Finite and infinite quantum systems (QUANTUM)

Giuliano Benenti

Center for Nonlinear and Complex Systems
Univ. Insubria, Como, Italy &
IS INFN - QUANTUM

OUTLINE

Investigation of the recent developments that have changed the status of quantum mechanics (a new "quantum revolution") and made the development of Quantum Technologies a European Flagship:

- quantum simulations and many-body physics,

- entanglement in applied quantum technologies,

- quantum thermodynamic machines,

- mesoscopic quantum dynamics of open systems, ...

National Coordinator: S. Pascazio (Bari)

Local coordinators: E. Ercolessi (Bologna), G. Benenti (Milano), G. Bimonte (Napoli), F. Benatti (Trieste)

Milano: G. Benenti, L. Molinari, F. Angaroni

Volta and the discovery of thermoelectricity

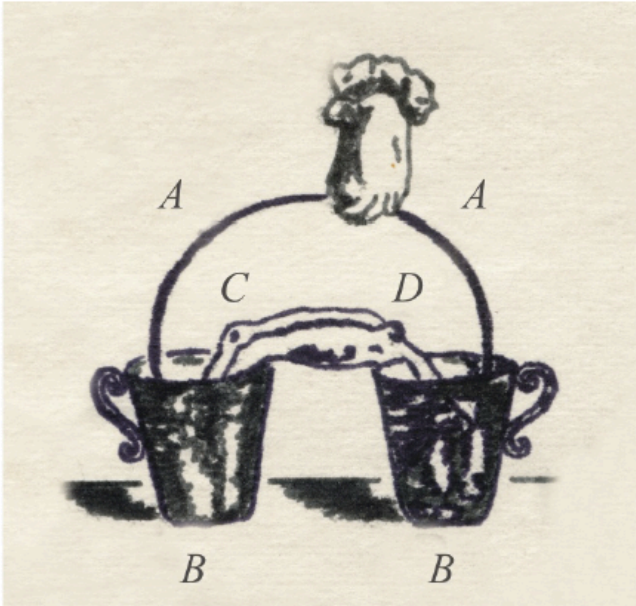


Fig. 3 Schematic of Volta's experiment that resulted in the discovery of thermoelectricity: A – metal (iron) arc; B – glasses with water; C and D – frog parts placed in the glasses with water.

(see Anatychuk et al, "On the discovery of thermoelectricity by A.Volta")

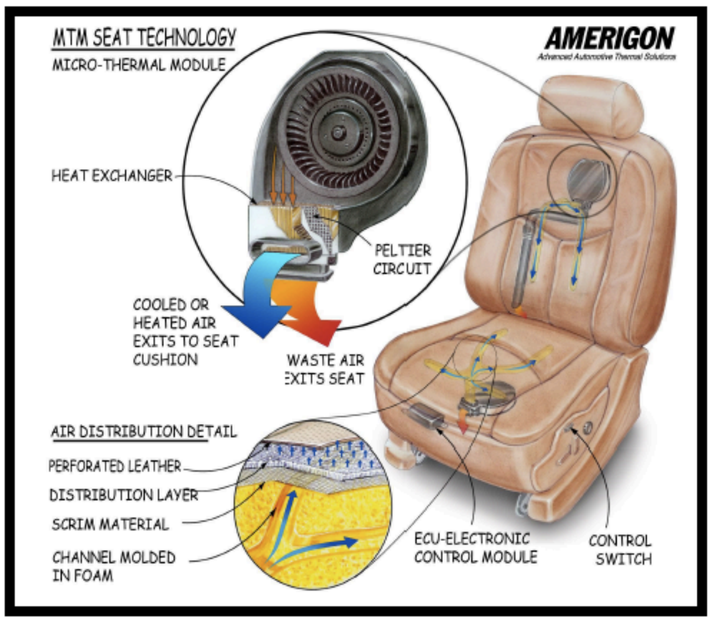
1794-1795: letters from Volta to Vassali. "*I immersed for some half-minute the end of such (iron) arc into boiling water and, without letting it to cool down, returned to experiments with two glasses of cold water. And it was then that the frog in water started contracting...*"

Thermoelectric phenomena

Thermoelectric (Peltier) refrigerators have poor efficiency compared to compressor-based refrigerators

Niche applications: space missions, medical applications, laboratory equipments, air conditioning in submarines (reliability and quiet operation more important than cost)

car's seats cooler/heater



Use vehicle waste heat to improve fuel economy

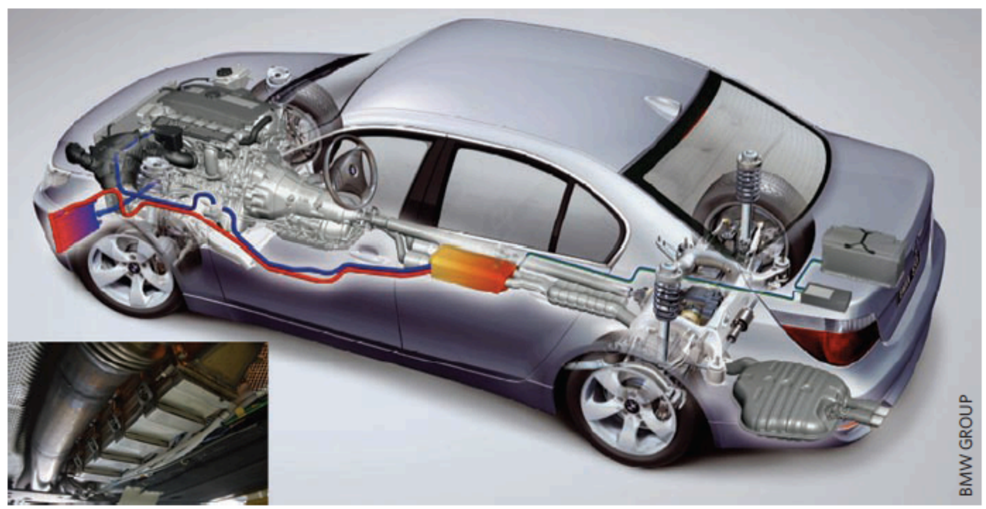


Figure 1 | Integrating thermoelectrics into vehicles for improved fuel efficiency. Shown is a BMW 530i concept car with a thermoelectric generator (yellow; and inset) and radiator (red/blue).

