Population Study of PWNe Using Chandra X-ray Observatory

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Abstract: Pulsar Wind Nebulae (PWNe) are some of nature's most unique laboratories for studying the high-energy particles produced by pulsars. The X-ray emission from PWNe carries information about the underlying distribution of accelerated particles which determine the observed properties of PWNe. Our analysis shows that these properties vary significantly even for the most compact PWN structures in the immediate vicinity of the pulsar where radiative cooling should play no role. In addition, the structures themselves show significant diversity (e.g. strongly varying relative strengths of the jet and torus components). Finally, the X-ray radiative efficiencies of PWNe vary by nearly 4 orders of magnitude. A likely explanation for the diversity of these compact structures and their observed properties are the different magnetic obliquity (offset between magnetic and spin axes) and viewing angles which also determine pulsar lightcurves. We explore possible connections between these properties.

X-ray Spectral Slopes for Compact PWNe

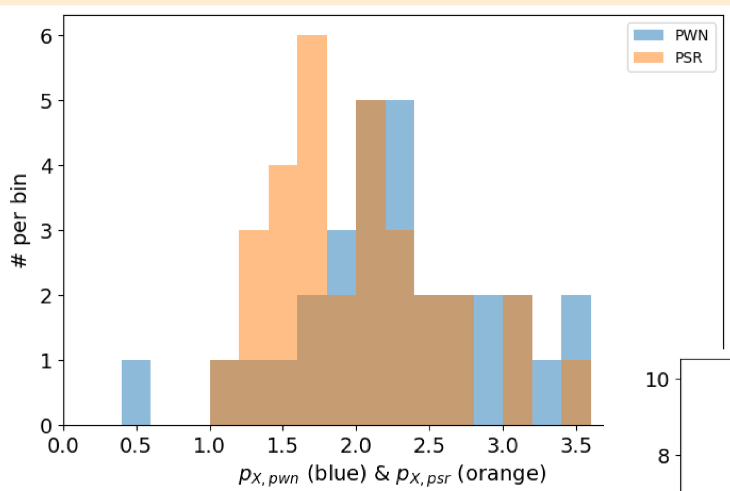
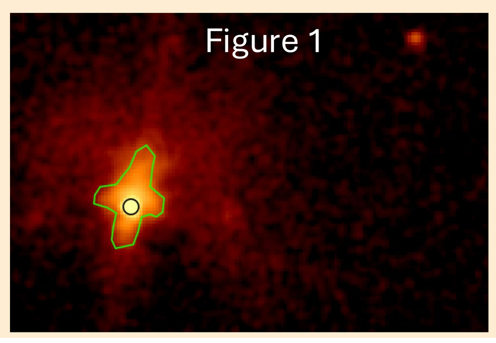


