Sébastien Clesse
(collaboration with J. Rocher)

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Centre of Phenomenology and Particle Physics (CP3), University of Louvain

Anamorphosis in hybrid inflation
How to avoid fine-tuning of initial conditions?

2nd. UniverseNet school - Oxford - September 22nd. to 26th. 2008

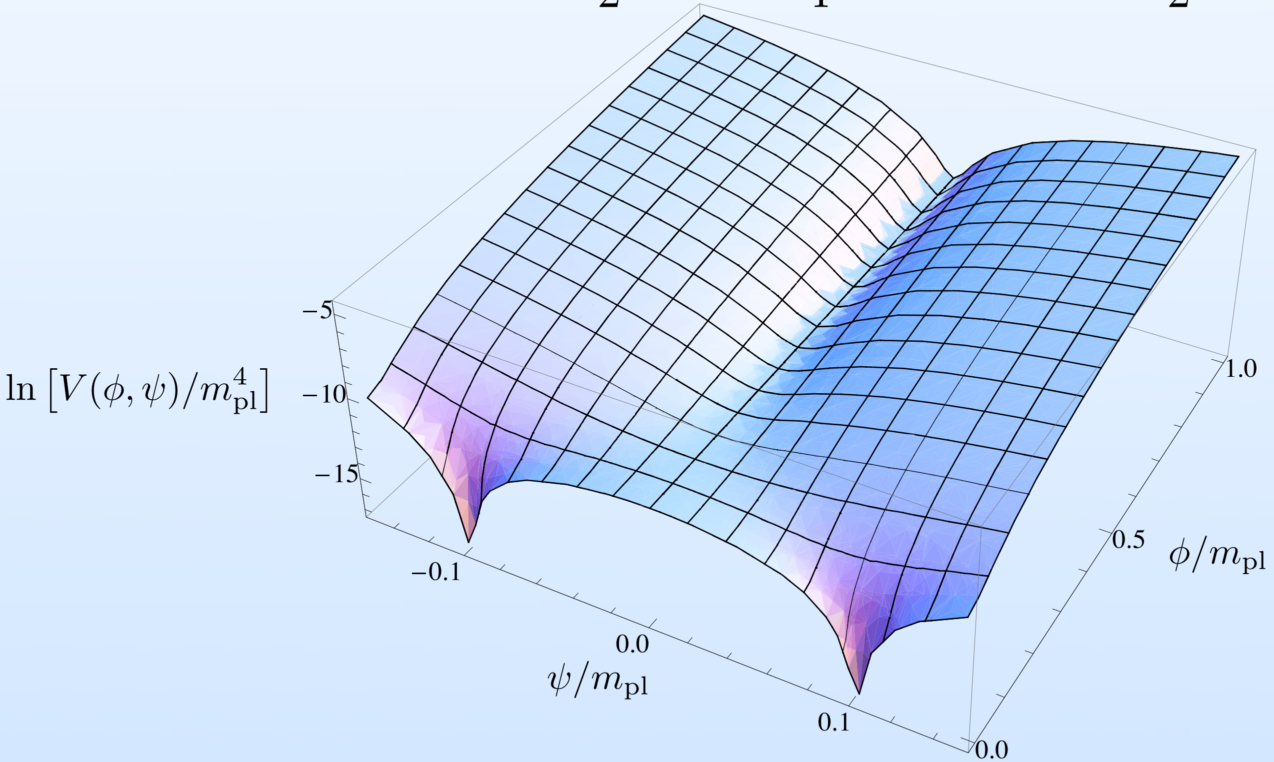
Outline

- Hybrid inflation
- Fine-tuning of the initial conditions
- How to avoid fine-tuning ?
  - Space of initial conditions
  - Anamorphosis points
- Robustness of predictions
  - Smooth Inflation
  - Shifted Inflation
  - Radion Inflation
- Conclusion and perspectives

1. Hybrid inflation

- **Inflaton** ϕ
- **Higgs-type auxiliary field** ψ
- **Hybrid potential** (Linde, astro-ph/9307002)

$$V(\phi,\psi) = \frac{1}{2}m^2\phi^2 + \frac{\lambda}{4}\left(M^2-\psi^2\right)^2 + \frac{\lambda'}{2}\phi^2\psi^2$$



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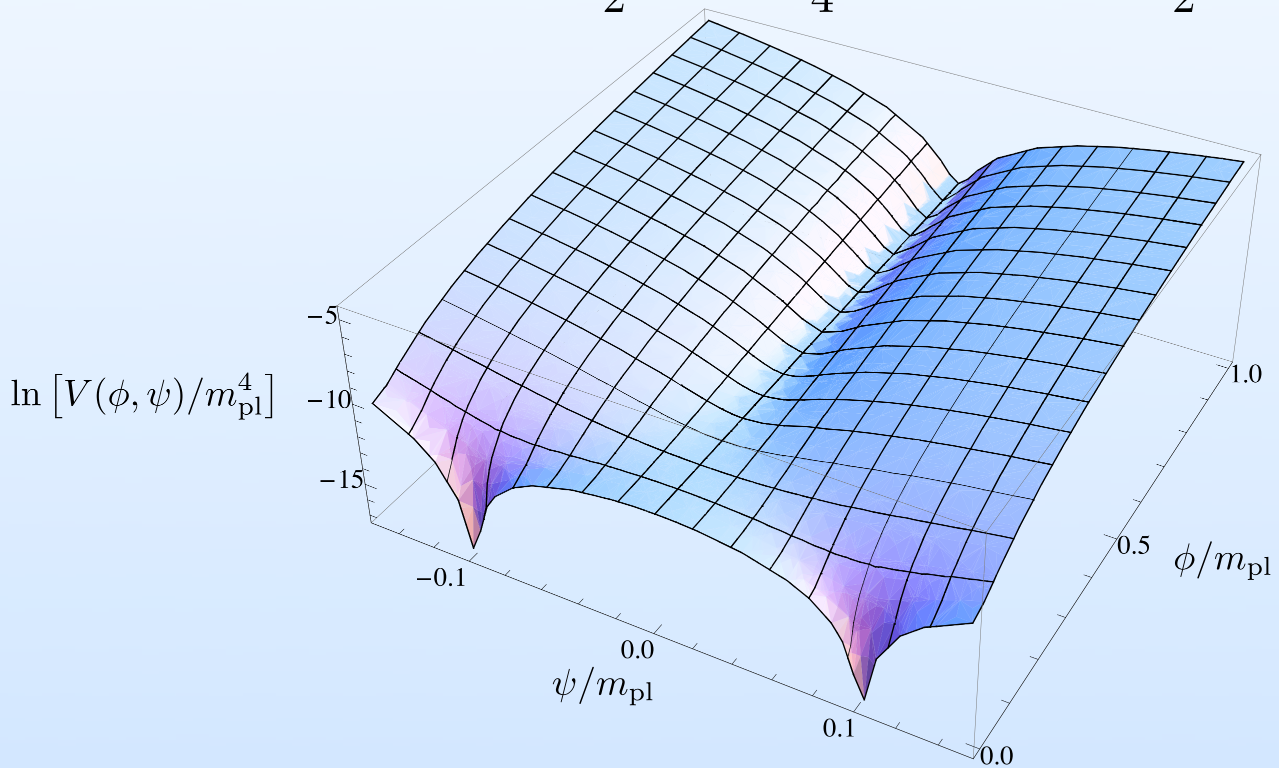
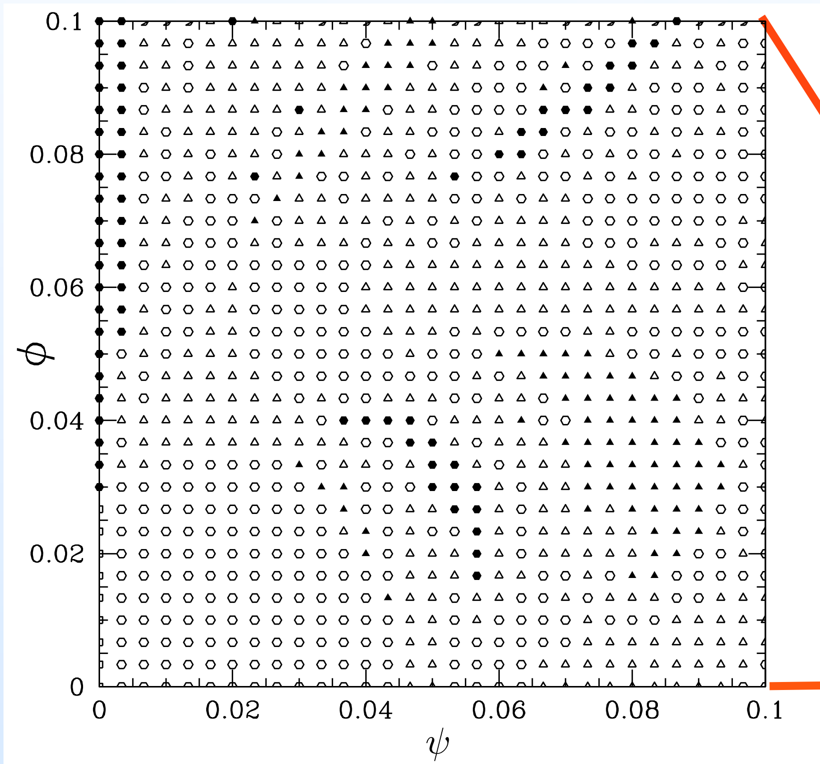


- **Question :** **What are regions in space of initial values of the fields leading to sufficient inflation ?**
- **Sufficient inflation : > 60 e-folds** **(null initial speeds for simplicity)**

2. Fine-tuning of the initial conditions...

Tetradis, astro-ph/9707214

$\lambda = \lambda' = 1, \ M = 0.03\ m_{\rm pl}, m = 10^{-6}\ m_{\rm pl}$



(in Planck mass)

Mendes, Liddle, astro-ph/0006020

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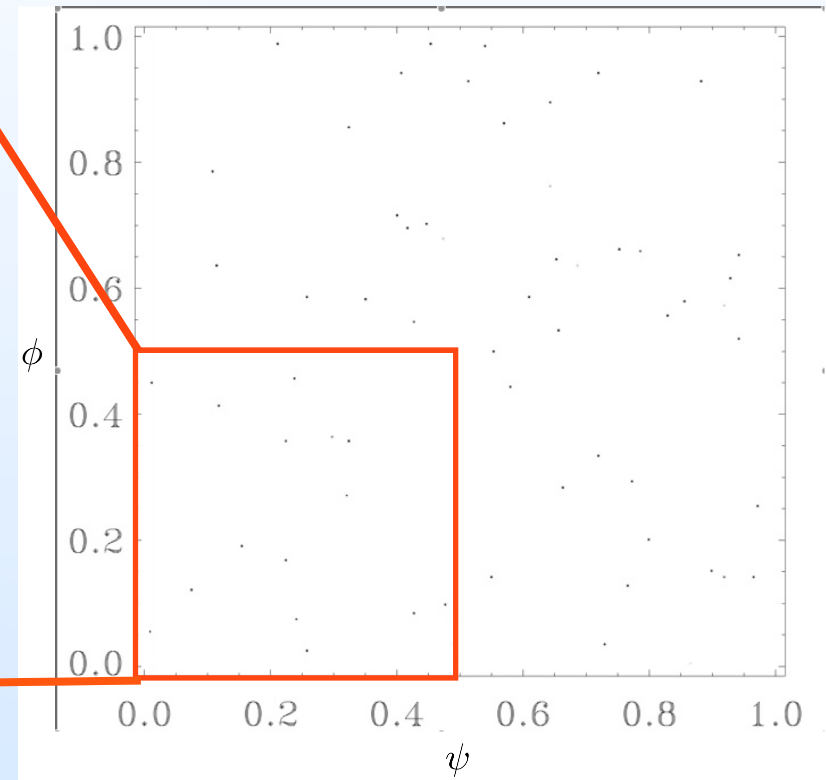

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2. Fine-tuning of the initial conditions...

1. Hybrid Inflation

2. Fine-tuning of initial conditions

3. How to avoid fine-tuning?

- Space of Initial Conditions

- Anamorphosis points

4. Robustness of predictions: 3 others models

- Smooth Inflation

- Shifted Inflation

- Radion Inflation

5. Conclusions and Perspectives

Questions...

