A Deep-Physics Look at Quantum Computing

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Overview

I. **The Problem of Badly Broken Promises**

II. **The Everett Generalization of Cat Splitting**

III. **The Problem of Assuming Orthogonality**

IV. **The Nature of Quantum Observation**

V. **New Approaches to Quantum Computing**

VI. **Quantum Computing Across Time**

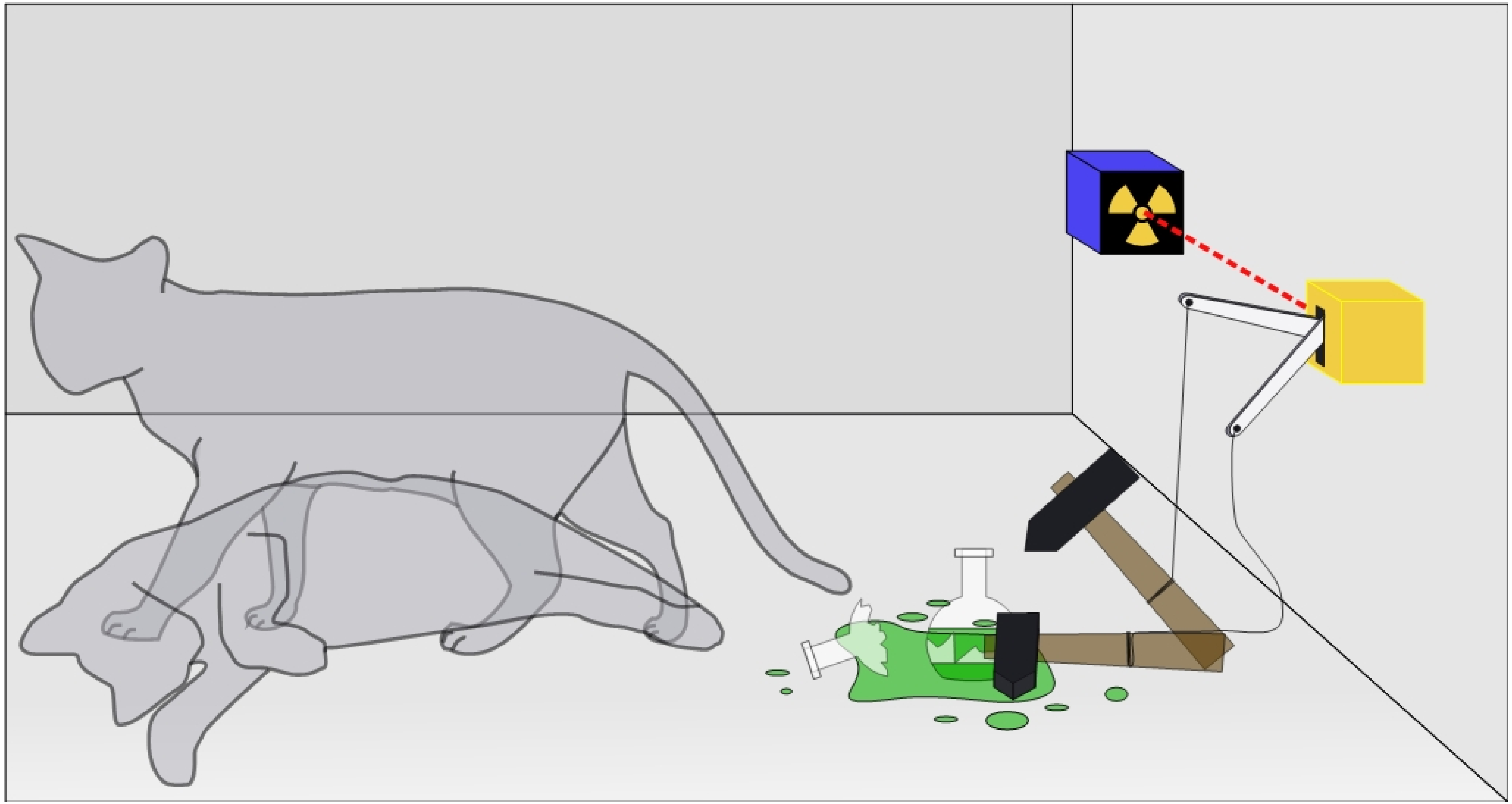
VII. **Quantum Computing in One Universe**

Part I.
The Problem of Badly Broken Promises

The Badly Broken Promises of Quantum Computing

- A vivid memory for those of us in communications security:
  - David Deutsch's **many-worlds-based** quantum computing was supposed to undermine all prime-number cryptography using only 15 qubits
  - Not 15 thousand… or 15 million… just 15 qubits
- What happened? Why does truly usable quantum computing continue to stump the world decades later?
- The deep answer lies in the physics assumed
  - There was a split in quantum physics perspectives between Richard Feynman (QED) and Hugh Everett (many-worlds)
  - Short version: Many worlds failed badly. My goal is to explain why.
- The good news: Past Wheeler and Feynman work hints at new paths that work at room temperature and very low energies

Schrödinger’s Attempt to Propose an Absurdity



Credit: Dhatfield, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4279886

Schrödinger's Original Thought Experiment

"One can even construct quite ridiculous cases. A cat is locked inside a steel chamber, together with the following diabolical machine, which must be secured against the cat's direct interference:

Inside a Geiger counter lies a tiny amount of radioactive substance — so small that, in the course of an hour, *perhaps* one of the atoms will decay, though it is equally probable that none will. Should it decay, the counter triggers and, via a relay, activates a small hammer that shatters a small vial of hydrocyanic acid.

If one leaves this entire system to itself for an hour, one would say that the cat is still alive, *provided* that no atom has decayed in the meantime, since the first atomic decay would have poisoned it. The ψ-function of the total system would express this by indicating that the living cat and the dead cat are (pardon the expression) 'mixed' or 'smeared' within it in equal parts."

— E. Schrödinger, *Die gegenwärtige Situation in der Quantenmechanik* [Teil 1 von 3]. Naturwissenschaften **23** (48), 807–812 [Nov.] (1935). Page 812, second paragraph, translated into English. https://informationphilosopher.com/solutions/scientists/schrodinger/Die_Situation.pdf

It's True: "Be Careful What You Say!"

- Schrödinger's *only* reason for coming up with his famous cat experiment was to show that extending quantum wave functions to complicated material states produces absurd outcomes

- Imagine his horror when…
  - Everyone else "maxed out" on superposing complicated material states
  - It became the *mantra* for proclaiming the Mysteries of the Quantum World
  - Schrödinger and Einstein allied in asserting that something is missing

- How was such a dramatic reinterpretation even possible?
  - Quantum state superposition *requires* ignorance of the internal state
  - In the absence of such information, there is no limit to what theorists can *presume* takes place, especially by extending classical continuum math models

Enter Hugh Everett

- Like Richard Feynman, Hugh Everett worked on his thesis under John Wheeler
- Feynman focused on producing a quantum interpretation of photons and electrons that was both radical and highly predictive
- Everett focused on producing a radical quantum interpretation that he specifically claimed did not predict *anything* new
- Pretty much anytime you hear about “multiverses” in the entertainment industry, that’s a direct impact of Everett’s ideas
- His other profound impact, mostly via David Deutsch, was on the design of devices intended to provide extremely powerful forms of quantum computing

Everett's Central Idea Was All About… Waves?

"A physical system is completely described … an element of a Hilbert space … [Traditional quantum theory says there] are two fundamentally different ways in which the state function can change:

- Process 1: The discontinuous change brought about by the observation of a quantity with eigenstates $\phi_1, \phi_2, \ldots,$ in which the state ψ will be changed to the state ϕ_j with probability $|(\psi, \phi_j)|^2$.
- Process 2: The continuous, deterministic change of state of an isolated system with time according to a wave equation $\partial\psi/\partial t = \mathbf{A}\psi$, where $\mathbf{A}$ is a linear operator."

— H. Everett III, *"Relative State" Formulation of Quantum Mechanics*. Reviews of Modern Physics **29** (3), 454–462 [Jul. 1] (1957).

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Other Everett Fundamentals

- Observer and observed become a single wave

> "… Subsystems do not possess states that are independent of the states of the remainder of the system … It is meaningless to ask the absolute state of a subsystem — one can only ask the state **relative** to … the remainder of the [system]."

- Observer and observed expand into entire unique universes

> "… with each succeeding observation ... the observer ... "branches" into a number of different states. Each branch represents a different outcome of the measurement and the corresponding eigenstate for the object-system state. All branches exist simultaneously in the superposition after any given sequence of observations."

— H. Everett III, *"Relative State" Formulation of Quantum Mechanics*. Reviews of Modern Physics **29** (3), 454–462 [Jul. 1] (1957).

Enter David Deutsch

- In 1985, David Deutsch wrote a paper proposing how properly designed reversible (non-entropic) logic gates could access almost indefinitely large information processing capabilities
- Deutsch explicitly invoked Everett's many-worlds model as one of the necessary pillars of his approach to quantum computing

> Computing machines resembling the universal quantum computer could, in principle, be built and would have many remarkable properties not reproducible by any Turing machine. These do not include the computation of non-recursive functions, but they do include 'quantum parallelism', a method by which certain probabilistic tasks can be performed faster by a universal quantum computer than by any classical restriction of it. **The intuitive explanation of these properties places an intolerable strain on all interpretations of quantum theory other than Everett's.**

— D. Deutsch, *Quantum theory, the Church-Turing principle and the universal quantum computer*, Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences **400** (1818), 97–117 (1985). https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1985.0070

- Deutsch "bet the farm" on accessing Everett's ever-expanding wave

Everett Would Have *Disagreed* With Deutsch (!)

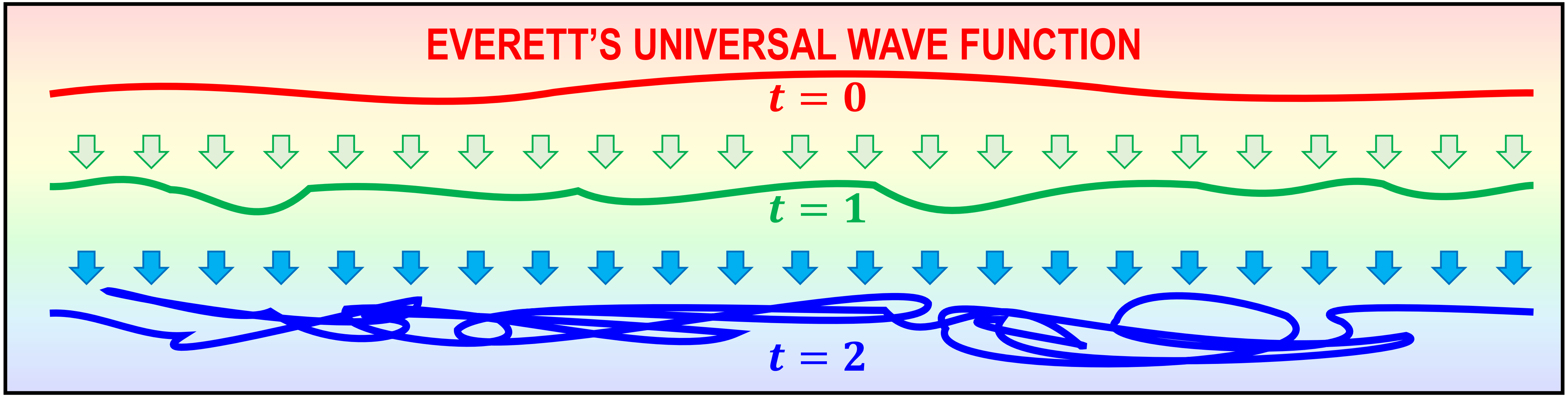
"It is unnecessary to suppose that all but one [branch is] destroyed, since **all the separate elements of a superposition individually obey the wave equation with complete indifference to … other [branches]**. This total lack of effect of one branch on another also implies that no observer will ever be aware of any 'splitting' process."

— H. Everett III, *"Relative State" Formulation of Quantum Mechanics.* Reviews of Modern Physics **29** (3), 454–462 [Jul. 1] (1957).

- Everett died (1982) before Deutsch published his computation idea (1985).
- Deutsch's idea depends directly on seeing *all* of Everett's expanding wave function, saying it placed an "intolerable strain" on anything less than Everett's infinitely expanding and elaborating universal wave function
- However, Everett claimed his model matched traditional quantum mechanics

Why Was Everett's Universal Wave So Important?

- Compared to all other quantum hypotheses, the unique feature of Everett's universal quantum wave function was that it had *no limit* to how detailed it would become over time
- Everett's idea, taken seriously, creates new universes with *every* particle quantum superposition event *anywhere in the universe*
- Everett's wave detail expansion would be "hyper-exponential" — an increase in complexity per unit of time so large that it is difficult to quantify

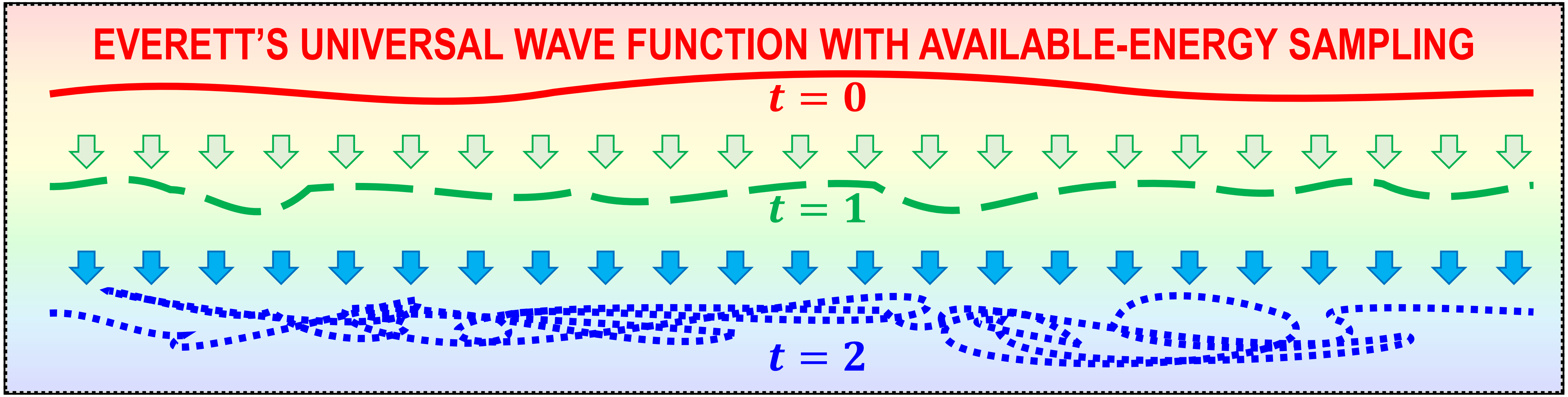


How Strong Was Deutsch's "Proof of Access"?

