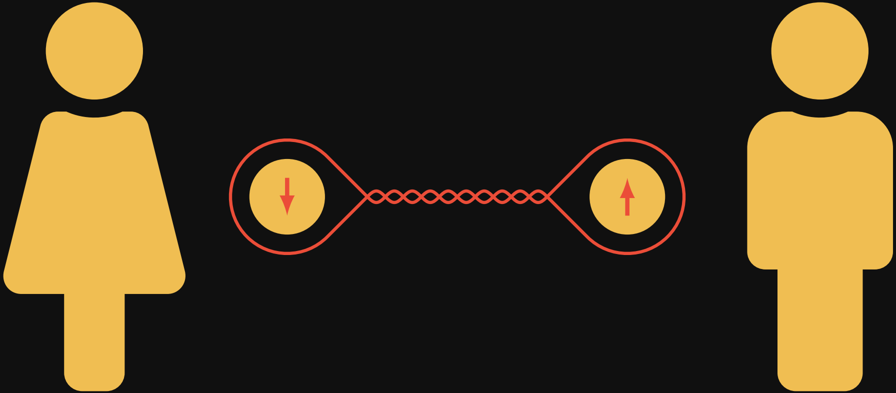


Aguiar Alves, Landulfo, and Pereira 2023, in preparation. Aguiar Alves 2023, `arXiv: 2305.17453 [gr-qc]`.

nonperturbative RG improvement

“exploding” cutoffs

matches $\overline{\text{MS}}$ qualitatively

first FRG flow for a particle detector

`meet.google.com/dum-fttr-hyz`

Aguiar Alves, Landulfo, and Pereira 2023, in preparation. Aguiar Alves 2023, `arXiv: 2305.17453 [gr-qc]`.

Quantum Einstein Cubic Gravity - *Gabriel Assant, Daniel Litim*

Higher-curvature gravities are of interest in the search for Asymptotically Safe Quantum Gravity theories.

f(R), R polynomials

[Lauscher, Reuter '02] [Codello, Percacci, Rahmede '08] [Machado, Saueressig '09] [Benedetti, Caravelli '12] [Dietz, Morris '12] [Falls, Litim, Nikolakopoulos, Rahmede '13,'14] [Falls, King, Litim, Nikolakopoulos, Rahmede '18]

higher-derivative

[Codello, Percacci '05] [Benedetti, Saueressig, Machado '09] [Niedermaier '09] [Falls, King, Litim, Nikolakopoulos, Rahmede '18]

natural to add higher curvature terms to UV complete gravity ⟷ **these can lead to ghosts (non-unitary modes)**

[Stelle '76]

Einsteinian gravities are ESPECIALLY INTERESTING even classically:

- **Only propagates a graviton on maximally symmetric backgrounds: ghost free, interesting for unitarity**

- **Interesting 4D classical BH solutions**

  - smoothly reduce to Schwarzschild BH

  [Bueno, Cano '17]
  [Hennigar, Mann '17]
  [Bueno, Cano, Hennigar '19]

  - softened singularity at the origin

  [Sajadi, Hendi '22]
  [Bueno, Cano, Hennigar, Lu, Moreno '22]

  - 1st law of BH thermo is exactly satisfied

<u>Example:</u> Einsteinian Cubic Gravity (ECG) is non-trivial and non-topological in 4D

$$\mathcal{L}^{d=4}_{\mathrm{ECG}} = \underbrace{\frac{1}{16\pi G_N}(-2\Lambda + R)}_{\text{Einstein-Hilbert}} + \underbrace{\alpha\chi_4}_{\text{Gauss-Bonnet}} + \underbrace{\xi\mathcal{P}}_{\text{ECG}}$$

Apply a RG-type argument to ECG. What survives in the quantum world?

- **Does this theory have fixed points? Can we extend the range of validity of ECG beyond the Planck scale?**
- **What are the quantum corrections of the RG improved BH solutions?**

‘Quantum Spacetime and the Renormalization Group 2023’

Sant'Elmo Beach Hotel, 2/10/2023

The role of the conformal factor in AS

Ultraviolet behavior of conformally reduced quadratic gravity [1]

Poster link: https://1drv.ms/b/s!AosslUPuXxdWo3WXhki_HK9Nqof2?e=WwxqO0

Speaker: Maria Conti
Università degli Studi dell’Insubria
INFN Milano Statale

Supervisor: S.L. Cacciatori
Università degli Studi dell’Insubria
INFN Milano Statale

Collaborators: A.M. Bonanno
Università degli Studi di Catania
INAF Osservatorio Astrofisico di Catania

