Quantum correlations and entanglement with bright light

Team: St. Andrews (Korolkova), Olomouc, CZ (Mista), Max Plank Institute for the Science of Light, Erlangen, DE (Leuchs group)

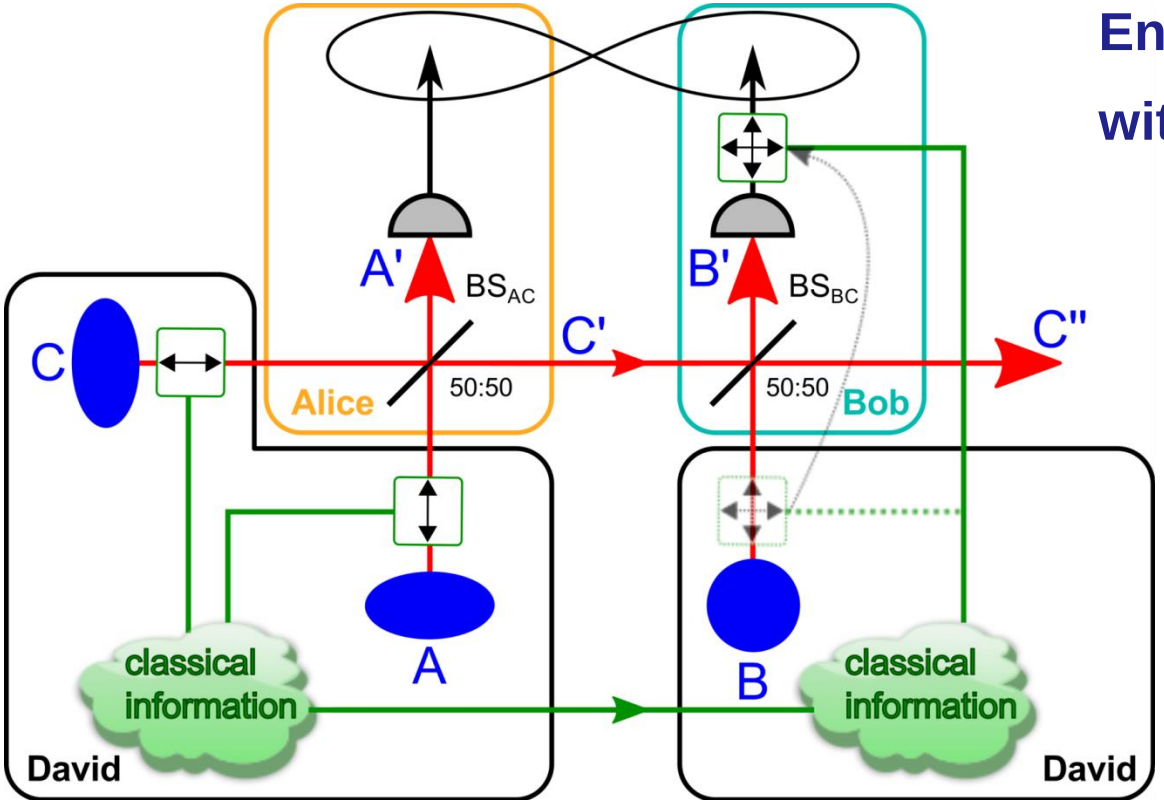
Noisy states, flow of quantum correlations in open system, (engineered) coupling to environment

– quantum information science in more real-world setting

Ch. Peuntinger, V. Chille, L. Mišta, N. Korolkova, M. Förtsch, J. Korger, Ch. Marquardt, G. Leuchs, Distributing entanglement with separable states, Phys. Rev. Lett. 111, 230506 (2013)

V. Chille, N. Quinn, C. Peuntinger, C. Croal, L. Mišta, Jr., Ch. Marquardt, G. Leuchs, N. Korolkova, Quantum nature of Gaussian discord: Experimental evidence and role of system -environment correlations, Phys. Rev. A 91, 050301(R) (2015)

C. Croal, Ch. Peuntinger, V. Chille, Ch. Marquardt, G. Leuchs, N. Korolkova, L. Mišta, Entangling the whole by beam splitting a part, Phys. Rev. Lett. 115, 190501 (2015)



