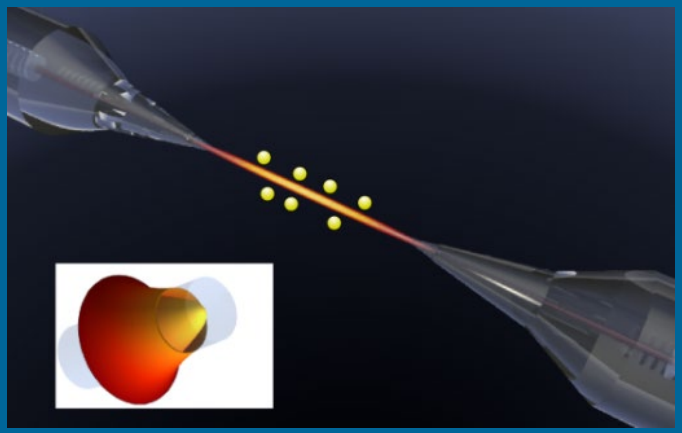
TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

VCQ
Vienna Center for Quantum Science and Technology

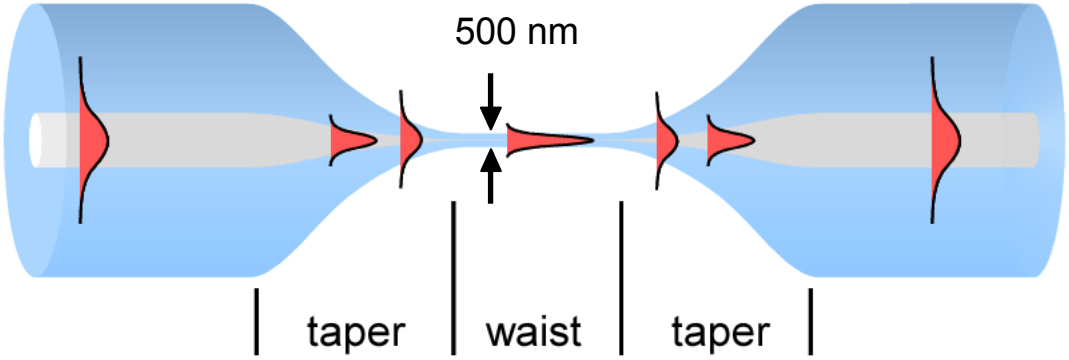
Quantum Optics with Laser-cooled Atoms Coupled to Optical Nanofibers

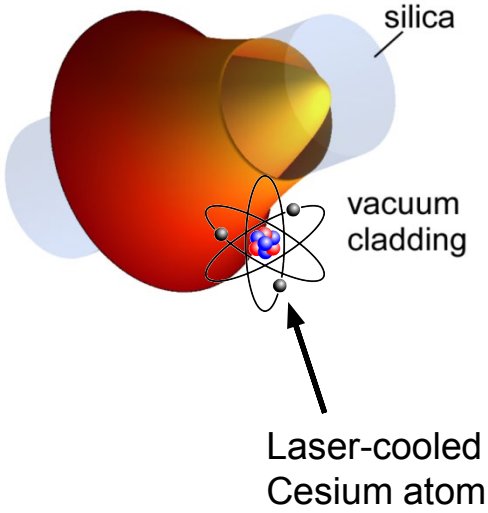


Vienna Center for Quantum Science and Technology
TU Wien – Atominstitut
COST Nanoscale Quantum Optics WG4

