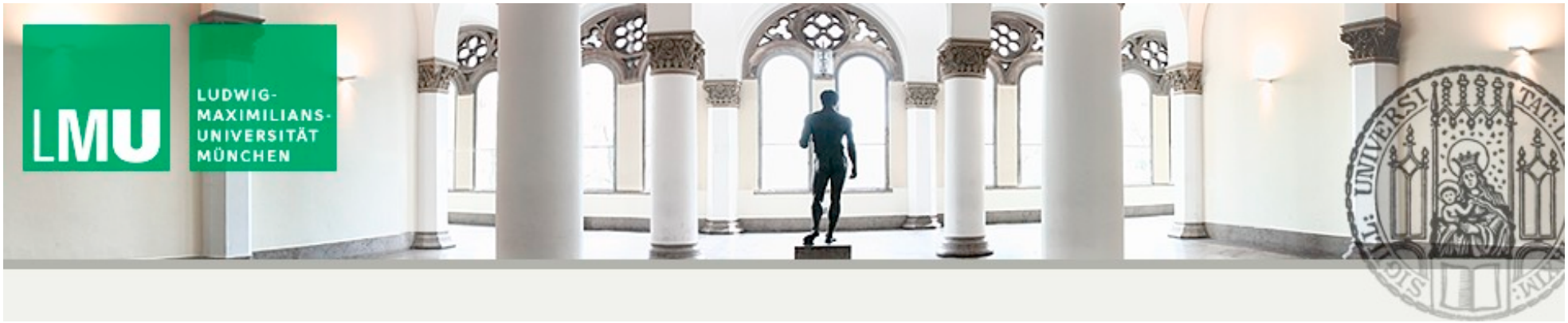
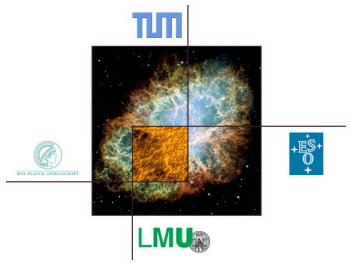
An up-date on Brane Inflation

Dieter Lüst, LMU (Arnold Sommerfeld Center)
and MPI für Physik, München



Leopoldina Conference, München, 9. October 2008



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in collaboration with Gia Dvali:
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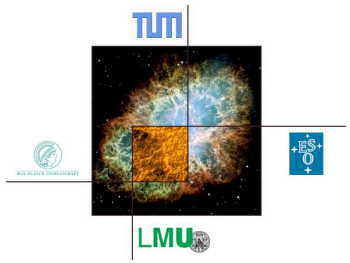

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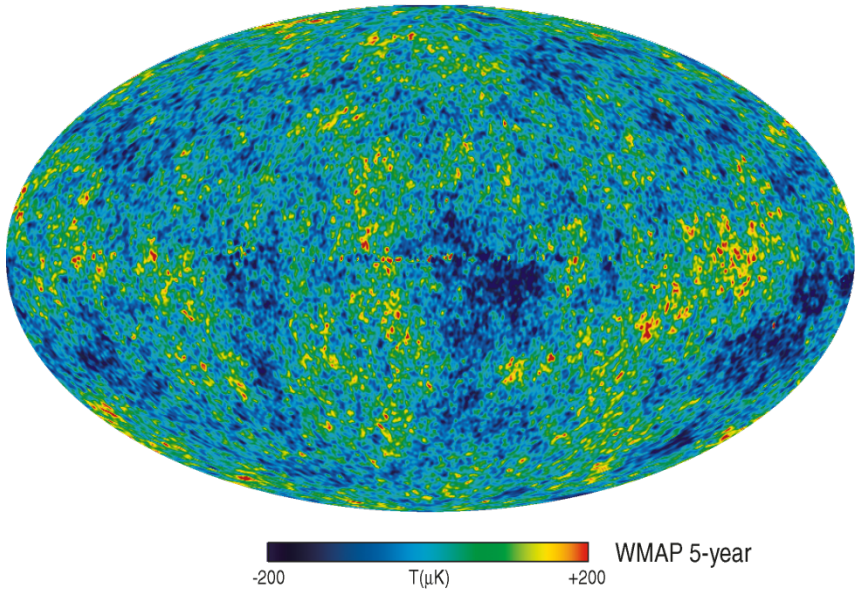
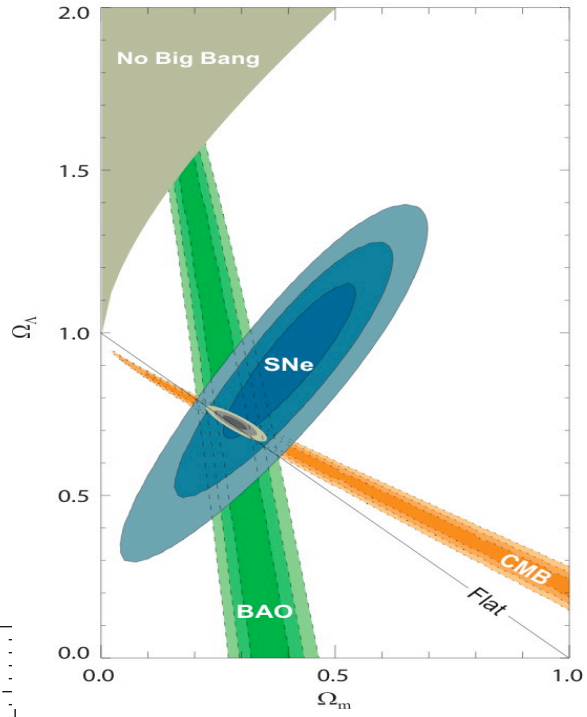
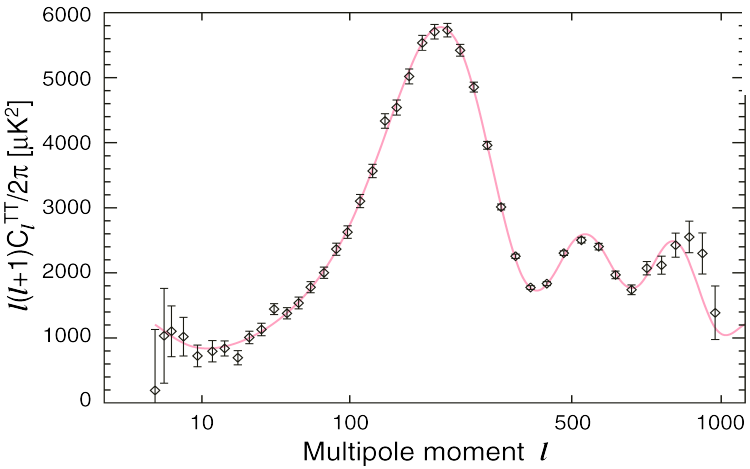
Precision cosmology:







Concordance and simplicity: $\Omega = 1, w = -1$

WMAP 5 CMB-data agree with:

almost scale invariant spectrum:

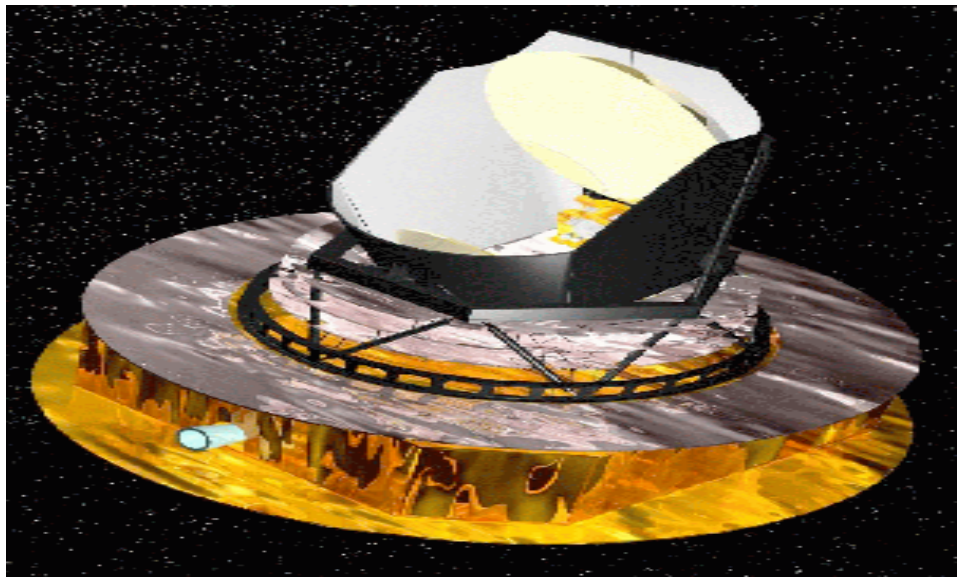
$$n_s = 0.96 \pm 0.013$$

(however without cosmic strings)

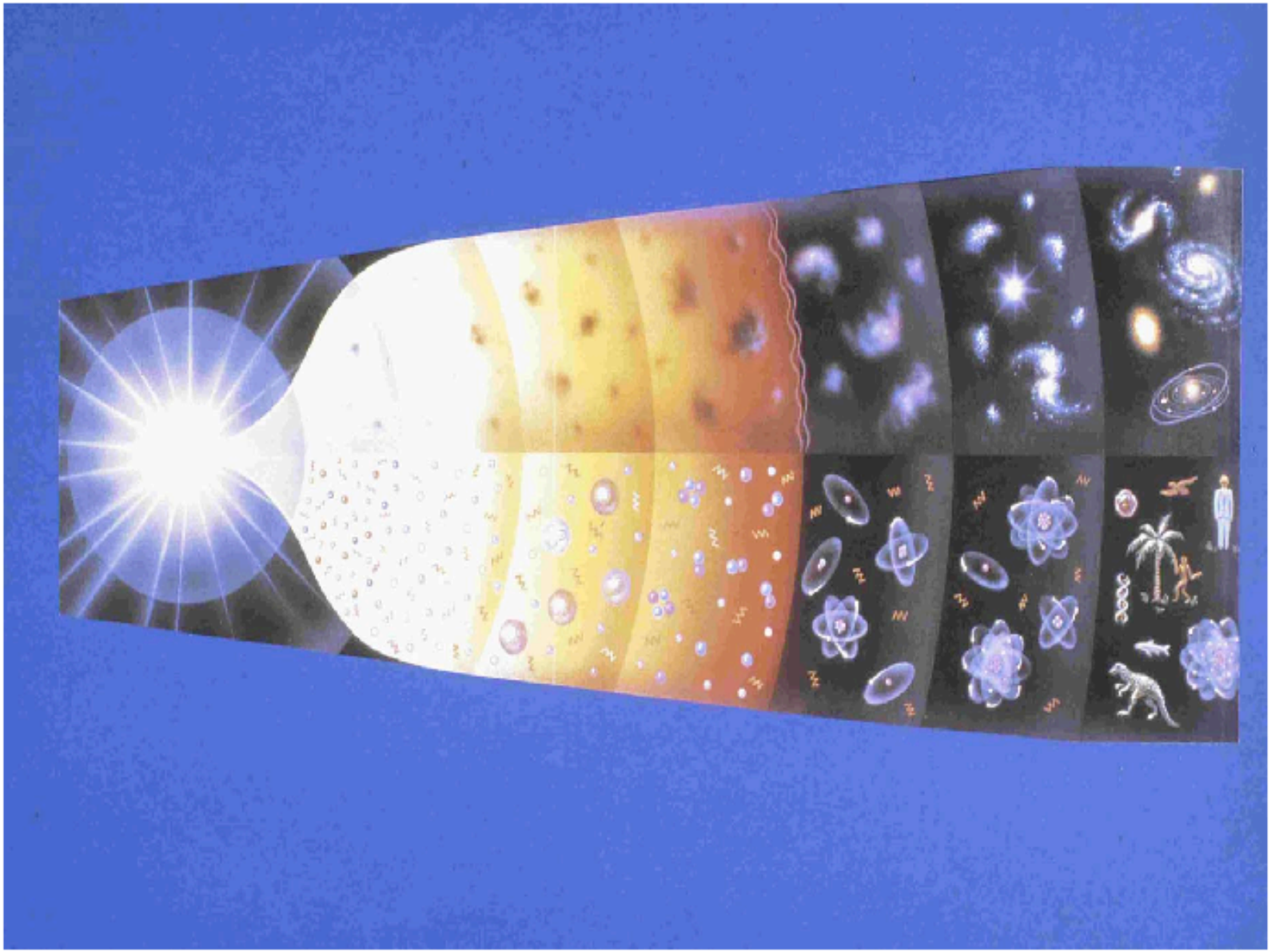
small tensor perturbations:

$$r \equiv \frac{\Delta_T^2}{\Delta_\phi^2}, \qquad r < 0.30$$

Expect improvement in these limits from Planck, SPIDER, Clover, QUIET, BICEP, EBEX, PolarBEAR, ...



These data can be nicely explained by an epoche of cosmic inflation in the early universe!



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  (Swampland approach)
- The challenge: obtain flat enough potentials

Conditions for slow roll inflation:

$$\epsilon = -\frac{\dot{H}}{H^2} = \frac{M_P^2}{2}\left(\frac{V'(\phi)}{V(\phi)}\right)^2 << 1\,,$$

$$\eta = \frac{\dot{\epsilon}}{\epsilon H} = M_P^2\left(\frac{V''(\phi)}{V(\phi)}\right) << 1\,,$$

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- Large field inflation: $\phi \geq M_P$

  e.g. chaotic inflation: $V(\phi) = \frac{1}{2}m^2\phi^2$

  (Linde (1983))

  $\Rightarrow$ gravitational waves, large r: $r = 0.01\left(\frac{\Delta\phi}{M_P}\right)^2$

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- Small field inflation: $\phi \leq M_P$

  $\Rightarrow$ Fine tuning of parameters!

