

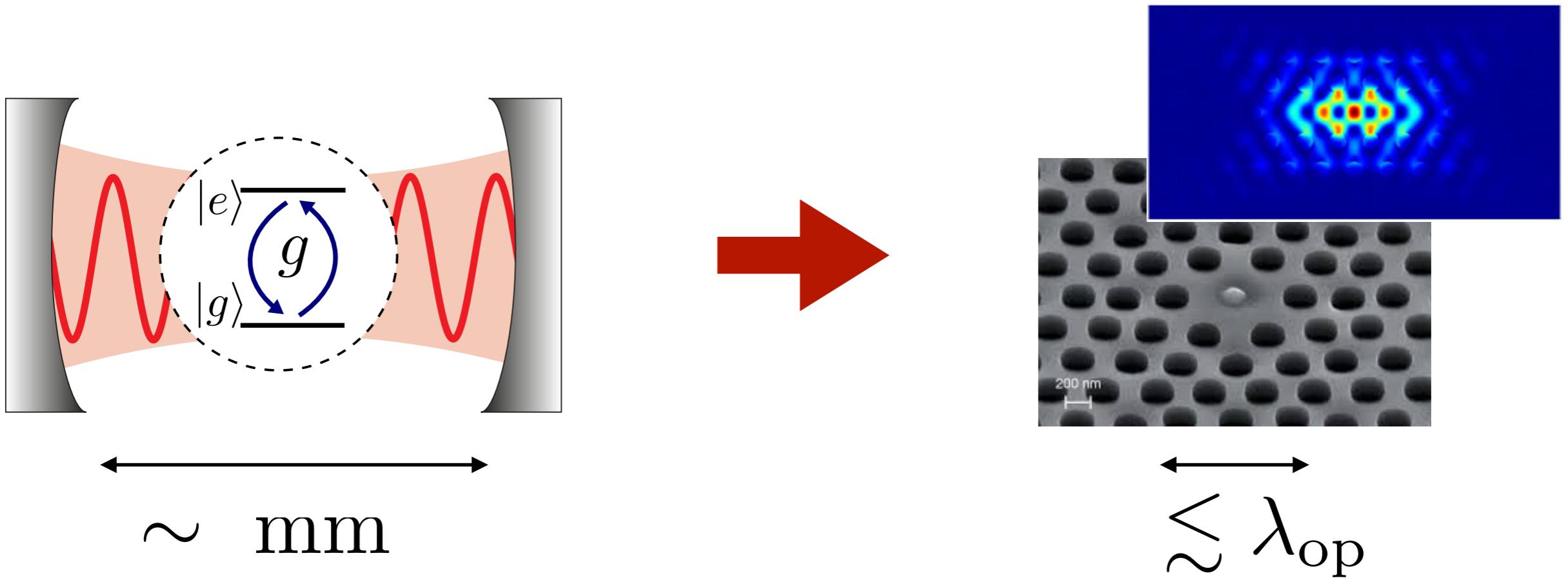
Working Group 4:

*Cooperative effects, correlations
& many-body physics*

WG4 Leader: Peter Rabl (TU Wien, Austria)

Brussels, April 4th, 2019

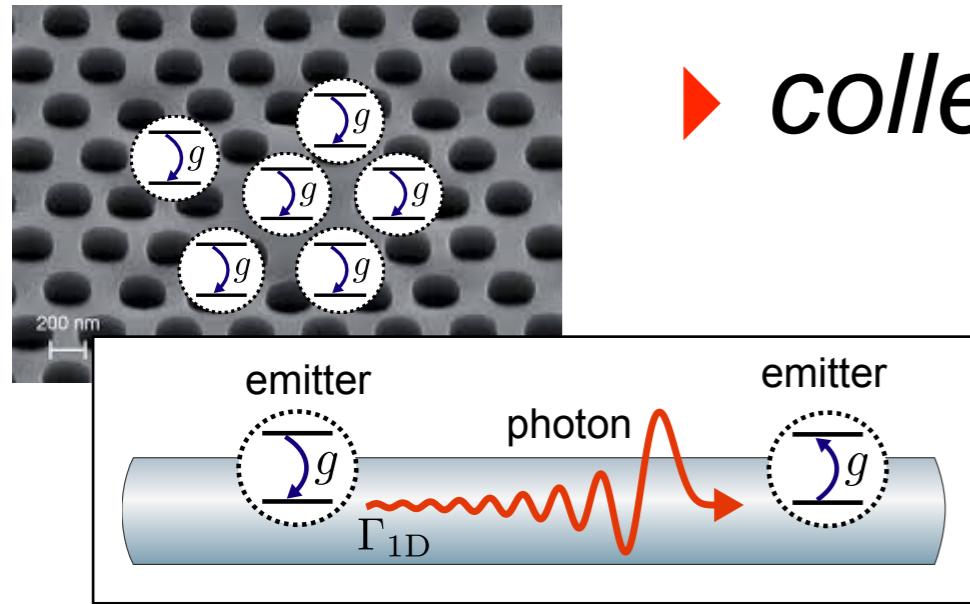
WG4 - Introduction



**Light-matter
coupling strength:**

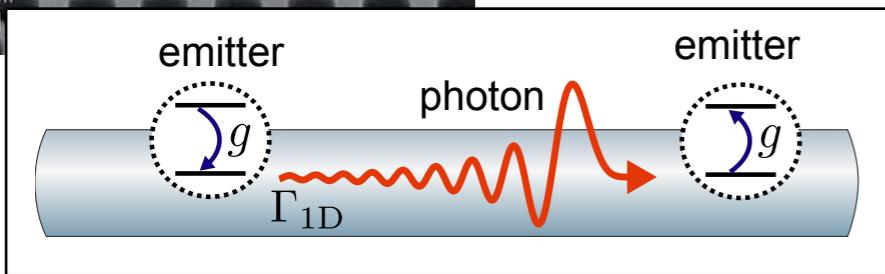
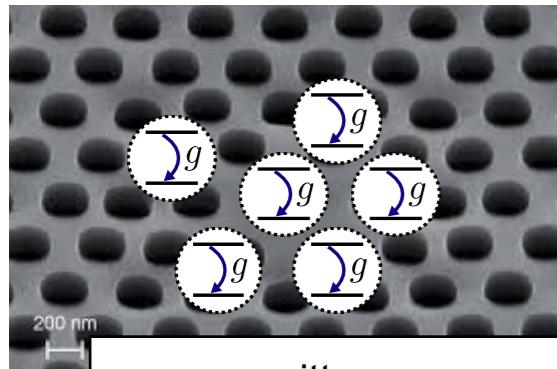
$$\hbar g = \sqrt{\frac{\mu^2 \hbar \omega}{2 \epsilon_0 V_{\text{mod}}}}$$

WG4 - Introduction



- ▶ collective & “ultra-strong” coupling
- ▶ photon-mediated interactions (long-range)

