Pulsar Wind Nebulae and PeVatrons : A Case Study of PWN G309.92-2.51 (The Salamander)

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Introduction

The sources of high-energy cosmic rays (CRs) have puzzled astronomers since their detection over a century ago. To probe these sources, we want to determine **which objects could accelerate CRs up to 10^{15} eV (1 PeV),** the 'knee' of the CR spectrum. One potential class of objects is **Pulsar Wind Nebulae (PWNe)**, which are detected in very high energies and **make up the largest population of gamma-ray sources in the galaxy** [1]. As well, PeV photons are now being detected from PWNe and other sources by LHAASO [2]. The analysis described here is of **the PWN in G309.92-2.51**, associated with the H.E.S.S source J1356-645 (**Figure 2**), and active energetic (3.1E36 erg/s) pulsar J1357-6429. The pulsar has a characteristic age of 7.3 kyr with a 166 ms period and distance of 2.5 kpc. **We name this source the Salamander nebula.**

Methods and Results

- Spectral analysis of Chandra, XMM-Newton, and NuSTAR data.
- Timing analysis detection of pulsations with XMM-Newton, f ~ 6.0178 Hz.
- Phase-resolved spectroscopy of XMM-Newton and NuSTAR to complement hard energy coverage of NuSTAR [3]. Pegged power-law fit from 0.5 - 10, 10 - 25 KeV yields photon indices 1.76 and 1.64 respectively and fluxes of -12.55 and -12.50.
- Spectral Energy Distribution (SED) analysis with a static *NAIMA* model [4] and a dynamical model as described in Gelfand et al. 2009 [5]. Included Fermi and H.E.S.S. data.
- Preliminary *NAIMA* model (**Figure 3**) results: maximum energy of 2.0 PeV, magnetic field of 1.5 μG. Dynamical PWN model (**Figure 4**), Case 1: maximum energy of 12.0 PeV, magnetic field of 0.3 μG. Case 2: maximum energy of 9.0 PeV, magnetic field of 0.28 μG.

Pulsar Wind Nebulae could be an elusive **source of high-energy cosmic rays**.

These sources are excellent **PeVatrons** candidates, capable of **accelerating particles up to 1 PeV.**

