Multi-messenger Modeling of Monogem Pulsar Halo

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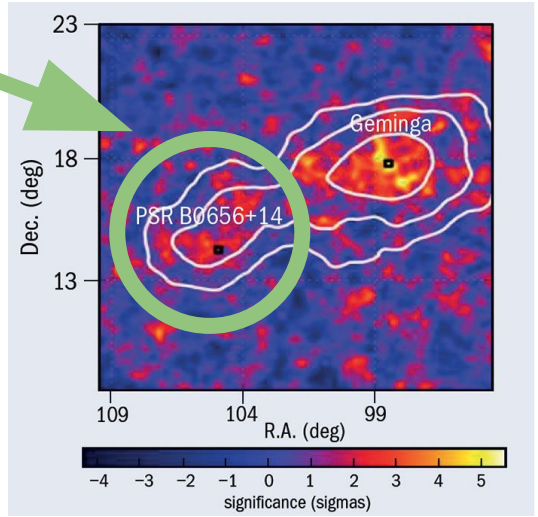

UNIVERSITY OF AMSTERDAM

GRAPPA

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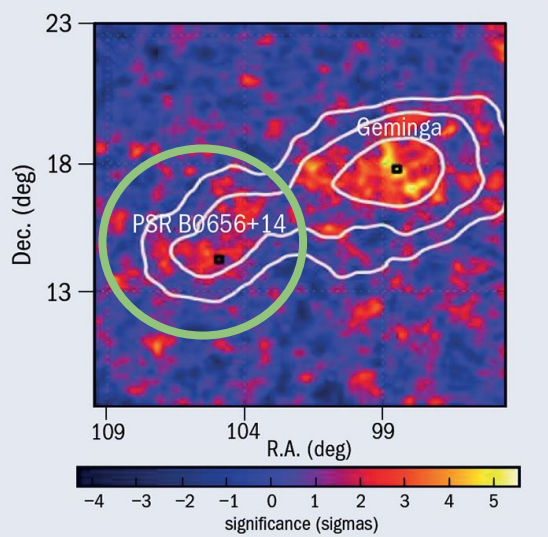
Content

- TeV halo around pulsars/PWN and their implications
- Modeling of the leptonic particle injection/propagation
- Simulation details
- Results: Inverse-compton(IC) and synchrotron emission
- Results: Positron contribution

TeV-halo of the Monogem Pulsar Wind Nebula (PWN)



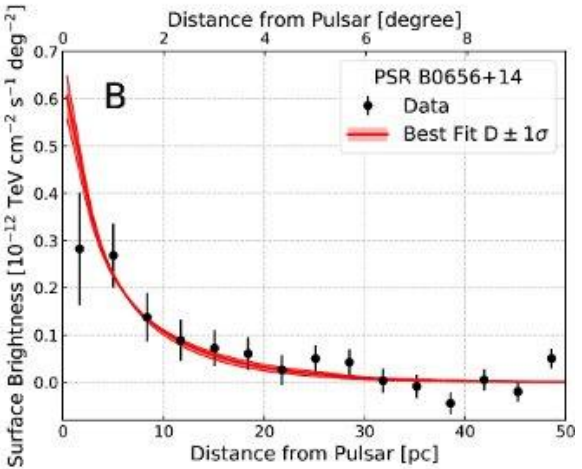
- Mid-aged (110kyr) pulsar associated with the Monogem ring (~65pc radius in X-ray)

- **HAWC** observed extended γ-ray emission around Geminga pulsar and PSR B0656+14 (Monogem) (2016)

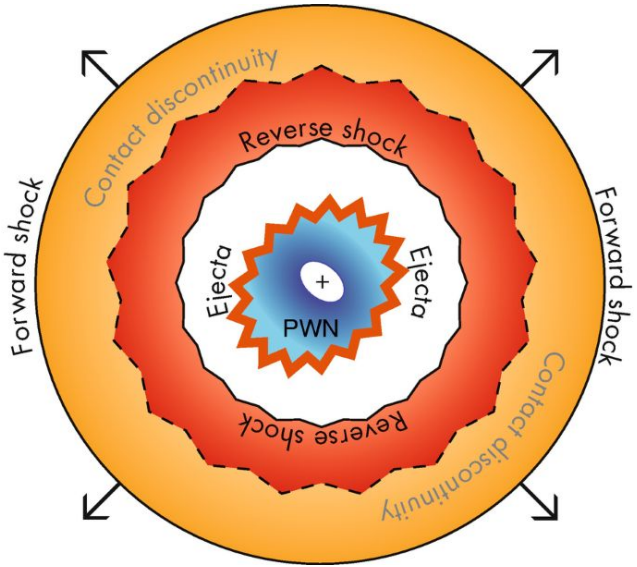
  Energy: 4-50 TeV

  TeV halo radius: ~25 pc

- **Suggestion:** Inverse-Compton (IC) emission from escaped electrons/positrons accelerated at the termination shock of pulsar wind nebula (PWN)

