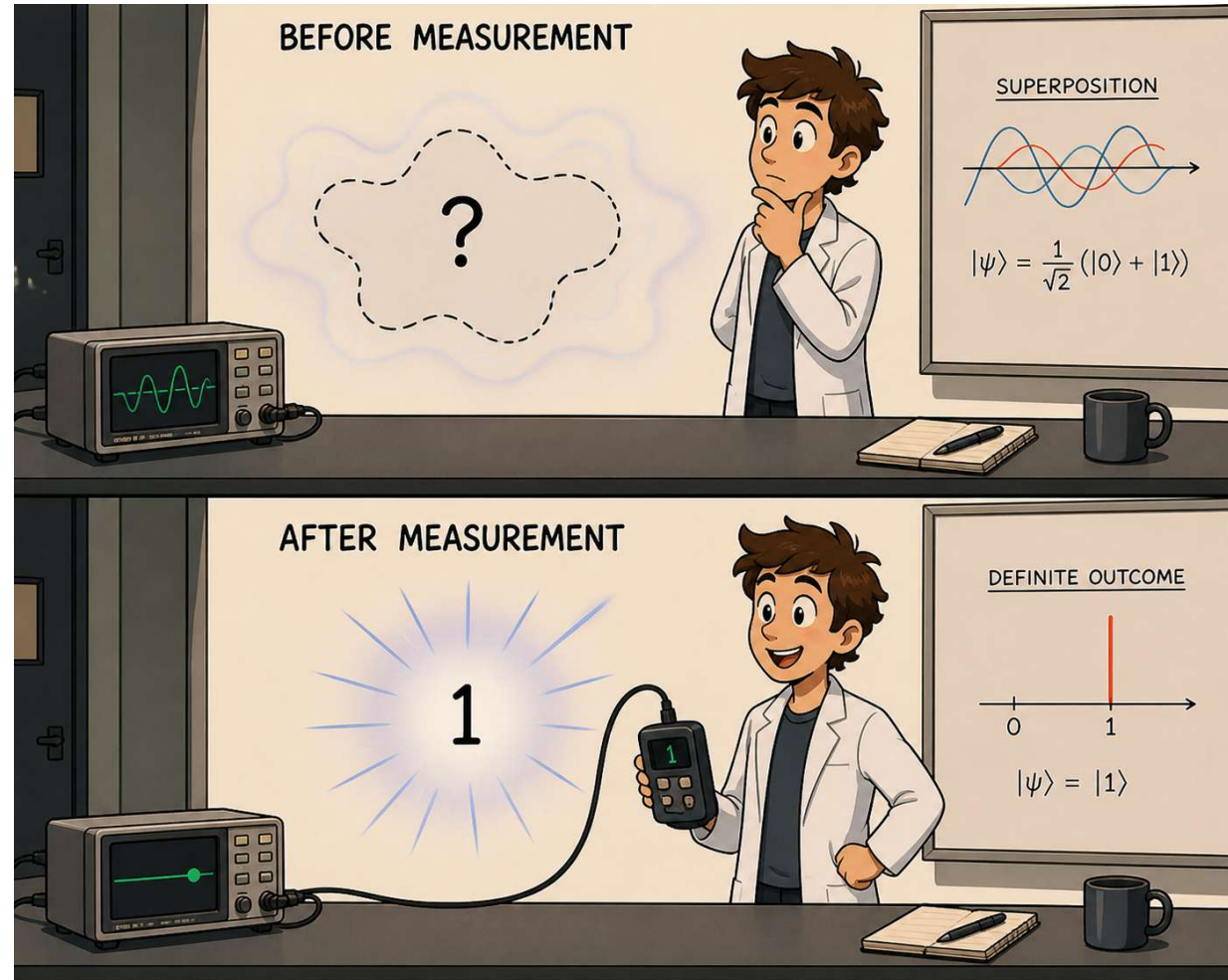


Reality, Explanation, and the Wave Function

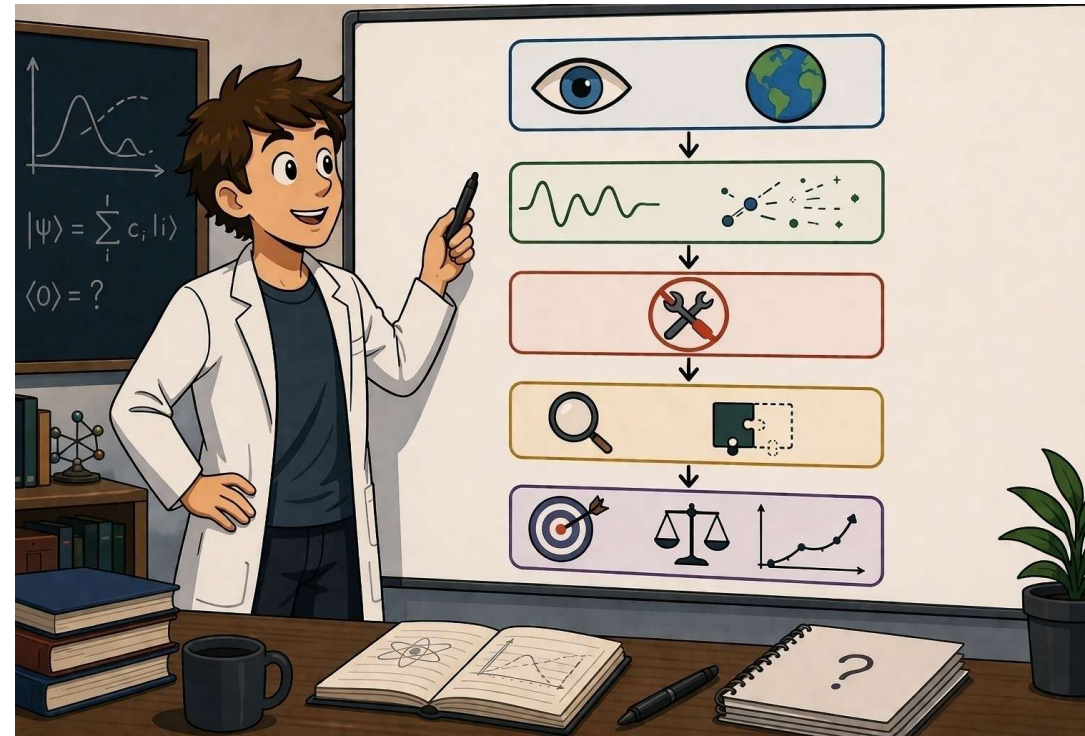
PART I: Quantum “Dealism”

- Valia Allori -- Unibg
- June 15, 2026
- XXIX Urbino International
Philosophy of Physics
Summer School



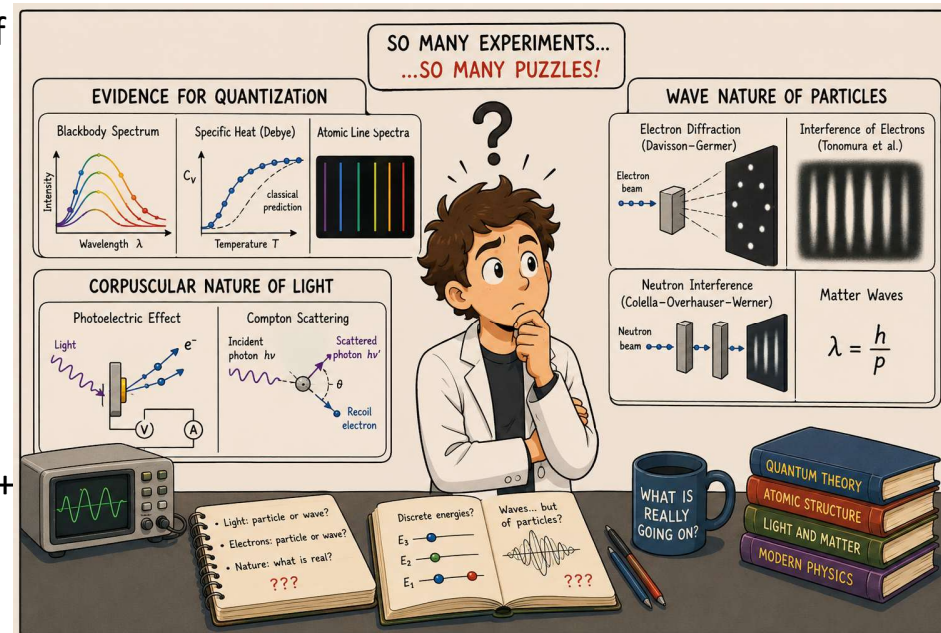
Outlook

- **A Methodological Claim:** solving the measurement problem is not an appropriate way of finding a quantum theory which tells you about nature (you need to do other things instead)
- **A consequence:** the wavefunction is not a physical field → part II
- Face **quantum phenomena** under a specific realist assumption
- **Against the “dogma”** - Do **not** “fix” the measurement problem
 - This is just a distraction, a red herring, a wild goose chase....
- Instead treat it as **evidence** of an inadequate theory
- Goal: find a theory that is empirically adequate **and explanatory** from the outset
 - Explanation in a specific sense
- Resulting focus:
 - The wavefunction isn't “a thing”



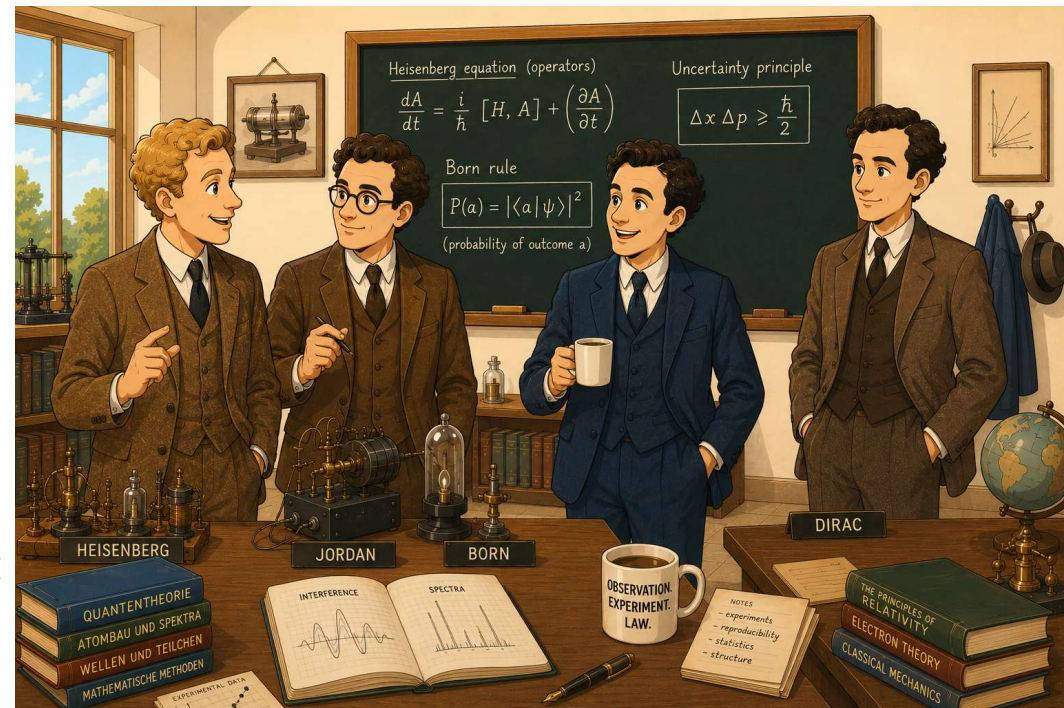
How the wave function became the center of everything

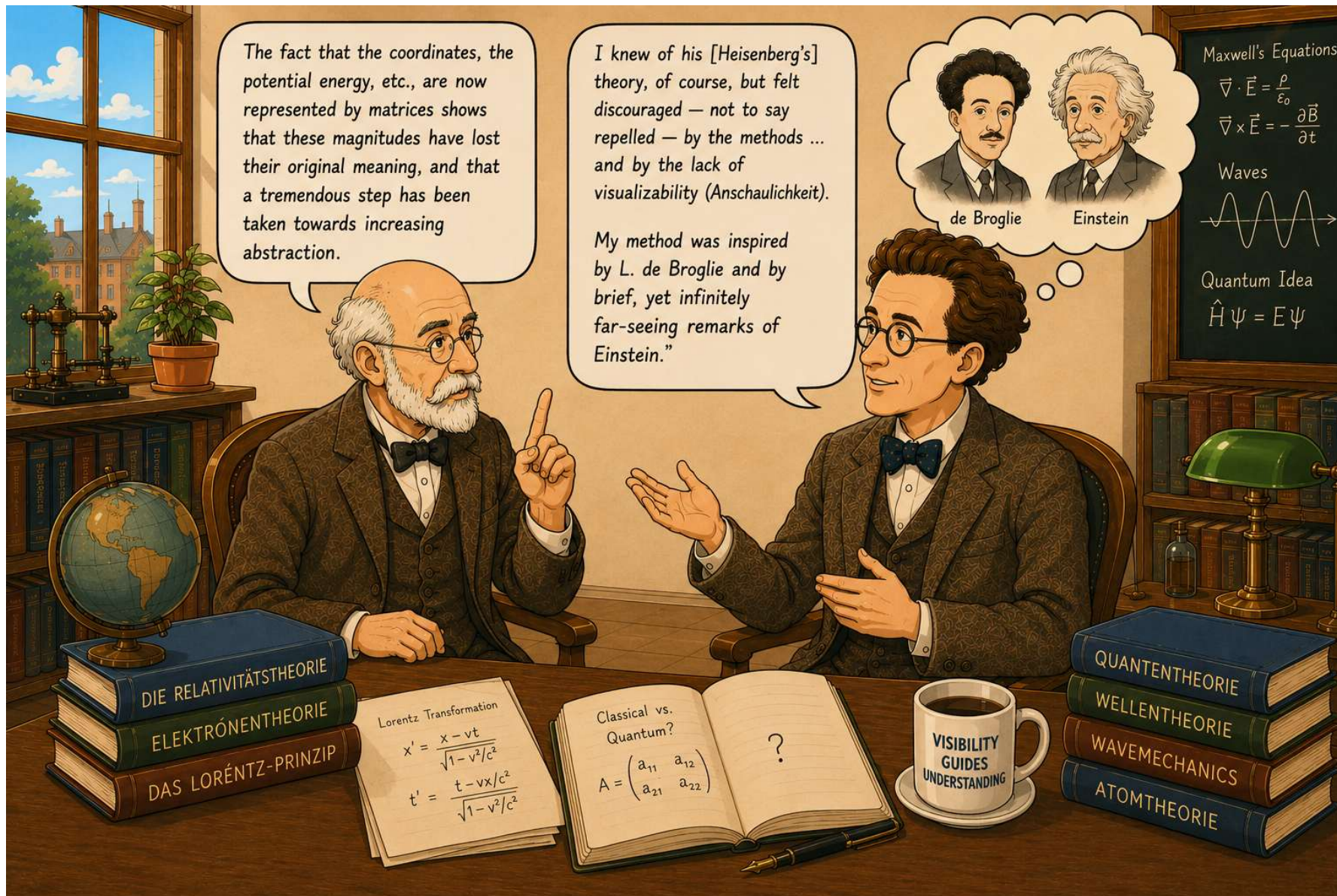
- ~1900-1920: “Uncooperating” experiments suggested:
 - **A-Quantization:**
 - Blackbody radiation, specific heats of solids,
 - atomic spectra, stability of the atom → Bohr’s model of the atom (1913)
 - Project (Bohr-Sommerfeld): determine the right **quantization rules** for the various quantities within the classical understating (matter=particles; light=wave)
 - Attempts to provide a systematization of the phenomena (“old” QM)
 - **B-unclear how to propose something “deeper”** (which fundamental ontology???)
 - **Particle aspect of light** (so far thought as a wave):
 - Planck (1900; Blackbody radiation and ultraviolet catastrophe)+ Einstein (1905, photoelectric effect)+ Compton (1922) : light (wave) has a particle associated with it (photon)
 - **Wave aspect of matter** (so far thought as corpuscular):
 - de Broglie (1923): matter (particles) has a wave associated with it
 - However: no equation for the matter wave
 - Davidson-Germer (1925): electron interference



The First Comprehensive and Coherent Formalism: Matrix Mechanics

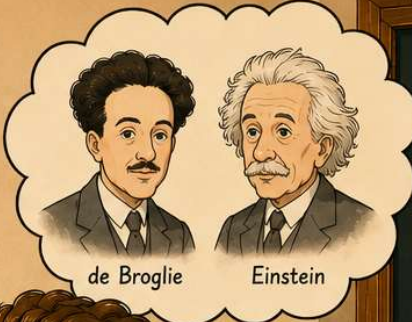
- 1925 Heisenberg (with Born and Jordan; indep. Dirac) developed 'matrix mechanics'
 - The first **COMPLETE and COHERENT systematization** of experimental results using matrices/operators
 - No dynamics, no spacetime, no objects
 - Focus on observables, forget about the rest
 - No wave function just yet
- Still, not clear **what to make of it from a physical rather than mathematical perspective**
- It says that operators describe observables (measurable physical quantities), but it does not explain what they are properties of; **what is the fundamental ontology**
- Main objection (from the realist): **it is not visualizable; too abstract**






The fact that the coordinates, the potential energy, etc., are now represented by matrices shows that these magnitudes have lost their original meaning, and that a tremendous step has been taken towards increasing abstraction.

