

These are a few of my favourite things

### Francesca Vidotto



with Hal HAGGARD, Sebastian STEMHAUS & Edward WILSON-EWING







![](_page_4_Picture_1.jpeg)

I have been told that your Hamiltonian constraint is a mess...

![](_page_5_Picture_1.jpeg)

There was progress, it has been made simple!

![](_page_5_Picture_3.jpeg)

# COVARIANT LOOP GRAVITY

![](_page_7_Picture_2.jpeg)

![](_page_8_Picture_0.jpeg)

![](_page_9_Picture_1.jpeg)

I have been told that you do not have a classical limit...

![](_page_10_Picture_1.jpeg)

There was progress, old confusions are clearing up!

![](_page_10_Picture_3.jpeg)

# COVARIANT LOOP GRAVITY

![](_page_11_Picture_2.jpeg)

# COVARIANT LOOP GRAVITY

# NUMERICS

MARKET AND ADDRESS OF THE OWNER OWNER OF THE OWNER OWNER

![](_page_12_Picture_3.jpeg)

![](_page_13_Picture_0.jpeg)

![](_page_14_Picture_1.jpeg)

I have been told that you cannot compute anything...

![](_page_15_Picture_1.jpeg)

Not any more, the numerical codes are getting better and better!

![](_page_15_Picture_3.jpeg)

AN EFFICIENT ALGORITHM FOR THE RIEMANNIAN 10*j* 

J. DANIEL CHRISTENSEN AND GREG EGAN

ABSTRACT. The 10j symbol is a spin network that appears in the partition ADDITATE THE THE AUTONOM TO A DEFINITION OF A APPEarD THE OF A APPEARD THE OF A APPEARD THE OF A APPEARD AND APPEA The mentary methods of calculating the 10j symbol require  $\mathcal{O}(j^9)$  or more oper-stiens and  $\mathcal{O}(i^2)$  or more space where i is the second second start of  $\mathcal{O}(i^2)$  or more space. The interval  $\mathcal{O}(j^2)$  or more space, where j is the average spin. We present an already have the transitions that the transition  $\mathcal{O}(j^2)$  or more space. and  $\mathcal{O}(J)$  or more space, where J is the average spin. We present an algorithm that computes the 10j symbol using  $\mathcal{O}(j^5)$  operations and  $\mathcal{O}(j^2)$  algorithm that computes the 10j symbol using  $\mathcal{O}(j^5)$  encoder  $\mathcal{O}(j^5)$  and  $\mathcal{O}(j^2)$ Space, and a variant that uses  $\mathcal{O}(j^6)$  operations and a constant amount of space. An implementation has been made available on the mat space. An implementation has been made available on the web.

The Barrett-Crane model of four-dimensional Riemannian quantum gravity [6] has been of significant interest recently [1, 2, 10, 12]. The model is discrete and well-defined, and the partition function for the Perez-Rovelli version has been rigor.

wour-wounted, and and particular remaining one is one is one record we would have been and and a second sec ously shown to converge [11] for a fixed whang may on space where the two main and physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the serves its stractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the way to understanding the less tractable but physical serves as a step along the serves as a step induces between and a buck and the way to understanding the root of according to the realistic Lorentzian version [7]. However, despite its simplicity, we are ically more realistic Lorentzian version [7].

withy more realising to convenient version [1]. However, we prove too comparently, we are currently lacking explicit numerical computations of the partition function and of expectation values of observables in the Riemannian model. These are necessary It has been shown [3] that the amplitudes in the Barrett-Crane model are alto test its large-scale behaviour and other physical properties. Ways non-negative, and therefore that the expectation values of observables can be approximated using the Metropolis algorithm. This greatly reduces the number of approximation using the interview opens argonium. This greatly reduces the time required to samples that must be taken, and thus the remaining obstacle is the time required to compute each sample. This paper presents a very efficient algorithm for doing these

compute each sample. This paper presents a very encodence argonium to wonts where omputations. The algorithm is used in [4] and [5] to understand the asymptotic of the partition function on a

winpusations. The argument is used in [2] and [2] to understand the dependence of the partition function on a behaviour of the 10j symbols and the dependence of the partition function on a To explain further, we need to describe the Barrett-Crane model in more detail. It has been formulated by Baez [2] as a discrete spin foam model, in which faces in the dual 2-skeleton of a fixed triangulation of spacetime are labeled by spins. The dual 2-skeleton consists of a dual vertex at the center of each 4-simplex of the The quar 4-Sherebook consists of a quar vertex at the center of each 4-Shipplex of the triangulation, five dual edges incident to each dual vertex (one for each tetrahedron is the base base of the triangulation) and the last filles incident to each dual vertex in the triangulation of the triangulation

in the boundary of the 4-simplex), and ten dual faces incident to each dual vertex (one to each dual vertex), and ten dual faces incident to each dual vertex). het the partition function for this model is the sum, over all labelings (one for each triangle in the boundary of the 4-simplex). more that contains the product of a 10*j* symbol  $A_{\text{stail}}$  in Section 2. is a Spin(4) spin

