

## Can Quantum Erasers with Time Crystals prove we live in a Multiverse or send Messages Back in Time

Tariq Khan  
Omaha, NE USA

A short and informal essay proposing a modification to the delayed-choice quantum eraser experiment by including time crystals as an additional feature. Possible results are considered including speculations on possible applications and philosophical interpretations. A proposed experiment using two observers at three points in time and a bank of delayed-choice quantum erasers each linked to a time crystal might either prove we live in a multiverse, possibly send messages back in time, or redefine or even refute the nature of time crystals. The hope is that this proposal can help the debate over the nature of the delayed-choice quantum eraser experiment and help further clarify the nature of time crystals versus time.

*"Time is the cruelest force of all."*  
-- Cixin Liu, Death's End

*"Time, time, time  
See what's become of me  
While I looked around for my possibilities...  
Seasons change with the scenery  
Weavin' time in a tapestry  
Won't you stop and remember me?"*  
-- Paul Simon lyrics, Hazy Shade of Winter

*"Time is but memory in the making"*  
-- Vladimir Nabokov

The experimental demonstration of time crystals at various major laboratories has recently been achieved in a remarkable technological leap from theory to reality.<sup>[1]</sup> This has led to speculations about their application in the booming and competitive Quantum Computing space. However, perhaps, another application or experiment is not only more obvious, but more essential to the future of mankind.

Time crystals are "a novel phase of matter that physicists have strived to realize for many years, a time crystal is an object whose parts move in a regular, repeating cycle, sustaining this constant change without burning any energy."<sup>[2]</sup> "Time crystals are also the first objects to spontaneously break time-translation symmetry, the usual rule that a stable object will remain the same throughout time. A time crystal is both stable and ever-changing, with special moments that come at periodic intervals in time."<sup>[2]</sup> In addition, a research group in 2021 claimed to have created a time crystal in a diamond.<sup>[3]</sup>

Another remarkable experiment and theoretical achievement related to Quantum Mechanics is the delayed-choice quantum eraser (DCQE) that evolved from the original quantum eraser proposal from John Wheeler.<sup>[4]</sup> The online encyclopedia Wikipedia has a useful high-level summary:

The delayed-choice quantum eraser experiment investigates a paradox. If a photon manifests itself as though it had come by a single path to the detector, then "common sense" (which John Wheeler and others challenge) says that it must have entered the double-slit device as a particle. If a photon manifests itself as though it had come by two indistinguishable paths, then it must have entered the double-slit device as a wave. Accordingly, if the experimental apparatus is changed while the photon is in mid-flight, the photon may have to revise its prior "commitment" as to whether to be a wave or a particle. Wheeler pointed out that when these assumptions are applied to a device of interstellar dimensions, a last-minute decision made on Earth on how to observe a photon could alter a situation established millions or even billions of years earlier. While delayed-choice experiments have

confirmed the seeming ability of measurements made on photons in the present to alter events occurring in the past, this requires a non-standard view of quantum mechanics. If a photon in flight is interpreted as being in a so-called "superposition of states", i.e., if it is interpreted as something that has the potentiality to manifest as a particle or wave, but during its time in flight is neither, then there is no time paradox.<sup>[5]</sup>

There exists a large philosophical debate over the interpretation of the results of the delayed-choice quantum eraser. Many scientists believe that the Hugh Everett "Many Worlds" or multiverse theory easily explains the experiment's apparent paradox while others believe that the consistency of the "rules" of Quantum Mechanics supersedes human concepts like locality or even time and that Quantum Mechanics thus can use retrocausal (backwards in time) actions or messages if needed to ensure consistent histories and to avoid any causal or logical paradoxes. These proponents believe that the experiment literally demonstrates retrocausal behavior. Retrocausality, or backwards causation, is defined as "a concept of cause and effect in which an effect precedes its cause in time and so a later event affects an earlier one - in quantum physics, the distinction between cause and effect is not made at the most fundamental level and so time-symmetric systems can be viewed as causal or retrocausal."<sup>[6]</sup> Physicist and author Sean Carroll describes in detail this debate in the September 21, 2019 entry of his online blog Preposterous Universe called *The Notorious Delayed-Choice Quantum Eraser*:

The electron is simply part of the wave function of the universe. It doesn't make choices about whether to be wave-like or particle-like. But a number of serious researchers in quantum foundations really do take the delayed-choice quantum eraser and analogous experiments (which have been successfully performed, by the way) as evidence of retrocausality in nature - signals traveling backwards in time to influence the past. ... To an Everettian, the result makes perfect sense without anything traveling backwards in time. The trickiness relies on the fact that by becoming entangled with a single recording spin rather than with the environment and its zillions of particles, the traveling electrons only became kind-of decohered. With just a single particle to worry about observing, we are allowed to contemplate measuring it in different ways. If, as in the conventional double-slit setup, we measured the slit through which the traveling electron went via a macroscopic pointing device, we would have had no choice about what was being observed. True decoherence takes a tiny quantum entanglement and amplifies it, effectively irreversibly, into the environment. In that sense the delayed-choice quantum eraser is a useful thought experiment to contemplate the role of decoherence and the environment in measurement. But alas, not everyone is an Everettian. In some other versions of quantum mechanics, wave functions really do collapse, not just the apparent collapse that decoherence provides us with in Many-Worlds. In a true collapse theory like GRW (Ghirardi-Rimini-Weber theory)<sup>[7]</sup> the process of wave-function collapse is asymmetric in time; wave functions collapse, but they don't un-collapse. If you have collapsing wave functions, but for some reason also want to maintain an overall time-symmetry to the fundamental laws of physics, you can convince yourself that retrocausality needs to be part of the story. Or you can accept the smooth evolution of the wave function, with branching rather than collapses, and maintain time-symmetry of the underlying equations without requiring backwards-propagating signals or electrons that can't make up their mind. <sup>[8]</sup>

