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Robustness

of

primordial tensor mode predictions

with G. Cabass, P. Creminelli and F. Vernizzi, 1706.03758 (JCAP)

Kyoto, February 9th 2018

Compare with scalars

- It is easy to play with scalar perturbations:

  1. choice of potential
  2. many scalars (effects on late Universe)
  3. speed of propagation c_s

  Room for many inflationary models

- It is not easy to play with gravity!

  GWs are direct probes of H

- Tensor power spectrum $\langle \gamma_{\boldsymbol{k}}^{s} \gamma_{-\boldsymbol{k}}^{s} \rangle$

  Can be modified by non trivial speed c_T?

- Tensor bispectra $\langle \gamma_{\boldsymbol{k}_1}^{s_1} \gamma_{\boldsymbol{k}_2}^{s_2} \gamma_{\boldsymbol{k}_3}^{s_3} \rangle$ and $\langle \zeta_{\boldsymbol{k}_1} \gamma_{\boldsymbol{k}_2}^{s_2} \gamma_{\boldsymbol{k}_3}^{s_3} \rangle$

  How many couplings at leading order in derivatives?

EFT of Inflation

Parametrize the most general dynamics compatible with symmetries

- Single clock: $\phi(t)$ $\longrightarrow$ ~~Time Diff.s~~

Cheung et al., 07

CCWZ approach:
classify fields in terms of representations of the unbroken group

Unitary Gauge: perturbations are eaten by the metric.

$$\longrightarrow \quad \left(t\,;\; g^{00}\,, \delta K\,, {}^{(3)}R\; \ldots\; ; R,\; \delta R_{\mu\nu}\delta R^{\mu\nu}\,, \ldots\right)$$

Focus on

- Tensor perturbations $\langle\gamma\gamma\rangle$ $\langle\zeta\gamma\gamma\rangle$ $\langle\gamma\gamma\gamma\rangle$
- Up to second order in derivatives.

$$\mathcal{L} = \frac{M_{Pl}^2}{2}\Big[R + 2\dot{H}g^{00} - 2\left(3H^2 + \dot{H}\right) +$$

$$+a_0\,{}^{(3)}R + a_1\,(\delta K_{\mu\nu})^2 + a_2\,{}^{(3)}R\,\delta N + b_1\,\delta N\,(\delta K_{\mu\nu})^2\Big]$$

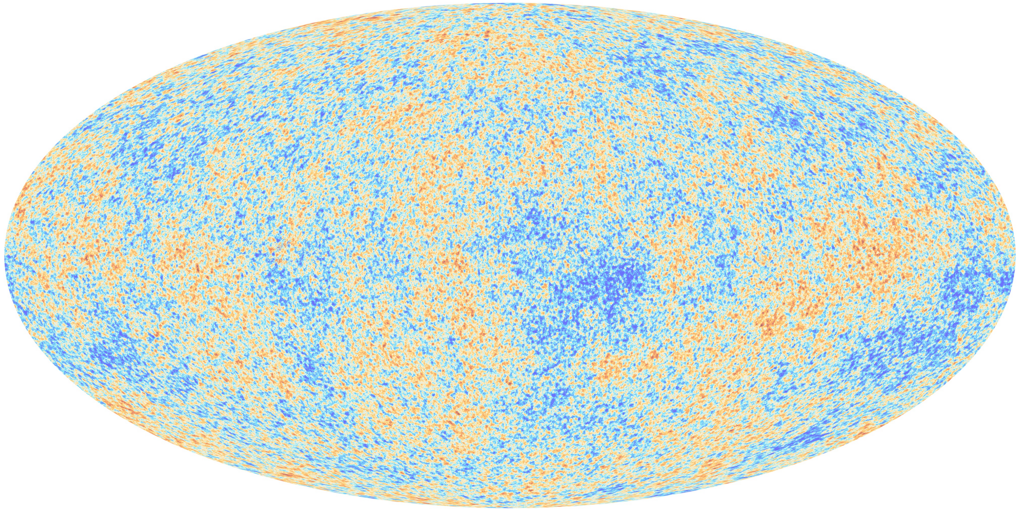
Many operators contribute to the primordial bispectra!

Inflationary observables: super-horizon correlation functions

$$\langle\zeta(\tau,\boldsymbol{k})\zeta(\tau,-\boldsymbol{k})\rangle,\quad \langle\gamma(\tau,\boldsymbol{k})\gamma(\tau,-\boldsymbol{k})\rangle$$

$$\langle\zeta(\tau,\boldsymbol{k}_1)\zeta(\tau,\boldsymbol{k}_2)\zeta(\tau,\boldsymbol{k}_3)\rangle,\ \ldots$$

$$|k_i\tau| \ll 1$$



Freedom to perform redefinitions of ζ and γ that decay outside the horizon. (e.g.: $\zeta \to \zeta + \lambda\frac{\mathrm{d}\zeta}{\mathrm{d}t}$)

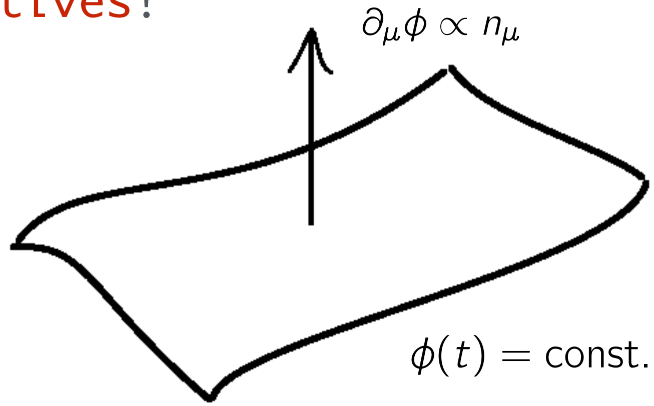
Used to simplify the action!

