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Galilean symmetry in the EFT of inflation: new shapes of NG

with G. D'Amico, J. Noreña, M. Musso, E. Trincherini, 1011.3004 (JCAP)

Galilean symmetry

Nicolis, Rattazzi, Trincherini 08

Shift symmetry on the gradient of a scalar

$$\phi \to \phi + b_\mu x^\mu + c$$

- What happens if I impose this on the inflaton?
- In particular can I get new shapes wrt $\dot{\pi}^3$ and $\dot{\pi}(\nabla\pi)^2$?
- Neat example of the EFT of inflation

Lowest order

Lowest derivative galileons give 2nd order eom

$$\mathcal{L} \sim (\partial\phi)^2(\partial^2\phi)^n\,, \quad n \leq 3 \qquad \longrightarrow \qquad (\partial^2\phi)^{n+1}$$

Use these operators for inflaton Lagrangian — Burrage, De Rham, Seery, Tolley 10

Non-Gaussianity given by cubic operators with 4 derivatives:

$$\ddot{\pi}\dot{\pi}^2\,, \quad \dot{\pi}^2\nabla^2\pi\,, \quad \dot{\pi}\nabla\dot{\pi}\nabla\pi\,, \; \ddot{\pi}(\nabla\pi)^2\,, \; \nabla^2\pi(\nabla\pi)^2$$

.... but using $\ddot{\pi} + 3H\dot{\pi} - c_s^2\nabla^2\pi/a^2 = 0$

all these operators are equivalent to the ones with 3 derivatives!

Non renormalization

Luty, Porrati and Rattazzi 03

The leading G. operators $\mathcal{L} \sim (\partial\phi)^2(\partial^2\phi)^n \;, \quad n \leq 3$ are not renormalized

Consistent to set them to zero

We consider operators with two derivatives on each field $(\partial^2\phi)^n$

WAIT! But now the EOM are of higher order! Ghosts!??!

No, we are going to impose the symmetry on the EFT of inflation
and treat higher derivative terms perturbatively

The EFT of inflation

with Cheung, Fitzpatrick, Kaplan, Senatore 07

It is the theory of **small** perturbations around an inflating background

We probe $\phi_0(t+\pi(t,\vec{x}))$ $H\pi = -\zeta \simeq 10^{-5}$ and $E \sim H$

Usually the regime of validity extends to much larger values of π

We are interested in

$$M_{\rm Pl}^2 \dot{H} (\partial\pi)^2 + M(\partial^2\pi)^3 + \ldots$$

Say with cubic term to be of order ~ 10^{-3} wrt the kinetic one.
Higher derivative terms are small and are (as usual) treated perturbatively

The theory will break down for large $H\pi$! **In particular $\pi \sim t$ is not within the EFT**

The action

Useful to introduce a “fake” scalar which linearly realizes Lorentz symmetry

$$\psi(t, \vec{x}) \equiv t + \pi(t, \vec{x})$$

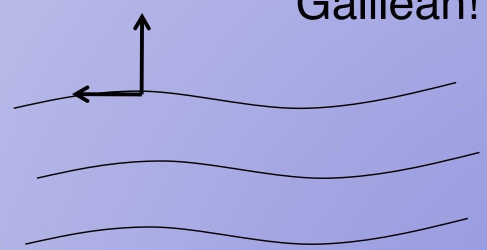
Building block: $\nabla_\mu \nabla_\nu \psi \equiv \Psi$

Build operators at a given order in π in terms of products of

$$[\Psi\Psi \ldots \Psi] \ldots [\Psi\Psi \ldots \Psi]$$

- Identify tadpoles
- Identify independent operators at each order
- Geometrical constructions does not help
- Mixing with gravity is subleading in slow-roll

Projectors are not Galilean!

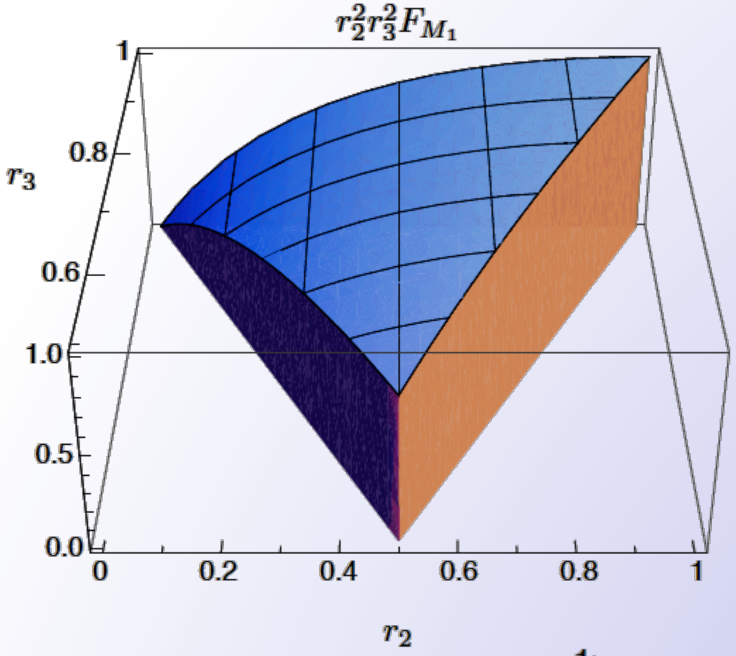


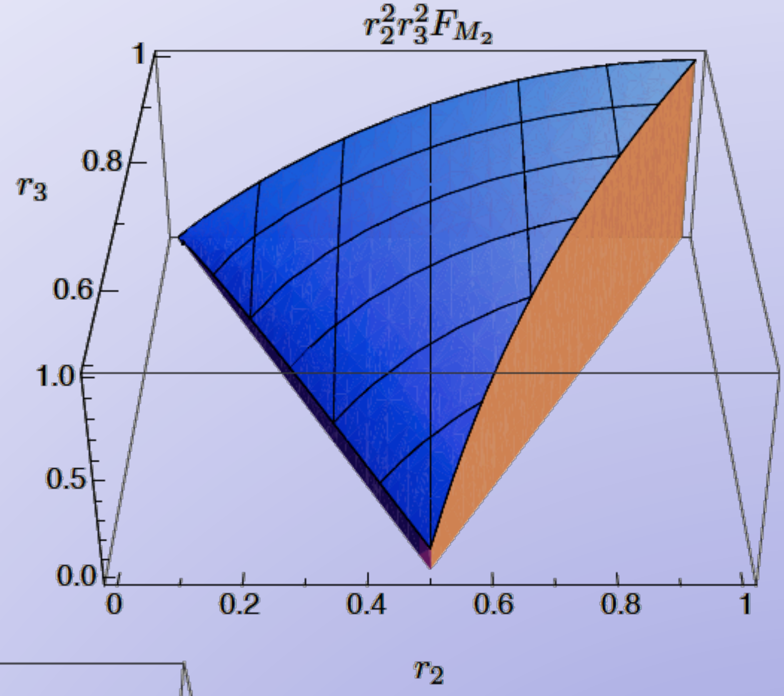
The cubic action

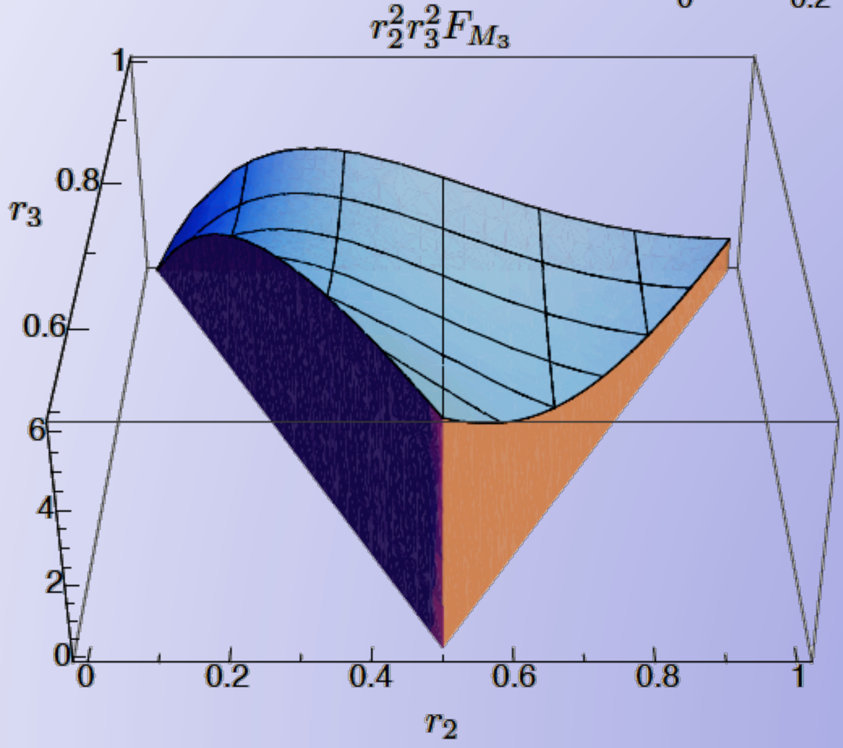
Final action has only 3 independent cubic operators:

$$S = \int \mathrm{d}^4x\, a^3 \Big[- M_{\rm Pl}^2 \dot{H} \left(\dot{\pi}^2 - \frac{(\partial_i \pi)^2}{a^2} \right) + M_1 \dot{\pi}^3 + M_2\, \dot{\pi} \frac{(\partial_i \dot{\pi} - H \partial_i \pi)^2}{a^2}$$
$$+ M_3 \left(\dot{\pi} \frac{(\partial_i \partial_j \pi)^2}{a^4} - 2H \dot{\pi} \dot{\pi}^2 + 3H^3 \dot{\pi}^3 \right) \Big]$$

Shapes







Surfing NG!

Similar to Bartolo etal 10

Constraints on parameters

