Spontaneous spin bifurcations in a Bose Einstein condensate of indirect excitons

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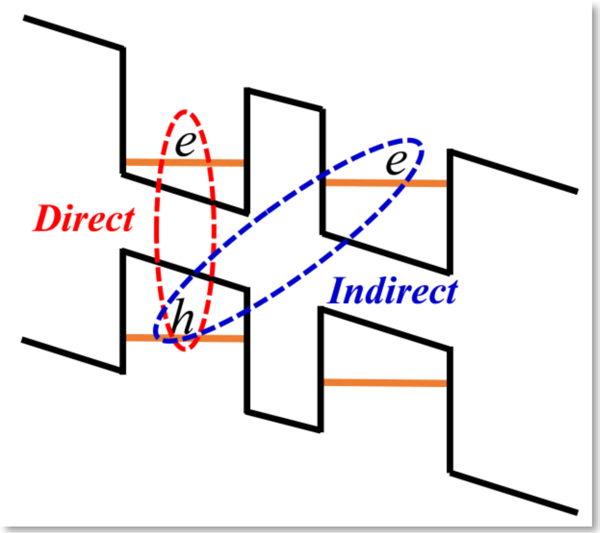
- **Introduction: excitons in quantum wells**

- **Spinor BEC and mean-field theory of indirect exciton (IX)**

- **Spontaneous spin bifurcations in IX BEC**

Excitons in quantum wells



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- **Indirect exciton (IX)**: electron and hole are confined to spatially separated quantum well layers

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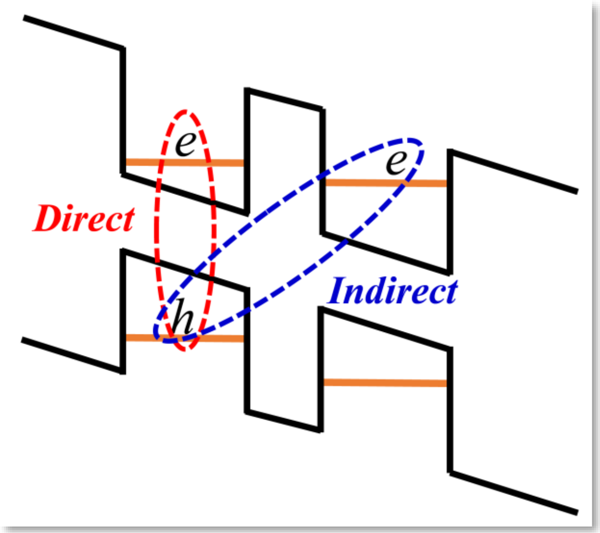

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Properties of indirect excitons (IXs):

✓ Long lifetime ✓ Built-in dipole moment

✓ Suppressed electron-hole exchange → Long spin relaxation lifetime

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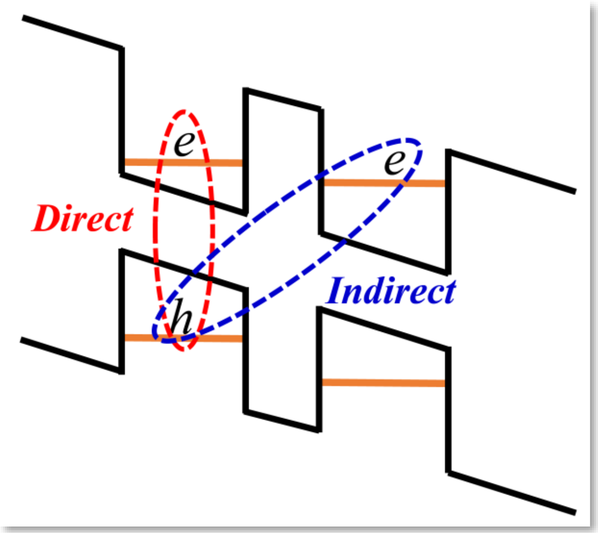

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To study physics of ultracold bosons in solid-state materials !

Exciton condensate

- **Cold exciton**: thermal de Broglie wavelength comparable to separation between excitons

$$\lambda_{dB} = \sqrt{\frac{2\pi\hbar^2}{mk_BT}} \quad \text{and} \quad \lambda_{dB} = 1/\sqrt{n} \longrightarrow T_{dB} = \frac{2\pi\hbar^2}{mk_B} n$$

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✓ Excitons in GaAs quantum wells:

$$n = 10^{10}\ \text{cm}^{-2} \ \text{and} \ m_{ex} = 0.2 m_0 \longrightarrow T_{dB} \sim 3\,K$$

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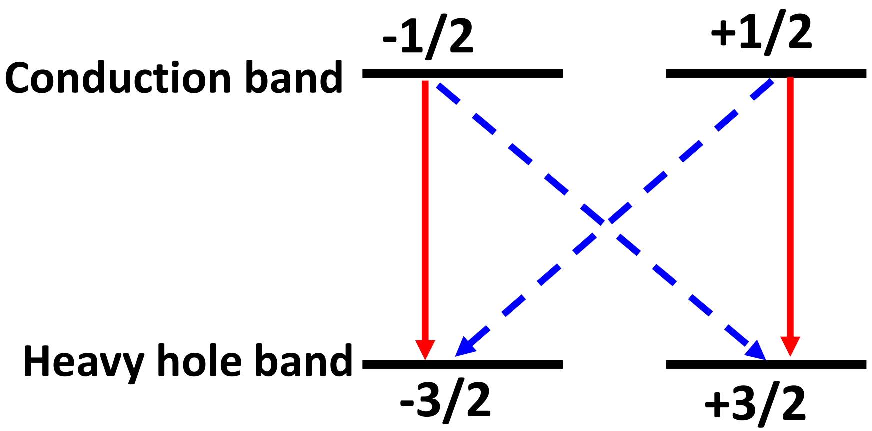
- **Indirex exciton can cool to 100mK within lifetime**

