UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

Fundamental Problems in Quantum Physics
BELL

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INFN
Sezione di Milano

Consiglio Sezione INFN

Milano, Luglio 2019

Outline

- General infos on BELL
- Non-Markovian dynamics in open quantum systems
- Collaborations and publications

BELL

- Involved units:

  Genova

  Pavia

  Milano

  Trento

  Trieste

  Cosenza

BELL

- Members of Milan unit:

Physics Department **(open quantum systems)**

Bassano Vacchini

Steve Campbell (just left, INFN Fellow)

Nina Megier (just arrived, AvH Fellow)

Andrea Smirne (arriving in fall)

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DI MILANO

Mathematics Department (field theory and general relativity)

Enrico Fermi

POLITECNICO
MILANO 1863

Mathematics Department (quantum measurement)

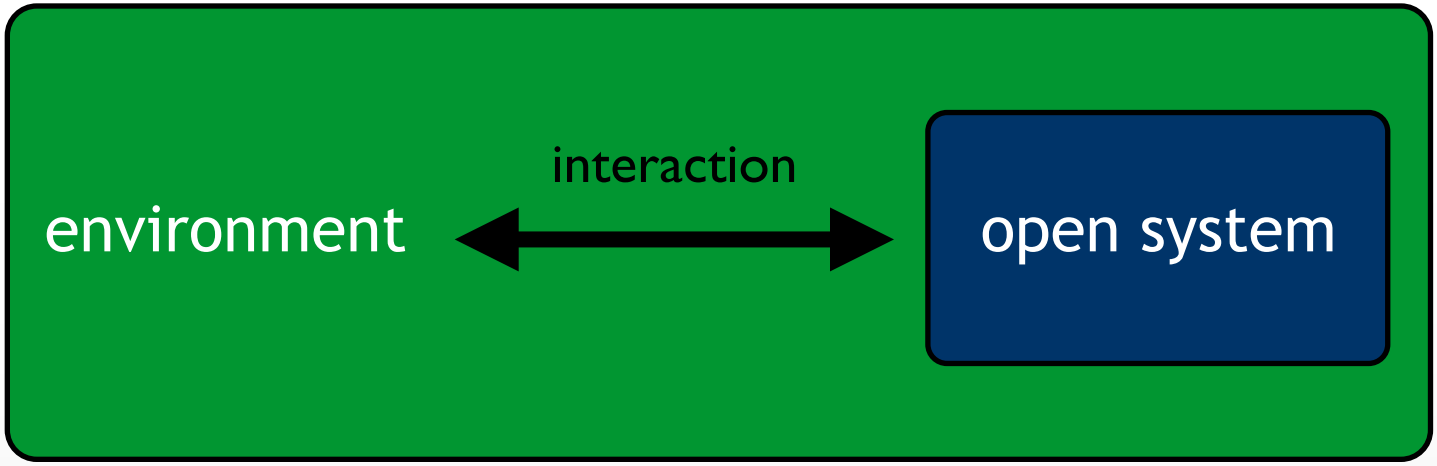
Alberto Barchielli

Alessandro Toigo

Outline

- General infos on BELL
- **Non-Markovian dynamics in open quantum systems**
- Collaborations and publications

Open quantum systems



Bipartite setting

$$H = H_S + H_E + H_I$$

$$H \in \mathcal{B}(\mathcal{H}_S \otimes \mathcal{H}_E) \qquad \rho_{SE} \in \mathcal{T}(\mathcal{H}_S \otimes \mathcal{H}_E)$$

memory

Reduced dynamics

$$\rho_S(0) \mapsto \rho_S(t) = \Phi(t)\rho_S(0)$$

Correlations

$$\rho_{SE}(t) \neq \rho_S(t) \otimes \rho_E(t)$$

[Davies, 1976; Alicki & Lendi, 1987; Breuer & Petruccione, 2002; Rivas & Huelga, 2012]

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Reduced dynamics

Quantum dynamics

$$\begin{cases} \frac{d}{dt}\rho_{SE}(t) = -\frac{i}{\hbar}[H, \rho_{SE}(t)] \\ \rho_{SE}(0) \end{cases} \Rightarrow \begin{cases} \frac{d}{dt}\rho_S(t) = \Phi(t)\rho_S(0) \\ \rho_S(0) \end{cases}$$

