Dissipative coupling of polariton condensates

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June 2013

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Outline

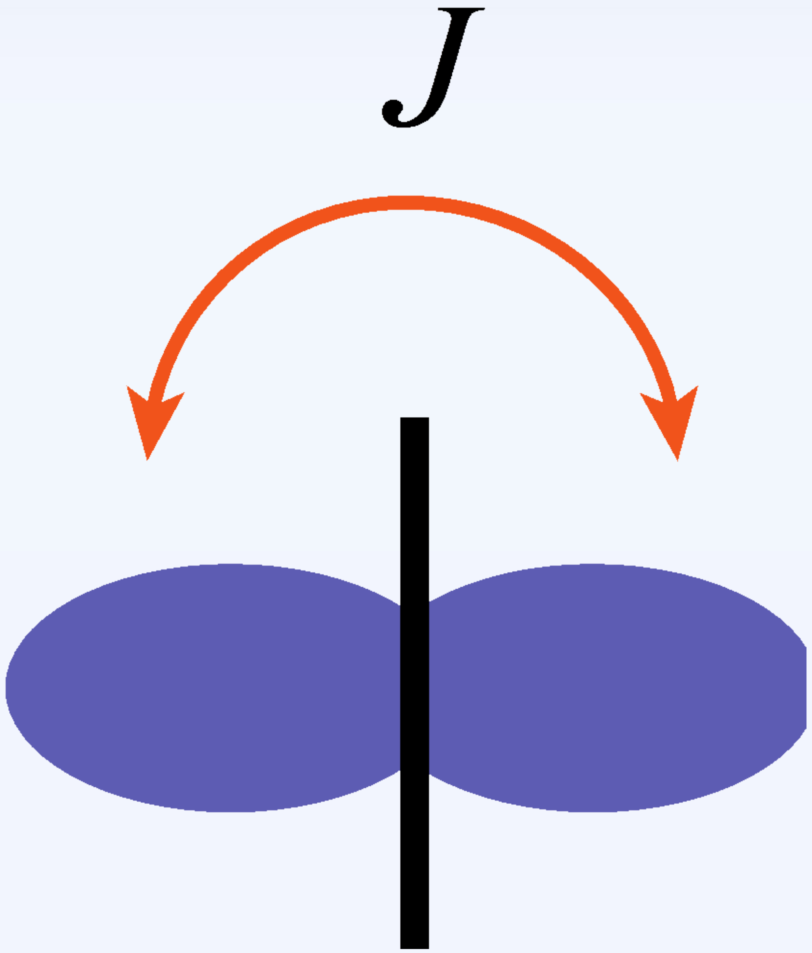
- Introduction
- Phase coupling
- Pseudospin coupling
- Conclusions

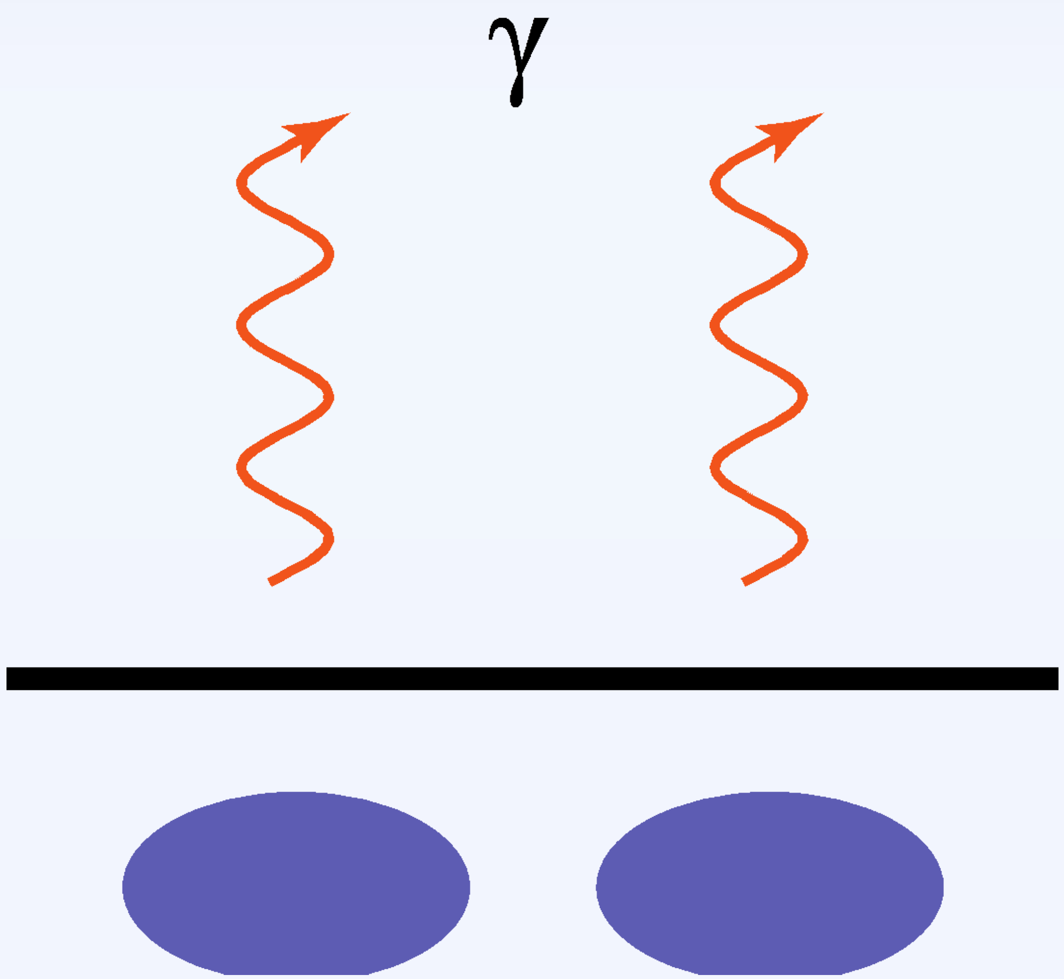
Coupling mechanisms in polariton condensates

- coherent (Josephson coupling)
  - tunnelling
    - K. G. Lagoudakis *et al.*, *Phys. Rev. Lett.* **105,** 120403 (2010)

- incoherent / dissipative
    - I. L. Aleiner, B. L. Altshuler & Y. G. Rubo, *Phys. Rev. B* **85,** 121301 (2012)

Josephson vs. Dissipative





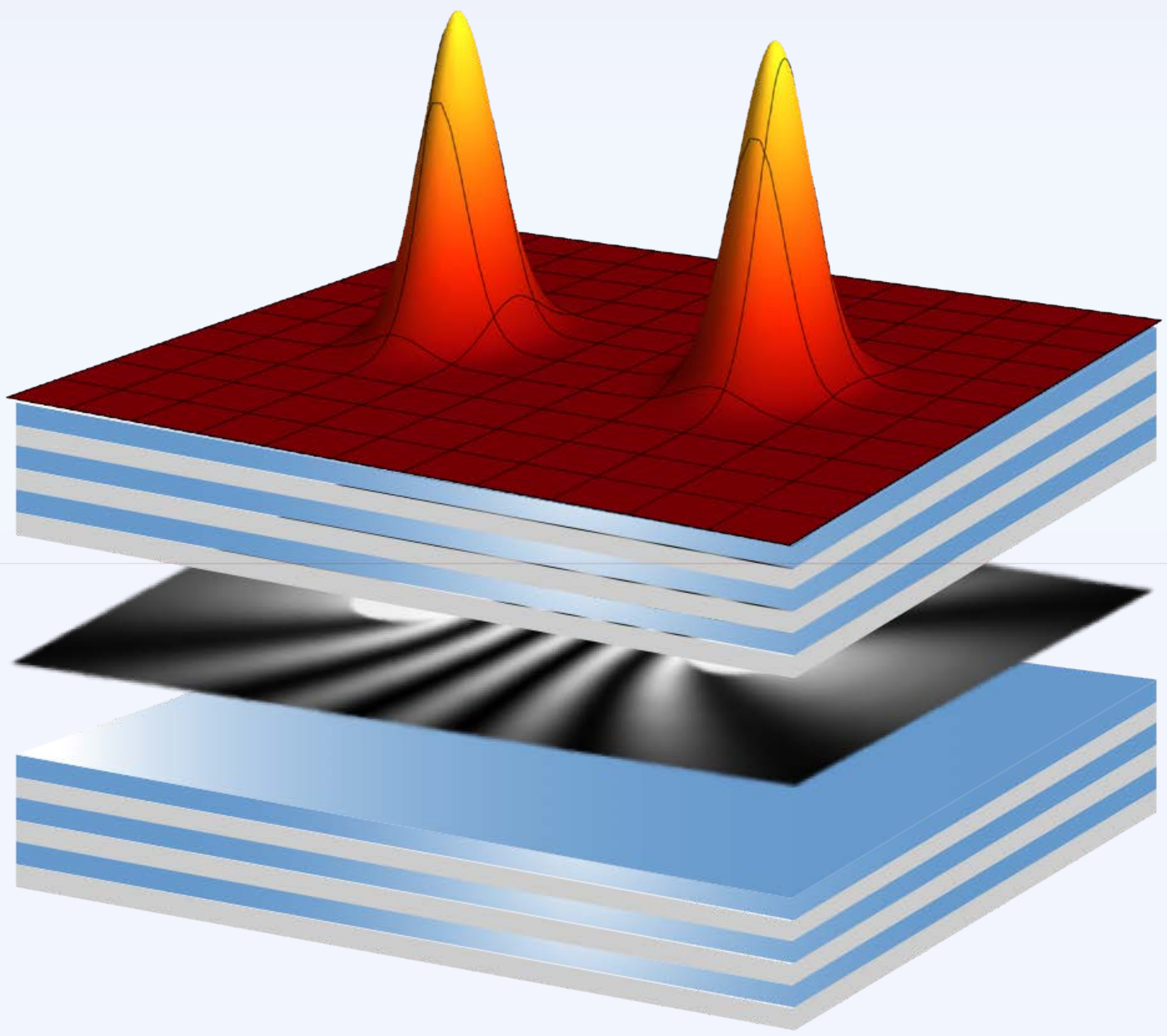
Josephson (coherent)

- symmetric (in-phase) states

Dissipative (incoherent)

