CONTROL OF SPATIAL QUANTUM FLUCTUATIONS USING PHOTONIC CRYSTALS

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funding by:
'Quantum light in microdevices'
'Quantum effects in complex systems'

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OUTLINE

1. INTRODUCTION:
- ***QUANTUM STATES OF LIGHT***
- ***NON-LINEAR SYSTEMS***
- ***PHOTONIC CRYSTALS***

2. DESCRIPTION OF THE MODEL AND METHODOLOGY

3. MAIN RESULTS

4. CONCLUSIONS AND OUTLOOK

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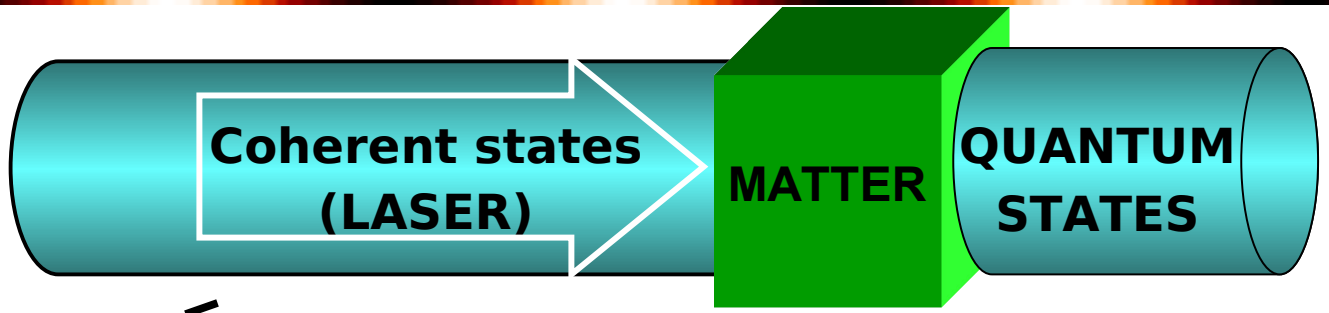
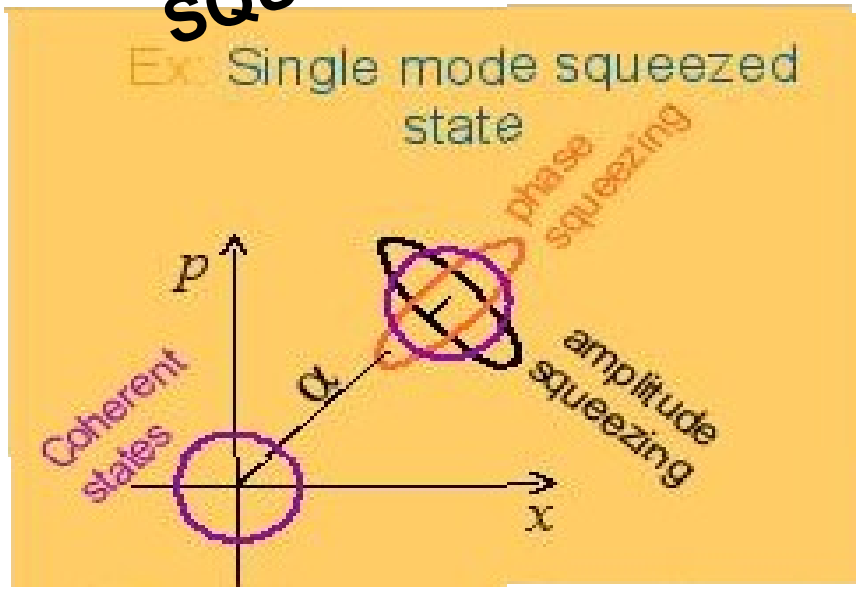
QUANTUM STATES OF LIGHT

