Todo list

NEUTRON STAR POWERED NEBULAE: A NEW VIEW ON PULSAR WIND NEBULAE WITH THE FERMI GAMMA-RAY SPACE TELESCOPE

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF PHYSICS
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FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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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.

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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. 135

2CG the second COS-B catalog. 10

2FGL the second *Fermi* catalog. 23, 24, 47, 131, 136

2PC the second *Fermi* pulsar catalog. 23–25, 133, 134

3EG the Third EGRET Catalog. 12

ACD Anti-Coincidence Detector. xii, 14, 15

AGILE Astro-rivelatore Gamma a Immagini LEggero. 12, 26

AGN active galactic nucleus. 24

arcsec second of arc. 41

ASI Italian Space Agency. 12

ATNF Australia Telescope National Facility. 19

BPL broken-power law. 50

CGRO the Compton Gamma Ray Observatory. 11

CGS the Centimetre-Gram-Second System of Units. 49–51

CMB cosmic microwave background. 43

CsI cesium iodide. 15

DOE United States Department of Energy. 12

ECPL exponentially-cutoff power law. 50

EGRET the Energetic Gamma Ray Experiment Telescope. xii, 10–13, 19, 25, 48, 55

ESA the European Space Agency. 10

FWHM full width at half maximum. 9

GBM Gamma-ray Burst Monitor. 14

GRB gamma-ray burst. 14

H.E.S.S. the High Energy Stereoscopic System. xxi, xxiv, 28, 29, 47, 58, 112, 114, 116, 117, 119, 124, 127, 128

HMB high-mass binary. 24

IACT Imaging air Cherenkov detector. 21, 58, 128, 131, 135

IC inverse Compoton. 7, 21, 23, 28, 29, 31, 32, 40, 41, 43, 44, 135

LAT the Large Area Telescope. iv, v, vii, xi–xiii, 14–18, 22–26, 28, 29, 40, 45, 51–53, 55, 131, 132, 134–137, 140–142, 144

LMC Large Magellanic Cloud. 21

LRT likelihood-ratio test. 49, 55

MIT the Massachusetts Institute of Technology. 7, 18

MSC massive star cluster. 134

MSP millisecond pulsar. 25, 36

NASA the National Aeronautics and Space Administration. 10–12

NRL the Naval Research Laboratory. 18

NS neutron star. 18, 21, 34, 35, 39

OG outer gap. 39, 40

OSO-3 the Third Orbiting Solar Observatory. xii, 9, 10

PC polar cap. 39

PL power law. 50

PSF point spread function. 16, 56, 135

PWN pulsar wind nebula. iv, v, xiv, xxv, 7, 19, 21, 23–26, 28, 29, 34, 38, 40–44, 51, 131, 132, 134–144

SA solid angle. 51, 52

SAS-2 the second Small Astronomy Satellite. 10, 11

SED spectral energy distribution. xiii, 26, 27

SN supernova. 19, 21

SNR supernova remnant. 16, 24, 26, 38, 40, 41, 51

TPC two pole caustic. 39, 40

UNID unidentified source. 134, 135

VHE very high energy. ix, xi, xiii, 21, 26–28, 44, 131–142

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 9.1, 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.

Table 9.1. The muliwavelenth properties of the VHE source and their associated LAT-detected pulsars.

