International Loop Quantum Gravity Seminar

quantum spacetime on a quantum simulator

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Tsinghua University
Mar 20

Outline

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- the basic tool used for quantum geometry: spin-network

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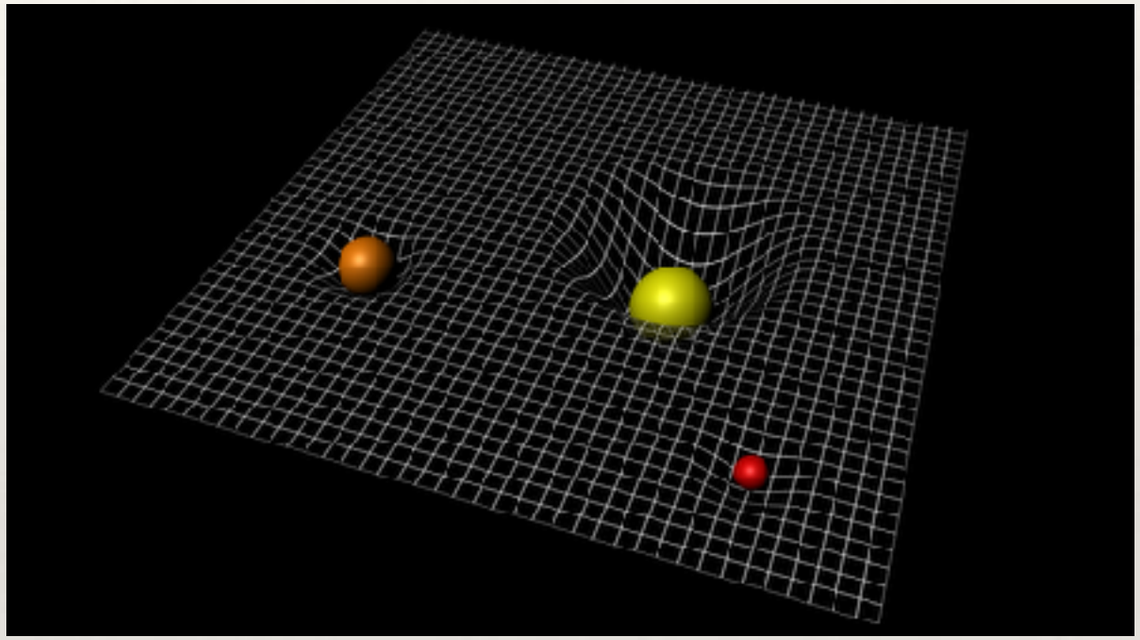

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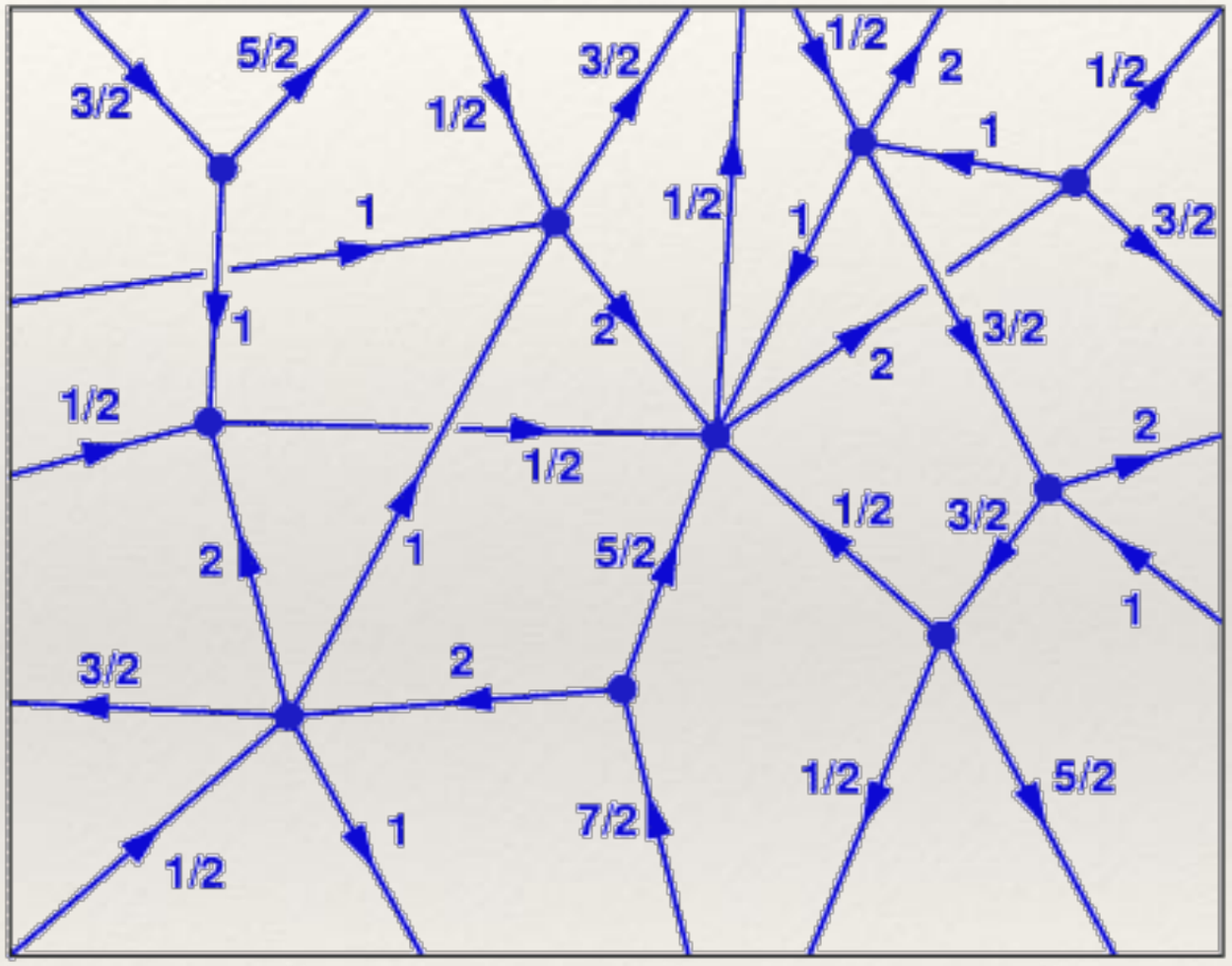
String theory --- begins with quantum field theory and tries to add gravity.

Loop quantum gravity --- begins with relativity and tries to add quantum features.