Using the analysis of Smith etal. 10 and WMAP7, we can put constraints on M_i

Choose equilateral template for M_1 and M_2: $f_{NL}^{\rm eq} \equiv \frac{k^6}{6\Delta_\Phi^2} B(k,k,k)$

$$f_{\rm NL}^{\rm eq} = 26 \pm 140 \,(68\% \,{\rm CL}) \longrightarrow \frac{M_1 H}{\varepsilon M_{\rm Pl}^2} = 240 \pm 1280 \quad \frac{M_2 H}{\varepsilon M_{\rm Pl}^2} = -80 \pm 470$$

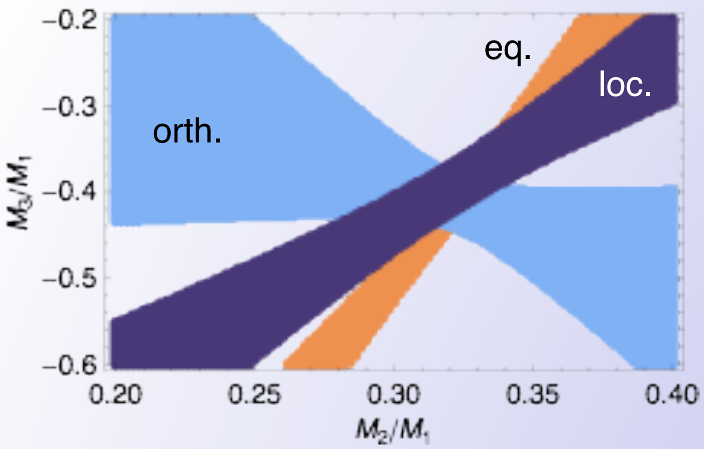
For M_3 we can use enfolded template (cos = 0.94): $f_{NL}^{\rm enf} \equiv \frac{k^6}{96\Delta_\Phi^2} B(k,k/2,k/2)$

$$f_{\rm NL}^{\rm enf} = 114 \pm 72 \,(68\% \,{\rm CL}) \longrightarrow \frac{M_3 H}{\varepsilon M_{\rm Pl}^2} = 830 \pm 530$$

