QG4

SPINFOAM

for cosmologists !

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based on the work in collaboration with Carlo Rovelli and Eugenio Bianchi

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AIM OF THE TALK

- *What is a* SPINFOAM *?*
- *What is its use in* COSMOLOGY *?*

STARTING POINT

- General Relativity → Cosmology

$$\begin{cases} R_{\mu\nu} - \frac{1}{2}\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu} \\ matter \end{cases}$$

$$ds^2 = dt^2 - a^2(t)\, d^3\vec{x}$$

$$+\ perturbations$$

$$\downarrow$$

$$\begin{cases} Friedmann\ eq.\ for\ a(t) \\ eq.\ for\ perturbations \end{cases}$$

CANONICAL QUANTIZATION: LQC

talks by Wilson-Ewing and Cailleteau

- **Hamiltonian quantum theory** *for a(t)* → $\Psi(a) \in \mathcal{H}_{LQC}$

$$H\,\Psi = 0$$

- *quantum theory* → *effective theory*

quantum Friedmann eq.

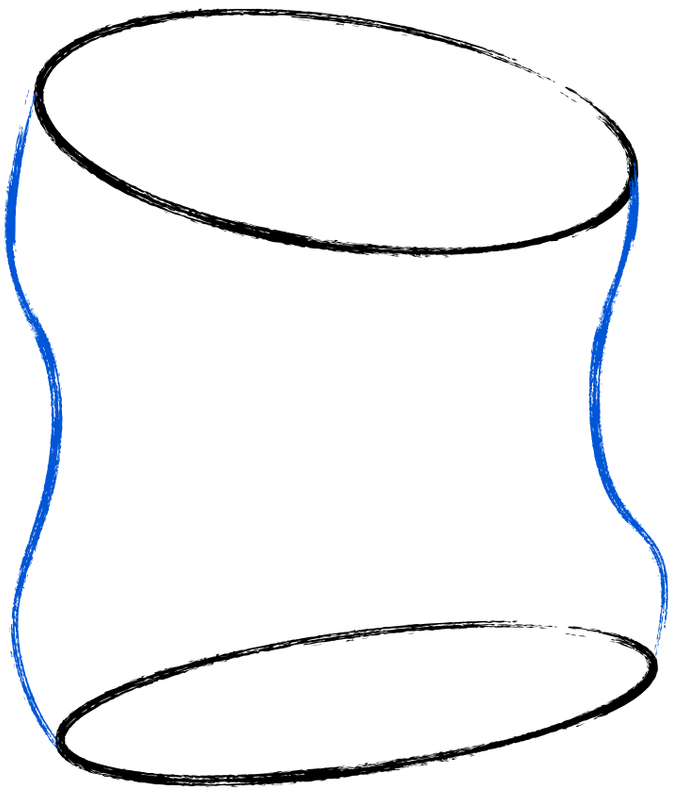
$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8}{3}\pi G\rho\left(1-\frac{\rho}{\rho_{cr}}\right)$$

- **Fluctuations** *on an effective quantum background*

Mukhanov-Sasaki eq.
for scalar/tensor perturbations

$$v'' - \left(1-2\frac{\rho}{\rho_{cr}}\right)\nabla^2 v - \frac{z''}{z}v = 0$$

COVARIANT QUANTIZATION: LQG



q'_{ij}

the universe at "time" t'

$$W(q'_{ij}, q_{ij}) \sim \int_{\partial g = q', q} Dq \; e^{i\,S}$$

q_{ij}

the universe at "time" t

graph = discretization of space

- expansion: *discretization of spacetime*

4d $\longleftrightarrow$ 2-complex $\mathcal{C}$ { - *vertices*, - *edges*, - *faces*

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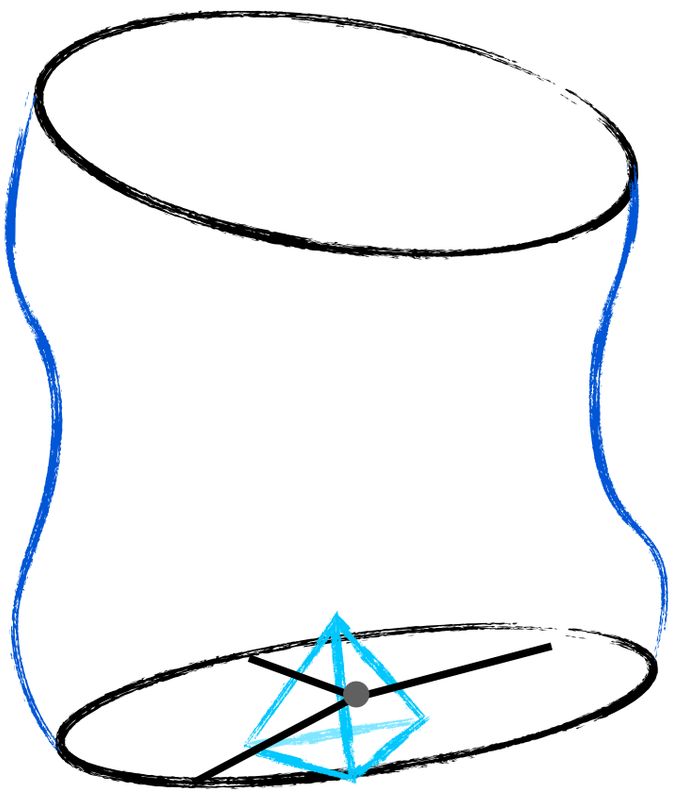

