|QET>

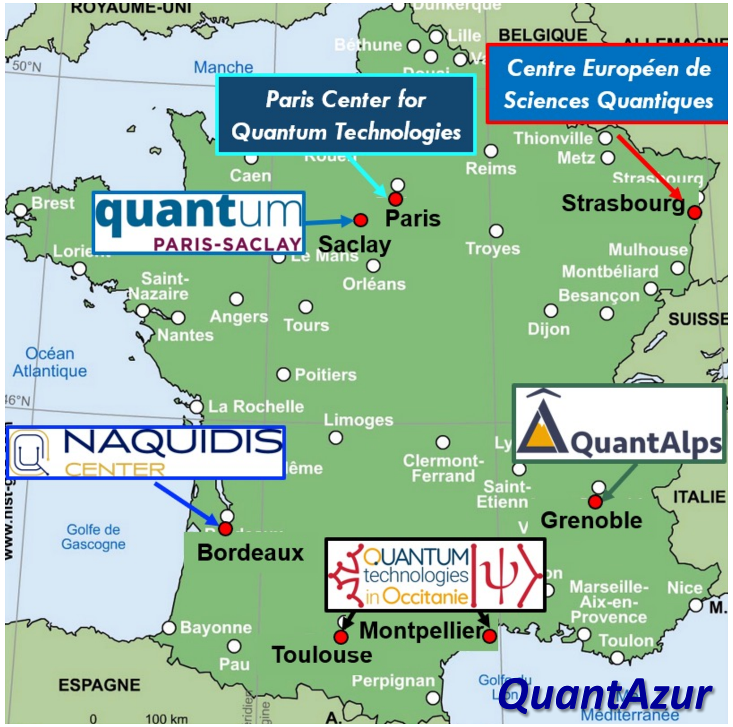
Quantum Energetics
Foundations, Applications

Alexia Auffèves, CNRS, MajuLab@CQT, Singapore

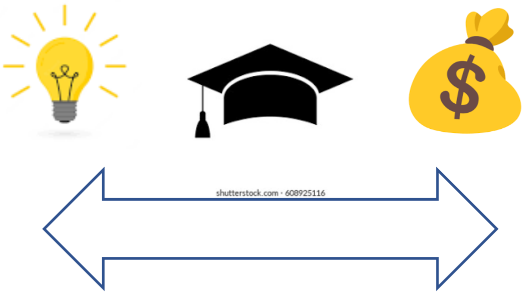
Congrès Général de la SFP
Paris, 3-7 juillet 2023

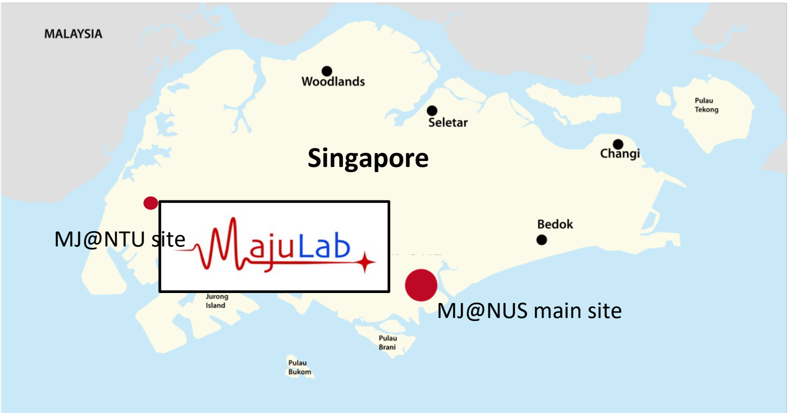
Centre for
Quantum
Technologies

French-Singaporean quantum centre



majulab.cnrs.fr





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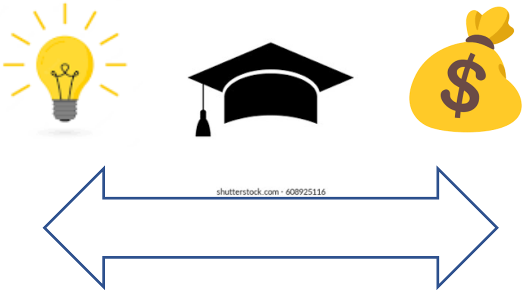
NUS National University of Singapore

Quantum energy team |QET>

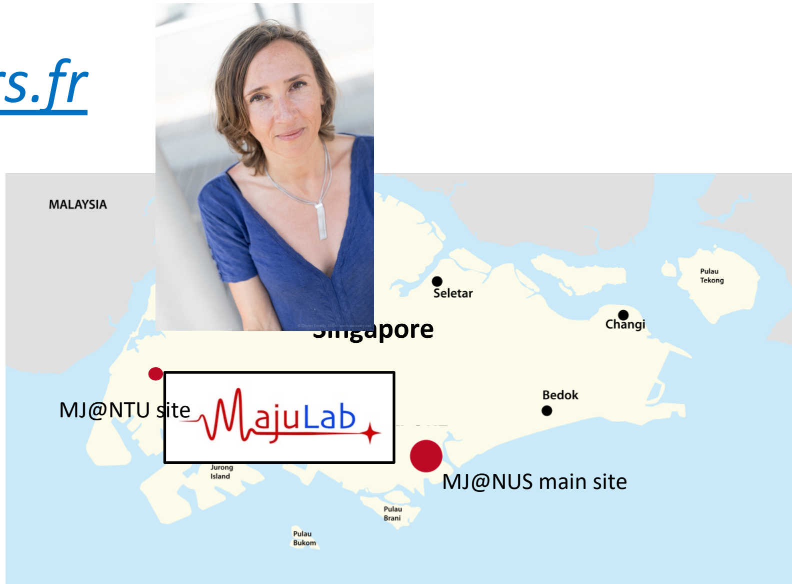
Robert Whitney

quantum-energy-team.cnrs.fr



Energetics of:
quantum measurement
quantum optics
quantum transport
quantum technologies

AA



Open positions for PhDs and post-docs!

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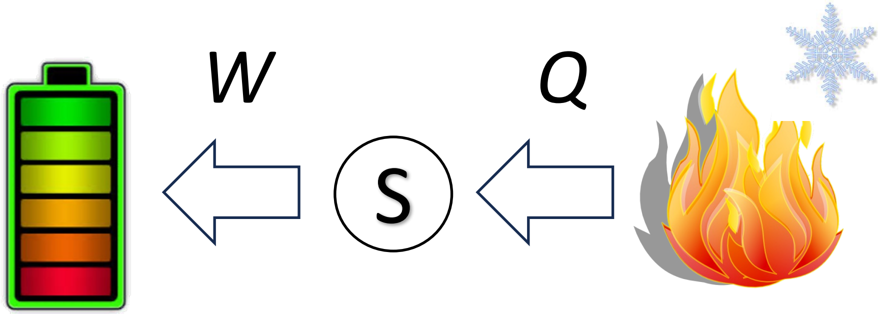
Outline

- From classical thermodynamics to quantum energetics
- Energetics of quantum measurement
- Energy-efficient quantum technologies

Outline

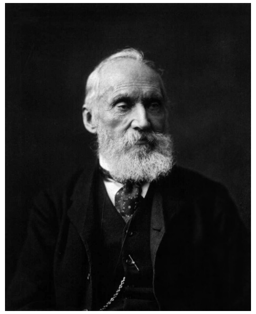
- **From classical thermodynamics to quantum energetics**
- Energetics of quantum measurement
- Energy-efficient quantum technologies

Macroscopic thermodynamics



S. Carnot
1796-1832

$$\eta \geq 1 - \frac{T_2}{T_1}$$

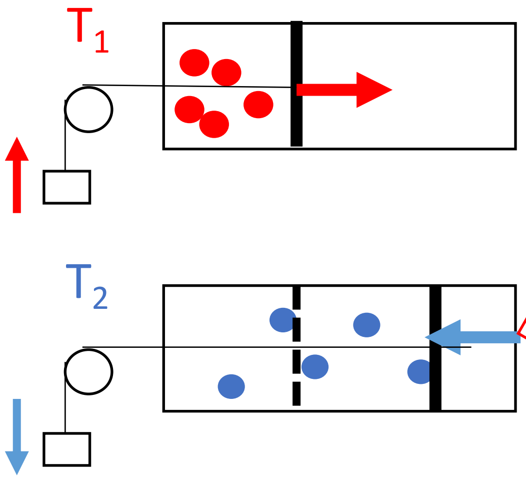


W. Thompson
1824-1907

M. Planck
1858-1947

$$\Delta_i S \geq 0$$

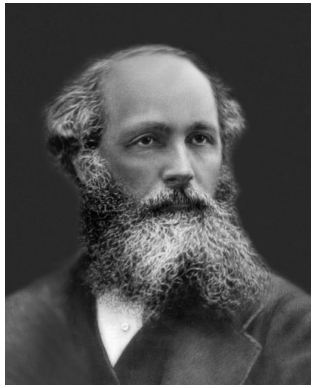
Onset of information thermodynamics



$$W_1 = -T_1 \Delta S$$
$$W_1 \leq 0$$

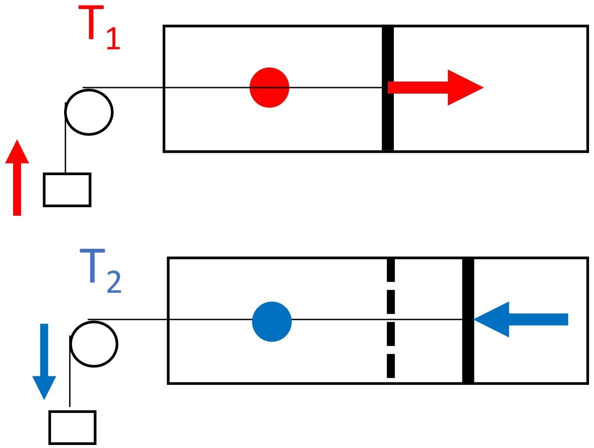
$$W_2 = -T_2 \Delta S$$
$$W_2 \geq 0$$

S. Carnot
1796-1832



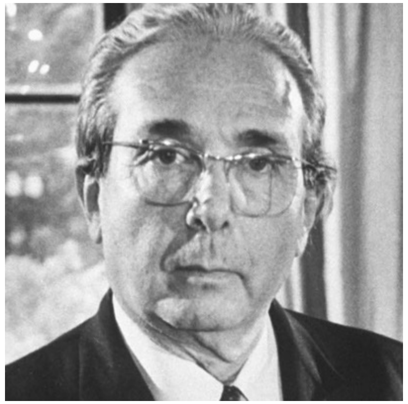
J. C. Maxwell
1831-1879

R. Landauer
1927-1999



$$W_1 = -k_B \, ln(2) T_1$$

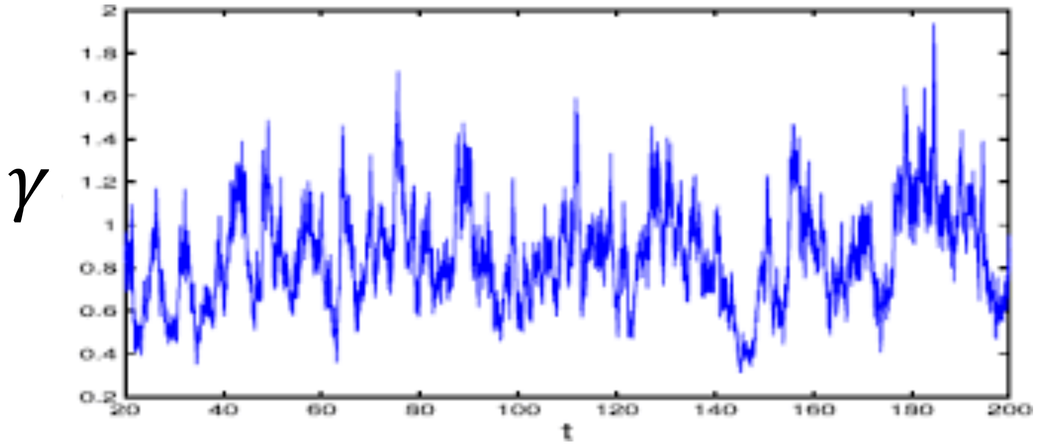
$$W_2 = k_B \, ln(2) T_2$$

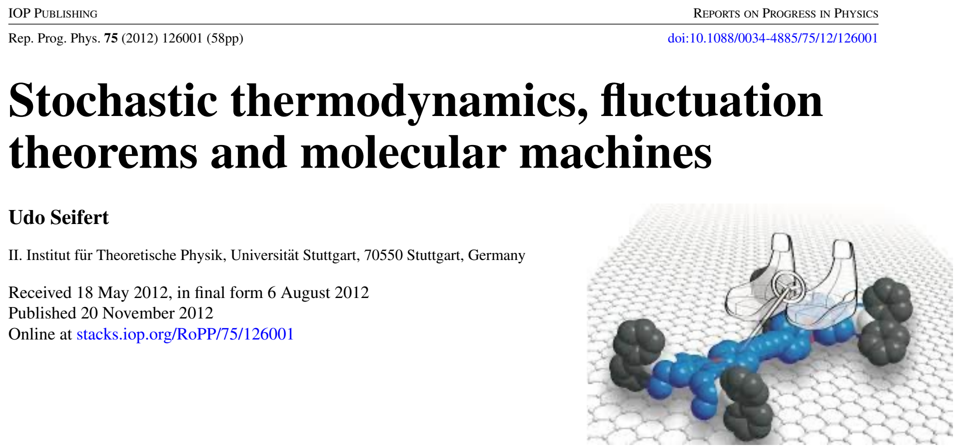


L. Szilard
1898-1964

Stochastic thermodynamics

Extends the concepts and laws of thermodynamics at the level of single trajectories





IOP Publishing — Reports on Progress in Physics

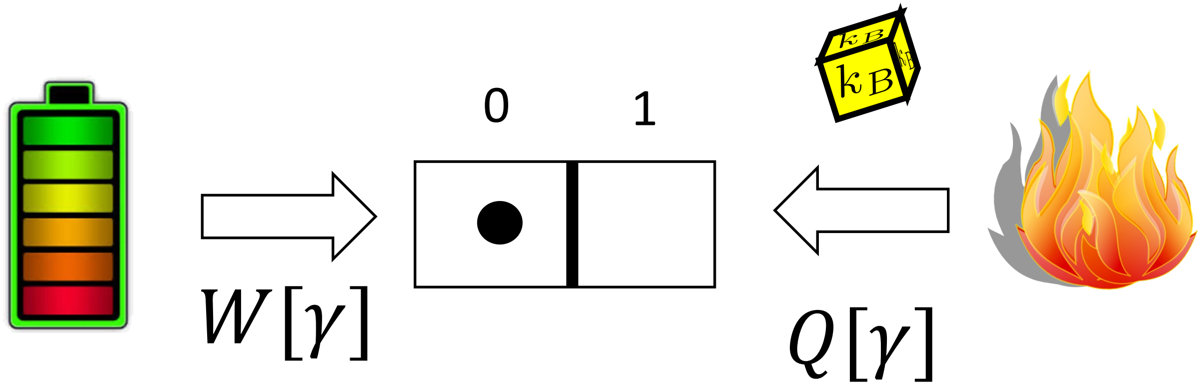
Rep. Prog. Phys. **75** (2012) 126001 (58pp) — doi:10.1088/0034-4885/75/12/126001

