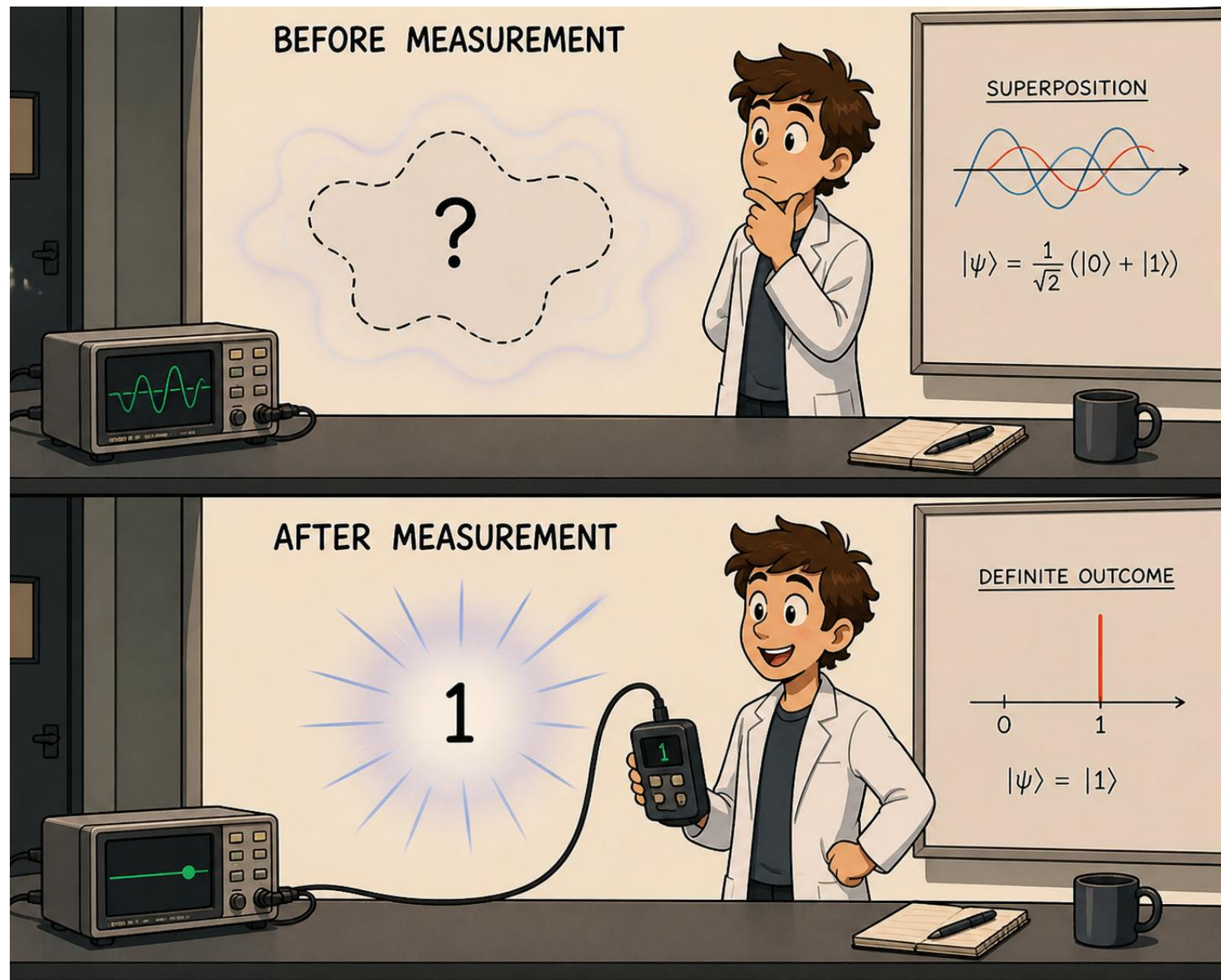


The Problem with the “Measurement Problem”

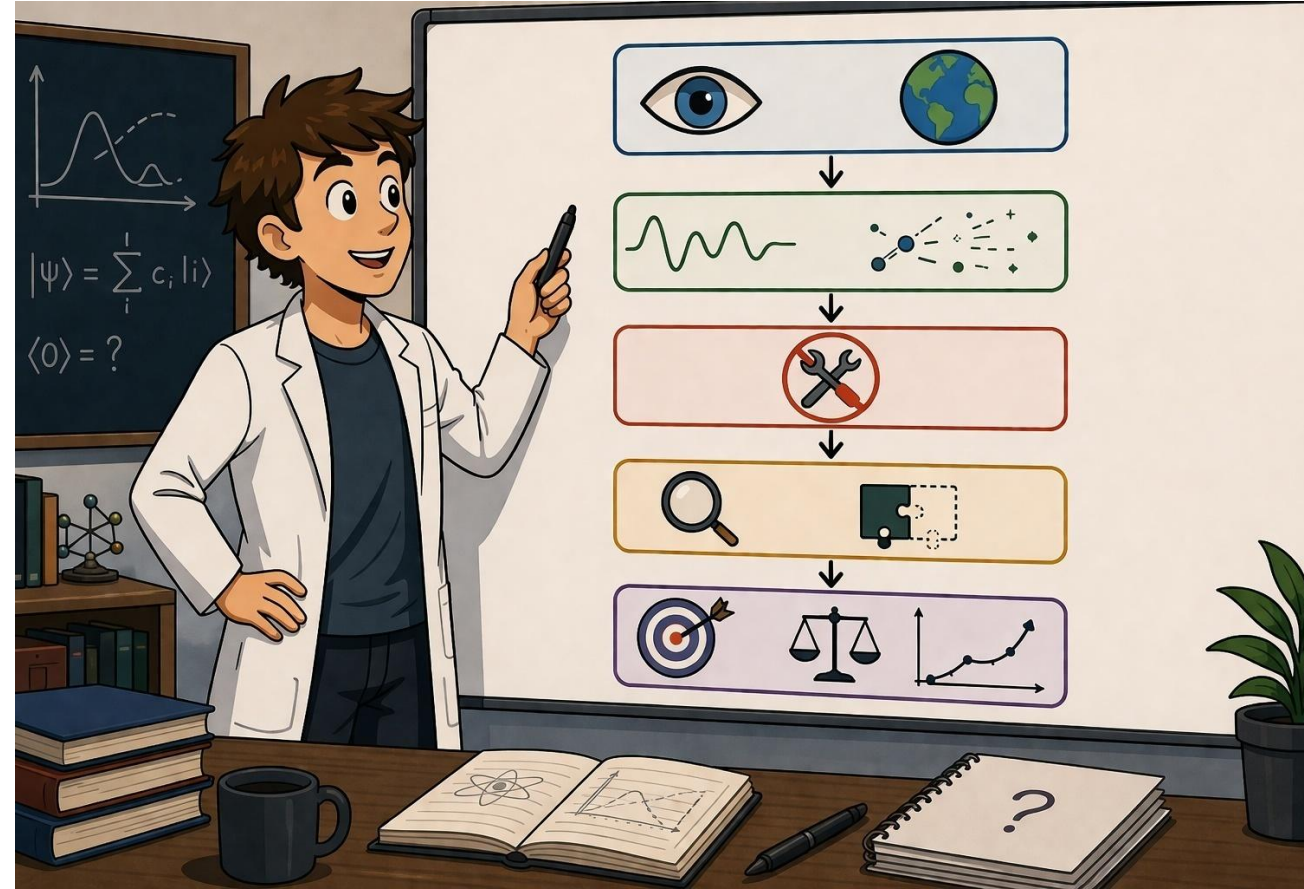


- Valia Allori -- Unibg
- May 4th, 2026
- Laws of Nature Series



Outlook --- A Methodological Claim: you do not find a realist quantum theory by solving the measurement problem

- Face **quantum phenomena** under a 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 real problem is not measurement, but **nonlocality**