Entanglement distribution without sending entanglement

$$0.8584 \pm 0.0005 < 1$$

the lower symplect. eigenvalue

A & B are entangled

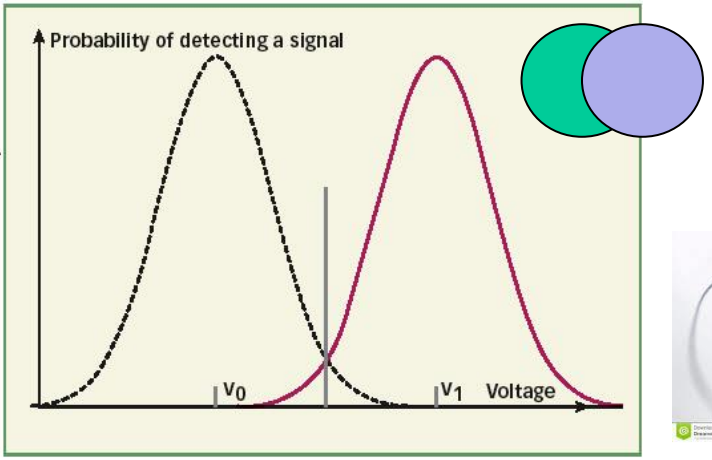
CV: Ch. Peuntinger et al., PRL 111, 230506 (2013); E. Vollmer et al., PRL 111, 230505 (2013)

DV: A. Fedrizzi et al., PRL 111, 230504 (2013) highlighted C. Silberhorn, Physics 6, 132 (2013)

Theory:

CV: L. Mista and N. Korolkova Phys. Rev. A 77, 050302(R) (2008), ibid 80, 032310 (2009).

DV: T. S. Cubitt, F. Verstraete, W. Dür, and J. I. Cirac, Phys. Rev. Lett. 91, 037902 (2003).



Quantum Digital Signatures

Alice sends a message to Bob, who in turn may pass it on to Charlie

Security: non-orthogonal quantum states cannot be distinguished deterministically and exactly

How can Bob tell that - message is from Alice,

- has not been tampered with;

How can Charlie - tell that Bob did not modify the message?

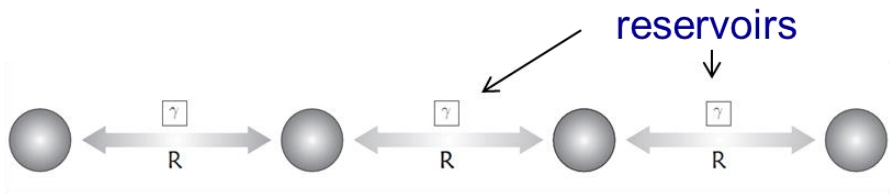
Using a conventional handwritten signature, Alice has previously distributed copies of her signature. Recipients compare the signature on a document with the previously distributed signature sample.

Collaboration

St. Andrews (Korolkova), Edinburgh (Andersson/Waalden), Max Plank Institute for the Science of Light, Erlangen, DE (Leuchs group)

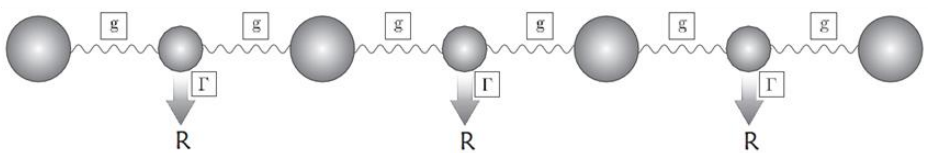
Coherent diffusive photonics: dissipatively coupled bosonic modes

Team: St. Andrews (Korolkova), Inst of Physics, Bel Nat Acad Sci, Minsk, BY (Mogilevtsev, Slepyan), Heriot Watt, Edinburgh, UK (Mukherjee, Thomson)



$$\frac{d}{dt}\rho = \sum_{j=1}^{N} \gamma_j \left(2A_j \rho A_j^\dagger - \rho A_j^\dagger A_j - A_j^\dagger A_j \rho\right)$$

