Massive Spin-2 particles and the swampland

Joan Quirant

Ben-Gurion University of the Negev

DFG German-Israeli Project Cooperation (DIP)

Holography and the Swampland

Based on 2311.00022 with S. Kundu and E. Palti and on 2405.10100

String Phenomenology 2024

Motivation

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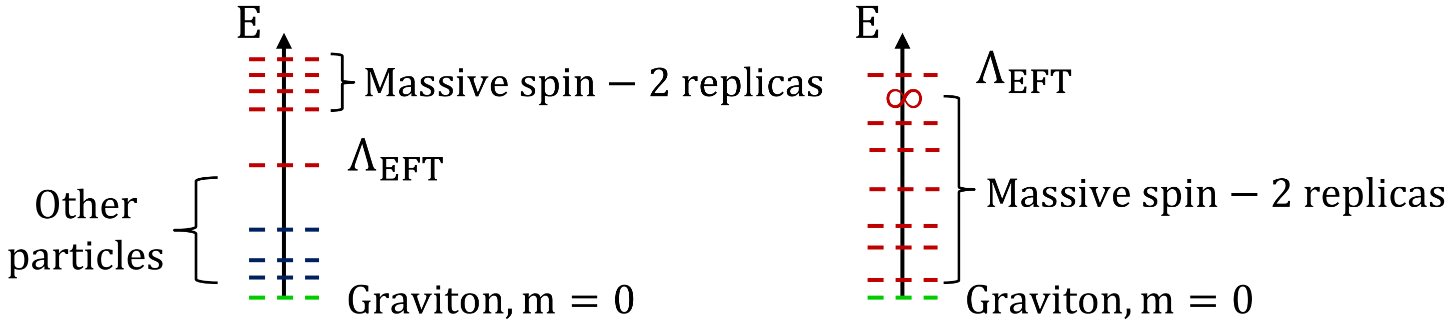
- Massive spin-2 particles appear in (string) compactifications
  - ➢ KK copies of the graviton
  - ➢ Top-down approach



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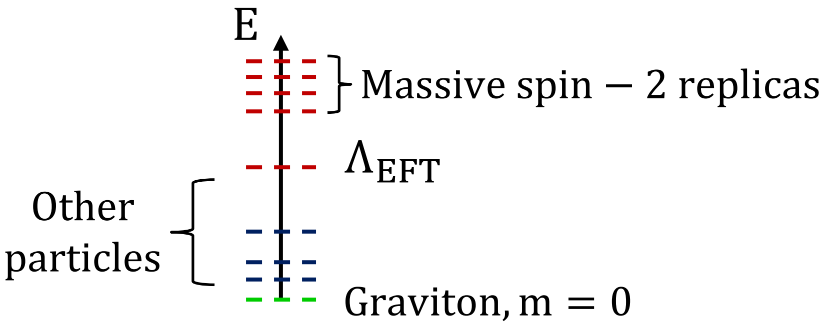

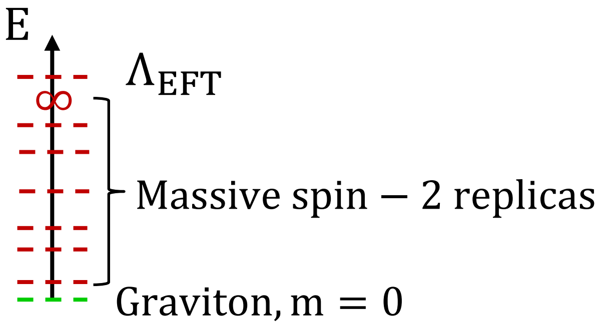

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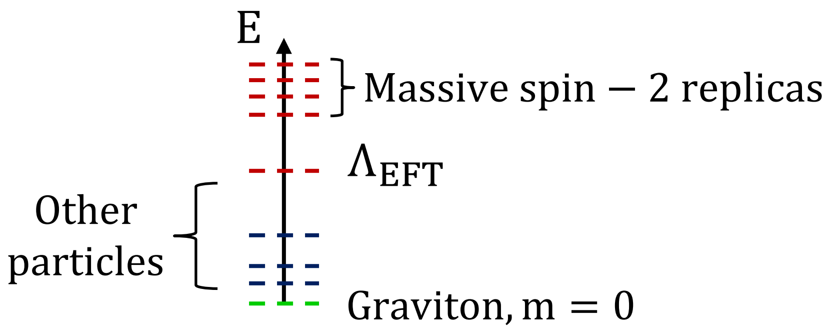

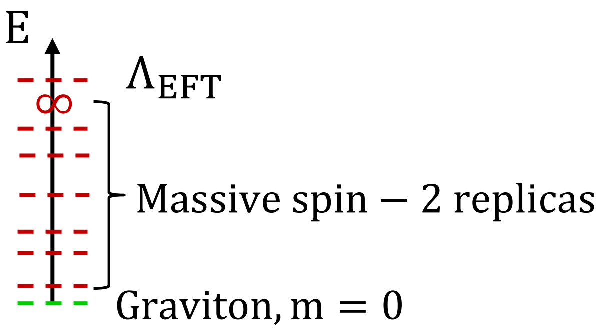

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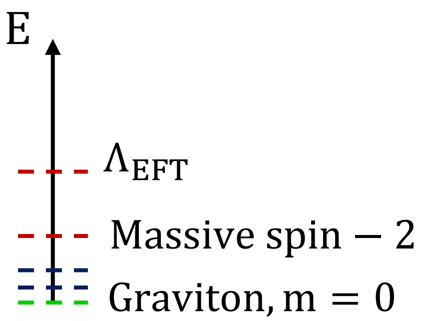
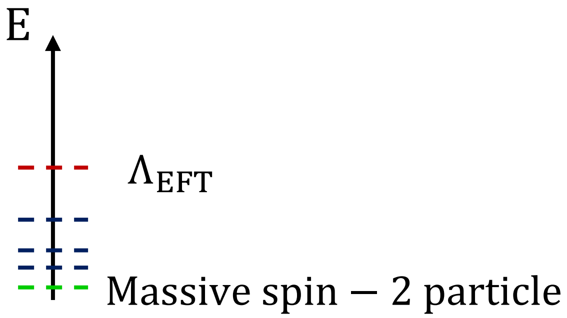
  - ➢ Gravity coupled to a massive spin-2 particle
  - ➢ Single massive spin-2 particle





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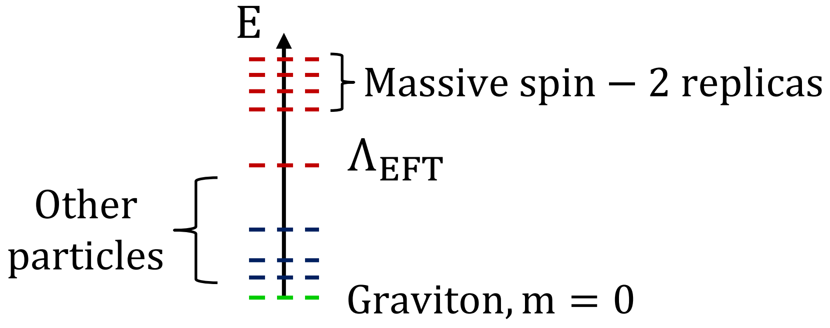

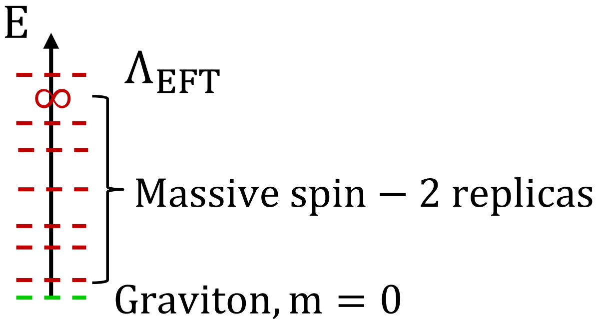

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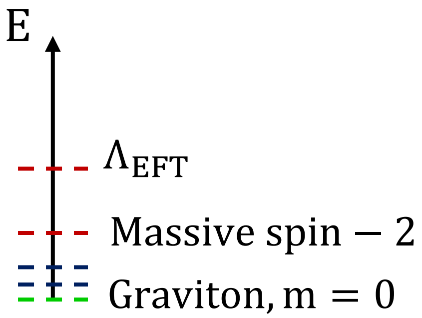

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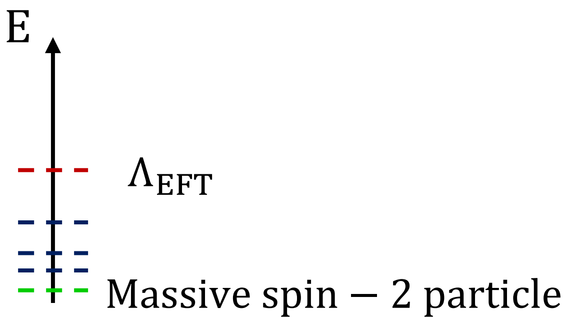

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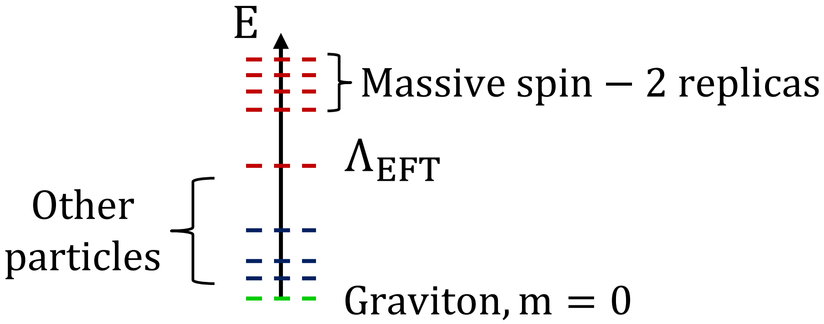

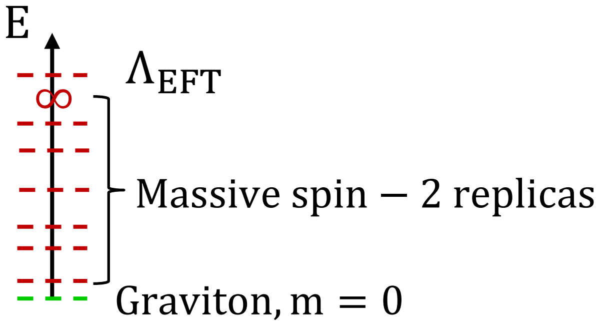

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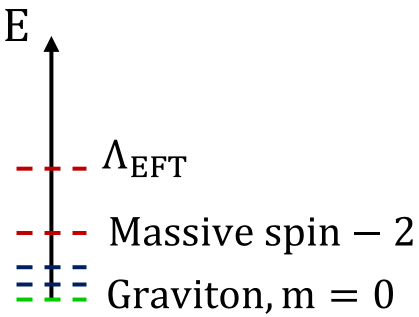

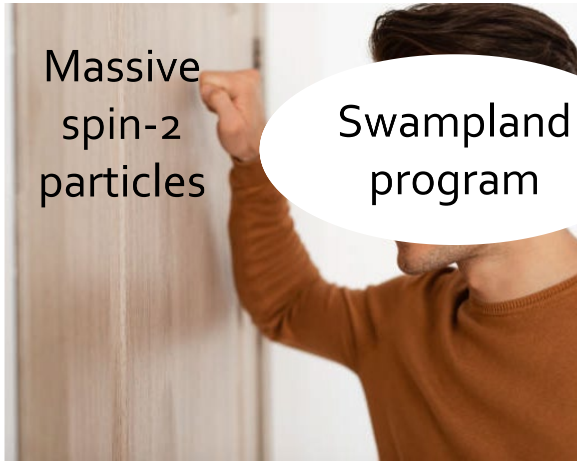

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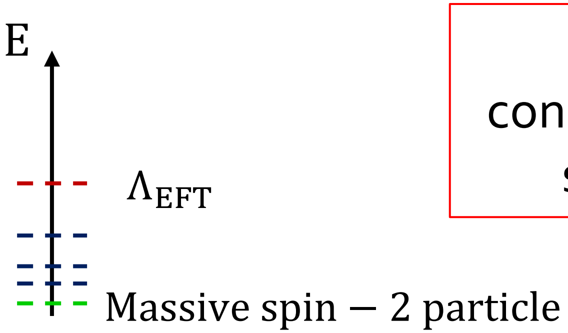


(Swampland) constraints for massive spin-2 particles?

Contents

0) Motivation

1) The Classical Regge Growth Conjecture (CRG)

2) One massive spin-2 particle

3) Several massive spin-2 particles

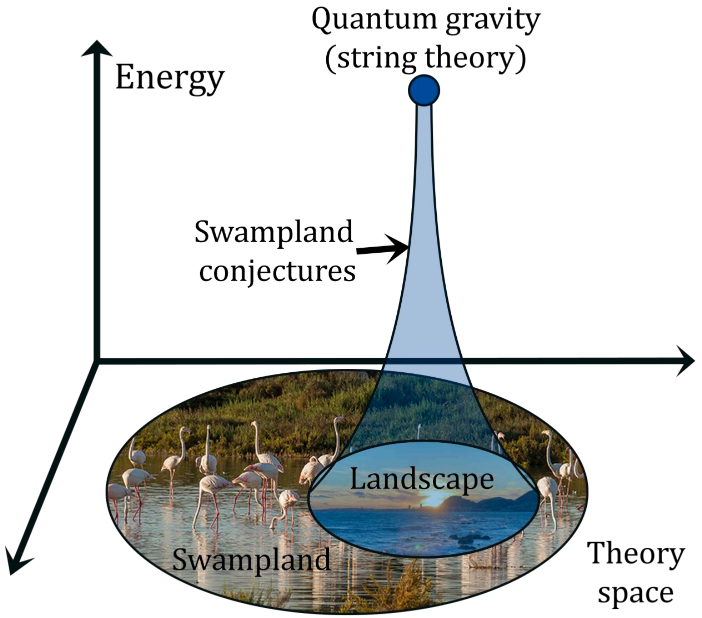
4) Conclusions and outlook

We will only consider $d = 4$ in this talk

Classical Regge Growth Conjecture

- We are all familiar with the swampland program

  - ➢ Properties EFT must satisfy to be compatible with quantum gravity.



