Thermal Inflation with an Inflaton Mass Coupled to a Light Auxiliary Scalar Field

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LANCASTER UNIVERSITY

Outline

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  - T_1: When T of thermal bath $\sim V_0^{\frac{1}{4}}$ of thermal inflation potential
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- Solves the moduli problem

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ϕ: Drives thermal inflation: Inflaton

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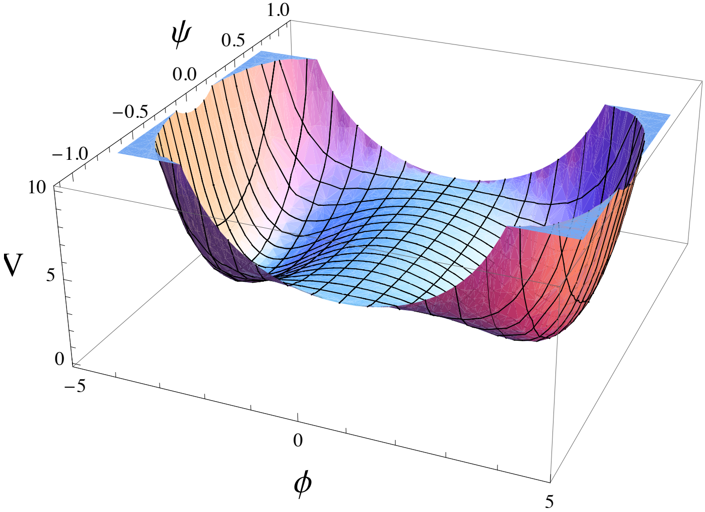
$$V(\phi, T, \psi) = V_0 + (g^2 T^2 - \frac{1}{2}m^2)\phi^2 + \lambda_n \frac{\phi^{2n+4}}{M_{Pl}^{2n}} + \frac{1}{2}m_\psi^2\psi^2$$

where

$$m^2 \equiv m_0^2 - 2h_\alpha^2 \frac{\psi^{2\alpha}}{M_{Pl}^{2\alpha-2}}$$

$$\alpha, n \geq 1$$



Arbitrary Units

T_1 and T_2

From

$$\rho_r = \frac{\pi^2}{30} g_* T^4$$

we obtain

$$T_1 \sim V_0^{\frac{1}{4}}$$

$$T_2 = \frac{m}{\sqrt{2}g}$$

Other Quantities

$$\langle\phi\rangle = \left(\frac{mM_{Pl}^{n}}{\sqrt{(2n+4)\lambda_n}}\right)^{\frac{1}{n+1}}$$

$$V_0 = \frac{n+1}{(2n+4)^{\frac{n+2}{n+1}}}\left(\frac{m_0^{2n+4}M_{Pl}^{2n}}{\lambda_n}\right)^{\frac{1}{n+1}} \qquad (V = 0 \text{ at the VEV})$$

$$H_{TI} \sim \frac{\sqrt{n+1}}{\sqrt{2n+4}^{\frac{n+2}{n+1}}}\left(\frac{m_0^{n+2}}{\sqrt{\lambda_n}M_{Pl}}\right)^{\frac{1}{n+1}}$$

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δN Formalism

$$\zeta = \delta N = \frac{dN}{dm}\delta m + \frac{1}{2!}\frac{d^2 N}{dm^2}\delta m^2 + \frac{1}{3!}\frac{d^3 N}{dm^3}\delta m^3 + \ldots$$

Therefore we obtain, to 3rd order

$$\zeta = \delta N = \frac{1}{\pi}\frac{\alpha H_* h_\alpha^2 \psi_*^{2\alpha-1}}{m^2 M_{Pl}^{2\alpha-2}} + \frac{1}{2\pi^2}\left(\frac{\alpha H_* h_\alpha^2 \psi_*^{2\alpha-1}}{m^2 M_{Pl}^{2\alpha-2}}\right)^2 + \frac{1}{3\pi^3}\left(\frac{\alpha H_* h_\alpha^2 \psi_*^{2\alpha-1}}{m^2 M_{Pl}^{2\alpha-2}}\right)^3$$

where we have used

$$\delta\psi_* = \frac{H_*}{2\pi}$$

as the most probable value of $\delta\psi_*$

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From N'' and N'^2 we obtain simply

$$f_{NL} = \frac{5}{6}$$

Constraining the Free Parameters

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- Taking the observed value

$$\mathcal{P}_\zeta^{\frac{1}{2}} = 4.9 \times 10^{-5}$$

we obtain, to 1st order, the constraint

$$\frac{\alpha H_* h_\alpha^2 \psi_*^{2\alpha-1}}{m^2 M_{Pl}^{2\alpha-2}} \sim 10^{-4}$$

