Emergent Cosmology from Quantum Gravity

A collective effort: D. Oriti, E. Wilson-Ewing, S. Gielen, M. Sakellariadou, A. Pithis, M. de Cesare, A. Polaczek, A. Jercher, A. Calcinari, R. Dekhil, X. Pang, L. Mickel, T. Ladstätter, P. Fischer, ...

Luca Marchetti

COSMO '23
IFT Madrid
14 September 2023

Department of Mathematics and Statistics
UNB Fredericton

Microscopic description

Background independent, pre-geometric

Macroscopic description

Cosmology

Geometries that are

- smooth;
- almost spatially homogeneous and isotropic;
- time-dependent.

Continuum limit problem

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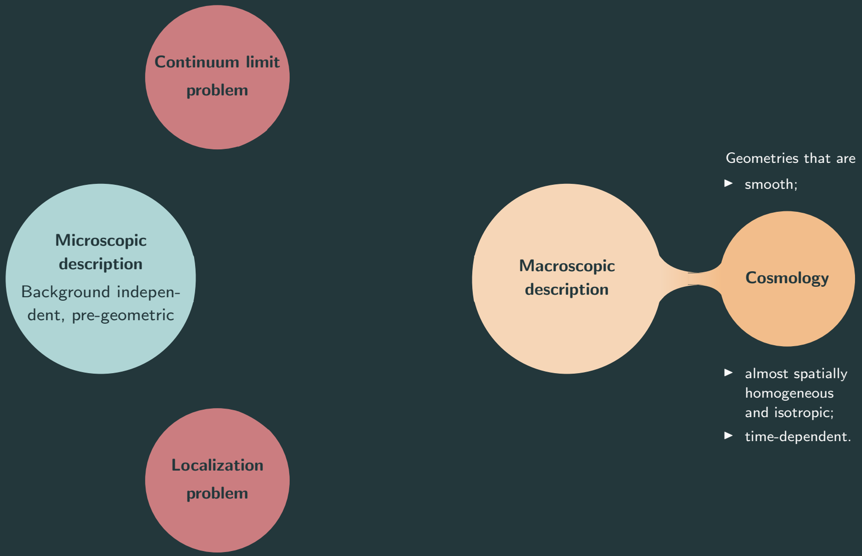
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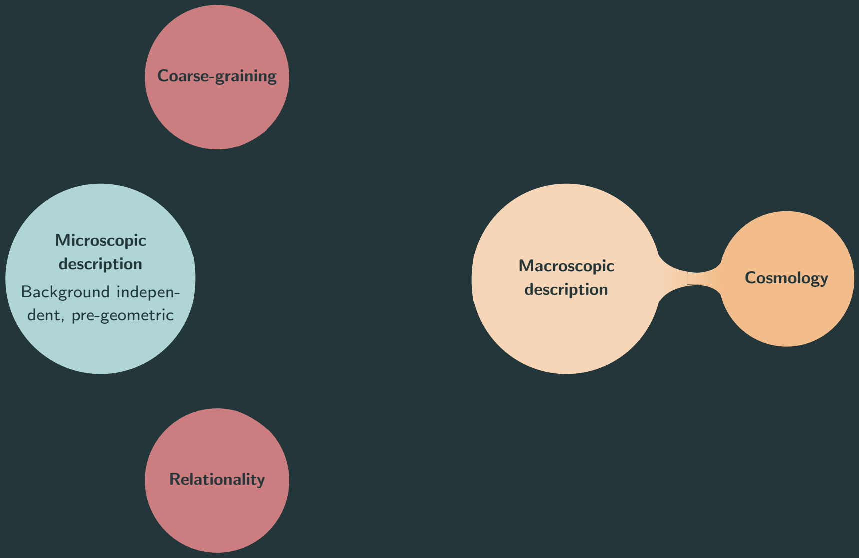
Coarse-graining
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Background independent, pre-geometric
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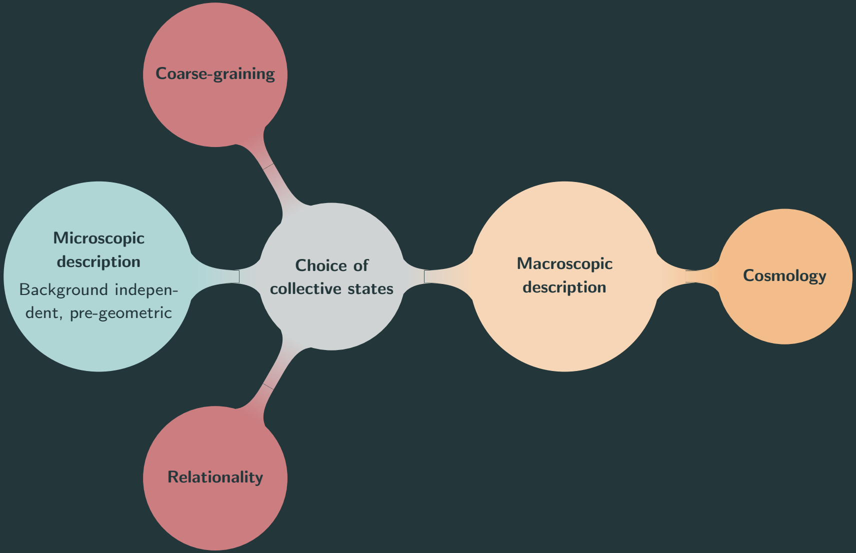