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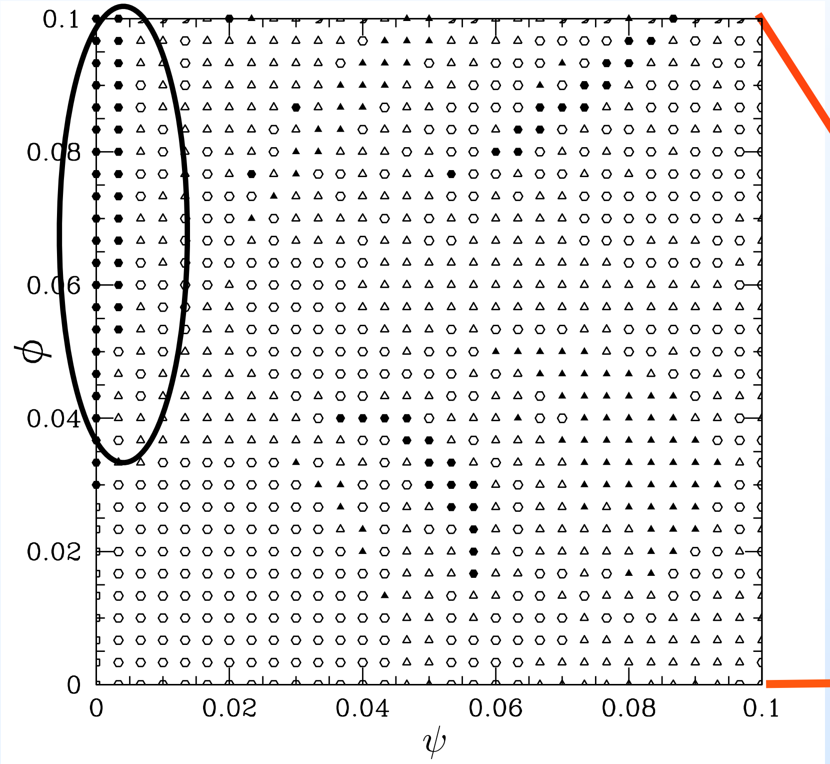

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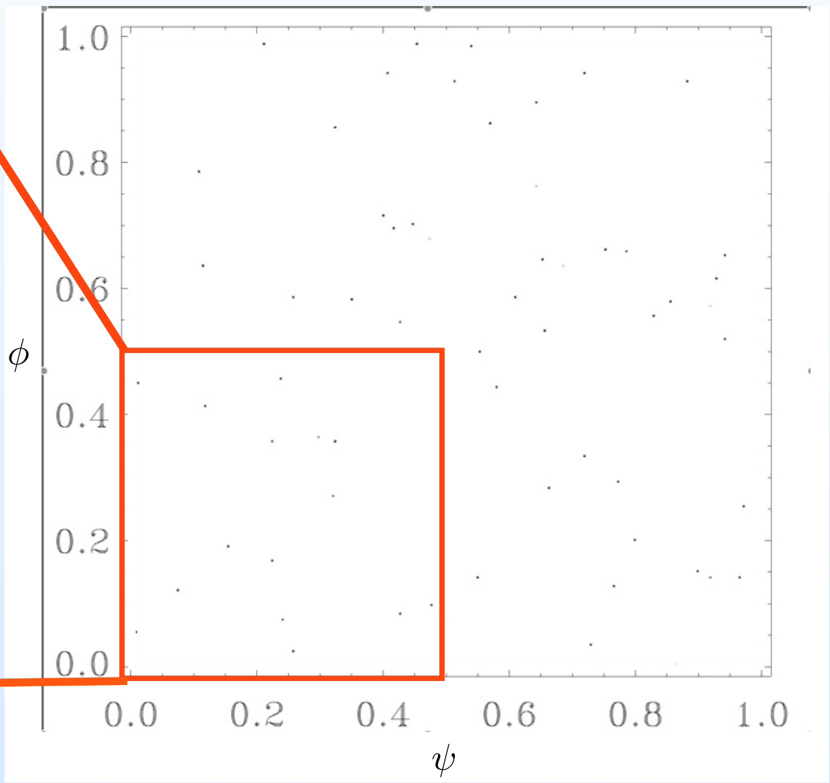

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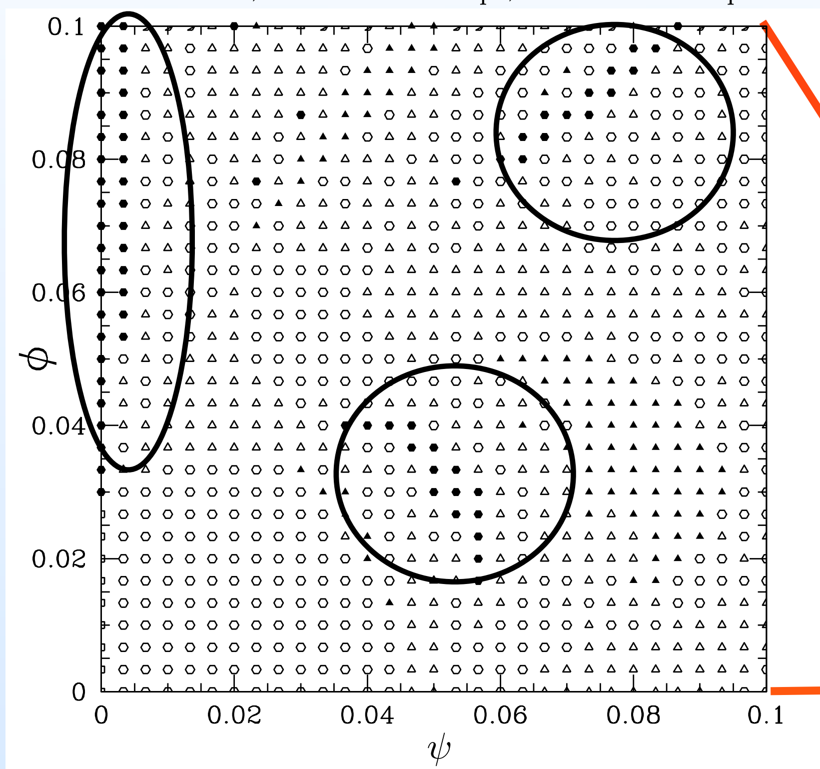

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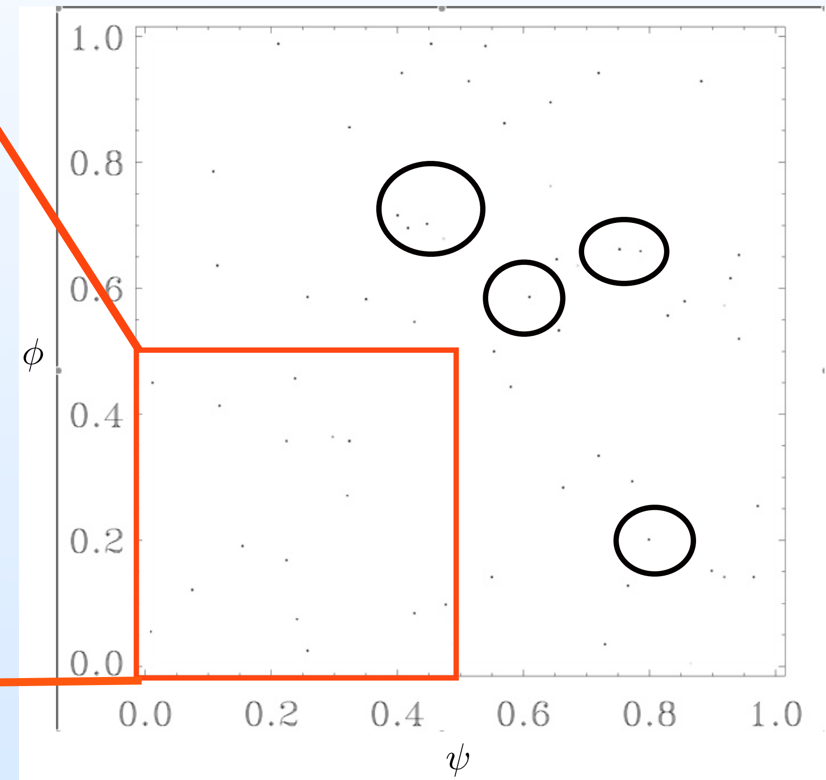

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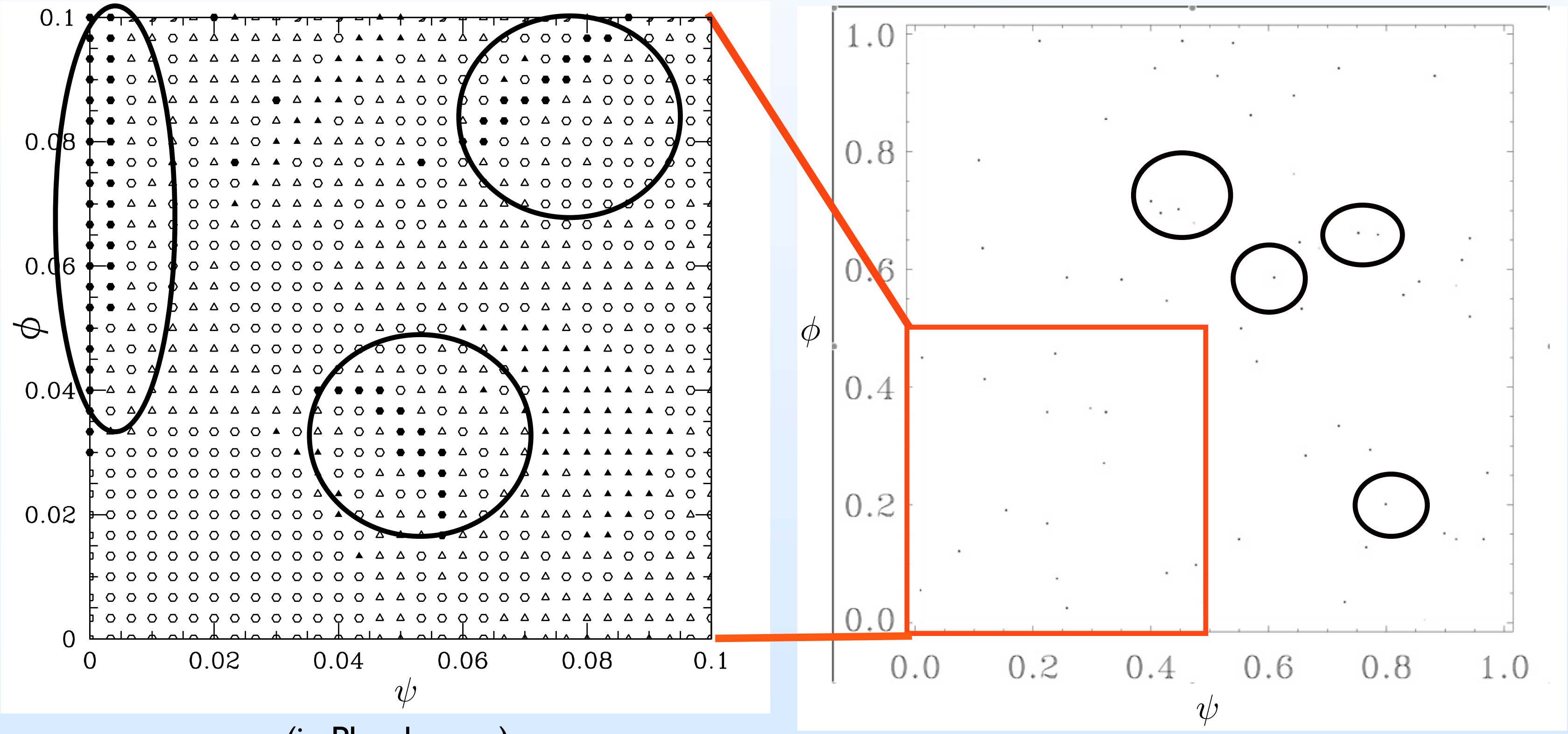