Fiber-based Light–Matter Interfaces

Tapered optical fibers with nanofiber waist



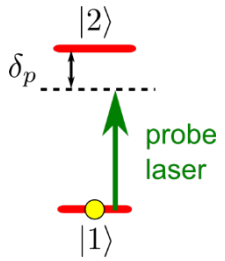


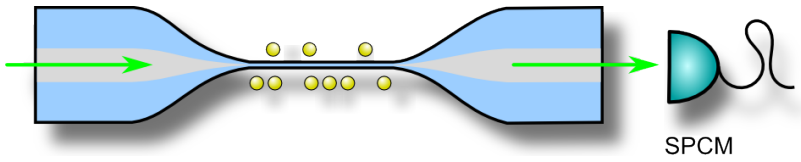
Key features

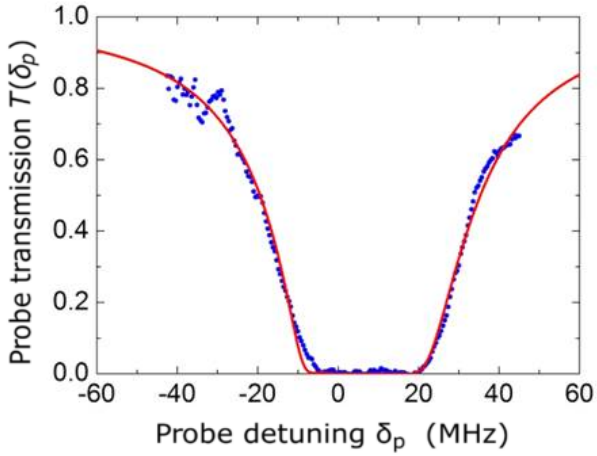
- Compatible with existing fiber-optical networks
- Nanophotonic waveguide structure
  ➔ ideal model system for nanoscale quantum optics

