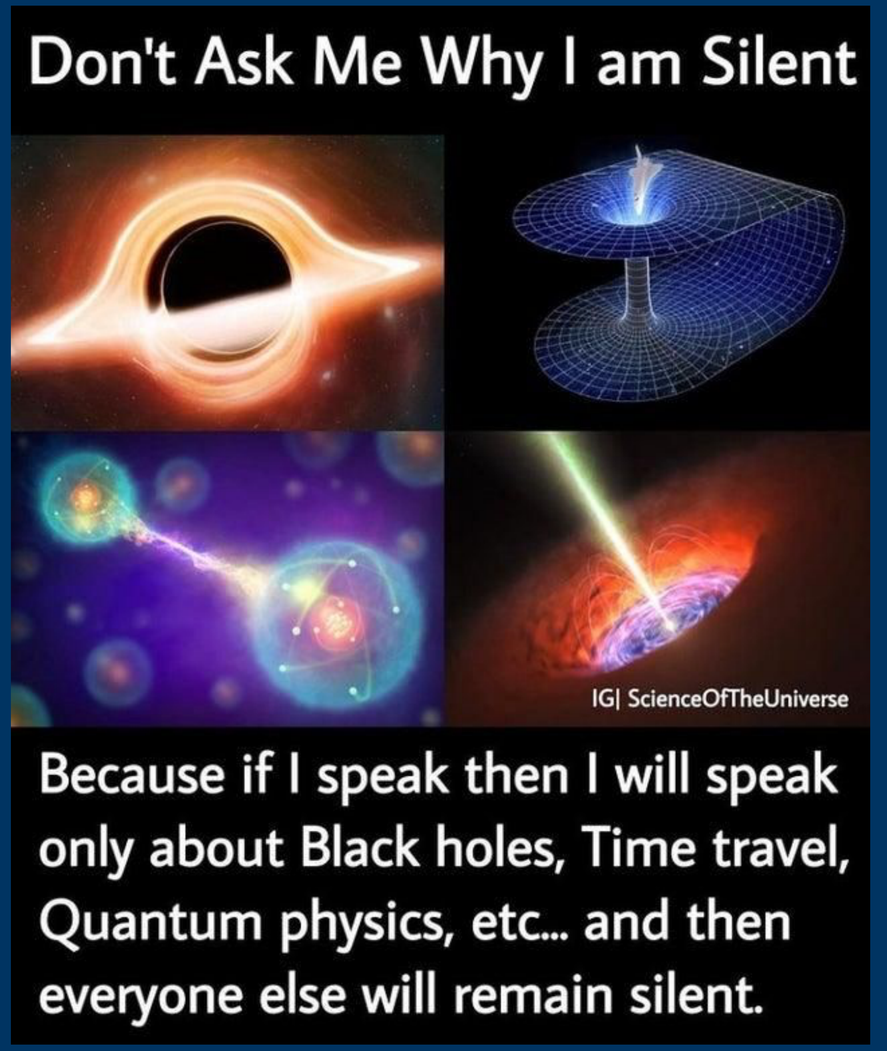
An Armchair Guide:

To Quantum Mechanics

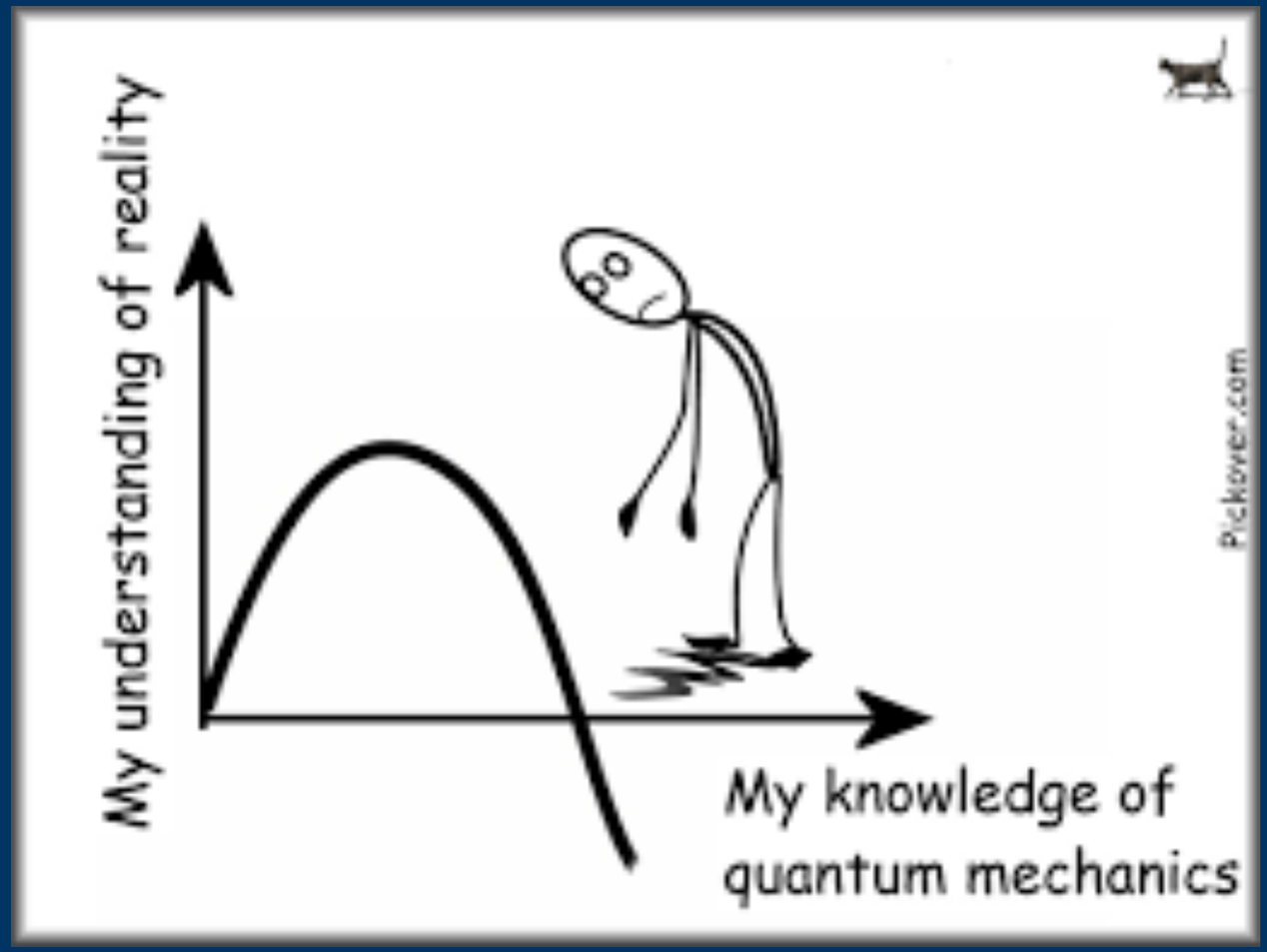


The Armchair Guide

Jonathan Allday

Session 5:

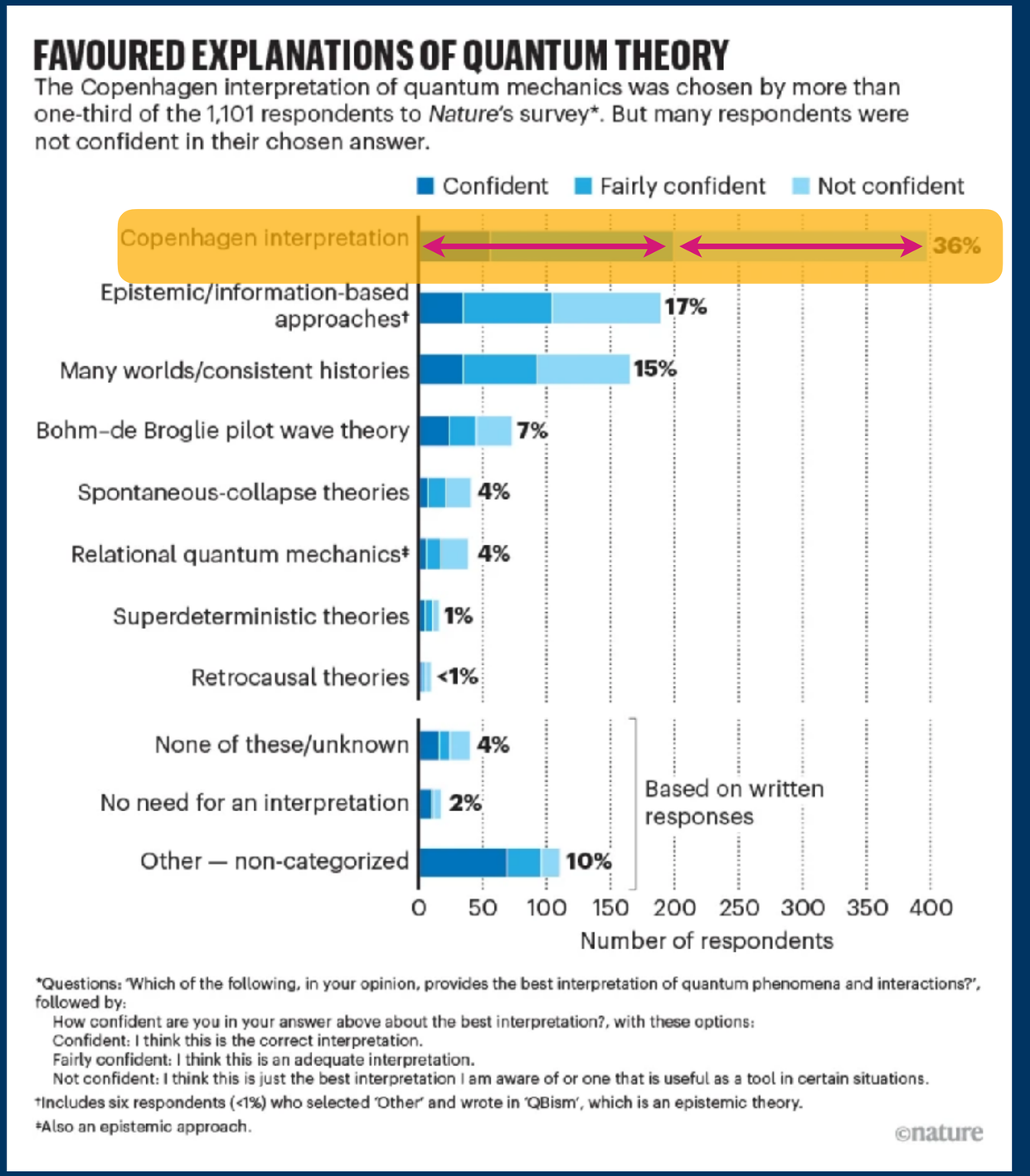
Interpretations



The popular view…

We e-mailed more than 15,000 researchers whose recent papers involved quantum mechanics, and also invited attendees of the centenary meeting, held on the German island of Heligoland, to take the survey.

The responses — numbering more than 1,100, mainly from physicists — showed how widely researchers vary in their understanding of the most fundamental features of quantum experiments.



*Questions: 'Which of the following, in your opinion, provides the best interpretation of quantum phenomena and interactions?', followed by:

How confident are you in your answer above about the best interpretation?, with these options:

Confident: I think this is the correct interpretation.

Fairly confident: I think this is an adequate interpretation.

Not confident: I think this is just the best interpretation I am aware of or one that is useful as a tool in certain situations.

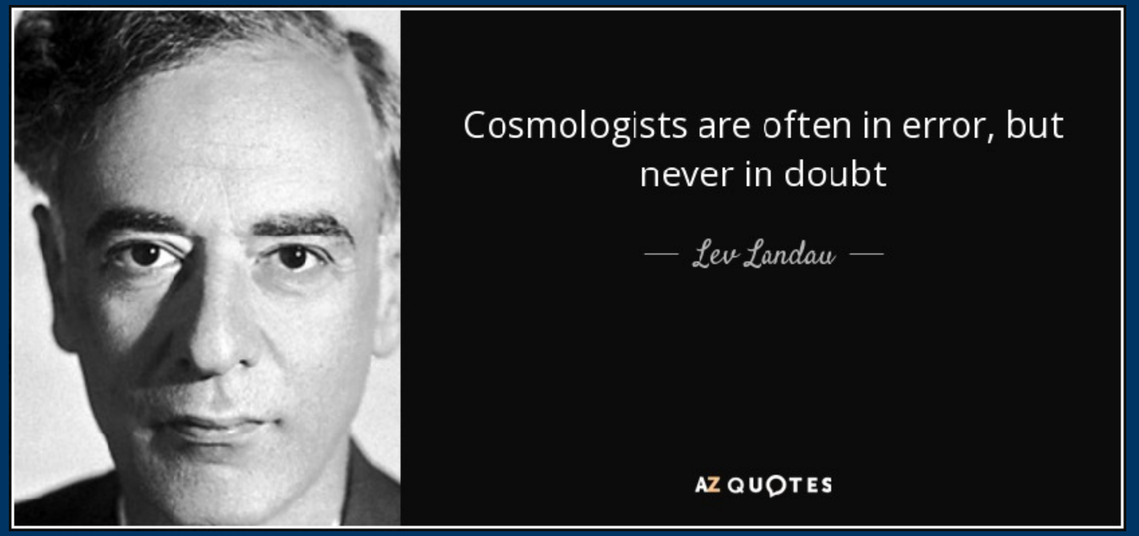
†Includes six respondents (<1%) who selected 'Other' and wrote in 'QBism', which is an epistemic theory.

