



甚高能脉冲星晕的搜寻与相似性研究



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- 脉冲星晕简介
- 3HWC J0631+107/LHAASO J0631+1040
- 脉冲星晕搜寻方法
- 脉冲星晕候选体
- 脉冲星晕性质
- 总结



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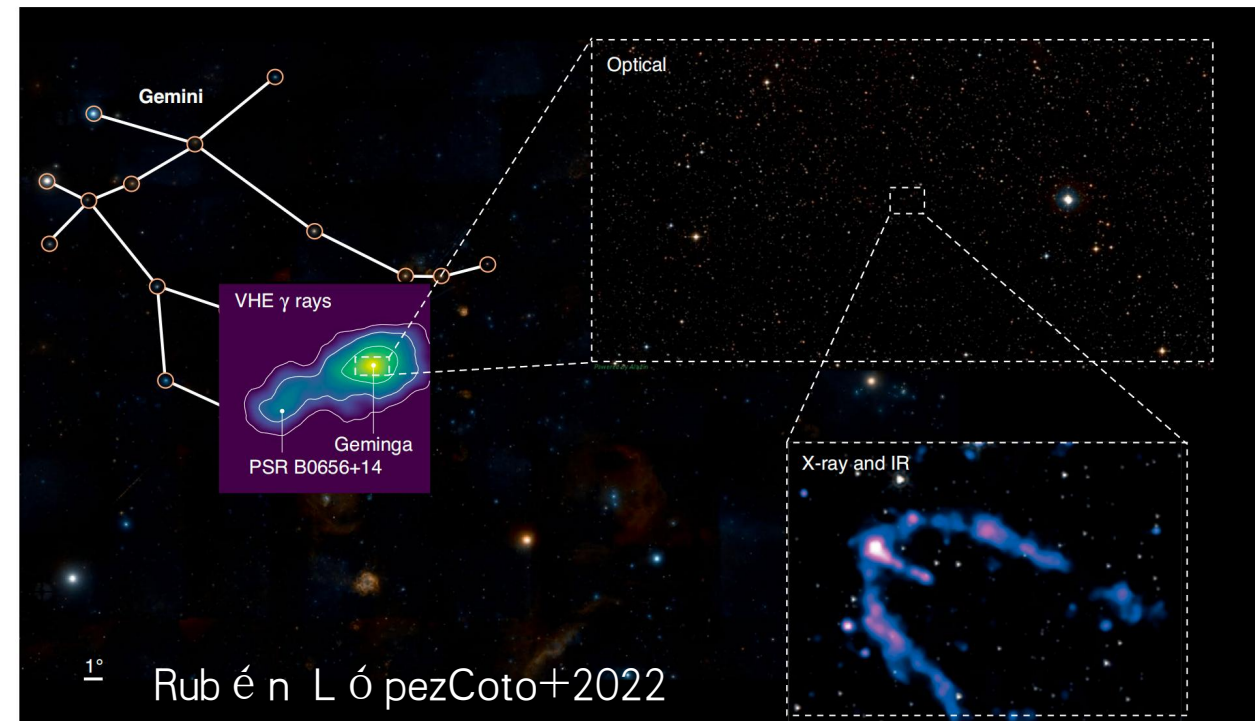
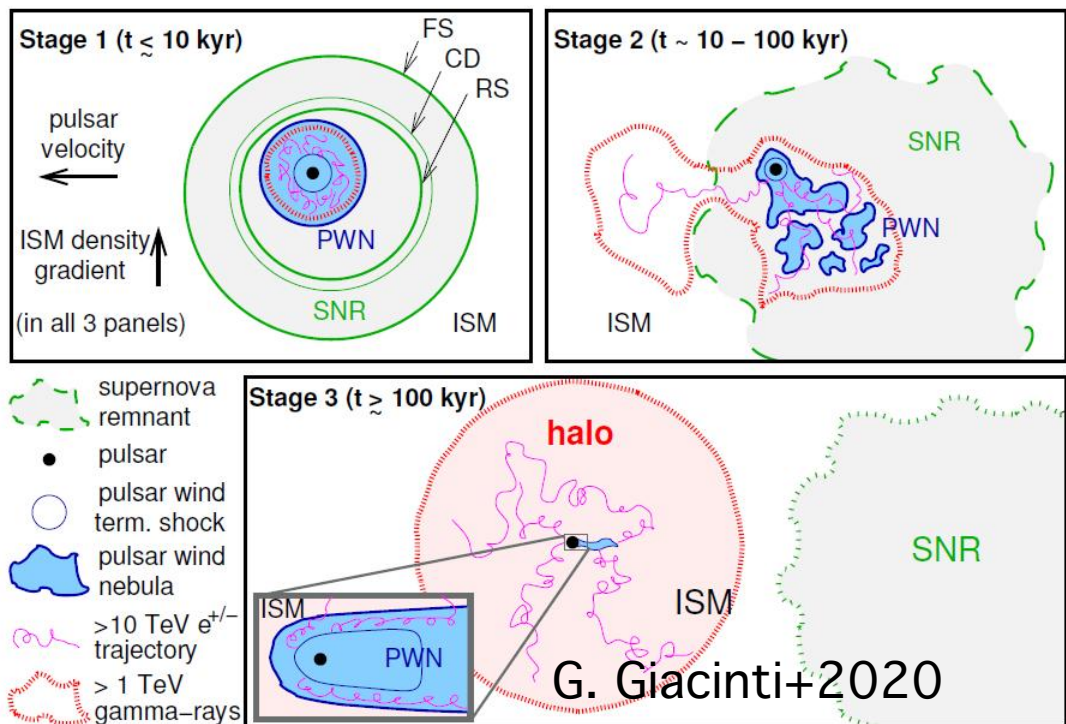


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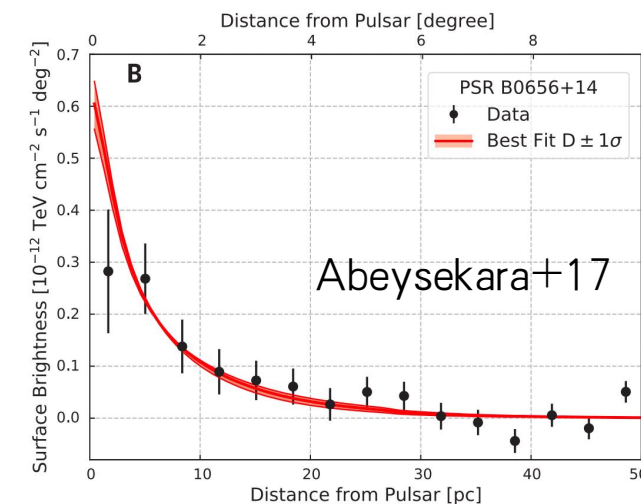
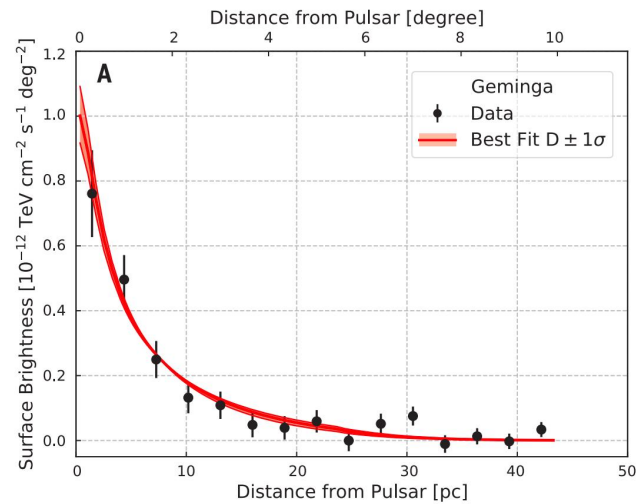
• 脉冲星晕简介

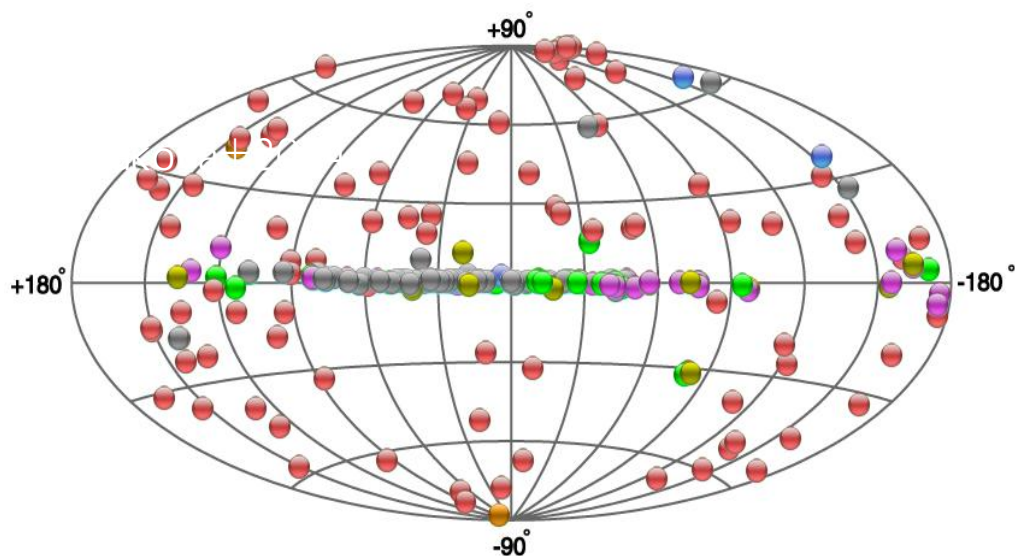
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脉冲星晕简介



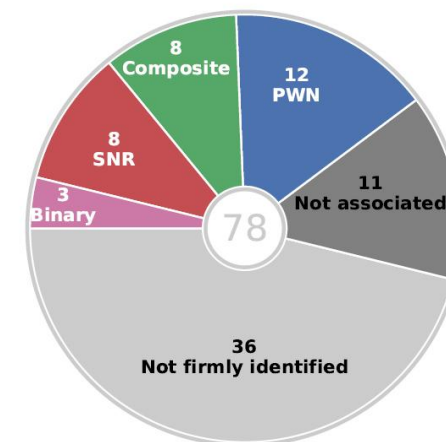
- 甚高能脉冲星晕 (pulsar TeV halos) 是近年来在中年脉冲星周围探测到的一类扩展的甚高能伽马射线辐射
- 理论预计脉冲星晕普遍存在于中年脉冲星周围, 但目前被证认并且有详细研究的脉冲星晕数量仅几例





