Two questions about gravity

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Two Questions

In this talk I ask two questions about the theory of gravity. In my opinion these questions

- Feel interesting and important and appear to touch on the fundamental issues.
- Nonetheless may prove possible to answer in the not too distant future.

Challenge 1: Enumerate all minimal classical consistent theories of gravity ‘in flat space’.

Clarrifications

- Classical gravity= Diff inv system of metric + optionally other fields.
- In flat space= Has a stable D dimensional Minkowski ‘vacuum’ soln. Excitations about this solution include D dim gravitons.
- Minimal: Admits no further consistent trunctations.
- Consistent= Obeys a set of physically motivated requirements (e.g. causality, positive energy . . .). Formulating the reasonable list of conditions is part of the challenge.

Classical Gravity: Warm up

Special case: The fields of the dynamical system consist of the *D* dimensional metric plus a finite number of additional *D* dimensional matter fields. Equations of motion have a finite number of derivatives. Conjecture: Only solution to warm up problem is given by the vacuum Einstein equations in *D* dimensional space.

Comments

- All familiar two derivative gravity-matter theories admit consistent trucation to vacuum Einstein equations for Einstein frame metric.
- Higher derivative theories are not necessarily counter examples as they may prove to be inconsistent. E.g. Einstein Gauss Bonnet violates causality.

Warm up challenge: Either prove conjecture or provide a counter example. Suggestion: a study of the second law for black holes might prove useful.

Gravity an infnite number of other fields.

Let us now allow gravity to interact with an infinite number of other fields. There are atleast two new solutions: (the universal sector of) the type II string and the Heterotic String.

Conjecture: There are no other consistent solutions.

Comments

- Type II theory on $R^4 \times Y$ admits a consistent truncation (to modes whose vertex operators are constructed only out of the R^4 CFT). This minimal 'universal sector' is independent of Y.
- Each solution of our challenge generates a tree level S matrix for gravitions. Our conjecture implies that there are exactly 3 such consistent S matrices (with poles but no cuts). These are the Einstein, Type II (Virasoro Shapiro) and Heterotic S matrices. Striking that we have found no other examples in almost 50 years of work on string theory. Perhaps this is evidence for our conjecture?

Challenge: Either prove conjecture or find a counterexample.

Cosmological Constant in Quantum Gravity

- Consider a model of quantum gravity in $D \geq 4$ dimensions that is non supersymmetric at low energies. Let the curvature mass scale of the vacuum geometry be given by M_{curv}. Let the cut off scale for gravitational contributions to the vacuum energy be given by M_{cut}. (M_{cut} could, for instance, be the SUSY restoration scale or a string scale). Let the Planck scale be given by M_{Pl}. Let

$$\left(\frac{M_{curv}}{M_{cut}}\right)^2 \ll \left(\frac{M_{cut}}{M_{Pl}}\right)^{D-2}$$

  where the inequality holds parametrically.
- The challenge is to show that no such model exists or find an example of such a model that is explicit enough to allow you to do actual calculations (e.g. 1 loop graviton 'scattering amplitudes')

Cosmological Constant: Comments

- Comments
- The contribution of g loop gravitational graphs to M_{curv}^2 is

$$\delta M_{curv}^2 \sim M_{cut}^2 \left[\left(\frac{M_{cut}}{M_{Pl}} \right)^{(D-2)} \right]^g .$$

A model in which

$$\left(\frac{M_{curv}}{M_{cut}} \right)^2 \ll \left(\frac{M_{cut}}{M_{Pl}} \right)^{D-2}$$

is thus one in which the physical value of M_{curv}^2 is smaller than the g loop contribution upto parametrically large g.

- Real world: $\frac{M_{curv}}{M_{cut}} \leq 10^{-45}$ while $\frac{M_{cut}}{M_{Pl}} \geq 10^{-15}$. This our challenge is to find any model of quantum gravity which shares this gross feature of the real world.
- Emphasize: A model that does not allow practical calculations does not solve our challenge

Possible Strategy

- Use the AdS/CFT correspondence.
- For the purposes of this slide I'm going to assume that the warm up conjecture above is correct. Now consider, e.g., a sequence of conformal large N matter Chern Simons theories with level k fermions in some representation of the gauge group. labelled by the level k. Large k implies weak coupling. Theory simple and boring. Make theory more interesting by reducing k down to values of order unity.
- Let us suppose it is possible to keep k small while maintaining conformal invariance. If we can somehow analyze the theory (e.g. bootstrap??) and demonstrate that all operators other than the stress tensor and multitraces become parametrically heavy in this limit, we would have found a holographic solution to our challenge.
- Can one find such a sequence of field theories or show that no such exists?