Cosmology of String Theory: Inflation and Beyond

F. Quevedo, Cambridge.   UNIVERSENET 2007. Mytilene

OUTLINE

- String Theory and 4D Inflation

FQ hepth/0210292

- Moduli Stabilization and the String Landscape (KKLT and LARGE volume scenarios)

- Inflation and Moduli Stabilization (open string vs closed string inflaton).

C. P. Burgess

0708.2865 [hep-th]

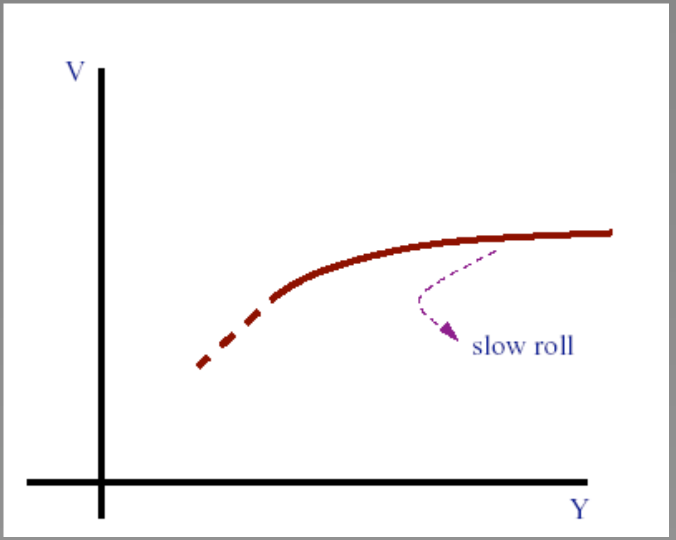
- After Inflation

MOTIVATION

- Inflation: very successful but is only ad-hoc scenario in search of a theory
- String theory: fundamental theory but lacks experimental tests.
- Is it possible to `derive’ inflation from string theory?

- Need to compute scalar potential from String theory satisfying slow-roll conditions:

$$\epsilon \equiv \frac{M_{Planck}^2}{2}\left(\frac{V'}{V}\right)^2 \ll 1\,,$$
$$\eta \equiv M_{Planck}^2 \frac{V''}{V} \ll 1\,.$$



Number of e-folds N>60

$$N(t) \equiv \int_{t_{init}}^{t_{end}} H(t')dt' = \int_{\psi_{init}}^{\psi_{end}} \frac{H}{\dot{\psi}} d\psi = \frac{1}{M_{Planck}^2}\int_{\psi_{end}}^{\psi_{init}} \frac{V}{V'} d\psi\,.$$

Density perturbations

$$\delta_H = \frac{2}{5}\mathcal{P}_{\mathcal{R}}^{1/2} = \frac{1}{5\pi\sqrt{3}}\frac{V^{3/2}}{M_p^3 V'} = 1.91 \times 10^{-5}\,,$$

$$n - 1 = \frac{\partial \ln \mathcal{P}_{\mathcal{R}}}{\partial \ln k} \simeq 2\eta - 6\epsilon\,, \qquad \frac{dn}{d\ln k} \simeq 24\epsilon^2 - 16\epsilon\eta + 2\xi^2\,.$$

$$n_{grav} = \frac{d\ln \mathcal{P}_{grav}(k)}{d\ln k} = -2\epsilon\,.$$

HISTORY

- t<1986 Calabi-Yau String Compactifications: Many free moduli (size and shape of extra dimensions) from g_{mn}, B_{mn}, φ, A_m^I

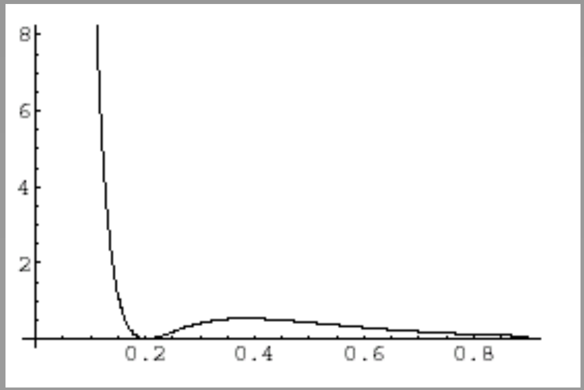
Candelas et al.

Dilaton S,
Kähler T
Complex structure U
Wilson lines W

- 1986<t<1991 Geometric moduli: candidate for inflaton fields. But no potentials (V=0).

Binetruy-Gaillard, Banks et al

- Or V too steep:



Brustein-Steinhardt

New Problems:

- **Overshooting**

(natural to end up in runaway)

Brustein-Steinhardt

- **Cosmological Moduli Problem**

(moduli overclose the universe or ruin nucleosynthesis)

Coughlan et al. 82

Banks et al. 94

De Carlos et al. 93

(t>1995) More moduli!

Open string moduli:

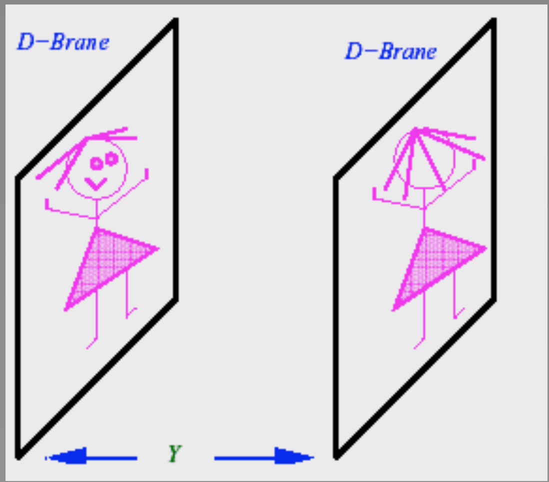
Brane separation

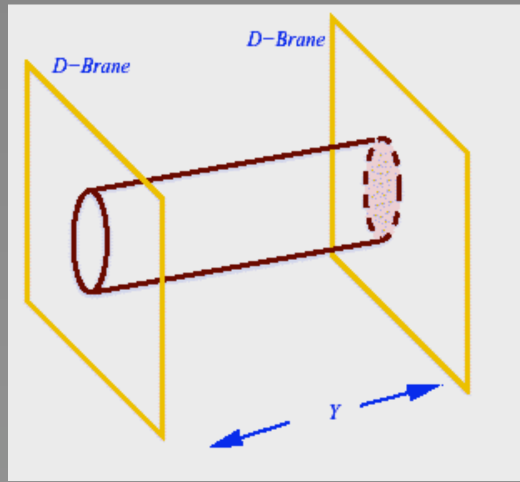
Also Wilson Lines

See Avgoustidis talk

- t=199 : D-brane inflation. But V=0 or non-calculable.