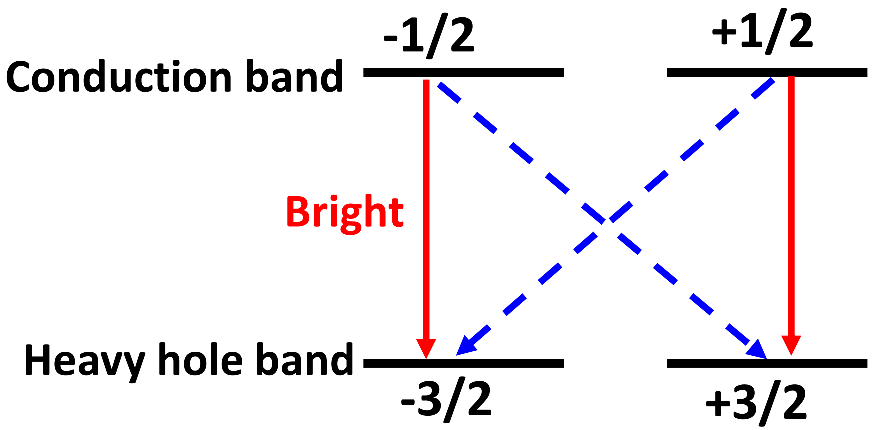
Butov, et al Phys. Rev. Lett. 86, 5608 (2001)

Spinor BEC of exciton



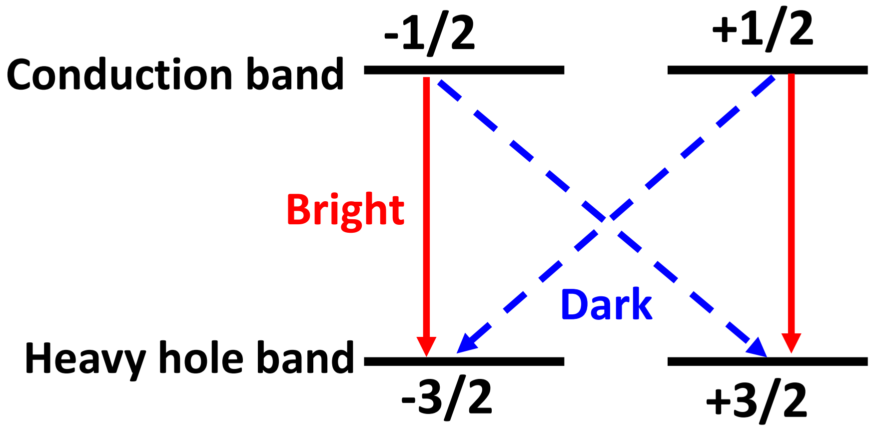
Zinc-blend semiconductor QWs (e.g. GaAs/AlGaAs system)