Reduced quantum dynamical map

$$\begin{array}{ccc} \rho_S(0) \otimes \rho_E & \xrightarrow{\text{unitary}} & \rho_{SE}(t) = U(t)\rho_S(0) \otimes \rho_E U(t)^\dagger \\ \Big\downarrow \mathrm{Tr}_E & & \Big\downarrow \mathrm{Tr}_E \\ \rho_S(0) & \xrightarrow{\Phi(t)} & \rho_S(t) \end{array}$$

Open quantum system dynamics

Semigroup composition law

$$\Phi(t)\Phi(s) = \Phi(t+s) \qquad t, s \geq 0$$

leading to

$$\Phi(t) = \exp(\mathcal{L}t)$$

$$\frac{d}{dt}\rho_S(t) = \mathcal{L}\rho_S(t)$$

break reversibility but retain CP

$$\mathcal{L}\rho = -i[H,\rho] + \sum_k \gamma_k \left[A_k \rho A_k^\dagger - \frac{1}{2}\{A_k^\dagger A_k, \rho\} \right]$$

GKLS generator also known as Lindblad form
Workhorse for open quantum systems by 40+ years now

[Kossakowski, RMP 1972; Gorini, Kossakowski & Sudarshan, JMP 1976; Lindblad, CMP 1976]

Quantum divisibility and contractivity

Composition law

$$\Phi(t,\tau)\Phi(\tau,s) = \Phi(t,s) \qquad t \geq \tau \geq s \geq 0$$

divisibility property of quantum dynamical map

CP-divisibility in that $\Phi(t,s)$ is CP $\forall\, t \geq s \geq 0$

Contractivity under trace distance

$$D(\rho_1(t+s), \rho_2(t+s)) \leq D(\rho_1(t), \rho_2(t))$$

monotonic decrease of trace distance between different initial states with elapsing time

[Breuer, Laine & Piilo, PRL 2009; Rivas, Huelga & Plenio, PRL 2010]

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Trace distance and distinguishability

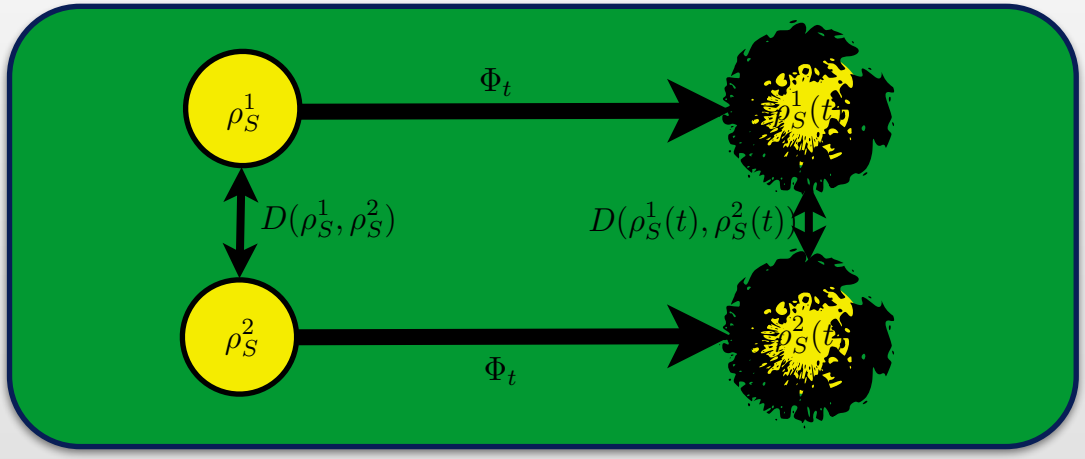
Distinguishability

Preparations ρ_1 and ρ_2 taking place with equal probability to be distinguished upon single measurement

Distinguishability affects optimal strategy

$$P_{\text{success}} = \frac{1}{2}(1 + D(\rho_1, \rho_2))$$

Distinguishability decreases under CPT map



[Helstrom 1976; Fuchs & al., IEEE 1999]