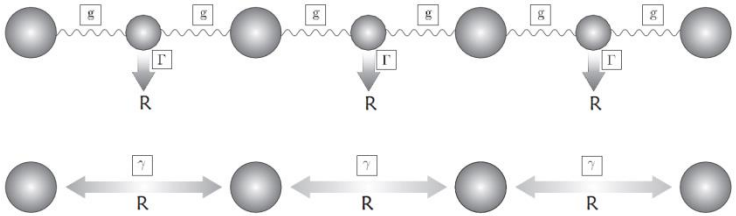
$A_j = a_j - a_{j+1}$ - Lindblad operators



γ_j - relaxation rates into *j*-reservoir

S. Mukherjee, D. Mogilevtsev, G. Ya. Slepyan, T. H. Doherty, R. R. Thomson, N. Korolkova: Dissipatively Coupled Waveguide Networks for Coherent Diffusive Photonics, accepted in Nature Comm., arXiv:1703.06025 [quant-ph].

Coupled tight-binding chain of harmonic oscillators



Lindblad ➔ Fokker-Planck for P-function ➔ Dynamics for coherent amplitudes

$$\frac{d}{dt}\alpha_k = -(\gamma_k + \gamma_{k-1})\alpha_k + \gamma_k \alpha_{k+1} + \gamma_{k-1}\alpha_{k-1}$$

- same equation as time-dependent classical random walk in 1D

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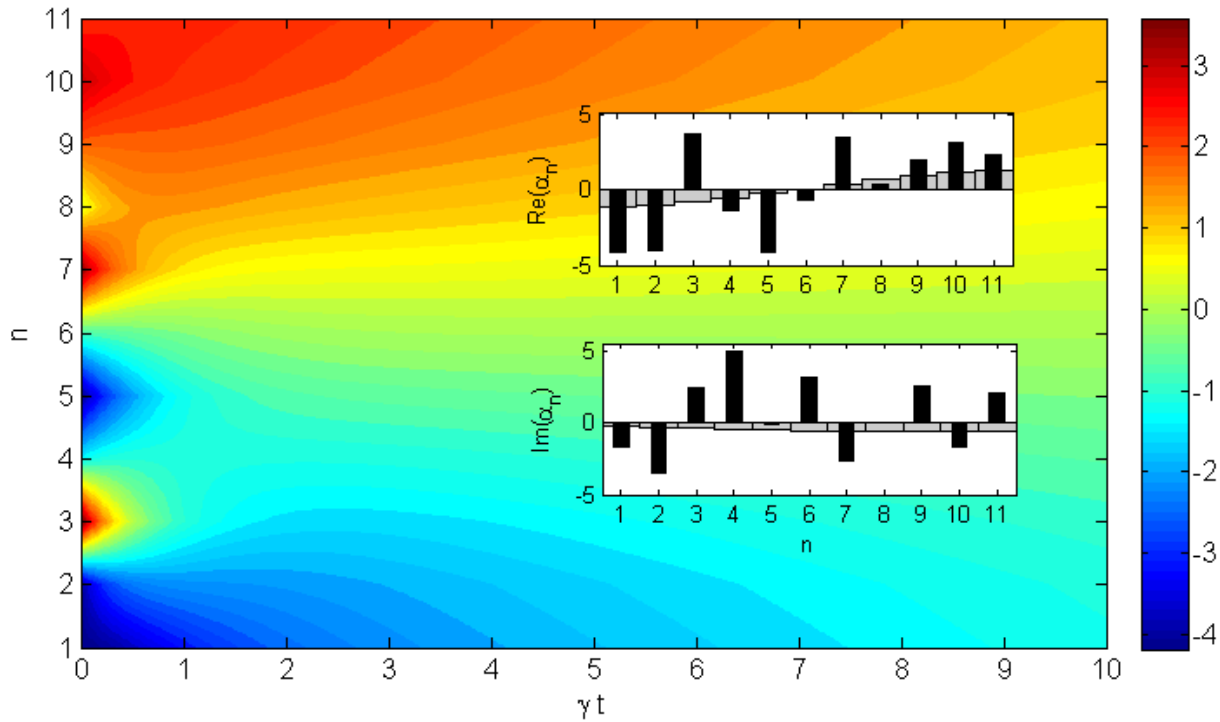
collective symmetrical superposition of all modes: $A_{sum} = \sum_{j=1}^{N+1} a_j / \sqrt{N+1}$