Quantum aspects relevant for nanoscale applications

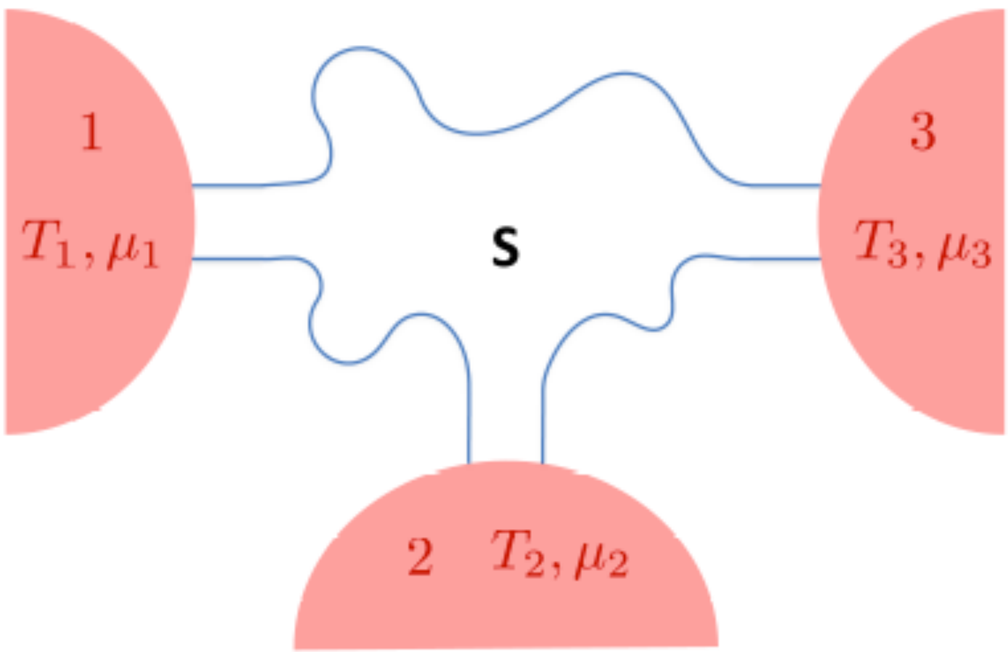
Mildred Dresselhaus et al. (Adv. Materials, 2007):

"a newly emerging field of low-dimensional thermoelectricity, enabled by material nanoscience and nanotechnology... Thermoelectric phenomena are expected to play an increasingly important role in meeting the energy challenge for the future..."

Small scale thermoelectricity could be relevant for cooling directly on chip, by purely electronic means. Nanoscale heat management is crucial to reduce the energy cost in many applications of microelectronics.

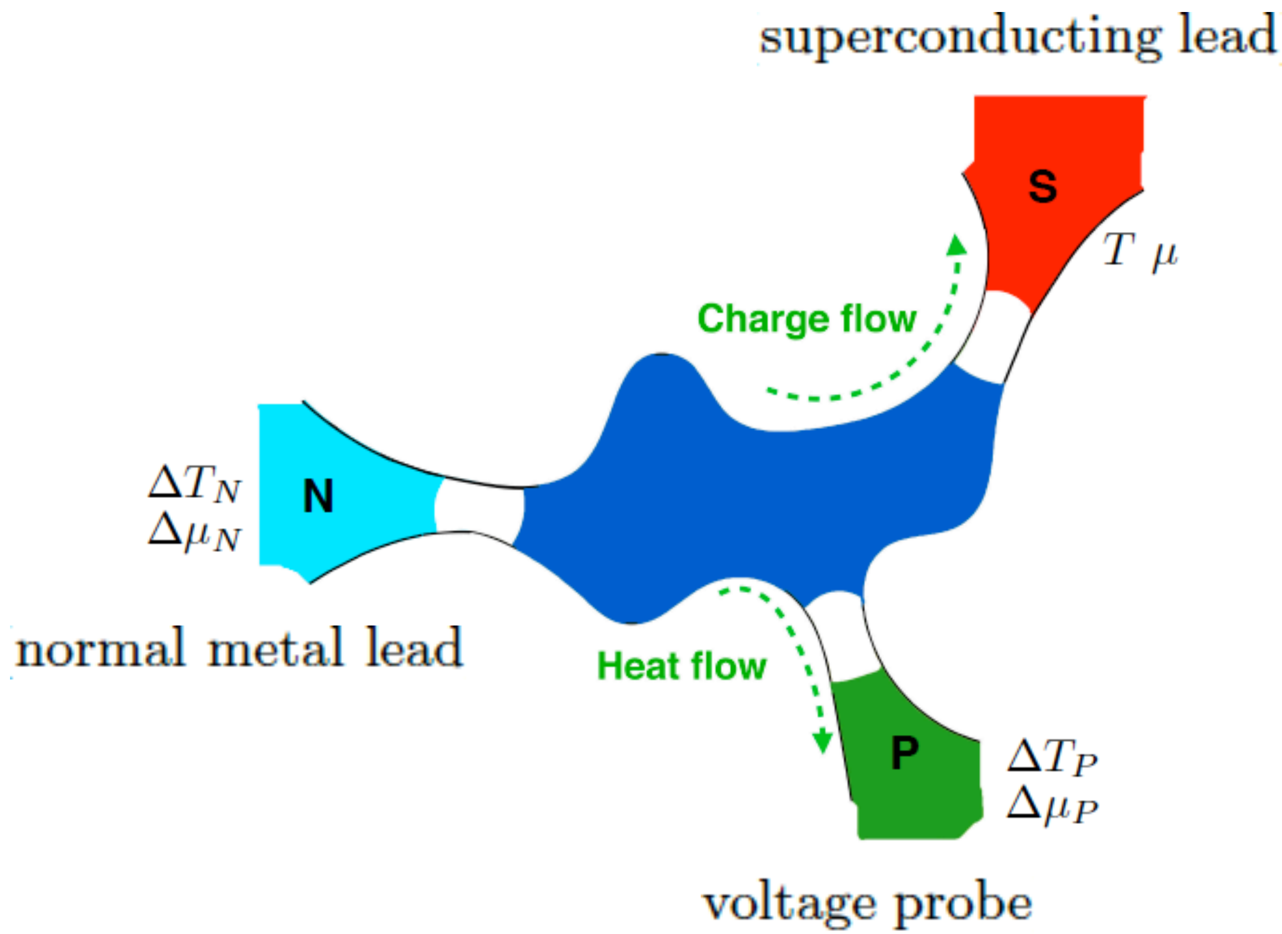
Multi-terminal thermoelectricity

Is it possible to exploit additional terminals to decouple charge and heat flows and improve thermoelectric efficiency?



