Particles, Astroparticles, Cosmology & Strings - Corfu`, 06.09 09

de Sitter & inflation in no-scale sugra

Laura Covi

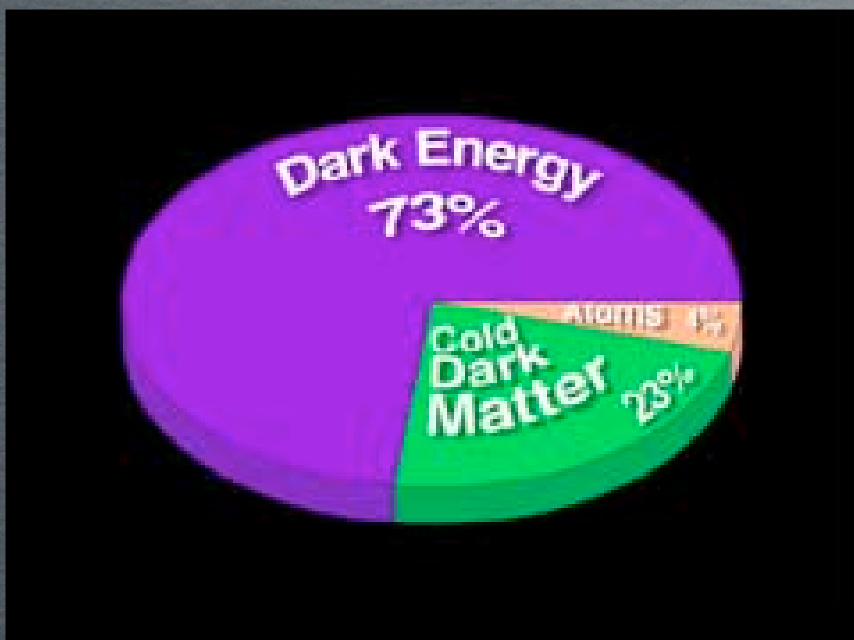
based on work with M. Gomez-Reino, C. Gross,
J. Louis, G. Palma, C. Scrucca

Outline

- Introduction & Motivation:
  The present Universe
- Part I: de Sitter solutions in no-scale SUGRA
- Part II: Inflation and the gravitino mass
- Outlook