Figure 2.1



$$p = 2\Gamma - 1$$

Γ – photon index
p – electron SED slope

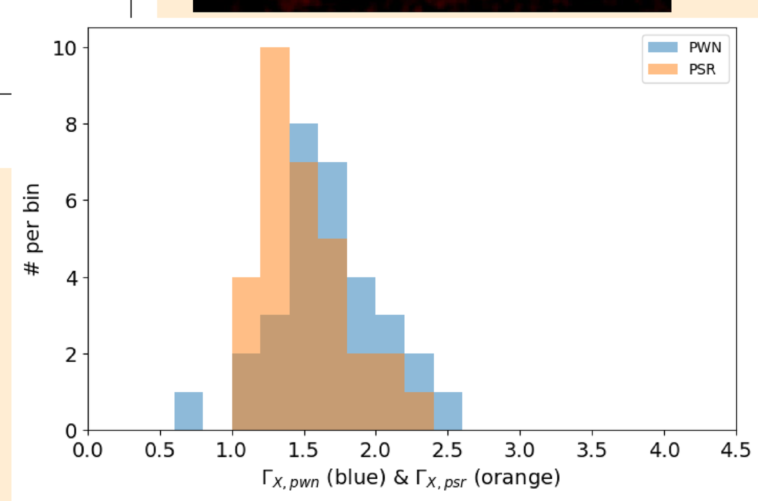


Figure 2.2

- The spectra were extracted consistently by defining two simple regions: the pulsar and compact nebula (referred to as PWN hereafter, see Figure 1).
- The PWN contains the small-scale structure such as torii and/or jets.
- An absorbed power-law (PL) model was used for the spectral fit for each region.
- The behavior of Γ may give evidence of the underlying acceleration mechanism in PWNe (Figures 2.1/2.2) [1,2].
- A weak correlation was found between the Γ's of the pulsar and PWN (r=0.25, Figure 3)