Stochastic thermodynamics, fluctuation theorems and molecular machines

Udo Seifert

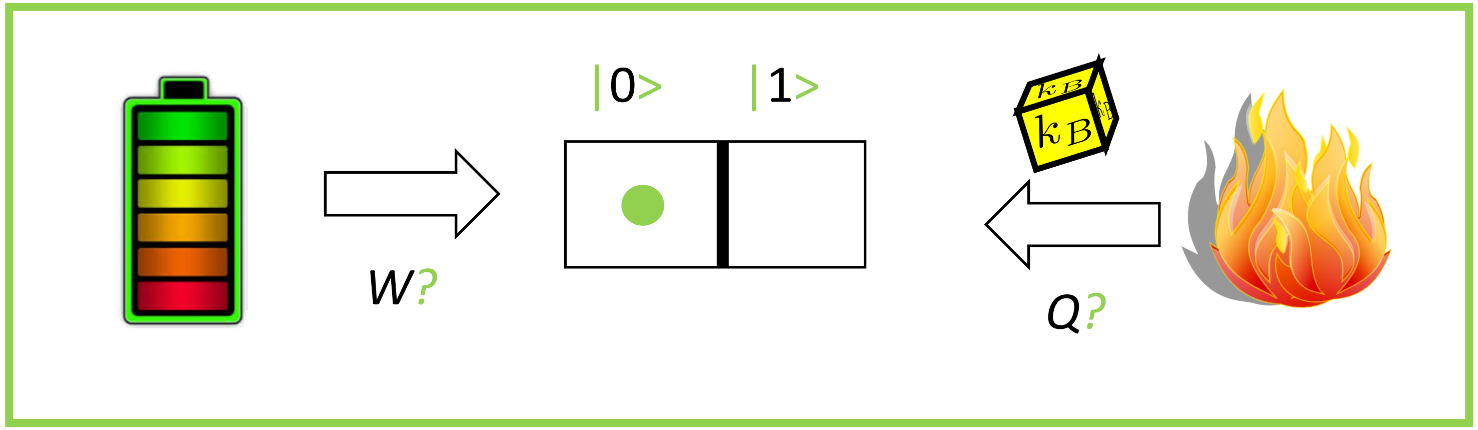
II. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

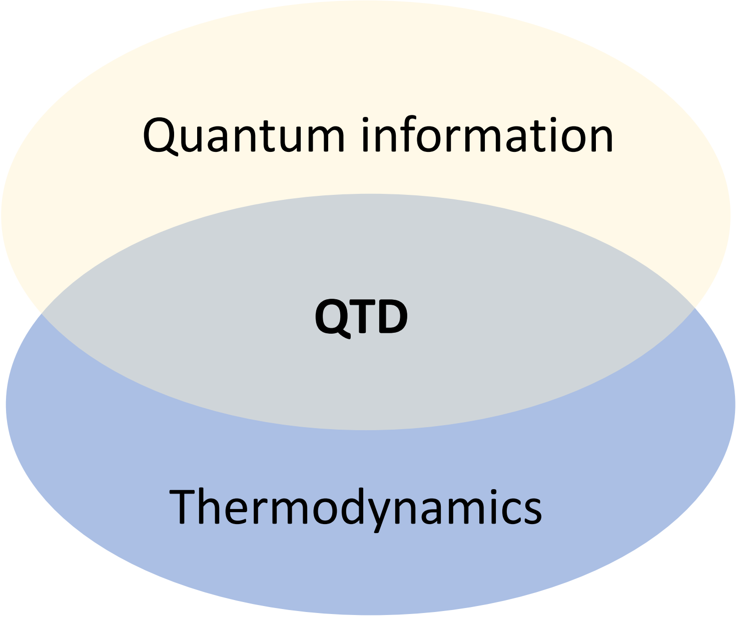
Received 18 May 2012, in final form 6 August 2012
Published 20 November 2012
Online at stacks.iop.org/RoPP/75/126001



- New meanings for work, heat, engines, irreversibility
- All you need is energy and randomness

Towards quantum thermodynamics I





Quantum advantages in engines?

- Quantum coherence as a resource
- Work cost of quantum coherence
- Quantum Maxwell's demons
- ...

Published: 01 June 2011

The thermodynamic meaning of negative entropy

Lídia del Rio, Johan Åberg, Renato Renner, Oscar Dahlsten & Vlatko Vedral

Nature **474**, 61–63 (2011) | Cite this article

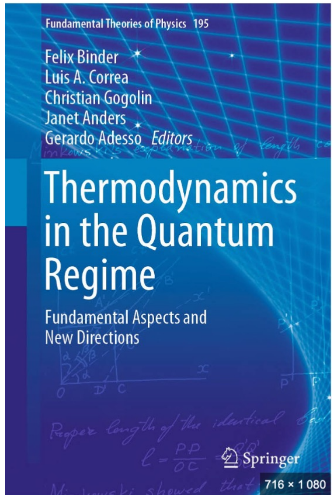
RESEARCH ARTICLE | PHYSICAL SCIENCES |

Observing a quantum Maxwell demon at work

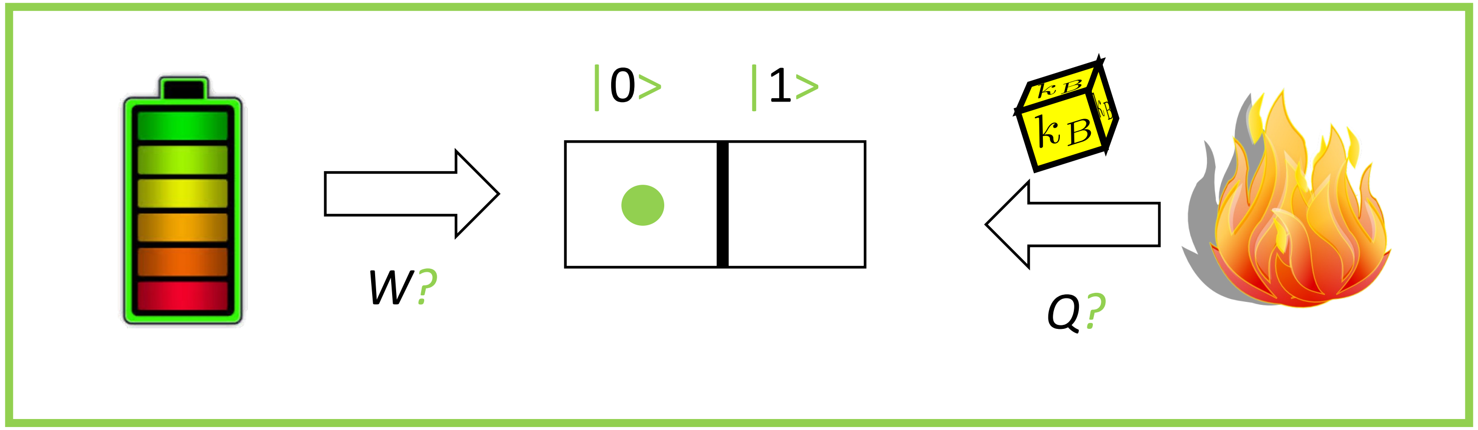
Nathanaël Cottet, Sébastien Jezouin, Landry Bretheau, Philippe Campagne-Ibarcq, Quentin Ficheux, Janet Anders, Alexia Auffèves, Rémi Azouit, Pierre Rouchon, and Benjamin Huard Authors Info & Affiliations

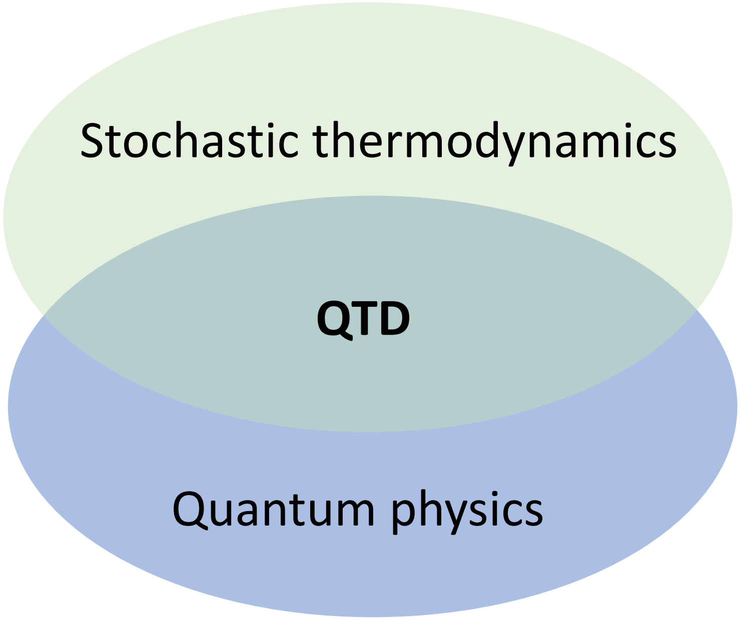
Edited by Steven M. Girvin, Yale University, New Haven, CT, and approved June 5, 2017 (received for review March 23, 2017)

July 3, 2017 | 114 (29) 7561-7564 | https://doi.org/10.1073/pnas.1704827114



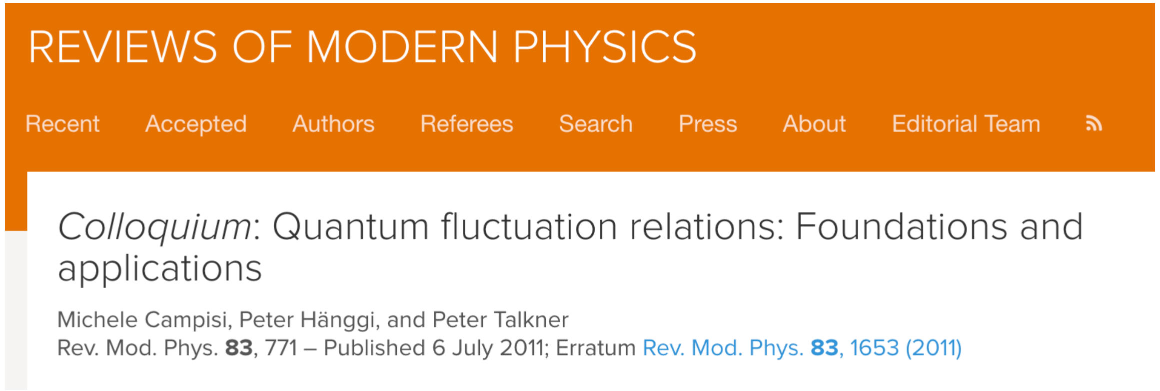
Towards quantum thermodynamics II





Quantum irreversibility?

- Quantum fundamental bounds
- Quantum fluctuation theorems
- …


REVIEWS OF MODERN PHYSICS

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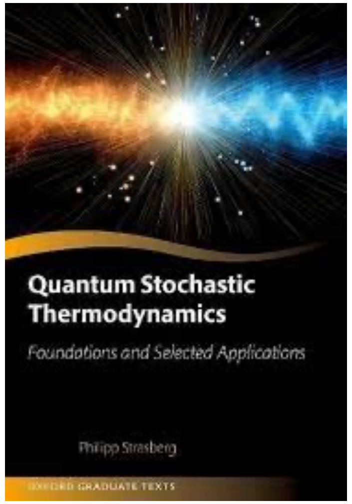
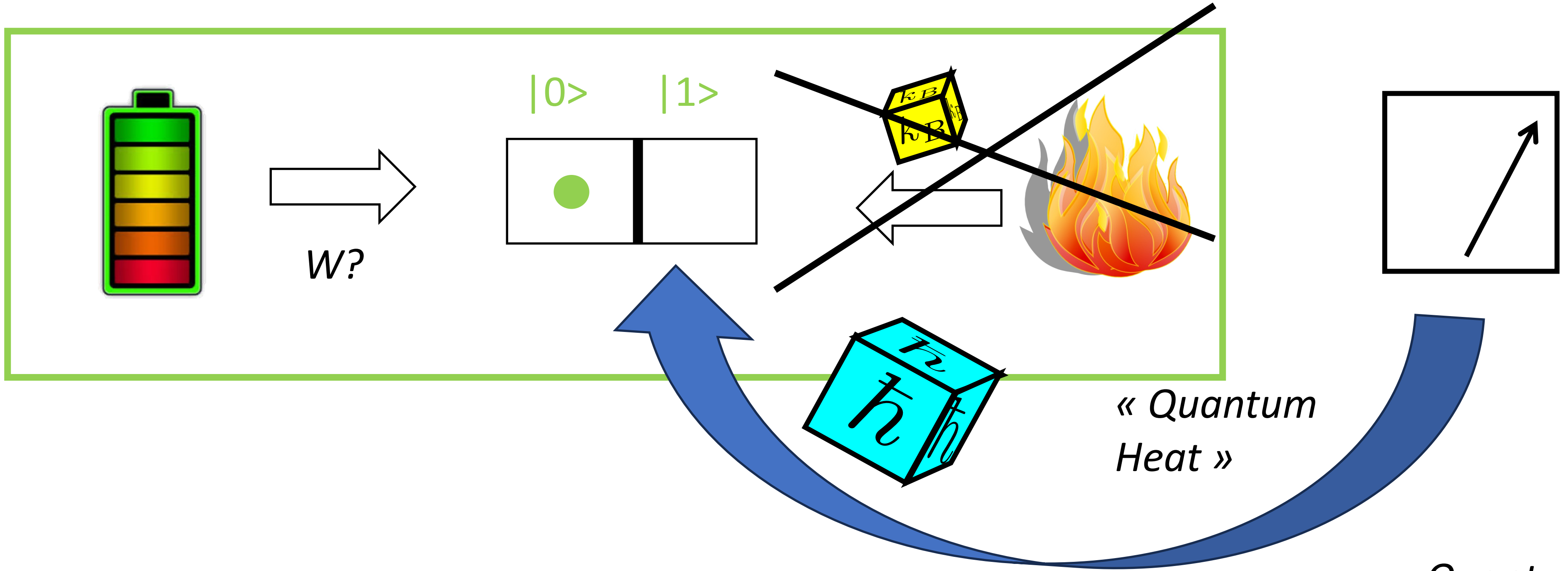
Colloquium: Quantum fluctuation relations: Foundations and applications

Michele Campisi, Peter Hänggi, and Peter Talkner

Rev. Mod. Phys. **83**, 771 – Published 6 July 2011; Erratum Rev. Mod. Phys. **83**, 1653 (2011)



