JOHN TEMPLETON FOUNDATION

SUPPORTING SCIENCE~INVESTING IN THE BIG QUESTIONS

Project: *Quantum Causal Structures*, ID 60609

Istituto Nazionale di Fisica Nucleare

The Galileo principle for general dynamical systems: Lorentz transformations from Quantum Theory

and a little bit more *(homogeneity, isotropy, and locality)*

Giacomo Mauro D'Ariano

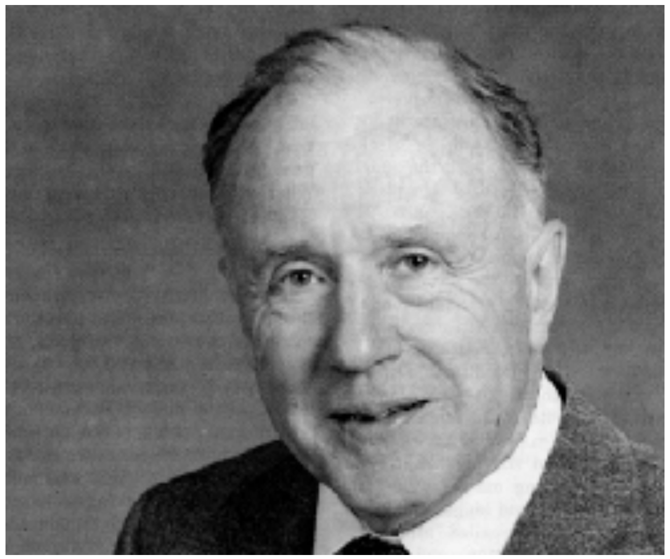
Università degli Studi di Pavia

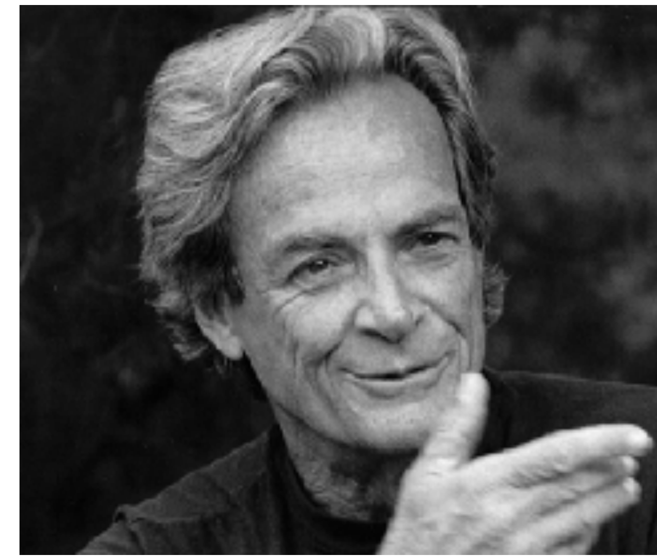
Frascati Labs

Training school: *Are spin-statistics connection and quantum theory exact? …*

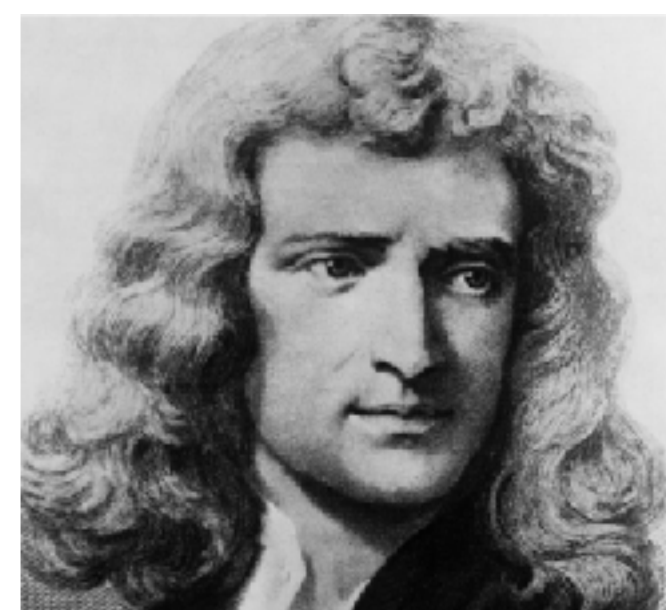
19-21 December 2016

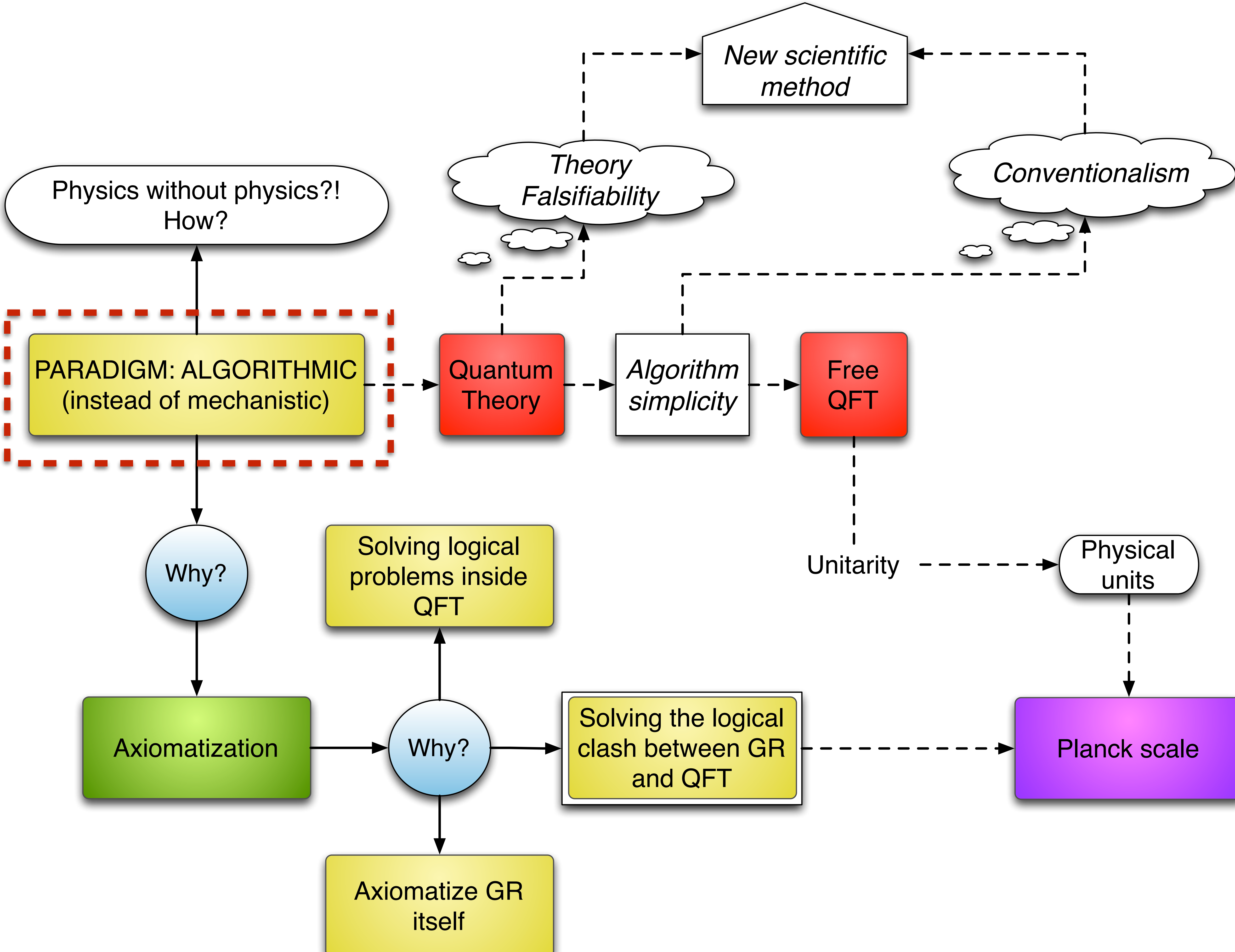
New *algorithmic* paradigm:
the physical law as an *algorithm*

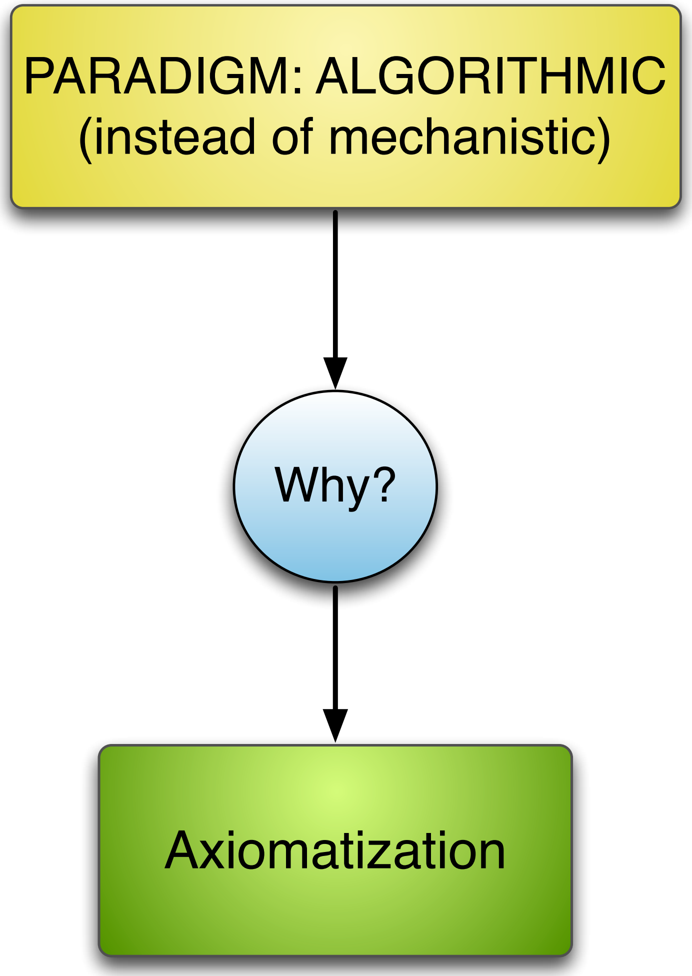




Old *mechanistic* paradigm:
the physical law as a *mechanism*




New scientific method
Theory Falsifiability
Conventionalism
Physics without physics?! How?
PARADIGM: ALGORITHMIC (instead of mechanistic)
Quantum Theory
Algorithm simplicity
Free QFT
Why?
Solving logical problems inside QFT
Unitarity
Physical units
Axiomatization
Why?
Solving the logical clash between GR and QFT
Planck scale
Axiomatize GR itself


PARADIGM: ALGORITHMIC
(instead of mechanistic)
Why?
Axiomatization

The information-theoretic paradigm

The first opportunity of solving the problem of axiomatization of physics

The investigations on the foundations of geometry suggest the problem: To treat in the same manner by means of axioms, those physical sciences in which mathematics plays an important part; in the first rank are the theory of probabilities and mechanics.

David Hilbert

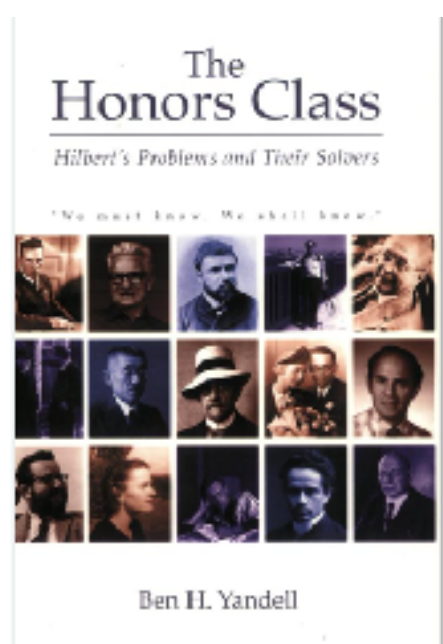
The VI Hilbert problem

The information-theoretic paradigm

The first opportunity of solving the problem of axiomatization of physics

Axiomatizing the theory of probabilities was a realistic goal: Kolmogorov accomplished this in 1933. The word 'mechanics' without a qualifier, however, is a Trojan horse."

Benjamin Yandell



The VI Hilbert problem

The information-theoretic paradigm

The first opportunity of solving the problem of axiomatization of physics

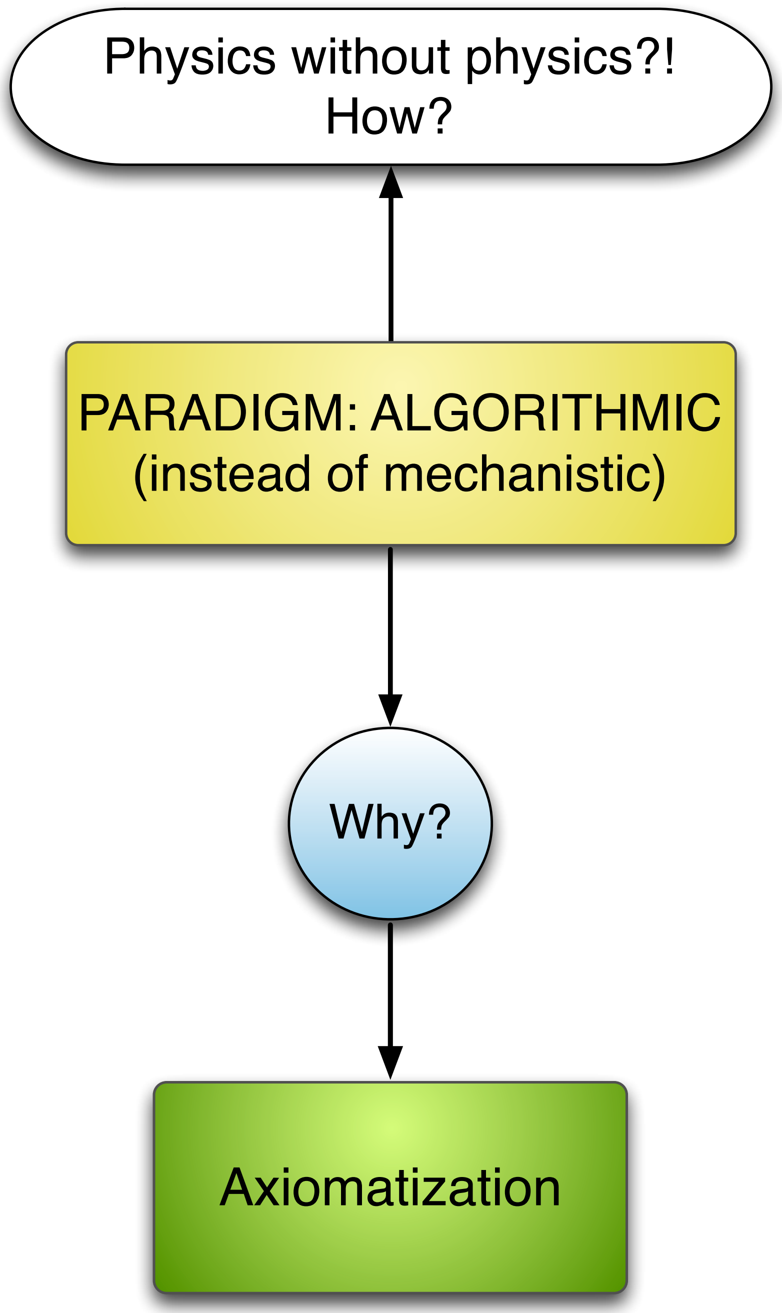
PROGRAM

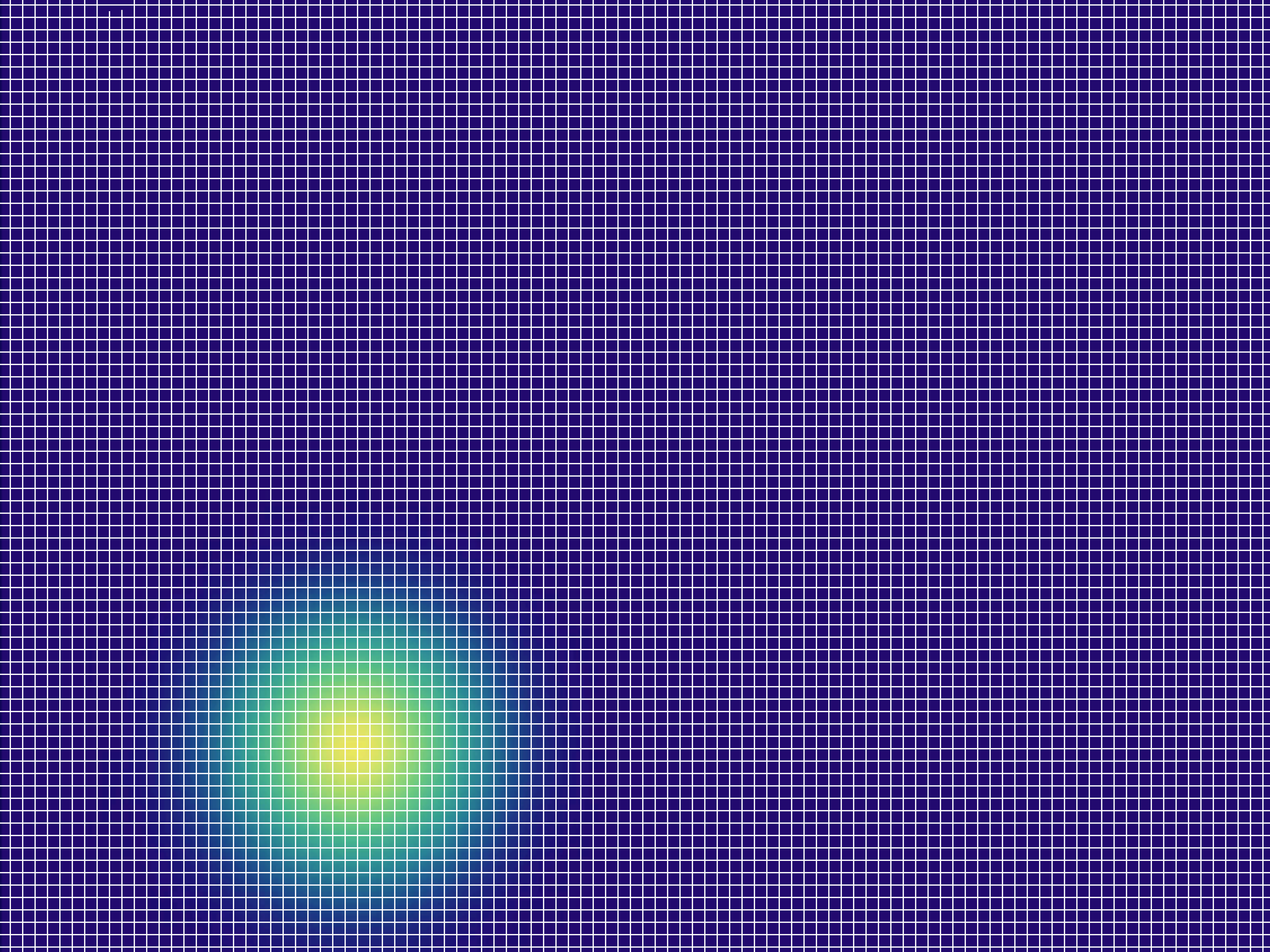
Derive Physics
from "principles" stated in form of purely mathematical axioms without physical primitives,
but having a thorough physical interpretation