Spinor BEC of exciton



Bright exciton: Sz=+1 and Sz=-1

Spinor BEC of exciton



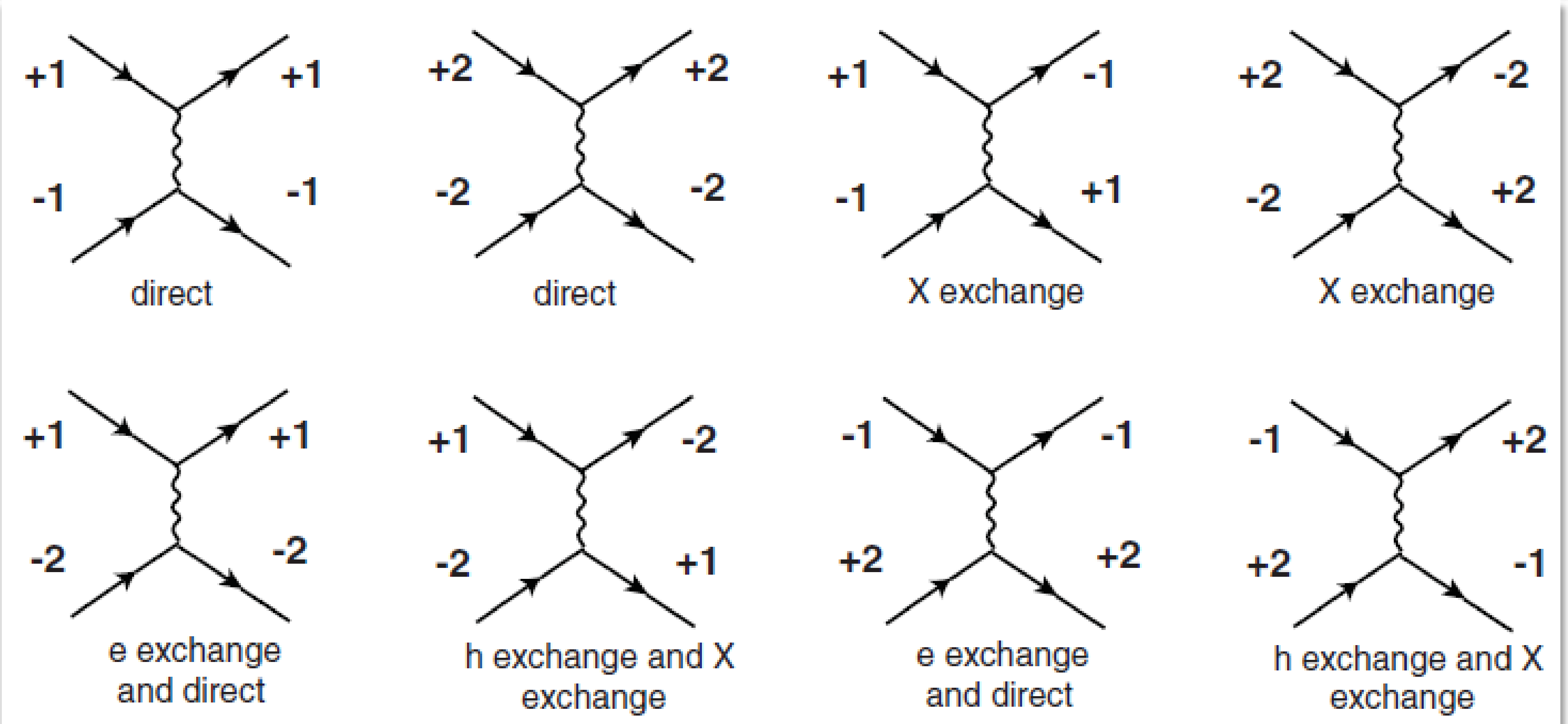
Bright exciton: Sz=+1 and Sz=-1

Dark exciton: Sz=+2 and Sz=-2

Spin dependent many-body interaction of IX condensate

Kyriienko et al PRB 86, 115324 (2012)

Spin dependent many-body interaction of IX condensate



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Mean-field theory of IX condensate

Gross-Pitaevskii type equations:

$$i\frac{d\varphi_{+1}}{dt} = \frac{i}{2}(P + W_1 - \Gamma - S)\varphi_{+1} - \left(\frac{i}{2}\gamma_{bd} - \varepsilon_{bd}\right)\varphi_{+1} + \left[\alpha_1|\varphi_{+1}|^2 + \alpha_2|\varphi_{-1}|^2\right]\varphi_{+1} + \alpha_3\left[|\varphi_{+2}|^2 + |\varphi_{-2}|^2\right]\varphi_{+1} + \alpha_4(\varphi_{-1})^*\varphi_{+2}\varphi_{-2} \quad (1)$$

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Incoherent optical pumping

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Effective dissipation rate

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Ratio of effective dissipation rate difference to energy difference: $\chi_P = (P - 2\gamma_{bd})/2\varepsilon_{bd}$

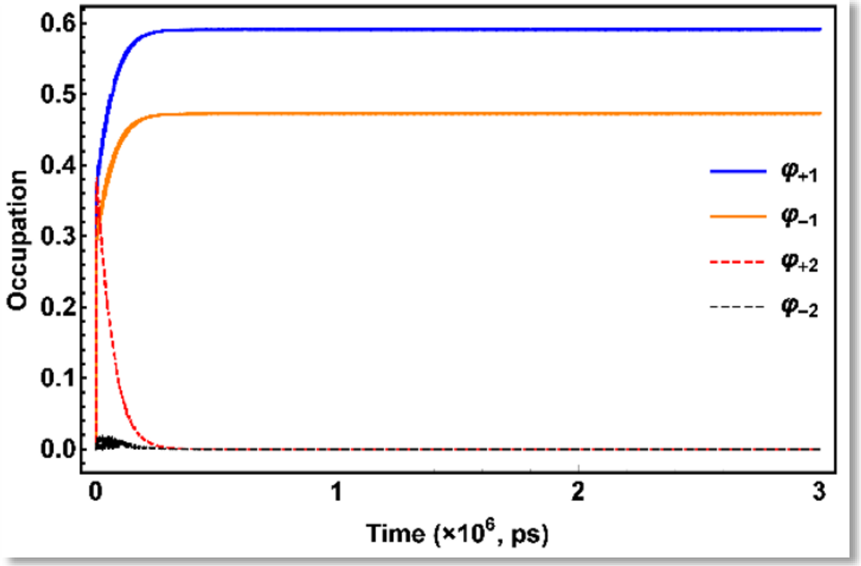
Pseudospin vector of IX condensate

$$S_x = \left(\varphi_{-1}^{*}\varphi_{+1} + \varphi_{+1}^{*}\varphi_{-1}\right) \Big/ \left(\left|\varphi_{+1}\right|^2 + \left|\varphi_{-1}\right|^2\right)$$

$$S_y = i\left(\varphi_{-1}^{*}\varphi_{+1} - \varphi_{+1}^{*}\varphi_{-1}\right) \Big/ \left(\left|\varphi_{+1}\right|^2 + \left|\varphi_{-1}\right|^2\right)$$

$$S_z = \left(\left|\varphi_{+1}\right|^2 - \left|\varphi_{-1}\right|^2\right) \Big/ \left(\left|\varphi_{+1}\right|^2 + \left|\varphi_{-1}\right|^2\right)$$

