Information Scrambling versus Decoherence—Two Competing Sinks for Entropy

PRX QUANTUM 2, 010306 (2021)

Akram Touil & Sebastian Deffner

Algunos intereses de nuestro Grupo

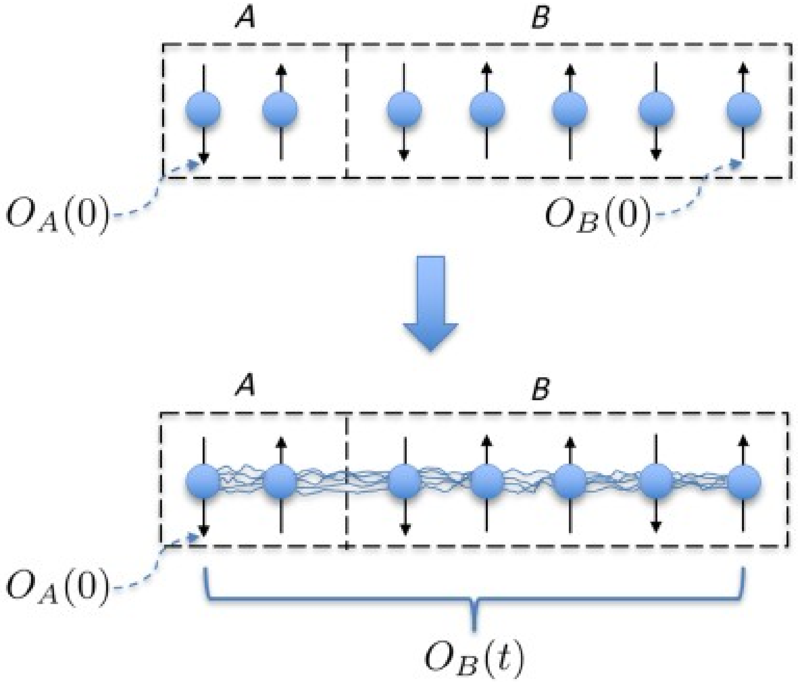
Una pregunta que nos une a todos:

¿Cómo se distribuye la información en sistemas cuánticos de muchos cuerpos?

- Entanglement
- Termodinámica cuántica
- Decoherencia
- Information Scrambling
- Caos y control cuántico
- Altas energías
- Iones atrapados

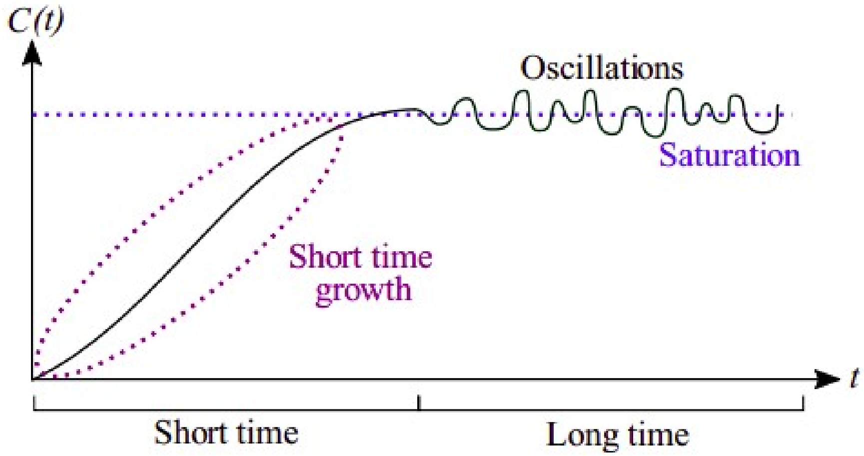
Information scrambling

Scrambling es el proceso en el cual **información local** se **dispersa** en forma de entrelazamiento y correlaciones a lo largo de un sistema de muchos cuerpos bajo una **dinámica unitaria.**



Out of time ordered correlators (OTOCS)

$$\mathrm{C(t)} = \langle [O_A, O_B(t)]^\dagger [O_A, O_B(t)] \rangle$$



PHYSICAL REVIEW E 100, 042201 (2019) – Emi Fortes, Wisniacki et al

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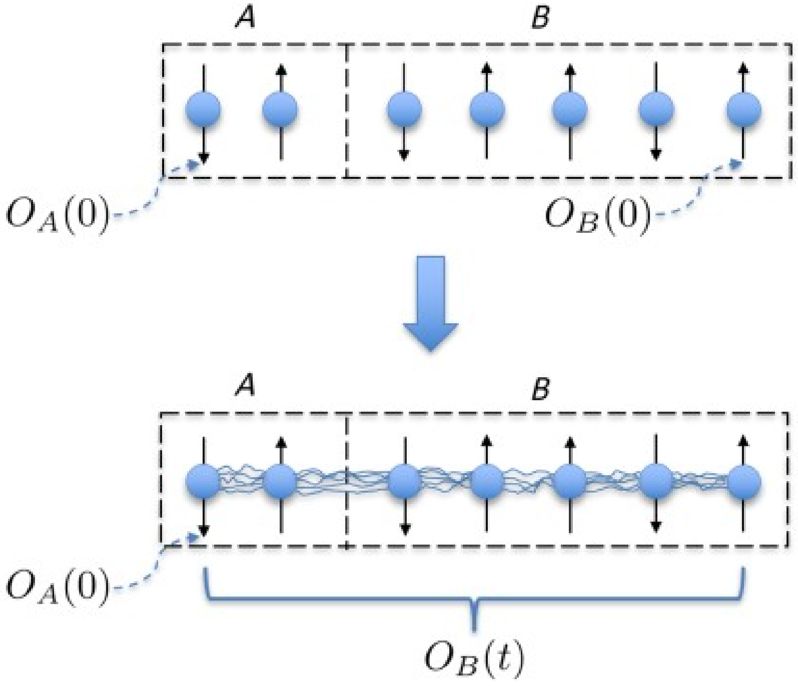


