Title: Seeing Orbifold GUTs In Primordial Non-Gaussianities - Speaker: Soubikh Kumar

Date: Dec 07, 2018 01:00 PM

URL: http://pirsa.org/18120010

Abstract: <p>The minimal Standard Model running of the gauge couplings gives us a hint of a Grand Unified Theory (GUT) at M_U ~ 10^14 GeV â€” a scale, however, too high to probe directly via collider searches. Fortunately, since the inflationary Hubble scale H can be as high as 5 x 10^13 GeV ~ M_U, such GUT scale states can be cosmologically produced during inflation and contribute to primordial non-Gaussianity (NG).</p>

<p>In this talk, I will explore the possibility of doing on-shell, mass-spin spectroscopy of GUT-states by studying such NG contributions in an extra-dimensional framework of orbifold GUTs. I will identify an interesting regime where the extra dimension is stabilized close to the onset of a horizon and find that the KK gravitons and KK gauge bosons can mediate observable NG providing a direct probe of orbifold GUTs.</p>

Seeing Orbifold GUTs in Primordial Non-Gaussianities

Soubhik Kumar
University of Maryland

Work with Raman Sundrum : 1811.11200

Particle Physics Seminar, Perimeter
Dec 7, 2018

Orbifold GUTs

SM gauge couplings seem to unify

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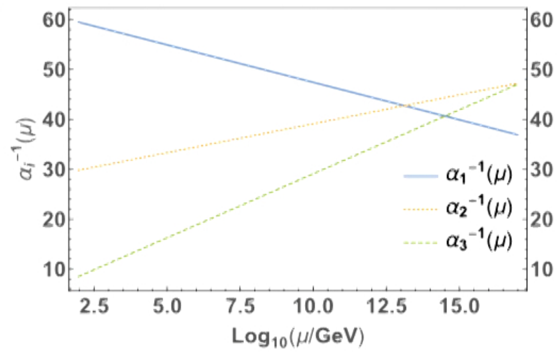
- Approximate meeting $\sim 10^{14}$ GeV



1-loop SM RGE

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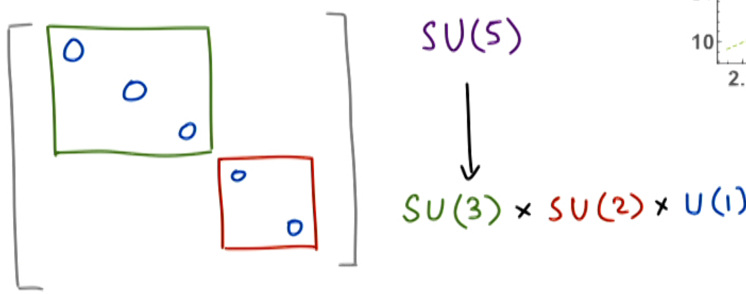
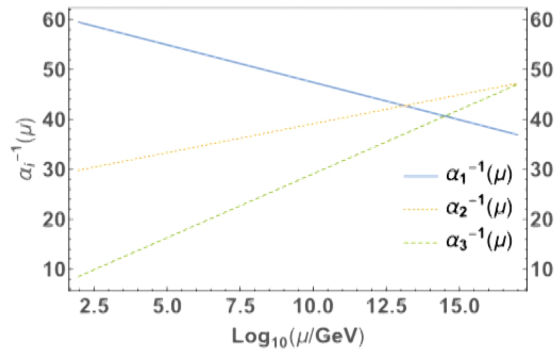
- e.g. SU(5) unification

Georgi, Glashow '74





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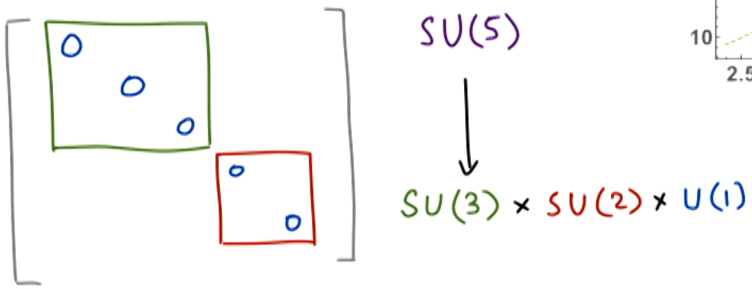
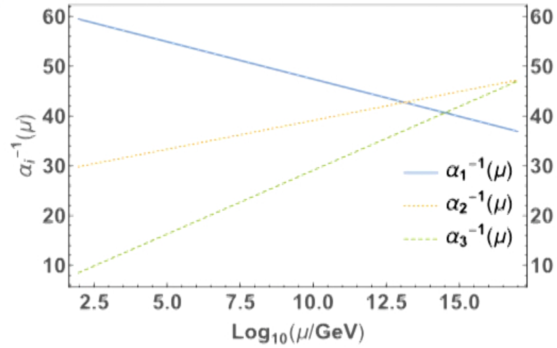


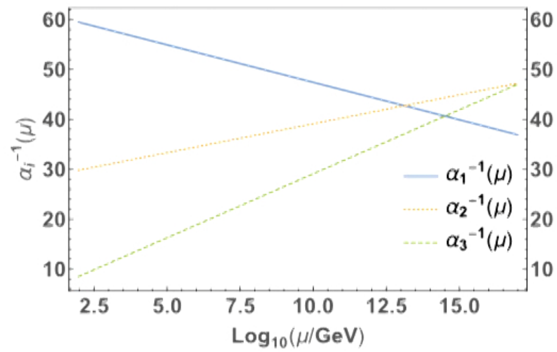


1-loop SM RGE

- Fewer parameters, explain SM quantum numbers etc.

New physics and unification

- Not a very precise unification:



1-loop SM RGE

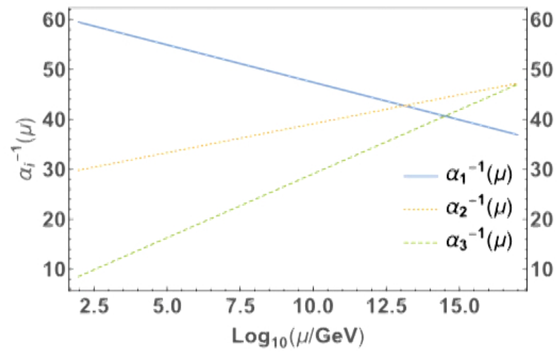
New physics and unification

- Not a very precise unification:
- Low scale SUSY
- High scale thresholds

$M_{pl} \sim 10^{18}$ GeV

$M_U \sim 10^{14}$ GeV

$M_{EW} \sim 100$ GeV



1-loop SM RGE

Model building constraints

- Minimal scenarios predict proton decay

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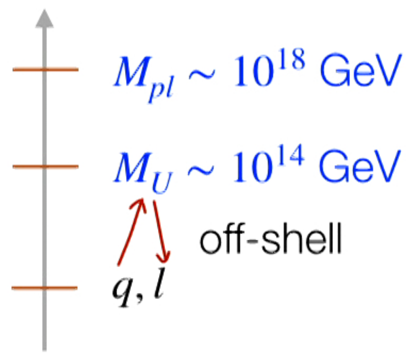

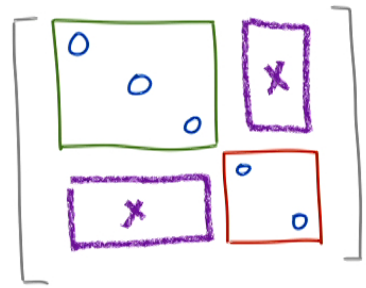

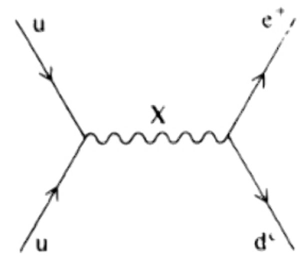

$$\Gamma \propto \frac{1}{m_X^4}$$

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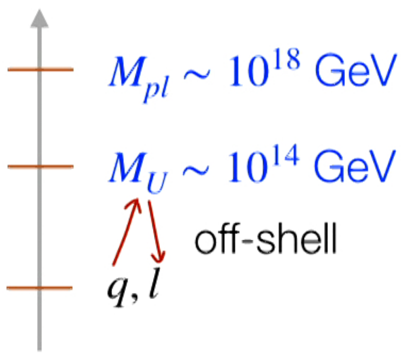