I knew of his [Heisenberg's] theory, of course, but felt discouraged — not to say repelled — by the methods ... and by the lack of visualizability (Anschaulichkeit).
My method was inspired by L. de Broglie and by brief, yet infinitely far-seeing remarks of Einstein."



Maxwell's Equations
 $\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$
 $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
Waves

Quantum Idea
 $\hat{H}\psi = E\psi$

DIE RELATIVITÄTSTHEORIE
ELEKTRONENTHEORIE
DAS LORÉNTZ-PRINZIP

Lorentz Transformation
 $x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$
 $t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}}$

Classical vs. Quantum?
 $A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$?

VISIBILITY GUIDES UNDERSTANDING

QUANTENTHEORIE
WELLENTHEORIE
WAVEMECHANICS
ATOMTHEORIE

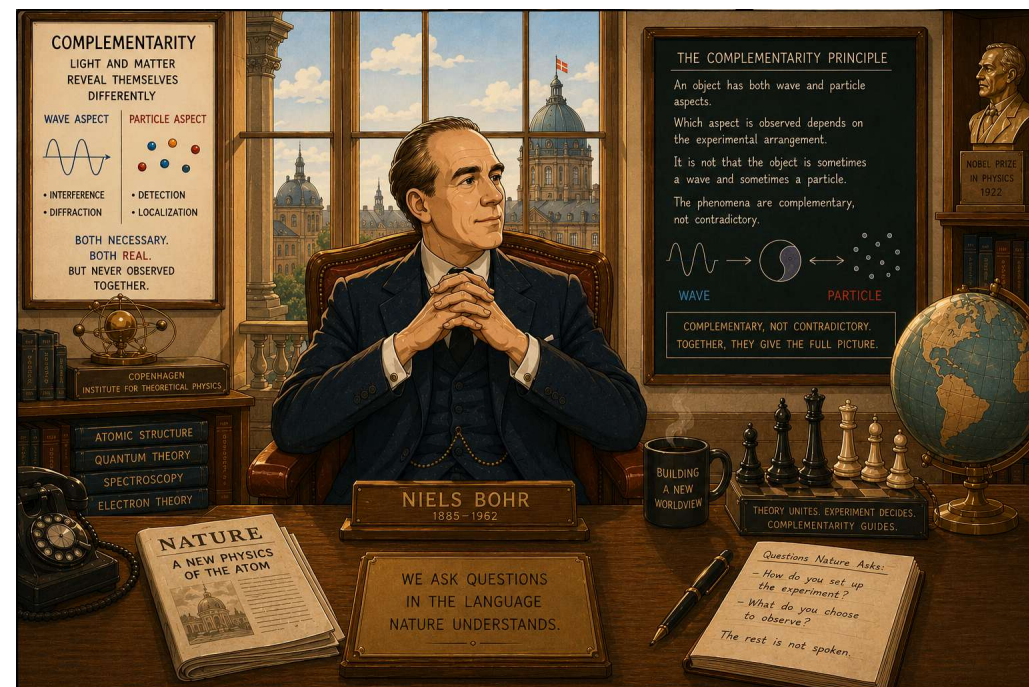
Wave Mechanics

- Schrödinger wanted more: he was not satisfied with just systematizations, he wanted to **understand where they come from**
- 1926: **wave mechanics** can explain the origin quantization rules from a fundamental ontology
 - Fundamental object (ontology): a **wave** (the wavefunction)
 - Evolution: deterministic linear equation (Schrödinger's equation)
- **Experimental** successes:
 - Hydrogen spectrum $\leftarrow \rightarrow$ nodes of the wavefunction
 - Localized wave packets $\leftarrow \rightarrow$ they appear as particles
- **Theoretical** success:
 - Equivalent to matrix mechanics but also visualizable
 - He thought that because of this his theory was better than Matrix Mechanics



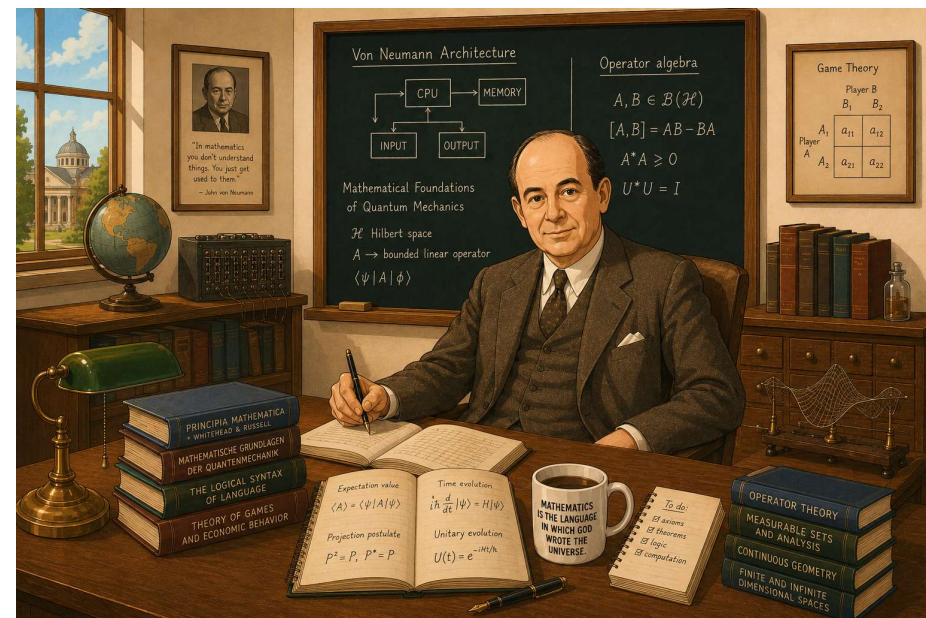
The Copenhagen Front

- 1927 Heisenberg discovered the **uncertainty relation**:
 - No simultaneous position-momentum measurement → No trajectories
- Initial internal disagreement within the Copenhagen school (Bohr favored particles, in 1927's Como lectures Bohr's **complementarity** came as a compromise)
- Later, they formed a **compact front against Schrödinger's** wave mechanics
 - Accused not being able to explain quantum jumps, even if it did
 - de Broglie's preliminary proposal for a complete quantum theory in terms of particles and waves was effectively shut down by a harsh criticism by Pauli (1927 Solvay)
- Nonetheless, **people started to use Schrödinger's formalism** as the quantum formalism because they were more familiar with waves and it was much easier to use



Von Neumann's axiomatization

- Nonetheless, given the linearity of the Schrödinger equation, wave mechanics predicts macroscopic superpositions which are not observed → when a measurement is performed, the evolution must suitable change (**von Neumann's collapse rule**)
- Moreover, matrix mechanics cleanly connected **observables** with linear self-adjoint operators, and neatly described the experimental statistics
- Thus, von Neumann's **axiomatization** of quantum mechanics is as follows:
 - State: in position base, the wavefunction [**THE WAVEFUNCTION ENTERS HERE**]
 - Observable properties: eigenvalues of suitable linear self-adjoint operators
 - Evolution of the state:
 - No measurement: S's equation (linear deterministic) → superpositions of properties
 - Measurement: vN's collapse (instantaneous stochastic) → random 'reduction' to one property
 - Measurement outcome: Born rule



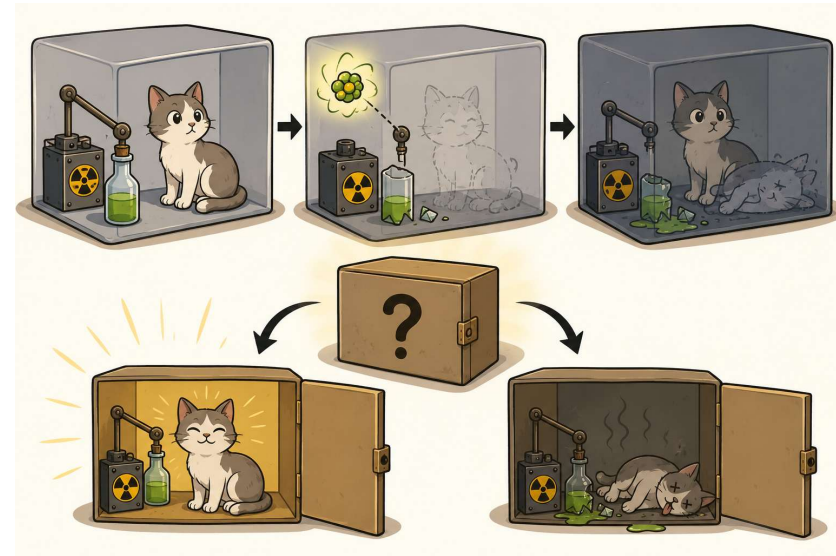
Nonlocality Arguments

- 1927-1935: if QM were complete, **locality would be false**
 - 1927 (Solvay): particle through one slit diffracts, so it is everywhere, while we observe only one spot → nonlocality of collapse
 - 1930 (Solvay): a photon in energy states superposition leaves box and travels far away. By measuring the box's weight, one 'creates' the photon's energy → nonlocality
 - 1935 (letter to Schrödinger): a wf in a box is divided into two halves. The boxes are sent in opposite direction. By opening one box, one affects the other → nonlocality
 - **1935, EPR**: A pair of entangled particles travel in opposite directions; results of experiments on each particle are anticorrelated → nonlocality
 - Thus, EPR concluded, there have to be 'hidden' variables, representing the pre-existing properties revealed by the experiment
 - Heisenberg replied that still, this does not contradict relativity understood as a theory of signals

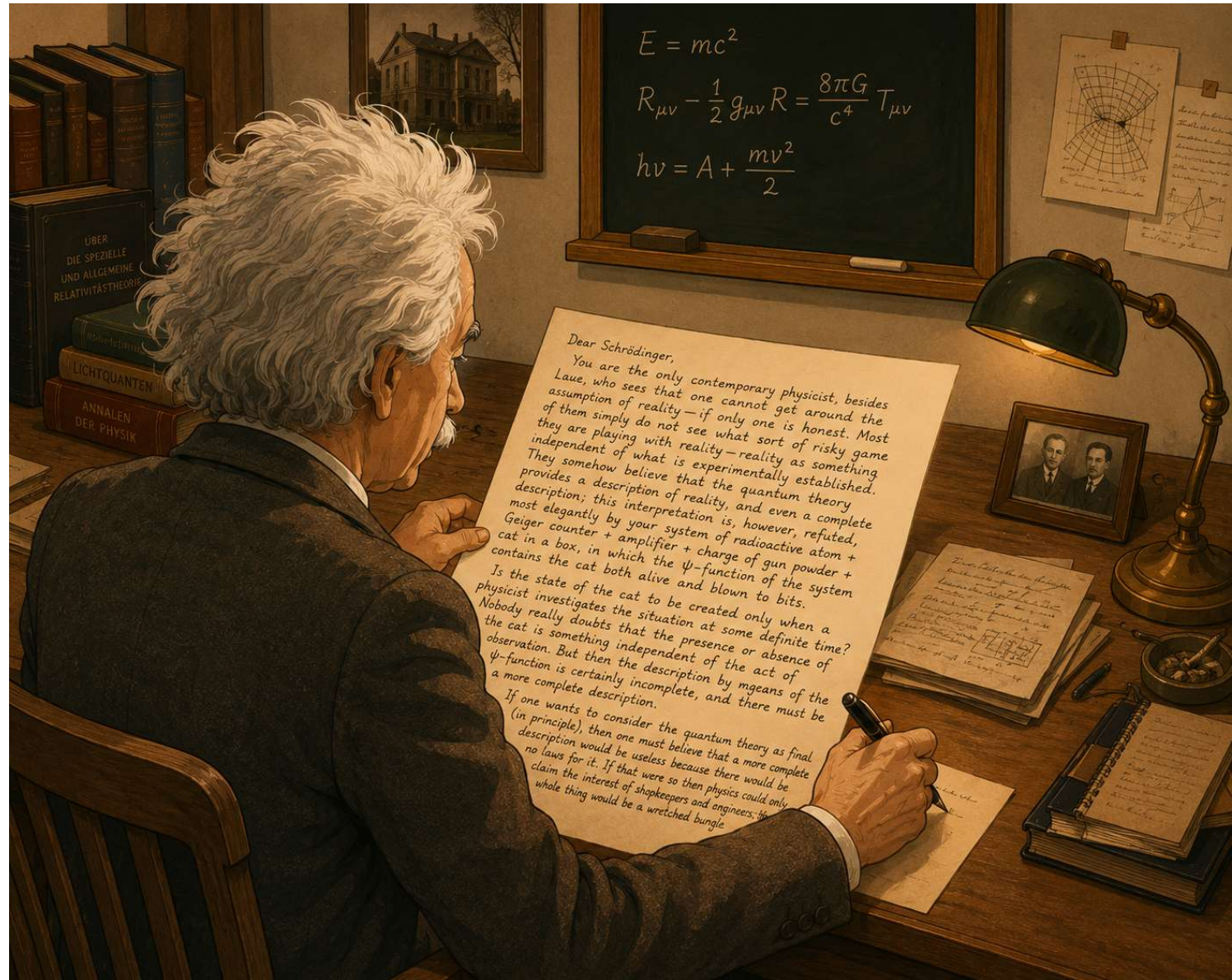


The Measurement Problem

- 1935: QM is incomplete (at least macroscopically) otherwise it would be falsified (there are **unobserved macroscopic superpositions**)
- 1935, Schrödinger **cat** paper:
 - a radioactive nucleus in decayed-not decayed superposition is coupled with a vial of poison to be released in a box where there's a cat. Thus, the cat is in a dead-alive superposition. However, when we open the box, the cat is either alive or dead.
 - The theory is **not empirically adequate**
- 1935, Einstein **bomb** example (letter to Schrödinger)
- Notice: the von Neumann collapse rule is a solution of the MP
 - However, it is generally regarded as **unsatisfactory**, because it is not precise enough because it does not specify **what a measurement is** and why it is not a physical interaction like any other



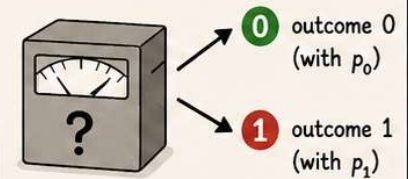
“Copenhagen people and co. “ did not get it





THE MEASUREMENT PROBLEM

FIVE SOLUTIONS, FIVE REJECTIONS



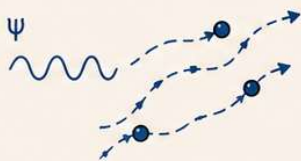
Each interpretation solves the measurement problem by rejecting one of the following claims:

- 1 The wave function is complete
- 2 The wave function evolves according to the Schrödinger equation
- 3 Measurements have one unique outcome
- 4 Measurement outcomes are absolute

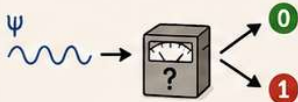
1. BOHM-DE BROGLIE (PILOT-WAVE)

REJECTS:

- 1 The wave function is complete



Particles have definite positions guided by the wave function.