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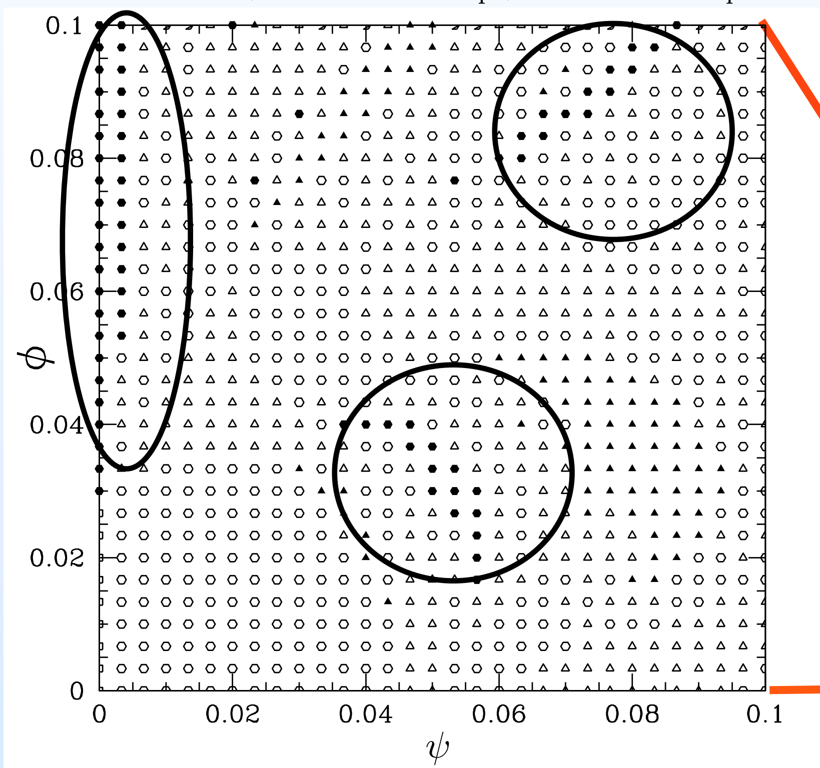

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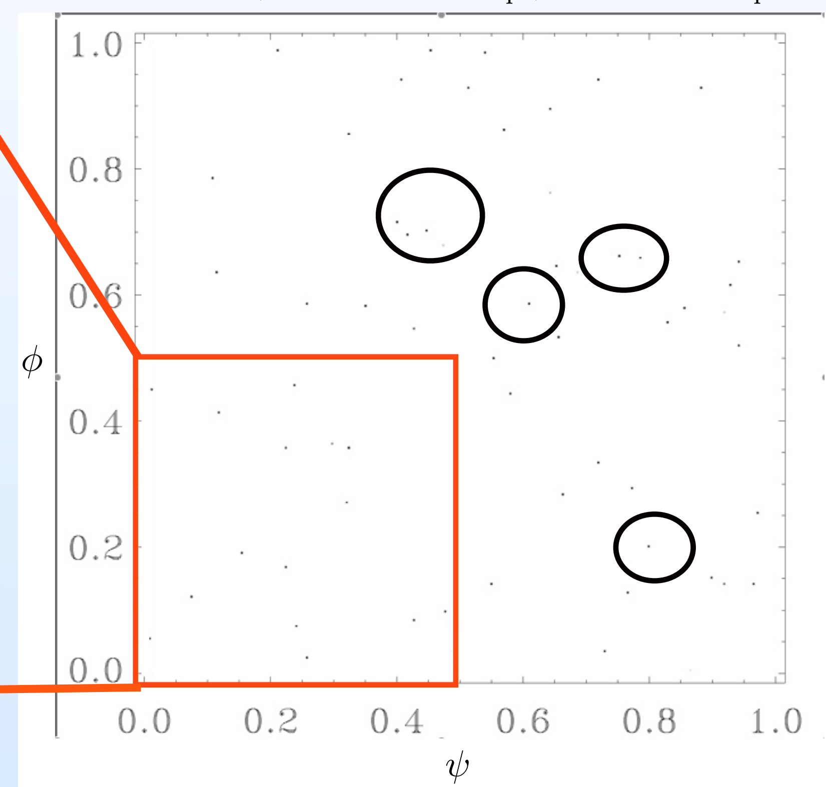

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- **Isolated points or structures ?**
- **Origin ?**

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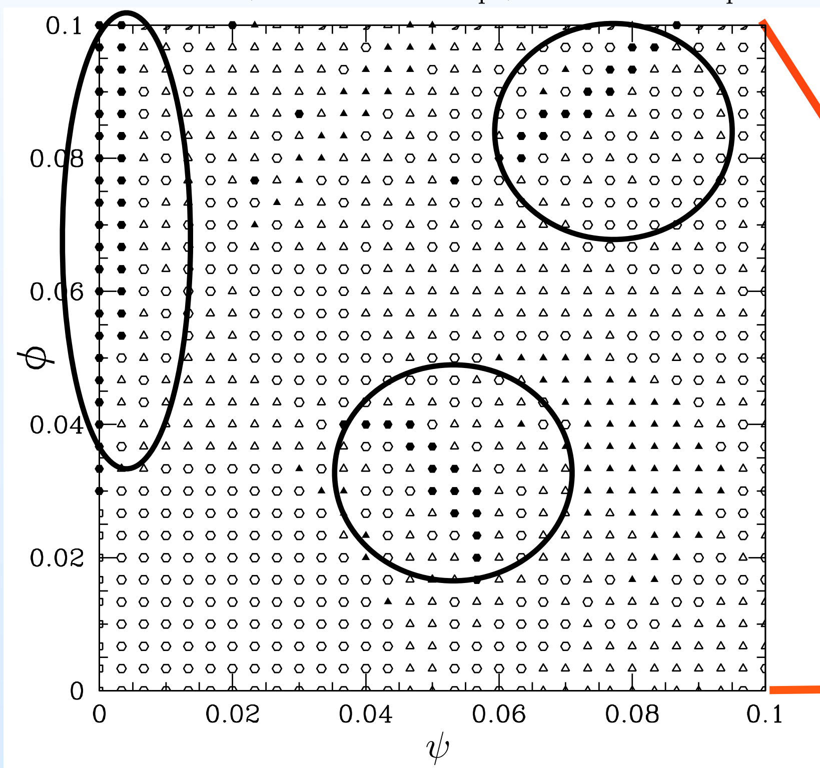

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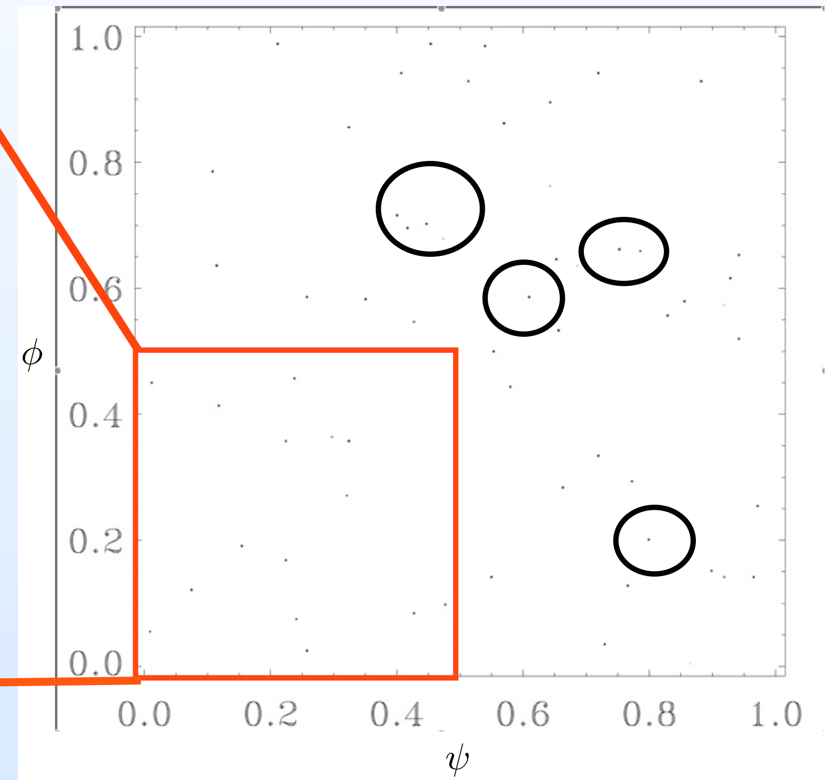

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- **Isolated points or structures ?**
- **Origin ?**
- **Quantification of successful areas ?**

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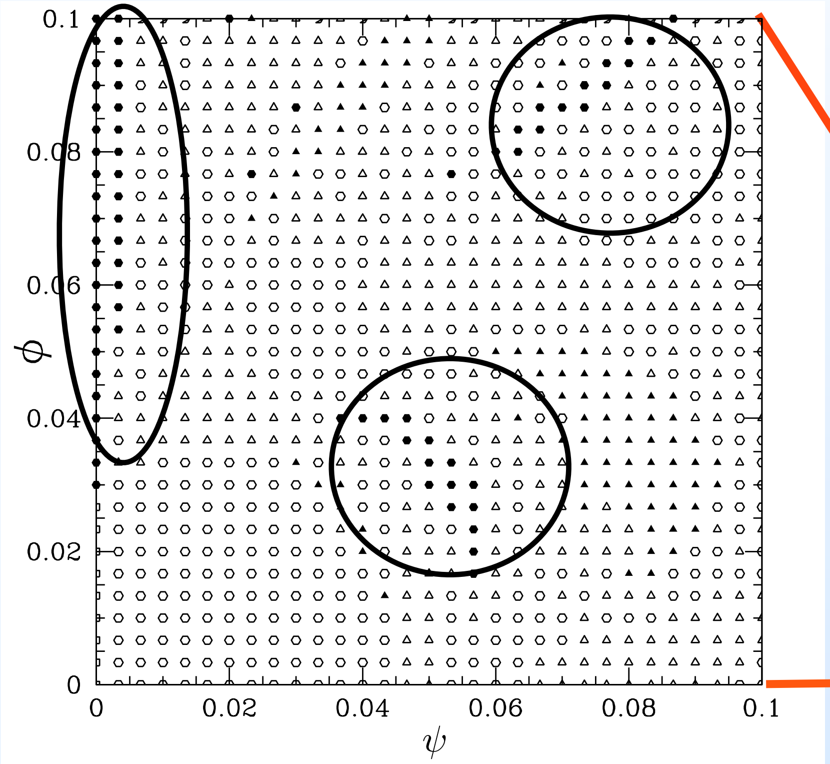

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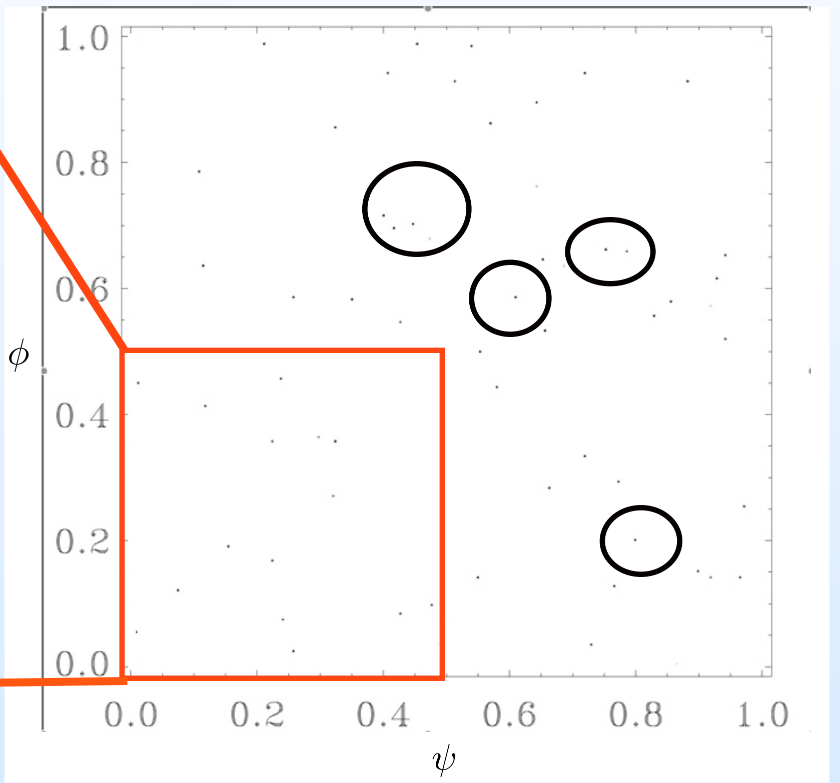