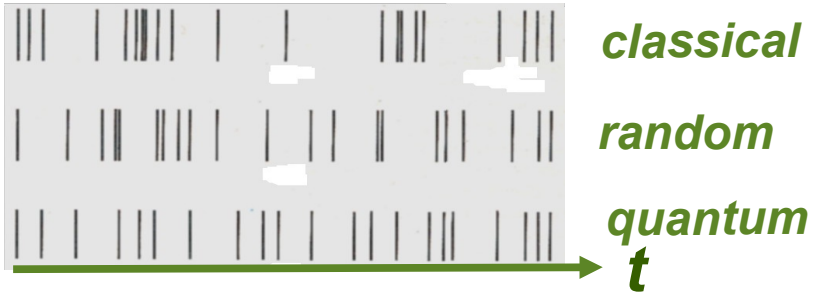


QUADRATURE SQUEEZING

(EPR) ENTANGLEMENT

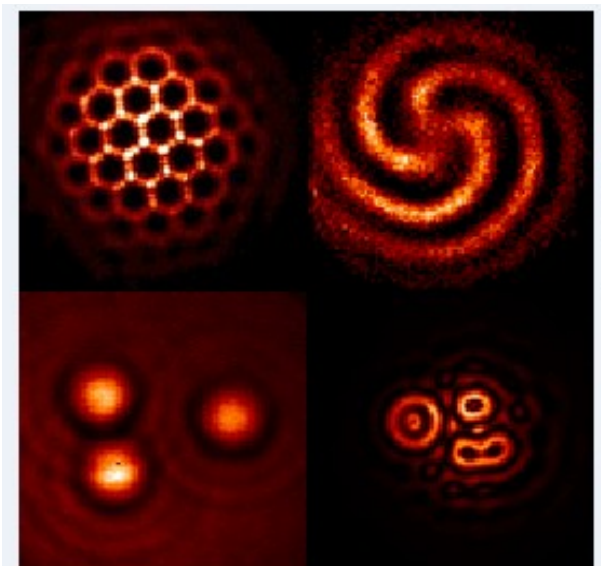


SPATIAL AND TEMPORAL ANTIBUNCHING



NON-LINEAR SYSTEMS

SPONTANEOUS PATTERN FORMATION



http://www.uni-muenster.de/Physik

HIGHER ORDER POLARIZATION:

RESPONSIBLE OF NON-LINEARITY BY COUPLING DIFFERENT WAVES

$$P = \chi E + \chi^{(2)} E^{(2)} + \chi^{(3)} E^{(3)} \ldots$$

Lugiato, L.A. & Lefever, R PRL **58** (1984)

PHOTONIC CRYSTALS

movement of e^- in a semiconductor

PERIODICITY of CRYSTAL:
BAND-GAP for e-

light in a photonic crystal

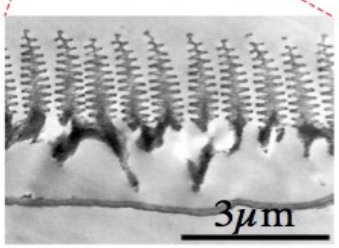
PERIODICITY of n:
BAND-GAP for photons

Photonic Crystals in Nature

Morpho rhetenor butterfly

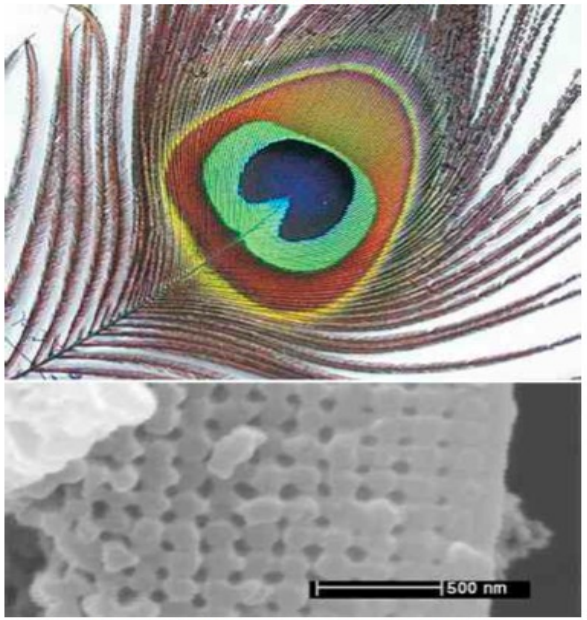
wing scale:

[P. Vukosic *et al.*, *Proc. Roy. Soc: Bio. Sci.* **266**, 1403 (1999)]



[also: B. Gralak *et al.*, *Opt. Express* **9**, 567 (2001)]