Towards quantum ~~thermodynamics III~~ energetics



Quantum measurement:
A source of randomness, entropy and energy

Article | Open Access | Published: 10 March 2017

The role of quantum measurement in stochastic thermodynamics

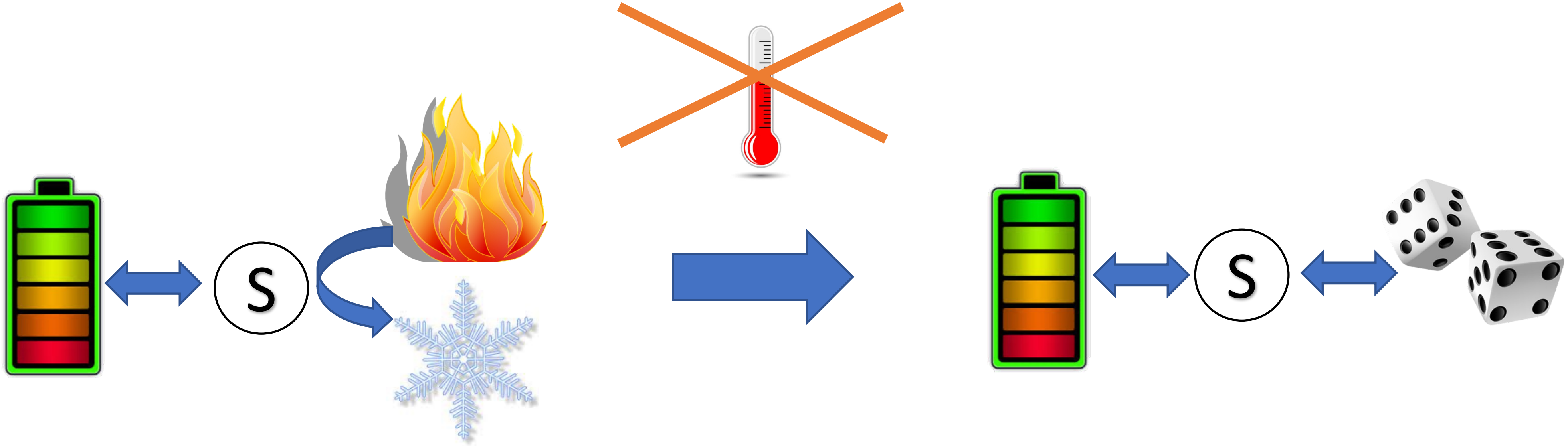
Cyril Elouard, David A. Herrera-Martí, Maxime Clusel & Alexia Auffèves

npj Quantum Information **3**, Article number: 9 (2017) | Cite this article

Propose to « rebuild quantum thermodynamics on quantum measurement »

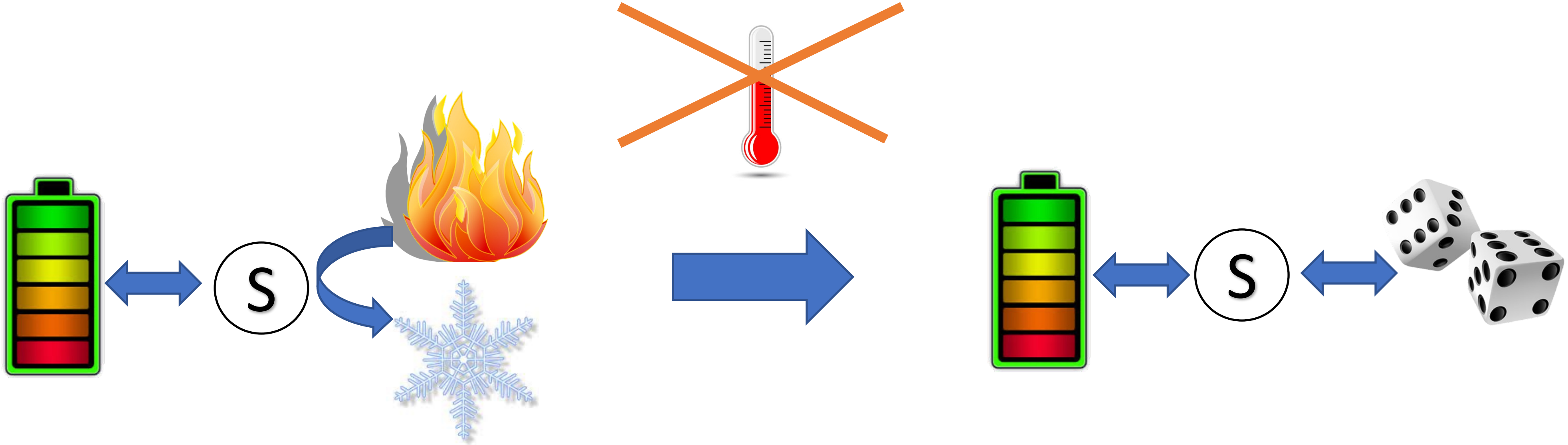
Emergence of quantum energetics

- Study of energy, entropy, information flows and their relations in the quantum world
- Cousin of quantum thermodynamics, but not necessary to have a temperature



Motivations

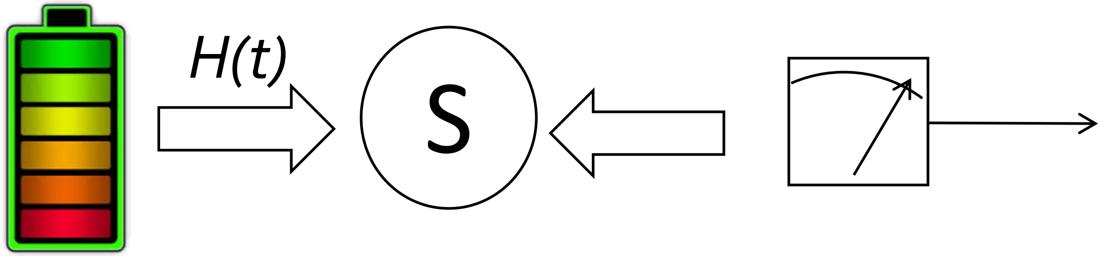
- Quantum noise as a resource (Can we turn heat into work?)
- Quantum batteries (Can I store and retrieve work at will?)
- Quantum irreversibility
- Quantum fluctuation theorems
- Minimal work costs, bounds and efficiencies



Outline

- From classical thermodynamics to quantum energetics
- **Energetics of quantum measurement**
- Energy-efficient quantum technologies

Scenery and definitions

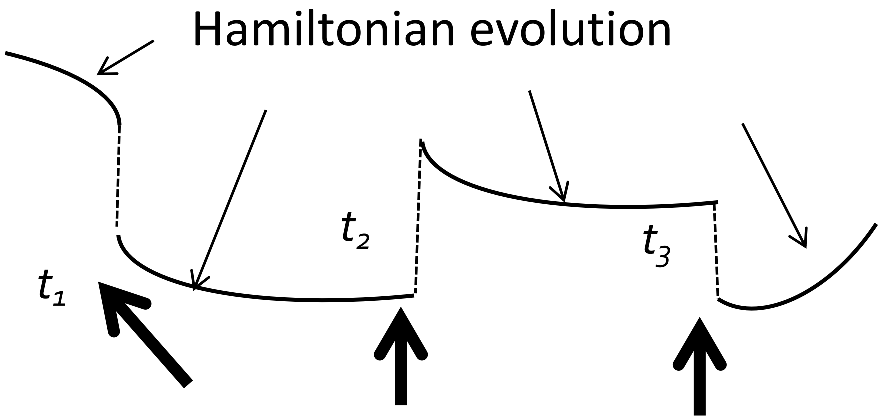


$\gamma := \{m(t_k)\}$

Stochastic quantum trajectory $|\psi_\gamma(t) >$

Internal energy $U_\gamma(t) := < \psi_\gamma(t)|H(t)|\psi_\gamma(t) >$

- **Work:** exchanged during the continuous (unitary) evolutions.
- **« Quantum heat »:** exchanged during the quantum jumps.
- $\Delta U_\gamma = W[\gamma] + Q_q[\gamma]$



Article | Open Access | Published: 10 March 2017

The role of quantum measurement in stochastic thermodynamics

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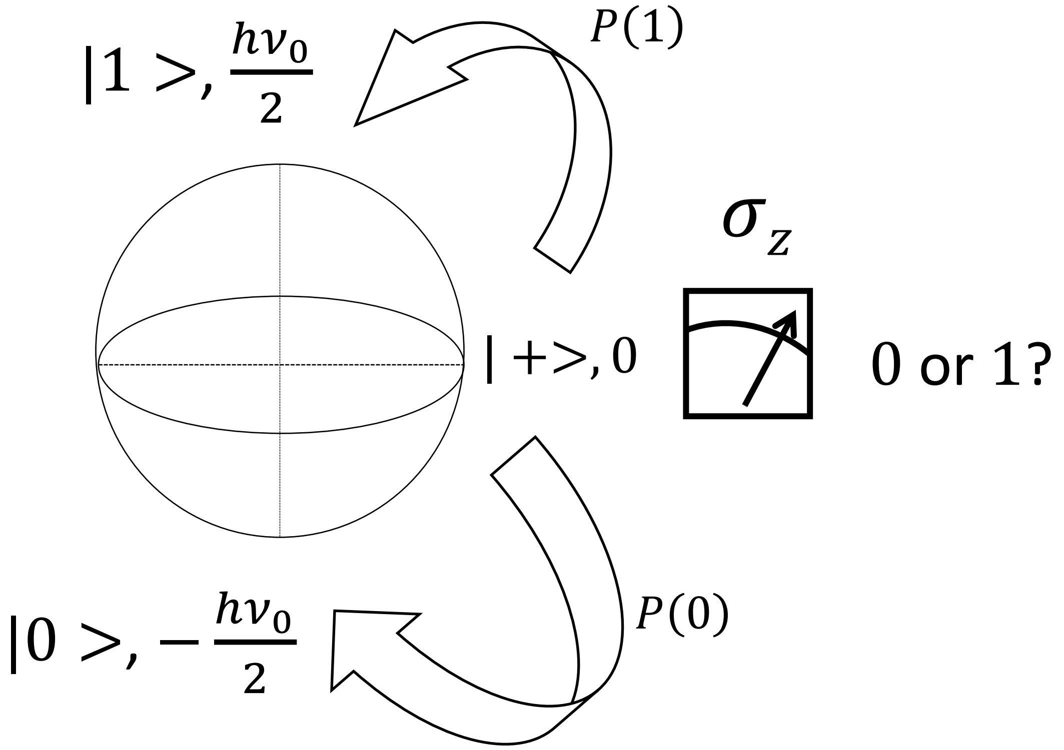
npj Quantum Information **3**, Article number: 9 (2017) | Cite this article

Example 1



System: a Qubit, $H = [h\nu_0/2]\,\sigma_Z$,
Transformation:

(i) Preparation in $|+> = \frac{1}{\sqrt{2}}(|0> + |1>)$

(ii) Measurement of σ_z

2 « stochastic trajectories »:

$$\gamma_1 = [|+>, |0>]$$
$$\gamma_2 = [|+>, |1>]$$

Energetic balance

Initial energy $U_i = 0$

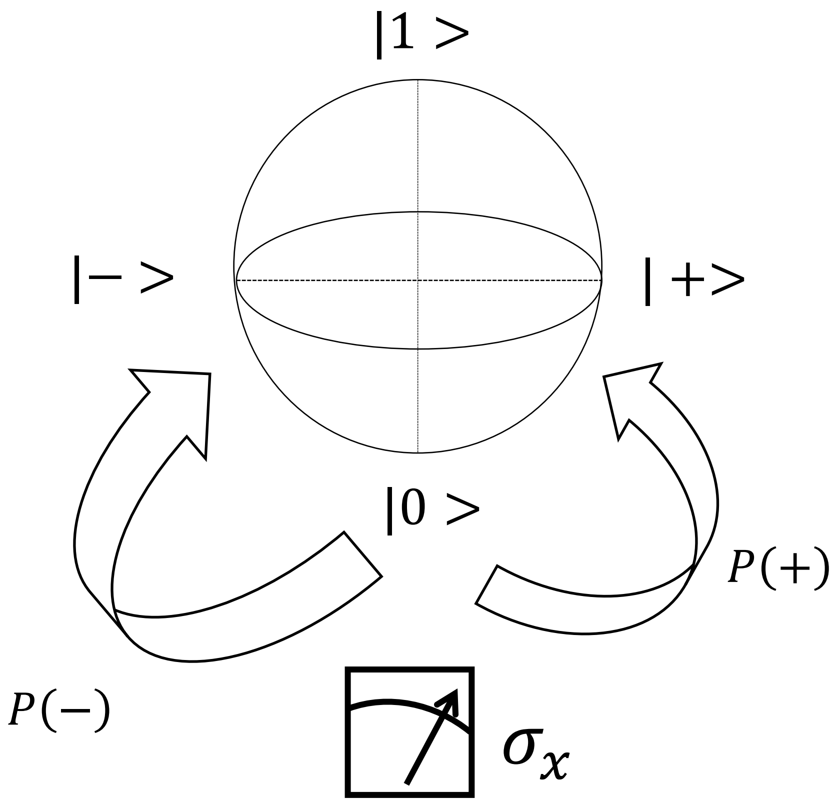
Final energy $U_f = \pm\, h\nu_0/2$

$$\Delta U[\gamma] = \pm\, h\nu_0/2 = Q_q[\gamma]$$

Energetic footprint of quantum measurement: « **Quantum heat »**

A purely quantum term due to measurement back-action

Example 2



$+$ or $-$?

System: a Qubit, $H = [h\nu_0/2]\,\sigma_Z$

Transformation:

(i) Preparation in $|0>$

(ii) Measurement of σ_x

2 stochastic trajectories:

- $\gamma_1 = [|0>, |+>]$
- $\gamma_2 = [|0>, |->]$

Energetic balance

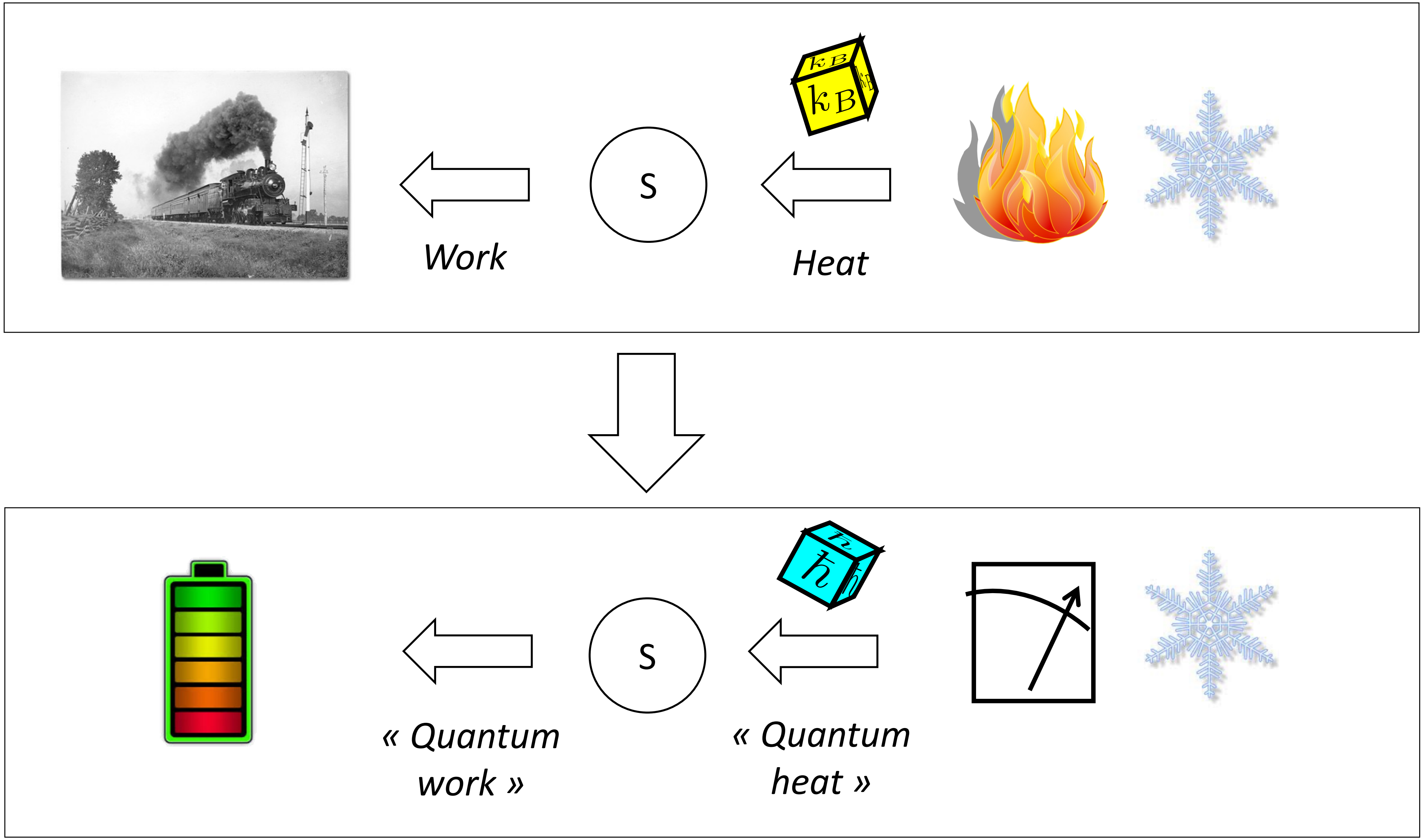
Initial energy $U_i = -h\nu_0/2$

Final energy $U_f = 0$

$$< \Delta U[\gamma] > = h\nu_0/2 = < Q_q[\gamma] >$$

- $[\sigma_x, H] \neq 0$ => « Quantum heat » is transferred on average
- **Let us use this property to build quantum engines!**