Application 1: Controlling fiber-guided Light

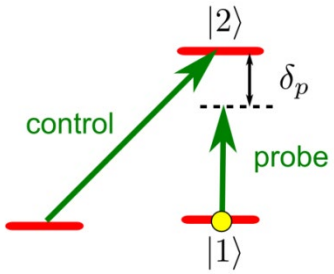
Transmission spectrum

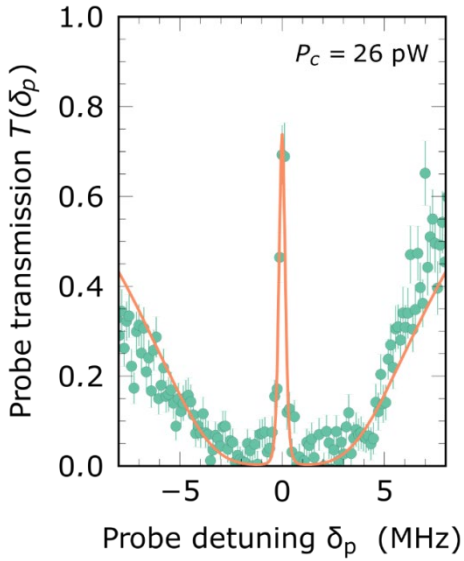






Electromagnetically-induced transparency





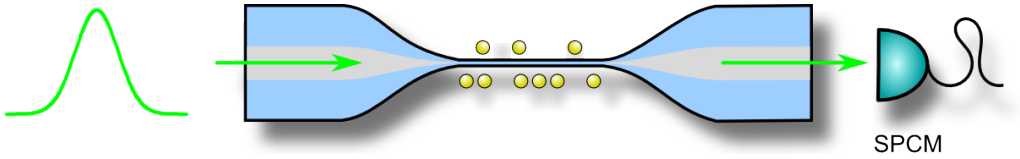
➔ Control of light with light

C. Sayrin et al., Optica **2**, 353 (2015)

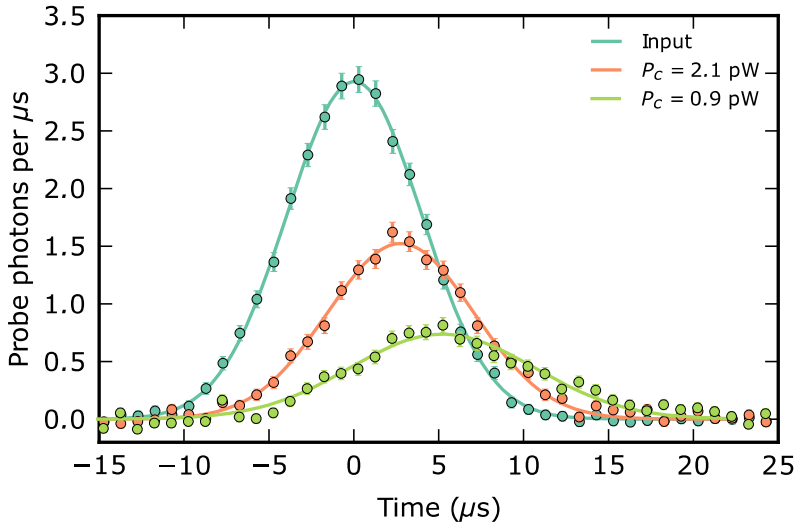
Application 1: Slow fiber-guided Light

Tune refractive index with light

- Group velocity decreases with control power



Slow fiber-guided light: Experiment



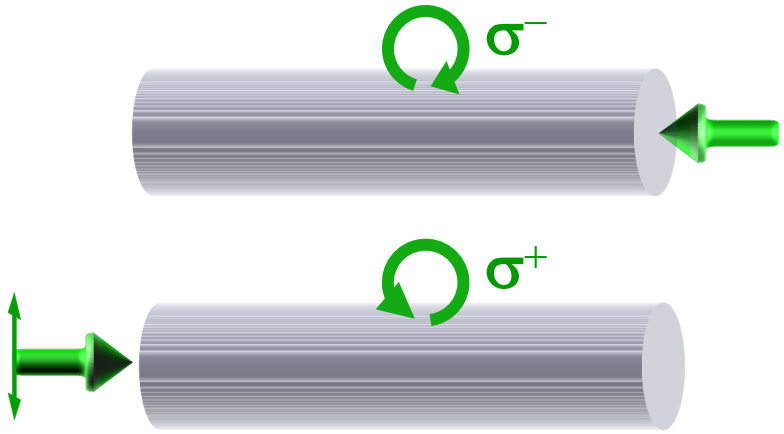
- Pulses slowed down to 50 m / s

➔ Nanophotonic delay line for fiber-guided light
(see also talk by M. Moreno)

C. Sayrin et al., Optica **2**, 353 (2015)

Application 2: Nanophotonic Optical Isolator

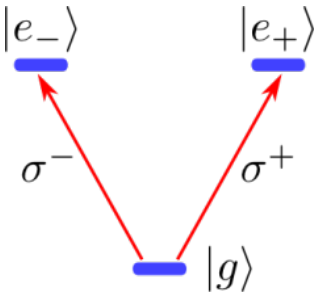
Polarization: What's new at the nanoscale?



➔ Link between local polarization and propagation direction

Recipe for Optical Isolator

- Imbalance the absorption of σ^+ - and σ^- light
  - Transition strength (Clebsch-Gordon coefficients)
  - Detuning (Zeeman effect)

