EmQM15 - Symposium Introduction

Jan Walleczek and Gerhard Grössing

Is the World Local or Nonlocal?

Towards an Emergent Quantum Mechanics
80 Years After EPR

Fetzer Franklin Fund Exploring Frontiers. Breakthroughs. Science.

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We start with a general orientation. Why ‘Emergence’?

What are the objectives of the symposium?

What to look out for during the next three days?

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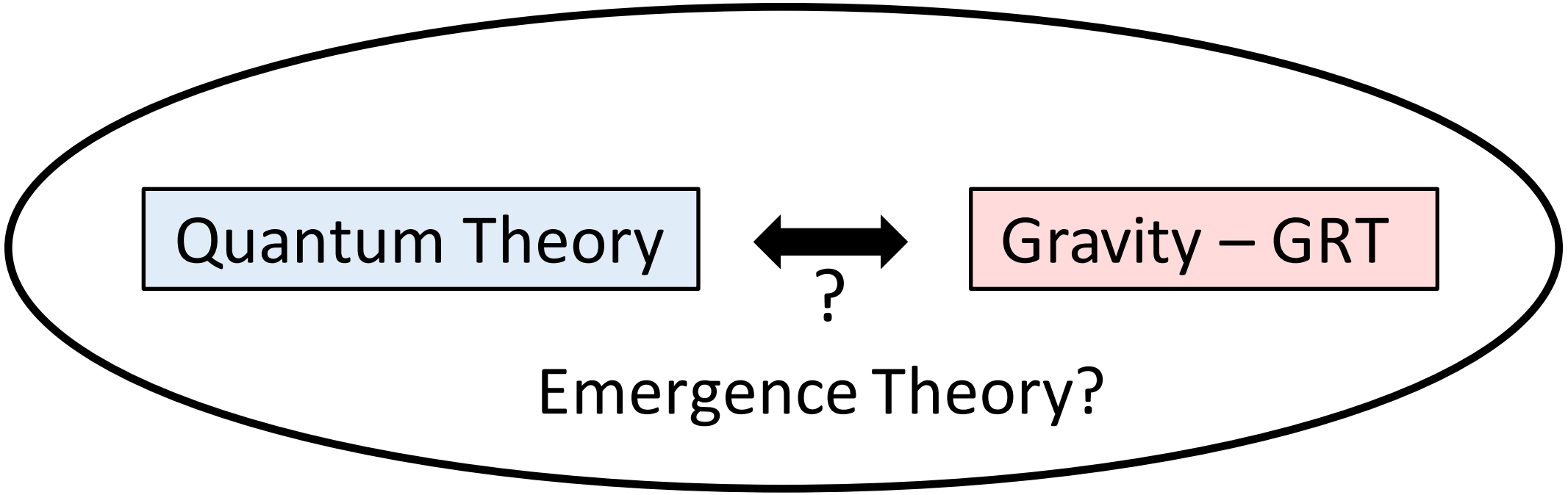
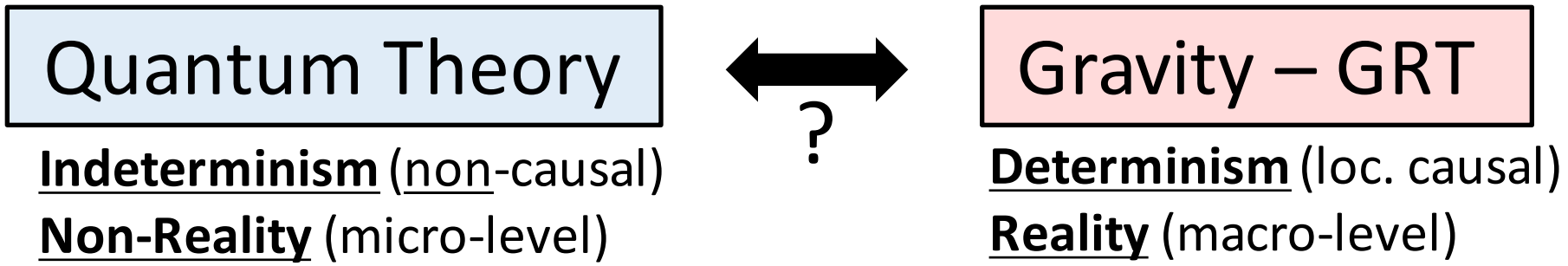
Towards Unification?

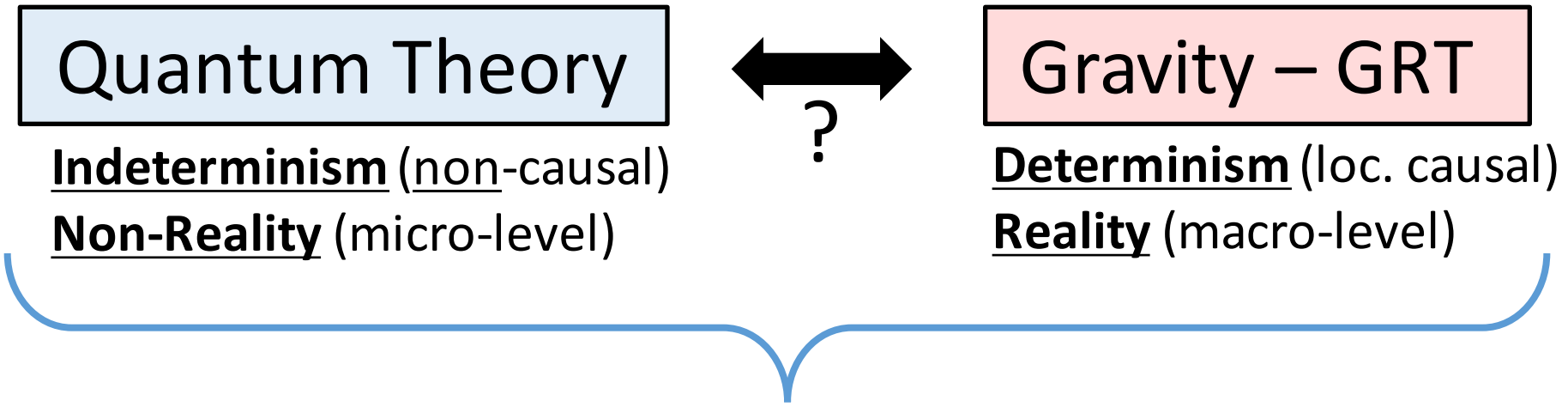


Towards Unification?



"There is no quantum world."
Niels Bohr

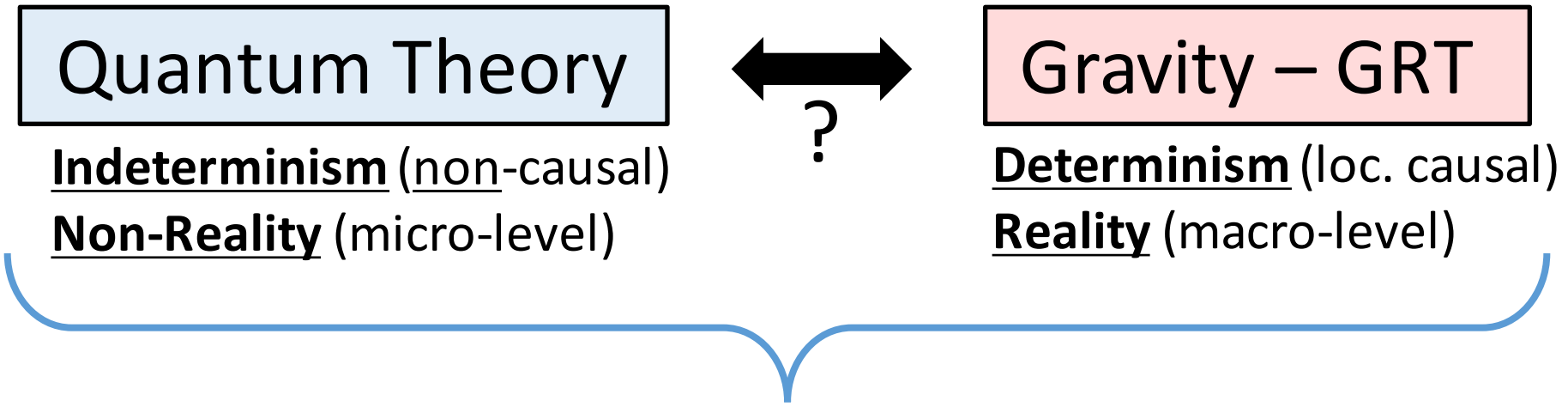
Towards Unification?



"Total Contradiction of Metaphysical Assumptions"

"The Measurement Problem!"

Towards Unification?



"Total Contradiction of **Metaphysical Assumptions**"

"The Measurement Problem!"

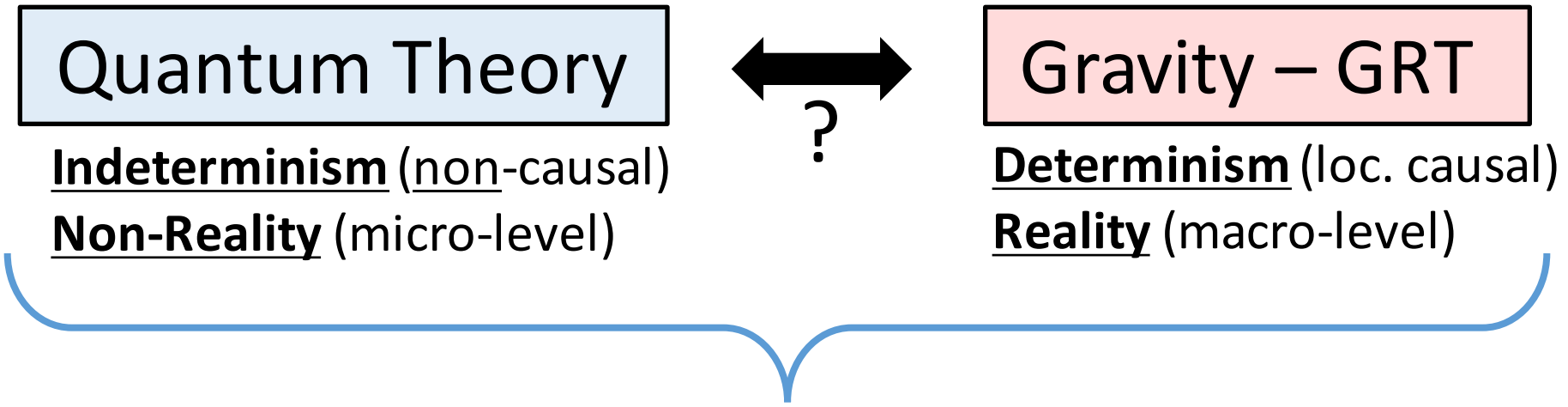
Why ‘Metaphysics’ in ‘Quantum Physics’?

What are metaphysical assumptions?

- Metaphysical is neither “mystical” nor “irrational”.
- A metaphysical analysis refers to the first principles, the foundational physical assumptions, which inevitably underpin any scientific analysis of nature.
- Metaphysical assumptions essentially constrain the application of any mathematical theory to quantum phenomena!

“World View of the Scientist”

Towards Unification?



