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Research Statement
November 29, 2018

Brief Summary

My research has spanned several major themes of contemporary theoretical physics. These include:

Theme	**Sub-topics**
Classical & Quantum Gravity	Loop quantum gravity (LQG), AdS/CFT, holographic superconductors, thermodynamic geometry of black holes
Quantum many body phenomena	Quantum hall effect, superconductivity, phases of the Hubbard model, DMRG, matrix & tensor product states
Machine Learning	Deep learning & neural networks via PyTorch & Theano

I will describe my research in the following order: current projects, future plans and finally past work.

Current Projects

At present I am working on the following different projects, which are at various stages of completion:

1. **Origin of Arrow of Time from Symmetry Breaking in Spin-Networks**: this work relies on the recognition that the tensor network state formalism used to describe many-body quantum states is essentially identical to the spin-networks which are the building blocks of spacetime in LQG. Using techniques developed for tensor networks, which allow one to make time-reversal symmetry into a local gauge symmetry, we can hope to ask and answer the question of whether the same can be done for spin-networks. If so, then the possibility arises that symmetry breaking of this *local* time-reversal gauge field can give rise to a macroscopic cosmological arrow of time. A preliminary version of this work was presented at the workshop EVONET18 on tensor network held at Max Planck Institute in Dresden in June 2018.

2. **Connecting LQG and String Theory via Quantum Geometry**: In arXiv:1711.05693 I have argued that the Nambu-Goto action of the bosonic string theory should be viewed as arising from the expectation value of the LQG area operator acting on an ensemble of spin-networks. This work represents one of the rst pieces of evidence for a direct relationship between String Theory and Loop Quantum Gravity. This work was presented in a talk at the 6th Tux workshop on Quantum Gravity in Feb 2018.

3. **Phases and Thermodynamic Geometry of Anti-deSitter Black Holes**: Alongwith my collaborators I am investigating the thermodynamic behavior of black holes in anti-deSitter spacetime. One aspect is the relationship between the horizon physics as described by the Damour-Navier-Stokes equation and phase transitions in the bulk as described by the black hole Van der Waal type equation of state.

4. **Identifying Phases of Spin-Networks via Deep Learning**: Deep learning has become a standard tool in the study of complex physical systems, in particular the analysis of phases of many-body quantum systems. With my student I am in the process of understanding how to apply deep learning techniques - in particular, the Restricted Boltzmann Machine (RBM) formulation - to understand phases of spin-networks in LQG.

5. **2$^{\text{nd}}$ Edition of "*LQG for the Bewildered*"**: With my collaborator Sundance Bilson-Thompson, I have authored an introductory text on Loop Quantum Gravity. The success of the first edition has led the editor to request us to prepare a second edition. We are currently in the process of editing, revising and expanding the contents of the first edition for this purpose.

Future Plans

The future is always difficult to predict. I cannot say with certainty as to what I will be working on five or ten years from now. However, there *are* certain goals I have in mind which I hope to accomplish over the next several years. These include:

1. ***To concretely establish the relationship between LQG and String Theory***: My paper arXiv:1711.05693 was only an initial attempt at connecting these two fields. Much more work is required to understand how the discrete structure of geometry in LQG will affect the corresponding stringy model. In a discrete background, the conformal symmetry of the string worldsheet will necessary be broken. This might provide an avenue to construct loop-string solutions which correspond to four-dimensional spacetime without the need for compactifications, supersymmetry or anthropic reasoning.

2. ***Experimental signatures of quantum gravity***: The upgraded LHC presents a novel opportunity for searching for signatures of quantum gravity. One possibility that I have suggested in arXiv:1208.3335 is that at or near the Planck scale the local symmetry group of spacetime will become $SL(2, Z)$ rather than $SL(2, C)$. This change should manifest itself in the form of gaps or steps in the spectra of particles produced in hadron collisions. A natural question is why should the Planck scale 10^{16} TeV be accessible at the LHC. As argued by me [1], and also in

[1] See my blog post "*The Planck Scale May Be Closer Than It Appears*" at quantumofgravity.com

prior work by Xavier Calmet and collaborators, a proper analysis of the running of Newton's constant strongly suggests that the *real* Planck scale will be much lower than its naive value of 10^{16} TeV.

3. ***LQG, Holography and Quantum Computation***: In one of my earlier papers (arXiv:1307.0096) I suggested a correspondence between particles of the standard model and unitary gates required for universal quantum computation. Since then several works by Preskill, Pastawski and collaborators relating quantum error correction to the question of determining the bulk/boundary correspondence in AdS/CFT have made the initial motivation behind my work appear much less speculative. I want to continue this earlier work and over time provide a more concrete mathematical foundation for this proposed correspondence between the standard model and quantum computation.

Past Work

My primary research interest lies in the field broadly referred to as *quantum gravity*. I did my graduate training at Pennsylvania State University, under Prof. Stephon Alexander and Prof. Martin Bojowald. My graduate work involved applying ideas from many-body phenomena - in particular, the formation of superconducting fermionic condensates (arXiv:hep-th/0609066, arXiv:hep-th/0702064) - in order to solve the cosmological constant problem.

While at Penn State I was also able to learn about *Loop Quantum Gravity*, which is considered the main competetitor to String Theory as a candidate theory of quantum gravity. With my collaborator Sundance Bilson-Thompson, I have written an introductory text on LQG, titled *LQG for the Bewildered*, published in 2017 by Springer Nature.

Other than LQG-inspired approaches to quantum gravity, I am also interested in and have made forays into several other areas of theoretical physics: quantum computation (arXiv:1307.0096), phase transitions in charged anti-deSitter black holes (arXiv:1312.7119, arXiv:1805.11053), tensor networks and matrix product states applied to loop quantum gravity (forthcoming work).

While it may appear that I am interested in many seemingly disjointed areas of theoretical physics, there is a common thread which runs through all my work - *the desire to understand how best to formulate a complete, consistent theory of quantum gravity.* For this purpose I have employed various tools from quantum information, many body physics and canonical quantum gravity. The shared motivation behind all of my work has been to understand how our smooth, classical spacetime arises from an underlying quantum substrate which might take the form of a tensor network or a Hubbard model on an abstract lattice. Of course, no theory of quantum gravity can be considered complete if it does not incorporate the particles of the standard model and their associated interactions. Therefore my work has also focused on trying to understand how elementary particles can be embedded within loop quantum gravity (arXiv:1002.1462), the relationship between elementary particles and quantum computation (arXiv:1307.0096) and the emergence of non-abelian gauge fields from defects in spin-networks (arXiv:1309.0652).