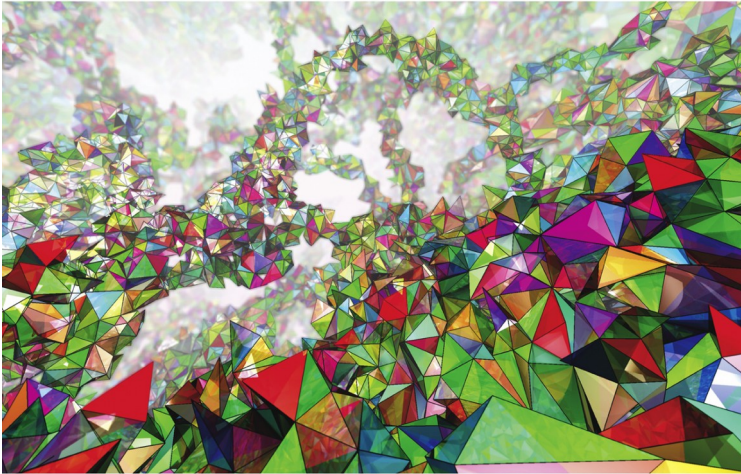# Covariant Loop Quantum Gravity - Spin Foams

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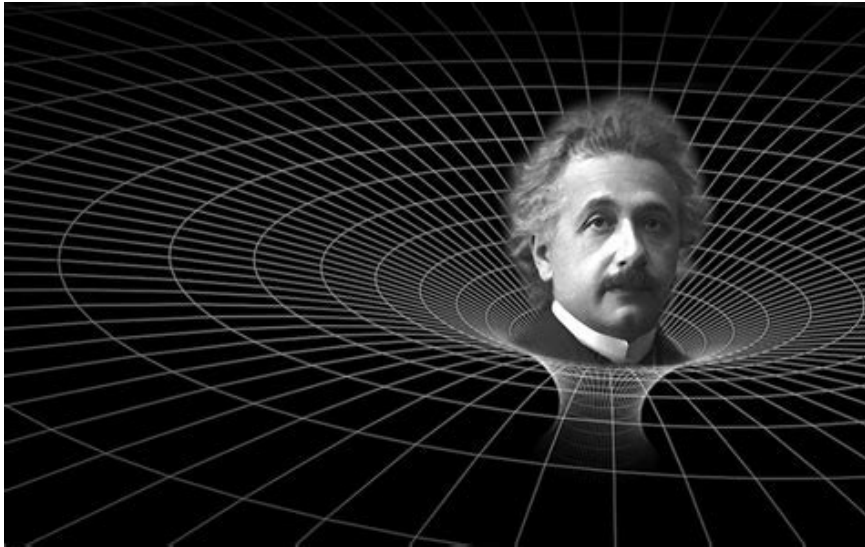
7th May 2021
GAIN Kick-off

Physics Today

- Three pillars of Physics:

- General Relativity: Physics of very large objects!

- Quantum Mechanics: Physics of very small things.
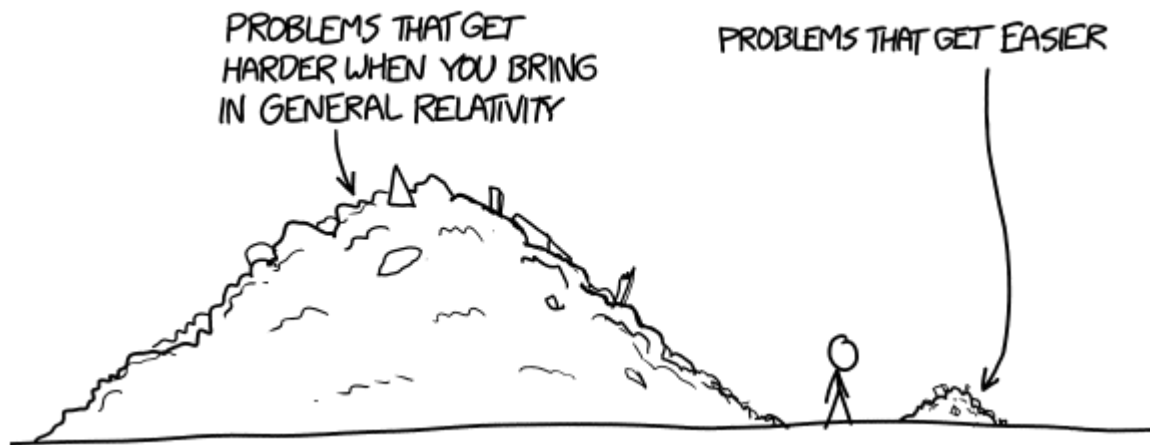
- Thermodynamics: Physics of time irreversability.