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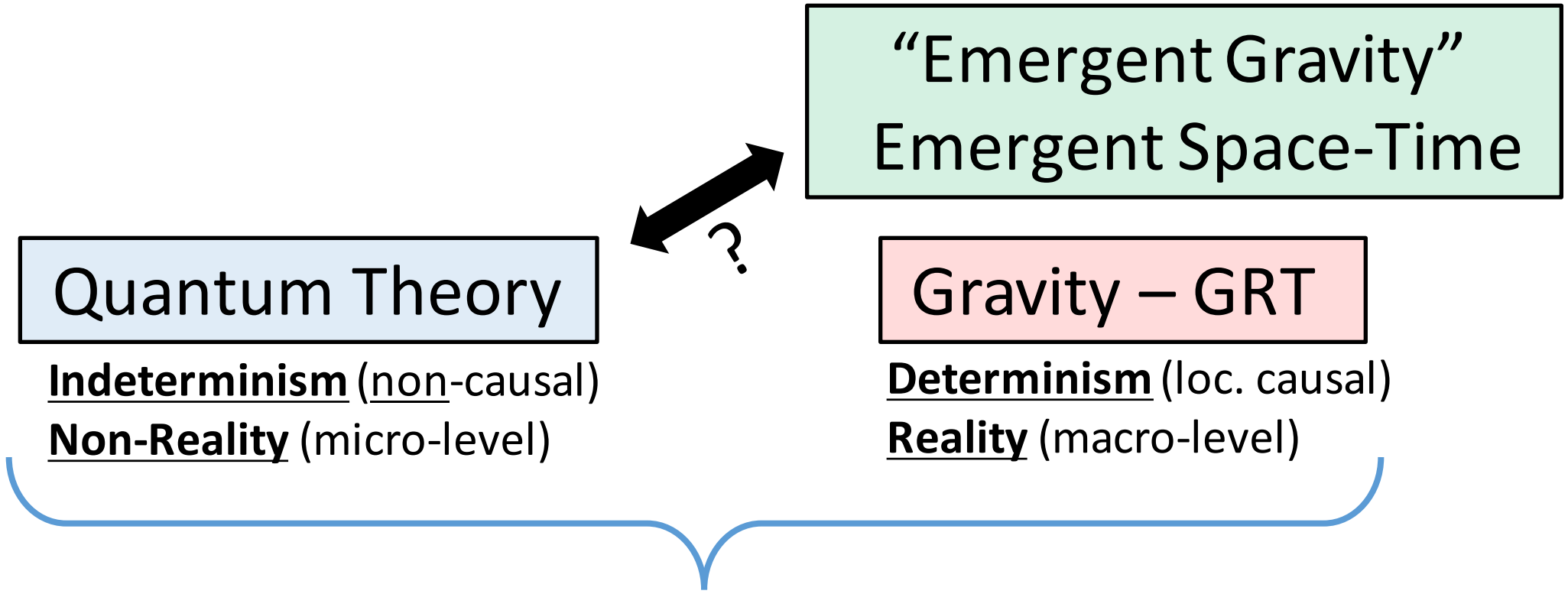


"Total Contradiction of **Metaphysical Assumptions**"

"The Measurement Problem!"

Towards Unification?

David Gross (2012):

"Many of us are convinced that space is an emergent, not fundamental concept. We have many examples of interesting quantum mechanical states, for which we can think of some (or all) of the spatial dimensions as emergent. Together with emergent space, we have the emergent dynamics of space and thus emergent gravity."

"Emergent Gravity"
Emergent Space-Time

"But it is hard to imagine how time could be emergent? How would we formulate quantum mechanics without time as a primary concept? Were time to be emergent, our understanding of quantum mechanics would have to change."

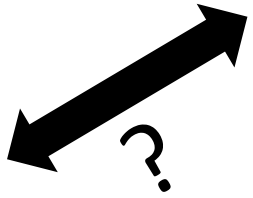
From: Yakir Aharonov Festschrift

Struppa and Tollaksen, Eds., (2012) "Quantum Theory: A Two-Time Success Story"

Towards Unification?

Emergent Quantum Mechanics (EmQM)

"Emergent Gravity"
Emergent Space-Time



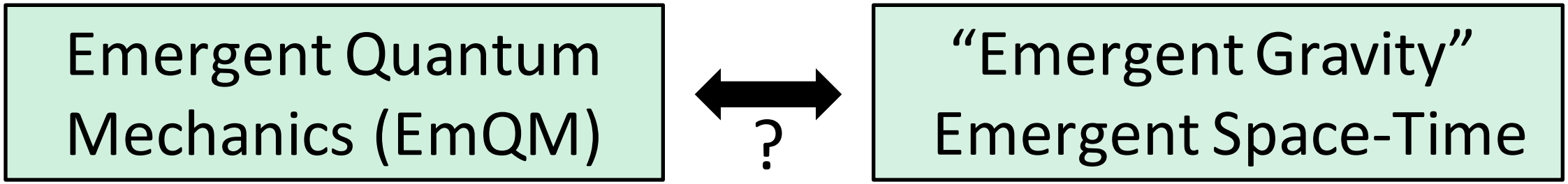
Quantum Theory

Indeterminism (non-causal)
Non-Reality (micro-level)

Gravity – GRT

Determinism (loc. causal)
Reality (macro-level)

Towards Unification?



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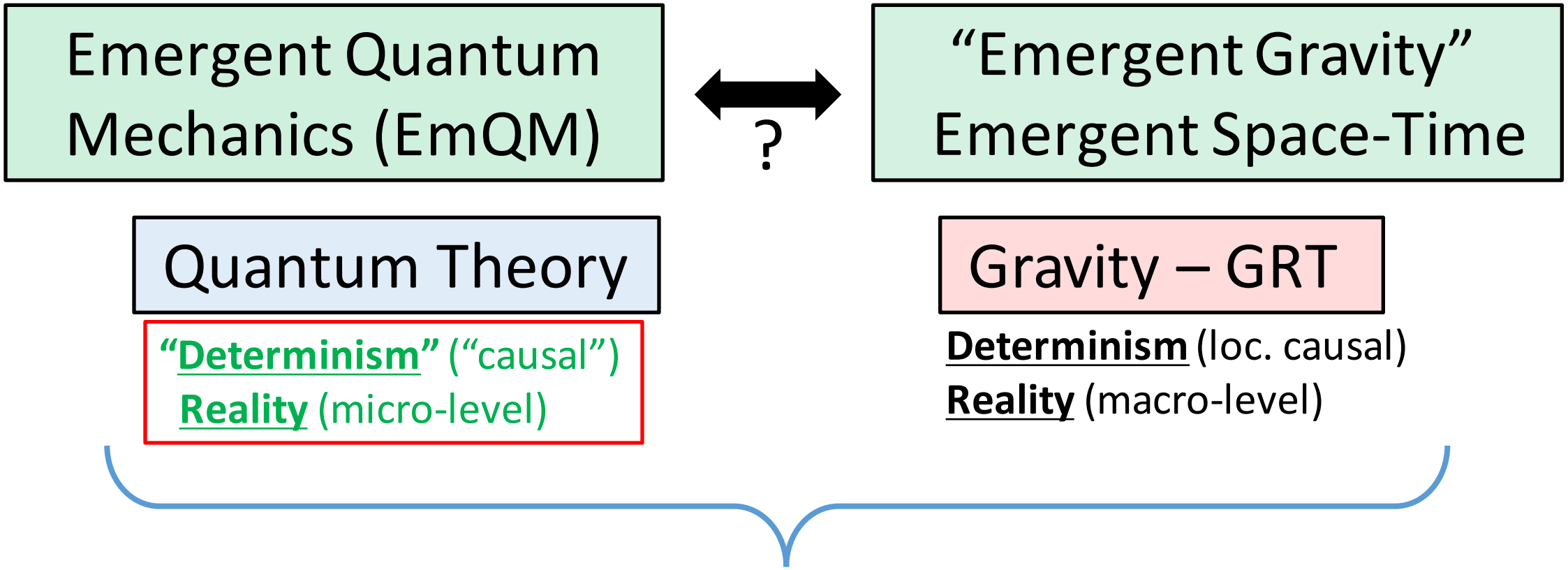

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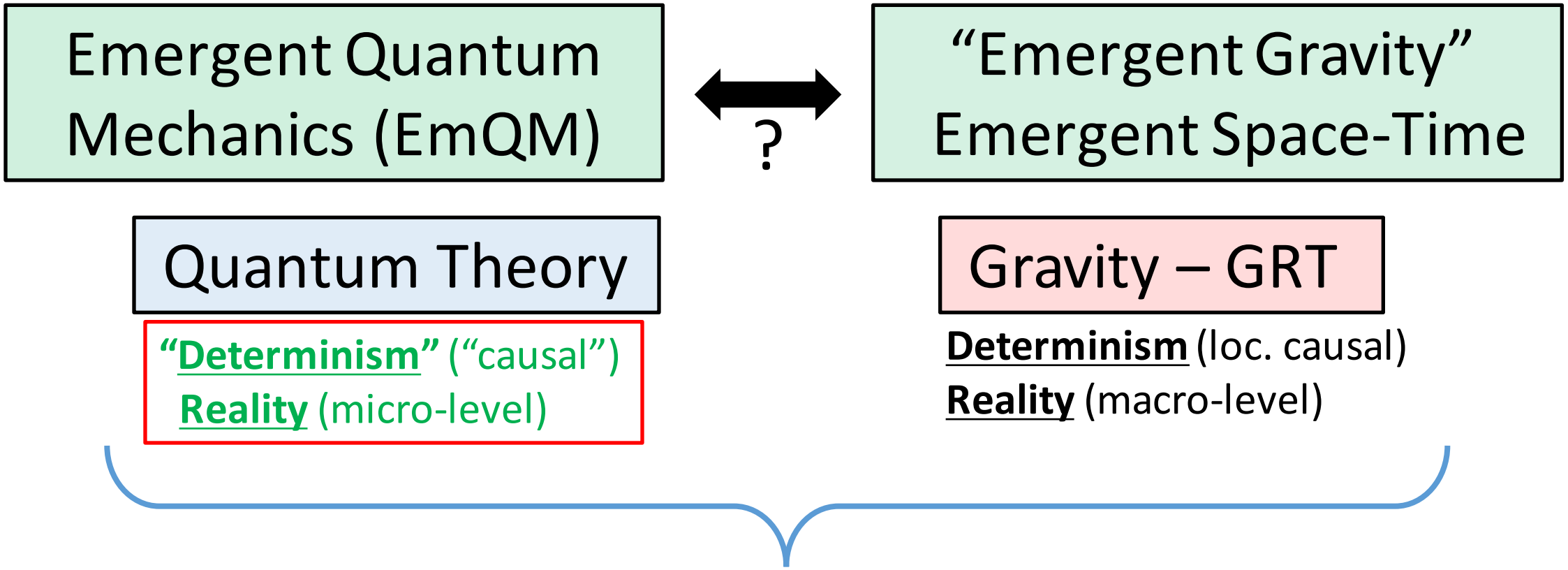
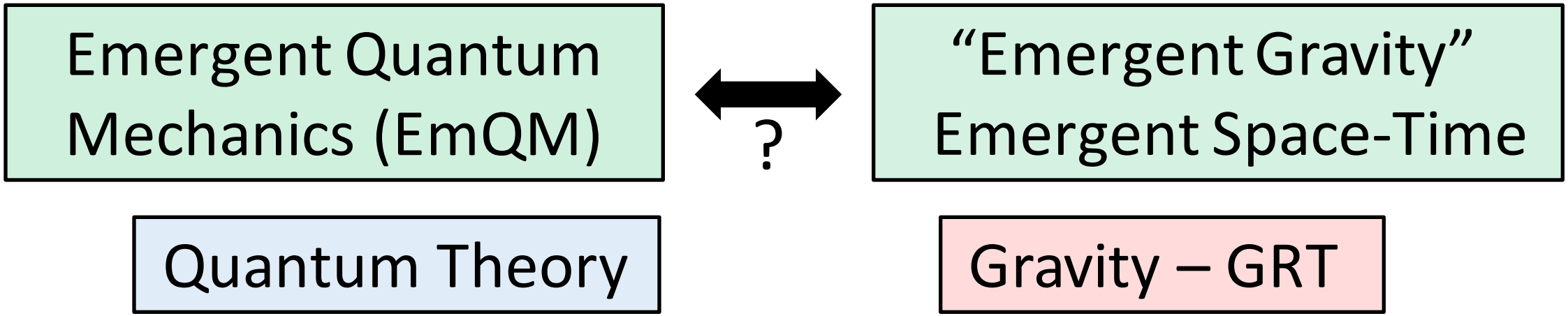


"**Less** Contradiction among **Metaphysical Assumptions?**"

"Resolving the Measurement Problem?"

Towards Unification?