Peacock feather



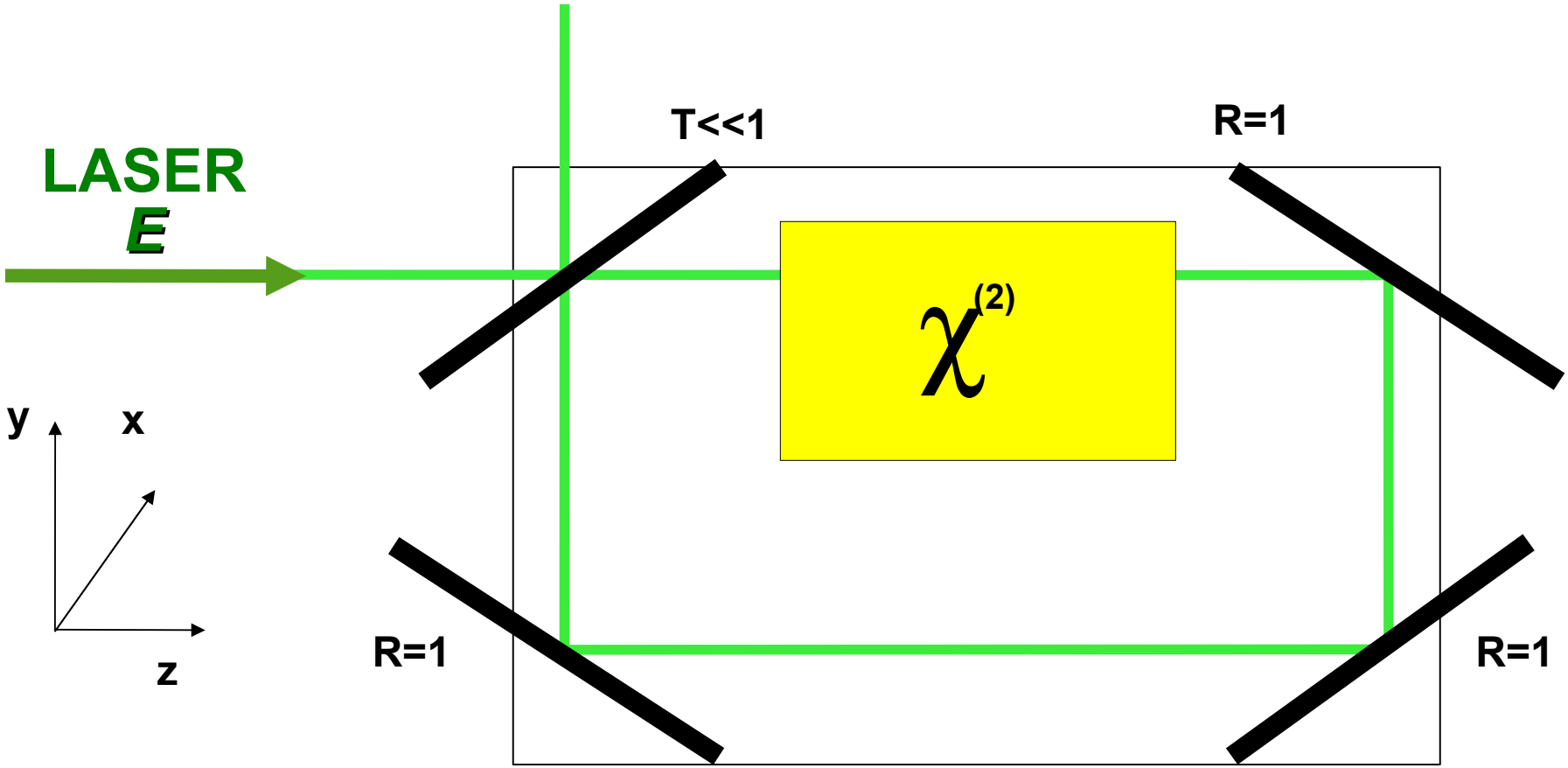
[J. Zi *et al*, *Proc. Nat. Acad. Sci. USA*, **100**, 12576 (2003)]
[figs: Blau, *Physics Today* **57**, 18 (2004)]

CAN WE CONTROL SPATIAL QUANTUM FLUCTUATIONS AND CORRELATIONS?