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Therefore, we require

$$m_\psi \ll H_*$$

and

$$\sqrt{4\alpha^2 - 2\alpha}\, h_\alpha \phi_* \left(\frac{\psi_*}{M_{Pl}}\right)^{\alpha-1} \ll H_*$$

- Need $\delta\psi$ frozen at $\delta\psi_*$ as if perturbations unfroze, would oscillate and therefore effect on value of ψ during thermal inflation would drastically reduce. Therefore, we require

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- As ϕ interacts with thermal bath, ψ and Standard Model fields and given that we have not observed ϕ particles, we require

$$m \gtrsim 1 \text{ TeV}$$

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  Bunch-Davies value:

$$\phi_* \sim \left(\frac{M_{Pl}^{2n} H_*^4}{\lambda_n} \right)^{\frac{1}{2n+4}}$$

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ϕ_*

- **Light ϕ with SUGRA corrections**

$$\Delta V \sim H_*^2 \phi_*^2$$

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$$\Delta V \sim H_*^2 \phi_*^2$$

$$m_{\phi,eff} \ll H_*$$

gives us just

$$m_0 \ll H_*$$

- m_0

$$
\left.\begin{array}{rl}
10^3 & \lesssim \\
\dfrac{10^{-\frac{3(n+1)}{n+2}}\sqrt{2n+4}}{\sqrt{n+1}^{\frac{n+1}{n+2}}}\left(\sqrt{\lambda_n}M_{Pl}\right)^{\frac{1}{n+2}} & \lesssim \\
100\sqrt{\alpha}h_\alpha \dfrac{H_*^\alpha}{M_{Pl}^{\alpha-1}} & \ll
\end{array}\right\} m_0 \left\{\begin{array}{ll}
< & g\sqrt{M_{Pl}H_*} \\
< & \left(\dfrac{g^{2n+2}}{\sqrt{\lambda_n}}\right)^{\frac{1}{n}} M_{Pl} \\
\ll & H_*
\end{array}\right.
$$

- ψ_*

$$H_* \ll \psi_* \ll 10^4 \alpha H_*$$

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- h_α

$$\frac{1}{\sqrt{4\alpha^2 - 2\alpha}} \frac{m_0 M_{Pl}^{\alpha-2}}{\psi_*^{\alpha-1}} < h_\alpha \ll \frac{1}{\sqrt{4\alpha^2 - 2\alpha}} \frac{m_0 M_{Pl}^{\alpha-1}}{\psi_*^{\alpha}}$$

- H_{TI}

$$\left.\begin{array}{r} 10^{-3} \lesssim \\ \dfrac{10^{\frac{3(n+2)}{n+1}}\sqrt{n+1}}{\sqrt{(2n+4)^{n+2}\lambda_n}^{\frac{1}{n+1}}}\dfrac{1}{M_{Pl}^{\frac{1}{n+1}}} \lesssim \end{array}\right\} H_{TI} \left\{\begin{array}{l} \lesssim H_* \\ \lesssim \dfrac{\sqrt{n+1}}{\sqrt{2n+4}^{\frac{n+2}{n+1}}}\left(\dfrac{(g\sqrt{H_*})^{n+2}\sqrt{M_{Pl}}^{n}}{\sqrt{\lambda_n}}\right)^{\frac{1}{n+1}} \\ \lesssim \dfrac{\sqrt{n+1}}{\sqrt{2n+4}^{\frac{n+2}{n+1}}}\left(\dfrac{g^4}{\lambda_n}\right)^{\frac{1}{n}} M_{Pl} \\ \ll \dfrac{\sqrt{n+1}}{\sqrt{2n+4}^{\frac{n+2}{n+1}}}\left(\dfrac{H_*^{n+2}}{\sqrt{\lambda_n}}M_{Pl}\right)^{\frac{1}{n+1}} \end{array}\right.$$

