A MODEL OF THE SPECTRAL EVOLUTION OF PULSAR WIND NEBULAE

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ABSTRACT

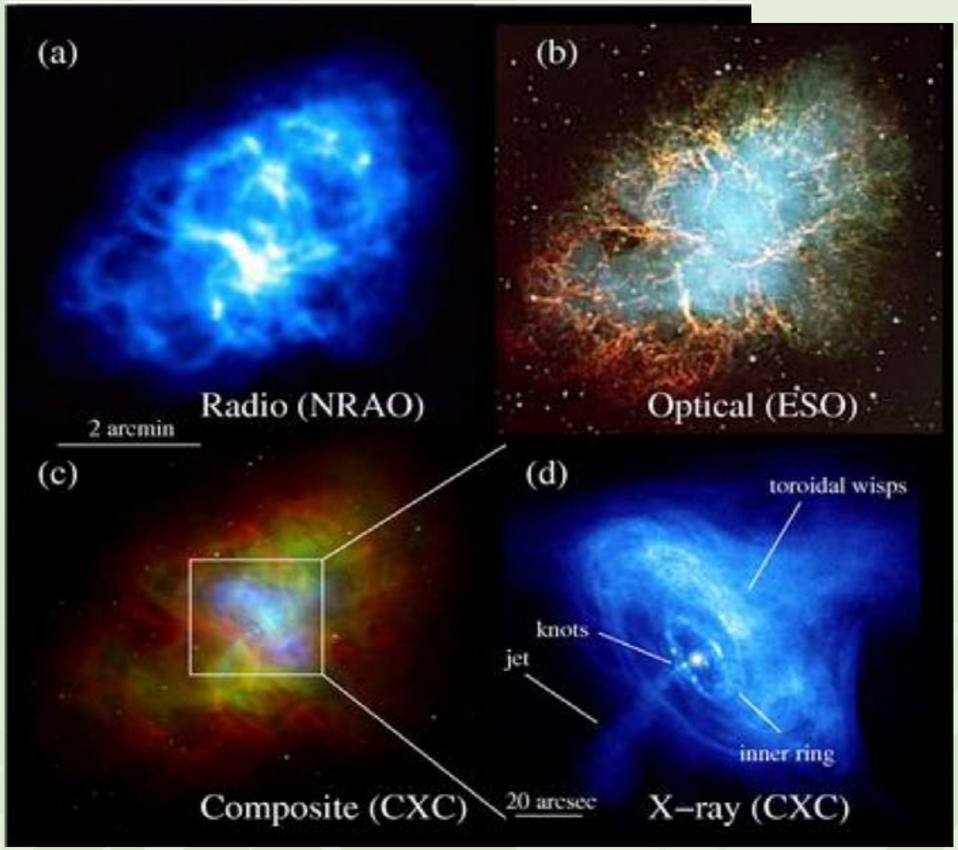
The emission of pulsar wind nebulae (PWNe) tells us the properties of the pulsars, the pulsar winds and their environments.

In this study, we study a spectral evolution of PWNe, because it is important for old PWNe to take into account the energy injected when they were young. We model the evolution of the magnetic field inside the uniformly expanding PWN and solve the evolution of the electron energy distribution function considering time dependent injection from the pulsar and cooling by radiative and adiabatic losses.

The model is calibrated by fitting the calculated spectrum to the observed Crab Nebula at an age of a thousand years. Our model is applicable to other PWNe.

