A new approach to time

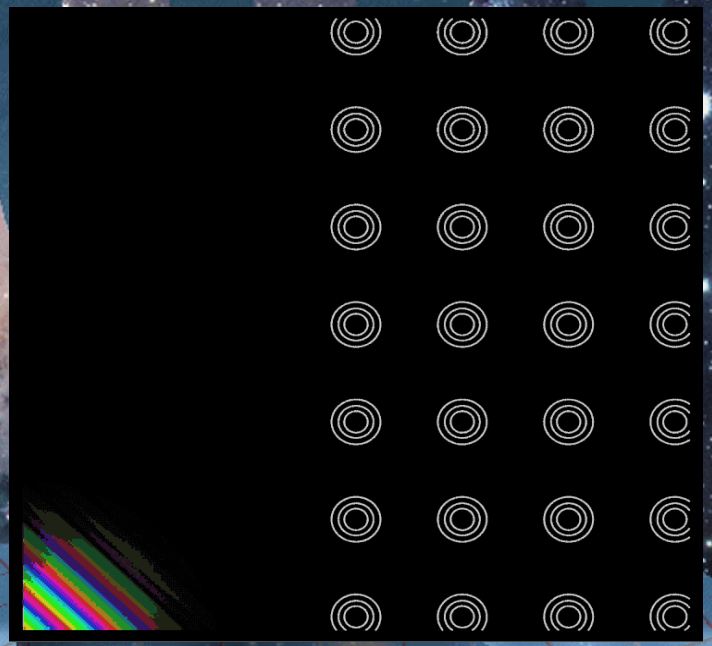
Jeff Tollaksen

and

Yakir Aharonov

Directors, Institute for Quantum Studies

Chapman University (quantum.chapman.du)



FQXi conference, Tuscany, Italy July 24, 2019

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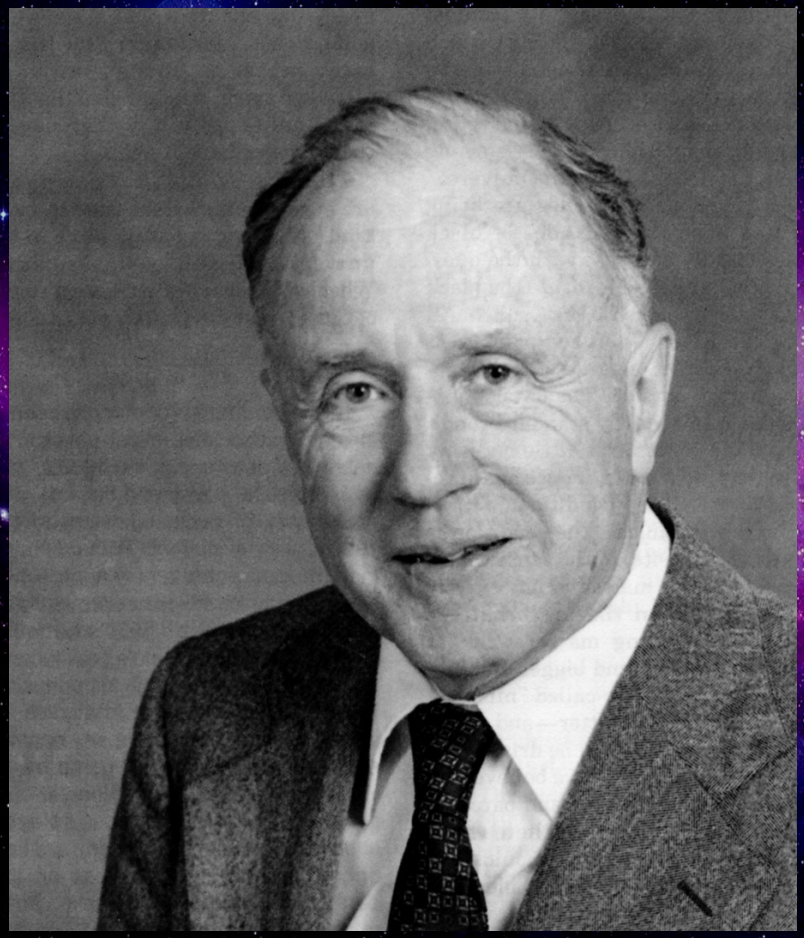
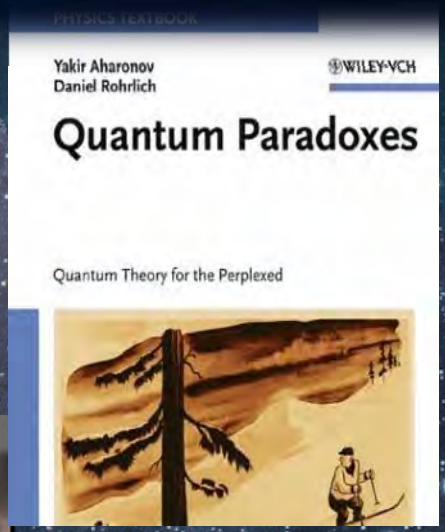
Radical Conservatism…



"Wheeler's often unconventional vision of nature was grounded in reality through the principle of radical conservatism, which he acquired from Niels Bohr: Be conservative by sticking to well-established physical principles, but probe them by exposing their most radical conclusions." – Kip Thorne

Gedanken-Experiment ⟹ Paradigm Shift

- Emphasize aspects of a problem that are unclear: make it look as paradoxical as possible
- Develop deeper, more grounded intuition
- Experimental metaphysics: all disciplines



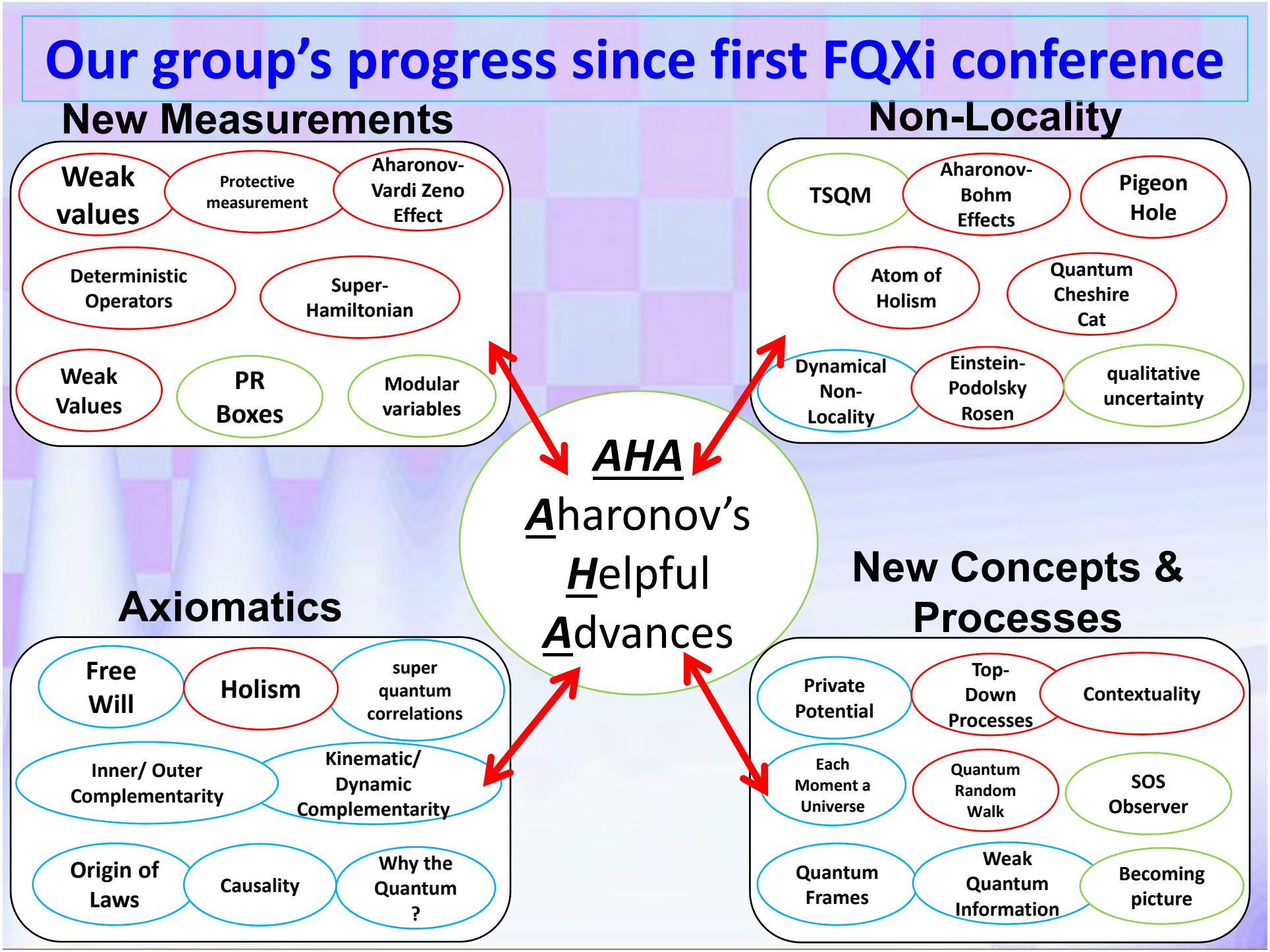
Aharonov et al
Gedanken-experimenting

because of Gedanken-Experiment, Einstein said: 'Bohm is my intellectual son'

Sir Anthony Leggett characterizing Aharonov's work as among the:

"... major revolutions in the history of physics and I mean really major revolutions like Copernicus, Galileo, Einstein..."

Our group's progress since first FQXi conference



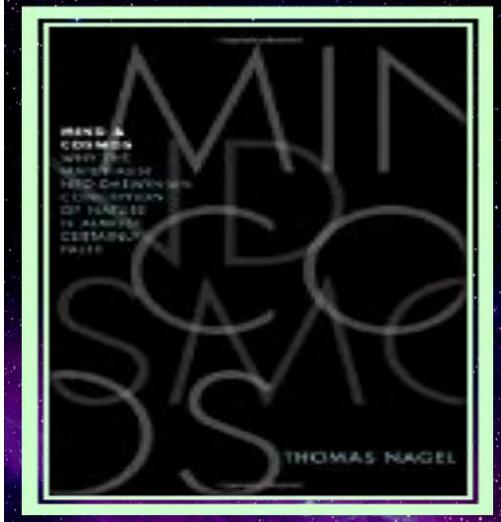
Gedanken-Experiment ⟹ Paradigm Shift

Applying gedanken-experiment methodology to *experimental metaphysics* and *inner laboratory*:

1. **Subjective experience of the flow of time**
2. **Experience of free will**
3. **Experience of a definite reality**

the deeper the sense of puzzlement or mystery, the higher will be the peaks of enjoyment in the resolution

Thomas Nagel



"[T]he fact that an organism has conscious experience at all means, basically, that there is something it is like to be that organism."

"What Is It Like to Be a Bat?" *The Philosophical Review* Oct. 19[illegible]

1. *"Emphasize the role of temporally extended developmental processes."*
2. *"Search for laws of nature that relate past, present and future in a way other than via some function that relates instantaneous states through time."*
3. *"Such organizational and developmental principles would be an irreducible part of nature."*

Mind and Cosmos (Oxford U. Press, 2012)

Response from Sean Carroll

"Back in the Dark Ages, a person with heretical theological beliefs would occasionally be burned at the stake. Nowadays, when a more scientific worldview has triumphed and everyone knows that God doesn't exist, the tables have turned, and any slight deviation from scientific/naturalist/atheist/Darwinian doctrine will have you literally tied to a pole and set on fire. ***Fair is fair.***"

One of my personal life-goals has been to bring together neuroscientists who can collaborate with us foundations-type physicists

- new Institute for Interdisciplinary Brain and Behavioral Sciences at Chapman University
- Amir Raz, Aaron Schurger, Uri Maoz, et al
- Thank you to Fetzer and Templeton making this possible

> **“consciousness must be explained on a more abstract level than that of neural wiring…. To remain within the realm of science, consciousness must be described in terms of what it does, and not how it does it.”**

"The unfolding argument: Why IIT and other causal structure theories cannot explain consciousness," A. Doeriga, A. Schurger, K. Hessf, M. Herzoga; Consciousness and Cognition 72 (2019) 49–59.

Some paradigm-shifts from our research relevant for time, causality

Our alternative formulations are completely equivalent to standard QM in so far as their predictions are concerned. But the underlying concepts are dramatically different. So if in the future QM has to be substantively changed to accommodate really new physics, these new formulations might provide a starting point.

Paradigm-shift #1: ***New Nonlocalities***

Paradigm-shift #2: ***Top-down causality***

Paradigm-shift #3: ***Axioms/why quantum***

Paradigm-shift #4: ***Becoming time***

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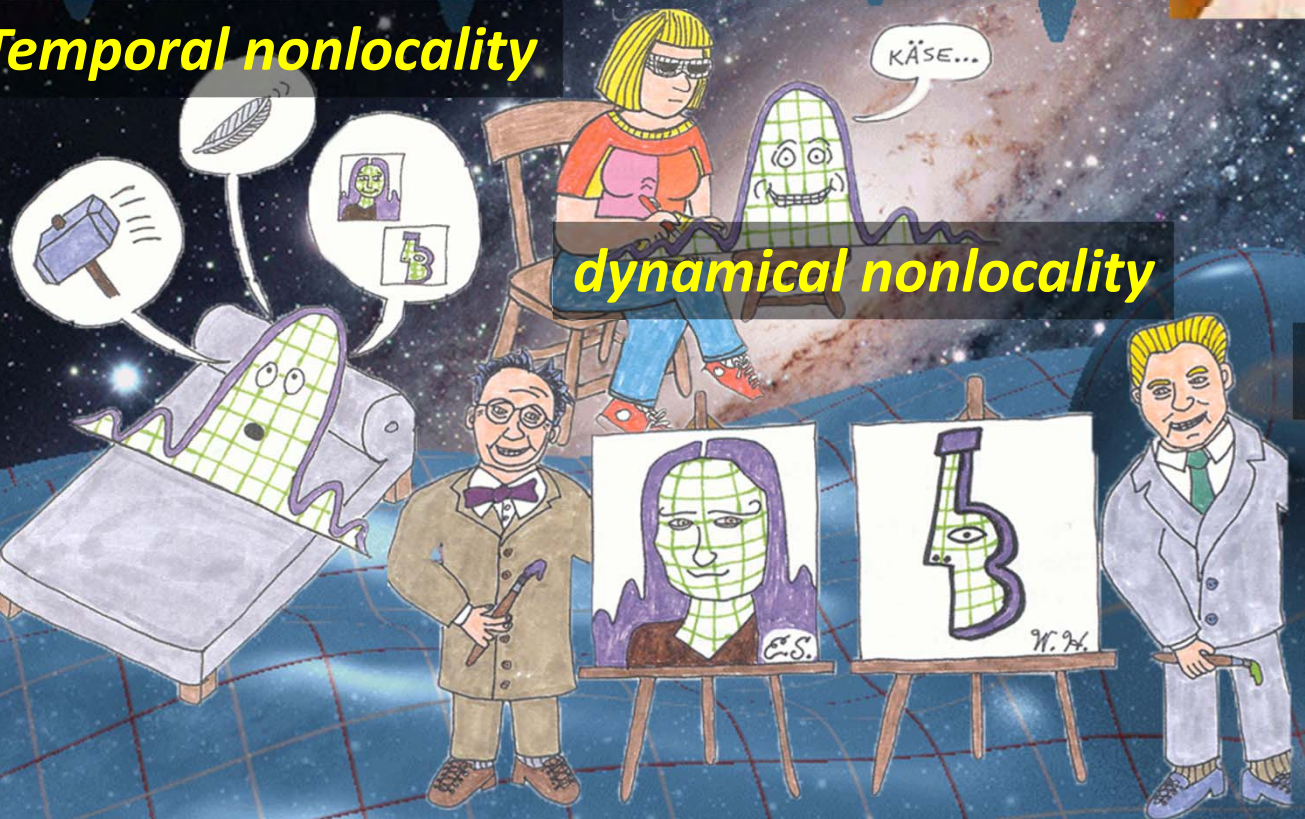
Paradigms shield themselves against falsification as part of normal science

The paradigm determines how you see the facts!

TS Kuhn, *The Structure of Scientific Revolutions*

Temporal nonlocality



dynamical nonlocality

Quantum miracles

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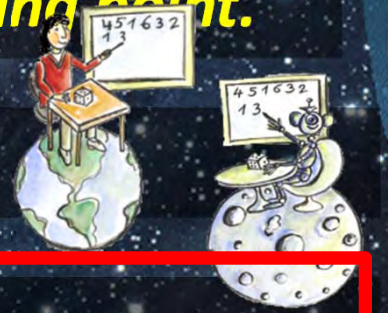

Paradigm-shift #1: ***New Nonlocalities***

Paradigm-shift #2: ***Top-down causality***

Paradigm-shift #3: ***Axioms/why quantum***

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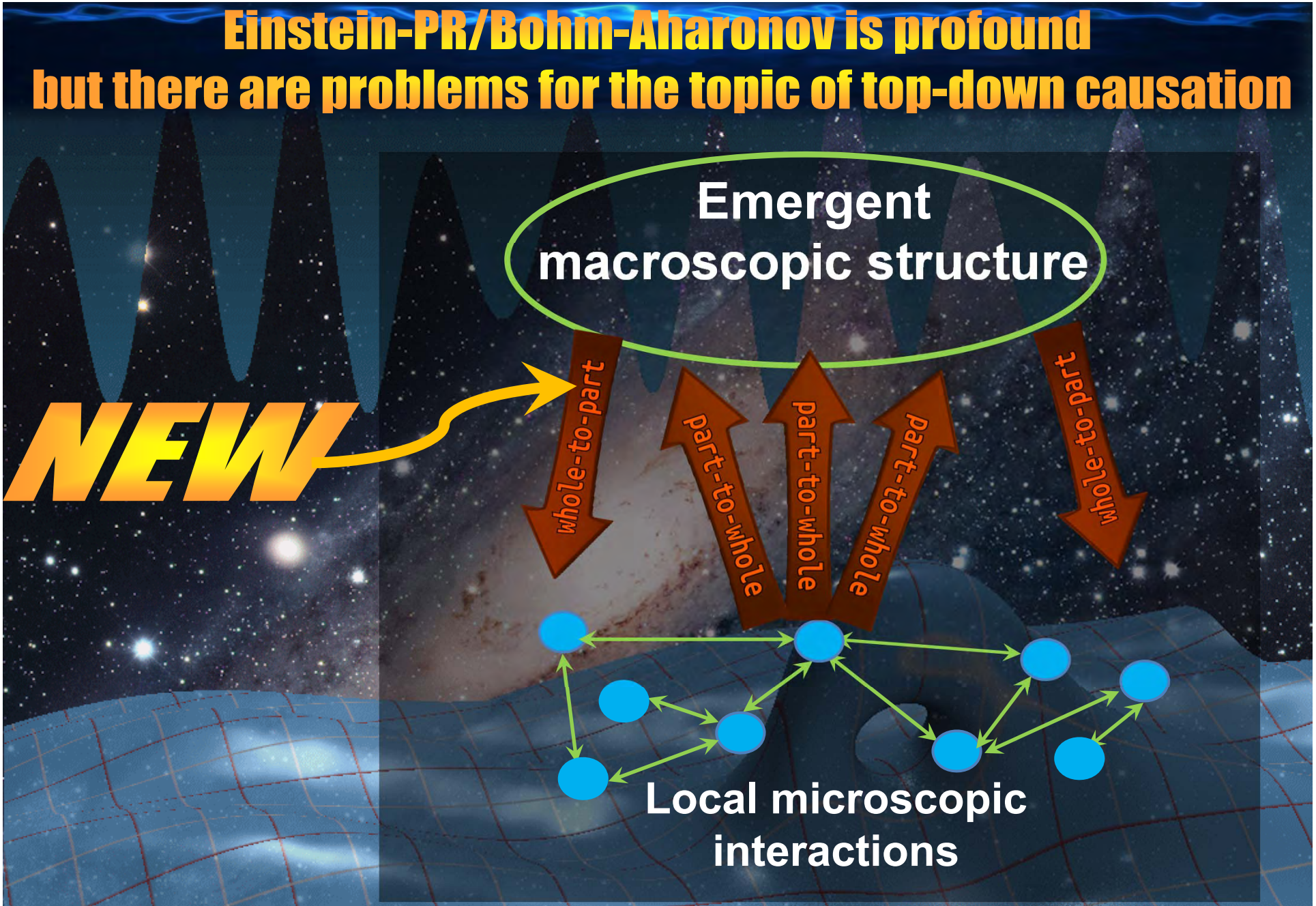
Einstein-PR/Bohm-Aharonov is profound but there are problems for the topic of top-down causation



Aharonov, Cohen, Tollaksen "A Completely Top-Down Hierarchical Structure in Quantum Mechanics", arXiv1709.07052; *Proceedings of the National Academy of Sciences*, (2018)

Some paradigm-shifts from our research relevant for time, causality

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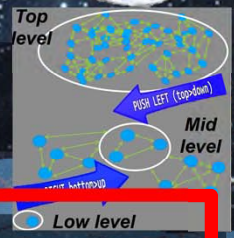
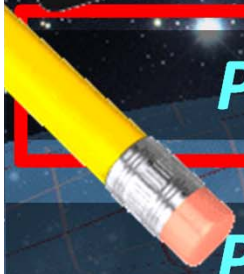
Paradigm-shift #1: New Nonlocalities



Paradigm-shift #2: Top-down causality



Paradigm-shift #3: Axioms/why quantum

Paradigm-shift #4: Becoming time

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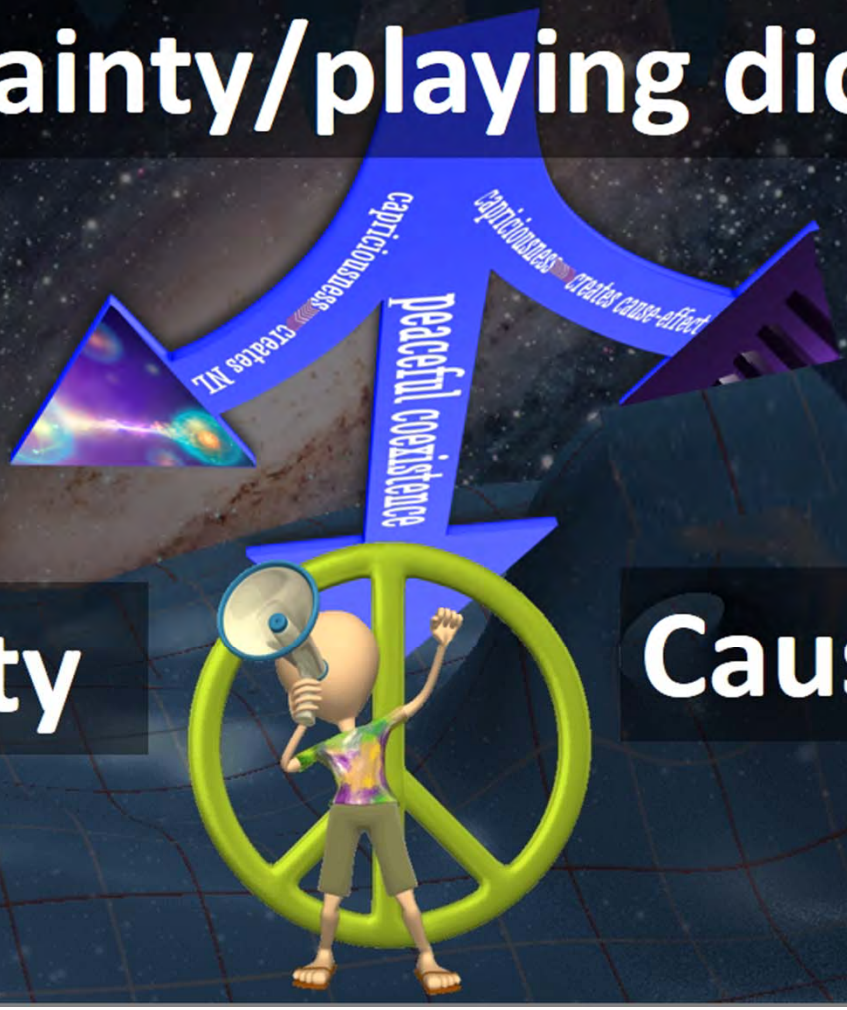
Why uncertainty?

re-design axioms of physics so that non-locality & new aspects of cause/effect are at deepest level

Uncertainty/playing dice



Nonlocality

Causality

Some paradigm-shifts from our research relevant for time, causality

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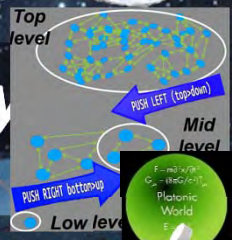
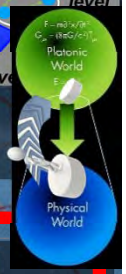


Paradigm-shift #1: ***New Nonlocalities***

Paradigm-shift #2: ***Holism & top-down causality***

Paradigm-shift #3: ***Axioms/why quantum***

Paradigm-shift #4: ***Becoming time***



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Each moment of time is a new universe

Some paradigm-shifts from our research relevant for 'becoming'

Our alternative formulations are completely equivalent to standard QM in so far as their predictions are concerned. But the underlying concepts are dramatically different. So if in the future QM has to be substantively changed to accommodate really new physics, these new formulations might provide a starting point.

