

Transition of Polar Cap Activity

**Shota Kisaka
(Hiroshima Univ.)**

Abstract

- Some radio pulsars show abrupt state transition, “mode changing”.
- The phenomena would be related to the internal variation due to the long timescale.
- We study the mechanism of simultaneous change in both radio and X-ray.

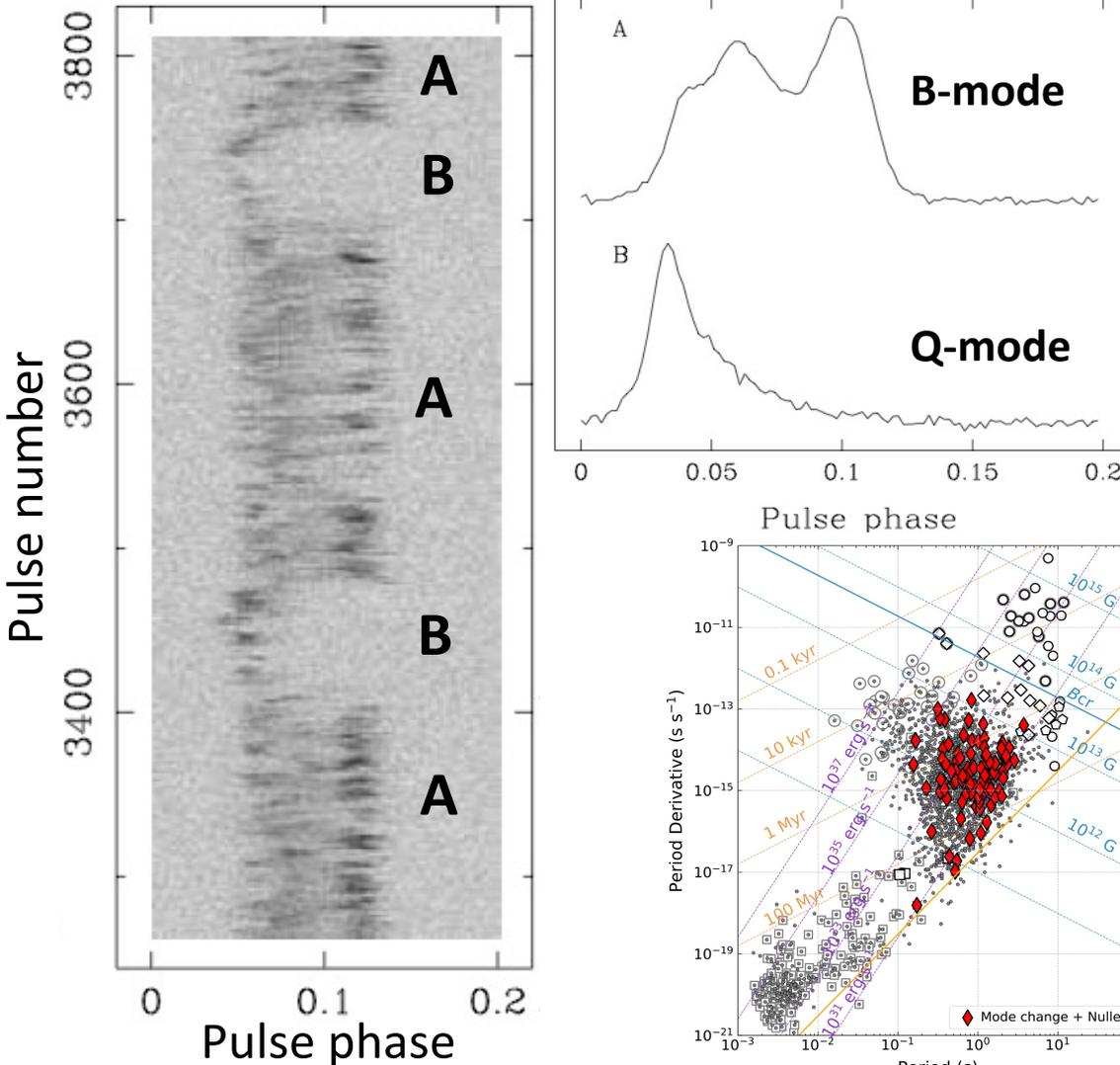


- Based on the non-stationary polar cap activity, we find the conditions of radio-X-ray correlation and anti-correlation.

Mode Changing

Mode changing = A discontinuous change in the pulse profile between two or more quasi-stable states.

Wang+ 07



Duration of a state is longer than a rotational period.
→ Internal variation origin?

Some fractions (> 1/3) of old pulsars (> 1 Myr) show mode changing.
→ Low efficiency of pair cascade?

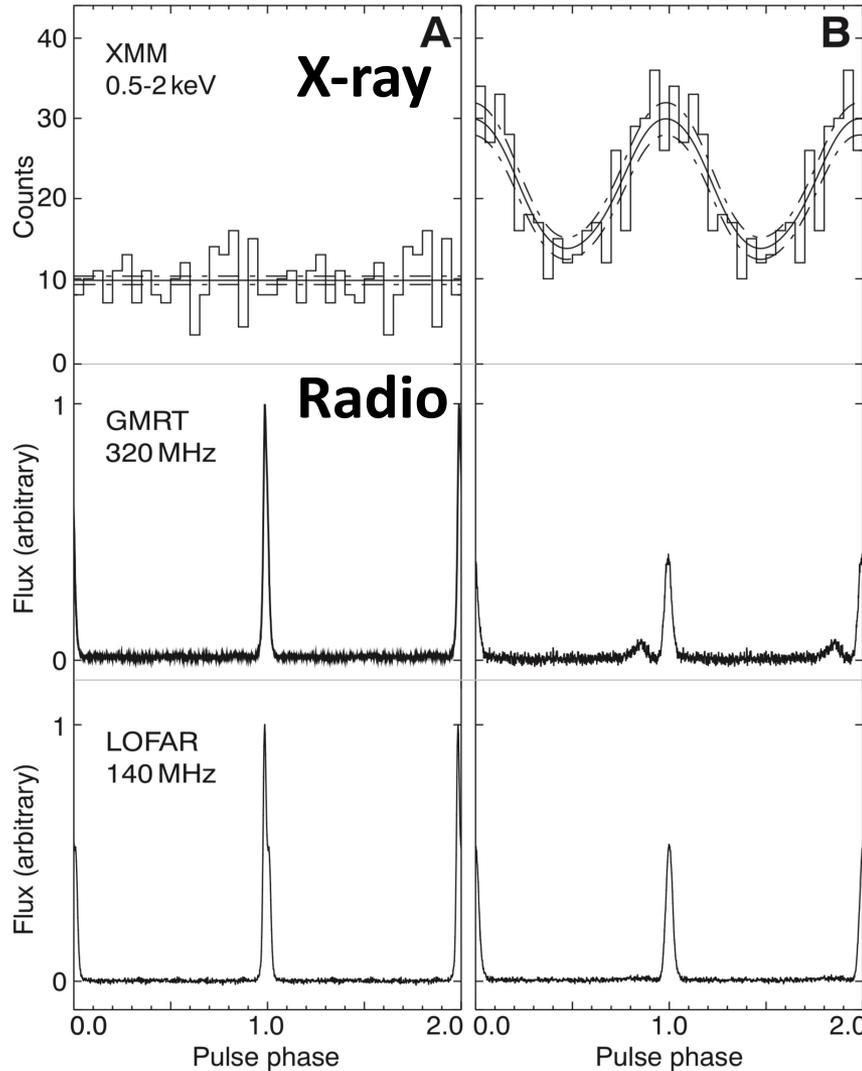
Enoto+ 19

Simultaneous change in radio and X-ray

Mode changing is related to pair cascade.