So, in our modern world with apparatus as described that are sensitive enough to create time crystals and perform delayed-choice quantum eraser experiments, could an experiment be conducted to "prove" we live in a multiverse? Otherwise, could an experiment actually send messages back in time or redefine, or even refute, the very definition of a time crystal? Consider this variation to the delayed-choice quantum eraser experiment.

We start with a bank of DCQEs - in our simple example there are four separate DCQEs. Each is linked to a time crystal via a sensor. The sensor, upon identifying an interference pattern output (where the "which path" information for photons are not known or have been erased), activates the time crystal. Note we also could setup the experiment where once "which path" information is known (causing the superposition to collapse in the DCQE) the sensor or trigger, via the final screen pattern where no interference pattern is

observed, then activates or creates the time crystal. The time crystal, when activated, lights up an LED of a letter, like the letters of the name "BOB," otherwise they are simply "XXXX." For our discussion, in the future our observer Alice, who setups up the experiment, will never observe the LED letters and our observer Bob will only observe the LED letters but never the quantum eraser output. At some point in the future, say on DAY 3, after the experiment has been created on DAY 1, our observer Alice will make the choice to "open the box" of the experiment and, in our experiment, erase "which path" information, thus creating an interference pattern in her present and, in theory, also in the past. One can consider this experiment with our DCQEs in a concealed box similar to the classic Schrodinger's Cat scenario where the lack of a decision or observation to "look in the box" keeps the experiment in a theoretical quantum mechanical superposition state until our later time in the future when Alice creates the interference pattern. However, in our experiment, the quantum eraser is not the direct trigger of the LED letters but, rather, the time crystals are. The time crystal, upon activation is a structure that is symmetric in time and thus exists, in theory, in the present and in the future - symmetry in time - theoretically upon creation. Thus, when a future act on a quantum eraser (the "delayed choice" act) collapses the experiment and thus causes the interference pattern on the screen to be observed, there is no longer any superposition of the screen however the activation of the time crystal "should" be set for that present moment and the future - immediately! In essence this would be the goal of the experiment to confirm. If the time crystal's effect is actually instantaneous into the future, then there could be paradoxical situations that could help us prove which possible theory of quantum reality we exist in.

The experiment can be explained better by separating the event timelines (T0, T1, T2) into a day 1, day 2, and day 3 diagram (Figure 1). On DAY 1, Alice builds the experiment with four banks of DCQE each linked to its own time crystal. Only Alice knows which DCQE connects to which of the time crystals to further "hide" any possible "which path" information that Bob might be able to deduce by seeing the output of the LED letters as we want Bob to only observe the LED letters and never the actual DCQE output directly. The four LED letters are XXXX upon the experiment's initial T0 creation. On DAY 2, Bob does not look into the box of the experiment, he only looks at the screen of four LED letters. In theory Bob will see the letters "BOBX" In this initial T1 timeline Bob does not talk to Alice yet. On DAY 3, Alice decides to collapse the experiment superposition that, in theory, should still exist (at least for her) and thus her delayed choice on DAY 3 collapses the experiment into screen output of an interference pattern in the present for Alice and, in theory, in the past although that can never be known by only the DCQE output alone. That activates the sensor and the LED letters "BOBX" can be seen on DAY 3 - but let's assume Alice does not even look at the LED letter output although it should still be XXXX until she makes the delayed choice. Alice is not aware of anything Bob has done in the past on DAY 2. Bob on DAY 4 will then inform Alice that he saw the letters "BOBX" on the LED screen on DAY 2. In this scenario, Alice has sent a message back in time to Bob, thus creating a paradox. The key assumption on the experiment is that the reality of Alice on DAY 3 effects the entire history of the experiment thus changing the DCQE screen output even back to DAY 1 that Alice can never go back into time and confirm and the DCQE has no way to leave a record of its change in the past relative to Alice on DAY 3. Here is the major assumption of the experiment that the time crystal, however, can leave a record in the past of this change by its assumed immediate ability to create a symmetry or entanglement relationship with the future via its future self being in existence. The other assumption is that Bob will see "BOBX" and not "XXXX" and that this does not automatically separate Bob from Alice into his own separate "branch" or universe in a multiverse.

If we logically assume that this creates a causal paradox, then how can we explain this if this turns out to be an actual physical result? Here we are drawn to the Hugh Everett multiverse or "alternate timeline" solution.<sup>[9]</sup> Here, in essence, a larger "reality space" of multiple universes exists where Bob either branches off upon his observation (the universe splits) or he enters a new universe or timeline that already exists (a la David Deutsch's multiverse where there is also already a parallel DAY 1 that exists in a different parallel Universe) and, thus, to avoid the casual paradox, the only way Bob can see "BOBX" is if he exists in a new reality that cannot change or prevent the action of Alice on DAY 3 or prevents Alice from sending information back in time in her universe (Figure 2).

