Cosmological symmetries and soft theorems

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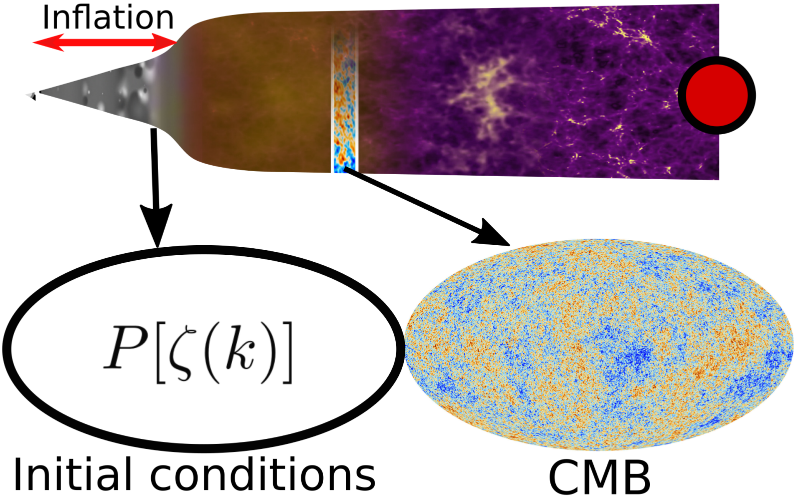
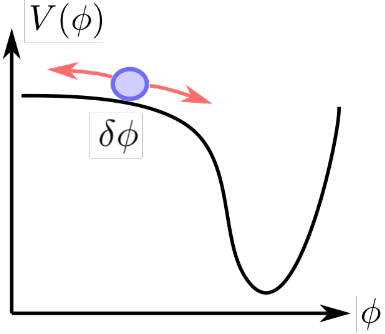
Outline

- What are cosmological correlators?
- Large gauge transformations and soft theorems
- Extension to non-attractor inflation

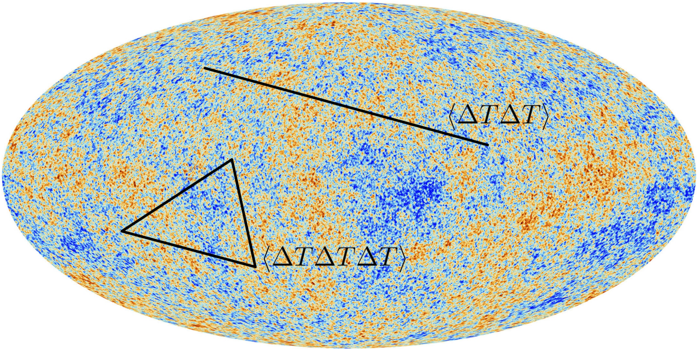

Inflation
$P[\zeta(k)]$
Initial conditions
CMB

Inflation generating Initial Conditions



$$\phi(\vec{x},t) = \phi_0(t) + \delta\phi(\vec{x},t)$$

$$\delta\phi \overset{\text{diff}}{\longleftrightarrow} \zeta$$



$$\langle \Delta T \Delta T \rangle, ... \xrightarrow{\text{Transfer Function}} \langle \zeta\zeta \rangle, \langle \gamma\gamma \rangle \quad (1)$$

For example,

$$\langle \zeta\zeta\zeta \rangle.$$

Compute via

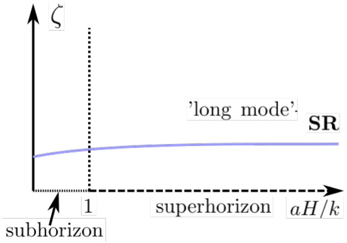
- In in-formalism
- Bootstrap
- Soft theorems = consistency relations

Non-linear Symmetries

Dilatation is non-linearly realised:

$$\zeta \to \zeta + \underbrace{\lambda(t)}_{\text{Long Mode}} + \underbrace{\lambda(t)\vec{x}\cdot\vec{\partial}\zeta}_{\text{Linear}} \quad (2)$$

- Diffeomorphism = symmetry action $\implies$ symmetry of ζ
- Is $\lambda(t)$ physical?
- Adiabatic mode condition: $\dot{\lambda} = 0$
- Ward Identity = Maldacena



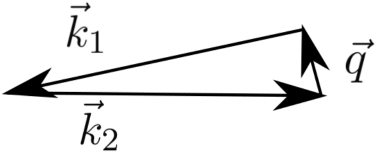


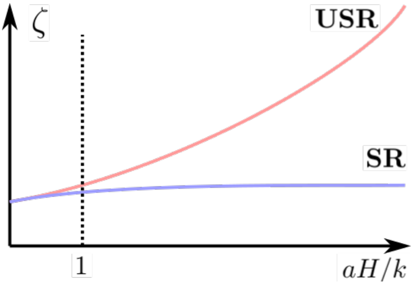
Figure: Squeezed Bispectrum

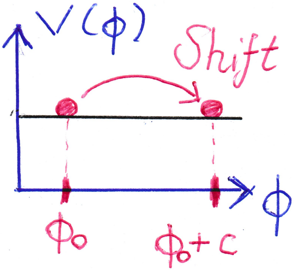
$$\lim_{q\to 0}\langle\zeta(\vec{q})\zeta(\vec{k}_1)\zeta(\vec{k}_2)\rangle' = (1-n_s)P(q)P(k_1) \qquad (3)$$

- There exist more non-linear symmetries $\leftrightarrow$ more CR's.

