ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

LASPE

Present status of polaritonic nonlinearities in planar III-nitride microcavities

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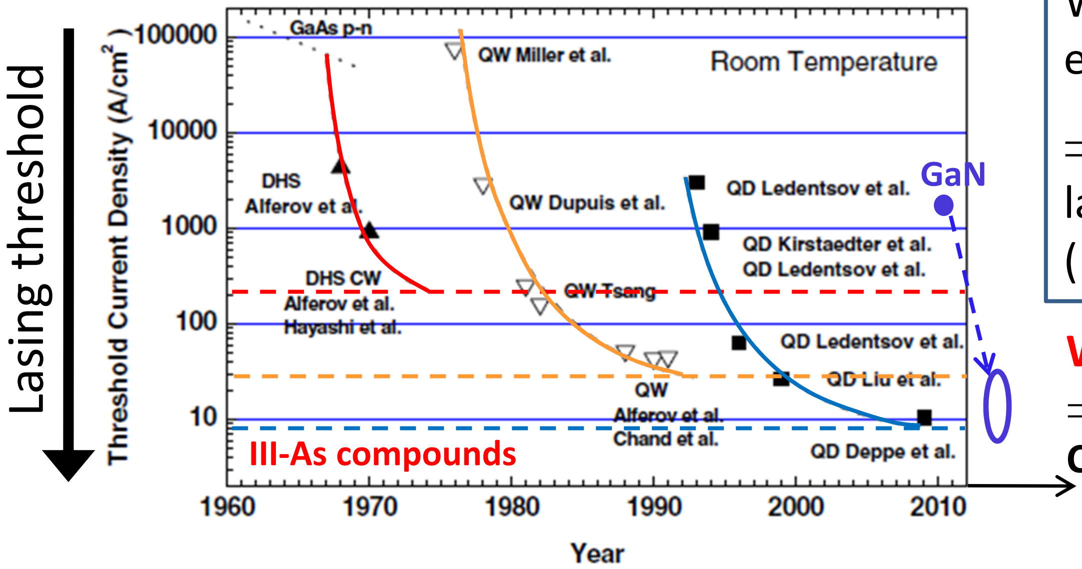
Motivations

Fundamental:

Study of bosonic condensation phenomena up to room temperature



Wide band gap semiconductors ⇒ large effective masses

⇒ high threshold current density for lasing, best GaN edge-emitting QW LDs (Nichia/Samsung) ~ 1-2 kA/cm²

What could be the next step?

⇒ **GaN polariton LDs** *SST 26, 014030 (2011)*

Cf. talk Marlene Glauser

N. N. Ledentsov, SST 26, 014001 (2011)

Applied:

Achieve room temperature electrical injection of cavity polaritons characterized with an ultra-low effective mass

⇒ Low threshold “lasers” without population inversion

A. Imamoglu et al., PRA 53, 4250 (1996)

Outline

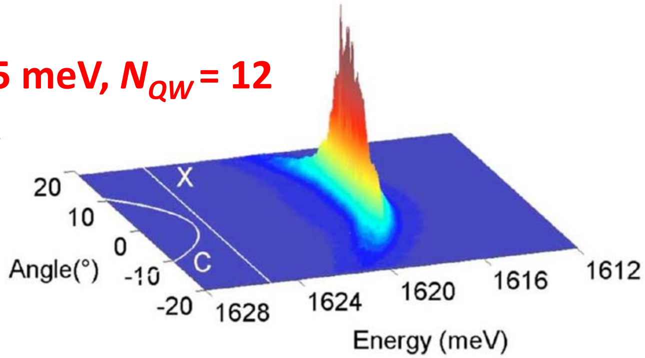
- Polariton condensation in planar microcavities: role of the detuning δ and temperature
- Impact of biexcitons on the relaxation mechanisms of polaritons
- A few hints on renormalization effects in III-nitride microcavities
- Conclusion and perspectives

Polariton nonlinearities in planar microcavities

GaAs

Ω_{VRS} **~ 15 meV,** N_{QW} **= 12**

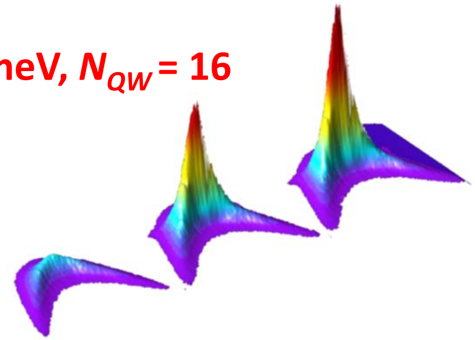
T_C **~ 40 K**



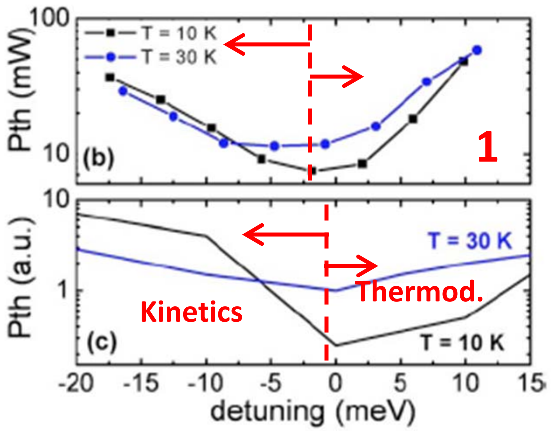
CdTe

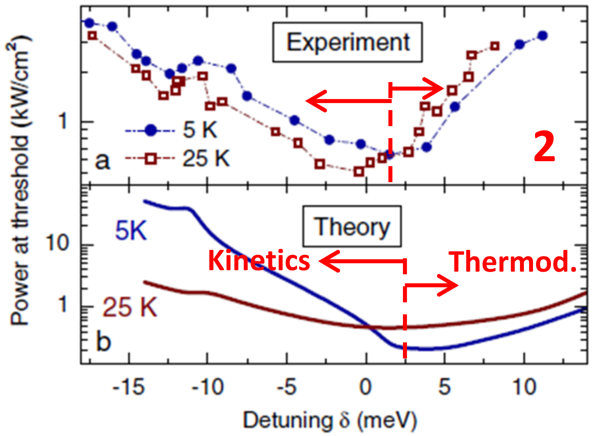
Ω_{VRS} **~ 26 meV,** N_{QW} **= 16**

T_C **~ 50 K**



- Relaxation bottleneck to overcome
- Key role of cavity photon lifetime to achieve spontaneous condensation
- Large QW number to reduce the exciton density per well