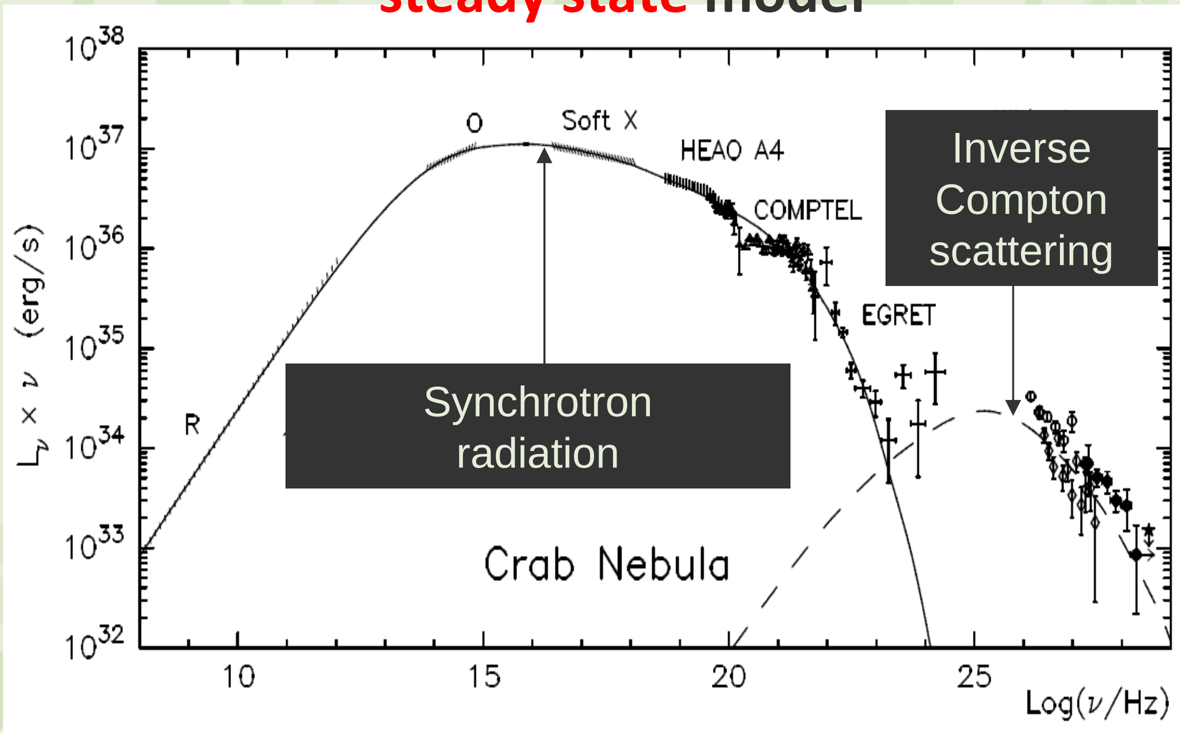
MOTIVATION

The Crab Nebula



Gaensler & Slane 2006

steady state model



Atoyan & Aharonian 1996

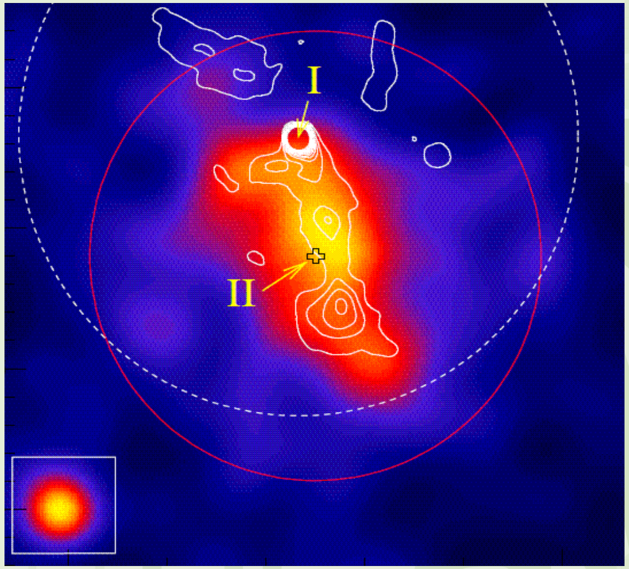
Observed in wide frequency ranges

Non-thermal radiation

How evolve the spectrum of the Crab Nebula ?

MOTIVATION

The Vela X Nebula

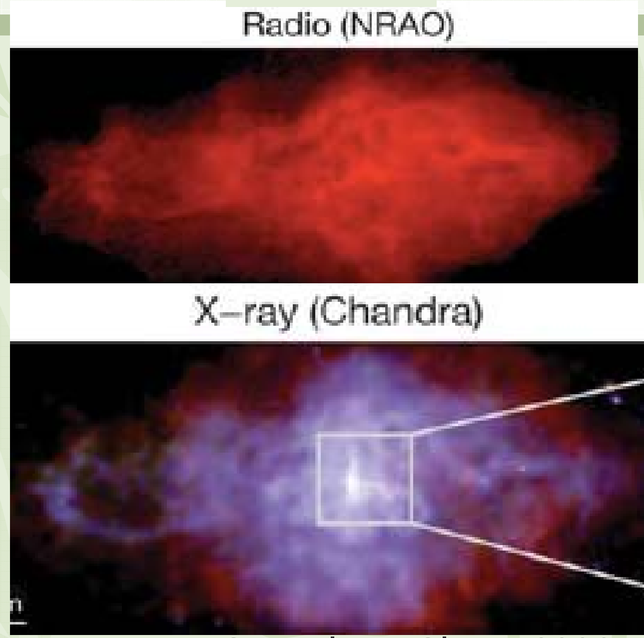


Aharonian+ 2006

HESS J1809-193

Aharonian+ 2007

3C58



Gaensler & Slane 2006

Old PWN (>10kyr) observed in gamma-rays.