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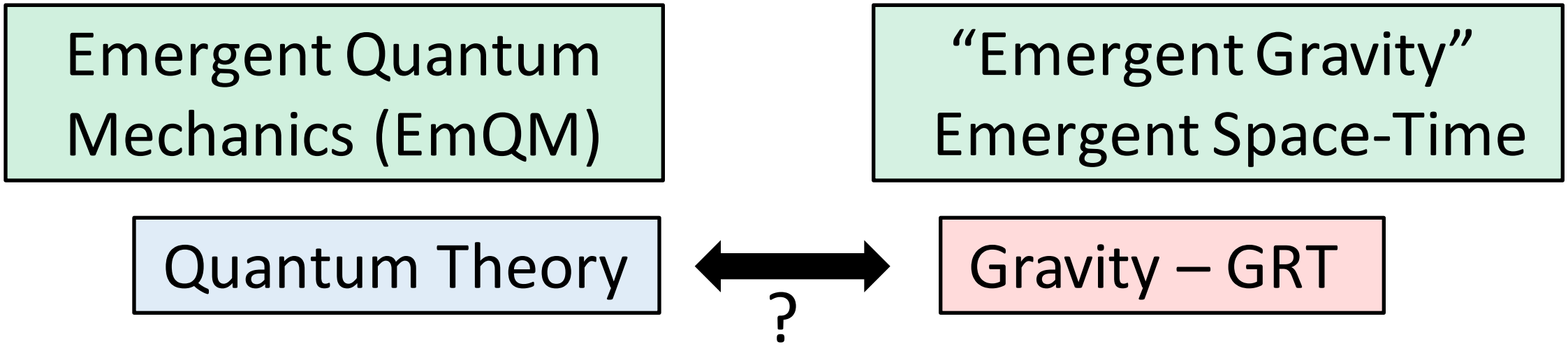

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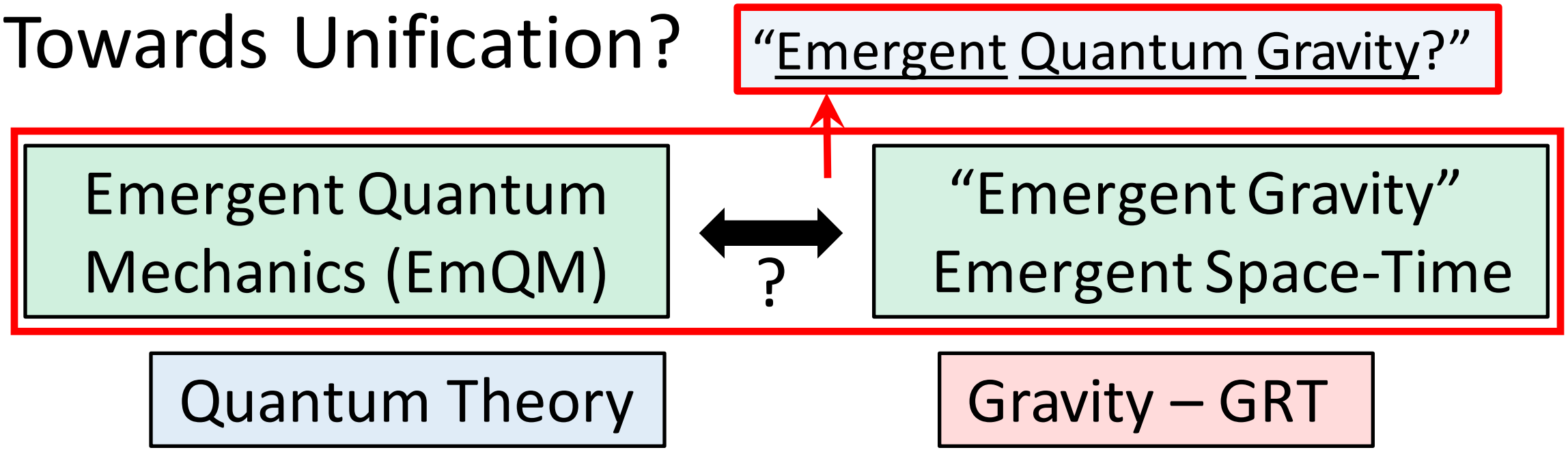


What is "Emergence"?

What is "Emergence"?

Complexity Theory
Chaos Theory
Self-organization Theory
Nonlinear Dynamics
Fractal Set Theory
Cellular Automata
Synergetics

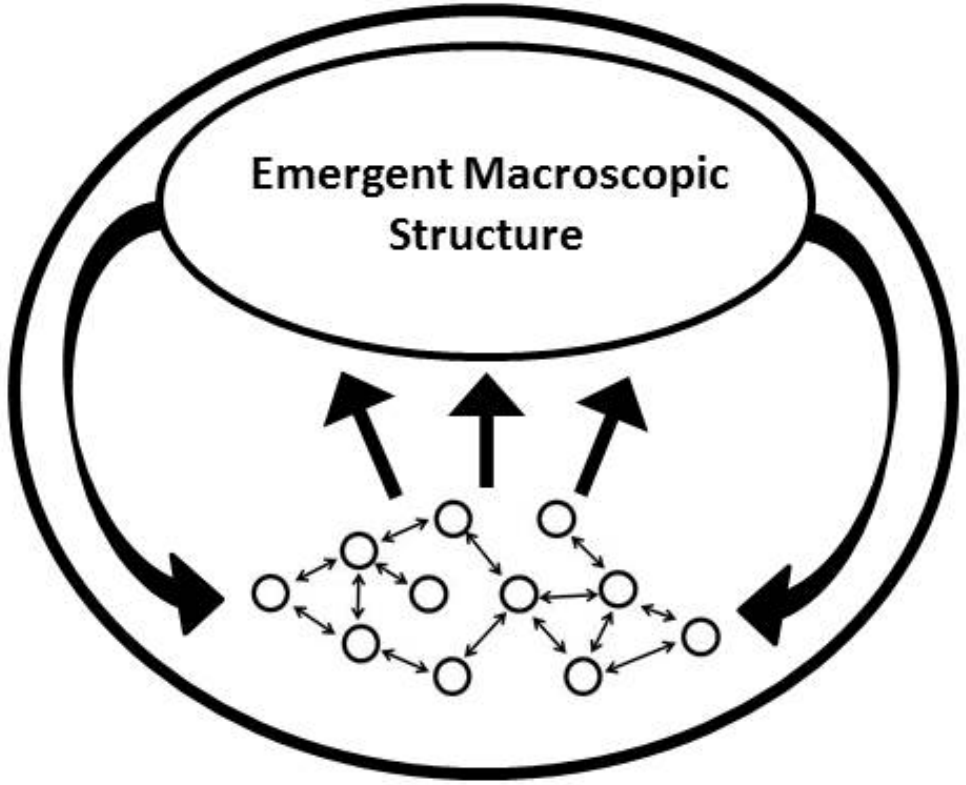
"**Emergent Events**" are characterized by:

"Sensitive Dependence on Initial Conditions"

"Global Order from Local Randomness"

"Indefinite to Definite State Transition"

What is “Emergence”?



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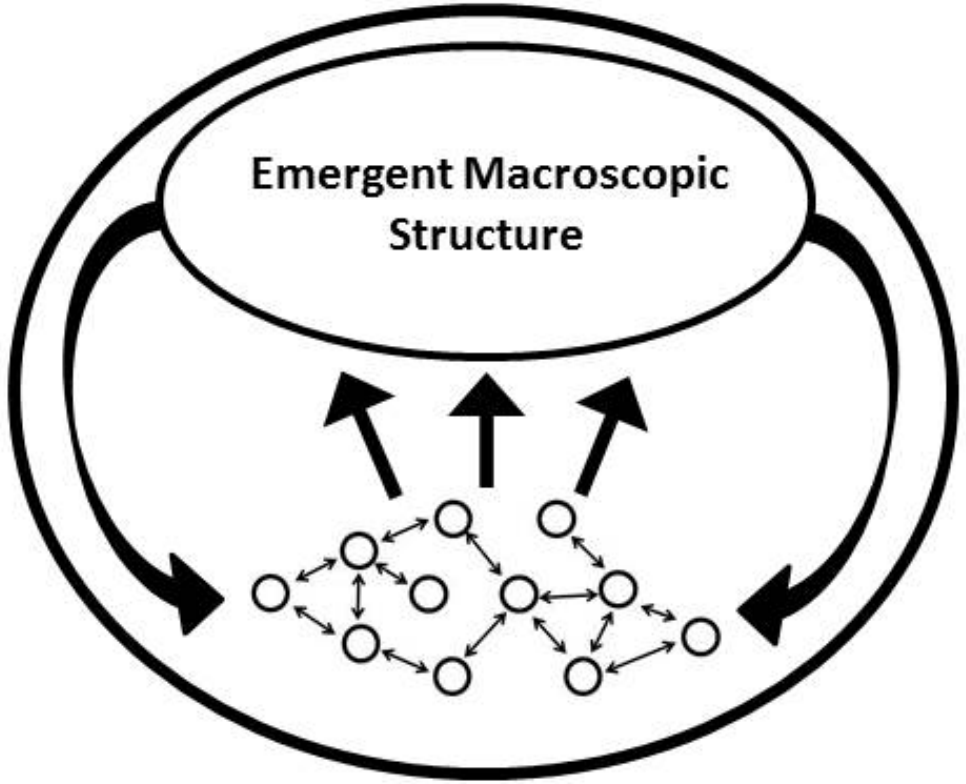


“**Emergent Events**”
are characterized by:

“Non-Equilibrium
Thermodynamics”

“Self-Referential,
Recursive processes”

“Computationally
non-reducible
processes”

What is "Emergence"?

"In-Principle Unpredictability of Individual Events"

Infinite amount of computational resources would be required!

"Determinism without Pre-Determinism"

"**Emergent Events**" are characterized by:

"Non-Equilibrium Thermodynamics"

"Self-Referential, Recursive processes"

"Computationally non-reducible processes"

What is “Emergence”?

Quantum Mechanics is incompatible with the proposition that measurement outcomes have pre-determined values independent of actual measurement.

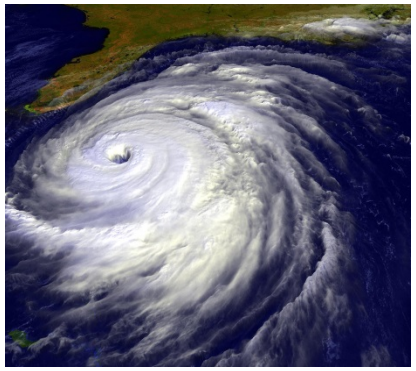
Emergent Quantum Mechanics (EmQM) agrees with Orthodox Quantum Mechanics!

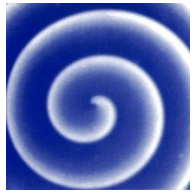
“Determinism without Pre-Determinism”

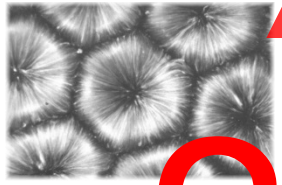
EmQM: Measurement in emergent processes describes the transition of an indefinite ontic structure (IOS) into a definite ontic structure (DOS).

What are "***Emergent Events/Structures***"?

[Self-Organizing Relational Dynamics]







Emergent Events Structures

Global

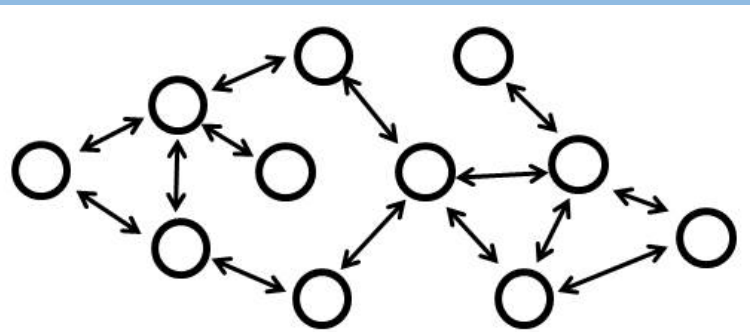
Macroscopic

?

