The Effective Strength of Gravity and the Scale of Inflation

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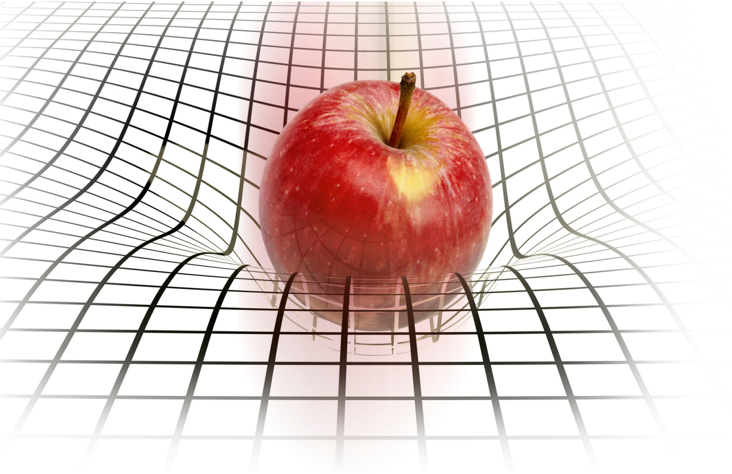
Based on:

I. Antoniadis, S.P.Patil; arXiv:1410.8845

I. Antoniadis, S.P.Patil; arXiv:1510.06759

What is the strength of gravity?



The Effective Strength of Gravity

For any given momentum transfer, gravitational interactions have a strength set by a characteristic scale M_* .

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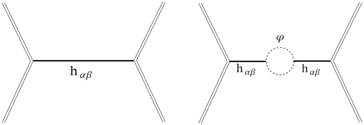
- N.B. There are many subtleties and caveat emptors when dealing with running quantities in EFT of gravity. (cf. Anber, Donoghue, arXiv:1111.2875; Bjerrum-Bohr et al, arXiv:1505.04974)

The Strong Coupling Scale

More concretely, *every* massive species contributes to lowering the scale at which strong gravitational effects become important.



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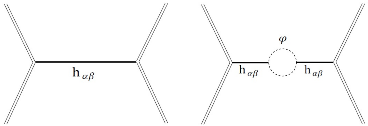

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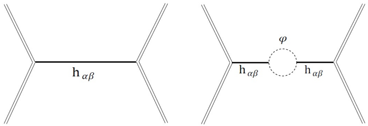

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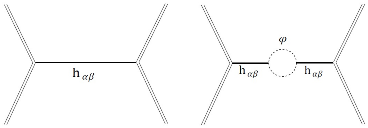

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- Comparison with the free propagator $1/(p^2M_{pl}^2)$ implies that the perturbative expansion fails at $p = M_{**}$ where $M_{**} \sim \frac{M_{pl}}{\sqrt{N}}$.

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Generalized to curved backgrounds, places bounds on maximum allowed curvature.

- $S = \frac{M_{pl}^2}{2}\int d^4x\sqrt{-g}\,R + \int d^4x\sqrt{-g}\,\left[c_1 R^2 + c_2 R^{\mu\nu}R_{\mu\nu}\right] + ...$
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- ... but also get contributions from higher curvature terms s.t.

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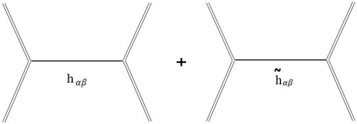
- Expansion breaks down when $H^2 \sim M_{pl}^2/N$.
- Corollary: it is not possible to consistently *infer* a scale of inflation H greater than $M_{pl}/\sqrt{N}$.

The Stength of Gravity

The *strength* of gravity M_* is an independent quantity[1]. Provided we are below M_{**} , any universally coupled species will also affect the *effective strength* of gravity depending on the process in question (equivalence principle, in general violated).

- KK gravitons do so universally for all conserved sources.



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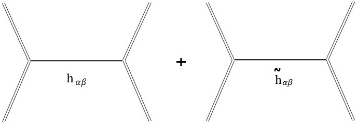

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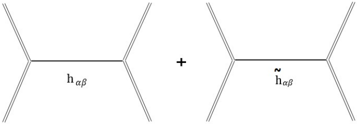

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- $M_*^2 = M_{pl}^2/N_*$, N_* counts the number of species with masses below the momentum transfer of the process in question.