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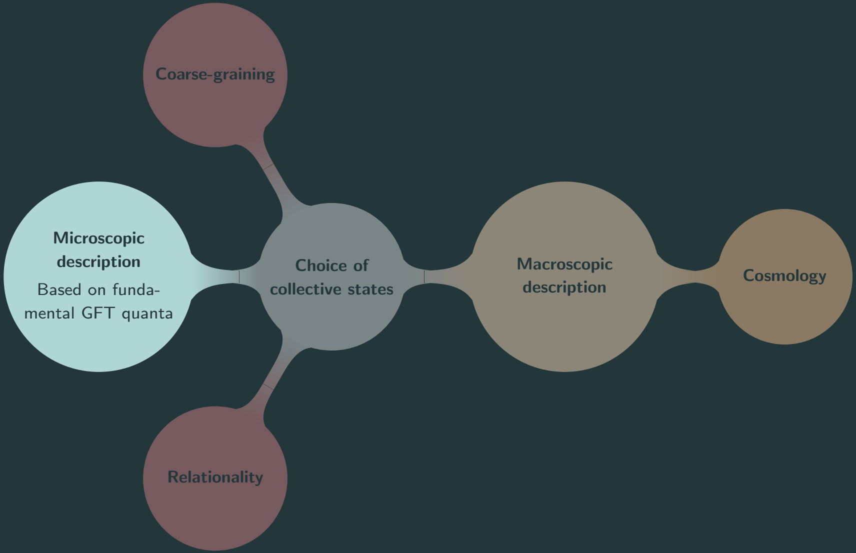
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The (T)GFT approach to quantum gravity

GFTs are QFTs of atoms of spacetime.

- Take seriously the idea of a microscopic structure of spacetime.
- Access to powerful field theoretic methods (Fock space, RG. . .)!

Oriti 0912.2441; Oriti 1110.5606; Oriti 1408.7112; Krajewski 1210.6257; Oriti 1807.04875; Gielen, Sindoni 1602.08104; . . .

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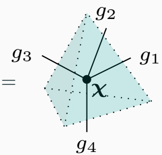
- GFT quanta are atoms of quantum 3-space, i.e. tetrahedra.
- Data associated to a single quantum are field data of a tetrahedron (g_a = gravitational, χ = scalar fields).

$$\varphi^\dagger(g_a, \chi)\,|0\rangle =$$



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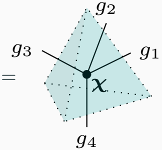
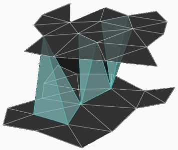
$\varphi^\dagger(g_a, \chi)\,|0\rangle =$ 

Group Field Theory Processes

- GFT Feynman diagrams (QG processes) are associated with 4d triangulated manifolds.
- Z_{GFT} = discrete matter-gravity path-integral.



