The status of Hořava gravity

Mario Herrero-Valea

Institute of Physics, Laboratory of Particle Physics and Cosmology
École Polytechnique Fédérale de Lausanne

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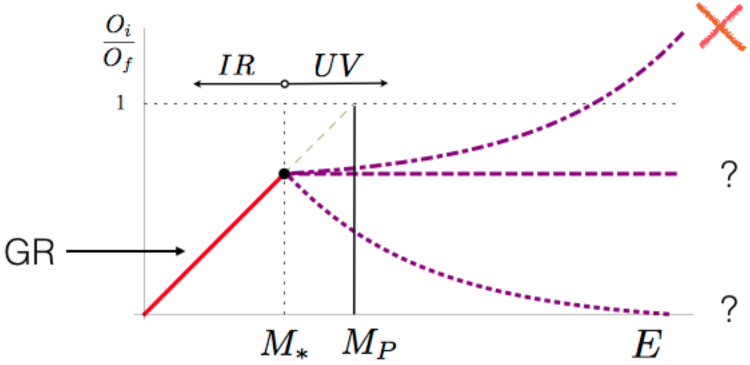
Can gravity be formulated as a pQFT?



[Figure by D. Blas]

A simple question

GR, $M_p^2\sqrt{g}R$ about a Minkowsky vacuum

$$\mathcal{L} \sim h^{\mu\nu}\frac{\mathcal{P}^{\mu\nu\alpha\beta}}{p^2}h^{\alpha\beta} + \frac{p^2}{M_p}O(h^3) + \frac{p^2}{M_p^2}O(h^4) + \ldots$$

The theory is non-renormalizable $\equiv$ infinite number of divergent diagrams

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Higher derivative gravity

$$M_p^2 R + \alpha R^2 + \beta R_{\mu\nu}R^{\mu\nu} \to \langle hh \rangle \sim \frac{M_P^2}{p^4 + p^2 M_p^2}$$

[K. S. Stelle, Phys. Rev. D 16, 953 (1977)]

However, it has a ghost

$$\langle hh \rangle \sim \frac{M_P^2}{p^4 + p^2 M_p^2} = \frac{1}{p^2} - \frac{1}{p^2 + M_p^2}$$

[Ostrogradski, M., Mem. Ac. St. Petersbourg, VI, 1850, 385]

The problem can be solved by allowing for a breaking of the boost invariance of the Lorentz group

26 Jan 2009

Quantum Gravity at a Lifshitz Point

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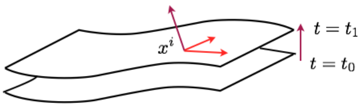
$$\langle hh \rangle \sim \frac{1}{\omega^2 + k^{2d} + c^2 k^2}$$

Anisotropic scaling $t \to b^d t$, $x^i \to b x^i$

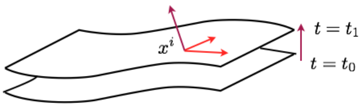
$$S \sim h_{ij} \left(\partial_t^2 + \partial_i^{2d} + \dots \right) h_{ab} + O(h^3)$$



ADM formulation

$$ds^2 = N^2 dt^2 + \gamma_{ij}(dx^i + N^i dt)(dx^j + N^j dt)$$

The non-linear theory



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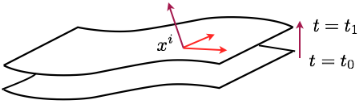

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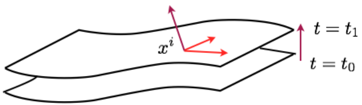

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$$S = \frac{1}{2G}\int dt d^d x\, N\sqrt{\gamma}\Big(\underbrace{K_{ij}K^{ij} - \lambda K^2}_{\partial_t^2} + \underbrace{\quad \mathcal{V} \quad}_{\partial_i^k, \quad k \le d}\Big)$$

$$\mathcal{V} \sim \left\{ R^3, \quad (a_i a^i)^3, \quad \Delta^2 R, \quad a_i a_j \Delta R^{ij}, \quad R^2, \quad R_{ijab}R^{ijab}, \quad R, \quad a_i a^i, \quad \partial_i a^i, \quad \dots \right\}$$

The theory can flow to GR if $\lambda \to 1$. It propagates a graviton and an extra scalar mode.

To be (projectable) or not to be

The role of N is particular, since there are no time derivatives of N

- Projectable version

$$N = N(t), \qquad a_i = 0$$

It is fully renormalizable. It contains less terms in $\mathcal{V}$ but there is a mode which undergoes strong coupling in the IR.

[A. Barvinsky, D. Blas, M. H-V., S. Sibiryakov and C. Steinwachs, Phys.Rev. D93 (2016) no.6, 064022]

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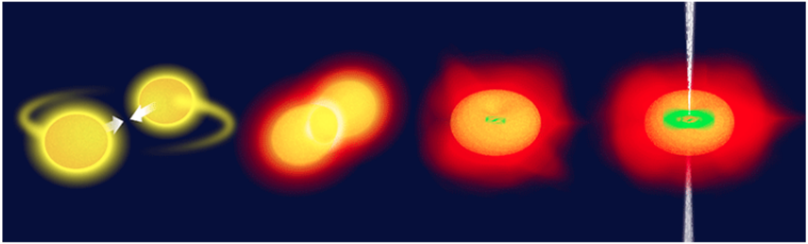
This was the status last summer



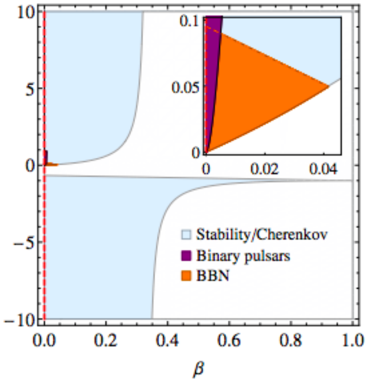
[APS/Alan Stonebraker, adapted from simulations by NASA/AEI/ZIB/M. Koppitz and L. Rezzolla]

$$c_T - 1 \leq 7 \times 10^{-16}$$

The status of the non-projectable model

$$\frac{1}{G}, \alpha, \beta, \gamma$$

$$|\beta| \leq 10^{-15}$$



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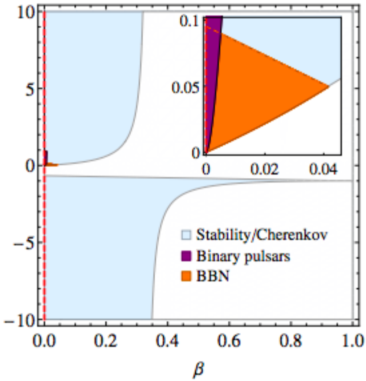

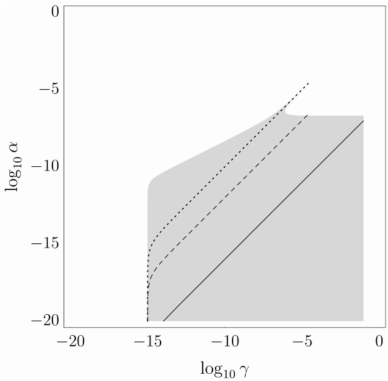

[Yagi, Blas, Yunes and Barausse, Phys.Rev.Lett. 112 (2014) no.16, 161101]

[Gümrükçüoğlu, Saravani, and Sotiriou, Phys.Rev. D97 (2018) no.2, 024032]

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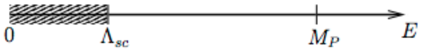

[Blas, Pujolas and Sibiryakov, JHEP 0910 (2009) 029]

We can study the UV structure in $2+1$ dimensions

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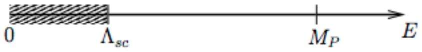

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Essential couplings

$$\lambda, \qquad \mathcal{G} = \frac{G}{\sqrt{\mu}}$$

Counter-terms are gauge invariant.

[A. Barvinsky, D. Blas, M. H-V., S. Sibiryakov and C. Steinwachs, Phys.Rev. D93 (2016) no.6, 064022]

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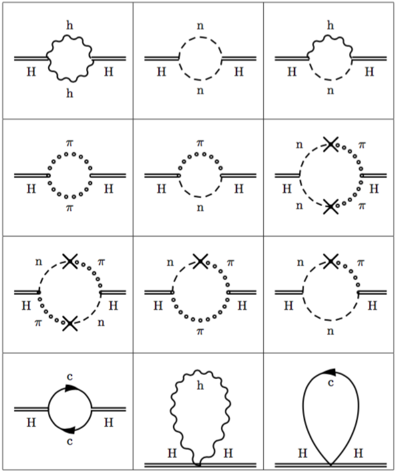
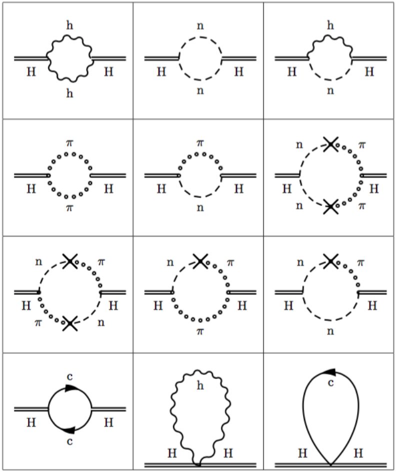


Figure 1. Feynman diagrams (bubbles and fishes) for the two point function of H_{ij}. The cross represents the mixed propagator $\langle n^i \pi^j \rangle$.

The vertices generically contain $\sim$ 100 terms due to multi-symmetries



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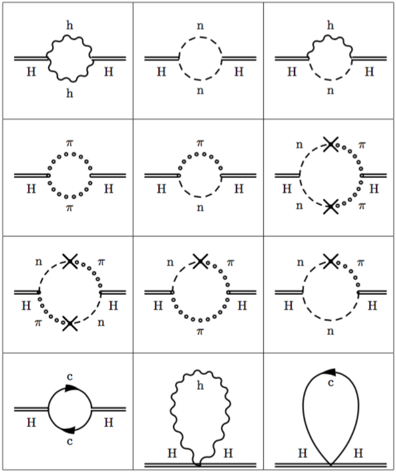

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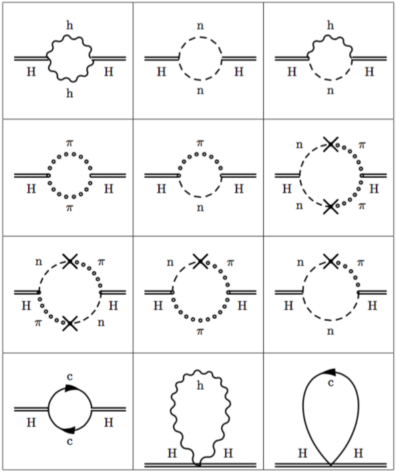

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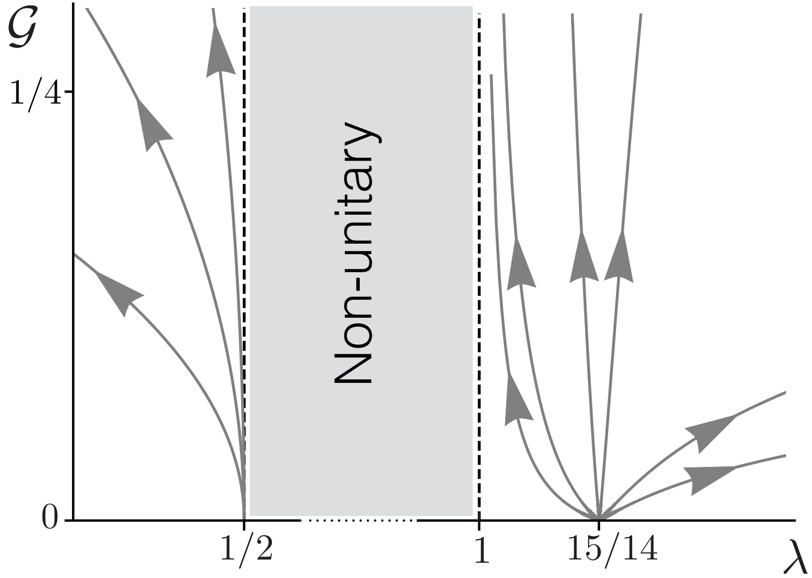
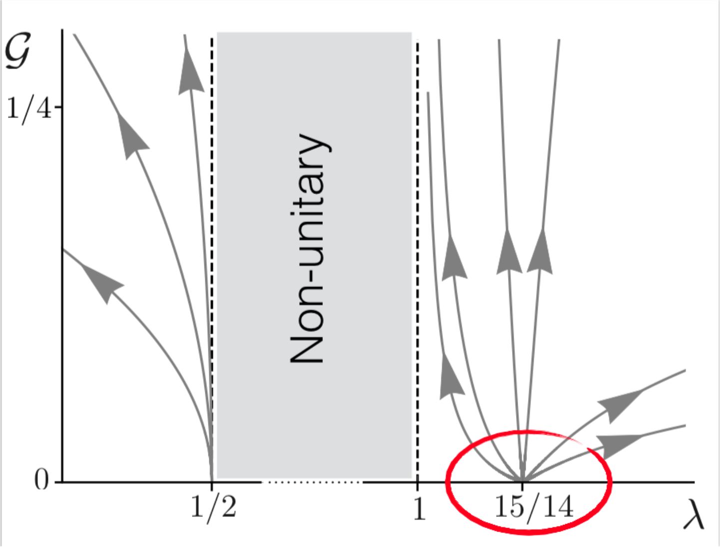
$$\beta(\lambda) = \frac{15 - 14\lambda}{64\pi} \sqrt{\frac{1-2\lambda}{1-\lambda}}\, \mathcal{G}$$