WG4 - Introduction

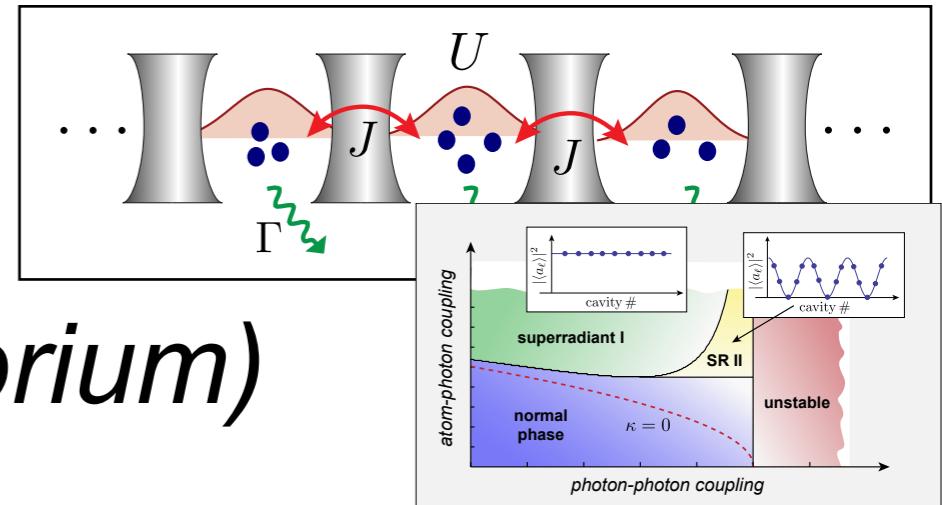


► collective & “ultra-strong” coupling

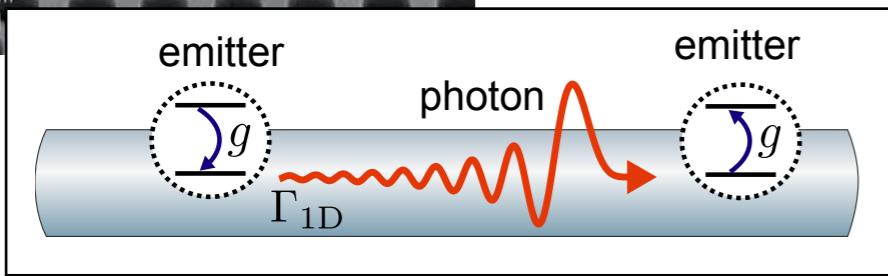
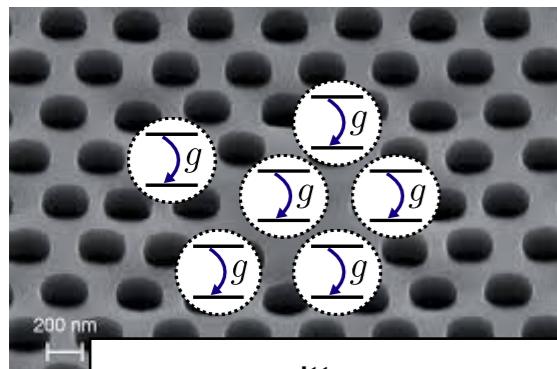
► photon-mediated interactions (long-range)

► strongly correlated photons

► quantum simulation (non-equilibrium)



WG4 - Introduction

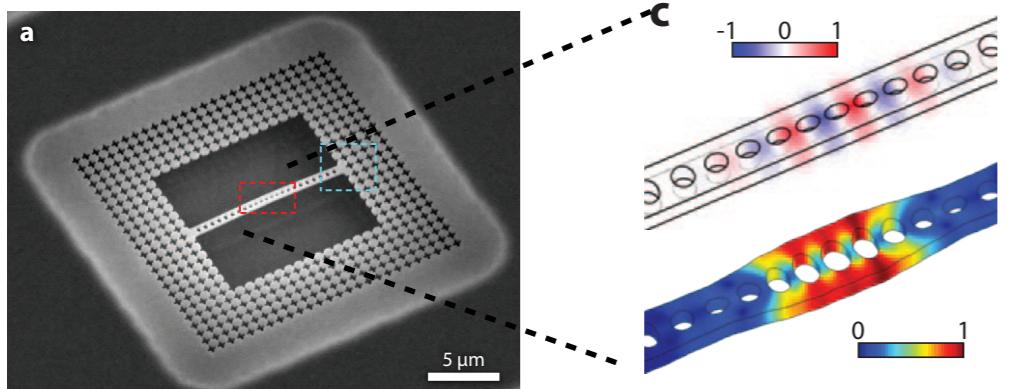
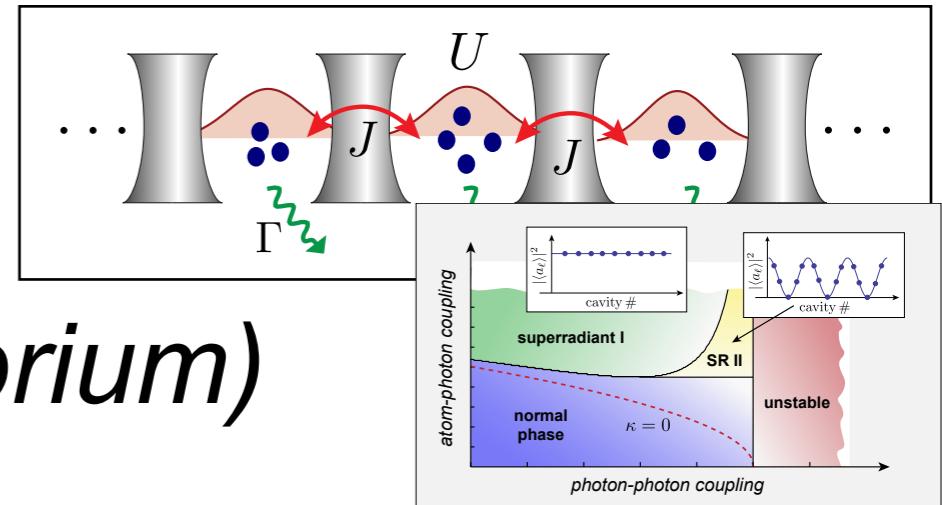


► collective & “ultra-strong” coupling

► photon-mediated interactions (long-range)

► strongly correlated photons

► quantum simulation (non-equilibrium)



(O. Painter, Caltech)

► huge optomechanical forces

► new (quantum) non-linearities

Objectives of WG4*

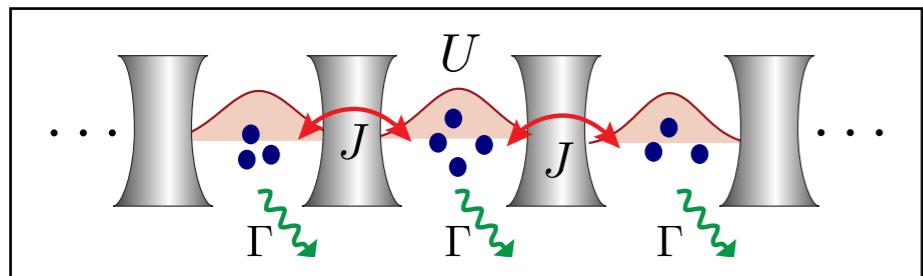
- To analyze **collective phenomena** (superradiance, self-organization, photon condensation, etc.) in the **quantum regime**.
- To develop **new experimental platforms** (optical, plasmonic, optomechanical) for collective light matter interactions at the nanoscale.
- To investigate **photonic quantum simulation** schemes with nano-photonic devices.
- To **coordinate** the different theoretical and experimental efforts.

*) NQO, Memorandum of Understanding

WG4 research: examples & highlights

Quantum simulation with light

1D photonics lattices



**2D + strong interactions
+ artificial magnetic field**



D. Angelakis (GR)

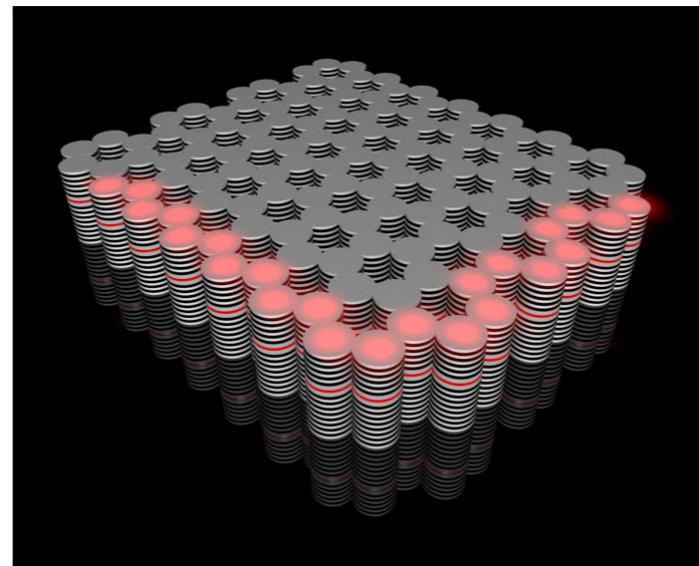


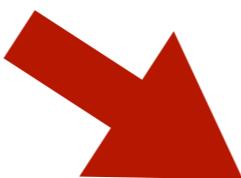
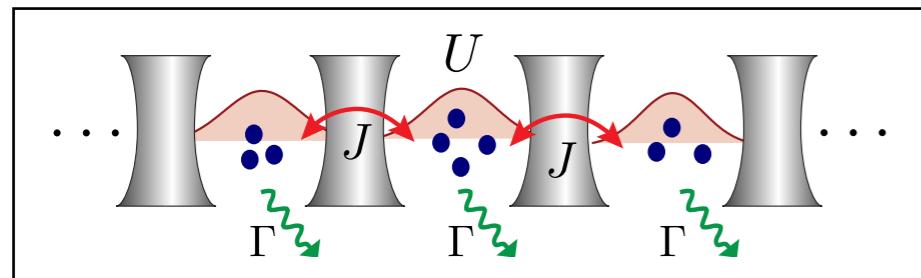
Illustration: Uni. Würzburg

► *Quantum Hall physics, topological insulators, ...*

COST groups: Angelakis (GR), Jaksch (UK), Ciuti (FR), Marquardt (DE), Hartmann (UK), Savona (CH), Rabl (AT), Plenio (DE), Fazio (IT), ...