Out of time ordered correlators (OTOCS)

$$\mathrm{C(t)} = \langle [O_A, O_B(t)]^\dagger [O_A, O_B(t)] \rangle$$

Desventajas:

- Arbitrariedad en los operadores que elijo
- No pueden distinguir entre scrambling auténtico de un sistema aislado y la decoherencia. Aunque en general se estudia scrambling solo en sistemas aislados...

Mejor medida: $\mathcal{I} \equiv \mathcal{I}(A:B) = S_A + S_B - S_{AB}$

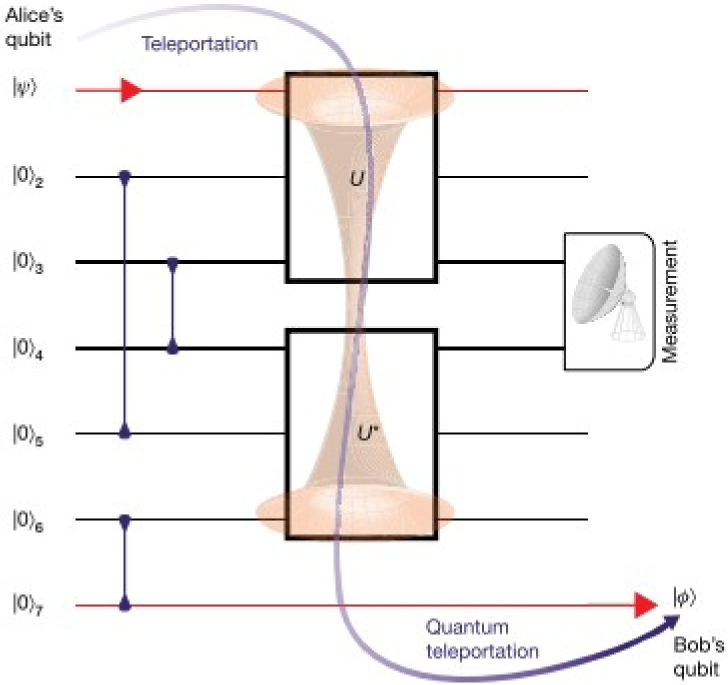
LETTER

https://doi.org/10.1038/s41586-019-0952-6

Verified quantum information scrambling

K. A. Landsman[1*], C. Figgatt[1,6], T. Schuster[2], N. M. Linke[1], B. Yoshida[3], N. Y. Yao[2,4] & C. Monroe[1,5]

Quantum scrambling is the dispersal of local information into many-body quantum entanglements and correlations distributed throughout an entire system. This concept accompanies the dynamics of thermalization in closed quantum systems, and has recently emerged as a powerful tool for characterizing chaos in black holes[1–4]. However, the direct experimental measurement of quantum scrambling is difficult, owing to the exponential complexity of ergodic many-body entangled states. One way to characterize quantum scrambling is to measure an out-of-time-ordered correlation function (OTOC); however, because scrambling leads to their decay, OTOCs do not generally discriminate between quantum scrambling and ordinary decoherence. Here we implement a quantum circuit that provides a positive test for the scrambling features of a given unitary process[5,6]. This approach conditionally teleports a quantum state through the circuit, providing an unambiguous test for whether scrambling has occurred, while simultaneously measuring an OTOC. We engineer quantum scrambling processes through a tunable three-qubit unitary operation as part of a seven-qubit circuit on an ion trap quantum computer. Measured teleportation fidelities are typically about 80 per cent, and enable us to experimentally bound the scrambling-induced decay of the corresponding OTOC measurement.



Information scrambling in general open quantum systems

Inicialmente: $\rho(0) = \rho_{\mathcal{S}}(0) \otimes \rho_{\mathcal{E}}^{\mathrm{eq}}$, donde: $\rho_{\mathcal{E}}^{\mathrm{eq}} = \exp(-\beta H_{\mathcal{E}})/Z_{\mathcal{E}}$

$H = H_{\mathcal{S}} \otimes \mathbb{I}_{\mathcal{E}} + \mathbb{I}_{\mathcal{S}} \otimes H_{\mathcal{E}} + h_{\gamma} \quad \dim(\mathcal{S}) = 2^{N_{\mathcal{S}}}$

Dos procesos ocurren simultáneamente:

- Scrambling en S
- Destrucción de las coherencias en S debido al entorno E

$$\mathcal{I} \equiv \mathcal{I}(A:B) = S_A + S_B - S_{AB}$$

$$\Delta\mathcal{I} = \underbrace{\Delta S_A + \Delta S_B}_{\text{Contribución unitaria}}$$

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$$\Delta S_{\mathcal{S}} = \mathcal{I}(\mathcal{S}:\mathcal{E}) + \Delta S_{\text{ex}} + D(\rho_{\mathcal{E}} || \rho_{\mathcal{E}}^{\text{eq}})$$

3 causas de desviación del scrambling unitario:

1) Correlaciones entre S y E
2) Intercambio de calor entre S y E
3) El alejamiento de E del equilibrio térmico

Entorno como testigo de scrambling

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$$\Delta\mathcal{I} = \Delta S_A + \Delta S_B - \Delta S_{\mathcal{S}} \Rightarrow \boxed{\Delta S_{\mathcal{S}} = \mathcal{I}(\mathcal{S}:\mathcal{E}) + \Delta S_{\text{ex}} + D(\rho_{\mathcal{E}} || \rho_{\mathcal{E}}^{\text{eq}})}$$

- Si E es un verdadero reservorio térmico...