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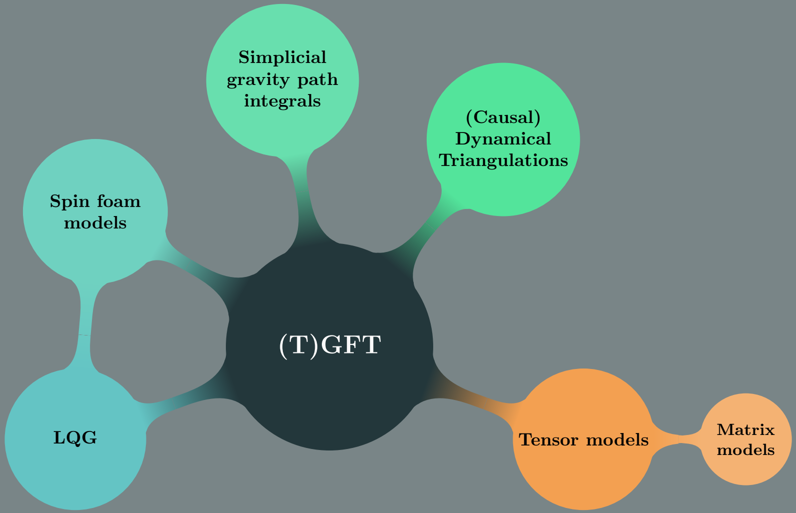
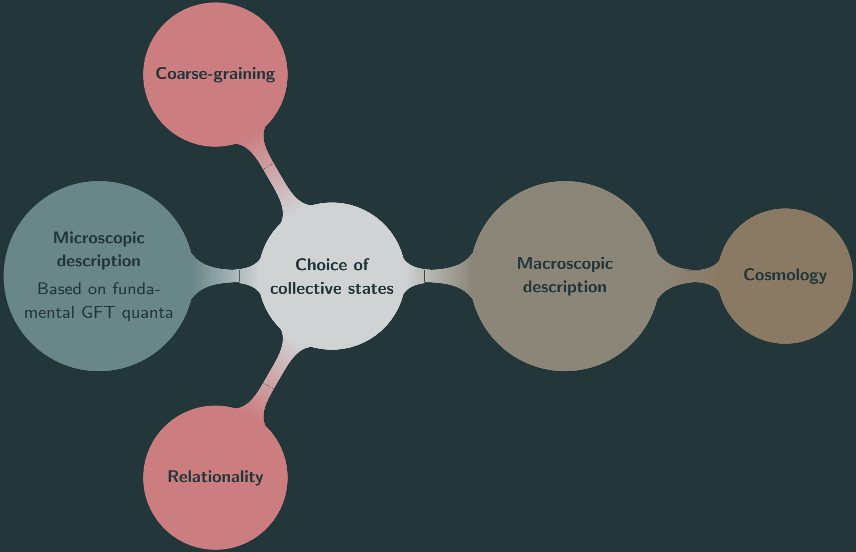


Simplicial gravity path integrals
(Causal) Dynamical Triangulations
Spin foam models
(T)GFT
LQG
Tensor models
Matrix models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QG coherent states

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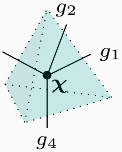

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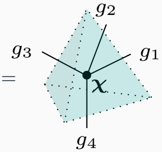

Collective states

GFT condensates

- From the GFT perspective, continuum geometries are associated to large number of quanta.
- The simplest states that can accommodate infinite number of quanta are condensate states:

$$|\sigma\rangle = \mathcal{N}_\sigma \exp\left[\int \mathrm{d}^{d_l}\chi \int \mathrm{d}g_a\, \sigma(g_a, \chi^\alpha)\hat{\varphi}^{\dagger}(g_a, \chi^\alpha)\right]|0\rangle\,.$$

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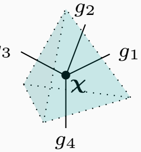
$\varphi^\dagger(g_a, \boldsymbol{\chi})\,|0\rangle =$ 

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- Macroscopic dynamics from (weakly interacting) mean-field approx. (saddle-point of Z_{GFT}).