Condensate at different electronic pump



$W = 0.005\ \mathrm{ns}^{-1}$

$\chi_p = 0.2$

Initial conditions for four components are arbitrarily set with a quite small asymmetry (~1%)

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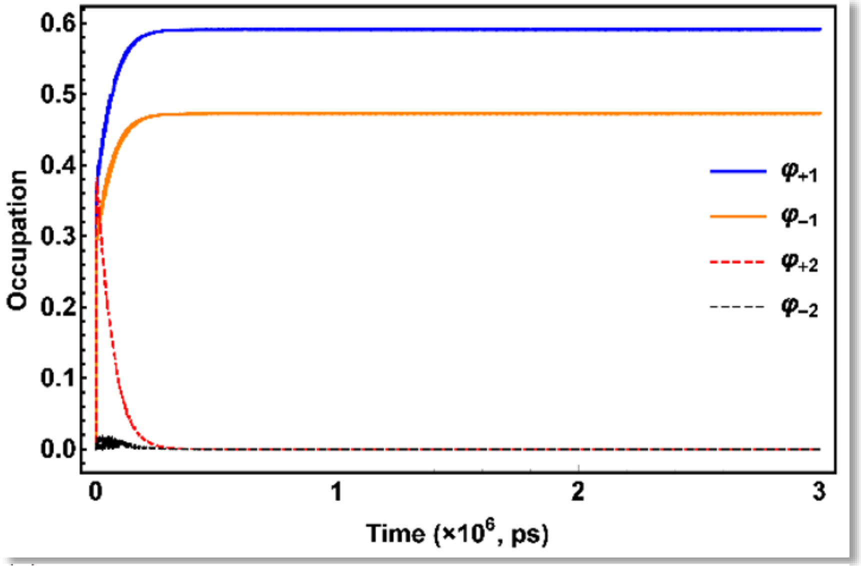

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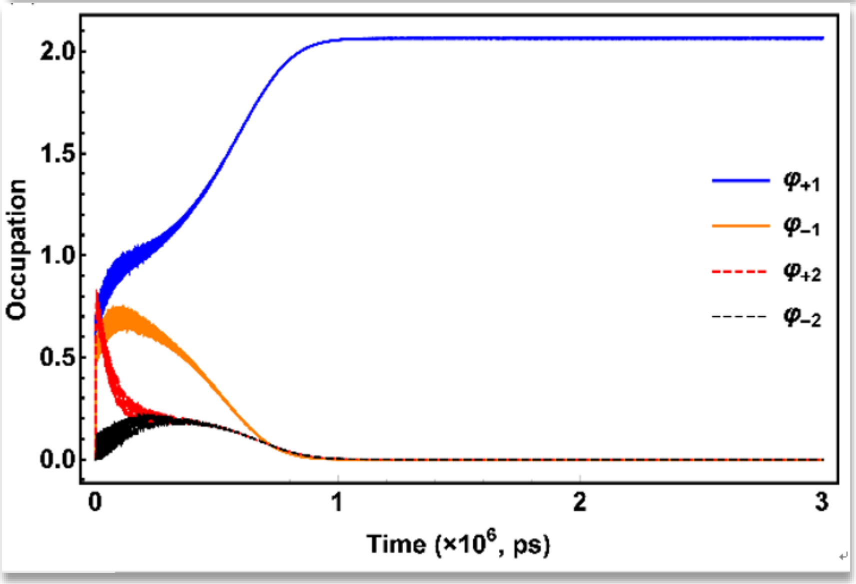

$W = 0.01 \ ns^{-1}$

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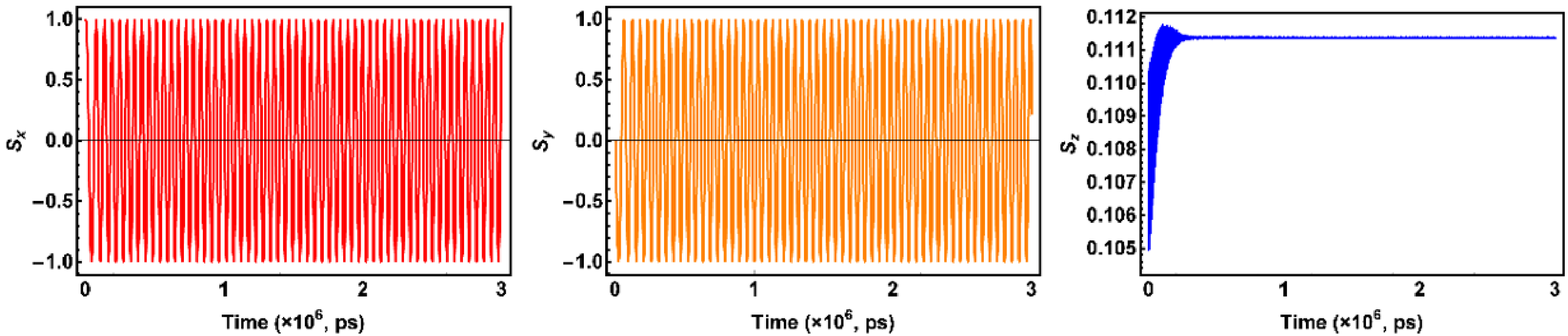
Pseudospin vector for bright excitons