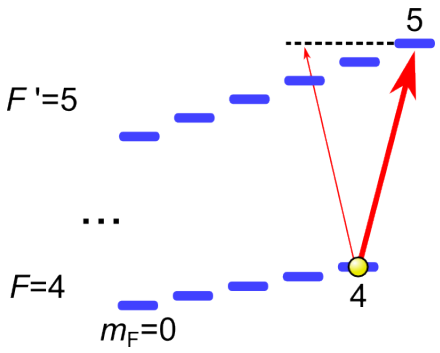


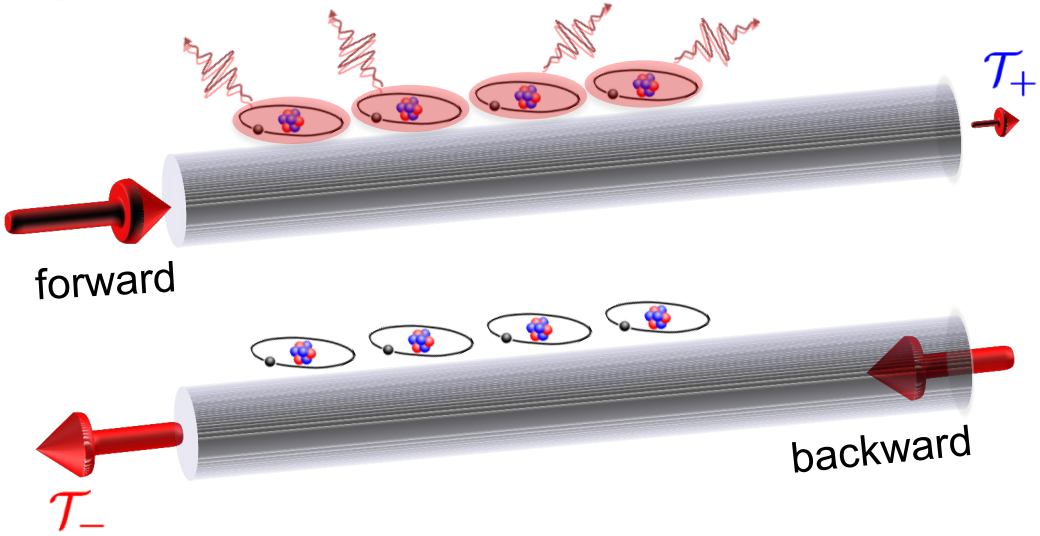
No. 50573/2014 Austrian Patent Office

C. Sayrin et al., Phys. Rev. X **5**, 041036 (2015)

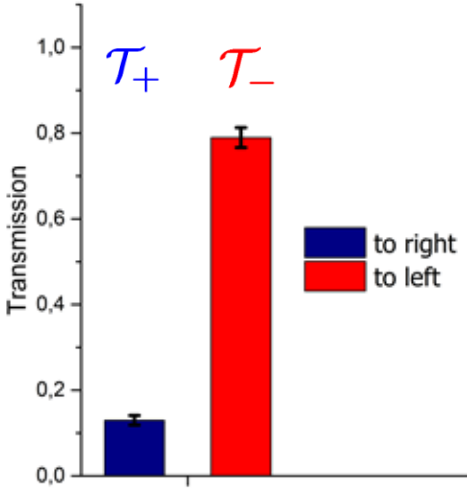
Application 2: Nanophotonic Optical Isolator

Implementation with Cesium atoms





Experimental results



- Novel optical isolator that works with only 30 atoms
- Review: Chiral Quantum Optics
  Nature **541**, 473 (2017)
  (with COST member P. Lodahl)

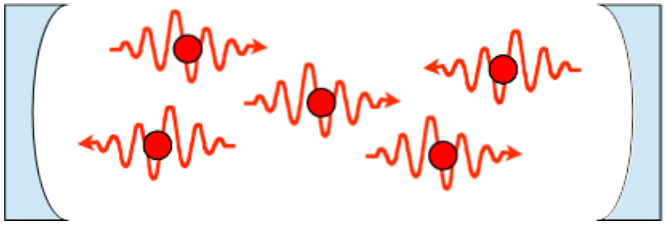
No. 50573/2014 Austrian Patent Office

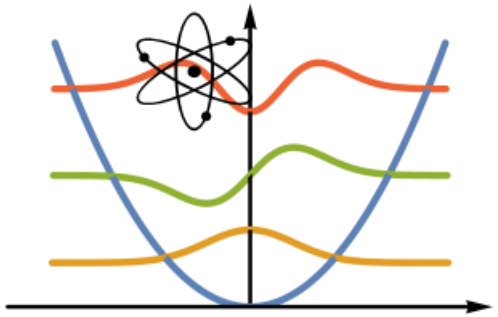
C. Sayrin et al., Phys. Rev. X **5**, 041036 (2015)

Application 3: Ultra-Strong Light–Matter Coupling

Quantum simulation of the quantum Rabi model

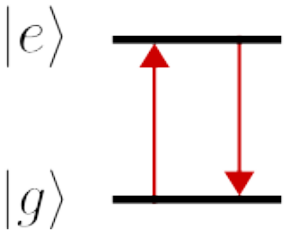
- "phonons are the new photons"





Typical trap frequencies: ~100 kHz

- Zeeman states correspond to the electronic levels of real atoms



Cesium level structure

P.S. et al., Phys. Rev. A **98**, 021801(R) (2018)
A. Dareau et al., Phys. Rev. Lett. **121**, 253603 (2018)

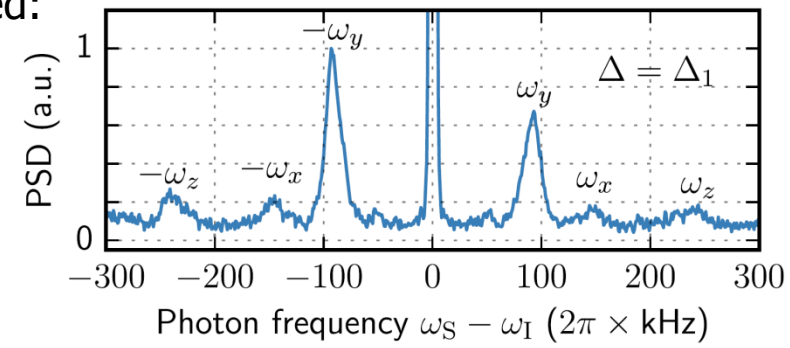
Application 3: Ultra-Strong Light–Matter Coupling