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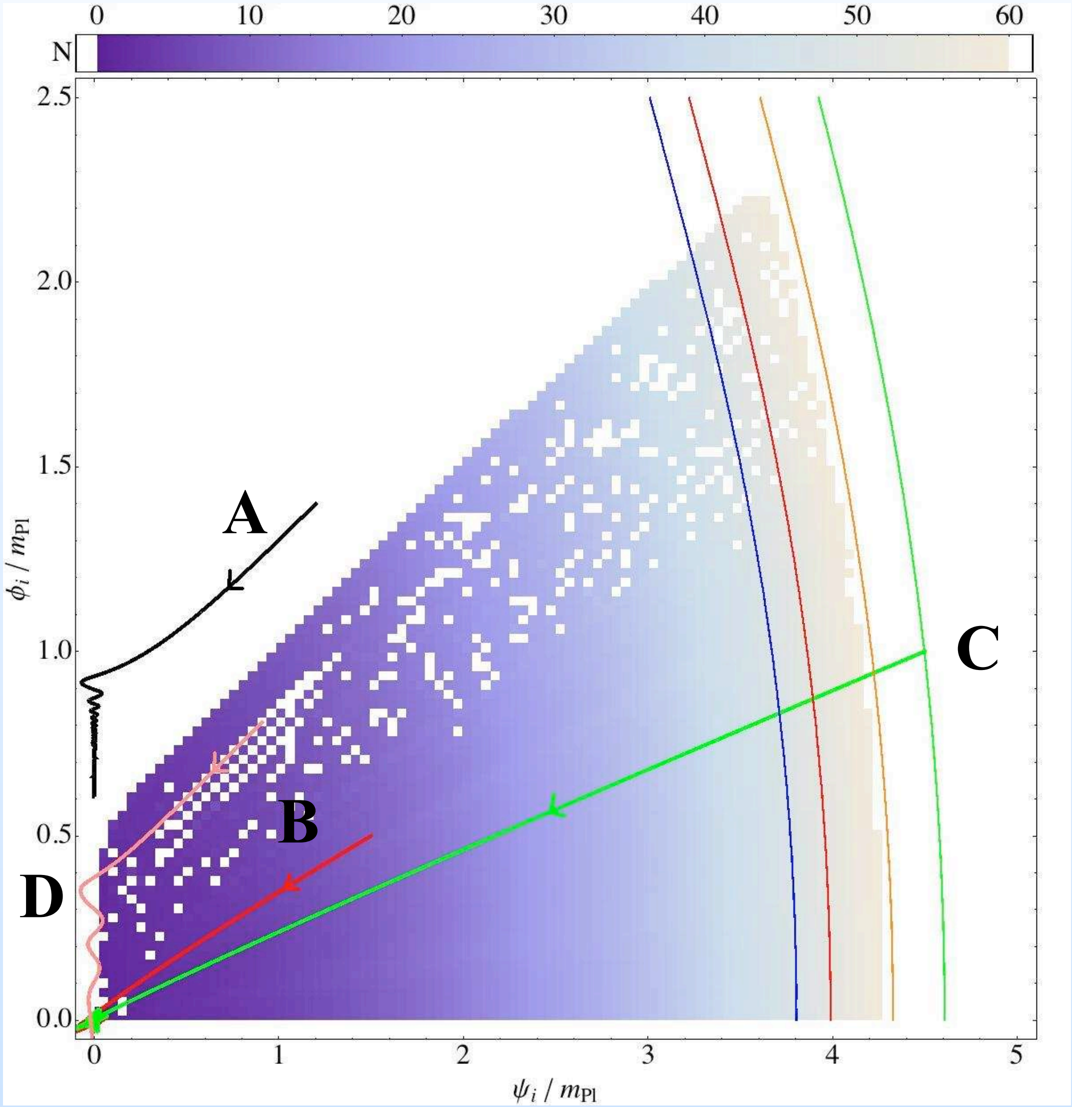
- Isolated points or structures ?
- Origin ?
- Quantification of successful areas ?

Numerical integration of exact 2-field dynamics to explore the space of initial conditions extended to super-planckian values

3. How to avoid fine-tuning ?

• Extended space of initial conditions



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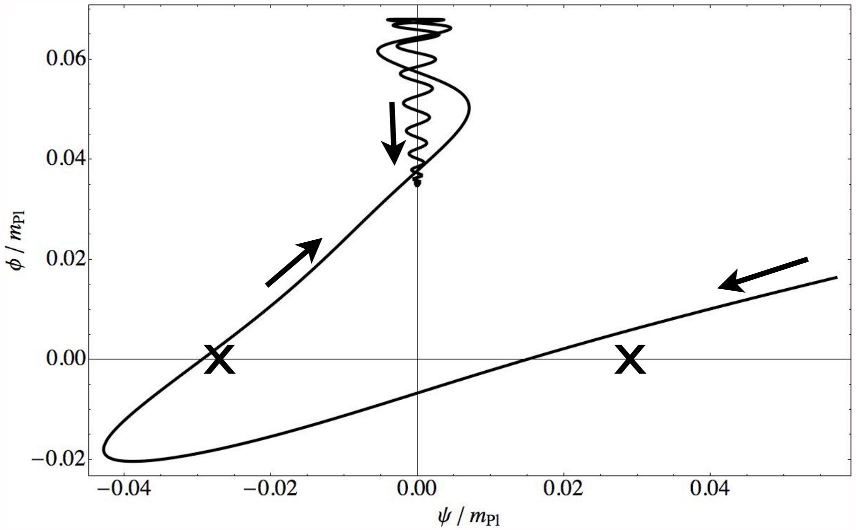

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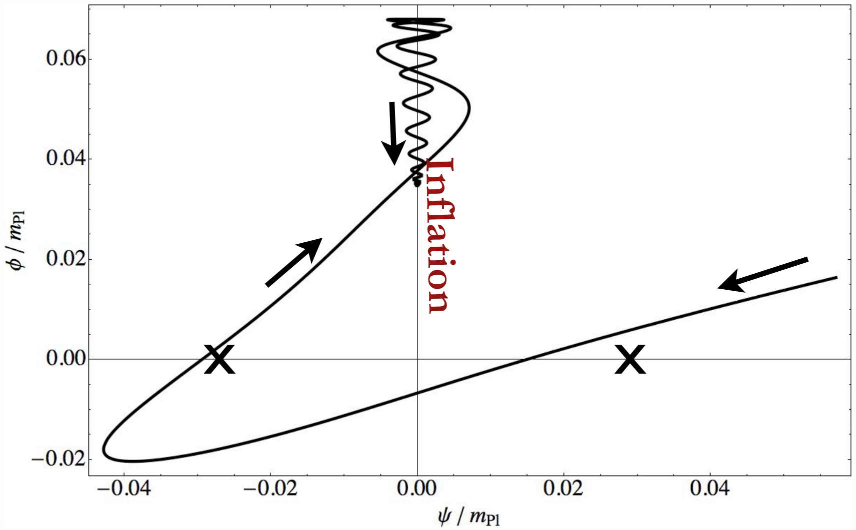

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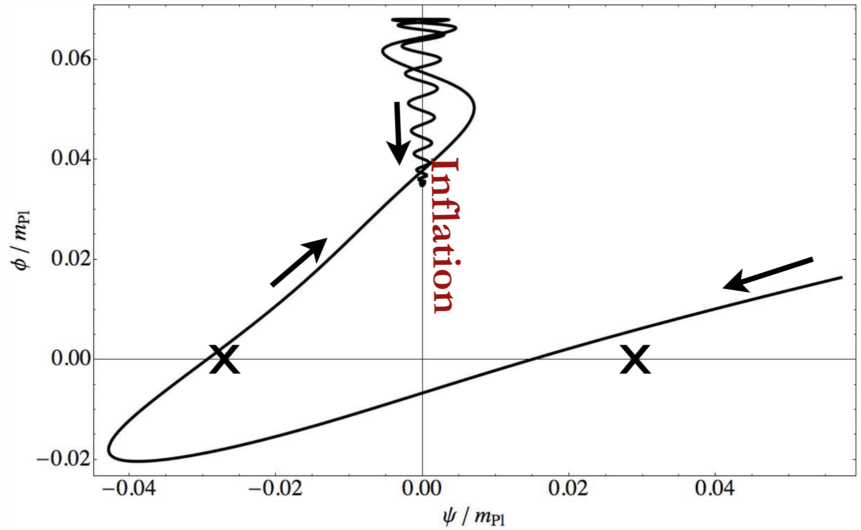

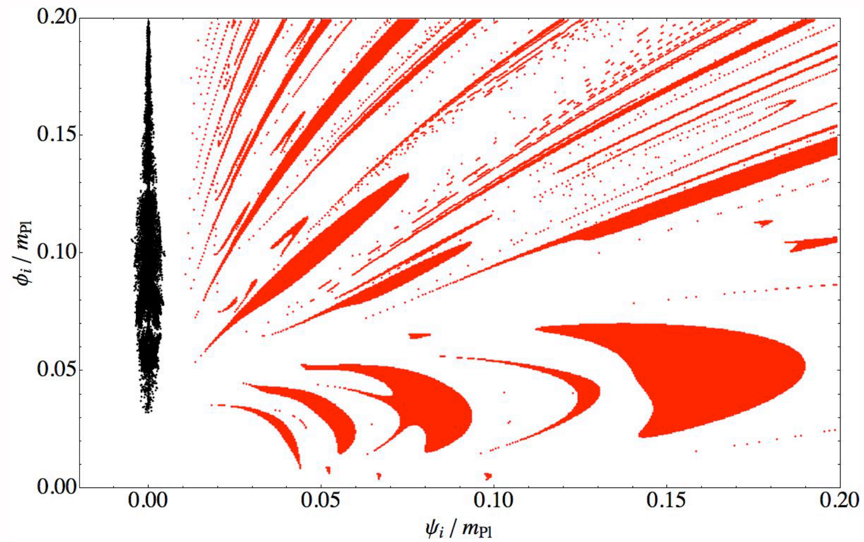

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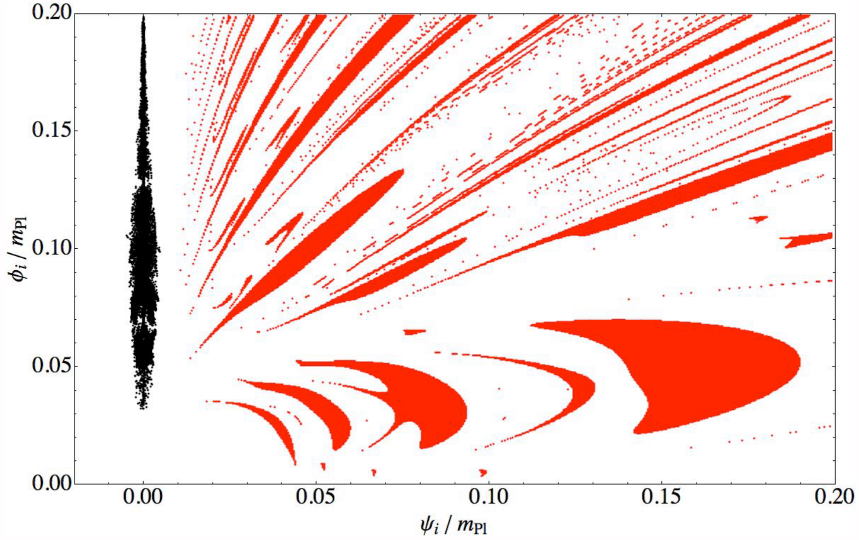

