Stochastic Acceleration Model of Very Young Pulsar Wind Nebula Associated with SN 1986J

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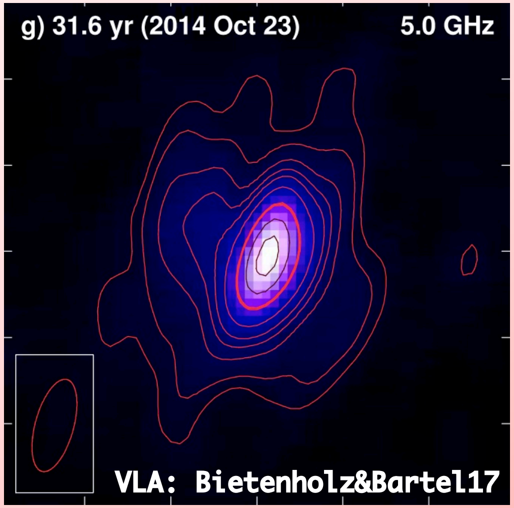
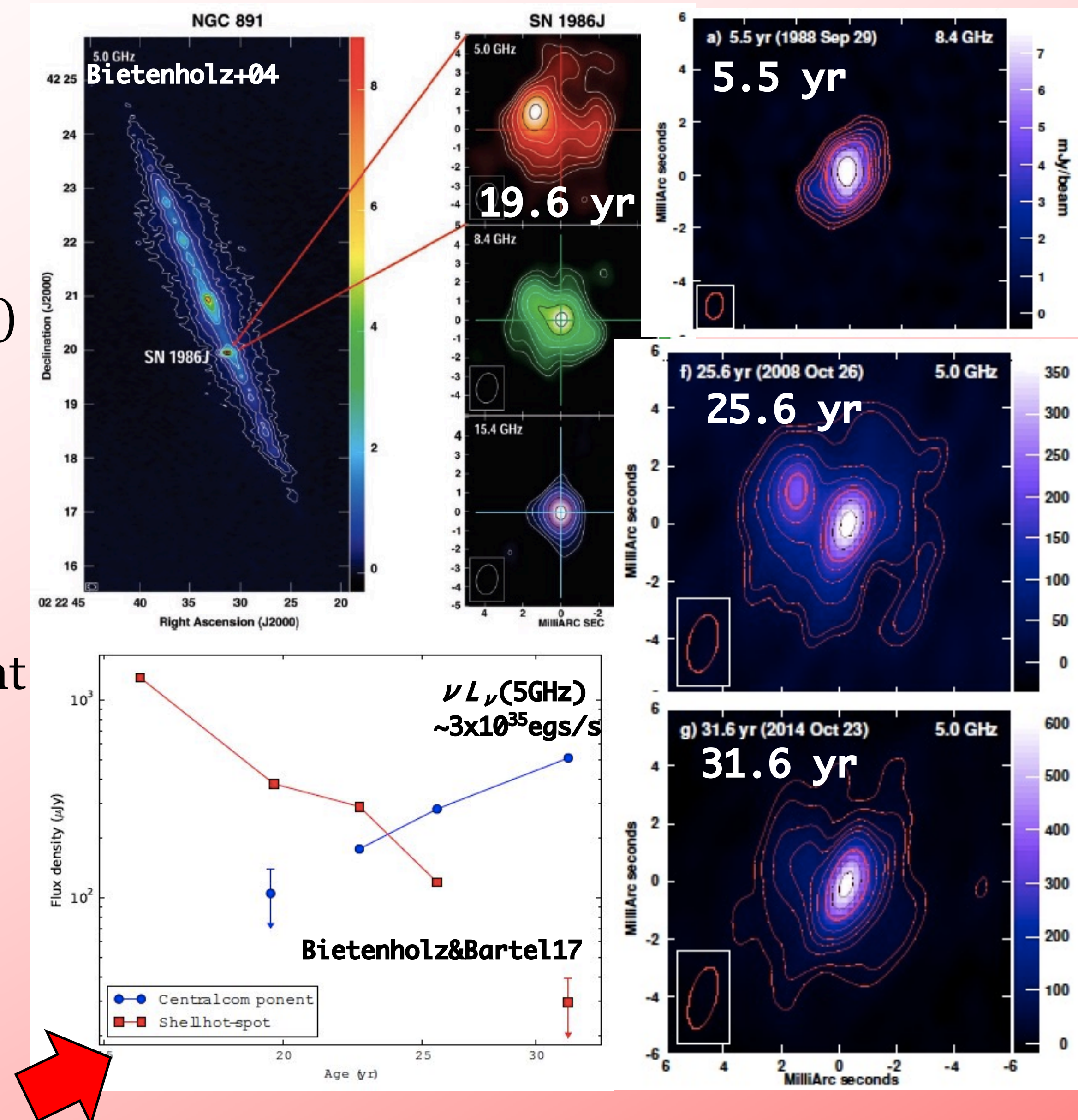