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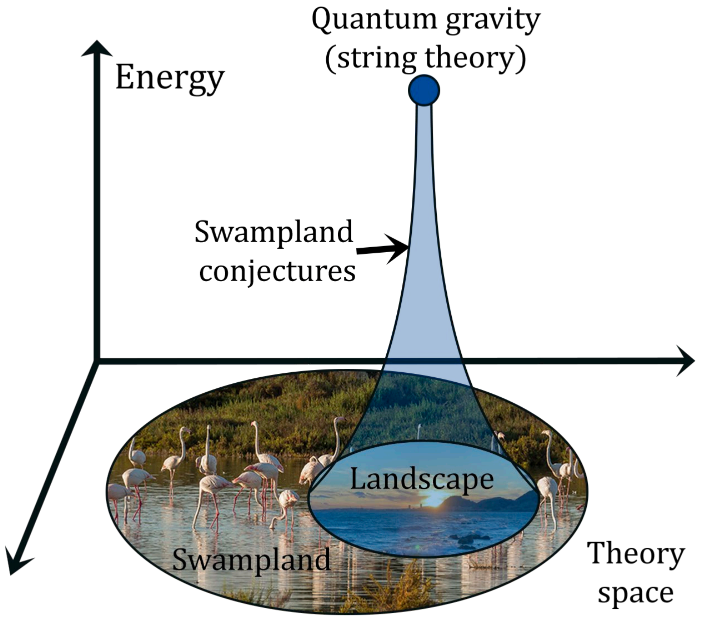

- Spin-2 conjecture Klaewer, Lüst, Palti '18
  - WGC to the helicity-1 mode of the massive spin-2 ($h_{\mu\nu}$) with mass m:

$h_{\mu\nu}$ and $g_{\mu\nu}$: $\Lambda_{\text{EFT}} \sim \frac{mM_p}{M_w}$

Only $h_{\mu\nu}$: $\Lambda_{\text{EFT}} \sim m$

Classical Regge Growth Conjecture

Chowdhury, Gadde, Gopalka, Halder, Janagal, Minwalla '19

- Classical Regge Growth (CRG) Conjecture

The S-matrix of a consistent classical theory cannot grow faster than s^2 at large s and fixed (and physical) t

➢ Classical: non analyticities can only be simple poles. Tree-level scattering

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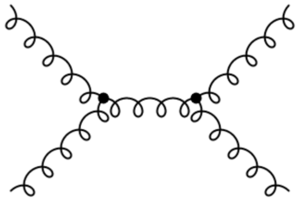
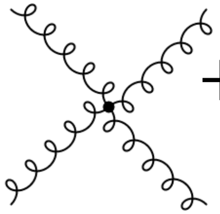
Any $2 \to 2$: $\mathcal{A} =$  $+$  $+$ exchange of other particles $\longrightarrow$ $\lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

$$s = -(p_1+p_2)^2 > 0,$$
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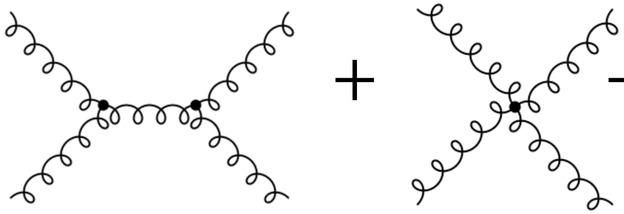
Any 2 → 2: $\mathcal{A} =$  exchange of other particles ⟶ $\lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

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  - ➢ True in any two-derivative theory for spin< 2. True for classical string scattering amplitudes and Einstein S-matrix

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  - ➢ It can be argued that in the 'impact parameter (δ) space': $S(\delta, s) \sim s^m$, $\mathrm{m} \leq 2$. Subtleties changing to the usual $S(t, s)$.
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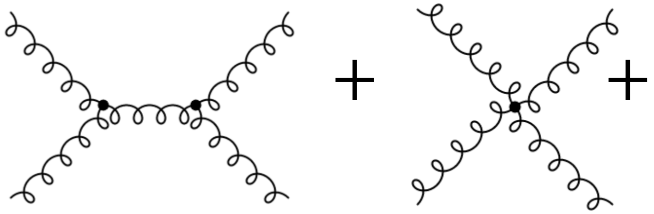
Any 2 → 2: $\mathcal{A} =$  exchange of other particles → $\lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

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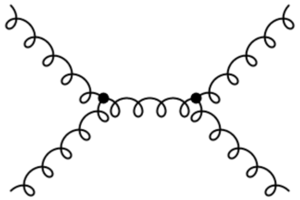
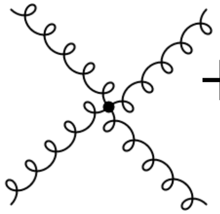
Any 2 → 2: $\mathcal{A} =$  +  + exchange of other particles ⟶ $\lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

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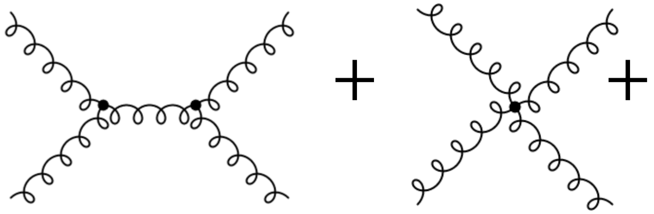
Any 2 → 2: $\mathcal{A} =$  exchange of other particles → $\lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

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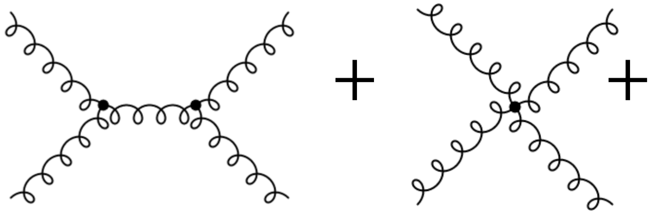
Any 2 → 2: $\mathcal{A} =$  exchange of other particles $\longrightarrow \lim_{s\to\infty} \frac{\mathcal{A}}{s^3} \to 0$

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- Apply the CRG to theories containing a single massive spin-2 particle $h_{\mu\nu}$ 😏

➢ Construct a theory where the scattering of $2 \to 2$ (identical) massive spin-2 particle goes like $\mathcal{A} \sim s^n, n \leq 2$?