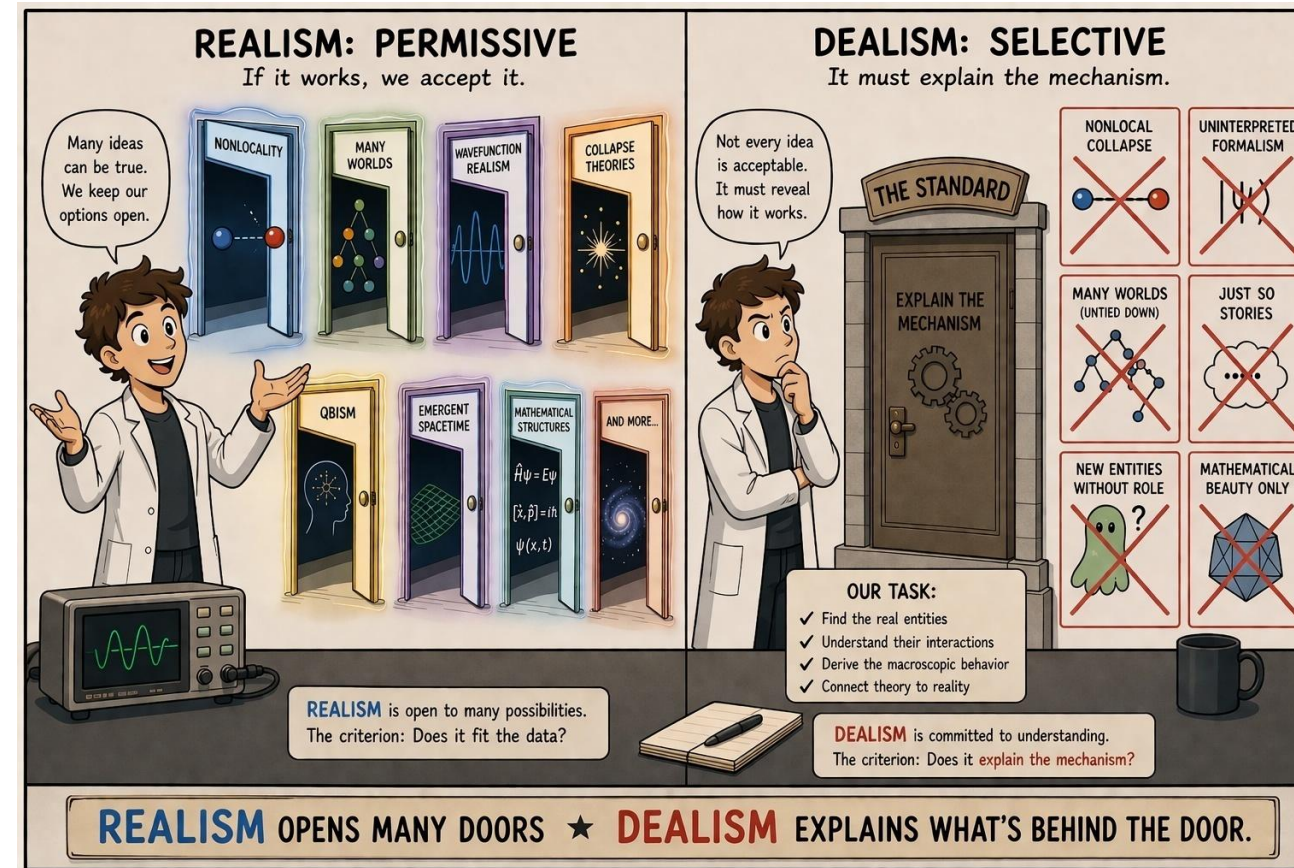
Realism

- 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)
 - “Weird” primitives (branching worlds)
- As long as
 - the theory is **empirically adequate** and has a **coherent interpretation**



From Realism to Dealism

- **DEALism** – “what’s the *real DEAL* behind the phenomena?”
- 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

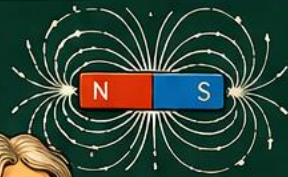
★ Realism. Mechanism. Intelligibility. ★
No mysteries—only explanations.

“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

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

“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 defending a “fixed” ontology



Realism keeps doors open

Dealism insists on opening them

Bill Dingblocks

- A (fictional) disciple of Lord Kelvin

BILL DINGBLOCKS
— Disciple of Lord Kelvin —

Physicist.
Explainer.
Dealist.

Clarity over mystery.
Mechanism over magic.
Reality over romance.

Cambridge, 1876

**NATURE IS INTELLIGIBLE.
OUR TASK IS TO EXPLAIN.**

BUILD THE MECHANISM.

1. State the phenomena.
2. Use the simplest adequate mechanics.
3. Test. Calculate. Compare with nature.
4. If it fails—revise, then generalize.
5. Never accept mystery as an explanation.

$m_1 \xrightarrow{F} m_2$
 $F \quad T \quad F$
Seek causes, not spiritualism.

DEALISM

Physics tells us which are the building blocks of reality, and how they work.

- REAL ENTITIES, REAL CAUSES**
The entities in our best theories are real. We seek the mechanisms that produce phenomena.
- SIMPLE FIRST, NOT ALWAYS SIMPLEST**
Start with the obvious and the well-tested. Escalate only when nature leaves no alternative.
- NO MYSTERY BY DEFAULT**
Strangeness is not profundity. It is usually a sign of incomplete understanding.
- LOCAL MECHANISMS WHEREVER POSSIBLE**
Nonlocal influences are a last resort. We seek explanations grounded in clear physical processes.
- EXPLAIN, DON'T MERELY FIT**
Agreement with observation is necessary but not sufficient. Our goal is understanding.
- OPEN TO NOVELTY, NOT FADDISH**
New ideas are welcome—if they illuminate, unify, and deepen explanation.

*Good physics is not about being first.
It is about being right.*

**WE DO NOT FEAR NEW TRUTHS.
WE ONLY FEAR BAD EXPLANATIONS.**

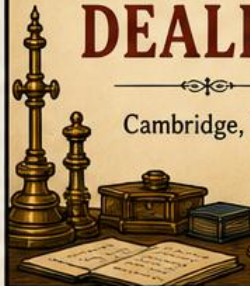
★ Bill Dingblocks 1876 ★

BILL DINGBLOCKS

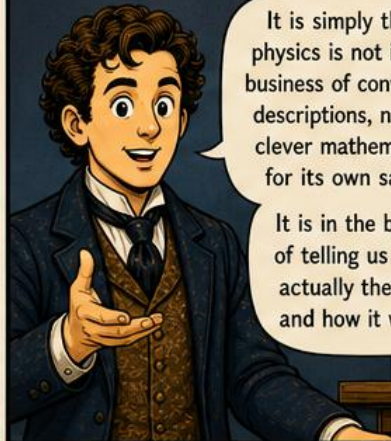
explains

DEALISM

Cambridge, 1876



"Dealism"?
Yes, I named
it myself.
Poorly, some
say.



It is simply this:
physics is not in the
business of convenient
descriptions, nor of
clever mathematics
for its own sake.

It is in the business
of telling us what is
actually there—
and how it works.

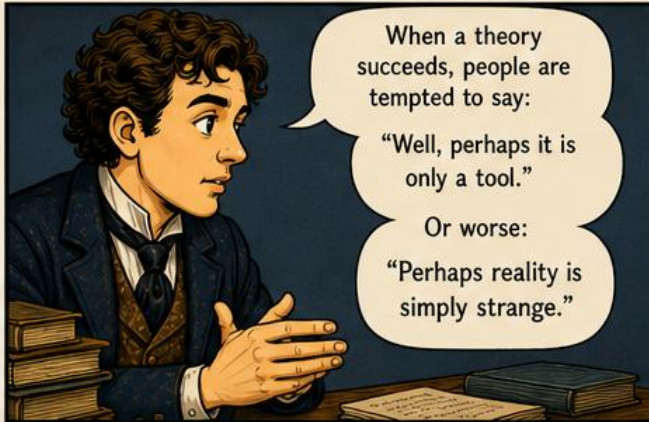
OUR TASK:
EXPLAIN.



$$F = ma$$



The *real deal*,
if you like.

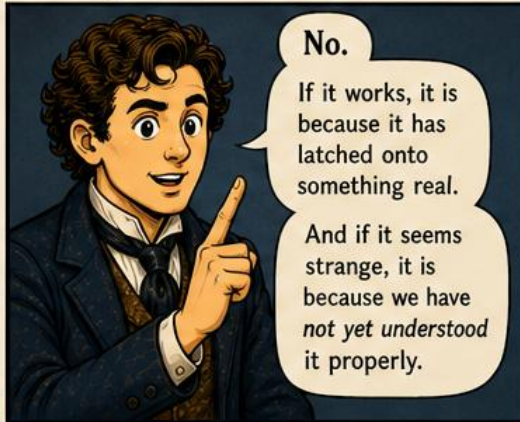


When a theory
succeeds, people are
tempted to say:

"Well, perhaps it is
only a tool."

Or worse:

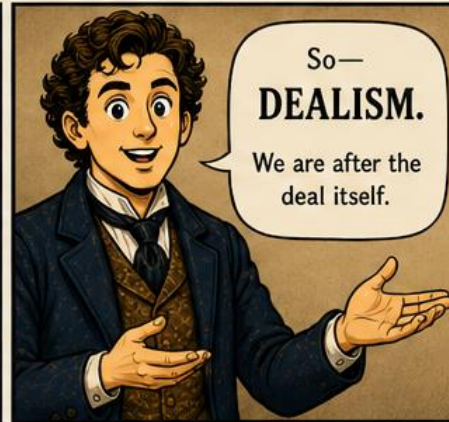
"Perhaps reality is
simply strange."



No.

If it works, it is
because it has
latched onto
something real.

And if it seems
strange, it is
because we have
not yet understood
it properly.



So—
DEALISM.

We are after the
deal itself.



Not the bookkeeping.



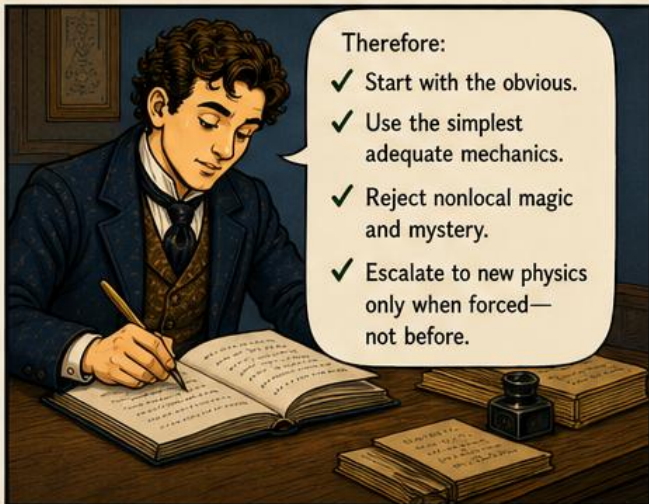
Not the appearances.



