Title: The Unreasonable Effectiveness of Curiosity

Date: Jun 21, 2016 09:45 AM

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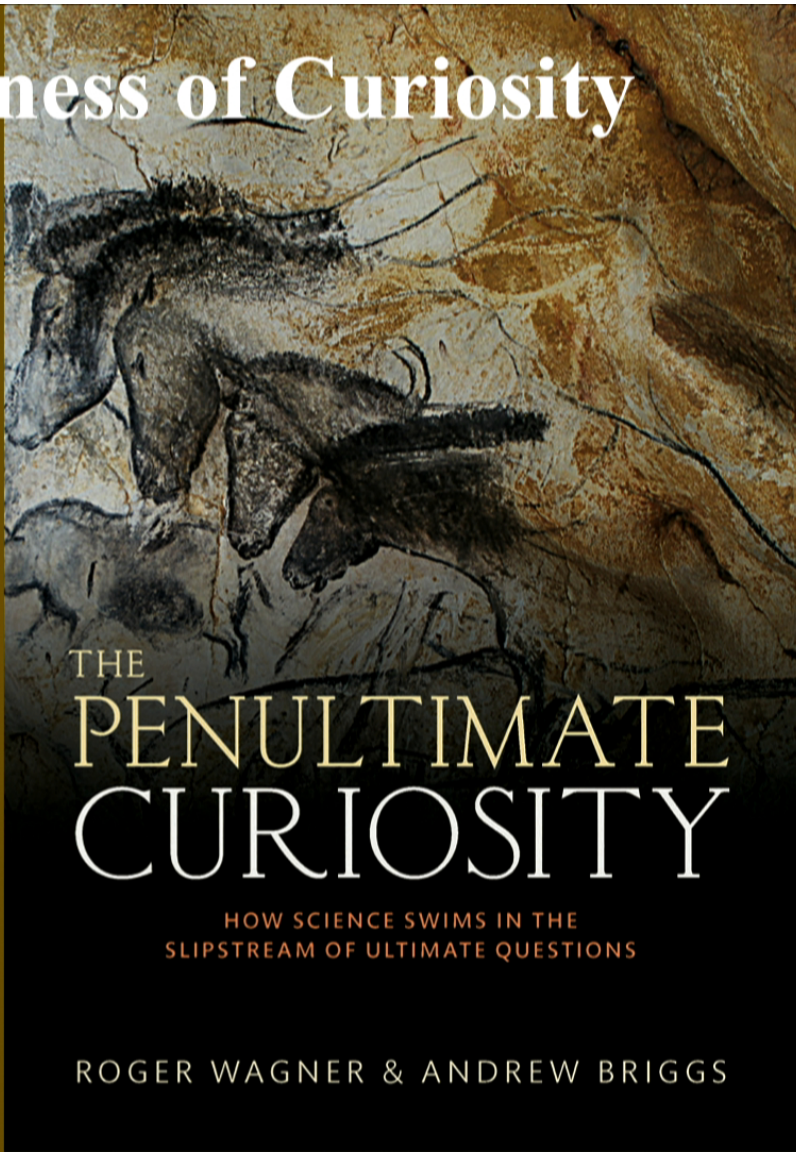
Abstract: Curiosity about how the world works can lead to beneficial progress in technology, and vice-versa. This kind of interplay can be found in quantum nanoscience, where foundationally motivated experiments and technologically motivated experiments often use similar materials and techniques, because both involve extending the realm of non-classical behaviour. At a higher level, curiosity about ultimate questions such as meaning and purpose can create an environment that is conducive to scientific breakthroughs, and many of the best minds in science have also been curious about deeper realities. Eugene Wigner described the miracle of the effectiveness of mathematics as a wonderful gift which we neither understand nor deserve. The same could be said of curiosity.

The Unreasonable Effectiveness of Curiosity

Concepts and Paradoxes in a Quantum Universe

Perimeter Institute

Andrew Briggs – June 21, 2016



The Unreasonable Effectiveness of Mathematics in the Natural Sciences

Richard Courant Lecture in Mathematical Sciences delivered at New York University, May 11, 1959

EUGENE P. WIGNER
Princeton University

"and it is probable that there is some secret here which remains to be discovered." (*C. S. Peirce*)

There is a story about two friends, who were classmates in high school, talking about their jobs. One of them became a statistician and was working on population trends. He showed a reprint to his former classmate. The reprint started, as usual, with the Gaussian distribution and the statistician explained to his former classmate the meaning of the symbols for the actual population, for the average population, and so on. His classmate was a bit incredulous and was not quite sure whether the statistician was pulling his leg. "How can you know that?" was his query. "And what is this symbol here?" "Oh," said the statistician, "this is π." "What is that?" "The ratio of the circumference of the circle to its diameter." "Well, now you are pushing your joke too far," said the classmate, "surely the population has nothing to do with the circumference of the circle."

26th-29th September 2010
St Anne's College Oxford

Co-Chairs: Andrew Briggs, Jeremy Butterfield and Anton Zeilinger

The Oxford Questions on the foundations of quantum physics
G.A.D. Briggs, J.N. Butterfield, A. Zeilinger. *Proc. R. Soc. A* **469**, 20130299 (2013)

The Oxford Questions

1. Time, irreversibility, entropy and information

2. The quantum-classical relationships

3. Experiments to probe the foundations of quantum physics

4. Quantum physics in the landscape of theories

5. Interaction with questions in philosophy

The Oxford Questions on the foundations of quantum physics
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The Oxford Questions

a. What experiments can probe macroscopic superpositions, including tests of Leggett-Garg inequalities?

b. What experiments are useful for large complex systems, including technological and biological?

c. How can the progressive collapse of the wave function be experimentally monitored?