Part I: Bounds from black hole decays:

(G. Dvali, arXiv:0706.2050)

Consider a theory with N species of particles with mass M:

$$N < N_{max} = \frac{M_{Planck}^2}{M^2}$$ M: scale of new physics

(A quantum black hole can emit at most N_{max} different particles)

This bound must be satisfied in every effective string vacuum that is consistently coupled to gravity!

E.g. if a scalar field in the effective potential gives mass to N particles via the Higgs effect: $M = M(\phi)$

$$M(\phi)^2 < \frac{M_{Planck}^2}{N}$$

Cosmological applications of this bound:

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- De Sitter vacua - inflation: Consider inflaton field ϕ

$$\ddot{\phi} + 3H\dot{\phi} + V(\phi)' = 0$$

ϕ is coupled to species of mass M:

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$g\phi \leq M_P\left(\dfrac{m\phi}{M_P^2}\right)^{\frac{1}{3}}$ ϕ cannot be arbitrarily large!

Bound forbids essentially large trans-planckian vevs:

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Bound forbids essentially large trans-planckian vevs:

$\Rightarrow$ Problem to see gravitational waves?

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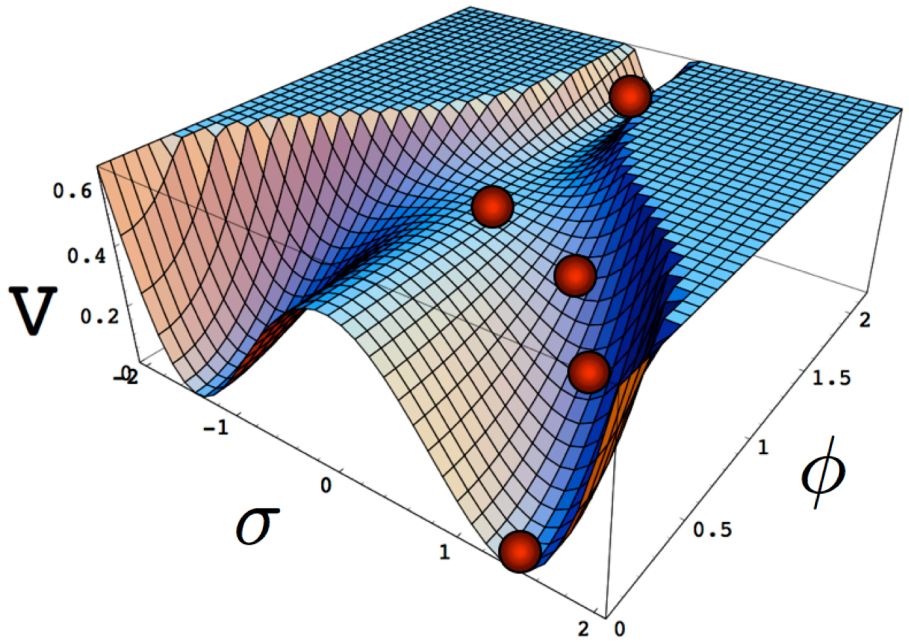
Bound forbids essentially large trans-planckian vevs:

(Silverstein, Westphal: large field range due to monodromy!)

(arXiv:0803.3085)

Similar bounds can be derived for D-term (hybrid) inflation.

(Linde (1993); Binetruy, Dvali (1996))



$$V(\phi) \simeq \mu^4 \left[1 + \frac{g^2}{16\pi^2} \ln \frac{g|\phi|}{Q} \right]$$

Black hole bound: $g^2\phi^2 \leq M_P^2$

(The same bound arise from the interactions of ϕ with fermions of mass $m_F \sim g\phi$.)

Part II: String/brane inflation:

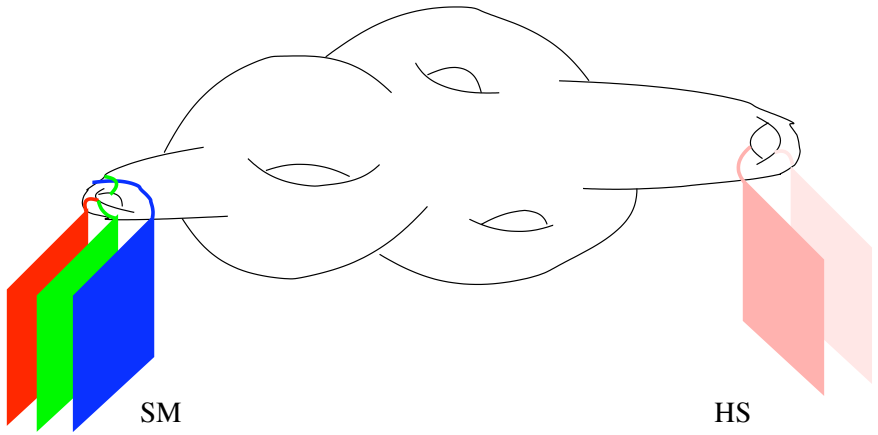
String theory lives in 10 space-time dimensions !

Compactification: $M_{10} = M_4 \otimes M_6$

M_4 : 4-dim. expanding FRW universe

Internal 6-dimensional compact space:

M_6 :



e.g. Calabi-Yau space

4d effective potential: stored internal, 6-dimensional energy:

$$V(M) = V(M') + V'(M', \phi) \quad \Rightarrow \quad V_0 + V(\phi)$$

Moduli fields

Steep potential

Stabilization of moduli M'

Cosmological constant Λ $(w = -1)$

Flat inflaton potential

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String landscape: $10^{500-1500}$ string vacua V_0 ?!

(Lerche, Lüst, Schellekens (1986); Bousso, Polchinski (2000); Kachru, Kallosh, Linde, Trivedi (2003); Susskind (2003); Douglas, Denef (2003))

Eternal inflation and string theory landscape

Inflationary universe may consist of many parts with different properties depending on the local values of the scalar fields, compactifications, etc.

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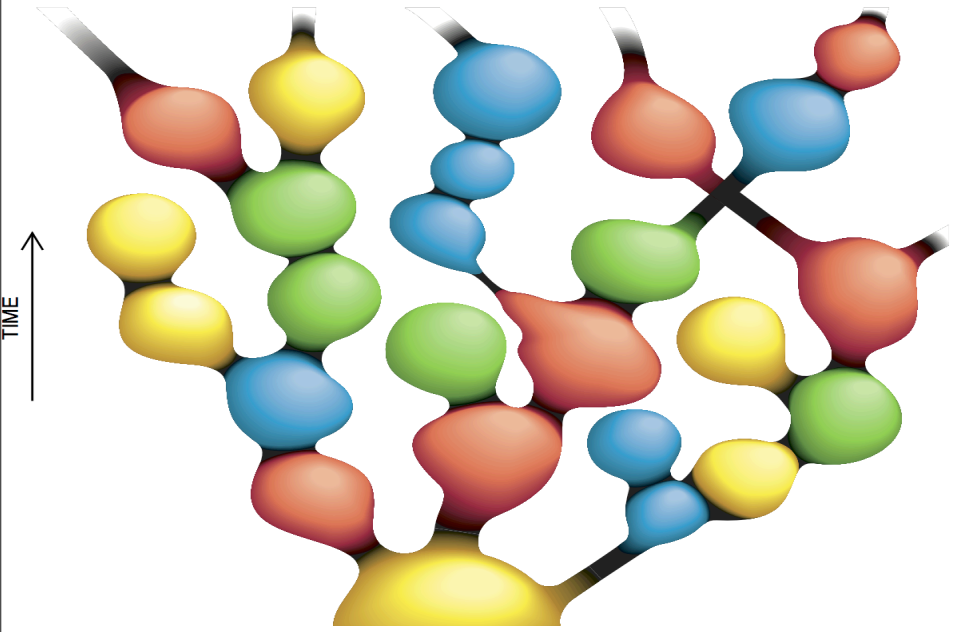