TeV unID source (possibly old PWN)

Young PWN (<5kyr) “not” detected in gamma-rays.

Can these varieties of PWNe characteristics be explained by the spectral evolution of PWNe ?

PURPOSES

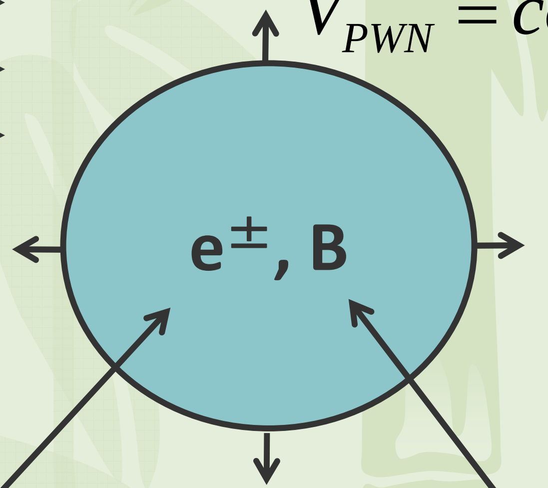
- Spectral evolution of the Crab Nebula.
- Dependence to the environments.
- Observed PWN variations.

MODEL: ASSUMPTIONS

Assume

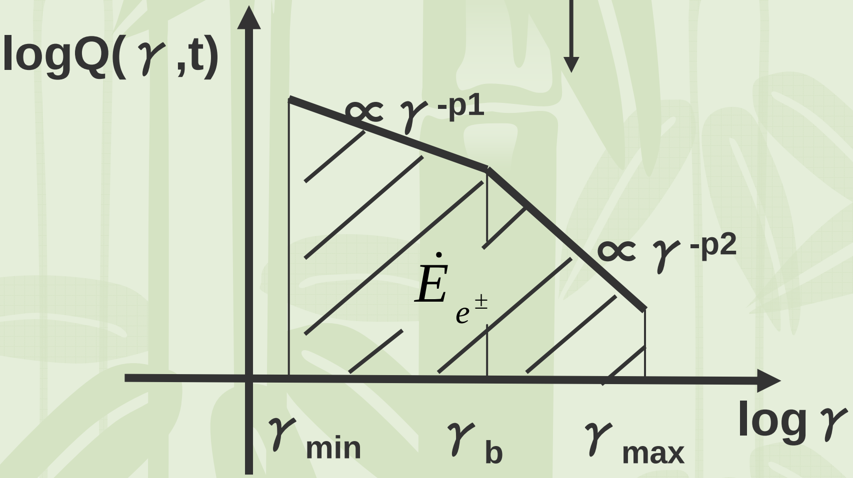
- **uniform sphere.**
- **constant expansion velocity.**
- **Non-thermal e± & the magnetic field.**
- **broken power-law for injected e± spectrum.**

$$V_{PWN} = const.$$



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

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



$$Q_{\rm inj}(\gamma, t) = \begin{cases} Q_0(t)(\gamma/\gamma_{\rm b})^{-p_1} & \text{for } \gamma_{\rm min} \le \gamma \le \gamma_{\rm b} \\ Q_0(t)(\gamma/\gamma_{\rm b})^{-p_2} & \text{for } \gamma_{\rm b} \le \gamma \le \gamma_{\rm max} \end{cases}$$

