Probing the Injected Particle Spectrum of the Mouse Pulsar Wind Nebula

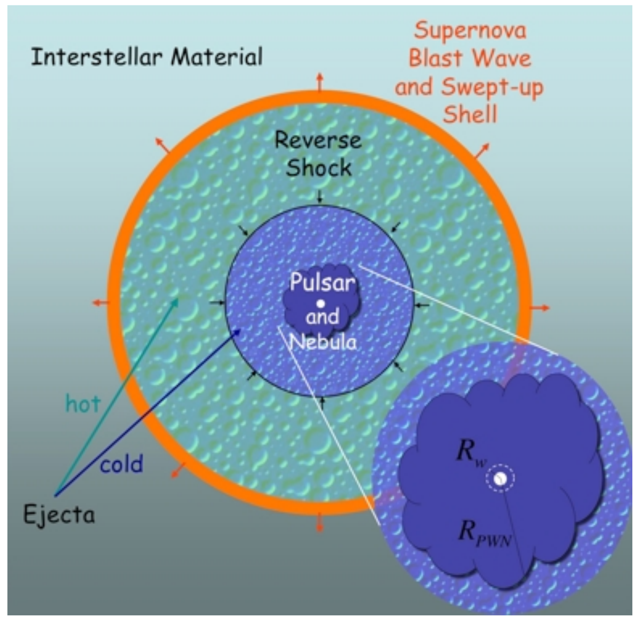
Y.-Y. Chan & C.-Y. Ng

Department of Physics, The University of Hong Kong

Presented by
Y.Y Chan,
MPhil Student

A pulsar wind nebula (PWN) is a synchrotron bubble formed when the relativistic outflow from a pulsar is shocked in the ambient medium. PWNe are relatively nearby objects, offering ideal laboratories for studying relativistic shocks. For a pulsar moving supersonically in the interstellar medium, the wind is confined by the ram pressure, resulting in a bow-shock PWN. These systems can be considered as in a steady state, thus, making the modeling much simpler than younger PWNe. We present a multi-wavelength study of the Mouse. We compile its spectral energy distribution using observations from VLA, GMRT, MOST, TMRT, Spitzer, *Chandra*, and *Fermi*. We then performed a detailed comparison with various injected particle distributions by taking into account synchrotron loss, synchrotron cooling as well as inverse Compton scattering.

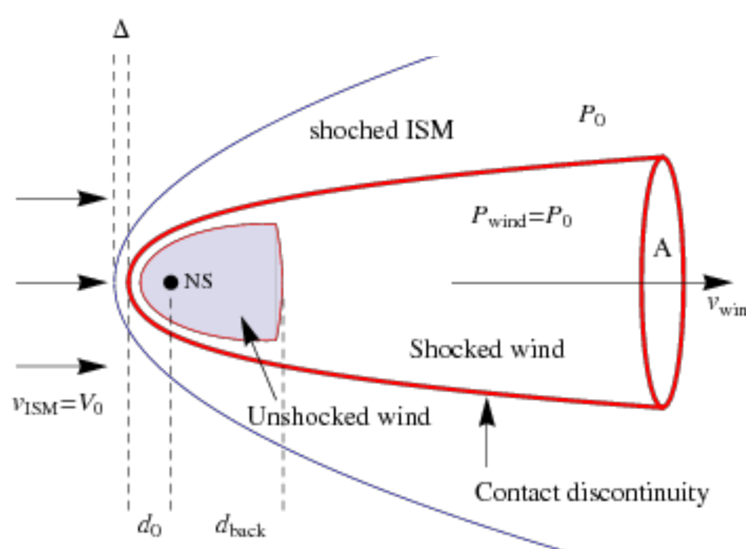
Pulsar Wind Nebula



Structure of a newly formed PWN(adopted from Gaensler & Slane 2006).