- reduction of threshold
- in-phase and anti-phase states

Geometry



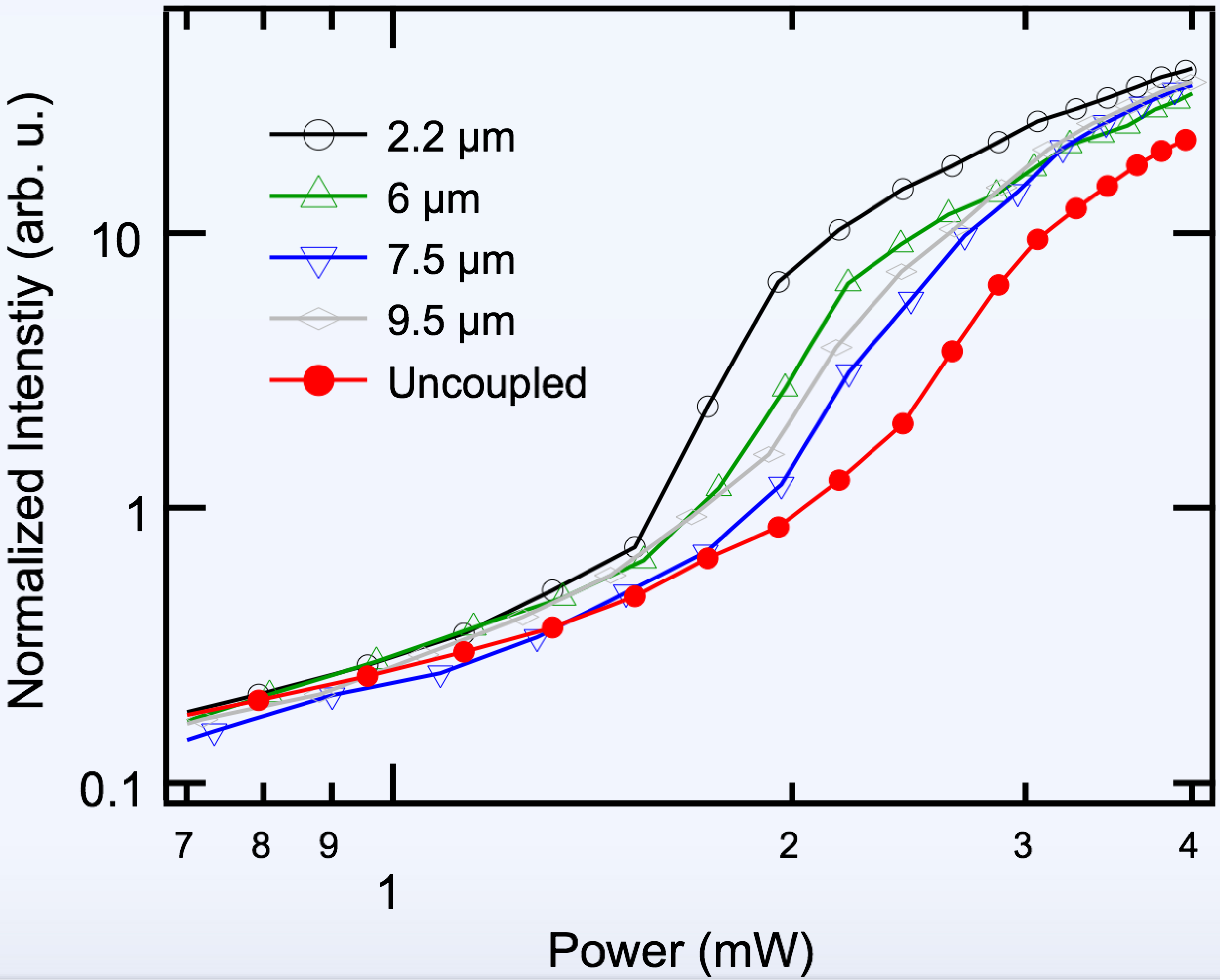
- non-resonant
- pulsed excitation
- spot diameter ~1.3µm

What we observe

two spatially separated polariton condensates:

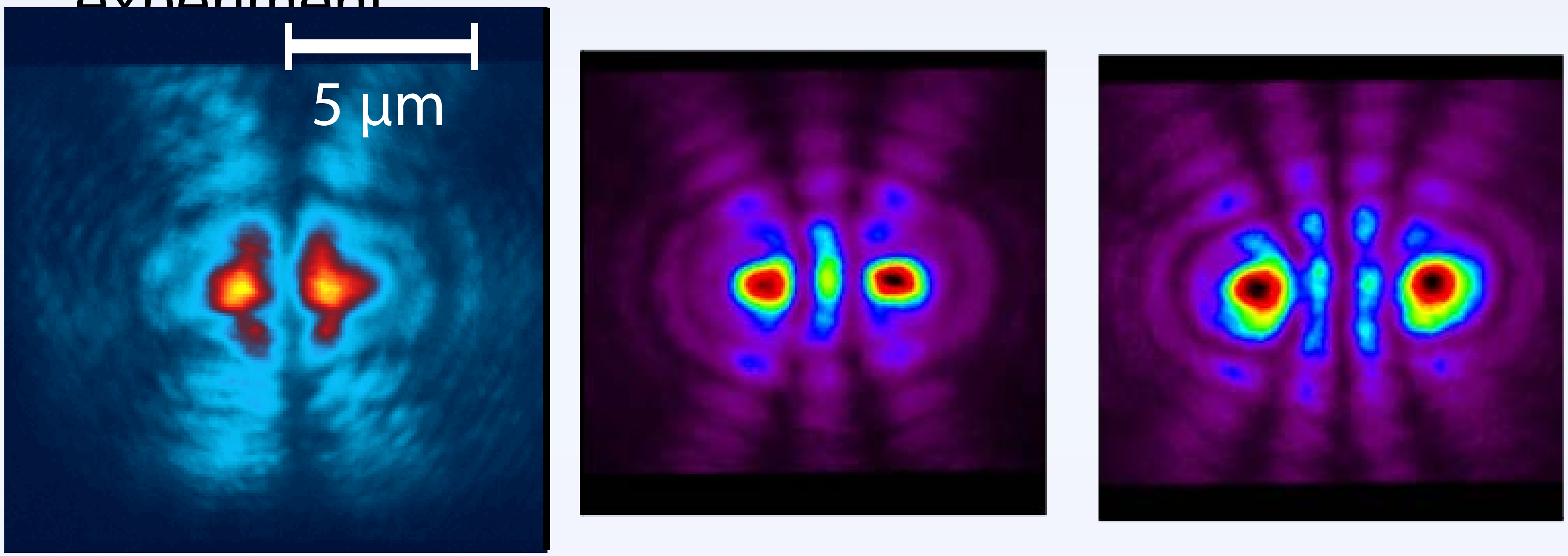
- reduction of threshold
- in-phase and anti-phase synchronization
- symmetry flipping by changing separation
- symmetry flipping in time
- correlation of pseudospins

Threshold vs. separation (first signature)

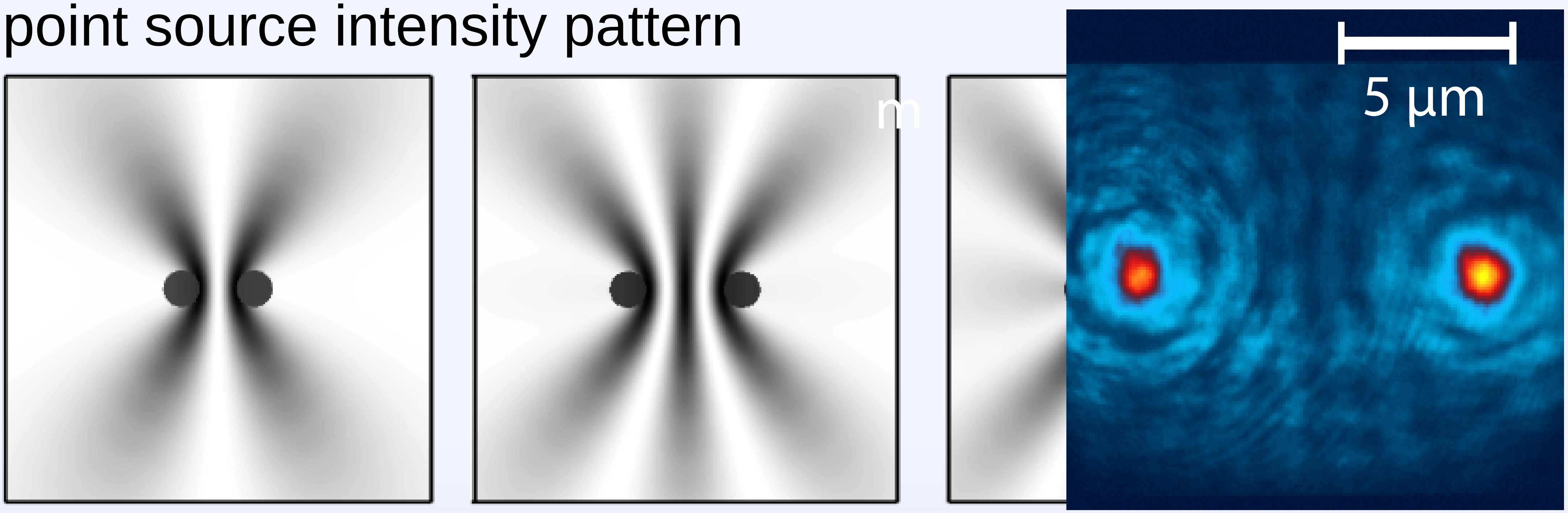


in-phase/anti-phase states (second signature)