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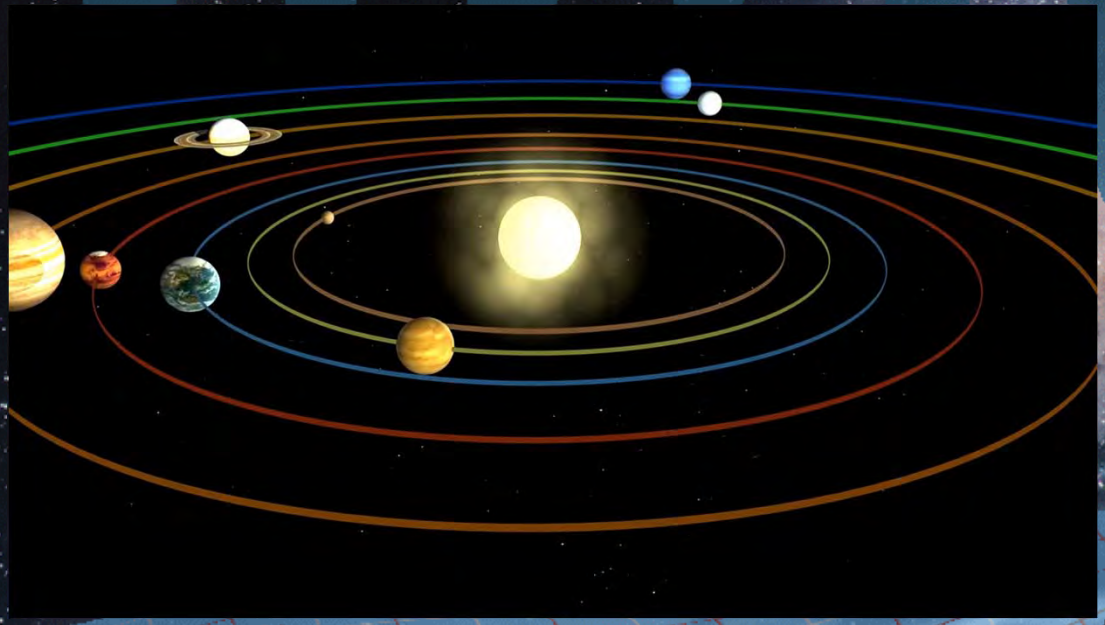
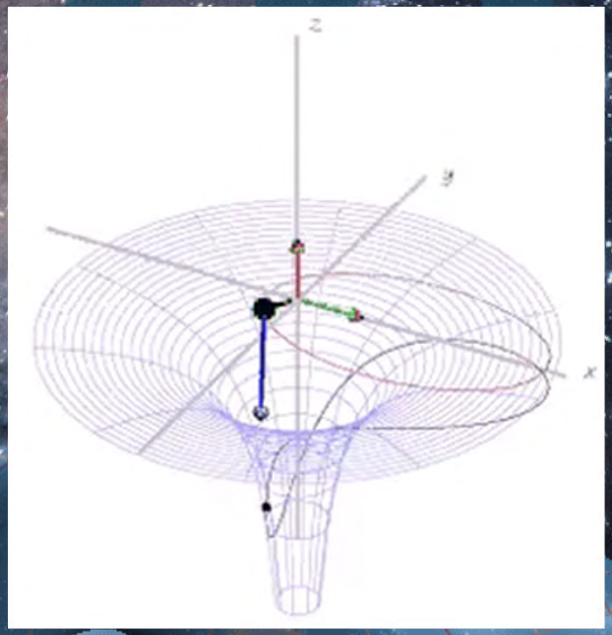
Classical physics: local equations of motion

Forces act in same place where particle is

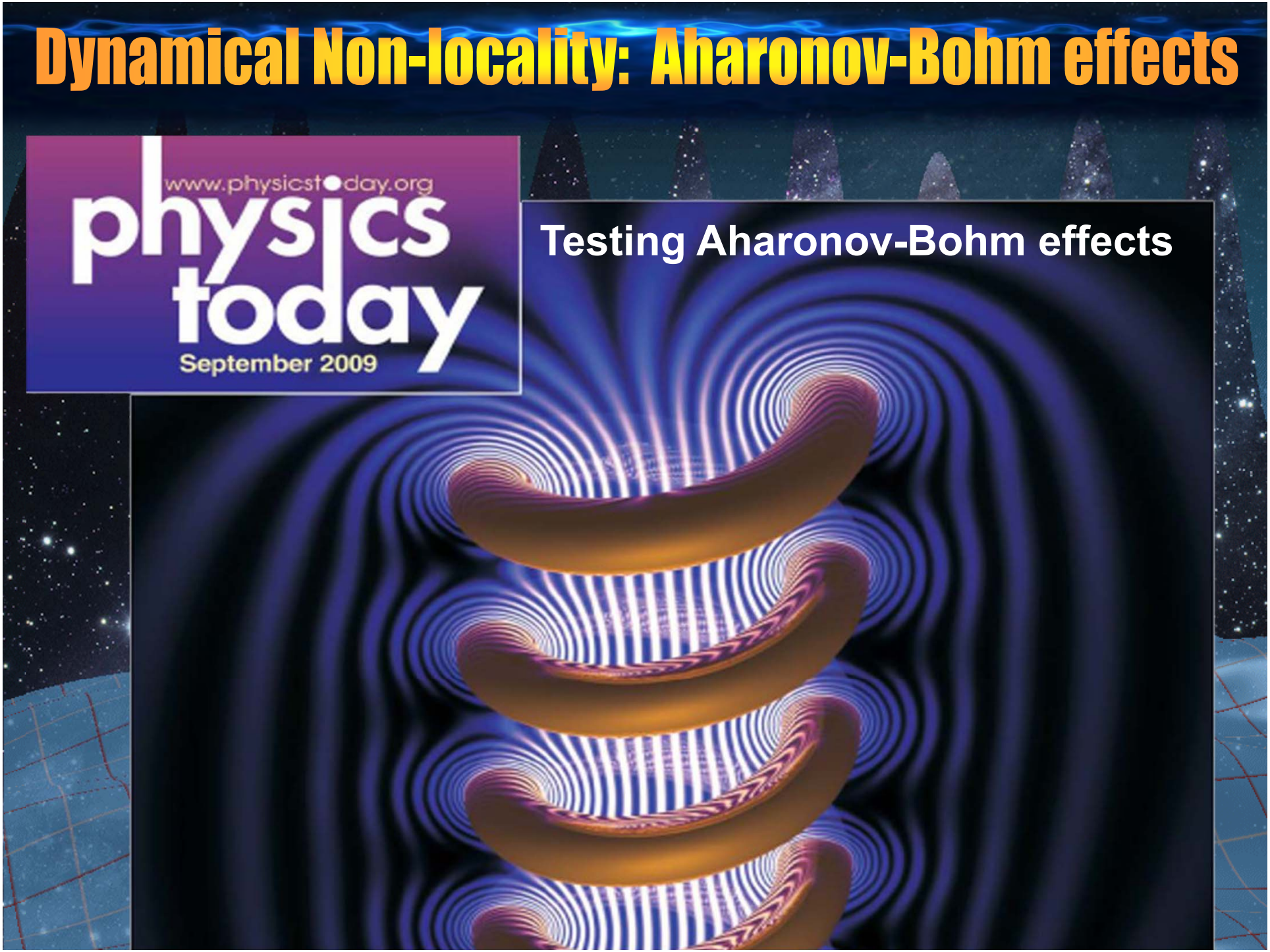




Dirac: little difference between CM equations-of-motion & QM

Aharonov, Cohen, Colombo, Landsberger, Sabadini, Struppa, Tollaksen, "Finally making sense of the double-slit experiment," *Proceedings of the National Academy of Sciences*, Vol 114 Iss 25 (2017)

Dynamical Non-locality: Aharonov-Bohm effects



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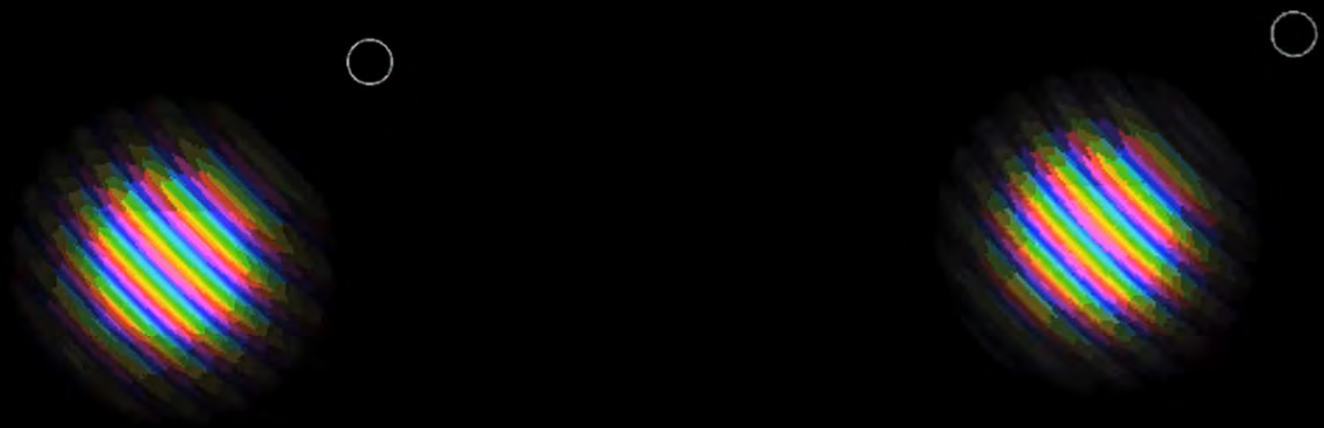
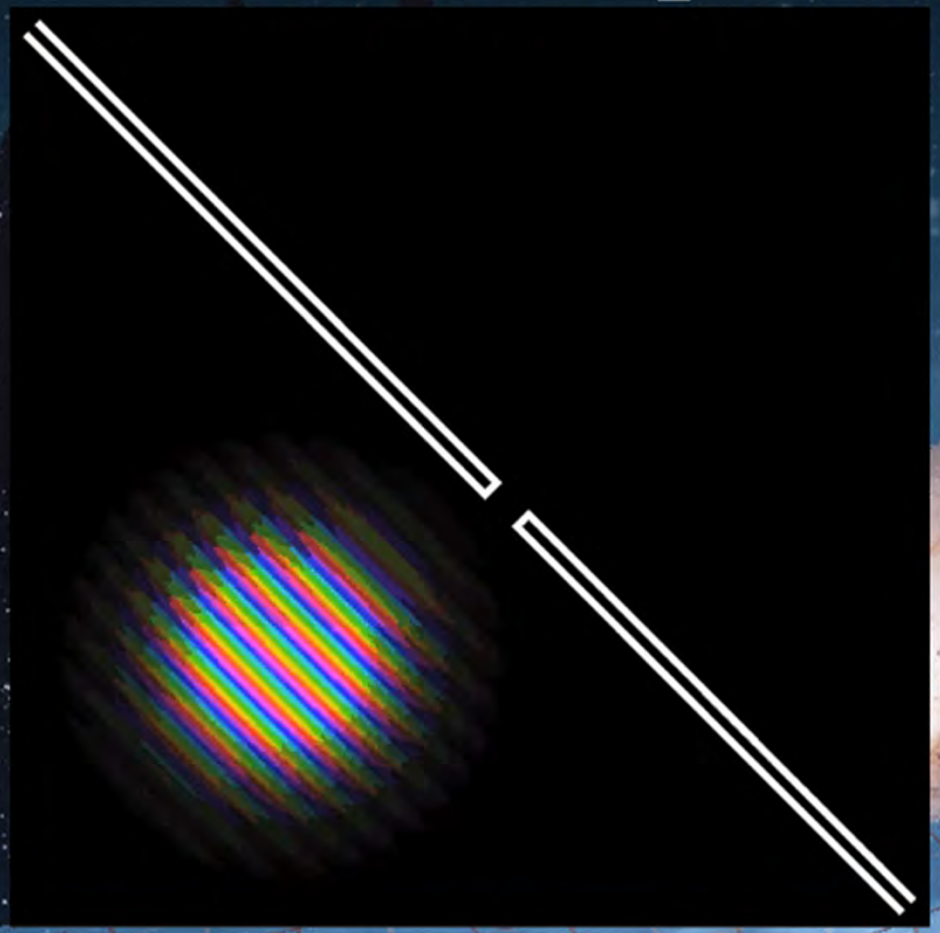
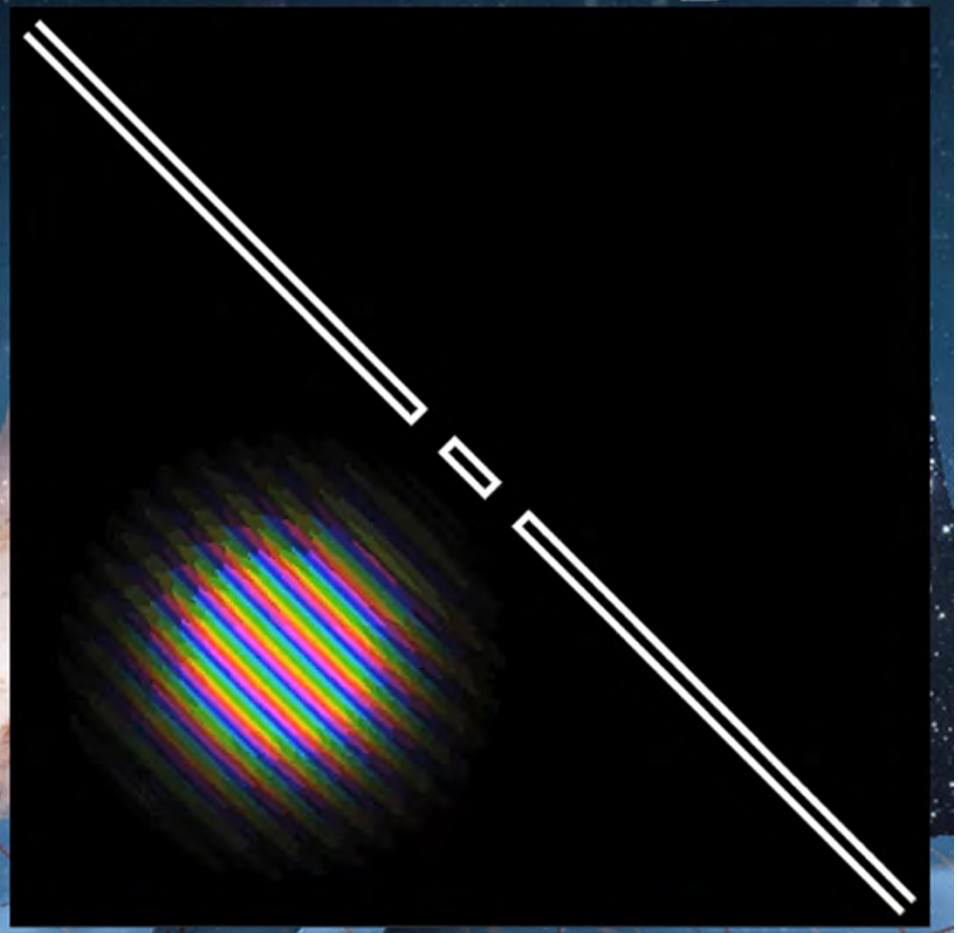


Wave-particle duality





- From perspective of a single particle, how can the opening or closing of the distant slit affect a particle that goes through the right slit?
- Feynman: "Nobody knows how it can be like that"

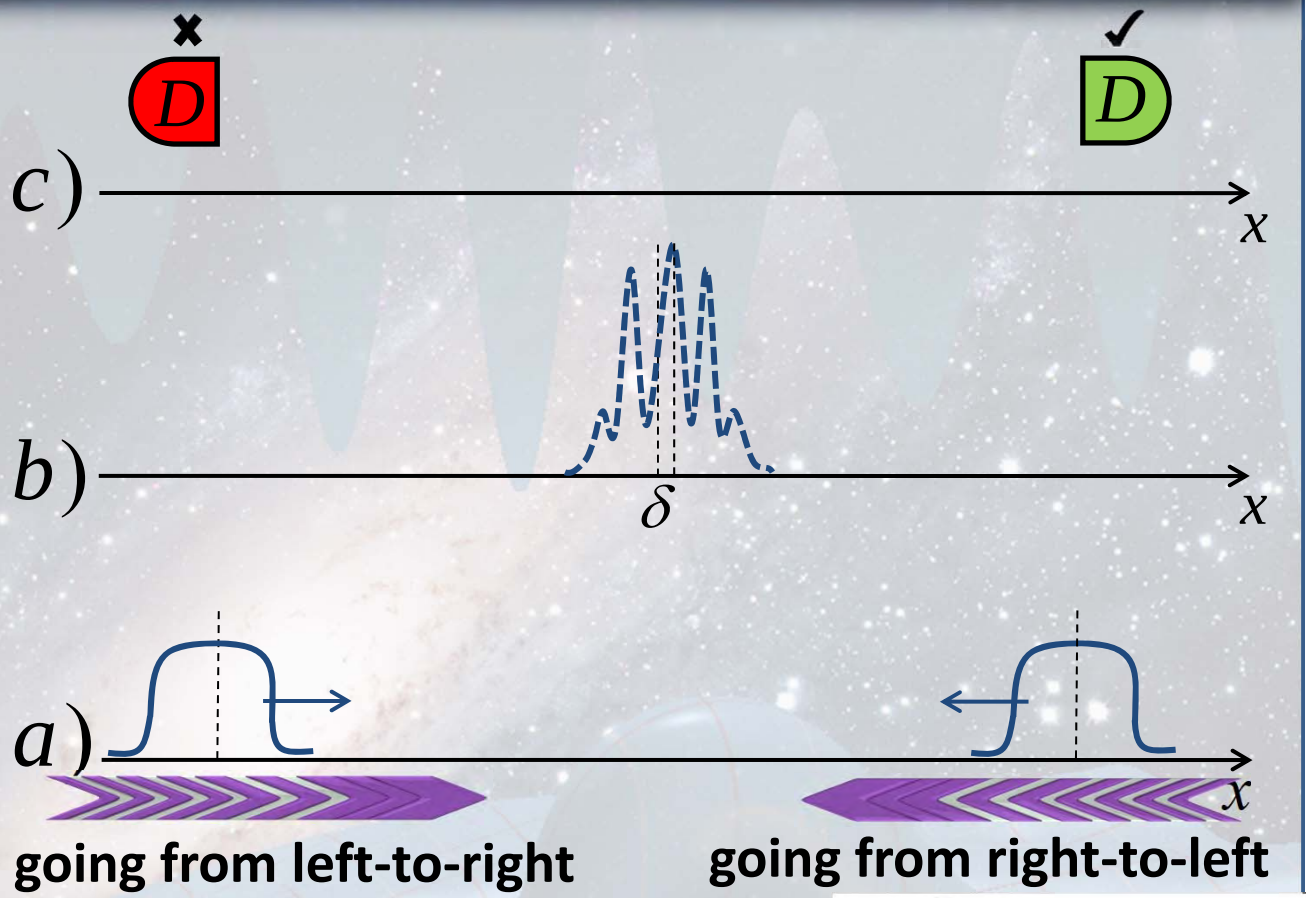
Aharonov, Cohen, Colombo, Landsberger, Sabadini, Struppa, Tollaksen, "Finally making sense of the double-slit experiment," *Proceedings of the National Academy of Sciences*, Vol 114 Iss 25 (2017)

Finally making sense of the double-slit experiment

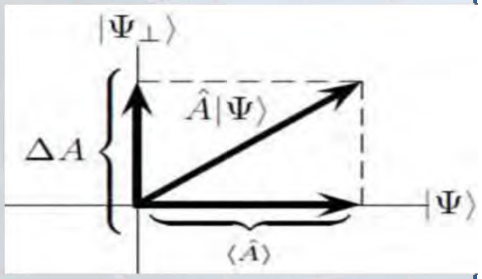
Weak measurement of the interference pattern.

The two wave packets are preselected in ‘a)’ and postselected in ‘c)’.

Weak measurements in ‘b)’ performed during intermediate time shows the usual interference pattern, despite the fact that right-hand detector *D* detects all particles as belonging to just 1 wave packet (moving from left-to-right)

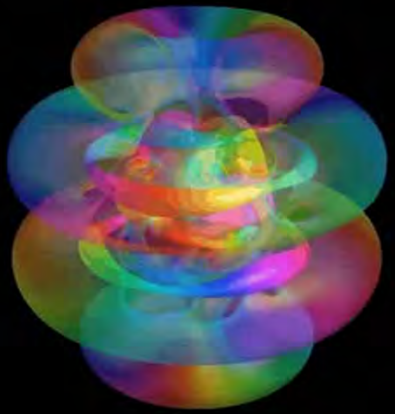


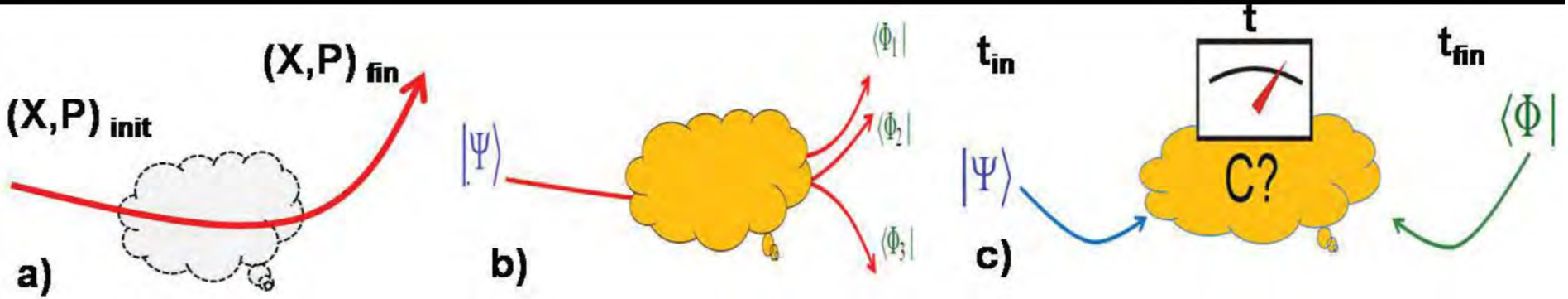
geometry of
$\hat{A}|\Psi\rangle=\langle\hat{A}\rangle|\Psi\rangle+\Delta A|\Psi_\perp\rangle$



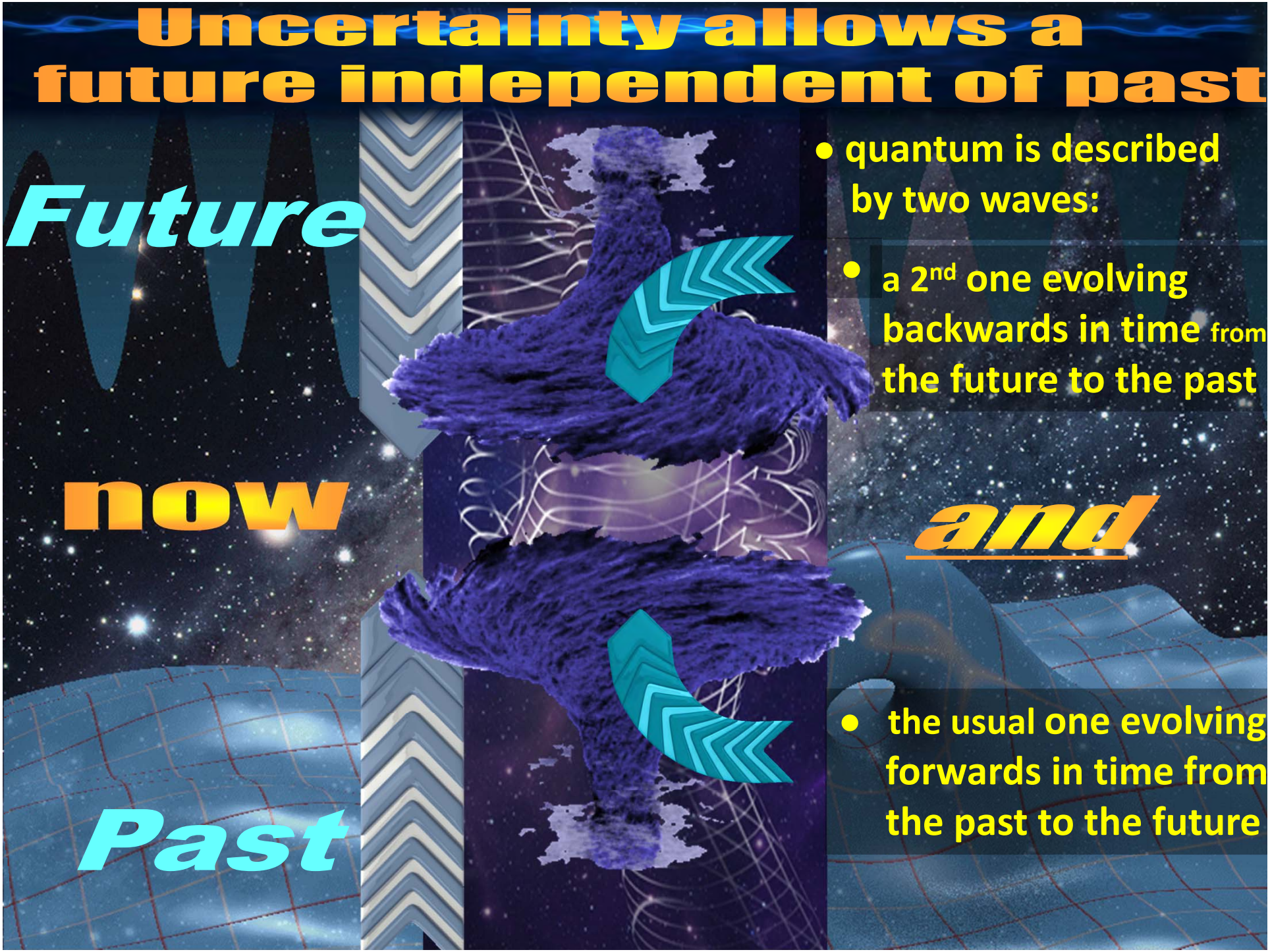
Aharonov, Cohen, Colombo, Landsberger, Sabadini, Struppa, Tollaksen, “Finally making sense of the double-slit experiment,” *Proceedings of the National Academy of Sciences*, Vol 114 Iss 25 (2017)

- 1st atom decays in 1 min





Uncertainty allows a future independent of past



- quantum is described by two waves:
  - a 2nd one evolving backwards in time from the future to the past

and

  - the usual one evolving forwards in time from the past to the future

The future is relevant to the present? Really?

We've got experiments, quantum miracles, etc
This still makes my head twist.

