若いTeVパルサー星雲のスペクトル進化

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Introduction

✓**Non-thermal spectrum (synchrotron & IC)**

➡ **Magnetized cloud of non-thermal e+- plasma (& ions)**

✓**Jet – torus structure**

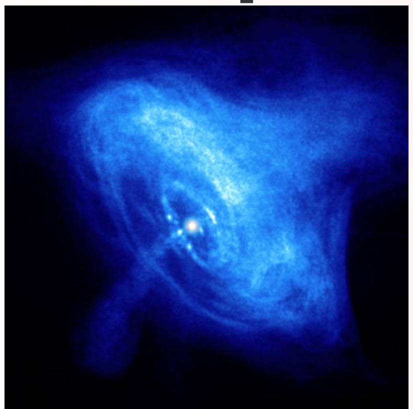
➡ **Powered by rotation powered pulsar**

✓**Expansion velocity V_{PWN} << c. Some are found in SNR.**

➡ **Confined by SNR**

✓**Flat radio spectrum & steep X-ray spectrum**

➡ **Broken power-law or two component injection**



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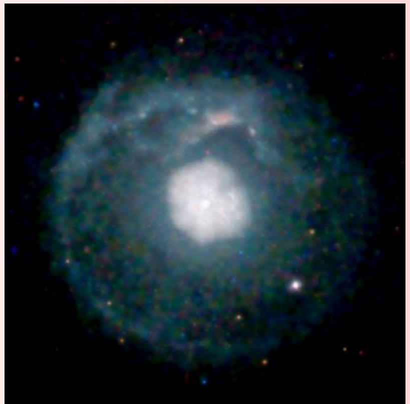
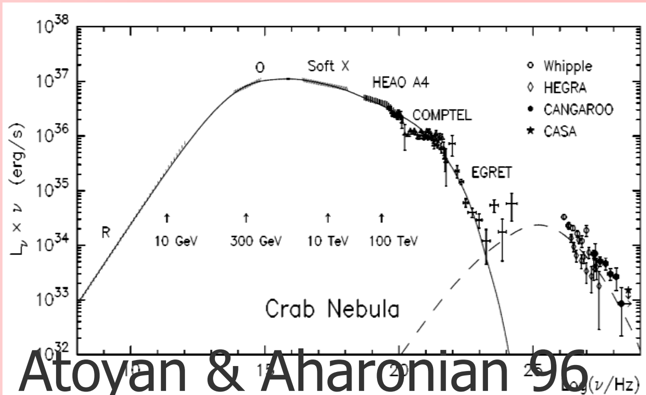




Atoyan & Aharonian 96

Problems

✓ **Pulsar parameters: spin energy & spin-down time**

$$L_{spin}(t) = \dot{E}_0 (1 + \frac{t}{\tau_0})^{-\frac{n+1}{n-1}}$$

✓ **Pair multiplicity κ: pulsar electrodynamics**

Radio obs. of Crab Nebula (~10^6 $\dot{n}_{GJ}$)

σ: EM energy flux / particle energy flux

✓ **σ problem: relativistic magnetized plasma flow**

σ >> 1 at light cylinder (strong B field) → σ << 1 at termination shock (strong dissipation needed)

✓ **Broken power-law distribution: particle acceleration**

Standard shock acceleration (e. g. DSA) cannot create such distribution.

Study with a spectral evolution model of PWNe

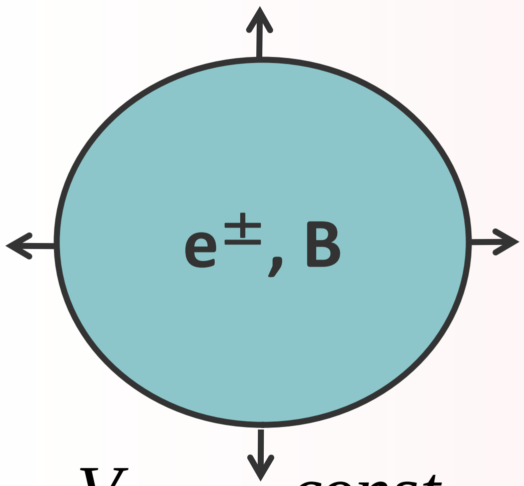
Model: Set Up

Applicable for nearly spherical young PWNe with know pulsar spin-down luminosity.