experiment



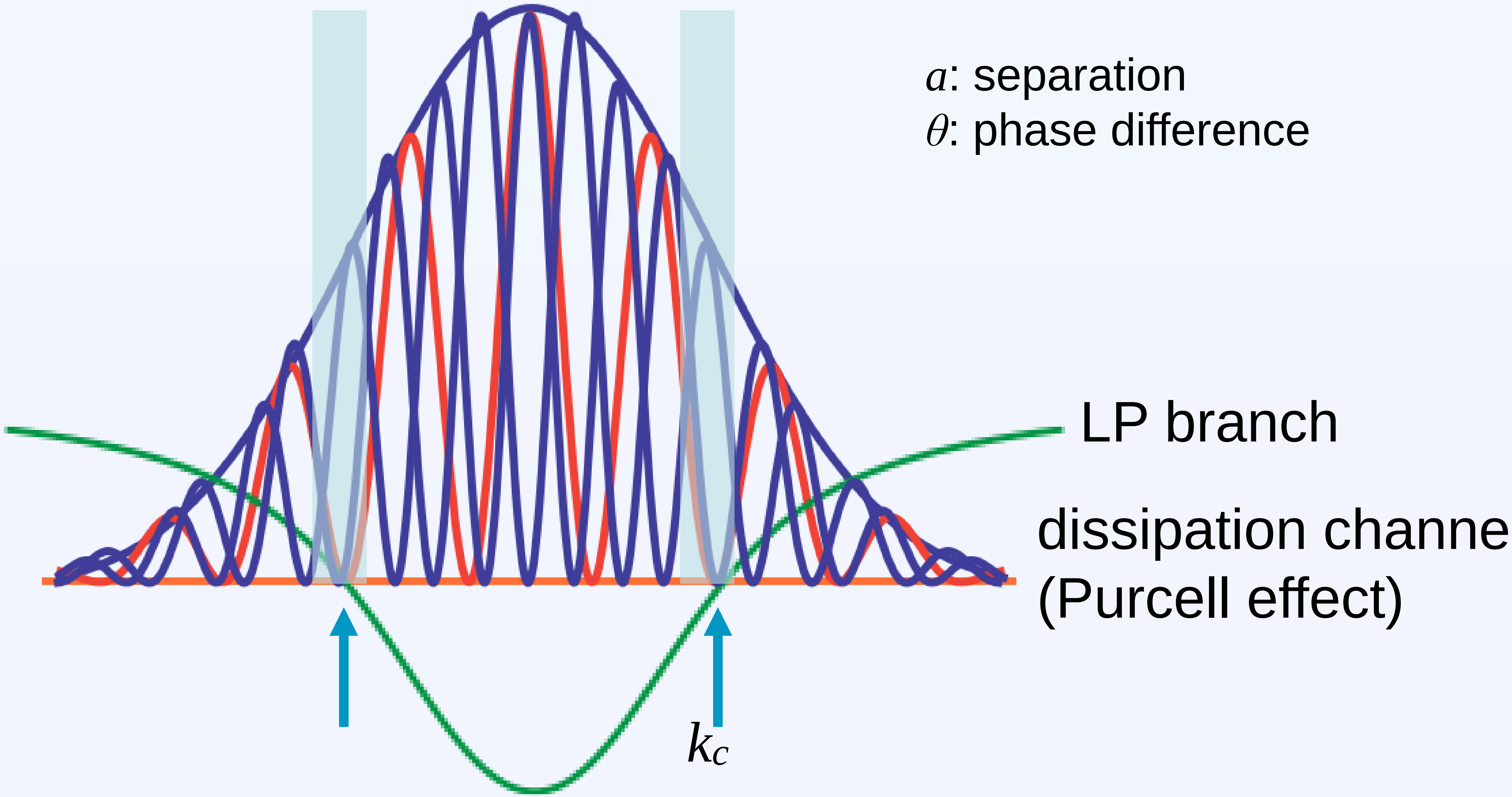
point source intensity pattern



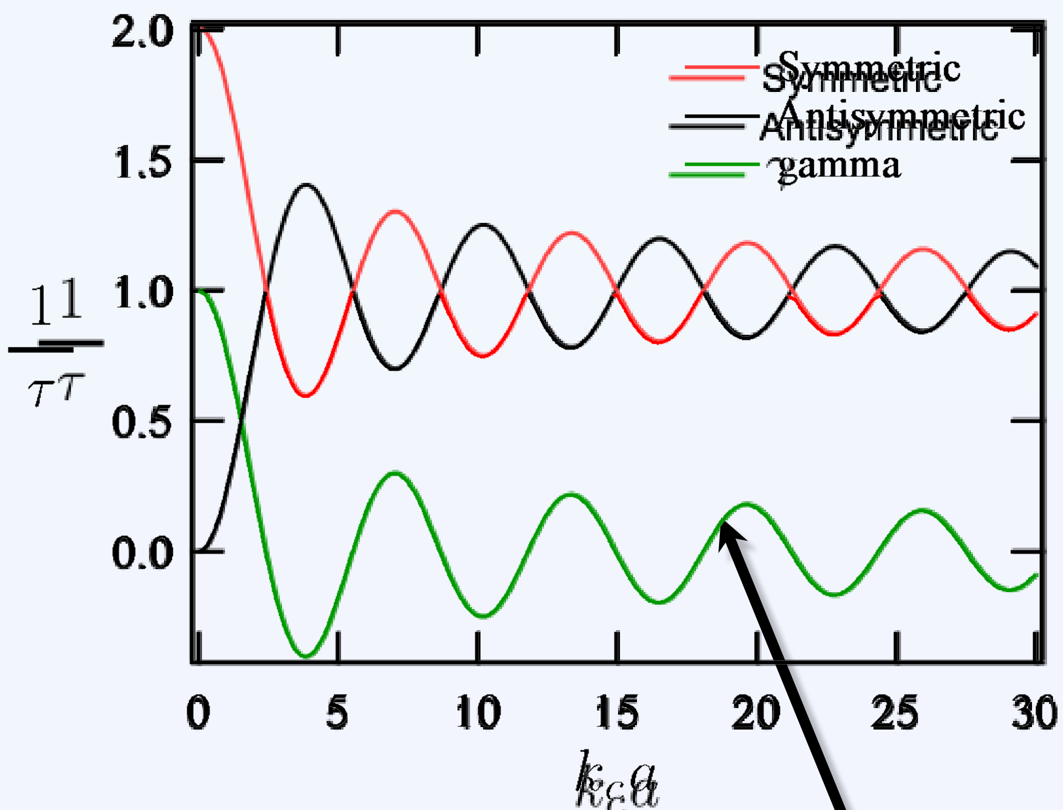
similar to G. Tosi *et al*,. *Nat Phys* **8**, 190 (2012)