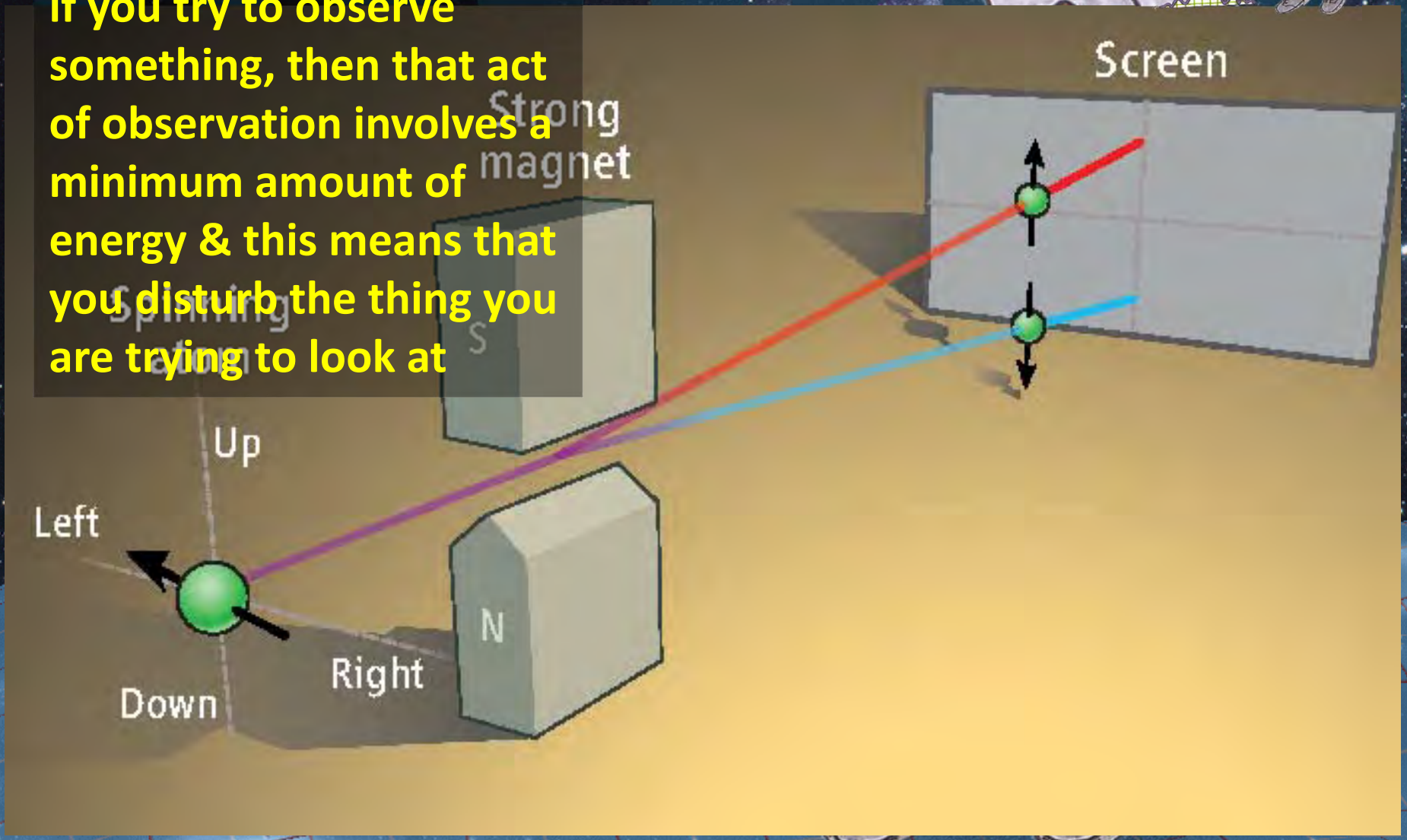
SKEPTICAL DOG
is SKEPTICAL

is SKEPTICAL

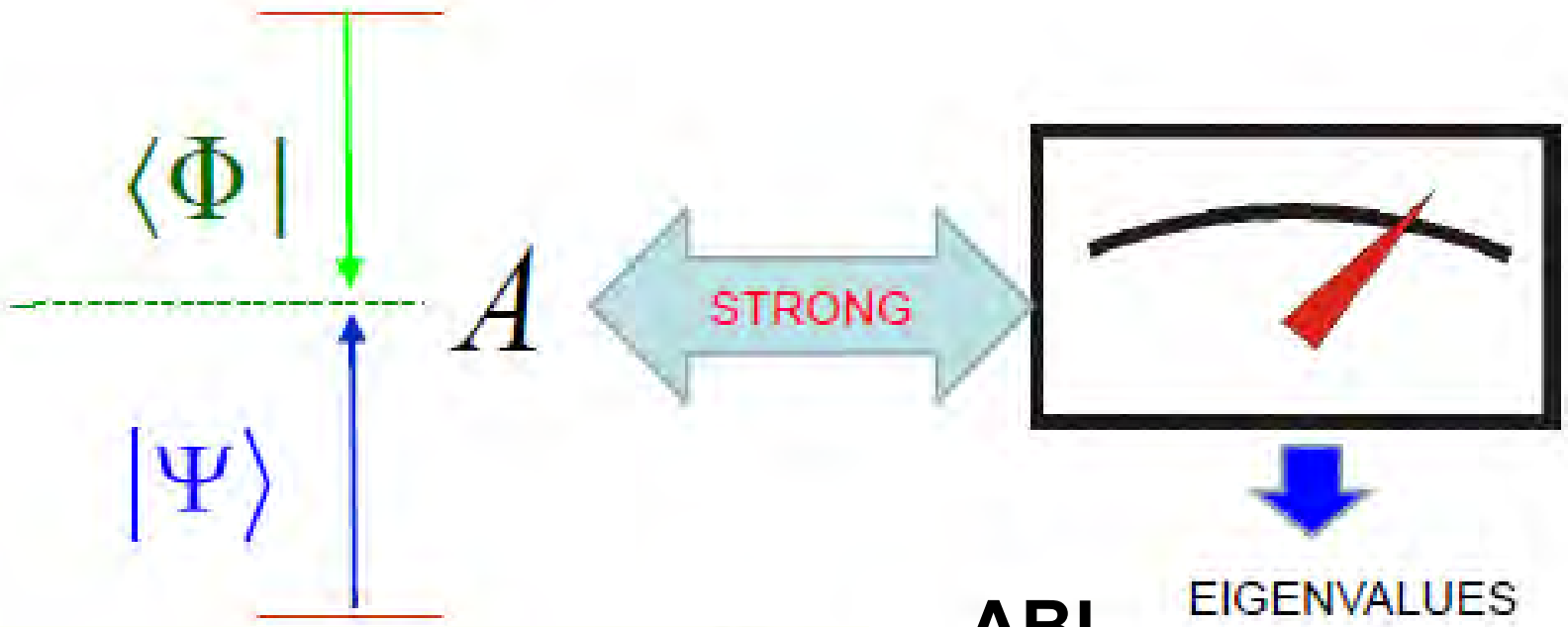
From one of Max Tegmark's FQXi talks

Ways of knowing: strong measurement

if you try to observe something, then that act of observation involves a minimum amount of energy & this means that you disturb the thing you are trying to look at

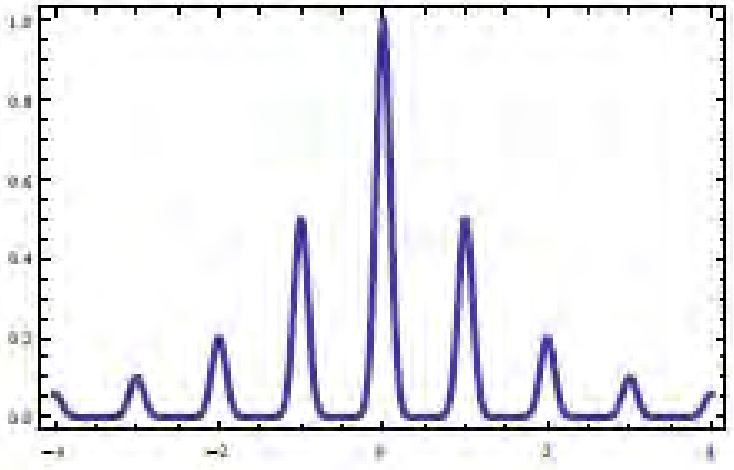


Strong measurements



EIGENVALUES

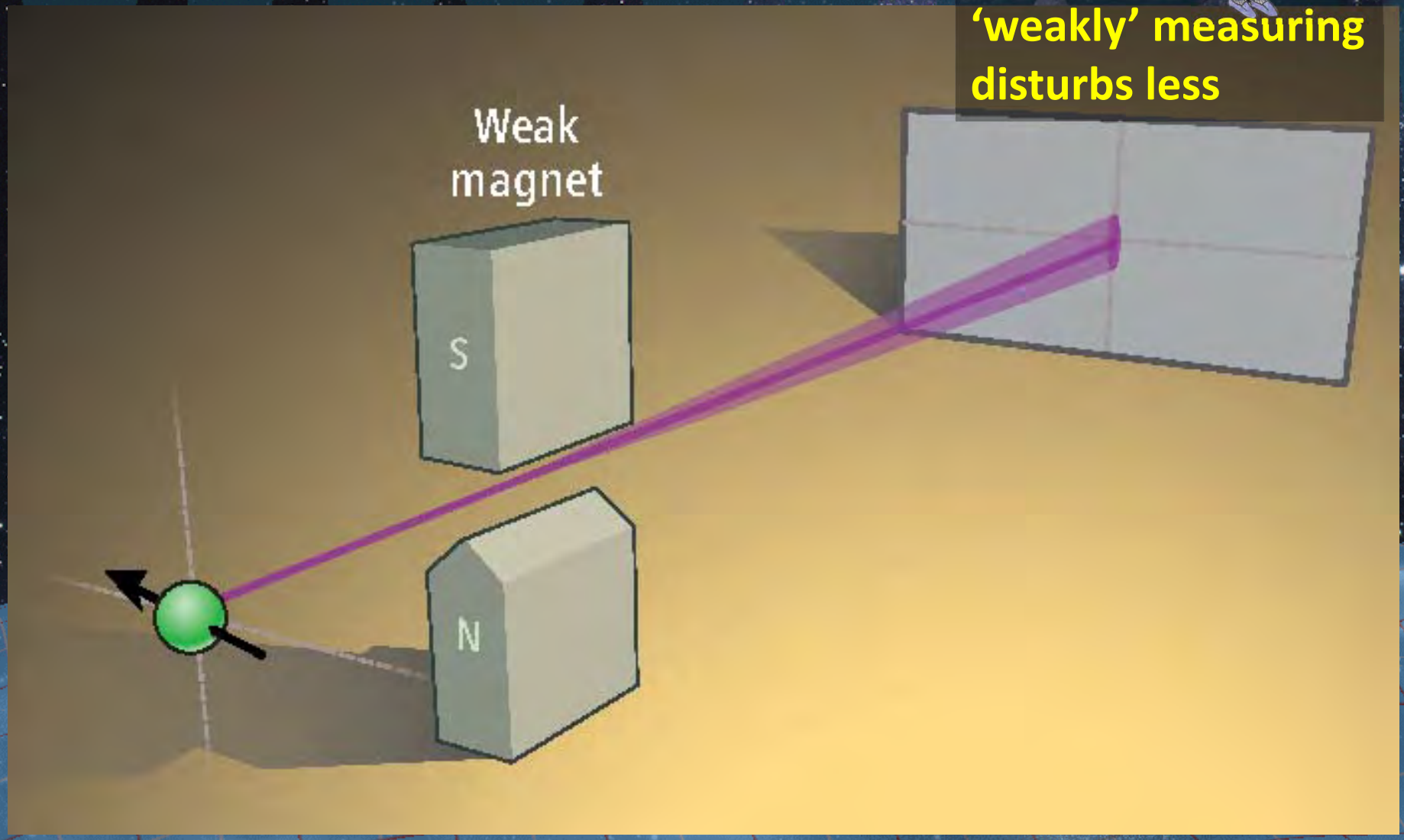
ABL

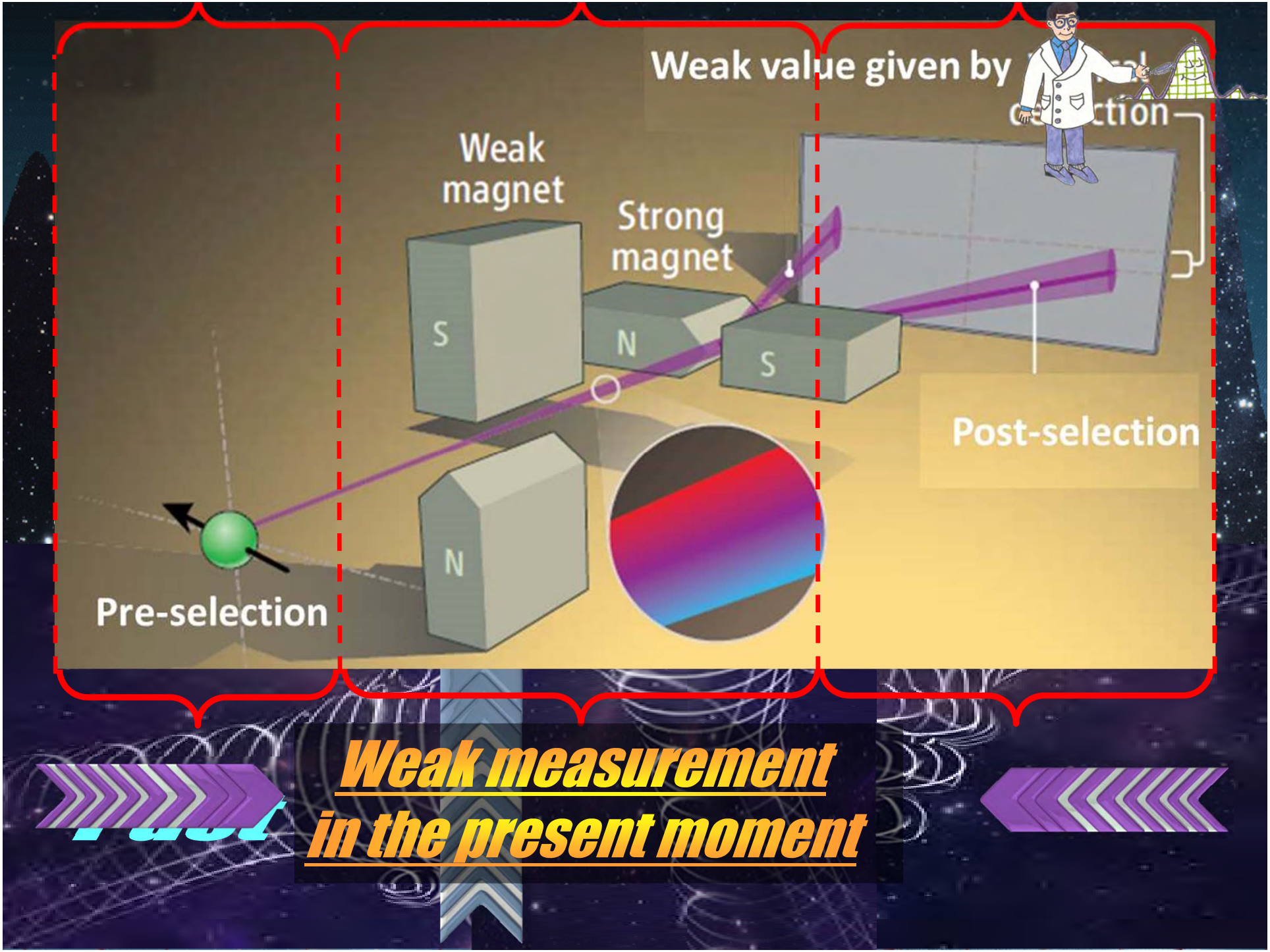


Courtesy Alter

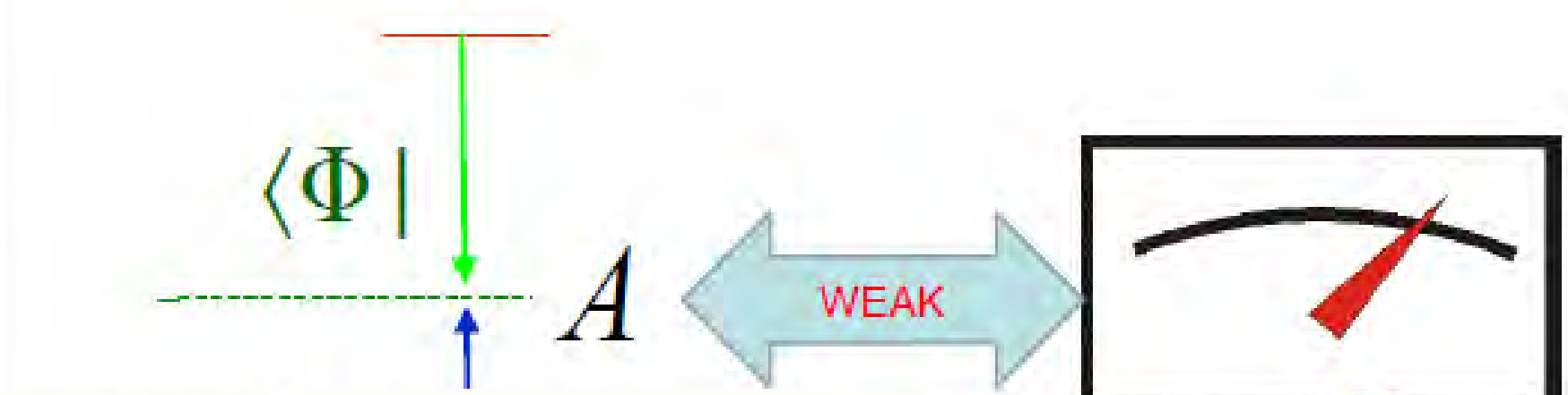
Ways of knowing: gentle measurement

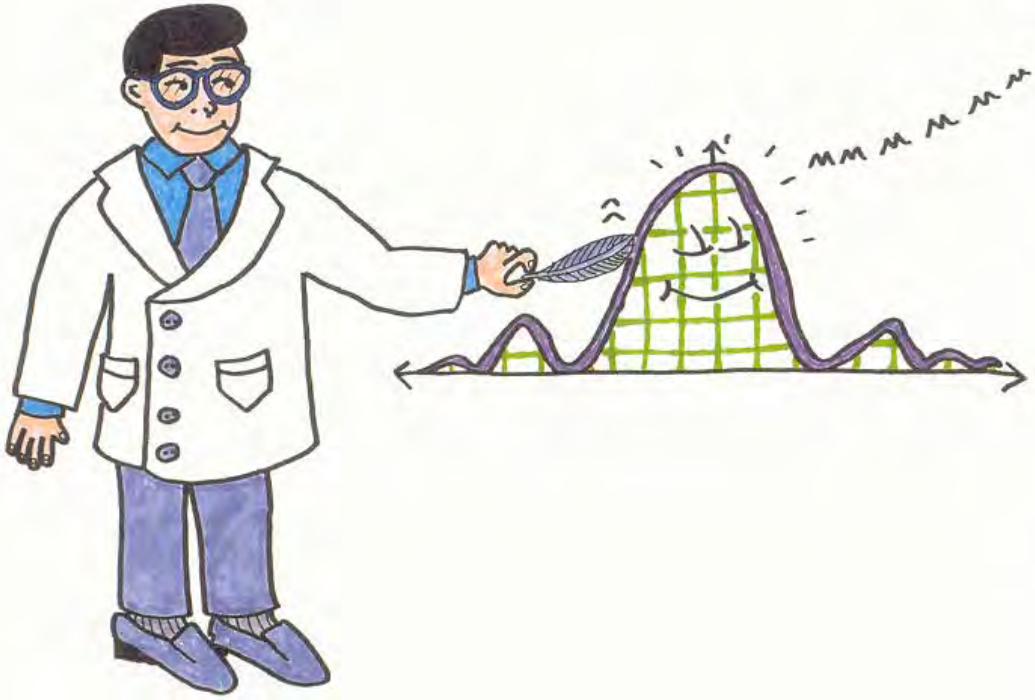
Making a weak measurement

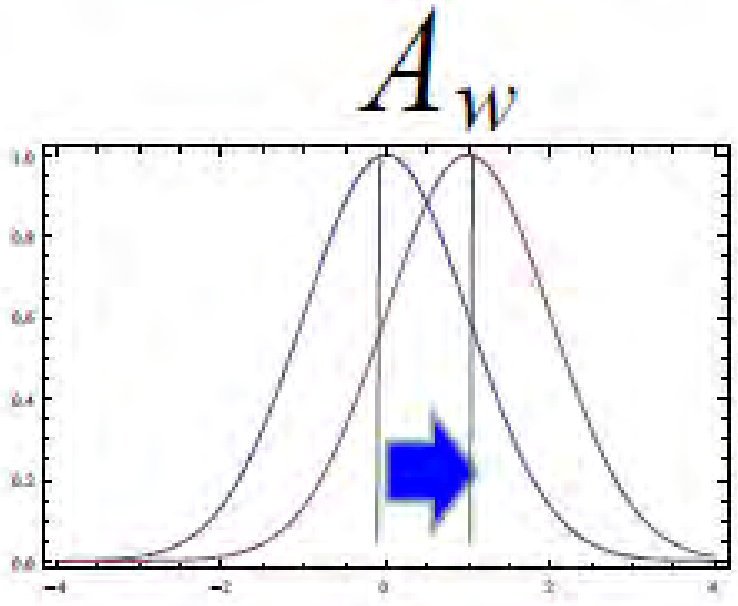



Weak value given by
Weak magnet
Strong magnet
S
N
S
N
Post-selection
Pre-selection
Weak measurement
in the present moment

Weak measurements







Courtesy Alter

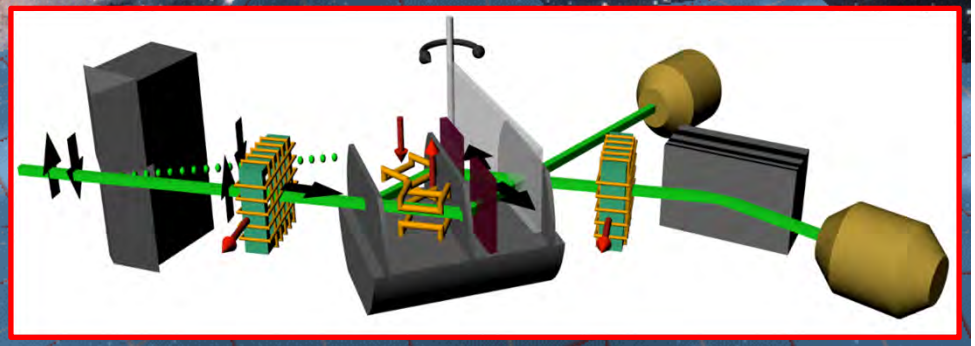
Quantum Miracle #1: Quantum Chesire Cat

‘Well I've often seen a cat without a grin,’ thought Alice ‘but a grin without a cat! It’s the most curious thing I ever saw in all my life

In my PhD, I introduced numerous new effects to emphasize: ‘and now for something completely different’

Quantum Miracle #1: Quantum Chesire Cat

Separating a particle from its properties seems impossible
If it is influenced only by its past and not its future

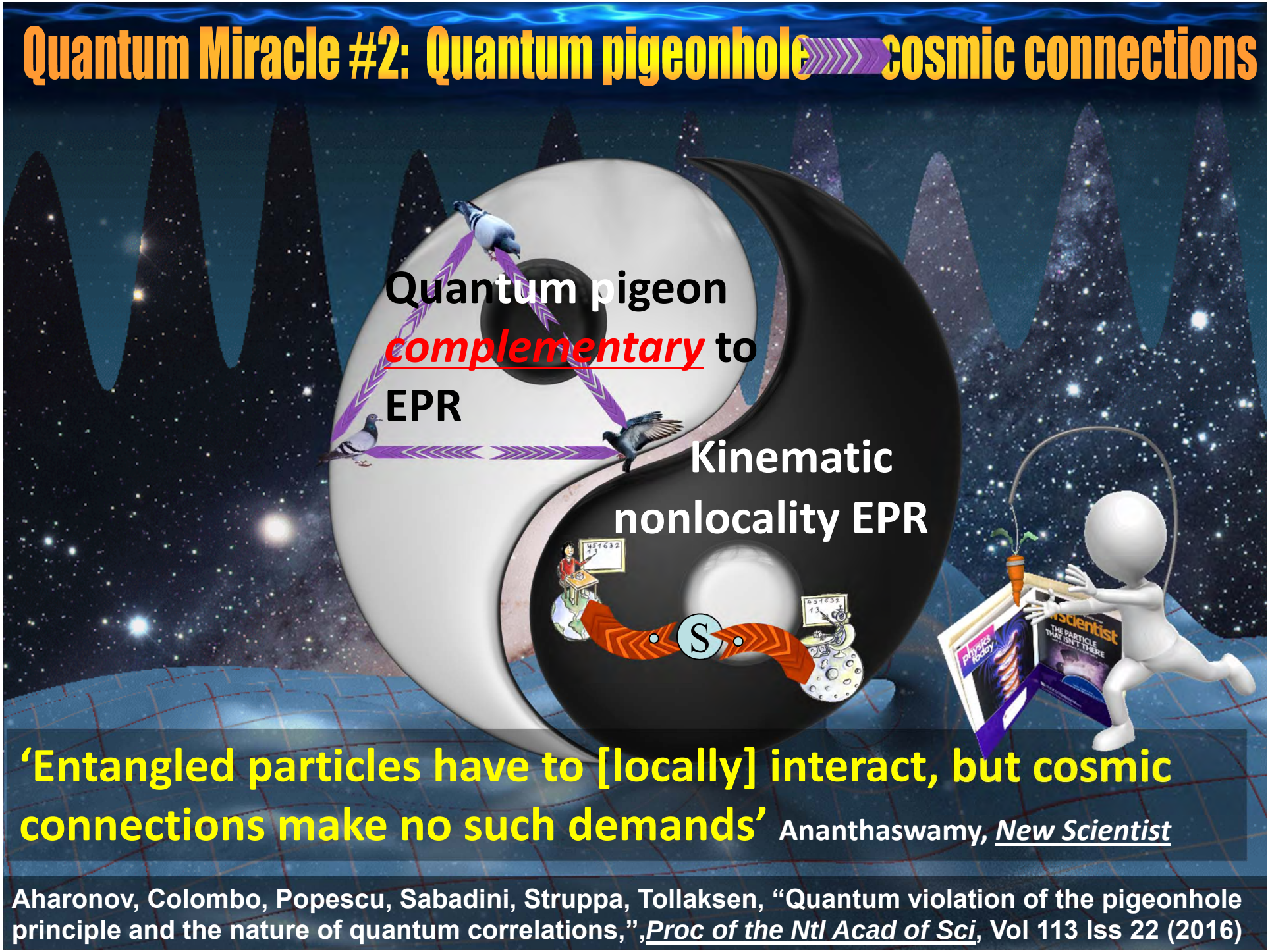


Experiment: Denkmayr, Geppert, Sponar, Lemmel, Matzkin, Tollaksen, Hasegawa; ***Nature Communications***;
Theory: Tollaksen 2001; Aharonov & Rohrlich 2005; Aharonov et al arXiv1202.0631; arXiv1203.4215

Quantum Miracle #2: Quantum pigeonhole principle

Aharonov, Colombo, Popescu, Sabadini, Struppa, Tollaksen, "Quantum violation of the pigeonhole principle and the nature of quantum correlations,",*Proc of the Ntl Acad of Sci*, Vol 113 Iss 22 (2016)

Quantum Miracle #2: Quantum pigeonhole ⟹ cosmic connections



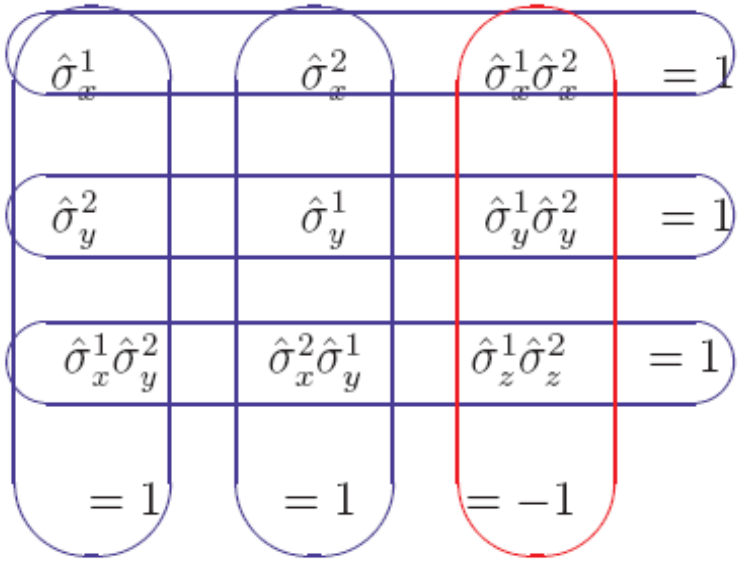
'Entangled particles have to [locally] interact, but cosmic connections make no such demands' Ananthaswamy, *New Scientist*