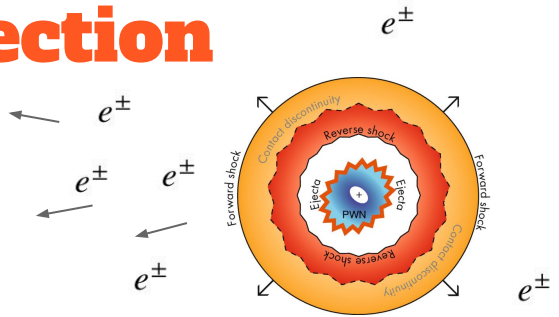


Cosmic Ray (CR) Acceleration at PWN



- The pulsar wind is driven by the pulsar spin down power
- Diffusive shock acceleration + Magnetic reconnection + Stochastic acceleration

Modeling of Leptonic Particle Injection



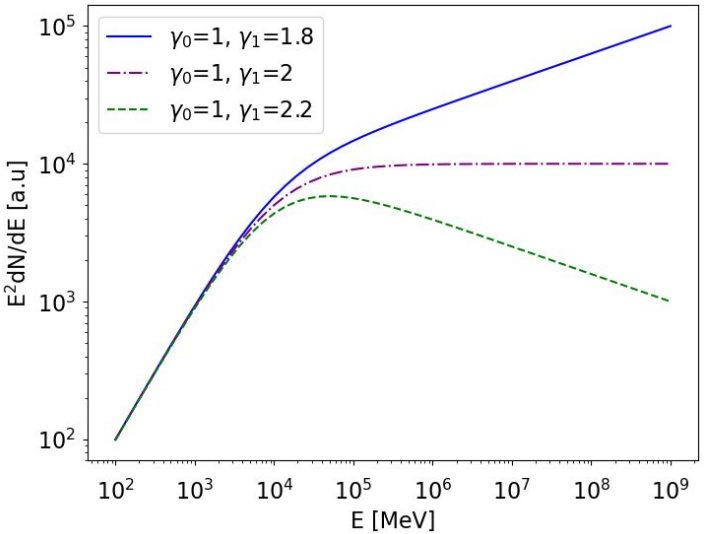
- Evolution of injection power

$$L_{e^{\pm}}(t) = \eta \dot{E}_0 \left(1 + \frac{t}{\tau_0}\right)^{-\frac{n+1}{n-1}}$$

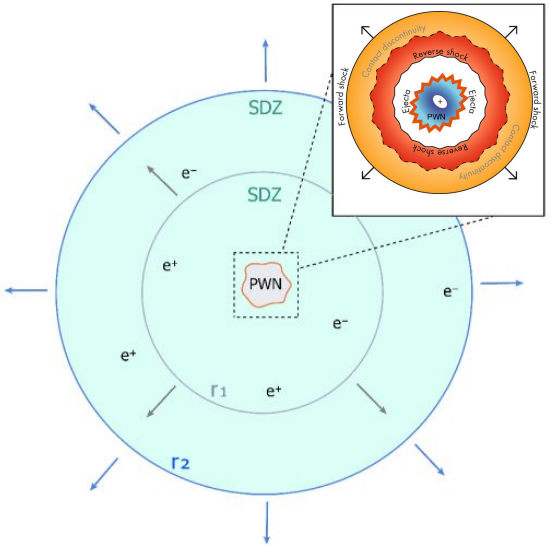
free parameter

- Smoothed broken power-law spectrum

$$\frac{dn_{e^{\pm}}}{dE} \propto E^{-\gamma_0} \left[1 + \left(\frac{E}{E_b}\right)^{\frac{\gamma_1 - \gamma_0}{s}}\right]^{-s}$$