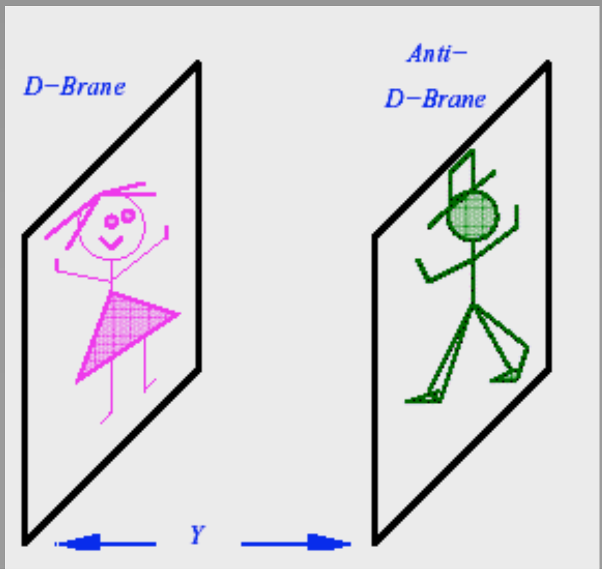
Dvali-Tye





- t=2001 Brane/Antibrane inflation:

Burgess et al., Dvali et al



$$V(Y) = A - \frac{B}{Y^{d_\perp - 2}},$$

$$A \equiv 2T_p V_{||} = \frac{2e^{\varphi}}{(M_s r_\perp)^{d_\perp}} M_s^2 M_{Planck}^2,$$

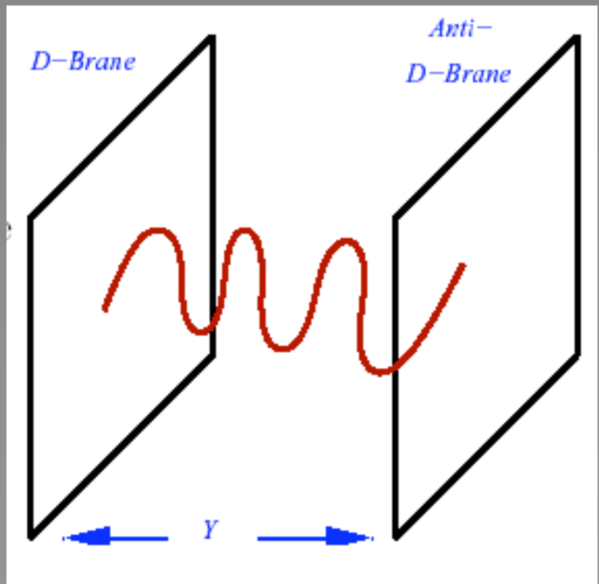
$$B \equiv \frac{\beta e^{2\varphi}}{M_s^8} T_p^2 V_{||} = \frac{\beta e^{\varphi} M_{Planck}^2}{M_s^{2(d_\perp - 2)} r_\perp^{d_\perp}}.$$

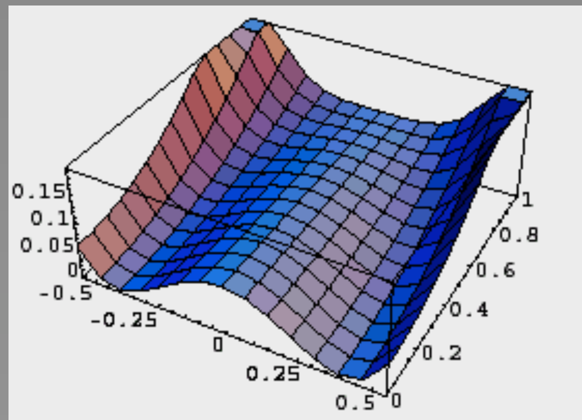
Generically no slow roll

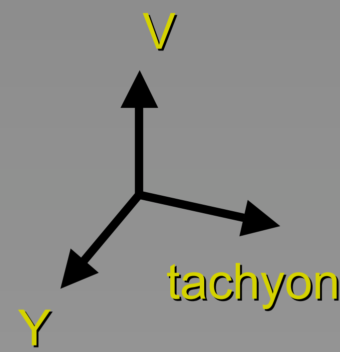
but…

End of inflation: Open string tachyon

Burgess et al.



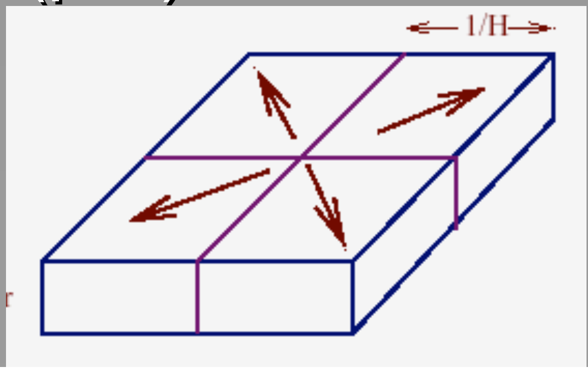




Tachyon complex → topological defects

D (p-2) branes → cosmic strings !

Sen, Burgess et al.



