Particle acceleration region of old pulsars

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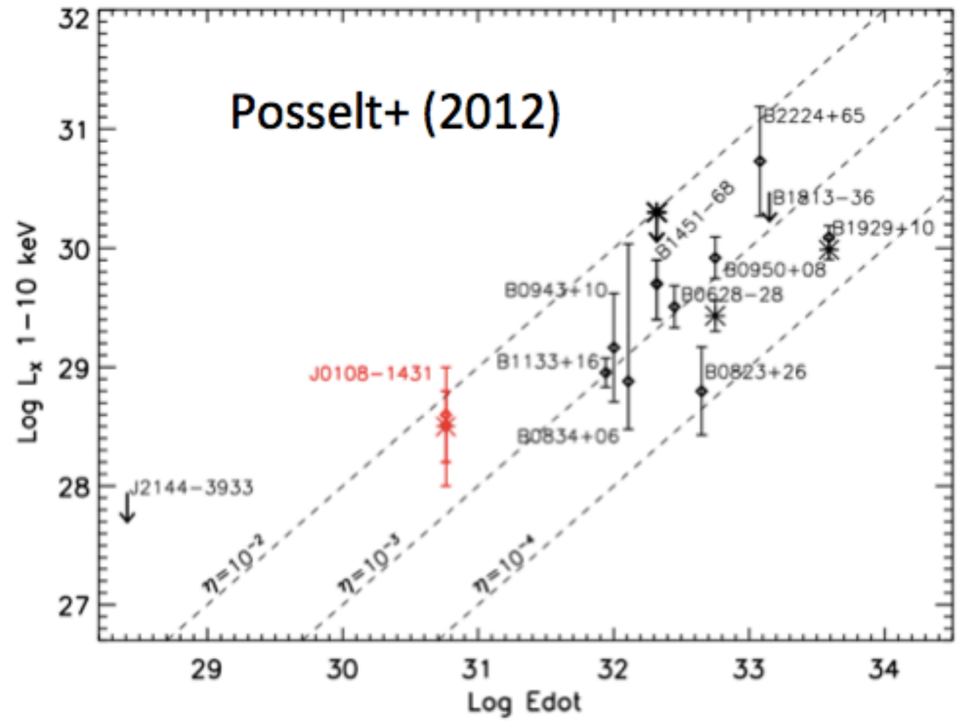
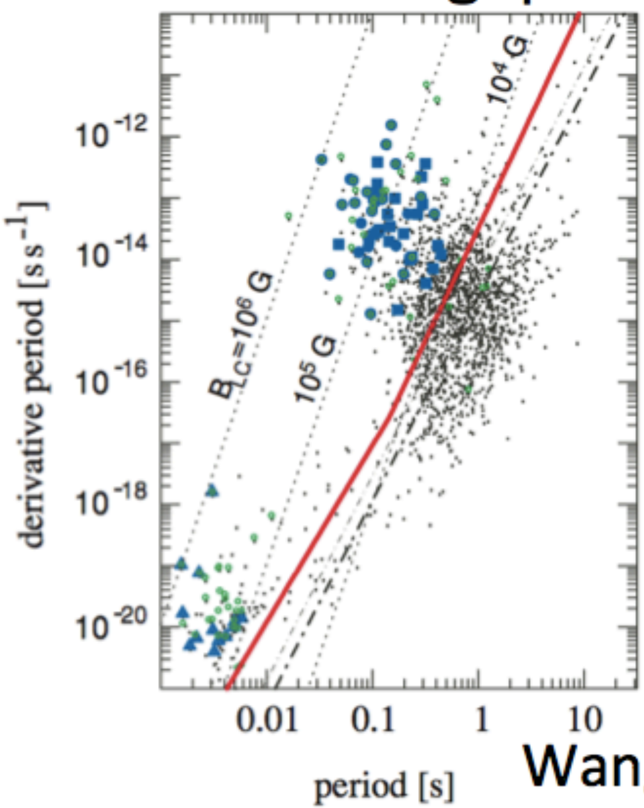
Old pulsars

"Old" pulsars : τ_c = P/2Pdot > 1Myrs, non-recycled

Non-thermal X-ray emission is detected.



- Outer gap



Wang & Hirotani (2011)

- Polar cap

→ Smaller than the cyclotron turnover frequency near the star.

