Gravitational Waves, Black Holes and Fundamental Physics
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The IR limit of Hořava Gravity

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ArXiv:1512.02250, 1706.06809, 1905.03798, w.i.p.

With: A. Barvinsky, D. Blas, L. Obradovic, S. Sibiryakov
and C. Steinwachs

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ma per seguir virtute e canoscenza
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Why we are not happy with GR?

- It does not extend to arbitrary high energies
- It lacks an explanation for observed gravitational phenomena

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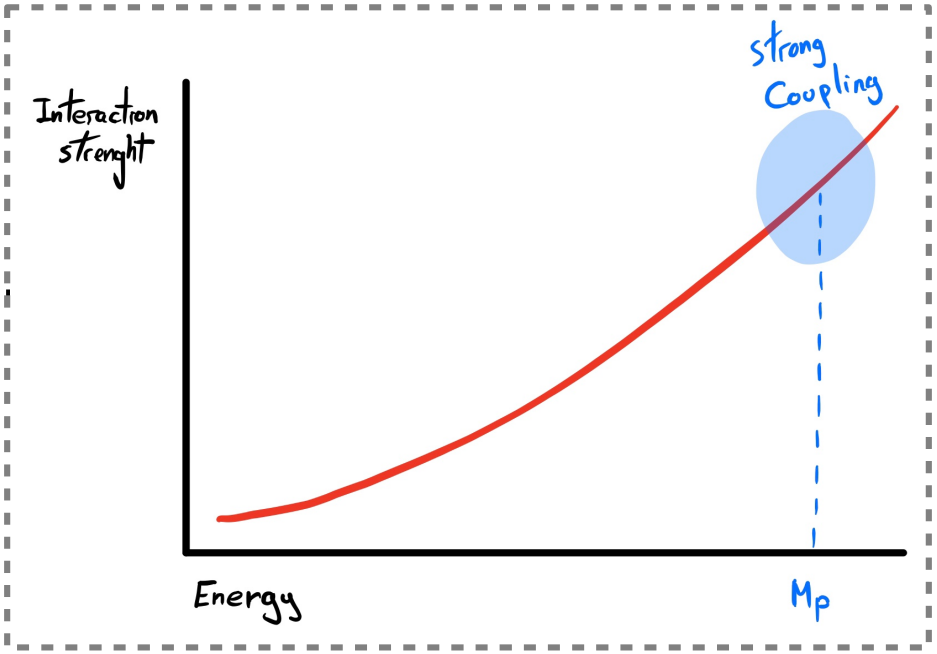

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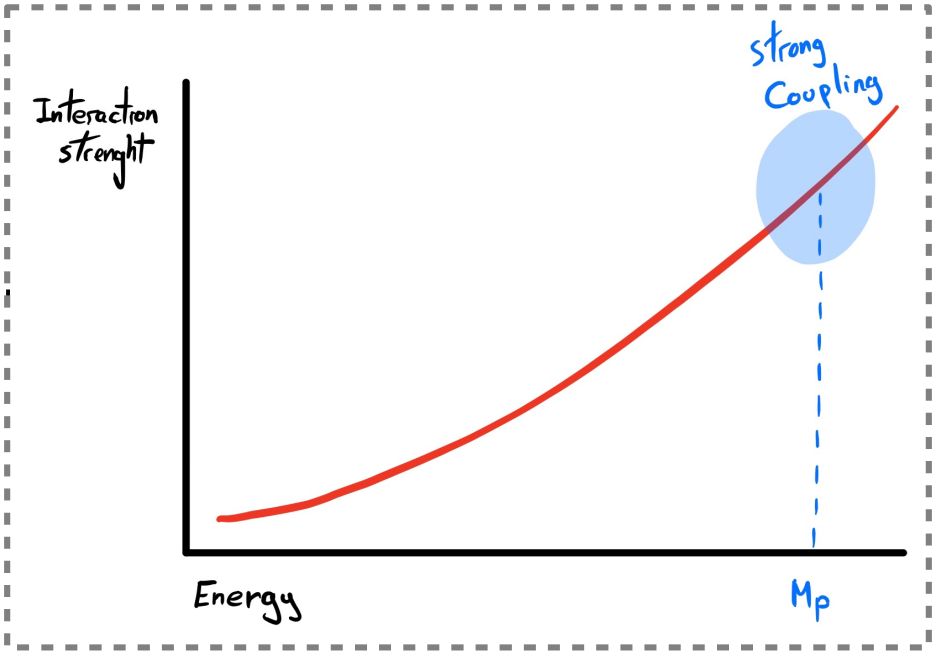

It lacks an explanation for observed gravitational phenomena

Dark Matter

Dark Energy

So what can we do?

- Add new degrees of freedom
- Modify the interactions

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Add new degrees of freedom

Hordensky, Beyond Hordensky, Dhost

String theory

Massive gravity

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However, Lorentz invariance is **very** constraining

Ghosts, lost of unitarity...