One can also speculate, akin to "Wigner's friend"<sup>[10]</sup> and Schrodinger's Cat<sup>[11]</sup> proposals, that because the experiment has not yet collapsed when Bob observers the LED letters that Bob is still part of superposition and that on DAY 2 Bob will still see XXXX. But the key difference with the design of this experiment is that it is intentionally designed to not be a "Wigner's friend" scenario. One can argue that any linkage at all between any possible system and observer will always makes it such however, if so, then that may break the symmetry of the time crystal by the definition of the time crystal. Otherwise, we are left with a

scenario where time crystals that are defined to be symmetric in present and future upon creation actually may not be and they also could merely “flow” through time like all other matter slower than light and are also thus subject to the same constraints of Wigner and Schrodinger quantum superposition challenges (Figure 3).

Again, to summarize the proposed experiment, on DAY 2 Bob sees either XXXX or BOBX. Then on DAY 4, three scenarios could occur when Bob goes to talk to Alice: 1) Bob saw XXXX so Bob, even without having any “which path” information, is still part of the large experiment akin to Schrodinger’s Cat at a larger scale (this is similar to the Wigner’s Friend scenario if Bob sees XXXX but Alice observes Bob still in the box as seeing BOBX), or 2) Bob has received on DAY 2 the message that Alice sent on DAY 3 - to the shock of Alice, or 3) Bob mentions to Cassandra in another universe that is part of a multiverse that he saw a message BOBX that Cassandra never sent (Figures 4-5).

The concepts of the delayed-choice quantum eraser experiment and time crystals are modern and complex concepts and best explained in simple diagrams (Figures 6-9)

It is thus the desire of the author to challenge technical universities and institutions to perform the experiment, that can be done with present technology, to confirm which scenario actually is observed and to help further define the behavior of time crystal’s behavior relative to past, present, and future symmetries.

# Figures

Figure 1.

The proposed experiment could possibly send messages back into time i.e., a retrocausal solution.

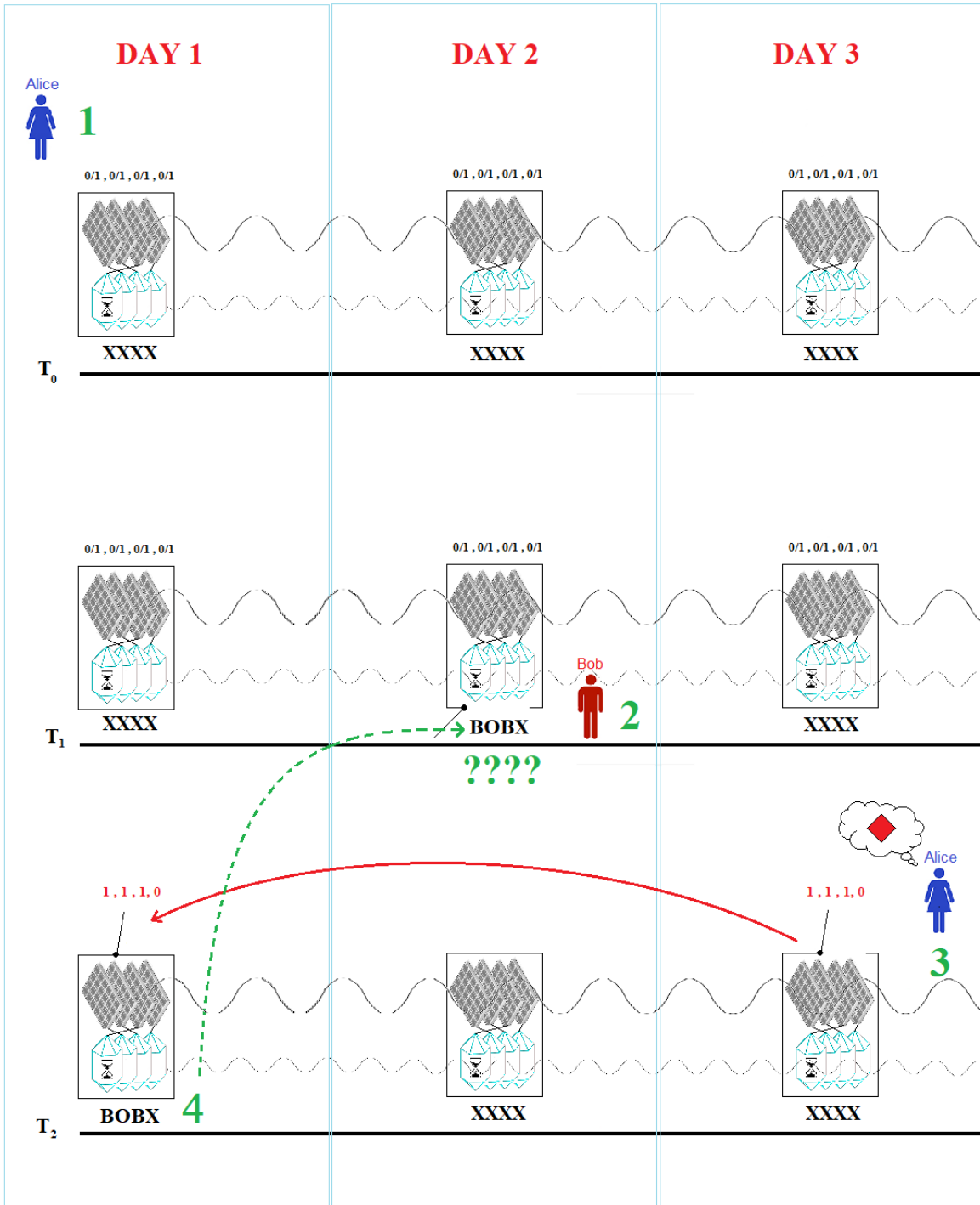


Figure 2.

