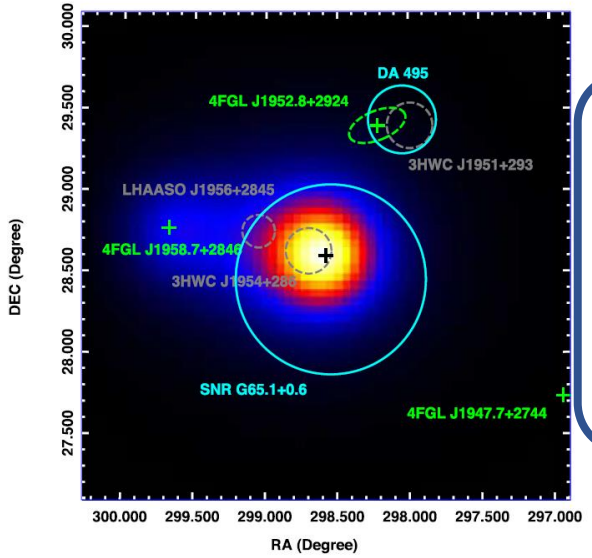
3HWC: 3rd HAWC catalog (Albert et al. 2020)



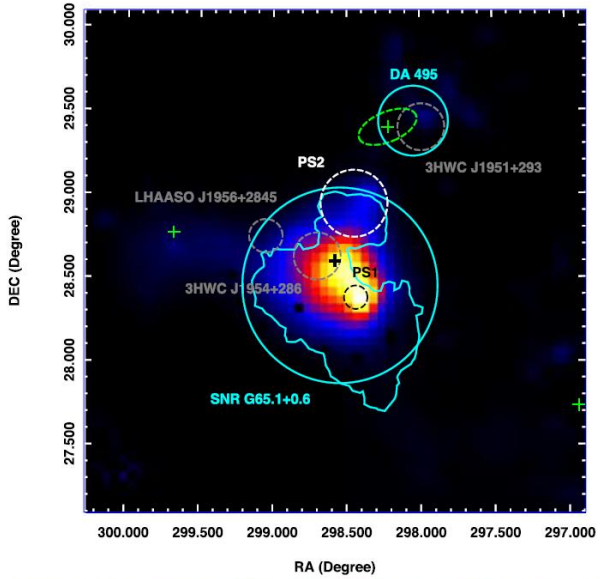
e.g., HESS sources

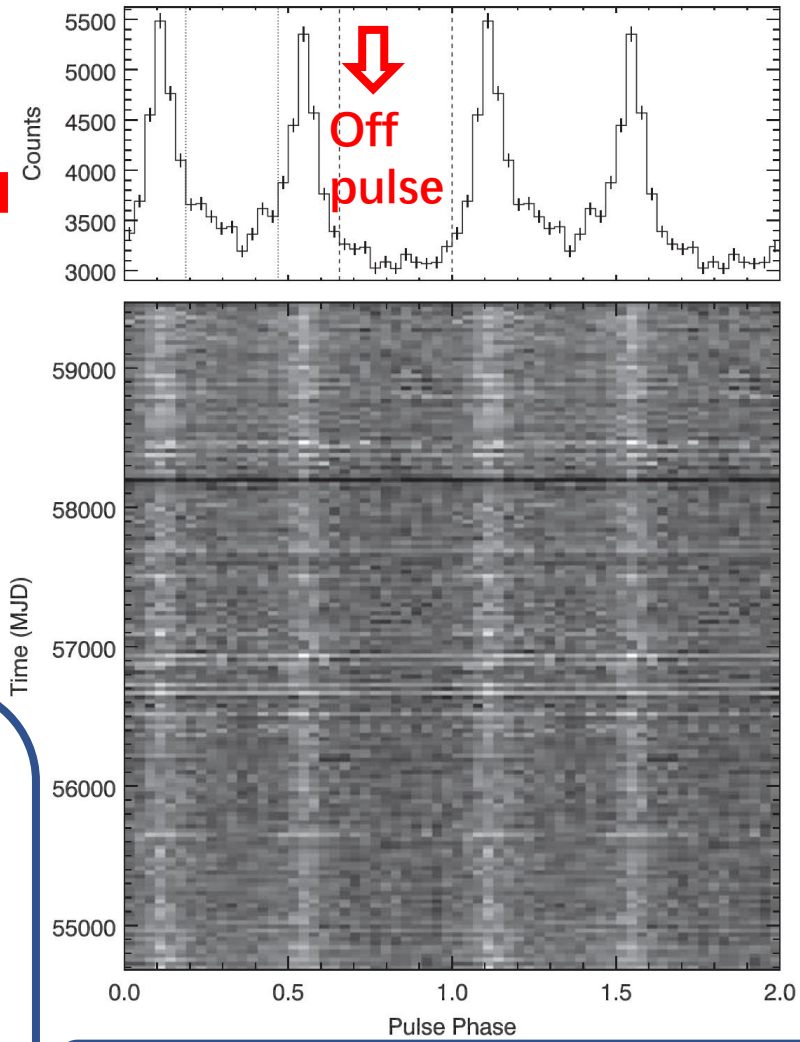
Significant fraction of these sources are un-indentified