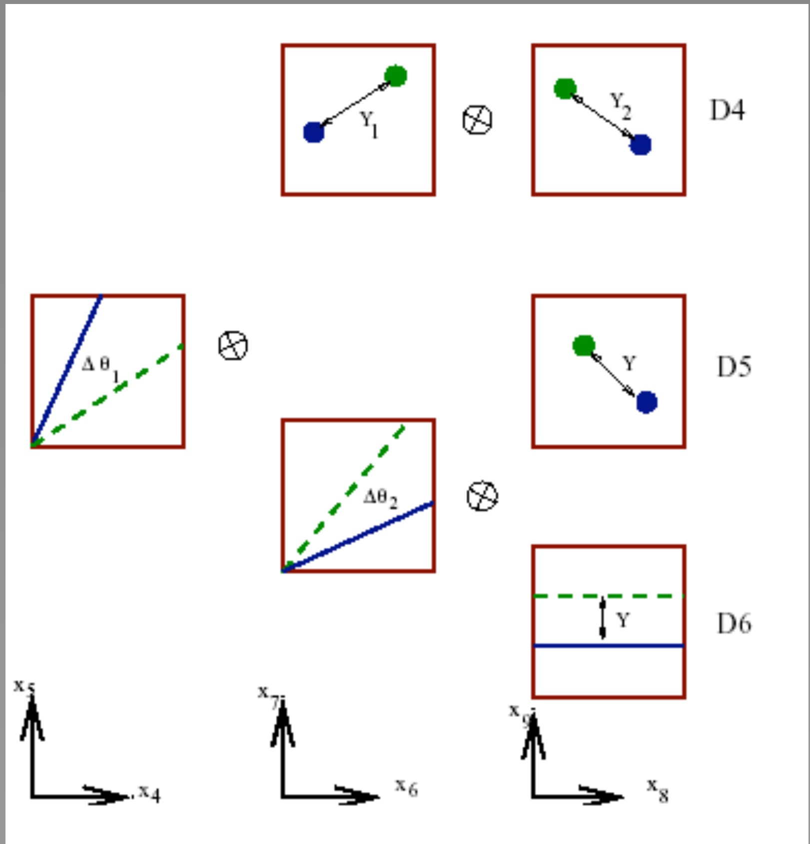
Tye et al.

Copeland et al.

Intersecting Brane Inflation

Garcia-Bellido et al.

Gomez-Reino, Zavala



Y: Inflaton

End of inflation: tachyon!!

Also: D3-D7 inflation

Kallosh et al.

Wilson Line Inflation

Avgoustidis-Cremades-FQ

T-Duality:

Dp-Branes ⟷ D(p+1)-Branes

Brane Separation ⟷ Wilson Lines

Angles ⟷ Magnetic Fluxes

Brane inflation ⟷ Wilson Line Inflation

Moduli Stabilisation and Supersymmetry Breaking

The Problem

- String/M-Theory unique but has many solutions or vacua.
- Degeneracy : Discrete + Continuous (SUSY) .
- Outstanding Problems:

SUSY breaking + Vacuum degeneracy.

History

- t<1986 Calabi-Yau String Compactifications: Many free moduli (size and shape of extra dimensions)

Dilaton S, Kähler T
Complex structure U
Wilson Lines W

CHSW

- 1986<t<1991 Gaugino condensation and T-duality

DIN, DRSW, K, FILQ, FMTV

Fix S and one T

- 1991<t<2002 More moduli! (D-brane positions)

- t>2002 GKP/ KKLT : Fluxes fix moduli

…GKP, KKLT, …

KKLT Scenario

…GKP, KKLT, …

Type IIB String on Calabi-Yau orientifold

Turn on Fluxes

$\int_a F_3 = n_a \qquad \int_b H_3 = m_b$

Size of cycle a = U_a

Superpotential $W = \int G_3 \wedge \Omega, \qquad G_3 = F_3 - iS\, H_3$

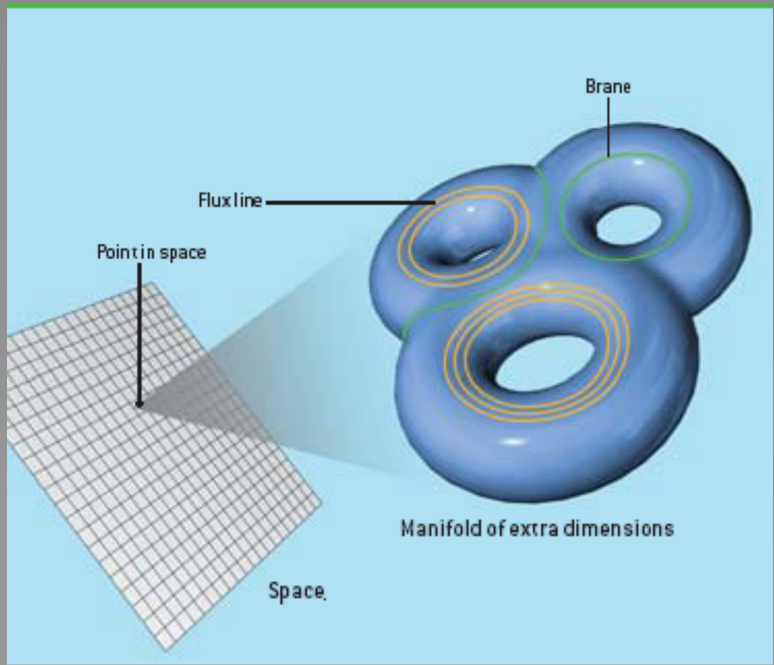
Scalar Potential: $V = e^K \; |D_a W|^2$

