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OBSERVATIONS OF PWNE WITH THE FERMI GAMMA-RAY  
SPACE TELESCOPE

A DISSERTATION  
SUBMITTED TO THE DEPARTMENT OF PHYSICS  
AND THE COMMITTEE ON GRADUATE STUDIES  
OF STANFORD UNIVERSITY  
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY

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April 2013

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

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Approved for the University Committee on Graduate Studies

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# List of Acronyms

**1FHL** the first *Fermi* hard-source list. 126

**2CG** the second COS-B catalog. 9

**2FGL** the second *Fermi* catalog. 22, 38, 122, 127

**2PC** the second *Fermi* pulsar catalog. 23, 124, 125

**3EG** the Third EGRET Catalog. 11

**ACD** Anti-Coincidence Detector. vii, 12

**arcsec** second of arc. 32

**BPL** broken-power law. 40

**CGRO** the Compton Gamma Ray Observatory. 10

**CGS** the Centimetre-Gram-Second System of Units. 40, 41

**ECPL** exponentially-cutoff power law. 40, 41

**EGRET** the Energetic Gamma Ray Experiment Telescope. xii, 9–11

**ESA** the European Space Agency. 9

**FWHM** full width at half maximum. 8

**GBM** Gamma-ray Burst Monitor. vii, 12



**IACT** Imaging air Cherenkov detector. 48, 119, 122, 126

**IC** inverse Compton. 6, 19, 20, 31, 32, 35, 126

**LAT** the Large Area Telescope. iv, v, vii, viii, 12, 22, 23, 122, 123, 125–128, 131, 132

**MIT** the Massachusetts Institute of Technology. 6, 13

**MSC** massive star cluster. 125

**MSP** millisecond pulsar. 27

**NASA** the National Aeronautics and Space Administration. 9, 10

**NRL** the Naval Research Laboratory. 13

**NS** neutron star. 13, 25, 26, 30

**OSO-3** the Third Orbiting Solar Observatory. xii, 8, 9, 22

**PL** power law. 40, 41

**PSF** point spread function. 126

**PWN** pulsar wind nebula. iv, v, xiii, 1, 6, 14, 25, 29, 31–35, 122, 123, 125–132

**SA** solid angle. 42, 43

**SAS-2** the second Small Astronomy Satellite. 9, 10

**SNR** supernova remnant. 29, 32, 41

**UNID** unidentified source. 125, 126

**VHE** very high energy. ix, xi, 122–131, 134

## Chapter 9

# Population Study of LATs-detected PWNe

Chapter ??

*This chapter is based the second part of the the paper “Constraints on the Galactic Population of TeV Pulsar Wind Nebulae using Fermi Large Area Telescope Observations” by Acero et al which is currently in prep.*

In Chapter 6, we search for new spatially-extended *Fermi* sources and found that spatial extension was an important characteristic for detecting new pulsar wind nebulae (PWNe). In the process, we discovered three new  $\gamma$ -ray emitting PWNs.

In Chapter 7, we then searched in the off-peak phase interval of the Large Area Telescope (LAT)-detected pulsars for new pulsar wind nebula and discovered 3C 58. Finally, in Chapter 8 we searched in the regions surrounding PWNs candidates detected at TeV energies for GeV-emitting PWNs 4 new PWNe candidates (HESS J1119–614, HESS J1303–631, HESS J1420–607, and HESS J1841–055) and 1 new PWN (HESS J1356–645)

In this chapter, we take the population of  $\gamma$ -ray emitting PWNs and PWNs candidates and study how thier multiwavlenth properties vary with propergies of the associated pulsar.

## 9.1 Summary of the PWNe detected by the LATs

## 9.2 The Evolution of $\gamma$ -ray Emitting PWNe with the Properties of their Pulsars

Here we need to cite Mattana et al. (2009).

Table 9.1.