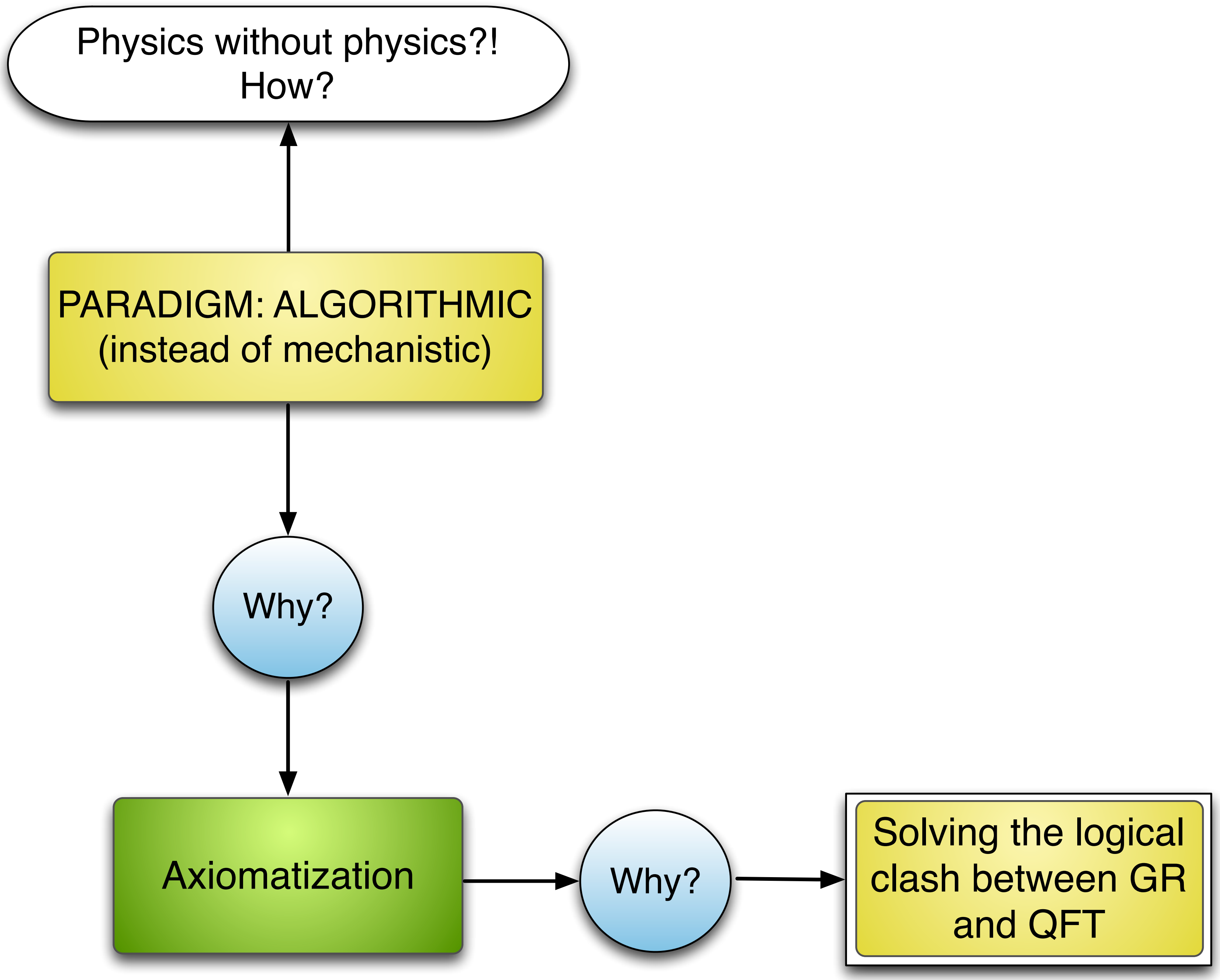
The VI Hilbert problem

---

physical primitives: mass, force, rods, clocks,…

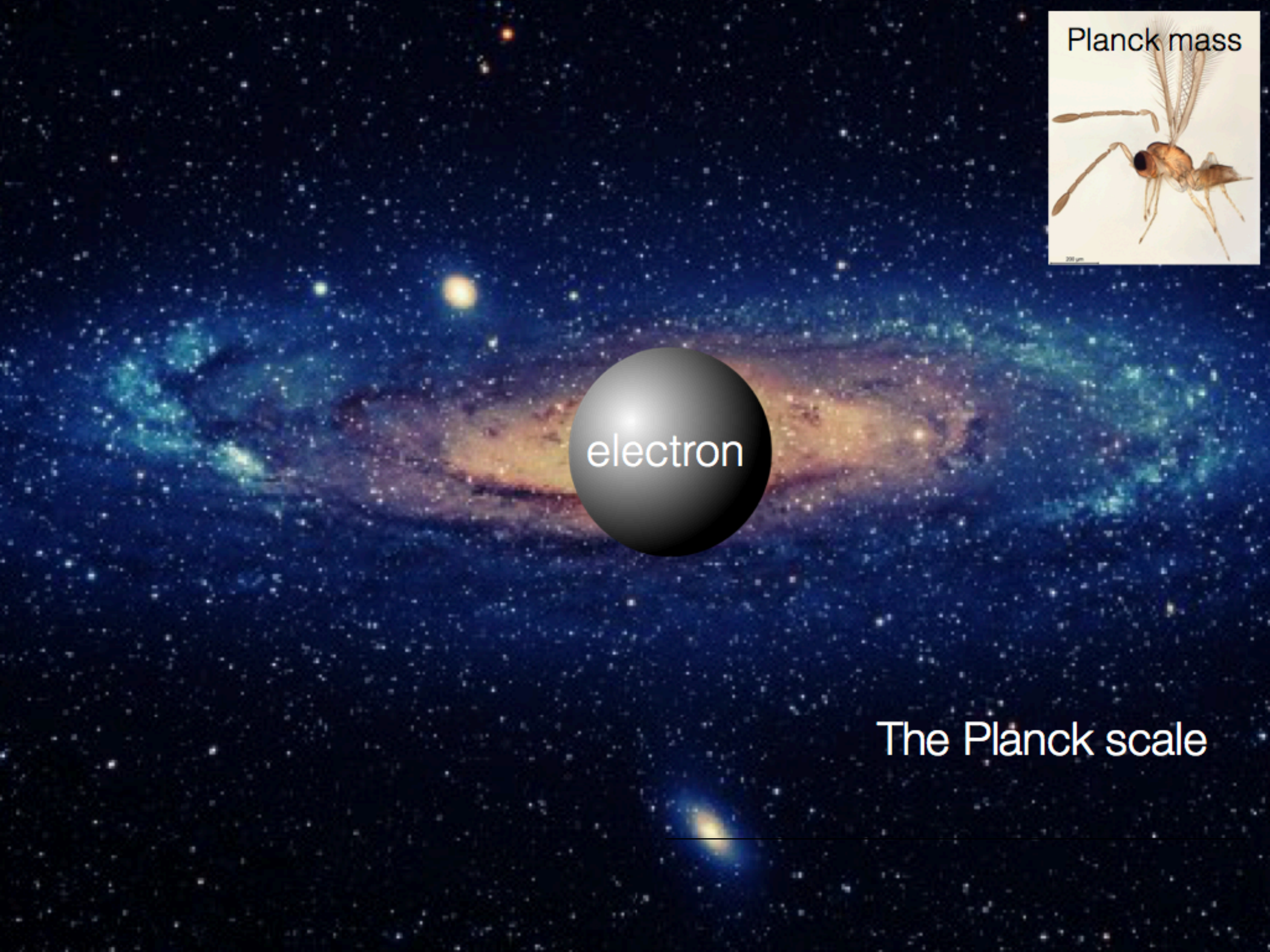

Physics without physics?!
How?
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Why?
Axiomatization




Physics without physics?!
How?
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Why?
Axiomatization
Why?
Solving the logical
clash between GR
and QFT

High-energy/short-distance correspondence breakdown

- Colliding two particles at Planck energy (.54MWh) produces a black hole!
- A particle with a too large mass ($2.18*10^{-5}$ g) becomes a black hole!
- *GR-QFT patching*: Planck scale

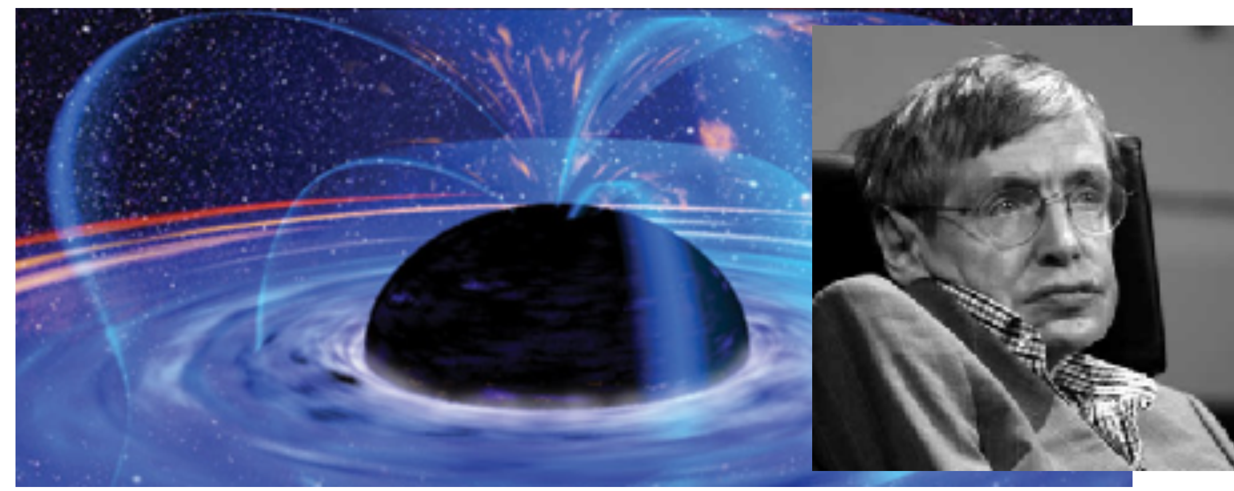

Planck mass
electron
The Planck scale

High-energy/short-distance correspondence breakdown

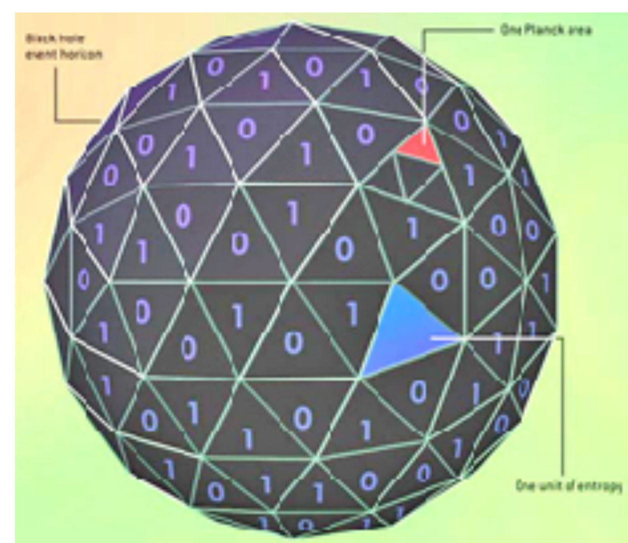
- Colliding two particles at Planck energy (.54MWh) produces a black hole!
- A particle with a too large mass ($2.18 * 10^{-5}$ g) becomes a black hole!
- *<u>GR-QFT patching</u>*: Planck scale

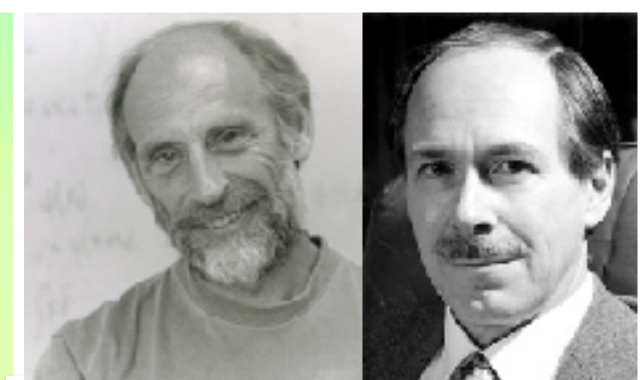
The information paradox

QT preserves information!
Do black hole preserve it?



Solution: Holographic principle?

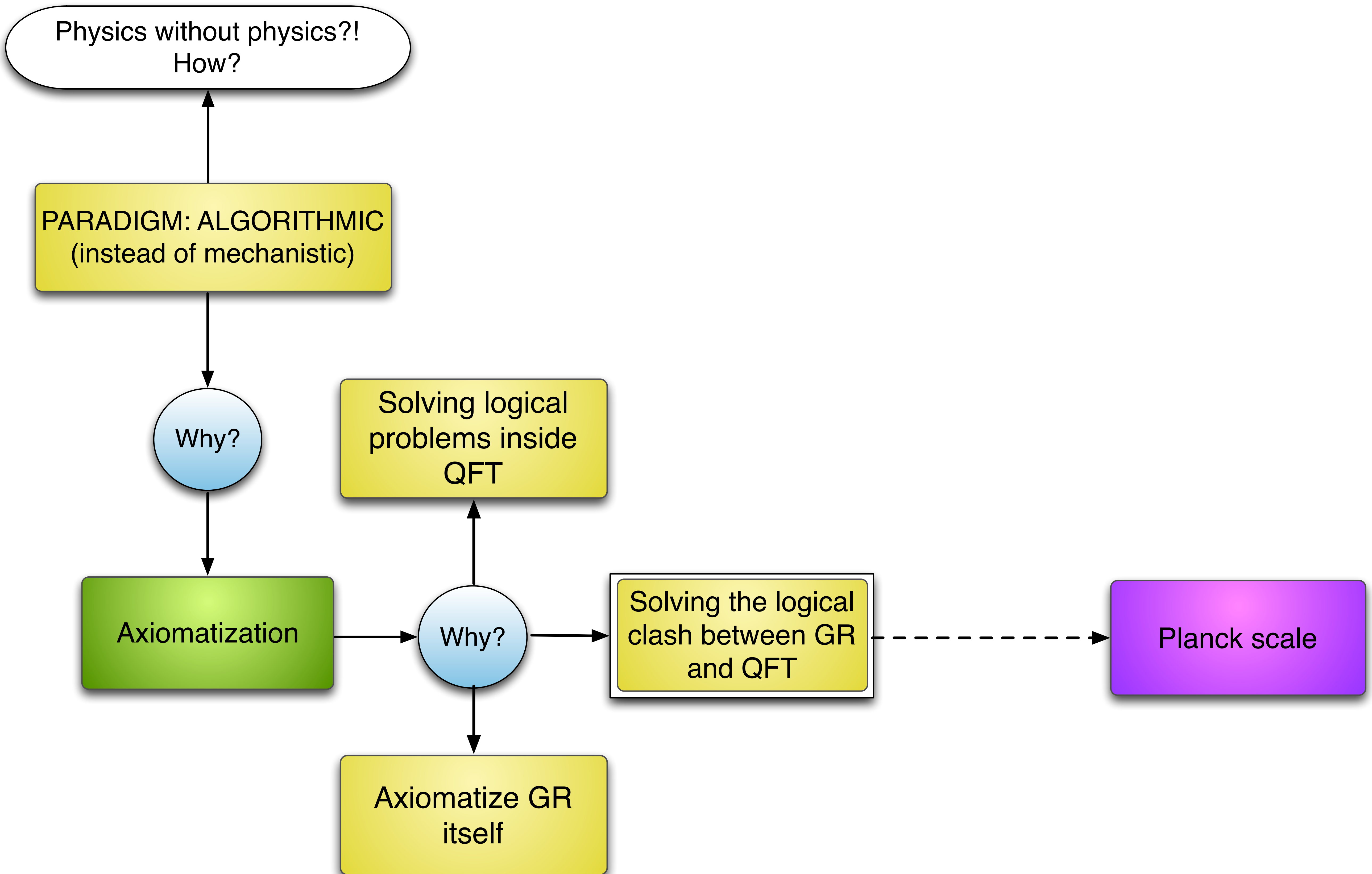




1 bit of information on every $.724 * 10^{-65}$ cm^2

Causality paradox

Pre-established (QT) vs dynamical (GR) causality


Physics without physics?!
How?
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Why?
Solving logical problems inside QFT
Axiomatization
Why?
Solving the logical clash between GR and QFT
Planck scale
Axiomatize GR itself

Localization issue in QFT

No Place for Particles in Relativistic Quantum Theories?

Hans Halvorson
Princeton University

Rob Clifton
University of Pittsburgh

10.8 Conclusion

Malament claims that his theorem justifies the belief that,

> . . . in the attempt to reconcile quantum mechanics with relativity theory. . . one is driven to a field theory; all talk about "particles" has to be understood, at least in principle, as talk about the properties of, and interactions among, quantized fields. (Malament 1996, 1)

In order to buttress Malament's argument for this claim, we provided two further results (Theorems 3 and 5) which show that the conclusion continues

We then went on to show that QFT does not permit an ontology of localizable particles; and so, strictly speaking, our talk about localizable particles is a fiction.

— albeit, if we understand this talk as really being about the properties of, and interactions among, quantized fields. Indeed, modulo the standard quantum measurement problem, RQFT has no trouble explaining the appearance of macroscopically well-localized objects, and shows that our talk of particles, though a *façon de parler*, has a legitimate role to play in empirically testing the theory.

Localization issue in QFT

Meinard Kuhlmann, a philosophy professor at Bielefeld University in Germany, received dual degrees in physics and in philosophy and has worked at the universities of Oxford, Chicago and Pittsburgh. As a student, he had an inquisitive reputation. "I would ask a lot of questions just for fun and because they produced an entertaining confusion," he says.

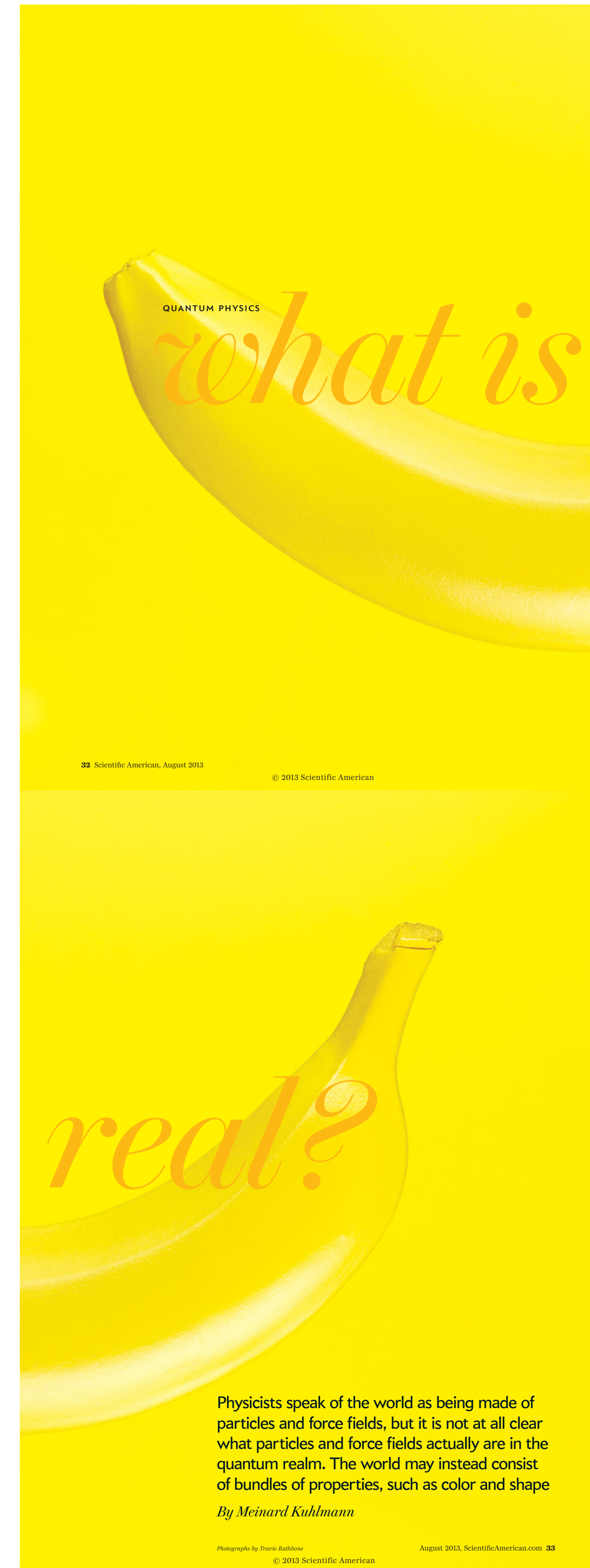
Physicists routinely describe the universe as being made of tiny subatomic particles that push and pull on one another by means of force fields. They call their subject "particle physics" and their instruments "particle accelerators." They hew to a Lego-like model of the world. But this view sweeps a little-known fact under the rug: the particle interpretation of quantum physics, as well as the field interpretation, stretches our conventional notions of "particle" and "field" to such an extent that ever more people think the world might be made of something else entirely.