Our work: technique to remove a pulsar's "contamination"

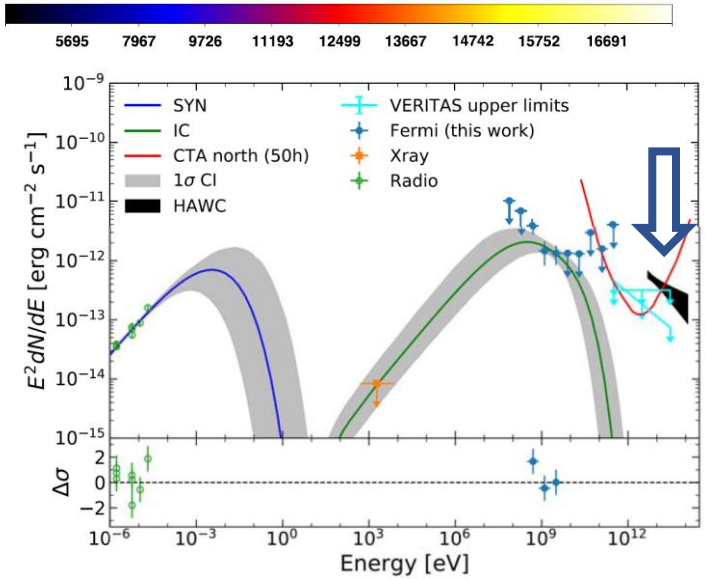


GeV TS map of the total Fermi-LAT data





Pulse profile of PSR J1954+2836

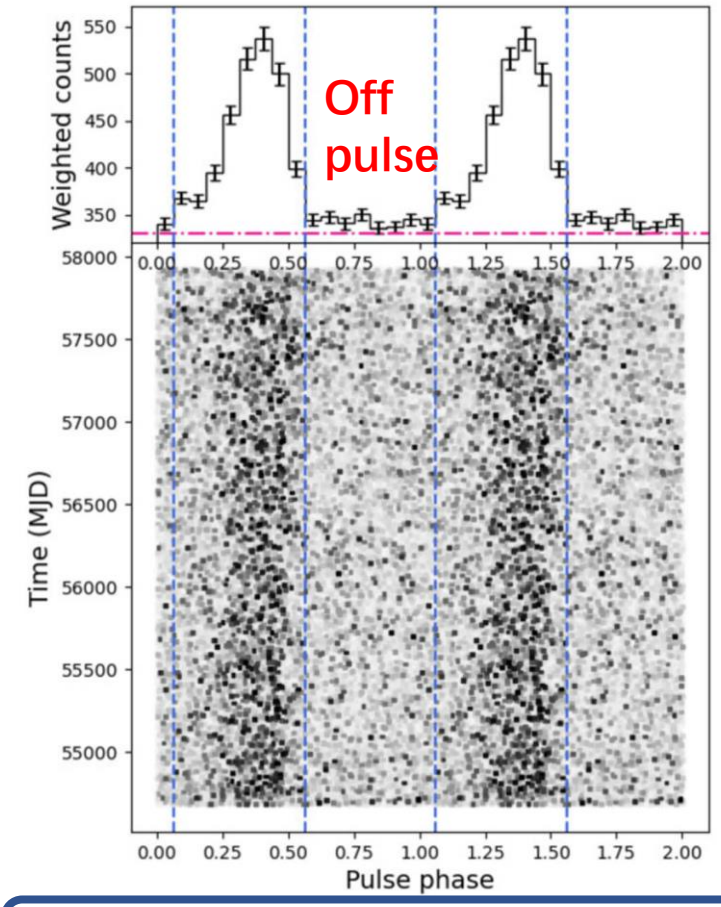


3HWC J1954+286:

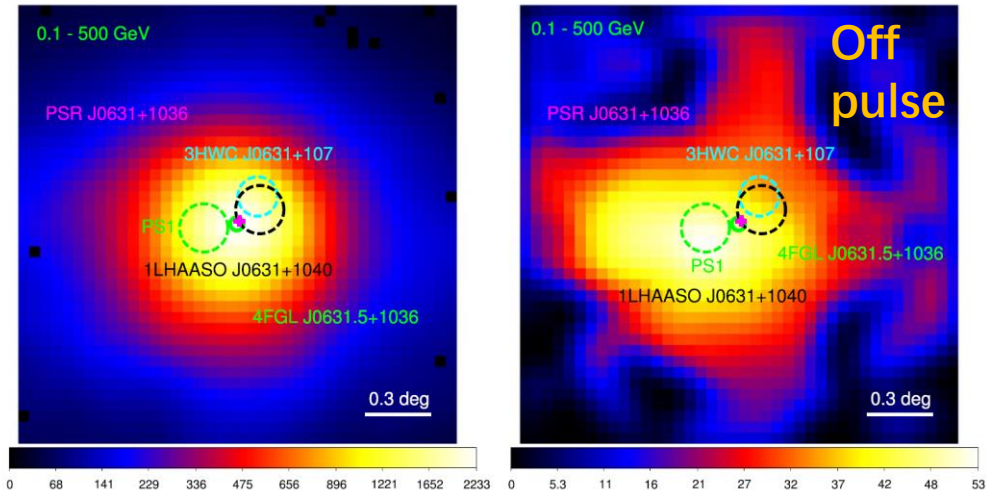
1. GeV emission dominated by a pulsar
2. After remove it, a points source is detected
3. Our analysis indicates GeV from an SNR (G65.1+0.6), HWC source possibly a TeV halo