The experiment could prove the existence of an Everettian or Deutsch Multiverse.

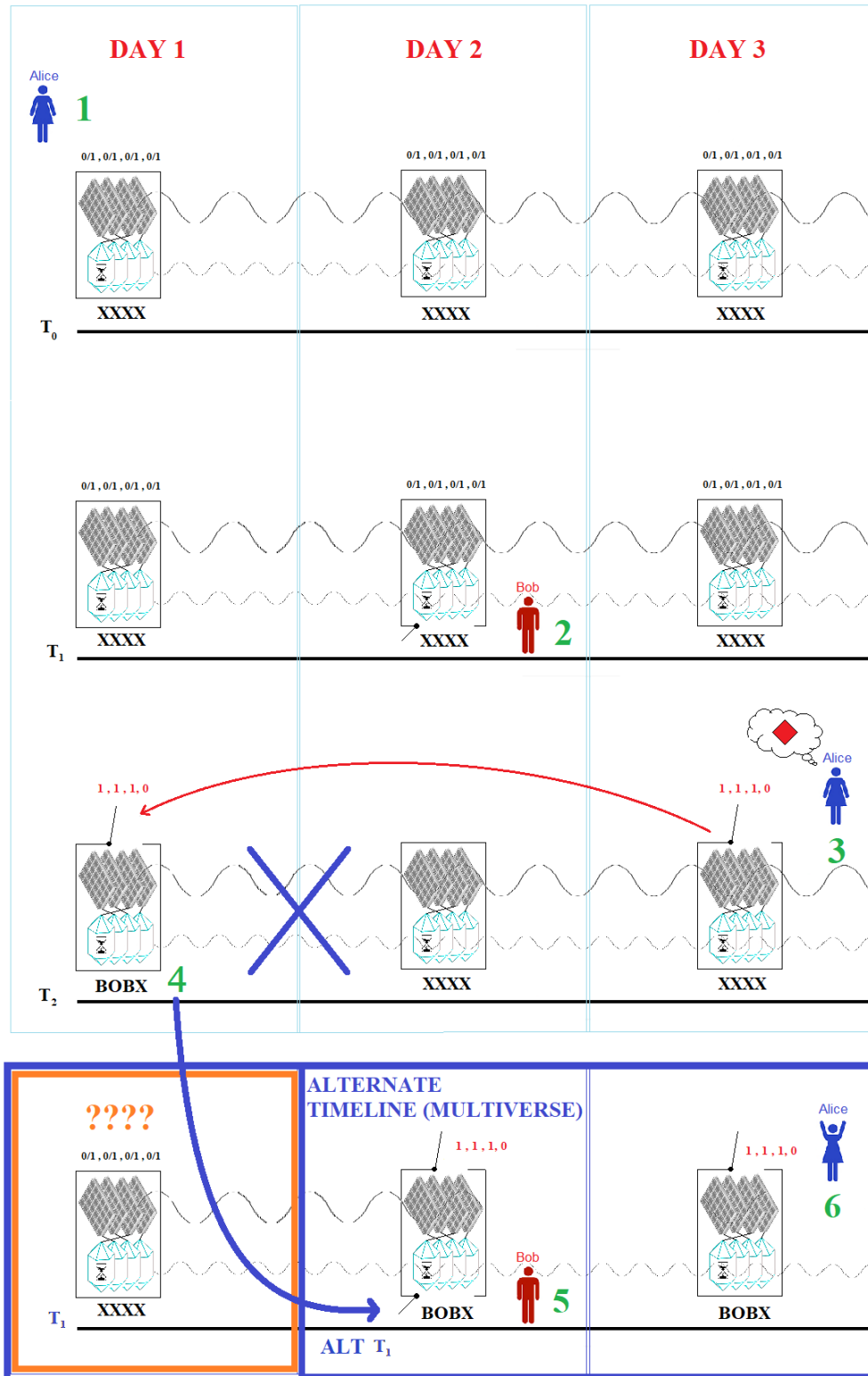


Figure 3.

The experiment may show that the role of time crystals requires clarification or limitations.