MODEL: BASIC EQUATIONS

Evolution of the magnetic field: the magnetic energy conservation

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

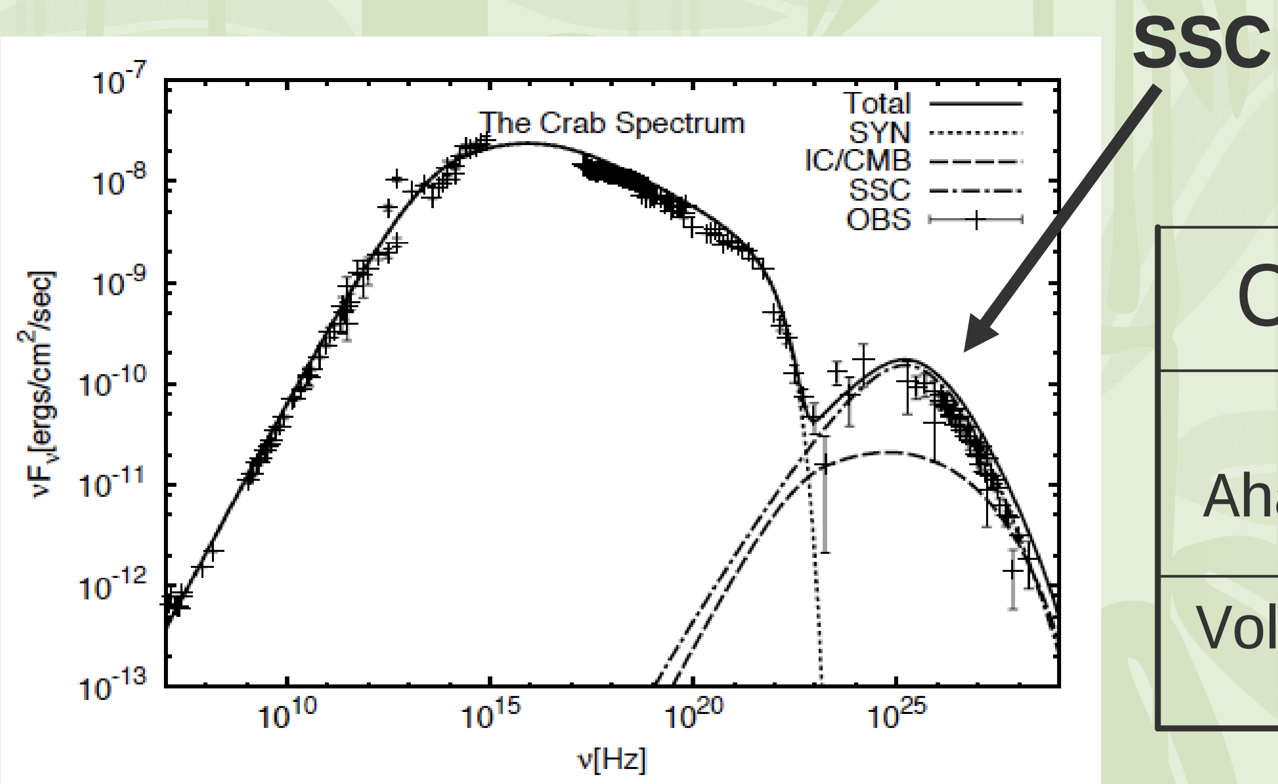
→ $B(t) \propto t^{-1.5}$, when $t \gg \tau_0$

Evolution of particle distibution: the continuity equation

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

$$\dot{\gamma} = -(\dot{\gamma}_{syn} + \dot{\gamma}_{IC} + \underline{\dot{\gamma}_{ad}})$$