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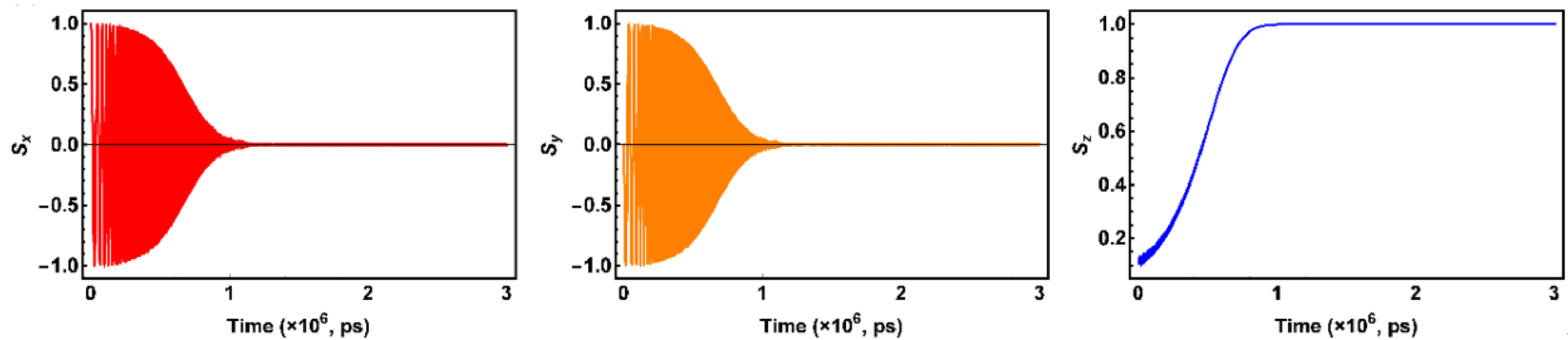

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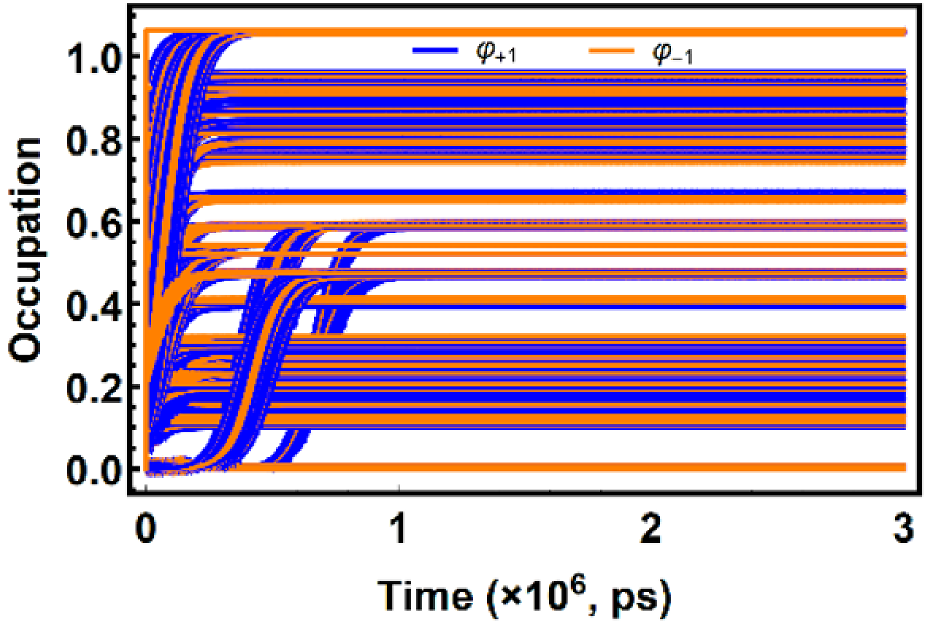
Random initial occupations



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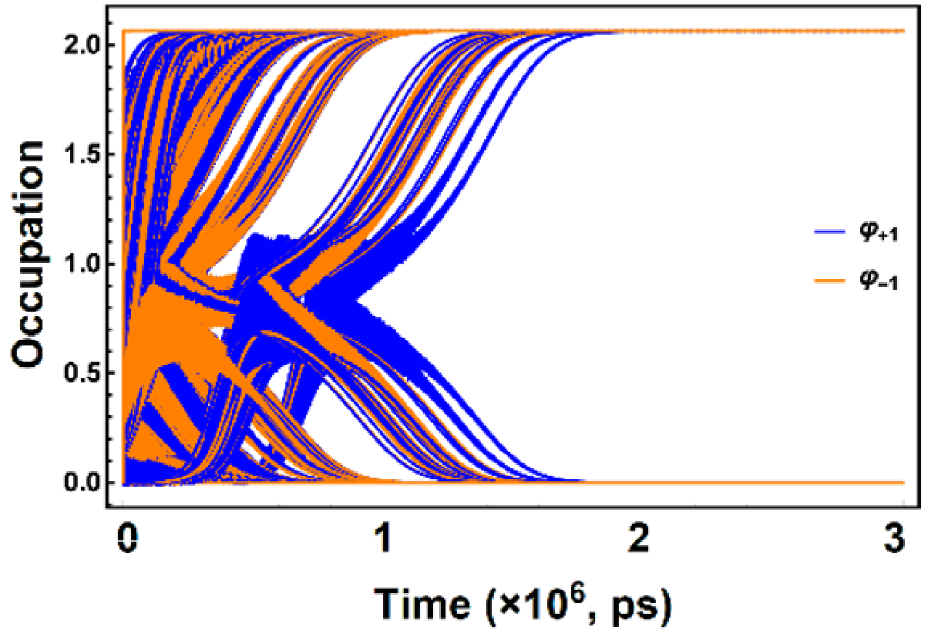