- Deutsch's proof of access to the multiverse was never strong
- His 1985 phrase "**intuitive explanation** of these properties [of quantum parallelism]" indicates it was more a hope than a proof
- I worked in the security world at that time, and recall it vividly:
  - Early claims were that incredibly small numbers of "universal computing" qubits, e.g., 15, would break every factoring-based encryption scheme (most were) in existence
  - Most nations freaked out at the possibility and began dumping in research cash
  - Early predictions *explicitly* labeled this as a "possibility to be proven," *not* a given
  - All early results failed miserably
  - But then, a funny thing happened…
- Folks began asserting that "noise" was the problem, and Deutsch was *still* correct. The problem was those darned engineers!

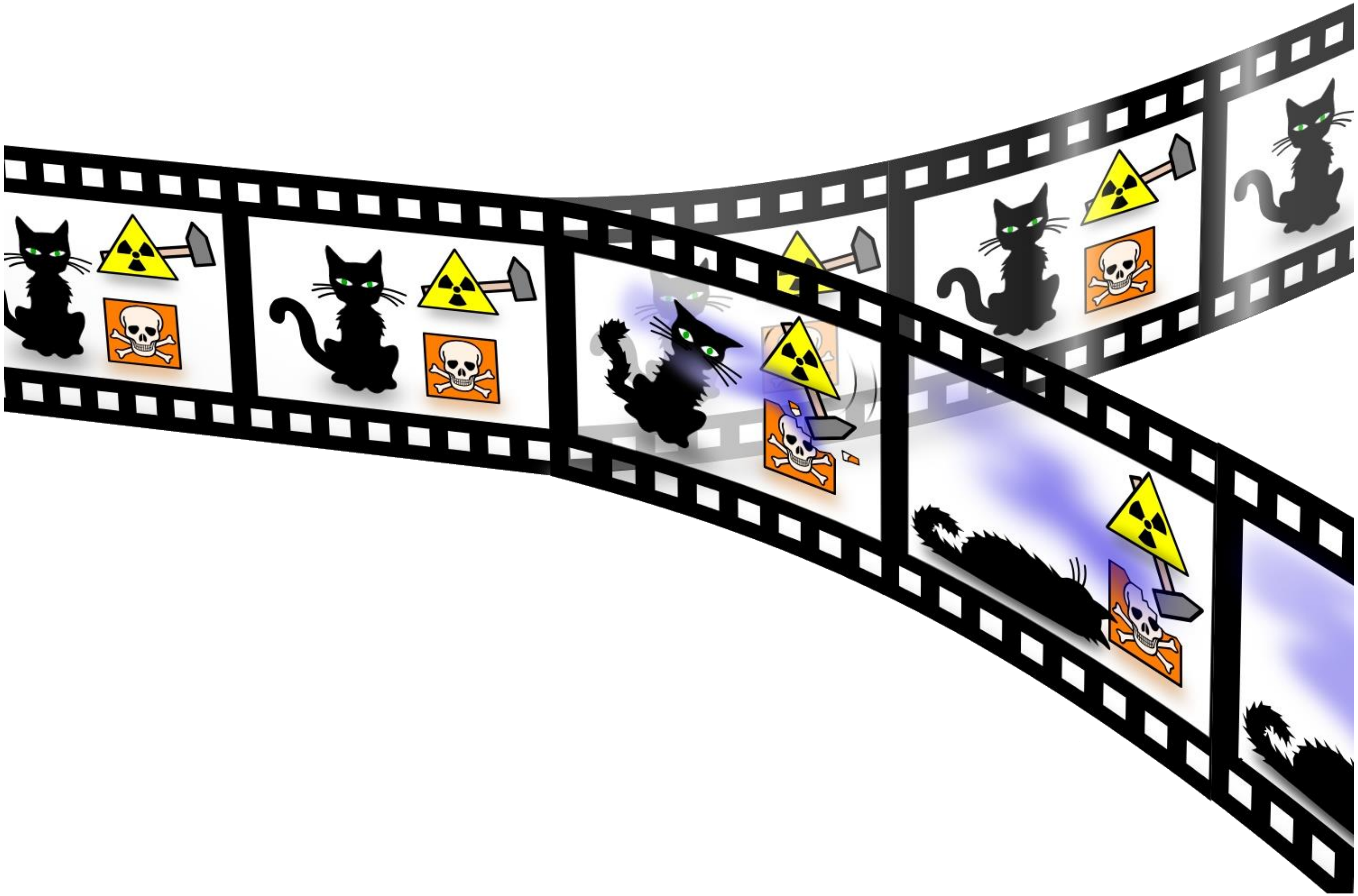
What Everett Likely Would Have Predicted

- Fully conventional quantum experiment outcomes — which are what Everett *explicitly* predicted for his wave model — follow a remarkably simple rule:
  - The amount of information returned stays directly proportional to the total energy used
  - E.g., one photon give only one "flash" showing a single tiny part what could be a very complicated overall shape. *Huge* number of photons are needed to see the full shape.
  - Deutsch's failures were not noise. He was just creating the world's worst wave computer
  - He "sampled" real quantum waves, but could have done it easier with, e.g., brighter lights

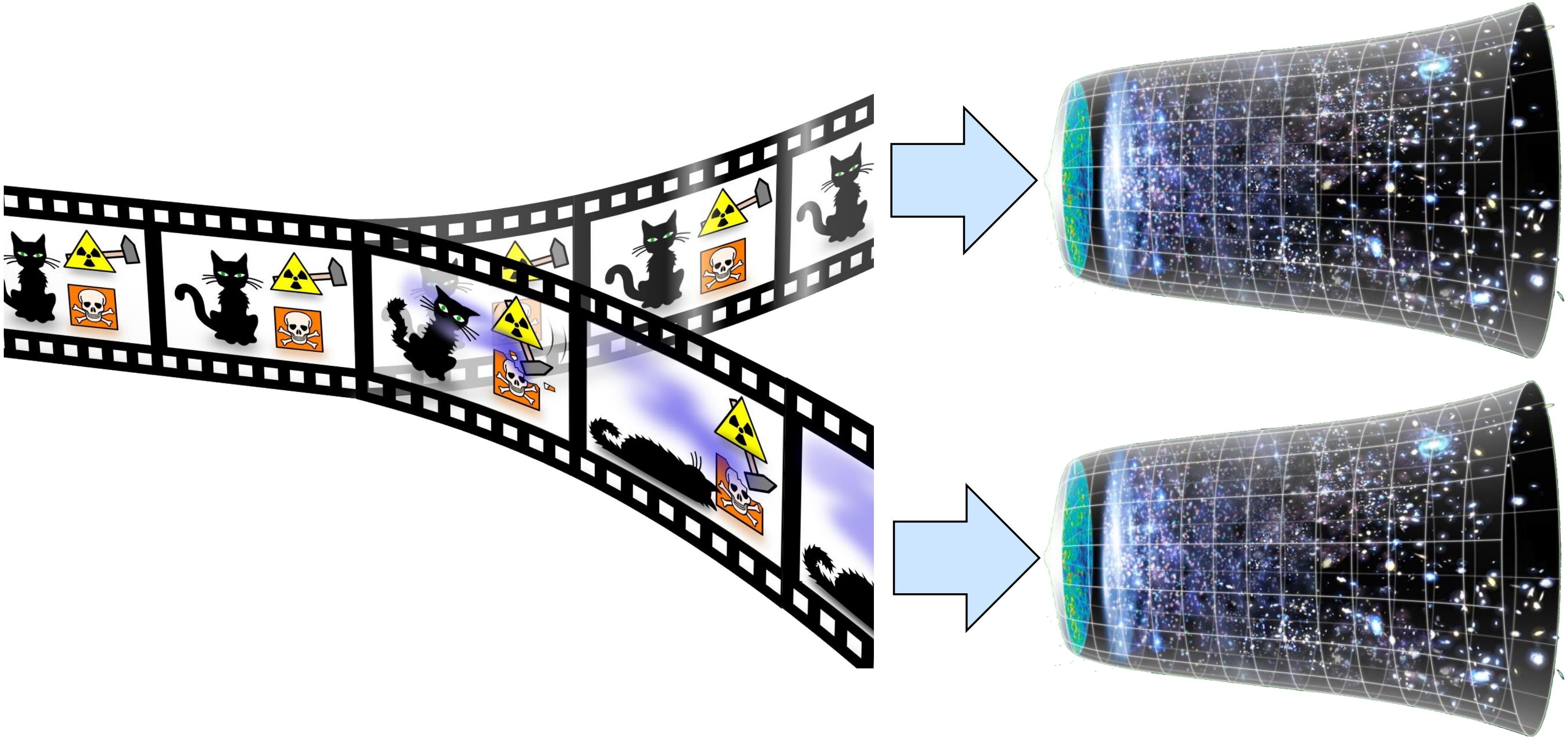


Part II.
The Everett Generalization of Cat Splitting

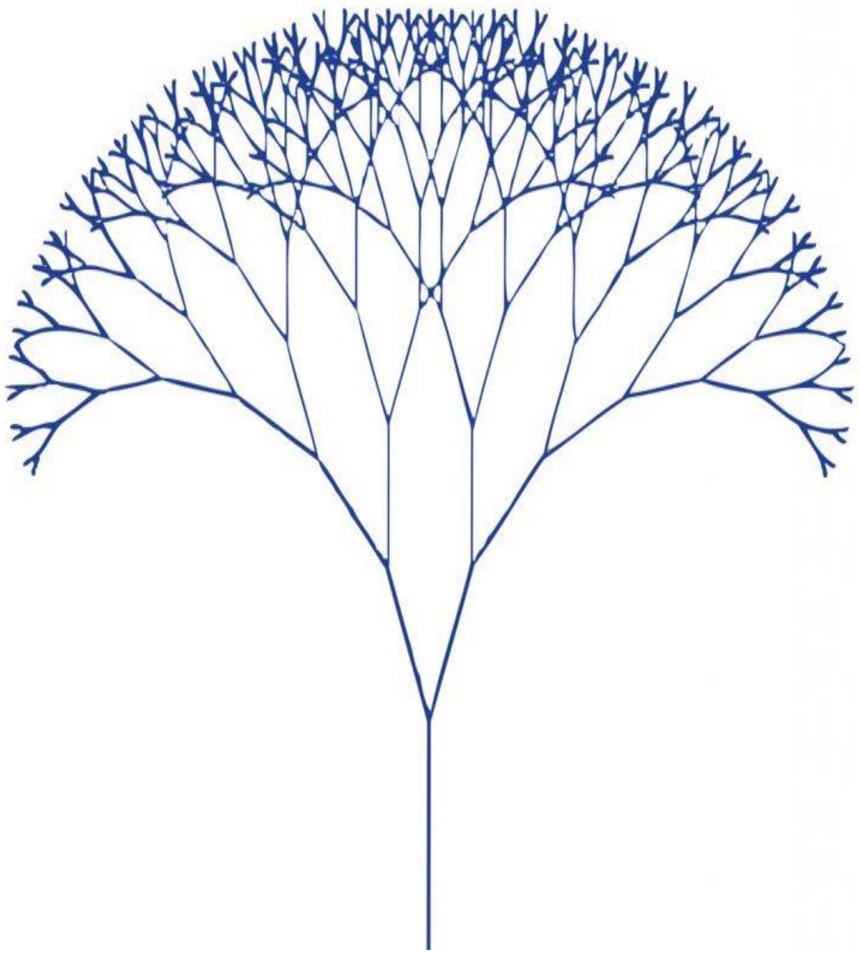
An Implication: The *Splitting* of Classical States



Everett's Enormous Amplification of The Cat



The Unimaginable Vastness of Everett Splitting



- In Everett's model, *every* quantum choice creates a new universe (!!)
- This splitting includes *every* pair of choices that experimental testing would see as unique outcomes
- "Staggering" does not begin to describe the number of universes that Everett's assumption generates
- The justification is that all of this is a *single* smooth wave function
- It was Feynman who first pointed out the "many worlds" implication

Everett’s (and von Neumann’s) Use of Hilbert Space

- Everett’s thesis **does not explain** how his universe states form
  - Actual quantum states and superpositions remain fully subject to important laws of physics, e.g., finite-speed propagation of information (important!)
- His thesis argument amounts to this:
  - “Hilbert generalized 3D space into an infinite number of dimensions.”
  - “If I *define* each dimension to be a separate, unique universe, then…”
  - “I can claim that letting a *single particle* in a laboratory here on earth go into a quantum superposition accesses two entirely new universes!”
- Everett (and von Neumann) seem to have had no clear understanding that the speed at which one can create universe states is limited by light speed

Everett's Use of von Neumann's Hilbert Spaces

If a composite system S, is composed of two subsystems S_1 and S_2, with associated Hilbert spaces H_1 and H_2, then, according to the usual formalism of composite systems, the Hilbert space for S is taken to be the tensor product of H_1 and H_1 (written $H = H_1 \otimes H_2$). This has the consequence that if the sets $\left\{\xi_i^{S_1}\right\}$ and $\left\{\eta_j^{S_2}\right\}$ are complete orthonormal sets of states for S_1 and S_2, respectively, then the general state of S can be written as a superposition:

$$\psi^S = \sum_{i,j} a_{ij} \xi_i^{S_1} \eta_j^{S_2} \; .$$

— H. Everett III, *"Relative State" Formulation of Quantum Mechanics*. Reviews of Modern Physics **29** (3), 454–462 [Jul. 1] (1957).