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- Si observo solo un fragmento de E (**Darwinismo cuántico**)

$$\mathcal{I}[\mathcal{S}:\mathcal{P}(\mathcal{E})] + \Delta S_{\text{ex}} \leq \Delta S_{\mathcal{S}}$$

Partición sobre E→ La cota es tight si $\mathcal{P}(\mathcal{E}) = \mathcal{E}$

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Partición sobre E→ La cota es tight si $\mathcal{P}(\mathcal{E}) = \mathcal{E}$

- En una dinámica puramente decoherente (sin disipación) $\Rightarrow \Delta S_{ex} = 0$

Mirando las correlaciones entre S y un fragmento de E, puedo aprender acerca del scrambling dentro de S

Master equation for decohering dynamics

$$\frac{\partial \rho_S}{\partial t} = -\frac{i}{\hbar}\,[H_S, \rho_S] - \sum_{i\neq j} \gamma_{ij}\ \langle i|\,\rho_S\,|j\rangle\,|i\rangle\,\langle j|$$

$(h_\gamma \ll 1)$. Ultra weak coupling regime

Dos escenarios:

- Scrambling + disipación + decoherencia (base computacional)
- Scrambling + decoherencia (base de energía) $\langle H_S(t)\rangle = \text{const.}$

Cinco sistemas:

1) Sachdev-Ye-Kitaev model
2) Wormhole in anti–de Sitter space
3) Disordered XXXmodel
4) Mixed-field Ising model
5) Lipkin-Meshkov-Glick model

$\dim(\mathcal{S}) = 2^6$

Partición A: 1 qubit

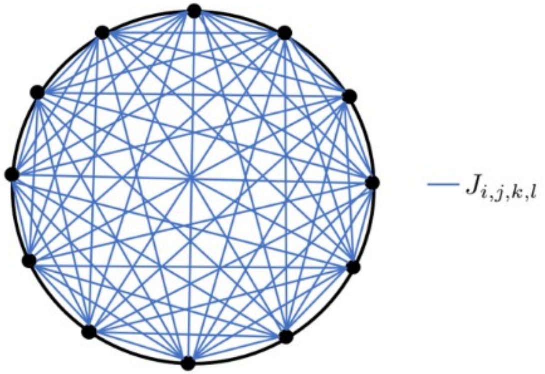
Partición B: El complemento

Máximo scrambling:

$\bar{\mathcal{I}} = 2\ln(2)$ sin entorno

$\bar{\mathcal{I}} < 2\ln(2)$ con entorno

Sachdev-Ye-Kitaev model

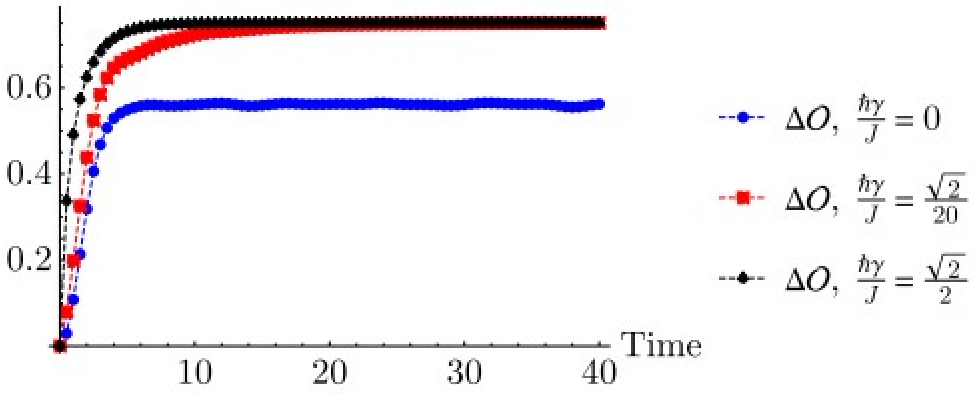


Un conjunto de qubits que interactúan todos con todos y caóticamente scramblean la información