WE CONSIDER A DEGENERATED TYPE I OPO EMBEDDING A PHOTONIC CRYSTAL

DESCRIPTION OF THE MODEL

Optical Parametric Oscillator



DESCRIPTION OF THE MODEL

Degenerated TYPE I Optical Parametric Oscillator

PARAMETRIC DOWN CONVERSION

$$\omega_{pump} \longleftrightarrow \omega_{signal} + \omega_{idler}$$

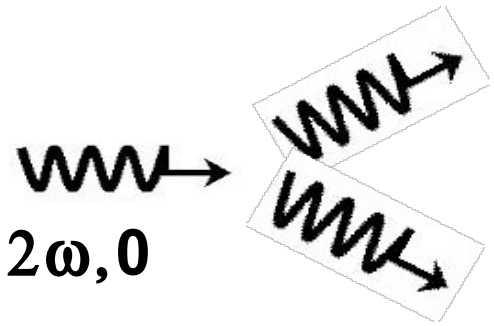
DEGENERATED

$$2\omega \longleftrightarrow \omega + \omega$$

$$\hat{H}_{int} \propto \hat{A}_{pump}(x,y)\hat{A}^{\dagger 2}_{signal}(x,y)$$

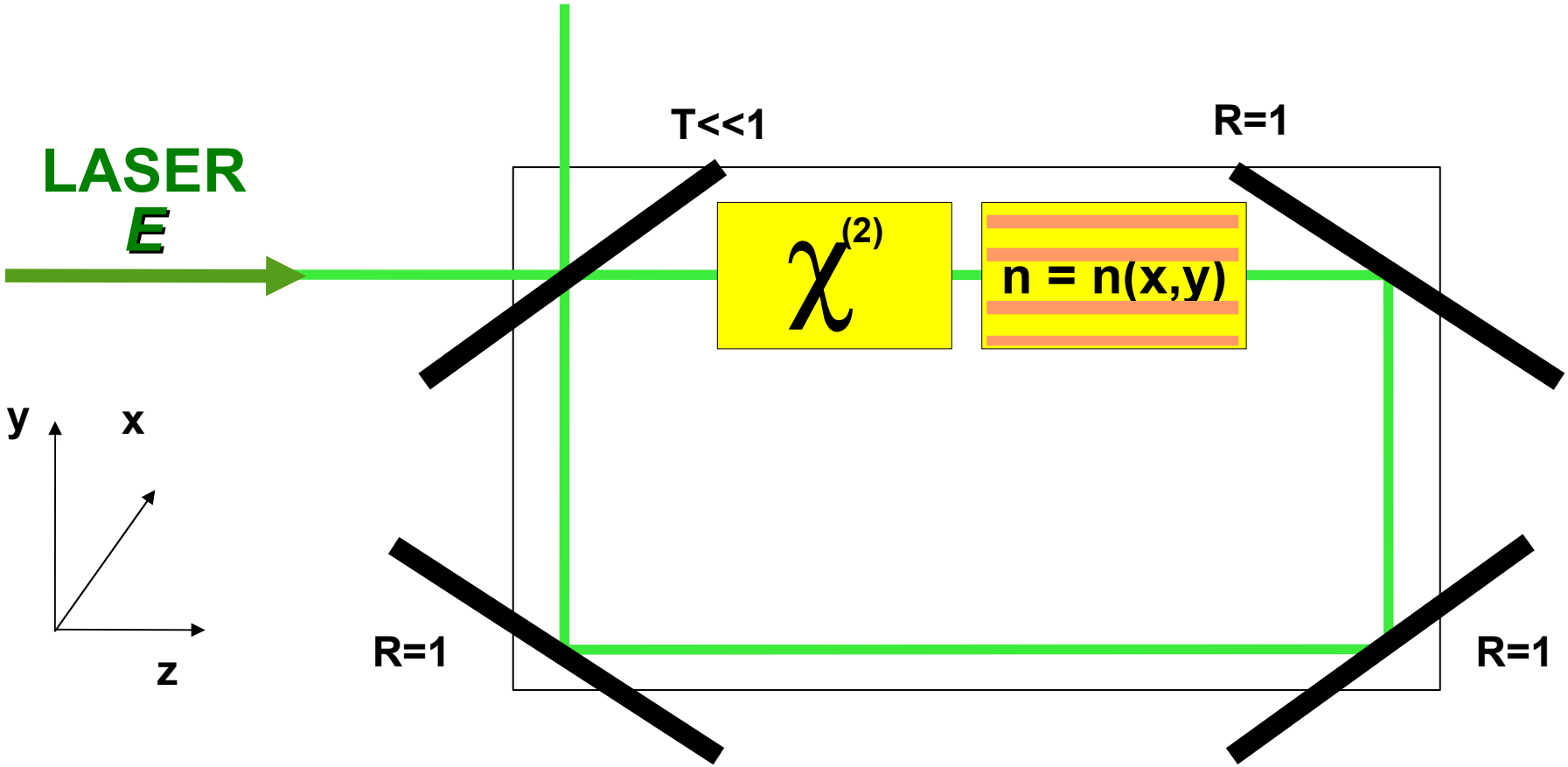
PUMP: ordinary polarization

SIGNAL and IDLER: extraordinary polarization



DESCRIPTION OF THE MODEL

Degenerated TYPE I Optical Parametric Oscillator with Photonic Crystal



$\Delta_0 \rightarrow \Delta_0 + I_0 \sin(k_{PC}\, x)$ and $\Delta_1 \rightarrow \Delta_1 + I_1 \sin(k_{PC}\, x)$

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METHODOLOGY

REPRESENTATIONS OF QUANTUM STATES OF LIGHT

from bosonic operators $\hat{A}_i, \hat{A}_i^\dagger$ *to phase space* α_i, α_i^*

MASTER EQUATION for an open system

$$\frac{\partial \hat{\rho}}{\partial t} = \frac{1}{i\hbar}[\hat{H}, \hat{\rho}] + \hat{\Lambda}\hat{\rho}.$$

$$\hat{H} = f(\hat{A}_i, \hat{A}_i^\dagger, ...)$$

depending on ordering

normal $< \hat{A}^\dagger \hat{A} > \leftrightarrow < \alpha^* \alpha >_P$

anti-normal $< \hat{A}\hat{A}^\dagger > \leftrightarrow < \alpha^* \alpha >_Q$

FOKKER-PLANCK EQUATION in Q under some approximations (non-linear system)

LANGEVIN EQUATION

STOCHASTIC DIFFERENTIAL EQUATION WITH QUANTUM NOISE SUITABLE TO NUMERICAL SIMULATIONS

Yuen & Tombesi, Opt. Commun. **59**, 155 (1986) and Zambrini & Barnett PRA **65**, 053810 (2002)

