

Quantum nonlocality based on finite-speed causal influences leads to superluminal signalling

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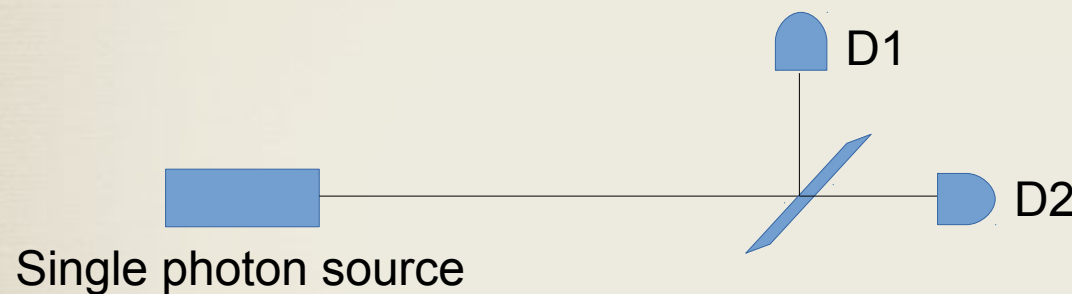
Joint work with

T. J. Barnea, Y.-C. Liang, S. Pironio, A. Acin, V. Scarani, N. Gisin
University of Geneva, ETH Zurich, Free university of Bruxelles, ICFO Barcelona

[Nat. Phys. 8, 867 (2012), Phys. Rev. A 88, 022123 (2013)]

Introduction

- Quantum theory gives probabilities



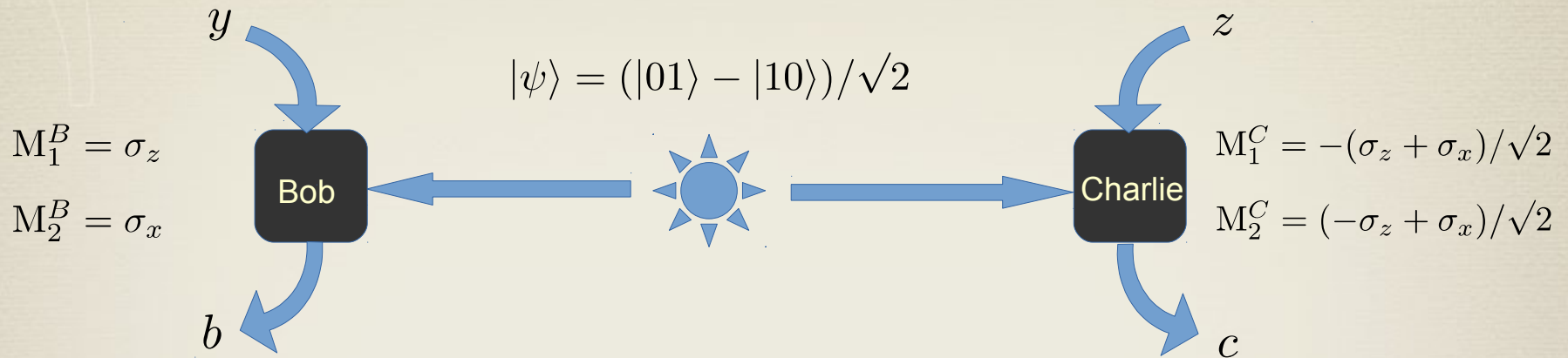
$$|1\rangle \rightarrow (|10\rangle + |01\rangle)/\sqrt{2}$$

$$P(\text{D1 clicks})=1/2$$

$$P(\text{D2 clicks})=1/2$$

- We observe individual realizations... Clicks add up to form the statistics
- “How do these events happen” not stated, but can be easily imagined
- Some situations can be harder to figure out...

