Not so Hidden Fields in Cosmology

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Windows on Quantum Gravity, IFT Madrid
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Based on:

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

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

I. Antoniadis, R. Durrer, S.P.Patil; in preparation

Introductory Remarks

Hidden fields, by definition do not couple at all to the visible sector (i.e. us). However they still gravitate.

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- In 'large' numbers, can consistently generate distinct signatures whose absence can bound the hidden field content of the Universe. (Pt II)

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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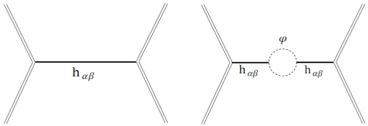
- Positive/negative energy solution attracted/ repulsed from source, effectively anti-screening it. Gravity appears to have gotten 'stronger'.
- N.B. There are many subtleties and caveat emptors when dealing with running quantities in EFT of gravity. (cf. Anber, Donoghue, arXiv:1111.2875; Bjerrum-Bohr 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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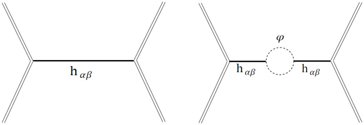

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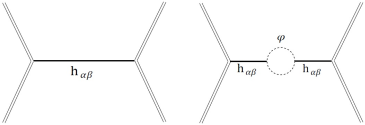

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- $c := N = \frac{4}{3}N_\phi + 8N_\psi + 16N_V$ Duff, Nucl. Phys. B 125, 334 (1977)

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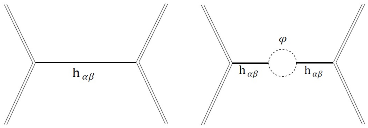

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- Comparison with the free propagator $1/(p^2M_{pl}^2)$ implies that the perturbative expansion fails at $p = M_{**}$ where $M_{**} \sim \frac{M_{pl}}{\sqrt{N}}$.

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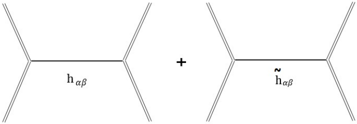
- Expansion breaks down when $H^2 \sim M_{pl}^2/N$.
- Corollary: it is not possible to consistently *infer* a scale of inflation H greater than $M_{pl}/\sqrt{N}$.

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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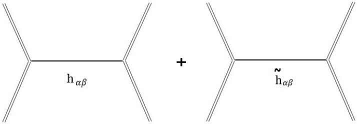

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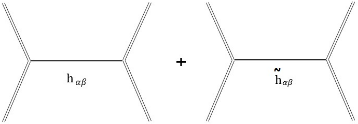

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- $M_*^2 = M_{pl}^2/N_*$, N_* counts the number of species with masses below the momentum transfer of the process in question.

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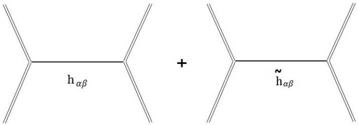

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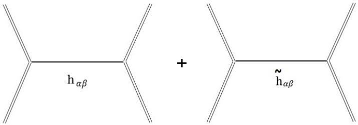

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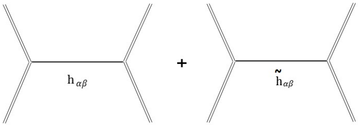

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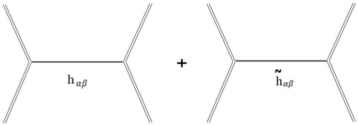

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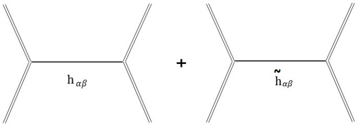

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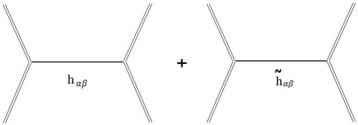

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- Non-minimal couplings do the same. $M_* = M_{pl}/N_*$, N_* a (process dependent) weighted index.

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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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$$\mathcal{P}_{\mathcal{R}} := \frac{H_*^2}{8\pi^2 M_{*s}^2\epsilon_*} = \mathcal{A}\times 10^{-10}; \quad \epsilon_* := -\dot{H}_*/H_*^2$$

Amplitude *fixed* by observations.

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- e.g. $r_* = 0.1$ implies $V_*^{1/4} = 7.6\times 10^{-3}M_{pl}/\sqrt{N_*}$. *Uncertain up to unknown* N_* *.*

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The *inferred* energy scale of inflation depends on the hidden field content of the universe.