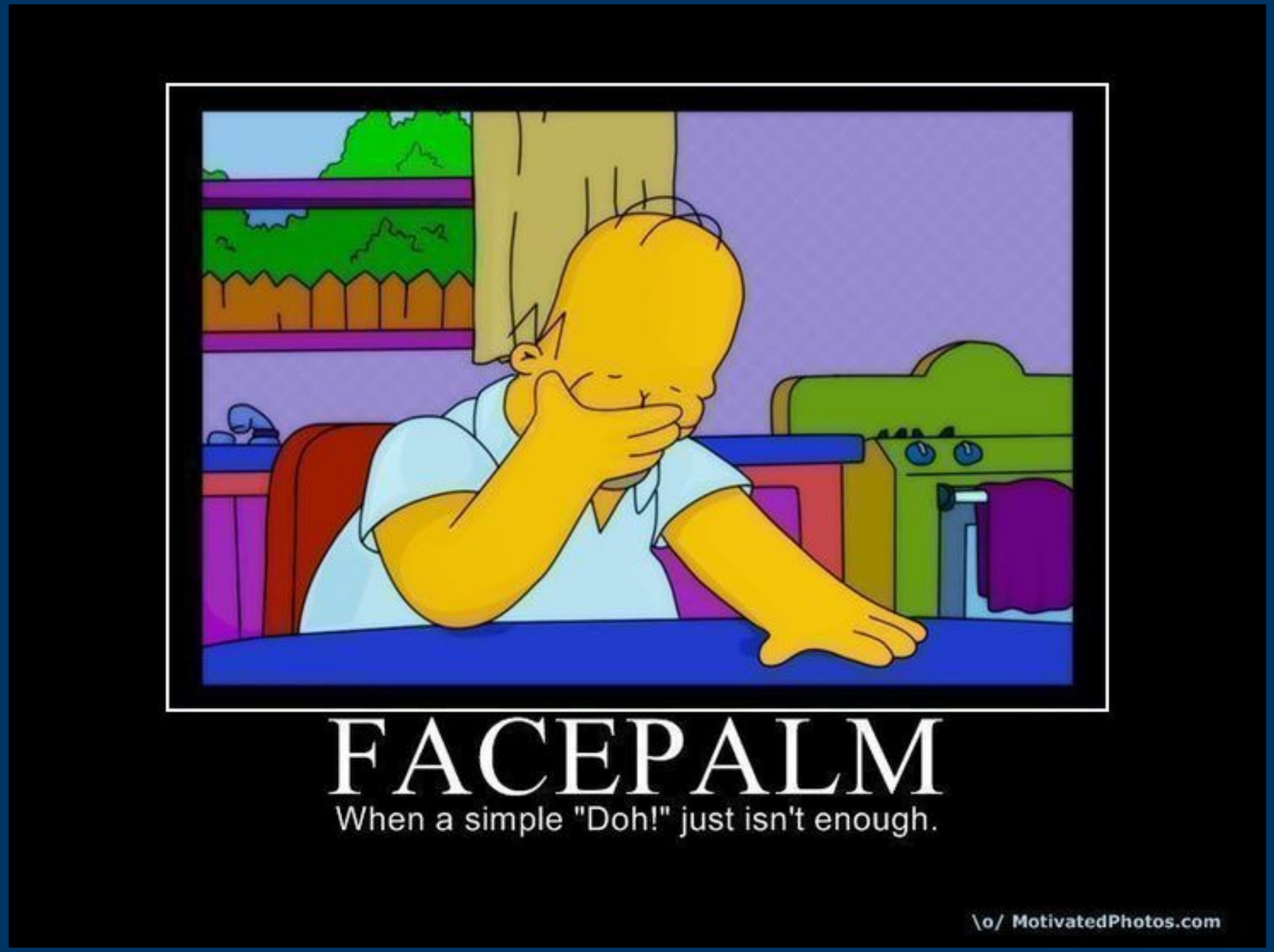
‡Also an epistemic approach.

Confidence limit

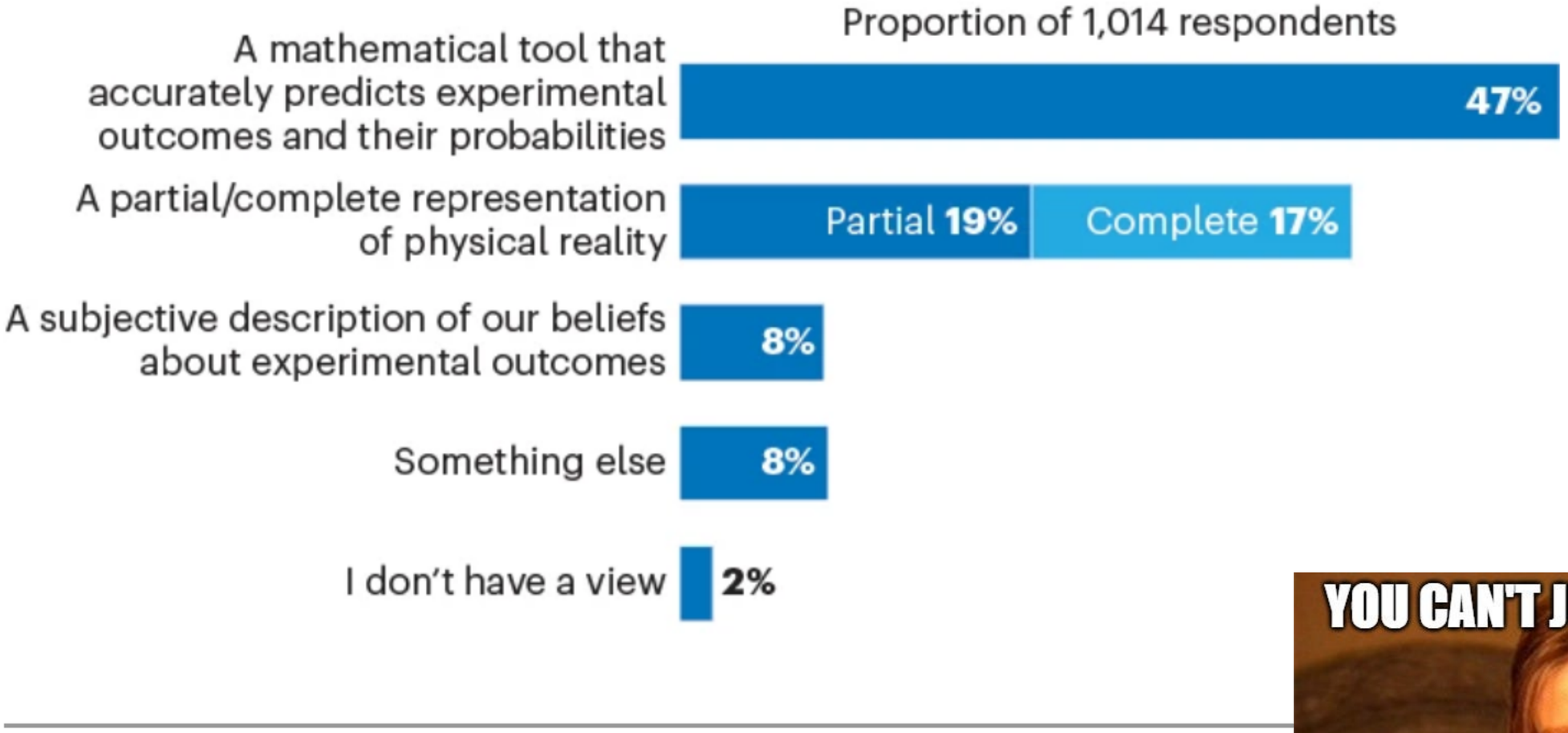
Asked about their confidence in their answer, only 24% of respondents thought their favoured interpretation was correct; others considered it merely adequate or a useful tool in some circumstances.

What's more, some scientists who seemed to be in the same camp didn't give the same answers to follow-up questions, suggesting inconsistent or disparate understandings of the interpretation they chose.

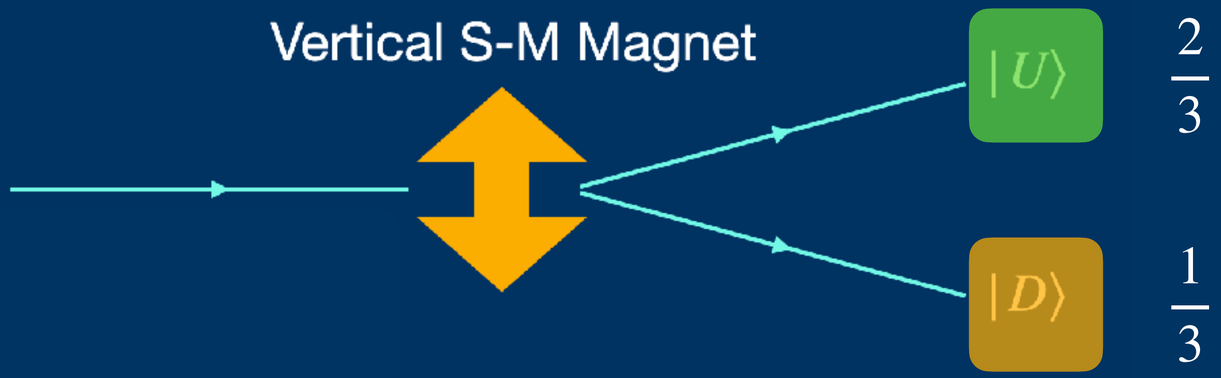



FACEPALM
When a simple "Doh!" just isn't enough.
\o/ MotivatedPhotos.com

WHAT IS THE WAVEFUNCTION?

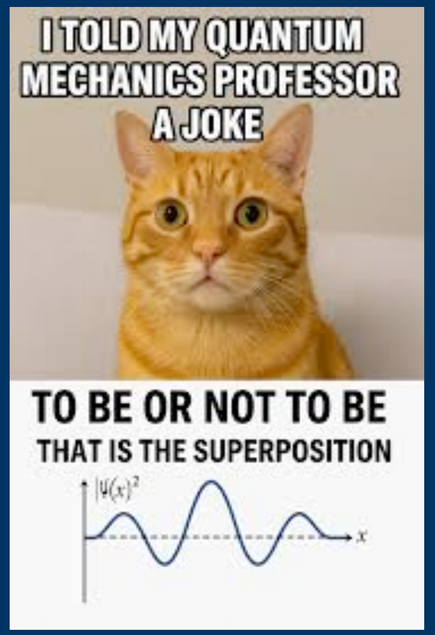


More on superpositions



Amplitudes

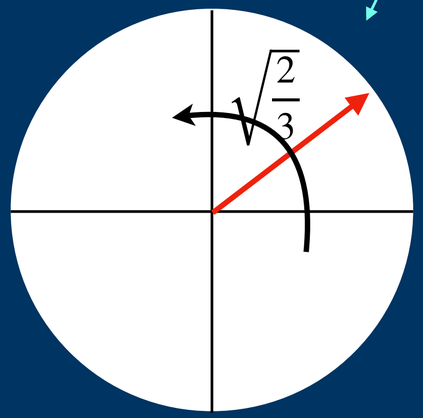
$$\Psi = \sqrt{\frac{2}{3}}|U\rangle + \sqrt{\frac{1}{3}}|D\rangle$$

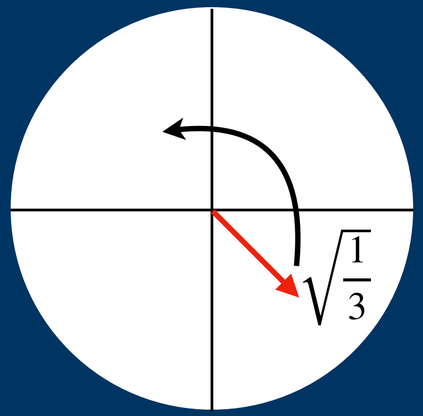


Each amplitude has a ‘phase’