Microscopic

Local

Random Interactions *of "Elemental" Units*



Local Microscopic Interactions

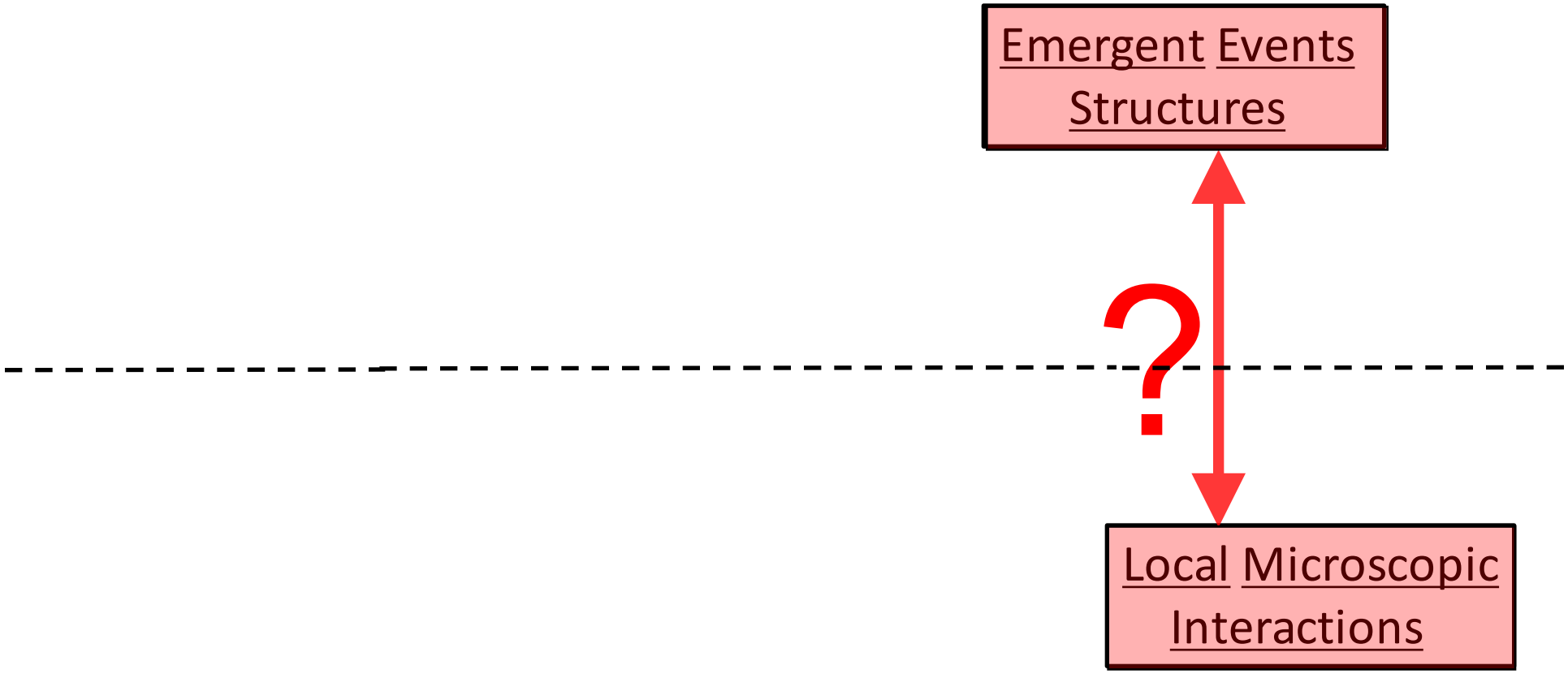
LONG-RANGE Correlations

UNPREDICTABLE Correlations

YET, DETERMINISTIC !

What are "***Emergent Events/Structures***"?

[Self-Organizing Relational Dynamics]



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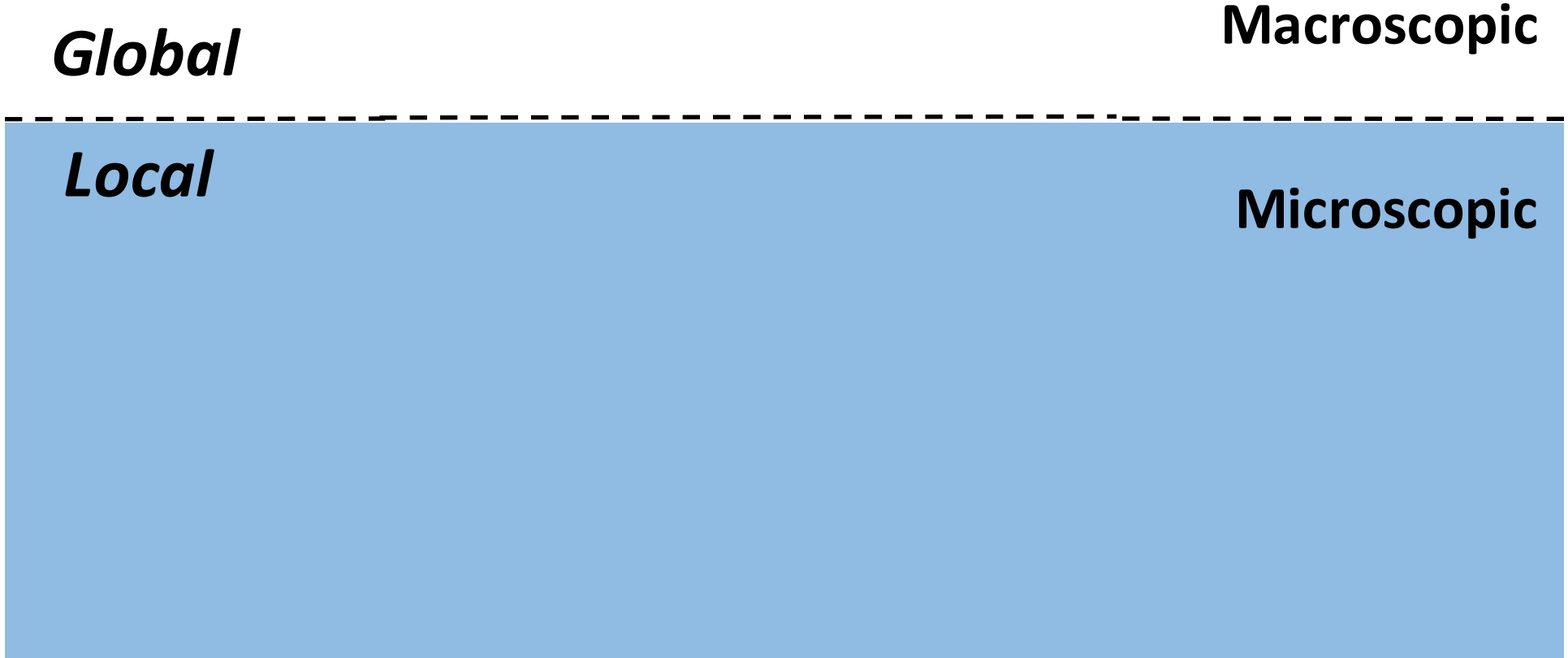

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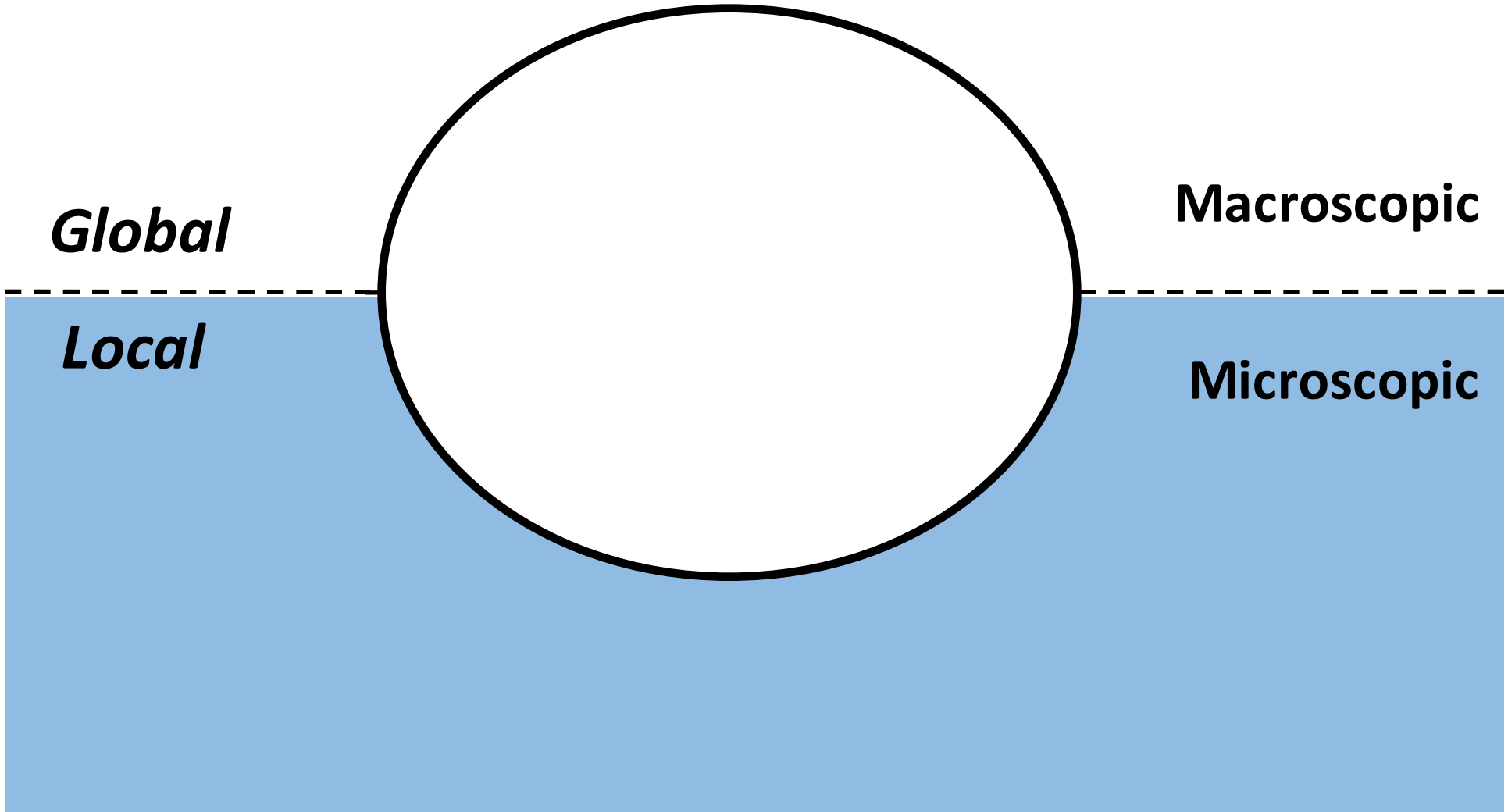
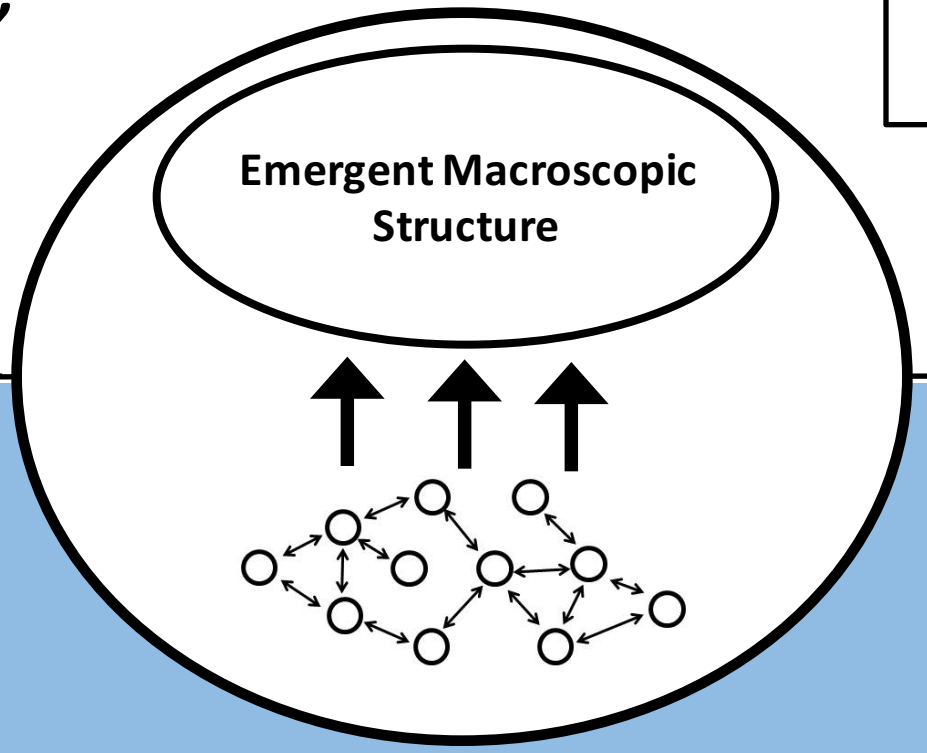


What are "***Emergent Events/Structures***"?

