Title: Polariton Graph Network

Speakers: Na Young Kim

Collection: Many-Body States and Dynamics Workshop II

Date: June 13, 2019 - 11:15 AM

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Exciton-Polariton Graphe Network

Quantum Innovation Laboratory

Na Young Kim

Institute for Quantum Computing

Waterloo Institute for Nanotechnology

Department of Electrical and Computer Engineering

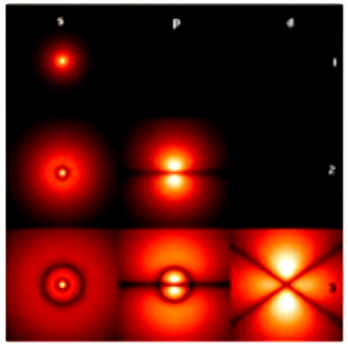
Department of Physics and Astronomy (Cross-appointed)

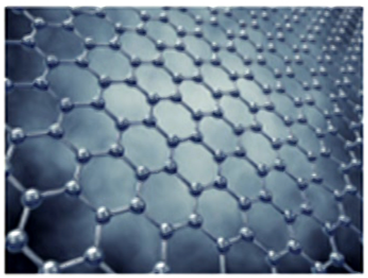
Department of Chemistry (Cross-appointed)

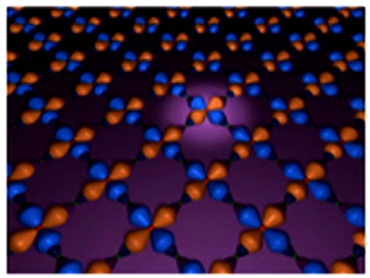
Perimeter Institute (Affiliate member)

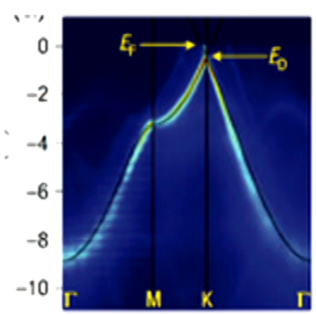
University of Waterloo

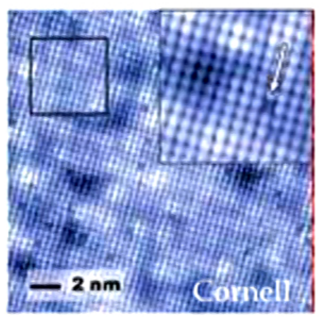
2019 June 12 IQC-PI 2 @ PI



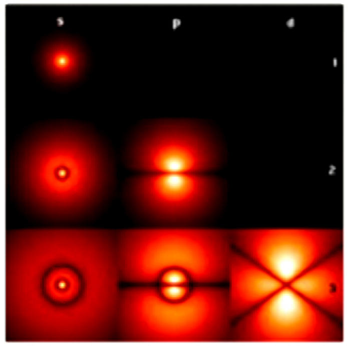


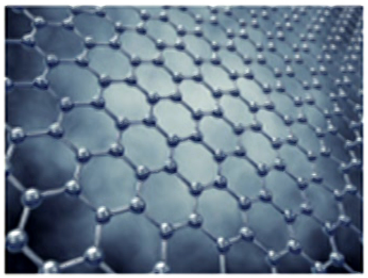


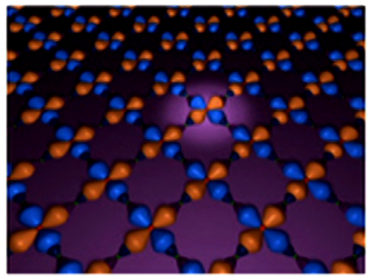


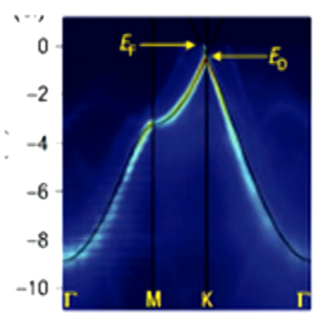


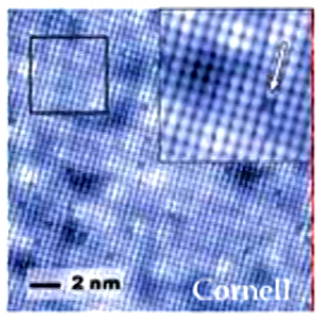
Images from Google gallery











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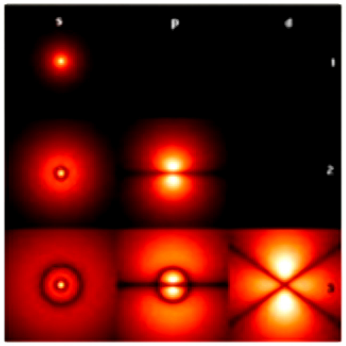
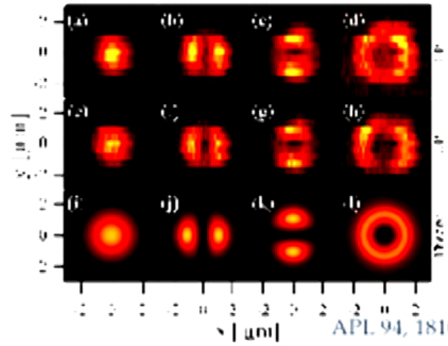
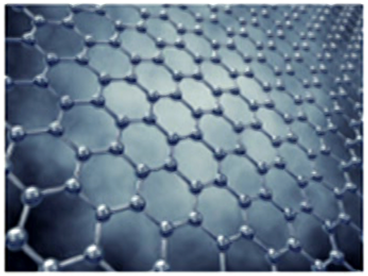
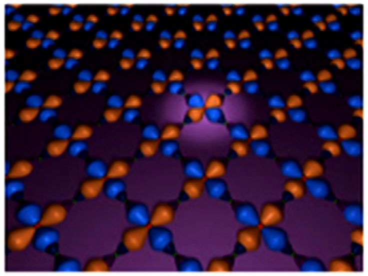
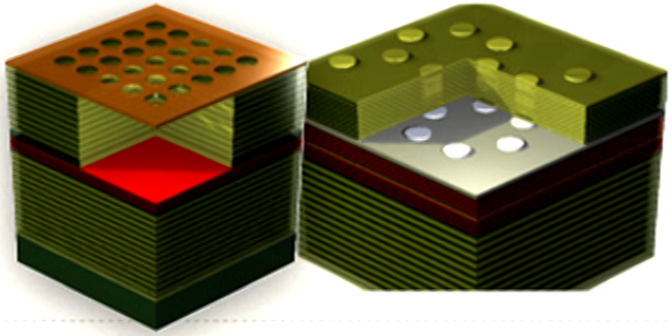


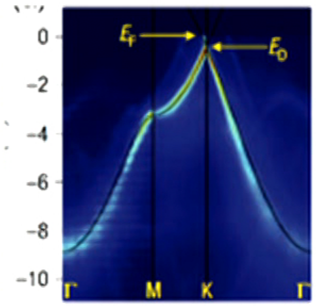


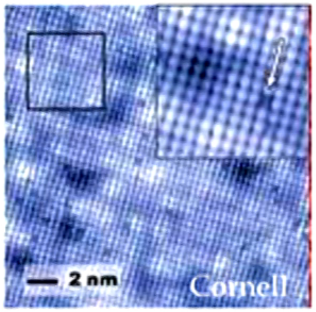
APL 94, 18103 (2009)

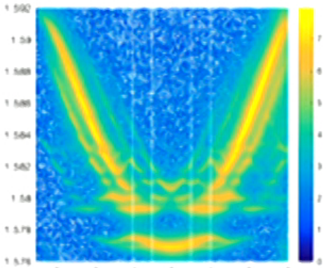


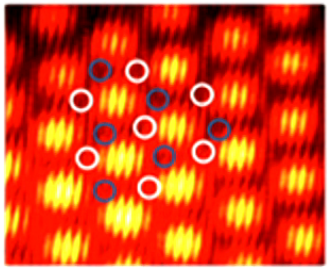












Images from Google gallery

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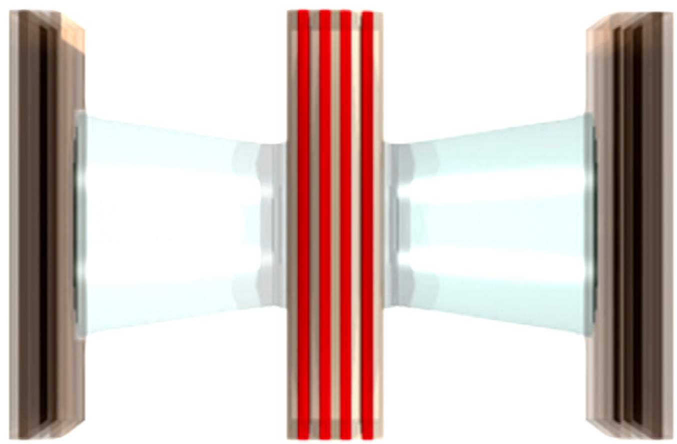
Microcavity Exciton-Polaritons

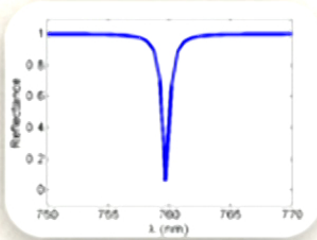


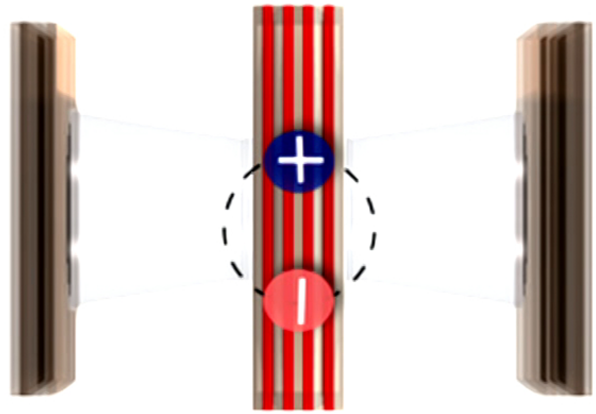
- **Strong Coupling** between cavity photons and quantum-wells
- **Direct Access** to polariton dynamics with leaked photons

Snoke, Littlewood, Phys. Today (2010)

Deng, Haug, Yamamoto, Rev. Mod. Phys. (2010)

Microcavity Exciton-Polaritons:





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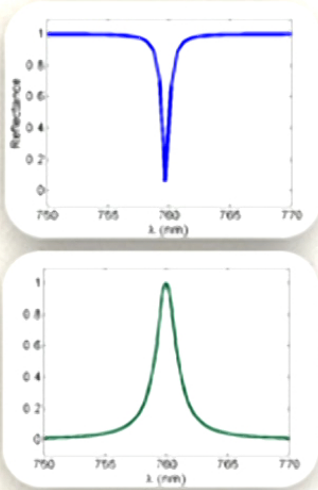
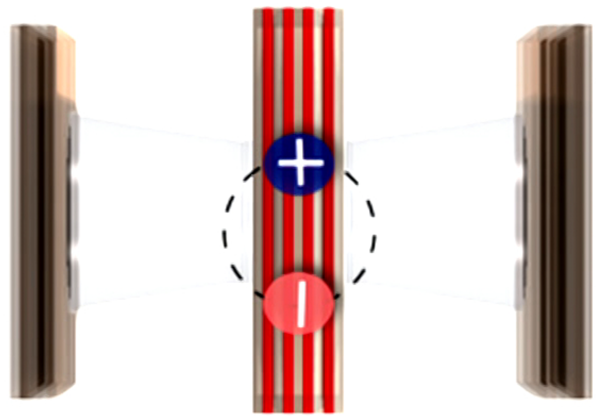




λ-sized Distributed Bragg Reflectors (DBRs)
2D Fabry-Perot Cavity

$$m_c \sim 10^{-5} m_e \;,\; \tau_c \sim 2-4 \text{ ps}$$

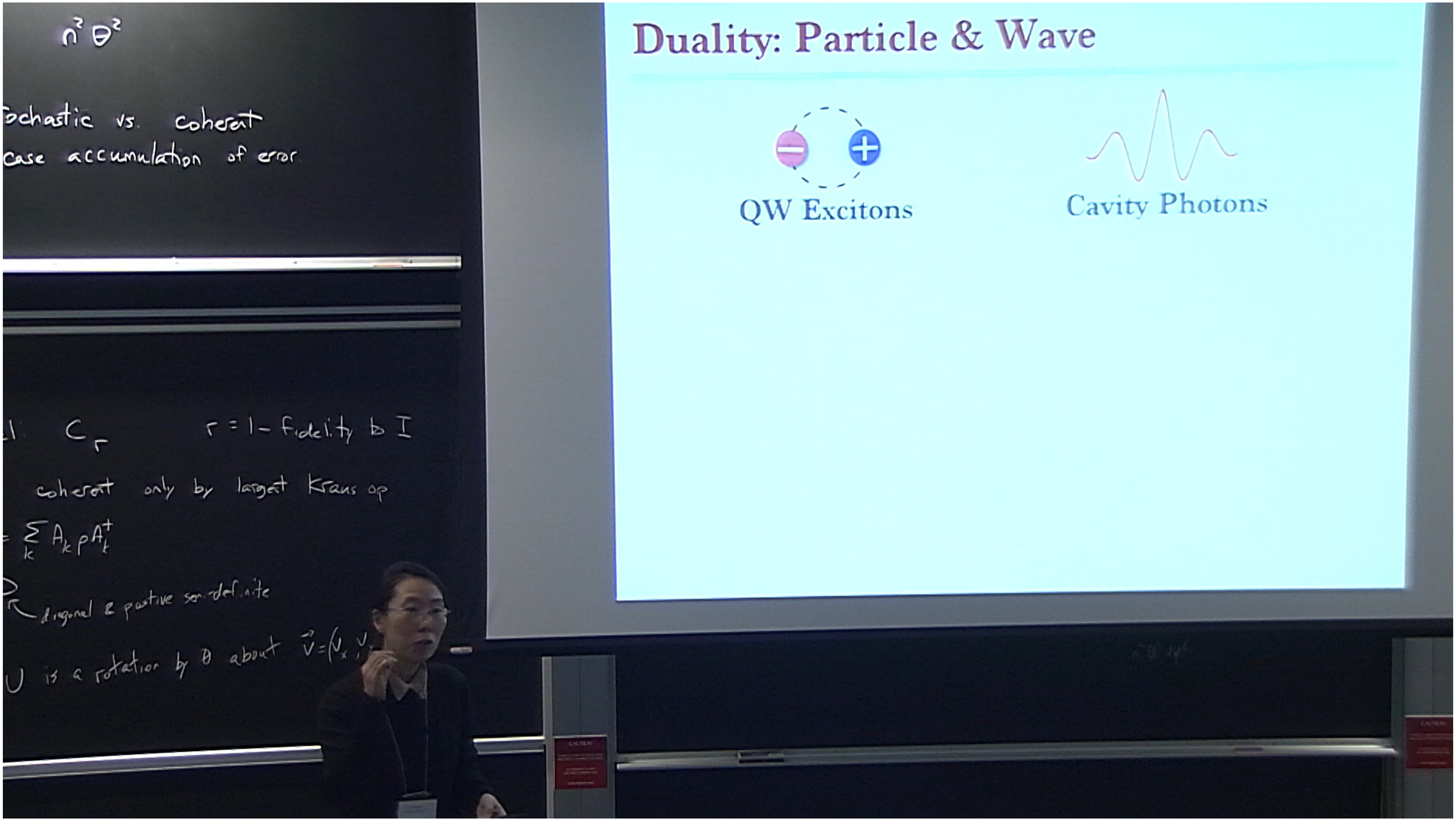
$$\hat{H}_{c,\vec{k}} = \hbar\omega_c \hat{c}^\dagger_{\vec{k}} \hat{c}_{\vec{k}}$$

Quantum-Well (QW) at the antinode of the cavity fields

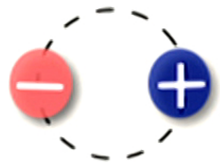
$$m_X \sim 10^{-1} m_e \;,\; \tau_X \sim 0.1-1 \text{ ns}$$

$$\hat{H}_{X,\vec{k}} = \hbar\omega_X \hat{a}^\dagger_{\vec{k}} \hat{a}_{\vec{k}}$$

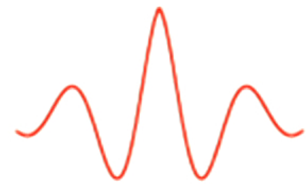
$$\hat{H}_{pol,\vec{k}} = \hbar\omega_{pol,\vec{k}} \hat{P}^\dagger_{\vec{k}} \hat{P}_{\vec{k}}$$


Duality: Particle & Wave
QW Excitons
Cavity Photons
coherent only by largest Kraus op
diagonal & positive semi-definite

Duality: Particle & Wave

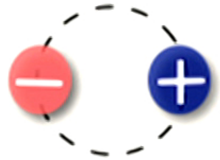


QW Excitons



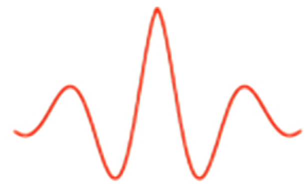
Cavity Photons

Duality: Particle & Wave



QW Excitons

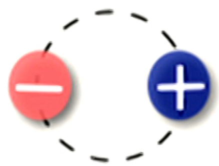
- massive, charge-neutral quasi-particles
- indistinguishable bosons $(na_B^2 < 1)$
- Coulomb exchange **interactions** $6E_B a_B^2/S$
- 1/2 pseudo-**spin**



Cavity Photons

- confined electromagnetic wave
- indistinguishable bosons
- Delocalized wave function
- very light effective mass
- finite lifetime

Duality: Particle & Wave



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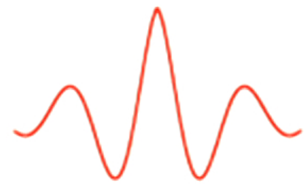
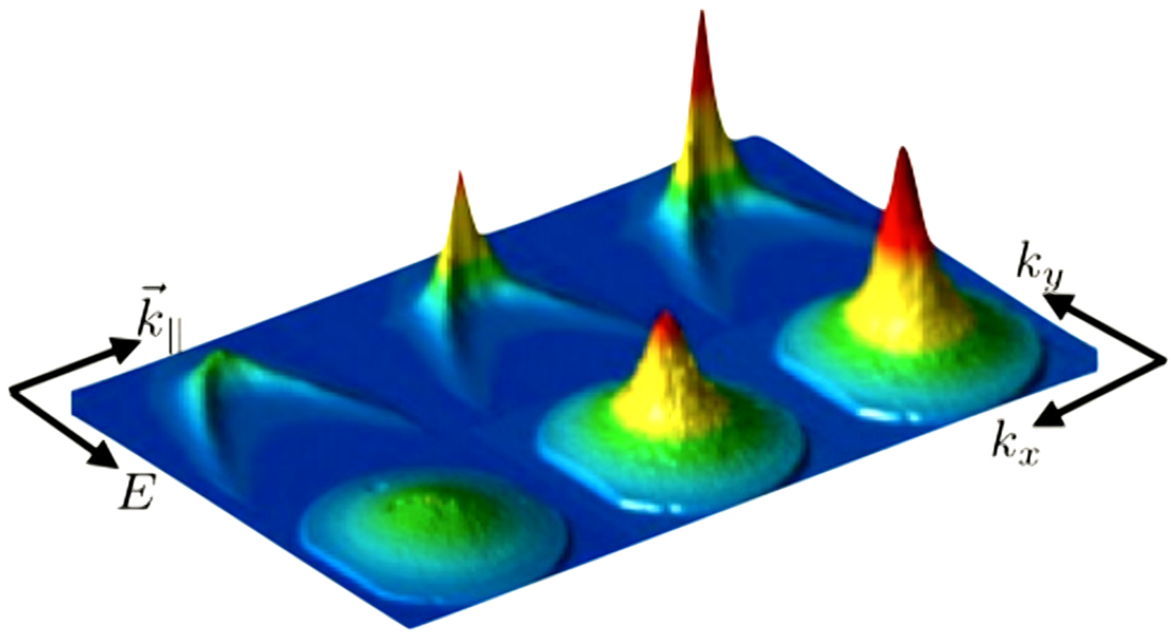


Cavity Photons

- confined electromagnetic wave
- indistinguishable bosons
- Delocalized wave function
- very light effective mass
- finite lifetime

Bosons

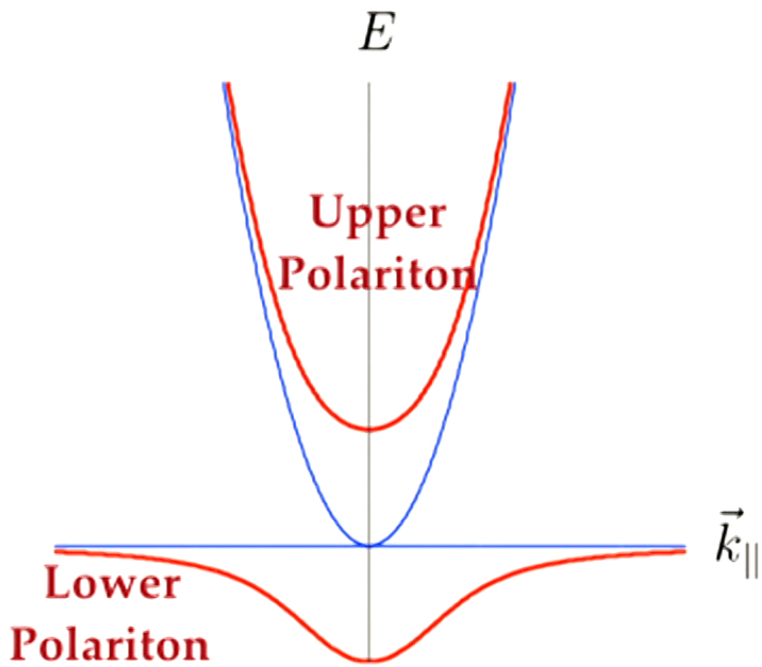
Microcavity Exciton-Polariton Condensation



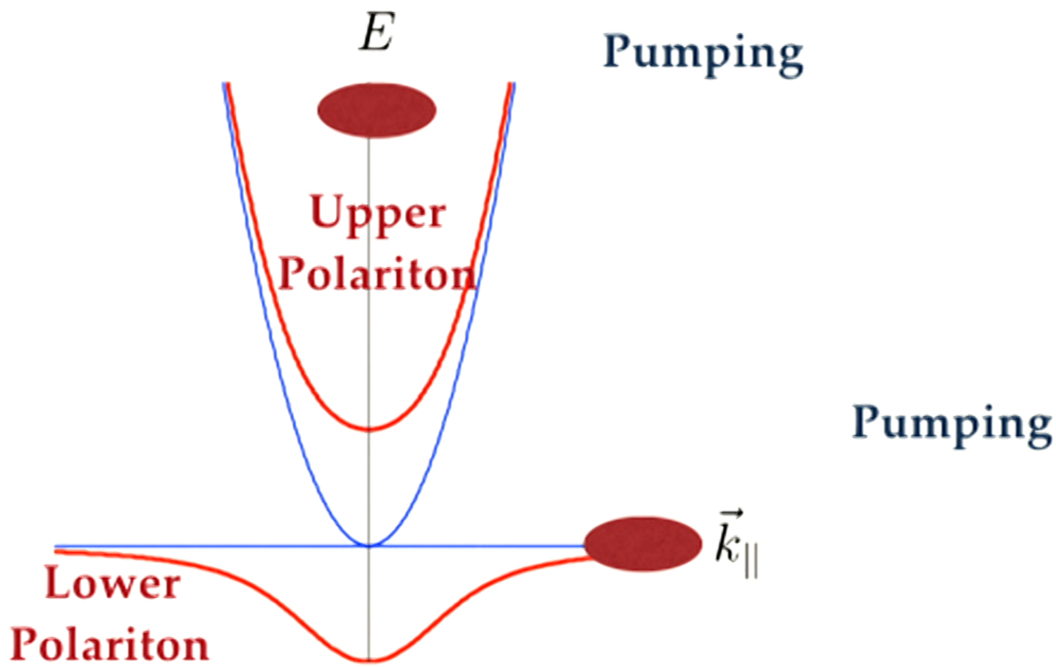
Macroscopic Occupancy in the zero-momentum ground state
Momentum space narrowing
Spectral line width narrowing

image taken from J. Kasprzak et al. Nature 410, 409 (2006)

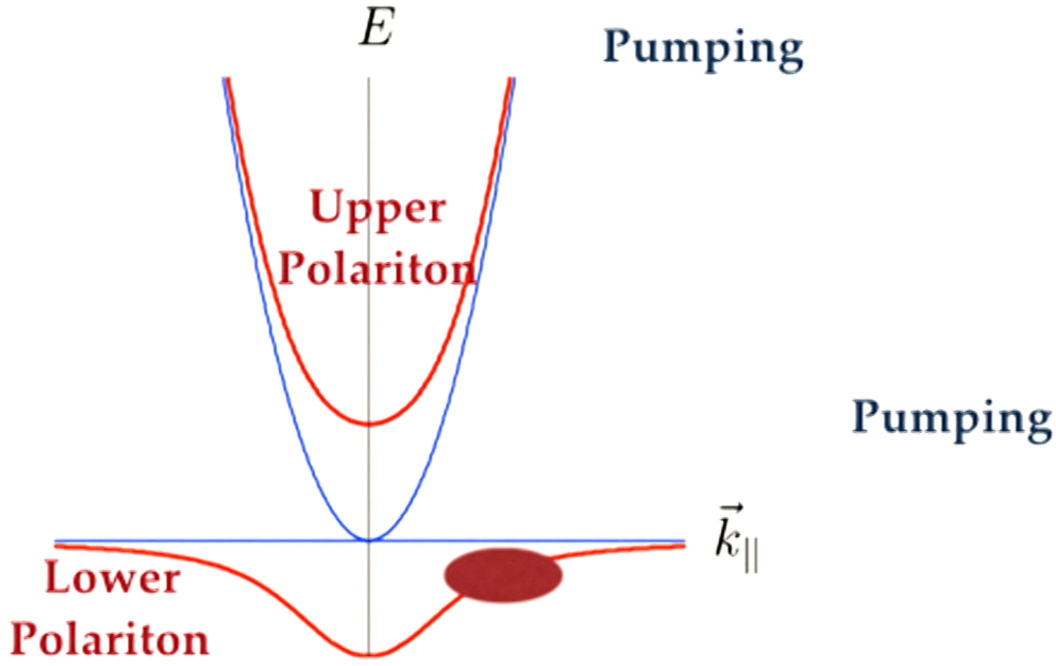
Dynamical Nature



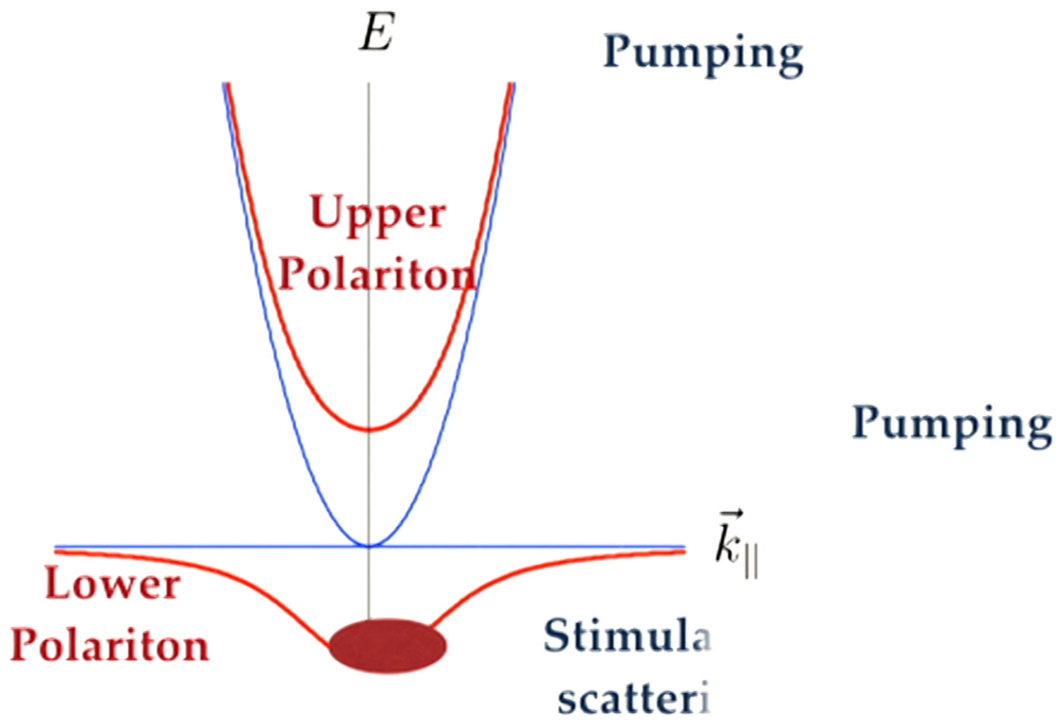
Dynamical Nature



Dynamical Nature



Dynamical Nature



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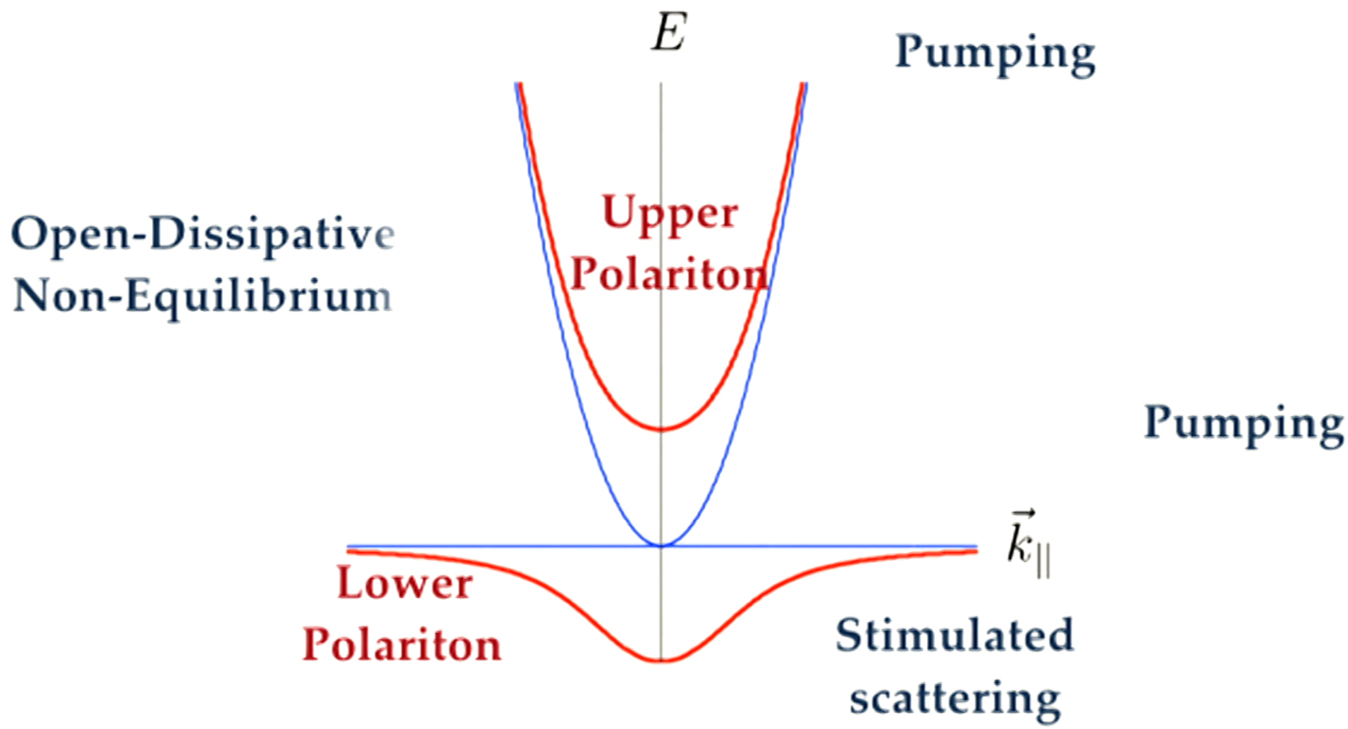
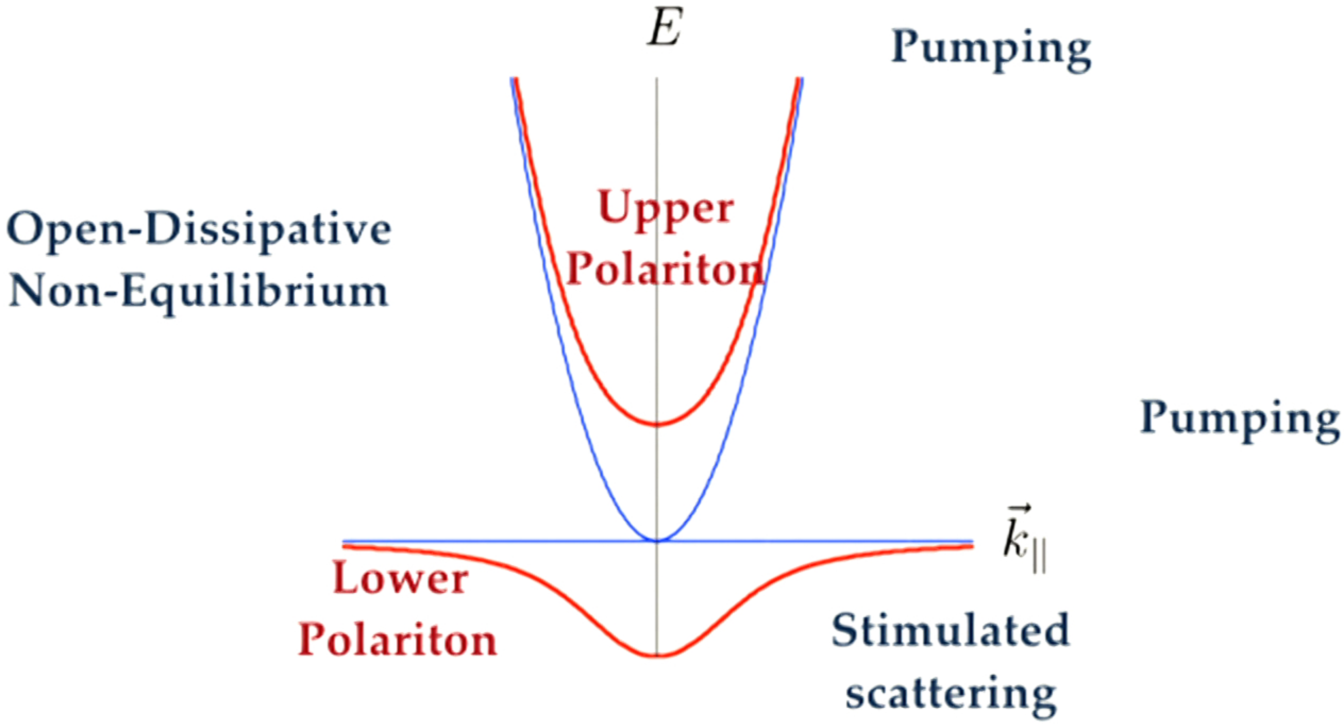
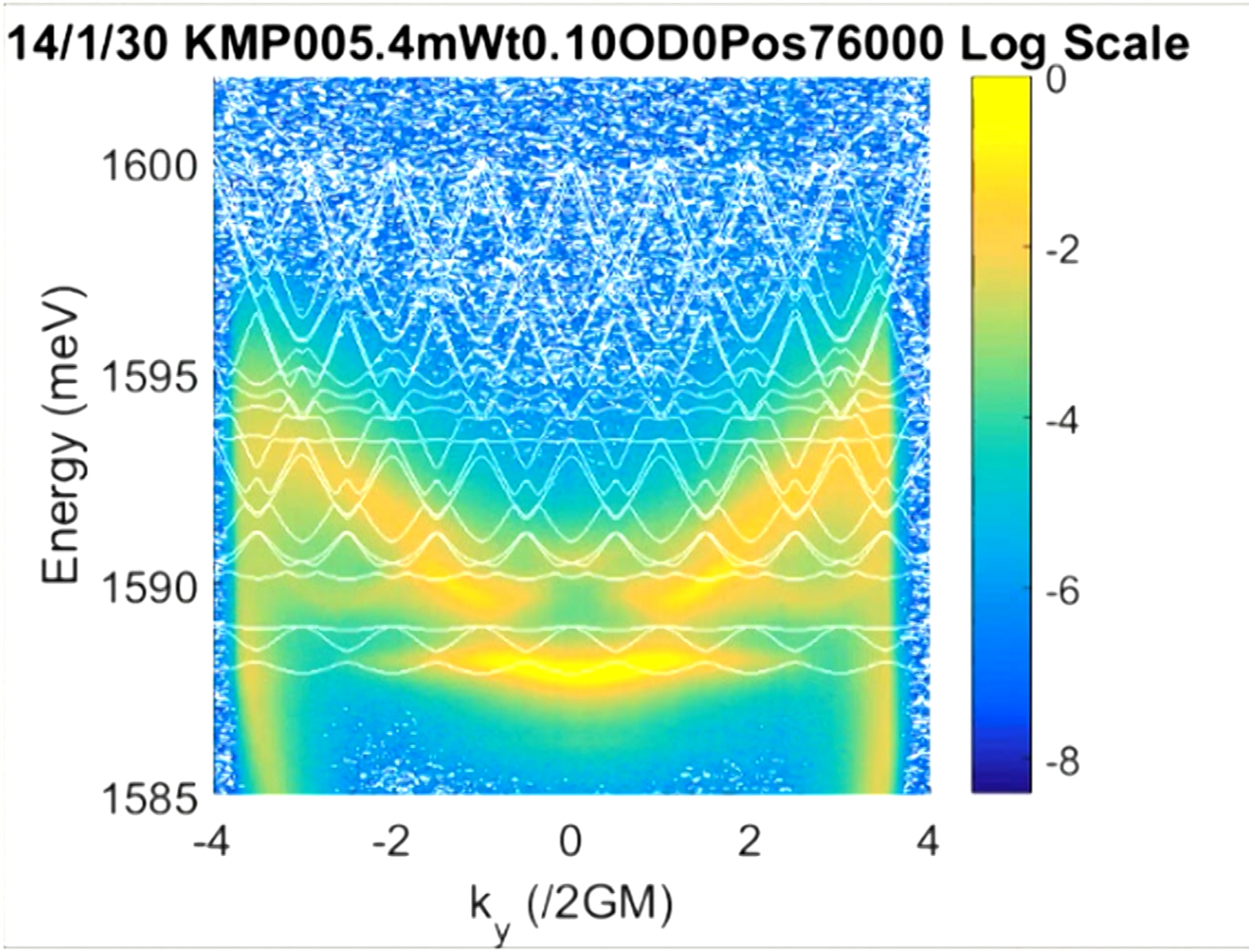


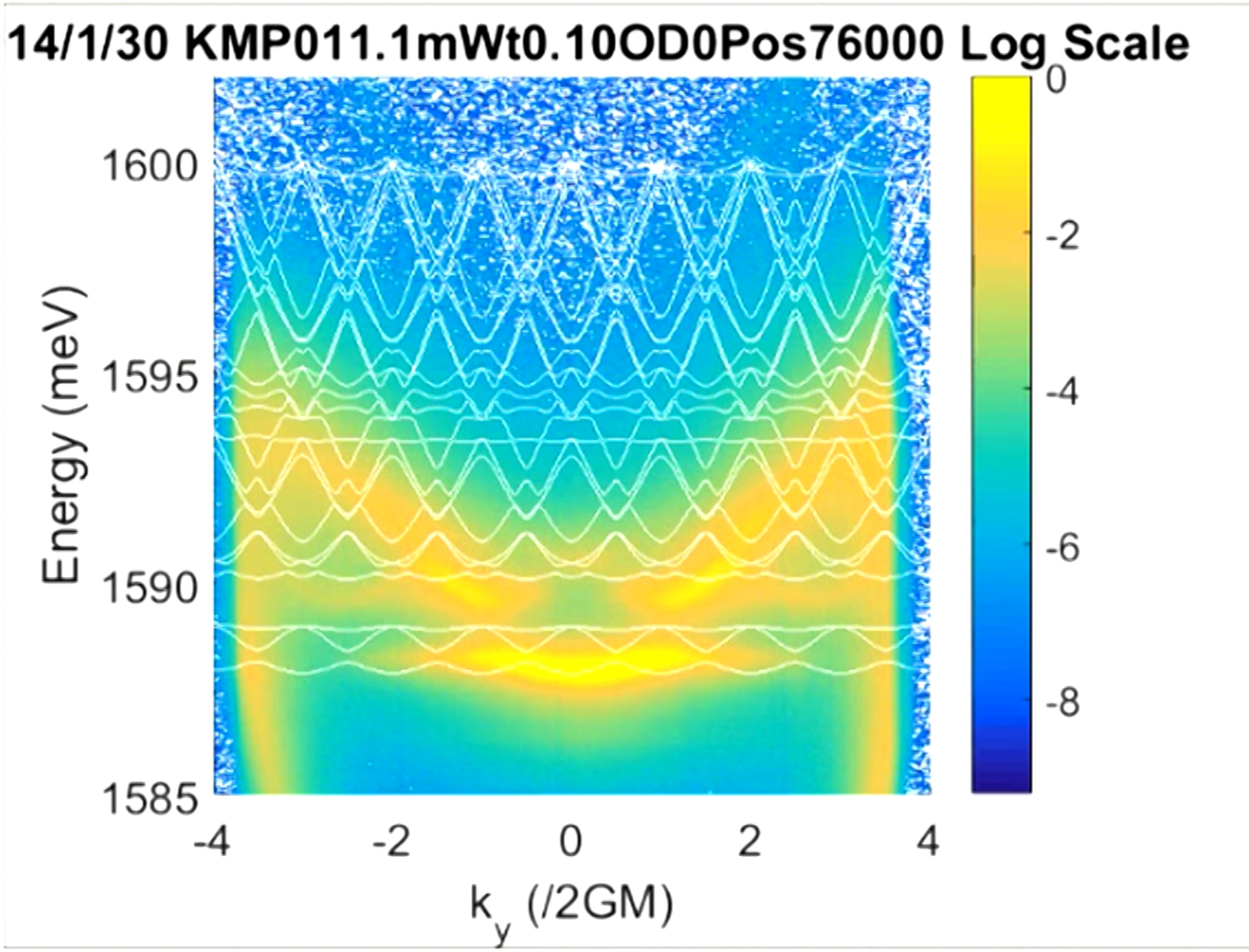
Dynamical Nature



Gain-dissipation



Taehyun Yoon, Haining Pan et al. (In Preparation)



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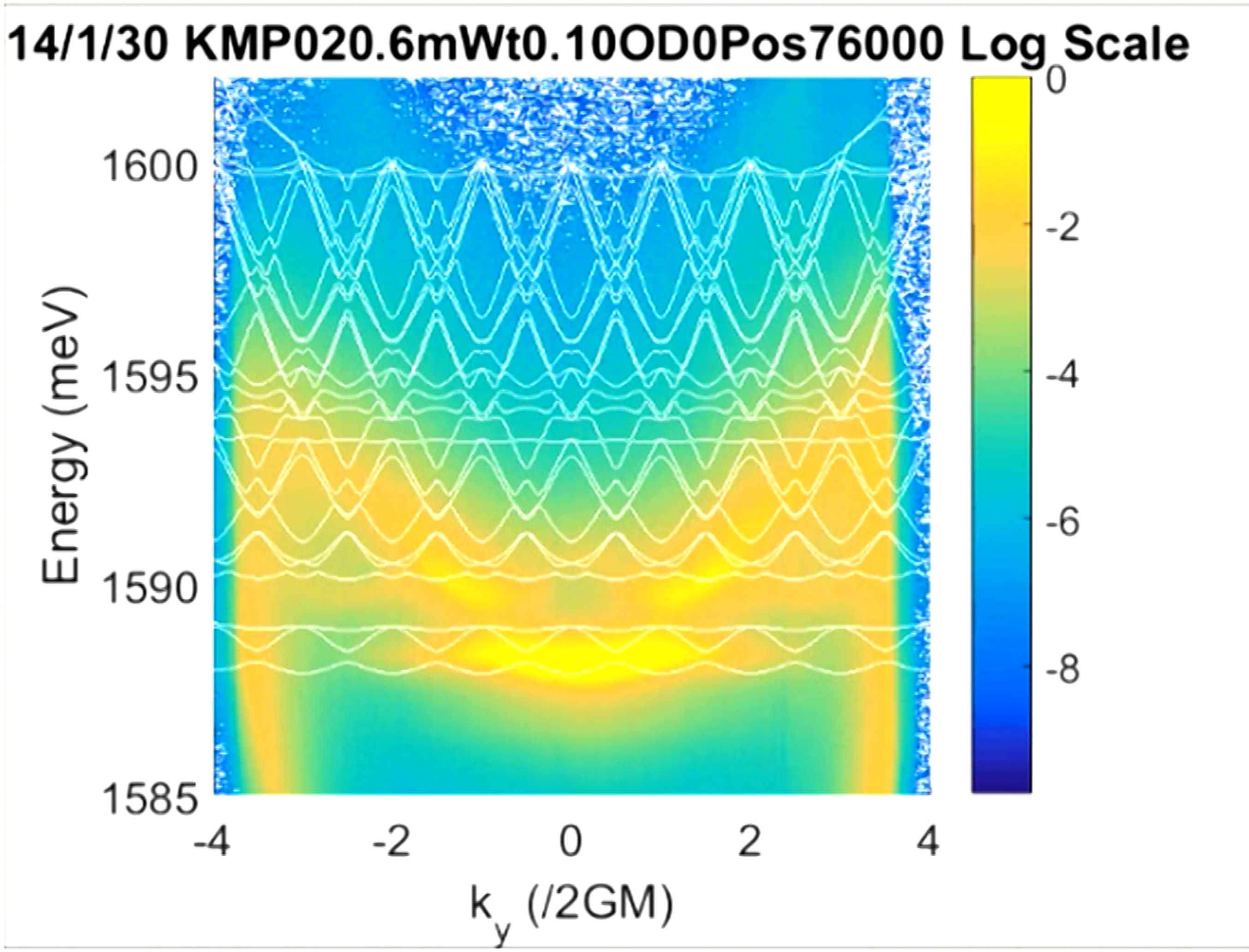

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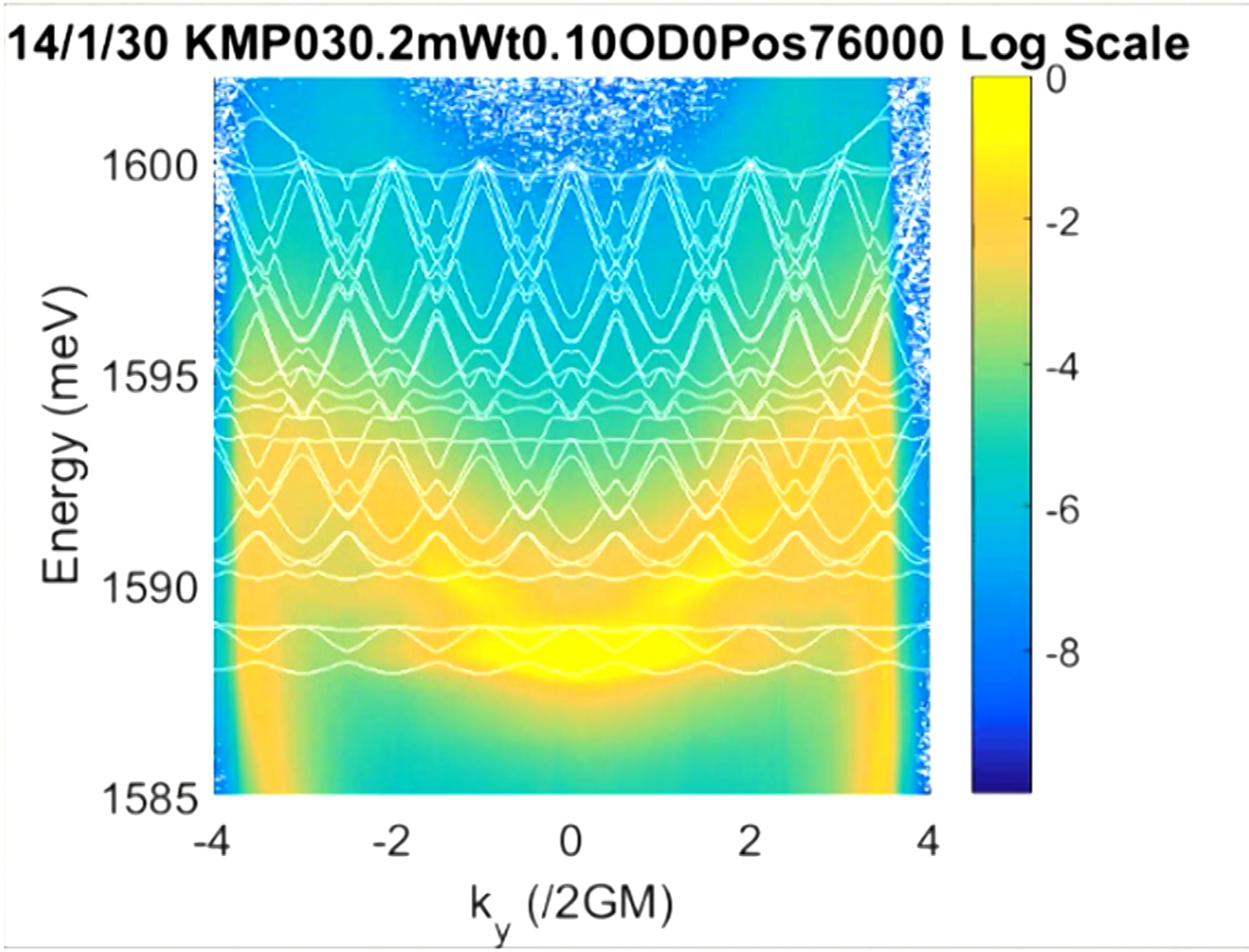

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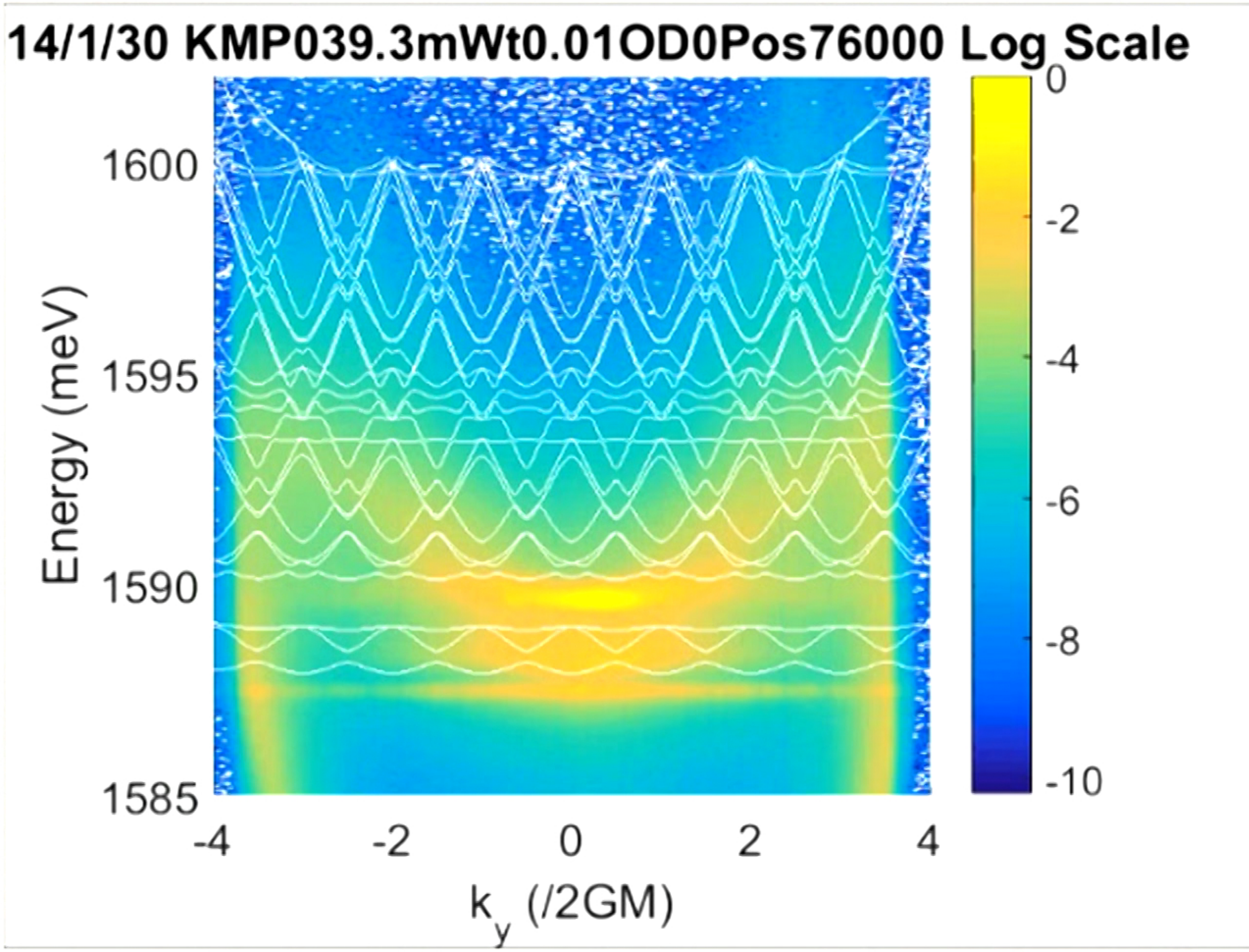

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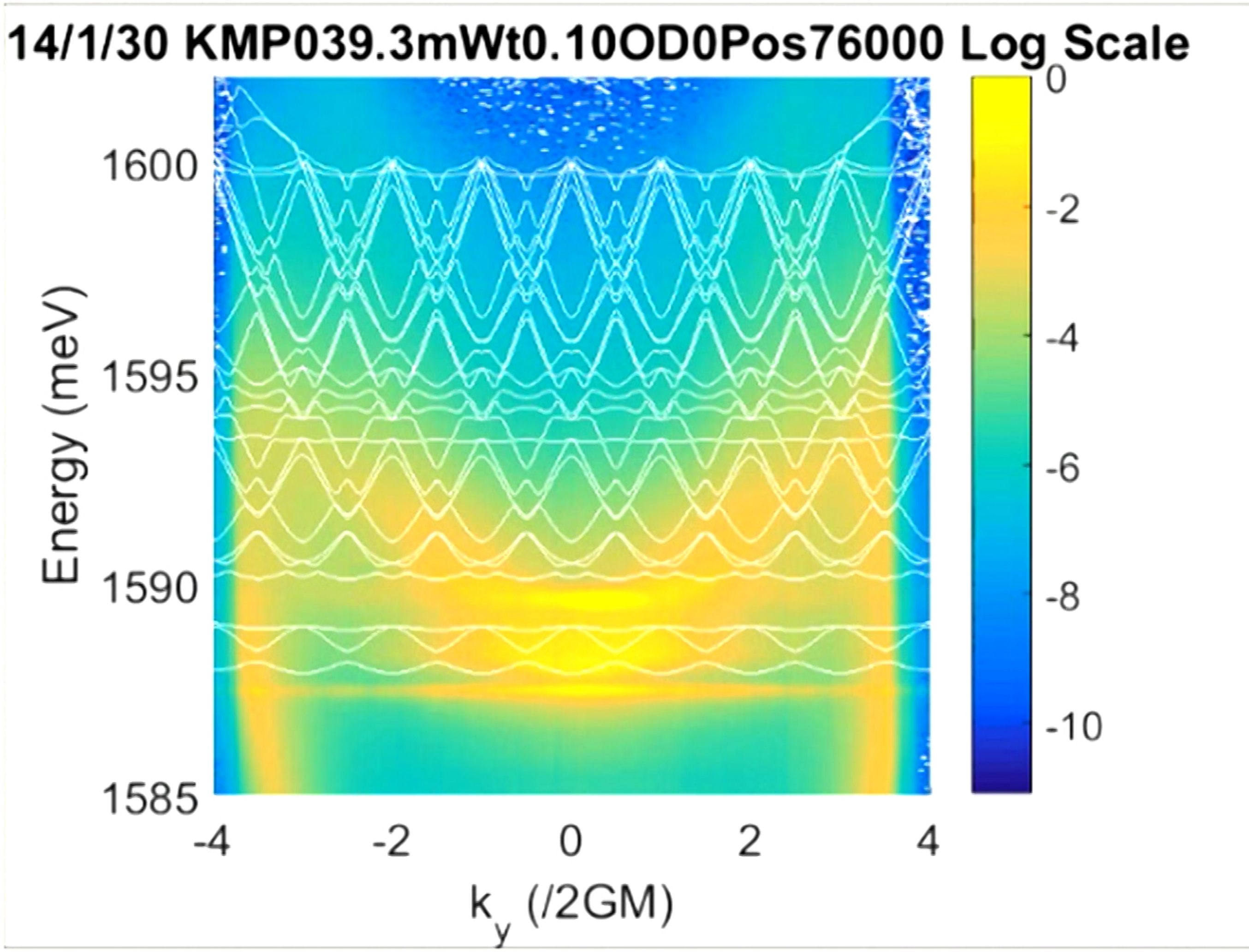

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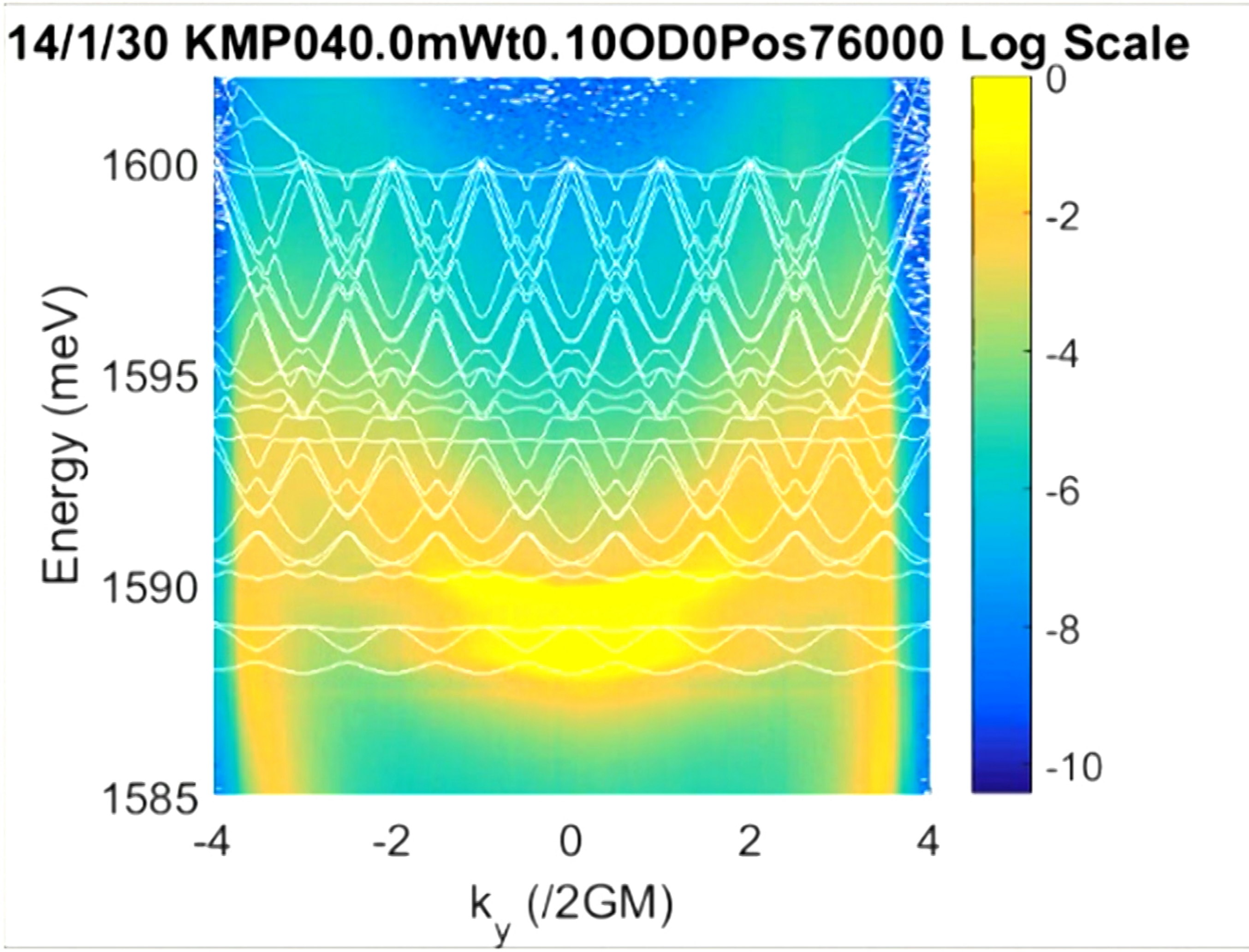

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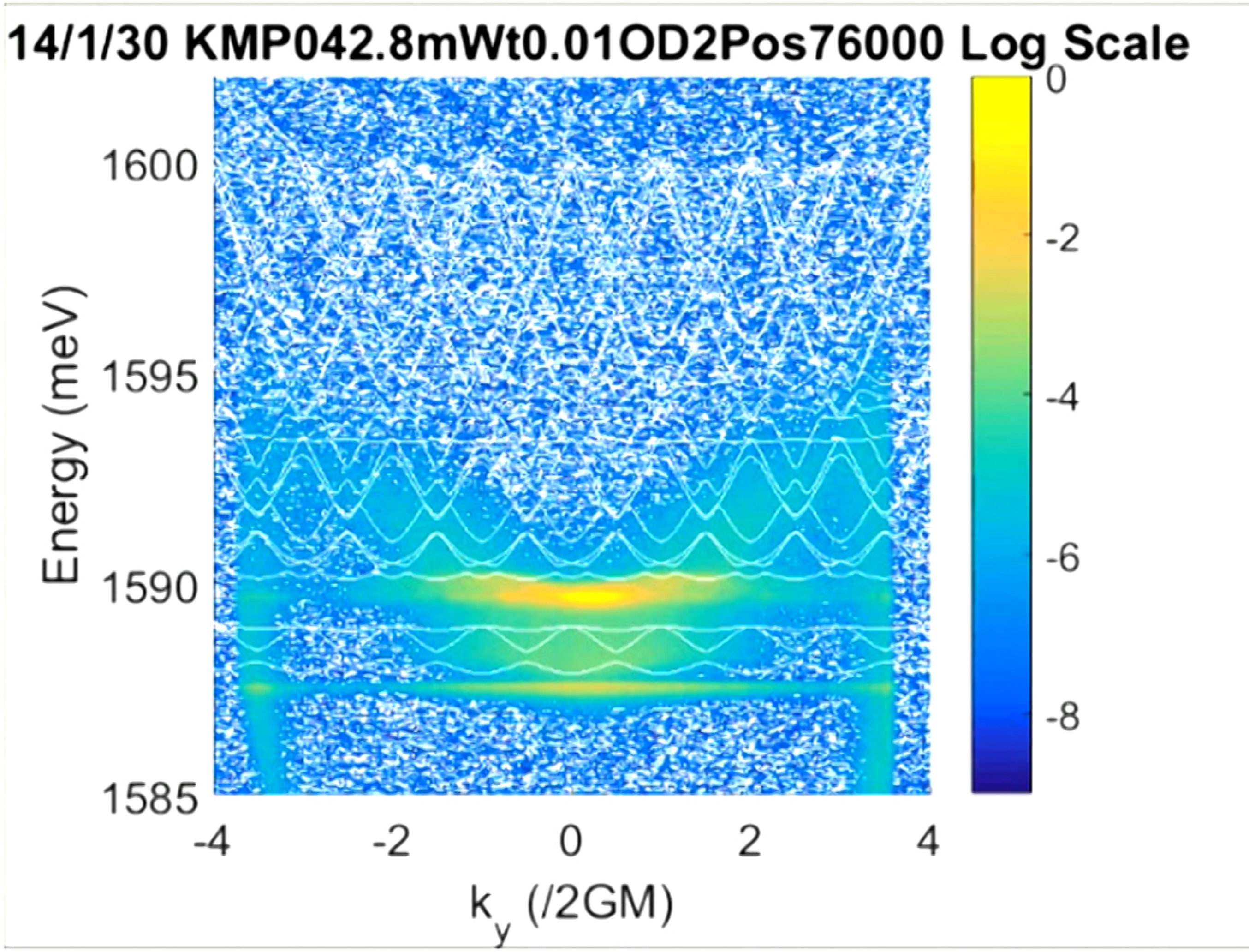

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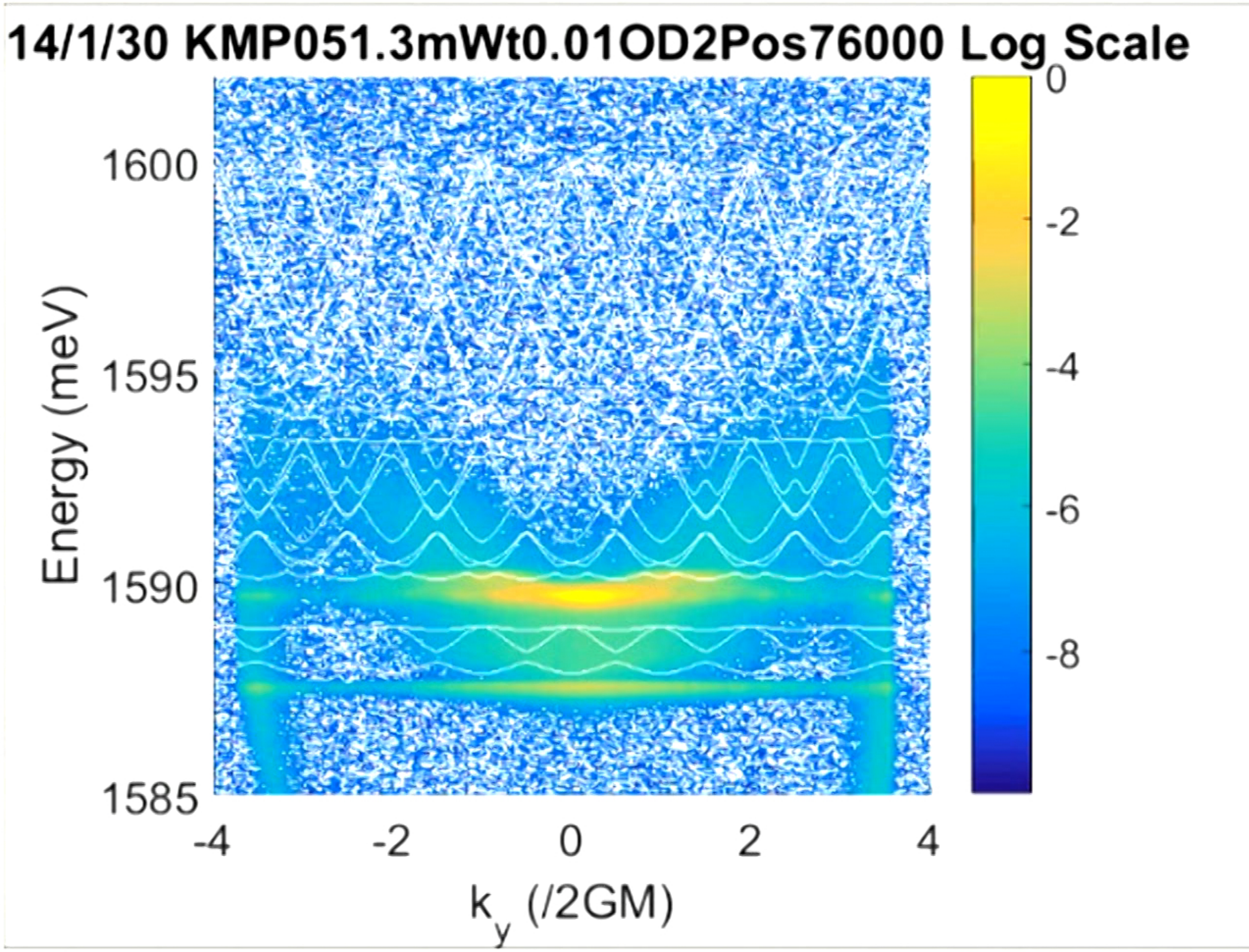

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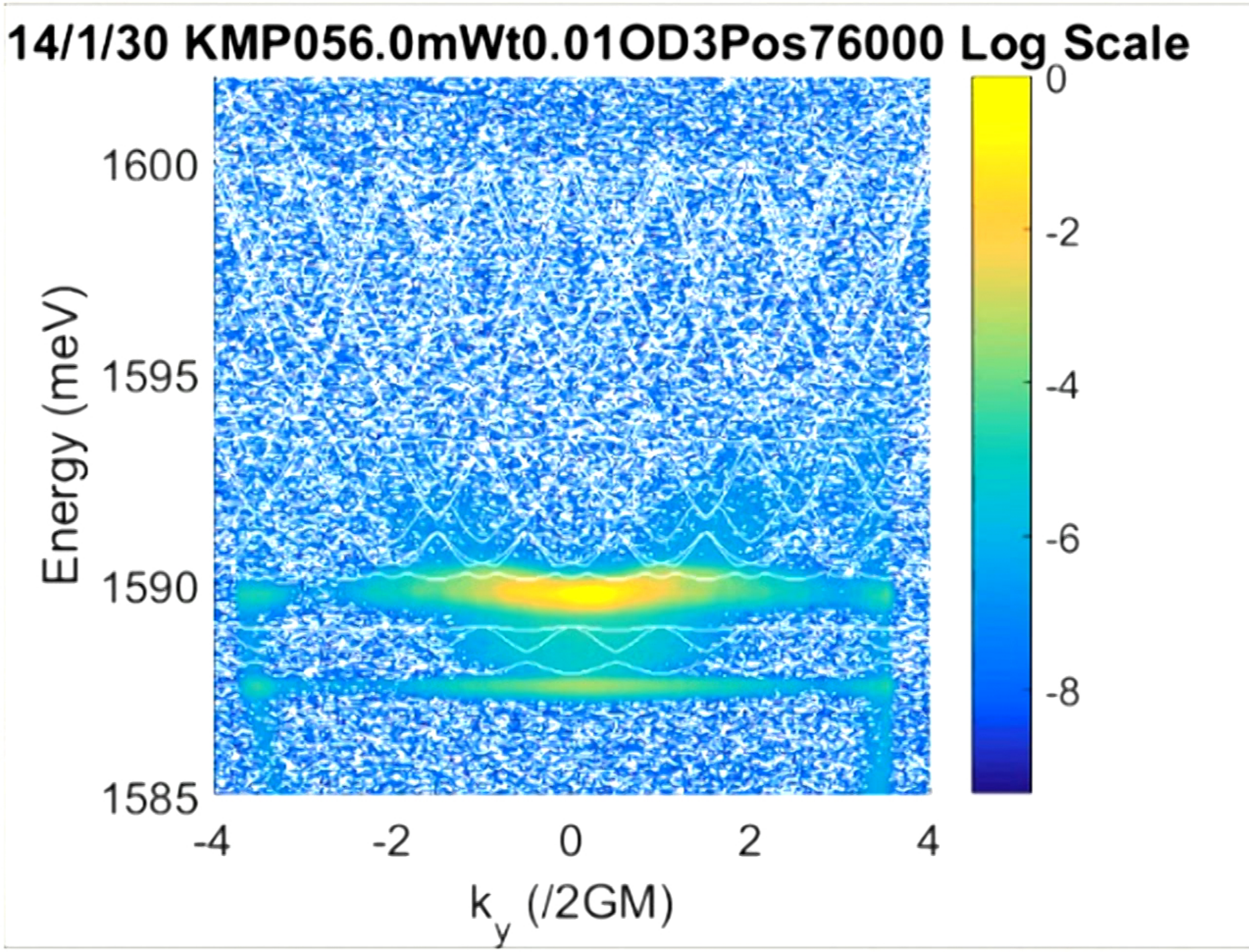

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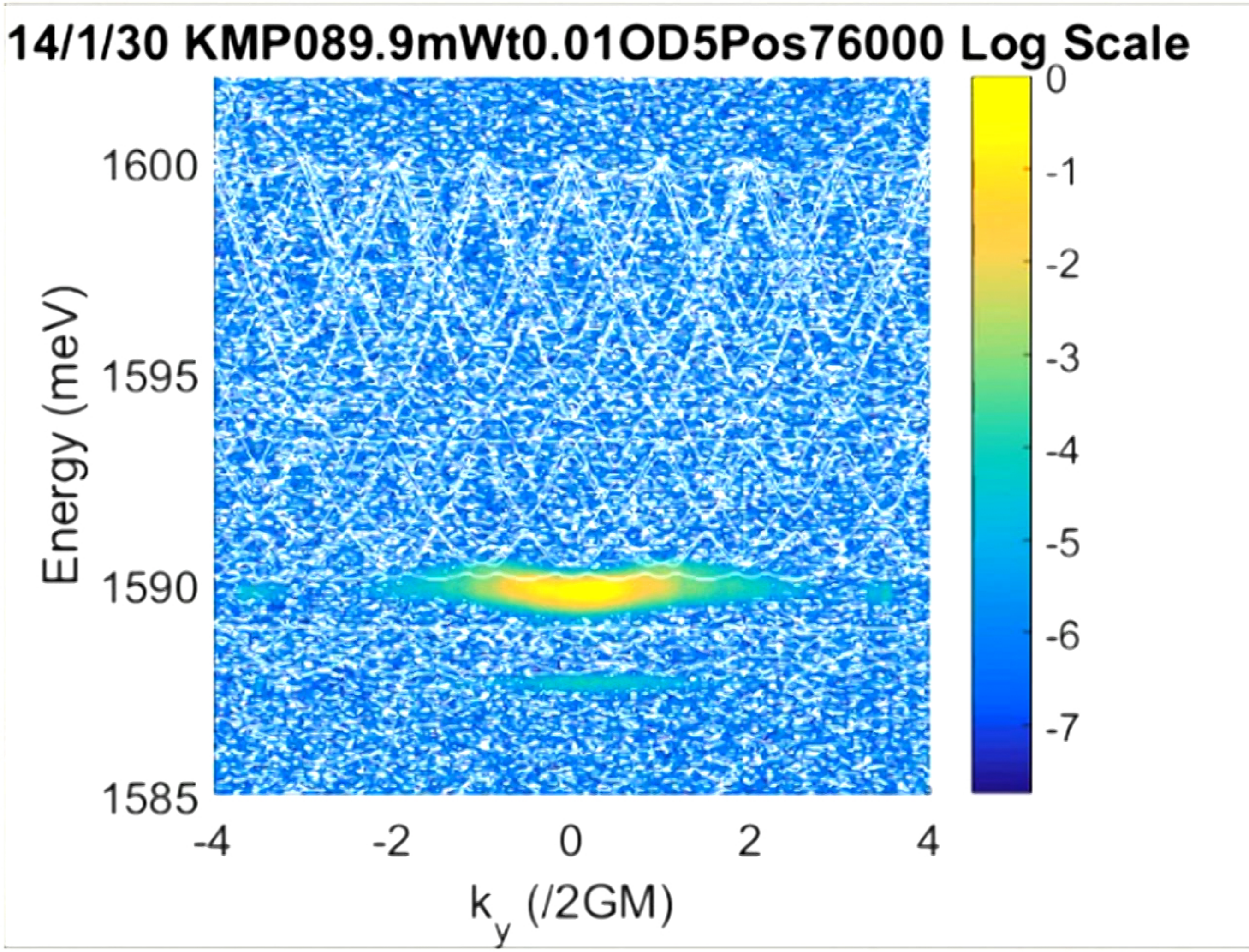

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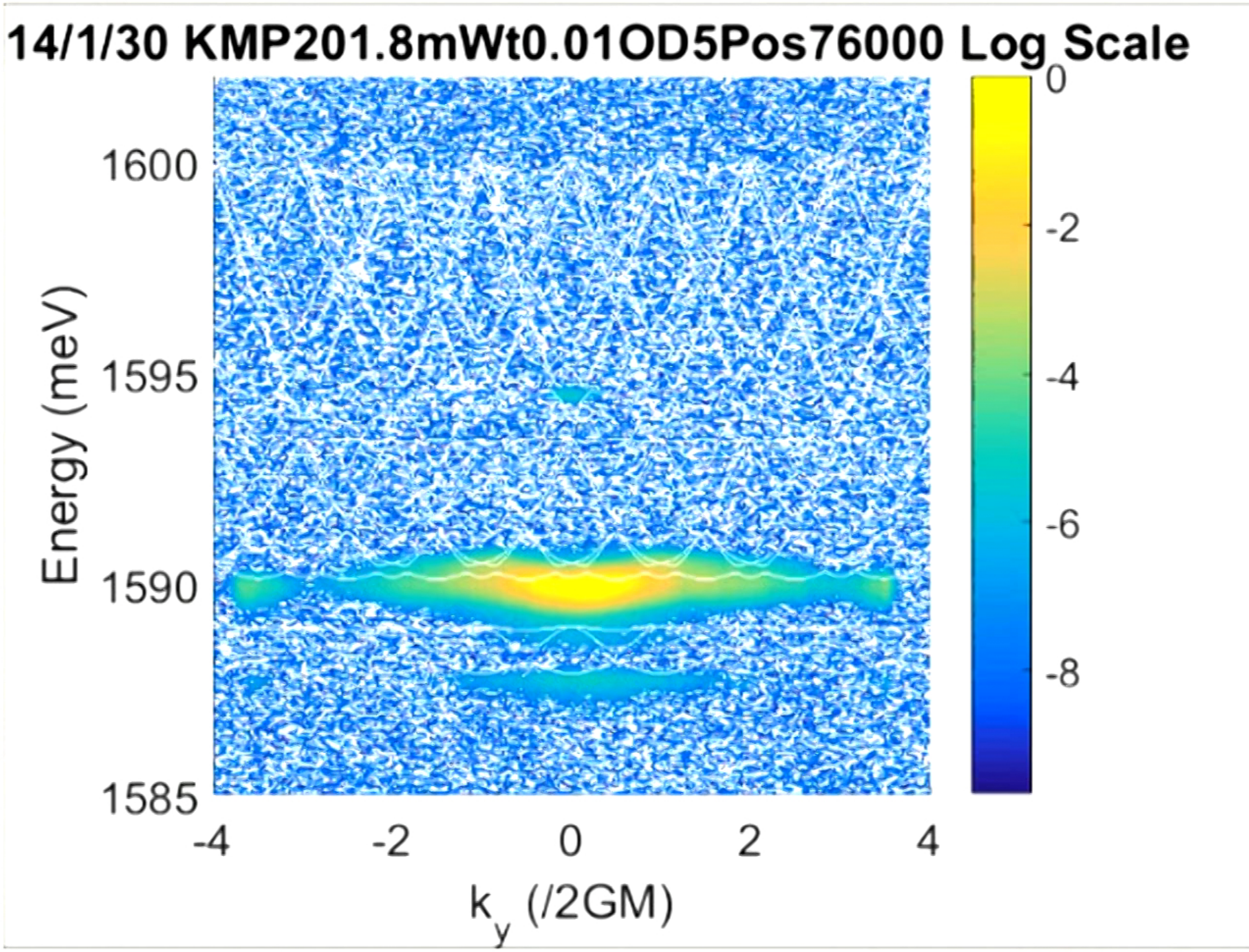

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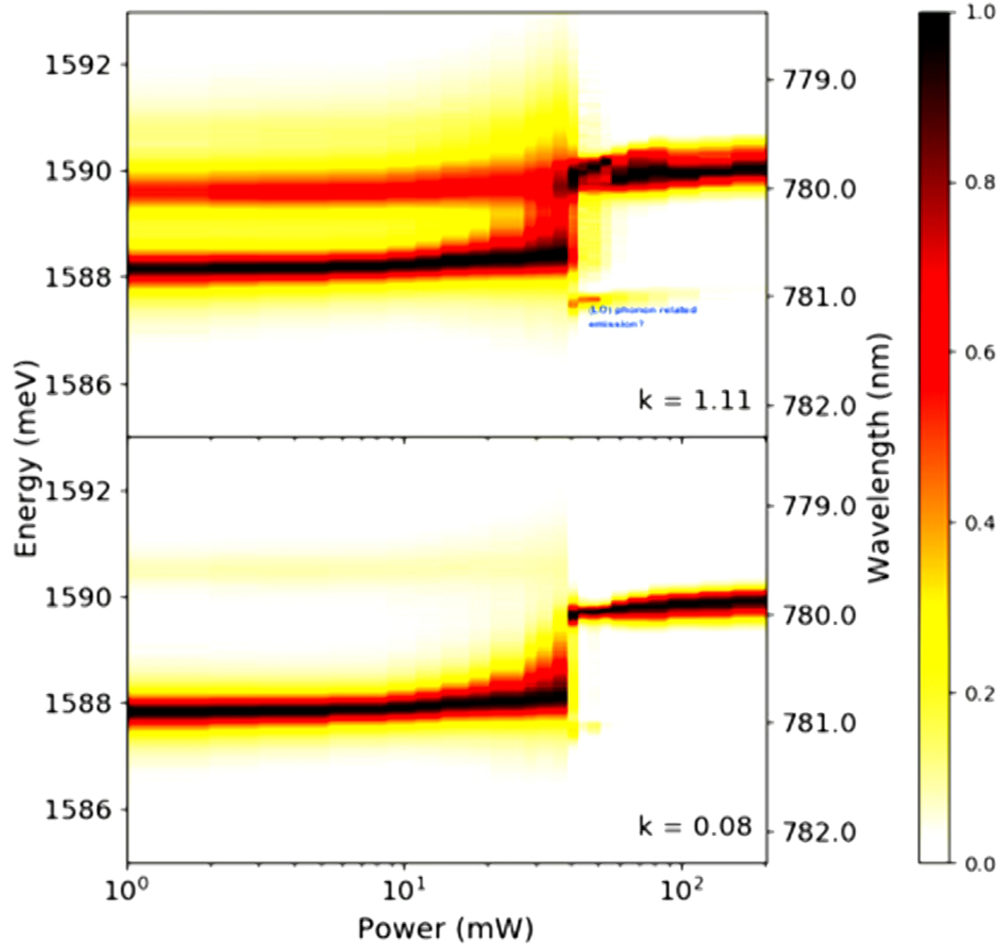
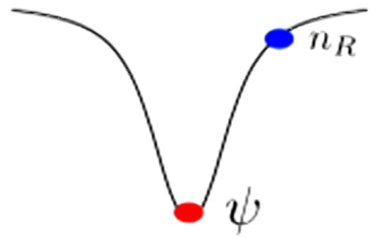
Microcavity Exciton-Polariton Condensation



Taehyun Yoon, Haining Pan et al. (In Preparation)

Open-Dissipative Condensates

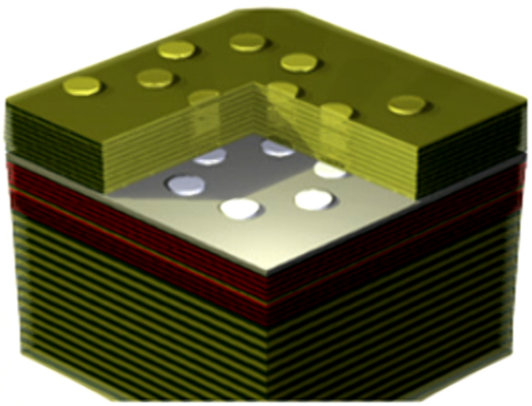
system order parameter $\psi(\vec{r}) = \sqrt{n(\vec{r})}e^{i\phi(\vec{r})}$

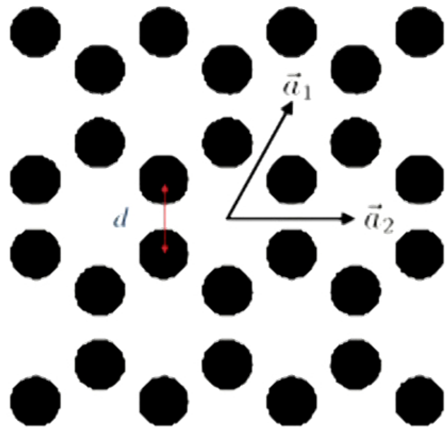


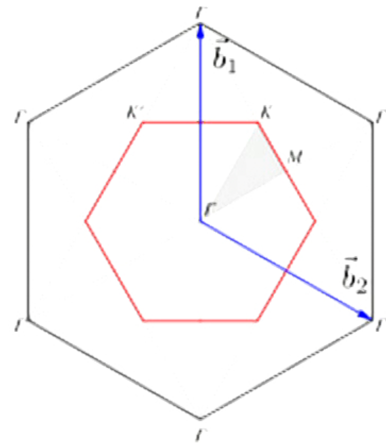
$$i\hbar\frac{\partial\psi}{\partial t} = (-\frac{\hbar^2\nabla^2}{2m} + V_{ext}(\vec{r}))\psi(\vec{r},t) - \frac{i\hbar}{2}[\gamma_c - R(n_R(\vec{r},t))]\psi(\vec{r},t) + (g_c|\psi(\vec{r},t)|^2 + g_R n_R(\vec{r},t))\psi(\vec{r},t)$$

$$\frac{\partial n_R(\vec{r},t)}{\partial t} = P(\vec{r}) - g_R n_R(\vec{r},t) - R(n_R(\vec{r},t))|\psi(\vec{r},t)|^2$$

Stronger Honeycomb Lattice Potential

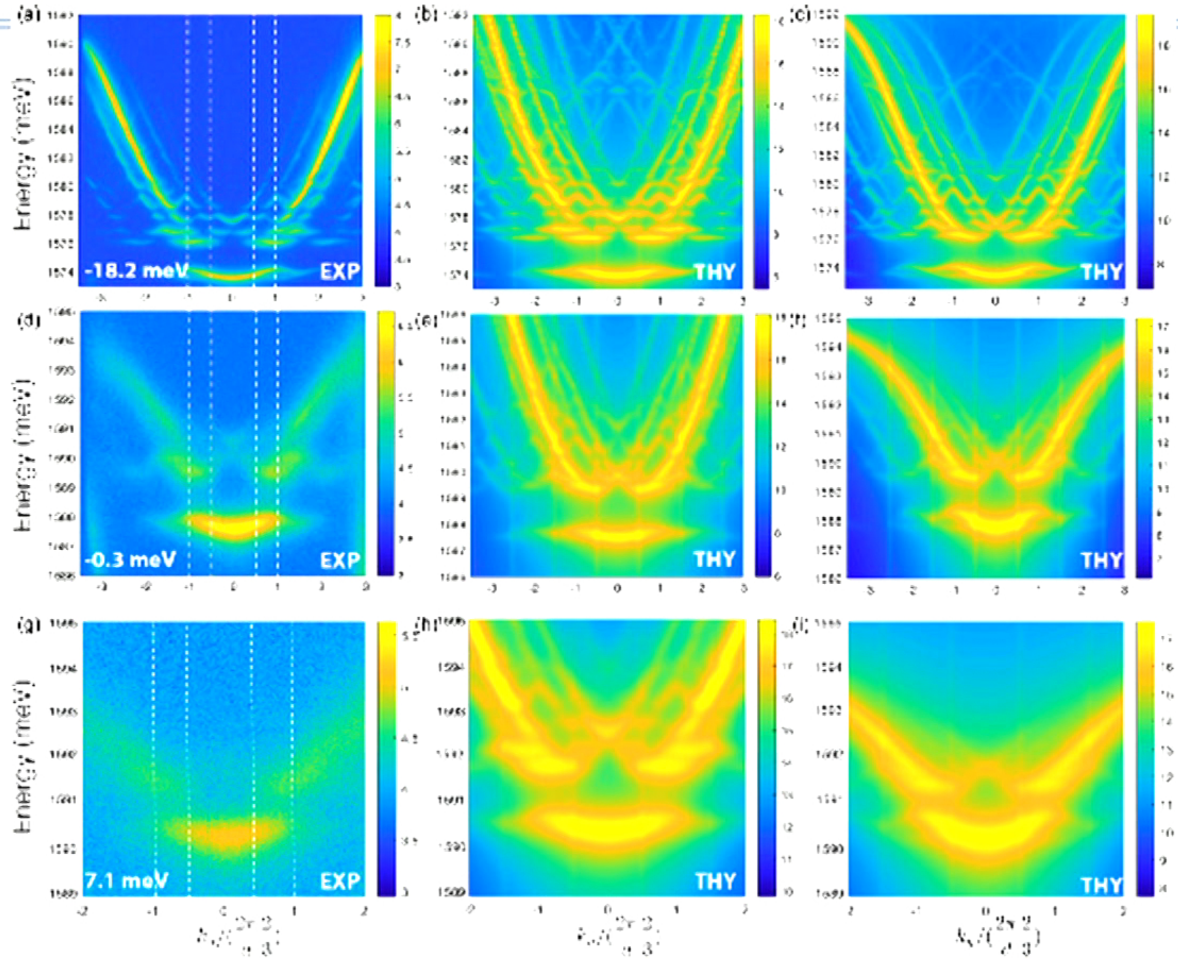






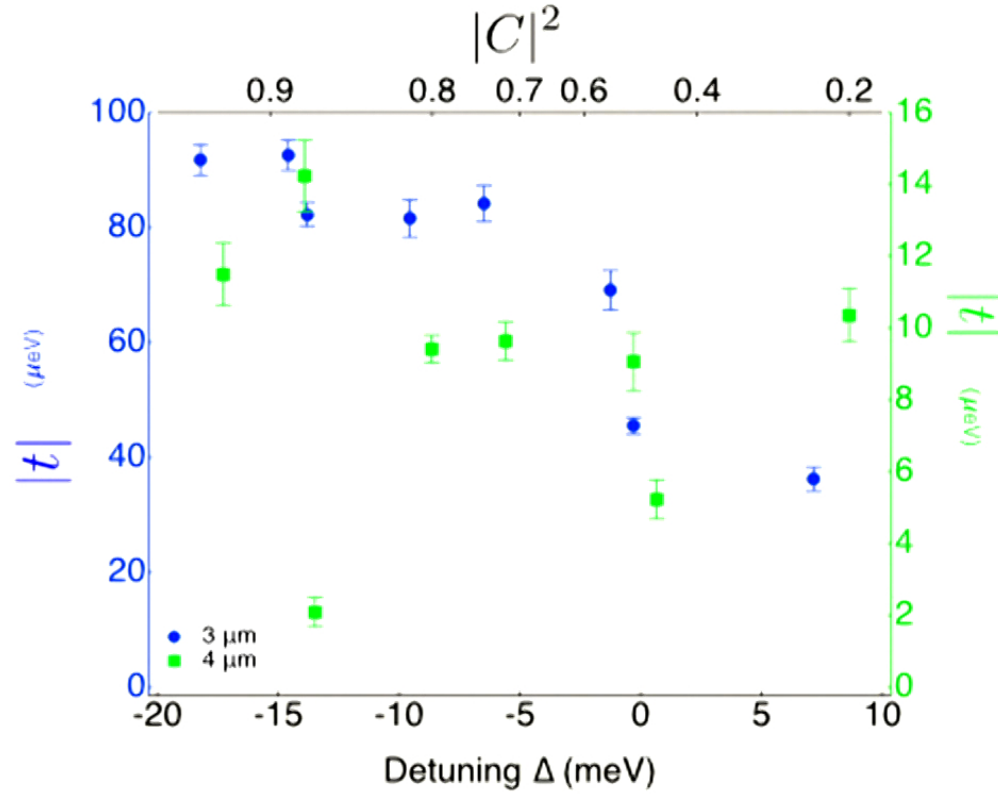
diameter of each site	$2\ \mu\mathrm{m}$
nearest-neighbor distance,	$d \in \{3, 4, 5, 7\}\ \mu\mathrm{m}$
Δ detuning	$\Delta \in \{-19, 9\}$ meV
equivalently, photonic fraction	$\lvert C\rvert^2 \in \{0.18, 0.92\}$
trap-potential height	$h \in \{2, 5\}$ meV

Band Structure - Honeycomb lattice



Haining Pan et al. PRB 99, 045302 (2019)

Nearest-Neighbor Hopping Integral t vs Δ



$$E(\vec{k}) = \pm t\sqrt{3 + f(\vec{k})} - t' f(\vec{k}) \qquad f(\vec{k}) = 2\cos(\sqrt{3}k_y a) + 4\cos(\frac{\sqrt{3}}{2}k_y a)\cos(\frac{3}{2}k_x a)$$

Haining Pan et al. PRB 99, 045302 (2019)

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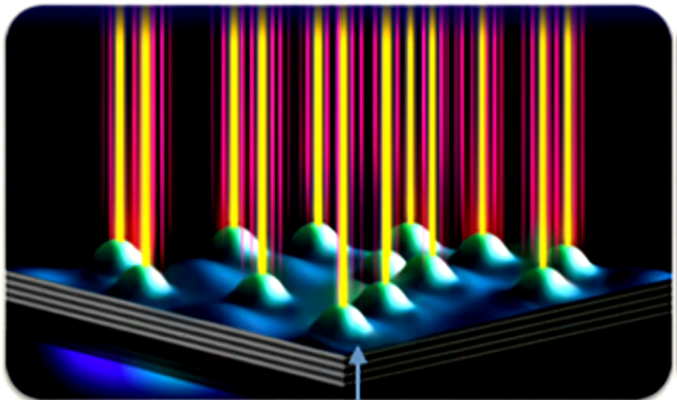
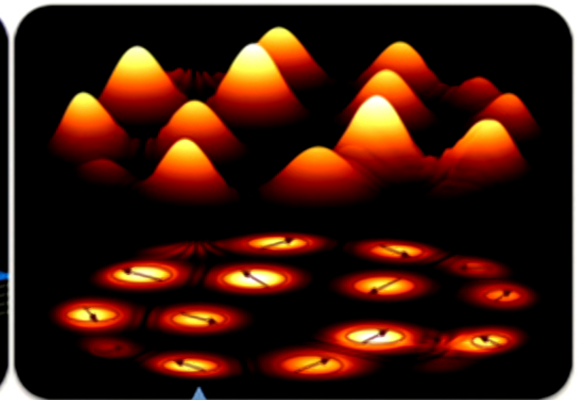




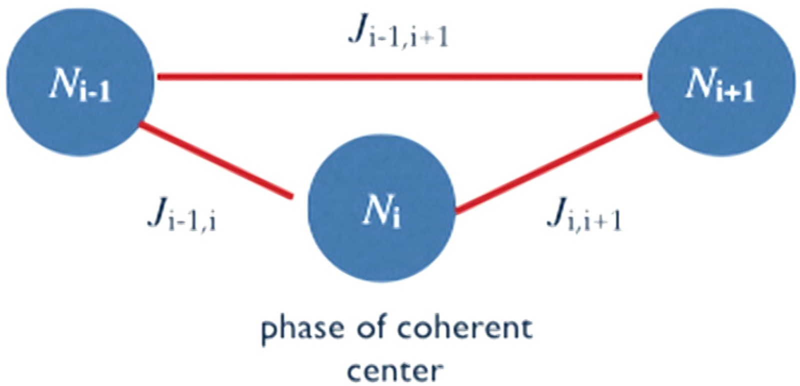
node = condensate

spin-polarized condensate

Operation Principle

$$H = -\sum_{i=1}^{N}\sum_{j=1}^{N} J_{ij}\cos(\theta_i - \theta_j)$$

Stage 1: Below threshold



Kalinin and Berloff, NJP 20, 113023 (2018)

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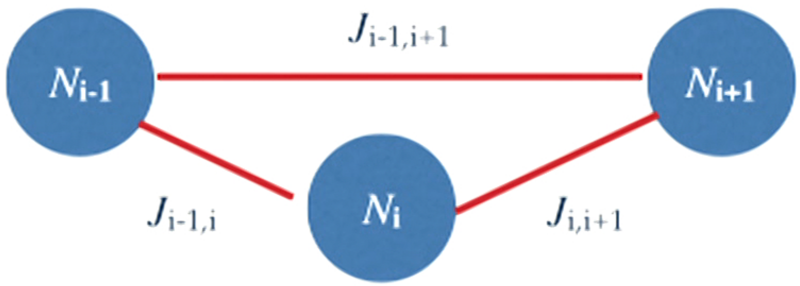


phase of coherent center

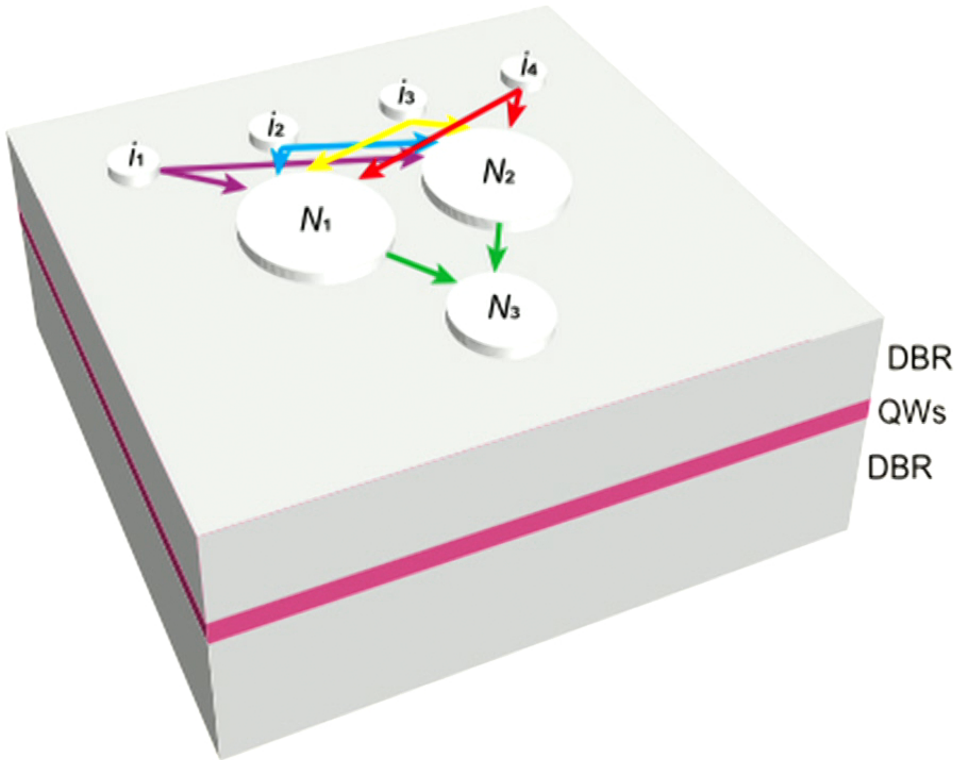
Stage 2: Above threshold

Macroscopic coherence maximizes gain (the total # of particles) and minimizes the Hamiltonian depending on phases

$$\min H$$

Kalinin and Berloff, NJP 20, 113023 (2018)

3-Node Neural Network Training



NP-complete Problem

Blum and Rivest, Neural Networks 5, 117 (1992)

Exciton-Polariton Graphe Network

Quantum Innovation Laboratory

Na Young Kim

Institute for Quantum Computing

Waterloo Institute for Nanotechnology

Department of Electrical and Computer Engineering

Department of Physics and Astronomy (Cross-appointed)

Department of Chemistry (Cross-appointed)

Perimeter Institute (Affiliate member)

University of Waterloo

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