Quantum simulation with light

1D photonics lattices

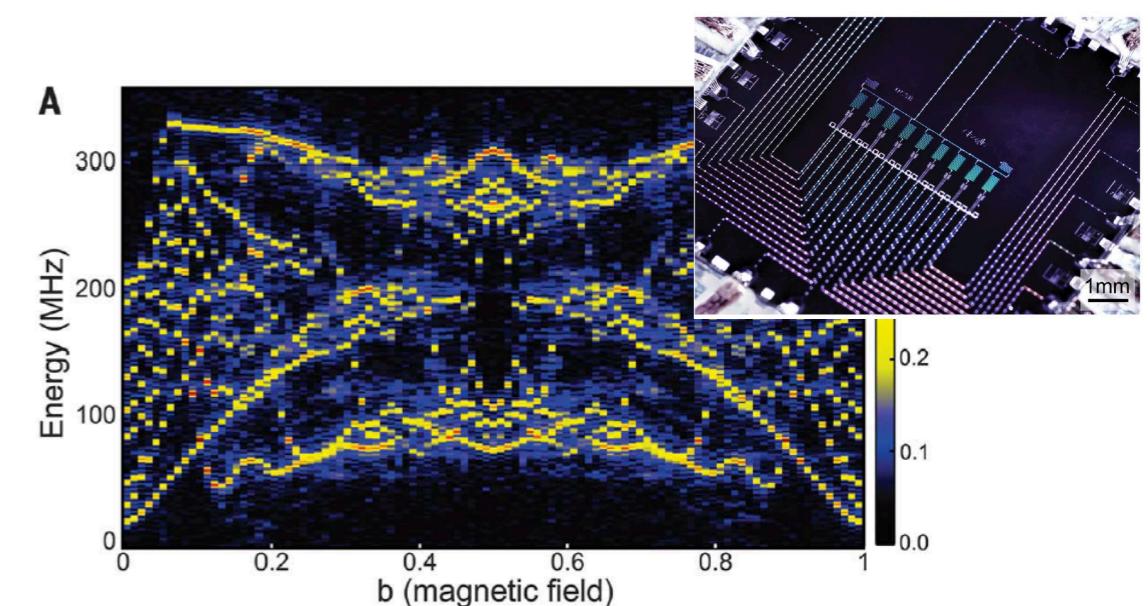


**strong interactions
+ artificial magnetic field**



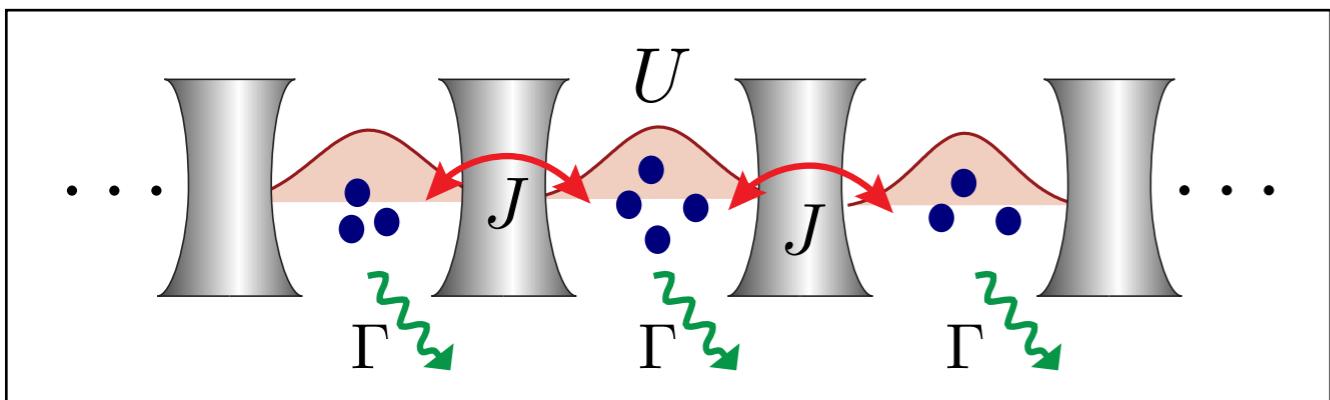
**COST
contribution!**

D. Angelakis (GR)

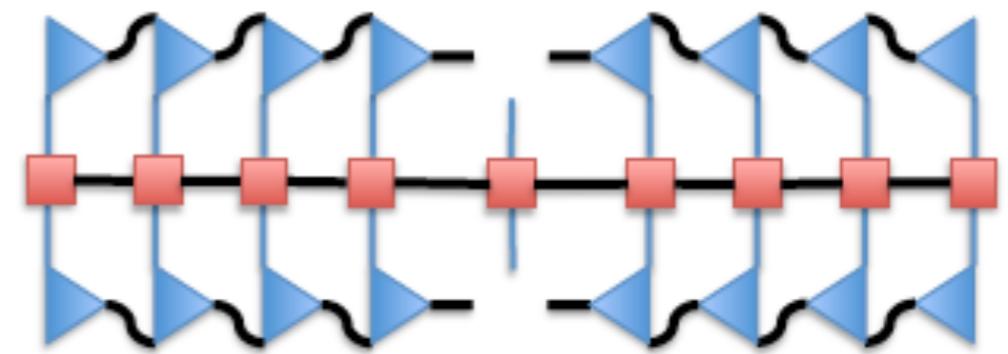
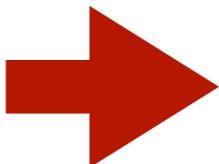


P. Roushan et al, Science 358, 1175 (2017)

Quantum simulation with light



$$\partial_t \hat{\rho}(t) = \mathcal{L} \hat{\rho}(t)$$



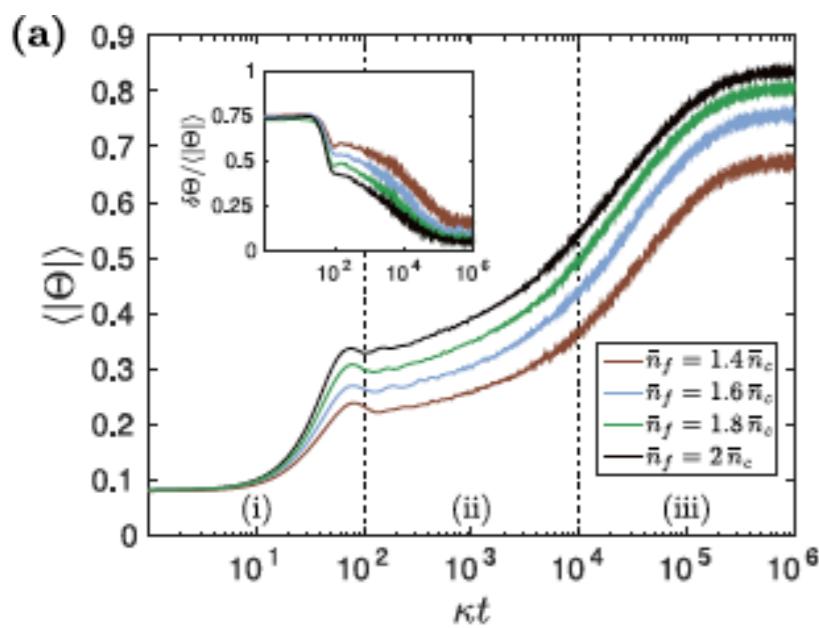
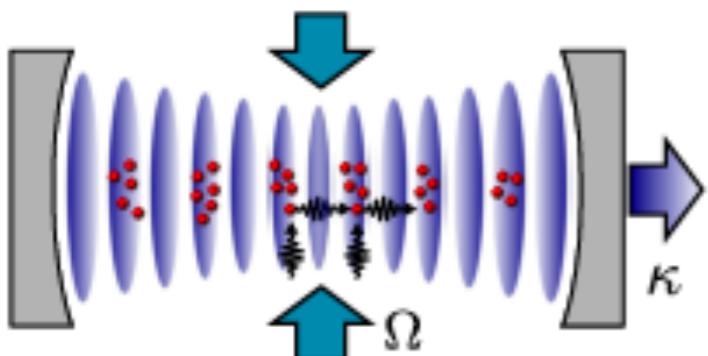
- *Efficient numerical methods to simulate dissipative many-body systems.*

