Hyperinflation: Stuck in the Swampland

Marios Bounakis

Cosmology from Home 2020

August 14, 2020

Overview

Overview of the talk.

Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond

Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond
- Motivation for Hyperinflation

Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond
- Motivation for Hyperinflation
- Hyperinflation-Background

Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond
- Motivation for Hyperinflation
- Hyperinflation-Background
- Hyperinflation-Perturbations

Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond
- Motivation for Hyperinflation
- Hyperinflation-Background
- Hyperinflation-Perturbations
- Observational Constraints

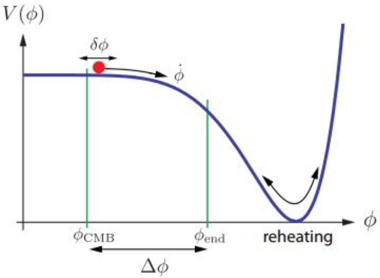
Overview

Overview of the talk.

- Single-field Slow-roll Inflation and Beyond
- Motivation for Hyperinflation
- Hyperinflation-Background
- Hyperinflation-Perturbations
- Observational Constraints
- Motivation for Further Work

Single-field Slow-roll Inflation and Beyond

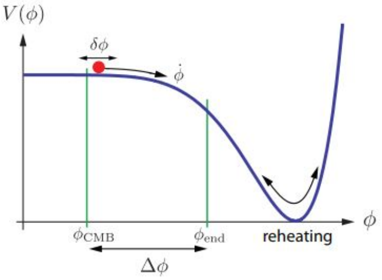
- Inflation[0]: Motivated by zero-order problems of C.S.M (Horizon& Flatness)
- Quantum fluctuations strecched out of the horizon seed LSS
- Single-field slow-roll: Scalar rolls down its potential [1]
- Agreement with observations[2]



[0] Adv. Ser. Astrophys. Cosmol. **3** (1987), 139-148
[1] Adv. Ser. Astrophys. Cosmol. **3** (1987), 149-153
[2] Astron. Astrophys. **594** (2016), A13 [arXiv:1502.01589 [astro-ph.CO]].
[3] Phys. Rev. D **49** (1994), 748-754 [arXiv:astro-ph/9307002 [astro-ph]]
[4] JHEP **01** (2020), 073 [arXiv:1907.10403 [hep-th]]

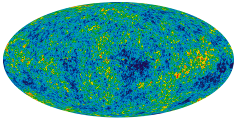
Single-field Slow-roll Inflation and Beyond

- Inflation[0]: Motivated by zero-order problems of C.S.M (Horizon& Flatness)
- Quantum fluctuations strecched out of the horizon seed LSS
- Single-field slow-roll: Scalar rolls down its potential [1]
- Agreement with observations[2]



⇒ Why bother with multiple fields, then?

- Natural from particle theory viewpt
- Richer phenomenology [3]
- "Swampland" Conjectures
- Non-Gaussianity Signatures [4]



[0] Adv. Ser. Astrophys. Cosmol. **3** (1987), 139-148

[1] Adv. Ser. Astrophys. Cosmol. **3** (1987), 149-153

[2] Astron. Astrophys. **594** (2016), A13 [arXiv:1502.01589 [astro-ph.CO]].

[3] Phys. Rev. D **49** (1994), 748-754 [arXiv:astro-ph/9307002 [astro-ph]]

[4] JHEP **01** (2020), 073 [arXiv:1907.10403 [hep-th]]

Motivation for Hyperinflation

- Required # of e-folds: ~~1-D, Potential Tuning~~
  $\Downarrow$
  2-D, Centrifugal force

[5] JCAP **02** (2008), 010 [arXiv:0709.2666 [hep-th]]
[6] Phys. Rev. Lett. **121** (2018) no.25, 251601 [arXiv:1705.03023 [hep-th]].
[7] JHEP **04** (2019), 172 [arXiv:1901.08603 [hep-th]].

Motivation for Hyperinflation

- Required # of e-folds: ~~1-D, Potential Tuning~~

  $\Downarrow$

  2-D, Centrifugal force

  - Spinflation[5]: $\mathbb{R}^2$ Field-space

$$S_{R^2} = \int dt\, d^3x \left[a^3(t) \left(-\frac{1}{2}(\nabla_\mu \rho)^2 - \frac{1}{2}(\nabla_\mu \phi)^2 - V(\rho) \right) \right] \tag{1}$$

Velocities redshift: angular motion becomes irrelevant.

---

[5] JCAP **02** (2008), 010 [arXiv:0709.2666 [hep-th]]

[6] Phys. Rev. Lett. **121** (2018) no.25, 251601 [arXiv:1705.03023 [hep-th]].

[7] JHEP **04** (2019), 172 [arXiv:1901.08603 [hep-th]].