✓**Expanding uniform sphere (one zone)**

✓**Constant velocity expansion (< 10kyr)**
include effects from SNR (E_{SN}, M_{ej}, etc.) into V_{PWN}.

✓**Injection from pulsar spin-down**
divided into non-thermal e+- & the B field



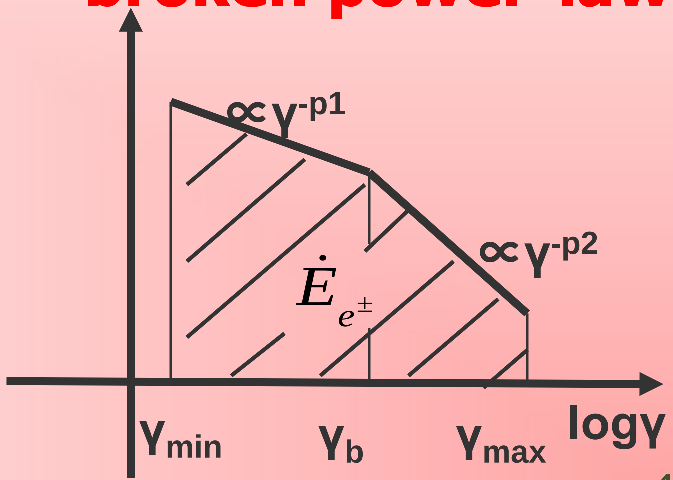
$$V_{PWN} = const.$$

$$\dot{E}_{e^{\pm}} = (1-\eta) L_{spin}(t)$$

$$\dot{E}_{B} = \eta L_{spin}(t)$$

η parameter is close to σ parameter.

broken power-law



Model: Evolutions

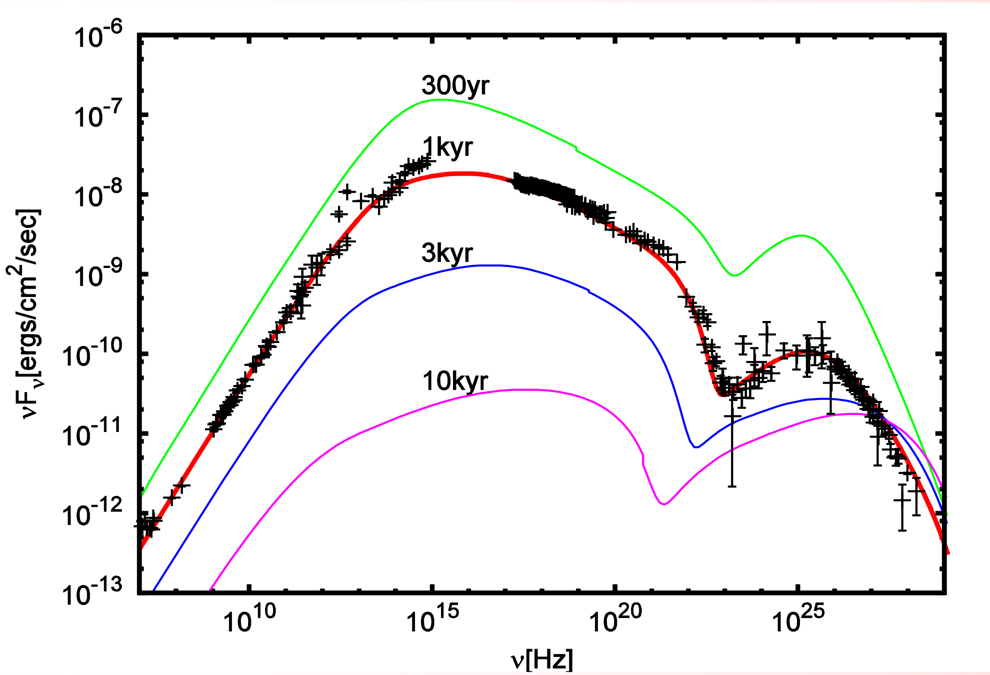
✓**Evolution of B field**

$$\frac{4\pi}{3}(R_{PWN}(t))^3 \cdot \frac{(B(t))^2}{8\pi} = \int_0^t \eta L_{\rm spin}(t')dt'$$