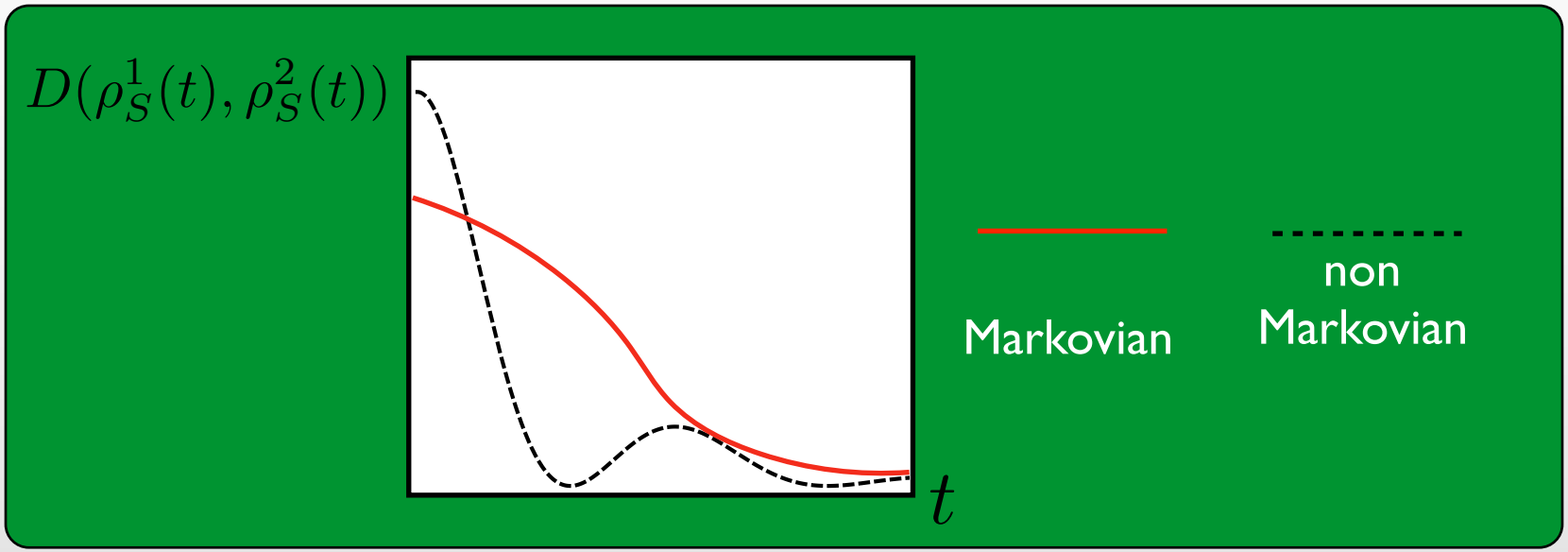
Markovian versus non-Markovian dynamics

Revival of distinguishability

Define a dynamics non-Markovian if

$$\exists\ \rho_1(0), \rho_2(0) \in \mathcal{S}(\mathcal{H})\ \exists\ t \geq s\ D(\rho_1(t), \rho_2(t)) > D(\rho_1(s), \rho_2(s))$$

e.g. due to revival in physical property



[Breuer, Laine & Piilo, PRL 2009; Breuer, Laine, Piilo & B.V. RMP 2016]

Qualify non-Markovianity

Connect non-Markovianity with memory

$$\mathcal{I}_{\rm int}(t) = D(\rho_S^1(t), \rho_S^2(t))$$
$$\mathcal{I}_{\rm ext}(t) = D(\rho_{SE}^1(t), \rho_{SE}^2(t)) - D(\rho_S^1(t), \rho_S^2(t))$$

$$\mathcal{I}_{\rm int}(t) + \mathcal{I}_{\rm ext}(t) = \mathcal{I}_{\rm int}(0) = \text{const}$$

with

$$\mathcal{I}_{\rm ext}(t) \leq D(\rho_{SE}^1(t), \rho_S^1(t) \otimes \rho_E^1(t)) + D(\rho_{SE}^2(t), \rho_S^2(t) \otimes \rho_E^2(t)) + D(\rho_E^1(t), \rho_E^2(t))$$

[Breuer, Laine & Piilo, PRL 2009; Breuer, Laine, Piilo & B.V. RMP 2016]