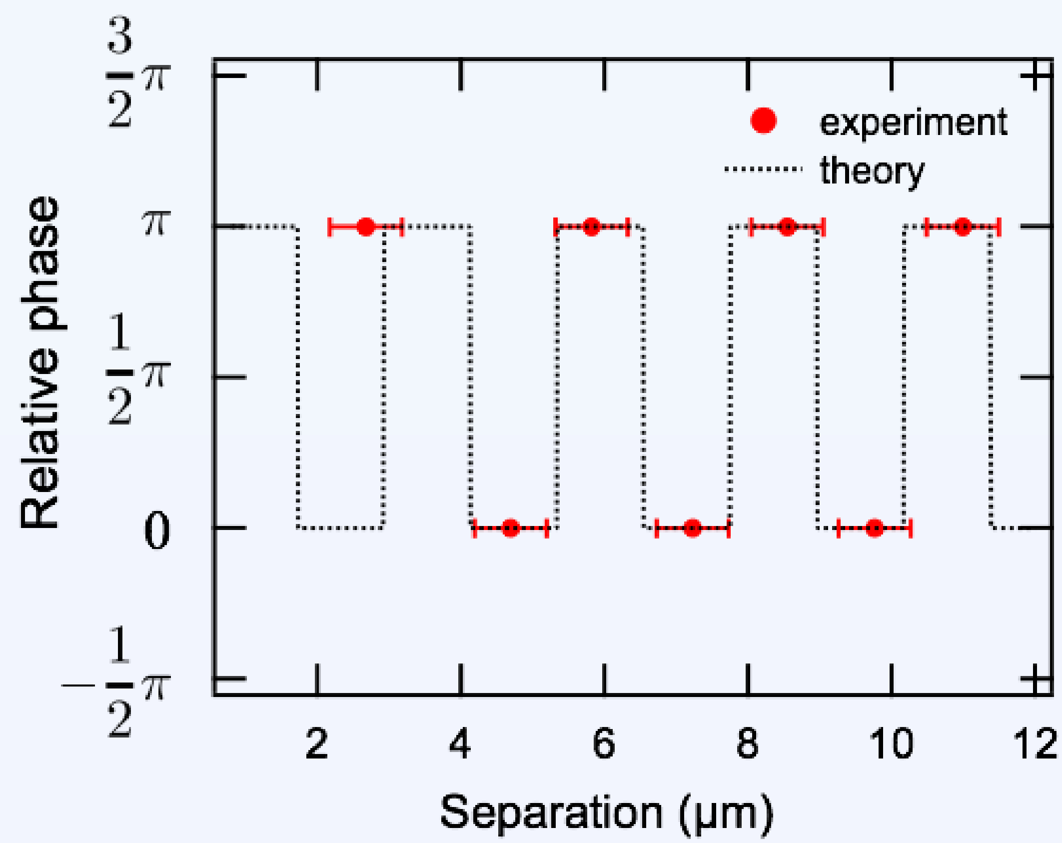
Coupling mechanism

$$\text{decay rate} = \Gamma(1 + J_0(k_c a)\cos\theta)$$



Phase vs. separation

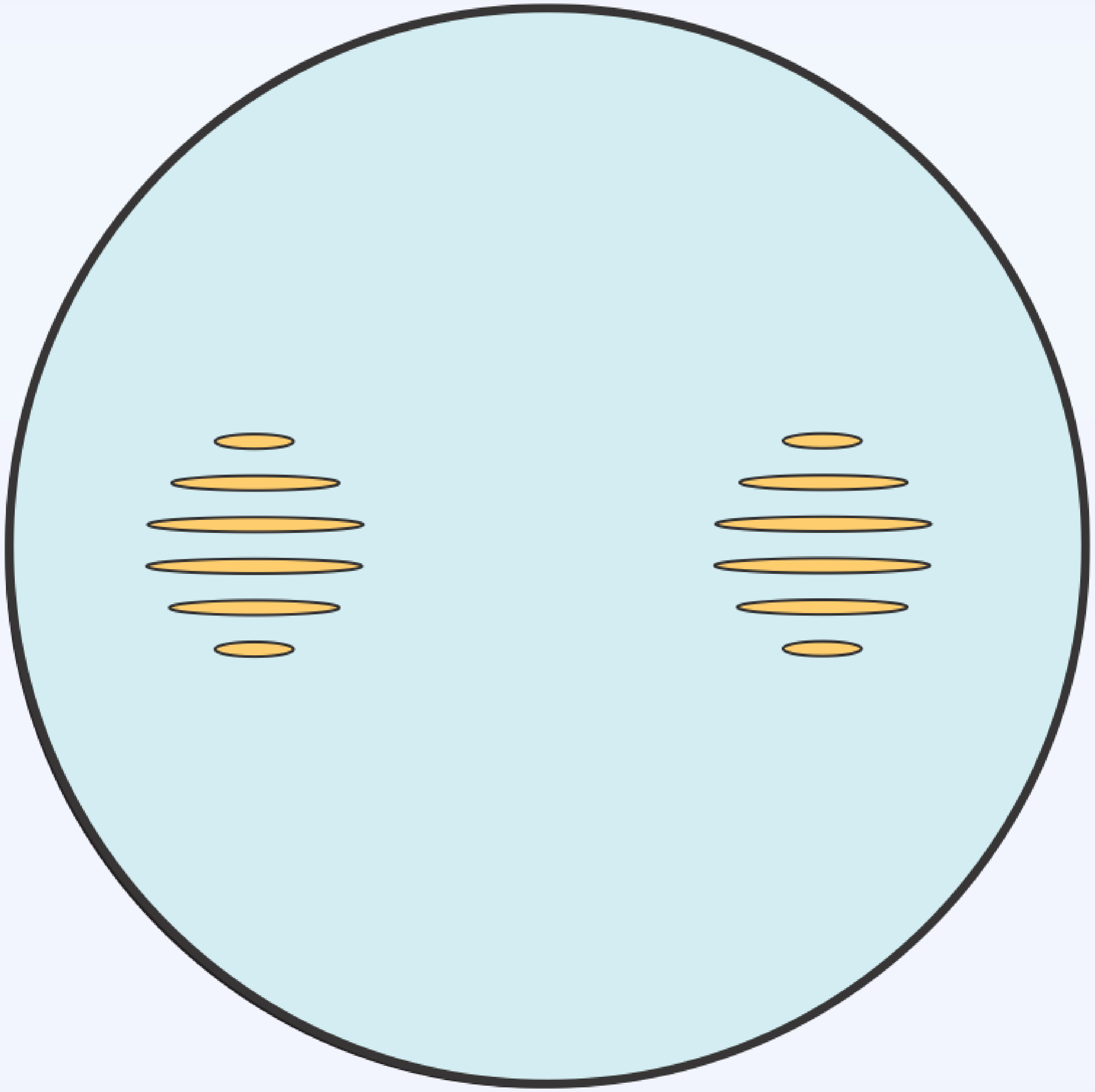




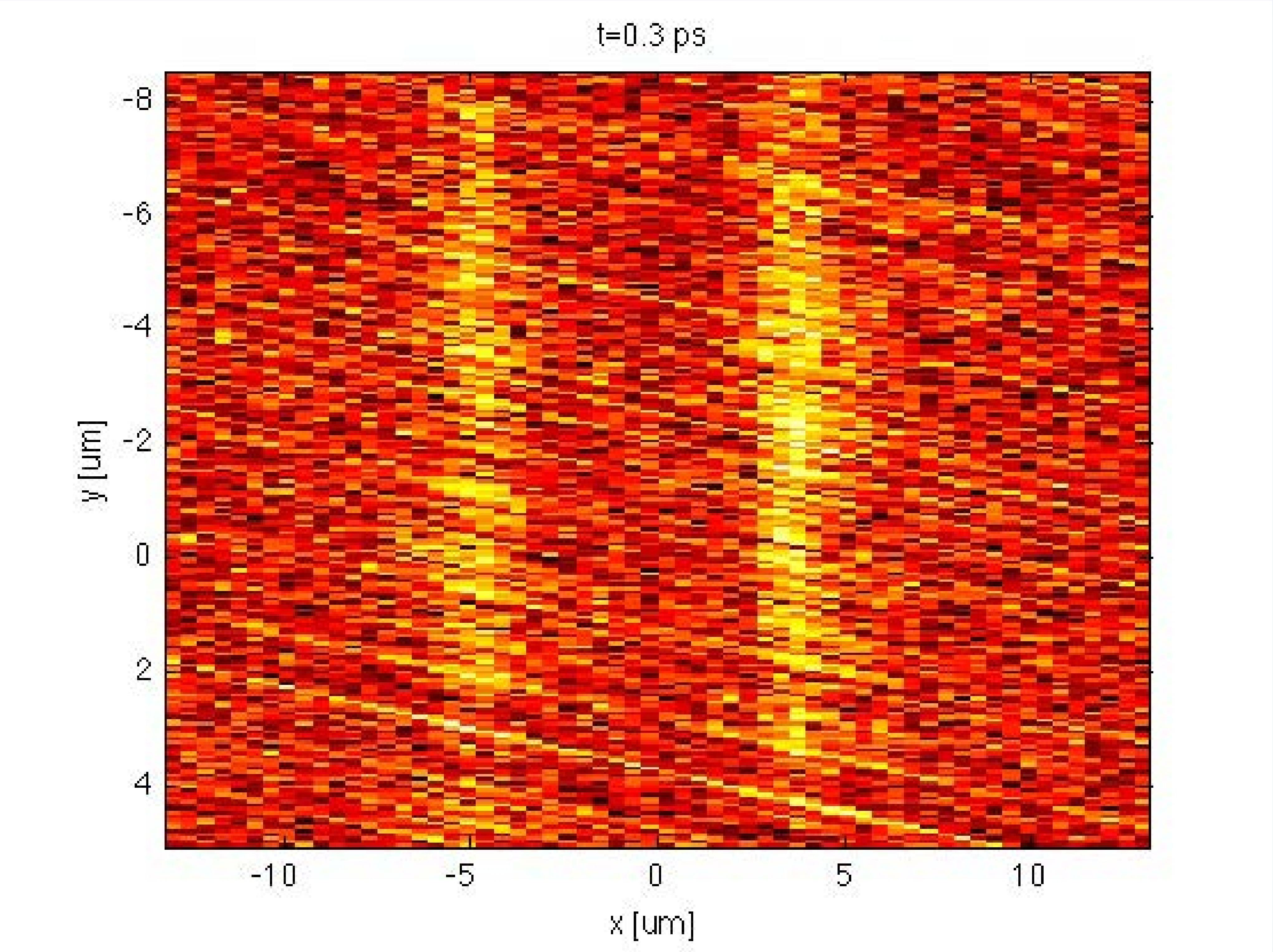
$$\text{decay rate} = \Gamma(1 + J_0(k_c a)\cos\theta)$$