- synchrotron bubble when the relativistic outflow from a pulsar is shocked in the ambient medium

Bow-shock PWNe

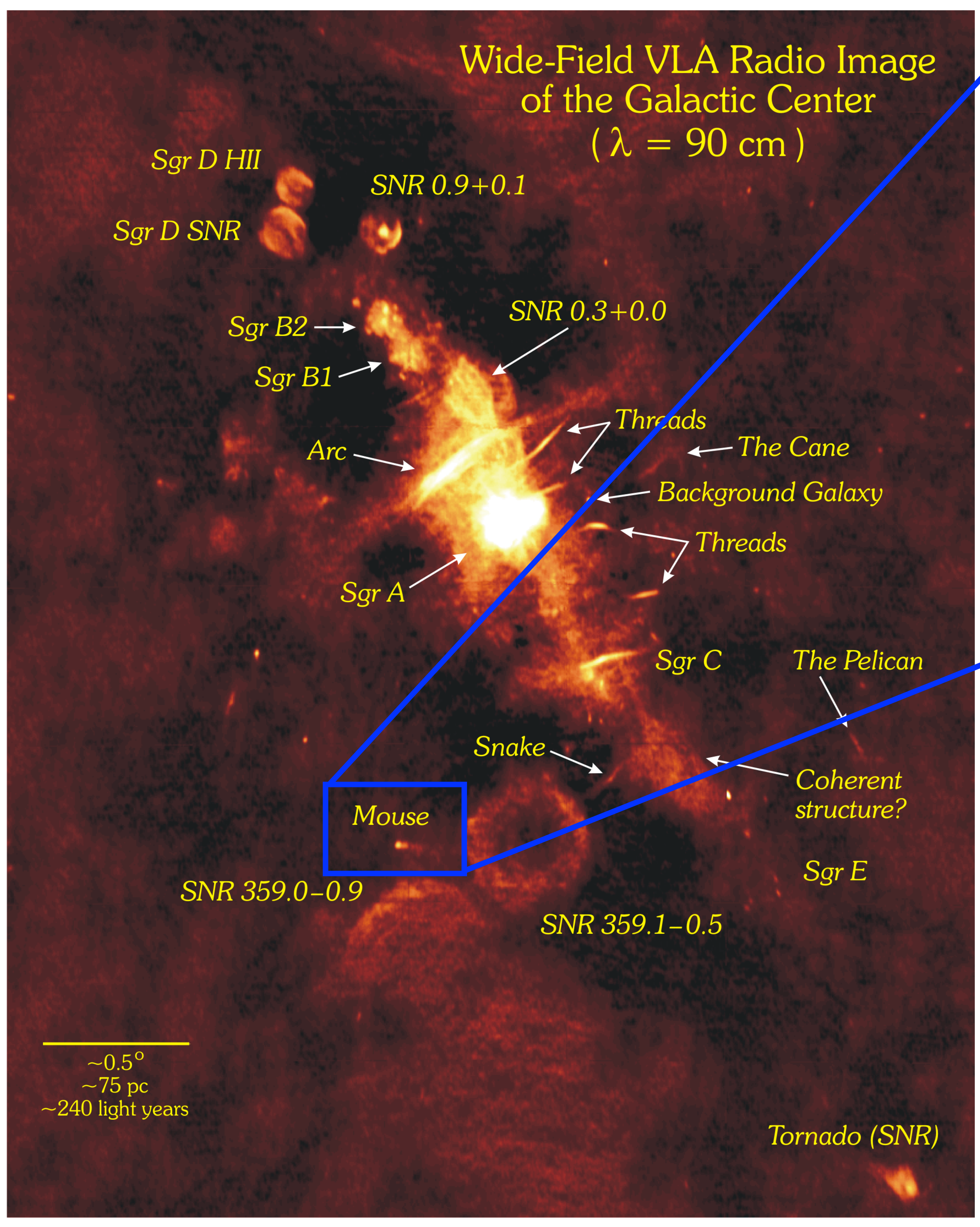


Structure of a bow-shock PWN (Morlino et al. 2016).