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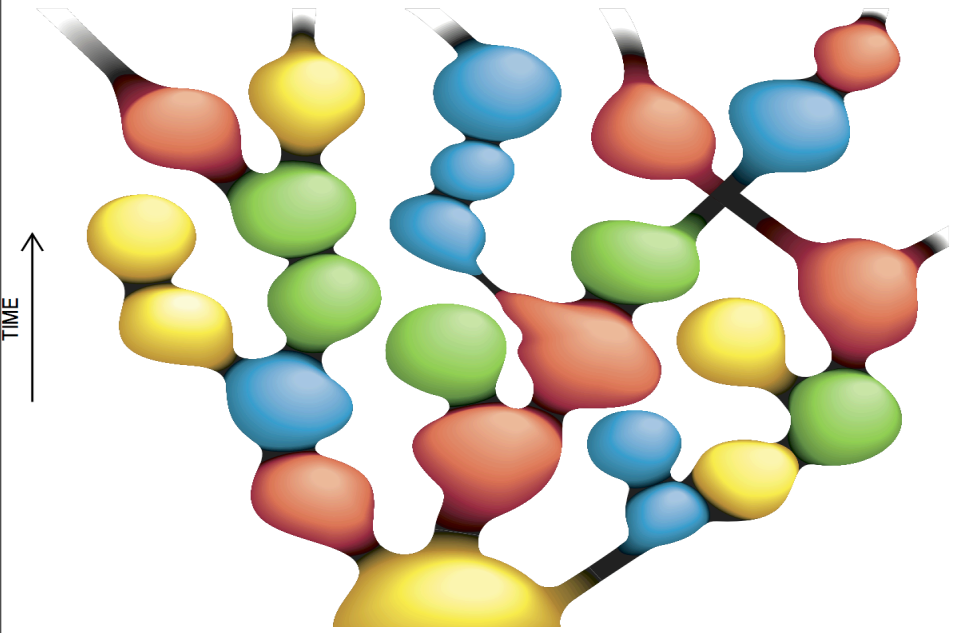

„An enormously large number of possible types of compactification which exist e.g. in the theories of superstrings should be considered not as a difficulty but as a virtue of these theories, since it increases the probability of the existence of mini-universes in which life of our type may appear. „

(A.Linde (1986))

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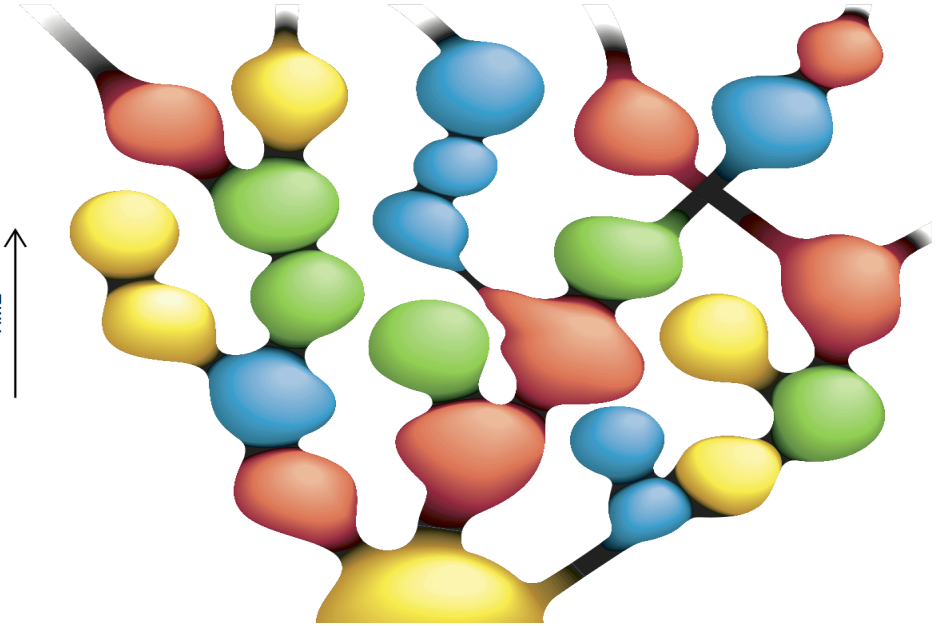

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Now, Dr. Witten allowed, dark energy might have transformed this from a vice into a virtue, a way to generate universes where you can find any cosmological constant you want. We just live in one where life is possible, just as fish only live in water.

The New York Times

June 3, 2008

Two scenarios for string inflation:

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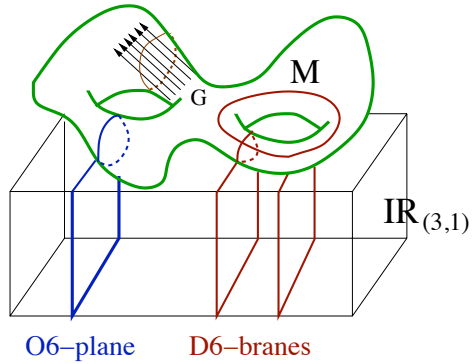
- Closed string inflation: inflaton is geometric modulus

Effective potential due to force from fluxes and strings/branes wrapped around cycles:



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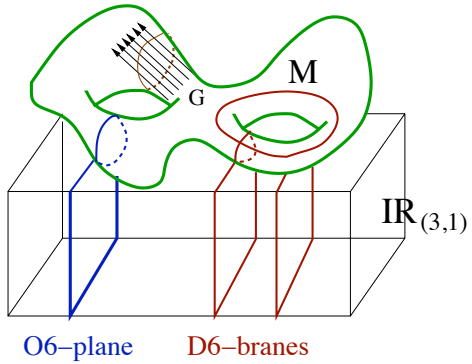
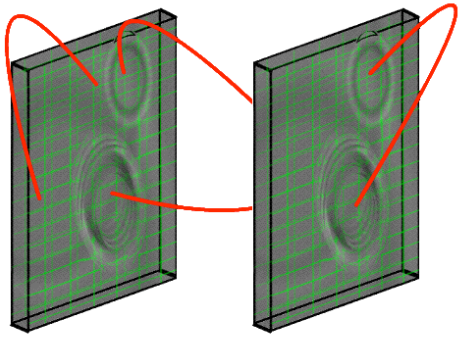


- Open string inflation:
  Inflaton is distance between D-branes:
  (Dvali, Tye (1999))

Effective potential due to force between branes:



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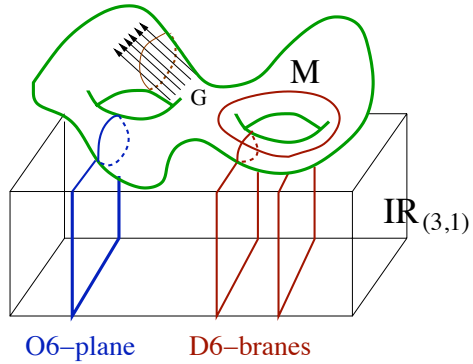

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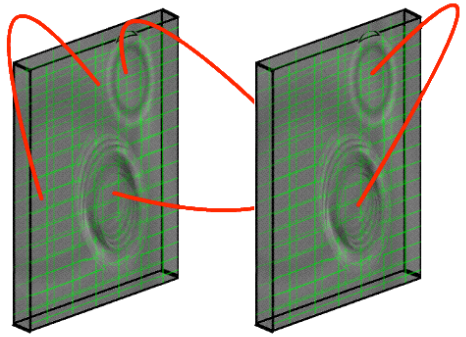


Generic problem: effective supergravity potential is generically non-flat:

$$V(\phi) = e^{K(\phi,\bar{\phi})}\left[|DW(\phi)|^2 - 3|W(\phi)|^2\right]$$

e.g. $K = \phi\bar{\phi}$

$V \sim e^{|\phi|^2}$ too steep!

Stringy realization of D-term (hybrid) inflation:

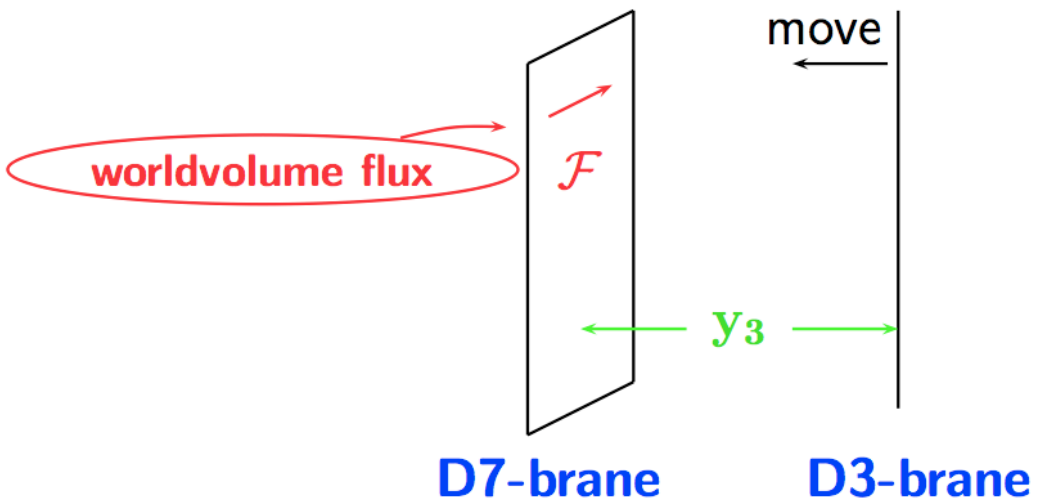
(Dasgupta, Herdeiro, Hirano Kallosh (2002);
Kallosh, Linde (2003); Dasgupta, Hsu, Kallosh, Linde, Zagermann (2003);
Haack, Kallosh, Krause, Linde, Lüst, Zagermann, arXiv:0804.3961)

- U(1) shift symmetry: naturally flat inflaton potential
- Cosmic strings after brane recombination

(Dvali, Kallosh, Van Proeyen (2003))

Type IIB orientifold with D3/D7-branes on

$$M_{10} = M_4 \otimes (K3 \times T^2/Z_2)$$



Inflaton field: D3-D7 distance on T^2

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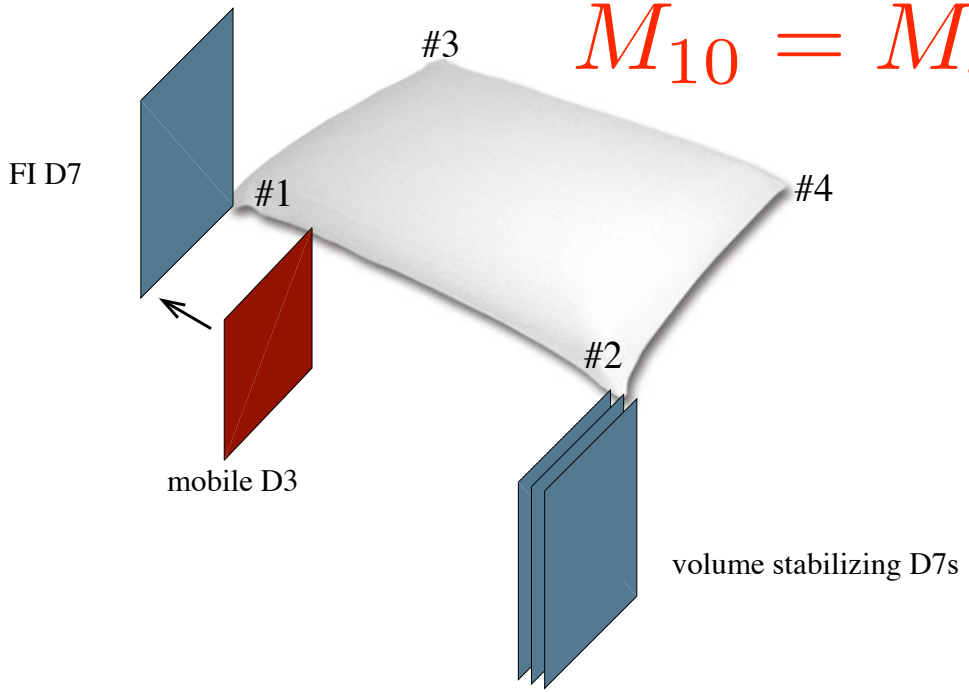


Inflaton field: D3-D7 distance on T^2

- Classical Kähler potential:

$$K = -\ln\Big[-8\,(\mathrm{Im}(s)\,\mathrm{Im}(t)\mathrm{Im}(u) - \frac{1}{2}\,\mathrm{Im}(s)\,(\mathrm{Im}(y_7^k))^2 - \frac{1}{2}\,\mathrm{Im}(u)\,(\mathrm{Im}(y_3^r))^2)\Big]$$

K3 volume — Complex structure of T^2 — Dilaton — D7 positions — D3 positions

Moduli fields M

- Superpotential (from fluxes and gaugino condensation):

$$W = W_0(t, u, y_7^r) + A\; e^{-8i\pi^2 s/N}$$

W fixes s, t, u, y_7 $\Rightarrow$ Landscape of possibilities!

K & W do not depend on $\mathrm{Re}(y_3)$ $\Rightarrow$ $\phi \sim \mathrm{Re}(y_3)$

Good inflaton candidate!