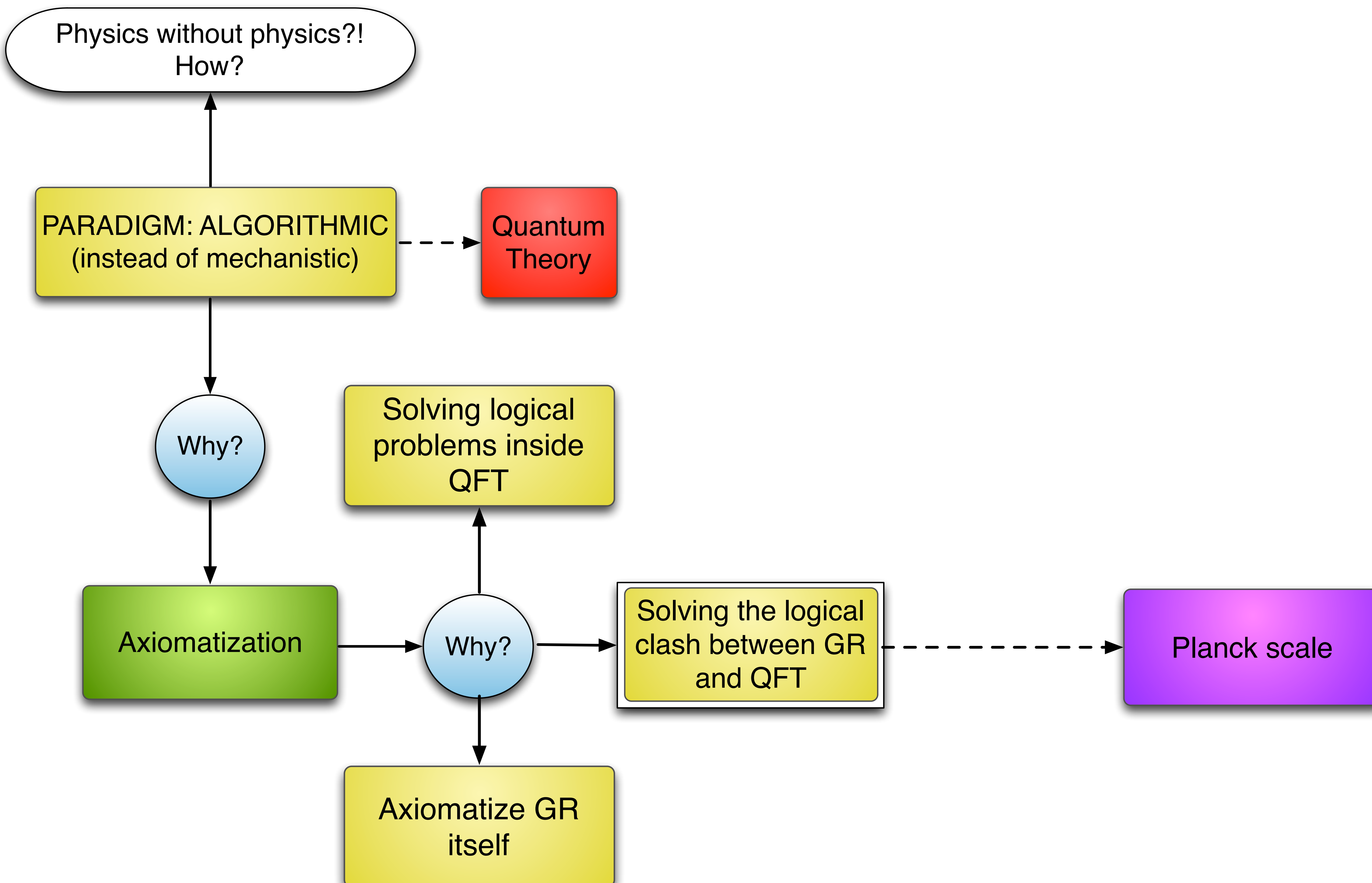
The problem is not that physicists lack a valid theory of the subatomic realm. They do have one: it is called quantum field theory. Theorists developed it between the late 1920s and early 1950s by merging the earlier theory of quantum mechanics with Einstein's special theory of relativity. Quantum field theory provides the conceptual underpinnings of the Standard Model of particle physics, which describes the fundamental building blocks of matter and their interactions in one common framework. In terms of empirical precision, it is the most successful theory in the history of science. Physicists use it every day to calculate the aftermath of particle collisions, the synthesis of matter in the big bang, the ex-

ican articles. However compelling it might appear, it is not at all satisfactory.

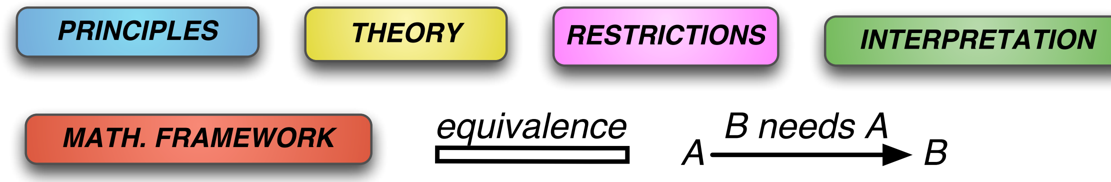
For starters, the two categories blur together. Quantum field theory assigns a field to each type of elementary particle, so there is an electron field as surely as there is an electron. At the same time, the force fields are quantized rather than continuous, which gives rise to particles such as the photon. So the distinction between particles and fields appears to be artificial, and physicists often speak as if one or the other is more fundamental. Debate has swirled over this point—over whether quantum field theory is ultimately about particles or about fields. It started as a battle of titans, with eminent physicists and philosophers on both sides. Even today both concepts are still in use for illustrative purposes, although most physicists would admit that the classical conceptions do not match what the theory says. If the mental images conjured up by the words "particle" and "field" do not match what the theory says, physicists and philosophers must figure out what to put in their place.

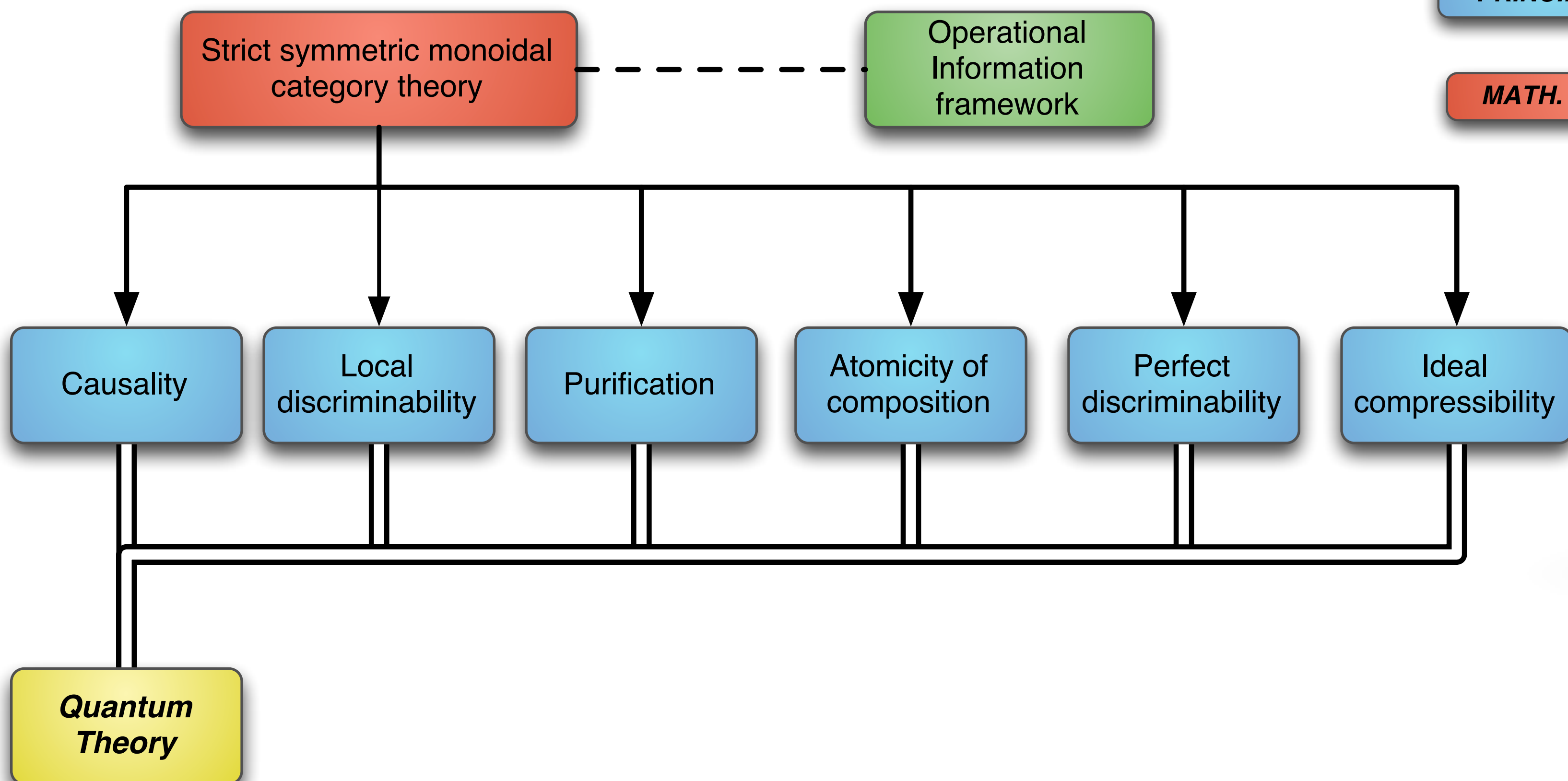
With the two standard, classical options gridlocked, some philosophers of physics have been formulating more radical alternatives. They suggest that the most basic constituents of the material world are intangible entities such as relations or properties. One particularly radical idea is that everything can be reduced to





Physics without physics?! How?
PARADIGM: ALGORITHMIC (instead of mechanistic)
Quantum Theory
Why?
Solving logical problems inside QFT
Axiomatization
Why?
Solving the logical clash between GR and QFT
Planck scale
Axiomatize GR itself





Principles for Quantum Theory

Selected for a Viewpoint in *Physics*

PHYSICAL REVIEW A **84**, 012311 (2011)

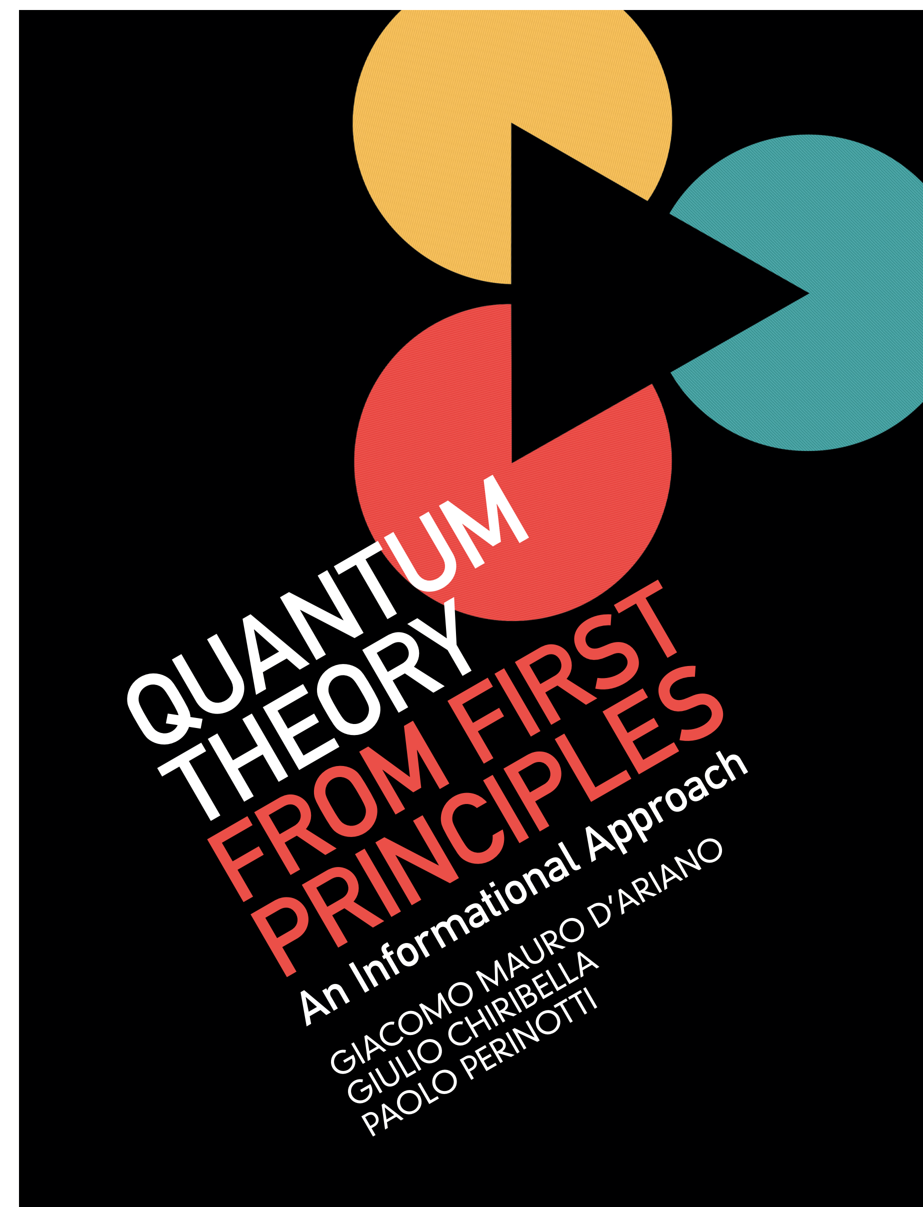
Informational derivation of quantum theory

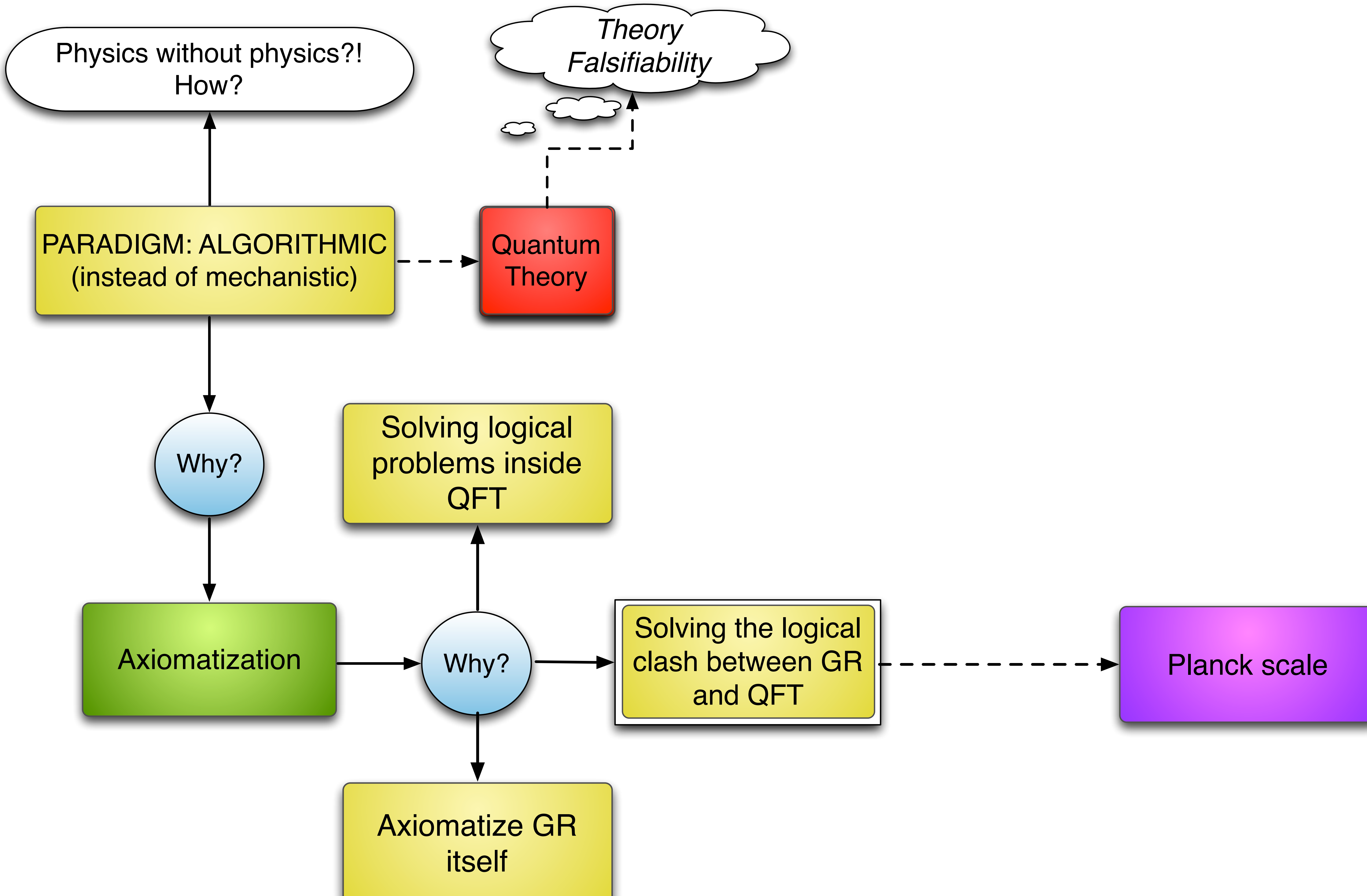
Giulio Chiribella*
Perimeter Institute for Theoretical Physics, 31 Caroline Street North, Ontario, Canada N2L 2Y5†

Giacomo Mauro D'Ariano‡ and Paolo Perinotti§
QUIT Group, Dipartimento di Fisica "A. Volta" and INFN Sezione di Pavia, via Bassi 6, I-27100 Pavia, Italy‖
(Received 29 November 2010; published 11 July 2011)

We derive quantum theory from purely informational principles. Five elementary axioms—causality, perfect distinguishability, ideal compression, local distinguishability, and pure conditioning—define a broad class of theories of information processing that can be regarded as standard. One postulate—purification—singles out quantum theory within this class.

DOI: 10.1103/PhysRevA.84.012311 PACS number(s): 03.67.Ac, 03.65.Ta





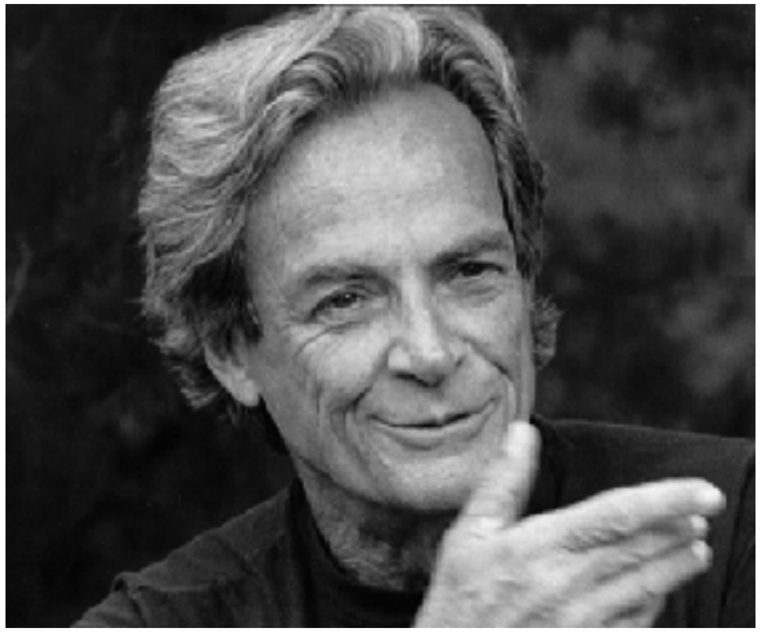
Physics without physics?!
How?
Theory
Falsifiability
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Quantum
Theory
Why?
Solving logical
problems inside
QFT
Axiomatization
Why?
Solving the logical
clash between GR
and QFT
Planck scale
Axiomatize GR
itself

But now how to derive the “mechanics”,
namely: quantum field theory,
special relativity, …
without using physical primitives,
mechanics, kinematics, space, time,…?