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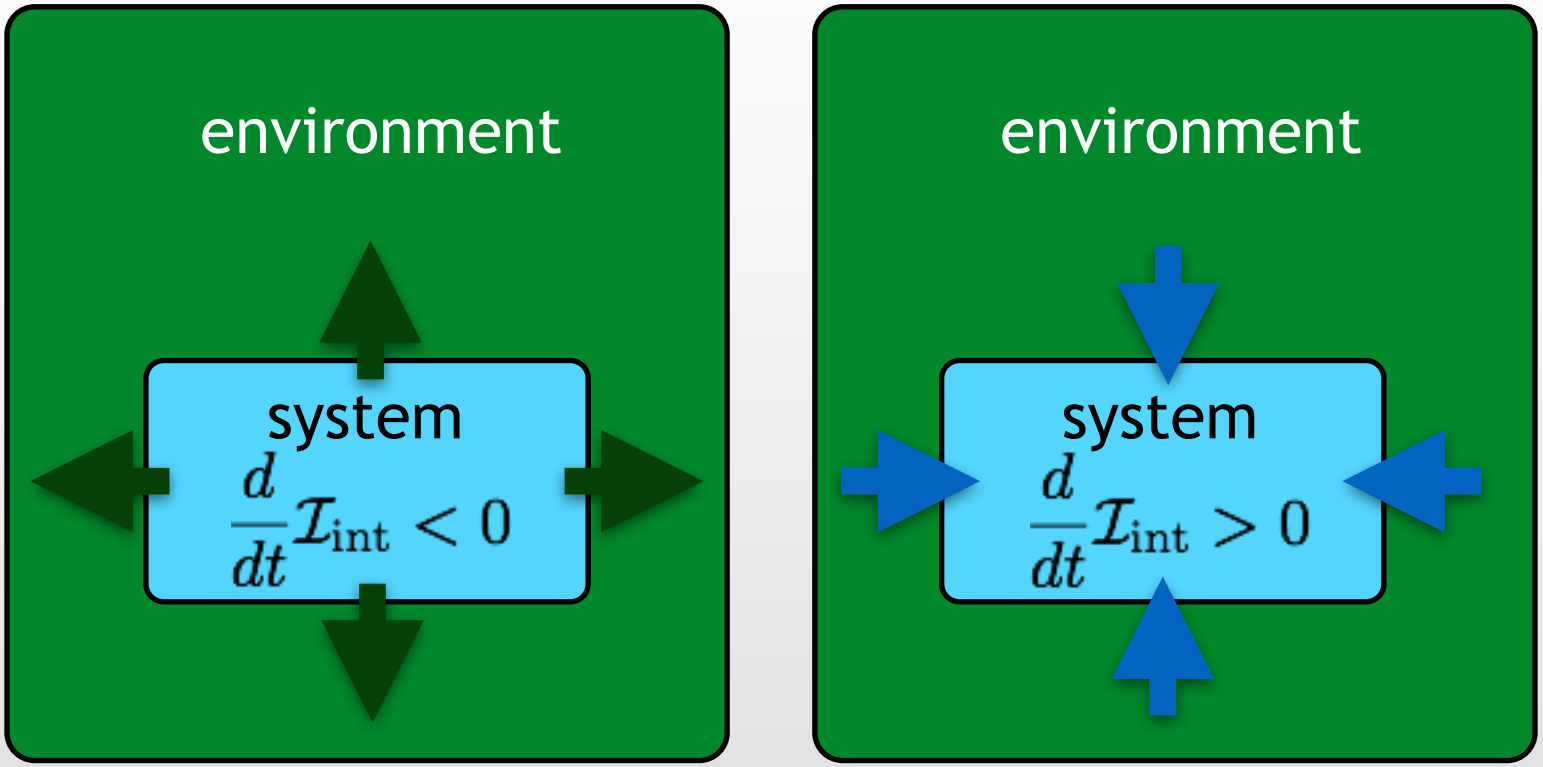
Qualify non-Markovianity

Information backflow

Interpretation of $\frac{d}{dt} D(\rho_1(t), \rho_2(t))$



[Breuer, Laine & Piilo, PRL 2009; Breuer, Laine, Piilo & B.V. RMP 2016]

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Precursors of non-Markovianity

