Not Even Wrong, ten years later: a view from mathematics on prospects for fundamental physics without experiment

Peter Woit

Columbia University

Rutgers Physics Colloquium, February 3, 2016

Outline

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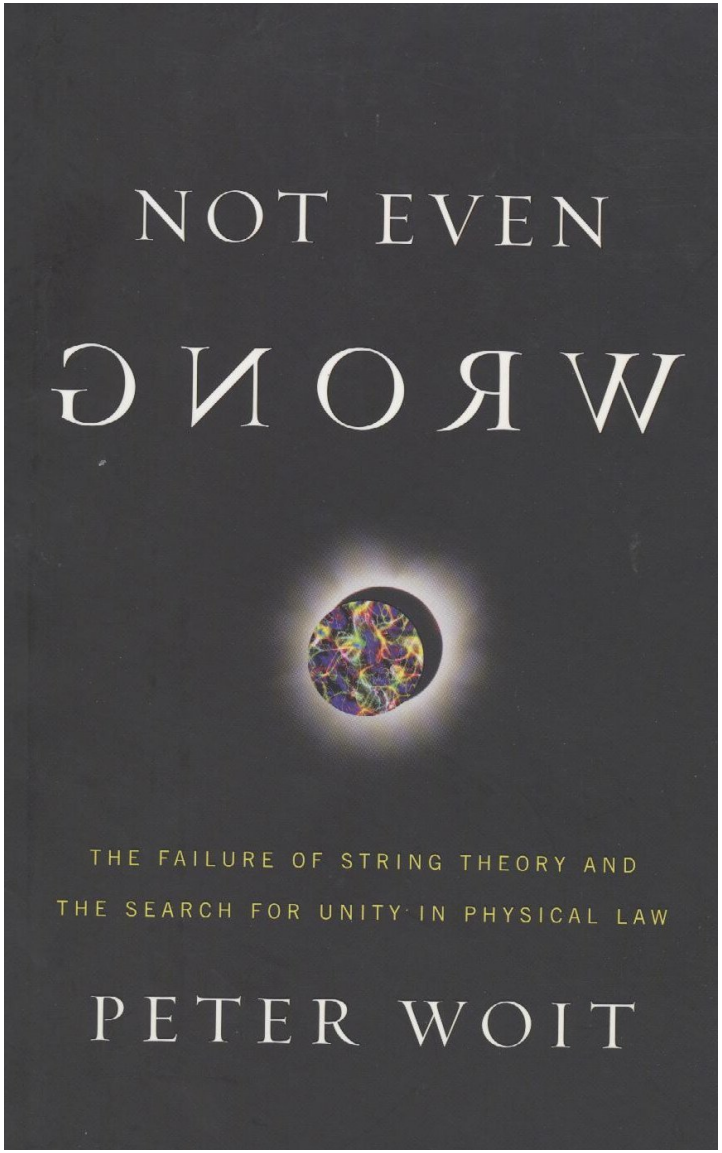
- Evidence for deep connections between math and physics: quantum mechanics and representation theory
- Speculation about relevance of ideas from representation theory to better understanding the Standard Model.

Not Even Wrong: the book



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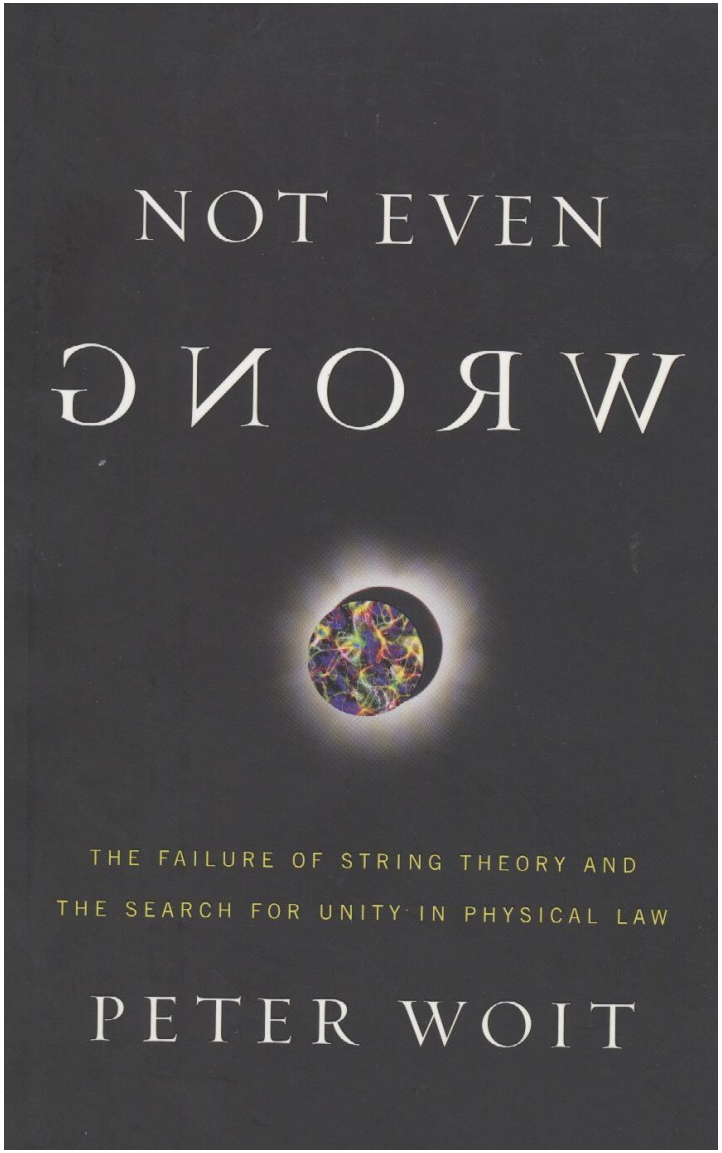

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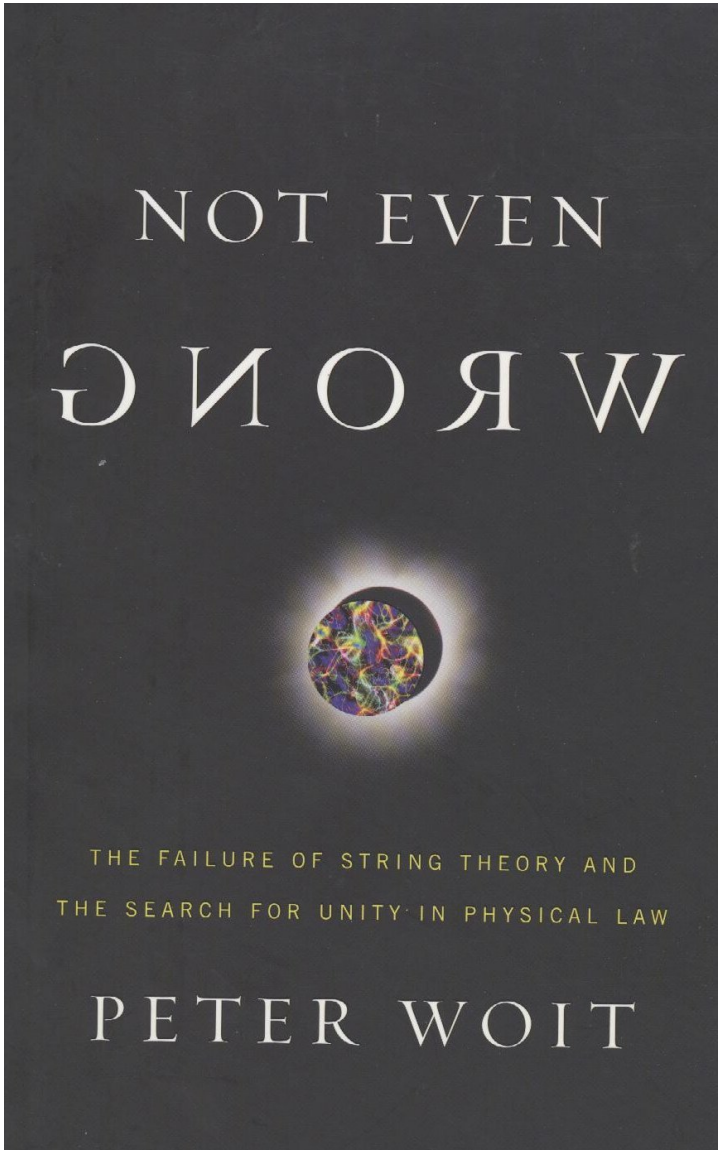