INFN Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DELL’INSUBRIA

[1] **A. Bonanno**, **M. Conti** and **S. Cacciatori**, ‘*Ultraviolet behavior of conformally reduced quadratic gravity*’, Phys. Rev. D, vol. 108 (2023)

AS: promising results and still open problems

The question : is there a way to renormalize gravity non perturbatively? [2]

AS: looking for a NGFP!

$$\Gamma[g_{\mu\nu}] = \int d^d x \sqrt{g} \left\{ q_0 + q_1 R + q_2 R^2 + \cdots \right\}$$

- At the moment many results have been obtained, but always working with truncations! [3,4]
- Working with general **f(R)** has been not as effective up until now...[3,4,5]

[2] **S. Weinberg**, in '*General Relativity: An Einstein centenary survey*', ed. **S.W. Hawking** and **W. Israel**, 790–831, Cambridge University Press (1979)
[3] **P.F. Machado** and **F. Saueressig**, '*On the renormalization group flow of f(R)-gravity*', Phys. Rev. D, Vol. 77 (2008)
[4] **K. Falls** *et. al.* , '*Asymptotic safety of quantum gravity beyond Ricci scalars*', Phys. Rev. D, Vol. 97, Issue 8 (2018)
[5] **M. Demmel** *et al.* , '*RG flows of Quantum Einstein Gravity on maximally symmetric spaces*', JHEP, Vol. 06 (2014)

Less is more: the role of conformally reduced theories

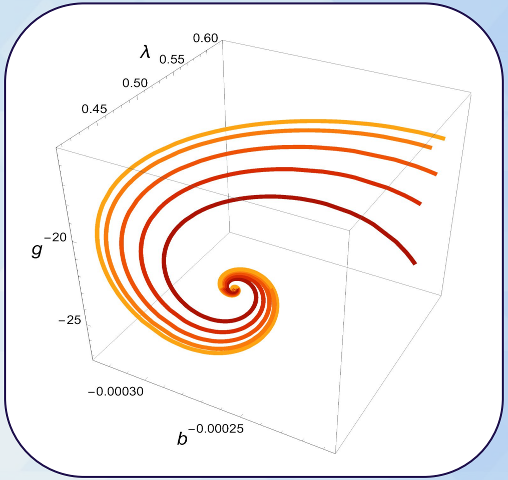
CREH All the metrics involved are **conformal factors** of a reference metric $g_{\mu\nu} = \phi^2 \hat{g}_{\mu\nu}$

Simplicity:
we only deal with a scalar field!

Promising pre-existing results:
Reuter UV FP for EH theory in both spherical and flat geometry! [6]

What happens at bigger curvatures? **R+R²**

Spoiler



And if so… do we recover similar characteristics with the full theory results?

[6] **A. Bonanno** and **F. Guarnieri**, '*Universality and symmetry breaking in conformally reduced quantum gravity*', Phys. Rev. D, vol. 86, Issue 10, (2012)

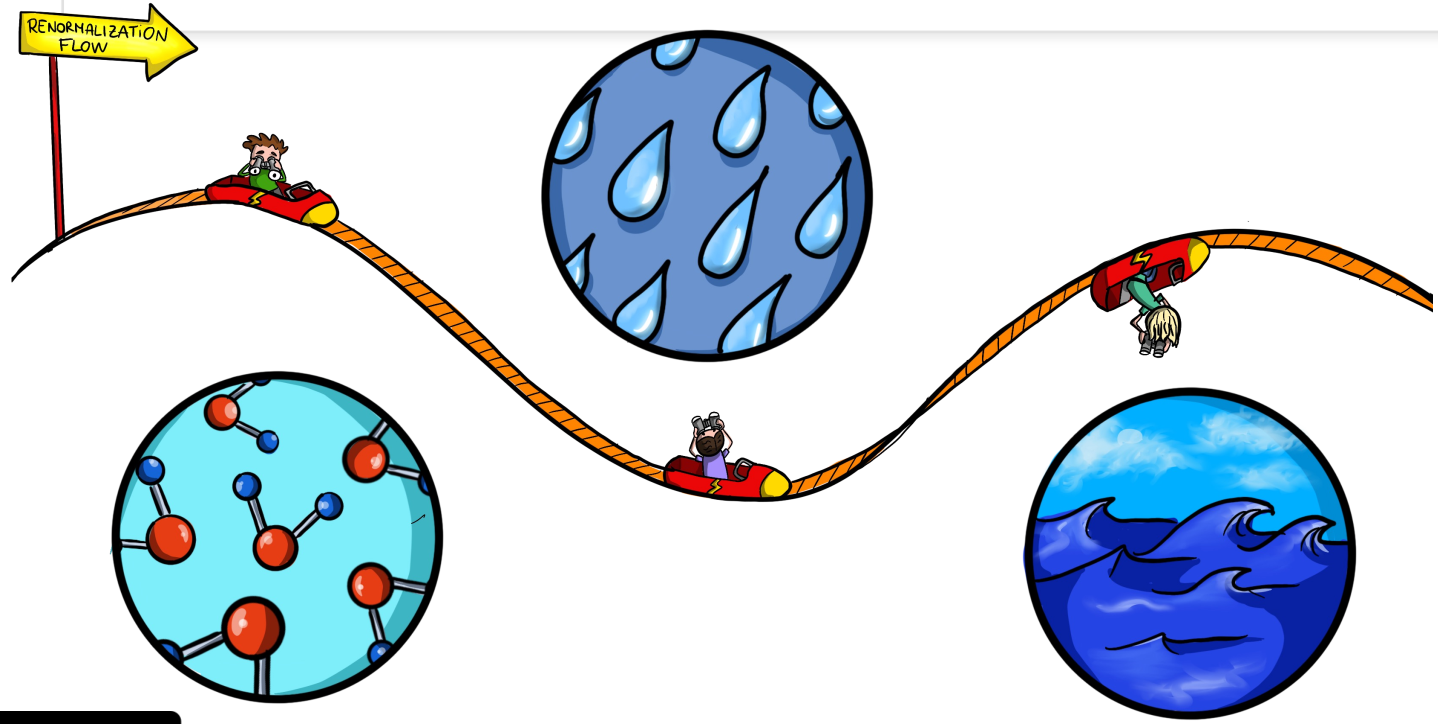
Functional Renormalization Group in perturbative Algebraic Quantum Field Theory

Edoardo D'Angelo

Department of Mathematics, University of Genova

Istituto Nazionale di Fisica Nucleare (INFN)
Istituto Nazionale di Alta Matematica (INdAM-GNFM)

How to go with the Lorentzian flow



- Choose an Ansatz for the effective average action
- Choose a state for the free theory
- Compute the Hadamard expansion
- Flow!

$$\partial_k \Gamma_k = -\frac{1}{2}\int_x \partial_k q_k(x) : G_k : (x,x)$$

SCAN ME

Follow for more!

Zoom Meeting ID: 850 0332 5266 Passcode: 4U3BNc

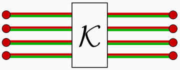
https://us05web.zoom.us/j/85003325266?pwd=Svh0ir1CaHfbzsFRJaqibX8Bj9O2PO.1

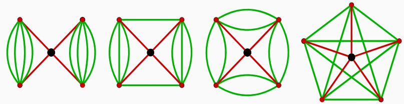
Landau-Ginzburg Analysis of Lorentzian TGFTs

based on 2209.04297 (Marchetti, Oirit, Pithis, Thürigen) & wip

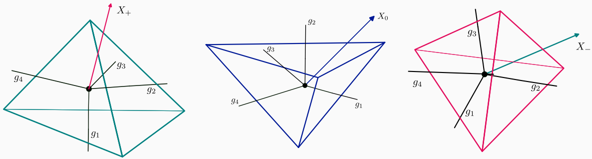
Tensorial **G**roup **F**ield **T**heories

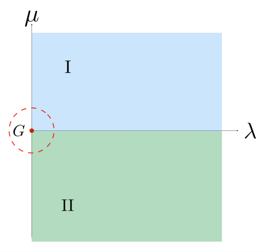
are non-local field theories of spacetime





- Mean-field analysis around the Gaussian fixed point
- Include all causal building blocks of spacetime





Alexander Jercher

MCQST

October 2, 2023

Non-perturbative aspects of two-dimensional $T\overline{T}$ deformed scalar theory from functional renormalization group

arXiv:2309.15584

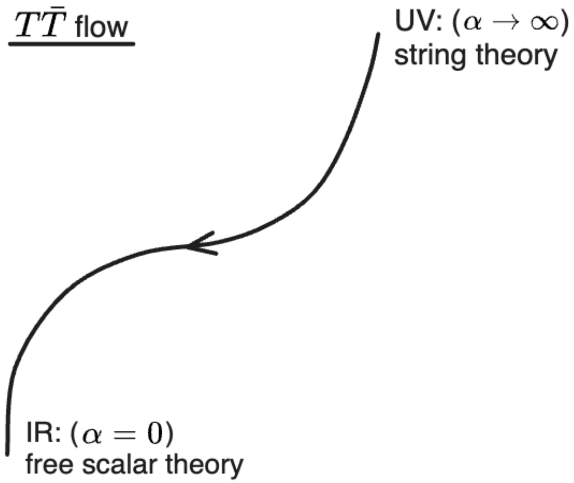
Jie Liu (Jilin Univ., China),
Junichi Haruna (Osaka Univ., Japan),
Masatoshi Yamada (Jilin Univ., China)