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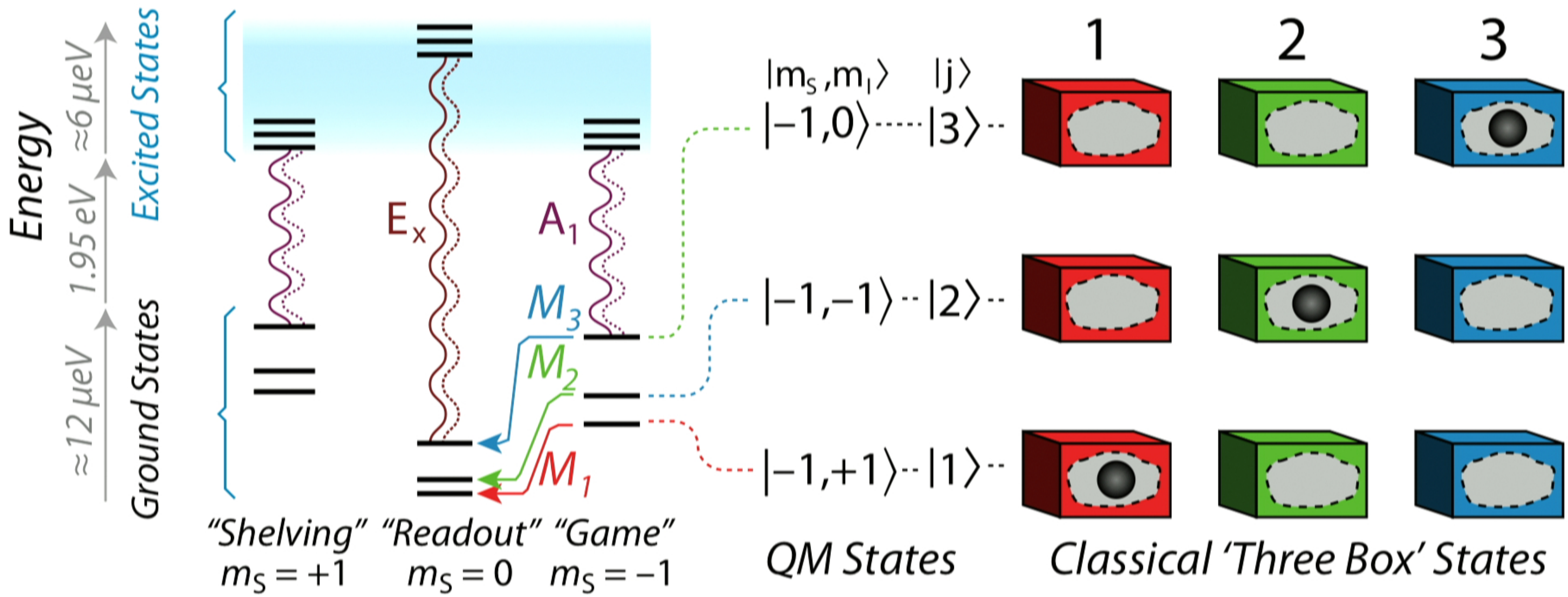
Quantum three box paradox

- Rules: Alice may open only box 3, Bob has boxes 1 and 2.
- Alice tells Bob: "I'll place the ball in the box in position 3 and then shuffle the boxes randomly. You can open box in position 1 *or* 2 (but not both) – I promise not to look. Then I'll shuffle the boxes again and open box 3."
- Alice wagers Bob: "I bet that I can use box 3 to predict when you *saw* the ball in boxes 1 or 2. I can do this with > 50% odds."

R.E. George et al., *Proc. Natl. Acad. Sci.* **110**, 3777-3781 (2013)

Quantum three box paradox



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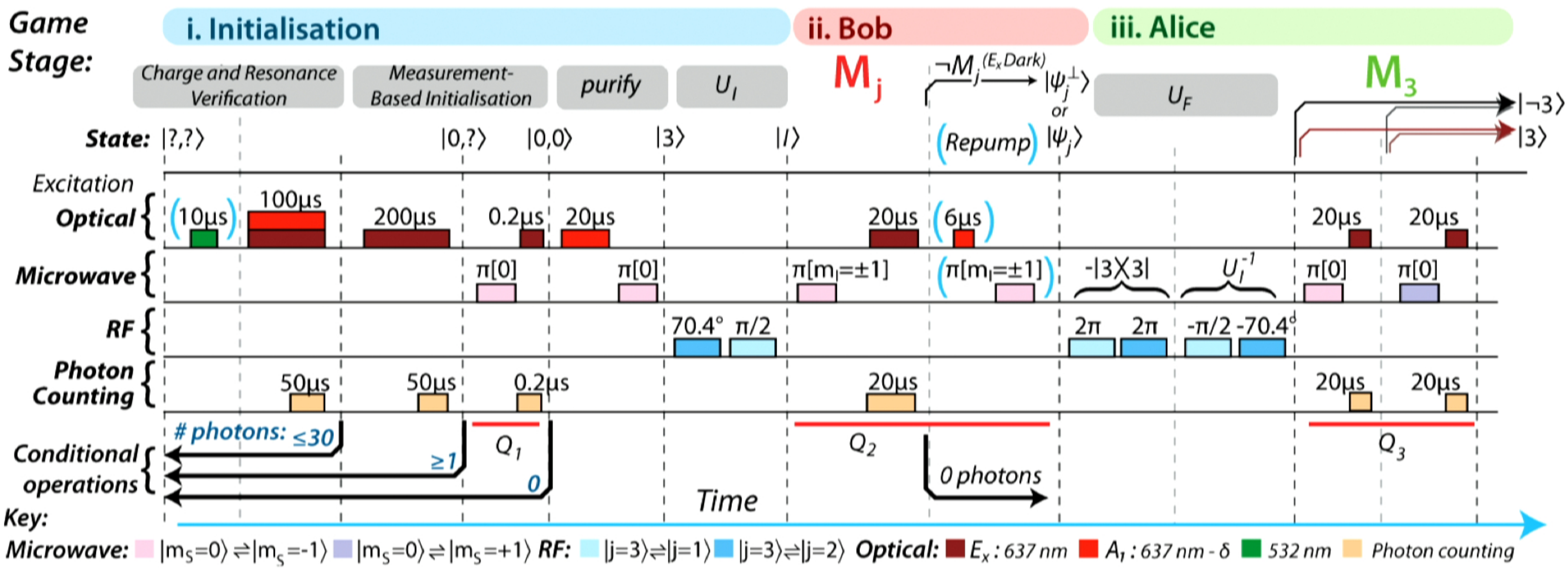

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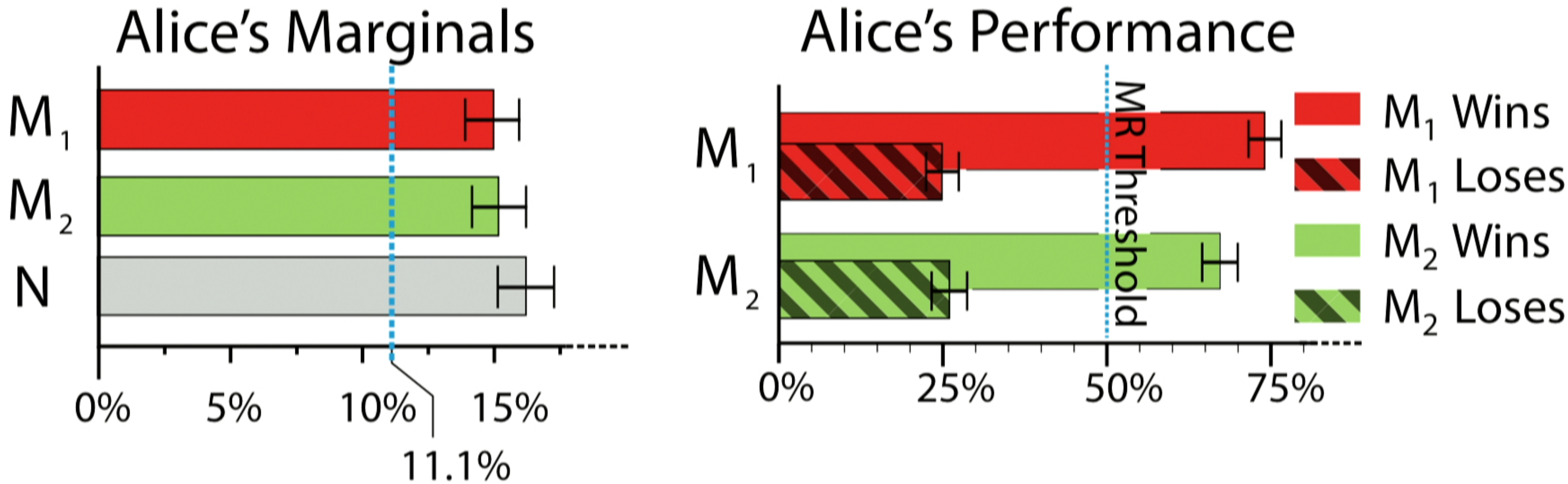
Quantum three box paradox



Do Alice's observations depend on Bob's?