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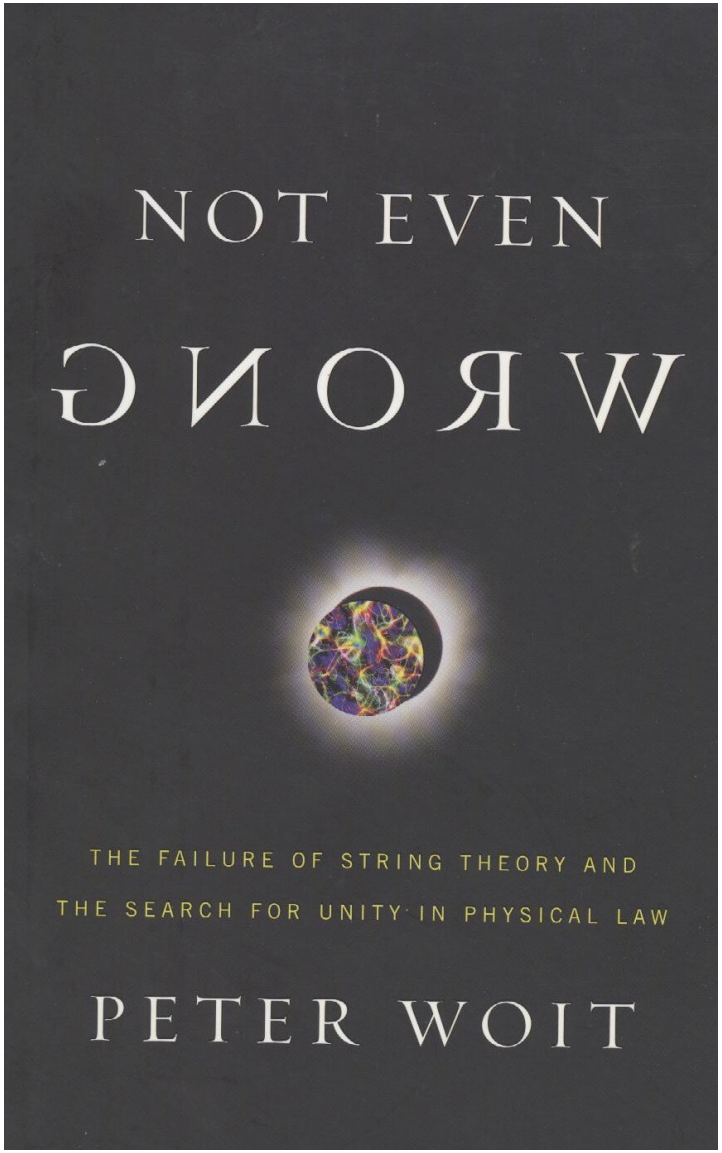

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Mid-2006: published around same time as Lee Smolin's *The Trouble with Physics*. The "String Wars" kick off.

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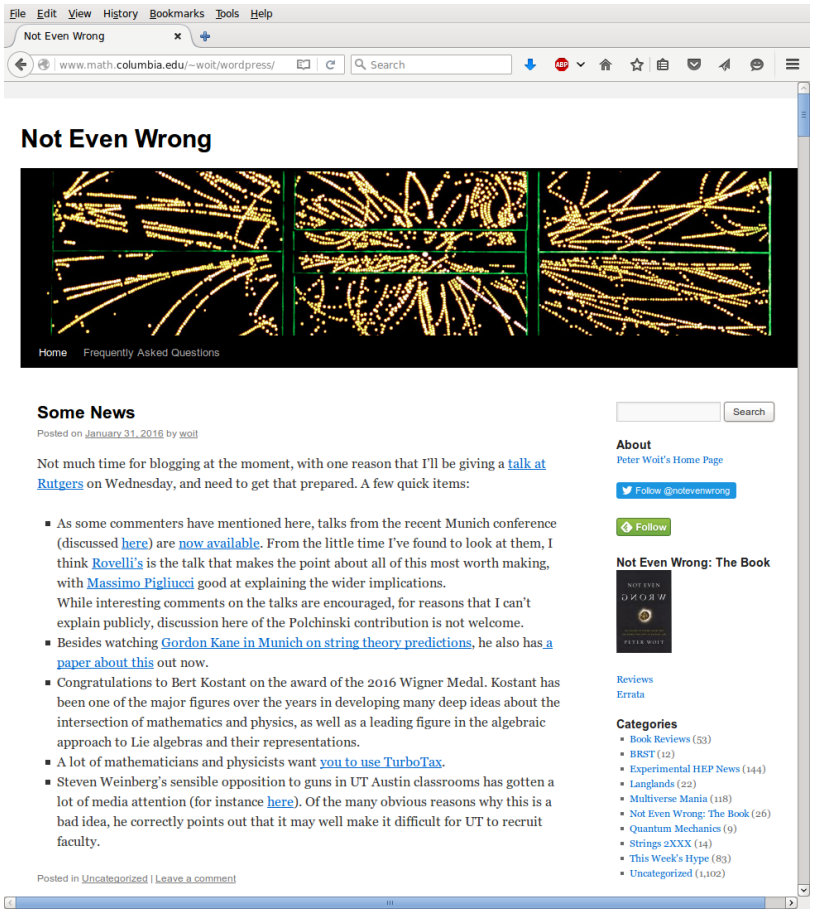

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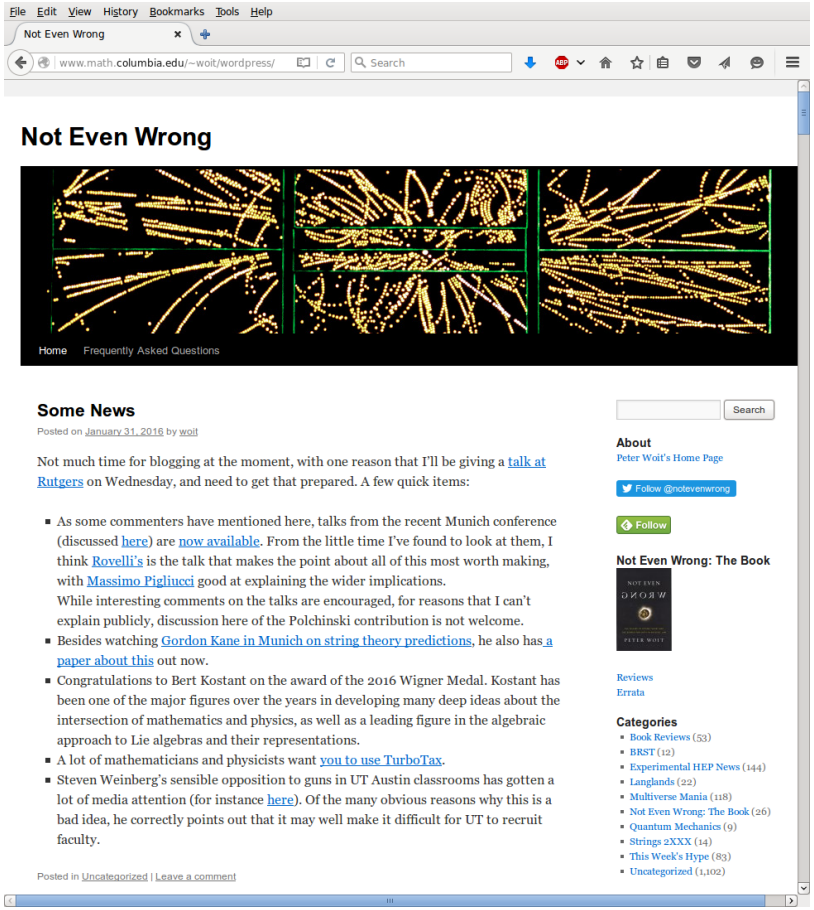

