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Effective LTB: from dust collapses to regular black holes

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Black Holes

Gain insights by modeling the dynamical process of a gravitational collapse scenario with corrections from LQG.

- Our playground: spherical symmetric model with dust (perfect fluid, no pressure), solving Einstein's field equations: **Lemaître-Tolman-Bondi spacetimes**
- **Effective** description: classical model with corrections from LQG

General strategy of our approach:

- **Mimic** classical gauge fixing procedure in effective model
  $\Rightarrow$ Reduce general spherical symmetric spacetime to its LTB sector
- Start with **general** ansatz for effective model (not only motivated from $\overline{\mu}$-scheme and its reduced quantization [Chiou, Ni, Tang '12], [Gambini, Olmedo, Pullin '20])
- Receive effective LTB models as a 1+1 **field theory** model

Classical LTB model

classical LTB sector in spherical sym. spacetimes

- Impose spherical symmetry on triad and connection (A, E) and fix Gauß constraint

  [Bengtsson '90], [Bojowald Kastrup '00], [Bojowald, Swiderski '06]

$$H = \int \mathrm{d}x\,(NC + N^x C_x), \qquad \{K_x(x), E^x(y)\} = \{K_\phi(x), E^\phi(y)\} = G\delta(x, y)$$

- Spherical symmetric metric has form

$$\mathrm{d}s^2 = -N(x,t)^2 dt^2 + \frac{(E^\phi)^2}{|E^x|}(dx + N^x dt)^2 + |E^x| d\Omega^2\,.$$

- To get to the LTB solution, we need

$$N = 1 \qquad N^x = 0 \qquad G_x(x) = \frac{E^{x\prime}}{2E^\phi}(x) - \sqrt{1 + \mathcal{E}(x)} = 0$$

Gauge Fixings

The LTB sector can be reached by the two gauge fixings

$$\Big(C \longrightarrow G_T = T(x) - t\Big)\,, \qquad \left(C_x \longrightarrow G_x = \frac{E^{x\prime}}{2E^\phi}(x) - \sqrt{1 + \mathcal{E}(x)}\right)$$

Effective LTB models

Effective primary Hamiltonian

Consider effective model with temporal gauge fixed primary Hamiltonian

$$H_P^{\Delta}[N^x] = \int \mathrm{d}x \, (C^{\Delta} + N^x C_x)(x) \, ,$$

and the polymerized gravitational contribution of the scalar constraint

$$C^{\Delta}(x) = \frac{E^{\phi}}{2G\sqrt{E^x}} \left[-(1+f)E^x \left(\frac{4K_x K_{\phi}}{E^{\phi}} + \frac{K_{\phi}^2}{E^x} \right) + h_1 \left(\left(\frac{E^{x\prime}}{2E^{\phi}} \right)^2 - 1 \right) + 2\frac{E^x}{E^{\phi}} h_2 \left(\frac{E^{x\prime}}{2E^{\phi}} \right)' \right] .$$

The polymerization functions have classical limit

$$h_1(E^x) \to 1 \qquad h_2(E^x) \to 1 \qquad f(K_x/E^{\phi}, K_{\phi}, E^x) \to 0$$

$\Rightarrow$ Investigate dynamically stable reductions to LTB sector

effective LTB condition: $$G_x^{\Delta} = \frac{E^{x\prime}}{2E^{\phi}} - g_{\Delta}\left(\widetilde{K}_x, K_{\phi}, E^x, \mathcal{E}\right)$$

Results

Key results

- **Closure** of C^{Δ}, C_x algebra ensures **existence** of LTB reduction
- Can give **consistency** equations for various classes of effective models
  - models can have inverse triad and holonomy corrections **simultaneously**
  - **classical** LTB condition can also be embedded in certain effective models
  - K_x polymerization is very **restricted** ($\{C^{\Delta}[M], C^{\Delta}[N]\} \neq 0$ and only marginal case)
- Equations of motion in LTB sector are **decoupled** (we work in Lemaître coords.)

  $\Rightarrow$ Start with eff. LQC model and reconstruct eff. LTB model with same dynamics
- Can consider **different** radial coordinates due to underlying spherical symm. model
- Sometimes we can find underlying **covariant** Lagrangian $\Rightarrow$ regain **all** coord. trafos

Applications

dust collapse

- Due to decoupled EOM: **adapt** dynamics of shells to improved LQC dynamics
- **Analytical** solution for arbitrary dust profiles in marginally bound case $\mathcal{E}(x) = 0$
- **No** shell crossing singularities in vacuum and OS-collapse, but in inhomogeneous
- Underlying covariant Lagrangian given by **mimetic** gravity

polymerized vacuum solutions (also see Hongguang's talk)

- Consider effective LTB models with **conserved** (Hamiltonian) energy density C^{Δ}

  $\Rightarrow$ To specialize on effective vacuum case set $C^{\Delta} = 0$
- Rediscover **Birkhoff-like** theorem:

  gen. solution is **unique** one parameter family of stationary, asympt. flat solutions
- Schwarzschild-like coordinates: corresponds to **family** of metrics given by **monotonic** segments of solution written in Lemaître coordinates
- Vice virsa: from Schwarzschild-like metric can **reconstruct** effective sph. symm. Hamiltonian with underlying (mimetic) Lagrangian

Conclusion

Summary

- Our framework allows construction of effective LTB models with holonomy and inverse triad corrections under certain assumptions (no polymerization of diffeo)
- LQC model as starting point: field theoretic model for inhomogeneous dust collapses
  $\Rightarrow$Underlying mimetic model provides all coordinate transformations
- Powerful framework for effective vacuum solutions:
  different coordinates, polymerized Hamiltonian, covariant Lagrangian

Future work

- Extend analysis to inhomogenous dust collapses $\rightarrow$ Hongguangs talk
- Study further phenomenological properties like BH evaporation
- Consider non-marginally bound case and other types matter

Thank you for your attention!