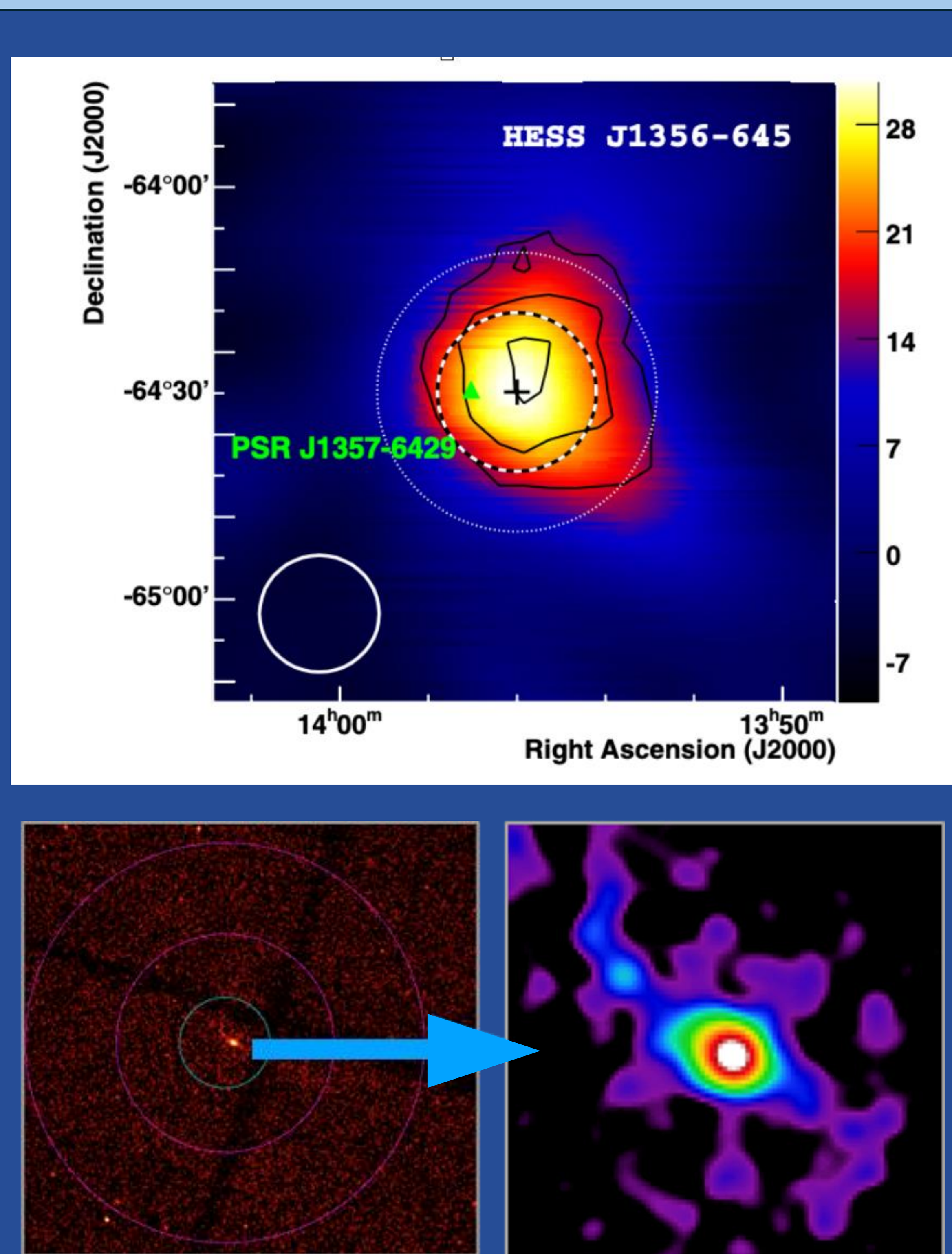

Figure 2: (top) High Energy Stereoscopic System (H.E.S.S.) detection of J1356-645 which is coincident with the Salamander PWN. (bottom) XMM-Newton and Chandra X-Ray telescope detections of the Salamander PWN.

Our preliminary study indicates that the **Salamander PWN** accelerates particles up to between **2 - 12 PeV**.

Along with results from other PWNe, this is a strong indication that **PWNe are Galactic leptonic PeVatrons.** The search for other such sources is underway within our collaboration [6].

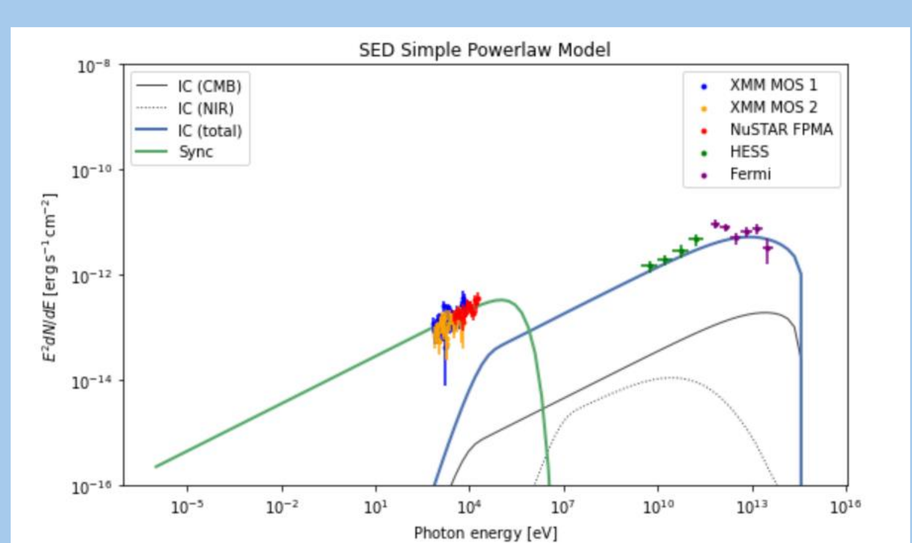

Figure 3: (above) A *NAIMA* SED simple power law model with Synchrotron and Inverse Compton components.