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Quadratic Gravity
Stelle, 1977
Fradkin & Tseytlin, 1981
Avramidi and Barvinsky, 1985

We abandon Lorentz invariance *at high energies*

This evades pathologies

No ghosts

No violation of unitarity

Only a finite number of interactions is required

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Hořava Gravity

P. Hořava (2009)

Hořava Gravity

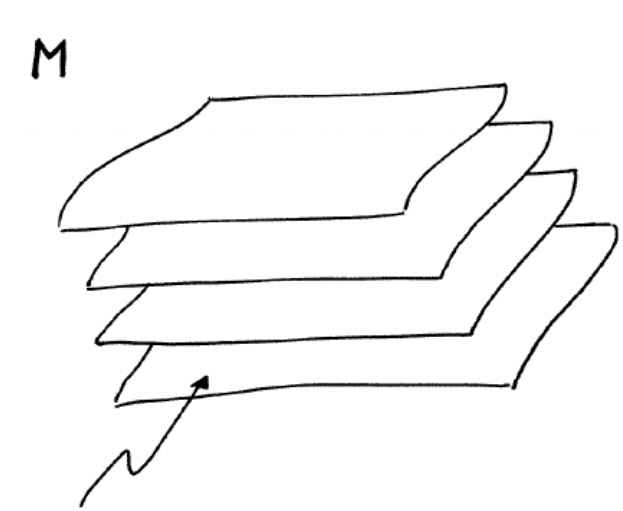
There is a privileged time direction (thus, Lorentz breaking)

The dynamical content is described in terms of ADM

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

It propagates a TT graviton and *an extra scalar mode*

$$S = \int dt\ d^d x\ N\sqrt{\gamma}\left(K_{ij}K^{ij} - \lambda K^2 - \mathcal{V}(R, \partial_i N)\right)$$



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5 terms in 2+1 dimensions
15 terms in 3+1 dimensions

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Non-projectable HG

There has been a very extensive study of BHs

Barausse, Liberti, Sotiriou

Problems for QFT:

Global constraint

Instantaneous interaction

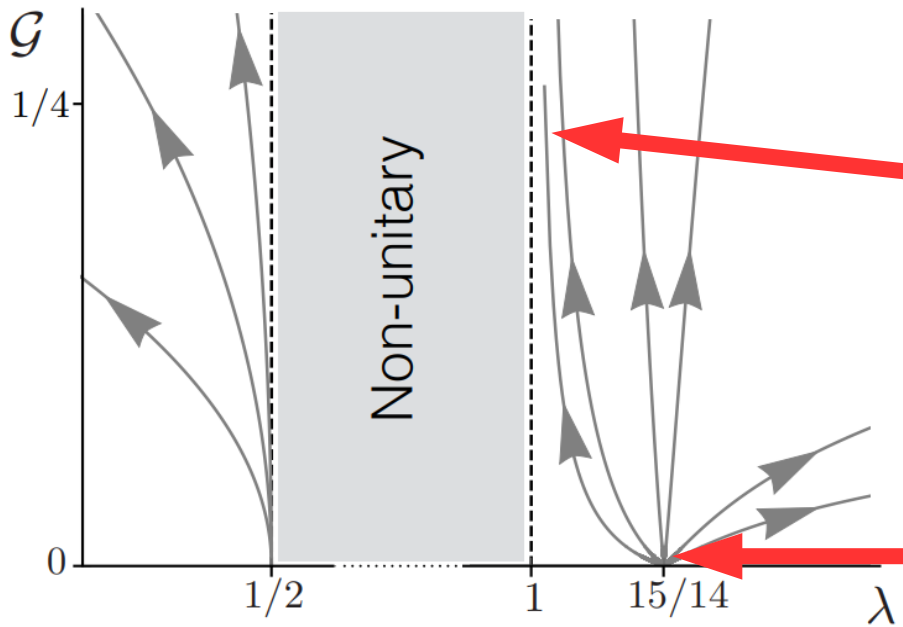
Projectable HG

Gauge-fix away the lapse

Avoids the pathologies

QFT well-defined

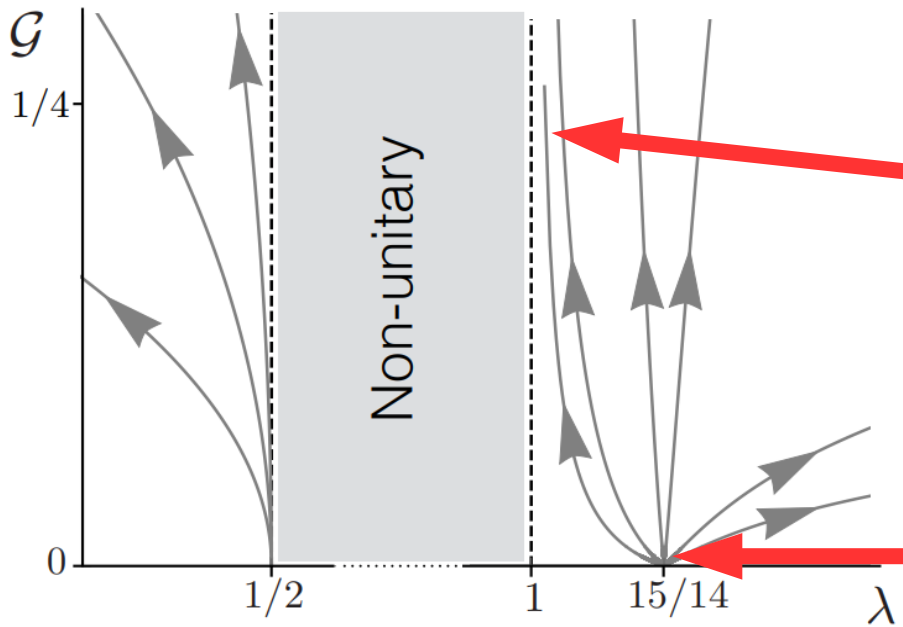
Bavinsky, Blas, H-V, Sibiryakov, Steinwachs