General Relativity I

- Started as special relativity (1905): motion near speed of light.
- Evolved into General Relativity (1915)
- Describes universe as 4D manifold with varying curvature.
- Objects follow geodesics.
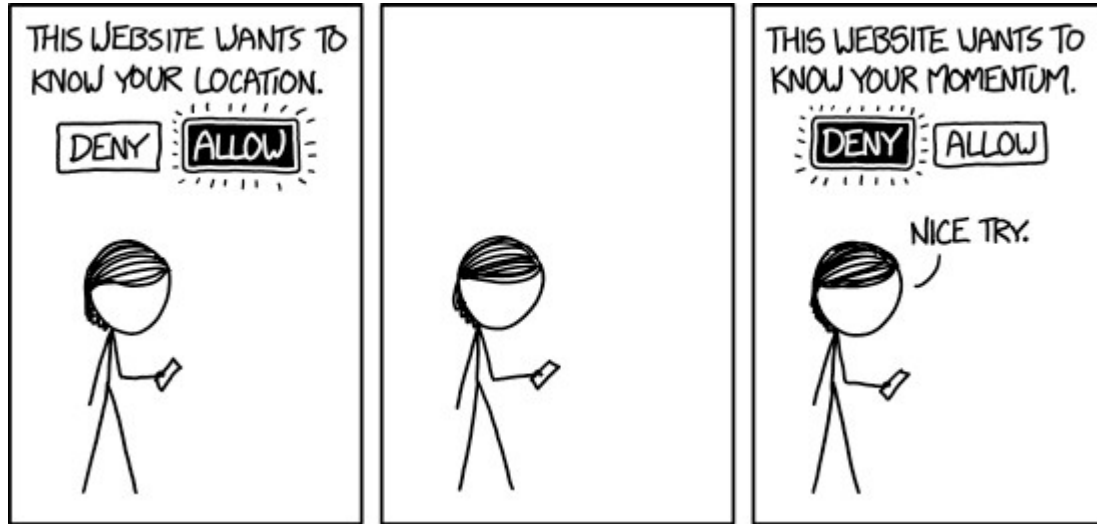- Cosmic speed limit of c on information transfer.

General Relativity II

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

PROBLEMS THAT GET HARDER WHEN YOU BRING IN GENERAL RELATIVITY

PROBLEMS THAT GET EASIER

- Describe universe with a metric, g, that obeys conditions (Einstein's field equation).

- Solutions highly non trivial, even for simple 2 body problem.

Quantum Mechanics I

- Uncertainty is key! On a fundamental level, nothing is certain (Heisenberg's Uncertainty Principle)

- QM started with Max Planck's attempt to describe Black Body Radiation.
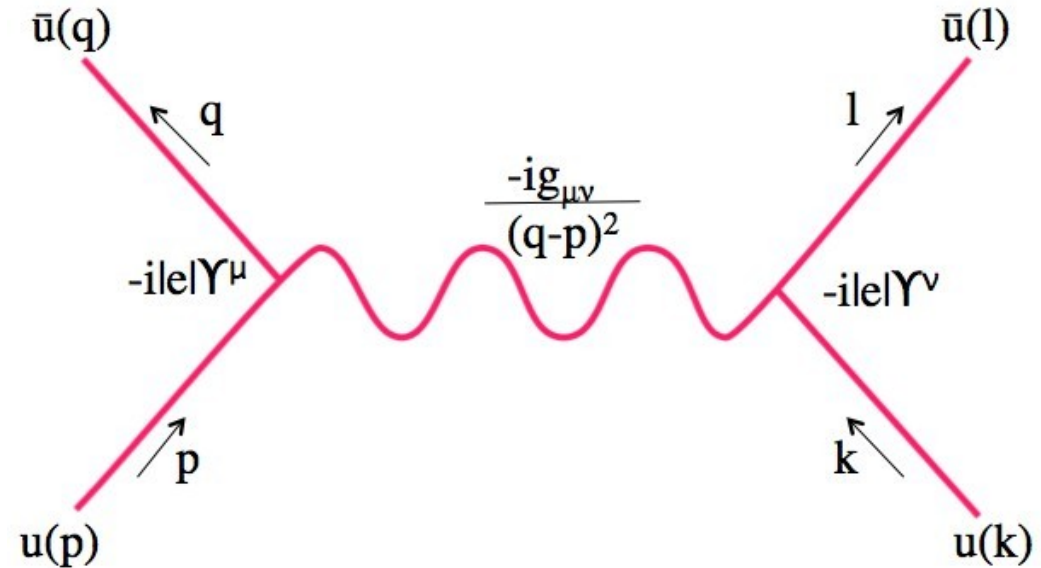
- Quantisation!