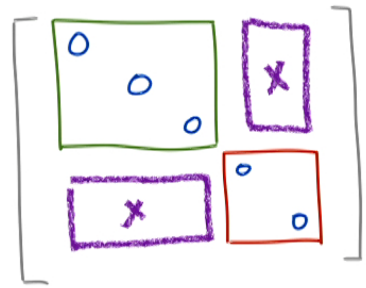

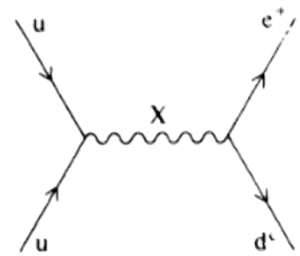

$$\Gamma \propto \frac{1}{m_X^4}$$

$$\tau(p \to e^+\pi^0) > 1.6 \times 10^{34} \text{ yrs} \Rightarrow m_X \gtrsim 5 \times 10^{15} \text{ GeV}$$

Super-K Collaboration '16

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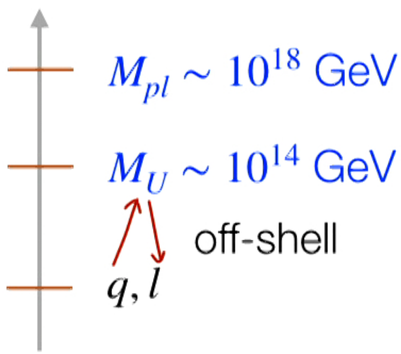

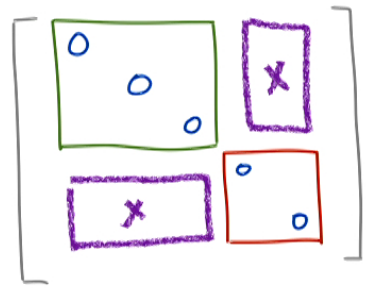

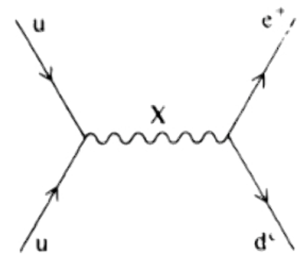

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- Naively rules out SM unification

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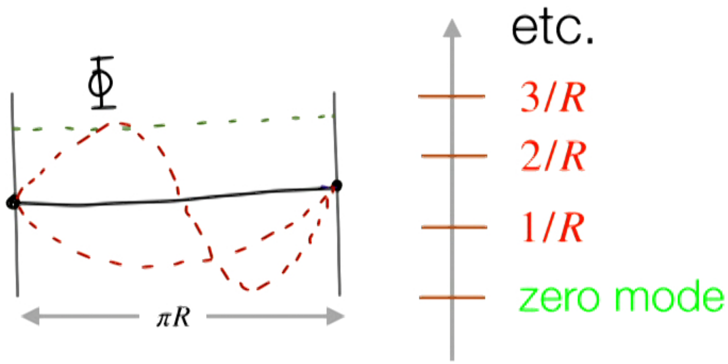

Kaluza-Klein decomposition

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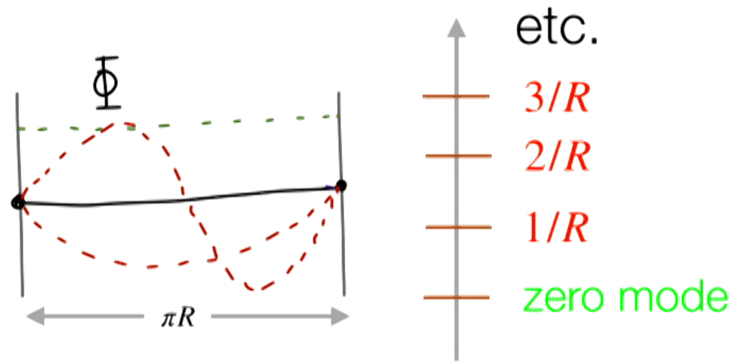
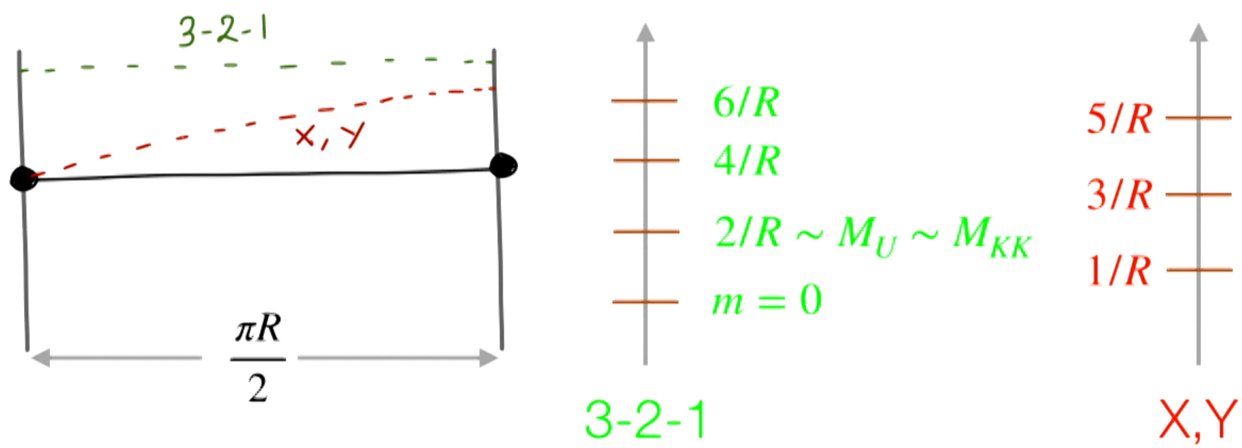
- Masses given by extra dimensional profiles
- Boundary conditions determine which fields should appear in the IR



GUT breaking via boundary conditions



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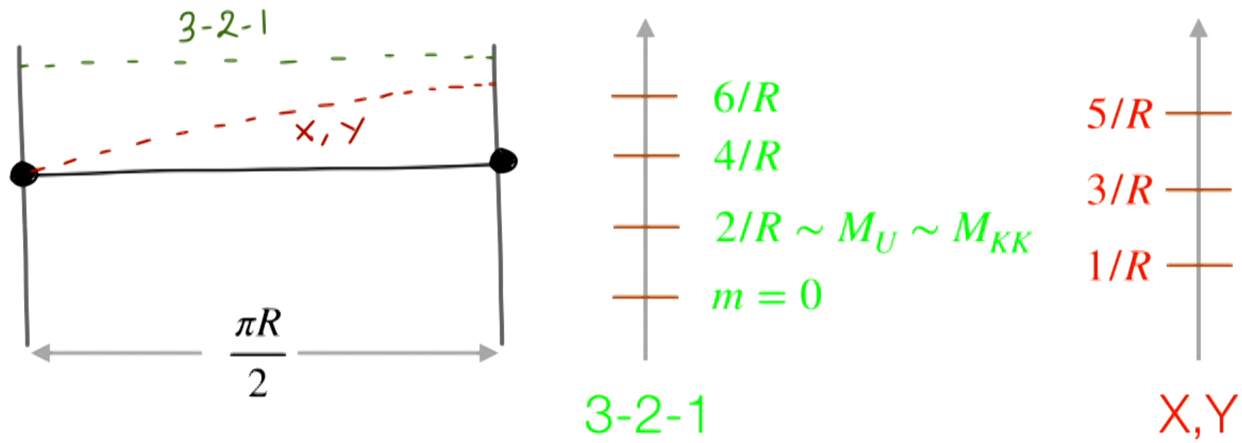
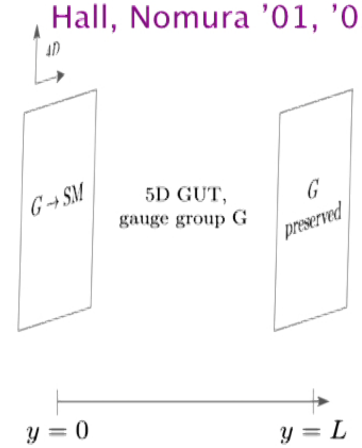


$$SU(5) \to SU(3) \times SU(2) \times U(1) \equiv 3-2-1$$

Orbifold unification

Kawamura '99, '00;
Hall, Nomura '01, '03



Orbifold unification

$$\int_0^L dy \left(\frac{1}{g_5^2} F_{MN} F^{MN} + \delta(y) \kappa_i F_{i,\mu\nu} F_i^{\mu\nu} \right)$$