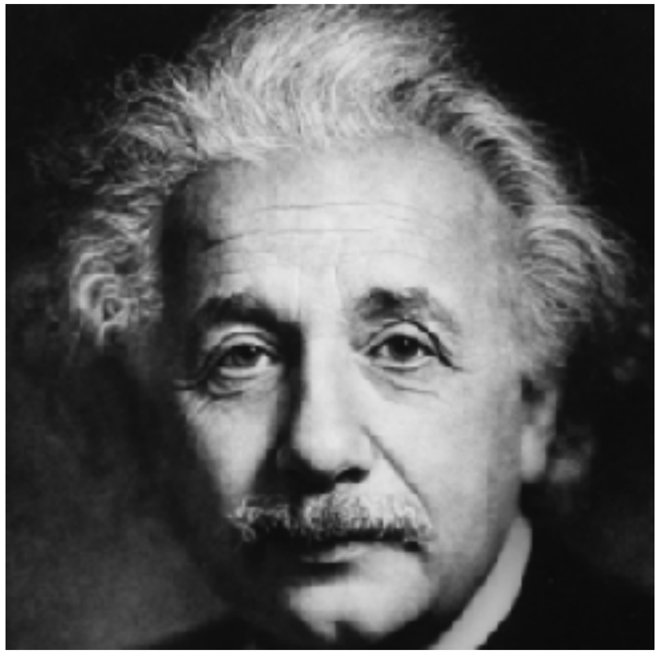
For example: how would you formulate the principle of relativity in algorithmic terms?

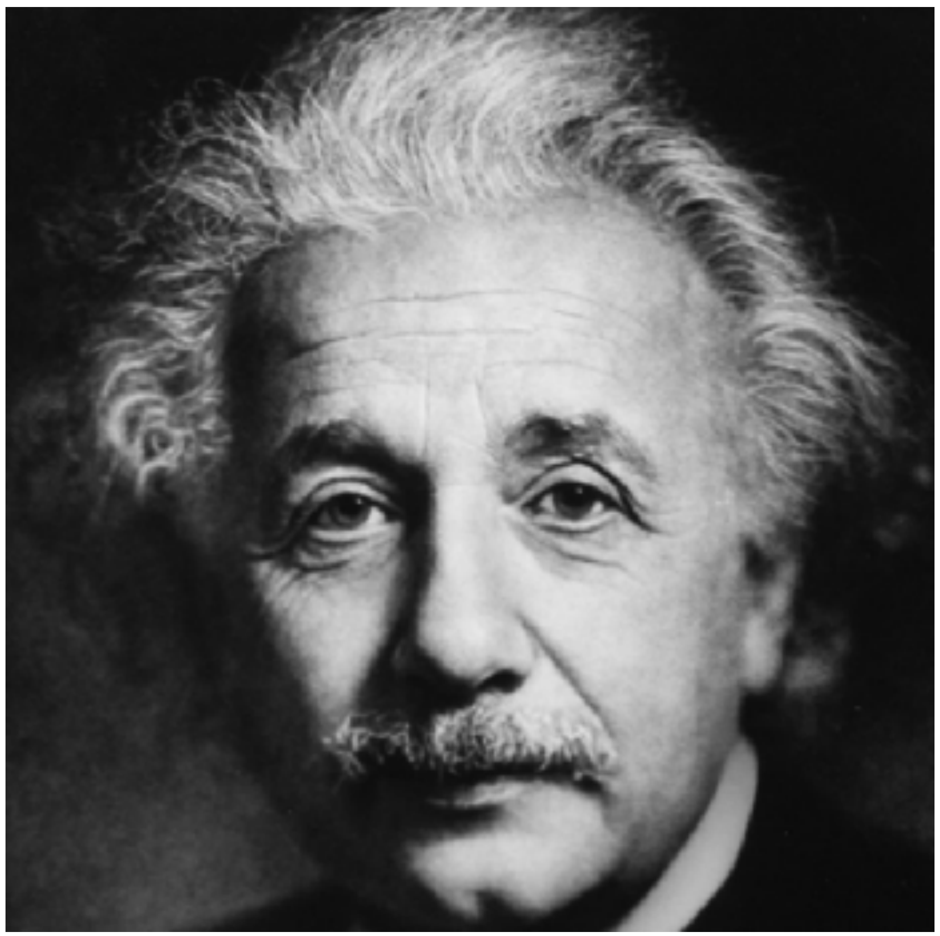
Algorithm → discreteness!

discrete



continuum



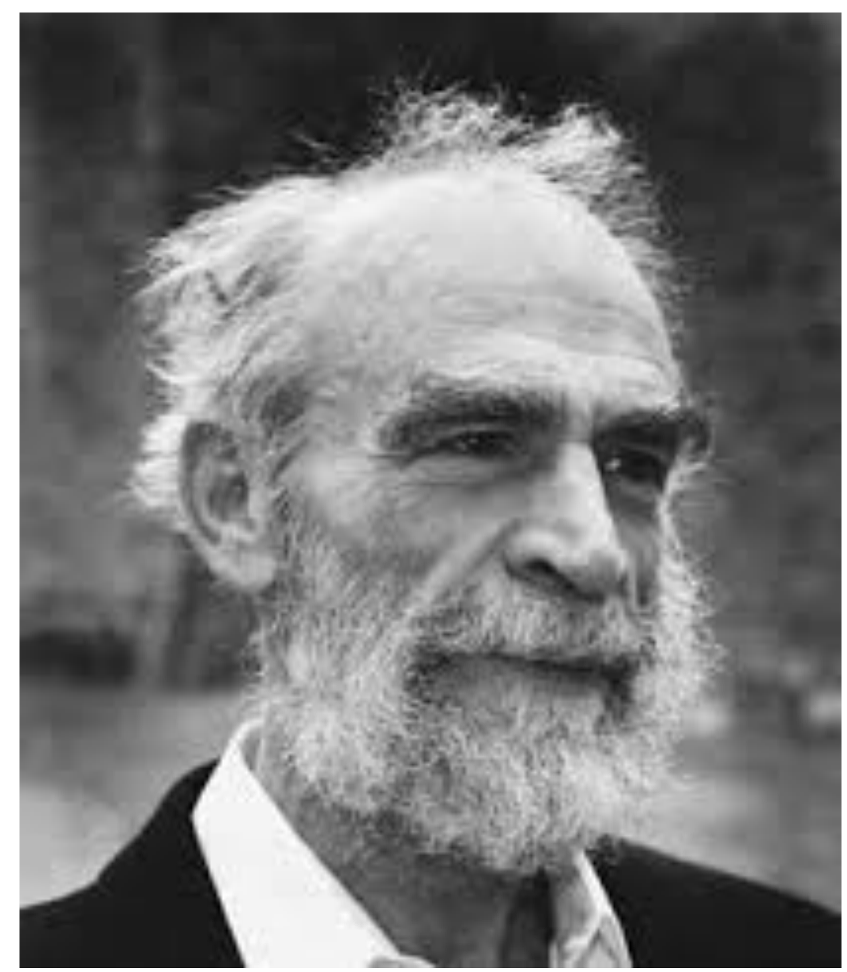


"But you have correctly grasped the drawback that the continuum brings. If the molecular view of matter is the correct (appropriate) one, i.e., if a part of the universe is to be represented by a finite number of moving points, then the continuum of the present theory contains too great a manifold of possibilities. I also believe that this too great is responsible for the fact that our present means of description miscarry with the quantum theory. The problem seems to me how one can formulate statements about a discontinuum without calling upon a continuum (space-time) as an aid; the latter should be banned from the theory as a supplementary construction not justified by the essence of the problem, which corresponds to nothing "real". But we still lack the mathematical structure unfortunately. How much have I already plagued myself in this way!"

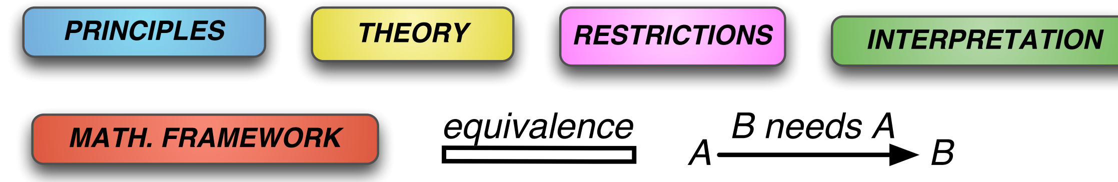
John Stachel in *From Quarks to Quasars: Philosophical Problems of Modern Physics,* University of Pittsburg Press, pag. 379

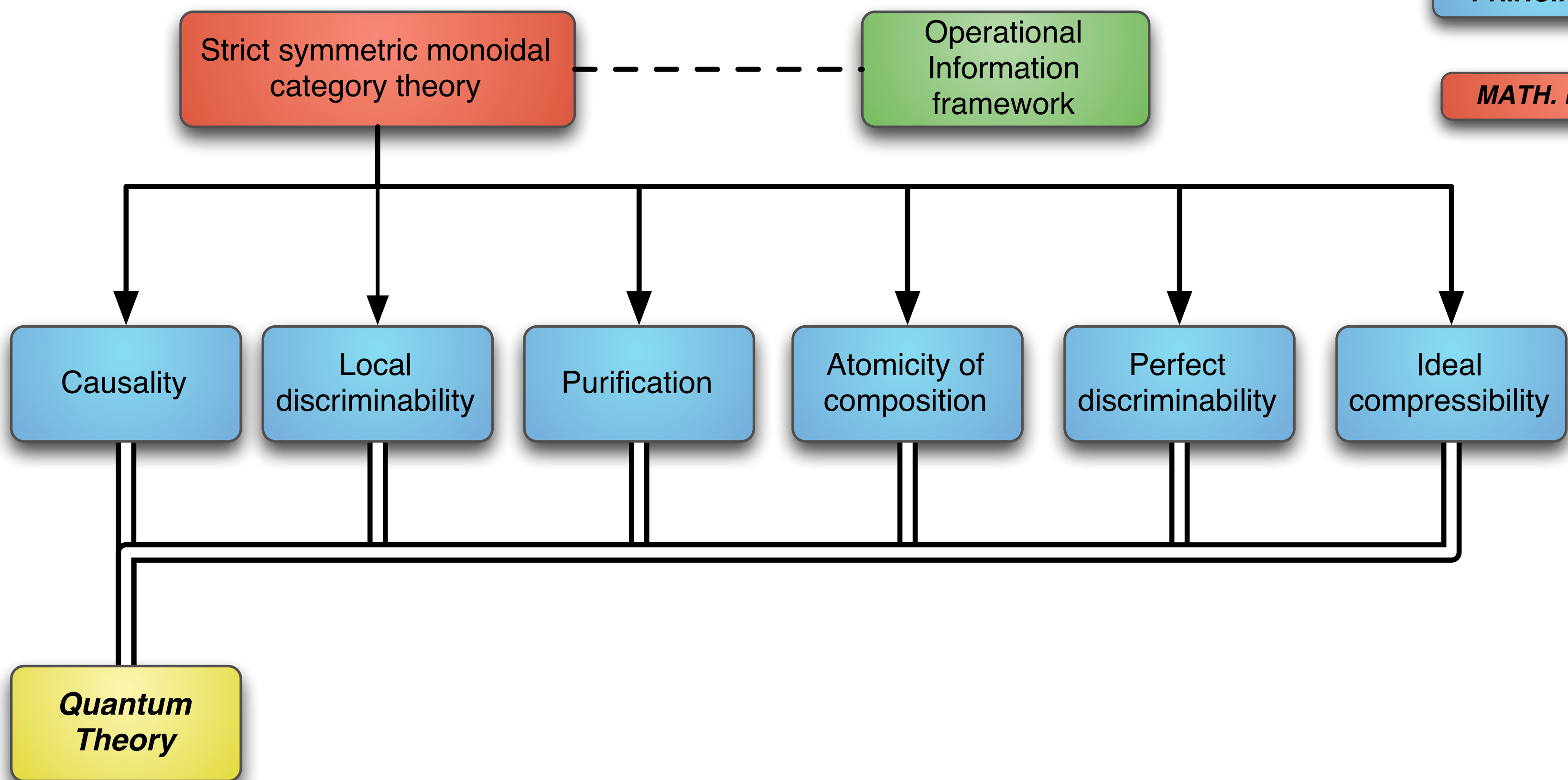
A new mathematics: *geometric group theory*

The geometrization of group theory



Mikhail Gromov





Principles for Mechanics

- *Mechanics (QFT) derived in terms of countably many quantum systems in interaction*

add principles

Min algorithmic complexity principle

JOHN TEMPLETON FOUNDATION
SUPPORTING SCIENCE~INVESTING IN THE BIG QUESTIONS

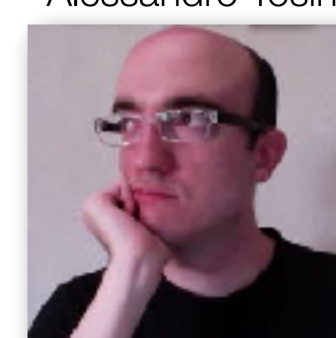
Project: *A Quantum-Digital Universe*, Grant ID: 43796