Source	$F_{1\text{ TeV}}^{30\text{ TeV}}$ ( $10^{-12}\text{erg cm}^{-2}\text{s}^{-1}$ )	$F_{1\text{ KeV}}^{10\text{ KeV}}$ ( $10^{-12}\text{erg cm}^{-2}\text{s}^{-1}$ )	PSR	$\dot{E}$ ( $\text{erg s}^{-1}$ )	$\tau$ (kyr)	Distance (kpc)
VERJ0006+727	...	...	PSRJ0007+7303	4.5e+35	13.9	$1.4 \pm 0.3$
Crab	$80 \pm 16$	$21000 \pm 4200$	PSR J0534+2200	4.6e+38	1.2	$2.0 \pm 0.5$
MGROJ0631+105	...	...	PSRJ0631+1036	1.7e+35	43.6	$1.00 \pm 0.20$
MGROJ0632+17	...	...	PSRJ0633+1746	3.2e+34	342	$0.2^{+0.2}_{-0.1}$
Vela-X	$79 \pm 21$	$54 \pm 11$	PSRJ0835-4510	6.9e+36	11.3	$0.29 \pm 0.02$
HESSJ1018-589	$0.9 \pm 0.4$	...	PSRJ1016-5857	2.6e+36	21	3
HESSJ1023-575	$4.8 \pm 1.7$	...	PSRJ1023-5746	1.1e+37	4.6	2.8
HESSJ1026-582	$5.9 \pm 4.4$	...	PSRJ1028-5819	8.4e+35	90	$2.3 \pm 0.3$
HESSJ1119-614	$2.3 \pm 1.2$	...	PSRJ1119-6127	2.3e+36	1.6	$8.4 \pm 0.4$
HESSJ1303-631	$27 \pm 1$	$0.16 \pm 0.03$	PSRJ1301-6305	1.7e+36	11	$6.7^{+1.1}_{-1.2}$
HESSJ1356-645	$6.7 \pm 3.7$	$0.06 \pm 0.01$	PSRJ1357-6429	3.1e+36	7.3	$2.5^{+0.5}_{-0.4}$
HESSJ1418-609	$3.4 \pm 1.8$	$3.1 \pm 0.1$	PSRJ1418-6058	4.9e+36	1	$1.6 \pm 0.7$
HESSJ1420-607	$15 \pm 3$	$1.3 \pm 0.3$	PSRJ1420-6048	1.0e+37	13	$5.6 \pm 0.9$
HESSJ1458-608	$3.9 \pm 2.4$	...	PSRJ1459-6053	9.1e+35	64.7	4
HESSJ1514-591	$20 \pm 4$	$29 \pm 6$	PSRJ1513-5906	1.7e+37	1.56	$4.2 \pm 0.6$
HESSJ1554-550	$1.6 \pm 0.5$	$3.1 \pm 1.0$	...	...	18	$7.8 \pm 1.3$
HESSJ1616-508	$21 \pm 5$	$4.2 \pm 0.8$	PSRJ1617-5055	1.6e+37	8.13	$6.8 \pm 0.7$
HESSJ1632-478	$15 \pm 5$	$0.43 \pm 0.08$	...	3.0e+36	20	3
HESSJ1640-465	$5.5 \pm 1.2$	$0.46 \pm 0.09$	...	4.0e+36	...	...
HESSJ1646-458B	$5.0 \pm 2.0$	...	PSRJ1648-4611	2.1e+35	110	$5.0 \pm 0.7$
HESSJ1702-420	$9.0 \pm 3.0$	$0.01 \pm 0.00$	PSRJ1702-4128	3.4e+35	55	$4.8 \pm 0.6$
HESSJ1708-443	$23 \pm 7$	...	PSRJ1709-4429	3.4e+36	17.5	$2.3 \pm 0.3$
HESSJ1718-385	$4.3 \pm 1.6$	$0.14 \pm 0.03$	PSRJ1718-3825	1.3e+36	89.5	$3.6 \pm 0.4$
HESSJ1804-216	$12 \pm 2$	$0.07 \pm 0.01$	PSRJ1803-2137	2.2e+36	16	$3.8^{+0.4}_{-0.5}$
HESSJ1809-193	$19 \pm 6$	$0.23 \pm 0.05$	PSRJ1809-1917	1.8e+36	51.3	$3.5 \pm 0.4$
HESSJ1813-178	$5.0 \pm 0.6$	...	PSRJ1813-1749	6.8e+37	5.4	4.7
HESSJ1818-154	$1.3 \pm 0.9$	...	PSRJ1818-1541	2.3e+33	9	$7.8^{+1.6}_{-1.4}$
HESSJ1825-137	$61 \pm 14$	$0.44 \pm 0.09$	PSRJ1826-1334	2.8e+36	21	$3.9 \pm 0.4$
HESSJ1831-098	$5.1 \pm 0.6$	...	PSRJ1831-0952	1.1e+36	128	$4.0 \pm 0.4$
HESSJ1833-105	$2.4 \pm 1.2$	$40 \pm 0$	PSRJ1833-1034	3.4e+37	4.85	$4.7 \pm 0.4$
HESSJ1837-069	$23 \pm 9$	$0.64 \pm 0.24$	PSRJ1836-0655	5.5e+36	2.23	$6.6 \pm 0.9$
HESSJ1841-055	$23 \pm 3$	...	PSRJ1838-0537	5.9e+36	4.97	1.3
HESSJ1846-029	$9.0 \pm 1.5$	$29 \pm 1$	PSRJ1846-0258	8.1e+36	0.73	5.1
HESSJ1848-018	$4.3 \pm 1.0$	...	...	...	...	6
HESSJ1849-000	$2.1 \pm 0.4$	$0.90 \pm 0.20$	PSRJ1849-001	9.8e+36	42.9	7
HESSJ1857+026	$18 \pm 3$	...	PSRJ1856+0245	4.6e+36	20.6	$9.0 \pm 1.2$
MGROJ1908+06	$12 \pm 5$	...	PSRJ1907+0602	2.8e+36	19.5	$3.2 \pm 0.3$
HESSJ1912+101	$7.3 \pm 3.7$	...	PSRJ1913+1011	2.9e+36	169	$4.8^{+0.5}_{-0.7}$

Table 9.1 (cont'd)

Source	$F_{1\text{ TeV}}^{30\text{ TeV}}$ ( $10^{-12}\text{erg cm}^{-2}\text{s}^{-1}$ )	$F_{1\text{ KeV}}^{10\text{ KeV}}$ ( $10^{-12}\text{erg cm}^{-2}\text{s}^{-1}$ )	PSR	$\dot{E}$ ( $\text{erg s}^{-1}$ )	$\tau$ (kyr)	Distance (kpc)
VERJ1930+188	$2.3 \pm 1.3$	$5.2 \pm 0.1$	PSRJ1930+1852	$1.2\text{e}+37$	2.89	$9^{+7}_{-2}$
VERJ1959+208	...	...	PSRJ1959+2048	$1.6\text{e}+35$	...	$2.5 \pm 1.0$
MGROJ2019+37	...	...	PSRJ2021+3651	$3.4\text{e}+36$	17.2	$10^{+2}_{-4}$
MGROJ2228+61	...	$0.88 \pm 0.02$	PSRJ2229+6114	$2.2\text{e}+37$	10.5	$0.80 \pm 0.20$

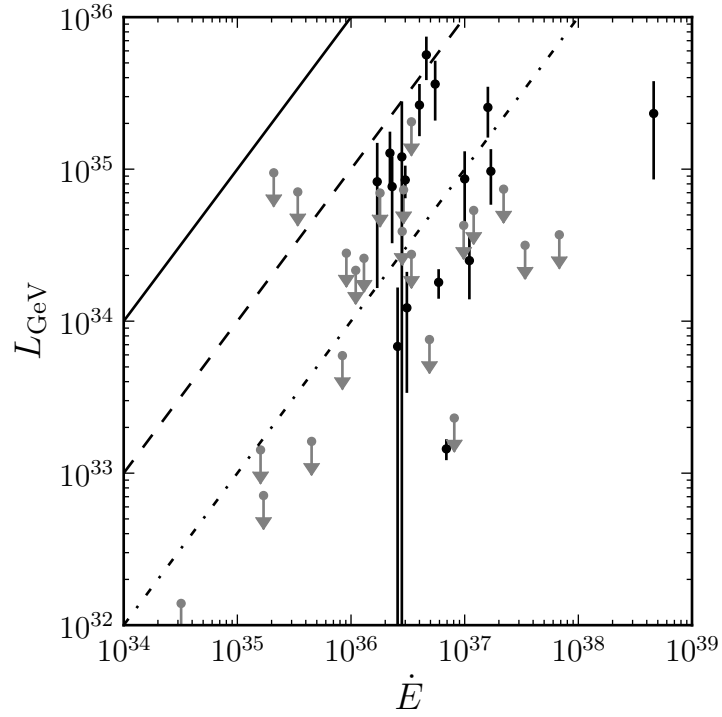


Figure 9.1 ...

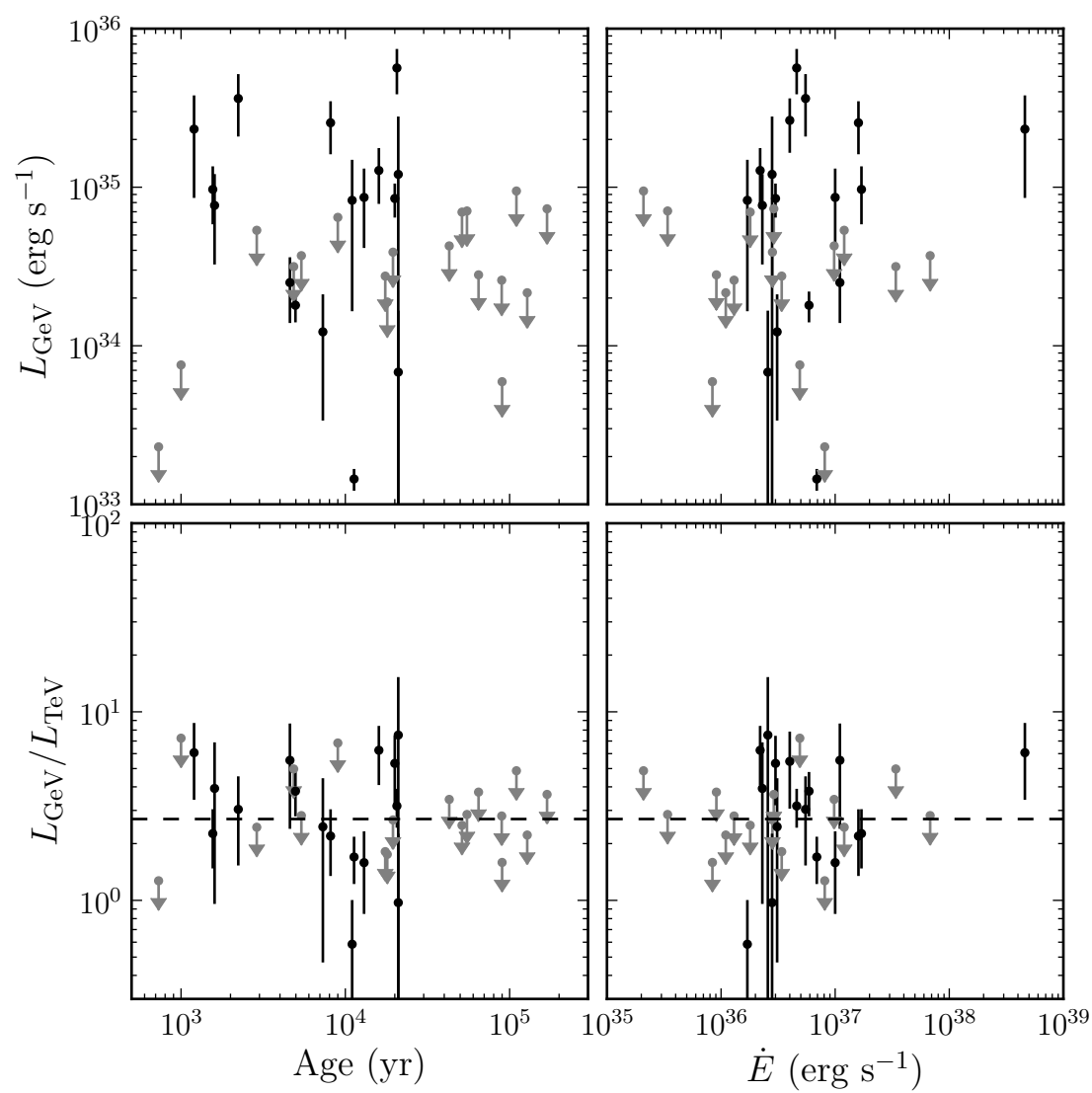


Figure 9.2 ...

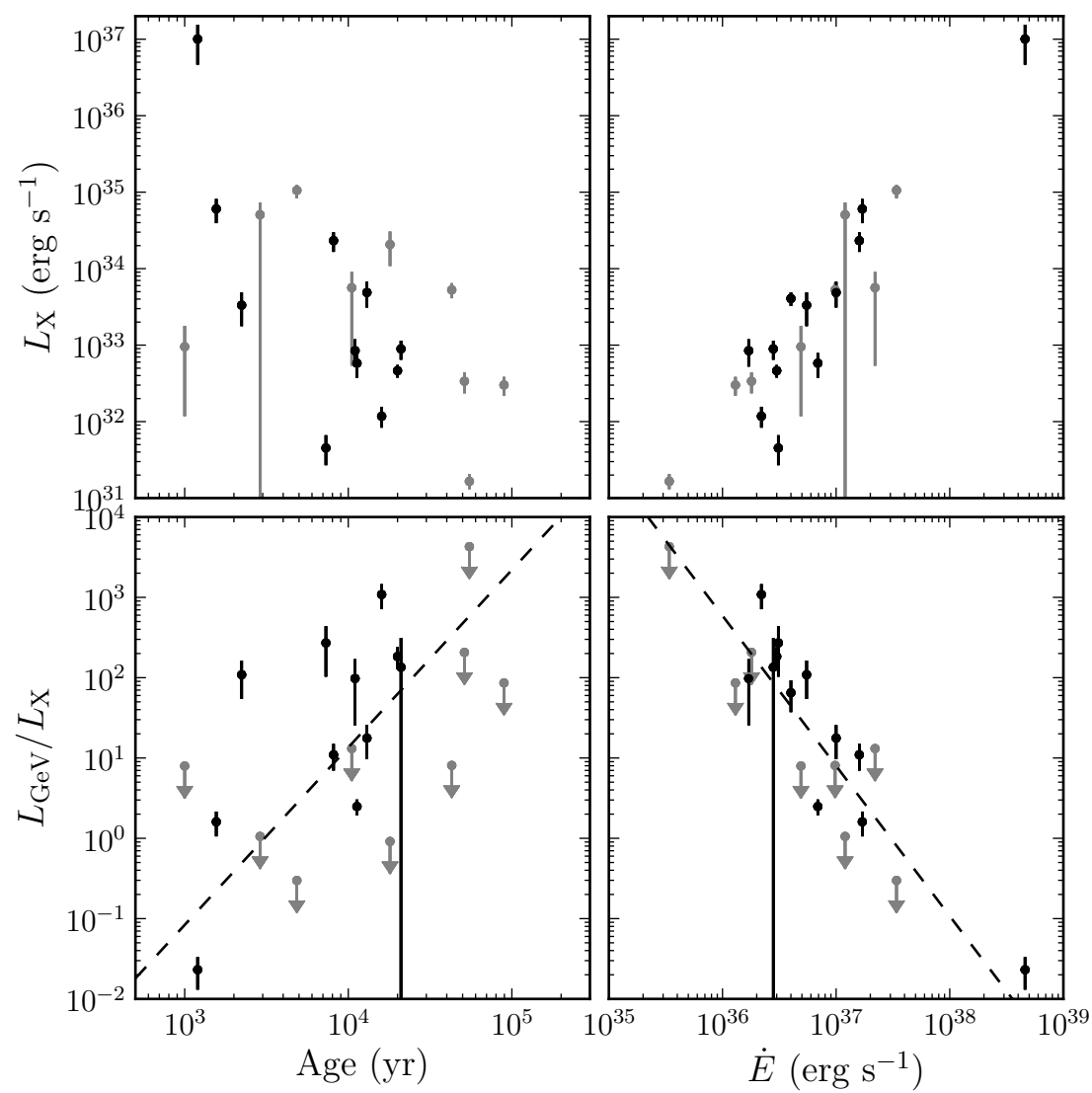


Figure 9.3 ...

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