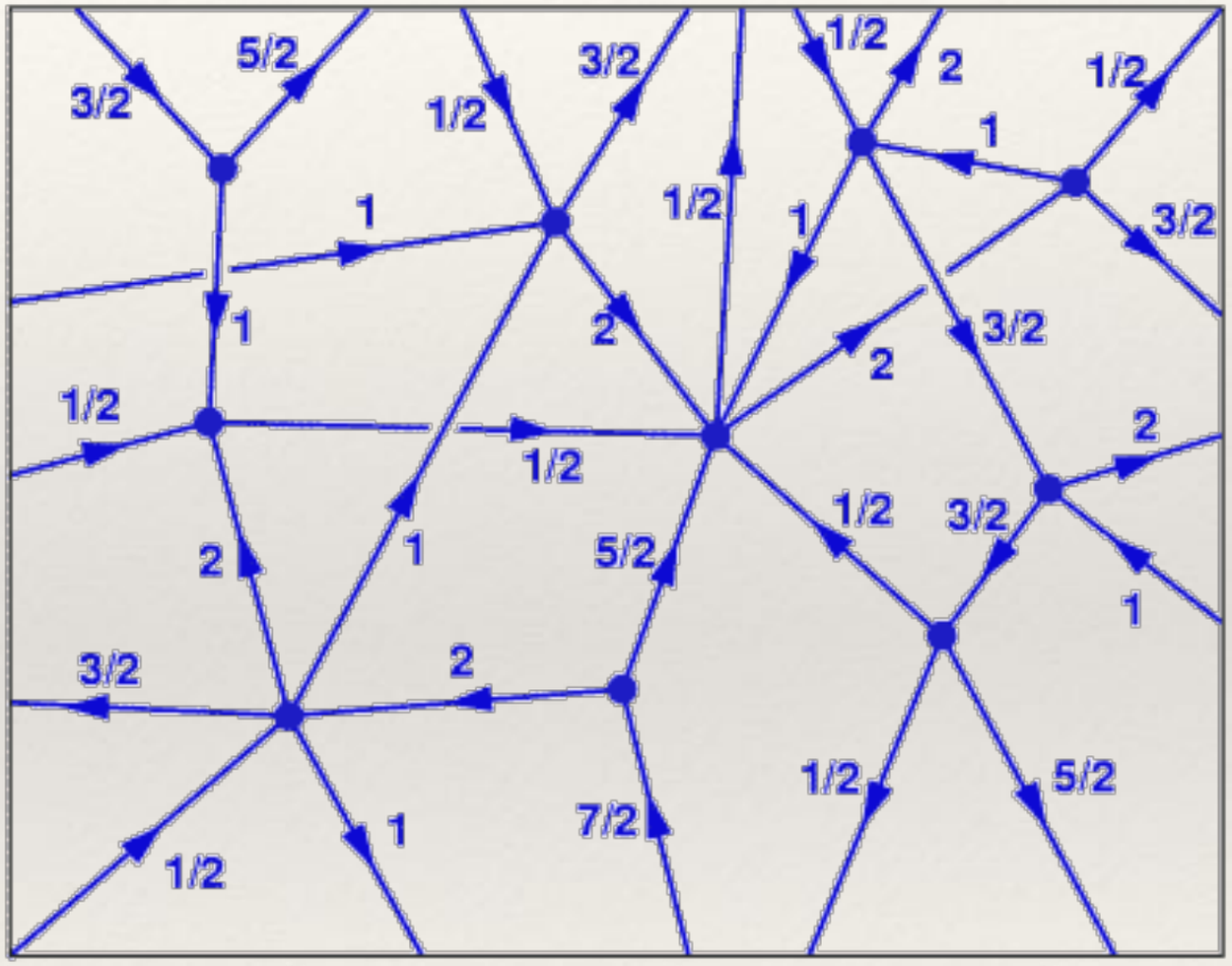
spin-network



Nodes + Lines+ Arrows +Labels = Spin network

spin-network

- a language to describe quantum geometry of space



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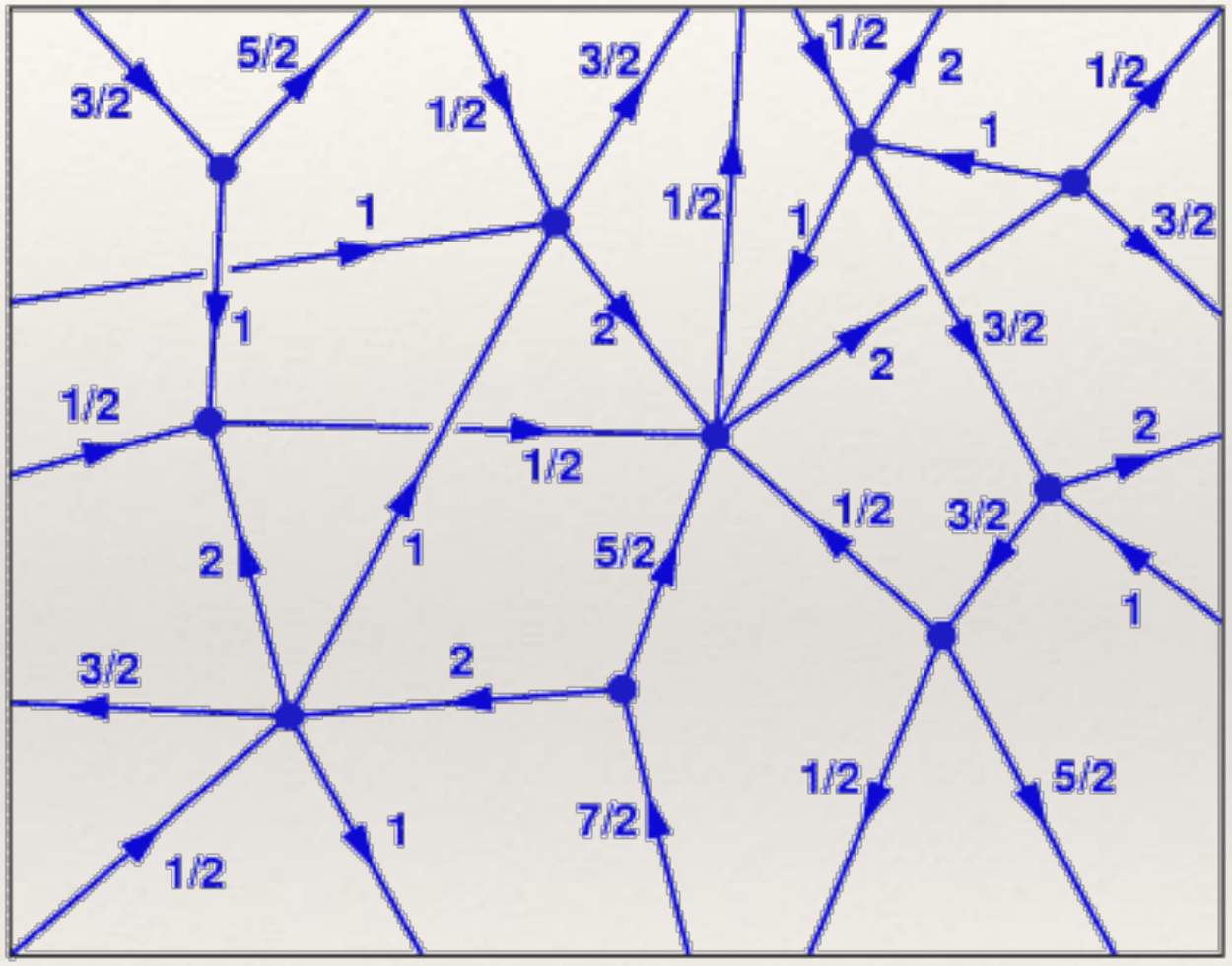
- a language to describe quantum geometry of space

- In Loop Quantum Gravity, at each point of time, geometry is concentrated on one dimensional structures, which is simply a network of one dimensional, oriented lines which are linked together at their end points to form a kind of net.