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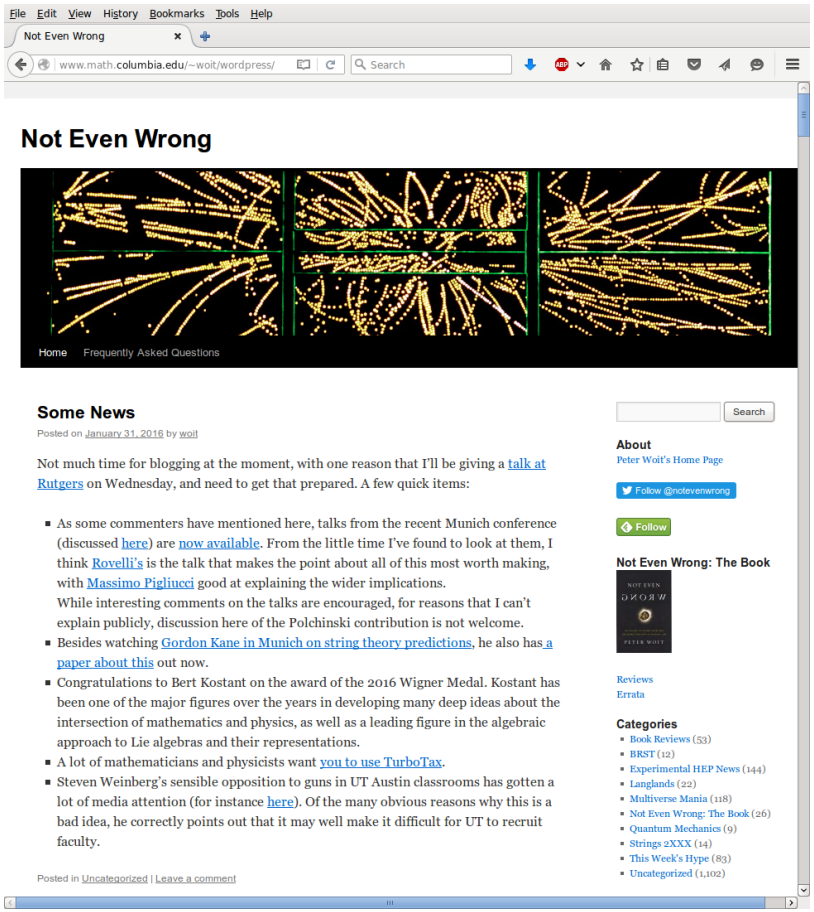

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- 41,335 comments
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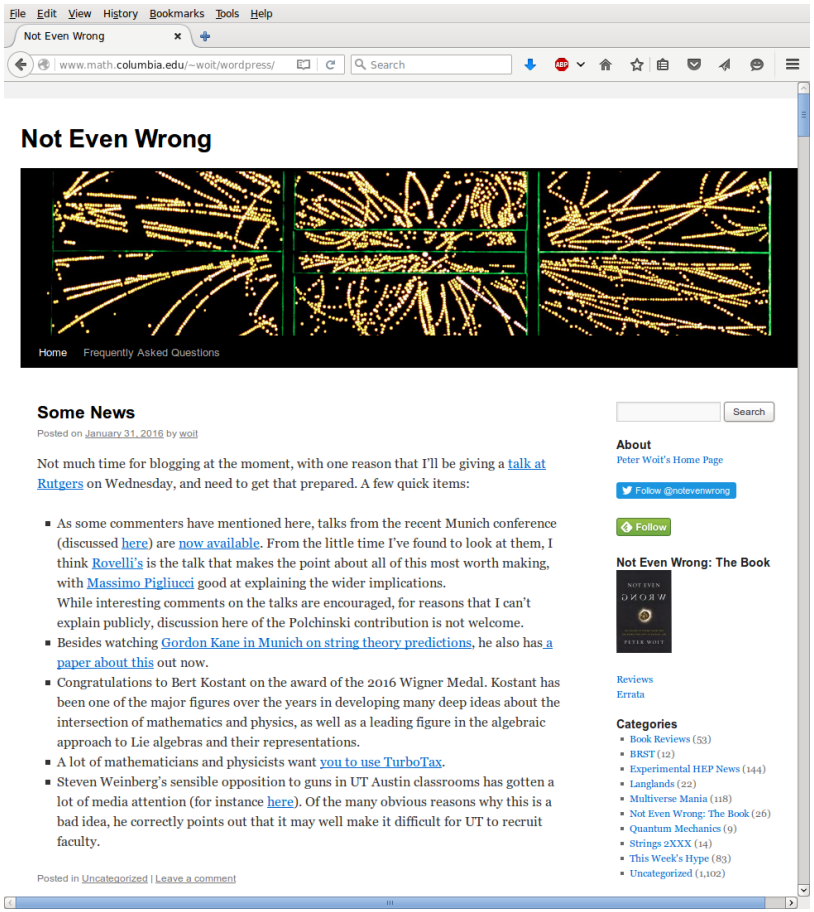

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`http://www.math.columbia.edu/~woit/blog`

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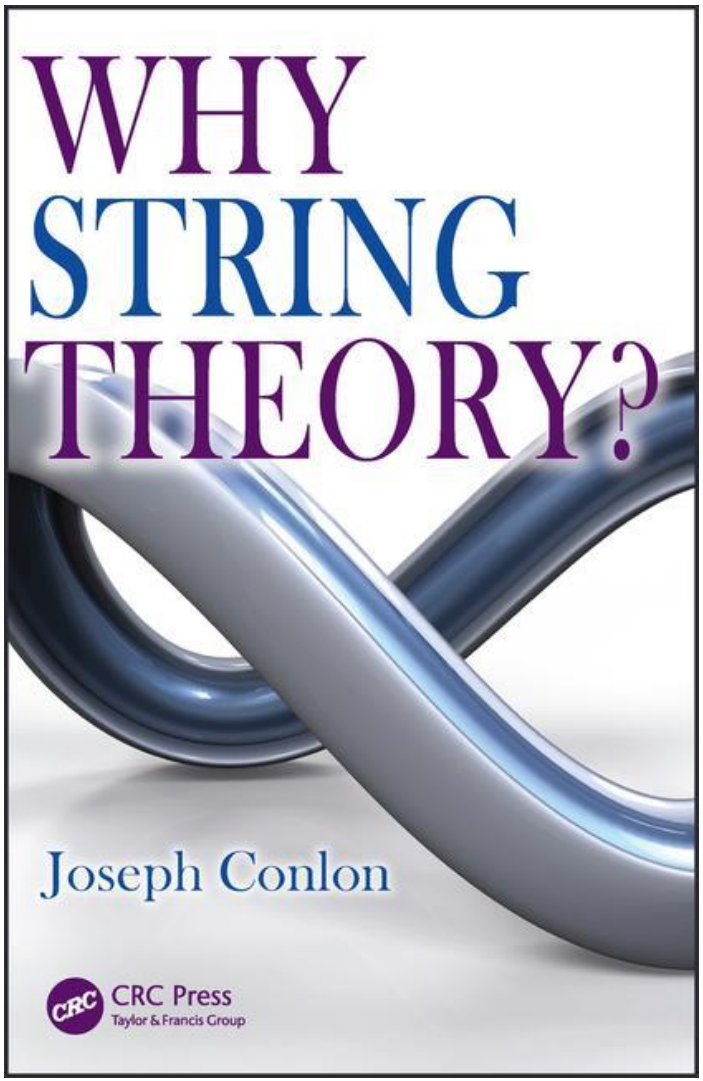
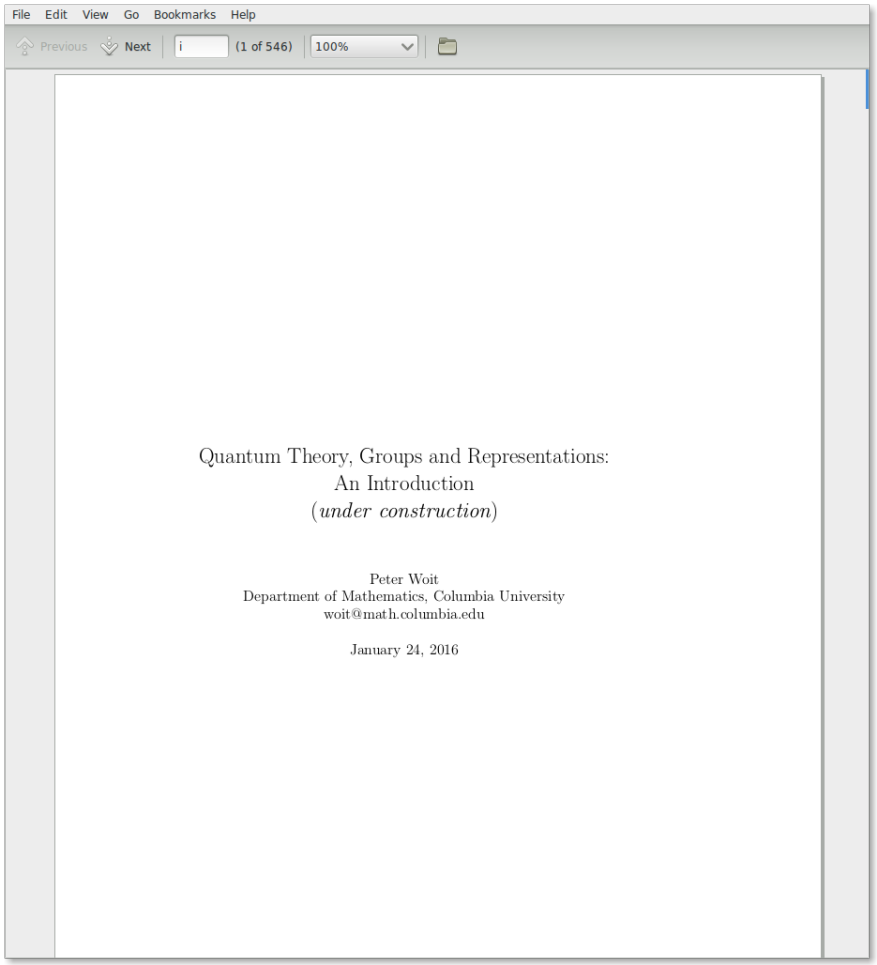