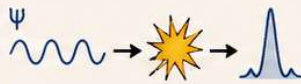


Additional variables exist (particle positions).

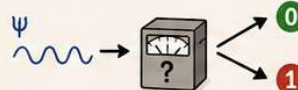
2. GRW (SPONTANEOUS COLLAPSE)

REJECTS:

- 2 The wave function evolves according to the Schrödinger equation



The wave function collapses spontaneously with a tiny probability.

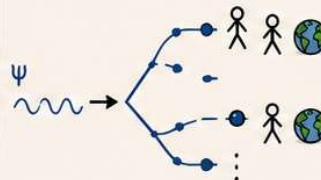


Objective random collapses modify the dynamics.

3. EVERETT (MANY-WORLDS)

REJECTS:

- 3 Measurements have one unique outcome



The universe splits into branches, each containing one outcome. All outcomes occur.



No collapse: all outcomes exist in parallel.

4. QBISM

REJECTS:

- 1 The wave function is objective



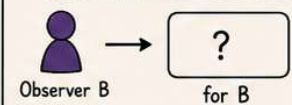
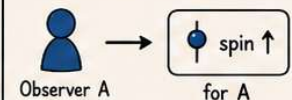
The wave function represents the agent's personal degrees of belief about future experiences.

Quantum states are subjective: tools for the agent's expectations.

5. RELATIONAL QM (RELATIONAL QUANTUM MECHANICS)

REJECTS:

- 4 Measurement outcomes are absolute



Outcomes exist only relative to a physical system (observer). There are no observer-independent facts.

Facts are relational, not absolute.



FIVE INTERPRETATIONS. FIVE DIFFERENT SACRIFICES. **NO CONSENSUS.**
Same experiments. Different metaphysics.

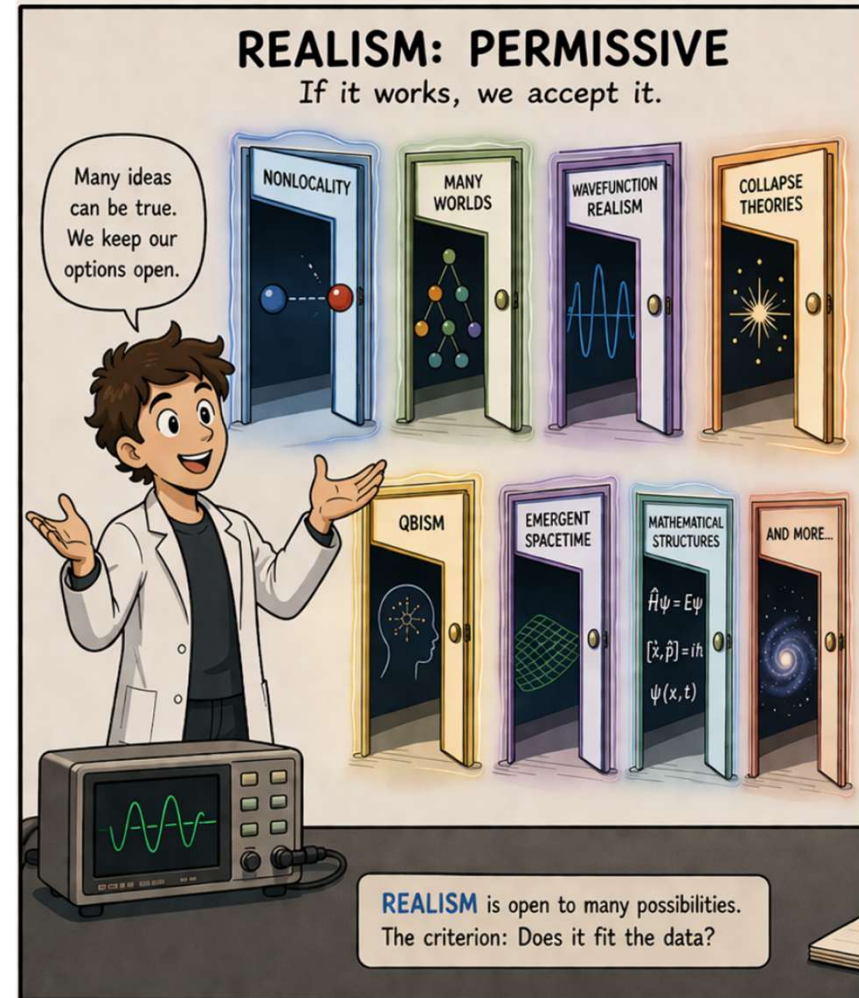
Claim

- Realist often focus on the measurement problem to make quantum theory amenable to a realist interpretation
- However, I think this is **not**:
 - the **problem** a realist would naturally look at
 - the realist **attitude** a pre-quantum realist would naturally have



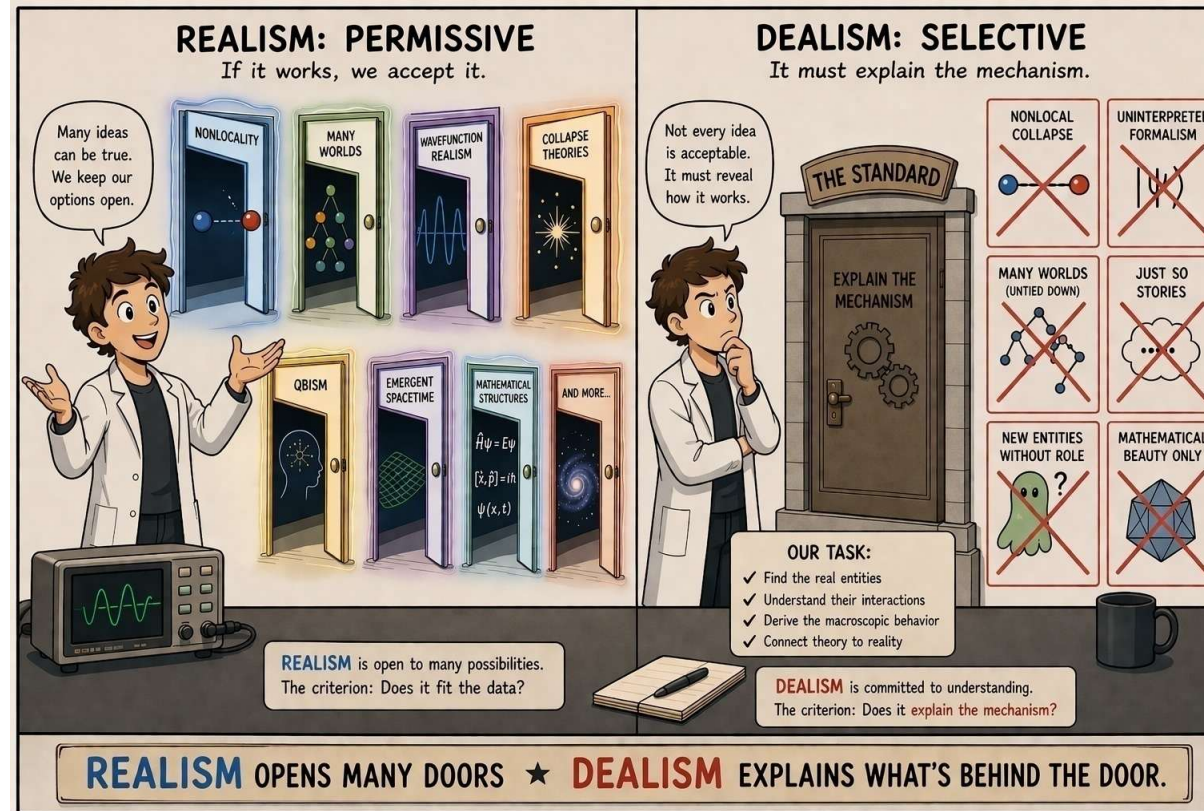
Digging deeper in the notion of Realism

- Scientific Realism (baseline)
 - Theories aim to describe reality
 - Entities are really out there
 - Approximate truth
- Fairly **permissive** - in the quantum domain a realist accepts
 - Nonlocality (dBB)
 - Indeterminism (GRW)
 - Unfamiliar ontology (wavefunctions in high-dimensional space; purely relational properties;...)
 - “Weird” primitives (branching worlds;....)
- As long as
 - the theory is **empirically adequate** and has a **coherent interpretation**



My point turned into a half Joke: From Realism to Dealism

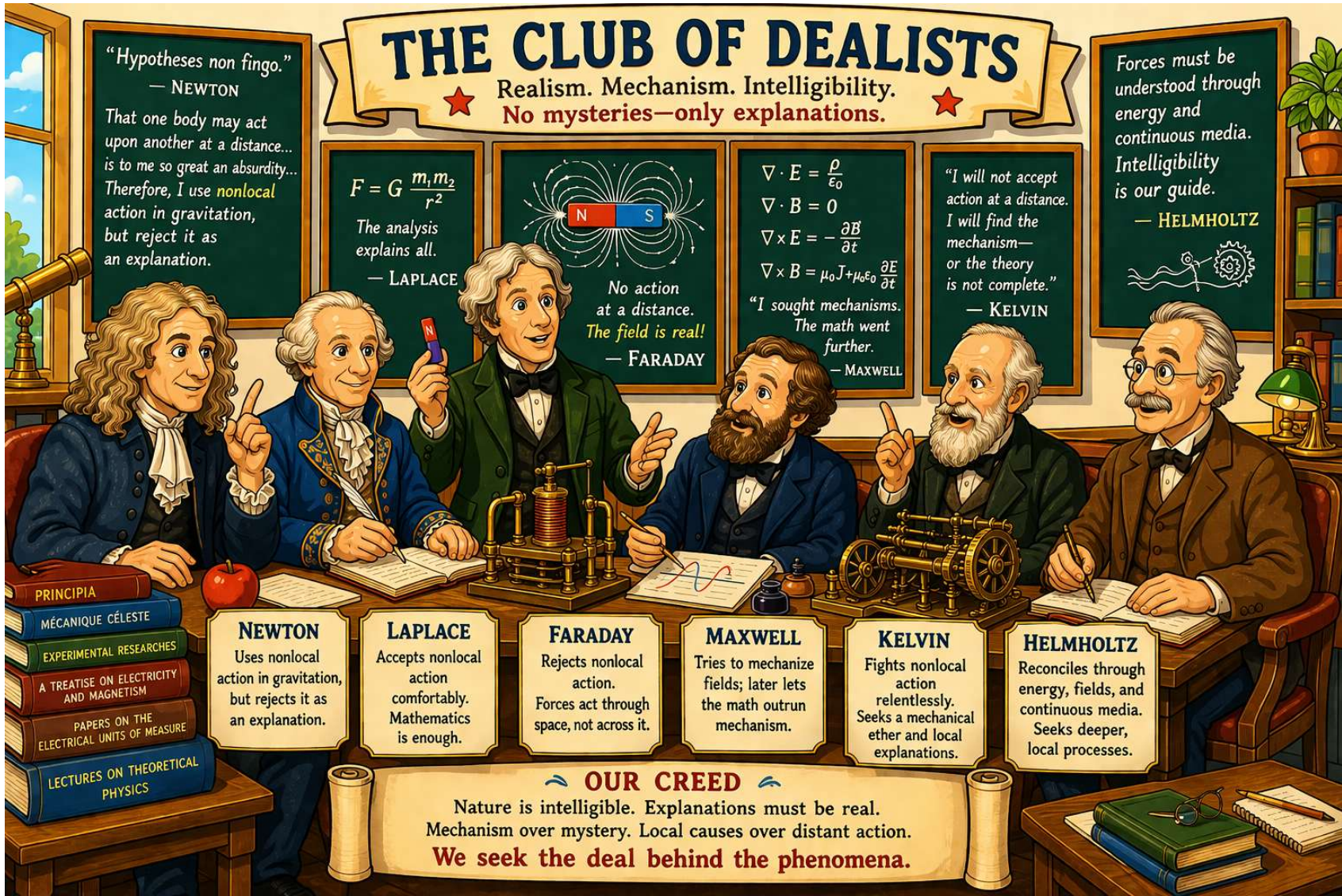
- **DEALism** – “what’s the *real DEAL* behind the phenomena?”
- The Dealist Methodology:
 - 1) Anti-mystery principle: **weirdness is a diagnostic of failure**
 - Realism: “QM is strange but true”
 - Dealism: “If it’s that strange, we probably haven’t explained it yet”
 - 2) Balance **simplicity and explanation**: start with the obvious; escalate only when it adds explanatory power
 - 3) Priority of explanation over accommodation in order to **understand**
 - Realism: saving the phenomena is enough to take a theory seriously
 - Dealism: explaining the macroscopic dynamics in terms of the microscopic dynamics (from past empirical success)



Past empirical success have led to an ontology of **micro entities** moving in **spacetime**, interacting via ‘cause’ and ‘effect’ (**local causality**: no simultaneous action at arbitrary distance), and **composing** macroscopic objects whose dynamics is **derivable** from the micro evolution -- see next

Dealism is what 19th-century realism looks like

- (when turned into a conscious rulebook)
- Not every physicist followed it strictly, but many *thought, argued and worked* this way
- Elements of Dealism in the typical 19th-century (and earlier) physicist:
 - **1. Primacy of mechanism.** They strongly preferred explanations in terms of particles, continua, forces, mechanical models. If you can't say what is moving and how, you haven't explained it
 - **2. Suspicion of “merely formal” theories.** They were uneasy with laws without underlying models
 - **3. “Start simple, escalate only if forced.”** They typically tried to reduce new phenomena to known mechanisms first, only introduced new entities when added explanation
 - **4. Confidence that nature is intelligible.** A deep working assumption is that the world has a coherent, understandable structure, that there is no irreducible mystery

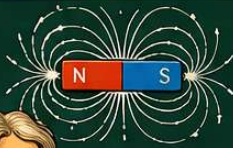


THE CLUB OF DEALISTS

★ Realism. Mechanism. Intelligibility. ★
No mysteries—only explanations.

“Hypotheses non fingo.”
 — NEWTON
 That one body may act upon another at a distance... is to me so great an absurdity... Therefore, I use **nonlocal** action in gravitation, but reject it as an explanation.

$F = G \frac{m_1 m_2}{r^2}$
 The analysis explains all.
 — LAPLACE


 No action at a distance.
 The field is real!
 — FARADAY

$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$
 $\nabla \cdot \mathbf{B} = 0$
 $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
 $\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$
 “I sought mechanisms. The math went further.”
 — MAXWELL

“I will not accept action at a distance. I will find the mechanism—or the theory is not complete.”
 — KELVIN

Forces must be understood through energy and continuous media. Intelligibility is our guide.
 — HELMHOLTZ

- PRINCIPIA
- MÉCANIQUE CÉLESTE
- EXPERIMENTAL RESEARCHES
- A TREATISE ON ELECTRICITY AND MAGNETISM
- PAPERS ON THE ELECTRICAL UNITS OF MEASURE
- LECTURES ON THEORETICAL PHYSICS

NEWTON
 Uses nonlocal action in gravitation, but rejects it as an explanation.

LAPLACE
 Accepts nonlocal action comfortably. Mathematics is enough.

FARADAY
 Rejects nonlocal action. Forces act through space, not across it.

MAXWELL
 Tries to mechanize fields; later lets the math outrun mechanism.