Quan tum Mechanics II
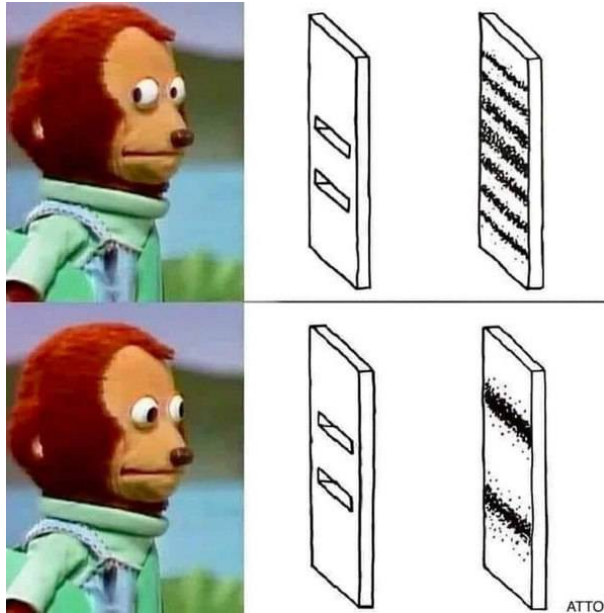
- Attempting to measure "collapses the wavefunction"
- Many interpretations of this, Copenhagen, many worlds, relational QM.
- Modern chemistry dependent on it working, electronics, many other fields.

Quantum Field Theory I

- Combining QM and Special Relativity.

- Second quantisation: Particles are now excited states of underlying fields.

- Simplest to describe with Feynman diagrams, which represent a way to calculate transition amplitudes.
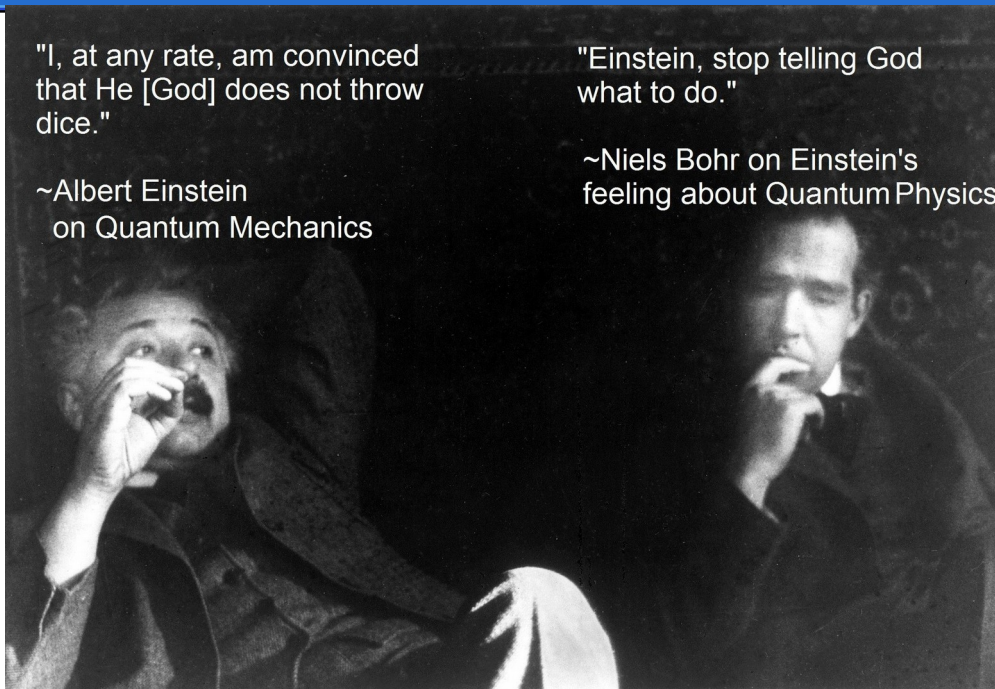
Quantum Field Theory II
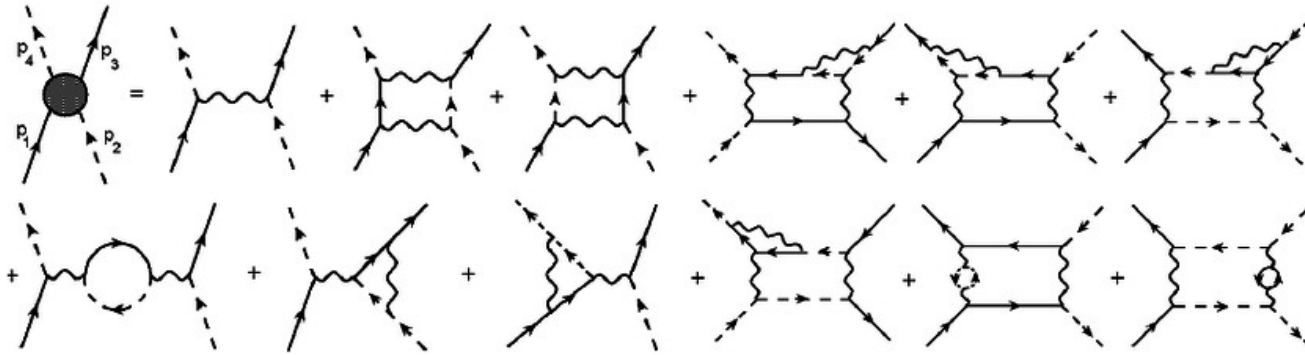
- Renormalisation required as infinite diagrams exist for each interaction. A process by which initial quantities are redefined to account for infinities emerging.