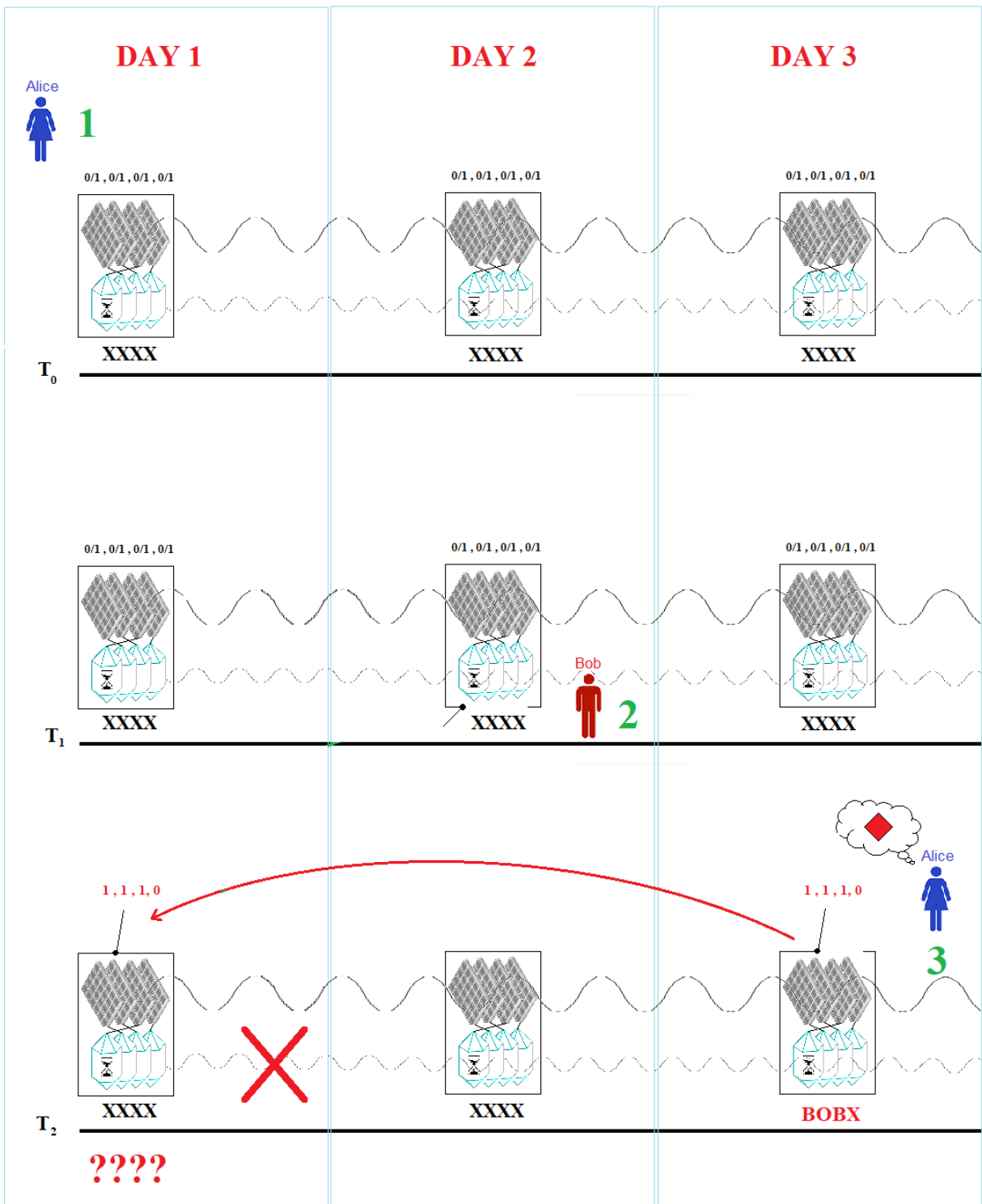


Figure 4.