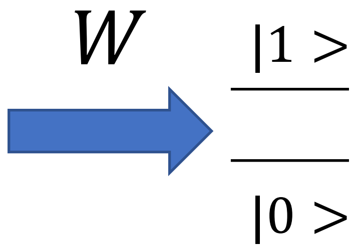
Measurement-powered engines (MPE)

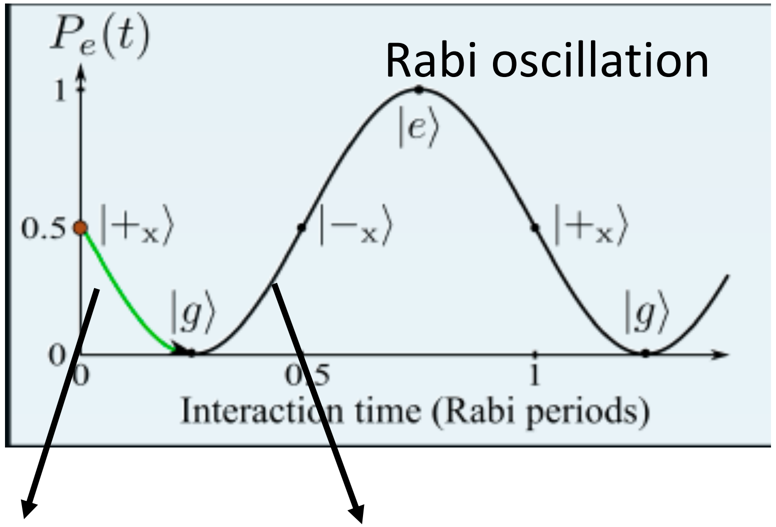


A simple measurement-powered engine

Coherent and reversible energy exchange between qubit and light

Resonant drive





$W \geq 0$ $W \leq 0$

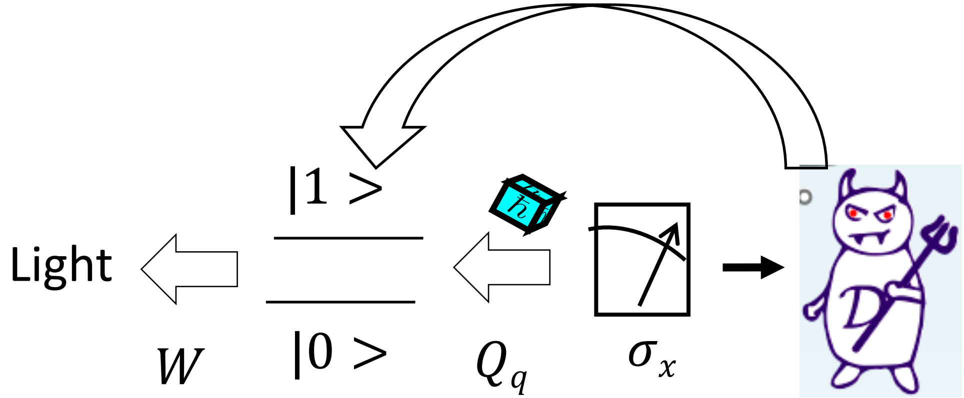
PRL **118,** 260603 (2017) PHYSICAL REVIEW LETTERS week ending 30 JUNE 2017

Extracting Work from Quantum Measurement in Maxwell's Demon Engines

Cyril Elouard,[1] David Herrera-Martí,[1] Benjamin Huard,[2,3] and Alexia Auffèves[1,*]
[1]*CNRS and Université Grenoble Alpes, Institut Néel, F-38042 Grenoble, France*
[2]*Laboratoire de Physique, Ecole Normale Supérieure de Lyon, 46 allée d'Italie, 69364 Lyon Cedex 7, France*
[3]*Laboratoire Pierre Aigrain, Ecole Normale Supérieure-PSL Research University, CNRS, Université Pierre et Marie Curie-Sorbonne Universités, Université Paris Diderot-Sorbonne Paris Cité, 24 rue Lhomond, 75231 Paris Cedex 05, France*

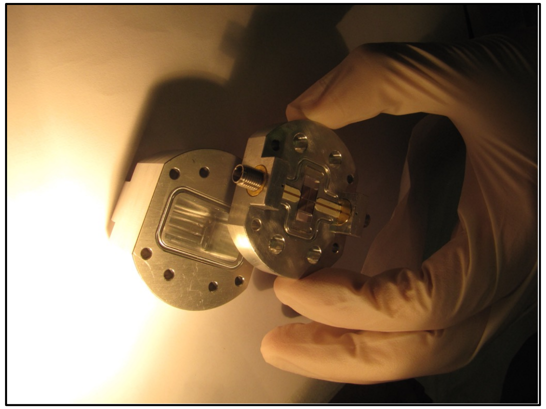
$|+>$ = good for work extraction ☺
$|->$ = bad for work extraction ☹

Experiment done @ ENS Lyon



Stabilize the qubit in $|+_x>$
Measurement of σ_x
Feedback in $|+_x>$

New quantum Maxwell's demon experiment
« Quantum heat » to work conversion

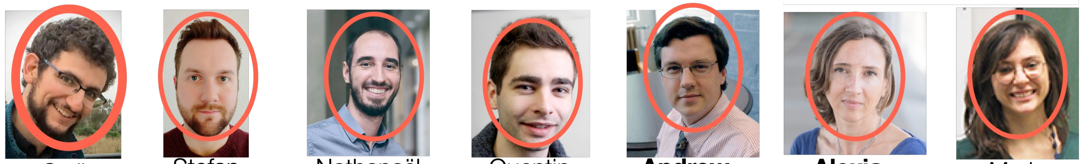


« Demonstration of a quantum engine fueled by qubit state measurement », writing in progress

Benjamin Huard **Audrey Bienfait** Rémy Dassonneville Jeremy Stevens Daniel Szombati Réouven Assouly

ENS DE LYON Alice & Bob

Guillaume Cauquil
Romain Cazali



Cyril Elouard, Stefan Zeppetzauer, Nathanaël Cottet, Quentin Ficheux, **Andrew Jordan**, **Alexia Auffèves**, Maria Maffei

FQXi FOUNDATIONAL QUESTIONS INSTITUTE

An idea that blossomed...

Quantum Stud.: Math. Found.
https://doi.org/10.1007/s40509-019-00217-2

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REGULAR PAPER

Check for updates

Quantum measurement engines and their relevance for quantum interpretations

Andrew N. Jordan · Cyril Elouard · Alexia Auffèves

PHYSICAL REVIEW LETTERS **120,** 260601 (2018)

Efficient Quantum Measurement Engines

Cyril Elouard[1,*] and Andrew N. Jordan[1,2,3]
[1]*Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627, USA*
[2]*Center for Coherence and Quantum Optics, University of Rochester, Rochester, New York 14627, USA*
[3]*Institute for Quantum Studies, Chapman University, Orange, California 92866, USA*

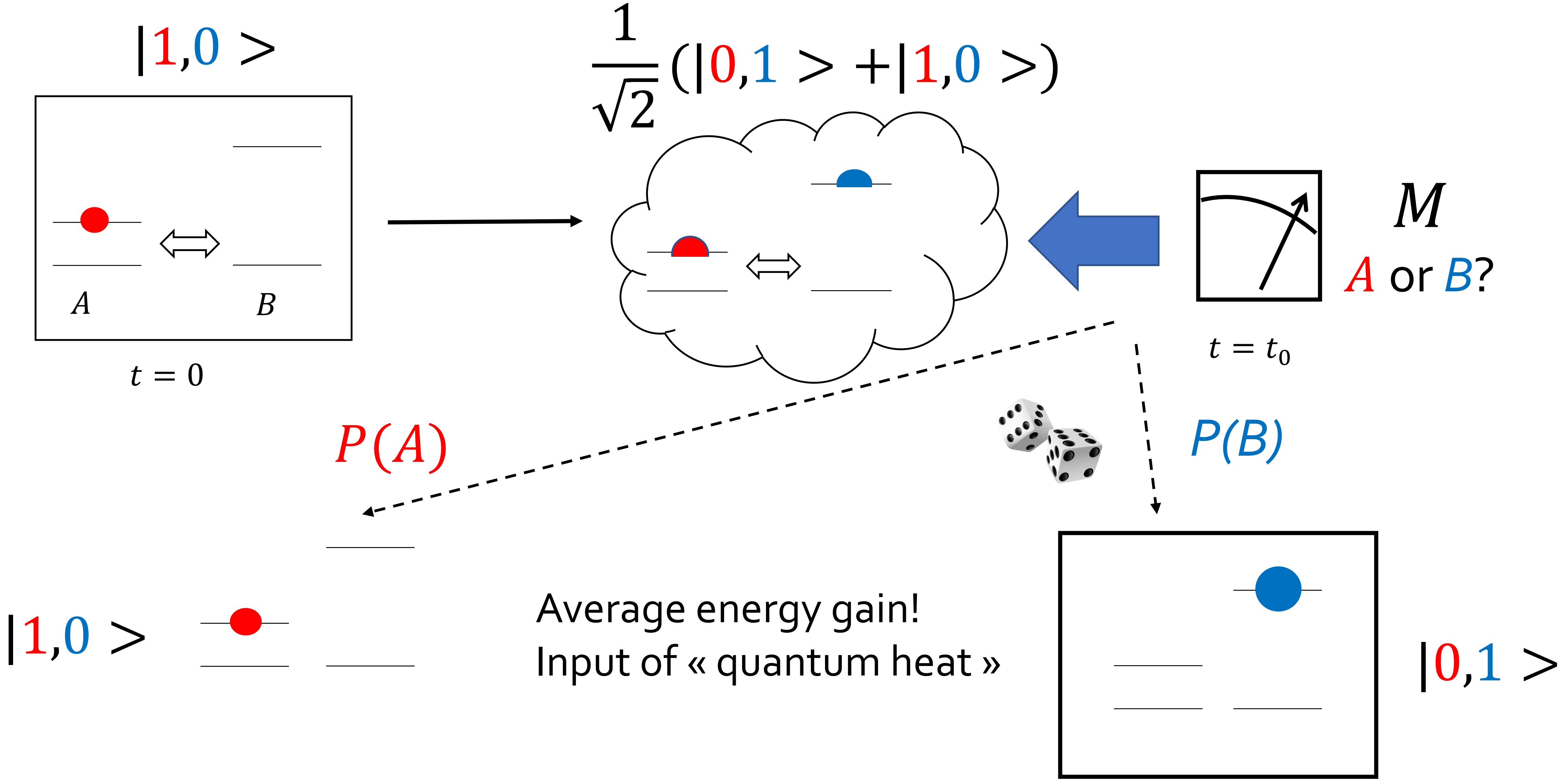
PHYSICAL REVIEW LETTERS **122,** 070603 (2019)

Editors' Suggestion   Featured in Physics

Quantum Measurement Cooling

Lorenzo Buffoni,[1,2] Andrea Solfanelli,[2] Paola Verrucchi,[3,2,4] Alessandro Cuccoli,[2,4] and Michele Campisi[2,4,5]
[1]*Department of Information Engineering, University of Florence, via S. Marta 3, I-50139 Florence, Italy*
[2]*Department of Physics and Astronomy, University of Florence, via G. Sansone 1, I-50019 Sesto Fiorentino (FI), Italy*
[3]*Istituto dei Sistemi Complessi, Consiglio Nazionale delle Ricerche, via Madonna del Piano 10, I-50019 Sesto Fiorentino (FI), Italy*
[4]*INFN Sezione di Firenze, via G.Sansone 1, I-50019 Sesto Fiorentino (FI), Italy*
[5]*Kavli Institute for Theoretical Physics, University of California, Santa Barbara, California 93106, USA*

Measurement-powered engine, season 2



Average energy gain!
Input of « quantum heat »

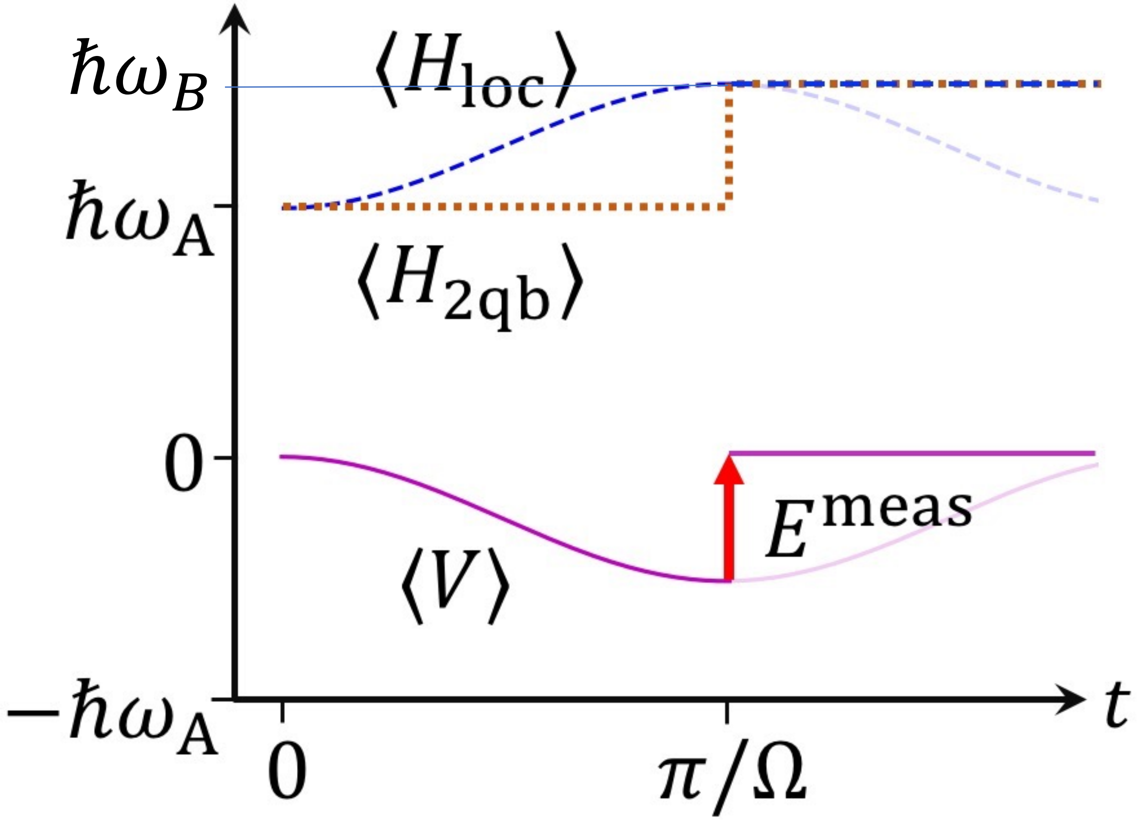
Measurement-powered engine, season 2

$$H_{2\text{qb}} = \underbrace{H_A + H_B}_{\text{« } H_{loc} \text{ »}} + V$$

$$H_A = \frac{\hbar\omega_A}{2}\sigma_z^A$$

$$H_B = \frac{\hbar\omega_B}{2}\sigma_z^B$$

$$V = \hbar\Omega(\sigma_+^A\sigma^B + \sigma_+^B\sigma^A)$$



V = correlation energy

E^{meas}= « measurement fuel » to erase correlations between qubits

Measurement-powered engine, season 2

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*
[3]*Department of Physics, Washington University, St. Louis, Missouri 63130, USA*
[4]*Institute for Quantum Studies, Chapman University, Orange, California 92866, USA*