Modeling of CR diffusion: 2-Zone diffusion model



- Small diffusion coefficient

$$D = \left(\frac{E}{E_0}\right)^{\delta} \times \begin{cases} D_{\mathrm{SDZ}}, & r < r_1, \\ D_{\mathrm{SDZ}} \left(\frac{D_{\mathrm{ISM}}}{D_{\mathrm{SDZ}}}\right)^{(r-r_1)/(r_2-r_1)}, & r_1 \le r \le r_2, \\ D_{\mathrm{ISM}}, & r > r_2. \end{cases}$$

- Hypothesis:

  A) Self-induced magnetic turbulence of CR propagation in the ISM

  B) Magnetic turbulence caused by expansion of parent SNR

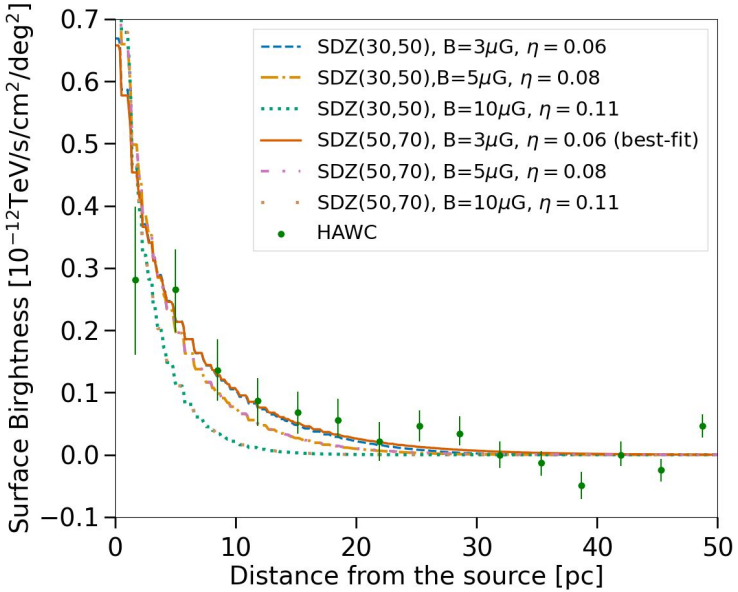
Simulating the Monogem PWN TeV-halo Using

- High resolution numerical simulation of propagation of relativistic charged particles in the Galactic scale
- $8 \times 8 \times 8\ \mathrm{kpc}^3$ box size
- 50 yrs timestep to catch the energy loss of the high energy electron/positrons