Motivation for Hyperinflation

- Required # of e-folds: ~~1-D, Potential Tuning~~

  $\Downarrow$

  2-D, Centrifugal force

  - Spinflation[5]: $\mathbb{R}^2$ Field-space

$$S_{R^2} = \int dt\, d^3x \left[a^3(t)\left(-\frac{1}{2}(\nabla_\mu\rho)^2 - \frac{1}{2}(\nabla_\mu\phi)^2 - V(\rho)\right)\right] \tag{1}$$

  Velocities redshift: angular motion becomes irrelevant.

  - Hyperinflation[6]: $\mathbb{H}^2$ field space with curvature scale M_H

$$S_{H^2} = \int dt\, d^3x \left[a^3(t)\left(-\frac{1}{2}(\nabla_\mu\rho)^2 - \frac{1}{2}M_H^2\, sinh^2\left(\frac{\rho}{M_H}\right)(\nabla_\mu\phi)^2 - V(\rho)\right)\right] \tag{2}$$

  field-space $J = M_H^2\, sinh^2\left(\frac{\phi}{M_H}\right)\dot{\psi}$ exponentially large

  $\Downarrow$

  Angular motion relevant throughout inflation.

---

[5] JCAP **02** (2008), 010 [arXiv:0709.2666 [hep-th]]

[6] Phys. Rev. Lett. **121** (2018) no.25, 251601 [arXiv:1705.03023 [hep-th]].

[7] JHEP **04** (2019), 172 [arXiv:1901.08603 [hep-th]].

Motivation for Hyperinflation

- Required # of e-folds: ~~1-D, Potential Tuning~~

  $\Downarrow$

  2-D, Centrifugal force

  - Spinflation[5]: $\mathbb{R}^2$ Field-space

$$S_{R^2} = \int dt\, d^3x \left[a^3(t) \left(-\frac{1}{2}(\nabla_\mu \rho)^2 - \frac{1}{2}(\nabla_\mu \phi)^2 - V(\rho) \right) \right] \quad (1)$$

    Velocities redshift: angular motion becomes irrelevant.

  - Hyperinflation[6]: $\mathbb{H}^2$ field space with curvature scale M_H

$$S_{H^2} = \int dt\, d^3x \left[a^3(t) \left(-\frac{1}{2}(\nabla_\mu \rho)^2 - \frac{1}{2} M_H^2\, sinh^2 \left(\frac{\rho}{M_H} \right) (\nabla_\mu \phi)^2 - V(\rho) \right) \right] \quad (2)$$

    field-space $J = M_H^2\, sinh^2 \left(\frac{\phi}{M_H} \right) \dot{\psi}$ exponentially large

    $\Downarrow$

    Angular motion relevant throughout inflation.

- F-S J delaying Inflation $\rightarrow$ Adiabatic Perturbations (scale invariant)

---

[5] JCAP **02** (2008), 010 [arXiv:0709.2666 [hep-th]]

[6] Phys. Rev. Lett. **121** (2018) no.25, 251601 [arXiv:1705.03023 [hep-th]].

[7] JHEP **04** (2019), 172 [arXiv:1901.08603 [hep-th]].

Motivation for Hyperinflation

- Required # of e-folds: ~~1-D, Potential Tuning~~

  $\Downarrow$

  2-D, Centrifugal force

  - Spinflation[5]: $\mathbb{R}^2$ Field-space

$$S_{R^2} = \int dt\, d^3x \left[a^3(t) \left(-\frac{1}{2}(\nabla_\mu \rho)^2 - \frac{1}{2}(\nabla_\mu \phi)^2 - V(\rho) \right) \right] \tag{1}$$

    Velocities redshift: angular motion becomes irrelevant.

  - Hyperinflation[6]: $\mathbb{H}^2$ field space with curvature scale M_H

$$S_{H^2} = \int dt\, d^3x \left[a^3(t) \left(-\frac{1}{2}(\nabla_\mu \rho)^2 - \frac{1}{2} M_H^2\, sinh^2 \left(\frac{\rho}{M_H} \right) (\nabla_\mu \phi)^2 - V(\rho) \right) \right] \tag{2}$$

    field-space $J = M_H^2\, sinh^2 \left(\frac{\phi}{M_H} \right) \dot{\psi}$ exponentially large

    $\Downarrow$

    Angular motion relevant throughout inflation.

- F-S J delaying Inflation $\rightarrow$ Adiabatic Perturbations (scale invariant)
- $\epsilon \approx 1$: Swampland Evaded[7] (?)

[5] JCAP **02** (2008), 010 [arXiv:0709.2666 [hep-th]]
[6] Phys. Rev. Lett. **121** (2018) no.25, 251601 [arXiv:1705.03023 [hep-th]].
[7] JHEP **04** (2019), 172 [arXiv:1901.08603 [hep-th]].