"Weak or Epistemic Emergence" → *"Theory Emergence"*

BOTTOM-UP CAUSALITY



Global

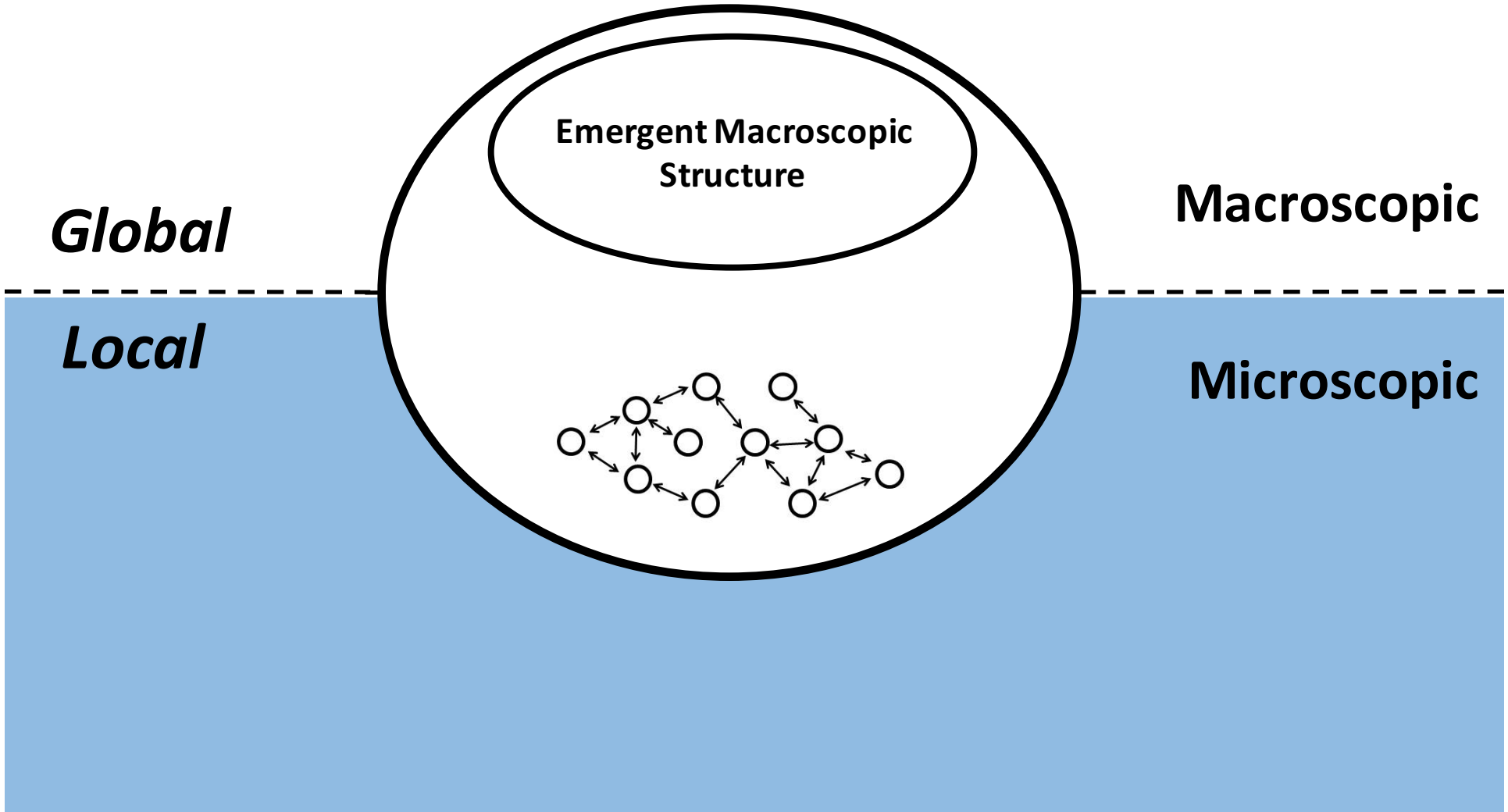
Macroscopic

Local

Microscopic

"SUPERVENIENCE": Global, emergent structures SUPERVENE on local processes described by reductionism.

What are "***Emergent Events/Structures***"?

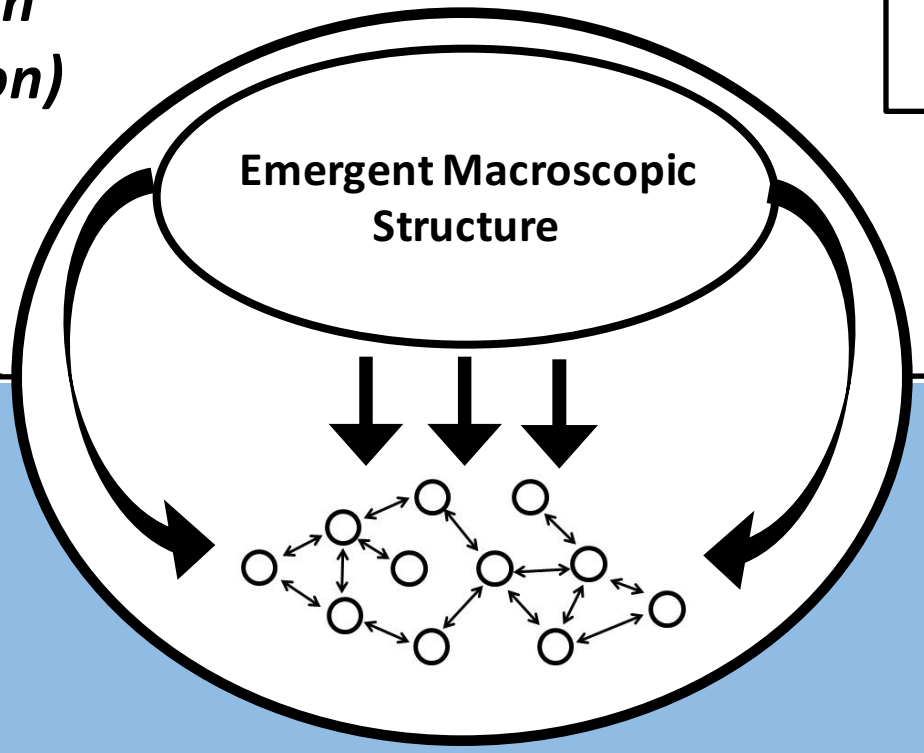


What are "***Emergent Events/Structures***"?

NOT Emergence! → *"Scientifically Untenable"*

(e.g. Aristotelian formal causation)

TOP-DOWN CAUSALITY



Global

Macroscopic

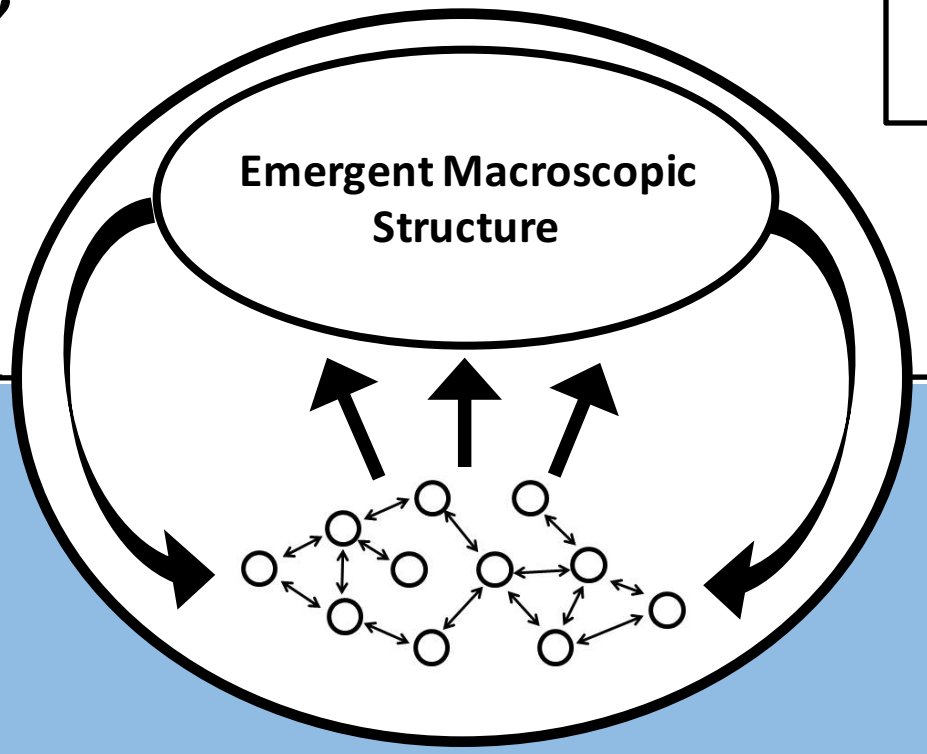
Local

Microscopic

What are "***Emergent Events/Structures***"?

