Manipulation of polariton condensates in semiconductor microcavity ridges

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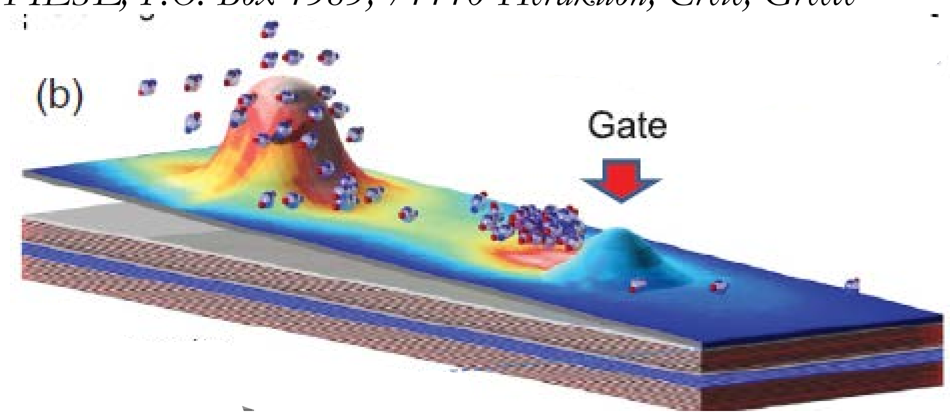


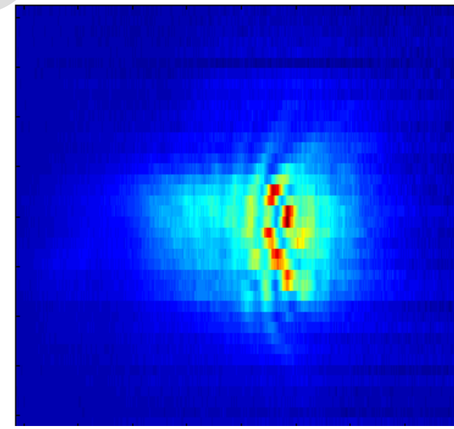
Manipulation of polariton condensates in semiconductor microcavity ridges

A. Amo, D. Sanvitto , F.P. Laussy, E. Del Valle, C. Tejedor

(UAM, Spain)

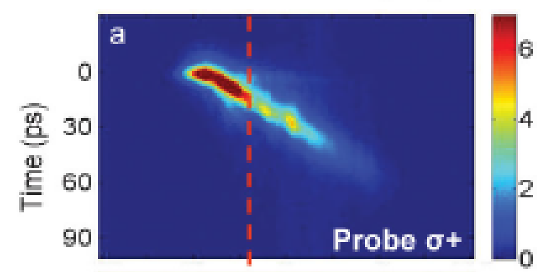
A. *Lemaitre*, J. Bloch **(CNRS, France)**

D. *Krizhanovskii*, M. S. Skolnick **(Univ. Sheffield, UK)**



C. Adrados, A. Bramati, E- Gacobino **(Université Pierre et Marie Curie, France)**

A. Kavokin **(University of Southampton, UK)**



A question

M. Lewenstein

SYMPOSIUM: LIGHT & MATTER @ THE QUANTUM LEVEL, 20/10/08

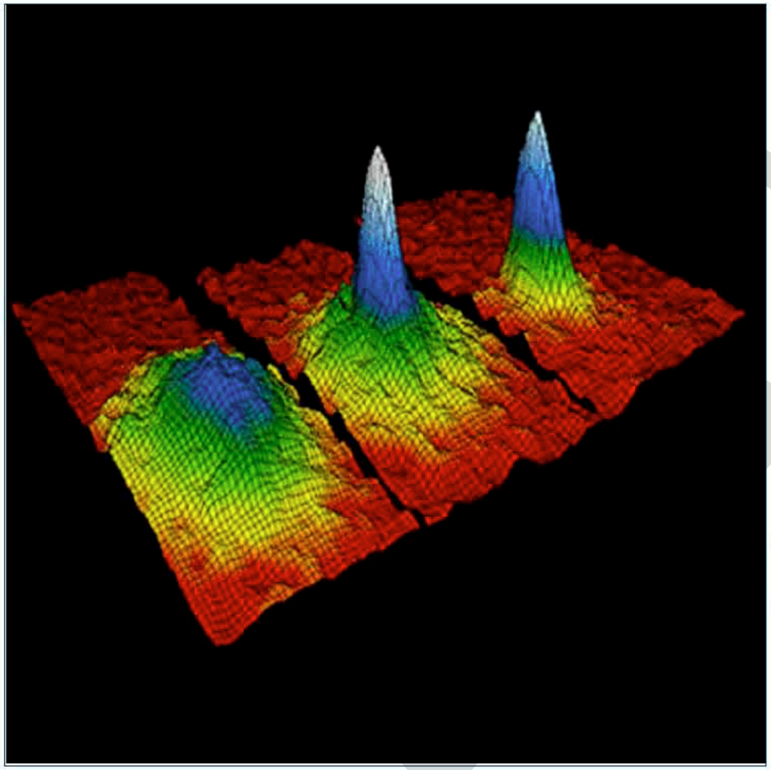
Atomic physics and quantum optics beat condensed matter physics ?

(attributed to Wolfgang Ketterle)

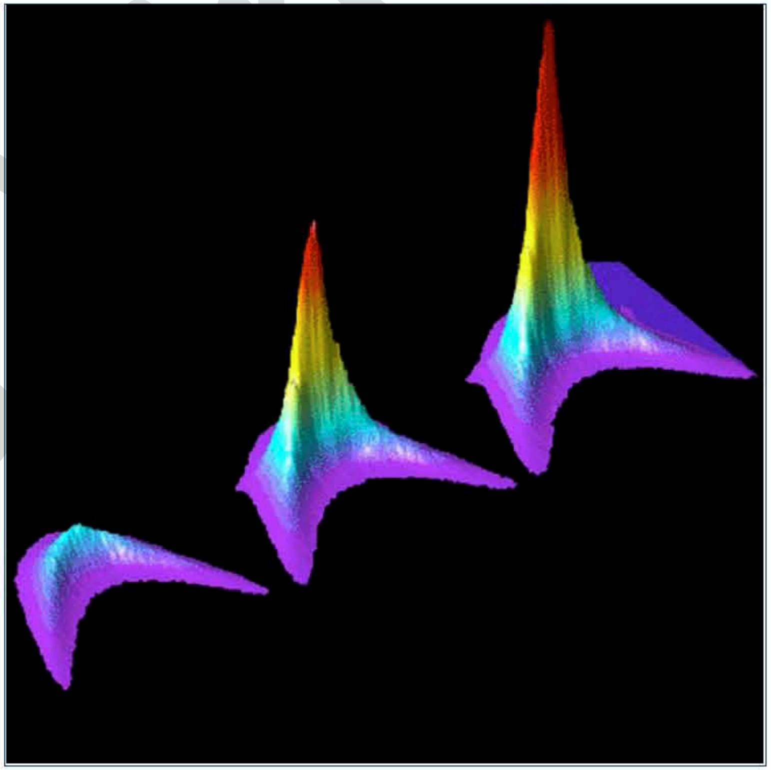
WELCOME to the homepage of the 2008 Latsis Symposium at EPFL on "Bose Einstein Condensation in dilute atomic gases and in condensed matter"

The Physics Nobel Prize in 2001 of Eric Cornell, Carl Wieman, Wolfgang Ketterle and recent publications in Journals such as Science and Nature have raised expectations in the field of Bose Einstein Condensation (BEC). The Symposium Latsis EPFL 2008 wishes to gather the experience developed by the " BEC Cold Atom" and the new "BEC Solid State" Communities. The Participants will have a unique opportunity to exchange ideas and compare findings. This will certainly lead to an unprecedented leap in BEC research, to the benefit of the two communities.

When: 28-30 January 2008
Where: EPF Lausanne, Switzerland



Observation of Bose-Einstein Condensation in a Dilute Atomic Vapor Science 1995



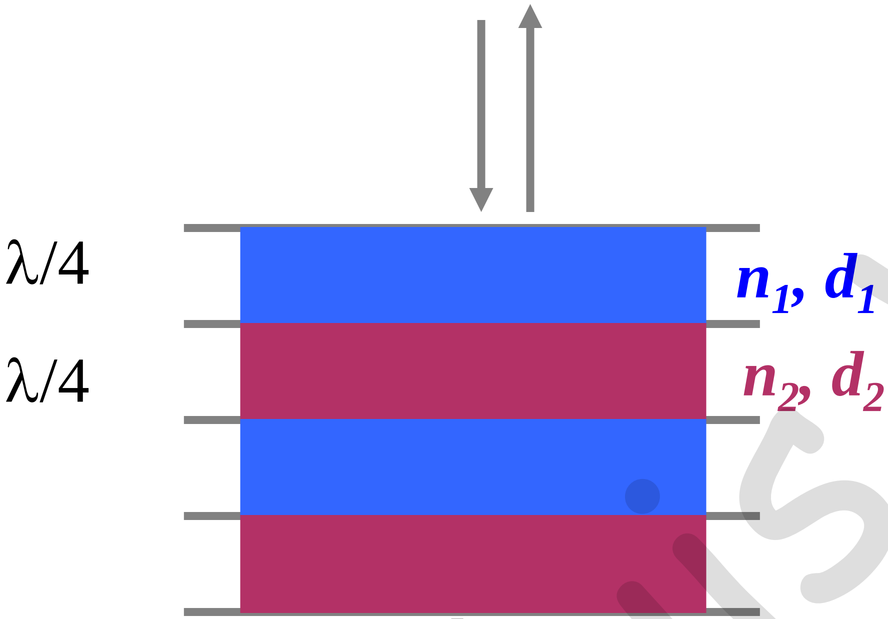
Bose-Einstein Condensation of exciton polaritons Nature 2006

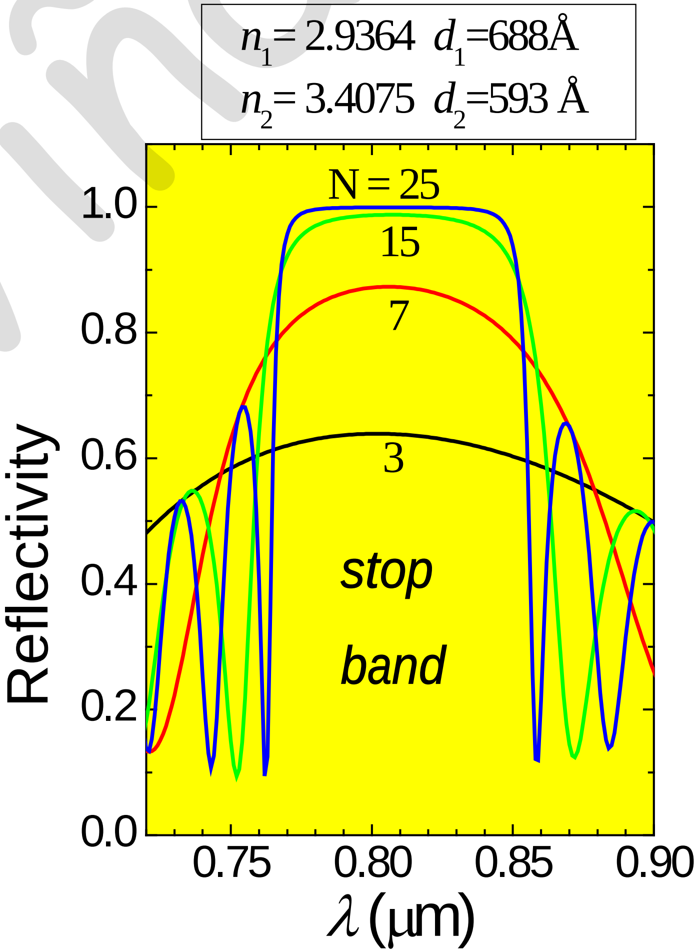
Outline

- Introduction
  microcavity polaritons
- Polariton BECs
- Dynamics of polariton fluids: the TOPO configuration
- Resonantly driven polaritons
  - Case of a long living quantum state put in motion
- Topological defects

Laser cavity(I)

Distributed Bragg Reflectors (DBR)



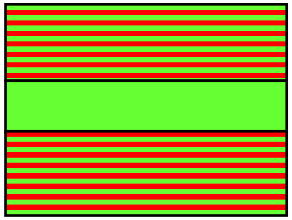


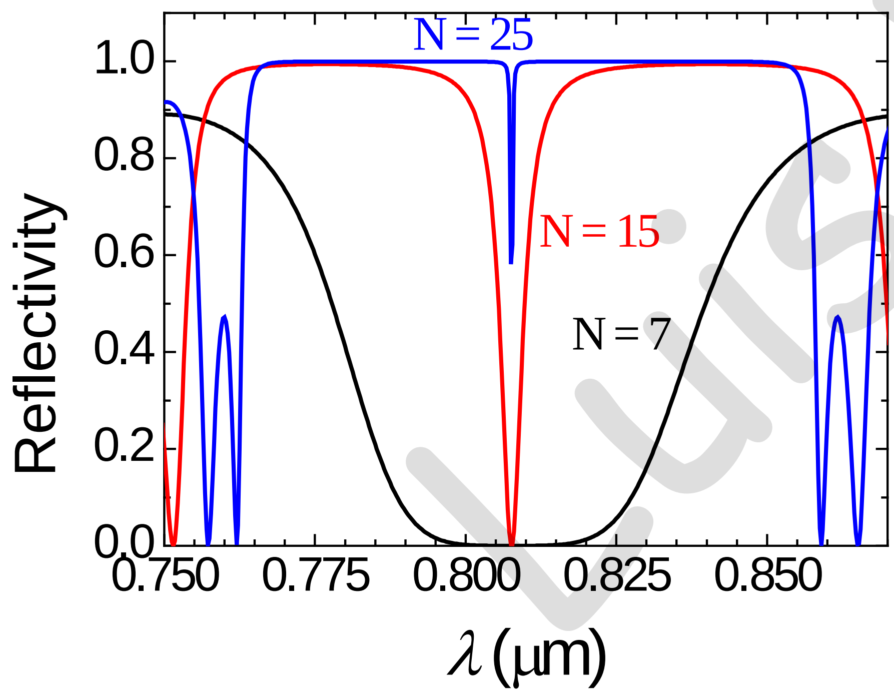
High reflectivity

- ***normal incidence***
- ***many periods***

Laser cavity(II)

- "Cavity" ⟷ open region (*d*) in the DBR
- "Defect" ⟶ Transmission increase (**R↓**)
- *d*=λ/2 ⟶ Transmission at center of "stop"band





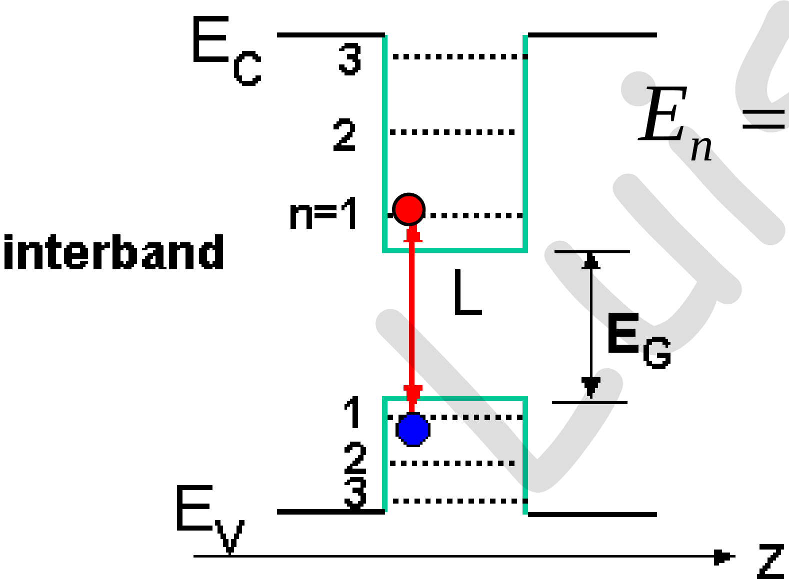
Emitter

in the cavity

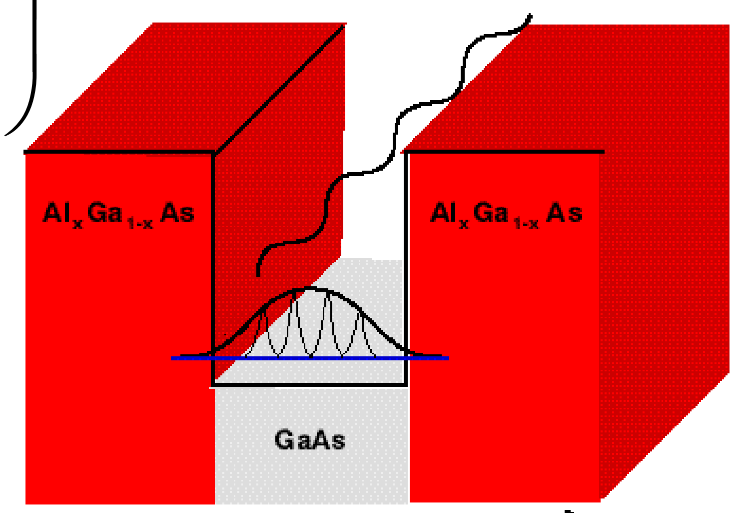
Emitter (I)

Quantum wells

- **Artificial structures**
- **Layers of ~10 nm, with different band gap**
- **Quantum mechanical confinement effects**

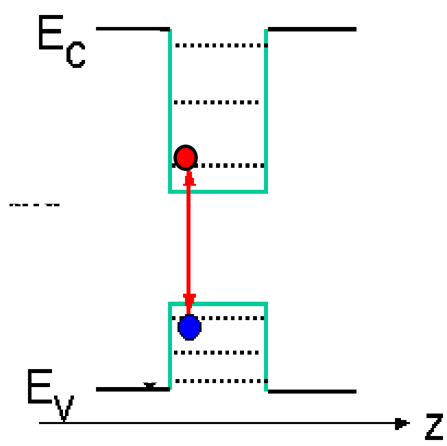


$$E_n = \frac{\hbar^2}{2m}\left(\frac{n\pi}{L}\right)^2$$

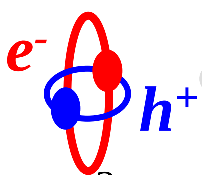


Excitons

Independent particles

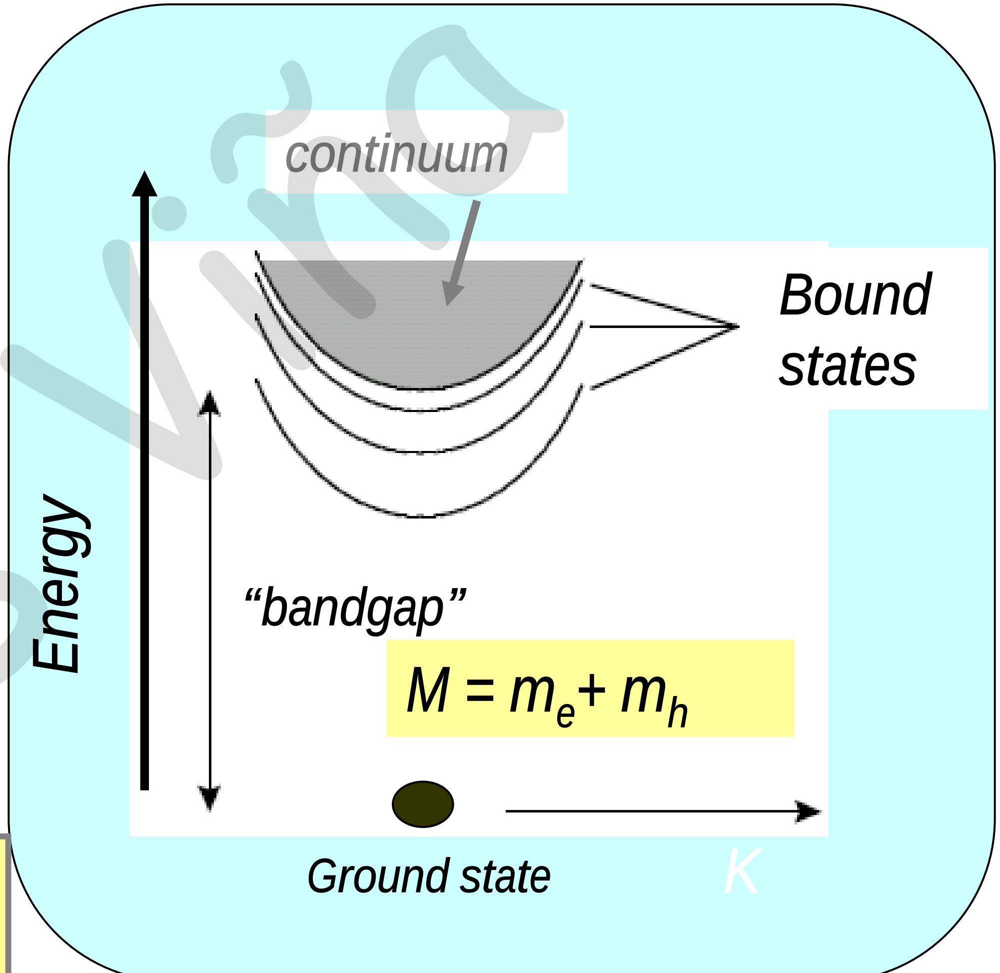


Coulomb interaction



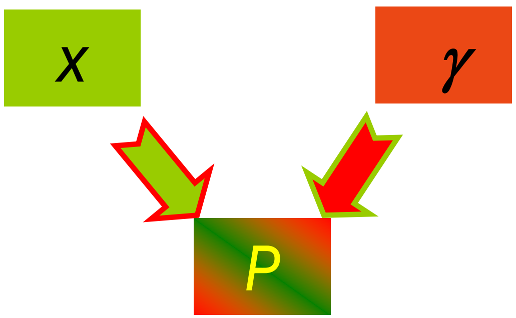
$$-\frac{e^2}{4\pi\varepsilon_r\varepsilon_o\left|\vec{r}_e-\vec{r}_h\right|}$$

$$\mu=\frac{m_e+m_h}{m_e\times m_h}$$



Integer Spin ⇒ Boson

Excitón-Polaritón (I)



$$g_0 = \vec{d} \bullet \vec{E}_0$$

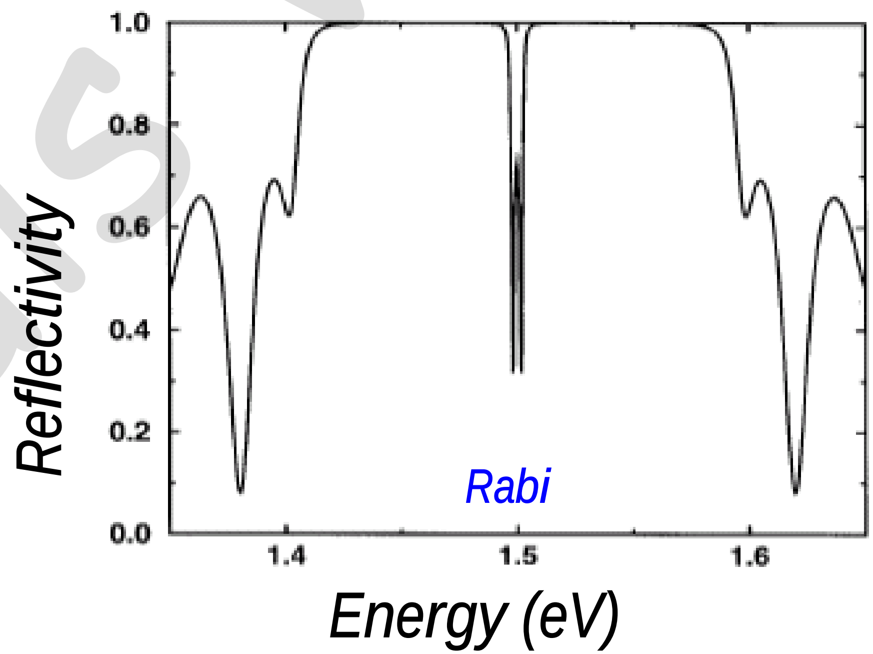
Integer Spin

⇓

Boson

Strong coupling

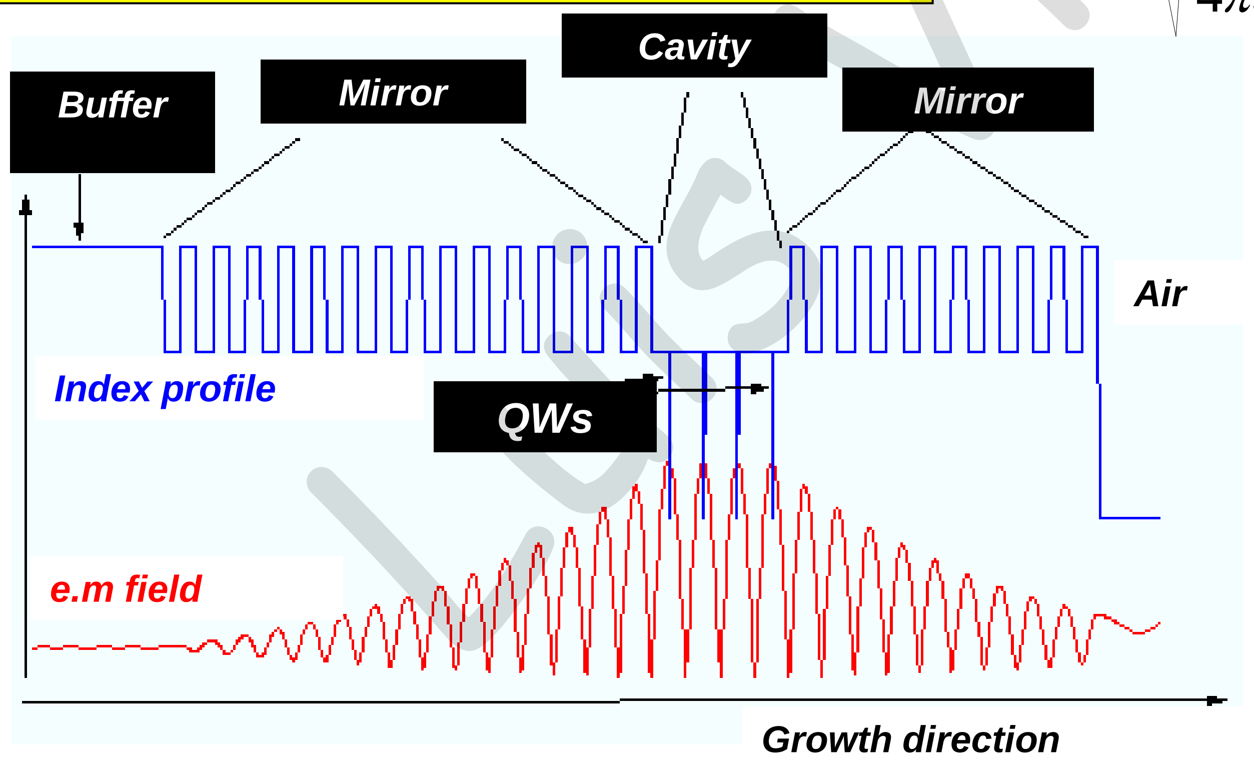
- *Slow dumping rates*
- *Oscillations* $|X, \gamma\rangle \leftrightarrow |\gamma, X\rangle$
- *Mode anticrossing* ➔ *Rabi*



Excitón-Polaritón (II)

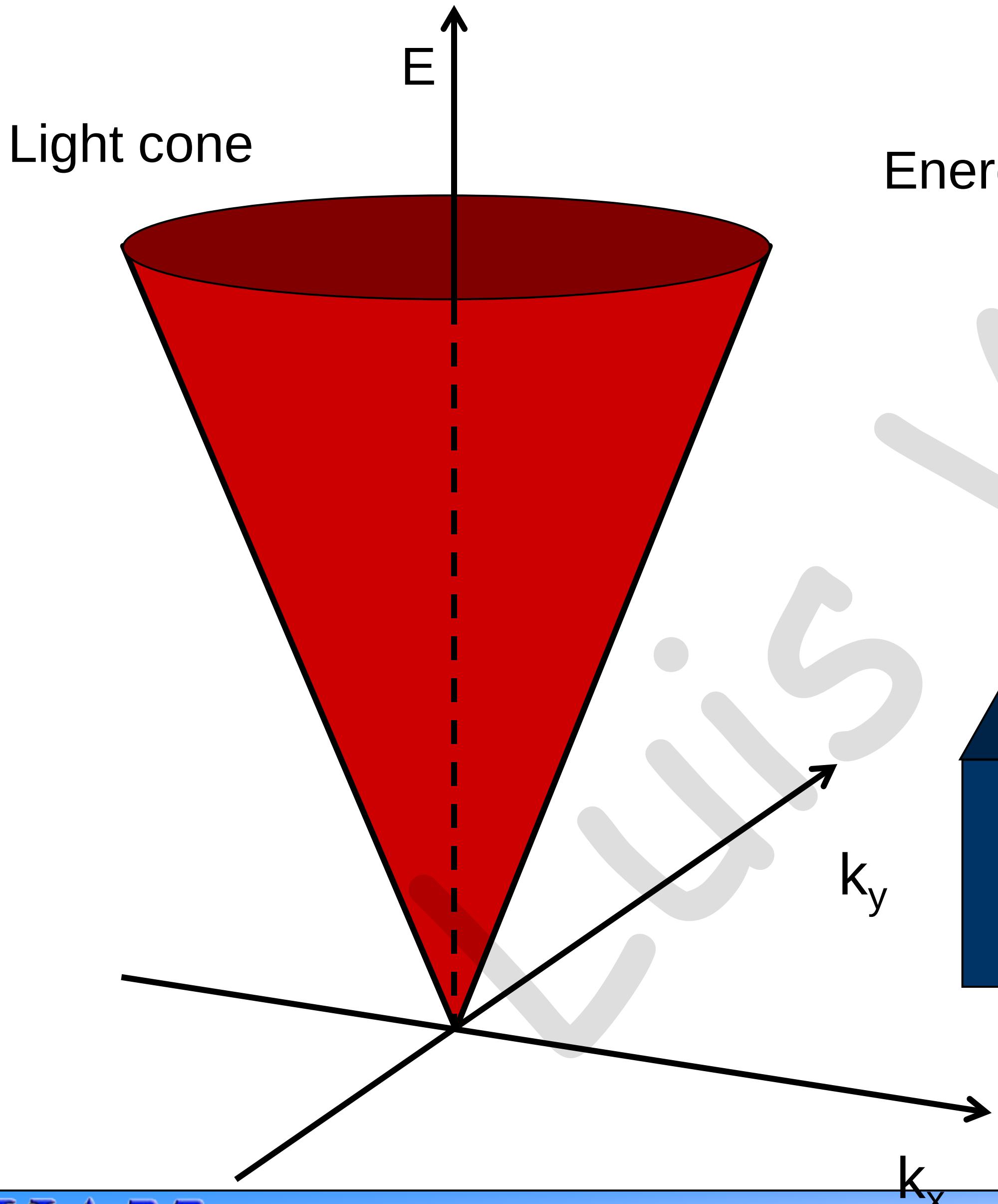
Matter-radiation interaction optimization

$$\Omega = 2\sqrt{\frac{e^2}{4\pi\varepsilon_0\varepsilon_r}\,\frac{2\pi}{m_0}\,\frac{N}{L_{eff}}\,f_X}$$