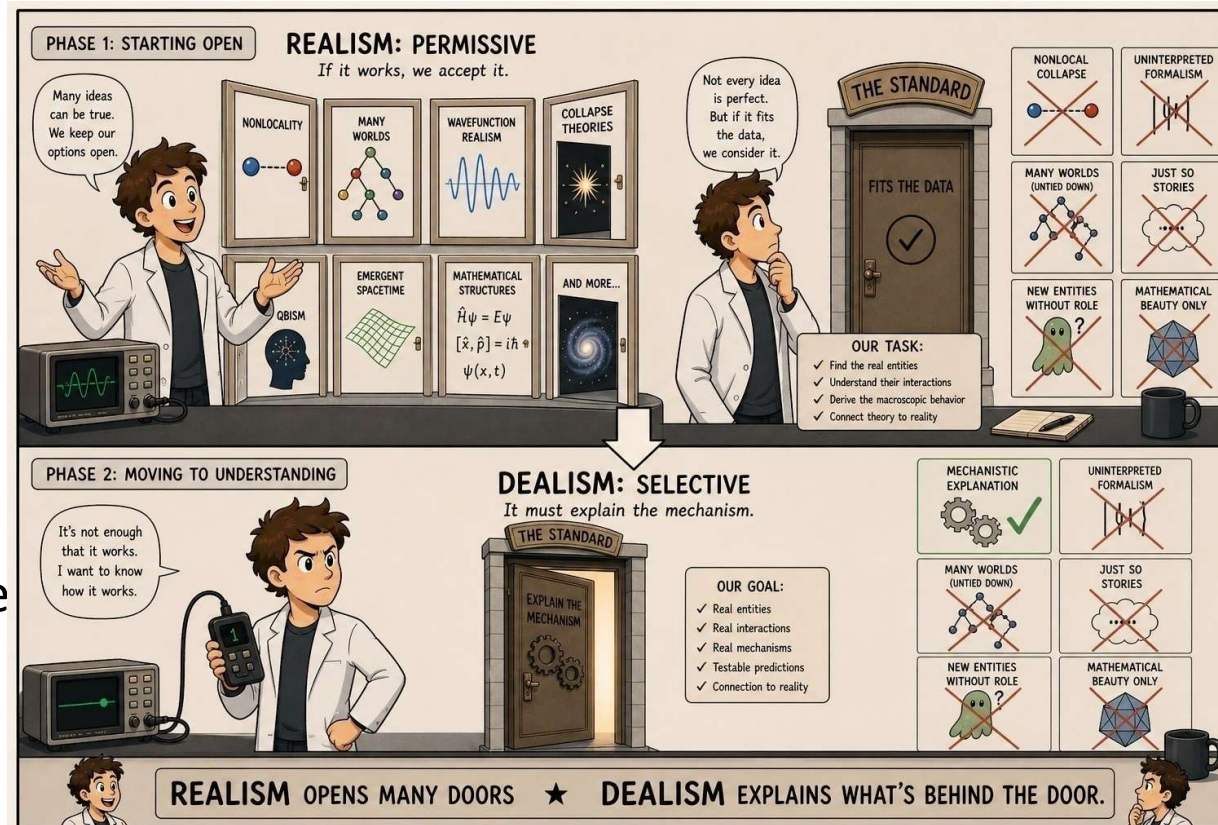
KELVIN
 Fights nonlocal action relentlessly. Seeks a mechanical ether and local explanations.

HELMHOLTZ
 Reconciles through energy, fields, and continuous media. Seeks deeper, local processes.

OUR CREED
 Nature is intelligible. Explanations must be real.
 Mechanism over mystery. Local causes over distant action.
We seek the deal behind the phenomena.

Realism vs Dealism

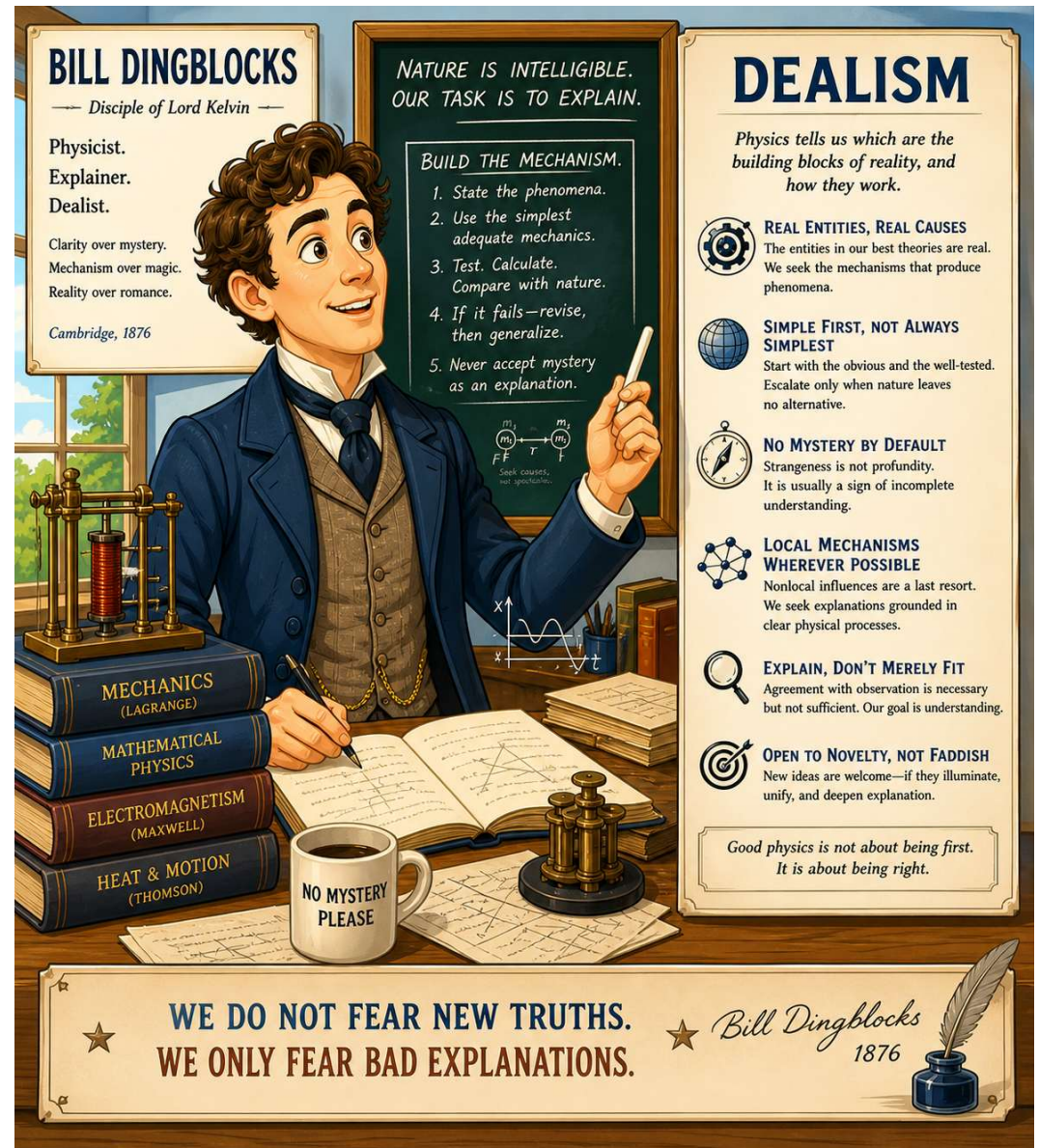
- Difference in **Scope**
 - Realism says: our theories describe reality, however strange it turns out to be
 - Dealism says: our theories describe reality; but if that reality looks too strange, the theory is probably not deep enough yet
- Different in **Spirit**
 - Realism is epistemic confidence (“the theory is true-ish”)
 - Dealism is methodological discipline (“the explanation must be clean”)
- The Dealist has a **clear research strategy**, they not defend a “fixed” ontology

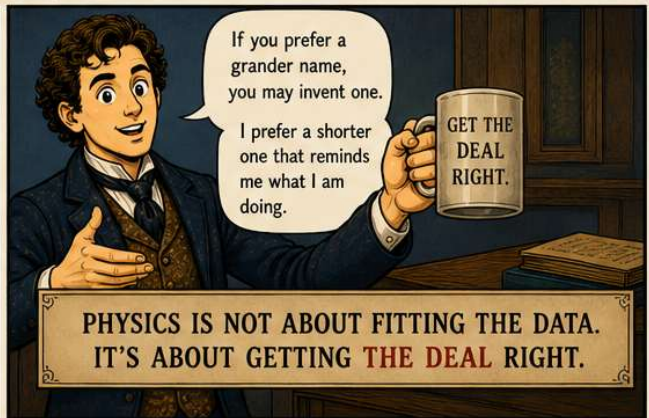
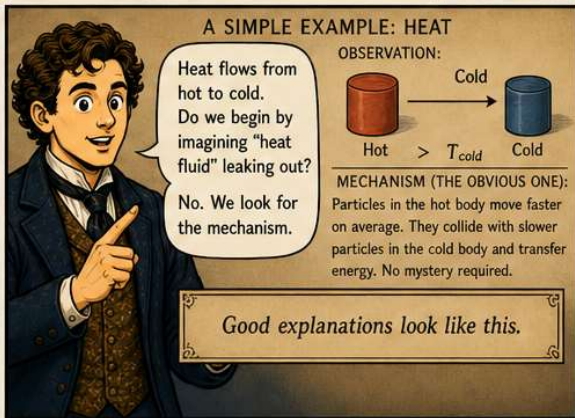
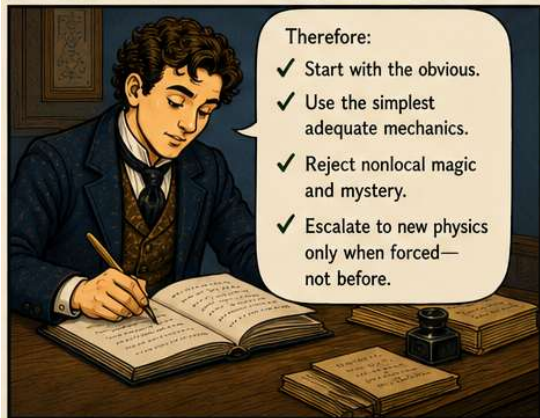
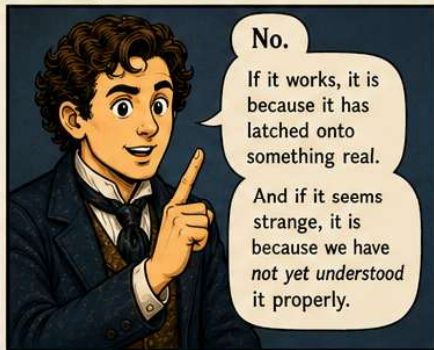
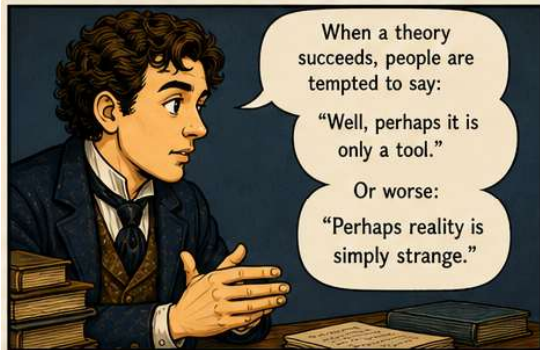
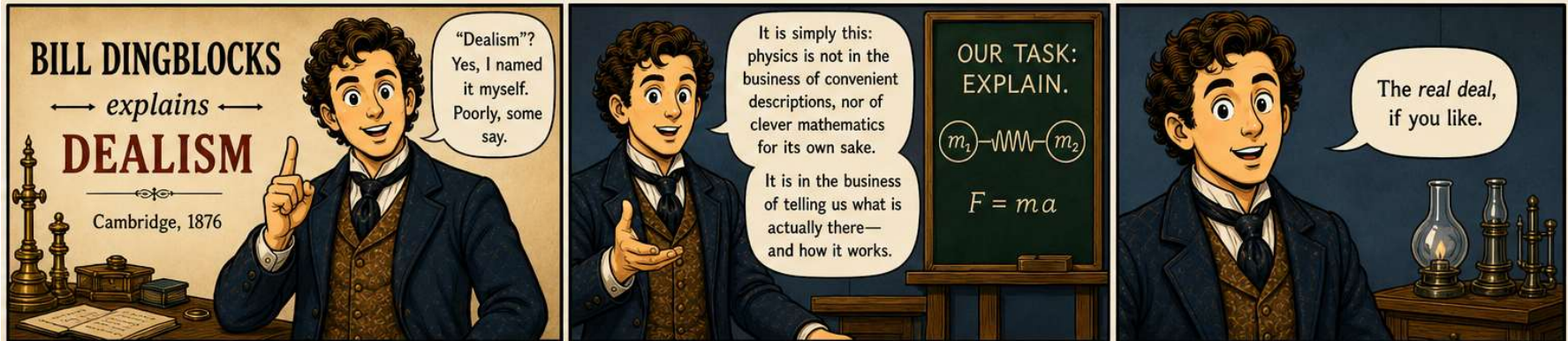


Realism keeps doors open
Dealism insists on **opening them**

Bill Dingblocks

- A (fictional) disciple of Lord Kelvin





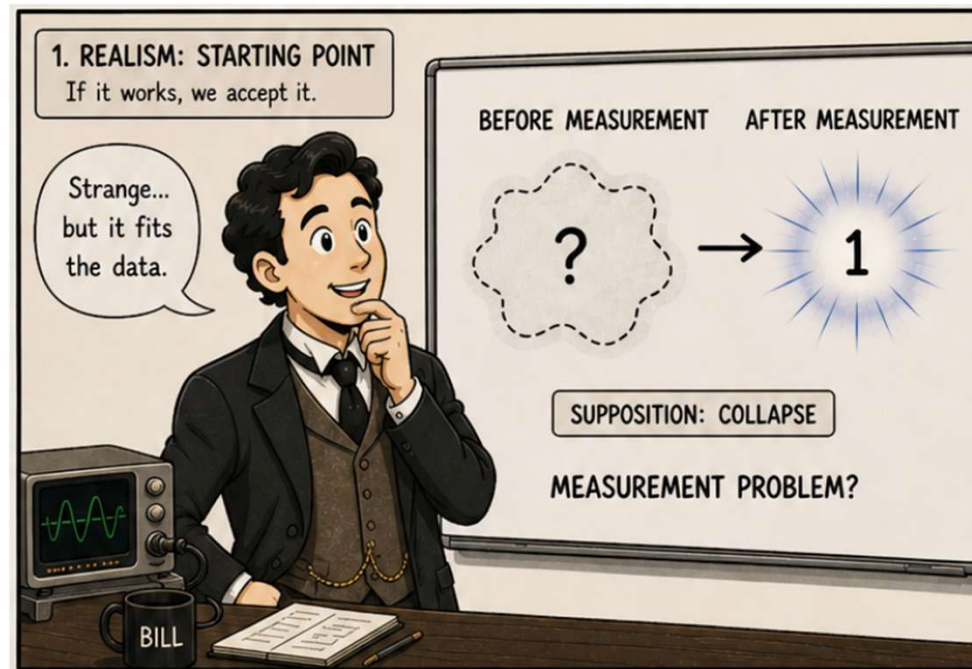
Dealism and the Quantum

- A 19th-century realist never faced nonlocal entanglement, collapse, fundamental indeterminism ...
- “What if Bill (a 19th-century realist, namely a dealist) were *teleported* into 1932 and *refused* to lower their standards?”



A Realist Reaction to Quantum Phenomena

- **Starting Point - Assume scientific realism** → The goal of physics is to describe what really exists and how it works
- We are confronted with **quantum phenomena** → Interference, entanglement, correlations, nonlocal collapse, etc.
- **The Standard Move made by the realist (“the dogma of quantum realism”)**
 - Take standard quantum mechanics
 - Notice that:
 - It predicts superpositions at all scales
 - We do **not observe** macroscopic superpositions
 - Formulate the **measurement problem**: “Why don’t we see what the theory says should happen?”
 - Then: **modify** interpretation (collapse postulate, pilot-wave, spontaneous collapse, many-worlds, consciousness...)



A Dealist Reaction to Quantum Phenomena



- **Methodological Principle (Dealist)**

- Do not begin by “repairing” a formalism, begin by explaining the phenomena
- Dealist Diagnosis:
 - The standard move begins from the **wrong starting point**
- Why? Because the measurement problem is a problem of **empirical adequacy**
- It arises only **after** accepting a theory that is not empirically adequate at face value

A Dealist Reaction to Quantum Phenomena

• Step 1 — Reframe

• If a theory predicts unobserved macroscopic phenomena, then **it is not yet acceptable**

• Step 2 — Reject the Task

• The goal is **not** to “fix the measurement problem: that assumes the theory is basically right and only needs patching or **reinterpretation**”

• Step 3 — New Task

• Treat the measurement problem as a **symptom**, not a target. So instead look for a theory that:

- is **empirically adequate from the start**
- provides **clear mechanisms**
- avoids ad hoc fixes (collapse, branching, etc.)