"Strong or Ontic Emergence" → *"Physical Emergence"*

RELATIONAL CAUSALITY



Global

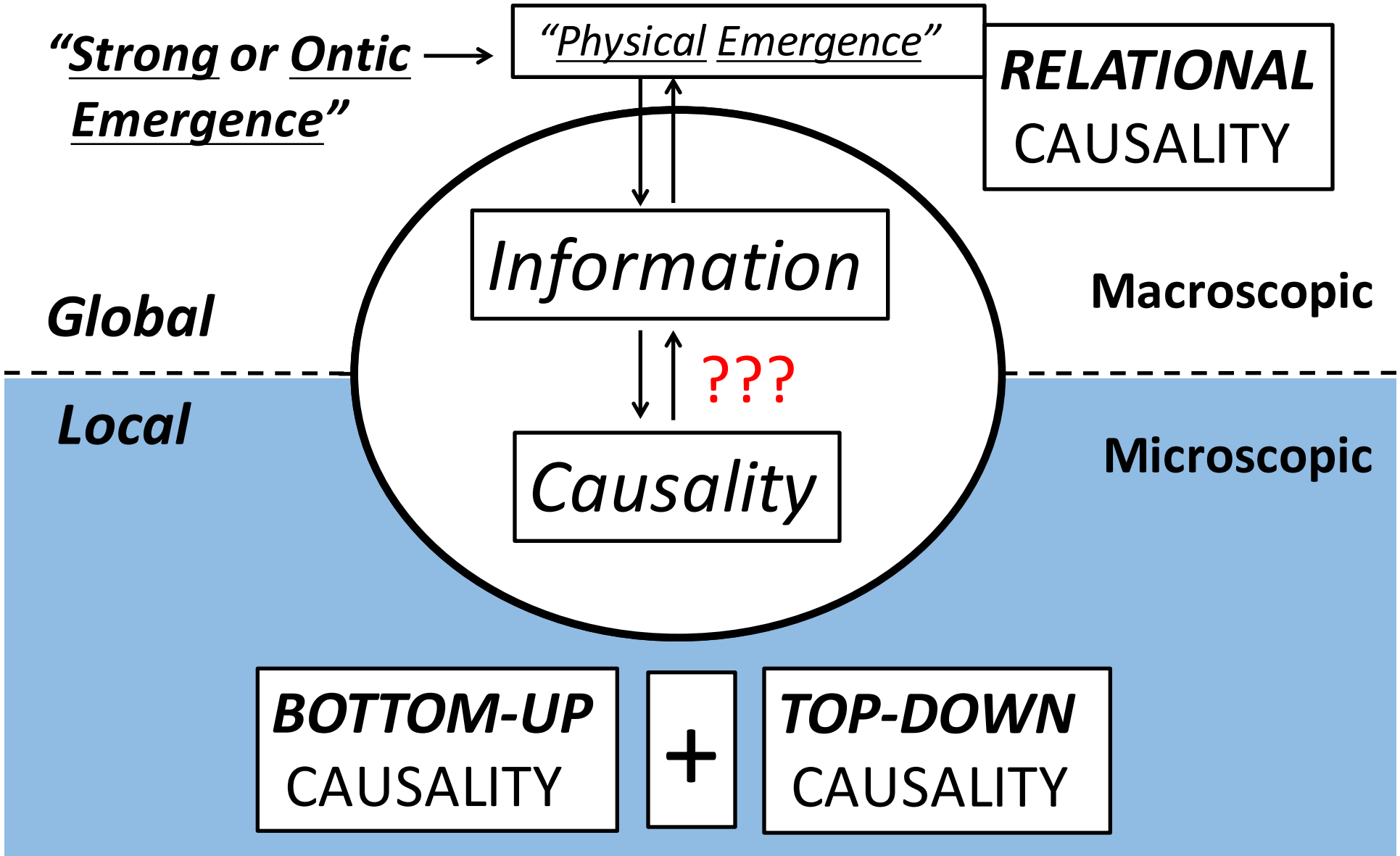
Macroscopic

Local

Microscopic

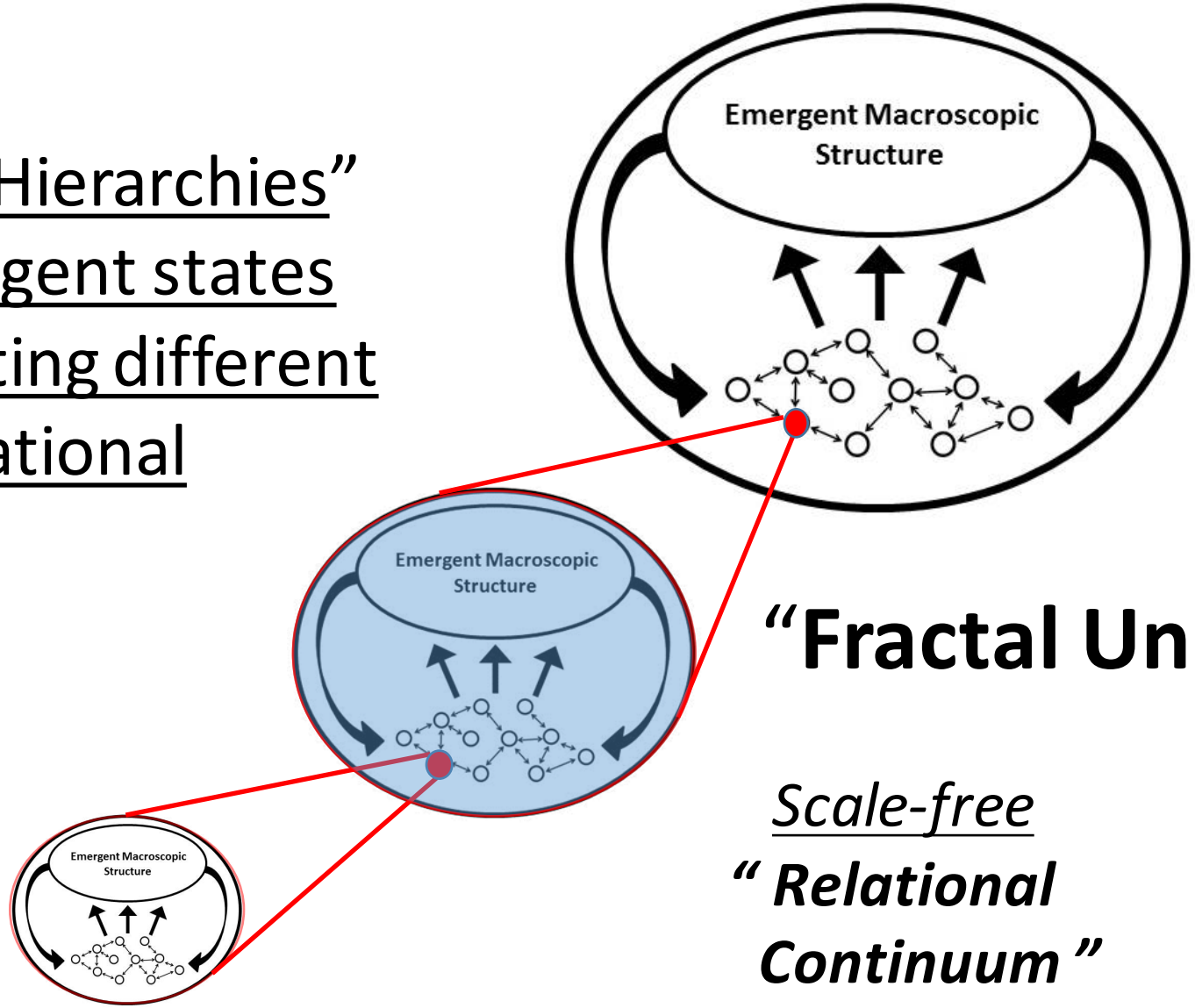
BOTTOM-UP CAUSALITY + ***TOP-DOWN*** CAUSALITY

What are "***Emergent Events/Structures***"?



What are "***Emergent Events/Structures***"?

"Nested Hierarchies"
of emergent states
connecting different
organizational
levels

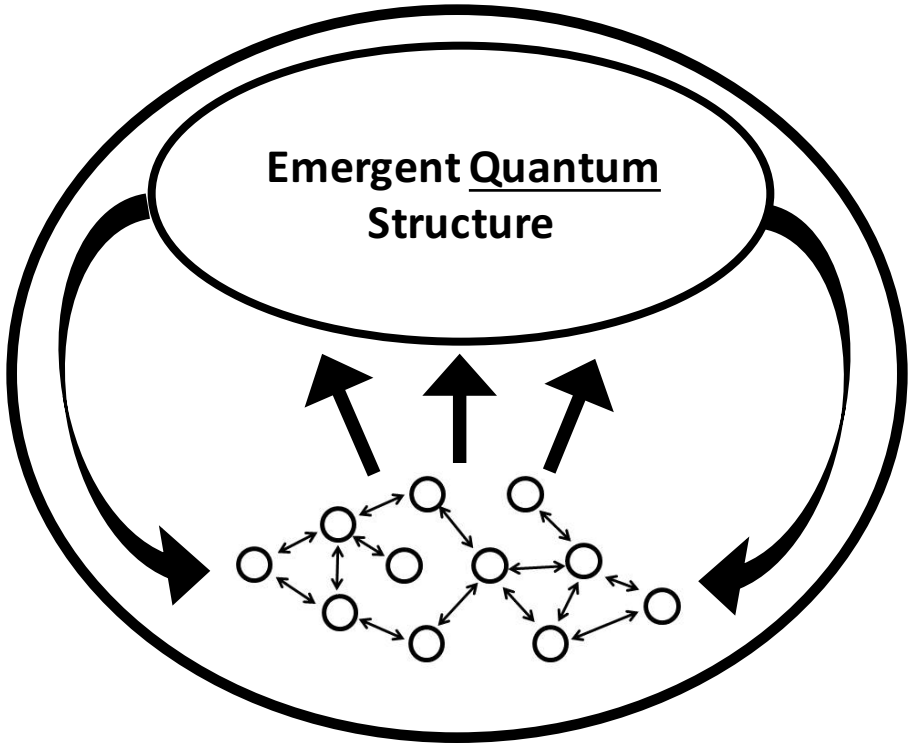


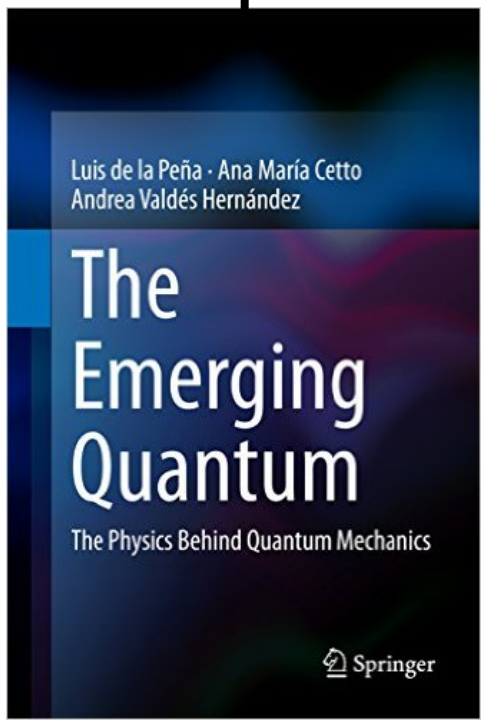
"Fractal Universe"

Scale-free
" Relational Continuum "

An Emergent ***Quantum Structure***?

The Emerging Quantum (2015) Springer
de la Pena, **Cetto**, **Valdes-Hernandez**





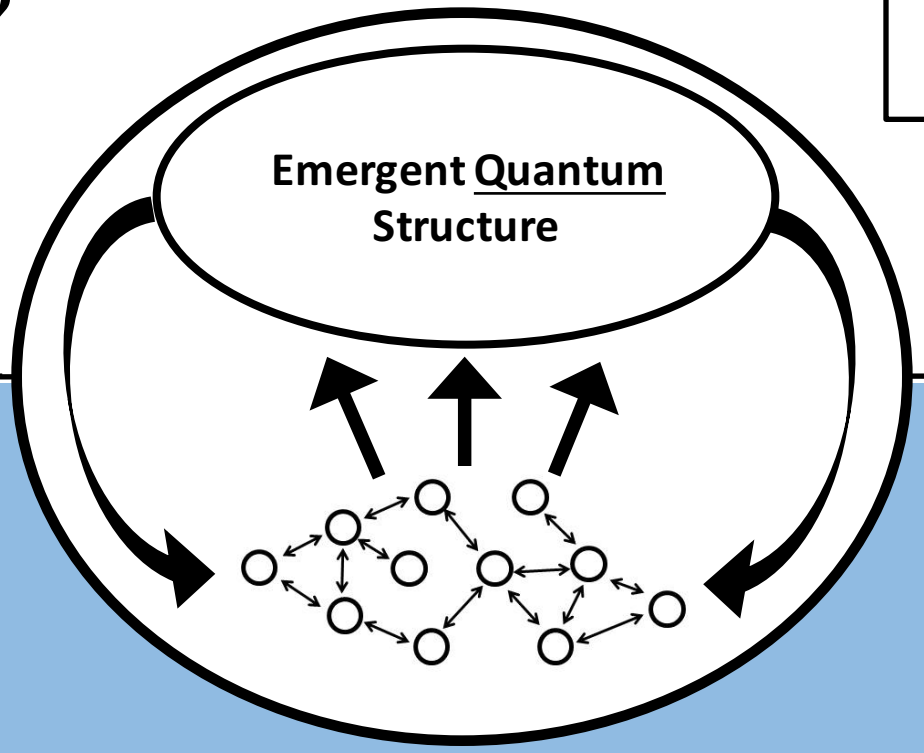
An Emergent ***Quantum Structure***?