Setting the Stage

The action: Rescaling the fields w.r.t. the F-S curvature scale, $\Phi^a \to \frac{\phi^a}{M_H}$

$$S = \frac{1}{2}\int d^D x\,\sqrt{-g}\,\left[M_p^2\,R - M_H^2\mathcal{G}^{ab}(\phi)\partial_\mu\phi^a\partial_\nu\phi^b\,g^{\mu\nu} - 2V\right]. \tag{3}$$

$g^{\mu\nu}$ is the FRW metric $ds^2 = -dt^2 + a(t)\delta_{ij}dx^i dx^j$

[8] Phys. Rev. D **96** (2017) no.10, 103533 [arXiv:1707.05125 [hep-th]]

Setting the Stage

The action: Rescaling the fields w.r.t. the F-S curvature scale, $\Phi^a \to \frac{\phi^a}{M_H}$

$$S = \frac{1}{2}\int d^D x\,\sqrt{-g}\,\left[M_p^2\,R - M_H^2\mathcal{G}^{ab}(\phi)\partial_\mu\phi^a\partial_\nu\phi^b\,g^{\mu\nu} - 2V\right]. \qquad (3)$$

$g^{\mu\nu}$ is the FRW metric $ds^2 = -dt^2 + a(t)\delta_{ij}dx^i dx^j$

The F-S Metric: $d\Sigma = d\rho^2 + f^2(\rho)\,d\phi^2$

For $\rho >> 1$, $f(\rho) = M_H\,sinh(\rho) \approx M_H\,e^\rho$

[8] Phys. Rev. D **96** (2017) no.10, 103533 [arXiv:1707.05125 [hep-th]]

Setting the Stage

The action: Rescaling the fields w.r.t. the F-S curvature scale, $\Phi^a \to \frac{\phi^a}{M_H}$

$$S = \frac{1}{2} \int d^D x \sqrt{-g} \left[M_p^2 R - M_H^2 \mathcal{G}^{ab}(\phi) \partial_\mu \phi^a \partial_\nu \phi^b g^{\mu\nu} - 2V \right]. \quad (3)$$

$g^{\mu\nu}$ is the FRW metric $ds^2 = -dt^2 + a(t)\delta_{ij} dx^i dx^j$

The F-S Metric: $d\Sigma = d\rho^2 + f^2(\rho)\, d\phi^2$

For $\rho >> 1$, $f(\rho) = M_H\, sinh(\rho) \approx M_H\, e^\rho$

The Potential[8]:

$$V(\rho) \approx V_0\, e^{\frac{M_H^2}{M_p^2} p\, \rho}, \qquad p \equiv \frac{M_p^2}{M_H^2} \frac{\partial\, [\ln V]}{\partial \rho} \quad (4)$$

[8] Phys. Rev. D **96** (2017) no.10, 103533 [arXiv:1707.05125 [hep-th]]

Setting the Stage

The action: Rescaling the fields w.r.t. the F-S curvature scale, $\Phi^a \to \frac{\phi^a}{M_H}$

$$S = \frac{1}{2}\int d^D x\,\sqrt{-g}\,\left[M_p^2\,R - M_H^2\mathcal{G}^{ab}(\phi)\partial_\mu\phi^a\partial_\nu\phi^b\,g^{\mu\nu} - 2V\right]. \qquad (3)$$

$g^{\mu\nu}$ is the FRW metric $ds^2 = -dt^2 + a(t)\delta_{ij}dx^i dx^j$

The F-S Metric: $d\Sigma = d\rho^2 + f^2(\rho)\,d\phi^2$

For $\rho >> 1$, $f(\rho) = M_H\,sinh(\rho) \approx M_H\,e^\rho$

The Potential[8]:

$$V(\rho) \approx V_0\,e^{\frac{M_H^2}{M_p^2}p\,\rho}, \qquad p \equiv \frac{M_p^2}{M_H^2}\frac{\partial\,[\ln V]}{\partial\rho} \qquad (4)$$

The coordinates: Projections of the F-S velocity $\perp$& $\parallel$ to the Killing direction $k_a = (0, f(\rho))$: $(x, y) \equiv (\rho', f(\rho)\,\phi')$.

[8] Phys. Rev. D **96** (2017) no.10, 103533 [arXiv:1707.05125 [hep-th]]

Setting the Stage

The action: Rescaling the fields w.r.t. the F-S curvature scale, $\Phi^a \to \frac{\phi^a}{M_H}$

$$S = \frac{1}{2} \int d^D x \sqrt{-g} \left[M_p^2 R - M_H^2 \mathcal{G}^{ab}(\phi) \partial_\mu \phi^a \partial_\nu \phi^b g^{\mu\nu} - 2V \right]. \quad (3)$$

$g^{\mu\nu}$ is the FRW metric $ds^2 = -dt^2 + a(t)\delta_{ij} dx^i dx^j$

The F-S Metric: $d\Sigma = d\rho^2 + f^2(\rho)\, d\phi^2$

For $\rho >> 1$, $f(\rho) = M_H\, sinh(\rho) \approx M_H\, e^\rho$

The Potential[8]:

$$V(\rho) \approx V_0\, e^{\frac{M_H^2}{M_p^2} p\, \rho}, \qquad p \equiv \frac{M_p^2}{M_H^2} \frac{\partial\, [\ln V]}{\partial \rho} \quad (4)$$

The coordinates: Projections of the F-S velocity $\perp \& \parallel$ to the Killing direction $k_a = (0, f(\rho))$: $(x, y) \equiv (\rho', f(\rho)\, \phi')$.