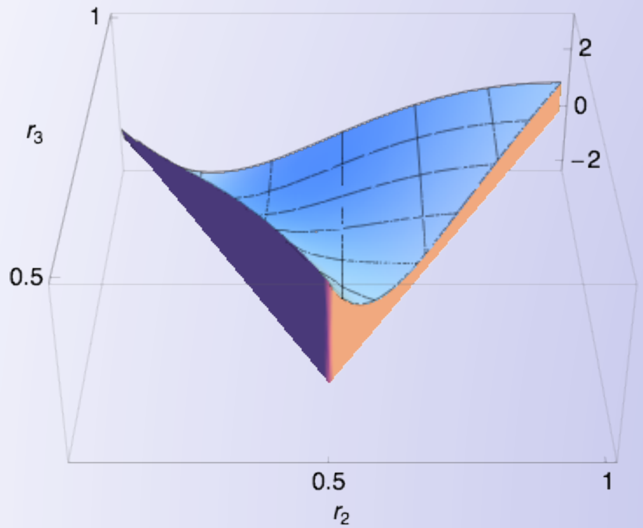
New shapes: orthogonal to orthogonal

Orthogonal shape is found by tuning coefficients requiring small cosines with local and equilateral

Can we extend the space of shapes with our new operators? YES



Template	Cosine
Local	-0.15
Equilateral	0.03
Orthogonal	0.06
Enfolded	-0.03



Look where |cos| < 0.2

Intersection point at

$M_2 = 0.32\ M_1$, $M_3 = -0.42\ M_1$

This would require a dedicated template...

4-point function

Standard EFT: $\mathcal{L}_{1-\partial} = (\partial\pi_c)^2 + \frac{1}{\Lambda^2}(\partial\pi_c)^3 + \frac{1}{\Lambda^4}(\partial\pi_c)^4 + \dots$

$$\mathrm{NG}_3 \equiv \frac{\langle\zeta^3\rangle}{\langle\zeta^2\rangle^{3/2}} \simeq \frac{\mathcal{L}_3}{\mathcal{L}_2}\bigg|_{E\sim H} \simeq \left(\frac{H}{\Lambda}\right)^2 \qquad \mathrm{NG}_4 \equiv \frac{\langle\zeta^4\rangle}{\langle\zeta^2\rangle^2} \simeq \frac{\mathcal{L}_4}{\mathcal{L}_2}\bigg|_{E\sim H} \simeq \left(\frac{H}{\Lambda}\right)^4$$

$$\Longrightarrow \quad \mathrm{NG}_4 \sim \mathrm{NG}_3^2$$

Non-minimal galilean action: $\mathcal{L} = (\partial\pi_c)^2 + \frac{1}{\Lambda^2}(\partial^2\pi_c)^2 + \frac{1}{\Lambda^5}(\partial^2\pi_c)^3 + \frac{1}{\Lambda^8}(\partial^2\pi_c)^4 + \dots$

$$\mathrm{NG}_3 \simeq \left(\frac{H}{\Lambda}\right)^5 \qquad \mathrm{NG}_4 \simeq \left(\frac{H}{\Lambda}\right)^8$$

$$\Longrightarrow \quad \mathrm{NG}_4 \sim \mathrm{NG}_3^{8/5}$$

For a given cubic NG our model predicts a larger 4 pt function

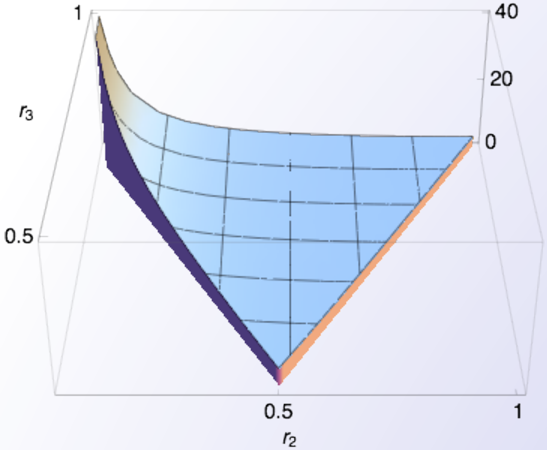
$f_{\mathrm{NL}} = 100$ implies $\tau_{\mathrm{NL}} \sim 10^4$ vs. $\tau_{\mathrm{NL}} \sim 10^5$