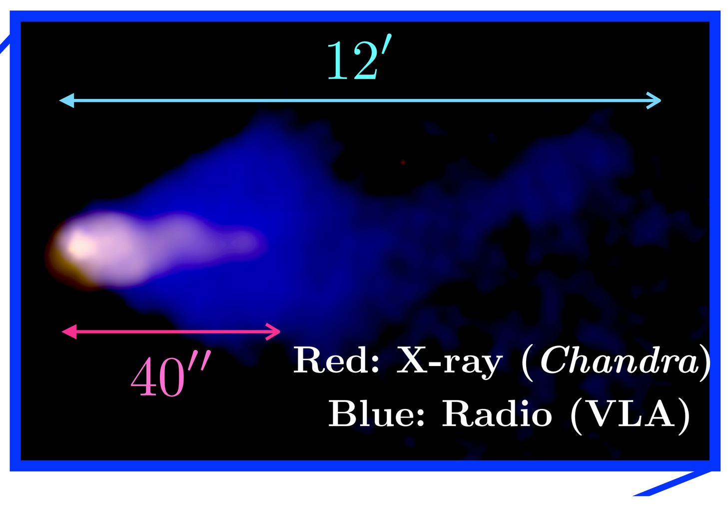
-Final phase in the PWN evolution
-The central pulsar is moving supersonically in ISM

G359.23-0.82: The Mouse PWN

- Bow-shock PWNe
- Discovered by Yusef-Zadeh & Bally (1987)
- Powered by PSR J1747-2958
- distance: 5kpc



90-cm VLA image of the Galactic center region(from LaRosa et al. 2000); The blue box indicates the location of the Mouse.



VLA-Chandra image of the mouse (Gaensler et al. 2004, Yusef-Zadeh & Bally 1987). The red and blue colour represent X-ray and radio images, respectively.

Parameters	Values
Right Ascension, α (J2000)	$17^h47^m15^s.882$
Declination, δ (J2000)	$-29^h58^m01^s.07$
Epoch of position (MJD)	52613
Spin period, P	98.8 ms
Spin period derivative, $\dot{P}$	$6.132 \times 10^{-14}\,\mathrm{s\,s^{-1}}$
Dispersion measure, DM	$101.5\,\mathrm{pc\,cm^{-3}}$
Spin-down power, $\dot{E}$	$2.5 \times 10^{36}\,\mathrm{erg\,s^{-1}}$
characteristic age	25 kyr
Surface magnetic field, B	2.5×10^{12} G

Physical parameters of the central pulsar, PSR J1747–2958 (Camilo et al. 2002); Hales et al. 2009; Manchester et al. 2005).