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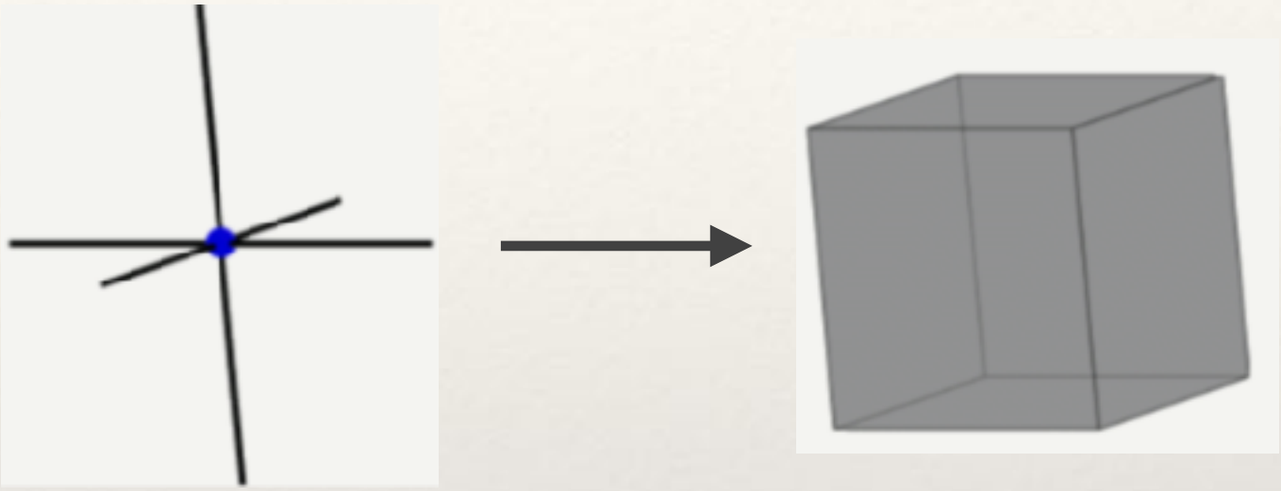
- vertex with its lines can be corresponding to a geometry shape.



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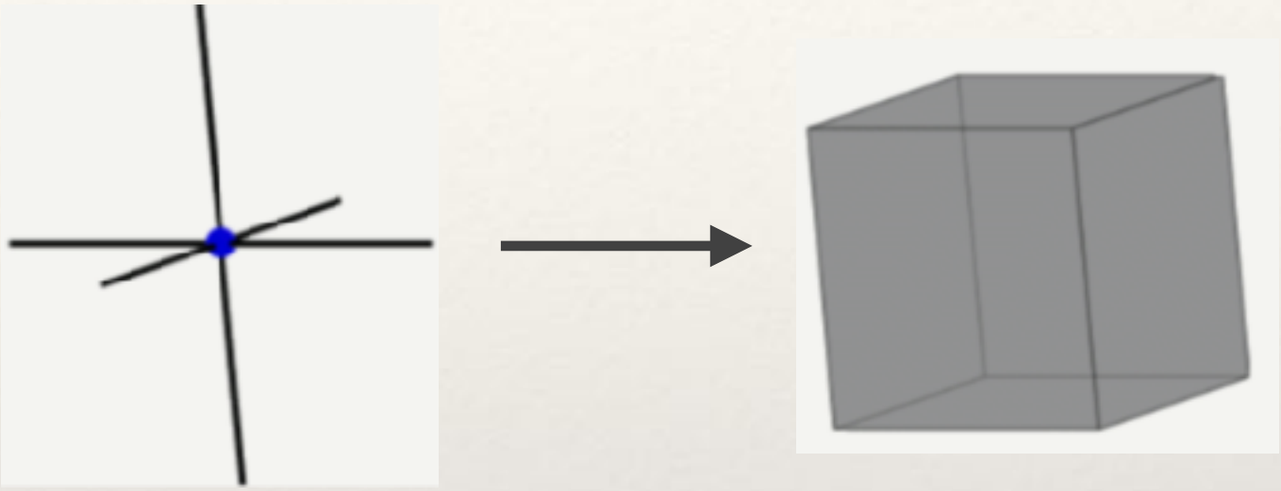
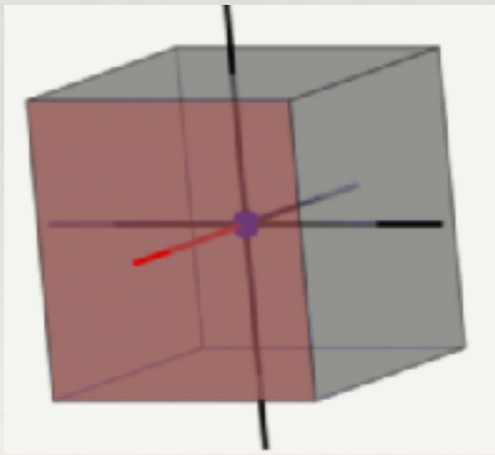


- As a simple example, take the following vertex and six lines, you can associate it with a solid cube object.



fabric the spacetime

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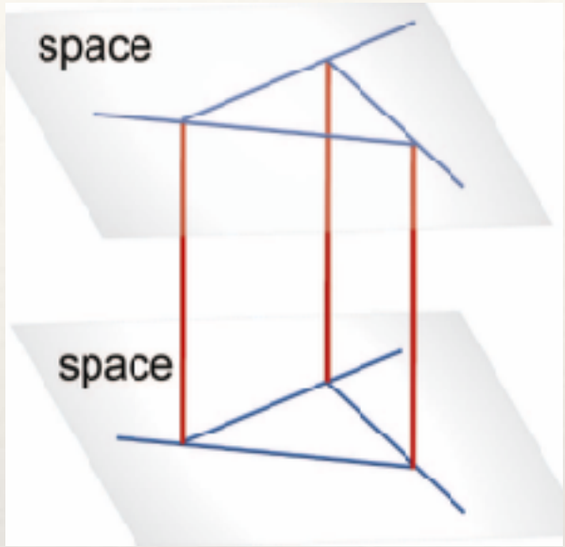

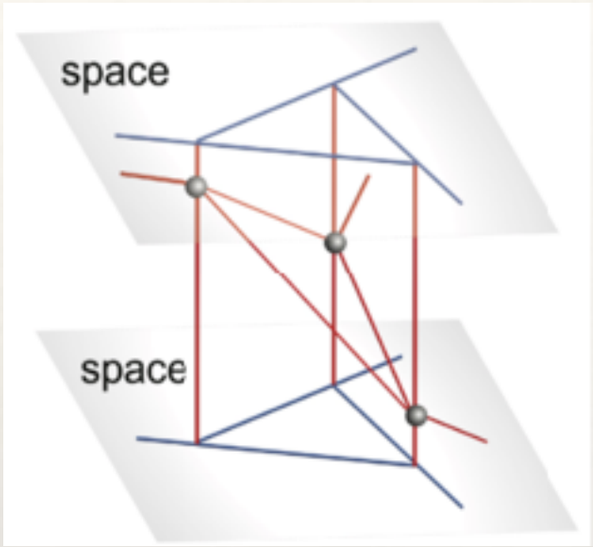

- static quantum spacetime.

- dynamical quantum spacetime

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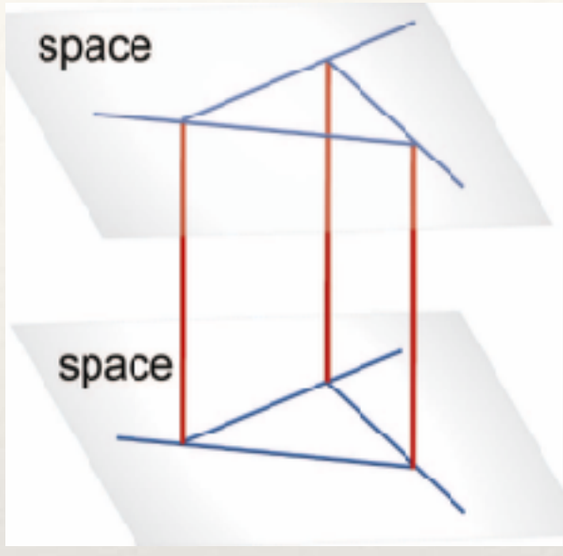

