Loop Quantum Gravity and planck Scale Phenomenology

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1 Introduction

Of the different approaches to quantum gravity, the best developed, from the point of view of addressing the key theoretical questions a quantum theory of gravity must answer, is loop quantum gravity[1]. While string theory appears to better address the issue of unification, at least so far, it fails to provide a background independent approach to the quantum mechanics of spacetime geometry-a necessary condition for any quantum theory of gravity. Moreover, many key conjectures remain unproven, including perturbative finiteness and consistency, which have not been demonstrated for any string theory past second order in perturbation theory[2]. By contrast, loop quantum gravity appears to provide a consistent and finite background independent approach to quantum gravity. There is recent progress on several issues, including accounting for the black hole entropy [8], and giving a precise quantum mechanical description of the earliest phases of the evolution of the universe [9, 10]. Furthermore, it gives unique predictions of novel quantum gravitational phenomena, such as the discreteness of area, volume and other observables.

However, in this new era of quantum gravity phenomenology, a quantum theory of gravity must pass a stricter test to be taken as a serious candidate: it must make unambiguous predictions for the upcoming experiments which probe the Planck scale.

One way such predictions may arise is by modifications of the energy-momentum relations of low energy physics, of the form,

$$E^2 = p^2 + m^2 + a l_P E^3 + b l_P^2 E^4 + \dots \tag{1}$$

Related to this may be corrections to other of the basic kinematical formula of special relativity including energy-momentum conservation laws and the

[1] For some reviews, see [1, 3, 4, 6, 7]
[2] For a summary of the status of the main conjectures of string theory, see [6].

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actions of Lorentz transformations on energy-momentum eigenstates. As described in other papers in this volume, such corrections are in fact amenable to experimental test [11, 12, 13, 14] in present and near future experiments.

In this contribution I would like to do three things. First I will describe the present state of the results relevant for predictions of quantum gravity phenomenology from loop quantum gravity. Second I will give an introduction to some aspects of loop quantum gravity, in particular those having to do with the theory in the presence of a non-zero cosmological constant, Λ[3] Third, I will describe one approach to deriving Planck scale corrections to energy momentum relations from matter fields, of the form of (1). This approach is based on studying the theory for nonzero Λ, and then deriving predictions for zero or very small Λ, corresponding to our universe by taking the limit $\Lambda \to 0$. For reasons I will explain shortly, it may be very helpful to approach the problem of making predictions for the phenomenology with $\Lambda = 0$ through a limit of this kind.

2 What Should Theory Predict for Phenomenology

There is a key question that any quantum theory of gravity must answer if it is to provide predictions for low energy phenomenology: *What is the fate of Poincaré and Lorentz invariance when Planck scale corrections to the semiclassical limit are taken into account?*

This question arises because Poincaré and *global* Lorentz invariance cannot be symmetries of any quantum theory of gravity. This is because they are not symmetries of general relativity, and any correct quantum theory of gravity must have general relativity as the low energy limit. Poincaré and global Lorentz invariance are only symmetries of one particular solution to general relativity: Minkowski spacetime. It happens that Minkowski spacetime is, under certain choices of asymptotic conditions and with $\Lambda = 0$ the ground state of the classical theory. As such it has the maximal number of symmetries of any spacetime.

But general relativity is a dynamical theory of spacetime, which is background independent, in the sense that no single spacetime-not even Minkowski spacetime-appears in the formulation of the action, equations of motion and Hamiltonian. A particular solution may have symmetries, but those are not symmetries of the dynamics of the theory. From the point of view of the full theory, the symmetries of any classical solution-even the ground state-play no fundamental role.

So in classical general relativity, Poincaré and global Lorentz invariance are only accidental, emergent symmetries that characterize the low energy limit. Such must be true for any quantum theory of gravity that has general relativity as a classical limit.

[3] These parts of the paper are cannibalized from a previous review [5].