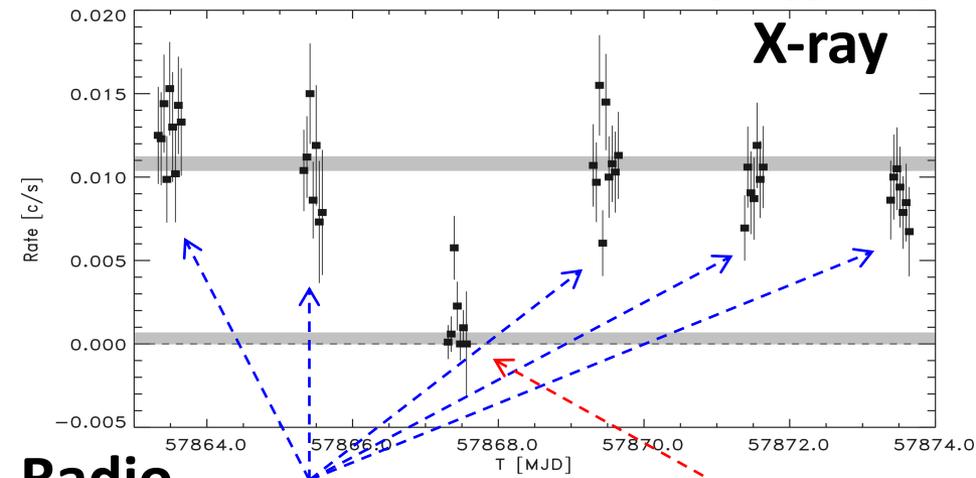
B0943+10

Hermesen+ 13

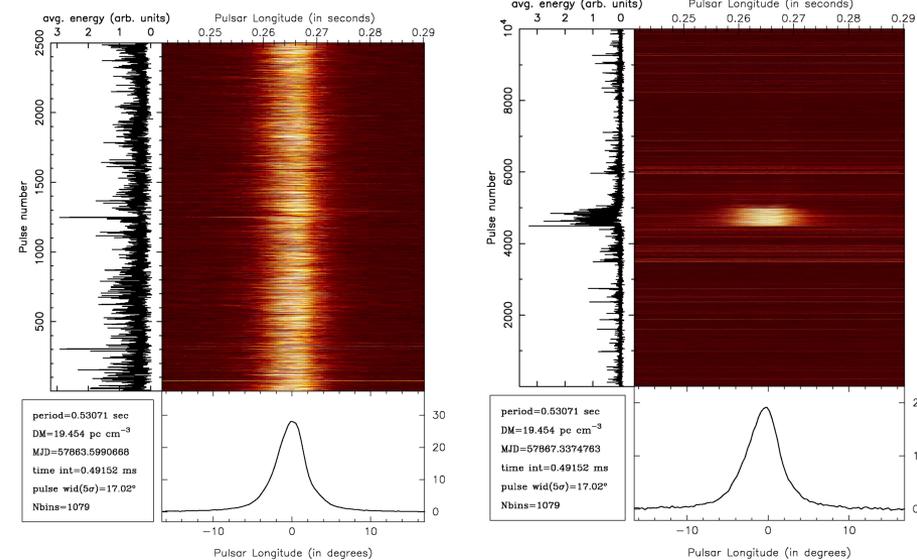


B0823+26

Hermesen+ 18



Radio

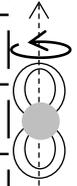


Here, we propose the radio-X-ray mode changing model.

Observation Summary

No trend?

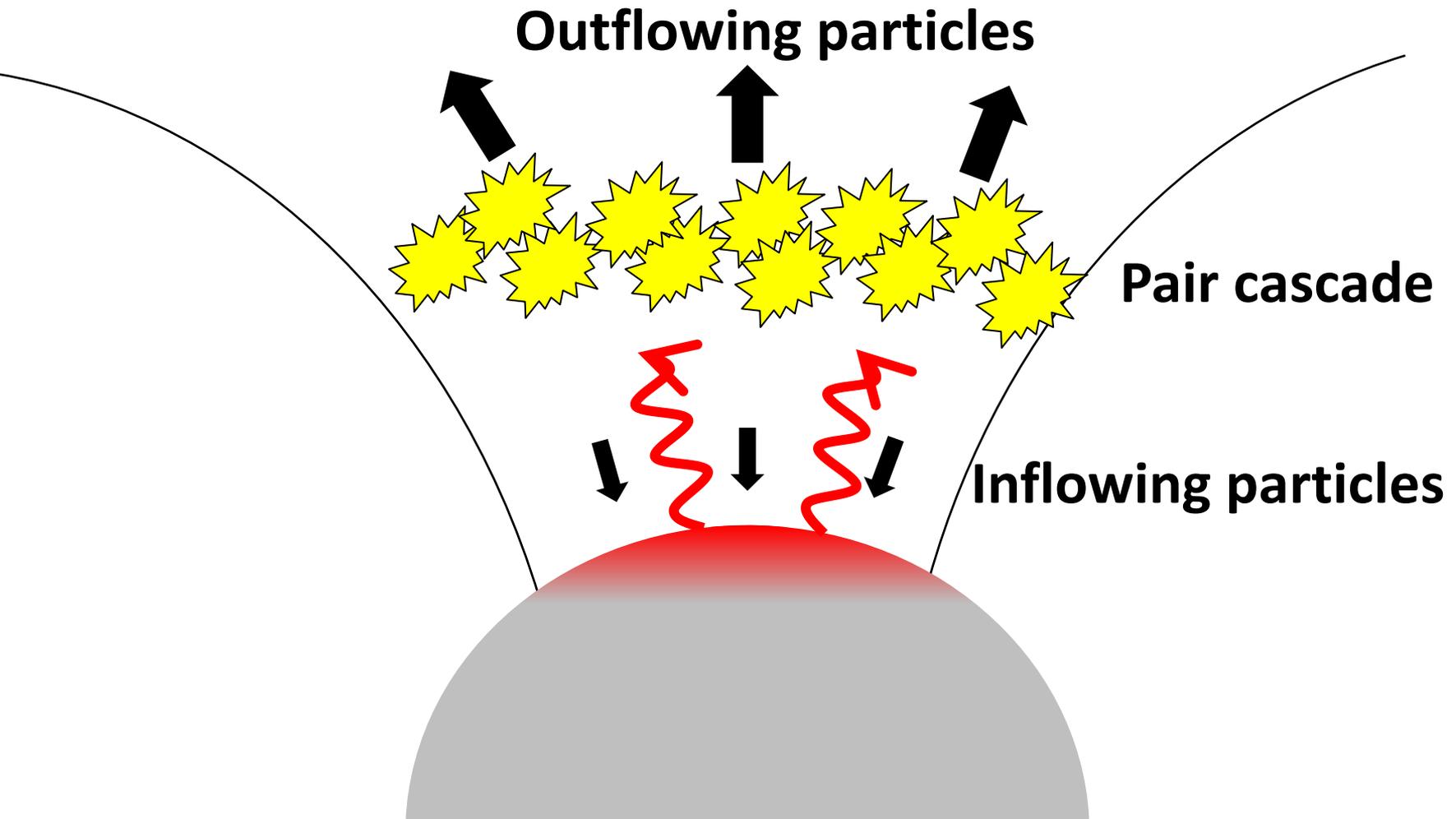
Table 1. Comparison of three mode-switching pulsars observed in X-rays

	PSR B0943+10	PSR B0823+26	PSR B1822-09
P [s]	1.1	0.53	0.77
\dot{P} [$s\ s^{-1}$]	3.5×10^{-15}	1.7×10^{-15}	5.3×10^{-14}
τ [Myr]	5	5	0.2
B [G]	2×10^{12}	9.6×10^{11}	6.5×10^{12}
\dot{E}_{rot} [$erg\ s^{-1}$]	10^{32}	4.5×10^{32}	4.6×10^{33}
Distance [kpc]	0.89 	0.31	0.26 
Likely geometry	<u>\simaligned</u>	<u>\simorthogonal</u>	<u>\simorthogonal</u>
Mode duration	\sim hours	\sim hours (also nulling)	few minutes
Radio interpulse	No	Yes	Yes (in Q-mode)
Radio pre/postcursor	precursor in Q-mode	postcursor in B-mode	in B-mode
Drifting subpulses	in B-mode	Yes	No
X-ray flux	<u>brighter in Q-mode</u>	<u>brighter in B-mode</u>	<u>constant</u>
L_X [$erg\ s^{-1}$]	$\sim 2 \times 10^{29}$	$\sim 2 \times 10^{28}$	$\sim 3 \times 10^{29}$
Total X-ray spectrum	BB+PL (or BB+BB)	BB+BB (or BB+PL)	BB+BB
Spectral-timing analysis	<u>BB pulsed</u> <u>PL unpulsed</u>	<u>favors BB+BB</u>	<u>both BB pulsed</u>
References	Mereghetti <i>et al.</i> 2016	Hermsen <i>et al.</i> 2018	Hermsen <i>et al.</i> 2017

X-ray Emission

We focus on the thermal component.