Paolo Perinotti

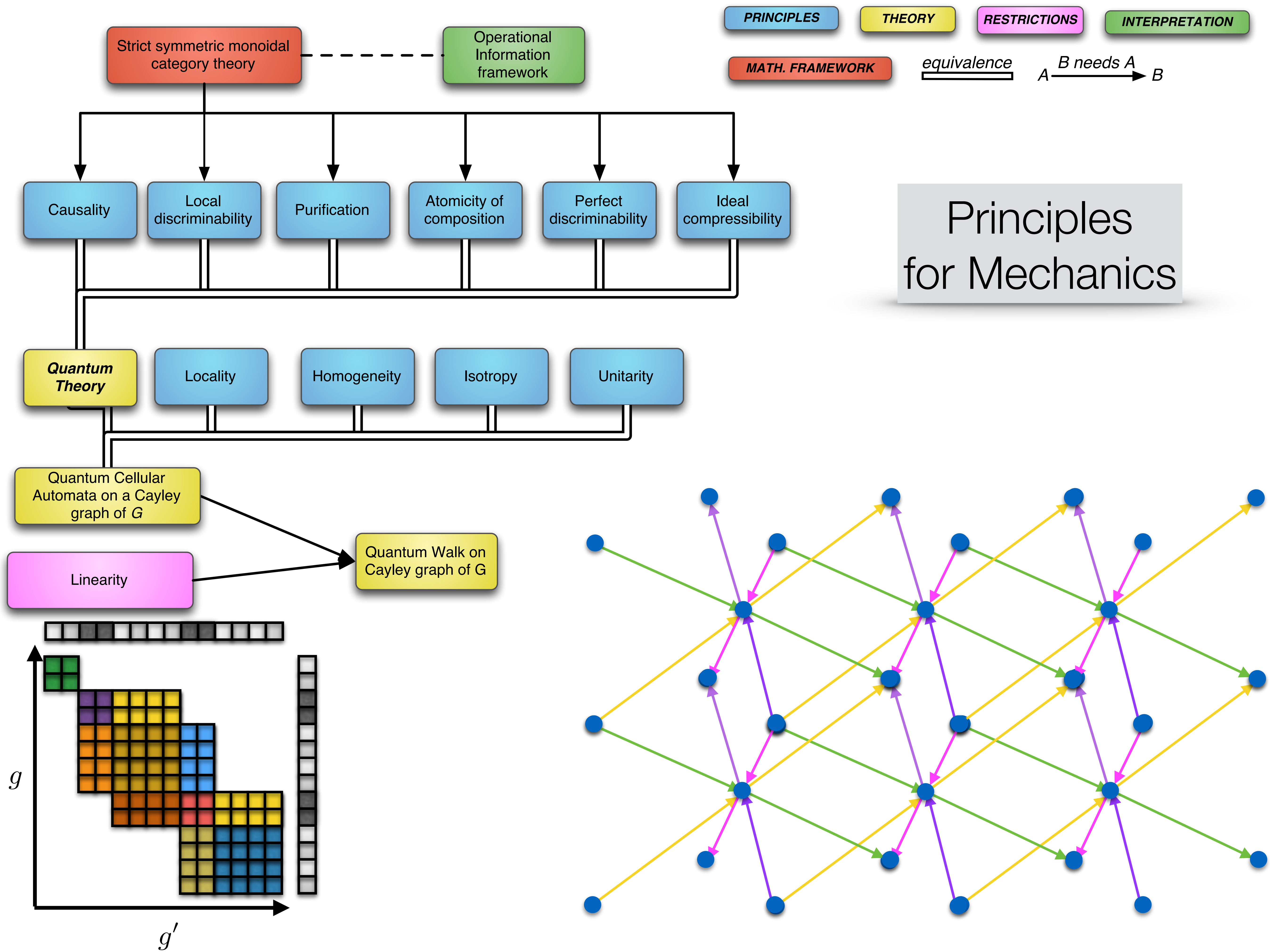
Alessandro Bisio

Alessandro Tosini

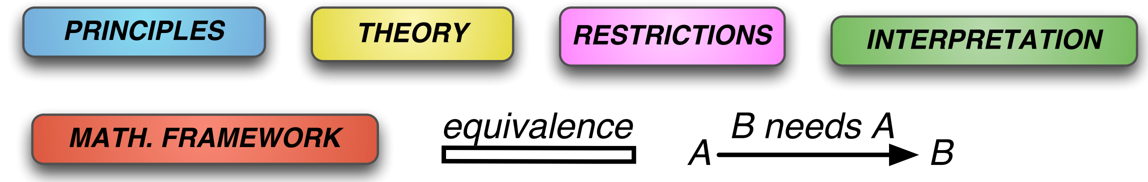
Marco Erba

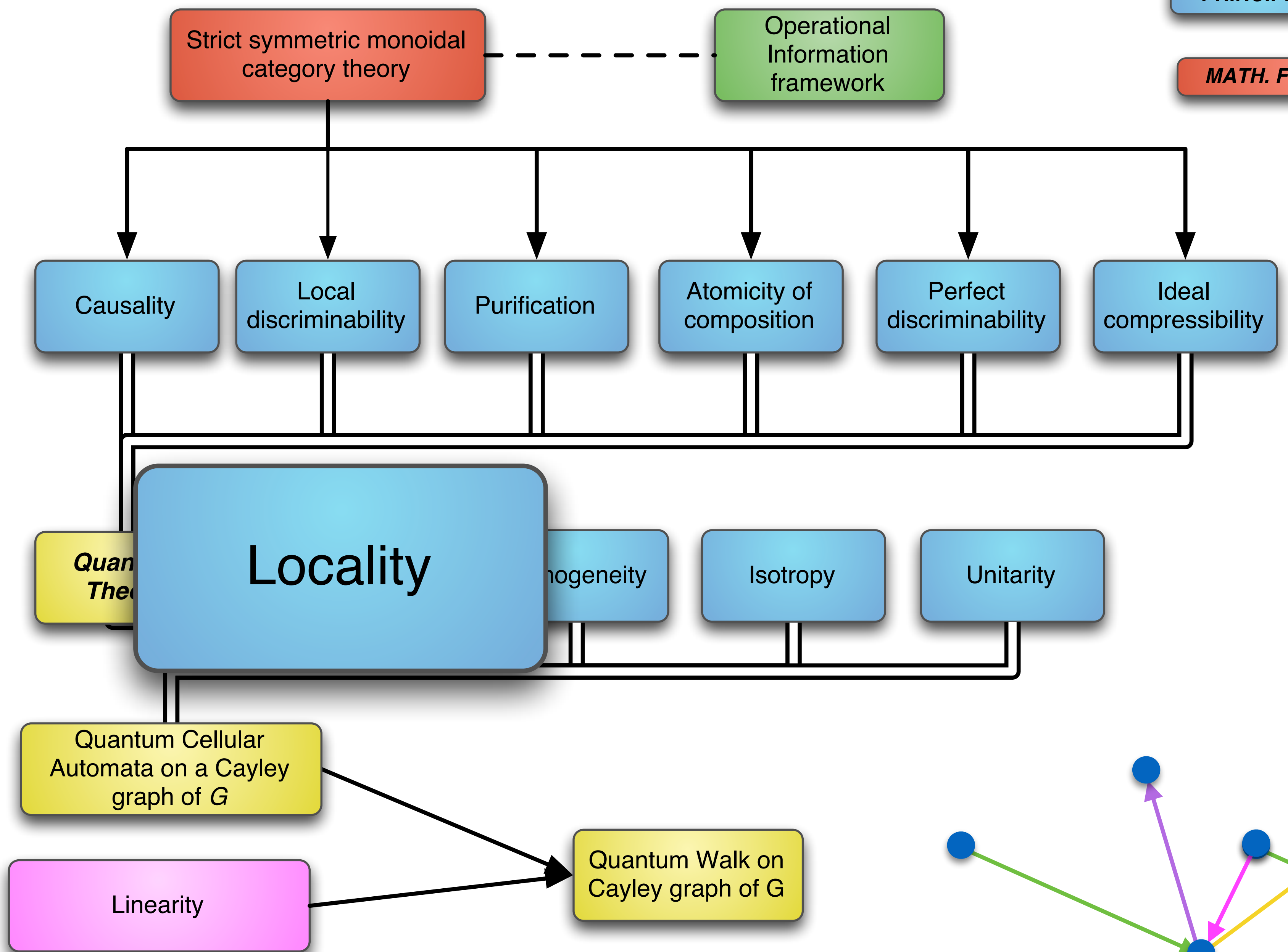


Nicola Mosco

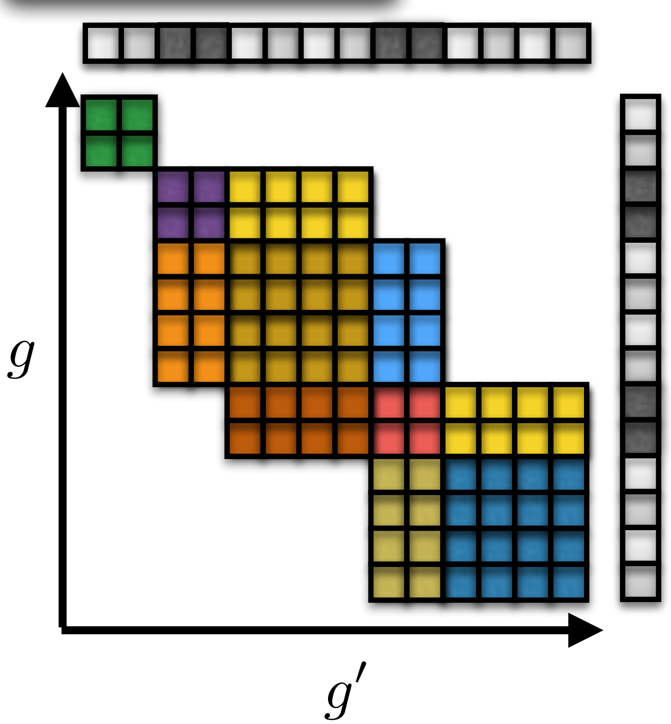


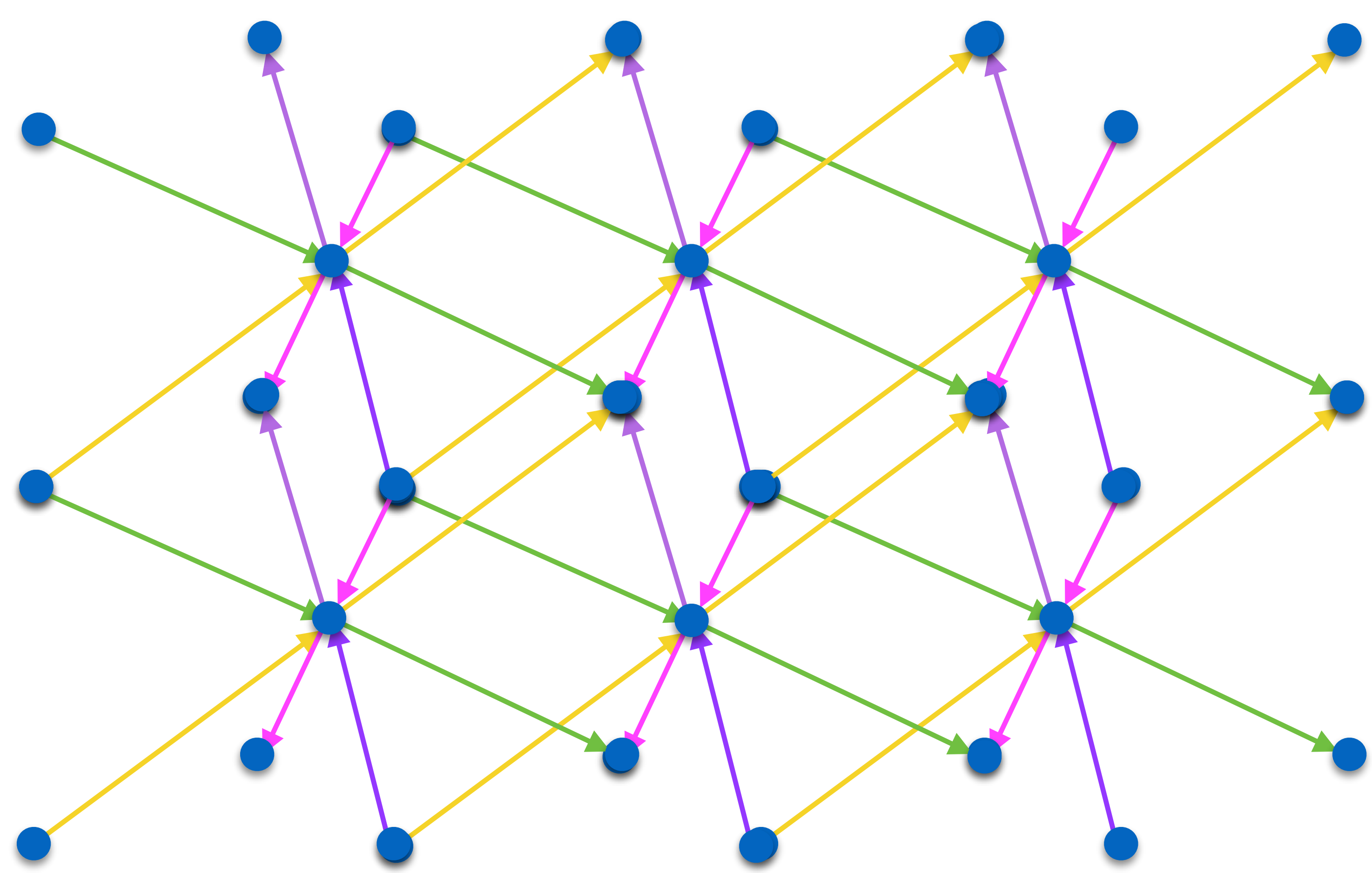
PRINCIPLES
THEORY
RESTRICTIONS
INTERPRETATION
MATH. FRAMEWORK
equivalence
B needs A
A
B
Strict symmetric monoidal category theory
Operational Information framework
Causality
Local discriminability
Purification
Atomicity of composition
Perfect discriminability
Ideal compressibility
Principles for Mechanics
Quantum Theory
Locality
Homogeneity
Isotropy
Unitarity
Quantum Cellular Automata on a Cayley graph of G
Quantum Walk on Cayley graph of G
Linearity
g
g′

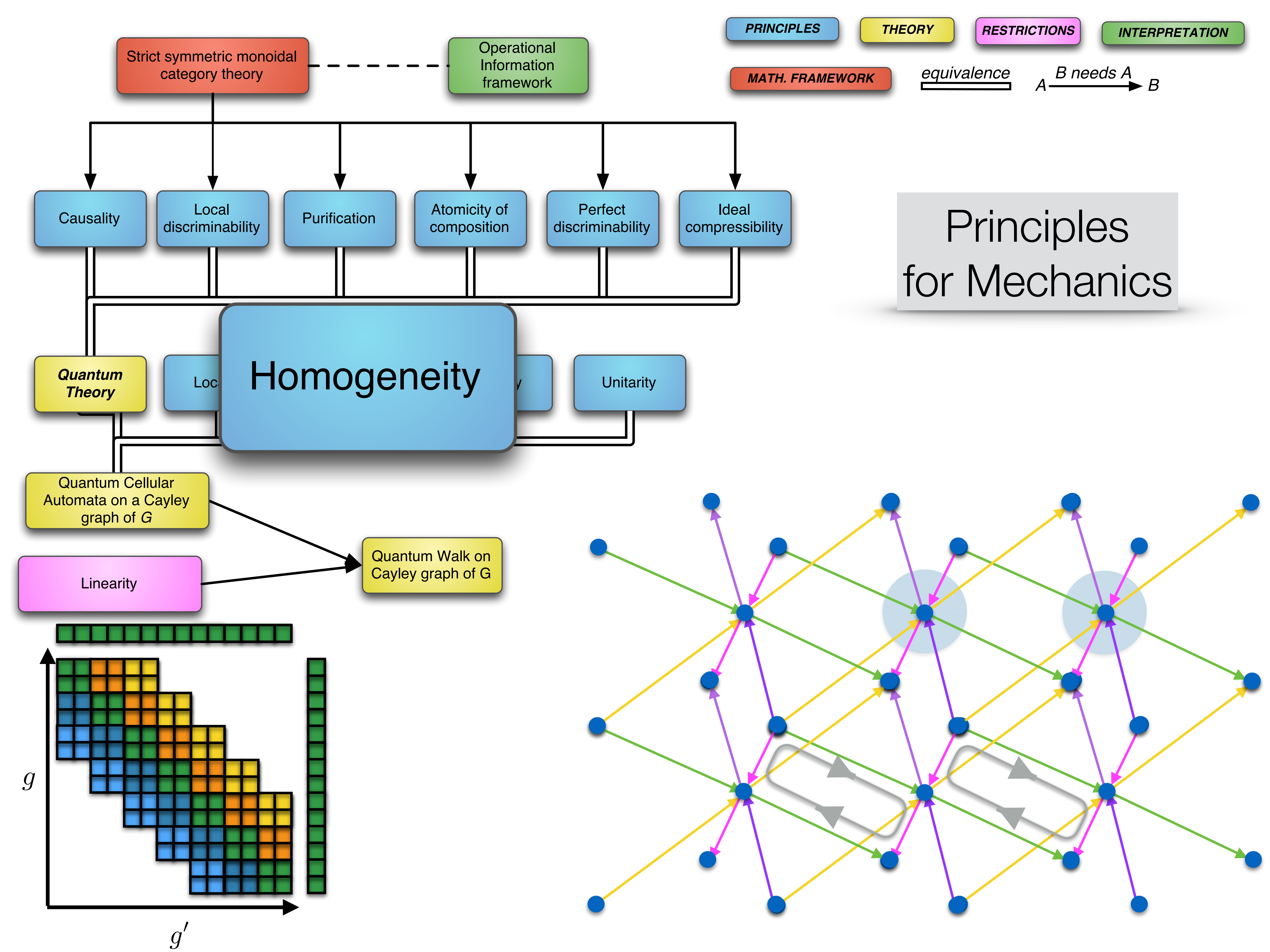


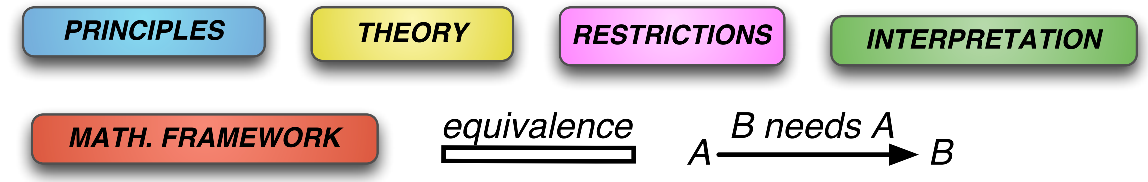


Principles for Mechanics

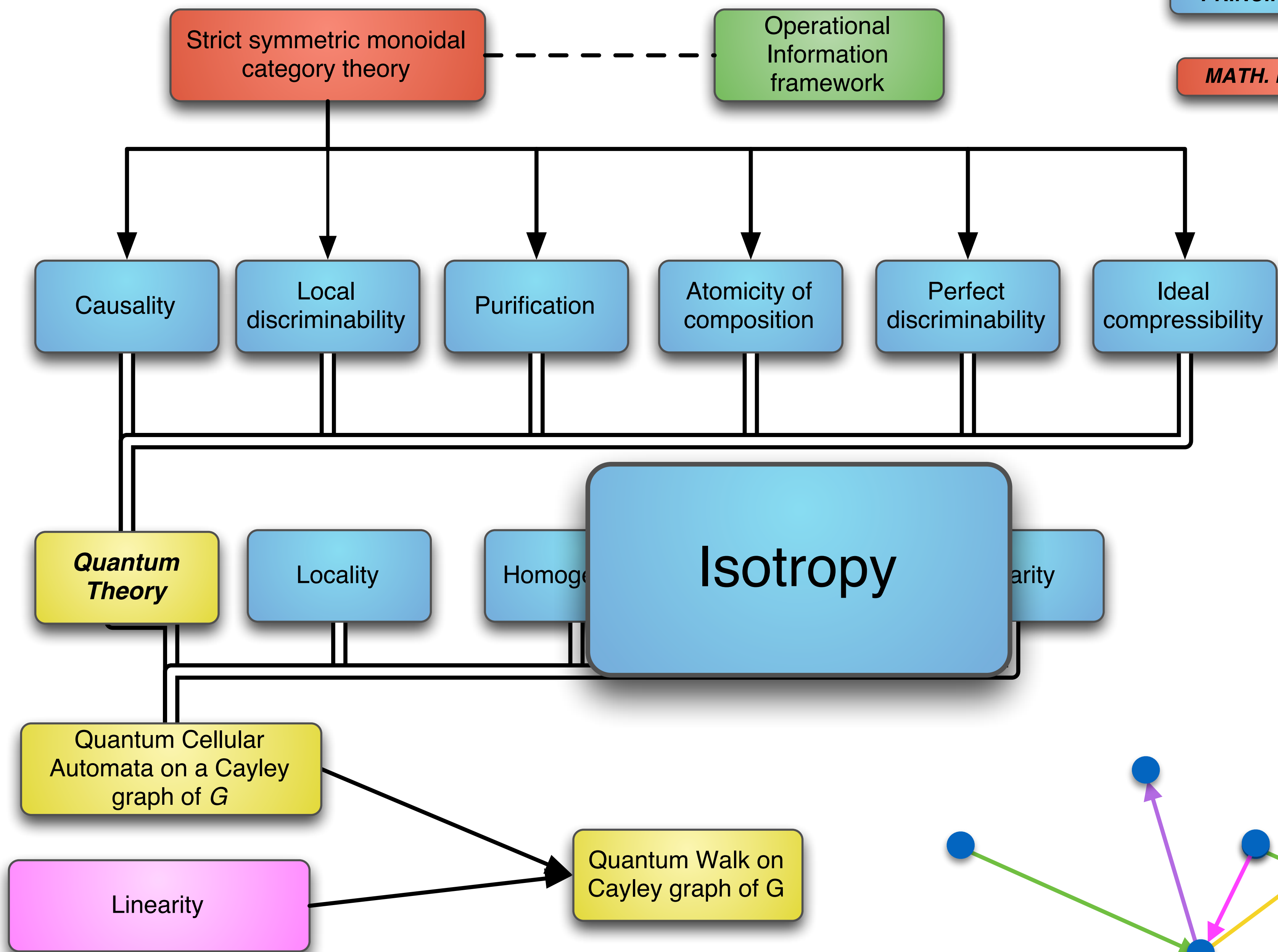


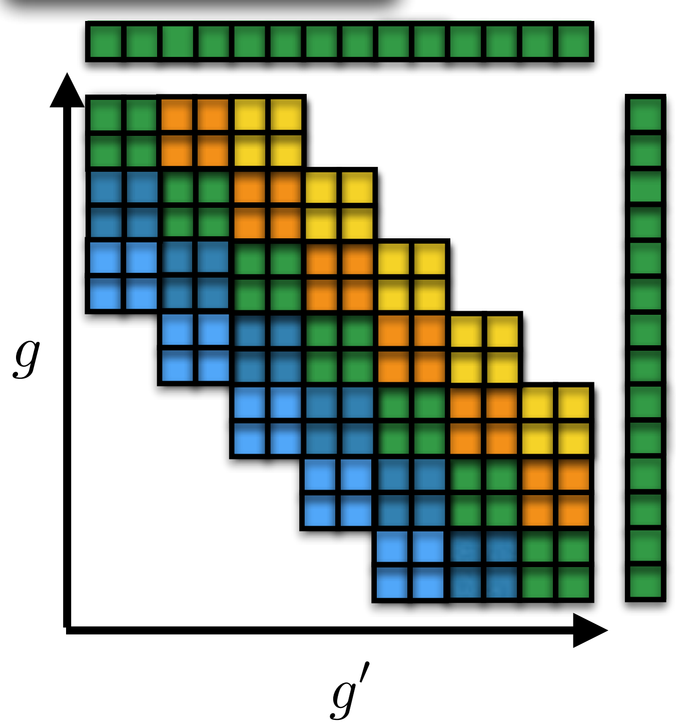


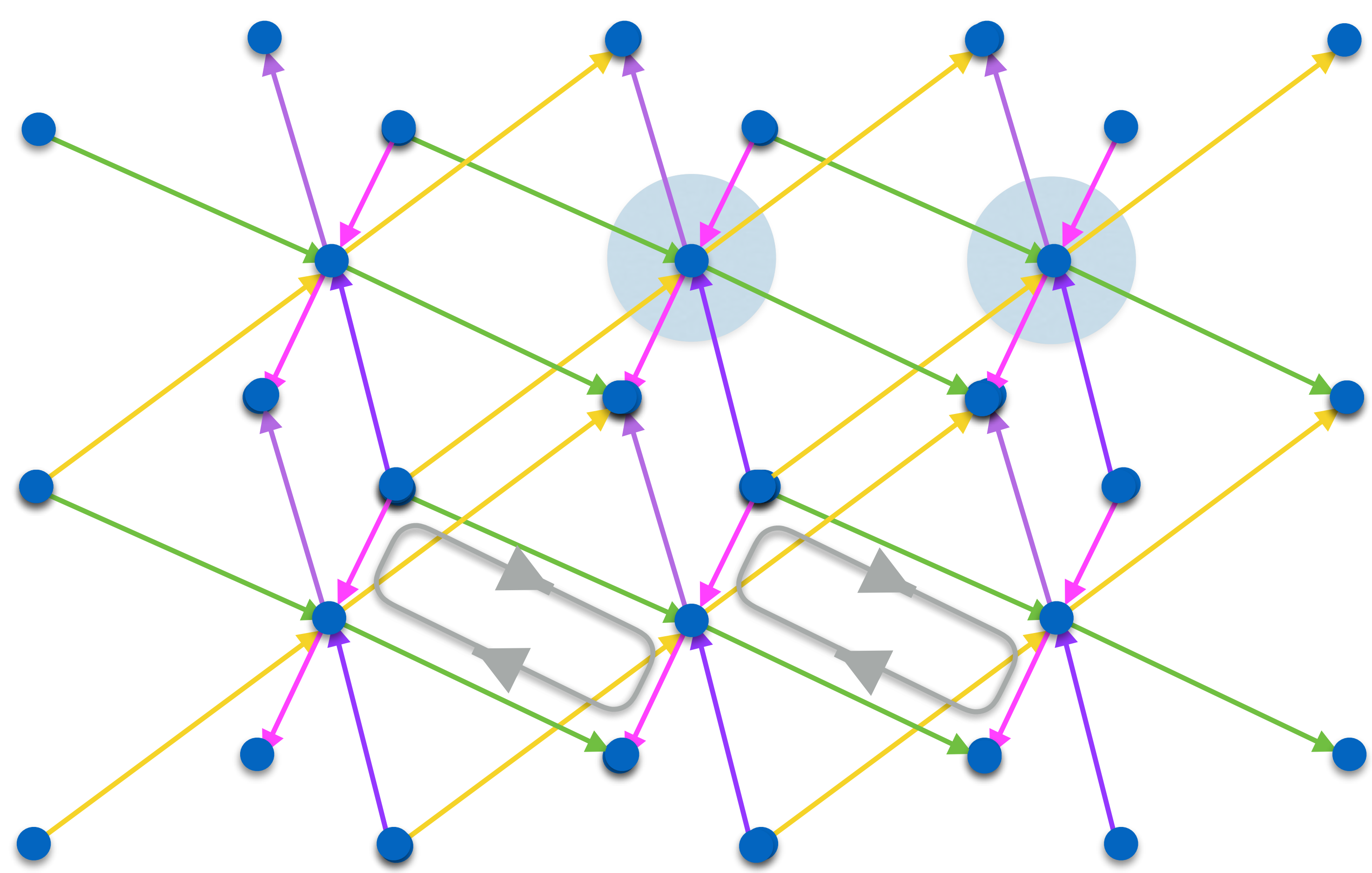

PRINCIPLES
THEORY
RESTRICTIONS
INTERPRETATION
MATH. FRAMEWORK
equivalence
B needs A
A
B
Strict symmetric monoidal category theory
Operational Information framework
Principles for Mechanics
Causality
Local discriminability
Purification
Atomicity of composition
Perfect discriminability
Ideal compressibility
Quantum Theory
Homogeneity
Unitarity
Quantum Cellular Automata on a Cayley graph of G
Quantum Walk on Cayley graph of G
Linearity
g
g′