3

AN EFFICIENT ALGORITHM FOR THE RIEMANNIAN 10*j* 

J. DANIEL CHRISTENSEN AND GREG EGAN

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#### SCHILD'S LADDER GREG EGAN

![](_page_18_Picture_24.jpeg)

\*Cognitive wonder at its challenging best." -Locus

#### A NOVEL

![](_page_18_Picture_27.jpeg)

# COVARIANT LOOP GRAVITY

# NUMERICS

MARKET AND ADDRESS OF THE OWNER OWNER OF THE OWNER OWNER

![](_page_19_Picture_3.jpeg)

# QUANTUM INFORMATION

# COVARIANT LOOP GRAVITY

# NUMERICS

![](_page_20_Picture_4.jpeg)

![](_page_21_Picture_0.jpeg)

![](_page_22_Picture_1.jpeg)

Yet you do not have holography, tensor networks, spacetime from entanglement...

![](_page_23_Picture_1.jpeg)

These are part of a larger story that we understand actually better...

![](_page_23_Picture_3.jpeg)

CONSTRAINTS **SYMMETRIES** BOUNDARIES PARTITIONS

# **QUANTUM INFORMATION ENTANGLEMENT ENTROPY QUANTUM REFERENCE FRAMES**

**COVARIANT THERMODYNAMICS** S PERSPECTIVAL ARROW OF TIME **CLOCK DEFINITION** 

![](_page_24_Picture_3.jpeg)

![](_page_24_Picture_4.jpeg)

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# PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY

PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY

## **MY FAVOURITE THINGS**

- Spinfoam primordial vacuum state (high correlations?)
- Cosmological bounce (with matter, no inflation?)
- White holes and remnants (astrophysical effects? pre-bounce?)

![](_page_27_Picture_4.jpeg)

## **MY FAVOURITE THINGS**

- Spinfoam primordial vacuum state (high correlations?)
- Cosmological bounce (with matter, no inflation?)
- White holes and remnants (astrophysical effects? pre-bounce?)

Too good not to fit together?

![](_page_28_Picture_8.jpeg)

![](_page_28_Picture_9.jpeg)

![](_page_28_Picture_10.jpeg)

![](_page_28_Picture_11.jpeg)

# PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY

PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY PHENOMENOLOGY

![](_page_30_Picture_0.jpeg)

![](_page_31_Picture_0.jpeg)

We do not have direct access to the Plank scale.

![](_page_32_Picture_3.jpeg)

We do not have direct access to the Plank scale.

![](_page_33_Picture_3.jpeg)

We do not have direct access to the Plank scale.

![](_page_34_Picture_4.jpeg)

We do not have quantum-gravity measurements.

We do not have direct access to the Plank scale.

![](_page_35_Picture_4.jpeg)

X

We do not have quantum-gravity measurements.

- Supersymmetric particles
- Violation Lorentz Invariance
- Cosmological variation of couplings
- Quantum decoherence and state collapse
- TeV Black Holes
- Generalized uncertainty principle
- Violation of discrete symmetries

We do not have direct access to the Plank scale.

X

We do not have quantum-gravity measurements.

- QG imprint on initial cosmological perturbations

![](_page_37_Picture_0.jpeg)

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- Supersymmetric particles
- Violation Lorentz Invariance
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- Generalized uncertainty principle
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- Speed of the gravitons
- Gravitational Wave Echo
- Planck scale spacetime fuzziness
- ...
- Entangled Masses?

![](_page_37_Picture_16.jpeg)

- QG imprint on initial cosmological perturbations

![](_page_38_Picture_0.jpeg)

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- Cosmological variation of couplings
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- . . .
- Entangled Masses?

X

Supersymmetric particles
Violation Lorentz Invariance
QG imprint on initial cosmological perturbations

# PHENOMENOLOGY NOT BY BRUTE FORCE BUT SMART THINKING

![](_page_39_Picture_1.jpeg)

# NEW IDEAS FOR PHENOMENOLOGY ARE FROM ANYWHERE

# LARGE TELESCOPES

÷¢

# TEVASTRONOMY

# QUANTUM SIMULATION

![](_page_40_Picture_3.jpeg)

# LARGE TELESCOPES

# ATOM INTERFEROMETRY

# TEVASTRONOMY

# QUANTUM SIMULATION

![](_page_41_Picture_4.jpeg)

![](_page_42_Figure_0.jpeg)

![](_page_43_Picture_0.jpeg)