k_c: cavity mode wave vector
a: separation
θ: phase difference

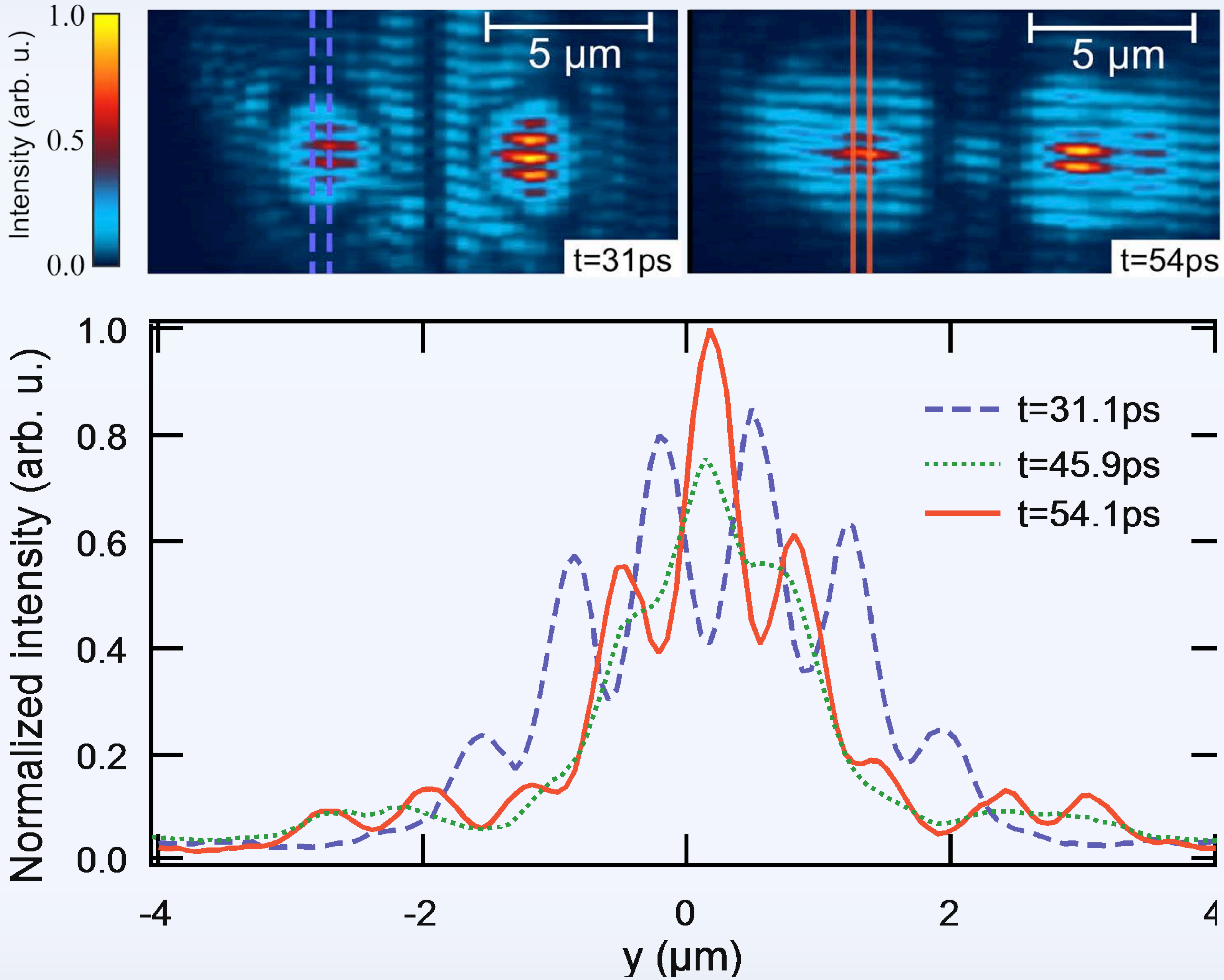
Interferometry



Symmetry flipping in time



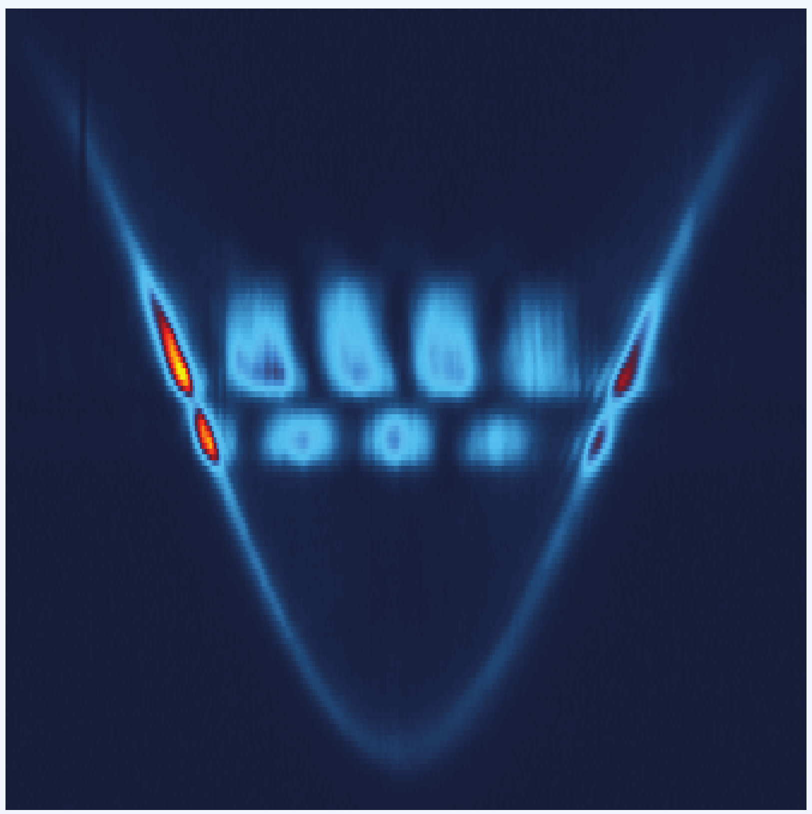
Symmetry flipping in time



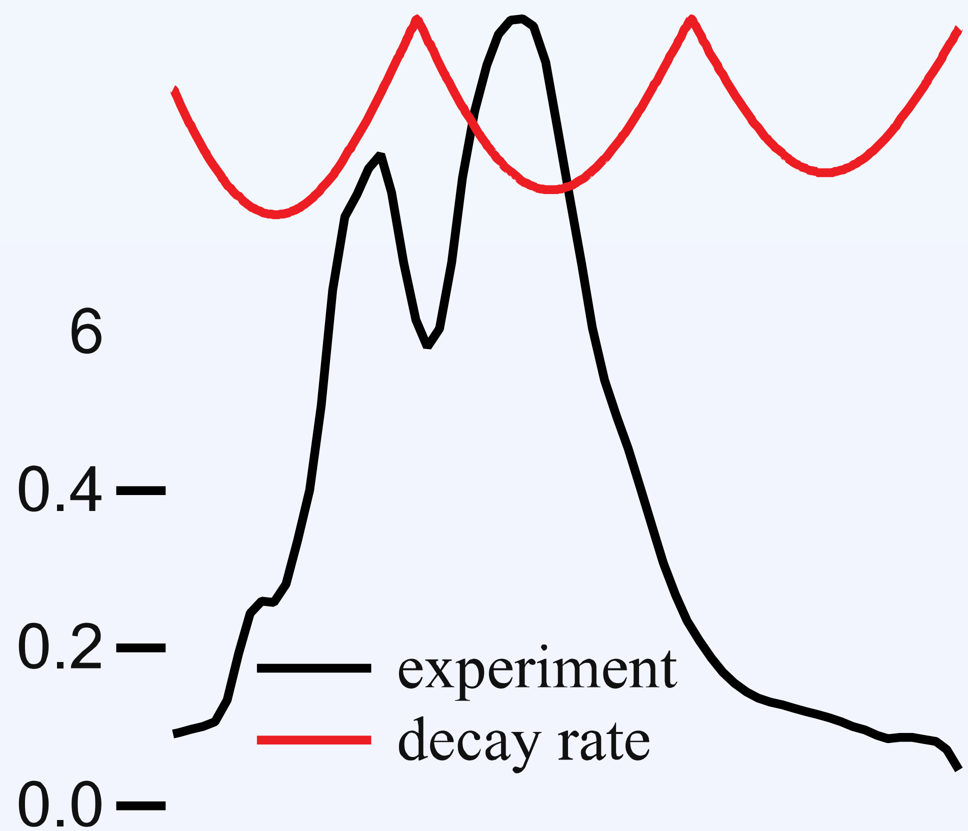
momentum-space

$$\text{decay rate} = \Gamma(1 + J_0(k_c a)\cos\theta)$$

Energy (meV)



$k_{\|}\ (\mu m^{-1})$



multi-particle wave function

$$\psi = e^{i\theta} \begin{bmatrix} \psi_+ \\ \psi_- \end{bmatrix}$$

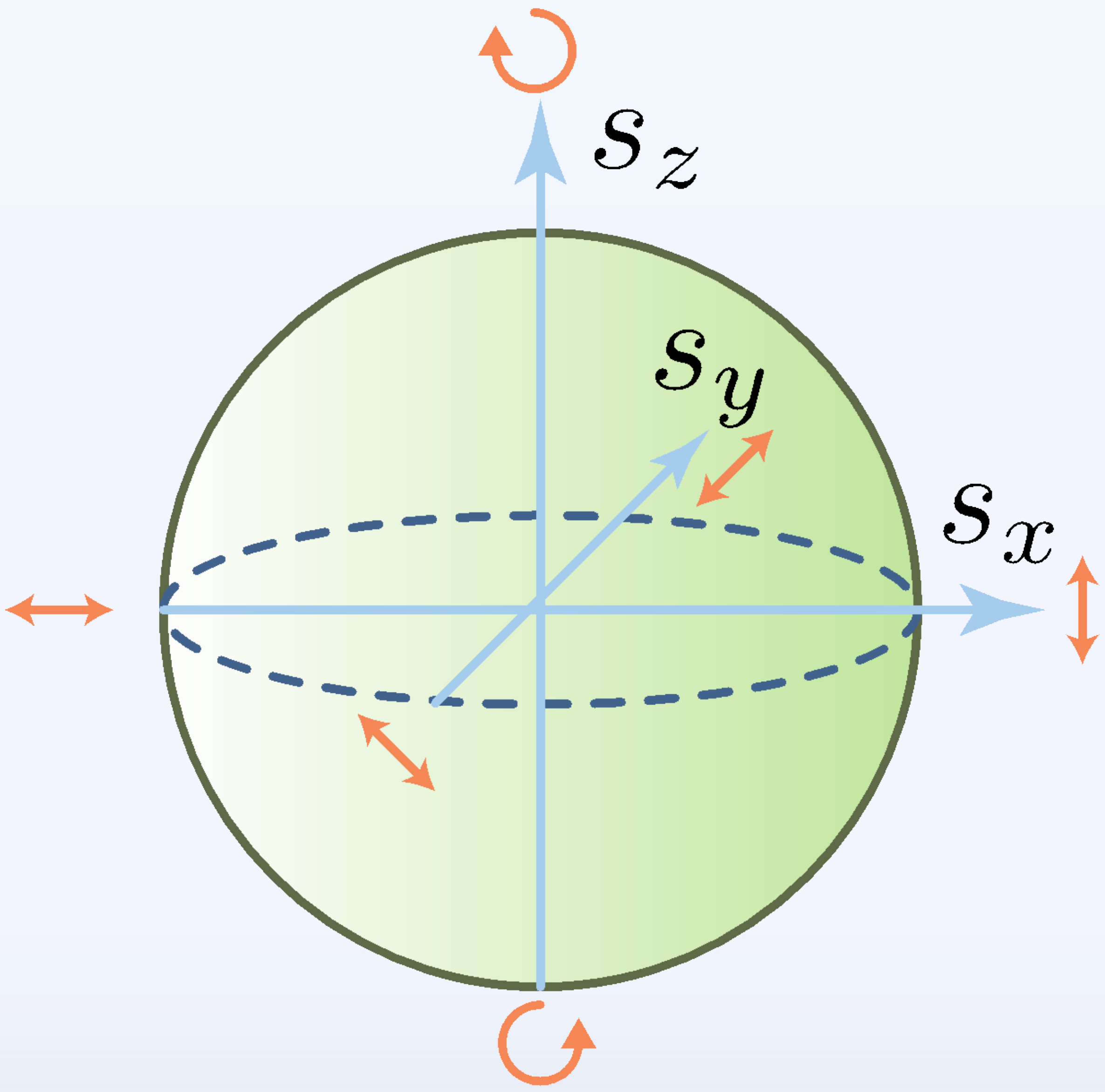
pseudospin (stokes parameter)