Can she tell which box he looked in?

Can she tell whether he looked at all?

Can Alice win?

By how much?

R.E. George et al., *Proc. Natl. Acad. Sci.* **110**, 3777-3781 (2013)

Quantum three box paradox

$$\langle K \rangle = \langle Q_1 Q_2 \rangle + \langle Q_2 Q_3 \rangle + \langle Q_1 Q_3 \rangle$$

$$\langle K \rangle = \frac{4}{9}\left[1 - \left\{P_{M_1}(B \mid A) + P_{M_2}(B \mid A)\right\}\right] - 1$$

Macrorealist: $P_{M_1}(B \mid A) + P_{M_2}(B \mid A) \leq 1 \Rightarrow \langle K \rangle \geq -1$

Quantist: $P_{M_1}(B \mid A) + P_{M_2}(B \mid A) \leq 2 \Rightarrow \langle K \rangle \geq -\frac{13}{9} = -1.4\dot{4}$

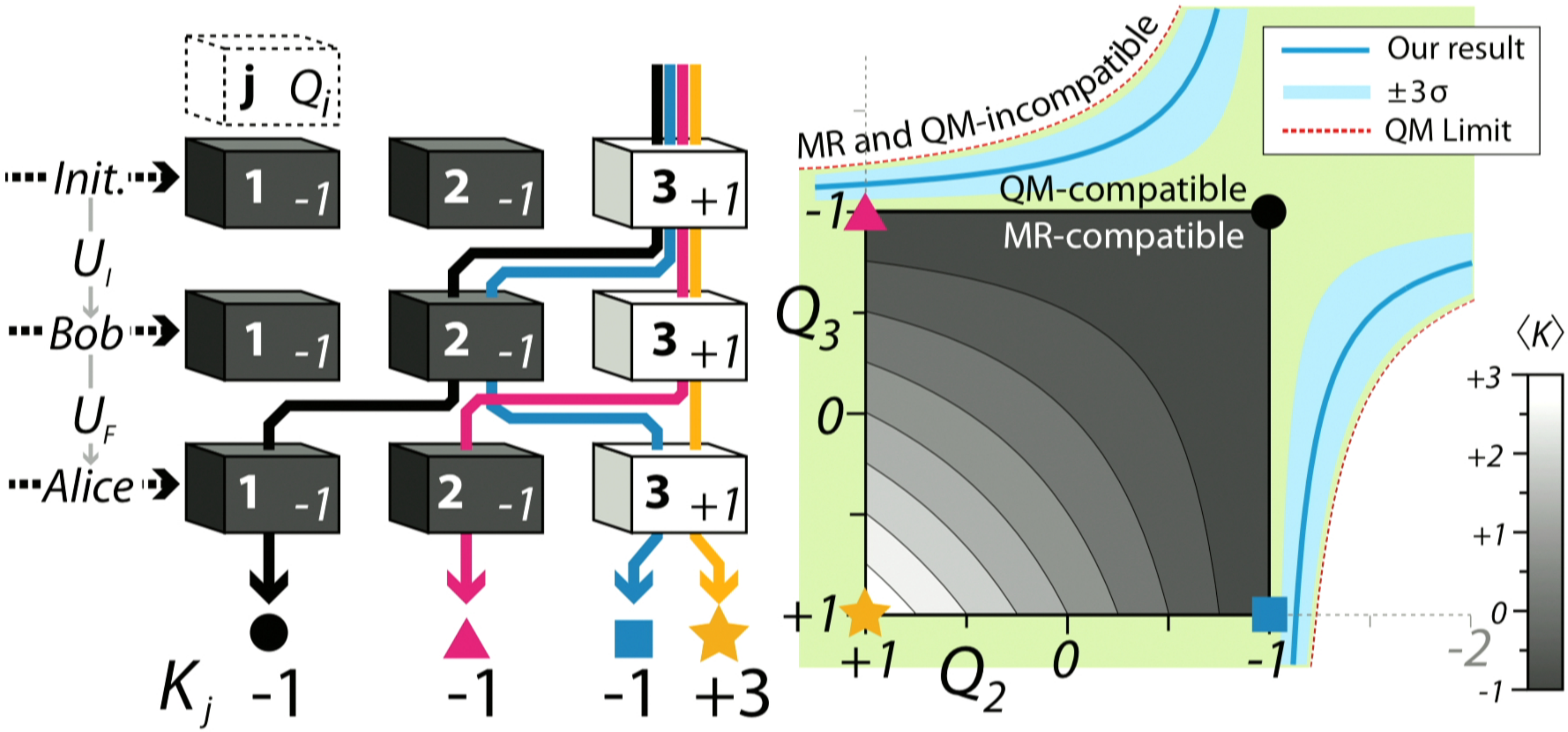
experiment: $\langle K \rangle = -1.265 \pm 0.023$

$11.3\ \sigma$ under fair sampling assumptions

$7.8\ \sigma$ if attributed to Alice cheating

R.E. George et al., *Proc. Natl. Acad. Sci.* **110**, 3777-3781 (2013)

Quantum three box paradox



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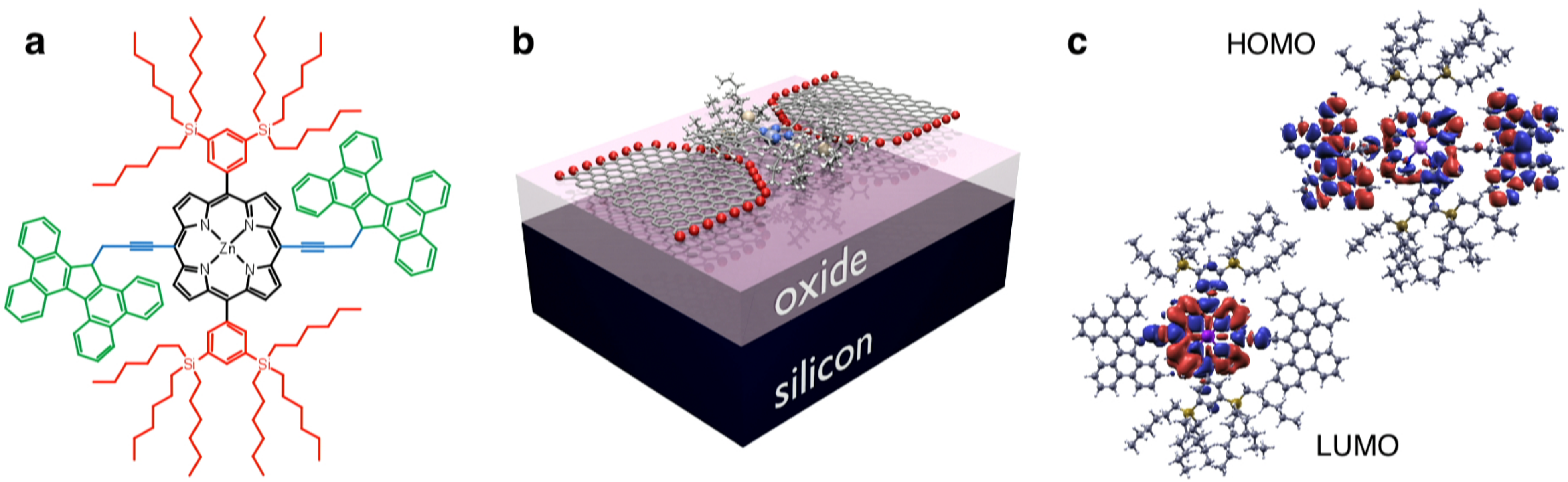
Graphene-porphyrin single-molecule transistors



J.A. Mol *et al.*, *Nanoscale* **7**, 13181–85 (2015)

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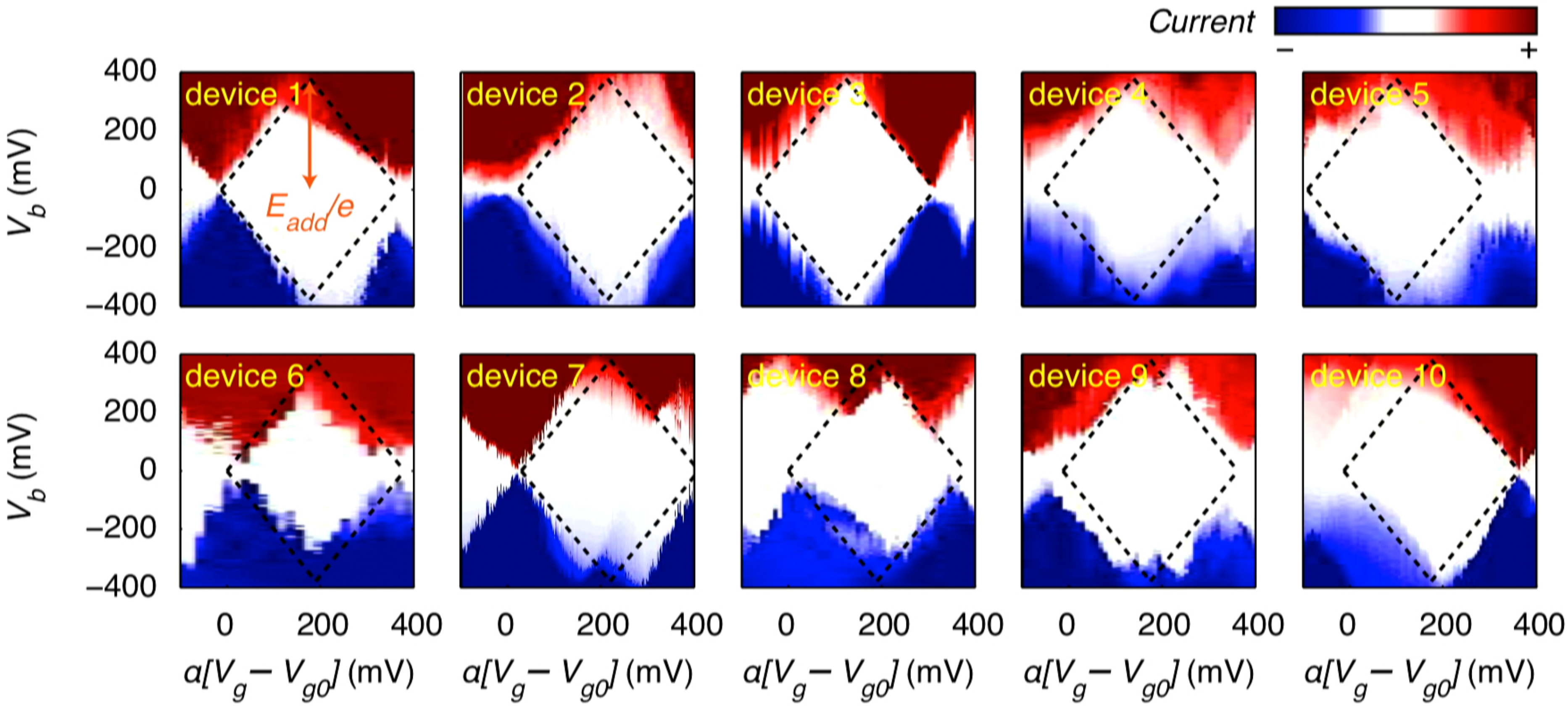

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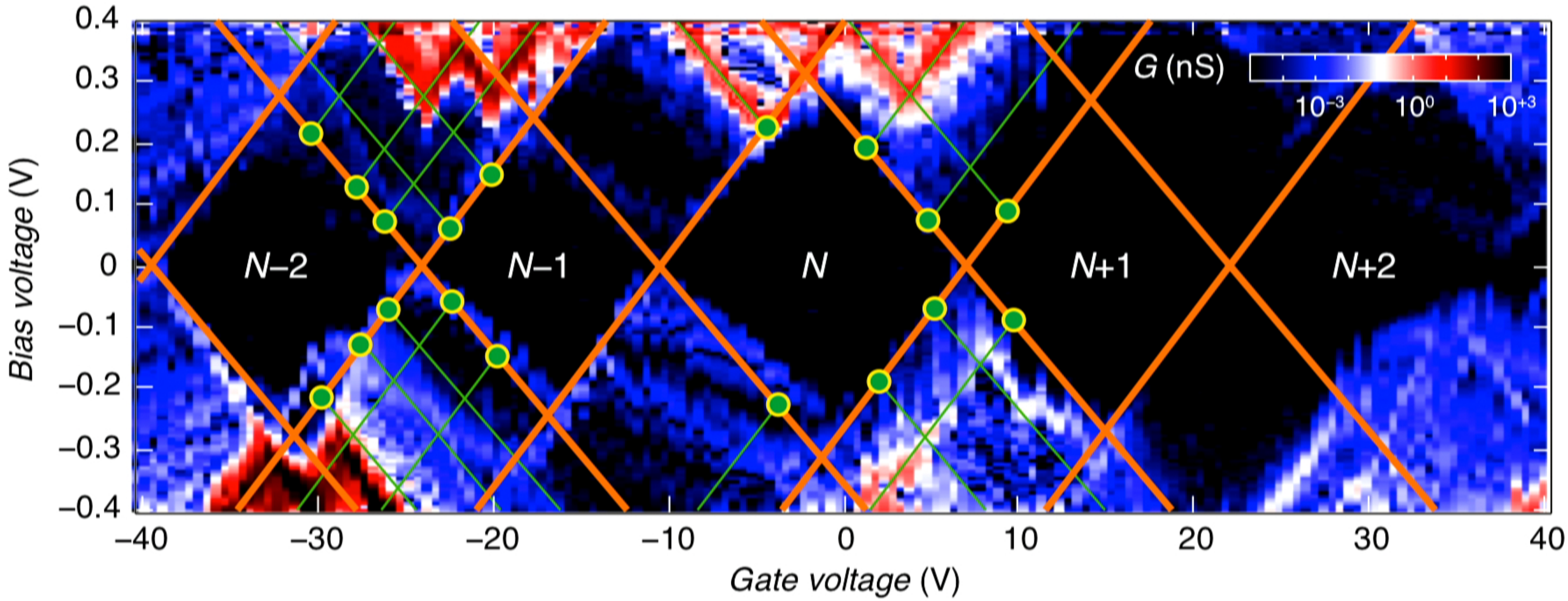

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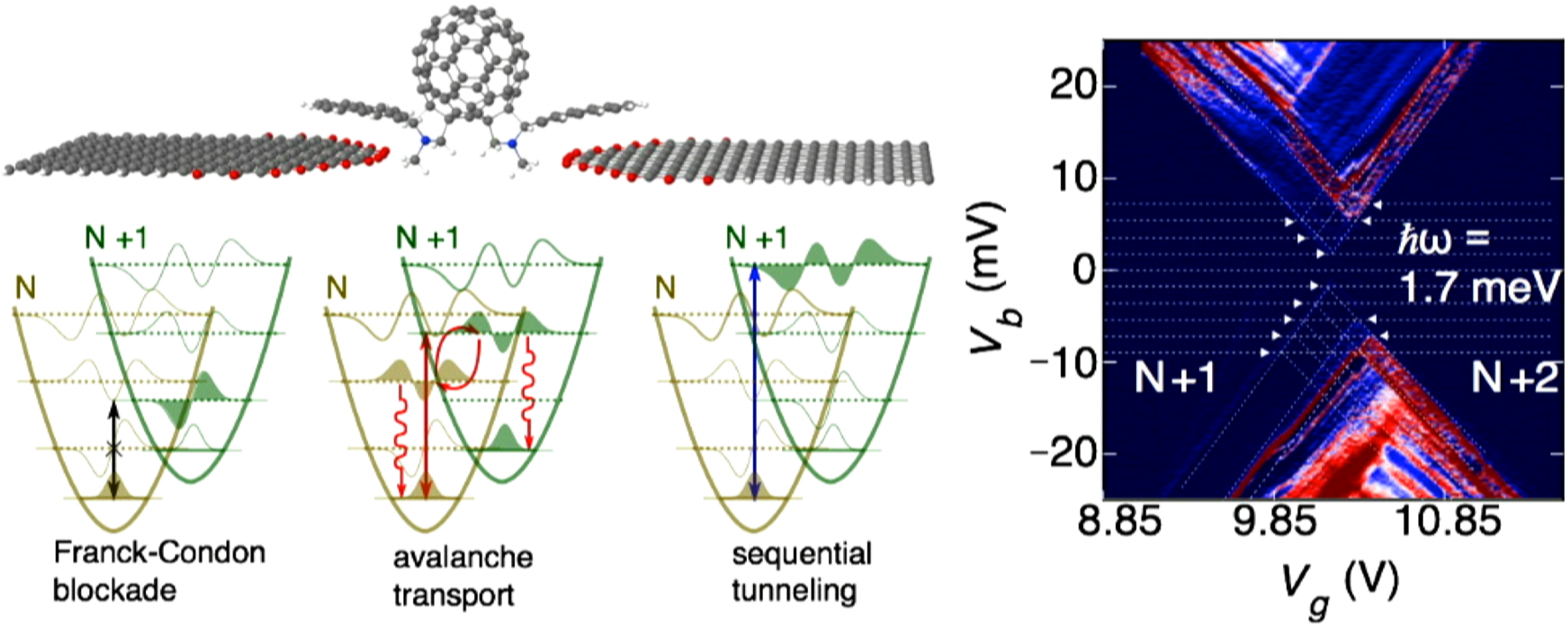

C.S. Lau *et al.*, *Nano Lett*. **16**, 170–176 (2016)

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Detecting continuous spontaneous localisation

CSL could be detected in an ion trap of size ~ 1 cm at a pressure of 10^{-13} Pa in a time of ~1 minute.

For an osmium sphere the maximum ERR in free space is 1.57×10^{-33} J s^{-1} or 6.8 nK per minute.

Can you detect a temperature rise of 10 nK in 90 s, or equivalently 100 nK after 15 minutes?

Y. Li *et al.*, arXiv:1605.01881

Detecting continuous spontaneous localisation

Energy raising rate

$$\Upsilon = \chi \hbar^2 \lambda r_c \rho u^{-2}$$

$\lambda \sim 10^{-16}\ \mathrm{s}^{-1}$

$r_c \sim 10^{-7}$

ρ is density

u is mass of body

Contributions to heating

1. Mechanical vibrations
2. Electric field noise
3. Magnetic field noise
4. Background gas collisions
5. Electric dipole radiation
6. Scattering black body radiation

Y. Li *et al.*, arXiv:1605.01881

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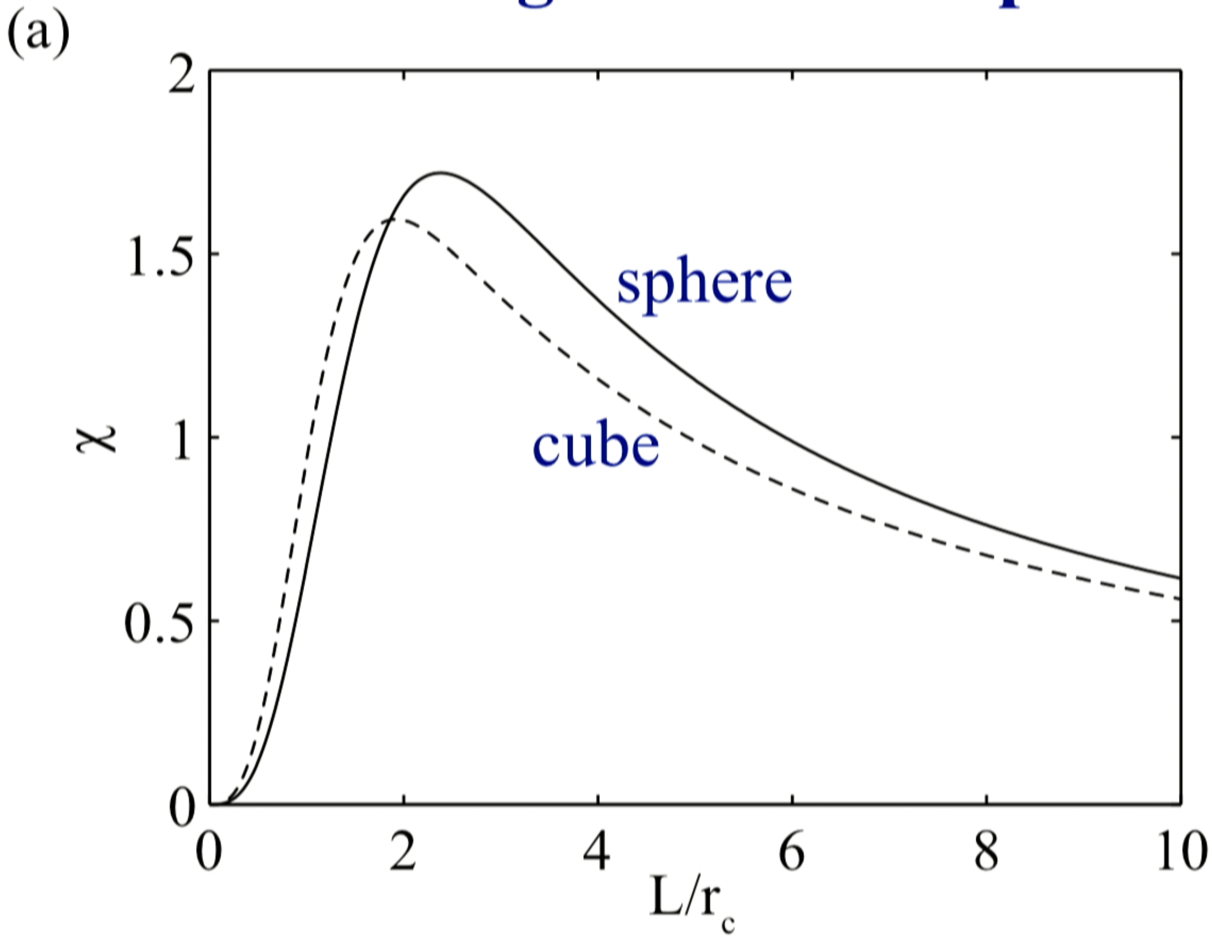

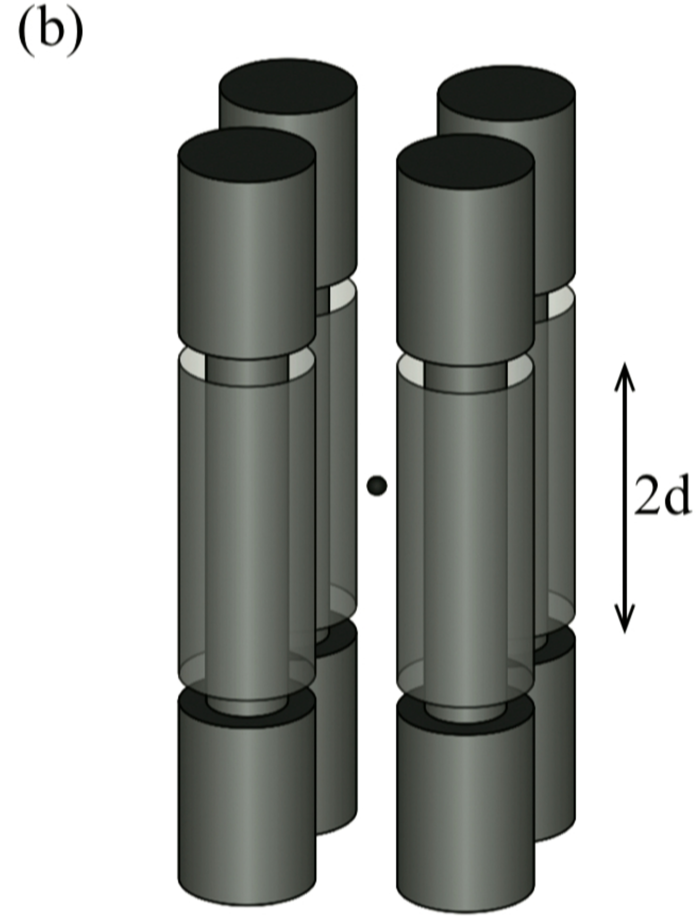

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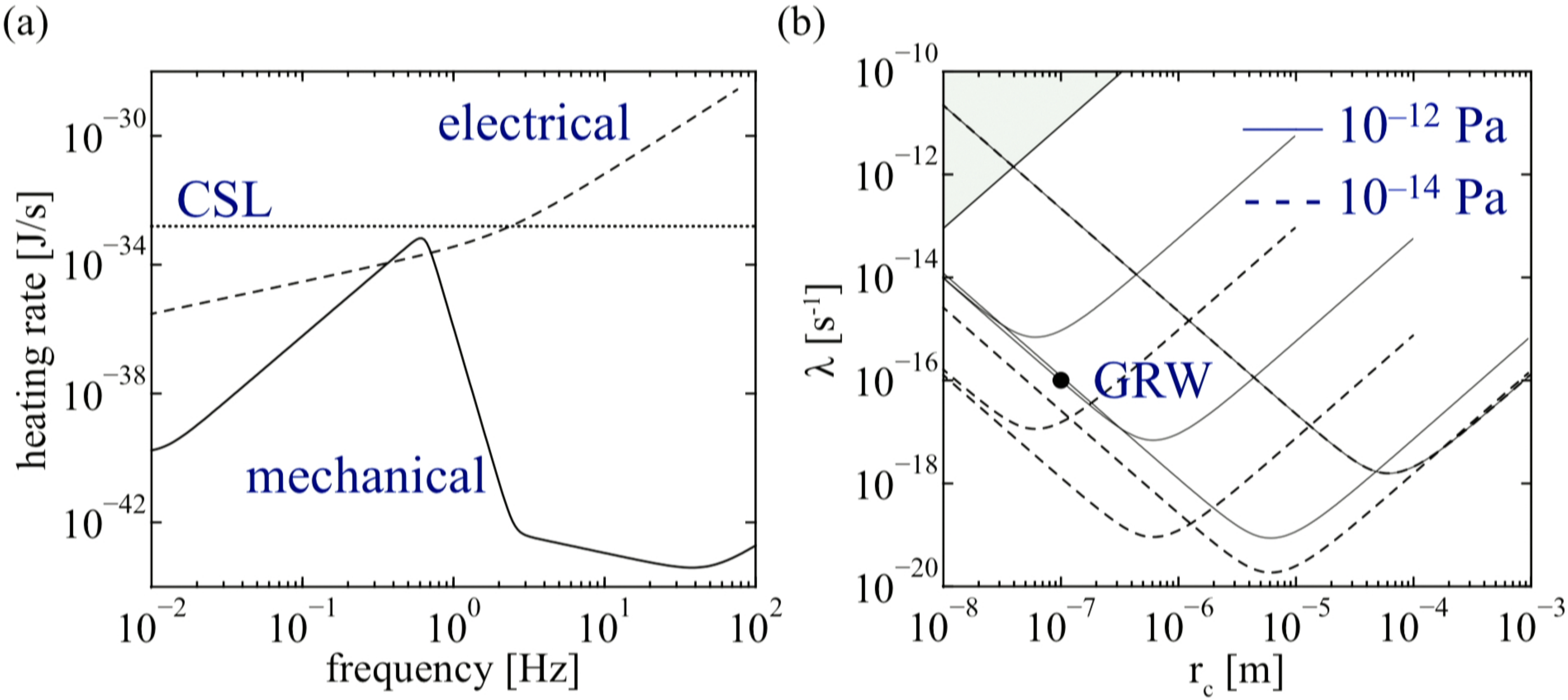