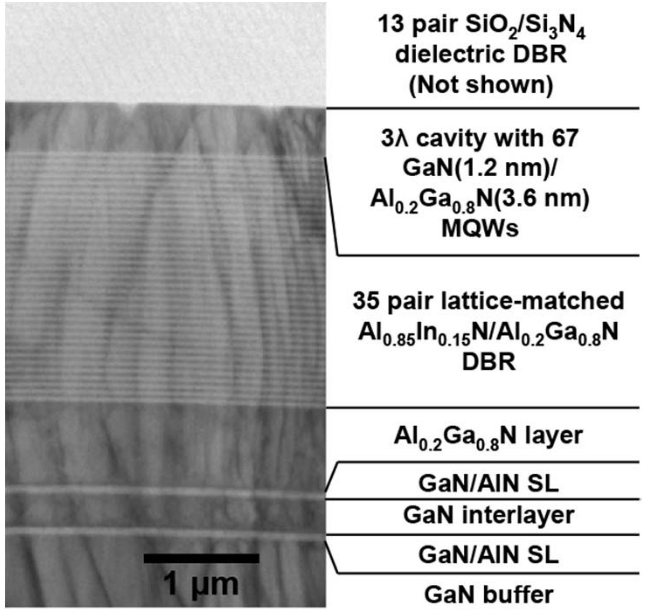




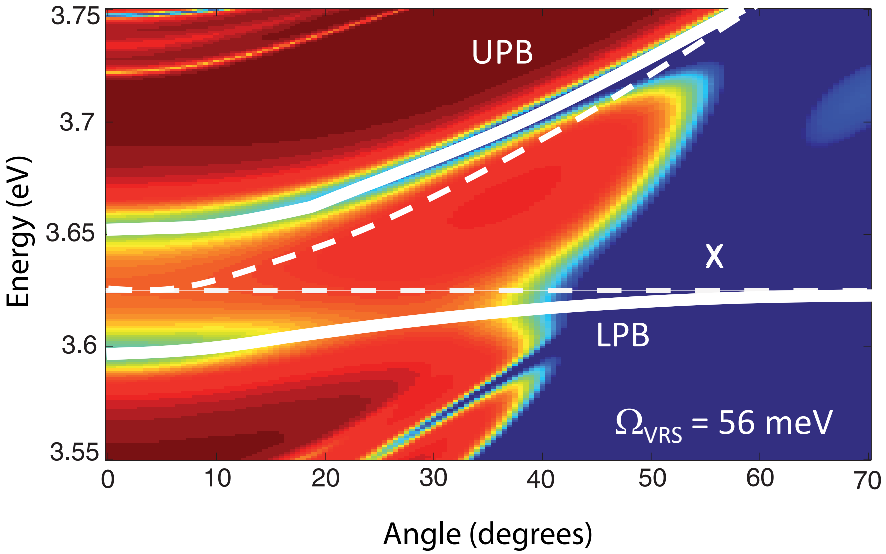
- **Temperature-dependent optimum δ but limited Δ*T* range accessible**

[1]E. Wertz et al., APL 95, 051108 (2009);
[2]J. Kasprzak et al., PRL 101, 146404 (2008)

Planar III-N microcavity for polariton studies



Large QW number to increase Rabi splitting

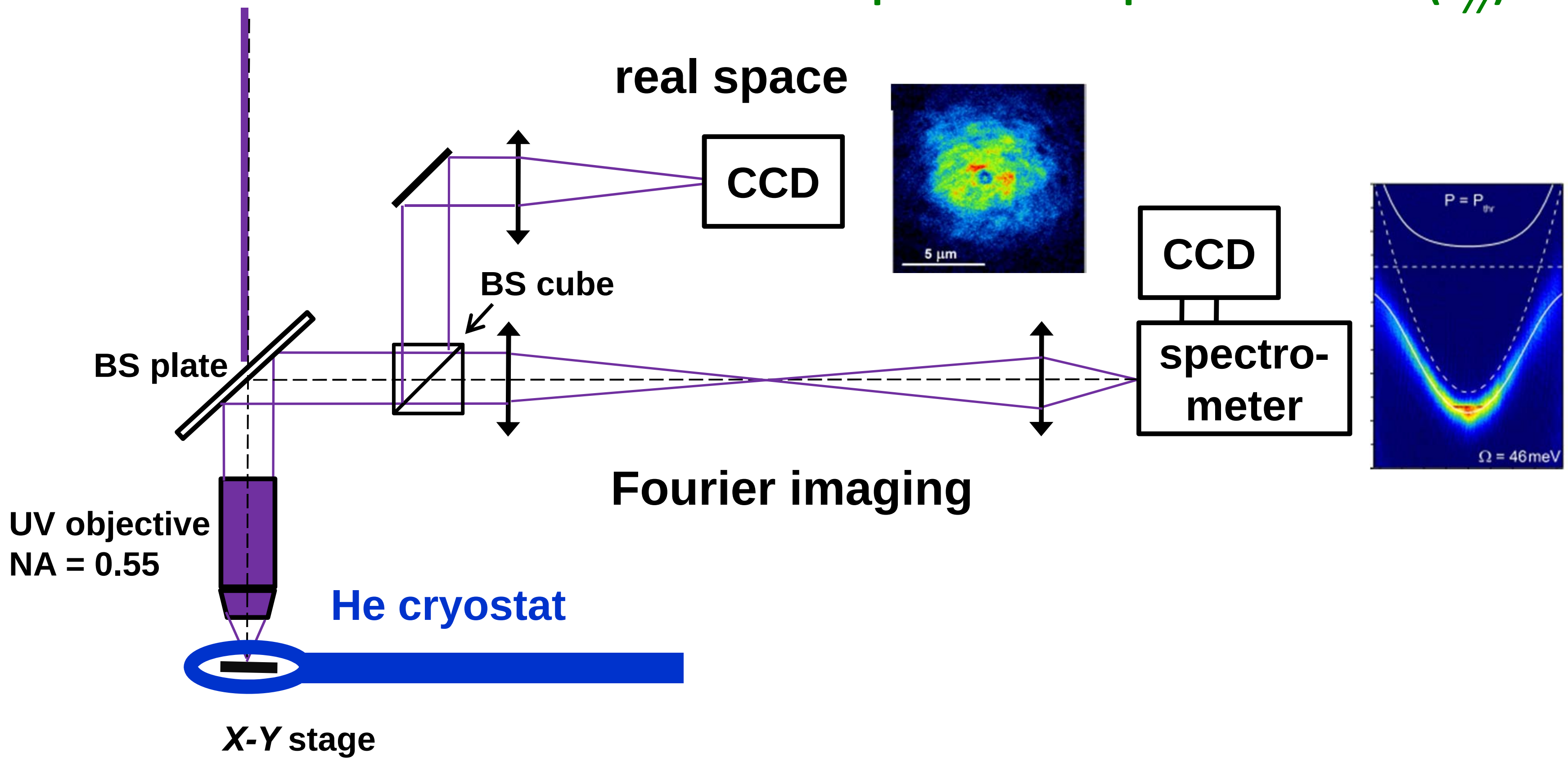


PRB 77, 085310 (2008)

Experimental setup

1- Fourier PL setup: Ar^+ (244 nm, cw) or Nd:YAG (266 nm, quasi-cw)