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- For putatively low scale inflationary models, extra species can bring down the scale of inflation even further. Collider constraints?
- Given $M_* \leq M_{pl}$ and that $M_{**} = M_{pl}/N$, N being *total* no of species, can infer the absolute bound $N \leq \frac{9.15}{r_*} \times 10^7 \left(\frac{M_{pl}^2}{M_{*T}^2}\right)$

A Maximally Boring Universe?

Lets say as per the standard picture $M_* = M_{pl}$ all the way up to M_{**} . LHC Run II turns up nothing new. DM is completely non-interacting. We see nothing beyond what is consistent with Gaussian, scale invariant perturbations...

Nothing still tells us something

We may also convert the non-observation of primordial non-Gaussianity in to constraints on the hidden field content of the universe. In preparation, w/ I.Antoniadis and R.Durrer

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- ... the non-observation of which could bound the field content of the hidden universe.

Hidden sector bounds

Starting with the action of gravity + the inflaton + N light scalars:

- $S = \frac{M_{pl}}{2}\int d^4x\sqrt{-g}R - \frac{1}{2}\int d^4x\sqrt{-g}\left[\partial_\mu\phi\partial^\mu\phi + 2V(\phi)\right]$
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The in-in formalism in one slide

Work in the in-in formalism to compute corrections to finite time correlation functions. Primarily interested in computing the late (finite) time correlator

- $\langle\widehat{\mathcal{R}}_{\vec{k}_1}(\tau)\widehat{\mathcal{R}}_{\vec{k}_2}(\tau)\widehat{\mathcal{R}}_{\vec{k}_3}(\tau)\rangle := (2\pi)^3\delta^2(\vec{k}_{123})\mathcal{B}(\vec{k}_1,\vec{k}_2,\vec{k}_3)$ where $\vec{k}_{123} := \vec{k}_1 + \vec{k}_2 + \vec{k}_3$.

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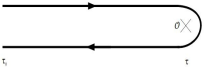

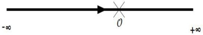

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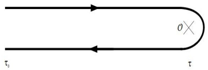

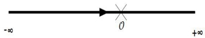

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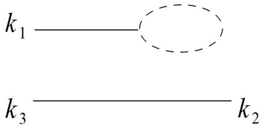
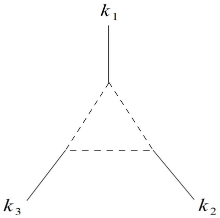
- Or equivalently in terms of the original operator basis: $\langle\mathcal{O}(\tau)\rangle = \sum_{n=0}^{\infty} i^n\int_{\tau_0}^{\tau} d\tau_n\int_{\tau_0}^{\tau_n} d\tau_{n-1}\ldots\int_{\tau_0}^{\tau_2} d\tau_1\langle[H_I(\tau_1),[H_I(\tau_2),\ldots[H_I(\tau_n),\mathcal{O}(\tau)]\ldots]]\rangle$

Weinberg arXiv:hep-th/0506236

Hidden sector bounds

(very loosely– lots of cancellations between fields on different contours in the diagrammatic version of the in-in formalism)





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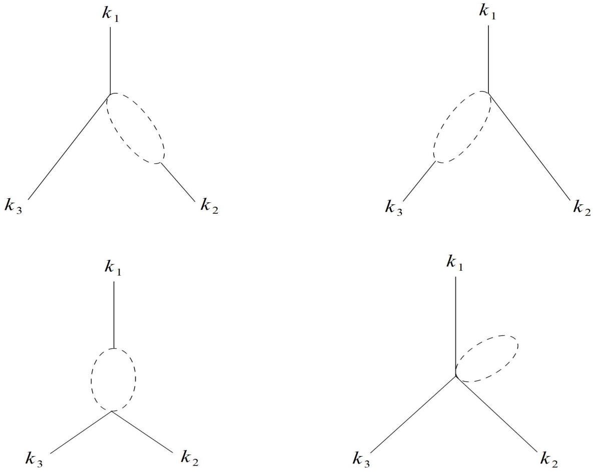