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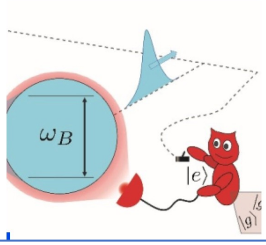
cnrs

INP Recherche Innovation International Talents



Accueil › Actualités

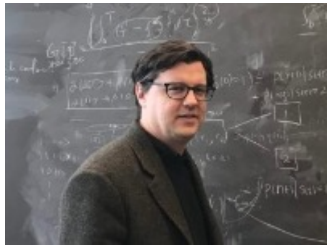
Extraire de l'énergie de la mesure quantique

02 juillet 2021 RÉSULTAT SCIENTIFIQUE

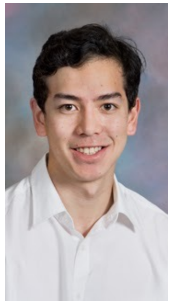
PHYS ORG

A two-qubit engine powered by entanglement and local measurements

26 April 2021, by Ingrid Fadelli



A. Jordan, Chapman University, IQS



S. Rogers, Chapman University

K. Murch, Saint Louis University

P. Camati, I. Néel & Oxford

L. Bresque, I. Néel

Characterizing the measurement fuel

Work or heat? Link with information extraction? Irreversible or controllable? Resource or cost?
=> One should model the measuring apparatus....

Wanted: theory of quantum measurement

Cours C. Cohen-Tannoudji, Coherence quantique et dissipation, 1989-1990

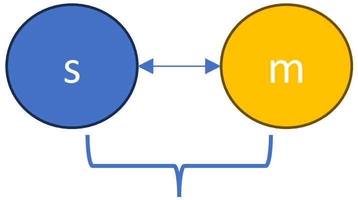
31.10.89

IV-1

Difficultés d'une théorie quantique de la mesure

La chaîne infinie de von Neumann. Où l'arrêter ?

J. von Neumann
1903-1957



Pre-measurement

$$|+>|0_m> \to \frac{1}{\sqrt{2}}(|0,0_m> + |1,1_m>)$$

For S: « $0+1$ » $\to$ 0 or 1

For S+M: $|00_m> + |11_m> = |++_m> + |--_m>$

No preferred basis

Characterizing the measurement fuel

Work or heat? Link with information extraction? Irreversible or controllable? Resource or cost?
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Wanted: theory of quantum measurement

Cours C. Cohen-Tannoudji, Coherence quantique et dissipation, 1989-1990

31.10.89

IV.1

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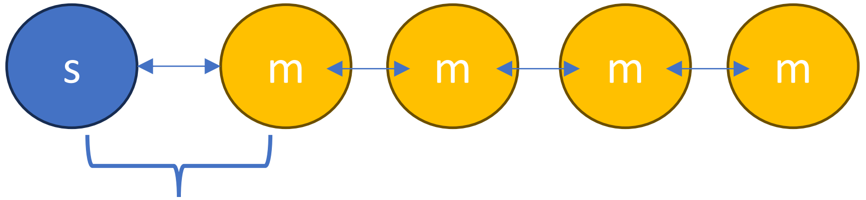
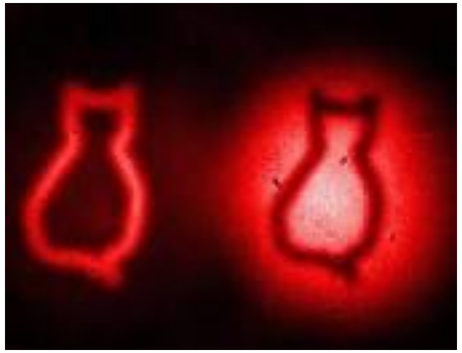


Gigantic entangled state



Characterizing the measurement fuel

Work or heat? Link with information extraction? Irreversible or controllable? Resource or cost?
=> One should model the measuring apparatus....

Wanted: theory of quantum measurement

Cours C. Cohen-Tannoudji, Coherence quantique et dissipation, 1989-1990

COLLÈGE DE FRANCE 1530

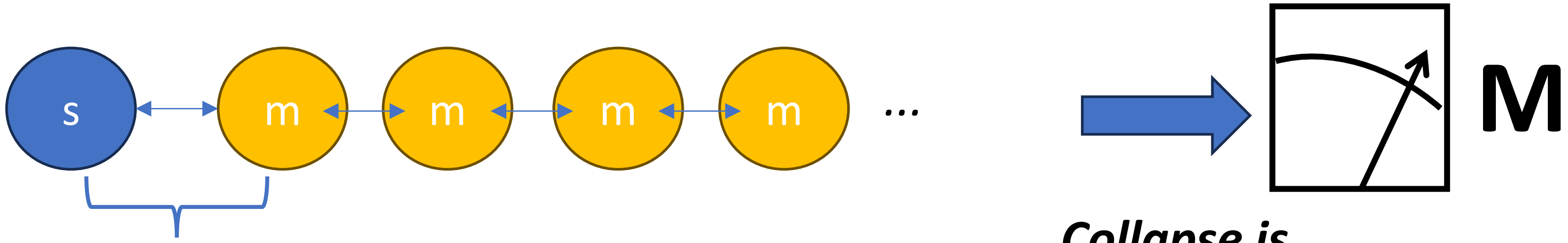
31.10.89

IV.1

Difficultés d'une théorie quantique de la mesure

La chaîne infinie de von Neumann. Où l'arrêter ?

J. von Neumann
1903-1957

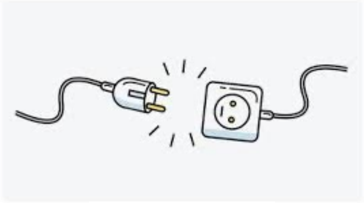


Pre-measurement

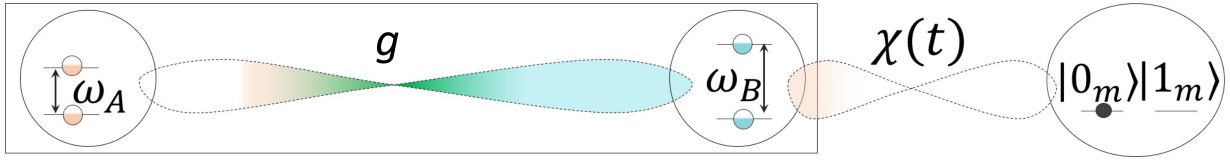
Collapse is necessary!

Energetics of the pre-measurement

$$H_{\text{tot}} = H_A + H_B + V + V_m(t)$$



Switch on @ t_0
Switch off @ t_m



$|1, 0, 0_m > \to |1,0, 0_m >$
$|0,1, 0_m > \to |0,1, 1_m >$

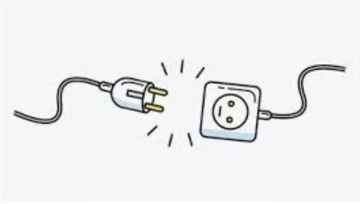
$$\frac{1}{\sqrt{2}}(|0,1 > +|1,0 >)|0_m > \to \frac{1}{\sqrt{2}}(|0,1,1_m > +|1,0,0_m >)$$

A et B $\to$ A ou B

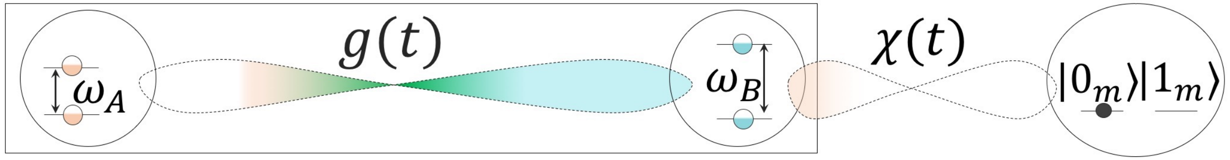
Erasure of correlations between A and B

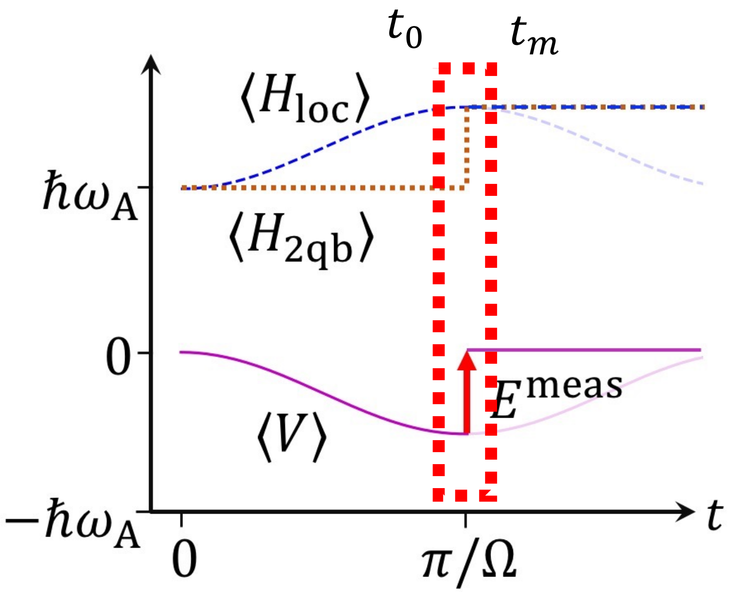
From the qubits' viewpoint: good measurement model

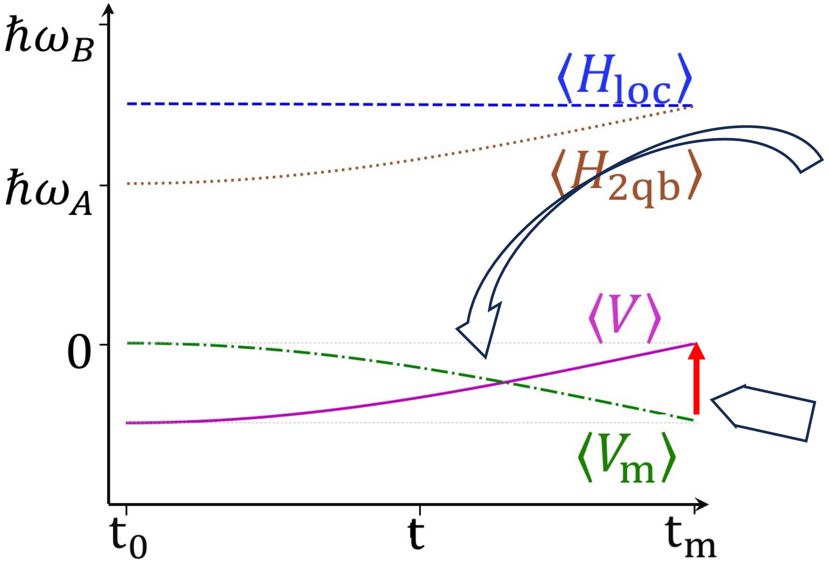
Energetics of pre-measurement



Dynamics of energy exchanges
Complete energy balance including the quantum meter and the agent



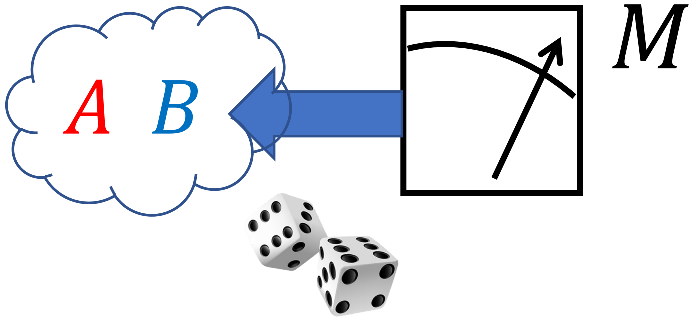




Pre-measurement = Relocalisation of the correlation energy

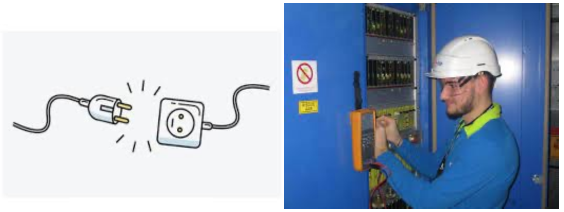
E^{meas} = Work paid by the agent during the switch-off

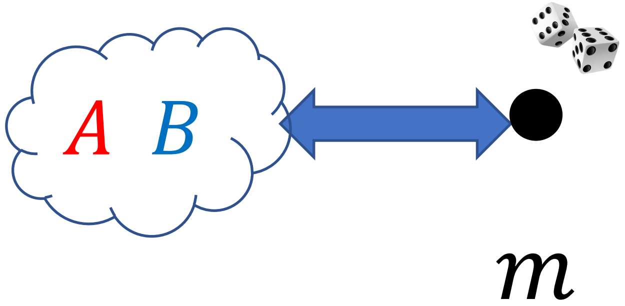
Measurement fuel: Work or heat?



Projective measurement of AB

- ✓ Measurement postulate
- ✓ Irreversible transfer of energy and entropy
- ✓ « Heat »



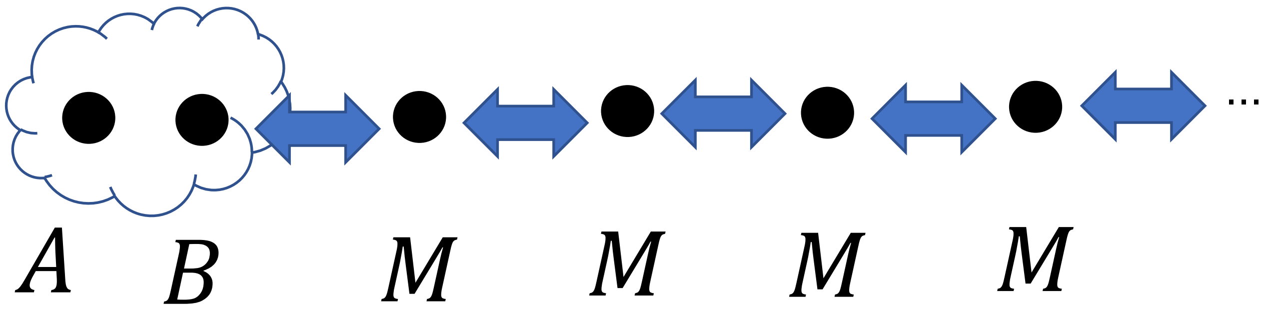


Pre-measurement of AB with quantum meter m

- ✓ for ABm: Unitary operation - Reversible, entropy preserving energy input => « Work » payed by the agent
- ✓ for AB: Transfer of energy and entropy => « Heat »

Is quantum heat fundamental?