Minimum $D_a W = 0$ Fixes U_a and S

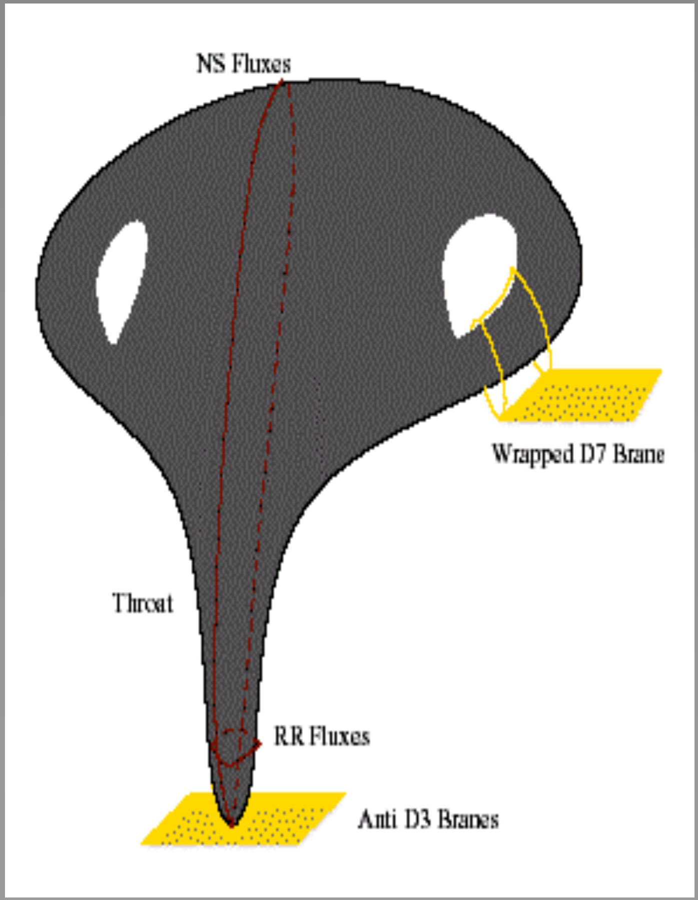
T moduli unfixed: No-Scale models

GKP

4D Compactifications



- To fix Kähler moduli: Non-perturbative D7 effects



Fluxes — Non-perturbative

$$W = W_0 + \sum_i A_i e^{-a_i T_i},$$

Volume

$$K = -2 \log [\mathcal{V}]$$

SUSY AdS minimum

$$V = e^K \left[G^{i\bar{j}} D_i W \bar{D}_j \bar{W} - 3|W|^2 \right],$$

$$D_i W \equiv \frac{\partial W}{\partial T_i} + W \frac{\partial K}{\partial T_i} = 0.$$

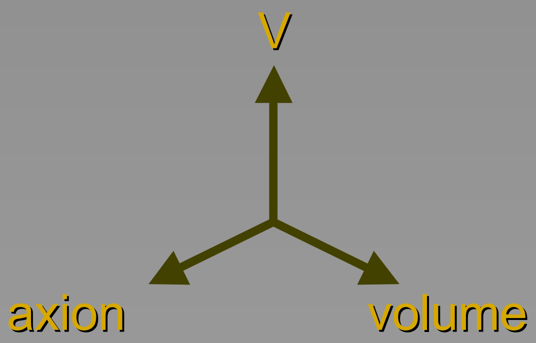
$(W_0 << 1)$

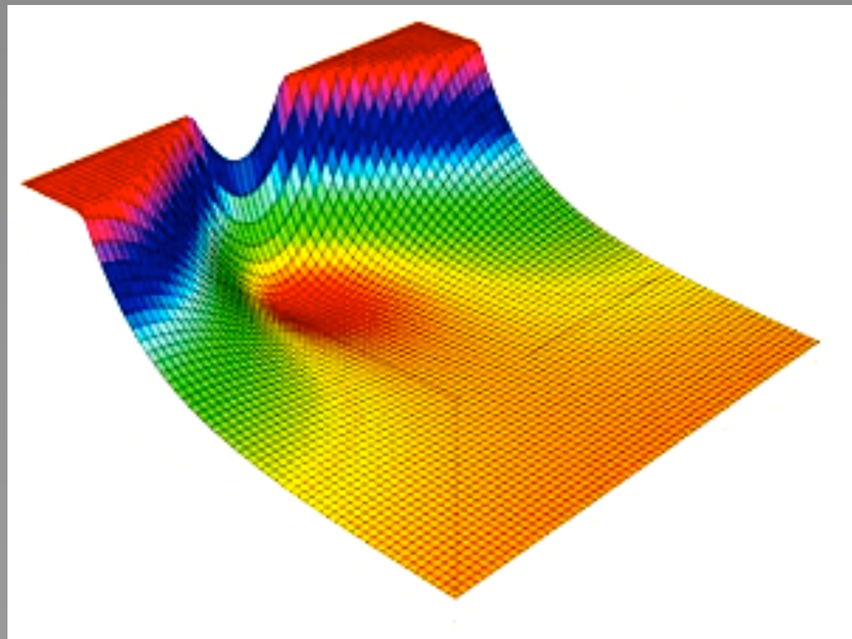
- Lifting to de Sitter (add anti D3 branes, D-terms, etc.)

