Multi-field α-attractor in fundamental theory

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Outline

1. inflation

2. dark matter

$$ds^2 = \frac{3\alpha(dr^2 + r^2 d\theta^2)}{1 - r^2}$$

$$ds^2 = \frac{3\alpha(d\tau^2 + d\chi^2)}{4\tau^2}$$

$$r = \tanh\left(\frac{\phi}{\sqrt{6\alpha}}\right)$$

$$\tau = e^{-\sqrt{\frac{2}{3\alpha}}\varphi}$$

$$V(r) \sim V(0)(1 - ae^{-\sqrt{\frac{2}{3\alpha}}\phi} + \cdots)$$

$$V(\tau) \sim V(0)(1 - \tilde{a}e^{-\sqrt{\frac{2}{3\alpha}}\varphi} + \cdots)$$

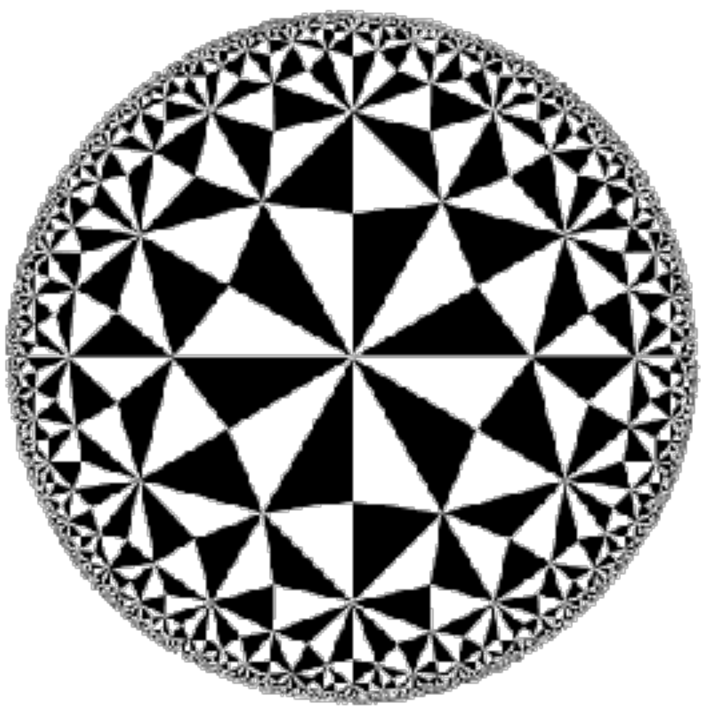
Outline

1. **inflation**

2. **dark matter**

α-attractor from fundamental theory

Hyperbolic geometry



From

M-theory/11D supergravity
➡ 4D N=8 supergravity

superstring
➡10D supergravity on $T_2 \times T_2 \times T_2$

4D N=1 supergravity reduction

$$\mathcal{L} \supset \sum_{i=1}^{7} \frac{\partial\tau_i \partial\tau_i + \partial\chi_i \partial\chi_i}{4\tau_i^2}$$

7-disk moduli with $\alpha_i = \frac{1}{3}$

Merger of α-attractors

We find α=1/3 (r~0.001) in fundamental theory

Is it possible to have r > 0.001?

