Simons dialogue:
Higher structures and fundamental problems in physics

Anton Kapustin Christoph Schweigert

August 28, 2023

Unsolved problems in physics I

We have to get an overview what fundamental problems in physics are.
Here is a link to a wikipedia page.

Some problems I am not suggesting for discussion (but I am open to discuss)

- Is there a theory of everything?
- Is it problematic to have dimensionless parameters?
- Anthropic principle, multiverses
- Extra dimensions, homogeneity of the universe, fate and origin of the universe
- Turbulence, solutions of the Navier-Stokes equations
- High temperature superconductivity, Bose-Einstein condensation

Unsolved problems in physics II

Some problems I suggest for the discussion:

- Convergence of perturbation series, even for the standard model. This is necessary to make real predictions in a mathematically precise sense.
- Dark matter: it seems that our understanding of the field content necessary to describe fundamental physics is incomplete. It is not clear that it is enough just to add few more fields and coupling to a Langrangian.
  Is this where the new breakthrough is most likely?
- Analysis of gravitational waves. Theoretically, gravitational waves are unsurprising. Do they open up a new observational window on fundamental physics? (Cf. constancy of speed of light.)
- Quantum gravity. It is easy to see that there is a problem, but what does give us hints from the observational side?
- Quantum computing, in particular to find a substrate for quantum computing

Possible roles of higher structures

Higher structures

- structure data
- exhibit their symmetries.

Some comments based on a personal bias:

- Structures like Morita theory of fusion categories can help to find *new coordinates* in which computations become feasible. This at least helps certain computations, e.g. in quantum computing.
- New relations for correlates and amplitudes, e.g. via non-invertible symmetries. Do they lead to constraints on amplitudes that makes it easier to control them?
- Higher symmetries as a bridge between homotopy theory and QFT. Do higher symmetries in QFT mean that we understand even less about QFT than we thought?
- Quantum Gravity: non-local observables, holographic models.
- Should languages for quantum computing take higher structures into account? (Graphical calculus for GV categories is higher dimensional.) This reaches out to higher structures in computing and logic, arguable a promising field.

General questions

- What are the problems in physics where more mathematical rigor and new mathematical tools would be most desirable? Does one need mathematical rigor to make progress in physics?
- Are there areas of physics where theory is way behind experiment? (Possible answer: nonequilibrium statistical mechanics)