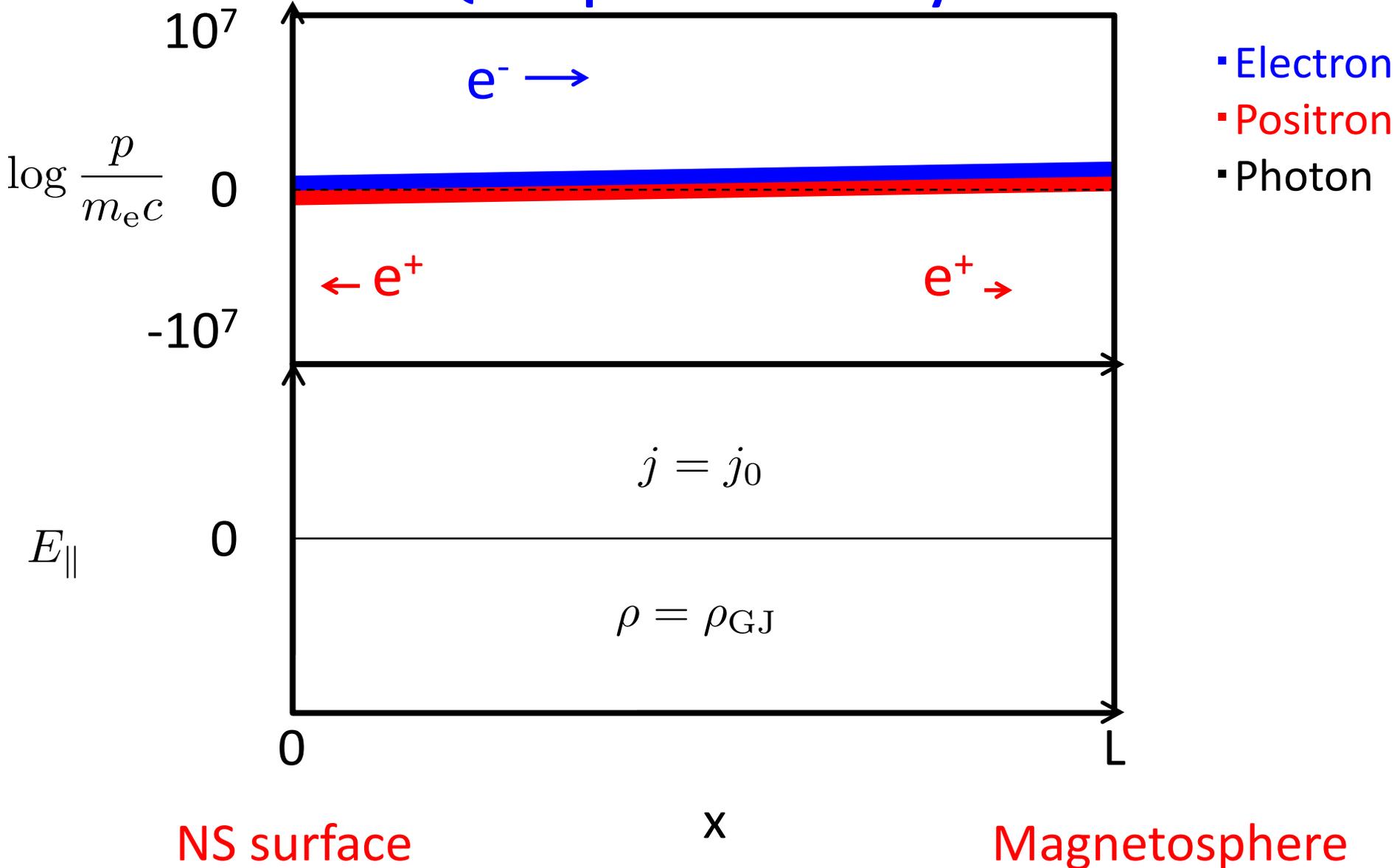
Inflowing particles due to pair cascade collide with the star surface. The surface is heated and emit thermal radiation in X-ray (~ 0.3 keV).



Polar Cap Activity

Timokhin 10
Timokhin & Arons 13
Timokhin & Harding 15, 19

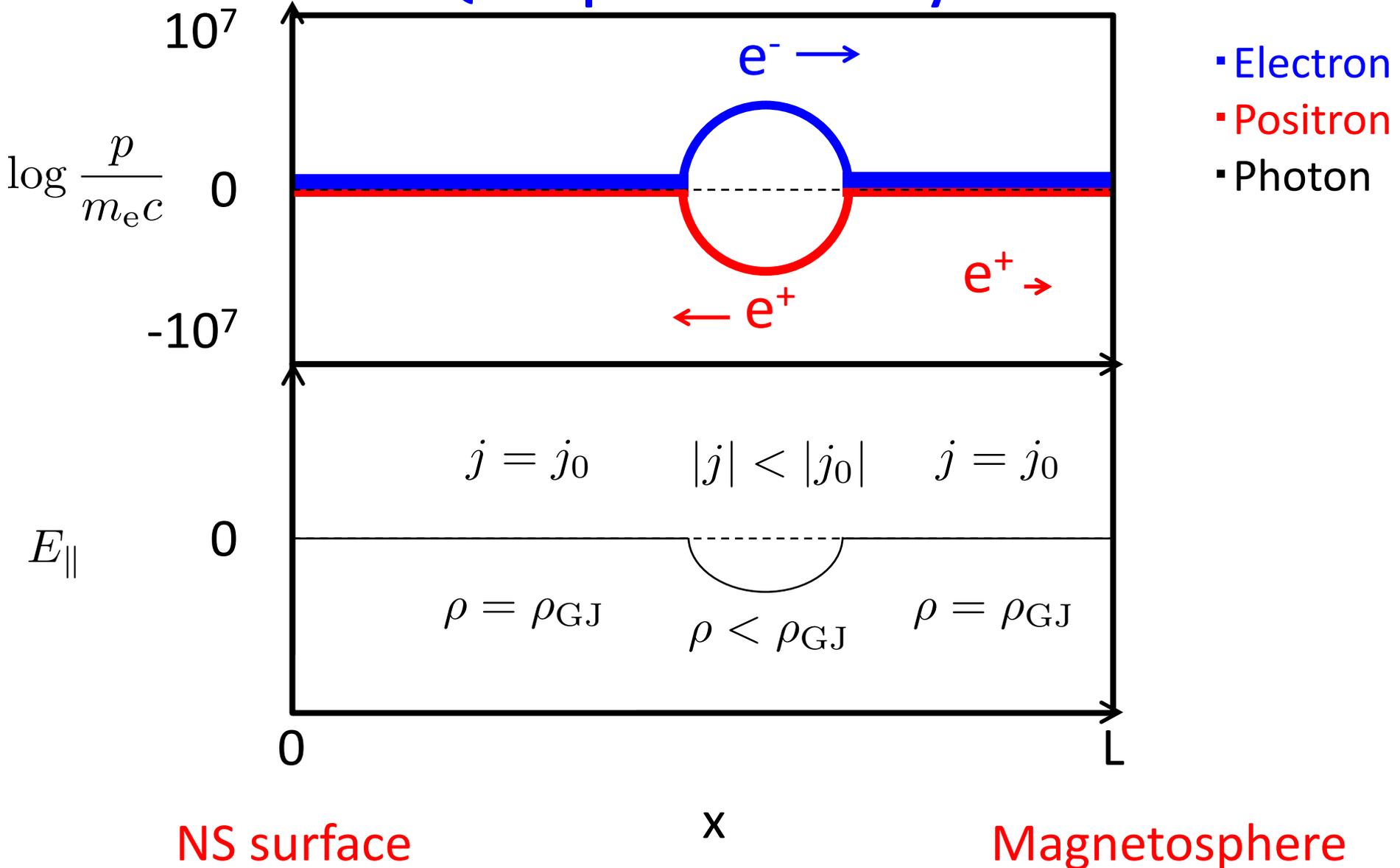
Quasi-periodic activity



Polar Cap Activity

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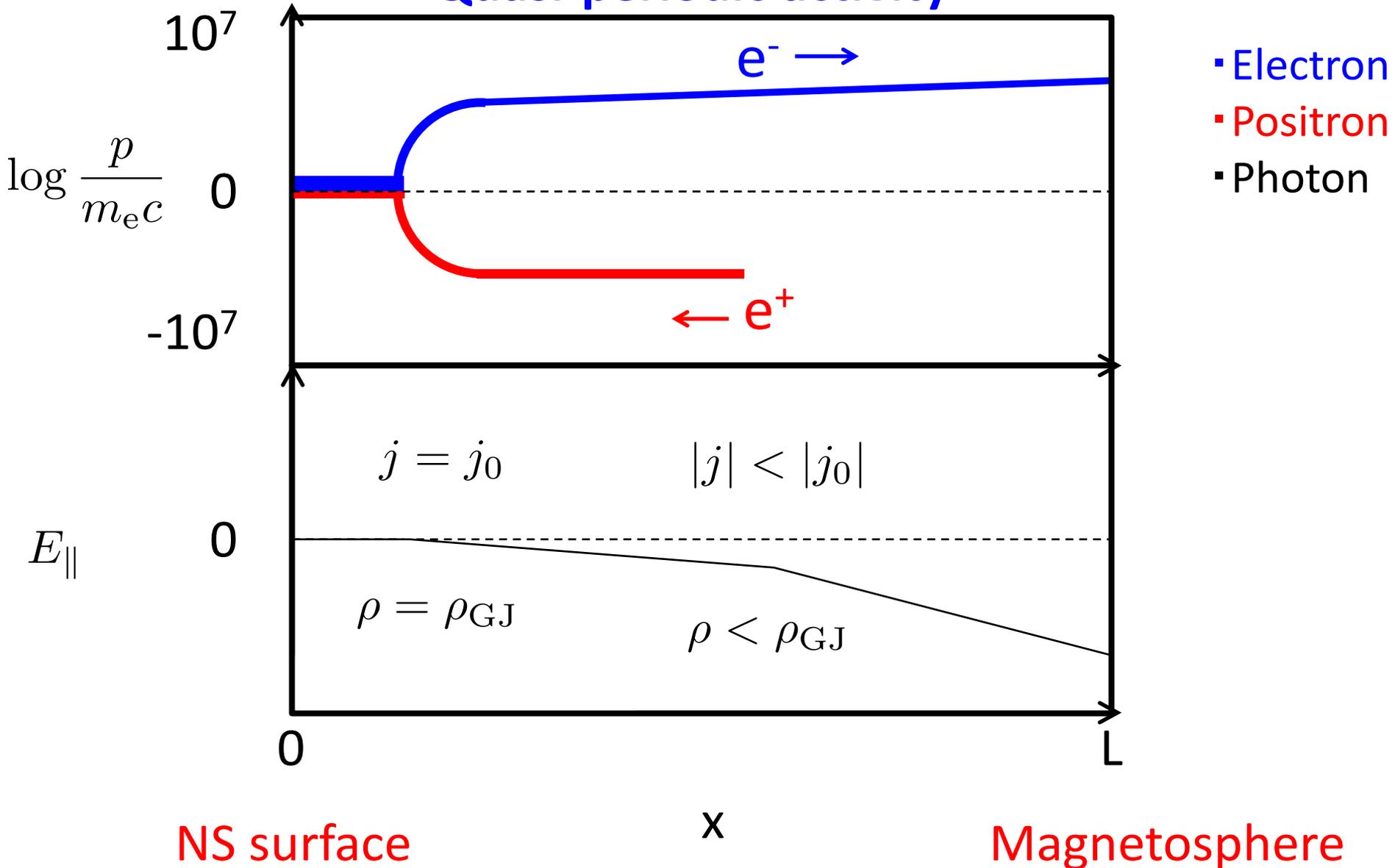
Quasi-periodic activity