Finally in 2015, a book with the counter-argument I was expecting. Recommended if you want to hear a sensible opposite point of view.

A very different book



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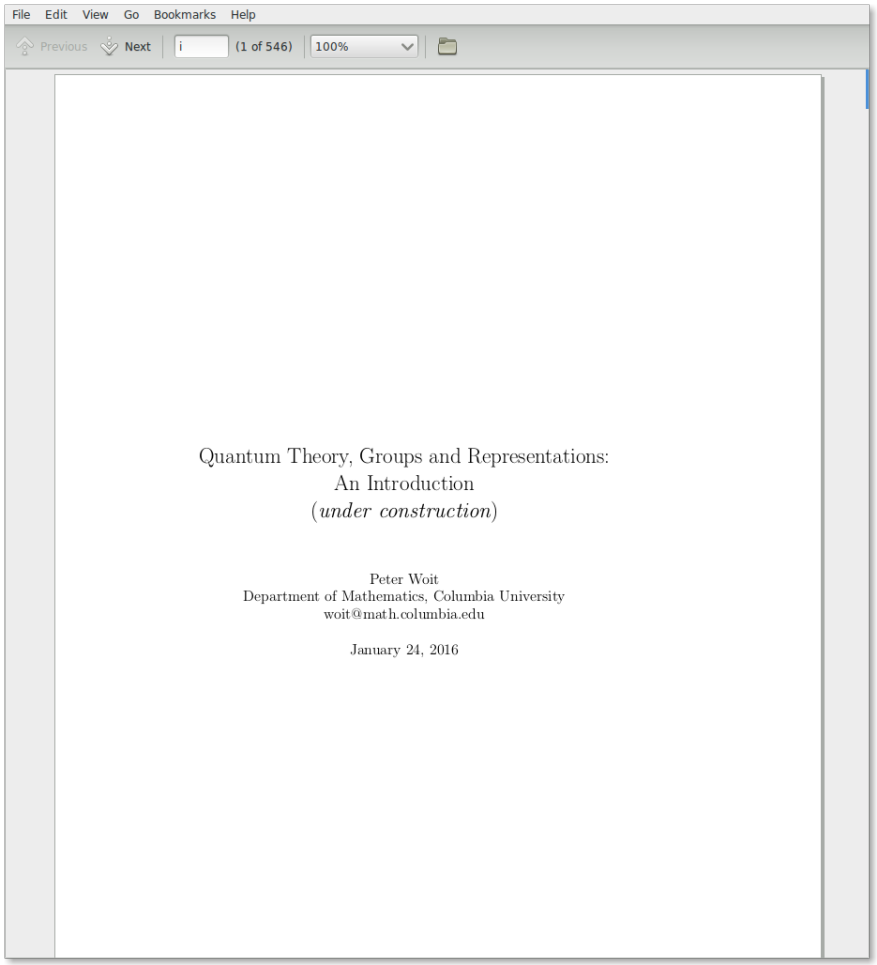

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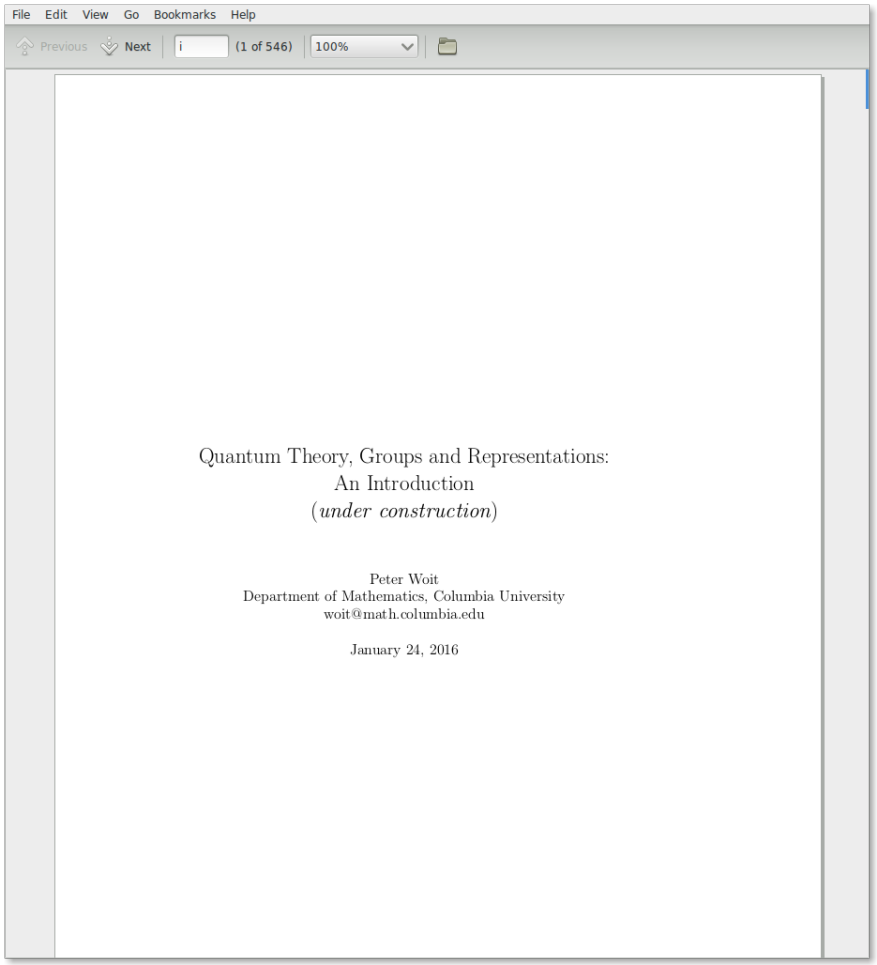