"Strong or Ontic Emergence" →

"Quantum Emergence"

RELATIONAL CAUSALITY

Quantum State →



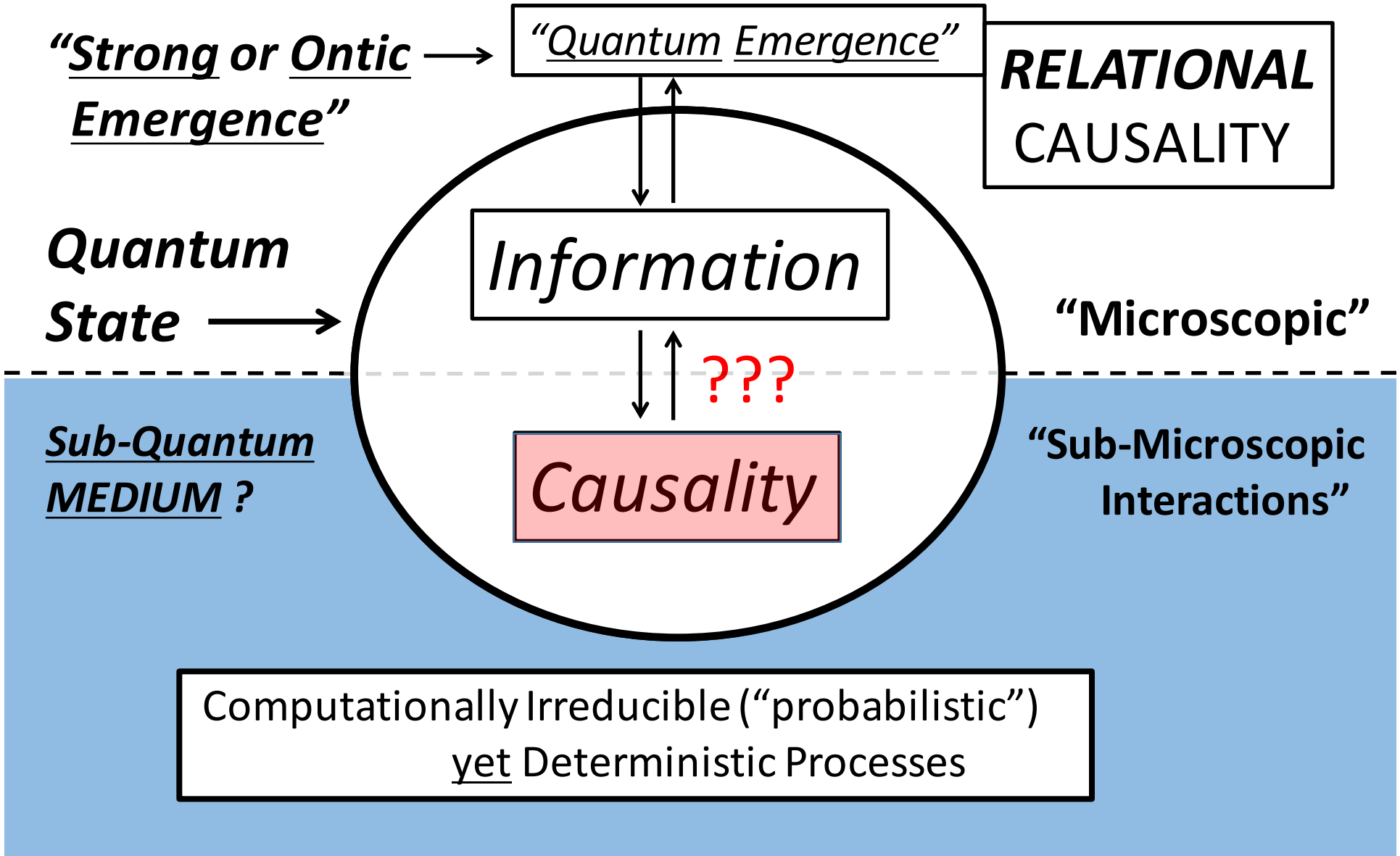
"Microscopic"

Sub-Quantum MEDIUM ?

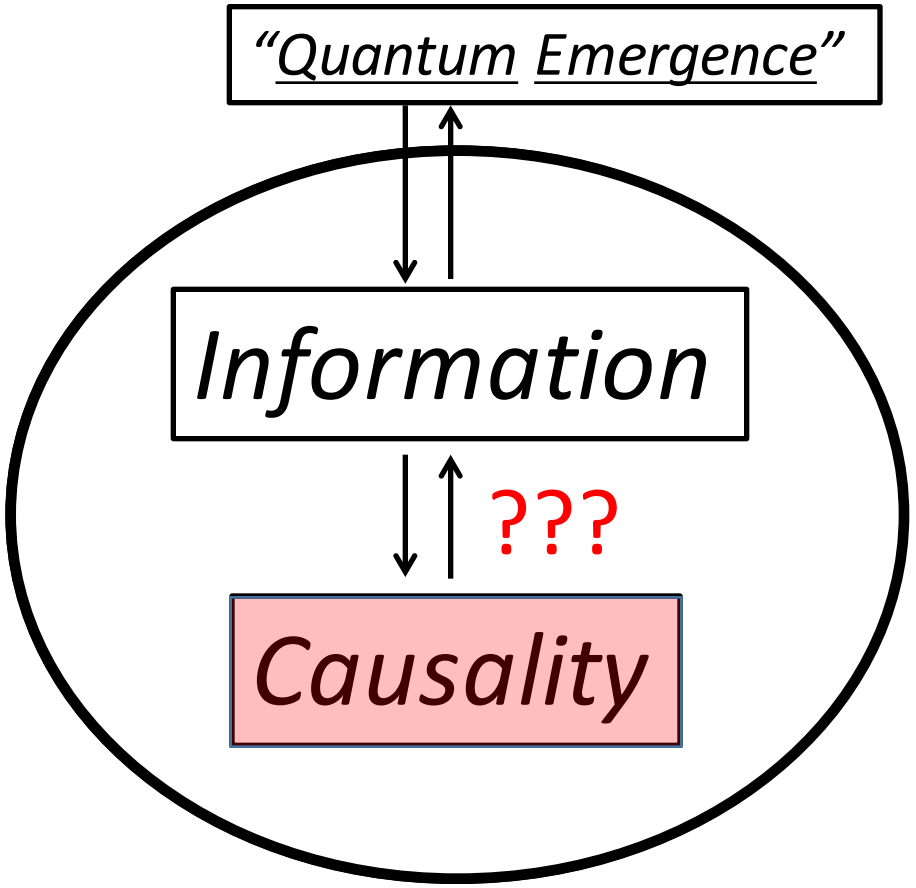
"Sub-Microscopic Interactions"

Computationally Irreducible ("probabilistic") yet Deterministic Processes

An Emergent ***Quantum Structure***?



An Emergent ***Quantum Structure***?

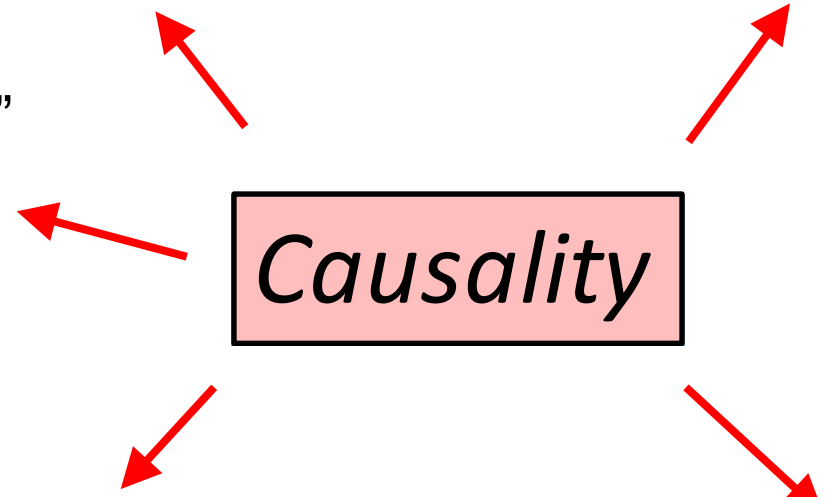


An Emergent ***Quantum Structure***?

Towards a "New Causality"?

Nonlocal Causality
e.g., Bohm/Hiley, Bell, Maudlin.

Time-symmetric "Causality"
e.g., Aharonov/Tollaksen



Relational Causality
e.g., Walleczek/Grössing

Quantum Causality and Indefinite Causal Order:
"We have only begun to scratch the surface of quantum causality. The deeper we dig the more questions arise."

Časlav Brukner
Nature Phys. (2014)

What if causality is not fundamental?

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EmQM15 Symposium Objectives

1. Is the world local or nonlocal? What is nonlocality?
2. If nonlocal, i.e., superluminal, influences exist, then why can't they be used for superluminal signalling and communication?
3. How is the role of the scientific observer/agent to be accounted for in realistic approaches to quantum theory?
4. How could recent developments in the field of space-time as an emergent phenomenon advance new insight at this research frontier?
5. What new experiments might contribute to new understanding?

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What is “Nonlocality”?

Einstein, Podolsky, and Rosen (1935) Phys. Rev. 47, 777-780.
Can quantum-mechanical description of physical reality be considered complete?

Bohm (1952ab) Phys. Rev. 85, 166-179; 180-193.
A Suggested Interpretation of the Quantum Theory in terms of “Hidden” Variables.

Bell (1964) Physics 1, 195-200.
On the Einstein Podolsky Rosen Paradox.

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Nonlocality: *“… means that what you do here has immediate consequences in remote places.”*

John S. Bell, Interview at CERN in 1990

What the exact nature is of this “immediate consequence” of nonlocality is what is under dispute ever since EPR (1935)!

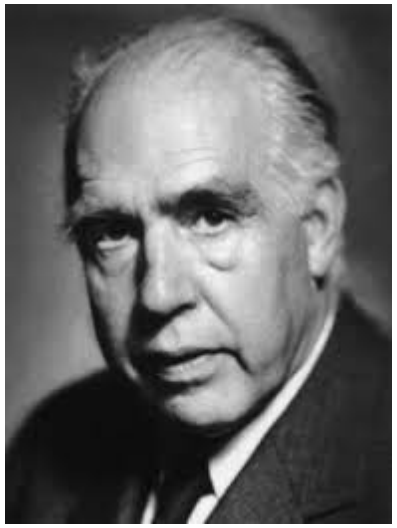
What is “Nonlocality”?

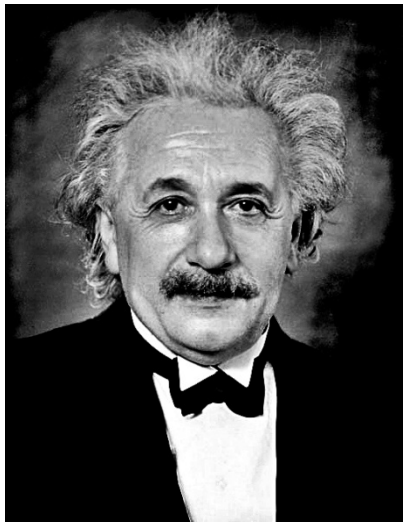
Einstein, Podolsky, and Rosen (1935) Phys. Rev. 47, 777-780.
Can quantum-mechanical description of physical reality be considered complete?

EPR (**1935**) had concluded that ‘orthodox quantum theory’ must be incomplete, because otherwise the world would actually have to be “nonlocal”! [“Violation of local realism!”]

Einstein rejected what he called “spooky action at-a-distance”, or, as Bell said later, the idea that actions here can have “immediate consequences” on remote places!

What is “Nonlocality”?





Bohr and Einstein Agree!

“There cannot exist “real nonlocal influences”,
i.e., ‘intrinsic, or objective, nonlocality’!”

What is “Nonlocality”?

Bohm (1952ab) Phys. Rev. 85, 166-179; 180-193.

A Suggested Interpretation of the Quantum Theory in terms of “Hidden” Variables.

In **1952**, along comes David Bohm, and publishes an alternative approach towards accounting for quantum correlations based upon the “forbidden idea” of “intrinsic, or objective, nonlocality”.

In **2015**, 80 years after EPR, we call such nonlocal quantum theories ontological or **ψ-ontic quantum theories**.

What is “Nonlocality”?

Bohm (1952ab) Phys. Rev. 85, 166-179; 180-193.

A Suggested Interpretation of the Quantum Theory in terms of “Hidden” Variables.

Is the world local or nonlocal?

According to ψ-ontic, realist, quantum mechanics, the world is nonlocal.

According to Bohm’s theory, the world is not “intrinsically random” but “fundamentally interconnected”.

What is “Nonlocality”?

According to the textbook, **operationalist** (Copenhagen, epistemic, etc.) interpretation of **quantum mechanics**, what is represented by “nonlocality”?

Orthodox Quantum Mechanics

"Operationalist Quantum Mechanics"

Quantum Theory

Indeterminism (non-causal)
Non-Reality (micro-level)

e.g., Copenhagen Interpretation (Bohr)

"There is no quantum world. There is only abstract quantum physical description."

"It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature."

What is "Nonlocality"?

According to the textbook, **operationalist** (Copenhagen, epistemic, etc.) interpretation of **quantum mechanics**, what is represented by "nonlocality"?

"**Operationalist** Quantum Theory": Negative Definition

"Nonlocal correlations are correlations that cannot be explained by a local realist theory".

"**Realist** Quantum Theory": Positive Definition

"Nonlocal correlations are correlations that can be explained by a nonlocal realist theory".

Two Ways of Interpreting Bell's Theorem (with "free choice")
[vis-a-vis 'Nonlocal Correlations']

Two World Views

Operationalist
Quantum Theory

⇨ LOCALITY + ~~REALITY~~

UN-REALITY
Intrinsic Randomness
Non-Causal Subjectivity

The world is **local**
and
irreducibly **random**!

