Title: Can a qubit be your friend? Why experimental metaphysics needs a quantum computer

Speakers: Howard Wiseman Series: Quantum Foundations Date: April 16, 2021 - 5:00 PM

URL: http://pirsa.org/21040019

Abstract: Experimental metaphysics is the study of how empirical results can reveal indisputable facts about the fundamental nature of the world, independent of any theory. It is a field born from Bellâ $\in^{TM}$ s 1964 theorem, and the experiments it inspired, proving the world cannot be both local and deterministic. However, there is an implicit assumption in Bellâ $\in^{TM}$ s theorem, that the observed result of any measurement is absolute (it has some value which is not â $\in^{T}$ relative to its observerâ $\in^{TM}$ ). This assumption may be called into question when the observer becomes a quantum system (the â $\in \infty$ Wignerâ $\in^{TM}$ s Friendâ $\in^{\bullet}$  scenario), which has recently been the subject of renewed interest. Here, building on work by Brukner, we derive a theorem, in experimental metaphysics, for this scenario [1]. It is similar to Bellâ $\in^{TM}$ s 1964 theorem but dispenses with the assumption of determinism. The remaining assumptions, which we collectively call "local friendliness", yield a strictly larger polytope of bipartite correlations than those in Bell's theorem (local determinism), but quantum mechanics still allows correlations outside the local friendliness polytope. We illustrate this in an experiment in which the friend system is a single photonic qubit [1]. I argue that a truly convincing experiment could be realised if that system were a sufficiently advanced artificial intelligence software running on a very large quantum computer, so that it could be regarded genuinely as a friend. I will briefly discuss the implications of this far-future scenario for various interpretations and modifications of quantum theory.

[1] Kok-Wei Bong, AnÃ-bal Utreras-AlarcÃ<sup>3</sup>n, Farzad Ghafari, Yeong-Cherng Liang, Nora Tischler, Eric G. Cavalcanti, Geoff J. Pryde and Howard M. Wiseman,&nbsp;"A strong no-go theorem on the Wignerâ€<sup>TM</sup>s friend paradox",&nbsp;Nature Physics&nbsp;(2020).

# CAN A QUBIT BE YOUR FRIEND?

Why experimental metaphysics needs a quantum computer

# Howard M. Wiseman







A thoughtful "Local Friendliness" no-go theorem: A formulation using four metaphysical and two technological assumptions, each with relevance for quantum interpretations

> Howard M. Wiseman, Eric G. Cavalcanti, and Eleanor G. Rieffel





# Outline



#### Introduction

- Motivation
- Bell's Theorem
- Wigner's musings



The Griffith Experiment

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- Beyond the Toy Experiments
- Implications for Interpretations

### Conclusions

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Conclusions	

Introduction Motivation

# A novel customer for a quantum computer:

Philosophers wanting to advance experimental metaphysics

## metaphysics | meta-frziks |

plural noun [usually treated as singular]

the branch of philosophy that deals with the first principles of things, including abstract concepts such as being, knowing, identity, time, and space:





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Introduction Bell's Theorem

## Bell's 1964 Theorem

Physics Vol. 1, No. 3, pp. 195-290, 1964 Physics Publishing Co. Printed in the United States

#### ON THE EINSTEIN PODOLSKY ROSEN PARADOX\*

J. S. BELL<sup>†</sup> Department of Physics, University of Wisconsin, Madison, Wisconsin

(Received 4 November 1964)



the statistical predictions of quantum mechanics are incompatible with separable predetermination. [That is, in any] theory in which parameters ... determine the results of individual measurements, ... there must be a mechanism whereby the setting of one measurement device can influence the reading of another instrument, however remote.

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#### Introduction Bell's Theorem

Since 2015, Bell experiments rule out the conjunction of these **metaphysical** assumptions

- Absoluteness of observations. An observation is a real single event, and not 'relative' to anything or anyone.
- Predetermination of observable events. For any observable event *A*, and any event *α* in the past light cone of *A*, there is a space-like hypersurface *S* containing *α* such that all events on, or variables defined on, *S*, plus *free choices* subsequent to *S*, suffice to determine *A*.
- Local action. Any free choice x, made in a manner appropriate for a randomized experiment, is, for the purpose of that experiment, correlated only with events in its future light cone.

(Not the same as **Local causality** or **Locality**. Also rules out **Superdeterminism.)** 



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«It is natural to ask about the situation if one does not make [an] observation oneself but lets someone else carry it out. What is the wave function if my **friend** looked [at the quantum object]? The answer is that ... one could [only] attribute a wave function to the joint system [of] friend plus object,  $\alpha(\psi_1 \times \chi_1) + \beta(\psi_2 \times \chi_2)$  [which] follows from the linearity of [Schrödinger's] equation. [This] appears absurd because it implies that my friend was in a state of suspended animation before he answered my question [about what he saw].

It follows that [Schrödinger's equation] cannot be linear if [it] is accepted ... that "my friend" has the same types of impressions and sensations as I.»



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Introduction

Wigner's 1961 musings on the QMP

**Remarks on the Mind-Body Question** 

Wigner's musings

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Brukner's Scenario: Bell+Wigner

# Outline

#### Introduction

- Motivation
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- Wigner's musings
- A New Theorem, A New Experiment

   Brukner's Scenario: Bell+Wigner
   The Griffith Theorem
   The Griffith Experiment

   In Hilbert Space, No One Can Hear You Dream
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   Implications for Interpretations

#### 4) Conclusions

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- Incorporate "Wigner's friends" into a Bell experiment.
- The idea: get rid of predetermination by making the friends' observations play the role of the hidden variables λ.
- One of the assumptions is (contrary to Wigner) that the friends can be in superpositions, and do not collapse the wavefunction.
- Brukner's formalization of his metaphysical assumptions made them as strong as Bell's assumption of local predetermination.
- © But we found a new theorem, using a much weaker formalization (much weaker assumptions than Bell).

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# 2 A New Theorem, A New Experiment Brukner's Scenario: Bell+Wigner The Griffith Theorem The Griffith Experiment

- In Hilbert Space, No One Can Hear You Dream
  - Beyond the Toy Experiments
  - Implications for Interpretations

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**Superpowers** is *not* a metaphysical assumption. Its truth can be decided experimentally, for a given Wigner and a given friend.

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A New Theorem, A New Experiment

The Griffith Experiment

# Technical and Experimental Details





# The Griffith Experiment and Beyond

- The experiment violated a LF inequality by >17 SDs.
- However, each 'friend' was a single qubit (photon path), making four qubits in total (so that we did not require real <u>superpowers</u>).
- Can a qubit be a friend? Obviously not a real friend, which is why we called it a "microscopic proof-of-principle version".
- What about real experiment? What makes a 'friend' a real friend?
  - A sufficiently large/complex quantum system? Interesting direction. But there are numerous different criteria and no agreed thresholds.
  - «An irreversible act of amplification»[Bohr⊨Wheeler]? Yeeees, but that won't work here because for the experiment the observation must be reversible (at least according to standard QM).
  - A sentient being with «the same types of impressions and sensations as I»[Wigner]? The best feasible option.
  - But how could the evolution of a sentient observer be *unitarily reversed*? It would have to be an AI realized on an *enormous* fault-tolerant quantum computer.

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Beyond the Toy Experiments

# Outline



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#### In Hilbert Space, No One Can Hear You Dream Beyond the Toy Experiments

### Practicalities of such an experiment

- We could consider simulating a whole biological organism, and its environment. Probably  $\gg 10^{24}$  logical qubits.
- The simpler option (probably  $\gg 10^{12}$  logical qubits): simulating just a mind. *i.e.*, running a human-level artificial intelligence algorithm.
- For us to become friends with Charlie, a two-way communication channel to the external world would be needed.
- But during the experiment Charlie would have to be completely isolated for a second or so of experiential time, and his evolution would then have to be reversed so that he had no memory of that experience having ever happened.
- Would Charlie would willingly participate in such an experiment?

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• Would the experiment get ethical approval, even if Charlie agreed?

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Beyond the Toy Experiments

# Constructing a theorem without <a>Superpowers</a>

The conjunction of these assumptions<sup>1</sup> is a contradiction:

- Physicalism. Any thought supervenes upon a physical process in the brain (or other information-processing unit as appropriate).
- Ego Absolutism. Such of my thoughts that I believe I could, if asked, communicate to another party are absolutely real.
- Friendliness. If, by open-ended communication, an independent party displays cognitive ability on par with my own, then Ego
   Absolutism is as true for them, *mutatis mutandis*, as it is for me.
- Human-Level Artificial Intelligence is possible (*i.e.* digitally).
- Universal quantum computing can be done at extremely large scale, and very fast.
- Local action. Any (human-level) free choice x, ..., is correlated only with events in its future light-cone.

<sup>1</sup>(The ones in brick are not metaphysical; they are empirical but open.)



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Implications for Interpretations

# How do some interesting interpretations stack up?

Interpretation / Modification	Local Action	Physic -alism	Ego Abs.	Friend -liness	HL-AI	UQC
Consc. → Collapse						
<i>e.g.</i> Wigner	Y	Y	Y	Y	У	N
H.L.I.⇒Collapse						
e.g. Penrose	?	Y	Y	Y	N	У
'P.O.' Spont. Collapse						
e.g. GRWf,GRWm	Y	Y	Y	Ν	У	У
Relativism						
e.g. QBism, Everett	Y?	Y	Ν	Y	У	У
Single-Minded MWI						
e.g. Albert & Loewer	Y	Ν	Y	Y	У	У
Hidden Variables						
<i>e.g.</i> Bohm	N	Y	Y	?	У	У
'No Interpretation'						
e.g. most physicists	Y	Y	Y	у	У	Y
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Beyond the Toy Experiments

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Beyond the Toy Experiments

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#### Conclusions

# Take-home messages

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- Non-testable metaphysical assumptions can have falsifiable empirical consequences *in conjunction*.
- In the case of Bell, falsified empirical consequences.
- Continued advances in Artificial Intelligence, Q-computing (and Q-comms) will open a *new frontier* in experimental metaphysics.
- Specifically, we could rule out the conjunction of:
  - Physicalism. Any thought supervenes upon a physical process ....
  - **Ego Absolutism**. ... [M]y thoughts ... are absolutely real.
  - Friendliness If ... [a] party displays cognitive ability on par with my own, then Ego Absolutism is as true for them ... as it is for me.
  - Local action. Any (human-level) free choice can be assumed to be uncorrelated with events outside its future light-cone.
- We have performed a proof-of-concept experiment in this area.





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