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We have investigated parameter space assuming that ψ was in Bunch-Davies vacuum state prior to primordial inflation, i.e. the most probable value for ψ_* is

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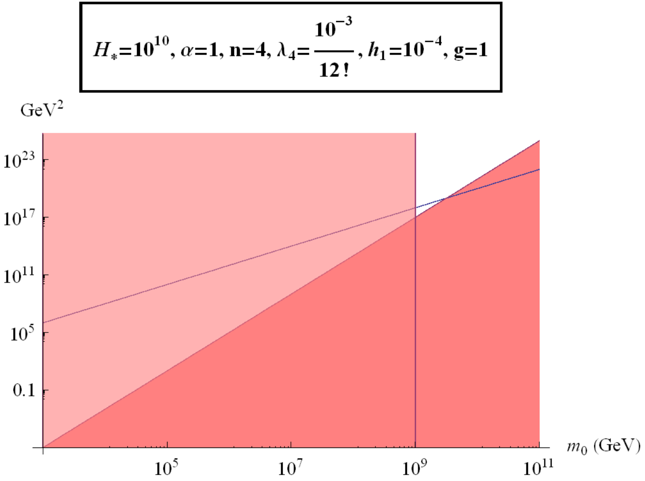
This yields a constraint on m_ψ

$$\frac{10^{-4} H_*}{\alpha} \ll m_\psi \ll H_{TI}$$

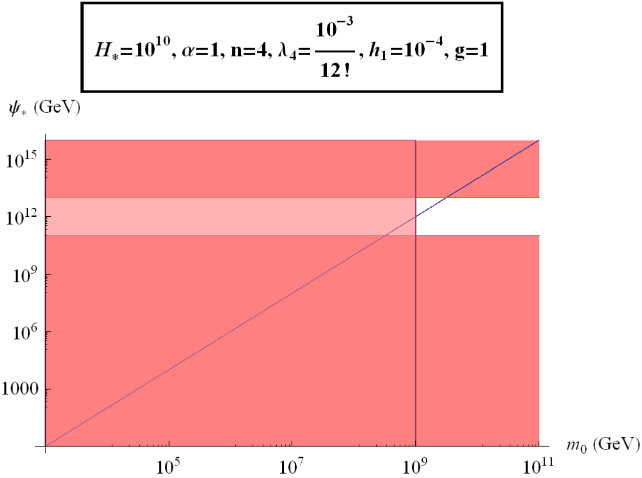
Parameter Space

$m_0 \gg$ Interaction Term



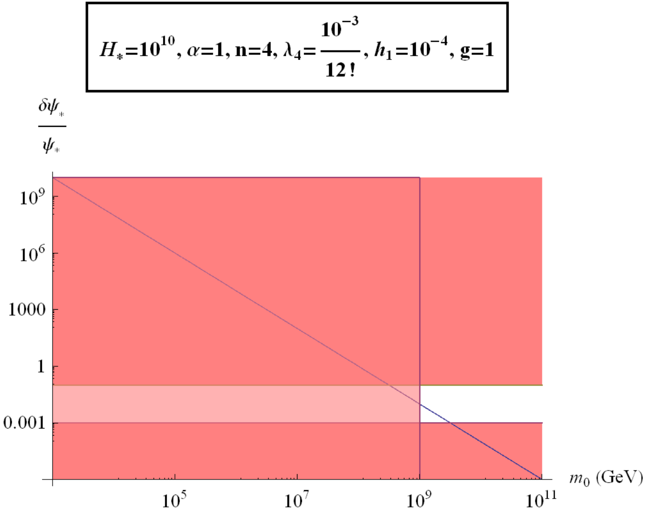
Parameter Space

ψ_*



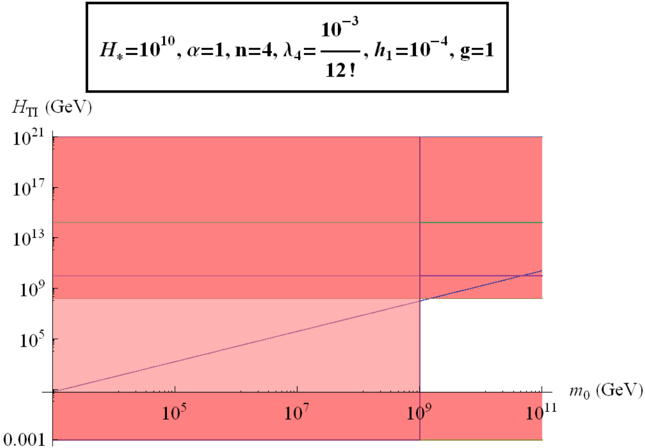
Parameter Space

$\frac{\delta\psi_*}{\psi_*}$



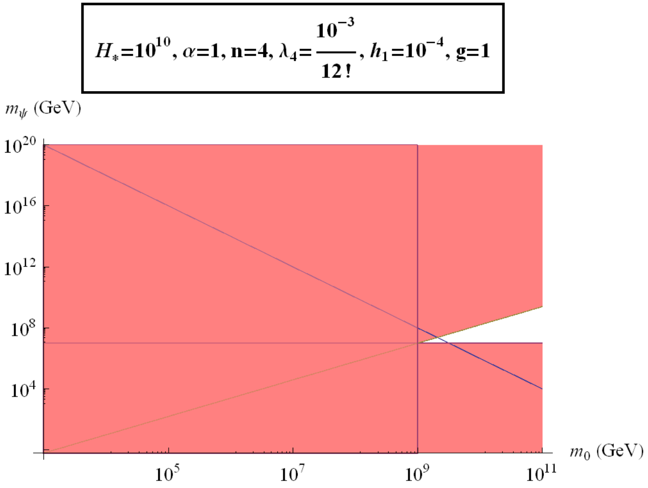
Parameter Space

H_{TI}



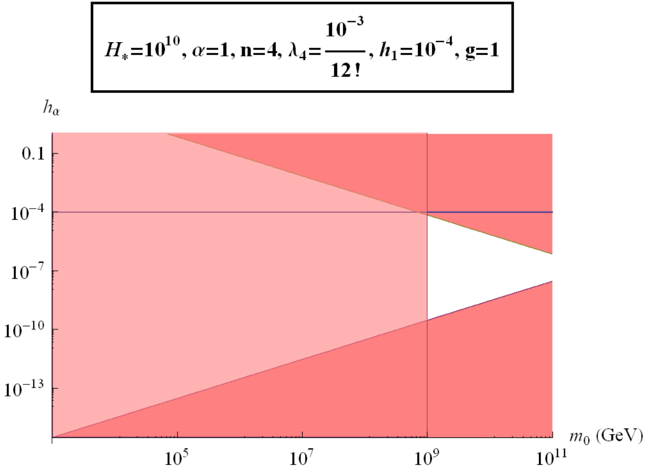
Parameter Space

m_ψ



Parameter Space

h_α



Parameter Space

Prediction of Model

Parameter	Value
α	1
n	4
g	$\sim 10^{-2} - 1$
h	$\sim 10^{-4}$
λ_4	$\sim \frac{10^{-3}}{12!}$
m_0	$\approx 1.5 \times 10^9$ GeV
H_*	10^{10} GeV

Parameter Space

Prediction of Model

Quantity	Value
m_ψ	4.4×10^7 GeV
ψ_*	2.3×10^{12} GeV
$\frac{\delta\psi_*}{\psi_*}$	4.4×10^{-3}
$\langle\phi\rangle$	4.0×10^{17} GeV
T_1	2.0×10^{13} GeV
T_2	$\sim 10^9 - 10^{11}$ GeV
H_{TI}	1.6×10^8 GeV
N_{TI}	$5.2 - 9.8$

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- *Paper in preparation*

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- Maybe look at other potentials/general potential for auxiliary field

Thank you

Any questions?

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