Aharonov, Colombo, Popescu, Sabadini, Struppa, Tollaksen, "Quantum violation of the pigeonhole principle and the nature of quantum correlations,",*Proc of the Ntl Acad of Sci*, Vol 113 Iss 22 (2016)

Quantum Miracle #2: Quantum pigeonhole >>>> cosmic connections

US National Academy of Sciences votes 'Quantum Pigeonhole" best paper out of all the hard sciences published in 2017

Weak Values and Contextuality



- **BKS theorem posits that no noncontextual hidden variable theory (NCHVT) can explain the predictions of QM**
- **For any quantum state, an NCHVT must assign a single eigenvalue to every observable of a system, such that it has the same value regardless of which context (set of commuting observables) it is measured in.**
- **Proof: any NCHVT assignment violates predictions of QM**

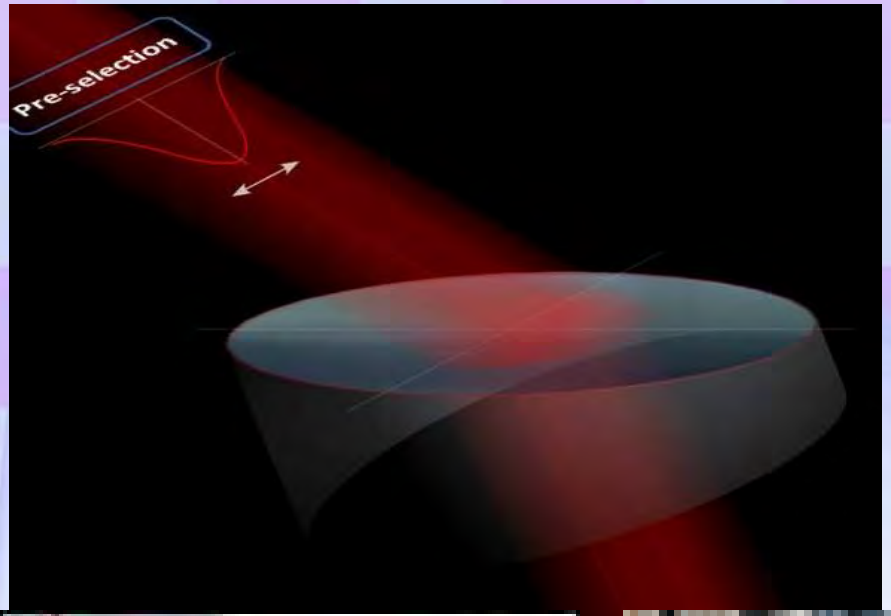
  Tollaksen, *Journal of Physics A*, 40 (2007) 9033-9066)

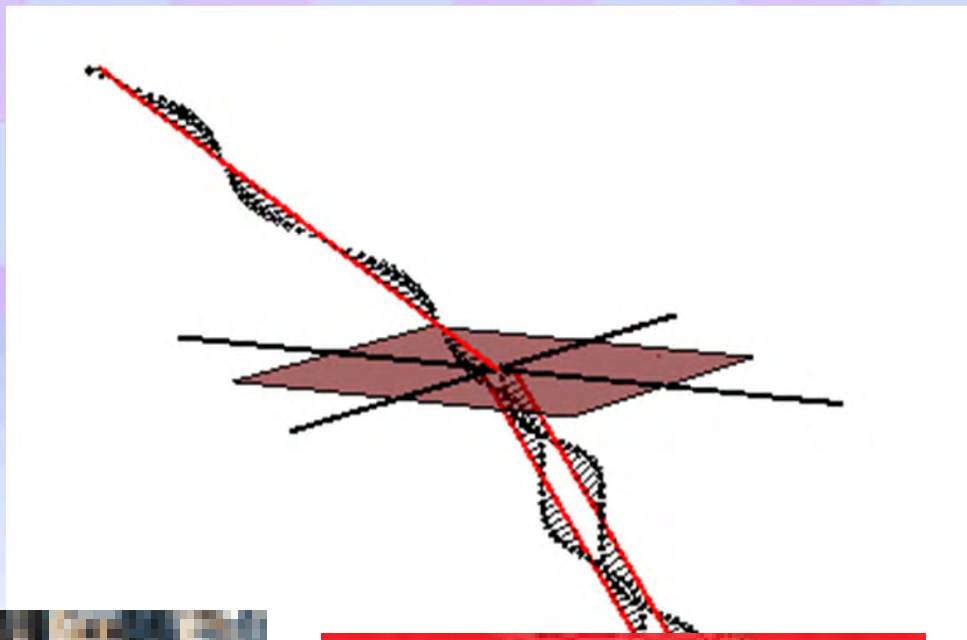
Weak Values and Contextuality

- **Confined BKS contextuality, PPS paradoxes, and anomalous weak values, are just different aspects of the same fundamental conflict between classical and quantum reality**
- **This conflict can be witnessed by measuring anomalous weak values in PPS ensembles**
- **PPS paradoxes are resolved by considering the weak values of all observables as physical, rather than the NCHVT eigenvalue assignments**
- Tollaksen, ***Journal of Physics A***, 40 (2007) 9033-9066); M Waegell, JT "Contextuality, Pigeonholes, Cheshire Cats, Mean Kings, and Weak Values," arXiv: 1505.00098; M.F. Pusey, "Anomalous weak values are proofs of contextuality," ***Physical Review Letters***, 113, 200401 (2014); M.S. Leifer and M.F. Pusey, "Is a time symmetric interpretation of quantum theory possible without retrocausality?" ***PROCEEDINGS OF THE ROYAL SOCIETY A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES*** Volume: 473 Issue: 2202 Article Number: 20160607 Published: JUN 1 2017

New paradigm for amplifying signals (AAV effect)

- Enhanced sensitivity by 10^4 (Hosten, Kwiat, *Science* 2/8/08)





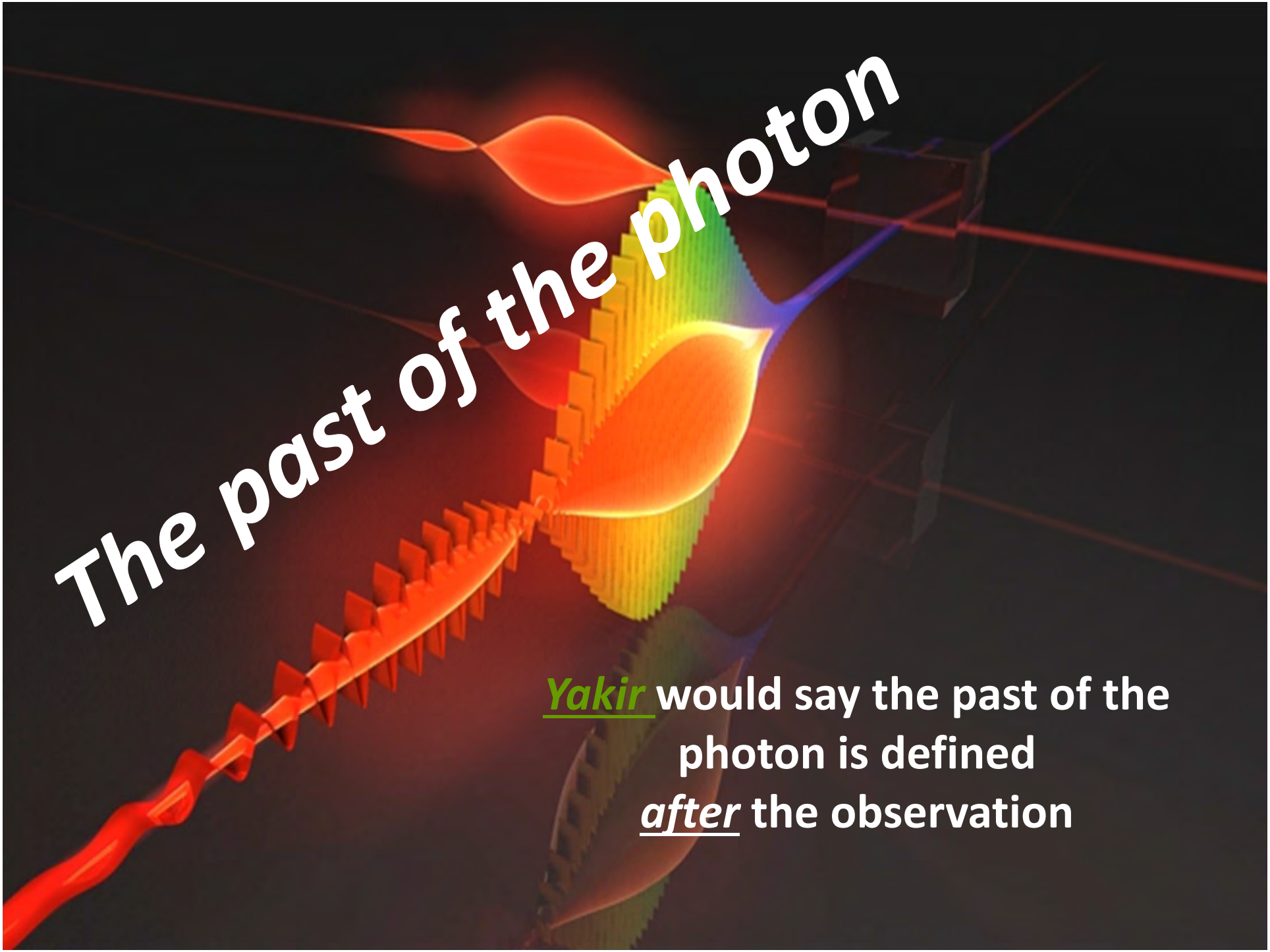
...07)...at

New paradigm for amplifying signals-deflection

The beam would move by a micron traveling across the US

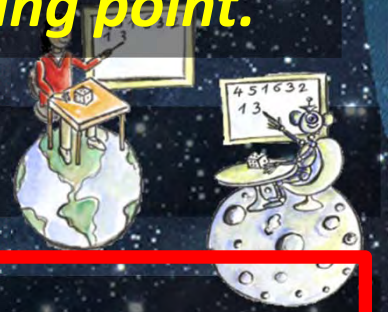
Courtesy Jordan

See Dixon, Starling, Jordan, Howell, PRL, 102, 173601 (2009)+many other articles


The past of the photon
Yakir would say the past of the photon is defined after the observation

Some paradigm-shifts from our research relevant for 'becoming'

Our alternative formulations are completely equivalent to standard QM in so far as their predictions are concerned. But the underlying concepts are dramatically different. So if in the future QM has to be substantively changed to accommodate really new physics, these new formulations might provide a starting point.



Paradigm-shift #1: ***New Nonlocalities***

Paradigm-shift #2: ***Top-down causality***

Paradigm-shift #3: ***Axioms/why quantum***

Paradigm-shift #4: ***Becoming time***

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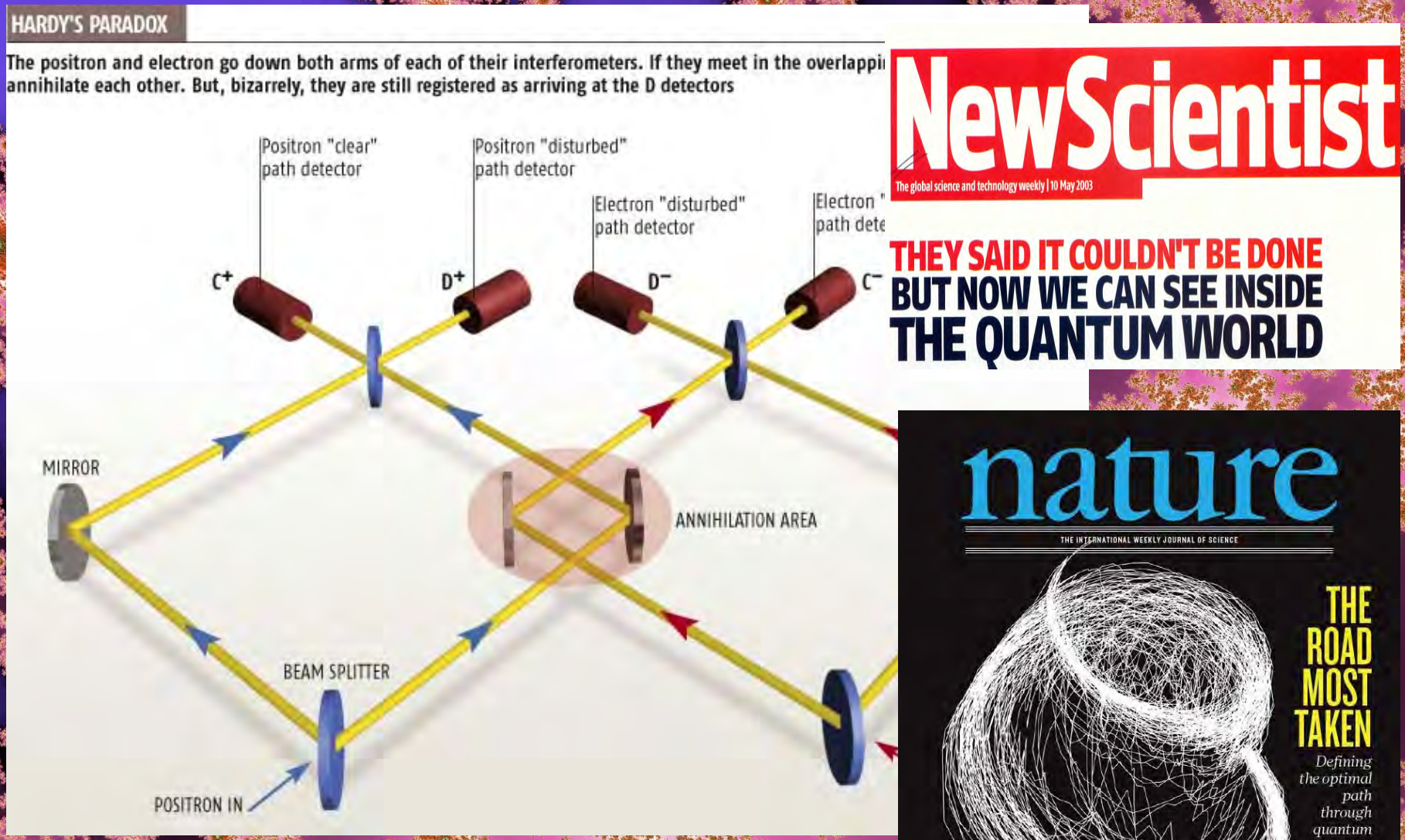
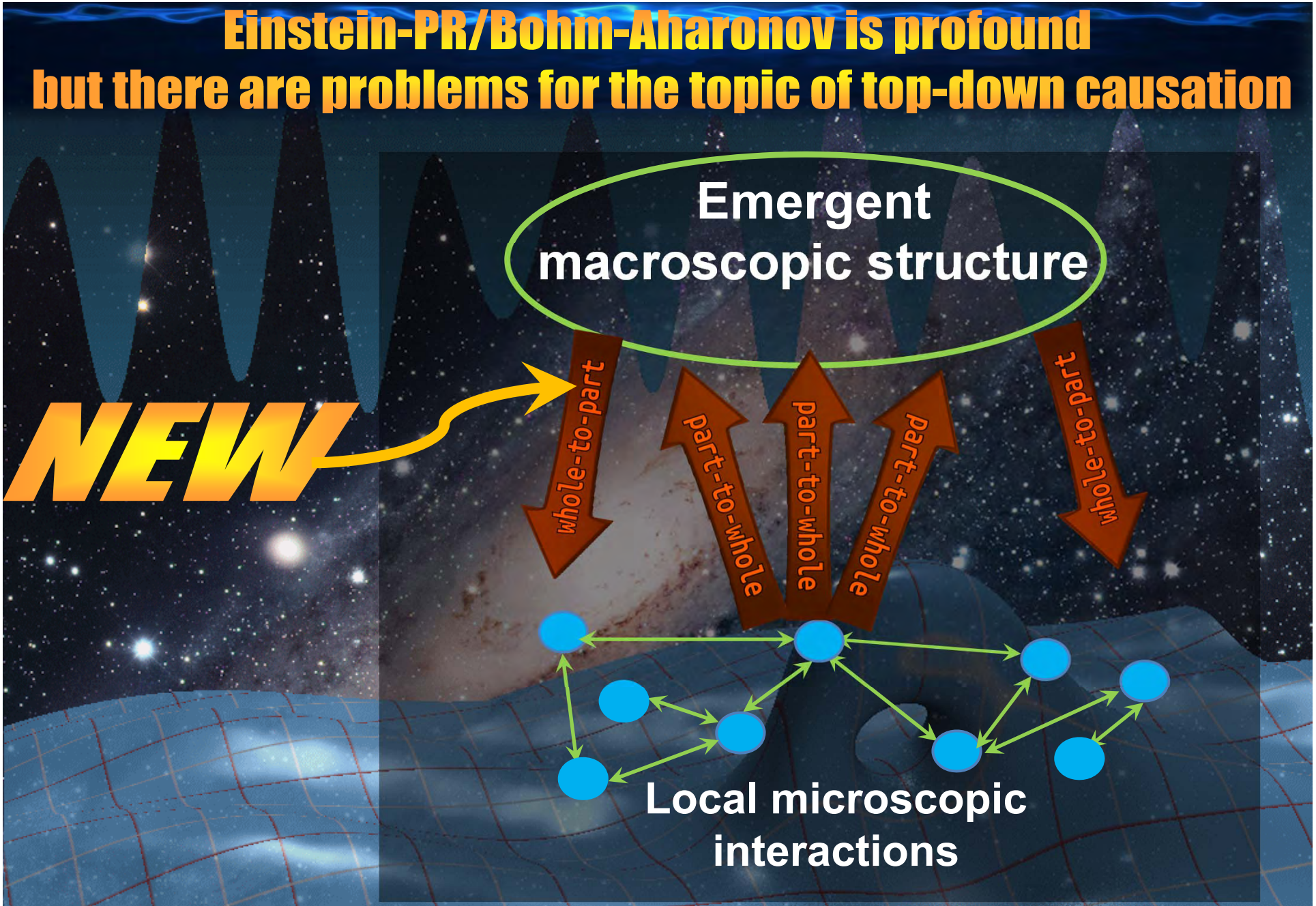
Quantum Miracle #3: atom of Holism & top-down causation



Aharonov, Botero, Popescu, Reznik, Tollaksen, "Revisiting Hardy's Paradox: Counterfactual Statements, Real Measurements, Entanglement and Weak Values" *Phys Lett A*, v301, 130

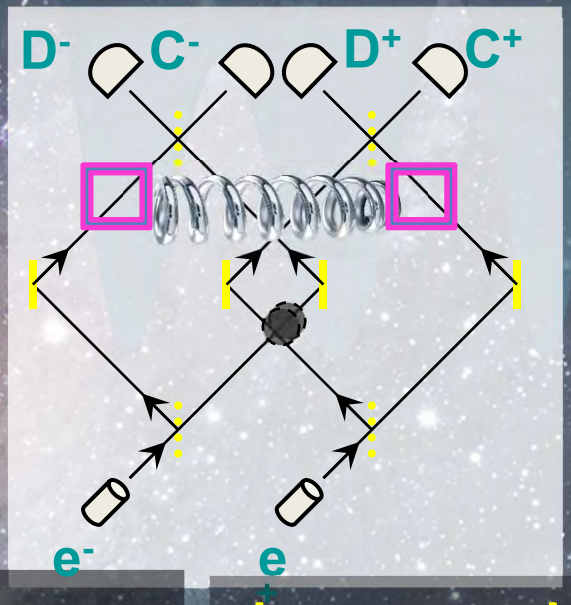
Einstein-PR/Bohm-Aharonov is profound but there are problems for the topic of top-down causation



Aharonov, Cohen, Tollaksen "A Completely Top-Down Hierarchical Structure in Quantum Mechanics", arXiv1709.07052; *Proceedings of the National Academy of Sciences*, (2018)

Quantum Miracle #3: atom of Holism & top-down causation

- While there is no particle in either outer path
- Nevertheless, the interaction between the 2 paths/boxes tells us there *is a particle in each box* only when we look at the whole, ie both boxes



No particle here

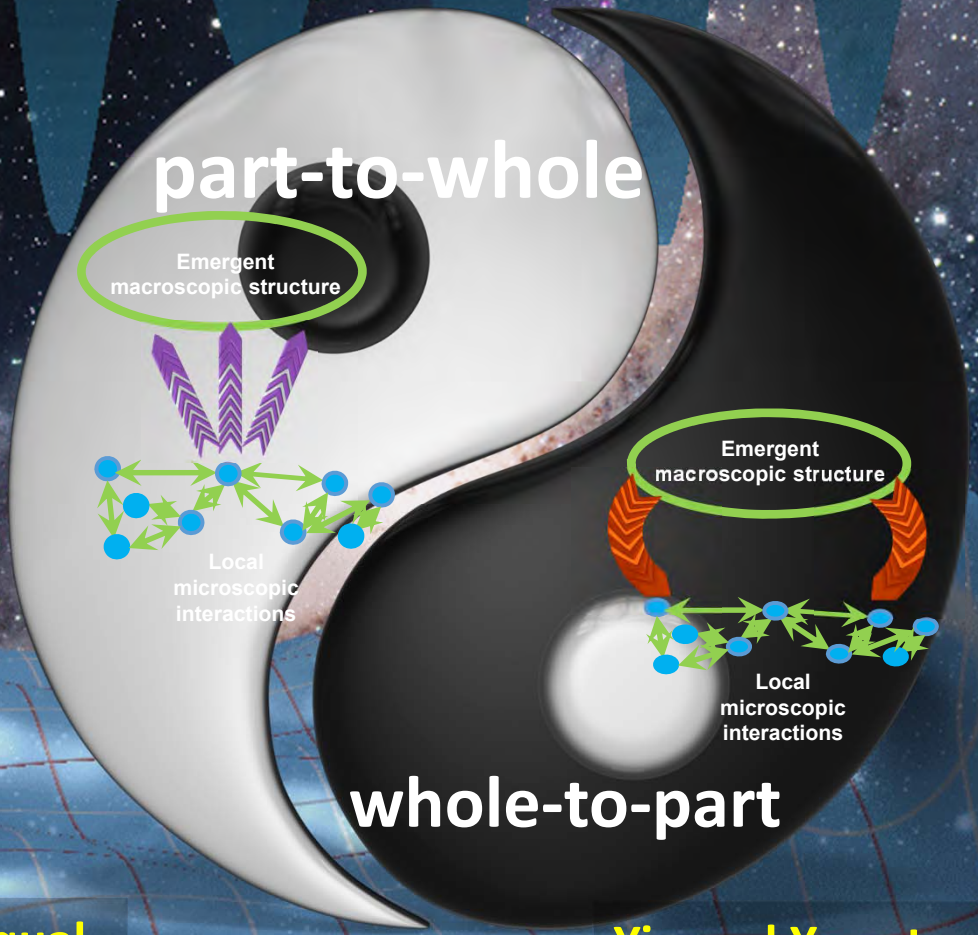
No particle here

there are Wholes that have causal and measureable effects that are not reducible to any combination of parts

Aharonov, Cohen, Tollaksen "A Completely Top-Down Hierarchical Structure in Quantum Mechanics", arXiv1709.07052 ; Aharonov, Botero, Popescu, Reznik, Jeff Tollaksen, "Revisiting Hardy's Paradox: Counterfactual Statements, Real Measurements, Entanglement and Weak Values" *Phys Lett A*, v301, 130; JT 2001

AHA also introduced complementarity between part ⟶ whole & whole ⟶ part

Yin & yang cannot exist separately-they embrace each other in complete harmony

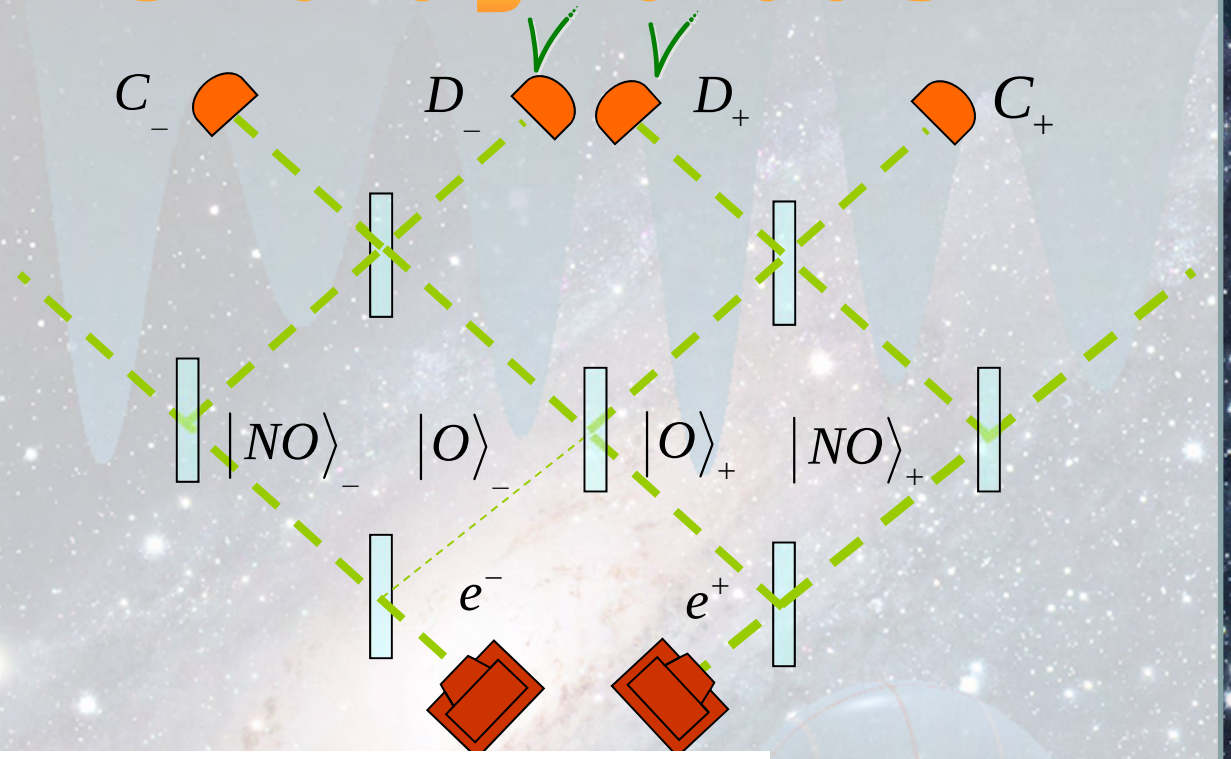


Yin and Yang are equal

Yin and Yang together form a whole

Aharonov, Cohen, Tollaksen "A Completely Top-Down Hierarchical Structure in Quantum Mechanics", arXiv1709.07052; *Proceedings of the National Academy of Sciences*, (2018)