(Rudak & Dyks 1999)

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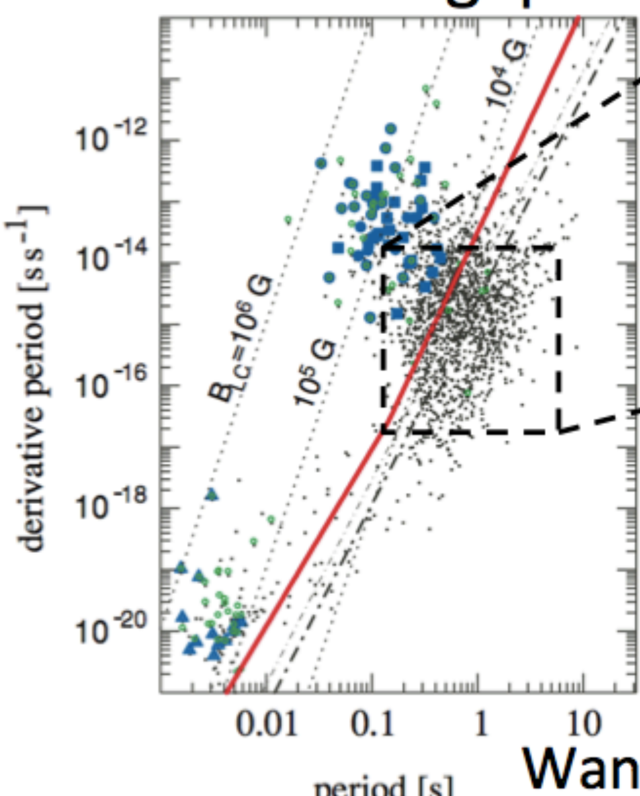

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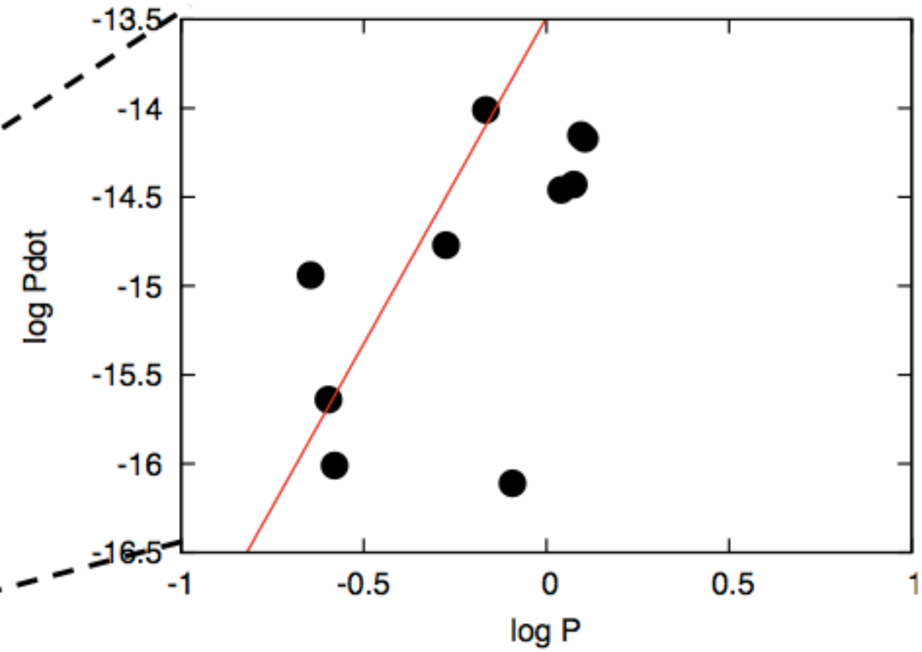