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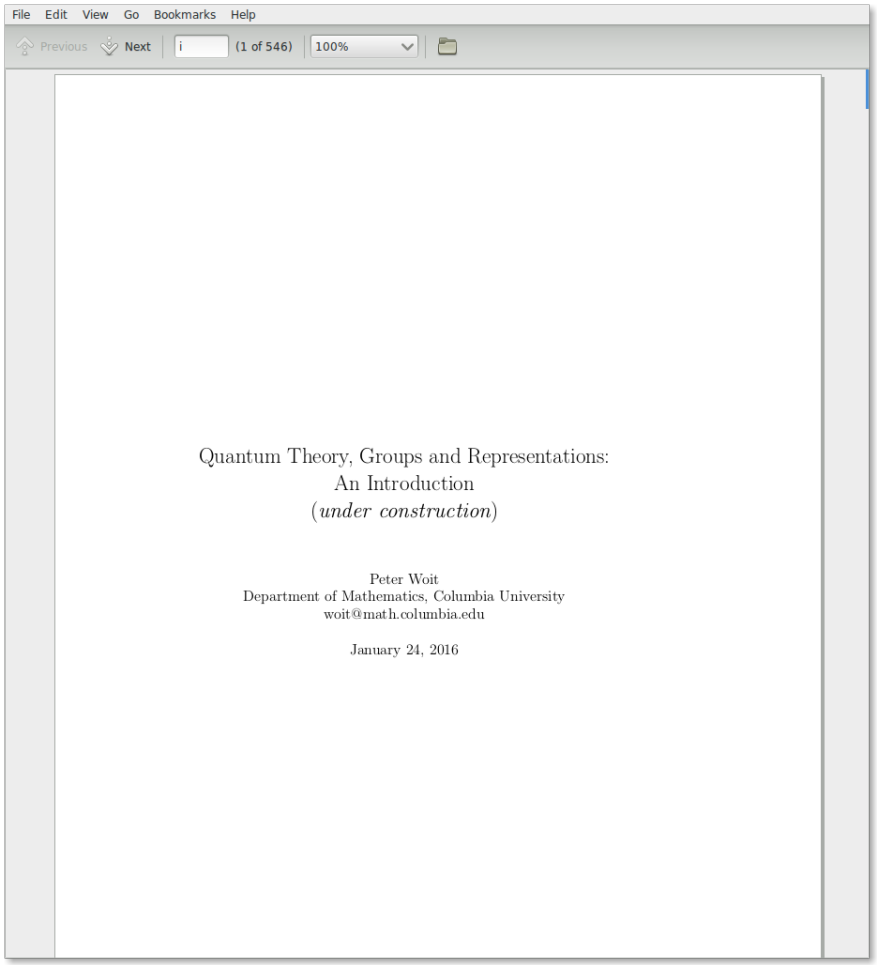

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Some comments

String unification: the vision

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Get effective supergravity theory in 4d at low energy, unified theory of SM + quantum gravity.

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7 known families of Calabi-Yaus, each one parametrized by moduli spaces of various dimensions from 36 to 203.
The plan: pick family, find dynamics that fixes the moduli, get the SM.

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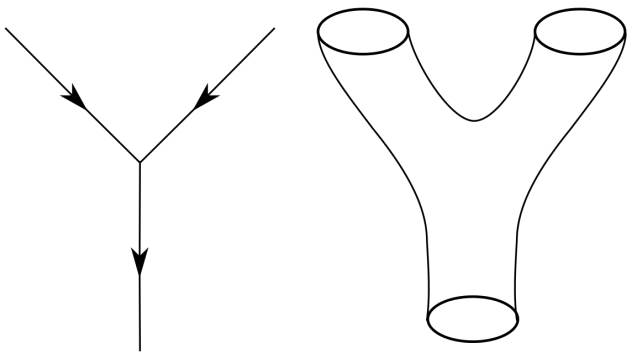
Fundamental problem

It appears that you can get just about any low energy physics you want, depending what you do with the extra dimensions. No predictions about observable physics.

String unification: the source of the problem



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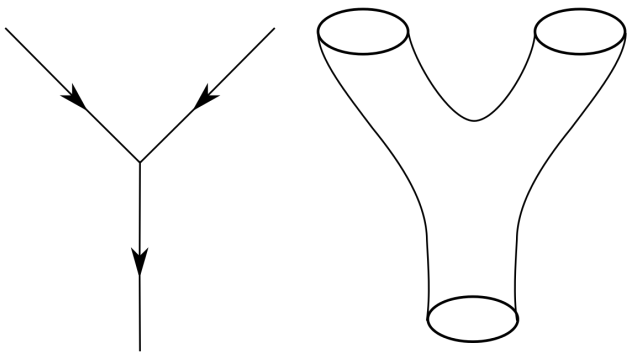

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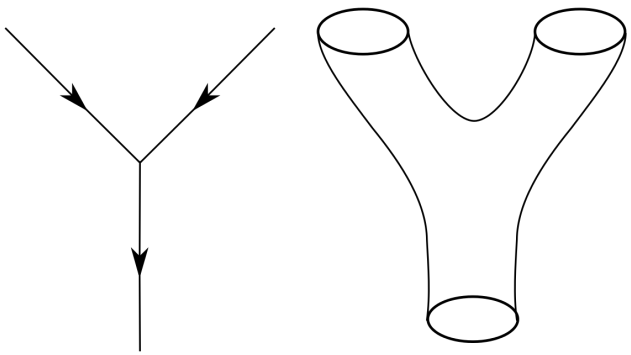

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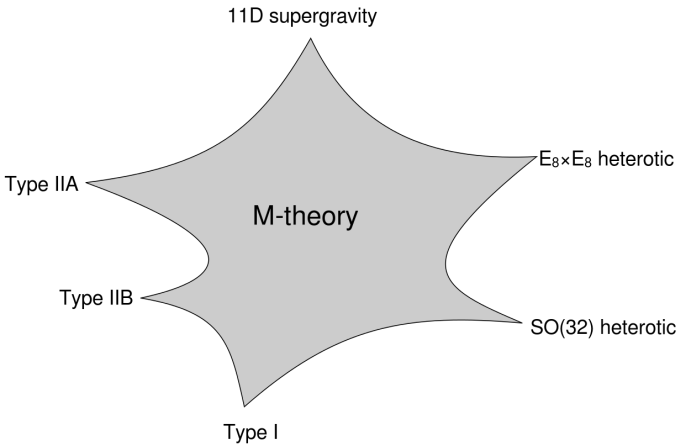
- Don't get the phenomena of QFT: non-trivial vacuum, non-perturbative behavior. Need a "non-perturbative string" or "string field" theory to get true, not approximate, "string vacua".

