

The 16th International West Lake Symposium on Physics of Fusion and Space Plasmas
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High-field physics in neutron-star radio emissions

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Outline

- ◆ Background

- ◆ Radio-wave and γ -photon interaction

 - ⇒ Zhang & Wu, *Astrophys. J.* (2022)

- ◆ Circularly-polarized radio pairs and an explanation

 - ⇒ Wu, *Astrophys. J. Lett.* (2024)

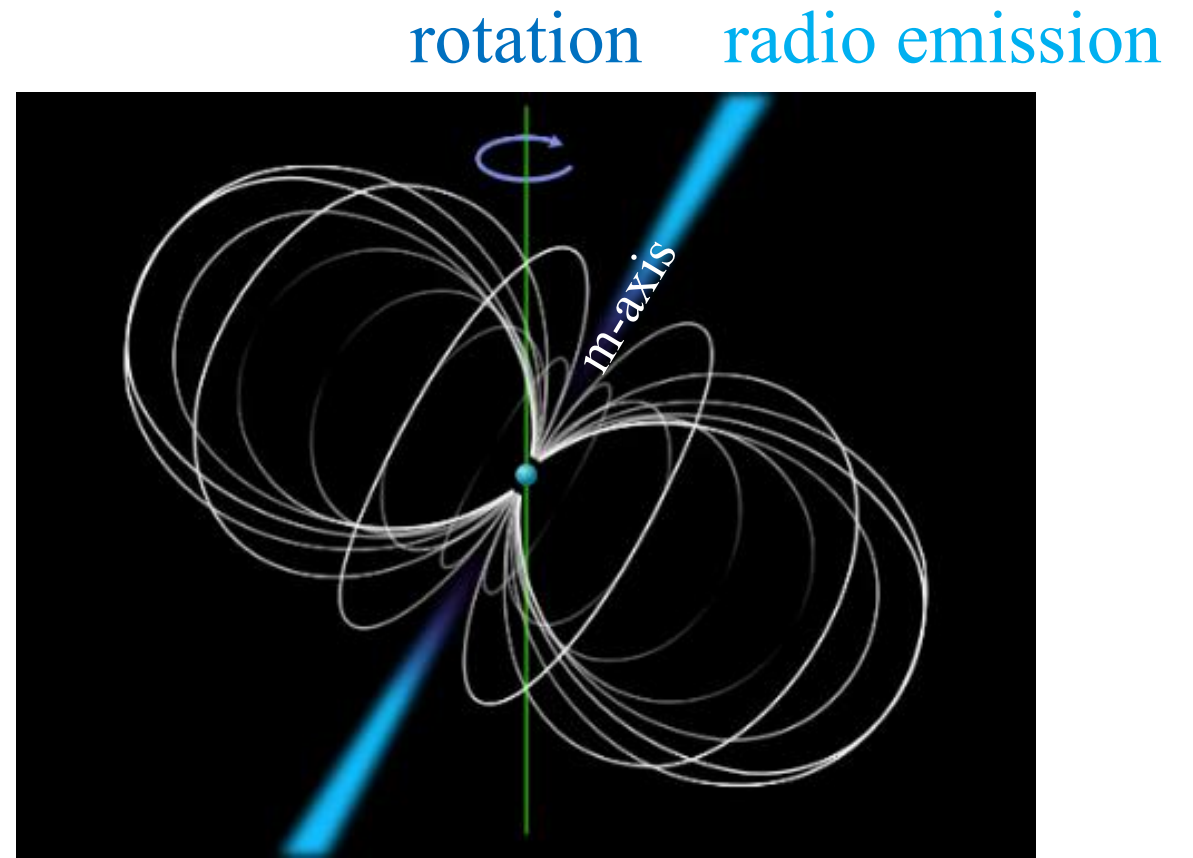
- ◆ Circular polarization of FRB by PIC

 - ⇒ Deng & Wu, *Mon. Not. R. Astron. Soc.* (2026)

- ◆ Summary

Neutron star

- ◆ Star → supernova → neutron star (20km-diam.), black hole
- ◆ Neutron star: pulsar, magnetar
- ◆ Pulsar: Bell (1967), $\sim 1e12Gs$
- ◆ Magnetar: $\sim 1e14Gs$



Coherent radio emission

source	radio emission	strength factor a_0
~3000 pulsars	typical	~1,000
~20 pulsars	giant pulse	~10,000,000
~200 magnetars	fast radio burst (FRB*)	~10,000,000

$$* a_0 \equiv \frac{eE}{mc\omega_0}; \text{ intense laser: } a_0 \sim 100$$

*FRB: the important accidental discovery (Lorimer 2007)

Theory

- ◆ ~ 100 models were proposed
- ◆ No agreement yet for weak emission
- ◆ More challenging for more intense emission
- ◆ Unknown plasma activities in magnetosphere

Melrose *et al.* MNRAS (2021)

