Inflation and Dark Energy from α-Attractors

Marco Scalisi

Van Swinderen Institute - RUG

university of groningen

based on

"Inflation, de Sitter Landscape and Super-Higgs Effect"
[arXiv: 1411.5671] R. Kallosh, A. Linde and MS

"Cosmological Attactors from α-scale Supergravity"
[arXiv: 1503.07909] D. Roest and MS

"Cosmological α-Attactors and de Sitter Landscape"
[arXiv: 1506.01368] MS

September 10th, 2015 - COSMO - Warsaw

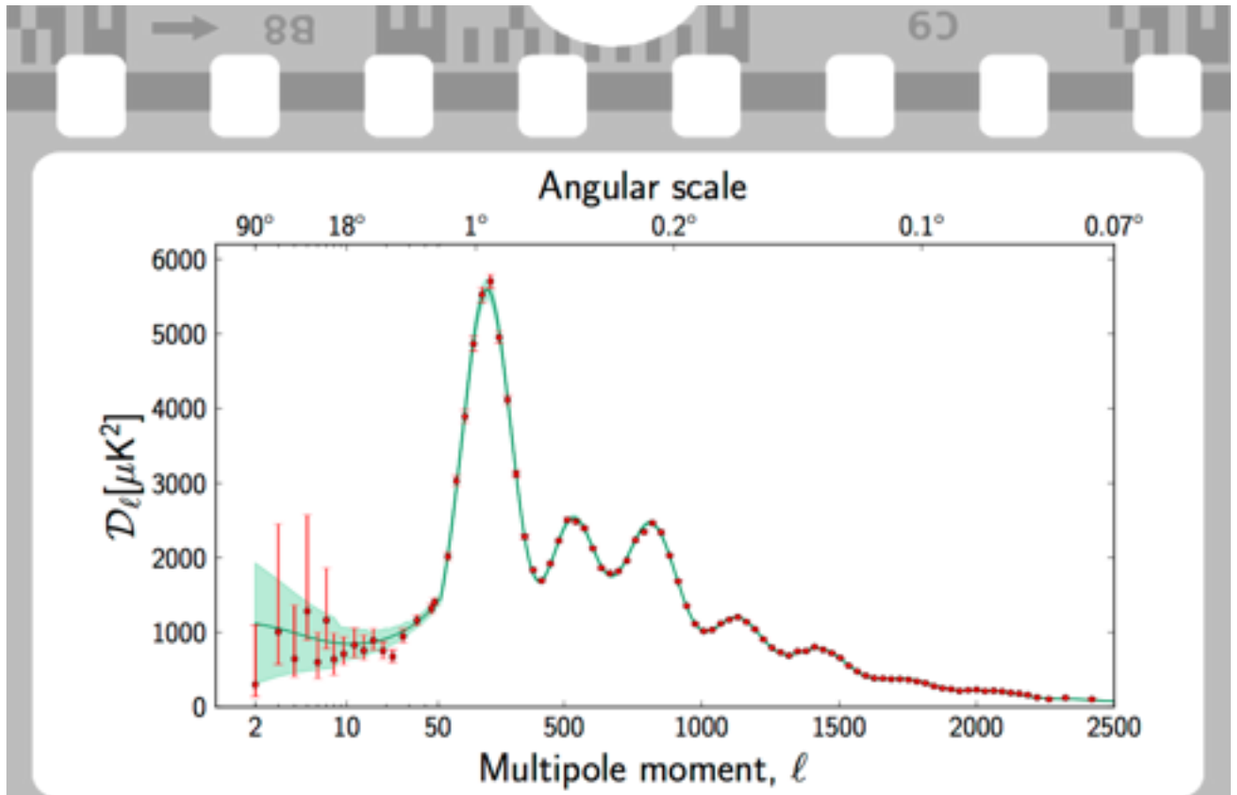
outline

1. A snapshot of our Universe

2. Embedding in UV physics scenarios

3. Cosmology of α-Attractors

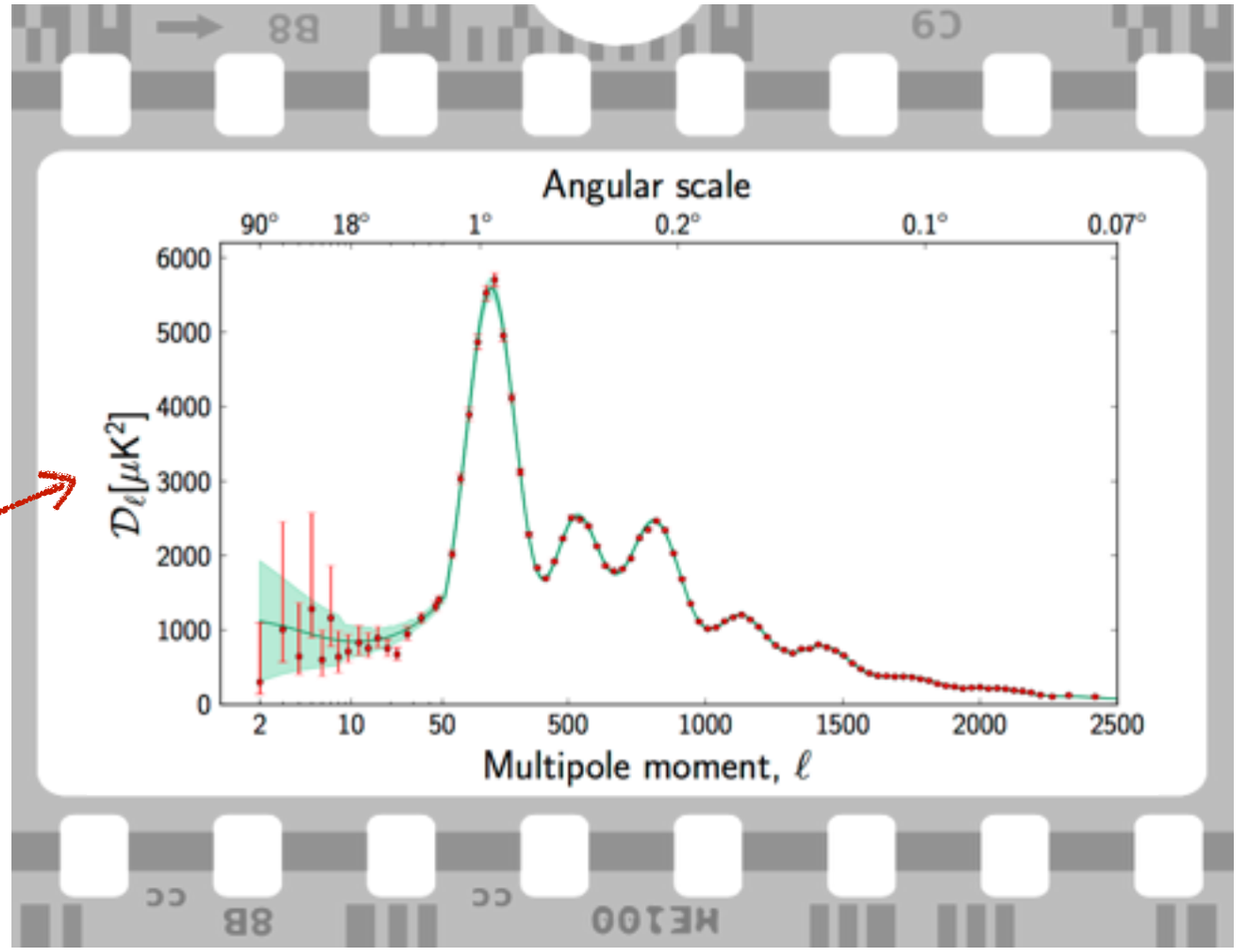
A snapshot of our Universe


Angular scale
90°
18°
1°
0.2°
0.1°
0.07°
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell[\mu K^2]$
2
10
50
500
1000
1500
2000
2500
Multipole moment, ℓ

homogeneous

temperature fluctuations are small

$$\Delta T \lesssim 10 \mu K$$



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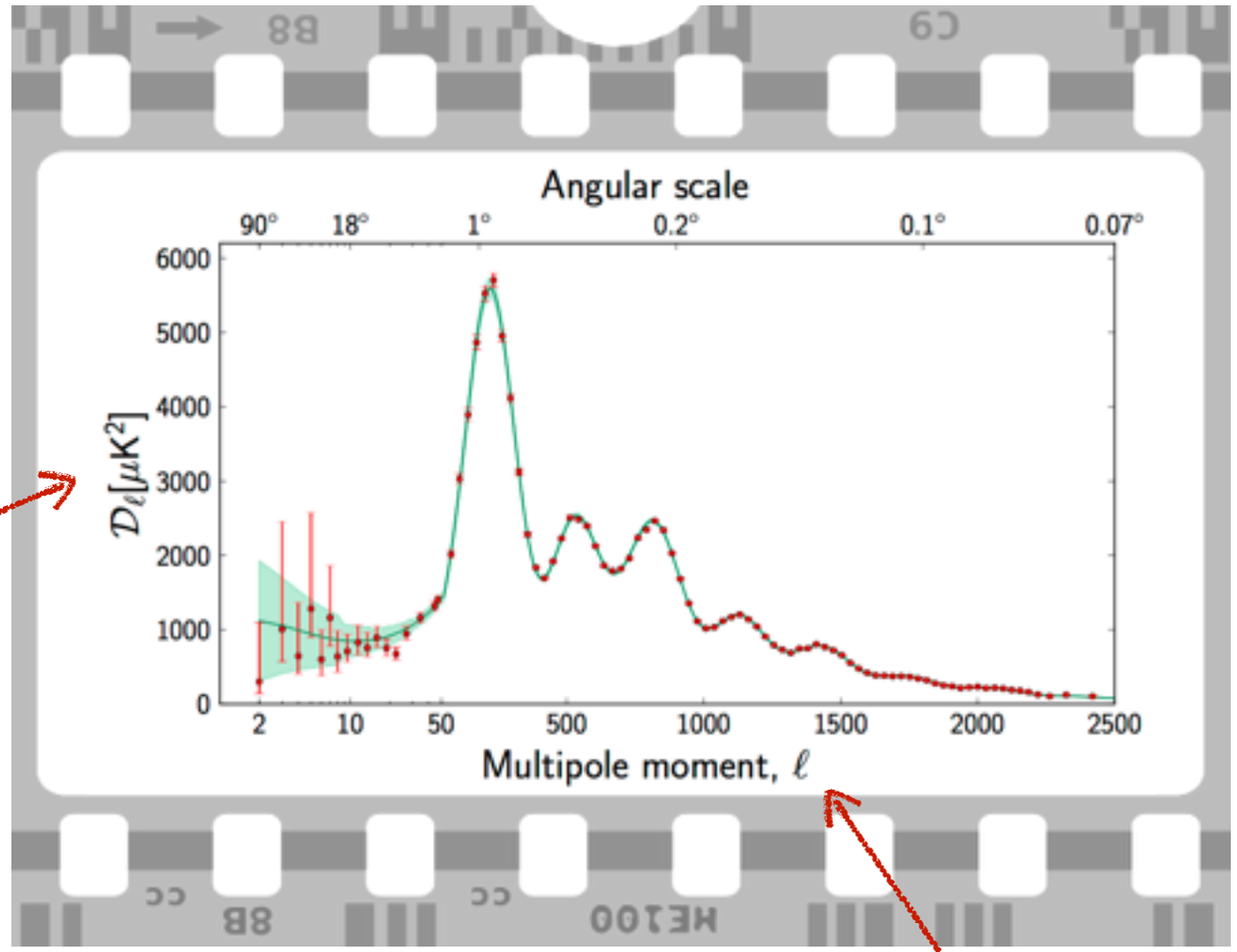