M-theory conjecture

1995: M-theory

Conjectural non-perturbative theory



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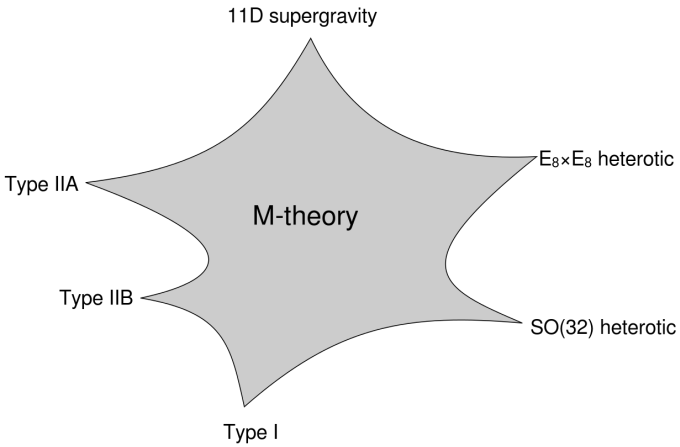

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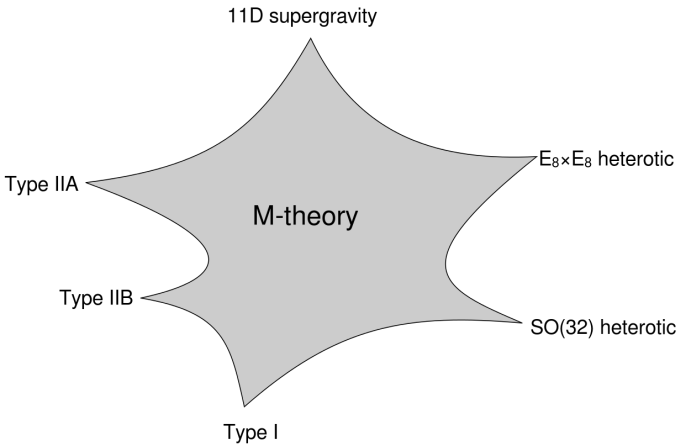

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Current situation: "string theory" is not a theory, but a conjecture there is a theory

Typical summary talk by David Gross, Strings 20XX. "The big open questions are: What is string theory? What are the underlying symmetries of string theory?"

Fallout from string unification failure: Hype

Science

The New York Times ON THE WEB

April 4, 2000

Physicists Finally Find a Way to Test Superstring Theory

Related Articles

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Diagram

- A Far-Out Theory to Describe What's Out There

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By GEORGE JOHNSON

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Keith Meyers/The New York Times

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STRING THEORY IS TESTABLE, EVEN SUPERTESTABLE

Many believe that superstring theory, because of its extraordinarily tiny length scale and gargantuan energy scale, cannot be tested. That belief is a myth.

Gordon Kane

Suppose we could understand the laws of nature that govern the particles and their interactions, and in addition why the laws are as they are, and also how the universe evolved and perhaps even how it originated—an active research area today. That understanding—a theory—would be formulated not in terms of everyday units, but rather units built from constants such as the speed of light, Planck's constant and Newton's constant. From those constants one obtains the natural scales: the Planck length ($\sim 10^{-31}$ cm) and the Planck mass ($M_P \sim 10^{19}$ GeV/c^2). I will call this theory the primary theory, a name I like because it suggests that as we go through a hierarchy of effective theories, from macroscopic sizes to atoms to nuclei, we end at a primary one that is not related to another at a deeper level.

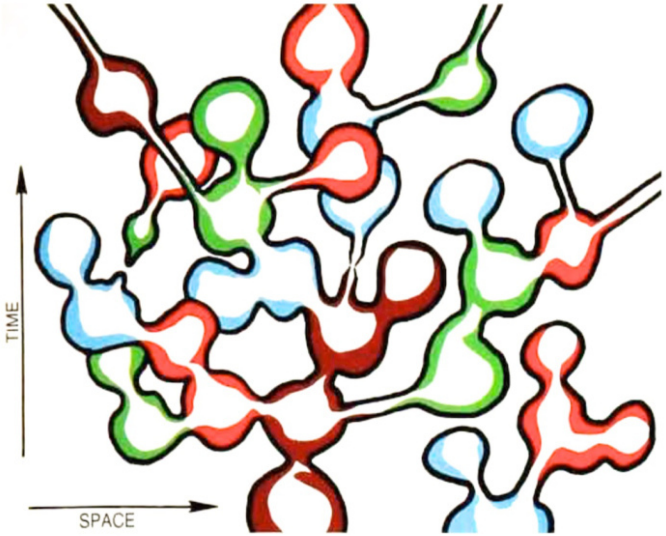
right-handed fermions are treated differently)—that is, why there is a muon and a tau so like the electron—will have passed a big test. It must also explain why matter comes as quarks and leptons but not as other possible forms such as leptoquarks. The theory will predict that there should or should not be additional kinds of matter that can be detected in collider experiments, such as particles to complete a representation of a larger group.

Similarly, the Standard Model of particle physics is based on certain symmetries under interchange of the particles: an SU(3) symmetry for interchanging quarks of different colors, an SU(2) symmetry for interchanging the up and down quarks and so on, and a U(1) symmetry for which the particles have different eigenvalues. Why those symmetries and no others?

String theory "predictions" of superpartner masses: 250 Gev (1997), $1.5 \pm .2$ TeV (arXiv:1601.07511)

Fallout from string unification failure: the Multiverse

Where string theory unification vision has ended up



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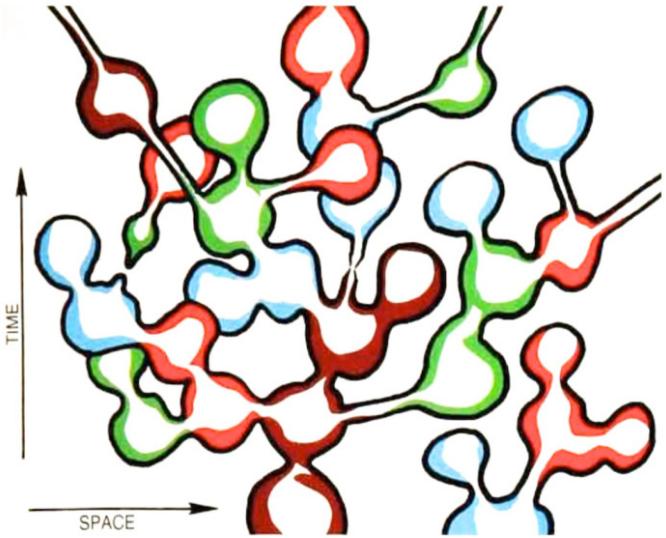

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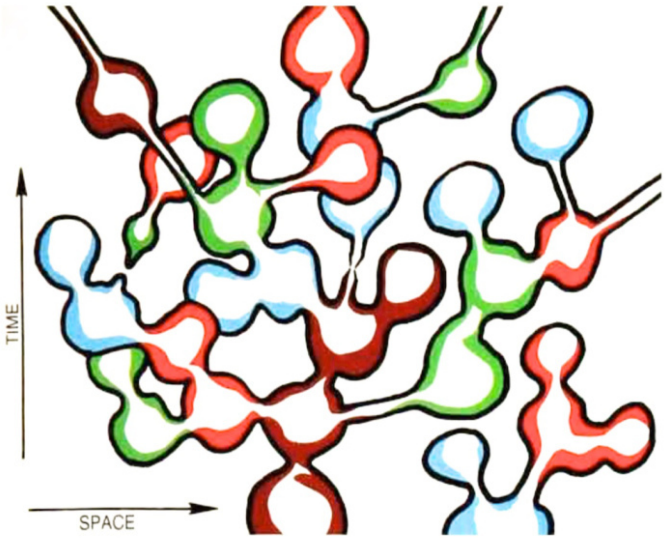

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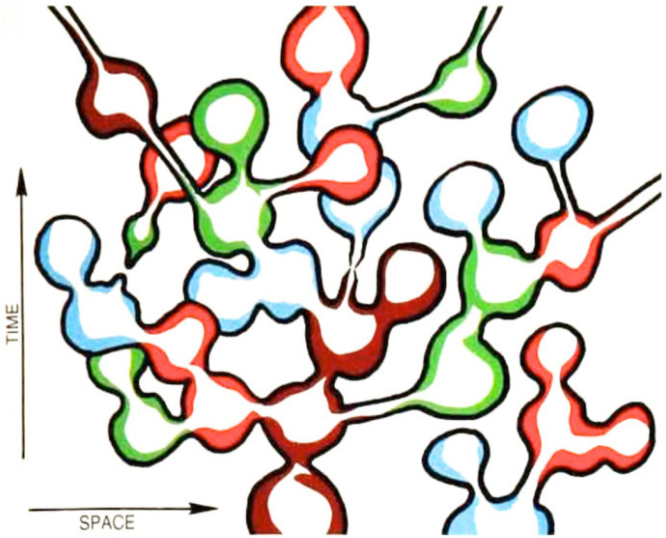

