Subject: LS10228

Manuscript code: LS10228

RECVD: Tue Nov  7 18:20:46 2006
Resubmission to: Physical Review Letters
Resubmission type: resubmit

Replaced files:
lqgrv-sh.tex 11-07-2006

Details of changes:
In light of the questions raised by the referee, we have modified our paper to make it more clear. We hope the modified version can be published in PRL.

The following are our response to the referee’s comments:

Referee:
This paper claims to have constructed a bosonic lattice theory which has as its low energy excitations only spin 2 modes. Furthermore, the equation of motion of these modes is shown to reproduce linearized Einstein gravity and as such the authors claim to have constructed a lattice model of quantum gravity.

As far as I can see it their philosophy is to start from a model built from two index valued lattice fields which generically would possess low energy excitations corresponding to spin 0, 1 and 2 fields. They then choose carefully the dynamics in such a way that the spin 0 and 1 excitations are lifted to high mass leaving only helicity 2 fields as massless. Furthermore, they then find that the latter modes satisfy the linearized equations of GR.

Response:
The above is an accurate summery of the paper.

Referee:
However, key points of their argument are missing; they do not give any real argument as to how strong fluctuations of the spin 0 and spin 1 modes lead to the appearance of a mass gap or indeed how a gauge invariance subsequently appears. A reference is made to an example of an emergent U(1) gauge theory but even in this case no real calculations are made to support this claim. If this paper is to be taken seriously an effort should be made to support these central claims.

Response:
The key point of our argument is the following: (a) We show that the helicity +2/-2 modes are semiclassical in the $n_G \gg 1$ limit. (b) We also show that helicity 0, +1/-1 modes has strong quantum fluctuations. (c) As a general rule of thumb, strong fluctuating compact modes on lattice are gapped, since strong fluctuation make space-time correlation short ranged. The compactness is needed since it defines what "strong" means. Strong fluctuations are fluctuations that are much larger than compactification radii. In a long paper that we are writing, we will show rigorously that the helicity 0, +1/-1 modes are all gapped in the $U_{1,2} \gg J,g$ limit.

A rigorous discussion of emergence of $U(1)$ gauge symmetry is discuss by Hastings and Wen. The long paper that we are writing will give a more detailed discussion on the emergence of linearized diffeomorphism (but at a less rigorous level). We like to point out that the discussion of emergence of gauge symmetry is quit formal since gauge symmetry itself is not physical in the sense that it cannot be measured. The gapping of helicity 0, +1/-1 modes and the masslessness of helicity +2/-2 modes are physical. This why we concentrate on discussing the dynamics of modes.

Referee:
Even if this basic result can be demonstrated the claim that this is a quantum theory of gravity is much too strong. As far as I see it they have at most shown that the classical low energy limit of this theory is linearized GR. But their model does not get the nonlinear terms in the Einstein action right

Response:
This is a very important point. As have been remarked in the paper (see the last paragraph of the paper), our model may not produce the nonlinear terms in the Einstein action. However those nonlinear terms are irrelevant at low energies. So we can fine tune the lattice model to reproduce those irrelevant terms. From this point of view, the result of this paper points to a new research direction: find the symmetry or conditions on the lattice model so that the Einstein nonlinear terms emerge naturally without fine tuning.

Referee:
[Their model] will presumably break down at energies on the scale of the mass gap. For a genuine quantum of gravity the behavior of the theory at high energies must also be under control which is not shown here. The fact that they have a lattice theory is not enough - eventually one would like to understand how to model the high energy behavior by some sort of continuum theory at which point divergences will generically arise.

Response:
We do not agree with the statement that "For a genuine quantum of gravity the behavior of the theory at high energies must also be under control which is not shown here." Our model has finite cut-off and its high energy behaviors are totally under control by construction. Our model will not break down at energies on the scale of the mass gap (which is the Planck scale). Certainly, at energies on the scale of Planck mass, our model will not resemble Einstein gravity. We think this is good, since Einstein gravity is not well defined at quantum level at the Planck scale. One of the point we try to stress in this paper is that it is a wrong direction to try to model the high energy behavior of quantum gravity by some sort of continuum theory. We try to show that if we start with a model with a finite cut-off, then we can put gravity and quantum theory together where gravity is emergent and appears only at low energies.
We feel that our results and approach may open up new research directions in the field of quantum gravity. So we hope the paper may be published in PRL.

Referee:
For these reasons I cannot recommend publication of this paper in PRL in the present form. I believe a substantial rewriting of the paper is minimally required to address these concerns.

Response:
The referee has raised several very important points. We have modified the paper to address those points. 
(a) We changed the title and modified many other parts of the paper to stress that we only reproduced linearized Einstein gravity.
(b) We add the following near the end of the paragraph below eq (9):
"The key in our argument is the gapping of helicity $0$ and $\pm 1$ modes. Clearly, in the model \eq{HUJg}, those modes are strongly fluctuating and strongly interacting modes. Those modes also have a very narrow band width and arise from compact degree freedom on lattice. The compact and strongly interacting modes with flat bands are in general gapped. The gapless helicity $\pm 2$ modes are very classical in the large $n_G$ limit. They should survive the gapping of the helicity $0$ and $\pm 1$ modes."
(c) We also shorten other parts of paper to satisfy the length limit of PRL.