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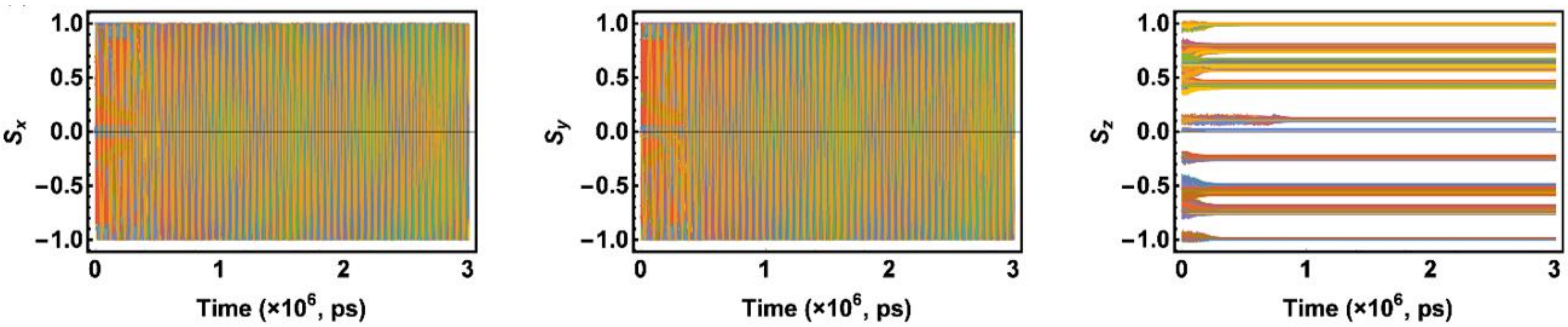

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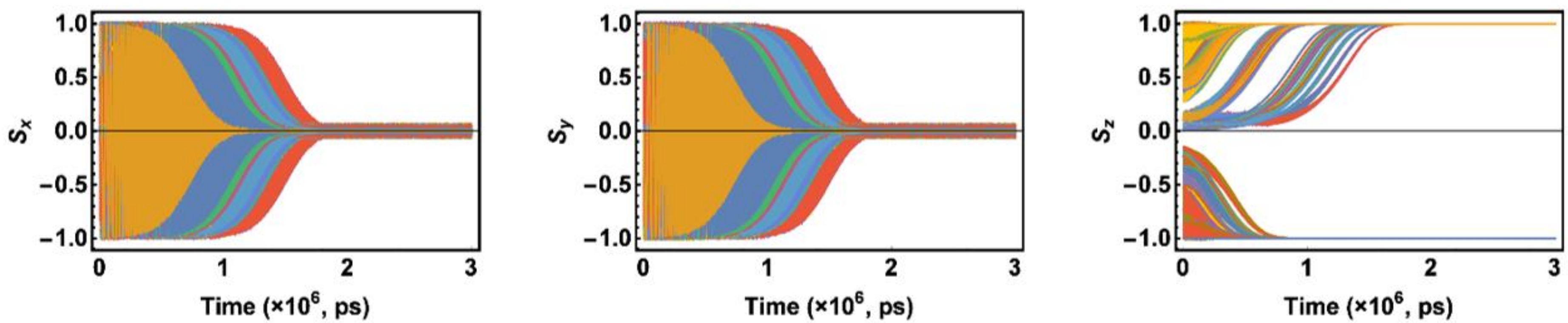