Changes with time

At a rate that depends on energy…





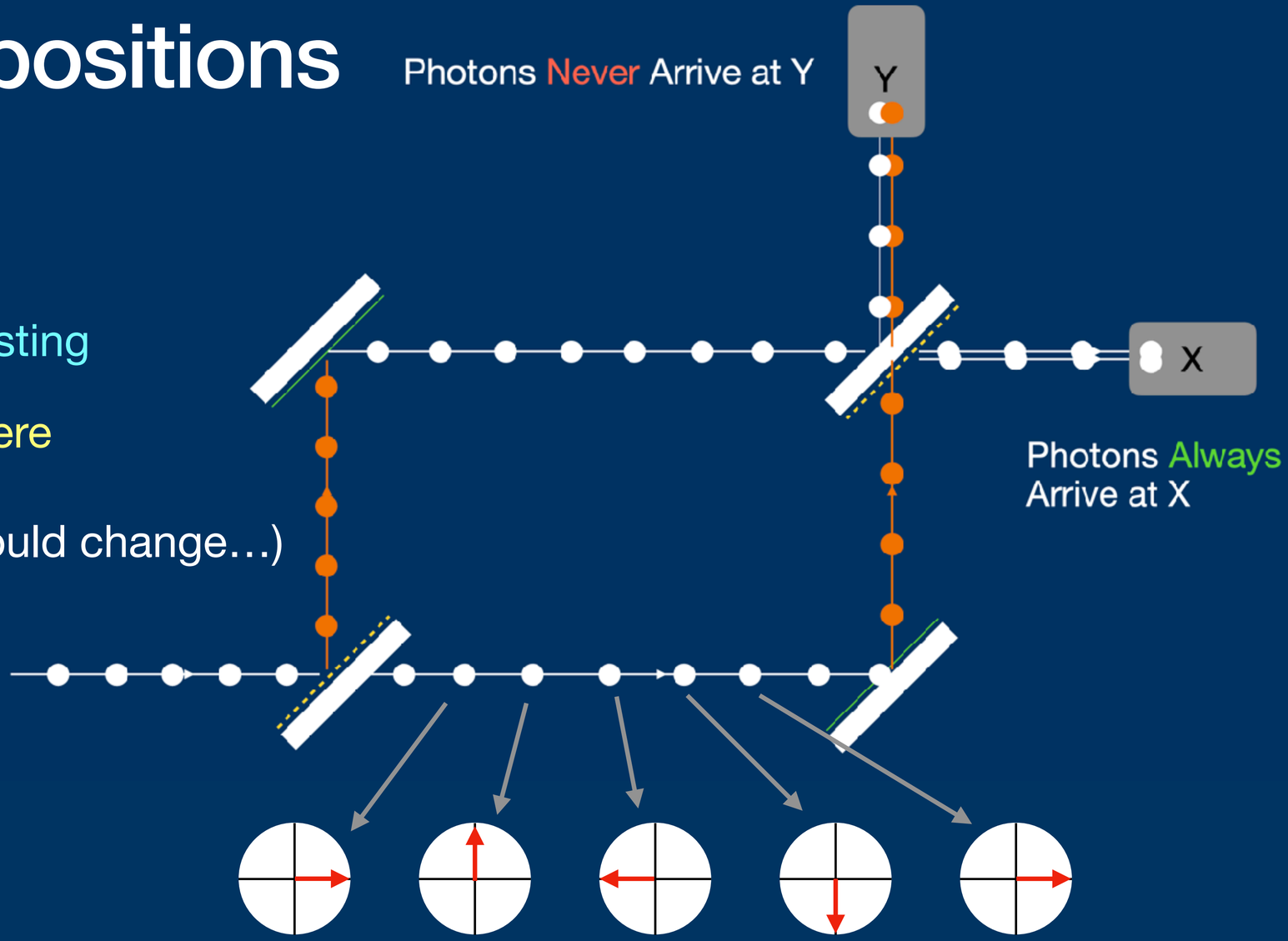
More on superpositions

At each point along ‘path’

Amplitude for a photon manifesting

If we were to put detector there

(But if we did the amplitude would change…)



Phase changes with position

As well as rotating with energy…

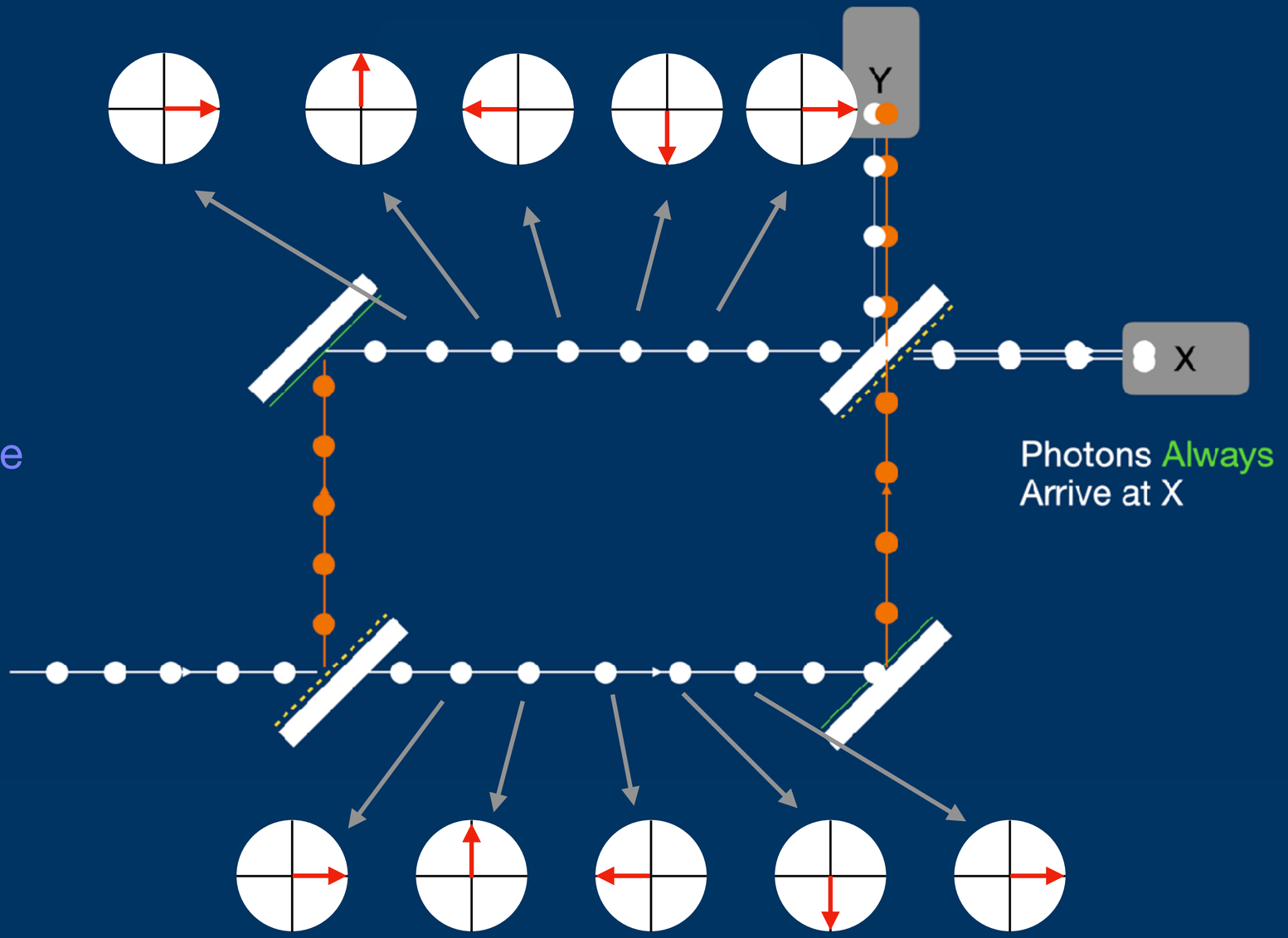
More on superpositions

Phase along the other ‘path’

While there is a fixed phase difference

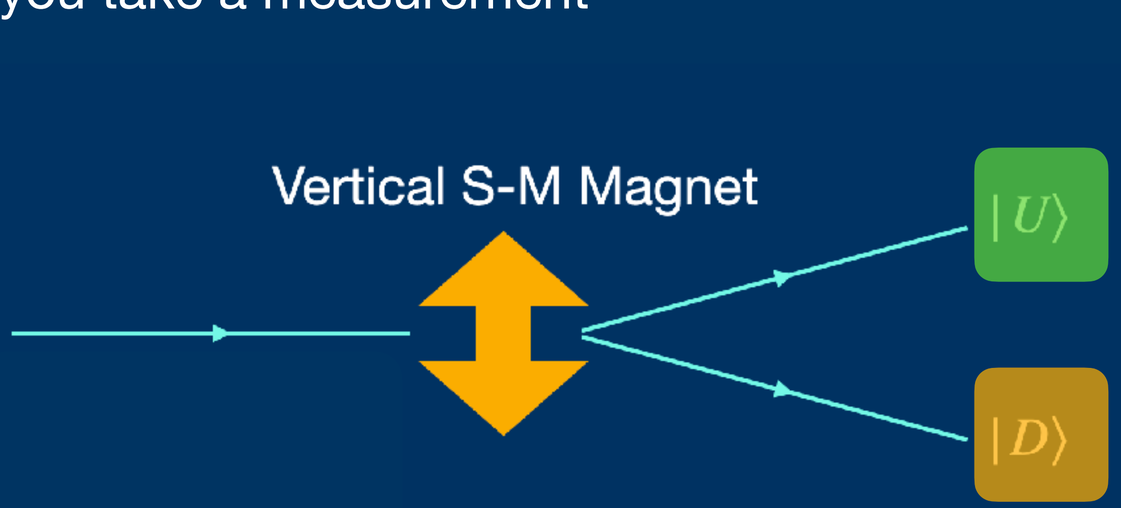
Between possibilities

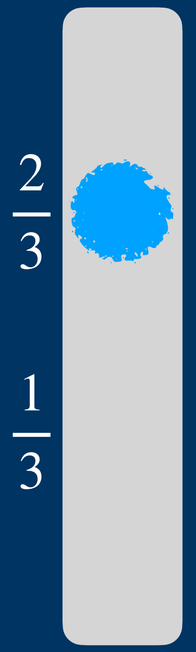
‘Interference’ takes place



And just like that…

When you take a measurement





This amplitude becomes 1

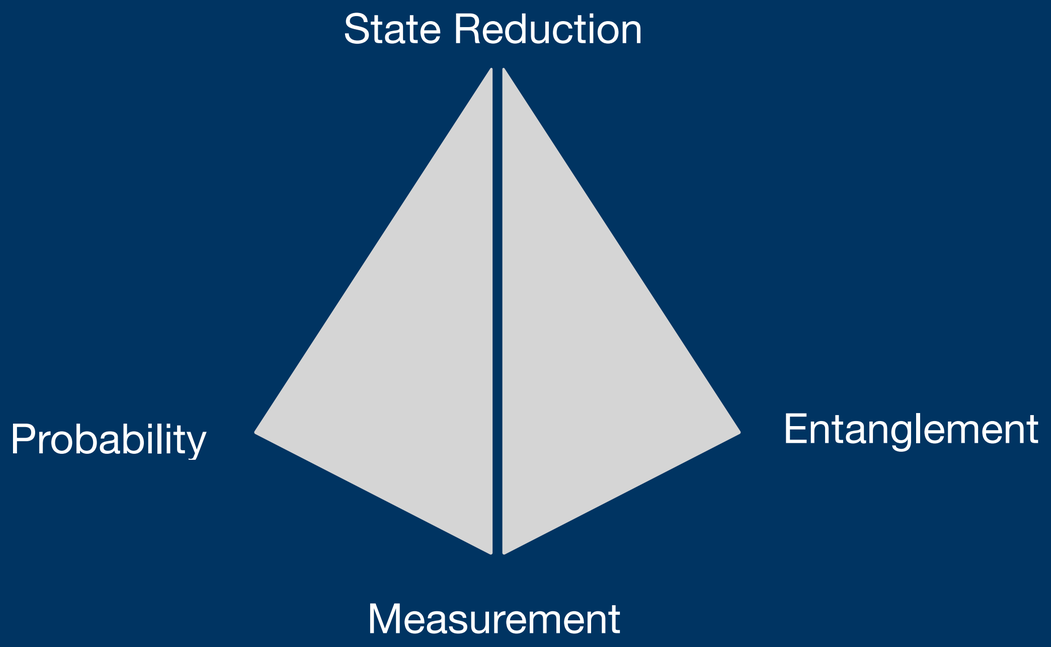
This amplitude becomes 0

$$\Psi = \sqrt{\frac{2}{3}}|U\rangle + \sqrt{\frac{1}{3}}|D\rangle \rightarrow |U\rangle$$

A quaternary of problems

However, in quantum theory another - and quite different - change of state can occur, and that is when measurements are made. This is the so-called reduction of the state vector, which is one of the four central problems around which most discussions of the interpretation of quantum theory take place.

Within either a pragmatic or a strict instrumentalist approach to quantum theory, one can just about avoid these issues with a clear conscience, but major difficulties arise if one tries to move towards a more realist position, in which states, properties, or both, are posited of individual streams.



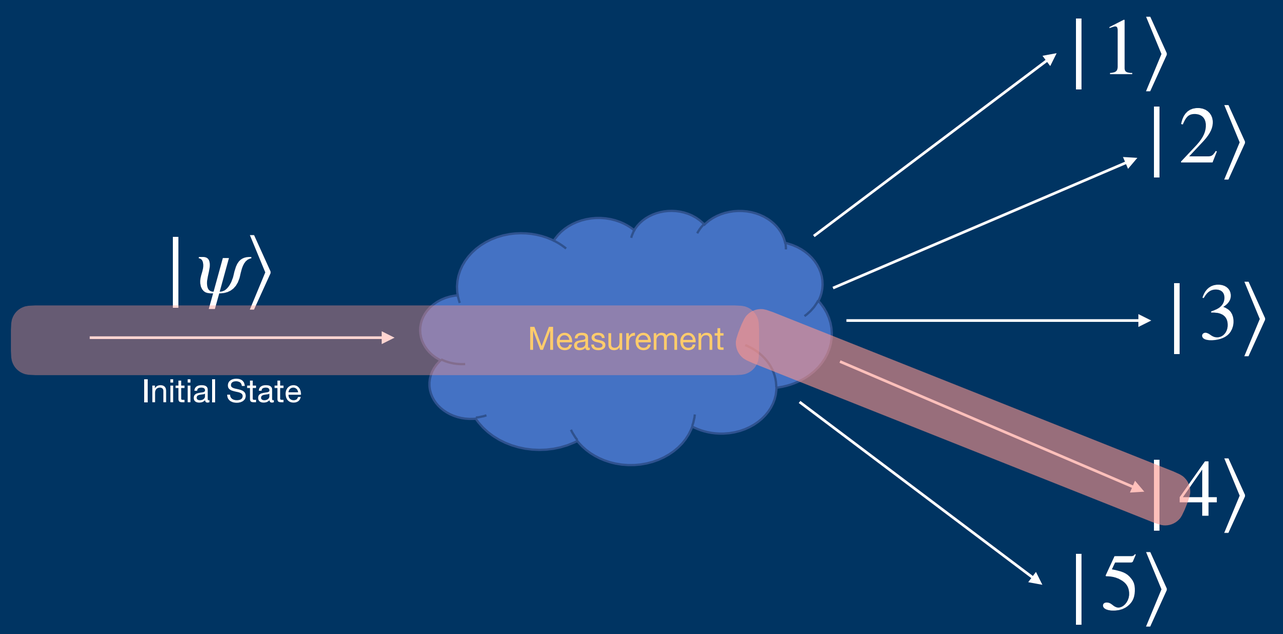
C J Isham Lectures on Quantum Theory. Mathematical and structural foundations P149

Q1 & Q2 State Reduction

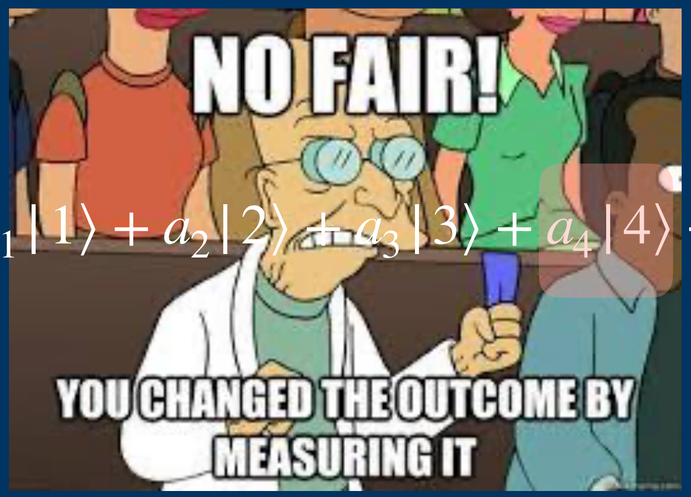
- The measurement problem
  - Does the system have values before the measurement?
  - What causes the transition?
  - Causes the possible to become actual?
    - Collapse of state

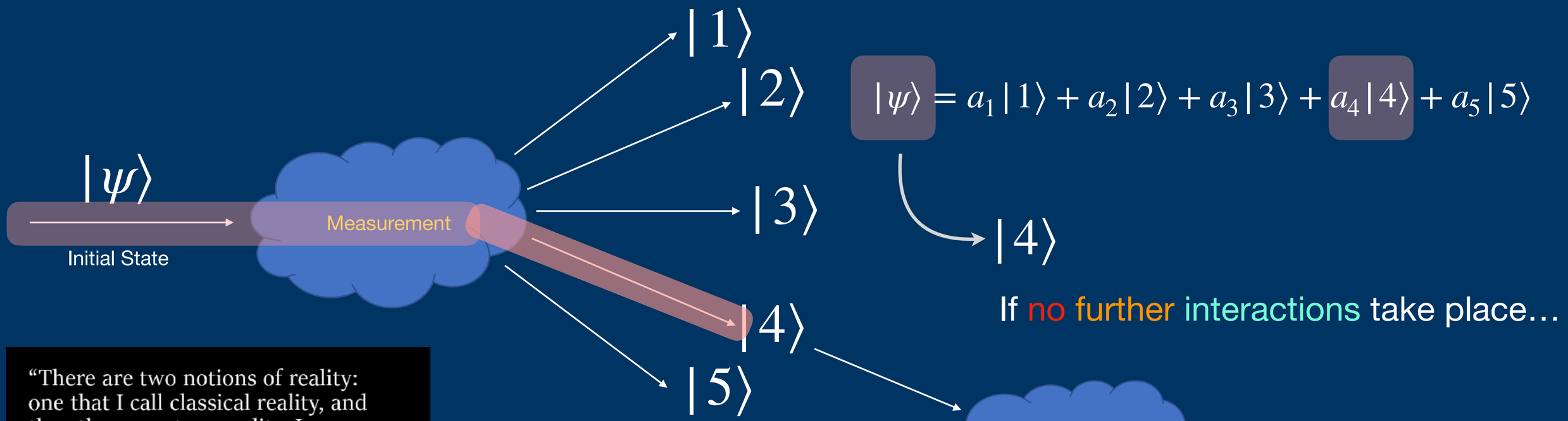
Traditional QM has no account of this

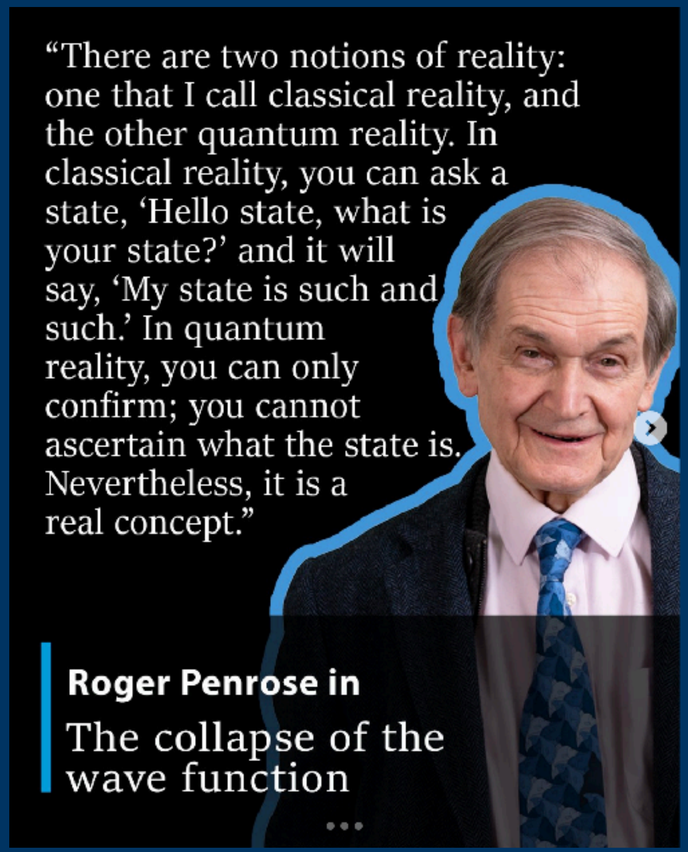
Yet cannot function without something



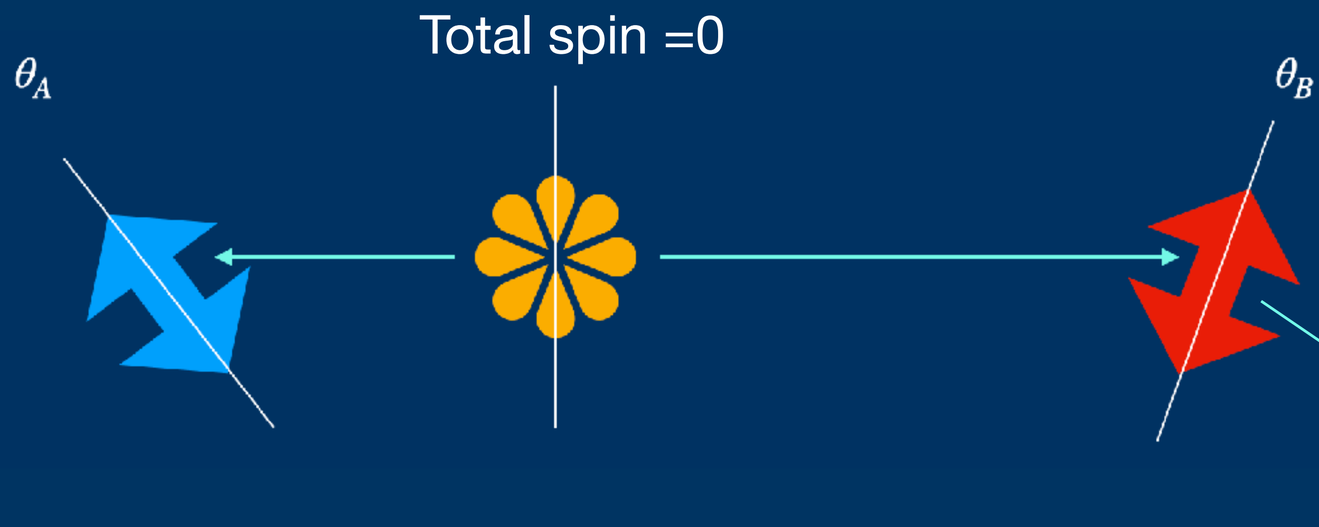
$$|\psi\rangle = a_1|1\rangle + a_2|2\rangle + a_3|3\rangle + a_4|4\rangle + a_5|5\rangle$$

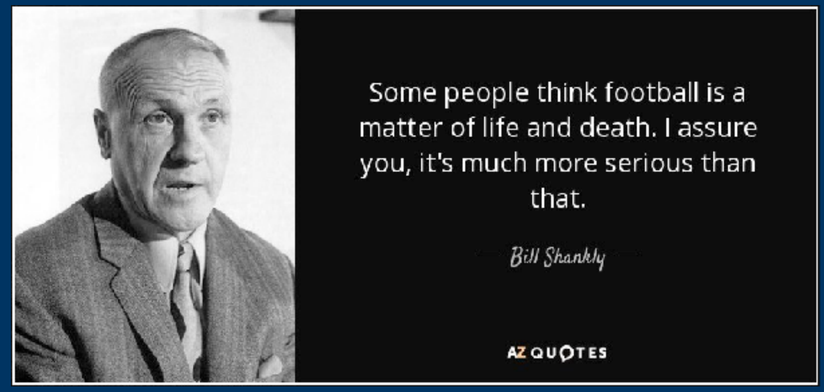



$|1\rangle$
$|2\rangle$
$|3\rangle$
$|4\rangle$
$|5\rangle$
$|\psi\rangle$
Initial State
Measurement
$|\psi\rangle = a_1|1\rangle + a_2|2\rangle + a_3|3\rangle + a_4|4\rangle + a_5|5\rangle$
$|4\rangle$
If no further interactions take place…
Measurement
$|4\rangle$


"There are two notions of reality: one that I call classical reality, and the other quantum reality. In classical reality, you can ask a state, 'Hello state, what is your state?' and it will say, 'My state is such and such.' In quantum reality, you can only confirm; you cannot ascertain what the state is. Nevertheless, it is a real concept."
Roger Penrose in
The collapse of the wave function
...

Alice and Bob





When the first $|U\rangle$ partner arrived

Bob got down, $|D'\rangle$

Does that mean his angle is the same?

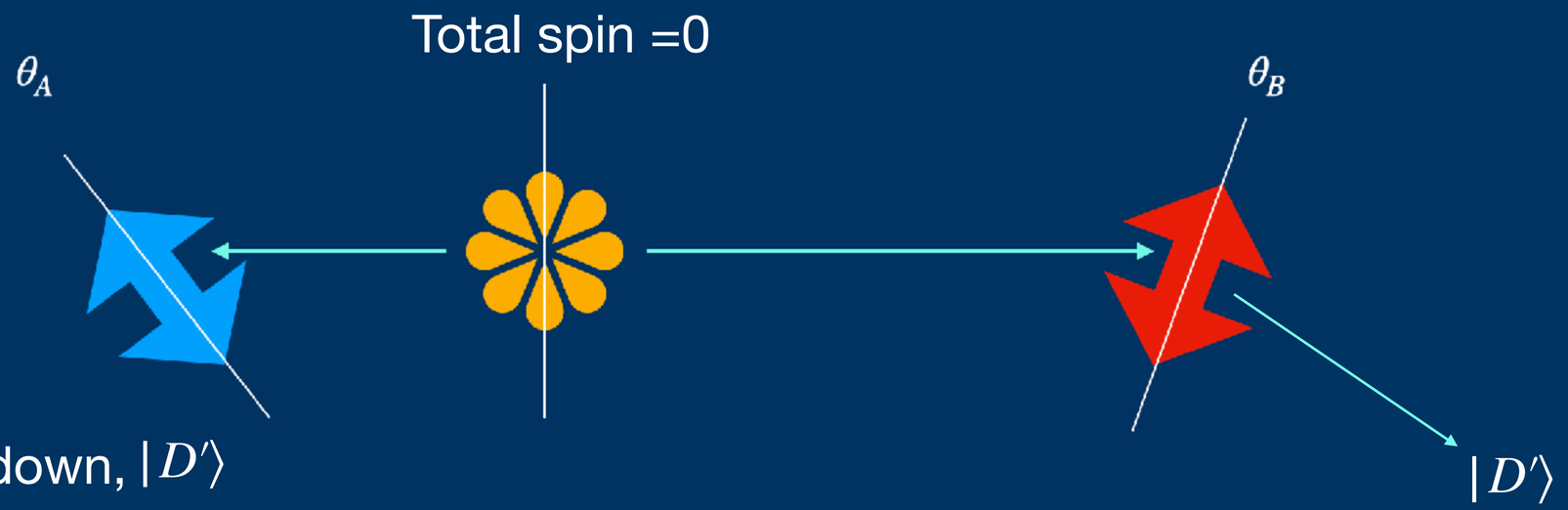
Turn it into a game

Alice sets her angle

Tells Bob: “I will tell you when I get $|U\rangle$ along my angle”

Challenges Bob to determine her angle from his data

Alice and Bob



Bob gets down, $|D'\rangle$

Does that mean his angle is the same?