The Hardy Paradox



$$|\psi_i\rangle = \frac{1}{\sqrt{3}}[|O\rangle_+|NO\rangle_- + |NO\rangle_+|O\rangle_- + |NO\rangle_+|NO\rangle_-]$$

$$|\psi_f\rangle = \frac{1}{2}(|O\rangle_+ - |NO\rangle_+)(|O\rangle_- - |NO\rangle_-)$$

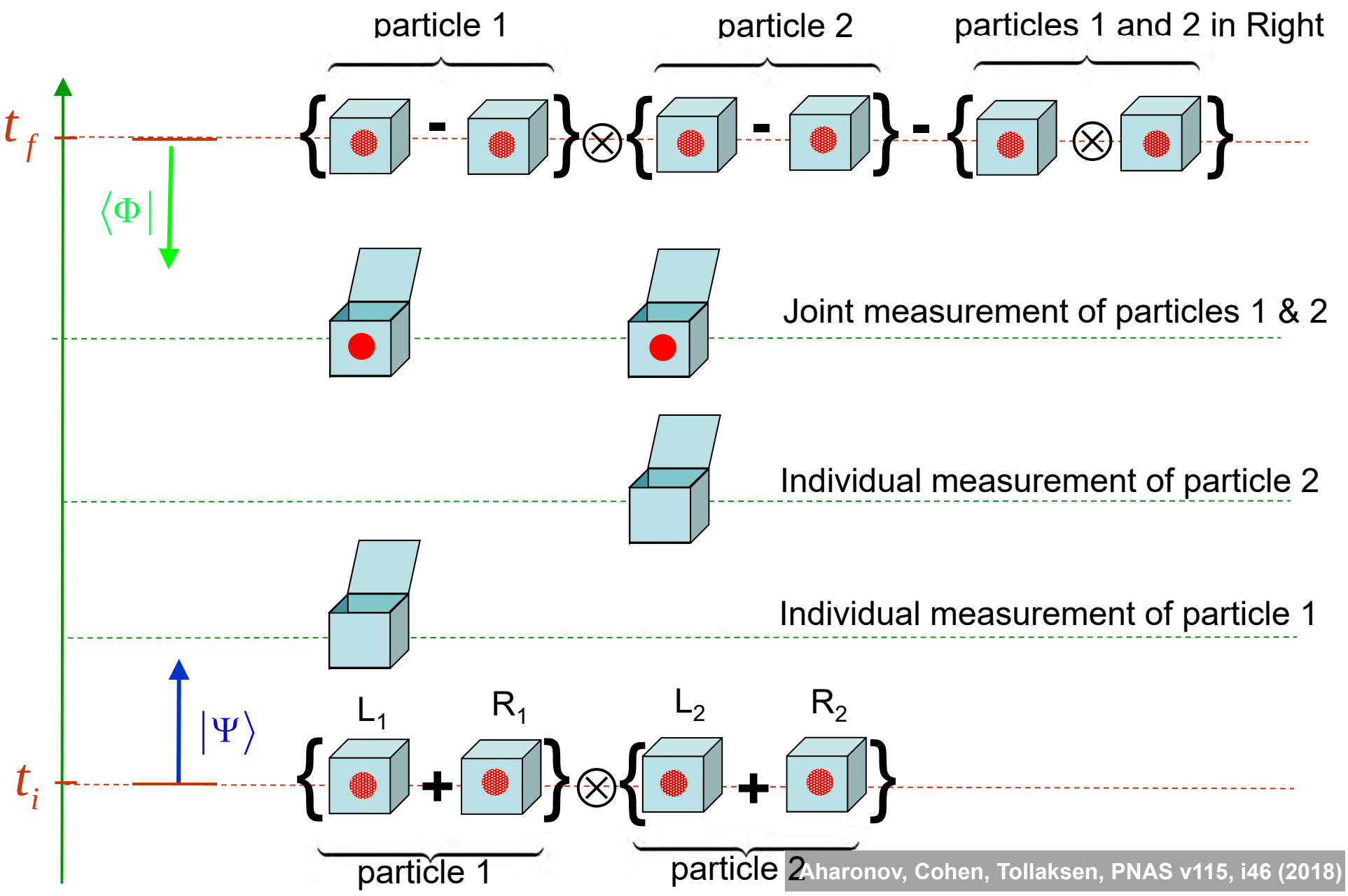
$$\langle \Pi_O^- \Pi_O^+ \rangle_w = 0 \qquad \langle \Pi_{NO}^- \Pi_{NO}^+ \rangle_w = -1 \qquad \langle \Pi_{NO}^- \Pi_O^+ \rangle_w = \langle \Pi_O^- \Pi_{NO}^+ \rangle_w = +1$$

$$\langle \Pi_{NO}^- \rangle_w = \langle \Pi_{NO}^- \Pi_O^+ \rangle_w + \langle \Pi_{NO}^- \Pi_{NO}^+ \rangle_w = 1 - 1 = 0$$

$$\langle \Pi_{NO}^+ \rangle_w = \langle \Pi_O^- \Pi_{NO}^+ \rangle_w + \langle \Pi_{NO}^- \Pi_{NO}^+ \rangle_w = 1 - 1 = 0$$

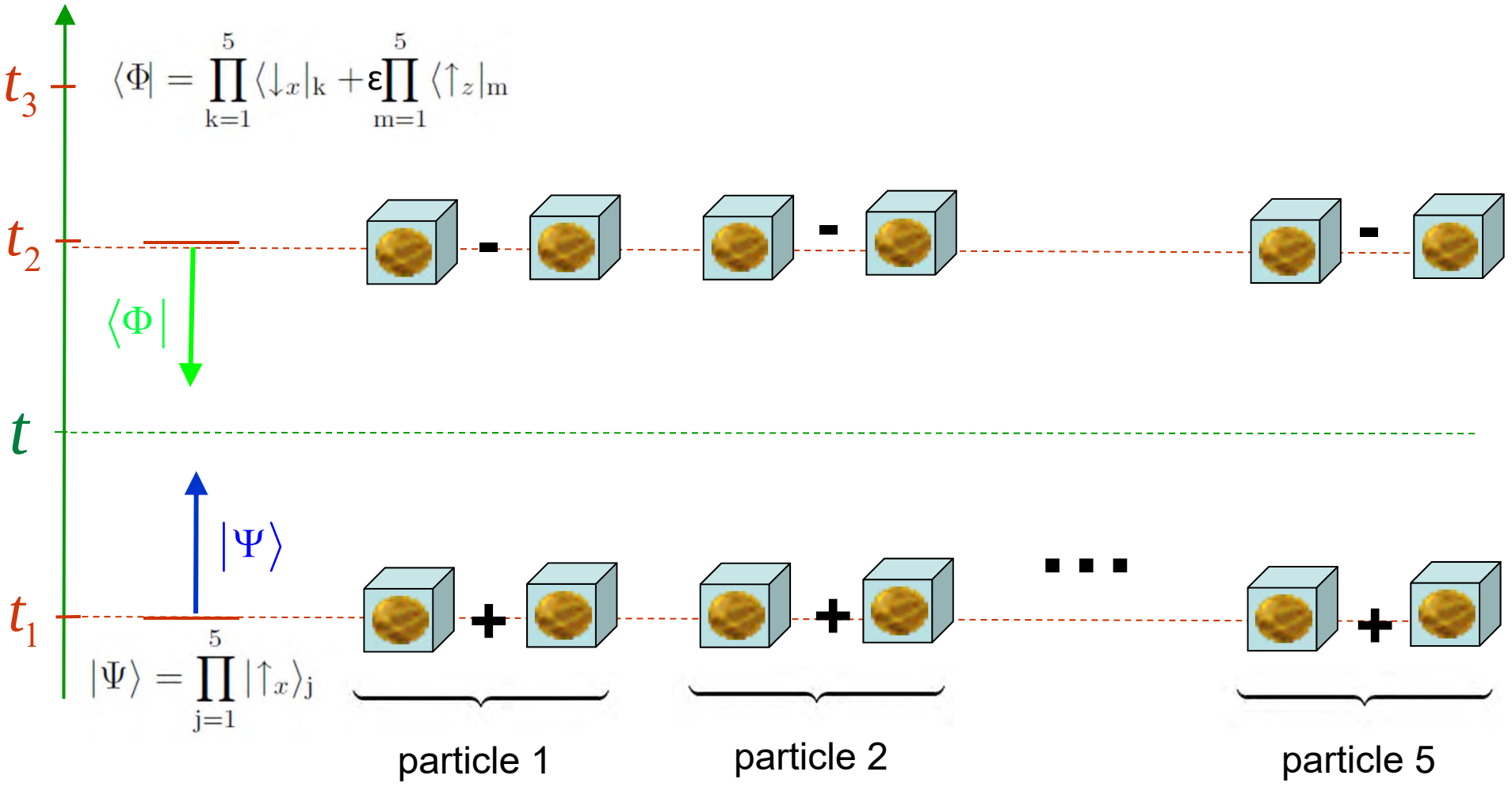
Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Generalization of top-down causality



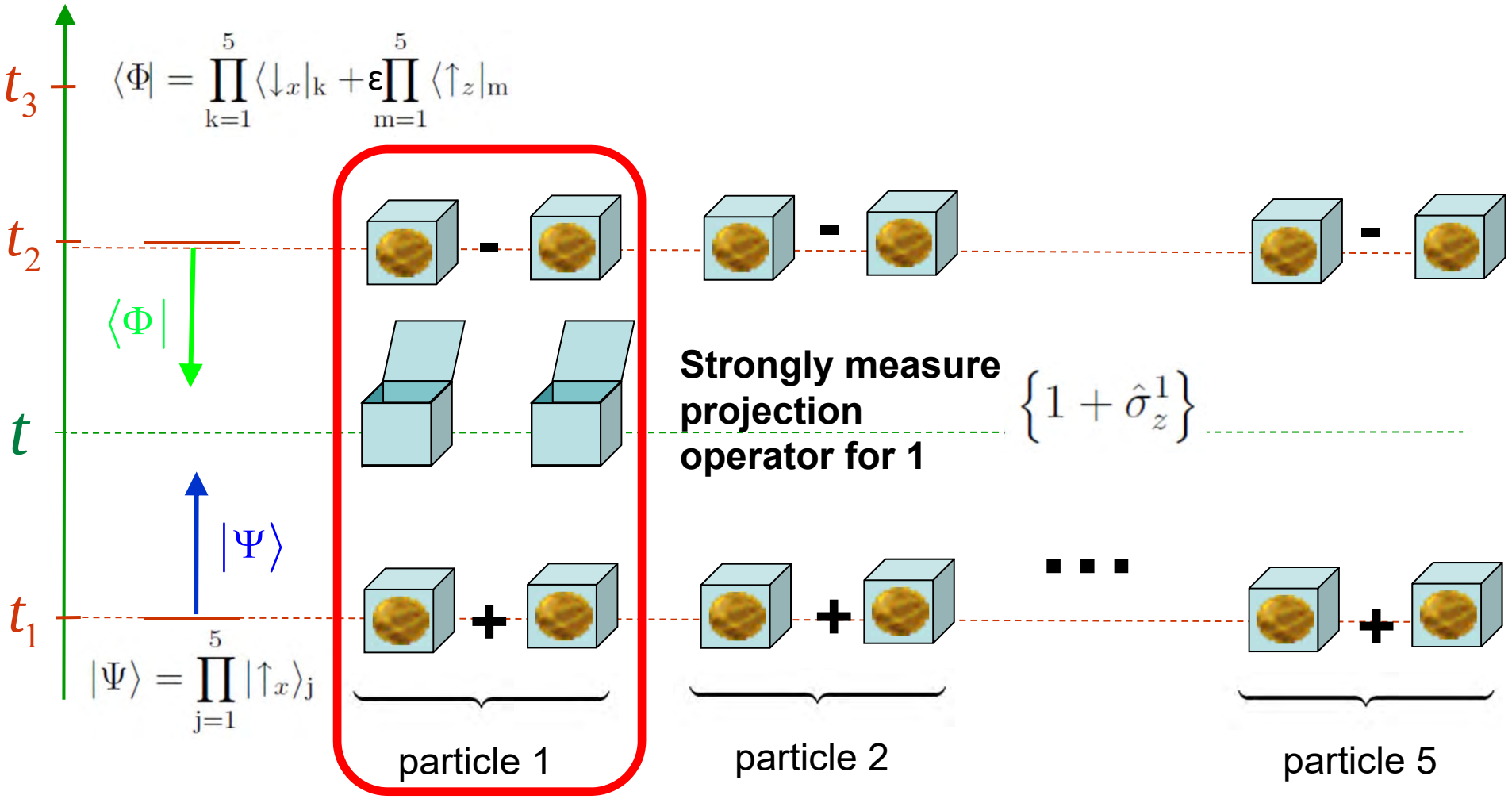
Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Generalization of top-down causality



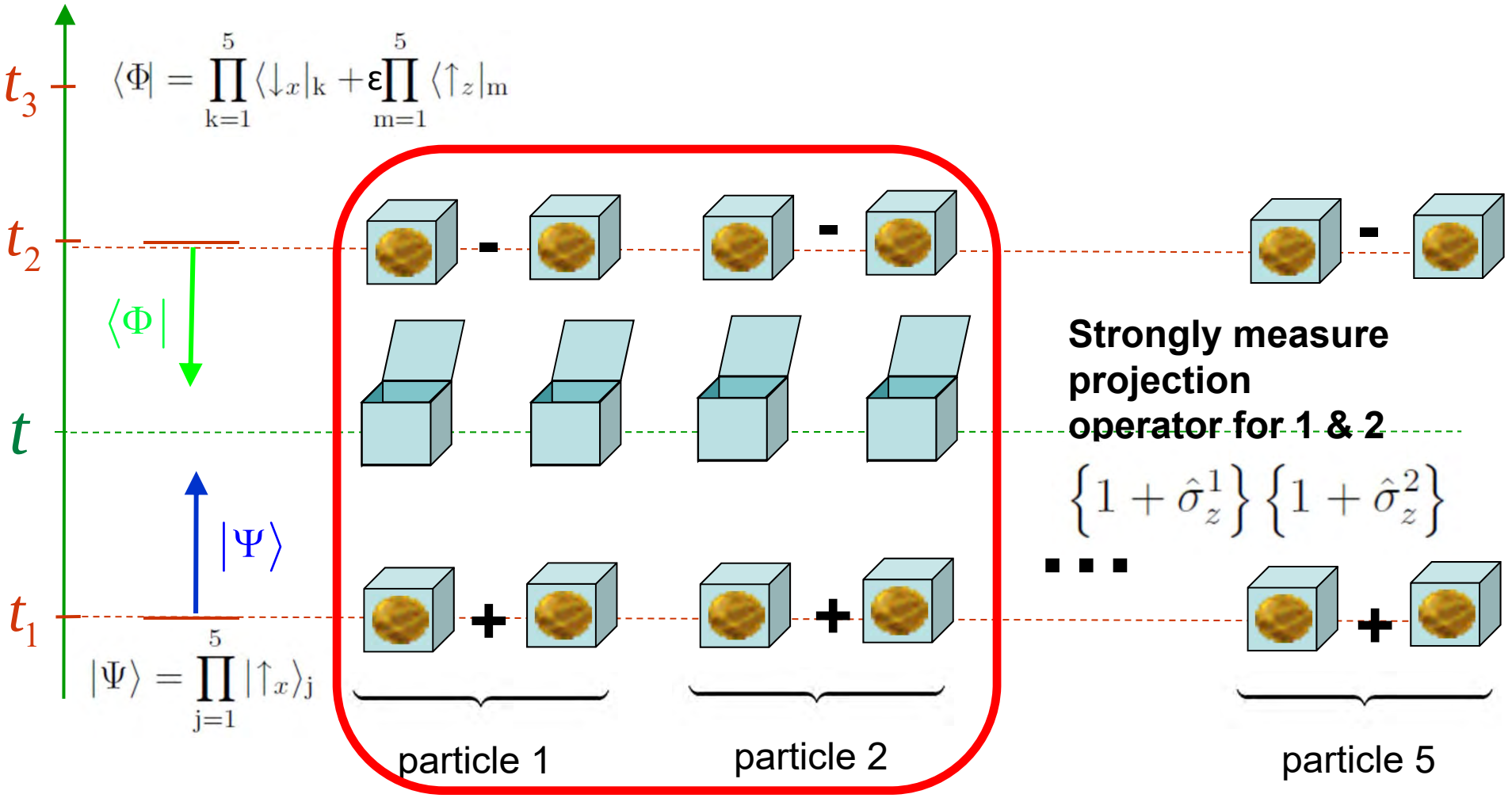
Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Generalization of top-down causality



Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

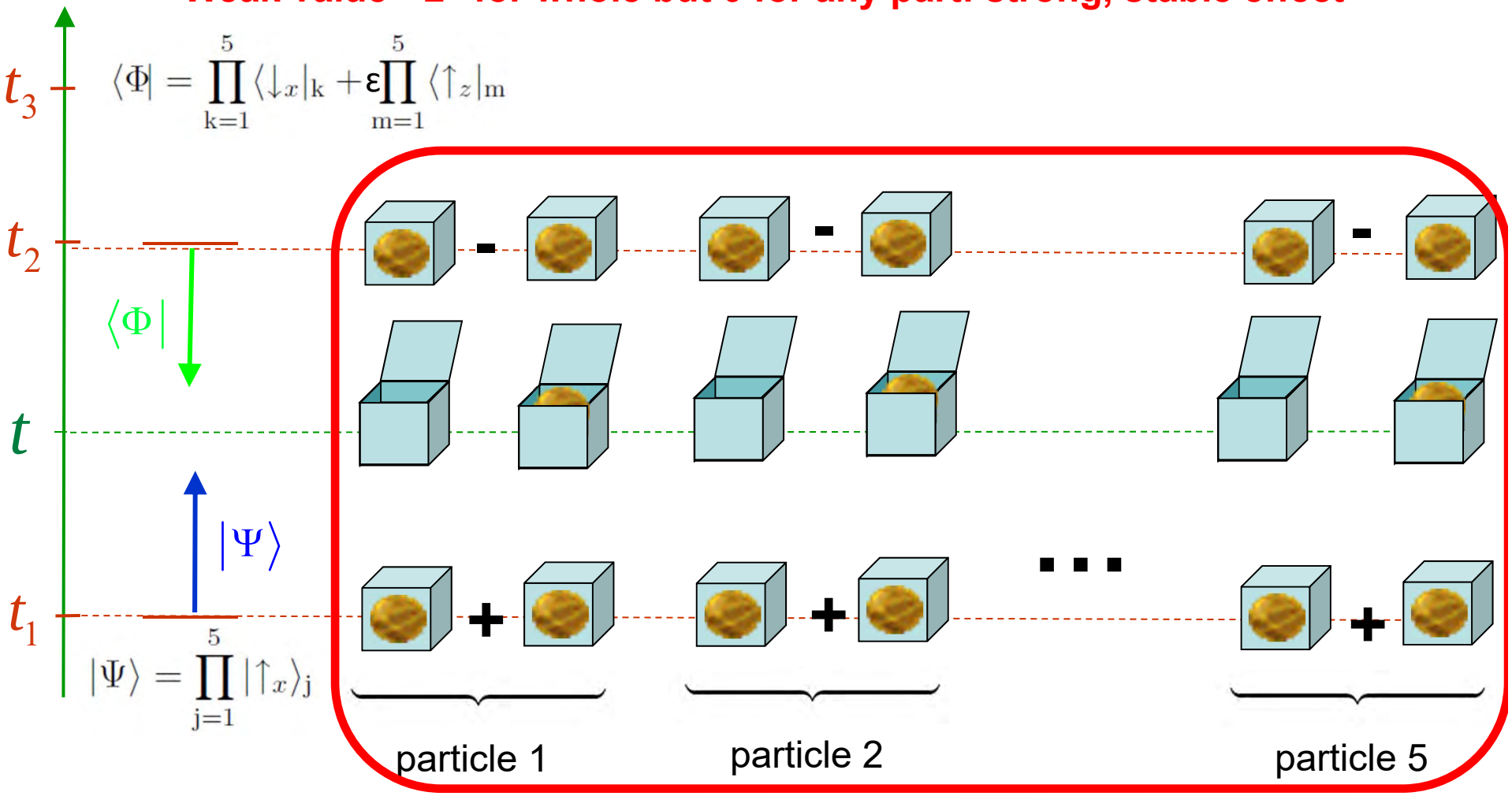
Generalization of top-down causality



Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Generalization of top-down causality

Weak value$\propto 2^N$ for whole but 0 for any part: strong, stable effect



≠0 only when strongly measure projection operator for all 5

$$\left\{1+\hat{\sigma}_z^1\right\}\left\{1+\hat{\sigma}_z^2\right\}\left\{1+\hat{\sigma}_z^3\right\}\left\{1+\hat{\sigma}_z^4\right\}\left\{1+\hat{\sigma}_z^5\right\}$$

Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Generalization of top-down causality

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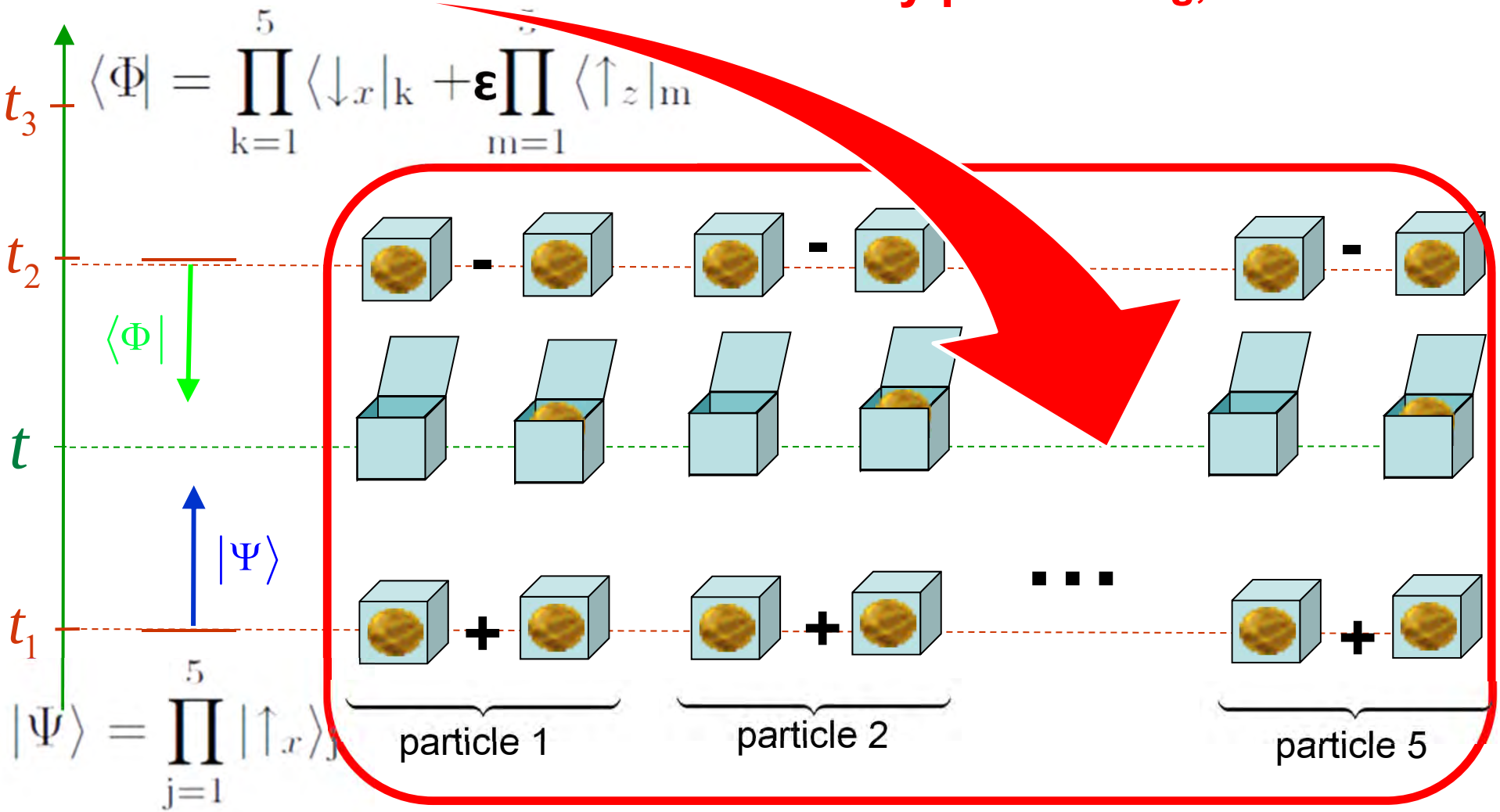

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Aharonov, Cohen, Tollaksen, PNAS v115, i46 (2018)

Quantum Reasoning

Bottom-up logic

- Having local information on observables $A_1,\ldots,A_n$ we can calculate correlations between them
- For instance $\langle AC\rangle,\langle AB\rangle,\ \langle BC\rangle$ in Bell's inequality
- Bell showed that local information is insufficient
- He did not imagine (probably) that in some cases local information tells us *absolutely nothing*!

Top-down logic

- Having nonlocal information on all correlations we can infer the local variables
- This approach seems to us now like the correct one in quantum mechanics

Generalization

- *N* Empty boxes with emergent correlations:

$$|\psi_i\rangle = \left(|0\rangle + |1\rangle\right)^{\otimes N} - |1\rangle^{\otimes N}$$

$$|\psi_f\rangle = \left(|0\rangle - |1\rangle\right)^{\otimes N}$$

- The 1-point (auto)correlation, 2-point correlations, 3-point correlations,...,(*N*-1)-point correlations vanish, but the *N*-point correlations are not zero!

New Kind of Entanglement

Can be generalized to many particle states and/or any spin

Other kinds of entanglement can be described classically using complex variables

(e.g. $\sigma_x = +1,\ \sigma_y = +1\ \ \sigma_z = i$ in the previous experiment

This one can't. It has no classical limit.

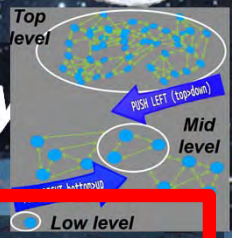
Plays an important role in the understanding of counterfactuals*

What happens when we consider the EM fields created by such charges?