- The concept of a Hilbert space is critical to all of Everett's model
- This von Neumann concept assumes "very cheap" orthogonality

von Neumann's Hilbert Spaces Generalize 3D Space

The equation

$$H\phi = \lambda\phi$$

as well as the requirement that a complete orthonormal set can be formed from its solutions, originates in an analogy with the case of finite dimensions, the $\Re_n$. In the $\Re_n$, H is a matrix

$$(h_{\mu\nu}),\quad \mu,\quad \nu = 1, \ldots, n, h_{uv} = \bar{h}_{\nu\mu}$$

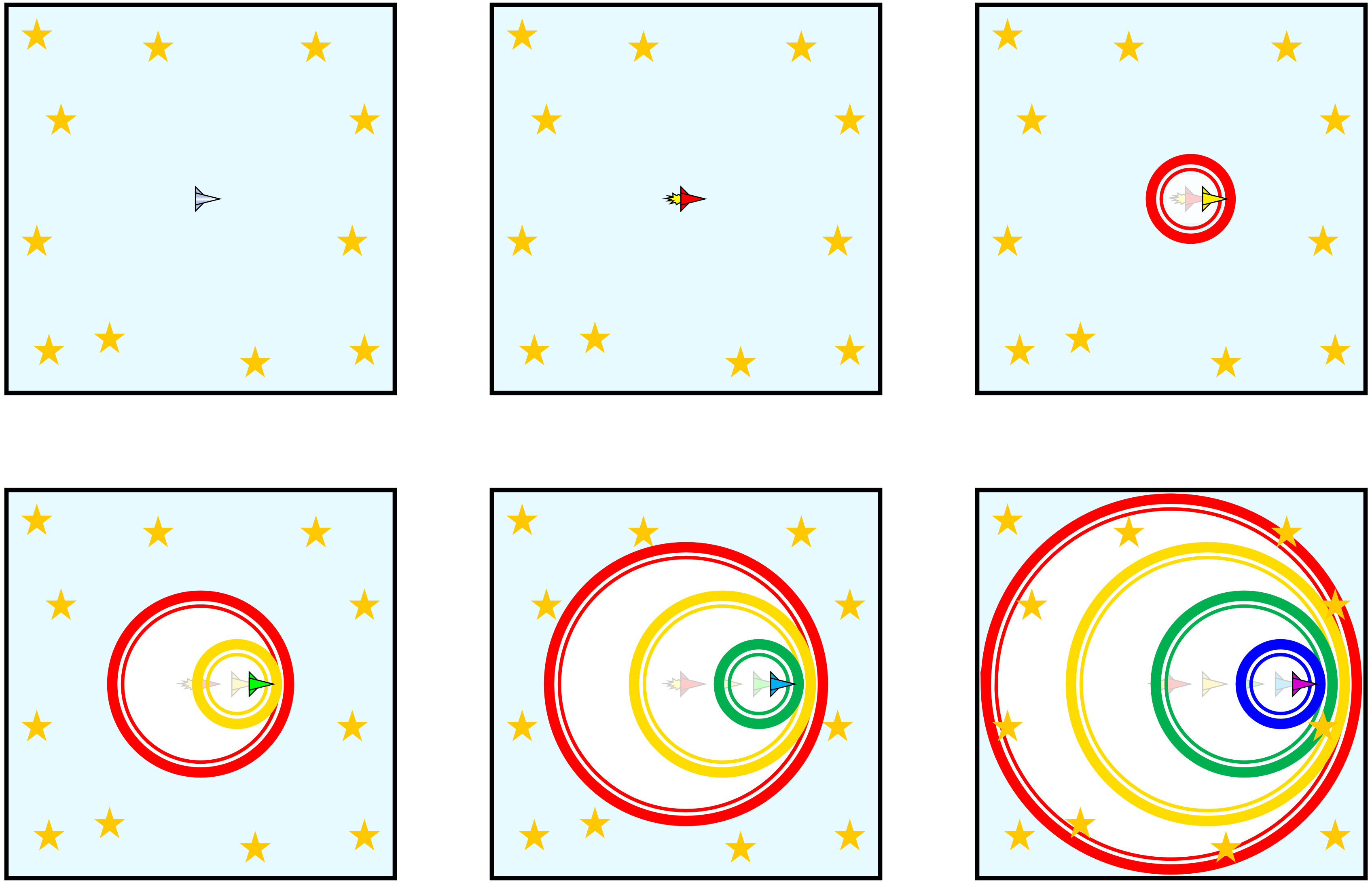
and it is a well-known algebraic fact that the solutions of $H\phi = \lambda\phi$, $\phi = (x_1, x_2, \ldots, x_n)$, i.e.,

$$\sum_{\nu=1}^{n} h_{\mu\nu} x_\nu = \lambda x_\mu \qquad (\mu = 1, \ldots, n)$$

form a complete orthonormal set.

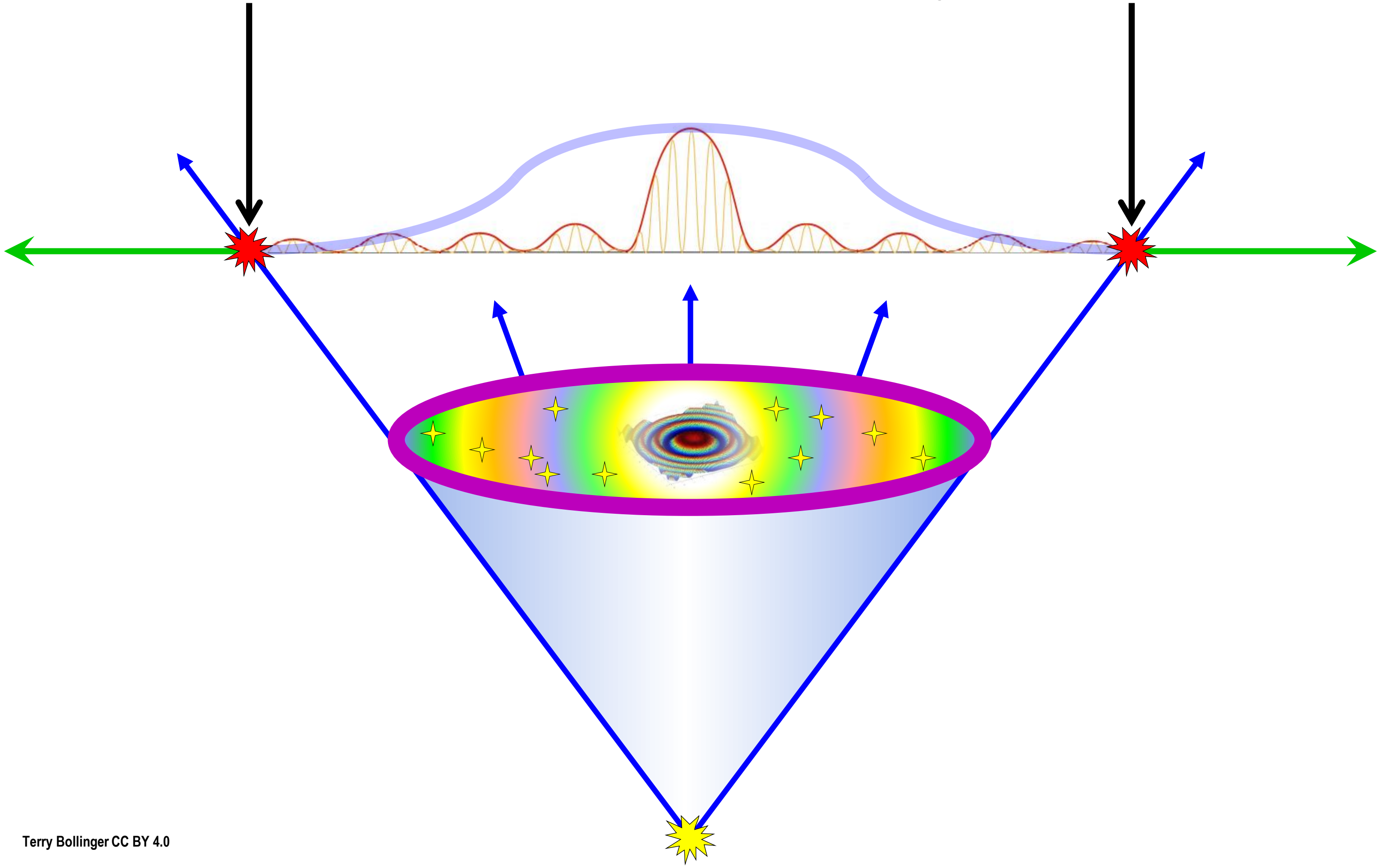
— J. von Neumann, *Mathematical Foundations of Quantum Mechanics*. Princeton University Press, 1955. https://vdoc.pub/download/mathematical-foundations-of-quantum-mechanics-3ba064mdvnag. Page 107.

Change Impacts Spread Very Slowly at Universe Scales



Light Cones Are Natural Quantum-Wave Boundaries

- **An alternative: Shift the infinite-momentum bump boundaries out to the light cone**
- **The resulting boundary spectrum then matches with the SR momentum spectrum**
- **An interesting implication: Light cones are fundamentally *quantum* phenomena**
- **A second implication: Dirac delta functions are the *least* physical of distributions**



Sources of State Change Misconceptions

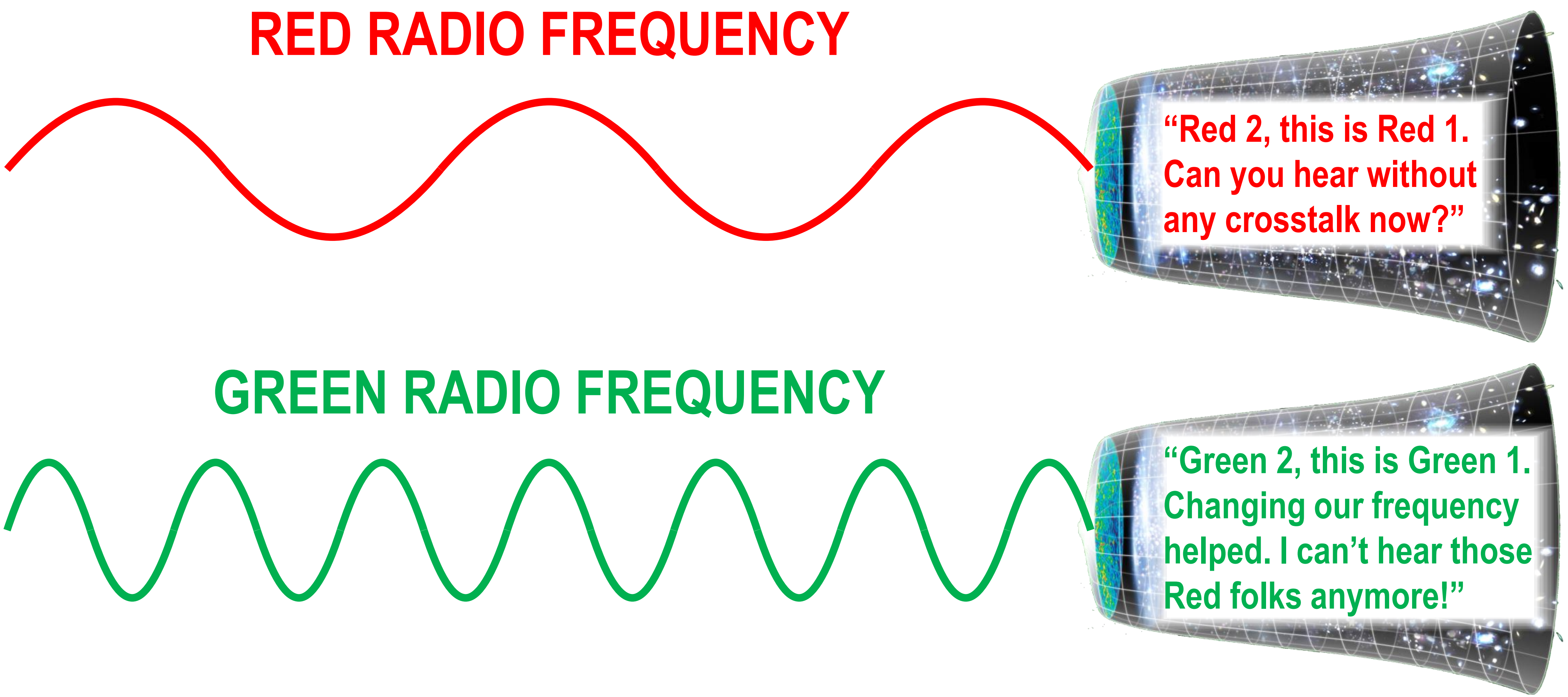
- Everett's relational model subtly *assumes* the predefined existence of unique, fully orthogonal universe states
- This is not apparent when he talks *only* about local quantum interactions that barely notice speed-of-light delays
- For *entire universes*, the delay issue *cannot* be ignored
- Entanglement can also confuse folks, since it provides the (false) appearance of superluminal information travel
- However, wave function *formation* never proceeds faster than light
- While extremely popular and incredibly effective for *local* quantum mechanics, von Neumann's use of Hilbert spaces is too simple

Part III.
The Problem of Assuming Orthogonality

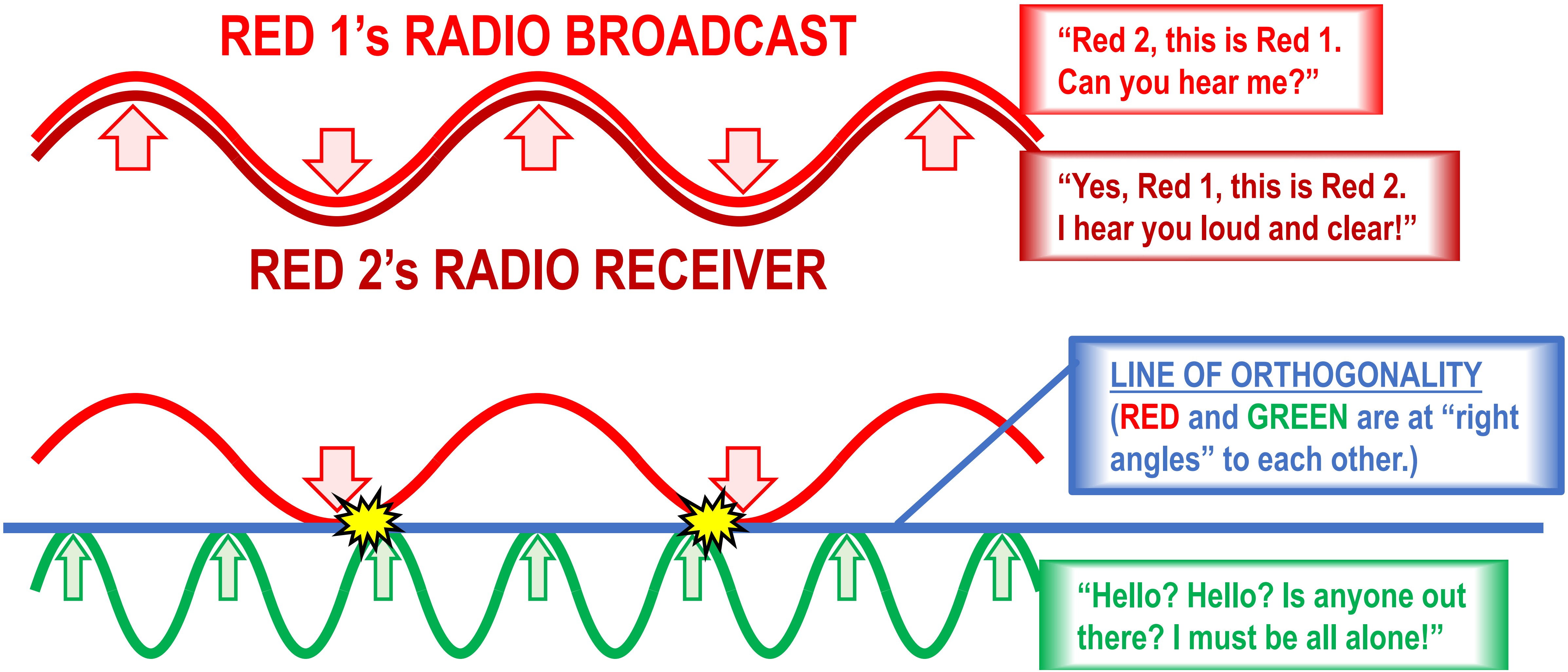
The Problem of Universe Orthogonality

- Everett's actual thesis argument focused on the concept of a *universal quantum wave*
- In his universal wave, each "choice" (e.g., dead or alive cat) becomes an added detail to the universal wave function
- No possibility (no wave detail) is ever discarded. His reasoning:
  - If you define a Hilbert space that *already has* an infinite number of universe states, the wave evolves smoothly, becoming more detailed
  - Note that Everett's model is circular since he *assumed* that the unique universe states in his model existed, without explaining how they form
  - A second serious issue: **How do you "find" *your* universe in the wave?**
  - The implicit answer in Everett's thesis is this: Just as radio stations can occupy individual "bands" that stay separate, "my" universe becomes a unique frequency "band" in the universal quantum wave