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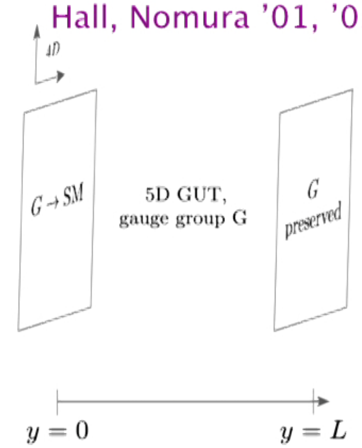

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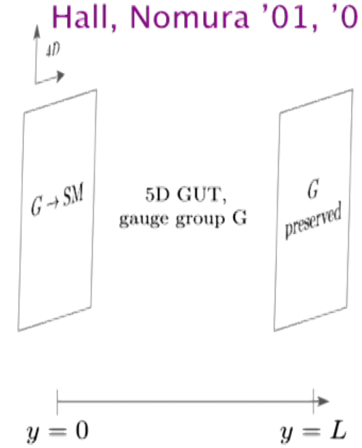

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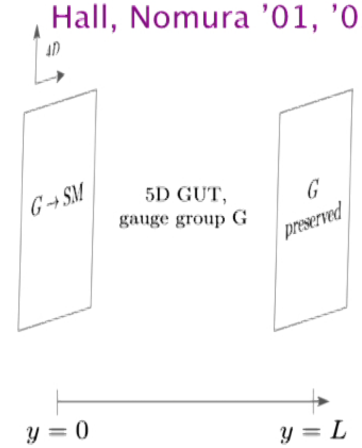

- At low energies,

$$\alpha_i^{-1}(\mu) = \frac{4\pi L}{g_5^2} + \frac{b_i}{2\pi} \log\left(\frac{m_{KK}}{\mu}\right) + 4\pi\kappa_i$$

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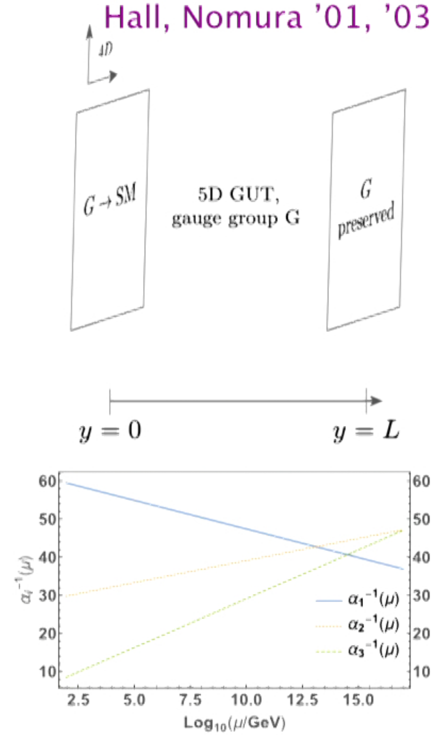

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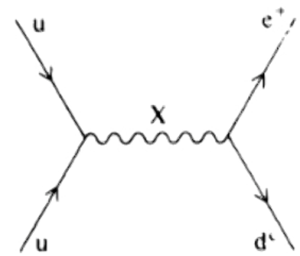
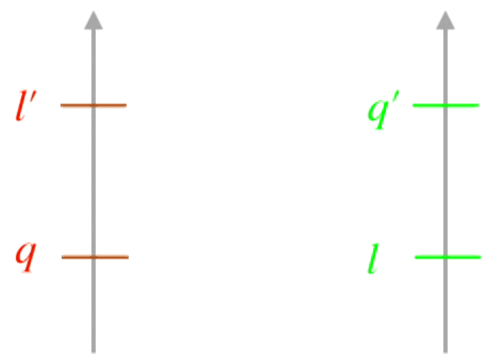
“Split” Multiplets to avoid proton decay



Not possible



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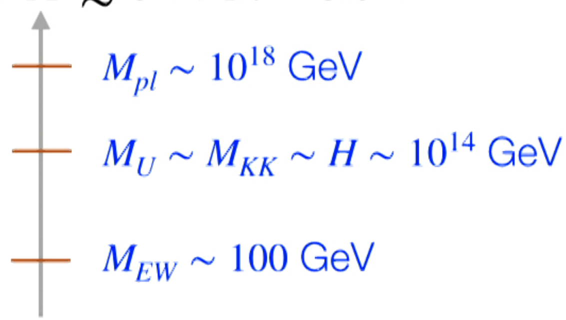

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- Time dependent inflationary background can produce GUT states and give rise to non-Gaussianity.

Cosmological correlations functions

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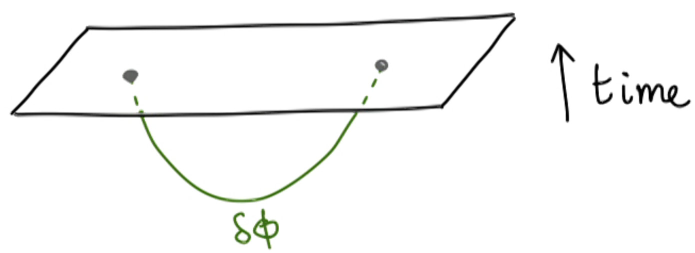
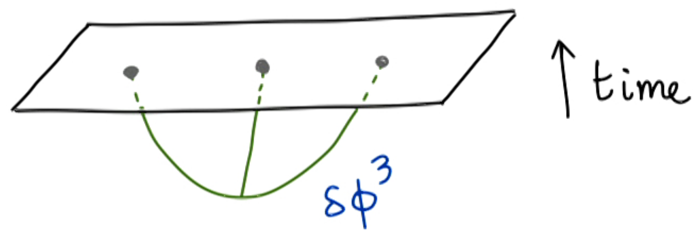


Interactions and non-Gaussianity



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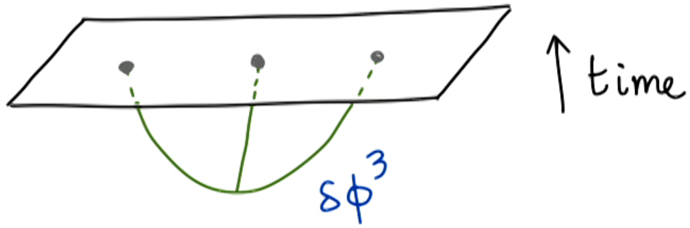

- Dimensionless measure of non-gaussianity (NG):

$$F(k_1, k_2, k_3) \equiv \frac{\langle \mathcal{R}(\overrightarrow{k}_1)\mathcal{R}(\overrightarrow{k}_2)\mathcal{R}(\overrightarrow{k}_3)\rangle'}{\langle \mathcal{R}(\overrightarrow{k}_1)\mathcal{R}(-\overrightarrow{k}_1)\rangle'\langle \mathcal{R}(\overrightarrow{k}_3)\mathcal{R}(-\overrightarrow{k}_3)\rangle'}$$

$$f_{\rm NL} = \frac{5}{18}F(k, k, k)$$

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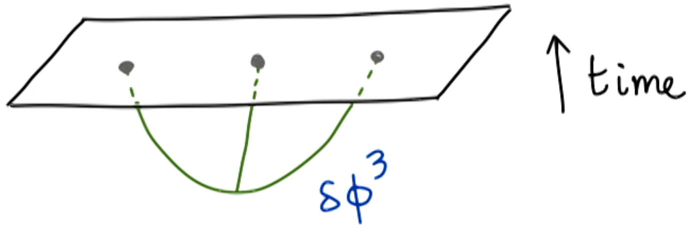