PSR vs. PWN Photon Indices

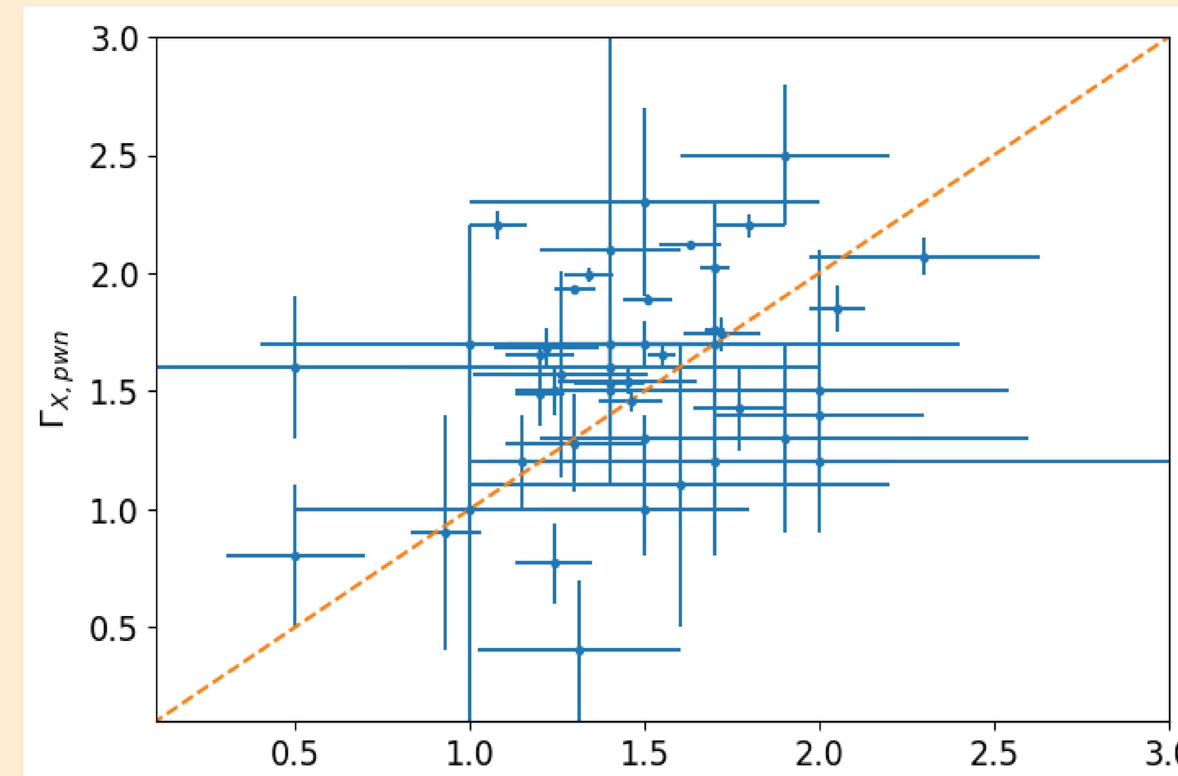
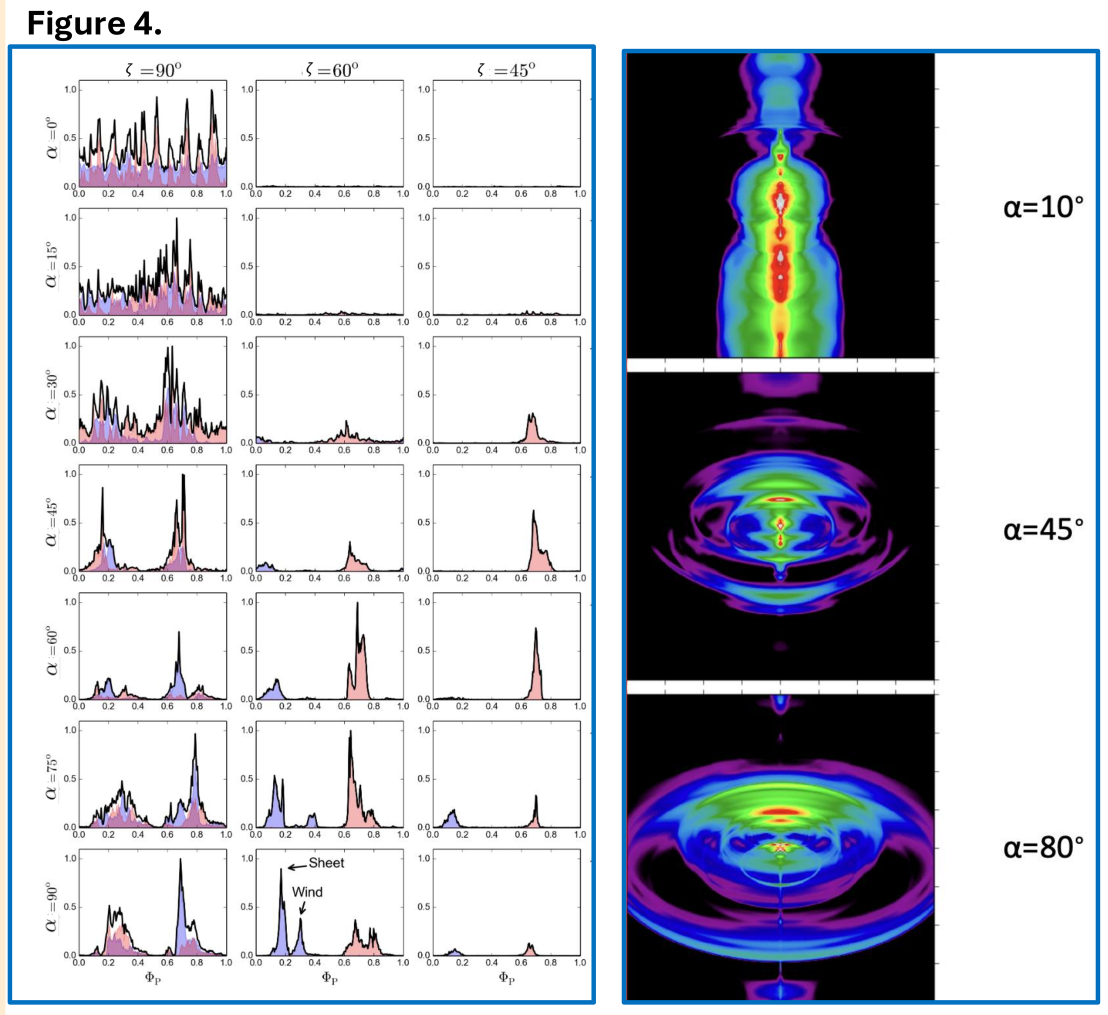


Figure 3

- Both compact PWN morphologies (and possibly luminosities and spectra) and pulsar lightcurves are expected to carry an imprint of pulsar magnetosphere geometry (magnetic dipole inclination angle α) and the viewing angle (ζ) (see Figure 4 with left panel adapted from [4] and right panel adapted from [5]).

Figure 4.



- However, there are additional factors that can affect the PWN morphology, brightness, and spectrum such as PWN compression due to the rapid pulsar motion or interaction with the SNR reverse shock.