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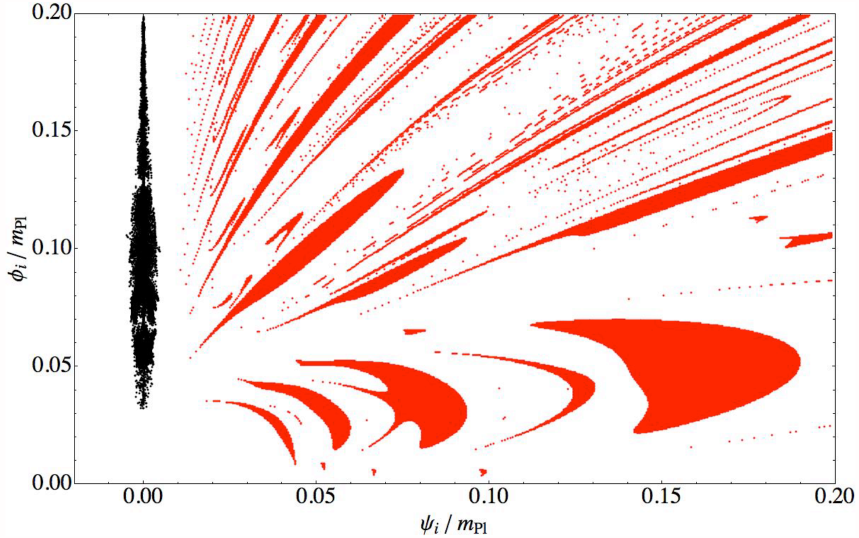


For $\phi, \psi < 0.2\ m_{\rm pl}$

Up to 20% of area are anamorphosis points

Anamorphosis is an elegant possibility

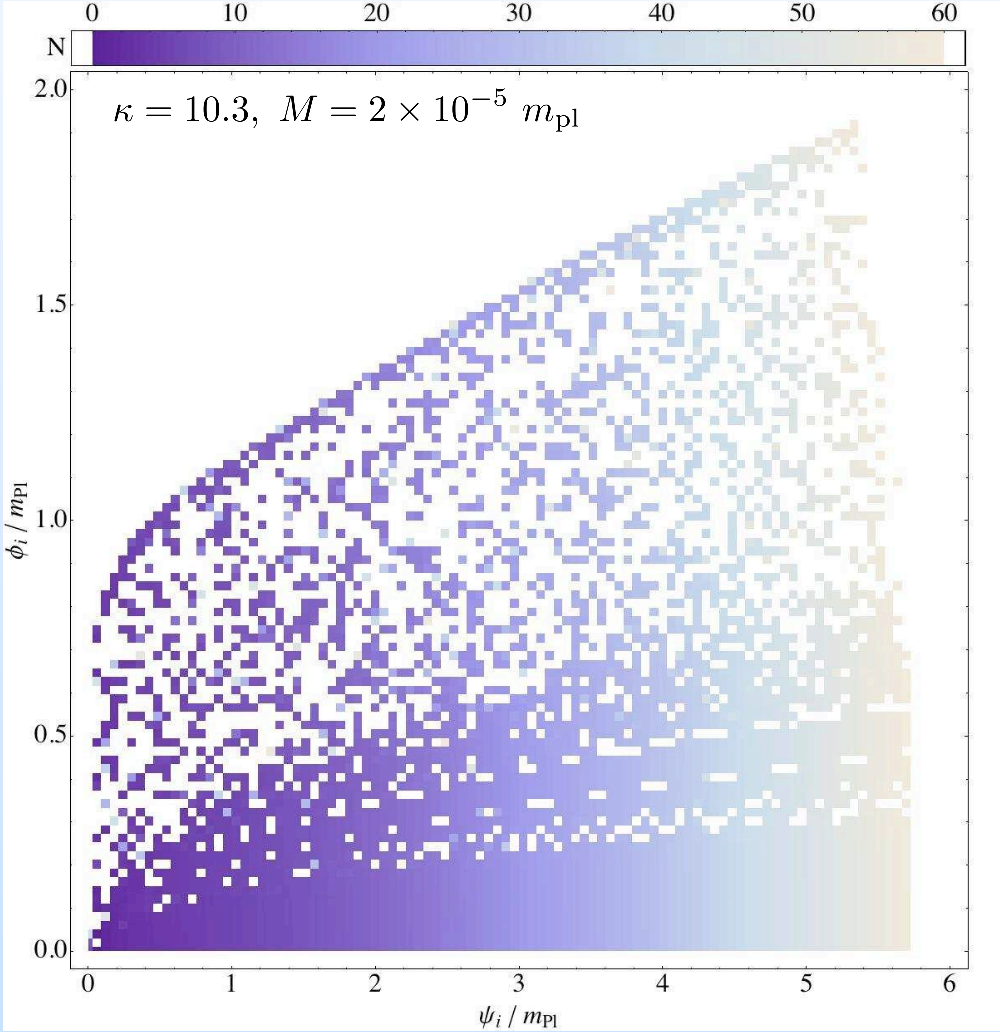
to avoid fine-tuning problem of initial conditions

4. Robustness of predictions

• **Smooth inflation:** *(Lazarides, Panagiotakopoulos, hep-ph/9506325)*

Effective 2-field potential (SUSY): $V(\phi,\psi) = \kappa^2\left(M^2 - \frac{\psi^4}{m_{\rm Pl}^2}\right)^2 + 2\kappa^2\phi^2\frac{\psi^6}{m_{\rm Pl}^4}$

2 valleys and a flat $\psi = 0$ direction ⇒ **No topological defects**



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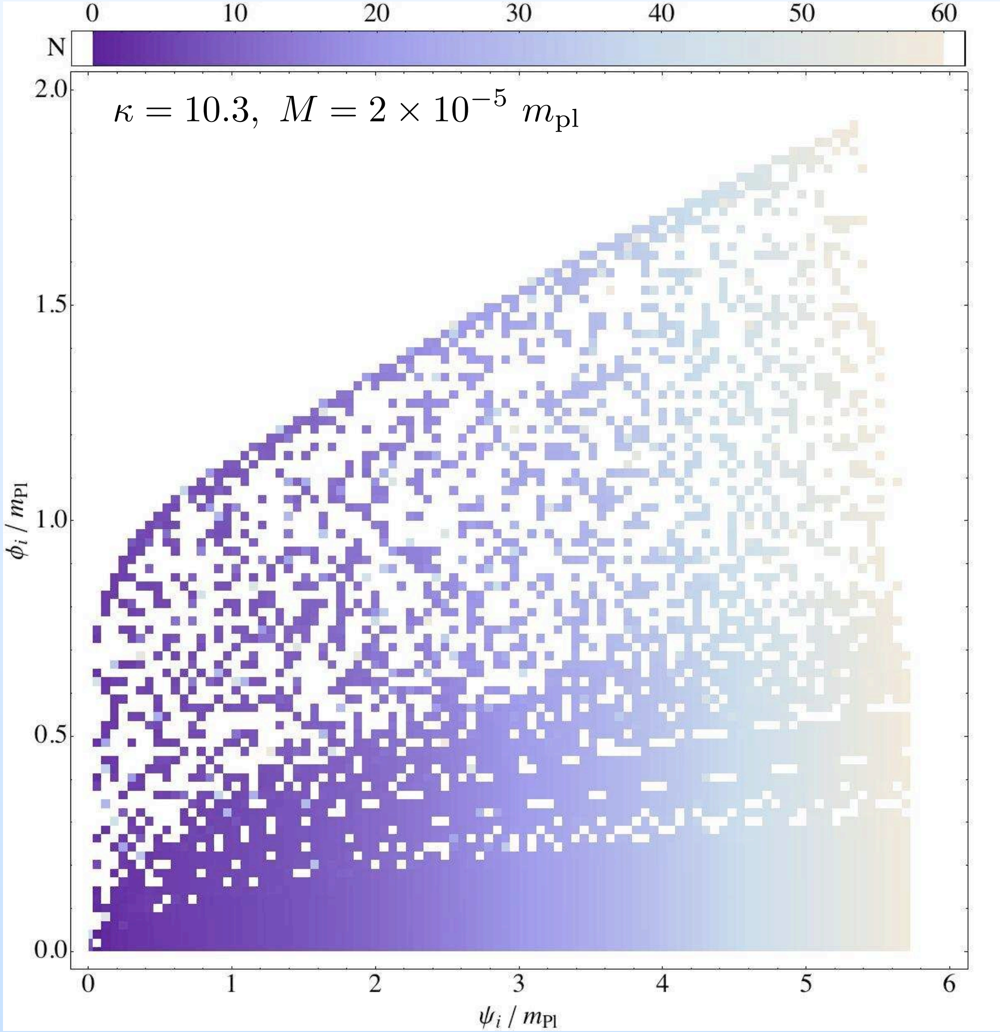

For $\phi, \psi < 0.2\ m_{\rm pl}$

Up to 50% of area are anamorphosis points

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• **Shifted inflation:** *(Jeannerot, Khalil, Lazarides, Shafi, hep-ph/0002151)*

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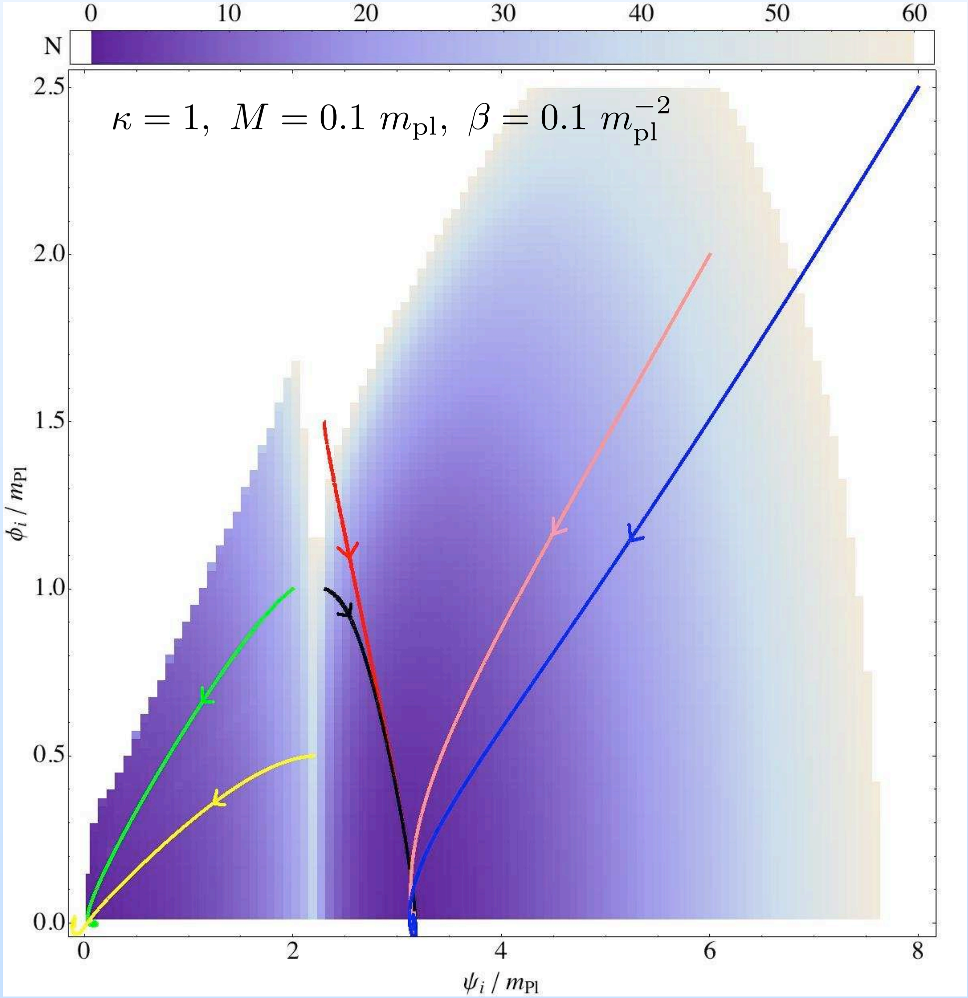
1 central + 2 parallel valleys



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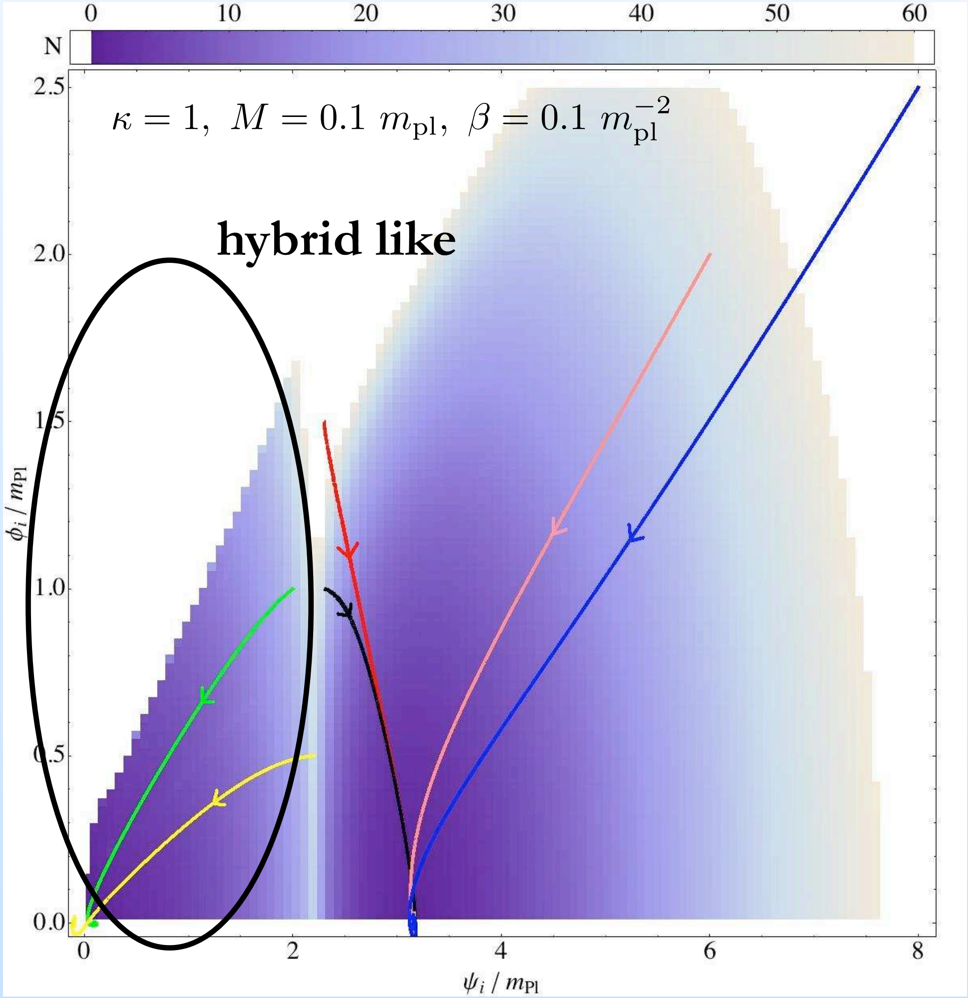

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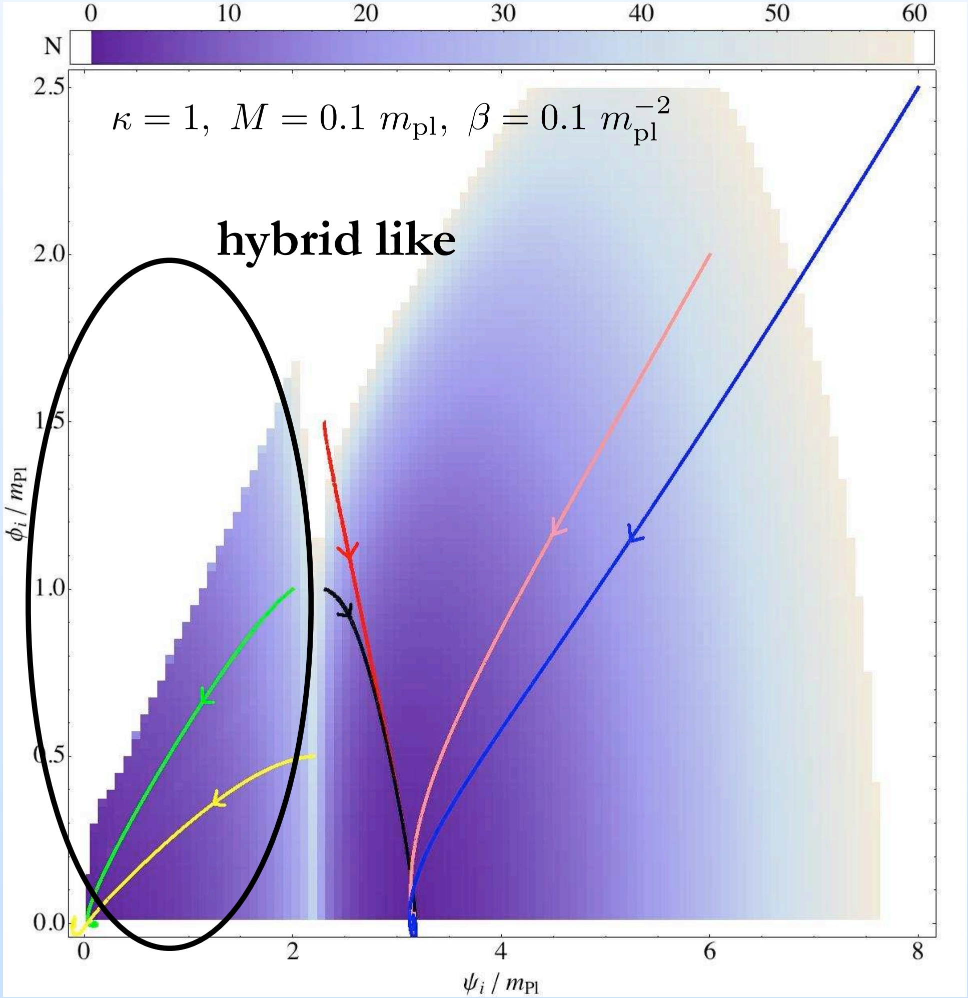


New unsuccessful region around the parallel valley without anamorphosis points

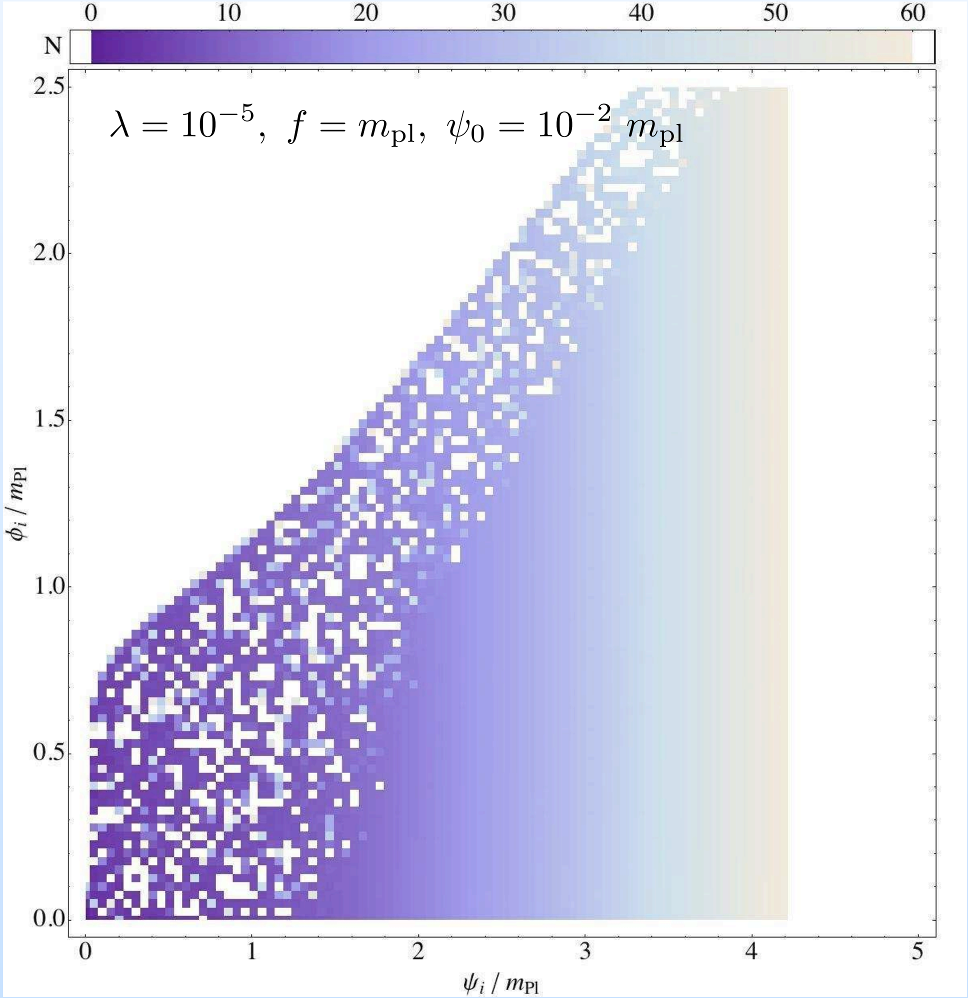
4. Robustness of predictions

• Radion assisted gauge inflation:

(M. Fairbairn, L.Lopez-Honorez, M.Tytgat, hep-ph/0302160)

Effective 2-field potential: $V(\phi,\psi) = \frac{1}{4}\frac{\phi^2}{f^2}\psi^4 + \frac{\lambda}{4}\left(\psi^2 - \psi_0^2\right)^2$

Super-planckian values allowed



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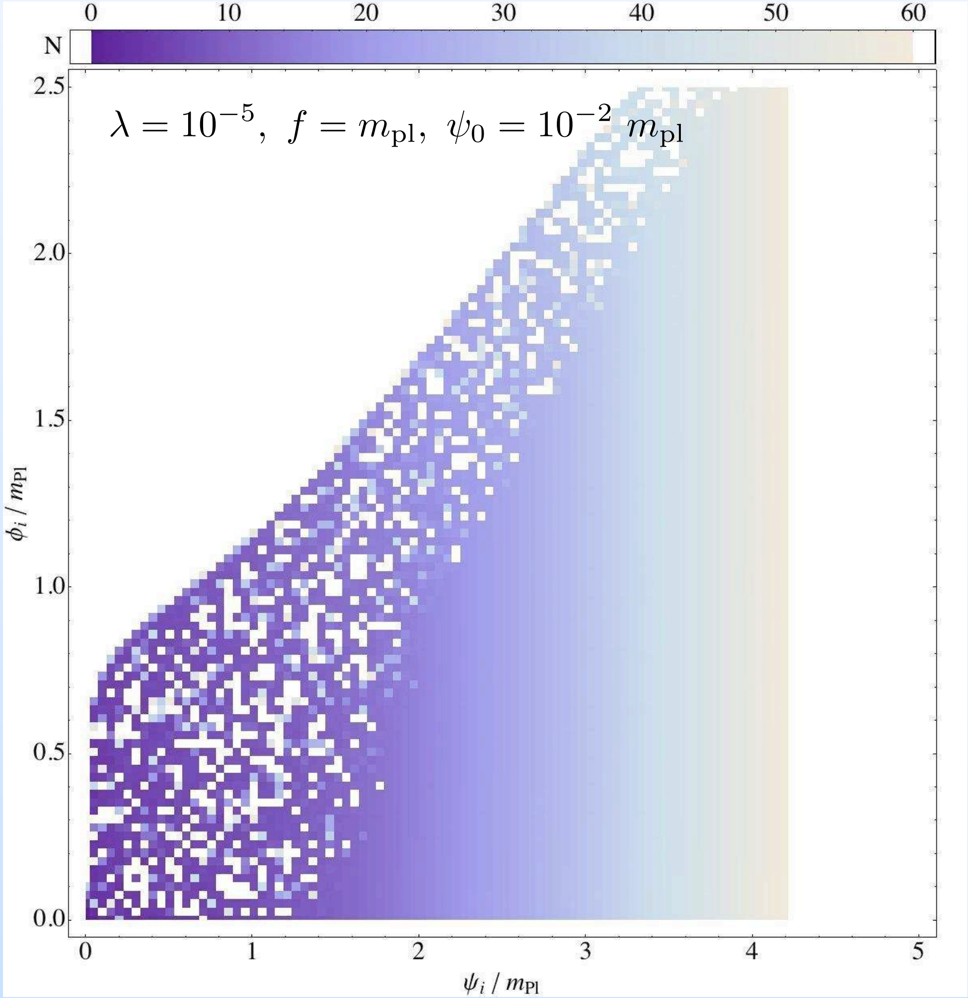

For $\phi, \psi < 0.2\ m_{\rm pl}$

Up to 25% of area are anamorphosis points

5. Conclusions and perspectives

✦ Hybrid inflation:

- Two ways to avoid the fine-tuning problem of initial field values
  - Extend the field-space to super-planckian values
  - Anamorphosis successful points (up to 20 %)

✦ Hybrid-type models:

- Observations seem to be robust
  - Smooth inflation: up to 50% due to anamorphosis
  - Shifted inflation: new unsuccessful zone due to parallel valley
  - Radion inflation: trans-planckian field justified
    up to 25% due to anamorphosis

✦ Perspectives:

- Fine-tuning problem in F-term and D-term inflation ?
- Other hybrid-type models ?
- Effect of initial speeds ?
- Spectral index ?