2d $T\bar{T}$ deformed scalar theory

$$S = \int \mathrm{d}^2 x \left[\frac{1}{2} (\partial_\mu \vec{\phi})^2 - \frac{m^2}{2} \vec{\phi}^2 + \alpha \det(T_{\mu\nu}) \right]$$

canonical mass dimension $[\alpha] = -2$

irrelevant deformation: perturbatively nonrenormalizable



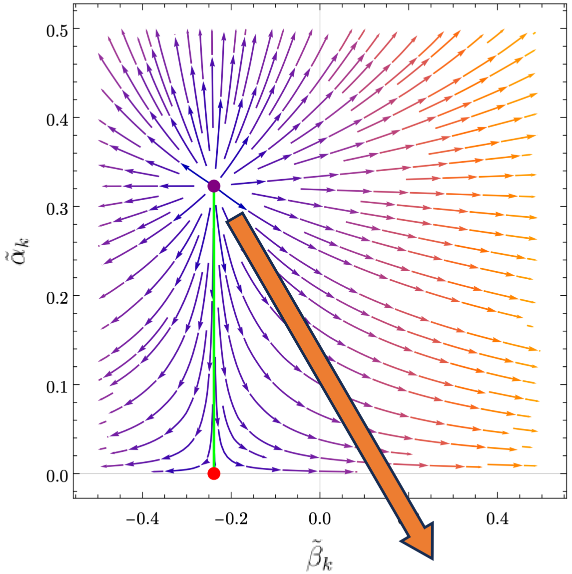
Fixed point structure in the non-perturbative regime?

Non-perturbative renormalizable

$$\Gamma_k = \int \mathrm{d}^2x \left[\frac{1}{2}(\partial_\mu \vec{\phi})^2 + \frac{m_k^2}{2}\vec{\phi}^2 + \frac{\kappa_k}{2} T_{\mu\nu} C^{\mu\nu} + \Lambda_k + \lambda_k C + \frac{Z_{C,k}}{2}(\partial_\rho C^{\mu\nu})^2 - \frac{1}{8\alpha_k}\det(C^{\mu\nu}) + \beta_k C_{\mu\nu} C^{\mu\nu} \right].$$

$C^{\mu\nu}$: auxiliary tensor field

Functional renormalization group



Non-trivial fixed point

Critical exponents of α

For Gaussian fixed point: $\theta_\alpha = -2$

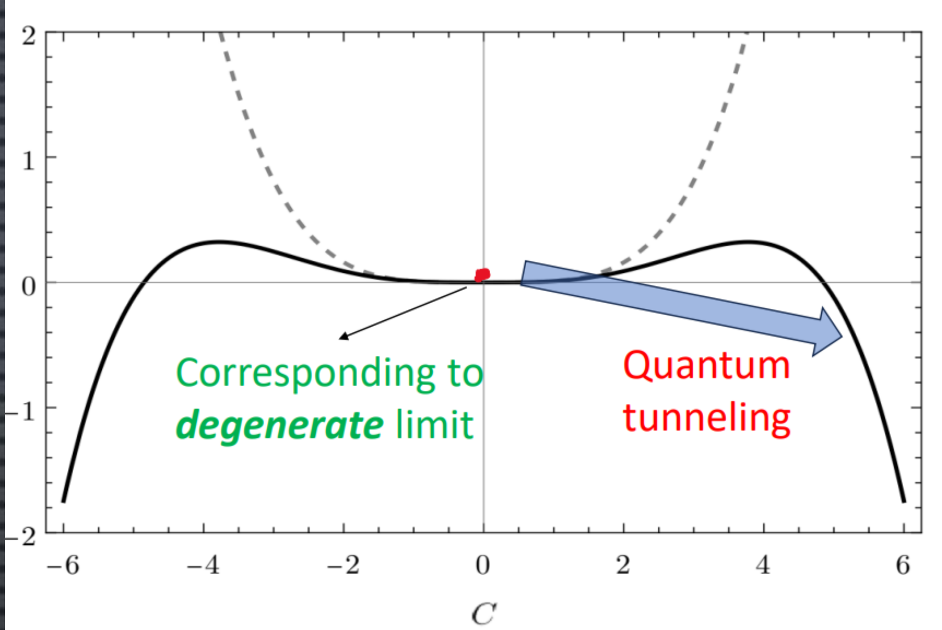
For non-trivial fixed point: $\theta_\alpha = 4.02$ (N=1)

Non-perturbative renormalizable

Irreversible vierbein postulate: Emergence of spacetime from quantum phase transition

Yadikaer Maitiniyazi,[*1] Shinya Matsuzaki,[*2] Kin–ya Oda,[+3] and Masatoshi Yamada[*4]
∗Center for Theoretical Physics and College of Physics, Jilin University, Changchun 130012, China
†Department of Mathematics, Tokyo Woman’s Christian University, Tokyo 167-8585, Japan

A model for quantum gravity based on the local-Lorentz symmetry and diffeomorphism.