Distinguishability revivals

$$B(\rho_S^1(t), \rho_S^2(t)) - B(\rho_S^1(s), \rho_S^2(s)) \leqslant$$

$$B(\rho_E^1(s), \rho_E^2(s)) + B(\rho_{SE}^1(s), \rho_S^1(s) \otimes \rho_E^1(s)) + B(\rho_{SE}^2(s), \rho_S^2(s) \otimes \rho_E^2(s))$$

$$B(\rho, \sigma) = \sqrt{2(1 - F(\rho, \sigma))}$$

Layer structure of environment

$$B(Tr_{E_1,\ldots,E_{k+1}} \rho_{SE}^1(s), Tr_{E_1,\ldots,E_{k+1}} (\rho_S^1(s) \otimes \rho_E^1(s))) \leqslant$$

$$B(Tr_{E_1,\ldots,E_k} \rho_{SE}^1(s), Tr_{E_1,\ldots,E_k} (\rho_S^1(s) \otimes \rho_E^1(s)))$$

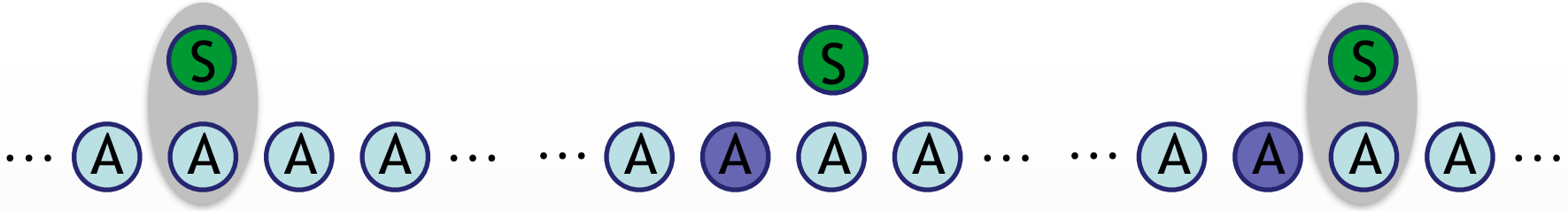
$$B(Tr_{E_1,\ldots,E_{k+1}} \rho_E^1(s), Tr_{E_1,\ldots,E_{k+1}} \rho_E^2(s)) \leqslant$$

$$B(Tr_{E_1,\ldots,E_k} \rho_E^1(s), Tr_{E_1,\ldots,E_k} \rho_E^2(s))$$

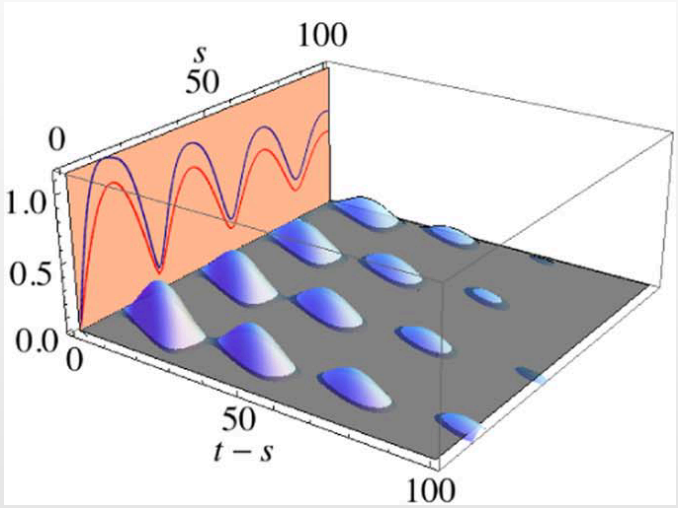
[Breuer, Laine & Piilo, PRL 2009; Breuer, Laine, Piilo & B.V. RMP 2016]