• Step 4 — Guiding Constraints

• Prefer:

- **Local or intelligible** mechanisms
- Clear ontology
- **Explanatory** transparency

• Accept novelty **only if it provides explanatory advantage**

FROM MEASUREMENT TO MECHANISM

1. REALISM: STARTING POINT
If it works, we accept it.

Strange... but it fits the data.

BEFORE MEASUREMENT → AFTER MEASUREMENT

QUESTION: ? → 1

SUPPOSITION: COLLAPSE

MEASUREMENT PROBLEM?

REALISM IS PERMISSIVE

- COLLAPSE ✓
- MANY WORLDS ✓
- WAVEFUNCTION REALISM ✓

2. DEALISM: SHIFT IN METHOD
It must explain the mechanism.

It's not enough that it works. I want to know how it works.

THE WRONG QUESTION:
Why don't we see such quantum phenomena in everyday life?

THE RIGHT QUESTION:
What mechanism produces the quantum phenomena we observe?

Preparation → ? → Observation

NOT ACCEPTABLE:

- UNEXPLAINED COLLAPSE
- JUST INTERPRETATION

OUR TASK:

- ✓ Identify the real entities
- ✓ Understand their interactions
- ✓ Derive the behavior
- ✓ Connect theory to reality

ACCEPTABLE DIRECTION:
FIND THE UNDERLYING MECHANISM

MECHANICS
STATISTICAL PHYSICS
DYNAMICAL SYSTEMS
CAUSAL STRUCTURE

REALISM ACCEPTS THE OUTCOME. ★ DEALISM ASKS WHAT PRODUCED IT.

DO NOT EXPLAIN THE MEASUREMENT. EXPLAIN THE MECHANISM.

Dealist Criteria for Explanation

- **1. Clear Ontology** - *What exists?* The theory must specify **what the world is made of**

- Entities should be:
 - well-defined and in spacetime
 - not purely formal (not just symbols in equations)
 - particles, fields, media, structures → great!
 - “the wavefunction just is” (without interpretation) → no

- **“What exists must be identifiable, not just symbols”**

- **2. Mechanism** - *What produces the phenomenon?*

There must be a **process**:

- how things interact
- how outcomes arise
 - collisions, propagation, interactions → great!
 - “it happens upon measurement” → no

- **“Show me how the outcome is produced”**

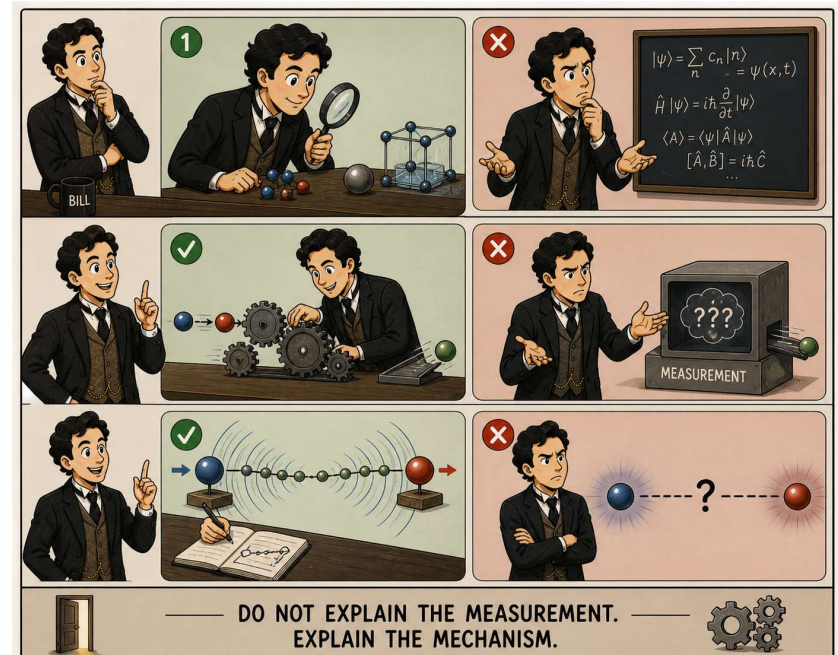
- **3. Locality** - *How does influence propagate?* Prefer:

- **local interactions** or at least **structured mediation**

Nonlocality is:

- not forbidden; but must be **explained, not assumed**
 - propagation through a field or medium → great!
 - instantaneous, unexplained correlations → no

- **“Influence must be mediated, not magical”**



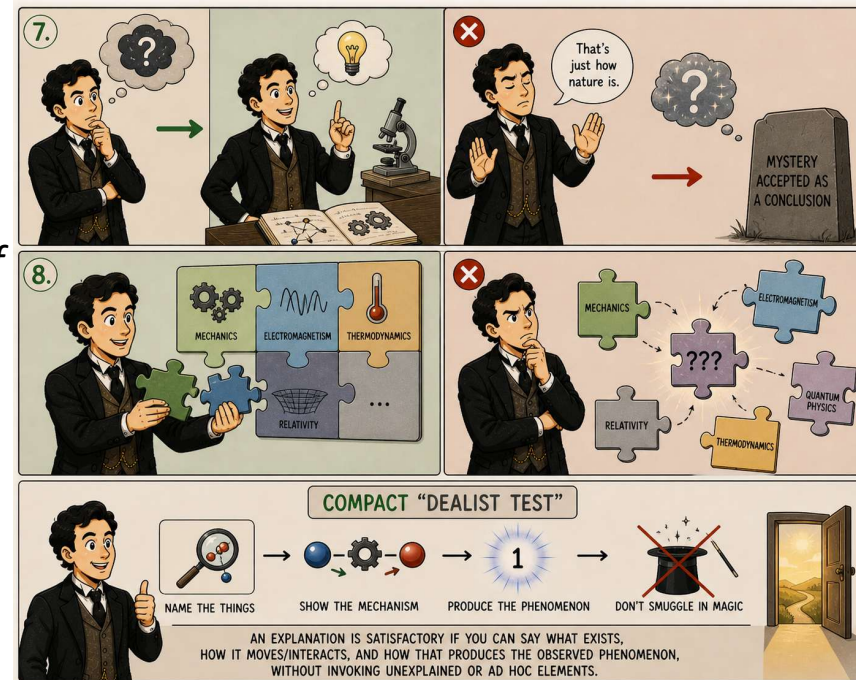
Dealist Criteria for Explanation

- **4. Empirical Adequacy (from the start)** - *Does it match what we observe?*
- A valid theory must not predict obviously unobserved phenomena (e.g. macroscopic superpositions)
- No “we’ll fix that later”
 - agreement with observation at all relevant scales → great!
 - patching with ad hoc rules → no
- **“If it predicts nonsense, reject immediately”**
- **5. Explanatory Priority over Formal Fit** - *Does it explain, not just calculate?* Matching data is **necessary but not sufficient**
- The theory must tell you **why** the equations work
 - derivation from underlying structure → great!
 - treating equations as final truth → no
- **“Math comes from mechanism, not the other way around”**
- **6. Simplicity as a Starting Point** - *Have we tried the obvious first?*
- Begin with:
 - known physics
 - minimal assumptions
- Only escalate if “forced”
 - “can classical or near-classical mechanisms do it?” → great!
 - jumping to exotic ontology too early → no
- **“Don’t conjure ontology before exhausting simple mechanisms”**



Dealist Criteria for Explanation

- **7. No Mystery as a Stopping Point** - Is “mystery” being treated as an answer?
 - “That’s just how nature is” is **not acceptable**
 - Strangeness = **signal of incomplete explanation**
 - mystery leads to research program → great!
 - mystery is accepted as a conclusion → no
 - **“Mystery is a starting point, not endpoint”**
- **8. Unity (optional but powerful)** - Does it connect with the rest of physics?
 - Prefer explanations that:
 - integrate with existing theories
 - reuse known principles
 - **“Good theories connect; bad ones isolate”**
- **“Dealist Test”** - An explanation is satisfactory if:
 - You say **what exists, how it moves/interacts, and how that produces the observed phenomenon**, without invoking unexplained or ad hoc elements
- **“Name the things, show the mechanism, and don’t smuggle in magic”**



APPLYING THE DEALIST METHOD TO: STANDARD QUANTUM MECHANICS

<p>1. CLEAR ONTOLOGY ✓</p> <p>Physical entities with clear properties.</p>	<p>✗</p> <p>"The wavefunction just is."</p> <p>Not a physical entity.</p>	<p>2. MECHANISM ✓</p> <p>Interactions produce outcomes.</p>	<p>✗</p> <p>"Collapse upon measurement."</p> <p>No mechanism shown.</p>	<p>3. LOCALITY / STRUCTURED MEDIATION ✓</p> <p>Influence propagates through a field.</p>	<p>✗</p> <p>Instantaneous nonlocal correlations.</p> <p>Unexplained spooky action.</p>	<p>4. EMPIRICAL ADEQUACY ✓</p> <p>Matches observed phenomena.</p>	<p>✗</p> <p>Predicts unobserved macroscopic superpositions.</p> <p>Not empirically adequate.</p>
<p>5. EXPLANATORY PRIORITY OVER FORMAL FIT ✓</p> <p>Equations derived from mechanism.</p>	<p>Equations taken as fundamental truth.</p> $i\hbar \frac{\partial \psi}{\partial t} = \hat{H} \psi$ $\psi(x,t)$ <p>No Why. Just formalism.</p>	<p>6. SIMPLICITY AS A STARTING POINT ✓</p> <p>Use known physics. Escalate only if needed.</p>	<p>Jump to exotic ontology early.</p> <p>Many-Worlds</p> <p>Pilot-wave</p> <p>Strings...</p> <p>Too much, too soon.</p>	<p>7. NO MYSTERY AS A STOPPING POINT ✓</p> <p>Strangeness = signal. Leads to research.</p>	<p>✗</p> <p>Mystery treated as final answer.</p>	<p>8. UNITY ✓</p> <p>Connects with the rest of physics.</p>	<p>✗</p> <p>Isolated. Doesn't integrate.</p>

9. DEALIST TEST – DOES STANDARD QM PASS?

What exists?	✓	✗ Wavefunction status unclear.
What is the mechanism?	✓	✗ Collapse not explained.
How does influence propagate?	✓	✗ Nonlocal correlations unexplained.
Does it match observations?	✓	✗ Yes, at many scales.
Does it explain (why)?	✓	✗ Why equations work? Not answered.
Is it simple to start with?	✓	✗ Jumps to abstract formalism.
Does it stop at mystery?	✗	✗ Often, yes.
Is it unified?	✗	✗ Tensions remain.

VERDICT

✗

STANDARD QUANTUM MECHANICS

DOES NOT FULLY PASS THE DEALIST TEST.

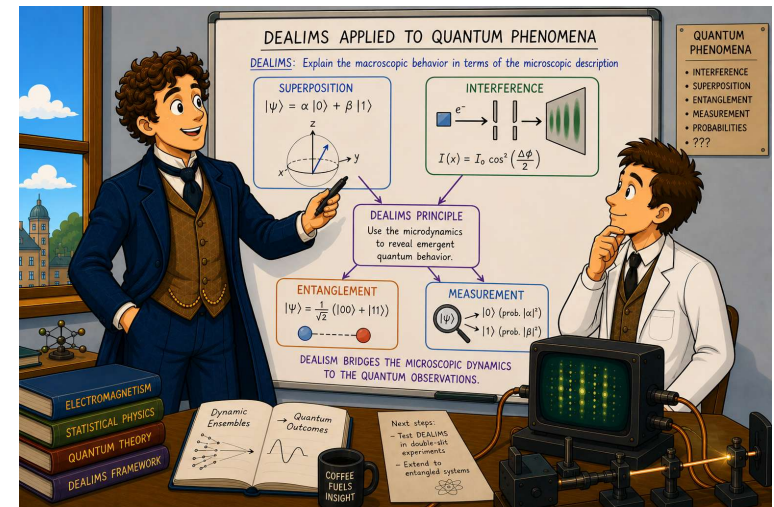
A DEALIST ALTERNATIVE – WHAT WE SEEK

Physical entities (field, particles, medium) Local interactions and mechanism Propagation through fields or media Observed quantum phenomena

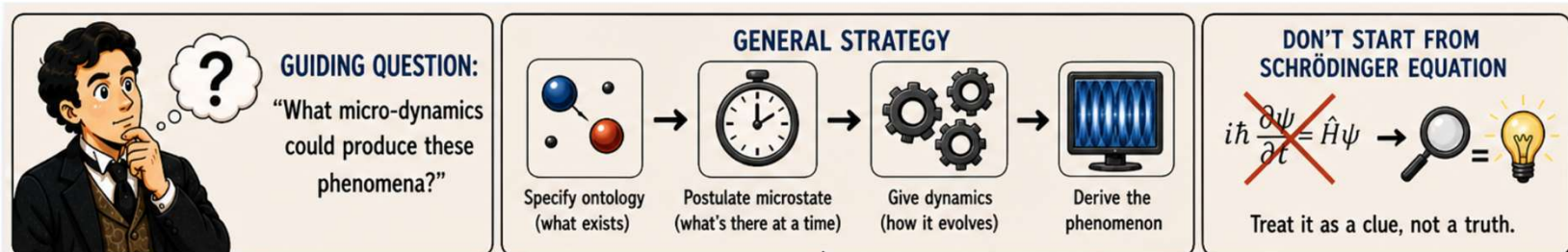
✓ **EXPLAIN QUANTUM PHENOMENA BY NAMING THE THINGS, SHOWING THE MECHANISM, AND PRODUCING THE OUTCOMES – NO MAGIC.**

More on Dealist Explanation

- A phenomenon is **explained** when you can **trace it back (=reduce)** to the time evolution of a well-defined microstate under clear dynamical laws
- Example (dealist-approved): **Heat**
 - Entities: molecules
 - State: positions and velocities
 - Dynamics: collisions
 - Result: temperature = average kinetic activity
 - Macroscopic behavior = reduced to micro-dynamics
- A theory **fails** the dealist standard if it:
 - gives only input-output rules (operators as observables)
 - lacks a clear microstate (wavefunction)
 - introduces ad hoc processes (“collapse happens”)
 - or leaves interactions unexplained (measurement)
- **Mechanism** = a **mapping** from microstate to macrostate over time, grounded in explicit entities and interactions, from which observed phenomena can be **derived**
- “Tell me what exists at a given moment, tell me how it changes, and show me how that produces what I see”