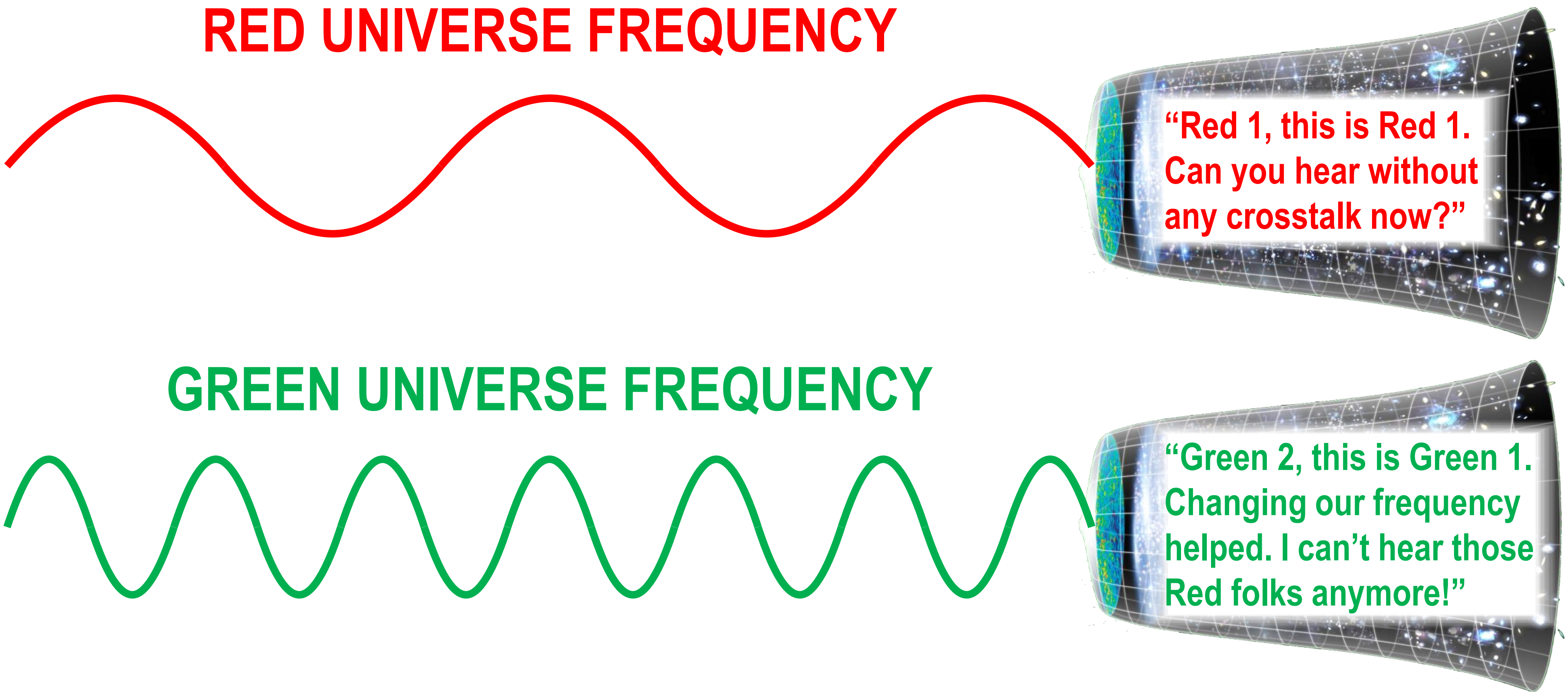
Regular Repetition is the Key to Band Separation



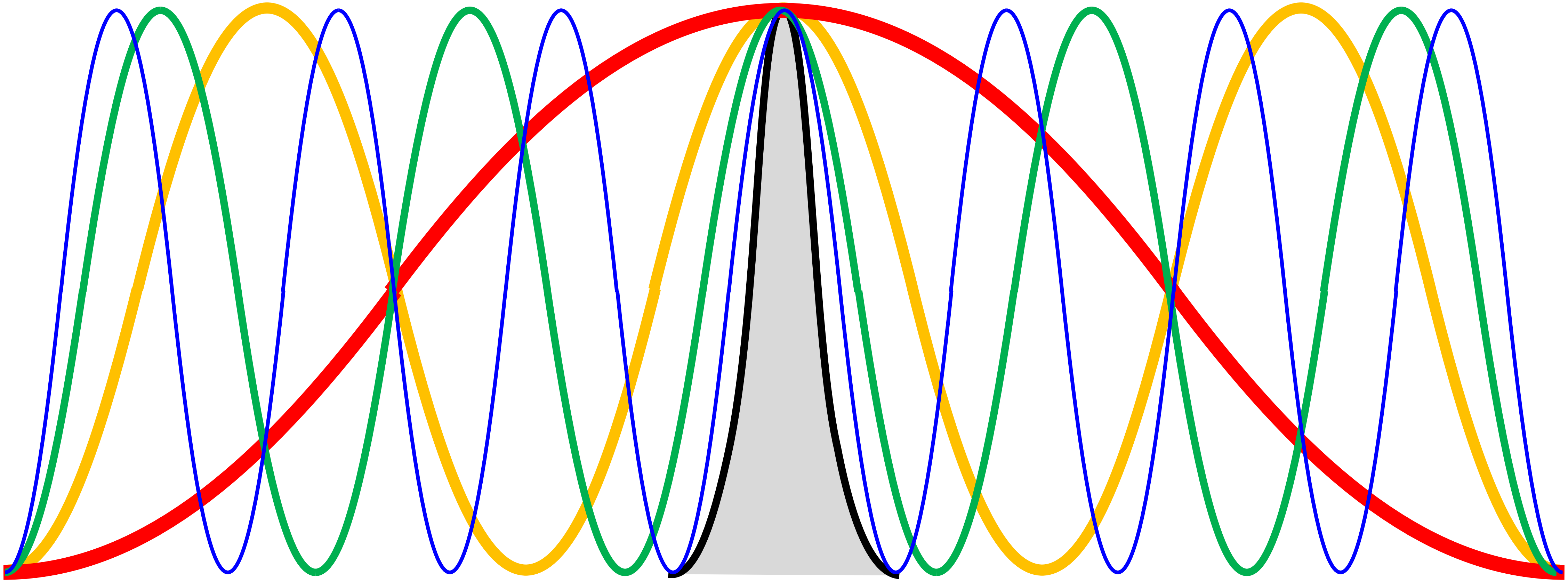
Repetition as a "Lock and Key" (Fourier) Separator



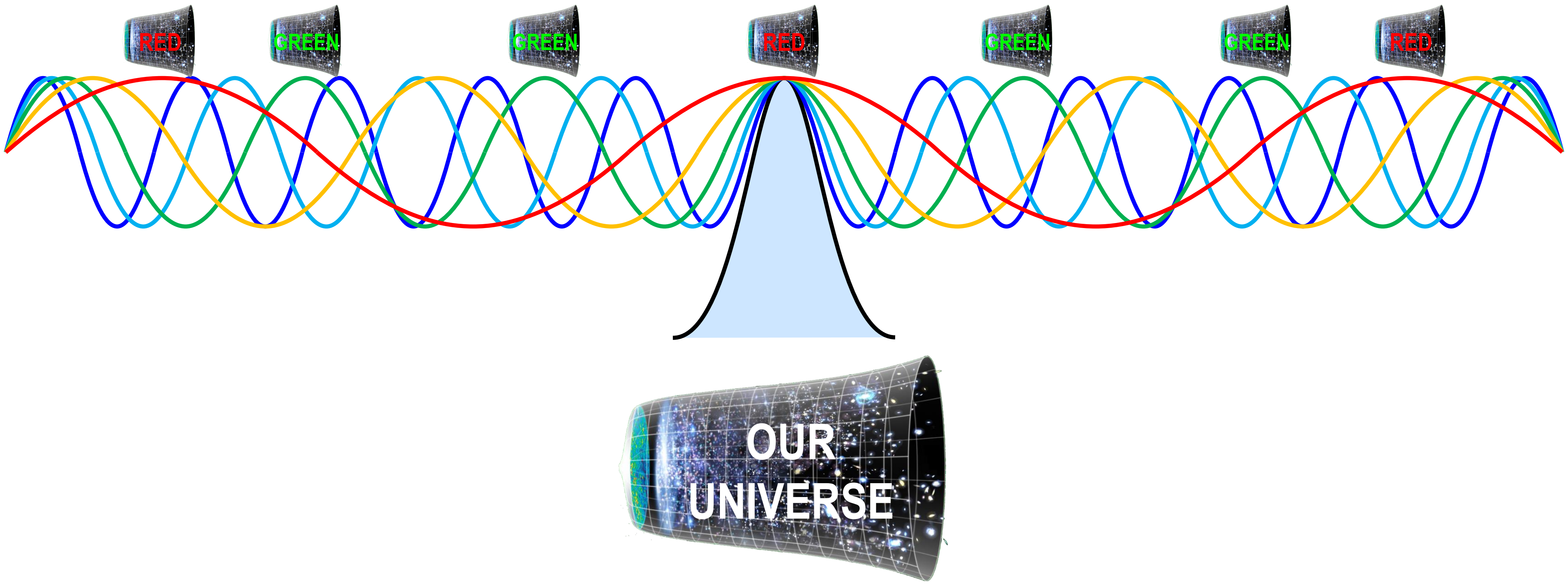
Each Split Creates a Very Tiny Universe Difference



Peak Matching: A Lazy Way to Check Fourier “Isolation”

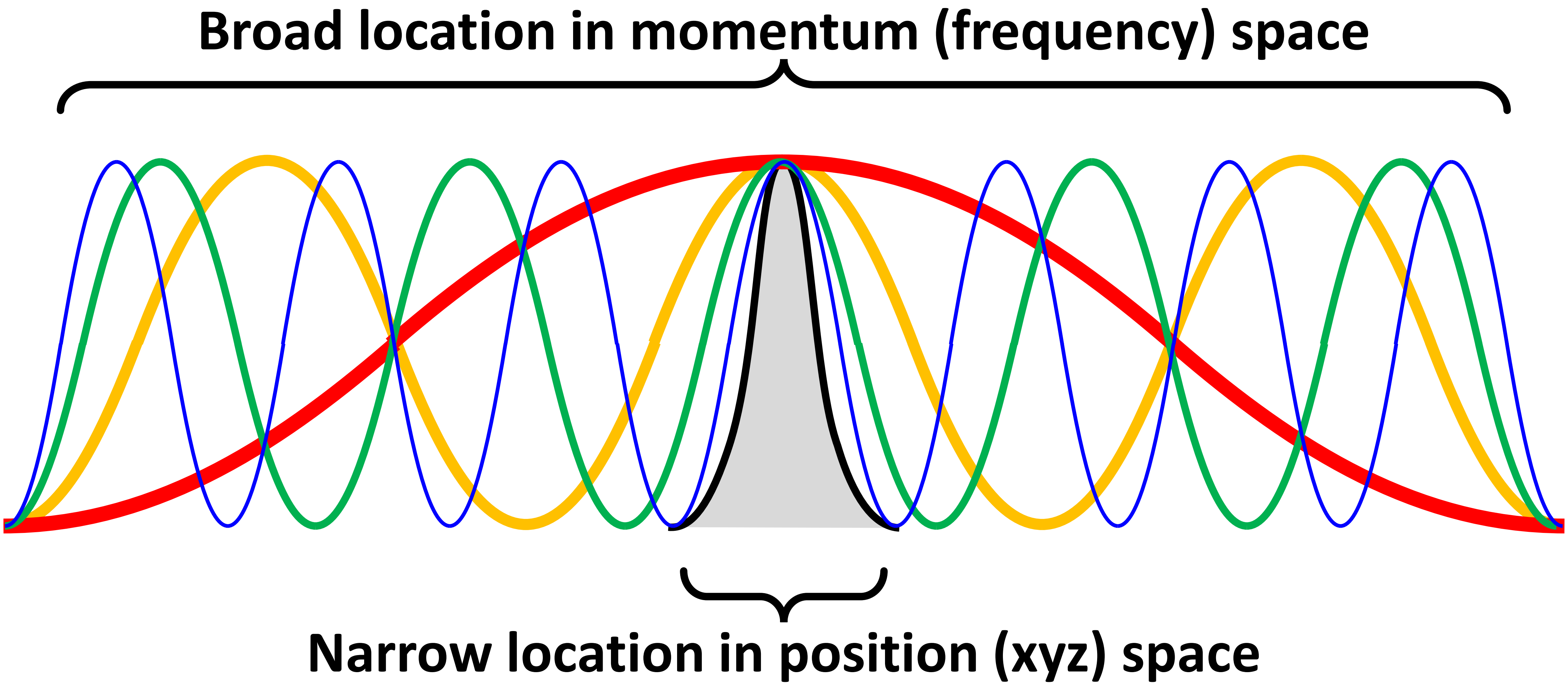


Houston, We Have a Crosstalk Problem!