Conserved: average of any function of $A_{sum},\ A^\dagger_{sum}$

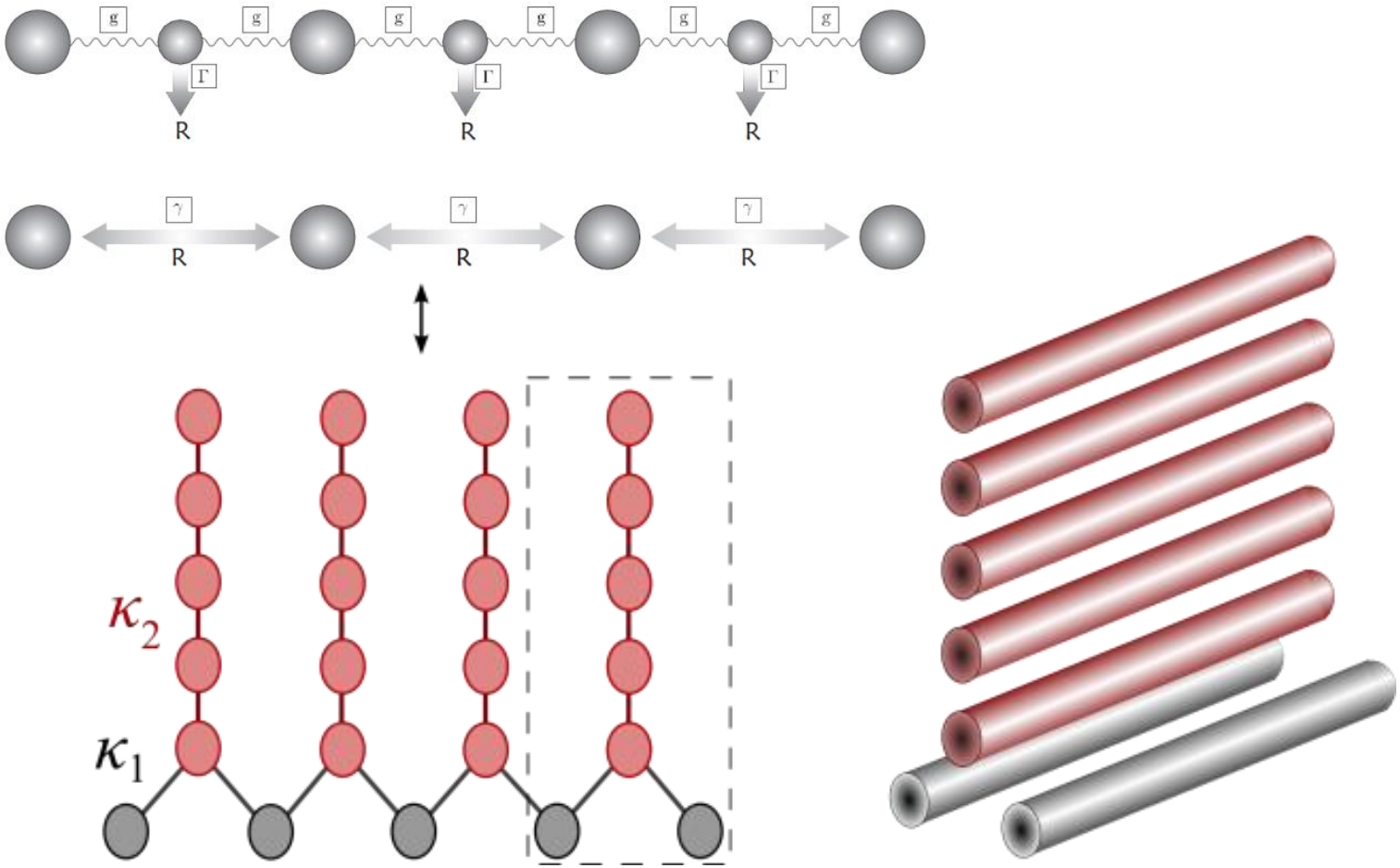
$$W_1 = \sum_{k=1}^{N+1} \langle a_k(t) \rangle = \sum_{k=1}^{N+1} \langle a_k(0) \rangle$$