EoM $\to$ autonomous system:

$$\begin{aligned} x' &= -(3 - \epsilon)(x + p_\rho) + y^2 \\ y' &= -(3 - \epsilon + x)\, y \end{aligned} \quad (5)$$

and the Hubble flow parameter, in the small field limit $M_H \leq 10^{-3} M_p$

$$\epsilon = \frac{M_H^2}{2\, M_p^2} [x^2 + y^2] \to 0. \quad (6)$$

[8] Phys. Rev. D **96** (2017) no.10, 103533 [arXiv:1707.05125 [hep-th]]

Background Dynamics - Gradient

Scaling solutions: $\epsilon' = 0$

Background Dynamics - Gradient

Scaling solutions: $\epsilon' = 0$

- $[x, y] = [-p_\rho, 0] \Rightarrow$ Local Lyapunov exponents $(\lambda_1, \lambda_2) = (-3, p-3)$.

$$\begin{aligned} \rho &= \rho_0 - \frac{1}{3}\rho'(0)\, e^{-3N} - pN \\ \phi &= \phi(0) + \frac{1}{p-3}\phi'(0)\, e^{(p-3)N} \end{aligned} \tag{7}$$

Background Dynamics - Gradient

Scaling solutions: $\epsilon' = 0$

- $[x, y] = [-p_\rho, 0] \Rightarrow$ Local Lyapunov exponents $(\lambda_1, \lambda_2) = (-3, p-3)$.

$$
\begin{aligned}
\rho &= \rho_0 - \frac{1}{3}\rho'(0)\, e^{-3N} - pN \\
\phi &= \phi(0) + \frac{1}{p-3}\phi'(0)\, e^{(p-3)N}
\end{aligned}
\tag{7}
$$

Stable solution: $p < 3$

- $\rho' \to -p$
- $\phi' \to 0$

Unstable solution: $p > 3$

- $\rho' \to -3$
- ϕ' increases

Background Dynamics - Gradient

Scaling solutions: $\epsilon' = 0$

- $[x, y] = [-p_\rho, 0] \Rightarrow$ Local Lyapunov exponents $(\lambda_1, \lambda_2) = (-3, p-3)$.

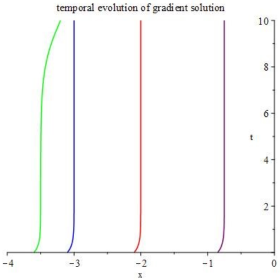
$$\begin{aligned} \rho &= \rho_0 - \frac{1}{3}\rho'(0)\, e^{-3N} - pN \\ \phi &= \phi(0) + \frac{1}{p-3}\phi'(0)\, e^{(p-3)N} \end{aligned} \tag{7}$$

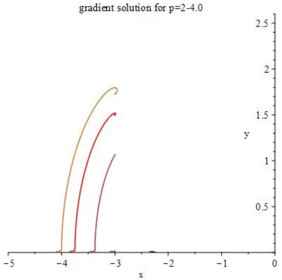
Stable solution: $p < 3$

- $\rho' \to -p$
- $\phi' \to 0$

Unstable solution: $p > 3$

- $\rho' \to -3$
- ϕ' increases





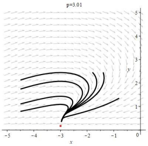
Background Dynamics - Hyperbolic

- $[x, y]_{Hyper} = \left[-3, \pm\sqrt{3p-9}\right]$. Iff $p \geq 3$, potivity of square root argument.
  $\Rightarrow$ The local Lyapunov exponents
  $(\lambda_1, \lambda_2) = (-\frac{3}{2} + \frac{3}{2}\sqrt{9 - \frac{8}{3}p}, -\frac{3}{2} - \frac{3}{2}\sqrt{9 - \frac{8}{3}p})$

Background Dynamics - Hyperbolic

- $[x, y]_{Hyper} = \left[-3, \pm\sqrt{3p-9}\right]$. Iff $p \geq 3$, potivity of square root argument.
  $\Rightarrow$ The local Lyapunov exponents
  $(\lambda_1, \lambda_2) = (-\frac{3}{2} + \frac{3}{2}\sqrt{9 - \frac{8}{3}p}, -\frac{3}{2} - \frac{3}{2}\sqrt{9 - \frac{8}{3}p})$

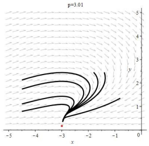
- $3 < p < 3.375$ real eigenvalues
  $\lambda_1 \neq \lambda_2 < 0$
  critical point is a stable node.