$$r = \frac{12\alpha}{N^2}$$

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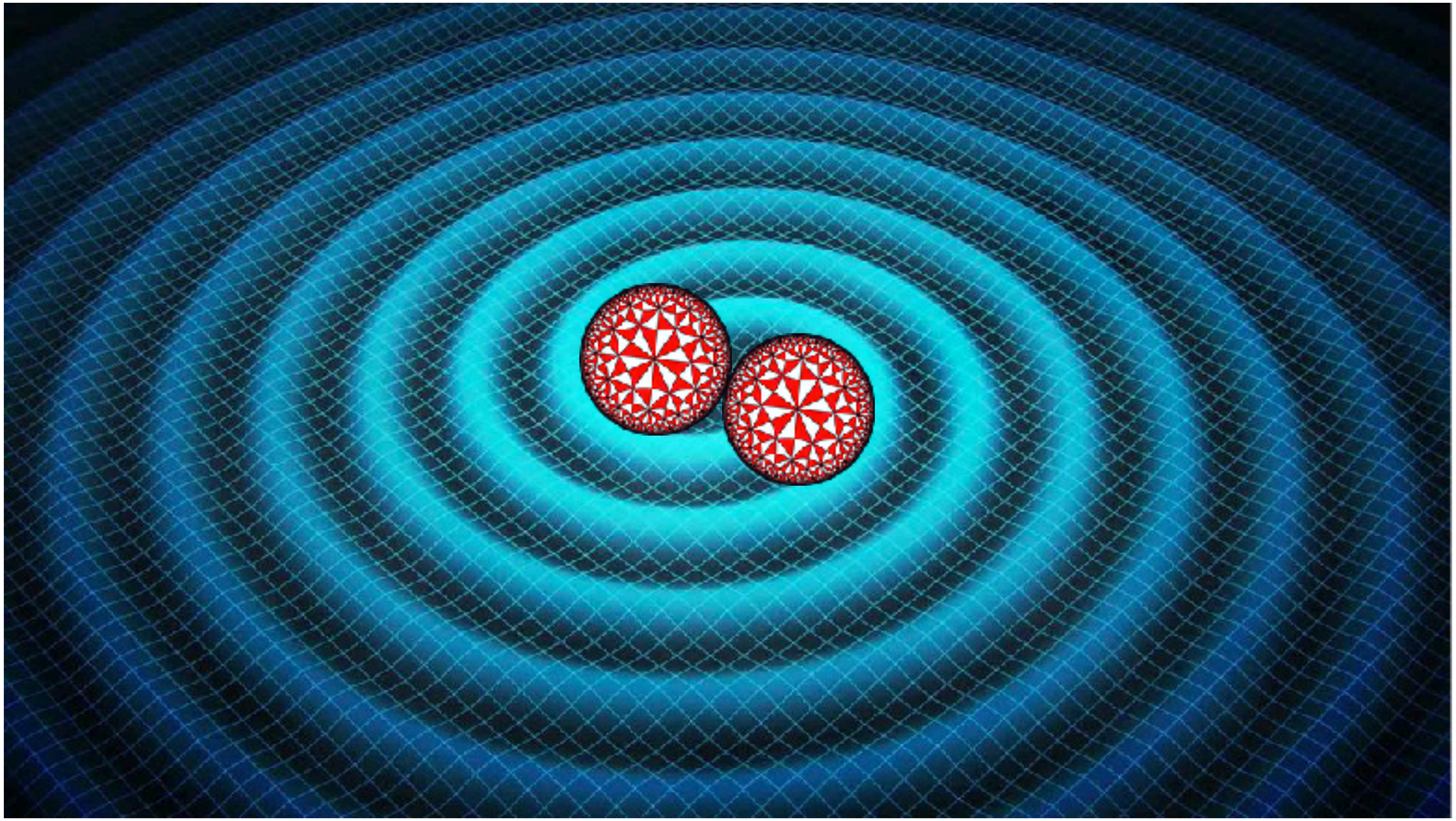


Merger of α-attractors

We find α=1/3 (r~0.001) in fundamental theory

Is it possible to have r > 0.001?

$$r = \frac{12\alpha}{N^2}$$

$$\mathcal{L} = -\frac{3\alpha_1}{4\tau_1^2}\partial\tau_1\partial\tau_1 - \frac{3\alpha_2}{4\tau_2^2}\partial\tau_2\partial\tau_2 - V$$