Source	$F_{1\ \mathrm{TeV}}^{30\ \mathrm{TeV}}$ (10^{-12}erg cm^{-2}s^{-1})	$F_{2\ \mathrm{keV}}^{10\ \mathrm{keV}}$ (10^{-12}erg cm^{-2}s^{-1})	PSR	$\dot{E}$ (erg s^{-1})	τ (kyr)	Distance (kpc)
VER J0006+727	···	···	PSR J0007+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
MGRO J0631+105	···	···	PSR J0631+1036	1.7e+35	43.6	1.00 ± 0.20
MGRO J0632+17	···	···	PSR J0633+1746	3.2e+34	342	$0.2^{+0.2}_{-0.1}$
Vela−X	79 ± 21	54 ± 11	PSR J0835−4510	6.9e+36	11.3	0.29 ± 0.02
HESS J1018−589	0.9 ± 0.4	···	PSR J1016−5857	2.6e+36	21	3
HESS J1023−575	4.8 ± 1.7	···	PSR J1023−5746	1.1e+37	4.6	2.8
HESS J1026−582	5.9 ± 4.4	···	PSR J1028−5819	8.4e+35	90	2.3 ± 0.3
HESS J1119−614	2.3 ± 1.2	···	PSR J1119−6127	2.3e+36	1.6	8.4 ± 0.4
HESS J1303−631	27 ± 1	0.16 ± 0.03	PSR J1301−6305	1.7e+36	11	$6.7^{+1.1}_{-1.2}$
HESS J1356−645	6.7 ± 3.7	0.06 ± 0.01	PSR J1357−6429	3.1e+36	7.3	$2.5^{+0.5}_{-0.4}$
HESS J1418−609	3.4 ± 1.8	3.1 ± 0.1	PSR J1418−6058	4.9e+36	1	1.6 ± 0.7
HESS J1420−607	15 ± 3	1.3 ± 0.3	PSR J1420−6048	1.0e+37	13	5.6 ± 0.9
HESS J1458−608	3.9 ± 2.4	···	PSR J1459−6053	9.1e+35	64.7	4
HESS J1514−591	20 ± 4	29 ± 6	PSR J1513−5906	1.7e+37	1.56	4.2 ± 0.6
HESS J1554−550	1.6 ± 0.5	3.1 ± 1.0	···	···	18	7.8 ± 1.3
HESS J1616−508	21 ± 5	4.2 ± 0.8	PSR J1617−5055	1.6e+37	8.13	6.8 ± 0.7
HESS J1632−478	15 ± 5	0.43 ± 0.08	···	3.0e+36	20	3
HESS J1640−465	5.5 ± 1.2	0.46 ± 0.09	···	4.0e+36	···	···
HESS J1646−458B	5.0 ± 2.0	···	PSR J1648−4611	2.1e+35	110	5.0 ± 0.7
HESS J1702−420	9.0 ± 3.0	0.01 ± 0.00	PSR J1702−4128	3.4e+35	55	4.8 ± 0.6
HESS J1708−443	23 ± 7	···	PSR J1709−4429	3.4e+36	17.5	2.3 ± 0.3
HESS J1718−385	4.3 ± 1.6	0.14 ± 0.03	PSR J1718−3825	1.3e+36	89.5	3.6 ± 0.4
HESS J1804−216	12 ± 2	0.07 ± 0.01	PSR J1803−2137	2.2e+36	16	$3.8^{+0.4}_{-0.5}$
HESS J1809−193	19 ± 6	0.23 ± 0.05	PSR J1809−1917	1.8e+36	51.3	3.5 ± 0.4
HESS J1813−178	5.0 ± 0.6	···	PSR J1813−1749	6.8e+37	5.4	4.7
HESS J1818−154	1.3 ± 0.9	···	PSR J1818−1541	2.3e+33	9	$7.8^{+1.6}_{-1.4}$
HESS J1825−137	61 ± 14	0.44 ± 0.09	PSR J1826−1334	2.8e+36	21	3.9 ± 0.4
HESS J1831−098	5.1 ± 0.6	···	PSR J1831−0952	1.1e+36	128	4.0 ± 0.4
HESS J1833−105	2.4 ± 1.2	40 ± 0	PSR J1833−1034	3.4e+37	4.85	4.7 ± 0.4
HESS J1837−069	23 ± 9	0.64 ± 0.24	PSR J1836−0655	5.5e+36	2.23	6.6 ± 0.9
HESS J1841−055	23 ± 3	···	PSR J1838−0537	5.9e+36	4.97	1.3
HESS J1846−029	9.0 ± 1.5	29 ± 1	PSR J1846−0258	8.1e+36	0.73	5.1
HESS J1848−018	4.3 ± 1.0	···	···	···	···	6
HESS J1849−000	2.1 ± 0.4	0.90 ± 0.20	PSR J1849−001	9.8e+36	42.9	7
HESS J1857+026	18 ± 3	···	PSR J1856+0245	4.6e+36	20.6	9.0 ± 1.2
MGRO J1908+06	12 ± 5	···	PSR J1907+0602	2.8e+36	19.5	3.2 ± 0.3
HESS J1912+101	7.3 ± 3.7	···	PSR J1913+1011	2.9e+36	169	$4.8^{+0.5}_{-0.7}$
VER J1930+188	2.3 ± 1.3	5.2 ± 0.1	PSR J1930+1852	1.2e+37	2.89	9^{+7}_{-2}
VER J1959+208	···	···	PSR J1959+2048	1.6e+35	···	2.5 ± 1.0
MGRO J2019+37	···	···	PSR J2021+3651	3.4e+36	17.2	10^{+2}_{-4}
MGRO J2228+61	···	0.88 ± 0.02	PSR J2229+6114	2.2e+37	10.5	0.80 ± 0.20