isotropic

flat

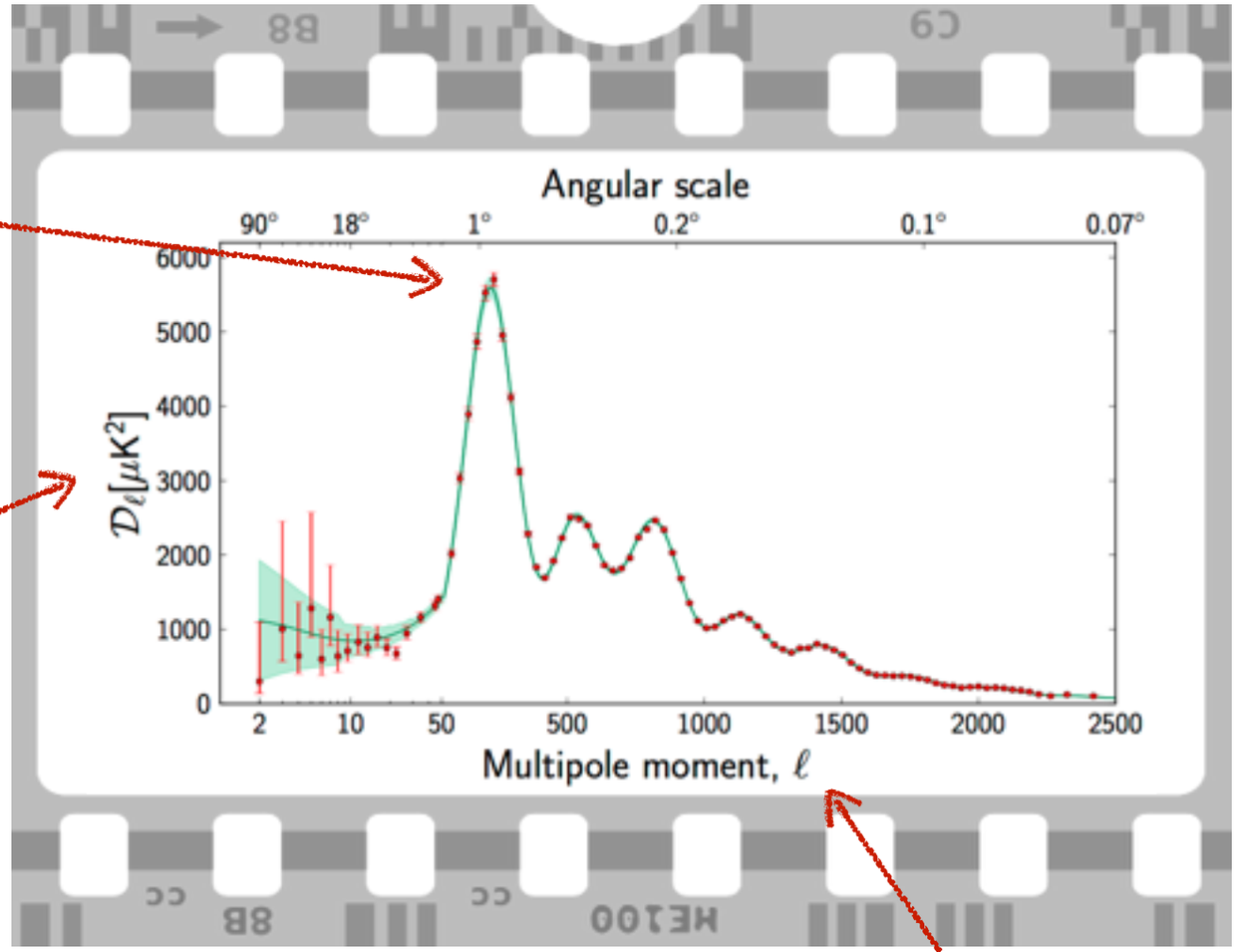
position of the first peak

$l \sim 200$

homogeneous

temperature fluctuations are small

$\Delta T \lesssim 10 \mu K$



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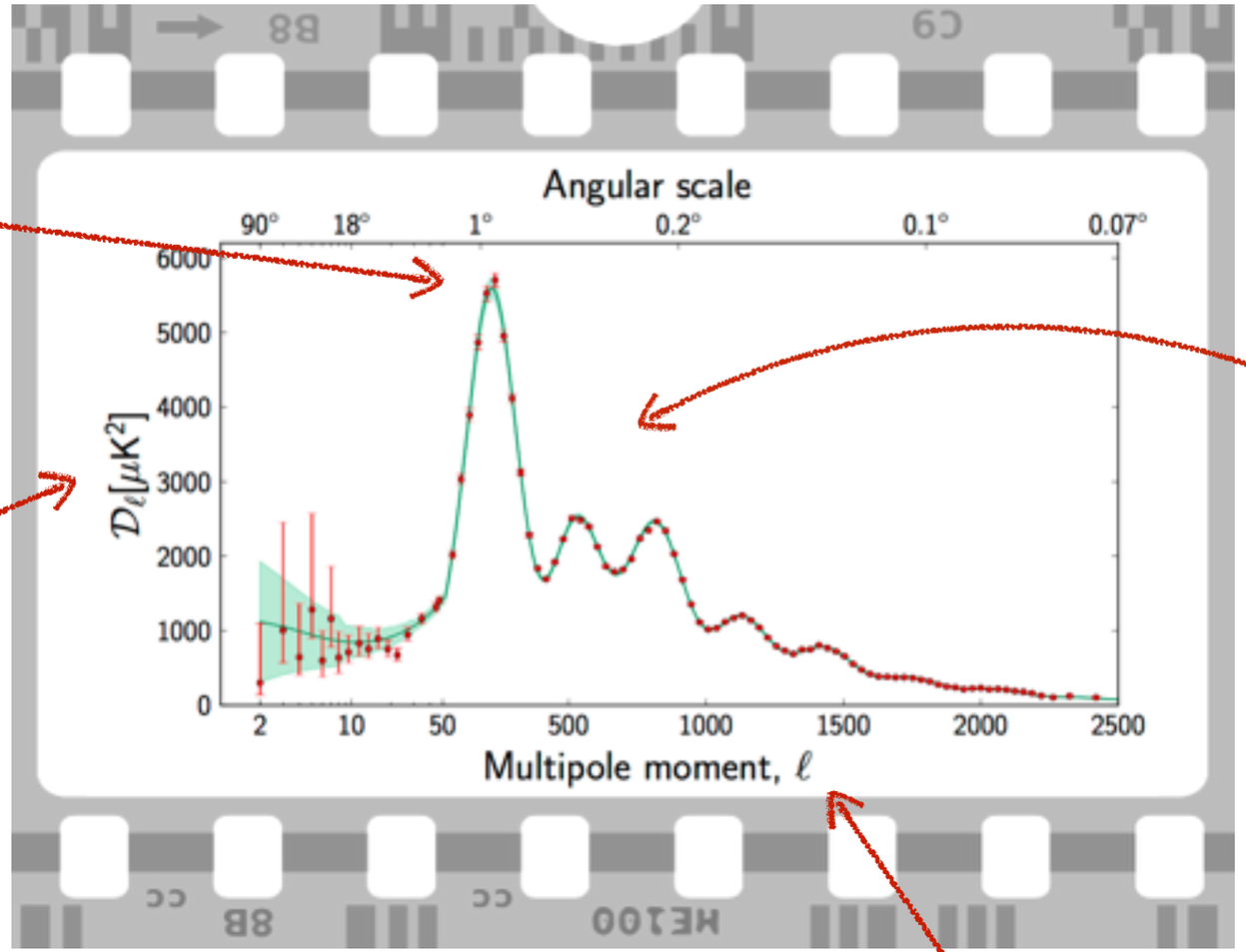
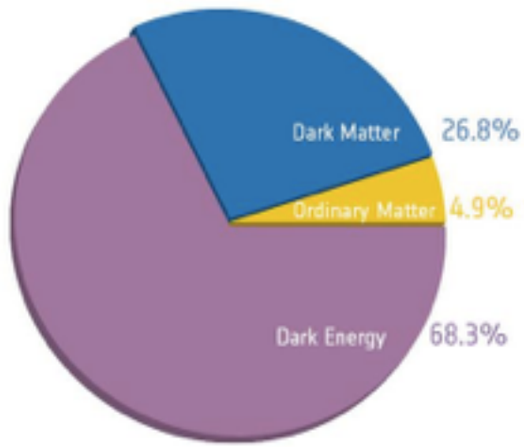