1. What are degrees of freedom of Gravity?
2. Dynamical origin of spacetime.
3. Toward quantum gravity.

Poster

- **Irreversible vierbein**
- **Analogy with O(N) non-linear sigma model**
- **Action with Irreversible vierbein postulate**
- **Local Lorentz (LL) and General coordinate (GC) transformations**
- **Dynamical generation of flat spacetime from spinor loop**

Boundaries and renormalization:
the variational principle of gravity at different scales

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INFN, Section of Trieste
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MA PER SEGUIR VIRTUTE E CANOSCENZA • SISSA •

On the resilience of the gravitational variational principle under renormalization (To appear in JHEP)

Boundaries and renormalization

- Bulk and boundary couplings have *matching conditions*
  - Boundary conditions on fields determine the boundary Lagrangian
- Bulk and boundary couplings have different running

- So far: Consistent renormalization of Newton constant(s)
  - Gauge fields
  - Gravitons
  - Scalar fields

  Gauge invariance
- What we looked for: Consistent renormalization of higher-order couplings

The ambient space formalism: a toolkit for the conformal anomaly

Gregorio Paci
gregorio.paci@phd.unipi.it

Based on a work in progress in collaboration with O. Zanusso

Quantum Spacetime and the Renormalization Group 2023

Istituto Nazionale di Fisica Nucleare

Università di Pisa

Sant'Elmo Beach Hotel, Sardinia, 2023-10-6

The conformal (trace) anomaly is signalled by the non-zero vev

$$-\frac{2g_{\mu\nu}}{\sqrt{g}}\frac{\delta\Gamma[g]}{\delta g_{\mu\nu}} = \langle T^{\mu}{}_{\mu}\rangle = aE_d + \sum_I b_I W_{d,I} + a'\nabla_\mu \mathcal{J} \neq 0. \tag{1}$$

The different contributions to the anomaly are[1]

- a-anomaly: the Euler density
- b-anomalies: the sum of all Weyl invariant scalars
- a'-anomalies (or trivial anomalies): total derivatives terms.

They can also be understood imposing the Wess-Zumino consistency conditions, which state that the Weyl group is abelian.

[1] S. Deser and A. Schwimmer, Phys. Lett. B 309, 279-284 (1993)

The toolkit: ambient space formalism

The ambient metric[2] in coordinates $x^A \overset{*}{=} (t, x^\mu, \rho)$ is

$$\tilde{g} = \tilde{g}_{AB} dx^A dx^B \overset{*}{=} 2\rho dt^2 + 2t dt d\rho + t^2 h_{\mu\nu}(x,\rho) dx^\mu dx^\nu, \tag{2}$$

$\rho = 0$ is a null cone. Two crucial aspects: **1)** $T = t\partial_t$ is an homothety of $\tilde{g}$ (scale transf) and **2)** Ricci flatness $\tilde{R}_{AB} = 0$. This condition can be solved around $\rho = 0$ to fix terms in the exp

$$h_{\mu\nu}(x,\rho) = \sum_{p \geq 0} \frac{\rho^p}{p!} h^{(p)}{}_{\mu\nu}, \tag{3}$$

where $h^{(p)}{}_{\mu\nu} = (\partial_\rho)^p h_{\mu\nu}|_{\rho=0}$ and $h^{(0)}{}_{\mu\nu} = g_{\mu\nu}$.

Weyl $g'_{\mu\nu} = e^{2\sigma} g_{\mu\nu}$ are induced by a subgroup of ambient diffeo: covariance on $\rho = 0$ is realized as diffeo covariance in the ambient manifold.

Our results show that the ambient space gives all the ingredients in (1) and gives a general simple algorithm to integrate this equation.

[2] Fefferman and C. R. Graham, Ann. Math. Stud. 178, 1-128 (2011)

A regular black hole from an effective Action for collapsing matter in quantum gravity

Antonio Panassiti (Università degli Studi di Catania)
in collaboration with Alfio Bonanno and Daniele Malafarina

- Oppenheimer-Snyder model in General Relativity:

gravitational collapse ⟶ Schwarzschild black hole

- Our model implementing the idea of an *asymptotically safe gravitational interaction*:

gravitational collapse ⟶ some regular black hole

How?

