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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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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(Roger Romani)

Approved for the University Committee on Graduate Studies

Contents

List of Tables

List of Figures

List of Acronyms

1FHL the first *Fermi* hard-source list. 146

2CG the second COS-B catalog. 9

2FGL the second *Fermi* catalog. 19, 22, 43, 89, 142, 147, 149

2LAC the second LAT AGN catalog. 5

2PC the second *Fermi* pulsar catalog. 19, 22, 144, 145

3EG the third EGRET catalog. 10

ACD Anti-Coincidence Detector. 13

AGILE Astro-rivelatore Gamma a Immagini LEggero. 10, 12, 25

AGN active galactic nucleus. 22

arcsec second of arc. 38

ASI Italian Space Agency. 10

ATNF Australia Telescope National Facility. 16

BPL broken-power law. 46

CGRO the Compton Gamma Ray Observatory. 9, 10

CGS the Centimetre-Gram-Second System of Units. 45

CMB cosmic microwave background. 30, 40

CsI cesium iodide. 13

CTA the Cherenkov Telescope Array. 158

DOE United States Department of Energy. 10

ECPL exponentially-cutoff power law. 46

EGRET the Energetic Gamma Ray Experiment Telescope. xiii, 8–11, 16, 44, 50

ESA the European Space Agency. 9

GBM Gamma-ray Burst Monitor. 12

GRB gamma-ray burst. 12

H.E.S.S. the High Energy Stereoscopic System. xxii, xxv, 25, 26, 54, 109, 111, 113, 114, 116, 121, 124, 125, 158

HMB high-mass binary. 22

IACT Imaging air Cherenkov detector. 19, 54, 125, 142, 143, 158

IC inverse Compoton. 7, 19, 21, 23, 25, 26, 29, 37, 38, 40, 41, 146, 158

IRF instrument response function. 4, 47

LAT Large Area Telescope. v, vi, viii, xii–xiv, 4, 5, 12–16, 19–23, 26, 37, 41–43, 47–49, 51, 89, 142, 143, 146–148, 150–153, 155, 158

LMC Large Magellanic Cloud. 19

LRT likelihood-ratio test. 44, 50

MIT the Massachusetts Institute of Technology. 16

MSC massive star cluster. 145

MSP millisecond pulsar. 22, 33

NASA the National Aeronautics and Space Administration. 8, 10

NRL the Naval Research Laboratory. 16

NS neutron star. 16, 17, 31, 32, 35, 36

OG outer gap. 37

OSO-3 the Third Orbiting Solar Observatory. xiii, 7, 8

PC polar cap. 37

PL power law. 46

PSF point spread function. 13, 43, 48, 49, 51, 146

PWN pulsar wind nebula. v, xv, xxvii, 4, 5, 7, 17, 19, 22, 23, 25, 26, 31, 35, 37–41, 47, 53, 142, 143, 145–159

SA solid angle. 47

SAS-2 the second Small Astronomy Satellite. 8, 9

SED spectral energy distribution. xiv, 23, 24

SN supernova. 17

SNR supernova remnant. 16, 22, 25, 35, 37, 38, 47

TPC two pole caustic. 37

UNID unidentified source. 143, 145

VHE very high energy. x, xii, xiv, 5, 19, 24–26, 40, 41, 43, 142–153, 155, 158, 159

Chapter 10

Outlook

Since the observation of the Crab Nebula in 1989 (Weekes et al. 1989), we have learned much about the high-energy inverse Compoton (IC) emission from pulsar wind nebula (PWN). The current generation of very high energy (VHE) experiments (the High Energy Stereoscopic System (H.E.S.S.), Magic, and Veritas) have drastically expanded the population of PWN observed at γ-ray energies and PWNe are the most populous class of VHE sources in the Galaxy. Now, using the Large Area Telescope (LAT) on board *Fermi*, we have detected a large fraction of these VHE PWN at GeV energies and one PWN not yet detected at VHE energies.

The next great improvement in our knowledge of PWN will most likely come from future Imaging air Cherenkov detectors (IACTs). The proposed the Cherenkov Telescope Array (CTA) (Actis et al. 2011) will would have a much improved effective area and angular resolution, allowing for the discovery of more VHE PWN as well as improved imaging of PWN candidates.

As was the case for HESS J1825−137 energy-dependent morphology at VHE energies can be used to unambiguous identify VHE emission as being caused by a PWN (Aharonian et al. 2006c). Similarly, Van Etten & Romani (2011) showed for HESS J1825−137 that detailed spatial and spectral observations combined with multi-zone modeling of a PWN can be constraining detailed properties of the PWN. Detailed energy-dependent imaging of a larger sample of PWN will allow us a greater understanding of the physics of pulsar winds.

In addition, the Crab nebula has challenged our basic understand of the physics of PWN. It is possible the more detailed observations could uncover additional variable PWN, which could help to shine light on the nature of the variable emission.

Finally, because of the large density of PWN-emitting VHE sources in the galactic plane, it is important to identify VHE PWN to help in the search for new source classes. There is significant potential for discovery of new source classes in the sources that are not classified as PWN. If the past is any guide towards the future, there is much still to be learned about PWNe.

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