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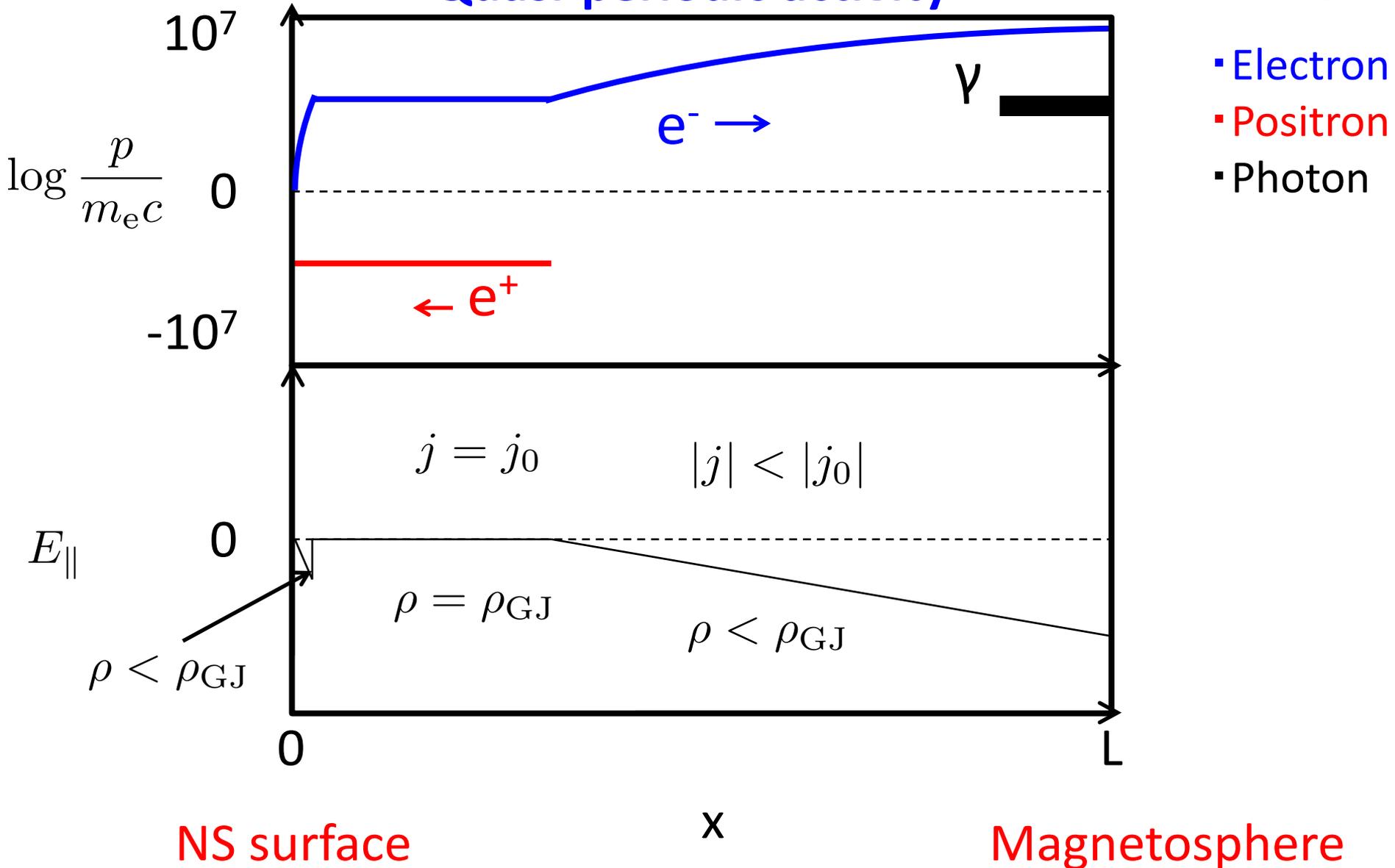
Quasi-periodic activity