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1. Find all possible on-shell cubic vertices (parity even and parity odd). Following Costa, Penedones, Poland, Rychkov `11

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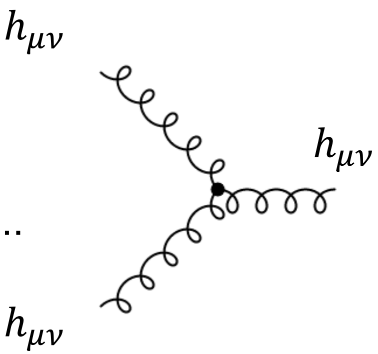
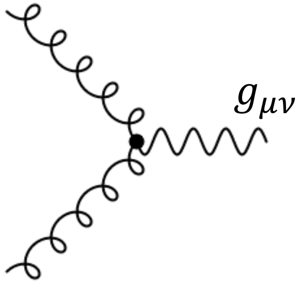


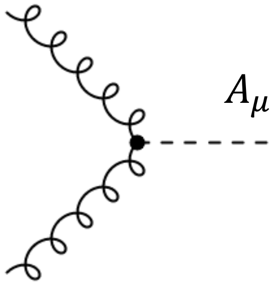
4 even, 2 odd

Massless spin-2



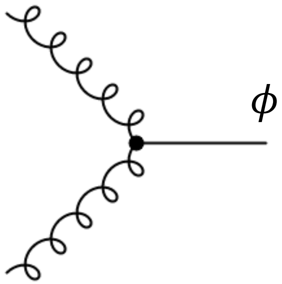
5 even, 4 odd

Massive spin-1



2 even, 2 odd

Scalar



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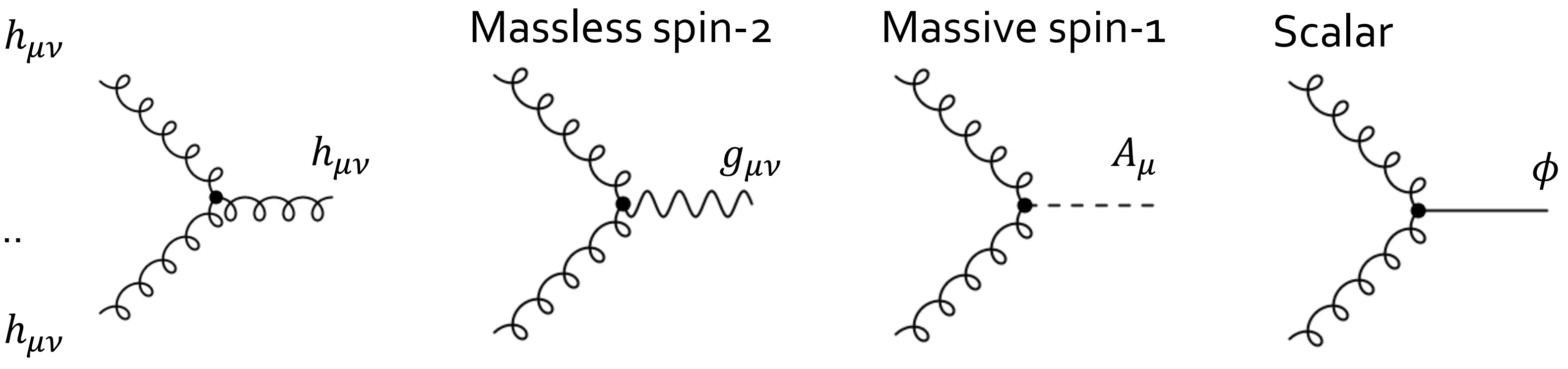

4 even, 2 odd | 5 even, 4 odd | 2 even, 2 odd | 2 even, 2 odd

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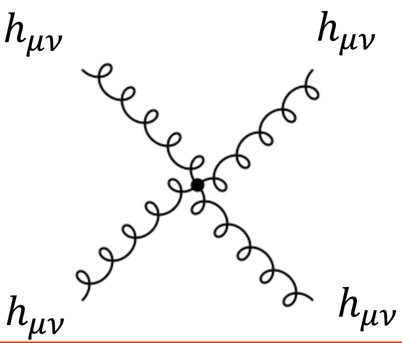
2. Find all possible Lorentz-invariant quartic vertices (finite number of derivatives). Using Bonifacio, Hinterbichler, Rose '19

Many ($\sum_{a=1}^{201} f_a(s,t) T_a$) operators (consider any finite number of derivatives)



E.g. $h^{\mu}_{\nu} h^{\alpha}_{\mu} h^{\beta}_{\alpha} h^{\nu}_{\beta}$, $\partial^{\lambda} h^{\mu}_{\nu} \partial_{\lambda} h^{\alpha}_{\mu} h^{\beta}_{\alpha} h^{\nu}_{\beta}$, …

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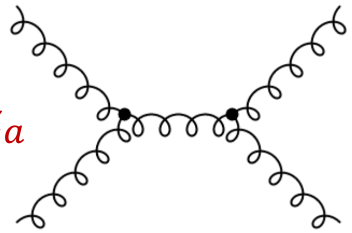
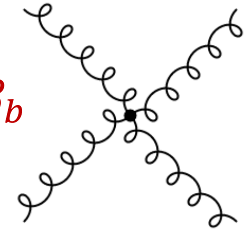
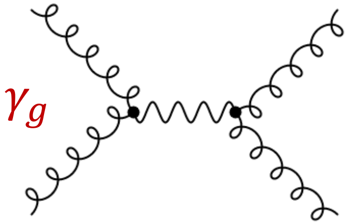
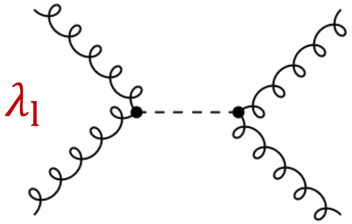
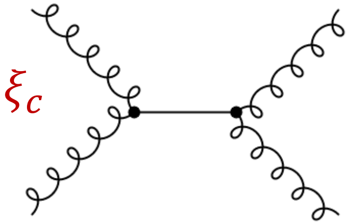
$A_{\text{total}} = \sum \ \alpha_a$  $+ \ \beta_b$  $+ \ \gamma_g$  $+ \ \lambda_{\text{l}}$  $+ \ \xi_c$ 

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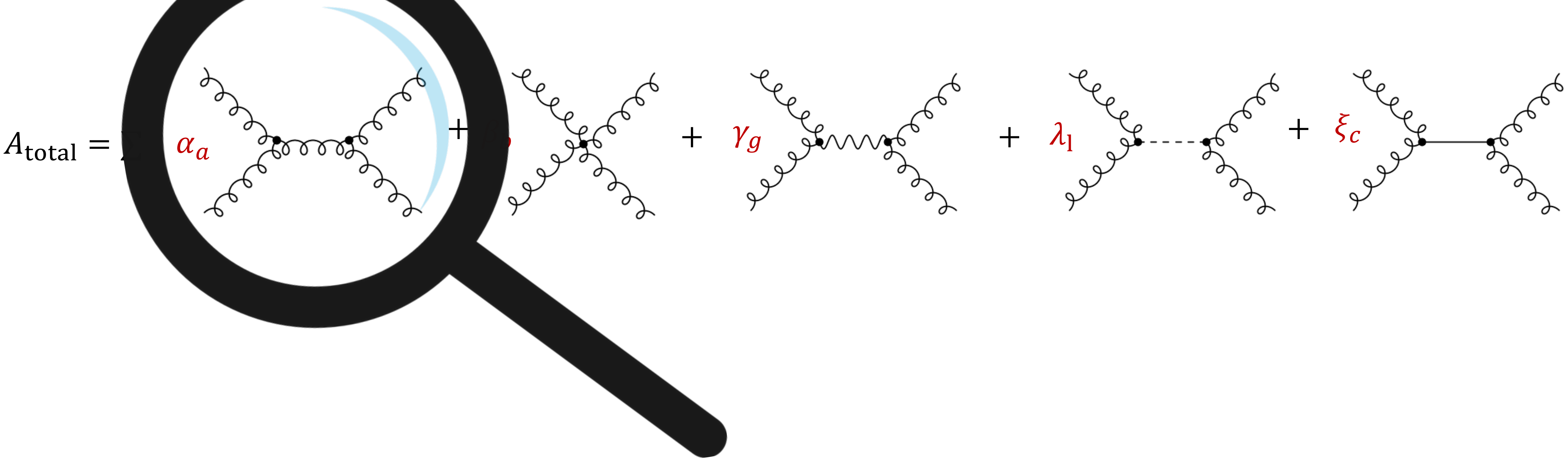