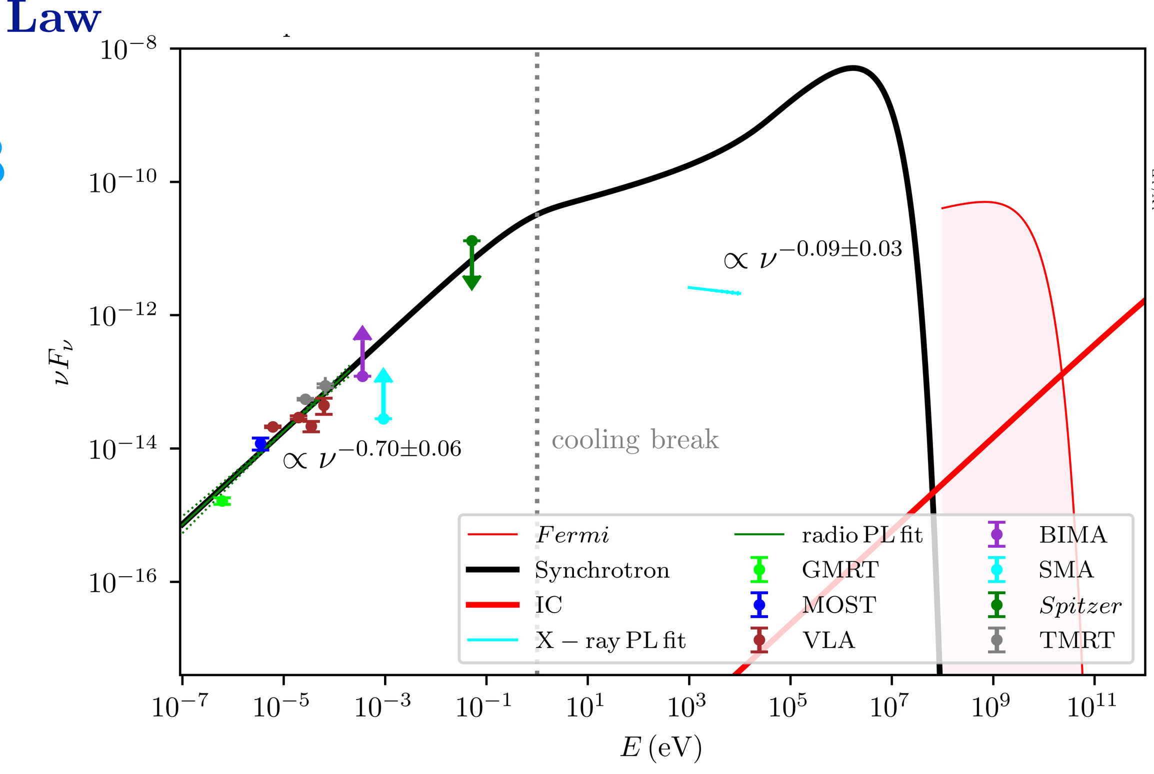
WHY 'THE MOUSE'?

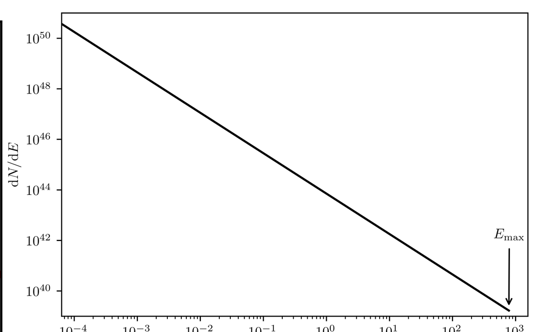
- Good object for studying relativistic shock
  - bright
  - Well-defined
- Can be considered as steady state
  - simple modeling

Testing Acceleration Theories

Power Law? Broken Power Law ? Maxwellian + Power Law?