For dissipatively coupled chain of two-level systems ("fermionic chain") see:
D Mogilevtsev, G Ya Slepyan, E Garusov, Ya Kilin and N Korolkova: Quantum tight-binding chains with dissipative coupling, New J. Phys. 17, 043065 (2015).



Amplitudes of the coherent states propagating through the dissipatively coupled chain of 11 modes. Insert: initial (black bars) and final (grey bars) distributions of real and imaginary parts of coherent amplitudes at $\gamma t = 10$

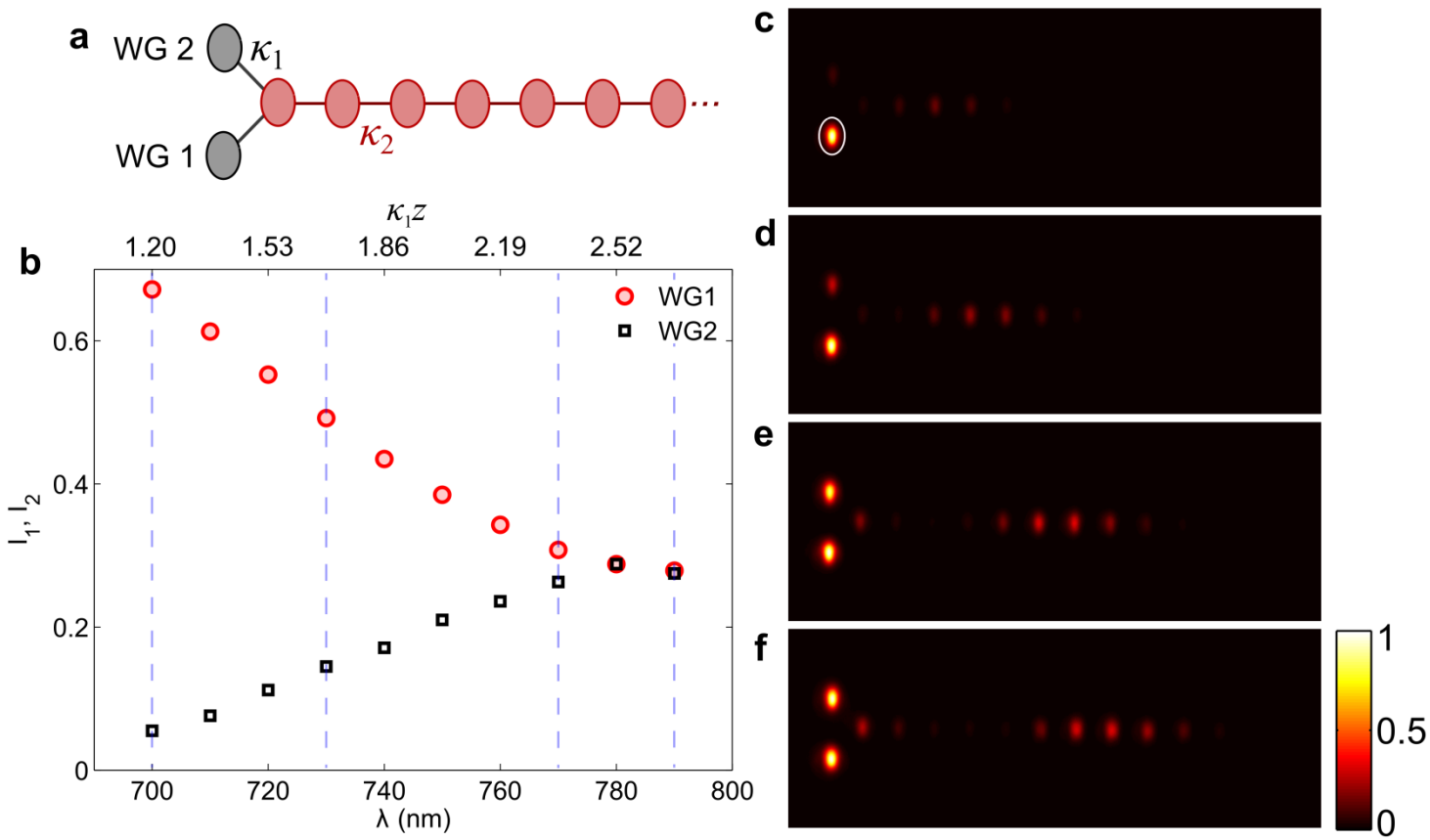
The states are always coherent with amplitudes α_n