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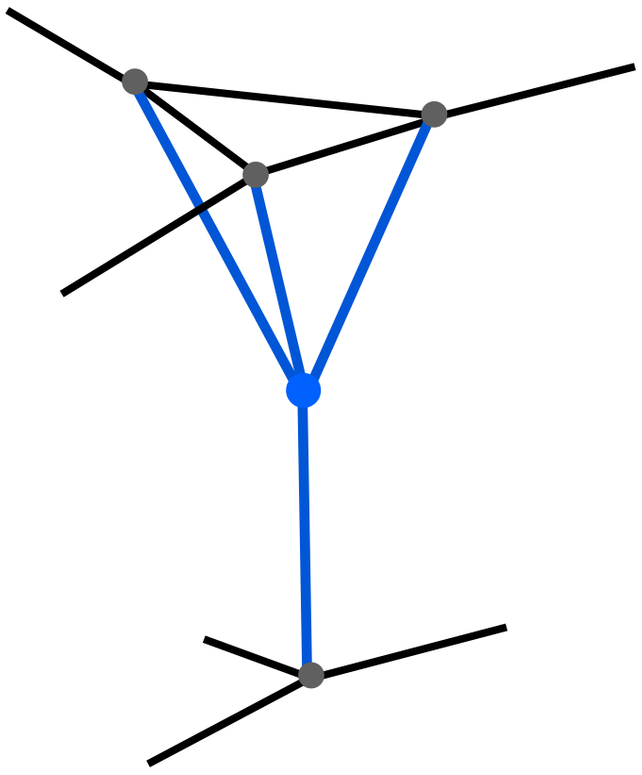

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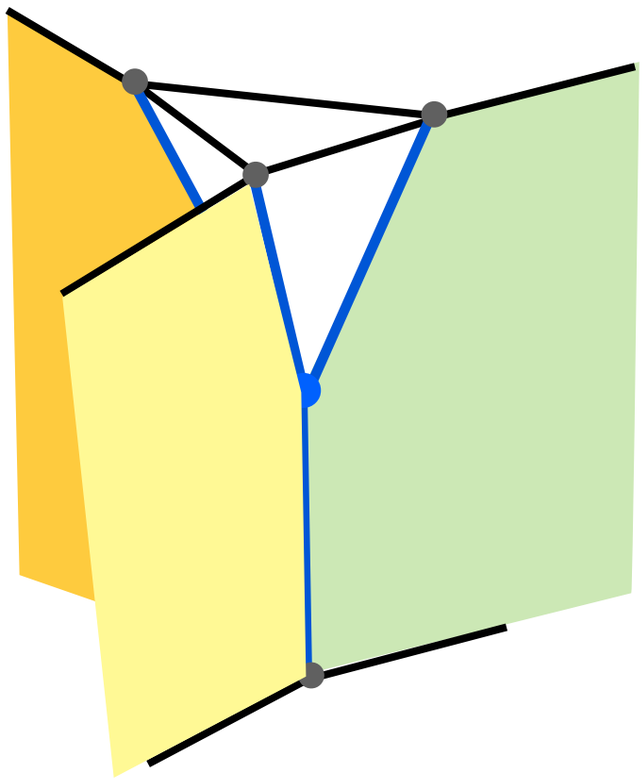

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concretely...

- *the states on the graph are well defined in full LQG* — *Bianchi Magliaro Perini (Ashtekar...Thiemann...)*
- *transition amplitudes* — **E***ngle* **P***ereira* **R***ovelli Livine.. Freidel... Alesci,.. Lewandowski, Kaminski, Kisielowski*
- *classical limit* — *Barrett, Dowall, Fairbain, Gomes Hellmann, Alesci...*