(F. Mazza, R. Bosisio, G. B., V. Giovannetti, R. Fazio, F. Taddei, New J. Phys. **16**, 085001 (2014))

Heat-charge separation

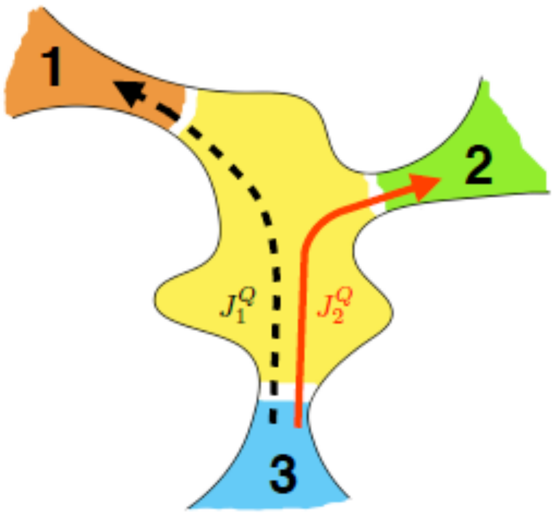


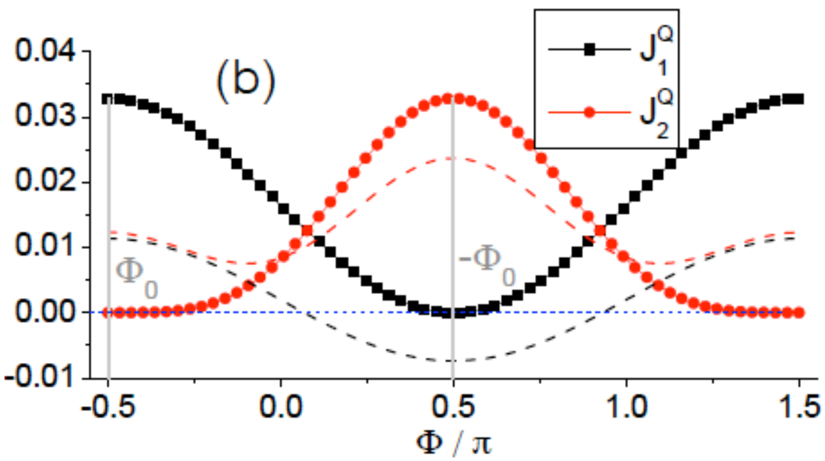
Improved thermoelectric performances (both power and efficiency) in the low-temperature regime

(F. Mazza, S. Valentini, R. Bosisio, G.B., R. Fazio, V. Giovannetti, F. Taddei, PRB **91**, 245435 (2015))

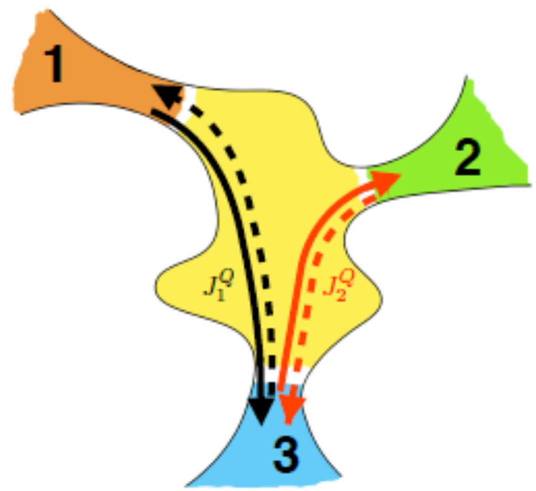
Nanoscale heat management: Magnetic thermal switch

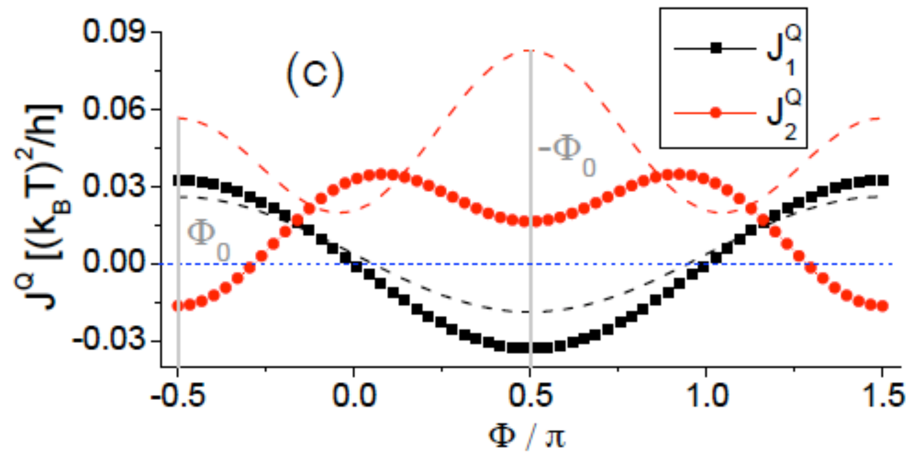
Heat path selector:





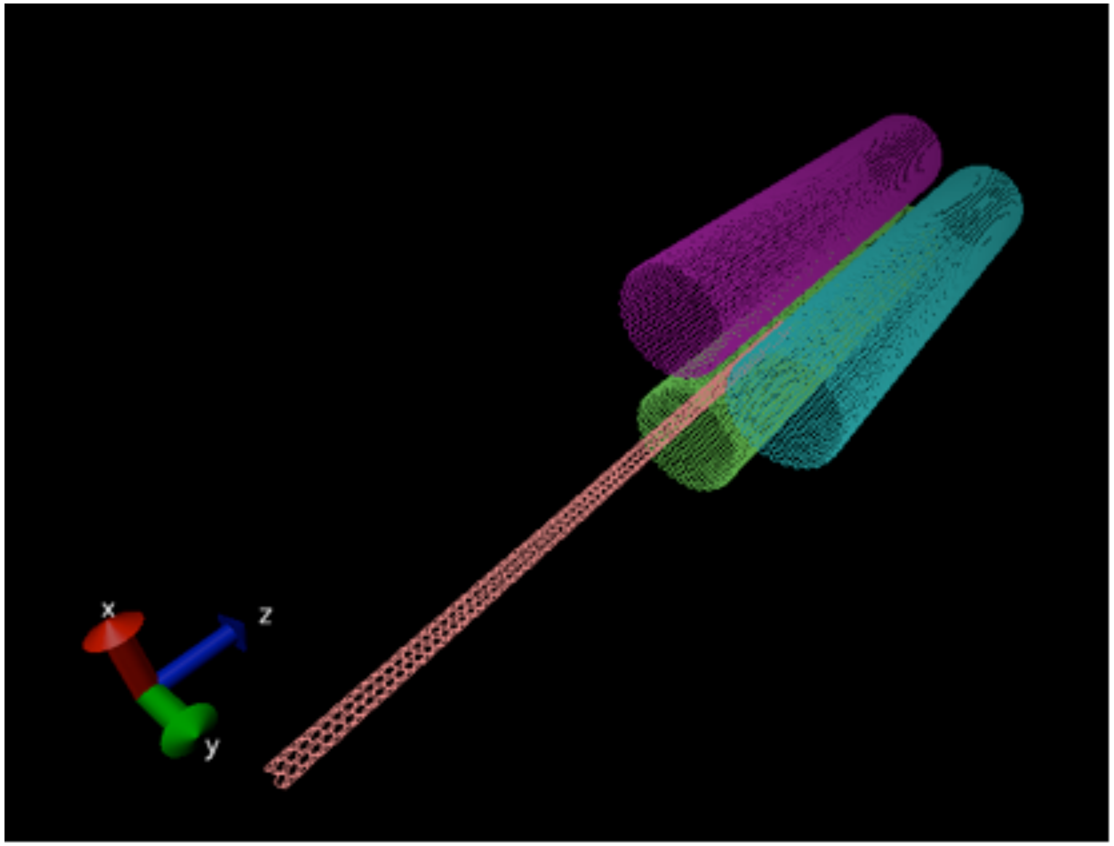
Fully reversible heat:





(R. Bosisio, S. Valentini, F. Mazza, G.B., V. Giovannetti, R. Fazio, F. Taddei, PRB **91**, 205420 (2015) [marked as Editors' suggestion])

Nanodevices for thermal rectification

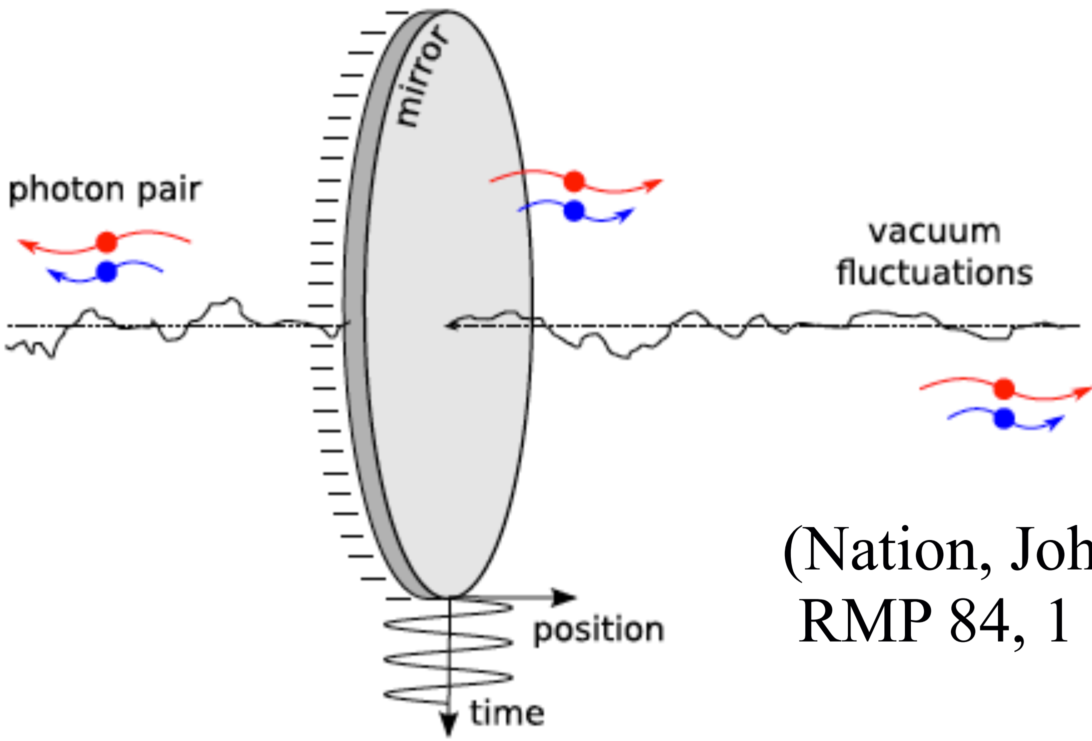


Carbon nanotube bundles

Interplay between contact (Kapitza) thermal resistance and thermal rectification. R up to 1.2 (work in progress)

Dynamical Casimir effect
and quantum information protocols

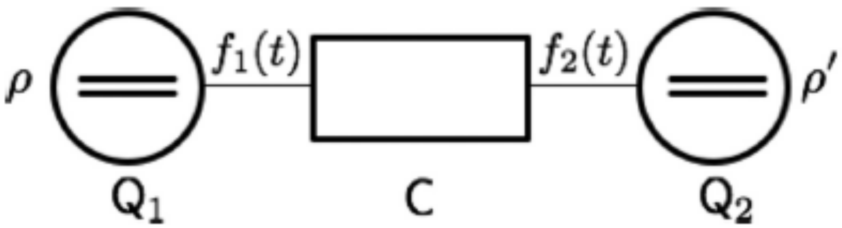
The DCE concerns the generation of real photons from the vacuum due to time-dependent boundary conditions