Access to the polariton dispersion curve $E(k_{//})$



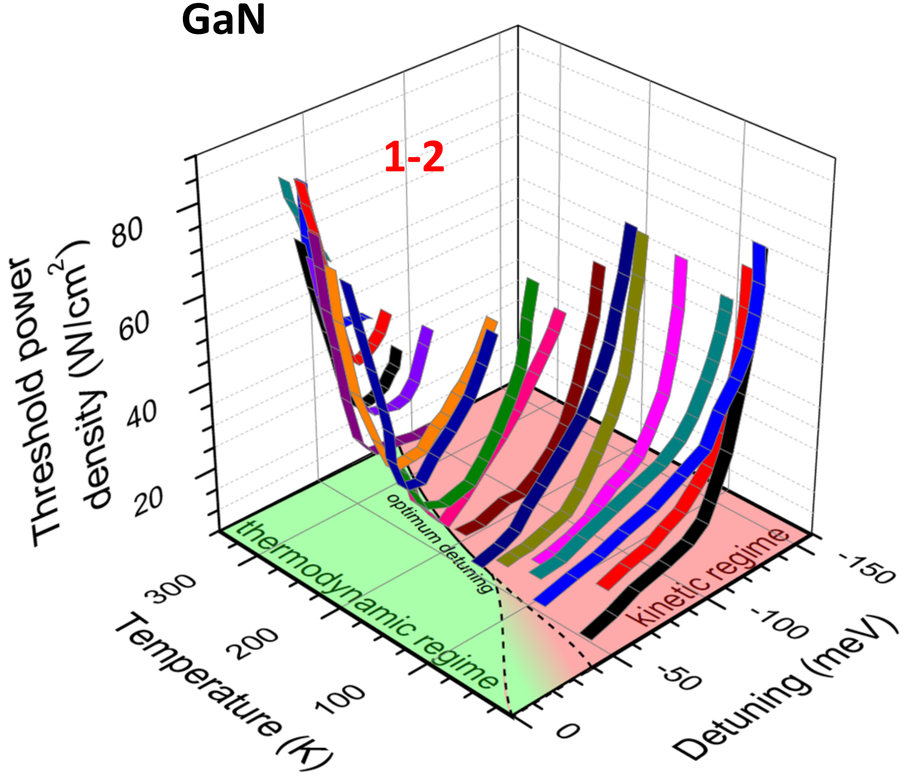
2- Time-resolved PL setup: Ti:sapphire (280 nm, 2 ps) + monochrom. + streak camera

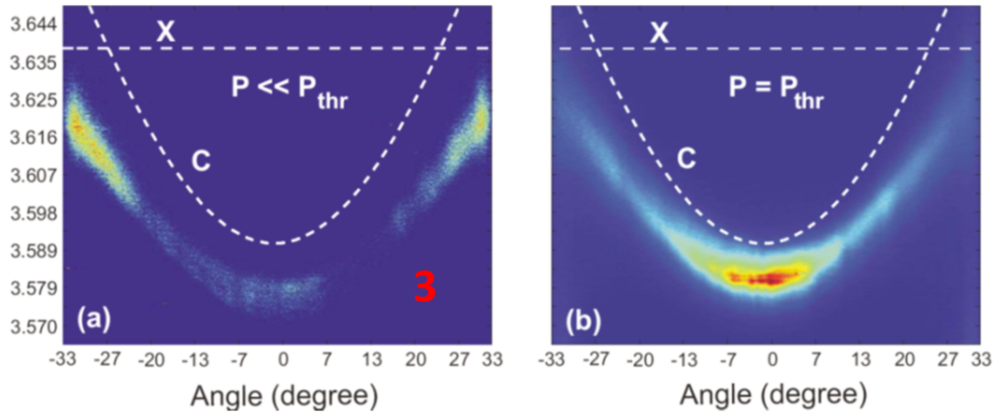
Temporal evolution of the PL at $k_{//} = 0$

Polariton condensation phase diagram

(δ, T, P_{thr}) diagram[1-2]

GaN



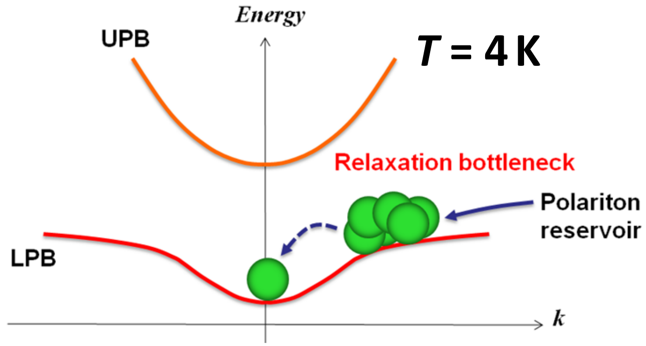


Thermalized population in the vicinity of the ground state with T_{eff}= 300 ± 10 K
⇒ signature of nonequilibrium polariton BEC at room temperature

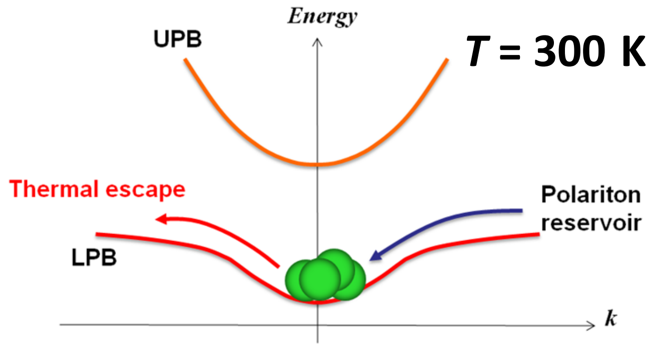
[1]*PRB 80, 233301 (2009);* [2]*PRB 81, 125305 (2010);*[3]*PRL 104, 166402 (2010)*

Polariton condensation phase diagram

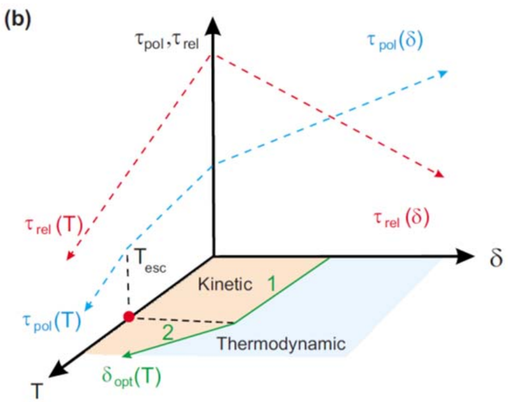
Large negative detuning and low temperature
- inefficient polariton relaxation
→ **increasing threshold (kinetic regime)**



Less negative detuning and elevated temperatures
- enhanced scattering efficiency
→ **decreasing threshold (toward/or thermod. regime)**

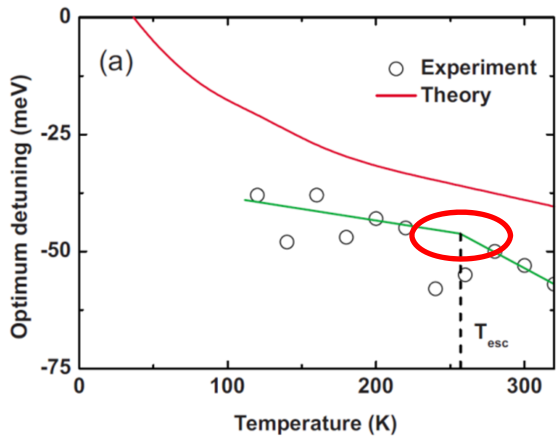


Competition between kinetic and thermodynamic condensation regimes: impact of phonon scattering term ⇒ shift of $\delta_{opt}(T)$ toward more negative δ values with increasing T(K)[1-2]