Radiative Efficiencies & pulsar lightcurves

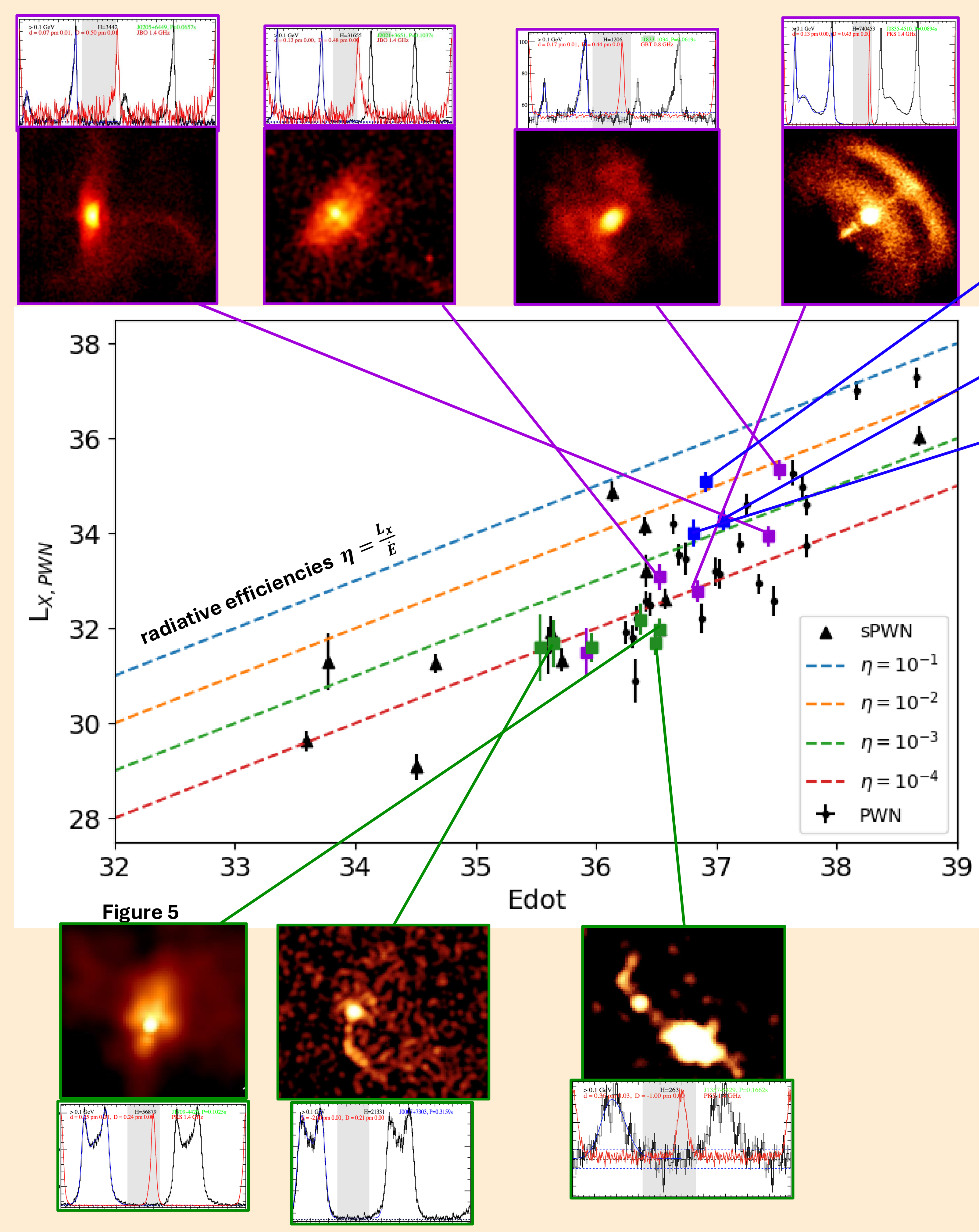
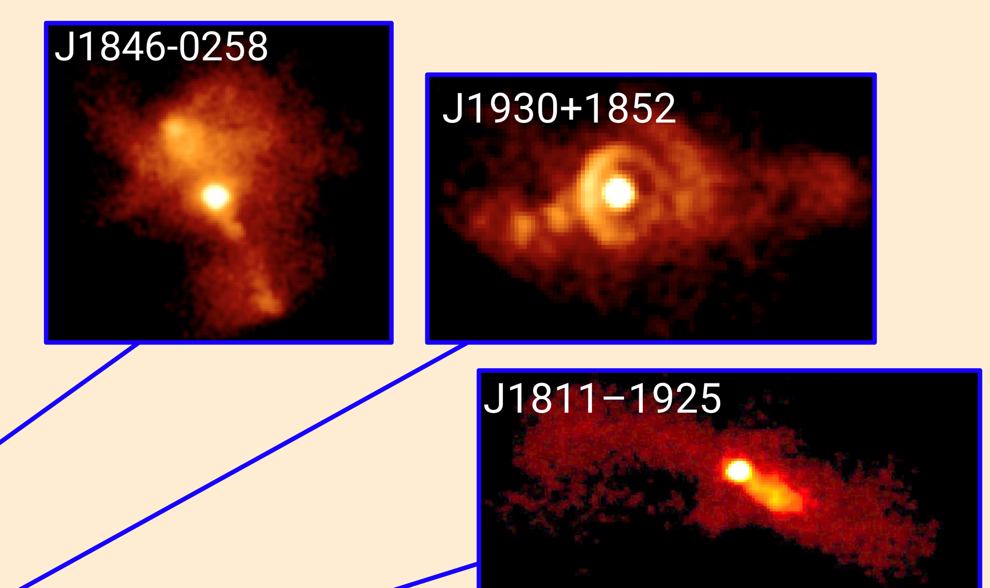