"Dust collapse in asymptotic safety: a path to regular black holes",
e-Print: 2308.10890 [gr-qc]

Starting point: a modified Action (Markov-Mukhanov, 1985)

$$S = \frac{1}{16\pi G_N}\int d^4x\sqrt{-g}\,[R + 2\chi(\epsilon)\mathcal{L}]\,.$$

matter Lagrangian

χ(ε) is a multiplicative gravity-matter coupling function

ε is the energy-density of the perfect fluid matter source

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \boxed{\frac{\partial(\chi\epsilon)}{\partial\epsilon}}T_{\mu\nu} + \frac{\partial\chi}{\partial\epsilon}\epsilon^2 g_{\mu\nu} \quad \longleftrightarrow \quad \boxed{8\pi G(\epsilon) = \frac{\partial(\chi\epsilon)}{\partial\epsilon}}$$

Choice of G(ε):

$$G(k) = \frac{G_N}{1 + G_N k^2/g_*} \longrightarrow G(\epsilon) = \frac{G_N}{1+\xi\epsilon} \longrightarrow$$

Next: study of the field equations…

Thank you for your attention

Asymptotic Safety in generalized Proca theories

L. Heisenberg, G. Lambiase, A.B. Platania, **S. Rufrano Aliberti**

Abstract

We investigate the possible ultraviolet completion of a subclass of generalized Proca theories. Technically, this analysis involves deriving the beta functions of the theory and investigating their fixed points and corresponding stability properties.

Analyzed Lagrangian

The subclass of generalized Proca theories considered is up to the second order of the vector field, *i.e.*

$$\mathscr{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} m^2 A_\mu A^\mu + \frac{1}{16\pi G}\{R - 2\Lambda\} + g_4 R\, A_\mu A^\mu$$

Results

	Dimensionless couplings				Critical Exponents			
	λ_k^*	g_k^*	${g_2}_k^*$	${g_4}_k^*$	θ_1	θ_2	θ_3	θ_4
Gaussian Fixed Point	0	0	0	0	2	2	−2	0
Non-Gaussian Fixed Point	0.1859	0.6663	0.2416	−0.08977	−1.052	1.628 − i2.935	1.628 + i2.935	−1.764

Thermodynamics of Quantum-Improved Black Holes in Asymptotic Safety

Giorgia Russo
giorgiahprusso@gmail.com

University of Pisa

2 October 2023

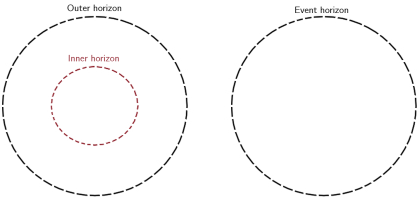
Objective: Study the structure and thermodynamics of quantum-improved **rotating BHs** within **Asymptotic Safety**

How?

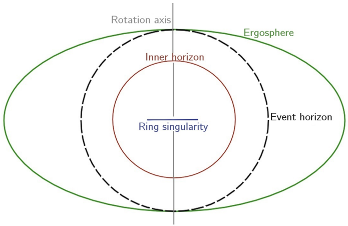
- We start with the **Bonanno-Reuter scale identification**

$$G(r) = \frac{G_0 r^3}{r^3 + \tilde{\omega} G_0 (r + \gamma G_0 M)}$$

- We apply the Azreg-Aïnou algorithm to the BRBH



Static, spherically symmetric metric



Rotating, axially symmetric metric

- We analyze the properties of the resulting BH

Covariant spin-parity decomposition of the Torsion and Path Integrals

Dario Sauro

PhD student at the University of Pisa

Quantum Spacetime and the Renormalization Group 2023
Sant'Elmo Beach Hotel

Based on gr-qc/2304.08360, in collaboration with R. Martini and G. Paci

IN SUPREMÆ DIGNITATIS 1343
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Flat-space spin-parity eigenstates of the Torsion

[Baldazzi, Percacci, Melichev, Annals of Physics 438 (2022) : 168757]

$$T^{\rho}{}_{\mu\nu} = \frac{1}{d-1}(\delta^{\rho}{}_{\nu}\tau_{\mu} - \delta^{\rho}{}_{\mu}\tau_{\nu}) + \frac{1}{3!(d-3)!}\varepsilon^{\sigma\rho}{}_{\mu\nu}\theta_{\sigma} + \kappa^{\rho}{}_{\mu\nu}$$

	ha	ta
Field variable	$\kappa^{\rho}{}_{\mu\nu},\ \tau_{\mu}$	θ_{μ}
ttt	$2^{-}, 1^{-}$	0^{-}
$ttl + tlt + ltt$	-	1^{+}
$\frac{3}{2}ltt$	$1^{+},$	-
$ttl + tlt - \frac{1}{2}ltt$	$2^{+}, 0^{+}$	-
$tll + ltl + llt$	1^{-}	-
lll	-	-