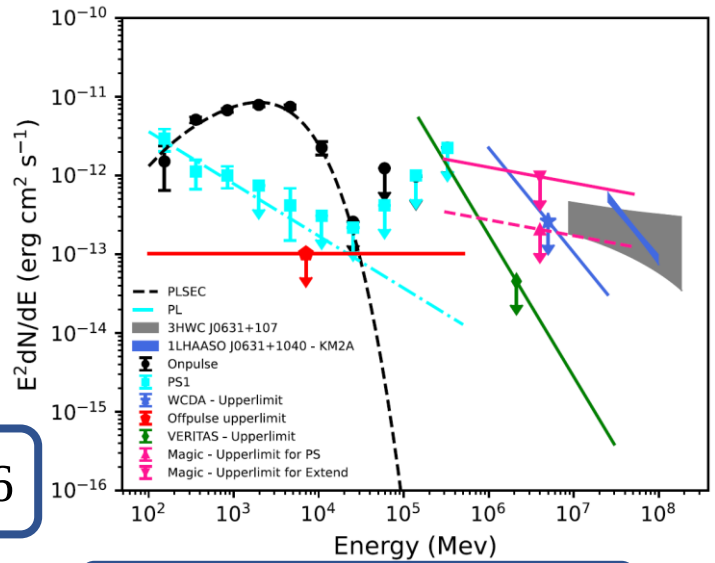
Xing et al. 2022 (ApJ)

Another good case: 3HWC J0631+107



Pulse profile of PSR J0631+1036

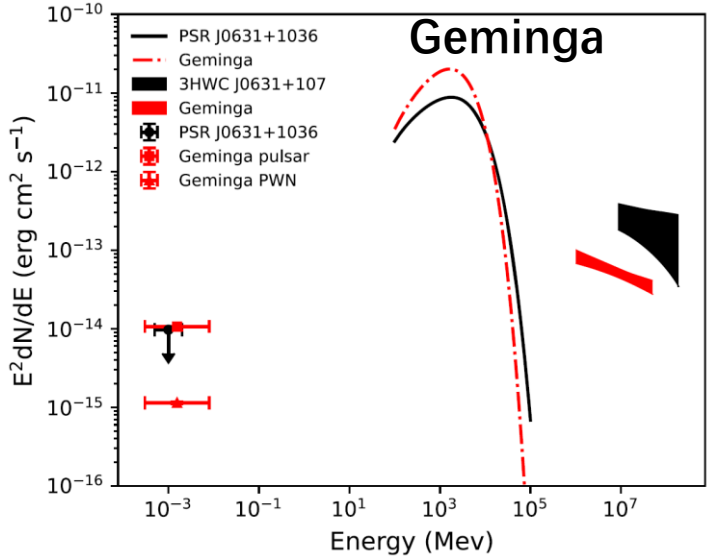




GeV-TeV spectrum

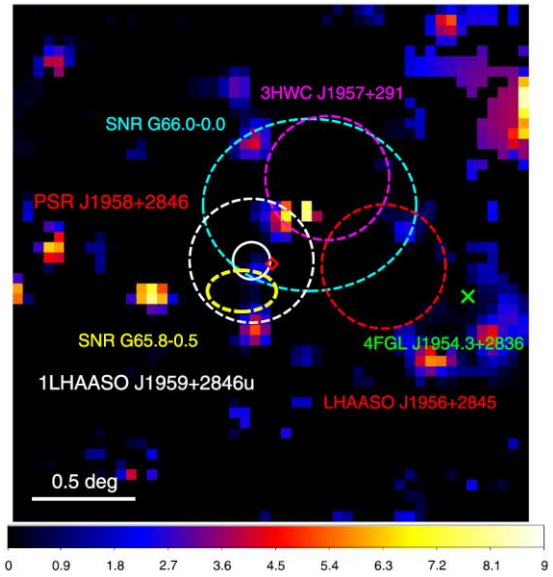
Zheng, Wang, Xing 2023 (ApJ)