Power Law





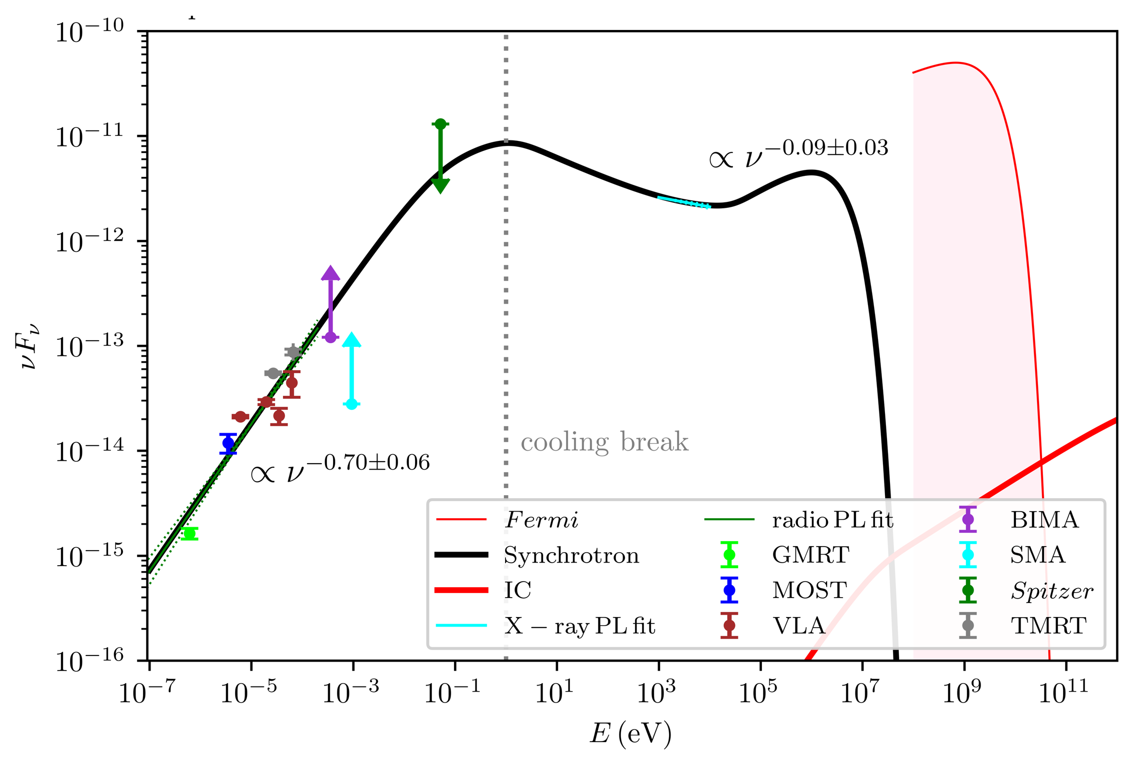
$$\frac{dN}{dE} = N_0\left(\frac{E}{E_0}\right)^{-p}$$

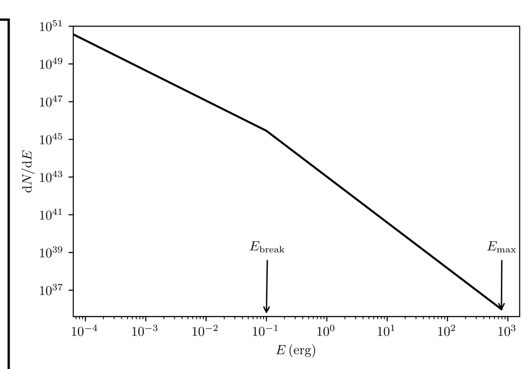
$N_0 = 2.5 \times 10^{49}$ $\quad p = 1.60$

$E_0 = 3.40 \times 10$ erg $\quad E_{max} = 800$ erg

- Suggested by Fermi acceleration
- Cannot reproduce the X-ray spectrum

Broken Power Law





$$\frac{dN}{dE} = N_0\left(\frac{E}{E_0}\right)^{-p_1} \text{ for } E < E_{break}$$