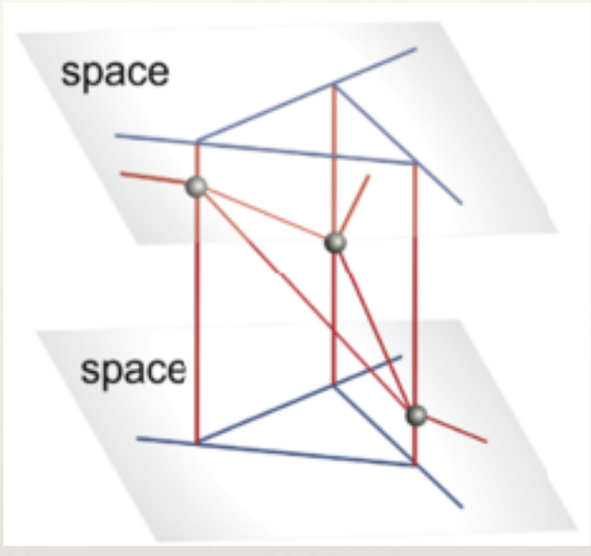

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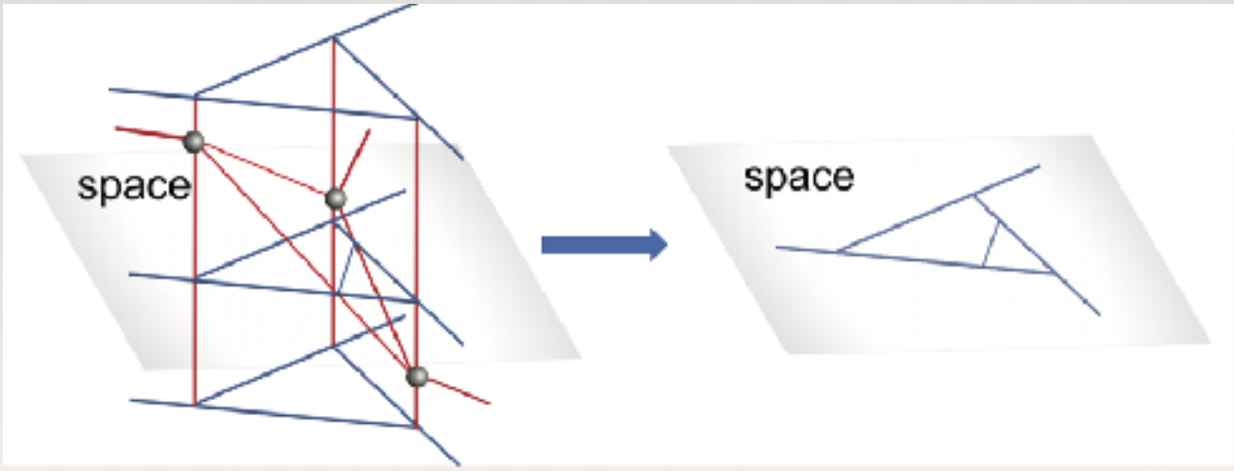

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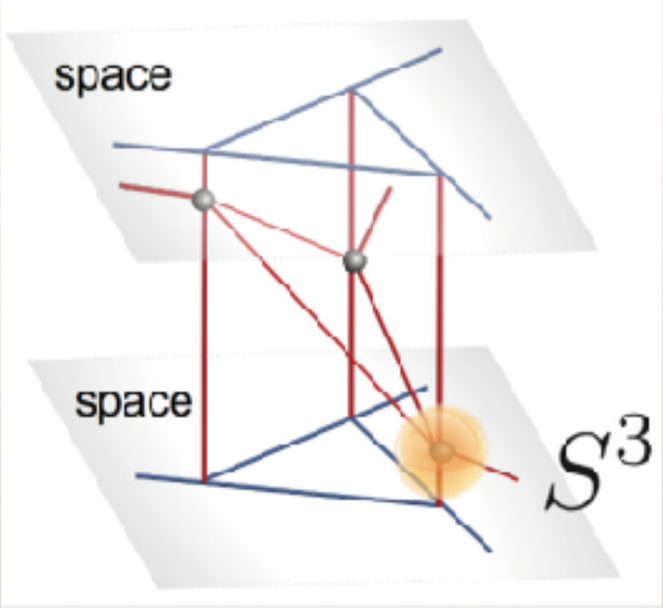
- focus on one vertex and make a closure



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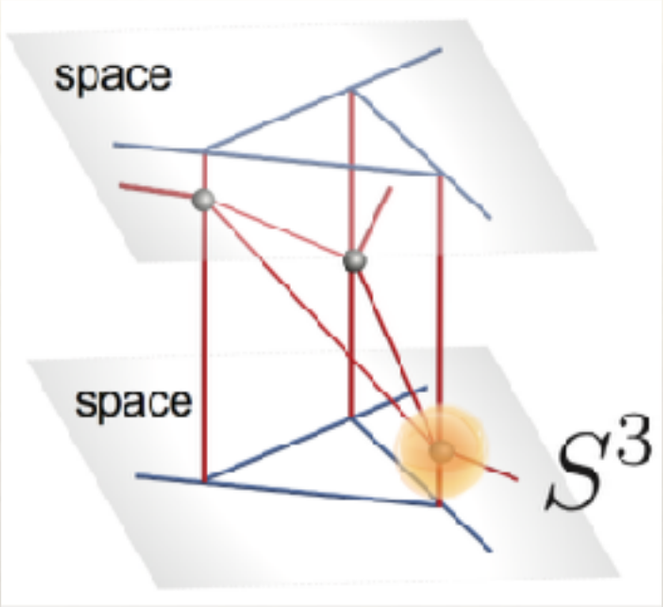
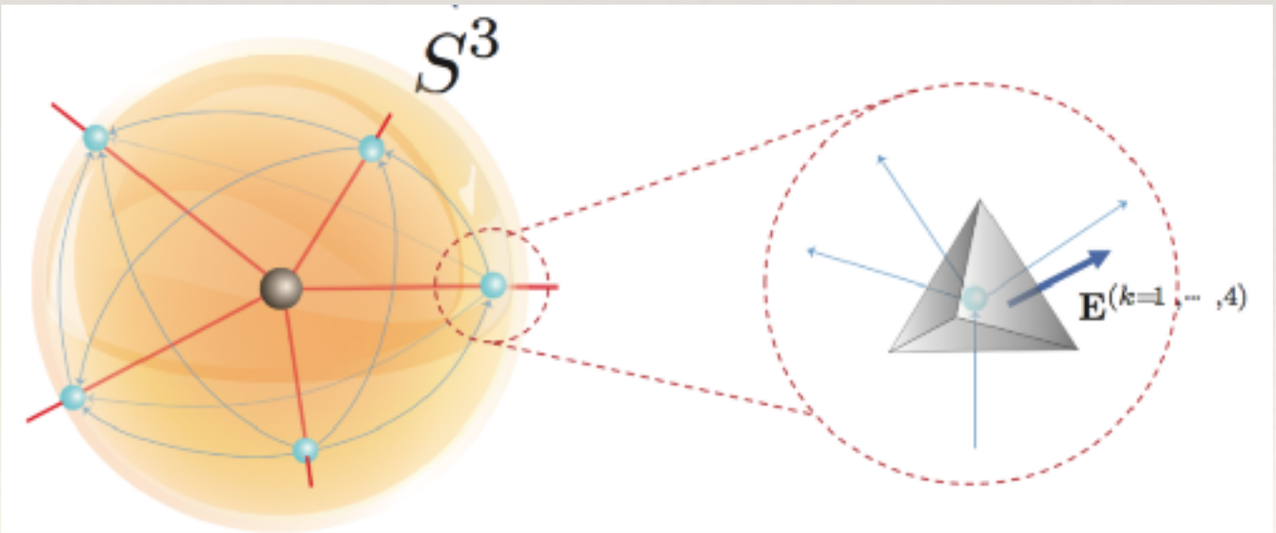


- focus on one blue vertex



Experiment Design

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- which states corresponds to the quantum tetrahedron?