It depends on your favourite interpretation…



Everett, churches of unitarity…

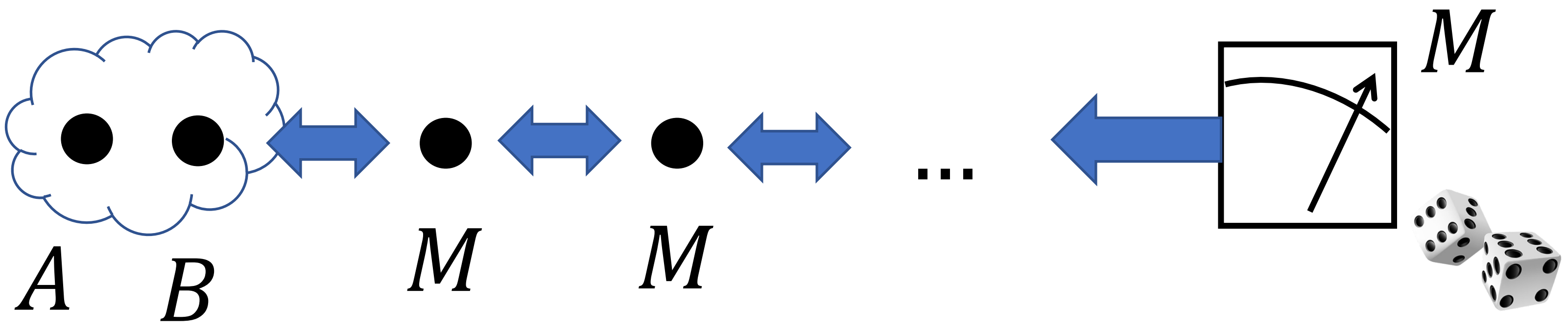
Measurement = creation of massive entanglement by unitary transformations

Reversible, entropy preserving

Measurement fuel= Work

Is quantum heat fundamental?

It depends on your favourite interpretation…



Von Neumann's legacy , Copenhagen, CSM…

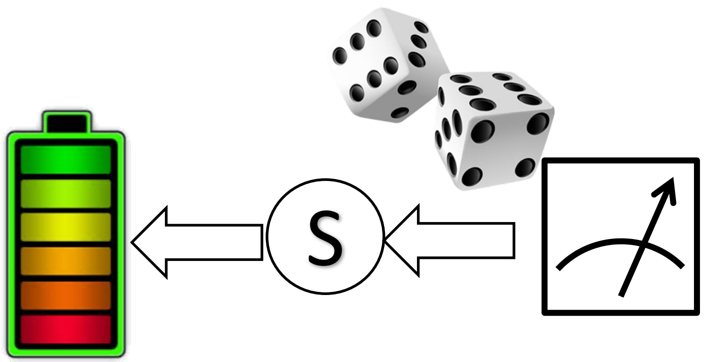
Always a classical measurement to break the channel

Irreversible, not entropy preserving

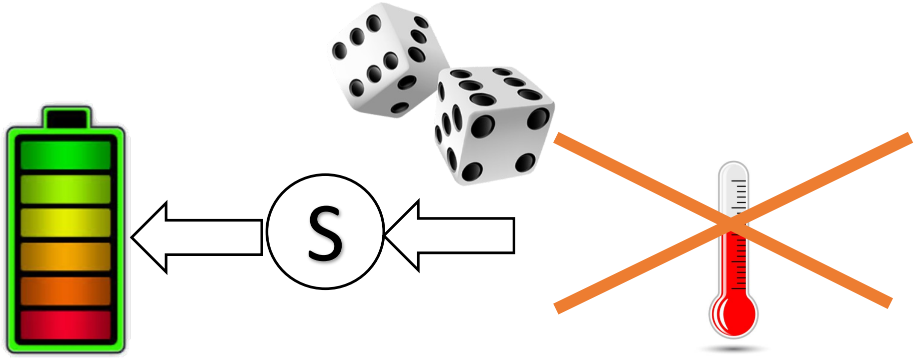
Measurement fuel = heat

First conclusions on quantum energetics

- *Study of energy and entropy flows in the quantum realm*
- *No temperature, but a source of randomness*
- *Two typical situations:*



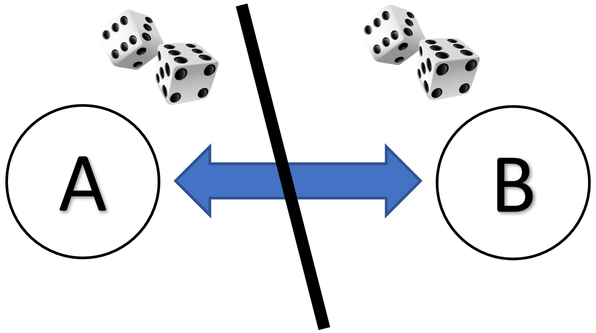
Measurement backaction
Measurement-powered engines



Coupling with a non-equilibrium reservoir, driven-dissipative systems

- *These are open systems*
- *Big debates about heat and work **definitions**, and how to **measure** them*

A safer situation: bipartite quantum energetics



Bipartite isolated quantum system
Autonomous => Global energy conservation
Characterization of energy exchanges between A and B

P. Camati
I. Néel &
Oxford

Work-like and heat-like energy flows, measurable quantities

I. Maillette de Buy Wenniger,
Imperial College

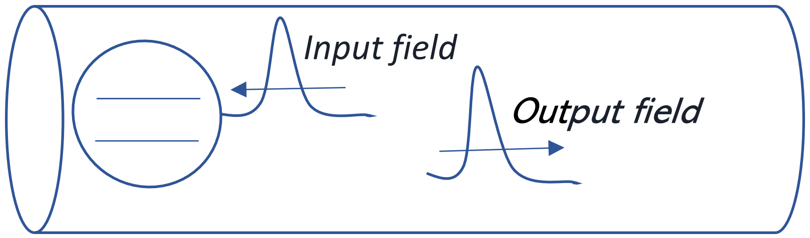
P. Senellart
C2N

Experimental analysis of energy transfers between a quantum emitter and light fields

I. Maillette de Buy Wenniger[1], S. E. Thomas[1], M. Maffei[2], S. C. Wein[2,3], M. Pont[1], N. Belabas[1], S. Prasad[2], A. Harouri[1], A. Lemaître[1], I. Sagnes[1], N. Somaschi[4], A. Auffèves[*5,6], P. Senellart[*1]

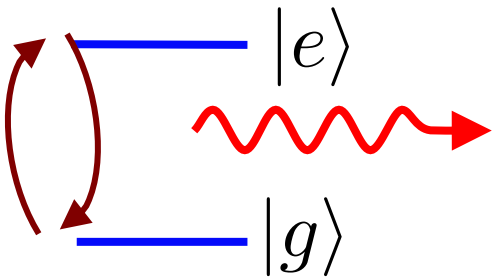
[1] *Centre for Nanosciences and Nanotechnology, CNRS, Université Paris-Saclay, UMR 9001, 10 Boulevard Thomas Gobert, 91120 Palaiseau, France*
[2] *Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France*
[3] *Institute for Quantum Science and Technology and Department of Physics and Astronomy, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
[4] *Quandela SAS, 10 Boulevard Thomas Gobert, 91120 Palaiseau, France*
[5] *MajuLab, CNRS-UCA-SU-NUS-NTU International Joint Research Laboratory*
[6] *Centre for Quantum Technologies, National University of Singapore, 117543 Singapore, Singapore*

Application of BQE: Energetics of qubit-light interactions

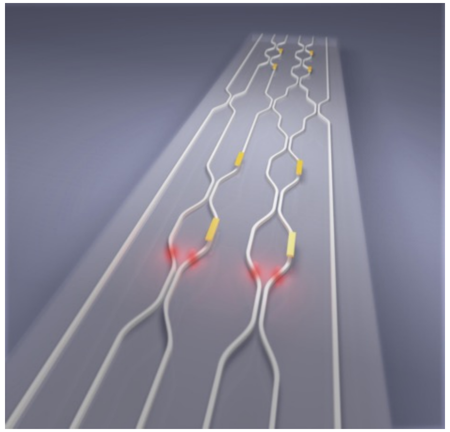


Energy cost of a quantum gate?

of quantum light sources?



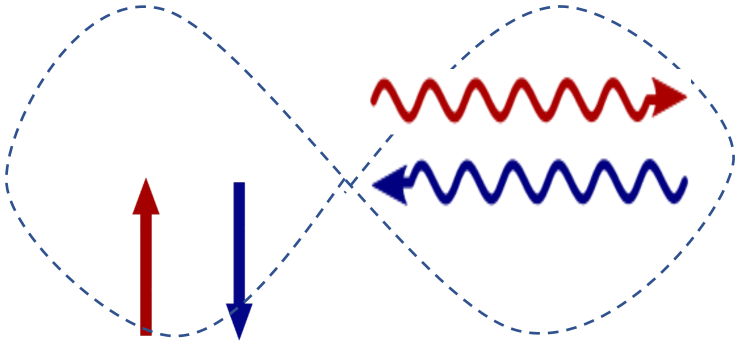
of linear quantum gates?



BQE provides an excellent framework to analyze:

- Fundamental mechanisms and devices of quantum optics
- Energy cost of quantum technologies

of quantum interfaces?



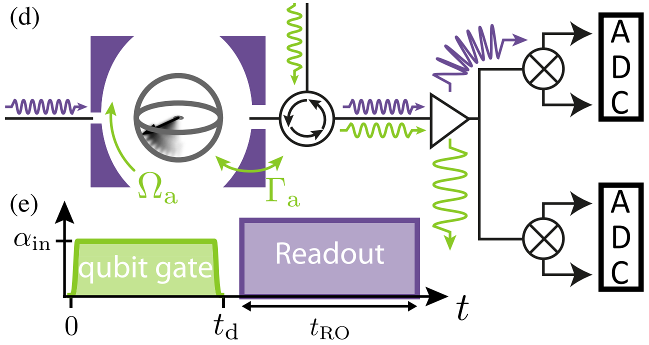
Energetics of quantum primitives

Experiment

PHYSICAL REVIEW LETTERS **129**, 110601 (2022)

Energetics of a Single Qubit Gate

J. Stevens,[1] D. Szombati,[1] M. Maffei,[2] C. Elouard,[3] R. Assouly,[1] N. Cottet,[1] R. Dassonneville,[1] Q. Ficheux,[1] S. Zeppetzauer,[1] A. Bienfait,[1] A. N. Jordan,[4,5] A. Auffèves,[2] and B. Huard[1]



Experiment

PHYSICAL REVIEW LETTERS **128**, 220506 (2022)

Energetic Cost of Measurements Using Quantum, Coherent, and Thermal Light

Xiayu Linpeng,[1] Léa Bresque,[2] Maria Maffei,[2] Andrew N. Jordan,[3,4] Alexia Auffèves,[2] and Kater W. Murch[1,*]



Benjamin Huard ENS Lyon

Kater Murch Saint Louis, USA

Andrew Jordan Chapman, USA

Theory

arXiv > quant-ph > arXiv:2205.09623

Search...

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Quantum Physics

[Submitted on 19 May 2022 (v1), last revised 12 May 2023 (this version, v2)]

Energy-efficient quantum non-demolition measurement with a spin-photon interface

Maria Maffei, Bruno O. Goes, Stephen C. Wein, Andrew N. Jordan, Loïc Lanco, Alexia Auffèves


S. Wein Quandela

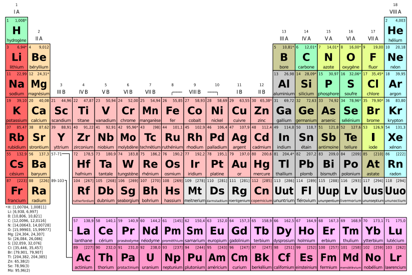
M. Maffei Bari University

Outline

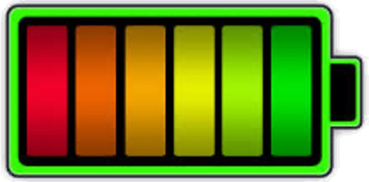
- From classical thermodynamics to quantum energetics
- Energetics of quantum measurement
- **Energy-efficient quantum technologies**

A very schematic view on human activities

Materials



Energy



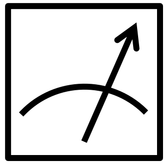
Resources R

Machine

Efficiency η

$$\eta = M / R$$

Target result

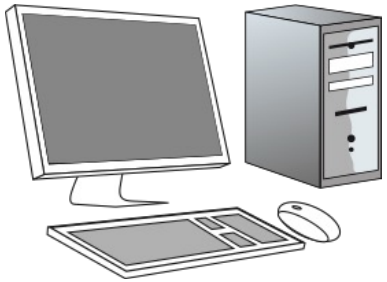


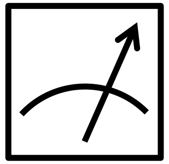
Performance metric M

Purpose of science and technology: increase efficiencies

Classical computing energy efficiency

R = Power consumption





M = Number of FLoating-point Operations Per second (FLOPs)

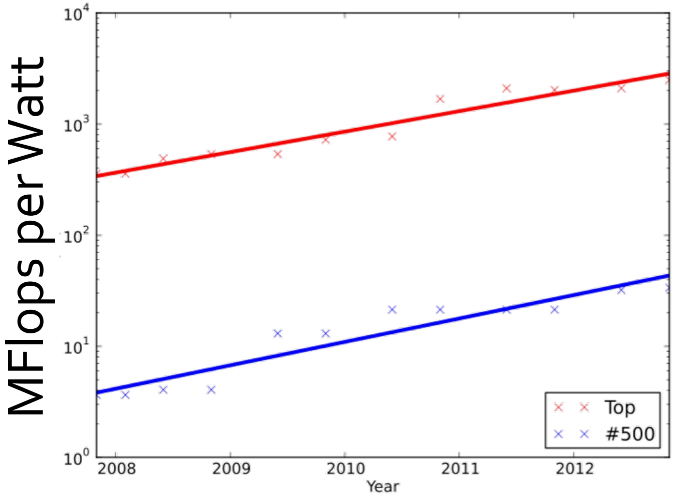
η = Performance per Watt (FLOPs/W)