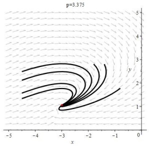
Background Dynamics - Hyperbolic

- $[x, y]_{Hyper} = \left[-3, \pm\sqrt{3p-9}\right]$. Iff $p \geq 3$, potivity of square root argument.
  $\Rightarrow$ The local Lyapunov exponents
  $(\lambda_1, \lambda_2) = (-\frac{3}{2} + \frac{3}{2}\sqrt{9 - \frac{8}{3}p}, -\frac{3}{2} - \frac{3}{2}\sqrt{9 - \frac{8}{3}p})$

- $3 < p < 3.375$ real eigenvalues
  $\lambda_1 \neq \lambda_2 < 0$
  critical point is a stable node.



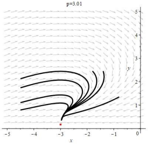
- $p = 3.375$ single eigenvalue, $\lambda = -\frac{3}{2}$
  improper stable node



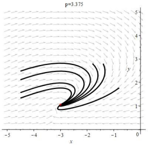
Background Dynamics - Hyperbolic

- $[x, y]_{Hyper} = \left[-3, \pm\sqrt{3p-9}\right]$. Iff $p \geq 3$, potivity of square root argument.
  $\Rightarrow$ The local Lyapunov exponents
  $(\lambda_1, \lambda_2) = (-\frac{3}{2} + \frac{3}{2}\sqrt{9 - \frac{8}{3}p}, -\frac{3}{2} - \frac{3}{2}\sqrt{9 - \frac{8}{3}p})$

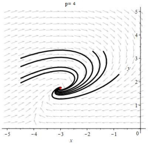
- $3 < p < 3.375$ real eigenvalues
  $\lambda_1 \neq \lambda_2 < 0$
  critical point is a stable node.



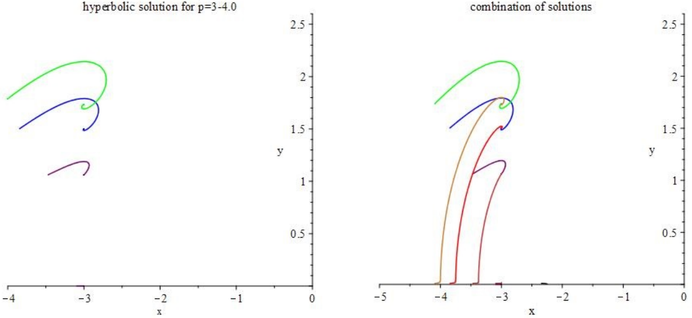
- $p = 3.375$ single eigenvalue, $\lambda = -\frac{3}{2}$
  improper stable node



- $p > 3.375$ compl. conjugate eigenvalues
  $Re(\lambda) < 0$
  system spirals towards stable focus

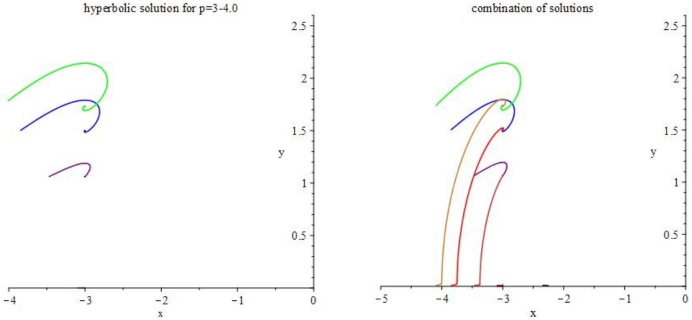


Background Dynamics - Combined



For $p > 3$ the gradient solution is unstable and for any $y_{in} \neq 0$, the system evolves exponentially fast towards the hyperbolic solution.

Background Dynamics - Combined

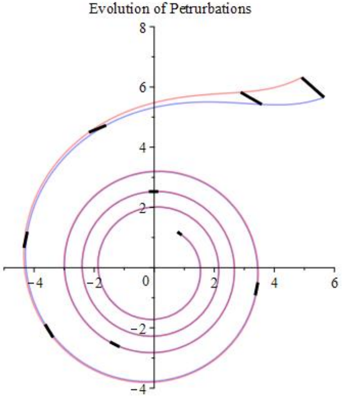


For $p > 3$ the gradient solution is unstable and for any $y_{in} \neq 0$, the system evolves exponentially fast towards the hyperbolic solution.

Hyperinflation is an attractor in the regime that gradient solution is a repeller.

Perturbation Dynamics - Heuristic

Evolution of two neighboring trajectories in the configuration F-S:



Expected behaviour:

- Adiabatic (along the trajectory) perturbations asymptote to a constant
- Isocurvature (normal to the trajectory) vanish

Perturbation Dynamics - Numerical

$\Rightarrow$ Switch to Local Orthogonal Basis.
Define the adiabatic & entropic[9] directions:

$$\hat{\sigma}^a = \frac{\dot{\phi}^a}{\dot{\sigma}}, \qquad \hat{s}^a = \frac{1}{\sqrt{\mathcal{G}}}\,\epsilon^{ab}\,\hat{\sigma}^b\,\mathcal{G}_{bc}. \tag{8}$$

where $\dot{\sigma} = \sqrt{G_{ab}\dot{\Phi}^a\,\dot{\Phi}^b}$ the background field velocity.