Principles for Mechanics



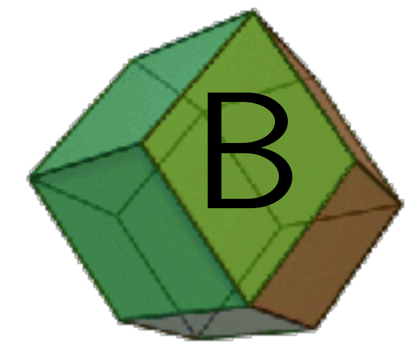




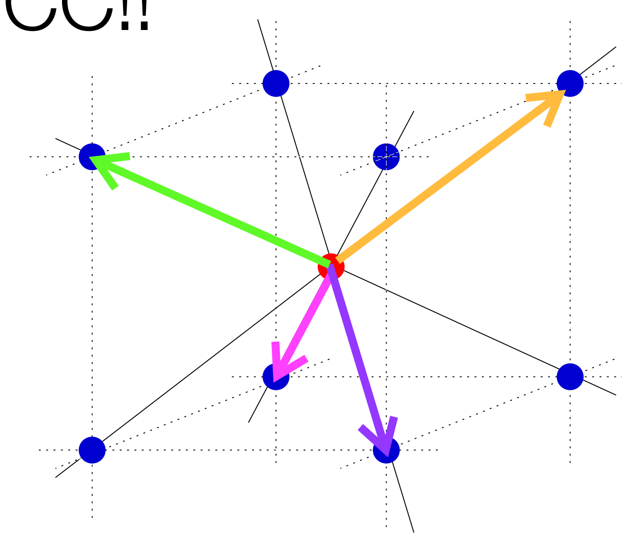
D'Ariano, Perinotti,
PRA **90** 062106 (2014)

The Weyl QW

☞ Minimal dimension for nontrivial unitary *A:* s=2



Unitarity + isotropy ⇒ for d=3 the only Cayley is the BCC!!



Unitary operator: $$A = \int_B^{\oplus} d\mathbf{k}\, A_{\mathbf{k}}$$

Two QWs connected by P

$$\begin{aligned} A_{\mathbf{k}}^{\pm} = & -i\sigma_x(s_x c_y c_z \pm c_x s_y s_z) \\ & \mp i\sigma_y(c_x s_y c_z \mp s_x c_y s_z) \\ & - i\sigma_z(c_x c_y s_z \pm s_x s_y c_z) \\ & + I(c_x c_y c_z \mp s_x s_y s_z) \end{aligned}$$

$$s_\alpha = \sin\frac{k_\alpha}{\sqrt{3}}$$

$$c_\alpha = \cos\frac{k_\alpha}{\sqrt{3}}$$

D'Ariano, Perinotti,
PRA **90** 062106 (2014)

Physical interpretation: Weyl equation

$$i\partial_t\psi(t) \simeq \frac{i}{2}[\psi(t+1)-\psi(t-1)] = \frac{i}{2}(A-A^\dagger)\psi(t)$$

$$\begin{aligned}\frac{i}{2}(A^{\pm}_{\mathbf{k}} - A^{\pm\dagger}_{\mathbf{k}}) = &+\sigma_x(s_x c_y c_z \pm c_x s_y s_z)\\ &\pm\sigma_y(c_x s_y c_z \mp s_x c_y s_z)\\ &+\sigma_z(c_x c_y s_z \pm s_x s_y c_z)\end{aligned}$$

"Hamiltonian"

$k \ll 1$ ⇒ $i\partial_t\psi = \frac{1}{\sqrt{3}}\boldsymbol{\sigma}^{\pm}\cdot\mathbf{k}\,\psi$ ☜ Weyl equation! $\boldsymbol{\sigma}^{\pm} := (\sigma_x, \pm\sigma_y, \sigma_z)$

Two QCAs connected by P

$$\begin{aligned}A^{\pm}_{\mathbf{k}} = &- i\sigma_x(s_x c_y c_z \pm c_x s_y s_z)\\ &\mp i\sigma_y(c_x s_y c_z \mp s_x c_y s_z)\\ &- i\sigma_z(c_x c_y s_z \pm s_x s_y c_z)\\ &+ I(c_x c_y c_z \mp s_x s_y s_z)\end{aligned}$$

$$s_\alpha = \sin\frac{k_\alpha}{\sqrt{3}}$$

$$c_\alpha = \cos\frac{k_\alpha}{\sqrt{3}}$$

D'Ariano, Perinotti, PRA **90** 062106 (2014)

Dirac QW $\oplus$

Local coupling: $A_{\mathbf{k}}$ coupled with its inverse with off-diagonal identity block matrix

$$E^{\pm}_{\mathbf{k}} = \begin{pmatrix} nA^{\pm}_{\mathbf{k}} & imI \\ imI & nA^{\pm\dagger}_{\mathbf{k}} \end{pmatrix}$$

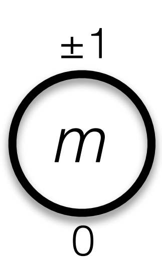
$$n^2 + m^2 = 1 \qquad n, m \in \mathbb{R}$$

$$\omega^{E}_{\pm}(\mathbf{k}) = \cos^{-1}[n(c_x c_y c_z \mp s_x s_y s_z)]$$

Dirac in relativistic limit $k \ll m \ll 1$

m: mass, $m^2 \leq 1$

n^{-1}: refraction index



!

Bisio, D'Ariano, Perinotti, Ann. Phys. **368** 177 (2016)

Maxwell QW $\otimes$

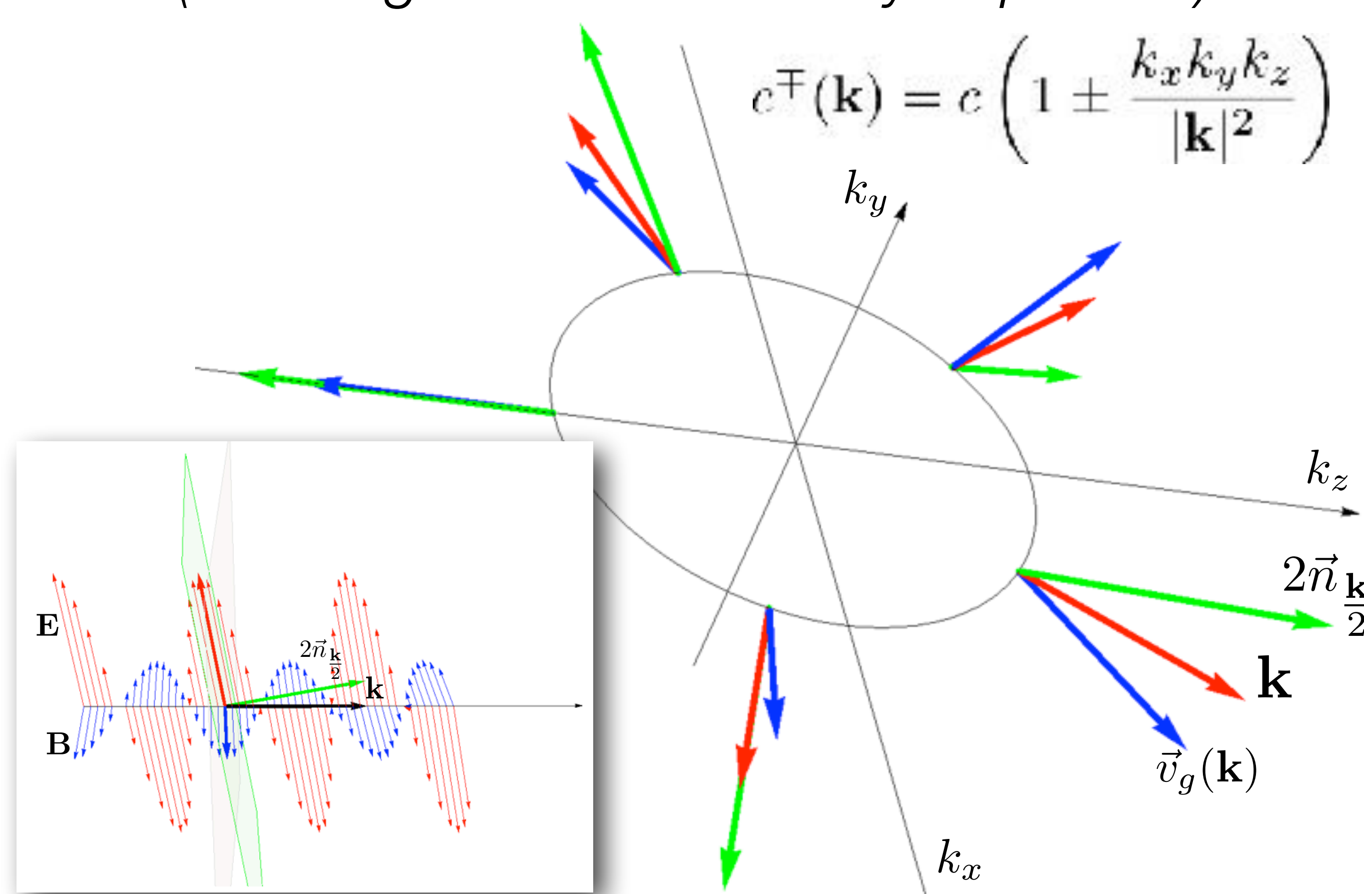
$$M^{\pm}_{\mathbf{k}} = A^{\pm}_{\mathbf{k}} \otimes A^{\pm *}_{\mathbf{k}}$$

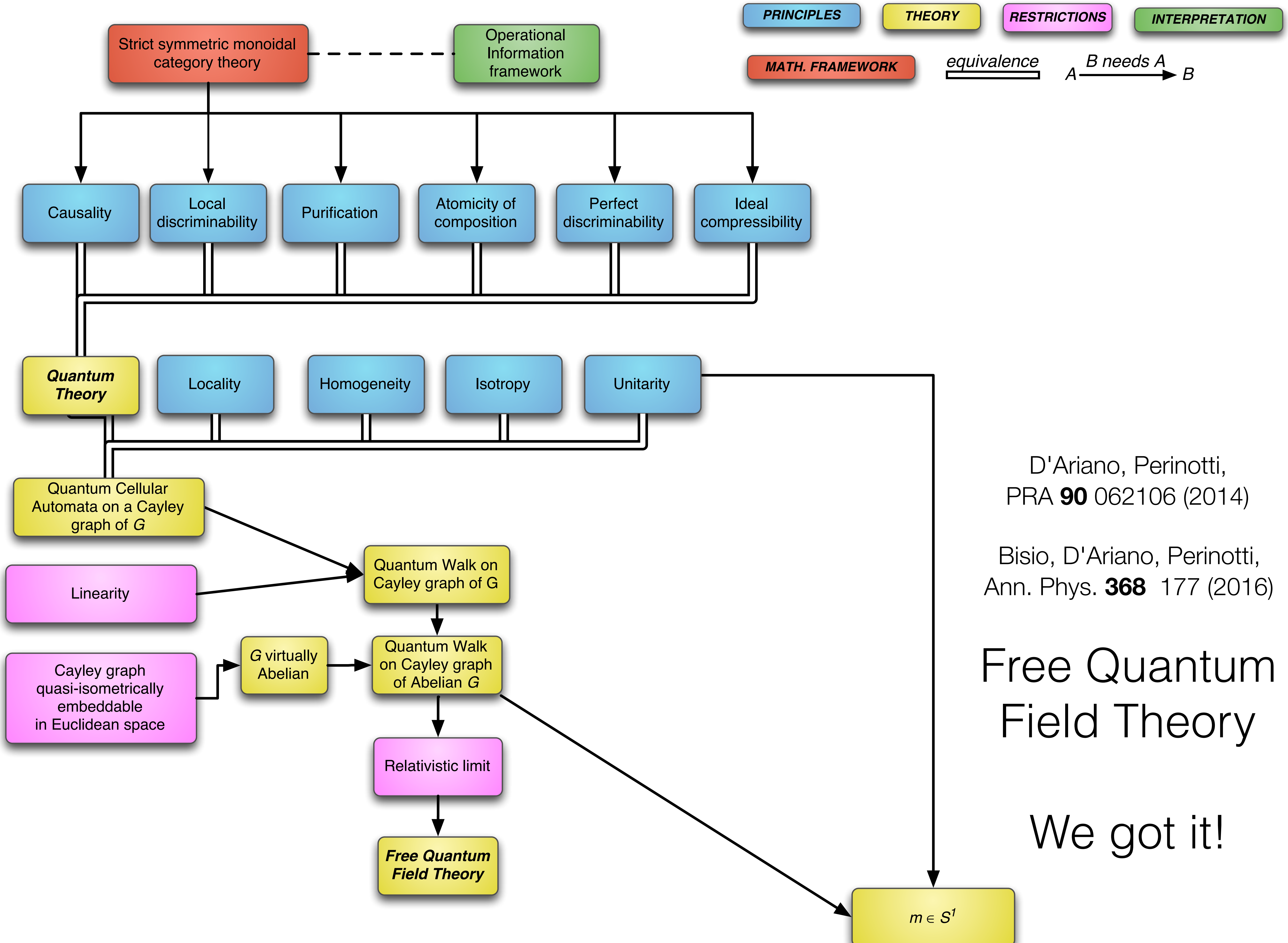
$$F^{\mu}(\mathbf{k}) = \int \frac{\mathrm{d}\,\mathbf{q}}{2\pi} f(\mathbf{q}) \tilde{\psi}(\tfrac{\mathbf{k}}{2} - \mathbf{q}) \sigma^{\mu} \varphi(\tfrac{\mathbf{k}}{2} + \mathbf{q})$$

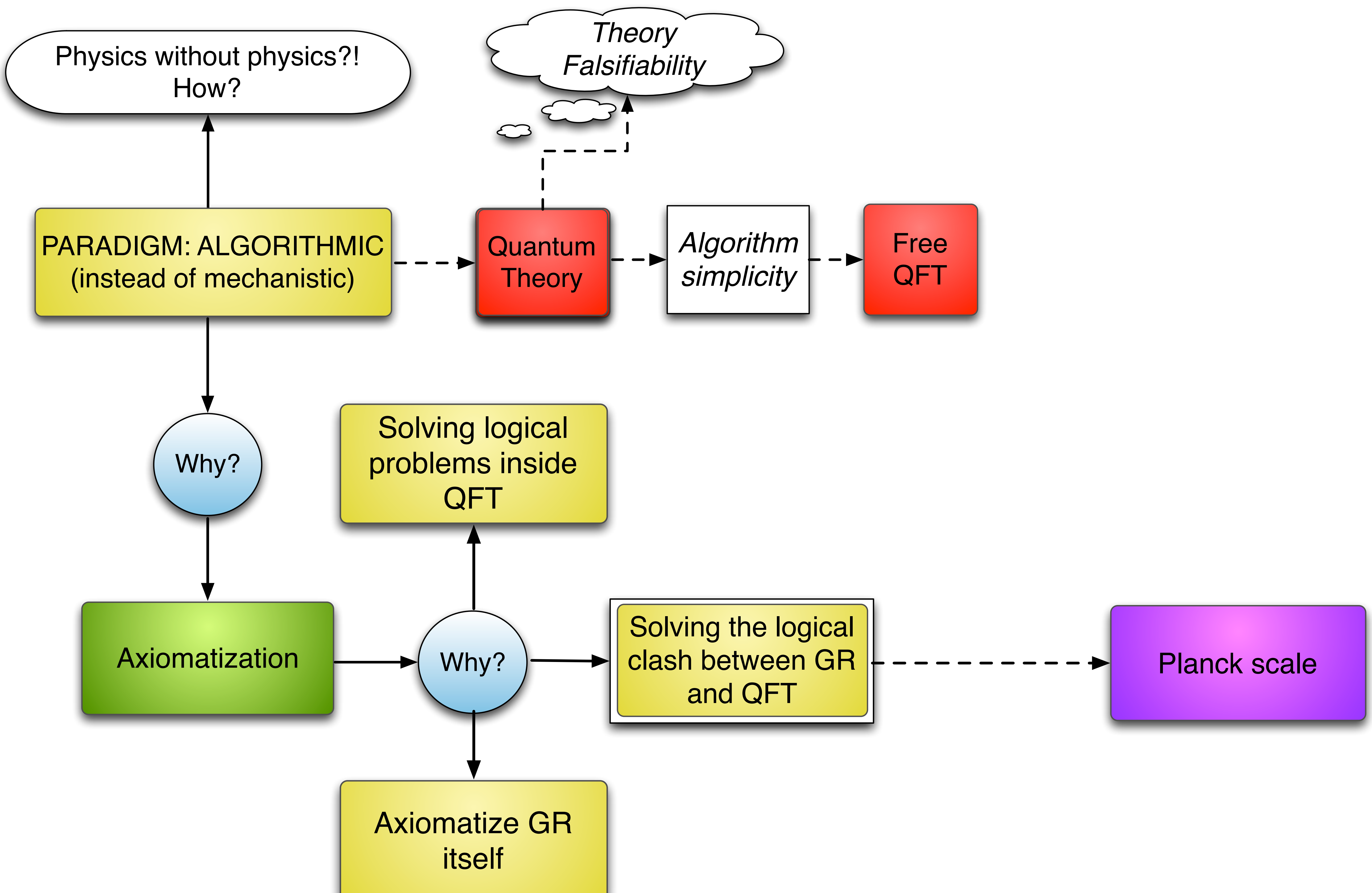
Maxwell in relativistic limit $k \ll 1$

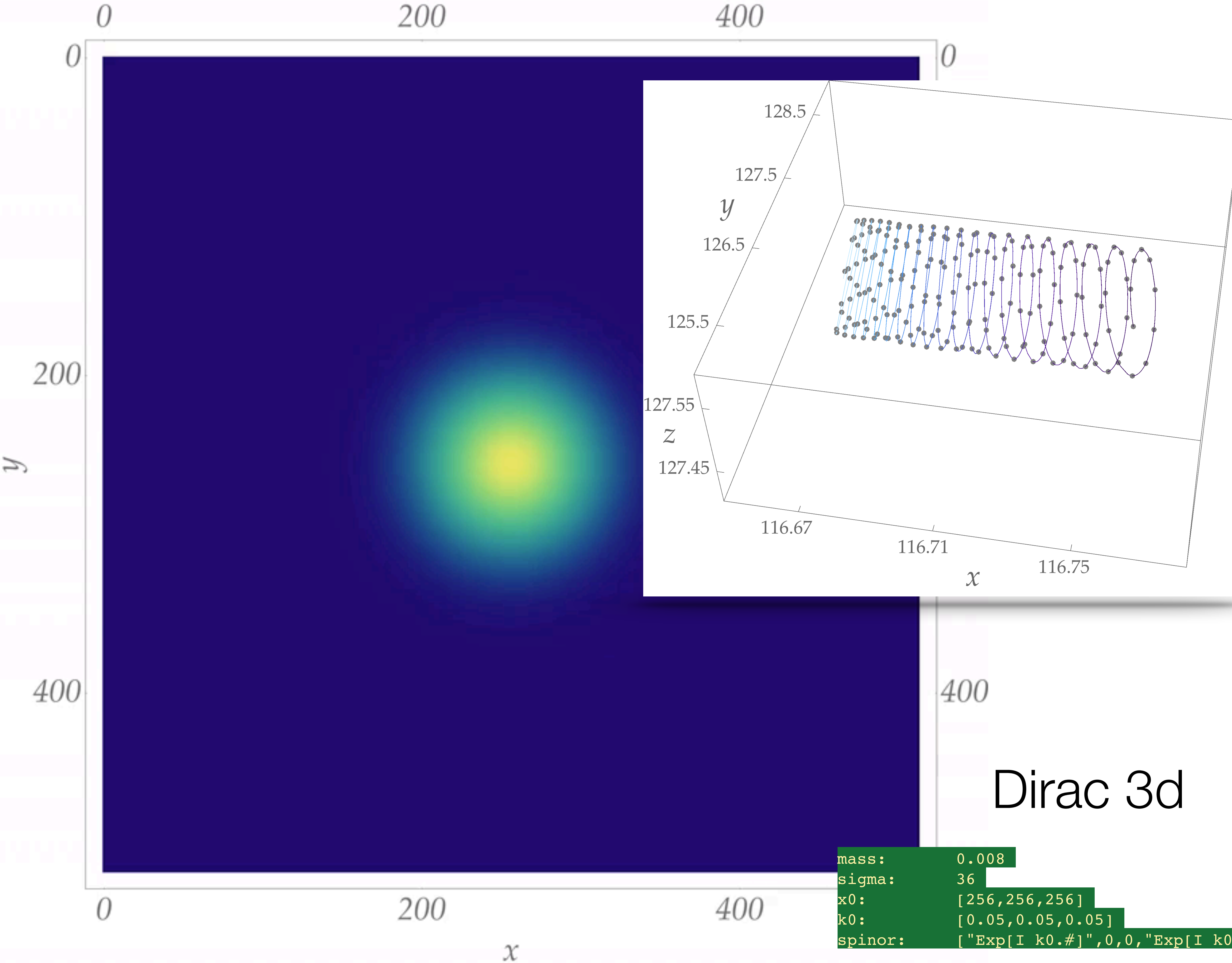
Boson: emergent from convolution of fermions