Note. — For the VHE PWN candidates, their multiwavelenth properties. This table includes the X-ray flux in the 1 TeV to 30 TeV energy range, the [INSERT MANUALLY]

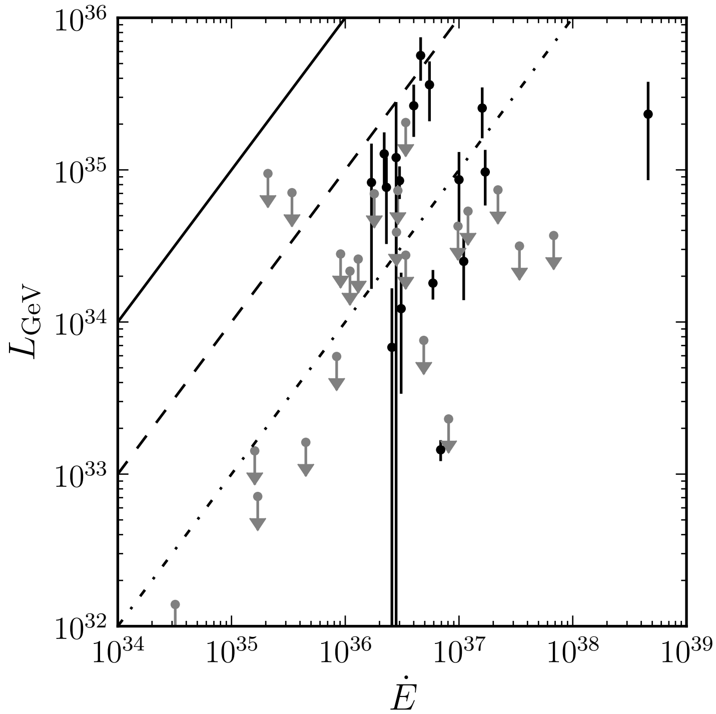

Figure 9.1 The observed γ-ray luminosity compared to the observed spin-down luminosity for all PWN candidates presented in Table 9.1.

In Figure 9.1, 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 9.2...

Next, we will discuss Figure 9.3...