Implementation

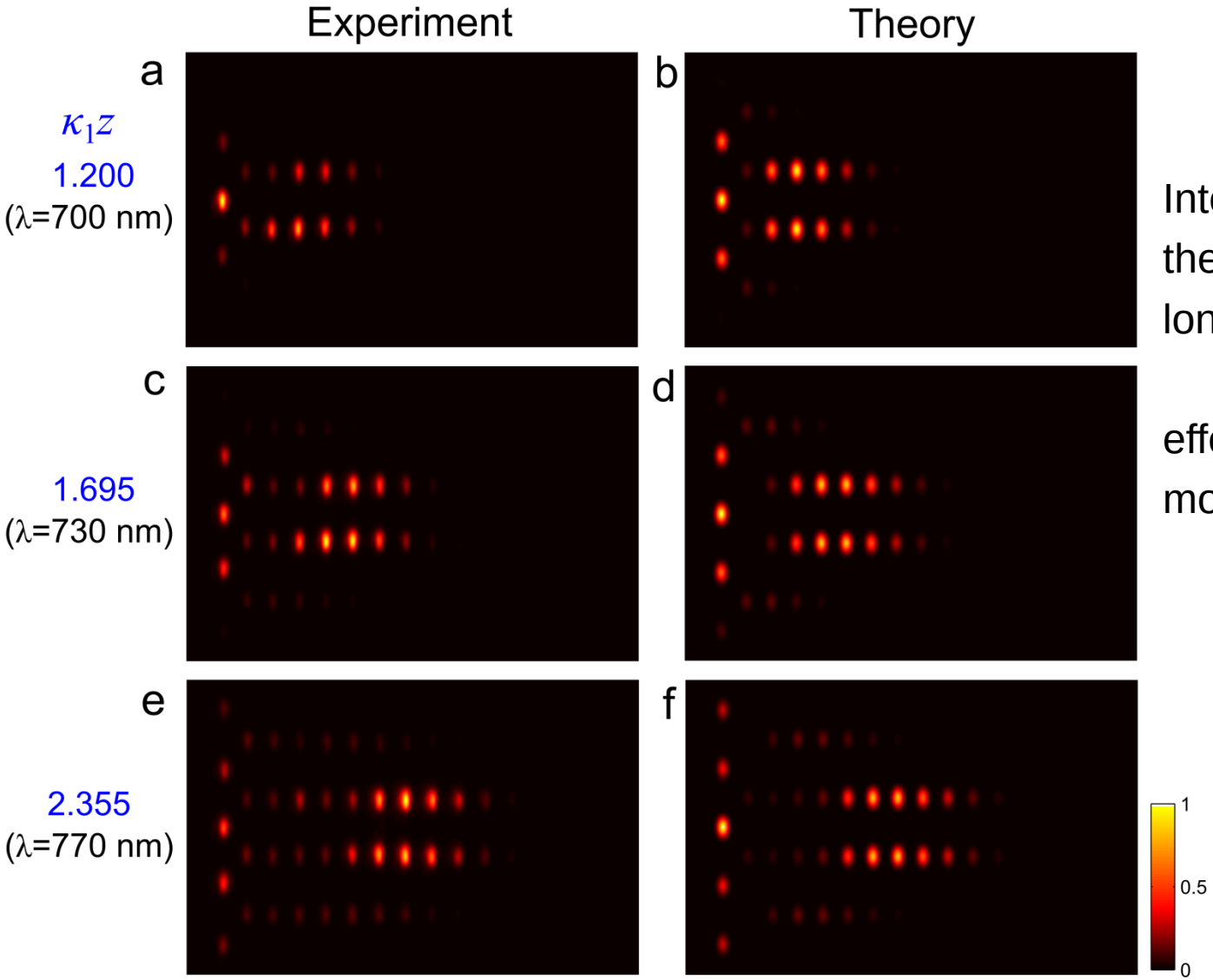
Experiment: Sebabrata Mukherjee and Robert Thomson, Photonic Instrumentation Group, Heriot Watt Univ, UK