Some paradigm-shifts from our research relevant for 'becoming'

- *New 'Becoming' picture developed from new weak values, holisms & non-localities which lead to fundamental, new:*
  understandings, theorems & experimental realizations
- *Bridging paradoxes to deeper models of dynamic:*
  awareness, consciousness, free will & more

Paradigm-shift #1: New Nonlocalities



Paradigm-shift #2: Holism & top-down causality

Paradigm-shift #3: Axioms/why quantum

Paradigm-shift #4: Becoming time

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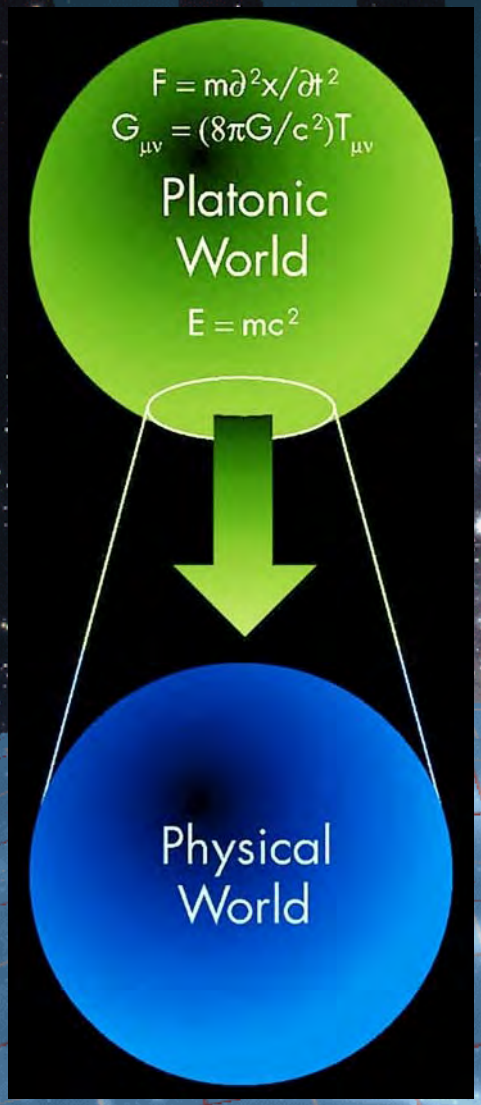
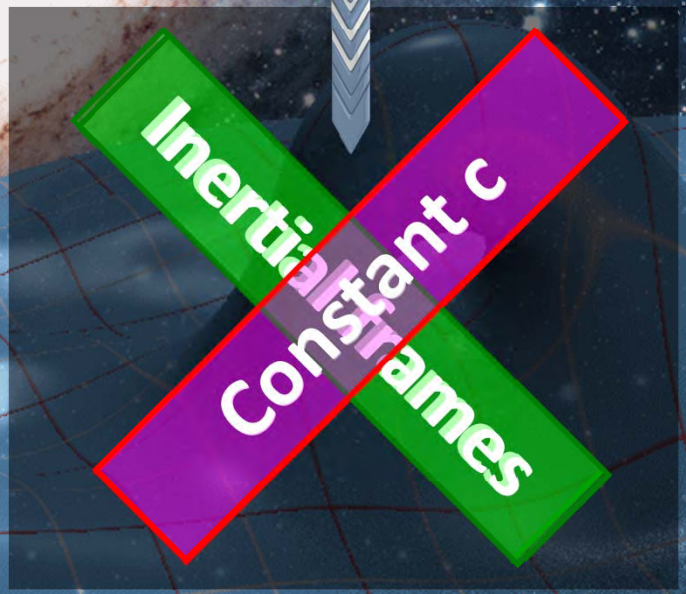
Start with deepest, intuitive axioms

- Question: What, indeed, is so "special" about special relativity?
- Answer: SR's two axioms nearly contradict each other & are in tension
- only 1 unique theory can reconcile nearly polar opposite axioms (i.e. special relativity)





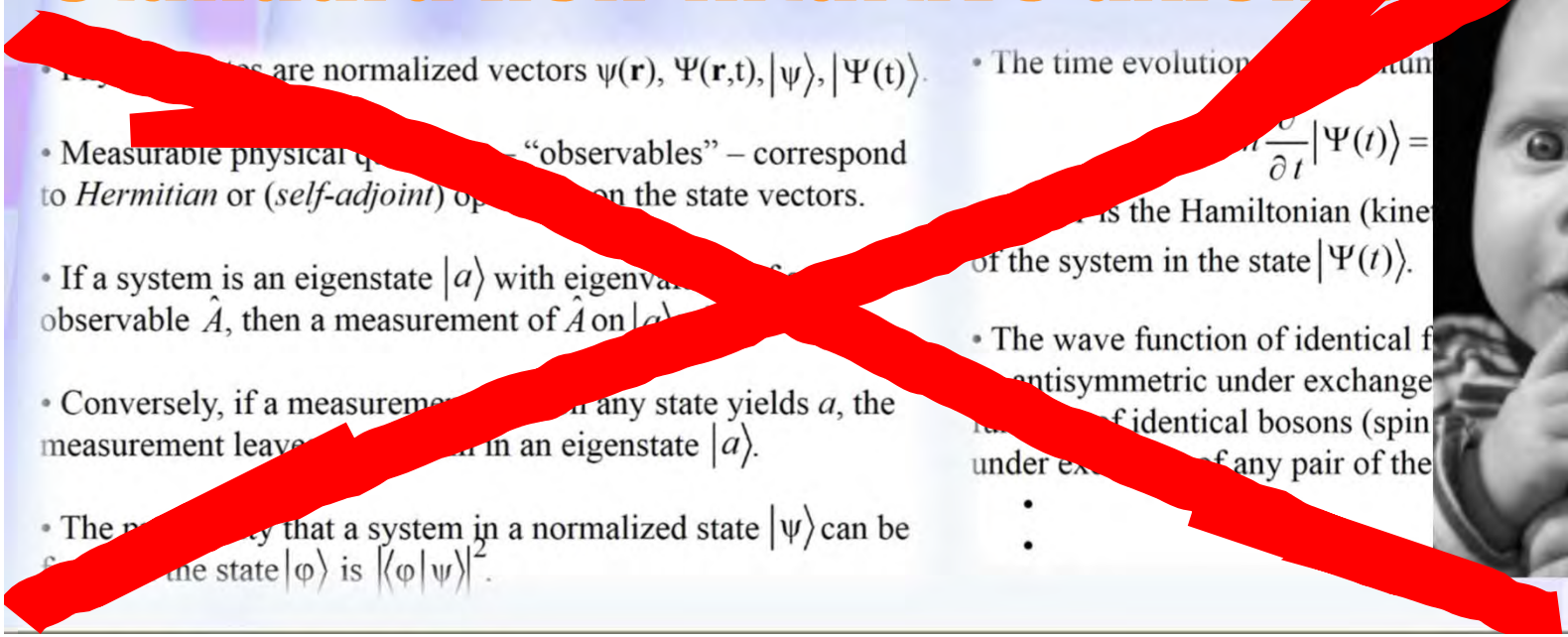
Methodology: start with more intuitive axioms for QM

Quantum Mechanics

↓

Nonlocality ☮ Causality

Standard non-intuitive axioms



- ... are normalized vectors $\psi(\mathbf{r})$, $\Psi(\mathbf{r},t)$, $|\psi\rangle$, $|\Psi(t)\rangle$.
- Measurable physical q... "observables" – correspond to *Hermitian* or (*self-adjoint*) op... on the state vectors.
- If a system is an eigenstate $|a\rangle$ with eigenva... observable $\hat{A}$, then a measurement of $\hat{A}$ on $|a\rangle$...
- Conversely, if a measureme... any state yields a, the measurement leave... in an eigenstate $|a\rangle$.
- The p...y that a system in a normalized state $|\psi\rangle$ can be f... the state $|\varphi\rangle$ is $|\langle\varphi|\psi\rangle|^2$.
- The time evolution... $i\hbar\frac{\partial}{\partial t}|\Psi(t)\rangle =$ ...is the Hamiltonian (kine... of the system in the state $|\Psi(t)\rangle$.
- The wave function of identical f... antisymmetric under exchange... f identical bosons (spin... under ex... f any pair of the...

Is nature capricious?

Aharonov & group asked
"*Why* does God play dice?"

We found that nature gains
something very beautiful & exciting
by playing dice

Why the Quantum?

Y. Aharonov & (independently) A. Shimony: Quantum mechanics, as well, reconciles two things that nearly contradict each other:

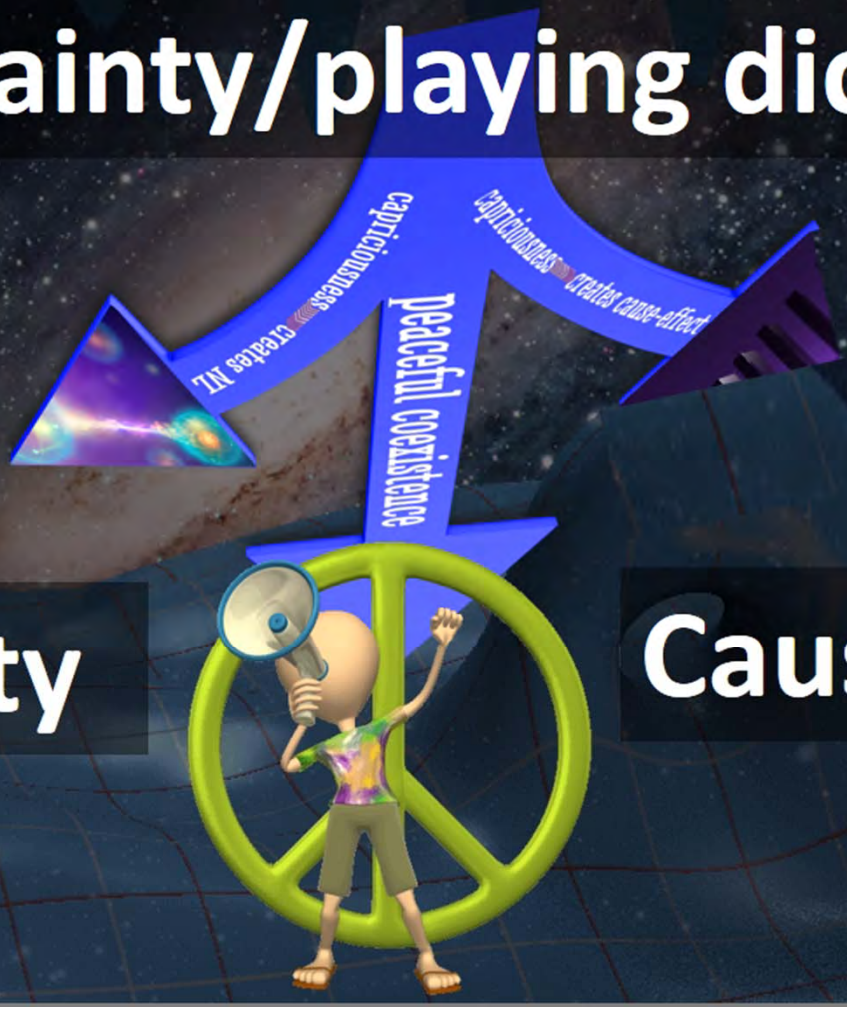
Can we derive a part of quantum mechanics from these axioms?

Aharonov: Quantum mechanics must include uncertainty.

Why uncertainty?

re-design axioms of physics so that non-locality & new aspects of cause/effect are at deepest level

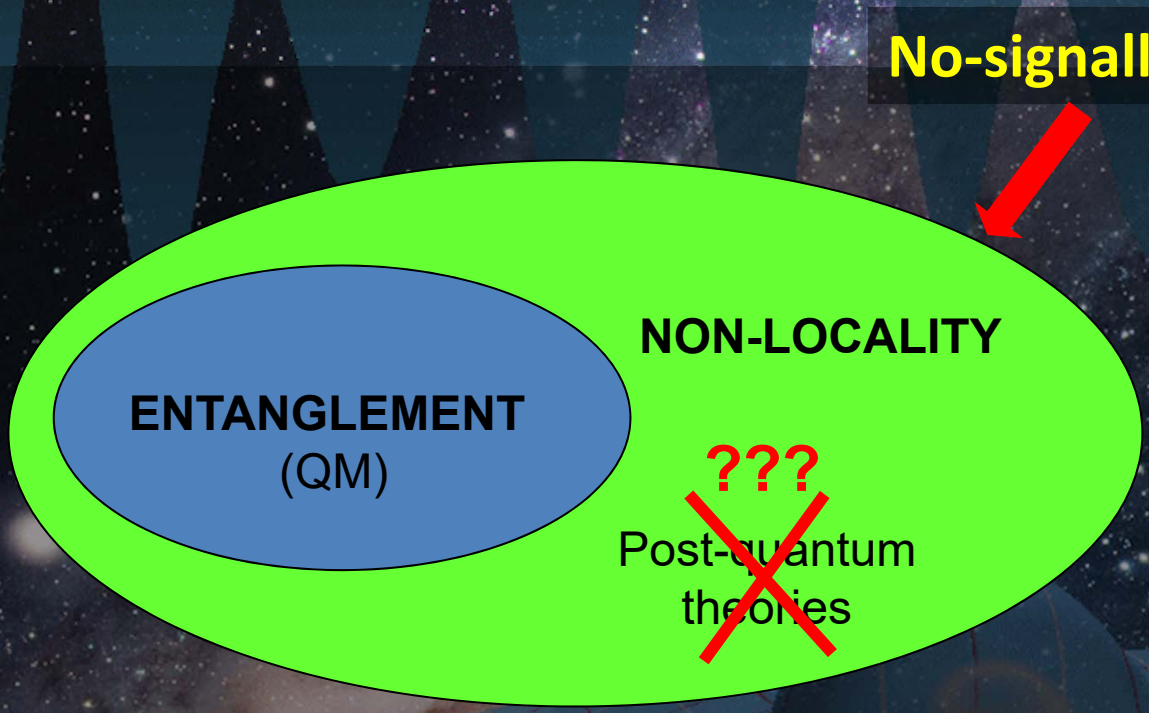
Uncertainty/playing dice



Nonlocality

Causality

Why the Quantum?
Why is quantum non-locality limited ?



Much Popescu-Rohrlich-box work deals with the realm that is not reality, nevertheless, there are many new, fascinating results

Why uncertainty?

NOUMENAL SPACE

UNIQUENESS FREE WILL

$F = m\partial^2x/\partial t^2$

$G_{\mu\nu} = (8\pi G/c^2)T_{\mu\nu}$

Platonic World

$E = mc^2$

Physical World

re-design axioms of physics so that holism, free will & new aspects of cause/effect are at deepest level *has enriched each axiom*

Richer nonlocality
(eg nonlocal in time)

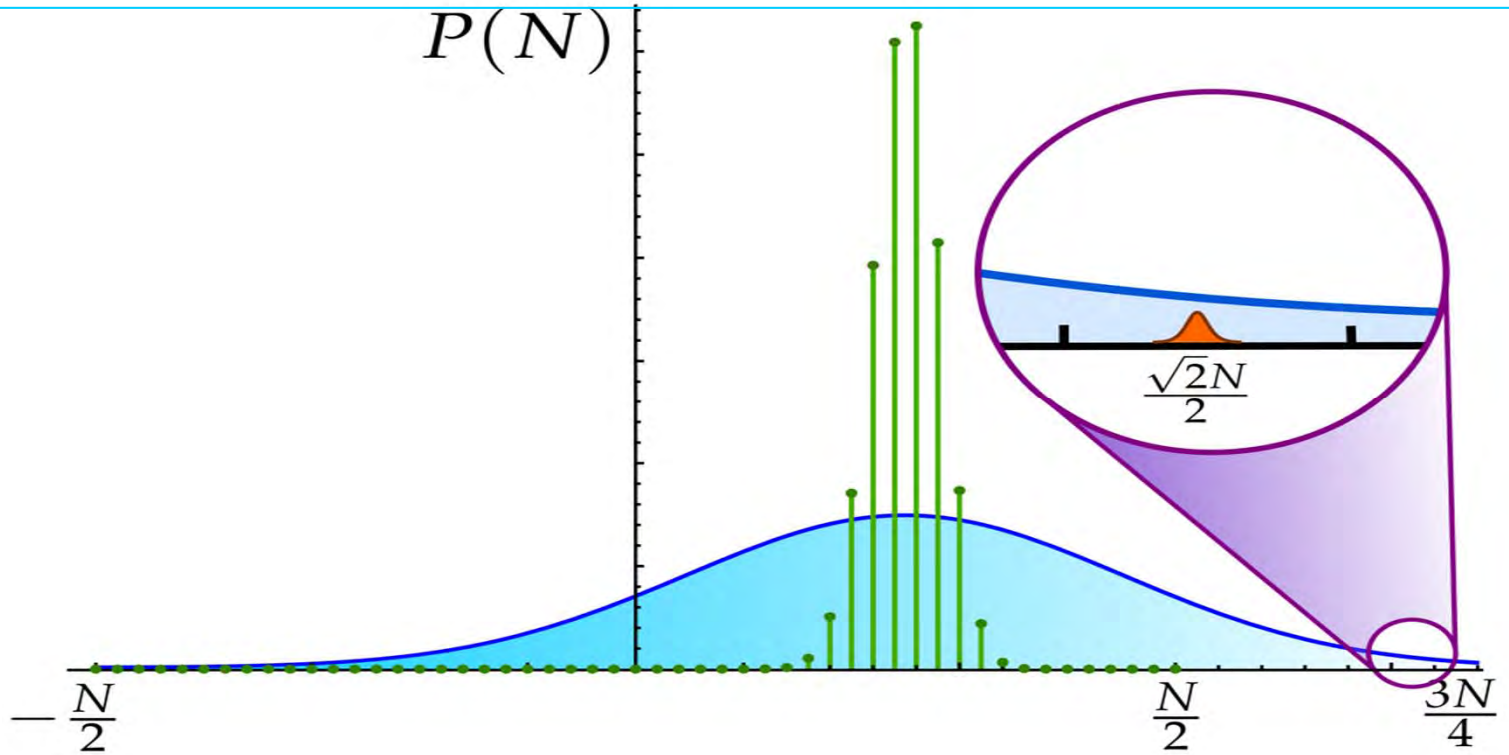
Richer causality

Deepest axiom level

Derivative axiom level

Uncertainty/playing dice

Weak values, causality & free will: game of errors



- Probability for different outcomes of $S_{45°}$ for a system of N spin-1⁄2 particles preselected in $|S_z = N/2\rangle$
- Green represents measurement outcomes for an ideal measurement without postselection
- Blue curve represents probabilities in a weak measurement
- After postselection for $|S_x = N/2\rangle$, only the red distribution way out in the tail survives
- After WM, we could perform more precise measurement of $S_{45°}$
- Uncertainty derived from nonlocality in time, causality, and free will
- Leads to new concept of "weak information": Bohm told us this is 1st implicate order

Some paradigm-shifts from our research relevant for 'becoming'

- *New 'Becoming' picture developed from new weak values, holisms & non-localities which lead to fundamental, new:*
  understandings, theorems & experimental realizations
- *Bridging paradoxes to deeper models of dynamic:*
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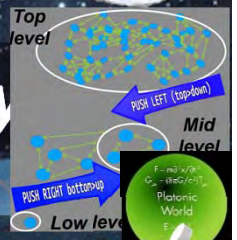

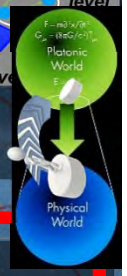

Paradigm-shift #1: New Nonlocalities

Paradigm-shift #2: Holism & top-down causality

Paradigm-shift #3: Axioms/why quantum

Paradigm-shift #4: Becoming time

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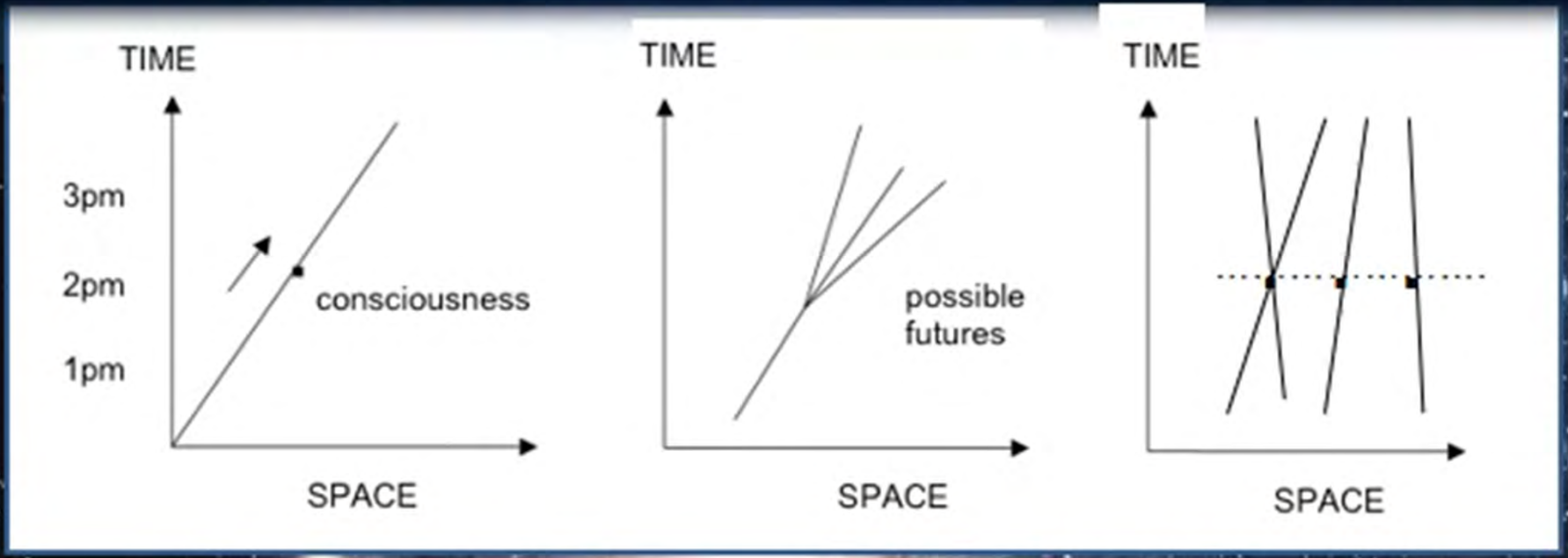
"Everything -past, present, and future—is there at once."



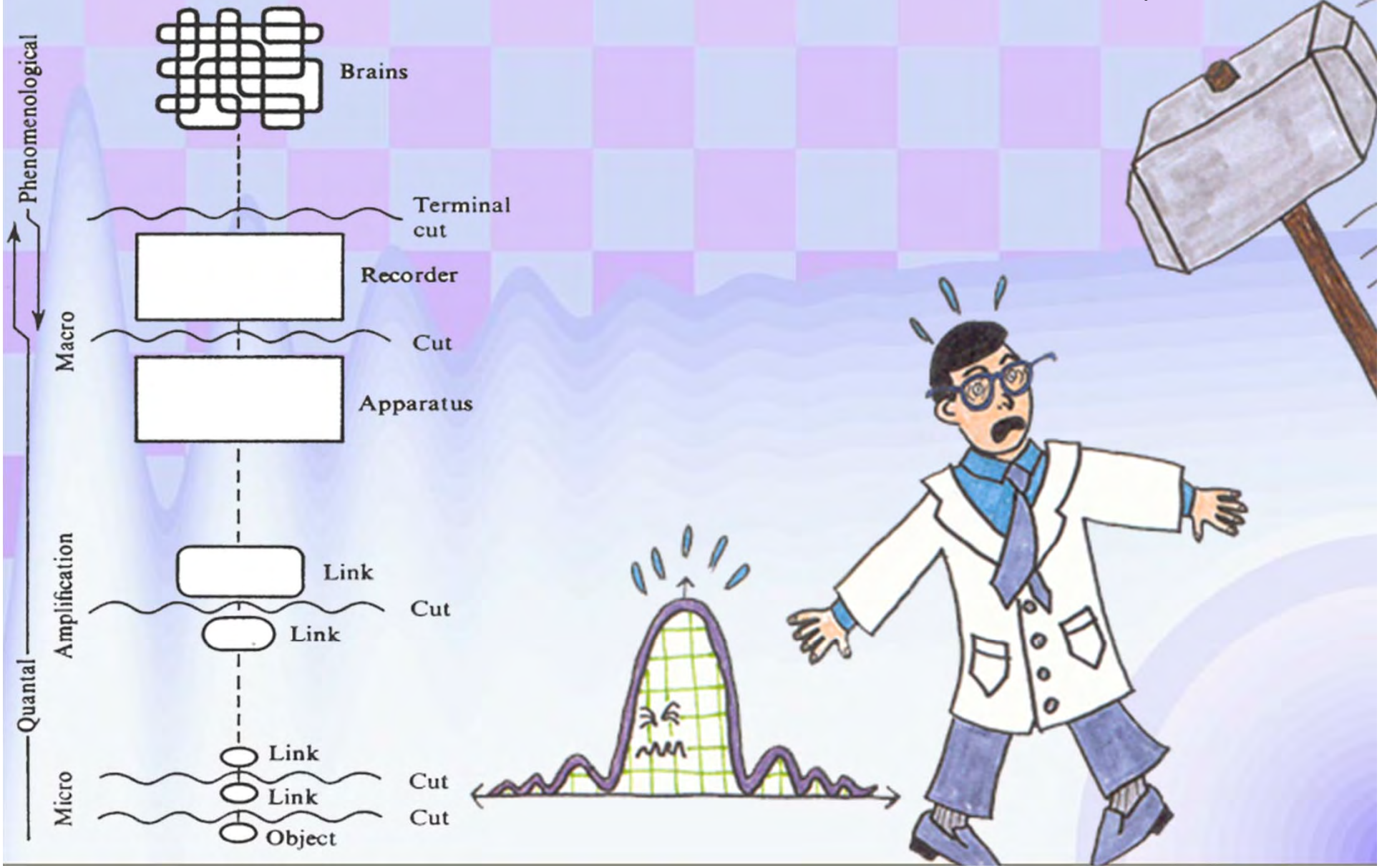
Special Relativity cannot describe:

1. flow of conscious time
2. conscious interaction with physical world
3. Uncertainty Principle
4. collapse of quantum wave function
5. coordination of different consciousnesses.

