Shift Symmetric Orbital Inflation

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Based on work with Ana Achúcarro, Dong-Gang Wang, Gonzalo Palma, Oksana Iarygina, Ed Copeland

arXiv: 1901.03657 (Achúcarro, Copeland, Iarygina, Palma, Wang, YW)
1906.xxxxx (Achúcarro, Palma, Wang, YW)
1906.xxxxx (Achúcarro, YW)

The success of single-field inflation

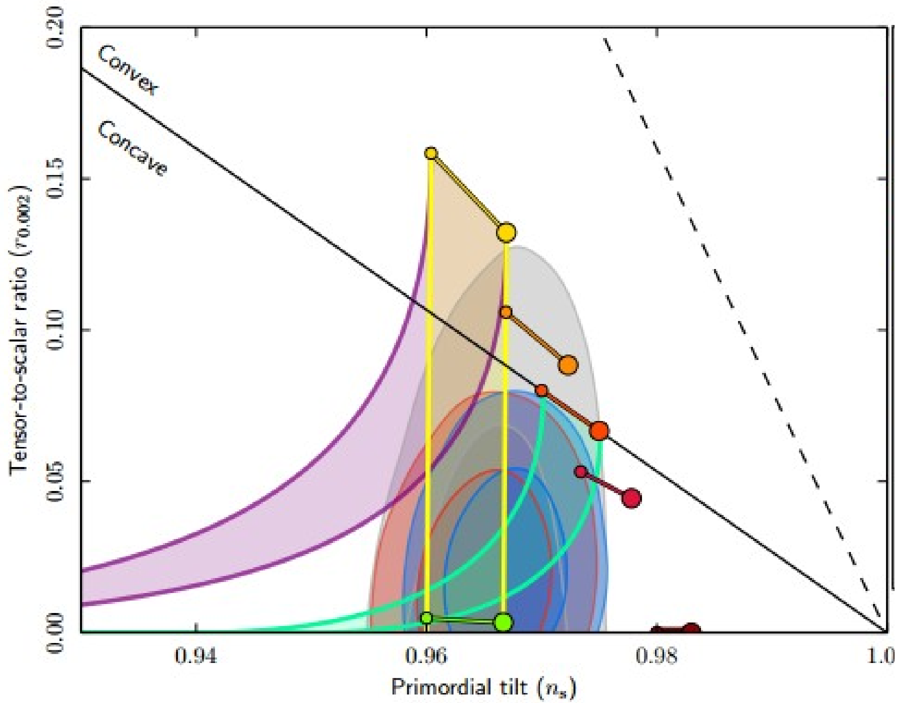
Solves horizon & flatness problem

Provides seeds for structure formation

(Guth, Linde, Starobinksy, Mukhanov)

Consistent with CMB data

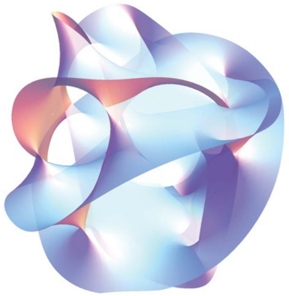
- Small but non-zero spectral tilt
- Small tensor-to-scalar ratio
- Small primordial non-Gaussianity
- Small isocurvature perturbations



(Planck collaboration, 2018)

Theoretical challenges

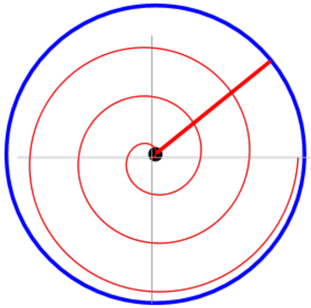
UV embeddings of inflation typically contain multiple scalar fields living on a curved field space



→ they may interact with the inflaton (stabilize them all?)

Recent "swampland conjectures" suggest that inflation takes place in a small patch of field space (Ooguri & Vafa, 2007 Ooguri, Palti, Shiu & Vafa 2018)

→ curved trajectories (Achucarro & Palma, 2018)



$$|\Delta\phi| \leq \mathcal{O}(1)M_p$$

A simple multi-field framework

It’s desirable to have a **simple framework** that can deal with multi-field inflation with curved trajectories & curved field spaces

To address questions like

(1) What symmetries may protect the inflationary dynamics?