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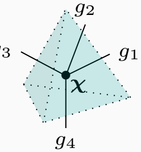
$$\varphi^\dagger(g_a, \boldsymbol{\chi})\,|0\rangle =$$ 

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- Macroscopic dynamics from (weakly interacting) mean-field approx. (saddle-point of Z_{GFT}).
- Relational localization implemented at an effective level on observable averages on condensates:

$$\sigma_x = (\text{fixed peaking function } \eta_x) \times (\text{dynamically determined reduced wavefunction } \tilde{\sigma})\,,$$

$$\downarrow$$

$$\langle \hat{\mathcal{O}} \rangle_{\sigma_x} \simeq \mathcal{O}(x)$$

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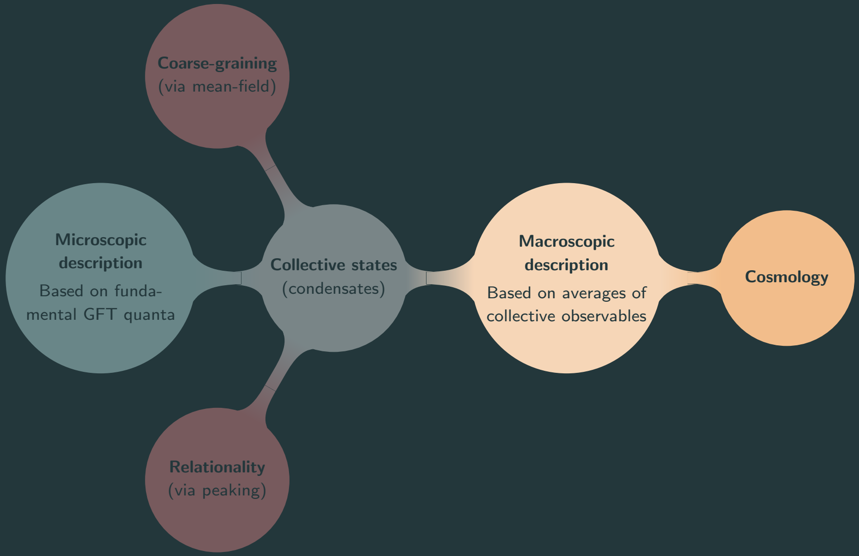
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(via peaking)

Homogeneous and isotropic sector

No interactions

Modified Friedmann dynamics

LM, Oriti 2008.02774-2112.12677; Oriti, Sindoni, Wilson-Ewing 1602.05881; Ladstätter, LM, Oriti (to appear); Oriti, Pang 2105.03751.

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Inhomogeneous (scalar and isotropic) sector

Setting

Classical

- 4 MCMF reference fields (χ^0, χ^i),
- 1 MCMF matter field ϕ dominating e.m. budget and relationally inhomog. wrt. χ^i.

Quantum

- Beyond condensates: time- and spacelike tetrahedra.

Inhomogeneities = quantum entanglement

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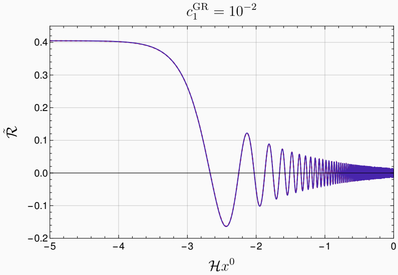
Classical dynamics with trans-Planckian QG effects

Results

✓ QG corrections to the dynamics of trans-Planckian scalar isotropic pert.

✓ Good GR matching at larger scales.



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⚠ Physical (perhaps observable) consequences of trans-Planckian suppression?