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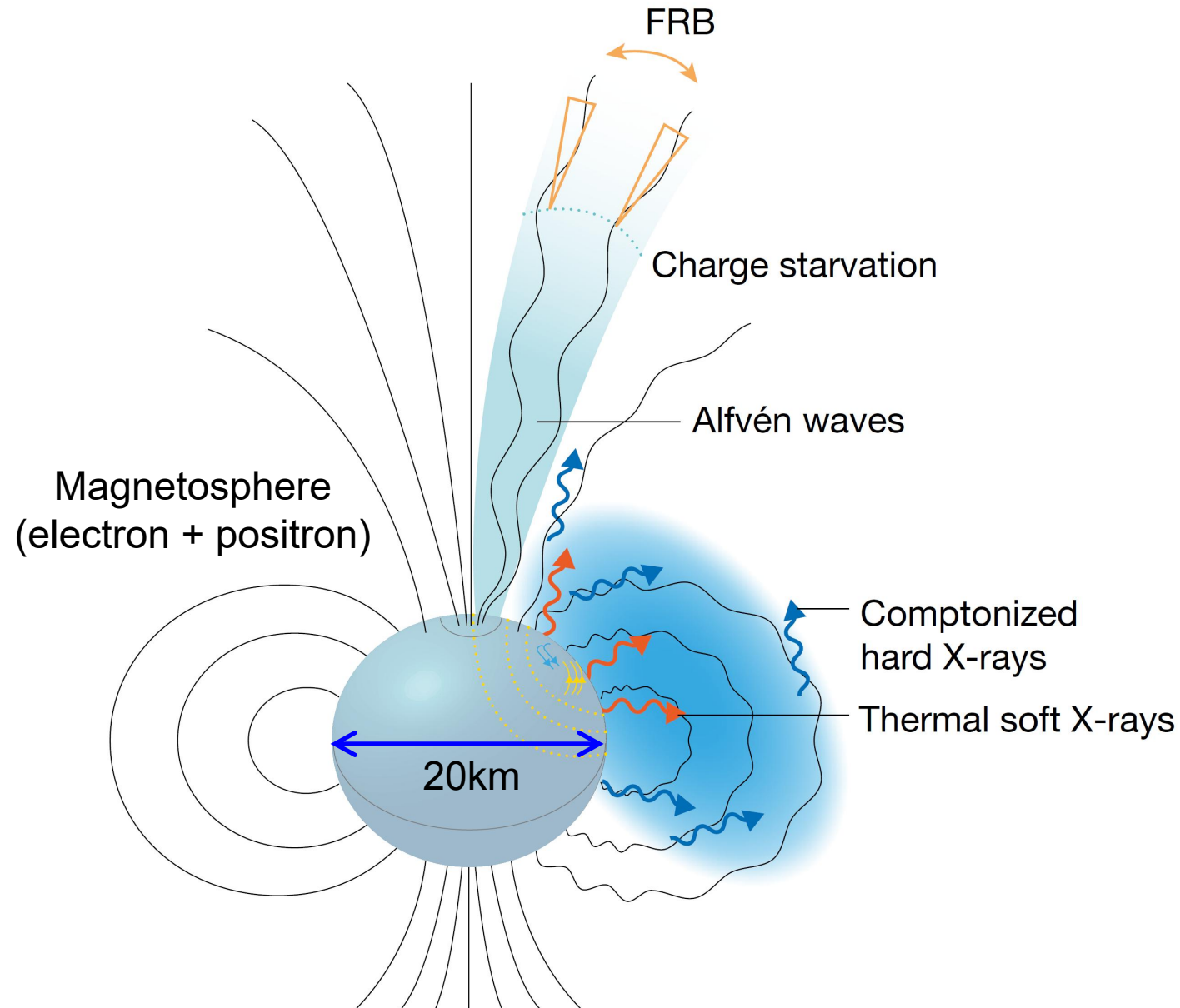
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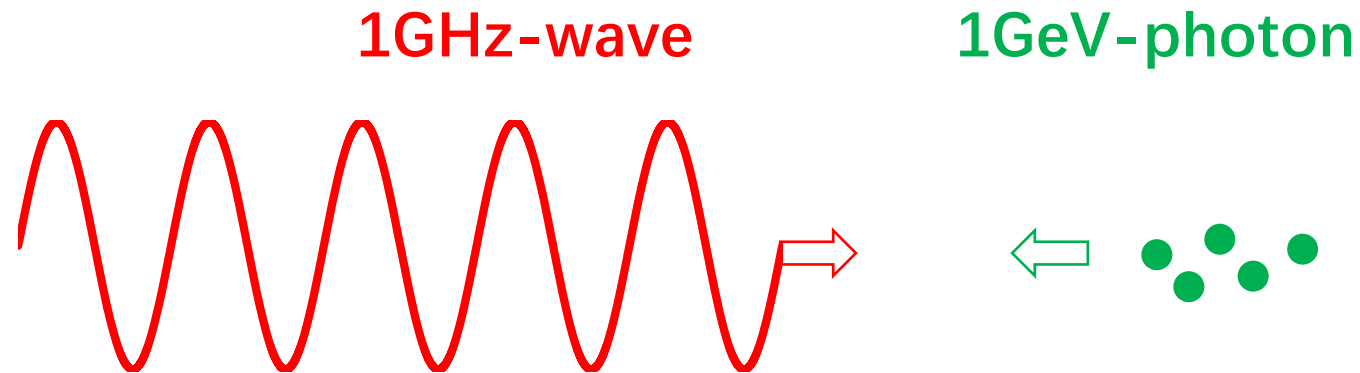
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◆ Summary

Magnetosphere



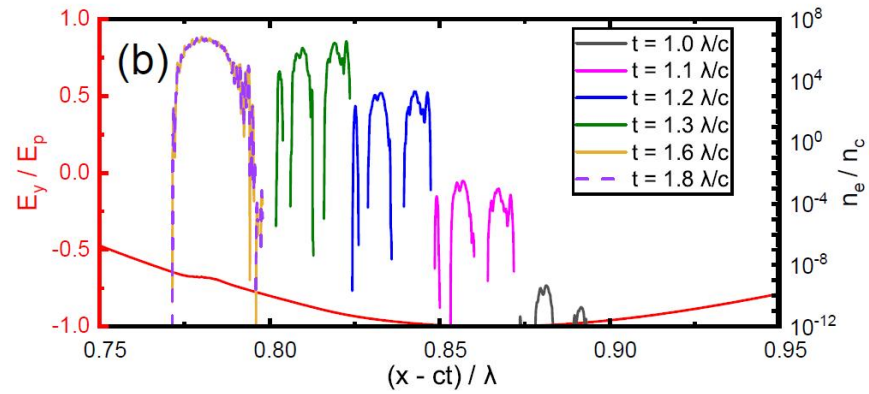
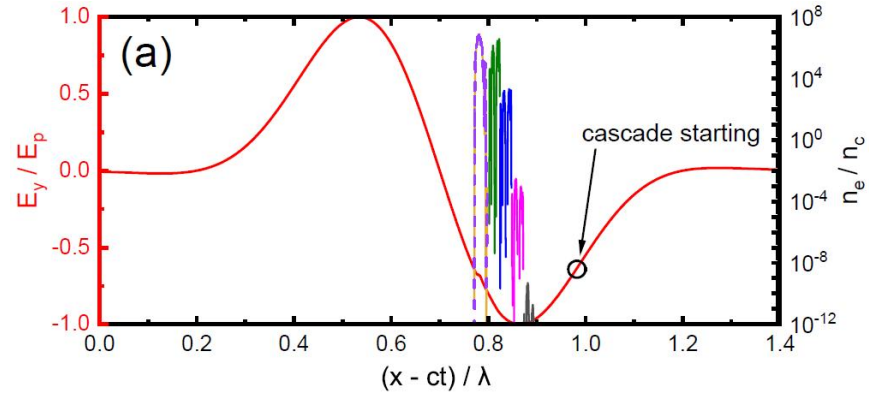
Radio-wave and γ -photon interaction