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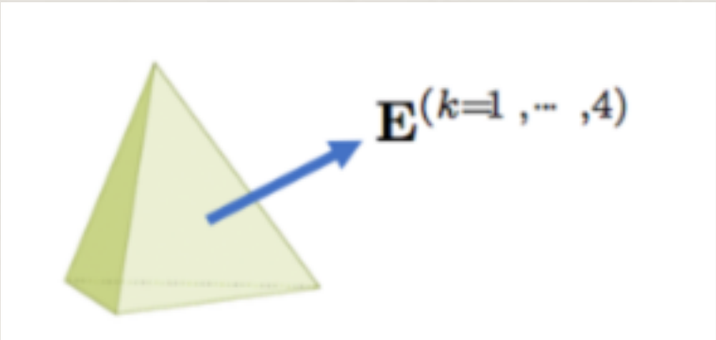
- a classical geometry of tetrahedron in a 3d Euclidean space gives 4 oriented areas E(k=1,⋯,4) = (E(k), E(k), E(k))



Experiment Design

- 1. from the theoretical calculation of general relativity, E(k) satisfies the Poisson bracket.

$$\left\{E_a^{(m)}, E_b^{(k)}\right\} = 8\pi G_N \sum_c \varepsilon_{abc} E_c^{(k)} \delta^{mk}$$

- Then, the quantization promotes E(k) to operators Eˆ(k) . we replace the poisson bracket with the commutator , [,] = ih{ , } gives precisely the commutation relation of Jˆ(k)'s , if

$$\hat{\mathbf{E}}^{(k)} = 8\pi \ell_P^2 \hat{\mathbf{J}}^{(k)}$$

A. Ashtekar, A. Corichi, and J. A. Zapata, Class. Quant. Grav. 15, 2955 (1998), gr-qc/9806041.

Experiment Design

- 2. we could get the SU(2) invariance and the geometrical interpretation.

$$\mathbf{E}^{(1)} + \mathbf{E}^{(2)} + \mathbf{E}^{(3)} + \mathbf{E}^{(4)} = 0$$

- So a state satisfy the condition:

$$\left(\hat{\mathbf{J}}^{(1)} + \hat{\mathbf{J}}^{(2)} + \hat{\mathbf{J}}^{(3)} + \hat{\mathbf{J}}^{(4)}\right) |i_n\rangle = 0.$$

- are just the invariant tensor state

quantum simulation

Experiment Set-up

If you can’t make it, fake it.

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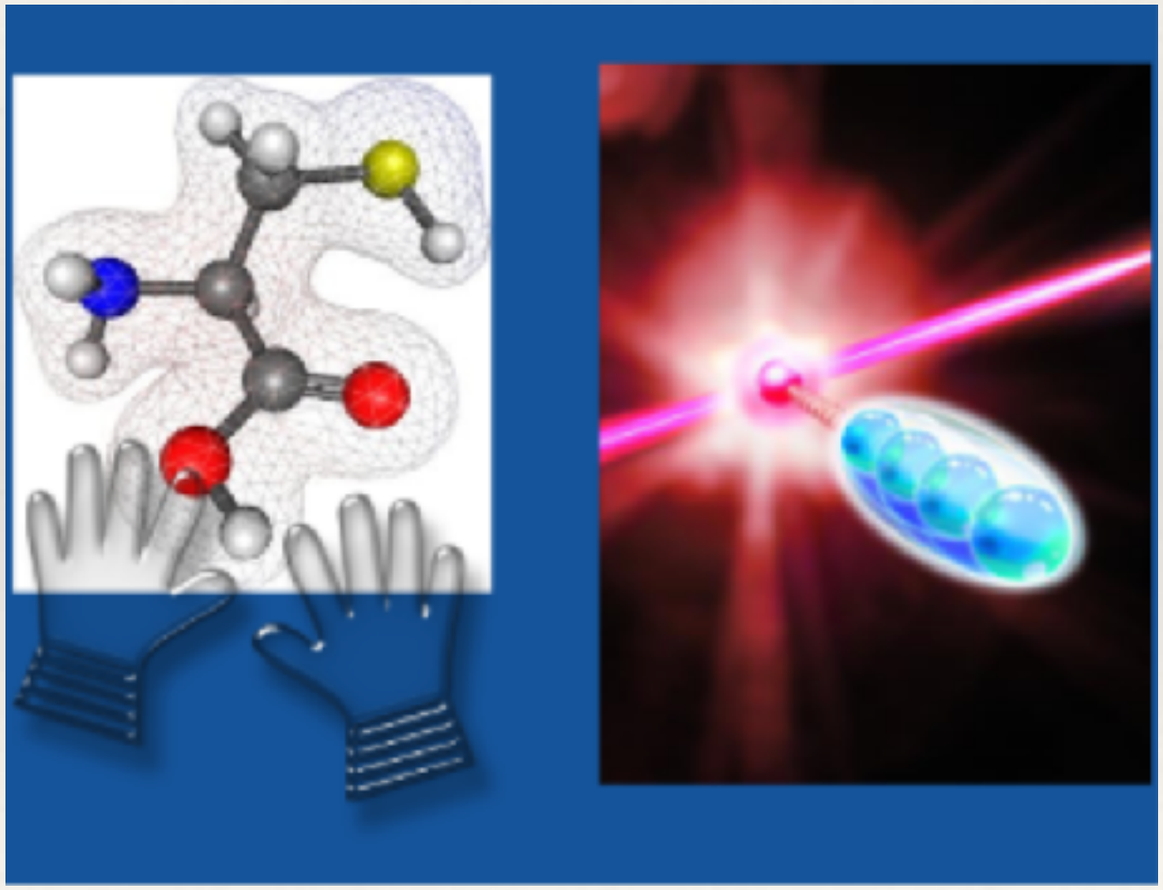

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- Purpose: to simulate an aimed Hamiltonian using the NMR system Hamiltonian.

$$H_{int} + H_{rf} \longrightarrow H_{aim}$$

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$$\text{Hint+Hrf} \longrightarrow \text{Haim}$$

- In NMR system, the internal Halmitonian

$$\mathcal{H}_{int} = \sum_{j=1}^{4} \pi \nu_j \sigma_z^j + \sum_{j<k,=1}^{4} \frac{\pi}{2} J_{jk} \sigma_z^j \sigma_z^k$$

- by adding the ingredient of radio-frequency pulse

$$\mathcal{H}_{rf} = -\frac{1}{2}\omega_1 \sum_{i=1}^{4} (\cos(\omega_{rf} t + \phi)\sigma_x^i + \sin(\omega_{rf} t + \phi)\sigma_y^i)$$

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- The evolution of the aimed Halmitonian during a certain time t can be almost simulated:

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- can be replaced by the average effect of the evolution of NMR system:

$$U^{NMR} = e^{-\int_0^t i(H_{\text{int}}+H_{rf})\,dt}$$

Experiment Set-up

- What we usually do? if provided a designed Unitary evolution

$$U = U_{free} U_{local} \ldots U_{free} U_{local}$$

$$\downarrow$$

$$U = e^{-\int_0^t iH_{\text{int}}\,dt} e^{-\int_0^t i(H_{\text{int}}+H_{rf})\,dt} \ldots e^{-\int_0^t iH_{\text{int}}\,dt} e^{-\int_0^t i(H_{\text{int}}+H_{rf})\,dt}$$

NMR quantum simulator

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pics from: web.physics.ucsb.edu/~msteffen/hp02_shor.ppt