isotropic

content of matter in the Universe

position of the first three peaks



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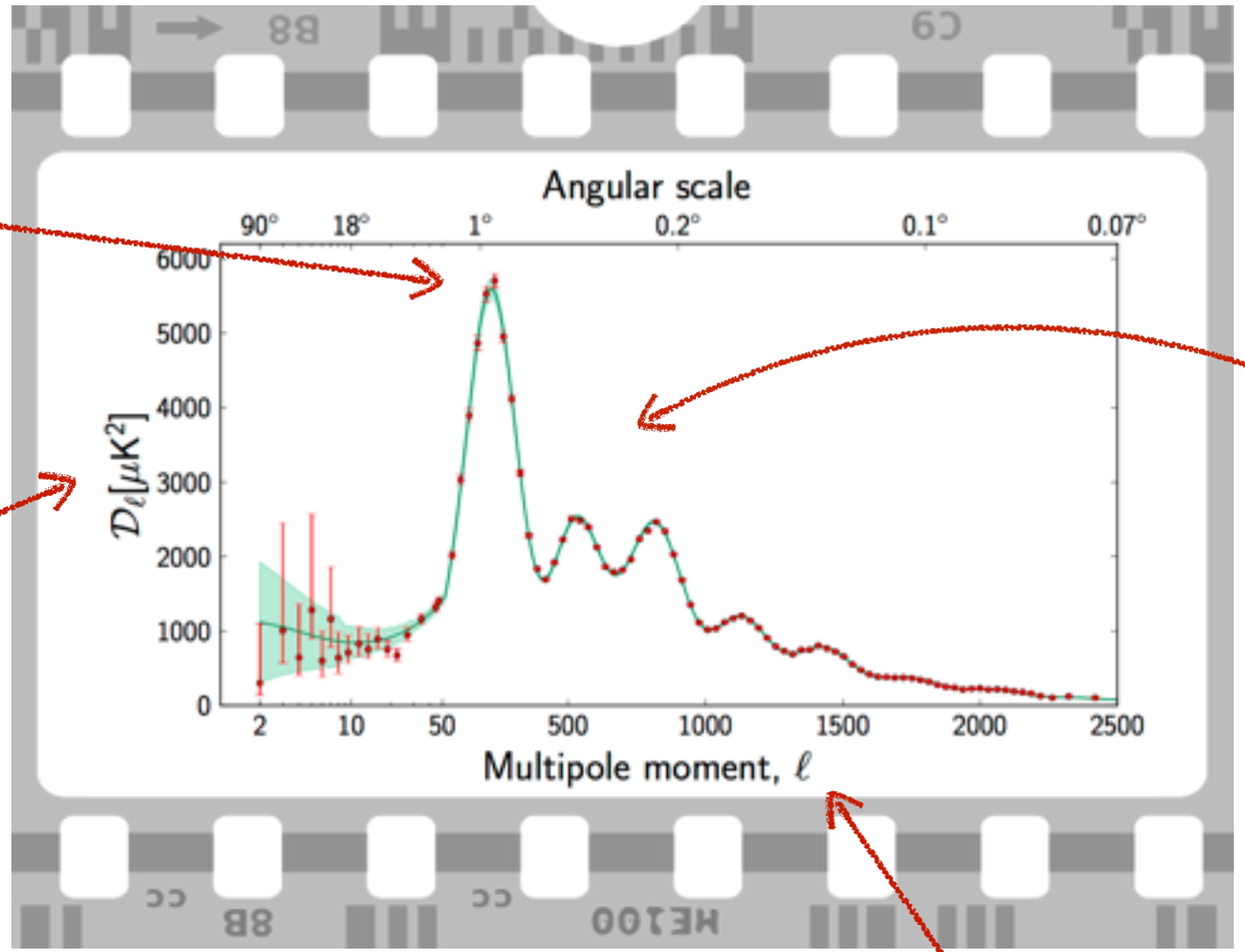

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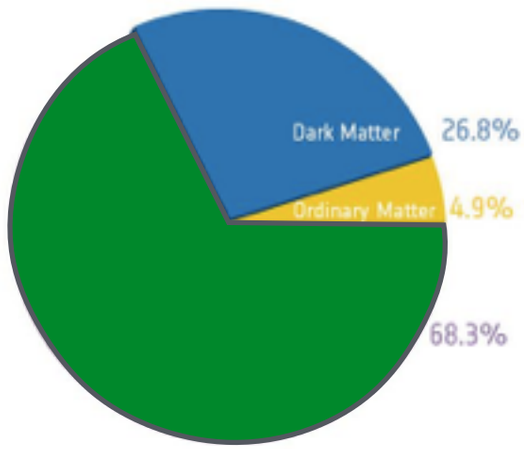


isotropic

Inflation

Dark Energy

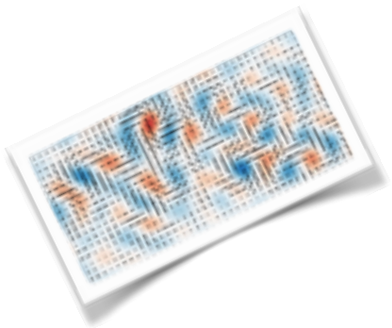
Inflation

Dark Energy

Phase of **accelerated** expansion

sourced by the **potential energy** of a **scalar field**

$$V(\phi) > 0$$



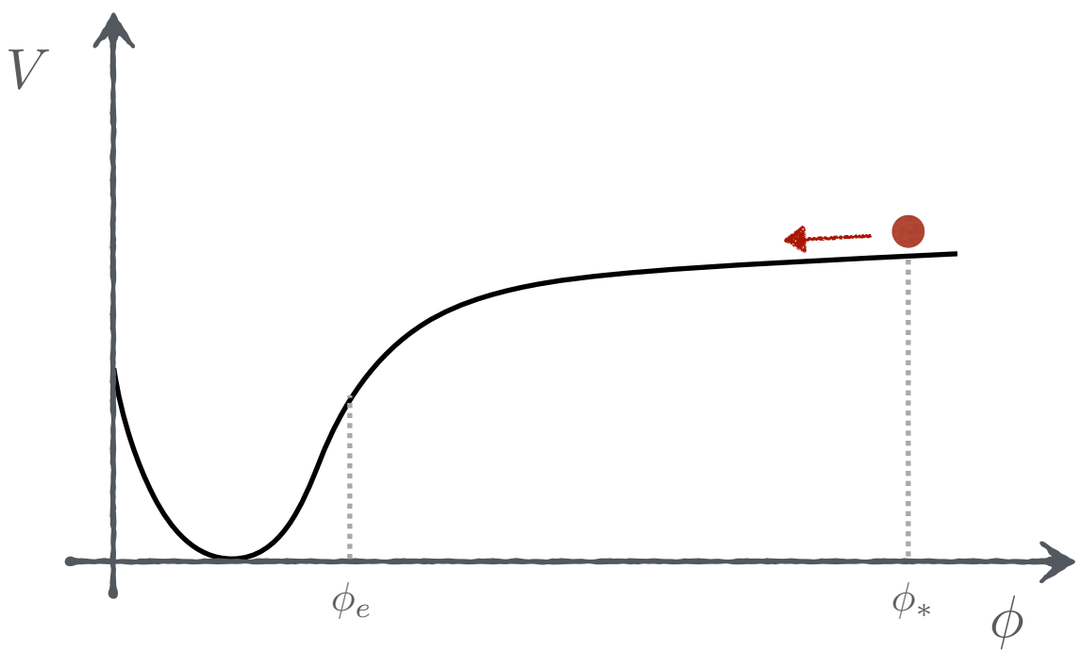
Evolution of the Universe

$V_{\rm infl} \sim 10^{-2}$

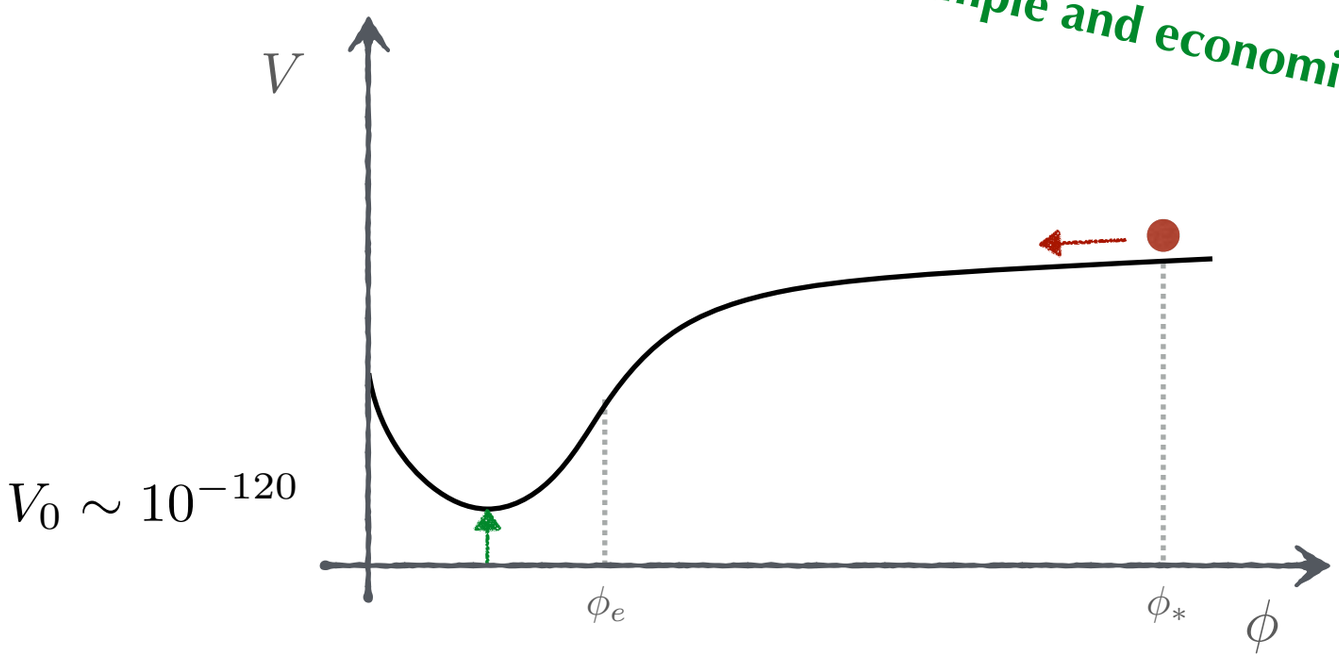
$V_{\rm DE} \sim 10^{-120}$

Inflation

Dark Energy



Inflation



simple and economical idea!