(2) What’s the role of the field space geometry? (See also Guidetti’s, Anguelova’s, Cespedes’ talks)

(3) What are the signatures of new physics?

A lightning review of multi-field effects

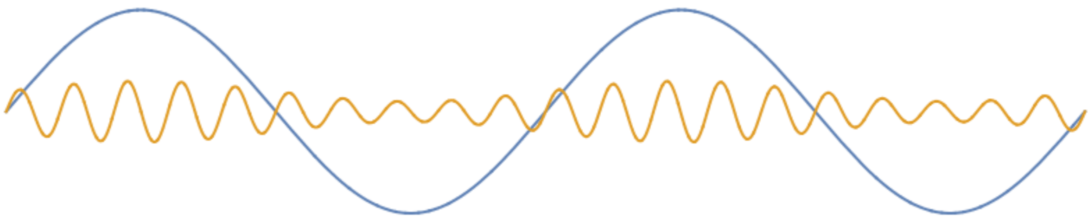
(1) Primordial non-Gaussianities

(2) Isocurvature perturbations

Primordial non-Gaussianities

Consider e.g. extra fields during inflation

Interactions = mode coupling

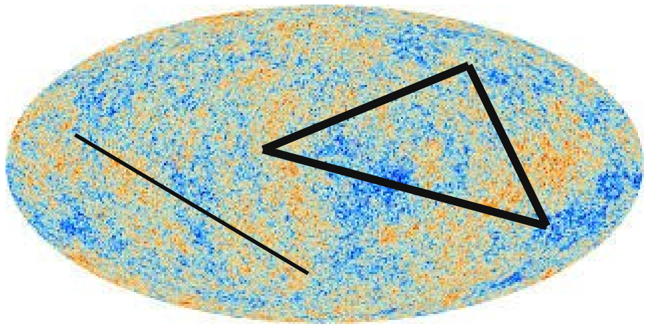


A long wave modulates the amplitude of a short wave

Correlation between different modes

$$\langle \mathcal{R}(k_1)\mathcal{R}(k_2)\mathcal{R}(k_3)\rangle \neq 0$$

non-zero **bispectrum** (non-Gaussian statistics)



Bispectrum = FT three-point correlation

Why do we care about primordial non-Gaussianities?

PNG is a smoking gun for single field

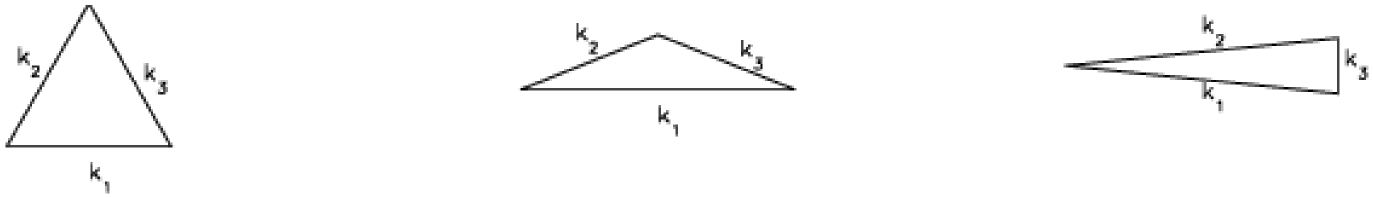
All canonical single field models of inflation can be ruled out by detecting a violation of the **single field consistency relation**

$$f_{\rm NL} = \frac{5}{12}(1 - n_s)$$

(Maldacena, 2002
Creminelli, Zaldarriaga, 2004)

PNG is a probe of fundamental physics

Derivative interactions / strong interactions with heavy fields / multiple light fields / cosmological collider physics / alternatives to inflation / ...

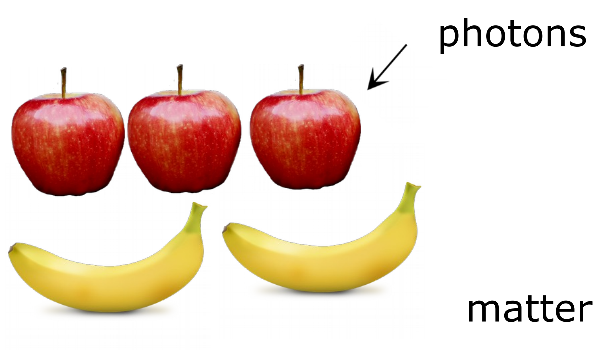


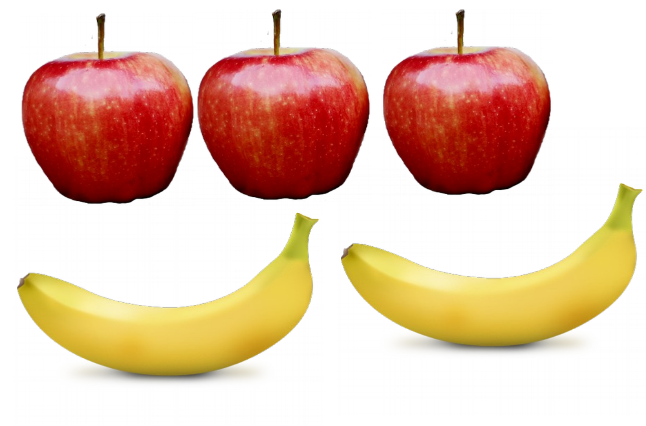
Isocurvature perturbations

Curvature = adiabatic perturbations

Local expansion of homogeneous background (time shift)

Composition universe the same, but overall *number density* varies





Single field inflation creates adiabatic perturbations that are conserved on SH scales

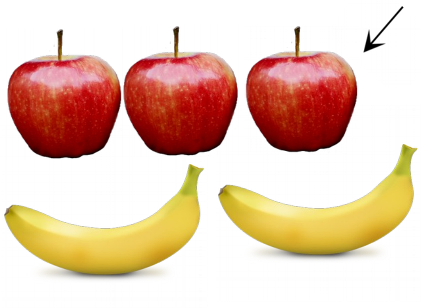
(Weinberg, 2003)

Isocurvature perturbations

Isocurvature = non-adiabatic perturbations

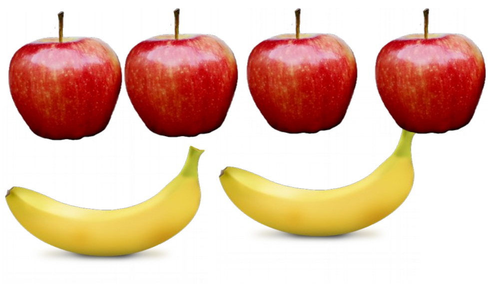
NOT-adiabatic

Composition universe is *not* the same, *relative ratio of species varies*



photons

matter



Multi-field inflation is generically expected to produce large isocurvature pt* and $f_{NL} \sim O(1)$ primordial non-Gaussianities

(Alvarez et al, 2014)

*Except when reheating washes it out completely

Inflation with light coupled scalars

BAD because:

- They source curvature perturbations → **large non-Gaussianities**
- Light scalars don't decay → **isocurvature pt**

Inflation with light coupled scalars

GOOD because:

- They **efficiently** source curvature perturbations → **smaller nG**
- Light scalars don't decay → **dynamically suppressed**

These systems are as multi-field as can be
But look a lot like single field !

Simplest extension of the single field EFT

$$S^{(2)} = \frac{1}{2}\int d^4x a^3 \left[2\epsilon\dot{\mathcal{R}}^2 - 2\epsilon\frac{(\partial_i\mathcal{R})^2}{a^2}\right]$$ (Single field)

(Two field)

Curvature perturbation

Isocurvature perturbation

$$S^{(2)} = \frac{1}{2}\int d^4x a^3 M_p^2 \left[2\epsilon\left(\dot{\mathcal{R}} - \omega\sigma\right)^2 - 2\epsilon\frac{(\partial_i\mathcal{R})^2}{a^2} + \dot{\sigma}^2 - \mu^2\sigma^2 - \frac{(\partial_i\sigma)^2}{a^2}\right]$$

Efficiency of interaction

Isocurvature mass

Simplest extension of the single field EFT

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(Single field)

(Two field)

Bottom up simplest: static coefficients

$$S^{(2)} = \frac{1}{2}\int d^4x a^3 M_p^2 \left[2\epsilon\left(\dot{\mathcal{R}} - \omega\sigma\right)^2 - 2\epsilon\frac{(\partial_i\mathcal{R})^2}{a^2} + \dot{\sigma}^2 - \mu^2\sigma^2 - \frac{(\partial_i\sigma)^2}{a^2}\right]$$

Efficient coupling

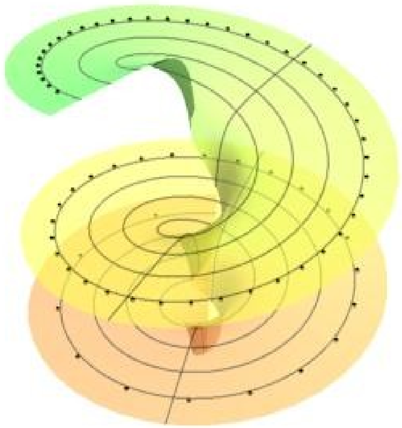
Small mass

How to realize this explicitly?
Phenomenology?
What are the symmetries protecting the coefficients?

Main obstacle: no potential gradient flow

Inflationary trajectories generically do not follow the potential gradient flow

$$\dot{\phi}^a \not\propto -\nabla^a V$$



→ **The potential does not reflect the symmetries of the perturbations**

Orbital Inflation

To appear soon in (Achúcarro, YW)

Idea: consider inflationary models that attract to the Hubble gradient flow

$$\dot{\phi}^a = -2M_p^2 G^{ab} H_{,b}$$

(Generalization of single-field Hamilton-Jacobi, Salopek & Bond 1990)

+ align this with an isometry of field space, e.g. 'angular' θ direction

$$\sqrt{-g}^{-1}\mathcal{L} = \frac{1}{2}\left[e^{2\rho/R_0}(\partial\theta)^2 + (\partial\rho)^2\right] - V(\rho,\theta)$$

$$\dot{\rho} = 0 \quad \text{and} \quad \dot{\theta} \neq 0$$

Axion, dilaton

This gives a set of possible Hubble parameters → family of potentials that admit a constant coupling ω

$$V = 3H^2 - 2G^{ab}H_{,a}H_{,b}$$

Exact solution

To appear soon in (Achúcarro, YW)

Remarkably, the background attractor is an exact solution

$$\dot{\phi}^a = -2M_p^2 G^{ab} H_{,b}$$

The Hubble parameter also determines the properties of the perturbations

e.g. if $\dot{\rho} = 0 \quad \text{and} \quad \dot{\theta} \neq 0$

$$H(\theta, \rho) = W(\theta) X(\rho)$$

Determines ε, η, ..

Determines the couplings with the isocurvature perturbations

Applications of Orbital Inflation

(1) Playground for Quasi-Single-Field Inflation (Chen, Wang, 2010)

(2) We can exactly solve the phenomenology of Orbital Inflation in the limit of small isocurvature mass and a small radius of curvature

(3) We gain new insights on the symmetries that protect the inflationary dynamics

Applications of Orbital Inflation

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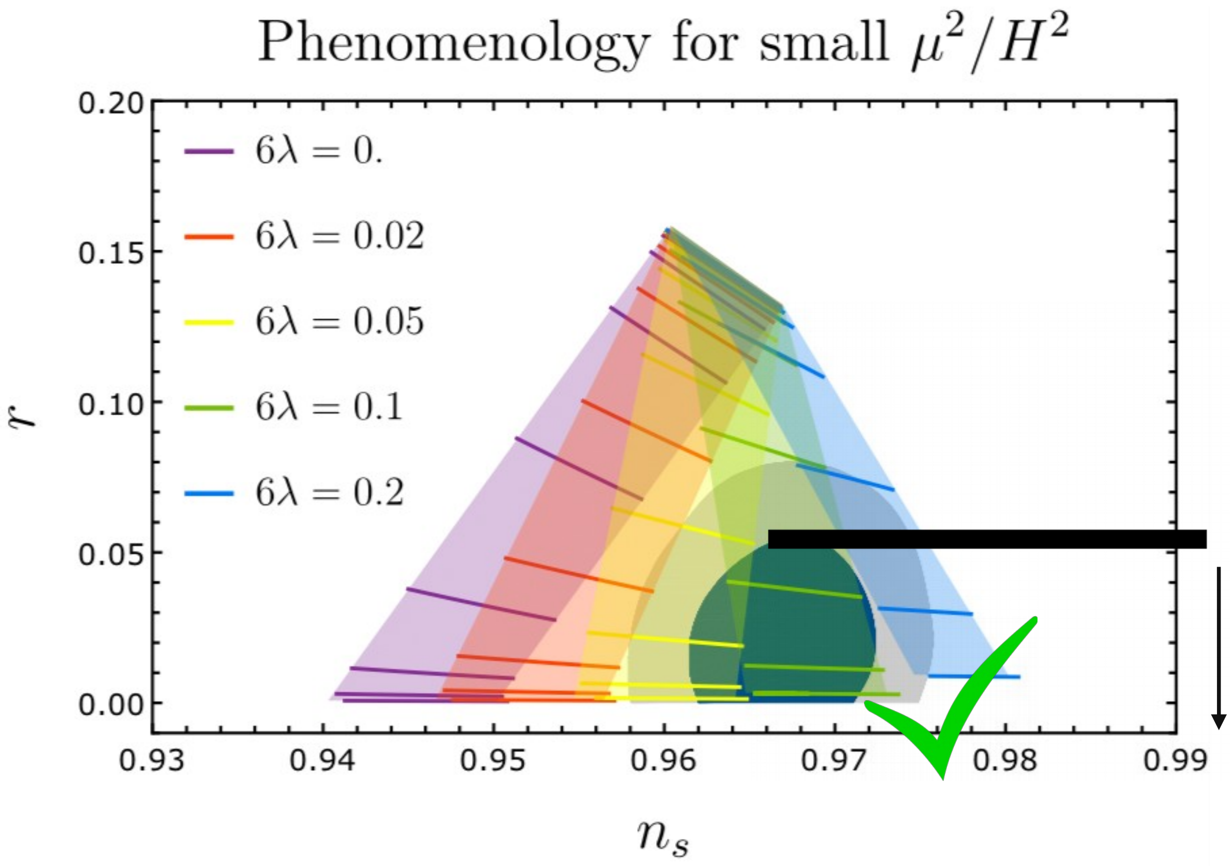
Phenomenology for small isocurvature mass

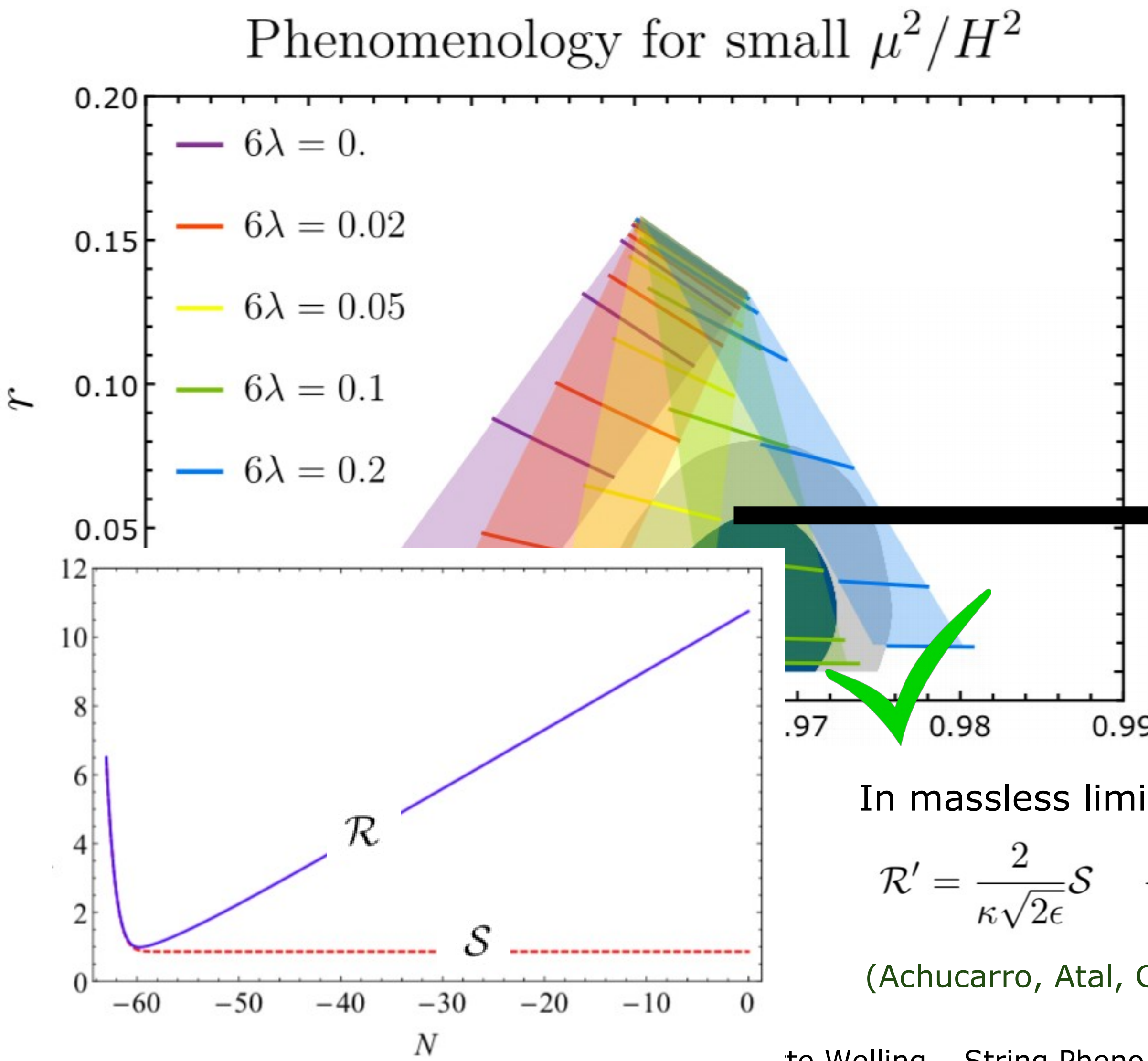


ε: starting point

λ: sets mass. Angle in which it vans out in (ns, r) plane

κ^{-1}: sets efficiency interaction. Reduction r

Phenomenology for small isocurvature mass



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"Single clock" regime
isocurvature pt suppressed
but consistency relation violated!

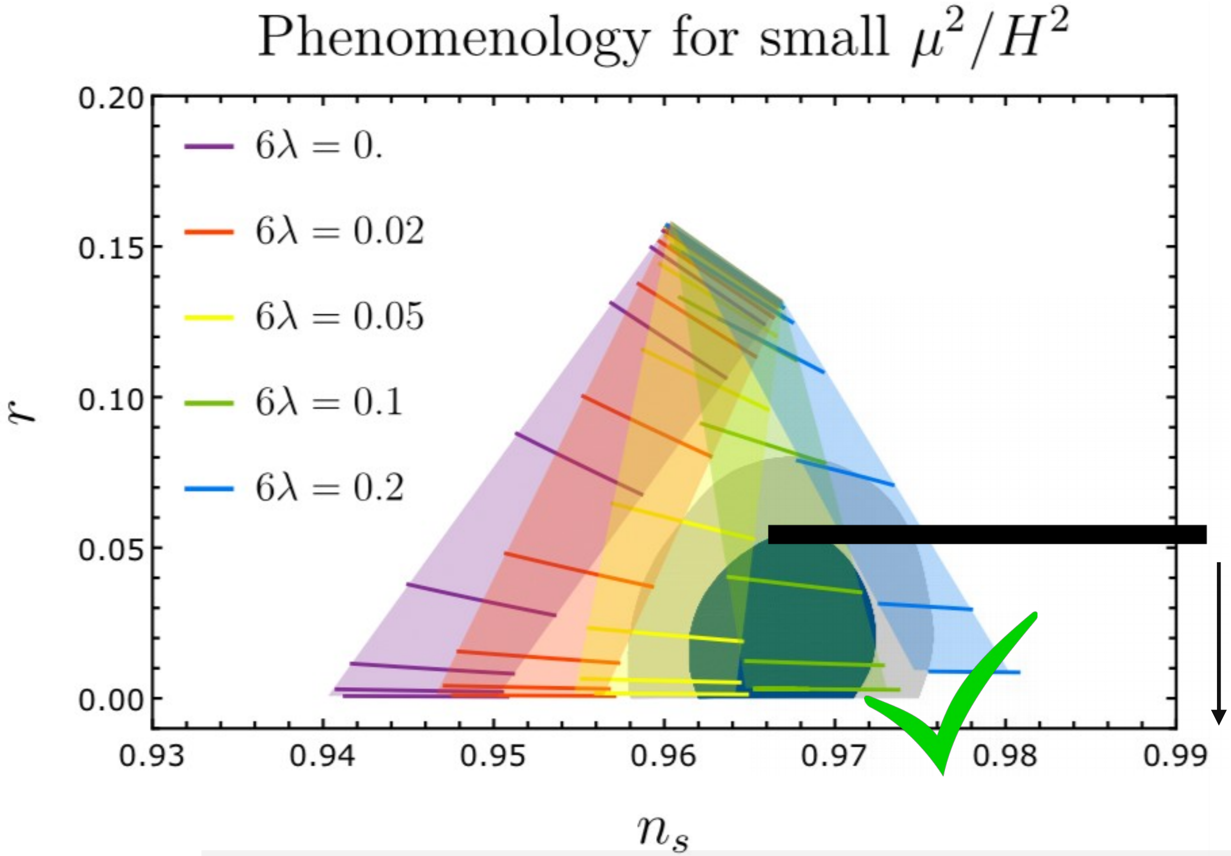
In massless limit λ = 0

$$\mathcal{R}' = \frac{2}{\kappa\sqrt{2\epsilon}}\mathcal{S} \longrightarrow \mathcal{R}_{\text{end}} \approx \frac{2\Delta N}{\kappa\sqrt{2\epsilon}}\sigma_* \longrightarrow P_{\mathcal{R}} \gg P_{\mathcal{S}}$$

(Achucarro, Atal, Germani, Palma)

Phenomenology for small isocurvature mass

To appear soon in (Achúcarro, YW)



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"Single clock" regime
isocurvature pt suppressed
but consistency relation violated!

$$f_{\rm NL} = -\frac{5}{12}\left(\alpha\kappa + \lambda\frac{10 - \mathbb{R}\kappa^2}{2}\right) + \frac{5}{N_\rho}\frac{2 - \mathbb{R}\kappa^2}{12\kappa}$$

$$N_\rho = \frac{1}{\kappa\lambda}\left(1 - e^{-2\lambda\Delta N}\right)$$

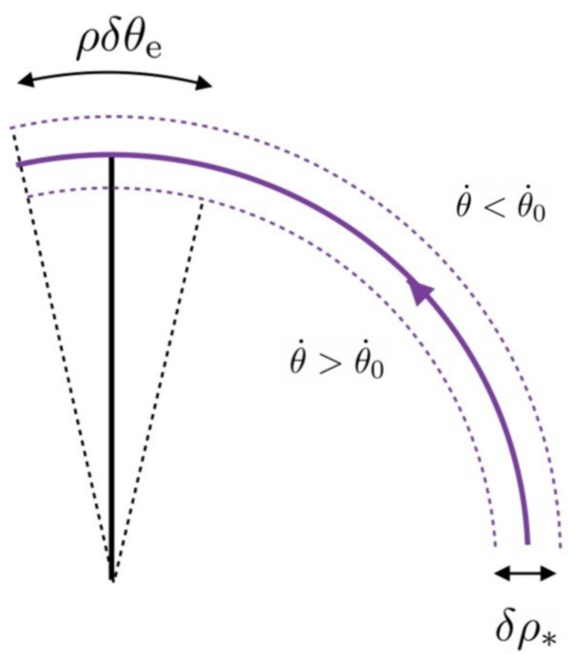
Small if λ, α are suppressed!

Scaling similarity ↔ massless fields

Inspecting the massless case H = H(θ) in more detail

$$S_\phi = -\frac{1}{2}\int d^4x\sqrt{-g}\left((\partial\rho)^2 + e^{2\rho/R_0}(\partial\theta)^2 + \Lambda\left(\theta^2 - \frac{2p}{3e^{2\rho/R_0}}\right)\right)$$

It has a scaling similarity !



Relating BG solutions

$$\rho(x) \to \rho'(x') = \rho(x) + \Lambda c$$
$$\theta(x) \to \theta'(x') = e^{-c\Lambda/R_0}\theta(x)$$
$$x^\mu \to x'^\mu = e^c x^\mu$$

$$S \to S' = e^{2c}S$$

Perturbations

$$\rho(x) = \bar\rho(t + \pi(x)) + \mathcal{S}(x)$$
$$\theta(x) = e^{-\mathcal{S}(x)/R_0}\bar\theta(t + \pi(x))$$

Massless isocurvature pt

Scaling similarity ↔ massless fields

To appear soon in (Achúcarro, Palma, Wang, YW)

We can generalize this to the family of potentials

$$S_\phi = -\frac{1}{2}\int d^4x\sqrt{-g}\left((\partial\rho)^2 + e^{2\rho/R_0}(\partial\theta)^2 + \sum_m c_m \theta^{2n-2m} e^{-2m\rho/R_0}\right)$$

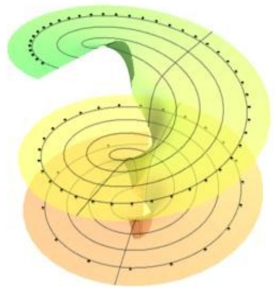
Same scaling similarity → massless perturbation AND small self-interactions

$$f_{\rm NL} \approx \frac{5}{12}\left(\frac{2\epsilon}{n} + \eta - \frac{2\dot\rho}{R_0 H}\right)$$

(If the radial field has a sufficiently small velocity)

In multi-field set-ups f_{NL} becomes slow-roll suppressed if:
- The isocurvature pt are responsible for the final curvature pt
- The isocurvature self interactions are small

Conclusions



Orbital Inflation: a class of exact multi-field attractors in curved field spaces and with curved trajectories

In the limit of small isocurvature self interactions and a small radius of curvature Orbital Inflation mimics the phenomenology of single-field inflation

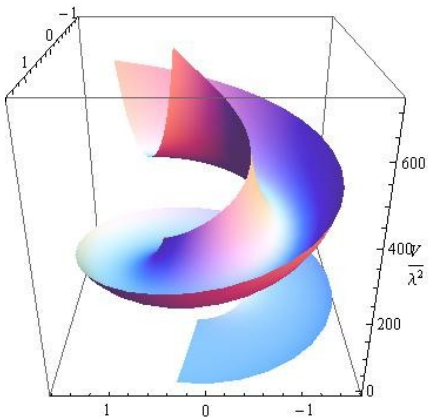
A scaling similarity can explain the above properties

Successful inflation doesn't necessarily require to stabilize all light fields!!

Thank you!

Old slides

Derivative interactions



Example: a potential which forces the inflaton to turn at constant radius

$$\mathcal{L} = \frac{1}{2}\rho^2\dot{\theta}^2 + \frac{1}{2}\dot{\rho}^2 - V(\rho,\theta) + \ldots$$

Expand around bg: derivative coupling proportional to turn rate

$$\mathcal{L} = \frac{1}{2}(\rho_0 + \delta\rho)^2(\dot{\theta}_0 + \delta\dot{\theta})^2 + \frac{1}{2}\delta\dot{\rho}^2 - V(\rho,\theta) + \ldots$$

$$\supset 2\rho_0\dot{\theta}_0\underline{\delta\rho\delta\dot{\theta}}$$

This happens whenever background trajectory $\neq$ geodesic

Derivative interactions

General quadratic action:

$\mathcal{R}$: curvature pt

σ : isocurvature pt

$$S^{(2)} = \frac{1}{2}\int d^4x a^3 M_p^2 \left[2\epsilon\left(\dot{\mathcal{R}} - \omega\sigma\right)^2 - 2\epsilon\frac{(\partial_i\mathcal{R})^2}{a^2} + \dot{\sigma}^2 - \mu^2\sigma^2 - \frac{(\partial_i\sigma)^2}{a^2}\right]$$

The coupling constant is proportional to the turn rate ω

The effective mass μ is given by $\mu^2 = V_{NN} + \epsilon M_p^2 H^2 \mathbb{R} + 3\omega^2$