Quantum versus Gravity.

- QFT on curved spacetime possible for small curvature. e.g. Hawking radiation. Not useful when curvature large.

- In quantum gravity, the background is a field dependent on the mass fields. Everything is coupled.


"I, at any rate, am convinced that He [God] does not throw dice."

~Albert Einstein
  on Quantum Mechanics

"Einstein, stop telling God what to do."

~Niels Bohr on Einstein's feeling about Quantum Physics

- In QM, infinite speed information transfer, in GR, it is c.

- In GR manifold is smooth, but QM describes strong fluctuations at small scale.
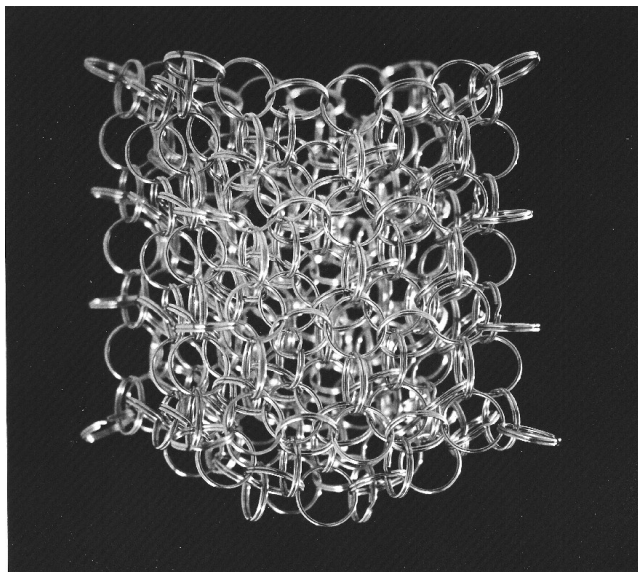
Quantum Gravity

