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]

Bottom line

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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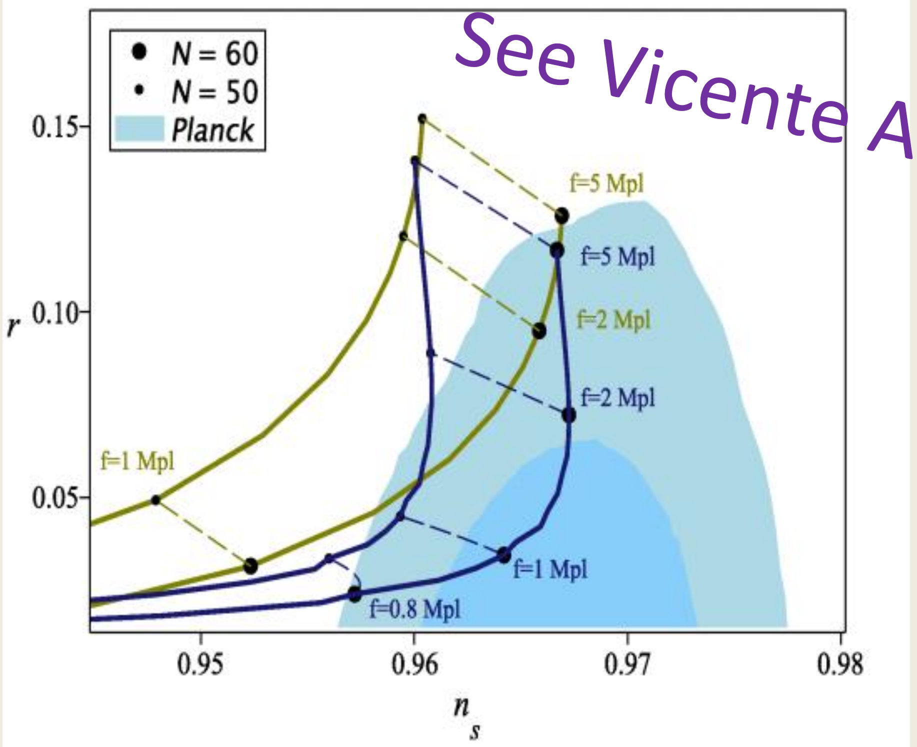
E.g. the predictions for r and n_s

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

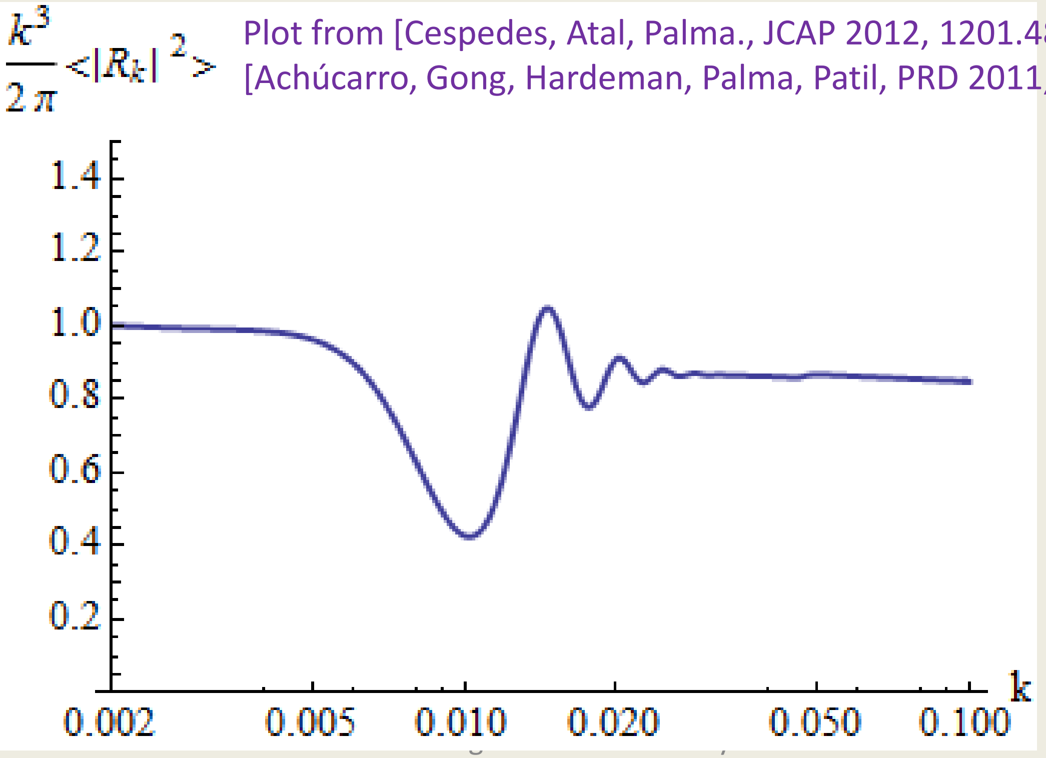


See Vicente Atal's talk

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

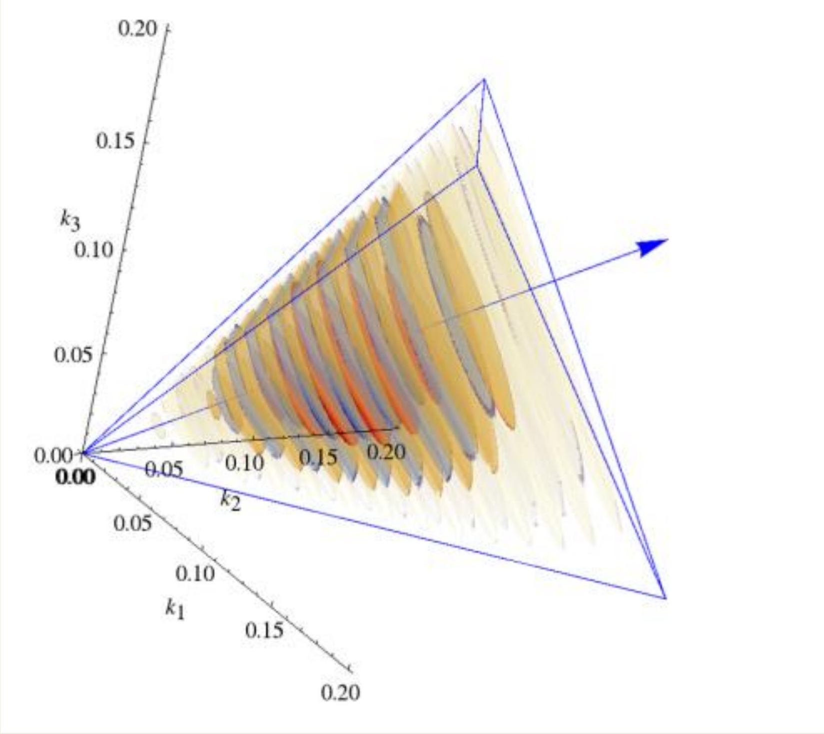
Plot from [Cespedes, Atal, Palma., JCAP 2012, 1201.4848]
[Achúcarro, Gong, Hardeman, Palma, Patil, PRD 2011, 1010.3693]



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.

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Consider single field inflation as EFT

from multi-field inflation with heavy fields.

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Do heavy fields influence the observables?

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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, Gong, Hardeman, Palma, Patil, JCAP 2011, 1005.3848 / PRD 2011, 1010.3693 / JHEP 2012, 1201.6342]
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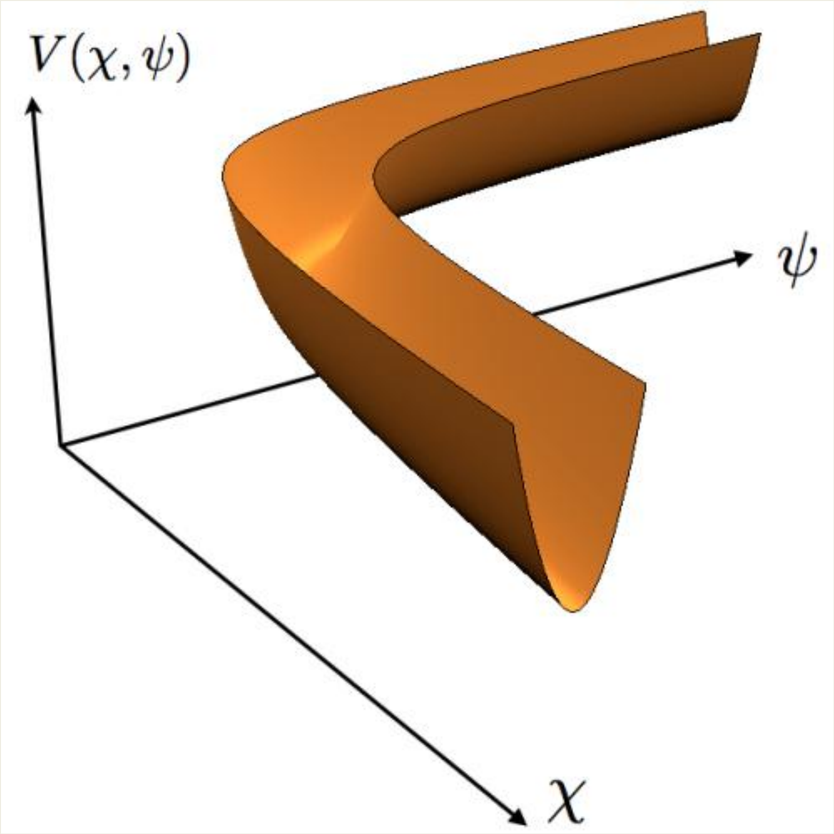
For a recent review see [Chluba, Hamann, Patil, 1505.01834]

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]
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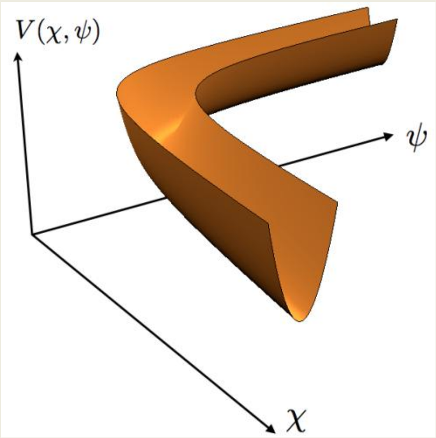
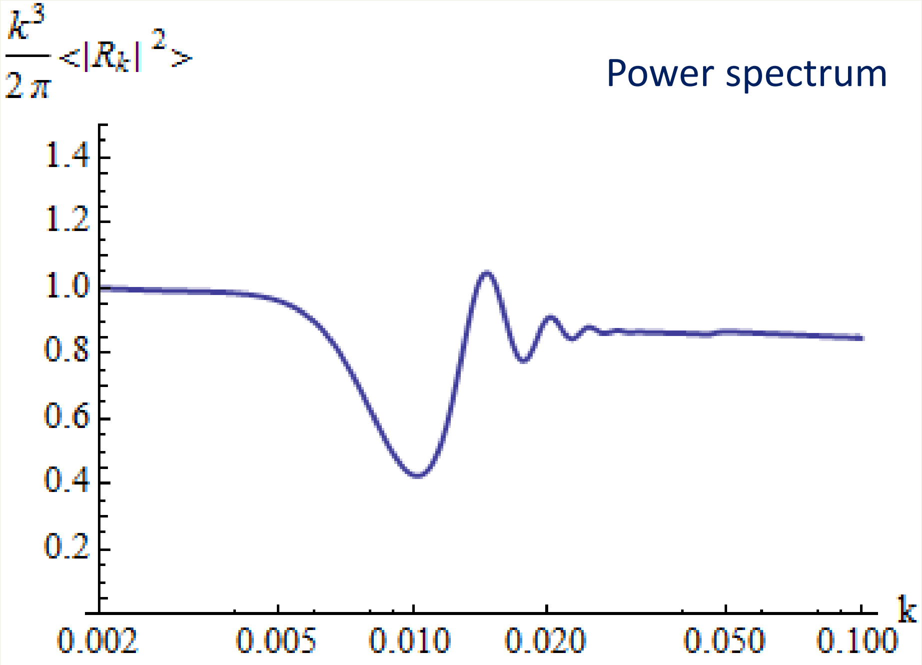


A sudden turn gives rise to oscillations in the power spectrum (and bispectrum).



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]

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Turn = Not Geodesic

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

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

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Mismatch between geodesics field space and valley potential?

→ Curved trajectory

Tangent and normal decomposition

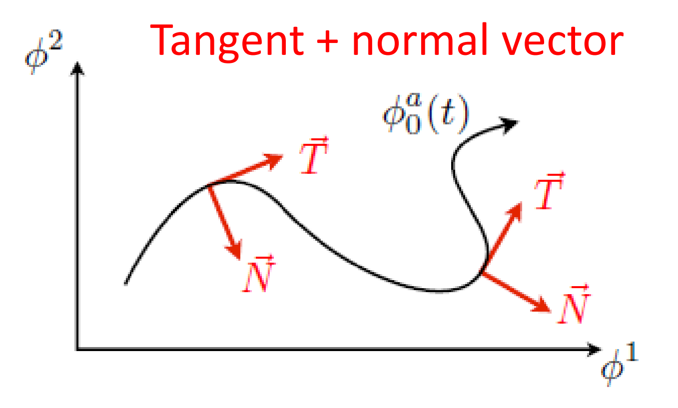
[Gordon, Wands, Bassett, Maartens, PRD 2001, hep-ph/0107272], [Groot Nibbelink, van Tent, CQG 2002, hep-ph/0107272], for a recent review see [YW, MSc Thesis 2014, 1502.04369]

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

$$\ddot{\mathcal{F}} + 3H\dot{\mathcal{F}} + \frac{k^2}{a^2}\mathcal{F} + \underbrace{(M^2 - \dot{\theta}^2)}_{N^a N^b V_{ab} + \epsilon H^2 \mathrm{R}}\mathcal{F} = 2\dot{\sigma}\frac{\dot{\theta}}{H}\dot{\mathcal{R}}$$

Field speed $\dot{\sigma}$

Radius of curvature κ



Turn rate

$$\boxed{\dot{\theta} = \pm\frac{\dot{\sigma}}{\kappa}}$$

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

$$\ddot{\mathcal{R}}_c + \frac{k^2}{a^2}\mathcal{R}_c = 2\dot{\theta}\dot{\mathcal{F}}$$

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High and low frequency solutions

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

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

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

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

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Constraints on validity

$$M^2/H^2 >> 1$$

Massive enough

$$\left|\dot{\omega}_+/\omega_+^2\right| << 1$$

$$\left|\ddot{\theta}/\dot{\theta}\right| << \sqrt{\left|M^2 - \dot{\theta}^2\right|}$$

Adiabatic condition:
Turn not too sharp

$$\frac{M^2 - \dot{\theta}^2}{H^2} > 0$$

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 $\mathcal{R}$

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

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Turn rate

From here compute power spectrum and higher order correlation functions

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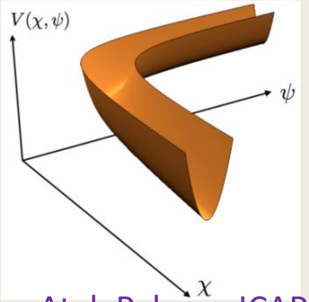
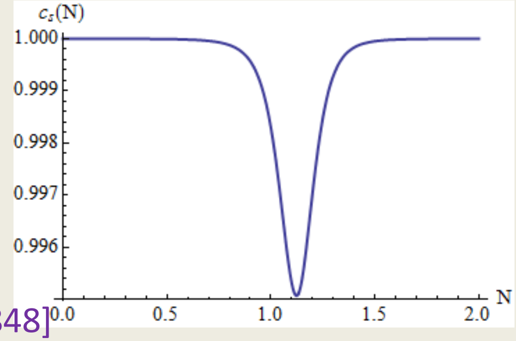
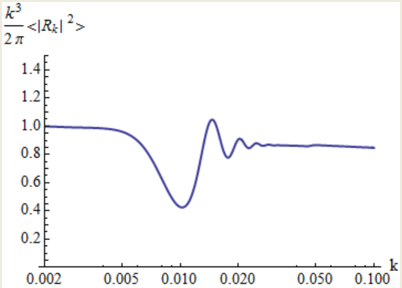
Example: transient reduced speed of sound







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Turn rate

→ Always compute turn rate to find how observables are affected

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]

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- Vicente’s talk (next one)

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