Quantum Rabi model Hamiltonian

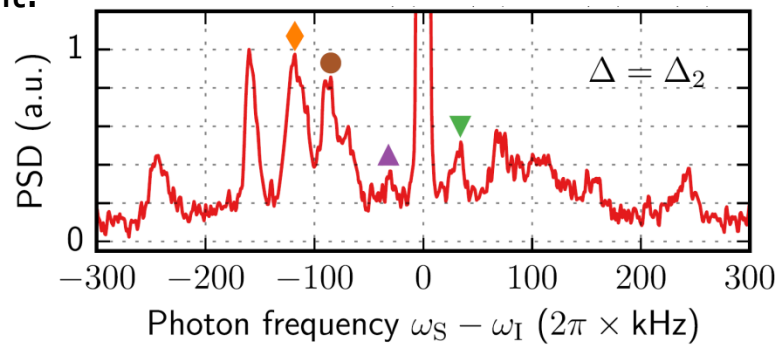
$$\frac{\hat{H}}{\hbar} = \omega \hat{a}^\dagger \hat{a} + \omega_0 \hat{F}_y + \frac{g}{\sqrt{N}}(\hat{a} + \hat{a}^\dagger)(\hat{F}_+ + \hat{F}_-)$$

Experimental signature

detuned:



resonant:



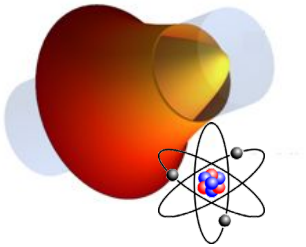
- Vacuum Rabi splitting observed
  ➔ coherent ultra-strong coupling
- Cooperative enhancement
- New versatile platform to study non-perturbative light-matter coupling (with COST member P. Rabl)

P.S. et al., Phys. Rev. A **98**, 021801(R) (2018)
A. Dareau et al., Phys. Rev. Lett. **121**, 253603 (2018)

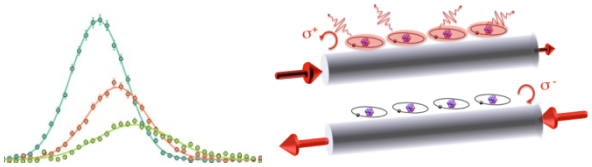
Conclusion

Cold atoms trapped around optical nanofibers

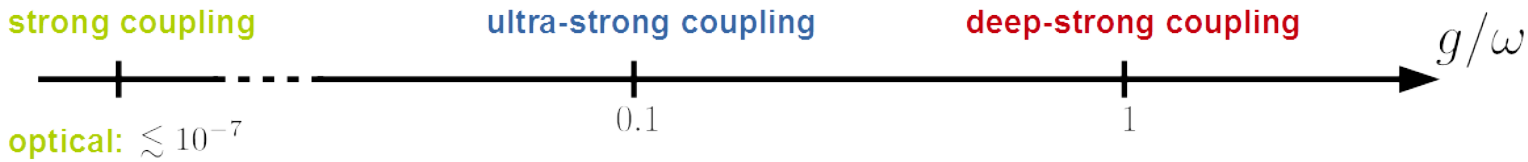
- Excellent model system for Nanoscale Quantum Optics



- Many new applications & new paradigm of Chiral Quantum Optics



- New platform to explore extreme light-matter coupling



Acknowledgements

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FWF
NEXT lite
erc
MARIE CURIE ACTIONS
Studienstiftung des deutschen Volkes
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CoQuS
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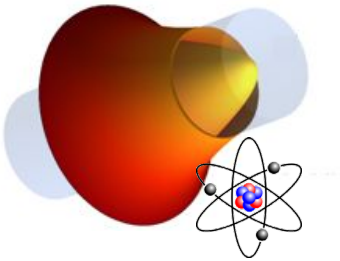
COST MP1403 NANOSCALE QUANTUM OPTICS
ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN



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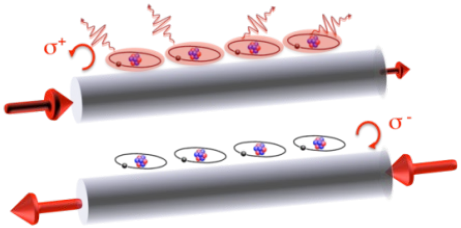

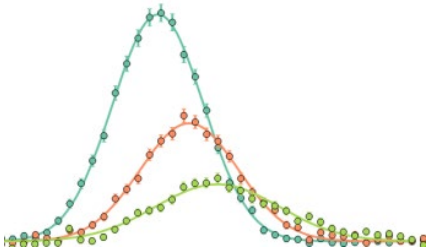

Thank you for your attention