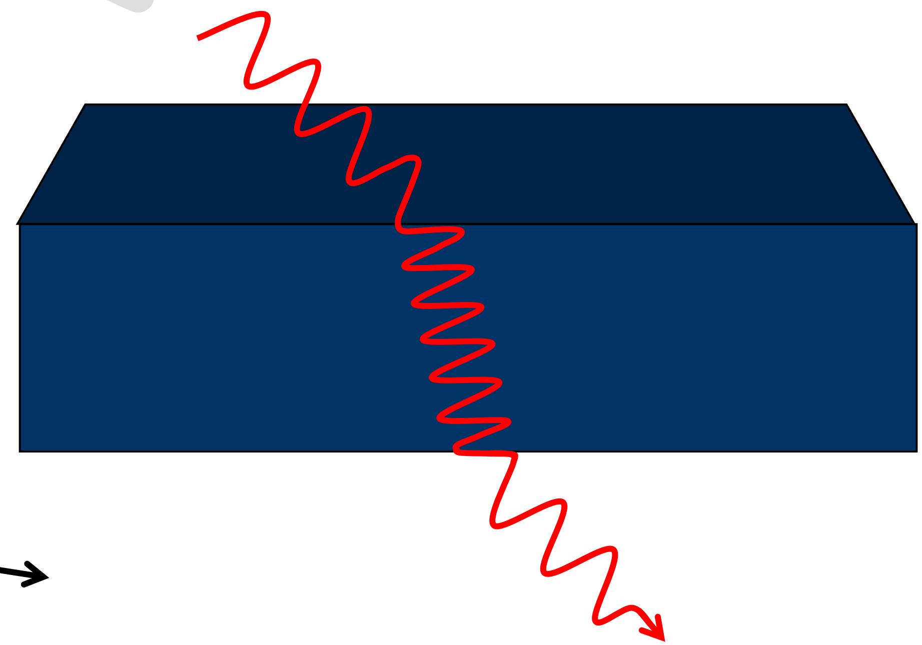
Position

Semiconductor microcavities

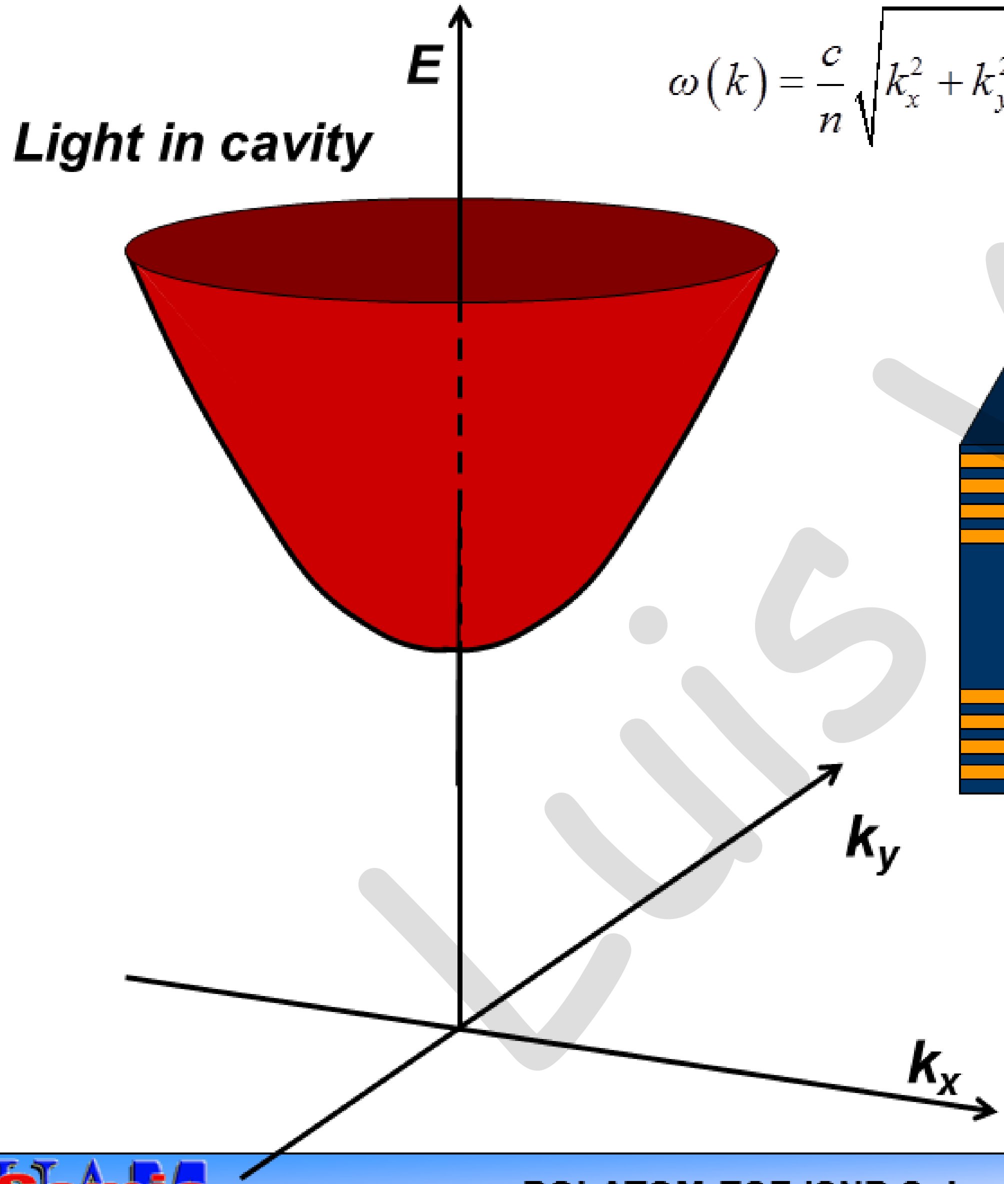


Energy dispersion for a photon in a solid

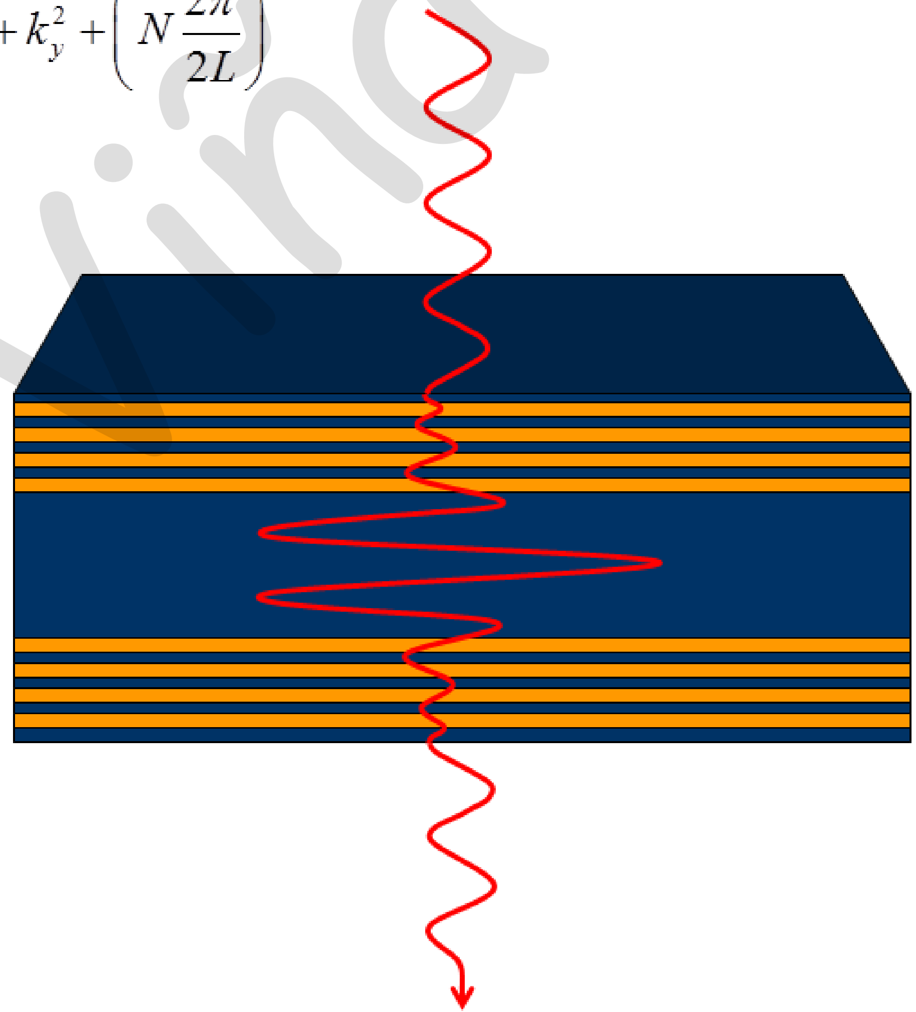
$$\omega = \frac{c}{n}\left|\vec{k}\right|$$



Semiconductor microcavities



$$\omega(k) = \frac{c}{n}\sqrt{k_x^2 + k_y^2 + \left(N\frac{2\pi}{2L}\right)^2}$$



Semiconductor microcavities

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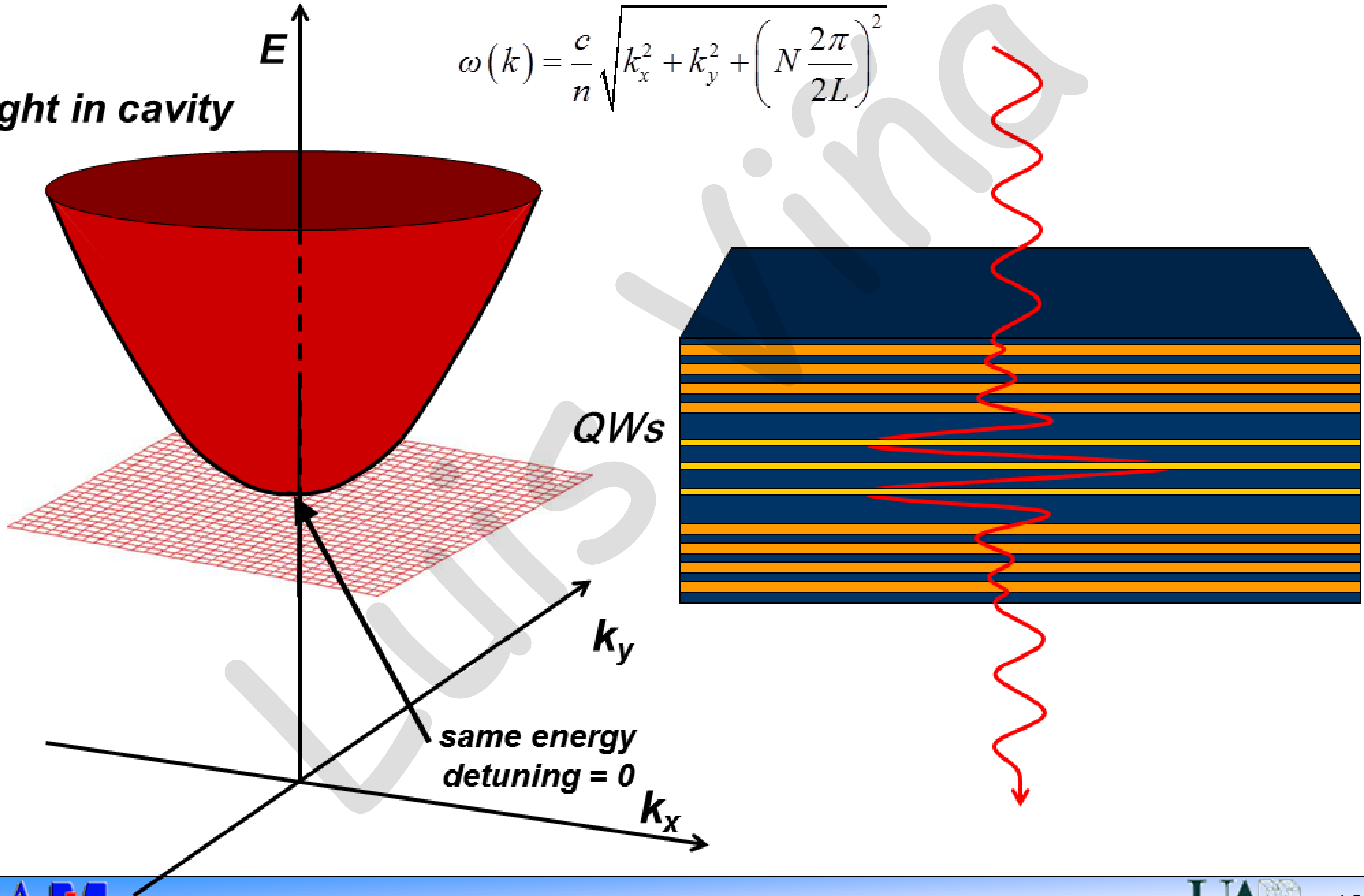

Semiconductor microcavities

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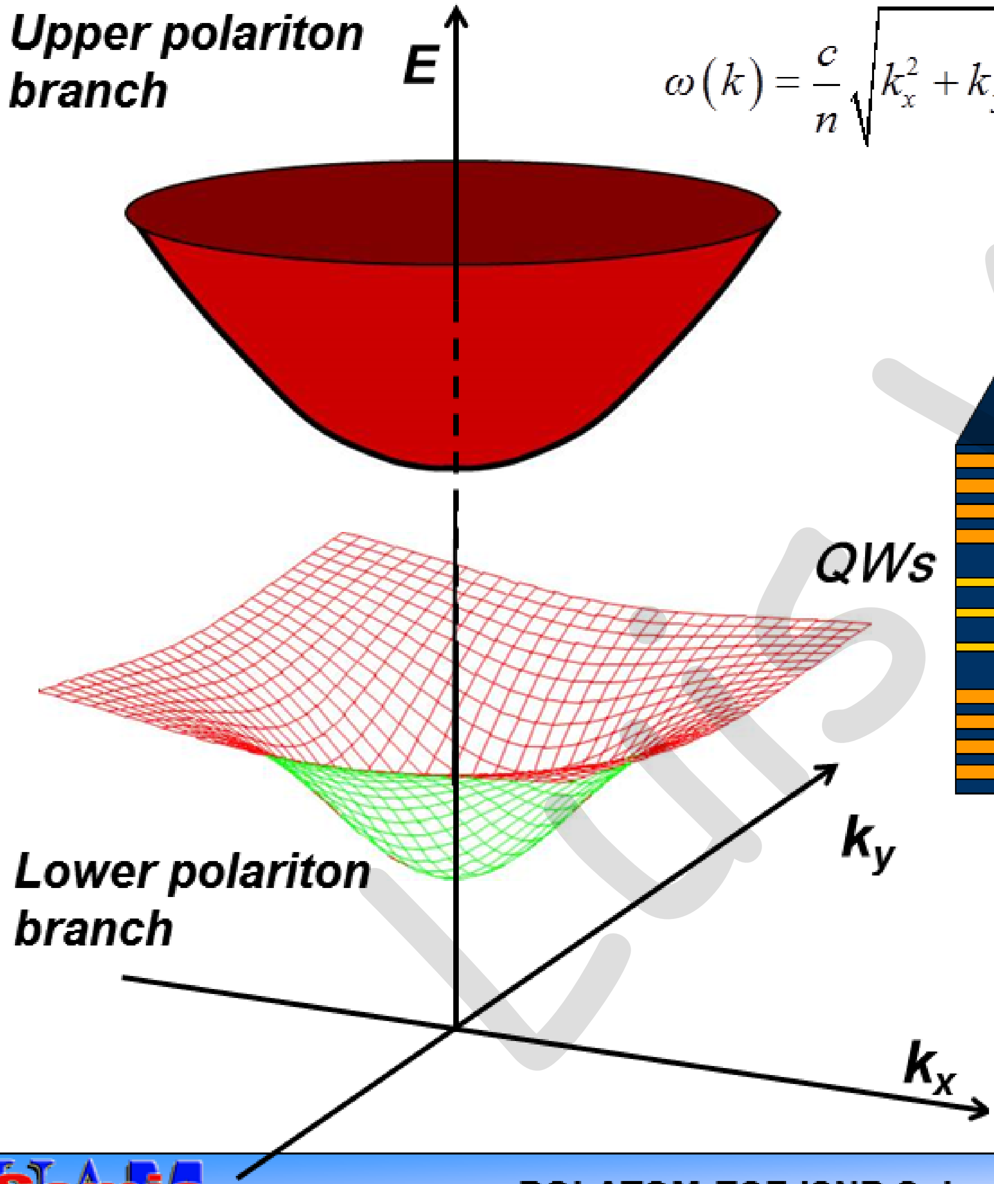
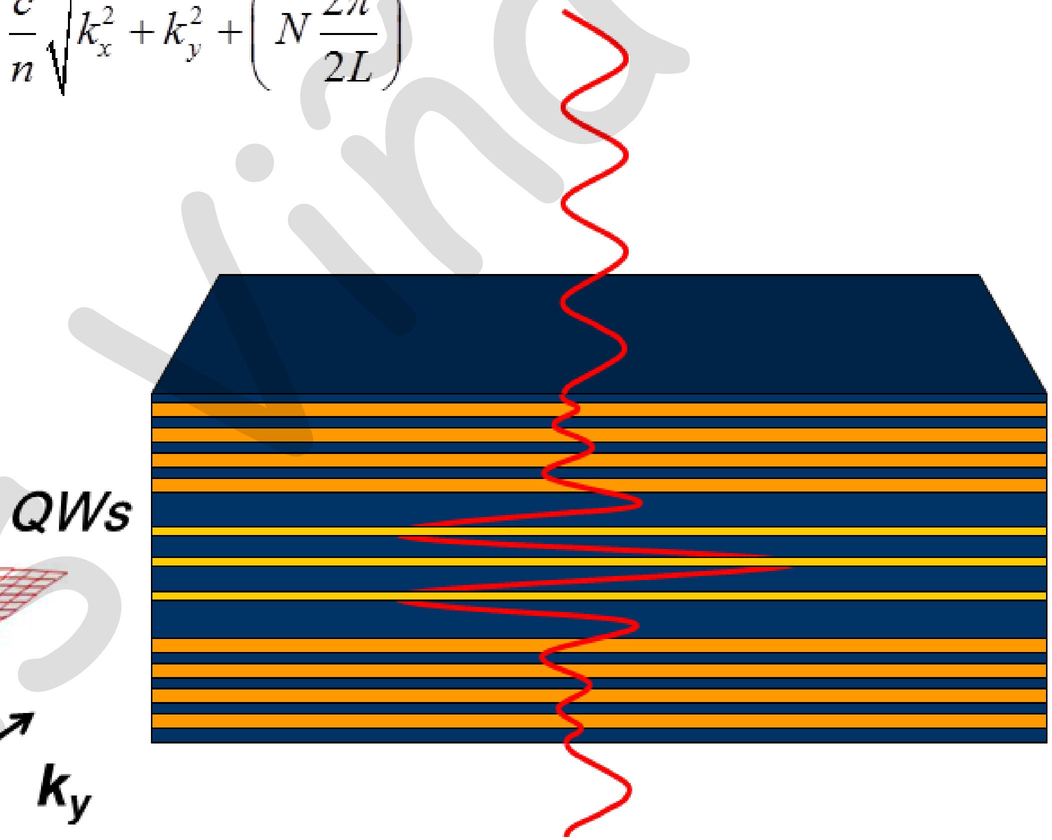




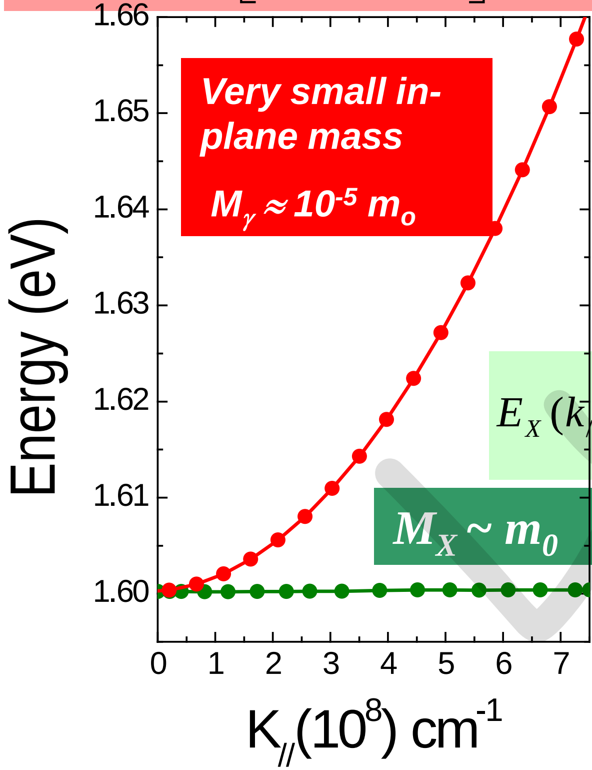
$$\mathcal{H}_{pol}\left(k_{\parallel}\right) = \begin{pmatrix} \hbar\omega_c\left(k_{\parallel}\right) & \hbar\Omega_R \\ \hbar\Omega_R & \hbar\omega_x\left(k_{\parallel}\right) \end{pmatrix}$$

Dispersion relations

Along growth direction (confinement): $K_z = 2\pi/L$

De-coupled

$$E_\gamma(k_{//}) = \frac{\hbar c}{n}\left[\left(\frac{2\pi}{L}\right)^2 + k_{//}^2\right]^{1/2} == E_0\left(1+\frac{\hbar^2 c^2 k_{//}^2}{E_0^2 n^2}\right)^{1/2}$$



Very small in-plane mass

$M_\gamma \approx 10^{-5}\, m_o$

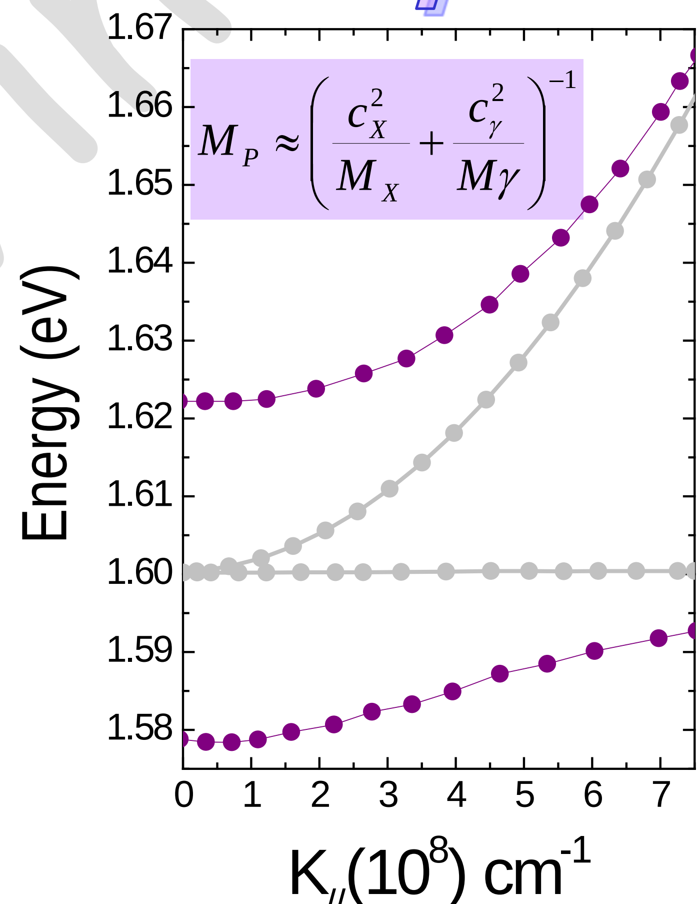
$$E_X(k_{//}) = \frac{\hbar^2 k_{//}^2}{2M_X}$$

$M_X \sim m_0$

$$K_{//} = \frac{E}{\hbar c}\sin\theta$$

Coupled

$$M_P \approx \left(\frac{c_X^2}{M_X} + \frac{c_\gamma^2}{M\gamma}\right)^{-1}$$



Strong coupling régime: observation of the anti-crossing

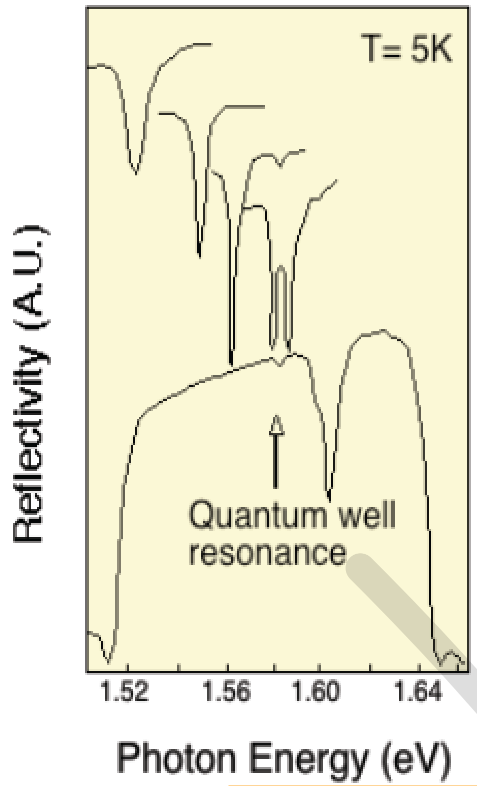
changing detuning by moving on wedge sample

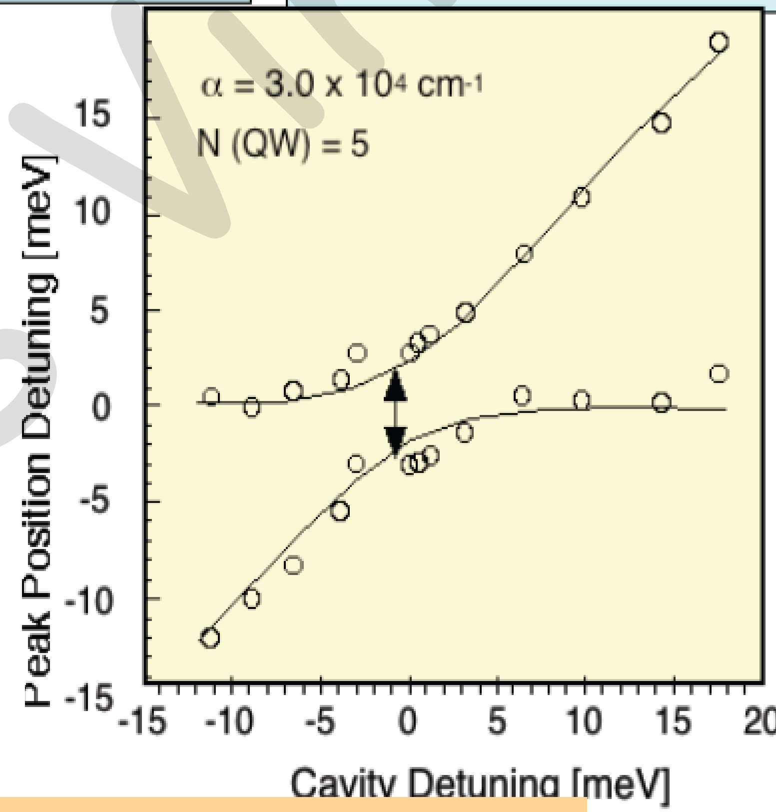
$$\hbar\Omega = dE_0 = d\sqrt{\frac{\hbar\omega_{ph}}{\varepsilon_0 V_{cav}}}$$

implies

.photon lifetime longer than Rabi period

.exciton damping slower than rabi oscillation





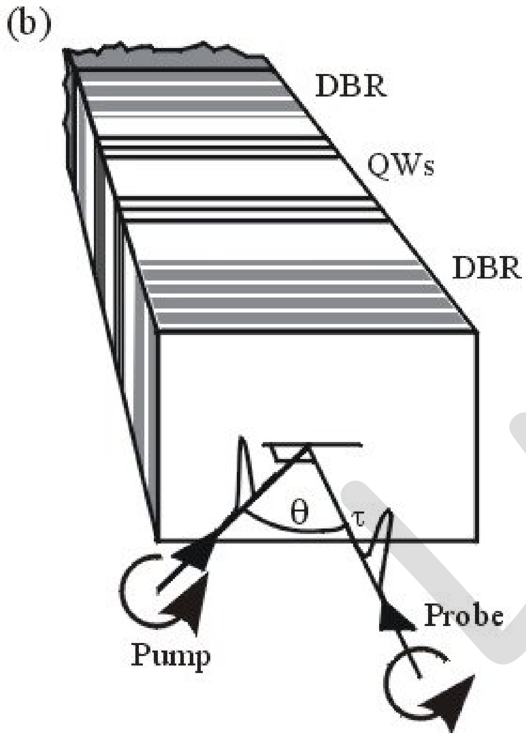
C. Weisbuch *et al.*, Phys. Rev. Lett. **69**, 3314 (1992)

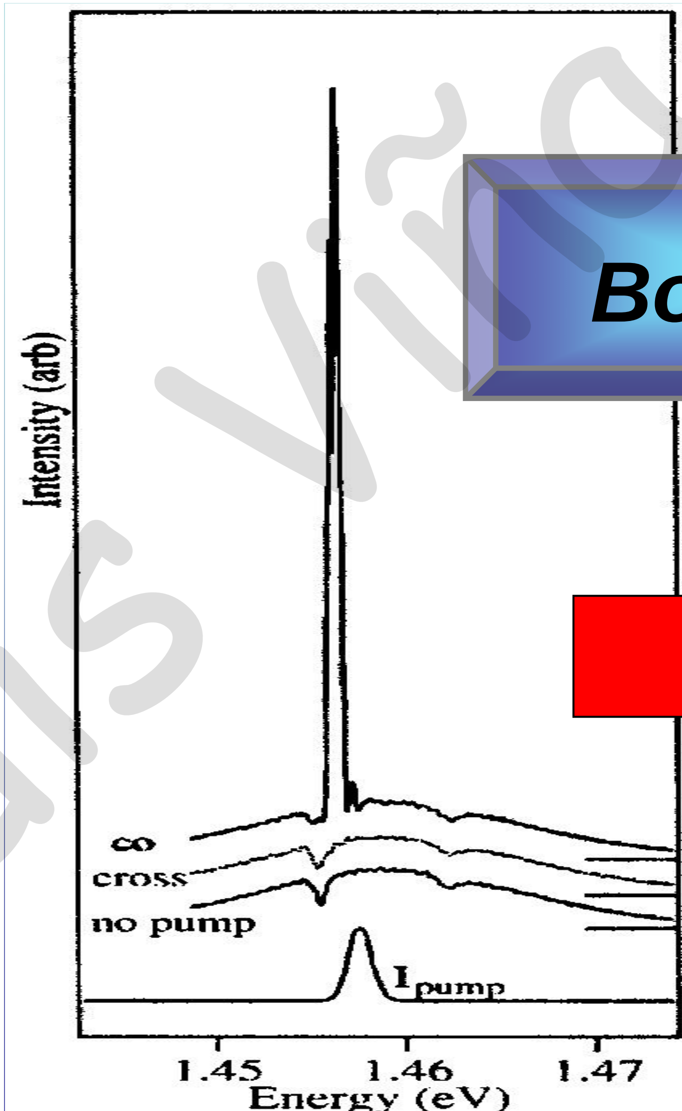
Angle-Resonant Stimulated Polariton Amplifier

P.G. Savvidis et al. Phys. Rev. Lett. 84, 1547 (2000)

Reflectivity:

"pump & probe"

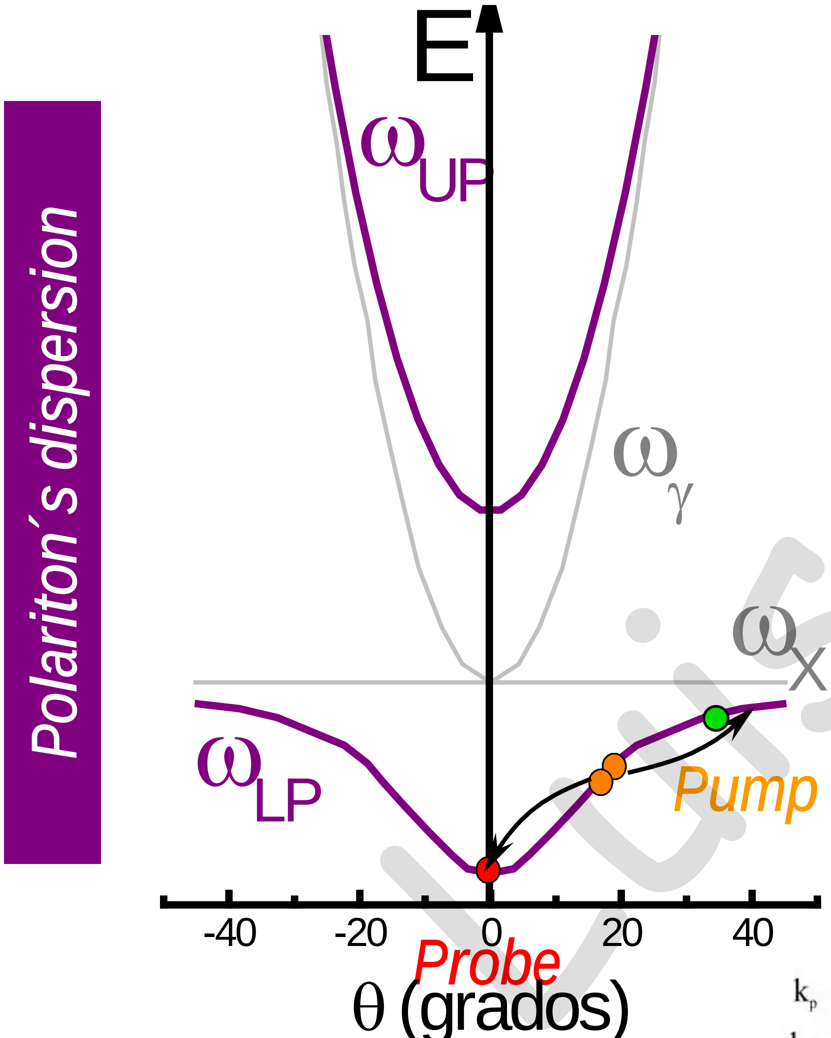


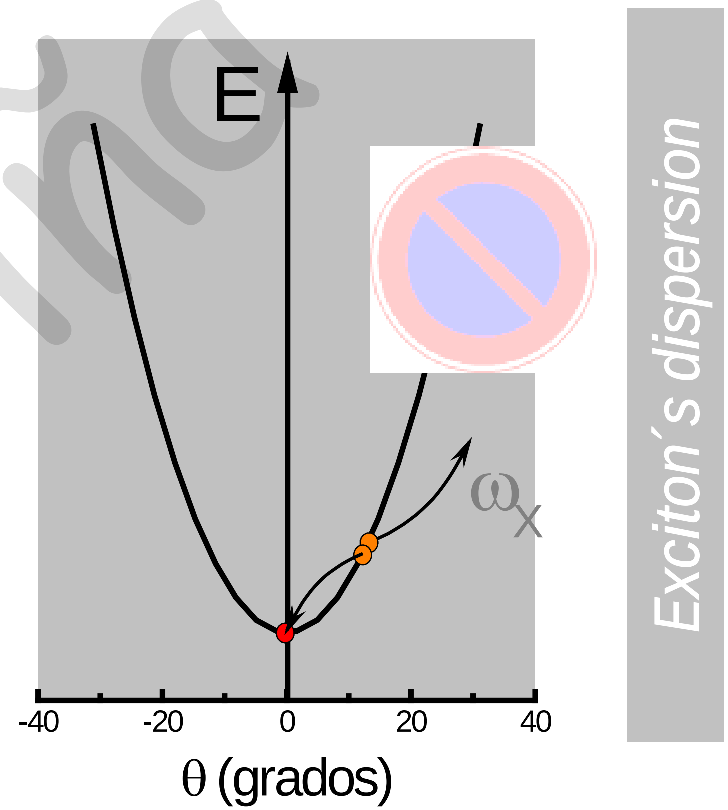


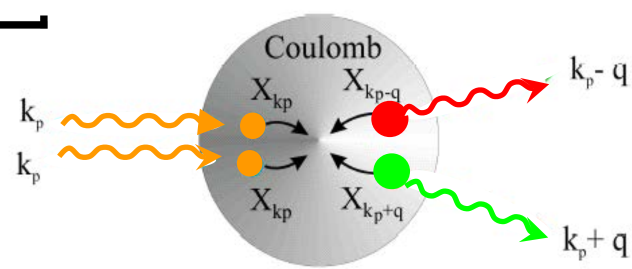
Bosons

Gain 700%

Stimulated scattering



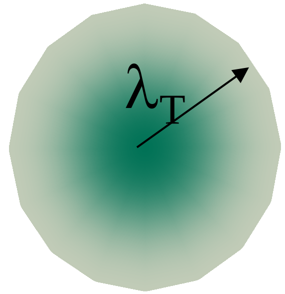




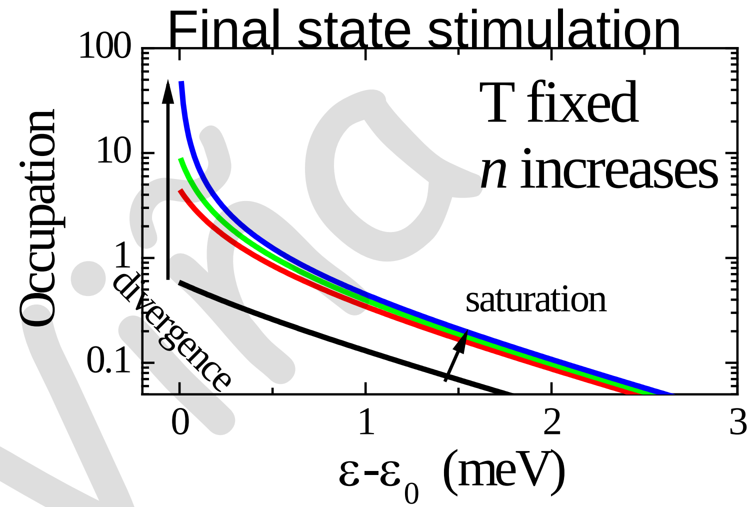
Atomic BECs

$$f_{BE} = \frac{1}{\exp\left(\frac{\varepsilon - \mu}{k_B T}\right) - 1}$$

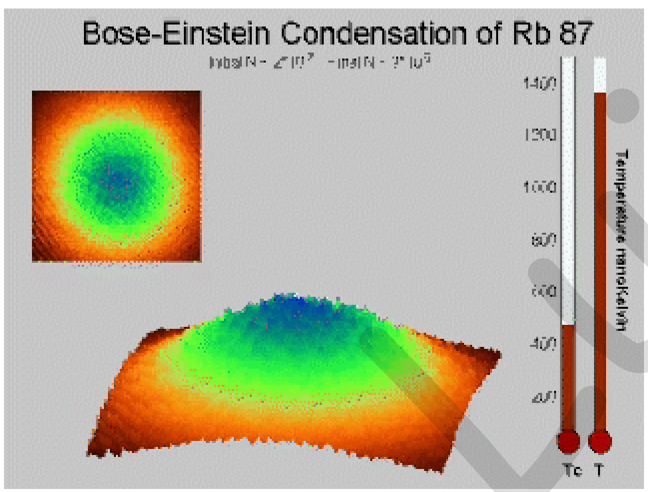
$$\lambda_T = \left(\frac{2\pi\hbar^2}{m k_B T}\right)^{\frac{1}{2}}$$