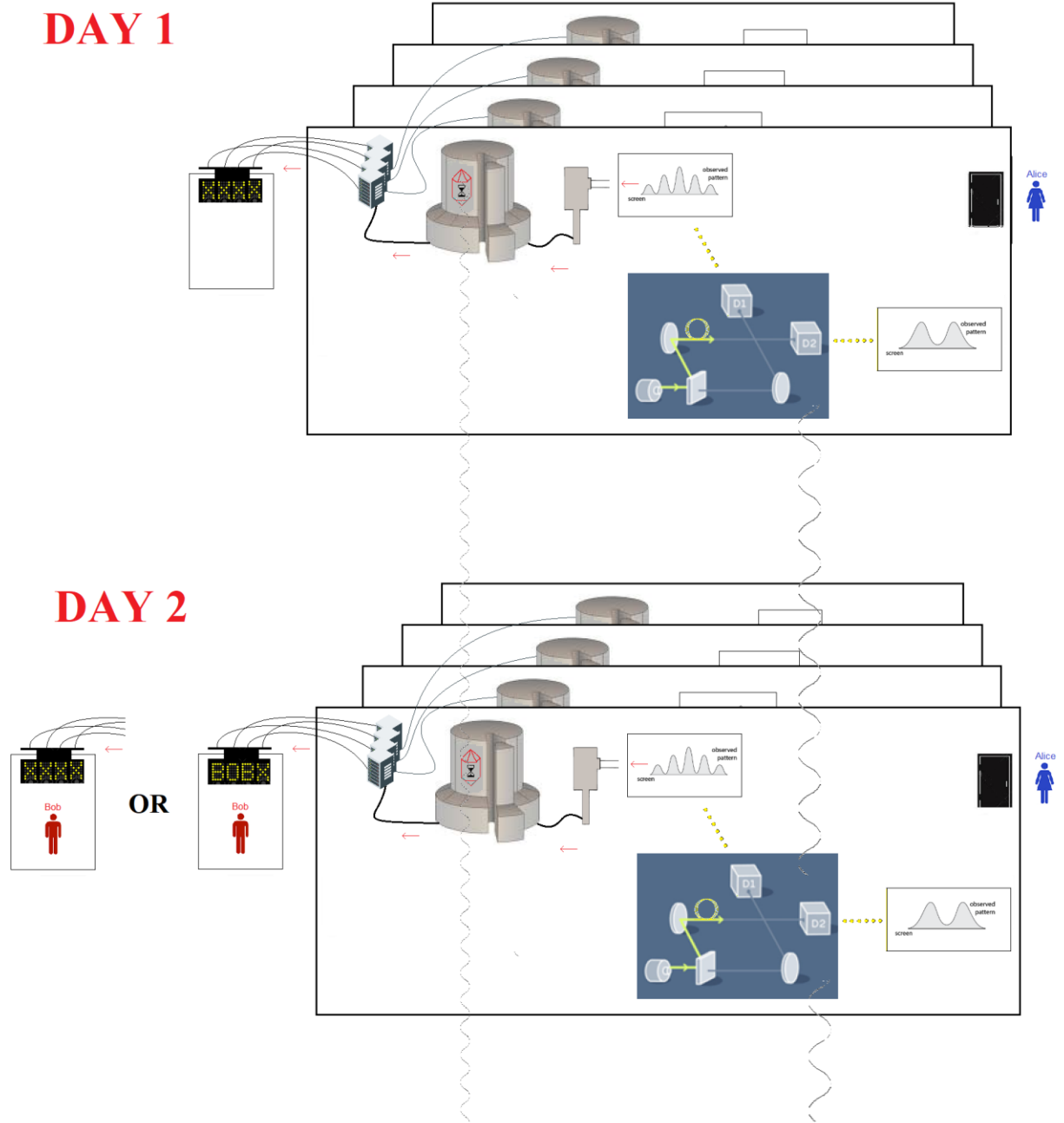
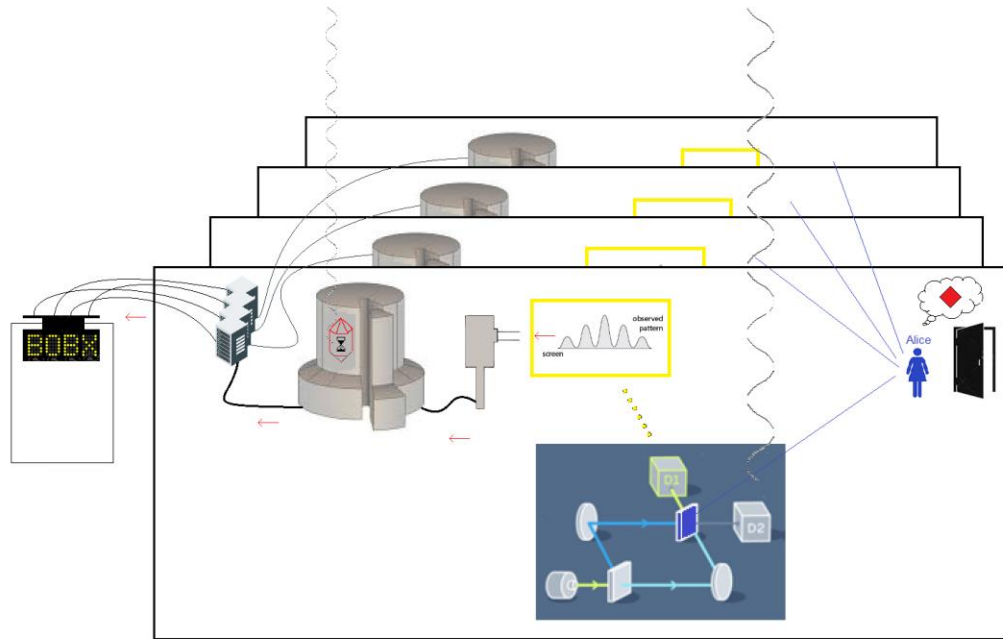


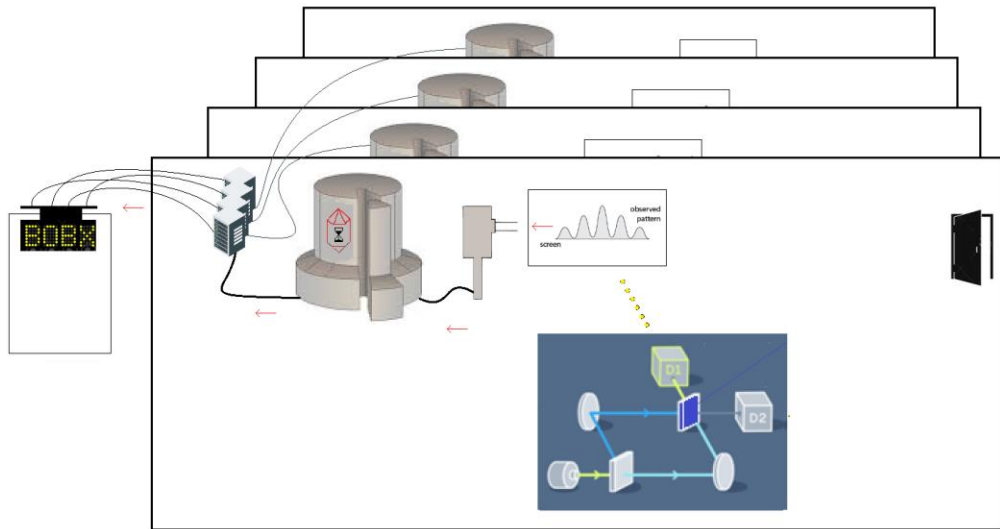


Figure 5.

**DAY 3**



**DAY 4**



Alice Bob OR Alice Bob OR Bob Cassandra

Figure 6.