Koomey's law

η doubles every 18 months

Saturation since 2010

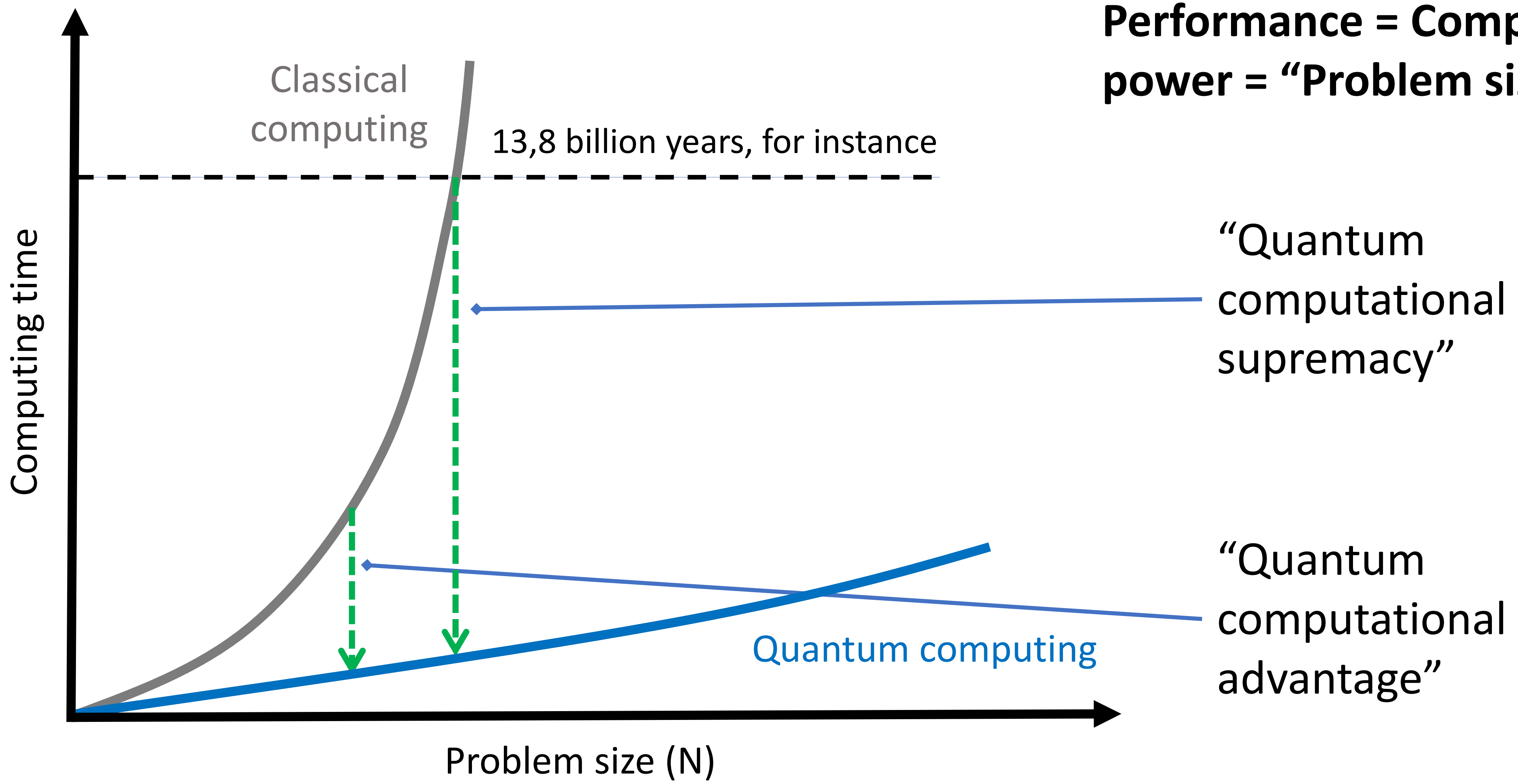
Supercomputers



ICT global electricity consumption in 2020: **11%** (Puebla et al, 2020)

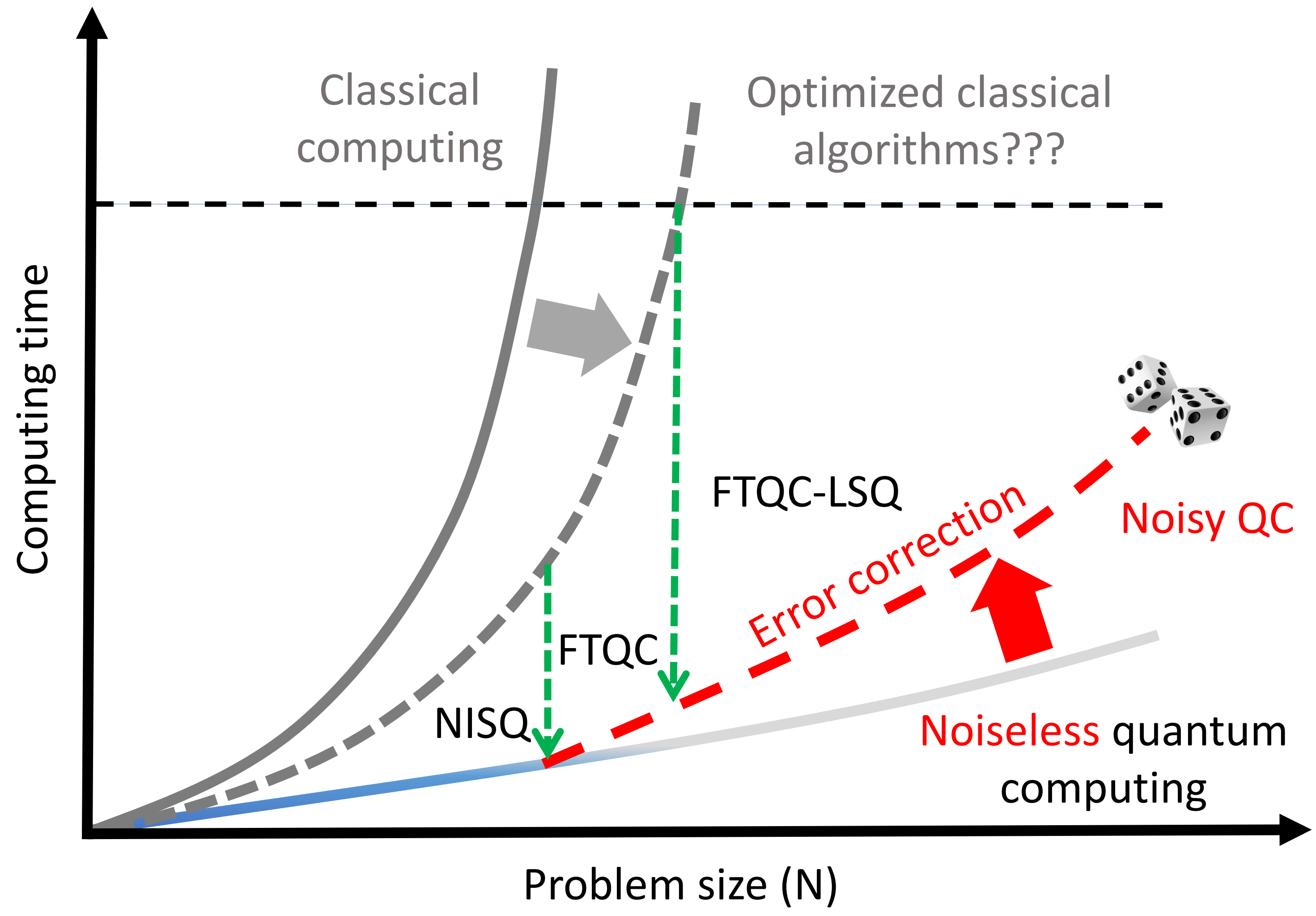
No expected gain in efficiency due to end of Koomey's law

The promise of quantum computing



Performance = Computing power = “Problem size”/Time

Quantum computing current challenges

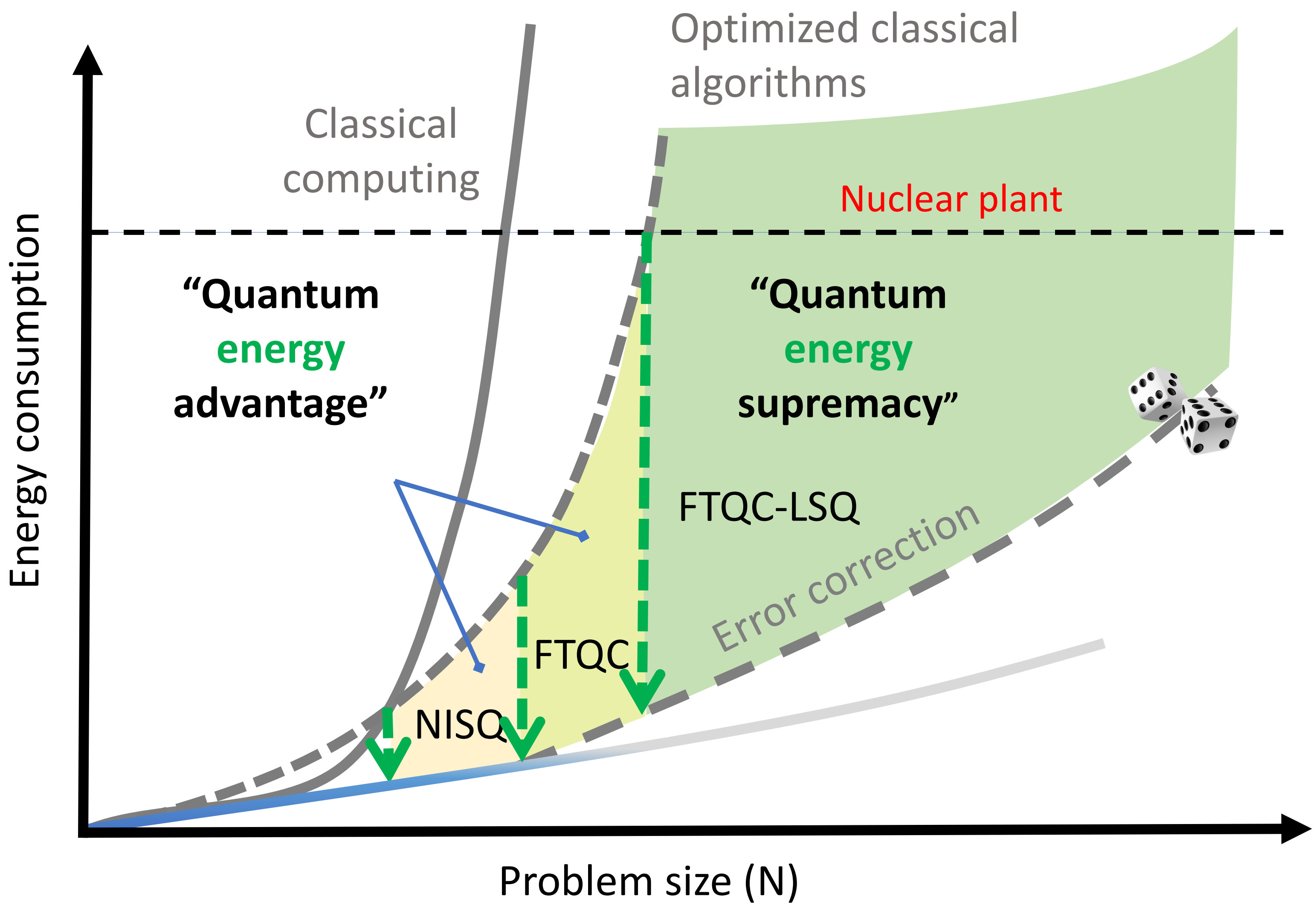


Quantum computing community challenges

⇒ Noise resilience of quantum supremacy & advantage?

⇒ Usecases of various computing regimes

Boosting energy efficiency with quantum?



Efficiency = Problem size/Energy

“Quantum energy advantage”:
=> when a quantum computer solves a problem with less energy than best in-class classical computers and algorithms.
=> when a qc solves larger problems with the same energy

Fellous-Asiani et al, *Optimizing Resource Efficiencies for Scalable Full-Stack Quantum Computers, arXiv 2209.05469*

Energy hog or energy advantage?

RESEARCH-ARTICLE

Energy Cost of Quantum Circuit Optimisation: Predicting That Optimising Shor's Algorithm Circuit Uses 1 GWh

Authors: Alexandru Paler, Robert Basmadjian Authors Info & Claims

ACM Transactions on Quantum Computing, Volume 3, Issue 1 • March 2022 • Article No.: 3
1–14 • https://doi.org/10.1145/3490172

Is quantum computing green? An estimate for an energy-efficiency quantum advantage

Daniel Jaschke[1, 2, 3] and Simone Montangero[1, 2, 3]
[1]*Institute for Complex Quantum Systems, Ulm University, Albert-Einstein-Allee 11, 89069 Ulm, Germany*
[2]*Dipartimento di Fisica e Astronomia "G. Galilei" & Padua Quantum Technologies Research Center, Università degli Studi di Padova, Italy I-35131, Padova, Italy*
[3]*INFN, Sezione di Padova, via Marzolo 8, I-35131, Padova, Italy*
(Dated: May 25, 2022)

The question must be tackled now

PRX QUANTUM **3,** 020101 (2022)

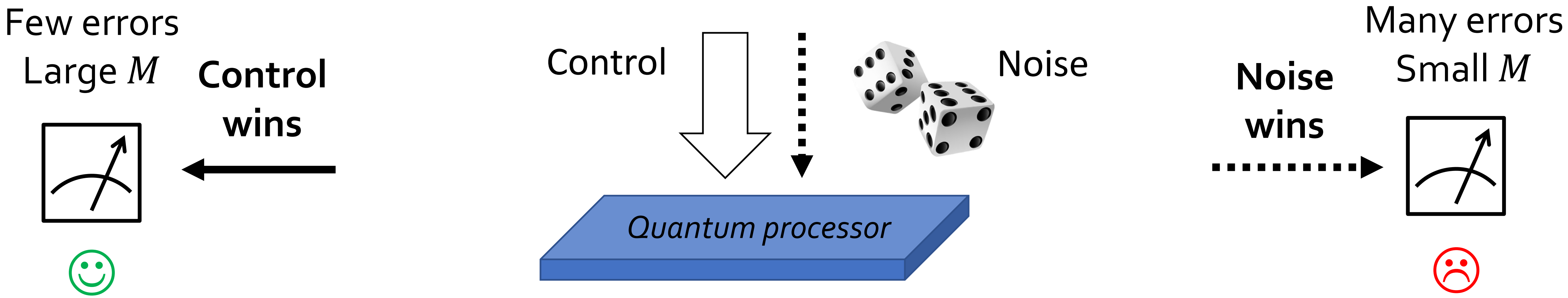
Perspective

Quantum Technologies Need a Quantum Energy Initiative

Alexia Auffèves*
Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble 38000, France

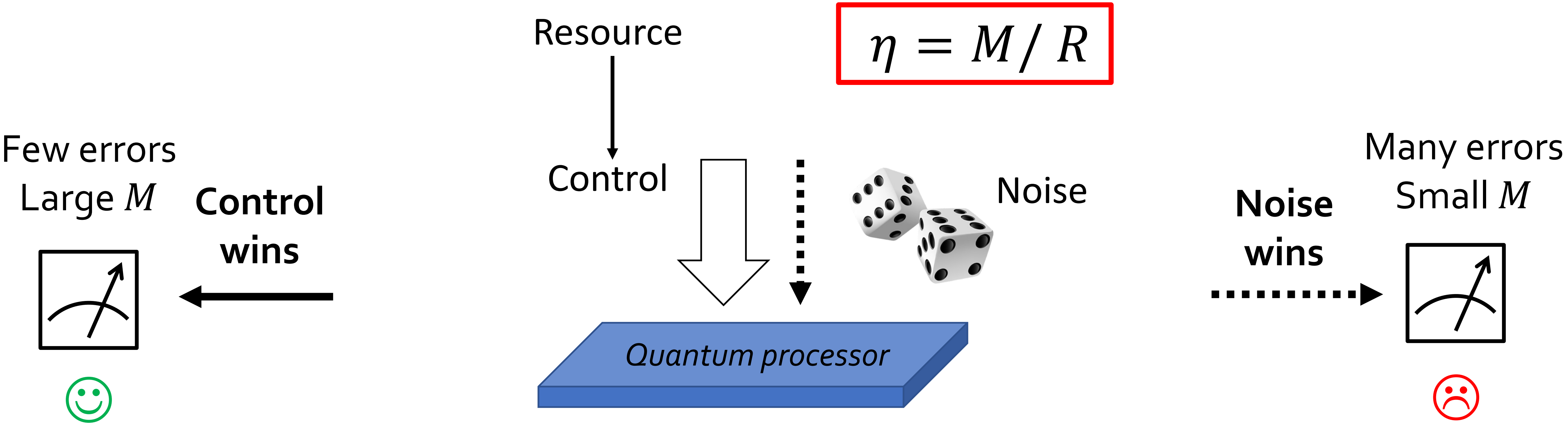
(Received 18 November 2021; revised 11 April 2022; published 1 June 2022)