Can’t tell…

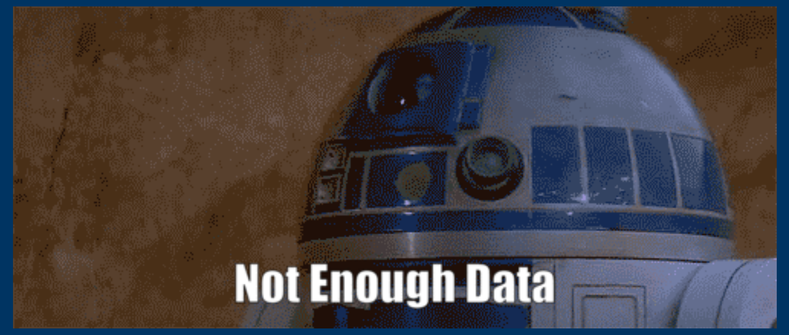
If it is the same Bob will get down 100% of the time

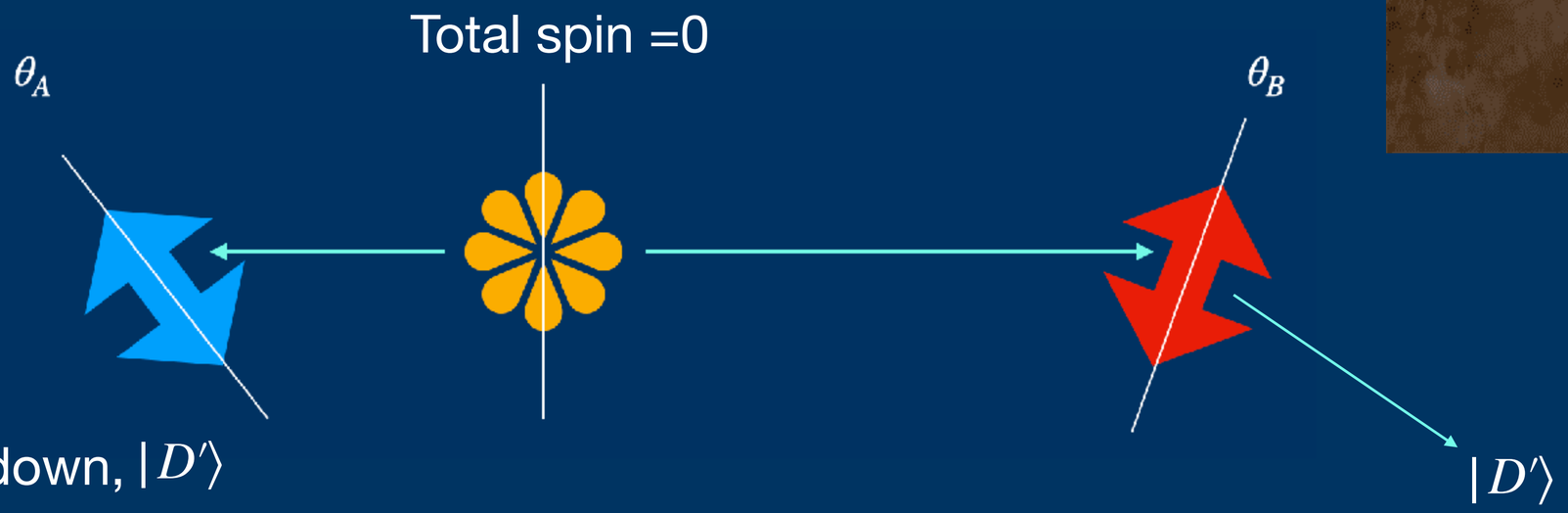
If not the same Bob will get down some proportion of the time

} Can’t tell from one result

Could even be ‘unlucky’…get down repeatedly, just by chance

Alice and Bob





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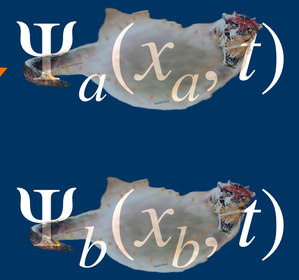
Q3 Entanglement

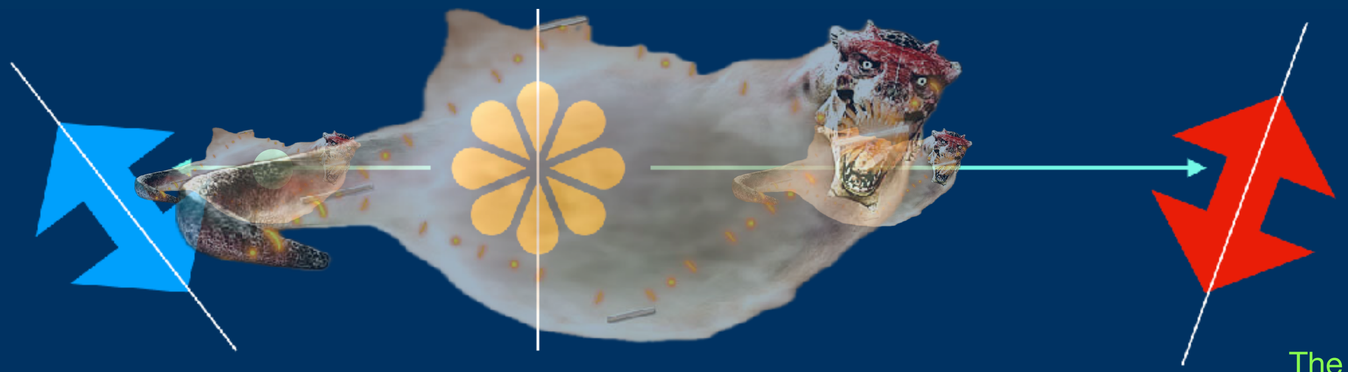


When two systems, of which we know the states by their respective representatives, enter into temporary physical interaction due to known forces between them, and when after a time of mutual influence the systems separate again, then they can no longer be described in the same way as before, viz.

by endowing each of them with a representative of its own. …

By the interaction the two representatives (or Ψ-functions) have become entangled.

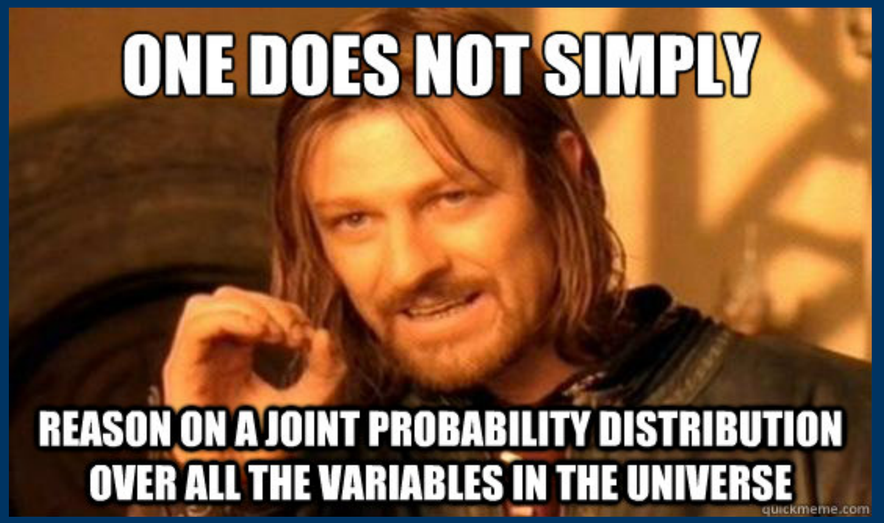
$$\Phi(x_a, x_b, t) \neq \Psi_a(x_a, t) \times \Psi_b(x_b, t)$$



The Entangled state is new and not a simple ‘product’ of the separate states

Q4 Probability

- Probability is frequently used in physics
  - When we don't have enough detail to calculate exactly
  - When we have too much detail
    - Can't track all 10^{20} particles in a gas
      - So we can't calculate exactly
      - Calculate what is most likely to happen
    - But, always an exact calculation is in principle possible
    - These are classical probabilities



Quantum Probability

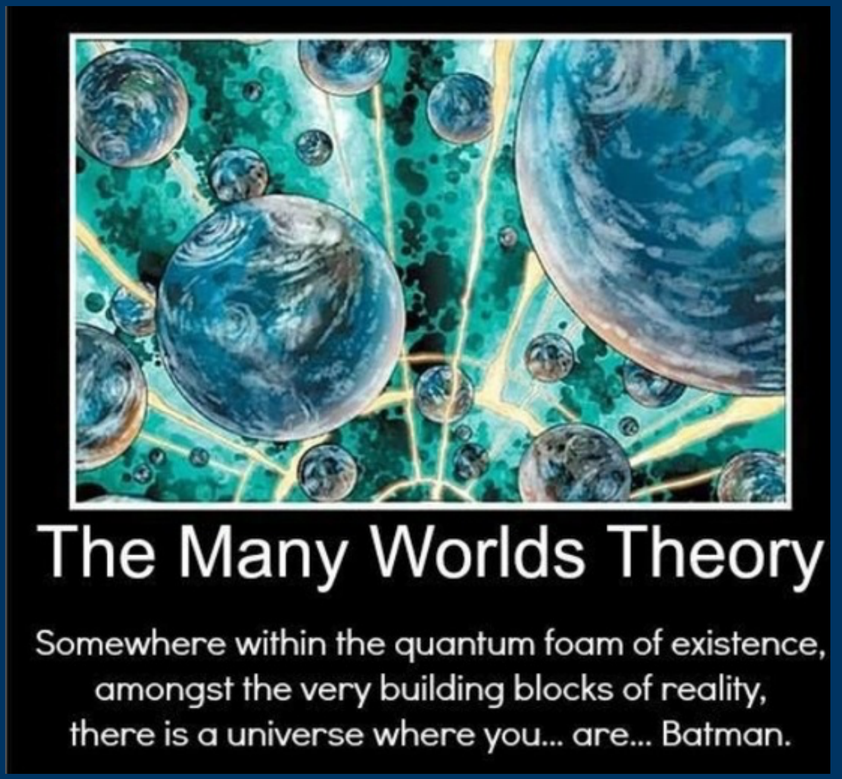
- In (traditional) quantum theory, some probabilities are very different
  - This is a quantum (fundamental) probability
    - Expressing randomness in the universe
      - Not that we don't have enough physics / detail to calculate exactly
      - There is no physics that determines where the particle will be
    - It has the potential (potentia) to be in many places
    - One of which will be manifest in a measurement - state collapse

Options…

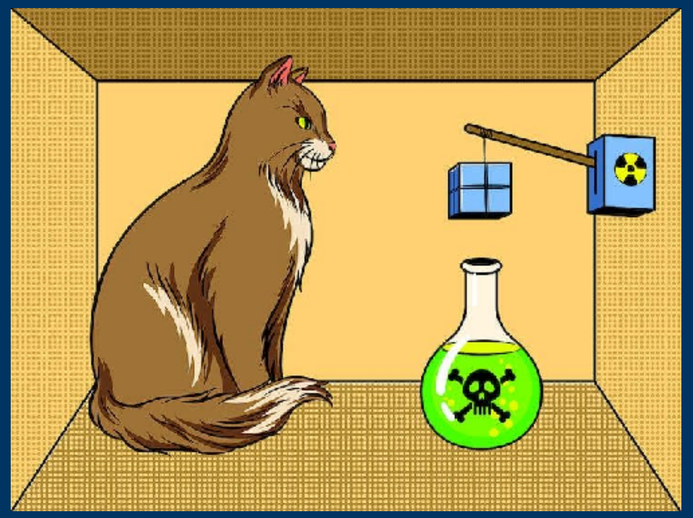
- The state refers to a collection of objects, not an individual
  - Collapse is simply a change in our information
  - Wave function is a calculation tool
    - Not really fully describing reality
  - But…hard to explain interference at single electron level…

Options…

- State collapse does not happen
  - Many Worlds interpretation
    - Each outcome branches into a separate decohering world