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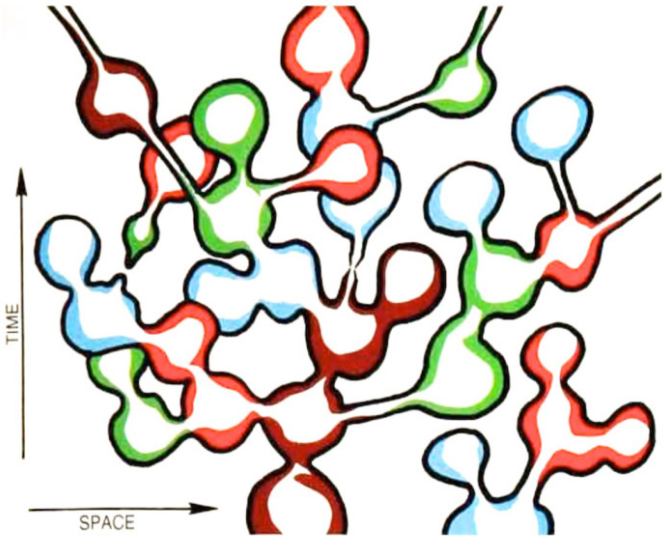

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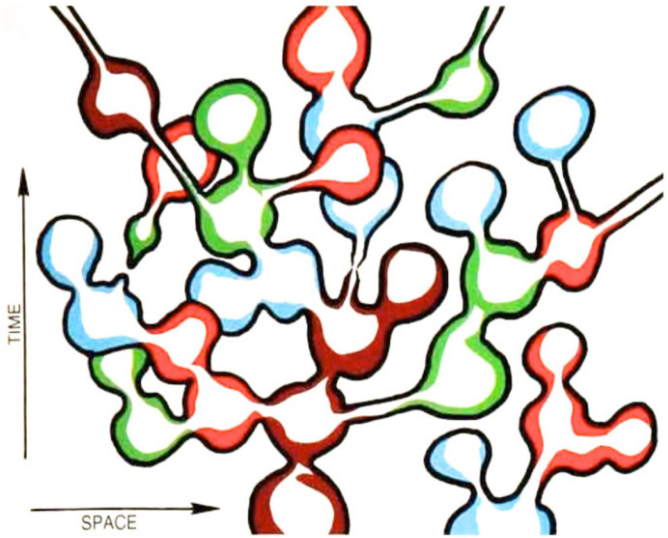

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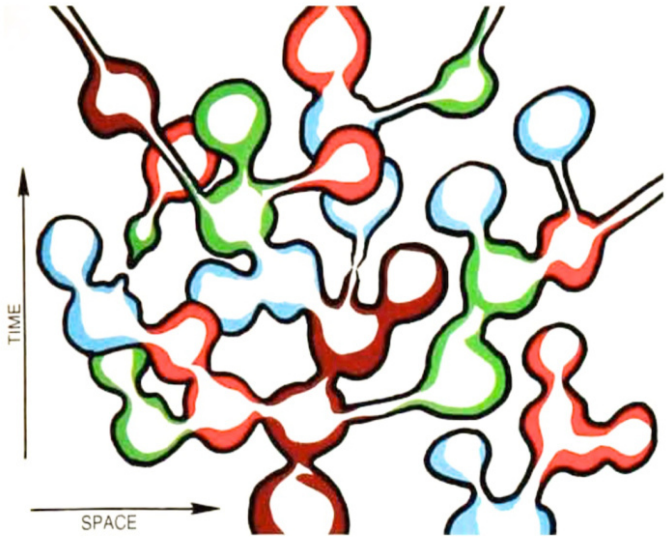

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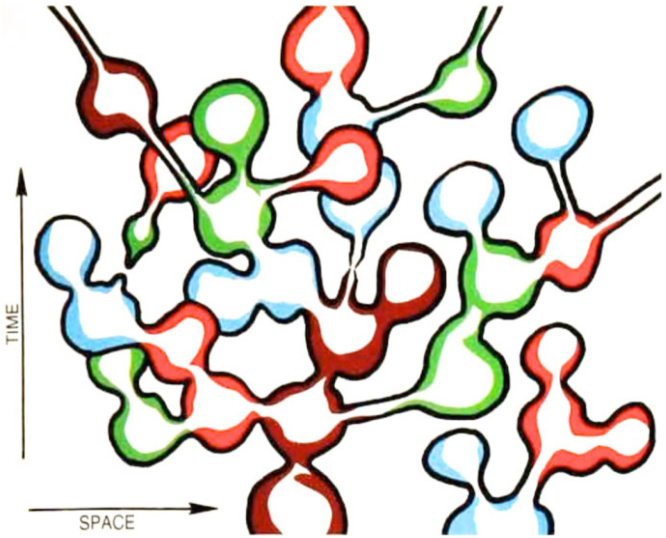

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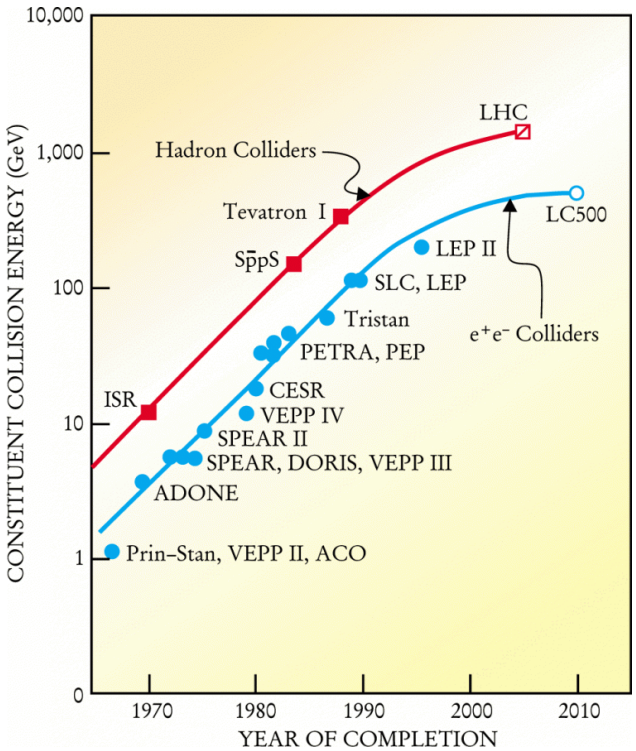
Students taught that we can't ever do better than this, not worth trying.

The end of (a certain kind of) physics?



Next e^+e^- machine: 2 x LEPII, 2030s?

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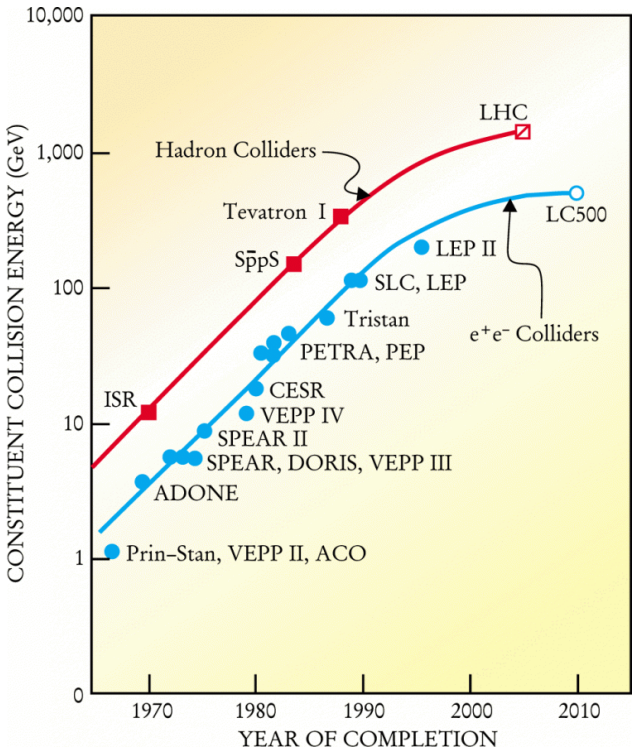

