Cosmic Inflation Meets Particle Physics

Phys.Lett.B679:428-432, 2009
Antusch, Bastero-Gil, Dutta, King, Kostka
Phys.Lett.B677:221-225, 2009
Antusch, Dutta, Kostka
JCAP 0901:040, 2009
Antusch, Bastero-Gil, Dutta, King, Kostka

and some ongoing work ....

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MPI Project Review
December 15th 2009

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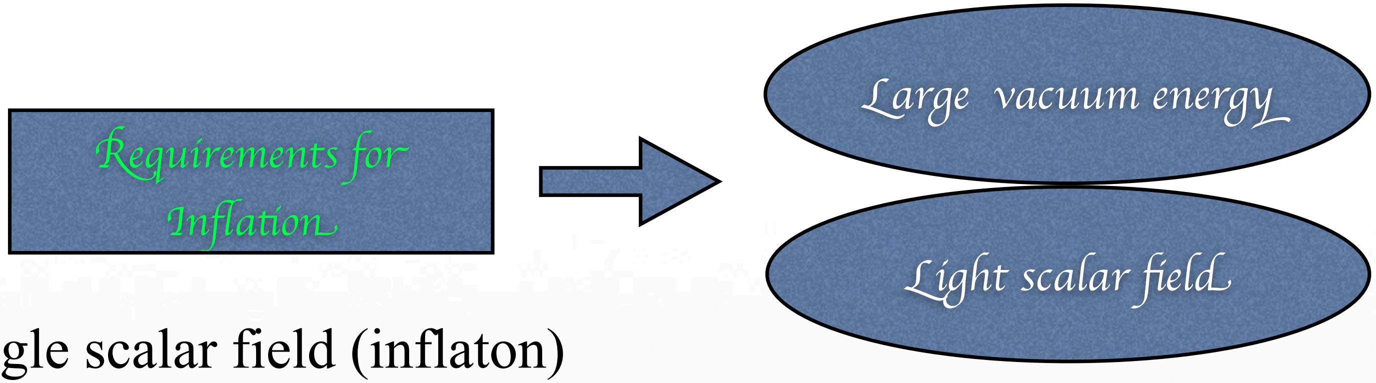
Prologue: Liberating Inflaton



Requirements for Inflation

Large vacuum energy

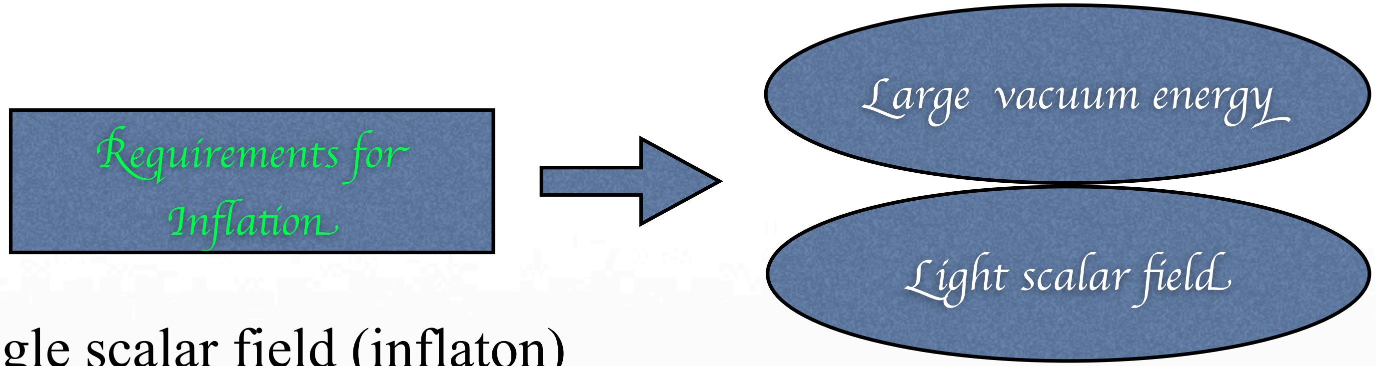
Light scalar field

Single scalar field (inflaton)
usually plays the role for both

Alternatives (phenomenological): Curvaton, modulated reheating etc

$m_\phi \sim H$

Prologue: Liberating Inflaton



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Alternatives (phenomenological): Curvaton, modulated reheating etc

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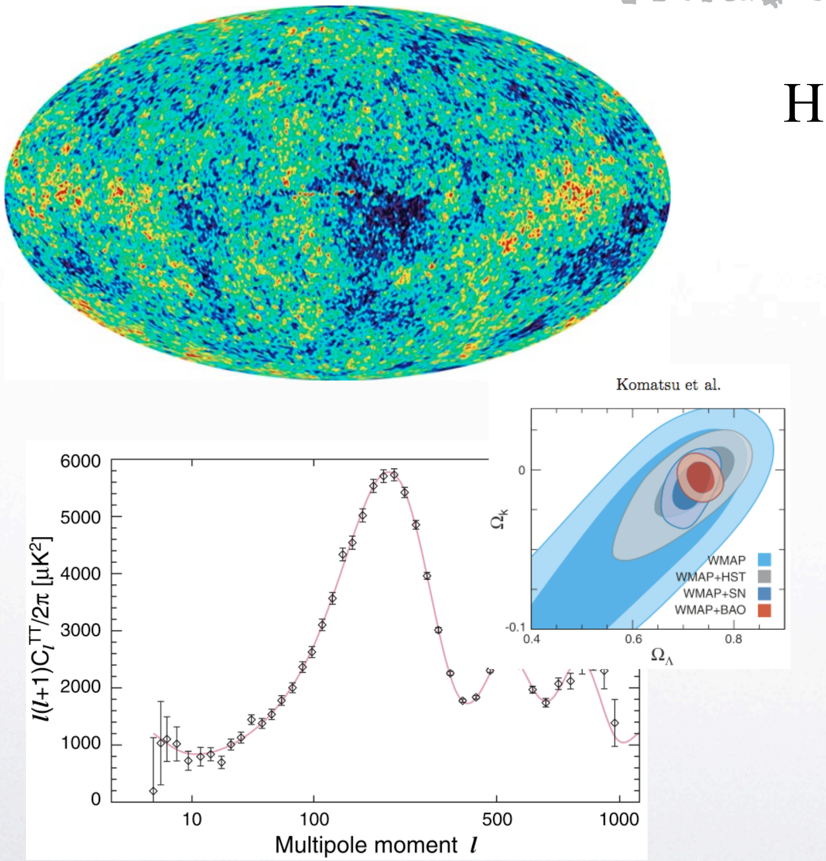
Alternative (model building): Vacuum energy contribution comes from the F-term of a non-inflaton field

What we know ..



Homegneous and isotropic $\Delta T/T \sim 10^{-5}$

Horizon problem

Spatially flat $-0.0178 < \Omega_k < 0.0066$

$$\frac{k}{H^2a^2} = \Omega - 1$$

Flatness problem

How to solve ..

Accelerated growth of scale factor → *INFLATION*

Guth, Linde, Starobinsky

Generic predictions:

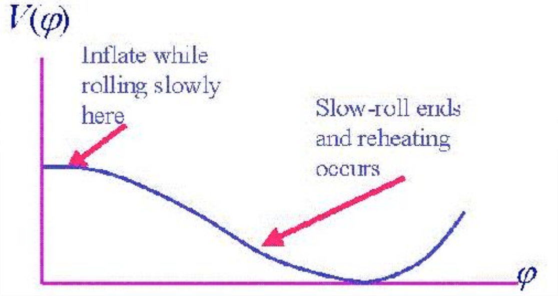
- Isotropy and Homogeneity
- Spatial flatness
- Absence of cosmological relics
- Perturbations from quantum perturbations

Model dependent prediction:

- Statistical properties of perturbations

Inflation 101

Canonical scalar field with $V(\phi) >> \frac{1}{2}\dot{\phi}^2$



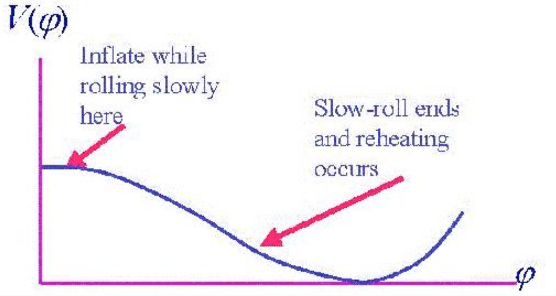
$$P = \frac{1}{2}\dot{\phi}^2 - V(\phi) \simeq -V(\phi)$$

$$\rho = \frac{1}{2}\dot{\phi}^2 + V(\phi) \simeq V(\phi)$$

$$\Rightarrow \quad P \simeq -\rho$$

Requirement for accelerated expansion: $P < -\frac{1}{3}\rho$

Inflation 101



Slow-roll parameters:

$\epsilon = M_P^2(V'/V)^2$ $\quad$ $\eta = M_P^2(V''/V)$

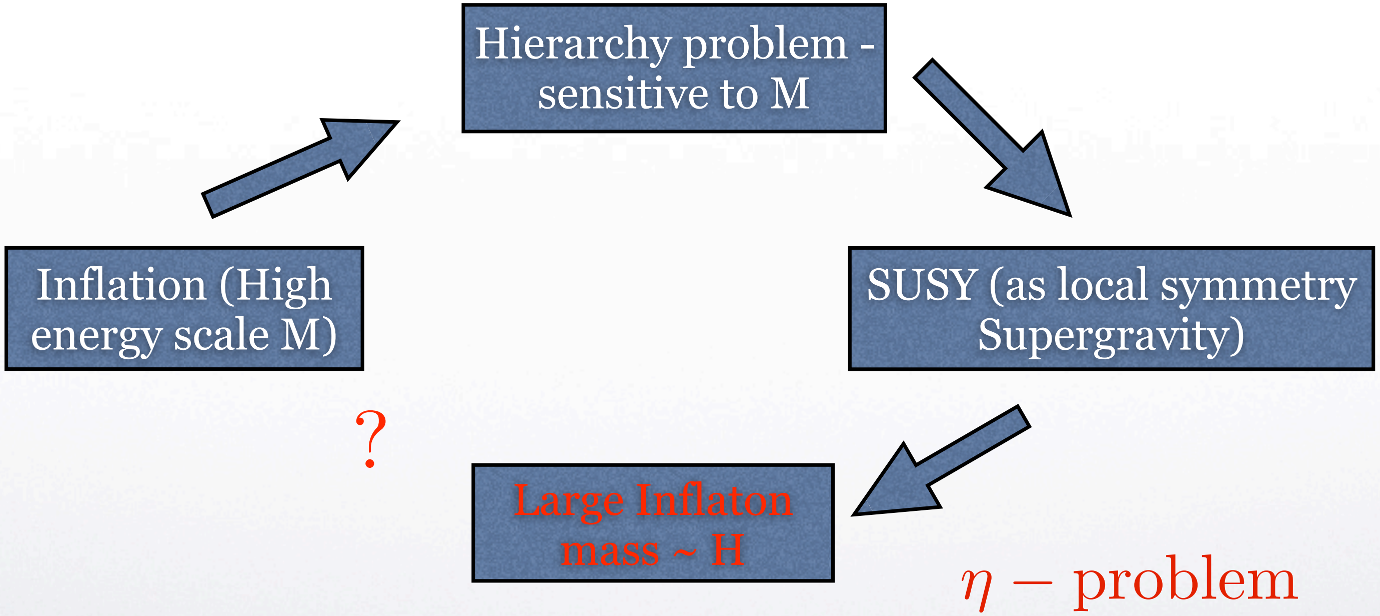
$m_\phi << H_{inf}$ $\quad$ $H^2 = \frac{1}{3M_P^2}(V(\phi) + \frac{1}{2}\dot{\phi}^2)$

Curvature perturbations: $P_{\mathcal{R}}^{1/2} = \frac{1}{2\sqrt{3}\pi}\frac{V^{3/2}}{|V'|}$

Scalar spectral index: $n_s = 1 - 6\epsilon + 2\eta$

WMAP 5 data: $n_s = 0.96 \pm 0.015$

connection to particle physics ..



Hierarchy problem - sensitive to M

SUSY (as local symmetry Supergravity)

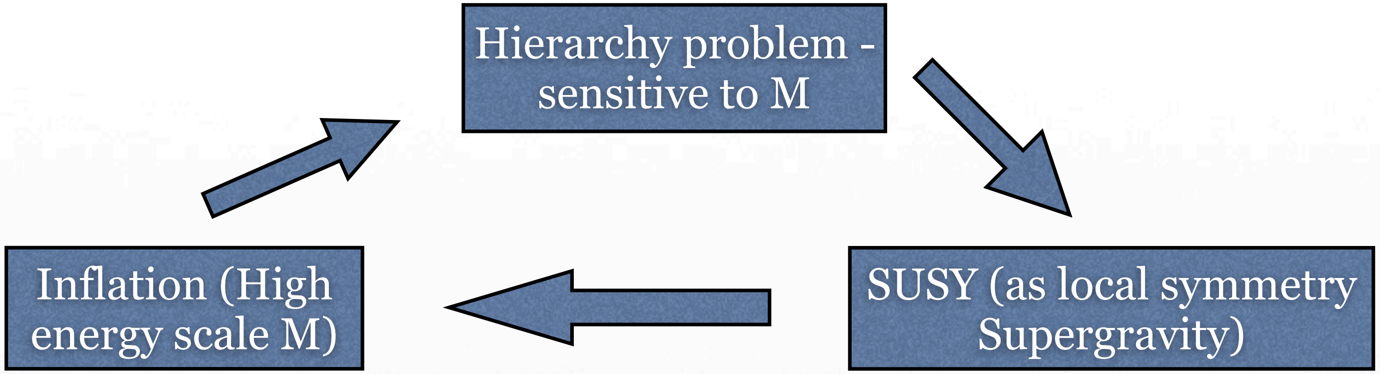
Large Inflaton mass ~ H

Inflation (High energy scale M)

?

$\eta - \text{problem}$

connection to particle physics ..



Hierarchy problem - sensitive to M

SUSY (as local symmetry Supergravity)

Inflation (High energy scale M)

η - problem in SUGRA

SUSY models must be incorporated in local SUSY theory

Superpotentail W → $W +$ Kahler potential K

$$V = e^{K/M_P^2}[K^{i\bar{j}} D_i W D_{\bar{j}} W^* - \frac{3}{M_P^2}|W|^2] \qquad D_i W = W_i + W K_i$$

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Model independent

$$V(\phi) = e^{K(\phi)/M_P^2} V_0 \sim V_0(1 + \frac{\phi^2}{M_P^2} + ..) \sim V_0 + 3H^2\phi^2 \Rightarrow \eta \sim 1 \qquad m_\phi \sim H$$

$$K \sim \phi^2$$

Copeland, Liddle, Lyth, Stewart, Wands; Dine, Randall, Thomas

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Model dependent

$$K^{i\bar{j}} D_i W D_{\bar{j}} W^* - 3|W|^2$$

Example: Brane inflation *Kachru et.al (2003)* $\eta = 2/3$

ways to move ..

$$V = e^{K/M_P^2}[K^{i\bar{j}}D_iWD_{\bar{j}}W^* - \frac{3}{M_P^2}|W|^2]$$

ϕ inflaton field and S noninflaton field

Conditions: $W = W_\phi = 0$ $W_S \neq 0$

Stewart (94)

Antusch, Bastero-Gil, K.D, King, Kostka (08)

$$\Downarrow$$

$$D_\phi \to 0 \qquad D_S \to W_S$$

$$\Downarrow$$

$$V = e^K K^{S\bar{S}}|W_S|^2$$

Vacuum energy not from inflaton F-term

Impose symmetry on Kahler potential - tree level flat inflaton potential

(explicit models later)

Avenues

- Specific choice of Kahler potential (*Murayama, Suzuki, Yanagida, Yokoyama*)

$$K = \frac{3}{8}\eta + \eta^2 \qquad\qquad \eta = T + T^* + \phi_i^* \phi^i$$

  Tuning of parameters

- Symmetry requirement of Kahler potential

  - Shift symmetry (*Kawasaki, Yamaguchi, Yanagida; Brax and Martin*)

$$\Phi \to \Phi + iCM_P \Longrightarrow K = K(\Phi + \Phi^*) \quad Im(\Phi) \text{ is inflaton}$$

  - Heisenberg symmetry (*Gaillard, Murayama, Olive*)

$$K = f(\rho) \qquad\qquad \rho = T + T^* - |\Phi|^2$$

more discussions later ...

Interval

- Generic SUGRA contributions can be controlled by symmetry
- Model dependent contributions are plagued with coupling between inflaton and moduli sectors *Brax, van de Bruck, Davis, Davis ('06)*
- Dynamics needs to be checked carefully

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Introduce Tribrid Inflation

Framework: 'Tribrid Inflation'

- Introduce an extra chiral field S - 'spectator' field
  Vacuum energy for inflation $F_S = W_S \neq 0$

- $F_i = W_i = 0$ $(i = \Phi, H)$ Stewart

  inflaton water-fall

- During inflation $W = 0$

- An example: $W = \kappa S(H^2 - M^2) + g(\Phi, H)$

  $V = |F_S|^2 = \kappa^2 M^4$ ~ constant

Antusch, Bastero-Gil, K.D, King, Kostka

Comparison

'Standard' Hybrid

$$W = \kappa\Phi(H^2 - M^2)$$

Vacuum energy $\sim |F_\Phi|^2$

During inflation $W \neq 0$

Tribrid

$$W = \kappa S(H^2 - M^2) + g(\Phi, H)$$

Vacuum energy $\sim |F_S|^2$

During inflation $W = 0$

e.g. (s)neutrino inflation

$$g(\Phi, H) = \frac{\lambda}{M_*}\Phi^2 H^2$$

Antusch, Bastero-Gil, King, Shafi

‘Tribrid’ reduces couplings

An example calculation:

$$V_F = e^{\mathcal{K}}[M^4 + V_2(T)|W_{inf}|^2 + 2Re(V_1(T)W^*_{inf}) + V_S(T)]$$

Brax, van de Bruck, Davis, Davis (‘06)

Imposing $W_{inf} = 0$ reduces several problematic couplings

Main source of problem $|W_{inf} + W(T)|^2 \rightarrow |W(T)|^2$

Realizations

- Shift symmetry `Antusch, K.D, Kostka`

  Heisenberg symmetry `Antusch, Bastero-Gil, K.D, King, Kostka`

- Symmetry breaking term in the Superpotential provides necessary slope

- Associated modulus with Heisenberg symmetry is stabilized by large vacuum energy during inflation

  - coupling between modulus and spectator field S is important

with Heisenberg symmetry

Heisenberg symmetry protects flat directions from generic SUGRA corrections   Gaillard, Murayama, Olive ('95)   Gaillard, Lyth, Murayama ('98)

$\delta T = \epsilon_i^* \phi^i, \qquad \delta \phi^i = \epsilon^i$ Binetruy, Gaillard ('87)

Invariant combinations: $\rho = T + T^* - |\phi|^2$

Impose symmetry: $K = f(\rho)$

Special case: $K = -3 \; ln \; \rho$ No scale form

An example

$$W = \kappa S(H^2 - M^2) + \frac{\lambda}{M_*}\phi^2 H^2$$

Vacuum energy from $F_S \neq 0$

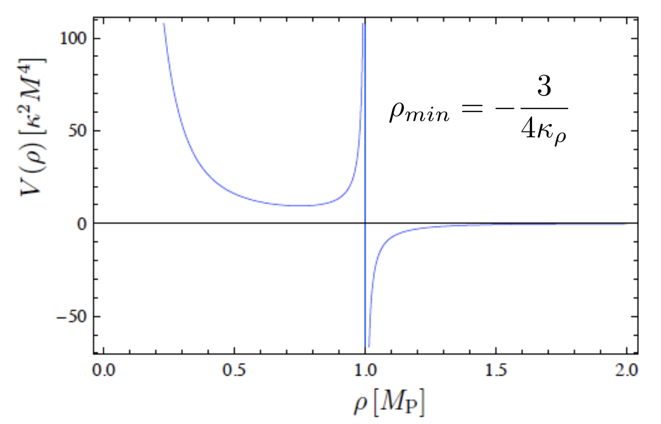
$W_{inf} = 0$

$$K = |H|^2 + (1 + \kappa_s |S|^2 + \kappa_\rho \rho)|S|^2 + f(\rho)$$

During inflation S = H = 0

Antusch, Bastero-Gil, K.D, King, Kostka

$$\boxed{V_{tree}(S = H = 0) = \kappa^2 M^4 \frac{e^{f(\rho)}}{1 + \kappa_\rho \rho}}$$



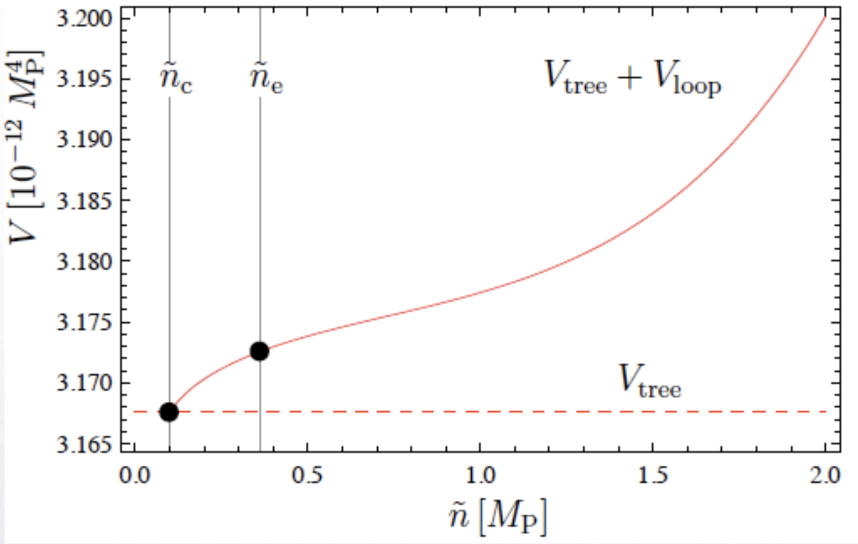
tree-level $m_\phi = 0$

$m_H, m_S >> H$ during inflation

Loop potential

$\phi^2 H^2$ in superpotential breaks the symmetry

Only H mass contributes to the loop potentials

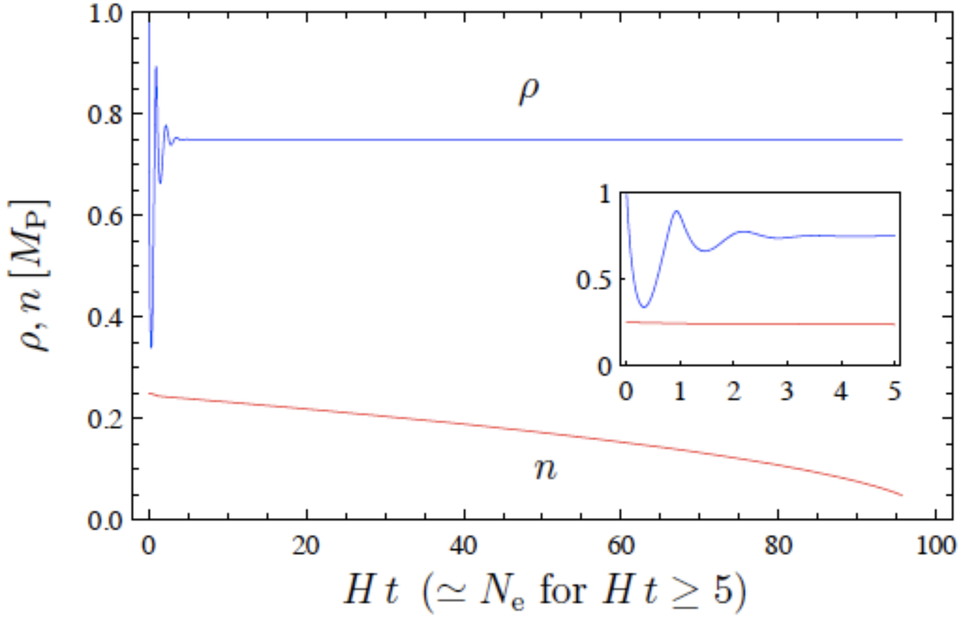


$\kappa = 0.05, \quad \lambda/M_* = 0.2$

$\epsilon << \eta$ and η negative

Dynamics of the fields

Non-minimal kinetic terms



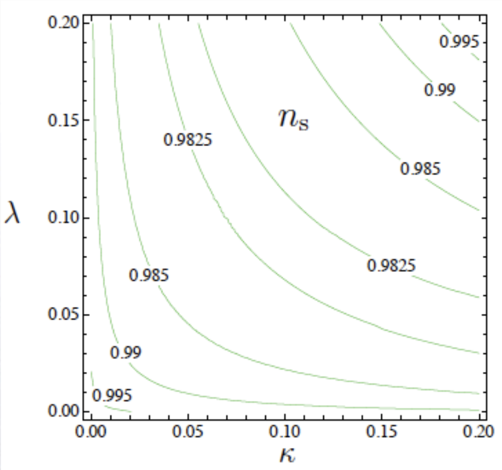
$$V(n,\rho) = V_{tree}(\rho) + V_{loop}(n,\rho)$$

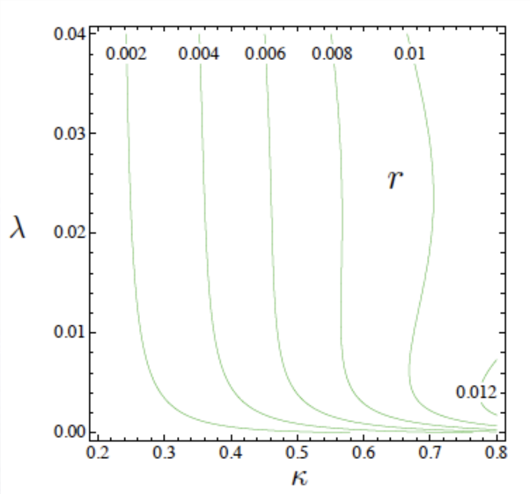
Predictions

$\kappa = 0.05, \quad \lambda/M_* = 0.2$ Similar to standard hybrid models

$M \simeq 3 \ \times 10^{-3} \ M_P$ $n_s \simeq 0.98$

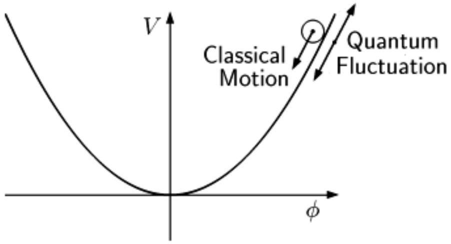
$r \simeq 10^{-4}$ $\dfrac{dn_s}{d \ ln \ k} \simeq -10^{-3}$





Chaotic Inflation

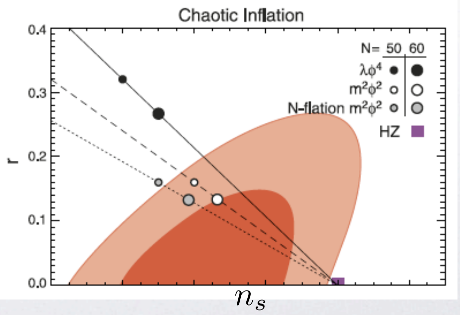
$$V(\phi) = \frac{1}{2} m^2 \phi^2$$



$$\epsilon = M_P^2 (V'/V)^2$$

$$\eta = M_P^2 (V''/V)$$

- Large field models of inflation $\Delta\phi \sim M_P$
- 'Possibly' observable tensor perturbations - *Lyth*
- In good agreement with WMAP
  5-year data



Komatsu et.aL

Framework

Heisenberg Symmetry $\rho = T + T^* - |\Phi|^2$

Antusch, Bastero-Gil, K.D, King, Kostka

Modulus Inflaton

$W = M\Phi X$ $K = (1 + \kappa_X |X|^2 + \kappa_\rho \rho)|X|^2 + f(\rho)$

F-term of the X field contributes to the vacuum energy

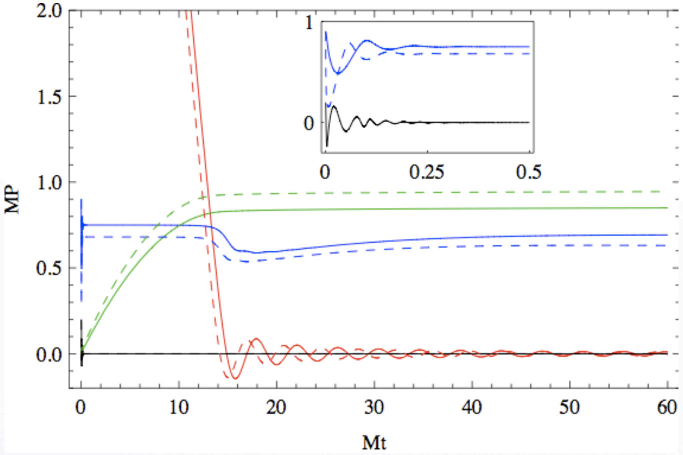
X = 0 during inflation

$$V_F = \frac{M^2|\phi|^2}{\rho^3(1+\kappa_\rho \rho)}$$

Tree level potential is NOT flat

$m_\rho^2 \sim |W_X|^2$ $m_\phi \sim M << H$

Dynamics of the fields



$$\ddot{x} + 3\,H\,\dot{x} + \frac{1}{(1+\kappa_\rho \rho)}\,(\kappa_\rho\,\dot{\rho}\,\dot{x} + V_x) = 0$$

$$\ddot{\varphi} + 3\,H\,\dot{\varphi} - \frac{1}{\rho}\,\dot{\rho}\,\dot{\varphi} + \frac{\rho}{3}\,V_\varphi = 0$$

$$\ddot{\rho} + 3\,H\,\dot{\rho} - \frac{1}{\rho}\,\dot{\rho}^2 + \dot{\varphi}^2 - \frac{\kappa_\rho}{3}\,\rho^2\,\dot{x} + \frac{2}{3}\,\rho^2\,V_\rho = 0$$

Predictions:

$n_s \sim 1 - 2/N \sim 0.97$

$r \sim 8/N \sim 0.13$

Loop corrections negligible and only mass renormalization

GUT model (in progress)

Goal: Construction of a SUSY model where inflaton is NOT a gauge singlet

Outline: Inflation happens along a D-flat direction when F-term dominates - Introduction of inflaton field in the conjugate representation also.

$$W = S(\frac{< X >}{\Lambda} H\bar{H} - M^2) + \frac{\lambda_{ij}}{\Lambda} R_i R_j \bar{H}\bar{H} + \frac{\gamma}{\Lambda}\bar{R}\bar{R}HH + \frac{\zeta_i}{\Lambda} R_i \bar{R} H\bar{H}$$

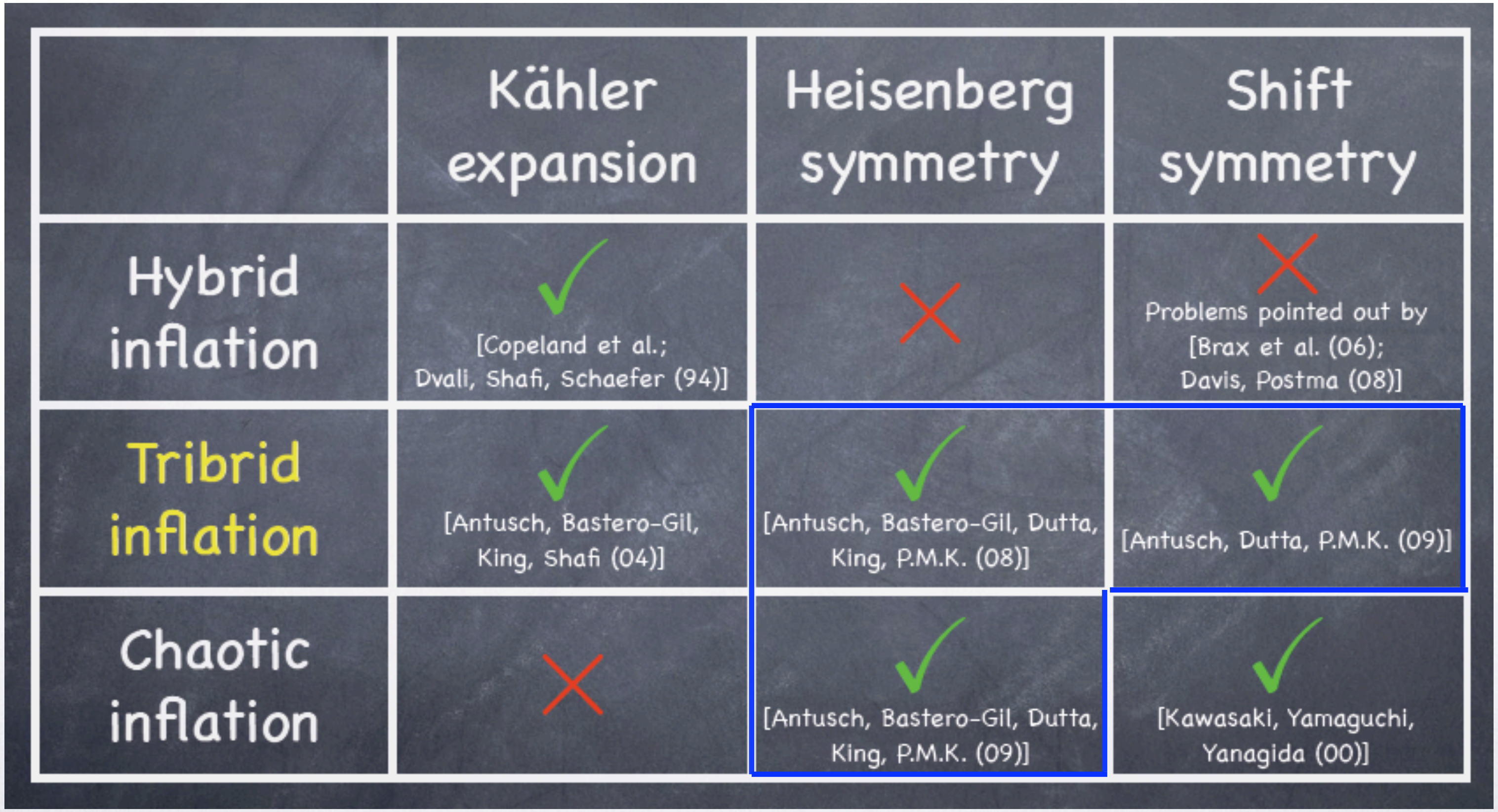
$$\Phi^2 H^2$$

Cosmic defects are not generated.

Two loop radiative mass corrections are suppressed

Dvali

Epilogue: Comparing Models



	Kähler expansion	Heisenberg symmetry	Shift symmetry
Hybrid inflation	✓ [Copeland et al.; Dvali, Shafi, Schaefer (94)]	✗	✗ Problems pointed out by [Brax et al. (06); Davis, Postma (08)]
Tribrid inflation	✓ [Antusch, Bastero-Gil, King, Shafi (04)]	✓ [Antusch, Bastero-Gil, Dutta, King, P.M.K. (08)]	✓ [Antusch, Dutta, P.M.K. (09)]
Chaotic inflation	✗	✓ [Antusch, Bastero-Gil, Dutta, King, P.M.K. (09)]	✓ [Kawasaki, Yamaguchi, Yanagida (00)]

Summary and Outlook

Embedding inflation model in SUGRA is a challenging task!

A new class of model, ‘Tribrid inflation’ has been introduced!

Particular realizations with Heisenberg and Shift symmetry!

New class is tailor made for solving SUGRA problems for inflation!

Future work: GUT embedding
String theory realizations
Leptogenesis

Thank You