Thank you for your attention…

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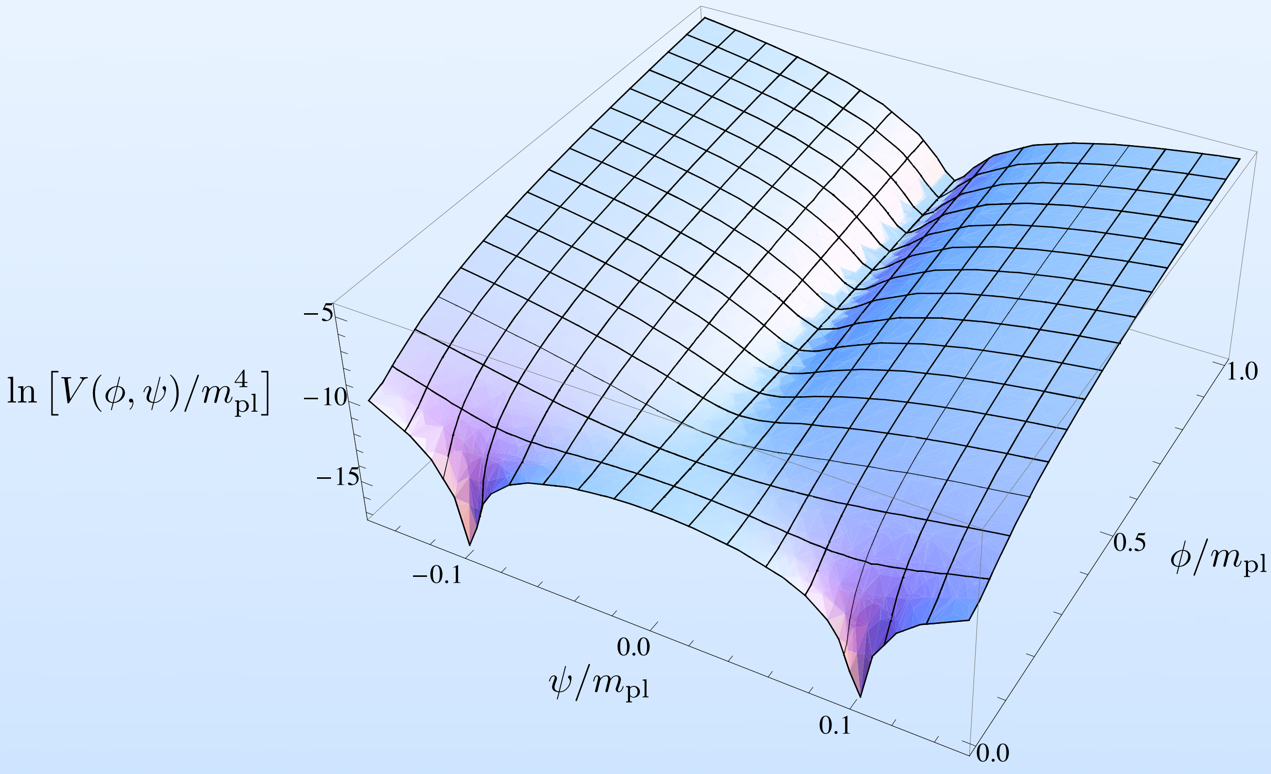

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- **1-field effective potential** $V(\phi) = \Lambda^4\left[1+\left(\frac{\phi}{\mu}\right)^2\right]$
- **First slow-roll parameter** $\epsilon_1 \equiv -\frac{\dot{H}}{H^2}$

inflation: $\epsilon_1 < 1$ **slow-roll approximation:** $\epsilon_1 \ll 1$

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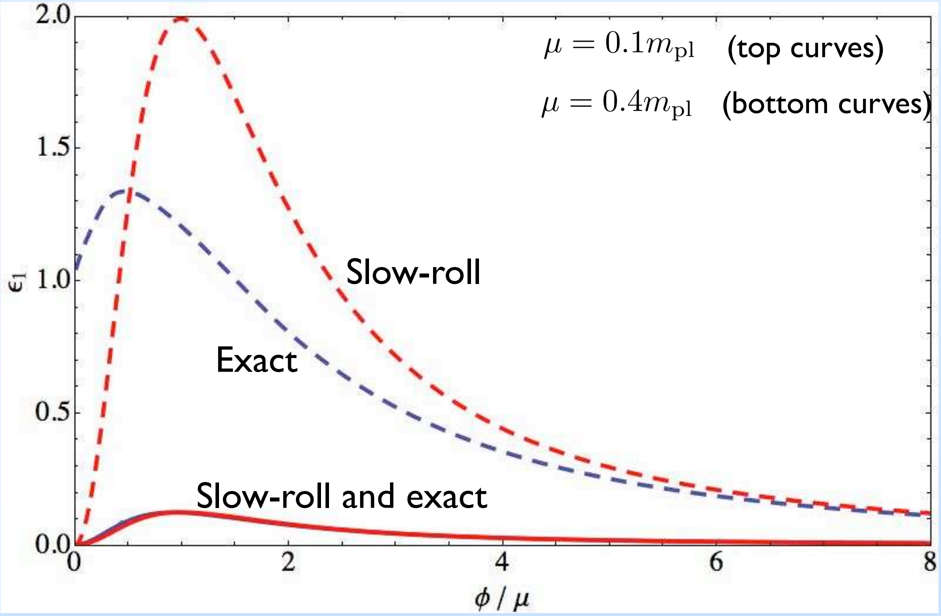


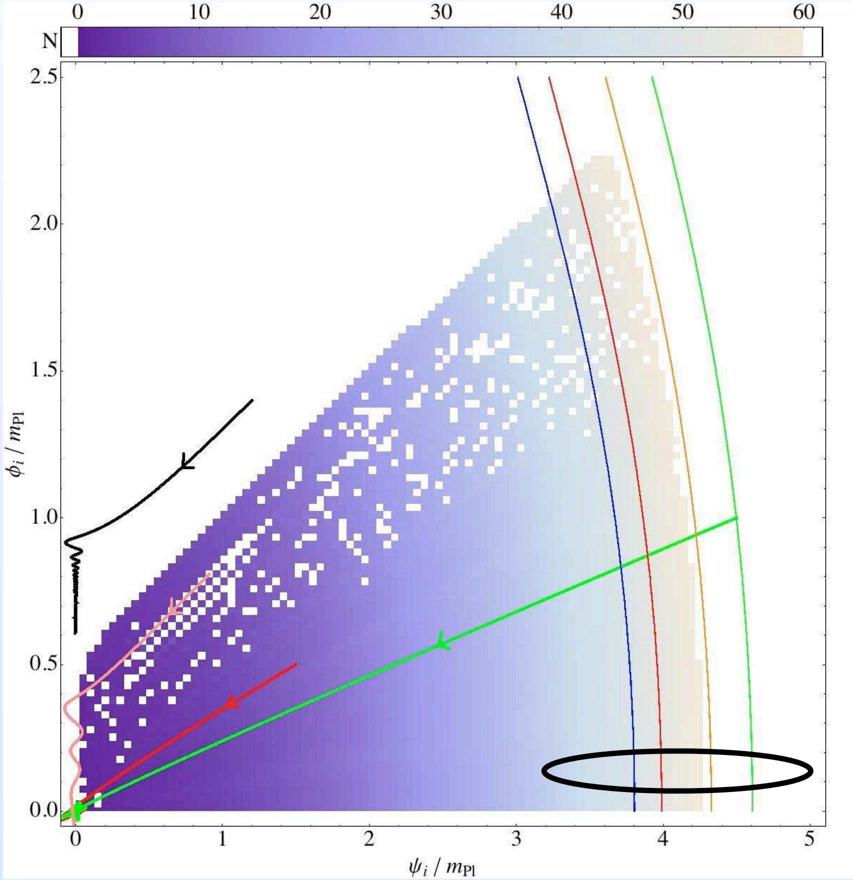
Slow-roll can be violated
⇒ Exact approach

Blue spectrum avoided

- **If critical point of instability is in the large field phase**
- **When slow-roll is violated**

3. How to avoid fine-tuning ?

• Super-Planckian initial conditions:



$\lambda = \lambda' = 1, \;\; M = 0.03 \; m_{\rm pl}, m = 10^{-6} \; m_{\rm pl}$

ϵ_1

$\epsilon_1 = 0.022, 0.020, 0.0167, 0.015$

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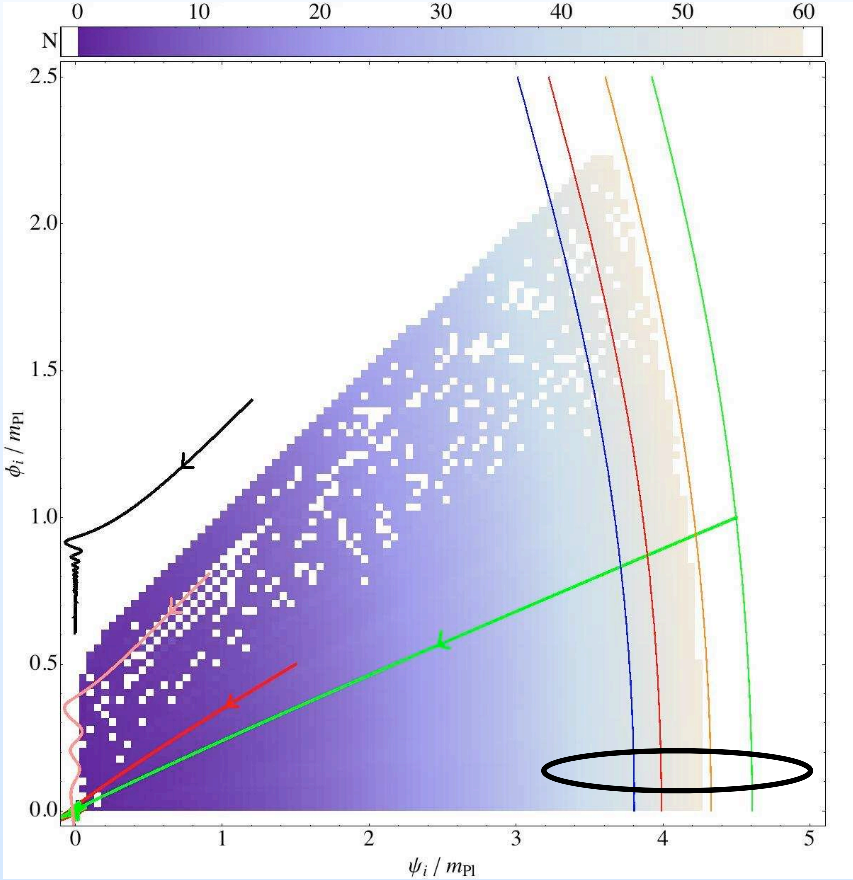

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Variation of potential parameters:

- **λ' reduced**
⇒ slope of the transition reduced
⇒ less "isolated" points
- **M or λ increases**
⇒ less "isolated" points
- **m has no effect until it is small**

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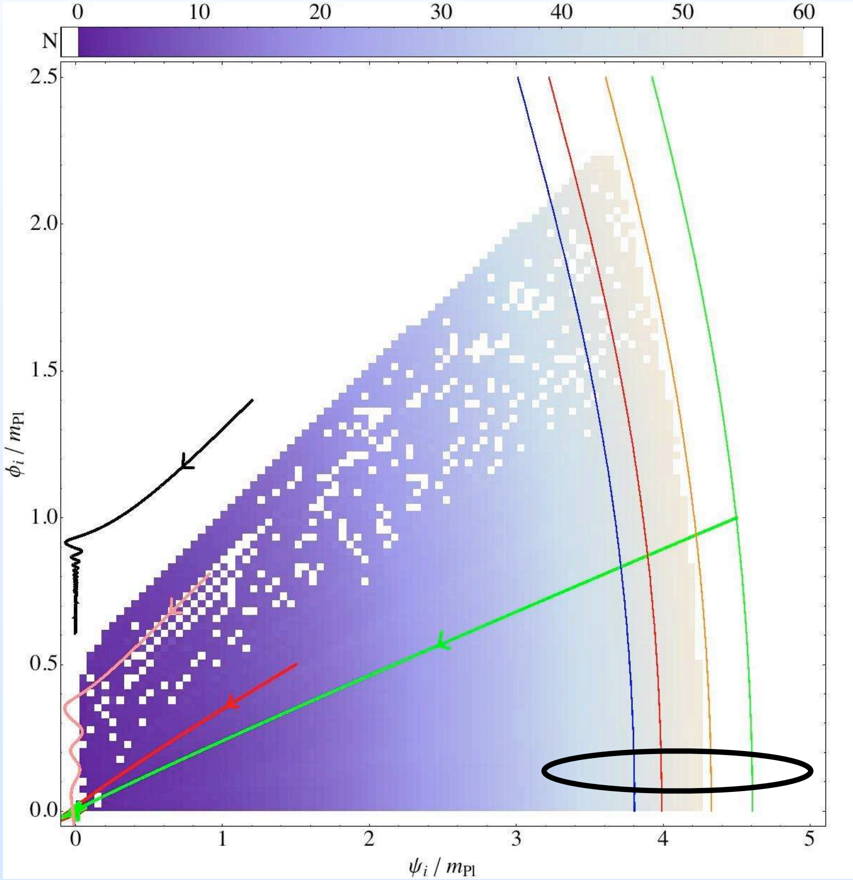

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Isocurves of ϵ_1 (first slow-roll par.)
$\epsilon_1 = 0.022, 0.020, 0.0167, 0.015$
(from left to right)

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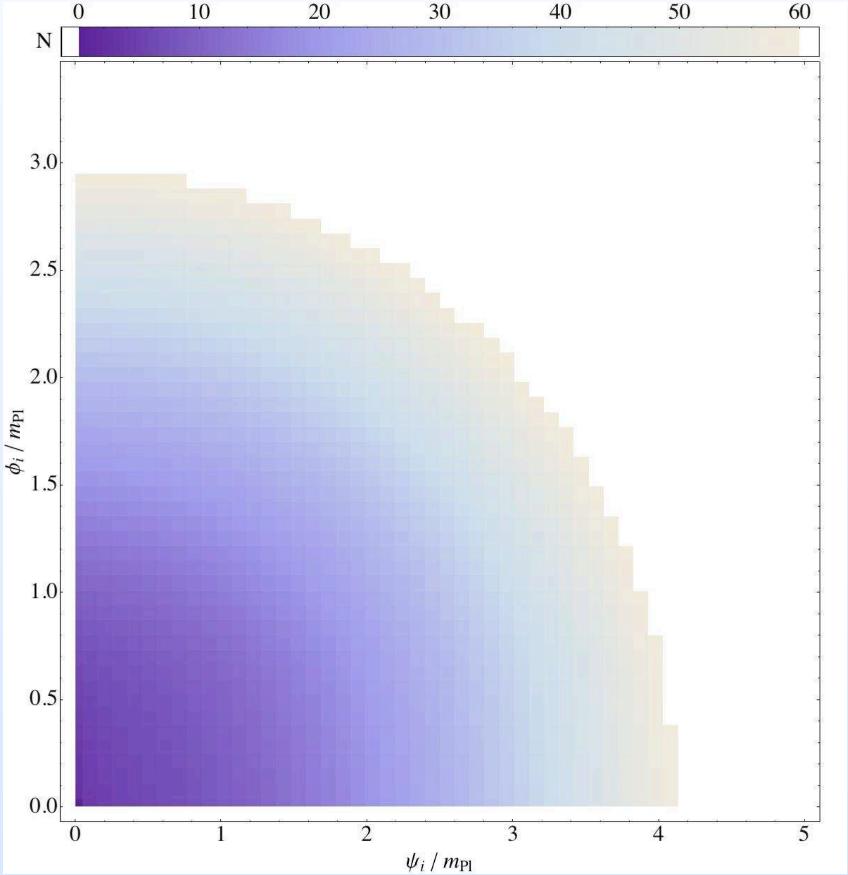

$\lambda = 1,\ \lambda' = 0.01,\ M = m = 0.001\ m_{\rm pl}$

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⇒ "small field" phase disappears due to slow-roll violation
⇒ elliptic unsuccessful region

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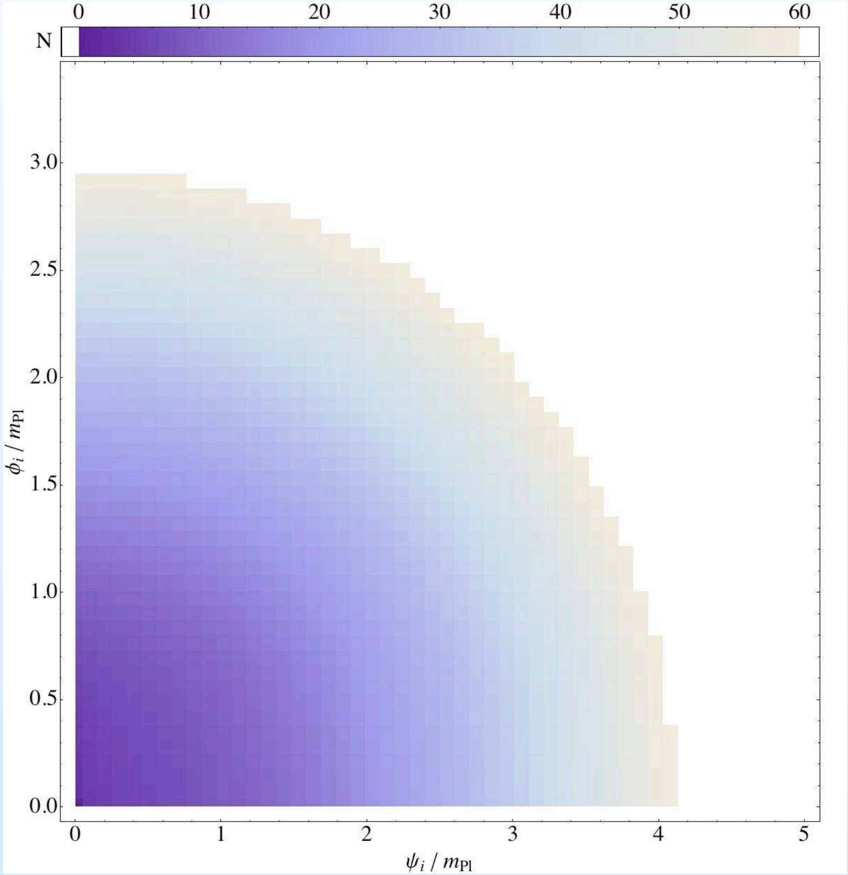

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If super-planckian values are allowed,

The fine-tuning problem is resolved!

1. Hybrid Inflation

2. Fine-tuning of initial conditions

3. How to avoid fine-tuning?

- Super-Planckian Initial Conditions
- Anamorphosis points

4. Robustness of predictions: 3 others models

- Smooth Inflation
- Shifted Inflation
- Radion Inflation

5. Conclusions and Perspectives

Questions...

• Slow-roll violations

• Varying parameters

• Grid with red spectrum prediction

• Shifted and Smooth models

• Radion model

4. Robustness of predictions

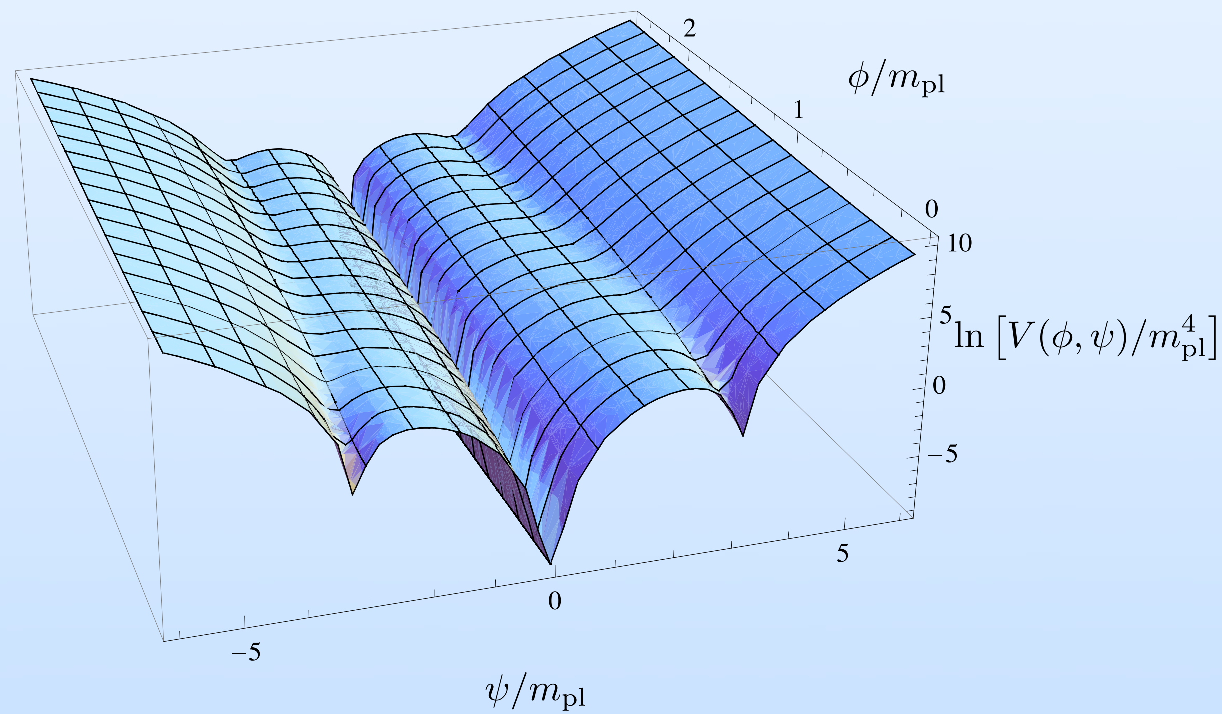
• Shifted inflation:

F-term superpotential + non-renormalizable term

Effective 2-field potential:

$$V(\phi,\psi) = \kappa^2 \left(\psi^2 - M^2 - \frac{\beta}{\kappa}\psi^4\right)^2 + 2\kappa^2\phi^2\psi^2\left(1 - 2\frac{\beta}{\kappa}\psi\right)^2$$

1 central + 2 parallel valleys



4. Robustness of predictions

• Shifted inflation:

F-term superpotential + non-renormalizable term

Effective 2-field potential:

$$V(\phi,\psi) = \kappa^2\left(\psi^2 - M^2 - \frac{\beta}{\kappa}\psi^4\right)^2 + 2\kappa^2\phi^2\psi^2\left(1 - 2\frac{\beta}{\kappa}\psi\right)^2$$

1 central + 2 parallel valleys

• Smooth inflation:

F-term superpotential + non-renormalizable term + Z_2 symmetry

Effective 2-field potential: $V(\phi,\psi) = \kappa^2\left(M^2 - \frac{\psi^4}{m_{\mathrm{Pl}}^2}\right)^2 + 2\kappa^2\phi^2\frac{\psi^6}{m_{\mathrm{Pl}}^4}$

4. Robustness of predictions

• Radion assisted gauge inflation:
(M. Fairbairn, L.Lopez-Honorez, M.Tytgat, hep-ph/0302160)

Gauge-type inflation :

- **φ phase of a Wilson loop wrapped around a compact 5th dim.**
- **Super-planckian values allowed**
- **Varying radius R of the extra-dimension** $\psi \equiv (2\pi R)^{-1}$

Effective 2-field potential: $$V(\phi,\psi) = \frac{1}{4}\frac{\phi^2}{f^2}\psi^4 + \frac{\lambda}{4}\left(\psi^2 - \psi_0^2\right)^2$$

2 valleys and a flat $\psi = 0$ direction

4. Mendes and Liddle set of parameters

Mendes, Liddle, astro-ph/0006020

$\lambda = \lambda' = 1, \; M = 0.004 \; m_{\rm pl}, m = 10^{-6} \; m_{\rm pl}$