Extra kink observed in the evolution of $\delta_{opt}(T)$ once escape from parabolic region of the LPB is allowed[1-2]

⇒ thermal detrapping from polariton ground state (specific feature due to matter-like character of polaritons)



[1]PRB 80, 233301 (2009); [2]PRB 81, 125305 (2010)

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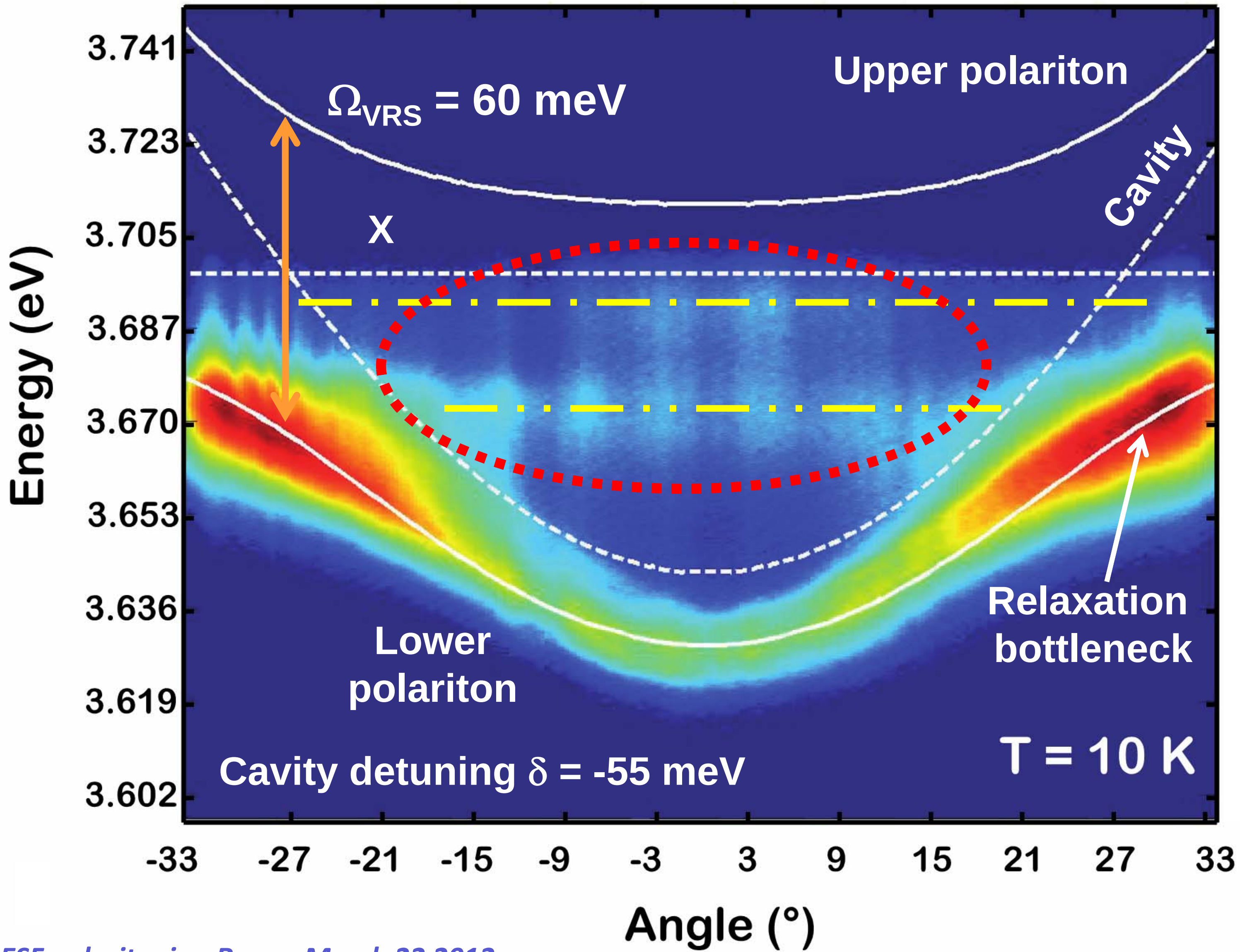
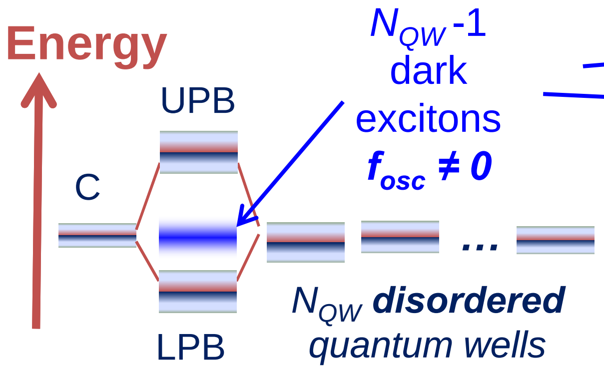
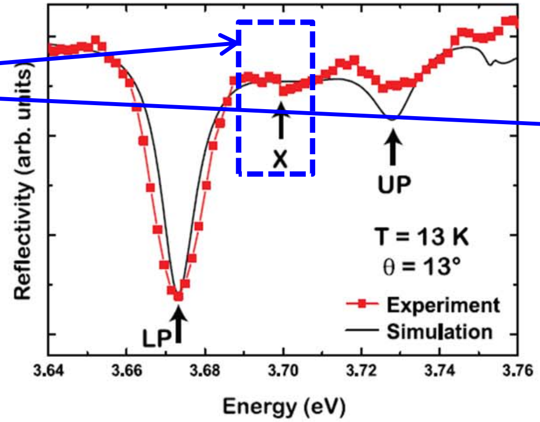
Fourier imaging spectroscopy: accurate farfield emission pattern



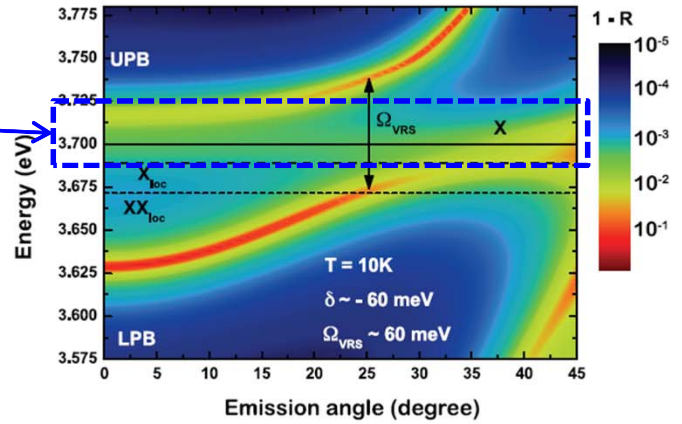
Two unidentified PL lines!