(De Broglie neutrino-theory of photon)




PRINCIPLES
THEORY
RESTRICTIONS
INTERPRETATION
MATH. FRAMEWORK
equivalence
B needs A
A
B
Strict symmetric monoidal category theory
Operational Information framework
Causality
Local discriminability
Purification
Atomicity of composition
Perfect discriminability
Ideal compressibility
Quantum Theory
Locality
Homogeneity
Isotropy
Unitarity
Quantum Cellular Automata on a Cayley graph of G
Linearity
Quantum Walk on Cayley graph of G
Cayley graph quasi-isometrically embeddable in Euclidean space
G virtually Abelian
Quantum Walk on Cayley graph of Abelian G
Relativistic limit
Free Quantum Field Theory
m ∈ S^1
D'Ariano, Perinotti,
PRA 90 062106 (2014)
Bisio, D'Ariano, Perinotti,
Ann. Phys. 368 177 (2016)
Free Quantum Field Theory
We got it!


Theory
Falsifiability
Physics without physics?!
How?
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Quantum
Theory
Algorithm
simplicity
Free
QFT
Why?
Solving logical
problems inside
QFT
Axiomatization
Why?
Solving the logical
clash between GR
and QFT
Planck scale
Axiomatize GR
itself



D'Ariano, Mosco, Perinotti, Tosini, arXiv:1603.06442

Dirac 3d

```
mass:        0.008
sigma:       36
x0:          [256,256,256]
k0:          [0.05,0.05,0.05]
spinor:      ["Exp[I k0.#]",0,0,"Exp[I k0.#]"]
```

The theory contains its own LTM standards

$$x = \frac{x_{[m]}}{a_*} \in \mathbb{Z}, \quad t = \frac{t_{[sec]}}{t_*} \in \mathbb{N}, \quad m = \frac{m_{[kg]}}{m_*} \in [0,1]$$

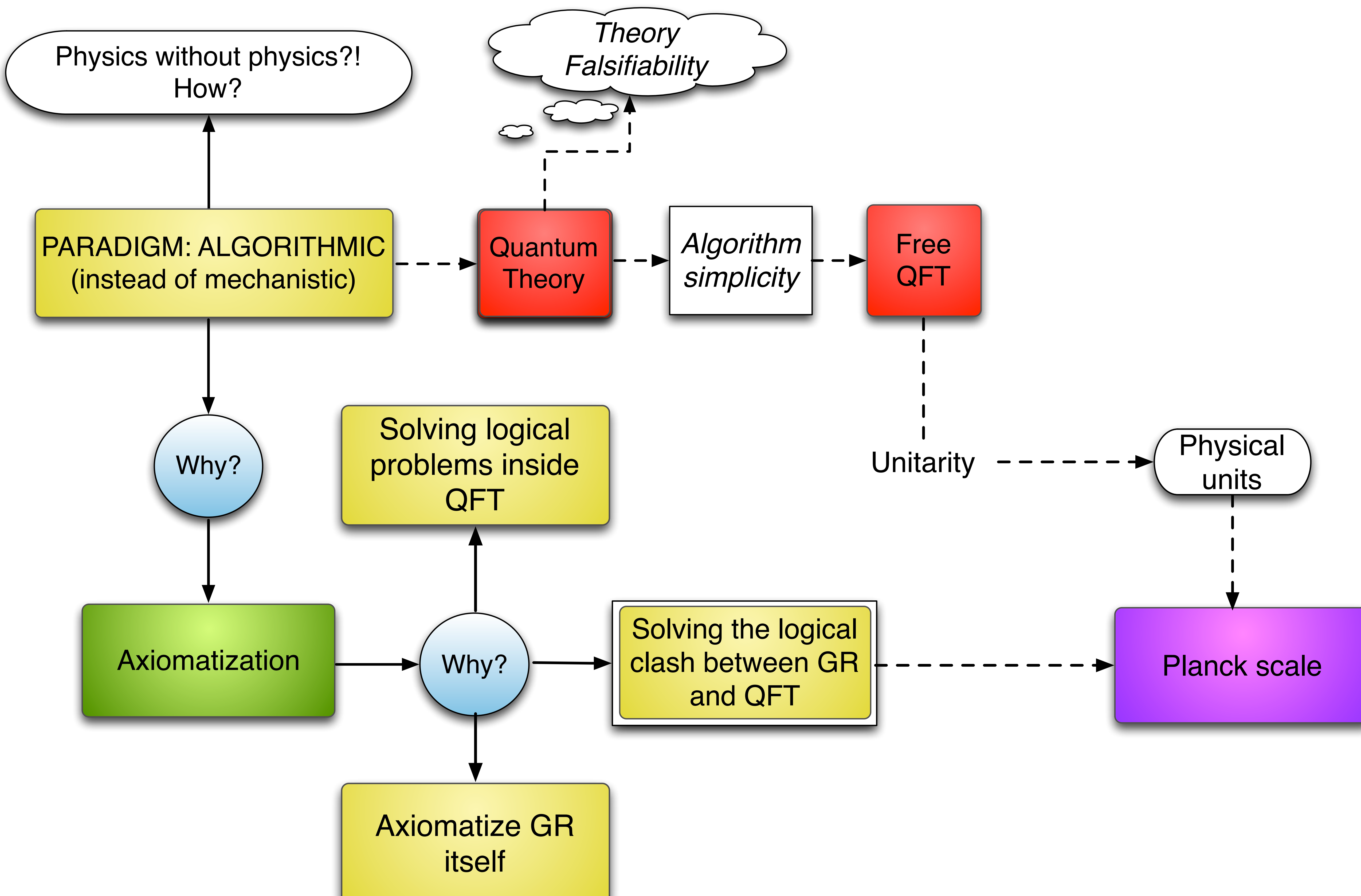
$$m_* \simeq \frac{1}{\sqrt{3}\pi} \frac{\hbar k}{c(k) - c(0)}$$

$$\begin{cases} c \equiv c(0) = \dfrac{a_*}{t_*} \\ \hbar = m_* a_* c \end{cases}$$

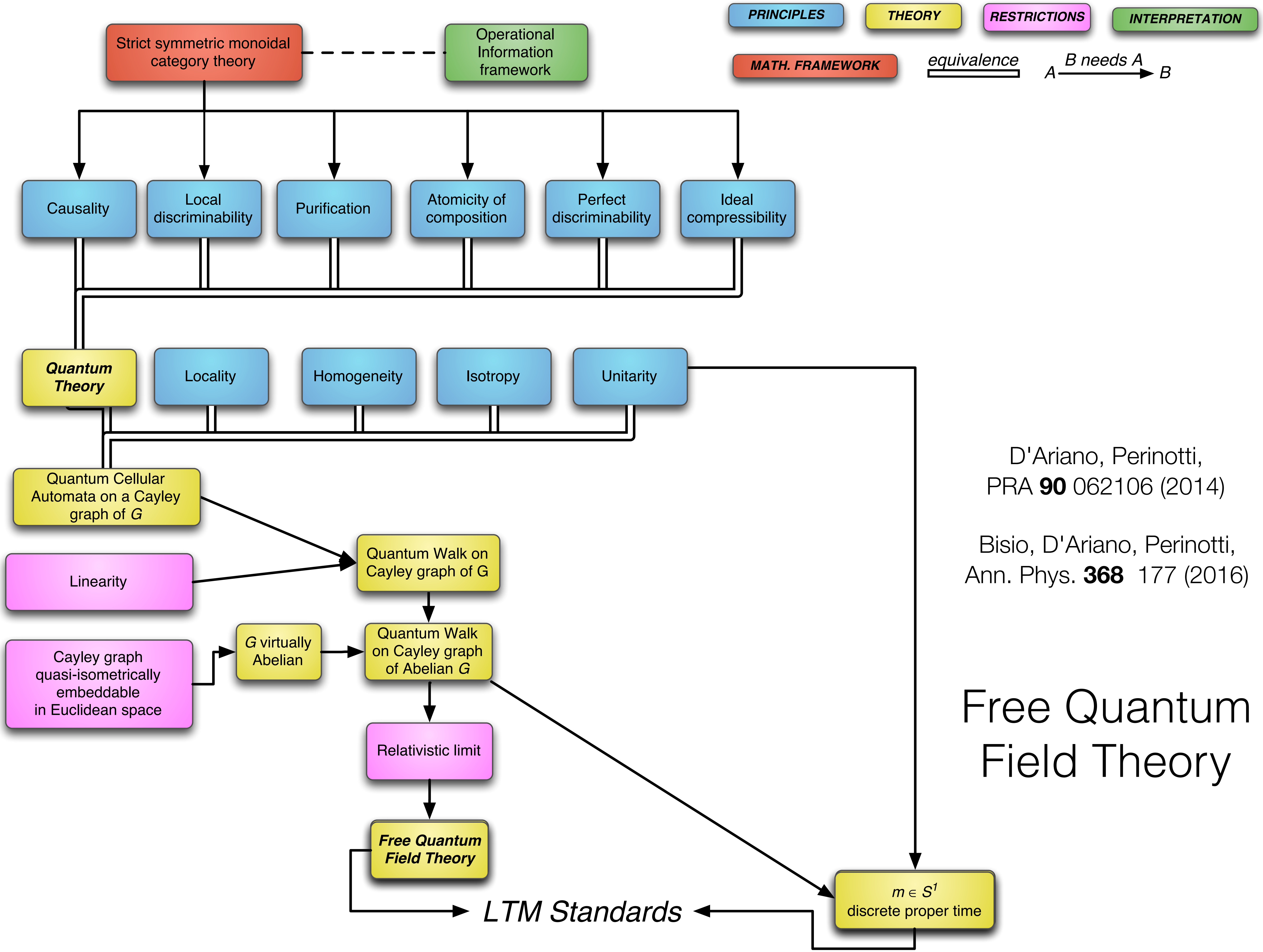
from the relativistic limit

Heuristic argument of the mini-black-hole:

m_* Planck mass


Physics without physics?!
How?
Theory
Falsifiability
PARADIGM: ALGORITHMIC
(instead of mechanistic)
Quantum
Theory
Algorithm
simplicity
Free
QFT
Why?
Solving logical
problems inside
QFT
Unitarity
Physical
units
Axiomatization
Why?
Solving the logical
clash between GR
and QFT
Planck scale
Axiomatize GR
itself

Free Quantum Field Theory



D'Ariano, Perinotti, PRA **90** 062106 (2014)

Bisio, D'Ariano, Perinotti, Ann. Phys. **368** 177 (2016)

D'Ariano, Perinotti, PRA **90** 062106 (2014)

Fidelity of the quantum walk with QFT

Fidelity with Dirac for a narrowband packets in the relativistic limit $k \simeq m \ll 1$

$$F = |\langle \exp\left[-iN\Delta(\mathbf{k})\right]\rangle|$$

$$\Delta(\mathbf{k}) := (m^2 + \tfrac{k^2}{3})^{\frac{1}{2}} - \omega^E(\mathbf{k})$$

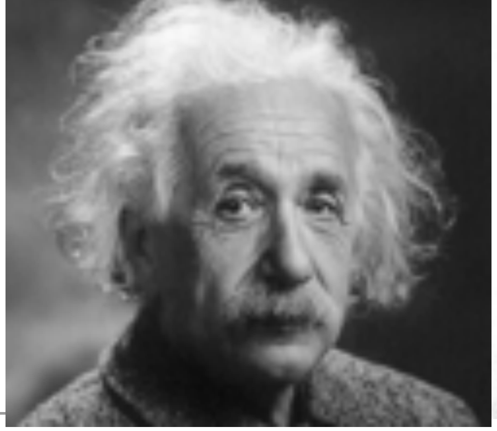
$$= \frac{\sqrt{3}k_x k_y k_z}{(m^2 + \frac{k^2}{3})^{\frac{1}{2}}} - \frac{3(k_x k_y k_z)^2}{(m^2 + \frac{k^2}{3})^{\frac{3}{2}}} + \tfrac{1}{24}(m^2 + \tfrac{k^2}{3})^{\frac{3}{2}} + \mathcal{O}(k^4 + N^{-1}k^2)$$

relativistic proton: $N \simeq m^{-3} = 2.2 * 10^{57} \Rightarrow t = 1.2 * 10^{14}\mathrm{s} = 3.7 * 10^6$ y

UHECRs: $k = 10^{-8} \gg m \Rightarrow N \simeq k^{-2} = 10^{16} \Rightarrow 5 * 10^{-28}$ s

Special relativity translated into quantum-algorithmic terms

Special Relativity from Quantum theory



Relativity Principle: Invariance of the dynamical law with the inertial frame

Inertial frame: a reference frame where the Newton inertia law holds for a mechanically isolated system

Maxwell equations → ***Einstein Special Relativity***

Poincaré group: group of changes of inertial frame that leave the dynamical law invariant.

Special Relativity from Quantum theory

Relativity Principle: Invariance of the dynamical law with the inertial frame

Inertial frame: a reference frame where energy and momentum are conserved for a mechanically *isolated* system.

Poincaré group: group of changes of inertial frame that leave the dynamical law invariant.

Special Relativity from Quantum theory

Relativity Principle: Invariance of the dynamical law with the inertial frame

Inertial frame: Representation of the dynamical law for given *values* of the constants of motion for an *isolated* system.

Dynamical law: expressed in terms of the values of the constants of motion.

Poincaré group: group of changes of inertial frame that leave the dynamical law invariant.

good for any dynamical system!

Special Relativity from Quantum theory

Relativity Principle: Invariance of the dynamical law with the inertial frame

Inertial frame: Representation of the physical law in terms of eigenspaces of the constants of the dynamics $k := (\omega, \mathbf{k})$

Dynamical law: eigenvalue equation

$$A_{\mathbf{k}}\psi(\mathbf{k},\omega) = e^{i\omega}\psi(\mathbf{k},\omega)$$

Poincaré group: group of changes of representations in terms of eigenspaces of the constants of dynamics that leave the eigenvalue equation invariant.

Quantum Walks

A. Bisio, G. M. D'Ariano, P. Perinotti,
Phys. Rev. A 94, 042120 (2016)

Special Relativity from Quantum theory

- Mathematical statement:
  invariance of eigenvalue equation under change of representation.

- Physical interpretation:
  invariance of the physical law under change of inertial reference frame.

- *m=0*
  i. Deformed Lorentz group SO(1,3)
  ii. Lorentz transformations are perfectly recovered for k,m≪1
  iii. For *k~1*: *Double Special Relativity* (Camelia-Smolin) [Relative locality]

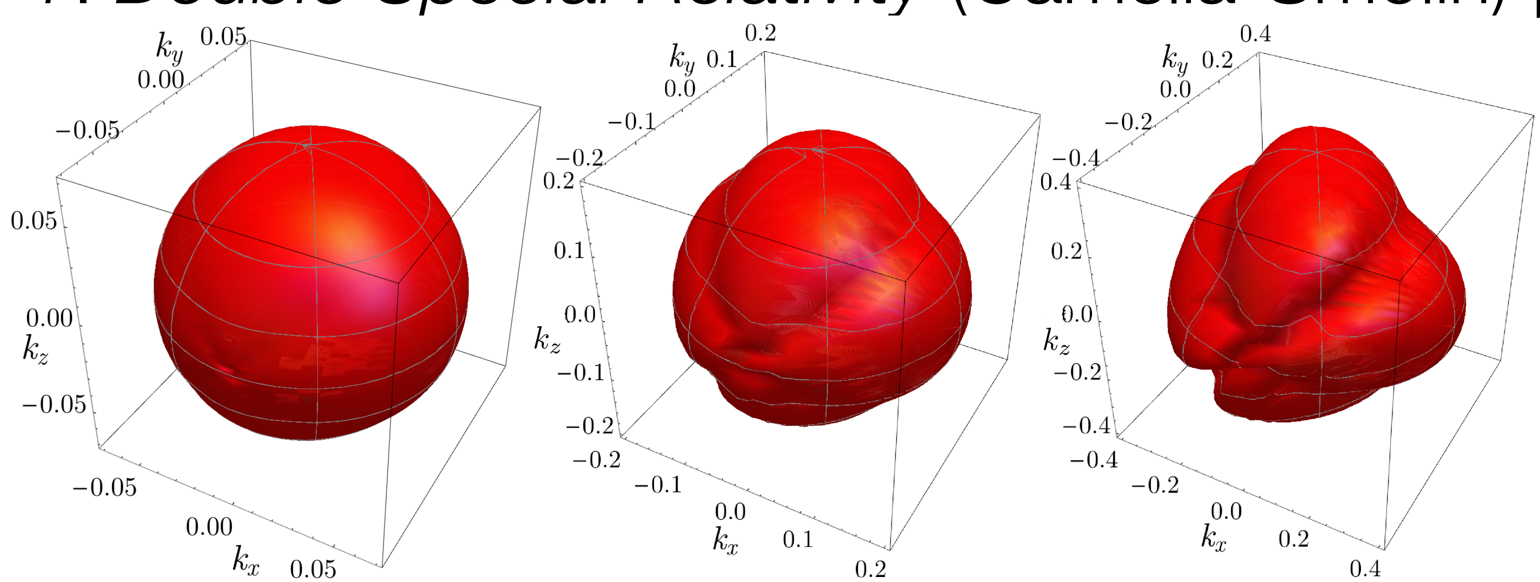


Fig. 2 (Colors online) The red surfaces represents the orbit of a wavevector $\mathbf{k} = (k_x, 0, 0)$ under the action of the deformed rotations $\mathcal{R} = \mathcal{D}^{(f)^{-1}} \circ R \circ \mathcal{D}^{(f)}$ where f is the function defined in Eq. (28). Left: $k_x = 0.07$. Middle: $k_x = 0.2$ Right: $k_x = 0.4$

A. Bisio, G. M. D'Ariano, P. Perinotti,
Phys. Rev. A 94, 042120 (2016)

Special Relativity from Quantum theory

- Mathematical statement:
  invariance of eigenvalue equation under change of representation.