- Scalar potential:

Supersymmetry gets broken by F-flux on D7-branes.

$$V(\phi) = V_D + V_{CW} = \frac{g^2\xi^2}{2}\left(1 + \frac{g^2}{4\pi^2}\ln\frac{\phi}{\sqrt{\xi}}\right)$$

FI-parameter

K & W are corrected by stringy quantum corrections:

$$K = -\ln[\cdots - c\ \mathrm{Im\ t}\ \mathcal{E}(y_3, y_7, t)]$$

$$W = W_0 + A\exp\left(\frac{8\pi^2 f_{D7}(M)}{c}\right)$$

$$= W_0 + A\left(\vartheta_1\left(\sqrt{2\pi}(y_3+\mu), t\right)\vartheta_1\left(\sqrt{2\pi}(y_3-\mu), t\right)\right)^{\frac{-1}{c}} e^{8i\pi^2 s/c}.$$

Gaugino condensation on D7-branes: one loop threshold corrections to gauge kinetic function:

$$f_{D7} = is - \frac{1}{8\pi^2}\ln\vartheta_1(\sqrt{2\pi}(y_3-\mu), t) - \frac{1}{8\pi^2}\ln\vartheta_1(\sqrt{2\pi}y_3+\mu, t) + \ldots$$

(Bachas, Fabre (1996); Lüst, Stieberger (2003); Berg, Haack, Körs (2003))

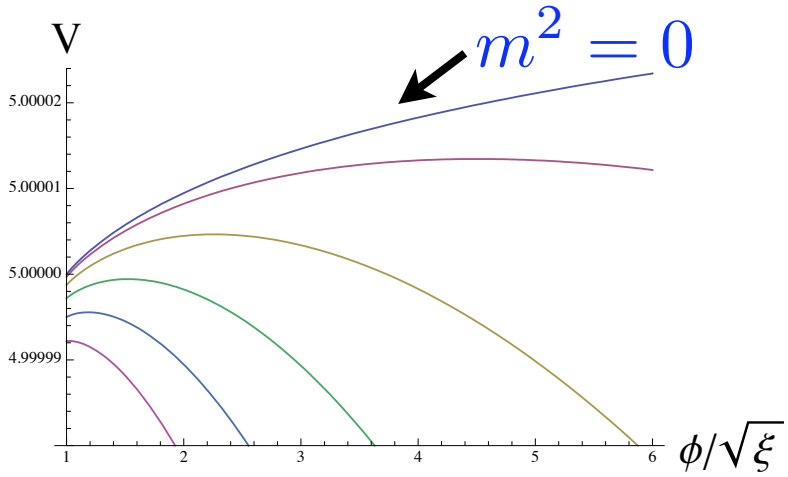
Additional y_3 dependence to the potential (destroys U(1) shift symmetry) $\Rightarrow$ mass term :

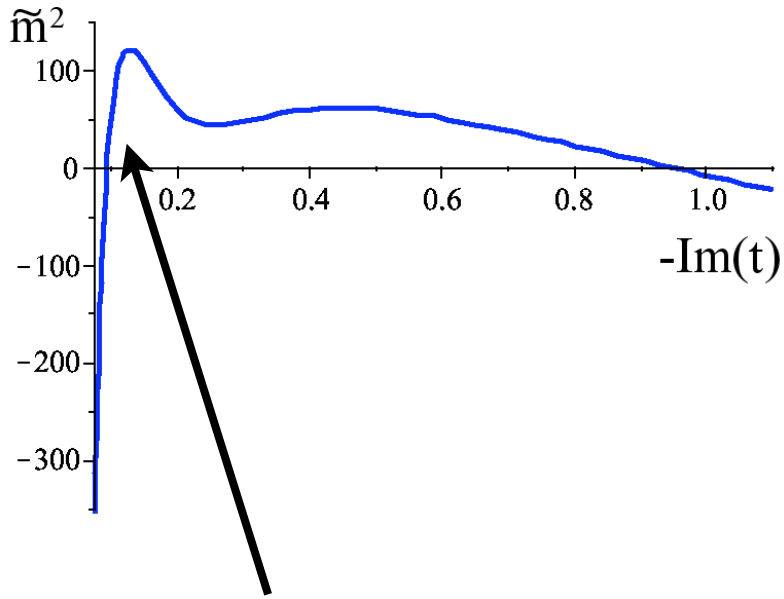
$$V(\phi) = V_D + V_{CW} = \frac{g^2\xi^2}{2}\left(1 + \frac{g^2}{4\pi^2}\ln\frac{\phi}{\sqrt{\xi}}\right) - \frac{m^2}{2}\phi^2 + \mathcal{O}(\phi^4)$$

Non-vanishing moduli dependent mass term :

$$m^2 = m^2(s,t,u) \;\Rightarrow\; \text{Mixed F- and D-term inflation !}$$

Inflaton potential:





One needs sufficiently small (positive) values for m^2

$\Rightarrow$ fine tuning of parameters s,t and u !

Question: can we find points in the landscape, where higher order corrections are suppressed?