Source Types

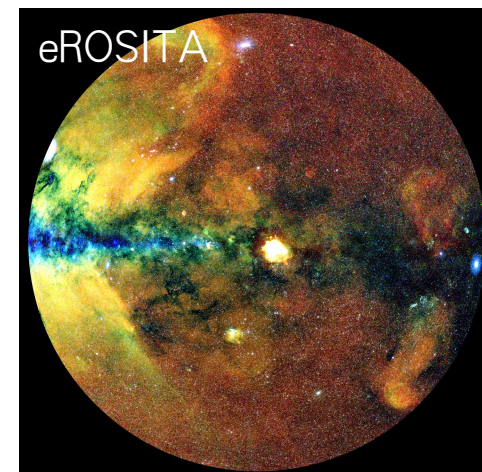
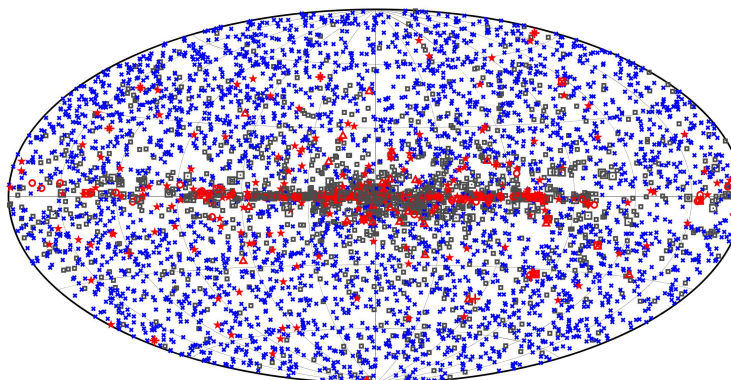
- PWN TeV Halo
PWN/TeV Halo
- XRB Nova Gamma BIN
Binary PSR
- HBL IBL GRB FSRQ LBL
AGN (unknown type) FRI
Blazar
- Shell Giant Molecular
Cloud SNR/Molec. Cloud
Composite SNR
Superbubble SNR
- Starburst
- DARK UNID Other
- Star Forming Region
Globular Cluster Massive
Star Cluster BIN
uQuasar Cat. Var. BL
Lac (class unclear) WR



TeV源天图 (TeVcat在线星表)

H.E.S.S. 银盘巡天星表
(H.E.S.S. Collaboration, 2018)

Fermi天图 (4FGL-DR4共7194个源)



在多波段的观测中，目前没有确切的证据表明探测到脉冲星晕的对应体





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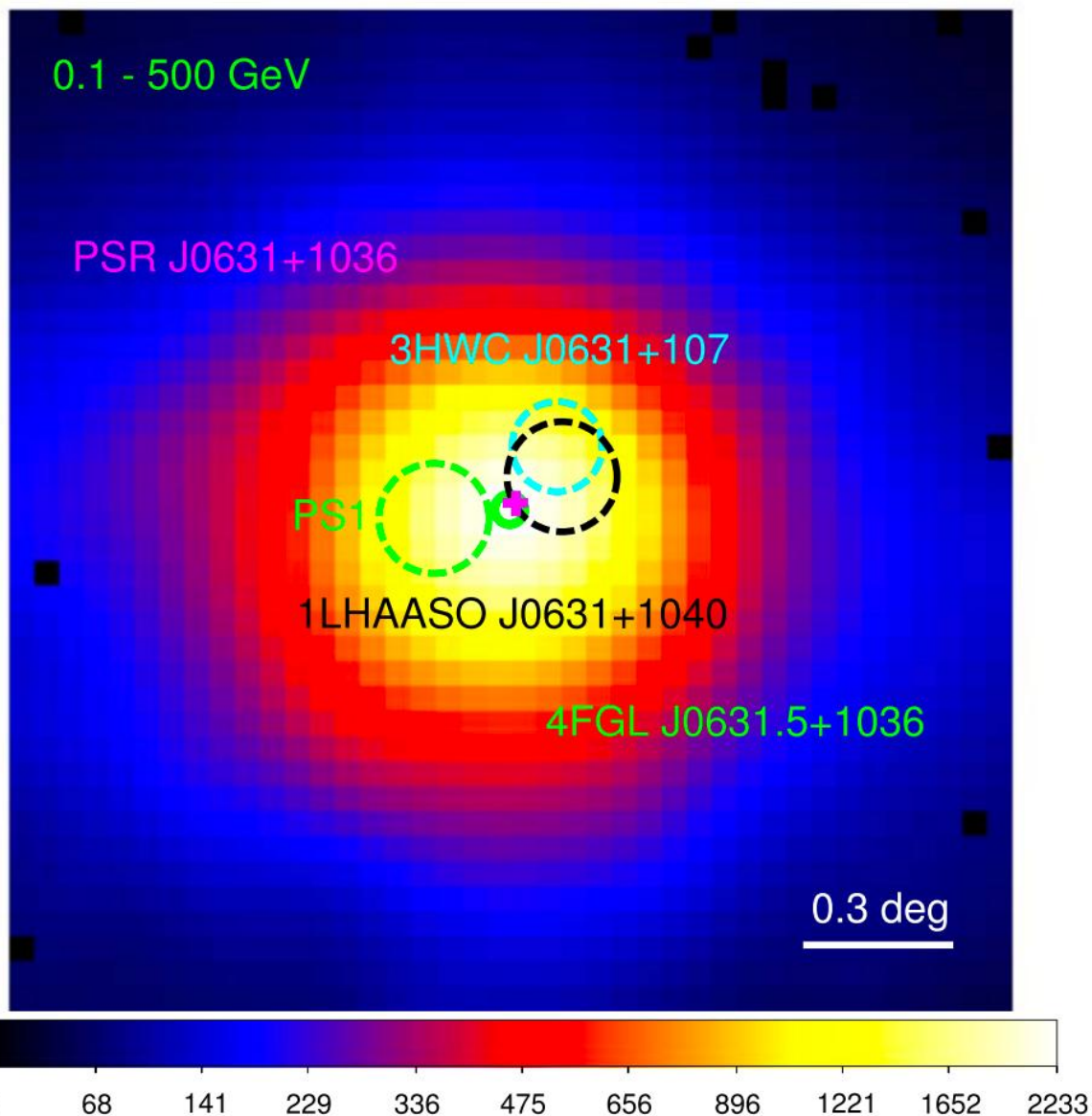
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PSR J0631+1036 (洋红色十字)

P_0 0.288 s

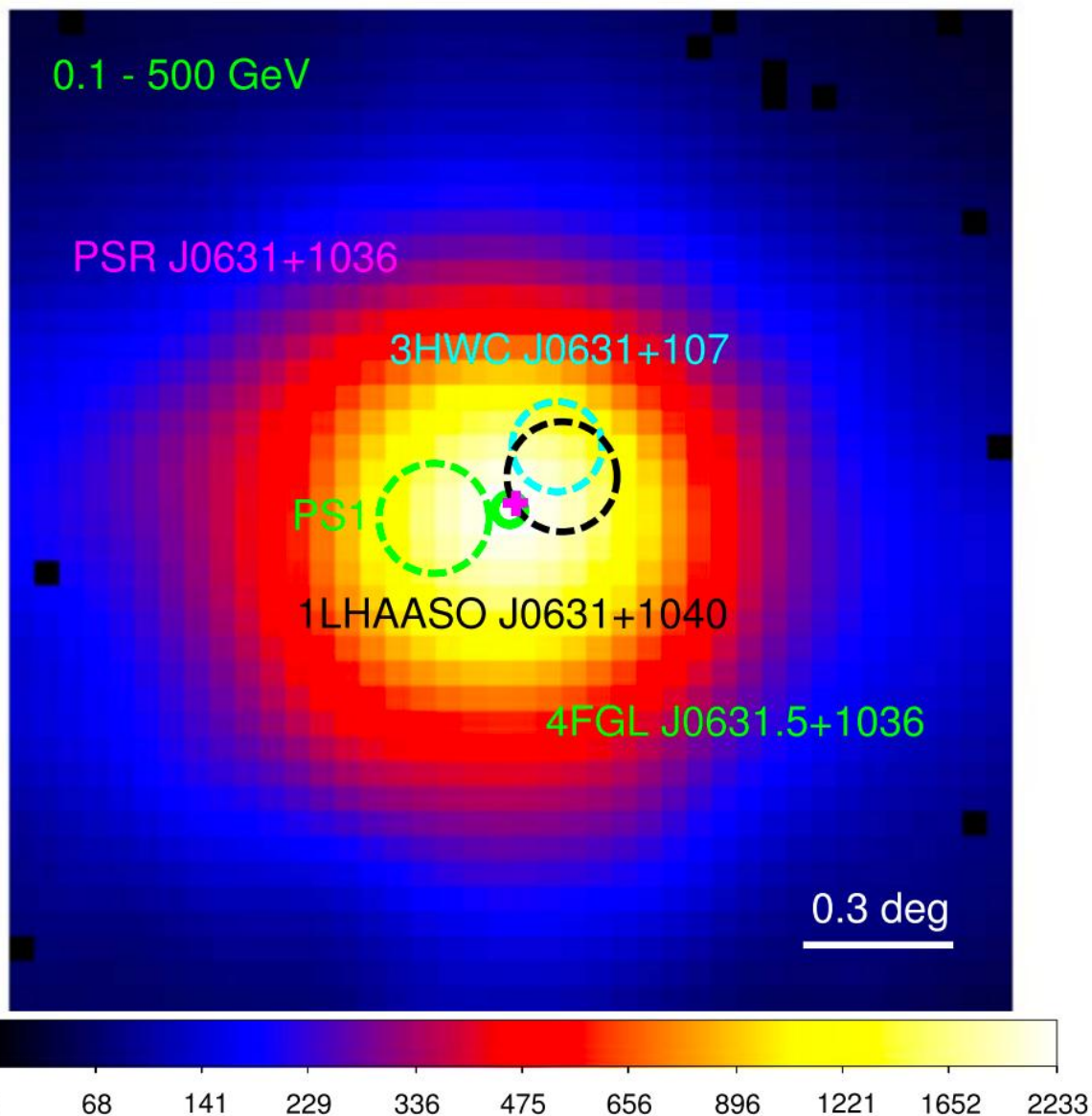
\dot{E} 1.7×10^{35} erg s $^{-1}$

Age 43.6 kyr

Distance 2.1 kpc

4FGL J0631.5+1036 (绿色实线)

脉冲星伽马射线对应体



3HWC J0631+107 (青色虚线圆)

能量范围 8.6 - 186.9 TeV

TS : 26.5

1LHAASO J0631+1040 (黑色虚线圆)