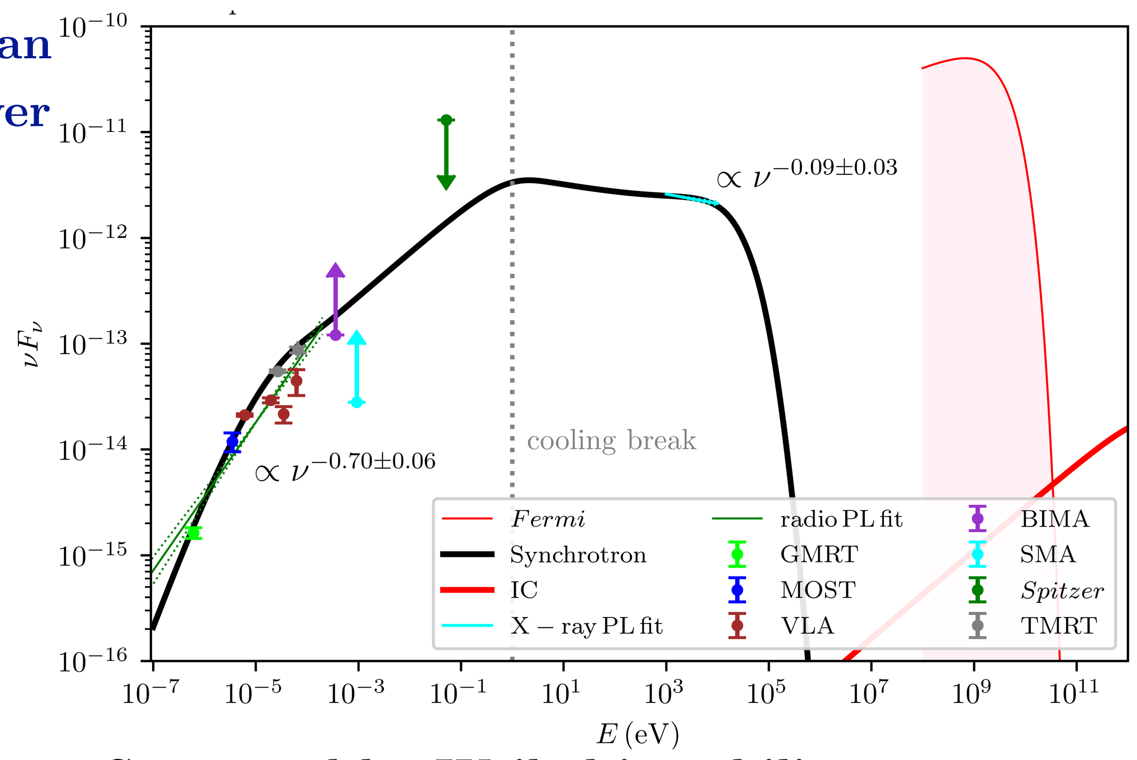
$$\frac{dN}{dE} = N_0\left(\frac{E_{break}}{E_0}\right)^{p_2-p_1}\left(\frac{E}{E_0}\right)^{-p_2} \text{ for } E > E_{break}$$

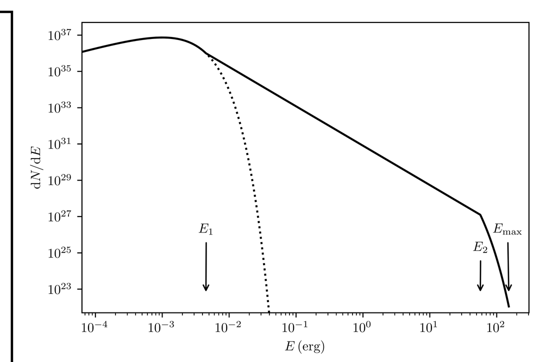
$N_0 = 2.5 \times 10^{49}$ $\quad p_1 = 1.60$ $\quad E_{break} = 0.1$ erg

$E_0 = 3.40 \times 10^{-4}$ erg $\quad p_2 = 2.43$ $\quad E_{max} = 800$ erg

- Suggested by magnetic reconnection
- Fits both radio and X-ray data

Maxwellian with Power Law





$$\frac{dN}{dE} = N_0\,E\exp(-E/E_0) \text{ for } E < E_1$$

$$\frac{dN}{dE} = N_0 C\,E^{-p} \text{ for } E_1 < E < E_2$$

$$\frac{dN}{dE} = N_0 C\,E^{-p}\exp\big(-(E-E_2)/E_{00}\big) \text{ for } E > E_2$$

where $C = E_1^{p+1}\exp(-E_1/E_0)$

$E_{max} = 800$ erg $\quad N_0 = 2 \times 10^{40}$

$E_1 = 0.0045$ erg $\quad p = 2.17$

$E_2 = 57.$ erg $\quad E_0 = 1 \times 10^{-3}$ erg

$E_{00} = 10$ erg

- Suggested by Weibel instability
- Fits both radio and X-ray data

Conclusion & Future Work

- Rule out simple predictions from Fermi acceleration
- Since we do not have enough data to provide constraints on the multi-wavelength SED, we cannot tell which one is the best model.
- If more data are provided, we can use formal χ^2 fit to determine which model is the best.

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