Not the romance.

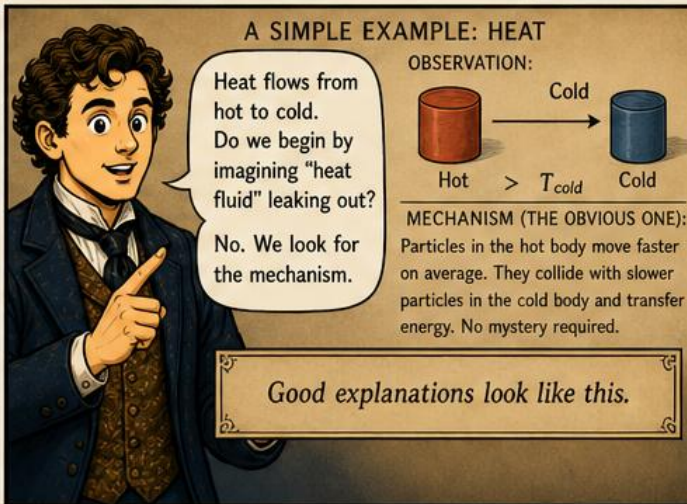


But the mechanisms
that produce the
phenomena.



Therefore:

- ✓ Start with the obvious.
- ✓ Use the simplest
adequate mechanics.
- ✓ Reject nonlocal magic
and mystery.
- ✓ Escalate to new physics
only when forced—
not before.

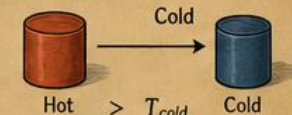


A SIMPLE EXAMPLE: HEAT

OBSERVATION:

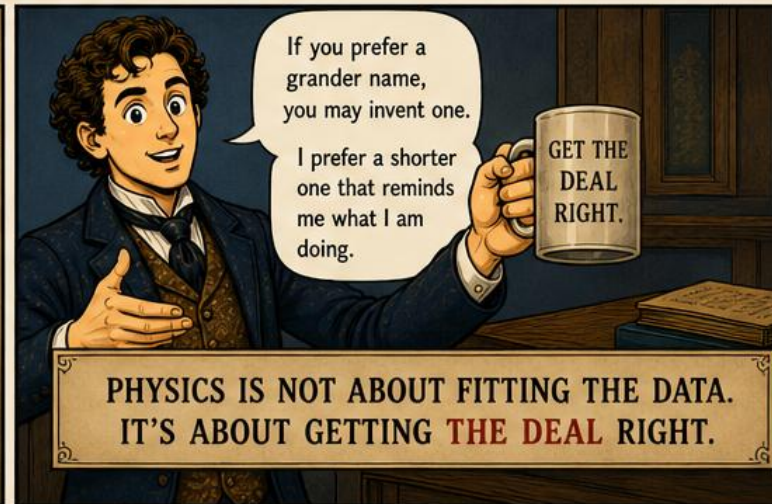
Heat flows from
hot to cold.
Do we begin by
imagining "heat
fluid" leaking out?

No. We look for
the mechanism.



MECHANISM (THE OBVIOUS ONE):
Particles in the hot body move faster
on average. They collide with slower
particles in the cold body and transfer
energy. No mystery required.

Good explanations look like this.



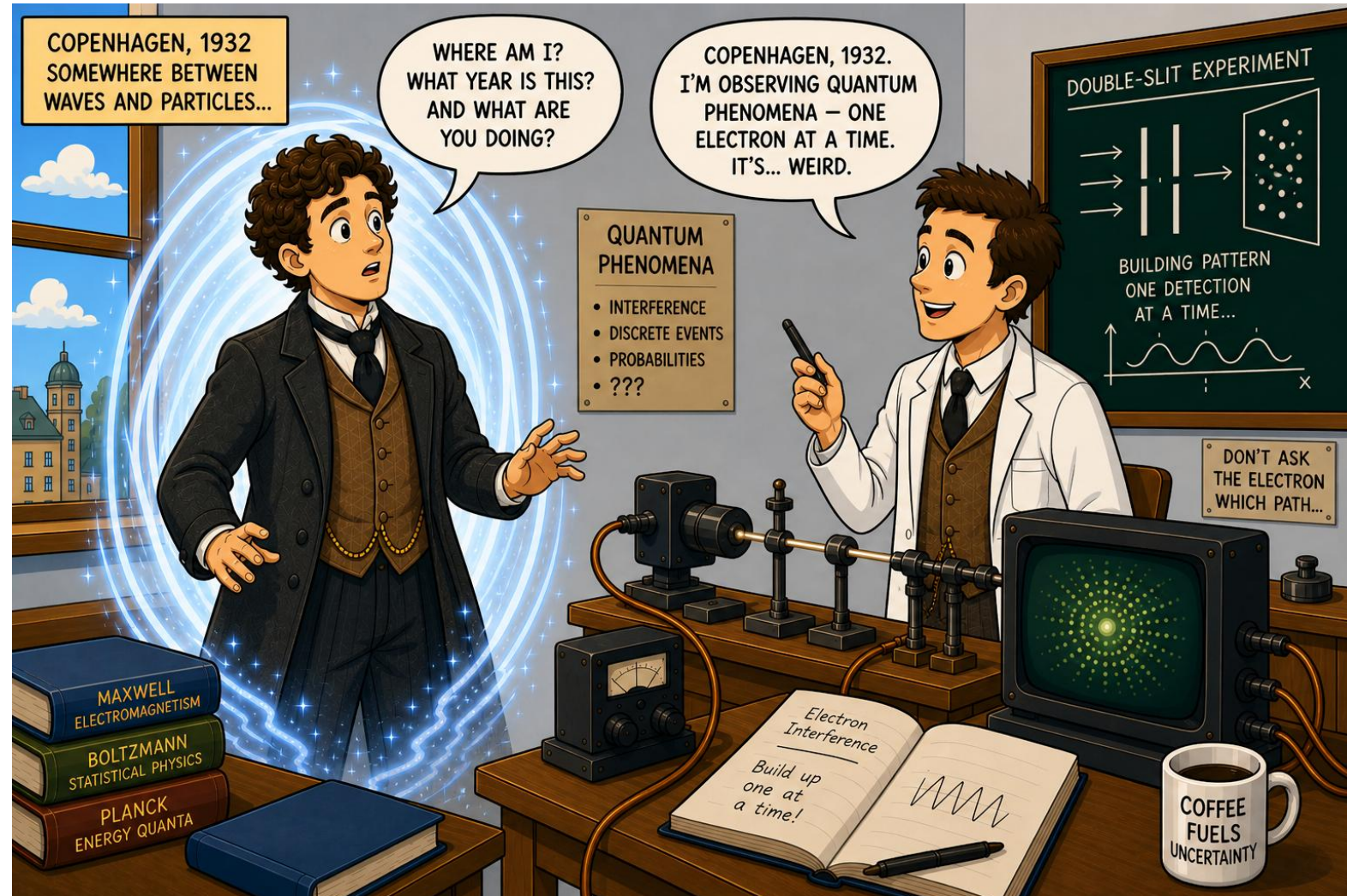
If you prefer a
grandier name,
you may invent one.

I prefer a shorter
one that reminds
me what I am
doing.

PHYSICS IS NOT ABOUT FITTING THE DATA.
IT'S ABOUT GETTING **THE DEAL** RIGHT.

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 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 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

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.

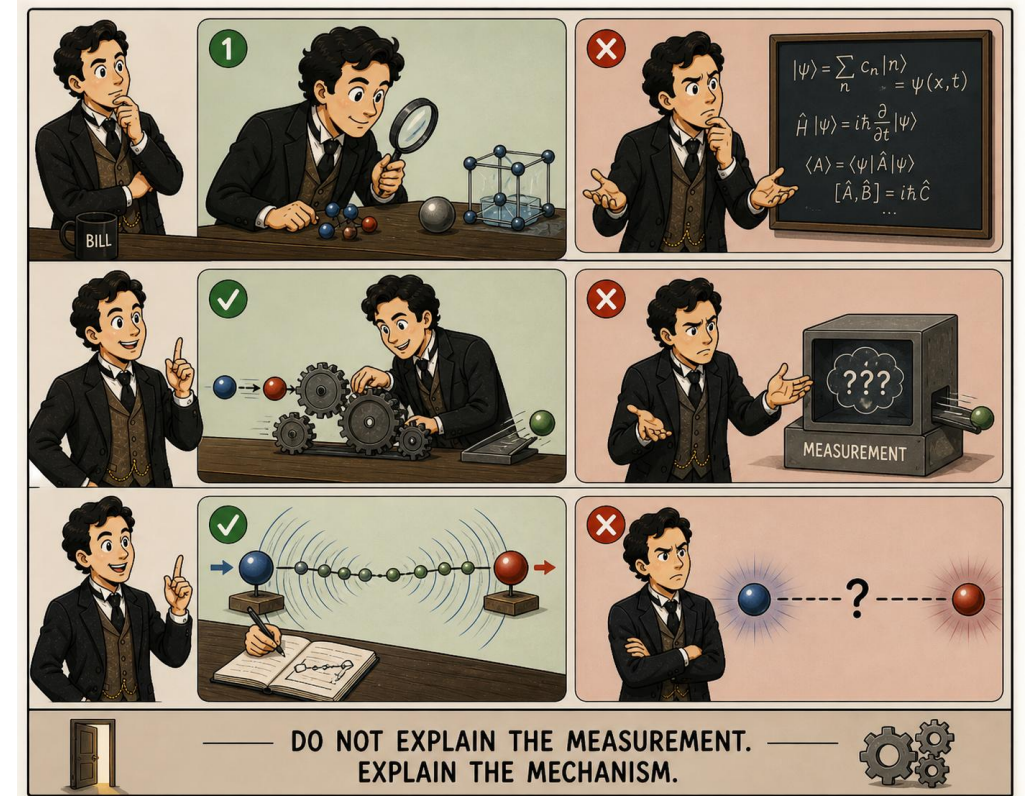
DO NOT EXPLAIN THE MEASUREMENT. EXPLAIN THE MECHANISM.