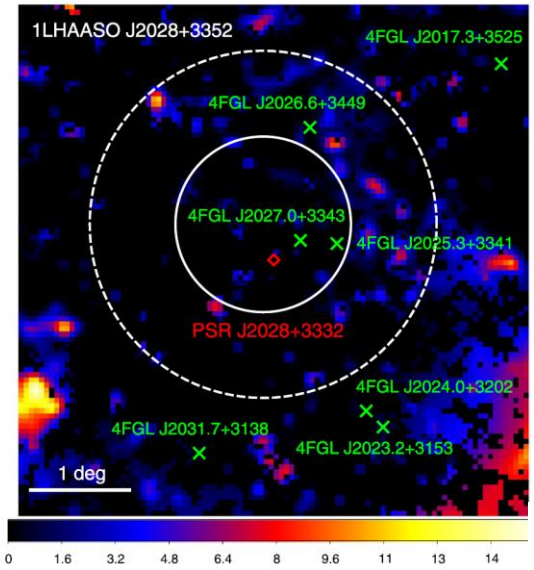
Comparison of the pulsar with the Geminga



- After removing the pulsar's GeV emission, we only obtain an upper limit
- The TeV emission is hard, not similar to that of an PWN
- The pulsar is highly similar to the Geminga
- We thus suggest this TeV source another TeV halo

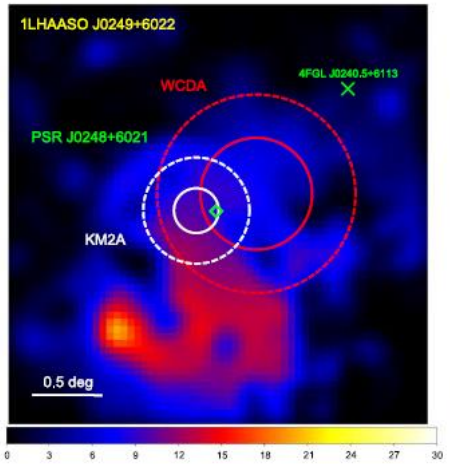
More similar sources identified



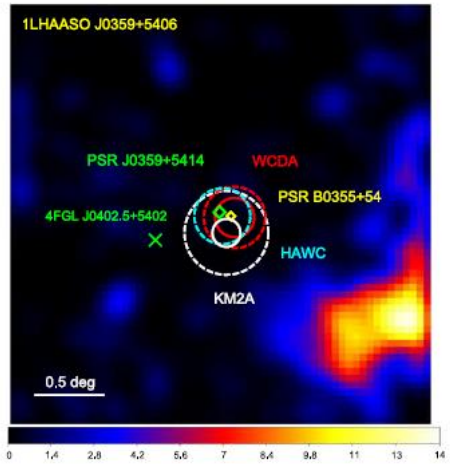


- 1LHAASO J1959+2846u (PSR J1958+2846)
- 1LHAASO J2028+3352 (PSR J2028+3332)
- HESS J1849-000 (or 1LHAASOJ1848-0001u; PSR J1849-0001, but this is an X-ray pulsar)

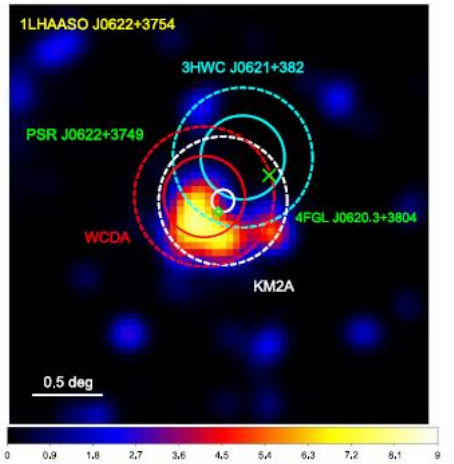
(Zheng & Wang 2023, 2024, ApJ)



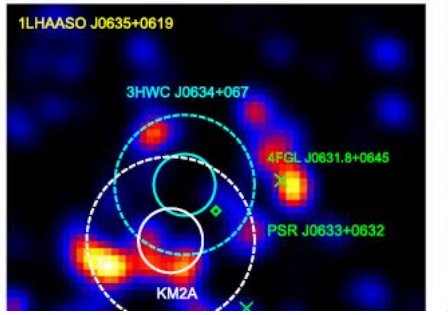
(a)

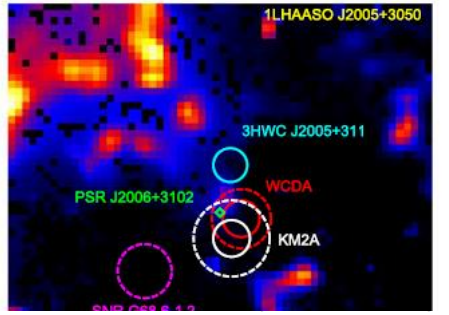


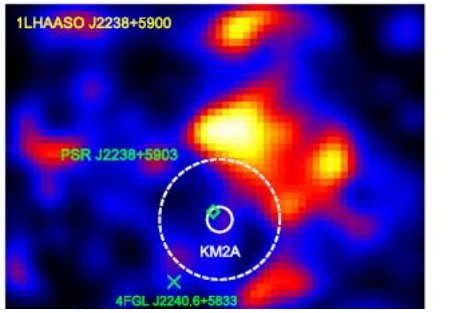
(b)



