Inevitable Large non-Gaussianity from Curvaton Models

Based on Lodman, Lu, and Randall (In Preparation)

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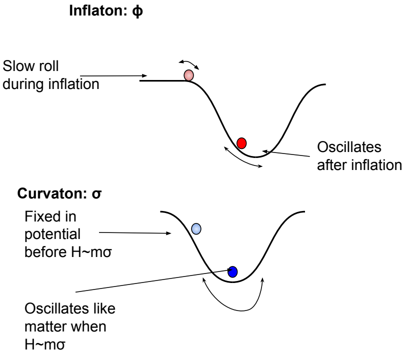
Introduction: Inflationary Observables

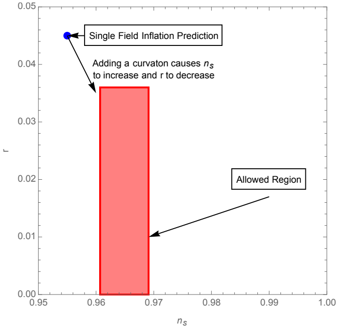
- Inflationary observables are used to constrain different inflation models
- Inflationary Observables:
  - Power Spectrum Amplitude: $A_s = 3.044 \pm 0.014$ (Planck 2018)
  - Spectral Tilt: $n_s = 0.9649 \pm 0.0042$ (Planck 2018)
  - Tensor-to-Scalar Ratio: $r \leq 0.036$ (Keck/BICEP 2018)
  - Non-Gaussianity: $f_{\rm NL}^{\rm (loc)} = \text{-}0.9 \pm 5.1$ (Planck 2018)
- **Single field inflation produces $f_{\rm NL}^{\rm (loc)}$ of order the slow roll parameters ($|f_{\rm NL}^{\rm (loc)}| < 0.05$)** (Maldacena 2002)



- Non-Gaussianity produced by curvatons is not constrained to be order the slow roll parameters. Therefore, we can achieve $f_{\mathrm{NL}}^{(\mathrm{loc})} \sim \mathcal{O}(1)$
- Curvatons provide a simple explanation for a potential observation of $f_{\mathrm{NL}}^{(\mathrm{loc})} \sim \mathcal{O}(1)$, which is still allowed by current constraints!

Curvatons Can "Save" Inflation Models:

- Inflation models are constrained by our observations of (n_s, r)
- Adding a curvaton $\rightarrow$ decrease r and increase n_s
- **Inflation models that do not satisfy (n_s, r) constraints because they generically produce r too large and n_s too small $\rightarrow$ potentially "saved" by adding curvaton**



What We Did:

- Overarching Question: When is large $f_{\mathrm{NL}}^{(\mathrm{loc})}$ ($|f_{\mathrm{NL}}^{(\mathrm{loc})}| > 0.05$) inevitably produced by single field inflation + curvaton models $\rightarrow$ model can be distinguished from single field inflation
  - Important: "Type" of model
    - Model satisfies (n_s, r) constraints without a curvaton
    - Model satisfies (n_s, r) with a curvaton (but not without)
    - Model does not satisfy (n_s, r) constraints even with a curvaton (we do not discuss this case)
- Methodology: Explored correlations between observables (both analytically and through systematic numerical scans of test models of each type)

- If the underlying inflation model DOES NOT satisfy (n_s, r) constraints without a curvaton, then adding a curvaton to fulfill these constraints will almost certainly lead to a large $f_{\rm NL}^{\rm (loc)}$ ($|f_{\rm NL}^{\rm (loc)}| > 0.05$)
- If the underlying inflation model DOES satisfy (n_s, r) constraints, then a large $f_{\rm NL}^{\rm (loc)}$ ($|f_{\rm NL}^{\rm (loc)}| > 0.05$) is only possible if (m_σ, σ) follow a tight scaling relation

Case 1: Inflation Model Does NOT Satisfy Constraints Without a Curvaton

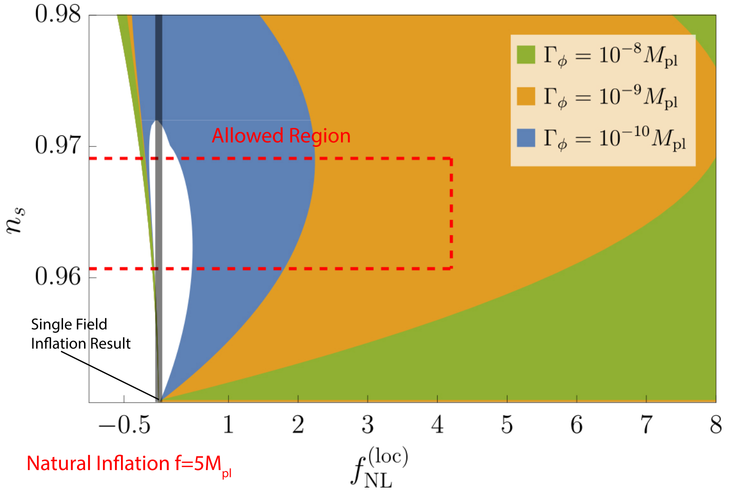
- From (Fonseca and Wands 2012):

$$\begin{aligned} f_{\rm NL}^{(\rm loc)} &= \left(\frac{5}{4R_\sigma} - \frac{5}{3} - \frac{5R_\sigma}{6}\right){\omega_\sigma}^2 \\ r &= 16\epsilon_*(1-\omega_\sigma) \\ n_s &= 1 - 2\epsilon_* + 2\eta_{\sigma\sigma}\omega_\sigma + (1-\omega_\sigma)(-4\epsilon_* + 2\eta_{\phi\phi}), \end{aligned} \quad (1)$$

where $\omega_\sigma = R_\sigma^2 \mathcal{P}_{S_G}/9\mathcal{P}_\zeta$, $R_\sigma = 3\Omega_\sigma/(4-\Omega_\sigma)$, $\Omega_\sigma = \frac{\rho_\sigma}{\rho_{\rm tot}}|_{H=\Gamma_\sigma} =$ weighted energy density in curvaton when it decays

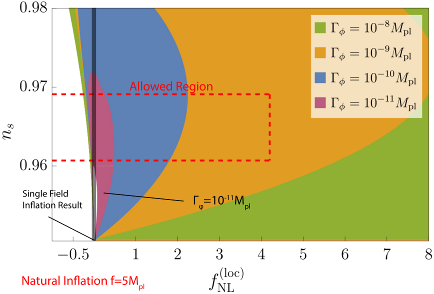
- Require a large curvaton contribution (large ω_σ) to "save" inflation model $\rightarrow |f_{\rm NL}^{(\rm loc)}| > 0.05$

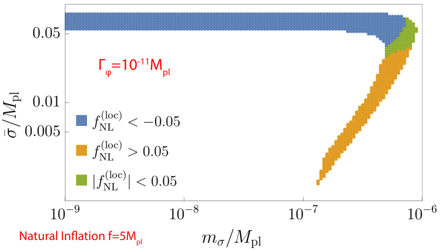
Case 1 Example Model: Natural Inflation + Curvaton



- Boundary of hole is the contour of $m_{\sigma_{\max}}$
- Why does decreasing Γ_ϕ not fix the problem?

Case 1 Example Model: Natural Inflation + Curvaton (2)





- $\Gamma_\phi \downarrow$, gap closes
- BUT very small (m_σ, σ) region produces small $f_{\rm NL}^{\rm (loc)}$
- Therefore, generically obtain large (distinguishable) $f_{\rm NL}^{\rm (loc)}$ from models of this type

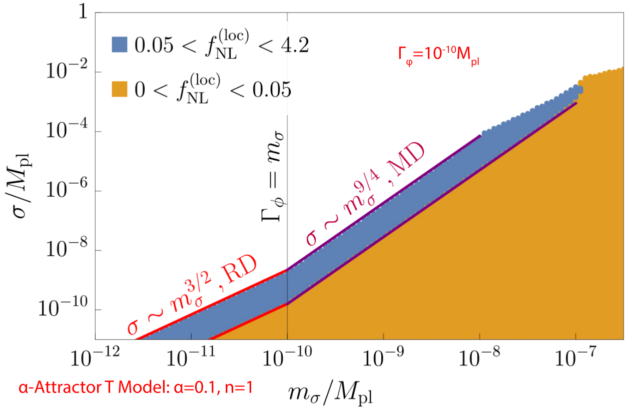
Case 2: Inflation Model Does Satisfy Constraints Without a Curvaton

- From (Fonseca and Wands 2012):

$$\begin{aligned} f_{\mathrm{NL}}^{(\mathrm{loc})} &= \left(\frac{5}{4R_\sigma} - \frac{5}{3} - \frac{5R_\sigma}{6}\right){\omega_\sigma}^2 \\ r &= 16\epsilon_*(1-\omega_\sigma) \\ n_s &= 1 - 2\epsilon_* + 2\eta_{\sigma\sigma}\omega_\sigma + (1-\omega_\sigma)(-4\epsilon_* + 2\eta_{\phi\phi}), \end{aligned} \tag{2}$$

  where $\omega_\sigma = R_\sigma^2 \mathcal{P}_{S_G}/9\mathcal{P}_\zeta$, $R_\sigma = 3\Omega_\sigma/(4-\Omega_\sigma)$, $\Omega_\sigma = \frac{\rho_\sigma}{\rho_{\mathrm{tot}}}|_{H=\Gamma_\sigma} =$ weighted energy density in curvaton when it decays
- Model already satisfies constraints $\rightarrow$ small curvaton contribution to observables
- Generically leads to $|f_{\mathrm{NL}}^{(\mathrm{loc})}| < 0.05$
- Achieving $|f_{\mathrm{NL}}^{(\mathrm{loc})}| > 0.05$ requires fulfilling a tight scaling relation between curvaton mass and amplitude

Case 2 Example Model: α-Attractor T Model + Curvaton



- Tight scaling relation between curvaton mass and amplitude required to achieve $|f_{\rm NL}^{(\rm loc)}| > 0.05$
  - Exact relationship depends on whether universe MD or RD when curvaton starts to oscillate
- Therefore, generically achieve indistinguishable $f_{\rm NL}^{(\rm loc)}$ ($|f_{\rm NL}^{(\rm loc)}| < 0.05$)

Conclusions

- Curvatons are light (compared to the inflaton) massive scalar particles that can explain an observation of $f_{\mathrm{NL}}^{(\mathrm{loc})} \sim \mathcal{O}(1)$
- Curvatons generically raise n_s and lower r, potentially making some ruled out inflation models viable again
- We found that an $f_{\mathrm{NL}}^{(\mathrm{loc})}$ value distinguishable from the single field inflaton prediction ($|f_{\mathrm{NL}}^{(\mathrm{loc})}| > 0.05$) occurs if the curvaton is required to make the model viable again
- In contrast, one generically achieves a indistinguishable $f_{\mathrm{NL}}^{(\mathrm{loc})}$ ($|f_{\mathrm{NL}}^{(\mathrm{loc})}| < 0.05$) if the model is viable without the curvaton, unless a very tight curvaton mass-amplitude scaling ratio is met
- These results have consequences for how we determine the viability of curvaton models when next generation experiments release results