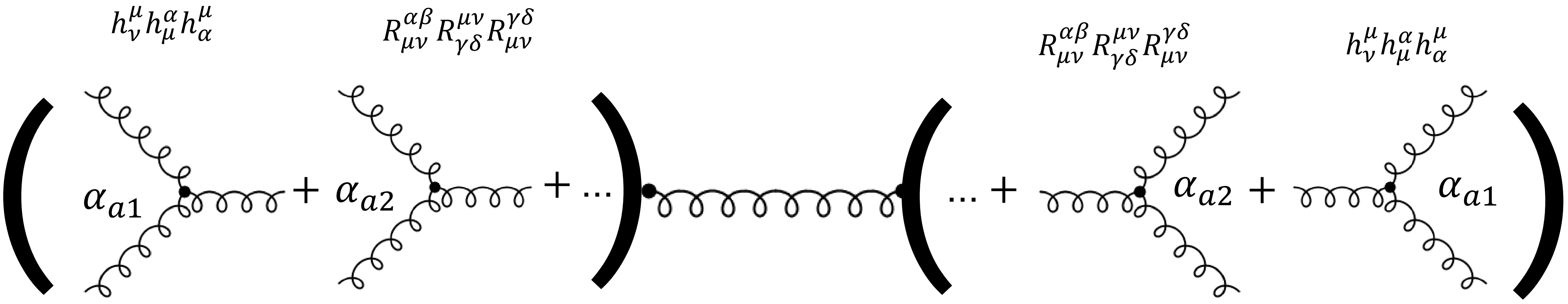
$h^{\mu}_{\nu} h^{\alpha}_{\mu} h^{\mu}_{\alpha}$
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α_{a1}
$+ \alpha_{a2}$
$+ \dots$
$\dots +$
$\alpha_{a2} +$
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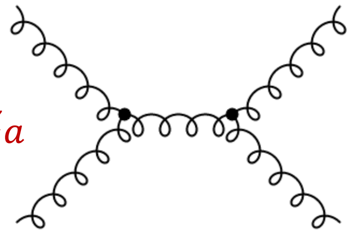
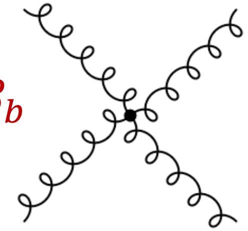
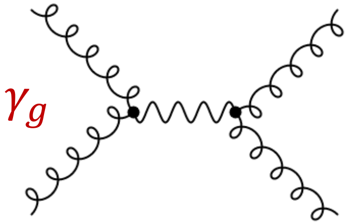
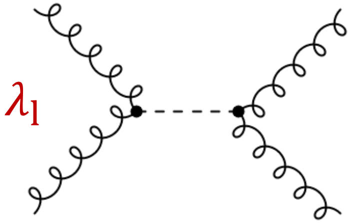
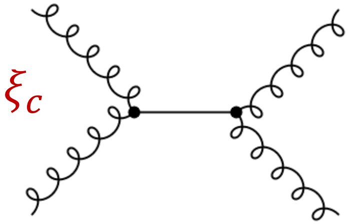
$A_{\text{total}} = \sum \; \alpha_a$  $+ \; \beta_b$  $+ \; \gamma_g$  $+ \; \lambda_l$  $+ \; \xi_c$ 

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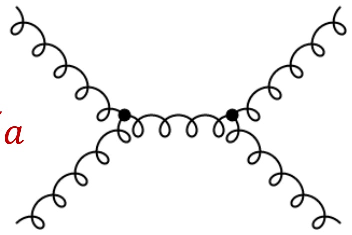
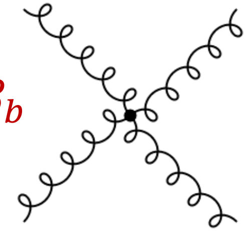
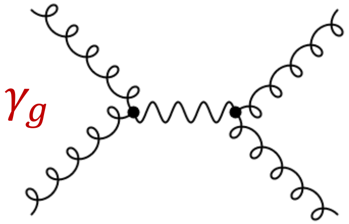
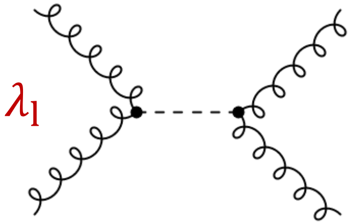
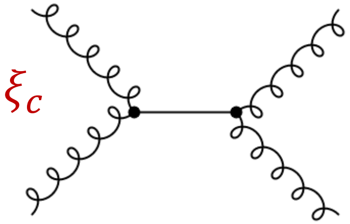
$A_{\text{total}} = \sum \quad \alpha_a$  $+ \ \beta_b$  $+ \ \gamma_g$  $+ \ \lambda_{\text{l}}$  $+ \ \xi_c$ 

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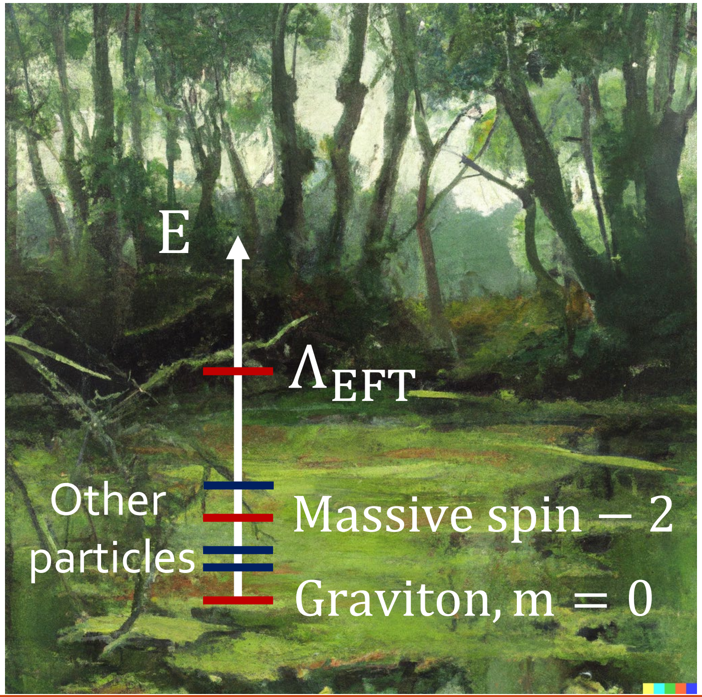