$$s_x = \frac{1}{2n}(\psi_-^* \psi_+ + \psi_- \psi_+^*)$$

$$s_y = \frac{i}{2n}(\psi_-^* \psi_+ - \psi_- \psi_+^*)$$

$$s_z = \frac{1}{2n}(|\psi_+|^2 - |\psi_-|^2)$$

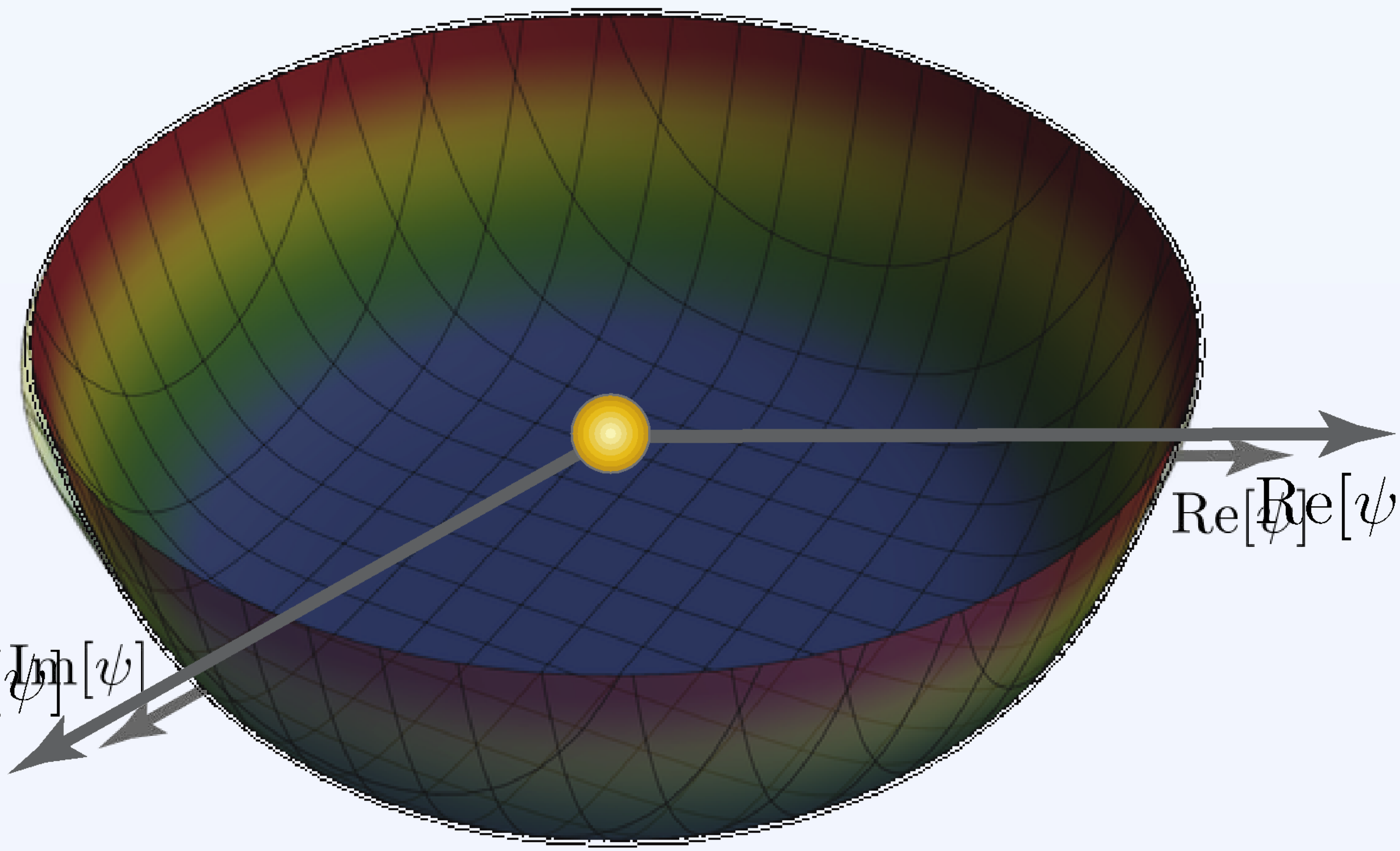
Poincaré sphere



F. P. Laussy *et al.*, *Phys. Rev. B* **73**, 035315 (2006)

Spontaneous symmetry breaking

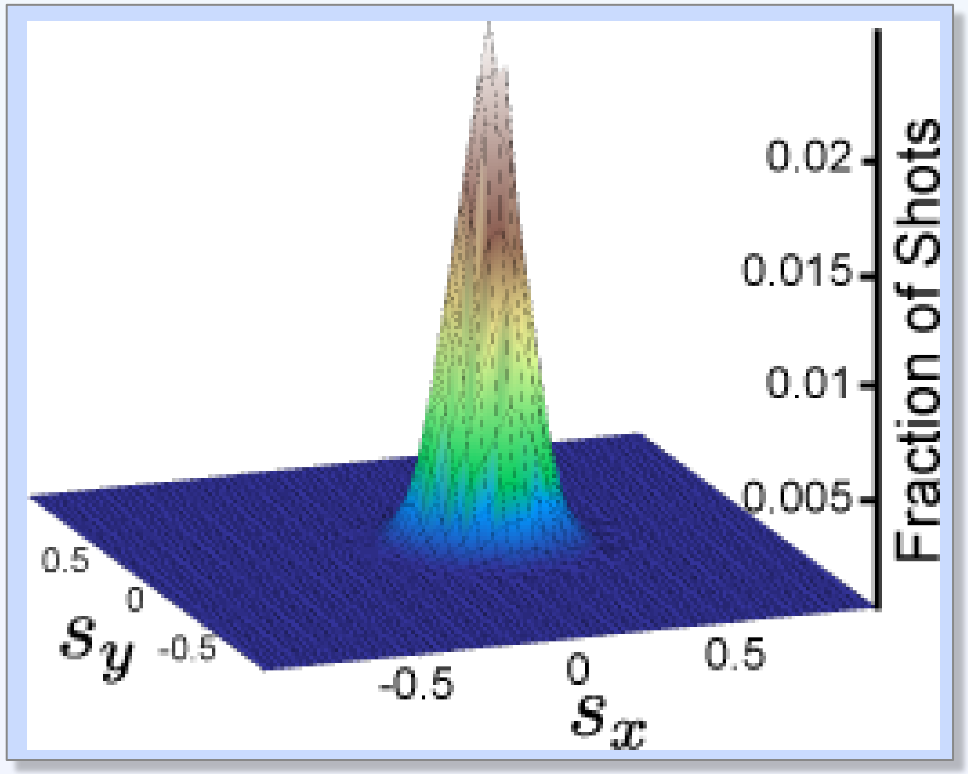
order parameter space



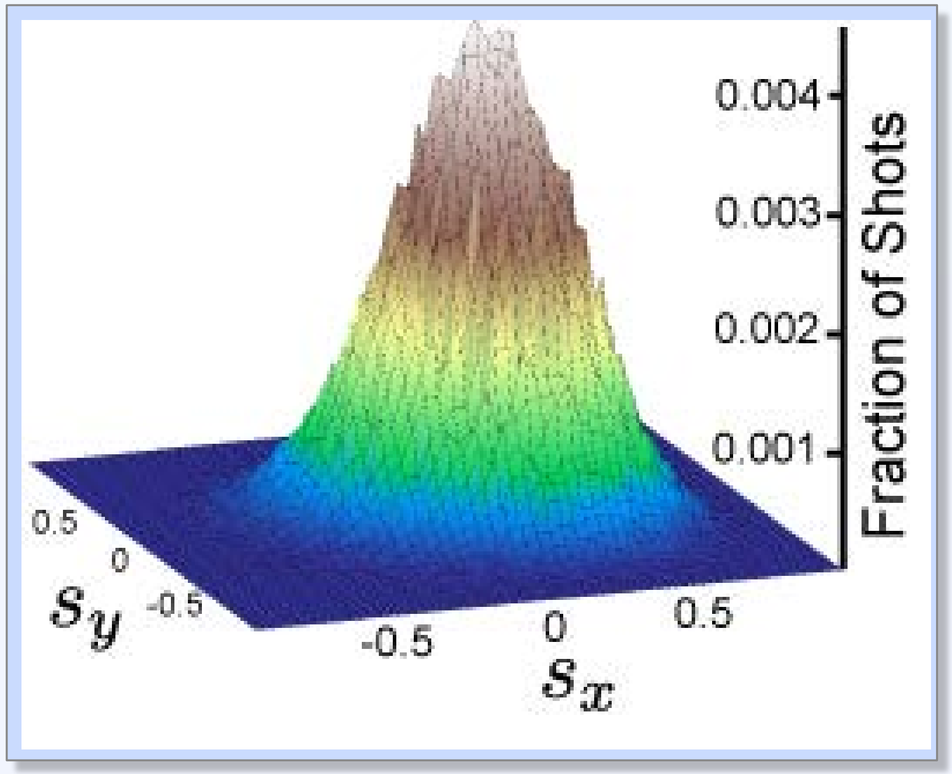
Y. G. Rubo, *physica status solidi (a)* **201,** 641–645 (2004)

Stochastic polarization buildup

Single-shot measurements



non-condensed

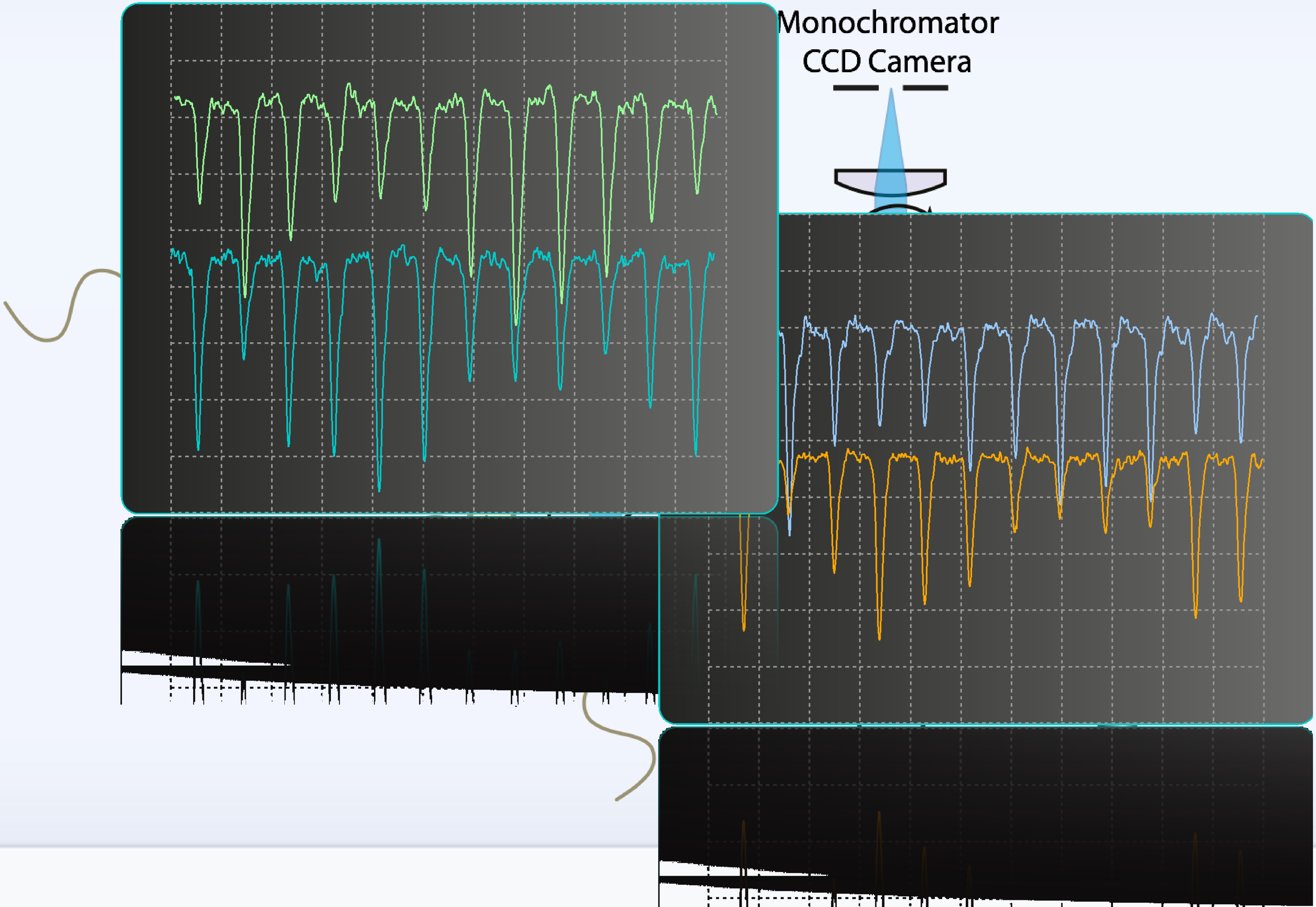


condensed

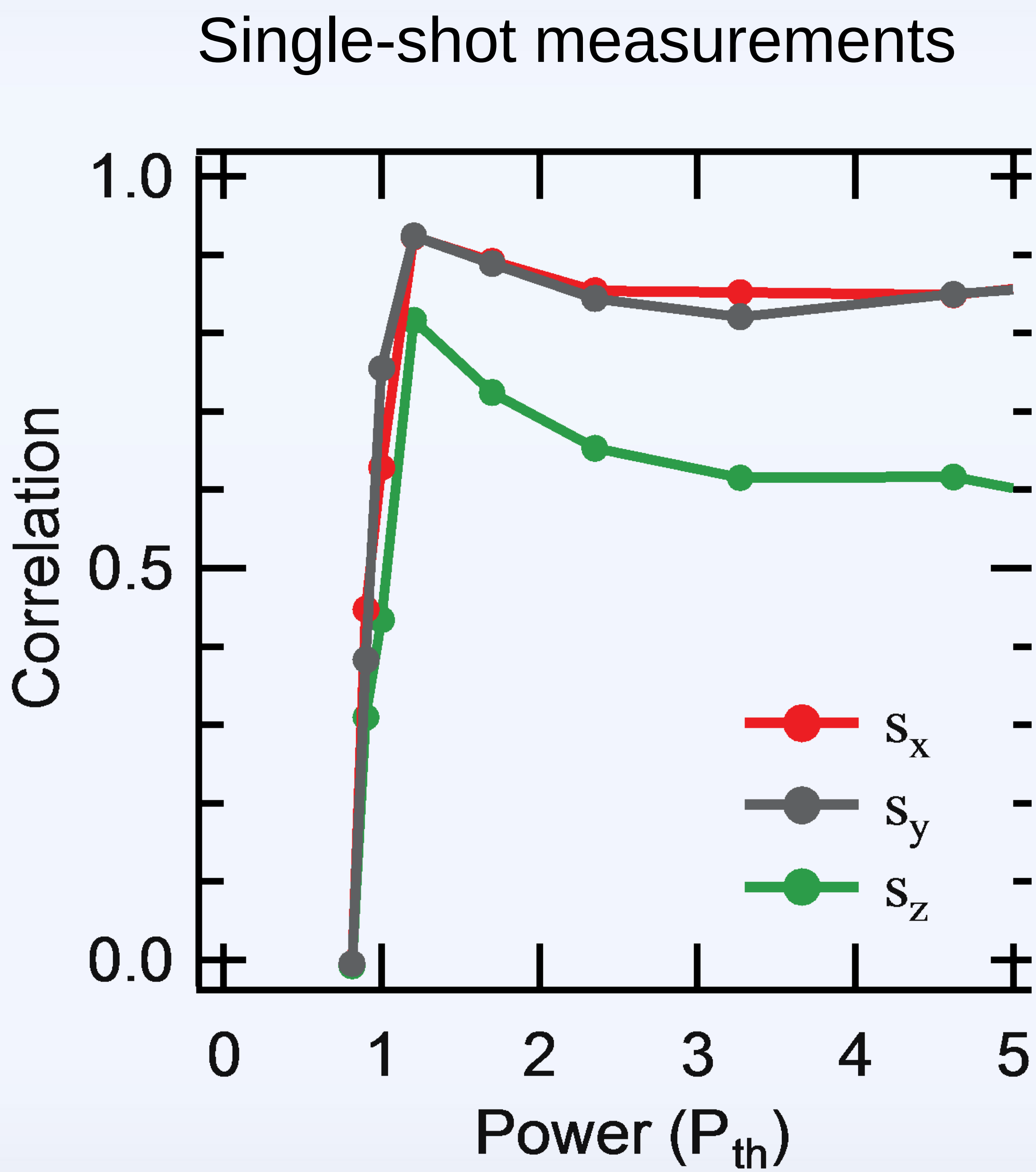
H. Ohadi et al. Phys. Rev. Lett. 109, 016404 (2012)