Figure 5

Gamma-ray quiet PWNe



- A few PWN with similar gamma-ray lightcurves are grouped by different color boxes.
- An example of gamma-ray and radio lightcurves (from [3]) for each group is shown along with CXO images
- Preliminary results do not support a straightforward dependence between compact PWN radiative efficiencies and gamma-ray lightcurve morphologies or presence vs. lack of gamma-ray emission.
- On the other hand, compact PWN morphologies (the relative strength of torus vs. jet components) appear to correlate with gamma-ray lightcurve morphologies and or presence vs. lack of gamma-ray emission.

PWN Photon Index vs. Radiative Efficiency

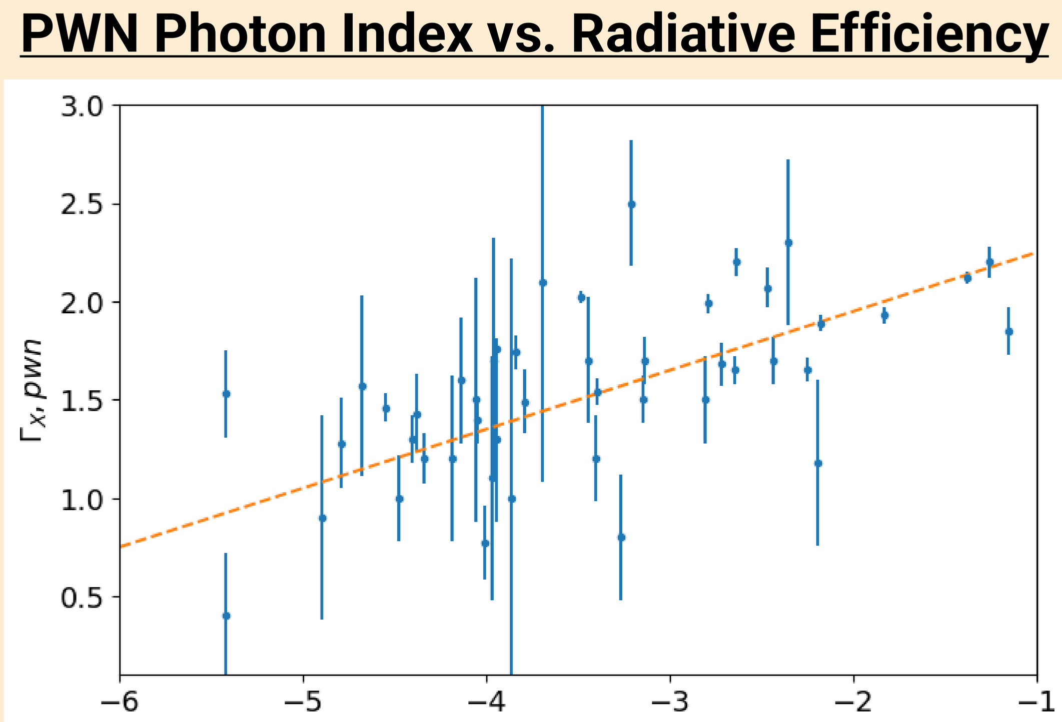


Figure 6

- There appears to be a correlation between η and Γ with harder spectra having lower radiative efficiencies (r=0.62, Figure 6).
- There is also a strong correlation between the pulsar's non-thermal luminosities and the compact PWN luminosities, which appear to be comparable, on average (r=0.89, Figure 7)

PSR/PWN Luminosities

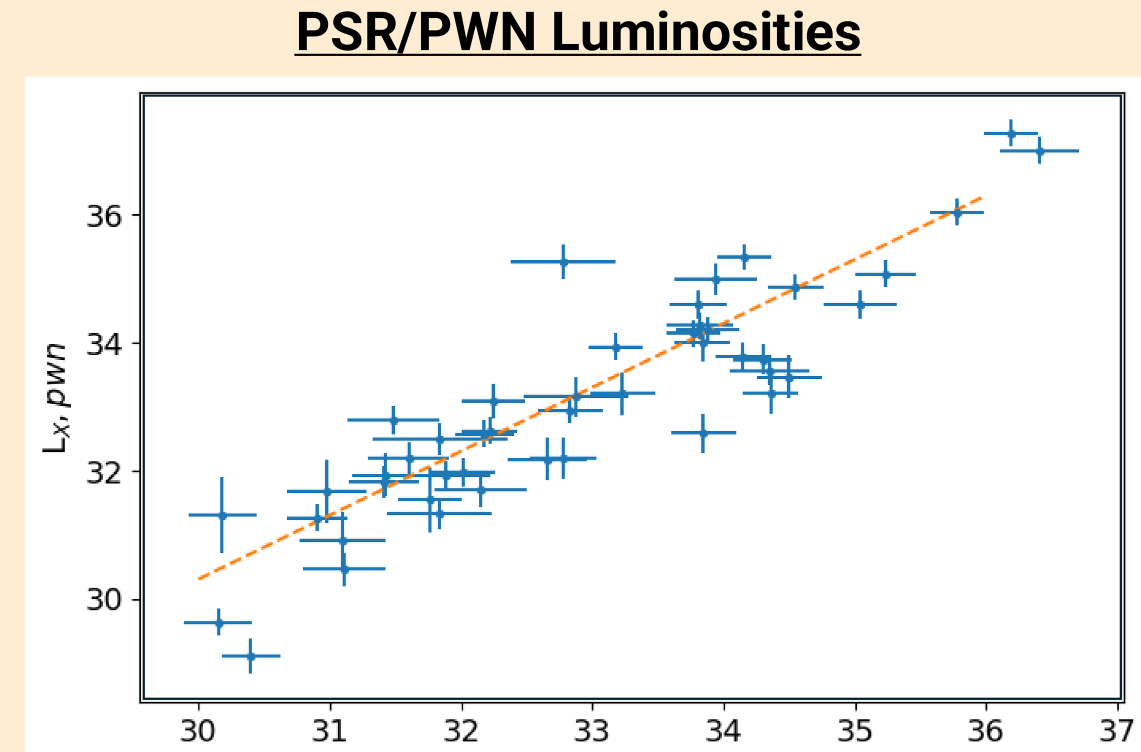


Figure 7

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