WCDA 未探测到

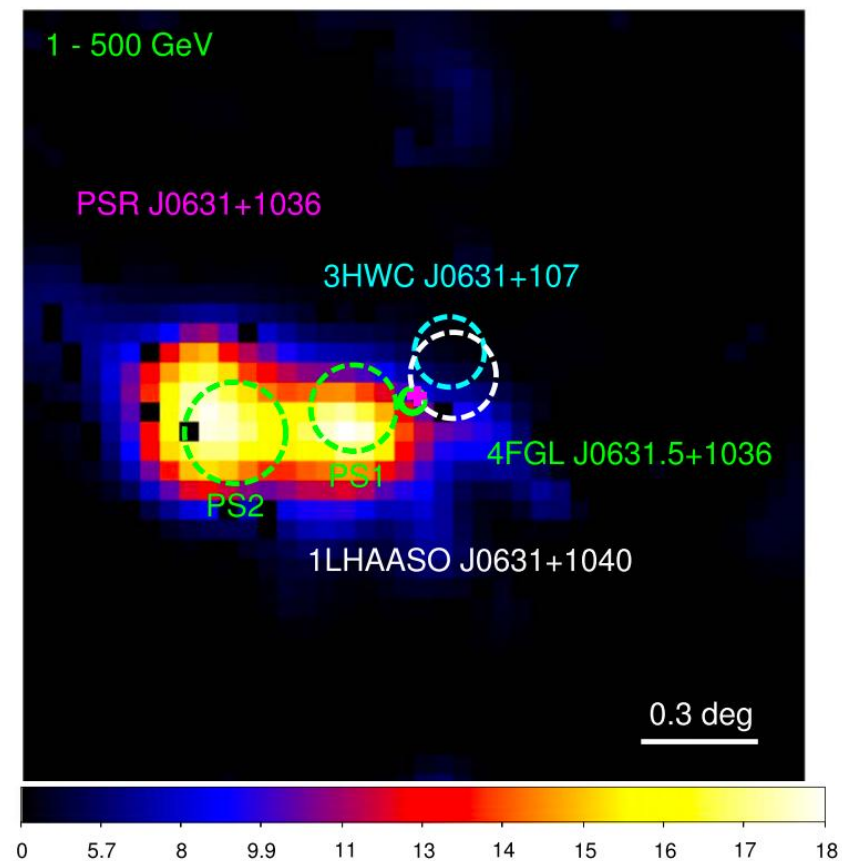
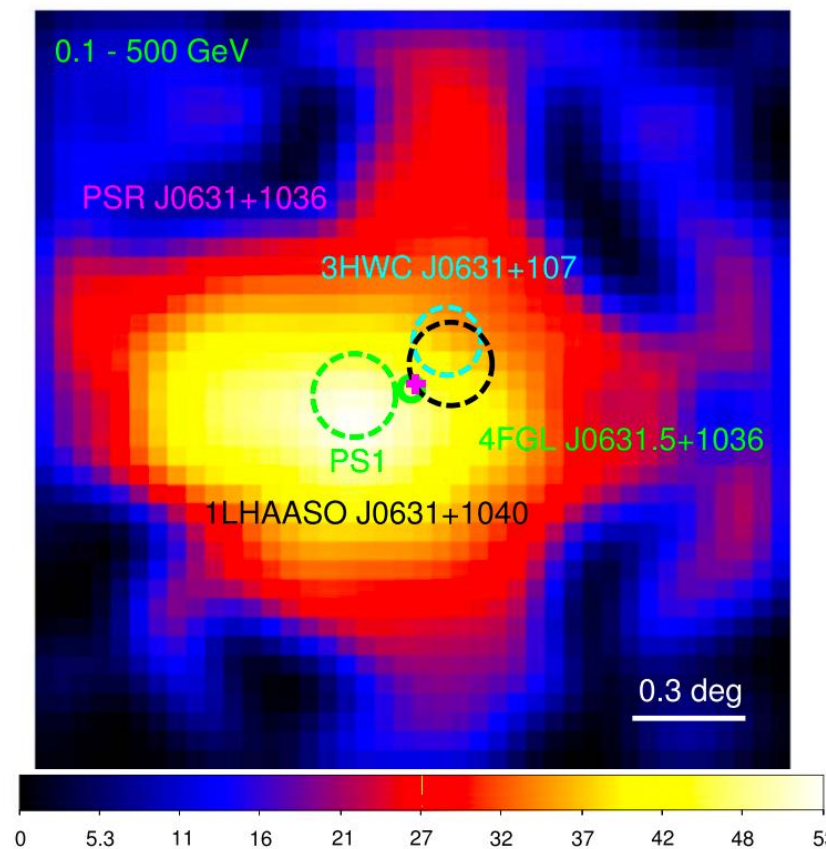
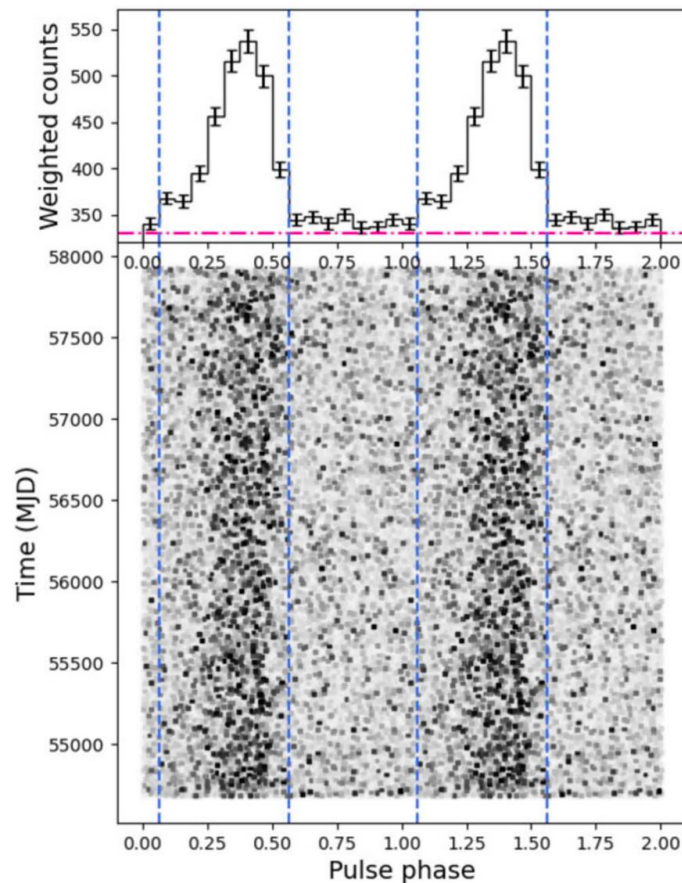
能量范围 1 - 25 TeV

KM2A

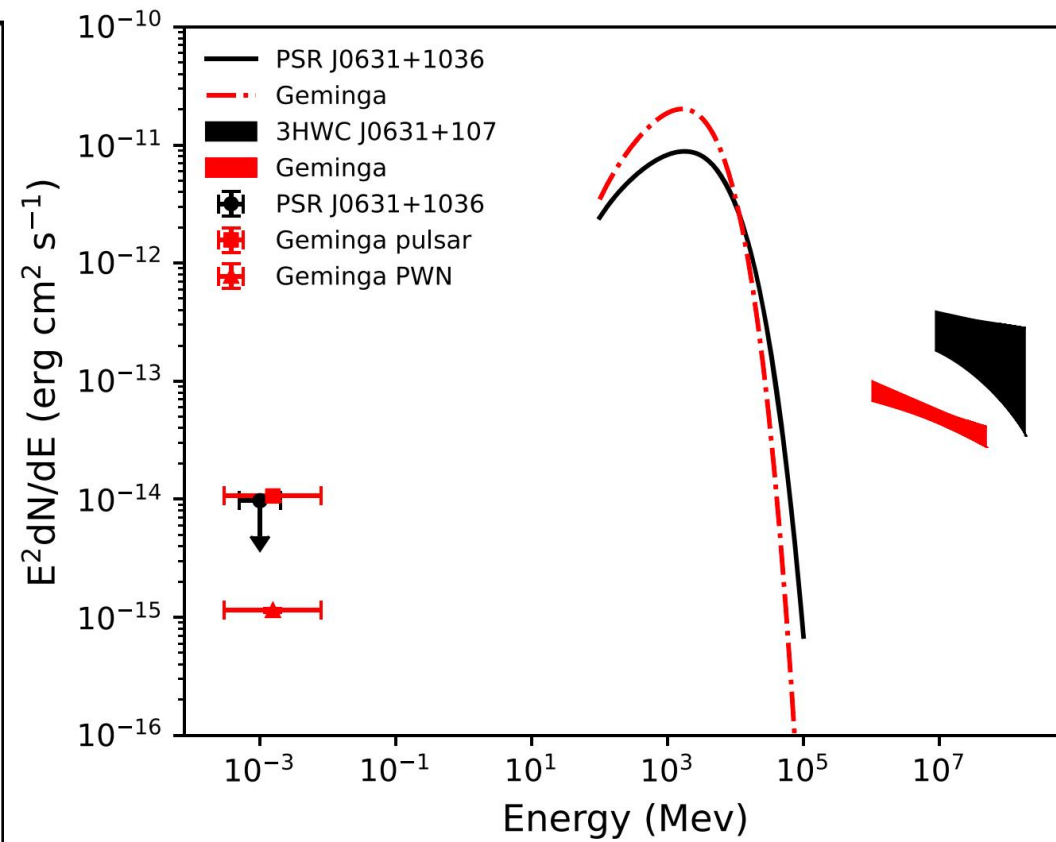
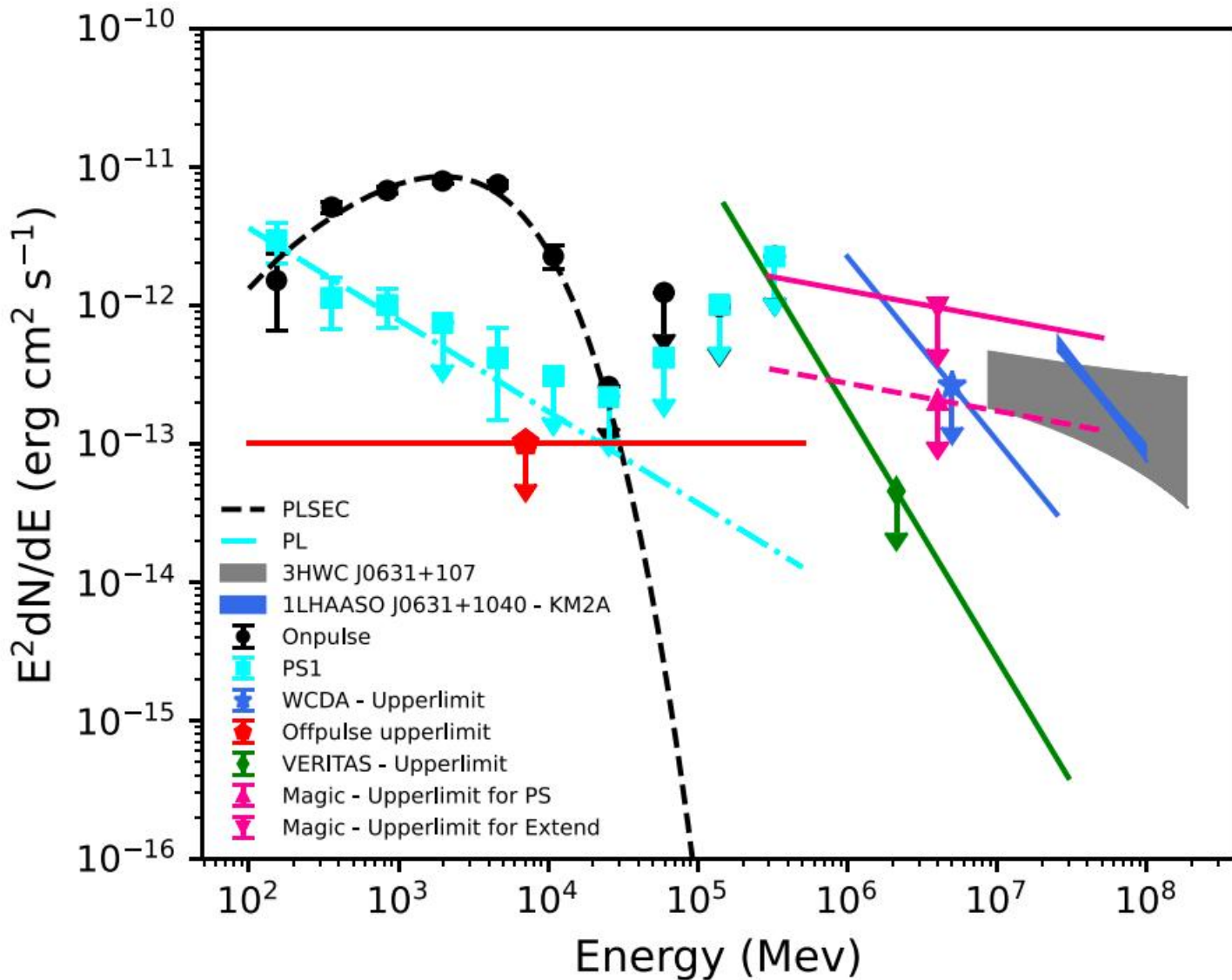
能量范围 25 - 100 TeV