S. Ferrara, R. Kallosh (2016)
R. Kallosh, A. Linde, T. Wrase, YY (2017)

if $\tau_1 = \tau_2 = \tau$

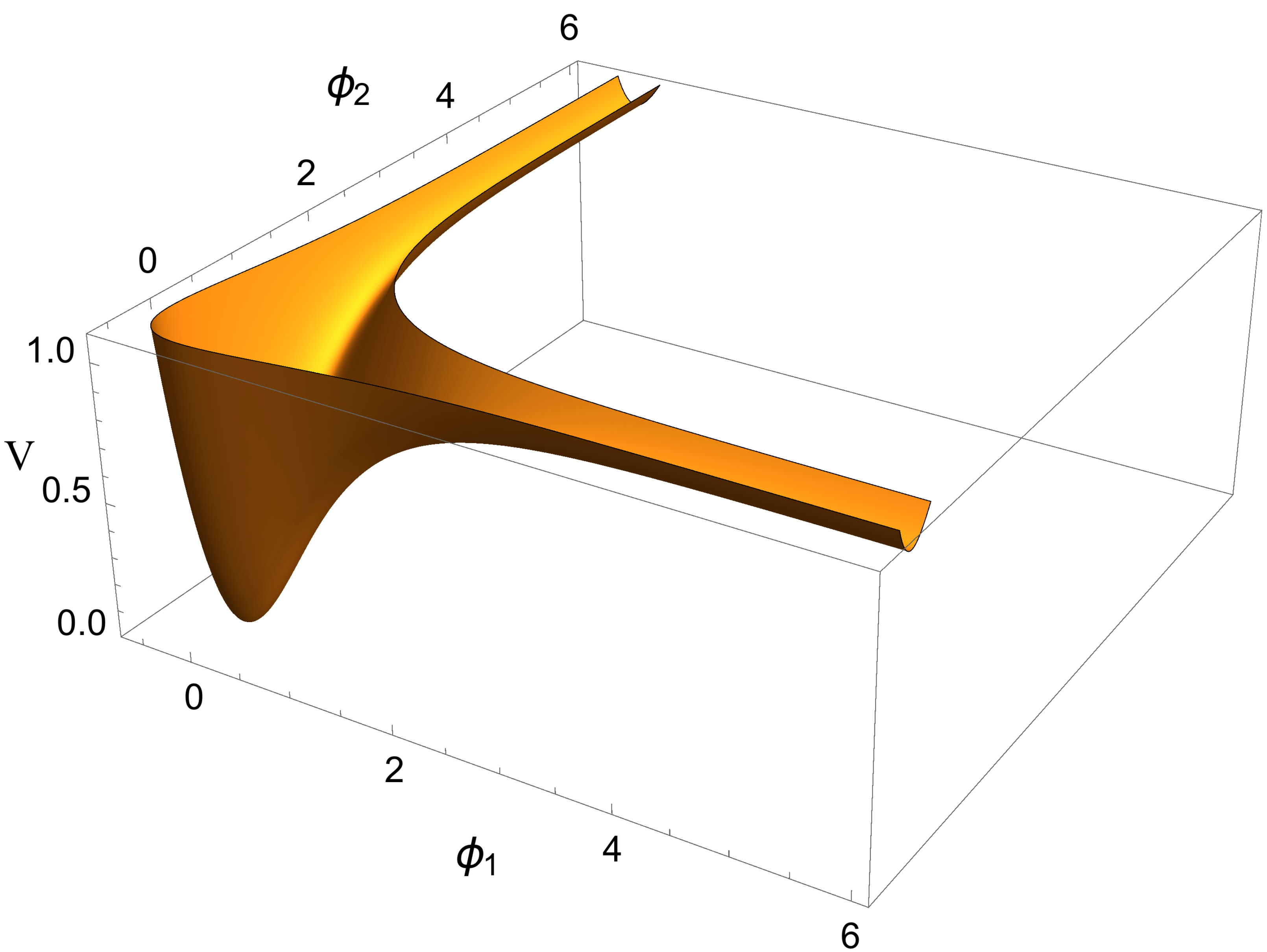
$$\mathcal{L} = -\frac{3(\alpha_1 + \alpha_2)}{4\tau^2}\partial\tau\partial\tau - V$$

Effective value increases!

Merger of α-attractors

e.g. $V = m^2|1 - T_1|^2 + m^2|1 - T_2|^2$

$T_i = \tau_i + i\chi_i$ **For** $\alpha_1 = \alpha_2 = \frac{1}{3}$ $\tau_i = e^{-\sqrt{2}\phi_i}$ $\chi_i = 0$



Merger of α-attractors

e.g. $V = m^2|1 - T_1|^2 + m^2|1 - T_2|^2 + M^2|T_1 - T_2|^2$

$$m \ll M$$

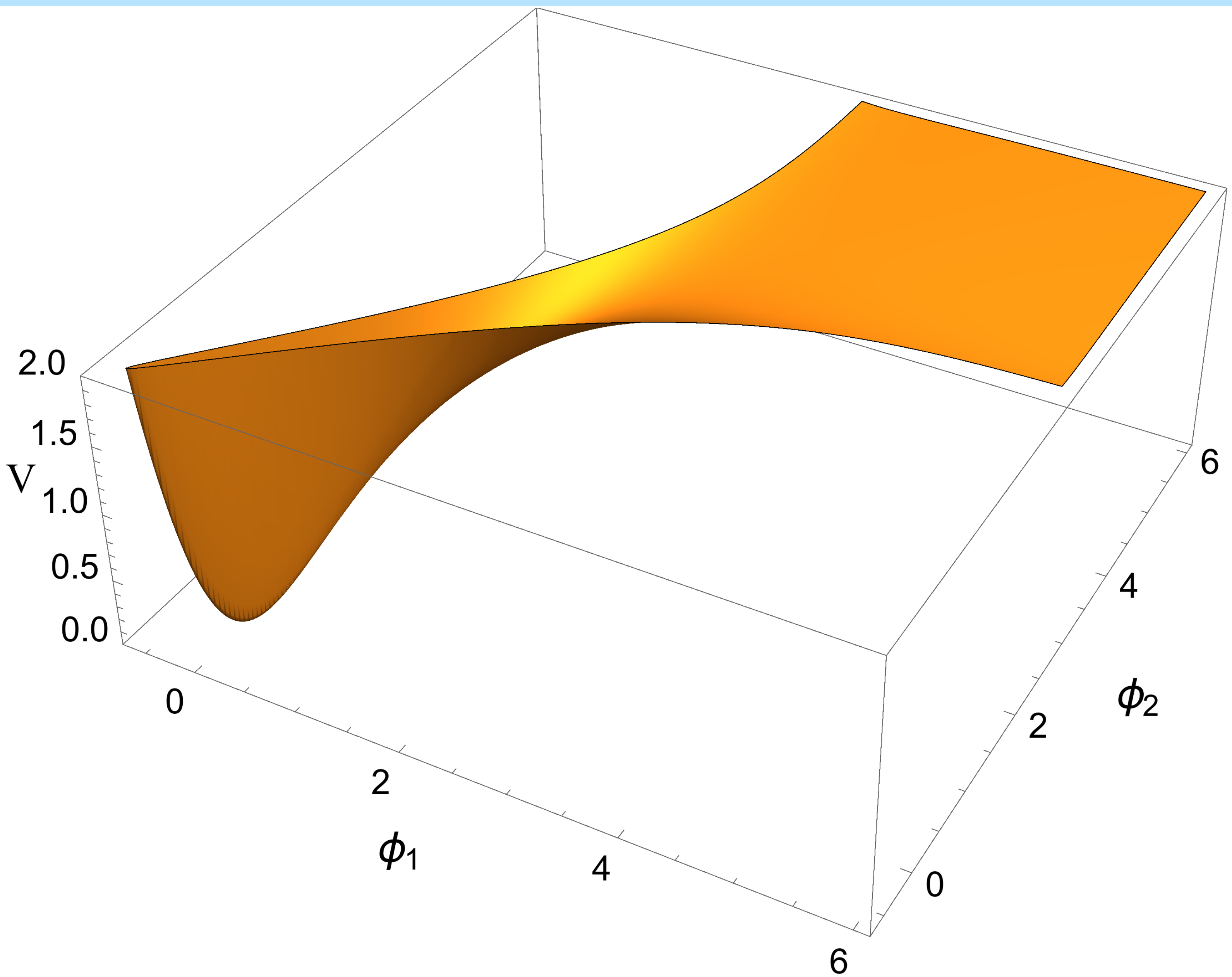
Inflation takes place along $T_1 = T_2$ $\quad \tau_1 = \tau_2 \rightarrow \alpha_{\rm eff} = \alpha_1 + \alpha_2$