But undergoes strong coupling now in the IR

There is a fixed point

Figure from 1706.06809



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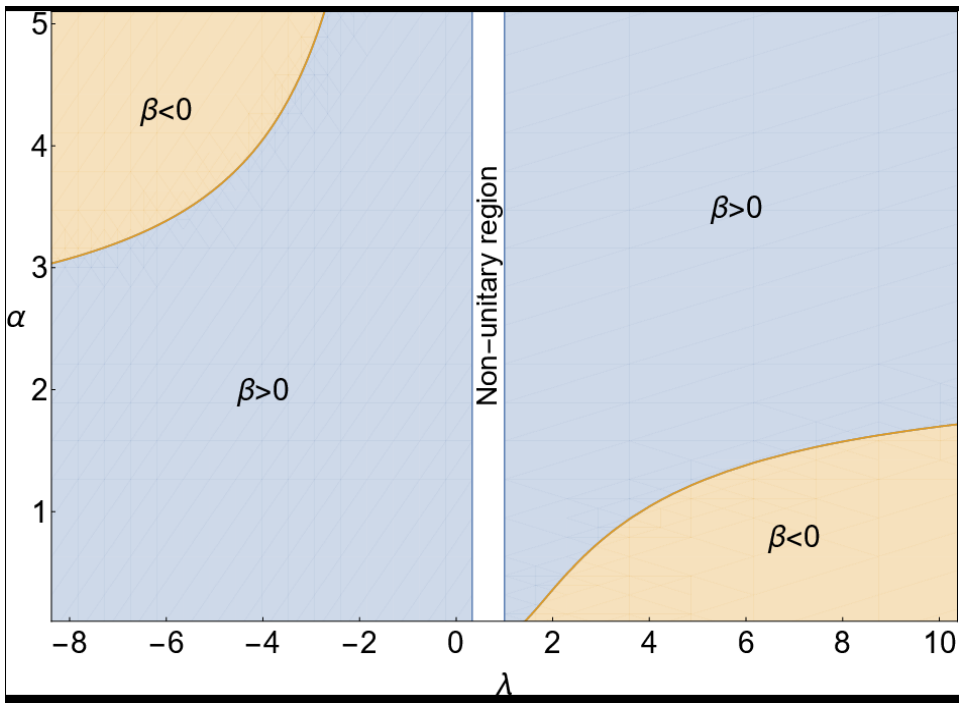

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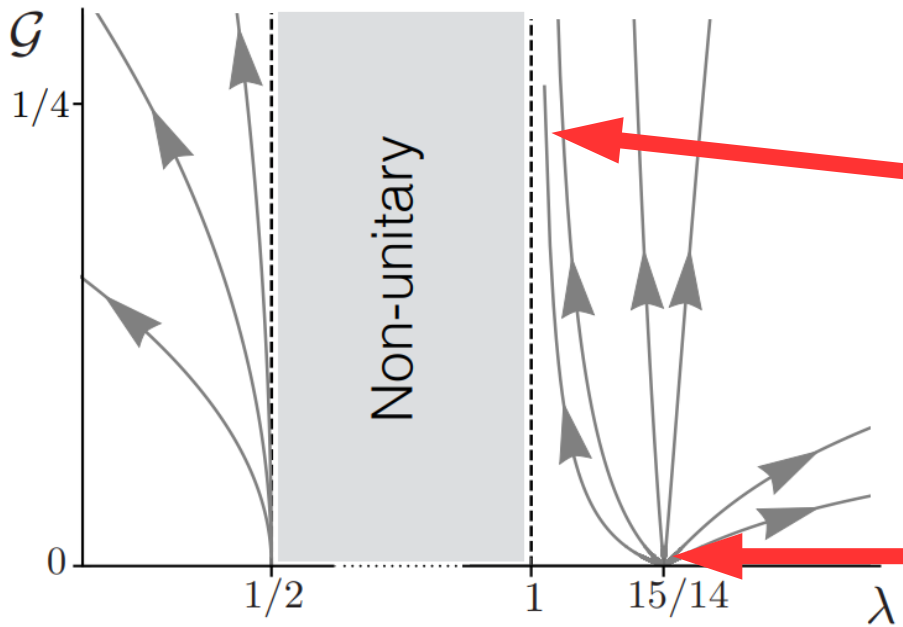

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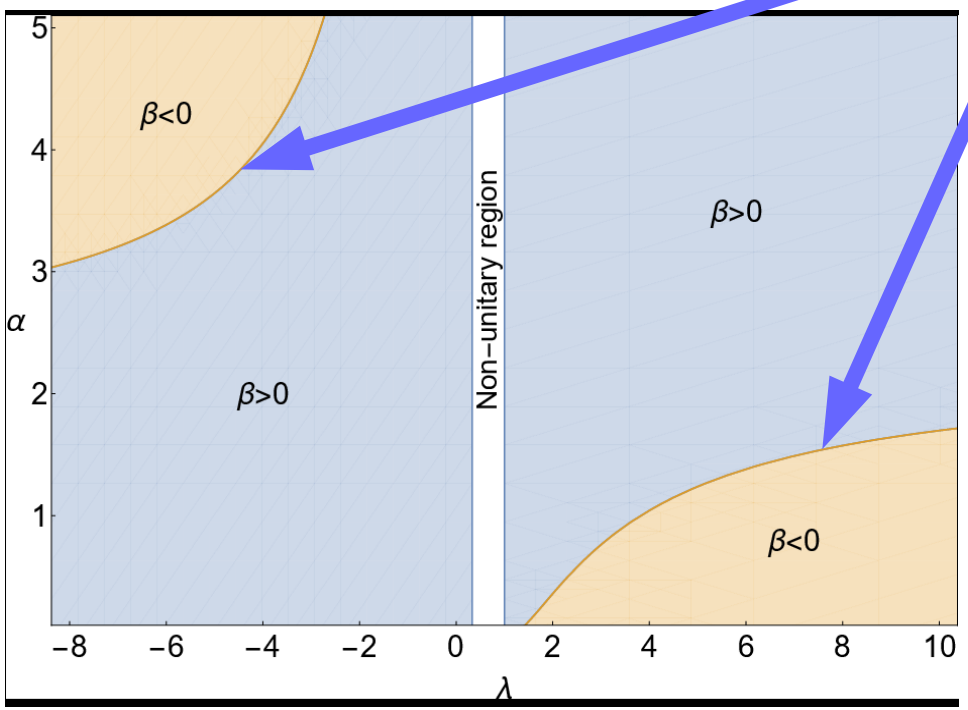