also: J.J. Baumberg et al. Phys. Rev. Lett 101, 136409 (2008)
sample: D. Bajoni et al. Phys. Rev. B 76, 201305 (2007)

Two Condensate Setup



Pseudospin correlation



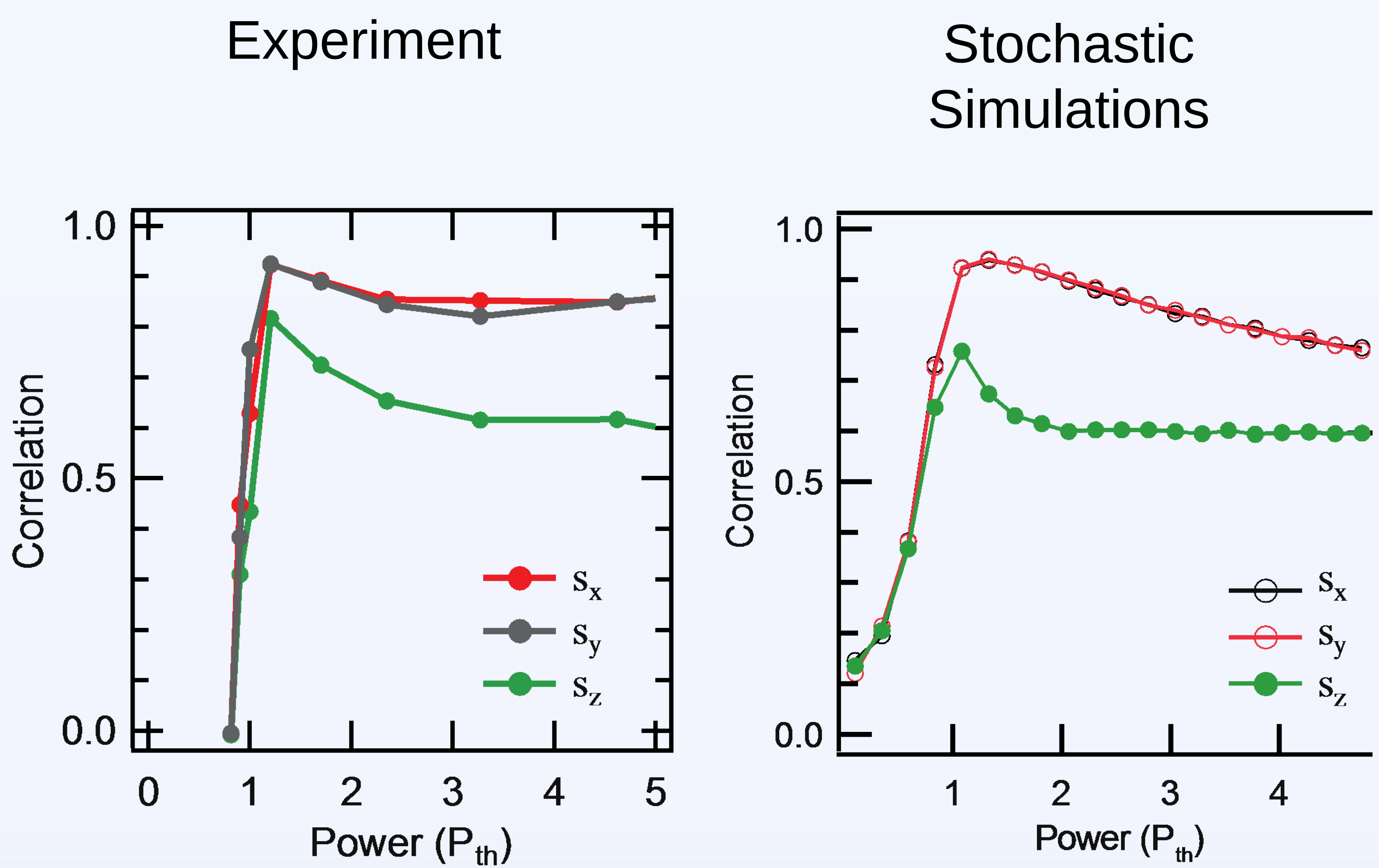
Theoretical simulation

$$+\frac{1}{2}\gamma\psi_{2,1}$$

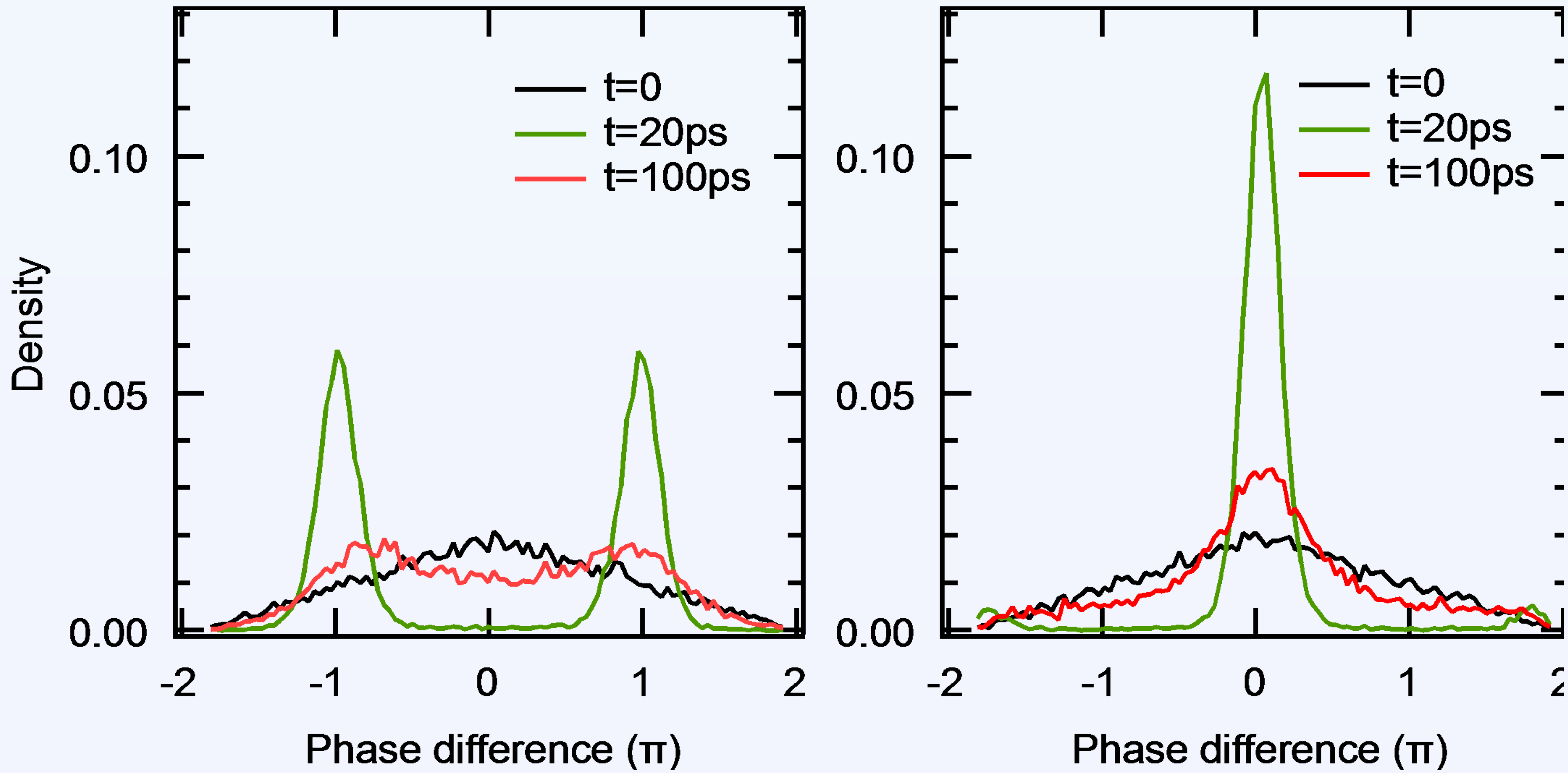
$$\boxed{\gamma = \pm\Gamma J_0(k_c a)}$$

- Aleiner, Altshuler & Rubo, Phys. Rev. B, 85, 121301 (2012)
- Read, Rubo & Kavokin, Phys. Rev. B, 81, 235315 (2010)

Stochastic simulation results



Stochastic simulation results



$\gamma > 0$

$\gamma < 0$

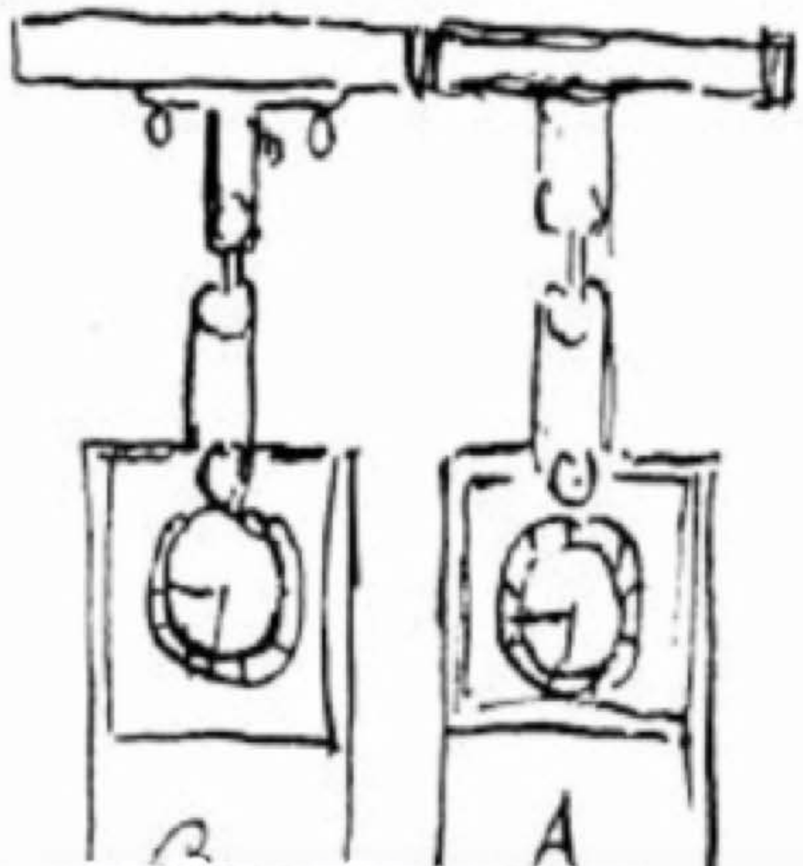
“An odd kind of sympathy”

huygens' clocks

V.