✓**Evolution of particle distribution (radiative & adiabatic cooling)**

$$\frac{\partial}{\partial t}N(\gamma,t) + \frac{\partial}{\partial \gamma}(\dot{\gamma}(\gamma,t)N(\gamma,t)) = Q_{\rm inj}(\gamma,t)$$

✓**Spectral evolution of the Crab Nebula** **Tanaka & Takahara '10 ApJ**



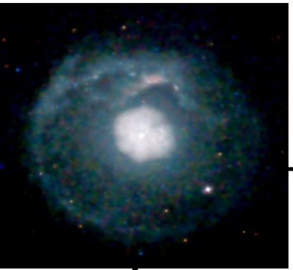
η=0.005 << 1, B(t_{age}) ~ 85μG

Current flux decreasing rate

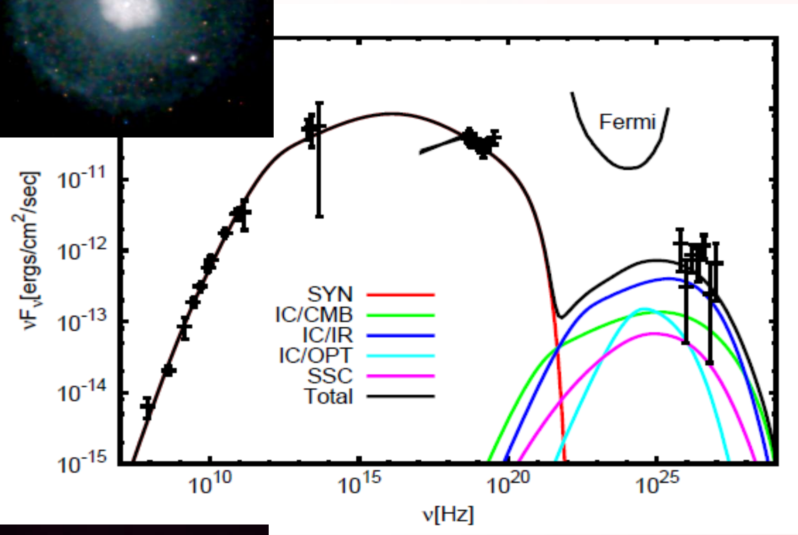
	radio[%/yr]	Opt.[%/yr]
Ours	-0.16	-0.24
Obs.	-0.17	-0.55

Young TeV PWNe

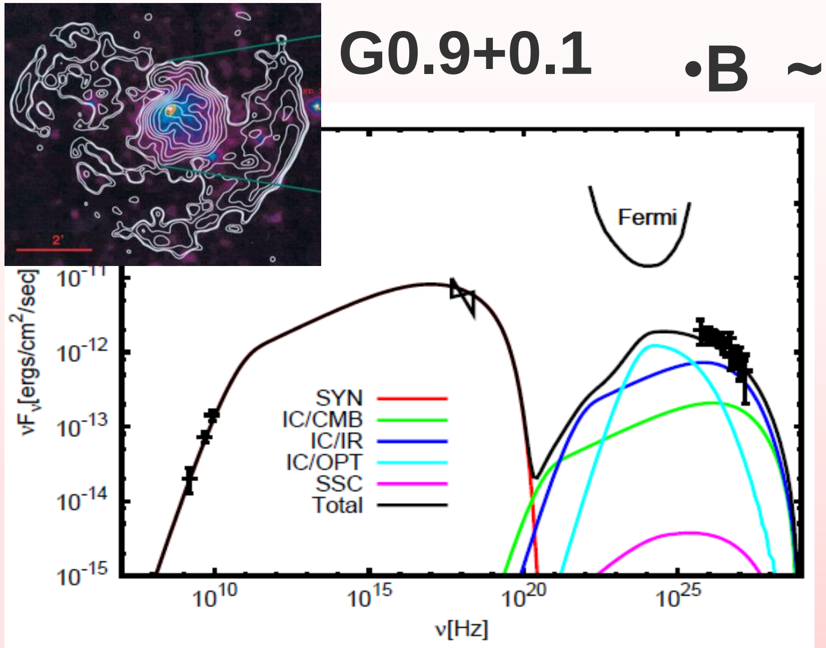
IC/ISRF dominate for all objects.