Precursors of non-Markovianity

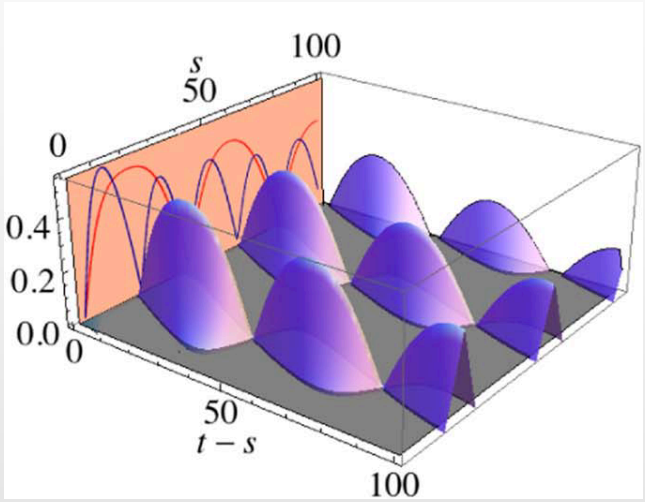
Collision model



Performance of precursors



Discrete variables



Continuous variables

[Campbell, Popovic, Tamascelli & B.V., NJP 2019]

Collaborations


H.-P. Breuer - Uni Freiburg - Germany


M. Paternostro - Uni Belfast - United Kingdom


S. Campbell - Trinity College Dublin - Ireland


F. Ciccarello, S. Lorenzo, G. Palma - Uni Palermo


J. Piilo - Uni Turku - Finland

Pubblications (2016-2018)

	Titolo	Autori	Sigla	Rivista	Autori BELL	Autori Totali
3	A time machine for free fall into the past	**Fermi, Davide** et al.	BELL	CLASSICAL QUANT GRAV , **16-35**	2	2
4	Determining quantum coherence with minimal resources	**Carmeli, Claudio** et al.	BELL	NEW J PHYS , **-20**	1	5
5	Entropy production and correlations in a controlled non-Markovian setting	**Popovic, Maria** et al.	BELL	PHYS REV A , **1-98**	2	3
6	Generalized trace distance approach to quantum non-Markovianity and detection of initial correlations	**Amato, Giulio** et al.	BELL	PHYS REV A , **1-98**	1	3
7	IDEAL characterization of isometry classes of FLRW and inflationary spacetimes	**Canepa, Giovanni** et al.	BELL	CLASSICAL QUANT GRAV , **3-35**	1	3
8	Local Casimir Effect for a Scalar Field in Presence of a Point Impurity	**Fermi, Davide** et al.	BELL	SYMMETRY-BASEL , **2-10**	2	2
9	Measurement Uncertainty Relations for Discrete Observables: Relative Entropy Formulation	**Barchielli, Alberto** et al.	BELL	COMMUN MATH PHYS , **3-357**	2	3
10	Mixing-induced quantum non-Markovianity and information flow	**Breuer, Heinz-Peter** et al.	BELL	NEW J PHYS , **-20**	1	3
11	On the constants for some fractional Gagliardo Nirenberg and Sobolev inequalities	**Morosi, Carlo** et al.	BELL	EXPO MATH , **1-36**	1	2
12	Precision thermometry and the quantum speed limit	**Campbell, Steve** et al.	BELL	QUANTUM SCI TECHNOL , **2-3**	1	3
13	State discrimination with postmeasurement information and incompatibility of quantum measurements	**Carmeli, Claudio** et al.	BELL	PHYS REV A , **1-98**	1	3
14	System-environment correlations and Markovian embedding of quantum non-Markovian dynamics	**Campbell, Steve** et al.	BELL	PHYS REV A , **1-98**	2	4