Bell experiment



$$\rightarrow P(bc|yz)$$





$$E_{yz} = P(b = c|y, z) - P(b \neq c|y, z)$$

$$CHSH = E_{11} + E_{12} + E_{21} - E_{22} \leq 2 \quad \text{violated}$$

- * How did the measurement devices produce the outcomes leading to these statistics?
- * Suggests that “Behind the scene something is going faster than light” (J. S. Bell, 1989)

Potential causes of correlations

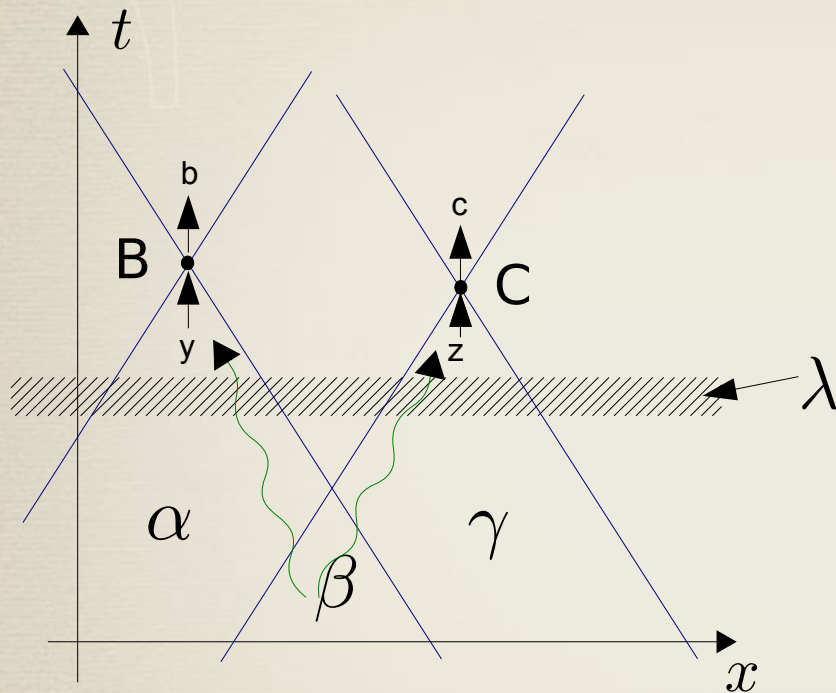
* B and C are correlated

- B  C
 - C  B
- } Direct influence
- A  B
 - A  C
- Common cause



* Does any of this fit with the quantum predictions?

Common causes



* Local causality:

$$b(y, \alpha, \beta), c(z, \beta, \gamma)$$

* λ screens off the past light cones

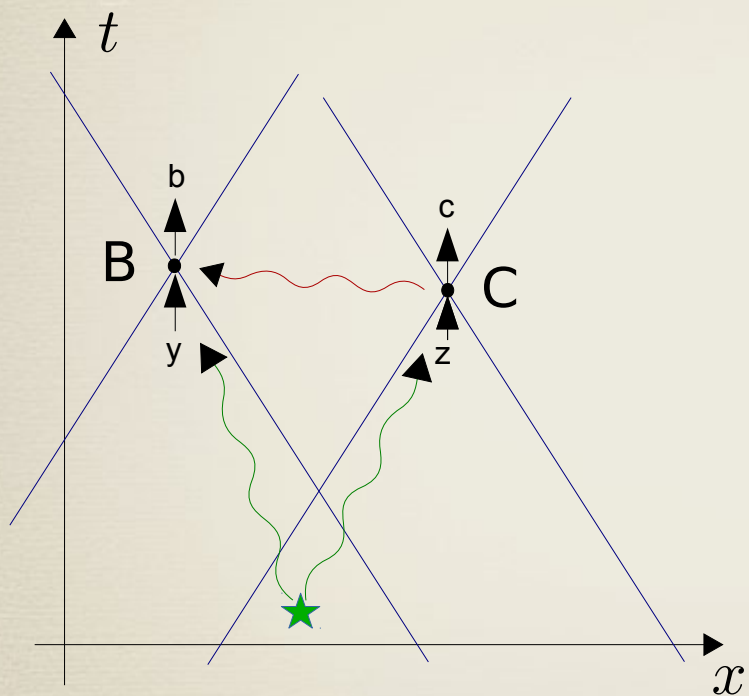
$$b(y, \lambda), c(z, \lambda)$$

$$P(bc|yz) = \sum_{\lambda} q(\lambda)P(b|y, \lambda)P(c|z, \lambda)$$

=> Bell inequalities

Nonlocal correlations don't proceed from common causes

Common causes + influences?



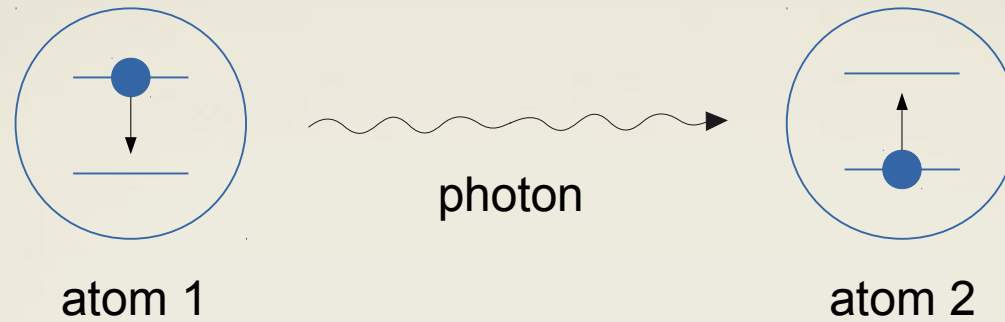
- * Can reproduce any quantum correlations

$$P_Q(bc|yz) = P_Q(c|z)P_Q(b|y, cz)$$

- * Influences must travel $\sim 10'000x$ faster than light
- * A finite speed v is sufficient: preserves a notion of propagation in space-time
- * Influences could remain hidden

Bell found a way to test for hidden variables.
Can we say anything about potential hidden influences?

Hidden? -- an analogy



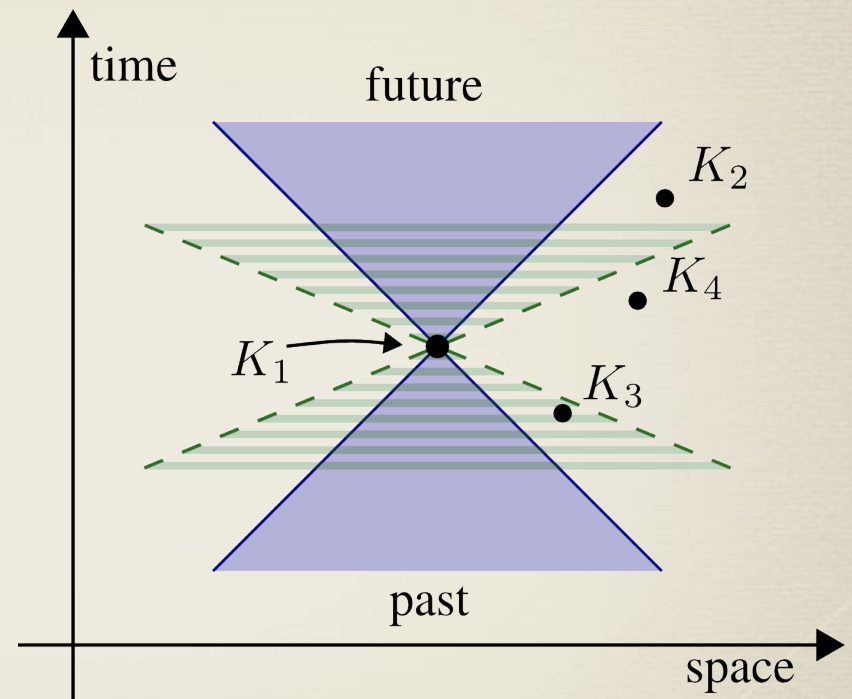
- * The Feynman propagator is non-zero outside the light-cone
- * This can be used to generate entanglement [1]
- * This doesn't open the possibility of faster-than-light communication

v-causality

- In a preferred reference frame
- Speed v arbitrary but finite
- v -cones play the role of light cones in local causality
- No-signalling expected to hold for observable correlations:

$$\sum_b P(bc|yz) = \sum_b P(bc|y'z)$$

Can one test this model?