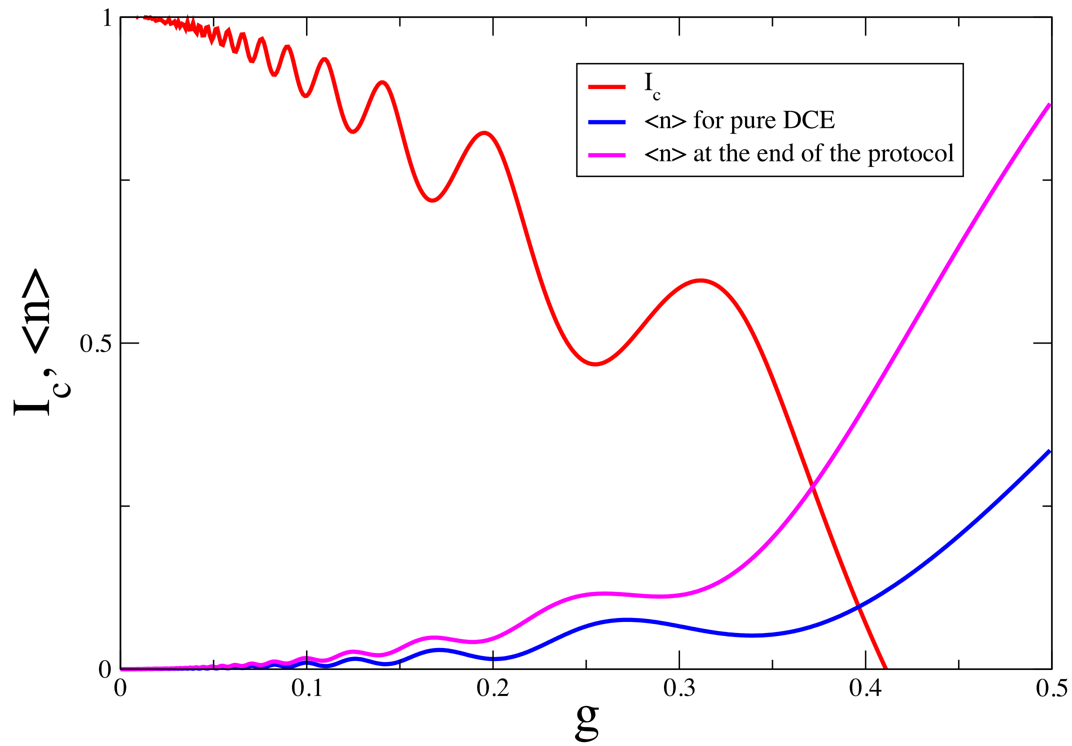


(Nation, Johansson, Blencowe, Nori, RMP 84, 1 (2012))

Related to Hawking radiation and Unruh effect

Coherent information degradation vs photon generation (in a quantum communication protocol)