Without repetition of a unique pattern to distinguish **RED** and **GREEN** from us, our universe shows up ***everywhere***

Sidenote: Fourier is the Source of Quantum Uncertainty



The State Isolation Issue Is Actually Much Worse

- The **changes** made by *one* quantum event are **unbelievably tiny** in comparison to the universe
- The entanglement that creates a single, unique **RED** or **GREEN** universe only happens **after the change has propagated** throughout our universe (!)
  - Creating a new **RED** and **GREEN** universe pair after a quantum split event thus would typically take **tens to hundreds of billions of years**
- That's just the start. It gets *much* worse:
  - The **smaller the change**, **the more "repetitions"** of the universe are needed to create an **orthogonal isolation** between them
  - The **full time** to isolate **RED** and **GREEN** thus is vast beyond imagining

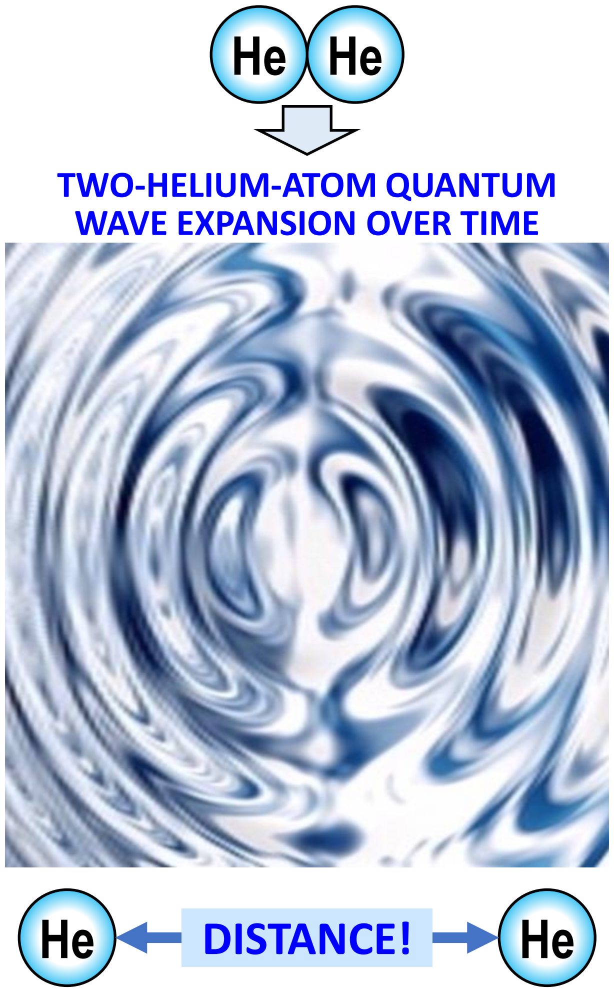
Piling On: Everett's Information Encoding Problem

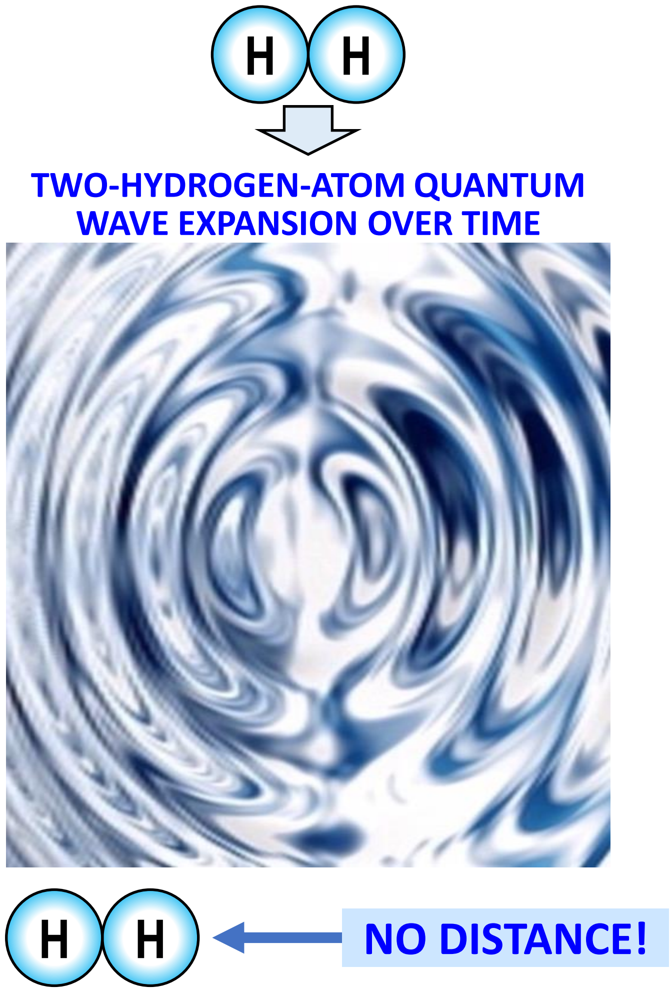
- **Radio Frequency (RF) Energy 101, Fundamental Principle #1**
  - Every finite-energy frequency has *finite* information capacity
  - This principle works very much like pixelation in a display screen
  - Higher frequencies represent higher pixelation densities, and lower frequencies represent lower pixelation densities
- Everett and others call the medium on which his universal wave function exists "energy," but there's a problem…
  - Everett's version of "energy" allows *infinite expansion of detail* without ever losing new details
  - Real energy does not work like this! Everett's energy is **pure magic**.
  - The entire reason for quantum mechanics was to recognize that the universe **does not allow infinite detail on anything**
- Another odd corollary: **Instantaneous gravitational collapse**

Part IV.
The Nature of Quantum Observation

What is “Quantum Observation,” Anyway?

Here’s a thought problem that clarifies the nature of “observation”:





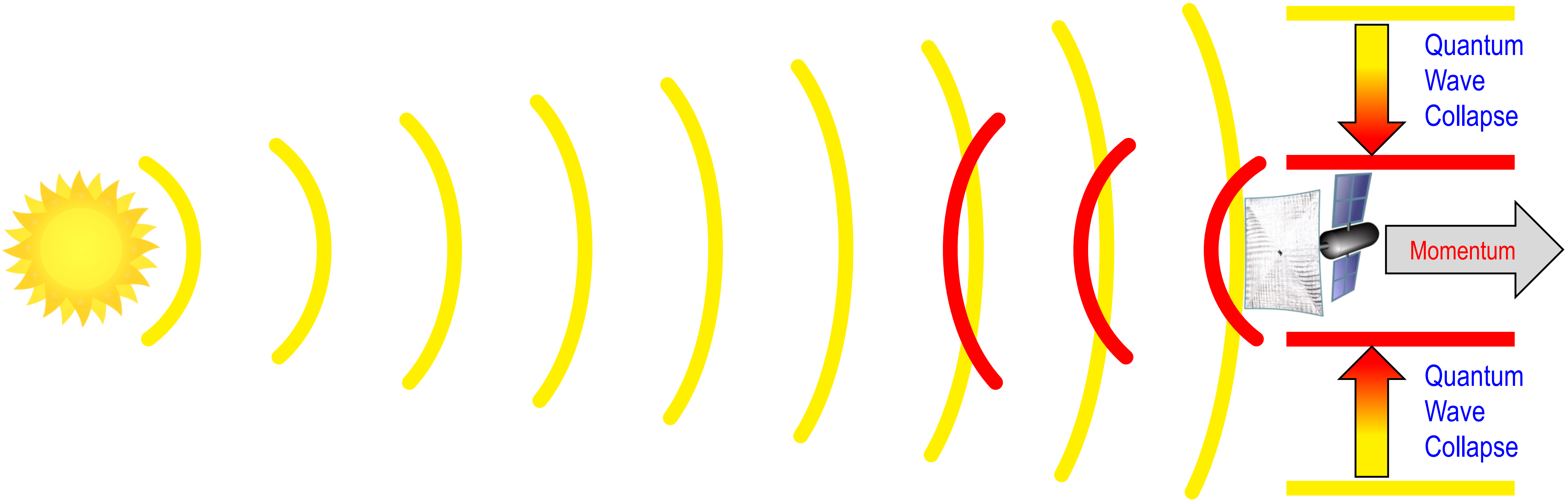
Q: Why do helium atoms “lose” each other, while very similar hydrogen atoms stay together?

A: Bonding means the hydrogen atoms **observe** each other constantly

More broadly: Any form of *bumping* allows two objects to “observe” **each other**

Acceleration is observation

Do We Have the Observer Problem Backwards?



- Specularly reflected photon waves are not absorbed by atoms
- However, they *are* detected by the momentum they impart

Quantum Observation Creates Classical Reality

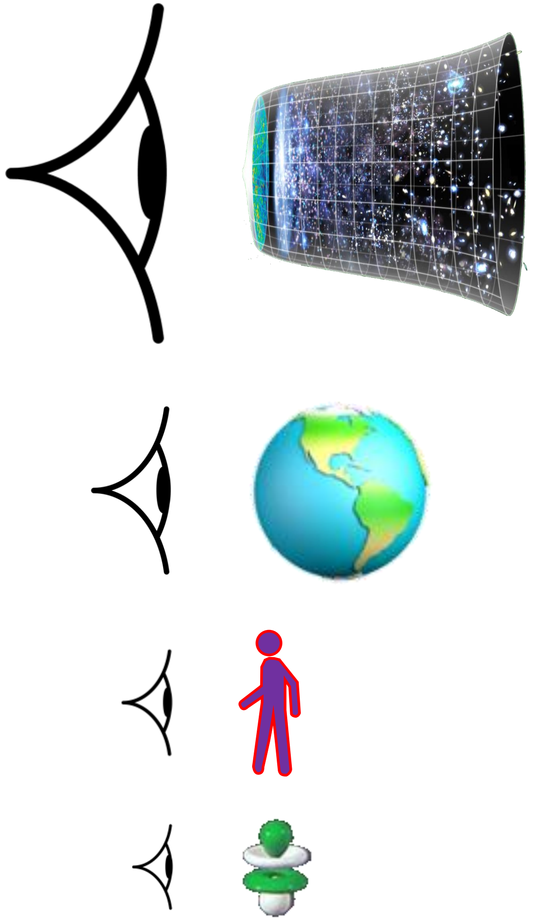
- **We make the concept of "observation" too abstract**
- The **classical world** in which we live is constructed from nearly continuous, bottom-up observation (force acceleration), starting with internal particle (color) and internal atomic (electric) forces
- The nature of "observation" baffles us for the same reason that talking about the need to drink water would baffle a fish
- It is only when we exclude bumping (e.g., by cooling molecules) that we begin to see isolated, separately identifiable examples
- Notably, actual observation is always a **two-way situation**
- **There is no observation "hierarchy" — no "ultimate" observer**

Why Bumping Is So Important

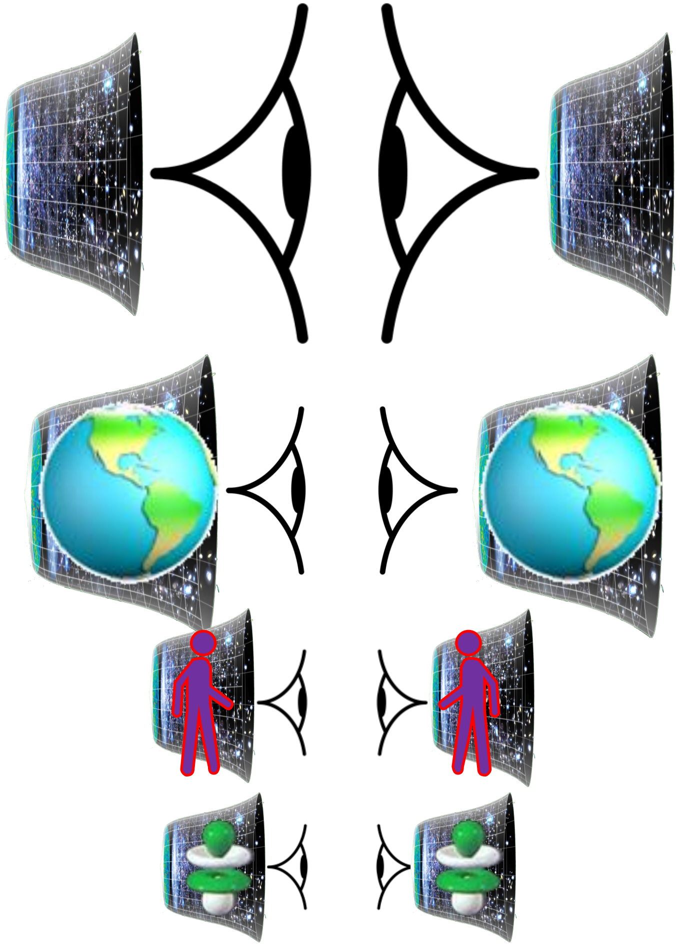
- Every bump of any two items alters the special relativity frames of those two objects
- The scale of the alteration doesn't matter — one photon is enough
- Size differences don't matter: Two electrons can bump, or one photon and a neutron star can "bump." Both collapse waves.
- The deeper story: Inertial frames are structured collaborations of matter and energy that follow the rules of quantum field theory
- *Usable* inertial frames are always defined by rulers and clocks
  - Forming inertial frames with matter attaches them to earlier histories
  - Inertial frames *never* occur without embedding in other inertial frames
  - Inertial frames are critical to understanding how the quantum world works

Three Theories of Quantum Observation

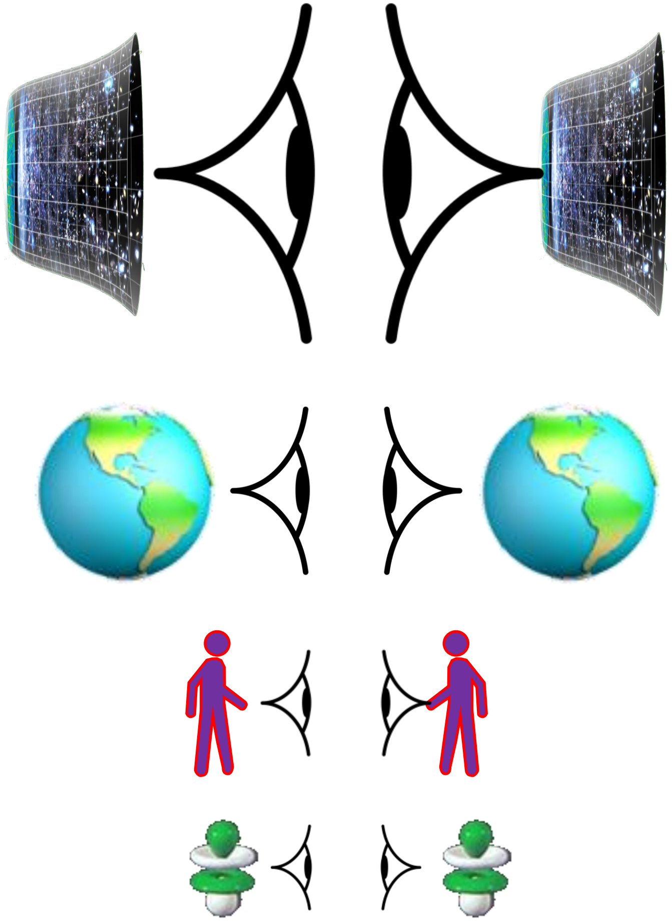
Wheeler Hierarchical Quantum Observers



Everett Relational Quantum Observers (Two New Universes Per Observation)



Bottom-Up Bump Quantum Observers



Part V.
New Approaches to Quantum Computing

Photons Don't *Have* to Travel in Straight Lines (!)