Field redefinitions

Most generic transformation ...

$$g_{\mu\nu} \to C(t, N, K, \dots) g_{\mu\nu} + D(t, N, K, \dots) n_\mu n_\nu + E(t, N, K, \dots) K_{\mu\nu} + \dots$$

... generates operators with too many derivatives!



$$\delta S_{\rm EH} = \frac{M_{\rm Pl}^2}{2} \int \mathrm{d}^4x \sqrt{-g}\, \underline{\underline{G_{\mu\nu}}}\, \delta g^{\mu\nu}$$

To preserve the # of derivatives in the action:

$$g_{\mu\nu} \to (f_1 + f_3\, \delta N + f_5\, \delta N^2) g_{\mu\nu} + (f_2 + f_4\, \delta N + f_6\, \delta N^2) n_\mu n_\nu$$

$(g^{00} \approx -1 + 2\delta N)$

An example

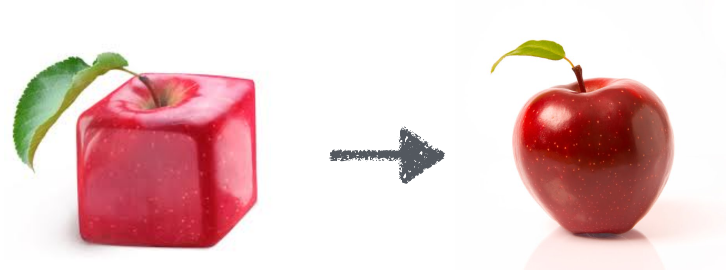
$$\mathcal{L}[g] = \mathcal{L}_{\mathrm{EH}+\phi}[g] + c_R\, {}^{(3)}\!R\, \delta N + c_K\, \delta N\, \delta K_{\mu\nu} \delta K^{\mu\nu}$$

Redefine $g_{\mu\nu} \to \tilde{g}_{\mu\nu} = (1 + f_3\, \delta N)\, g_{\mu\nu} + (1 + f_4\, \delta N)\, n_\mu n_\nu$

$$\mathcal{L}[g] = \mathcal{L}_{\mathrm{EH}+\phi}[g] + \left(c_R - \frac{f_3}{2} + \frac{f_4}{4} \right) {}^{(3)}\!R\, \delta N + \left(c_K - \frac{f_3}{2} - \frac{f_4}{4} \right) \delta N\, \delta K_{\mu\nu} \delta K^{\mu\nu}$$

Use f_3 and f_4 to set to zero the couplings!

Observables do not depend on c_K and c_R!



EFTI up to cubic order in perturbations and 2 derivatives

- After integration by parts: 17 operators.

  6 field redefinitions (f_i) $\rightarrow$ 6 redundant couplings!

  Minimal set: 11 operators!

- Predictions for $\langle\gamma\gamma\rangle$ and $\langle\gamma\gamma\gamma\rangle$ are the same as Einstein-Hilbert.

  Creminelli, Gleyzes, Noreña, Vernizzi, 14

- All the couplings contributing to scalar-tensor-tensor action beyond EH can be removed.

  $\langle\zeta\gamma\gamma\rangle$ is not fixed!
  Still affected by changes in the scalar sector.

Tensor-scalar-scalar 3-point function

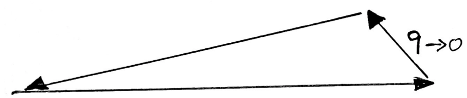
What about $\langle\gamma\zeta\zeta\rangle$? Not fixed!

After all the possible field redefinitions:

$$\mathcal{L} = \mathcal{L}_{\mathrm{EH}+\phi} + c_A \, n^\nu n^\lambda (\nabla_\nu n^\mu)(\nabla_\lambda n_\mu)$$

Two different shapes for $\langle\gamma\zeta\zeta\rangle$!

Still the squeezed behaviour is fixed and model independent!



$$\lim_{\boldsymbol{q}\to 0} \langle \gamma^s_{\boldsymbol{q}} \zeta_{\boldsymbol{k}} \zeta_{-\boldsymbol{k}-\boldsymbol{q}} \rangle' = -\langle \gamma^s_{\boldsymbol{q}} \gamma^s_{-\boldsymbol{q}} \rangle' \epsilon_{ij} k^i k^j \frac{d}{dk^2} \langle \zeta_{\boldsymbol{k}} \zeta_{-\boldsymbol{k}} \rangle'$$

Violated if there are extra tensors

LB, Creminelli, Mirbabayi and Noreña 16

Conclusions

- Robustness of tensor predictions in the EFTI
  - trivial speed of propagation for tensor modes
  - only EH contributes to the $\gamma\gamma\gamma$ and $\zeta\gamma\gamma$ couplings
  - $\langle\gamma\gamma\gamma\rangle$ fixed by $\langle\gamma\gamma\rangle$
  - Only one shape for $\langle\zeta\gamma\gamma\rangle$
- Violations would be extremely interesting: different symmetry pattern