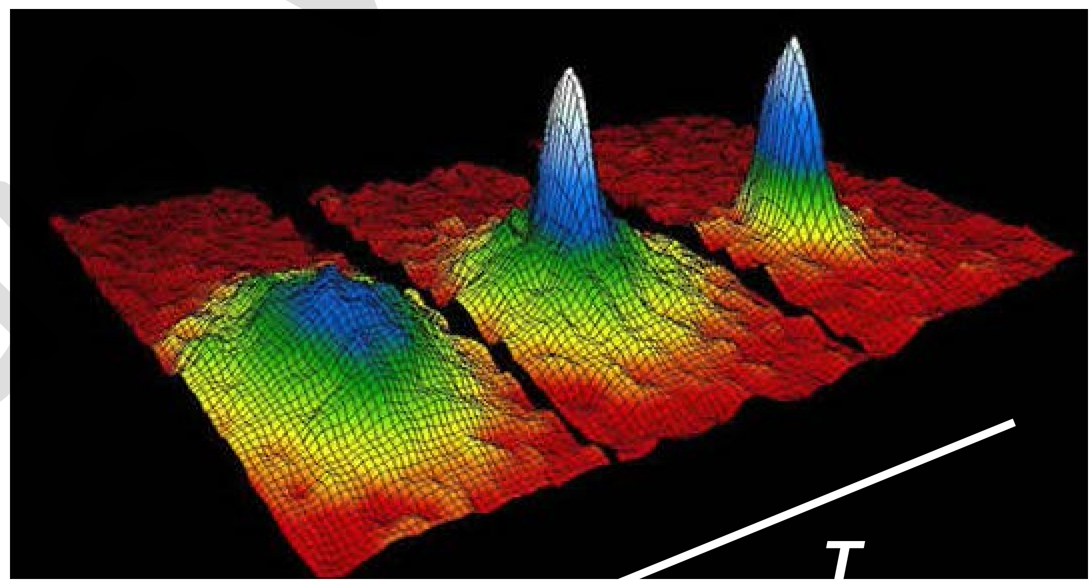
For T < T_{deg}
the particles-waves overlap



Long-range order



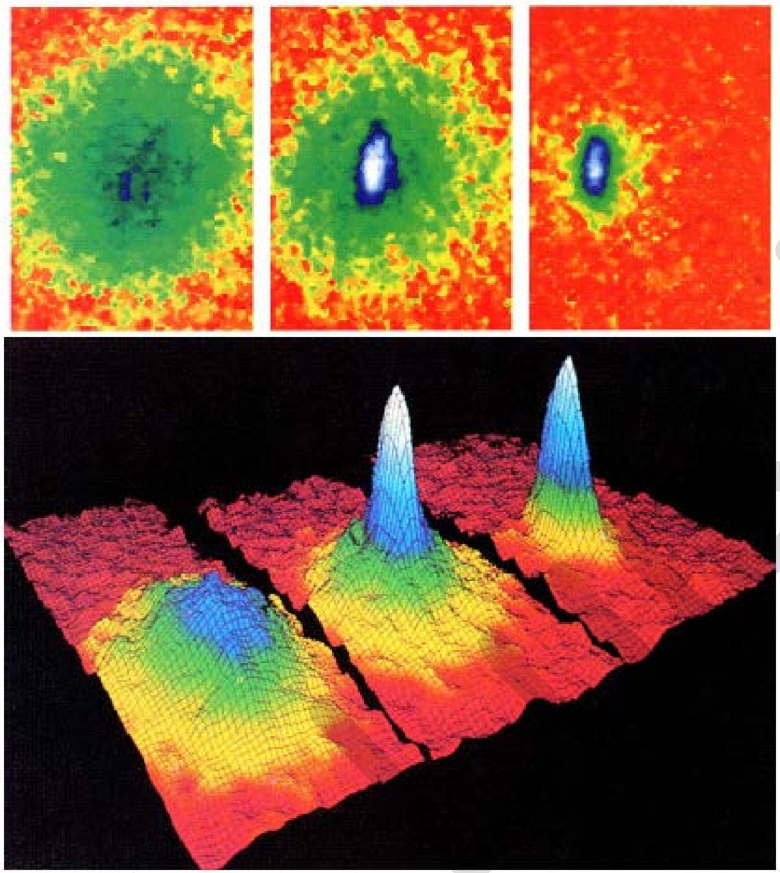
Cornell group (1995)



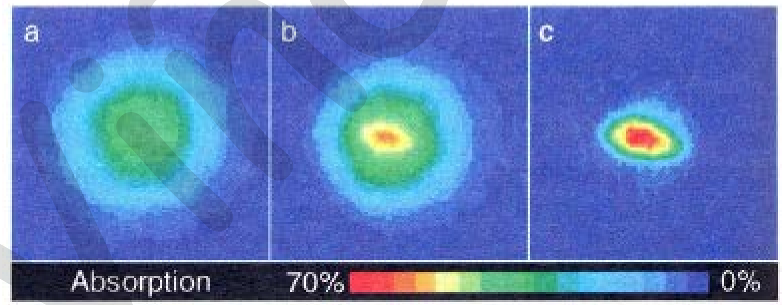
http://jilawww.colorado.edu/bec/

Bose-Einstein condensation in alkali atoms

http://jilawww.colorado.edu/bec/



Rubidium: Science **269**, 198 (1995)
JILA, Colorado

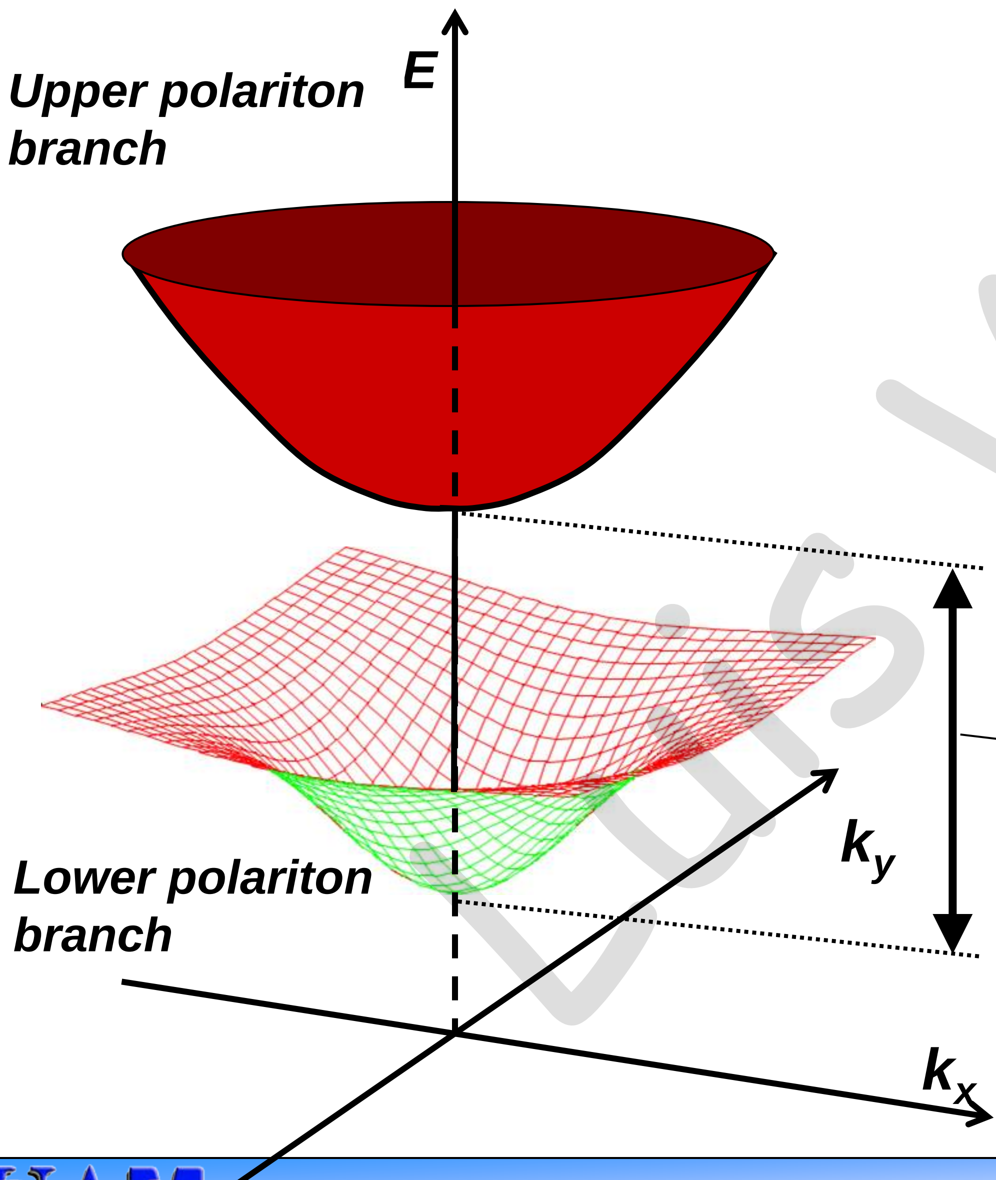


T

Sodium: PRL **75**, 3969 (1995)
MIT, Massachusetts

E.A. Cornell
W. Ketterle
C.E. Wieman

Semiconductor microcavities



Strong exciton confinement
Enhanced electromagnetic field

↓

Strong light-matter coupling

New eigenstates
POLARITONS

$$\hat{Q}_{UPB} = c \cdot \hat{P} + d \cdot \hat{X}$$

$$\hat{Q}_{LPB} = -d \cdot \hat{P} + c \cdot \hat{X}$$

Rabi splitting

$$\Omega_R^2 = \frac{\left(1+\sqrt{R}\right)^2}{2\sqrt{R}} \frac{c\Gamma_0}{n_{cav} L_{eff}}$$

Low polariton mass

“S” shaped dispersion

Momentum trap

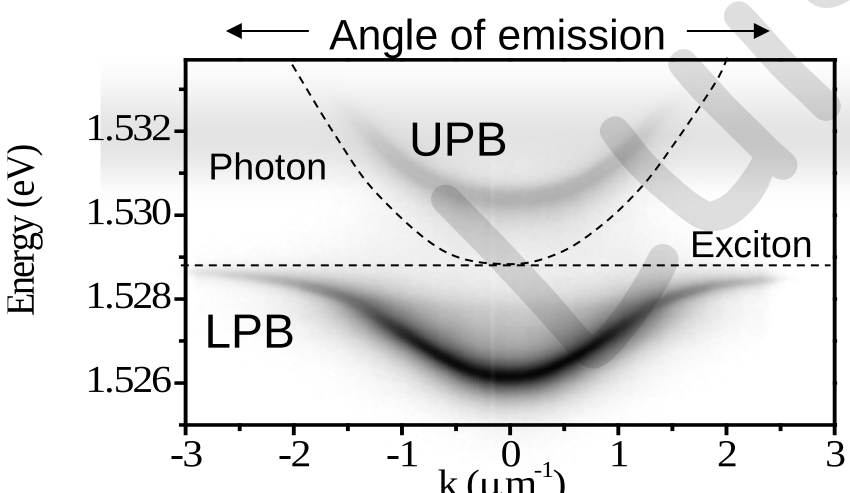
Polaritons

New eigenstates

POLARITONS

$$\hat{Q}_{UPB} = c \cdot \hat{P} + d \cdot \hat{X}$$

$$\hat{Q}_{LPB} = -d \cdot \hat{P} + c \cdot \hat{X}$$



Polariton lifetime: 2-8 ps (at k = 0)

PL experiment

Polaritons

New eigenstates
POLARITONS

$$\hat{Q}_{UPB} = c \cdot \hat{P} + d \cdot \hat{X}$$

$$\hat{Q}_{LPB} = -d \cdot \hat{P} + c \cdot \hat{X}$$

composite BOSONS

photonic content ⟷ very low mass

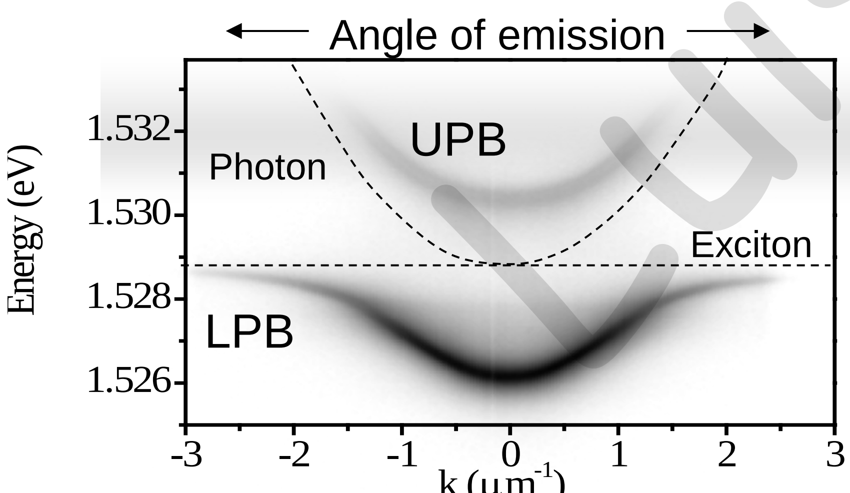
↓

High condensation temperature

10 K -300 K

$$\lambda_T = \left(\frac{2\pi\hbar^2}{m k_B T} \right)^{\frac{1}{2}}$$

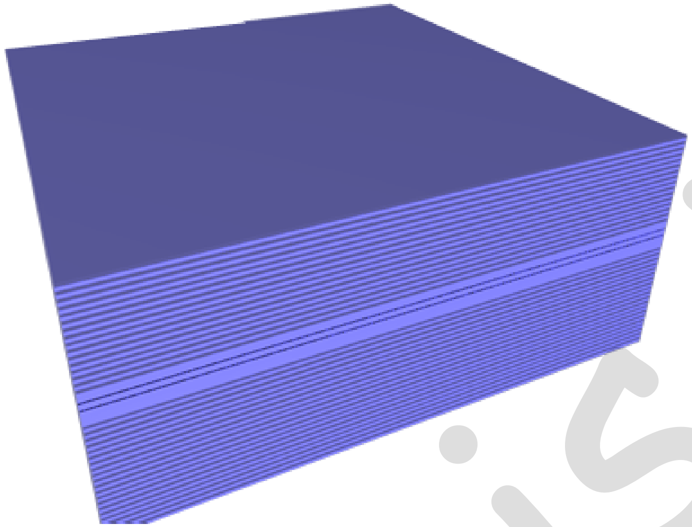
species	atomic gases	polaritons
mass m^*/m_0	10^4	10^{-5}
Bohr radius	10^{-1} Å	10^2 Å
λ_T at T_c	10^3 Å	10^4 Å
T_c	$< 1\mu$K	$10 - 300$K

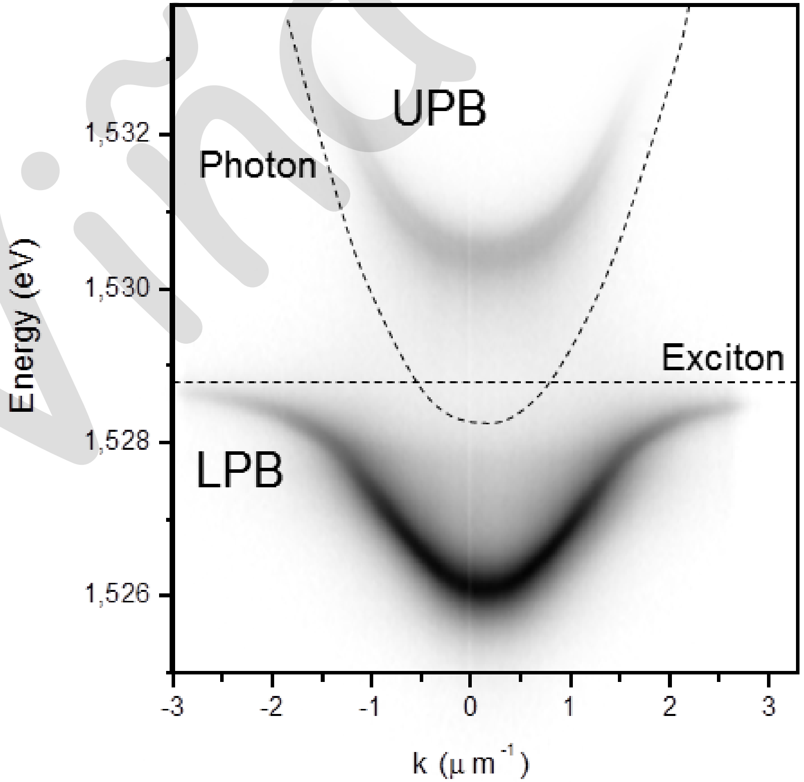


Polariton lifetime: 2-8 ps (at k = 0)

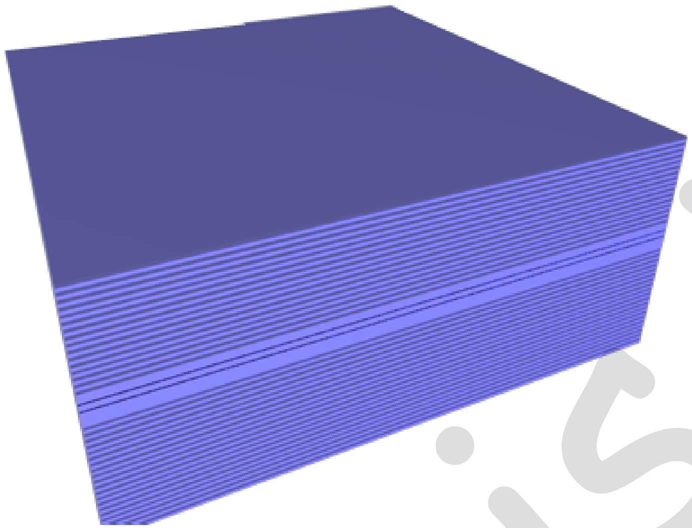
PL experiment

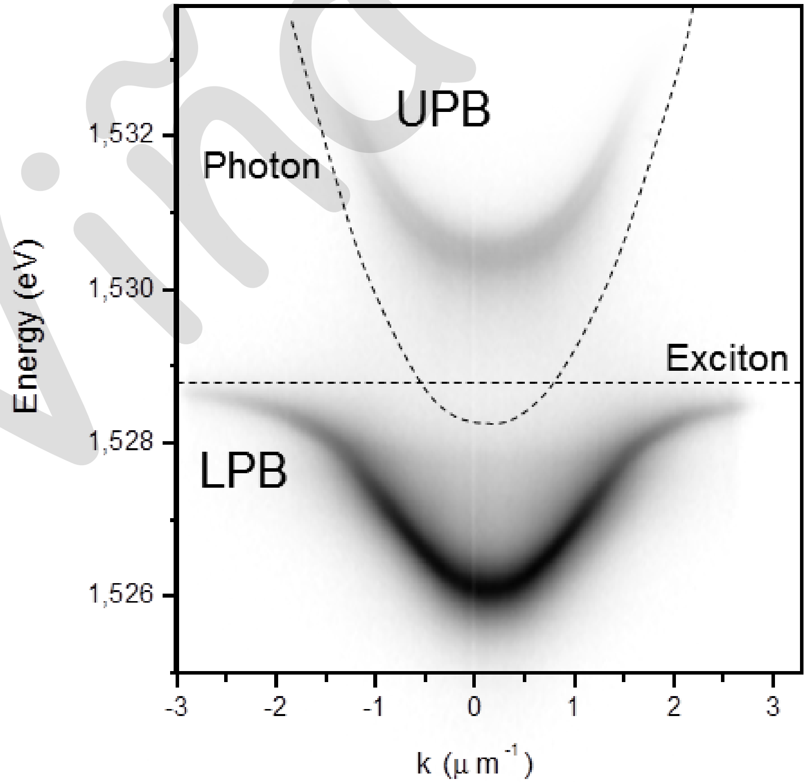
Polaritons



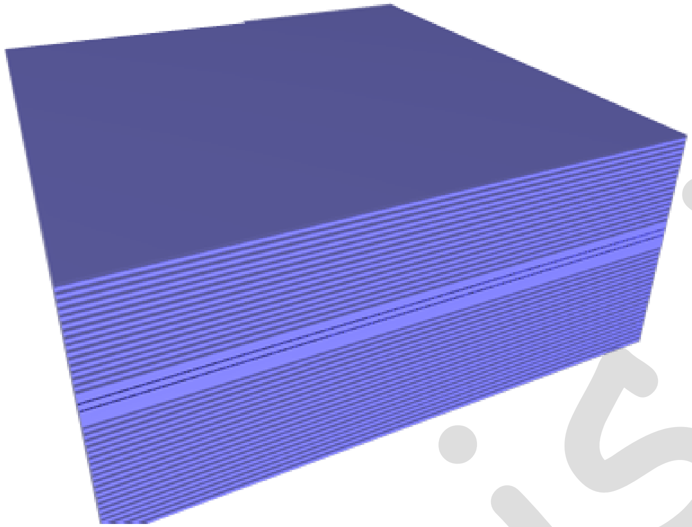

UPB
Photon
Exciton
LPB
Energy (eV)
1,532
1,530
1,528
1,526
-3
-2
-1
0
1
2
3
k (μ m^{-1})

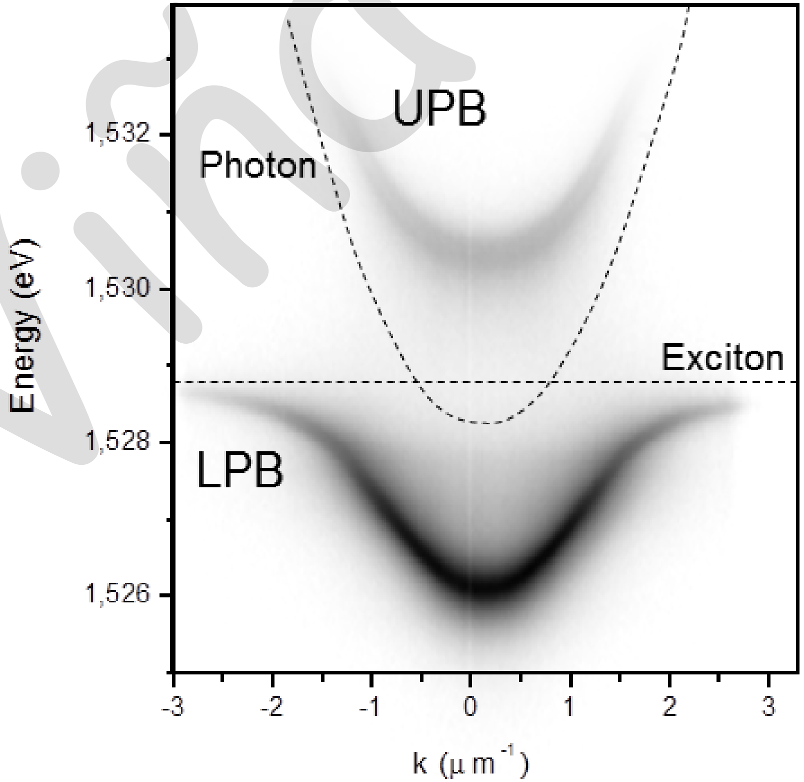
Polaritons




UPB
Photon
Exciton
LPB
Energy (eV)
1,532
1,530
1,528
1,526
-3
-2
-1
0
1
2
3
k (μ m⁻¹)

Polaritons



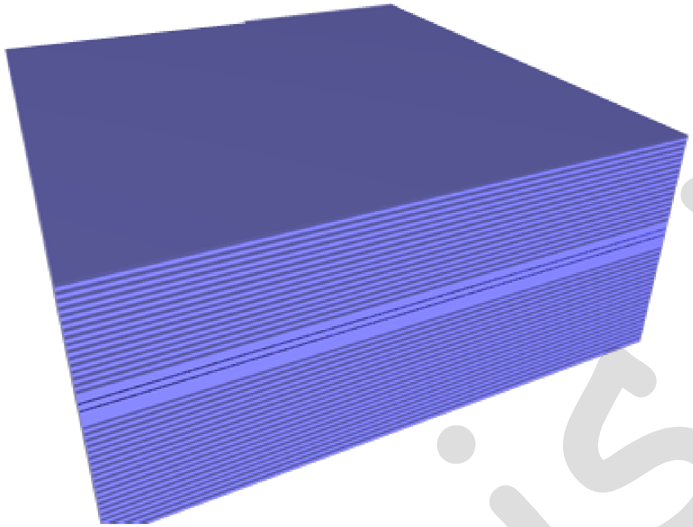


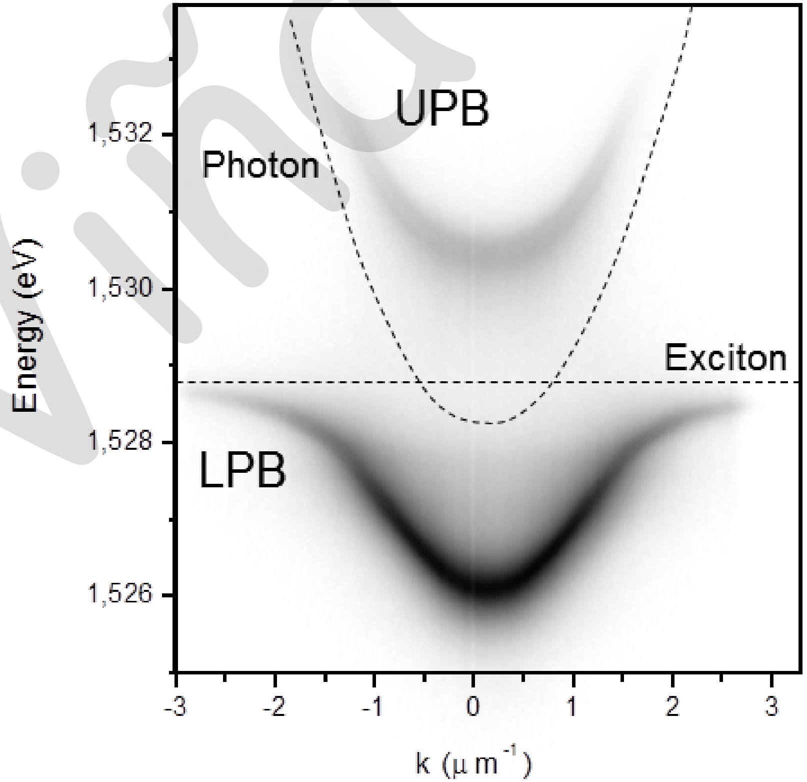
- Low mass (10^{-5} m_e) → low density of states

$$\lambda_T = \left(\frac{2\pi\hbar^2}{m k_B T} \right)^{\frac{1}{2}}$$

High condensation temperatures (10 K -300 K)

Polaritons





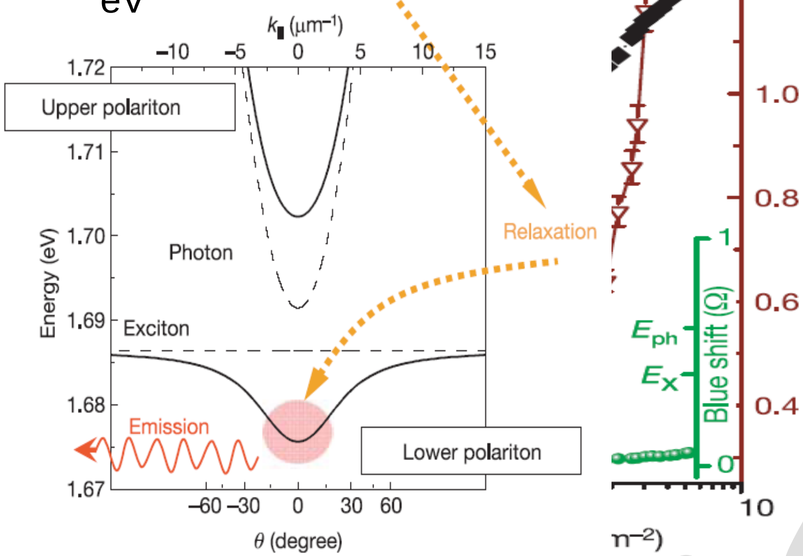
- Low mass (10^{-5} m_e) → low density of states
- Strong non-linearities (χ^3) → polariton OPO

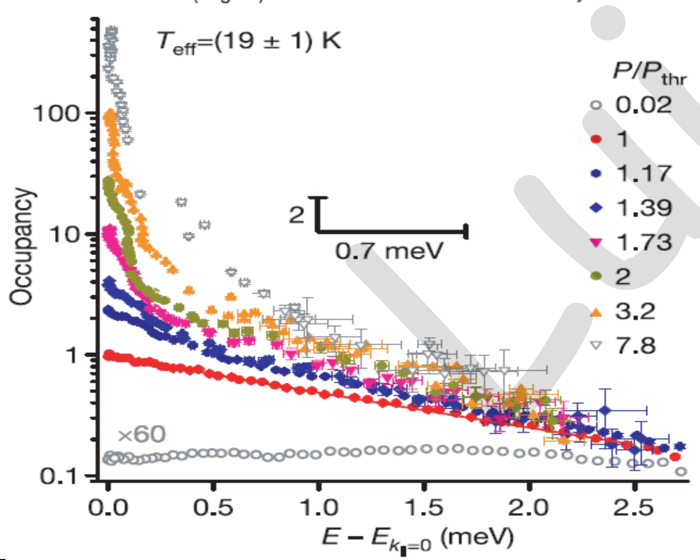
↓

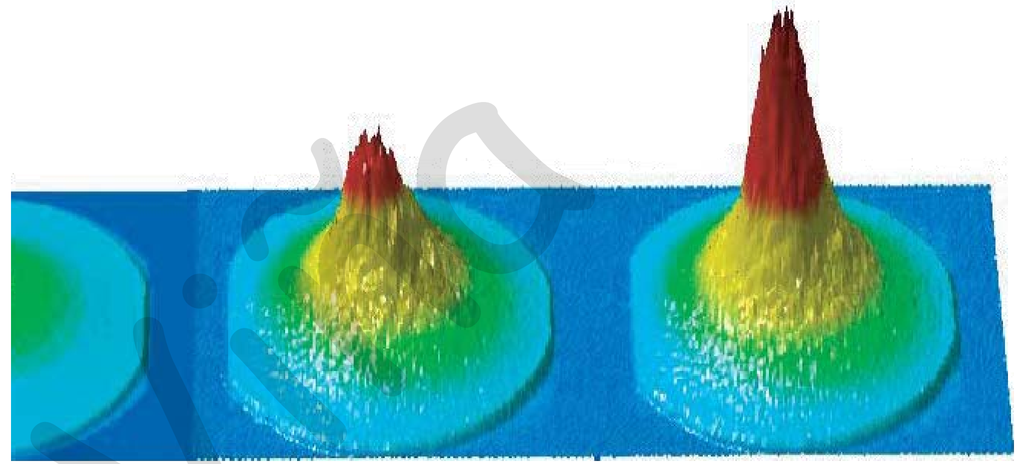
Ideal system to study interacting BEC

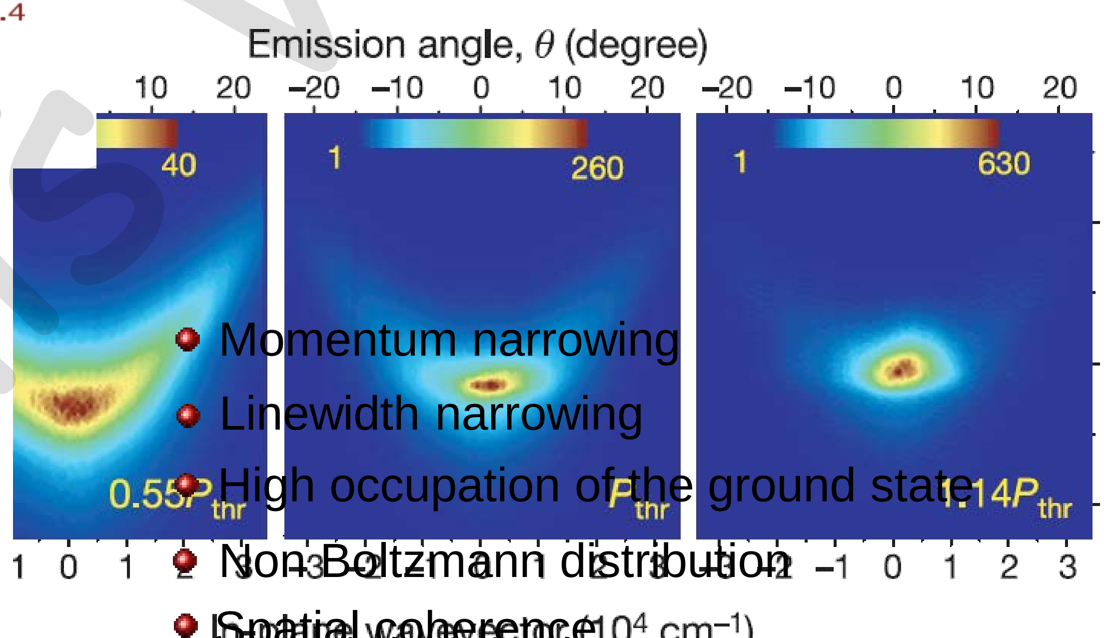
BEC of polaritons

Excitation CW laser 1.755 eV







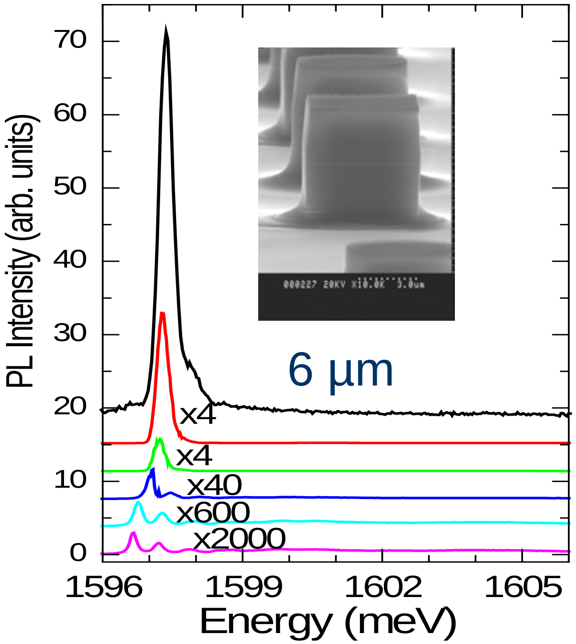


- Momentum narrowing
- Linewidth narrowing
- High occupation of the ground state
- Non-Boltzmann distribution
- Spatial coherence

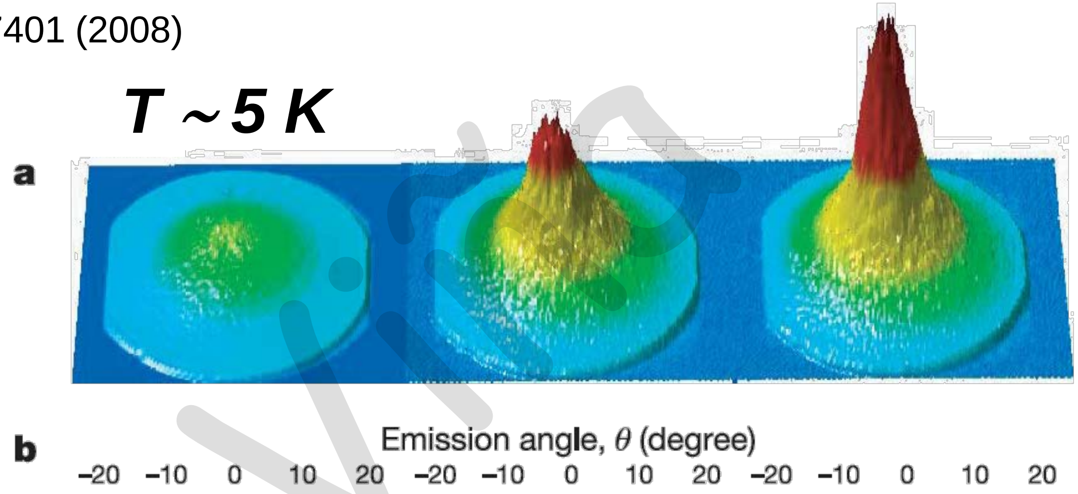
Kasprzak *et al.* Nature, **443**, 409 (2006)

BEC of polaritons

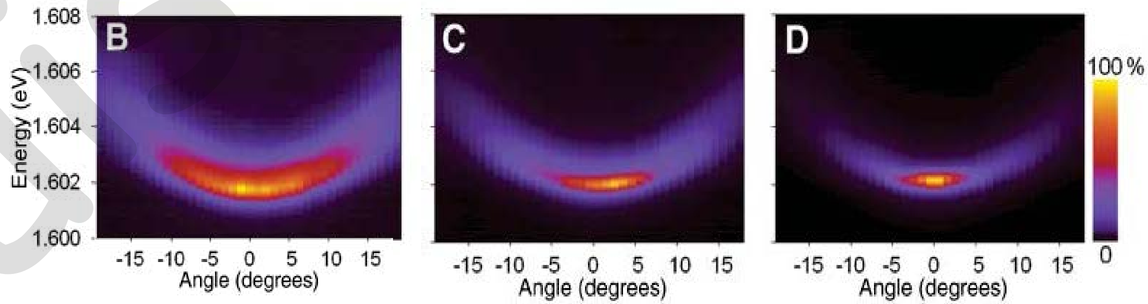
D. Bajoni *et al.*, Phys. Rev. Lett. **100**, 047401 (2008)

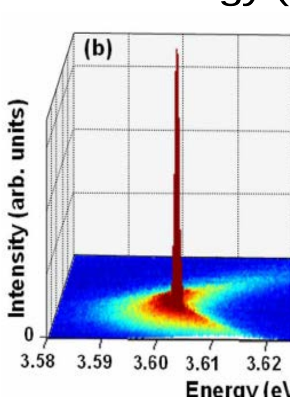


T ~ 5 K



J. Kasprzak *et al.* Nature*,* **443**, 409 (2006)





T ~ 300 K

R. Balili *et al.,* Science **316**, 1007 (2007)

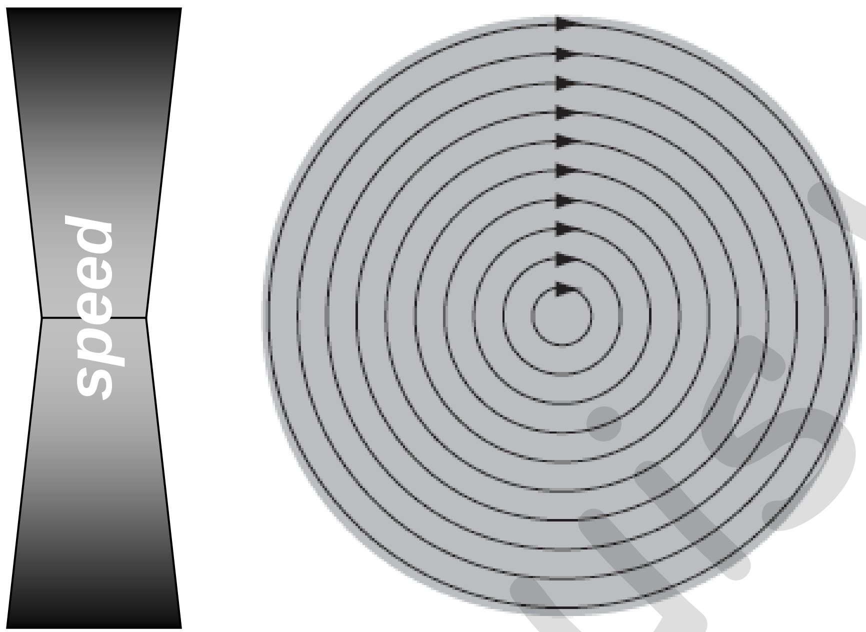
S. Christopoulos Phys. Rev. Lett. 2007,
G. Christmann App. Phys. Lett. 2008

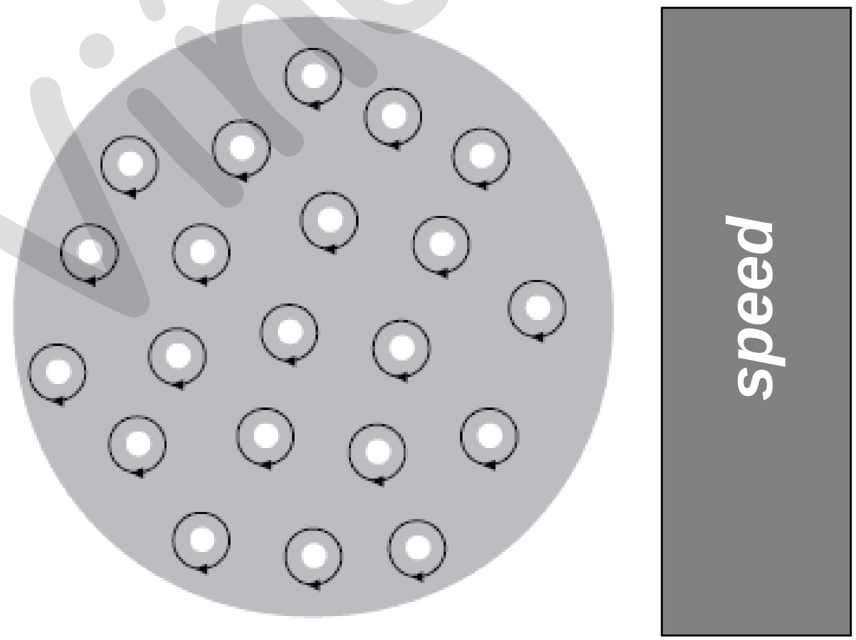
Superfluid flow of Helium through the pores of a glass & Helium fountain

http://www.youtube.com

Superfluidity: phenomenology

Normal fluid | **Superfluid**

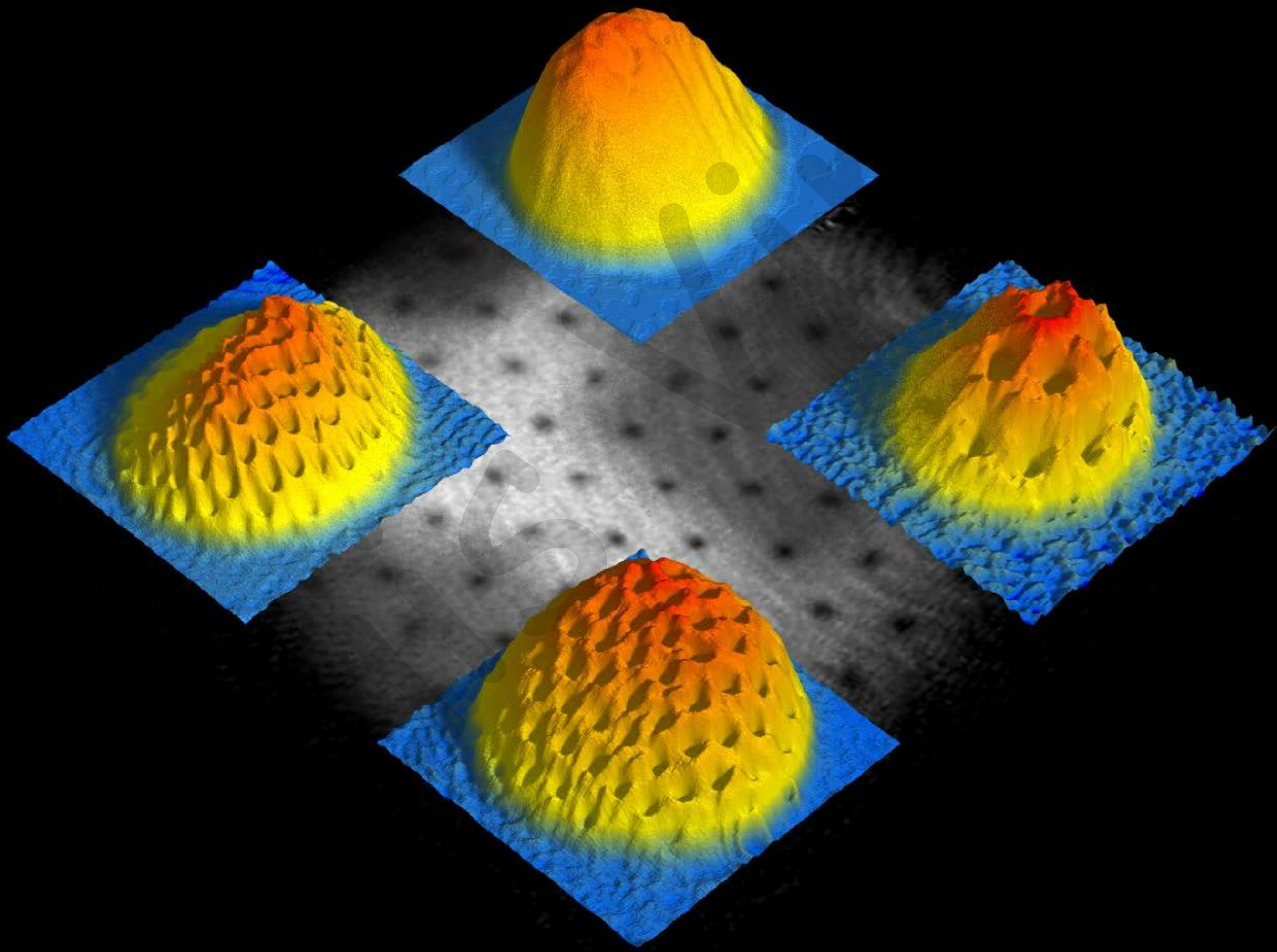




Quantum-mechanical particle in a circle: orbit $= n \times \lambda_{dB}$

Appearance of singular regions: arrays of vortices

Lattices of vortices in a BEC



W. Ketterle, MIT physics annual (2001)

Superfluidity: phenomenology

- Hess-Fairbank effect $\omega < \omega_c$ *superfluid cannot rotate*
- Quantized circulation $\omega > \omega_c$ *angular momentum is quantized*

} *continuity of the phase*

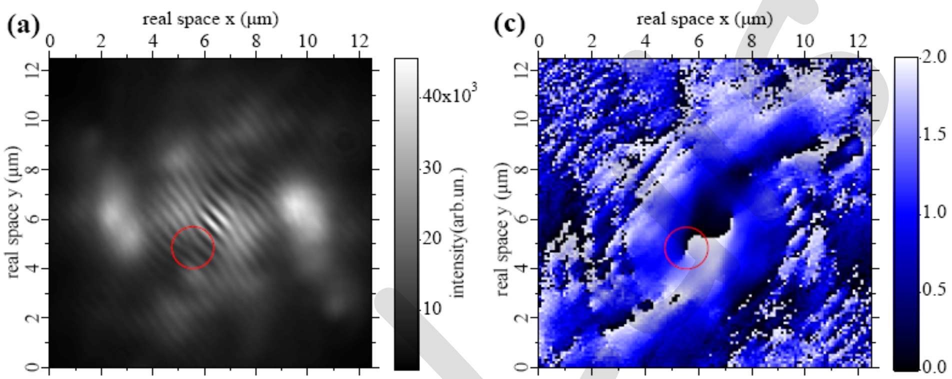
vortex formation

polariton BEC (spontaneous)

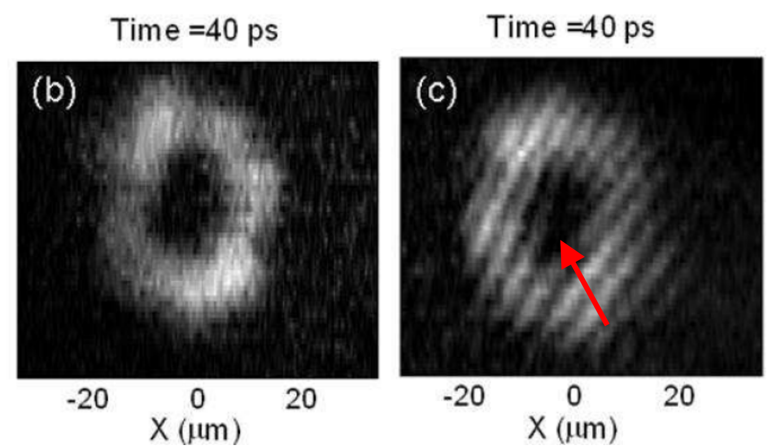
$$n = 1$$

polariton BEC (stirred)

$$n = 2$$



Lagoudakis *et al*., Nature Phys., **4**, 706 (2008)



Sanvitto et al., Nature Phys. 6, 527 (2010)

Superfluidity: definition

- Hess-Fairbank effect $\omega < \omega_c$ *superfluid cannot rotate*
- Quantized circulation $\omega > \omega_c$ *angular momentum is quantized*
- Persistent currents *circulation persists indefinitely*
- Frictionless flow ***no drag** on objects traversing the condensate if* $v_f < v_c$

  drag** if* $v_f > v_c$ ***Čerenkov regime

⬇

The Landau Criterion

in polaritons in semiconductor microcavities

Our experiments: dynamics of the polariton condensed phase

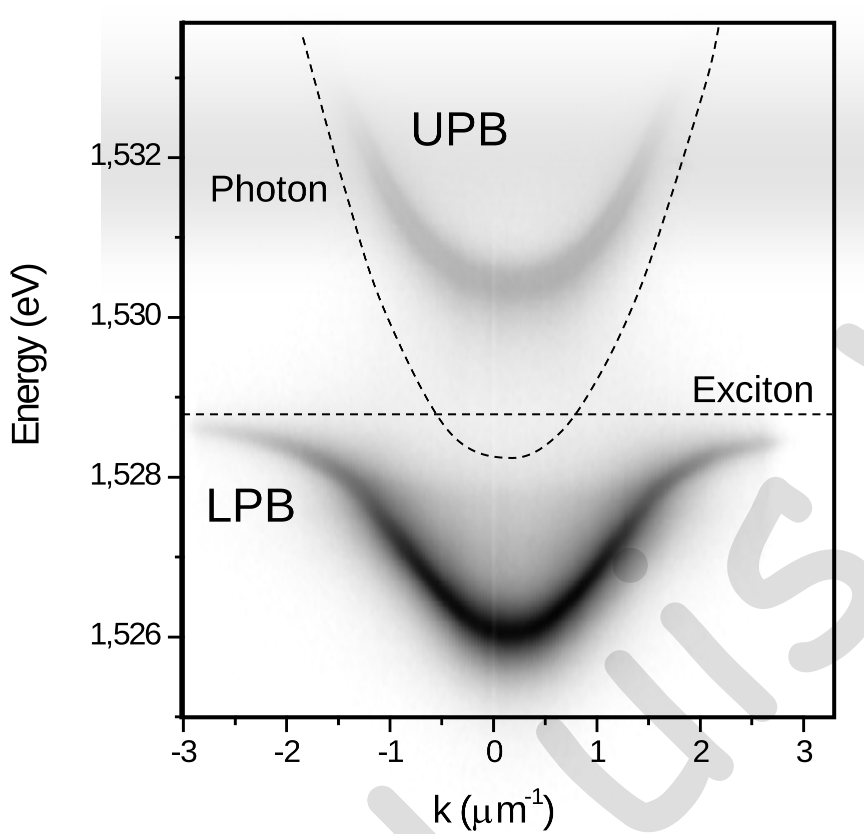
Polaritons in the OPO regime:

A quantum state put in motion

- **Creation of polariton fluids with *k* ≠ 0**
- **Interaction with defects**

Part I: Creation of polariton fluids with k ≠ 0

GOAL: make polaritons flow and study their excitations

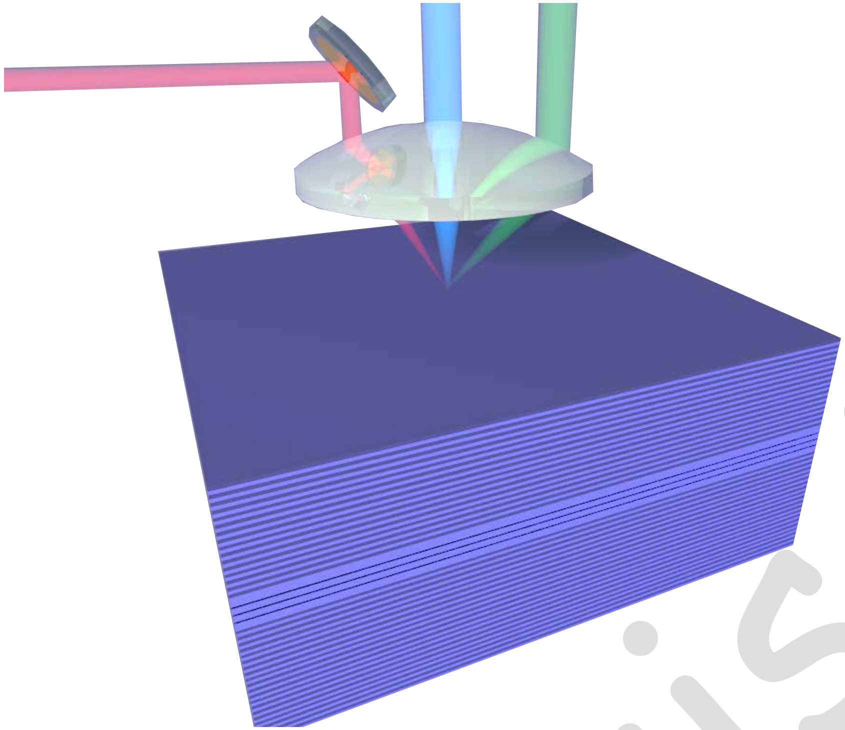


Creating a polariton fluid at k ≠ 0

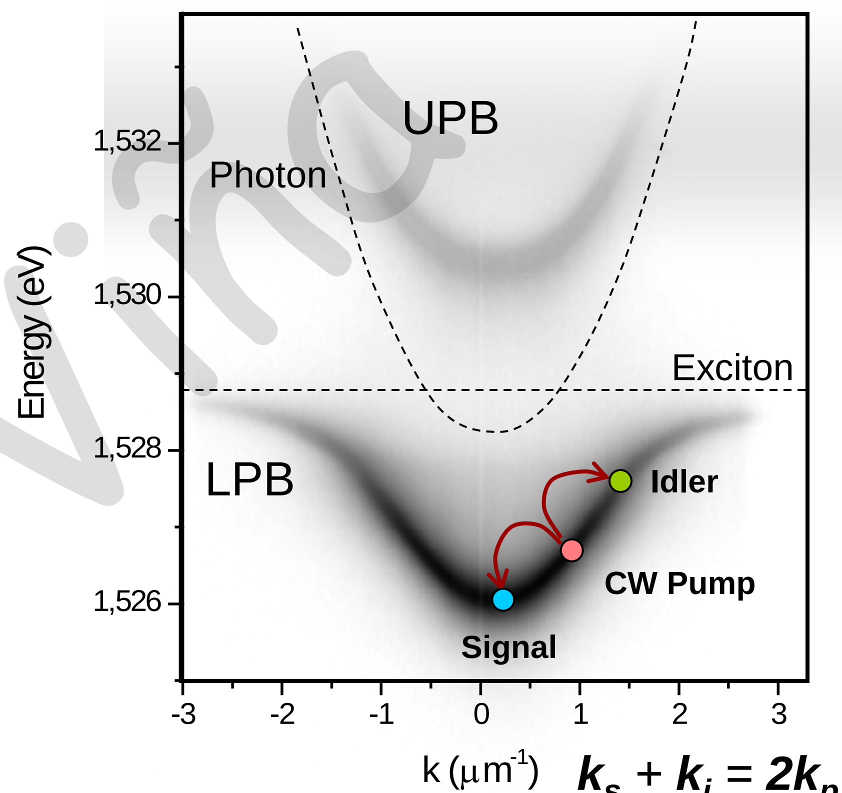
CHALLENGES:

- Kicking an initial polariton momentum
- Limited polariton lifetime (2-10 ps)
- Laser stray light in actual experiments

Making polaritons flow: OPO



$\lambda/2$ GaAs cavity with one InAs QW



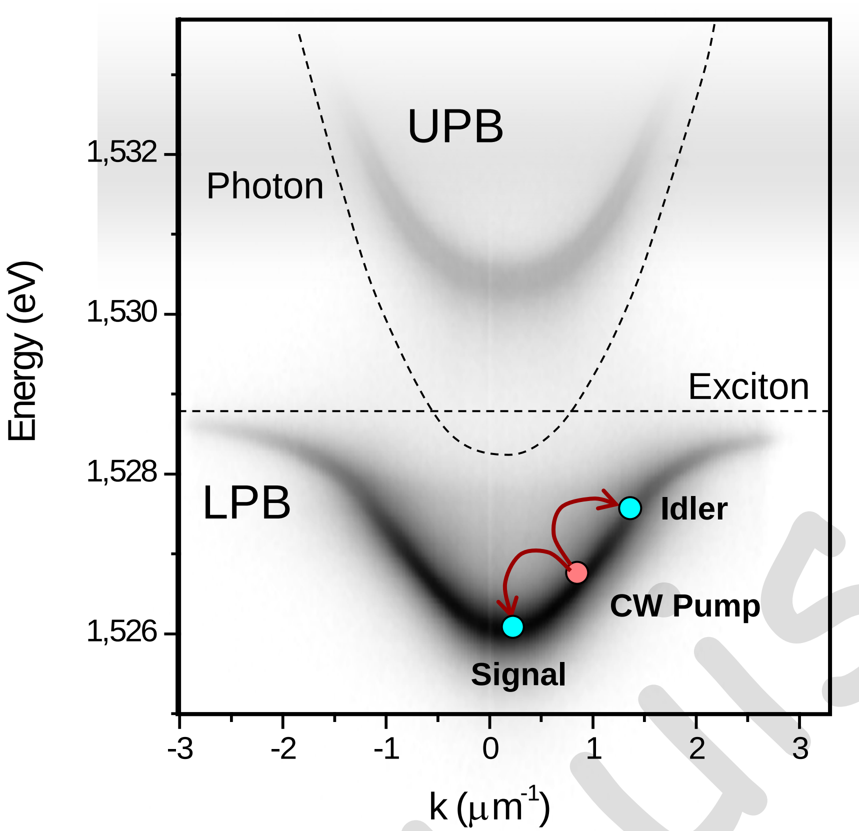
$$\boldsymbol{k_s + k_i = 2k_p}$$

$$\boldsymbol{E_s + E_i = 2E_p}$$

Scattering of pump polariton (k_p, E_p) into a signal (k_s, E_s) and an idler ($2k_p$-k_s, $2E_p$-E_s) stimulated by final state occupation

Condition on the phase: $2\varphi_{pump} = \varphi_{signal} + \varphi_{idler}$

Making polaritons flow: OPO



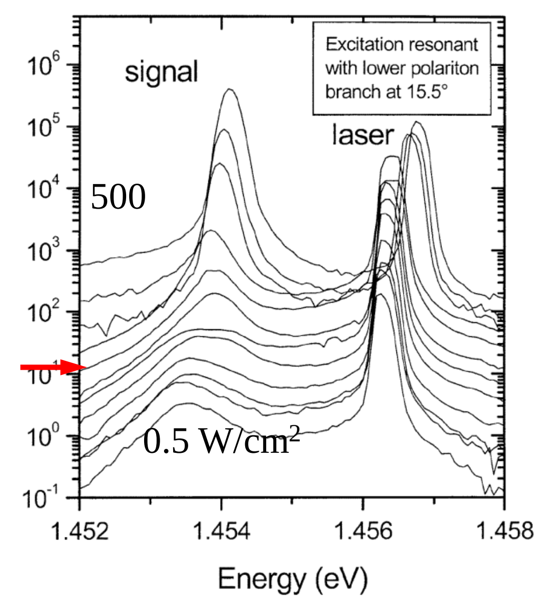
Pumping at the inflexion point

Spontaneous parametric scattering

Above a given threshold ⬇ Bosonic system

Stimulated parametric scattering to signal and idler modes at k = 0

Savvidis *et al.* PRL **84** 1547 (2000)
Stevenson *et al.* PRL **85** 3680 (2000)



Dispersion relation
+
pol-pol interactions

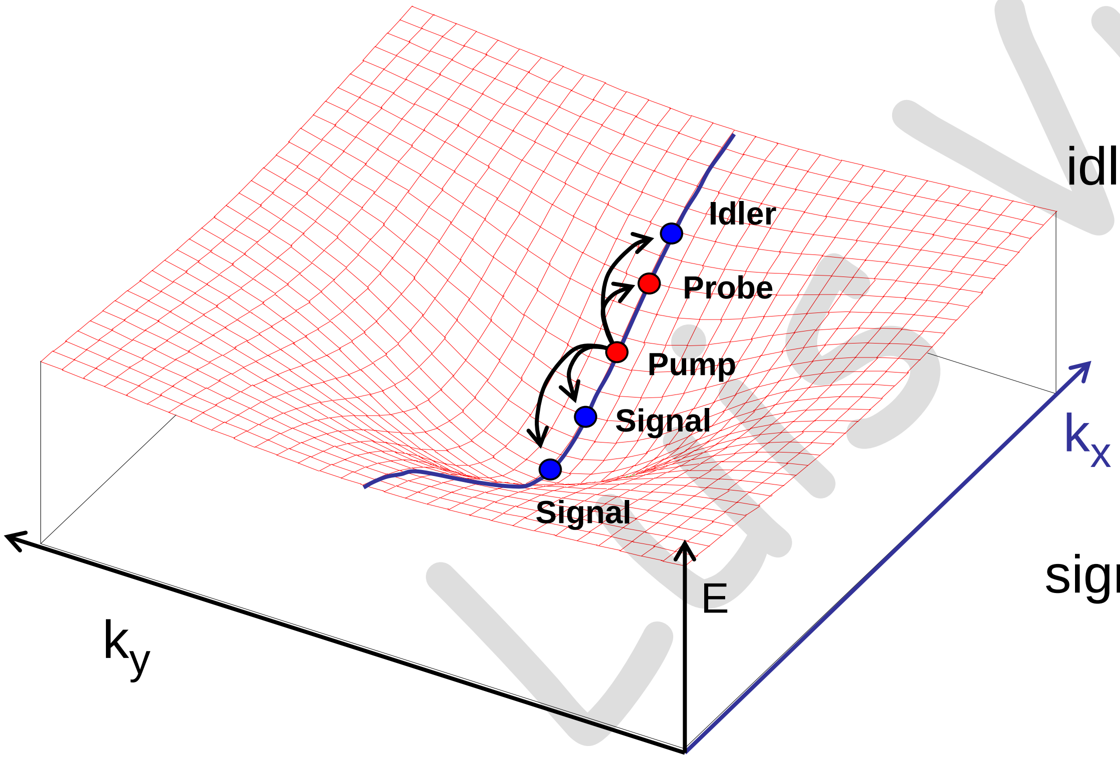
$$\begin{cases} k_s + k_i = 2k_p \\ E_s + E_i = 2E_p \end{cases}$$

How can we give a finite velocity to polariton condensates?

$$v_g = \frac{1}{\hbar}\frac{\partial E}{\partial k}$$

A pump only OPO takes always place at k=0

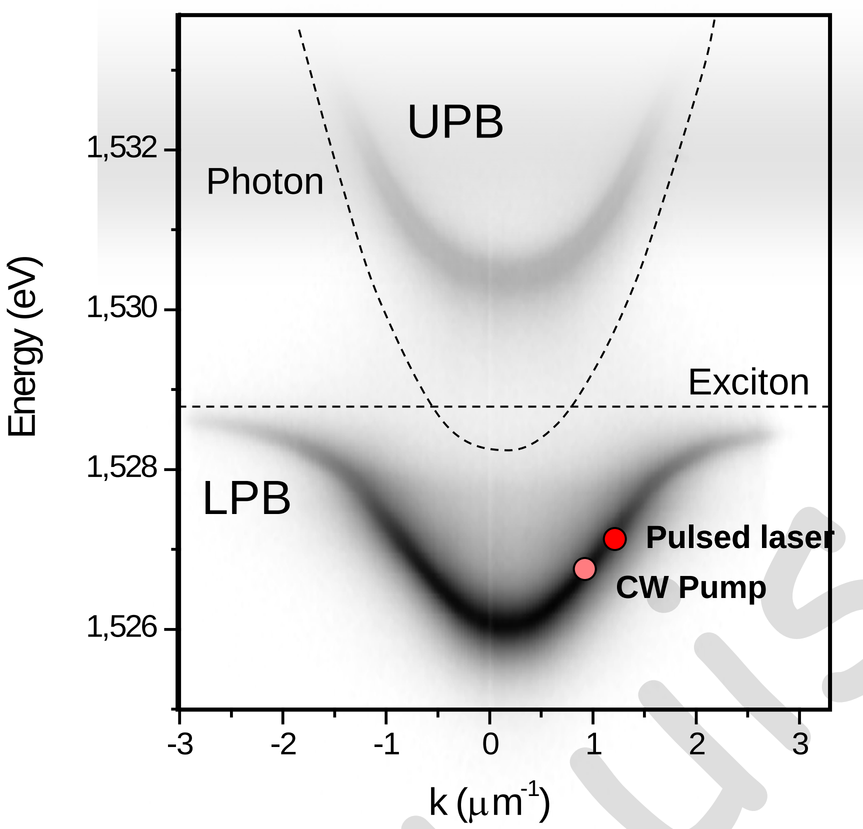
For the TOPO, the initial phase matching conditions of the idler determine the final state of the signal



idler → $k_x \approx 2k_{pump}$ / $k_x < 2k_{pump}$

signal → $k_x = 0$ / $k_x > 0$

Making polaritons flow: TOPO



The TOPO configuration

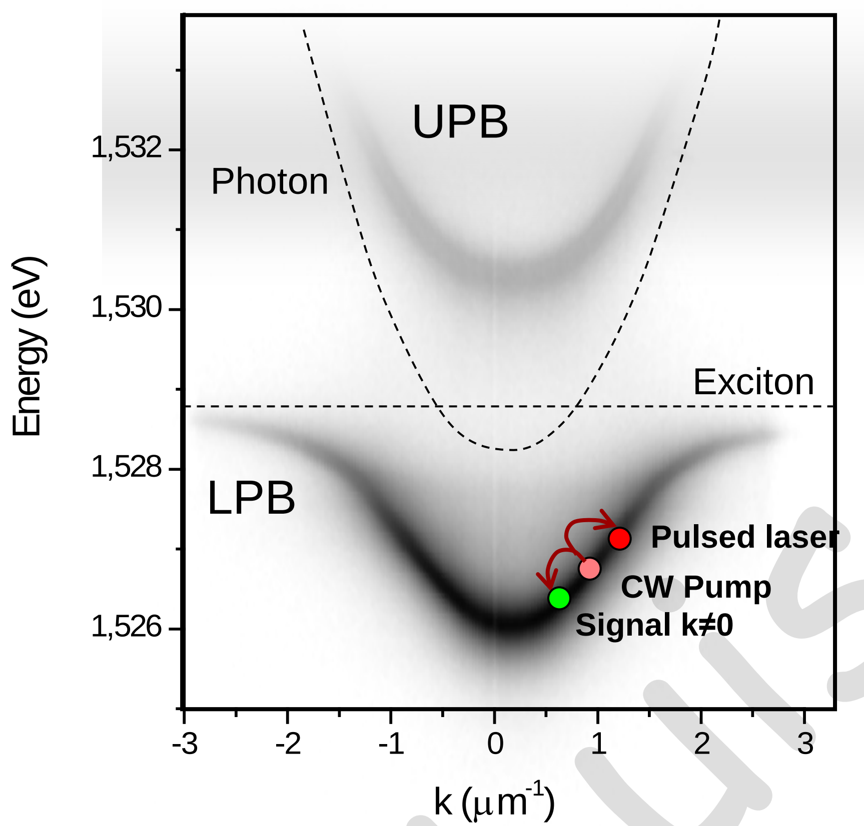
(triggered optical parametric oscillator)

- CW pump below spontaneous stimulation threshold
- **Pulsed** probe at a given *k*

Dispersion relation
+
pol-pol interactions

$$\begin{cases} \boldsymbol{k_s + k_i = 2k_p} \\ \boldsymbol{E_s + E_i = 2E_p} \end{cases}$$

Making polaritons flow: TOPO



The TOPO configuration
(triggered optical parametric oscillator)

- CW pump below spontaneous stimulation threshold
- **Pulsed** probe at a given *k*

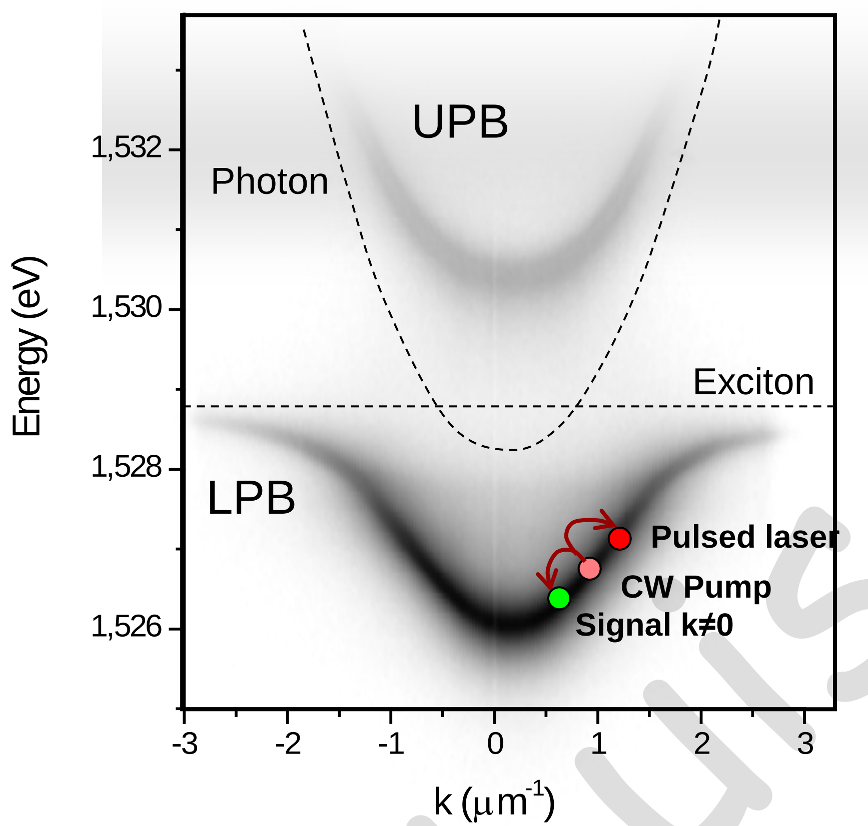
⬇

- Triggering of a signal state at $k \neq 0$
- Population at signal state is fed by the CW pump due to final state stimulation **even when the pulse laser is gone! (even for nanoseconds)**

Dispersion relation
+
pol-pol interactions

$$\begin{cases} k_s + k_i = 2k_p \\ E_s + E_i = 2E_p \end{cases}$$

Making polaritons flow: TOPO



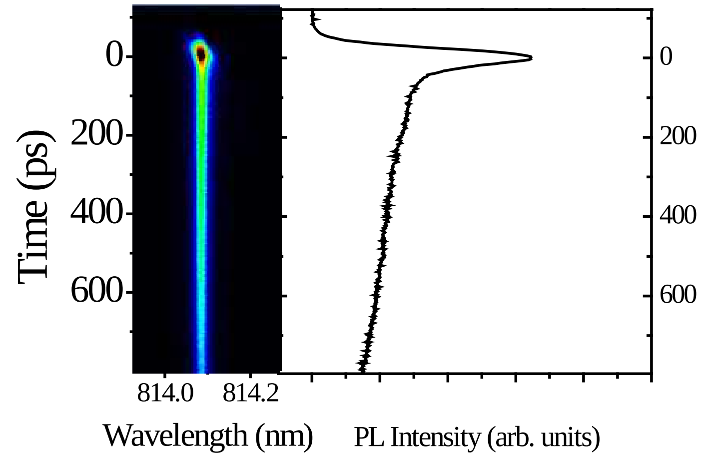
The TOPO configuration

(triggered optical parametric oscillator)

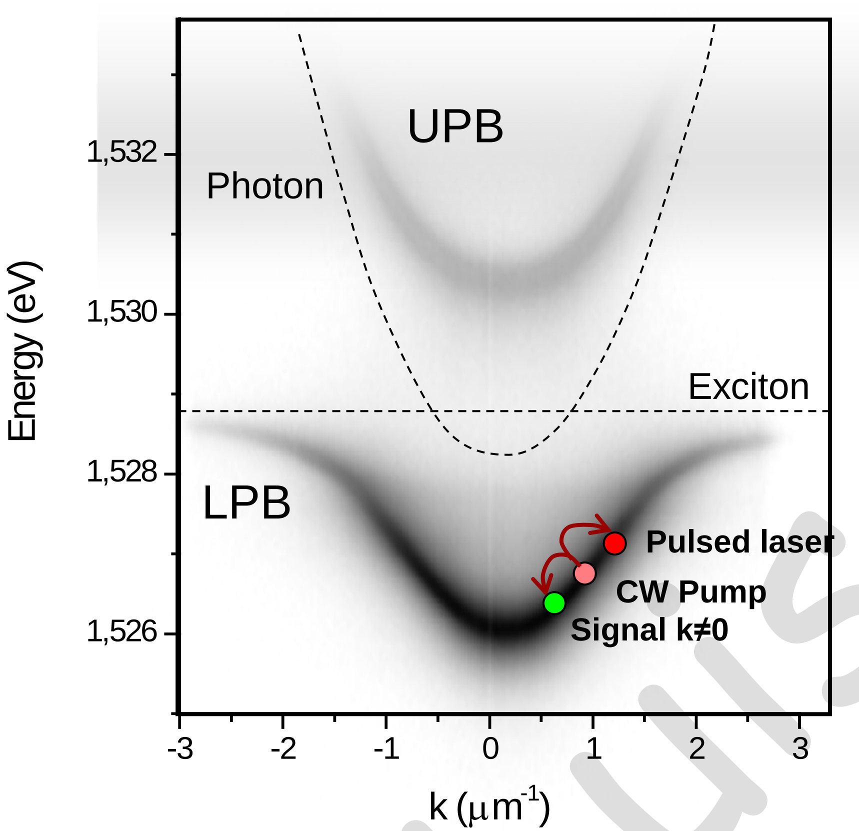
- CW pump below spontaneous stimulation threshold
- **Pulsed** probe at a given *k*
- Triggering of a signal state at $k \neq 0$
- Population at signal state is fed by the CW pump due to final state stimulation **even when the pulse laser is gone! (lasting for nanoseconds)**

Dispersion relation + pol-pol interactions

$$\begin{cases} k_s + k_i = 2k_p \\ E_s + E_i = 2E_p \end{cases}$$



Making polaritons flow: TOPO



Dispersion relation
+
pol-pol interactions

$$\begin{cases} k_s + k_i = 2k_p \\ E_s + E_i = 2E_p \end{cases}$$

The TOPO configuration

(triggered optical parametric oscillator)

- CW pump below spontaneous stimulation threshold
- **Pulsed** probe at a given *k*

↓

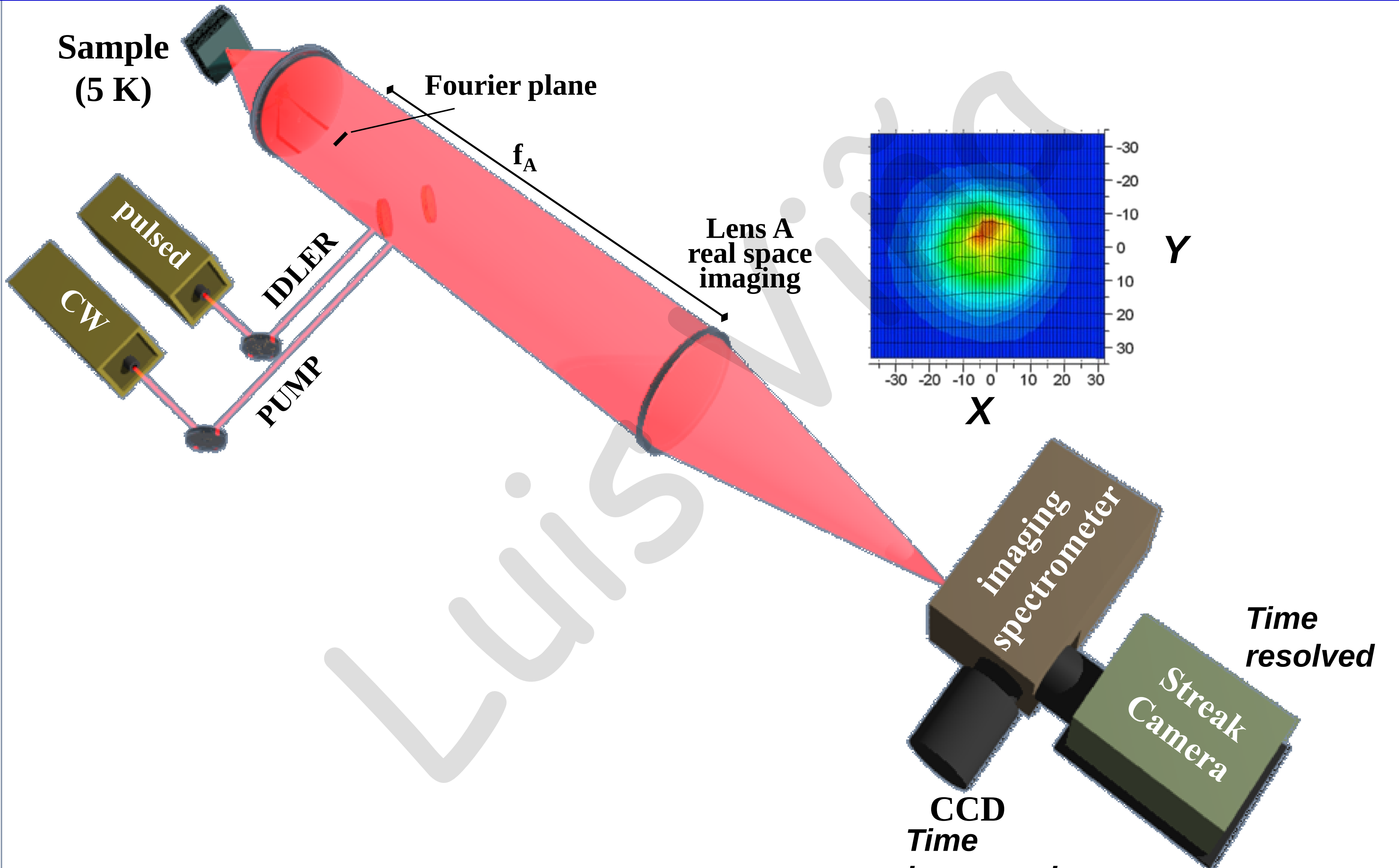
- Triggering of a signal state at $k \neq 0$
- Population at signal state is fed by the CW pump due to final state stimulation **even when the pulse laser is gone! (lasting for nanoseconds)**

Creating a polariton fluid at k ≠ 0

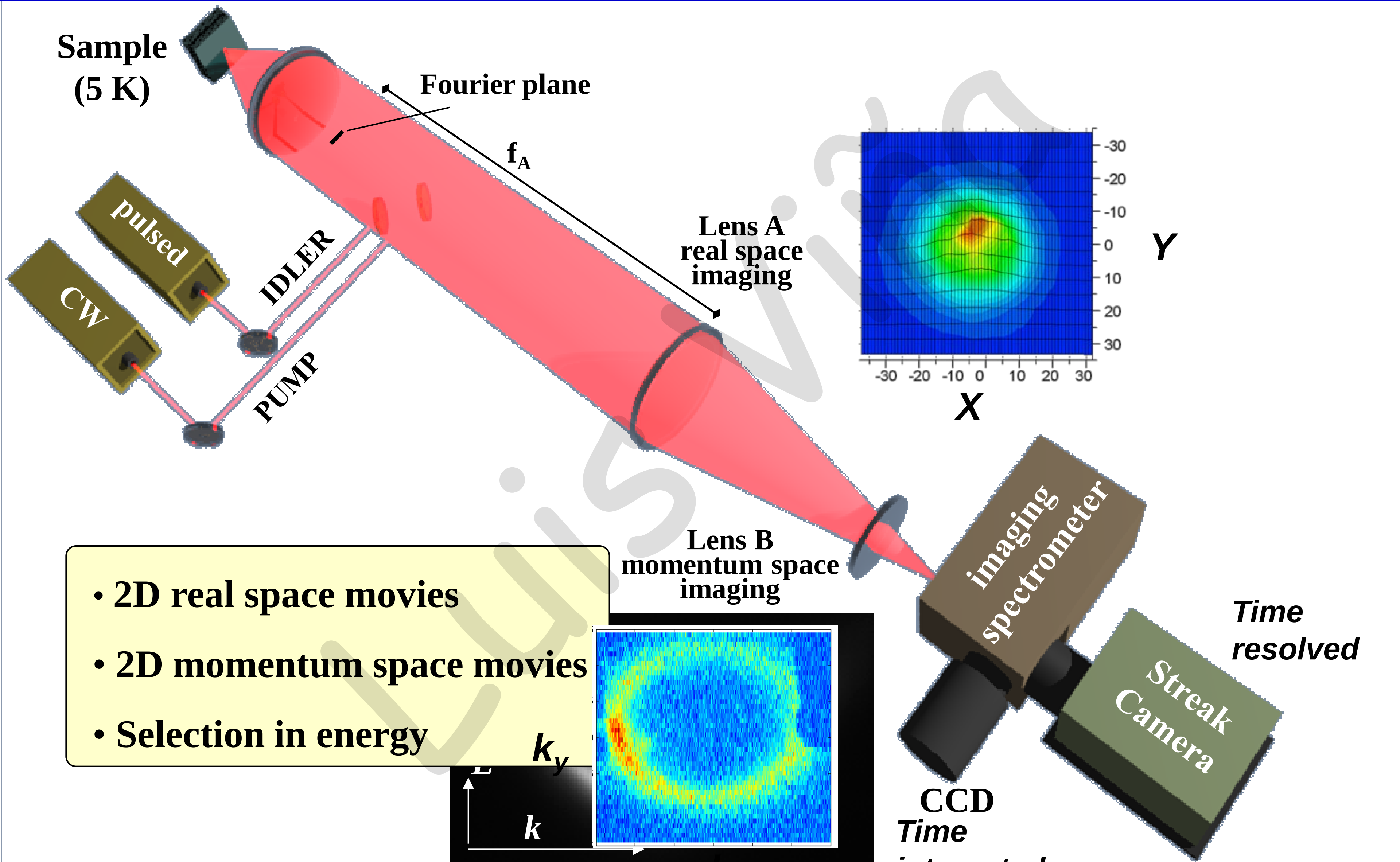
CHALLENGES:

- Kicking an initial polariton momentum ✓
- Limited polariton lifetime (2-10 ps) ✓
- Laser stray light in actual experiments ✓

The actual experiment: set-up

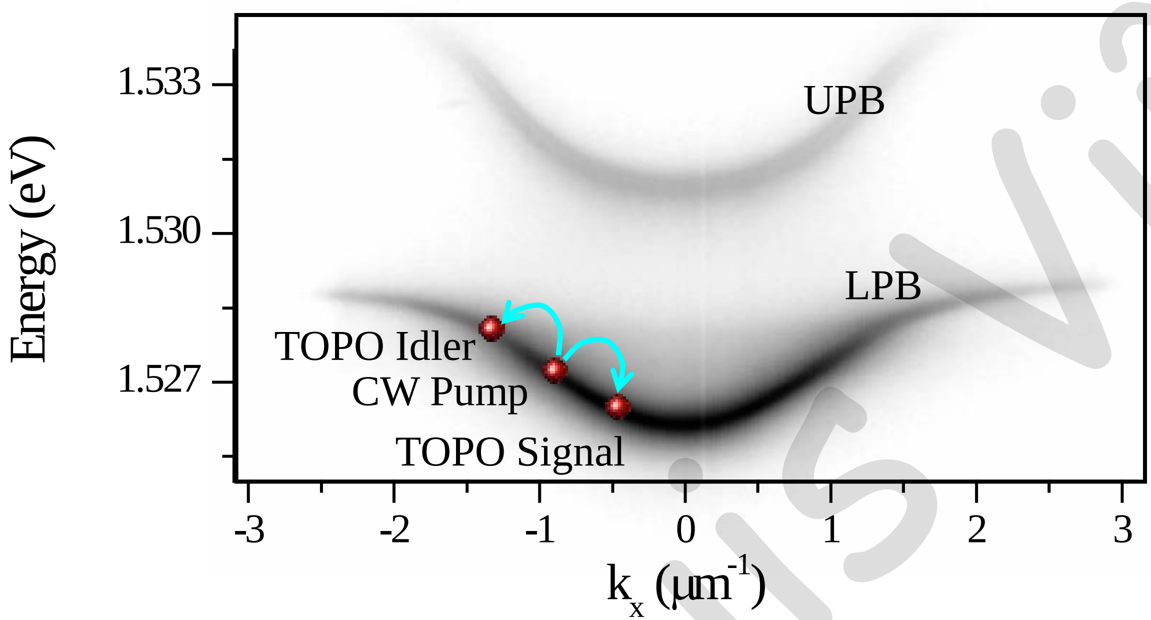


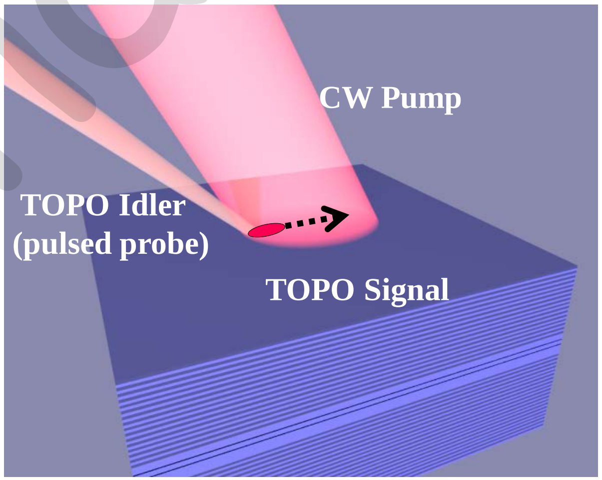
The actual experiment: set-up



- 2D real space movies
- 2D momentum space movies
- Selection in energy

Experiment preparation



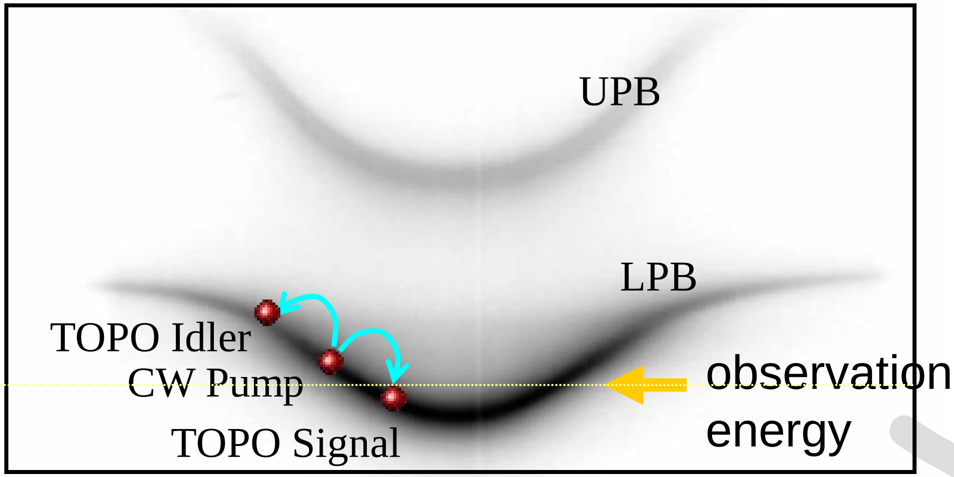


$$v_g = \frac{1}{\hbar}\frac{\partial E}{\partial k} > 0$$ ➡

Coexistence of **two fluids** with different velocities:

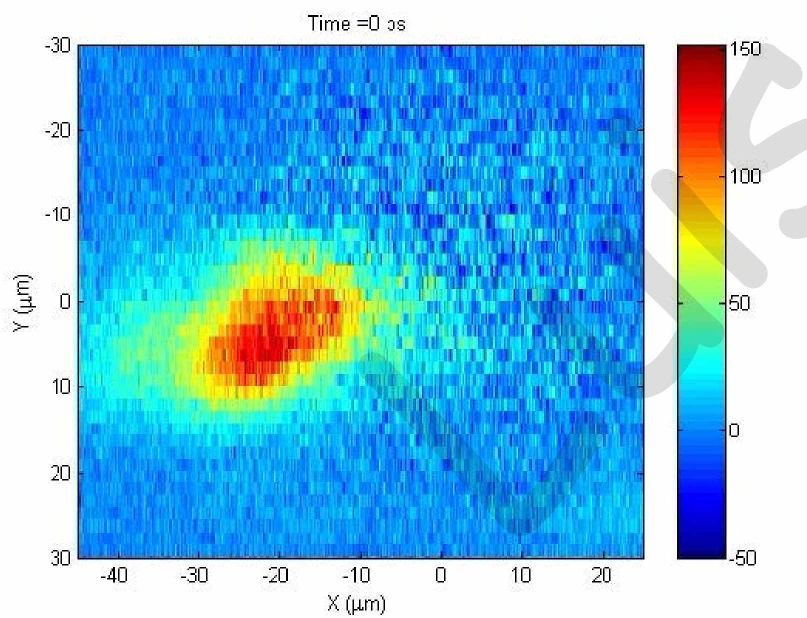
- Steady state CW (pump) ⟵ large spot
- Triggered OPO (signal) ⟵ small initial spot

Incoherent polariton flow

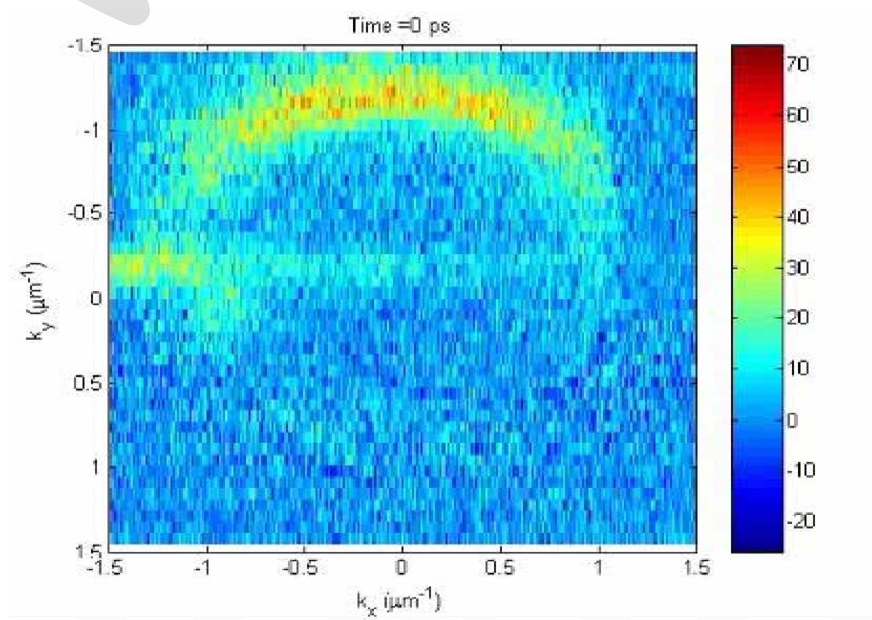


Low pump power

- Localization in shallow potential
- Not well defined ***k***

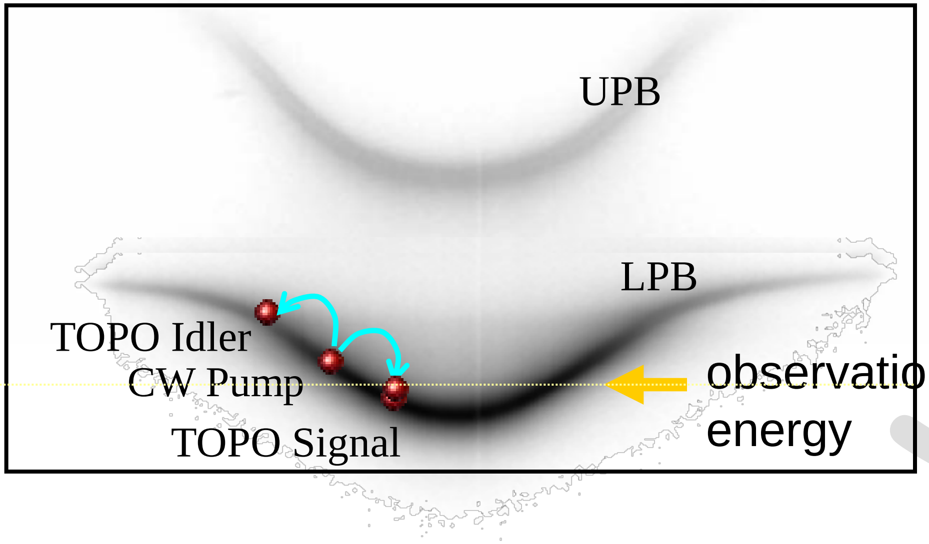


real space



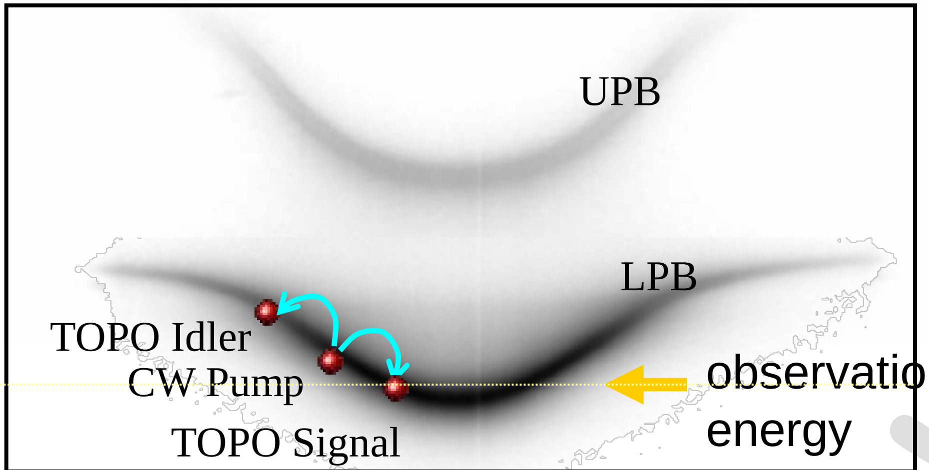
momentum space

Coherent polariton flow



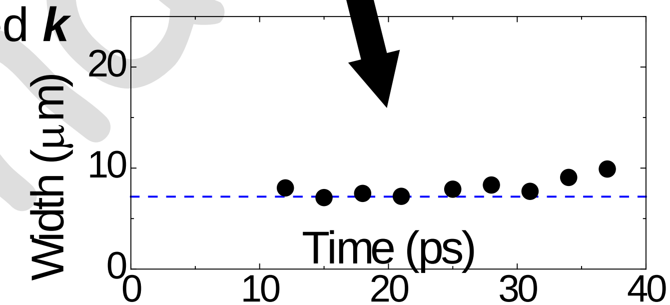
High pump power (blueshift)

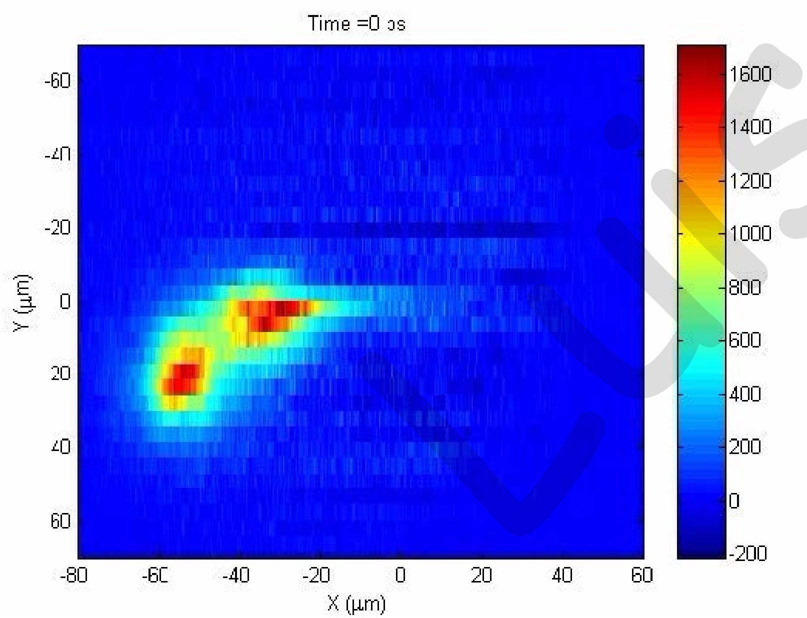
Coherent polariton flow



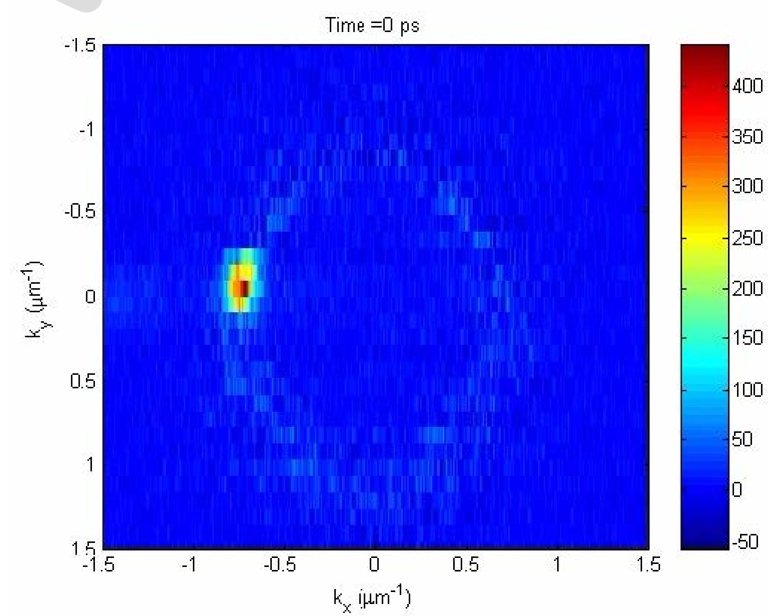
High pump power (blueshift)

- Unperturbed flow: **no expansion**
- Well defined ***k***
- ***1.7 μm/ps***





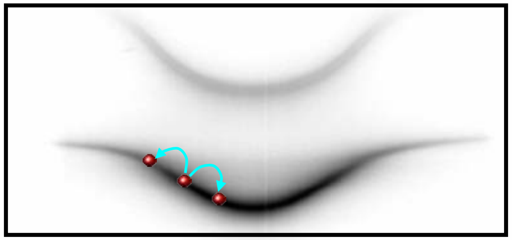
real space



momentum space

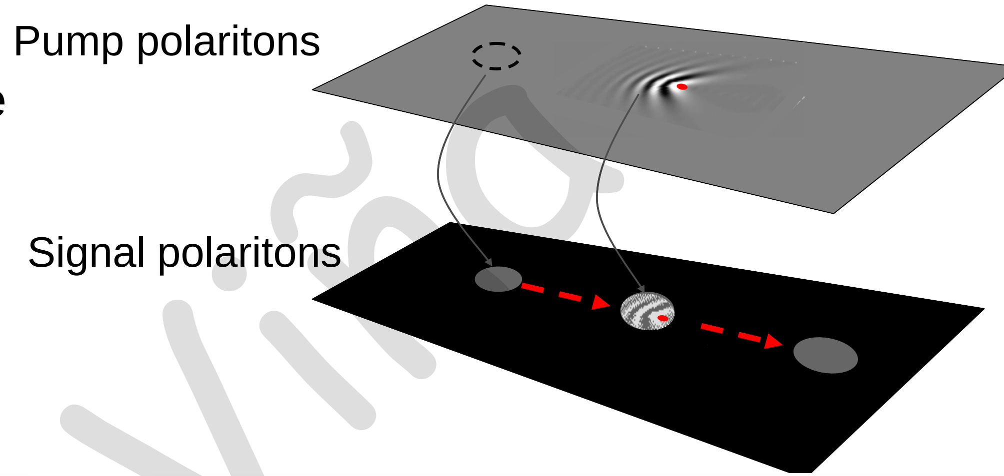
Part II: Interaction with defects

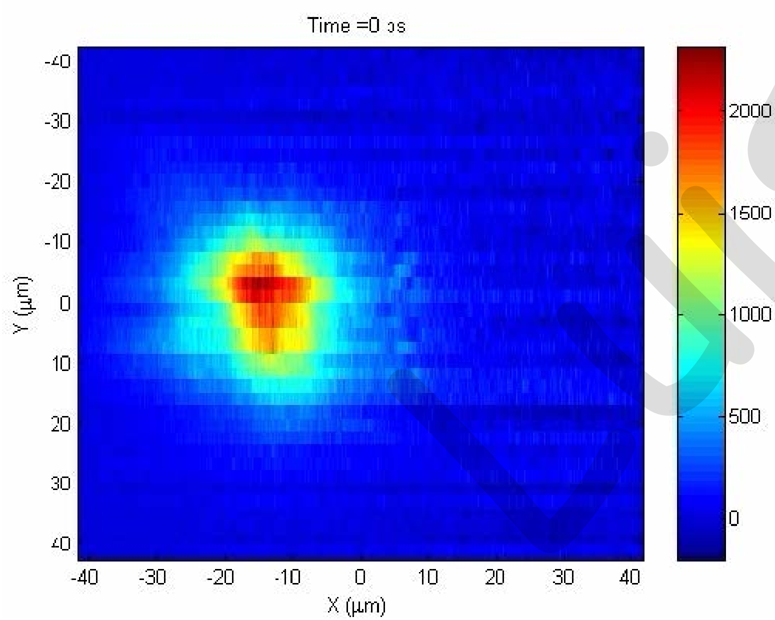
GOAL: study the excitations of the polariton fluids via interaction with defects



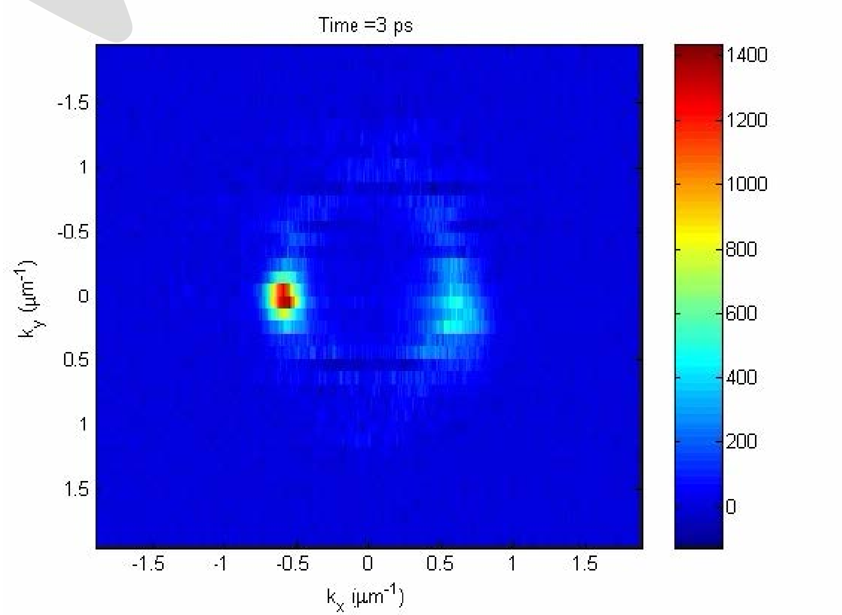
Interaction with small defect

- The defect is observed through the **Čerenkov** waves present at the pump state
- Signal fluid
  - **no scattering with the defect**
  - **well defined momentum**





real space

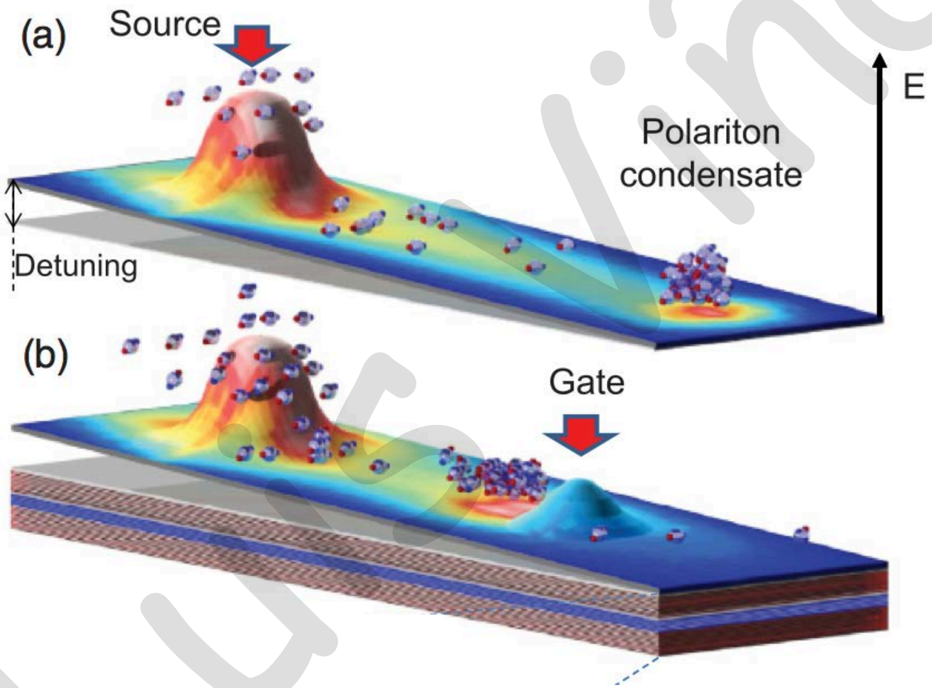


momentum space

Summary

- Polaritons allow for the dynamical study of their condensed state
- TOPO configuration:
  - ✓ creation of long lived polariton fluids with well defined *k*
- Linear dispersion → created by interactions
- Observation of Čerenkov shock waves
- Friction-less motion when passing through a defect
  - ✓ ***Superfluidity***

Dynamics of a polariton condensate transistor switch



1. *Motivations*

2. *Sample and previous work*

3. *Experiments*

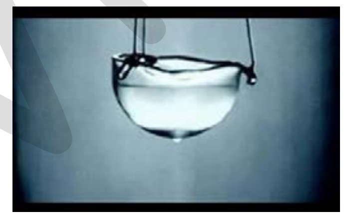
4. *Theory and simulations*

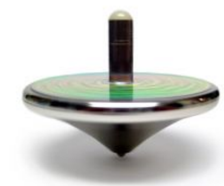
Motivations

On the polaritronic technology…

Bose-Einstein condensates as a tool for technological development

- ✓ *Coherence* $\Psi_0(r,t)$
- ✓ *Superfluid character*
- ✓ *Spin properties*





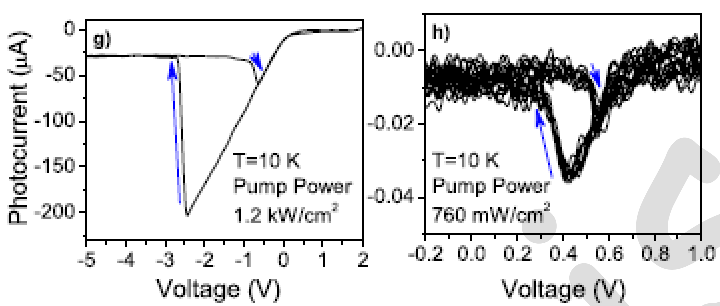
Why use polaritons?

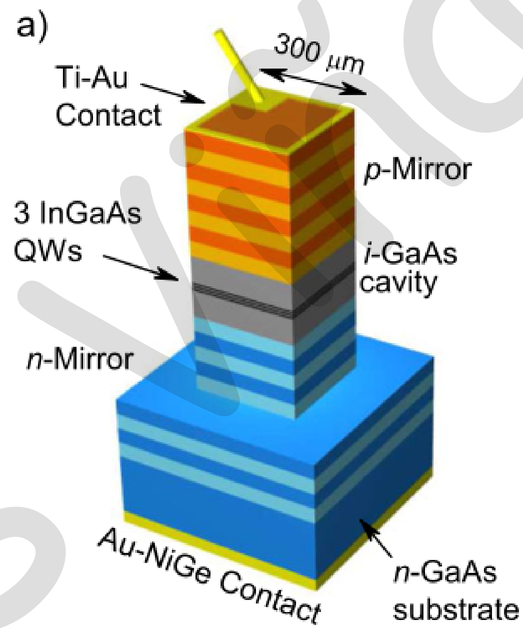
species	atomic gases	polaritons
mass m^*/m_0	10^4	10^{-5}
Bohr radius	10^{-1}Å	10^2Å
λ_T at T_c	10^3Å	10^4Å
T_c	$< 1\mu$K	$10 - 300$K

Motivations

On the polaritronic technology…

- ✓ *Optical gates*





PRL **101,** 266402 (2008) PHYSICAL REVIEW LETTERS week ending 31 DECEMBER 2008

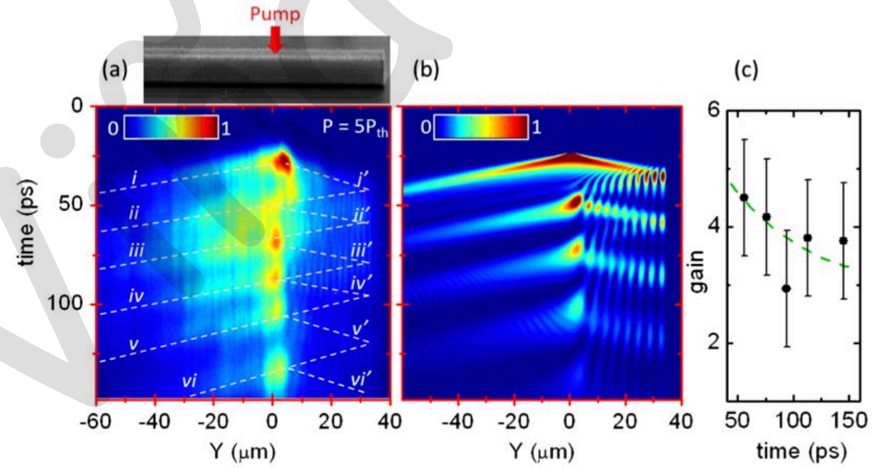
Optical Bistability in a GaAs-Based Polariton Diode

Daniele Bajoni,* Elizaveta Semenova, Aristide Lemaître, Sophie Bouchoule, Esther Wertz, Pascale Senellart, Sylvain Barbay, Robert Kuszelewicz, and Jacqueline Bloch†

Motivations

On the polaritronic technology…

✓ *Optical* **amplifiers**



PRL 109, 216404 (2012) PHYSICAL REVIEW LETTERS week ending 21 NOVEMBER 2012

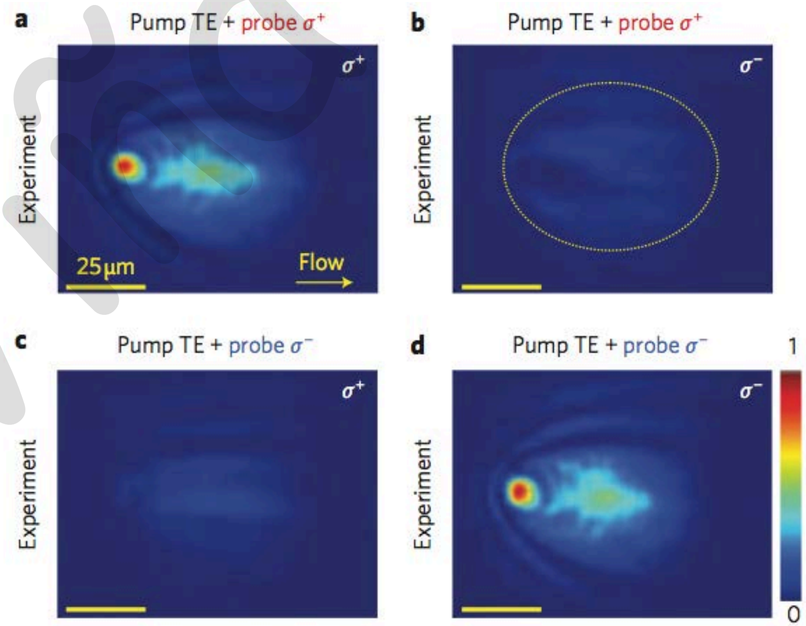
Propagation and Amplification Dynamics of 1D Polariton Condensates

E. Wertz,[1] A. Amo,[1] D. D. Solnyshkov,[2] L. Ferrier,[1] T. C. H. Liew,[3] D. Sanvitto,[4,5] P. Senellart,[1] I. Sagnes,[1] A. Lemaître,[1] A. V. Kavokin,[6,7] G. Malpuech,[2] and J. Bloch[1,*]

Motivations

On the polaritronic technology…

✓ *Spin-switches*



PRL **107,** 146402 (2011) PHYSICAL REVIEW LETTERS week ending 30 SEPTEMBER 2011

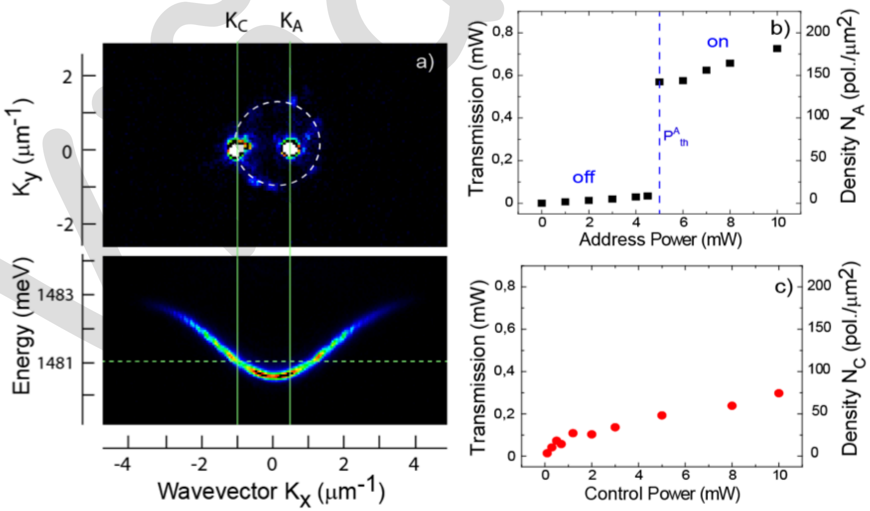
Motion of Spin Polariton Bullets in Semiconductor Microcavities

C. Adrados,[1] T. C. H. Liew,[2] A. Amo,[1,3] M. D. Martín,[4] D. Sanvitto,[4,5] C. Antón,[4] E. Giacobino,[1] A. Kavokin,[6,7] A. Bramati,[1] and L. Viña[4]

Motivations

On the polaritronic technology…

✓ *Transistors*



nature COMMUNICATIONS 4, 1778 (2013).

ARTICLE

DOI: 10.1038/ncomms2734

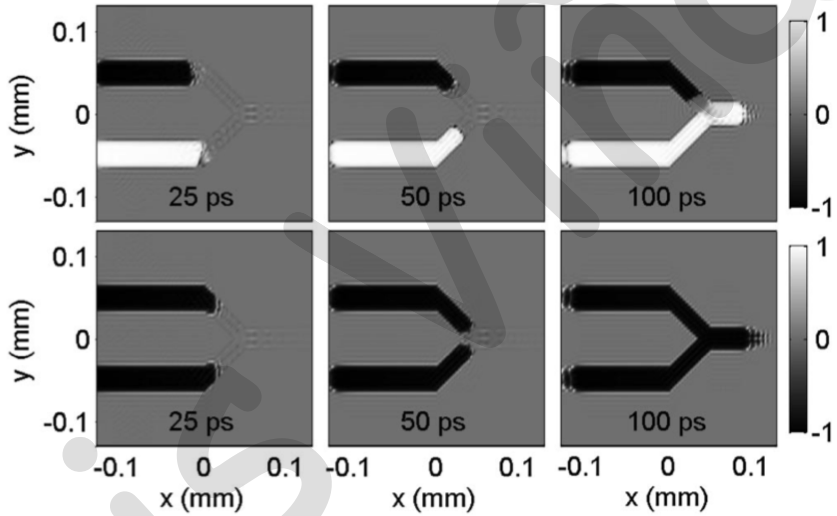
All-optical polariton transistor

D. Ballarini[1,2], M. De Giorgi[1,2], E. Cancellieri[3,4], R. Houdré[5], E. Giacobino[4], R. Cingolani[1], A. Bramati[4], G. Gigli[1,2,6] & D. Sanvitto[1,2]

Motivations

On the polaritronic technology…

✓ *Circuits*



PRL **101,** 016402 (2008) PHYSICAL REVIEW LETTERS week ending 4 JULY 2008

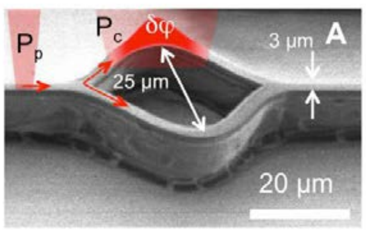
Optical Circuits Based on Polariton Neurons in Semiconductor Microcavities

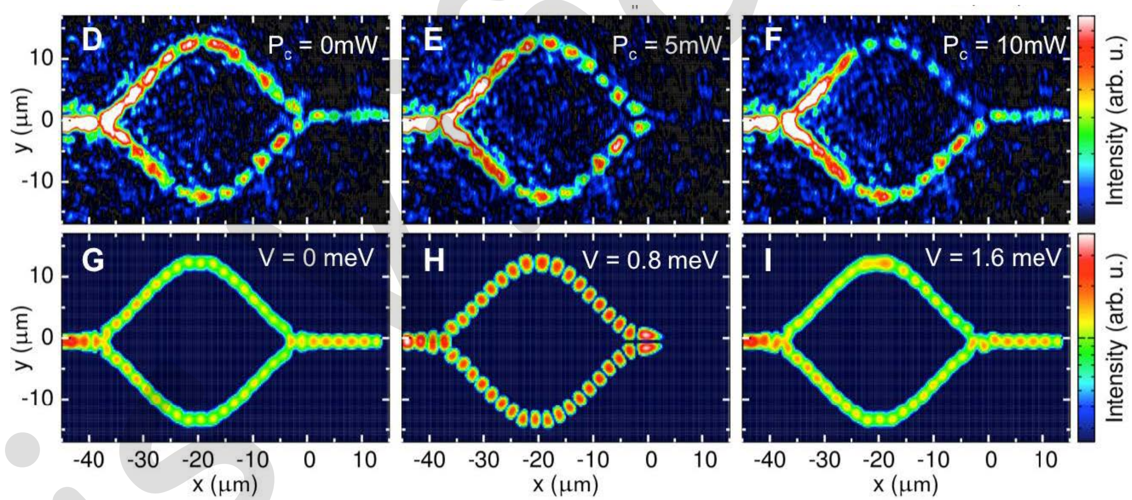
T. C. H. Liew,[1,2] A. V. Kavokin,[1,3] and I. A. Shelykh[2,4]

Motivations

On the polaritronic technology…

✓ Circuits





arXiv.org > cond-mat > arXiv:1303.1649

Search or Article

Condensed Matter > Mesoscale and Nanoscale Physics

Giant phase modulation in a Mach-Zehnder exciton-polariton interferometer

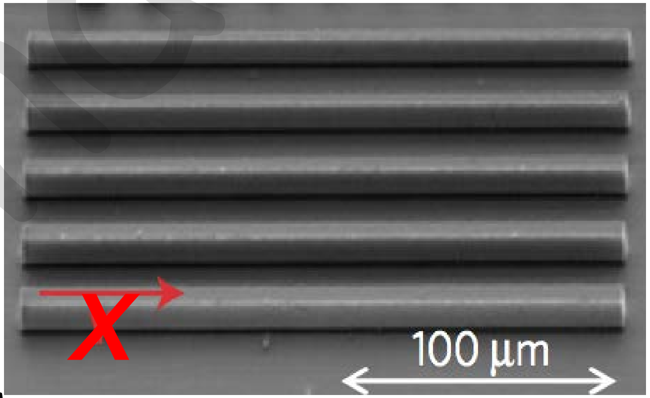
C. Sturm, D. Tanese, H.S. Nguyen, H. Flayac, E. Gallopin, A. Lemaître, I. Sagnes, D. Solnyshkov, A. Amo, G. Malpuech, J. Bloch

(Submitted on 7 Mar 2013)

Motivations

On the polaritronic technology…

Reducing the **dimensionality** by patterning the microcavities



Wire microcavities

Very long polariton effective **lifetimes**

Propagation of condensates over **macroscopic distances**

Manipulation of condensates using **repulsive local potentials** by photogeneration of excitons

***Superfluid** character:*

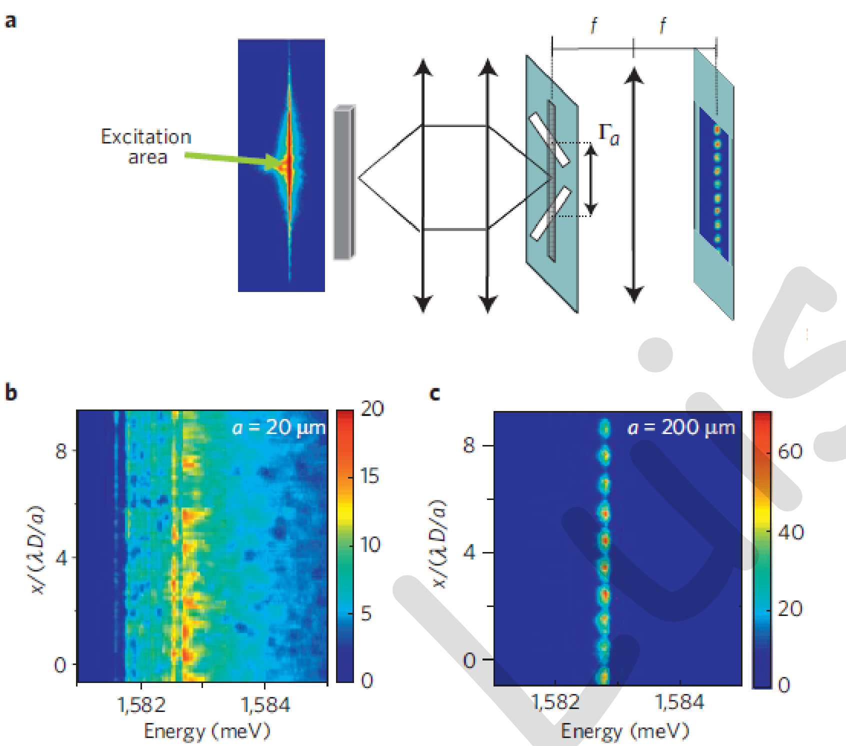
*High lateral **speed** of propagation*

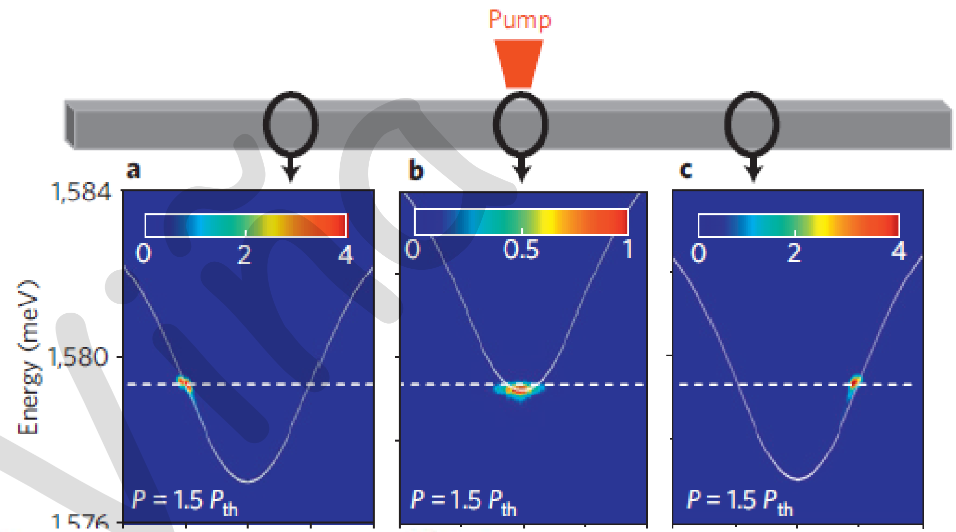
Ballistic transport without energy loss

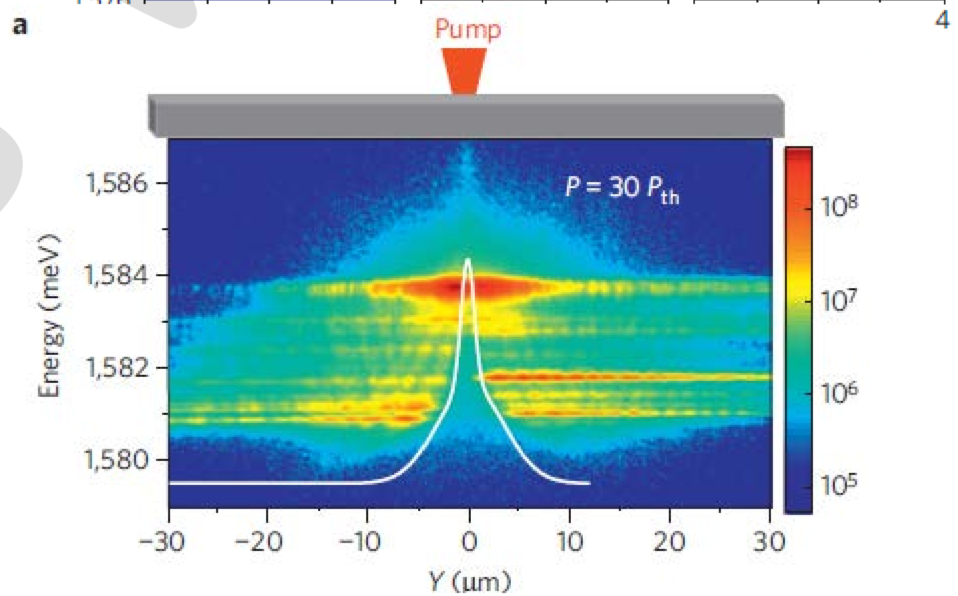
LETTERS
PUBLISHED ONLINE: 29 AUGUST 2010 | DOI: 10.1038/NPHYS1750
nature physics

Spontaneous formation and optical manipulation of extended polariton condensates

E. Wertz[1], L. Ferrier[1], D. D. Solnyshkov[2], R. Johne[2], D. Sanvitto[3], A. Lemaître[1], I. Sagnes[1], R. Grousson[4], A. V. Kavokin[5], P. Senellart[1], G. Malpuech[2] and J. Bloch[1]*

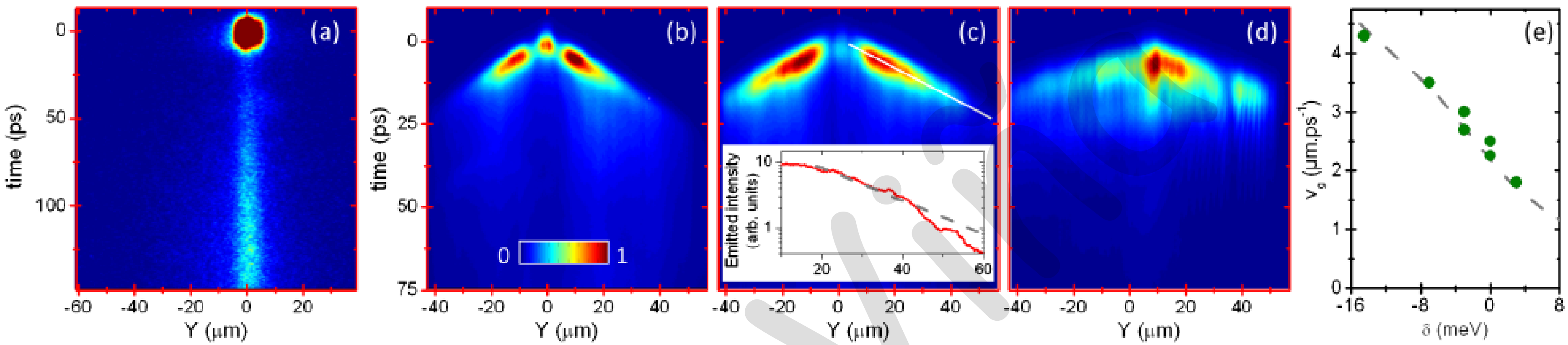






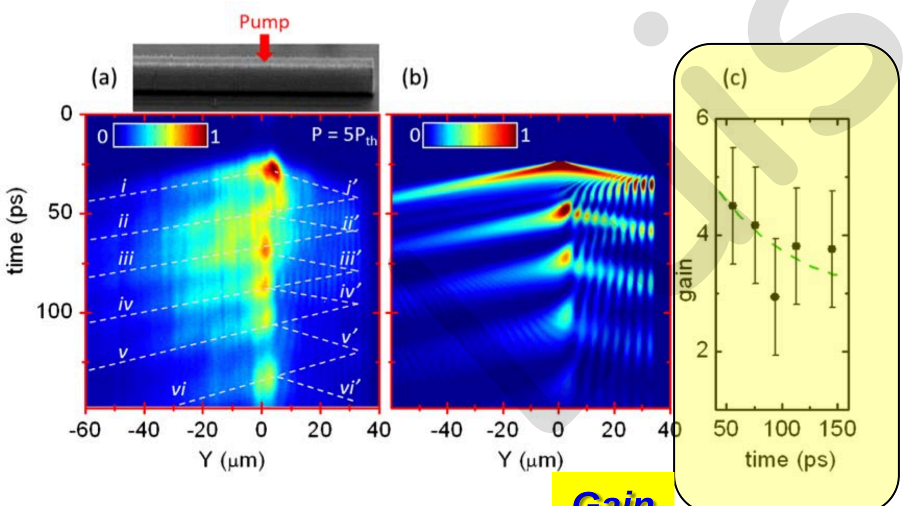
✓ *Optical amplifiers:* E. Wertz et al., PRL **109**, 216404 (2012)

Group velocity

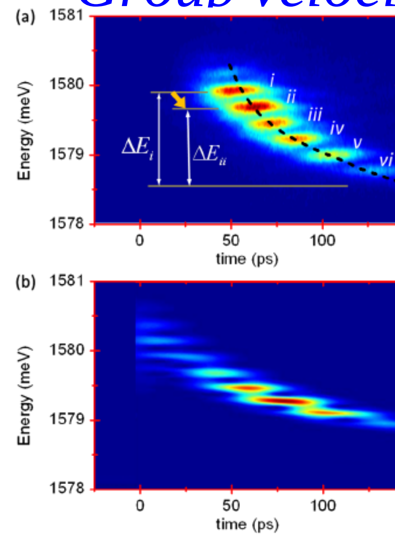


Below threshold	***Above threshold***	***Above threshold***	***Above threshold***
δ = - 3 meV	***δ = + 3 meV***	***δ = 0 meV***	***δ = - 10 meV***