KKLT, BKQ, SS

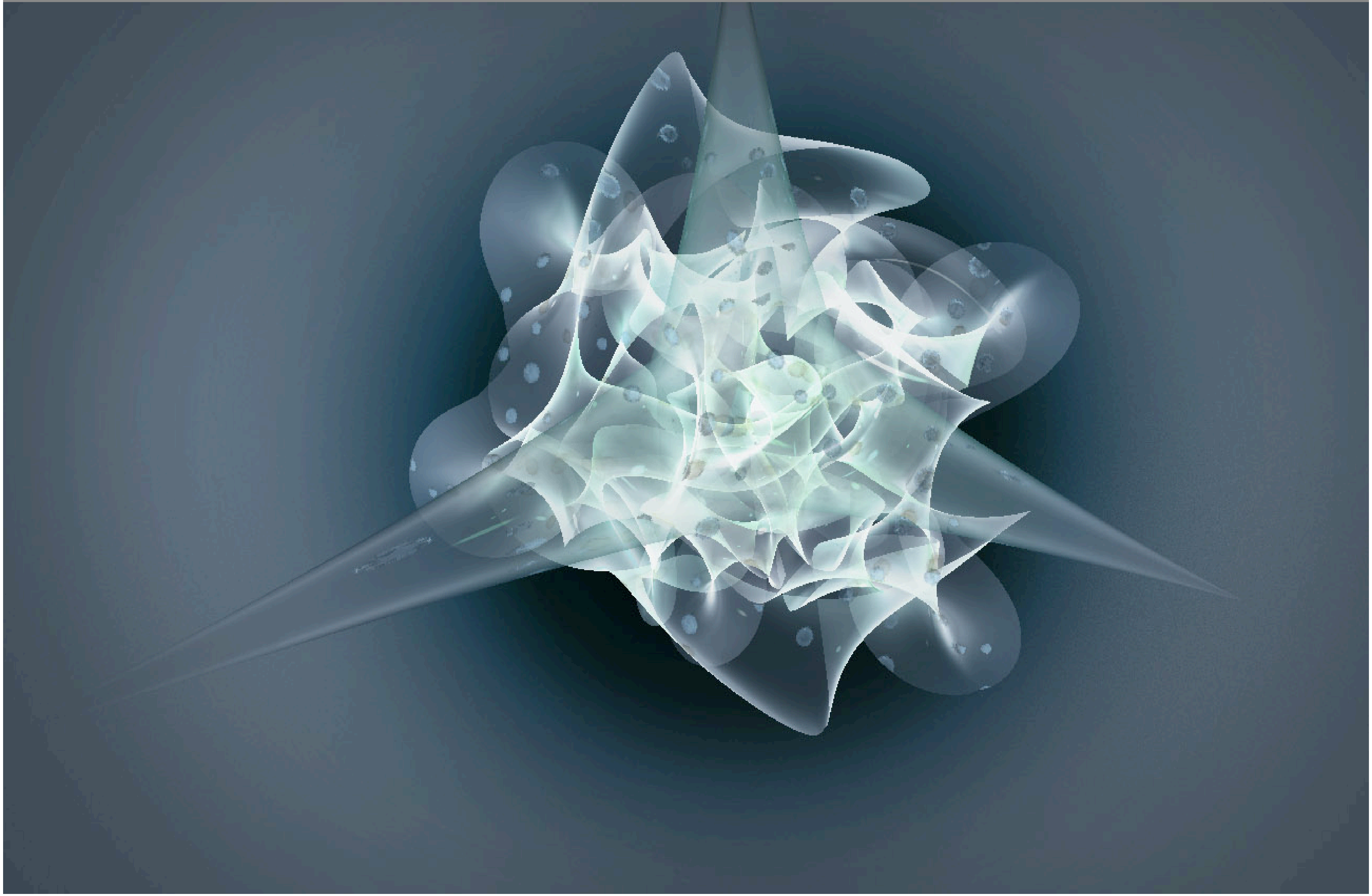
SUSY breaking term

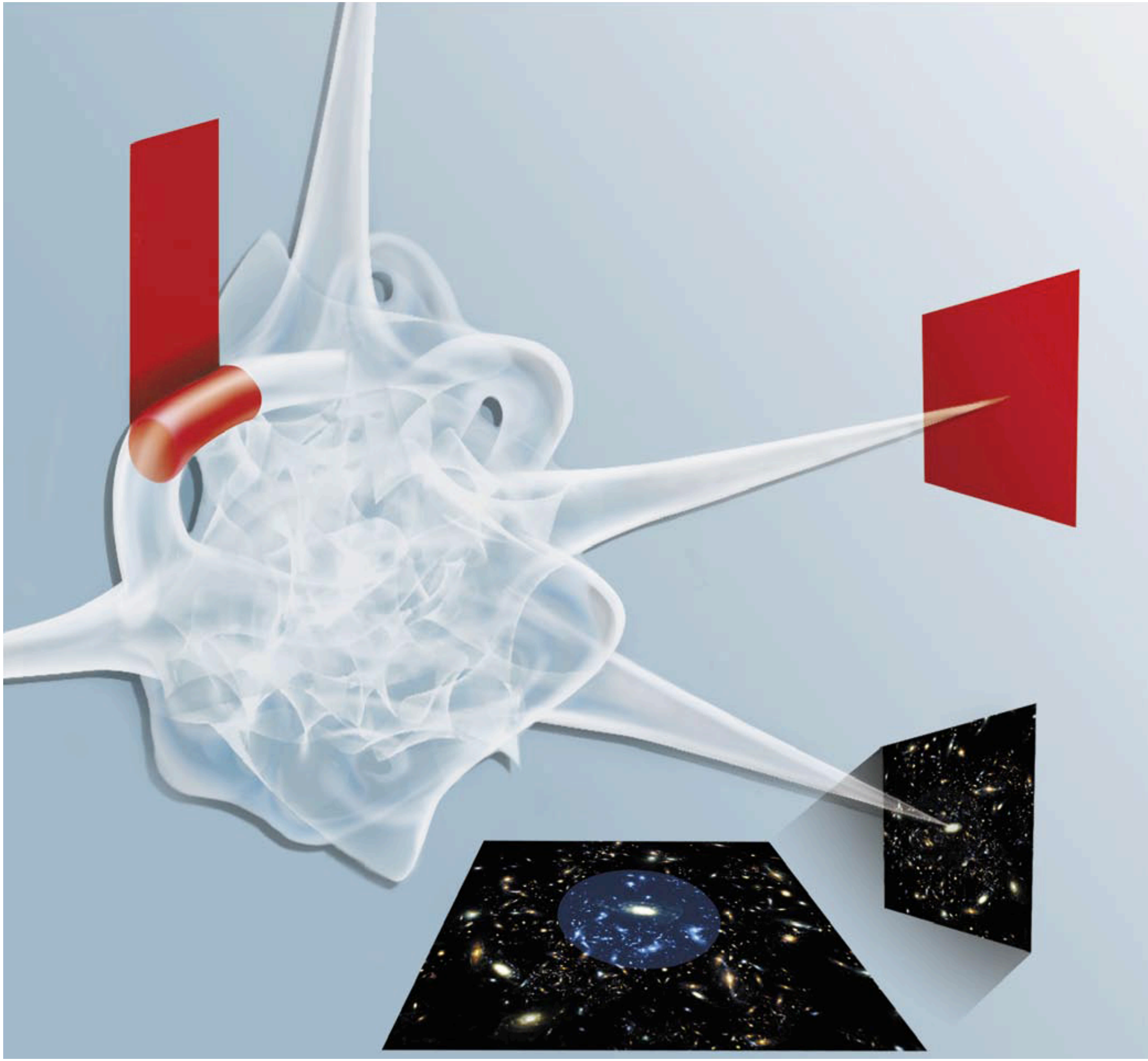
$$V = V_F + \delta V \,.$$





ALL MODULI STABILISED !