Vanishing mass: pure D-term inflation $\Rightarrow$ cosmic strings

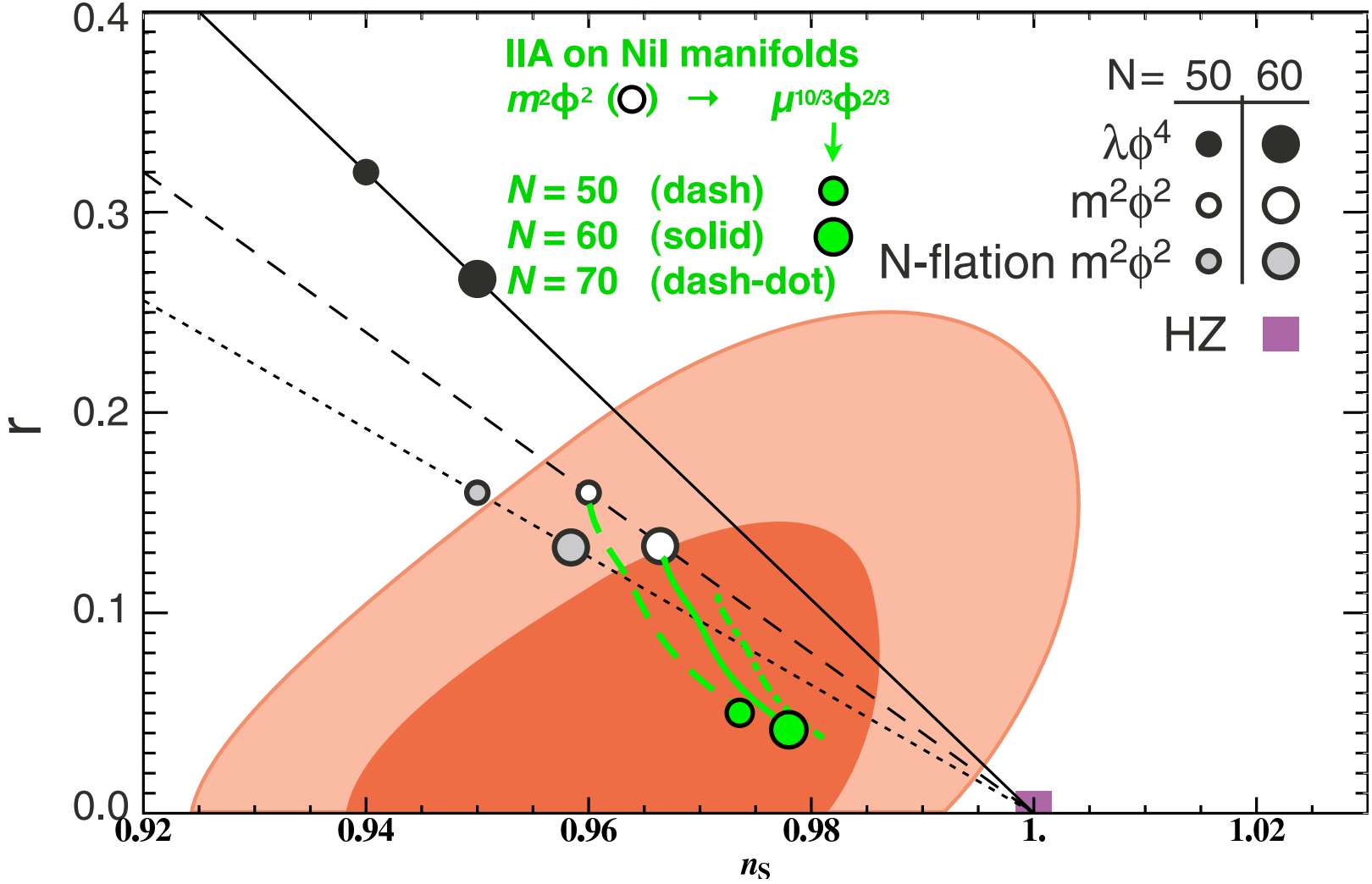
LMU

Summary:

MAX-PLANCK-GESELLSCHAFT

Summary:

Chaotic Inflation



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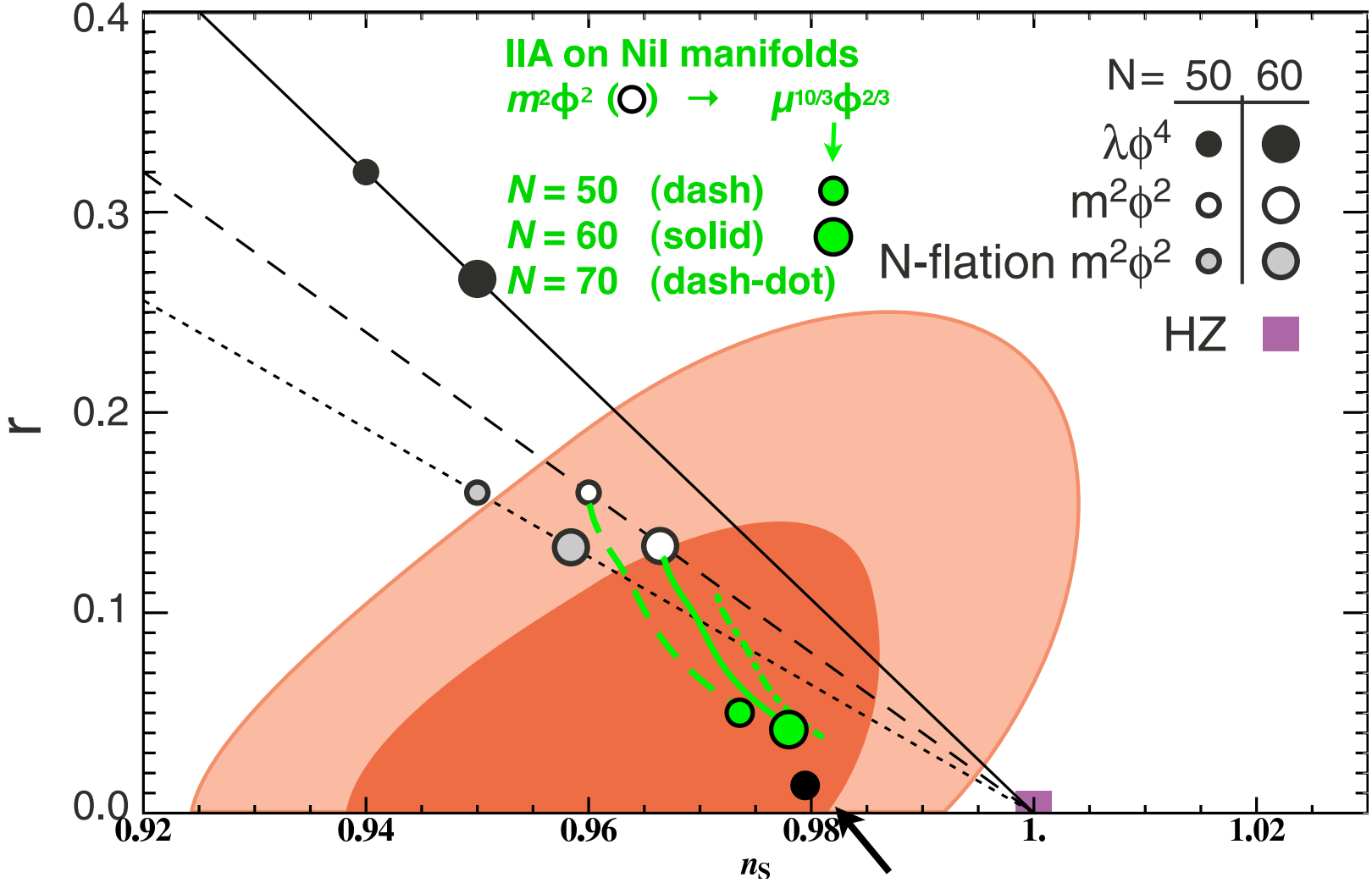
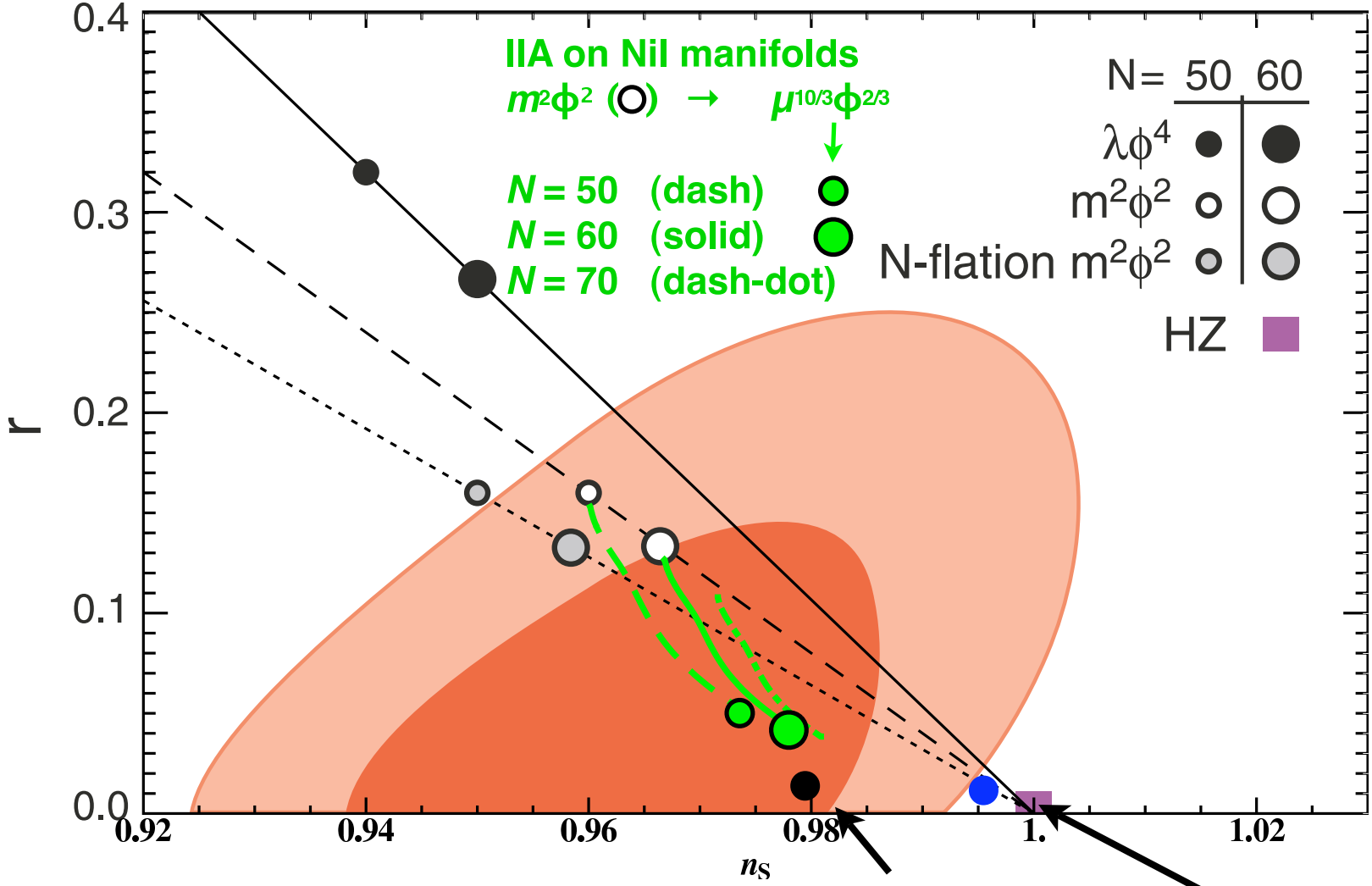