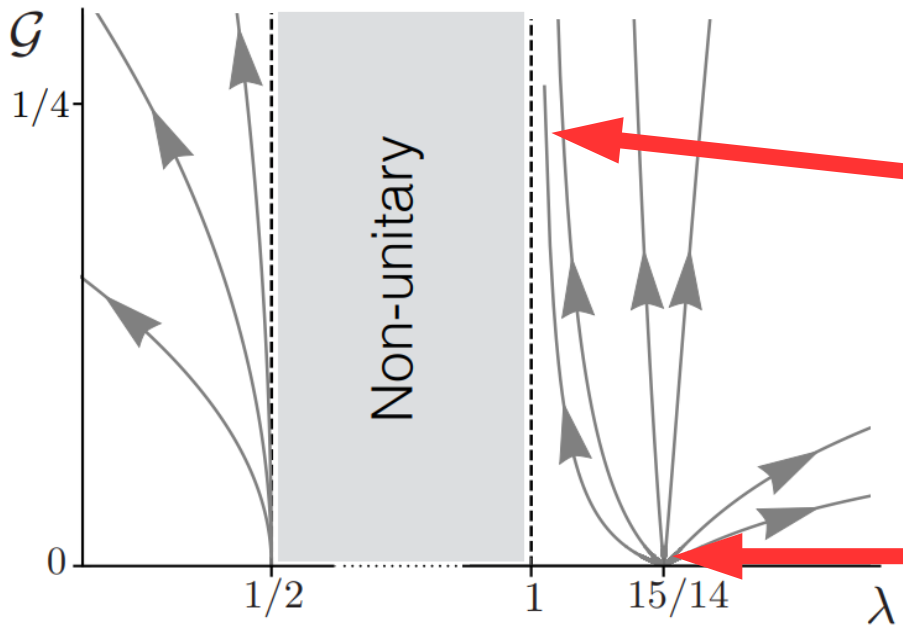

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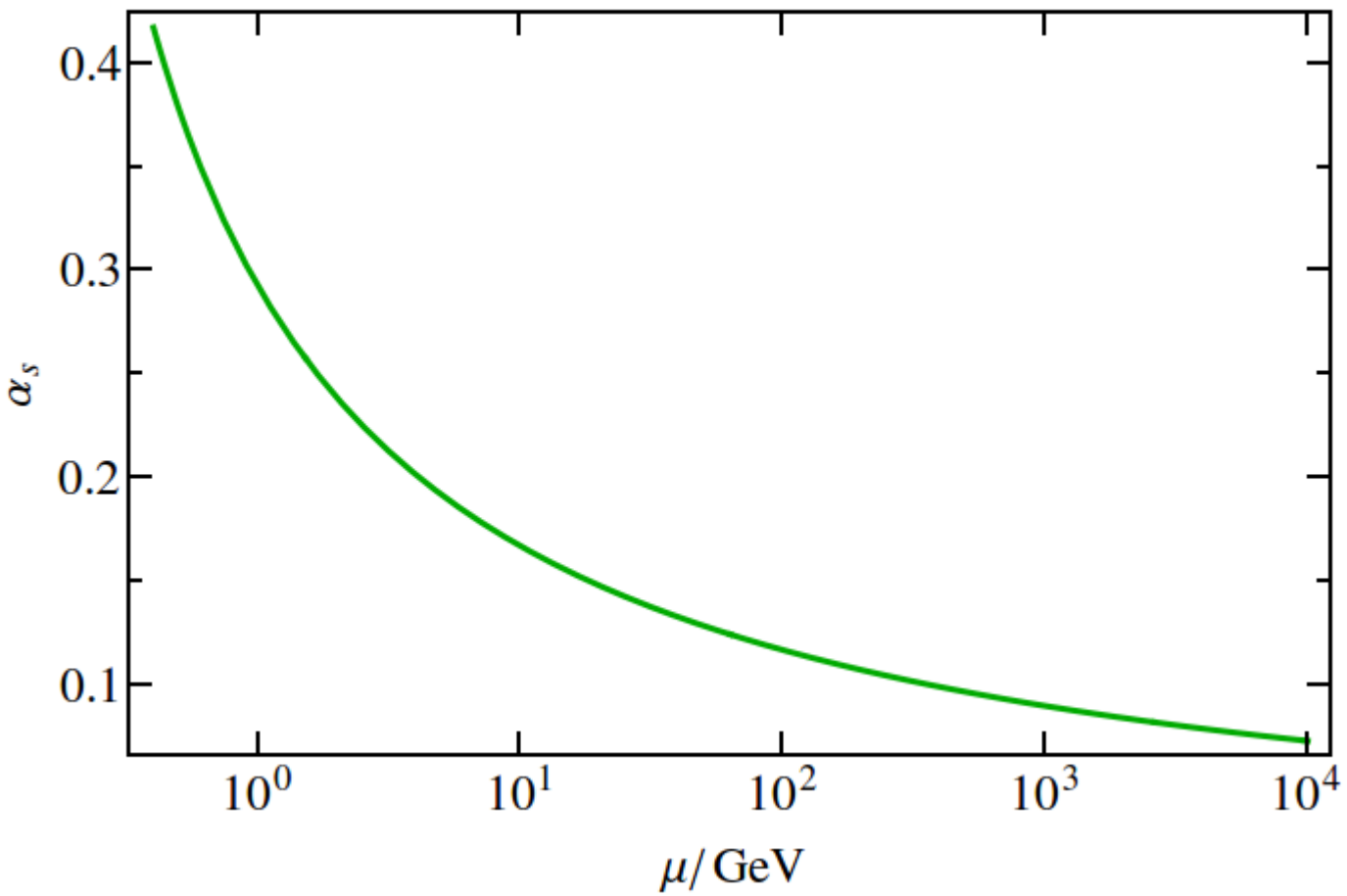
Phenomenology seems to be doomed

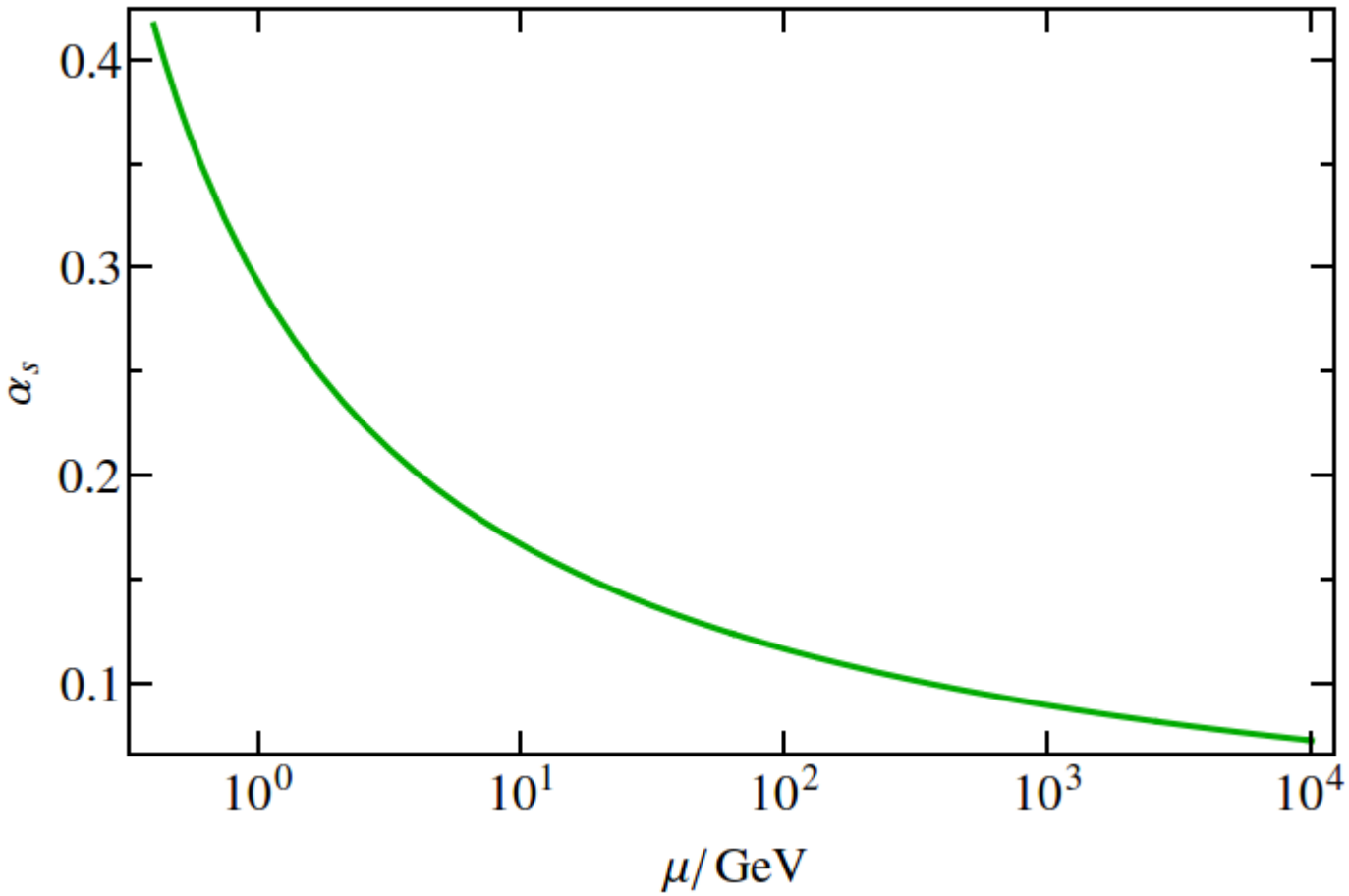
The theory flows in the IR to something which might not be General Relativity.