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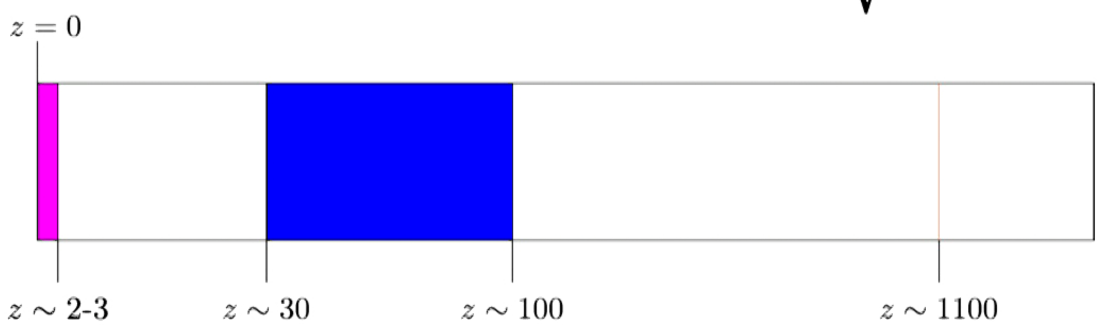
$$f_{\text{NL}} = \frac{5}{18} F(k, k, k)$$

- $\mathcal{O}(1)$ interaction strength implies $f_{\text{NL}} \sim 10^3 - 10^4$

Bounds on primordial non-Gaussianity

- Current bound from CMB roughly : $\delta f_{\rm NL} \lesssim \mathcal{O}(10)$ Planck 2015 1502.01592
- Number of modes matter : $\delta f_{\rm NL} \sim \dfrac{10^4}{\sqrt{N_{\rm Modes}}}$



Alvarez et. al. 1412.4671

Loeb, Zaldarriaga astro-ph/0312134

PLANCK : $N_{\rm Modes} \sim 10^7 \to \delta f_{\rm NL} \sim 10$ Completed.

LSS Surveys : $N_{\rm modes} \sim 10^8 \to \delta f_{\rm NL} \sim 1$ 2020

21-cm : $N_{\rm Modes} \sim 10^{16} \to \delta f_{\rm NL} \sim 0.001$ 20??

Cosmological collider physics

- H scale particles can decay into inflaton fluctuations

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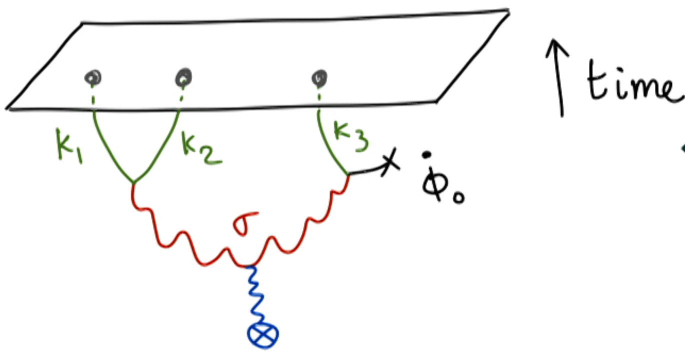

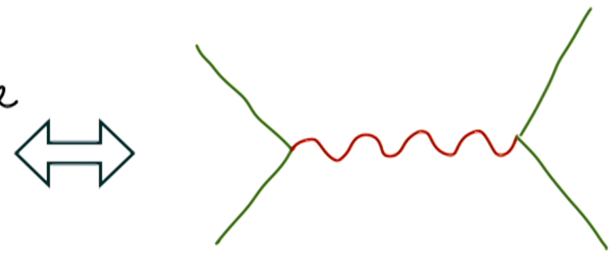

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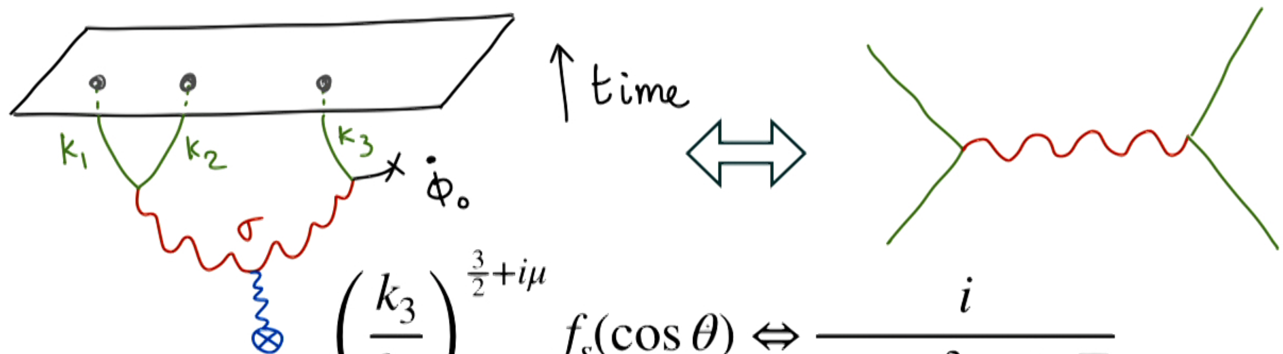

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$$f_s(\cos\theta) \Leftrightarrow \frac{i}{s - m^2 + im\Gamma}$$

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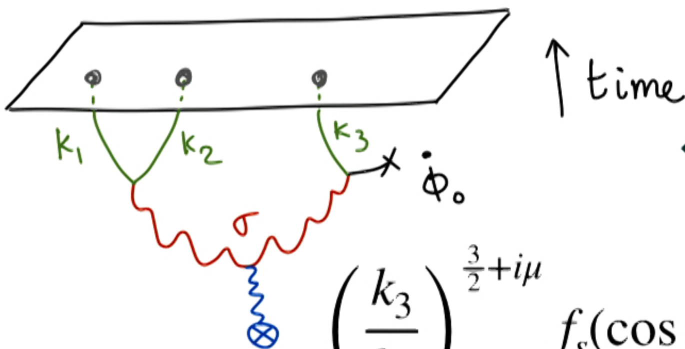

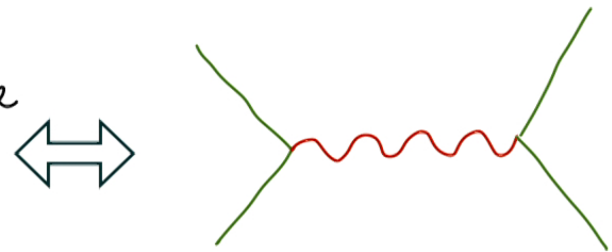

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- Can be extracted by studying "squeezed limit" of primordial non-Gaussian contributions.

Chen, Wang '09; Baumann, Green '11
Noumi et. al. '12
Arkani-Hamed, Maldacena '15
Lee et. al. '16
Meerburg et. al. '16, Kehagias, Riotto '17
...

Window of opportunity

- Loss of non-analyticity for

$$m \ll H$$

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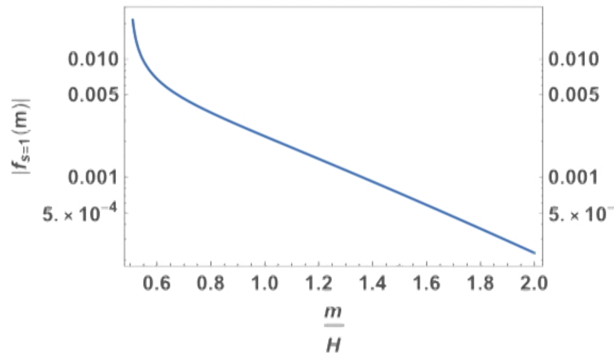

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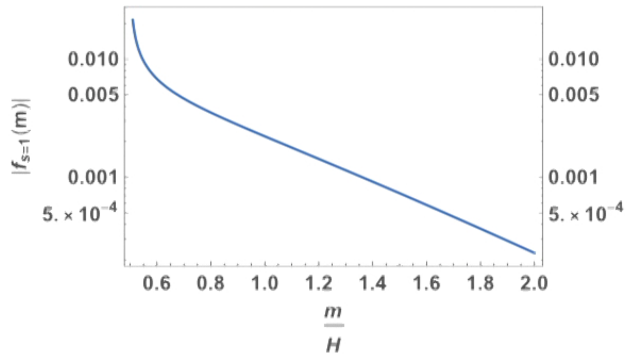