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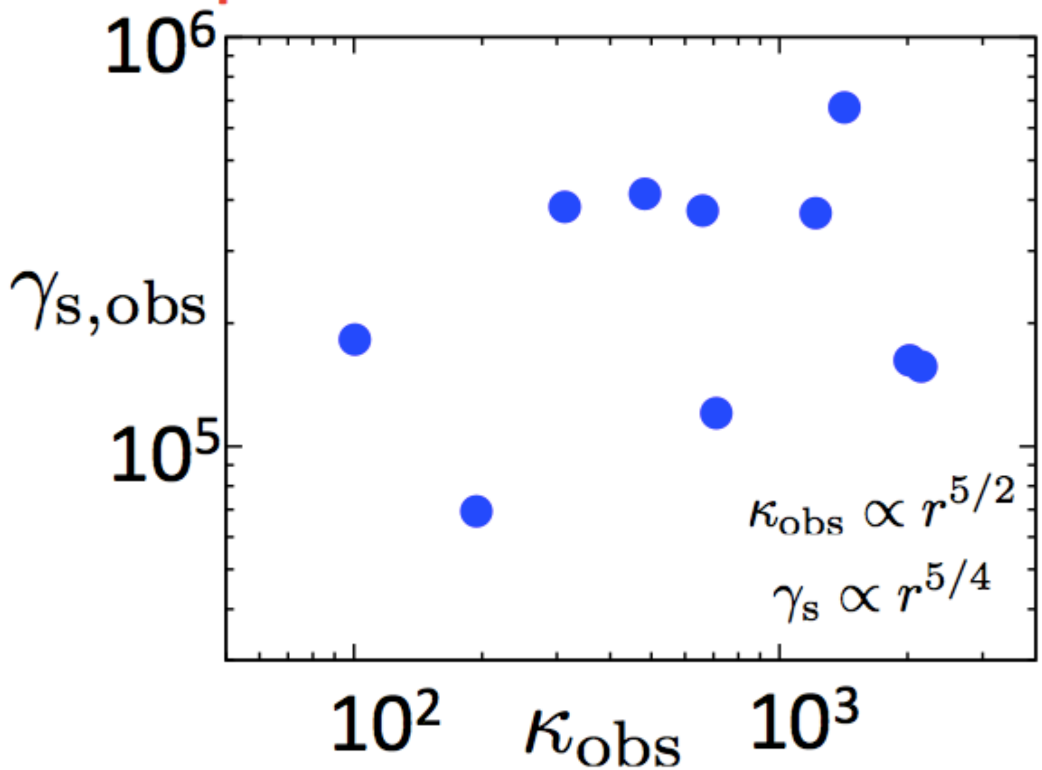
Synchrotron Emission

Frequency $\nu_{\rm syn} = \frac{3}{2}\gamma^2\nu_{\rm g}$

$$\nu_{\rm g} = \frac{eB\sin\alpha}{m_{\rm e}c}$$

Luminosity $L_{\rm syn} = \frac{2e^2}{3c}\gamma^2\nu_{\rm g}^2 N_{\rm s}$

If emission region $r = R_{lc}$, large values of $\gamma_{s,obs}$ and κ_{obs} are required.

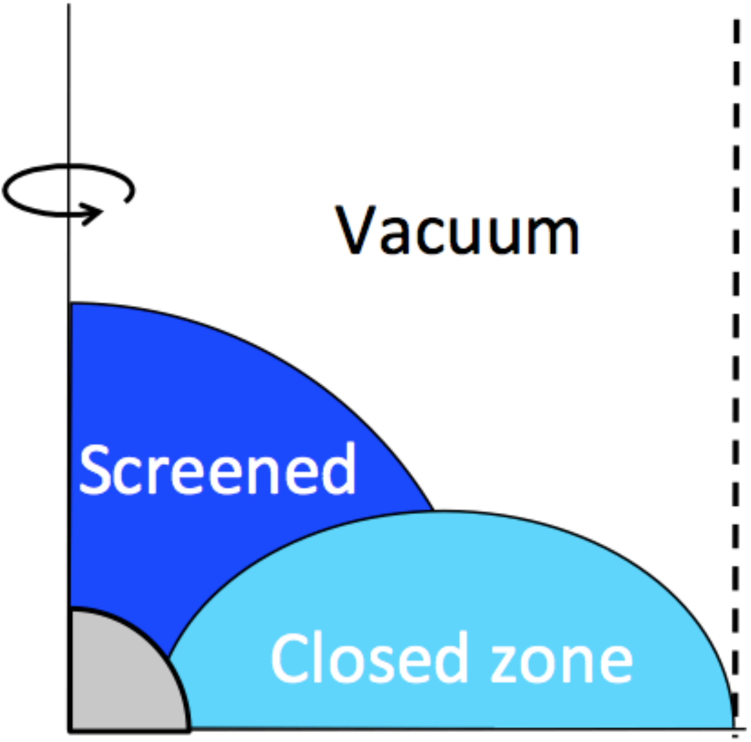


Model

Assumption

Incoming particles emit γ-ray and pair creation occurs.
Created pairs emit X-ray via synchrotron radiation.

