

Observer or Instrument?

The Physical Status of the Friend in Local Friendliness Experiments

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Abstract

No physical observer is external to the physical universe: every observer is itself composed of what it observes the rest of the universe to be made of. This is not a theorem of any physical theory; it is the standing assumption on which physical theories are built, and no theory of physics postulates an observer outside physics. The Wigner's-friend and Local Friendliness (LF) constructions [1,2] assign one participant, the "superobserver," the formal role of acting on an entire laboratory from outside it. That role is a mathematical device internal to the construction; nothing commits its physical implementation to being external to anything. The physical question these constructions raise is narrower and answerable: does a photonic Friend, implemented as the papers describe, carry the further properties - a persistent, independently accessible record - that the word "observer" carries in the original thought experiment, or only the coherent-memory properties the protocol requires? Reported LF violations [3,4] establish a precise result about the operational quantum systems used; extending it to observers with persistent records is a separate, experimentally approachable question. Sections 2–7 examine that question; Section 8 relates it to the Embedded-Observer No-Go Theorem [11], a different, purely kinematic instance of the same starting point.

1. A physical starting point

Postulate. The physical universe consists of everything that physically exists. No physical observer is external to it; every physical observer is itself a physical subsystem, composed of the same kind of stuff as whatever it observes. This is not derived here or anywhere else: no physical theory has ever postulated an observer external to physics, and the postulate is close to what "physical" means. It is not a claim this note argues for; it is the ground it stands on.

What follows from the postulate is not obvious. Wigner-type and Local Friendliness constructions assign a participant, conventionally called the superobserver, a formal role: it acts by an arbitrary unitary on an entire laboratory, Friend included, as though from outside that laboratory. Nothing in the postulate is challenged by this. The construction is a mathematical device - a unitary W on $H_{\text{Friend}} \otimes H_{\text{system}}$ - and by the postulate, whoever or whatever physically realizes W is, like the Friend, a subsystem of the same universe. The role is external to the description of one laboratory; the physical system that fills it is not external to anything.

This leaves a concrete physical question, and it is the one this note pursues: what does a photonic implementation of the Friend's role, of the kind actually built in the laboratory [3,4], establish about observers, as opposed to quantum systems that implement the operational role assigned to a "Friend"? The word carries more structure in the original thought experiment than the mere existence of a correlated degree of freedom: the Friend measures, obtains a result, stores it, and can subsequently use or report it. The experimental literature adopts an operational definition instead - a system that extracts information from another system and stores it in a physical memory [3] - and this note asks whether that operational memory is doing the same work as the persistent, accessible record the word suggests. The point is not new in outline; Section 5 collects where it has been raised before. It can be stated more sharply, and it points to a concrete experimental programme (Section 7).

2. What the LF theorem and its experiments establish

The LF framework builds on Brukner's extended Wigner's-friend argument [1] and was formalized as a theorem, and tested experimentally, by Bong et al. [4]. Two separated "Friends" each measure half of an entangled pair; two "superobservers" can each perform an arbitrary quantum operation on their own Friend's laboratory. Locality is a condition on the correlations between the two separated sides, so the construction is structurally bipartite, in the same sense that a Bell test requires two separated parties - there is no single-Friend version of the theorem. Three assumptions - Absoluteness of Observed Events, No-Superdeterminism, and Locality - give LF inequalities with no reference to quantum theory, on strictly weaker assumptions than Bell's. Quantum theory predicts violations provided a further premise holds: a superobserver must be able to perform arbitrary quantum operations on the Friend and her environment. Bong et al. prove that if quantum evolution is controllable on the scale of an observer in this sense, at least one of the three assumptions must fail. Wiseman, Cavalcanti and Rieffel [5] call this premise a technological assumption; it is the premise this note examines. Proietti et al. [3] preceded the LF formulation and tested an earlier, stronger CHSH-type inequality from Brukner's argument; the analysis below concerns the role of the Friend and applies to both experiments.

Bong et al. [4] scan a purity parameter μ across a family of two-qubit states and report a Bell violation without an LF violation at $\mu \approx 0.80$ – 0.81 , then a first genuine-LF violation at $\mu \approx 0.87$. Their two "Genuine LF" facets have LF bounds of 6 and 5 respectively; the first tolerates up to 18.3% white noise mixed into the source state before the violation disappears. This tunes the purity and entanglement of the state handed to the two Friends under an ideal, noiseless record; the photon-path memory itself stays fully coherent throughout the scan. It is, in the language of Section 4, entirely a probe of operational quantum memory - not a variation of how persistent or how decohered that record is. No existing LF experiment varies the latter.