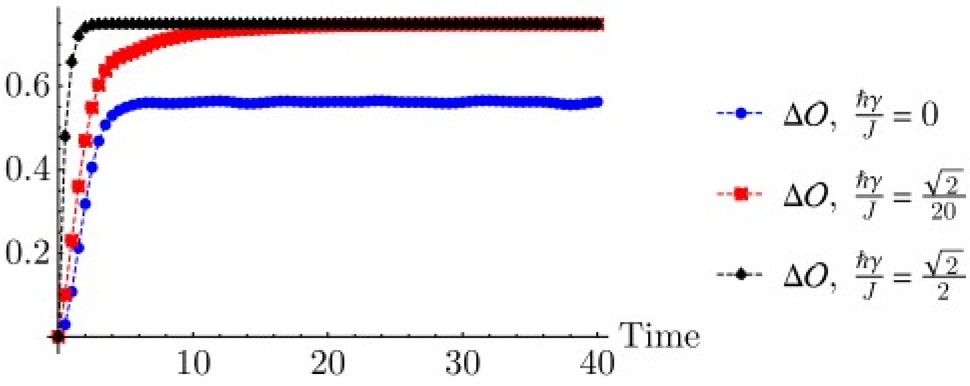
$$H_{\mathrm{SYK}} = - \sum_{1 \le i_1 < i_2 < i_3 < i_4 \le N} J_{i_1 i_2 i_3 i_4} \psi_{i_1} \psi_{i_2} \psi_{i_3} \psi_{i_4},$$

Mirando los OTOCS:

Decoherence in computational basis



Decoherence in energy basis



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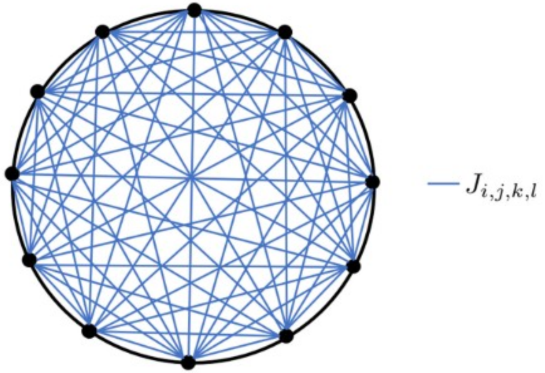

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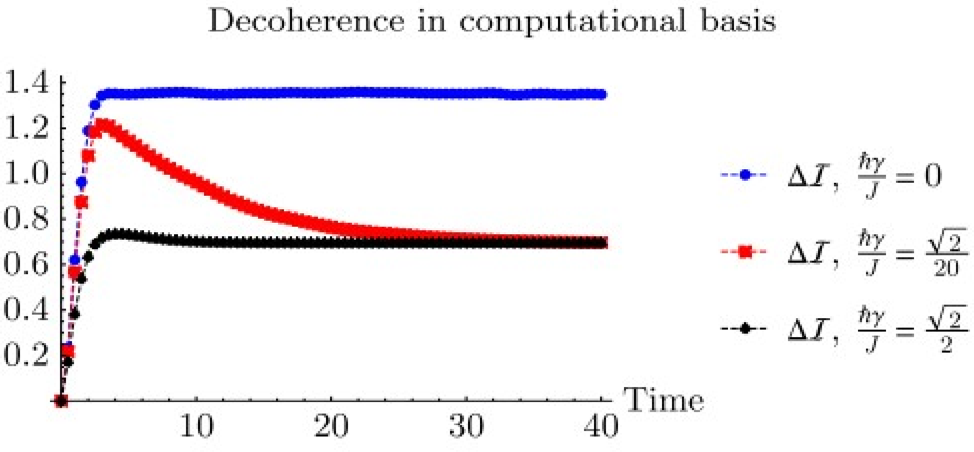
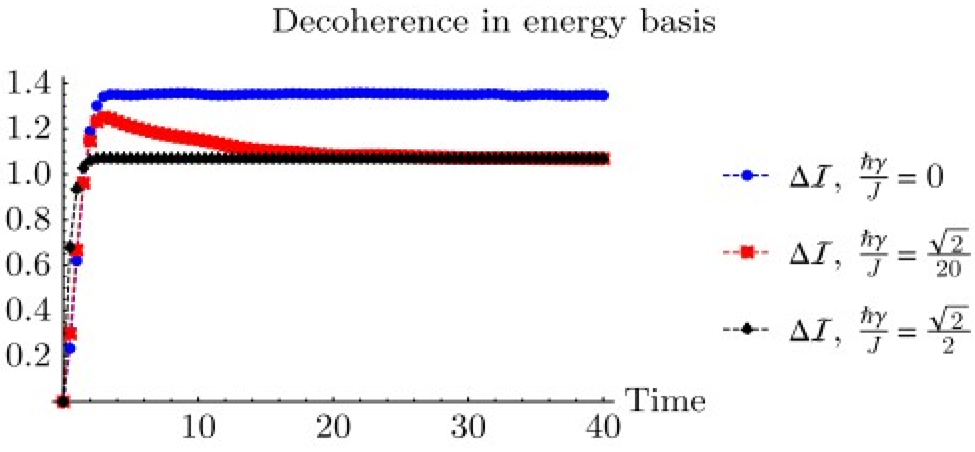
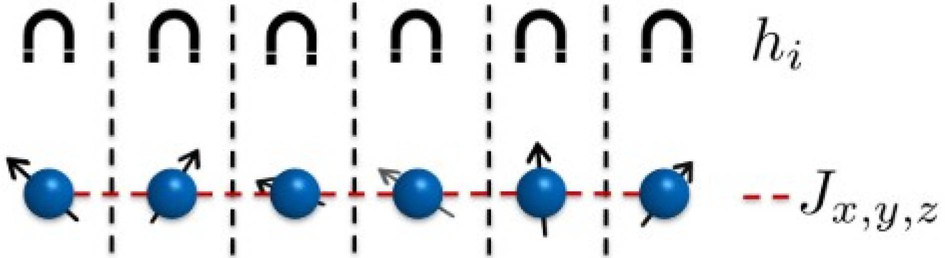
Mirando la información mutua:

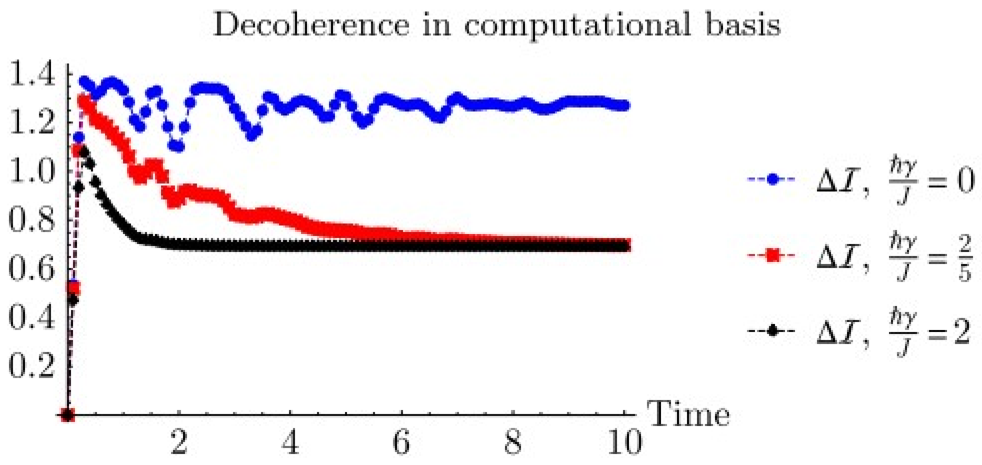


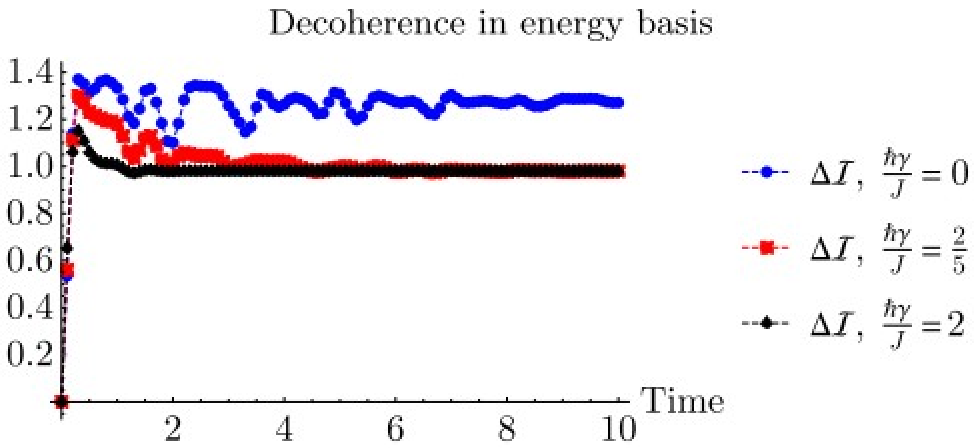


Disordered XXX model

$$H_{\mathrm{XXX}} = \sum_{\langle i,j \rangle} J \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j + \sum_{i=1}^{N} h_i \sigma_i^z,$$