- Quantum correlations are not reproduced outside v -cones

Revealing bipartite nonlocality

* Tripartite correlations $P(abc|xyz)$ which are

i. BC local and

ii. no-signalling

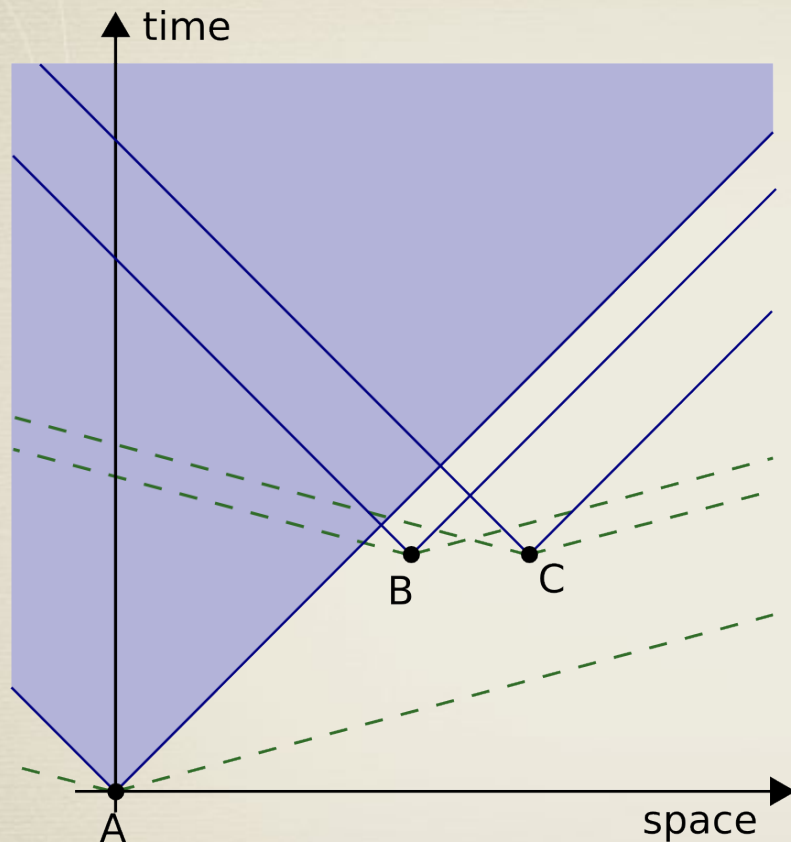
satisfy:

$$\begin{aligned} S = & -(-P_B(0|0) - P_B(0|1) - P_A(0|0) + P_A(1|0) - P_A(0|1) - P_A(1|1)) \\ & + P_{AB}(00|00) + P_{AB}(00|01) + P_{AB}(10|00) - P_{AB}(10|10) + 2P_{AB}(00|10) + 2P_{AB}(10|10) \\ & + 2P_{AB}(00|21) + P_{AB}(10|21) + P_C(0|0) + P_{AC}(00|00) - P_{AC}(00|10) - P_{AC}(10|10) \\ & - P_{AC}(00|20) - P_{AC}(10|20) - P_{AC}(10|01) + P_{AC}(00|11) + P_{AC}(10|11) - P_{AC}(00|21)) \\ & \leq 2 \end{aligned}$$

* This inequality doesn't involve any BC term

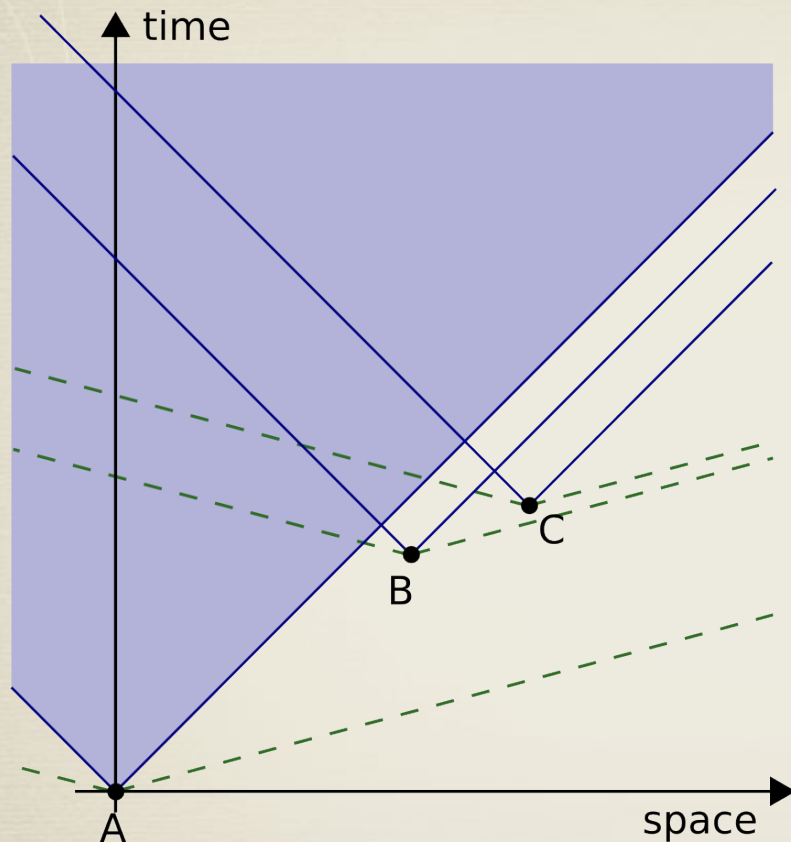
* It has a quantum violation

A particular scenario



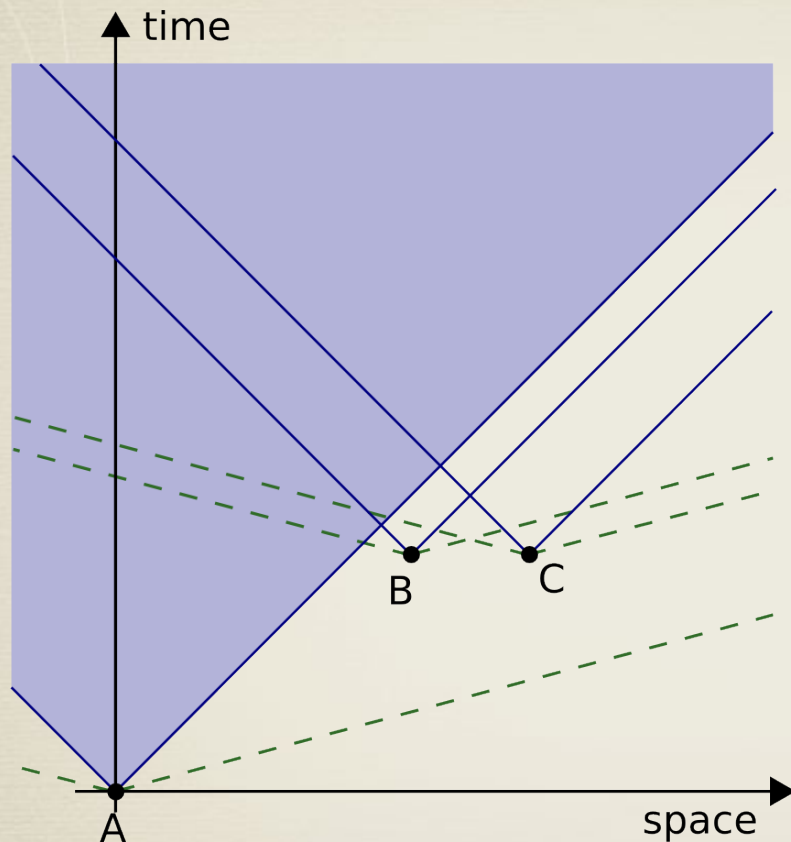
- * v-causality predicts:
 - BC local
 - Quantum AB and AC marginals
- * $S > 2$, so the correlations must be signalling
- * This allows for faster than light communication