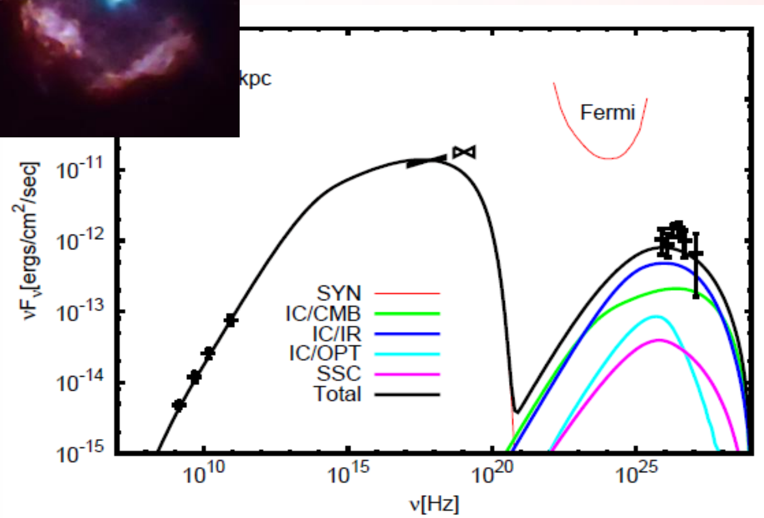
G21.5-0.9 •B ~ 64μB

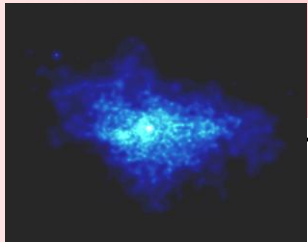


G0.9+0.1 •B ~ 15μB

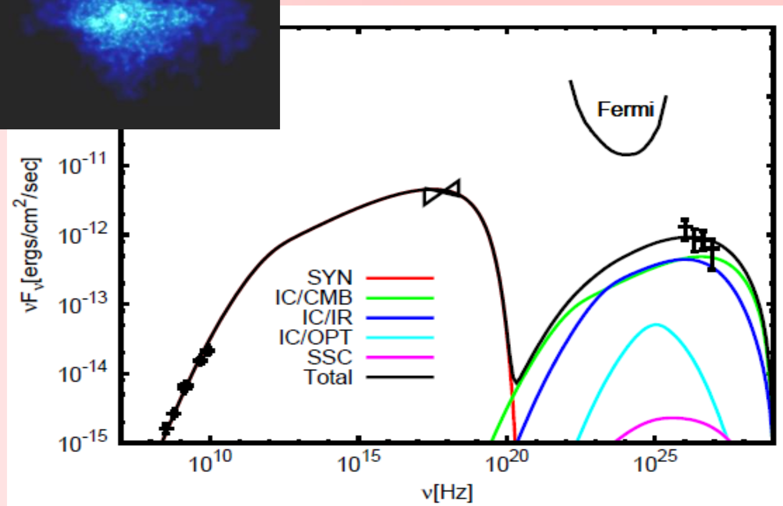


Kes 75 •B ~ 21μB



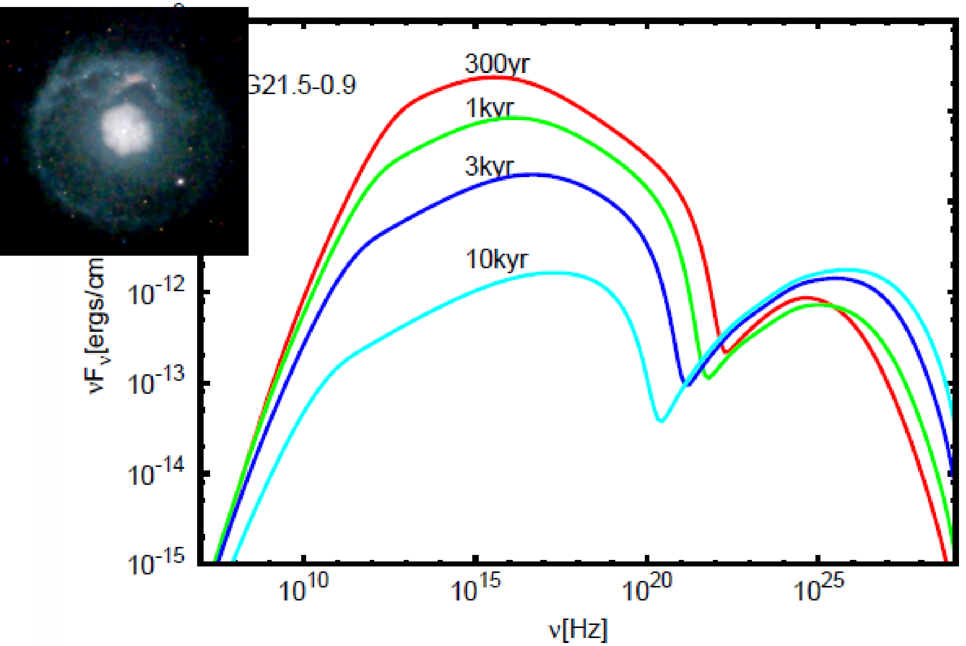


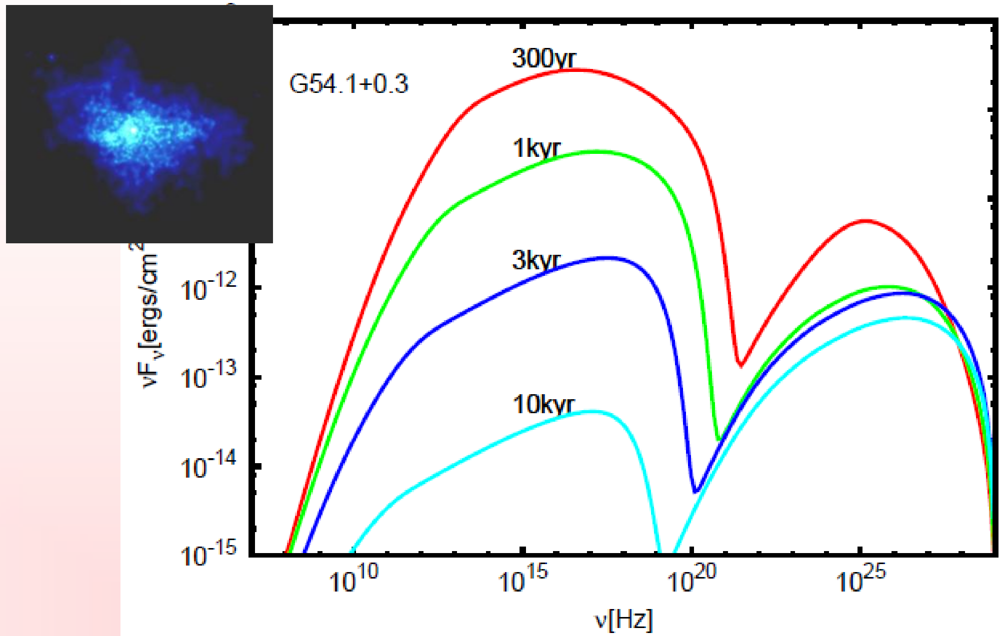
G54.1+0.3 •B ~ 6.7μB



Pulsar Parameters

Increase γ-rays = injection wins! **Decrease γ-rays = cooling wins!**





	Crab	G21.5-0.9	G0.9+0.1	Kes 75	G54.1+0.3
Age[kyr]	0.95	1.0	2.0	0.7	2.3
$\tau_c = P/2\dot{P}$[kyr]	1.24	4.85	3	0.73	3
τ_0[kyr]	0.7	3.9	3.2	1.5	0.6
$L_0 * \tau_0$[10^{48}ergs]	74	8.8	12	1.5	5.4

Diversity of pulsar parameters

Magnetization Parameter

All Young TeV PWNe need $10^{-4.3} < \eta < 10^{-1.8} << 1$ ($\sigma << 1$).