Y. Li *et al.*, arXiv:1605.01881


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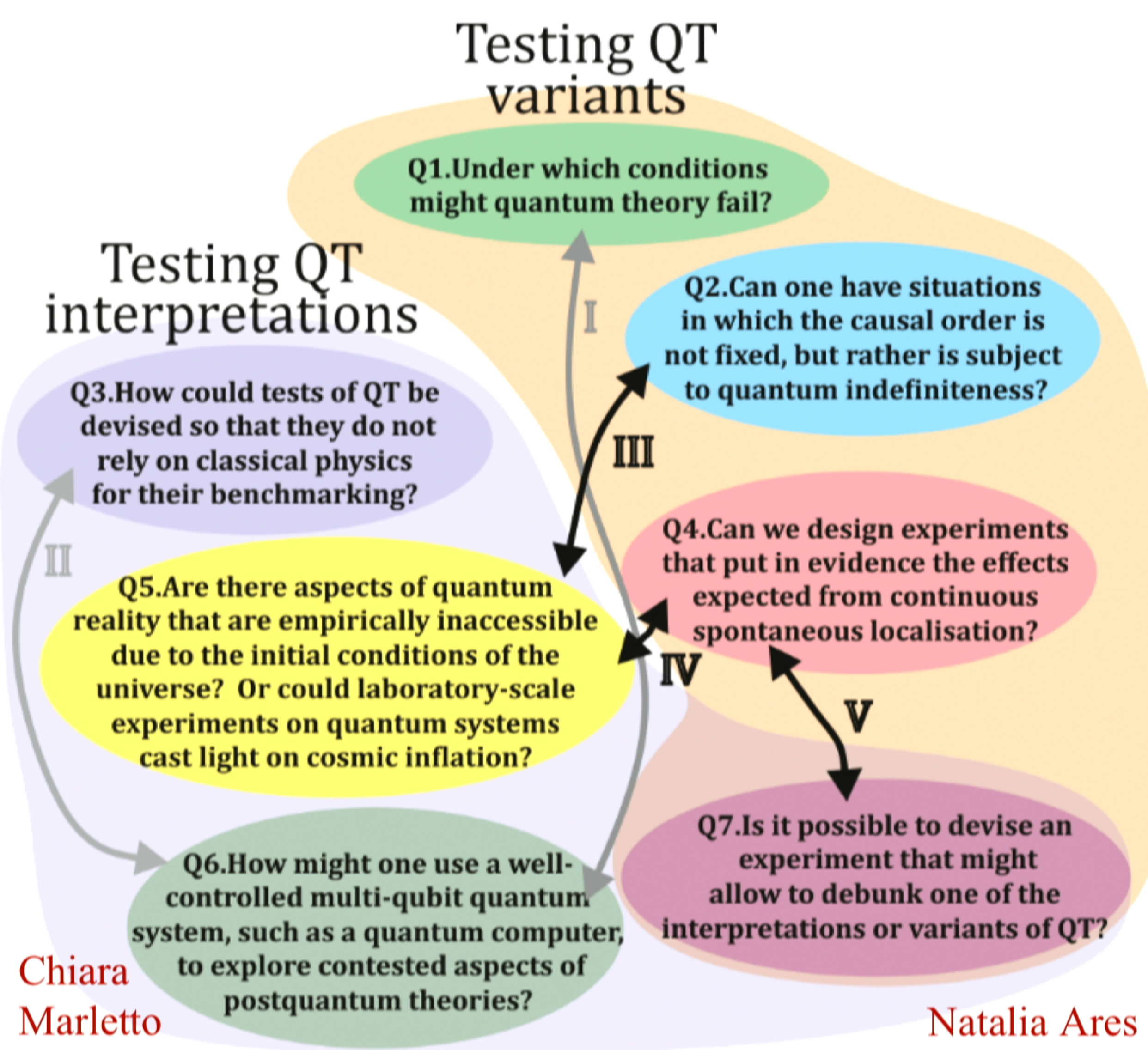
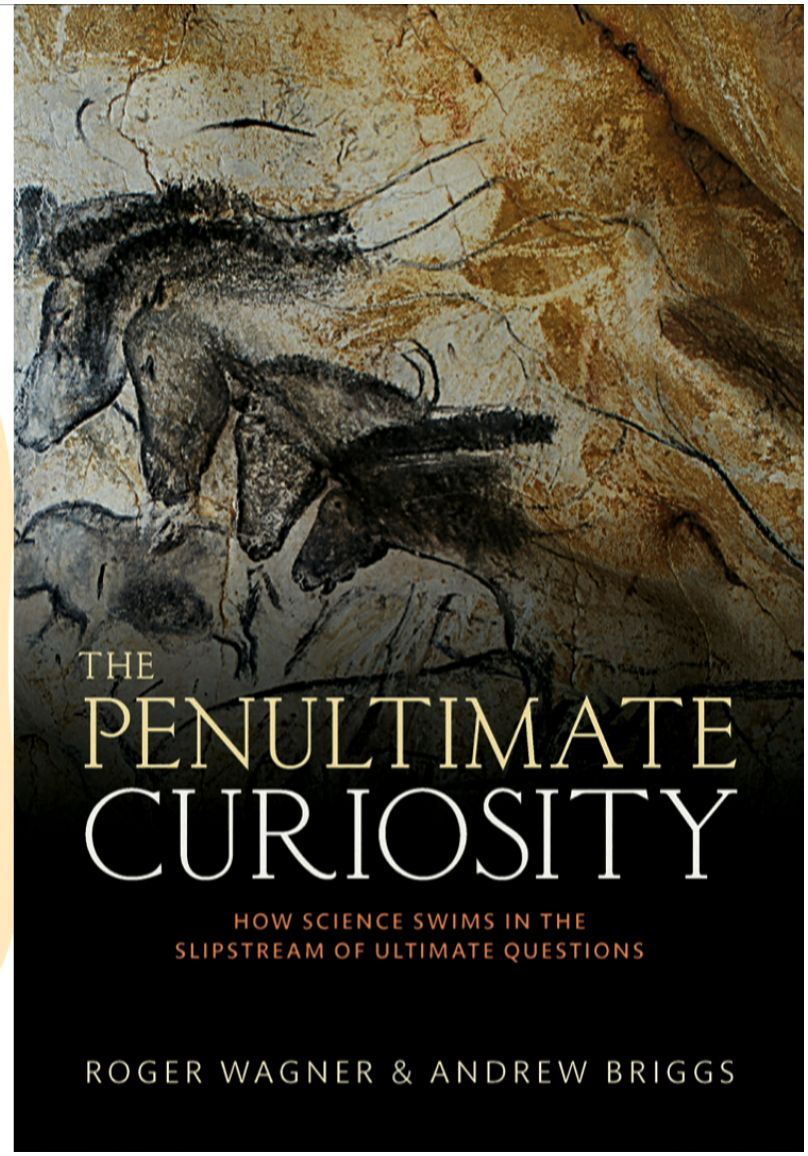