1665.

[Fig. 75.][2])



22 febr. 1665.

Diebus 4 aut 5 horologiorum duorum novorum in quibus catenulæ [Fig. 75], miram concordiam obſervaveram, ita ut ne minimo quidem exceſſu alterum ab altero ſuperaretur. ſed conſonarent ſemper reciprocationes utriusque perpendiculi. unde cum parvo ſpatio inter ſe horologia diſtarent, ſympathiæ quandam [3]) quasi alterum ab altero afficeretur ſuſpicari cœpi. ut experimentum caperem turbavi alterius penduli reditus ne ſimul incederent ſed quadrante horæ poſt vel ſemihora rurſus

Acknowledgements

UNIVERSITY OF Southampton

Sample:

Jacqueline Bloch and Aristide Lemaître

CLERMONT4

EPSRC
Engineering and Physical Sciences Research Council

Threshold / coupling parameter

$$\dot{\psi}_1 = -\frac{1}{2}\left(\Gamma\psi_1 + \gamma\psi_2\right),$$
$$\dot{\psi}_2 = -\frac{1}{2}\left(\Gamma\psi_2 + \gamma\psi_1\right)$$

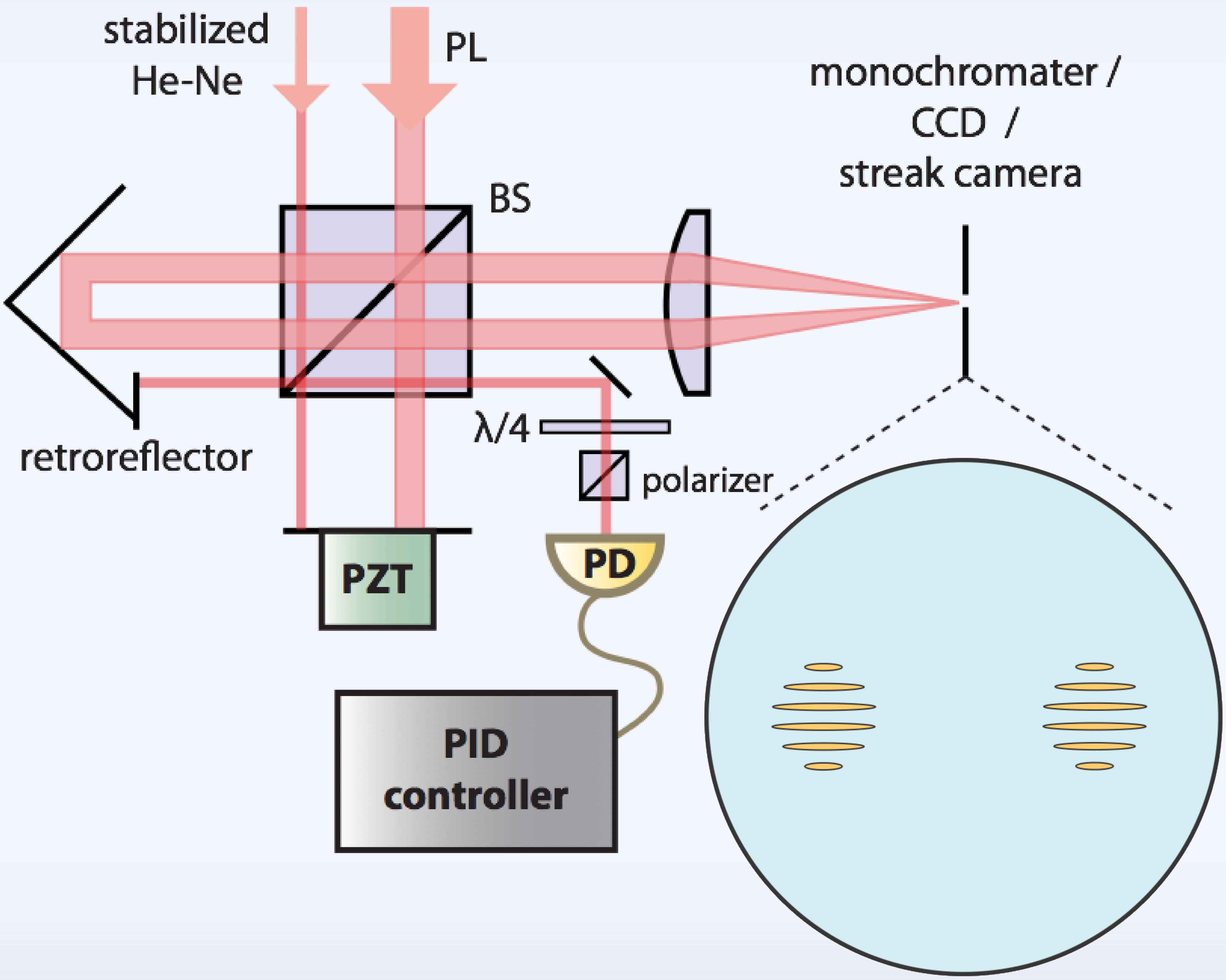
$$\psi_1 = \sqrt{n_1}e^{i\theta_1}$$
$$\psi_2 = \sqrt{n_2}e^{i\theta_2}$$

$$\dot{\psi}_1\psi_1 + \psi_1^*\dot{\psi}_1 = \dot{n}_1 = -\Gamma n_1 - \gamma\sqrt{n_1 n_2}\cos(\theta_1 - \theta_2),$$
$$\dot{\psi}_2\psi_2 + \psi_2^*\dot{\psi}_2 = \dot{n}_2 = -\Gamma n_2 - \gamma\sqrt{n_1 n_2}\cos(\theta_1 - \theta_2).$$

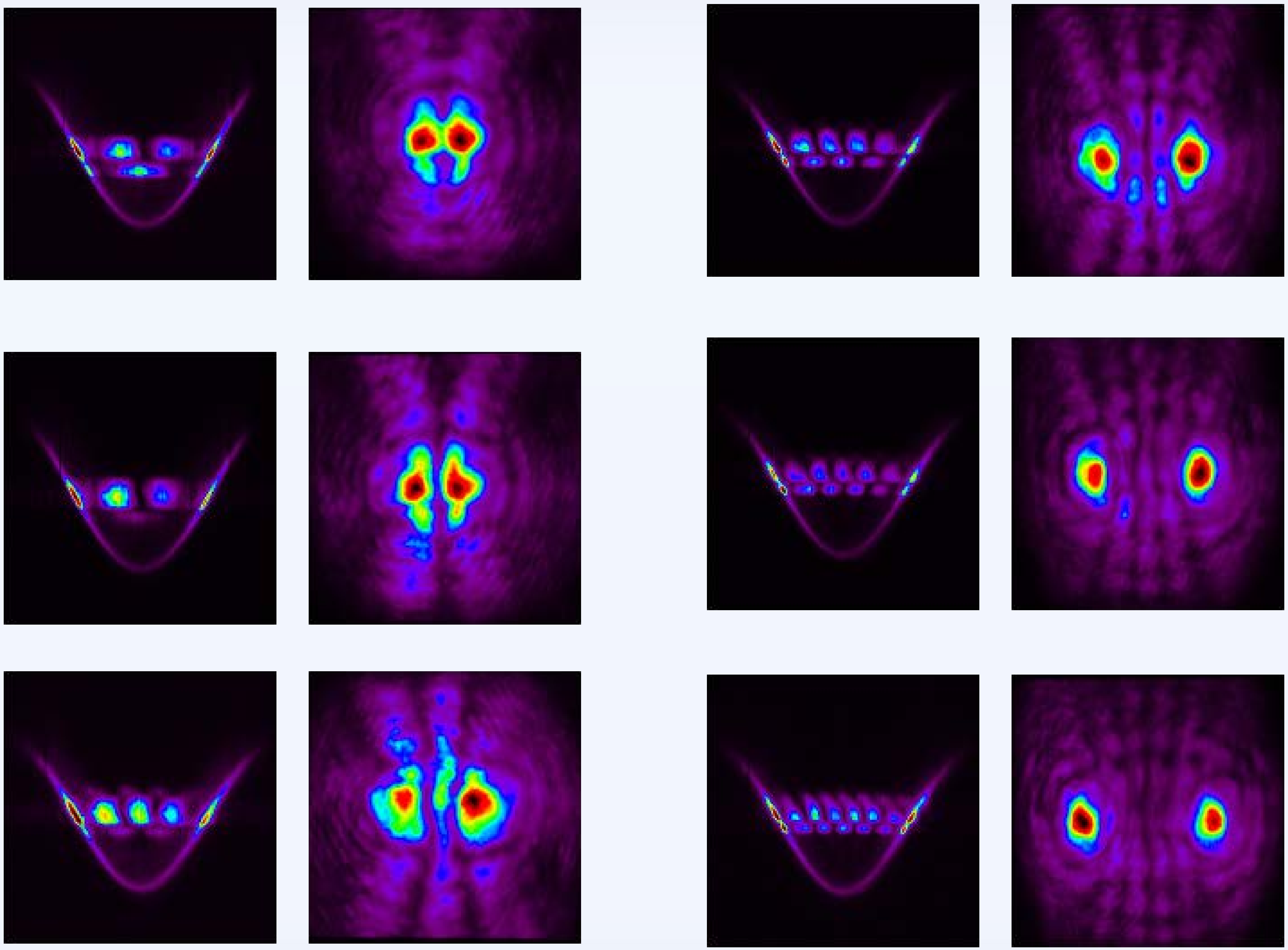
$$\text{if } n_1 = n2 = n \Rightarrow \dot{n} = -[\Gamma + \gamma\cos(\theta_1 - \theta_2)]n$$

Aleiner, Altshuler & Rubo, Phys. Rev. B 85, 121301 (2012)

Interferometry Setup



k-space / real-space vs. separation



Averaged threshold