A particular scenario



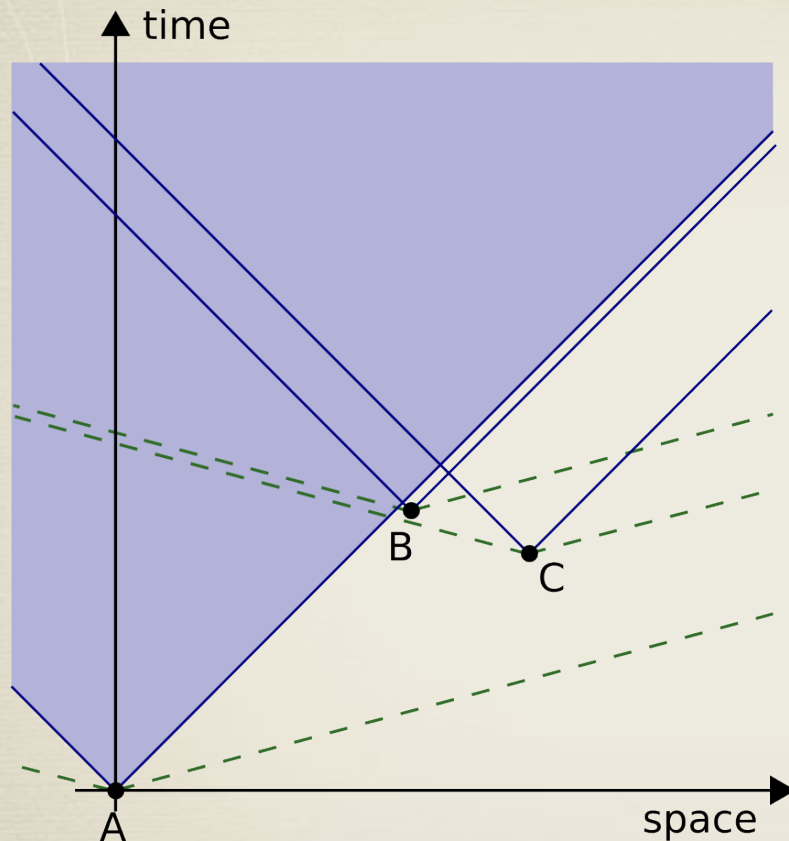
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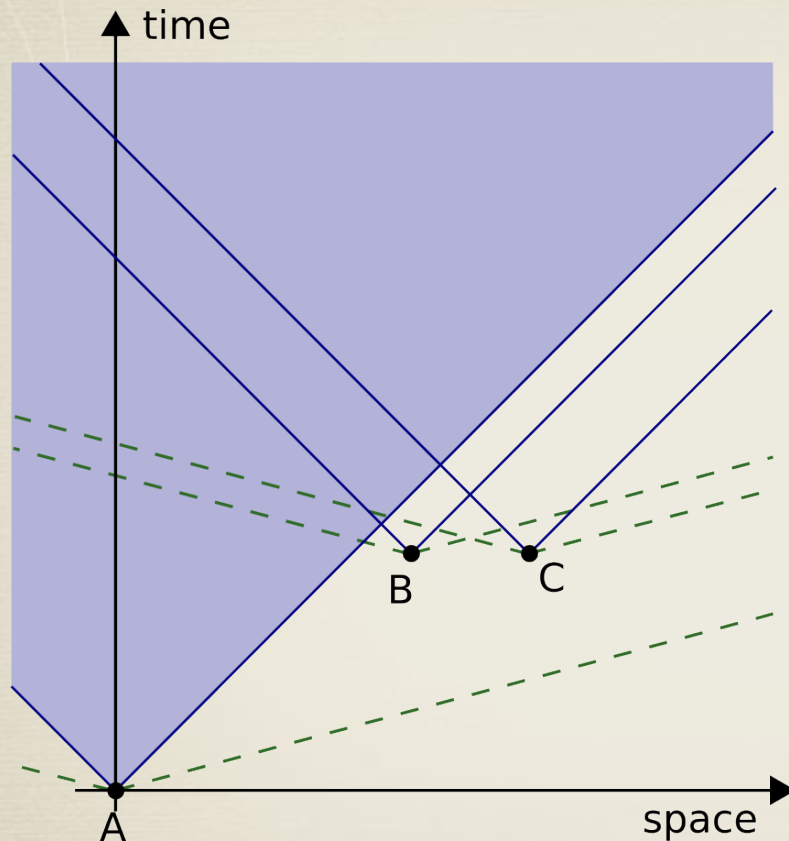
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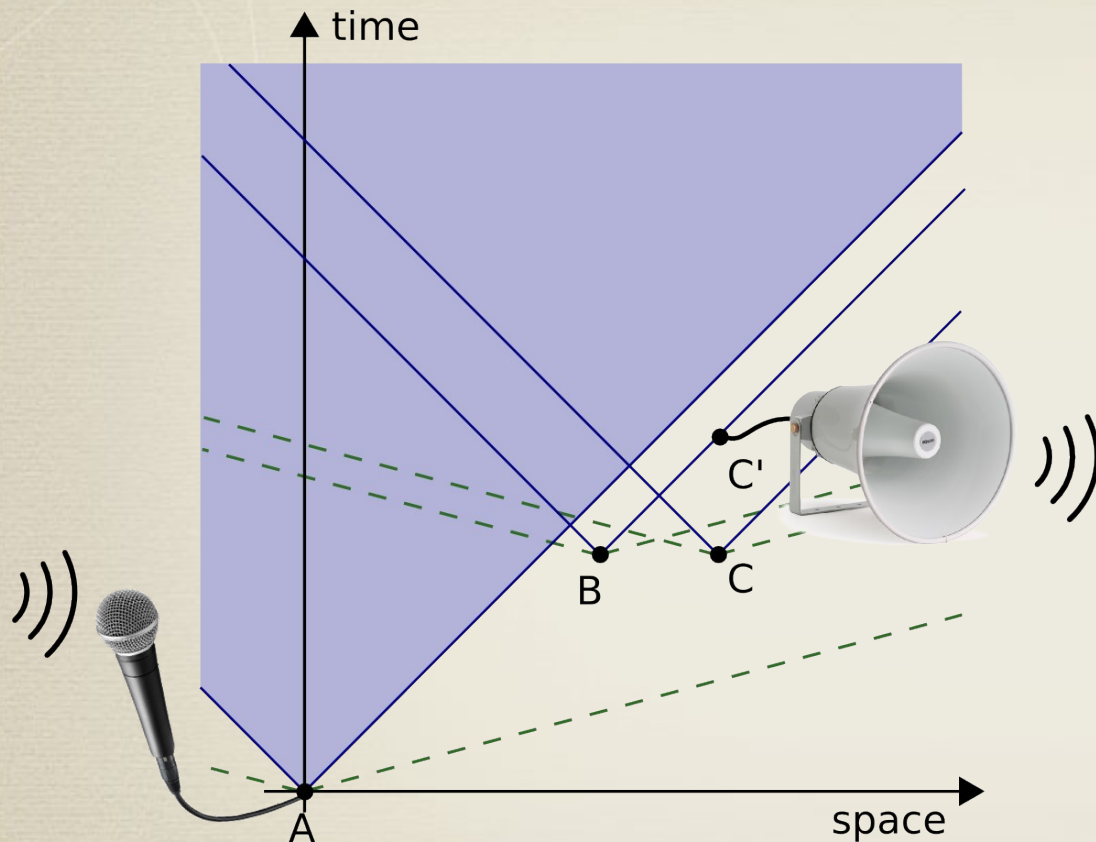
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The influences cannot remain hidden.

Conclusion

- * Influences “behind the scene”:
 - Either allow for faster than light communication
 - Or must be infinitely fast
- * The reasoning can be applied in other situations where a departure from quantum predictions is expected

Thank you for your attention