Todo list

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

Joshua Jeremy Lande
April 2013

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.

(Stefan Funk) Principal Adviser

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.

(Elliott Bloom)

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.

(Roger Romani)

Approved for the University Committee on Graduate Studies

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List of Acronyms

1FHL the first *Fermi* hard-source list. 122

2CG the second COS-B catalog. 8

2FGL the second *Fermi* catalog. 21, 36, 118, 123

2PC the second *Fermi* pulsar catalog. 22, 120, 121

3EG the Third EGRET Catalog. 9

ACD Anti-Coincidence Detector. 11

arcsec second of arc. 31

BPL broken-power law. 38

CGRO the Compton Gamma Ray Observatory. 8

CGS the Centimetre-Gram-Second System of Units. 38, 39

ECPL exponentially-cutoff power law. 38, 39

EGRET the Energetic Gamma Ray Experiment Telescope. 8–10

ESA the European Space Agency. 8

FWHM full width at half maximum. 6

GBM Gamma-ray Burst Monitor. 11

IACT Imaging air Cherenkov detector. 46, 115, 118, 122

IC inverse Compoton. 4, 18, 19, 30, 31, 34, 122

LAT the Large Area Telescope. iv, v, 11, 21, 22, 118, 119, 121–124, 127, 128

MIT the Massachusetts Institute of Technology. 6, 12

MSC massive star cluster. 121

MSP millisecond pulsar. 26

NASA the National Aeronautics and Space Administration. 7, 8

NRL the Naval Research Laboratory. 12

NS neutron star. 12, 24, 25, 28, 29

OSO-3 the Third Orbiting Solar Observatory. 6, 7, 20

PL power law. 38, 39

PSF point spread function. 122

PWN pulsar wind nebula. iv, v, 5, 13, 24, 28, 30–34, 118, 119, 121–128

SA solid angle. 40, 41

SAS-2 the second Small Astronomy Satellite. 7, 8

SNR supernova remnant. 28, 30, 31, 39

UNID unidentified source. 121, 122

VHE very high energy. 118–127, 130

Chapter 9

Population Study of LAT-detected PWNe

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 extenion was an important characteristic for detecting new pulsar wind nebulae (PWNe). In the process, we discovered three new γ-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 γ-ray emitting PWNs and PWNs candidates and study how thier multiwavlenth properties vary with propergies of the associated pulsar.

In Table 1.1, we compile the multiwavelenth properties of the very high energy (VHE) sources studied in Chapter 8. In particular, we include the spectrum observed at X-ray and VHE energies, the name of the associated pulsar, and the observed spin-down power, age, and distance of the pulsar.

Add figure caption to this table/make sure it automatically generates figure label

Table 9.1. The muliwavelenth propergies of the VHE source and their associated LAT-detected pulsar.

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

Table 9.1 (cont'd)

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

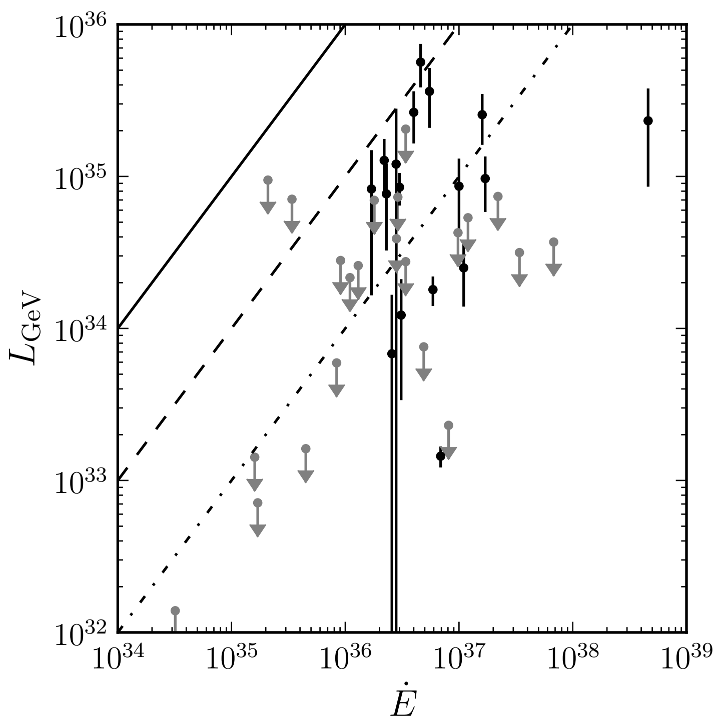

Figure 9.1 ...