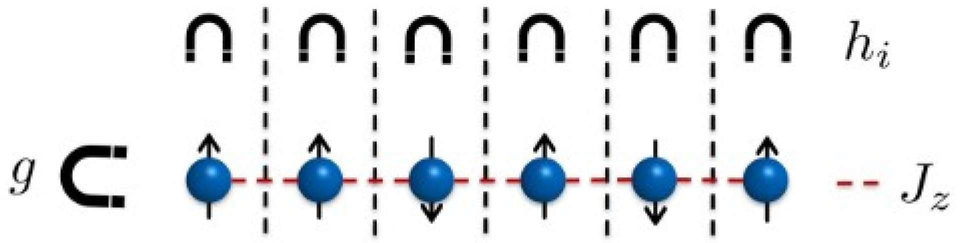




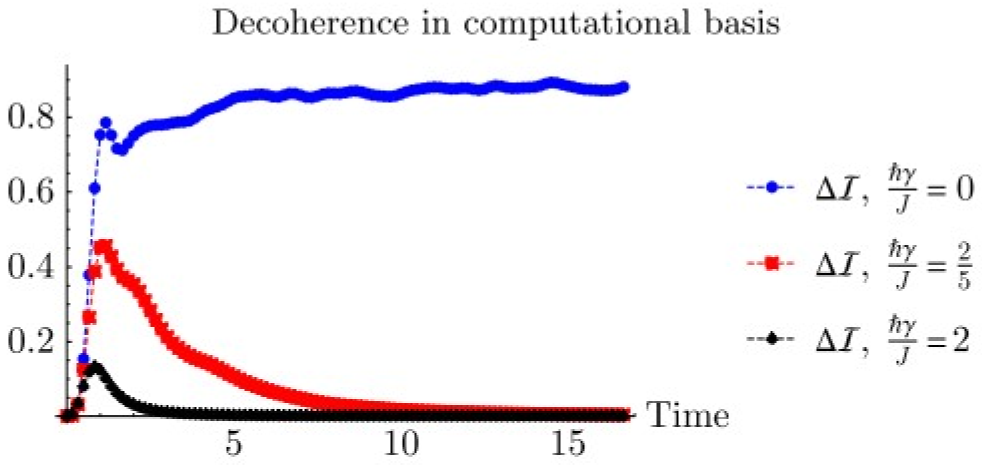


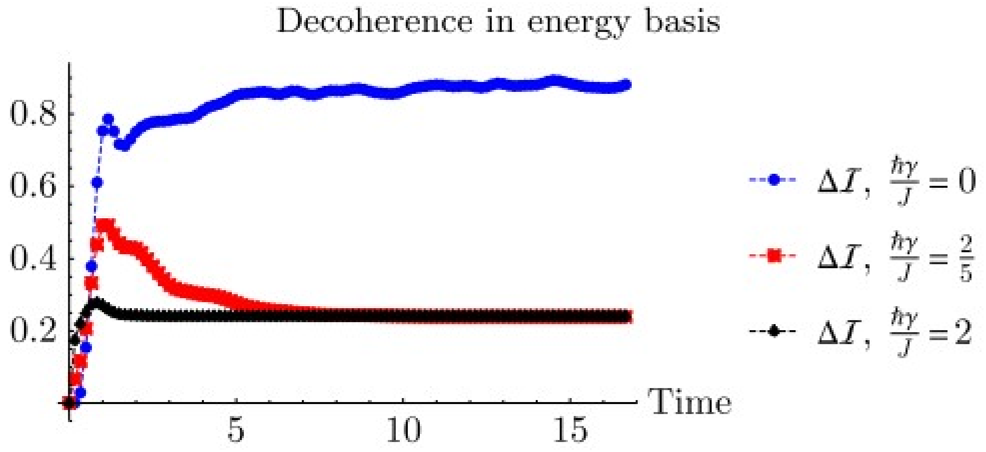
Mixed-fixed Ising model

$$H_{\mathrm{MFI}} = -J\sum_{i=1}^{N}\sigma_i^z\sigma_{i+1}^z - \sum_{i=1}^{N}h_i\sigma_i^z - g\sum_{i=1}^{N}\sigma_i^x.$$



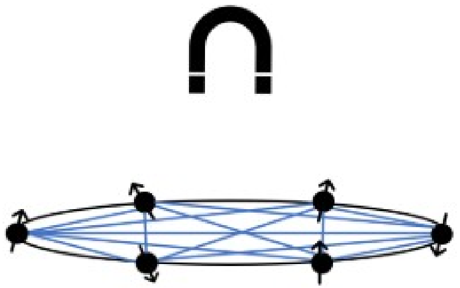
Information scrambling is not generally robust against decoherence





Lipkin-Meshkov-Glick model

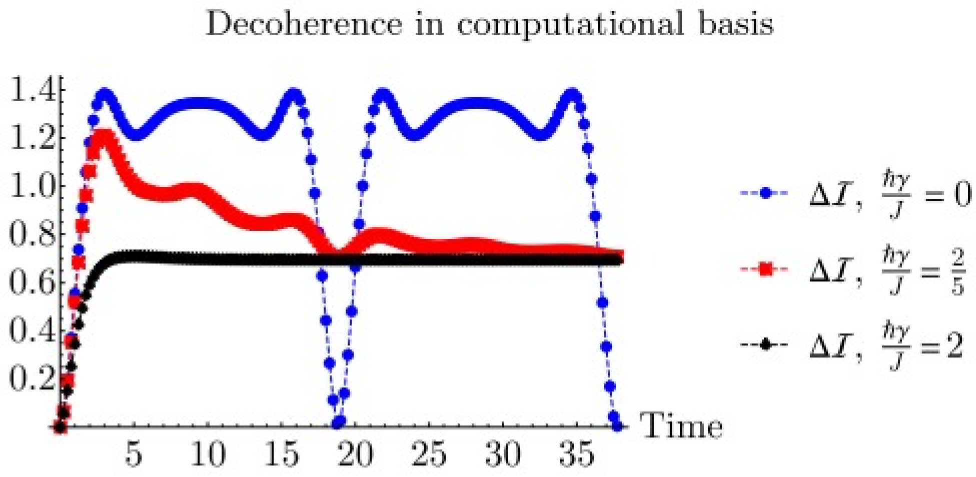
$$H_{\mathrm{LMG}} = -\frac{J}{N}\sum_{i<j}^{N}\left(\sigma_x^i\sigma_x^j + \sigma_y^i\sigma_y^j\right) - \sum_{i=1}^{N}\sigma_z^i,$$

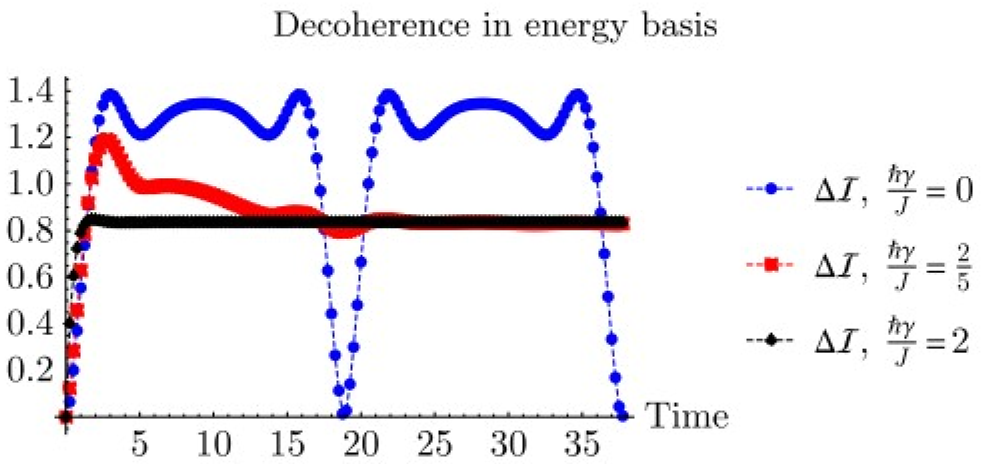


$g = 1$

$J_{x,y} = \frac{J}{N}$

Modelo integrable, sin scrambling unitario para todo tiempo.