Inflation & Dark Energy

Embedding in UV physics

Embedding in UV physics

(String theory or Supergravity)

is natural

high value of the potential energy
during inflation

$$10^{14} - 10^{15} GeV$$

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Possible explanation for the smallness of the CC

(String Theory Landscape)

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SUSY helps with scalar masses

basics of

Supergravity

basics of

Supergravity

SUSY

perfect correspondence
between **bosons** and
fermions

+

GR

=

allowing SUSY to be a
local symmetry

basics of

Supergravity

spin content

0 , 1/2 , 1 , 3/2 , 2

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scalar potential

$$V = e^K \left(K^{i\bar{j}} \mathcal{D}_i W \mathcal{D}_{\bar{j}} \bar{W} - 3|W|^2 \right)$$

K **Kähler potential**
hermitian function of Φ_i and $\bar{\Phi}_i$

W **Superpotential**
holomorphic function of Φ_i

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allowing SUSY to be a **local symmetry**

geometric theory

the fields Φ_i organize themselves in a **manifold** with metric

$$K_{i\bar{j}} = \partial_{\Phi_i}\partial_{\bar{\Phi}_j} K$$

↓

kinetic term

$$T = K_{i\bar{j}}\partial_\mu \Phi^i \partial^\mu \Phi^{\bar{j}}$$

spin content

0 , 1/2 , 1 , 3/2 , 2

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flat geometry

$$K = \Phi\bar{\Phi}$$

hyperbolic geometry

$$K = -3\alpha \ln\left(\Phi + \bar{\Phi}\right)$$

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generally difficult balance!

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generally difficult balance!

kill the negative term!

with a second superfield

$$K = K(\Phi, S)$$

$$W = S f(\Phi)$$

Kawasaki, Yamaguchi, Yanagida 2000

Kallosh, Linde, Rube 2010

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enhance of the positive term!

within one single superfield

$$K = -3 \ln \left[1 + \frac{\Phi + \bar{\Phi} + \zeta \left(\Phi + \bar{\Phi} \right)^4}{\sqrt{3}} \right]$$

Ketov, Terada 2014

Linde, Roest, Scalisi 2014

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[see Terada's talk]

always perfect balance!

within one single superfield

α-attractors

α=1/9 *Goncharov, Linde 1984*

any α *Roest, Scalisi 2015*

Linde 2015

kill the negative term!

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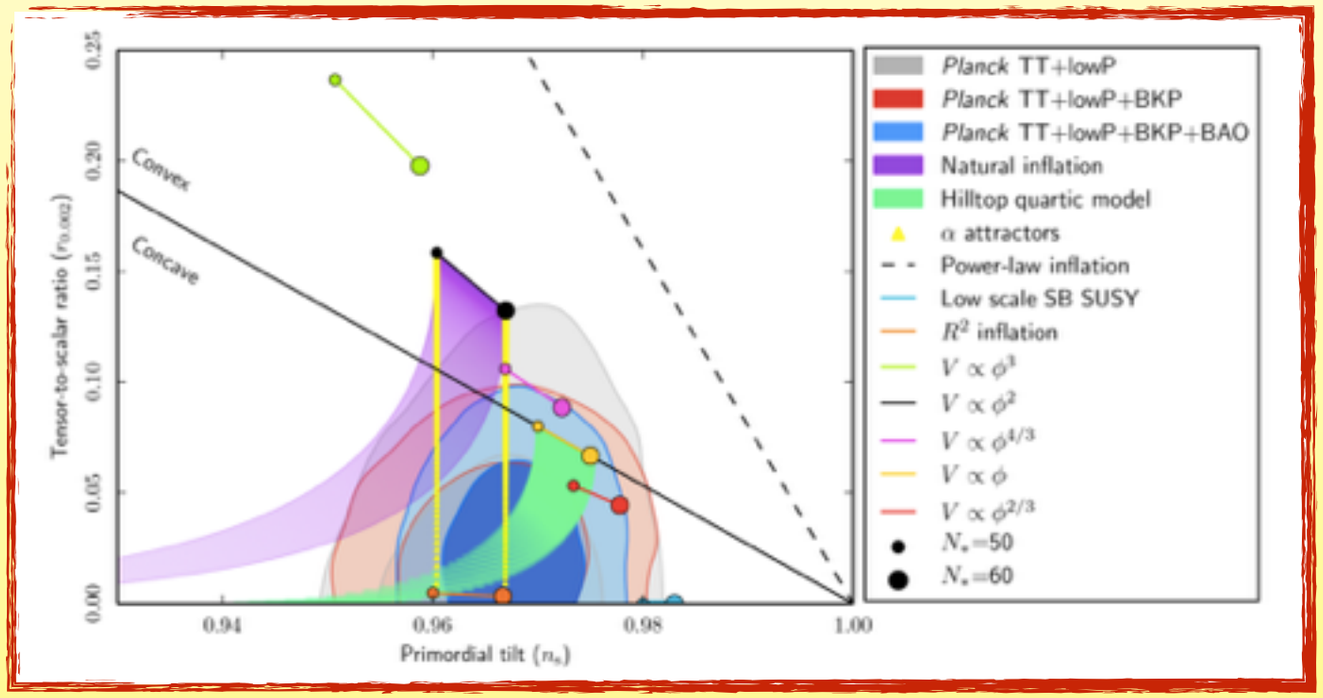
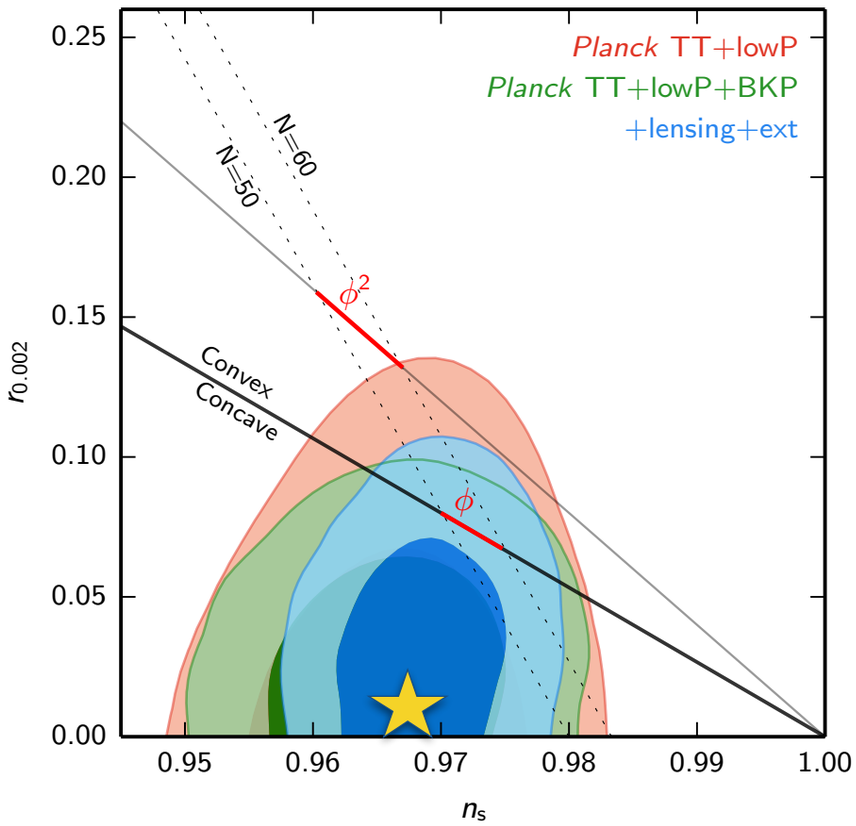
Cosmology of α-Attractors



“Planck’s coordinates”



$$n_s = 1 - \frac{2}{N} \qquad r = \frac{12\alpha}{N^2}$$

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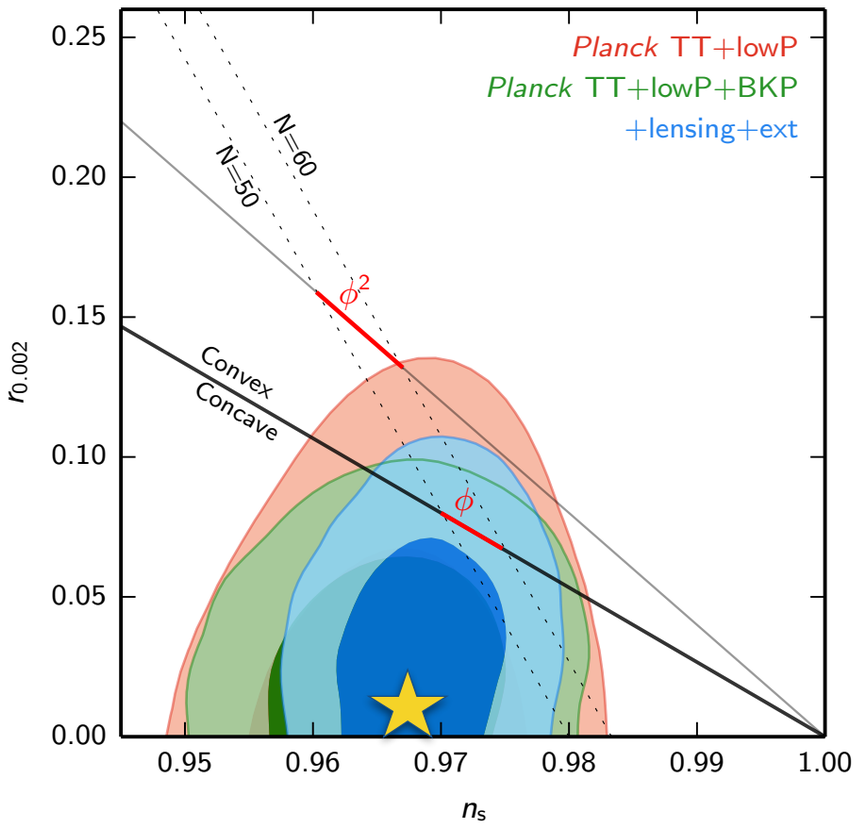

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$$W = generic$$

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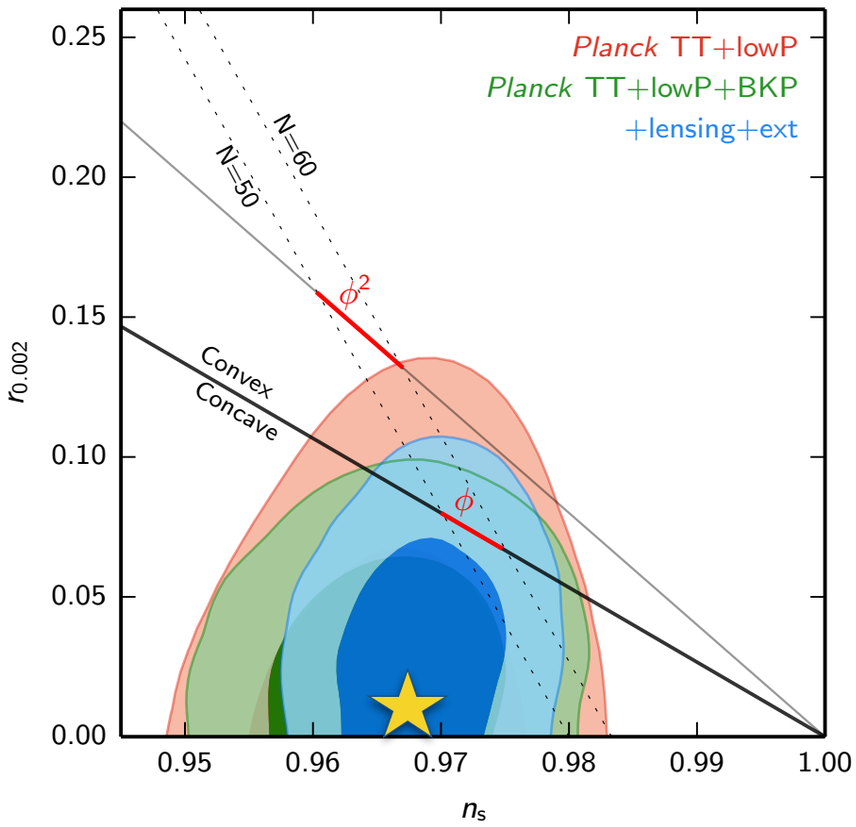

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- varying Kähler curvature $R_K = -\frac{2}{3\alpha}$

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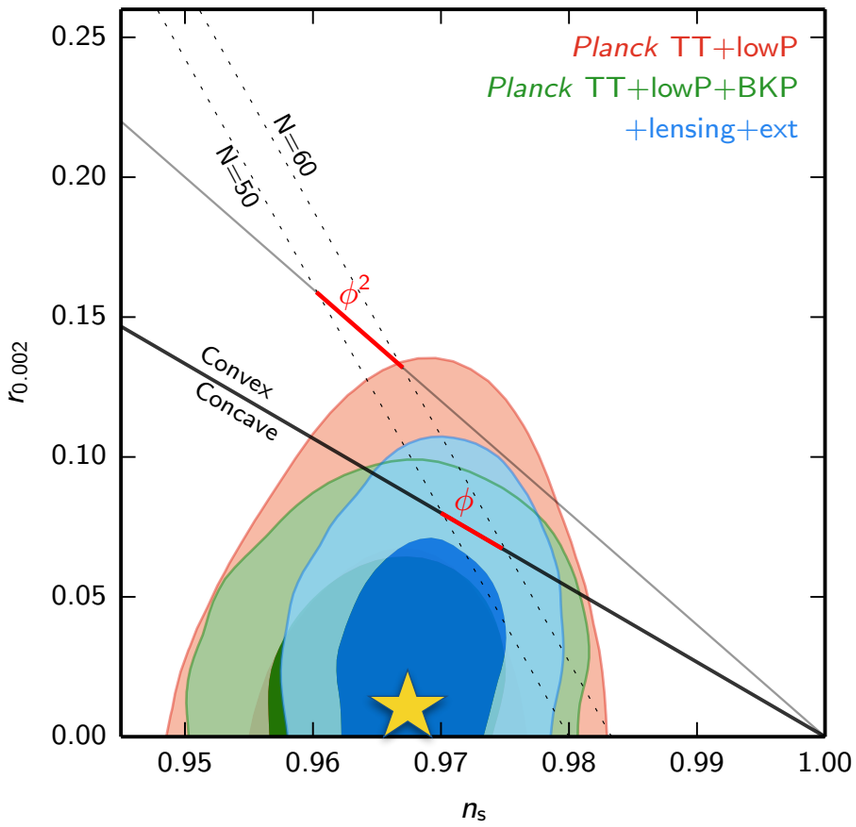

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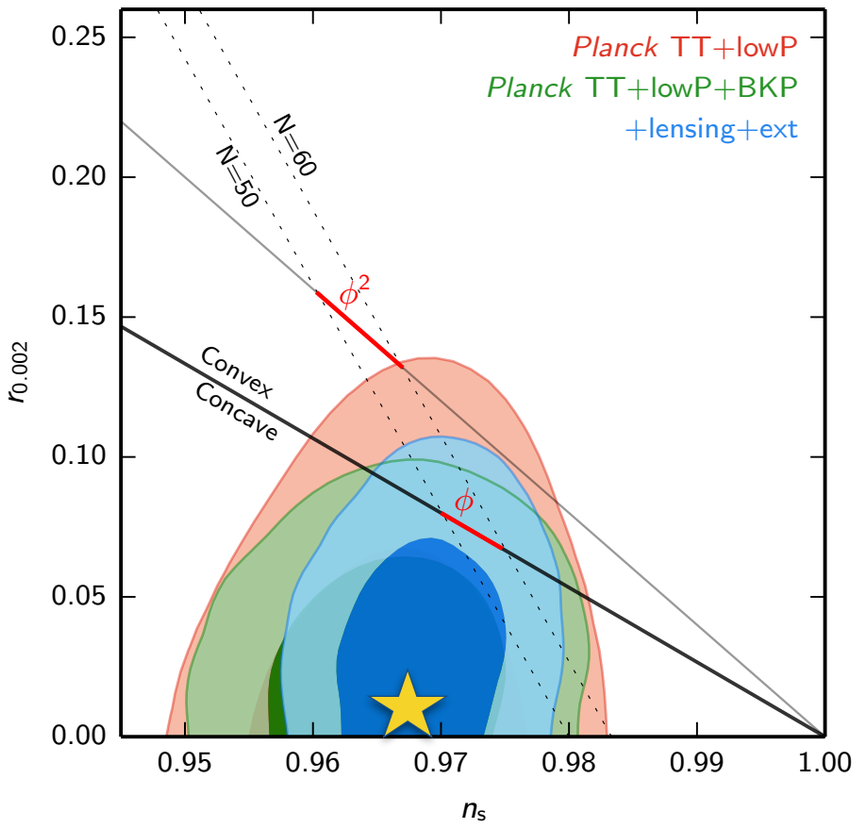

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Exponential fall-off from de Sitter

$$V = V_0 - V_1\, e^{-\sqrt{\frac{2}{3\alpha}}\varphi} + \dots$$

Single superfield α-attractors

Roest & MS 2015

$$K = -3\alpha \ln(\Phi + \bar{\Phi})$$

$$W = \Phi^{n-} - \Phi^{n+} F(\Phi)$$

with

$$F(\Phi) = \sum_n c_n \Phi^n$$

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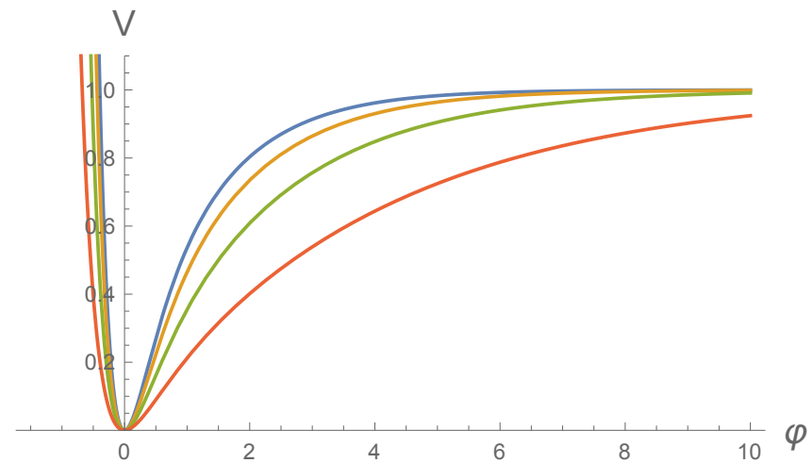
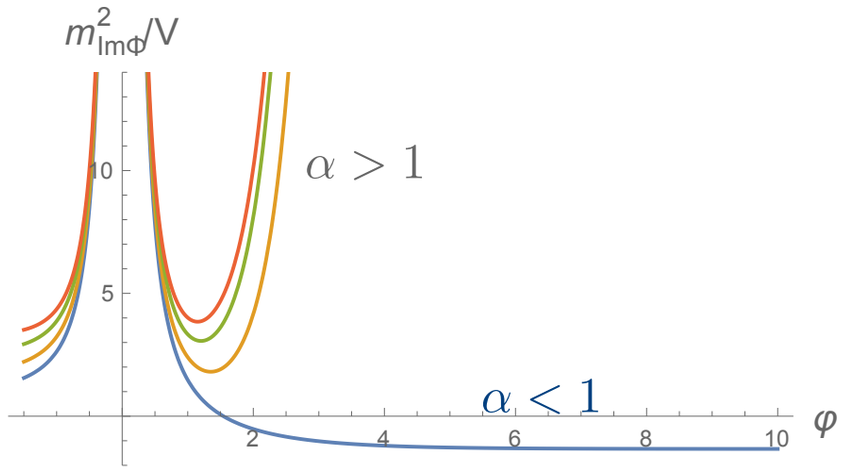
Simplest example

$$F(x) = 1 + 3\sqrt{\alpha} - 3\sqrt{\alpha}x$$





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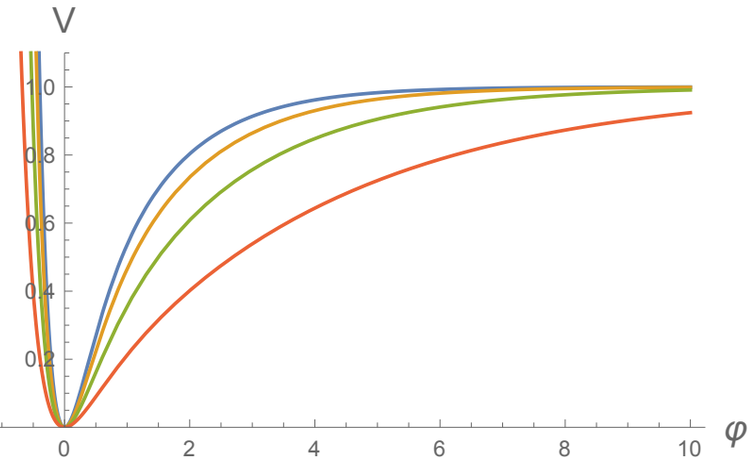