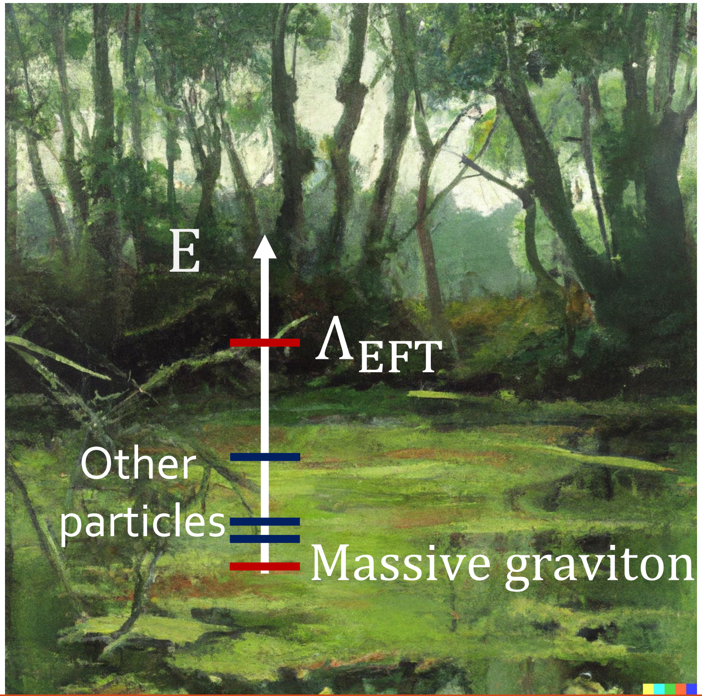

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🤔

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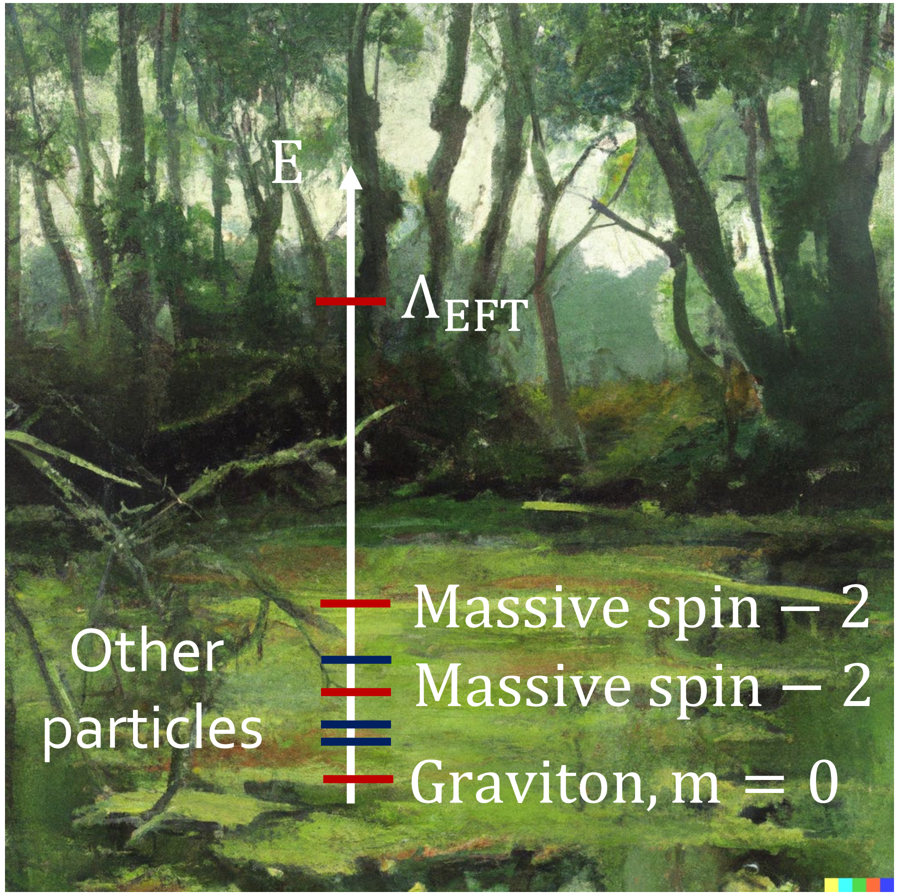

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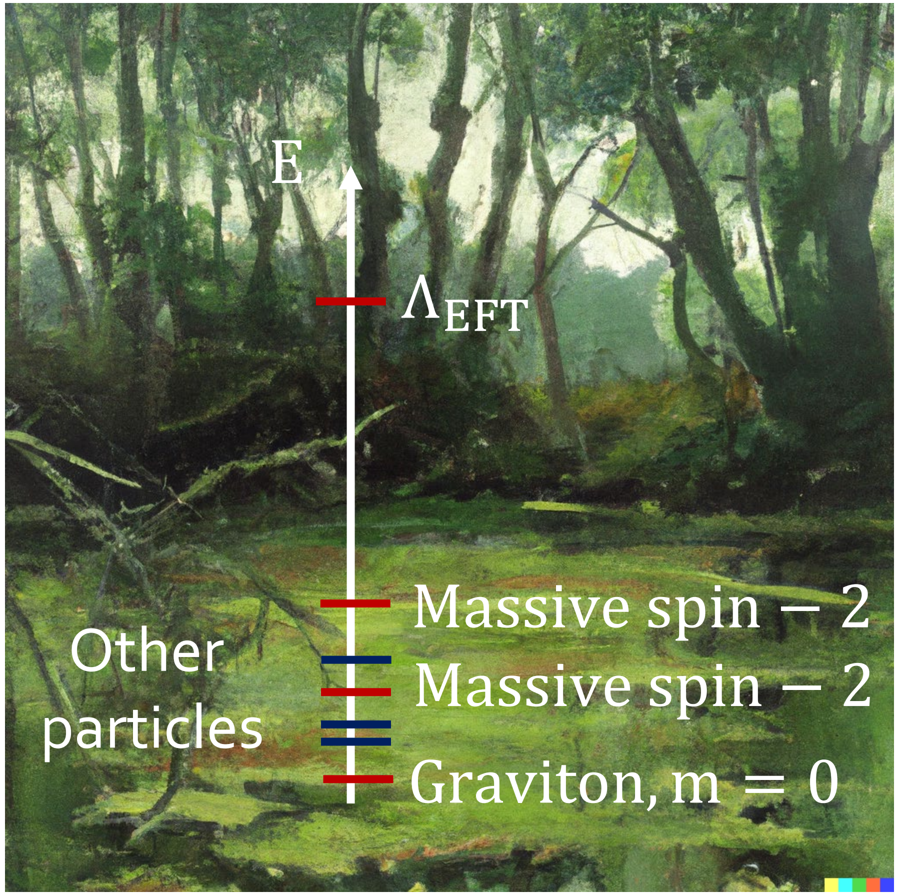

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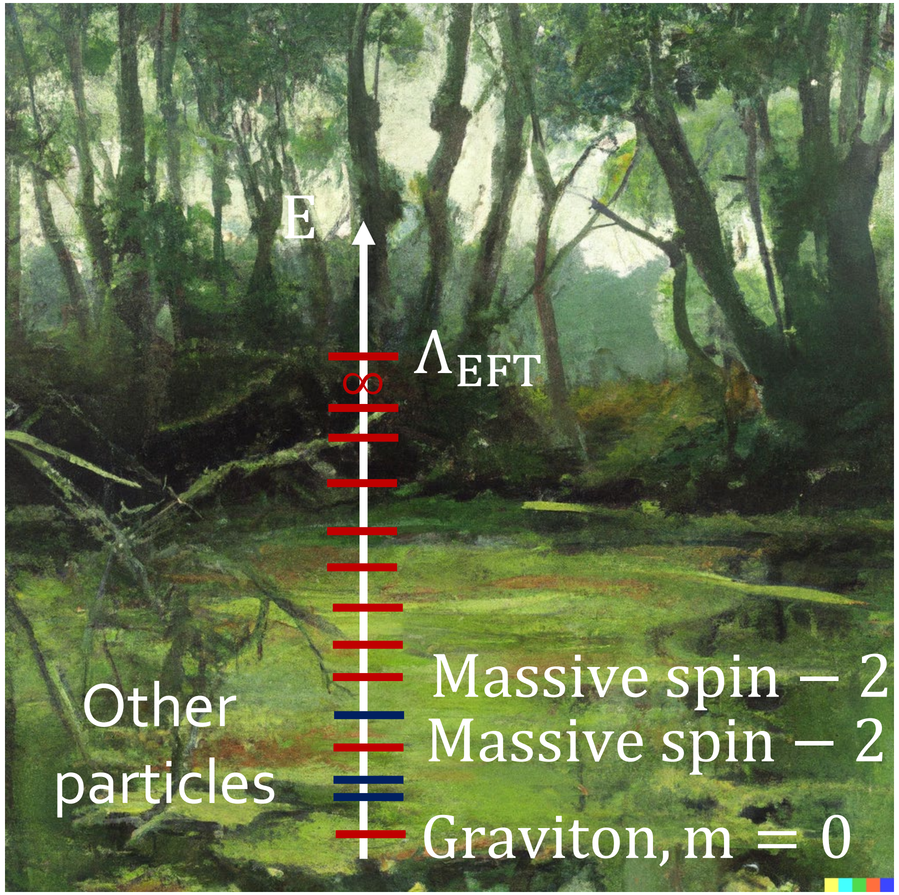

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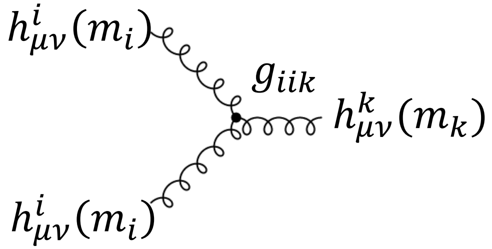

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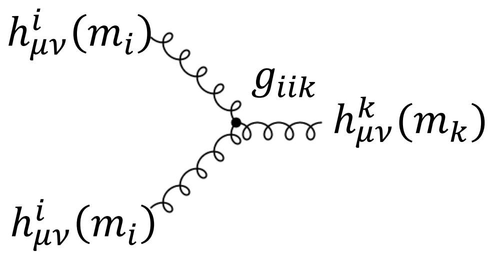

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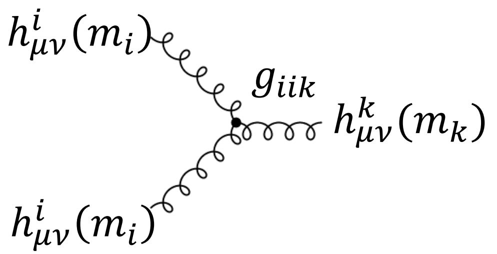

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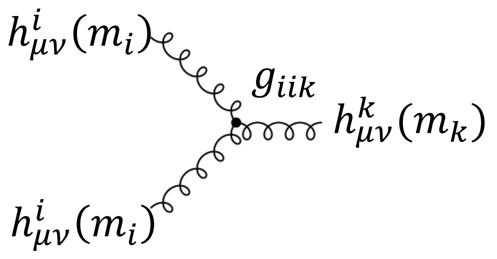

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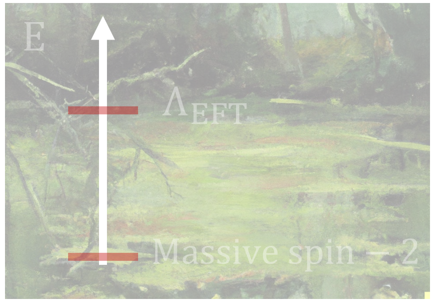

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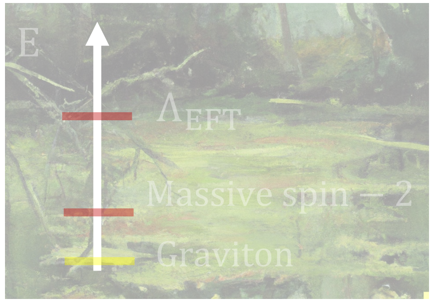

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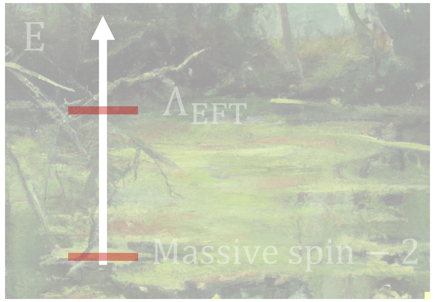

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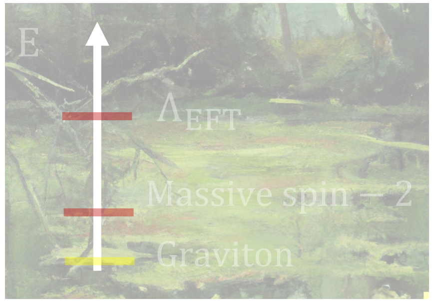

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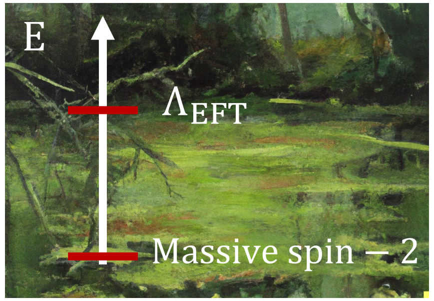

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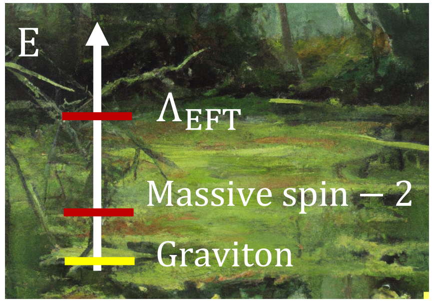