DESCRIPTION OF THE MODEL AND METHODOLOGY

KEY CONCEPTS

$E > E_{threshold}$ ⟶ **SIGNAL EMISSION**

DESCRIPTION OF THE MODEL AND METHODOLOGY

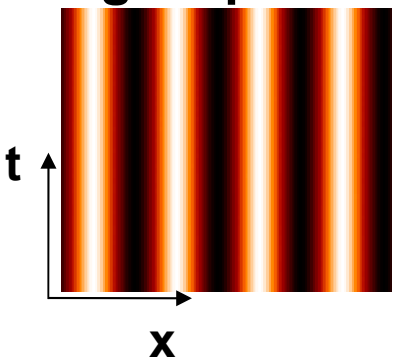
KEY CONCEPTS

$E > E_{thershold}$ → **SIGNAL EMISSION**

spatial dependence

$\Delta_1 < 0$ →

signal pattern



$$k_c = \frac{1}{\lambda_c} = \sqrt{\frac{-\Delta_1}{2}}$$

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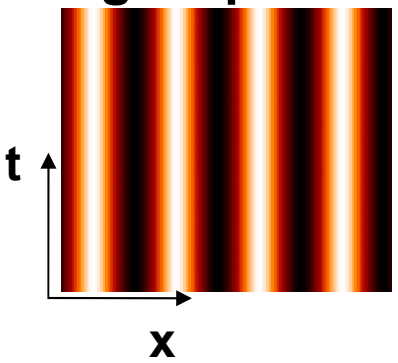


$$k_c = \frac{1}{\lambda_c} = \sqrt{\frac{-\Delta_1}{2}}$$

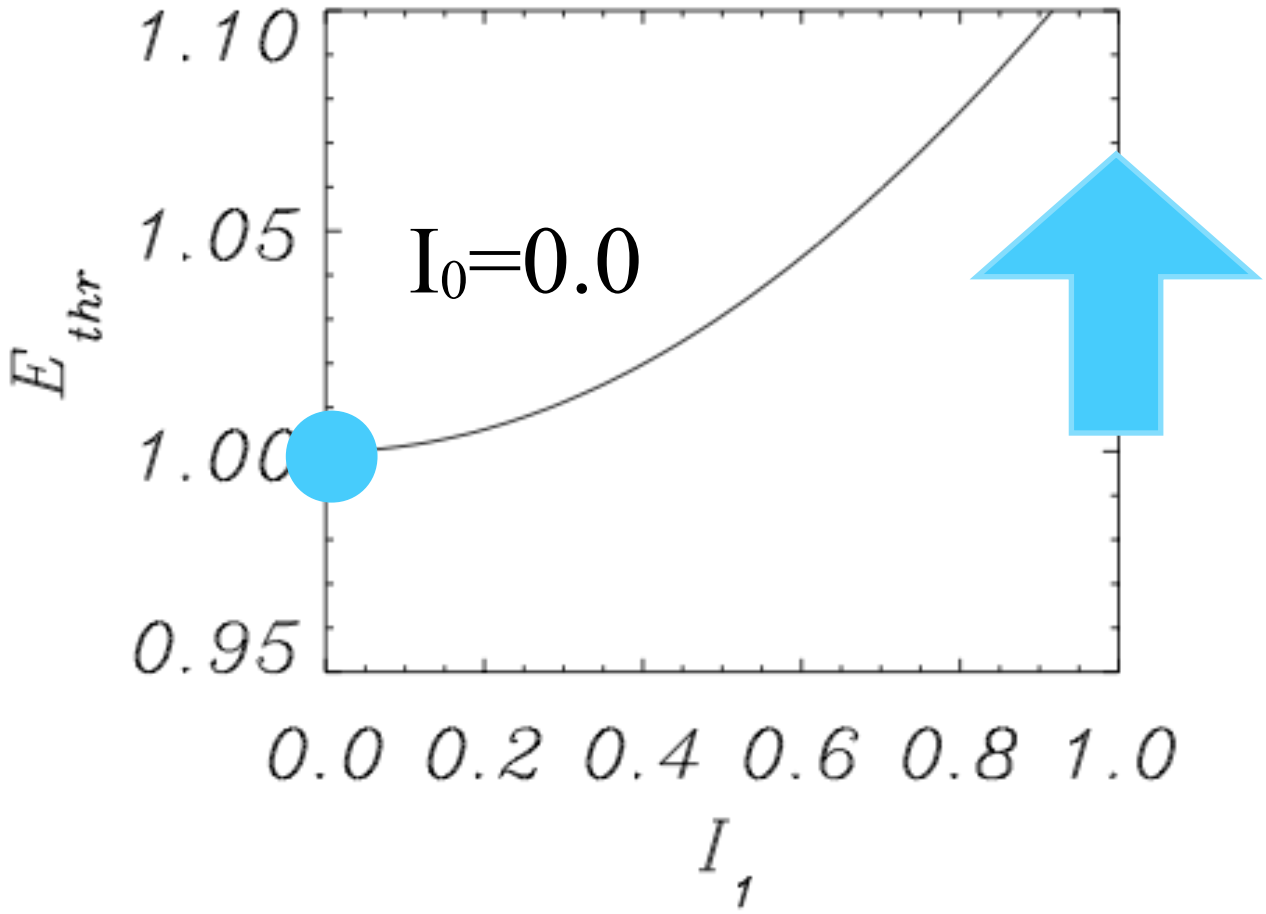
EMBEDDING THE PHOTONIC CRYSTAL

- modulation amplitudes: I_0, I_1
- modulation wavelenght: $\lambda_p \propto \lambda_c$

→ **RICH PHENOMENOLOGY**

MAIN RESULTS

CONTROL OF INSTABILITIES THRESHOLD WITH PHOTONIC CRYSTALS



PATTERN INHIBITION

Gomila, Zambrini, Oppo 92 PRL (2004) Gomila, Oppo, PRE **72**, 016614 (2005)

APPLIED PHYSICS LETTERS 93, 151114 (2008)

Control of broad-area vertical-cavity surface emitting laser emission by optically induced photonic crystals

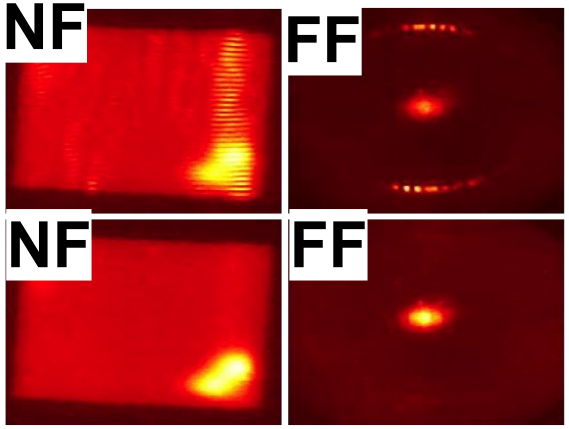
Bernd Terhalle,[1,a)] Neal Radwell,[2] Patrick Rose,[1] Cornelia Denz,[1] and Thorsten Ackemann[2]
[1]*Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, Corrensstraße 2/4, 48149 Münster, Germany*
[2]*SUPA and Department of Physics, University of Strathclyde, Glasgow, G40NG Scotland, United Kingdom*

November 1, 2008 / Vol. 33, No. 21 / OPTICS LETTERS

Experimental control of pattern formation by photonic lattices

N. Marsal,[1,*] D. Wolfersberger,[1] M. Sciamanna,[1] G. Montemezzani,[1] and D. N. Neshev[2]
[1]*Laboratoire Matériaux Optiques, Photoniques et Systèmes (LMOPS), CNRS UMR 7132, Unité de Recherche Commune à Supelec et Université Paul Verlaine de Metz, France*
[2]*Nonlinear Physics Centre, Research School of Physical Sciences and Engineering, Australian National University, Canberra, 0200 ACT, Australia*