(c)

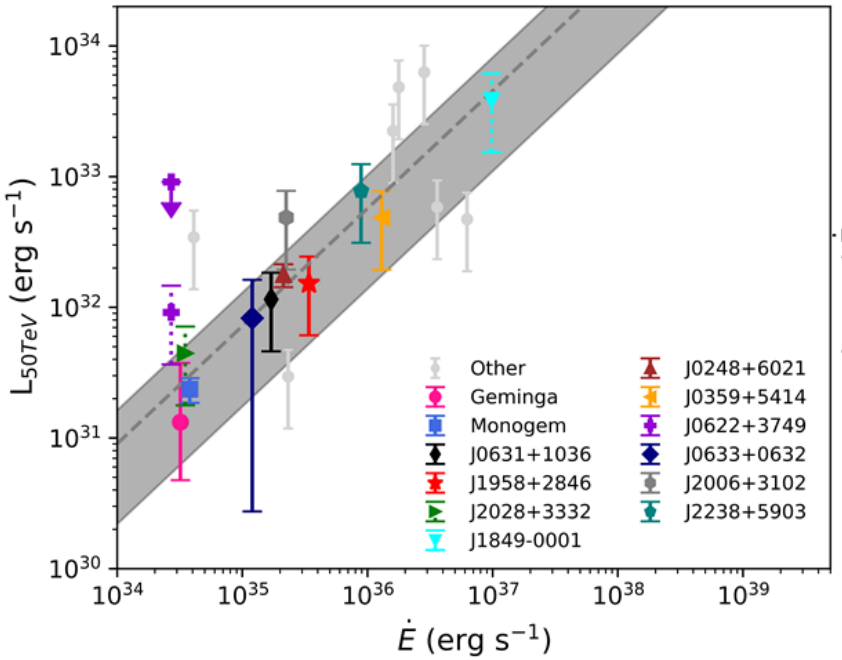


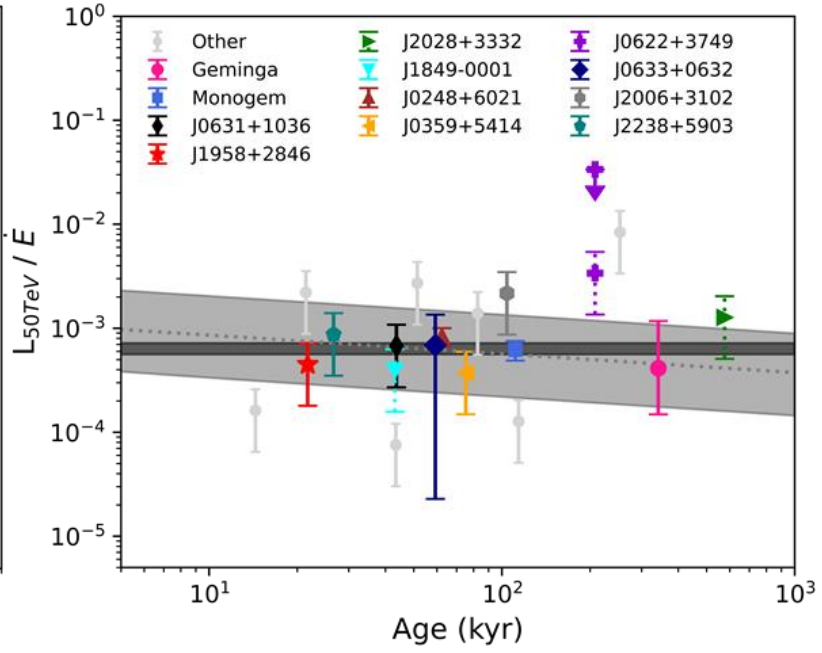


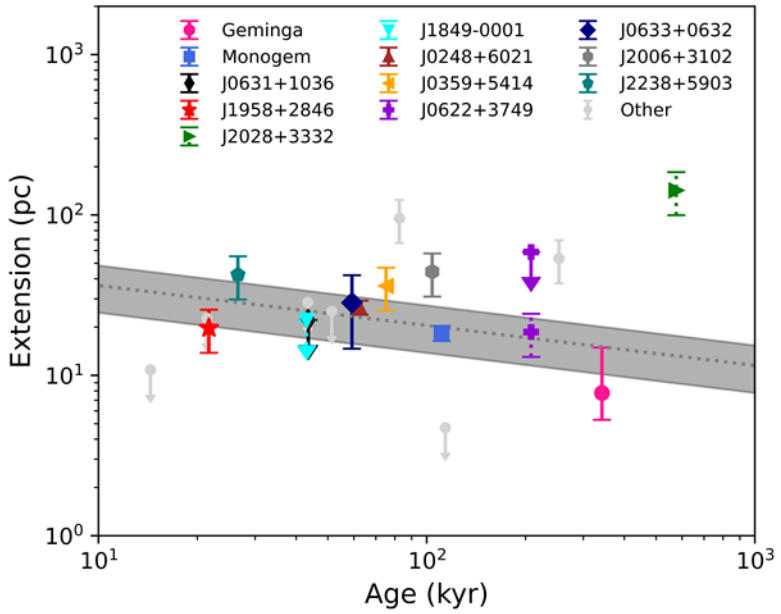


1LHAASO PSR	P_0 (s)	$\dot{P}$ (10^{-14})	$\dot{E}/10^{35}$ (erg s^{-1})	Distance (kpc)	Age (kyr)	$F_{X-ray}^{PSR}/10^{-13}$ (erg cm^{-2} s^{-1})	$F_{X-ray}^{PWN}/10^{-13}$ (erg cm^{-2} s^{-1})	$F_{50TeV}/10^{-13}$ (erg cm^{-2} s^{-1})	Extent (deg)
J0249+6022 J0248+6021	0.22	5.51	2.13	2.0 ± 0.2	62.4	< 9.0	...	3.72 ± 0.36	0.38 ± 0.08
J0359+5406 J0359+5414	0.08	1.67	13.0	3.45	75.2	0.09 ± 0.03	0.20 ± 0.03	3.40 ± 0.24	0.30 ± 0.04
J0622+3754 J0622+3749	0.33	2.54	0.27	<3.47	208	<0.14	...	5.68 ± 0.28	0.46 ± 0.03
J0635+0619 J0633+0632	0.30	7.96	1.20	$1.35^{+0.65}_{-0.65}$	59.2	0.33 ± 0.06	$1.17^{+0.11}_{-0.13}$	3.76 ± 0.40	0.60 ± 0.07
J2005+3050 J2006+3102	0.16	2.49	2.24	4.7	104	< 9.0	...	1.84 ± 0.20	0.27 ± 0.05
J2238+5900 J2238+5903	0.16	9.70	8.89	2.83	26.6	< 0.44	...	8.12 ± 0.48	0.43 ± 0.03