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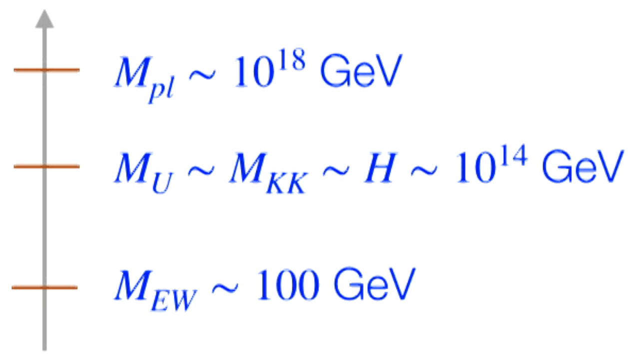

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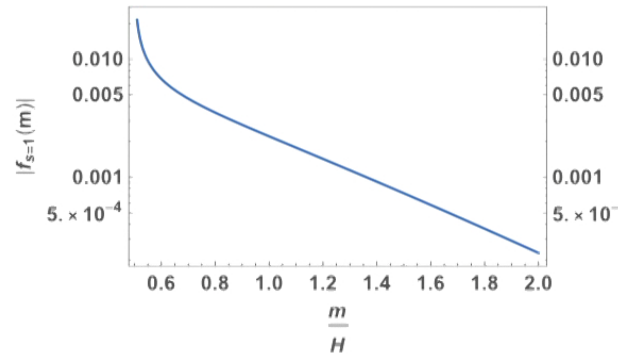

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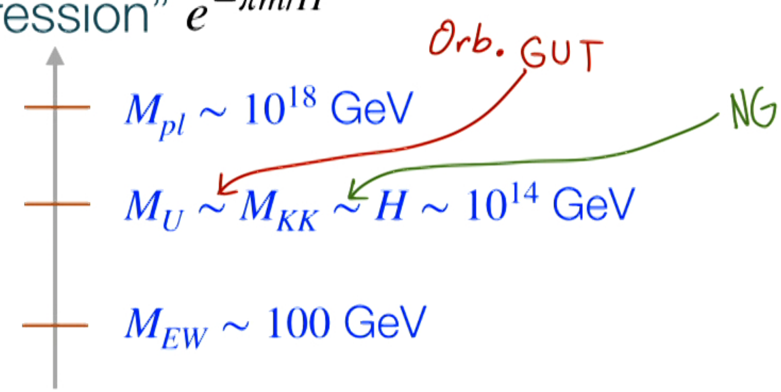

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Overview

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- Characterize the KK spectrum of graviton and gauge boson

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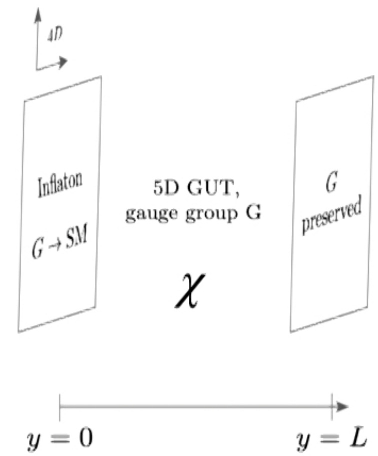
- Conclusion

General set-up



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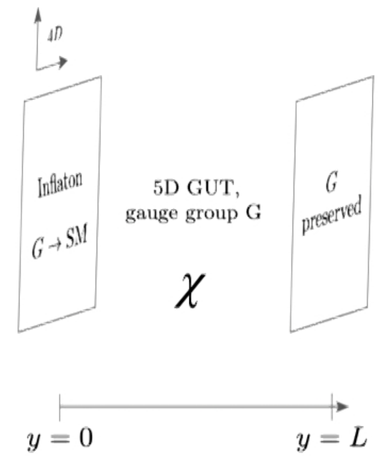

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$$H^2 - n(y)n''(y) - n'(y)^2 = \frac{1}{4M_5^3}\frac{n(y)^2}{3}\left(\frac{1}{2}\chi'(y)^2 + V(\chi) + \Lambda_5\right)$$

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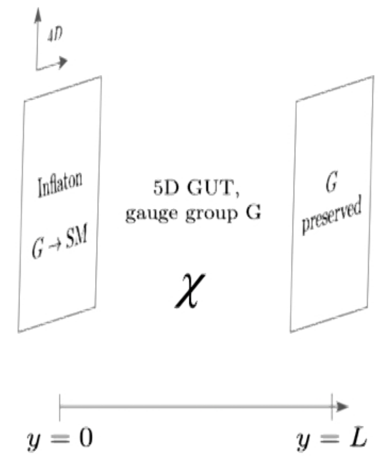

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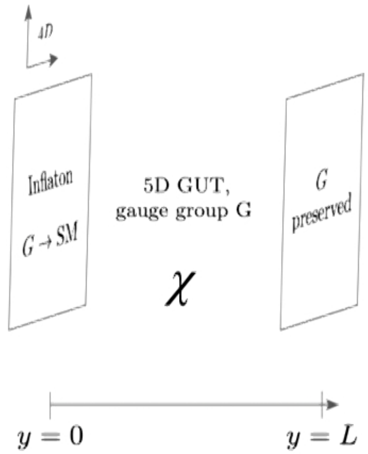
- Supplement with junction conditions



5D Geometry

- Solution in the absence of a bulk stress-energy tensor:

$$n(y) = 1 - Hy \qquad\qquad V_0 = 24 M_5^3 H > 0$$

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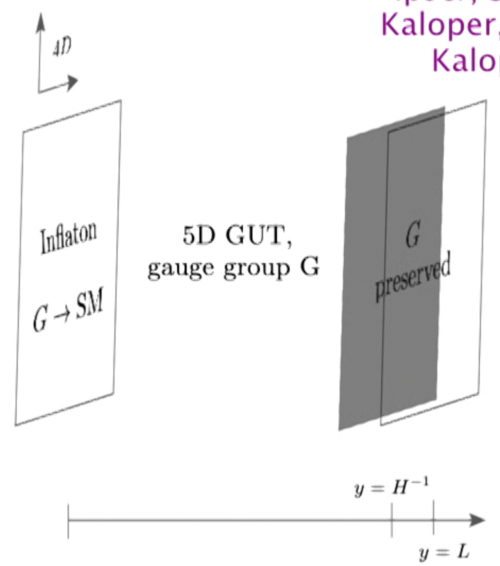

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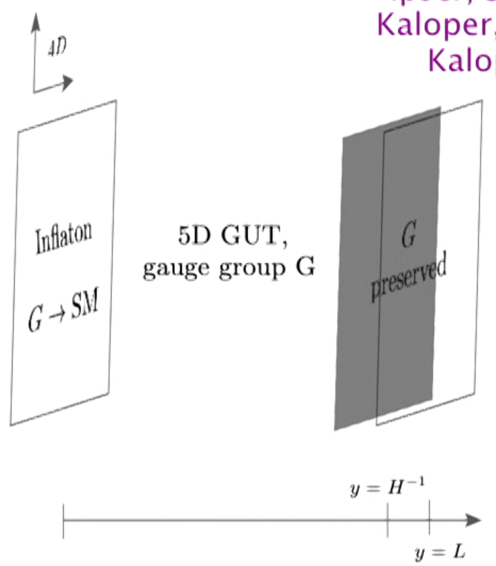
$$T_{\text{horizon}} = \frac{H}{2\pi}$$



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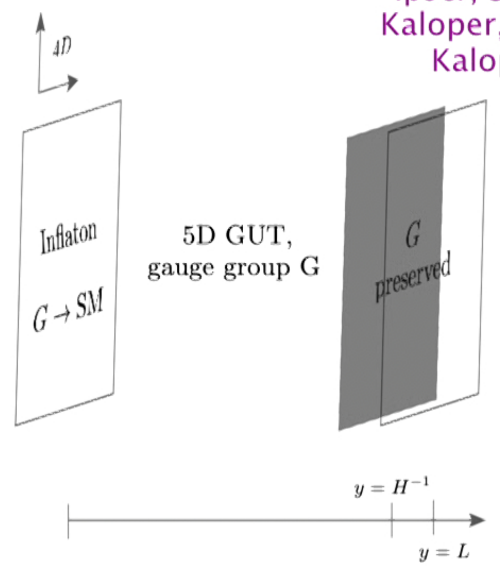
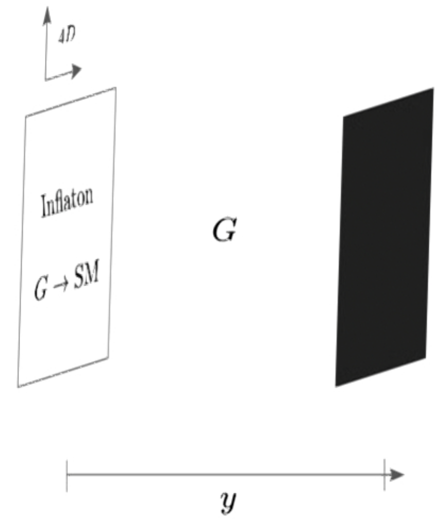