[9] Phys. Rev. D **63** (2000), 023506 [arXiv:astro-ph/0009131 [astro-ph]]

Perturbation Dynamics - Numerical

⇒ Switch to Local Orthogonal Basis.
Define the adiabatic & entropic[9] directions:

$$\hat{\sigma}^a = \frac{\dot{\phi}^a}{\dot{\sigma}}, \qquad \hat{s}^a = \frac{1}{\sqrt{\mathcal{G}}}\,\epsilon^{ab}\,\hat{\sigma}^b\,\mathcal{G}_{bc}. \tag{8}$$

where $\dot{\sigma} = \sqrt{G_{ab}\dot{\Phi}^a\,\dot{\Phi}^b}$ the background field velocity.
⇒ Zweibein transformation matrix is simple rotation for scaling solutions!

$$\begin{bmatrix} \hat{e}_\sigma \\ \hat{e}_s \end{bmatrix} = \begin{bmatrix} \frac{x}{\dot{\sigma}} & \frac{y}{f\,\dot{\sigma}} \\ \frac{y}{\dot{\sigma}} & -\frac{x}{f\,\dot{\sigma}} \end{bmatrix} \cdot \begin{bmatrix} \hat{e}_\rho \\ \hat{e}_\phi \end{bmatrix}, \tag{9}$$

Define $z = \ln(\frac{k_*}{k})$ and $k_* = a(t)\,H$ the wavelength of mode that exits the horizon at time t.

[9] Phys. Rev. D **63** (2000), 023506 [arXiv:astro-ph/0009131 [astro-ph]]

Perturbation Dynamics - Numerical

$\Rightarrow$ Switch to Local Orthogonal Basis.
Define the adiabatic & entropic[9] directions:

$$\hat{\sigma}^a = \frac{\dot{\phi}^a}{\dot{\sigma}}, \qquad \hat{s}^a = \frac{1}{\sqrt{\mathcal{G}}}\,\epsilon^{ab}\,\hat{\sigma}^b\,\mathcal{G}_{bc}. \tag{8}$$

where $\dot{\sigma} = \sqrt{G_{ab}\dot{\Phi}^a\,\dot{\Phi}^b}$ the background field velocity.
$\Rightarrow$ Zweibein transformation matrix is simple rotation for scaling solutions!

$$\begin{bmatrix} \hat{e}_\sigma \\ \hat{e}_s \end{bmatrix} = \begin{bmatrix} \frac{x}{\dot{\sigma}} & \frac{y}{f\,\dot{\sigma}} \\ \frac{y}{\dot{\sigma}} & -\frac{x}{f\,\dot{\sigma}} \end{bmatrix} \cdot \begin{bmatrix} \hat{e}_\rho \\ \hat{e}_\phi \end{bmatrix}, \tag{9}$$

Define $z = \ln(\frac{k_*}{k})$ and $k_* = a(t)\,H$ the wavelength of mode that exits the horizon at time t.

The perturbation e.o.m:

$$\begin{aligned} \partial_z^2\,{U^\sigma}_I + 3\,\partial_z {U^\sigma}_I + e^{-2z}\,{U^\sigma}_I + 6\,y\,{U^s}_I + 2\,y\,\partial_z {U^s}_I &= 0 \\ \partial_z^2\,{U^s}_I + 3\,\partial_z {U^s}_I + e^{-2z}\,{U^s}_I - 2\,y^2\,{U^s}_I - 2\,y\,\partial_z {U^\sigma}_I &= 0. \end{aligned} \tag{10}$$

[9] Phys. Rev. D **63** (2000), 023506 [arXiv:astro-ph/0009131 [astro-ph]]

Perturbation Dynamics - Numerical

⇒ Switch to Local Orthogonal Basis.
Define the adiabatic & entropic[9] directions:

$$\hat{\sigma}^a = \frac{\dot{\phi}^a}{\dot{\sigma}}, \qquad \hat{s}^a = \frac{1}{\sqrt{\mathcal{G}}}\,\epsilon^{ab}\,\hat{\sigma}^b\,\mathcal{G}_{bc}. \tag{8}$$

where $\dot{\sigma} = \sqrt{G_{ab}\dot{\Phi}^a\,\dot{\Phi}^b}$ the background field velocity.
⇒ Zweibein transformation matrix is simple rotation for scaling solutions!

$$\begin{bmatrix} \hat{e}_\sigma \\ \hat{e}_s \end{bmatrix} = \begin{bmatrix} \frac{x}{\dot{\sigma}} & \frac{y}{f\,\dot{\sigma}} \\ \frac{y}{\dot{\sigma}} & -\frac{x}{f\,\dot{\sigma}} \end{bmatrix} \cdot \begin{bmatrix} \hat{e}_\rho \\ \hat{e}_\phi \end{bmatrix}, \tag{9}$$

Define $z = \ln(\frac{k_*}{k})$ and $k_* = a(t)\,H$ the wavelength of mode that exits the horizon at time t.