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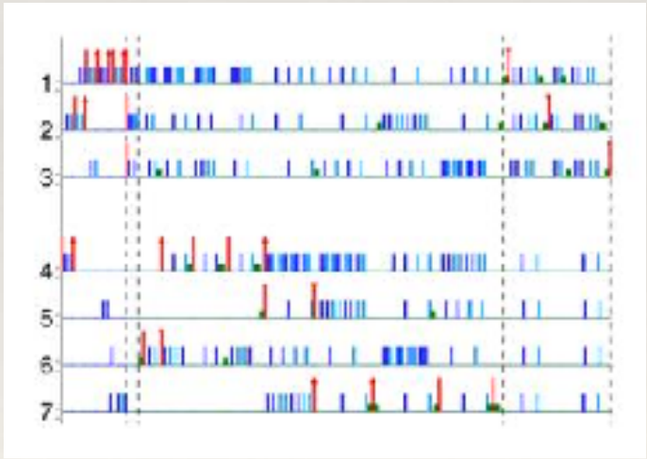

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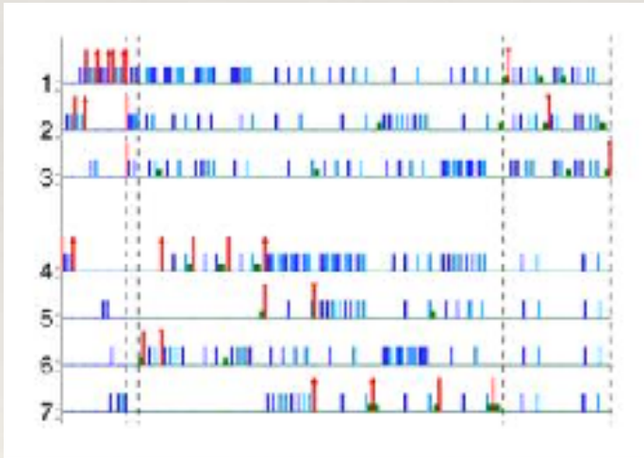

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Experiment Result

NMR quantum simulator

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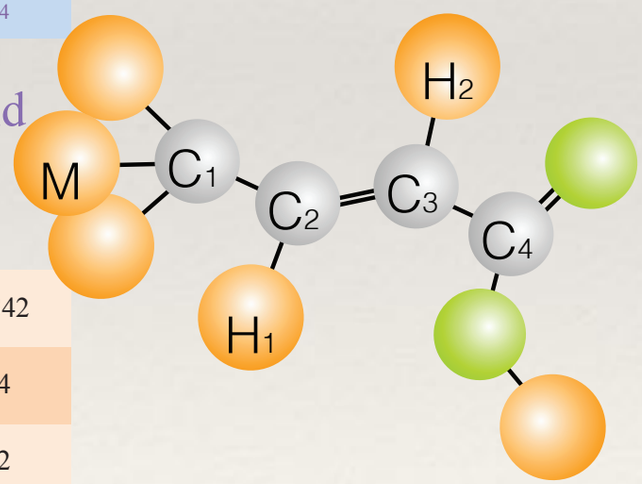
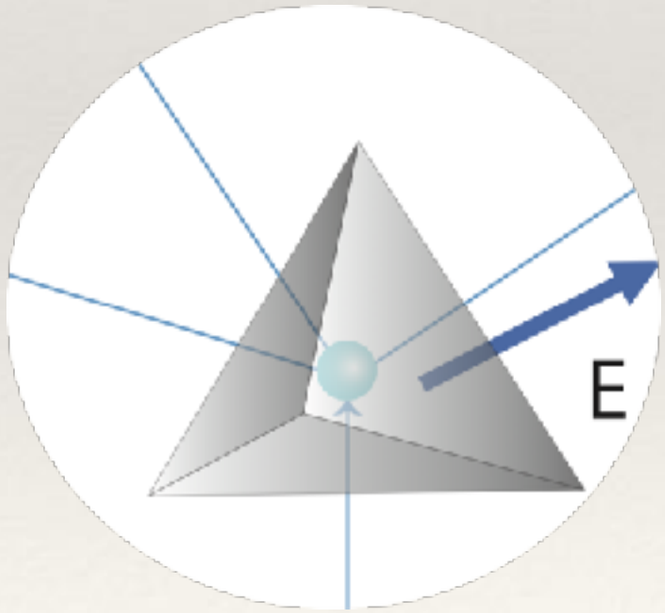
	C_1	C_2	C_3	C_4
C_1	-2989			
C_2	41.62	-25459		
C_3	1.46	69.66	-21592	
C_4	7.02	1.18	72.16	-29342
T_1	1.02	0.92	0.87	0.94
T_2^*	5.07	5.3	5.6	10.2

Crotonic Acid





initialization

Experiment Result

Preparation of the pseudo-pure state

David G. Cory, Amr F. Fahmy, and Timothy F. Havel. *Proceedings of the National Academy of Sciences*, 94(5):1634–1639, 1997.

$$\rho_{eq} = \frac{1-\epsilon}{16}\mathbb{I} + \epsilon(\gamma_{C1}\sigma_z^1 + \gamma_{C2}\sigma_z^2 + \gamma_{C3}\sigma_z^3 + \gamma_{C4}\sigma_z^4)$$

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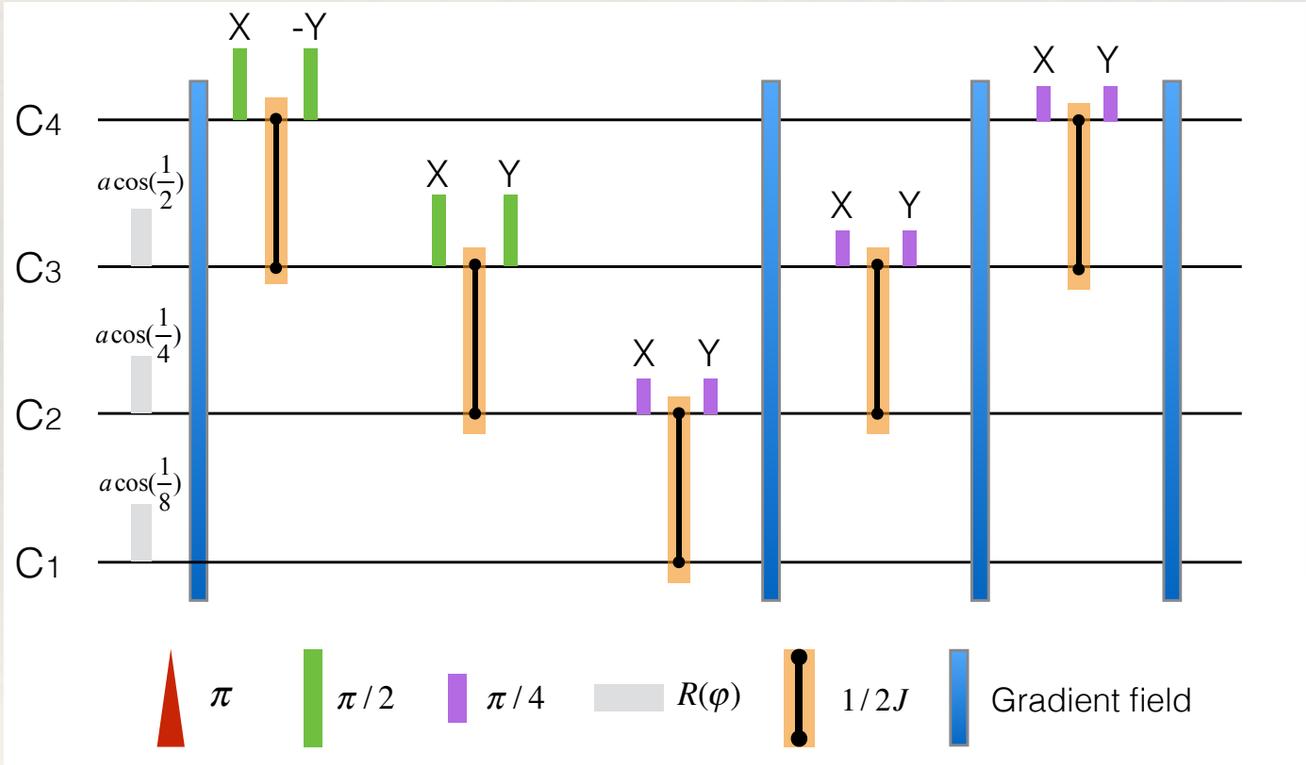