In Figure 1.1, we compare the observed luminosity at GeV energies to the spin-down power of the observed pulsar. This plot shows that all LAT-detected PWNs emmit a fraction $\lesssim 10\%$ of their spin-down energy into powering the γ-ray emission from the pulsar wind.

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

Next, we will discuss Figure 1.2...

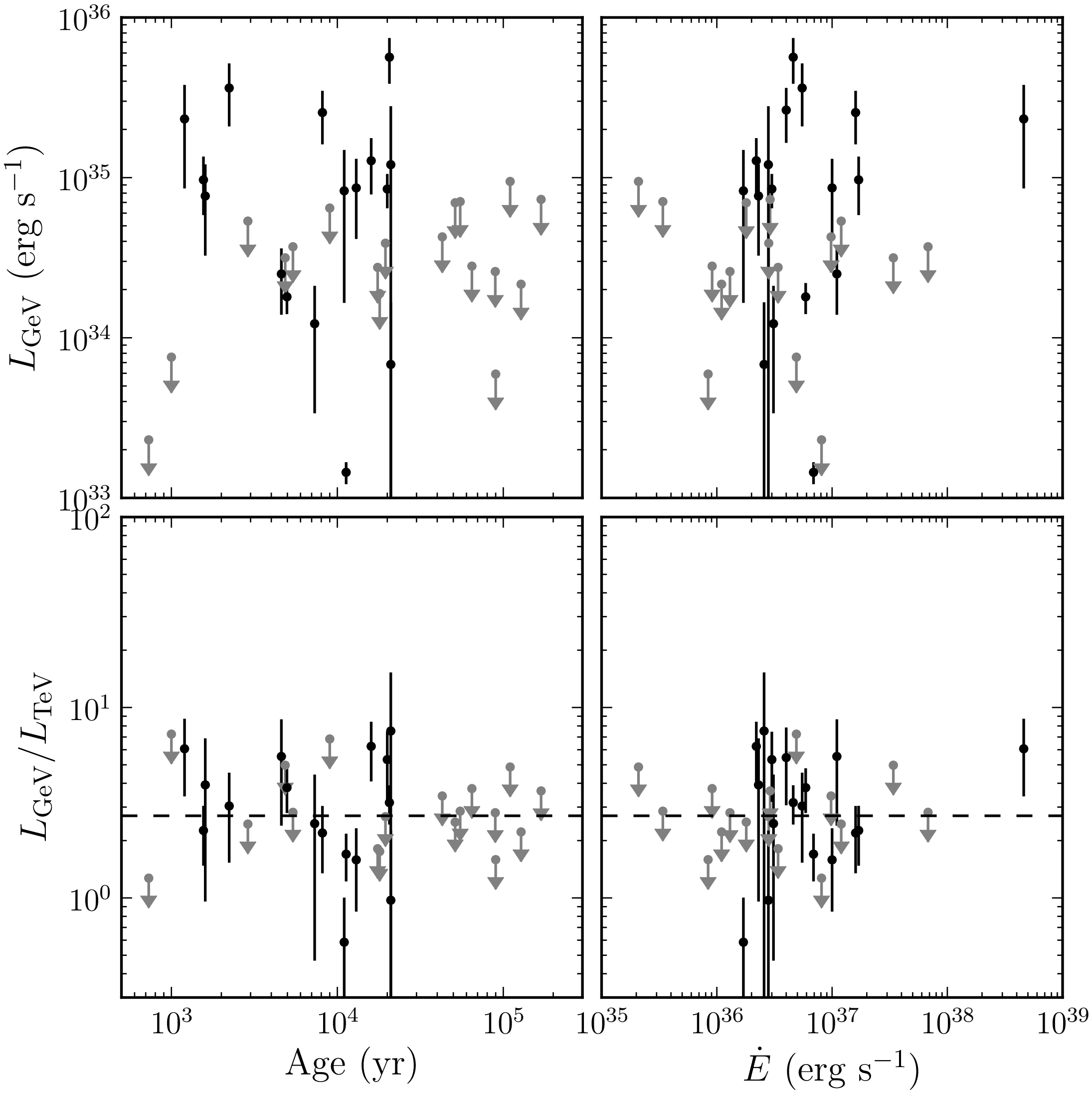
10^{36}
10^{35}
10^{34}
10^{33}
L_{GeV} (erg s^{-1})
10^{2}
10^{1}
10^{0}
$L_{\mathrm{GeV}}/L_{\mathrm{TeV}}$
10^{3}
10^{4}
10^{5}
Age (yr)
10^{35}
10^{36}
10^{37}
10^{38}
10^{39}
$\dot{E}$ (erg s^{-1})

Figure 9.2 ...