10, Dec. 2020, Connecting high-energy astroparticle physics
for origins of cosmic rays and future perspectives @ Kyoto/Zoom

Introduction

SN 1986J

- Radio discovery in 1986
- Exploded in 1983 (estimated)
- Hosted by NGC 891@10Mpc
- Decaying shell hotspot
- Increasing central component
- ~ 20 times! of Crab Nebula's luminosity for central component @ 5GHz



Going to fit this light curve with PWN model

Motivation

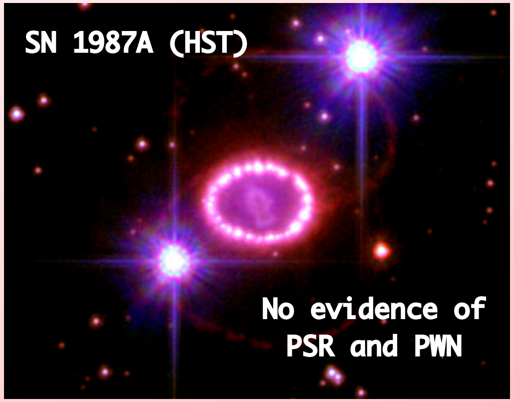
Birth properties P_0 & B_0 (dipole) of PSRs?

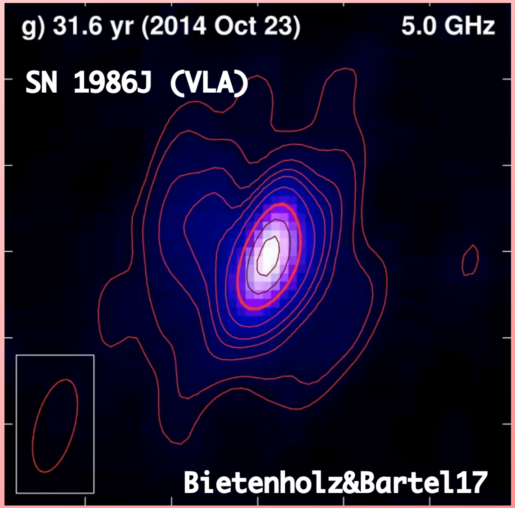
(higher-order properties: multipole B-field, radius, mass, ...)

- Youngest identified NS ≫ 100 yr
- Few extragalactic PSRs (some Magellanic and ULX/accreting PSRs)
- No direct observational evidence of P_0 of O(msec), but they are discussed as progenitor of GRBs, FRBs, SL-SNe, UHECRs etc.

⇨ Hunting fast-rotating young PSR!

- Observed PWNe are much luminous than their central PSR itself



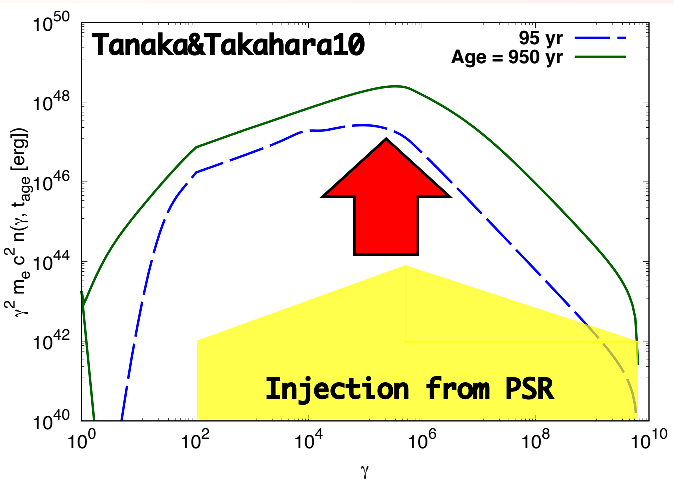


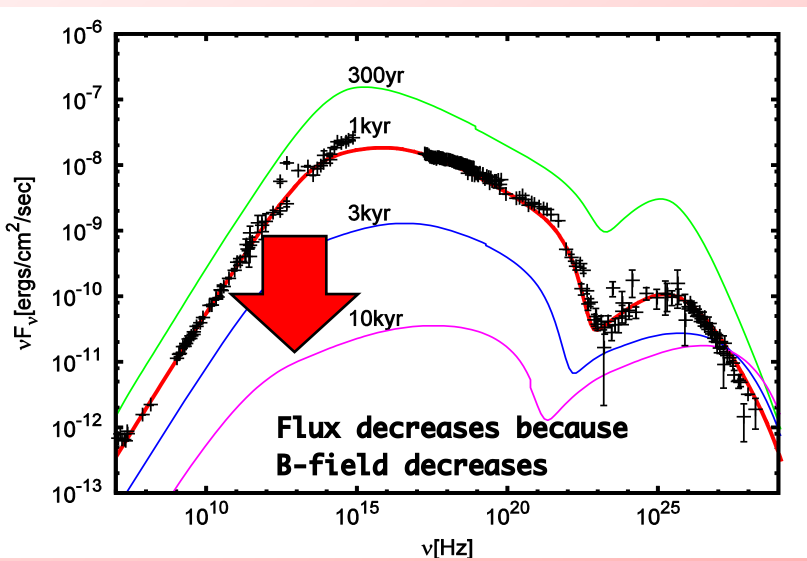
Hunting the youngest PWN to study its central PSR

Model

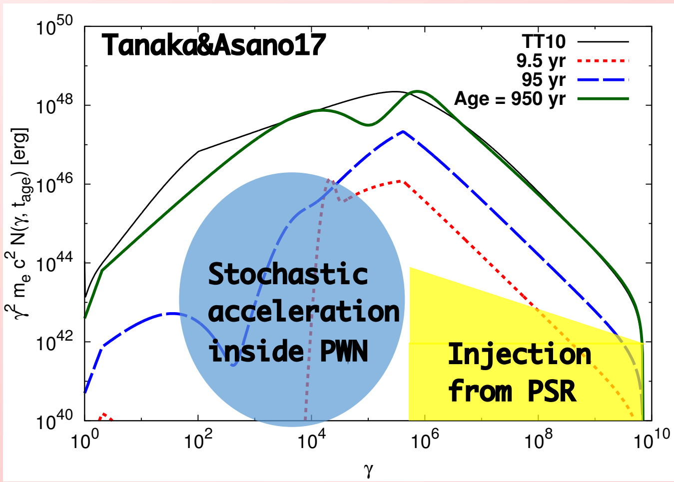
Flux evolution of PWNe

Conventional broken power-law model





Stochastic acceleration model



- Standard single PL injection + stochastic acceleration
- Radio-emitting particles increase more rapidly than broken PL model

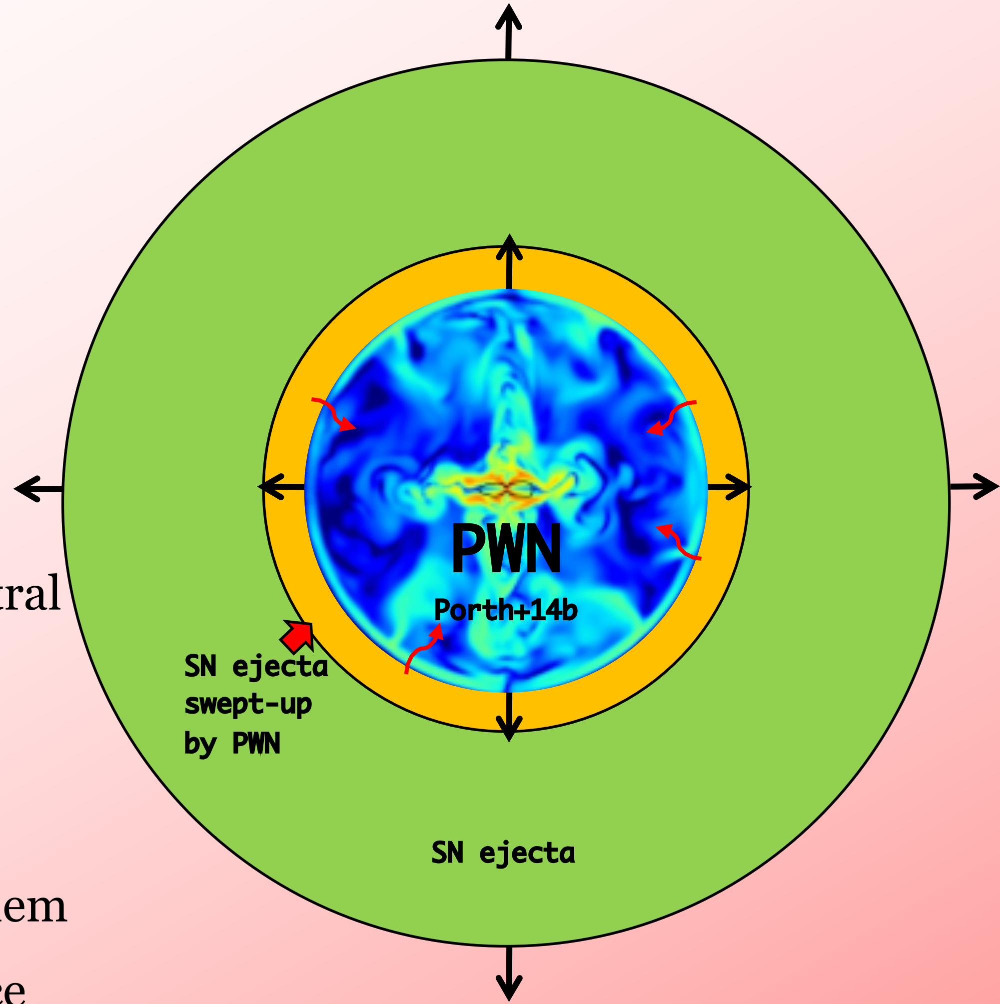
➡ Radio lumi. can increase with time even for optically thin regime (> 10yr)

One-zone Model

One-zone approx. for PWN

- Expanding PWN inside expanding SN ejecta **e.g., Gelfand+09, Bandiera+20**
- Supplying accelerated $e^{\pm}$ & B from central PSR e.g., Pacini&Salvati73, Kennel&Coroniti84
- Seeding low-energy electrons from SN ejecta and stochastically accelerating them to radio-emitting particles by turbulence **Tanaka&Asano17**
- B-field evolution of $\frac{4\pi}{3} R_{\rm PWN}^3(t) \frac{B^2(t)}{8\pi} = \eta_{\rm B} \int_0^t L_{\rm spin}(t')dt'$ **Tanaka&Takahara10**

$$L_{\rm spin} = (\eta_{\rm e} + \eta_{\rm B} + \eta_{\rm turb}) L_{\rm spin}$$



Stochastic Acceleration

$$\frac{\partial}{\partial t}N(\gamma,t)+\frac{\partial}{\partial\gamma}\left[\left(\underbrace{\dot{\gamma}_{\rm cool}(\gamma,t)}_{\text{cooling effects}}-\underbrace{\gamma^2 D_{\gamma\gamma}(\gamma,t)\frac{\partial}{\partial\gamma}\frac{1}{\gamma^2}}_{\text{stochastic accel.}}\right)N(\gamma,t)\right]=\underbrace{Q_{\rm PSR}(\gamma,t)}_{\text{from pulsar}}+\underbrace{Q_{\rm ext}(t)}_{\text{Extra injection}}$$

$$D_{\gamma\gamma}=\frac{\gamma_{\rm min}^2}{2\tau_{\rm acc,m}}\left(\frac{\gamma}{\gamma_{\rm min}}\right)^2\exp\left(-\frac{t}{\tau_{\rm turb}}\right)$$

- $\tau_{\rm acc,m}$: acceleration time normalized at $\gamma_{\rm min}$
- $\tau_{\rm turb}$: decay time-scale of turbulence

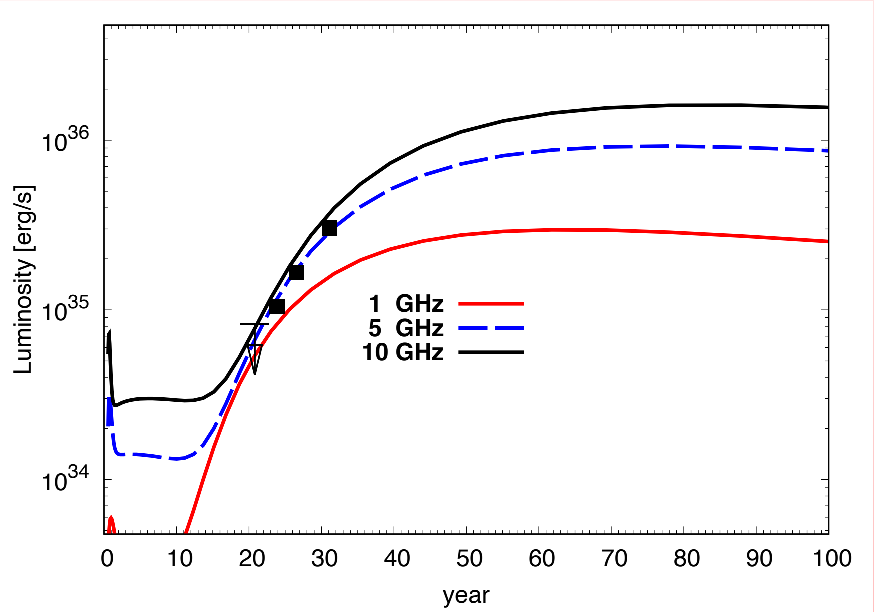
$$Q_{\rm ext}(\gamma,t)=f_{\rm inj}4\pi R_{\rm PWN}^2(t)v_{\rm PWN}(t)\,n_{\rm ej}(R_{\rm PWN}(t))\delta(\gamma-\gamma_{\rm inj})$$

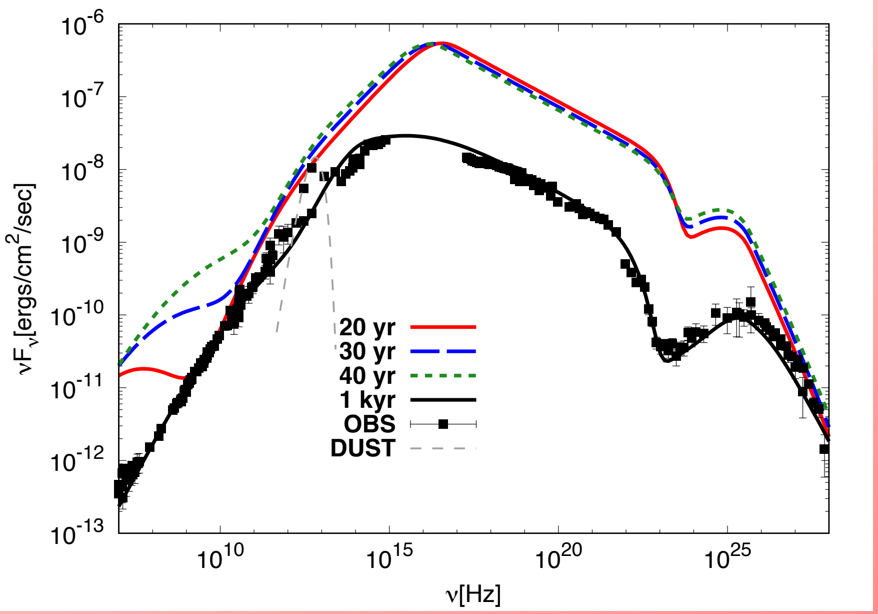
- $f_{\rm inj}$: injection efficiency $f_{\rm inj} \ll 1$ ($O(10^{-5})$)
- $\gamma_{\rm inj}$: injection energy $\gamma_{\rm inj} \sim 1$

Results & Conclusion

Results

- 5 GHz light curve of SN 1986J (<30 yr) and Crab spectrum (~950 yr) can be fitted simultaneously
- Crab's spin-down evolution
- $(\eta_B, \eta_{turb}) = (0.01, 0.5)$
- $(\tau_{acc,m}, \tau_{turb}) = (10, 80)$ yr
- f_{inj}=3 x 10^{-5}





Conclusions

- Stochastic acceleration model can reproduce observed radio flux increase of SN 1986J.
- Central component of SN 1986J would be PWN of Crab-like pulsar, i.e., not an extreme pulsar ($P_0 \sim O$(msec)).
- Future radio observation will distinguish the stochastic acceleration model from absorption (broken-PL) model.