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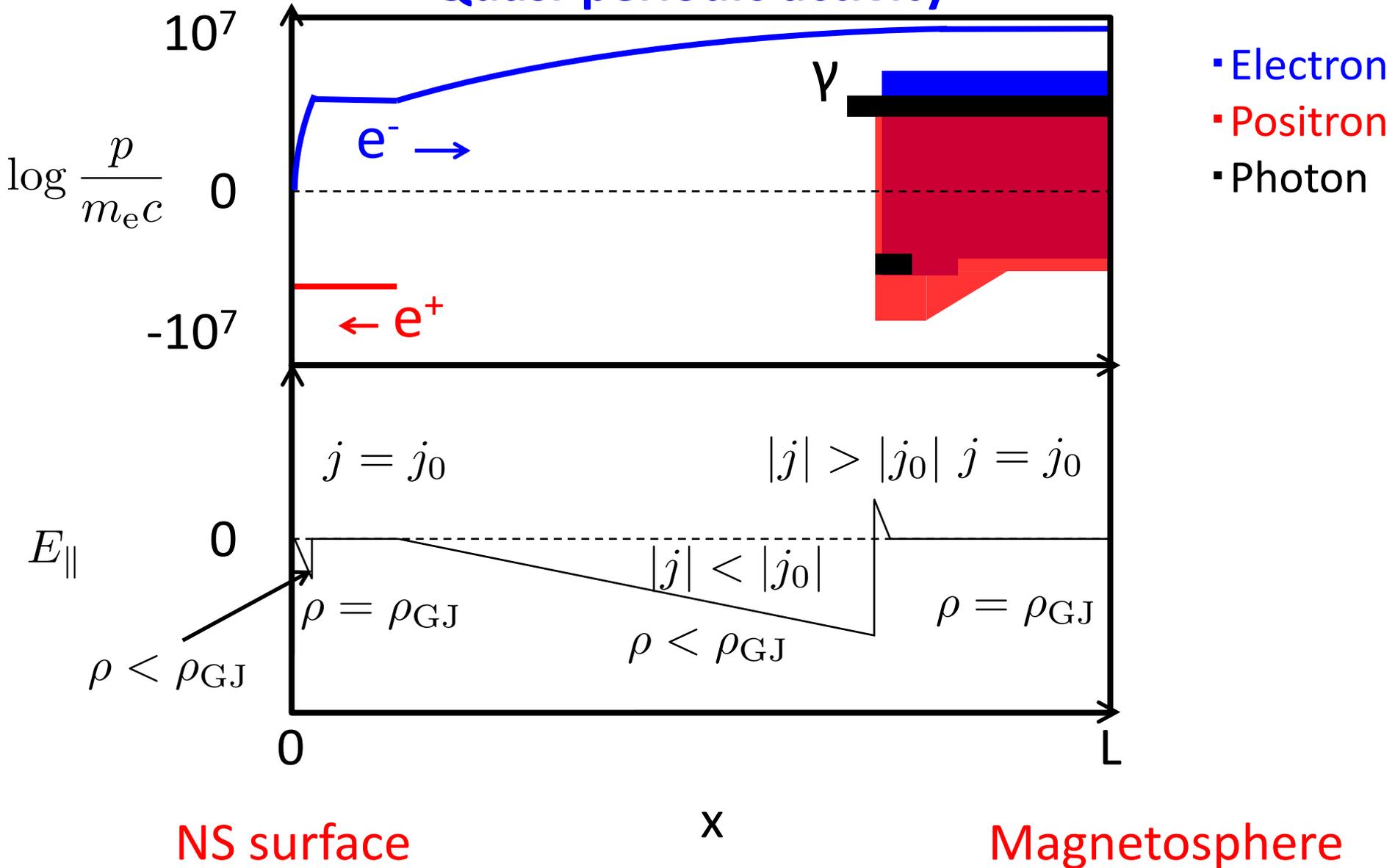
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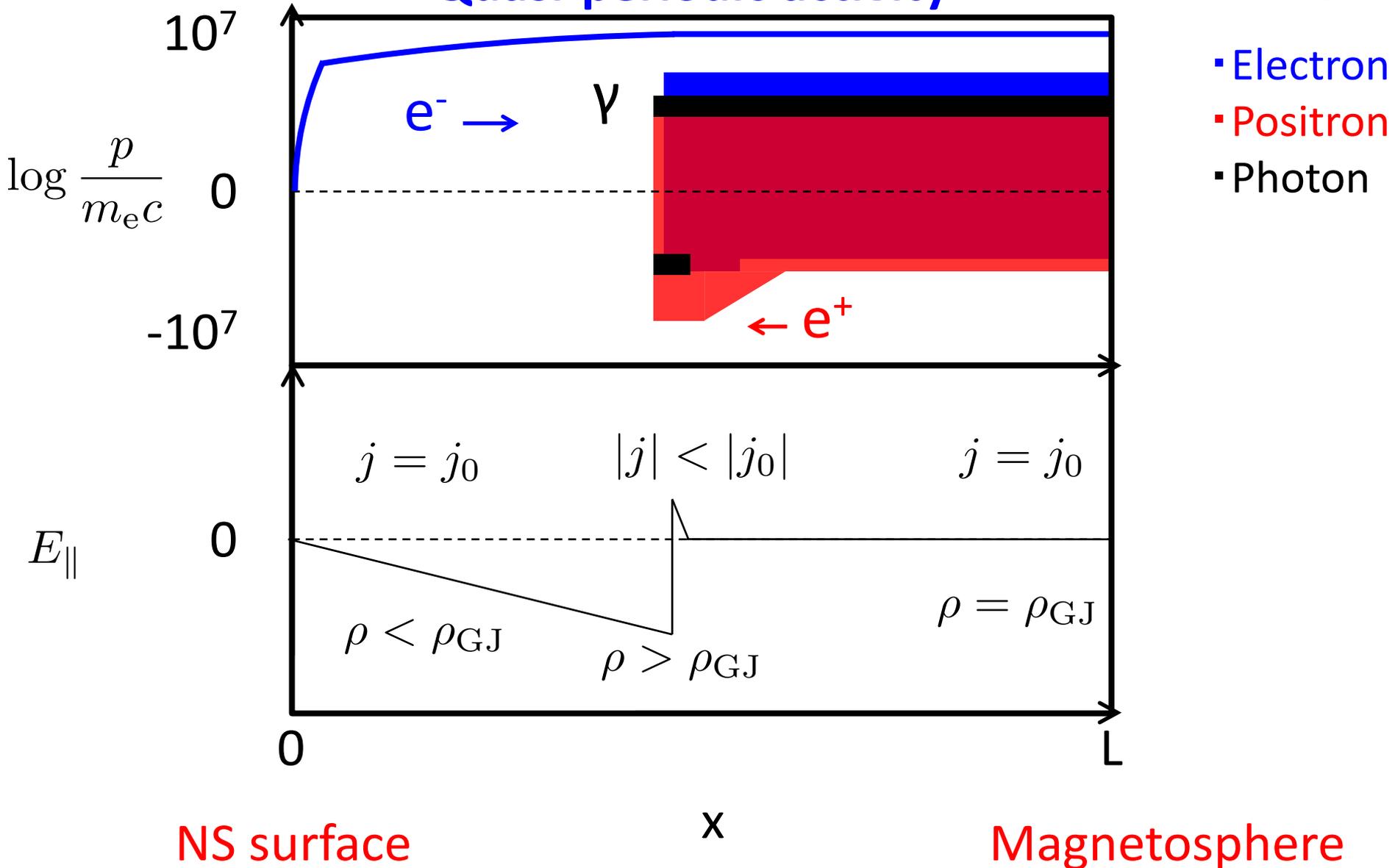
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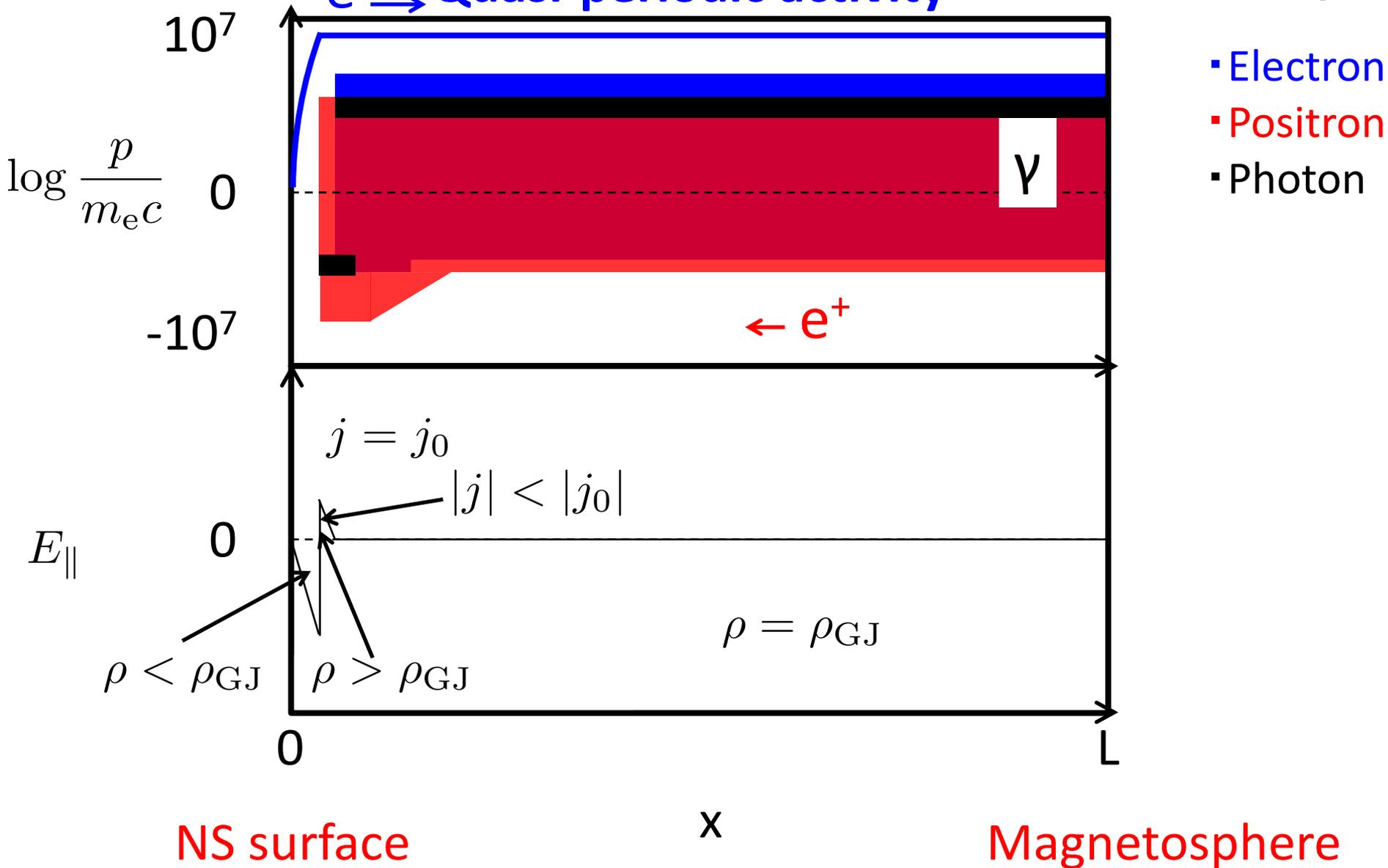
Quasi-periodic activity