Nothing in the derivation requires the Friend to be human, conscious, or macroscopic; the mathematical role is fixed by the measurement structure alone. This is a strength - no human observer is needed to run the test - and a limitation, if a violation is read as a statement about all possible observers without separately establishing that the implementation carries whatever further properties "observer" is meant to carry. Three levels are worth keeping apart: (I) the inequality follows from its assumptions, unconditionally; (II) the photonic experiments realize the required correlations and report violations, independently of whether the Friend is human; (III) reading a violation as a statement about observers in the stronger sense requires the further, unestablished identification experimental Friend $\equiv$ observer, which Sections 3–7 examine rather than assume.

3. The experimental Friend has a memory

It would be a mistake to say the Proietti et al. experiment uses the polarization of the measured photon as the Friend's memory. The architecture is more specific: the source supplies the photons that the two Friends measure, ancillary entangled pairs feed type-I fusion gates, and the measurement result is transferred to a separate photon that the authors explicitly identify as physical memory [3]. The experiment meets its own operational definition of an observer - information extracted from one system, stored in another. Any critique of these experiments must address the physical character and accessibility of that memory, not deny its existence.

4. Quantum memory versus persistent observer memory

In the idealized scenario the Friend's measurement produces a record definite from her perspective:

$$\frac{1}{\sqrt{2}} (|h\rangle + |v\rangle) \rightarrow \frac{1}{\sqrt{2}} (|h\rangle |M_h\rangle + |v\rangle |M_v\rangle), \langle M_h | M_v \rangle = 0.$$

But Wigner's subsequent measurement acts coherently on the joint system: he must be able to distinguish $\frac{1}{\sqrt{2}}(|h\rangle|M_h\rangle \pm |v\rangle|M_v\rangle)$, which amounts to coherently erasing the Friend's record. From the Friend's side M_h and M_v are distinguishable; from Wigner's side the joint state stays available for interference. Both descriptions are compatible with unitary quantum mechanics, and this exposes two different notions of memory.

An *operational quantum memory* may hold orthogonal record states while remaining part of a coherent state accessible to a later global operation; it encodes information perfectly at the level of quantum states. A *persistent record* is stronger: it must stay robust against subsequent coherent manipulation and remain independently accessible to the observer or to other systems, schematically $|M_h\rangle \rightarrow |M_h\rangle|E_h\rangle$, $|M_v\rangle \rightarrow |M_v\rangle|E_v\rangle$, $\langle E_h|E_v\rangle \approx 0$, so that the record is redundantly encoded in degrees of freedom outside the control of the Wigner-side experiment. The distinction is physical, not semantic: once redundantly encoded in an uncontrolled environment, the coherent operation an ideal Wigner measurement needs becomes physically much harder.

A stronger condition of observerhood would require a record that is definite, persistent, independently accessible, usable by the observer afterward, and still fully available for Wigner's coherent recombination. None of these properties is among the LF assumptions; the last is exactly the controllability premise of Section 2. The LF experiment operates precisely in the regime where the memory must stay coherent and controllable enough for the Wigner-side measurement - which does not invalidate it, but marks the operational regime of observerhood it tests.

5. What the literature already says

Several independent analyses bear on this distinction; they address different aspects and are not one theorem. Table 1 gives the finding each is cited for; none of it shows LF experiments are meaningless or that a quantum memory cannot be called a memory. Together they show that quantum information storage is not observerhood by definition, unless the further operational properties required for observerhood are specified.

Reference	What it adds
Bruckner [6]	A bare qubit lacks the structure for conventional observerhood; the issue is a physically meaningful record or preferred basis, not mere entanglement.
Elouard et al. [7]	The Frauchiger–Renner paradox splits into two logically distinct contexts - Wigner's full coherent control, or parts of the lab left untouched - tied to the agent's capacity to behave as an observer.
Baumann & Bruckner [8]	Any Friend awareness of Wigner's measurement, modelled as an extra register, conflicts with no-signalling in extended Wigner's-friend scenarios.
Groeneveld [9] (M.Sc., not peer-reviewed)	Argues [8]'s conclusion combines a perfectly isolated lab with a superobserver holding complete control - assumptions in tension.
Wiseman, Cavalcanti & Rieffel [5]	States the LF theorem assumes a reversible Friend, notes this is implausible for a human Friend, and proposes further assumptions plus a prospective experiment for a “thoughtful” Friend.
Relaño [10]	A decoherence framework in which measurement completes only once an uncontrolled environment monitors system+apparatus+observer; revisits Frauchiger–Renner and Bruckner scenarios.
Rivlin, Engineer & Baumann [12]	Adds an explicit decohering environment to Wigner's-friend scenarios via quantum Darwinism; LF-type effects persist in modified form under decoherence in their small numerical model.
Allard Guérin et al. [13]	Under seemingly natural assumptions, no joint probability distribution for the Friend's perceived outcomes at two times both depends linearly on the initial state and reproduces unitary quantum theory.

6. What the existing experiments do and do not decide

Proietti et al. realize an extended Wigner's-friend configuration with six photons and report a violation of Brukner's Bell-type inequality by about five standard deviations - not the later LF inequality of Bong et al. The authors qualify the conclusion themselves: it holds modulo potential loopholes and on the condition that the photons are accepted as observers. The supported conclusion is that the implemented photonic protocol violates that inequality under the stated experimental assumptions. The stronger statement - observer-independent facts are experimentally excluded for genuine observers - needs one further premise: that the operational photonic memory is physically equivalent, for the relevant conceptual purpose, to the persistent observer memory the Wigner's-friend interpretation assumes. Storing two distinguishable states in a memory photon does not by itself establish that equivalence.

The experiments neither "failed" - they demonstrated the correlations they were designed to test - nor show that photons cannot serve as observers; the experimental papers adopt a broader operational definition and satisfy it. The precise statement is that LF experiments establish observer-independence violations for the operational observer model used in the experiment. Three questions stay open: whether a coherent quantum memory constitutes a Friend in the strongest sense (the operational definition says yes; a stronger definition may ask for more, untested here); whether a genuinely persistent record can take part in Wigner's coherent measurement, and whether any boundary there is fundamental rather than a practical decoherence problem; and whether the conclusion extends to arbitrary embedded observers (Section 8).

7. What would close the gap: a controlled-memory experiment

A decisive experiment would specify observerhood independently of the LF inequality, with a Friend system offering: a distinguishable measurement record; a memory degree of freedom physically distinct from the measured system; a record that persists for a specified time; independent accessibility of the record by the Friend; a precisely characterized coupling to the environment; a quantitative criterion for the residual coherence available to Wigner; and a Wigner-side operation capable of testing that global coherence. Trapped ions, superconducting circuits, and spin registers are candidate platforms, where memory lifetime, coherence time, and access time (T_{memory} , $T_{\text{coherence}}$, T_{access}) can be measured directly rather than treating "memory" as binary, and where a decoherence parameter η ($\langle E_h | E_v \rangle = \eta$, $0 \leq |\eta| \leq 1$) can be varied continuously between a nearly coherent record ($|\eta| \approx 1$) and a strongly environmentally recorded one ($|\eta| \approx 0$).

In the simplest model, where the environment merely records the branch label, η multiplies the coherence available to Wigner exactly as in a dephasing channel of visibility $|\eta|$, so quantum theory predicts the violation degrades as $|\eta|$ decreases and disappears below a critical value set by the inequality. For the CHSH-type Brukner facet (classical bound 2, quantum maximum $2\sqrt{2}$), a multiplicative visibility $v = |\eta|$ requires $v 2\sqrt{2} > 2 \Leftrightarrow |\eta| > \frac{1}{\sqrt{2}} \approx 0.707$ - the same threshold as CHSH itself. This is a toy calculation, exactly the idealization Section 4 warns against building an interpretation on, and not a number an experiment would report. The closest existing number is different in kind: the 18.3% white-noise tolerance of Section 2 is a statement about the purity of the state supplied to the Friends, tuned by μ , not about the persistence of a memory record, which stays coherent throughout that experiment. The two answer different questions; no reported figure yet answers the one Section 7 poses.

What the experiment can do is replace an implicit choice by an explicit, quantitative one: LF violation for a Friend with a stated record persistence, environmental redundancy, accessibility, and residual coherent control - a sharper target than the binary question of whether a photon "is" an observer, and one that needs no appeal to consciousness or other unverifiable properties.

8. Relation to the Embedded-Observer No-Go Theorem

The Embedded-Observer No-Go Theorem [11] starts from the same postulate of Section 1, applied to a different, purely kinematic question. It models the observer as a proper tensor factor of a finite-dimensional closed quantum system and derives two obstructions: the observer's reduced state leaves open a whole manifold of global pure states, and its reduced evolution follows a fixed unitary law independent of the rest of the system if and only if the coupling is a product unitary, with a quantitative two-sided bound. It derives no inconsistency, involves no multi-observer protocol, and makes no claim about LF, interpretations, or experiments - nor does this note claim a bridge back. An LF violation neither confirms nor refutes those results, and they do not imply an LF inequality.