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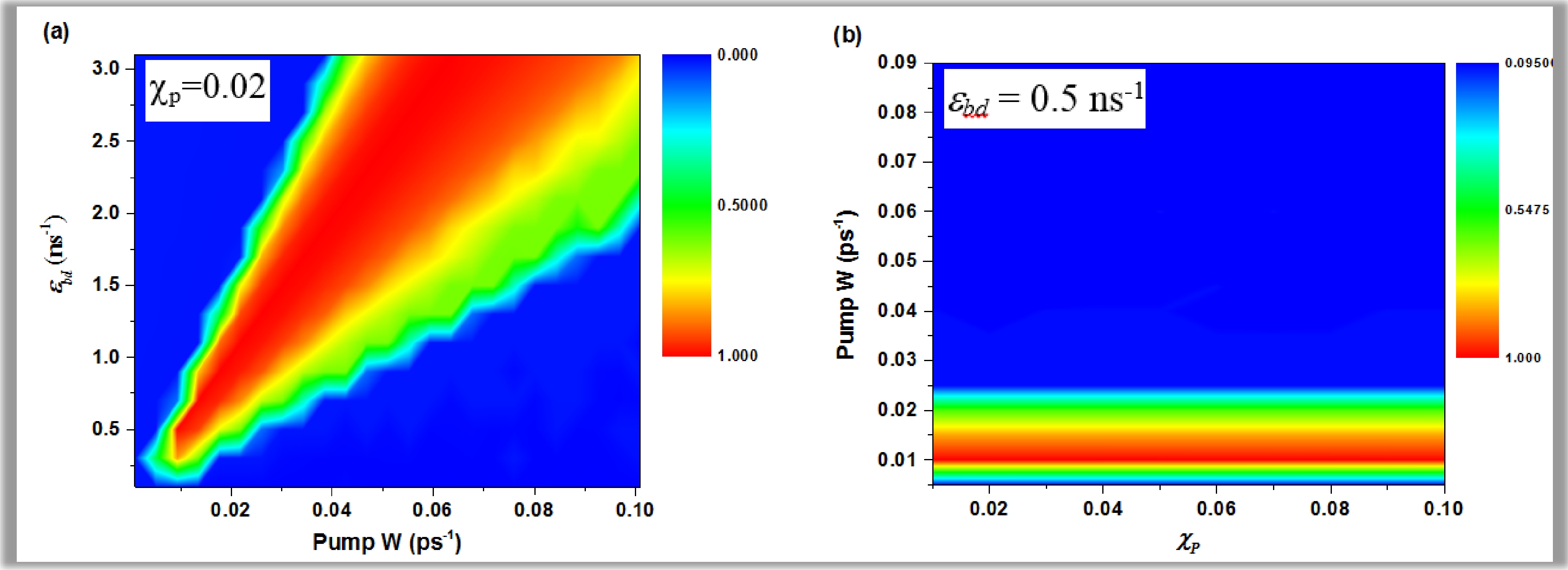
Phase diagram of condensate

Minimum of the pseudospin vector $|S_z|$



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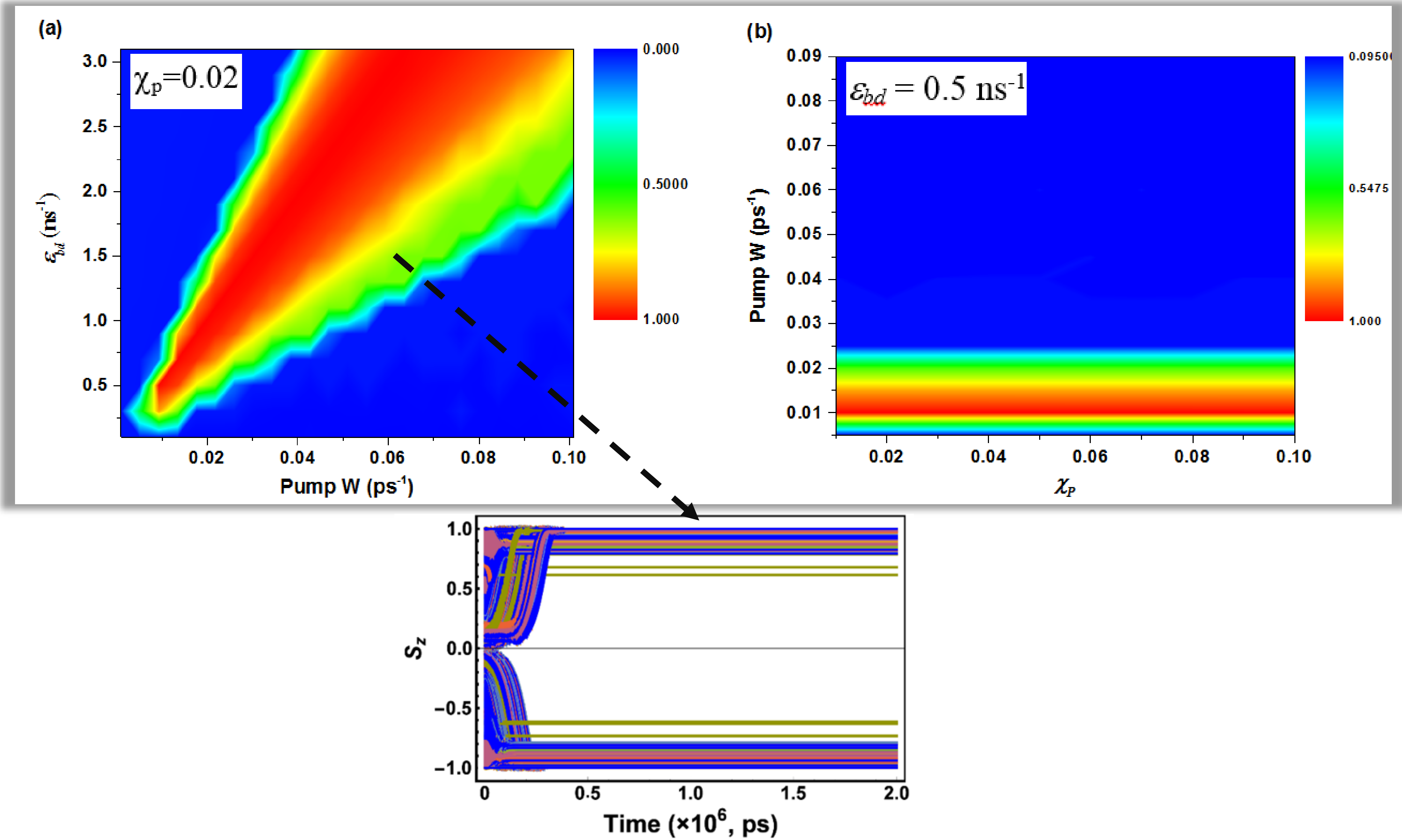