"Locality without Causality"

Realistic
Quantum
Theory

⇨ ~~LOCALITY~~ + REALITY

NON-LOCALITY
Einstein's
"spooky action at-a-distance"

Determinism
Causality
Objectivity
Ontology

The world is **nonlocal**
and
deeply **interconnected**!

"Causality without Locality"

Two Ways of Interpreting Bell's Theorem (with **"free choice"**)
[vis-a-vis 'Nonlocal Correlations']

Two World Views

Operationalist
Quantum Theory

⇨ How could "free will" prevail in a world that is "intrinsically random"?

The world is **local**
and
irreducibly **random**!

"Locality without Causality"

Realistic
Quantum
Theory

⇨ How could "free will" prevail in a world that is "fundamentally interconnected"?

The world is **nonlocal**
and
deeply **interconnected**!

"Causality without Locality"

An Open Question….

Operationalist Quantum Mechanics

and/or

Realist Quantum Mechanics ?

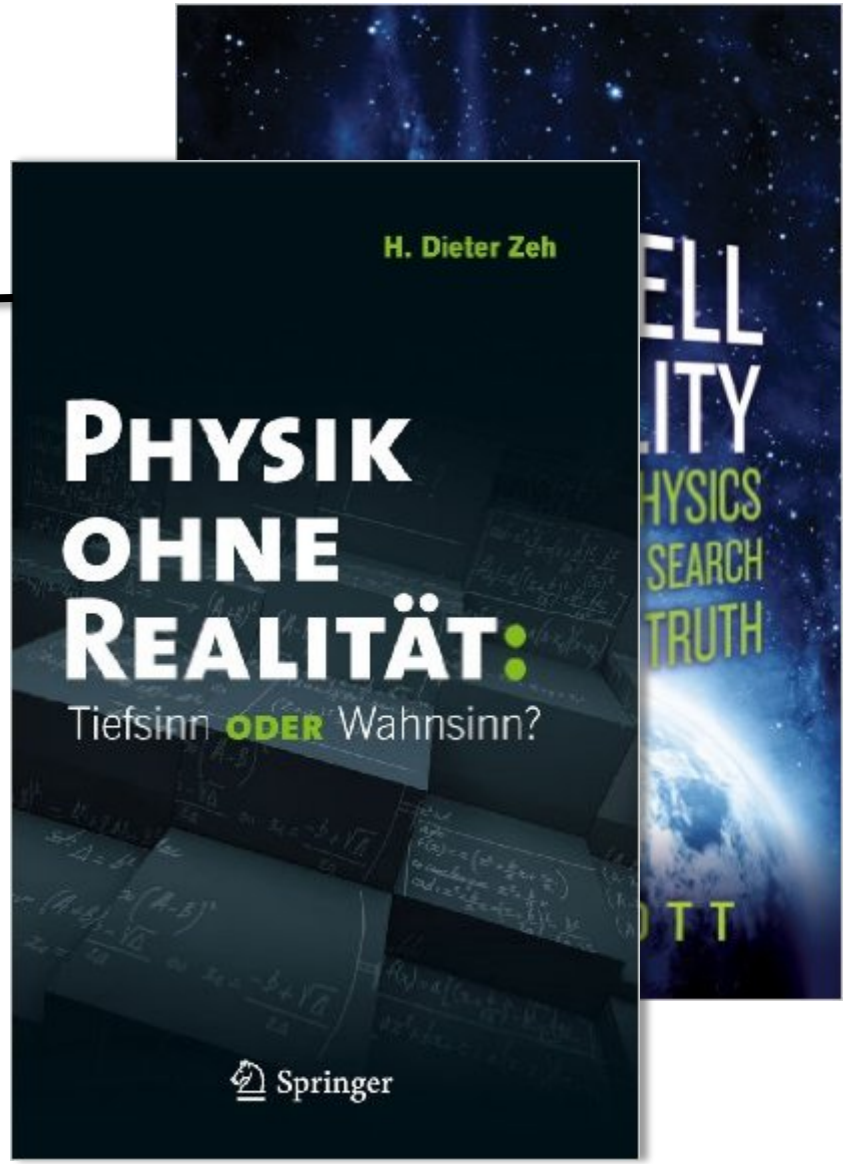
Objective

The EmQM15 Symposium "invites the open exploration of the quantum state as a reality."

PHYSICS WITHOUT REALITY:

Profound or Delusional?

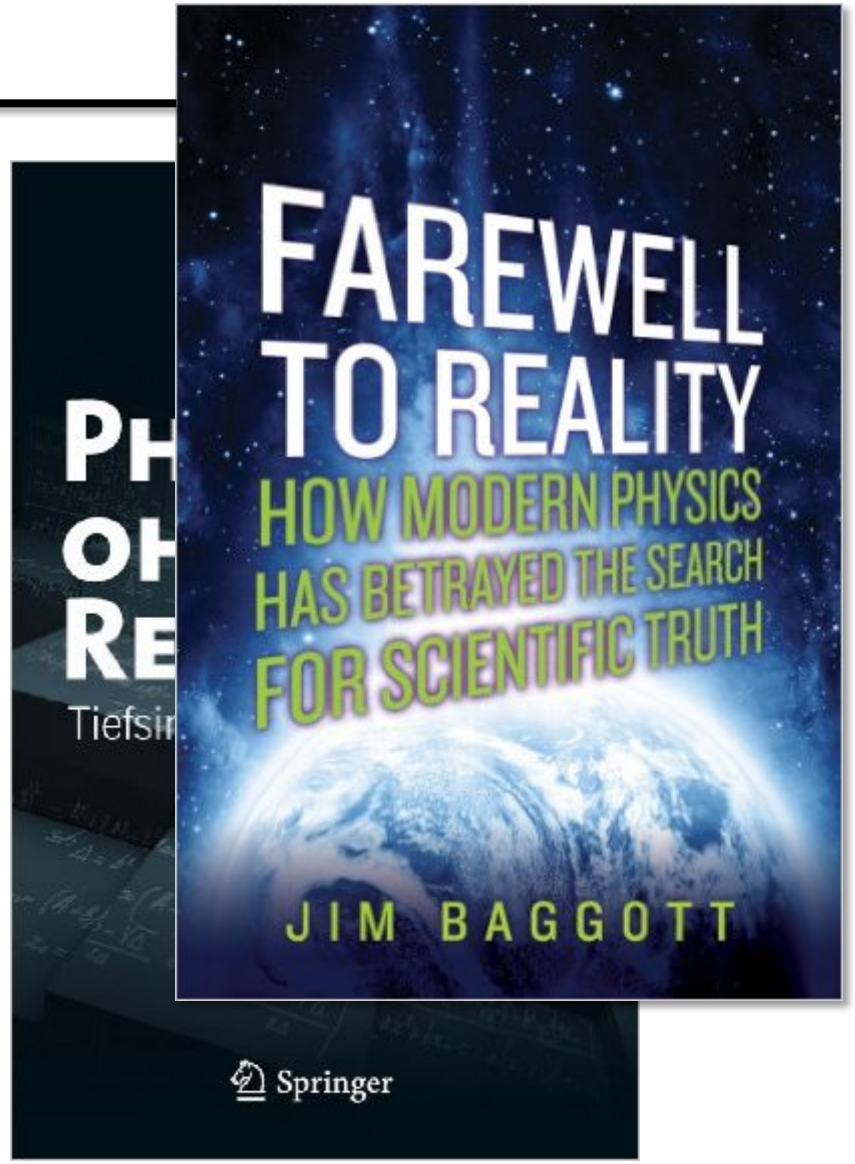
H. Dieter Zeh (2012)



FAREWELL TO REALITY:

How Modern Physics Has Betrayed the Search For Scientific Truth

Jim Baggott (2013)

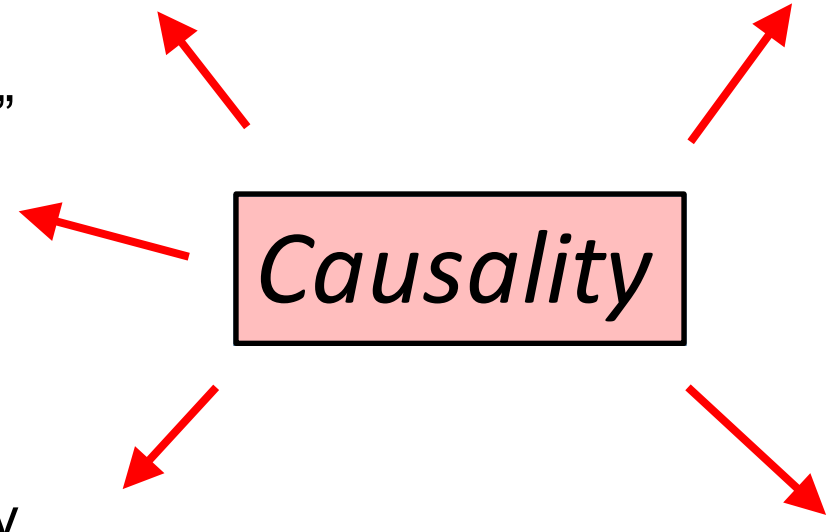


An Emergent ***Quantum Structure***?

Towards a "New Causality"? Towards a "New Reality"?

Nonlocal Causality
e.g., Bohm/Hiley, Bell, Maudlin.

Time-symmetric "Causality"
e.g., Aharonov/Tollaksen



Relational Causality
e.g., Walleczek/Grössing

Quantum Causality and Indefinite Causal Order:
"We have only begun to scratch the surface of quantum causality. The deeper we dig the more questions arise."

Časlav Brukner
Nature Phys. (2014)

What if causality is not fundamental?

An Emergent ***Quantum Structure***?

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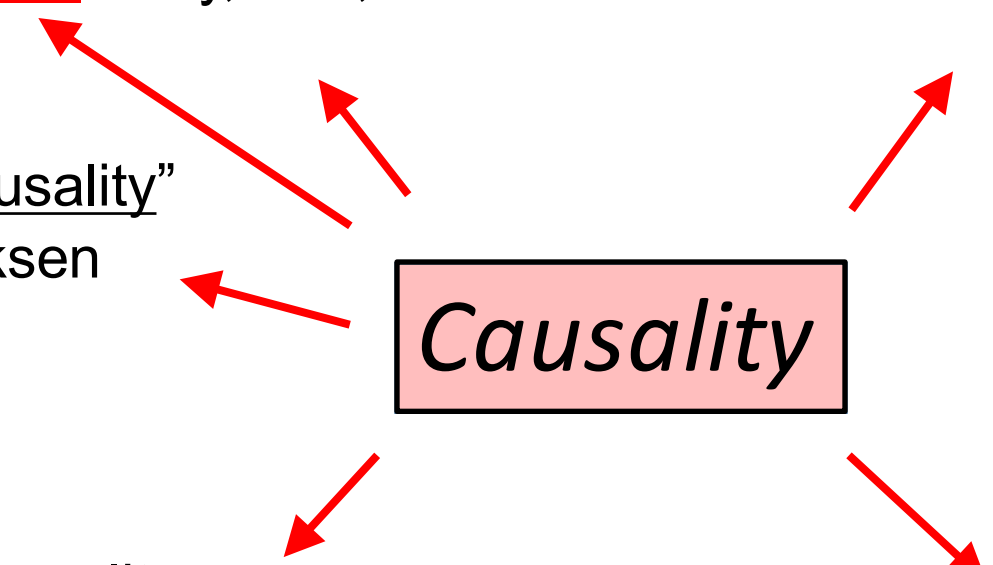

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Bohm (1952ab) Phys. Rev. 85, 166-179; 180-193.

A Suggested Interpretation of the Quantum Theory in terms of "Hidden" Variables.

Fetzer Franklin Fund
Exploring Frontiers. Breakthroughs. Science.

John Fetzer and David Bohm
at the Fetzer Institute (ca. 1990)

[Photo by courtesy of Jeff Tollaksen]

25 Years Ago

David Bohm was a
Science Scholar-in-Residence
at the Fetzer Institute

EmQM15

Prof. Basil Hiley

EmQM15
Opening Key Note Lecture

Prof. Yakir Aharonov

END