Observed values : L_{PL}, L_{BB}, T, ν_{obs}
Model parameters : r, η



Generalized gap model

$$E_{\parallel} \equiv \eta E_{\perp,\mathrm{GJ}} \quad 0 < |\eta| < 1$$

$$E_{\perp,\mathrm{GJ}} = \frac{r\Omega}{c} B \propto r^{-2}$$

cf. $$E_{\mathrm{vac}} \sim \frac{R_{\mathrm{NS}}^2}{r R_{\mathrm{lc}}} B \propto r^{-4}$$

Gap : $0 \leqq \rho \leqq \rho_{GJ}$ (if $\rho_{GJ} > 0$)
$\rho_{GJ} \leqq \rho \leqq 0$ (if $\rho_{GJ} < 0$)

Constraints (1/2)

- Emission regions locate within magnetospheres.

$$R_{\rm NS} < r < R_{\rm lc}$$

- Energy flux cannot exceed the spin-down luminosity.

$$\dot{N}_{\rm s}\gamma_{\rm s,obs}m_{\rm e}c^2(1+\sigma) < L_{\rm sd}$$

- Observed frequency should exceed the cyclotron turnover frequency.

$$\nu_{\rm obs} > \frac{eB}{m_{\rm e}c\alpha}$$

- Energy of pairs should exceed the observed ones.

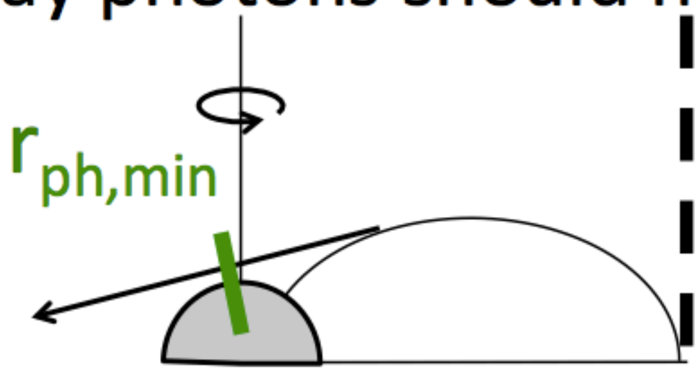
$$\gamma_{\rm s} > \gamma_{\rm s,obs}$$

Constraints (2/2)

- The products of two photon energies should exceed the γ-γ pair creation threshold. $h\nu_{\rm X} \times h\nu_\gamma > (m_{\rm e}c^2)^2$
- Created number of pairs should exceed the observed ones. $n_{\rm p} \times N_\gamma \tau_{{\rm X}\gamma} > n_{\rm s}$

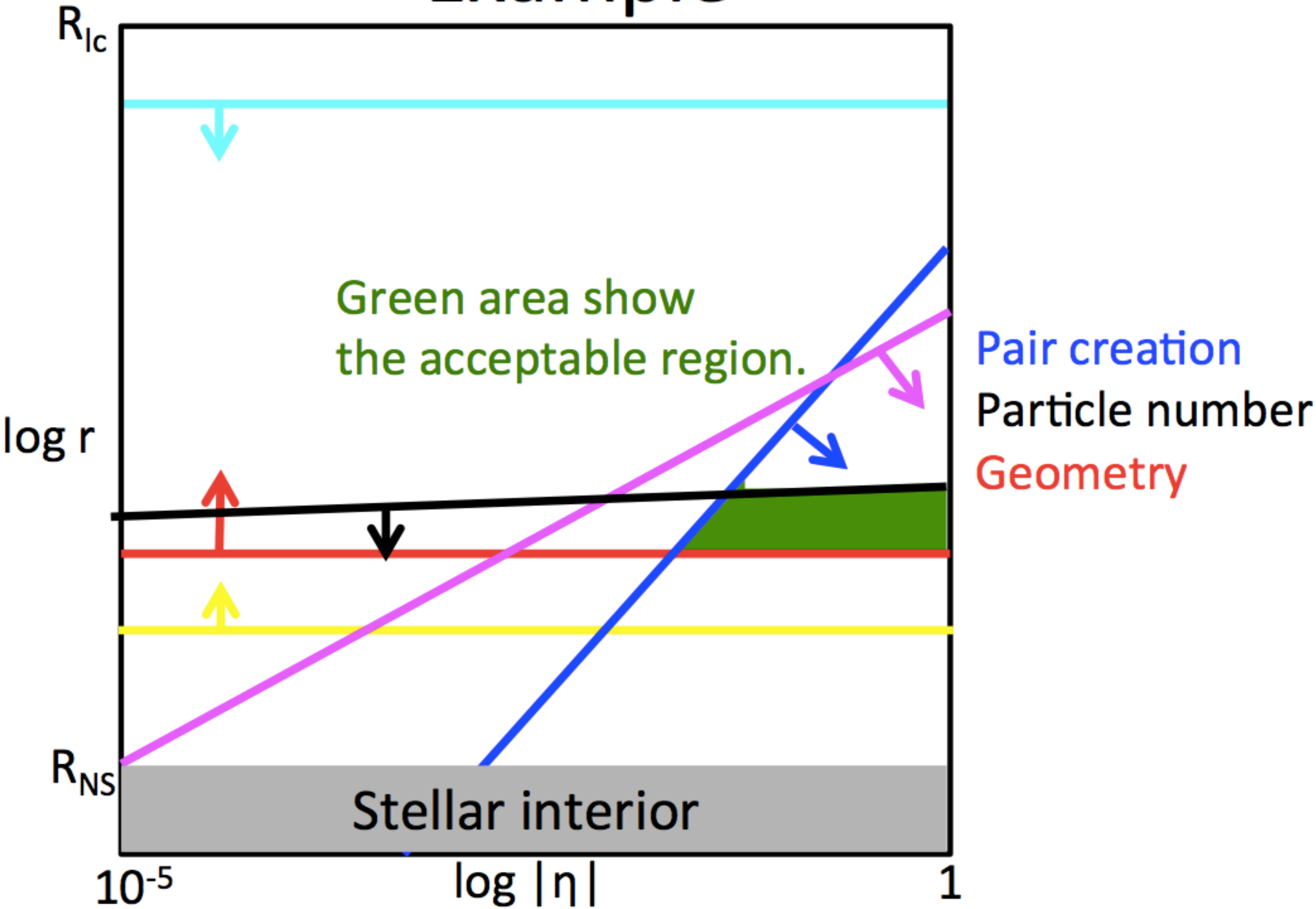
$L_{BB} \rightarrow n_p$: Number of primary particles
$\gamma_p \rightarrow N_\gamma$: Number of γ-ray photons from single $e^-(e^+)$
L_{BB}, $T \rightarrow \tau_{X\gamma}$: γ-γ optica' depth

- X-ray photons should not collide with the star.