	Titolo	Autori	Sigla	Rivista	Autori BELL	Autori Totali
1	All-optical quantum simulator of qubit noisy channels	**Cialdi, Simone** et al.	BELL	APPL PHYS LETT , **8-110**	1	7
2	Dynamics and asymptotics of correlations in a many-body localized system	**Campbell, Steve** et al.	BELL	EUR PHYS J D , **8-71**	1	3
3	Full counting statistics approach to the quantum non-equilibrium Landauer bound	**Guarnieri, Giacomo** et al.	BELL	NEW J PHYS , **-19**	2	6
4	Global and local thermometry schemes in coupled quantum systems	**Campbell, Steve** et al.	BELL	NEW J PHYS , **-19**	1	4
5	Ground state for a massive scalar field in the BTZ spacetime with Robin boundary conditions	**Bussola, Francesco** et al.	BELL	PHYS REV D , **10-96**	1	4
6	Maximally symmetric stabilizer MUBs in even prime-power dimensions	**Carmeli, Claudio** et al.	BELL	J MATH PHYS , **3-58**	1	3
7	Measurement Uncertainty Relations for Position and Momentum: Relative Entropy Formulation	**Barchielli, Alberto** et al.	BELL	ENTROPY-SWITZ , **7-19**	1	3
8	Modified Lorentz transformations in deformed special relativity	**Salesi, G.** et al.	BELL	INT J MOD PHYS A , **15-32**	1	4
9	Non-Markovianity by undersampling in quantum optical simulators	**Rossi, Matteo A. C.** et al.	BELL	INT J QUANTUM INF , **8-15**	1	7
10	Nonequilibrium quantum bounds to Landauer's principle: Tightness and effectiveness	**Campbell, Steve** et al.	BELL	PHYS REV A , **4-96**	2	4
11	Probing quantum state space: does one have to learn everything to learn something?	**Carmeli, Claudio** et al.	BELL	P ROY SOC A-MATH PHY , **2201-473**	1	4
12	Quantum Non-Markovian Piecewise Dynamics from Collision Models	**Lorenzo, Salvatore** et al.	BELL	OPEN SYST INF DYN , **4-24**	1	4
13	Quantum speed limits: from Heisenberg's uncertainty principle to optimal quantum control	**Deffner, Sebastian** et al.	BELL	J PHYS A-MATH THEOR , **45-50**	1	2
14	The Calabi complex and Killing sheaf cohomology	**Khavkine, Igor**	BELL	J GEOM PHYS , **-113**	1	1
15	Trade-Off Between Speed and Cost in Shortcuts to Adiabaticity	**Campbell, Steve** et al.	BELL	PHYS REV LETT , **10-118**	1	2

	Titolo	Autori	Sigla	Rivista	Autori BELL	Autori Totali
1	Colloquium: Non-Markovian dynamics in open quantum systems	**Breuer, Heinz-Peter** et al.	BELL	REV MOD PHYS , **2-88**	1	4
2	Covariant mutually unbiased bases	**Carmeli, Claudio** et al.	BELL	REV MATH PHYS , **4-28**	1	3
3	Current hot questions on the s process in AGB stars	**Lugaro, M.** et al.	BELL	J PHYS CONF SER , **-665**	1	9
4	Delayed luminescence induced by complex domains in water and in TEOS aqueous solutions	**Colleoni, C.** et al.	BELL	PHYS CHEM CHEM PHYS , **2-18**	1	9
5	Energy backflow and non-Markovian dynamics	**Guarnieri, G.** et al.	BELL	PHYS REV A , **1-93**	2	3
6	Energy backflow in strongly coupled non-Markovian continuous-variable systems	**Guarnieri, G.** et al.	BELL	PHYS REV A , **6-94**	1	5
7	Generalized Master Equations Leading to Completely Positive Dynamics	**Vacchini, Bassano**	BELL	PHYS REV LETT , **23-117**	1	1
8	Local zeta regularization and the scalar Casimir effect IV: The case of a rectangular box	**Fermi, Davide** et al.	BELL	INT J MOD PHYS A , **4-5-31**	1	2
9	Quantum Incompatibility in Collective Measurements	**Carmeli, Claudio** et al.	BELL	MATHEMATICS-BASEL , **3-4**	1	5
10	Quantum Noise from Reduced Dynamics	**Vacchini, Bassano**	BELL	FLUCT NOISE LETT , **3-15**	1	1
11	QUANTUM STOCHASTIC EQUATIONS FOR AN OPTO-MECHANICAL OSCILLATOR WITH RADIATION PRESSURE INTERACTION AND NON-MARKOVIAN EFFECTS	**Barchielli, Alberto**	BELL	REP MATH PHYS , **3-77**	1	1
12	Reduced dynamical maps in the presence of initial correlations	**Vacchini, Bassano** et al.	BELL	SCI REP-UK , **-6**	1	2
13	Stable pure state quantum tomography from five orthonormal bases	**Carmeli, Claudio** et al.	BELL	EPL-EUROPHYS LETT , **3-115**	1	5
14	Verifying the Quantumness of Bipartite Correlations	**Carmeli, Claudio** et al.	BELL	PHYS REV LETT , **23-116**	1	5