Hidden sector bounds

Last diagram– need to compute relevant fifth order vertex:

$$
\begin{aligned}
S_4 \;=\;& \frac{M_{pl}^2}{2}\int d^4x\, a^2 \Big\{ -\epsilon(\partial\mathcal{R})^2\mathcal{R} + a^2\left(\frac{9\mathcal{R}^2}{2} - \frac{3\mathcal{R}'\mathcal{R}}{\mathcal{H}} + \frac{\mathcal{R}'^2}{\mathcal{H}^2}\right)\left[\partial_i\partial_j\theta_1\partial_i\partial_j\theta_1 - (\partial^2\theta_1)^2\right] \\
&+ 2a^2\left(3\mathcal{R} - \frac{\mathcal{R}'}{\mathcal{H}}\right)\left[\partial_i\partial_j\theta_1\partial_i\partial_j\theta_2 - \partial^2\theta_1\partial^2\theta_2\right] + 9\epsilon\mathcal{R}^2\mathcal{R}'^2 - 12a^2\mathcal{R}\partial_j\theta_1\partial_j\mathcal{R}\partial^2\theta_1 - 6\epsilon\mathcal{R}\frac{\mathcal{R}'^3}{\mathcal{H}} \\
&- 6a^2\partial_l\theta_1\partial_l\mathcal{R}\partial_k\theta_1\partial_k\mathcal{R} - 4a^2\partial_l\theta_2\partial_l\mathcal{R}\partial^2\theta_1 - 4a^2\partial_l\theta_1\partial_l\mathcal{R}\partial^2\theta_2 + 4a^2\frac{\mathcal{R}'}{\mathcal{H}}\partial_l\theta_1\partial_l\mathcal{R}\partial^2\theta_1 + 2\epsilon\frac{\mathcal{R}'^4}{\mathcal{H}^2} \\
&+ \alpha_2^2\left(2\mathcal{H}' + 4\mathcal{H}^2\right) + \left(\frac{9\mathcal{R}^2}{2} - \frac{3\mathcal{R}'\mathcal{R}}{\mathcal{H}} + \frac{\mathcal{R}'^2}{\mathcal{H}^2}\right)\frac{\chi_a'\chi'^a}{M_{pl}^2} - 2a\frac{\chi_a'\partial_i\chi^a}{M_{pl}^2}\partial_i\theta_1\left(3\mathcal{R} - \frac{\mathcal{R}'}{\mathcal{H}}\right) \\
&- 2a\frac{\chi_a'\partial_i\chi^a}{M_{pl}^2}\partial_i\theta_2 + a^2\partial_i\theta_1\partial_j\theta_1\frac{\partial_i\chi_a\partial_j\chi^a}{M_{pl}^2} - \frac{\partial_i\chi_a\partial_i\chi^a}{M_{pl}^2}\left(\frac{\mathcal{R}^2}{2} + \frac{\mathcal{R}\mathcal{R}'}{\mathcal{H}}\right)\Big\}
\end{aligned}
$$

$$
\alpha_2 = -\frac{1}{2H}\frac{\partial_k}{\partial^2}\left\{-\frac{\dot\chi_a\partial_k\chi^a}{M_{pl}^2} - \partial_k\partial_i\theta_1\partial_i\mathcal{R} + 2\partial_i\theta_1\partial_i\partial_k\mathcal{R} - \partial_k\alpha_1\partial^2\theta_1 + \partial_i\alpha_1\partial_k\partial_i\theta_1 + \partial_k\mathcal{R}\partial^2\theta_1\right\}
$$

$$
\begin{aligned}
\theta_2 = \frac{\partial^{-2}}{4H}\Big\{ & -\frac{1}{M_{pl}^2}\left[\dot\chi_a\dot\chi^a + \frac{1}{a^2}\partial_i\chi^a\partial_i\chi^a\right] + \frac{8}{a^2}\mathcal{R}\partial^2\mathcal{R} - \frac{2}{a^2}(\partial\mathcal{R})^2 + (\partial^2\theta_1)^2 - \partial_k\partial_l\theta_1\partial_k\partial_l\theta_1 \\
&+ 4\dot{\mathcal{R}}\partial^2\theta_1 - 6\epsilon\dot{\mathcal{R}}^2 - 2\alpha_2\left[6H^2 + 2\dot H\right] - 12H\partial_i\theta_1\partial_i\mathcal{R}\Big\}
\end{aligned}
$$

Large N renormalization

Integrating out a large number of fields renormalizes everything. Have to make sure large N 's don't cancel. The propagator for $\mathcal{R}$ gets renormalized at one loop as[2] –

- $\frac{1}{\epsilon_R} = \frac{1}{\epsilon_B} + cN$

[2] More complicated topologies subleading in large N limit.

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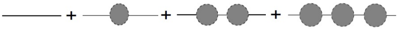

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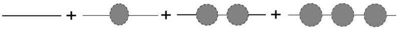

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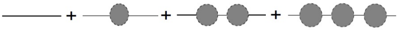

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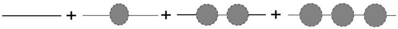

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