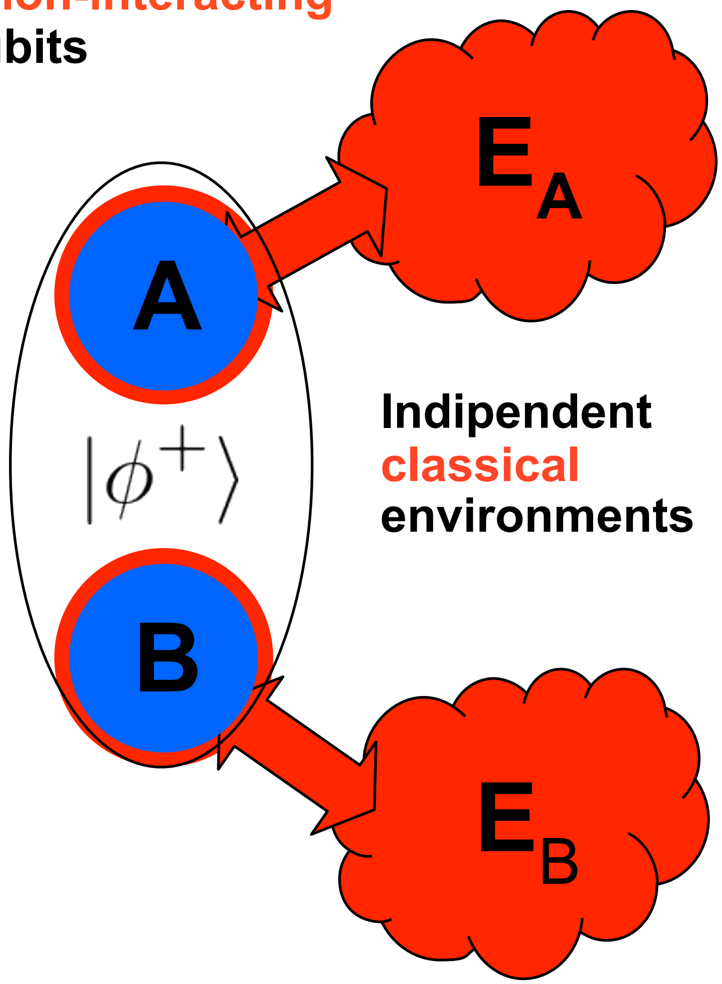




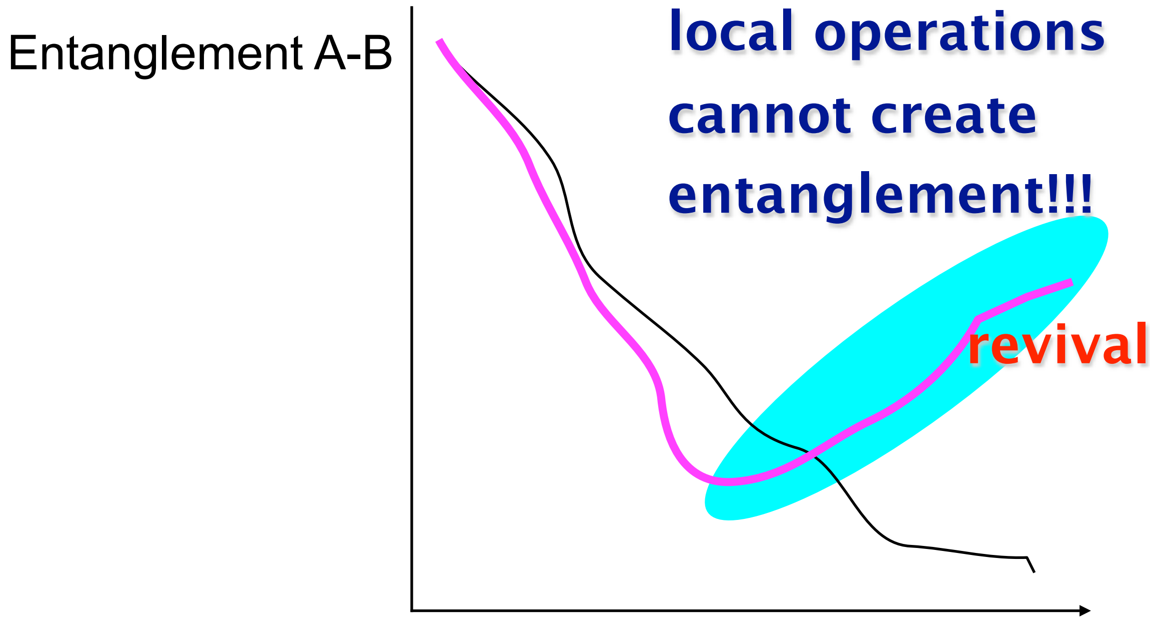
(G.B., A. D’Arrigo, S. Siccardi, G. Strini, PRB **90**, 052313 (2014))

Entanglement recovery by local operations

2 non-interacting qubits



Indipendent classical environments



How does entanglement revises?

No non-local operations

No exchange of quantum correlations system-environment

Stochastic low-frequency noise

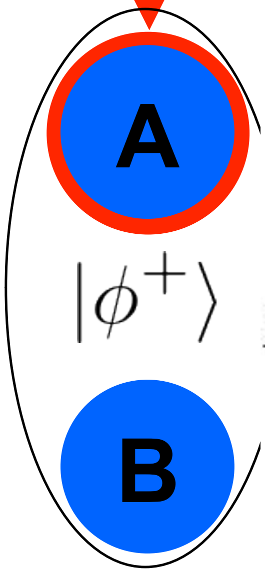
$$\mathcal{H}_A = -\frac{\Omega_A}{2}\sigma_z - \frac{\varepsilon(t)}{2}\sigma_z + \mathcal{V}(t,\bar{t})\sigma_x$$

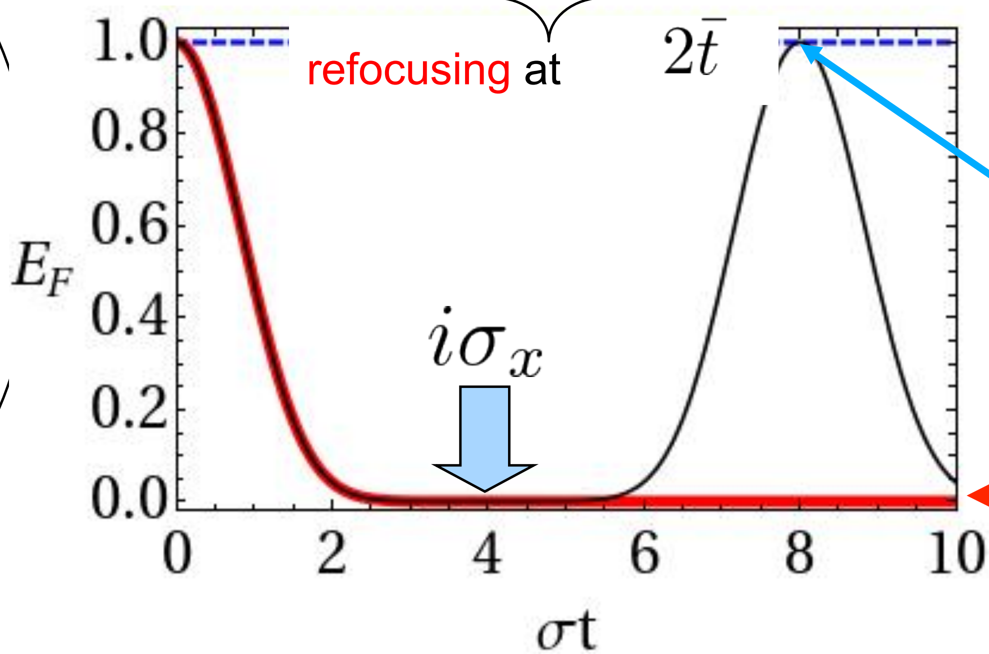
$$\mathrm{e}^{-i\sigma_x\pi/2} = -i\sigma_x$$ π -pulse around x

$$i\sigma_x$$

$$|\psi_\varepsilon(t)\rangle = e^{-i\frac{\Omega_A+\varepsilon}{2}\sigma_z(t-\bar{t})}\sigma_x e^{-i\frac{\Omega_A+\varepsilon}{2}\sigma_z\bar{t}}|\psi(0)\rangle$$

$$= \underbrace{e^{-i\frac{\Omega_A+\varepsilon}{2}\sigma_z(t-\bar{t})}e^{+i\frac{\Omega_A+\varepsilon}{2}\sigma_z\bar{t}}}_{2\bar{t}}\sigma_x|\psi(0)\rangle$$