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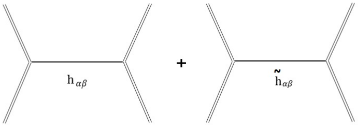

- For KK gravitons with mass M , we have tree level exchange:

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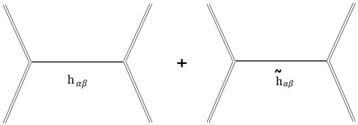

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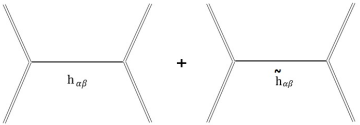

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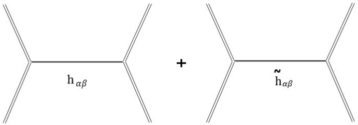

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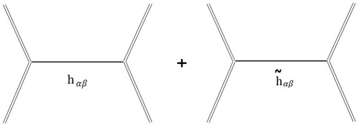

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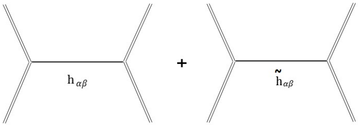

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- Non-minimal couplings do the same. $M_* = M_{pl}/N_*$, N_* a (process dependent) weighted index.

The Stength of Gravity and the Scale of Inflation

It is widely understood that any detection of primordial tensor modes in the CMB determines the scale of inflation. Or does it?

- In foliation were inflaton fluctuations are gauged away (comoving/ unitary gauge):

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- Consider a non-minimally coupled species with a mass between $10^{-2}\mathrm{eV}$ and the putative scale of inflation: $\Delta\mathcal{L}_{\rm eff} \sim \xi\,\eta^2\frac{T^\mu_\mu}{M^2_{pl}} \equiv -\xi\,\eta^2 R$

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- Naively: $\mathcal{L}_{\rm eff} \supset \frac{M_{pl}^2}{2}\left(1 - \frac{2\xi\eta^2}{M_{pl}^2}\right) R$
- $g_{\mu\nu} = \left(1 - \frac{2\xi\eta^2}{M_{pl}^2}\right)^{-1} \tilde{g}_{\mu\nu} := F^{-1}(\eta)\tilde{g}_{\mu\nu}$

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- Naively: $\mathcal{L}_{\rm eff} \supset \frac{M^2_{pl}}{2}\left(1 - \frac{2\xi\eta^2}{M^2_{pl}}\right) R$
- $g_{\mu\nu} = \left(1 - \frac{2\xi\eta^2}{M^2_{pl}}\right)^{-1} \widetilde{g}_{\mu\nu} := F^{-1}(\eta)\widetilde{g}_{\mu\nu}$
- $\mathcal{L}_{\rm eff} \supset \frac{M^2_{pl}}{2}\widetilde{R} + F^{-2}(\eta)\mathcal{L}_m\left[F^{-1}(\eta)\widetilde{g}_{\mu\nu}, \psi, A_\mu, \phi, \eta\right] + ...$

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- $M^2_{*s} = M^2_{pl}\frac{F^2(\eta_*)}{F^2(\eta_0)} \approx \frac{M^2_{pl}}{1+\widetilde{N}_*}$; where $\widetilde{N}_* := \sum_i g_i$ where for example, $g_i = 2\Delta(\xi_i\eta_i^2)/M^2_{pl}$.

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- Any positive detection (i.e. determination of r_*) implies

$$V_*^{1/4} = \frac{M_{pl}}{\sqrt{N_*}}\left(\frac{3\pi^2 \mathcal{A} r_*}{2\cdot 10^{10}}\right)^{1/4}; \quad N_* \sim (1 + N_{KK}^T)(1 + N_s)$$

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- * N.B. Higuchi bound: massive spin 2 fields inconsistent on dS backgrounds s.t. $m^2 < 2H^2$. However inflation is not dS, KK evidently gravitons are not described by the Fierz-Pauli Lagrangian *in progress* .

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- Given $M_* \leq M_{pl}$ and that $M_{**} = M_{pl}/N$, N being *total* number of species, can infer the absolute bound $N \leq \frac{9.15}{r_*} \times 10^7 \left(\frac{M_{pl}^2}{M_{*T}^2}\right)$