	Crab	G21.9-0.5	G0.9+0.1	Kes 75	G54.1+0.3
$\eta[10^{-3}]$	5	15	3	0.05	0.3
$B_{now}[\mu B]$	85	64	15	21	6.7

$\eta << 1$ arises from flux ratio of IC to syn.

$$\frac{P_{\rm IC}(t)}{P_{\rm syn}(t)} \sim f_{\rm KN} \frac{U_{\rm ph}(t)}{U_{\rm B}(t)},$$

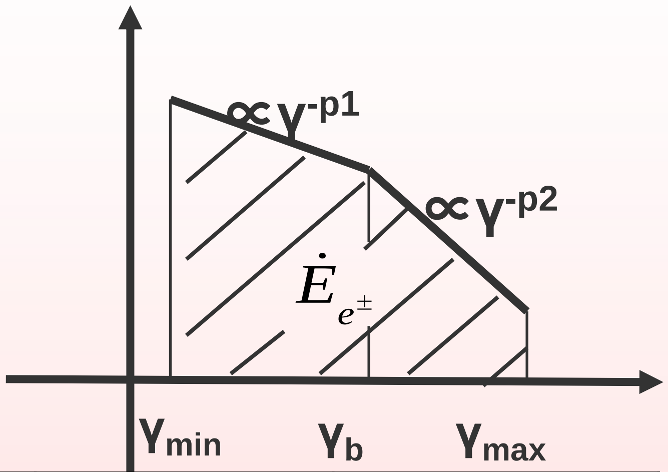
Non TeV PWNe (like 3C58 & B0540-69.3) can be formed by $\eta \sim 1$ pulsar winds?

Pair Multiplicity

Typical 'p1' and 'p2' give, 1<p1<2<p2

$$\dot{E}_{e^\pm} = \int Q_{inj} \gamma m c^2 d\gamma \approx \dot{N}_{e^\pm} \gamma_b m c^2$$

$$\dot{N}_{e^\pm} = \int Q_{inj} d\gamma \approx \gamma_{\min} Q_{inj}(\gamma_{\min})$$



	Crab	G21.9-0.5	G0.9+0.1	Kes 75	G54.1+0.3
γ_b [10^5]	6	1	0.4	1	3
γ_{min} [10^2]	<1	<30	-	<50	<200
p1	1.5	1.0	-	1.6	1.2
κ [10^4]	**<100**	**<12**	**8.3**	**<2.8**	**<2.3**

$$L_{spin}(t) = L_{wind} \approx \kappa \dot{n}_{GJ} \Gamma_{wind} m c^2 \quad \Rightarrow \quad \Gamma_{wind} \neq \gamma_b$$ **if γ_{min} exist.**

How the break energy (γ_b) is determined?

Broken Power-law Injection

	Crab	G21.9-0.5	G0.9+0.1	Kes 75	G54.1+0.3
p1	1.5	1.0	-	1.6	1.2
p2	2.5	2.55	2.6	2.5	2.55

✓p2 (high energy) ~2.5 for all ➡ one acceleration process?

✓1.0 < p1 < 1.6 or nothing for G0.9+0.1
Because p1 has variety, rela. Maxwellian + single power – law injection can reproduce radio spectrum of several PWNe.

$$\frac{\partial}{\partial t}N - \frac{\partial}{\partial \gamma}\frac{\gamma}{t}N = \delta(\gamma - \gamma_0) \quad \Rightarrow \quad N \propto \gamma^{-1}$$

✓Constant velocity expansion
✓Steady injection

One zone ➡ spatial structure may be important.

Summary

- ✓ Pulsars have individual characters.
  - ✓ Spin energy, spin-down time etc.
- ✓ Young TeV PWNe have small η.
  - ✓ Is large η possible for non-TeV PWNe. (future work)
- ✓ Pair multiplicity $\kappa > 10^4$ (broken power-law injection)
  - ✓ What is the origin to determine γb?
- ✓ Broken power-law injection
  - ✓ High energy : one process, low energy: adiabatic cooling?

(however, simple adiabatic cooling is not applicable to the Crab)