Multiple field inflation with additional heavy fields

Yvette Welling

Collaborators: Ana Achúcarro, Vicente Atal

[Ana Achúcarro, Vicente Atal, YW, JCAP 2015, 1503.07486]
[YW, MSc Thesis 2014, 1502.04369]
Stabilized heavy fields present during inflation can affect the dynamics of low energy degrees of freedom and leave their imprint on observables.
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E.g. the predictions for $r$ and $n_s$

Plot from [Ana Achúcarro, Vicente Atal, YW, JCAP 2015, 1503.07486]

See Vicente Atal’s talk
Stabilized heavy fields present during inflation can affect the dynamics of low energy degrees of freedom and leave their imprint on observables.

E.g. the primordial power spectrum

Plot from [Cespedes, Atal, Palma., JCAP 2012, 1201.4848]
[Achúcarro, Gong, Hardeman, Palma, Patil, PRD 2011, 1010.3693]
Stabilized heavy fields present during inflation can affect the dynamics of low energy degrees of freedom and leave their imprint on observables.

E.g. features in the bispectrum

Plot from [Achúcarro, Atal, Ortiz, Torrado, PRD 2013, 1311.2552]
Motivation: signatures of new physics

Single field inflation fits data well.
However there could be more fields present during inflation..
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However there could be more fields present during inflation.

Consider single field inflation as EFT from multi-field inflation with heavy fields.

[Cheung, Creminelli, Fitzpatrick, Kaplan, Senatore, JHEP 2007, 0709.0293]
Motivation: signatures of new physics

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Consider single field inflation as EFT from multi-field inflation with heavy fields.

Do heavy fields influence the observables?

[Cheung, Creminelli, Fitzpatrick, Kaplan, Senatore, JHEP 2007, 0709.0293]
Do they...?

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Yes, but.. prefactor can be large!

There are **three** scales of importance:

1. mass heavy field
2. curvature target space
3. curvature inflationary trajectory

[Achúcarro, Gong, Hardeman, Palma, Patil, JCAP 2011, 1005.3848]
[Burgess, Horbatch, Patil, JHEP 2013, 1209.5701]
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In particular inflationary trajectory can be curved. This couples perturbations.

→ Integrate out heavy modes with care.

[Achúcarro, Atal, Cespedes, Gong, Palma, Patil, PRD 2012, 1205.0710]
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For a recent review see [Chluba, Hamann, Patil, 1505.01834]
Intuitive example: a sudden turn

A sudden turn in the inflationary trajectory induced by a bend in the potential.

[Achúcarro, Gong, Hardeman, Palma, Patil, PRD 2011, 1010.3693]
[Cespedes, Atal, Palma., JCAP 2012, 1201.4848]
Intuitive example: a sudden turn

A sudden turn gives rise to oscillations in the power spectrum (and bispectrum).

Effects of heavy fields cannot be ignored!

Search for features:

[Achúcarro, Atal, Ortiz, Torrado, PRD 2013, 1311.2552]
See recent review [Chluba, Hamann, Patil, 1505.01834]

[Achúcarro, Gong, Hardeman, Palma, Patil, PRD 2011, 1010.3693]
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Turn = Not Geodesic

There could be “hidden” turns if field metric is non-trivial

\[ S_\phi = -\int d^4 x \sqrt{-g} \left[ \frac{1}{2} G_{ab}(\phi) \partial_\mu \phi^a \partial^\mu \phi^b + V(\phi) \right] \]
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\]

Mismatch between geodesics field space and valley potential?

→ Curved trajectory
**Tangent and normal decomposition**


\[
\dddot{\mathcal{R}} + (3 + 2\varepsilon - 2\eta)H\dot{\mathcal{R}} + \frac{k^2}{a^2} \mathcal{R} = -2\frac{H}{\dot{\sigma}} \left[ \dddot{\mathcal{F}} + (3 - \eta - \xi)H \dot{\mathcal{F}} \right]
\]

\[
\dddot{\mathcal{F}} + 3H \ddot{\mathcal{F}} + \frac{k^2}{a^2} \mathcal{F} + (M^2 - \dot{\theta}^2)\mathcal{F} = 2\dot{\sigma} \frac{\dot{\theta}}{H} \dddot{\mathcal{R}}
\]

Field speed $\dot{\sigma}$
Radius of curvature $\kappa$

**Turn rate**

\[
\dot{\theta} = \pm \frac{\dot{\sigma}}{\kappa}
\]

Measures deviation from geodesic

**Curvature perturbation**

\[
\mathcal{R} \equiv \frac{H}{\dot{\sigma}} T_a \delta \phi^a + \psi
\]

**Isocurvature perturbation**

\[
\mathcal{F} \equiv N_a \delta \phi^a
\]
Integrate out heavy modes

Following [Achúcarro, Atal, Cespedes, Gong, Palma, Patil, PRD 2012, 1205.0710] See also [Achucarro et al., JCAP 2011, 1005.3848], [Baumann, Green, JCAP 2011, 1102.5343], [Shiu, Xu, PRD 2011, 1108. 0981], [Cespedes et al., JCAP 2012, 1201.4848], [Gwyn, Palma, Sakellariadou, Sypsas, JCAP 2013, 1210.3020]

Coupled oscillators with derivative coupling

\[ \ddot{R}_c + \frac{k^2}{a^2} R_c = 2\dot{\theta} \dot{F} \]

\[ \ddot{F} + \frac{k^2}{a^2} F + (M^2 - \dot{\theta}^2) F = -2\dot{\theta} \dot{R}_c \]

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\[ R_c \equiv \frac{\dot{\sigma}}{H} R \]

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High and low frequency solutions

\[
\begin{pmatrix}
R_c \\
F
\end{pmatrix} =
\begin{pmatrix}
R_+ & R_- \\
F_+ & F_-
\end{pmatrix}
\begin{pmatrix}
e^{i\omega_+ t} \\
e^{i\omega_- t}
\end{pmatrix}
\]

\[ \omega_+^2 \approx M^2 + 3\dot{\theta}^2 \]

\[ \omega_-^2 \approx \frac{k^2}{a^2} c_s^2 \]

\[ c_s^{-2} = 1 + \frac{4\dot{\theta}^2}{M^2 - \dot{\theta}^2} \]
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Integrate out heavy modes

$$\begin{pmatrix} \mathcal{R}_c \\ \mathcal{F} \end{pmatrix} = \begin{pmatrix} \mathcal{R}_+ & \mathcal{R}_- \\ \mathcal{F}_+ & \mathcal{F}_- \end{pmatrix} \begin{pmatrix} e^{i\omega_+ t} \\ e^{i\omega_- t} \end{pmatrix}$$

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Constraints on validity

\[
M^2 / H^2 \gg 1 \quad \left| \frac{\dot{\omega}_+ / \omega_+^2}{\dot{\theta} / \dot{\theta}} \right| \ll 1 \quad \left| \frac{M^2 - \dot{\theta}^2}{H^2} \right| > 0
\]

Massive enough

Adiabatic condition: Turn not too sharp

Stability condition: Turn not too strong

See [Cespedes, Atal, Palma., JCAP 2012, 1201.4848]
Low energy EFT

See recent review [Chluba, Hamann, Patil, 1505.01834]

Integrating out heavy modes yields EFT for $\mathcal{R}$

$$S_{\text{eff}} = M_p^2 \int d^4 x a^3 \epsilon \left[ \frac{\dot{\mathcal{R}}^2}{c_s^2(t)} - \frac{(\nabla \mathcal{R})^2}{a^2} + O(\mathcal{R}^3 / a^3) \right]$$

$$c_s^{-2} = 1 + \frac{4 \dot{\theta}^2}{M^2 - \hat{\theta}^2}$$

From here compute power spectrum and higher order correlation functions
Low energy EFT

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$$

Turn rate

$$
\frac{1}{c_s^{-2}} = 1 + \frac{4 \dot{\theta}^2}{M^2 - \dot{\theta}^2}
$$

Example: transient reduced speed of sound

See recent review [Chluba, Hamann, Patil, 1505.01834]
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$\Rightarrow$ Always compute turn rate to find how observables are affected

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$C_s^{-2} = 1 + \frac{4\dot{\theta}^2}{M^2 - \dot{\theta}^2}$
Summary

• Stabilized heavy fields can influence dynamics of low energy degrees of freedom

[YW, MSc Thesis 2014, 1502.04369], [Ana Achúcarro, Vicente Atal, YW, JCAP 2015, 1503.07486]
Summary

• Stabilized heavy fields can influence dynamics of low energy degrees of freedom
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Summary

• Stabilized heavy fields can influence dynamics of low energy degrees of freedom
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• Integrate out heavy modes with care
• This could result in reduced speed of sound

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• Stabilized heavy fields can influence dynamics of low energy degrees of freedom
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• Check how observables are affected

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- Integrate out heavy modes with care
- This could result in reduced speed of sound
- Check how observables are affected
- Vicente’s talk (next one)

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