Para reflexionar...

- Scrambling como fenómeno ubicuo y transversal a muchos temas de investigación (del grupo)
- Compromiso entre la decoherencia interna de un sistema many-body y la decoherencia externa debido a un entorno (tiempos característicos)
- El entorno como testigo del scrambling (darwinismo)

Momento abstract

Advances in Space Quantum Communications

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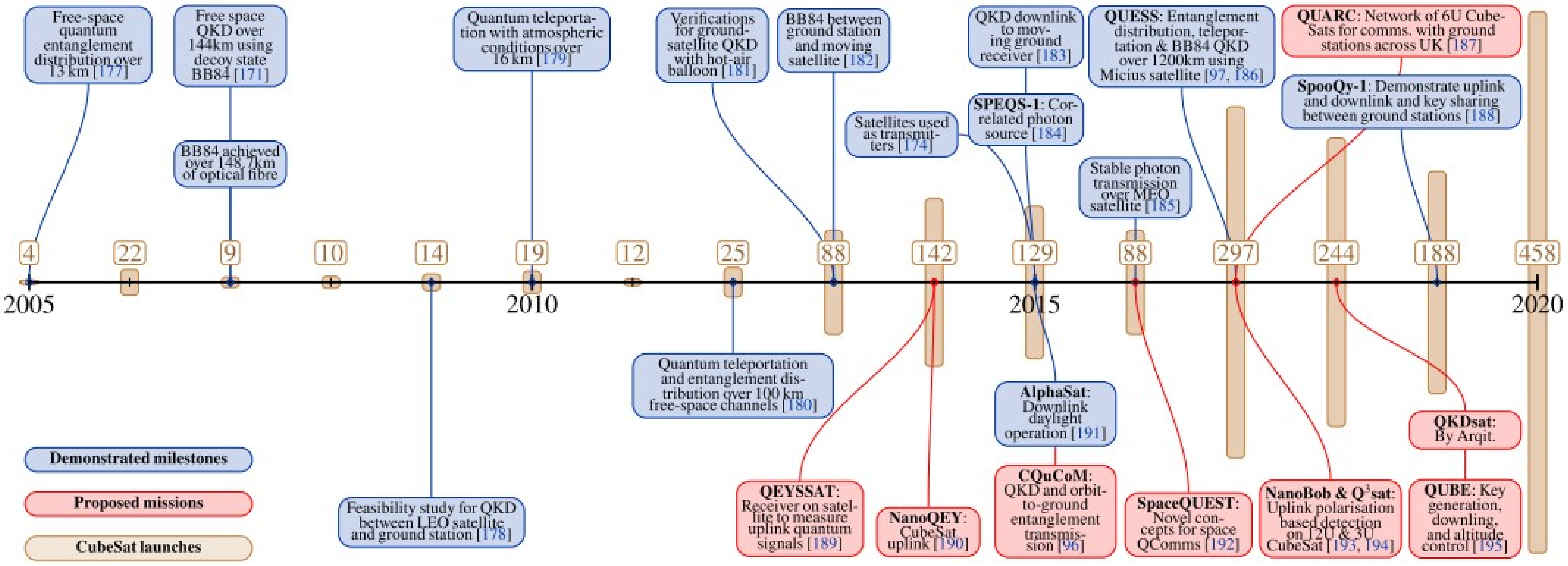
Jasminder S. Sidhu[1*], *Siddarth K. Joshi*[2], *Mustafa Gündoğan*[3], *Thomas Brougham*[1], *David Lowndes*[2], *Luca Mazzarella*[4], *Markus Krutzik*[3], *Sonali Mohapatra*[1,14], *Daniele Dequal*[5], *Giuseppe Vallone*[6,7], *Paolo Villoresi*[6], *Alexander Ling*[8,9], *Thomas Jennewein*[10,11] *Makan Mohageg*[4], *John Rarity*[2], *Ivette Fuentes*[12], *Stefano Pirandola*[13], *Daniel K. L. Oi*[1]

Abstract: Concerted efforts are underway to establish an infrastructure for a global quantum internet to realise a spectrum of quantum technologies. This will enable more precise sensors, secure communications, and faster data processing. Quantum communications are a front-runner with quantum networks already implemented in several metropolitan areas. A number of recent proposals have modelled the use of space segments to overcome range limitations of purely terrestrial networks. Rapid progress in the design of quantum devices have enabled their deployment in space for in-orbit demonstrations. We review developments in this emerging area of space-based quantum technologies and provide a roadmap of key milestones towards a complete, global quantum networked landscape. Small satellites hold increasing promise to provide a cost effective coverage required to realised the quantum internet. We review the state of art in small satellite missions and collate the most current in-field demonstrations of quantum cryptography. We summarise important challenges in space quantum technologies that must be overcome and recent efforts to mitigate their effects. A perspective on future developments that would improve the performance of space quantum communications is included. We conclude with a discussion on fundamental physics experiments that could take advantage of a global, space-based quantum network.