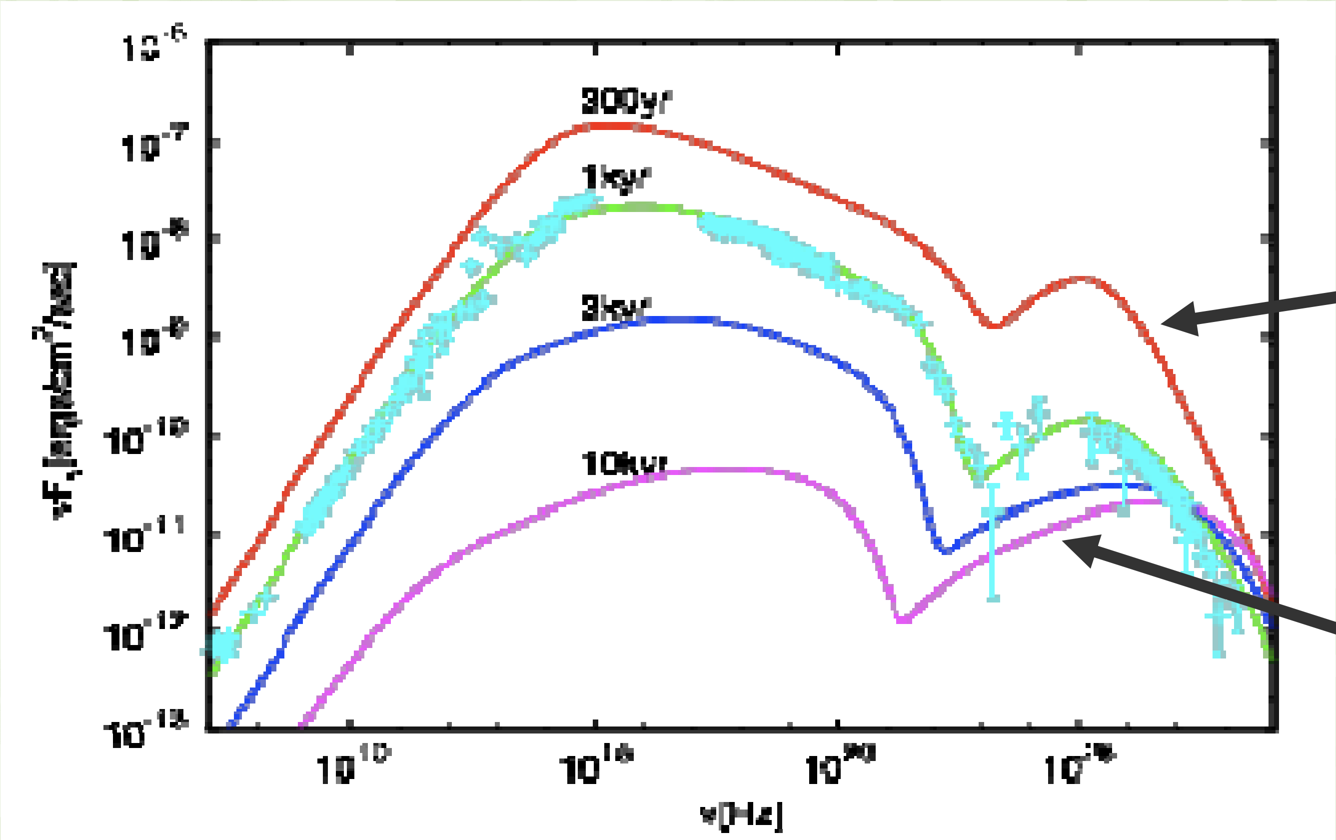
THE CRAB NEBULA
RECONSTRUCT CRRENT SPECTRUM



$$\eta = 0.003$$

Our model	~87 μ G
Atoyan & Aharonian (1996)	~300 μ G
Volpi et al. (2008)	~100 μ G