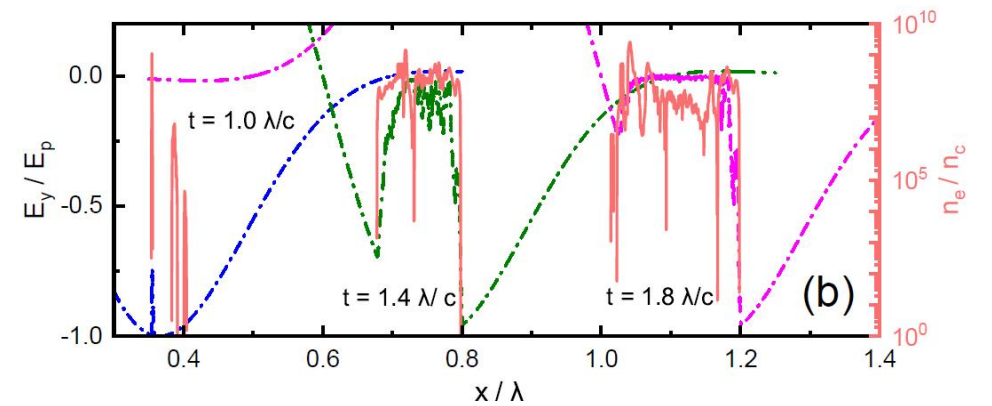
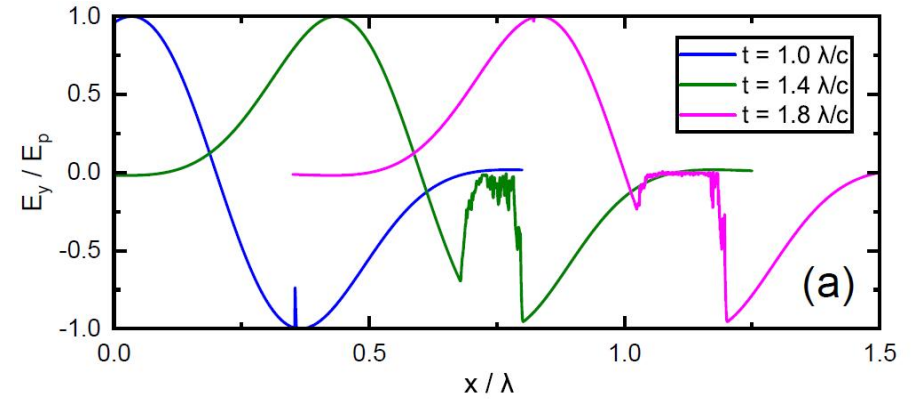
QED cascade

- ◆ Breit–Wheeler process: photon \rightarrow electron + positron
- ◆ Inverse Compton scattering: electron/positron \rightarrow photon

Simulation by JPIC1d-QED



$E=2.68e12$ V/cm



$E=3e12$ V/cm

Upper-limit of field strength

For 1GHz wave and 1GeV photons:

$$E=3e12 \text{ V/cm} \quad a_0 = \frac{eE}{mc\omega_0} = 2.8 \times 10^7$$

source	radio emission	strength factor a_0
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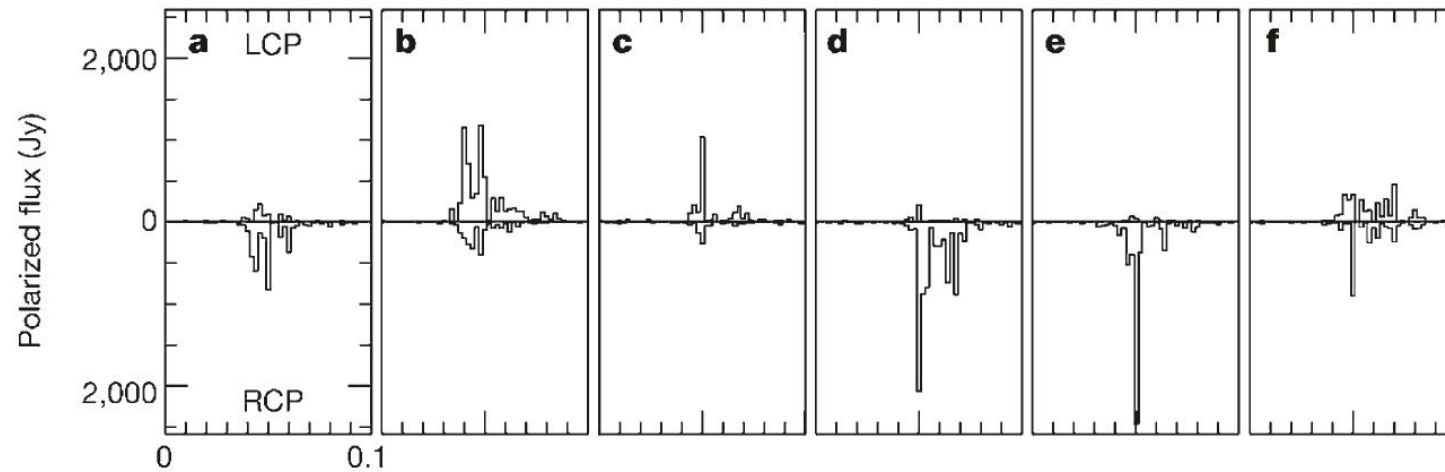
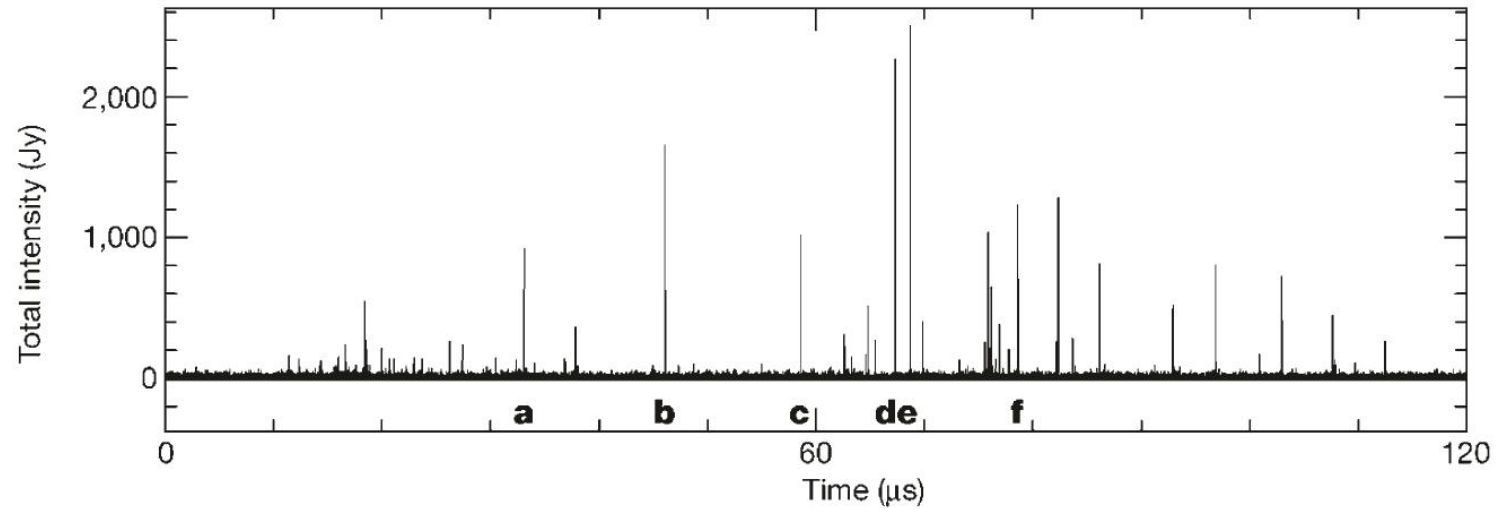
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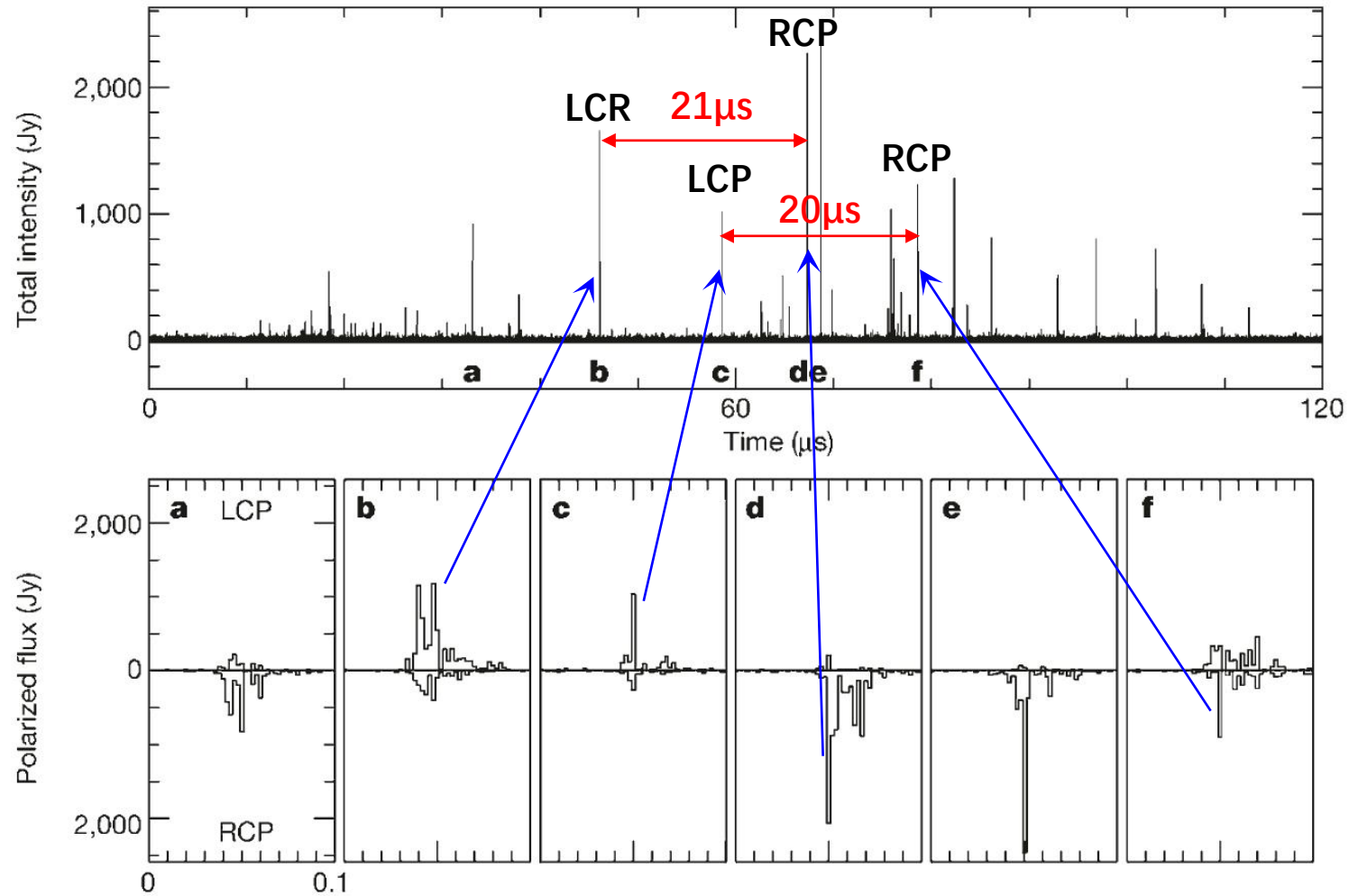
- ◆ Summary