Collective effects & phase transitions

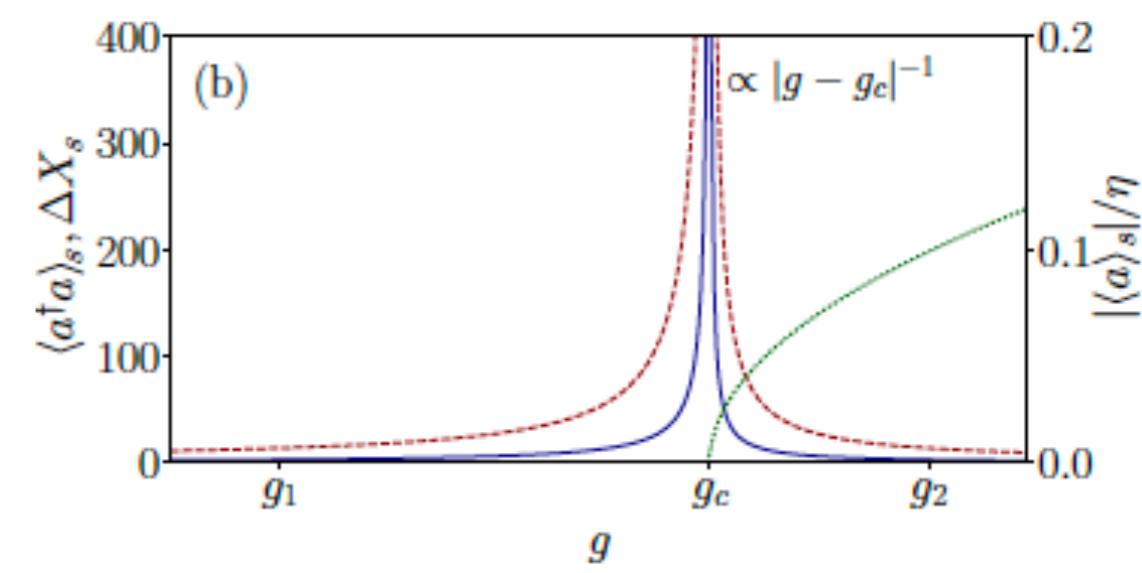
- ▶ Collective non-equilibrium physics
(prethermalization, ...)



M.-J. Hwang (DE)