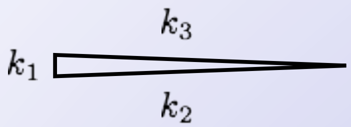
Possible to impose an approximate π -> -π symmetry to make 4pf dominant

Conclusions

- Galilean symmetry is one of the few symmetry we can impose
- **Do not assume very different backgrounds are within the validity of EFT**
- New (technically natural) shapes of the 3pf
- Potentially large 4-point function

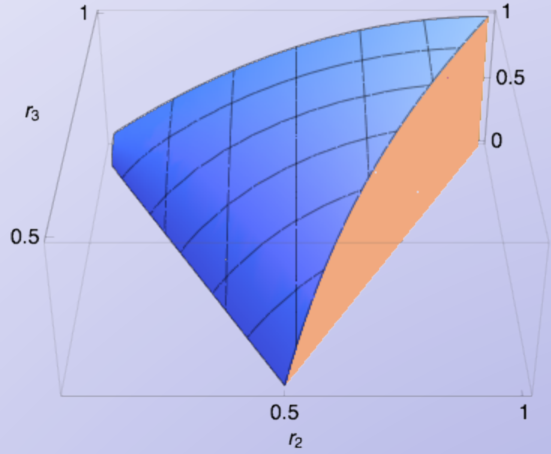
Shapes of non Gaussianities

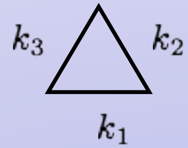




Local

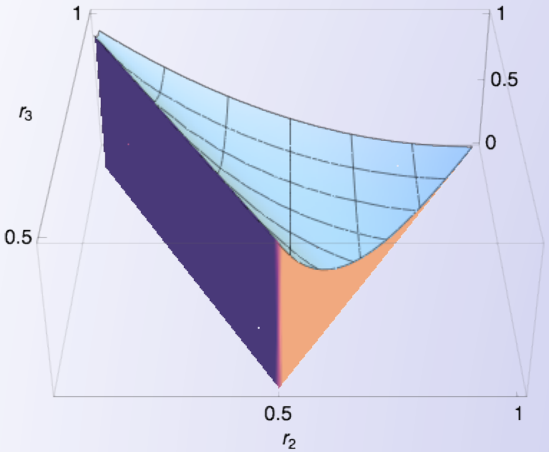
$$\pi^3$$

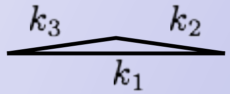




Equilateral

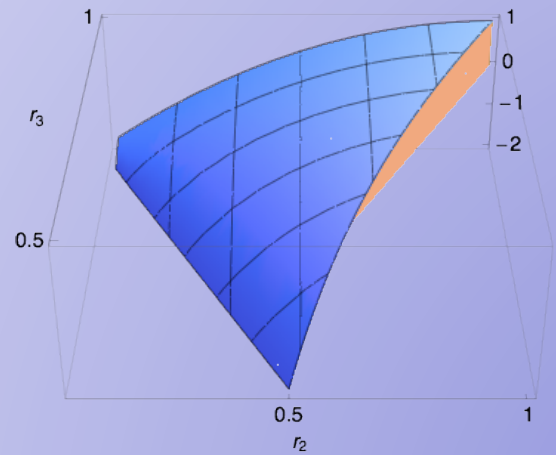
$$(\partial\pi)^3$$

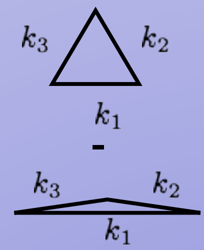




Enfolded

Modified vacuum





Orthogonal

$$\dot\pi\frac{(\partial_i\pi)^2}{a^2} + 5.4\frac{2}{3}\dot\pi^3$$