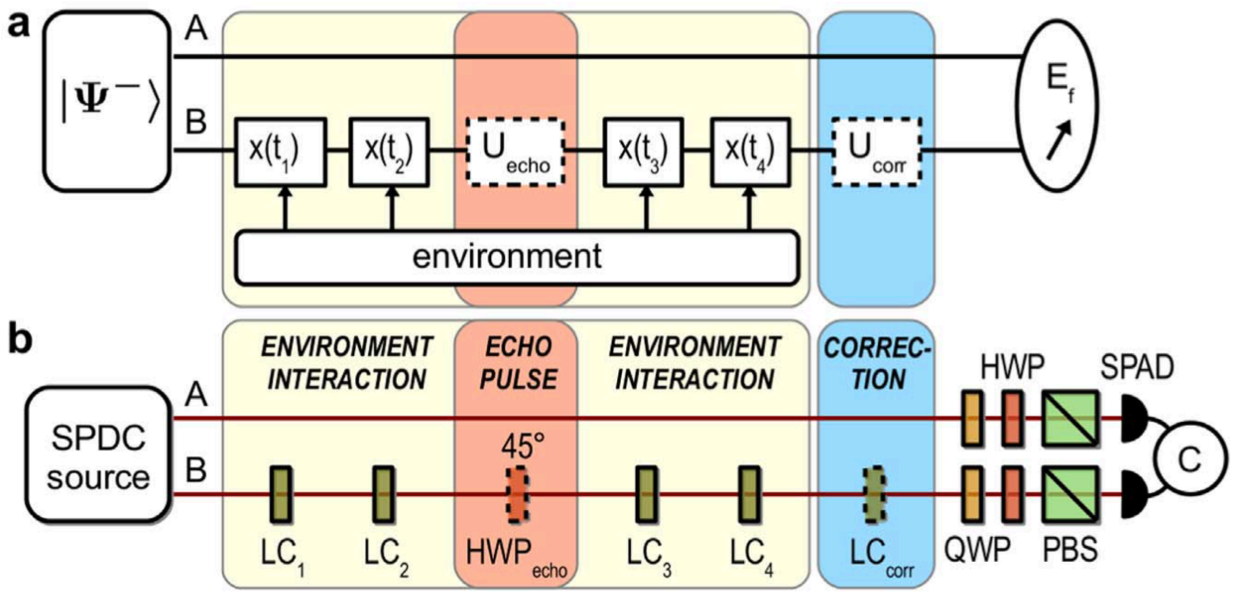
$$E_{av}\big(\mathcal{A}(t)\big) = 1$$

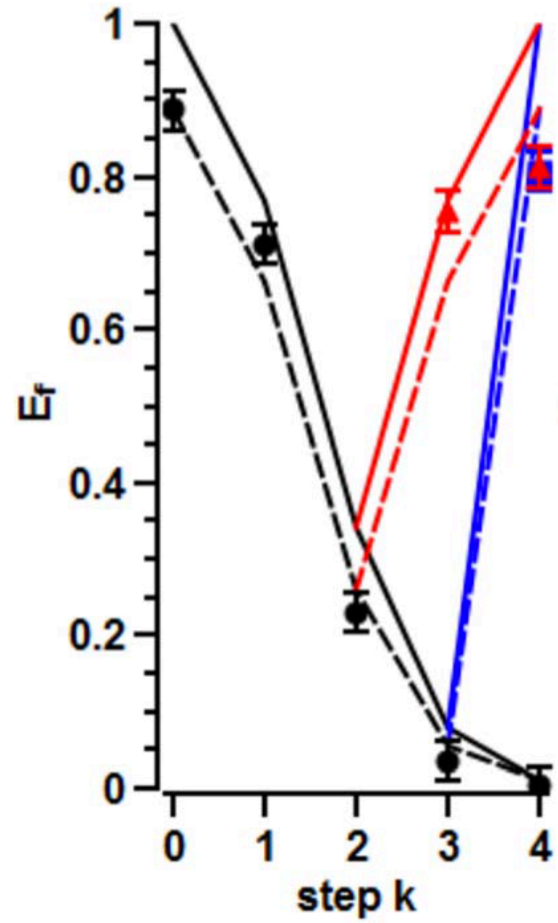
Complete recovery of Entenglement (for static noise)

$$E_F\Big(\rho(t \gg 1/\sigma)\Big) \simeq 0$$

(A. D'Arrigo, R. Lo Franco, G. B., E. Paladino, G. Falci, Ann. Phys. **350**, 211 (2014))

Experimental on-demand recovery of entanglement by local operations within non-Markovian dynamics





(A. Orieux, A. D'Arrigo, G. Ferranti, R. Lo Franco, G. B., E. Paladino, G. Falci. F. Sciarrino, P. Mataloni, Sci. Rep. **5**, 8575 (2015))

Summary (keywords)

Optimizing the performances of nanoscale quantum thermal engines

Heat management in nanodevices

Quantum information protocols in the ultra-strong coupling regime

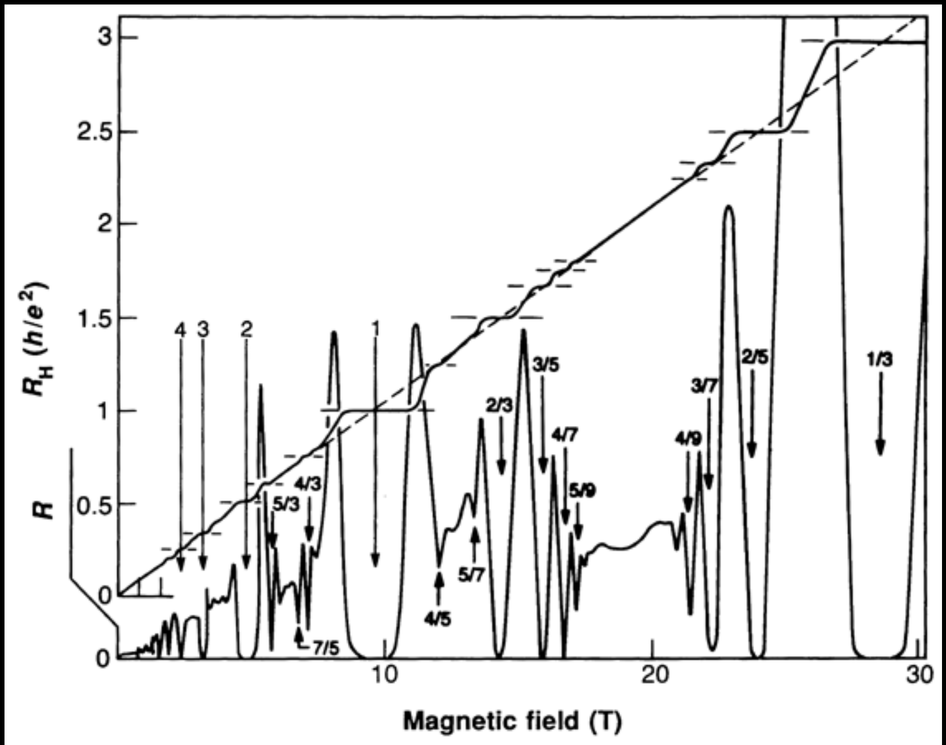
Quantum control and non-Markovian dynamics in distributed quantum networks