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”**



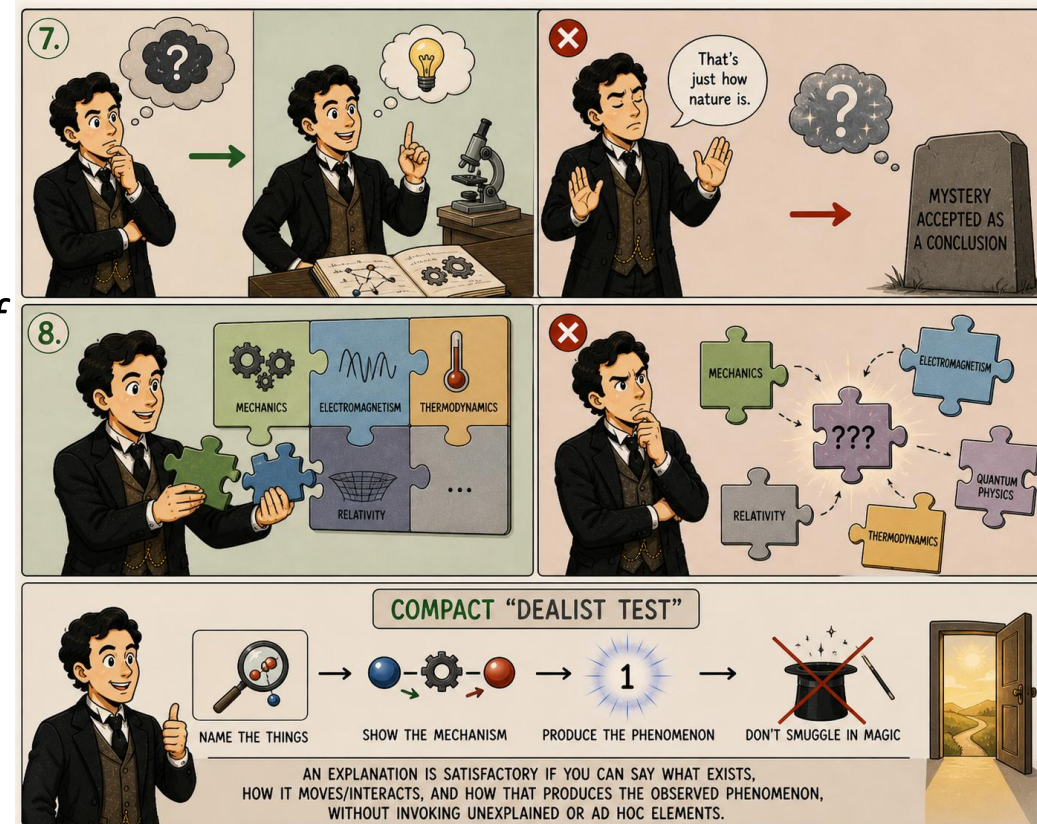
Dealist Criteria for Explanation

- **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

<h3>1. CLEAR ONTOLOGY</h3> <p>Physical entities with clear properties.</p>	<p>✓</p> <p>✗ "The wavefunction just is."</p> <p>Not a physical entity.</p>	<h3>2. MECHANISM</h3> <p>Interactions produce outcomes.</p>	<p>✓</p> <p>✗ "Collapse upon measurement."</p> <p>No mechanism shown.</p>	<h3>3. LOCALITY / STRUCTURED MEDIATION</h3> <p>Influence propagates through a field.</p>	<p>✓</p> <p>✗ Instantaneous nonlocal correlations.</p> <p>Unexplained spooky action.</p>	<h3>4. EMPIRICAL ADEQUACY</h3> <p>Matches observed phenomena.</p>	<p>✓</p> <p>✗ Predicts unobserved macroscopic superpositions.</p> <p>Not empirically adequate.</p>
<h3>5. EXPLANATORY PRIORITY OVER FORMAL FIT</h3> <p>Equations derived from mechanism.</p>	<p>✓</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>	<h3>6. SIMPLICITY AS A STARTING POINT</h3> <p>Use known physics. Escalate only if needed.</p>	<p>✓</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>	<h3>7. NO MYSTERY AS A STOPPING POINT</h3> <p>Strangeness = signal. Leads to research.</p>	<p>✓</p> <p>✗ Mystery treated as final answer.</p>	<h3>8. UNITY</h3> <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

✗

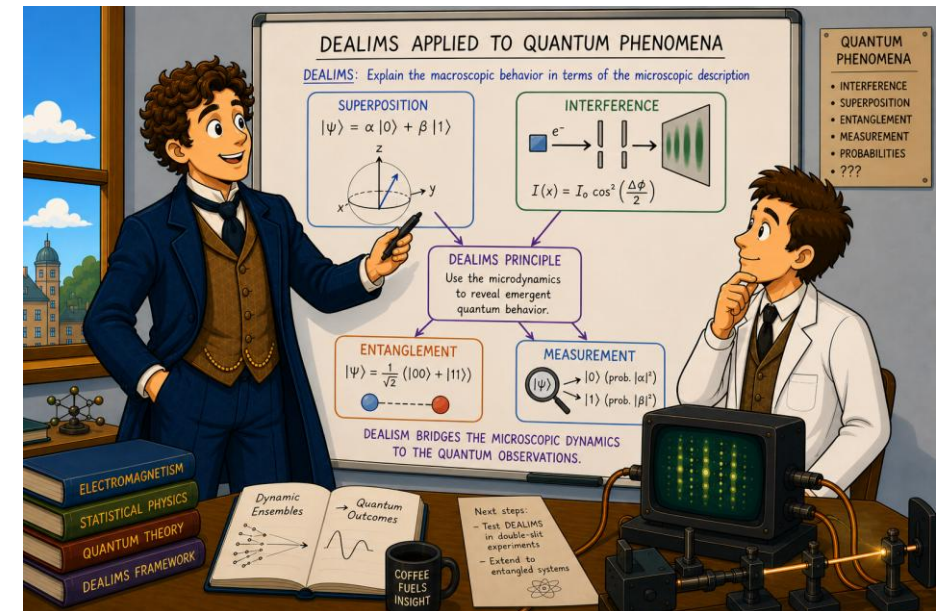
STANDARD QUANTUM MECHANICS DOES NOT FULLY PASS THE DEALIST TEST.

A DEALIST ALTERNATIVE – WHAT WE SEEK

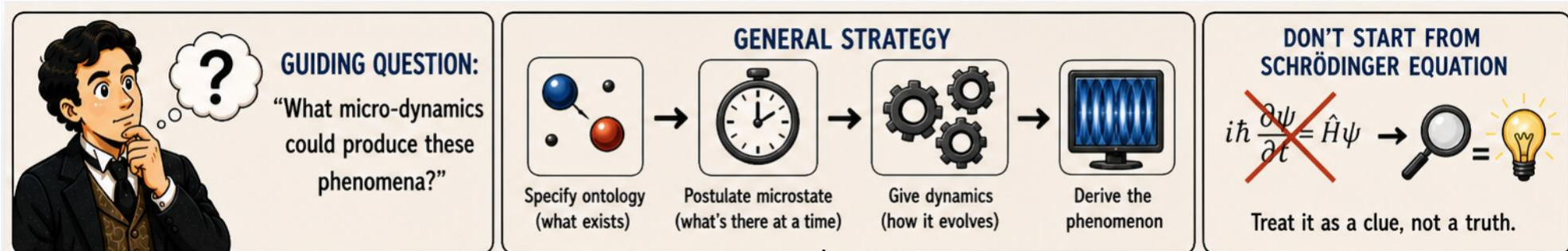
✓ EXPLAIN QUANTUM PHENOMENA BY NAMING THE THINGS, SHOWING THE MECHANISM, AND PRODUCING THE OUTCOMES – NO MAGIC.