Two directions merge

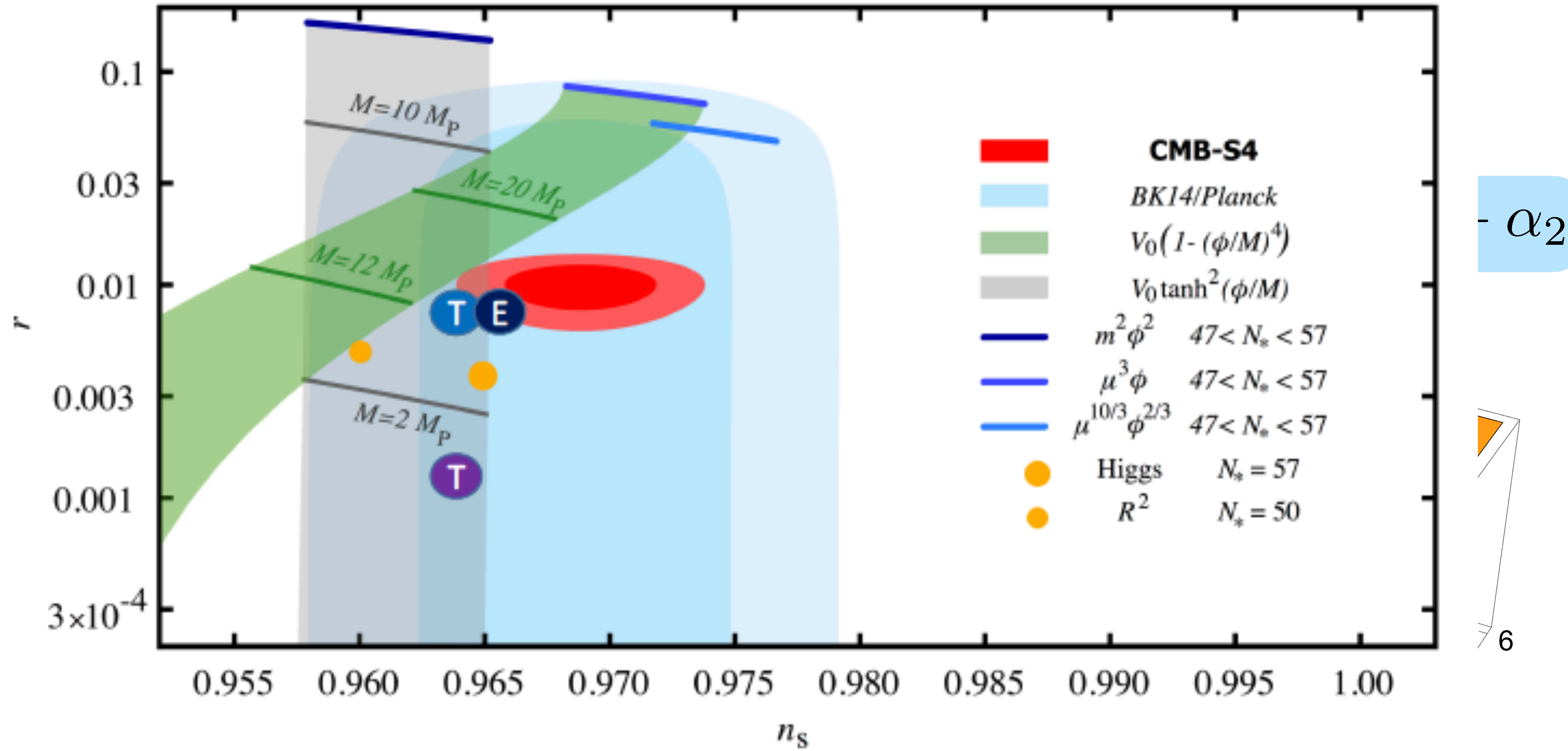
$$\alpha_1 = \alpha_2 = \frac{1}{3}$$

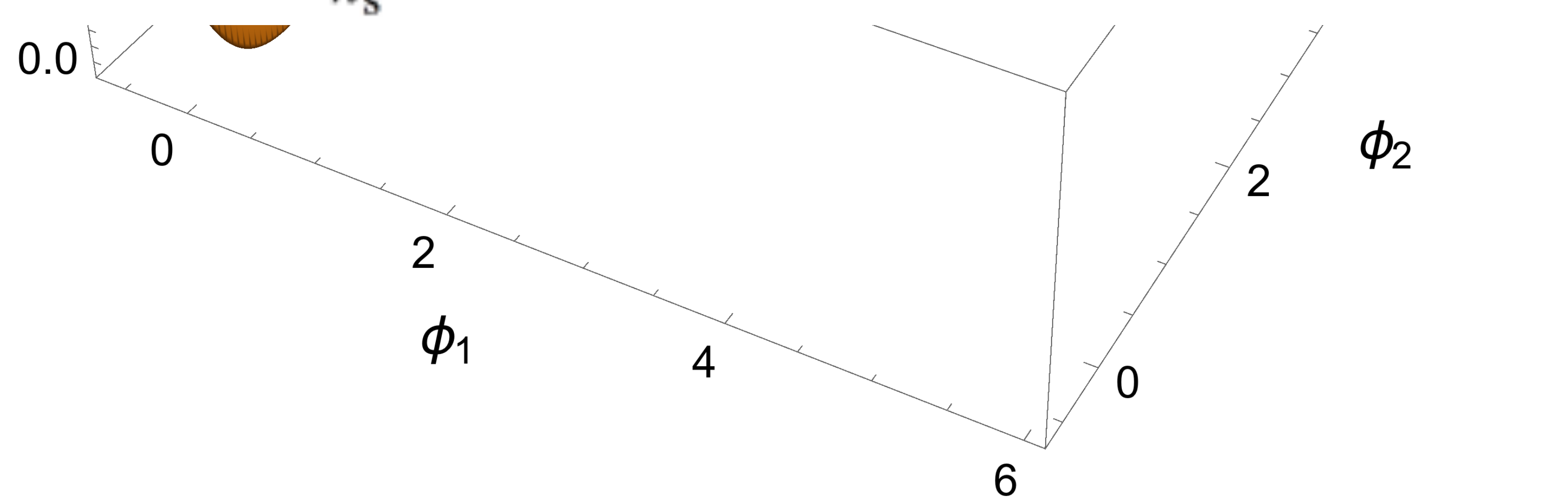
$$T_i = \tau_i + i\chi_i$$

$$\chi_i = 0 \quad \tau_i = e^{-\sqrt{2}\phi_i}$$



Merger of α-attractors





$\chi_i = 0 \quad \tau_i = e^{-\sqrt{2}\phi_i}$

Merger of α-attractors

More general merger $\tau_1 = \tau_2^p$ takes place in string theory:
Fibre inflation C.P. Burgess, M. Cicoli, F. Quevedo (2008)

$$\mathcal{L} \sim -\frac{\partial\tau_1\partial\tau_1}{4\tau_1^2} - \frac{2\partial\tau_2\partial\tau_2}{4\tau_2^2} - V$$

Moduli = (6D) CY volume: $\tau_1\tau_2^2 \sim \mathcal{V}^2$ $\mathcal{V}:$ Calabi-Yau volume

Coupling to other sector stabilizes the volume: $\mathcal{V} = const$

Generalized merger: $\tau_1 \sim \tau_2^{-2}$ $-\frac{\partial\tau_1\partial\tau_1}{4\tau_1^2} - \frac{2\partial\tau_2\partial\tau_2}{4\tau_2^2} \sim -\frac{6\partial\tau_2\partial\tau_2}{4\tau_2^2}$

R. Kallosh, A. Linde, D. Roest, A. Westphal, YY (2017)

$$\alpha_1 = \frac{1}{3},\ \alpha_2 = \frac{2}{3} \rightarrow \alpha_{\rm eff} = 2$$