*High level diagram of the Delayed Choice Quantum Eraser experiment.*<sup>[12]</sup>

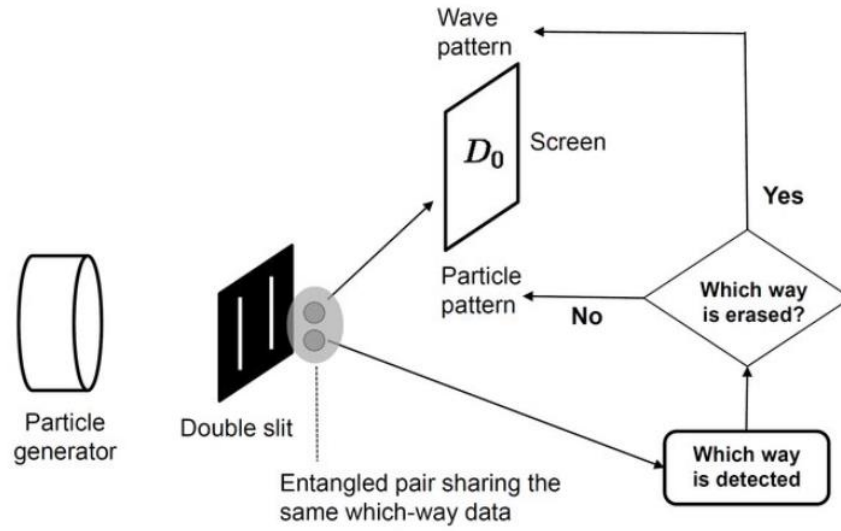


Figure 7.

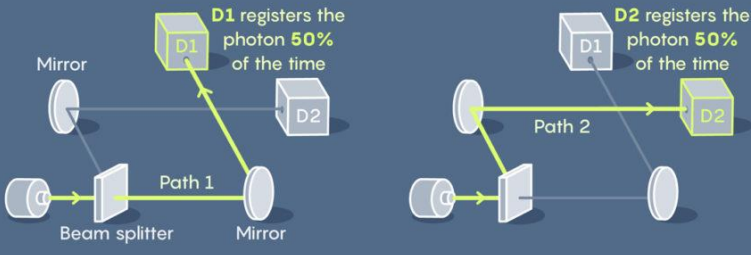
Step by step explanation of the Delayed-Choice experiment explained.[13]

### The Delayed-Choice Experiment Explained

Are quantum objects “real” when they’re not observed? The delayed-choice experiment demonstrates that they can’t be. It shows that an unobserved photon is neither a wave nor a particle.

**If the Photon Is a Particle**

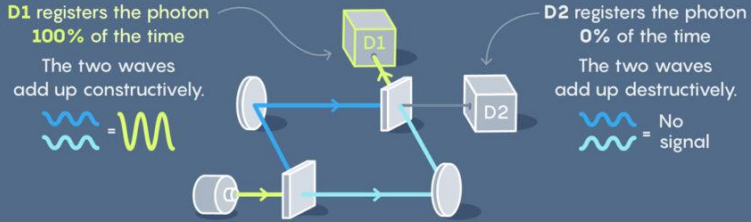
Fire a photon at a beam splitter. The photon acts as an indivisible particle. It takes either path 1 or path 2 and then goes on to hit detector D1 or D2.



**If the Photon Is a Wave**

Add a second beam splitter. This time the photon acts as a wave. It seemingly splits into two waves at the first beam splitter. The waves recombine at the second. The photon always hits only one of the detectors.

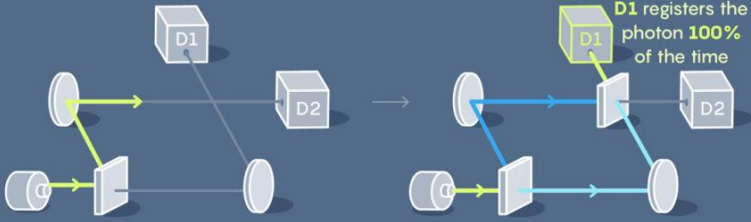
D1 registers the photon 100% of the time  
The two waves add up constructively.



D2 registers the photon 0% of the time  
The two waves add up destructively.  
No signal

**Delayed Choice**

Start with only one beam splitter. The photon should act like a particle. At the last moment, add the second beam splitter. The particle then suddenly changes to be wavelike, as if it was always going down both paths.