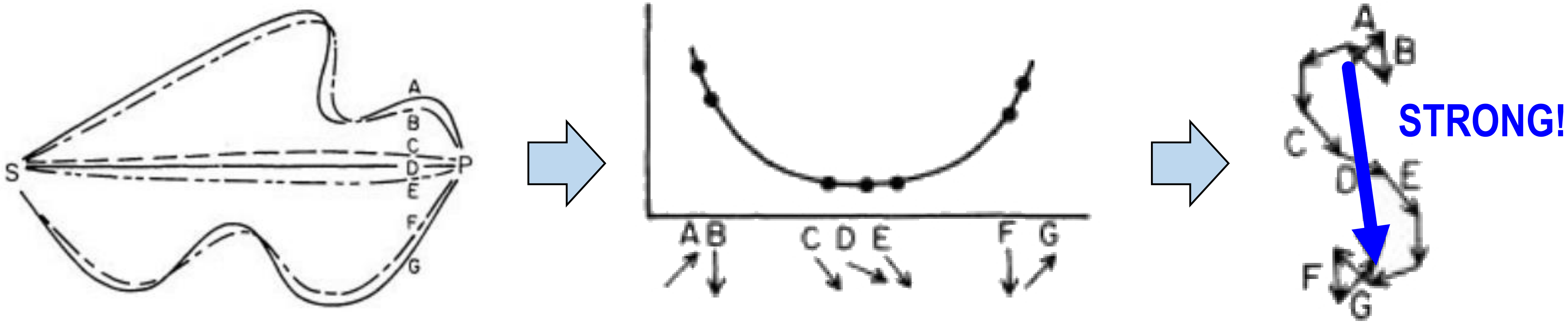


FIGURE 32. Quantum theory can be used to show why light appears to travel in straight lines. When all possible paths are considered, each crooked path has a nearby path of considerably less distance and therefore much less time (and a substantially different direction for the arrow). Only the paths near the straight-line path at *D* have arrows pointing in nearly the same direction, because their timings are nearly the same. Only such arrows near the straightest path count, because it is from them that we accumulate a large final arrow.

Glass Lenses Play Tricks on Photon Arrow Sums

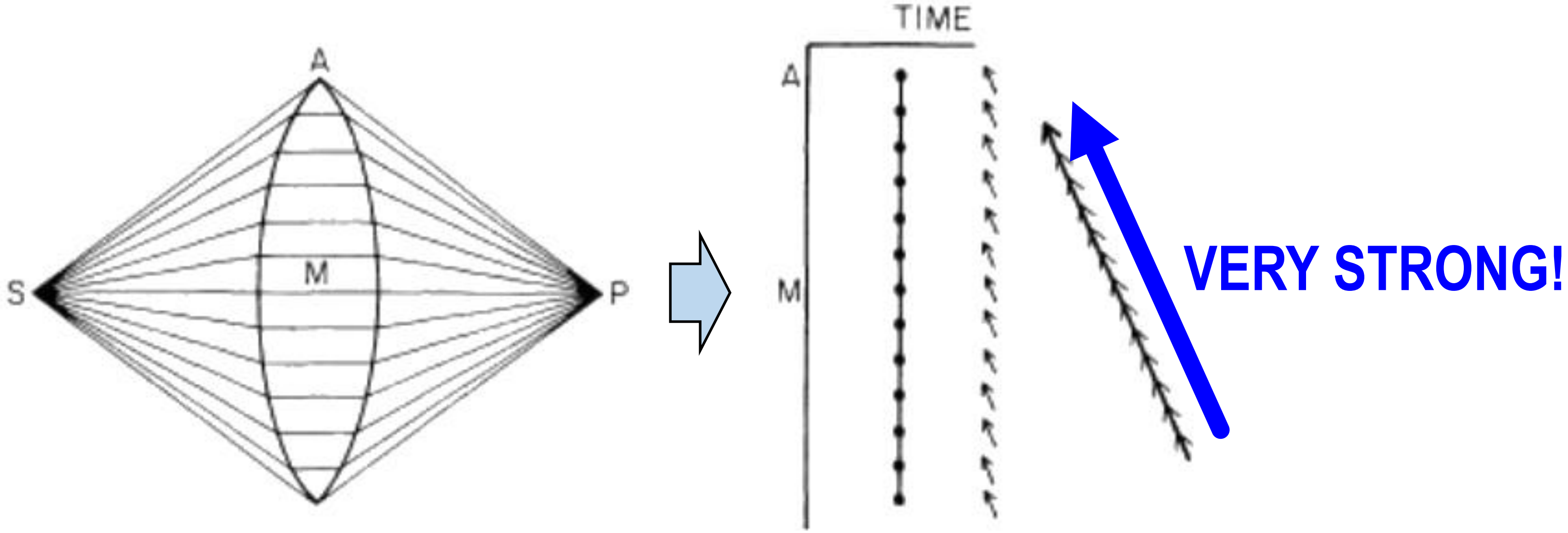
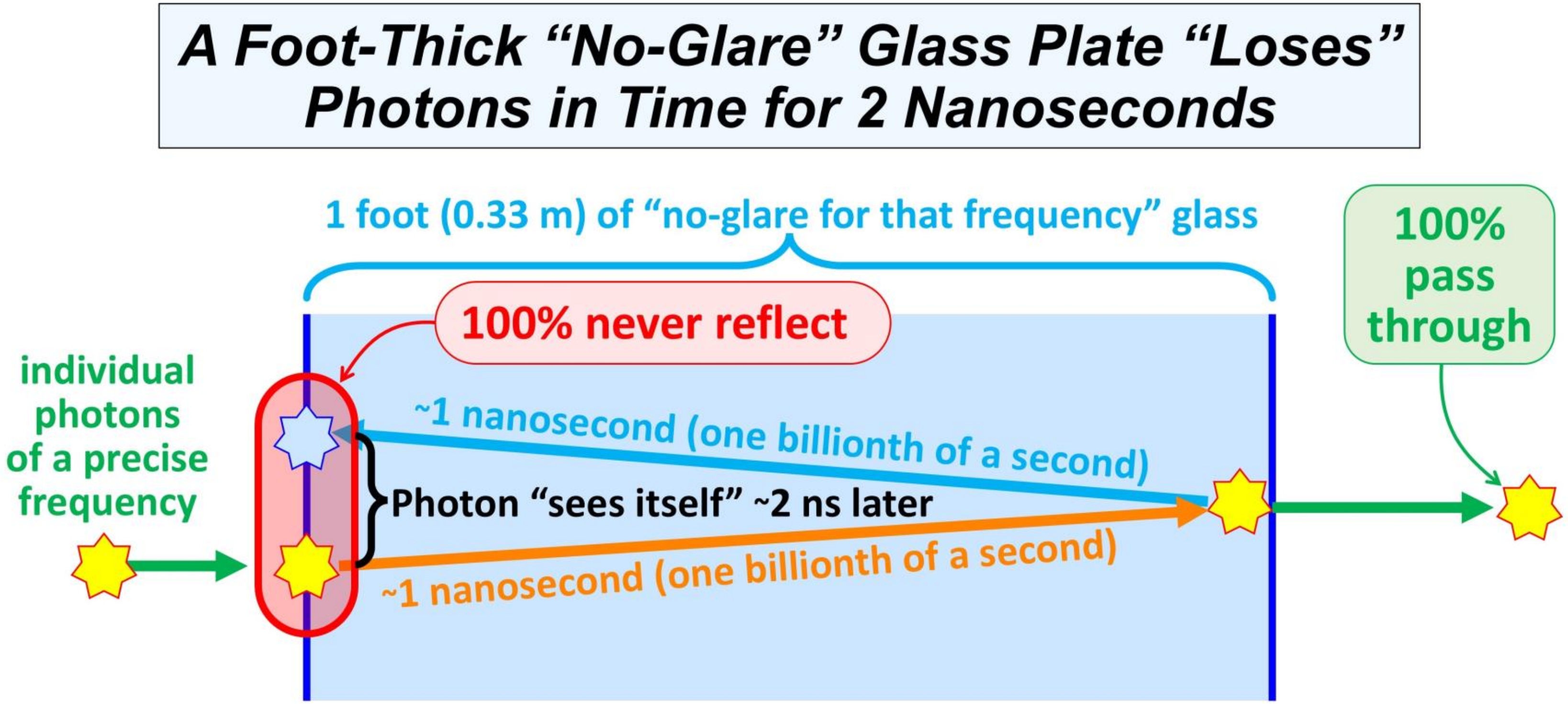


FIGURE 36. A "trick" can be played on Nature by slowing down the light that takes shorter paths: glass of just the right thickness is inserted so that all the paths will take exactly the same time. This causes all of the arrows to point in the same direction, and to produce a whopping final arrow — lots of light! Such a piece of glass made to greatly increase the probability of light getting from a source to a single point is called a focusing lens.

Photons Live Mostly in Momentum Space

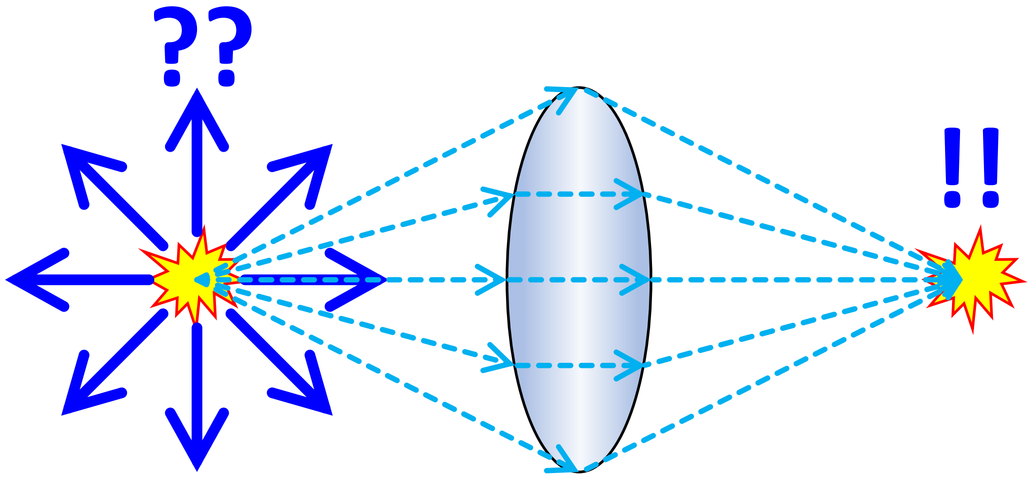
Because photons exist *mostly* in momentum-energy space, they lack simple locations in space and time, leading to baffling phenomena



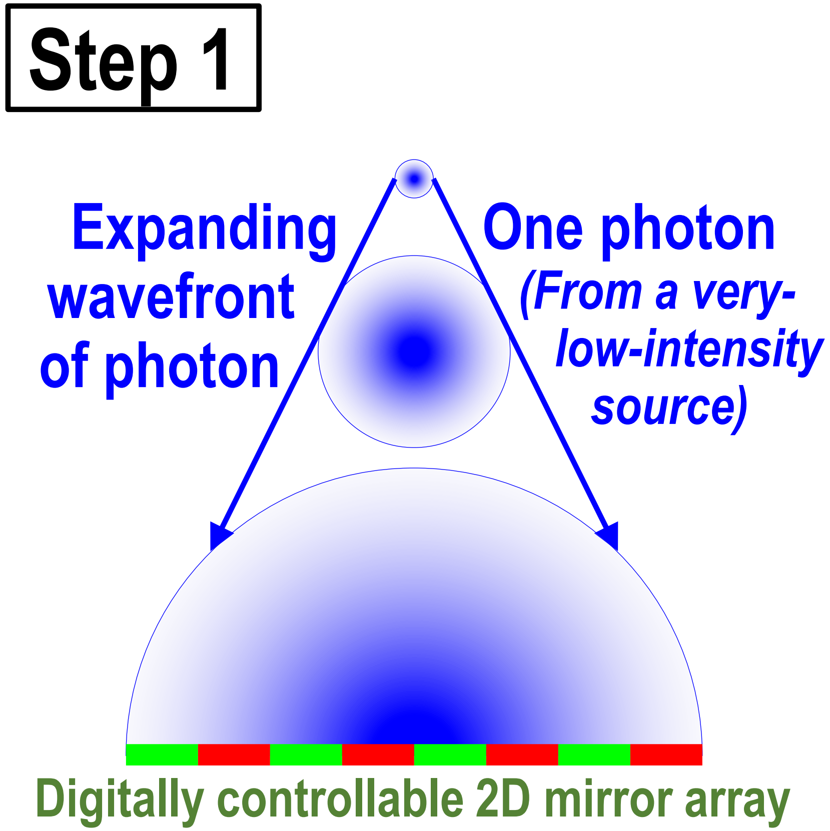
Two nanoseconds *after* the photon hits the glass front, its reflection from the far side of the glass cancels the existence of the reflection

Can Ambiguous Time Improve Probabilities?