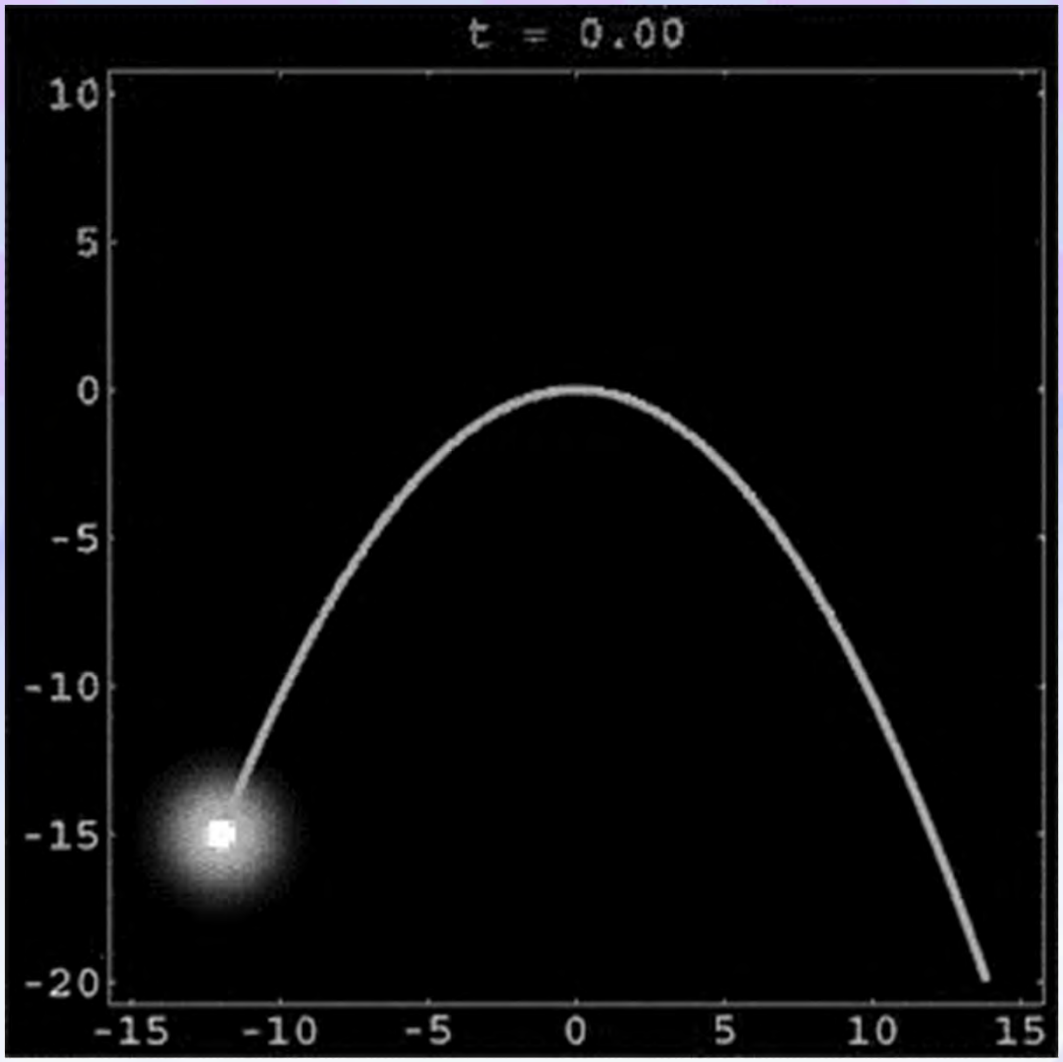
Courtesy B. Carr

When is a quantum measurement?

Where is the transition between classical and quantum?



Correspondence principle: micro->macro



Courtesy Thaller

Aharonov, Y., Botero, A., Nussinov, S., Popescu, S., **Tollaksen, J.**, Vaidman, L. "The classical limit of quantum optics," ***New Journal of Physics***, volume 15 (2013) 093006

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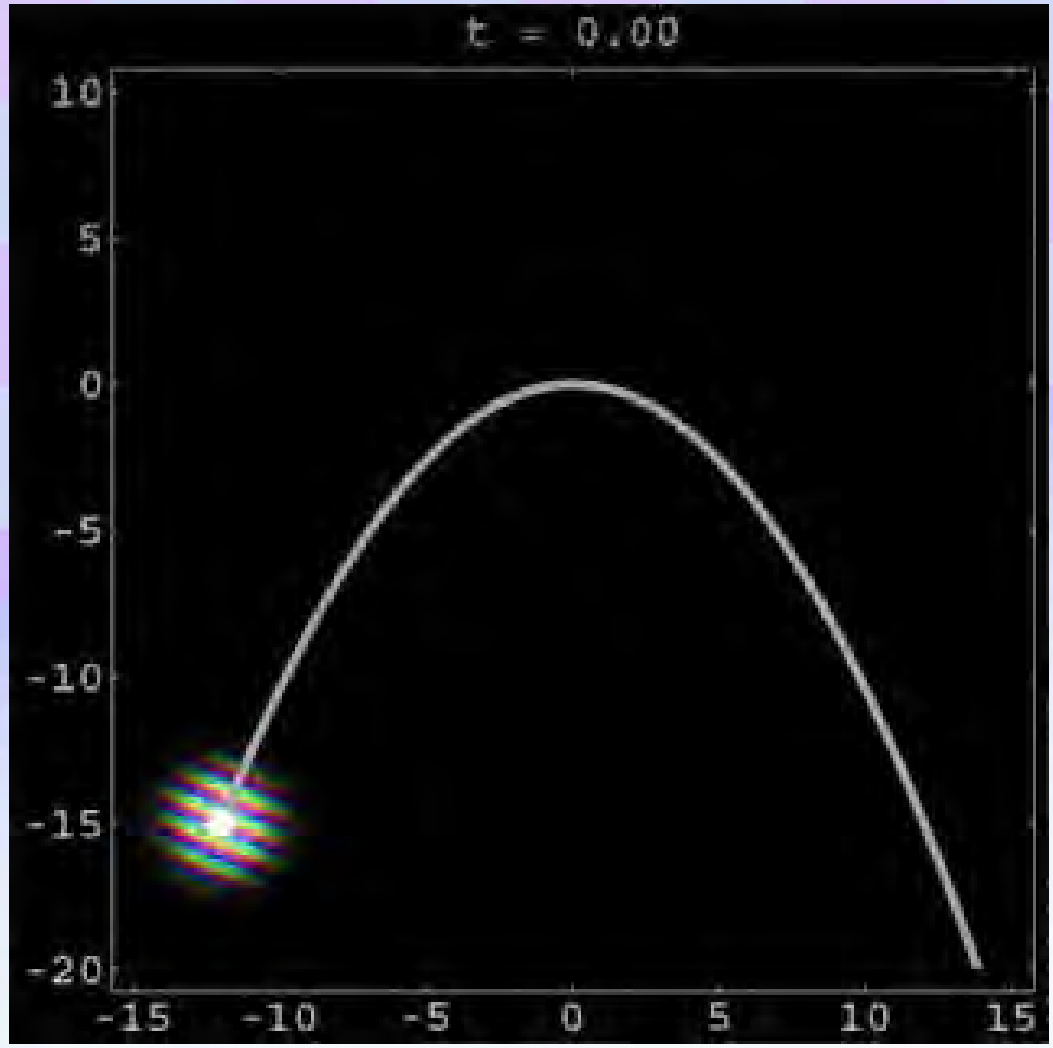
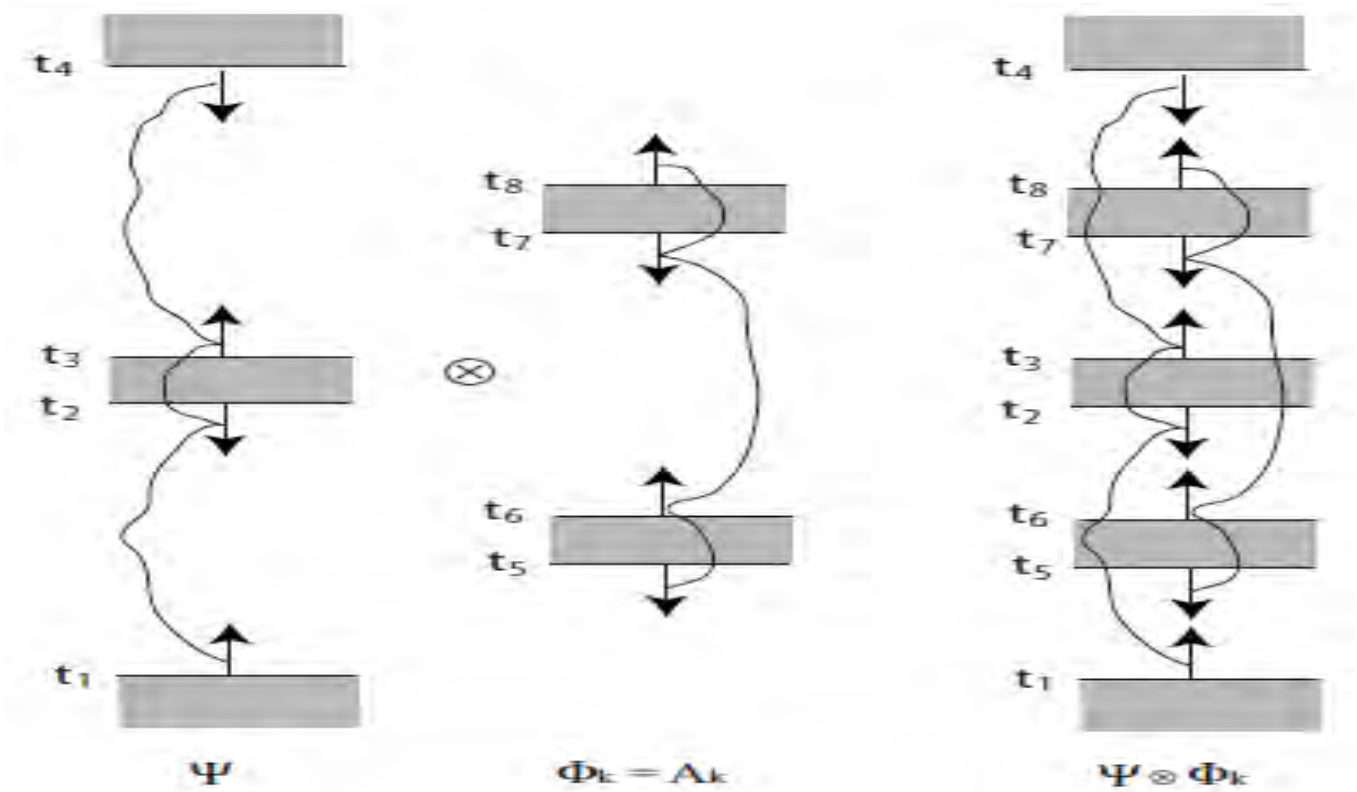


Aharonov, Y., Botero, A., Nussinov, S., Popescu, S., **Tollaksen, J.**, Vaidman, L. "The classical limit of quantum optics," ***New Journal of Physics***, volume 15 (2013) 093006

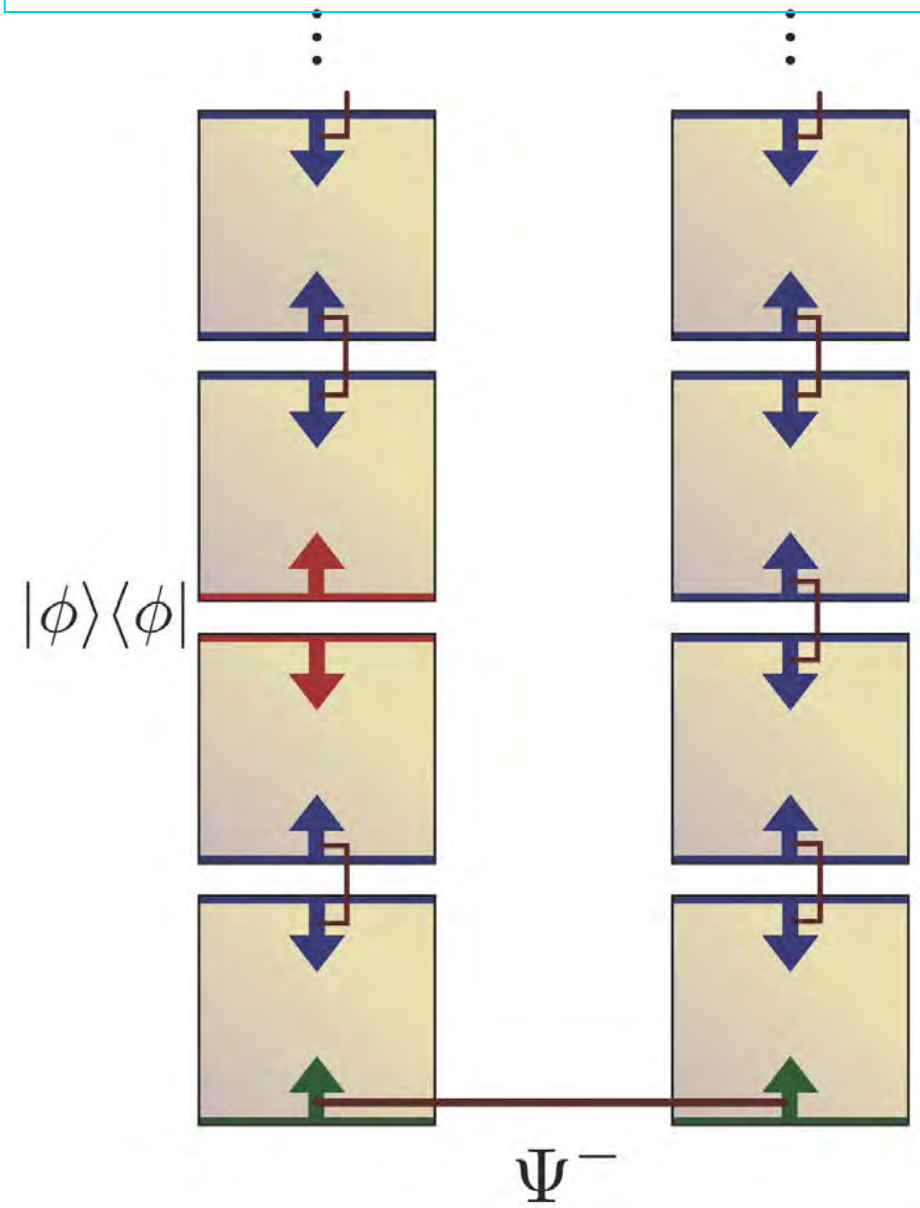
Free-will, multiple-time operators



- **Multiple-time states:** states & operators on equal footing
- New form of complementary

Aharonov, Popescu, JT, Vaidman, *Phys Rev A* 79, 052110 (May 1, 2009)

QM Generalization: Each moment of time a new universe



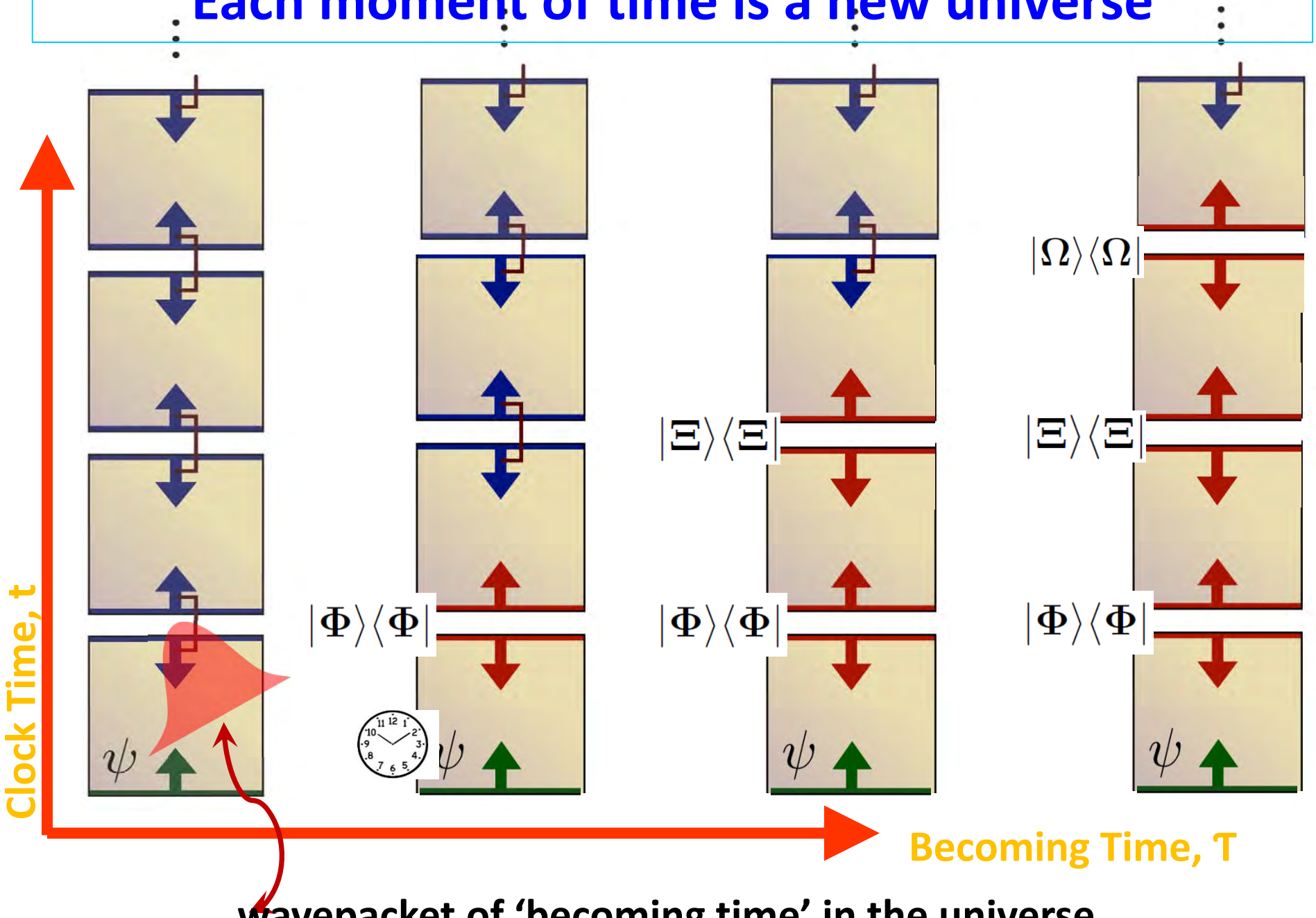
Two entangled spin 1/2 particles. Entanglement characterizes solely time t_0 where entanglement is produced. All other times are characterized by trivial time evolution, i.e. maximal entanglement between subsequent moments of time; there is however no entanglement between the particles associated to these times. Alice's measurement disentangles the time moments of her particle but have no effect on Bob's particle.

- **"Collapse" does not necessarily imply arrow of time at microscopic level**

Aharonov, JT, 2010, *Visions of Discovery*; Aharonov, Popescu, JT, arXiv:1305.1615

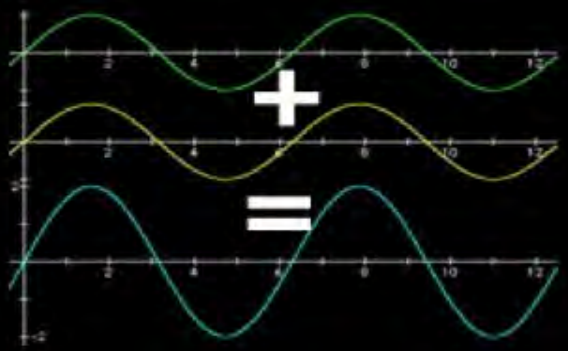
Aharonov, Popescu, JT, Vaidman, *Phys Rev A* 79, 052110 (May 1, 2009)

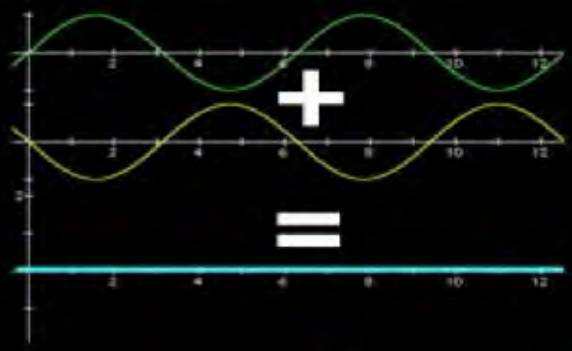
Each moment of time is a new universe



wavepacket of 'becoming time' in the universe

Superposition of laws





Constructive
Interference
Reinforcement

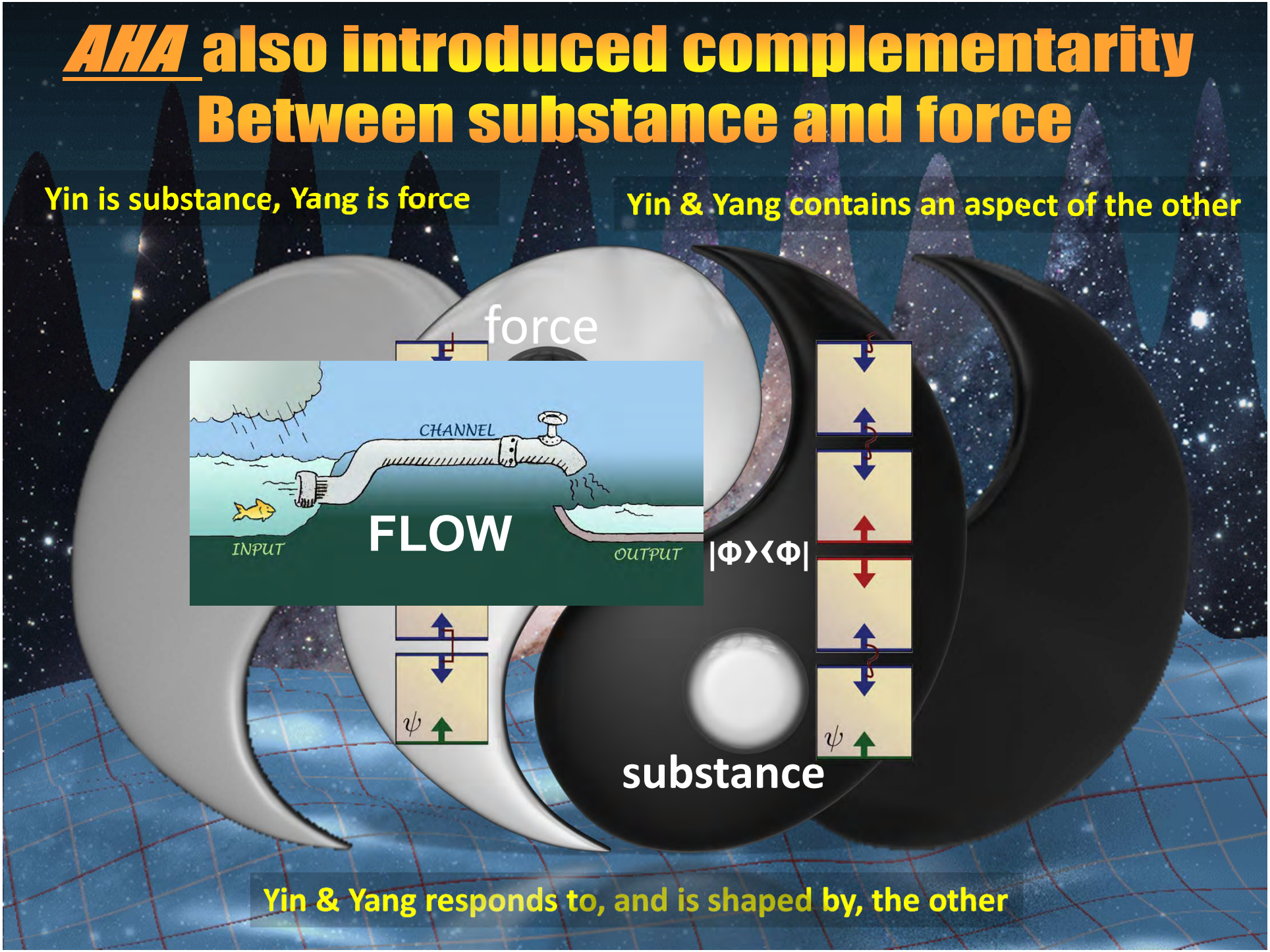
Destructive
Interference
Cancellation


C-SPACE
UNIQUENESS
FREE WILL
$F = m\partial^2x/\partial t^2$
$G_{\mu\nu} = (8\pi G/c^2)T_{\mu\nu}$
I-SPACE
$E = mc^2$
P-SPACE
new way of thinking about laws
NewScientist
June 30-July 6, 2007
HOW THE UNIVERSE GOT ITS LAWS
and our surprising role in shaping them