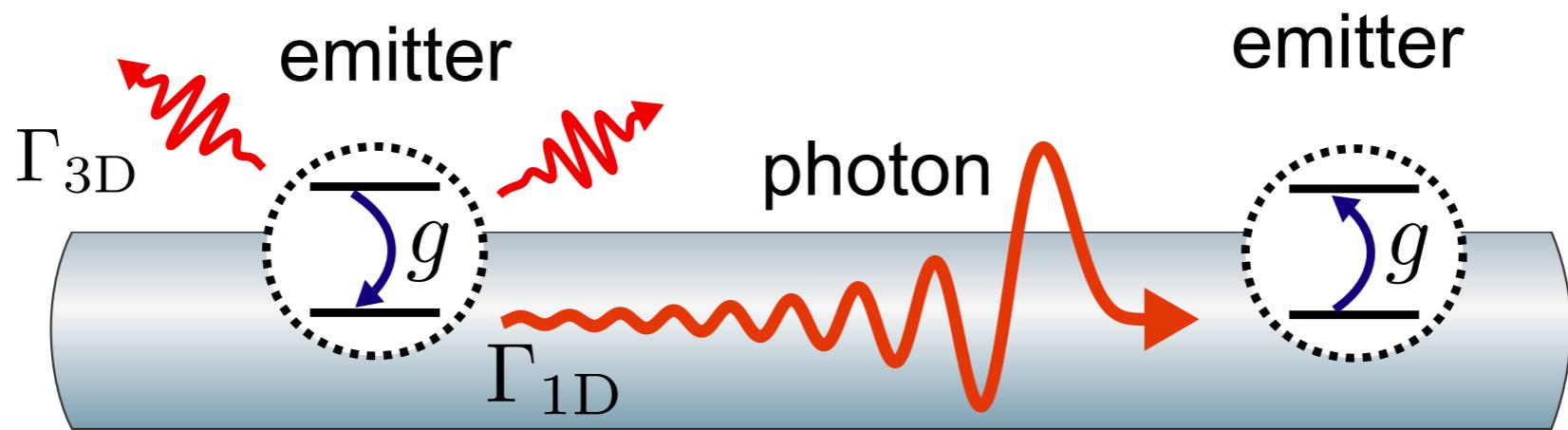


G. Morigi (DE)

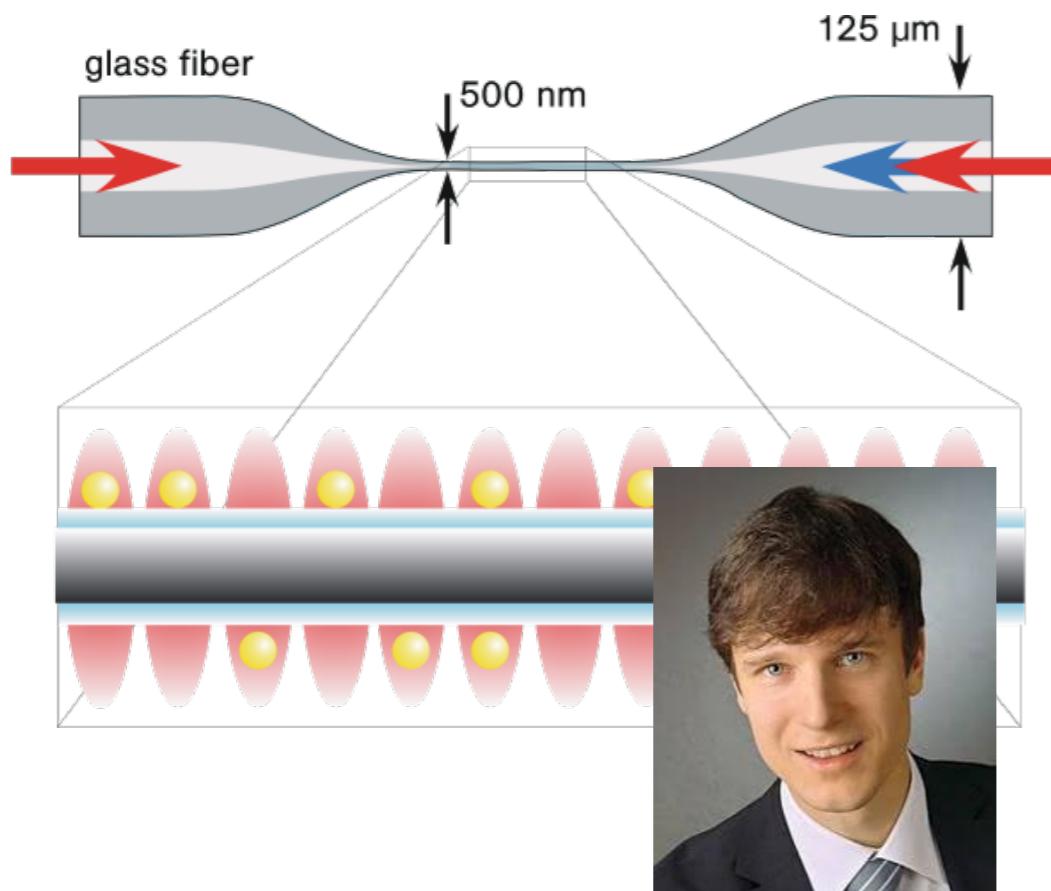
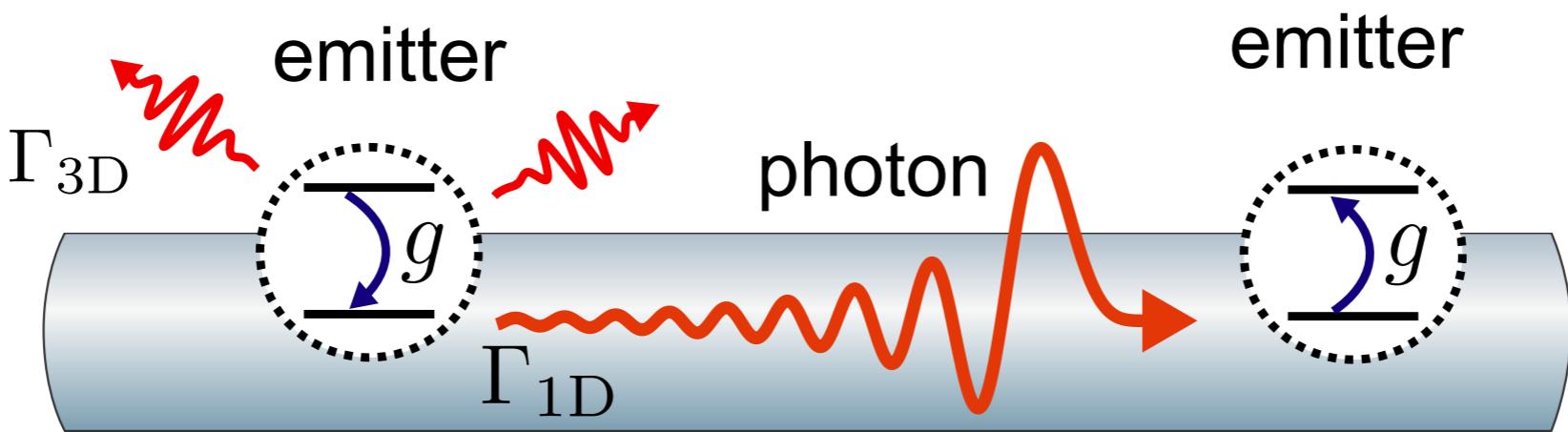


- ▶ Universality of dissipative phase transitions ?

Light-matter interactions in 1D

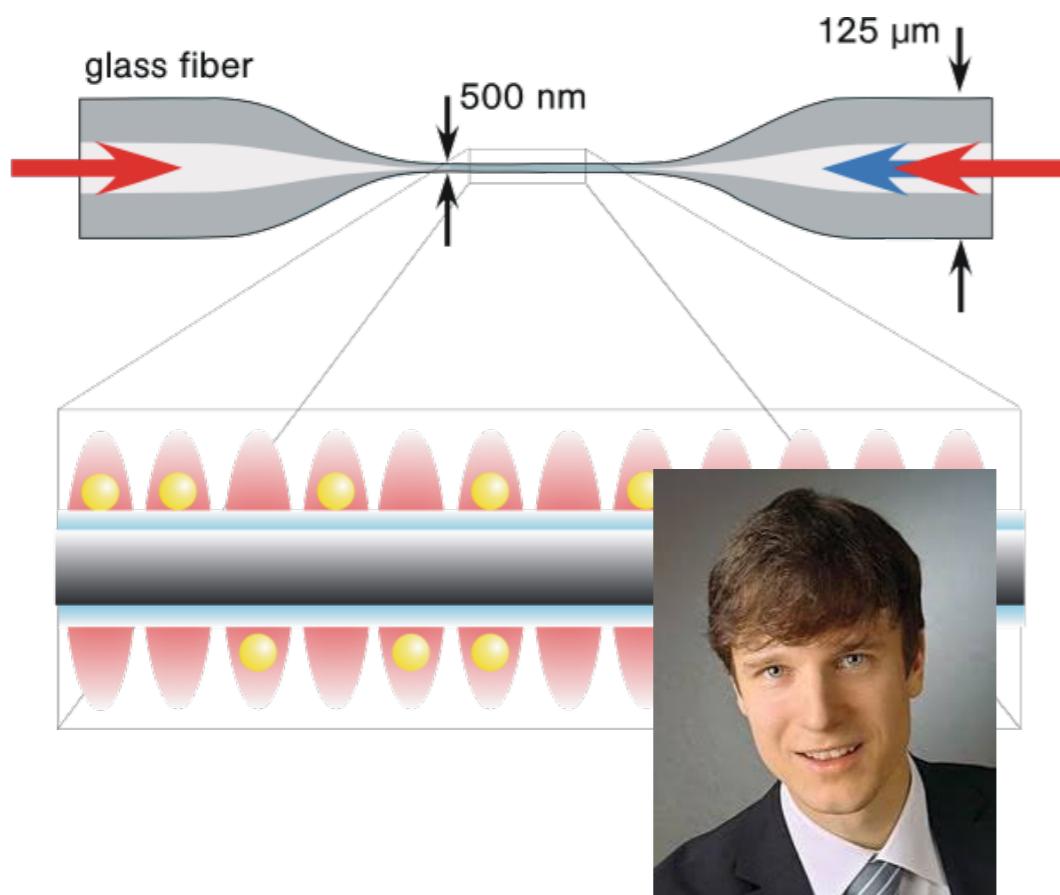
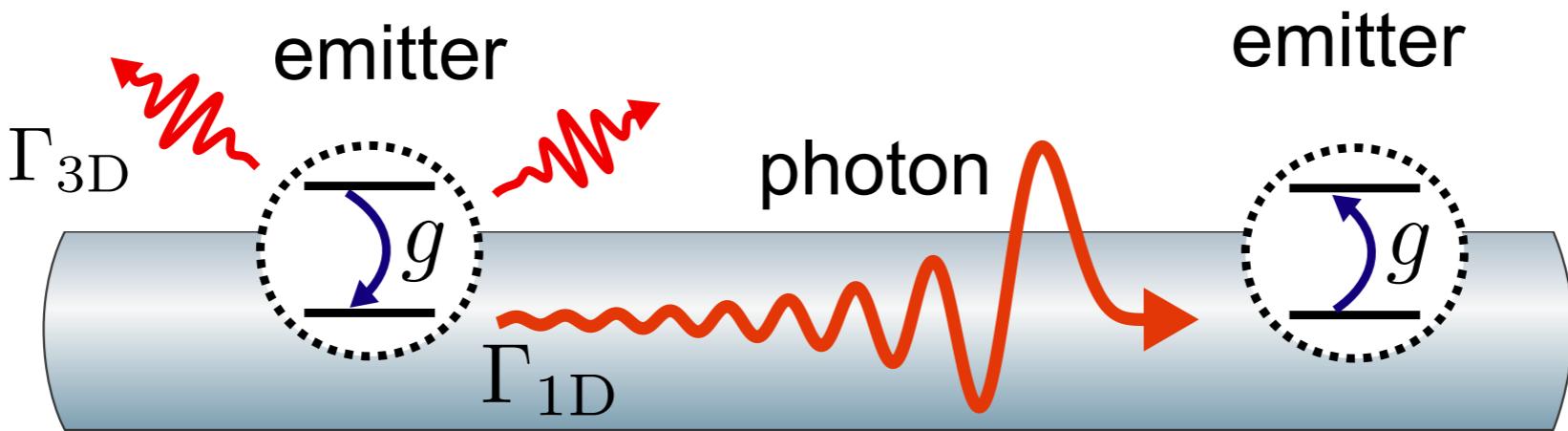