Devil's staircase phase diagram of the FQHE in the thin torus limit (PRL 116 (2016) 256803)

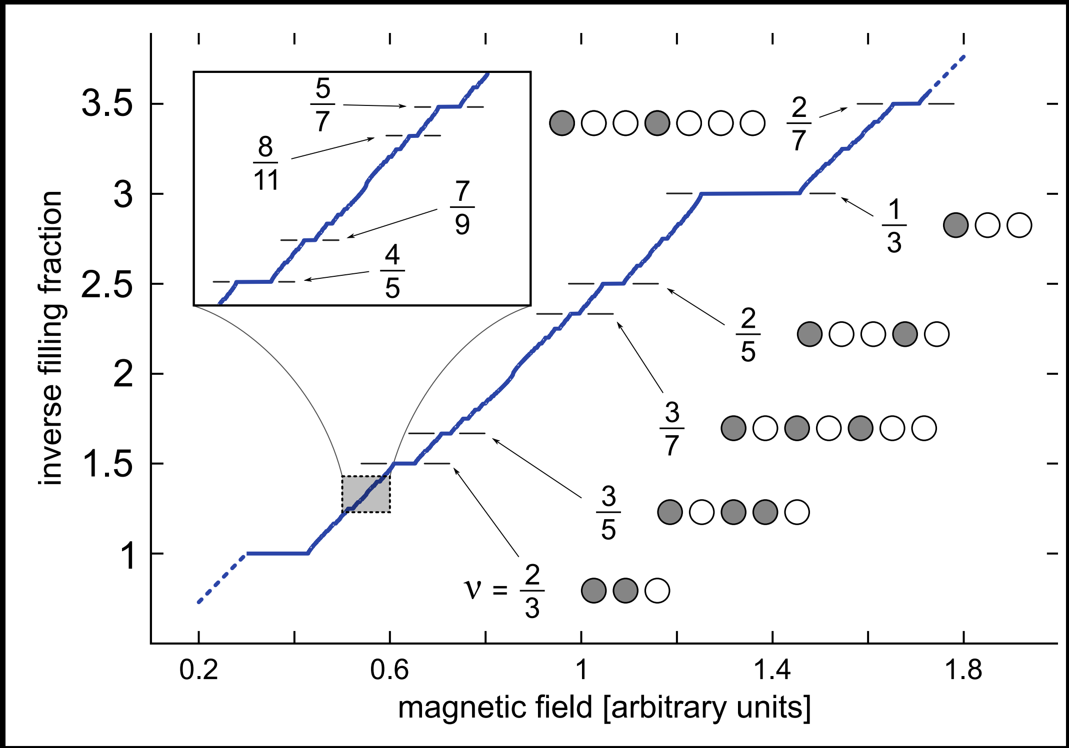
P.Rotondo, L.G.Molinari. P.Ratti. M.Gherardi

- We map the Quantum Hall Hamiltonian restricted to the subspace of the lowest Landau level (in the thin torus limit: Lx << magn. length << Ly) to a 1D long-range lattice model (exactly solved by Hubbard)
- Going back, we qualitatively reproduce the experimental diagram of transverse resistance vs B of FQHE

FQHE - EXPERIMENT



LATTICE CRYSTAL



A condition for a perfect-fluid space-time to be a generalized Robertson-Walker space-time

C. A. Mantica, L. G. Molinari, and U. C. De

Journal of Mathematical Physics 57, 022508 (2016)

Abstract: Generalized Robertson Walker spacetimes are the stage for perturbation of RW metric. We providea characterization in presence of a perfect fluid energy-momentum tensor.

On conformally recurrent manifolds of dimension greater than 4

C. A. Mantica, L. G. Molinari

Int. J. Geom. Meth. Mod. Phys. 5 (2016) 1650053

Scope: the ground state of the fractional QHE
People: LGM, Rotondo (postD), Di Gioacchino (Master thesis)
1) What is the analogous of the thin torus limit
in the symmetric gauge ? G.S. as a 2D Wigner crystal?
2) Laughlin's ansatz for GS for filling 1/m is surprisingly good.
What is its expansion on a basis of Slater states?

Scope: investigation of GRW in general relativity
People: LGM, C.A. Mantica, U.C.De (prof emeritus, Kolkata)
3) A Lorentzian manifold is a Generalized Robertson Walker
(GRW) spacetime iff a conformal Killing tensor exists of type
"perfect fluid" (in preparation)
4) an invited review on GRW spacetimes is in preparation
for Int. J. Geom. Meth. Mod. Phys.

QUANTUM-MI publications (2016)

1) W. Weiss, G. Benenti, G. Casati, I. Guarneri, T. Calarco, M. Paternostro and S. Montangero, Violation of Bell inequalities in larger Hilbert spaces: robustness and challenges, New J. Phys. 18, 013021 (2016).

2) G. Benenti, G. Casati, C. Mejia-Monasterio and M. Peyrard, From thermal rectifiers to thermoelectric devices, preprint arXiv:1512.06889 [cond-mat.stat-mech], in Springer Lecture Notes in Physics vol. 921 Thermal transport in low dimensions: from statistical physics to nanoscale heat transfer, edited by S. Lepri (2016).

3) G. Benenti, H. Ouerdane and C. Goupil, The thermoelectric working fluid: thermodynamics and transport, preprint arXiv:1602.06590 [cond-mat.stat-mech].

4) F. Angaroni, G. Benenti and G. Strini, Reconstruction of electromagnetic field states by a probe qubit, preprint arXiv:1605.02988 [quant-ph].

5) C. Goupil, H. Ouerdane, E. Herbert, G. Benenti, Y. D'Angelo and Ph. Lecoeur, Closed loop approach to thermodynamics, preprint arXiv:1606.03387 [cond-mat.stat-mech].

6) G. Benenti, G. Casati, K. Saito, and R. Whitney, Fundamental aspects of steady state heat to work conversion, preprint.