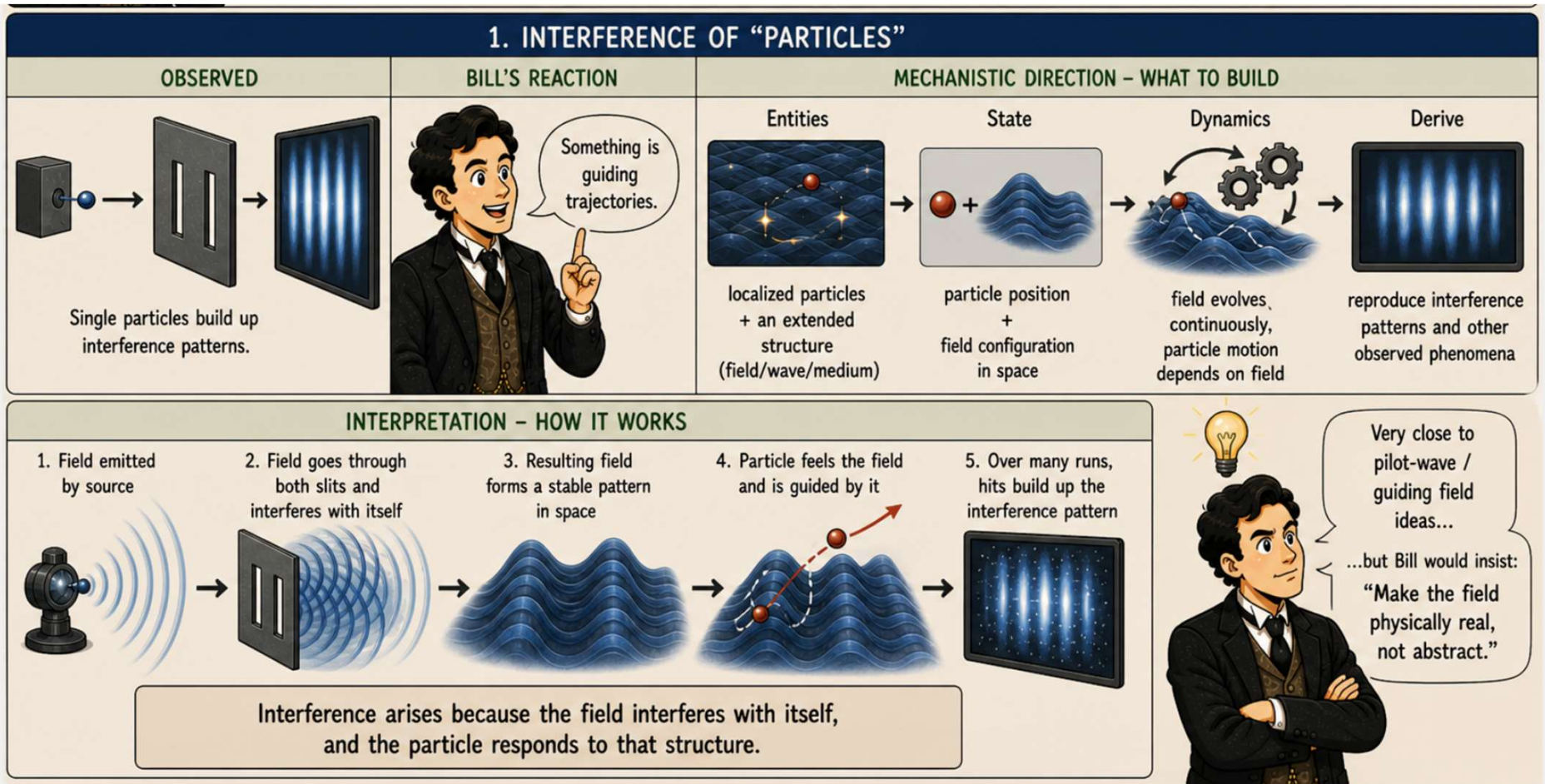
The Dealist's Program for Quantum Phenomena



- Guiding question: **“What micro-dynamics could produce these phenomena?”**
- **General Strategy**
- For each phenomenon:
 - **Specify ontology** (what exists)
 - **Postulate microstate** (what's there at a time)
 - **Give dynamics** (how it evolves)
 - **Derive the phenomenon** (what you observe)
- Do **not start from the Schrödinger equation** as fundamental truth; treat it as a **clue**

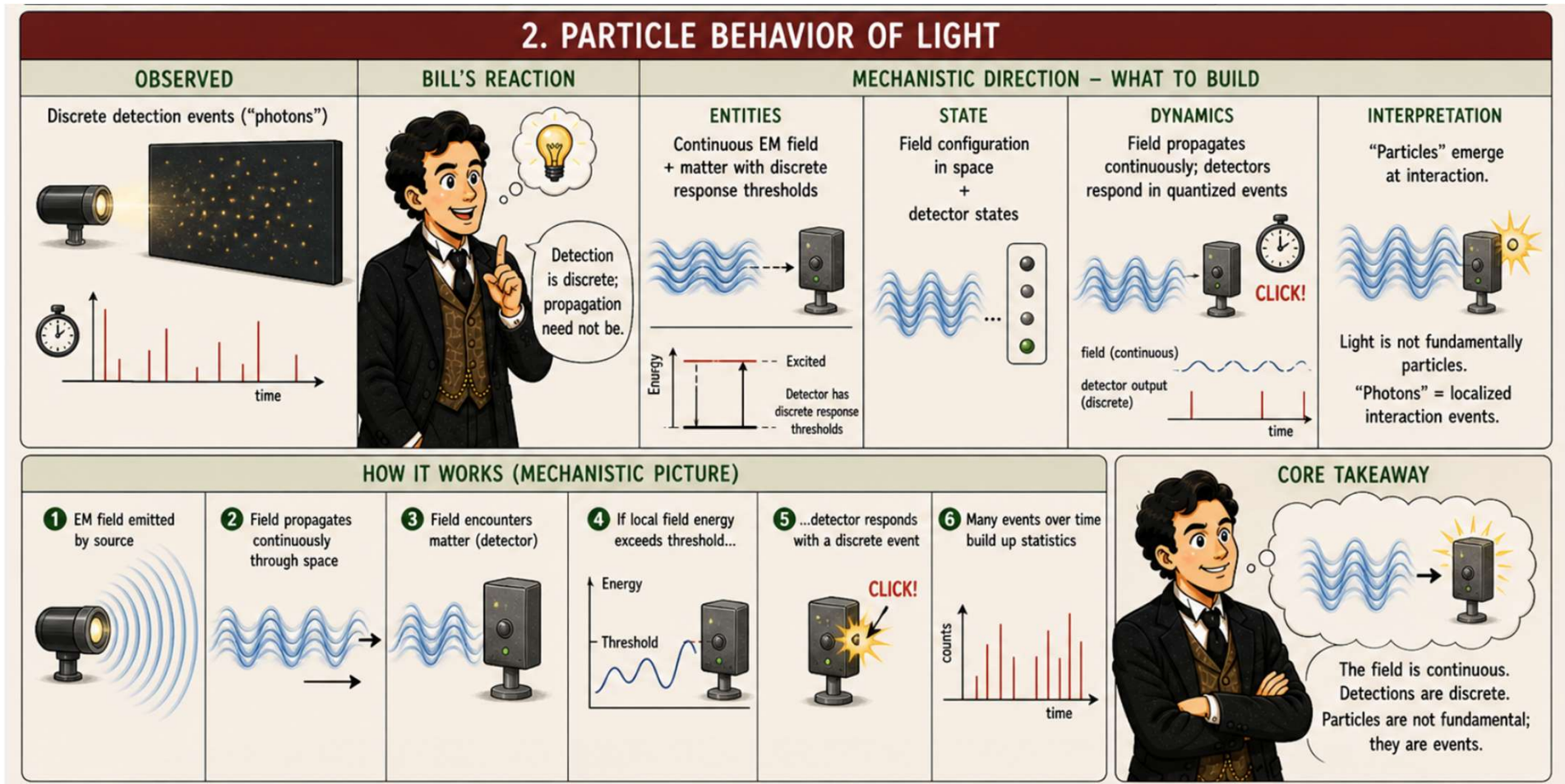
The Dealist's Program for Quantum Phenomena

- Guiding question: "What **micro-dynamics** could produce these phenomena?"



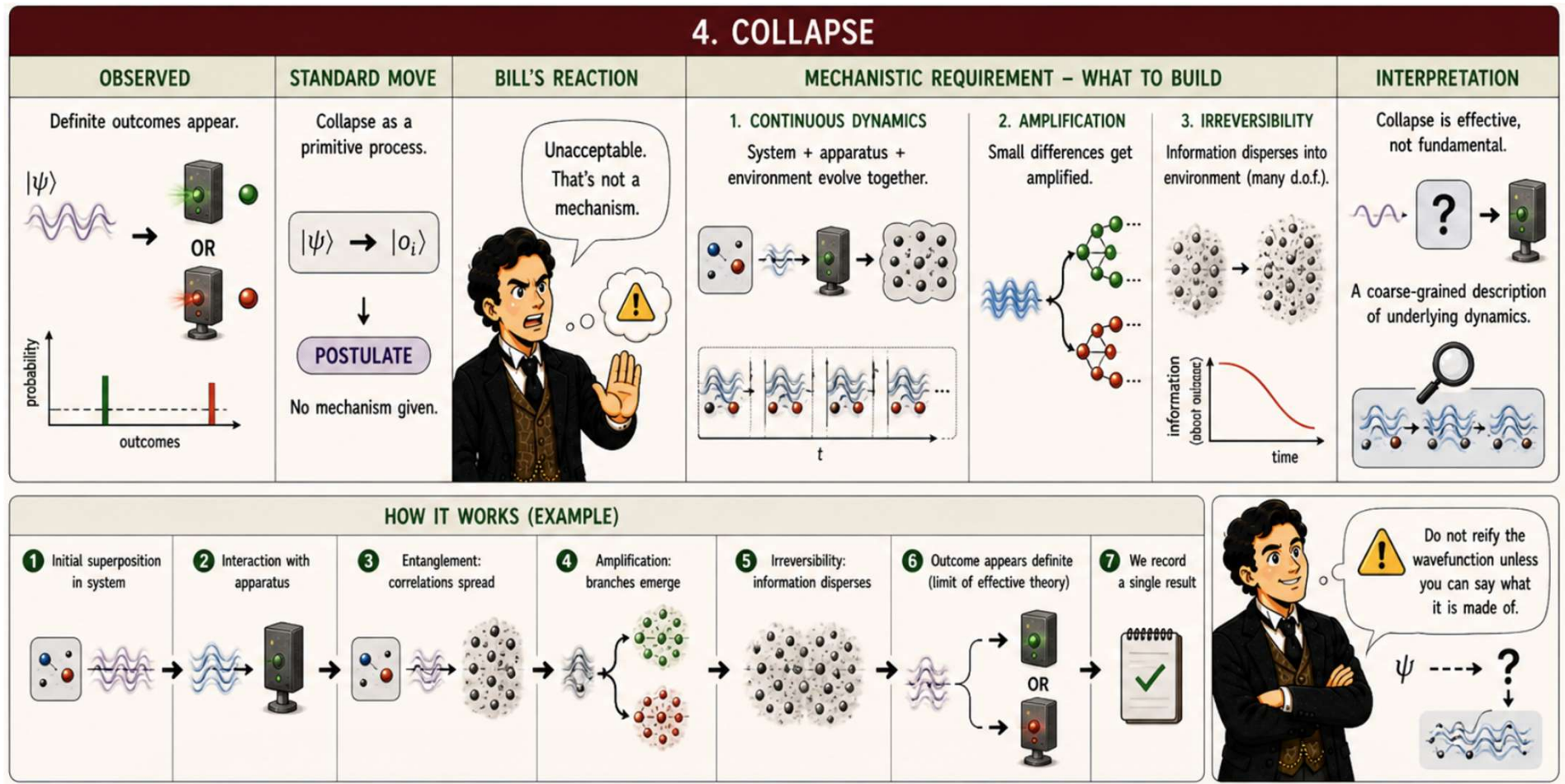
The Dealist's Program for Quantum Phenomena

- Guiding question: "What **micro-dynamics** could produce these phenomena?"



The Dealist's Program for Quantum Phenomena



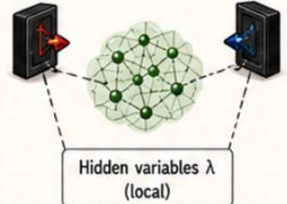
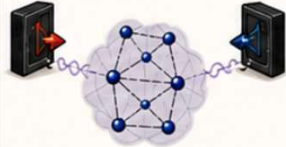
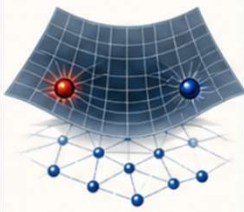


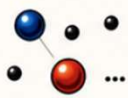
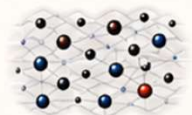

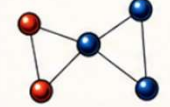
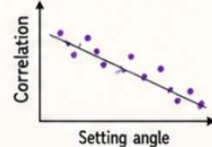


- Guiding question: "What **micro-dynamics** could produce these phenomena?"



The Dealist's Program for Quantum Phenomena

- Guiding question: "What **micro-dynamics** could produce these phenomena?"

5. NONLOCALITY (THE REAL PROBLEM)


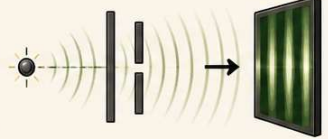

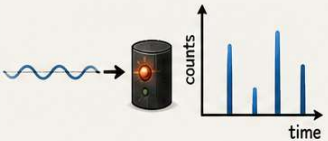


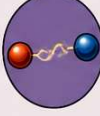
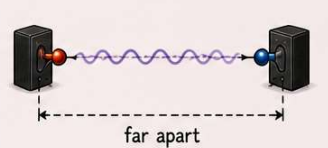
OBSERVED	BILL'S REACTION	MECHANISTIC OPTIONS (BILL MUST CHOOSE)			WHAT BILL REJECTS															
<p>Bell correlations + apparent instantaneous influence.</p>  <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr style="background-color: #f0f0f0;"> <th>Settings (A, B)</th> <th>Quantum Prediction</th> <th>Observed Correlations</th> </tr> </thead> <tbody> <tr> <td>A₁, B₁</td> <td>-cos θ₁₁</td> <td style="text-align: center;">✓</td> </tr> <tr> <td>A₁, B₂</td> <td>-cos θ₁₂</td> <td style="text-align: center;">✓</td> </tr> <tr> <td>A₂, B₁</td> <td>-cos θ₂₁</td> <td style="text-align: center;">✓</td> </tr> <tr> <td>A₂, B₂</td> <td>-cos θ₂₂</td> <td style="text-align: center;">✓</td> </tr> </tbody> </table> <p style="margin-top: 10px;">Violates Bell inequalities.</p>	Settings (A, B)	Quantum Prediction	Observed Correlations	A ₁ , B ₁	-cos θ ₁₁	✓	A ₁ , B ₂	-cos θ ₁₂	✓	A ₂ , B ₁	-cos θ ₂₁	✓	A ₂ , B ₂	-cos θ ₂₂	✓	<p>This is the actual crisis.</p>  <p style="margin-top: 20px;">Because it violates locality & intelligible mechanism.</p>	<p>OPTION A: HIDDEN LOCAL STRUCTURE</p> <p>Deeper variables restoring locality, but must evade Bell constraints (hard).</p>  <p style="text-align: center; border: 1px solid black; padding: 2px;">Hidden variables λ (local)</p> <p style="margin-top: 10px;">Must reproduce all correlations without faster-than-light influence.</p>	<p>OPTION B: MEDIATED NONLOCALITY</p> <p>Nonlocality is not instantaneous magic, but due to deeper structure (e.g. connectivity, constraints).</p>  <p style="margin-top: 10px;">Correlations arise via underlying structure that spans space.</p> <p style="margin-top: 10px;">No instantaneous action, but nonlocal connections exist.</p>	<p>OPTION C: MODIFY SPACETIME</p> <p>Locality is emergent. Underlying structure of reality is different.</p>  <p style="margin-top: 10px;">Correlations explained by deeper structure; locality emerges at large scales.</p>	<p style="text-align: center;">✗ Collapse across space instantly.</p>  <hr/> <p style="text-align: center;">✗ Correlations with no mechanism.</p> 
Settings (A, B)	Quantum Prediction	Observed Correlations																		
A ₁ , B ₁	-cos θ ₁₁	✓																		
A ₁ , B ₂	-cos θ ₁₂	✓																		
A ₂ , B ₁	-cos θ ₂₁	✓																		
A ₂ , B ₂	-cos θ ₂₂	✓																		
WHAT WOULD BE ACCEPTABLE TO BILL																				
<p>✓ Clear ontology (what exists).</p> 	<p>✓ Intelligible microstate (at each time).</p> 	<p>✓ Real dynamics (no jumps).</p> 	<p>✓ Causal structure (explicit).</p> 	<p>✓ Derivation of correlations (from mechanism).</p> 	<p>✓ Consistency with all data.</p> 	 <div style="border: 1px solid black; padding: 10px; margin-top: 10px;"> <p>The goal is not to save "quantum weirdness".</p> <p>The goal is to find a real, intelligible mechanism that makes these correlations inevitable.</p> <p style="text-align: center; font-size: 2em;">↓</p> <p style="text-align: center; font-weight: bold; font-size: 1.2em;">Mechanism > Mystery</p> </div>														


The Dealist's Program for Quantum Phenomena

- Putting it all together, this is **Bill's g picture**:
 - There are real entities (particles, fields, medium)
 - with definite microstates,
 - evolving via lawful dynamics,
 - producing interference, discreteness, outcomes
- And the wavefunction is not the mechanism; it is a summary of it


FINAL BILL-STYLE SUMMARY

“Interference tells us there is structure beyond particles;
Discreteness tells us interactions are quantized;
Collapse tells us our description is incomplete;
Nonlocality tells us we do not yet understand the structure of the world”


	INTERFERENCE		tells us there is structure beyond particles;
	DISCRETENESS		tells us interactions are quantized;
	COLLAPSE		tells us our description is incomplete;
	NONLOCALITY		tells us we do not yet understand the structure of the world



Our task is not to accept mystery,
but to build the real mechanisms that make these phenomena inevitable.