Simplify : semi-infinite extra dimension



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$$n(y)\frac{d}{dy} = \frac{d}{dz}$$

- KK decomposition:

$$\tilde{h}_{\mu\nu}(x,y) = \sum_l n^{-\frac{3}{2}}(y)\tilde{h}_{l,\mu\nu}(x)\psi_l(y)$$

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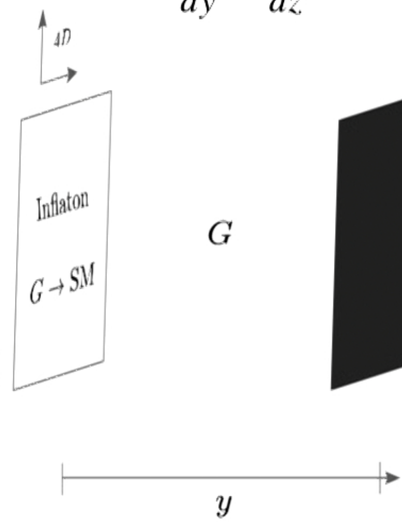

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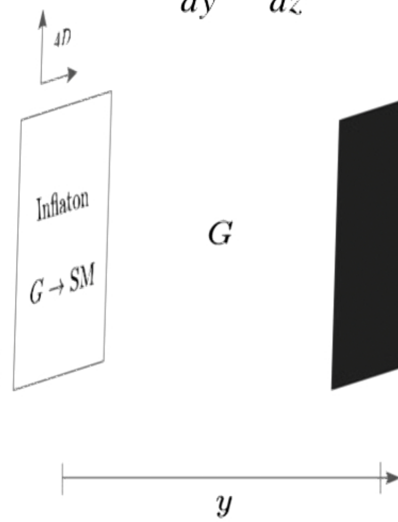

- Zero mode and KK graviton continuum: $m > 3H/2$ and obeys the Higuchi bound $m > \sqrt{2}H$

Higuchi '87

Garriga, Sasaki '99
Langlois et. al. '00
Karch, Randall '00

Introducing the second boundary

- Spectroscopy of discrete states : a second boundary.

Introducing the second boundary

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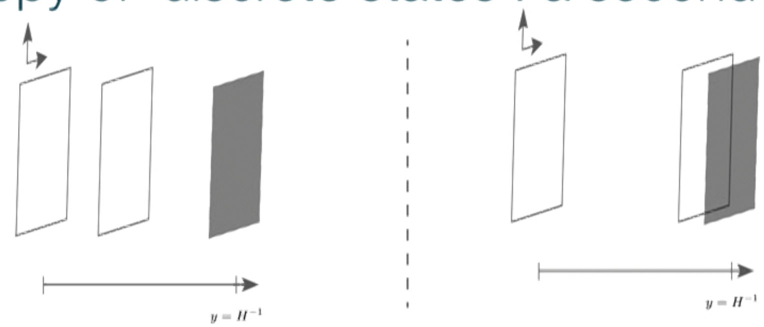

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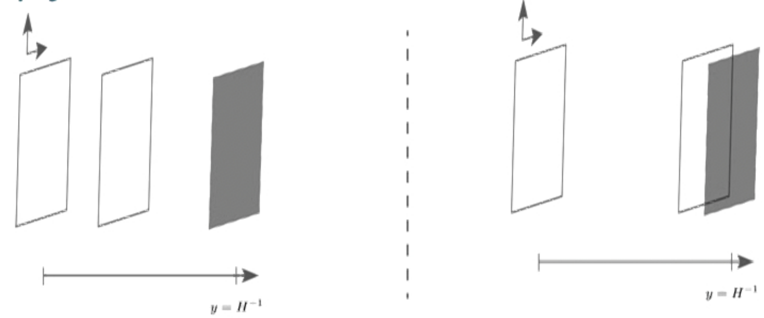

- Non-trivial! tachyonic radion:

$$ds^2 = -n(y)^2(1 - 2\Pi(x, y))dt^2 + n(y)^2 a(t)^2(1 - 2\Pi(x, y))d\vec{x}^2 + (1 + 4\Pi(x, y))dy^2$$

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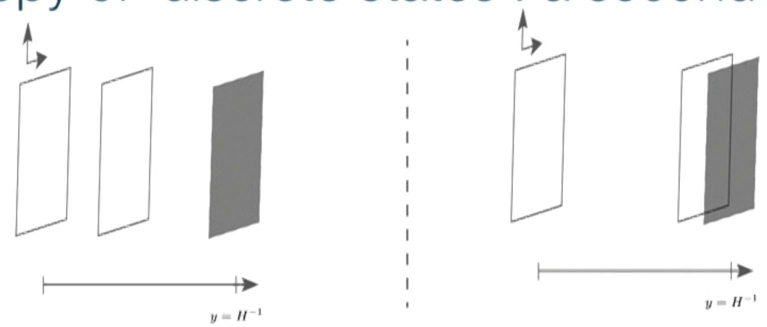

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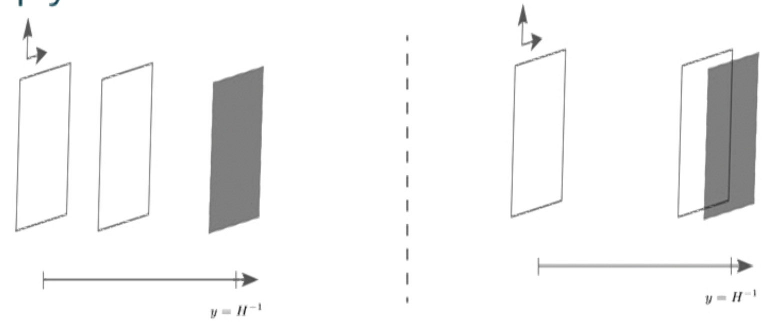

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- Need to stabilize.

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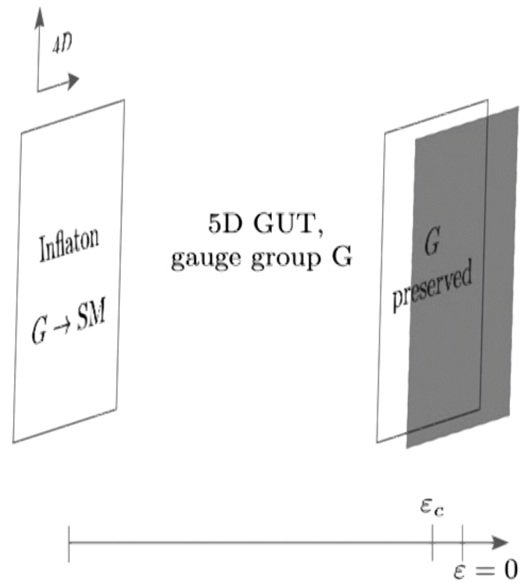
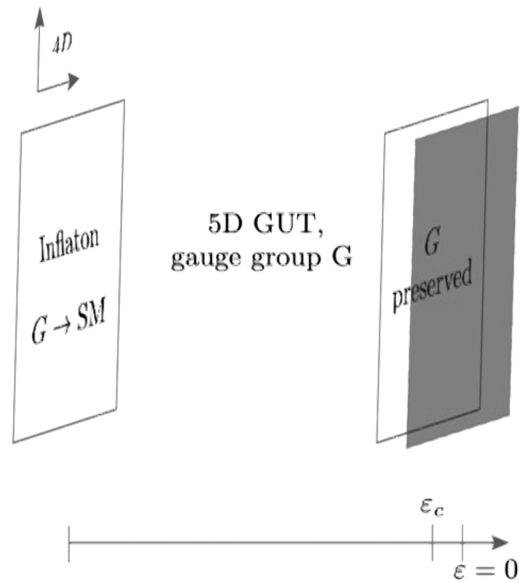
- Stabilization mechanism will necessarily have $\mathcal{O}(1)$ backreaction on the geometry and KK spectrum
- Needs to solve coupled 5D equations: technically difficult
- Analytical way to know a stabilization mechanism is working or not?