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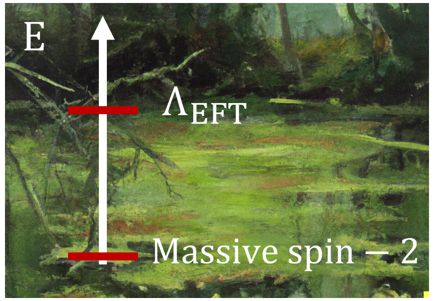

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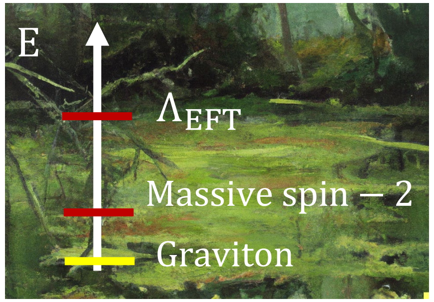

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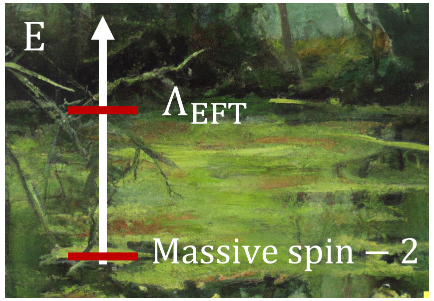
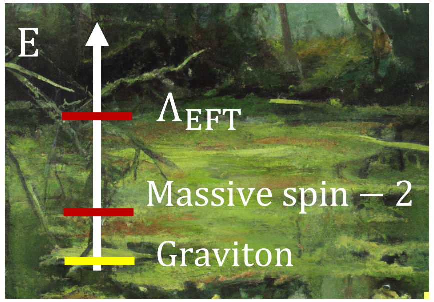
Related work: Bonifacio, Hinterbichler '20



Massive gravity



Gravity + finite # massive spin-2

General case?

- Prove the CRG conjecture. Have a more direct evidence in support of it. Apply it to other contexts.

- Stay tunned! 

Conclusions and outlook

Take home

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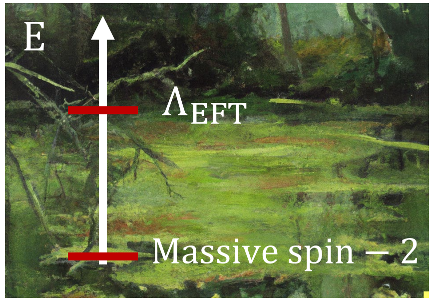

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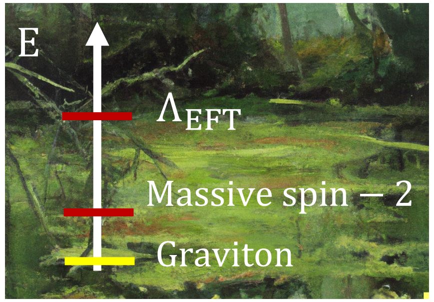

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Thank you for your attention! 🙂

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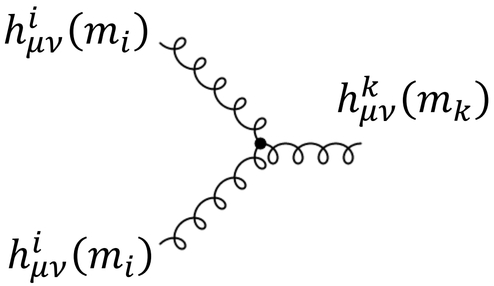

NEW

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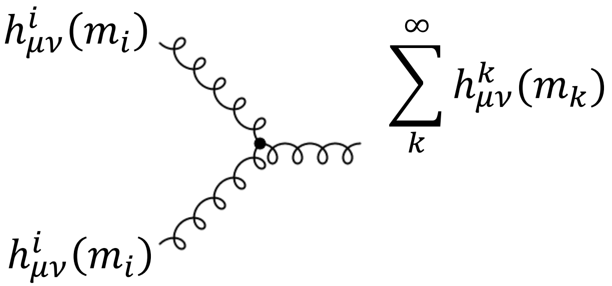

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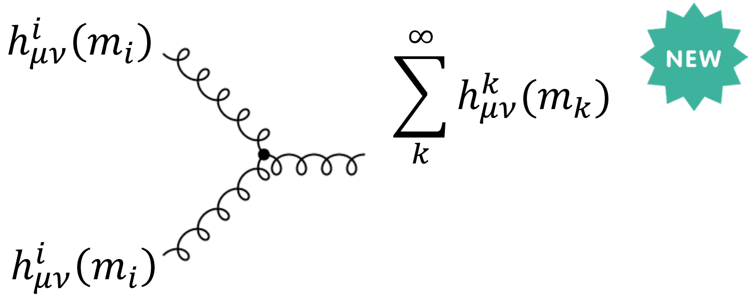

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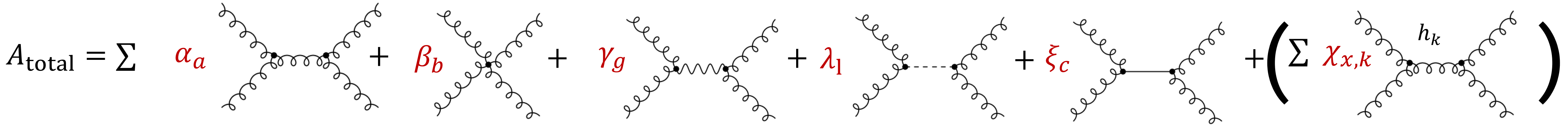

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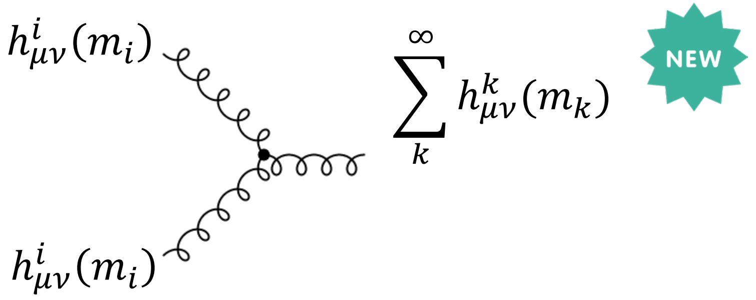

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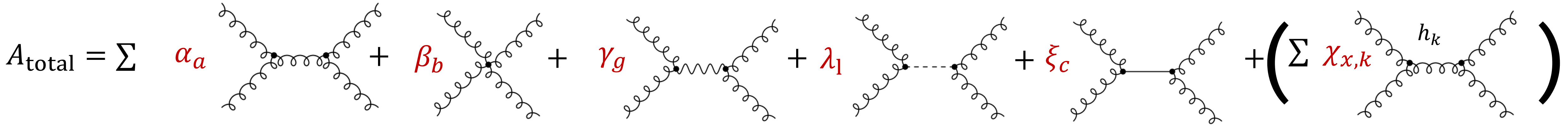

Technically very involved