TS : 141.6

在其它波段未探测到脉冲星风云和超新星遗迹



Phase Range (src)	$F_{0.1-500}/10^{-8}$ (photons $s^{-1} cm^{-2}$)	Γ	d	TS	$\log(L)$
Catalog values	...	1.85 ± 0.05	0.54 ± 0.07	2000	...
Whole data	3.01 ± 0.23	2.02 ± 0.03	0.47 ± 0.05	2570	...
On-pulse	2.23 ± 0.19	1.96 ± 0.04	0.62 ± 0.07	2279	...
Off-pulse (PS1)	1.35 ± 0.29	2.66 ± 0.13	...	60	763784.9
Off-pulse (2PS-PS1)	0.92 ± 0.41	2.63 ± 0.17	...	29	763786.9
(2PS-PS2)	0.45 ± 0.36	2.53 ± 0.25	...	9	...



脉冲星晕可能的性质?

- 在X射线和伽马射线没有明显发射
- 能谱峰值在25TeV



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与脉冲星相关联的甚高能TeV源

甚高能源:

- HGPS (HESS银盘巡天星表, 2018年78个源)
- 3HWC (三期HAWC源表, 2020年65个源)
- 1LHAASO (一期LHAASO星表, 2023年90个源)

对脉冲星Fermi-LAT数据进行Timing分析 去除脉冲辐射

基于Fermi-LAT数据开展:

- MeV-GeV能段辐射起源与TeV能段紧密关联
- 给出伽马射线辐射详细的观测信息

多波段观测 目标源清晰的物理图像

结合多波段观测:

- 不同起源在多波段上的表现不同
- 伽马射线观测空间分辨率差, 其他波段观测有较好的空间分辨率
- 获得尽可能多的信息, 帮助准确证认

目标源确定

- 在GeV能段没有辐射发射
- 有KM2A探测, WCDA没有探测
- X-ray等多波段没有明亮的脉冲星风云和超新星遗迹



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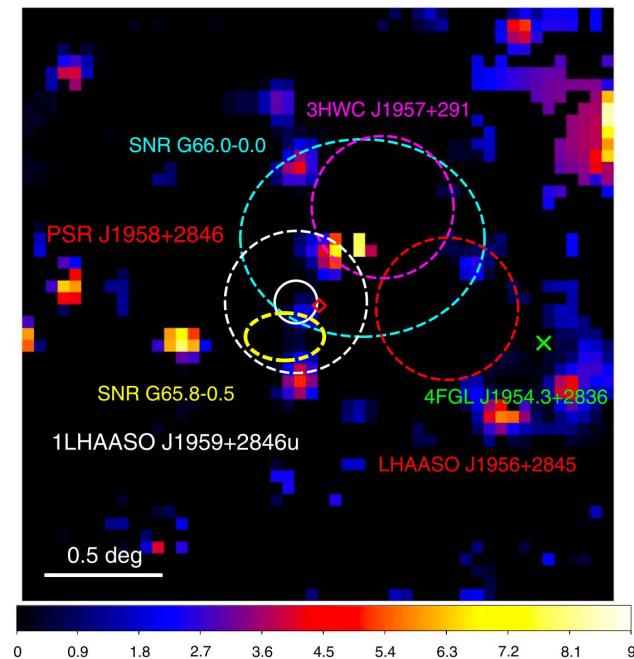


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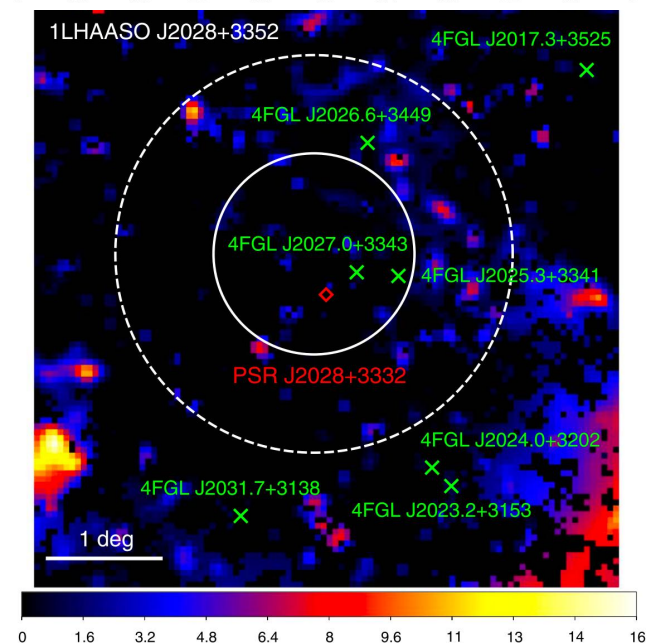
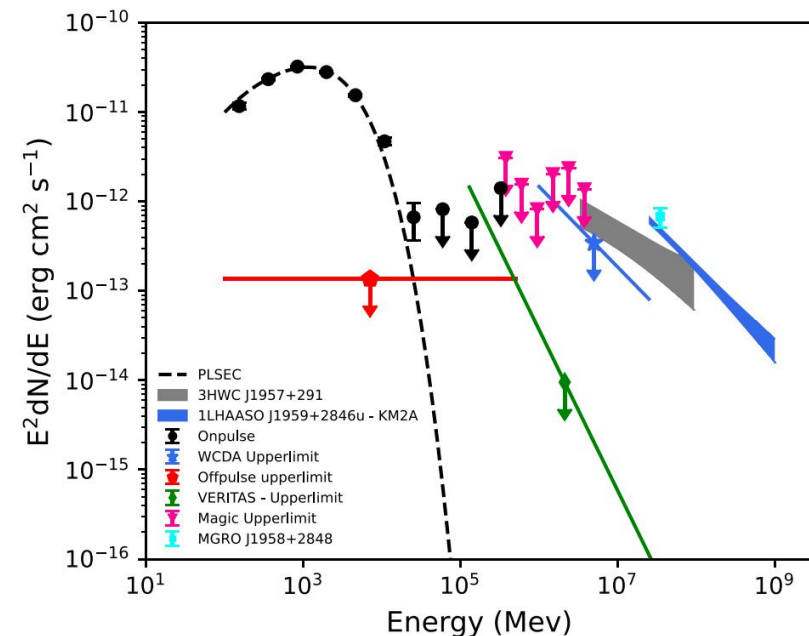
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PSR J1958+2846:

P_0 0.29 s
 \dot{E} 3.4×10^{35} erg s $^{-1}$
 Age 21.7 kyr
 Distance 1.95 kpc
 SNR G65.8-0.5
 SNR G66.0-0.0

4FGL J1958.7+2846
 3HWC J1957+291
 1LHAASO J1959+2846u

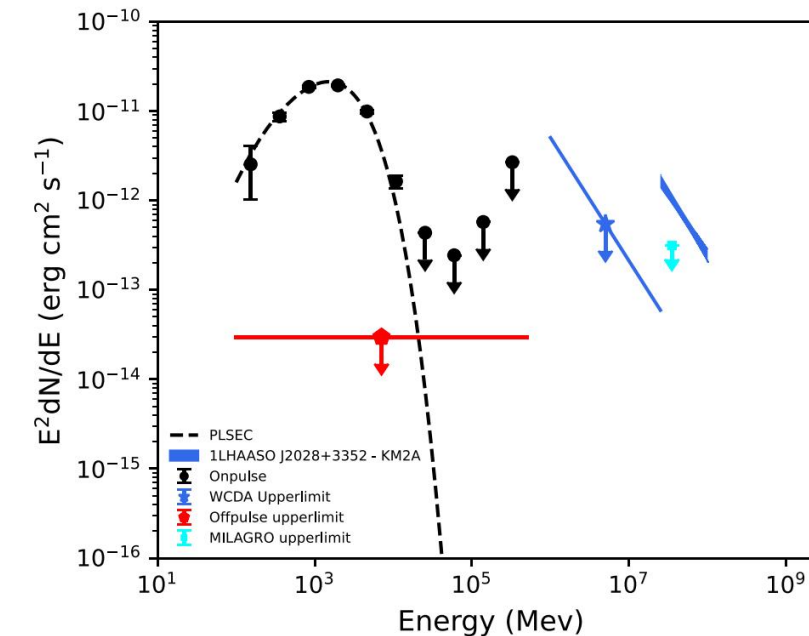


PSR J2028+3332:

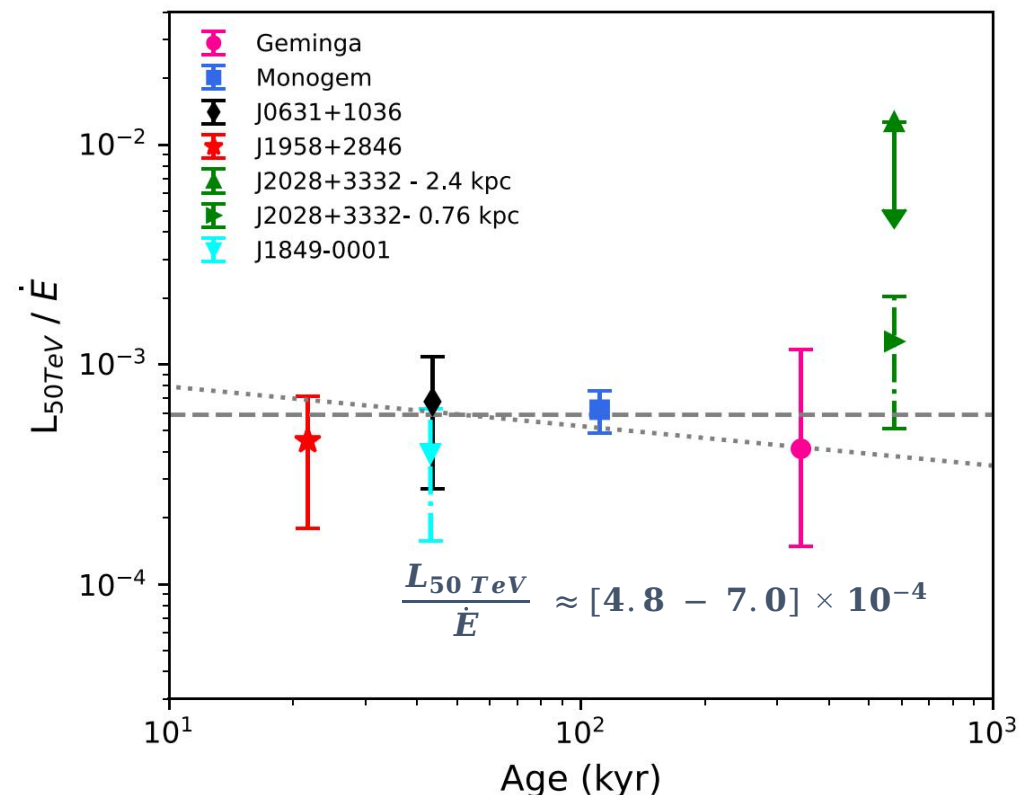
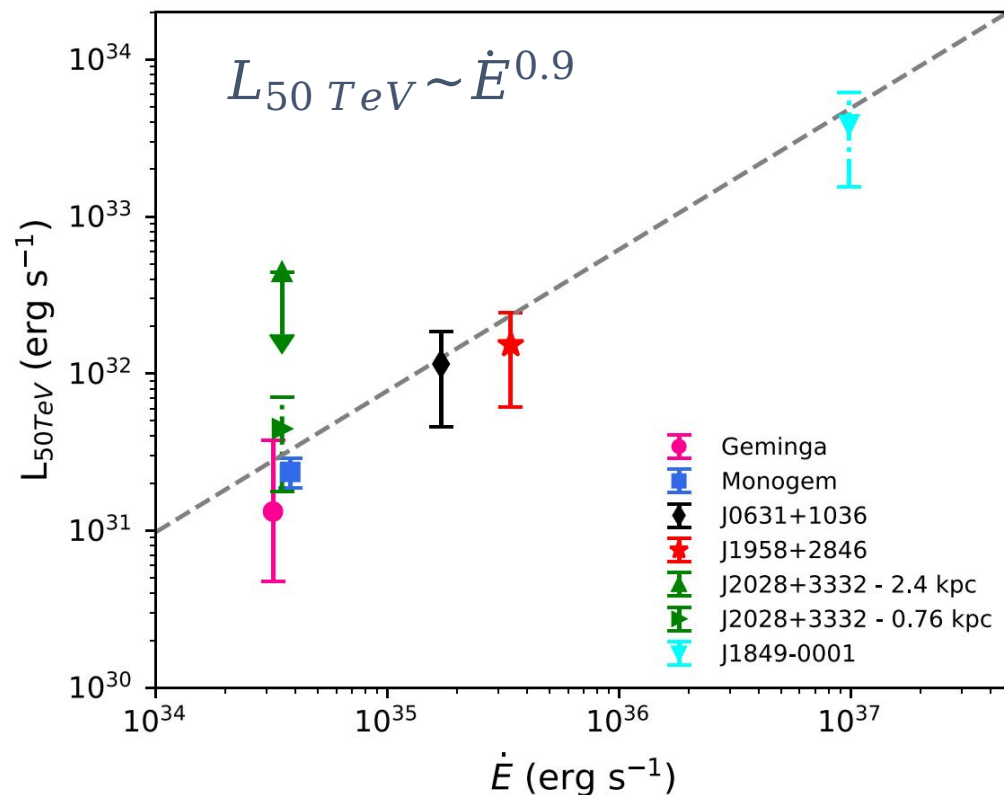
P_0 0.18 s
 \dot{E} 3.5×10^{34} erg s $^{-1}$
 Age 576 kyr
 Distance < 2.4 kpc

4FGL J2028.3+3331
 1LHAASO J2028+3352

未探测到
脉冲星风云
超新型遗迹



Pulsar	P (s)	\dot{P} 10^{-14}	\dot{E} 10^{-35} (erg s $^{-1}$)	Distance (kpc)	Age (kyr)	F_X^{PSR} 10^{-13} (erg cm $^{-2}$ s $^{-1}$)	F_X^{PWN} 10^{-13} (erg cm $^{-2}$ s $^{-1}$)	$F_{50 \text{ TeV}}$ 10^{-13} (erg cm $^{-2}$ s $^{-1}$)	References
Geminga	0.24	1.10	0.32	$0.25^{+0.23}_{-0.08}$	342	$7.51^{+0.07}_{-0.75}$	0.81 ± 0.03	17.68 ± 0.60	1, 2
Monogem	0.38	5.50	0.38	0.28 ± 0.03	111	23.5 ± 0.4	$0.083^{+0.057}_{-0.044}$	25.20 ± 0.92	1, 3
J0631+1036	0.29	10.47	1.7	2.11	43.6	≤ 0.09	...	2.16 ± 0.24	4, 5
J1958+2846	0.29	21.20	3.4	1.95	21.7	0.14 ± 0.04	0.04 ± 0.03	3.36 ± 0.28	4, 6
J2028+3332	0.18	0.49	0.35	≤ 2.4	576	0.05 ± 0.03	...	6.44 ± 0.76	7, 8
J1849-0001	0.04	1.42	98	7 (?)	43.1	38.0 ± 3.0	9.0 ± 2.0	6.56 ± 0.40	9

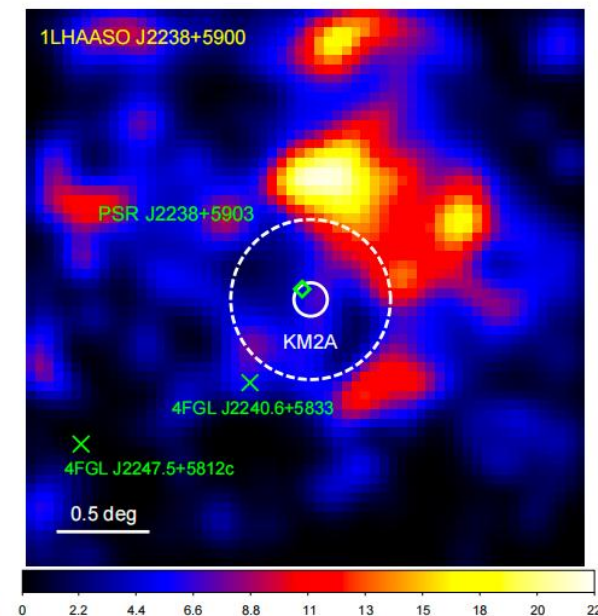
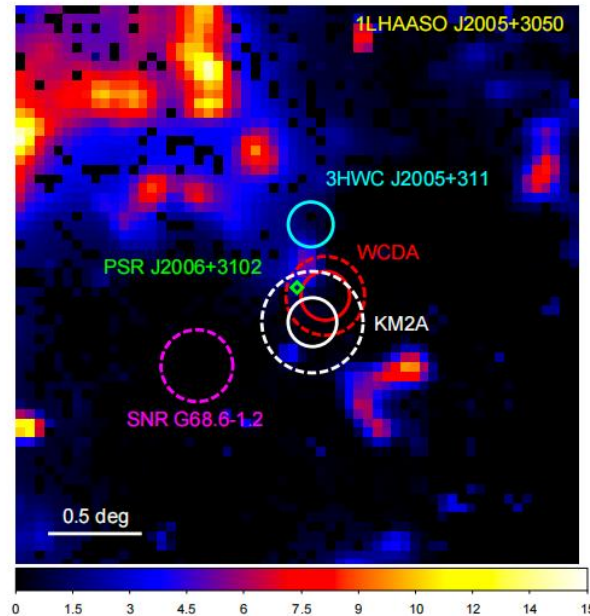
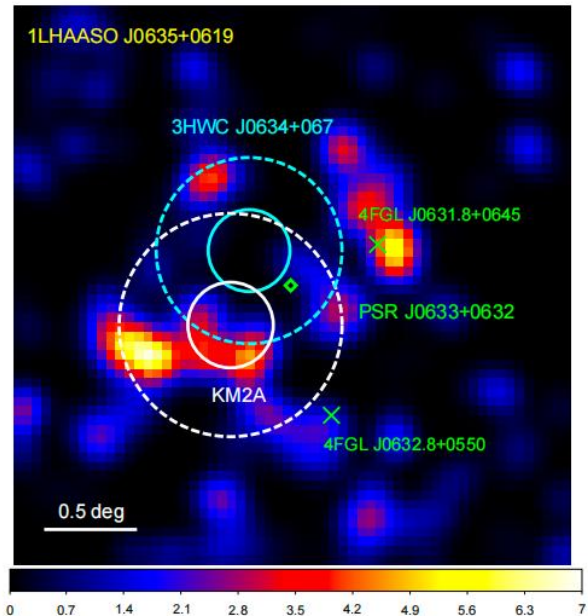
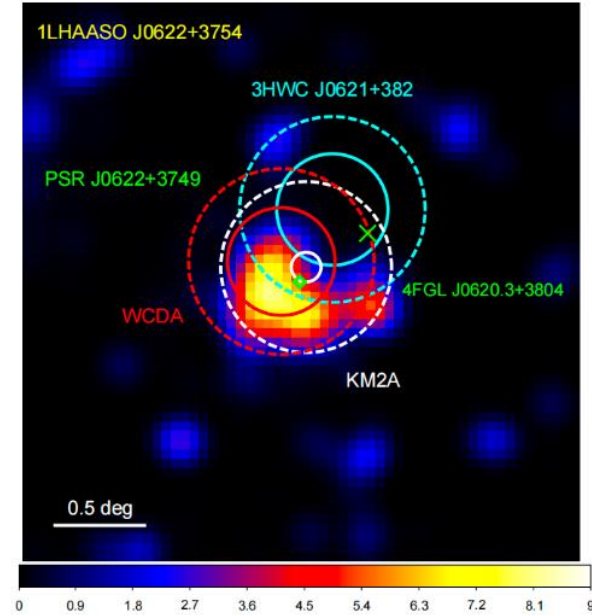
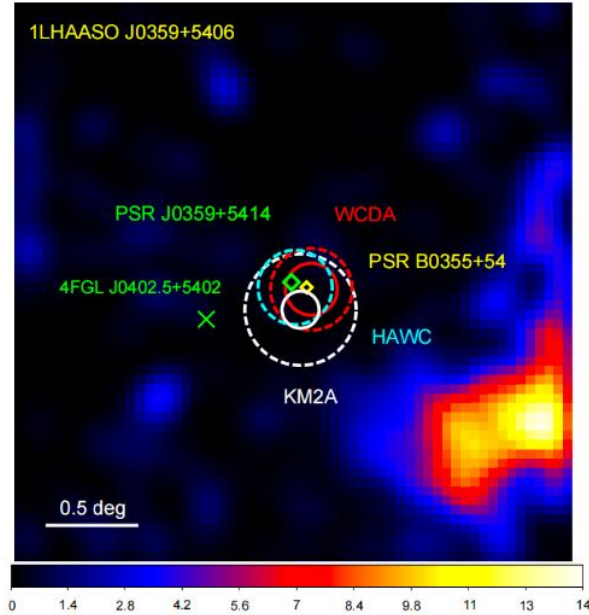
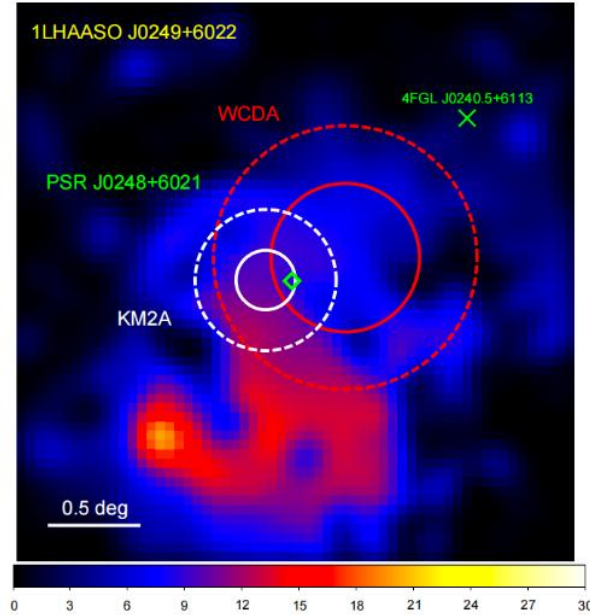