Experimental results for the simplest element



Experiment/simulation: Sebabrata Mukherjee and Robert Thomson, Photonic Instrumentation Group, Heriot Watt Univ, UK

Experimental/theoretical results for the 5 waveguide chain



Intensity distributions at the output of the 30-mm-long photonic lattice;

effectively - 5 coupled modes.

Experiment/simulation: Sebabrata Mukherjee and Robert Thomson, Photonic Instrumentation Group, Heriot Watt Univ, UK

Beyond the equalisation:

non-trivial stationary states: correlated; entangled; Gibbs state, … etc

diffusive dissipative distribution and localization

Combination of seemingly classical dynamics with distinctly quantum results

Random walk equation for coherent amplitudes

Multi-mode light flows like heat remaining coherent and even entangled

Optical equaliser – output symmetric over all states

Coherence flows like heat and behaves like heat

As reservoir:

retains coherence and transforms signals catalytically, non-Landauer erasure

(washes out any info about the signal without loosing energy and without loosing coherence)

2nd type phase transition from positive to negative temperatures

Energy density of stationary states for bosonic modes is given by Fermi-Dirac

Applications:

Quantum simulation, topological effects, modelling condensed matter systems etc

Next steps:

Nonlinear waveguides; engineered photon statistics

Ancilla Driven Quantum Computation

Team: St. Andrews (Korolkova, Nordgren, Guilian)

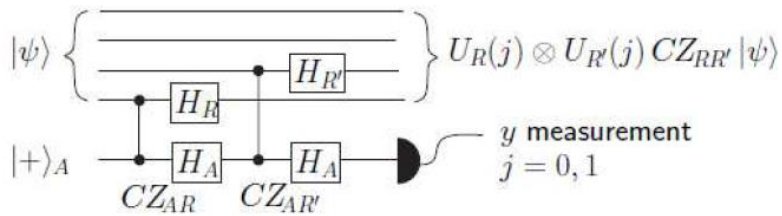
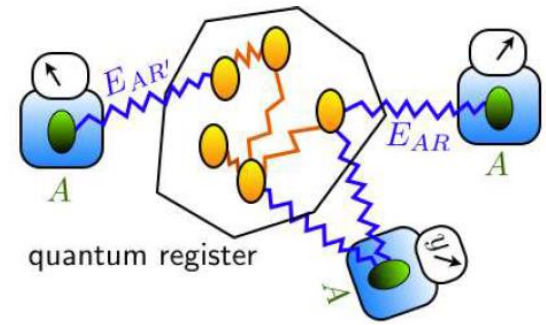
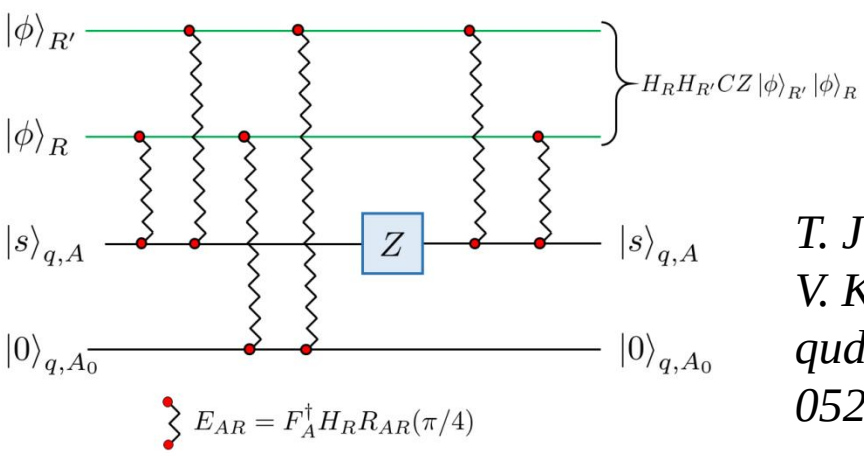