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”



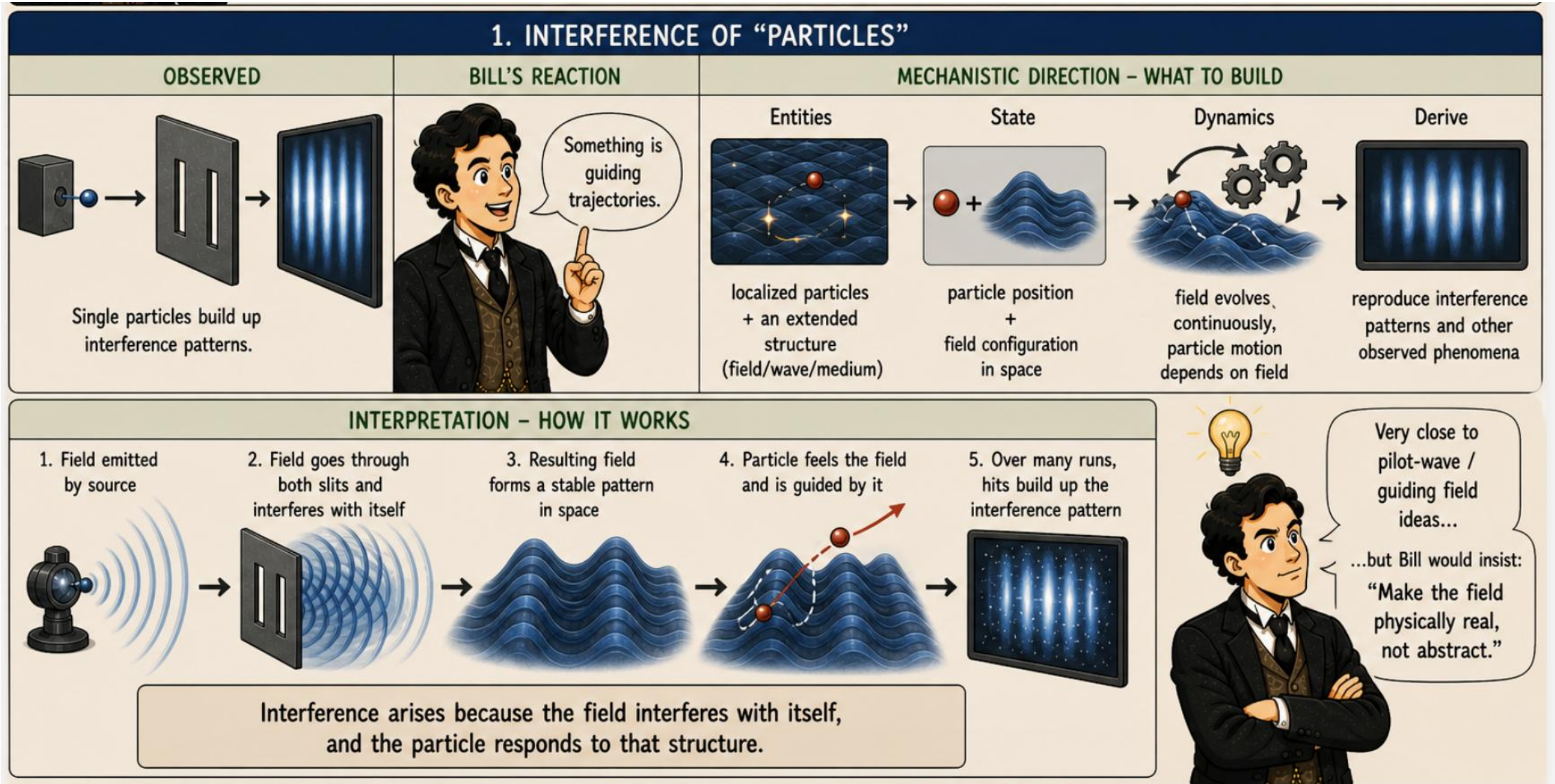
The Dealist's Program for Quantum Phenomena



- 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**

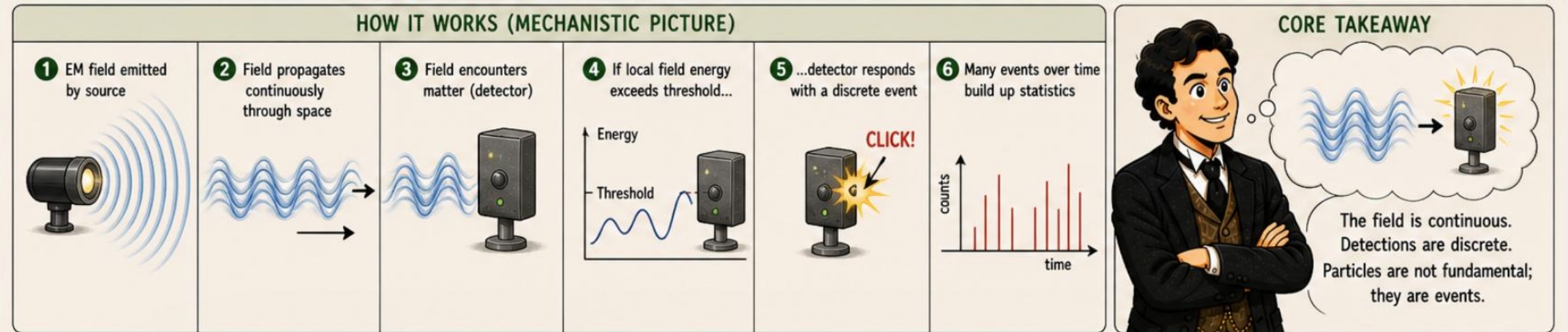
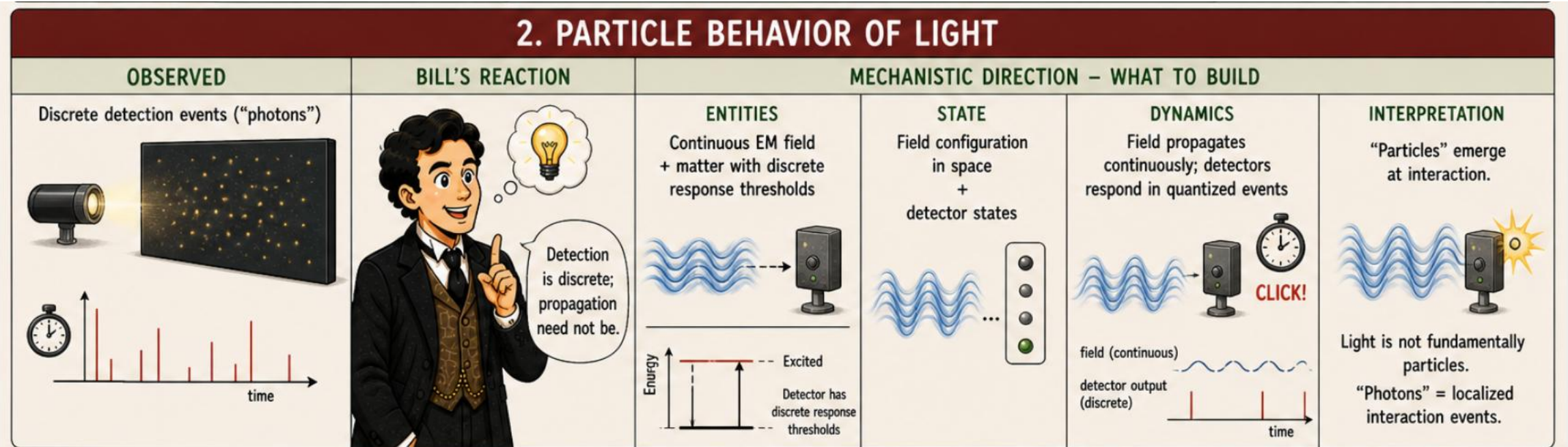
The Dealist's Program for Quantum Phenomena