AHA also introduced complementarity Between substance and force

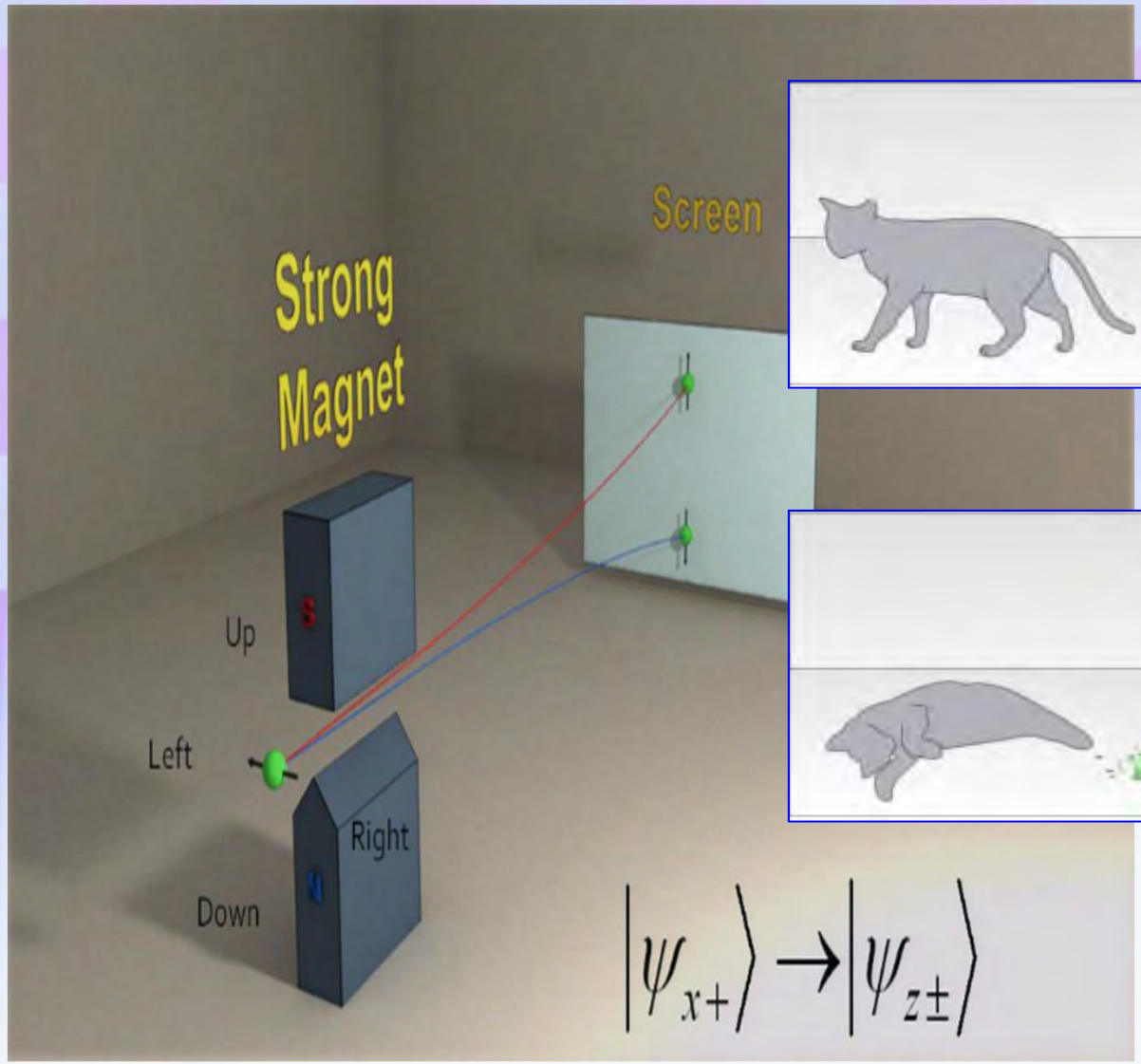
Yin is substance, Yang is force

Yin & Yang contains an aspect of the other

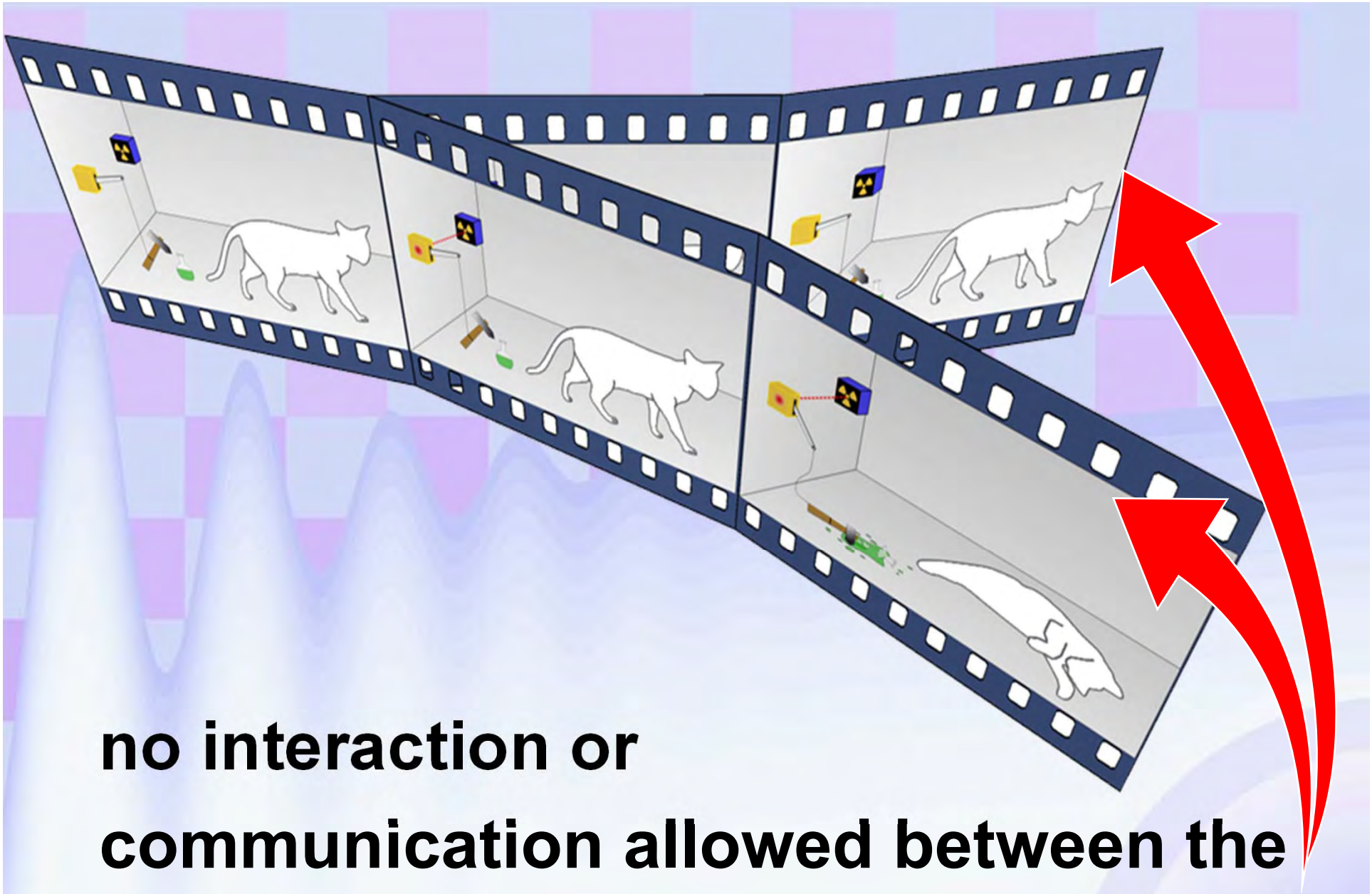


Yin & Yang responds to, and is shaped by, the other

Schrodinger's Cat



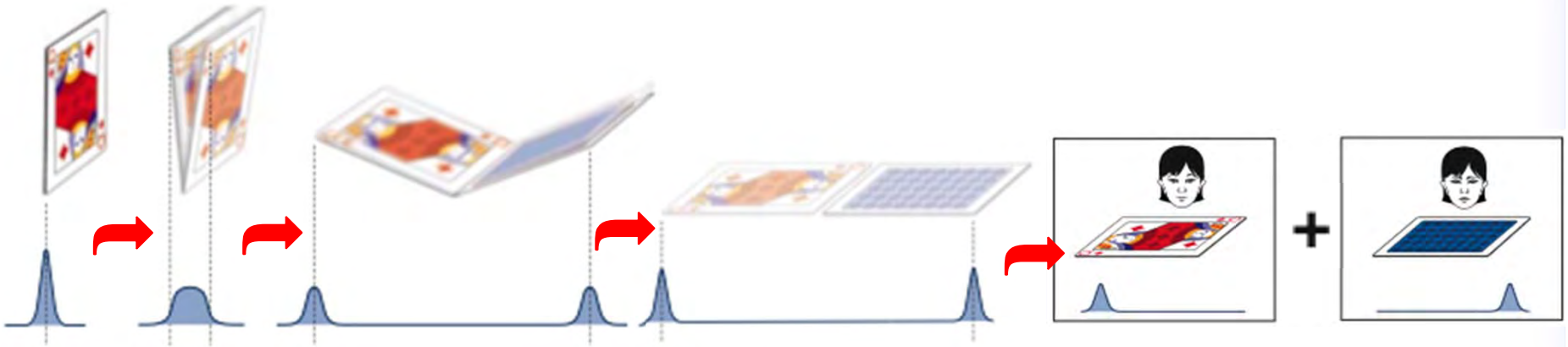
The spin-up vs. spin-down is analogous to the Schrodinger's Cat paradox, where instead a radioactive source is used: a single random quantum event has 50% probability to trigger a lever arm and break a flask containing deadly poison.

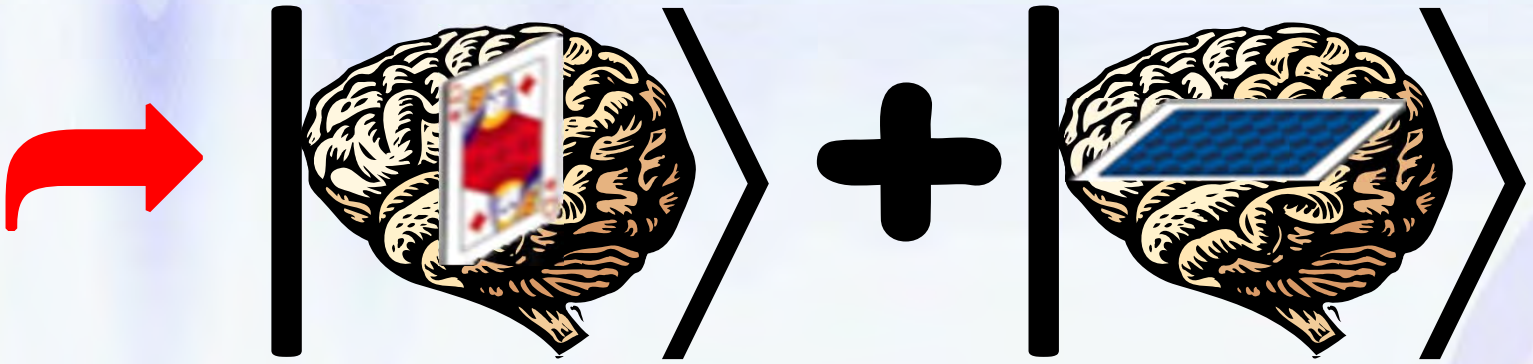


no interaction or

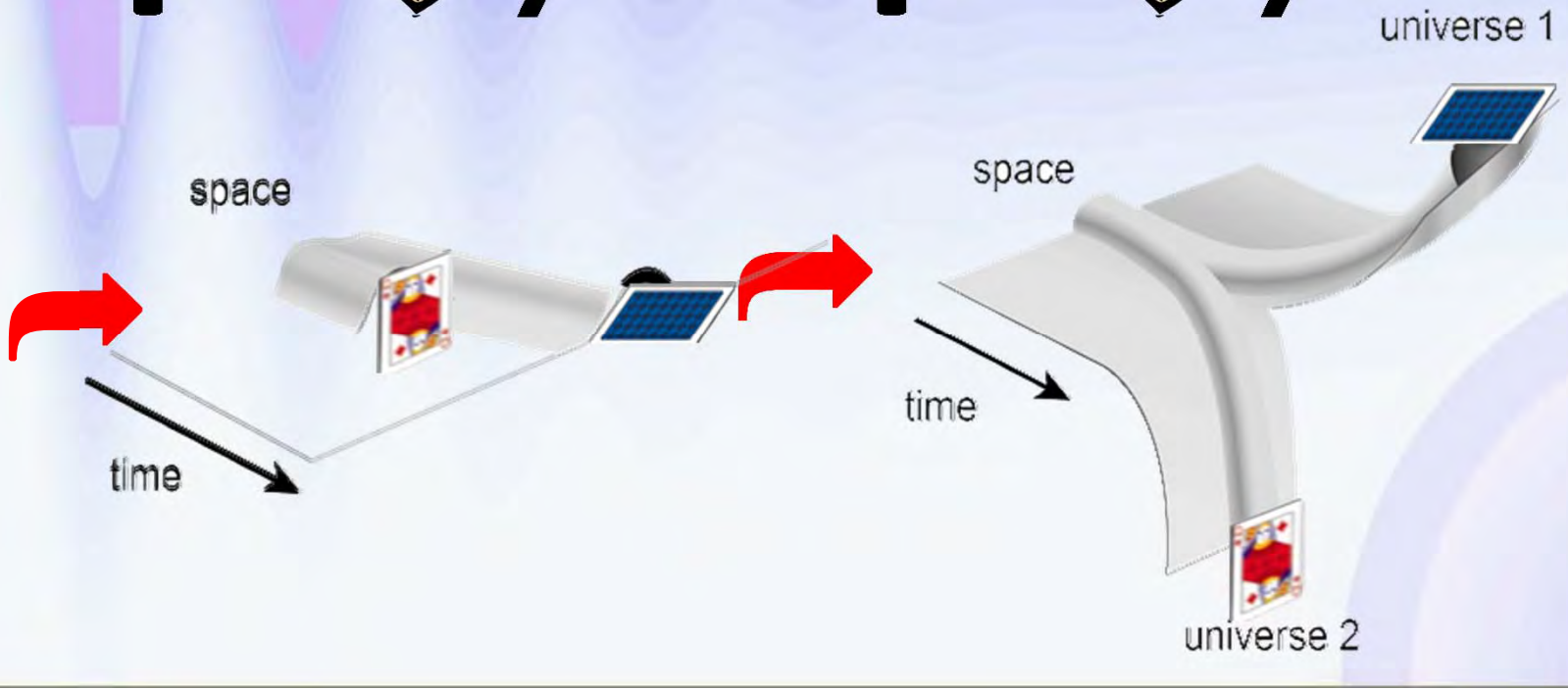
communication allowed between the different branches of many-worlds

Just before the point of many-worlds

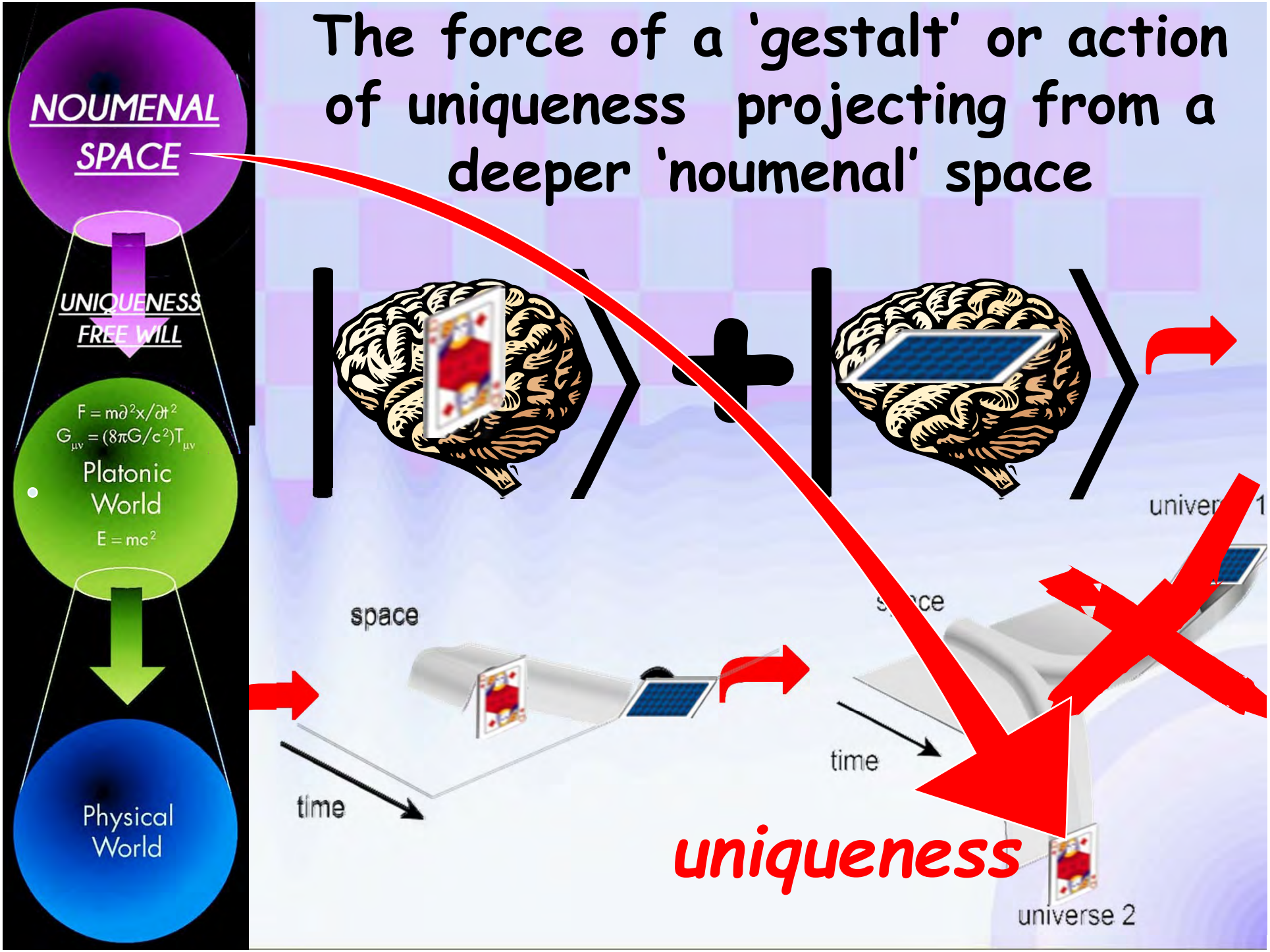


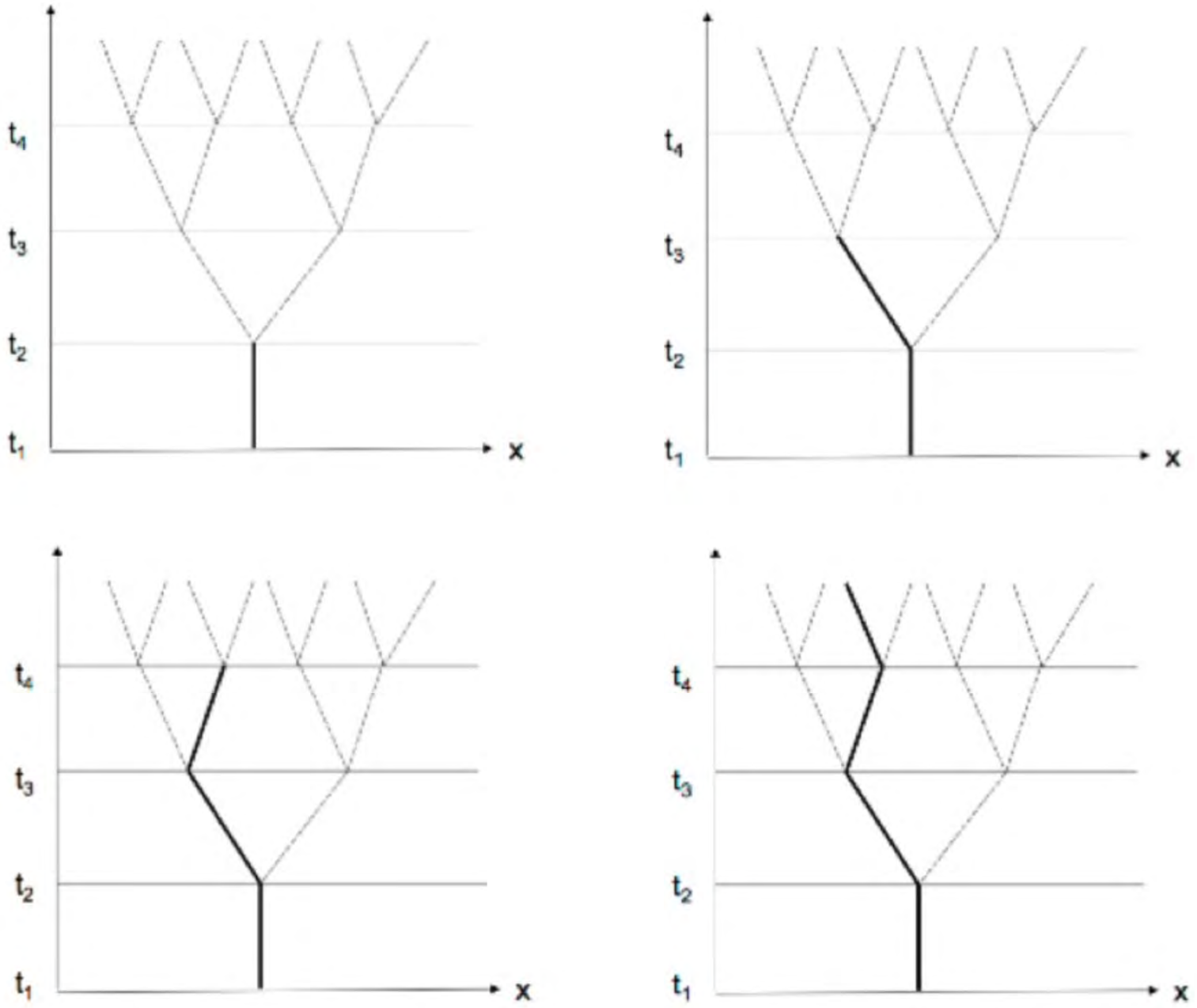


Two worlds start to split apart even while we are still attempting to have a single unitary experience. If this process is allowed to continue, then it would begin to 'fragment' our unitary experience of self



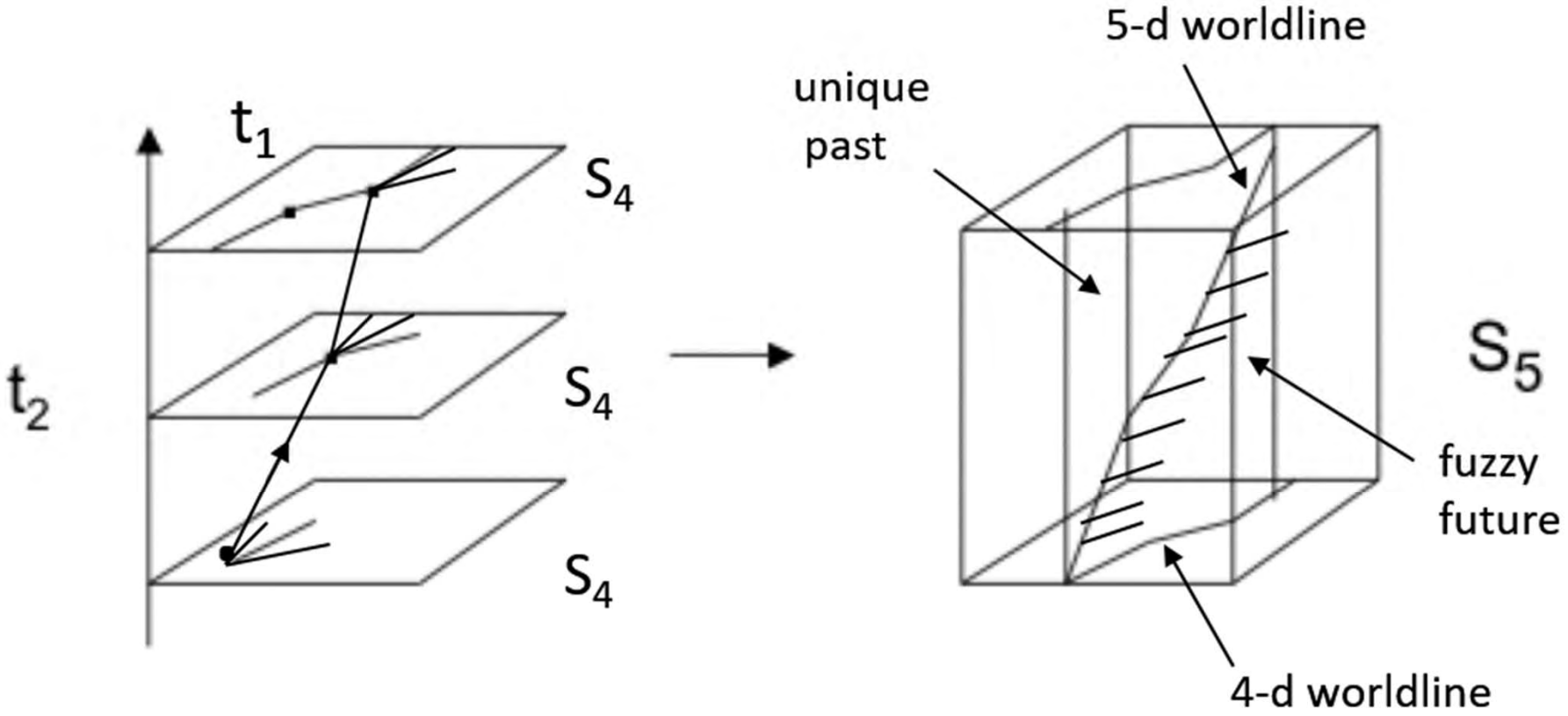
The force of a 'gestalt' or action of uniqueness projecting from a deeper 'noumenal' space





Courtesy B. Carr

Becoming time: Kairos, 5th dimension

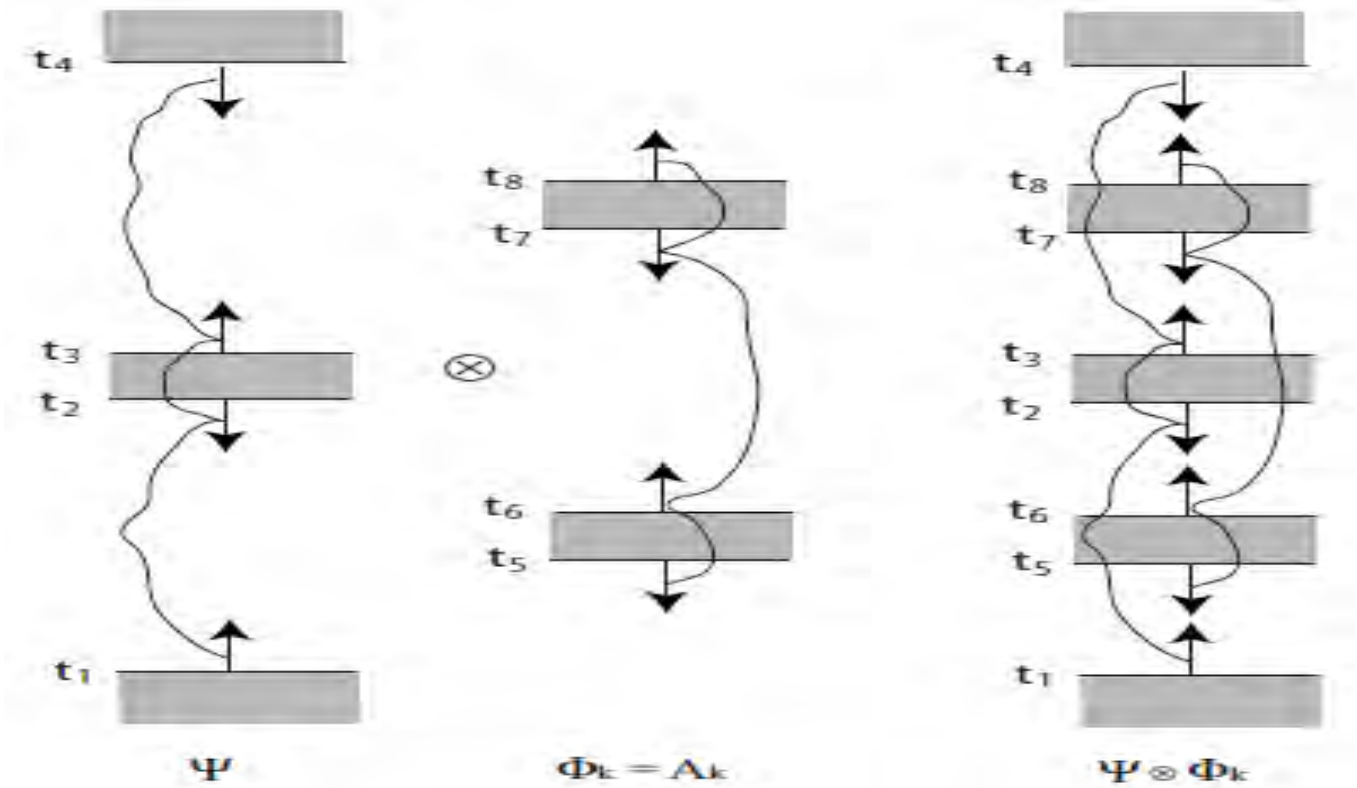


Courtesy B. Carr

Aharonov, JT, 2010, *Visions of Discovery*; Aharonov, Popescu, JT, arXiv:1305.1615

Aharonov, Popescu, JT, Vaidman, *Phys Rev A* 79, 052110 (May 1, 2009)

Open questions: we need completely new science to understand how free-will functions in gestalt-space



- **Multiple-time states:** states & operators on equal footing
- New form of complementary

Aharonov, Popescu, JT, Vaidman, *Phys Rev A* 79, 052110 (May 1, 2009)

Each moment of time is a new universe

Conclusions

- if your only tool is a hammer, then you tend t treat everything as if it were a nail
- To grasp the world more fully by grasping it gentl

See Quantum.chapman.edu

Members Include: