Gauge Non-Singlet Matter Inflation in Supergravity

Stefan Antusch

University of Basel
Department of Physics

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

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Outline

- Interesting solution to the η-problem in SUGRA inflation: Heisenberg symmetry with stabilised modulus

- New class of inflation models, very suitable for applying symmetry solutions to the η-problem: Tribrid Inflation

- New possibile connection to particle physics (application of 'Tribrid Inflation'): GNS Matter Inflation in Supergravity

- Novel possibility to realise inflation in the matter sector of string theories?

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Inflationary epoch in the early universe

- Requirements for “slow roll“ inflation

  → “Slow roll parameters” small: ε, $|\eta|$, ξ << 1, V ~ V_0 dominates

$$\epsilon = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2 , \quad \eta = M_P^2\left(\frac{V''}{V}\right) , \quad \xi = M_P^4\left(\frac{V'V'''}{V^2}\right)$$

“slope of V”　　　　“inflaton mass”

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The η-problem

- Challenge for realising inflation: Flat enough potential, $m_\phi << \mathcal{H}$

$$\mathcal{H} = \frac{\sqrt{V}}{\sqrt{3} M_P}$$

  - Generic (effective field theory)

$$V \subset V_0 \frac{\phi^\dagger \phi}{M_P^2} \Rightarrow m_\phi \sim \mathcal{H} \leftrightarrow \eta \sim 1$$

  - In supergravity (with K = $\phi^*\phi$ and V_0 from F-term)

$$V_F = \mathrm{e}^{K/M_P^2} \left(K^{i\bar{j}} D_i W \, D_{\bar{j}} W^* - \frac{3|W|^2}{M_P^2} \right)$$

$$V_F \sim \left(1 + \frac{\phi^\dagger \phi}{M_P^2} + \dots \right) V_0$$

with $D_i W := W_i + K_i W$

E.J Copeland, A.R. Liddle, D.H. Lyth, E.D. Stewart, D. Wands ('94)

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Approaches to solve the η-problem: 3 strategies

- Expansion of K in fields/M_P:

requires tuning of parameters! (at 1%-level)

$$K = |\phi|^2 + \frac{\lambda_\phi}{M_P^2}|\phi|^4 + \frac{\lambda_{\phi i}}{M_P^2}|\phi|^2|X_i|^2 + \ldots$$

- 'Shift' symmetry:

$$\phi \to \phi + i\alpha$$

$$K = f(\phi + \phi^*)$$

protects Im[ϕ] from obtaining a SUGRA mass by symmetry!

(used in many works ...)

- Heisenberg symmetry:

solves the η-problem for |ϕ| by symmetry!

$$T \to T + \mathrm{i}\,\beta\,, \quad T \to T + \alpha^*\,\phi + |\alpha|^2/2\,, \quad \phi \to \phi + \alpha$$

$$K = f(\rho)\,, \ \text{with} \quad \rho = T + T^* - |\phi|^2$$

Gaillard, Murayama, Olive ('95),
S.A., Bastero-Gil, Dutta, King, Kostka ('08,'09)

T: 'modulus field' → has to be stabilised

Approaches to solve the η-problem: 3 strategies

- Expansion of K in fields/M_P:

- 'Shift' symmetry:

- Heisenberg symmetry:

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Heisenberg symmetry solution to the η-problem

- Example for K:

$$K = -3 \ln \rho + |X|^2 + \kappa_\rho \frac{\rho |X|^2}{M_P} + \ldots, \text{ with } \quad \rho = T + T^* - |\phi|^2$$

Example: No-scale form; More general: f(ρ)

K invariant under Heisenberg symmetry

→ Field X: Provides the vacuum energy V_0 by $|F_X|^2$ during inflation

→ Consider suitable W with (i) $W_{inf} = 0$, $W_\phi = 0$ during inflation and (ii) which yields a tree-level ϕ-flat potential in global SUSY limit

→ Parameter κ_ρ: Couples ρ to V_0

S.A., M. Bastero-Gil, K. Dutta, S. F. King, P. M. Kostka ('08)

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Heisenberg symmetry solution to the η-problem

- Calculate L_{kin} and V_F:

✓ In the the (ϕ,ρ)-basis: no kinetic mixing between ϕ and ρ

$$\mathcal{L}_{\rm kin} = \frac{f''(\rho)}{4}\left(\partial_\mu \rho\right)^2 - \frac{f'(\rho)}{2}\left(\partial_\mu \phi\right)^2$$

✓ The F-term scalar potential depends only on ρ (and not on ϕ)

$$V_F \sim \frac{V_0}{\rho^3(1+\kappa_\rho \rho)}$$

→ η-problem solved!

→ ρ can be stabilsed by large V_0

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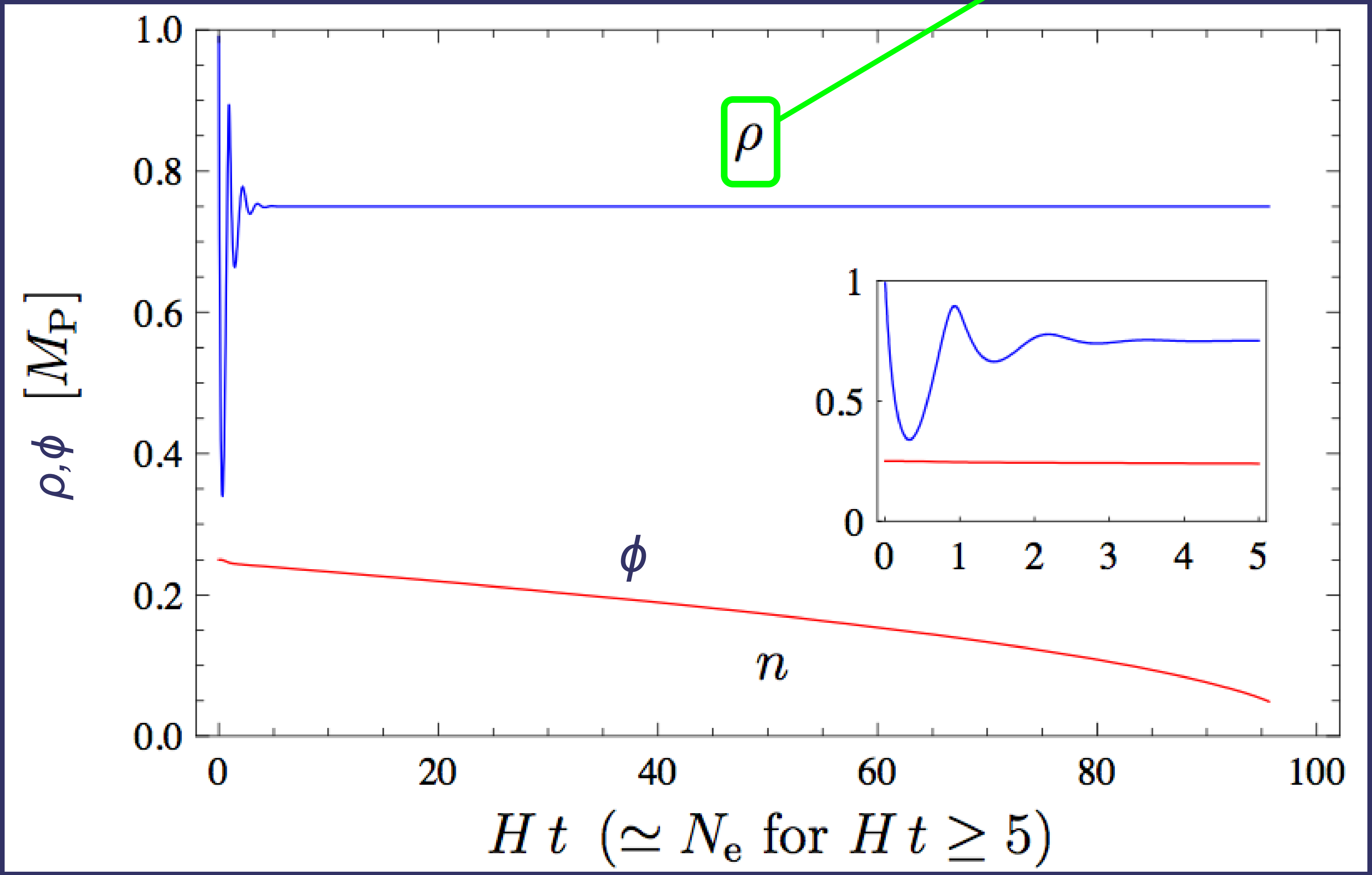
With V = $V_{tree} + V_{loop}$



Modulus field ρ gets stabilized quickly and allows for >> 60 e-folds of inflation!

S.A., M. Bastero-Gil, K. Dutta, S. F. King, P. M. Kostka ('08)

A new class of inflation models: Tribrid Inflation

- Simple example (singlet fields, global SUSY to start with):

$$W = X(H^2 - M^2) + \frac{1}{\Lambda} H^2 \Phi^2$$

Driving superfield

Waterfall superfield

Inflaton superfield

  - Three fields, X, H and Φ relevant for the model → “Tribrid Inflation“

First model of this class in: S.A., Bastero-Gil, King, Shafi (’04)
“Tribrid Inflation” in SUGRA: S.A., Dutta, Kostka (’09);
S.A., M. Bastero-Gil, K. Dutta, S. F. King, P. M. Kostka ('08)

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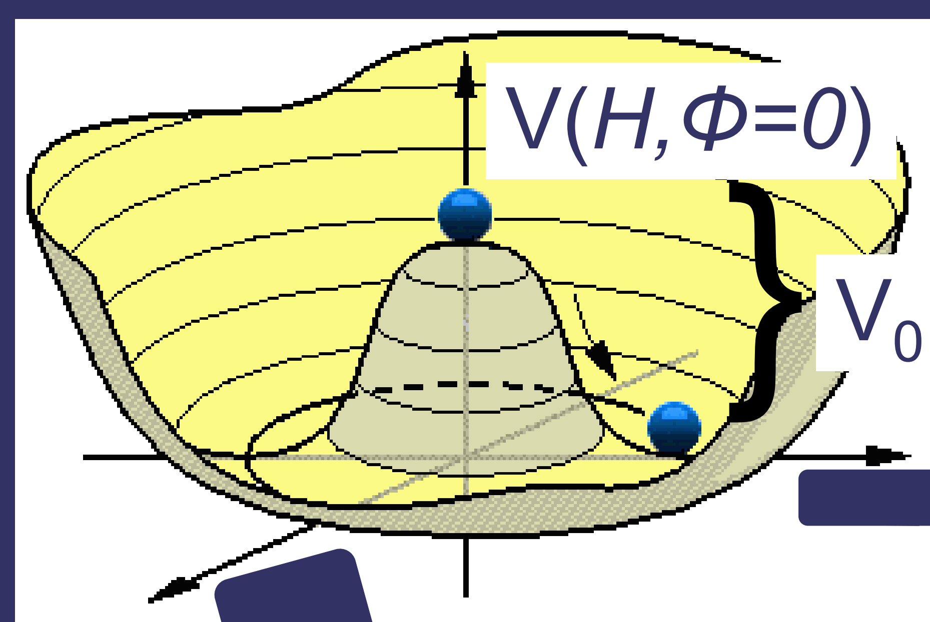
Driving superfield
(its F-term generates the potential for H and provides the vacuum energy V_0; During and after inflation: <X> = 0.)

$|F_X|^2 \Rightarrow$



Waterfall superfield
(contains the “waterfall field” (e.g. GUT- or Flavour-Higgs field) that ends inflation by a 2nd order phase transition)

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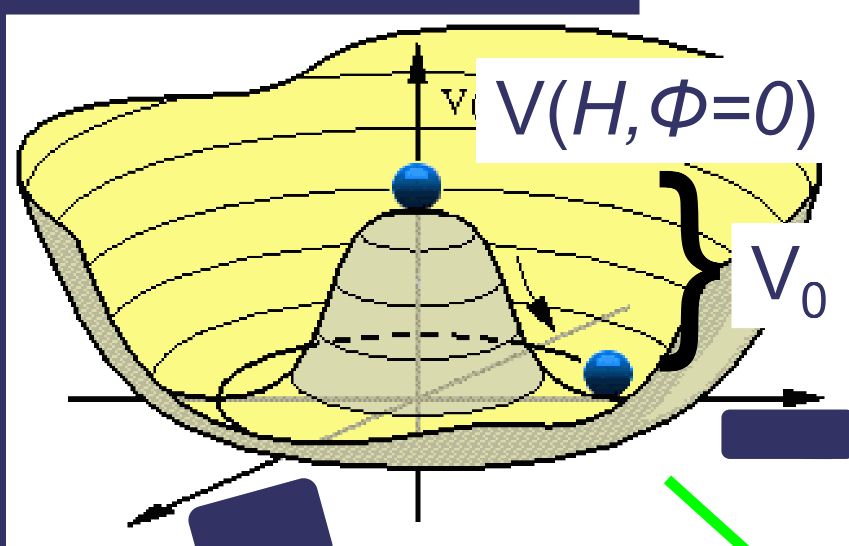
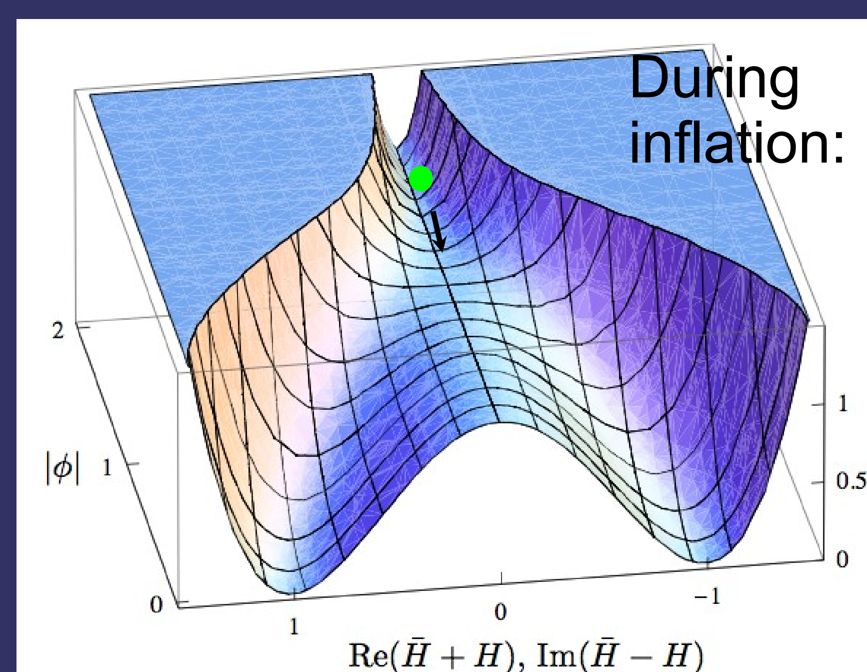


$\langle\phi\rangle > \phi_{crit}$



Inflaton superfield
(contains the inflaton field as scalar component;
For $\langle\phi\rangle > \phi_{crit}$ it stabilises H at $\langle H\rangle = 0$)

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→ Inflaton candidates are e.g.:

i) Right-handed Sneutrino
(in 'Tribrid Inflation'-type scenario):
S.A., Bastero-Gil, King, Shafi ('04)

ii) Unified Matter Sparticle
(16 of SO(10) SUSY GUT)
S.A., Bastero-Gil, Baumann, Dutta, King, Kostka ('10)

iii) Most general: D-flat direction of fields $f(\Phi_a)$coupling to H^2
S.A. Bastero-Gil, Baumann, Dutta, King, Kostka ('10)

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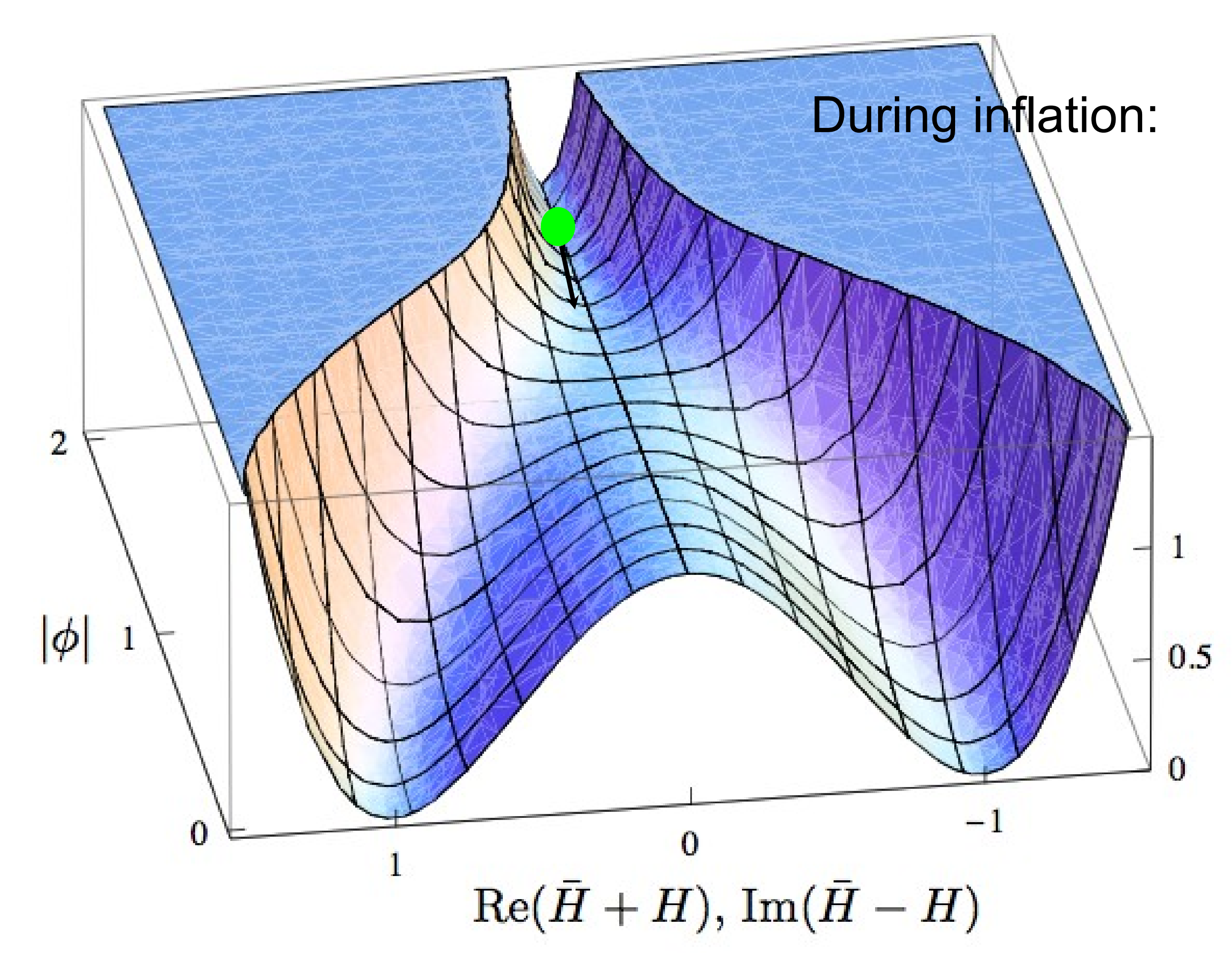

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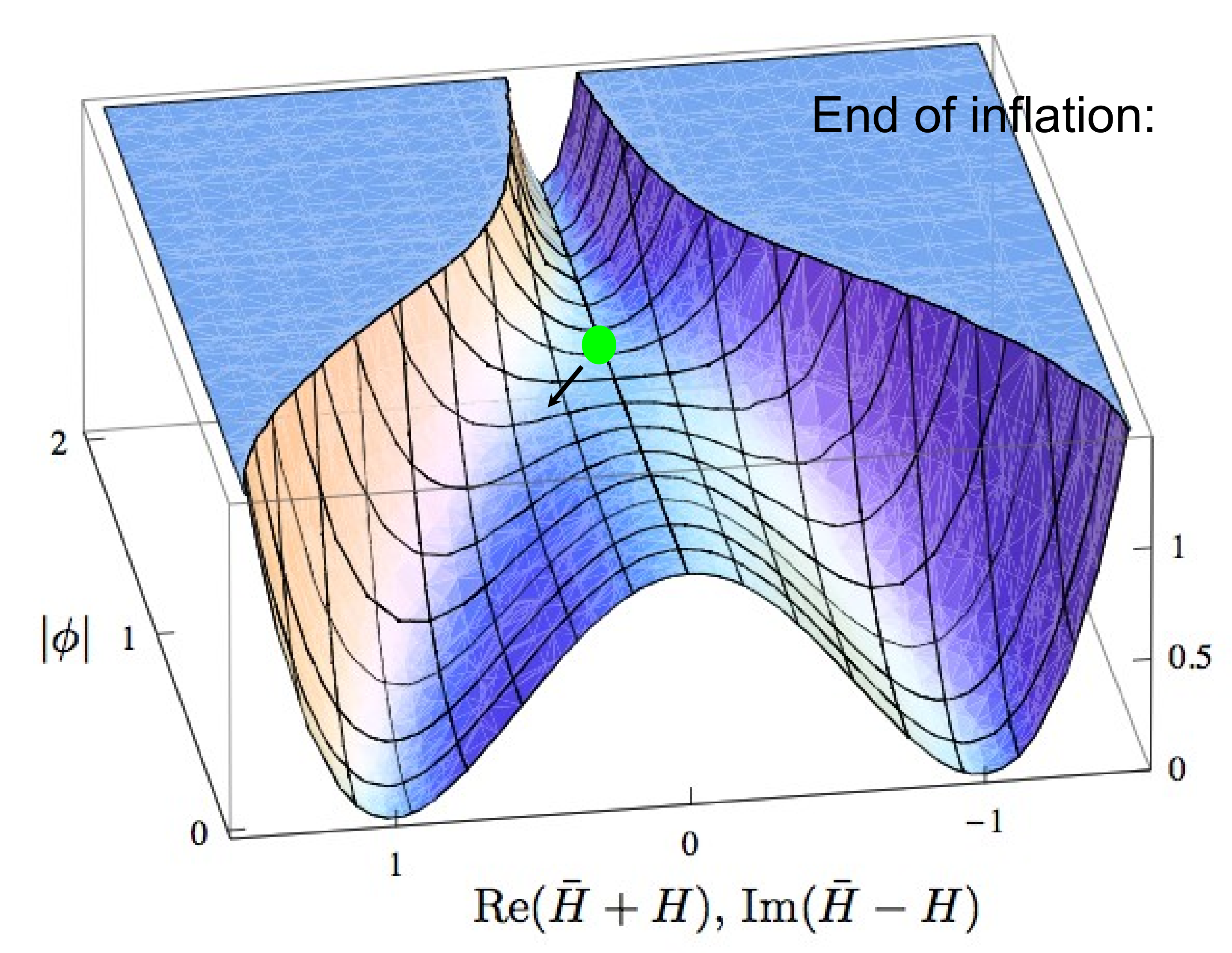

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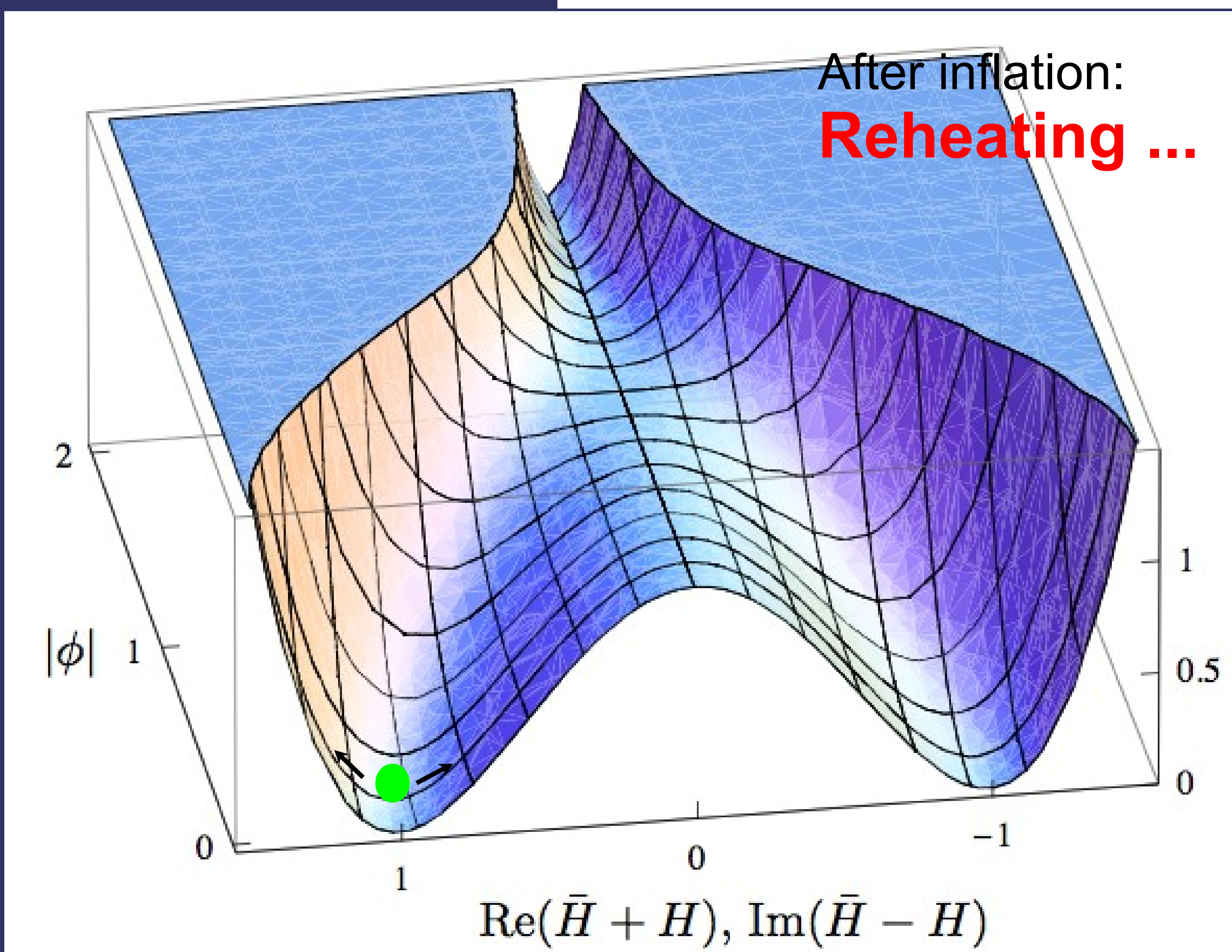

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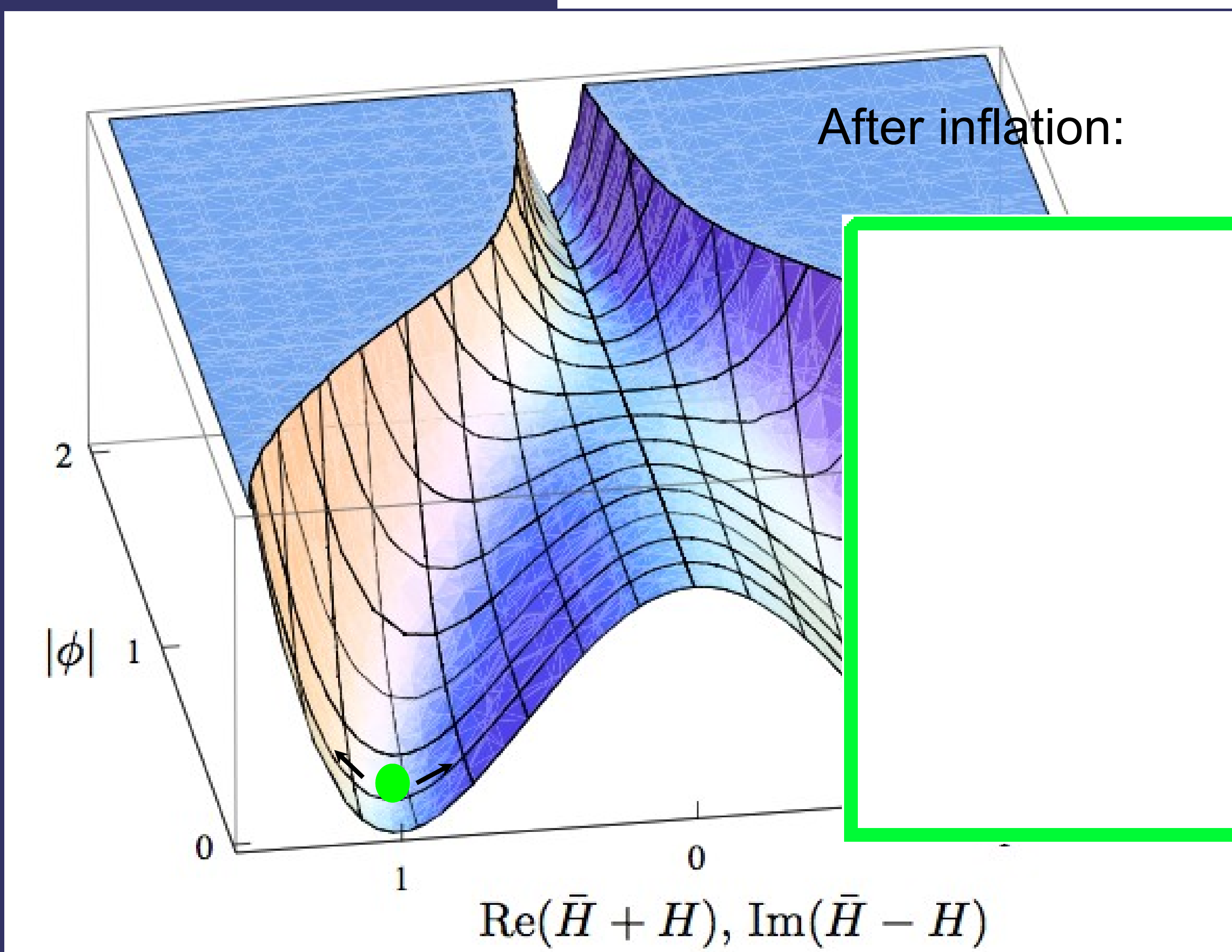

Recent study within 'hybrid-like' models:
'Sneutrino Hybrid Inflation and Leptogenesis'
S.A., Baumann, Domcke, Kostka ('10)

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Tribrid inflation in Supergravity

- Example model in SUGRA:

$$W = X(H^2 - M^2) + \frac{1}{\Lambda} H^2 \Phi^2$$

breaks the Heisenberg symmetry

$$K = -3 \ln \rho + |X|^2 + \kappa_\rho \frac{\rho |X|^2}{M_P} + \ldots, \text{ with } \rho = T + T^* - |\phi|^2$$

K invariant under Heisenberg symmetry

→ η-problem solved:

✓ Flat potential for ϕ at tree-level

✓ Slope from $V_{1\text{-loop}}$

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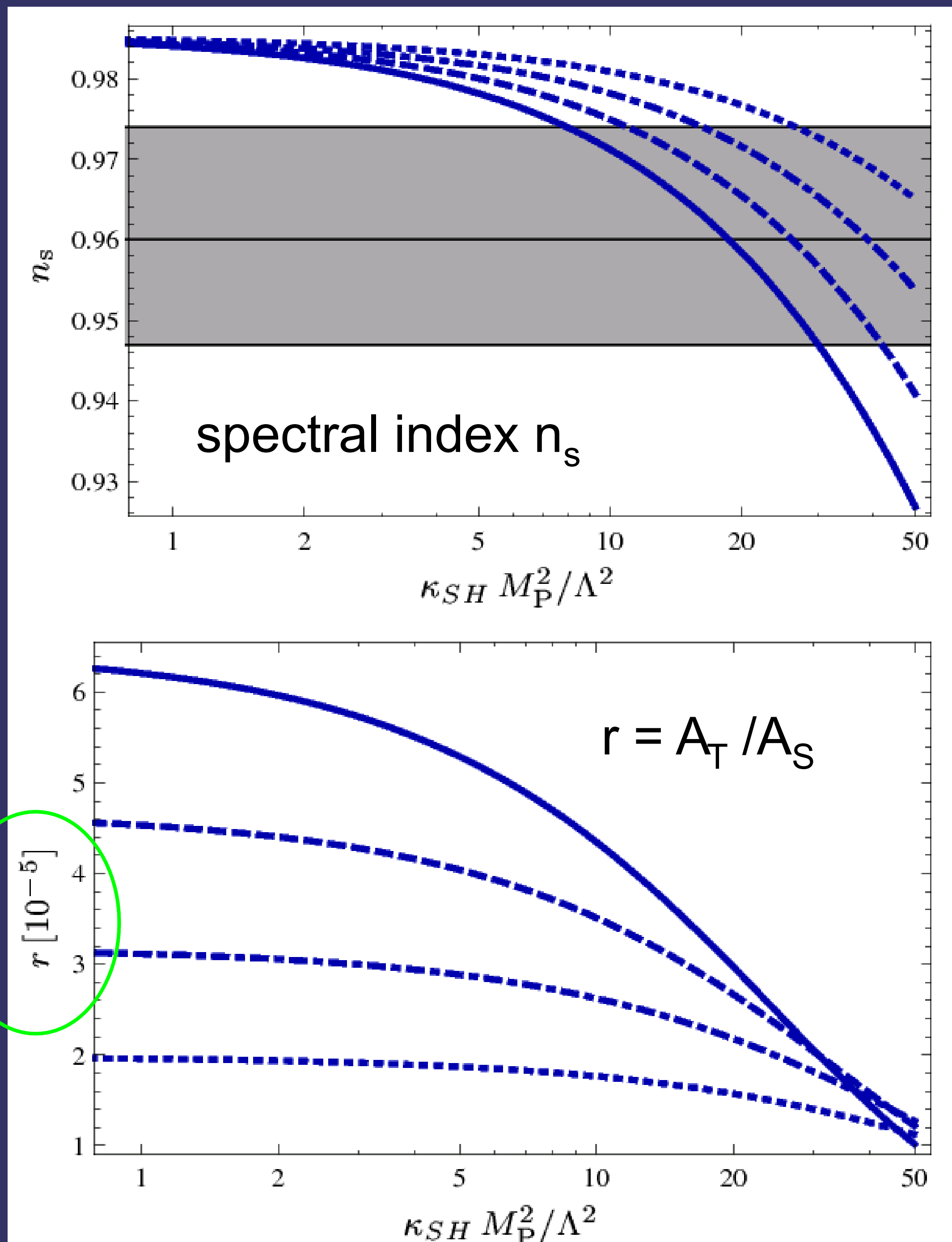
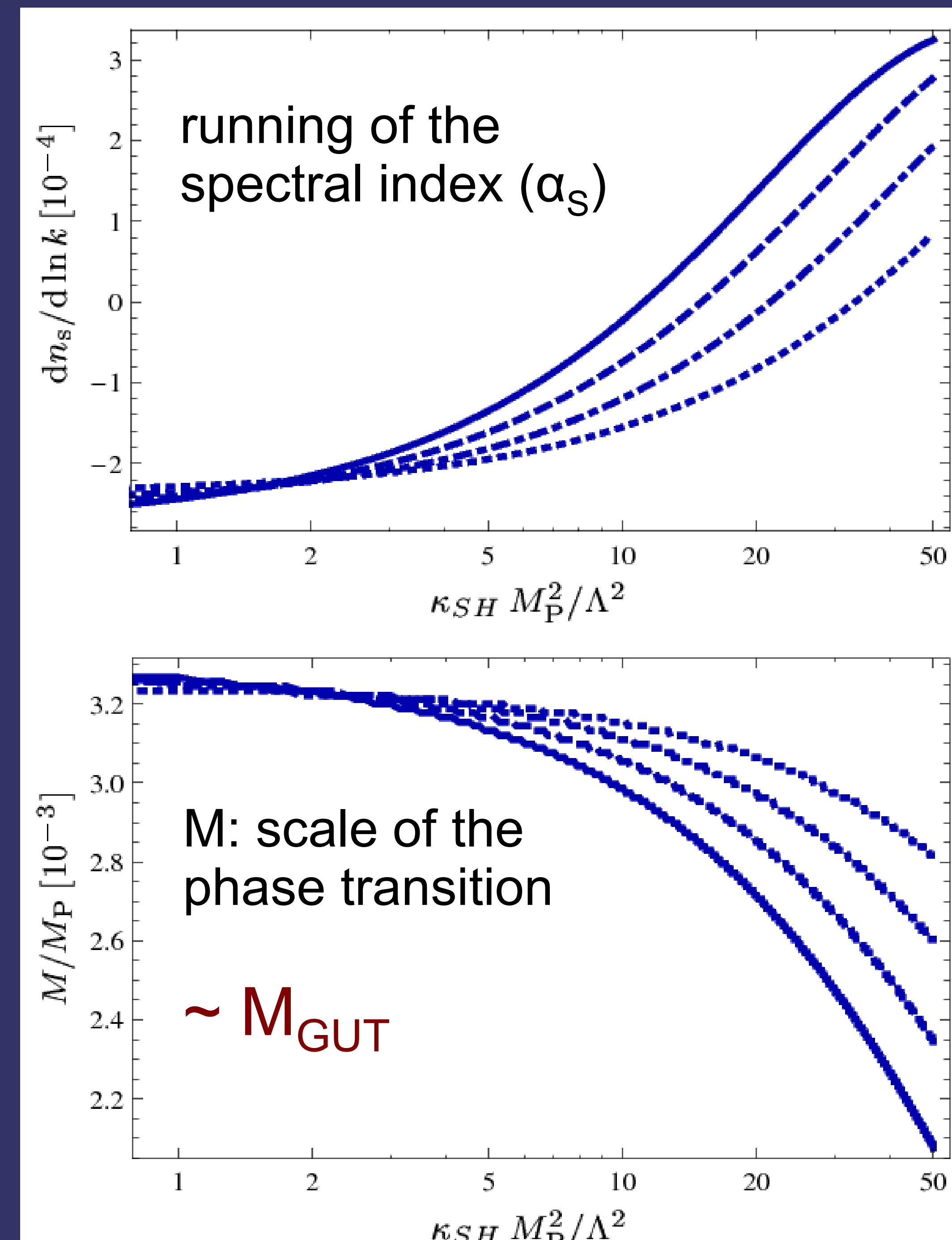
S.A., K. Dutta, P. M. Kostka ('09)



very small
(as typical for Hybrid-type models)



Example: Predictions in a toy model ...

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Applications

Can the inflaton be a Gauge Non-Singlet?

- Example model of GNS inflation in SUGRA:

$$W = X(\bar{H}H - M^2) + \frac{1}{\Lambda}(\bar{F}F_i)(\bar{H}H)$$

$$K = -3\ln\rho + \kappa_\rho \frac{\rho\,|X|^2}{M_P} + \ldots, \text{ with } \rho = T + T^* - \sum_i |F_i|^2 - |\bar{F}|^2$$

✓ Several additional challenges for GNS inflation ... all resolved!

F_i in representation 16 of SO(10)
$\bar{F}$ in representation $\overline{16}$ of SO(10)

$$\mathbf{16}_i = \begin{pmatrix} q_L & u^c_R & e^c_R & d^c_R & \ell_L & \nu^c_R \end{pmatrix}_i$$

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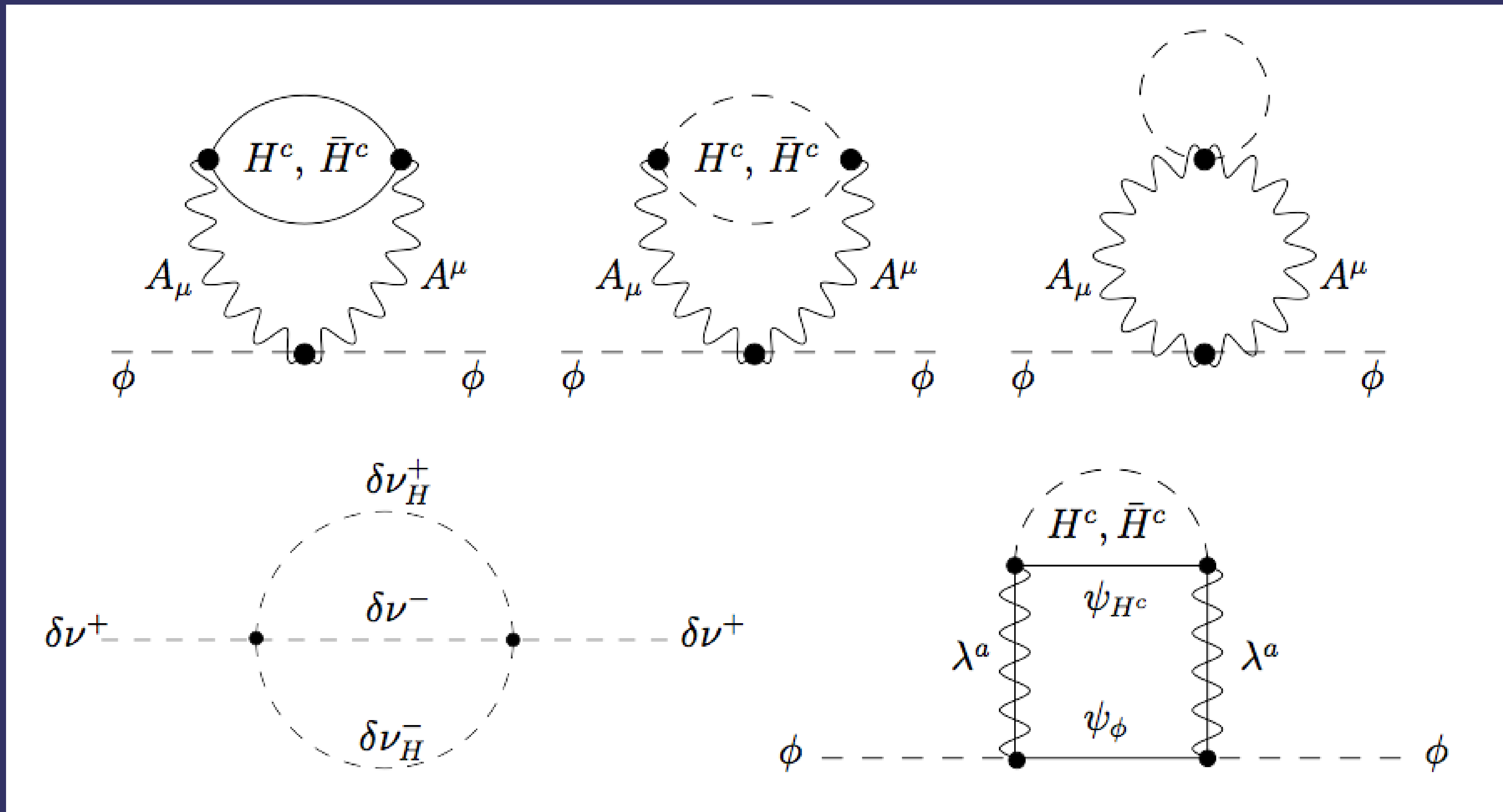

Typical problem: 2-loop mass contribution for non-singlets

$$\delta m^2 \sim \frac{g^4}{(4\pi)^4}\frac{|W_S|^2}{m_F^2} > \mathcal{H}^2$$

would spoil slow-roll inflation! Dvali '95

However in our class of models: gauge symmetry broken in the inflaton direction!

$$\delta m^2 \sim \frac{g^4}{(4\pi)^4}\frac{\mu^4}{M_g^2} \ll \mathcal{H}^2$$

suppressed by large gauge boson mass !

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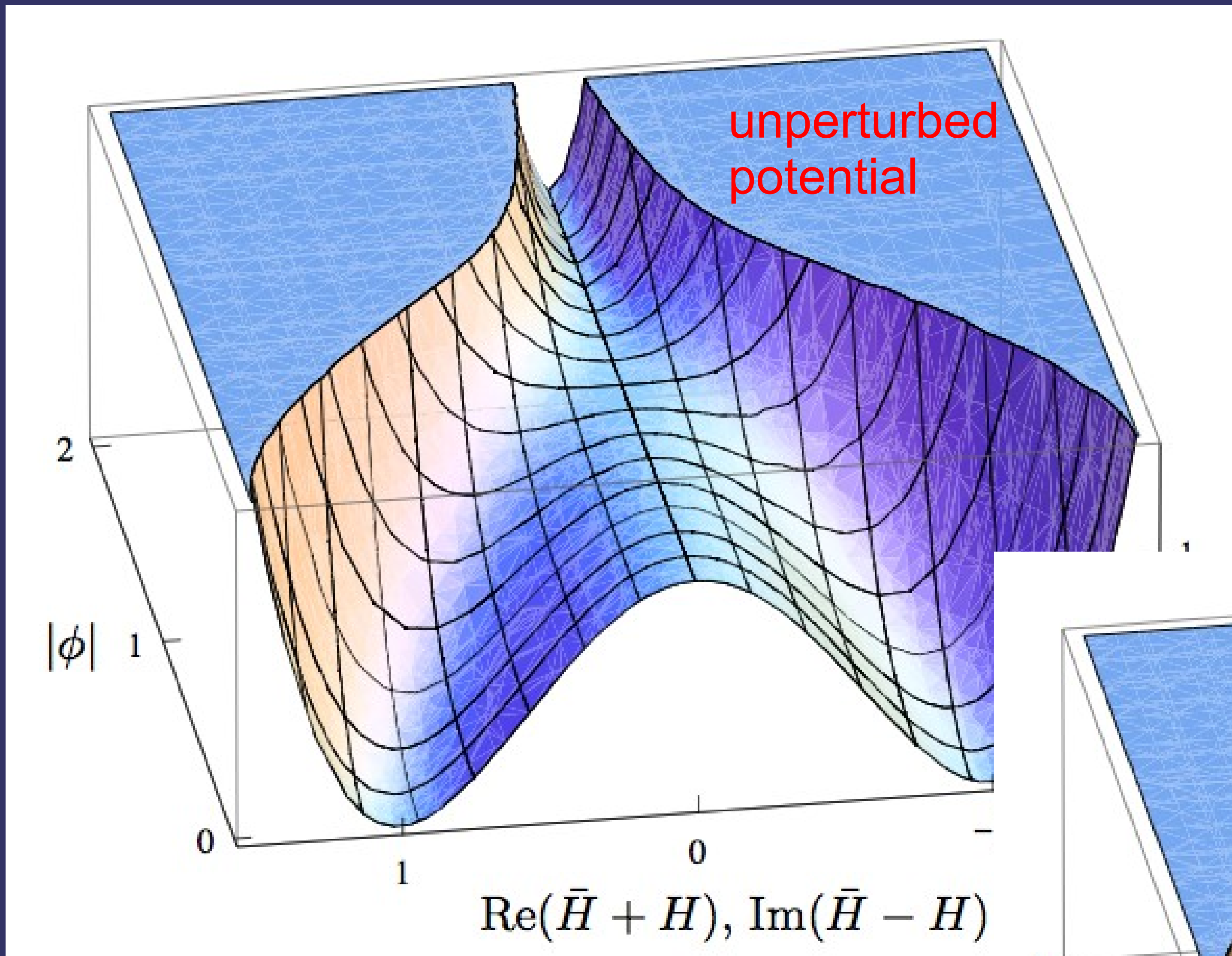

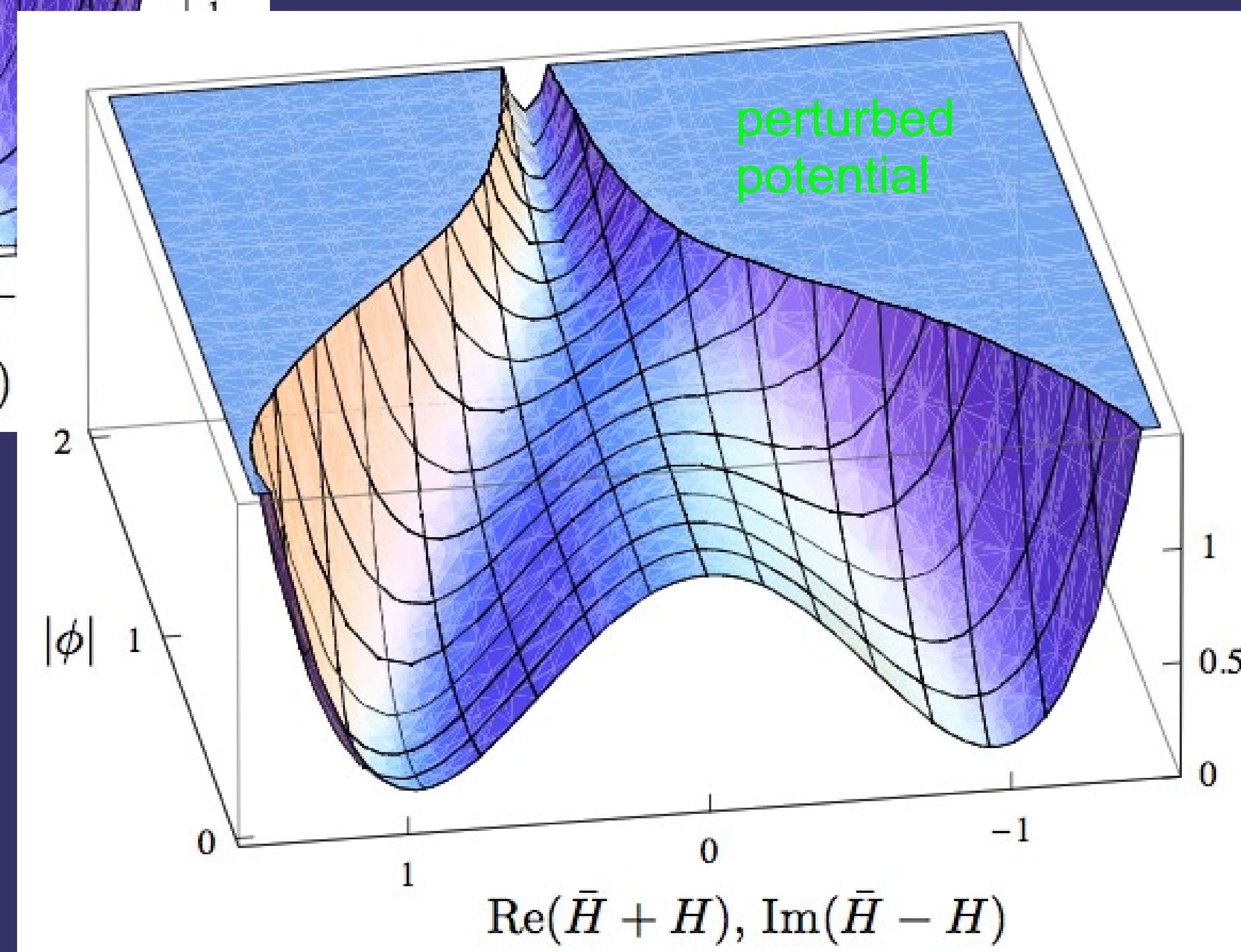

✓ Monopole problem can be solved:

- "Preferred waterfall direction" (no new monoples produced) *or by*
- Breaking SO(10) via a Minimal LR model (where only cosmic strings get produced, but no monopoles)

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Matter inflation in string theory?

- "Towards Matter Inflation in Heterotic String Theory":

  S.A., Dutta, Erdmenger, Halter ('11)

  - In heterotic string theory, Heisenberg symmetry is a property of the tree-level potential of untwisted matter fields (in the limit $g \to 0$).
  - A generalisation of the "tribrid" superpotential (with $W_{inf} \approx 0$, $W_{inf,\Phi} \approx 0$ during inflation) could give rise to inflation in the matter sector.

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- Generalisation could look similar to (with some features to be checked):

Inflaton = (tree-level) D-flat and F-flat direction

$$W = a(T_i)\, X \left[b(T_i)\, H^+ H^- - \langle \Sigma \rangle^2 \right] + c\,(T_i)\, f(\Phi_a)\, H^+ H^- + \widetilde{W}$$

$$K = -\sum_{i=1}^{2} \log(T_i + \bar{T}_i) - \log\left(T_3 + \bar{T}_3 - \sum_a |\Phi_a|^2 \right) + \widetilde{K}$$

= ρ_3; stabilised during inflation at large values and with large mass, by a suitable coupling between ρ_3 and X in K

- In addition:
  - Complex structure moduli stabilised; T_1 and T_2 stabilised by W; Dilaton stabilised by non-perturbative corrections to K (challenge!)

- Future: Check requirements; Search for explicit models ...

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Summary and Conclusions

- We discussed four recent developments ...

  ✓ Heisenberg symmetry with stabilised modulus: Interesting solution to the η-problem in SUGRA inflation

  ✓ Tribrid Inflation: New class of inflation models, very suitable for applying symmetry solutions to the η-problem

  ✓ Gauge Non-Singlet Matter Inflation in SUGRA GUTs: Inflaton field can be in a GUT matter representation, e.g. in 16 of SO(10)

  ✓ New approach towards realising inflation in the matter sector of heterotic string theory

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