“Usual” Solutions of the Measurement Problem: The Dealist Scorecard

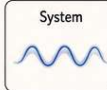


COPENHAGEN INTERPRETATION (Standard View)


Core idea: Quantum mechanics is a tool for calculating probabilities of measurement outcomes. It does not describe an underlying reality.

“Shut up and calculate.” – N. Bohr


IN ONE PICTURE



System

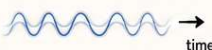

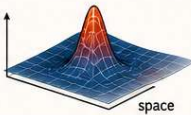



Measurement
(Interaction)



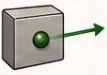
Outcome

Before measurement: described by a wavefunction
After measurement: one outcome is observed

<p>1. ONTOLOGY (What exists?)</p> <p>No claim about an underlying reality. Wavefunction is not a physical thing; it encodes knowledge about the system.</p> <div style="text-align: center;"> ψ ----> knowledge </div> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">Reality (if any) is outside the scope of the theory.</div>	<p>2. DYNAMICS (How it evolves?)</p> <p>Between measurements, systems evolve unitarily according to the Schrödinger equation.</p> <div style="text-align: center;"> $i\hbar \frac{\partial \psi}{\partial t} = \hat{H} \psi$  <p>time</p> </div> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">Deterministic evolution of the wavefunction.</div>	<p>3. MEASUREMENT / COLLAPSE (What happens?)</p> <p>When a measurement occurs, the wavefunction collapses instantaneously and randomly to an eigenstate.</p> <div style="text-align: center;">  <p>collapse</p> </div> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">Outcome is real. Collapse is a postulate.</div>	<p>4. VIEW OF THE WAVEFUNCTION (What is ψ?)</p> <p>A mathematical tool for predicting probabilities of outcomes.</p> <p>$\psi ^2 \rightarrow$ probability density</p> <div style="text-align: center;">  <p>space</p> </div> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">Not a physical object. Not something that “exists”.</div>	<p>5. KEY IDEA IN ONE LINE</p> <div style="text-align: center;">  </div> <p style="text-align: center;">Quantum mechanics tells us what we can say about measurement outcomes— not what reality is.</p> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">It’s a recipe for predictions, not a picture of the world.</div>
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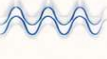
HOW A TYPICAL EXPERIMENT LOOKS

Prepare




Initial state $|\psi_0\rangle$

Evolve




Unitary evolution

Measure




Interaction with apparatus

Collapse





Random outcome is realized


Record



One result in the experimental record

STRENGTHS AND LIMITATIONS

<p style="font-weight: bold; color: green;">✓ STRENGTHS</p> <ul style="list-style-type: none"> Extremely successful at predicting all experimental results. Conceptually minimalist. No unobservables needed. <div style="text-align: center; color: green;">  </div>	<p style="font-weight: bold; color: red;">✗ LIMITATIONS (Bill's view)</p> <ul style="list-style-type: none"> Avoids the question of <i>what reality is</i>. Collapse postulate lacks a mechanism. Measurement problem remains unresolved. Unsatisfying for a theory of nature. <div style="text-align: center; color: red;">  </div>
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 **Bottom line:** Copenhagen gives excellent predictions, but remains silent about the underlying reality and how collapse happens.

- **Bill’s verdict:** “This is not a theory. It is a set of instructions” - **Total failure by dealist standards**

“Usual” Solutions of the Measurement Problem: The Dealist Scorecard



QBISM (Quantum Bayesianism) (Personalist Bayesian View)

Core idea: Quantum states are an agent's personal degrees of belief about possible outcomes of their future experiences.

Quantum mechanics is a coherence rule for updating those beliefs in light of new experiences.

“Quantum theory is not about reality; it is about an agent's expectations.”
– C. A. Fuchs

IN ONE PICTURE

Agent → Measurement (choice) → Experience (outcome) → Update (beliefs)

Has prior beliefs (probabilities) Agent chooses an action (measurement) Agent has an experience Agent updates beliefs (Bayesian update)

Quantum mechanics = rules for coherent belief updating.

<p>1. ONTOLOGY (What exists?)</p> <p>There is no claim about an objective quantum reality. The only things QBism talks about are agents, their experiences, and their beliefs.</p> <p style="text-align: center;">Agent Personal belief</p> <p style="border: 1px solid black; padding: 2px;">QBism is silent about what exists “out there”.</p>	<p>2. DYNAMICS (How it evolves?)</p> <p>No physical dynamics of a system. Between experiences, the agent keeps (or changes) their beliefs.</p> <p style="text-align: center;">Evolution is belief updating, not physical change.</p>	<p>3. MEASUREMENT / OUTCOME (What happens?)</p> <p>An outcome is an experience of the agent. There is no physical collapse. The payoff is simply the experience.</p> <p style="text-align: center;">No collapse in the world—only an experience for the agent.</p>	<p>4. VIEW OF THE WAVEFUNCTION (What is ψ?)</p> <p>ψ (or ρ) encodes an agent's personal probability assignments.</p> <p style="text-align: center;">A bookkeeping tool for the agent's expectations.</p>	<p>5. KEY IDEA IN ONE LINE</p> <p style="text-align: center;">Quantum states are personal; measurements are experiences; quantum mechanics is the mathematics of coherent belief and action.</p> <p style="border: 1px solid black; padding: 2px;">It's not about the world being one way or another.</p>
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HOW A TYPICAL EXPERIMENT LOOKS (FROM THE AGENT'S VIEW)

Repeat: learning is continual and personal.

STRENGTHS AND LIMITATIONS

<p>STRENGTHS</p> <ul style="list-style-type: none"> • Conceptually clear and consistent. • Solves measurement problem by redefining it. • Aligns with Bayesian probability and decision theory. • Focus on information, action, and experience. 	<p>LIMITATIONS (Bill's view)</p> <ul style="list-style-type: none"> • Avoids the question of what reality is. • Gives up explanatory power about underlying mechanisms. • Not a theory of the world—only of beliefs. • Unsatisfying if one seeks a real, intelligible ontology.
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BOTTOM LINE: QBism is a pragmatic, agent-centered approach: quantum mechanics helps agents navigate their experiences, but it makes no claims about an underlying objective reality.

- **Bill's verdict:** “You have abandoned the problem” - **Not even in the game**

“Usual” Solutions of the Measurement Problem: The Dealist Scorecard



RELATIONAL QUANTUM MECHANICS (RQM) (Rovelli-style)

CORE IDEA

States are not absolute. They are relational.
A quantum state represents the information one system has about another.
Reality is not a collection of things, but a web of relations.

Observer A Information of S for A System S Information of S for B Observer B

“The world is a network of interactions, not a container of objects.” — C. Rovelli

IN ONE PICTURE

Observer A System S Observer B

State $|\psi\rangle_{S|A}$ (relative to A) No absolute state State $|\phi\rangle_{S|B}$ (relative to B)

Different observers can assign different states to the same system.
No contradiction — only different relations.

<p>1. ONTOLOGY (What exists?)</p> <p>There are no observer-independent quantum properties. What exists are systems and relations (events). Events occur in interactions between systems.</p> <p>Event</p> <p>Reality = network of events (relations), not substances.</p>	<p>2. DYNAMICS (How it evolves?)</p> <p>There is no absolute evolution. State-update is relative to an observer's interaction. No Schrödinger equation for the universe.</p> <p>Branching relative to that observer.</p> <p>Unitary evolution + updates are all relative.</p>	<p>3. MEASUREMENT / OUTCOME (What happens?)</p> <p>Outcomes are events: interactions between systems. Different observers can see different outcomes. All outcomes are real — relative to someone.</p> <p>No objective collapse. Only relative facts.</p>	<p>4. VIEW OF THE WAVEFUNCTION (What is $\psi\rangle$?)</p> <p>Wavefunction = information an observer has about a system. It lives in the observer's information space, not physical space. No wavefunction of the universe.</p> <p>A state is always “of something for someone”.</p>	<p>5. KEY IDEA IN ONE LINE</p> <p>There is no absolute state. There are only relative states. There is no absolute outcome. There are only relative outcomes. Reality = relations. That's all.</p> <p>No absolute facts. Only relational facts.</p>	<p>6. RELATIONAL MECHANICS IN PRACTICE</p> <p>Use standard QM — but interpret states and results relationally. All predictions of standard QM are recovered. The difference is in what we say exists.</p> <p>Same formalism. Different meaning.</p>
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HOW A TYPICAL EXPERIMENT LOOKS (RQM VIEW)

<p>1. Preparation (Relation with A)</p> <p>A prepares S. A assigns state $\psi\rangle_{S A}$.</p>	<p>2. Interaction (A-S interaction)</p> <p>They interact. An event occurs.</p>	<p>3. Outcome for A (Relative fact)</p> <p>A sees outcome o_A. It's real — for A.</p>	<p>4. Later, B interacts (with S)</p> <p>B interacts with S.</p>	<p>5. Outcome for B (Relative fact)</p> <p>B sees outcome o_B. It's real — for B.</p>	<p>6. No contradiction</p> <p>$o_A \neq o_B$ Both are real (relatively).</p>
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STRENGTHS

- ✓ Solves the measurement problem without extra postulates.
- ✓ Natural emergence of classicality.
- ✓ Consistent, minimal, and background-independent.
- ✓ No preferred observers.
- ✓ Works within standard QM — same predictions, new interpretation.

LIMITATIONS (Robert's view)

- ✗ No underlying “thing” behind relations.
- ✗ Some find “no absolutes” philosophically uncomfortable.
- ✗ Does not (yet) derive Born rule or dynamics from deeper principle.
- ✗ Harder to visualize for those used to substance ontology.

BOTTOM LINE: Relational QM says: only interactions are real.
Quantum states are information one system has about another.
There is no absolute state, no absolute outcome — only relative facts in a web of relations.

IN SYMBOLS

State of S for A: $|\psi\rangle_{S|A}$
State of S for B: $|\phi\rangle_{S|B}$
Outcome for A: o_A
Outcome for B: o_B

No absolute state: $\nexists |\psi\rangle_S$
No absolute outcome: $\nexists o$
Reality = Relations (events)

• **Bill's verdict:** “You have dissolved the world into perspectives and lost what explains their consistency.” Replaces absolute states with relations; predictive success \neq ontology; fails explanatory criterion: why do different observers ultimately agree?

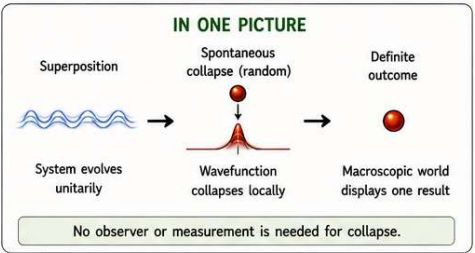
“Usual” Solutions of the Measurement Problem: The Dealist Scorecard



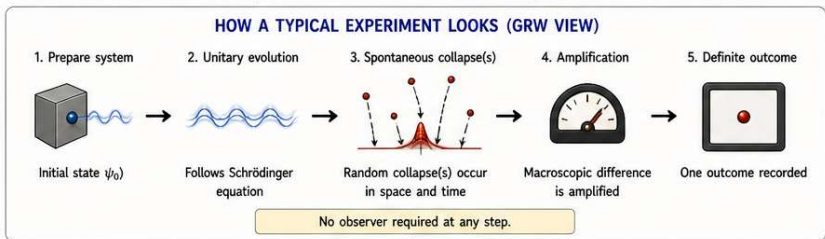
GRW (Ghirardi–Rimini–Weber Theory)
Spontaneous Collapse Model

Core idea: The wavefunction is real, but it undergoes spontaneous, random collapses in space and time. These collapses are **tiny** and rare for microscopic systems, but frequent enough for macroscopic systems to yield definite outcomes.

Collapse is real, objective, and part of the dynamics.



<p>1. ONTOLOGY (What exists?)</p> <p>The wavefunction ψ is a real physical field in 3D space. It describes the actual state of systems.</p> <p>Real wavefunction in physical space.</p>	<p>2. DYNAMICS (How it evolves?)</p> <p>Between collapses, ψ evolves unitarily (Schrödinger equation). At random times, a collapse occurs at a random location.</p> $i\hbar \frac{\partial \psi}{\partial t} = \hat{H}\psi$ <p>Stochastic modification of Schrödinger evolution.</p>	<p>3. MEASUREMENT / OUTCOME (What happens?)</p> <p>Outcomes arise from spontaneous collapses of the wavefunction. Macroscopic definiteness results from the accumulation of many tiny collapses.</p> <p>Repeated random collapses select one outcome.</p> <p>Collapse is objective, real, and observer-independent.</p>	<p>4. VIEW OF THE WAVEFUNCTION (What is ψ?)</p> <p>ψ is a real field in 3D space. It can be in superposition, but is subject to spontaneous collapses described by GRW parameters.</p> <p>Typical GRW parameters Collapse rate (per particle): $\lambda \sim 10^{-16} \text{ s}^{-1}$ Collapse width: $r_C \sim 10^{-7} \text{ m}$</p> <p>Small effect for microscopic systems, large effect for macroscopic ones.</p> <p>Real field + objective stochastic collapse law.</p>	<p>5. KEY IDEA IN ONE LINE</p> <p>Reality = wavefunction in 3D space that sometimes collapses randomly. Definite outcomes emerge from the dynamics itself, without needing observers.</p> <p>Spontaneous collapses make the world definite.</p>
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STRENGTHS AND LIMITATIONS

<p>STRENGTHS</p> <ul style="list-style-type: none"> ✓ Provides an objective mechanism for collapse. ✓ Explains why macroscopic outcomes are definite. ✓ Makes clear, testable predictions (small deviations from QM). ✓ Well-defined dynamics for all systems. 	<p>LIMITATIONS (Bill's view)</p> <ul style="list-style-type: none"> ✗ Introduces new parameters (λ, r_C) with no deeper derivation. ✗ Tiny deviations from QM so far experimentally unconfirmed. ✗ Ad hoc modification; needs a deeper ontological explanation.
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BOTTOM LINE: GRW adds real, spontaneous collapses to the dynamics so that definite outcomes arise objectively and naturally, without observers. It preserves quantum successes while giving a clear story for the measurement problem.

- **GRWm - Bill's verdict:** “You have replaced one mystery with another” - Collapse is still **primitive magic**, just legalized - **Fails mechanism criterion**

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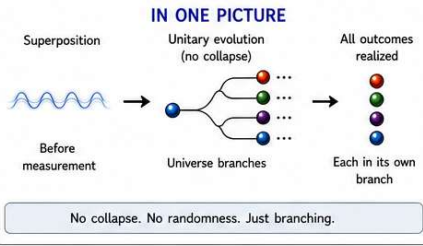
What does Many Worlds say?

MANY WORLDS INTERPRETATION (Everett / Wallace-style)

Core idea: The universal wavefunction never collapses. It always evolves unitarily and deterministically. When outcomes appear, the universe has branched: each outcome occurs in a different, non-communicating branch.

“Reality splits; all possibilities happen.” – D. Wallace

IN ONE PICTURE

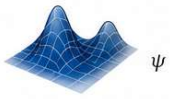


No collapse. No randomness. Just branching.

1. ONTOLOGY
(What exists?)

There is one universe described by a single wavefunction Ψ in configuration space.

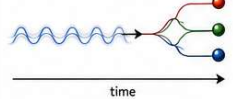
It evolves unitarily at all times. All branches are equally real.