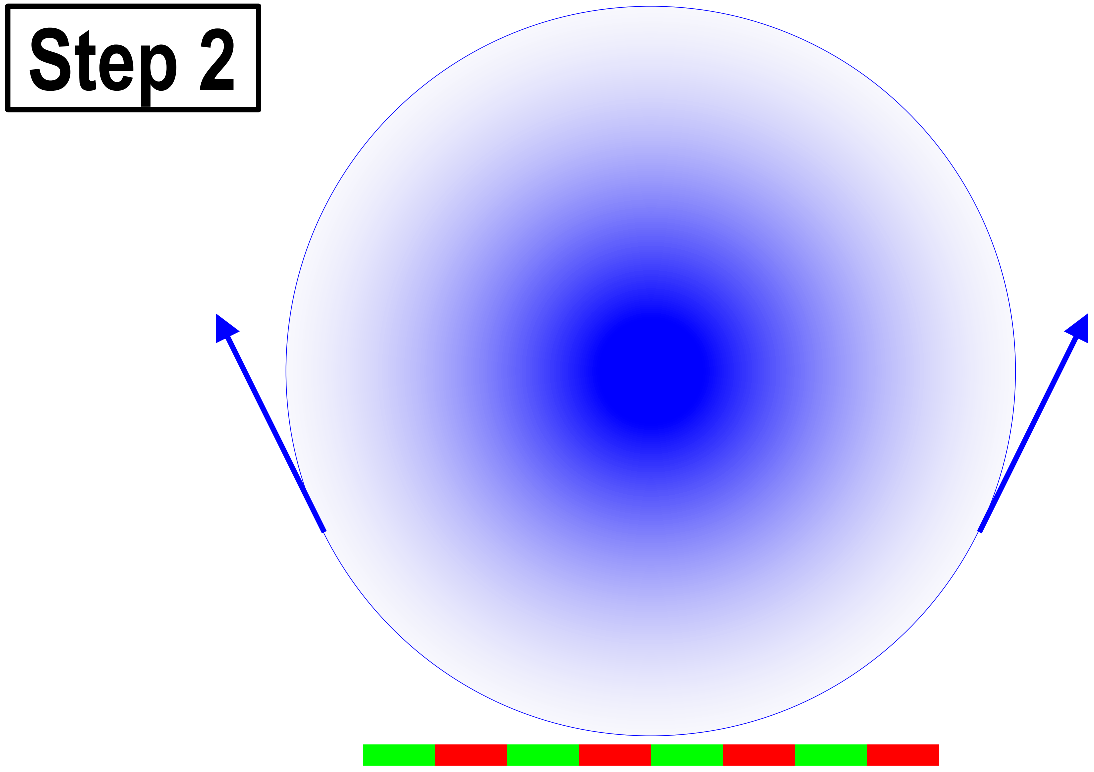
- Definitely! See examples on the previous two slides, where it can:
  - Help direct energy by making moving energy packets "self-interfere"
  - Reduce the odds of deleterious chemical reactions even in chaotic settings
- A specific example: If you send a photon out randomly and nominally in any direction, then, classically speaking, it should be almost impossible to recover
- But what if you use a quantum device better known as an *ordinary lens* to improve odds?
- Notable: The photosynthesis method used exciton lensing



Encoding Complex Images into Single Photons (1 of 2)



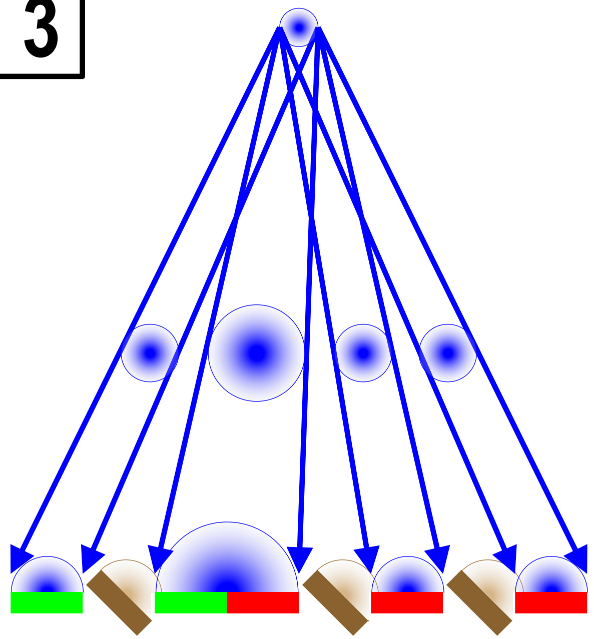
Digital multi-mirror device in all-flat, full-coherence, specular reflection mode



***No signals** (no qubits) except mirror location are encoded onto the reflected photon.*

Encoding Complex Images into Single Photons (2 of 2)

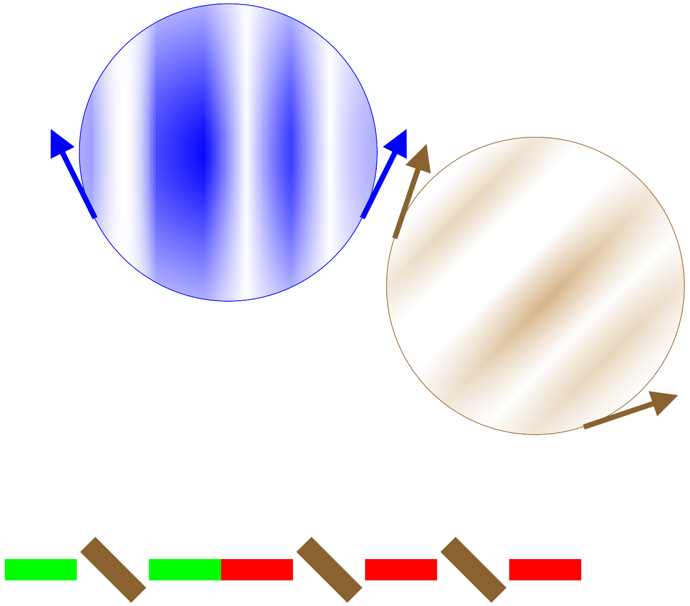
Step 3



Tilted mirrors split photon into two patterns

Selected coordinated groups of mirrors reflect photons coherently in either of two directions.

Step 4



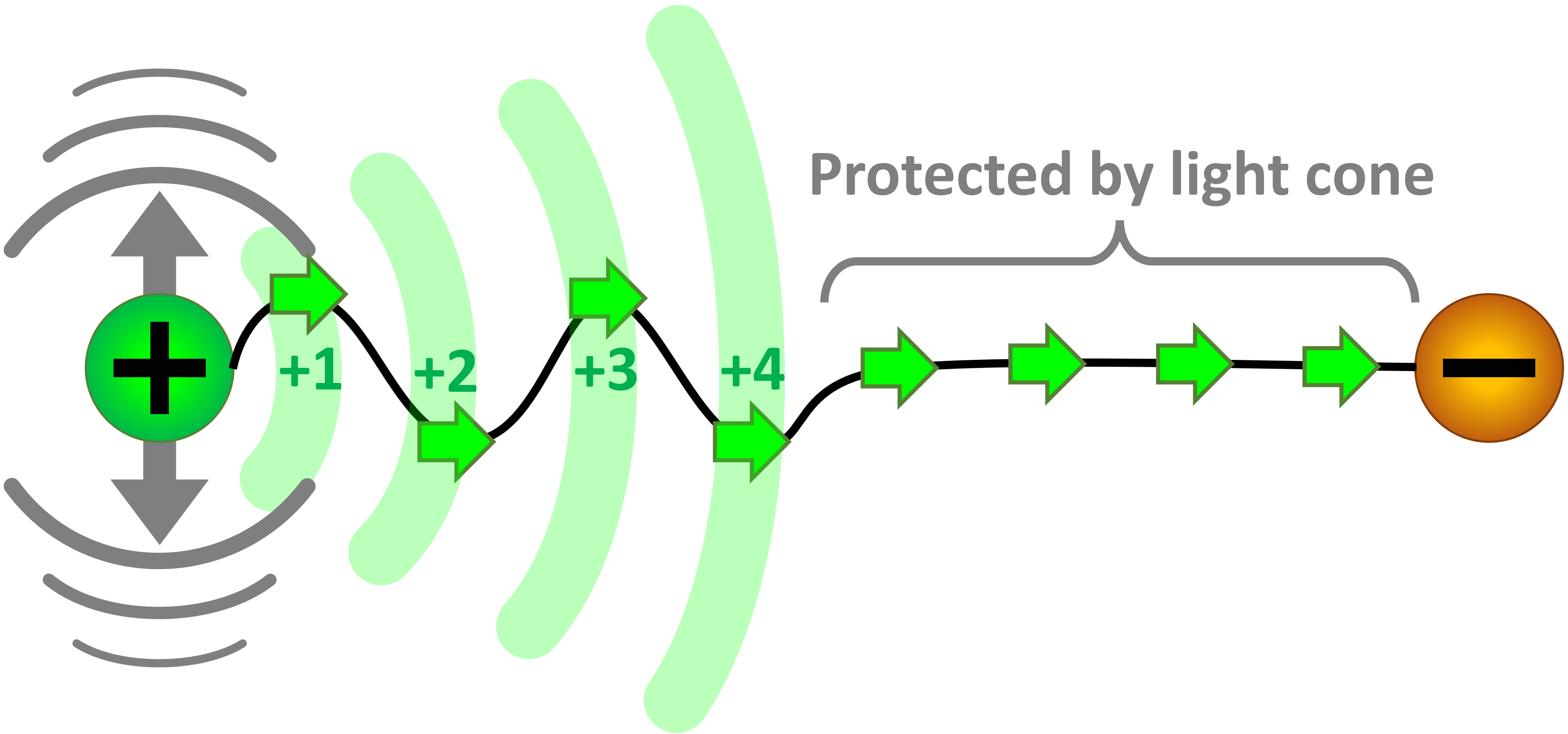
Complementary patterns separate but remain entangled with each other, since the photon can be detected in either wavefront, but not both.

Part VI.
Quantum Computing Across Time

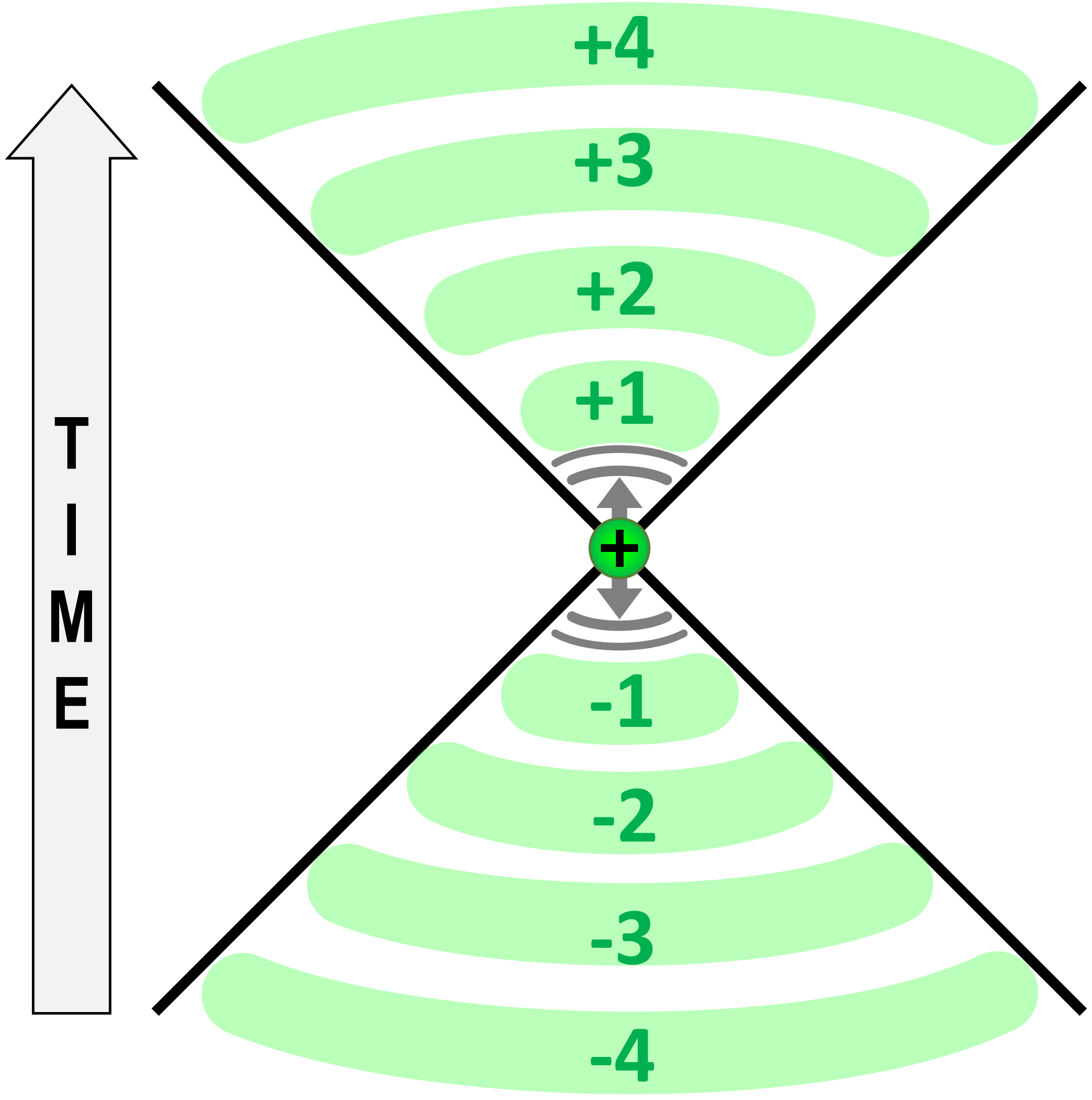
Wheeler, Feynman, and the Problem of Time

- Before developing his Nobel-Prize-Winning Quantum Electrodynamics (QED) method, Richard Feynman worked on a series of papers with his adviser, John Wheeler, in which they took decades-old time paradoxes in Maxwell's Equations seriously
- The result was a remarkable series of papers that questioned the nature of causality and inspired Feynman to develop his QED methodology. Here are two notable examples:
  - J. A. Wheeler and R. Feynman, *Interaction with the Absorber as the Mechanism of Radiation*. Reviews of Modern Physics, vol. **17** (2-3), 157 (1945) https://authors.library.caltech.edu/11095/1/WHErmp45.pdf
  - J. A. Wheeler and R. Feynman, *Classical Electrodynamics in Terms of Direct Interparticle Action*, Reviews of Modern Physics **21** (3), 425 (1949). https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.21.425

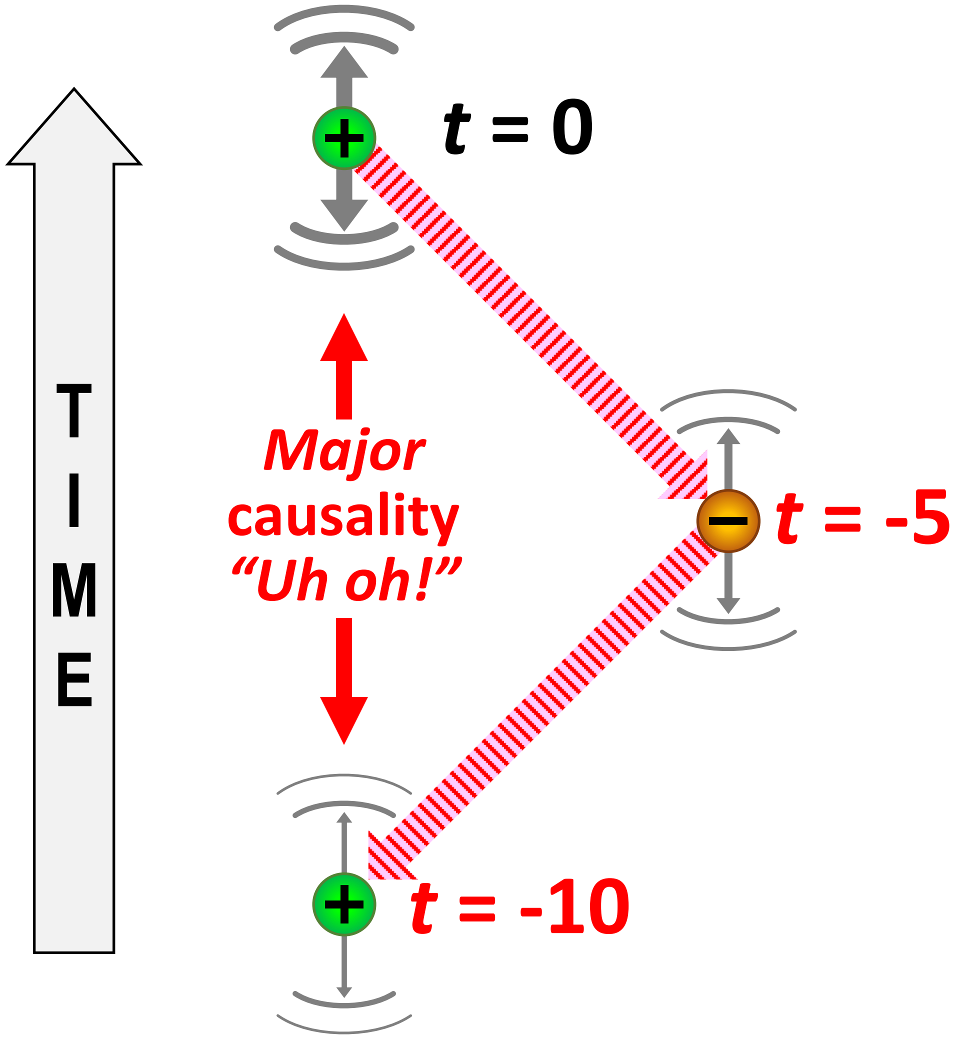
Jiggling the Source Creates Finite-Speed Waves