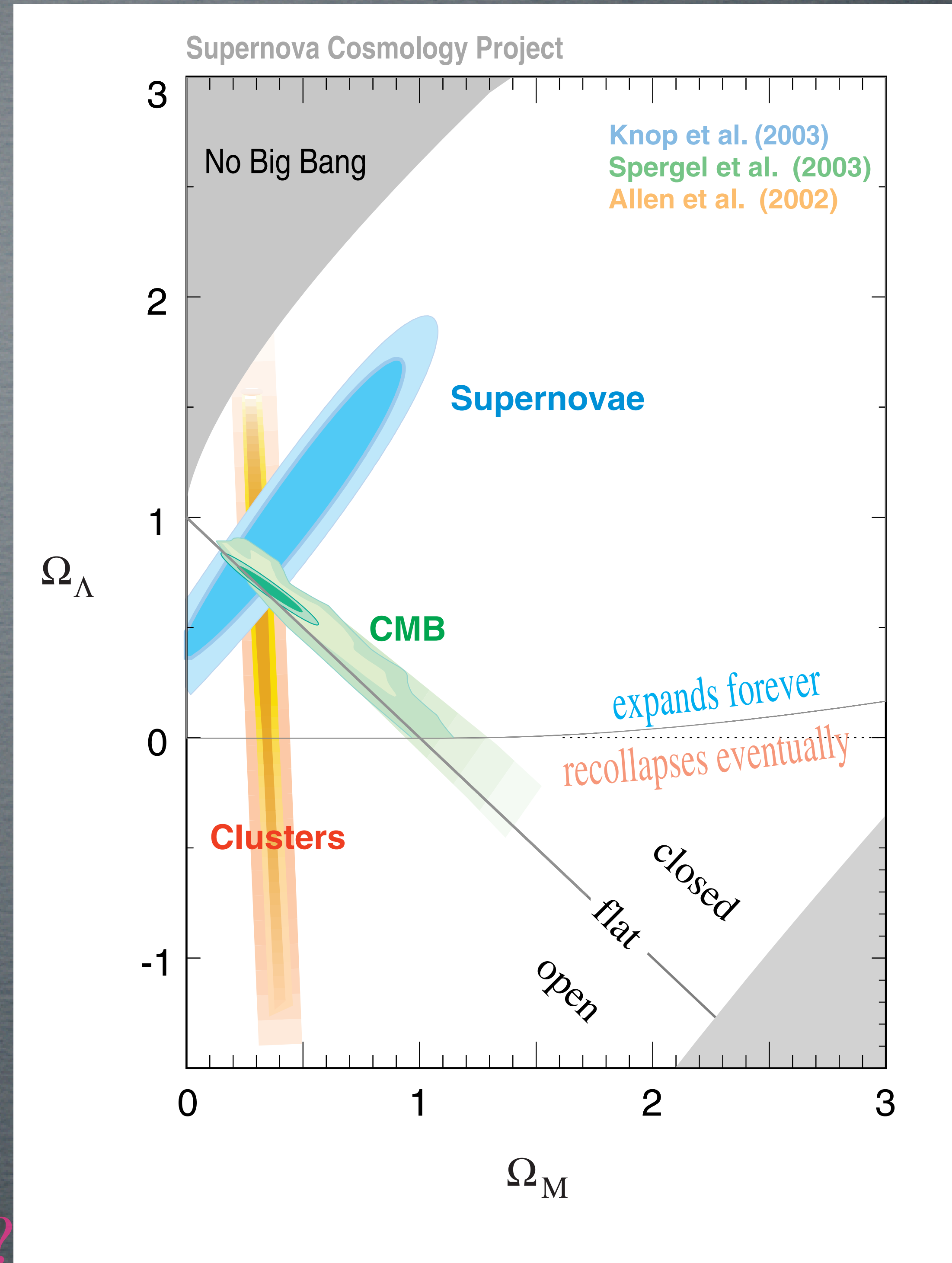
Introduction & Motivation

PRESENT ENERGY CONTENT



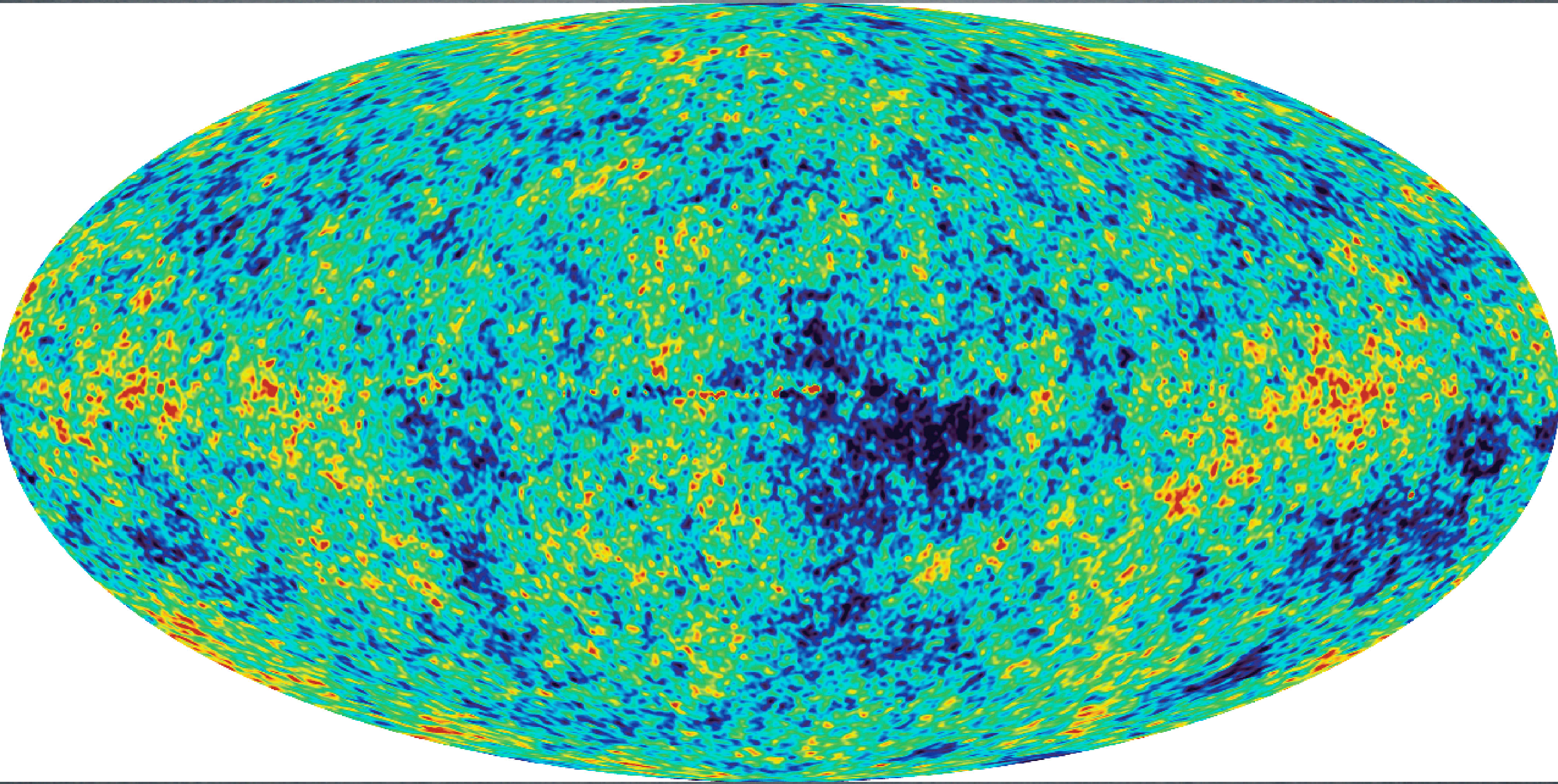
with traces of photons,

neutrinos & ... ?



What is DARK ENERGY ???

The Universe is NOT perfectly homogeneous !



[WMAP 06]

Tiny ripples on the black body spectrum at level of 0.01%...

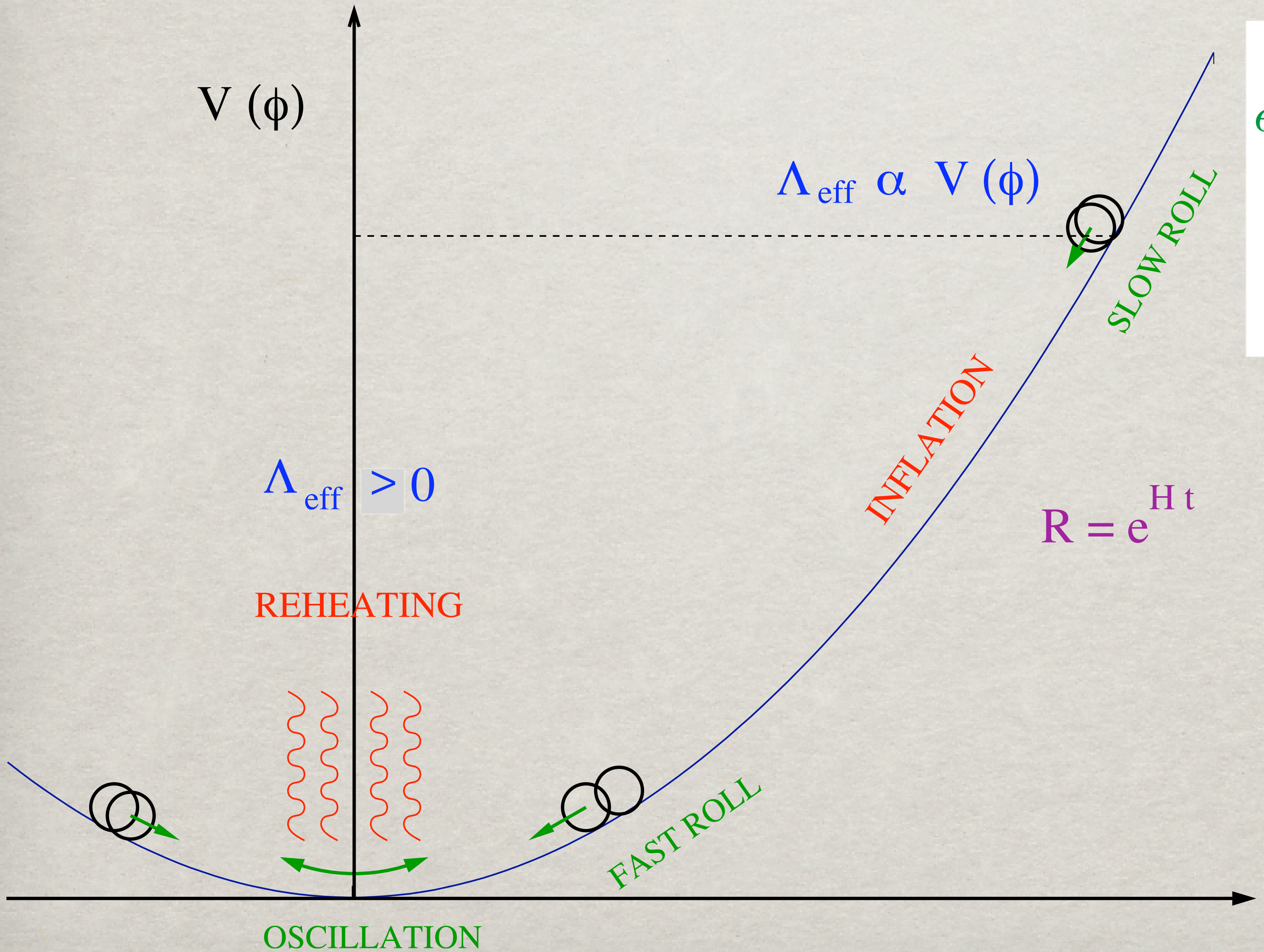
WHY IS THE UNIVERSE FLAT, HOMOGENEOUS & ISOTROPIC ?

WHAT CAUSED THE TINY RIPPLES, WHICH ARE ORIGIN OF STRUCTURE?

INFLATION

EARLY PHASE OF EXPONENTIAL EXPANSION

Inflation: driven by a scalar field ϕ



$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1$$

$$|\eta| = \left|\frac{V''}{V}\right| \ll 1$$

$R = e^{Ht}$ Quasi - de Sitter

de Sitter ?

WANTED: de Sitter !

- A positive cosmological constant, i.e. a (possibly metastable) de Sitter state provides at the moment the best fit to the data...
- A quasi de Sitter solution describe very well an inflationary phase since the slow roll parameters have to be small...
- Try to find a model which starts and finishes in a de Sitter !

WHY SUPERGRAVITY ?

- Theoretically attractive: supersymmetry gives gauge unification, solves hierarchy problem,etc...
- Provides a coherent framework to study different signal in high energy physics, astrophysics and cosmology.
- It is surely necessary to extend supersymmetry to supergravity to discuss cosmology !
- Allows extension to string theory...:
  the low energy 4D limit of some string theories is a N=1 supergravity of the no-scale type.

(quasi)de Sitter in SUGRA

- A de Sitter or quasi-de Sitter phase is needed to account for the present cosmological constant and for inflation

- But in SUGRA the absolute minima are either anti-de Sitter or Minkowski... and do not break SUSY !

$$V = e^K (K^{i\bar{j}} (W_i + K_i W)(\bar{W}_{\bar{j}} + K_{\bar{j}} \bar{W}) - 3|W|^2$$

- Also inflation is difficult $\rightarrow$ η problem
  the SUGRA potential is usually steep with $V'' \sim V$
  as long as one does not resort to some tuning...
  ... SLOW ROLL inflation not easy to realise !

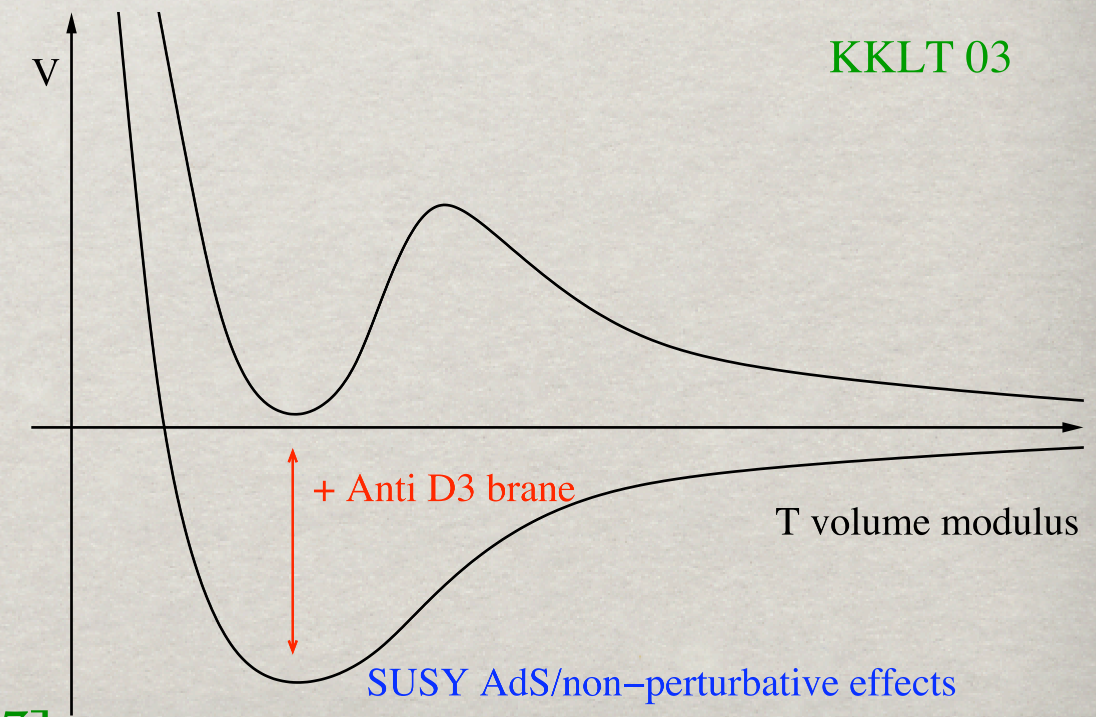
[Copeland et al 94; Guth, Randall & Thomas 94, ...]

de Sitter vacua and moduli stabilisation

- One of the historical problems of string theory is to stabilise all the moduli fields.

- Progress in the last years: possible to stabilise most moduli using flux compactifications !

- But in some models one has to rely to explicit SUSY breaking terms to stabilise all the moduli and up-lift the vacuum (e.g. KKLT...)



[Kachru, Kallosh, Linde & Trivedi 03]

Part I:
de Sitter in
no-scale SUGRA

SUGRA AND SCALAR FIELDS

Thanks to the Kaehler symmetry the scalar potential can be written very simply as a function of a single function

$$G(\Phi,\bar{\Phi}) = K(\Phi,\bar{\Phi}) + \ln\left[W(\Phi)\right] + \ln\left[\bar{W}(\bar{\Phi})\right]$$

i.e. the potential is $V(\Phi,\bar{\Phi}) = e^{G(\Phi,\bar{\Phi})}(G_i G^i - 3)$

where $G_i = \partial_{\Phi_i} G(\Phi,\bar{\Phi})$ is the derivative w.r.t. fields

and indices are lowered and raised by the metric and its inverse

$$g_{i\bar{j}} = \partial_{\Phi_i}\partial_{\Phi_{\bar{j}}} G(\Phi,\bar{\Phi}) \qquad g^{\bar{j}i} g_{i\bar{k}} = \delta_{\bar{j}\bar{k}}$$

Supersymmetry is broken if $\langle G_i \rangle \neq 0$

and the Goldstino field is given by $\eta = G_i \Psi^i$

Scalar mass matrix

- Project the scalar mass matrix along the Goldstino direction for any V and obtain

$$\lambda = e^{-G} V_{i\bar{j}} G^i G^{\bar{j}} = -\frac{2}{3} e^{-G} V (e^{-G} V + 3) + \sigma$$

where $\boxed{\sigma = \frac{2}{3}(g_{i\bar{j}} G^i G^{\bar{j}})^2 - R_{i\bar{j}n\bar{m}} G^i G^{\bar{j}} G^n G^{\bar{m}}}$

- A necessary condition for metastability is that λ is positive, then if $V > 0$ we need $\sigma > 0$

- Note: the curvature tensor depends only on the Kaehler potential, while the Goldstino direction on the whole G, including W

Simple Kaehler potentials

- Canonical Kaehler potential: $K = \bar{X}X$
  Zero higher derivatives and no curvature !
  For vanishing Λ :
$$\sigma = \frac{2}{3} \times 9 = 6 > 0$$

- Logarithmic Kaehler: $K = -n \ \ln\left[T + \bar{T}\right]$
  Constant curvature $R \sim 2/n$
  so we have
$$\sigma = 6 - \frac{18}{n} > 0 \ \rightarrow \ n > 3$$

  Same result also for $K = -n \ \ln\left[T + \bar{T} - \bar{X}X\right]$

- More in general the curvature is not constant...

No-Scale Kaehler

[Cremmer, Ferrara, Kounas & Nanoupoulos 83, ...]

- The no-scale property requires $K_i K^i = 3$ so that the cosmological constant is zero at tree level since the potential vanishes if $W_i = 0$

$$\begin{aligned} V &= e^{K(\Phi,\bar{\Phi})}\left[|W_i + K_i W|^2 - 3|W|^2\right] \\ &= e^{K(\Phi,\bar{\Phi})}\left[|W_i|^2 + 2Re[K_i W \bar{W}_i]\right] \end{aligned}$$

- For a single field the no-scale Kaehler is simply

$$K = -3\ln[T + \bar{T}]$$

The trouble of no-scale

- The problem is the logarithmic Kaehler potential...

$$K = -3\ln(T+\bar{T}) \qquad G = K + \ln(|W|^2)$$

- For a single modulus in de Sitter one mass is always negative for any superpotential W [Brustein & de Alwis 04]
- In general Minkowski metastable vacua with broken SUSY need the holomorphic sectional curvature for the metric $K_{i\bar{j}}$ to be bounded: $R_{i\bar{j}n\bar{m}}G^iG^{\bar{j}}G^nG^{\bar{m}} < 6$
[Gomez Reino & Scrucca 04]
- This result can be generalised to de Sitter into:

$$\sigma = \frac{2}{3}(g_{i\bar{j}}G^iG^{\bar{j}})^2 - R_{i\bar{j}n\bar{m}}G^iG^{\bar{j}}G^nG^{\bar{m}} > 0$$

- $\sigma = 0$ for $G_i \propto K_i$: NO GO for a single field !

[LC, Gomez Reino, Gross, Luis, Palma & Scrucca I 08]

Two moduli in strings

[LC, Gomez Reino, Gross, Luis, Palma & Scrucca I 08]

Heterotic Calabi-Yau

$$K = -\log(\mathcal{V})$$

$$\mathcal{V} = \frac{4}{3} d_{ijk} v^i v^j v^k$$

$$\Re(T^i) = v^i$$

Type II b orientifolds

$$K = -2\log(\mathcal{V})$$

$$\mathcal{V} = \frac{1}{48} d^{ijk} v_i v_j v_k$$

$$\Re(T^i) = \frac{1}{16} d^{ijk} v_j v_k$$

Then we have simply

$$\sigma \sim -\frac{3}{8} e^{4K} \frac{\Delta}{detg} |C|^4$$

$$\sigma \sim \frac{3}{8} e^{4K} \Delta\, detg\, |C|^4$$

Where Δ is the discriminant of the cubic polynomial

Build Tree Level de Sitter

It is possible also for NO-SCALE for more than 2 fields !!!

- Choose intersection numbers with the correct sign of Δ
- Taylor expand the superpotential W around the minimum up to 3rd order and fix the coefficients such that $V \sim 0, V' = 0$ and all masses (apart for the Goldstino partner fields) are positive; W_0 fixes the gravitino mass and the overall scale of the potential.
- Continue the potential away from the minimum using linear and exponential terms (at least 7 parameters needed for two fields with separable W)

[LC, Gomez-Reino, Gross, Palma, Scrucca 09]

Explicit Model(s)

[LC, Gomez-Reino, Gross, Palma, Scrucca 09]

Expand the superpotential around the minimum as

$$W = W_0 + W_i(T_i - T_i^0) + W_{ij}(T_i - T_i^0)(T_j - T_j^0)$$
$$+W_{ijk}(T_i - T_i^0)(T_j - T_j^0)(T_k - T_k^0) + \dots$$

heterotic: $\Delta < 0$

T_0^1	0.405666
T_0^2	0.749277

W_0	1.00000
W_1	1.64415
W_2	2.60392
W_{11}	−17.4400
W_{22}	3.82418
W_{111}	616.732
W_{222}	2.31275

orientifold: $\Delta > 0$

T_0^1	0.412741
T_0^2	0.714888

W_0	1.000000
W_1	2.021311
W_2	0.931223
W_{11}	0.999657
W_{22}	−0.797685
W_{111}	−0.827204
W_{222}	3.308820

Stringy Model(s)

[LC, Gomez-Reino, Gross, Palma, Scrucca 09]

Match to a string-inspired superpotential like

$$W = \Lambda + A_1 e^{a_1 T_1} + B_1 e^{b_1 T_1} + A_2 e^{a_2 T_2} + B_2 e^{b_2 T_2}$$

heteroteric: $\Delta < 0$

Λ	-5.97604×10^{-1}
A_1	-3.62358×10^{5}
B_1	-1.46692×10^{0}
A_2	7.98841×10^{-1}
B_2	7.49672×10^{-1}

a_1	4.36876×10^{1}
b_1	2.66924×10^{0}
a_2	-1.28225×10^{0}
b_2	5.33848×10^{0}

orientifold: $\Delta > 0$

Λ	2.63036×10^{1}
A_1	7.37726×10^{1}
B_1	-9.77287×10^{1}
A_2	-1.50213×10^{0}
B_2	-2.80545×10^{0}

a_1	3.49830×10^{-1}
b_1	2.79764×10^{-1}
a_2	7.30908×10^{0}
b_2	4.19646×10^{-1}

in units of

$m_{3/2}\mathcal{V}_H^{1/2}$ $\quad \mathcal{V}_H^{-1/3}$ $\quad m_{3/2}\mathcal{V}_0$ $\quad \mathcal{V}_0^{-2/3}$

Another way: corrected de Sitter

Subleading corrections can help, if they spoil the no-scale property and change the Kaehler curvature...

$$K = -n \log \left[\mathcal{V} + \hat{\xi} \right]$$

Then we obtain $\sigma \propto \hat{\xi}$ positive for positive $\hat{\xi}$

But then the mass along the Goldstino direction is suppressed compared to the gravitino mass:

$$\frac{\tilde{m}^2}{m_{3/2}^2} \propto \hat{\xi}$$

[LC, Gomez-Reino, Gross, Louis, Palma, Scrucca 08 I]

Part II: Inflation & the gravitino mass

What about inflation ?
A New η problem !

[LC, Gomez Reino, Gross, Luis, Palma & Scrucca II 08]

- In modular inflation eta is constrained:

$$\eta \leq -\frac{2}{3} + \frac{\sigma}{9\gamma\,(1+\gamma)} + \mathcal{O}(\sqrt{\epsilon})$$

where $\gamma = \frac{H_I^2}{m_{3/2}^2}$ for $m_{3/2}^2 = e^G = e^K |W|^2$

- To realise slow roll inflation, i.e. $\epsilon, |\eta| \sim 0$, we need

$$\sigma \geq 6\gamma(1+\gamma)$$

For $\gamma \ll 1$ this reduces to $\sigma > 0$ as for pure de Sitter, while for $\gamma \geq 1$ it is more stringent !
INFLATION at HIGH SCALE is more difficult !

What can we say then ?

- We need more than one field contributing to modular inflation..., possibly one which has a Kaehler potential with zero curvature, e.g.

$$K = -3\ln(T+\bar{T}) + \bar{X}X$$

- We can rely on quantum corrections to modify the curvature and allow de Sitter or inflation, but with some tuning...
- An early inflationary phase, makes present (at least metastable) de Sitter possible...
- Explicit model building still ongoing work !

General predictions:

- We need more than one modular field to allow for inflation: if it is not possible for realistic W to make all other states heavy, we can expect both isocurvature perturbations and non-gaussianities

- Low scale inflation is preferred ! Probably no gravity waves signal for modular inflation... apart if the gravitino mass was very large during inflation.

Outlook

Outlook

de Sitter in SUGRA is not so hopeless:

- We were able to build a model with a tree-level metastable de Sitter vacuum, but we need more than one modulus...
- No inflation in this model yet, but we are still exploring new directions:
  - exploit even more scalar fields
  - try to change substantially the gravitino mass during cosmological evolution
- Also some of the fields have a mass not larger than the gravitino mass: moduli problem ???