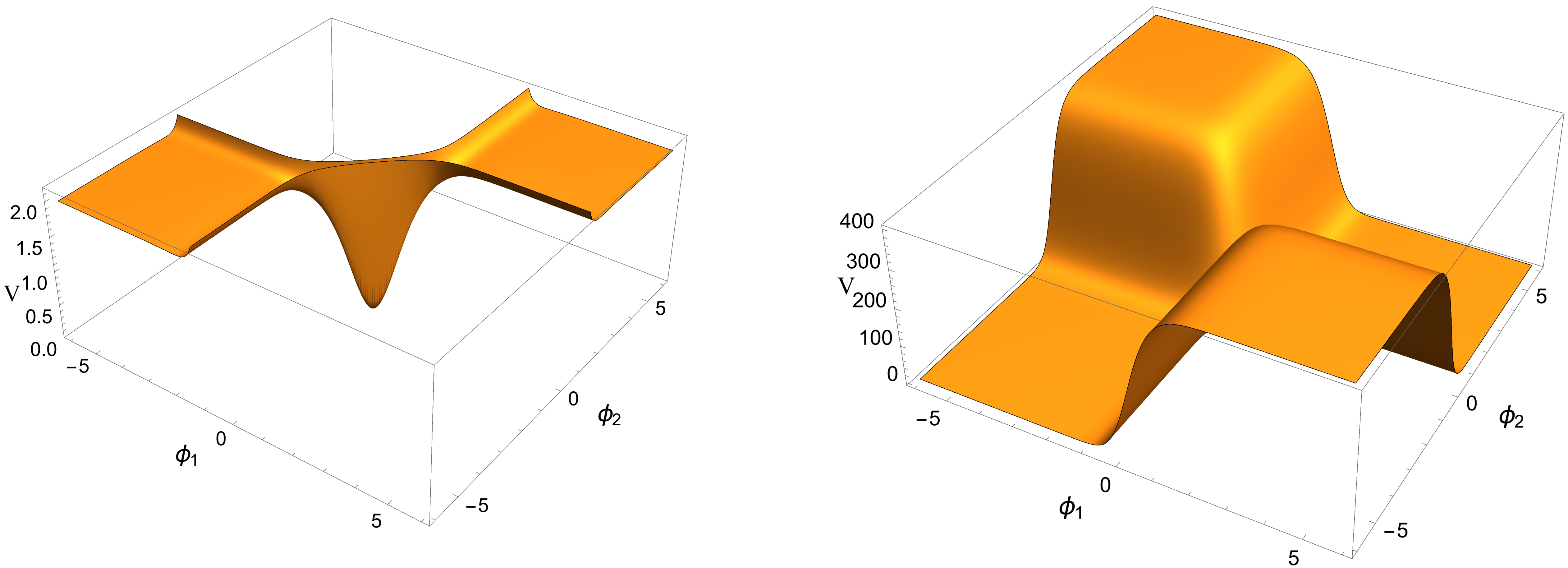
Merger of α-attractors may have important meanings in fundamental theories

Cascade inflation

R. Kallosh, A. Linde, D. Roest, YY (2017)

$$V = V_{\rm inf} + V_{\rm merger} \qquad V_{\rm merger} = V_{\rm merger}\left(e^{-\sqrt{\frac{2}{3\alpha_1}}\phi_1},\ e^{-\sqrt{\frac{2}{3\alpha_2}}\phi_2}\right)$$

Two (or more) inflationary region with different heights

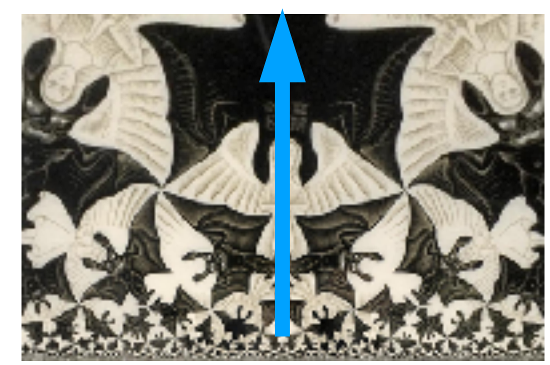


Application to
Initial condition problem, Dark energy, low-l power suppression etc.