Light-matter interactions in 1D

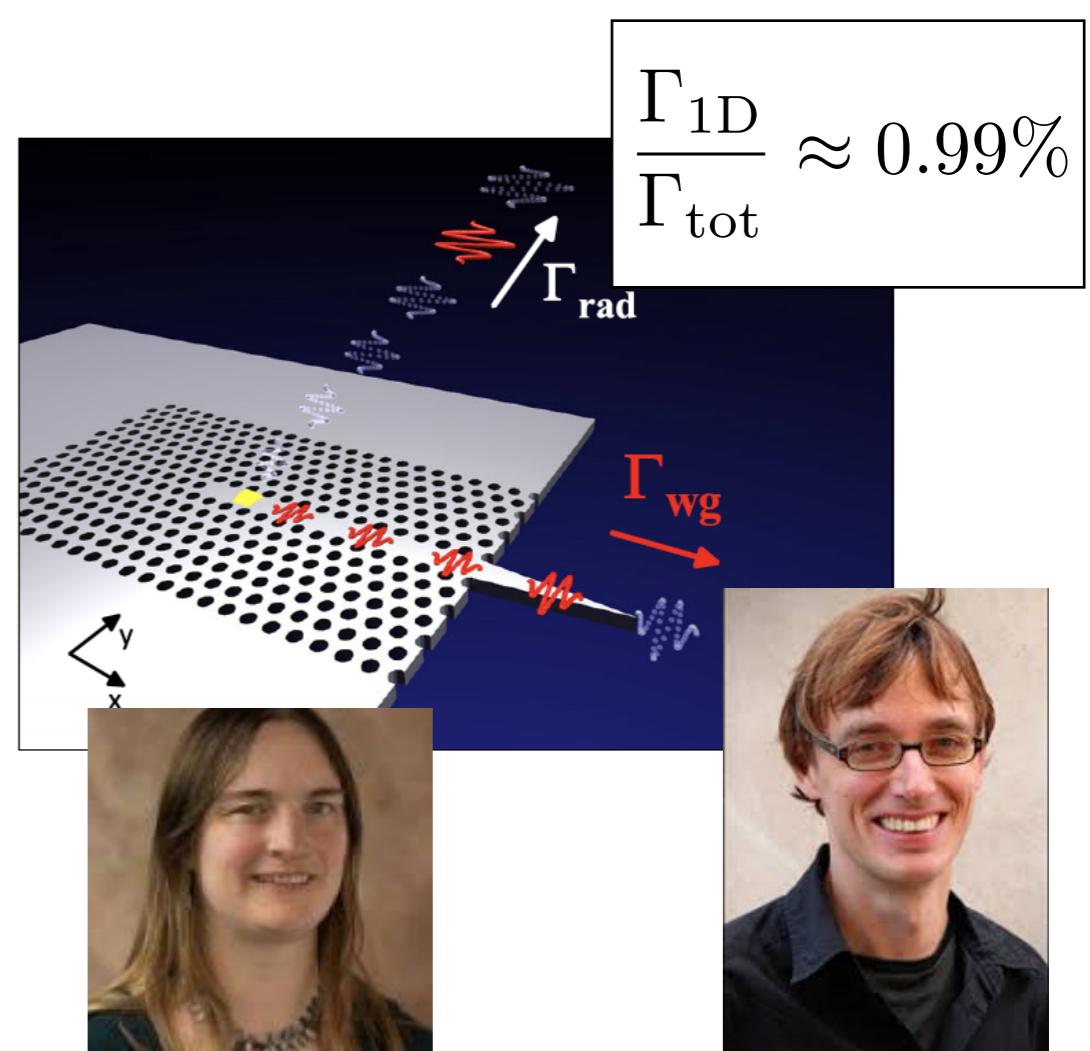


P. Schneeweiss (AT)
A. Rauschenbeutel

Light-matter interactions in 1D



P. Schneeweiss (AT)
A. Rauschenbeutel

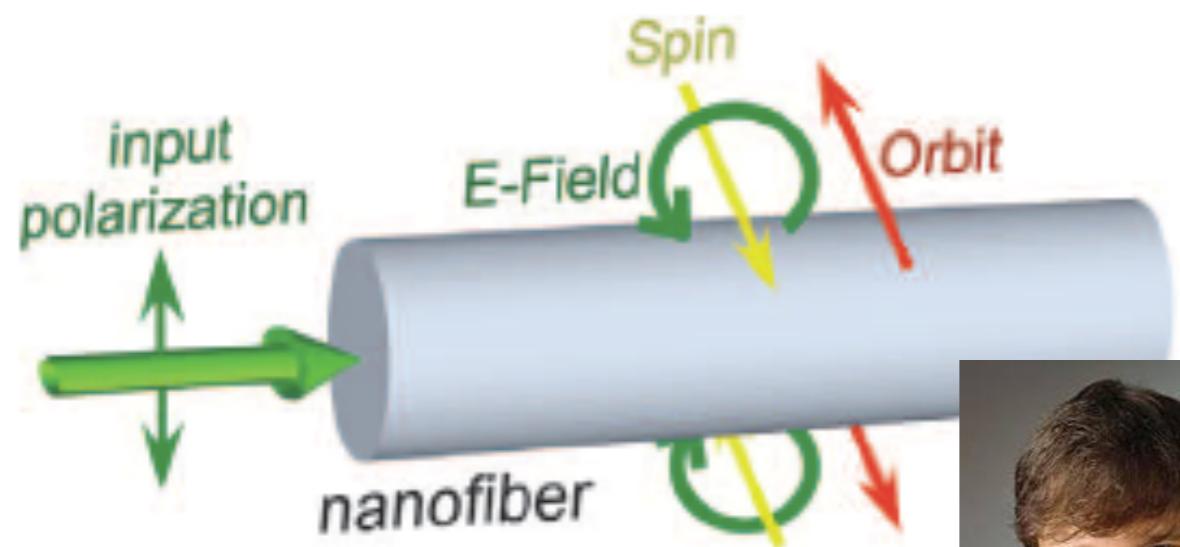


R. Oulton (UK)

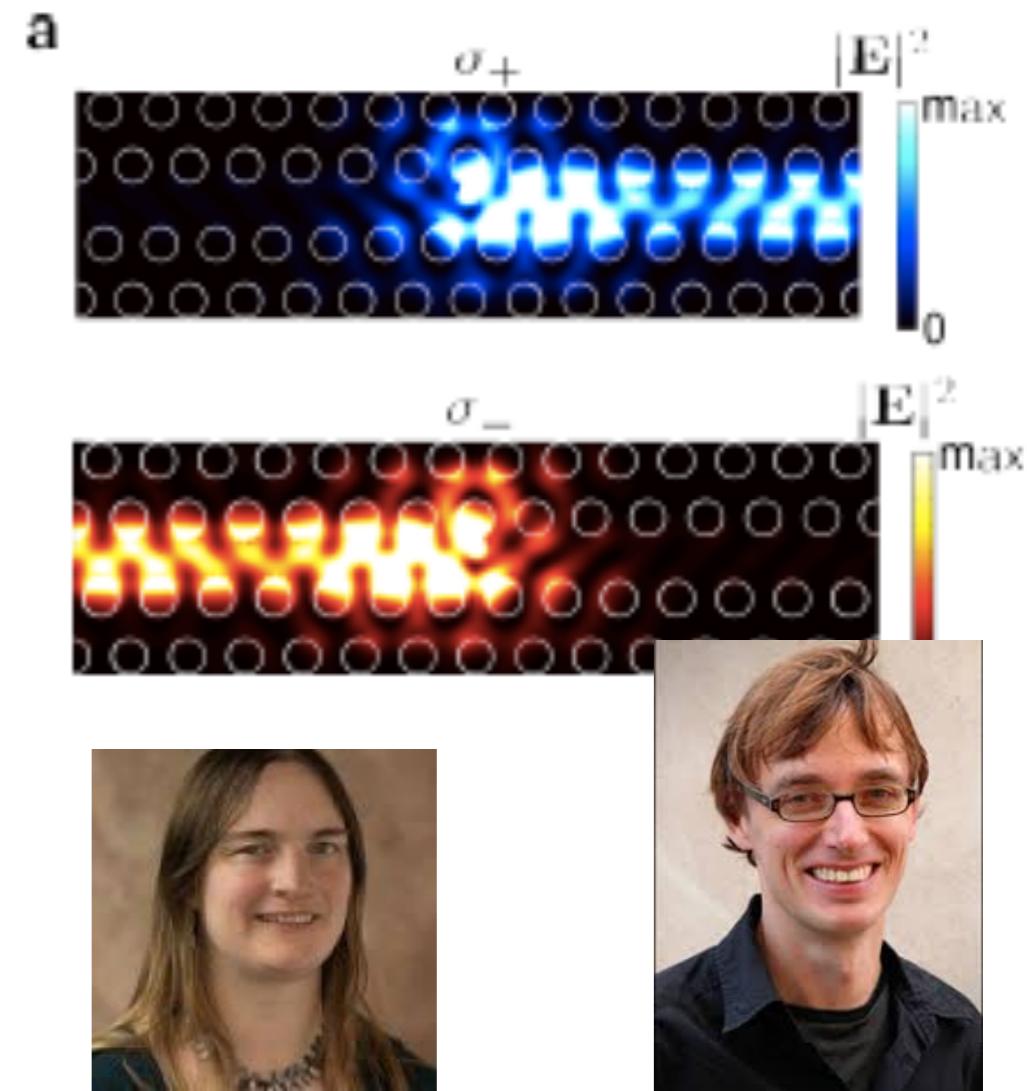
P. Lodahl (DK)