$r_{\rm ph,min} > R_{\rm NS}$

Example

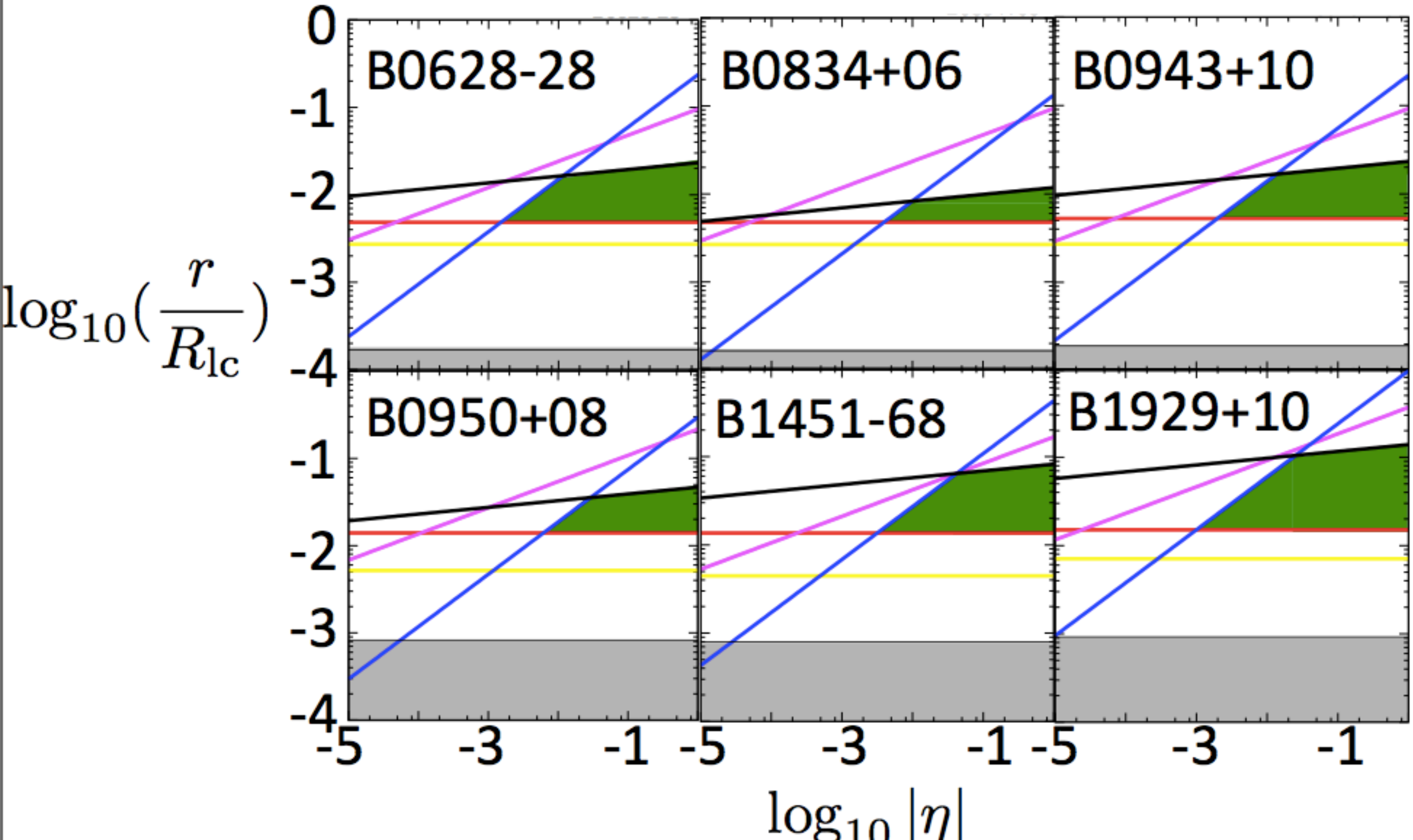


R_{lc}
log r
R_{NS}
Green area show
the acceptable region.
Pair creation
Particle number
Geometry
Stellar interior
10^{-5}
log |η|
1