Black Holes
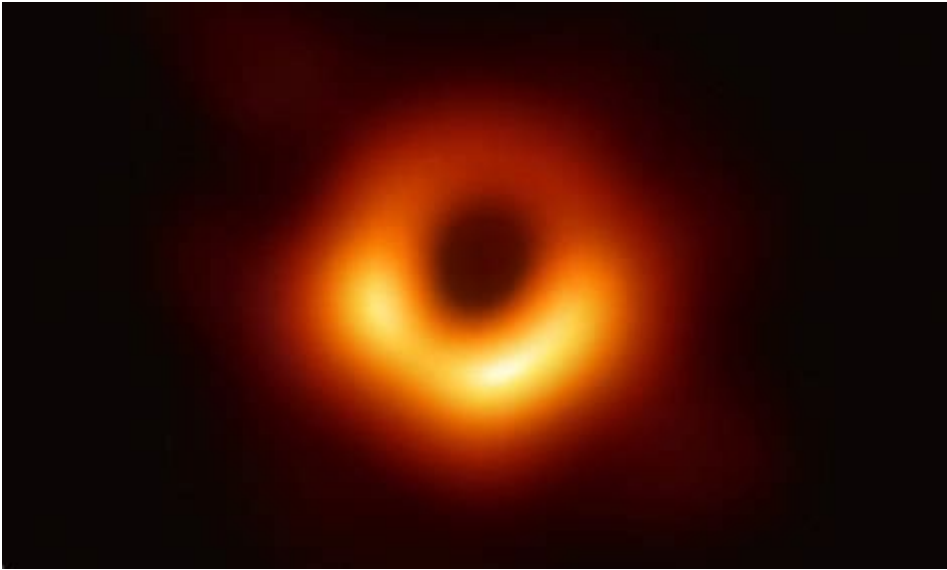
Early Universe (Big Bang?)
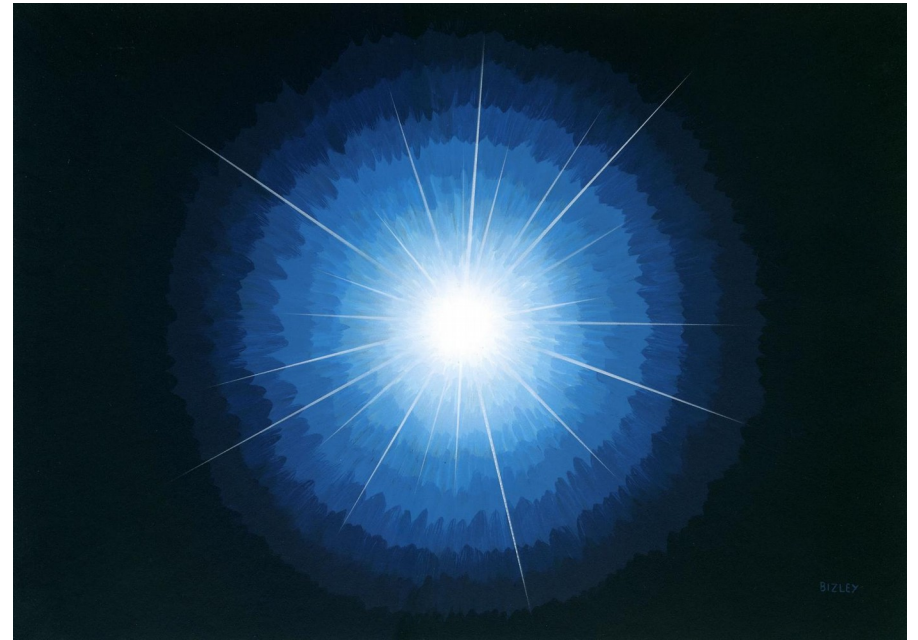
Loop Quantum Gravity I

- Takes GR as start, and quantises in same way as QM originally did. Quantising gravitational field (the metric)

- Operators emerge, area and volume operators.

- Areas and volumes in universe are discrete! Not continuous!

$$A = l_o^2 \sqrt{j(j+1)}, \quad j = 0, \frac{1}{2}, 1, \frac{3}{2}, 2, \ldots$$

Loop Quantum Gravity II

- Describes quantum geometry, as only 5 commutable quantities (4 area operators and 1 volume). The simplest 3D shape (tetrahedron requires 6)

- Spacetime is discrete, so why not replace with a graph?
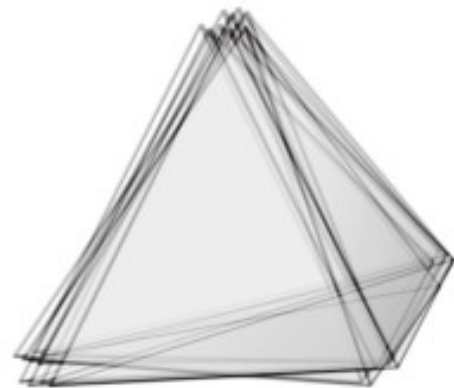
Spin Networks I