Dark excitons in real multiple QW microcavities



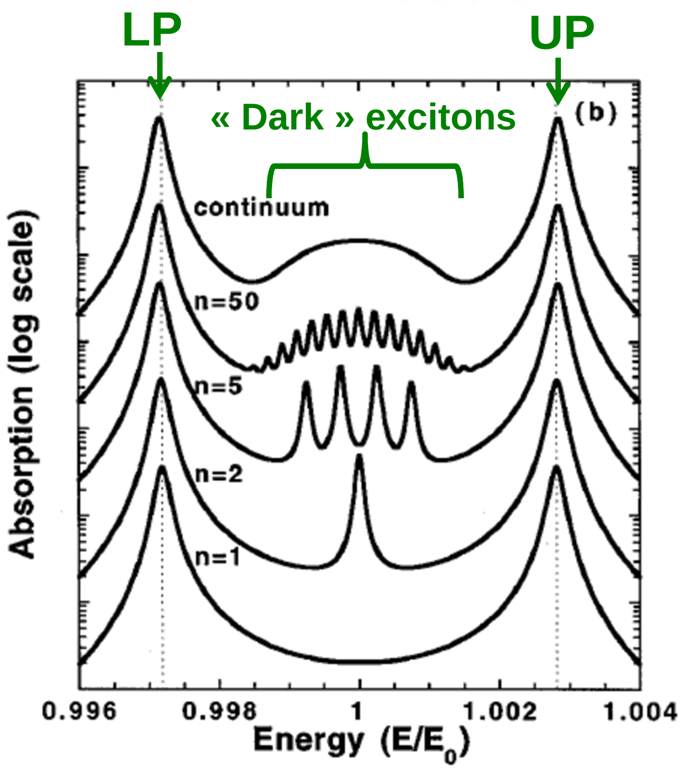


Transfer matrix simulations



In presence of *disorder*, redistribution of the oscillator strength from the polaritons to the dark modes

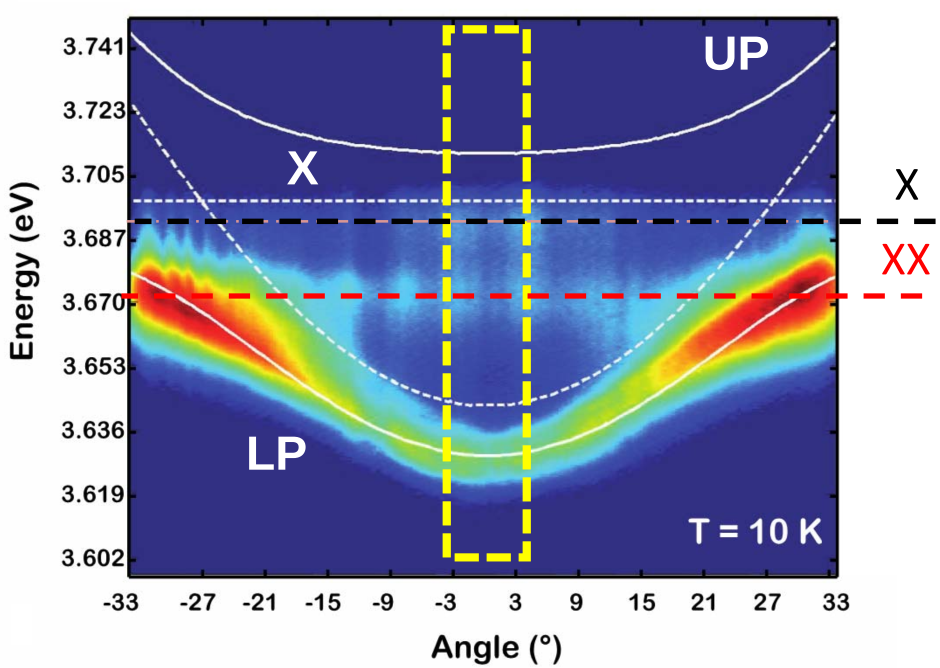
R. Houdré *et al.*, Phys. Rev. A 53, 2711 (1996)



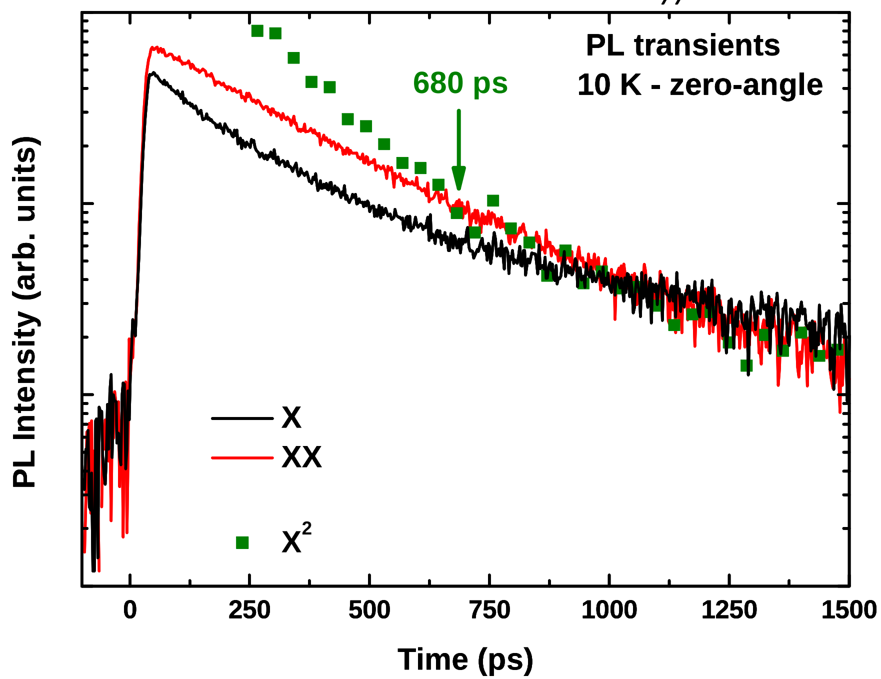
Dark excitons can bind to form cavity biexcitons