$$\frac{\Gamma_{1D}}{\Gamma_{\text{tot}}} \approx 0.99\%$$

Light-matter interactions in 1D



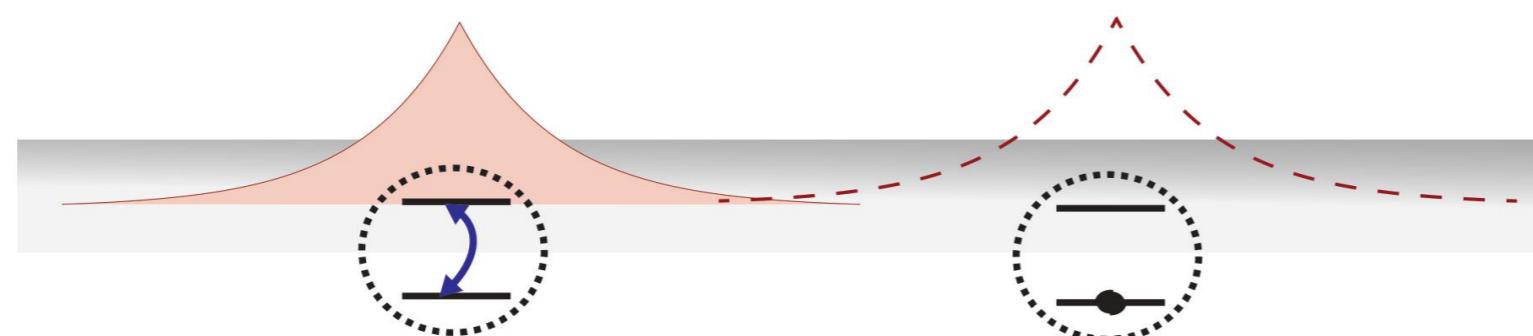
P. Schneeweiss (AT)
A. Rauschenbeutel



Nanoscale \Rightarrow Chiral light-matter interactions!

Joint (AT/DK) Review: Nature 541, 473 (2017)

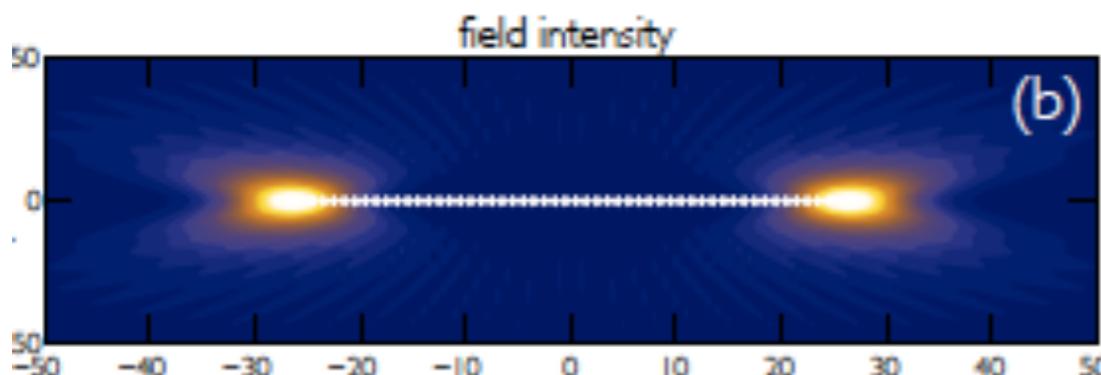
Light-matter interactions in 1D



$$v_g \ll c$$

- ▶ Atom-photon bound states & slow-light effects in nano-photonic waveguides.

many AT/ES collaborations!



M. Moreno



H. Ritsch

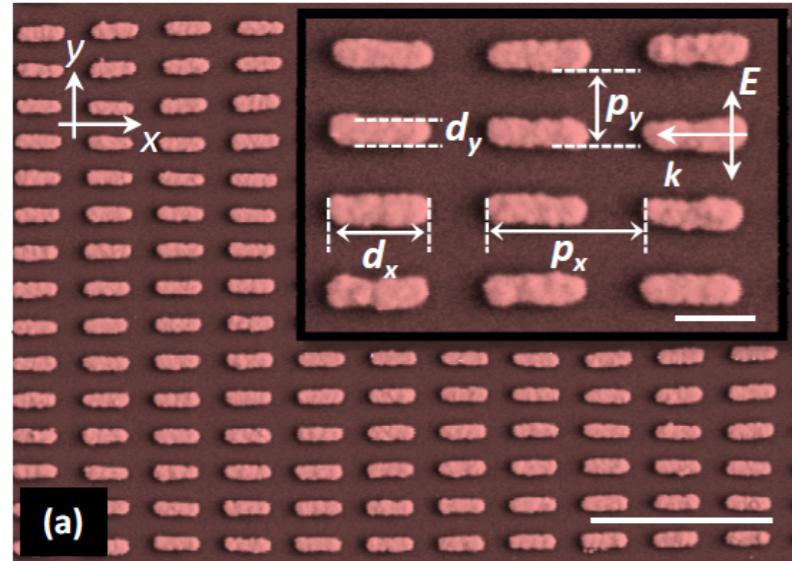


D. Chang

- ▶ Super-, sub- and “selective” radiance.

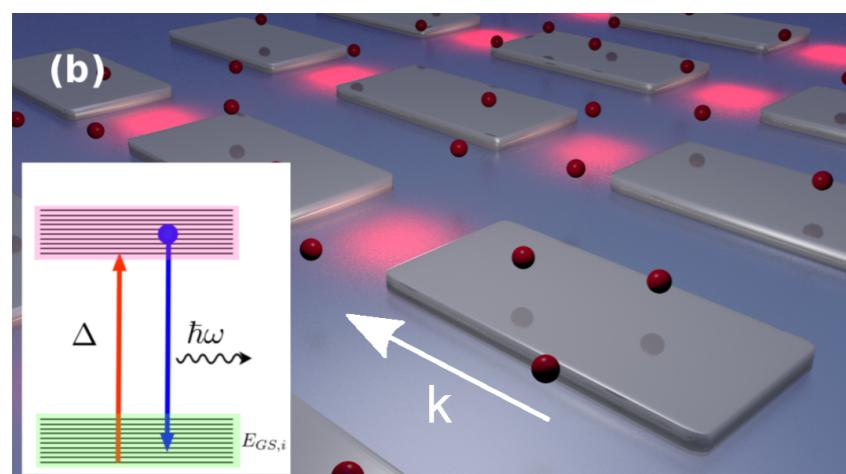
COST groups: Chang (ES), Garcia-Ripoll (ES), Ritsch (AT), Rabl (AT), ...