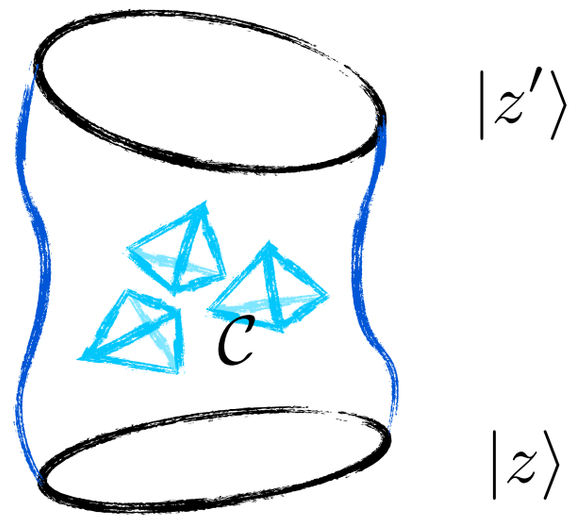
- idea

$$\langle W_{\mathcal{C}} | z, z' \rangle$$

- coherent states

$$|a, \dot{a}\rangle = \sum_{j_\ell, v_n} C_{j_\ell, v_n} \, |\Gamma, j_\ell, v_n\rangle$$

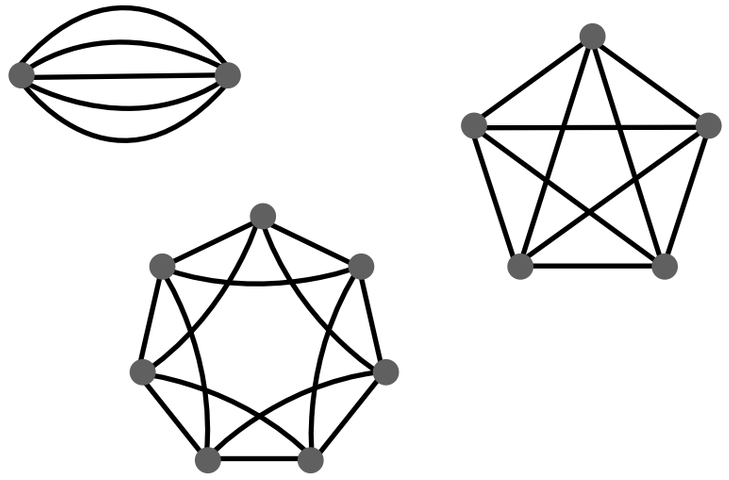
- RLRW $\quad |a, \dot{a}\rangle \longrightarrow |z\rangle \qquad z = \alpha\, \dot{a} + i\beta a$



Rovelli Vidotto Bianchi Marcianò Magliaro Perini

WHAT HAS BEEN DONE

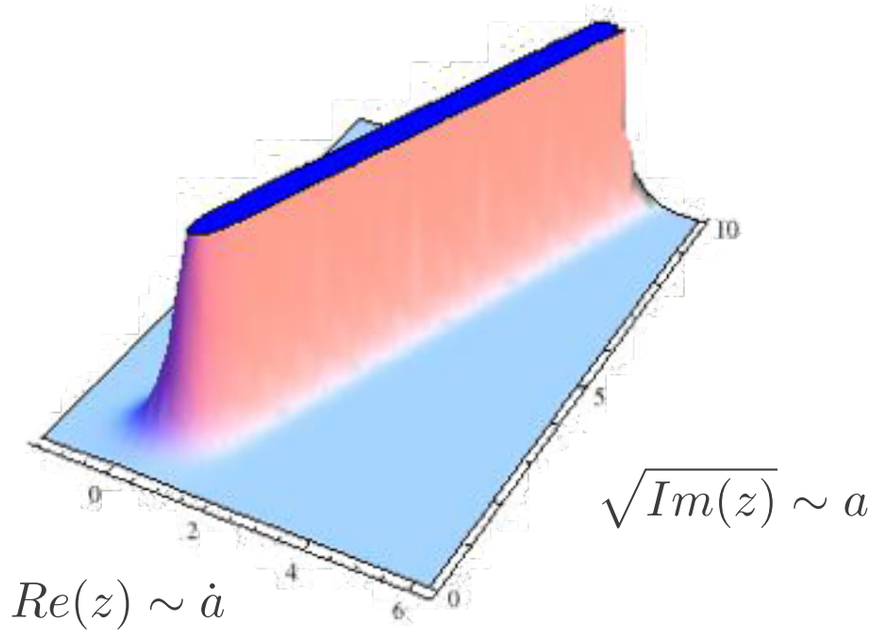
- *Regular graphs (same #link attached to each node)*



- *Analytic evaluation*
- *Numerical evaluation*

} Friedmann eq.

- *Euclidean and Lorentzian*
- *Cosmological constant:* $\Lambda = 0$ *and* $\Lambda > 0$



$Re(z) \sim \dot{a}$

$\sqrt{Im(z)} \sim a$

WHAT NEEDS TO BE DONE

- *Exploit different graphs*
- *Study the deep quantum regime*
- *Cosmological constant: quantum groups*
- *Coupling of matter*
- *Perturbations*

SUMMARY

- *Covariant LQG provides a framework for cosmology*
- *A tool to explore the deep quantum regime*
- *Study of fluctuations from the full quantum theory*

THANKS !

references: 1003.3483, 1011.4705, 1101.4049, 1107.2633.