R. Kallosh, A. Linde, D. Roest, YY (2017) Y. Akrami et al (2017) T. Fujita, S. Mizuno, YY, work in progress

Outline

1. inflation



2. dark matter

Axions in α-attractor

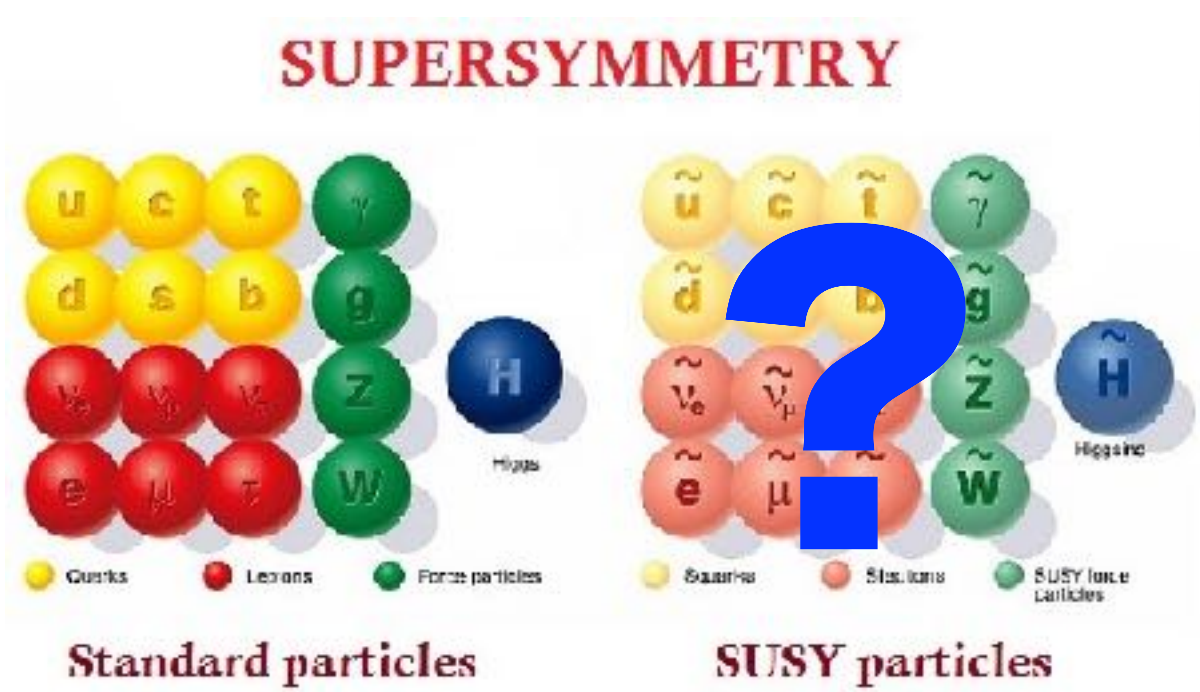
some issues of low scale supersymmetry (breaking)

- **LHC has not yet discovered**
- **Cosmological problems (e.g. gravitino/moduli)**
- **Decompactification problem in string models (KKLT/LVS)**

R. Kallosh, A. Linde (2004)
J. Conlon, R. Kallosh, A. Linde, F. Quevedo (2008)

a simple solution to these issues: $m_{3/2} \geq H$

What can be dark matter?



Axions in hyperbolic geometry

Axions in α-attractor

$$ds^2 = \frac{3\alpha dT d\bar{T}}{(T+\bar{T})^2} \qquad ds^2 = \frac{3\alpha dZ d\bar{Z}}{(1-Z\bar{Z})^2}$$

$$T = \tau + i\chi \qquad Z = re^{i\theta}$$

$$\chi \to \chi + c \qquad \theta \to \theta + \eta$$

(nonlinear) U(1) symmetry ➡ (light) axion field

Light axion & α-attractor inflation

$$\mathcal{L} = -\frac{3\alpha \partial T \partial \bar{T}}{(T+\bar{T})^2} - V(T+\bar{T}) \qquad \mathcal{L} = -\frac{3\alpha \partial Z \partial \bar{Z}}{(1-Z\bar{Z})^2} - V(Z\bar{Z})$$

small correction (~ axion potential) gives an axion mass

Axions in α-attractor

θ

χ

$$Z = re^{i\theta}$$

$$T = \tau + i\chi$$

Suppression of isocurvature perturbation

CDM = axion oscillation

Isocurvature perturbation

$$P_{\mathcal{S}} = \left(\frac{\delta \Omega_a}{\Omega_a} \right)^2 \propto f_a^2 \langle \delta \theta_*^2 \rangle$$

Constraint on isocurvature perturbation

$$P_{\mathcal{S}} < 0.03 P_\zeta$$

P. A. R. Ade et al. [Planck collaboration] (2015)

usual case: $\langle (f_a \delta \theta_*)^2 \rangle = \left(\frac{H}{2\pi} \right)^2$

e.g. for QCD axion

$$H_{\rm inf} < 0.86 \times 10^7 \mathrm{GeV} \left(\frac{f_a}{10^{11} \mathrm{GeV}} \right)^{0.408}$$

P. A. R. Ade et al. [Planck collaboration] (2015)

Suppression of isocurvature perturbation

$$\mathcal{L} = -\frac{1}{2}\partial\phi\partial\phi - \frac{3\alpha}{4}\sinh^2\left(\sqrt{\frac{2}{3\alpha}}\phi\right)\partial\theta\partial\theta - V(\phi)$$