- Network is dual of structure, but what if network is more fundamental object?
- Instead of links representing areas, have areas defined by the number of links cutting through.
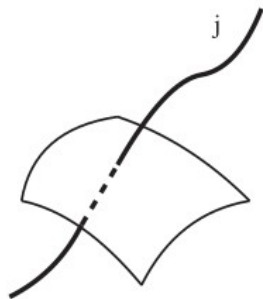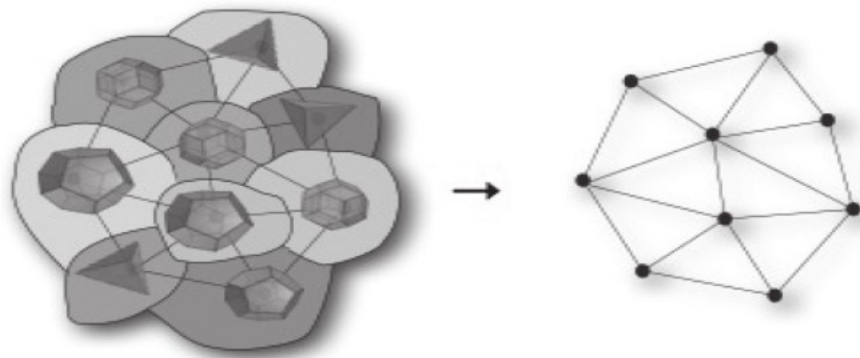
Spin Foams

- We live in 4D spacetime (don't tell the string theorists!) so need structures that connect 3D Spin Networks.

- Not just connect but tell us how probability for one space to change to another.

- Vertices are now related to 4D 4-simplices, edges to 3d tetrahedra.
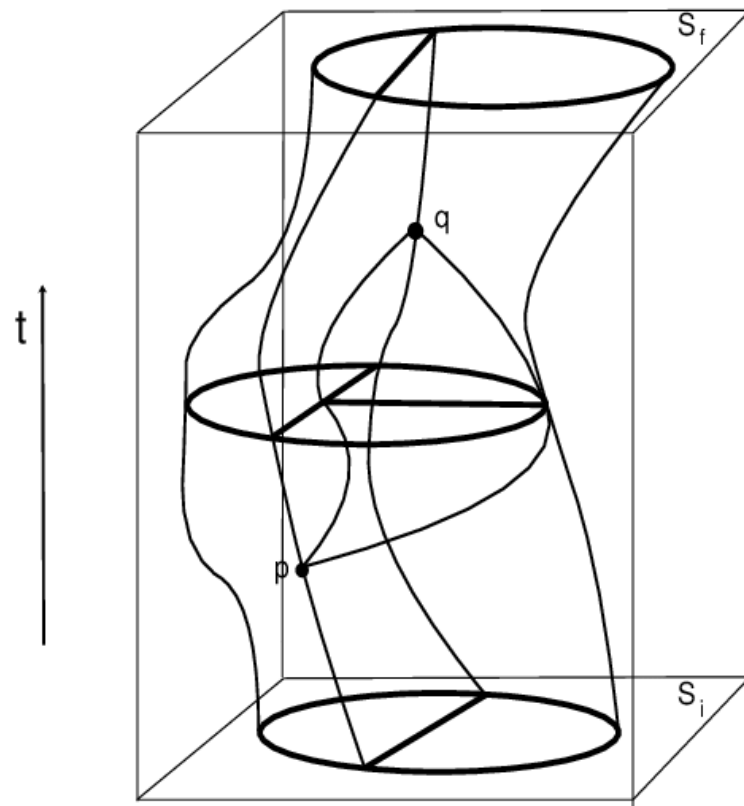
EPRL Model

$$W(h_\ell) = \int_{SU(2)} dh_{vf} \prod_f \delta(h_f) \prod_v A_v(h_{vf}),$$

where $h_f = h_{vf} h_{v'f} \ldots$ and the vertex amplitude is

$$A_v(h_{vf}) = \sum_{j_f} \int_{SU(2)} dg'_{ve} \prod_f d_{j_f} \, \mathrm{Tr}_{j_f}[g_{e'v} g_{ve} h_{vf}].$$

- Similar to Feynman's Diagrams and rules

- Work through diagram, assigning quantities (representations of SL(2,C) to edges and intertwiners to vertices)

- Integrate, Sum, Product and voila you have an amplitude for the process, related to probability!