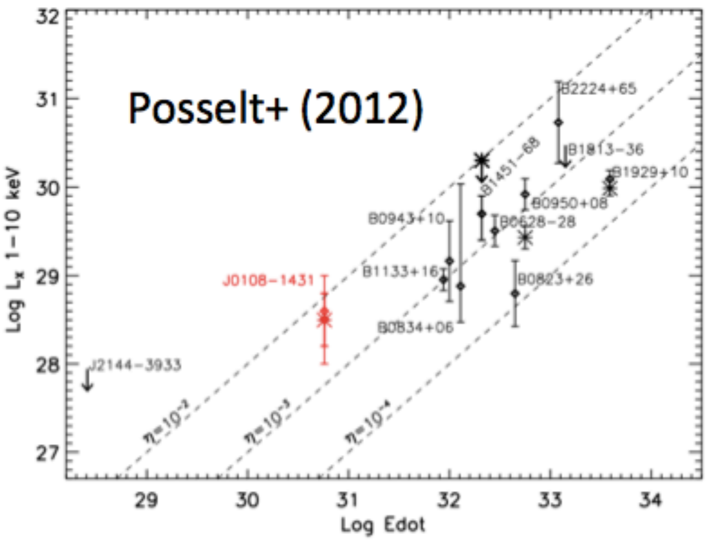
Results

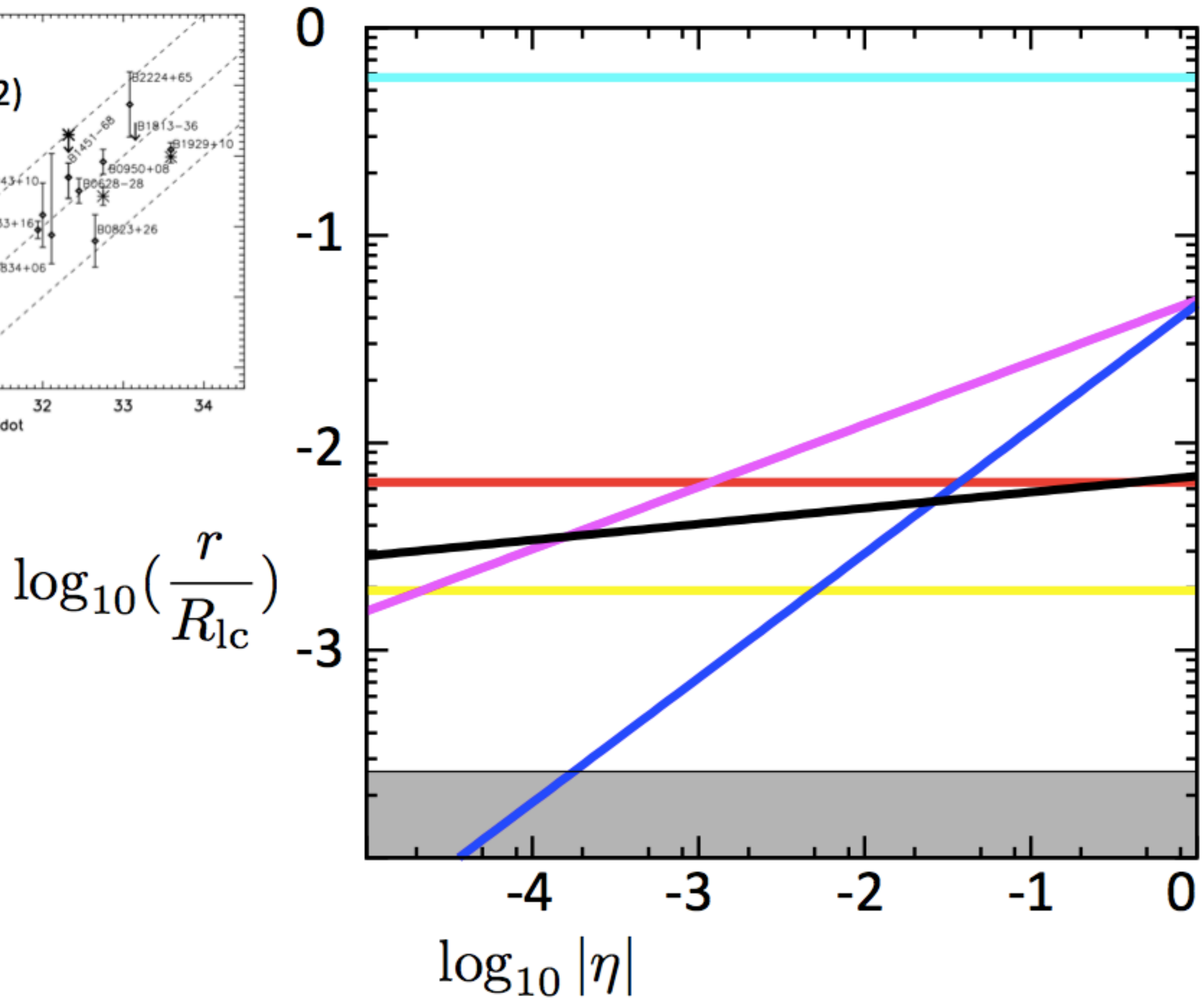
Acceleration (emission) region : $r \sim 10^{-2} R_{lc}$

