

# Emergence of gravitons from qbit models

Xiao-Gang Wen; MIT; July, 2009; FQXi



Zheng-Cheng Gu

# Seven wonders of our universe

- (1) Identical particles.
- (2) Gauge interactions.
- (3) Fermi statistics.
- (4) Tiny masses of fermions ( $\sim 10^{-20}$  of the Planck mass).
- (5) Chiral fermions. ( $SU(2)$  only couples to right-hand fermions)
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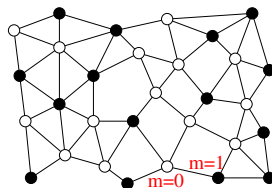
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- Everything has to come from something

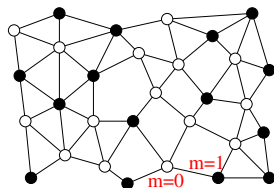
# Emergence approach

- Only one fundamental building block for everything: **qbits**
- Space = collection of qbits ( $10^{122}$  of them). No qbits, no space
- Empty space (vacuum) = ground state of qbits:  $\Phi_0(\{m_i\})$ .
- “Elementary” particles = collective excitations (such as topological defects, collective waves) above the ground states:  $\Phi(\{m_i\})$ .



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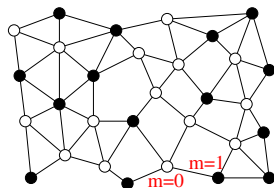
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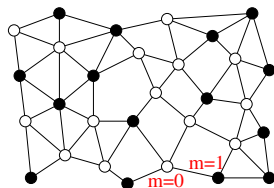
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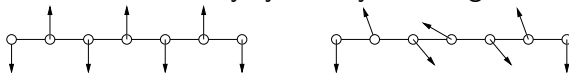
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- Standard topic in condensed matter → phases of quantum matter

# Can seven wonders emerge from an organization (an order)

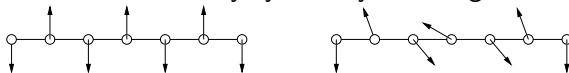
- Old picture of phases and phase transitions:  
All orders are described by symmetry breaking.



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- But the symmetry breaking states are unentangled states:  
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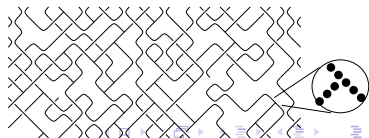
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- New states of matter and new kind of order <sup>Wen, 89</sup> (topological order) do exist (such as FQH states). They have **long range quantum entanglements**, such as string-net condensed state  
 $|\text{string-net cond.}\rangle = \sum |\text{string-net}\rangle$



# “The universe is a string-net liquid” – Zeeya Merali, New Scientist

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- Ends of strings (topological excitations) give rise to spin-1/2 fermions – the matter (leptons and quarks) Levin & Wen, 03

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**Can qbit model also unifies gravity?**

**Can gravitons emerge from a qbit model?**

# Two qbit models and the emergence of gravitons

Gu & Wen, arXiv:0907.1203

Gravitons = helicity  $\pm 2$  modes **as the only gapless excitations**

- L-type qbit model:  $\omega \propto k^3$  gravitons. Low energy Lagrangian:

$$\mathcal{L}_L(\mathcal{E}^{ij}, a_{ij}) = \mathcal{E}^{ij} \partial_0 a_{ij} - \frac{J}{2} C_j^j C_j^j - \frac{g}{2} R^{ij} R^{ij}$$

$$C_j^j = \epsilon^{imn} \partial_m \left( \mathcal{E}^{nj} - \frac{1}{2} \delta_{nj} \mathcal{E}^{ll} \right), \quad R^{ij} = \epsilon^{imk} \epsilon^{jln} \partial_m \partial_l a_{nk}$$

with the following emergent gauge transformation and constraints:

$$\begin{aligned} a_{ij} &\rightarrow a_{ij} + \partial_i f_j + \partial_j f_i, & \partial_i \mathcal{E}^{ij} &= 0 \\ \mathcal{E}^{ij} &\rightarrow \mathcal{E}^{ij} - (\delta_{ij} \partial^2 - \partial_i \partial_j) f_0, & R^{ii} &= 0 \end{aligned}$$

- Local gauge invariance:  $C_j^j$ ,  $R^{ij}$ , and  $\mathcal{L}_L$  are invariant under the above gauge transformations. (Maxwell type)
- The above gauge transformations are linearized diffeomorphism.

- N-type qbit model: Same Hilbert space as the L-type model but a different Hamiltonian.
- Under a semiclassical approach (which is known to be unreliable):  
 →  $\omega \propto k$  gravitons, described by low energy effective Lagrangian (in phase space):

$$\mathcal{L}_N(\mathcal{E}^{ij}, a_{ij}) = \mathcal{E}^{ij} \partial_0 a_{ij} - \frac{J}{2} [(\mathcal{E}^{ij})^2 - \frac{1}{2}(\mathcal{E}^{ii})^2] - \frac{g}{2} a_{ij} R^{ij}$$

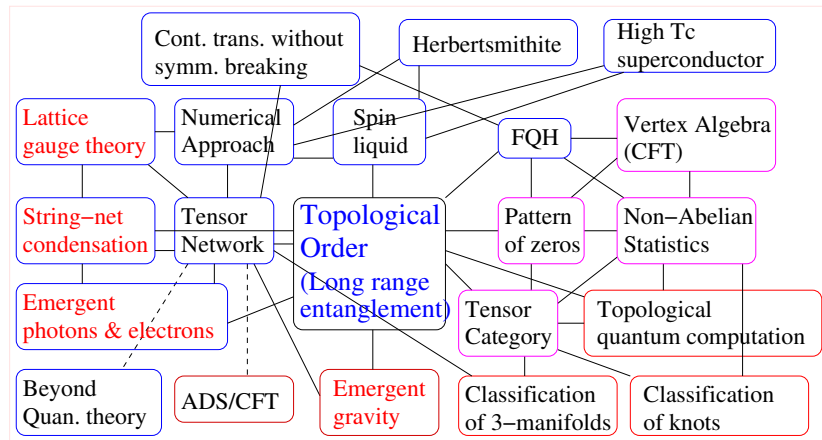
with the same gauge transformations and constraints:

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- Non-local gauge invariance:  $S = \int dt d^3x \mathcal{L}_N$  are invariant under the above gauge transformations, but  $\mathcal{L}_N \rightarrow \mathcal{L}_N + \partial F$ .  
(Chern-Simons type)
- **The Einstein equation emerges at low energies from  $\mathcal{L}_N$  at linear level.**

# A new paradigm of quantum physics

An overlap between condensed matter physics, particle physics, quantum gravity, quantum information, and mathematics.



# A working definition of quantum gravity

- (a) A quantum theory.
- (b) Its Hilbert space has a finite dimension.
- (c) The Hamiltonian is a sum of local operators.
- (a–c) → lattice qbit model (quantum spin model on a lattice).*
- (d) The gapless helicity  $\pm 2$  excitations are the only low energy excitations.
- (e) The helicity  $\pm 2$  excitations have a linear dispersion.
- (f) The gravitons interact in the way consistent with experimental observations.