1LHAASO PSR	P_0 (s)	\dot{P} (10^{-14})	$\dot{E}/10^{35}$ (erg s^{-1})	Distance (kpc)	Age (kyr)	$F_{X\text{-ray}}^{\text{PSR}}/10^{-13}$ ($\text{erg cm}^{-2} \text{s}^{-1}$)	$F_{X\text{-ray}}^{\text{PWN}}/10^{-13}$ ($\text{erg cm}^{-2} \text{s}^{-1}$)	$F_{50\text{TeV}}/10^{-13}$ ($\text{erg cm}^{-2} \text{s}^{-1}$)	Extension (deg)	References
J0249+6022								3.72 ± 0.36	0.38 ± 0.08	
J0248+6021	0.22	5.51	2.13	2.0 ± 0.2	62.4	< 9.0	–			1, 2
J0359+5406								3.40 ± 0.24	0.30 ± 0.04	
J0359+5414	0.08	1.67	13.0	3.45	75.2	0.09 ± 0.03	0.20 ± 0.03			3
J0622+3754								5.68 ± 0.28	0.46 ± 0.03	
J0622+3749	0.33	2.54	0.27	< 3.47	208	< 0.14	–			4
J0635+0619								3.76 ± 0.40	0.60 ± 0.07	
J0633+0632	0.30	7.96	1.20	$1.35^{+0.65}_{-0.65}$	59.2	0.33 ± 0.06	$1.17^{+0.11}_{-0.13}$			5
J2005+3050								1.84 ± 0.20	0.27 ± 0.05	
J2006+3102	0.16	2.49	2.24	4.7	104	< 9.0	–			6
J2238+5900								8.12 ± 0.48	0.43 ± 0.03	
J2238+5903	0.16	9.70	8.89	2.83	26.6	< 0.44	–			4
J0542+2311u								11.72 ± 0.48	0.98 ± 0.05	
B0540+23	0.25	1.54	0.41	1.57	253	0.08 ± 0.04	–			4
J1740+0948u								1.64 ± 0.16	< 0.11	
J1740+1000	0.15	2.13	2.32	1.23	114	0.24 ± 0.02	0.60 ± 0.06			7, 8
J1809-1918u								37.84 ± 5.08	< 0.22	
J1809-1917	0.08	2.55	17.8	3.27	51.4	$0.47^{+0.01}_{-0.04}$	2.6–4.9			9
J1813-1245								5.68 ± 1.08	< 0.31	
J1813-1246	0.05	1.76	62.4	2.64	43.4	10.80 ± 0.10	< 1.5			10
J1825-1256u								20.32 ± 1.68	< 0.2	
J1826-1256	0.11	12.1	36.0	1.55	14.4	$1.04^{+0.14}_{-0.13}$	$0.85^{+0.10}_{-0.09}$			11
J1825-1337u								40.40 ± 2.44	< 0.18	
J1826-1334	0.10	7.53	28.4	3.61	21.4	0.16 ± 0.04	$4.5^{+0.3}_{-0.2}$			12
J1928+1746u								2.88 ± 0.28	< 0.16	
J1928+1813u								9.92 ± 0.64	0.63 ± 0.03	
J1928+1746	0.07	1.32	16.0	4.34	82.6	< 0.08	–			13