Decoherence



That d***d cat…

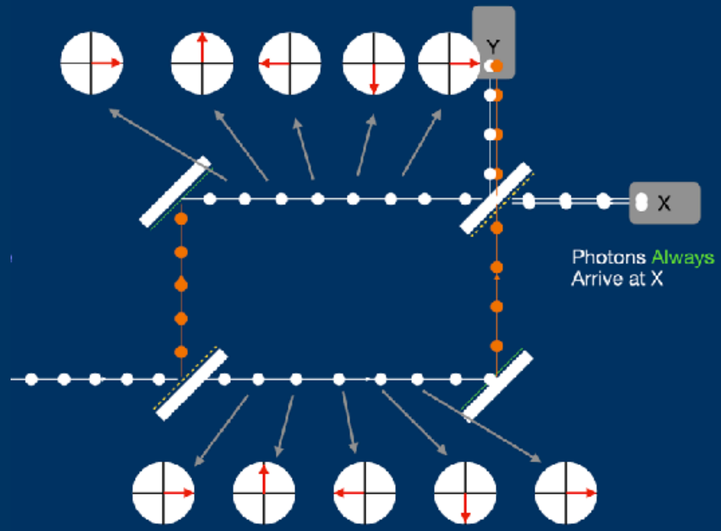
An example of entangled states

Remember…

Get quantum interference

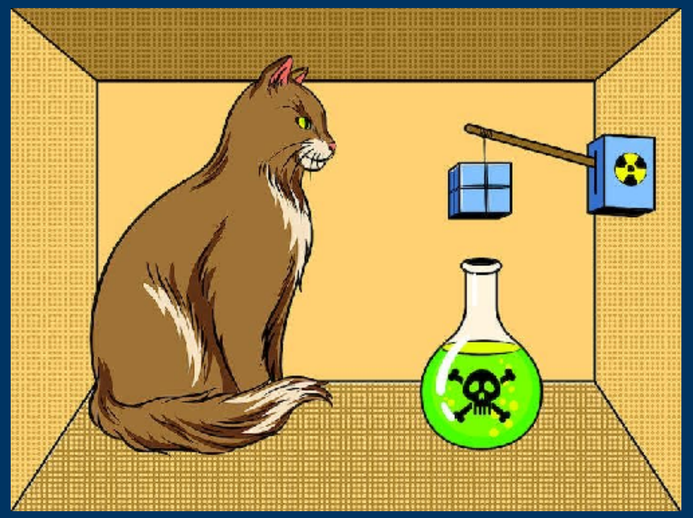
While a fixed phase difference

Between options



$$\Psi_{\text{☣}} = |\text{😾}\rangle\,|\text{⚗}\rangle\,|\text{⚛}\rangle + |\text{😼}\rangle\,|\text{⚗}\rangle\,|\text{⚛}\rangle$$

Decoherence



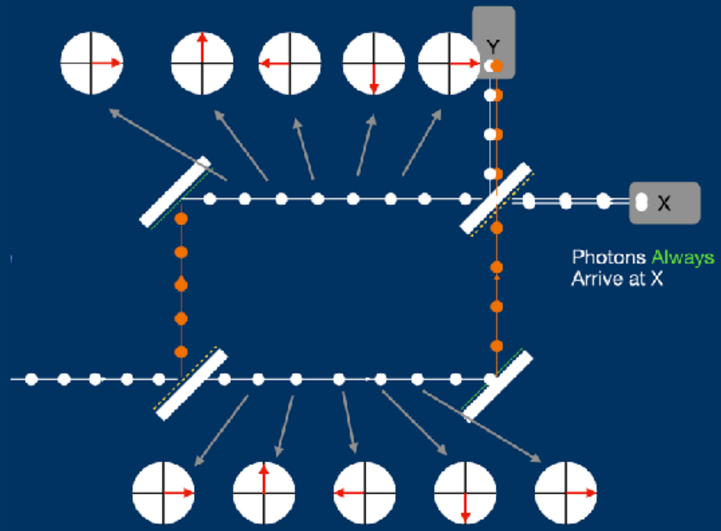
Sooner or later…

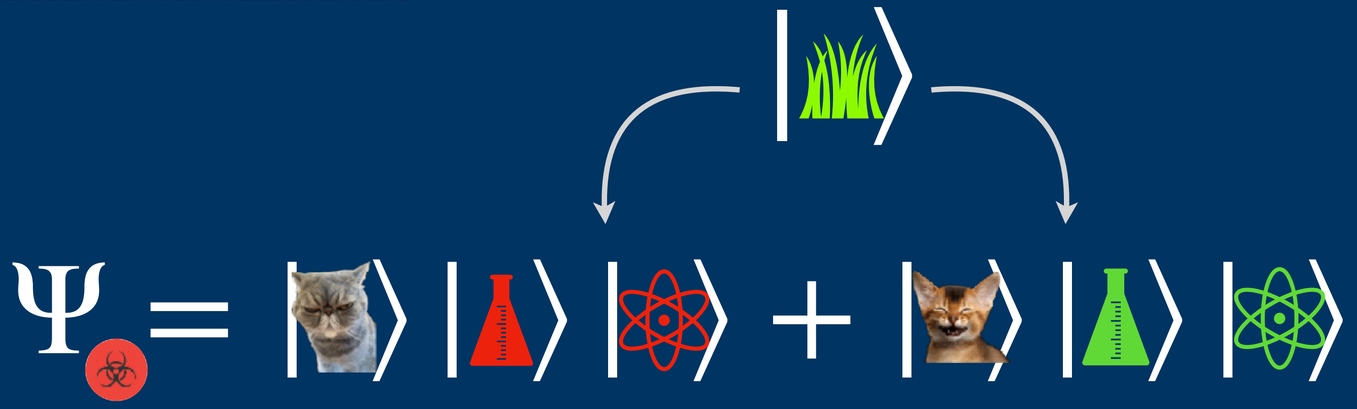
Quantum system must

Interact with the environment

Environmental factors / states

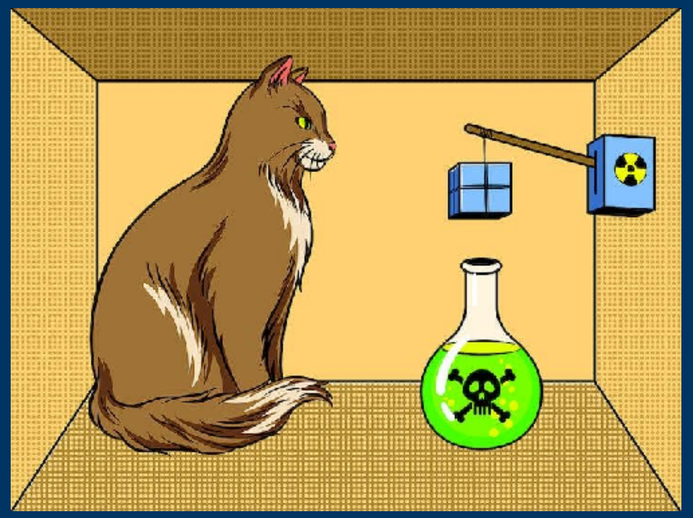
Get entangled in…





Decoherence

$$\Psi_{\text{☣}} = |\text{cat}\rangle\,|\text{flask}\rangle\,|\text{atom}\rangle\,|\text{grass}\rangle + |\text{cat}\rangle\,|\text{flask}\rangle\,|\text{atom}\rangle\,|\text{grass}\rangle$$



The phase of these factors

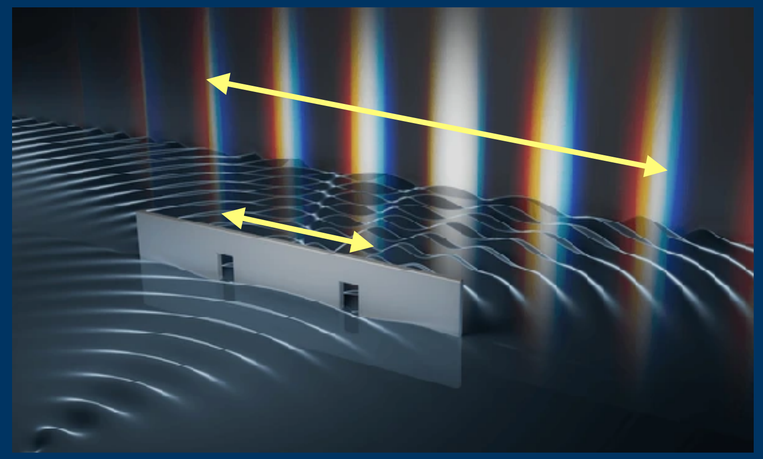
Fluctuates widely

Effectively randomly

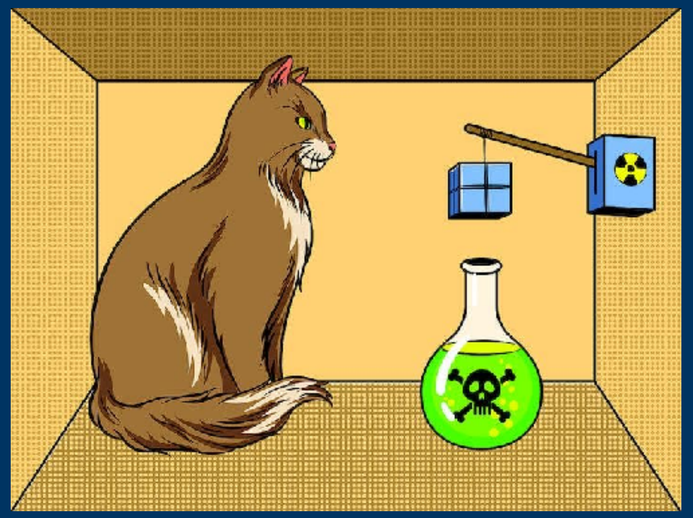
Like having slits that shift about

Causes the pattern to shift about

‘Greys out’ the interference



Decoherence



Each portion can now effectively evolve separately

World 1

World 2

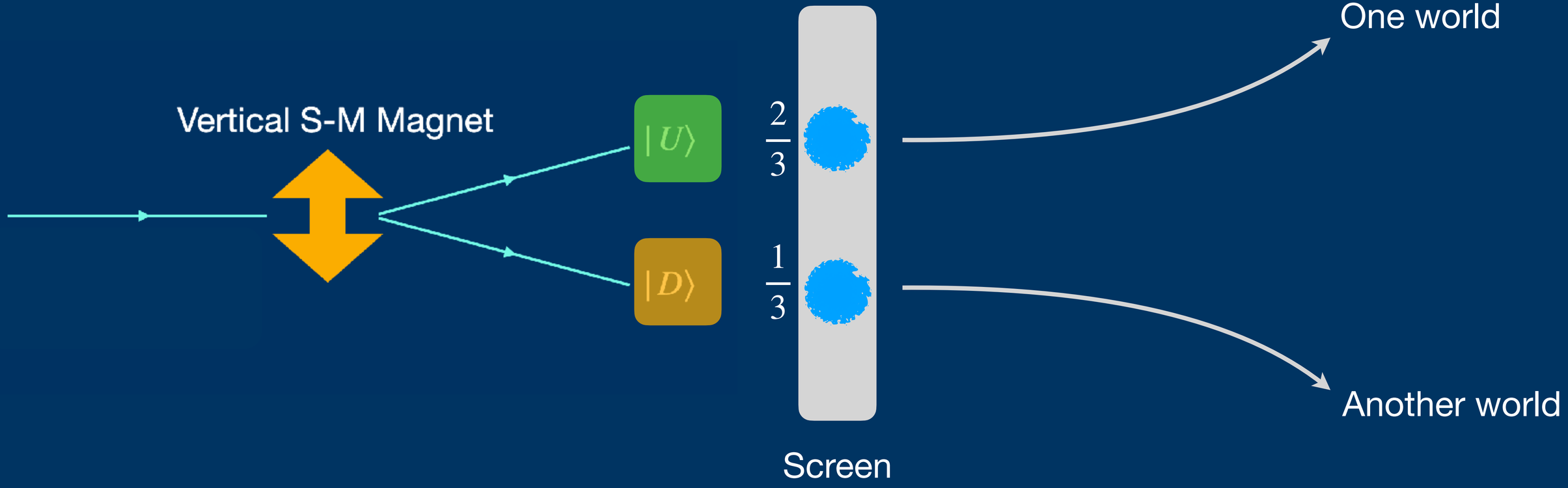
Options…

- State collapse does not happen
  - Many Worlds interpretation
    - Each outcome branches into a separate decohering world

Becoming separate worlds

But…

In this scenario - what is probability?



$$\Psi = \sqrt{\frac{2}{3}}|U\rangle + \sqrt{\frac{1}{3}}|D\rangle$$

What can the amplitudes mean?