A Crab giant pulse



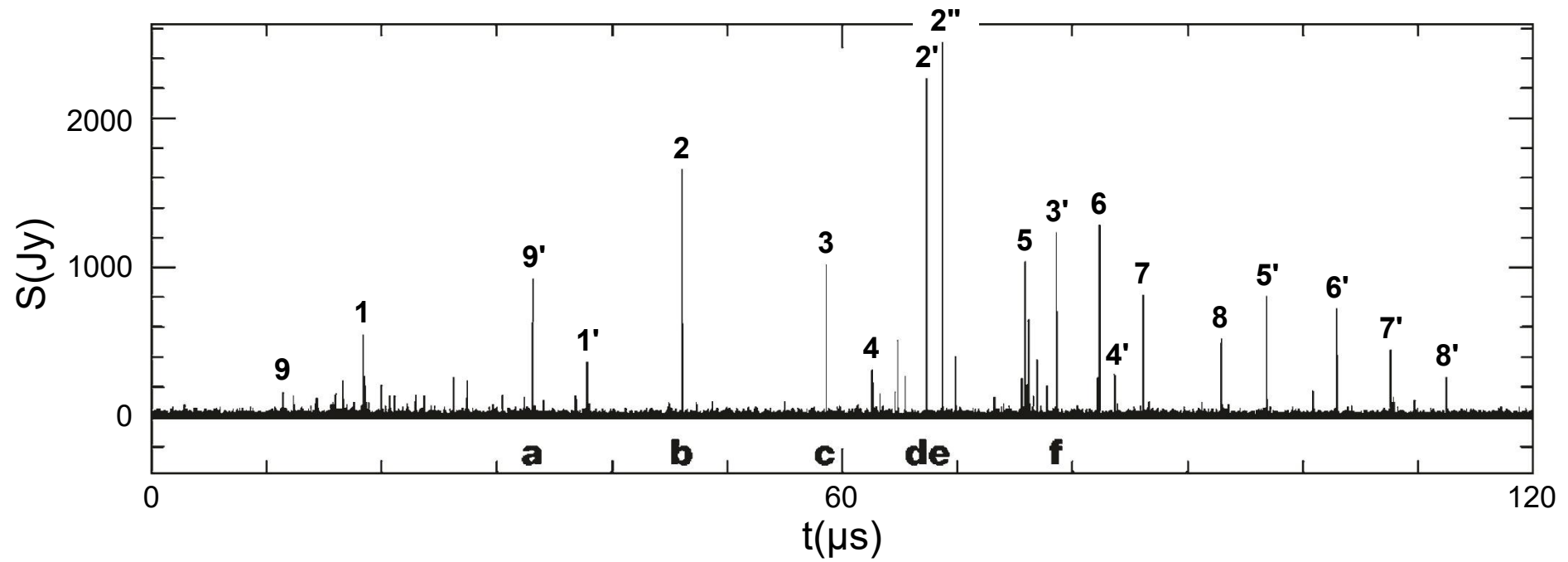
Hankins *et al.*, Nature (2003)

Radio pairs seen by me



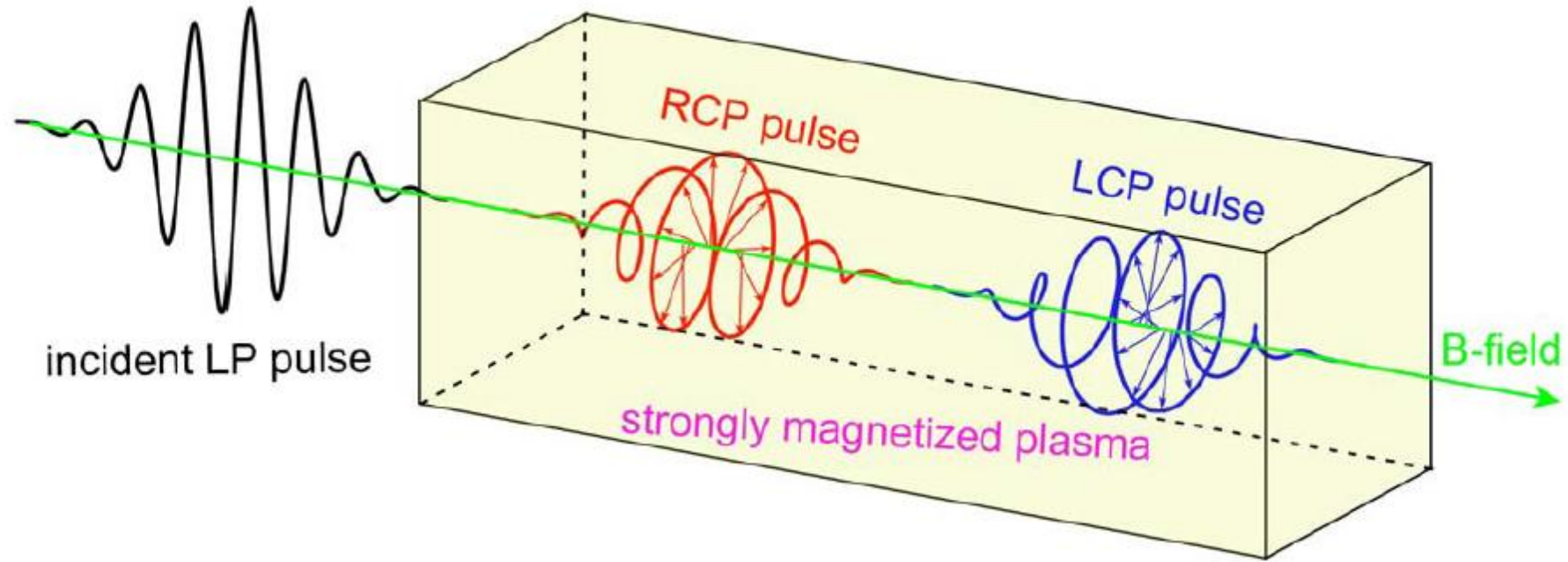
LCP: left circular polarized **RCP:** right circularly polarized

Radio pairs



$$\langle \Delta T_{pairs} \rangle = 20.7 \pm 0.79 \mu\text{s}$$

Extreme Faraday effect in electron-ion plasma



Weng *et al.*, *Optica* (2017)

Key assumption

- ◆ There is **no Faraday effect** in common pair plasmas
- ◆ Pair plasmas in NS must be **highly asymmetrical**
- ◆ Different density or energy for electrons and positrons

Relativistic-corrected dispersion relation

$$\text{LCP: } \frac{k^2 c^2}{\omega^2} = 1 - \frac{\omega_{pe}^2}{\omega(\omega + \omega'_B)}$$

$$\frac{v_{g,L}}{c} = \frac{\sqrt{1 - \frac{\omega_{pe}^2}{\omega(\omega + \omega'_B)}}}{1 + \frac{-\omega'_B \omega_{pe}^2}{2\omega(\omega + \omega'_B)^2}}$$

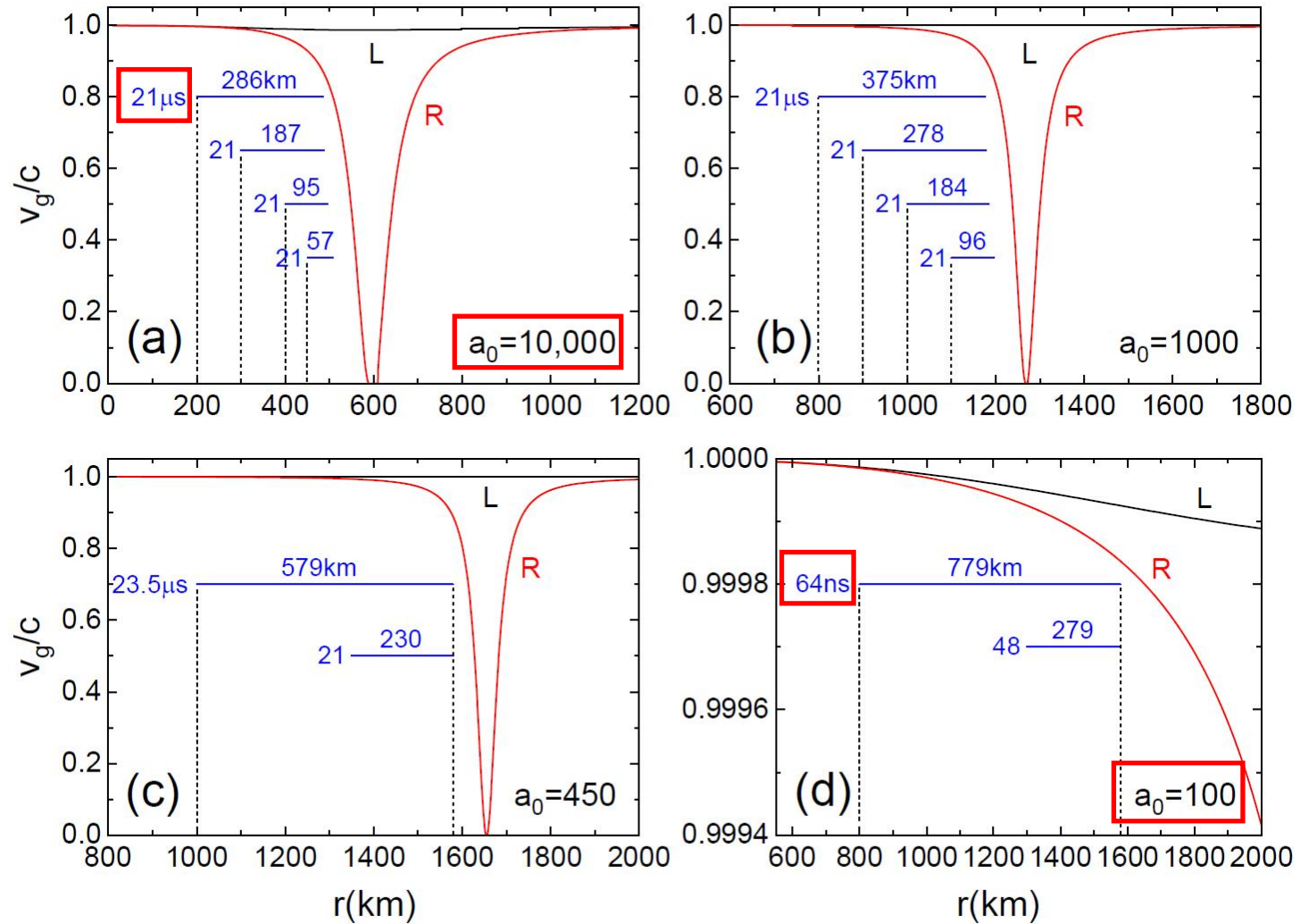
$$\text{RCP: } \frac{k^2 c^2}{\omega^2} = 1 - \frac{\omega_{pe}^2}{\omega(\omega - \omega'_B)}$$

$$\frac{v_{g,R}}{c} = \frac{\sqrt{1 - \frac{\omega_{pe}^2}{\omega(\omega - \omega'_B)}}}{1 + \frac{+\omega'_B \omega_{pe}^2}{2\omega(\omega - \omega'_B)^2}}$$

$$\boxed{\omega'_B = \omega_B / a_0} \quad \omega_B \equiv eB / m$$

$$m \rightarrow ma_0$$

Extreme Faraday effect in relativistic regime



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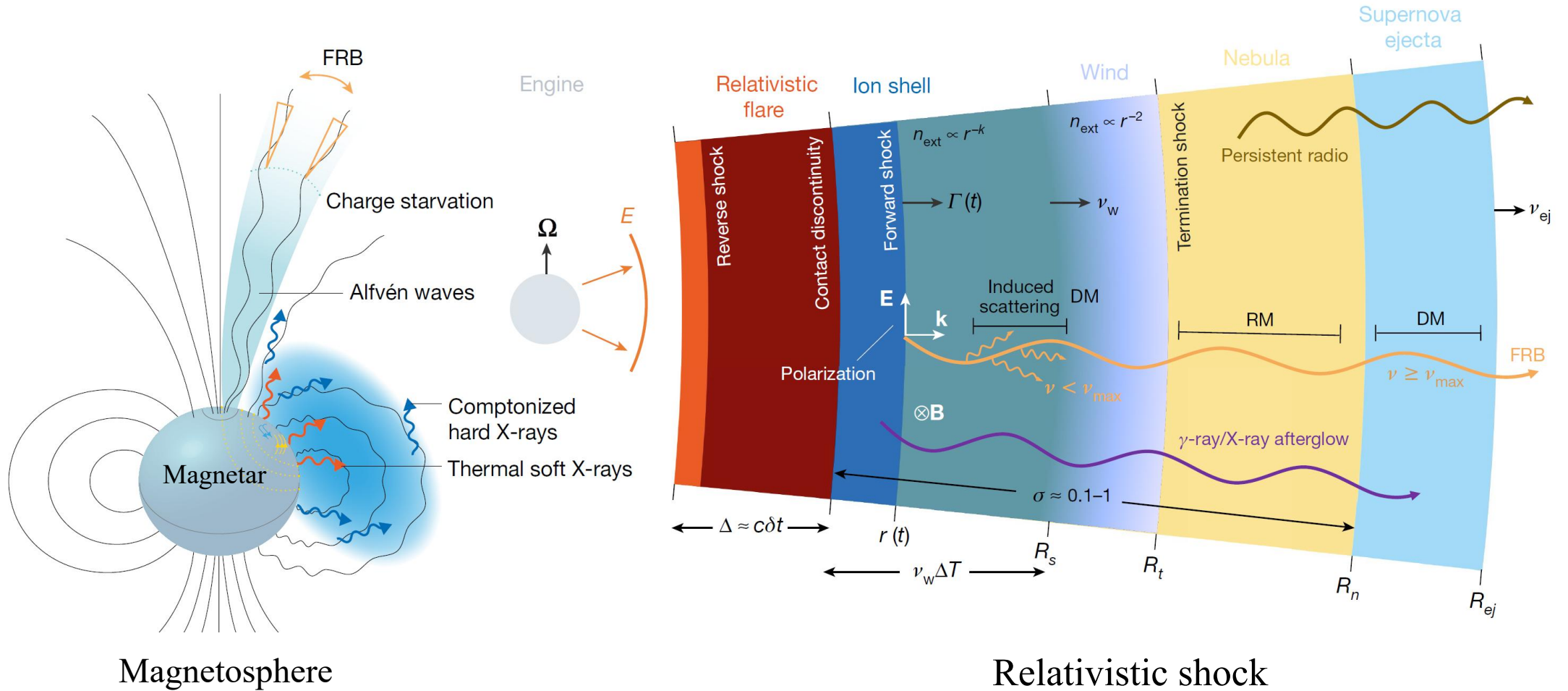
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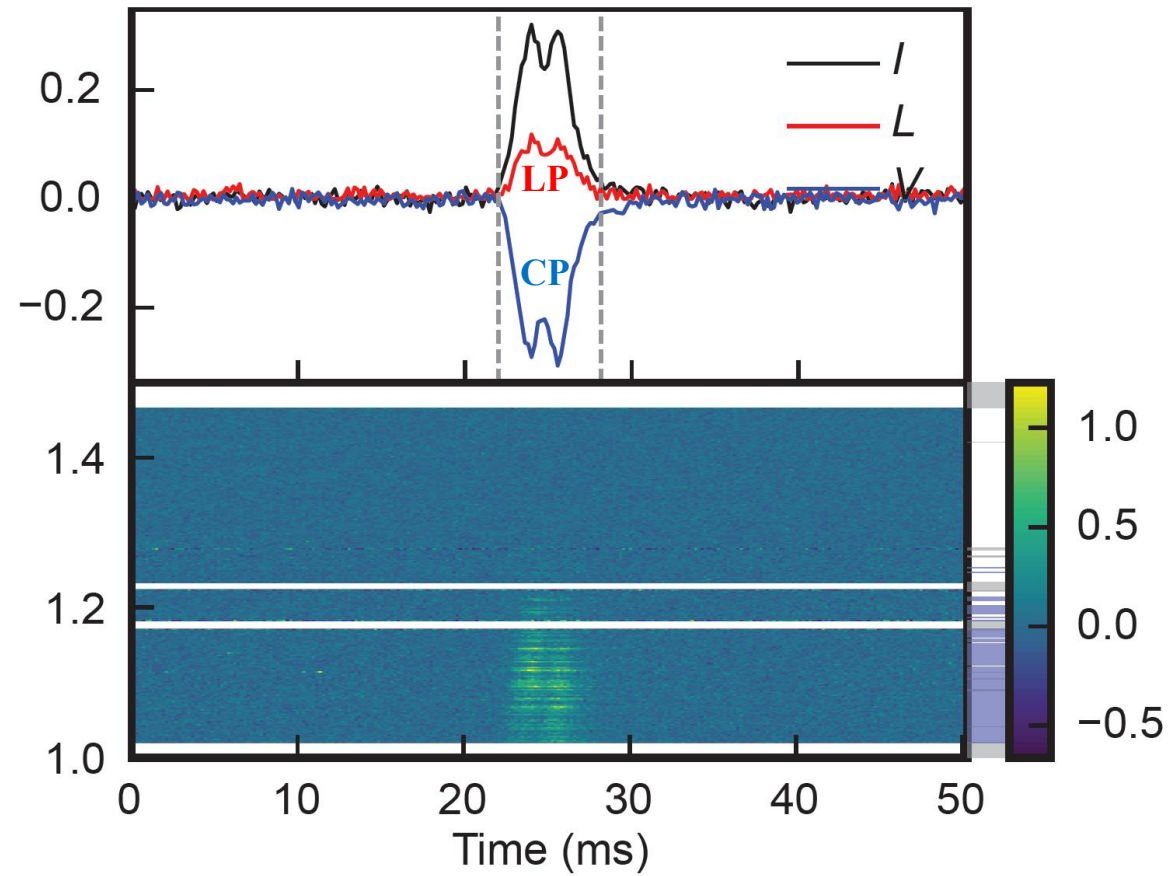
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Origin of FRB

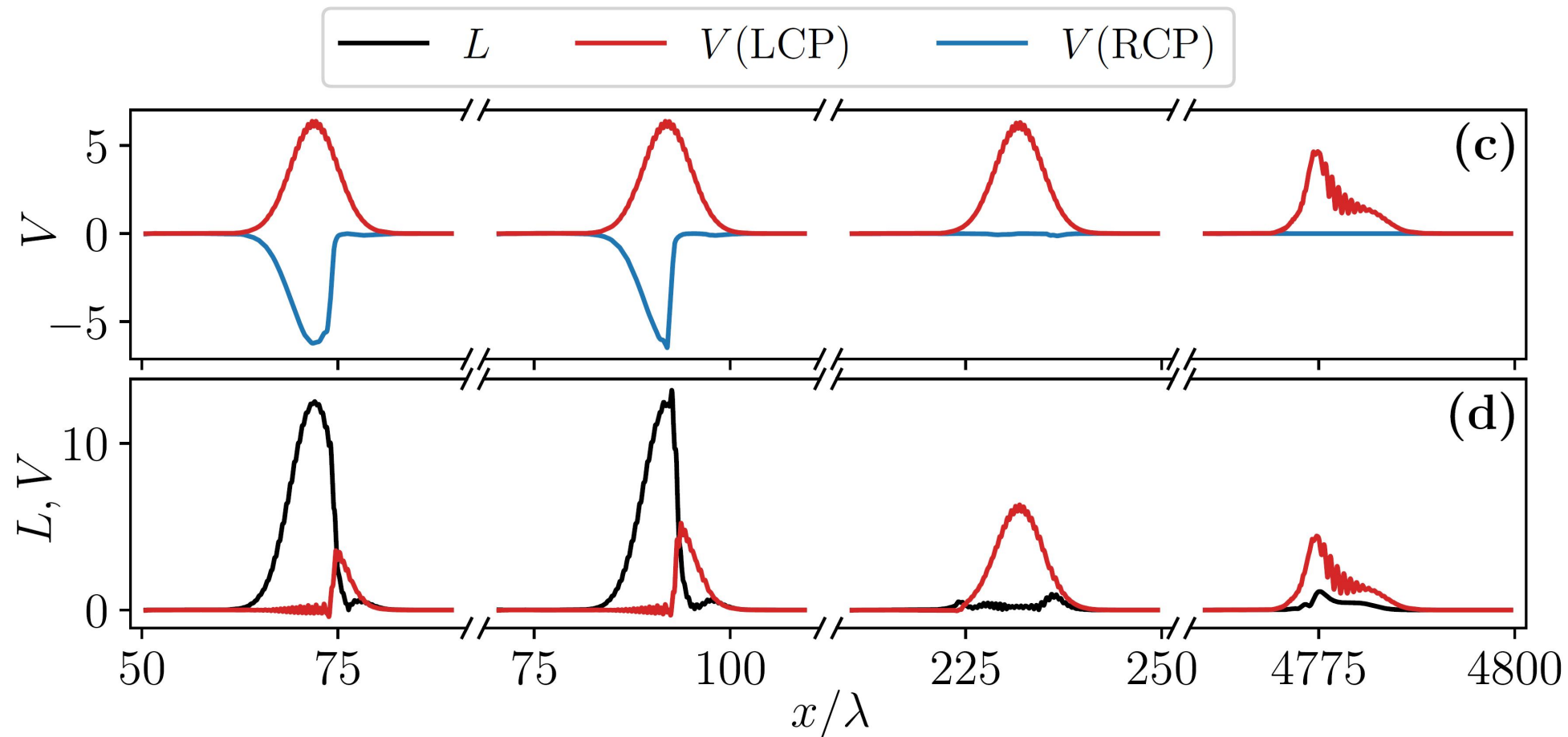


CP degree of 90%



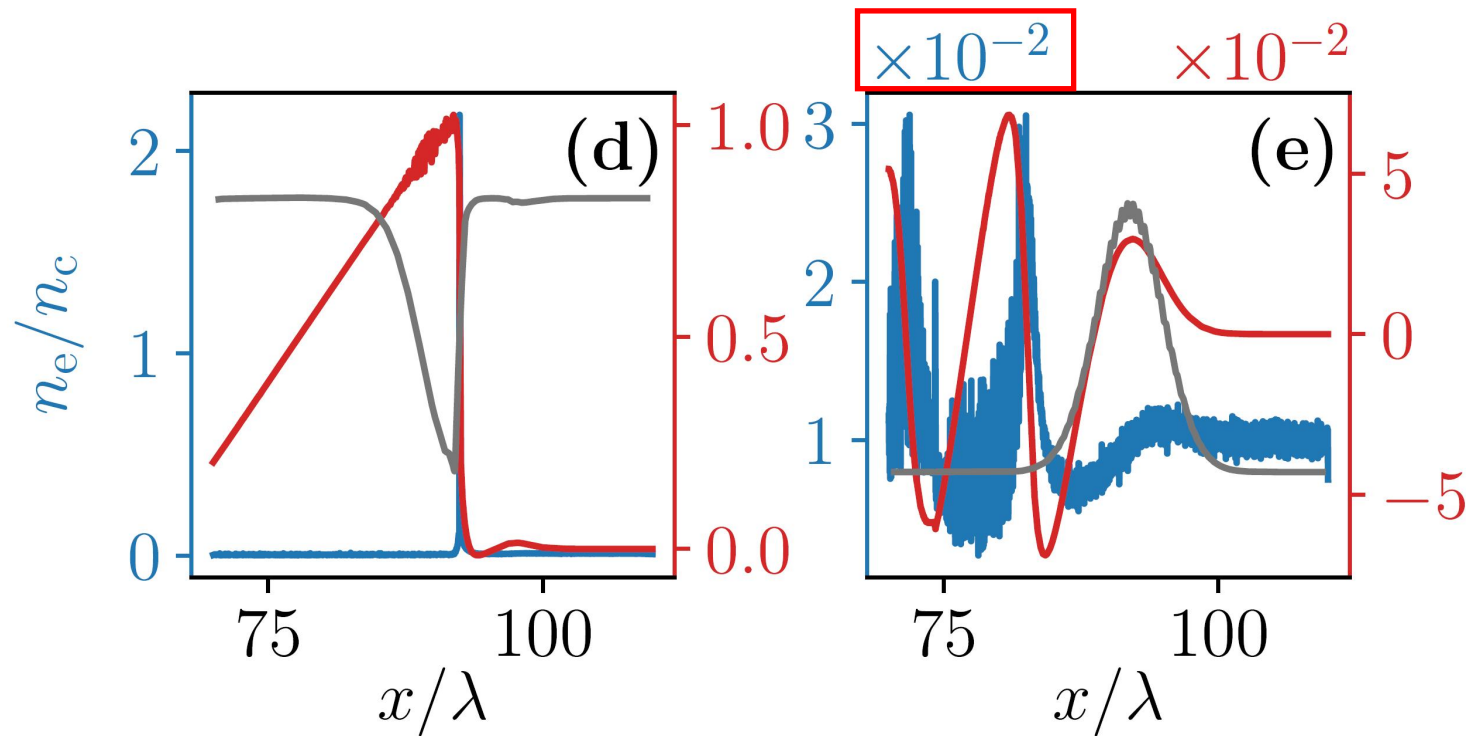
Jiang *et al.*, Natl. Sci. Rev. (2025)

PIC simulation



Asymmetrical-pair-plasmas: $a_0 = 5$, $b \equiv eB_0 / m\omega_0 = 1.5$

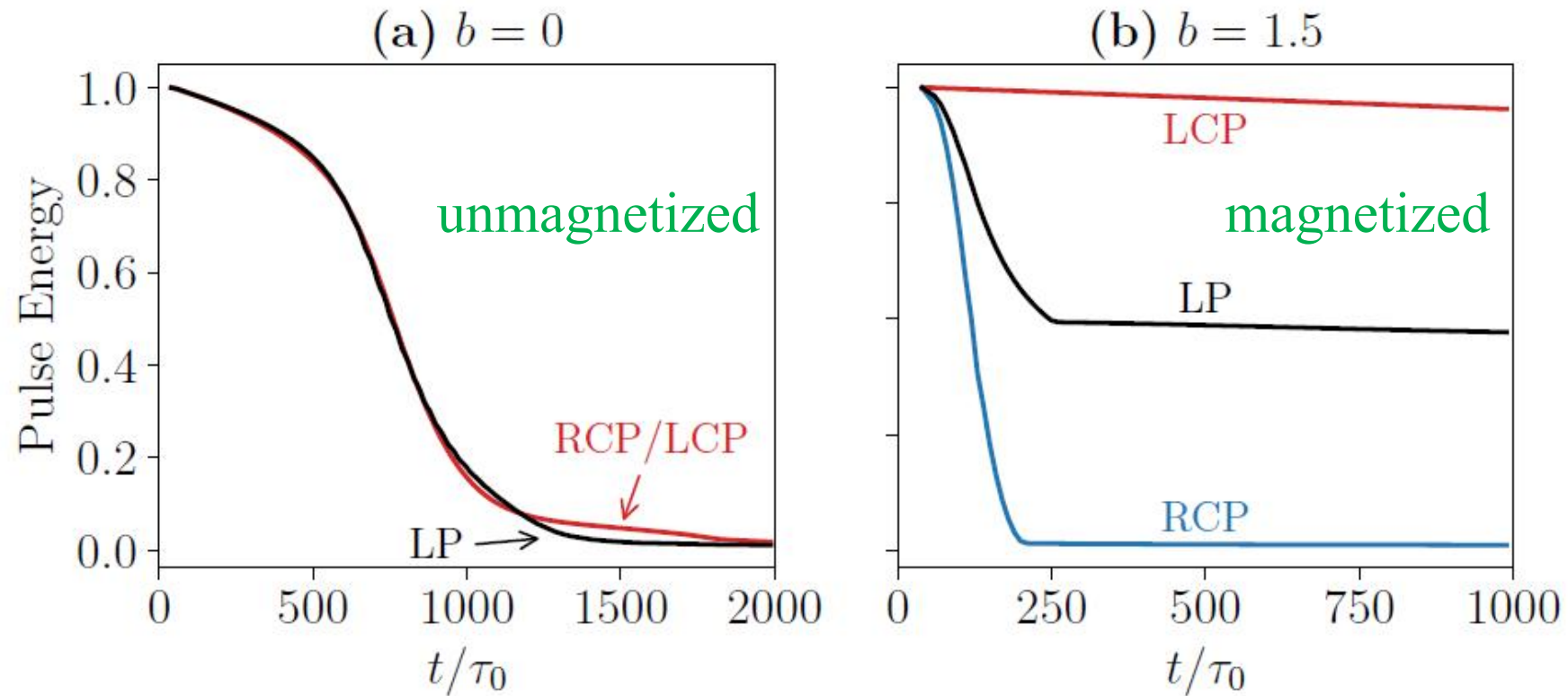
Plasma waves by CP drivers



RCP: enhanced

LCP: suppressed

Asymmetrical decay



Summary

- ◆ Highly-asymmetrical pair plasmas in NS (few people believe)
- ◆ Relativistic-nonlinear effect is important for NS emissions
- ◆ More extreme & exotic than relativistic-laser plasma

$$a_0 \equiv \frac{eE}{mc\omega_0} \sim 10,000,000 \text{ in } 10^{14}\text{Gs-magnetified pair plasmas}$$