RESULT: THE CRAB NEBULA EVOLUTION



SSC

decrease fast with time

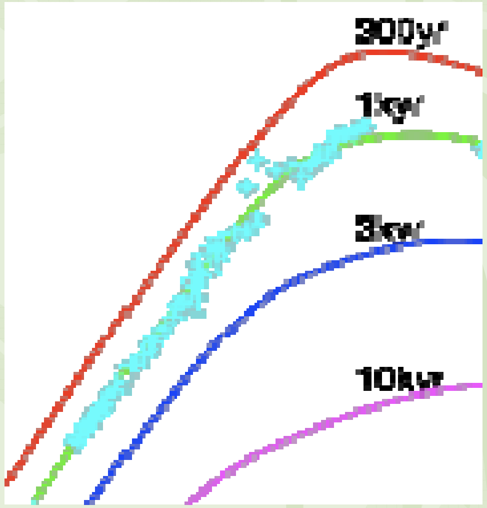
IC/CMB

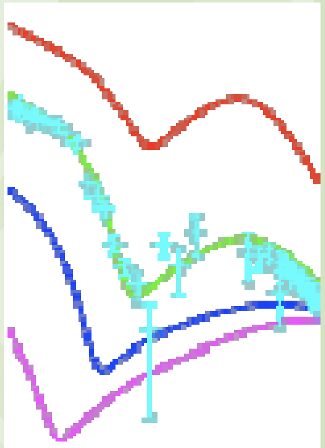
almost constant

THE CRAB NEBULA FLUX DECREASE RATE

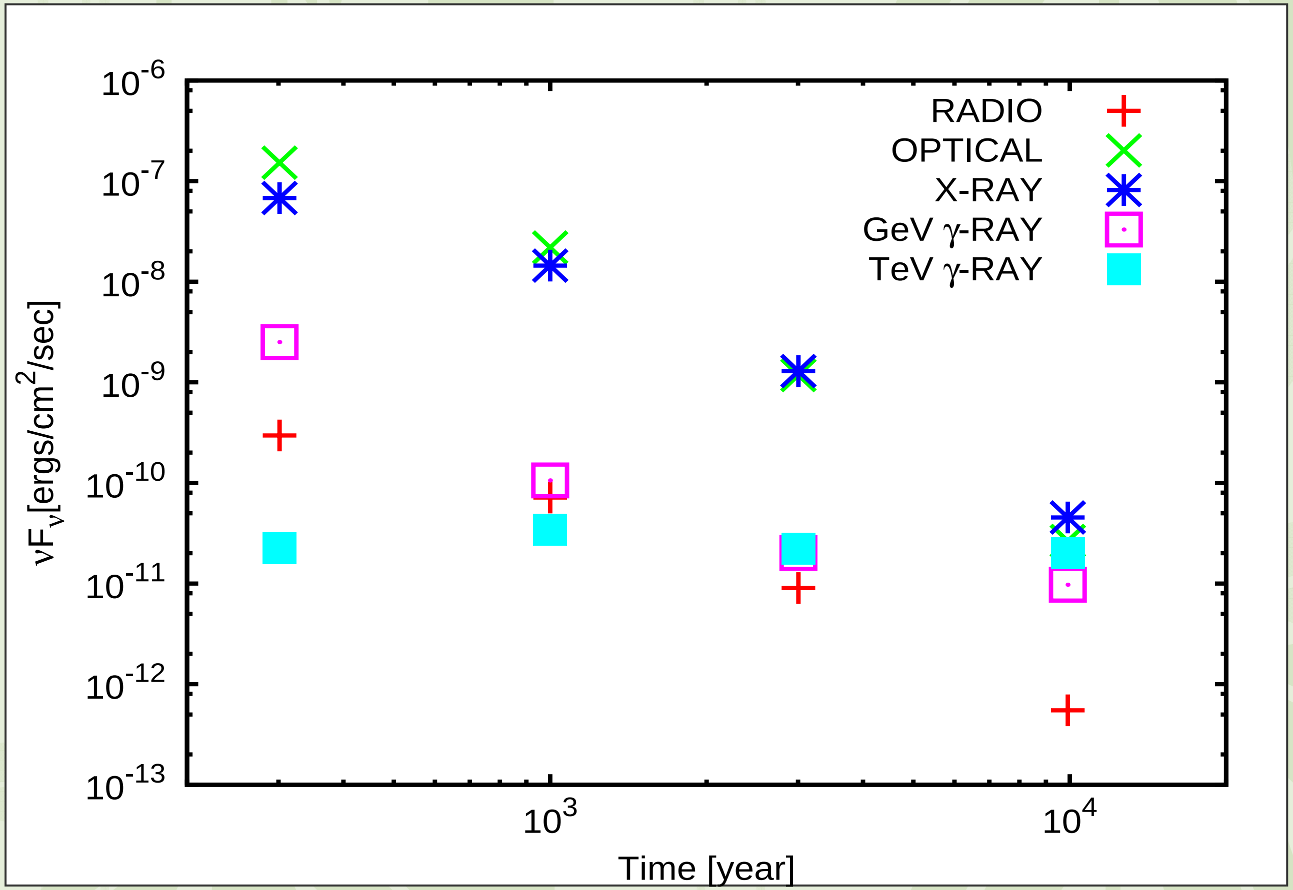
	Radio	Optical	5GeV
Our model	-0.16 % / yr	-0.22 % / yr	**-0.36 % / yr**
Observations	-0.17 % / yr Vinyaikin `07	-0.55 % / yr Smith `03	***Fermi*, tells me !**

Almost consistent!!