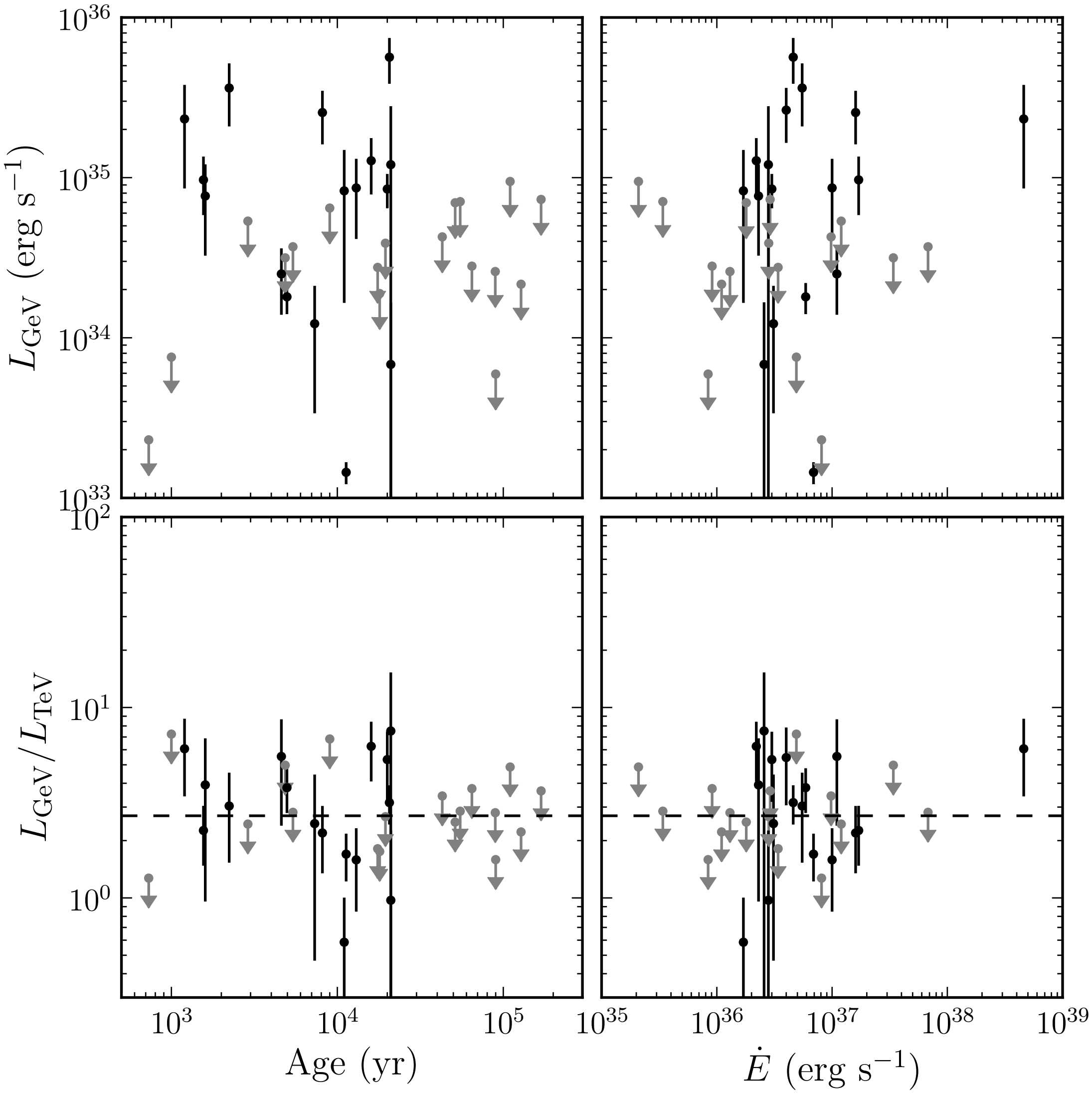
10^{36}
10^{35}
10^{34}
10^{33}
L_{GeV} (erg s^{-1})
10^{2}
10^{1}
10^{0}
$L_{\mathrm{GeV}}/L_{\mathrm{TeV}}$
10^{3}
10^{4}
10^{5}
Age (yr)
10^{35}
10^{36}
10^{37}
10^{38}
10^{39}
$\dot{E}$ (erg s^{-1})

Figure 9.2 ...