Testing QT variants
Q1.Under which conditions might quantum theory fail?
Testing QT interpretations
I
Q2.Can one have situations in which the causal order is not fixed, but rather is subject to quantum indefiniteness?
Q3.How could tests of QT be devised so that they do not rely on classical physics for their benchmarking?
III
Q4.Can we design experiments that put in evidence the effects expected from continuous spontaneous localisation?
II
Q5.Are there aspects of quantum reality that are empirically inaccessible due to the initial conditions of the universe? Or could laboratory-scale experiments on quantum systems cast light on cosmic inflation?
IV
V
Q7.Is it possible to devise an experiment that might allow to debunk one of the interpretations or variants of QT?
Q6.How might one use a well-controlled multi-qubit quantum system, such as a quantum computer, to explore contested aspects of postquantum theories?
Chiara Marletto
Natalia Ares


THE
PENULTIMATE
CURIOSITY
HOW SCIENCE SWIMS IN THE
SLIPSTREAM OF ULTIMATE QUESTIONS
ROGER WAGNER & ANDREW BRIGGS

Electricity consumption in ICT

1. Globally, ICT sector uses 4.6% of the overall world electricity (900 million MWh in 2012).
   a) Expected to double within the next ten years
2. 29% for data centers
   a) 1.4% of global electricity usage
3. 37% for telecommunication
   a) 1.7% of global electricity usage
4. 34% for end use devices (phones, PCs etc.)
   a) 1.6% of global electricity usage

Miller, J., Bird, L., Heeter, J., Gorham, B.
Renewable Electricity Use by the U.S. Information and Communication Technology (ICT) Industry.
NREL – Report **NREL/TP- 6A20-64011** July 2015

Electricity consumption in ICT

WiMAX wide area wireless data access /bit	10 μJ
Sending a bit over the internet /bit	1 μJ
Optical wavelength-division multiplexed link /bit	10 nJ
Reading from DRAM /bit	30 pJ
Communicating a bit off chip /bit	10 pJ
Floating point operation /bit	1 pJ
Energy stored in DRAM cell	10 fJ
Switching one CMOS gate	1 fJ
1 electron at 1 V (1 eV)	0.16 aJ = 160 zJ
Landauer limit $k_B T \ln 2$ at $T = 300$ K	3 zJ

David Miller, Stanford, *Royal Society e-Futures*, May 14, 2013

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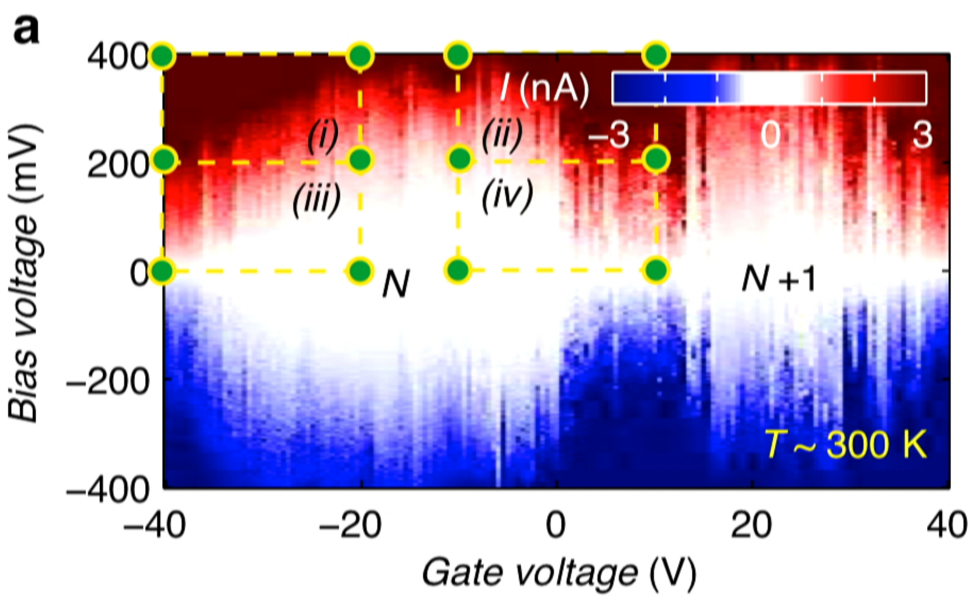

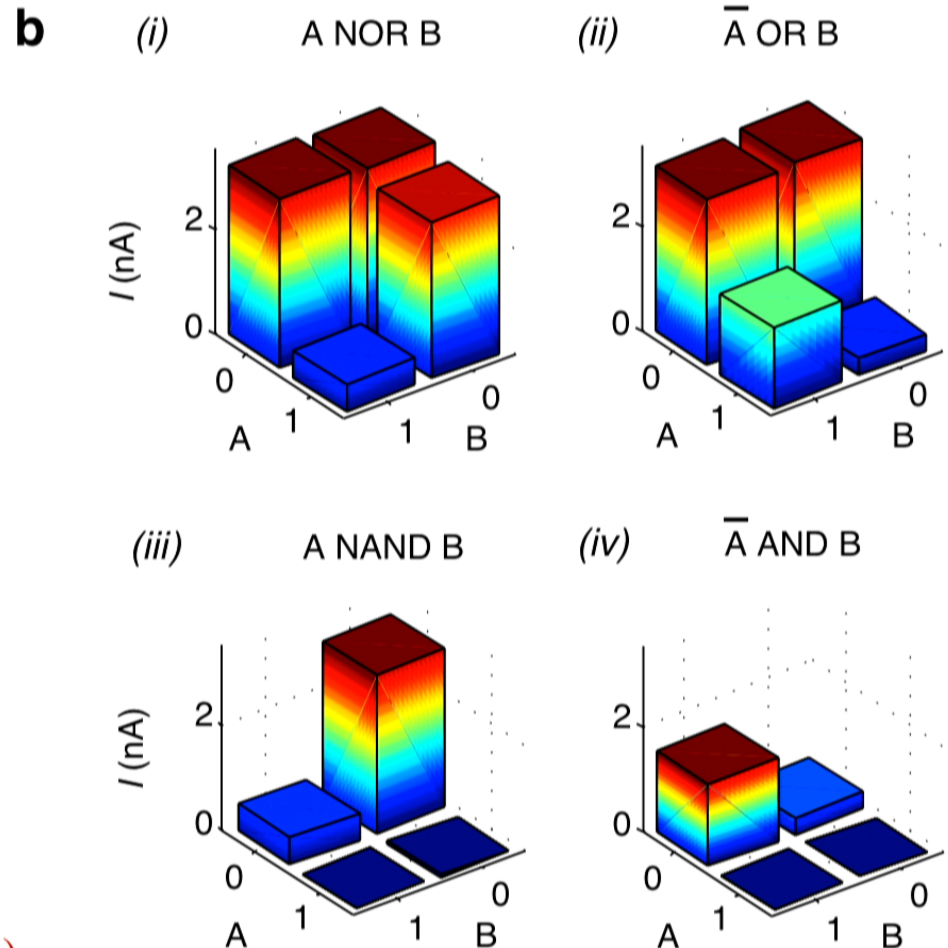

J.A. Mol *et al.*, *Nanoscale* **7**, 13181–85 (2015)

The Unreasonable Effectiveness of Curiosity

There will be many occasions when we are challenged about the real-world benefits of our work. When someone asks: "What is the earthly use of knowing that?" We should be strong enough, and confident enough to reply: "You know, I've absolutely no idea what use it might be. But isn't it fascinating?"

Vice-Chancellor's Oration, Oxford
(7 October 2014)