Strength of $E_{||}$: $\eta \sim 10^{-2}$-1



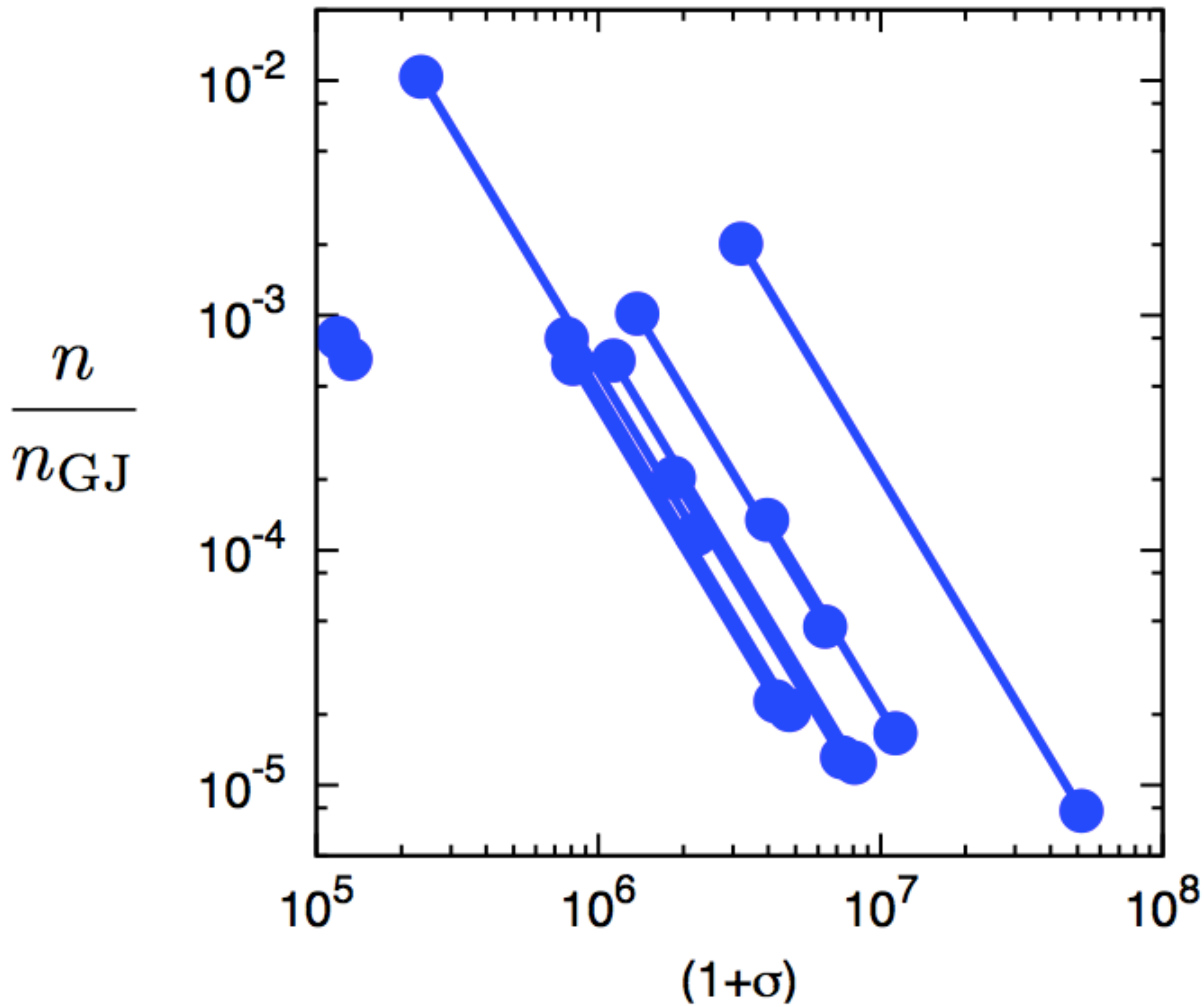
Result (PSR J0108-1431)





Steady gap?

The created number density of particles are smaller than that of Goldreich-Julian ones.



Summary

- We try to explain the non-thermal X-ray emission from old pulsars based on the synchrotron radiation.
- We find that if there is strong electric field ($\eta \sim 0.1$) at the region $\sim 10^{-2} R_{lc}$, the non-thermal emission from secondary particles reproduces the observed X-ray luminosity.
- Because the pair creation rate is not enough to maintain the sustainability of the acceleration gap, our results implicate the time-dependent behavior.