Need for interdisciplinarity



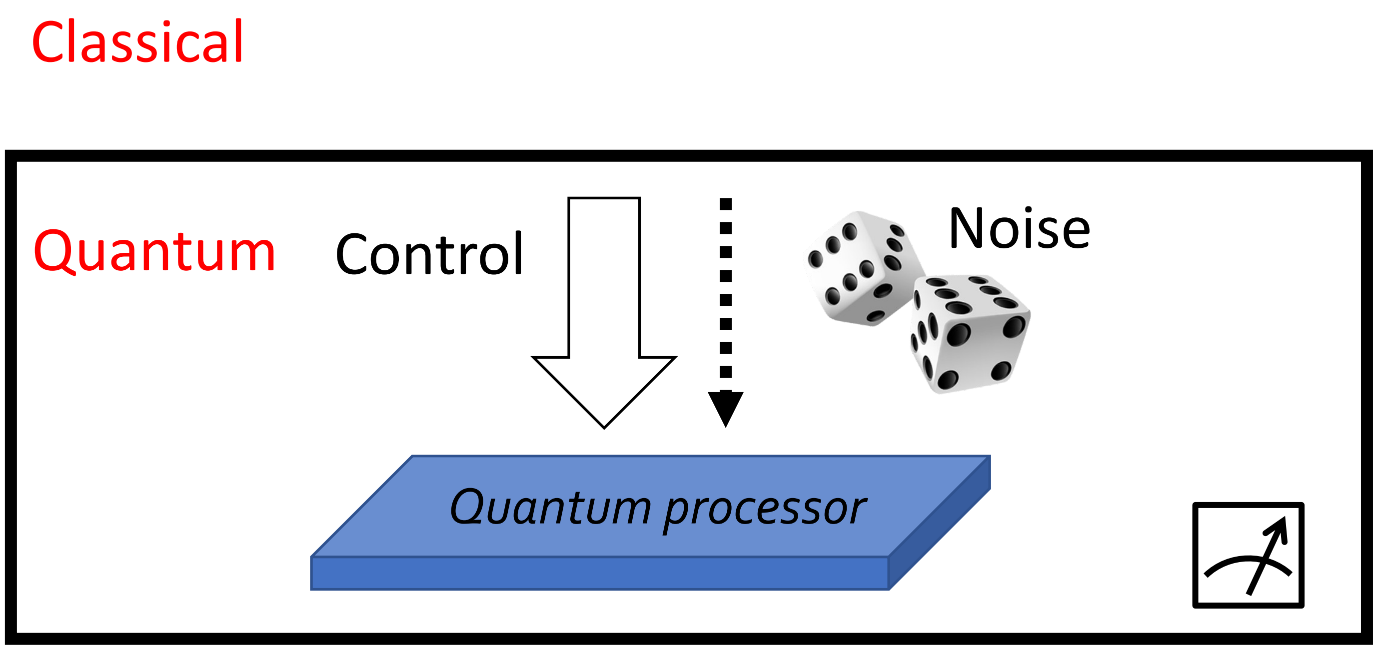
Performance emerges at the quantum level

Need for interdisciplinarity



Resource-efficiency optimizations at the quantum level
Skills from **quantum energetics / quantum information**

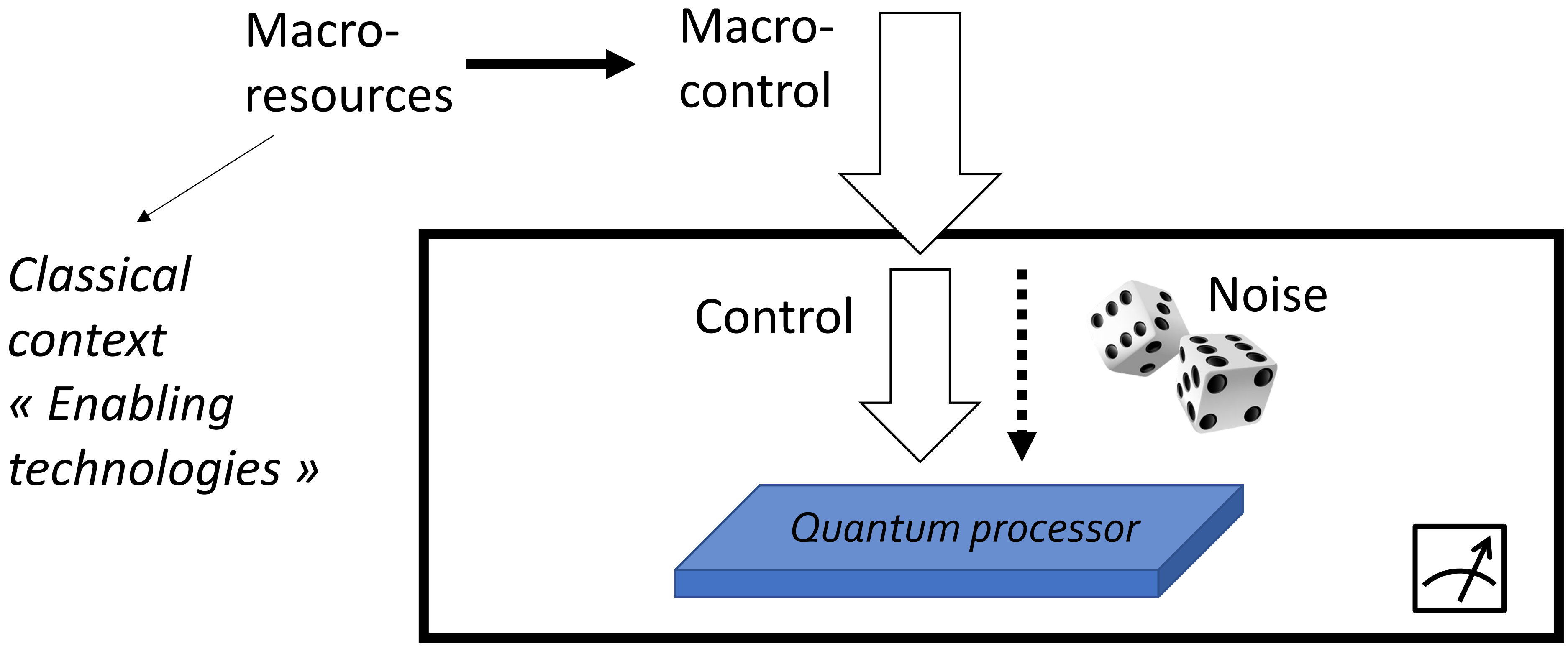
Need for interdisciplinarity



Creating a quantum/classical boundary = a non-equilibrium situation

Resource cost of trapping a Schrödinger cat?

Need for interdisciplinarity



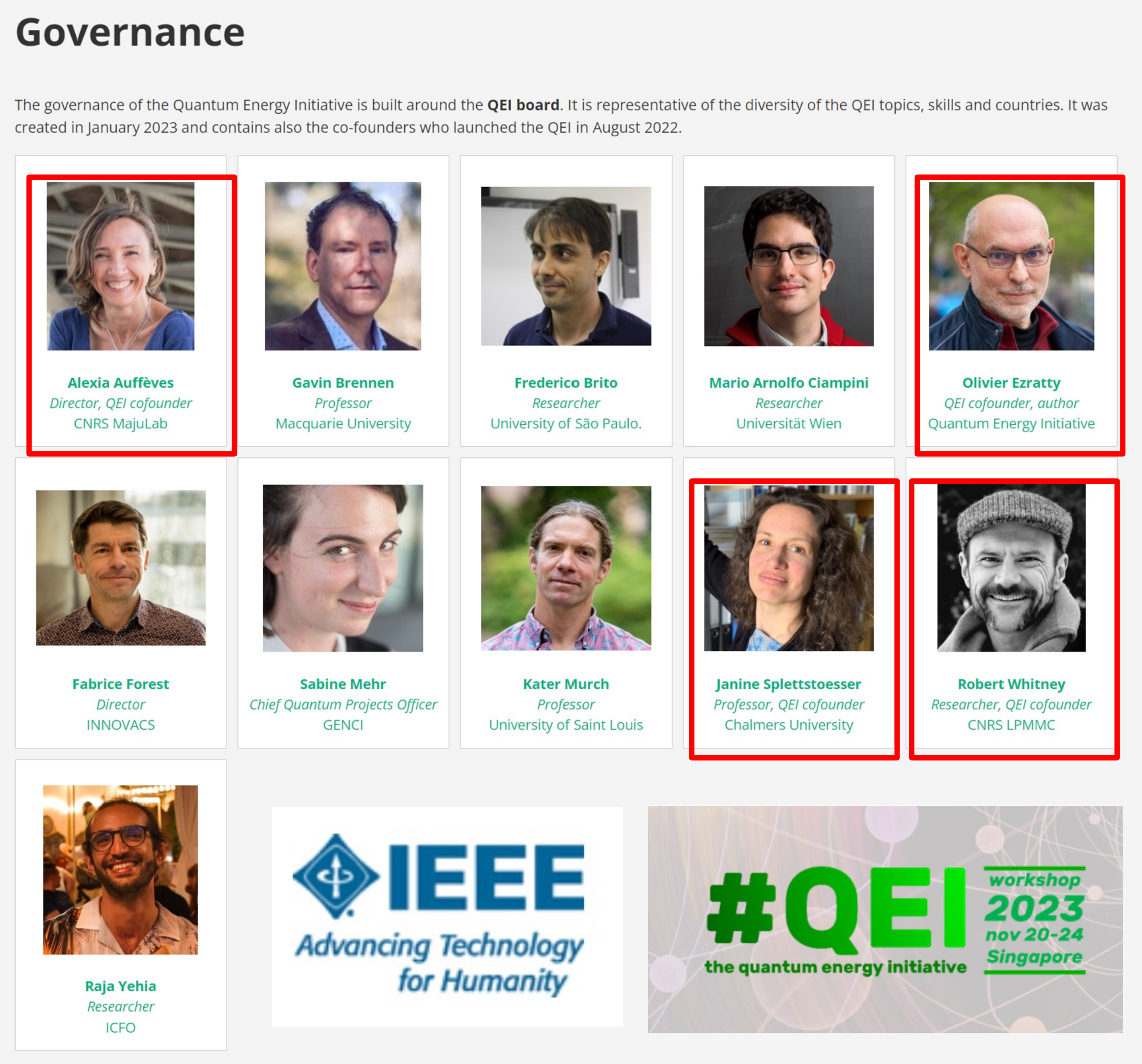
$$\eta = M / R$$

Resource efficiency = a hybrid figure of merit
Need to articulate different levels of description in a crossed-disciplinary research lines => the QEI

Timeline

Jun 2022 : PRXQ QEI Vision paper
Aug 2022 : QEI website & Manifesto
Jan 2023 : QEI board creation
May 2023 : QEI WG@IEEE kickoff
July 2023 : 325 participants, 49 countries, 29 partners
July 2023 : YouTube channel
Oct 2023 : COST network deadline
Nov 2023 : First QEI workshop, Singapore

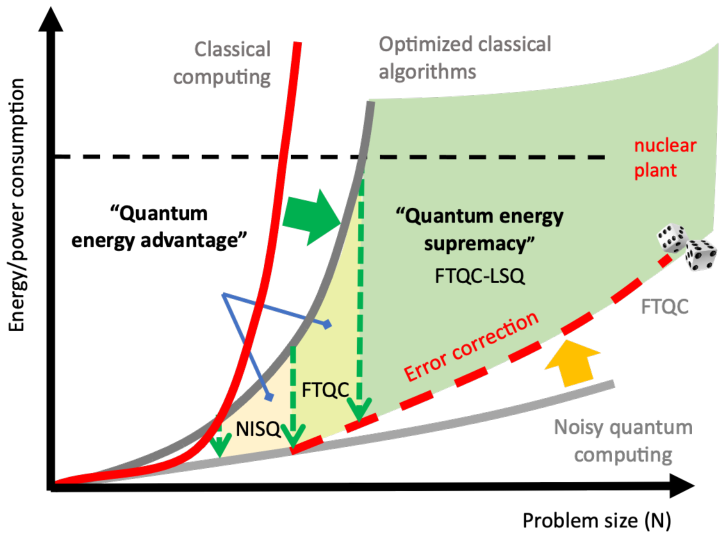
www.quantum-energy-initiative.org
https://qei2023.sciencesconf.org/

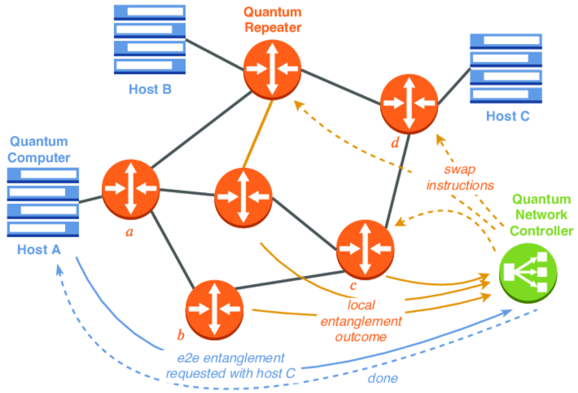


#QEI
the quantum energy initiative

Key scientific questions and missions

A worldwide, crossed-disciplinary community





Conditions of a quantum energy advantage

Fundamental bounds and relation to macroscopic energy costs...

Resource optimizations

Impact on industrial roadmaps

Standard of energy efficiency for quantum computing...

Extension to other quantum technologies

Quantum communications, sensors, machine learning...

#QEI workshop 2023

the quantum energy initiative

nov 20-24
Singapore

https://qei2023.sciencesconf.org/

Scientific & Organizing committee

A.Auffèves (CNRS MajuLab CQT)
Y. Gao (NUS MajuLab CQT)
O. Ezratty (QEI)
Ye Jun (A*Star)
N. Ng (NTU MajuLab)
D. Poletti (SUTD MajuLab)
J. Splettstoesser (Chalmers Univ.)
R. Whitney (CNRS LPMMC)

Topics:

- Fundamental quantum devices
- Algorithmic resources
- Classical information thermodynamics
- Quantum hardware
- High Performance Computing

Plenary speakers

M. Devoret (Yale)
S. Matsuoka (RIKEN)
M. Ueda (Tokyo)
P. Zoller (ICOQI)

Open for registrations!

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QUANTUM ENGINEERING PROGRAMME SINGAPORE

MajuLab

Quantum Energetics

Foundations, Applications