Collective Effects in Quantum Plasmonics



“Quantum plasmonic lattices”

- single emitter strong coupling
- plasmon-plasmon interactions



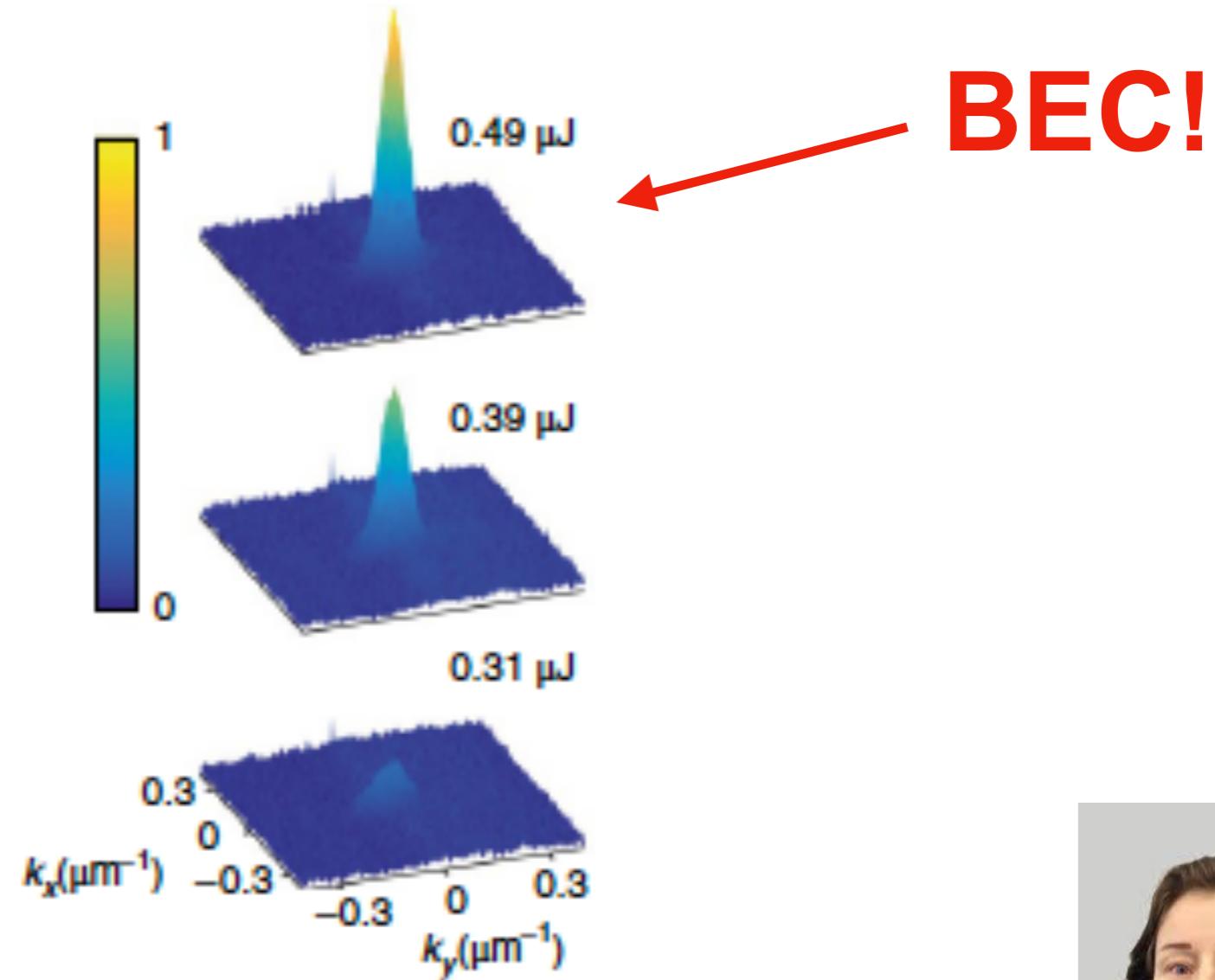
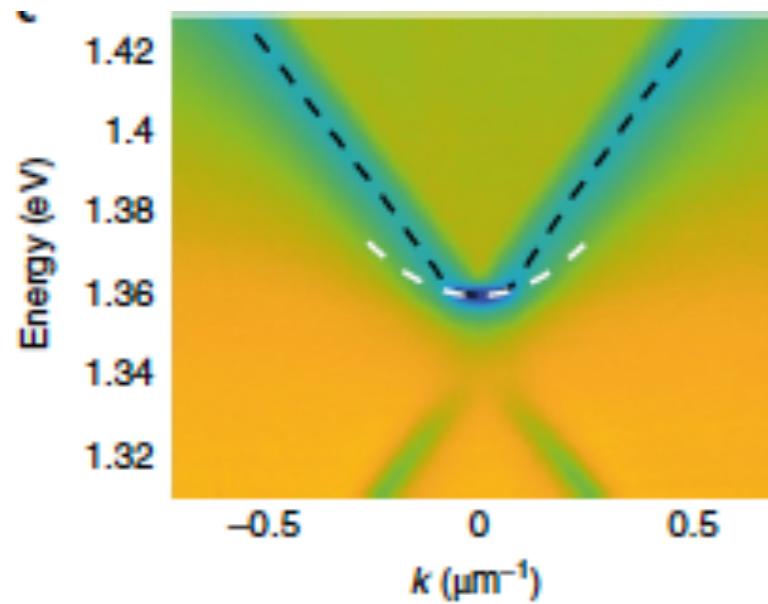
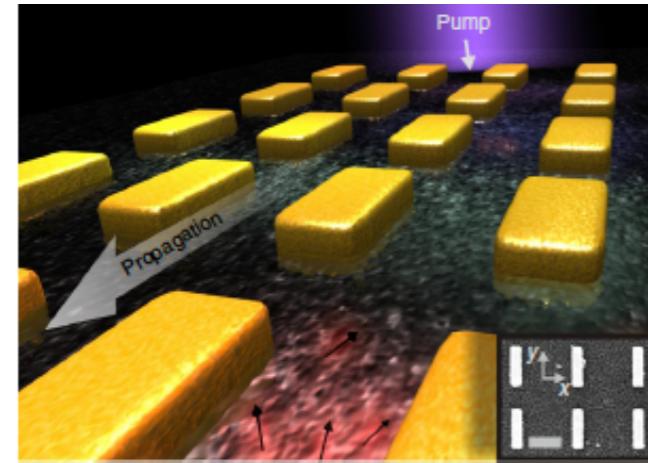
“Condensation phenomena in plasmonics”

Phys. Rev. A 90, 053604 (2014)



P. Törmä (Finland)

Bose-Einstein Condensate of Plasmons



Meetings & training

WG4 meetings

I) Barcelona, ICFO (Spain, 2015)

Local Organization:
D. Chang



II) Crete (Greece, 2016)

Local Organization:
D. Angelakis



III) Helsinki (Finland, 2017)

Local Organization:
P. Törmä



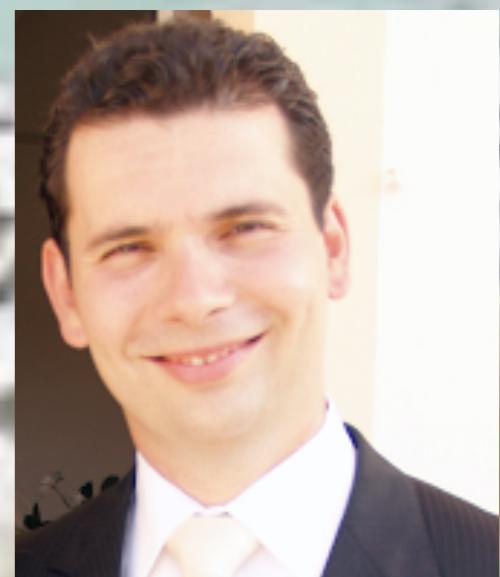
+ general NQO meetings (Belgrade, Prague, Brussels, ...)

“MANY BODY QUANTUM OPTICS: BRIDGING NANOPHOTONICS WITH CONDENSED MATTER AND MATERIAL SCIENCE”

-) *Summer school*

-) *Inter. conference (high-level)*

-) *WG4 meetings*



NQO “*Spin-Off*” Events

“Numerical methods for open quantum many-body systems”

Workshops in Vienna (2016), Madrid (2017), Munich (2018)
(many NQO participants)

“Light-matter interactions in low dimensions”

International Conference at ICFO (2017)
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Thank you for your attention!