Full decomposition

$$
\begin{aligned}
T^{\rho}{}_{\mu\nu} = {} & \frac{1}{d-1}\left(\delta^{\rho}{}_{\nu}\tau_{\mu} + \delta^{\rho}{}_{\nu}\partial_{\mu}\varphi - \delta^{\rho}{}_{\mu}\tau_{\nu} - \delta^{\rho}{}_{\mu}\partial_{\nu}\varphi\right) \\
& + \frac{1}{3!(d-3)!}\varepsilon^{\sigma_1\cdots\sigma_{d-3}\rho}{}_{\mu\nu}\left(\theta_{\sigma_1\cdots\sigma_{d-3}} + \nabla_{[\sigma_1}\pi_{\sigma_2\cdots\sigma_{d-3}]}\right) \\
& + \kappa^{\rho}{}_{\mu\nu} + \nabla_{\mu}\overline{S}^{\rho}{}_{\nu} - \nabla_{\nu}\overline{S}^{\rho}{}_{\mu} + 2\nabla^{\rho}A_{\mu\nu} + \nabla_{\mu}A^{\rho}{}_{\nu} - \nabla_{\nu}A^{\rho}{}_{\mu} \\
& + \nabla^{\rho}\nabla_{\mu}\zeta_{\nu} - \nabla^{\rho}\nabla_{\nu}\zeta_{\mu} - \frac{1}{d-1}\left[\delta^{\rho}{}_{\nu}\left(R^{\lambda}{}_{\mu}\zeta_{\lambda} - \Box\zeta_{\mu}\right) - (\nu\leftrightarrow\mu)\right]
\end{aligned}
$$

Functional measure and Jacobian

[Codello, Percacci, Rahmede, Annals of Physics 324, (2009) : 414 – 469]

$$DT^{\rho}{}_{\mu\nu} = J\ D\tau_{\mu} D\varphi D\theta_{\mu} D\pi D\kappa^{\rho}{}_{\mu\nu} DS^{\rho}{}_{\nu} DA_{\mu\nu} D\zeta_{\mu}$$

From the normalization and taking the max. sym. limit we find

$$J = \left[det'_{\varphi}(-\Box)\right]^{\frac{1}{2}} \left[det'_{\pi}(-\Box)\right]^{\frac{1}{2}} \left[det_S\left(-\Box + \frac{R}{d-1}\right)\right]^{\frac{1}{2}} \times$$

$$\times \left[det_A\left(-\Box - \frac{(d-2)R}{d(d-1)}\right)\right]^{\frac{1}{2}} \left[det_{\zeta}\left(-\Box^2 - \frac{R^2}{d^2}\right)\right]^{\frac{1}{2}}$$

Evaluation on an S^4 yields the second Seeley-DeWitt coefficient

$$b_4{}^{\mathrm{tot}} = \frac{223}{270} R^2$$

The End

Thank you for your attention,
questions are welcome!

ERG for continuous tensor network and holography

Gota Tanaka (Doshisha University)

Central goal of our research: extract the geometry of bulk spacetime from quantum field theory (without gravity) on the boundary of the bulk.

⇨ We focused on the continuous tensor network models because they give networks that can be interpreted as continuous bulk spacetime.

The major finding of our study: non-perturbative differential equation for wave functionals

$$-\Lambda\partial_\Lambda\Psi_\Lambda[\varphi] = -\frac{1}{2}\int d^d\vec{p}\,\dot{C}_\Lambda(0,\vec{p})\left\{\frac{\delta\Psi_\Lambda}{\delta\varphi(p)\delta\varphi(-p)} + \frac{1}{\Psi_\Lambda}\frac{\delta\Psi_\Lambda}{\delta\varphi(p)}\frac{\delta\Psi_\Lambda}{\delta\varphi(-p)}\right\}$$
$$-\int d^d\vec{p}\,\frac{\dot{C}_\Lambda(0,\vec{p})}{C_\Lambda(0,\vec{p})}\varphi(\vec{p})\frac{\delta\Psi_\Lambda}{\delta\varphi(p)} - \frac{V}{2}\Psi_\Lambda\int d^d\vec{p}\,\frac{\dot{C}_\Lambda(0,\vec{p})}{C_\Lambda(0,\vec{p})}.$$

Wave functionals that are solutions to this equation are considered to represent the continuous tensor network, and we expect to extract the bulk geometry from them.