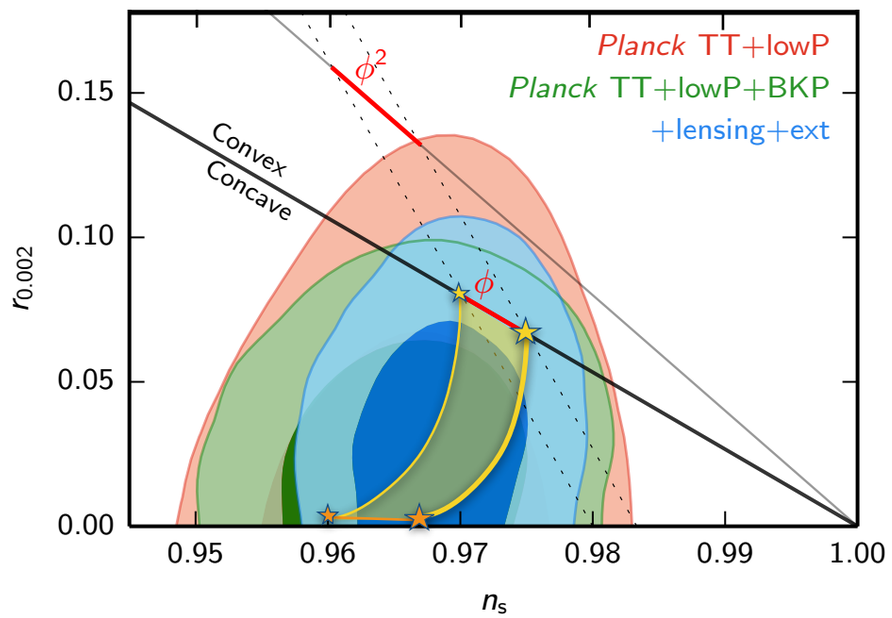

Single superfield α-attractors

Roest & MS 2015

Just Inflation!

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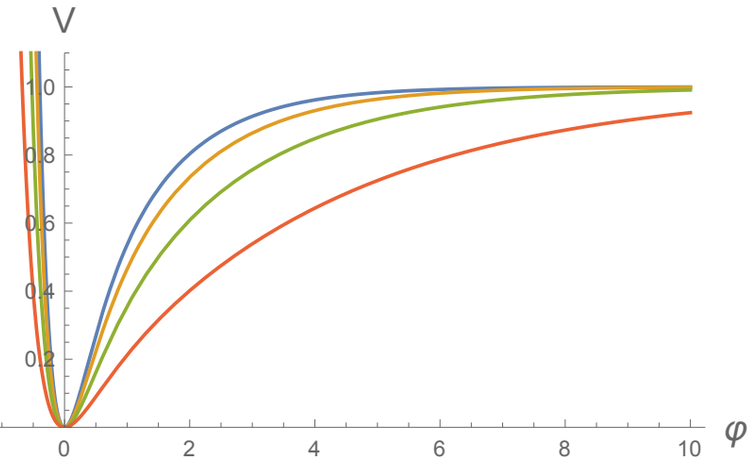

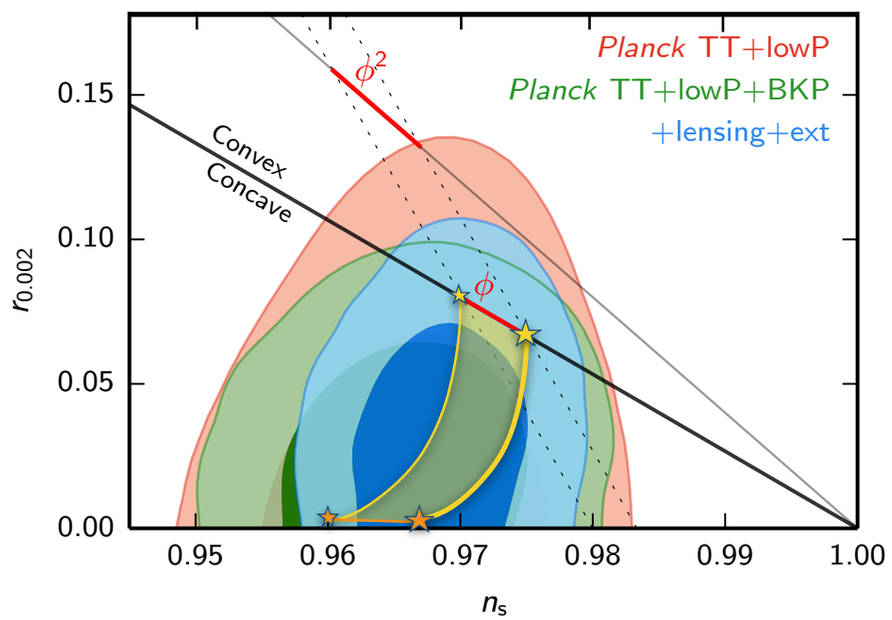

The nilpotent superfield and de Sitter

$$S(x,\theta) = s(x) + \sqrt{2}\lambda(x)\theta + F(x)\theta^2$$

The nilpotent superfield and de Sitter

$$S(x,\theta) = s(x) + \sqrt{2}\lambda(x)\theta + F(x)\theta^2$$

$$S^2(x,\theta) = 0$$

$$S(x,\theta) = \frac{\lambda\lambda}{2F} + \sqrt{2}\lambda\theta + F\theta^2$$

no scalar! **just fermions!**

Volkov, Akulov 1972,1973
Rocek; Ivanov, Kapustnikov 1978
Lindstrom, Rocek 1979
Casalbuoni, De Curtis, Dominici, Feruglio, Gatto 1989
Komargodski, Seiberg 2009

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naturally related to de Sitter

Kallosh, Wrase 2014-2015
Kallosh, Quevedo, Uranga 2015
Bergshoeff, Freedman, Kallosh, Van Proyen 2015
[see Quevedo's talk on Friday]

interesting cosmological application

Antoniadis, Dudas, Ferrara, Sagnotti 2014
Ferrara, Kallosh, Linde 2014
Kallosh, Linde 2014
Dall'Agata,Zwirner 2014
Kallosh, Linde, MS 2014

α-Attractors **+ nilpotent sector** $S^2(x,\theta)=0$

MS 2015

Carrasco, Kallosh, Linde 2015

$$K = -3\alpha \ln\left(\Phi + \bar{\Phi}\right) + S\bar{S}$$

α-Attractors + **nilpotent sector** $S^2(x,\theta)=0$

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- **Enhancement of the attractor structure**

generic expansion of the superpotential

$$W = f(\Phi) + g(\Phi)S \quad \longrightarrow$$

α-Attractors

$$V = V_0 - V_1\, e^{-\sqrt{\frac{2}{3\alpha}}\varphi} + \dots$$

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- **Stability** $\forall\alpha$

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- **Stability** $\forall\alpha$

- **Useful framework to describe inflation, dark energy and SUSY breaking**

α-Attractors **+ nilpotent sector** $S^2(x,\theta)=0$

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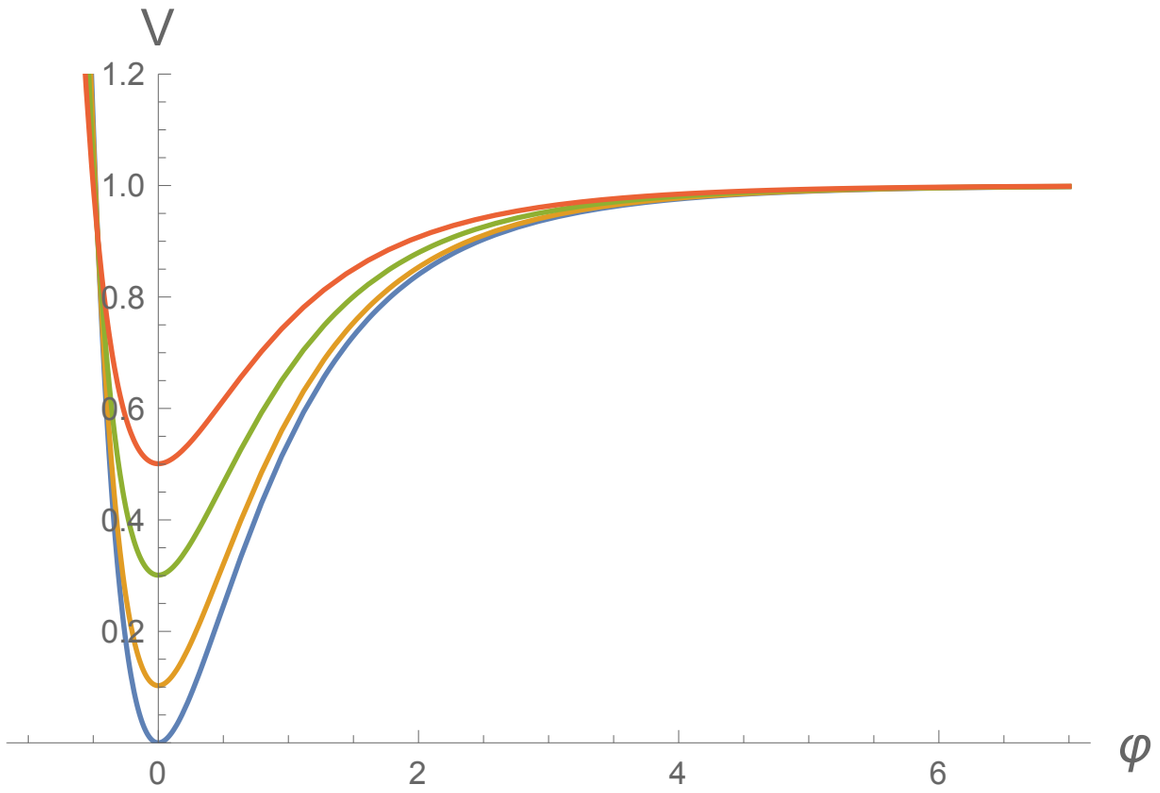
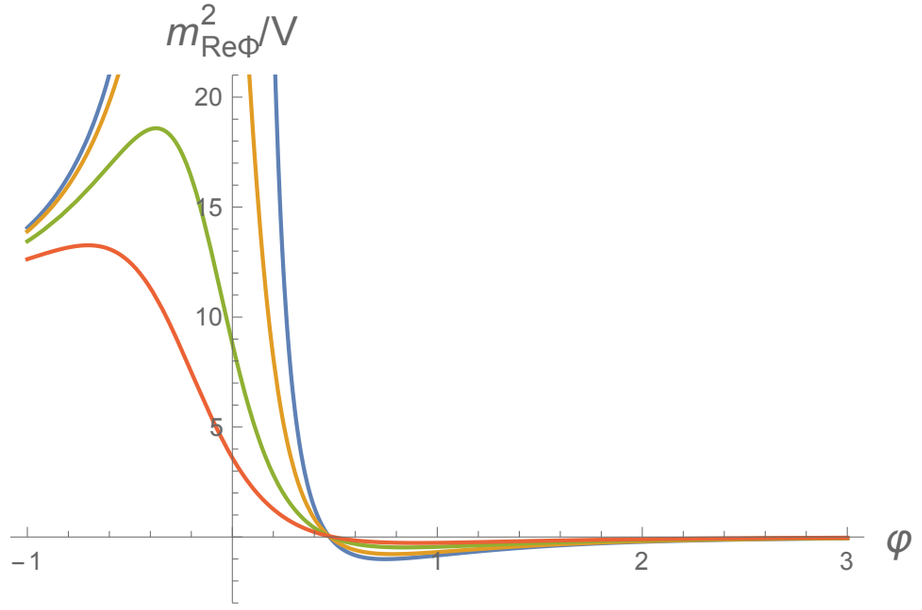
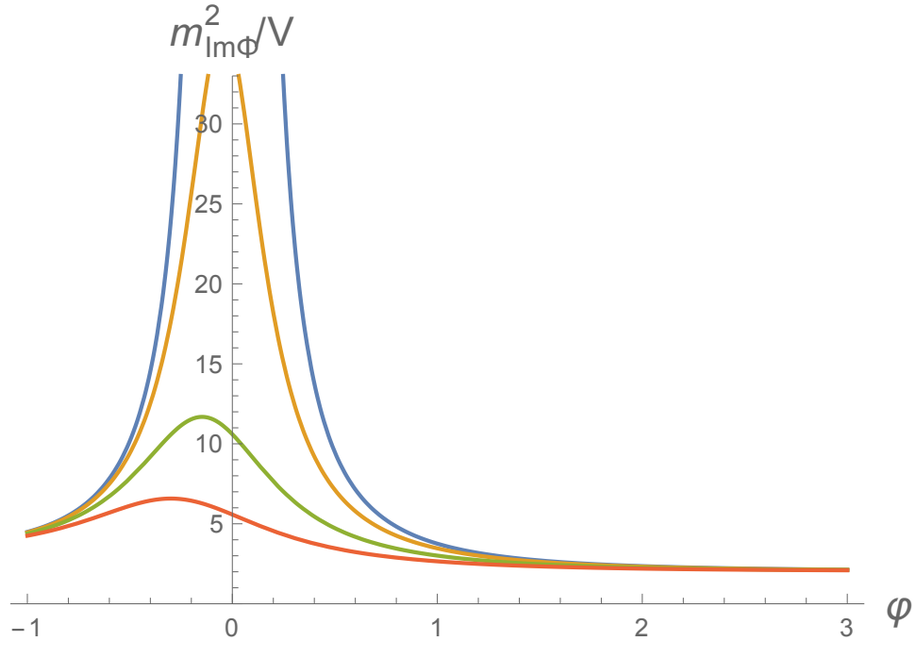
Carrasco, Kallosh, Linde 2015