Both papers instantiate the postulate through the same kind of modelling identification - observer = subsystem - stated in each as an assumption of the framework, not a derived property of observers: a tensor factor in [11], an operationally defined memory-holding system here. Neither paper derives the postulate; both examine what follows once it is taken seriously, from two different directions -kinematic and exact there, operational and experimental here.

Nesting depth is a separate matter, on which no claim is made here. The LF construction is a finite nested configuration, the Friend's laboratory inside the superobserver's description; a single Friend pair already suffices for LF violation, which is sufficient to derive and test the inequality but does not by itself establish a result for arbitrary-depth embedding $F_1 \subset F_2 \subset \dots \subset F_N$. The Embedded-Observer paper treats iterated extension only within its own tensor-factor kinematics and derives no inconsistency from it, so it is not a substitute; nested-reasoning arguments of another kind are known [2]. Whether an N -level LF-type result exists, and how it would relate to the Embedded-Observer results, remains open.

9. Conclusion

No physical observer is external to the universe; that is the starting point, not a conclusion this note reaches. What follows is narrower: the LF theorem is a mathematically well-defined conditional no-go result, and photonic experiments report genuine violations of the associated inequalities [3,4]. In the Proietti et al. experiment the Friend's memory is a separate ancillary photon, correctly described as memory. The open issue is not the absence of memory but whether a coherent, externally controllable quantum memory carries the further properties - persistence, independent accessibility - the word "observer" carries in the Wigner's-friend thought experiment. The literature of Section 5 gives independent reasons to take that distinction seriously without invalidating the experiments: LF violation is not by itself an experimental validation of every notion of observerhood. Memory lifetime, environmental redundancy, accessibility, and residual coherent control can be specified quantitatively, and Section 7 outlines how.

References

- [1] Brukner, Č. (2018). A no-go theorem for observer-independent facts. *Entropy*, 20, 350.
- [2] Frauchiger, D., & Renner, R. (2018). Quantum theory cannot consistently describe the use of itself. *Nature Communications*, 9, 3711.
- [3] Proietti, M., Pickston, A., Graffitti, F., Barrow, P., Kundys, D., Branciard, C., Ringbauer, M., & Fedrizzi, A. (2019). Experimental test of local observer independence. *Science Advances*, 5(9), eaaw9832.
- [4] Bong, K.-W., Utreras-Alarcón, A., Ghafari, F., Liang, Y.-C., Tischler, N., Cavalcanti, E. G., Pryde, G. J., & Wiseman, H. M. (2020). A strong no-go theorem on the Wigner's friend paradox. *Nature Physics*, 16, 1199–1205.
- [5] Wiseman, H. M., Cavalcanti, E. G., & Rieffel, E. G. (2023). A “thoughtful” Local Friendliness no-go theorem: a prospective experiment with new assumptions to suit. *Quantum*, 7, 1112.

- [6] Brukner, Č. (2021). Qubits are not observers - a no-go theorem. arXiv:2107.03513.
- [7] Elouard, C., Lewalle, P., Manikandan, S. K., Rogers, S., Frank, A., & Jordan, A. N. (2021). Quantum erasing the memory of Wigner's friend. *Quantum*, 5, 498.
- [8] Baumann, V., & Brukner, Č. (2024). Wigner's friend's memory and the no-signaling principle. *Quantum*, 8, 1481.
- [9] Groeneveld, O. S. (2024/2025). Wigner's Friend: Memory, Awareness and Observer-Dependent Realities. Master's thesis, TU Delft Repository (not peer-reviewed).
- [10] Relaño, A. (2019). Decoherence framework for Wigner's friend experiments. arXiv:1908.09737.
- [11] Materov, S. (2026). The Embedded-Observer No-Go Theorem: Non-Reconstructibility, Non-Autonomy, and Their Quantitative Form for Tensor-Factor Observers in Finite-Dimensional Closed Quantum Systems. September 2026. DOI: 10.5281/zenodo.23066381
- [12] Rivlin, T., Engineer, S., & Baumann, V. (2025). Emergence of classicality in Wigner's friend scenarios. arXiv:2507.21221.
- [13] Allard Guérin, P., Baumann, V., Del Santo, F., & Brukner, Č. (2021). A no-go theorem for the persistent reality of Wigner's friend's perception. *Communications Physics*, 4, 93.