Physical mechanism

Two possible mechanisms:

1. **Strong cross-spin interaction.**

Physical mechanism

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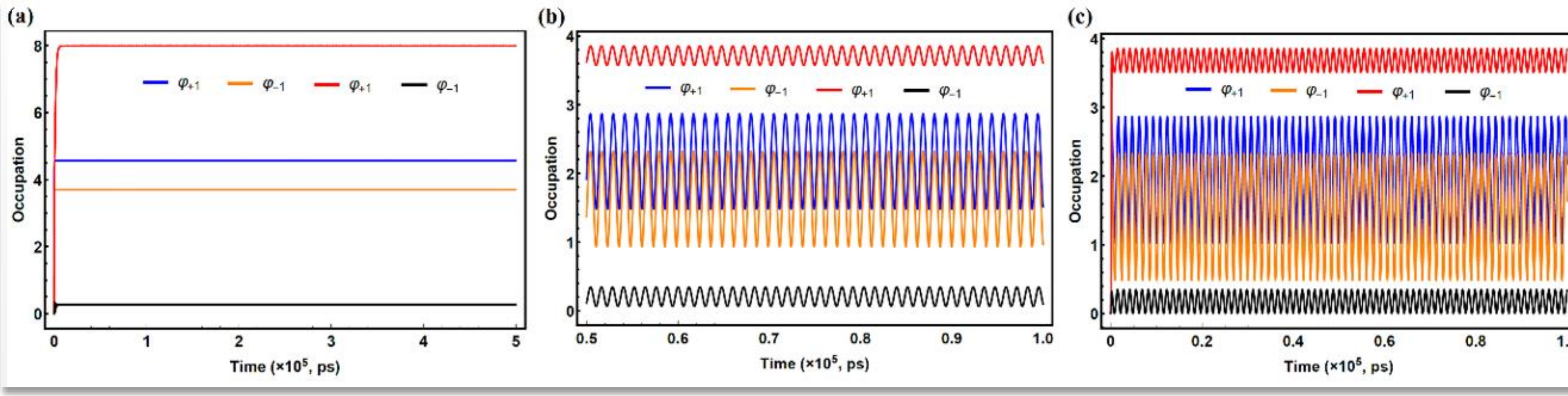
1. **Strong cross-spin interaction.** ✕

2. **Polarization energy splitting and dissipation difference between bright and dark excitons.**

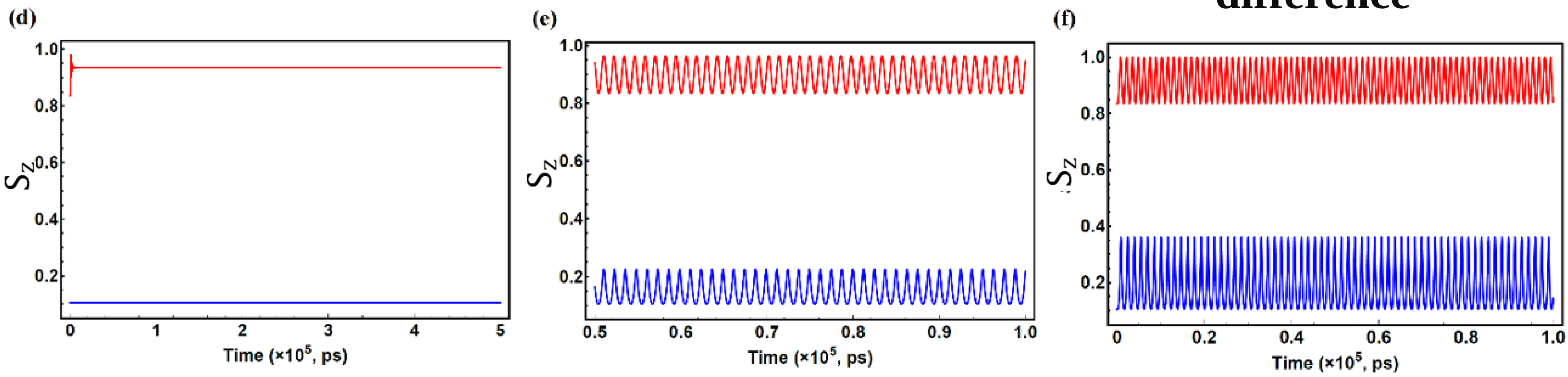
Physical mechanism



Zero energy splitting

Zero dissipation difference

Zero energy splitting and dissipation difference



Summary

- A spontaneous parity-symmetry breaking spin bifurcation for bright excitons occurs under non-resonant linearly polarized pumping.

- Condensate for bright excitons spontaneously and stochastically adopts one of two spin-polarized configurations S_z depending on initial occupations.

- Spontaneous spin bifurcations is attributed to the small energy splitting and difference in dissipation rates between bright and dark excitons in IX systems.

Thanks