Summing-up

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$$K = -3\alpha \ln\left(\Phi + \bar{\Phi}\right) + S\bar{S} \qquad W = f(\Phi) + g(\Phi)S$$

  - stability for any value of α
  - attractor structure is enhanced
  - more direct connection with string theory inspired models

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Extra slides

Single superfield α-attractors

Roest & MS 2015

GEOMETRIC α-ATTRACTORS

$$K = -3\alpha \ln(\Phi + \bar{\Phi})$$

$$W = \Phi^{n_-} - \Phi^{n_+} F(x)$$

with

$$x \equiv \Phi$$

$$R_K = -\frac{2}{3\alpha}$$

stable $\alpha > 1$

Kähler transformation
+
field redefinition
+
$\alpha \to \infty$

FLAT α-ATTRACTORS

$$K = -\frac{1}{2}\left(\Phi - \bar{\Phi}\right)^2$$

$$W = e^{\sqrt{3}\Phi} - e^{-\sqrt{3}\Phi} F(x)$$

with

$$x \equiv e^{-2\Phi/\sqrt{3\alpha}}$$

$$R_K = 0$$

stable $\forall \alpha$

building blocks of *W*

curvature

SAME SCALAR POTENTIAL
ALONG THE REAL AXIS

α-Attractors + nilpotent sector $S^2(x,\theta)=0$

MS 2015

Carrasco, Kallosh, Linde 2015

GEOMETRIC α-ATTRACTORS

FLAT α-ATTRACTORS

$$K = -3\alpha \ln\left(\Phi + \bar{\Phi}\right) + S\bar{S} \quad \xrightarrow{\text{flat limit}} \quad K = -\frac{1}{2}\left(\Phi - \bar{\Phi}\right)^2 + S\bar{S}$$

- **Enhancement of the attractor structure**

generic expansion of the superpotential

$$W = f(x) + g(x)S \quad \longrightarrow \quad V = V_0 - V_1\, e^{-\sqrt{\frac{2}{3\alpha}}\varphi} + \dots$$

α-Attractors

- **Stability** $\forall\alpha$

- **Useful framework to describe inflation, dark energy and SUSY breaking**

No-scale supergravity

Cremmer, Ferrara, Kounnas, Nanopoulos 1983
Ellis, Lahanas, Nanopoulos, K. Tamvakis 1984

$$K = -3\ln\left(\Phi + \bar{\Phi}\right)$$

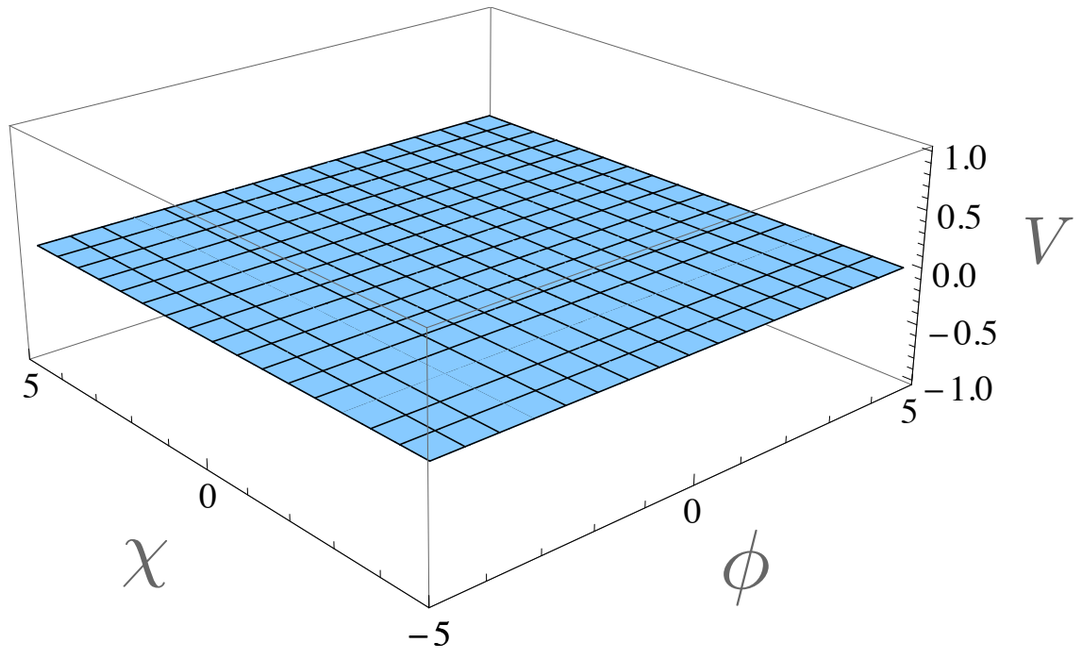
$$W = 1$$

inversion of the field
+
Kähler transformation

$$K = -3\ln\left(\Phi + \bar{\Phi}\right)$$

$$W = \Phi^3$$

$$V = 0 \qquad \forall(\phi, \chi)$$



$$\Phi = \phi + i\chi$$

No-scale supergravity **and dS**

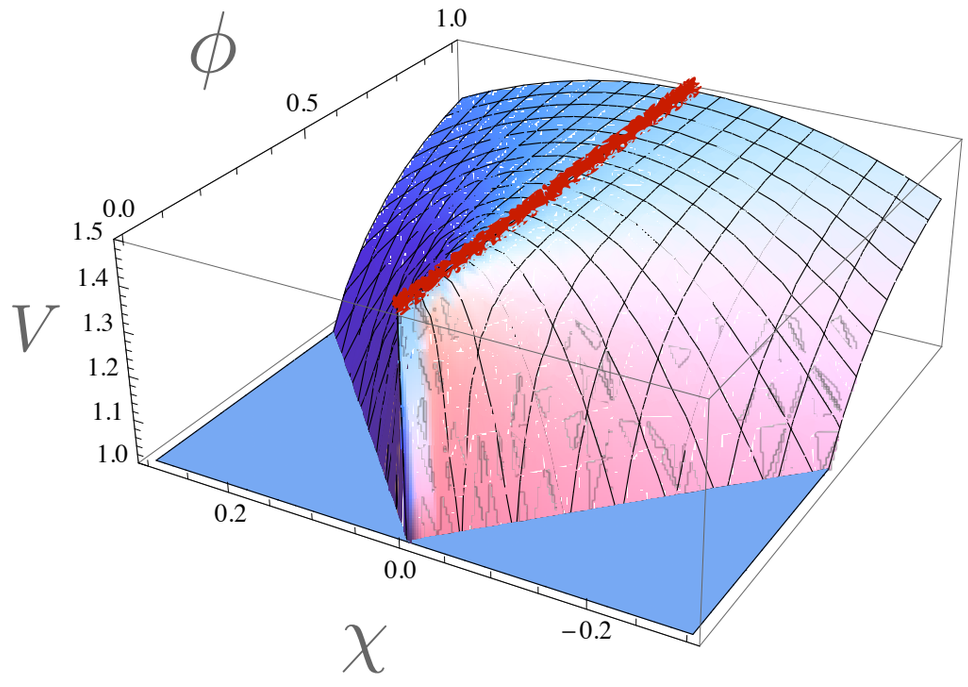
Roest & MS 2015

$$K = -3 \ln \left(\Phi + \bar{\Phi} \right)$$

$$W = 1 - \Phi^3$$

$$V = \frac{3}{2}$$

at $\chi = 0$



unstable de Sitter !

