Optically controlled angular-momentum generation in a polaritonic quantum fluid

S.M.H. Luk, N.H. Kwong, P. Lewandowski, S. Schumacher, R. Binder

University of Arizona
University of Paderborn

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Objective:

Address the following question:

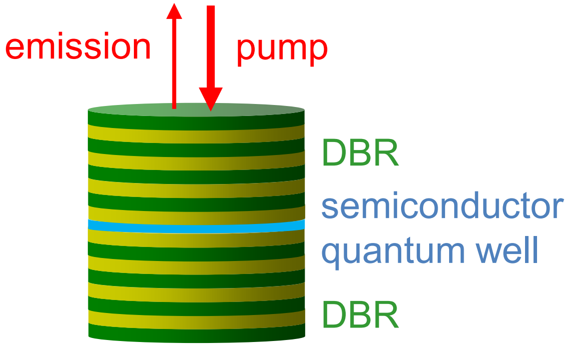
Conventional pattern formation is based on instabilities of linear momentum states. Is it possible there exist analogous pattern-formation processes but based on orbital-angular momentum instead of linear momentum states?

Do four-wave mixing instabilities and pattern formation analogous to those obtained with linear momentum also exist for orbital angular momentum?

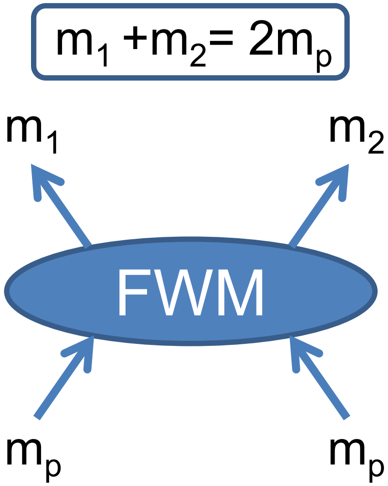
	Linear momentum	**Orbital angular momentum**
pump wave + signal wave	$\vec{k}_p, \vec{k}_s$	m_p, m_s
↓ **four-wave mixing**	↓	↓
FWM wave	$\vec{k}_f = 2\vec{k}_p - \vec{k}_s$	$m_f = 2m_p - m_s$
pump wave + FWM wave	$\vec{k}_p, \vec{k}_f$	m_p, m_f
↓ **four-wave mixing**	↓	↓
signal wave	$\vec{k}_{ff} = 2\vec{k}_p - \vec{k}_f = \vec{k}_s$	$m_{ff} = 2m_p - m_f = m_s$

feedback and possible dynamic instability

Sketch of semiconductor microcavity with distributed Bragg reflectors (DBR)



Schematic of four-wave mixing (FWM) scattering process involving orbital angular momentum (OAM) state m_i, with m_p being them pump OAM



Theoretical Basis

Gross-Pitaevskii equation with source S in x,y basis:

$$i\hbar\frac{\partial\Psi^{\pm}}{\partial t}=\left[\hbar\omega_0-\frac{\hbar^2}{2M}\nabla^2+V-i\gamma\right]\Psi^{\pm}+T^{++}\,|\,\Psi^{\pm}\,|^2\;\Psi^{\pm}+T^{+-}\left|\Psi^{\mp}\right|^2\Psi^{\pm}+S^{\pm}$$

Expansion in OAM states: $$\Psi^{\pm}(\mathbf{r},t)=\sum_{m\in\mathbb{Z}}\psi_m^{\pm}(r,t)e^{im\phi-i\omega_p t}$$

Gross-Pitaevskii equation in OAM basis:

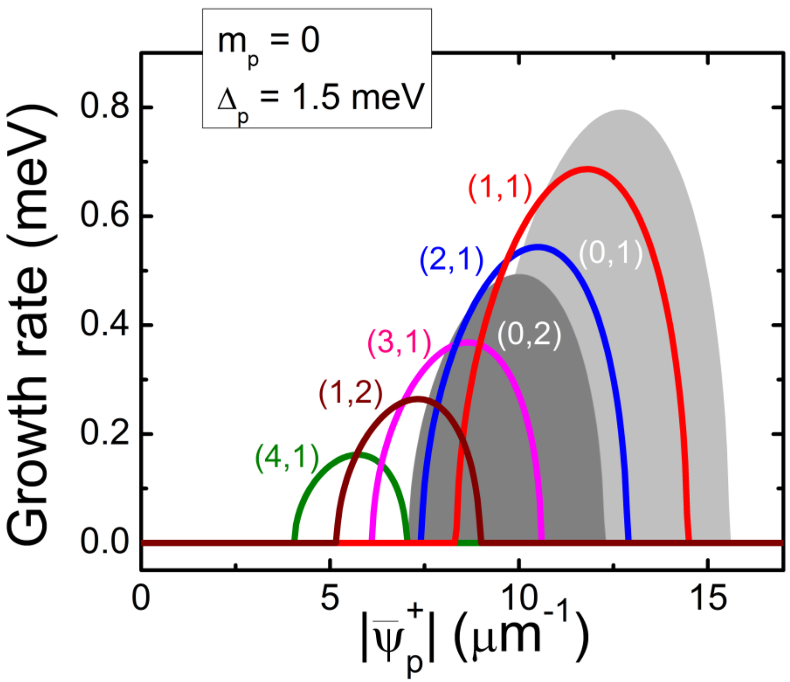
$$i\hbar\frac{\partial}{\partial t}\psi_m^{\pm}(r,t)=\left[-L_m+V(r)\right]\psi_m^{\pm}(r,t)+s_m^{\pm}(r,t)$$
$$+\sum_{m'm''m'''}\delta_{m+m''',m'+m''}\left[T^{++}\psi_{m'''}^{\pm*}(r,t)\psi_{m'}^{\pm}(r,t)\psi_{m''}^{\pm}(r,t)+T^{+-}\psi_{m'''}^{\mp*}(r,t)\psi_{m'}^{\mp}(r,t)\psi_{m''}^{\pm}(r,t)\right]$$

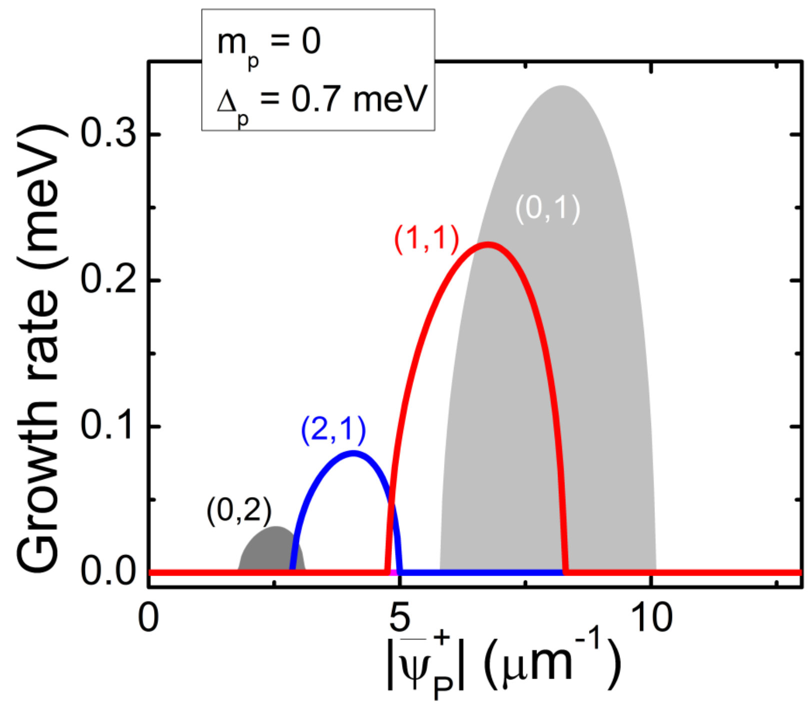
$$L_m=\frac{\hbar^2}{2M}\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}+k_p^2-\frac{m^2}{r^2}\right)+i\gamma \qquad \frac{\hbar^2k_p^2}{2M}=\Delta_p=\hbar(\omega_p-\omega_0)$$

Results of linear stability analysis for constant (in r) pump

$$\hbar\lambda = -i\gamma \pm \sqrt{(\varepsilon_{mn} - 2T^{++}|\bar{\psi}_p^+|^2)^2 - (T^{++}|\bar{\psi}_p^+|^2)^2} \qquad \varepsilon_{mn} = \frac{\hbar^2}{2M}\left[k_p^2 - (\alpha_{mn}/R)^2\right]$$

Signal growth outside pump growth = candidate for OAM instability





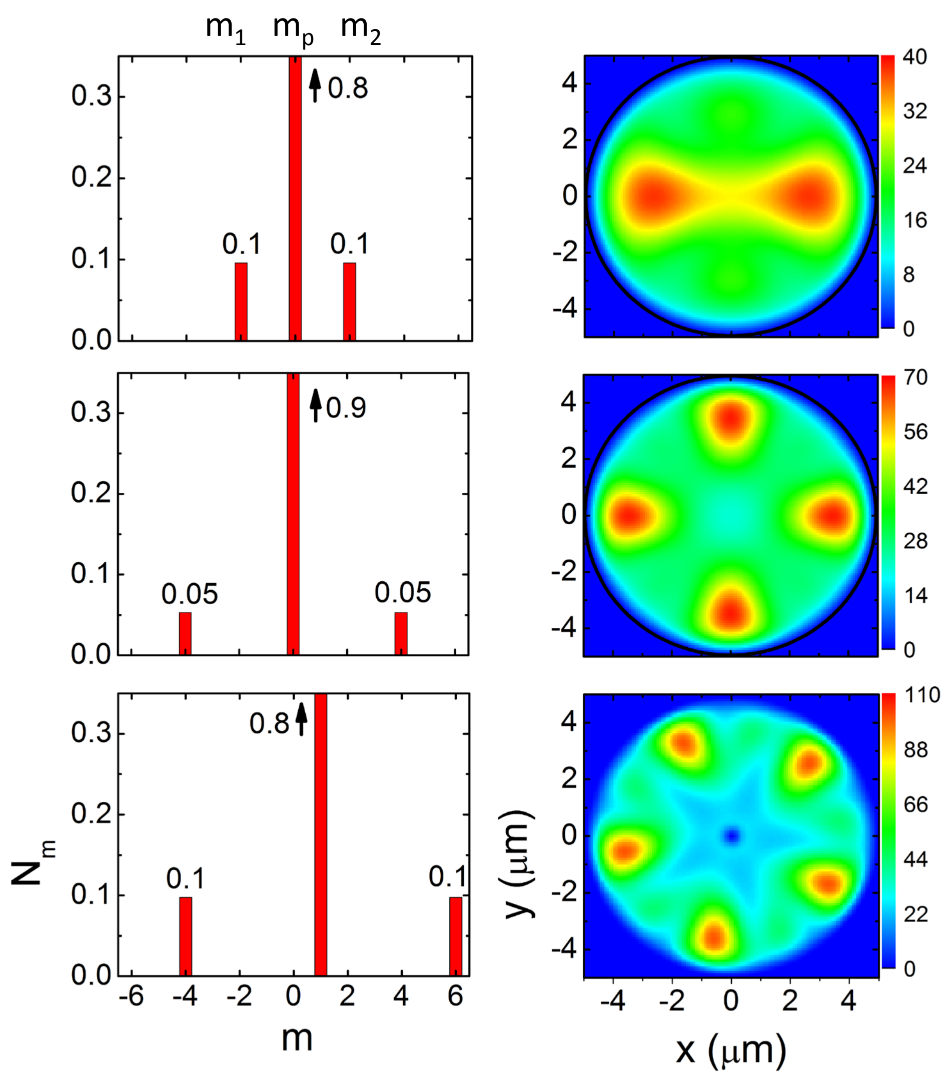
Notation: (|m|,n) = OAM and n-th zero of Bessel function, $J_m(\alpha_{mn})=0$

Pump growth shown as grey shaded area

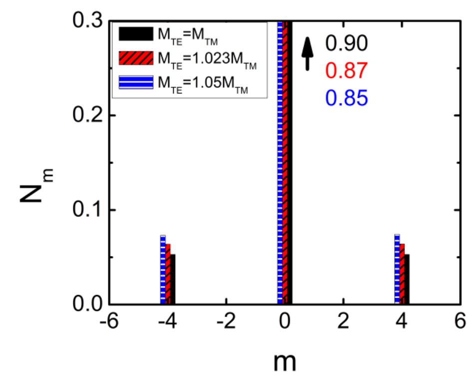
Signal growth rates as lines

Results of numerical simulation

Fraction of polariton number Polariton density



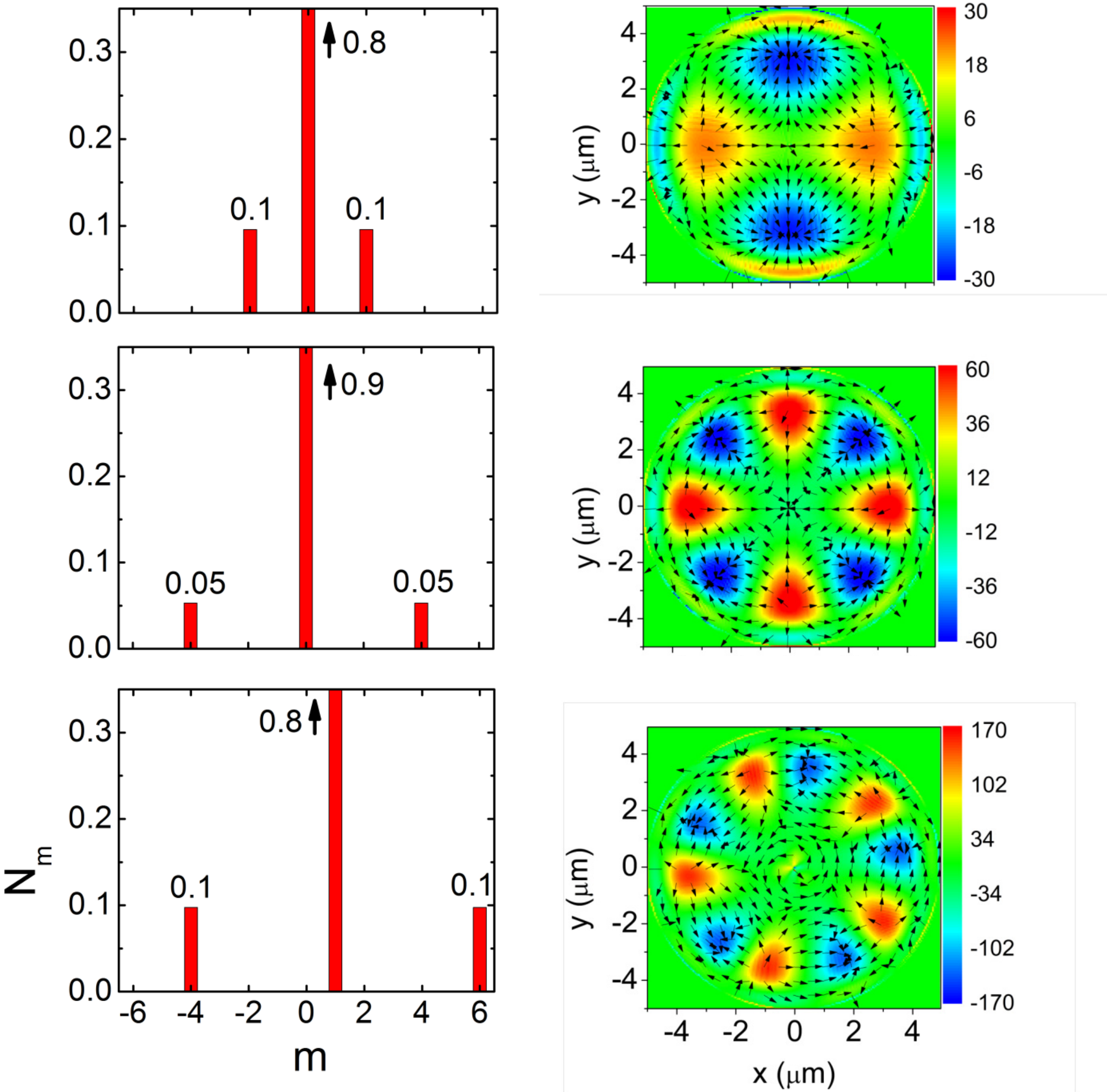
Inclusion of polariton spin-orbit interaction, TE-TM splitting, make no qualitative difference



Instability can lead to substantial fractions of OAM states not included in the pump.

Luk, Kwong, Lewandowski, Schumacher, Binder, Phys. Rev. Lett. 119, 113903 (2017)

Current density (arrows) and divergence of current (color)



OAM instabilities yield generation-annihilation pairs, i.e. pairs where divergence of current have different signs. These are in contrast to well-known vortex-anti-vortex pairs.

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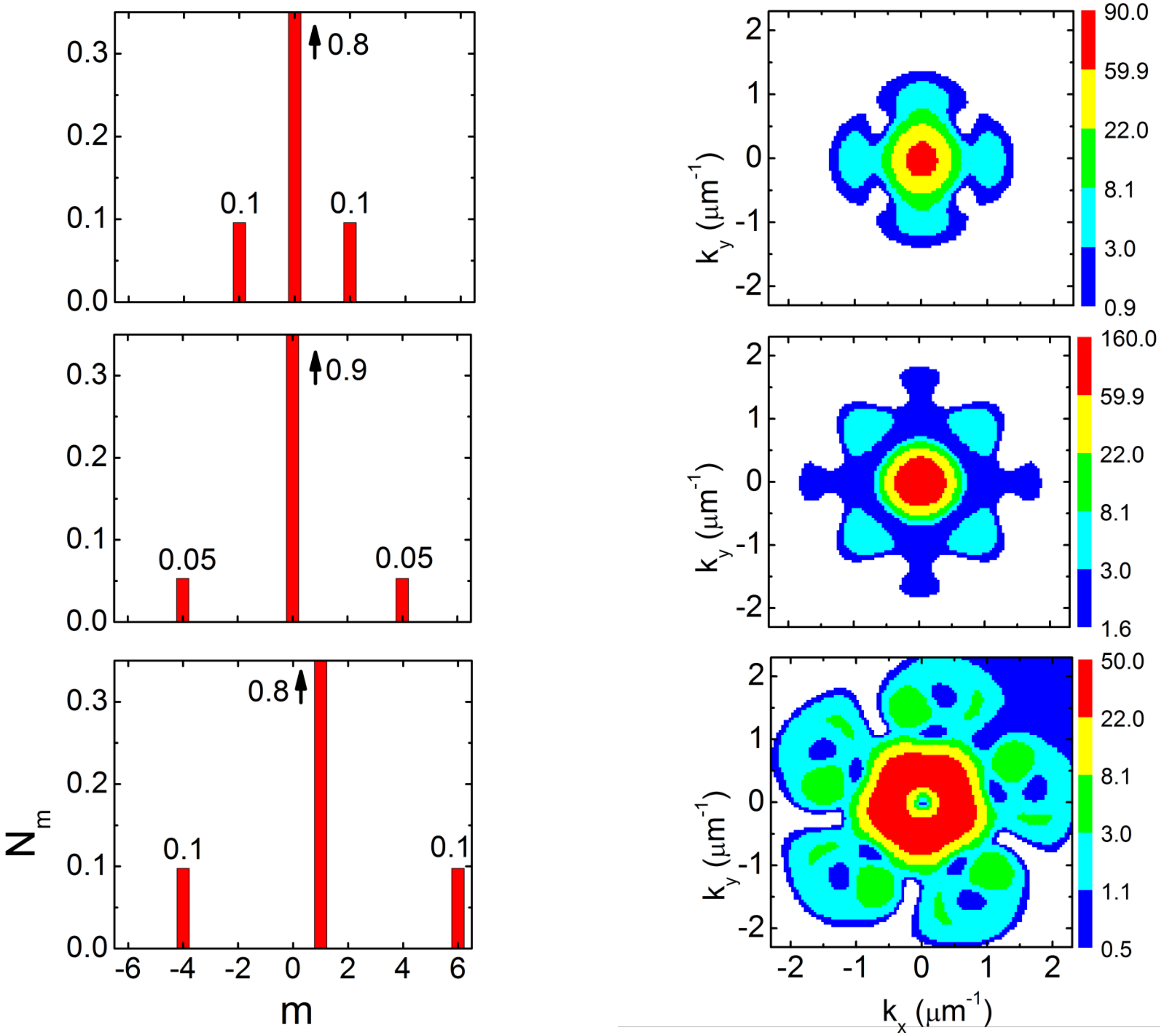
Far-field patterns



Luk, Kwong, Lewandowski, Schumacher, Binder, Phys. Rev. Lett. 119, 113903 (2017)