Near horizon analysis



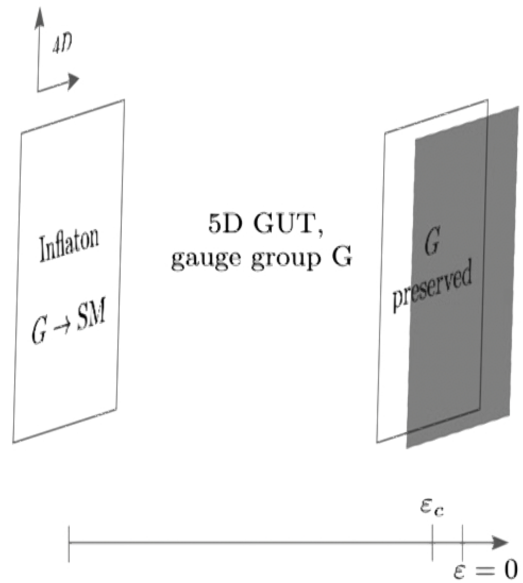
Near horizon analysis

- Very near the horizon $n(\varepsilon) \approx H\varepsilon$



Near horizon analysis

- Very near the horizon $n(\varepsilon) \approx H\varepsilon$
- New small parameter $H\varepsilon_c$, solve perturbatively in that.



Avoiding the tachyonic instability

- Background solution can be obtained order by order:

$$n(\varepsilon) = H\varepsilon - \frac{1}{72}v^2 m_\chi^2 H\varepsilon^3 + \cdots$$

$$\chi(\varepsilon) = \sqrt{4M_5^3}\left(v + \frac{1}{10}v m_\chi^2 \varepsilon^2 + \cdots\right)$$

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$$\Pi(x,\varepsilon) \propto (H\varepsilon)^{\frac{1}{2}\pm\nu} + \cdots \qquad \nu = \sqrt{\frac{9}{4} - \frac{m_r^2}{H^2}}$$

KK graviton wavefunction on inf. boundary

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- Would not change the inflaton-KK graviton overlap significantly

Model independent inf-KK graviton coupling

$$-\frac{\psi(0)}{M_4}\int d^4x\sqrt{-g}\,\partial^\mu\phi\partial^\nu\phi\tilde{h}_{\mu\nu} + \cdots$$

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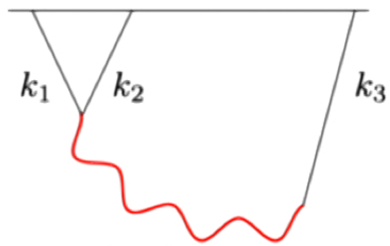

$k_3 \ll k_1 \approx k_2$

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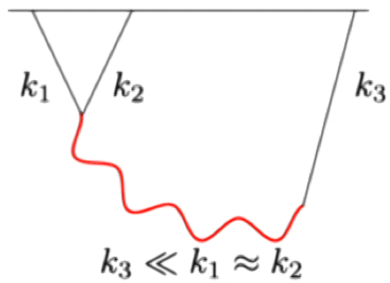
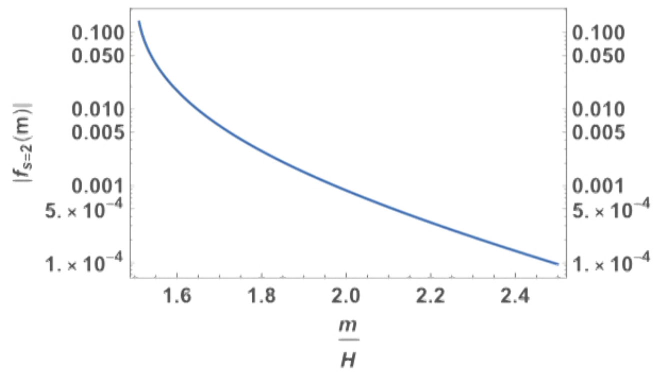


- Strength of NG in terms of tensor-to-scalar ratio:

$$F\sim\frac{\psi(0)}{M_4}\times\frac{\psi(0)\dot{\phi}_0}{M_4}\times\frac{\dot{\phi}_0}{H^2}\sim\frac{\dot{\phi}_0^2}{M_4^2H^2}\times\psi(0)^2\sim r\times\psi(0)^2$$

Explicit form of KK graviton mediated NG

$$r = 0.1;$$
$$\psi(0) = 1$$



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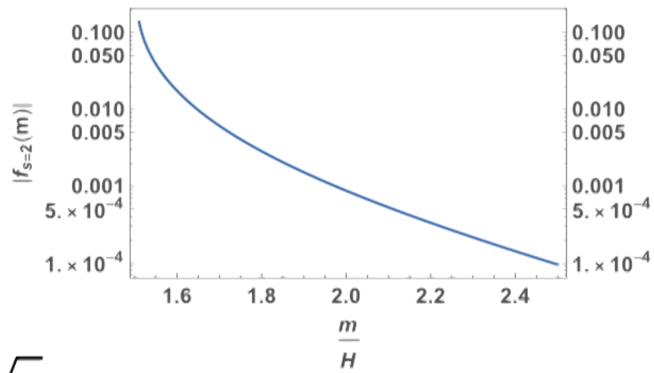

$$F = \psi(0)^2 \frac{r}{8} \times (\cos^2\theta - \frac{1}{3}) \frac{\sqrt{\pi}}{8(1+4\mu_2^2)^2 \cosh(\pi\mu_2)} \qquad \theta = \hat{k}_3 \cdot \hat{k}_1$$

$$\times \left(A(\mu_2)(1 + i \sinh \pi\mu_2) \left(\frac{k_3}{k_1} \right)^{3/2 + i\mu_2} + (\mu_2 \to -\mu_2) \right)$$

$$A(\mu) = (-27 + 120 i\mu + 152\mu^2 - 32 i\mu^3 + 16\mu^4)\Gamma(5/2 + i\mu)\Gamma(-i\mu)2^{-2i\mu}$$

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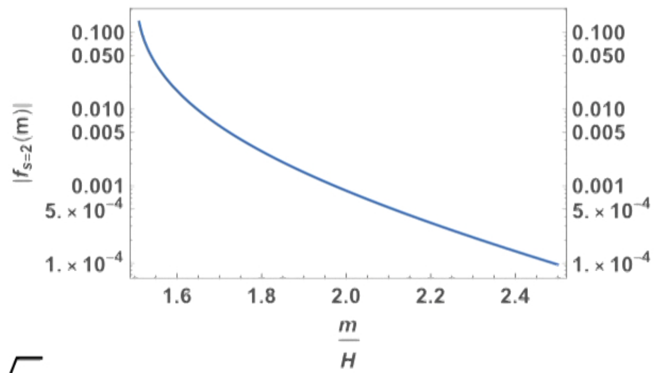

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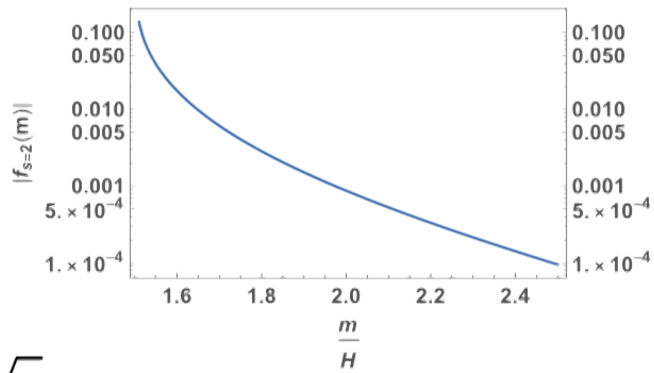

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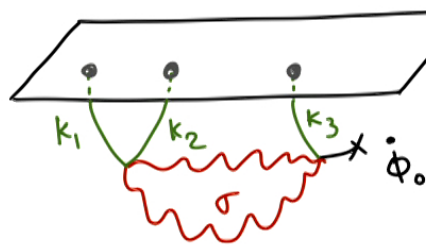