FIGURE 8 TAKEN FROM [35]

ADQC implementation of the CZ gate. Two registers (R, R') are coupled sequentially to the ancilla via $E_{AR(R')}$. A y-measurement on the ancilla produces the CZ operation between the registers up to a local correction.



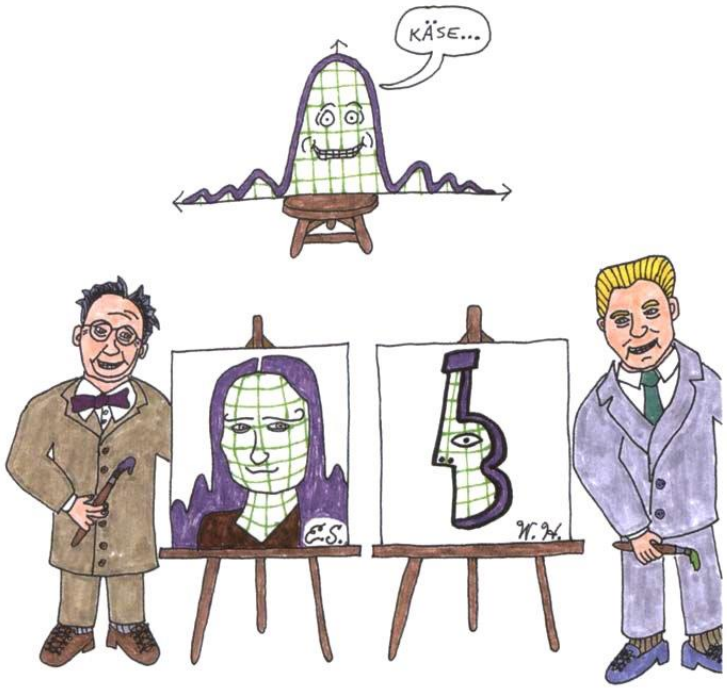
J. Anders et al, Phys. Rev. A 82, 020301(R) (2010)

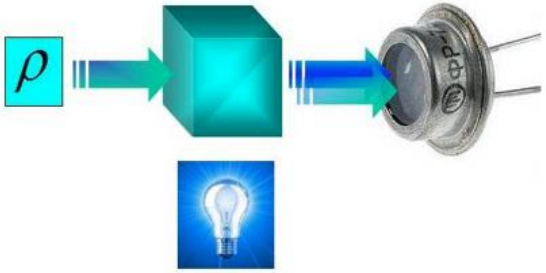


T. J. Proctor, M. Giulian, N. Korolkova, E. Andersson, V. Kendon: Ancilla-driven quantum computation for qudits and continuous variables, Phys. Rev. A 95, 052317 (2017).

Quantum tomography by imperfections

Team: St. Andrews (Korolkova), Inst of Physics, Bel Nat Acad Sci, Minsk, BY (Mogilevtsev), Paderborn, DE (Tiedau, Bartley, Silberhorn)



J. Tiedau, V. S. Shchesnovich, D. Mogilevtsev, V. Ansari, G. Harder, T. Bartley, N. Korolkova, Ch. Silberhorn: Trading quantum states for temporal profiles: tomography by the overlap, submitted to New J. Phys., arXiv:1708.08463 [quant-ph].

G. Harder, D. Mogilevtsev, N. Korolkova, Ch. Silberhorn: Tomography by noise, Phys. Rev. Lett. 113, 070403 (2014).