Next, we will discuss Figure 1.3. . .

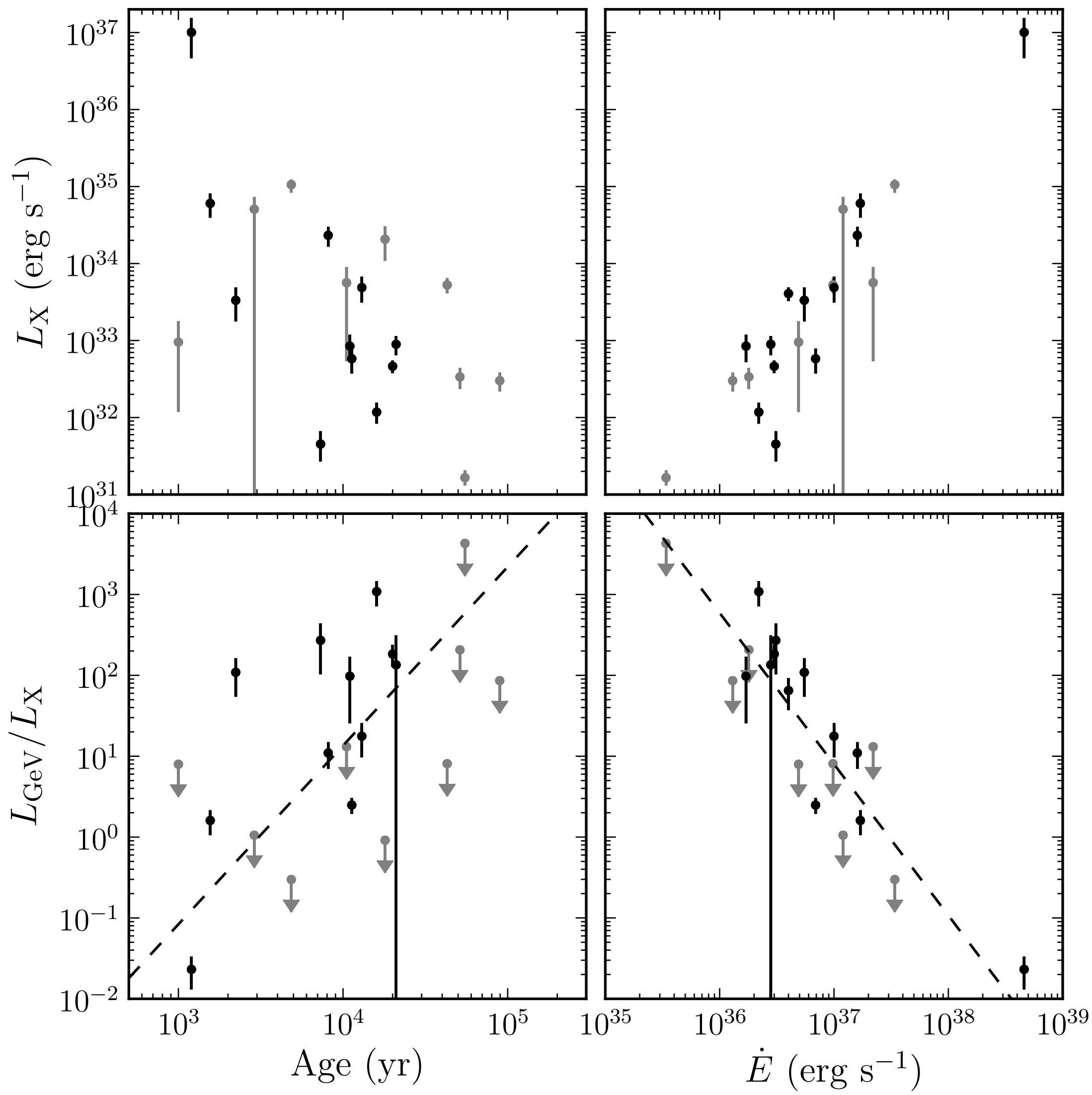
L_X (erg s^{-1})
L_{GeV}/L_X
Age (yr)
$\dot{E}$ (erg s^{-1})
10^{37}
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{5}
10^{35}
10^{36}
10^{38}
10^{39}

Figure 9.3 ...

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