Universe

D3 Brane

or

D7 Brane

Exponentially Large Volumes

Argument:

- In general:

$$\begin{aligned} \mathcal{K} &= \mathcal{K}_0 + \mathcal{K}_p + \mathcal{K}_{np} \approx \mathcal{K}_0 + J, \\ W &= W_0 + W_{np} \approx W_0 + \Omega, \end{aligned}$$

- Then:

$$V = V_0 + V_J + V_\Omega + \cdots,$$

$$V_0 \sim W_0^2, \quad V_J \sim J W_0^2, \quad V_\Omega \sim \Omega^2 + W_0 \Omega,$$

- Usually V_0 dominates but $V_0=0$ (no-scale $G^{-1}_{i\bar{k}} \mathcal{K}_i \mathcal{K}_{\bar{k}} = 3$)
- Dominant term is V_J unless $W_0 << 1$ (KKLT)

Exponentially Large Volumes

BBCQ, CQS

- Perturbative corrections to K
- At least two Kähler moduli ($h_{21}>h_{11}>1$) Example :

$$\mathbb{P}^4_{[1,1,1,6,9]},$$

$$\mathcal{K} = -2\ln\left(\frac{1}{9\sqrt{2}}\left(\tau_b^{3/2} - \tau_s^{3/2}\right) + \frac{\xi}{2g_s^{3/2}}\right)$$

$$W = W_0 + A_s e^{-a_s T_s}.$$

Non SUSY AdS

$$V=\sum_{\Phi=S,U}\frac{\hat{K}^{\Phi\bar{\Phi}}D_\Phi W\bar{D}_{\bar{\Phi}}\bar{W}}{\mathcal{V}^2}+\frac{\lambda(a_sA_s)^2\sqrt{\tau_s}e^{-2a_s\tau_s}}{\mathcal{V}}-\frac{\mu W_0a_sA_s\tau_se^{-a_s\tau_s}}{\mathcal{V}^2}+\frac{\nu\xi|W_0|^2}{g_s^{3/2}\mathcal{V}^3}$$

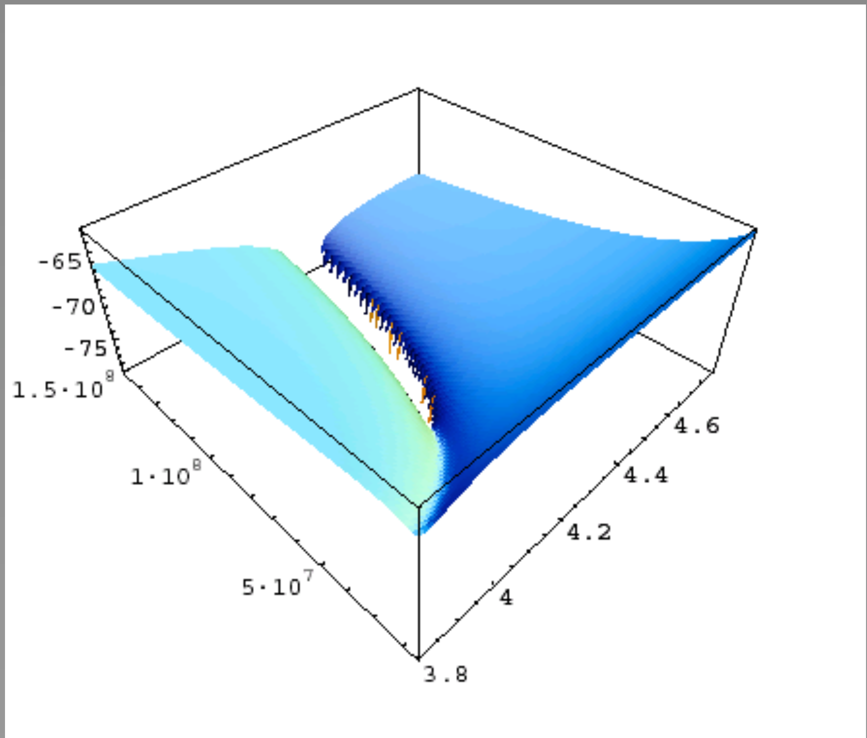
$$\mathcal{V}\sim e^{a_s\tau_s}\gg 1 \text{ with } \tau_s\sim\frac{\xi^{2/3}}{g_s}.$$

Scale	$\mathcal{V}_s$	g_sN	N if $g_s=0.1$
GUT	4600	2.25	22
Intermediate	4.6×10^9	0.85	9
TeV	4.6×10^{27}	0.30	3