Possibly phases of non-attractor → what non-Gaussian signature?

Problem: non-constant long mode,




V(ϕ)
Shift
ϕ
ϕ0
ϕ0+c

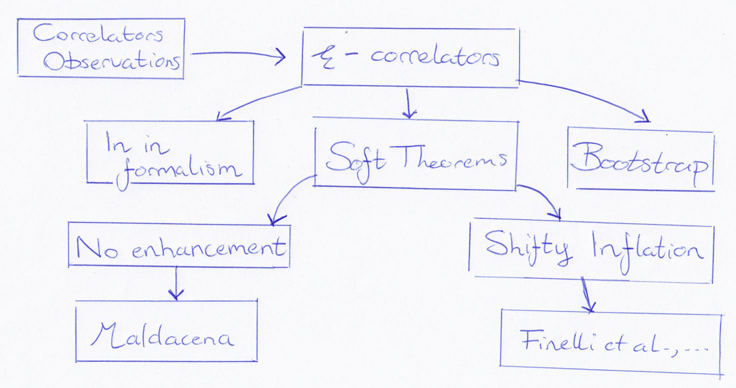
Non-linear symmetry on ζ:

$$\zeta \to \zeta + \underbrace{H\xi^0(t)}_{\text{time diff}} + \underbrace{\frac{1}{3}\partial_i \xi^i(t, \mathbf{x})}_{\text{space diff}} + \underbrace{\xi^\mu \partial_\mu \zeta}_{\text{linear}} \tag{4}$$

Additional term in CR [Finelli2018]:

$$\begin{aligned}\lim_{q\to 0}\langle \zeta(\vec{q})\zeta(\vec{k}_1)\zeta(\vec{k}_2)\rangle' =& (1-n_s)P(q)P(k_1) \\ &- \frac{\dot{\phi}}{2\ddot{\phi}H}\dot{P}(q)\left(H(n_s-1)P(k)+\dot{P}(k)\right)\end{aligned} \tag{5}$$

Summary


Correlators
Observations
ξ - correlators
In in
formalism
Soft Theorems
Bootstrap
No enhancement
Shifty Inflation
Maldacena
Finelli et al., ...

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Derivation step #1

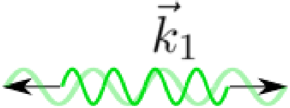

Figure: Rescaling

$$\langle \zeta_L(\vec{x}_1)\zeta_S(\vec{x}_2)\zeta_S(\vec{x}_3)\rangle = \langle \zeta_L(\vec{x}_1)\zeta(\tilde{\vec{x}}_2)\zeta(\tilde{\vec{x}}_3)\rangle \tag{6}$$

Infinitesimal rescaling:

$$\tilde{\vec{x}} = (1+\zeta_L)\vec{x}$$

$$\langle \zeta_L(\vec{x}_1)\zeta_S(\vec{x}_2)\zeta_S(\vec{x}_3)\rangle = \langle \zeta_L(\vec{x}_1)\zeta(\tilde{\vec{x}}_2)\zeta(\tilde{\vec{x}}_3)\rangle \tag{6}$$

Taylor expand:

$$\langle \zeta_L\zeta\zeta\rangle + \left\langle \zeta_L \left[\zeta_L \vec{x}\cdot\vec{\partial}(\zeta\zeta)\right]\right\rangle = \langle \zeta_L\zeta_L\rangle' \, \vec{x}\cdot\vec{\partial}\, \langle\zeta\zeta\rangle' \tag{7}$$

Figure: Long and rescaled short do not correlate

Derivation step #3

$$\langle \zeta_L(\vec{x}_1)\zeta_S(\vec{x}_2)\zeta_S(\vec{x}_3)\rangle = \langle \zeta_L(\vec{x}_1)\zeta(\tilde{\vec{x}}_2)\zeta(\tilde{\vec{x}}_3)\rangle \tag{6}$$

Taylor expand:

$$\cancel{\langle \zeta_L \zeta\zeta\rangle} + \left\langle \zeta_L \left[\zeta_L \vec{x}\cdot\vec{\partial}(\zeta\zeta)\right]\right\rangle = \langle \zeta_L\zeta_L\rangle' \, \vec{x}\cdot\vec{\partial}\,\langle\zeta\zeta\rangle' \tag{7}$$

In Fourier space, the result:

$$\begin{aligned}\lim_{q\to 0}\langle \zeta(\vec{q})\zeta(\vec{k}_1)\zeta(\vec{k}_2)\rangle' &= \langle \zeta_L\zeta_L\rangle' \left(-3 - \vec{k}\cdot\frac{\partial}{\partial\vec{k}}\right)\langle\zeta\zeta\rangle' \\ &= (1-n_s)P(q)P(k_1)\end{aligned} \tag{8}$$