$$\beta(\mathcal{G}) = -\frac{16 - 33\lambda + 18\lambda^2}{64\pi(1-\lambda)^2} \sqrt{\frac{1-\lambda}{1-2\lambda}}\, \mathcal{G}^2$$



$\mathcal{G}$
1/4
0
Non-unitary
1/2
1
15/14
λ



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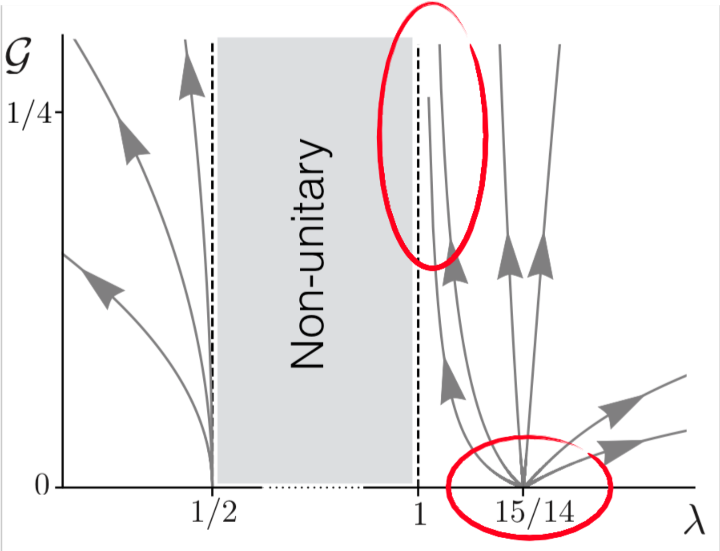

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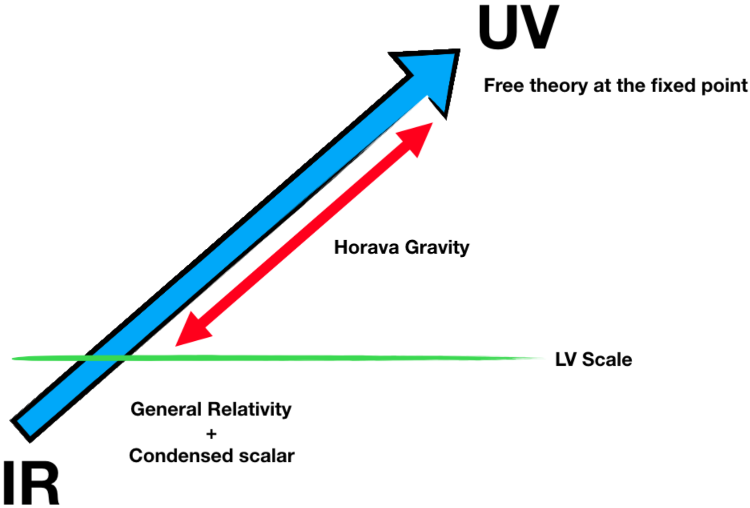
UV
Free theory at the fixed point
Horava Gravity
LV Scale
General Relativity
+
Condensed scalar
IR

Conclusions

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