https://arxiv.org/abs/2103.12749 (23-03-21)



https://arxiv.org/abs/2103.12749 (23-03-21)

Detectable Signature of Quantum Friction on a Sliding Particle in Vacuum

Fernando C. Lombardo,[1,2] Ricardo S. Decca,[3] Ludmila Viotti,[1] and Paula I. Villar[1,2]

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[3] *Department of Physics, Indiana University-Purdue University Indianapolis. Indianapolis, Indiana 46202, USA*

Spatially separated bodies in relative motion through vacuum experience a tiny friction force known as quantum friction. This force has so far eluded experimental detection due to its small magnitude and short range. Quantitative details revealing traces of the quantum friction in the degradation of the quantum coherence of a particle are presented. Environmentally induced decoherence for a particle sliding over a dielectric sheet can be decomposed into contributions of different signatures: one solely induced by the electromagnetic vacuum in presence of the dielectric and another induced by motion. As the geometric phase has been proved to be a fruitful venue of investigation to infer features of the quantum systems, herein we propose to use the accumulated geometric phase acquired by a particle as a quantum friction sensor. Furthermore, an innovative experiment designed to track traces of quantum friction by measuring the velocity dependence of corrections to the geometric phase and coherence is proposed. The experimentally viable scheme presented can spark renewed optimism for the detection of non-contact friction, with the hope that this non-equilibrium phenomenon can be readily measured soon.

Comments: 10 pages, 8 figures, to appear in Advanced Quantum Technologies.

https://arxiv.org/abs/2103.11979 (23-03-21)

Experimental quantum phase discrimination enhanced by controllable indistinguishability-based coherence

Kai Sun,[1,2] Zheng-Hao Liu,[1,2] Yan Wang,[1,2] Ze-Yan Hao,[1,2] Xiao-Ye Xu,[1,2] Jin-Shi Xu,[1,2,*] Chuan-Feng Li,[1,2,†] Guang-Can Guo,[1,2] Alessia Castellini,[3] Ludovico Lami,[4] Andreas Winter,[5] Gerardo Adesso,[6] Giuseppe Compagno,[3] and Rosario Lo Franco[7,‡]

Quantum coherence, a basic feature of quantum mechanics residing in superpositions of quantum states, is a resource for quantum information processing. Coherence emerges in a fundamentally different way for nonidentical and identical particles, in that for the latter a unique contribution exists linked to indistinguishability which cannot occur for nonidentical particles. We experimentally demonstrate by an optical setup this additional contribution to quantum coherence, showing that its amount directly depends on the degree of indistinguishability and exploiting it to run a quantum phase discrimination protocol. Furthermore, the designed setup allows for simulating Fermionic particles with photons, thus assessing the role of particle statistics (Bosons or Fermions) in coherence generation and utilization. Our experiment proves that independent indistinguishable particles can supply a controllable resource of coherence for quantum metrology.

Propuesta teórica:

Indistinguishability-enabled coherence for quantum metrology

Alessia Castellini, Rosario Lo Franco, Ludovico Lami, Andreas Winter, Gerardo Adesso, and Giuseppe Compagno
Phys. Rev. A **100**, 012308 – Published 8 July 2019

https://arxiv.org/pdf/2103.14802.pdf (27-03-21)

PHYSICAL REVIEW LETTERS **126,** 120605 (2021)

Editors' Suggestion

Two-Qubit Engine Fueled by Entanglement and Local Measurements

Léa Bresque,[1] Patrice A. Camati,[1] Spencer Rogers,[2] Kater Murch,[3] Andrew N. Jordan,[2,4] and Alexia Auffèves[1,*]
[1]*Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France*
[2]*Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627, USA*
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We introduce a two-qubit engine that is powered by entanglement and local measurements. Energy is extracted from the detuned qubits coherently exchanging a single excitation. Generalizing to an N-qubit chain, we show that the low energy of the first qubit can be up-converted to an arbitrarily high energy at the last qubit by successive neighbor swap operations and local measurements. We finally model the local measurement as the entanglement of a qubit with a meter, and we identify the fuel as the energetic cost to erase the correlations between the qubits. Our findings extend measurement-powered engines to composite working substances and provide a microscopic interpretation of the fueling mechanism.

DOI: 10.1103/PhysRevLett.126.120605

Me hizo acordar a:

The importance of being measurement

Esteban Calzetta

Energy exchanges under form of heat is neither the most natural or efficient way to operate an engine in the quantum realm. Recently there have been in the literature several proposals for "quantum measurement engines" where energy is fed into the machine by operations which otherwise would be conducive to quantum measurements on the working substance (henceforth "the system"). In the analysis of the working of these devices, oftentimes it is assumed that the only effect of measurement is to turn the state of the system from whatever prior state to an eigenstate of the measured property, and energy exchanges are determined therefrom. This ignores the intricacies of the quantum measurement process. We propose a simple model of a quantum measurement engine where the measurement process may be analyzed in detail, and therefore energy exchanges, and limitations on their duration, may be traced more fully.

https://arxiv.org/abs/1909.13178 (2019)