Projectable HG is then just a toy model.



Credit: Wikipedia

QCD



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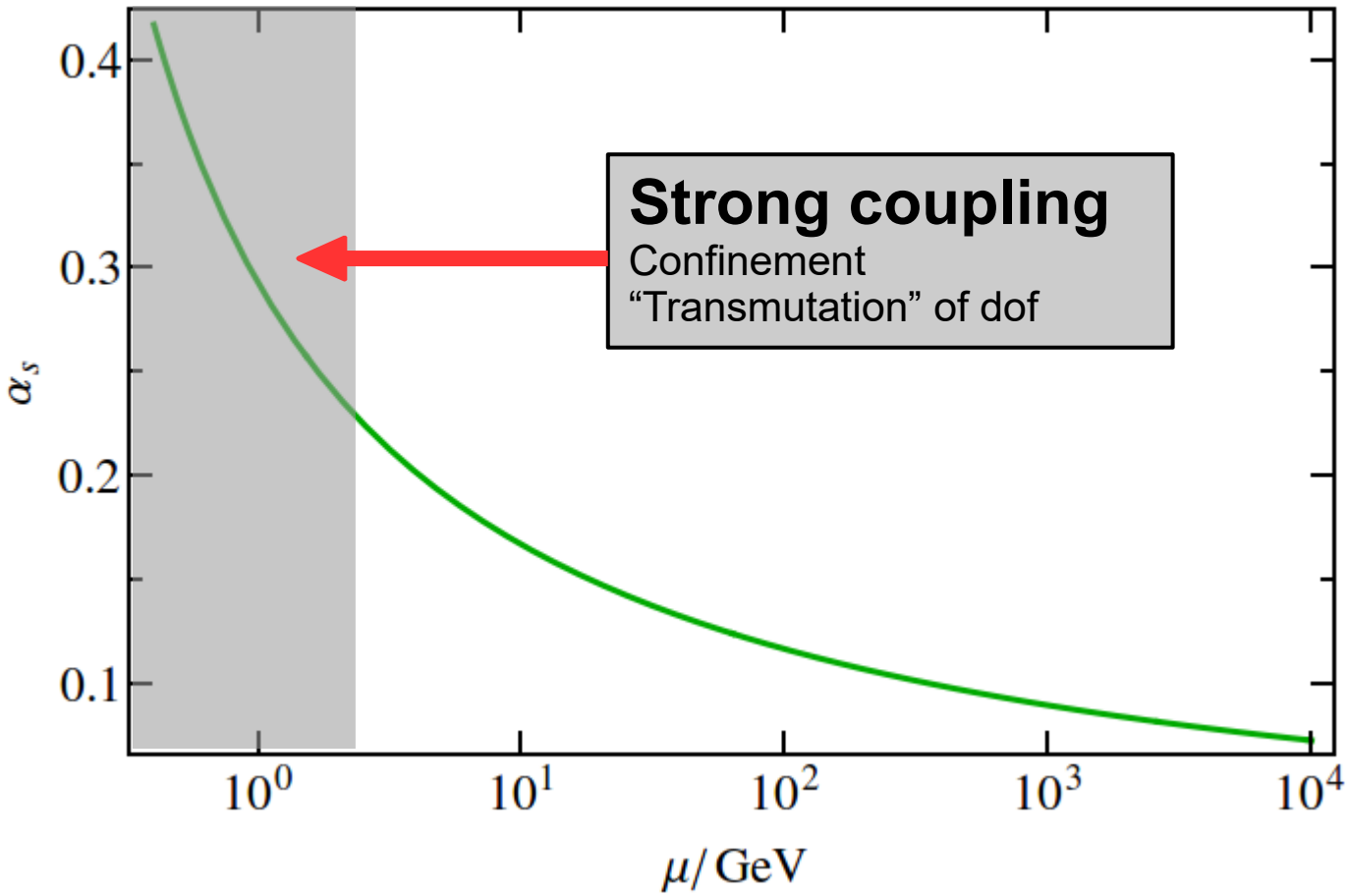

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What if?

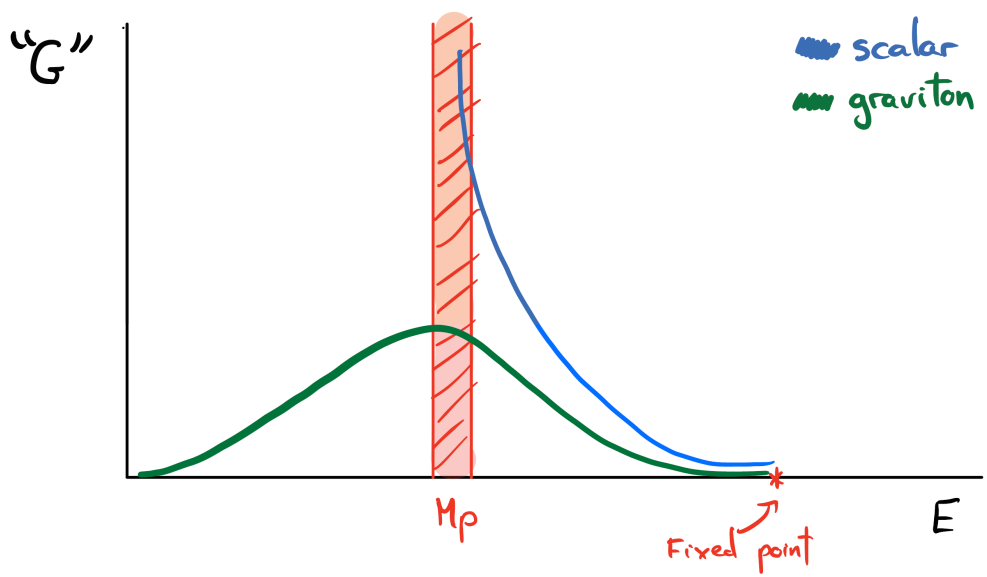
The strong coupling only appears in self-interactions of the scalar mode

Mukohyama (2009)

Gravity mediated interactions of matter always weak

Graviton interactions always weak

The scalar condenses à la QCD -----> Dark Matter



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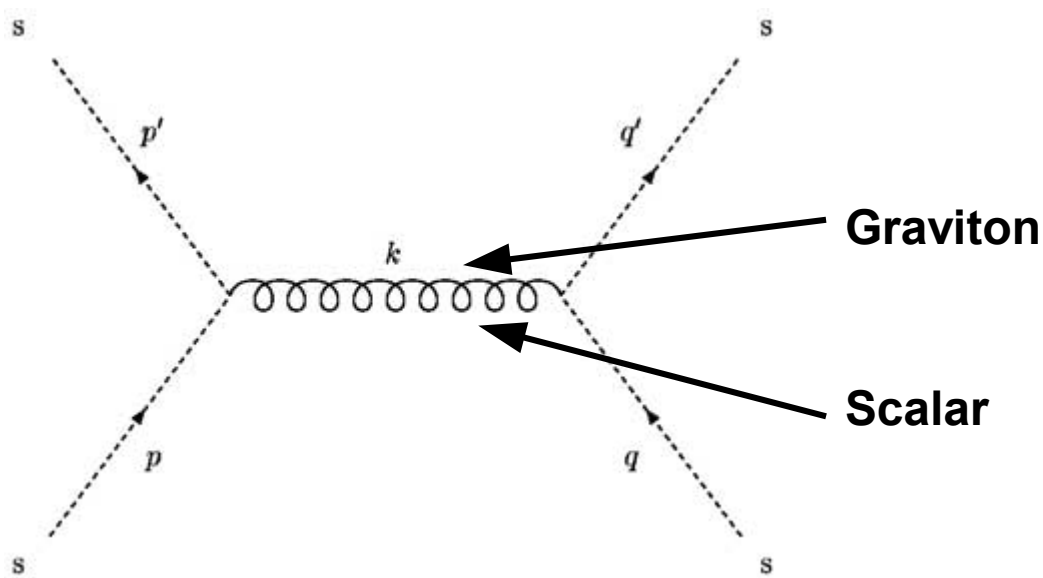
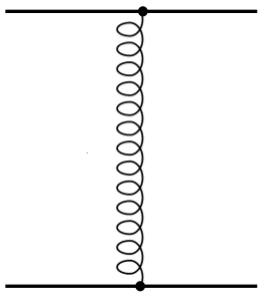
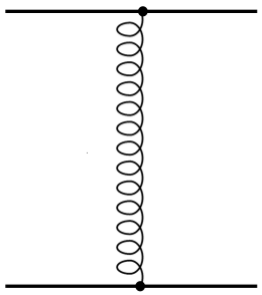




$$= -\frac{8G}{1-\cos(\theta)}\left(3m^2 + 2q^2 + (m^2 + 2q^2)\cos(\theta)\right)$$



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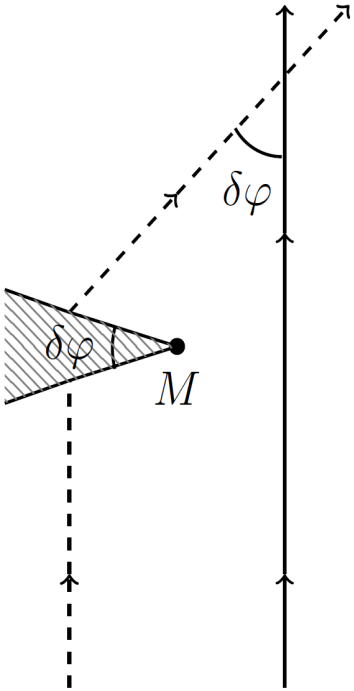
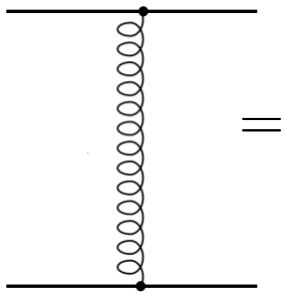
This corresponds to scattering by a conical defect