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



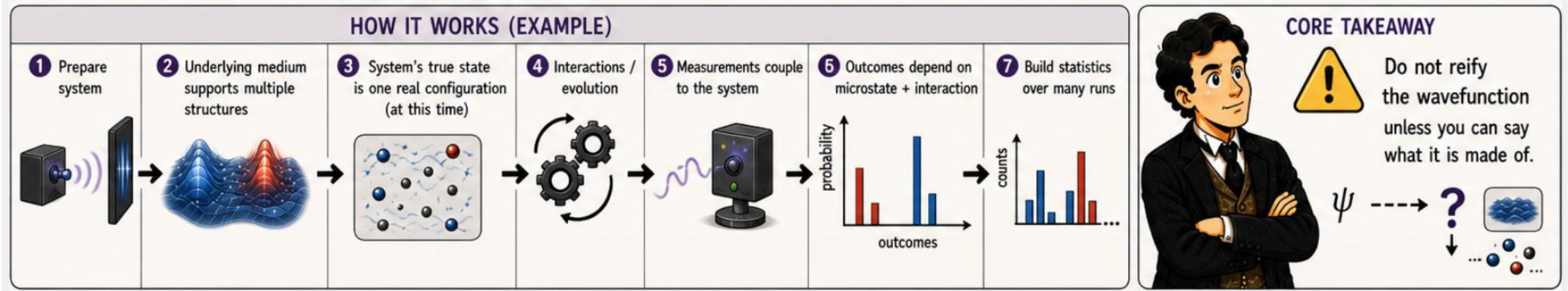
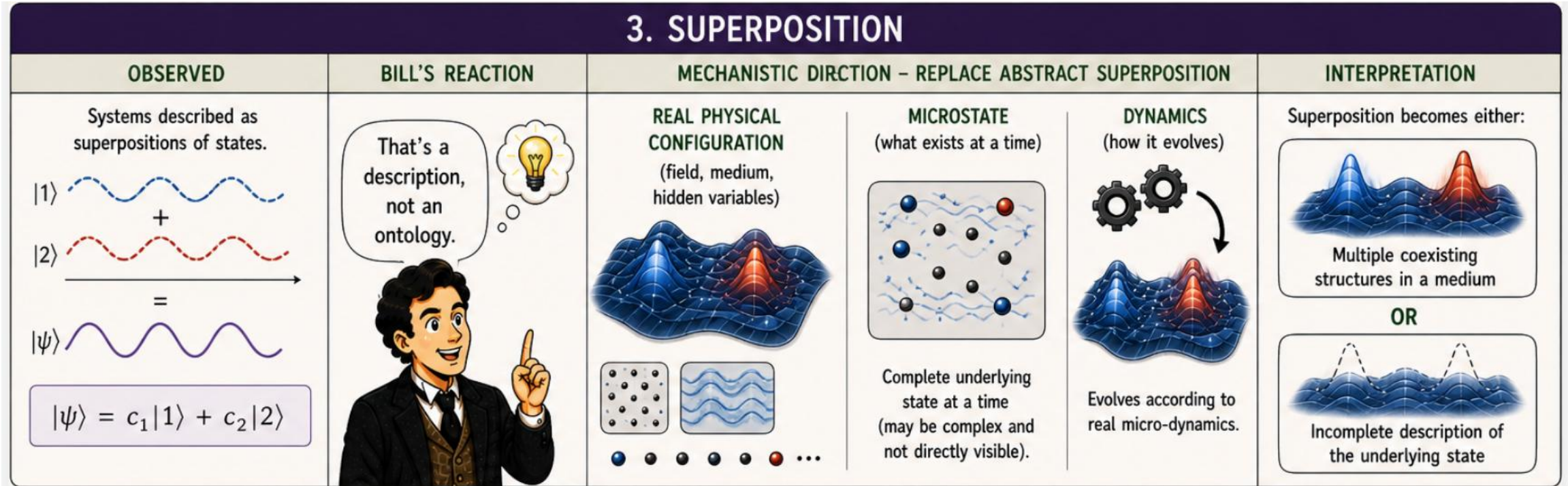
The Dealist's Program for Quantum Phenomena

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



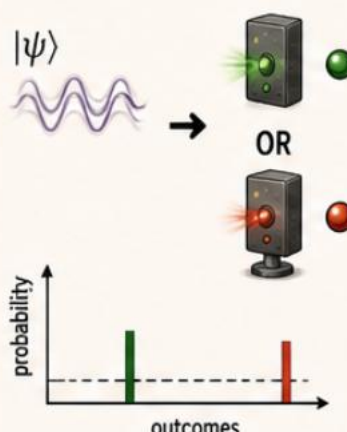

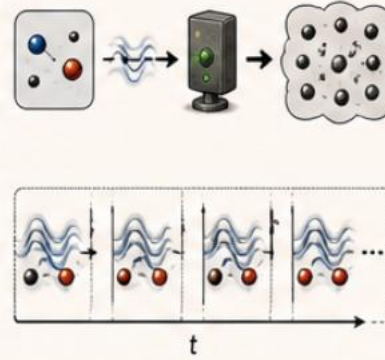
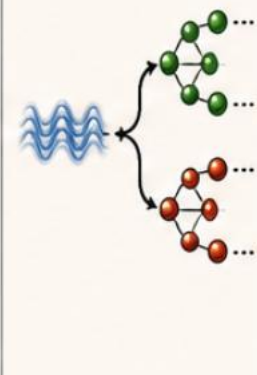
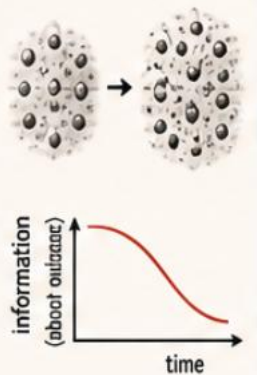
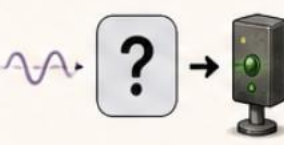
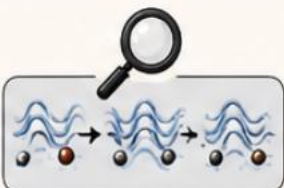
The Dealist's Program for Quantum Phenomena

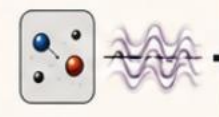
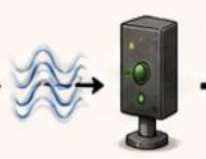
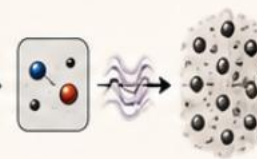
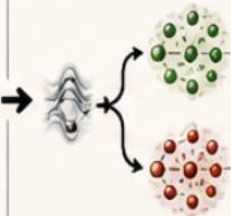

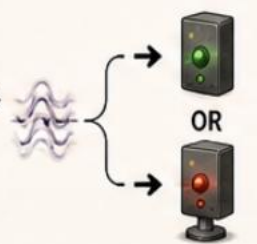

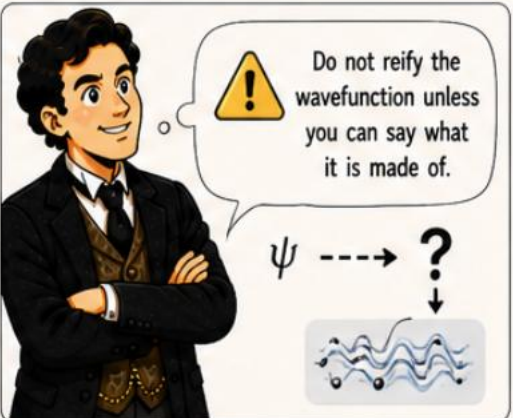
- Guiding question: "What **micro-dynamics** could produce these phenomena?"



The Dealist's Program for Quantum Phenomena

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



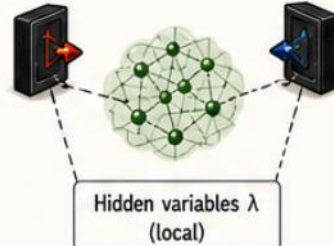
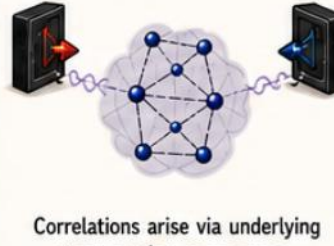
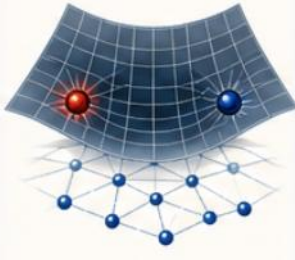


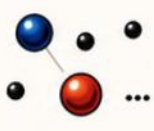
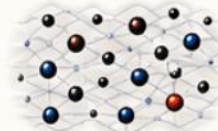

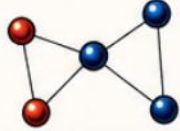
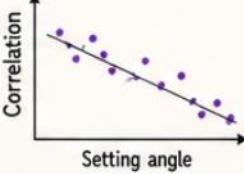


4. COLLAPSE						
OBSERVED	STANDARD MOVE	BILL'S REACTION	MECHANISTIC REQUIREMENT – WHAT TO BUILD		INTERPRETATION	
<p>Definite outcomes appear.</p> 	<p>Collapse as a primitive process.</p> $ \psi\rangle \rightarrow o_i\rangle$ <p>↓</p> <p>POSTULATE</p> <p>No mechanism given.</p>	<p>Unacceptable. That's not a mechanism.</p> 	<p>1. CONTINUOUS DYNAMICS System + apparatus + environment evolve together.</p> 	<p>2. AMPLIFICATION Small differences get amplified.</p> 	<p>3. IRREVERSIBILITY Information disperses into environment (many d.o.f.).</p> 	<p>Collapse is effective, not fundamental.</p>  <p>A coarse-grained description of underlying dynamics.</p> 

HOW IT WORKS (EXAMPLE)						
<p>1 Initial superposition in system</p> 	<p>2 Interaction with apparatus</p> 	<p>3 Entanglement: correlations spread</p> 	<p>4 Amplification: branches emerge</p> 	<p>5 Irreversibility: information disperses</p> 	<p>6 Outcome appears definite (limit of effective theory)</p> 	<p>7 We record a single result</p> 
						