$$m_\chi^2 < 0$$

α-scale supergravity **and stable dS**

Roest & MS 2015

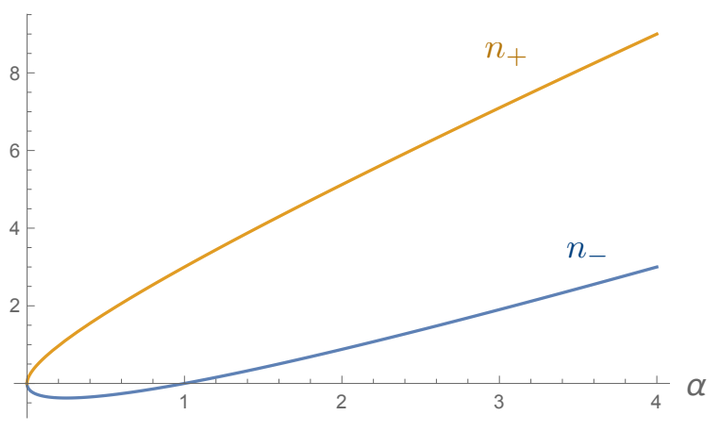
$$K = -3\alpha \ln\left(\Phi + \bar{\Phi}\right)$$

$$R_K = -\frac{2}{3\alpha}$$

$$W = \Phi^{n-} - \Phi^{n+}$$

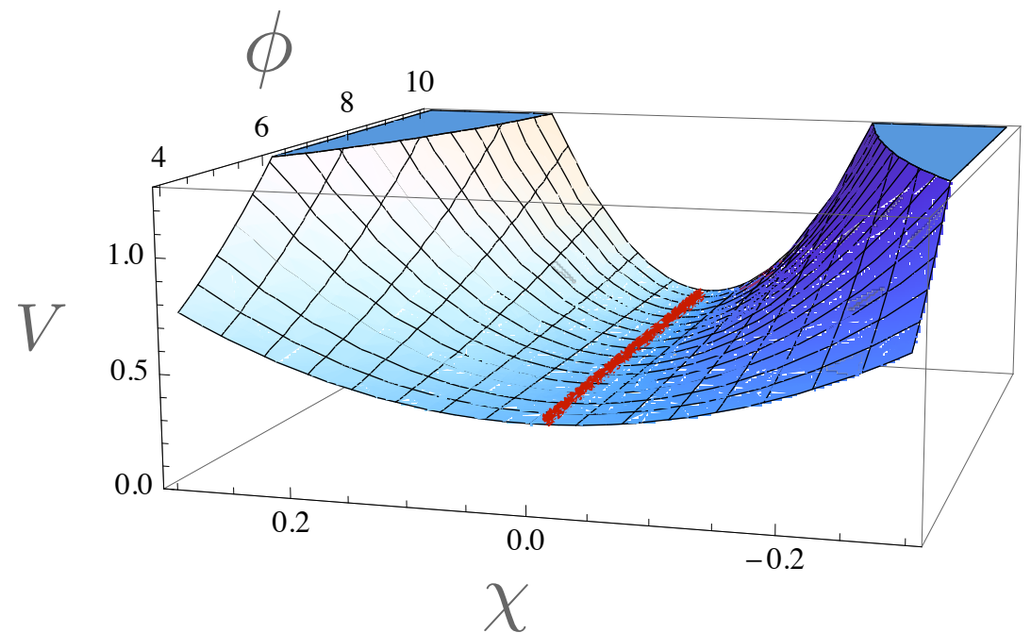
with

$$n_\pm = \frac{3}{2}\left(\alpha \pm \sqrt{\alpha}\right)$$



$$V = 3 \cdot 2^{2-3\alpha}$$

at $\chi = 0$



stable for $\alpha > 1$

- more direct connection with **string theory inspired models**

e.g. $\alpha = \dfrac{2}{3}$

$$K = -2\ln\left(\Phi + \bar{\Phi}\right) + S\bar{S}$$

$$W = \left(a_0\Phi + a_1\Phi^2 + ...\right) + \left(b_0\Phi + b_1\Phi^2 + ...\right)S$$

α-scale supergravity **and stable dS**

Roest & MS 2015

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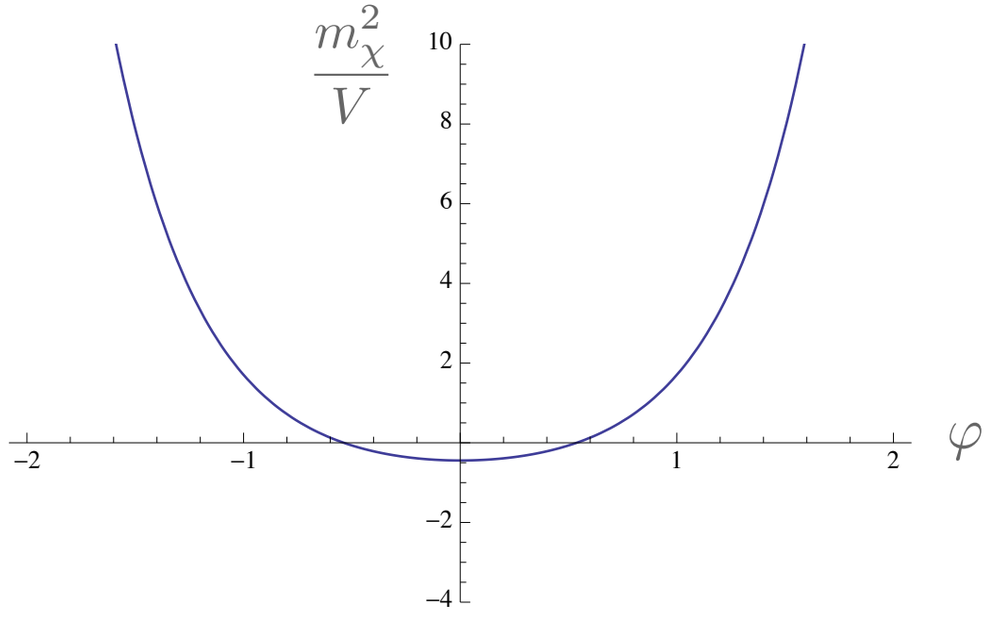
$$n_\pm = \frac{3}{2}\left(\alpha \pm \sqrt{\alpha}\right)$$

$$m_\chi^2 = -\frac{4V}{3\alpha}\left[1 - (\alpha - 1)\sinh^2\left(\sqrt{\frac{3}{2}}\varphi\right)\right]$$



$$\alpha > 1$$

α-scale supergravity **and stable dS**

Roest & MS 2015

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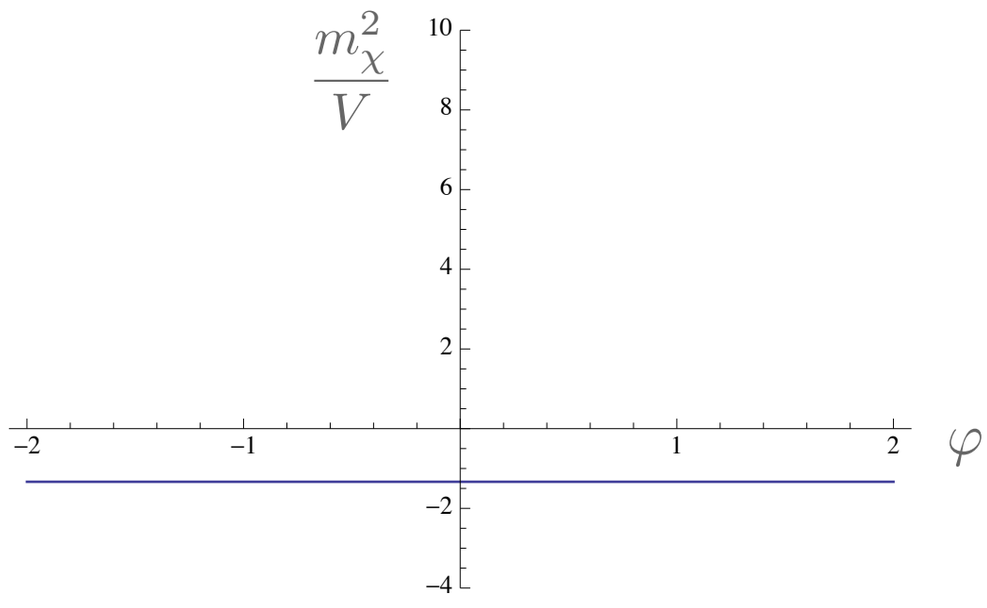

$$\alpha = 1$$

α-scale supergravity **and stable dS**

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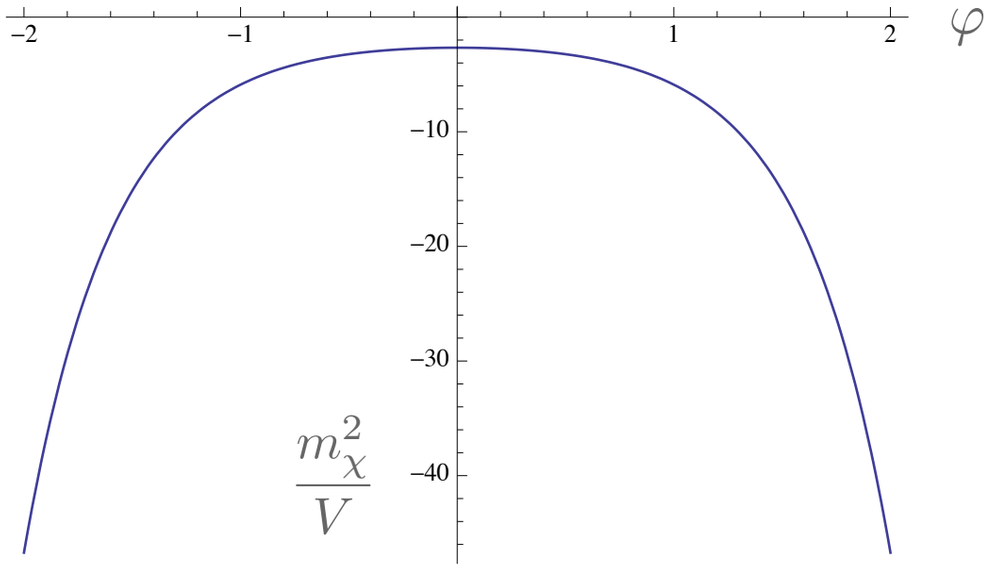

$\alpha < 1$