The Simple Scary Part: The Wave Goes Both Ways



The Problem: You Now Can Impact Your Past



The Strange Issue of Recoil

- Contrary to what you likely have heard…
  - Maxwell's equations cannot explain all electromagnetic phenomena if they are interpreted *only* in the future direction
  - The missing behavior: Recoil after charge acceleration
  - The only fully conserving momentum-energy source of local recoil is the particle that absorbs the photon in the future
  - That particle could be billions of years in the future
- An experiment: Shine a laser into the darkest part of space
  - With sufficiently good instruments, you can detect a recoil effect
  - That recoil is a testable example of the future affecting you now

The Wheeler-Feynman Advanced Effects Paradox

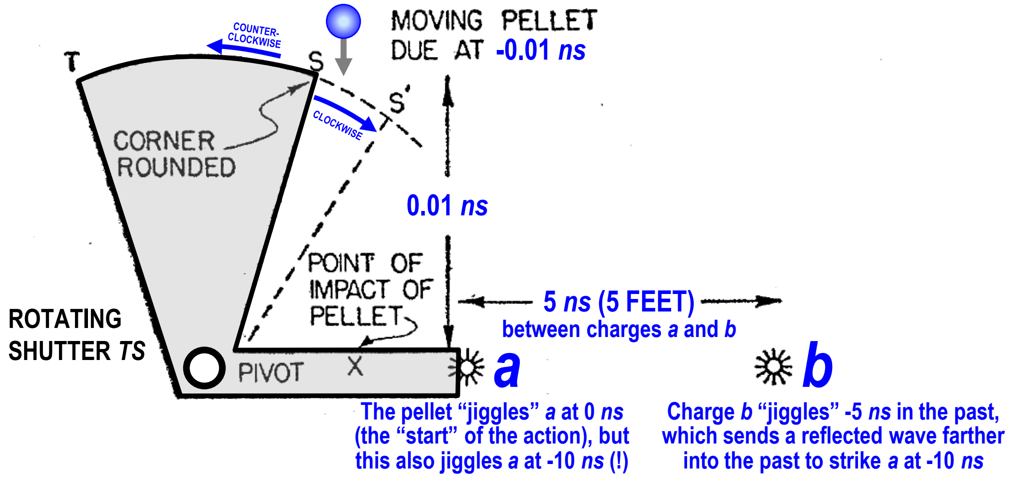


Fig. 1. The paradox of advanced effects. Does the pellet strike X at **0 *ns*** ? If so, the advanced field from ***a*** sets ***b*** in motion at **-5 *ns*** , and ***b*** moves ***a*** at **-10 *ns***. Thereby the shutter TS is set in motion and the path of the pellet is blocked, so it cannot strike X at **0 *ns***. If it does not strike X at **0 *ns*** , then its path is not blocked at **-0.01 *ns*** via this chain of actions, and therefore the pellet ought to strike X.

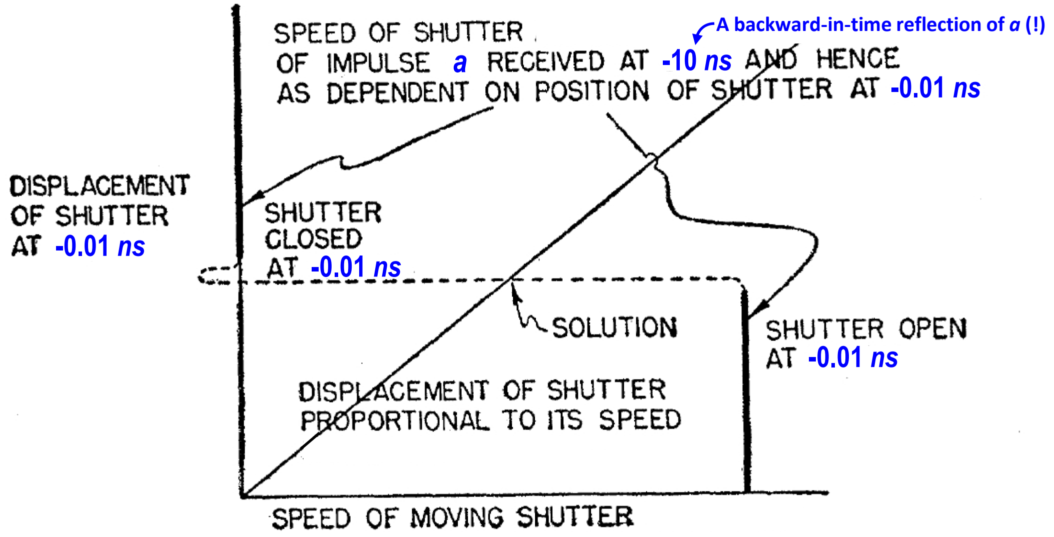
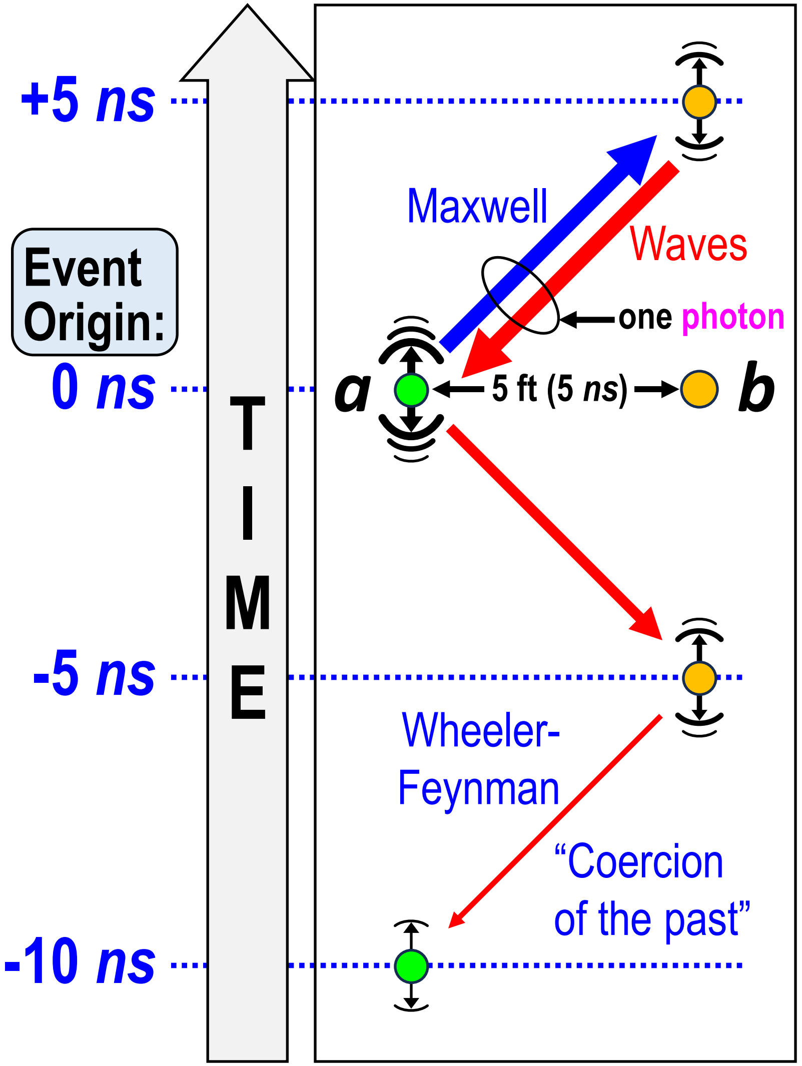


Fig. 2. Analysis and resolution of the paradox of advanced effects. The action of the shutter on the pellet—the interaction of past and future—is continuous (dashed line in diagram) and the curves of action and reaction cross. See text for physical description of solution.

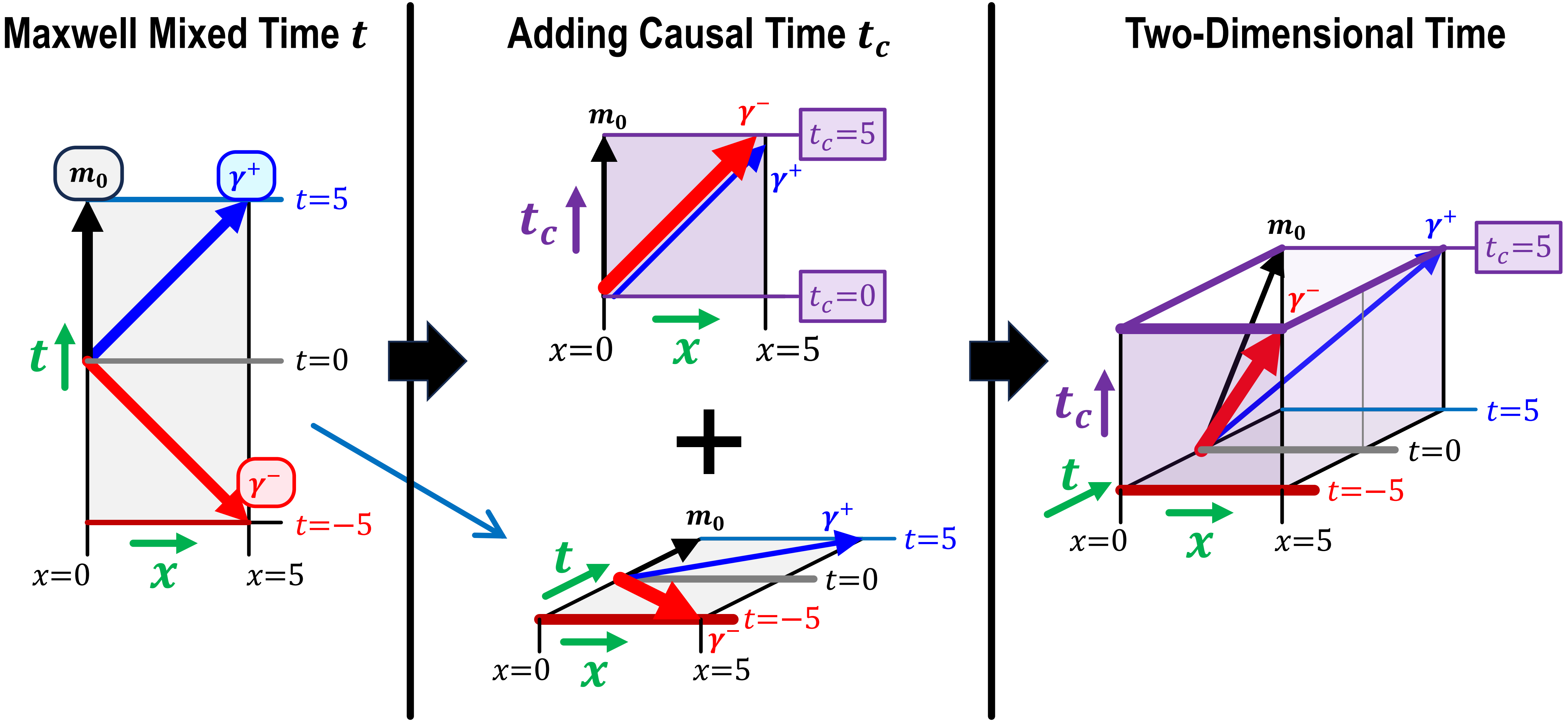
J. A. Wheeler and R. Feynman, *Classical Electrodynamics in Terms of Direct Interparticle Action*. Reviews of Modern Physics **21** (3) (1949). Pages 426, 427. https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.21.425

Quantum Insights in the Wheeler-Feynman Model

- Maxwell's Wave (MW) solutions *are not photons* (and *not particles*)
  - MWs propagate *equally* into the future (forward time) and past (reverse time)
  - MWs cannot explain "photon recoil"
- Wheeler's (rather opaque) shutter analogy makes a critical point:
  - MWs *coerce* all options into a single solution that stays invariant over time
  - A **photon** summarizes that consensus



Quantum Computing in Two-Dimensional Time



Nobel Laureate Hopfield on Probability Bending

J. J. Hopfield, *Electron Transfer Between Biological Molecules by Thermally Activated Tunneling*. Proceedings of the National Academy of Sciences 71 (9), 3640–3644 [Sep.] (1974). https://www.pnas.org/doi/abs/10.1073/pnas.71.9.3640

p. 3640: “The overall effectiveness of … photosynthesis … depends both on there being a large electron transfer rate for desired transfers, and a small rate for inappropriate transfers. … The simplest … coupling of electronic states to molecular thermal motions … to calculate the temperature-dependent electron transfer rate … involves tunneling. [p. 3644] … The tunneling matrix element is generally not appreciably temperature dependent.”

J. J. Hopfield, *Kinetic Proofreading: A New Mechanism for Reducing Errors in Biosynthetic Processes Requiring High Specificity*. Proceedings of the National Academy of Sciences, 71 (10), 4135–4139 [Oct.] (1974). https://www.pnas.org/doi/abs/10.1073/pnas.71.10.4135

Abstract, p. 4135: “The specificity with which the genetic code is read in protein synthesis … can be increased … by a process defined here as kinetic proofreading. … Known reactions which … appear … useless or deleterious … are … essential to the proofreading function.”

Part VII.
Quantum Computing in *One* Universe

Summary of Important Themes

- There is no such thing as a multiverse
- There is no such thing as "simple" time
- Quantum collapse is bumping, which is "two-way observation"
- Collapse is *basis* of classical physics, and is incredibly common
- Quantum computing is very common (biomolecules, for example)
- Fourier transforms are way more important that tensor math
- Lensing is a good start for new methods
- The real future is… well, figuring out how to make the *future* participate in calculations we do *now*. It's all about time.