W_0~1-10

String scale: $Ms^2=Mp^2/V$

Non SUSY AdS



W_0~1-10

String scale: $M_s^2 = M_p^2 / \mathcal{V}$

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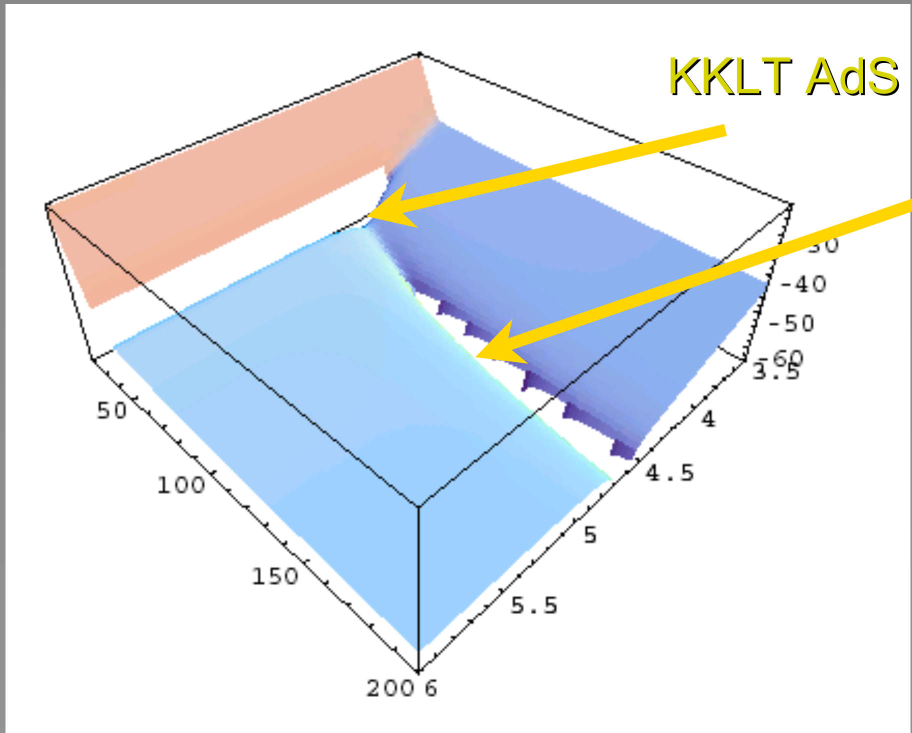
KKLT AdS