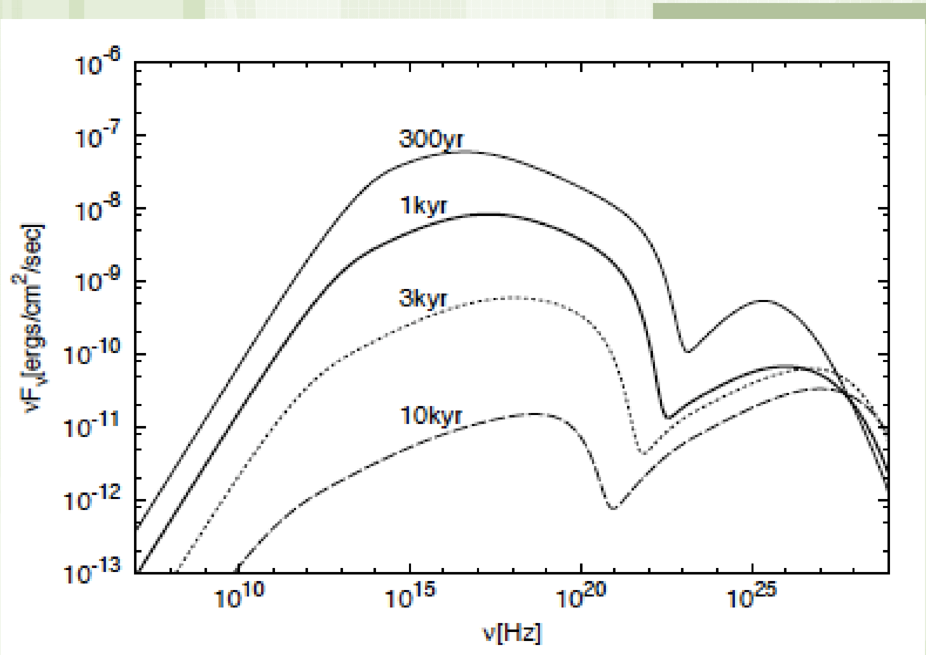
RESULT: THE CRAB NEBULA FLUX RATIO



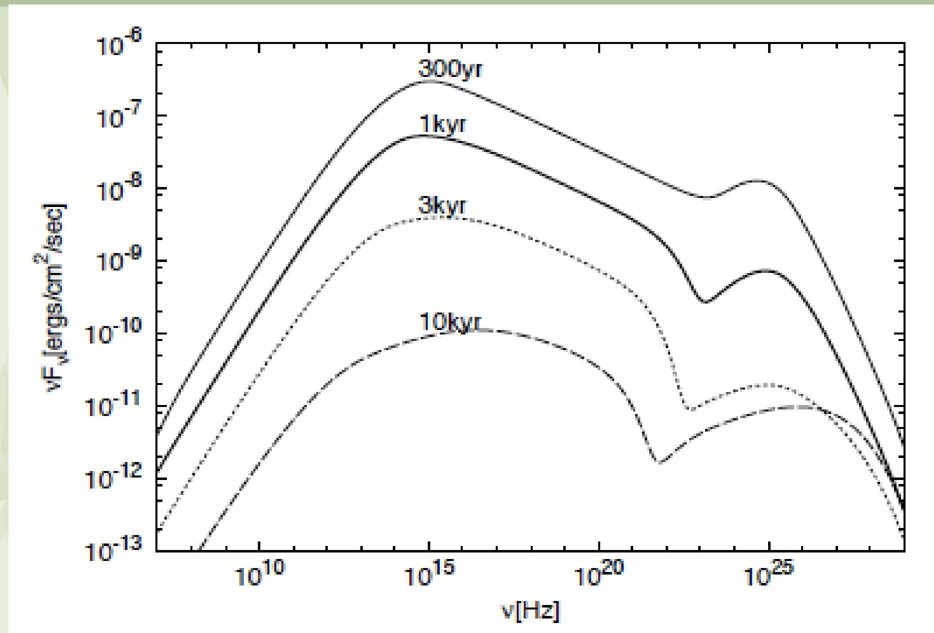
F_{IC} / F_{syn} increases with time.

Old PWNe candidate of unidentified gamma-rays sources.

DEPENDENSE TO EXPANSION VELOCITY



Rapid expansion (twice velocity)



Slow expansion (a half velocity)