Properties





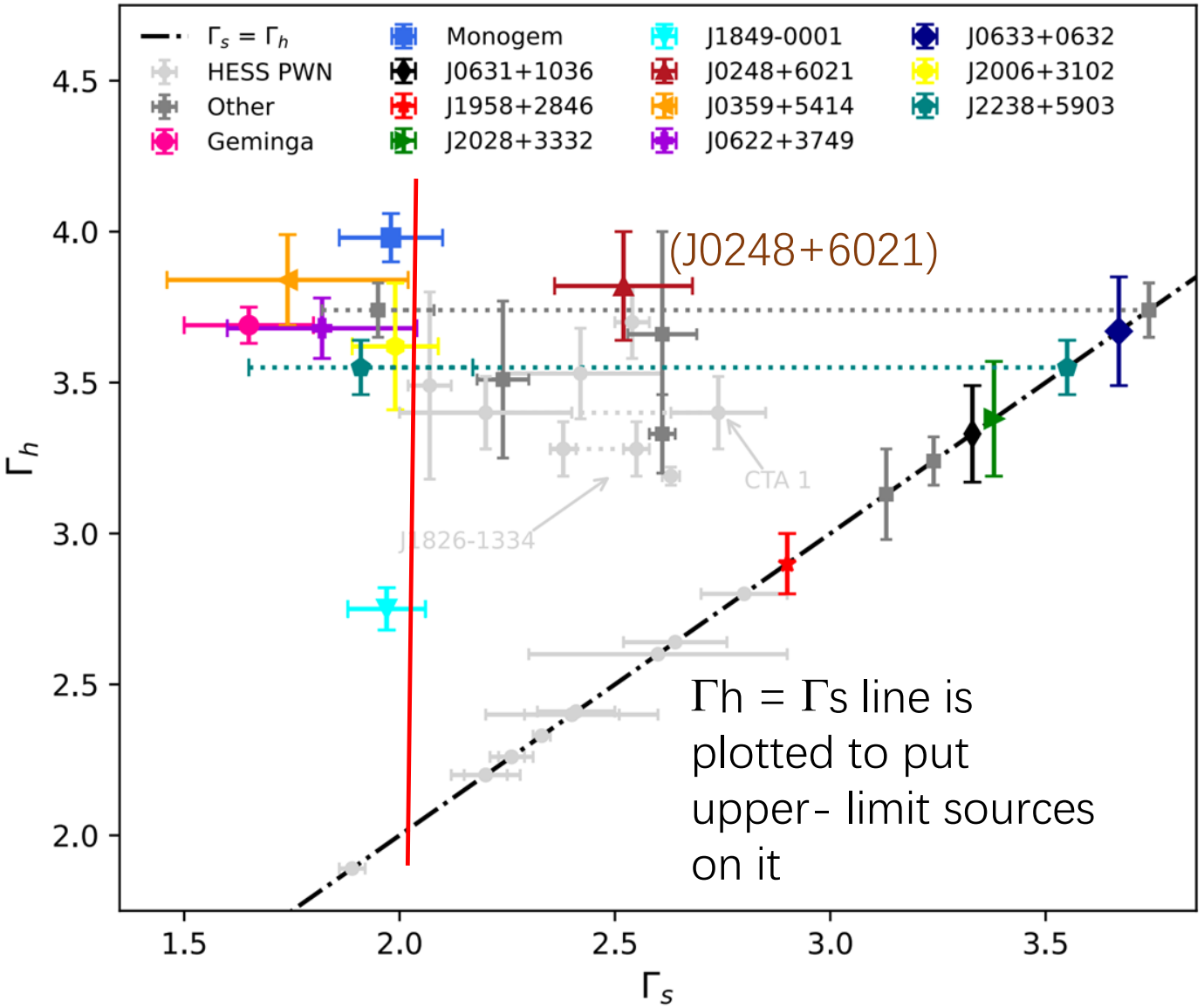


$$L_{50\,TeV} \sim \dot{E}^{0.9}$$

$$\frac{L_{50\,TeV}}{\dot{E}} \approx 6.4 \times 10^{-4}$$

$$Size \sim \tau_{kyr}^{-0.25}$$

Difference from the pulsar wind nebulae

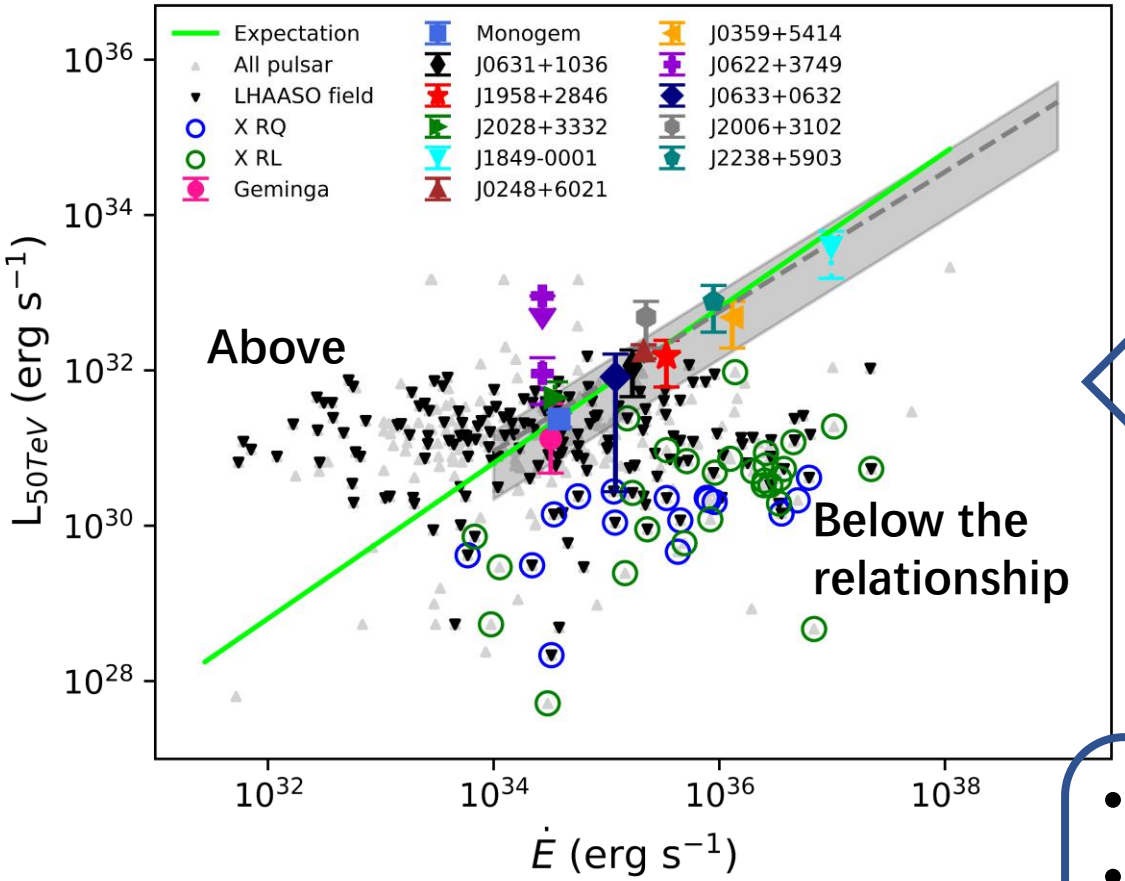


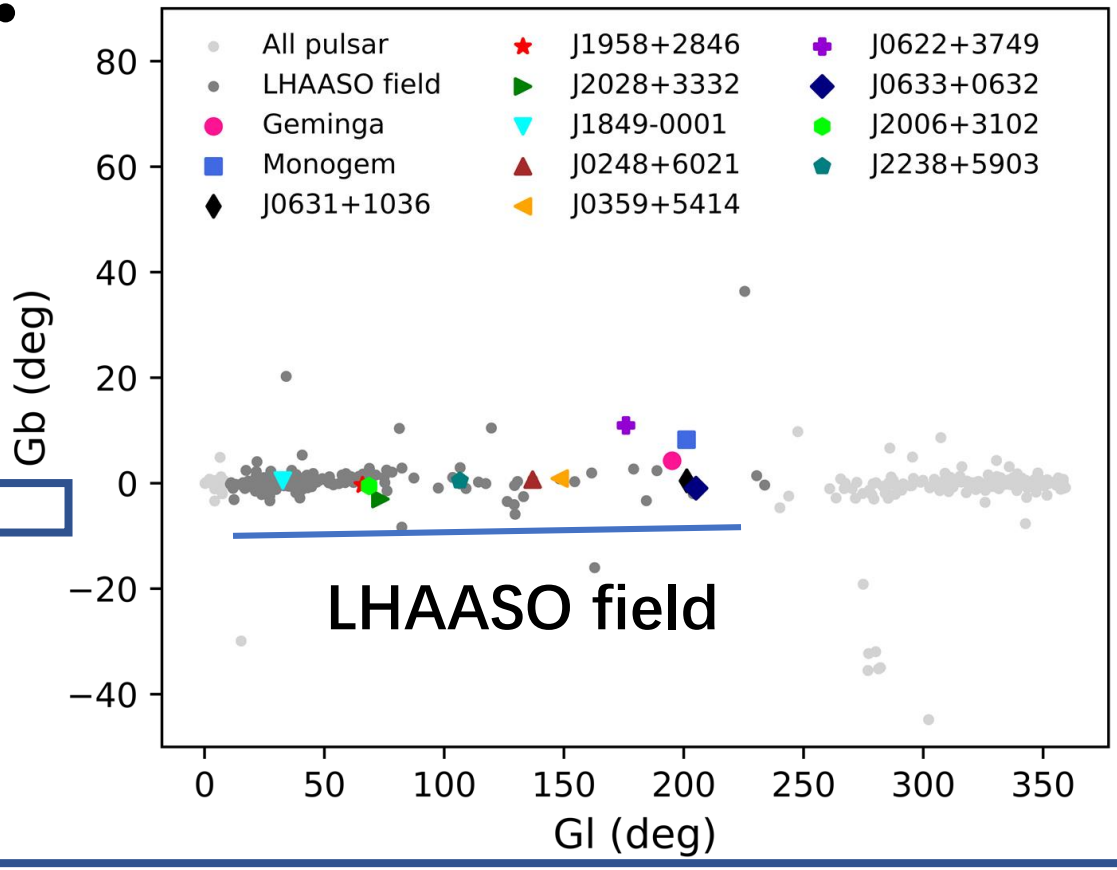
- Γs, index at 1-10 or 1-25 TeV
- Γh, index at 25-100 TeV

1. Most HESS PWNe (except Vela) are at the right of the red line (Γs > 2), soft
2. Most TeV halo candidates, plus Geminga and Monogem, are at the left, hard

TeV PWNe (grey data points) from HESS Collaboration (2017)

More detectable halos?