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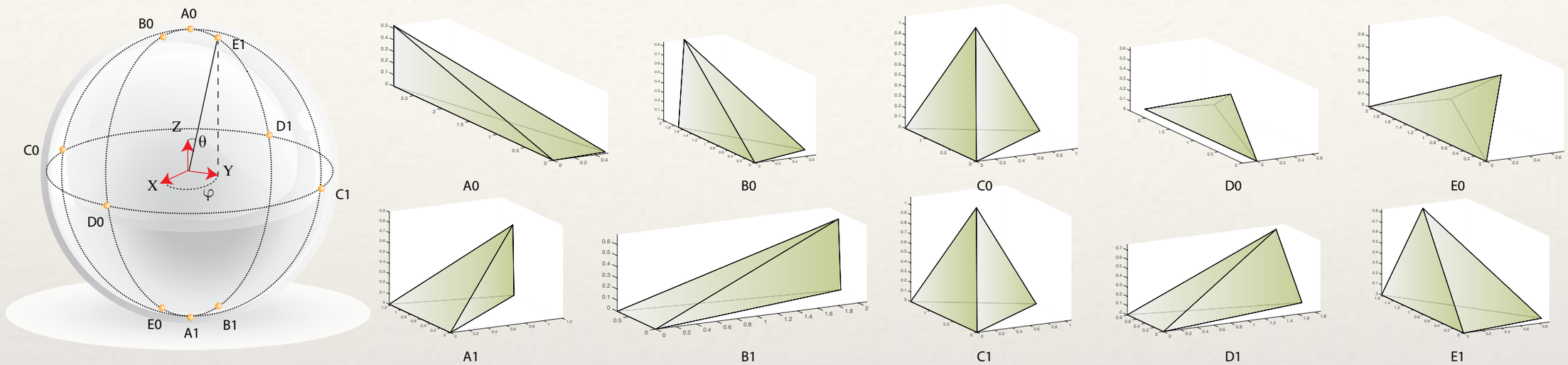

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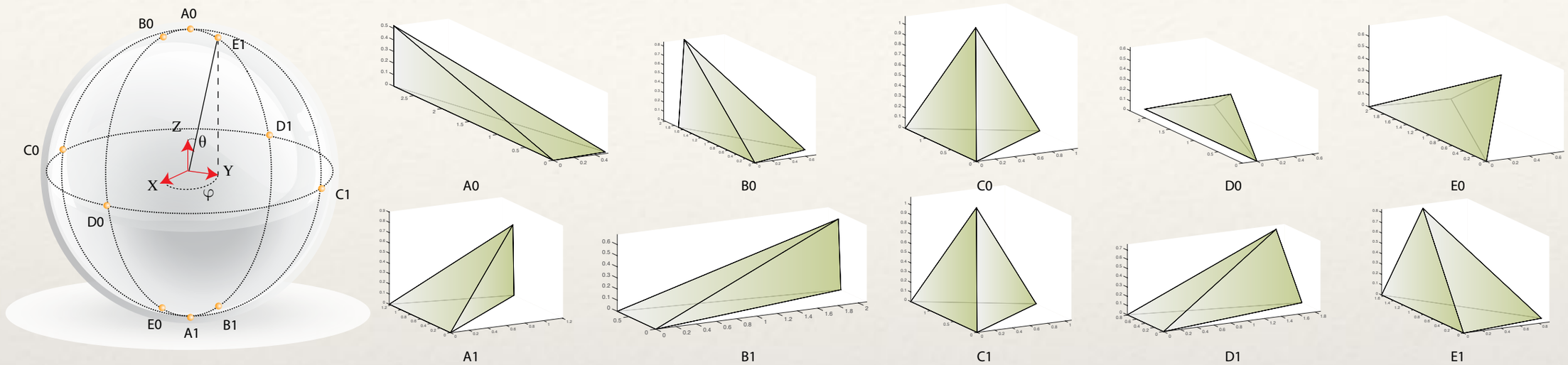
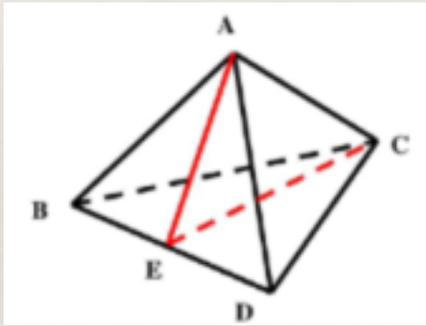


- Measure the dihedral angular



- Show the Dynamics

$$\bigotimes_{l=1}^{10} \langle \epsilon_l | \bigotimes_{n=1}^{5} | i_n \rangle = A(i_1, \cdots, i_5)$$

Experiment results

- Measure Geometry
- A tetrahedron can be uniquely determined by six individual variables.

$$\widehat{\cos\theta_{km}} = \frac{\hat{\mathbf{E}}^{(k)} \cdot \hat{\mathbf{E}}^{(m)}}{\sqrt{\hat{\mathbf{E}}^{(k)} \cdot \hat{\mathbf{E}}^{(k)}}\sqrt{\hat{\mathbf{E}}^{(m)} \cdot \hat{\mathbf{E}}^{(m)}}} = \frac{4}{3}\hat{\mathbf{J}}^{(k)} \cdot \hat{\mathbf{J}}^{(m)}$$

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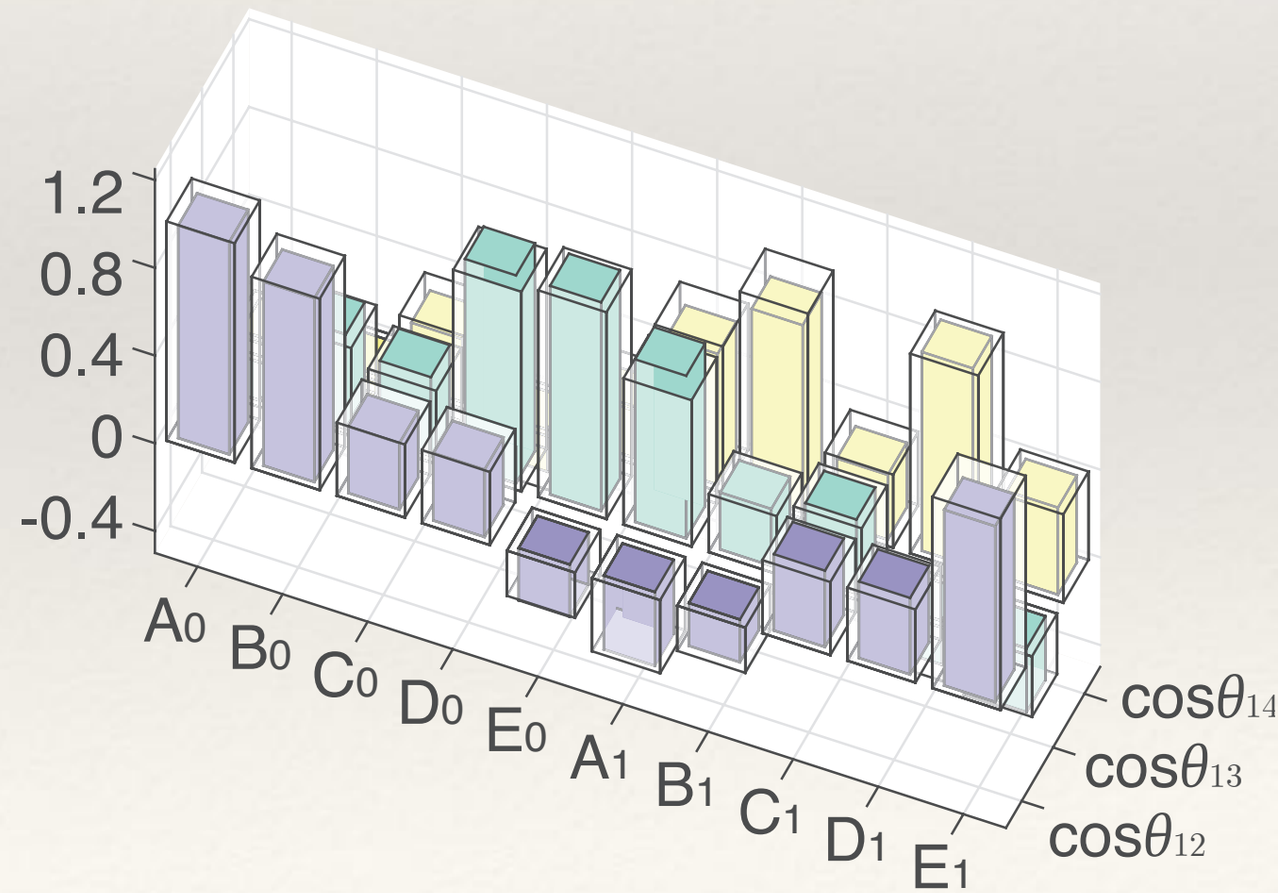
- In the figure, the transparent columns represent the theoretical values, while the coloured ones represent the experimental results.