The perturbation e.o.m:

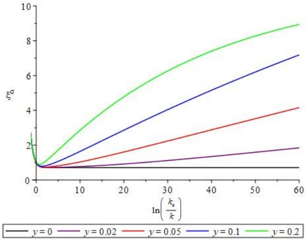
$$\begin{aligned} \partial_z^2\,U^\sigma{}_l + 3\,\partial_z U^\sigma{}_l + e^{-2z}\,U^\sigma{}_l + 6\,y\,U^s{}_l + 2\,y\,\partial_z U^s{}_l &= 0 \\ \partial_z^2\,U^s{}_l + 3\,\partial_z U^s{}_l + e^{-2z}\,U^s{}_l - 2\,y^2\,U^s{}_l - 2\,y\,\partial_z U^\sigma{}_l &= 0. \end{aligned} \tag{10}$$

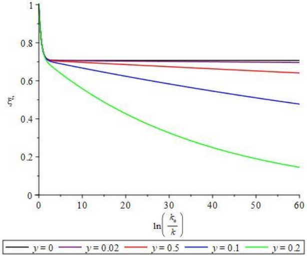
Initilisation ansatz: $z \to -\infty$, modes are decoupled, unaffected by the field-space curvature induced mixing.

$$U^{(\sigma,s)}_{initial} = \frac{H}{\sqrt{k^3}}\,\frac{\sqrt{\pi}}{2}\,e^{-(\frac{3}{2}z)}\,H_{\frac{3}{2}}(z) \tag{11}$$

[9] Phys. Rev. D **63** (2000), 023506 [arXiv:astro-ph/0009131 [astro-ph]]

Perturbation Dynamics - Plots



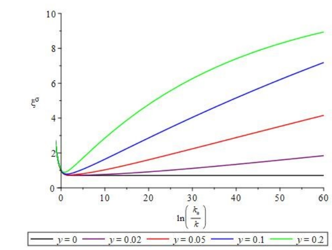


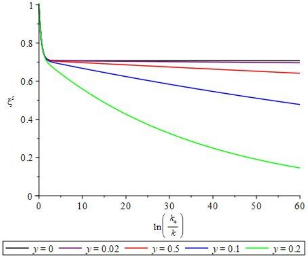
$\Rightarrow$ As y increases, the modes reach their respective asymptote faster

$$\downarrow$$

$$n_s^{ad} = 1 + \frac{d \ln[\mathcal{P}_\sigma]}{d(\ln k)} \rightarrow \text{unobservable : Constraint } y < 1.$$

Perturbation Dynamics - Plots



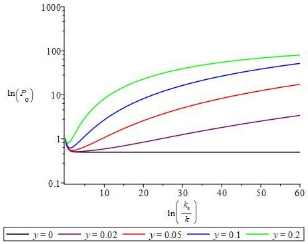


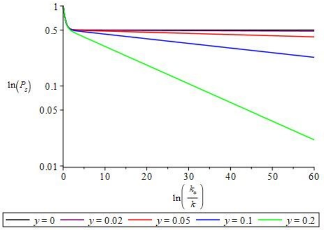
$\Rightarrow$ As y increases, the modes reach their respective asymptote faster

$$\downarrow$$

$$n_s^{ad} = 1 + \frac{d\ln[\mathcal{P}_\sigma]}{d(\ln k)} \rightarrow \text{unobservable : Constraint } y < 1.$$

$\Rightarrow$ Power Spectrum: $\mathcal{P}_\sigma = \frac{k^3}{2\pi^2}|U|^2, \qquad \mathcal{P}_s = \frac{k^3}{2\pi^2}|V|^2.$

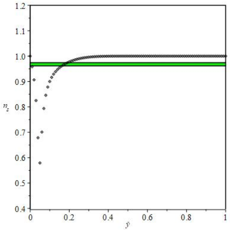




Observational Constraints

$\Rightarrow$ Measured[10] value of adiabatic perturbations spectral index:

$$n_s = 0.968 \pm 0.006$$
$$\downarrow$$
$$0.8 \times 10^{-2} \leq y \leq 10^{-2} \ \&$$
$$0.16 \leq y \leq 0.19.$$



[10] Astron. Astrophys. **594** (2016), A13[arXiv:1502.01589 [astro-ph.CO]].