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: #f2f2f2;"> <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="text-align: center; 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="text-align: center; margin-top: 10px;">Because it violates locality & intelligible mechanism.</p>	<p>OPTION A: HIDDEN LOCAL STRUCTURE Deeper variables restoring locality, but must evade Bell constraints (hard).</p>  <p style="text-align: center; margin-top: 10px;">Must reproduce all correlations without faster-than-light influence.</p>	<p>OPTION B: MEDIATED NONLOCALITY Nonlocality is not instantaneous magic, but due to deeper structure (e.g. connectivity, constraints).</p>  <p style="text-align: center; margin-top: 10px;">Correlations arise via underlying structure that spans space.</p> <p style="text-align: center; margin-top: 10px;">No instantaneous action, but nonlocal connections exist.</p>	<p>OPTION C: MODIFY SPACETIME Locality is emergent. Underlying structure of reality is different.</p>  <p style="text-align: center; margin-top: 10px;">Correlations explained by deeper structure; locality emerges at large scales.</p>	<p style="text-align: center; color: red; font-weight: bold;">✗ Collapse across space instantly.</p>  <hr/> <p style="text-align: center; color: red; font-weight: bold;">✗ 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". 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>														


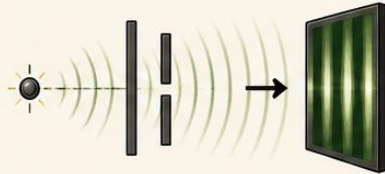

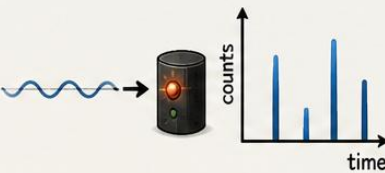

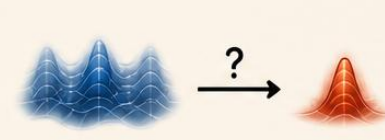
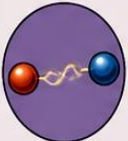
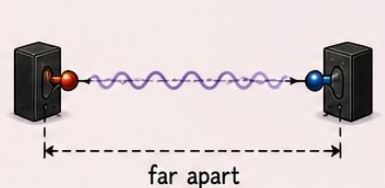
The Dealist's Program for Quantum Phenomena



- 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”


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

 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

- Which ones actually meet Bill’s criteria for a mechanism? The Dealist scorecard
- Bill’s verdict: “This is not a theory. It is a set of instructions” - Total failure by dealist standards




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



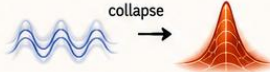
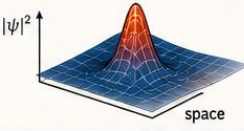

→

Measurement
(Interaction)


→


Outcome


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

<p style="text-align: center; font-weight: bold;">1. ONTOLOGY (What exists?)</p> <p style="font-size: x-small;">No claim about an underlying reality. Wavefunction is not a physical thing; it encodes knowledge about the system.</p> <div style="text-align: center; margin: 10px 0;"> 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 style="text-align: center; font-weight: bold;">2. DYNAMICS (How it evolves?)</p> <p style="font-size: x-small;">Between measurements, systems evolve unitarily according to the Schrödinger equation.</p> <div style="text-align: center; margin: 10px 0;"> $i\hbar \frac{\partial \psi}{\partial t} = \hat{H}\psi$  </div> <div style="border: 1px solid gray; padding: 2px; font-size: x-small; text-align: center;">Deterministic evolution of the wavefunction.</div>	<p style="text-align: center; font-weight: bold;">3. MEASUREMENT / COLLAPSE (What happens?)</p> <p style="font-size: x-small;">When a measurement occurs, the wavefunction collapses instantaneously and randomly to an eigenstate.</p> <div style="text-align: center; margin: 10px 0;">  </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 style="text-align: center; font-weight: bold;">4. VIEW OF THE WAVEFUNCTION (What is ψ?)</p> <p style="font-size: x-small;">A mathematical tool for predicting probabilities of outcomes.</p> <p style="font-size: x-small;">$\psi ^2 \rightarrow$ probability density</p> <div style="text-align: center; margin: 10px 0;">  </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 style="text-align: center; font-weight: bold;">5. KEY IDEA IN ONE LINE</p> <div style="text-align: center; margin: 10px 0;">  </div> <p style="font-size: x-small; 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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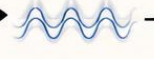
HOW A TYPICAL EXPERIMENT LOOKS

Prepare




Initial state $|\psi_0\rangle$

Evolve



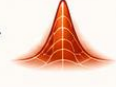
Unitary evolution

Measure




Interaction with apparatus

Collapse



Random outcome is realized

Record



One result in the experimental record

STRENGTHS AND LIMITATIONS

✓ STRENGTHS

- Extremely successful at predicting all experimental results.
- Conceptually minimalist.
- No unobservables needed.

✗ LIMITATIONS (Bill’s view)

- Avoids the question of *what reality is*.
- Collapse postulate lacks a mechanism.
- Measurement problem remains unresolved.
- Unsatisfying for a theory of nature.

💡 **Bottom line:** Copenhagen gives excellent predictions, but remains silent about the underlying reality and how collapse happens.

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“Usual” Solutions of the Measurement Problem

- Which ones actually meet Bill’s criteria for a mechanism? The Dealist scorecard
- Bill’s verdict: “You have abandoned the problem” - Not even in the game (anti-realist)



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 style="text-align: center;">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="text-align: center; border: 1px solid black; padding: 2px;">QBism is silent about what exists “out there”.</p>	<p style="text-align: center;">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; border: 1px solid black; padding: 2px;">Evolution is belief updating, not physical change.</p>	<p style="text-align: center;">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;">Agent acts (measurement) Agent experiences an outcome</p> <p style="text-align: center; border: 1px solid black; padding: 2px;">No collapse in the world—only an experience for the agent.</p>	<p style="text-align: center;">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; border: 1px solid black; padding: 2px;">A bookkeeping tool for the agent’s expectations.</p>	<p style="text-align: center;">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="text-align: center; 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)

1. Prior beliefs 2. Choose measurement 3. Experience outcome 4. Update beliefs 5. Plan next action

Agent assigns probabilities Agent decides what information to seek Agent has one experience Use quantum rules (Born + Bayes) Agent chooses next measurement

Repeat: learning is continual and personal.


STRENGTHS AND LIMITATIONS

<p style="text-align: center;">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 style="text-align: center;">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.

“Usual” Solutions of the Measurement Problem

- Which ones actually meet Bill’s criteria for a mechanism? The Dealist scorecard
- GRWm - Bill’s verdict: “You have replaced one mystery with another” -Collapse is still **primitive magic**, just legalized - **Fails mechanism criterion**



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.

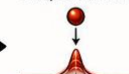
IN ONE PICTURE

Superposition




System evolves unitarily

Spontaneous collapse (random)



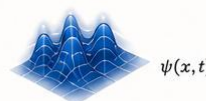
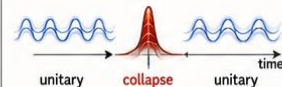
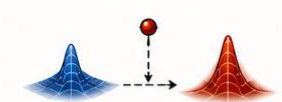

Wavefunction collapses locally

Definite outcome



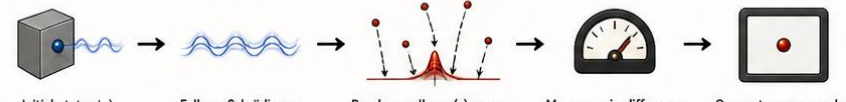
Macroscopic world displays one result

No observer or measurement is needed for collapse.

1. ONTOLOGY (What exists?)	2. DYNAMICS (How it evolves?)	3. MEASUREMENT / OUTCOME (What happens?)	4. VIEW OF THE WAVEFUNCTION (What is ψ ?)	5. KEY IDEA IN ONE LINE
The wavefunction ψ is a real physical field in 3D space. It describes the actual state of systems.  <p style="text-align: center;">$\psi(x, t)$</p> <div style="background-color: #e8f5e9; padding: 5px; text-align: center; margin-top: 5px;"> Real wavefunction in physical space. </div>	Between collapses, ψ evolves unitarily (Schrödinger equation). At random times, a collapse occurs at a random location. $i\hbar \frac{\partial \psi}{\partial t} = \hat{H}\psi$  <div style="display: flex; justify-content: space-around; font-size: small;"> unitary collapse unitary </div> <div style="background-color: #e8f5e9; padding: 5px; text-align: center; margin-top: 5px;"> Stochastic modification of Schrödinger evolution. </div>	Outcomes arise from spontaneous collapses of the wavefunction. Macroscopic definiteness results from the accumulation of many tiny collapses.  <p style="text-align: center;">Repeated random collapses select one outcome.</p> <div style="background-color: #e8f5e9; padding: 5px; text-align: center; margin-top: 5px;"> Collapse is objective, real, and observer-independent. </div>	ψ is a real field in 3D space. It can be in superposition, but is subject to spontaneous collapses described by GRW parameters. <div style="background-color: #e8f5e9; padding: 5px; font-size: x-small; margin-top: 5px;"> Typical GRW parameters Collapse rate (per particle): $\lambda \sim 10^{-16} \text{ s}^{-1}$ Collapse width: $r_c \sim 10^{-7} \text{ m}$ </div> <div style="background-color: #e8f5e9; padding: 5px; font-size: x-small; margin-top: 5px;"> Small effect for microscopic systems, large effect for macroscopic ones. </div> <div style="background-color: #e8f5e9; padding: 5px; text-align: center; margin-top: 5px;"> Real field + objective stochastic collapse law. </div>	 Reality = wavefunction in 3D space that sometimes collapses randomly. Definite outcomes emerge from the dynamics itself, without needing observers. <div style="background-color: #e8f5e9; padding: 5px; text-align: center; margin-top: 5px;"> Spontaneous collapses make the world definite. </div>

HOW A TYPICAL EXPERIMENT LOOKS (GRW VIEW)

1. Prepare system
2. Unitary evolution
3. Spontaneous collapse(s)
4. Amplification
5. Definite outcome



Initial state ψ_0
Follows Schrödinger equation
Random collapse(s) occur in space and time
Macroscopic difference is amplified
One outcome recorded

No observer required at any step.