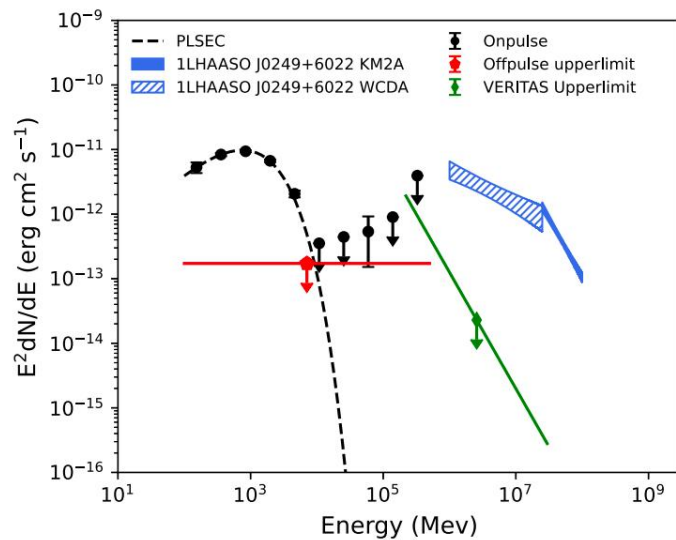
较好的候选体

可能的候选体

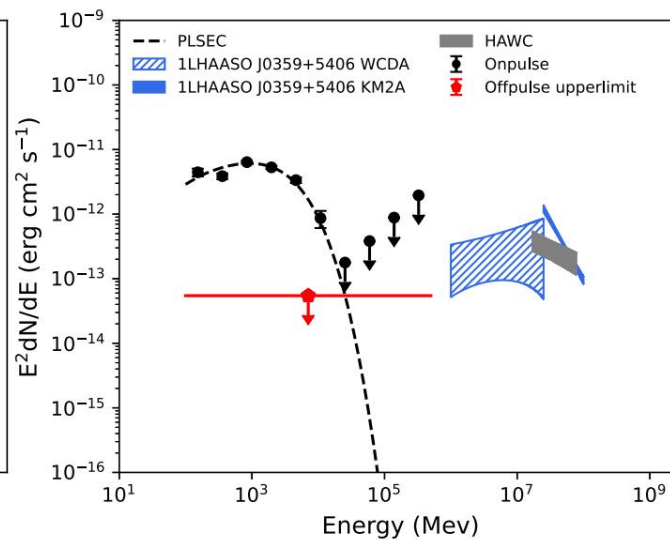
较好的候选体



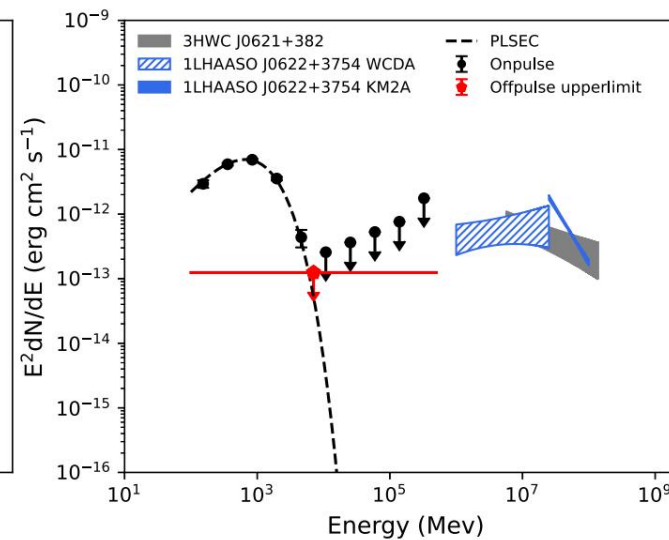
较好的候选体



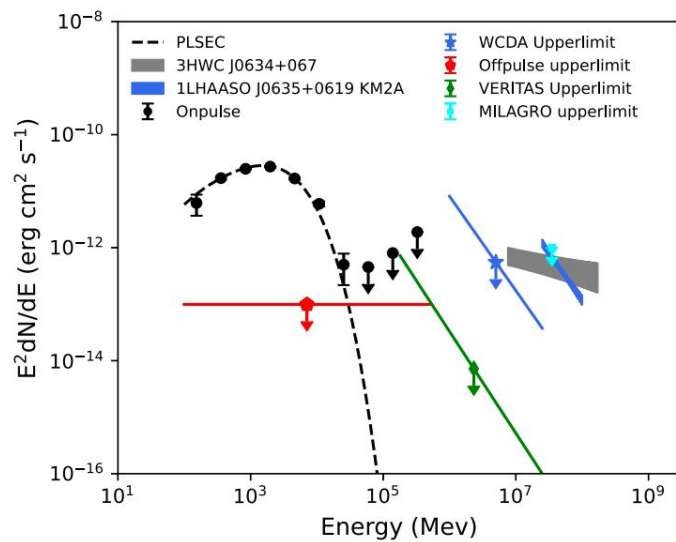
(a) PSR J0248+6021



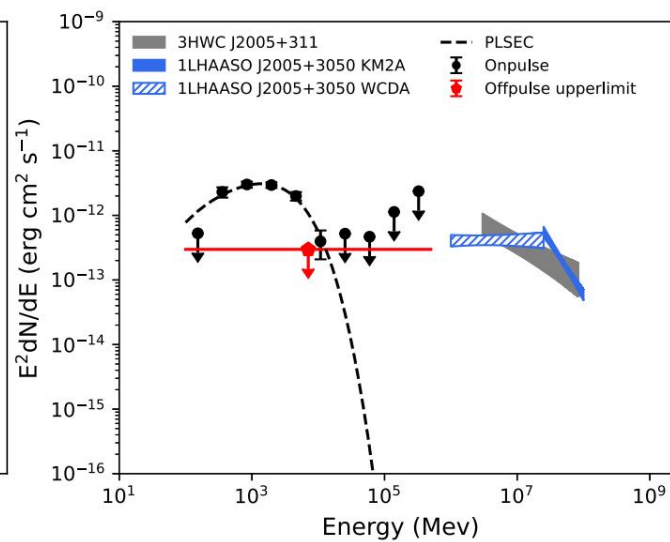
(b) PSR J0359+5414



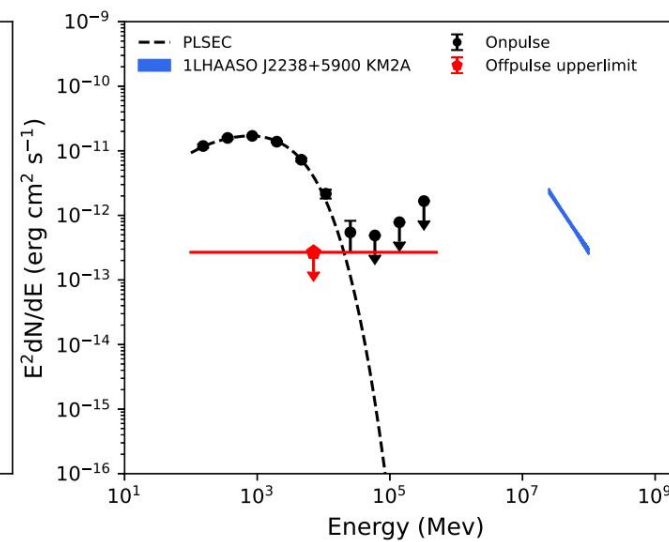
(c) PSR J0622+3749



(d) PSR J0633+0632

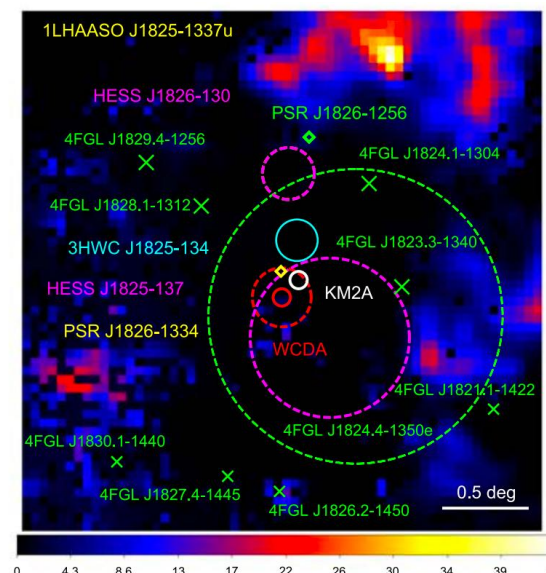
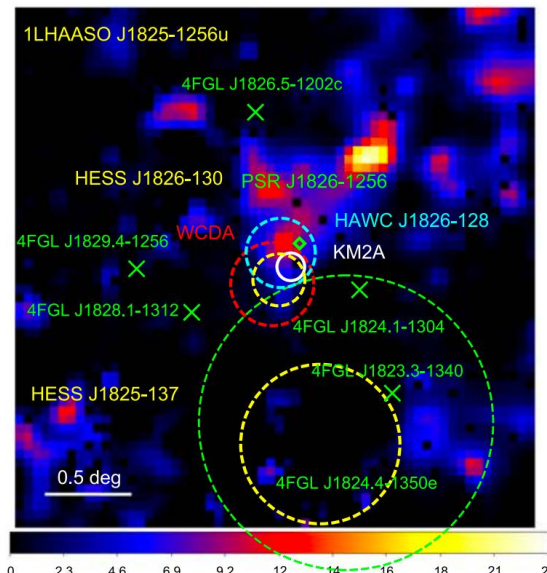
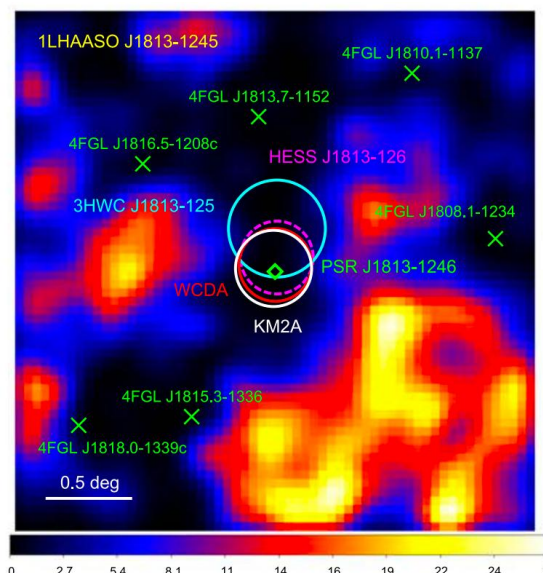
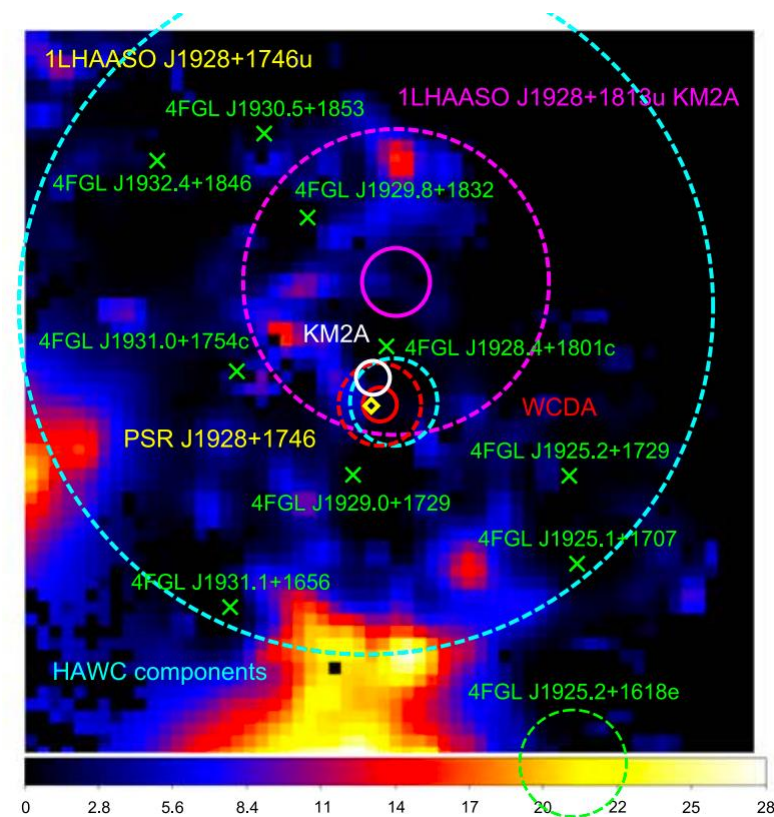
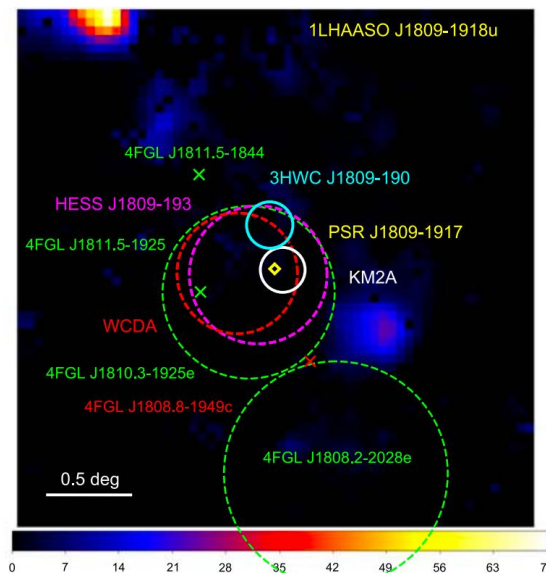
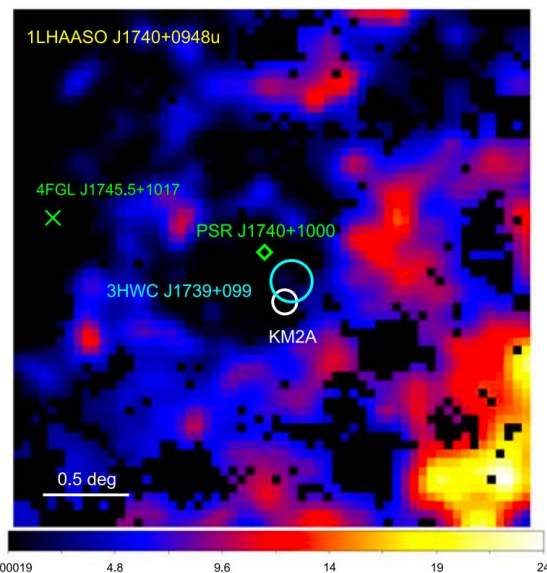
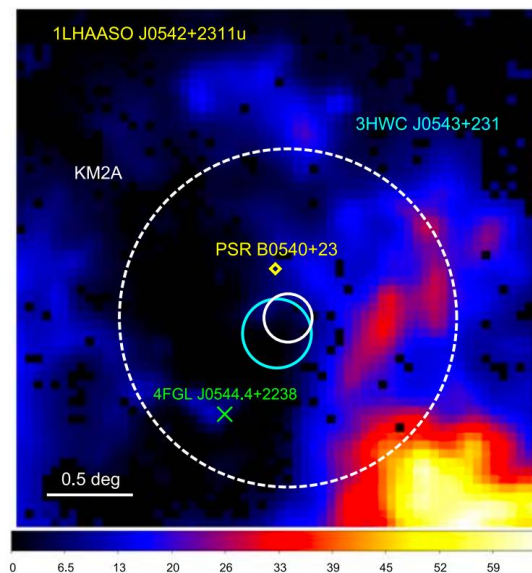