GR in 2+1 dimensions

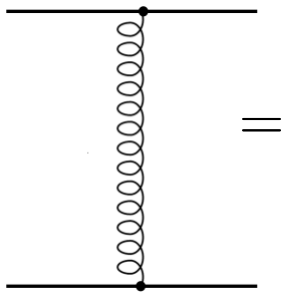




$$= -\frac{128G}{(q^2(1-\cos(\theta))}(m^4 + 6m^2q^2 + 4q^4 + 2q^2(m^2 + 2q^2)\cos(\theta))$$

Which again matches the result of GR in 3+1

Note the pole in q^2=0!!



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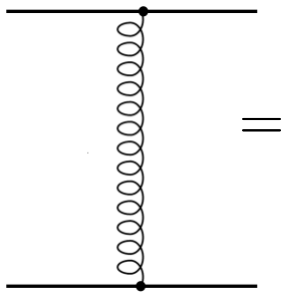
We find that interactions by the scalar mode are always suppressed when q->0 with respect to gravity

No vDVZ discontinuity



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Conclusions

Hořava Gravity is a proposal for a UV completion of GR

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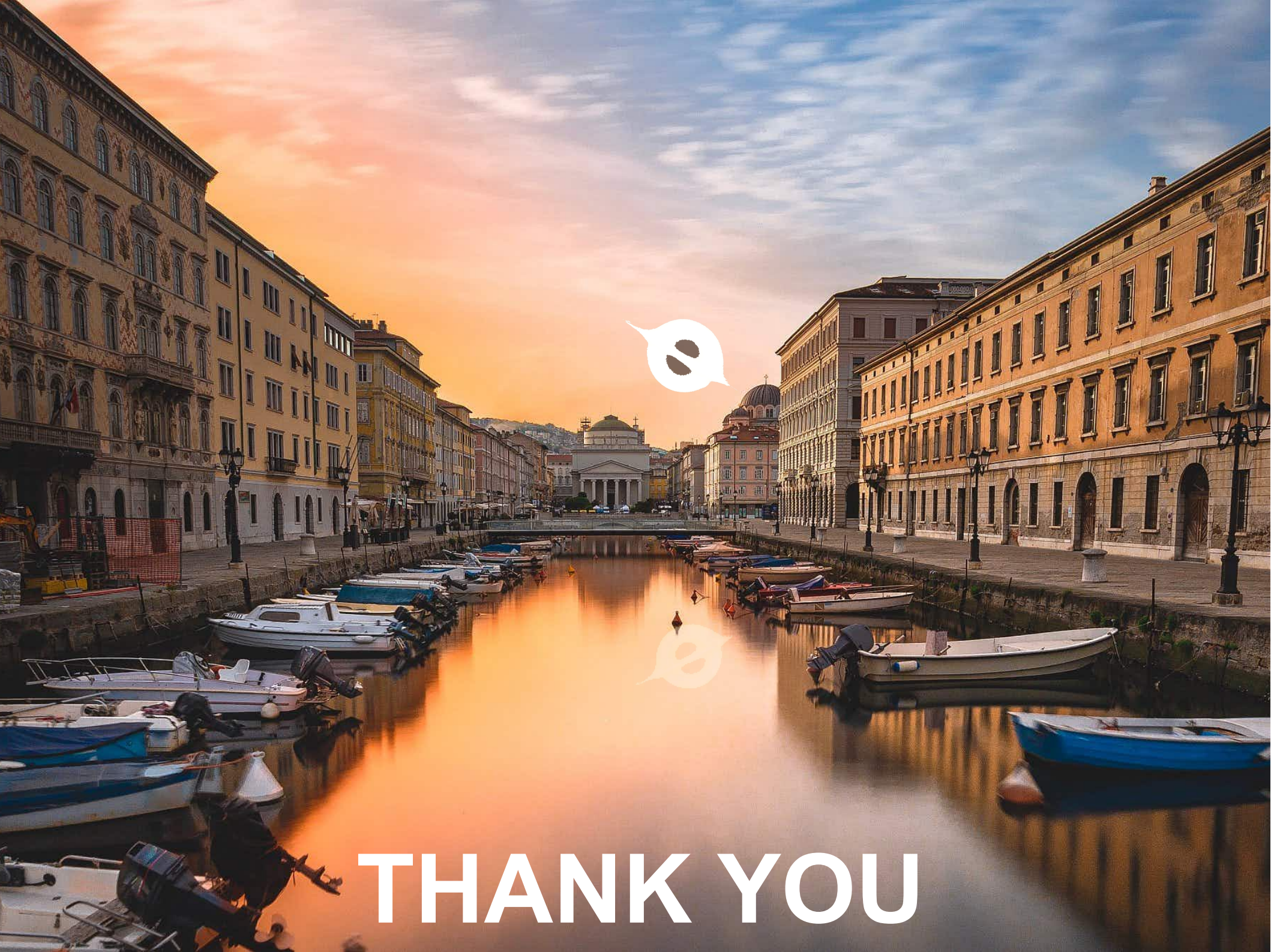
THANK YOU