K3 x T2 orientifold : with quantum corrections

Summary:

Chaotic Inflation



K3 x T2 orientifold : with quantum corrections

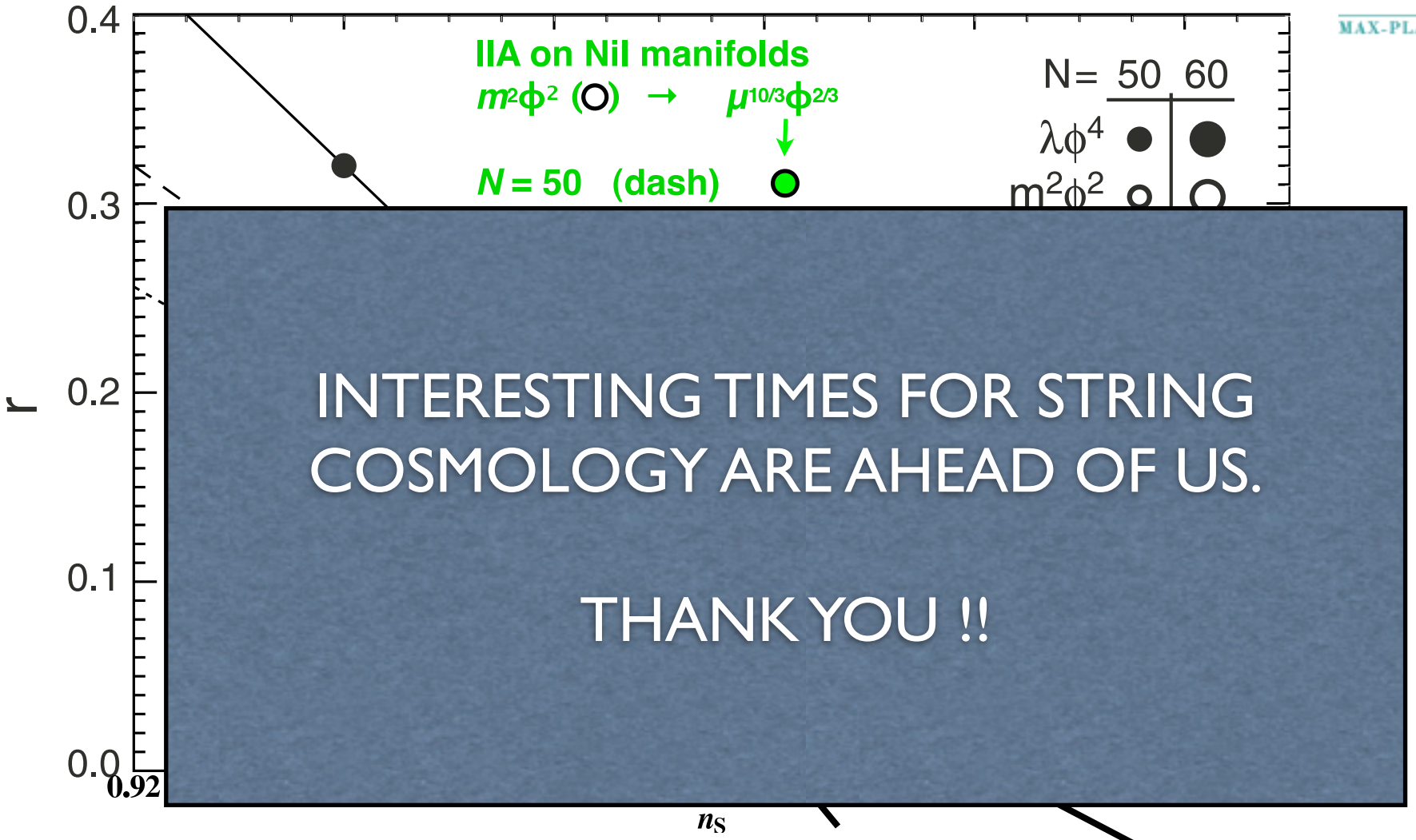
With very small quantum correction: in addition cosmic strings

$$G\mu = \frac{\xi}{4} \simeq 7 \times 10^{-7}$$

(Bevis, Hindmarsh, Kunz, Urrestilla, arXiv:astro-ph/0702223)

Summary:

Chaotic Inflation



INTERESTING TIMES FOR STRING COSMOLOGY ARE AHEAD OF US.

THANK YOU !!

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