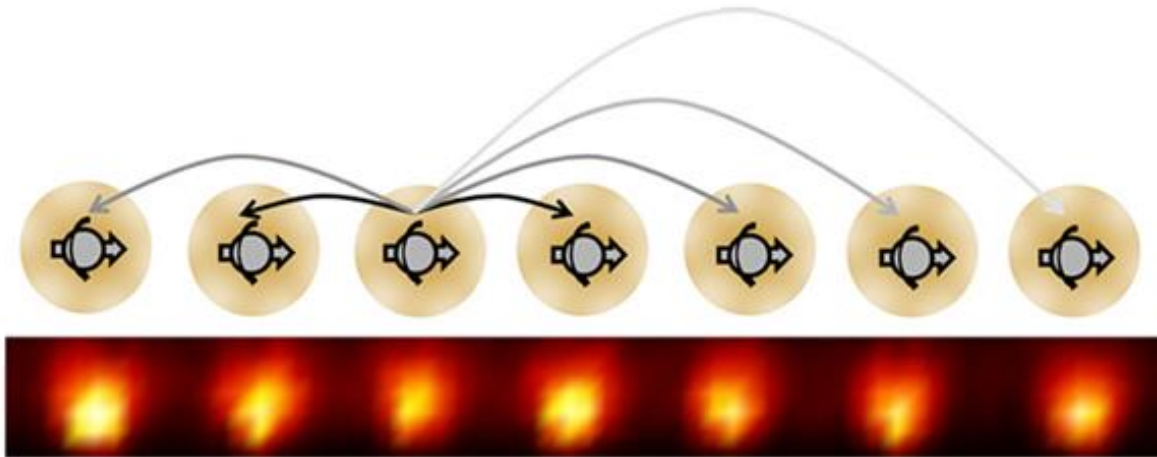


**CONCLUSION:** Either the addition of the beam splitter sent a signal backwards in time to influence the photon’s initial behavior, or photons do not have definite, intrinsic properties when they are not being observed.

Source: Lucy Reading-Ikkanda/Quanta Magazine

Figure 8.

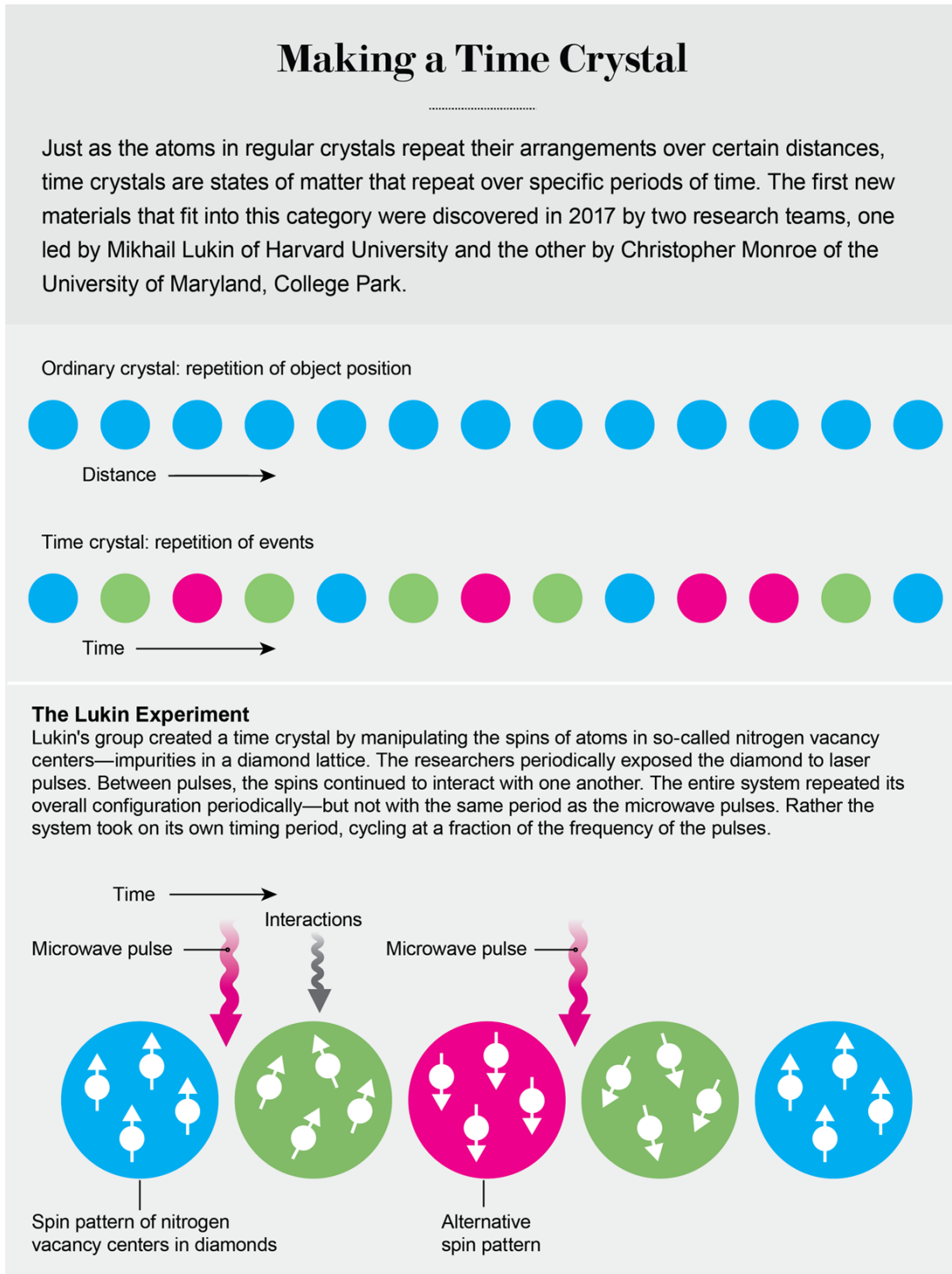
*This experiment can show if long-range interactions associated with Time Crystals is instantaneous or not or not at all. [14]*



**A one-dimensional chain of ytterbium ions was turned into a time crystal by physicists at the University of Maryland, based on a blueprint provided by UC Berkeley's Norman Yao. Each ion behaves like an electron spin and exhibits long-range interactions indicated as arrows. (Image courtesy of Chris Monroe)**

Figure 9.

*Background on the creation of Time Crystals.[1]*



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