Experiment results

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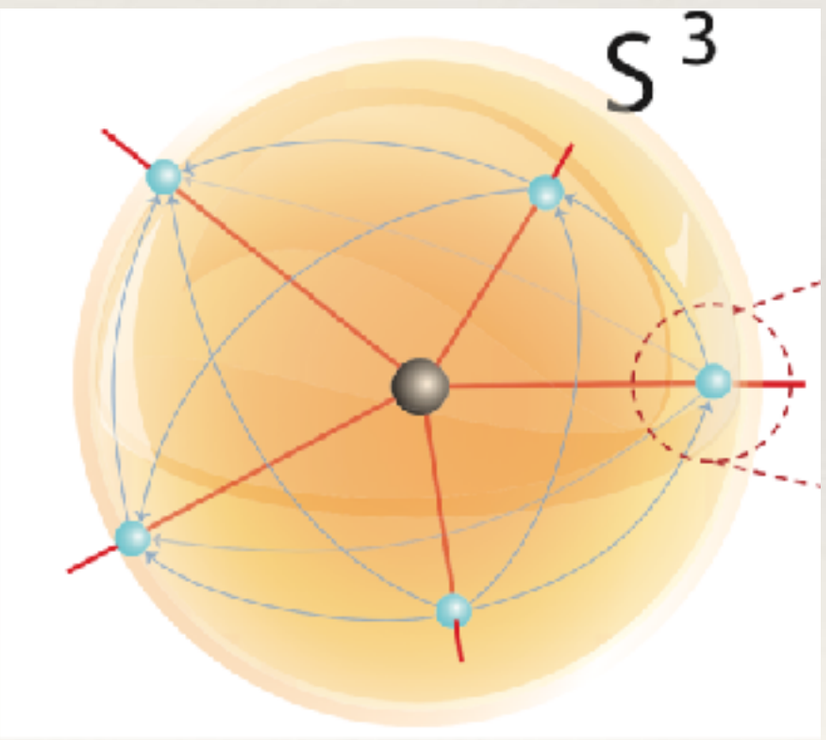

Experiment results

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- the vertex amplitude of the quantum spacetime at the Planck level in Ooguri's model

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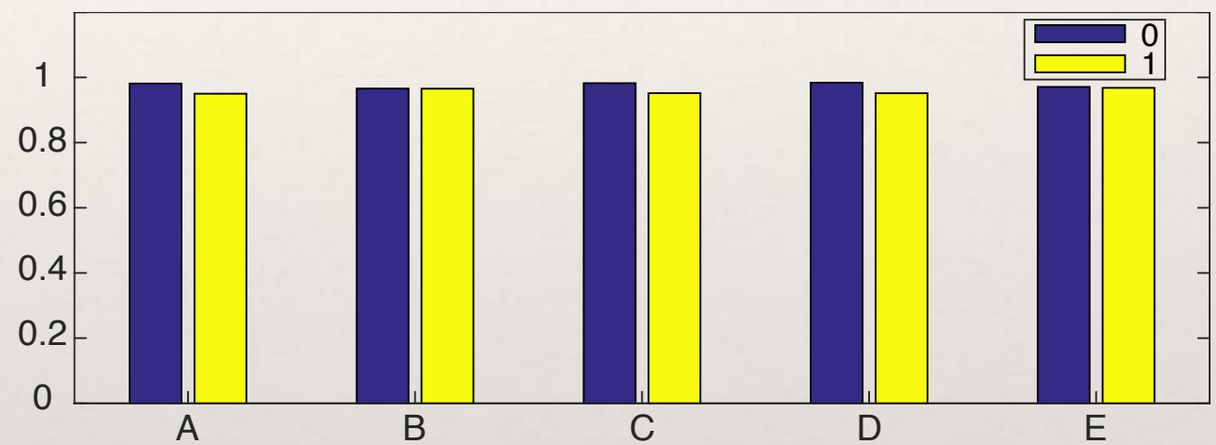

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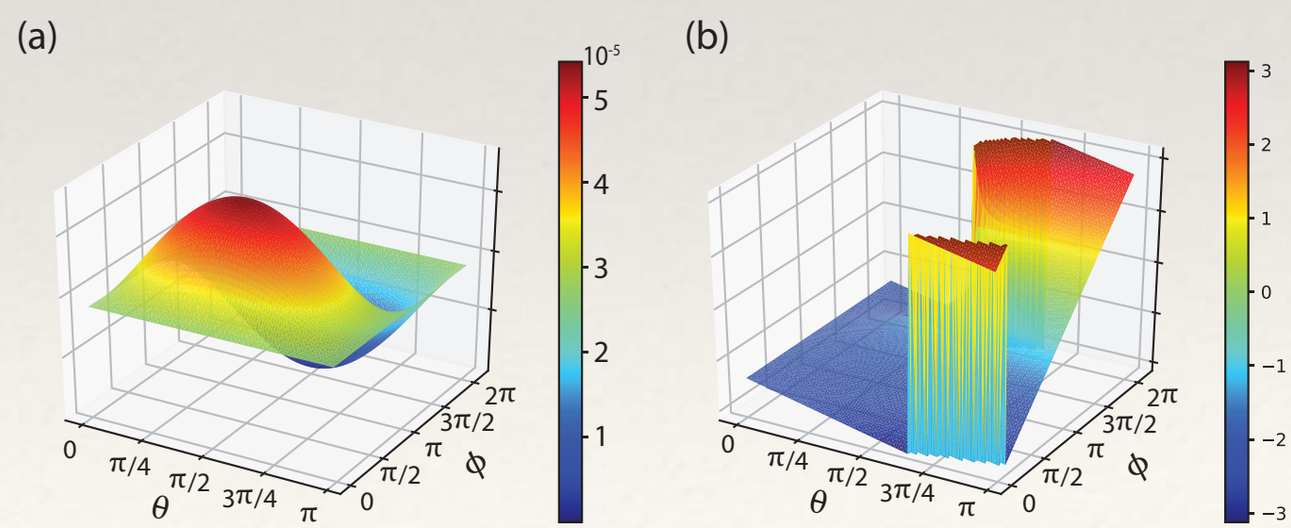

Thank You!

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