David Deutsch

Decision Theory

My method is to analyse the behaviour of a rational decision-maker who is faced with decisions involving the outcomes of future quantum-mechanical measurements…

I shall prove that … he necessarily makes decisions as if [the Born-rule] were true

Becoming separate worlds

The usual probabilistic terminology of quantum theory is justifiable … provided that one understands it all as referring ultimately to the behaviour of rational decision-makers

Close your eyes and hope…

Just before experimental result appears

Shut your eyes…

Your subjective uncertainty is the probability

Becoming separate worlds

Close your eyes and hope…

Just before experimental result appears

Shut your eyes…

Your subjective uncertainty is the probability

Becoming separate worlds

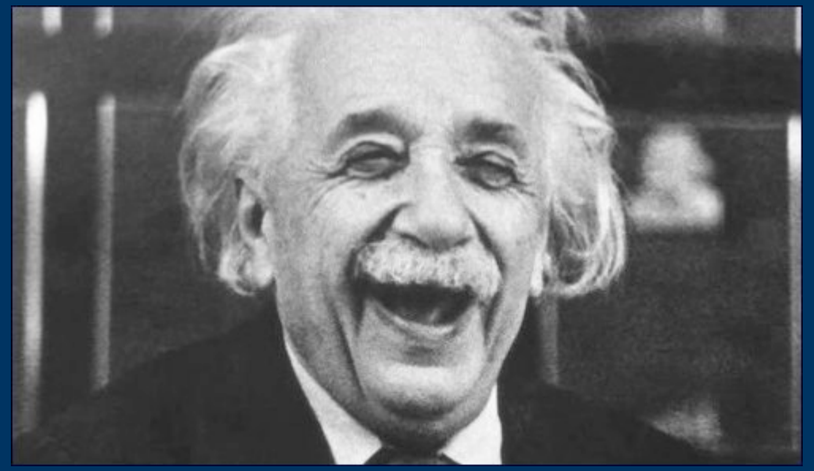
Important…

If Many Worlds is correct…

Einstein need not have worried

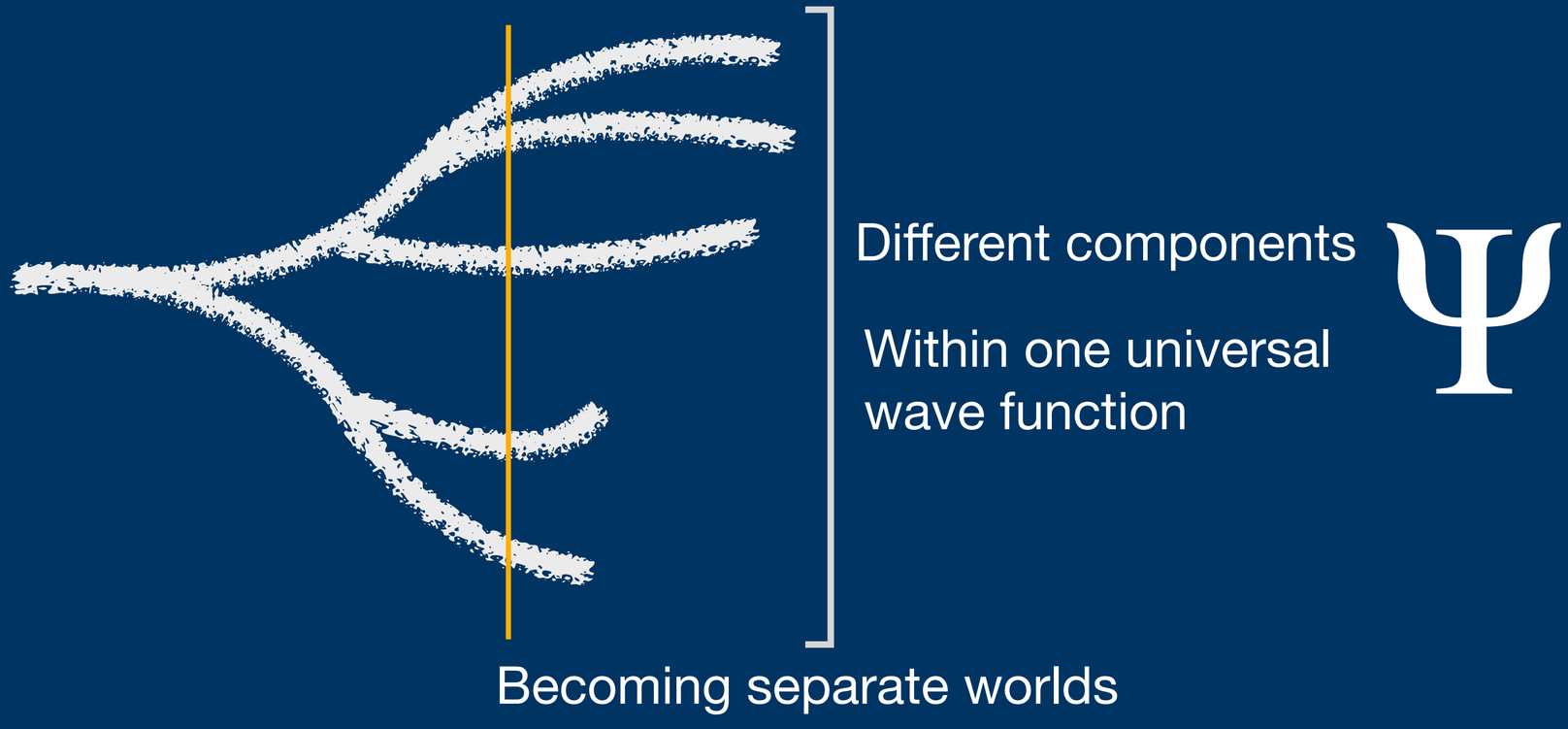
QM is completely deterministic

Becoming separate worlds



Important 2…

This is NOT the multiverse



Different components

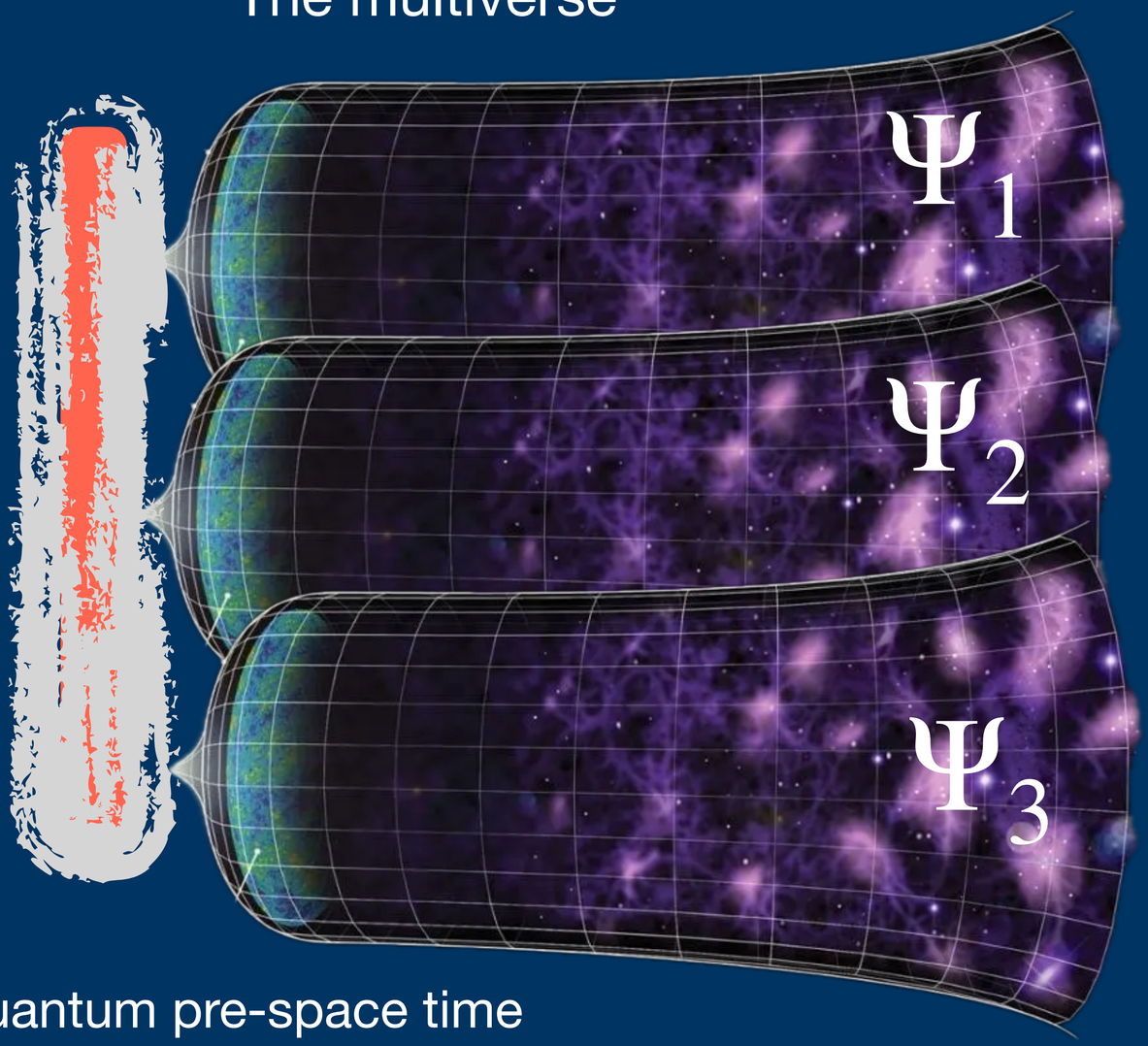
Within one universal wave function

Ψ

Becoming separate worlds

Important 2…

The multiverse



Different universes

Separate wave functions

Possibly distinct laws

Quantum pre-space time

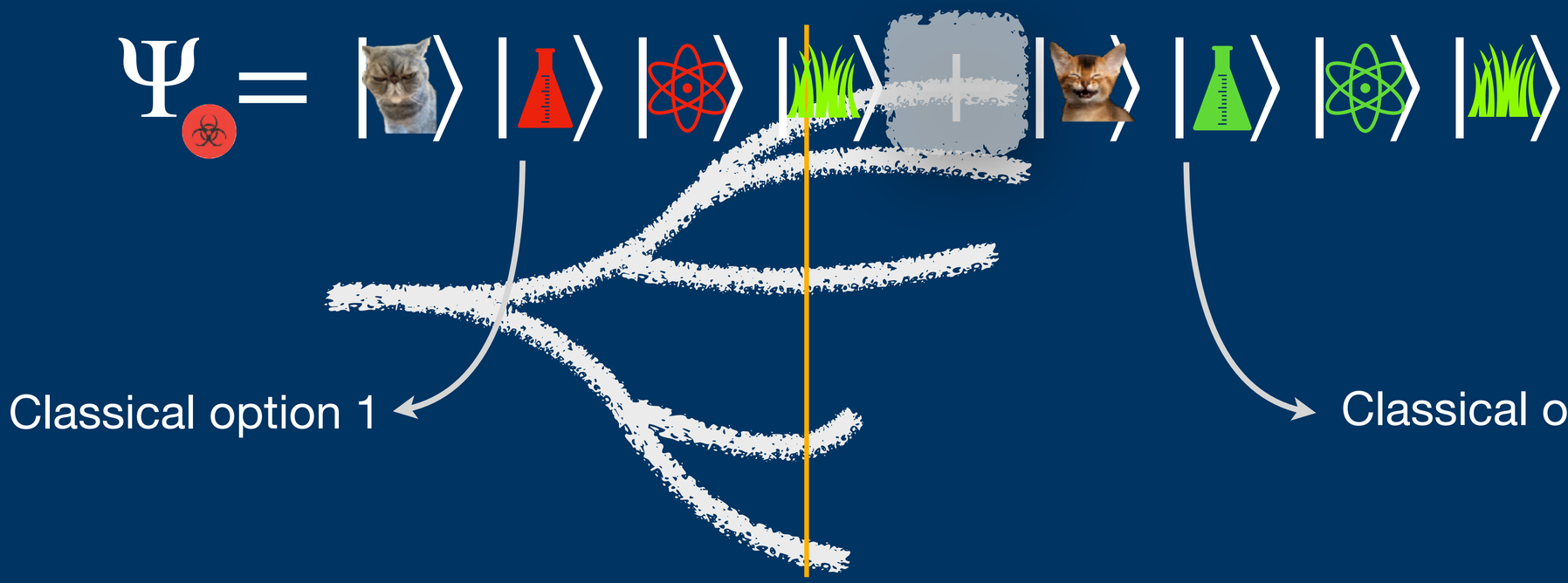
Another option…

Once environmental decoherence has bitten

Quantum interference has gone

The classical world has arisen

Physics has done its job…



Neo-Copenhagenism

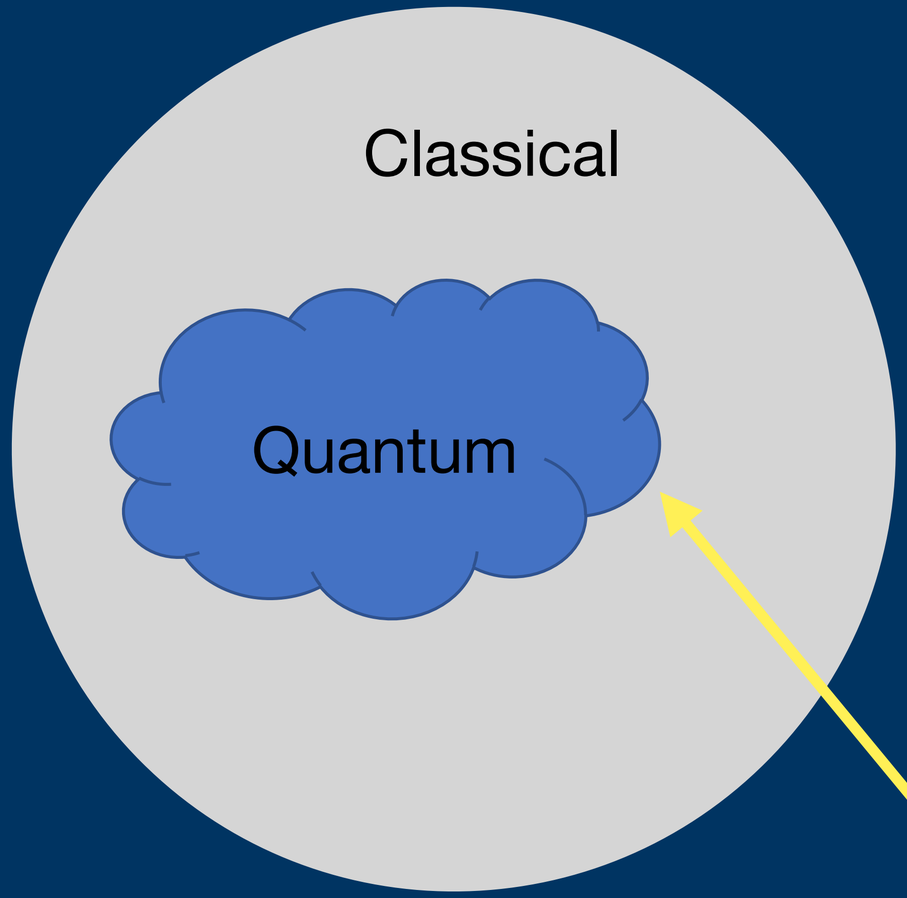
In the system to which the quantum mechanical formalism is applied, it is of course possible to include any intermediate auxiliary agency employed in the measuring process [but] some ultimate measuring instruments must always be described entirely on classical lines, and consequently kept outside the system subject to quantum mechanical treatment.