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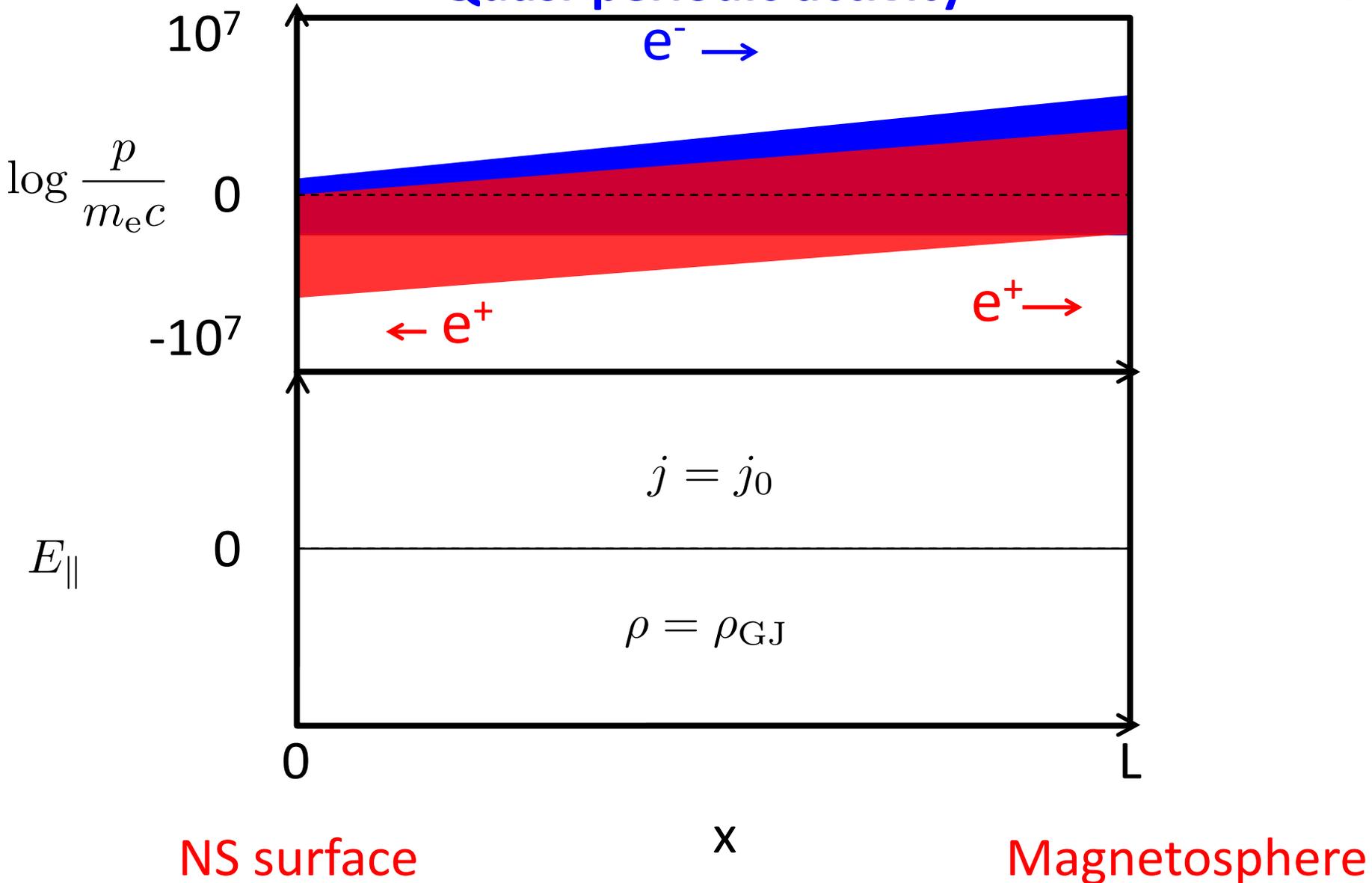
$e^- \rightarrow$ Quasi-periodic activity



Polar Cap Activity

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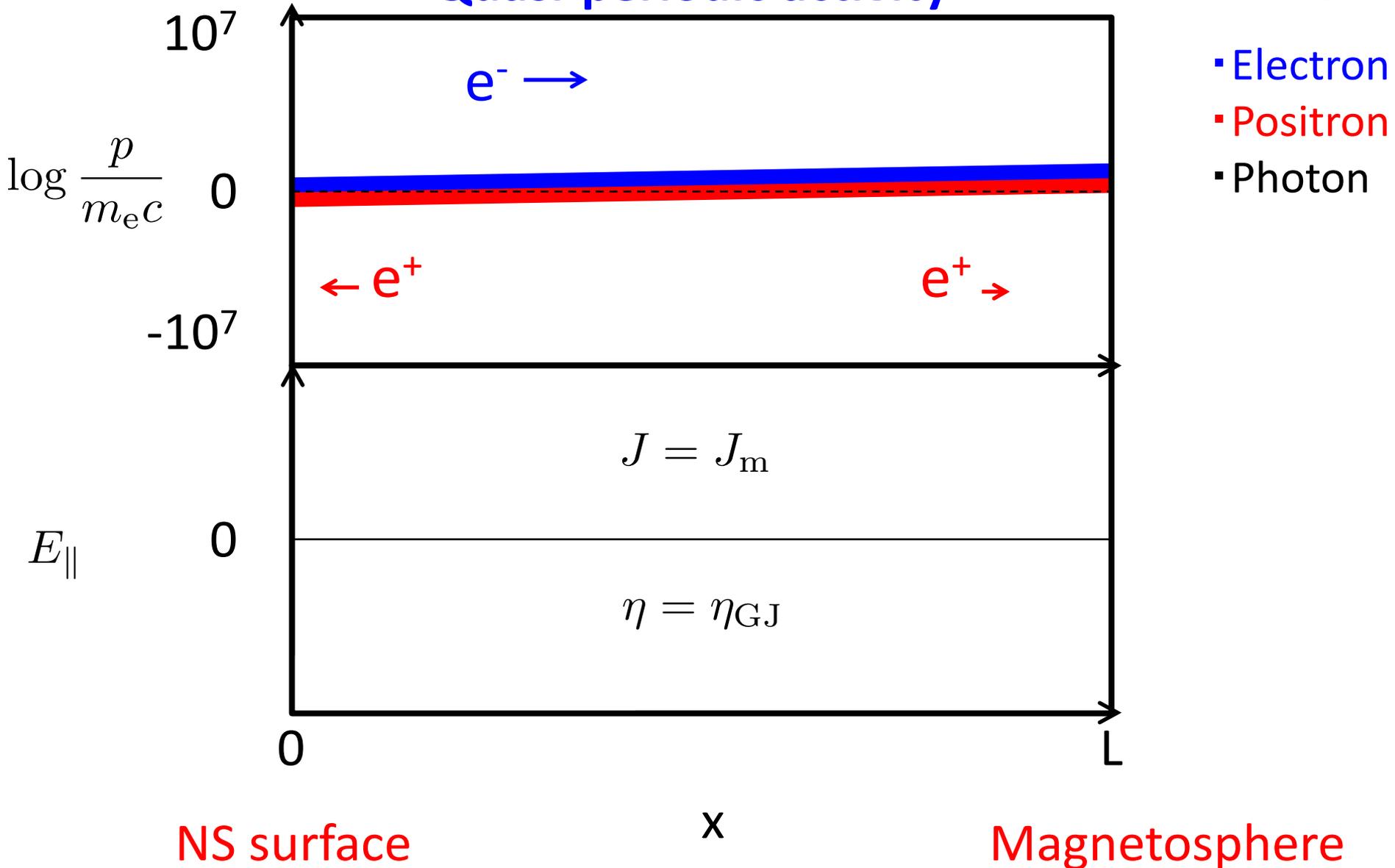
Quasi-periodic activity



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Quasi-periodic activity

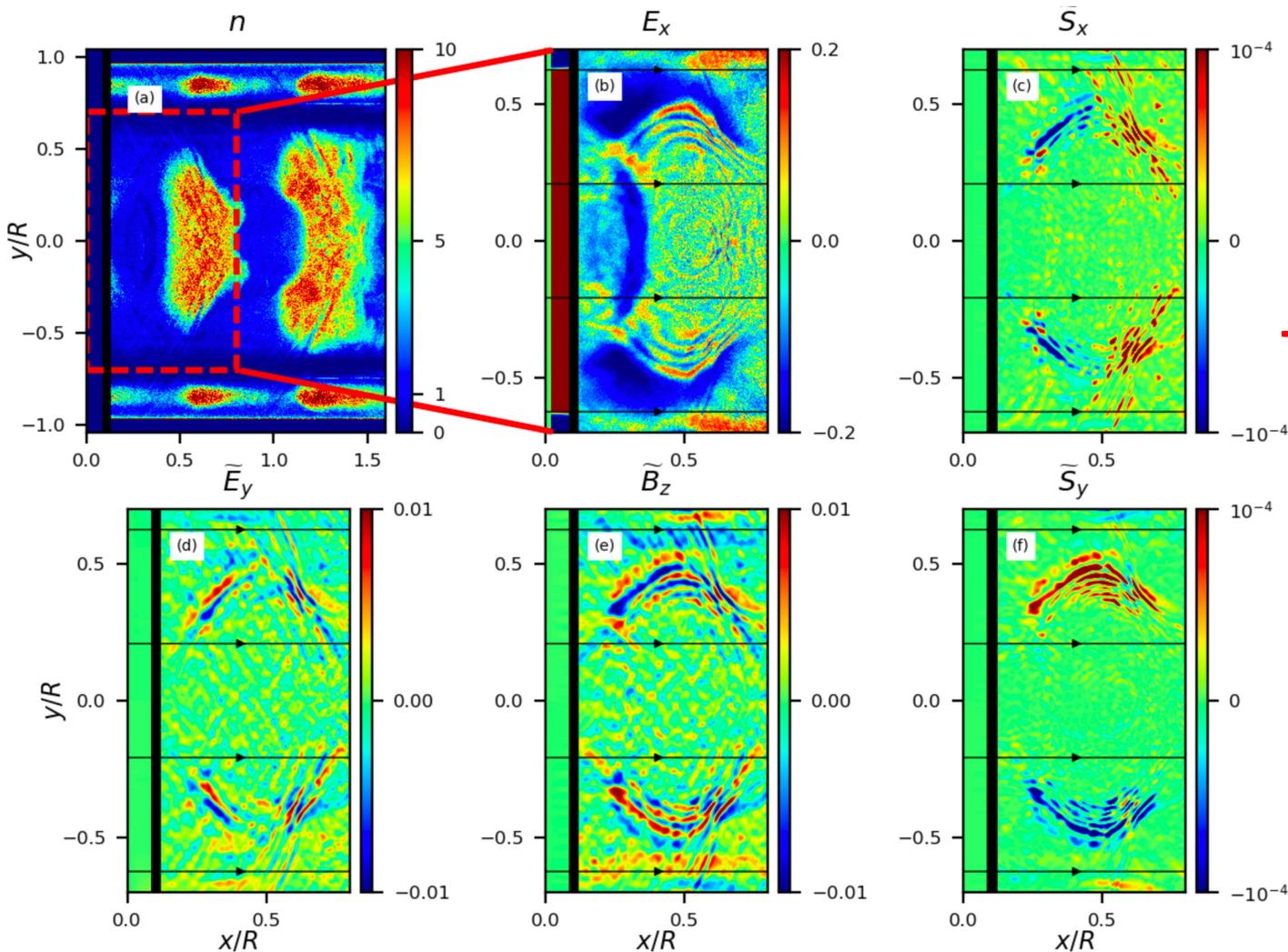


Radio Emission

The cause of the pulsar coherent radiation has remained a mystery.