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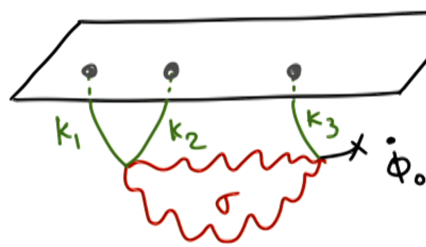

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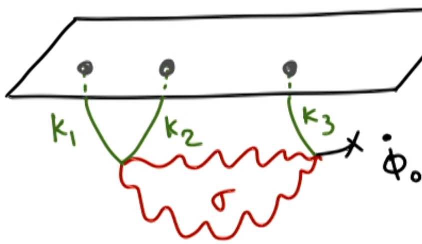

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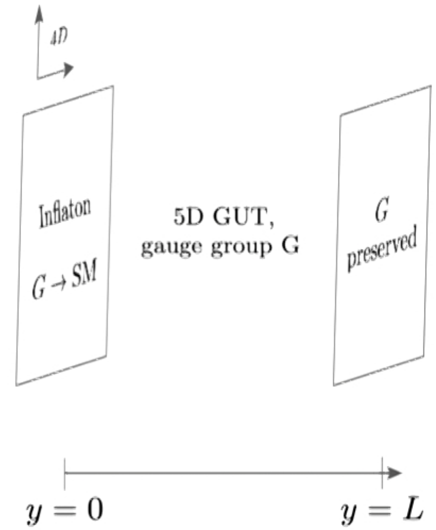
- Need to look for states neutral under the residual group for tree level NG

SO(10) GUT



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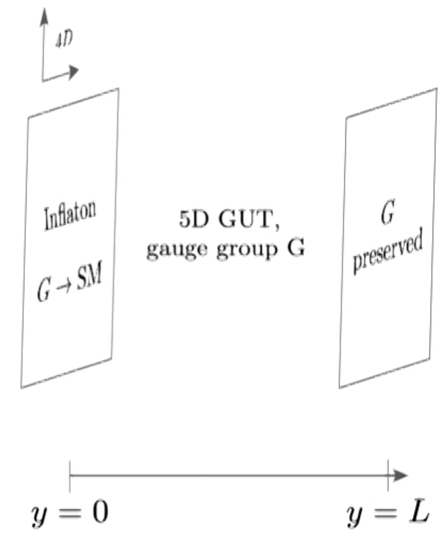
$$G = SO(10) \to SU(3) \times SU(2) \times U(1)$$



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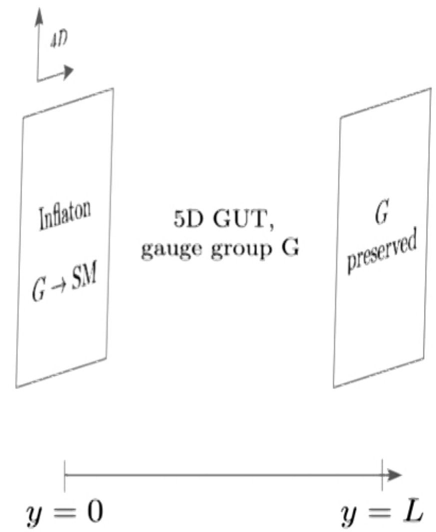

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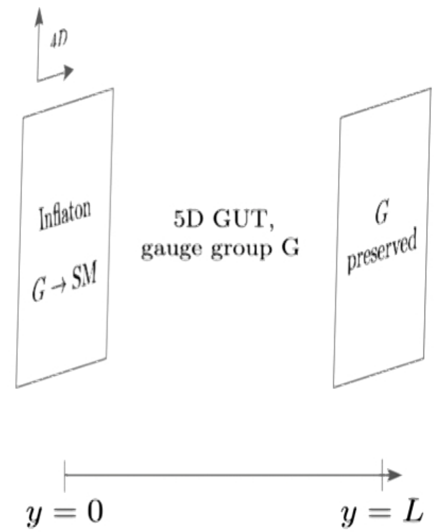

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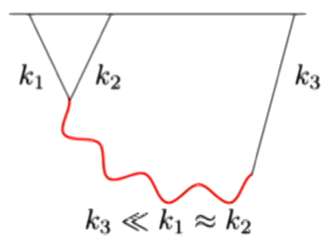
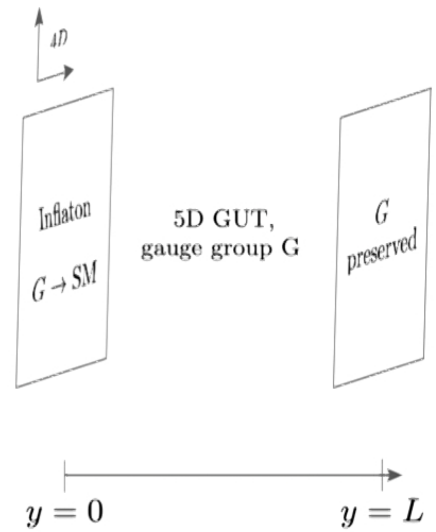
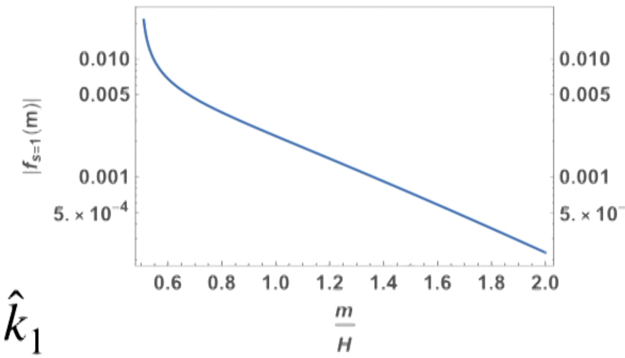




Explicit form of KK gauge boson mediated NG

$$\rho = 0.3$$

$$\vartheta'(0) = 1$$



$$\theta = \hat{k}_3 \cdot \hat{k}_1$$

$$F = \left(\frac{\rho}{m}\right)^2 \frac{1}{16\pi}\Gamma(\frac{3}{2} + i\mu_1)\Gamma(\frac{3}{2} - i\mu_1)\cosh(\pi\mu_1)\vartheta'(0)^2 \times \sin^2\theta$$

w/ Sundrum '17

$$\times \left(B(\mu)(1 - i\sinh(\pi\mu_1))\left(\frac{k_3}{k_1}\right)^{\frac{5}{2}+i\mu_1} + (\mu_1 \to -\mu_1) \right)$$

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Explicit form of KK gauge boson mediated NG

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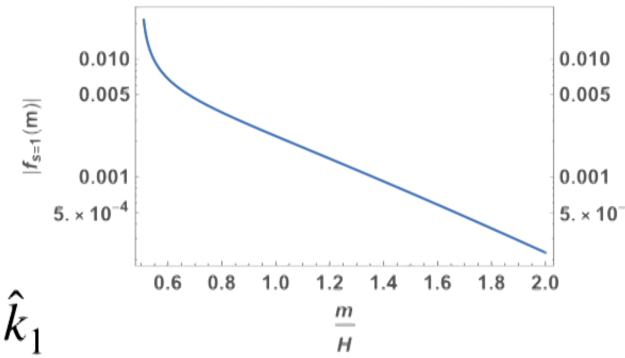

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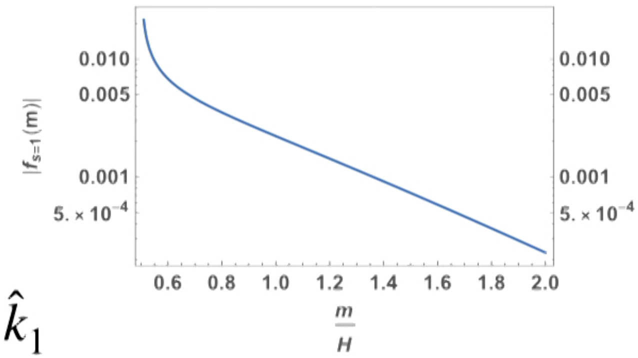

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SU(5) GUT

- If SM gauge group remains unbroken then can have tree level NG due to KK modes of $U(1)_Y$, but suppressed
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- Scenario of "heavy-lifting": h, Z can mediate observable NG

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- Determination of the warp factor in the entire extra dimension

DeWolfe et. al. '99