Constraining Vector Dark Matter Models from Quantum Gravity

Arthur Ferreira Vieira
University of Southern Denmark and Fluminense Federal University

Setup of the Dark Abelian SM extension

https://syddanskuni.zoom.us/j/61762699755

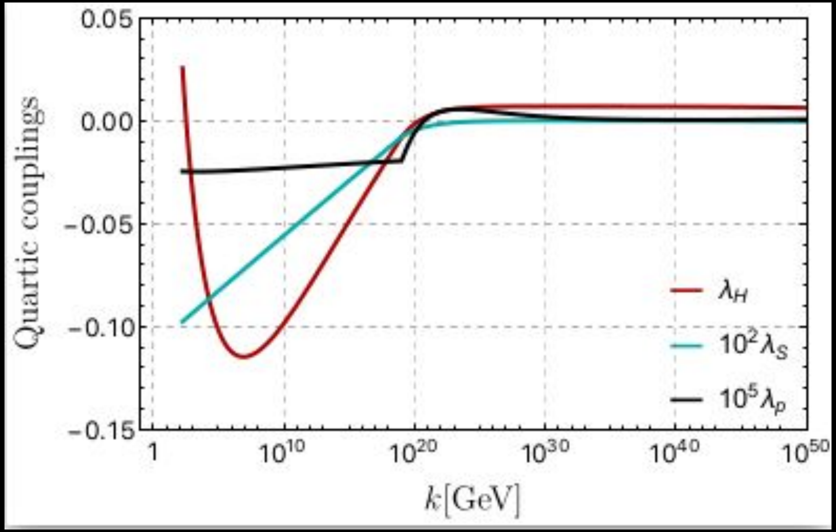
$$\Gamma_{k,\mathrm{DM}}^{U(1)_D} = \Gamma_{k,\mathrm{SM}}^{0} + \int_x \sqrt{g}\left[\tfrac{1}{4}V_{\mu\nu}V^{\mu\nu} + (D_\mu S)^*(D^\mu S)\right.$$
$$\left. m_\Phi^2 \Phi_i^\dagger \Phi_i + \frac{\lambda_H}{6}(\Phi_i^\dagger \Phi_i)^2 + m_D^2 S^* S + \frac{\lambda_D}{6}(S^* S)^2 + 2\lambda_p (\Phi_i^\dagger \Phi_i)(S^* S)\right]$$

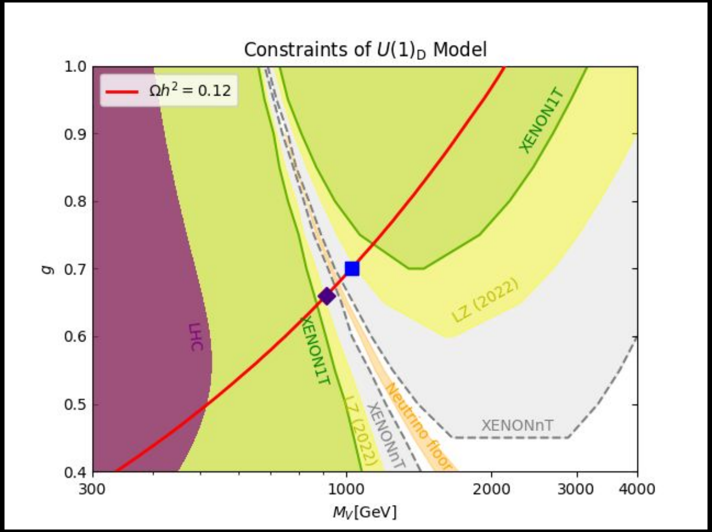
- DM candidate: V_μ
- No additional d.o.f. such as dark fermions
- Higgs-top-bottom system coupled with gauge interactions of $U(1)_\mathrm{Y} \times SU(2)_\mathrm{L} \times SU(3)_\mathrm{C}$
- Kinetic mixing between the dark vector and gauge field hypercharge prohibited: $\cancel{V_{\mu\nu} B^{\mu\nu}}$

October 2nd, 2023

in collaboration with Gustavo P. de Brito, Astrid Eichhorn, Mads T. Frandsen, Martin Rosenlyst and Mattias E. Thing

Constraints from ASQG and direct detection





- Benchmark value for dark gauge coupling: $g_D(M_V = 911\,\mathrm{GeV}) = 0.10$
- Hints at incompatibility: negative quartic couplings in the IR and we lie in the excluded region for by XENON1T where DM is overproduced from freeze-out.