The leading candidate is EM wave generated in nonstationary pair plasma discharges.

Propagating pair bursts with non-uniform across B-field → **coherent EM wave**



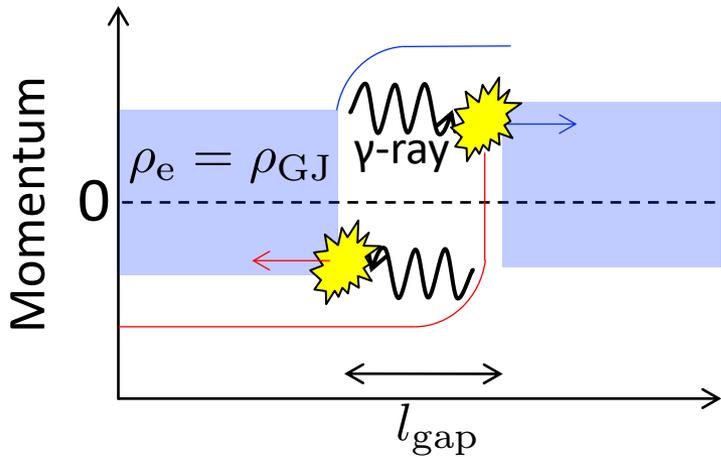
The assumption

Quasi-periodic state
→ B-mode

Quasi-steady states
→ Q-mode

Condition of Oscillation

Periodic



Closure relation

An injected particle create at least one particles in the gap (multiplicity > 1).

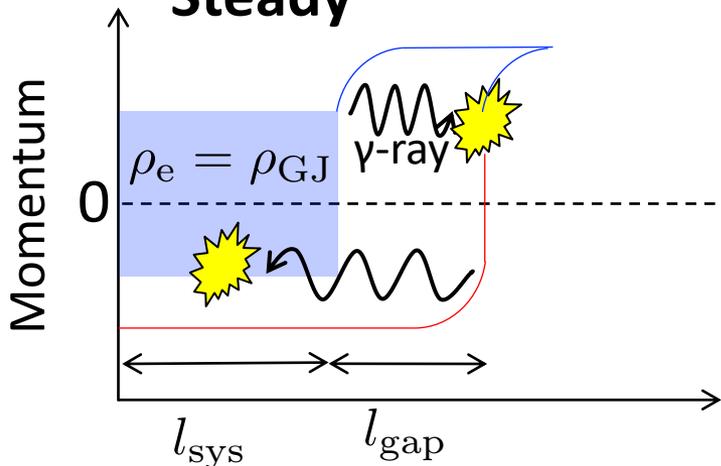
$$n_{\text{ph}}^2 \left(\frac{l_{\text{gap}}}{l_{\text{pair}}} \right)^2 > 1$$

n_{ph} : Number of γ -ray photons emitted from a particle

l_{pair} : Pair creation mean free path

l_{gap} : Gap width

Steady



Closure relation

An injected particle create at least one particles in the screened region.

l_{sys} : Length of screened region

$$n_{\text{ph}}^2 \left(\frac{l_{\text{gap}} l_{\text{sys}}}{l_{\text{pair}}^2} \right) > 1$$

Test Calculation

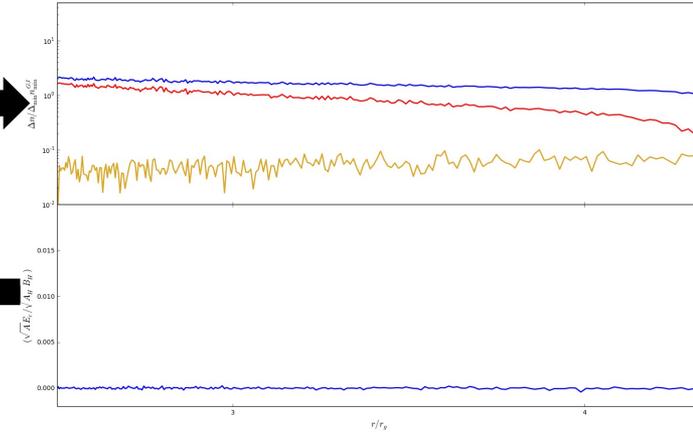
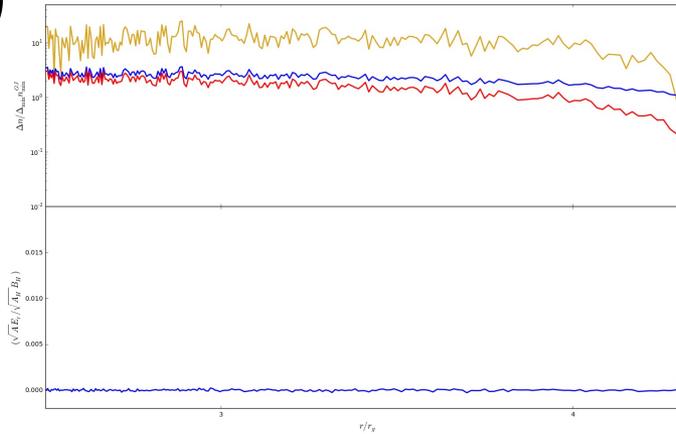
Details of setups
See SK+20, 21

PIC simulation for pair cascade

Periodic
(Short I_{pair})

Number density

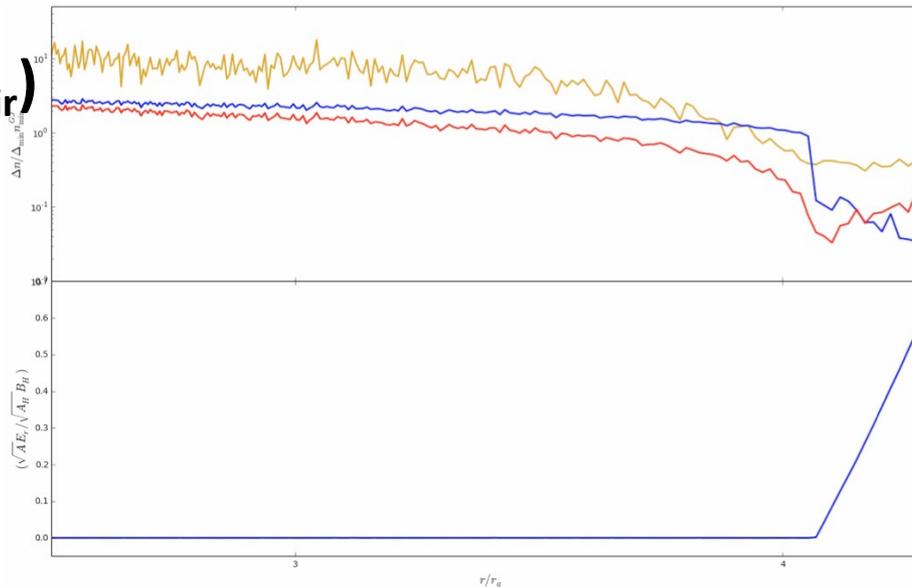
E-field



Steady
(Long I_{pair})