An Application: Black Holes I

- The idea: Black Holes can turn into White Holes, main difference is subtly different metric.

- Archetypal example for geometry transition Spin Foams were designed for.

- Can stabilise the problem of black hole singularity.
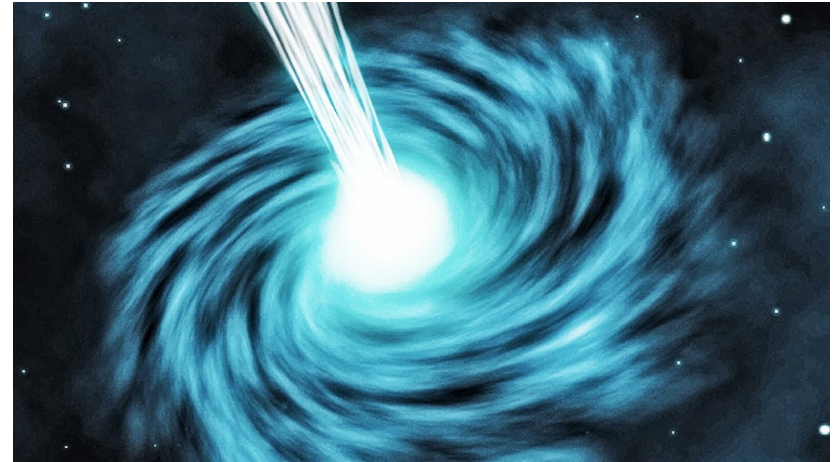
An Application: Black Holes II

- Best attempt so far, very simple graph, small number of vertices.

- Calculation attempted by D'Ambrosio and Christodoulou

- Current answer, Probability of transition is Exp(-M^2)

- Only can happen near end of of Black Hole lifetime
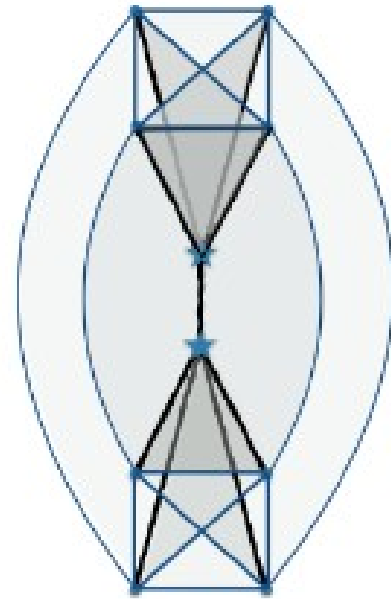
Spinfoam 2-complex

Problems

- Problem of complexity: Calculations are already very difficult for simple graphs, require large approximations, for proper calculations extremely complex graphs required, how can we simplify these problems?

- Bubbles. When there is a closed structure in foam, extra infinities emerge in calculation, how can these be resolved?
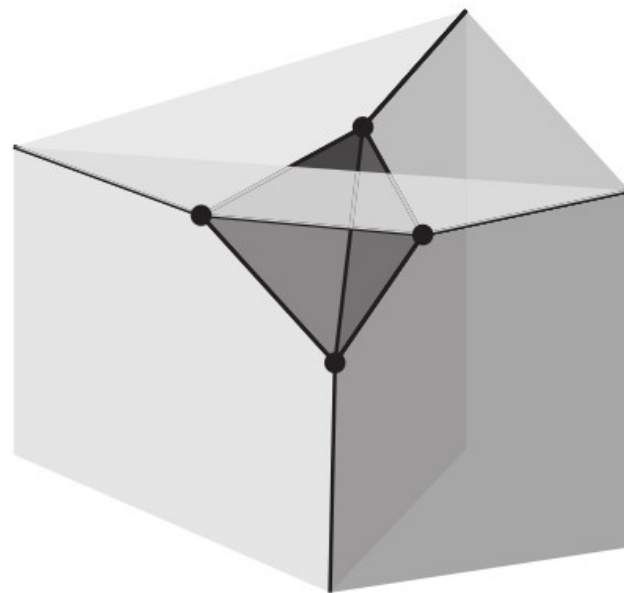
Thank you!

Good luck to Josephine, Silvia and Alice!