no PC

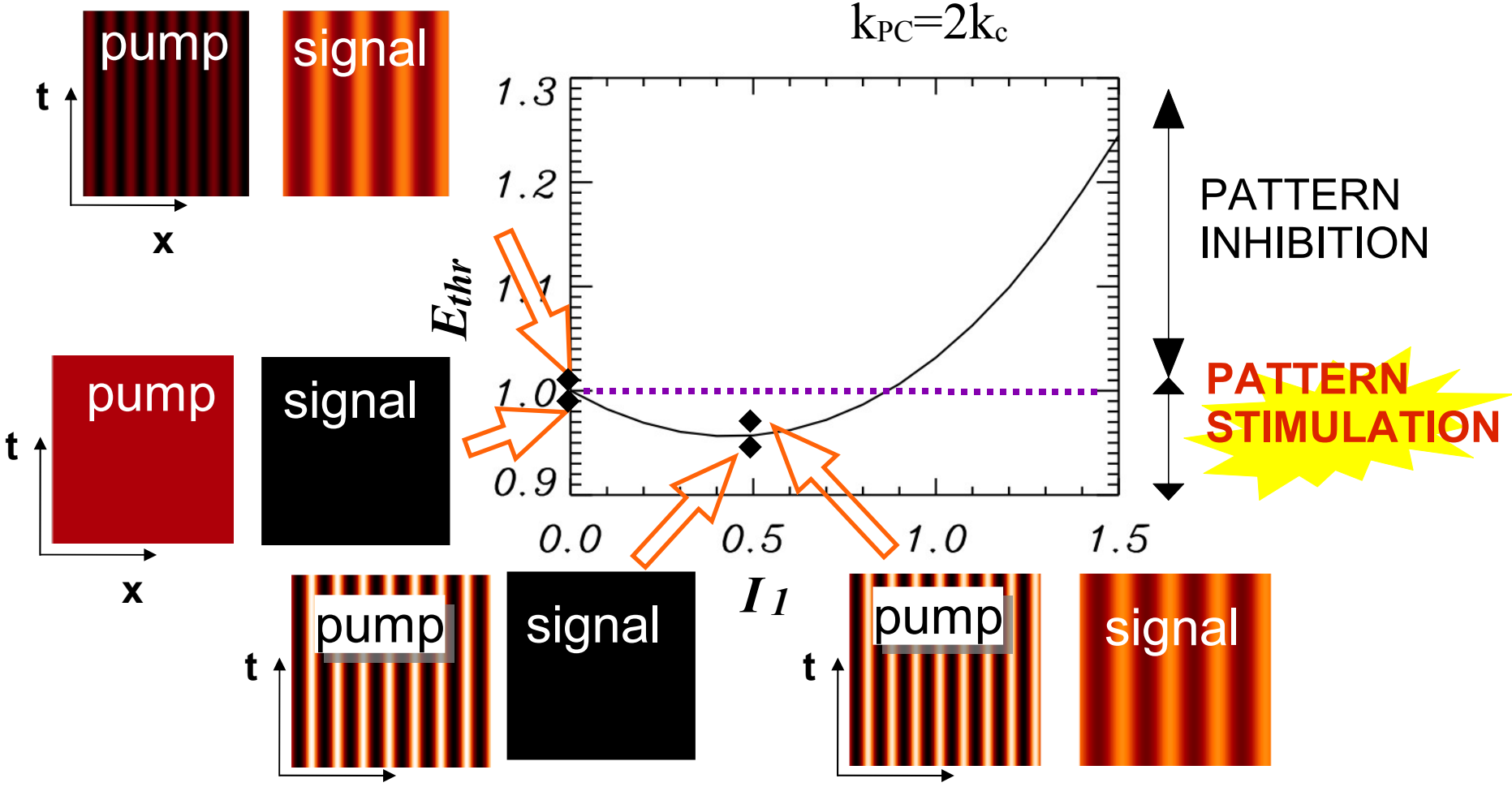


with PC

MAIN RESULTS

CONTROL OF PATTERN FORMATION THRESHOLD

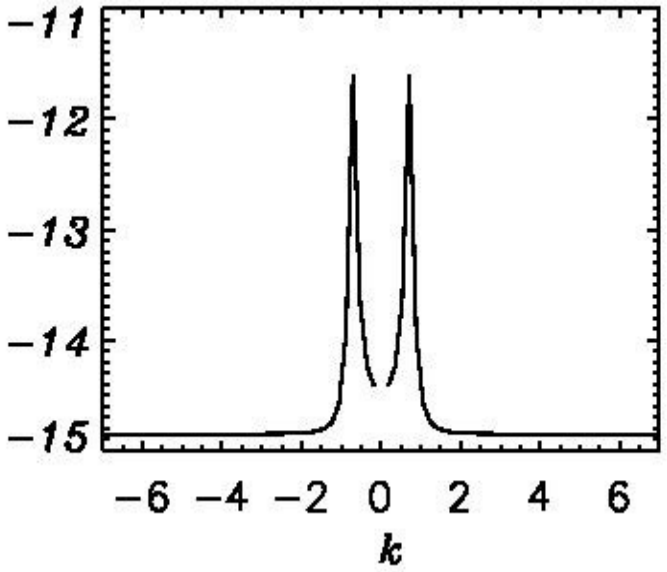
MORE GENERAL CASE: $I_0=I_1$, $k_{PC}=2k_c$