Number density

E-field



- Electron
- Positron
- Photon

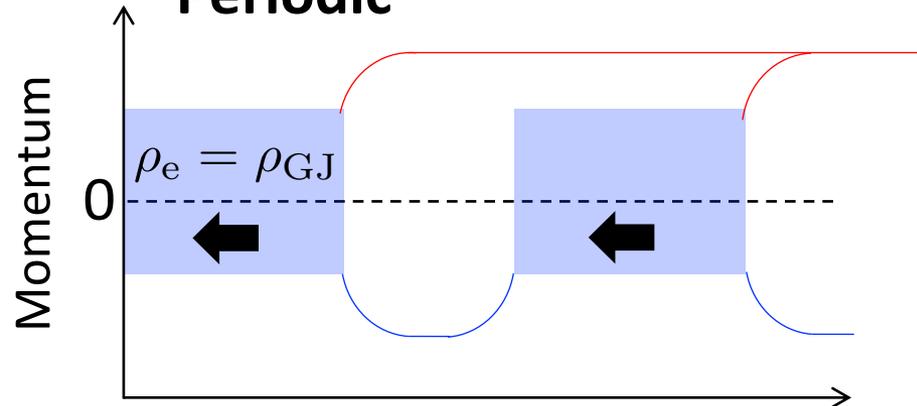
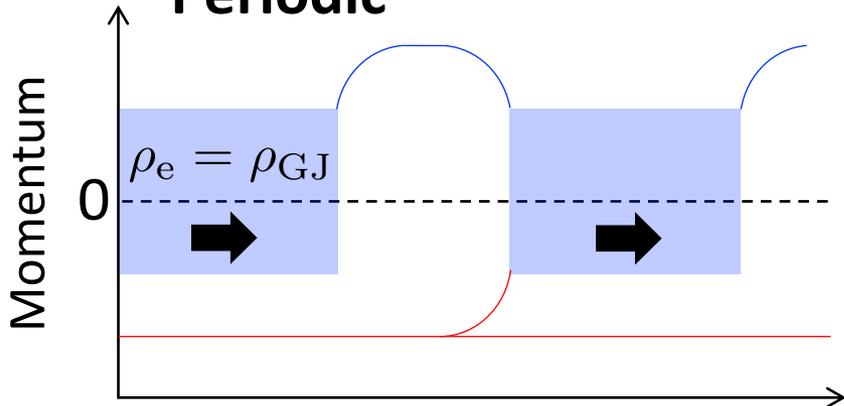
Current Dependence

$j_0/\rho_{GJ}c > 0$ (GJ current)

$j_0/\rho_{GJ}c < 0$ (anti-GJ current)

Periodic

Periodic

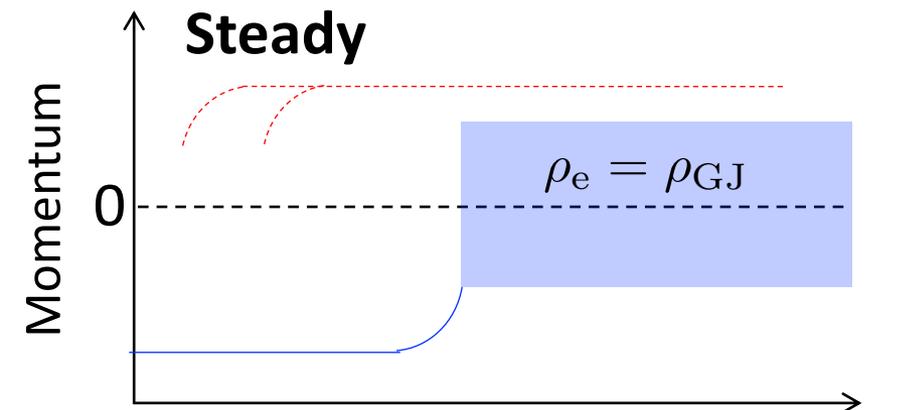
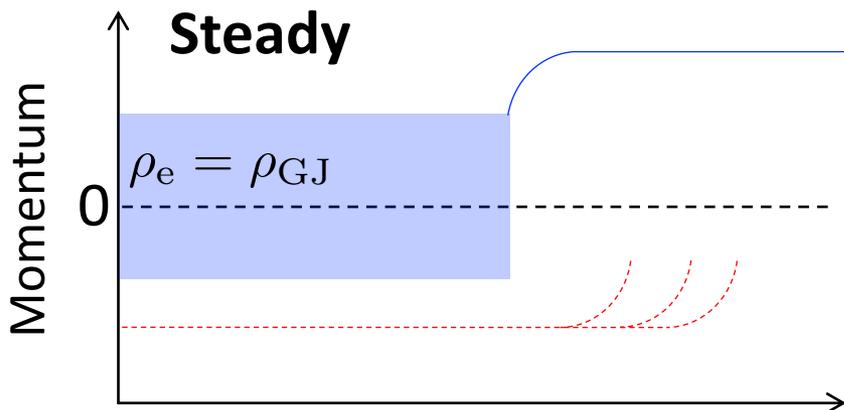


Radio : **B-mode** X-ray : **B-mode**

Radio : **B-mode** X-ray : **Q-mode**

Steady

Steady



Radio : **Q-mode** X-ray : **Q-mode**

Radio : **Q-mode** X-ray : **B-mode**

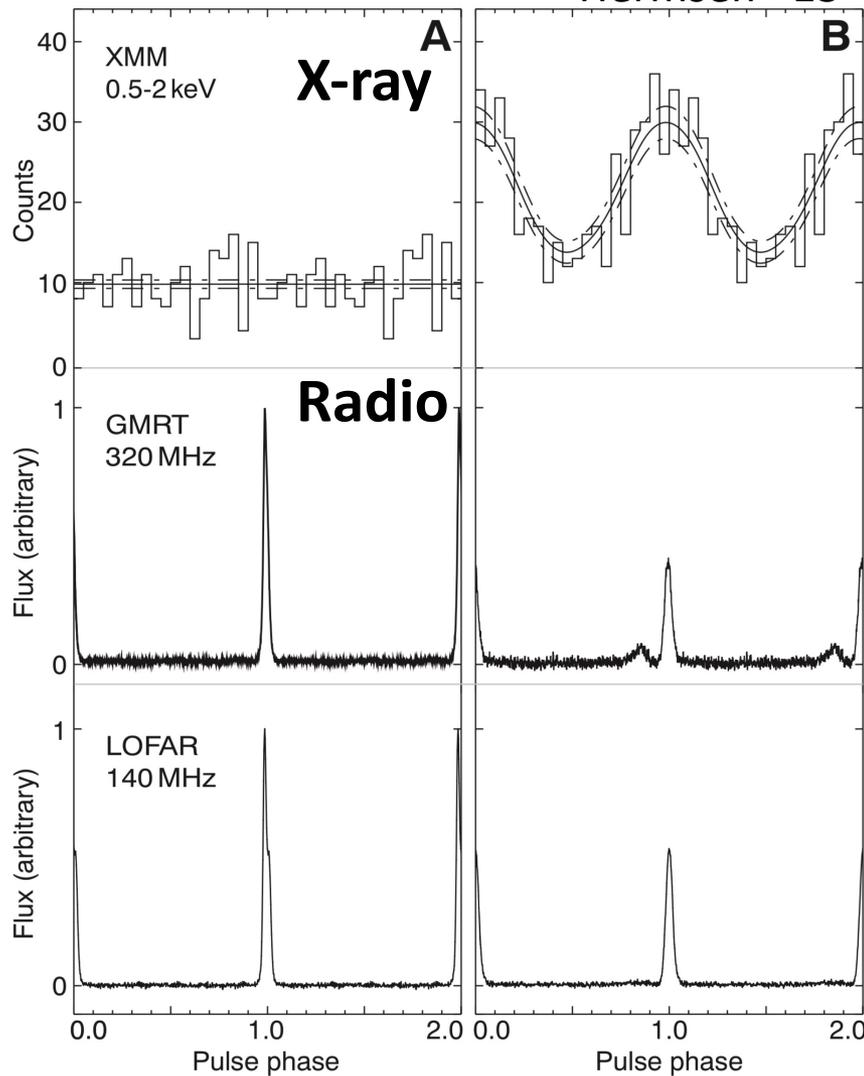
Interpretation

Anti-GJ current dominant
 → Radio-X-ray anticorrelation

GJ current dominant
 → Radio-X-ray correlation

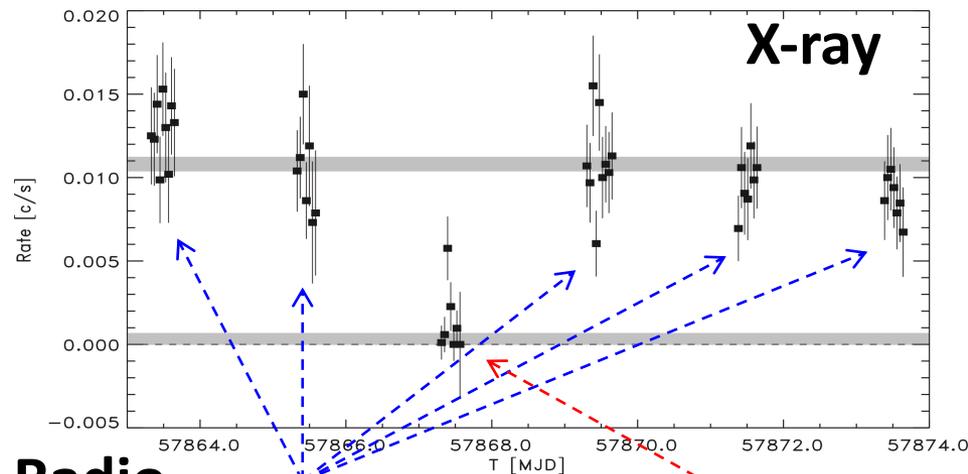
B0943+10

Hermesen+ 13



B0823+26

Hermesen+ 18



Radio