N. Bohr, New Theories in Physics, International Institute of International Co-operation, Paris, 1939.

- In other words
  - At some level, a device must be treated classically
  - This is where the entanglement stops
    - This is not wholeness
      - Actually its drawing a line across the world
      - Heisenberg cut

Huh?

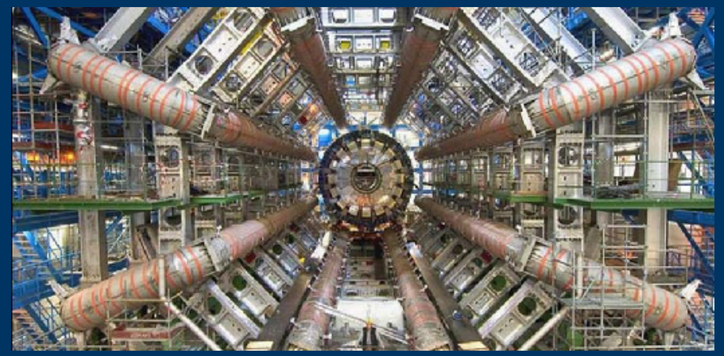
Neo-Copenhagenism



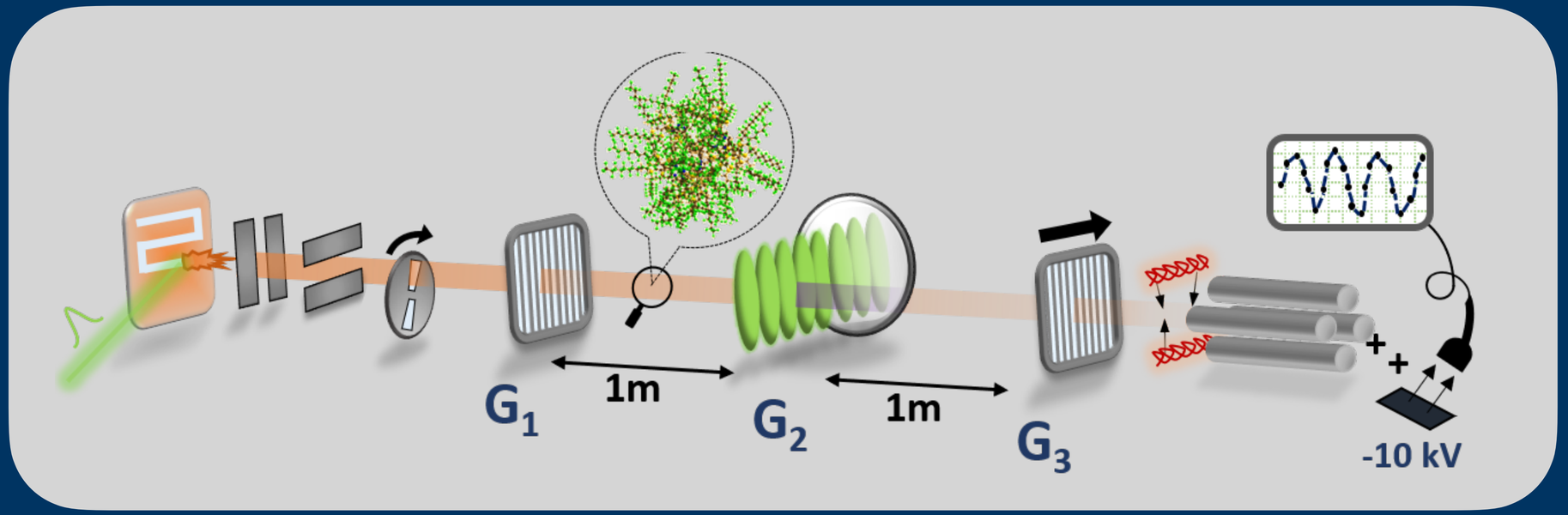
Boundary ‘Heisenberg Cut’

the use, as measuring instruments, of rigid bodies sufficiently heavy to allow a completely classical account of their relative positions and velocities

N. Bohr, Quantum Physics and Philosophy: Causality and Complementarity, in Philosophy at Mid Century, Florence, 1958.

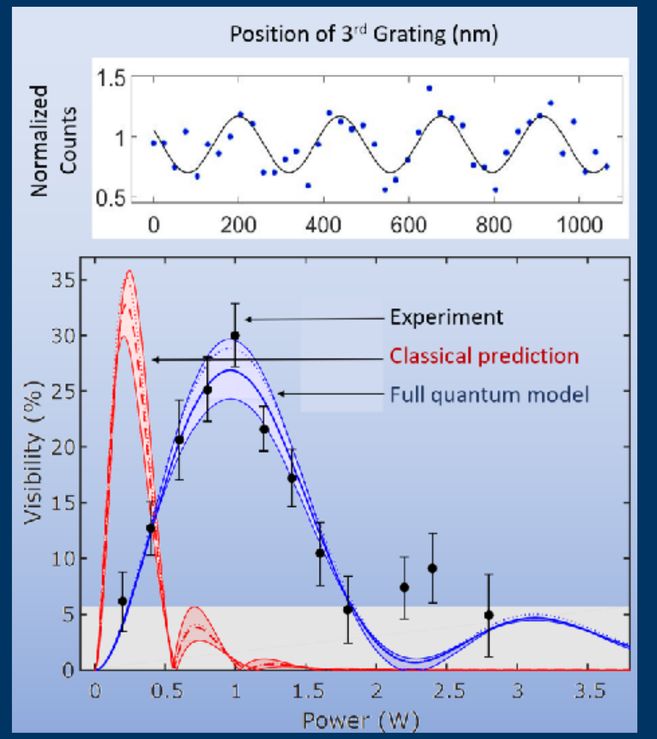


Where is the boundary…?



Interference between molecules

Containing ~ 2 000 atoms…

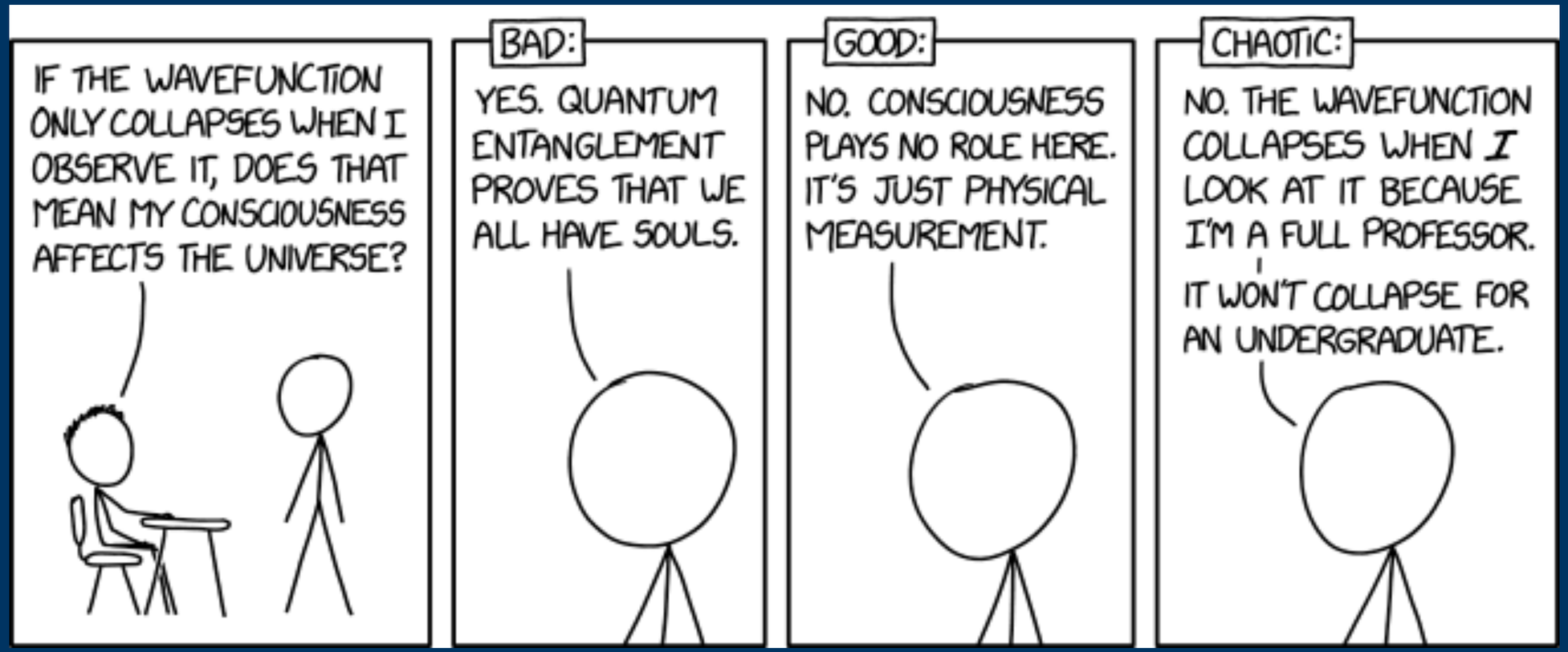


Images provided by the Quantum Nanophysics Group, University of Vienna, based on Fein et al., Nat. Phys. 15, 1242 (2019)

Mind triggers state collapse

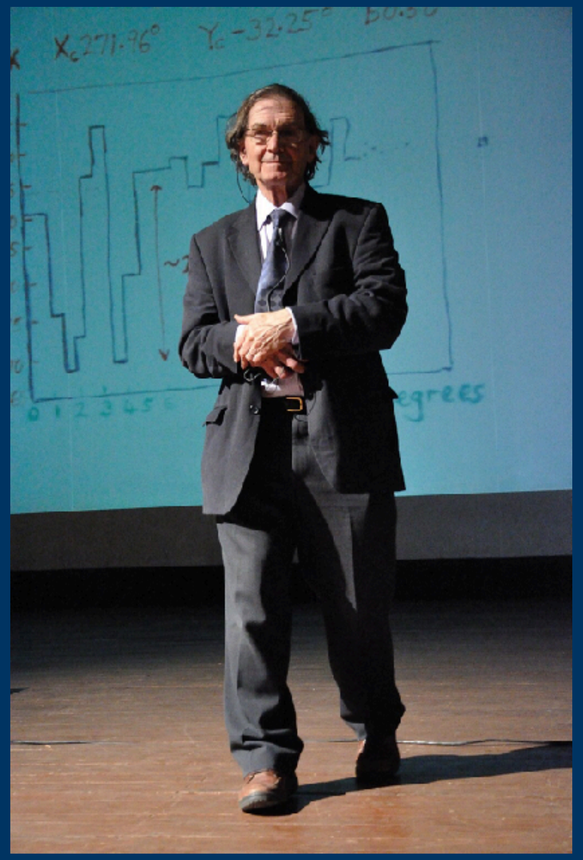
- Places the ‘cut’ at consciousness
  - Drawing a boundary between physical and non-physical - dualist
  - Not integrating mind into physics
    - No mechanism here
  - How did the world get on without consciousness?
    - Panpsychism???
      - Wheeler’s retrocausality….
    - Promissory transcendentalism???

Quantum Physics and the Power of the Mind: Find Out How Quantum Physics and The Law of Attraction Function and How This Can Change Your Life


IF THE WAVEFUNCTION ONLY COLLAPSES WHEN I OBSERVE IT, DOES THAT MEAN MY CONSCIOUSNESS AFFECTS THE UNIVERSE?
BAD:
YES. QUANTUM ENTANGLEMENT PROVES THAT WE ALL HAVE SOULS.
GOOD:
NO. CONSCIOUSNESS PLAYS NO ROLE HERE. IT'S JUST PHYSICAL MEASUREMENT.
CHAOTIC:
NO. THE WAVEFUNCTION COLLAPSES WHEN I LOOK AT IT BECAUSE I'M A FULL PROFESSOR.
IT WON'T COLLAPSE FOR AN UNDERGRADUATE.

Options…(3)

- Objective collapse
  - The wave function exists in the implicate layer of reality
  - World of objective potentiality (potentia)
  - Collapse is an objective change in the wave function brought about by:
    - Interaction with a complex system
    - Active information
    - Non-computable space-time geometrical influence (Penrose)



Roger Penrose

When you study
Quantum Mechanics: