USR regime in MFI

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OUTLINE

- Introduction: the single-component case
- Multi-field inflation: state-of-the-art
  - Motivation and some results
  - Curved Field Space
- USR in MFI
  - Motivation
  - Results

INTRODUCTION

Single field cosmologies are successful enough

- Single Field Inflation (SFI) predicts n_s - 1, r, *Gaussian* fluctuations
- Matter bounces are dual to SFI, can be modeled by a single field
  - De Sitter Expansion ⇔ Matter contraction
  - 1st order ⇔ Background
- Away from CMB scales: NG, PBHs, Secondary GWs, and more

How? Using more fields

Some of those could be present for SF

- Inflation: interactions, non-BD vacuum, bounce-inflation
- Deviation from slow-roll: **Ultra-slow-roll** and PBHs
- Bouncing: need more investigation wrt NGs
    - No literature on PBHs yet!
- Multi-field models present all of those more naturally

MULTI-FIELD INFLATION:

STATE-OF-THE-ART

Not only phenomenology backs MFI up

- Theoretical motivation:
  - Swampland conjecture: de Sitter w/ just one field
  - GUT scale
- Observational hints?
  - CMB statistical anomalies

There are many types of MFI

- Curvaton Model: 1 field for background, 1 for perturbations
  - [Guimarães, Falciano ‘21]: reconstruction from f_{NL}
  - [Tays Miranda et al.]: communication on Monday!
- Complex fields: radial and angular inflation, Quasi-single-field
- Many epochs of inflation: a stage for each field
  - The transition between stages is important!

There are many types of MFI

- Curved Field Space: non-canonical kinetic terms
  - **Class of models I'm working with now**
- Hyperbolic field space: destabilized background
  - Large entropy perturbations
  - Non-Gaussianities? – in progress
- **Including Ultra-Slow-Roll!**

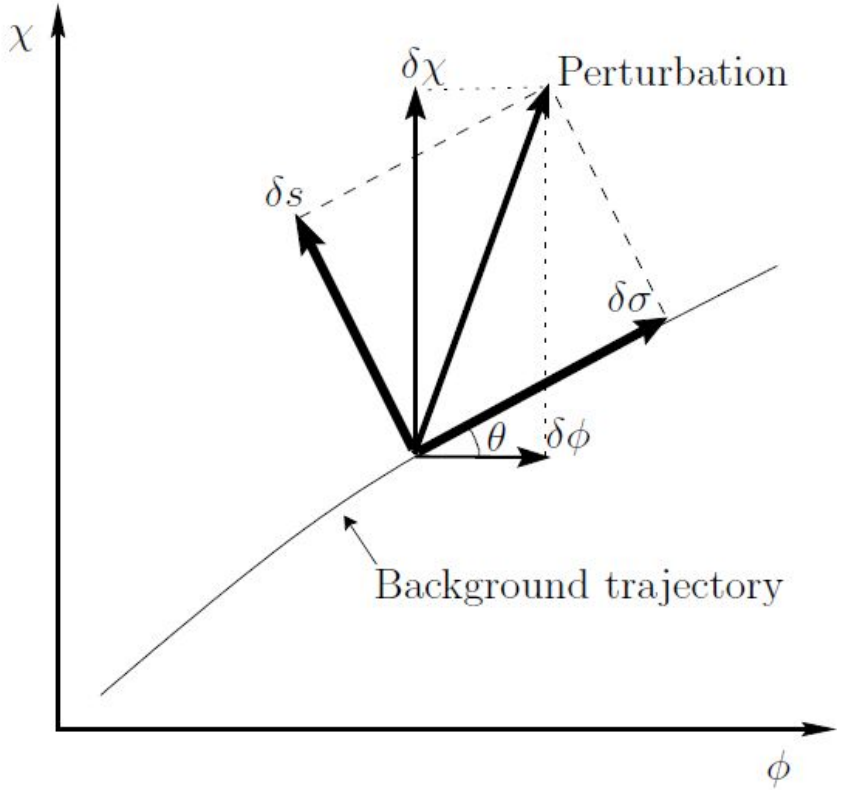
The main effect of MFI: entropy perturbations

- 2 or more fields result in the production of entropy perturbations
- Curvaton: entropy to curvature perturbations **post** inflation
- Other models: curvature perturbations grow thanks to mixing:

$$\dot{\zeta} \approx 2\eta_{\perp} \frac{H^2}{\dot{\sigma}} \mathcal{Q}_s$$

- The $\eta_{\perp}$ parameter: how the trajectory bends in the target space

Adiabatic and Entropy perturbations



- Inflaton φ: curvature
- Secondary χ: entropy
- $\eta_\perp \Leftrightarrow$ variation of Θ
- Coupling/Enhancement requires the **bending** of the trajectory

The perturbations

- In MFI there is a mixing of entropy and curvature perturbations

$$f_{\mathrm{acop}\,\sigma} = \partial_t \left(2H\eta_\perp \mathcal{Q}_s\right) - \left(\frac{\dot{H}}{H} + \frac{U_{,\sigma}}{\dot{\sigma}}\right) 2H\eta_\perp \mathcal{Q}_s$$

$$f_{\mathrm{acop}\,s} = -2\dot{\sigma}\eta_\perp \dot{\zeta}$$

- The bending is necessary for the mixing

Why curved field space models?

- Non-canonical kinetic terms mix the fields (perturbations too)
  - The target space is curved. In particular, **negatively curved**

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[-\frac{1}{2}\mathcal{G}_{IJ}(\phi^K)\partial_\mu\phi^I\partial^\mu\phi^J - U(\phi^K)\right]$$

- Literature: Hyperinflation, α-attractors, side-tracked inflation
- **Rapid turn**: large $\eta_\perp$ parameter ⇔ large perturbations and mixing

What if the bending is *really* strong?

- Perturbation mass term gets negative! Transient instability

$$\frac{m_s^2}{H^2} = \frac{U_{,ss}}{H^2} + \epsilon_H \mathcal{R}_{fs} - \eta_\perp^2$$

- Enough for the fluctuations to grow orders of magnitude
- If it grows enough, leads to PBHs and Secondary GWs!
- Goes back to positive values, entropy modes decay

ULTRA-SLOW-ROLL IN MFI:

ENHANCED TURNING RATE

USR in SFI – what it is?

- Field speed **really** small – the **ultra slow** part of the name
- Why? **Really flat potential** – new approximation to EoM:

$$\ddot{\phi} + 3H\dot{\phi} \simeq 0$$

- First slow-roll parameter ϵ_H reduces drastically – $10^{-8\sim-9}$
- Second slow-roll parameter: η_H ~ 3 defines USR
- (SR) Inflation **ends** for USR to begin

USR in SFI – Motivation

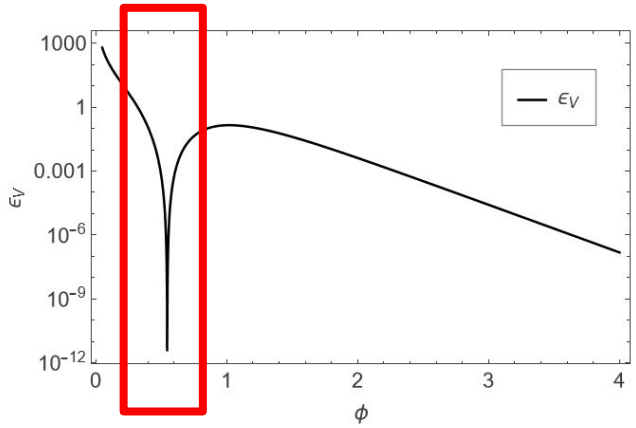
- Motivation: production of Primordial Black Holes
- Enhancement of perturbations: (even) smaller ϵ_H

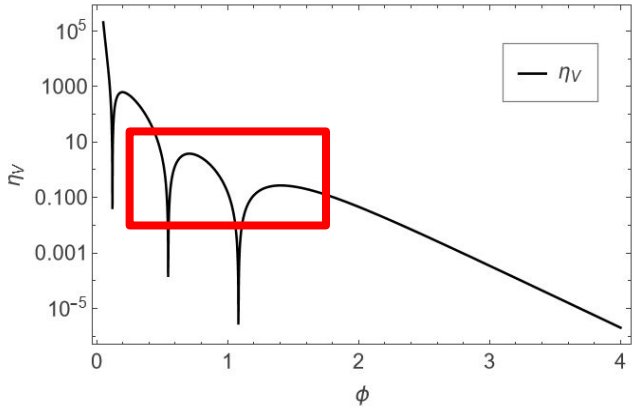
$$\mathcal{P}_\zeta \propto \epsilon_H{}^{-1}$$

- Perturbations of order 10^{-3} or higher → Primordial Black Holes
  - Collapse after re-entry!
  - Secondary GW's

USR in SFI – Motivation

- (Potential) Slow-Roll Parameters



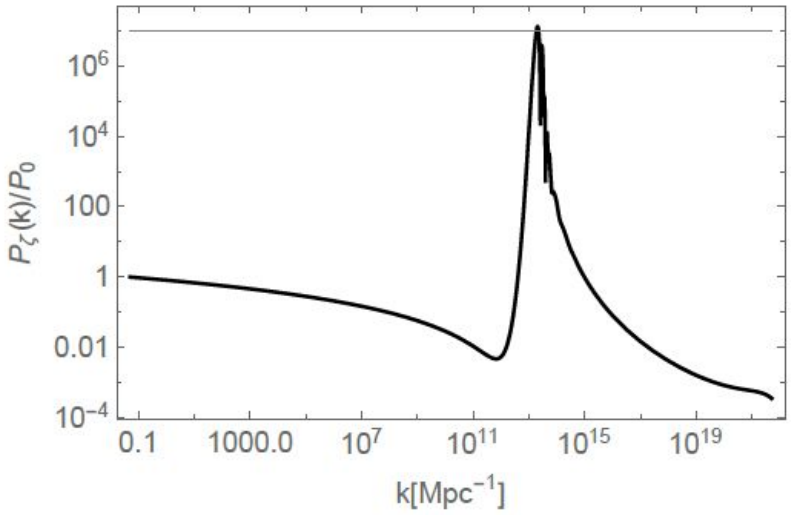


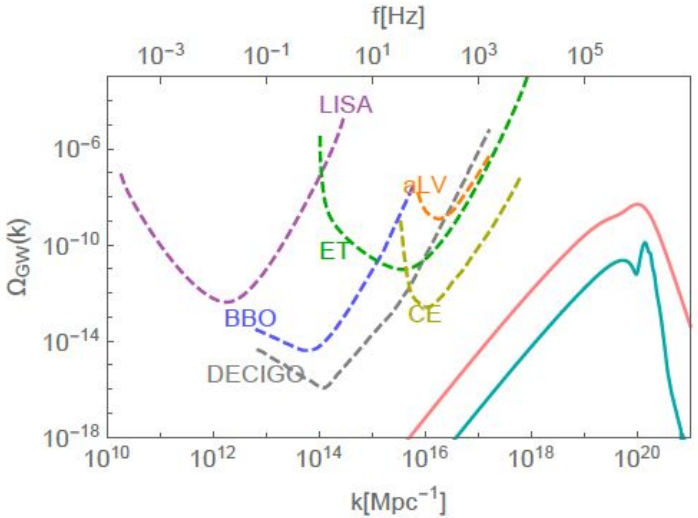
USR in MFI

- USR already causes η_{H} to grow
- Potential energy reduces, Kinetic energy as well
  - Secondary field becomes more important to the background
  - What does it means for the **turning**?
- Curved Field Space: stronger turning!

Example from the literature: α-attractors + USR

- [Iacconi et al '21]: USR for α-attractor model (CFS)
- Large amplification of perturbations: PBHs and GWs





Is this behavior generic? Example

- Due to the USR regime, the bending of the trajectory seems to be inevitable
- **Proposal:** USR regime for inflaton + quadratic secondary
  - **CFS:** similar do hyperinflation – exponential terms in the metric

$$V(\varphi) = V_0 \left[\varphi - \varphi^2 + \frac{1}{3}\varphi^2 \right]^2 \qquad \mathcal{G}_{IJ} = \begin{pmatrix} \xi_1 e^{\chi} & 0 \\ 0 & \xi_2 e^{\varphi.\delta} \end{pmatrix}$$

The equations of motion are highly mixed

- Mixing due to CFS, no interaction at U(φ, χ) level

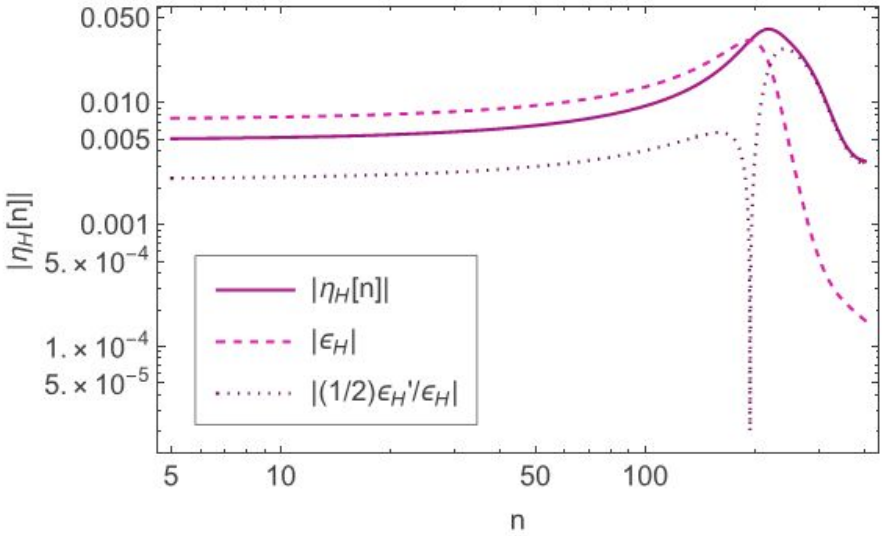
$$H^2\varphi'' + HH'\varphi' + H^2\varphi'\chi' - H^2\frac{\delta}{2}\frac{\xi_2}{\xi_1}e^{\varphi\delta}e^{-\chi}\chi' + 3H^2\varphi' + \frac{e^{-\chi}}{\xi_1}U_{,\varphi} = 0$$

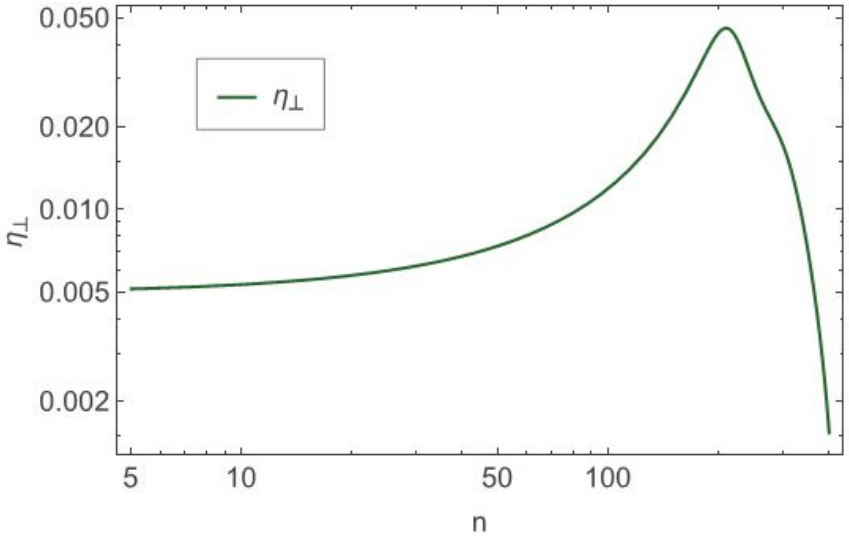
$$H^2\chi'' + HH'\chi' + H^2\varphi'\chi' - H^2\frac{1}{2}\frac{\xi_1}{\xi_2}e^{-\varphi\delta}e^{\chi}\varphi' + 3H^2\chi' + \frac{e^{-\varphi\delta}}{\xi_2}U_{,\chi} = 0$$

- Toy model: metric parameters equal to 1, masses chosen so that the inflaton dominates over the secondary throughout

Numerical results for background values

- Key parameters: η_{H} and $\eta_{\perp}$ – there is a connection between both





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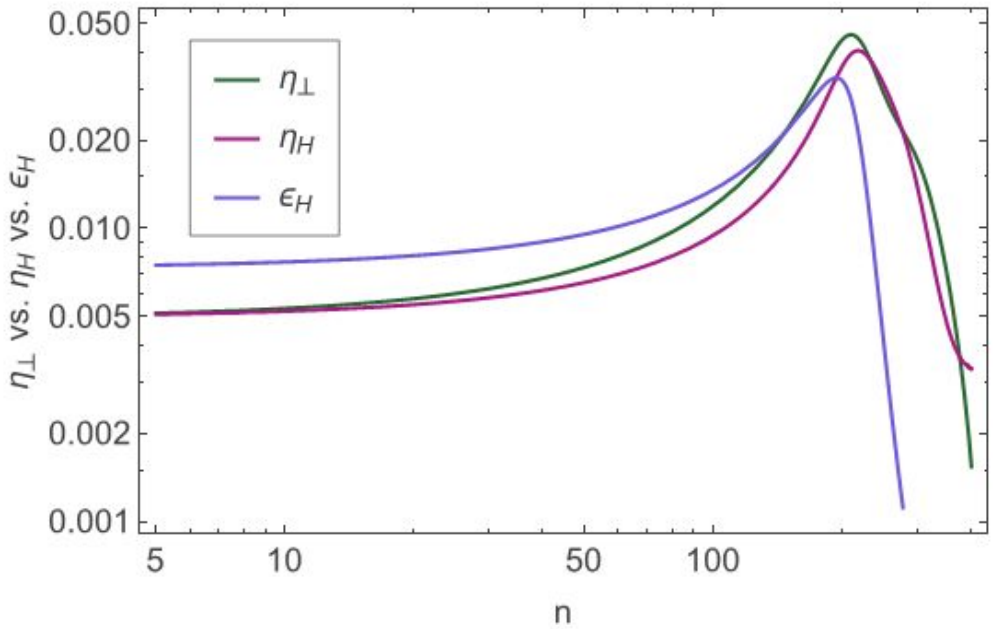


Both parameters are highly dependent on ϵ_H

- When it varies fast, the parameters grow! Dependence on ϵ_H'

$$\epsilon_H = -\frac{H'}{H} \qquad \eta_H = \epsilon_H - \frac{1}{2}\frac{\epsilon'_H}{\epsilon_H}$$

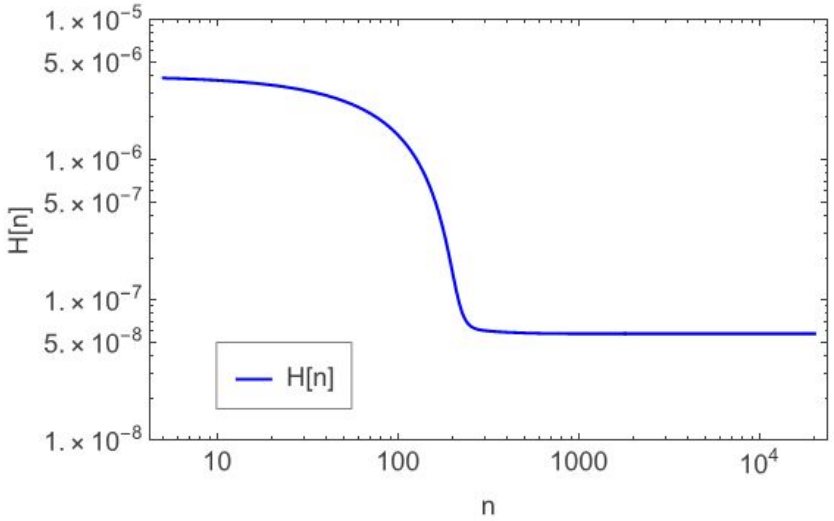
- USR regime needs ϵ_H to vary fast!
  - Otherwise inflation lasts too much – reheating constraints
  - The faster we go from SR to USR – reaching condition $\epsilon_H = 1$

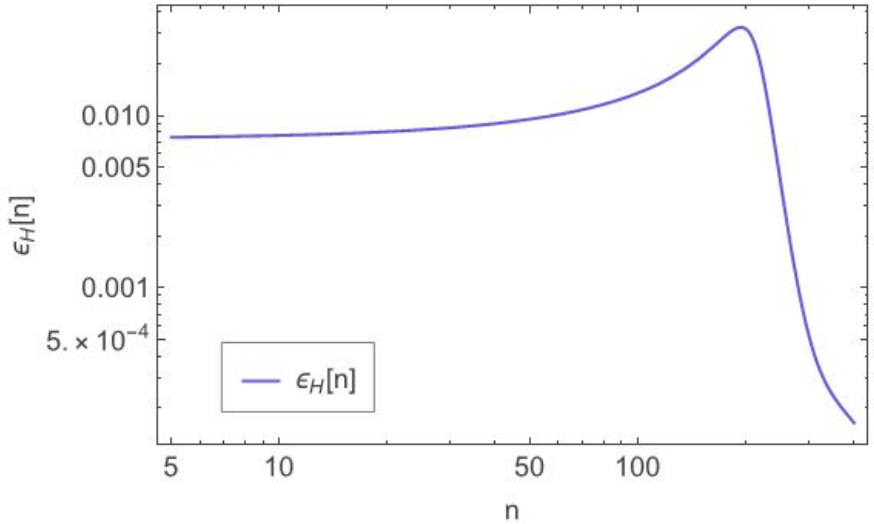
Both parameters are highly dependent on ϵ_H

- When it varies fast, both parameters grow!
- Secondary Field + FS can enhance this behavior!
- Large $\eta_\perp$ ⇔ Large ϵ_H' ⇔ deviation from SR
  - Might mean the end of inflation, ϵ_H of order unity
- Similarities to old MFI models – double inflation

Field space metric can hinder the models too

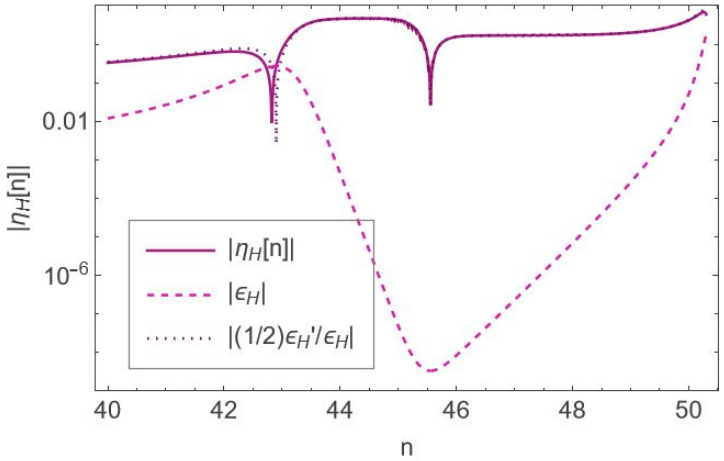
- Issue: eternal USR – depends on field space metric!





Metric and Secondary Field dependence

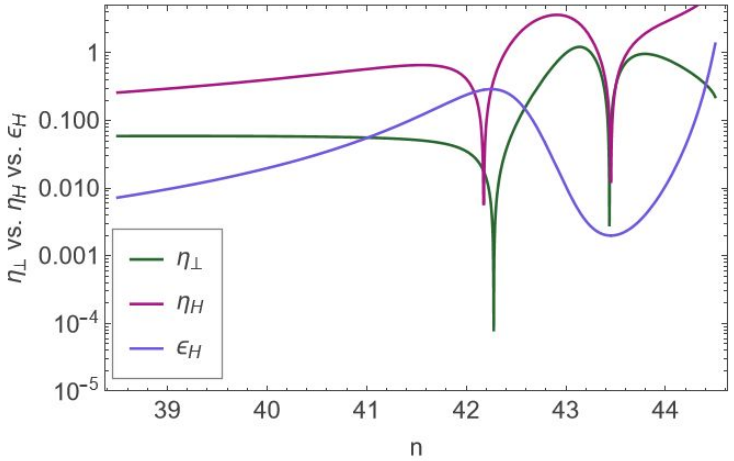
- Starting from a more realistic model - SFI case:



- Brief USR, η_H peaks during the **transition**

Metric and Secondary Field dependence

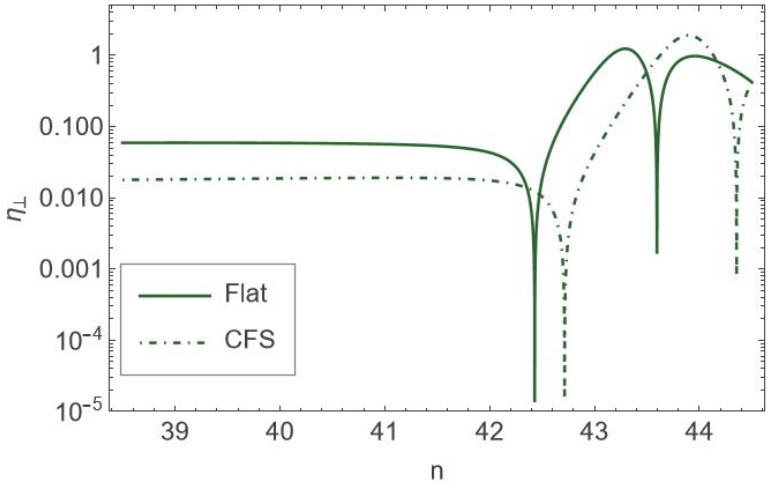
- Addition from secondary field: η_H and ϵ_H

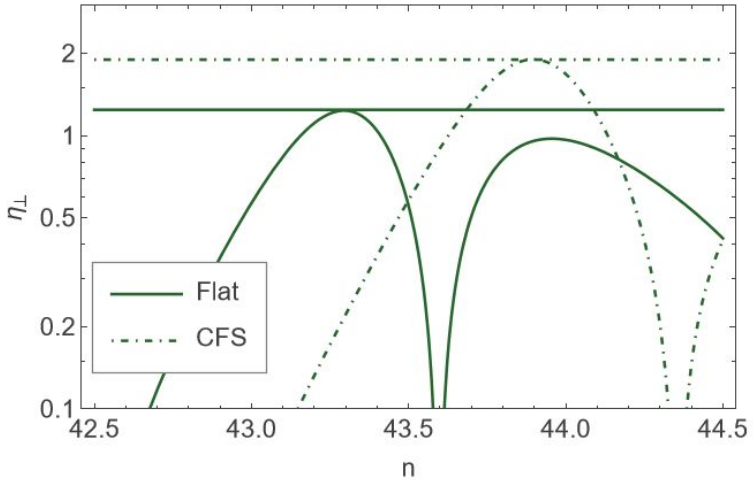


- Larger ϵ_H, turning rate ~1 – not a complete USR regime
- Narrower η_H, which reflects on perturbations – future work

Metric and Secondary Field dependence

- Curved Field Space: Hyperinflation type





- Enhances $\eta_\perp$ – different curvature changes it for better or worse

USR depends not only on inflaton potential

- Transient instability can occur for large $\eta_{\perp}$
- MFI + CFS + enough change of ϵ_{H}
  - Future steps – minimum amount of change in ϵ_{H}
- Testing USR model with CFS – different metrics, different 2nd field
- Next: full perturbations + PBH + SGW **+ NG**
  - NG are likely peaked at **flattened configuration**

CONCLUSION

Multi field cosmologies have a richer phenomenology

- Single field cosmologies can’t predict some effects
- Multi field inflation is supported by theoretical arguments
- MFI + CFS predicts scale-dependent behavior, can be put to test
  - PBHs and GWs: growth of scalar perturbation at smaller scales
  - NG: **needs to be checked!** Can’t violate current constraints
- Dependencies on Field Space Metric and Secondary Field!
  - Ultra-Slow-Roll may be spoiled!

ACKNOWLEDGMENTS