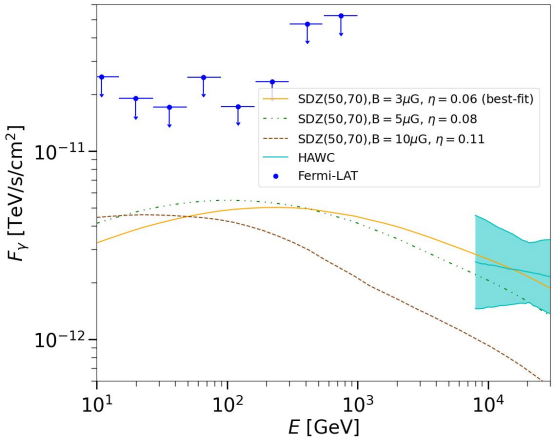
Inverse-Compton Emission

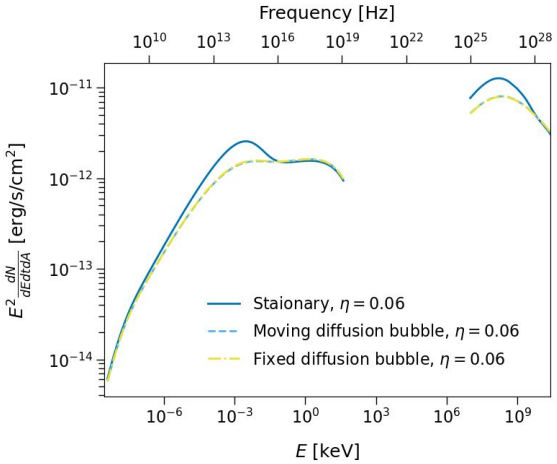
Surface Brightness

→ η: injection efficiency

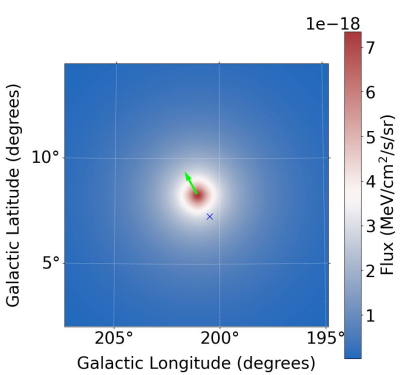


Vary B field

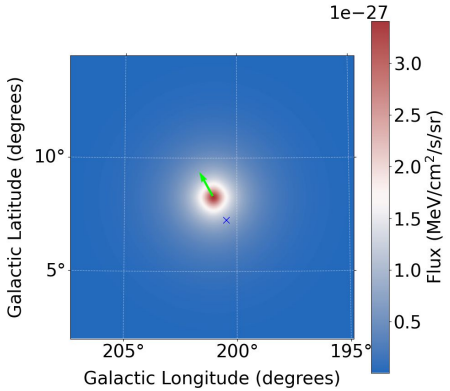




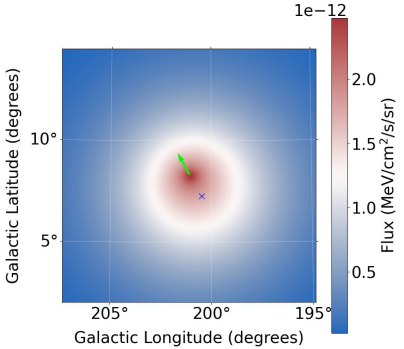
Monogem Halo Emission Morphology



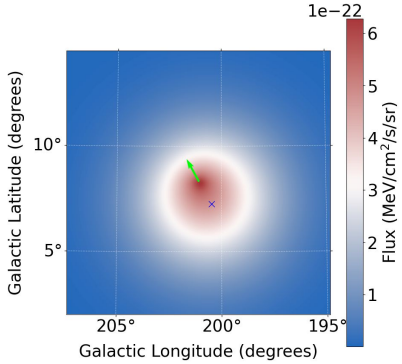
10 TeV



5 keV

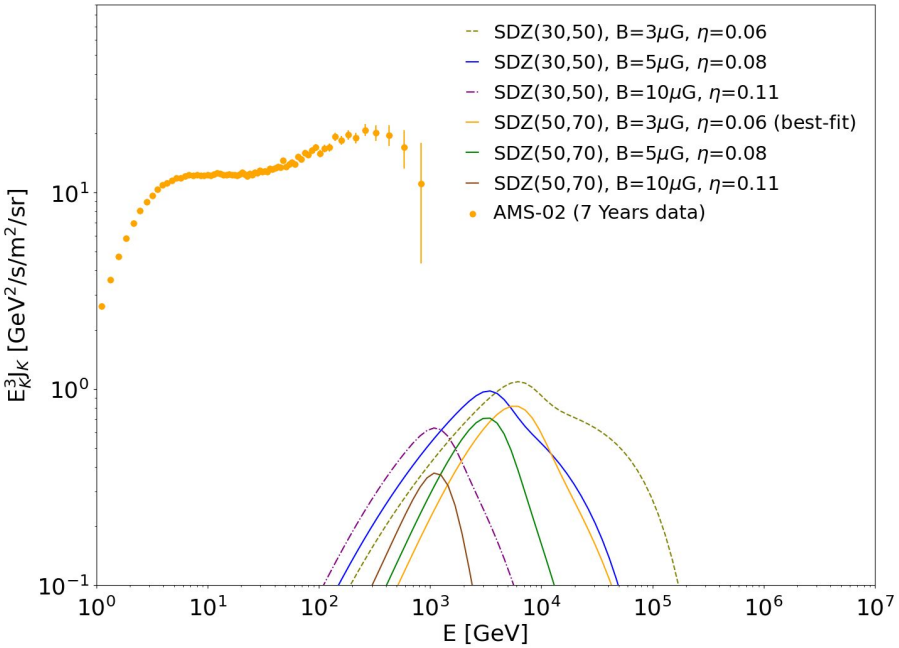


10 GeV



100 Hz

Positron Flux from Monogem Pulsar



- The positron contribution from Monogem to the flux observed on Earth is ~10%
- The higher the magnetic field around the source, the positron flux at Earth peaks at a lower energy

Take-Home Message

- TeV-halo can be reproduced by introducing O(10 pc) size CR slow diffusion region with close to average Galactic magnetic field around the PWN

- Observation of extended GeV and radio halo can be crucial in differentiating model parameters

- Theoretical investigation of the origin of slow diffusion in those regions are important