- Physical interpretation:
  invariance of the physical law under change of inertial reference frame.

- *m=0*
  i. Deformed Lorentz group SO(1,3)
  ii. Lorentz transformations are perfectly recovered for k,m≪1
  iii. For *k~1*: *Double Special Relativity* (Camelia-Smolin) [Relative locality]

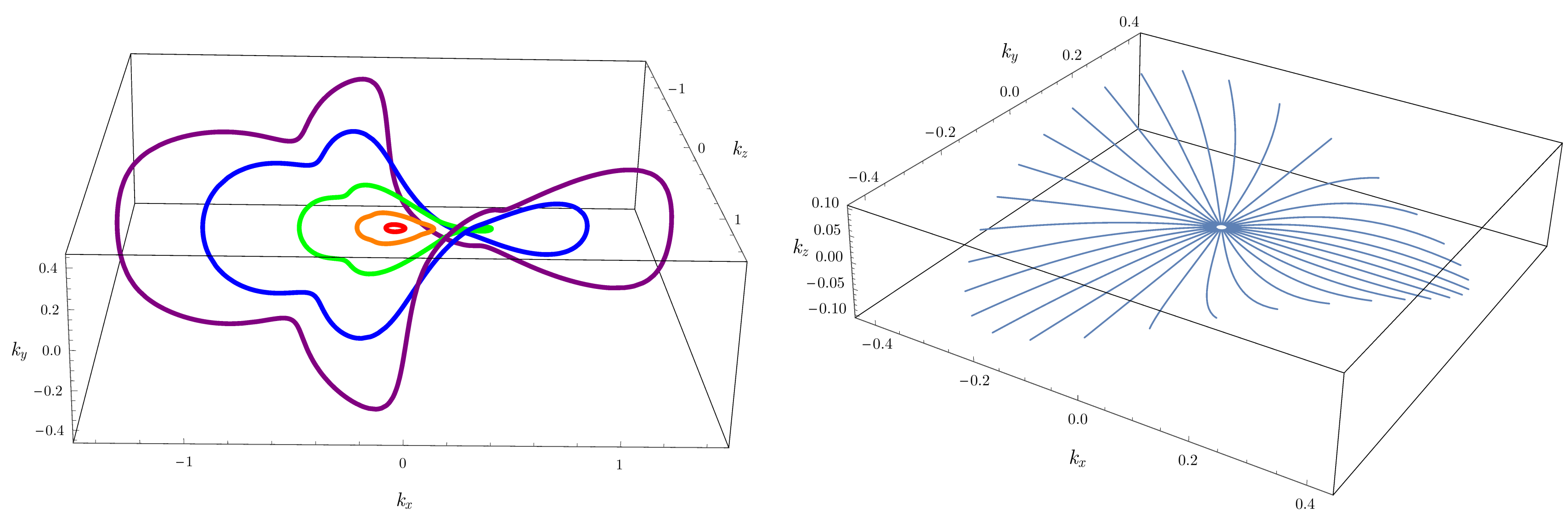


FIG. 2: The distortion effects of the Lorentz group for the discrete Planck-scale theory represented by the quantum walk in Eq. (6). Left figure: the orbit of the wavevectors $\mathbf{k} = (k_x, 0, 0)$, with $k_x \in \{.05, .2, .5, 1, 1.7\}$ under the rotation around the z axis. Right figure: the orbit of wavevectors with $|\mathbf{k}| = 0.01$ for various directions in the (k_x, k_y) plane under the boosts with $\boldsymbol{\beta}$ parallel to $\mathbf{k}$ and $|\boldsymbol{\beta}| \in [0, \tanh 4]$.

A. Bisio, G. M. D'Ariano, P. Perinotti,
Phys. Rev. A 94, 042120 (2016)

Special Relativity from Quantum theory

- Mathematical statement:
  invariance of eigenvalue equation under change of representation.

- Physical interpretation:
  invariance of the physical law under change of inertial reference frame.

- *m=0*
  i. Deformed Lorentz group SO(1,3)
  ii. Lorentz transformations are perfectly recovered for $k,m \ll 1$
  iii. For *k~1*: *Double Special Relativity* (Camelia-Smolin) [Relative locality]

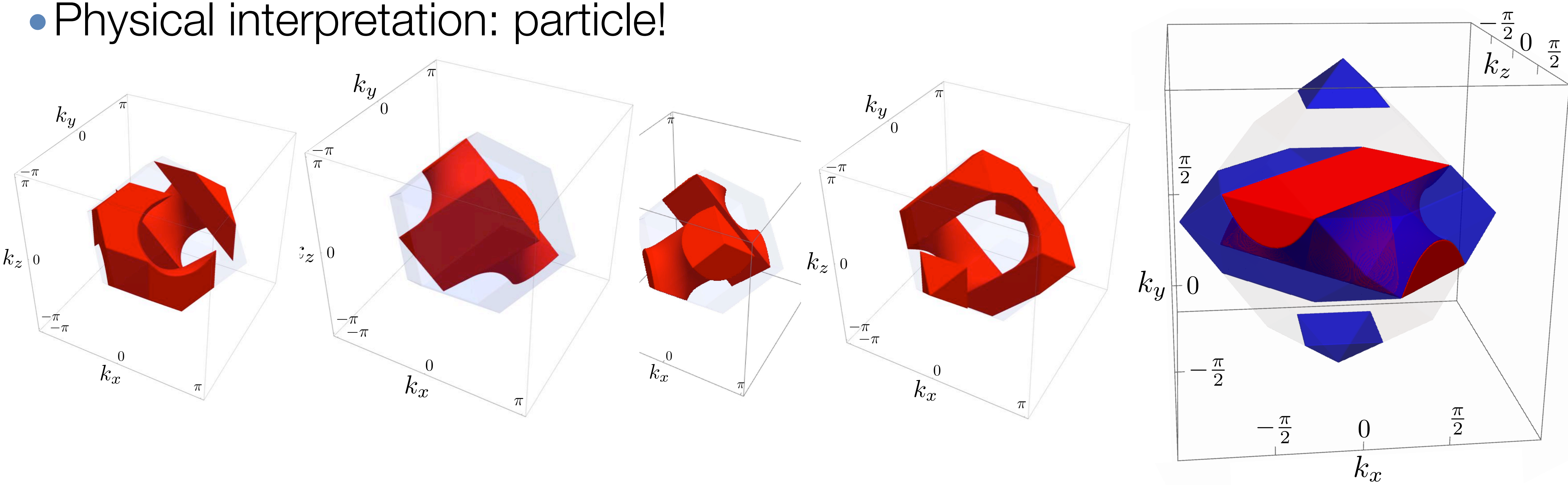
- *m>0* Deformed De Sitter group SO(1,4)

A. Bisio, G. M. D'Ariano, P. Perinotti,
Phys. Rev. A 94, 042120 (2016)

Particle notion without mechanics

- Mathematical statement:
  irreducible representation of the group of invariance of dynamics (deformed Poincaré group).

- Physical interpretation: particle!

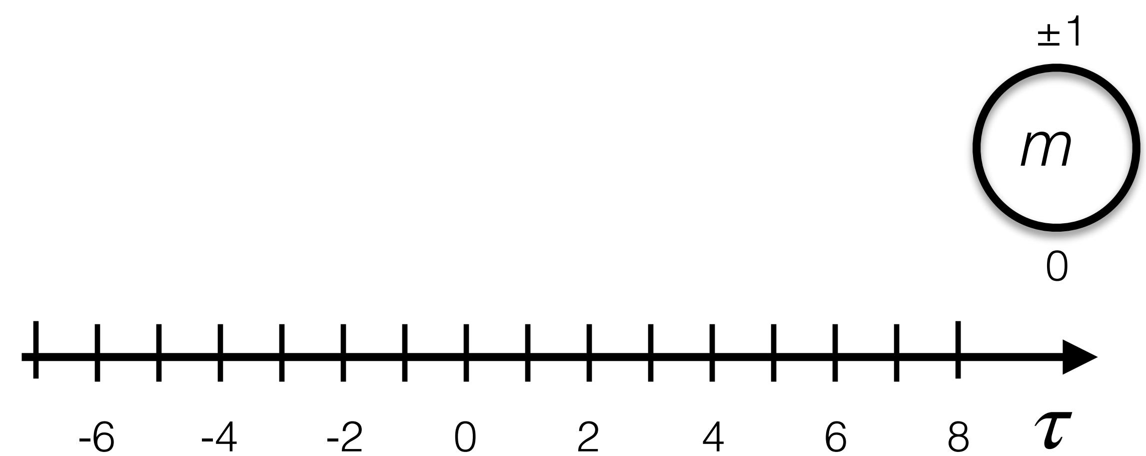


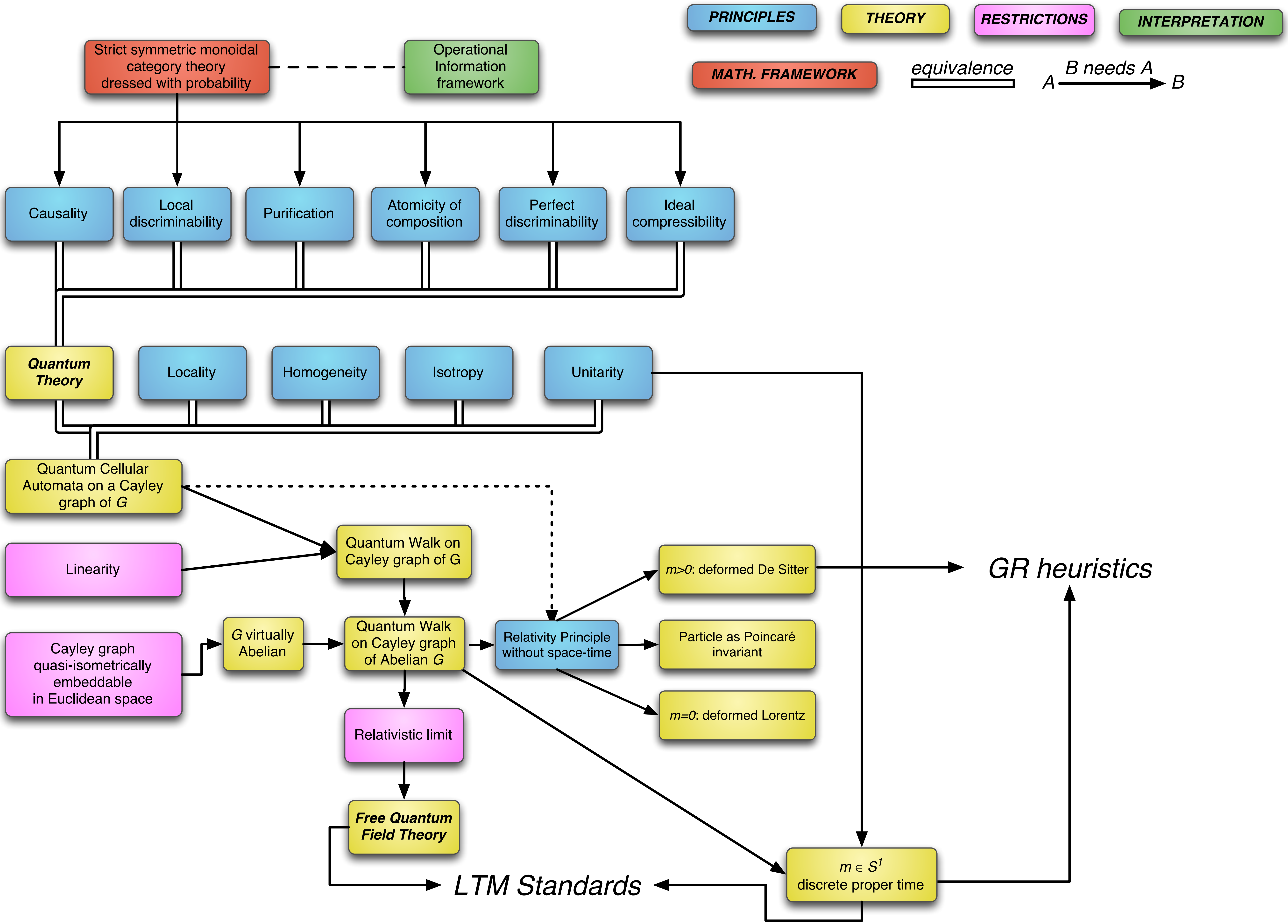
- The Brillouin zone separates into four Poincaré-invariant regions diffeomorphic to balls, corresponding to four different particles.

Internal coherence of the theory

- Mathematical statement: topology of domain of the particle mass is a circle
- Physical interpretation: proper time is discrete!

$$H(q_\alpha, p_\alpha, \tau, m) = \sum_\alpha p_\alpha \dot{q}_\alpha + c^2 m \dot{\tau} - L$$





PRINCIPLES
THEORY
RESTRICTIONS
INTERPRETATION
MATH. FRAMEWORK
equivalence
B needs A
A
B
Strict symmetric monoidal category theory dressed with probability
Operational Information framework
Causality
Local discriminability
Purification
Atomicity of composition
Perfect discriminability
Ideal compressibility
Quantum Theory
Locality
Homogeneity
Isotropy
Unitarity
Quantum Cellular Automata on a Cayley graph of G
Linearity
Quantum Walk on Cayley graph of G
Cayley graph quasi-isometrically embeddable in Euclidean space
G virtually Abelian
Quantum Walk on Cayley graph of Abelian G
Relativity Principle without space-time
m>0: deformed De Sitter
Particle as Poincaré invariant
m=0: deformed Lorentz
GR heuristics
Relativistic limit
Free Quantum Field Theory
LTM Standards
m ∈ S1 discrete proper time

Besides, …

Vladimir Ignatowski derived the Lorentz transformations from homogeneity, isotropy, reciprocity, …

W. A. von Ignatowsky, Verh. Deutsch. Phys. Ges. 12 (1910), 788–796; Phys. Zeitsch. 11 (1910), 972–976;

see: S. Liberati, Annals of Physics **298**, 167–185 (2002)

Conventionality

Homogeneity, simultaneity, … unfalsifiable principles?

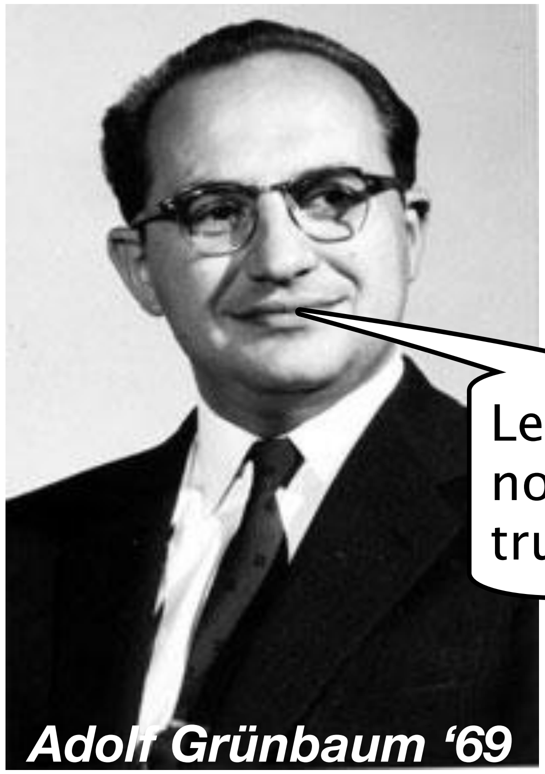
Theory simplicity!

Minimal algorithmic complexity of the physical law

Symmetries!

Galileo principle!

Clock uniformity is only for simplicity of description, and the most precise clock is the one that simplifies the logical coherence fo the theoretical description

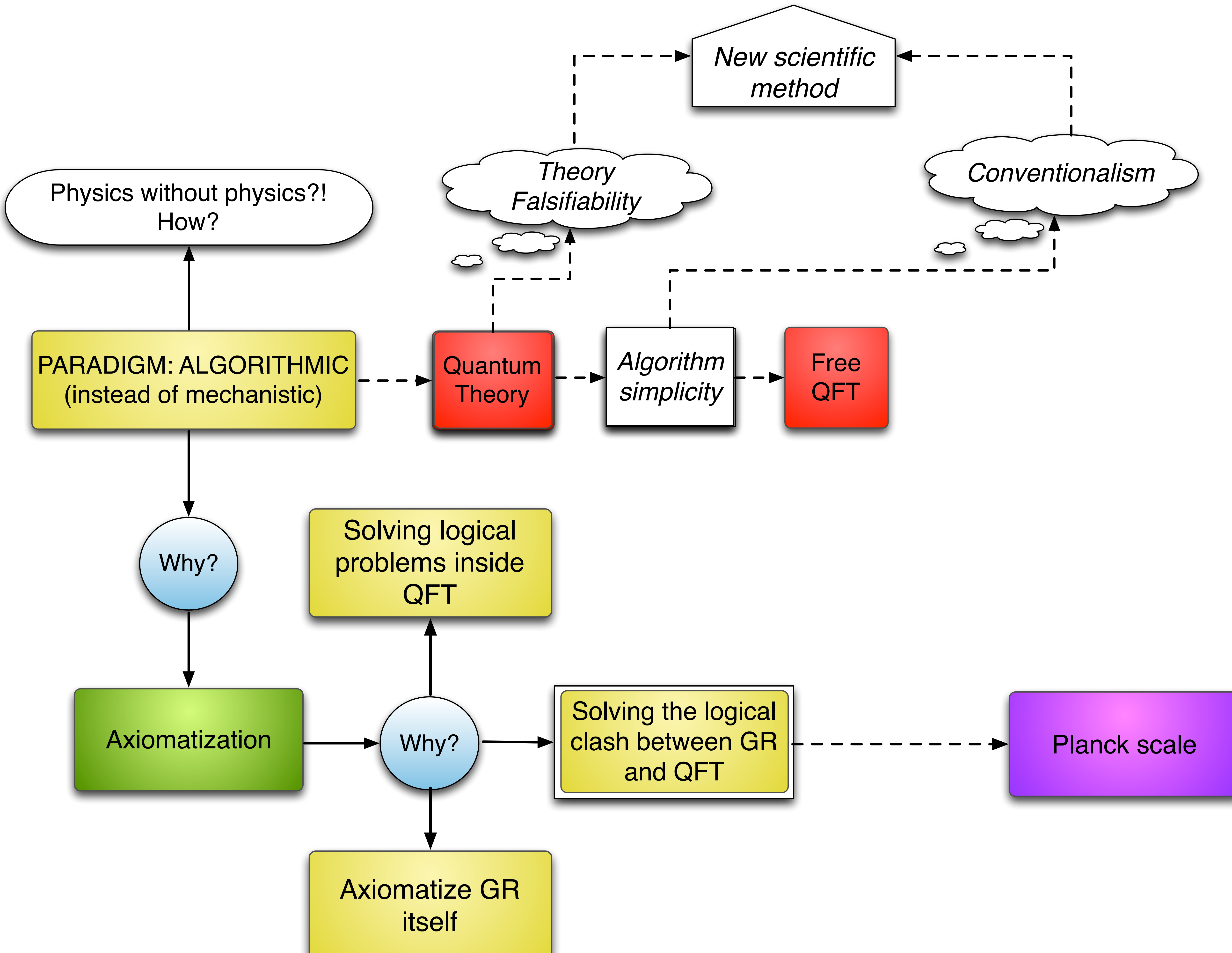


Lengths in different places are not comparable, and the same is true for time intervals

To determine simultaneity of distant events we need to know a speed, to measure a speed we need to know simultaneity of different events ... We can only determine the two-way average speed of light ...

Within the same reference frame simultaneity is conventional!

I reject conventionality of simultaneity one the basis that the structure of Minkowski space-time is intimately connected to the Einstein notion of simultaneity, and a different convention would destroy the whole construction.


New scientific method
Theory Falsifiability
Conventionalism
Physics without physics?! How?
PARADIGM: ALGORITHMIC (instead of mechanistic)
Quantum Theory
Algorithm simplicity
Free QFT
Why?
Solving logical problems inside QFT
Axiomatization
Why?
Solving the logical clash between GR and QFT
Planck scale
Axiomatize GR itself

γνῶθι σεαυτὸν