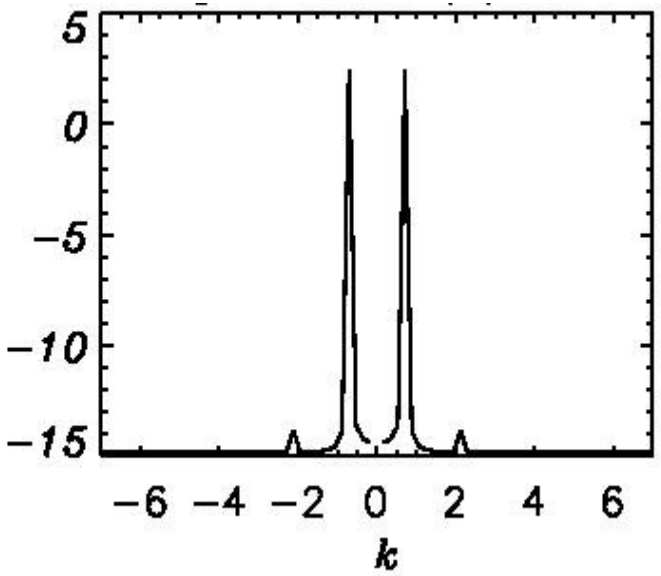
MAIN RESULTS

QUANTUM CORRELATIONS

$\log\langle I_{signal} \rangle$ > without photonic crystal FAR FIELD



Below threshold



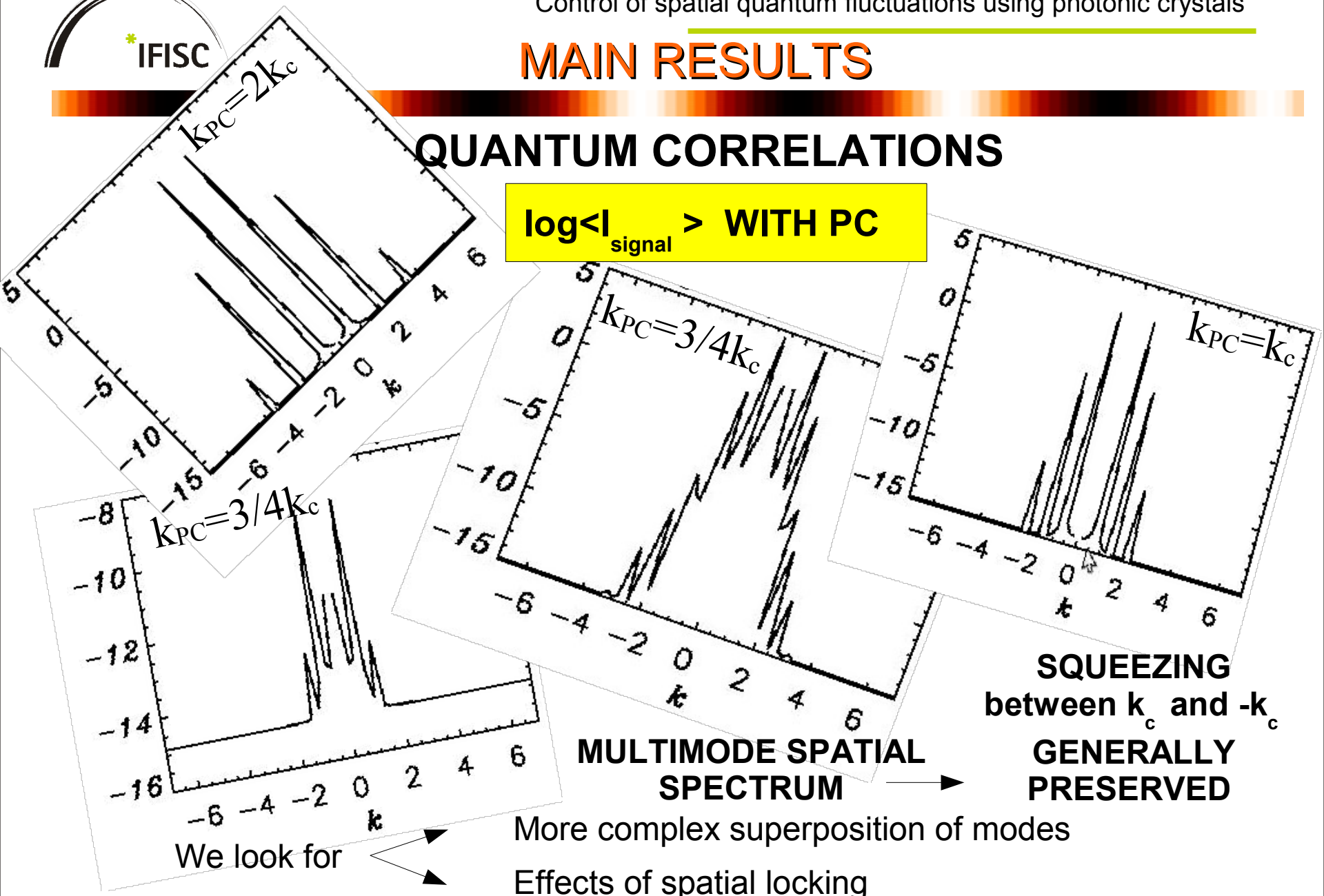
Above threshold

EPR entanglement between k_c and $-k_c$

MAIN RESULTS

QUANTUM CORRELATIONS

$\log\langle I_{signal} \rangle$ > WITH PC



SQUEEZING between k_c and $-k_c$

MULTIMODE SPATIAL SPECTRUM → **GENERALLY PRESERVED**

We look for

- More complex superposition of modes
- Effects of spatial locking

CONCLUSIONS

- **Photonic Crystals in OPOs allow to tune the parametric threshold**

- **Squeezing between k_c and $-k_c$ generally preserved when embeding Photonic Crystals**

IN PROGRESS

- **Explore role of wavelength and amplitudes of PC**

- **Two modes squeezing and EPR entanglement**

THANK YOU!