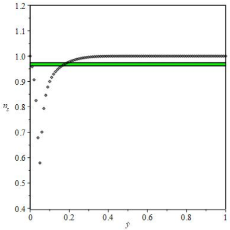
Observational Constraints

⇒ Measured[10] value of adiabatic perturbations spectral index:

$$n_s = 0.968 \pm 0.006$$

$$\downarrow$$

$$0.8 \times 10^{-2} \leq y \leq 10^{-2} \ \& \ 0.16 \leq y \leq 0.19.$$



⇒ The tensor-to-scalar ratio:

$$r_* = \frac{\Delta_t^2(k)}{\Delta_s^2(k)} = \frac{4\,M_H^2}{M_p^2}\,\frac{9+y^2}{< |U_k|^2 >} \qquad (12)$$

Observational bound[10], $r < 0.10$. Numerically, $|U_k|^2 < 50$

$$\downarrow$$

$$\frac{M_H^2}{M_p^2}\,p < \frac{5}{12}. \qquad (13)$$

[10] Astron. Astrophys. **594** (2016), A13[arXiv:1502.01589 [astro-ph.CO]].

Observational Constraints

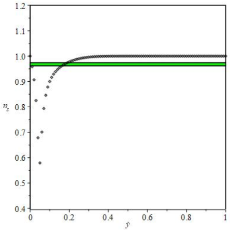
$\Rightarrow$ Measured[10] value of adiabatic perturbations spectral index:

$$n_s = 0.968 \pm 0.006$$

$$\downarrow$$

$$0.8 \times 10^{-2} \leq y \leq 10^{-2} \;\&$$

$$0.16 \leq y \leq 0.19.$$



$\Rightarrow$ The tensor-to-scalar ratio:

$$r_* = \frac{\Delta_t^2(k)}{\Delta_s^2(k)} = \frac{4\,M_H^2}{M_p^2}\,\frac{9+y^2}{<|U_k|^2>} \qquad (12)$$

Observational bound[10], $r < 0.10$.
Numerically, $|U_k|^2 < 50$

$$\downarrow$$

$$\frac{M_H^2}{M_p^2}\,p < \frac{5}{12}. \qquad (13)$$

Permitted values for ϵ:

$$\epsilon = \frac{M_H^2}{2M_p^2}\left[x^2 + y^2\right] = \frac{3\,M_H^2}{2\,M_p^2}\,p < 5/8 \qquad (14)$$

[10] Astron. Astrophys. **594** (2016), A13[arXiv:1502.01589 [astro-ph.CO]].

Observational Constraints

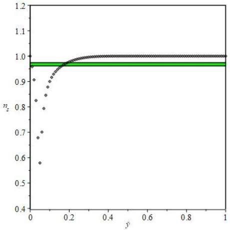
⇒ Measured[10] value of adiabatic perturbations spectral index:

$$n_s = 0.968 \pm 0.006$$

$$\downarrow$$

$$0.8 \times 10^{-2} \leq y \leq 10^{-2} \ \&$$

$$0.16 \leq y \leq 0.19.$$



⇒ The tensor-to-scalar ratio:

$$r_* = \frac{\Delta_t^2(k)}{\Delta_s^2(k)} = \frac{4\,M_H^2}{M_p^2}\,\frac{9+y^2}{<|U_k|^2>} \qquad (12)$$

Observational bound[10], $r < 0.10$.
Numerically, $|U_k|^2 < 50$

$$\downarrow$$

$$\frac{M_H^2}{M_p^2}\,p < \frac{5}{12}. \qquad (13)$$

Permitted values for ϵ:

$$\epsilon = \frac{M_H^2}{2M_p^2}\left[x^2 + y^2\right] = \frac{3\,M_H^2}{2\,M_p^2}\,p < 5/8 \qquad (14)$$

⇒ Direct contradiction with the "Swampland" deSitter conjecture: $\epsilon \approx 1$.
Hyperinflation still stuck in the Swampland

[10] Astron. Astrophys. **594** (2016), A13[arXiv:1502.01589 [astro-ph.CO]].

Motivation for Further Work

- Background & Perturbation dynamics: ✓

Motivation for Further Work

- Background & Perturbation dynamics: ✓
- Cosmological Impliations: ✓

Motivation for Further Work

- Background & Perturbation dynamics: ✓
- Cosmological Impliations: ✓
- 2- & Higher point functions : ?

Motivation for Further Work

- Background & Perturbation dynamics: ✓
- Cosmological Impliations: ✓
- 2- & Higher point functions : ?

  $\Downarrow$

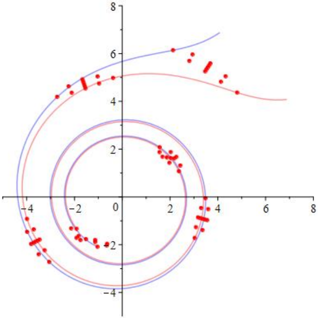
  I-R limit: Stochastic Hyperinflation!

Motivation for Further Work

- Background & Perturbation dynamics: ✓
- Cosmological Impliations: ✓
- 2- & Higher point functions : ?

  $\Downarrow$

  I-R limit: Stochastic Hyperinflation!
  Non-Gaussian Signature ...



Thank you for your attention!