Group velocity $\sim 1/\sqrt{m_P}$

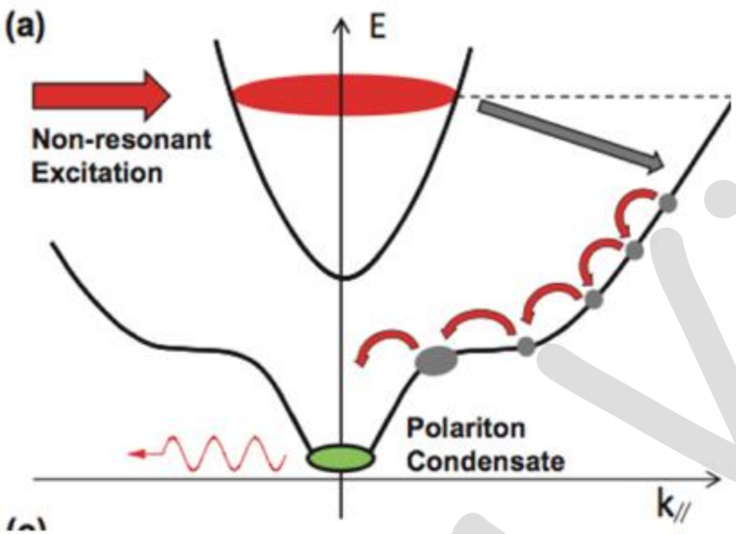


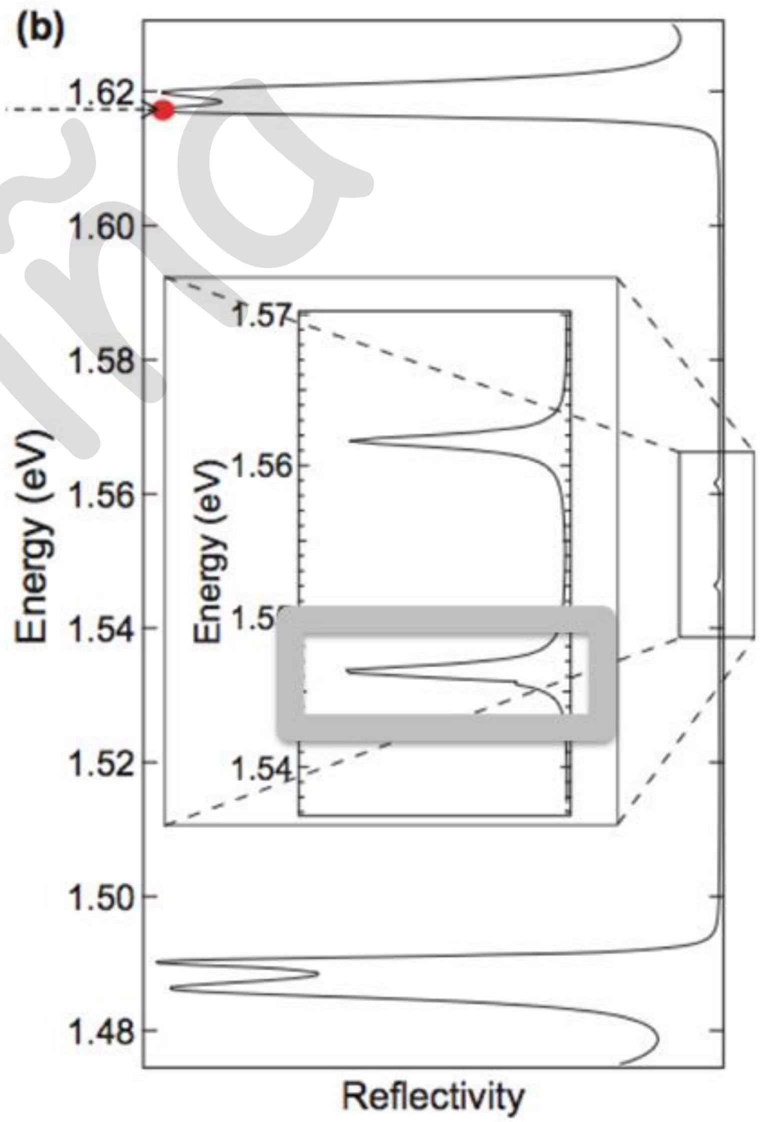
Gain



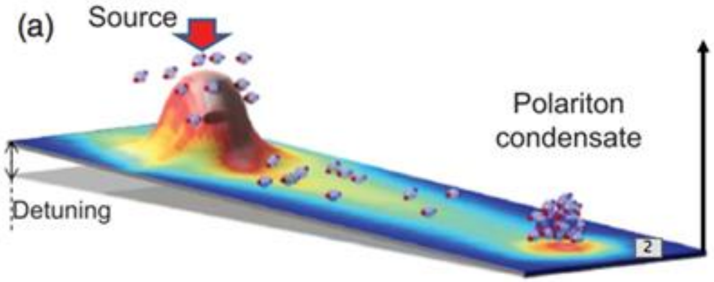
Energy relaxation

Sample and previous work

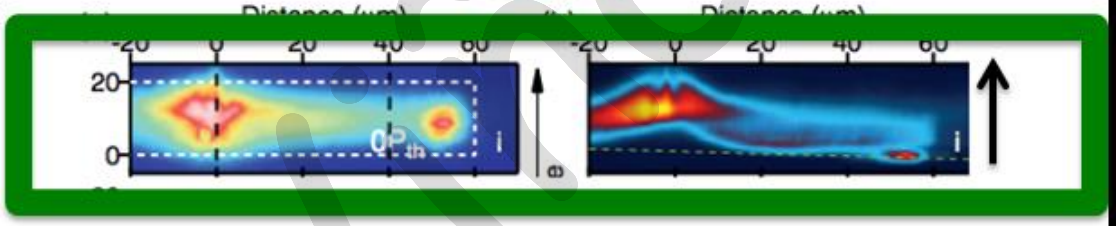


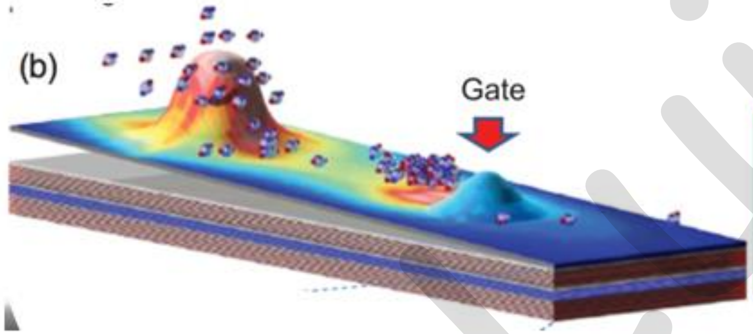


Sample and previous work

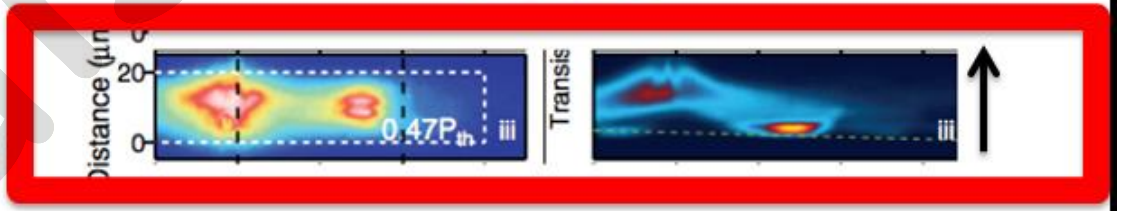


ON

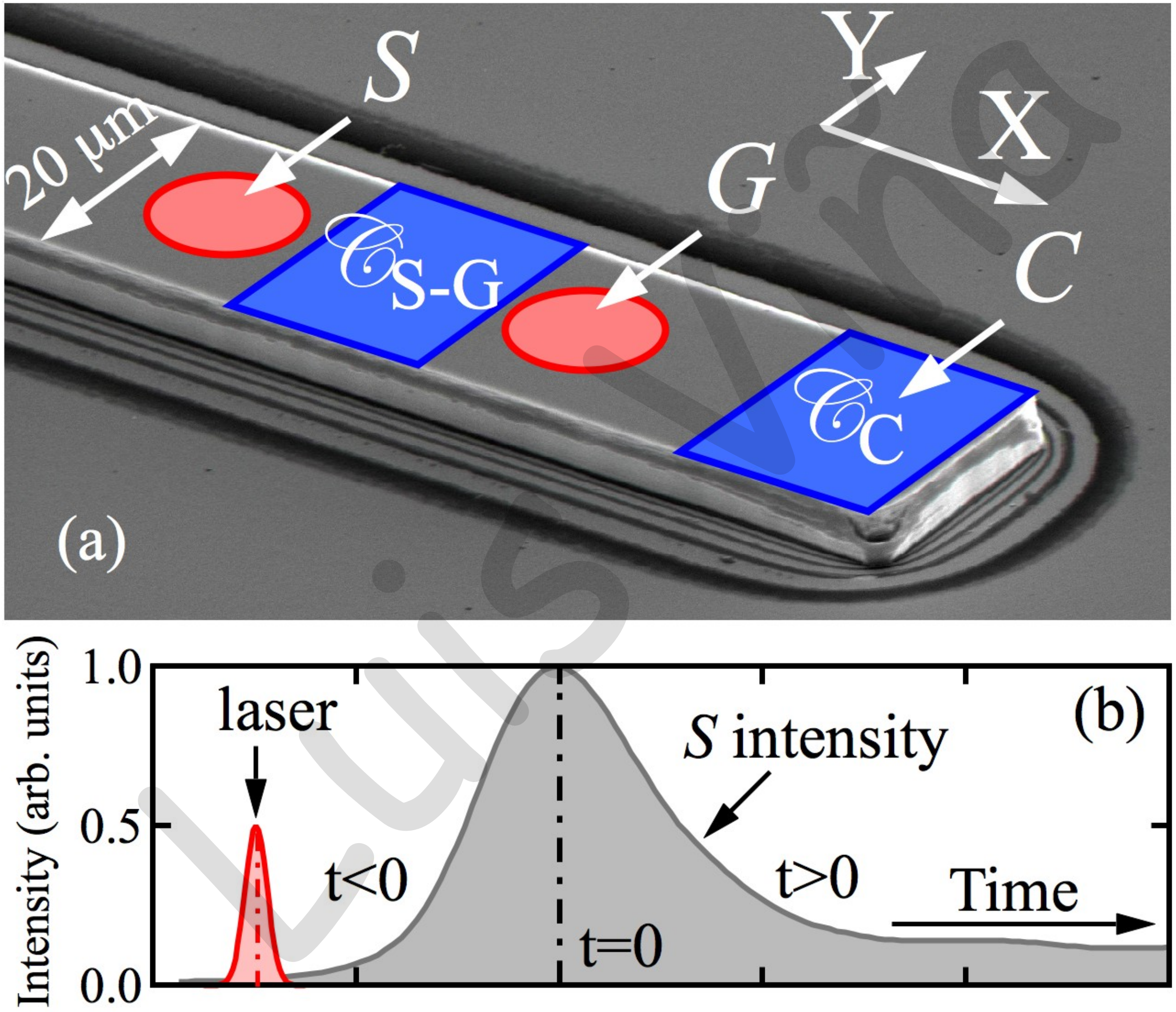




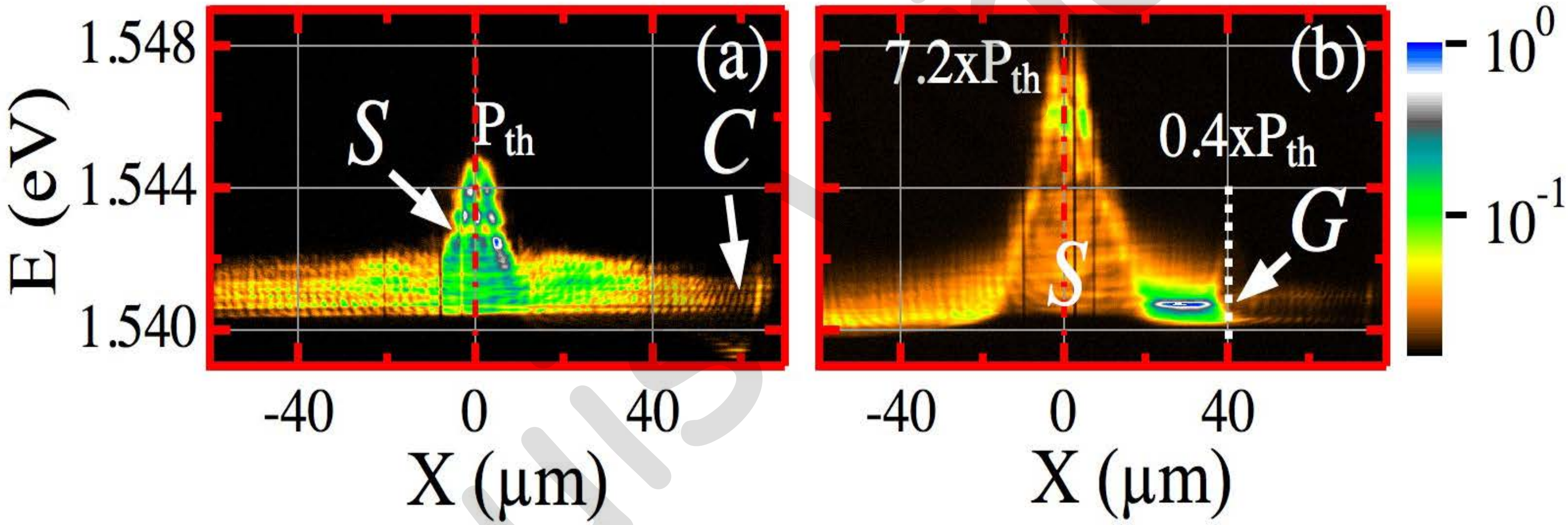
OFF



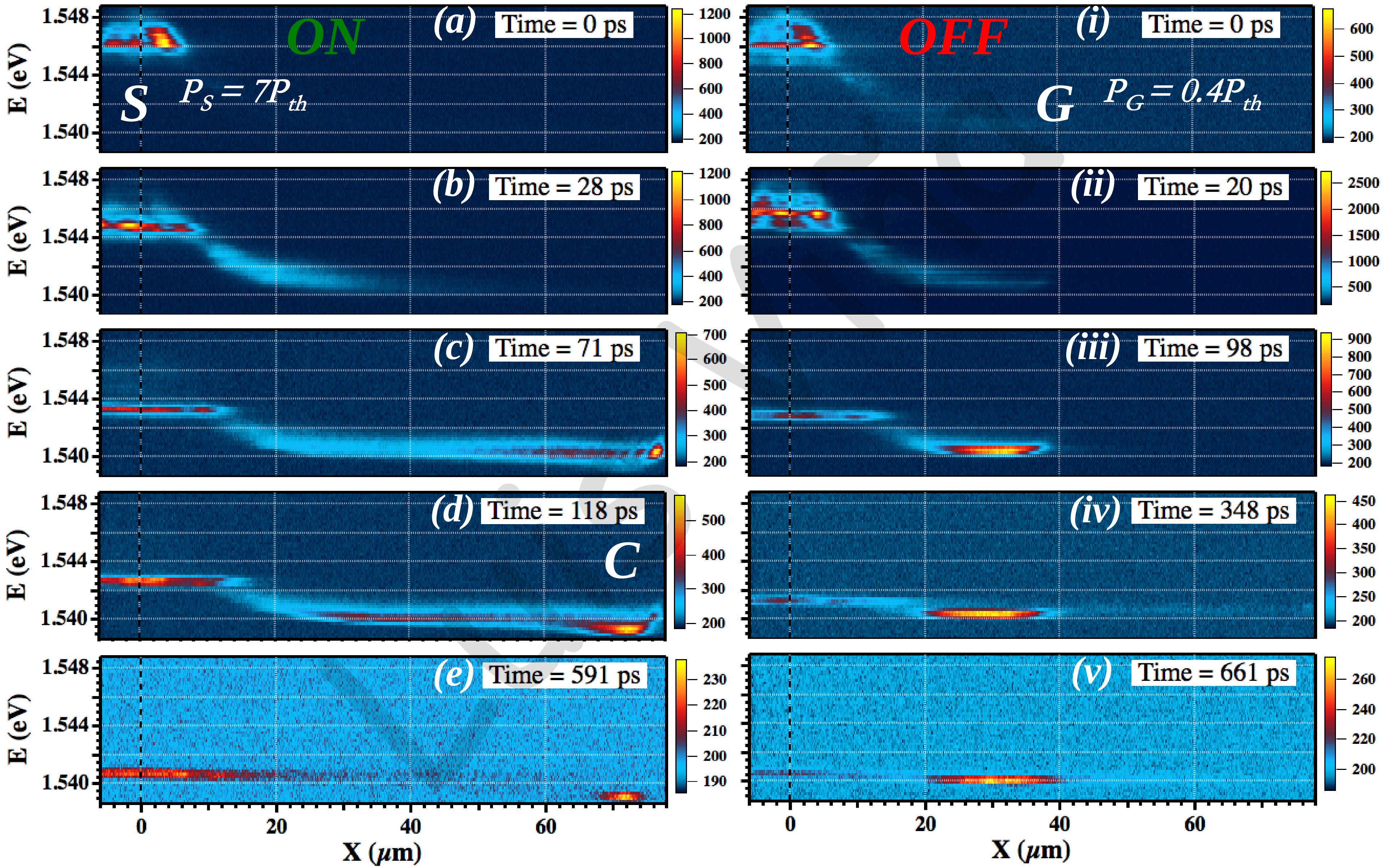
Experimental setup



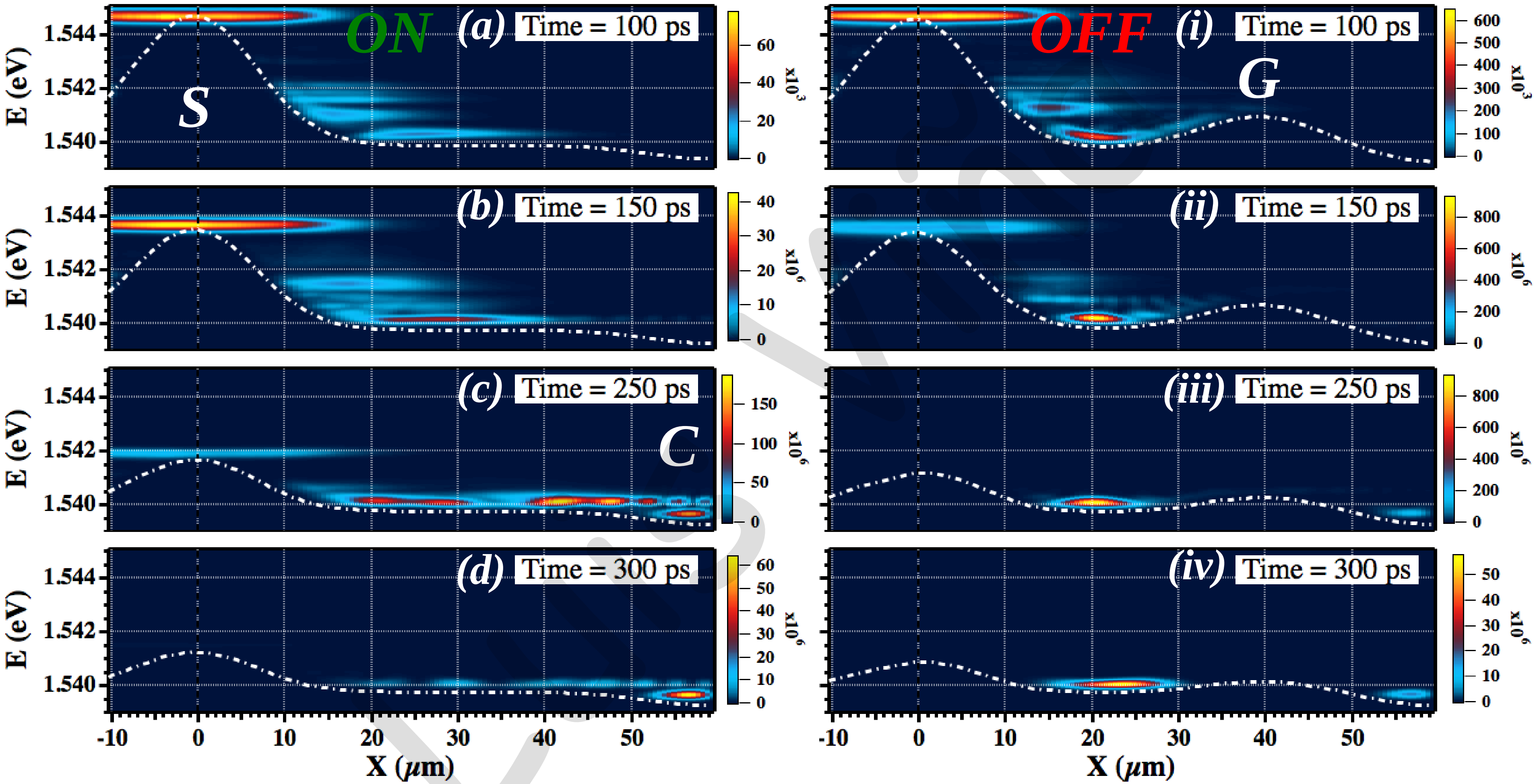
Experiments: pulsed exitation
time-integrated



Experiments

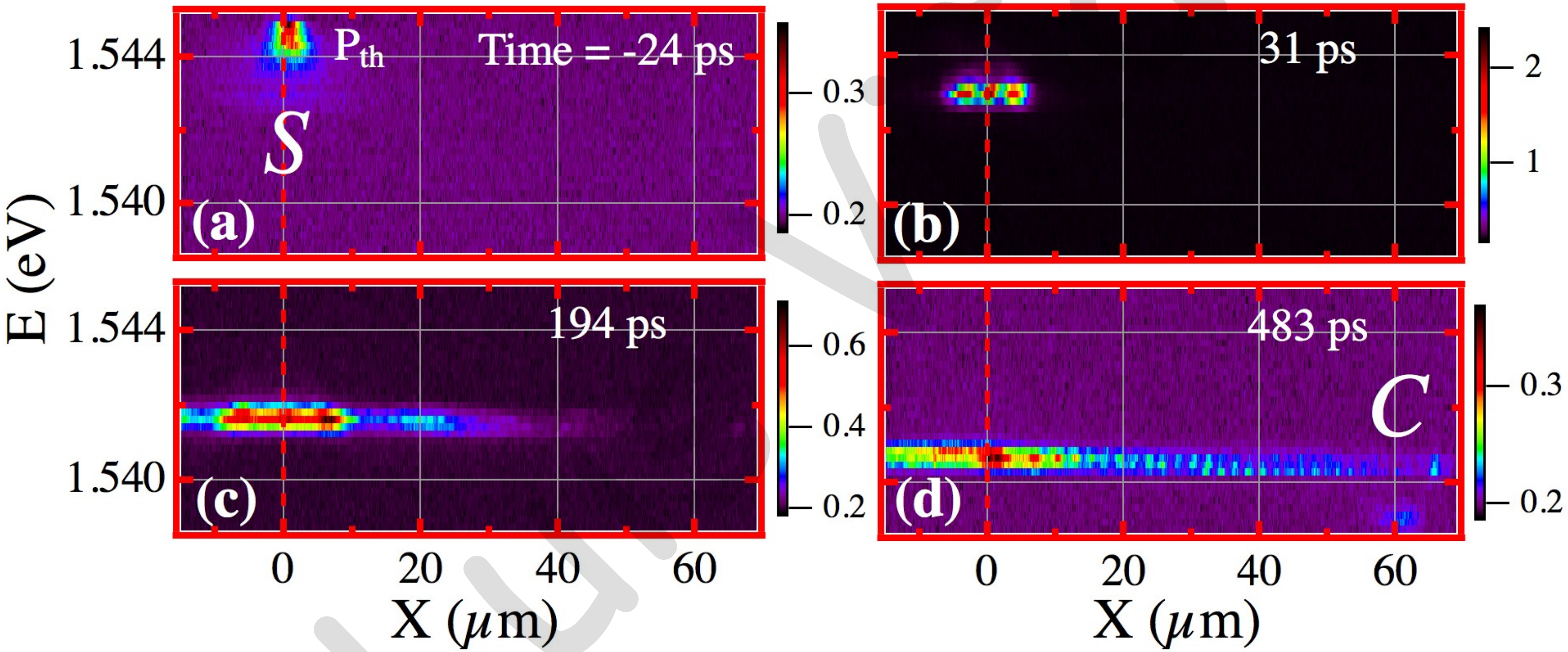


Simulations - Gross–Pitaevskii Equation

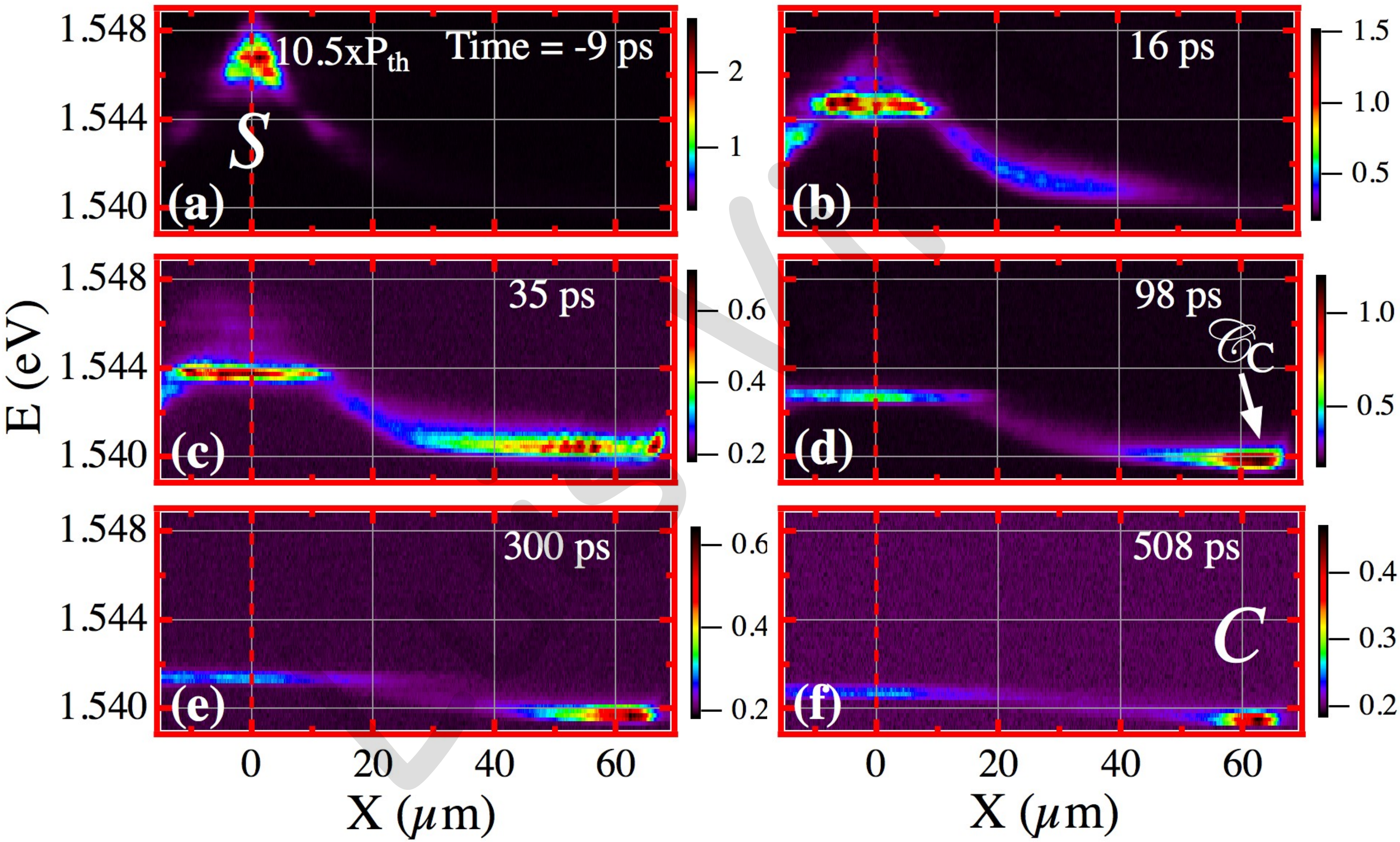


By… **T.C.H. Liew,** *School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore*

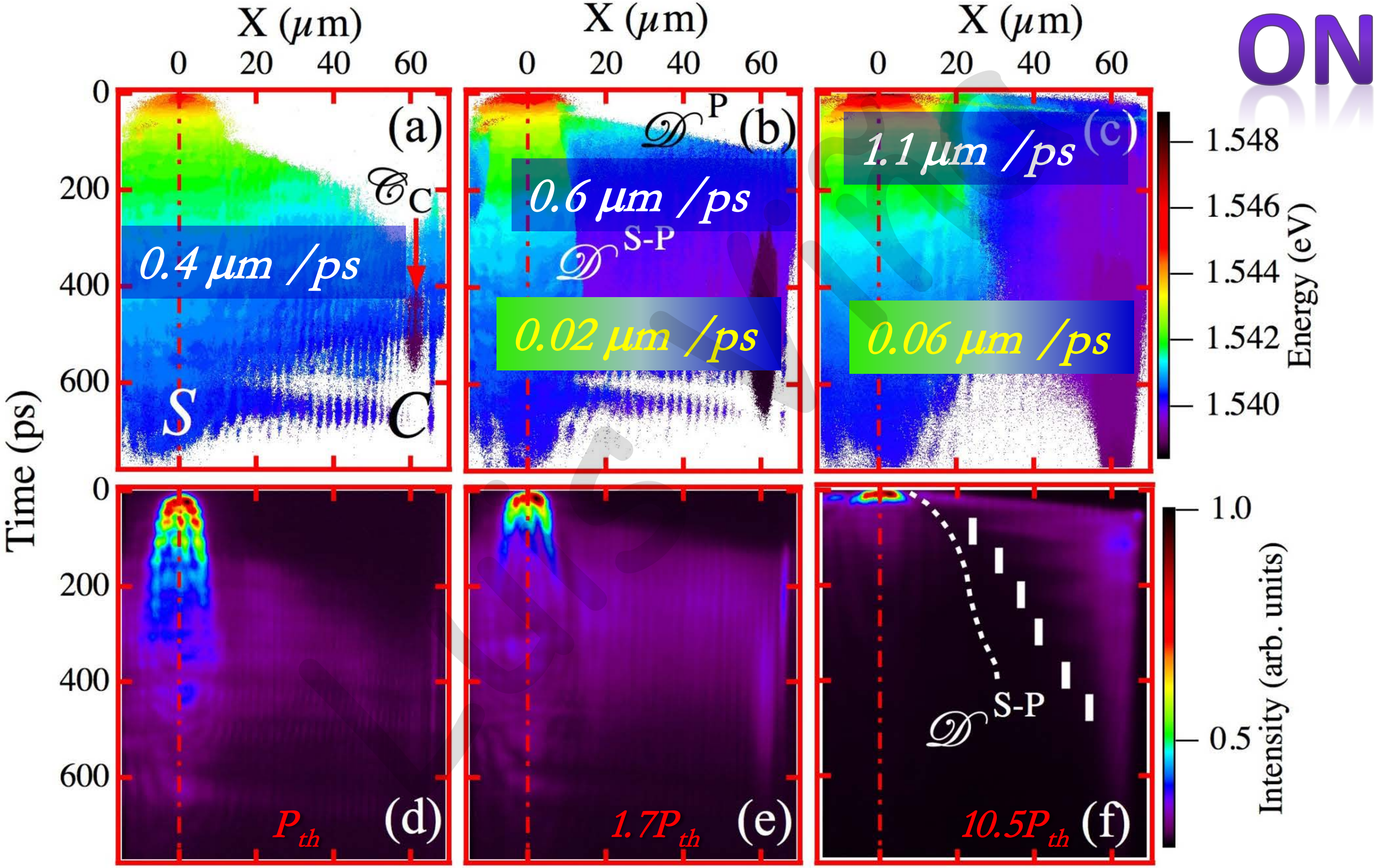
Experiments – S only at P_{th}



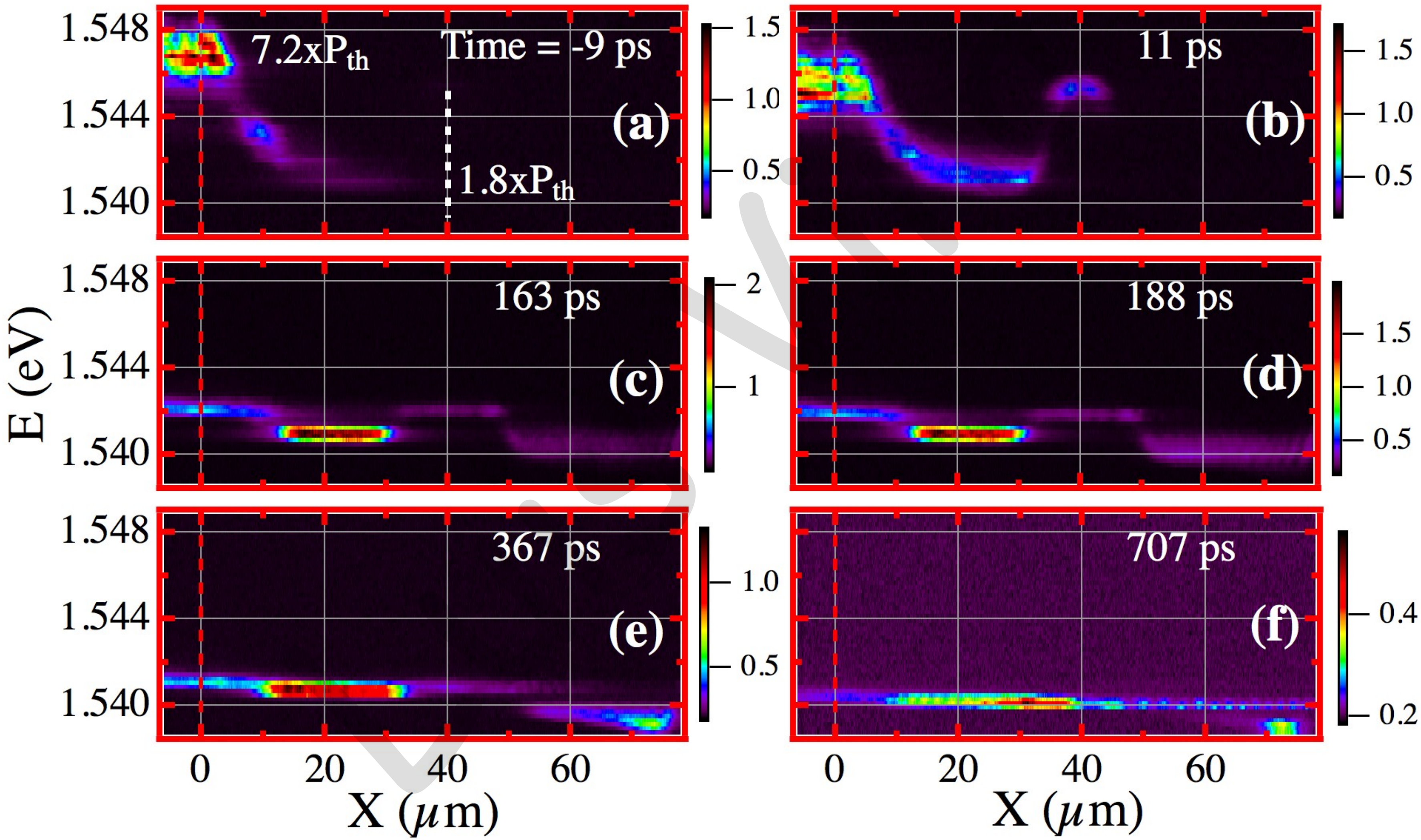
Experiments – S only at *$10.5P_{th}$*



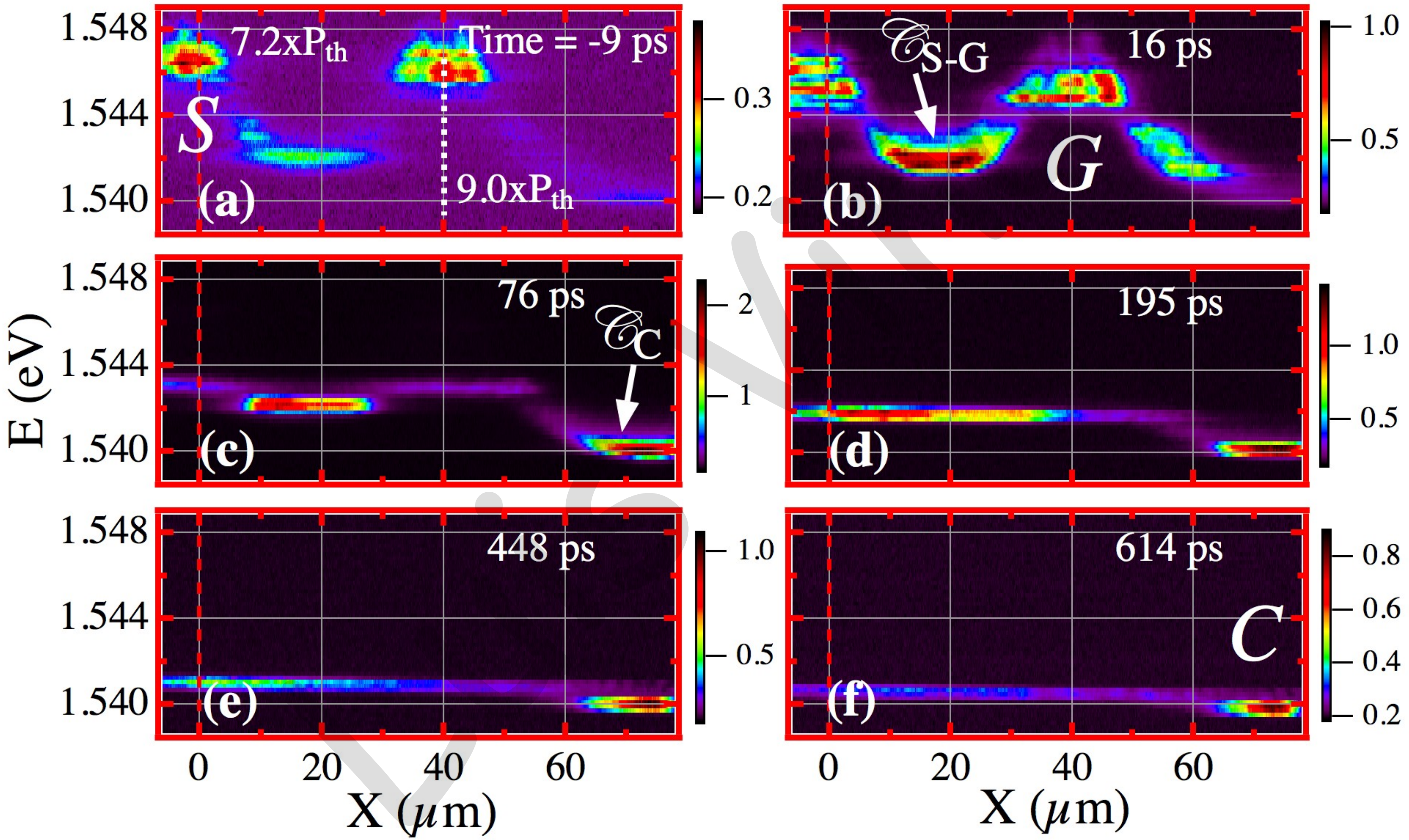
Energy and Intensity decay dynamics



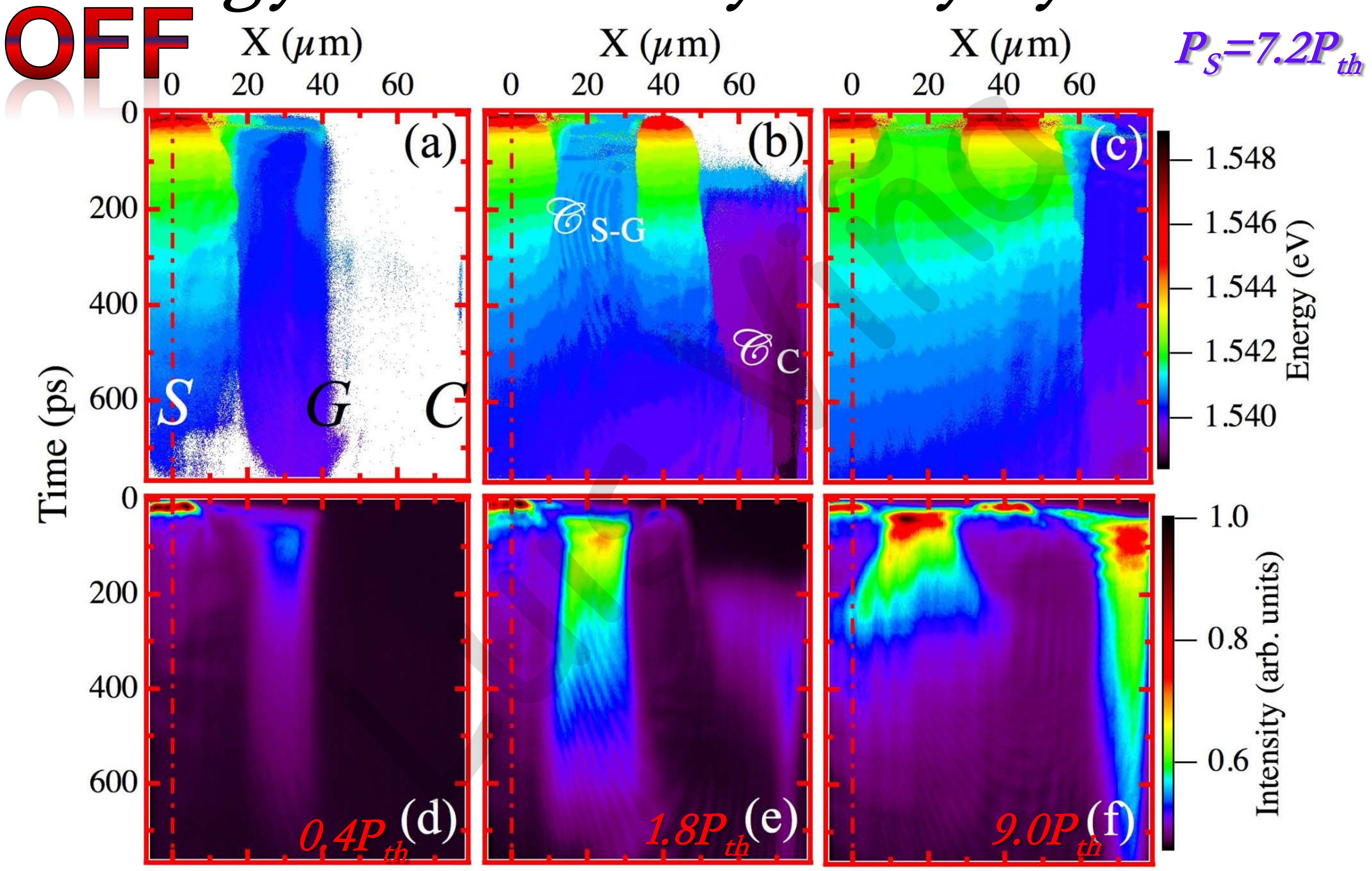
Experiments – S @ 7.2P_{th} & G @ 1.8P_{th}



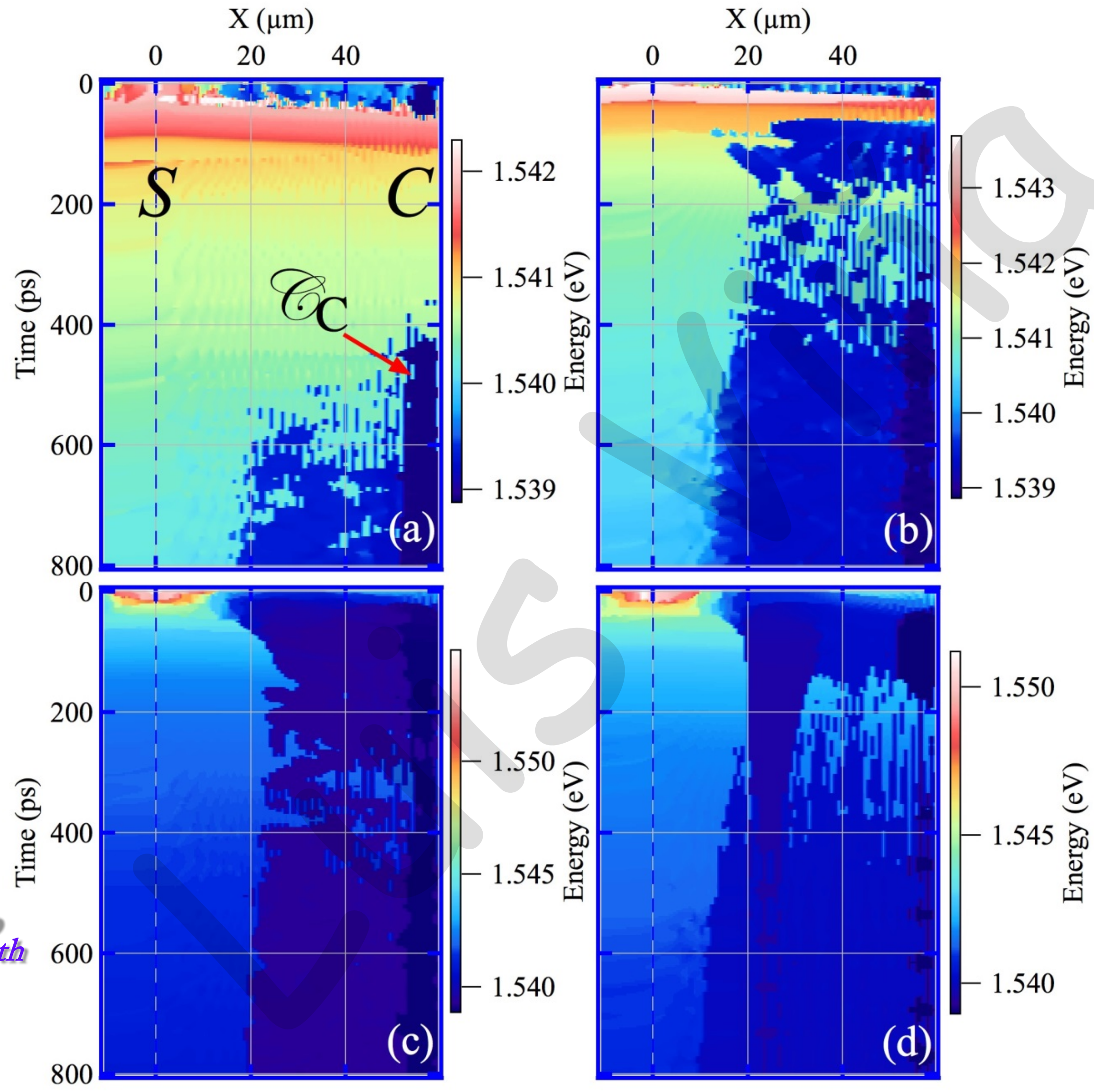
Experiments – S @ 7.2P$_{th}$ & G @ 9.0P$_{th}$



Energy and Intensity decay dynamics



Energy decay dynamics: Simulations



$P_S=P_{th}$

$P_S=10.5P_{th}$

ON

$P_S=1.7P_{th}$

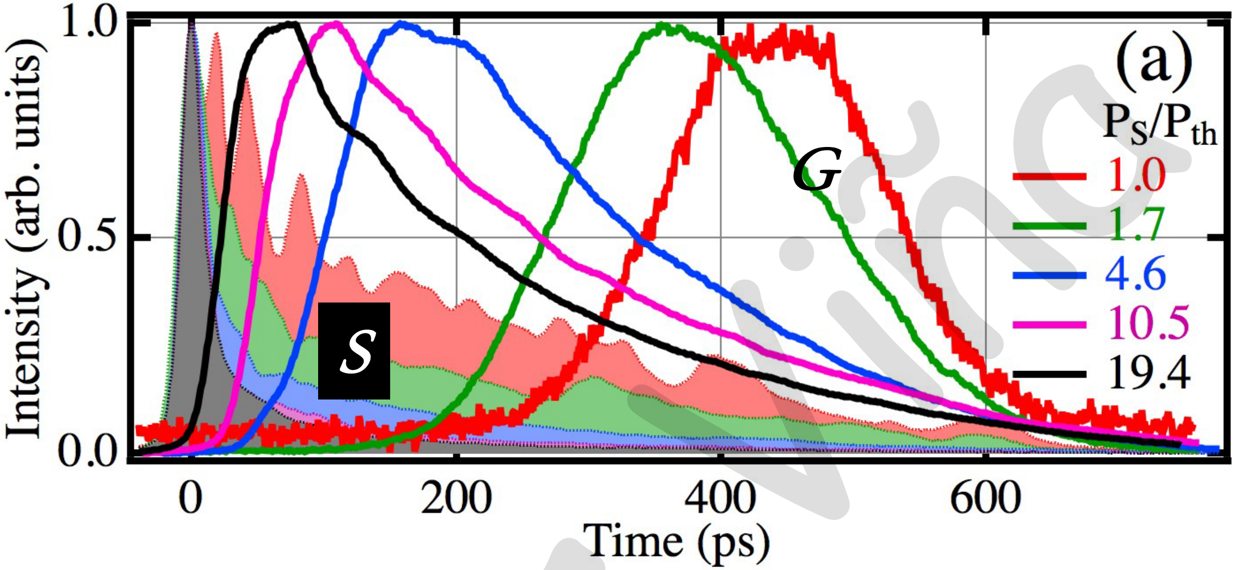
OFF

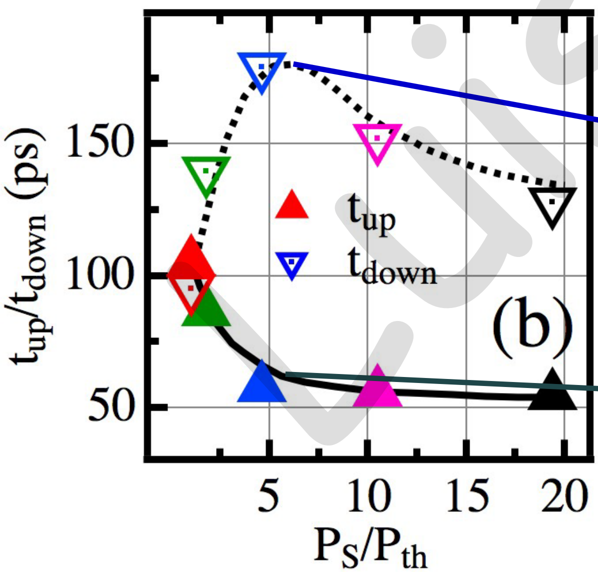
$P_S=7.2P_{th}$

$P_G=0.4P_{th}$

Optimization of the device

$S \leftrightarrow G = 60\ \mu m$



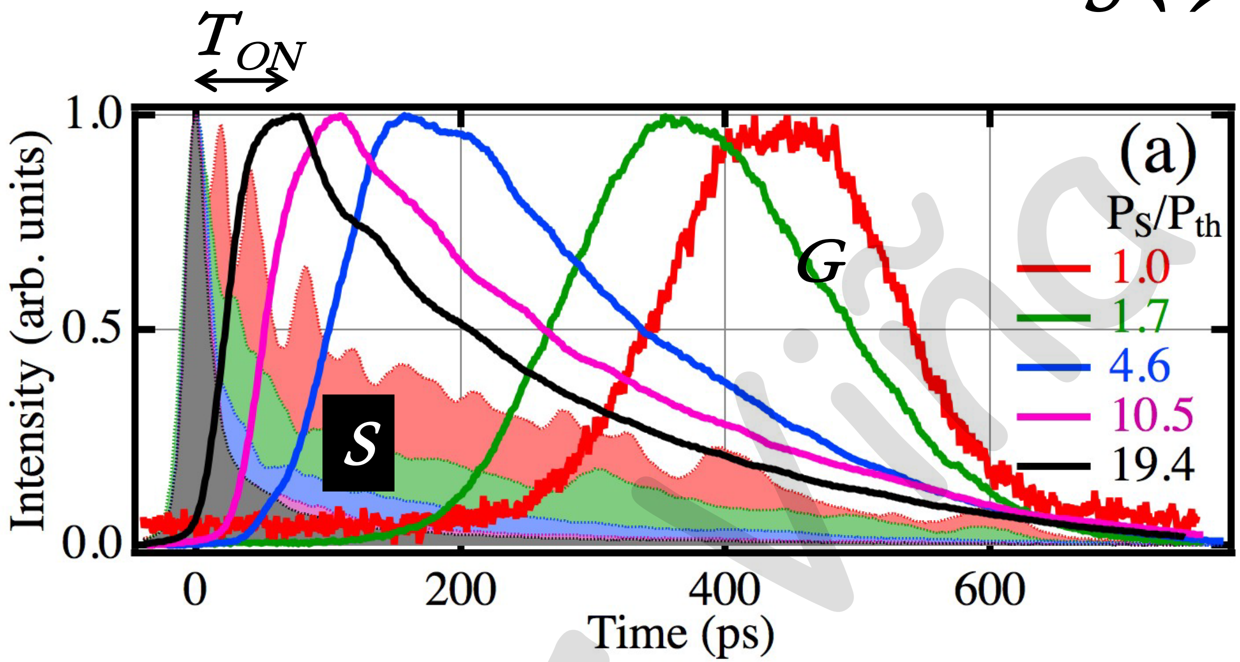


Long lived ON (t_{down}):
Optimal power = 7 P_{th}

Fast response (t_{up}):
Optimal power ≥ 7 P_{th}

Optimization of the device

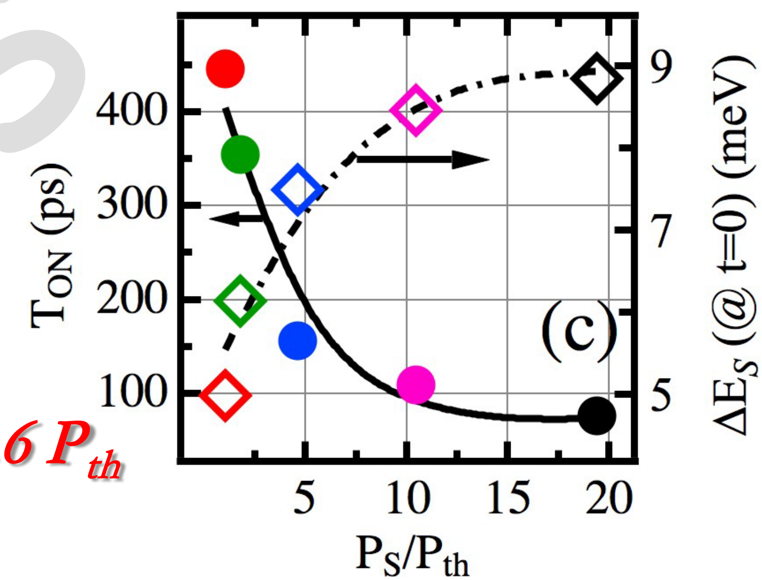
$S \leftrightarrow G = 60\ \mu m$



T_{ON} minimum 80 ps

$v_P \sim 1.1\ \mu m/ps$

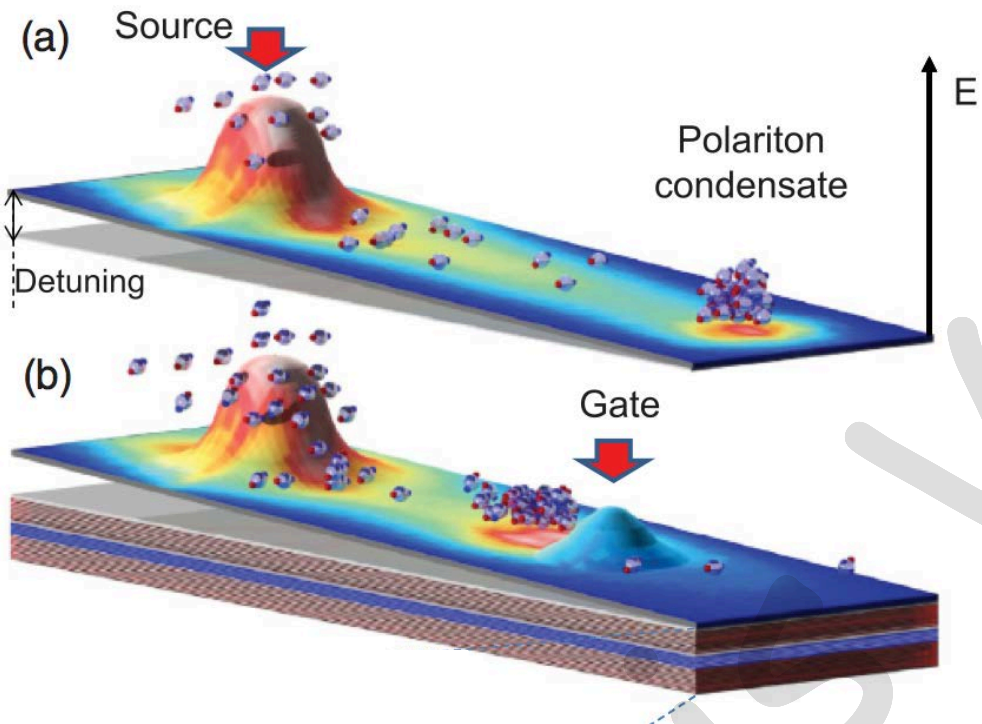
Optimal Gate power $0.6\ P_{th}$



Summary

- ✓ Full dynamics study for the **ON/OFF states** of an **all-optical polariton condensate transistor switch**, which is promising for high-speed inter-chip and intra-chip communication for core-based integrated circuits.
- ✓ The results are interpreted as a result of **polariton condensate propagation and energy relaxation** in a dynamic potential due to the exciton reservoir, which can be **optically controlled**.

Thank you very much…



…Funding

- ✓ *Spanish MEC MAT2011-22997*
- ✓ *CAM (S-2009/ESP-1503)*
- ✓ *FP7 ITN's "Clermont4" (235114)*
- ✓ *"Spin-optronics" (237252)*
- ✓ *INDEX (289968)*

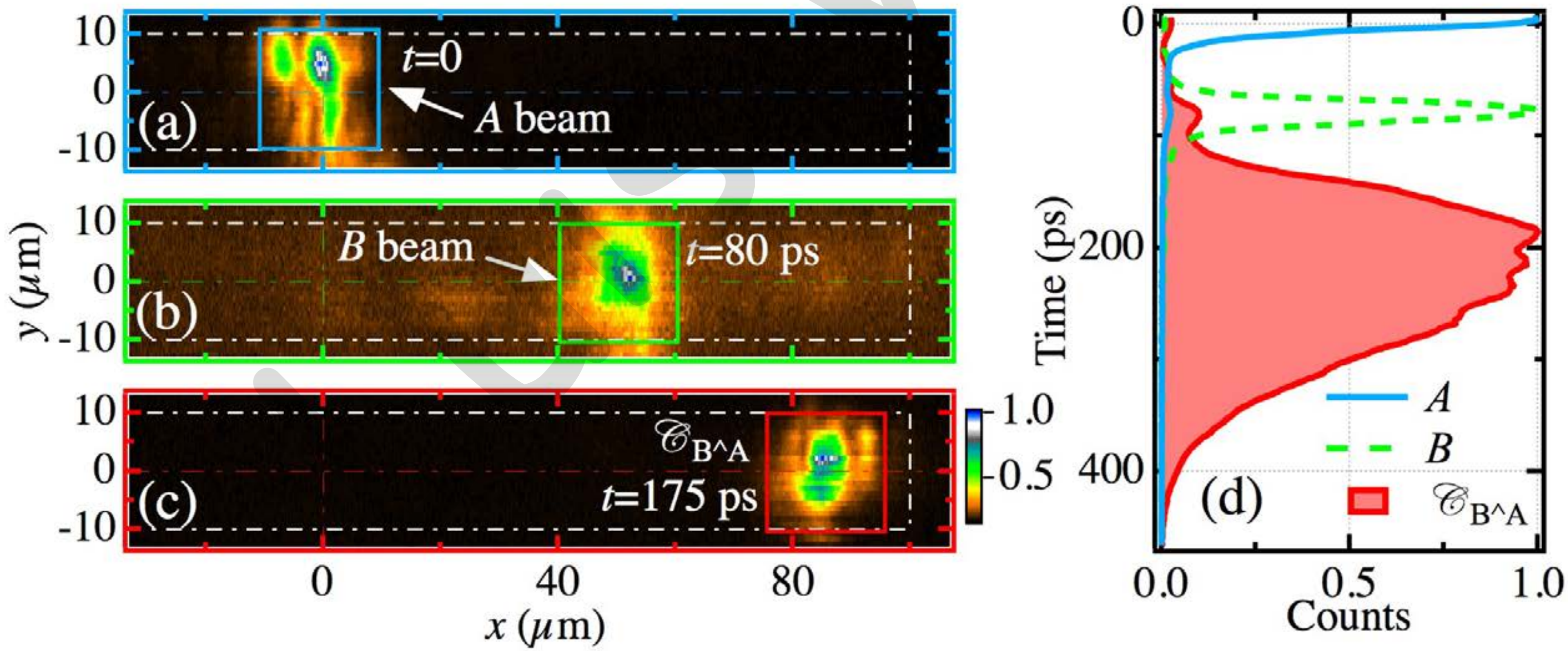
More information about this work…

C. Antón, et al., Appl. Phys. Lett. 102, 105301 (2013).

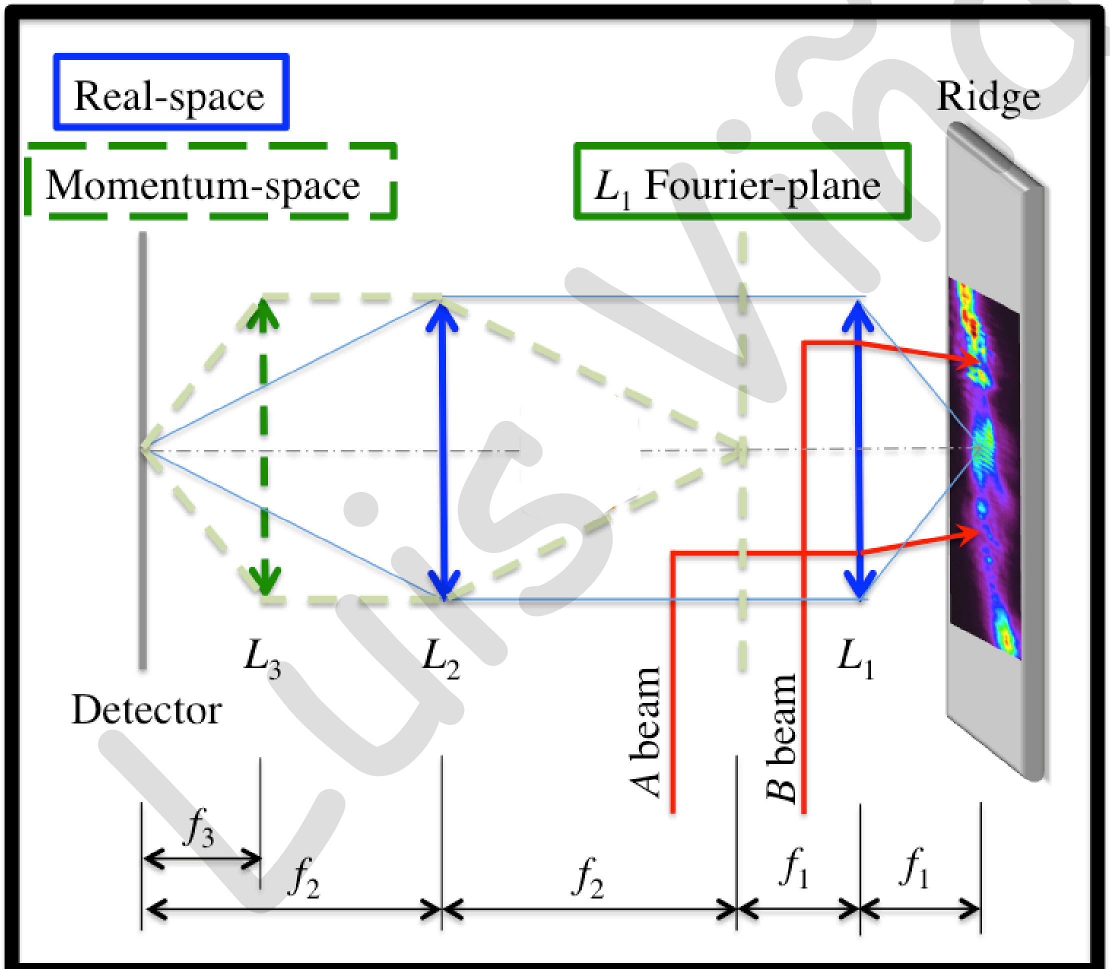
C. Antón, et al., Phys. Rev. B. 88, 035313 (2013).

AND For ballistic propagation → quasi-resonant excitation

if the pulses don´t arrive simultaneously?

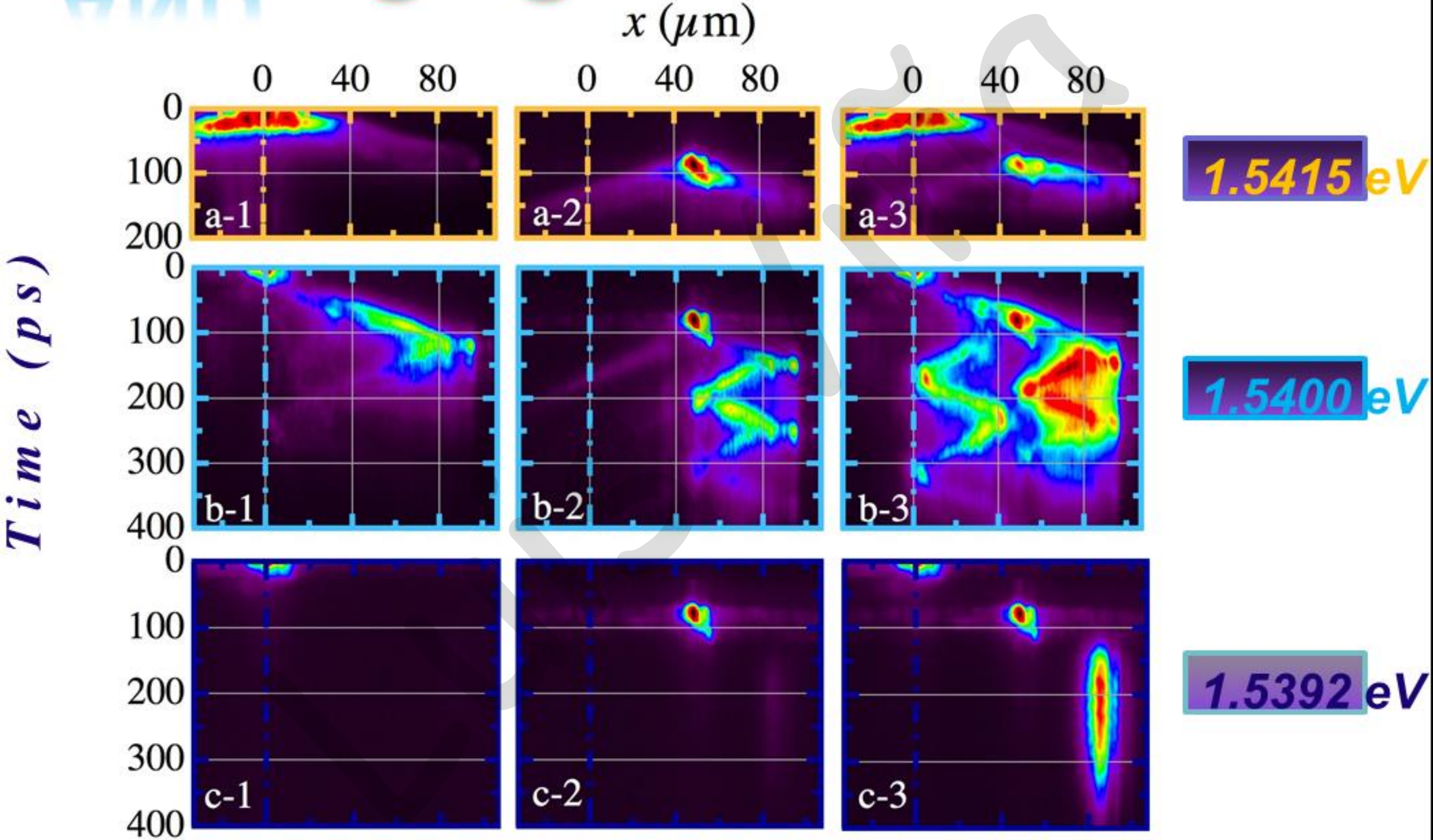


Setup



Real-space
Momentum-space
L_1 Fourier-plane
Ridge
Detector
L_3
L_2
L_1
A beam
B beam
f_3
f_2
f_2
f_1
f_1

AND logic gate



AND logic gate