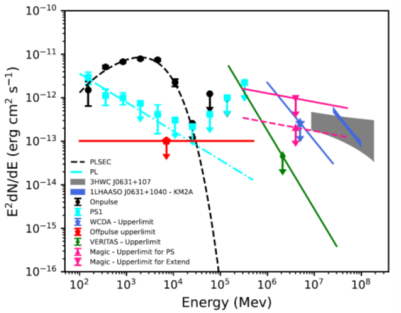


LHAASO upper limits on middle-aged pulsars

- Green line: $\frac{L_{50\,TeV}}{\dot{E}} \approx 6.4 \times 10^{-4}$
- Dark: middle-aged pulsars in the LHAASO field
- Grey: those not in the LHAASO field
- Circles: gamma-ray pulsars with X-ray emission?

Summary

Thank you for your attention!



1. We have developed a method to remove pulsars' emission, allowing us to better study the fields of TeV sources
2. We have found 10 candidate pulsar TeV halos:
   - They are positionally coincident with a middle-aged pulsar
   - For each of them, after removing the pulsar's GeV emission, only an upper limit is obtained, indicating the TeV source's emission is hard
   - Their luminosities at 50 TeV are approximately proportional to Edot of the pulsars
   - Their TeV emissions are harder than those of the PWNe
3. We have checked the detectability of halos of middle-aged pulsars:
   - 170 of them are in the LHAASO field
   - ~half of them are expected to have TeV fluxes higher than the LHAASO sensitivity => no TeV halos?
   - Most of the above sources are gamma-ray pulsars with X-ray emission
   - Older pulsars tend to be found with halos? ~100 remain to be checked