Y. Ema, K.Hamaguchi, T. Moroi, K. Nakayama (2016)
A. Linde, YY, work in progress

axion has large kinetic coefficient

$$\langle (f_a\delta\theta_*)^2\rangle = \left(\frac{f_a}{f_*}\right)^2 \langle (f_*\delta\theta_*)^2\rangle = \left(\frac{f_a}{f_*}\right)^2\left(\frac{H}{2\pi}\right)^2$$

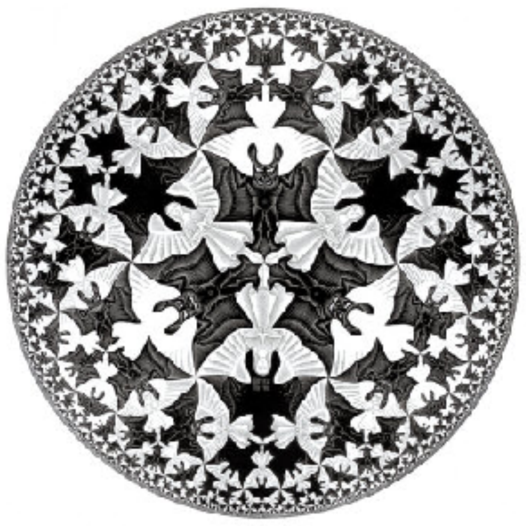
*** cano. axion (today)**

$$a = f_a\theta$$

where $f_*^2 = \frac{3\alpha}{2}M_{\rm pl}^2\sinh^2\left(\sqrt{\frac{2}{3\alpha}}\phi_*\right) \sim \frac{8N^2M_{\rm pl}^2}{3\alpha}$

c.f. usual case $\langle (f_a\delta\theta_*)^2\rangle = \left(\frac{H}{2\pi}\right)^2$

**Compared with the usual case,
quantum fluctuation is extremely suppressed**



Summary

Multiple hyperbolic moduli from fundamental theory

Merger of α-attractors

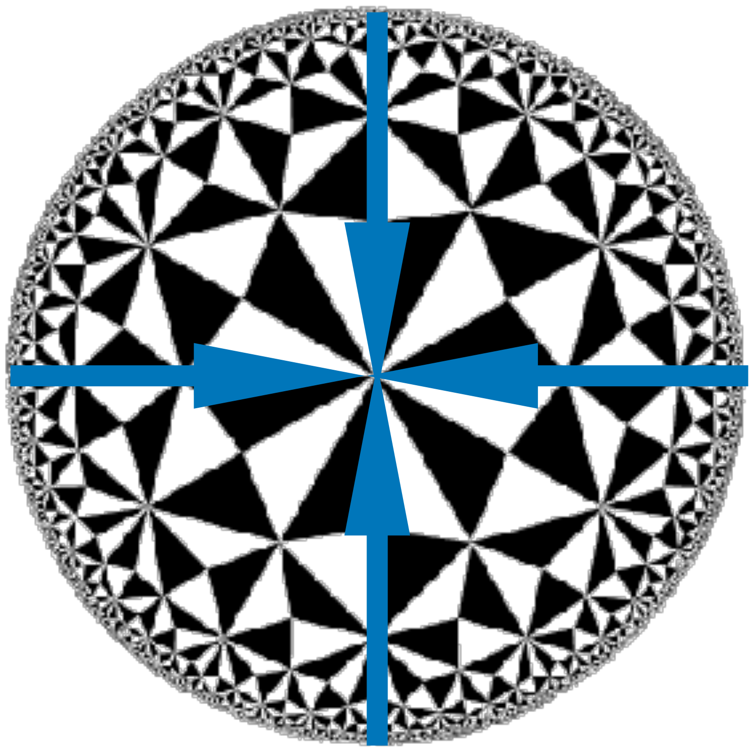
- **increases PGW amplitude**
- **is realized as e.g. moduli stabilization of extra dim.**
- **leads to cascade inflation**

Axions in hyperbolic geometry is a good dark matter candidate:

- **It can be naturally light even for high SUSY breaking**
- **Isocurvature perturbation is suppressed by geometric effect**
- **If U(1) = PQ sym., strong CP is also solved**

Various mysteries (DM, DE, strong CP…etc) might be explained by (multiple) hyperbolic moduli field!

Appendix



U(1) symmetric α-attractor

Coupling α-attractor to SUSY breaking field
No superpotential for inflaton-axion multiplet
U(1) symmetric Kahler potential

YY (2018)

$$K = K(T+\bar{T}, S, \bar{S}) \quad \textbf{or} \quad K = K(Z\bar{Z}, S, \bar{S})$$

$$W = W_0(1+S)$$

inflaton potential purely from ~~SUSY~~

$$V|_{S\text{-fixed}} = V(T+\bar{T}) \text{ or } V(Z\bar{Z})$$

Mass splitting between inflaton and axion due to SUSY

axion potential is introduced as small correction