STRENGTHS AND LIMITATIONS

STRENGTHS

- ✓ 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.

LIMITATIONS (Bill's view)

- ✗ 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.



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.

“Usual” Solutions of the Measurement Problem

- Which ones actually meet Bill’s criteria for a mechanism? The Dealist scorecard
- Bill’s verdict: “You have kept the equations and lost the explanation” - Predictive success ≠ mechanism - Fails explanatory clarity

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.

5. KEY IDEA IN ONE LINE

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
Follows Schrödinger equation

3. Interaction / branching
Entanglement creates branches

4. Decoherence
Branches become effectively independent

5. You observe
You experience one outcome in one branch

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

STRENGTHS AND LIMITATIONS

STRENGTHS	LIMITATIONS (Bill's view)
<ul style="list-style-type: none"> ✓ 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. 	<ul style="list-style-type: none"> ✗ 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.

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“Usual” Solutions of the Measurement Problem

- Which ones actually meet Bill’s criteria for a mechanism? The Dealist scorecard
- 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**

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.

1. ONTOLOGY (What exists?)

Matter exists as point particles with definite positions in 3D space.

The wavefunction is an objective, nomological entity (not a field) that encodes the interactions.

$\psi(x_1, x_2, \dots, x_N, t)$

Particles + nomological wavefunction.

2. MICROSTATE (What is the complete state?)

The complete state is:

- the wavefunction $\psi(x_1, \dots, x_N, t)$ (encodes interactions)
- the actual particle positions $(x_1(t), \dots, x_N(t))$

Microstate = (ψ, X)
 $X = (x_1, \dots, x_N)$

Deterministic and complete.

3. DYNAMICS (How it evolves?)

Two laws govern the evolution.

(1) Schrödinger equation for the wavefunction

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

(2) Guiding equation for particle velocities

$$\dot{X}_k = v_k^\psi(X, t)$$

(depends on ψ and all positions)

Clear laws. No collapse.

4. MECHANISM (How do outcomes arise?)

Particles follow continuous trajectories guided by ψ .

Interference arises from the structure of ψ acting on particle motion.

Interference explained mechanistically.

5. KEY IDEA IN ONE LINE

Particles have definite positions and follow precise trajectories that are guided by a nomological wavefunction encoding their interactions.

A clear, realistic, mechanistic picture of quantum phenomena.

HOW A TYPICAL EXPERIMENT WORKS (DOUBLE-SLIT EXAMPLE)

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.

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:

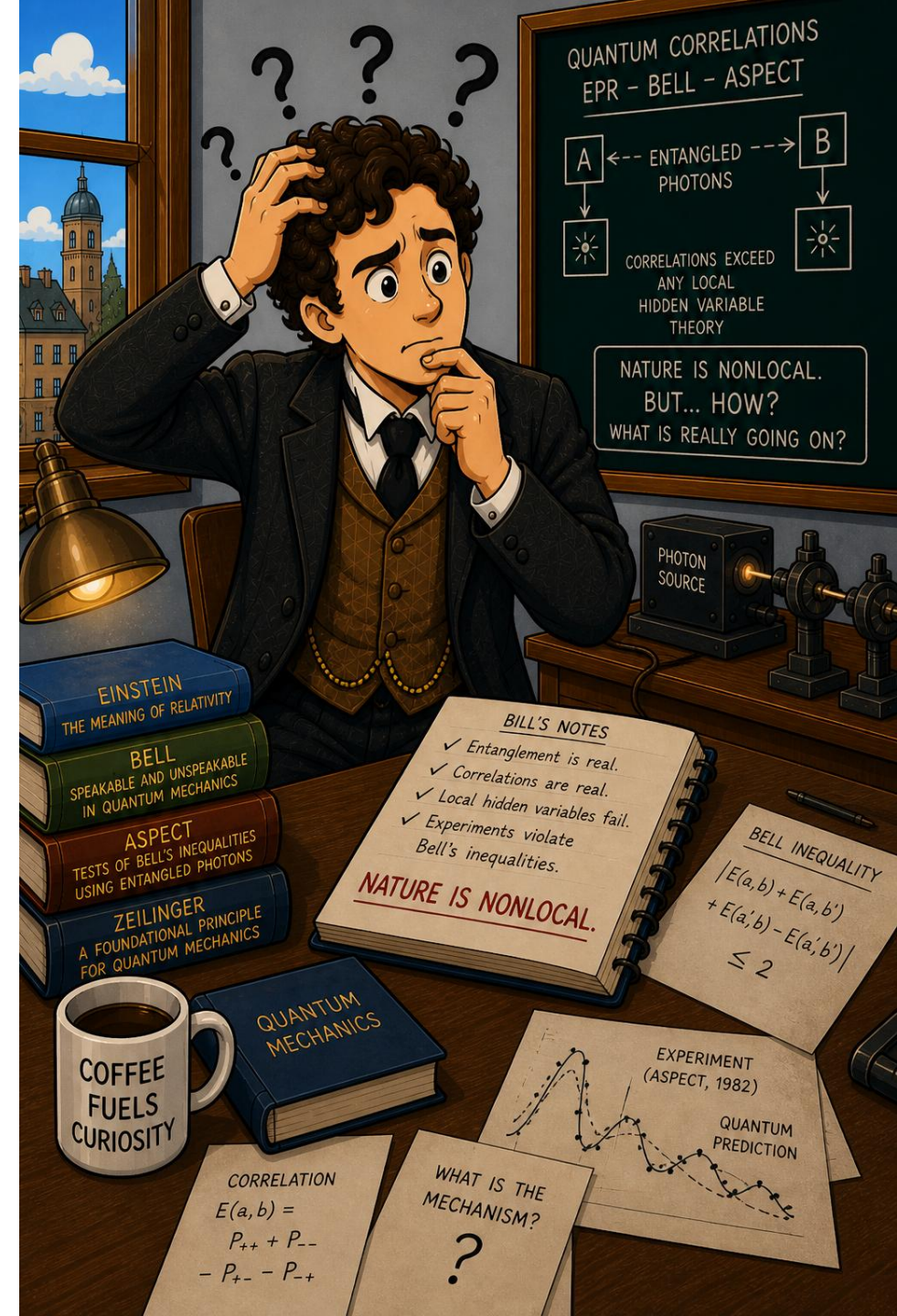
- Premise 1 (EPR+Bell): **Locality+ SQM** \rightarrow (EPR) \rightarrow hidden-variables \rightarrow (Bell) \rightarrow **new predictions**
 - Premise 2 (Aspect): **no new predictions**
 - Therefore, a local theory is empirically inadequate
- No theory can have:
 - Local interaction
 - Empirical adequacy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

• Options?



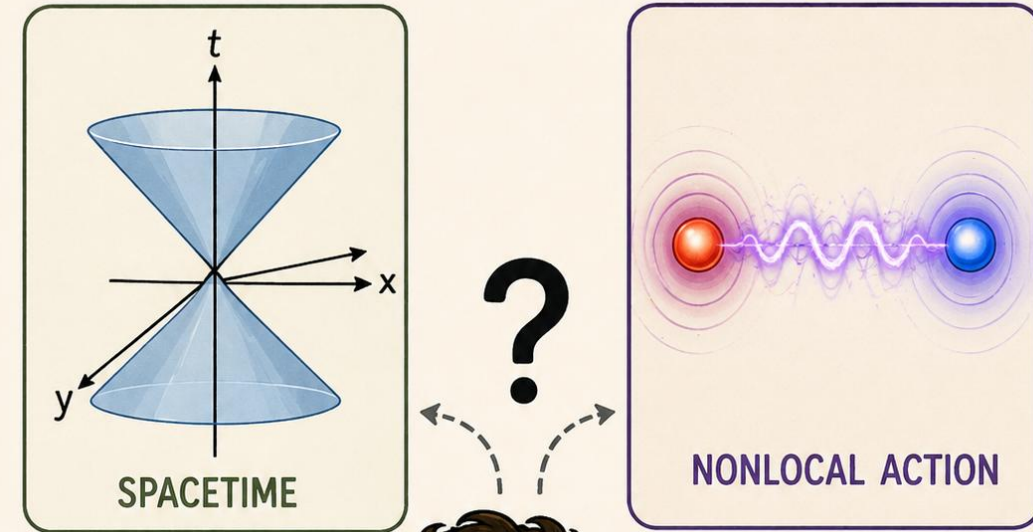
Options?

- **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 is compatible with QM which is nonlocal
- Bill wouldn't accept this... or would he?



Thank you!