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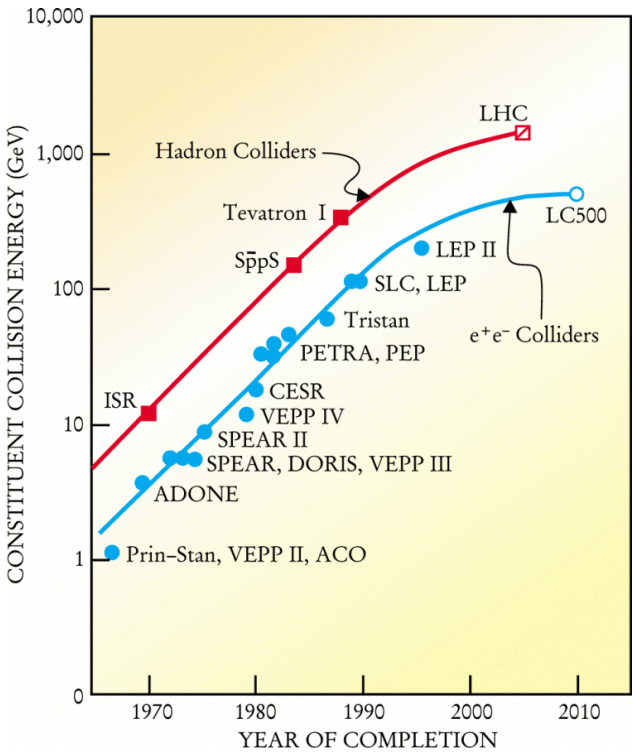

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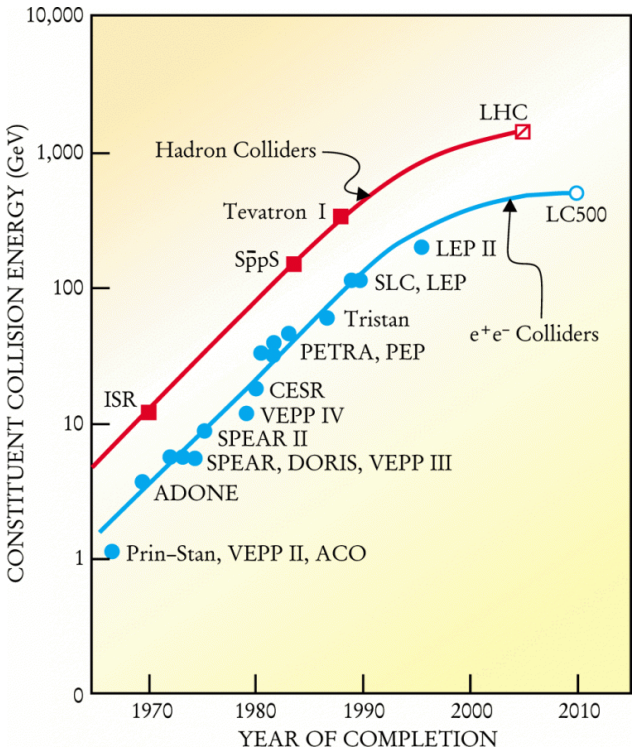

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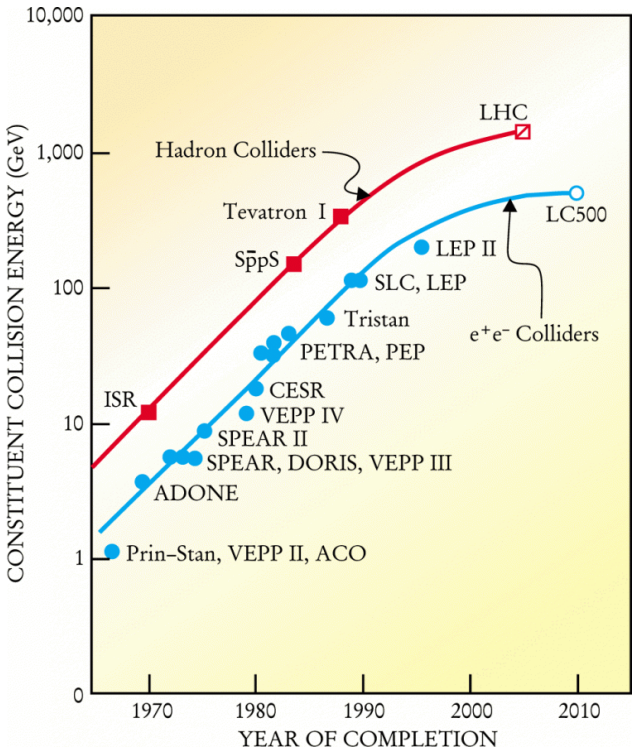

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Do we really need to change the philosophy of science? Susskind: the problem is the "Popperazi".

Mathematics: a non-empirical science

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Mathematics suffers from some of the same inherent difficulties as theoretical physics: great successes during the 20th century were based on the discovery of sophisticated and powerful new theoretical frameworks, hard and time-consuming to master. Increasingly difficult to do better, as the easier problems get solved (see John Horgan's "End of Science" argument).

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Highly abstract mathematics is in a very healthy state, with recent solutions of long-standing problems:
1994: Fermat's Last Theorem (Taylor-Wiles)
2003: Poincaré Conjecture (Perelman)

Mathematics: some methodological lessons

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Riemannian geometry (1867 -)
Lie group representations (1925 -)
Index theorem (1960 -)
Ehresmann connections (1950 -)

Physics

General relativity (1915 -)
Quantum mechanics (1925 -)
Dirac equation (1928 -)
Yang-Mills theory (1954 -)

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More recent examples

Topological quantum field theories

For history told from this point of view, see *Not Even Wrong*

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Radical Platonism

Basic mathematical objects exist, are congruent with basic physics objects

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But then how can one hope to make progress without experimental guidance?

Implications I

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- Non-perturbative treatment of gauge symmetry (BRST)

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Note: multiverse advocates claim indirect tests are possible, just test string theory vacua with eternal inflation. True, but string theory is untestable due to multiverse. Circularity.

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The Standard Model and representation theory

Some ideas from representation theory

- Dirac cohomology.
- Geometric representation theory and categorification.

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The mysterious part: how does classical behavior emerge?

Nothing to say about this

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A unitary representation of a Lie group G gives exactly these mathematical structures:

- A complex vector space $V = \mathcal{H}$, the representation space.
- For each element of the Lie algebra of G (the tangent space at the identity of the group), one gets a linear operator on H (for mathematicians, skew-adjoint. Multiply by i to get physicist's self-adjoint operator).

Where do these axioms come from? II

Taking as Lie algebra the functions on phase space (the Poisson bracket makes these a Lie algebra), associating operators to functions by

$$f \to -iO_f$$

is a representation exactly when you satisfy Dirac's relation (setting $\hbar = 1$)

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These are not all "symmetries"

One get a representation like this, even though all operators don't commute with the Hamiltonian. For example, just looking at functions $f = x, g = p, 1$, get "Heisenberg Lie algebra" and operators satisfying

$$[X, P] = i\mathbf{1}$$

But, never have $[X, H] = 0$ for Hamiltonian operator.

Group representations are not just symmetries

A group and its representation theory govern the basic structure of quantum mechanics, not just symmetries of a Hamiltonian

Much, much more detail in current book project

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Evidence for radical Platonism...

Structure of the Standard Model

Path integral expression of the problem. Want to compute, for certain functionals F

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What follows is rank speculation

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Could the Dirac equation and spinors of the SM somehow play this sort of role in a new representation theory story?

Geometric representation theory and categorification

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Does the QFT operation of integrating over $\mathcal{A}/\mathcal{G}$ have an interpretation in terms of the representation theory of $\mathcal{G}$? Very little is understood mathematically about how to think about representations of this kind of infinite dimensional group.

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Thanks for your attention!