G. C. La Rocca *et al.*, J. Opt. Soc. Am. B 15, 652 (1998)

Exciton and biexciton dynamics



TR-PL decays taken at $k_{//} = 0$

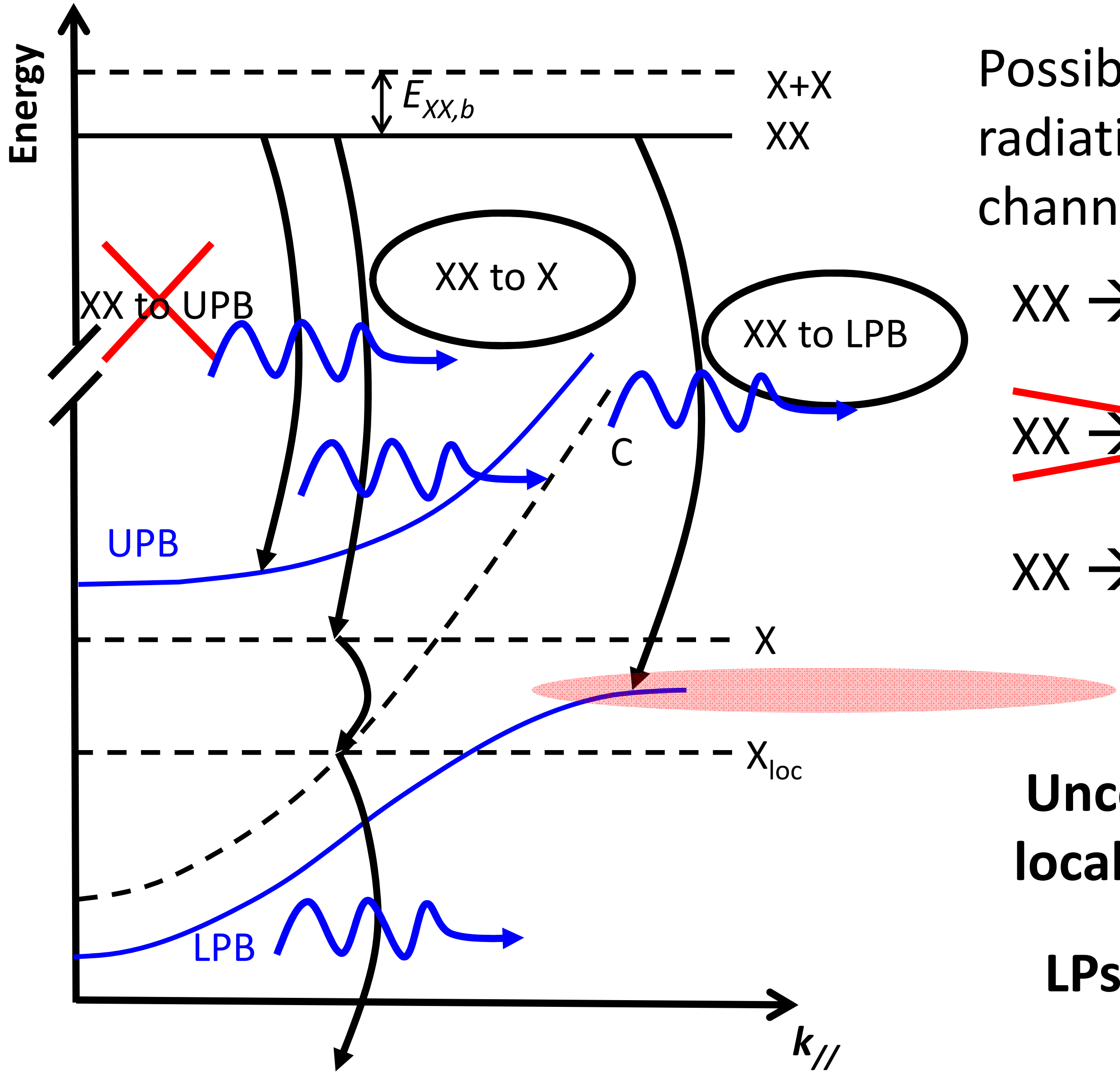


At quasi-thermal equilibrium $2X \leftrightarrow XX \Rightarrow I_{XX} \propto I_X^2$

Observation of “cavity biexcitons”

Do biexcitons play a role in the relaxation mechanisms of polaritons?

Biexciton luminescence in the full cavity



Possible cavity biexciton radiative dissociation channels:

XX → photon + LPB

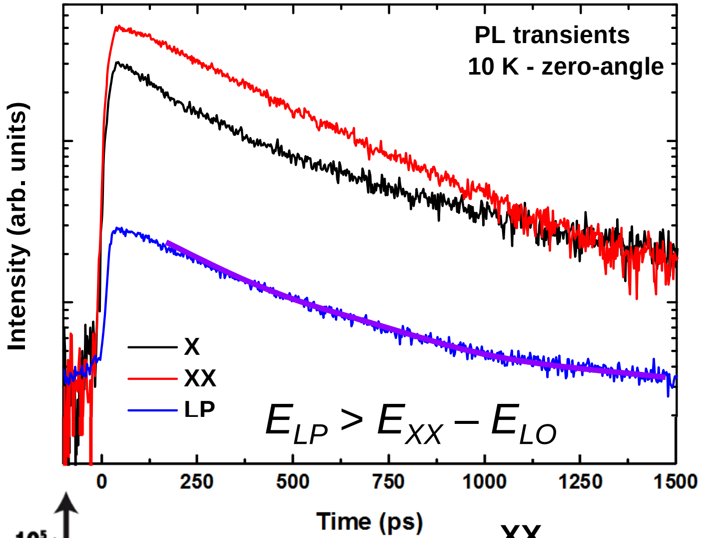
~~XX → photon + UPB~~

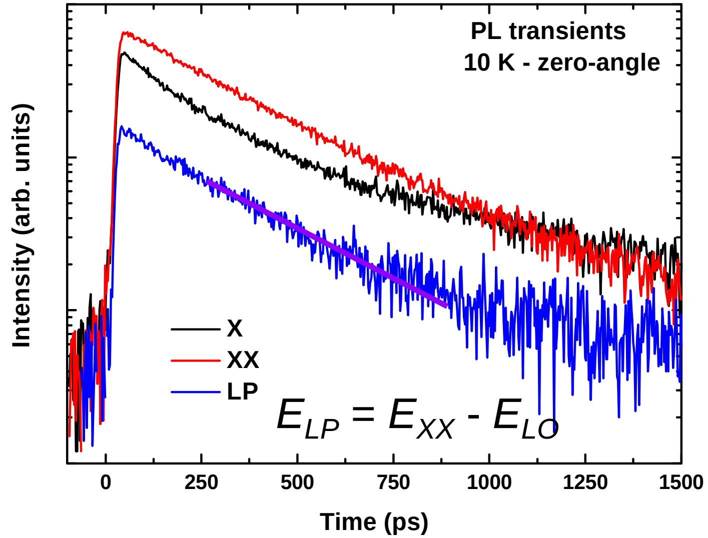
XX → photon + X

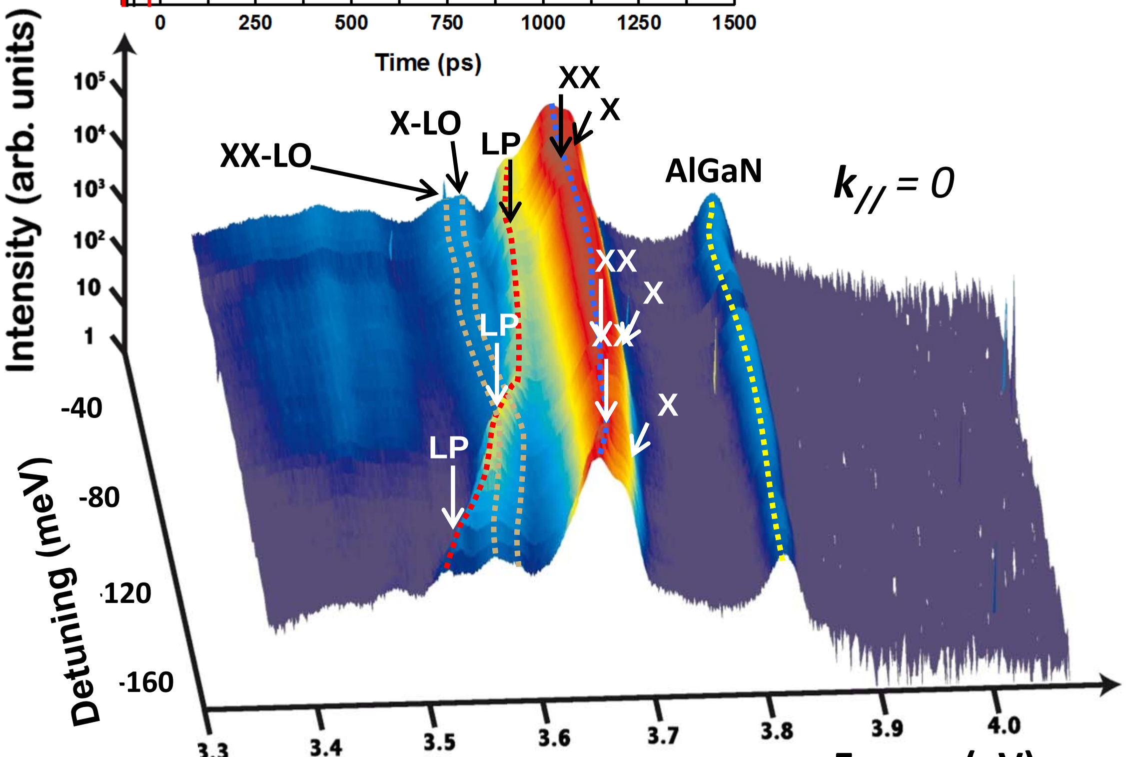
Uncoupled excitons get localized and recombine

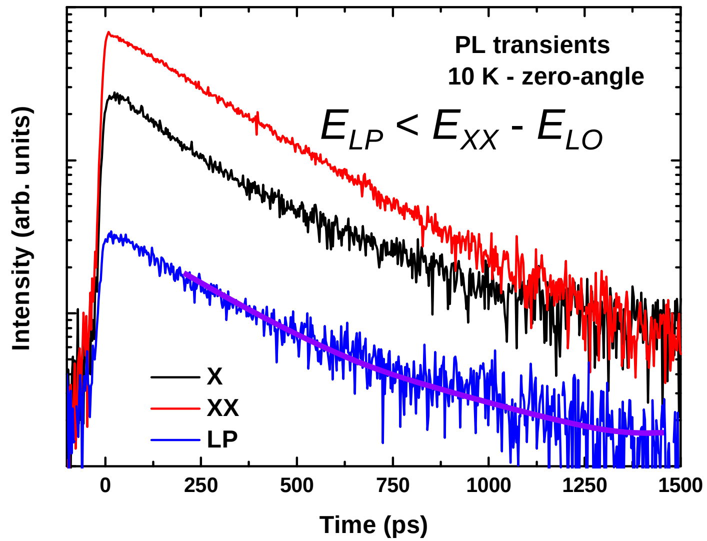
LPs accumulate in the reservoir

LPB relaxation dynamics



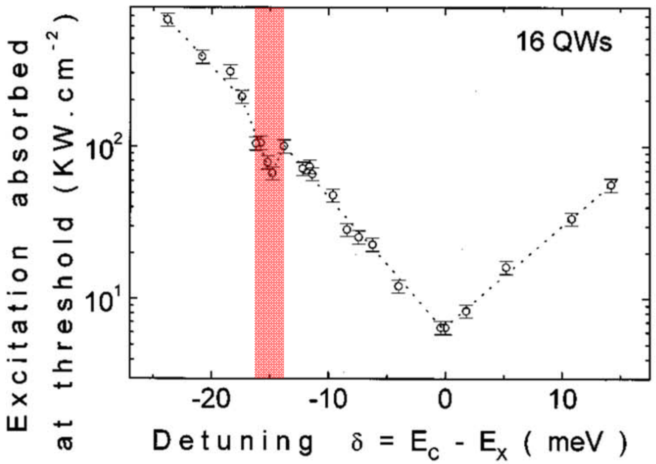






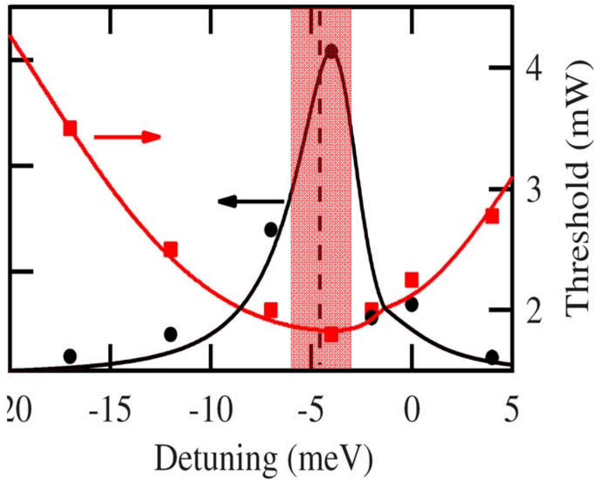
Enhanced relaxation efficiency

CdTe



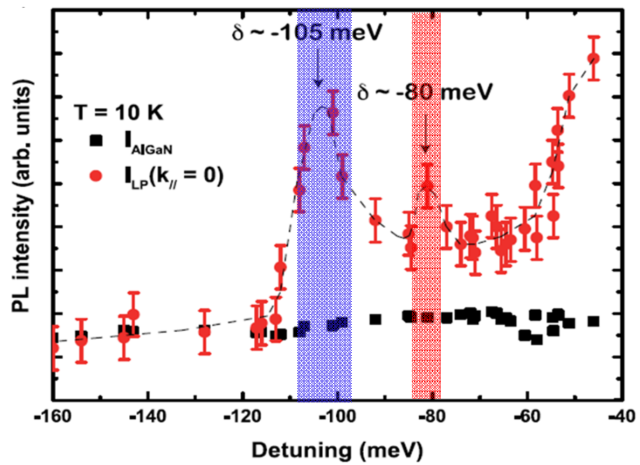
F. Boeuf *et al.*, Phys. Rev. B **62**, R2279 (2000)

GaAs



M. Maragkou *et al.*, Appl. Phys. Lett. **97**, 111110 (2010)

GaN



P. Corfdir *et al.*, submitted to Phys. Rev. B

<u>GaAs, CdTe and GaN</u>

Increased LP relaxation efficiency when $E_X - E_{LPB}(k_{//} = 0) = \hbar\omega_{LO}$

<u>GaN only</u>

Increased LP relaxation efficiency when $E_{XX} - E_{LPB}(k_{//} = 0) = \hbar\omega_{LO}$

Extra polariton relaxation channel mediated by cavity biexcitons

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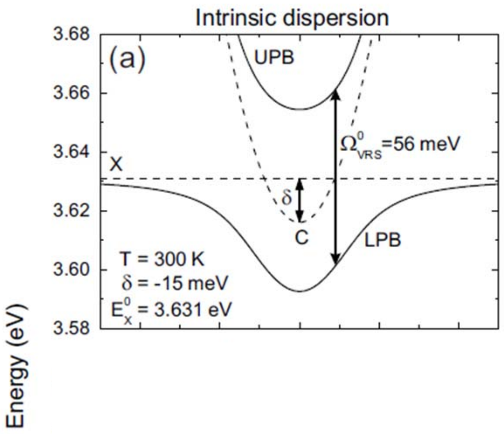
Renormalization of polariton branches: the standard picture

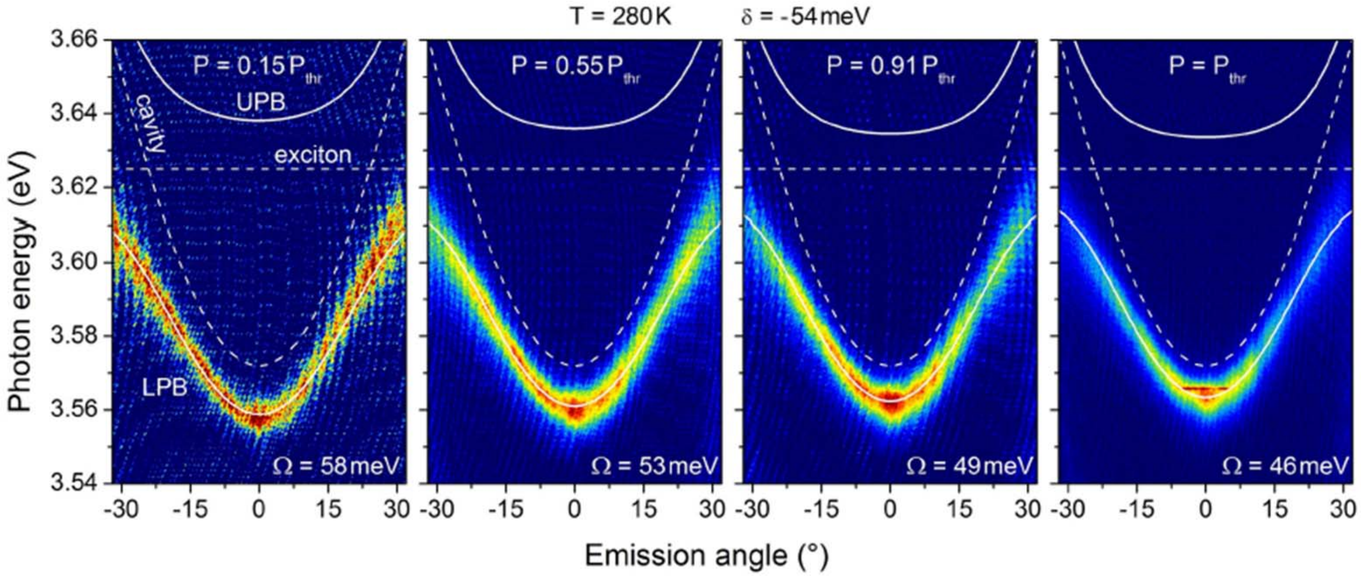


Renormalized dispersion curve

$$\tilde{E}_{LPB/UPB}\left(k_{//},\delta,n\right)=\frac{1}{2}\left[E_C\left(k_{//}\right)+E_X\left(k_{//}\right)+\delta E_X\left(n\right)\right]$$
$$-\frac{1}{2}\sqrt{\left(E_C\left(k_{//}\right)-E_X\left(k_{//}\right)-\delta E_X\left(n\right)\right)^2+4g^2\left(n\right)}$$

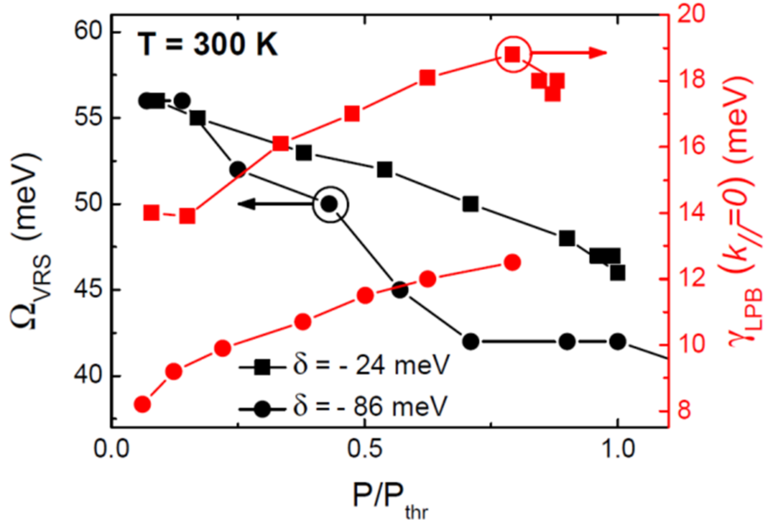
Nearly rigid blueshift of LPB and predicted linear shift of the LPB ground state with *n*

Renormalization of polariton branches: experimental facts

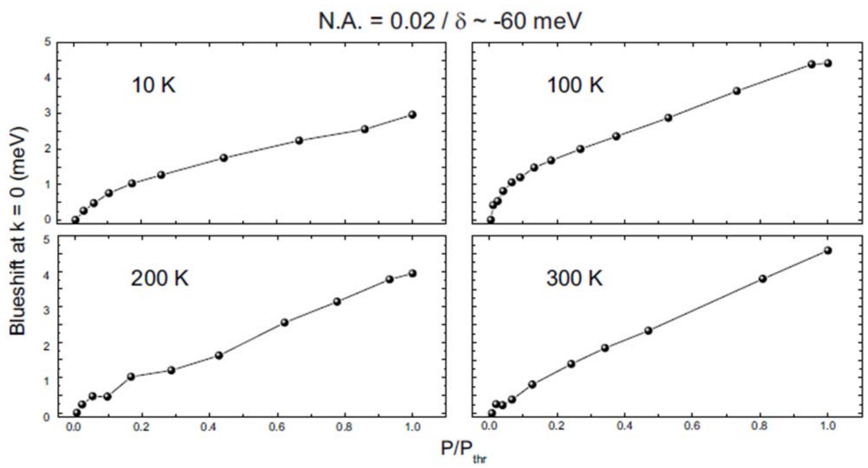


- Nearly no change observed at large $k_{//} \Rightarrow$ saturation is the dominant renormalization effect
- Ω_{VRS} extracted from coupled oscillator model with constant E_X and E_C values
- Ω_{VRS} decreased by 20% between 0.15 and 1 P_{thr}

Renormalization of polariton branches: impact of δ and *T*



- Saturation effects seem to decrease with increasing δ values!
- Slow down of Ω_{VRS} decrease when crossing P_{thr}



- Blueshift at $k_{//}$ = 0 showing a clear deviation from linearity for T < 200 K
- Possible role of biexcitons (E_{XX}^{b}~ 22 meV) in a system dominated by saturation effects (GaAs model not applicable)

⇒ several remaining open questions likely due to specificities of saturation effects in a system with small a_B^{2D}!

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Conclusion and perspectives

- Polariton condensation phase diagram from 4 to 340 K in GaN MQW microcavity (access to kinetic and thermodynamic relaxation regimes)
- Experimental signature of biexciton-mediated polariton relaxation
- Anomalous renormalization behavior (sublinear blueshift of LPB), key role of saturation effects + biexcitons?

- Study the properties of polariton condensates over a wide range of temperatures including renormalization, biexcitonic effects
- Electrical injection of polaritons in III-N microcavities (Marlene Glauser)
- System *a priori* suitable for (i) investigating ultrafast OPA and OPO properties @ 300 K (solitons?), (ii) realizing coherent THz light emitters (nonpolar microcavities)

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Thank you for your attention!

Enhanced relaxation efficiency