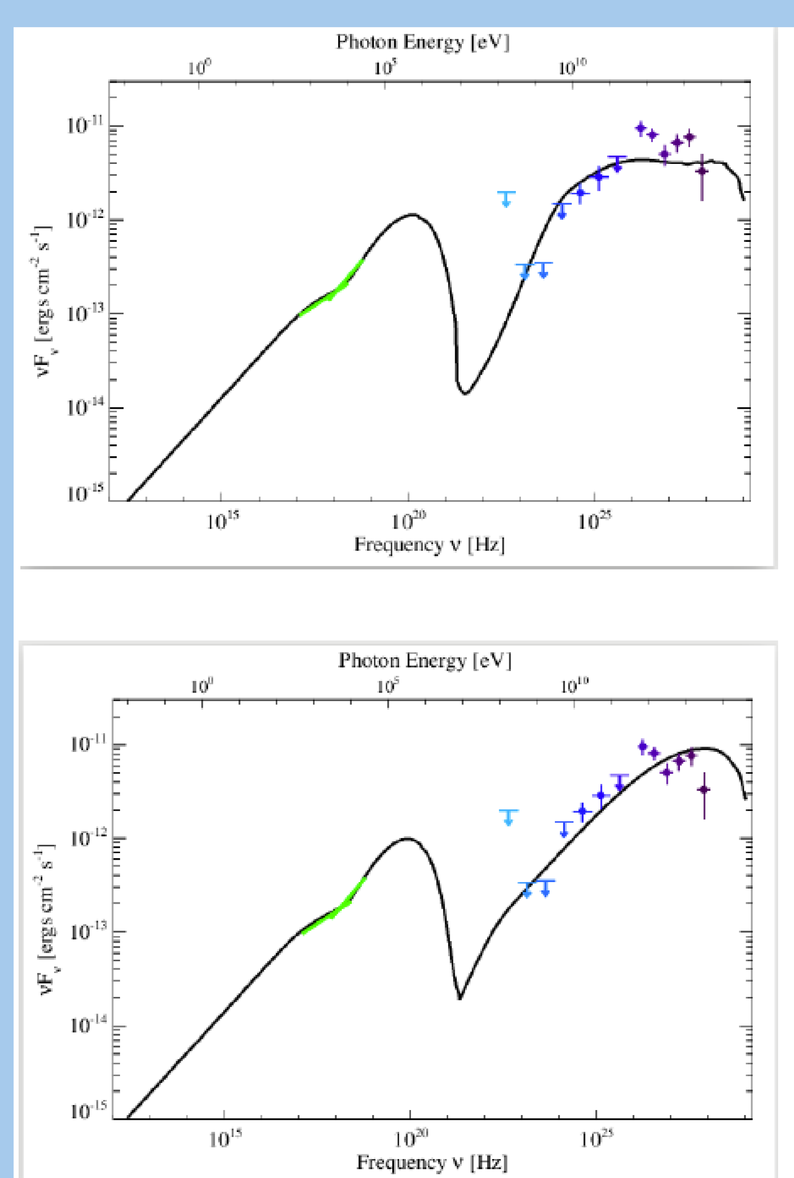

Figure 4: (right top) Case 1 of the dynamical SED model, with a higher temperature and density of added Inverse Compton field.
(right bottom) Case 2 of the dynamical SED model. Lower values for added Inverse Compton field.

Conclusion and Future Work

Our multi-wavelength study of the Salamander indicates an **energy maximum beyond 1 PeV using a leptonic model**, establishing the PWN as a **strong PeVatron candidate.** The resulting magnetic fields are quite low and may require further investigation. Each of the maximum injected particle energy results were greater than 1 PeV. The Salamander PWN results, along with those from other studies such as the Dragonfly and Eel PWNe [6], should strengthen the tie between **PWNe as PeVatrons**, and **PWNe as a source of galactic CRs.** The **next step** in the Salamander analysis is to constrain the SED modelling with the **addition of new radio data**, in collaboration with the EMU/POSSUM team (J. West et al.).

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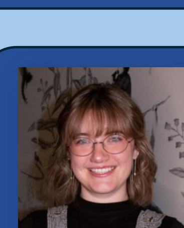

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