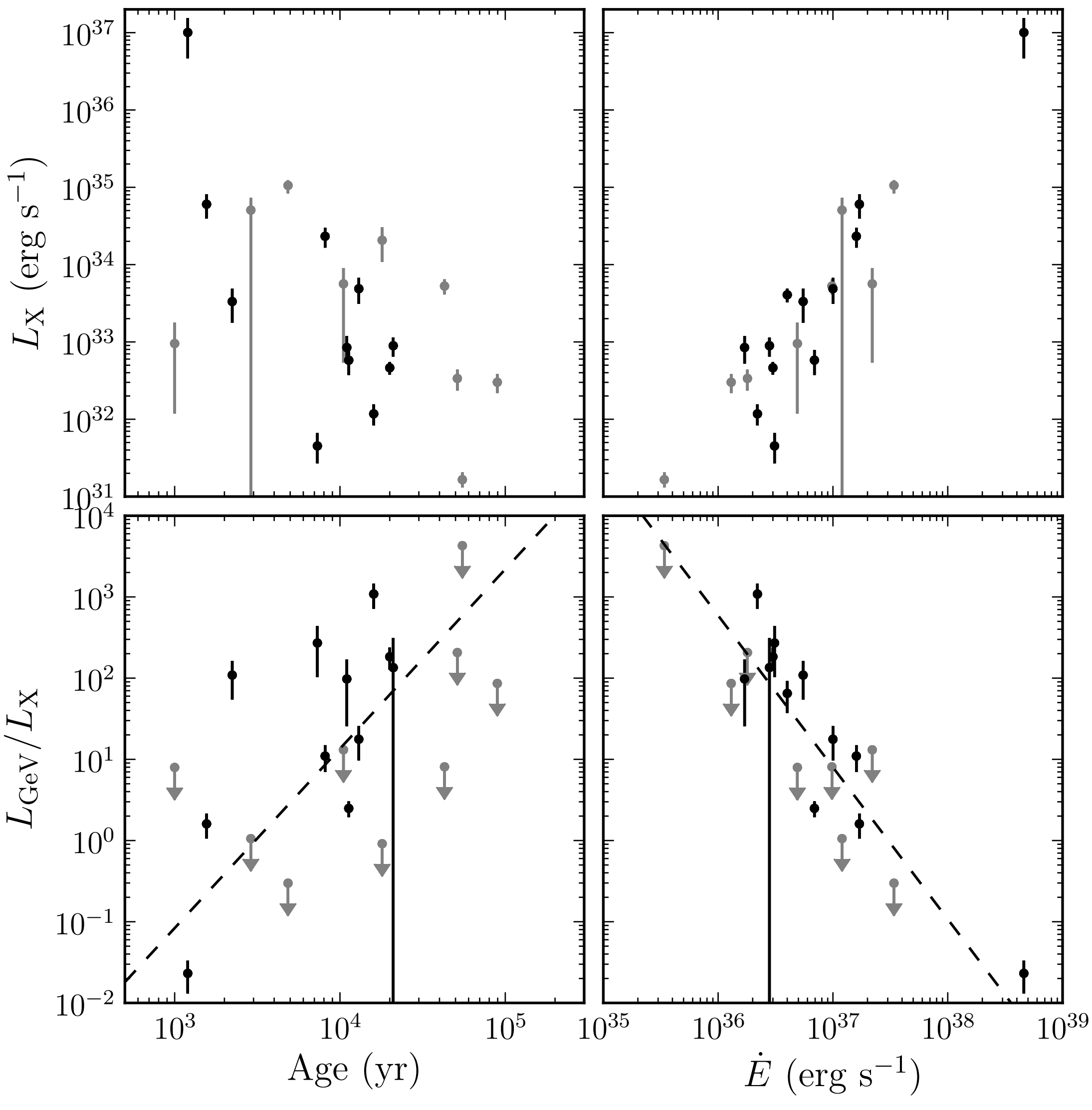
10^{37}
10^{36}
10^{35}
10^{34}
10^{33}
10^{32}
10^{31}
L_X (erg s^{-1})
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
L_{GeV}/L_X
10^{3}
10^{4}
10^{5}
Age (yr)
10^{35}
10^{36}
10^{37}
10^{38}
10^{39}
$\dot{E}$ (erg s^{-1})

Figure 9.3 ...

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