⚠ EFT/modified gravity description?

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⚠ Different fundamental d.o.f. $\longrightarrow$ different perturbation dynamics?

⚠ Scalar field perturbations? EFT description?

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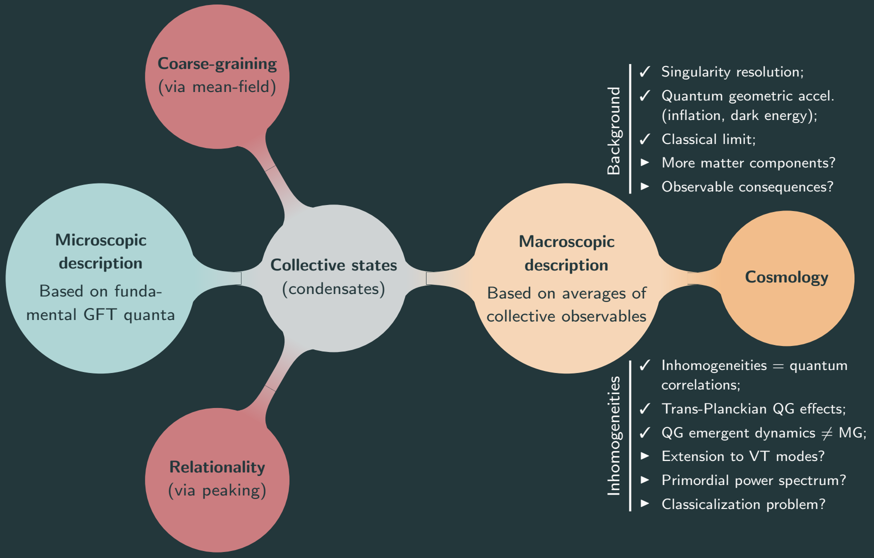
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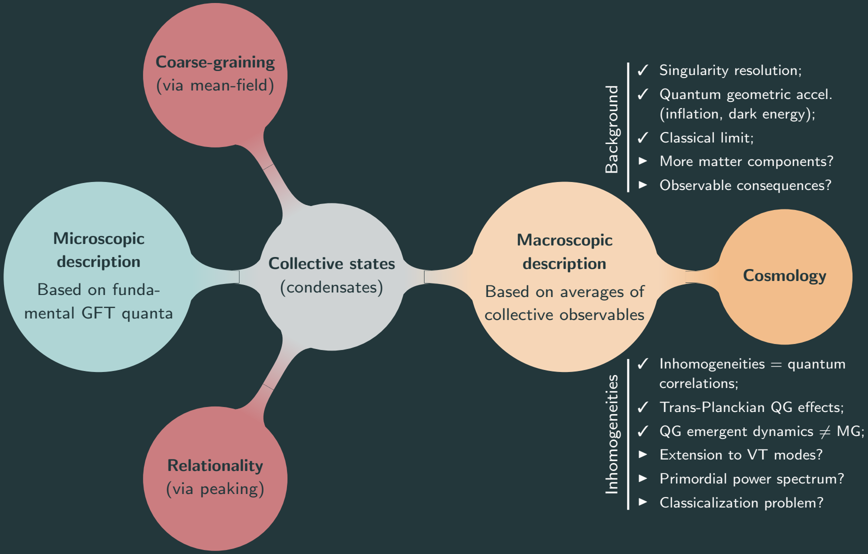
(condensates)
Relationality
(via peaking)
Macroscopic description
Based on averages of collective observables
Cosmology
Background
✓ Singularity resolution;
✓ Quantum geometric accel. (inflation, dark energy);
✓ Classical limit;
► More matter components?
► Observable consequences?
Inhomogeneities
✓ Inhomogeneities = quantum correlations;
✓ Trans-Planckian QG effects;
✓ QG emergent dynamics ≠ MG;
► Extension to VT modes?
► Primordial power spectrum?
► Classicalization problem?



More results to come! Stay tuned or (even better) tell us what to look for!