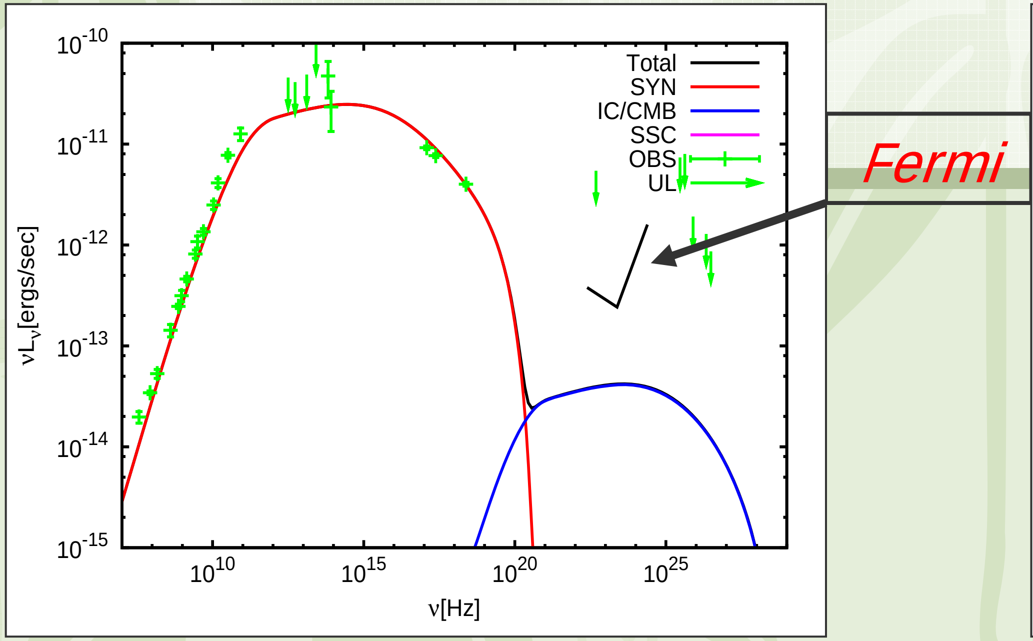
Weak F_{syn} → large F_{IC} / F_{syn}

Strong F_{syn} → small F_{IC} / F_{syn}

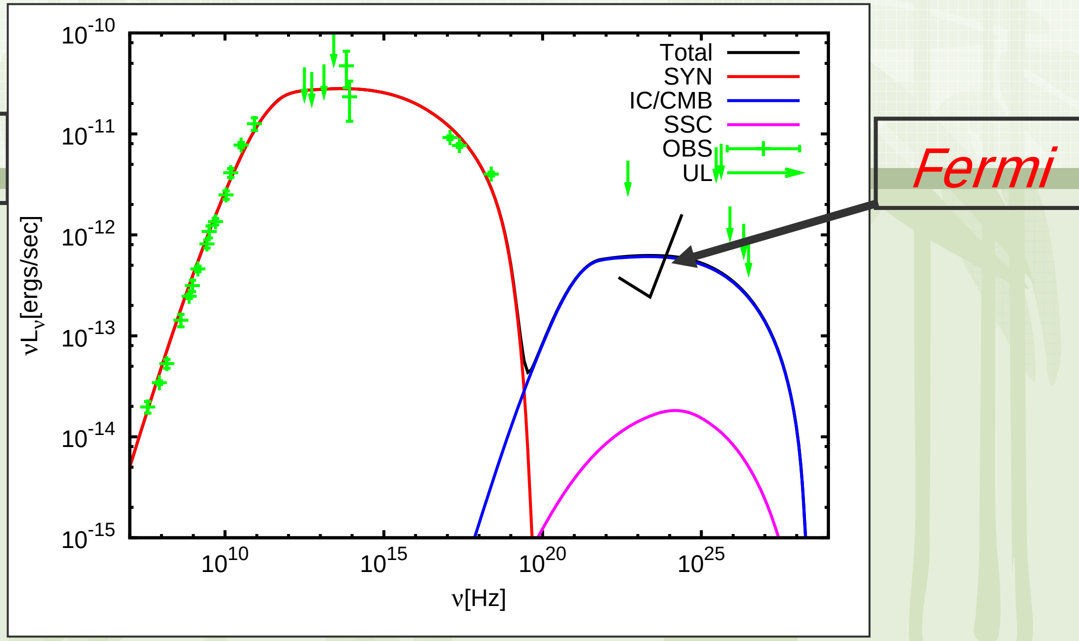
Rapid expansion is favored for gamma-ray unidentified sources.

3C58

MODEL 1



MODEL2



	η	t_{age}(kyr)	V_{PWN}(km/s)
model1	0.5, (17 μG)	1.5	2800
model2	0.005, (33 μG)	4.0	860

- If t_{age} > 4kyr, the PWN 3C58 is detectable with *Fermi*.
- Unrelated to SN1181.

SUMMALY

- We calculate the spectral evolution of the PWN.

- the Crab Nebula

1. From spectral fitting, $B(t_{age}) \sim 87\mu G$.
2. F_{IC} / F_{syn} increases with time.
3. Radio evolution is consistent.

- 3C58

1. Unrelated to SN1181.
2. If t_{age} > 4kyr, the PWN 3C58 is detectable with *Fermi.*

- Applicable to other PWNe.