One real wavefunction for the whole universe.

2. DYNAMICS
(How it evolves?)

The wavefunction evolves by the Schrödinger equation—always. No collapse postulate.

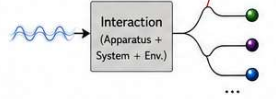
$$i\hbar \frac{\partial \Psi}{\partial t} = \hat{H} \Psi$$


Deterministic unitary evolution for the whole universe.

3. MEASUREMENT / OUTCOME
(What happens?)

During a measurement-like interaction, branches form, each carrying a different outcome.

You find yourself in one branch.




All outcomes occur—in different, non-interacting branches.


4. VIEW OF THE WAVEFUNCTION
(What is ψ ?)

Ψ is real and physically meaningful. It lives in high-dimensional configuration space.

Branches correspond to (approximately) non-overlapping regions.



The wavefunction encodes the entire branching structure.



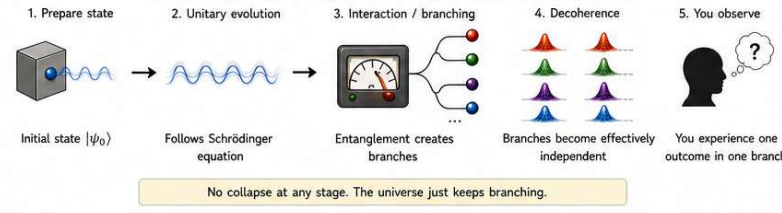
Reality = one quantum world that branches.

All outcomes happen. You see one because you are in one branch.

No collapse—just branching.

HOW A TYPICAL EXPERIMENT LOOKS (MANY WORLDS VIEW)

1. Prepare state
2. Unitary evolution
3. Interaction / branching
4. Decoherence
5. You observe



No collapse at any stage. The universe just keeps branching.

STRENGTHS AND LIMITATIONS

STRENGTHS

- ✓ Purely unitary—no ad hoc collapse.
- ✓ Simple, elegant ontology.
- ✓ Explains why all outcomes are possible: they all occur.
- ✓ Consistent with quantum theory and decoherence.
- ✓ No new parameters or hidden variables.

LIMITATIONS (Bill's view)


- ✗ No mechanism for branching—only the wavefunction's smooth evolution.
- ✗ Cannot explain why distinct outcomes arise; it only says they exist.
- ✗ At best, offers an explanation in terms of emergent patterns at various levels of description (functionalism).
- ✗ Leaves the structure that produces these patterns unexplained.

BOTTOM LINE: Many Worlds keeps only the Schrödinger equation and takes it universally. It explains observations via branching, but provides no underlying mechanism—only emergent patterns at best.

- **Bill's verdict:** “You have kept the equations and lost the explanation” - Predictive success \neq mechanism - **Fails explanatory criterion**

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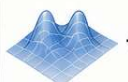
BOHMIAN MECHANICS (PILOT-WAVE)

Core idea: Particles have definite positions at all times. They are guided by an object that encodes their interactions, and evolves by Schrödinger's equation. The wavefunction is not a physical field. It is an objective, nomological entity that encodes the laws of interaction between particles.


“The wavefunction is not a physical wave; it is something more abstract which determines the phenomena.” – L. de Broglie

IN ONE PICTURE


Wavefunction
(nomological object)



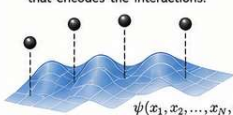
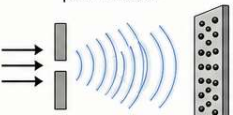

Particles
(positions)



Guided motion
(trajectories)




The wavefunction encodes interactions between particles. Particles move under its influence. It evolves and guides.


<h4>1. ONTOLOGY</h4> <p>(What exists?)</p> <p>Matter exists as point particles with definite positions in 3D space.</p> <p>The wavefunction is an objective, nomological entity (not a field) that encodes the interactions.</p>  <p style="font-size: x-small;">$\psi(x_1, x_2, \dots, x_N, t)$</p> <p style="font-size: x-small; border: 1px solid gray; padding: 2px;">Particles + nomological wavefunction.</p>	<h4>2. MICROSTATE</h4> <p>(What is the complete state?)</p> <p>The complete state is:</p> <ul style="list-style-type: none"> • the wavefunction $\psi(x_1, \dots, x_N, t)$ (encodes interactions) • the actual particle positions $(x_1(t), \dots, x_N(t))$ <div style="border: 1px solid gray; padding: 5px; margin-top: 5px; font-size: x-small;"> <p>Microstate = (ψ, X)</p> <p>$X = (x_1, \dots, x_N)$</p> </div> <p style="font-size: x-small; border: 1px solid gray; padding: 2px; text-align: center;">Deterministic and complete.</p>	<h4>3. DYNAMICS</h4> <p>(How it evolves?)</p> <p>Two laws govern the evolution.</p> <p>(1) Schrödinger equation for the wavefunction</p> <div style="border: 1px solid gray; padding: 5px; margin-top: 5px; font-size: x-small;"> $i\hbar \frac{\partial \psi}{\partial t} = \hat{H} \psi$ </div> <p>(2) Guiding equation for particle velocities</p> <div style="border: 1px solid gray; padding: 5px; margin-top: 5px; font-size: x-small;"> $\dot{X}_k = v_k^\psi(X, t)$ <p style="font-size: x-small;">(depends on ψ and all positions)</p> </div> <p style="font-size: x-small; border: 1px solid gray; padding: 2px; text-align: center;">Clear laws. No collapse.</p>	<h4>4. MECHANISM</h4> <p>(How do outcomes arise?)</p> <p>Particles follow continuous trajectories guided by ψ.</p> <p>Interference arises from the structure of ψ acting on particle motion.</p>  <p style="font-size: x-small; border: 1px solid gray; padding: 2px; text-align: center;">Interference explained mechanistically.</p>	<h4>5. KEY IDEA IN ONE LINE</h4>  <p style="font-size: x-small;">Particles have definite positions and follow precise trajectories that are guided by a nomological wavefunction encoding their interactions.</p> <p style="font-size: x-small; border: 1px solid gray; padding: 2px; text-align: center;">A clear, realistic, mechanistic picture of quantum phenomena.</p>
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HOW A TYPICAL EXPERIMENT WORKS (DOUBLE-SLIT EXAMPLE)

Source

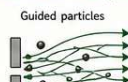


Wavefunction evolves




ψ passes through both slits

Guided particles




Trajectories guided by ψ

Interference pattern builds up



Pattern emerges from the motion of many particles

Detection



Each particle arrives at a definite place and time

No collapse. Just continuous guided motion.


STRENGTHS (very dealist-friendly)

- ✓ Ontology: particles with definite positions
- ✓ Microstate: particle positions + wavefunction (nomological)
- ✓ Dynamics: clear laws (guiding equation + Schrödinger)
- ✓ Mechanism:
 - particle trajectories guided by a real structure (ψ encodes interactions)
 - interference explained mechanistically

👍 This is the closest thing to a dealist success.

PROBLEM (big one)

✗ Nonlocality is explicit and fundamental.



The velocity of one particle depends instantaneously on others.

BOTTOM LINE: Bohmian Mechanics gives a clear ontology, dynamics, and mechanism. It explains interference and measurement outcomes without collapse. Its great strength is clarity; its great cost is fundamental nonlocality.

- **Bill's verdict:** “This is a mechanism, but not yet an acceptable one” - Good: explanation, clarity / Bad: violates locality at the fundamental level - **Best current model, but not final**

Where we are: Two constraints on any theory

They are both empirical -Bill's reading: "The theory we have is not OK. Do not fix measurement; fix the theory"

• 1. Measurement problem

• Schrödinger +Einstein

- Premise 1: A **linear, universally valid wave equation** leads to macroscopic superpositions
 - Premise 2: These are **not observed**
 - Therefore, a **linearly evolving wave ontology** is **empirically inadequate**
- No theory can have:
- Linear wave ontology
 - Empirical adequacy
 - So,
 - If you want waves, they do not evolve linearly (you need to get rid of superpositions)
 - GRW-style
 - If you want particles, you have to "add" them: SQM has just the wavefunction
 - dBB-style
- Both options show the theory is not adequate



Where we are: Two constraints on any theory

They are both empirical -Bill's reading: "The theory we have is not OK. Do not fix measurement; fix the theory"

• 2. Nonlocality problem

• EPR + Bell + Aspect:

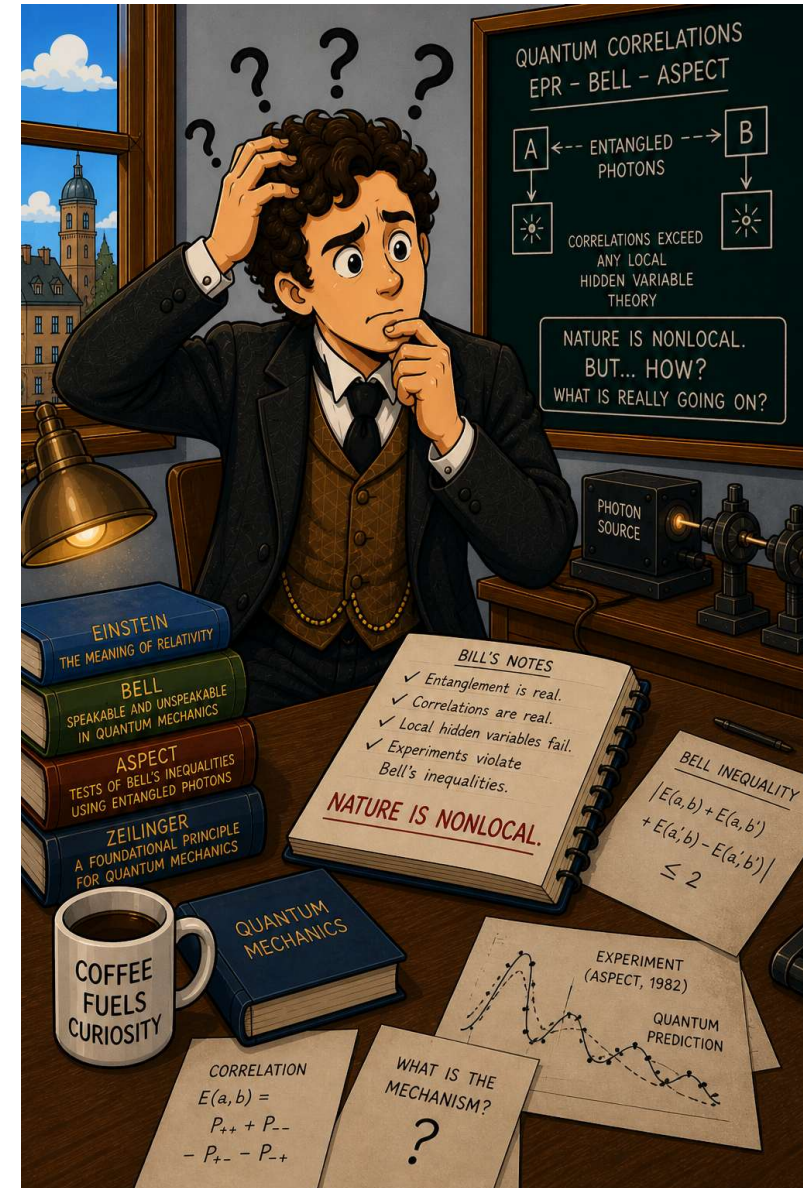
- Premise 1 (EPR+Bell): **Locality+ SQM** → (EPR) → hidden-variables → (Bell) → **new predictions**
- Premise 2 (Aspect): **no new predictions**
- Therefore, a local theory is empirically inadequate
- No theory can have:
 - Local interaction
 - Empirical adequacy
- **Therefore:** You must **give up on locality**
- Bill: "Can we resist the derivation from 'local hv theory' to 'new predictions'?"
 - Reject statistical independence → worse than rejecting locality!

• Options?



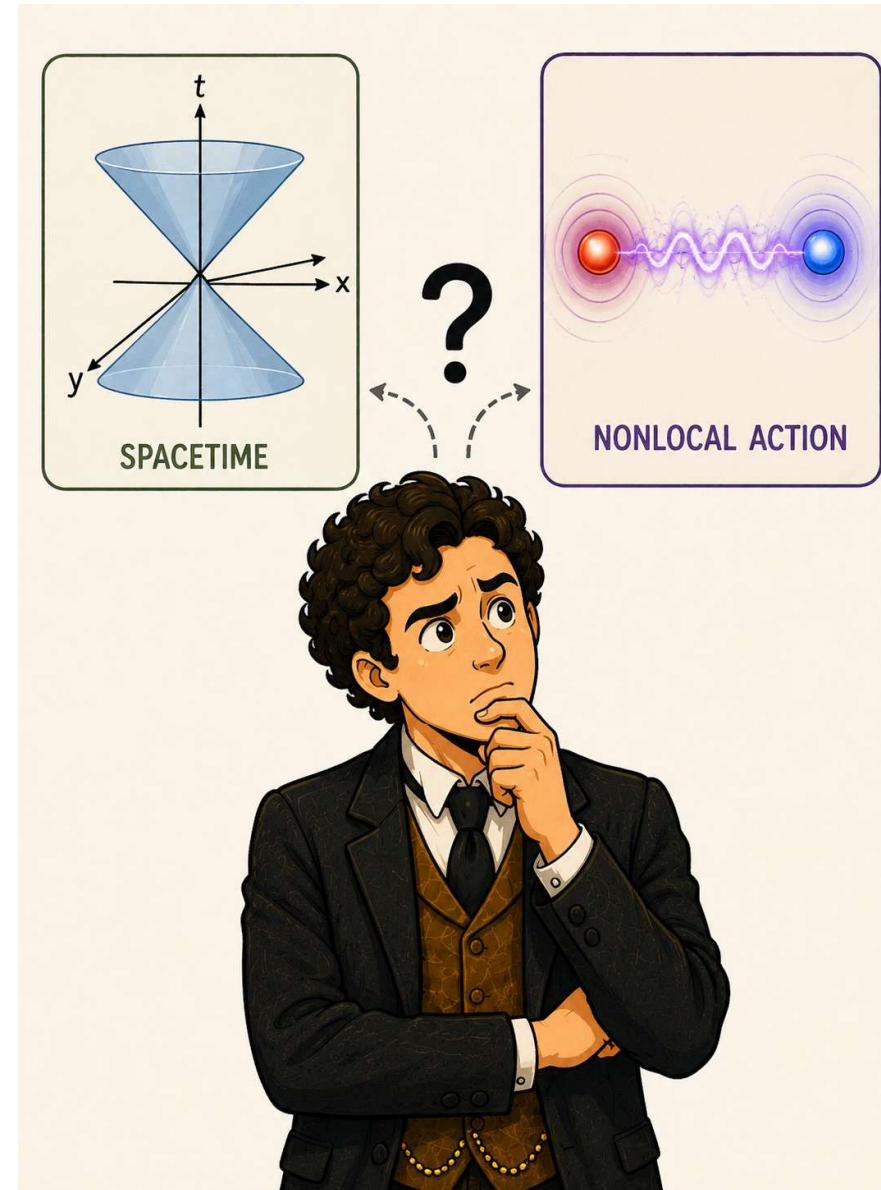
Options?

- **You tell me!**
 - Find a mechanism for **nonlocal** interaction of **separable** matter?
 - Assume a **non-separable** ontology interacting **locally**?
 - ???
- Notice:
- This is **problematical already** without even entering in the question of whether this theory is compatible with special or general relativity....



Does Unity Led to Incompleteness?

- **What Bill accepted:**
 - Experiments say there are no superpositions
 - SQM says superpositions exist
 - So, **SQM is not empirically adequate**
 - We need to **add a spatiotemporal ontology** (assuming we don't want to go nonlinear) to make it compatible with relativity, which is about spacetime
- **The dealist requirement of unity leads to this temptation:**
 - Experiments say interaction is nonlocal
 - Relativity is local
 - So, **relativity is not empirically adequate**
 - We need to **add some nonlocal structure** to spacetime to make it compatible with QM which is nonlocal
- Bill wouldn't accept this... or would he?



Thank you!