(e) PSR J2006+3102



(f) PSR J2238+5903

可能的候选体





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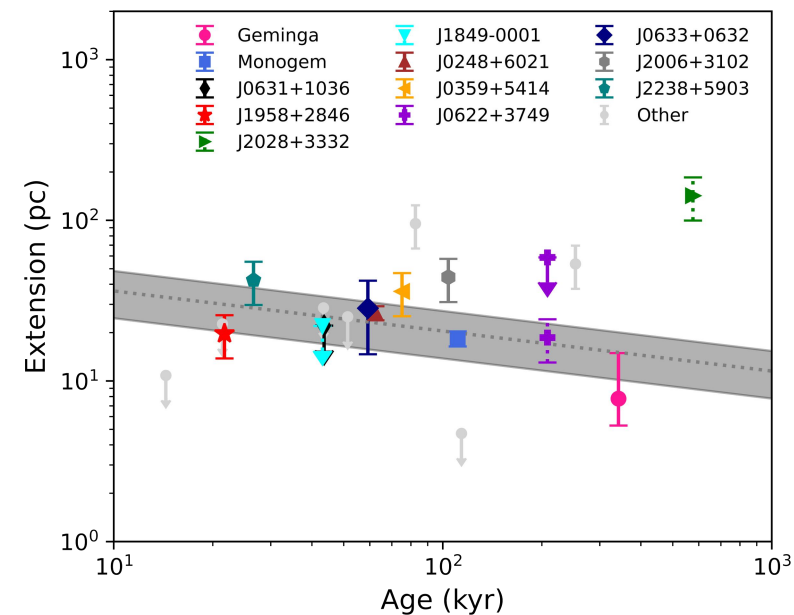
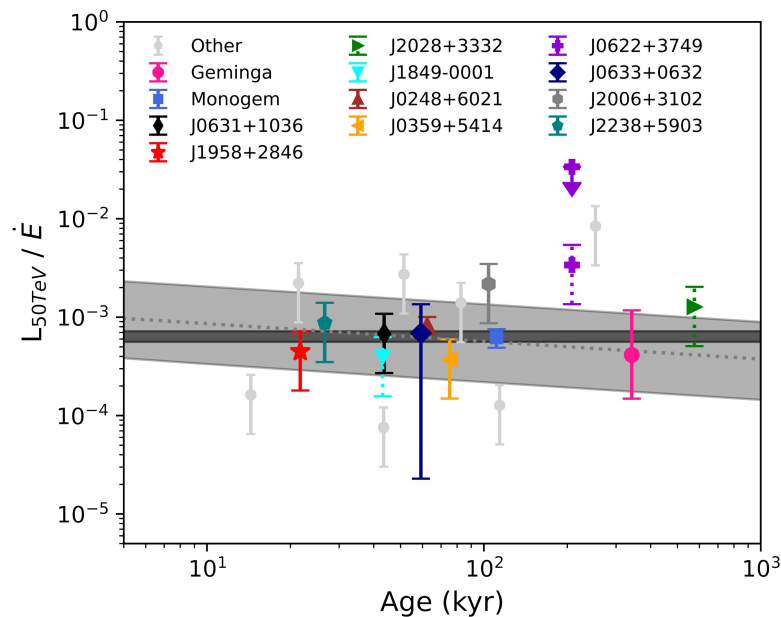
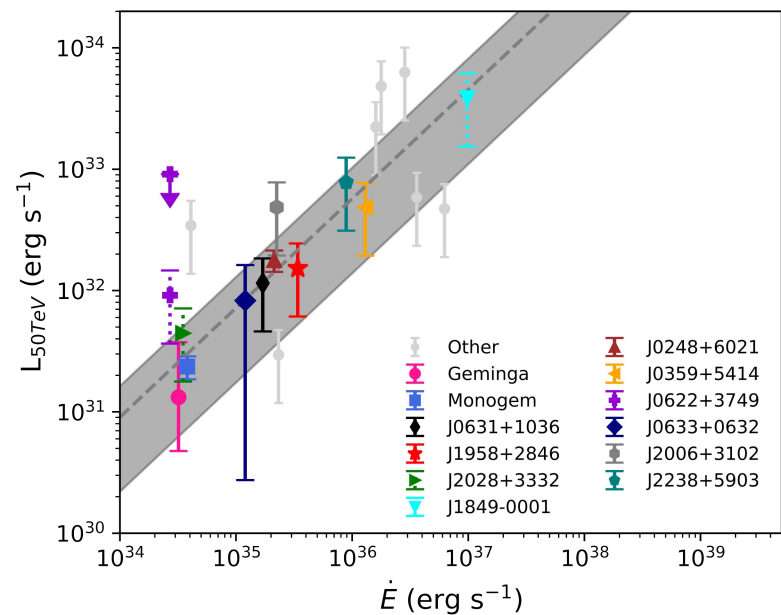
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$$L_{50\text{TeV}} \sim \dot{E}^{0.9}$$

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

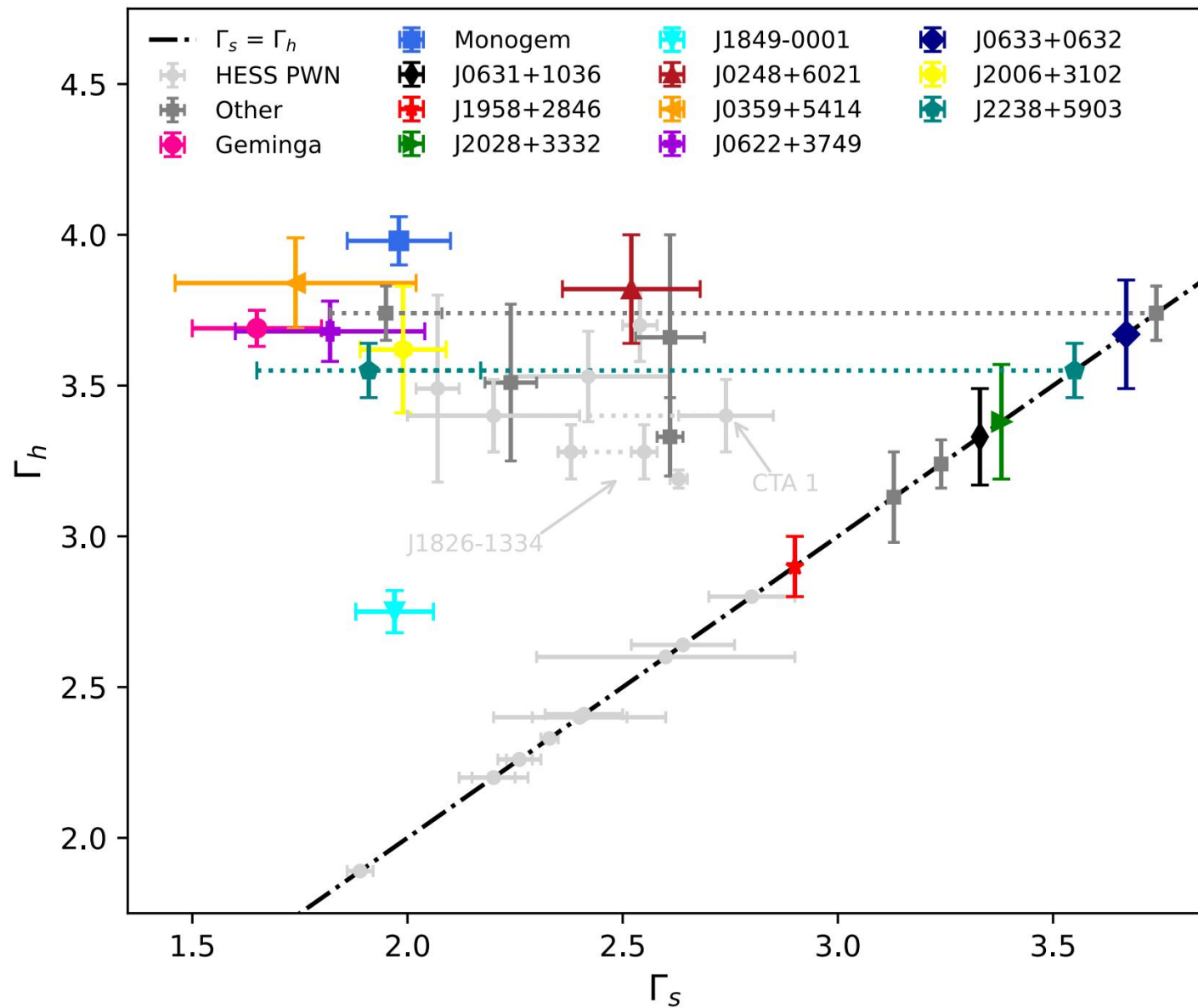
$$S \sim \tau_{\text{kyr}}^{-0.25}$$

Γ_s
WCDA测量谱指数 (1-25 TeV)
H.E.S.S.测量谱指数 (~ 30 TeV)

Γ_h
KM2A测量谱指数 (25-100 TeV)

脉冲星风云
在1-25 TeV能段有较软的谱指数 > 2

脉冲星晕
在1-25 TeV能段有较硬的谱指数 < 2
或者在此能段辐射较弱





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- 脉冲星晕简介
- 3HWC J0631+107/LHAASO J0631+1040
- 脉冲星晕搜寻方法
- 脉冲星晕候选体
- 脉冲星晕性质
- **总结**

目前近我们的工作证认超10个脉冲星晕候选体

可能的脉冲星晕性质

- 脉冲星晕甚高能光度与脉冲星自转能近乎正相关，且两者之间的比例可能为常量；
- 脉冲星晕扩展范围随脉冲星年龄增加有减小的趋势；
- 多数脉冲星晕在X射线和GeV能段没有可探测到的辐射。

脉冲星晕与星风云可能的区别

- 脉冲星风云在1–25 TeV能段有较软的谱指数 >2 ；
- 脉冲星晕在1–25 TeV能段有较硬的谱指数 <2 ，或者在此能段辐射较弱。

3HWC J0631+107/LHAASO J0631+1040: A TeV Halo Powered by the Pulsar J0631+1036?

Zheng, Wang and Xing, ApJ, 2023

Two Candidate Pulsar TeV Halos Identified from Property–similarity Studies

Zheng and Wang, ApJ, 2023

Finding Candidate TeV Halos among Very–High Energy Sources

Zheng and Wang, ApJ, 2024

感谢大家聆听！

请各位老师、同学提出宝贵意见！