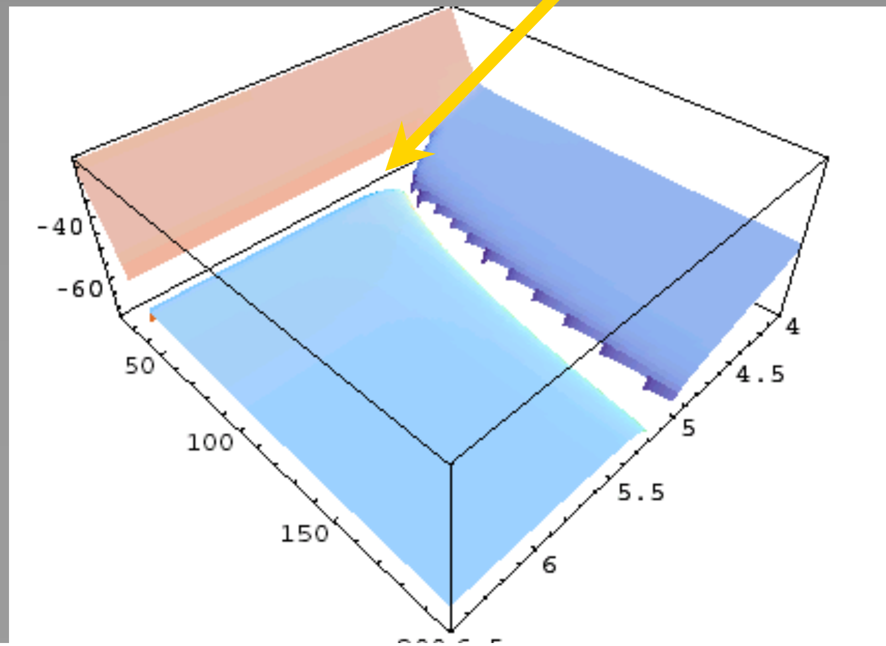
Non SUSY AdS



$W_0 \sim 10^{-10}$

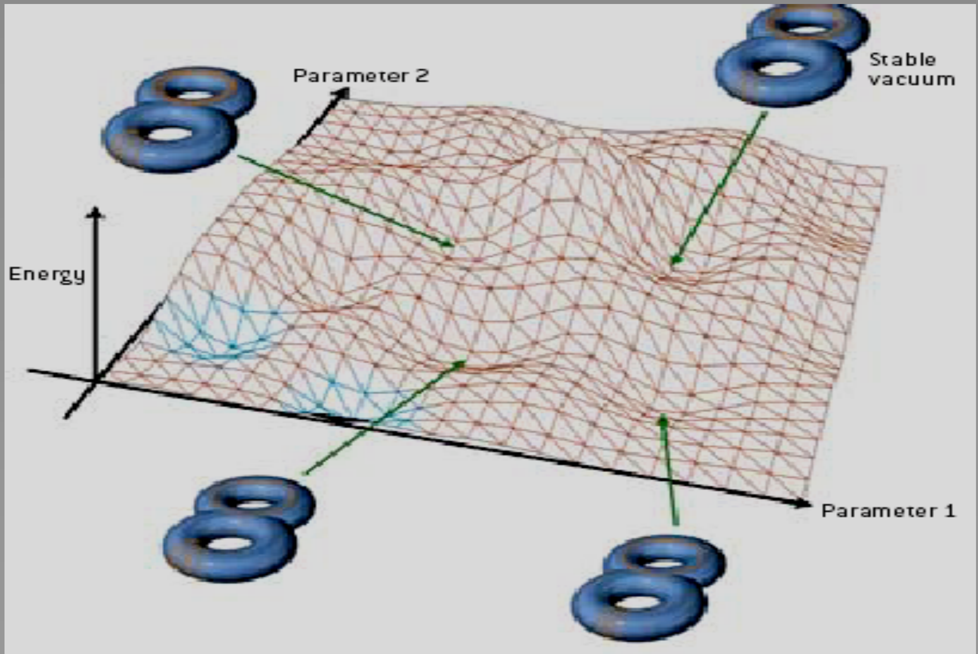
Both minima close

$W_0 < 10^{-11}$



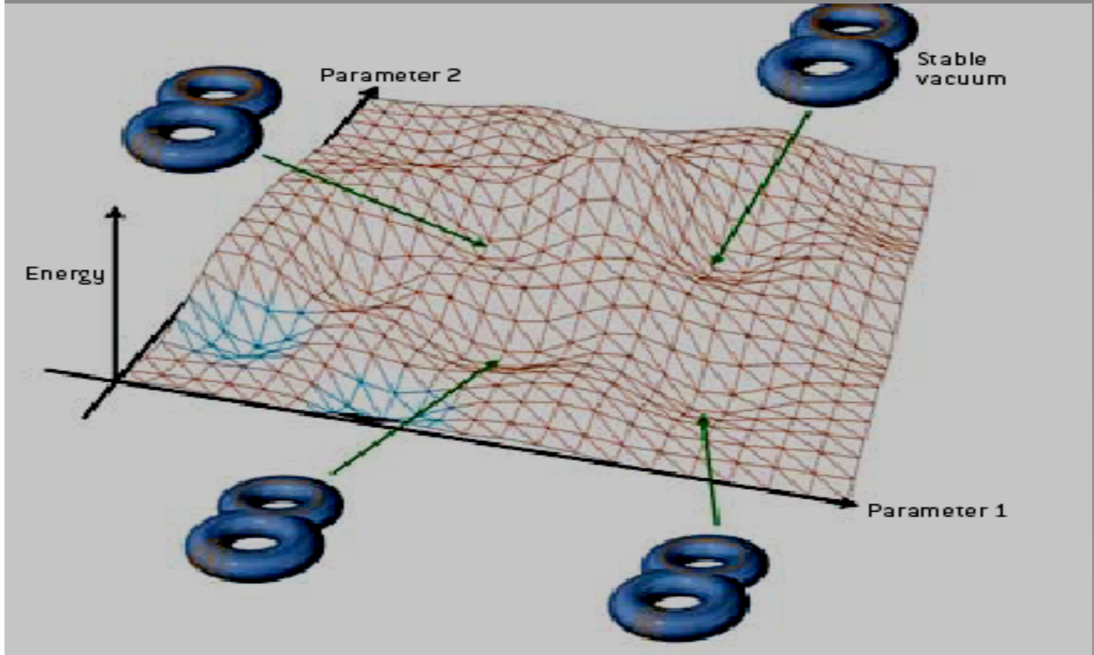
The Landscape

The Landscape

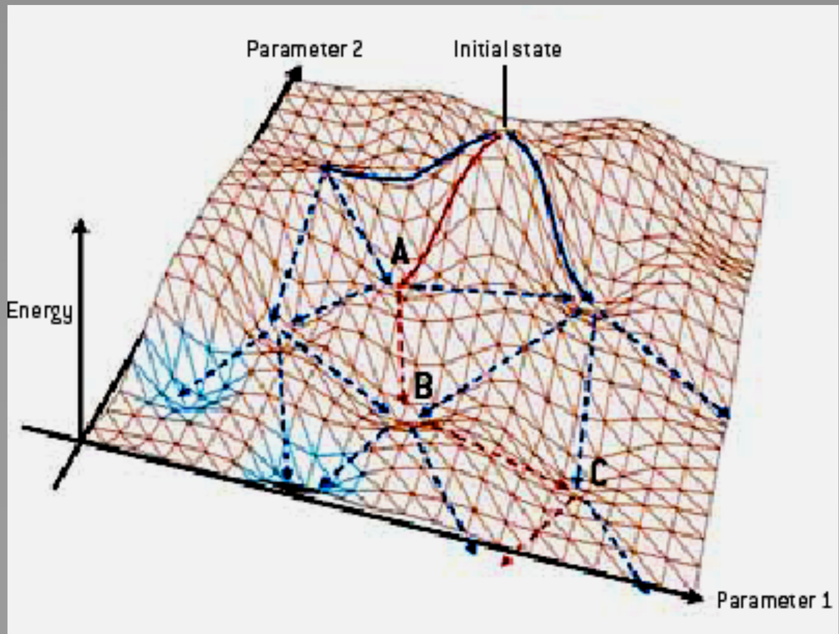


- Huge number of discrete vacua $>10^{500}$
- Statistics AD, DD, DDF, GKTT,CQ,BGHLW
- Randall-Sundrum warping from strings! GKP
- Non SUSY de Sitter
- Dark energy? BP
- SM on D3/D7branes CG-MQU
- Soft SUSY breaking?
- Inflation?

Populating the Landscape

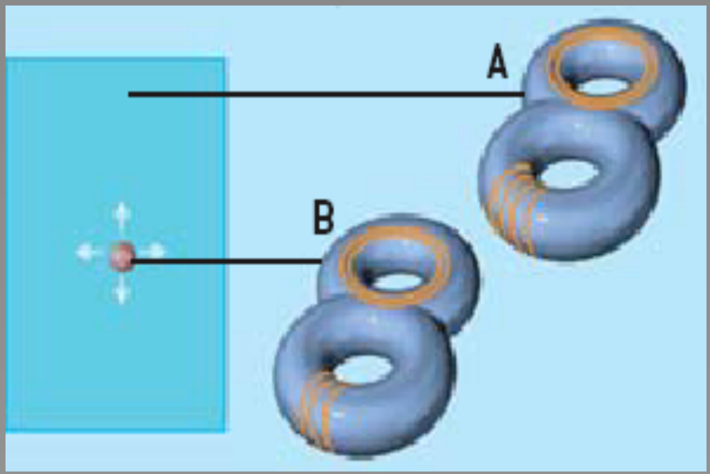


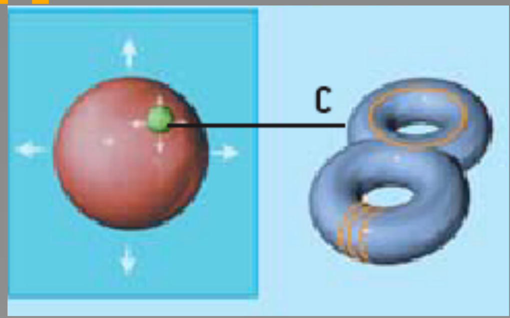
Classical Solutions

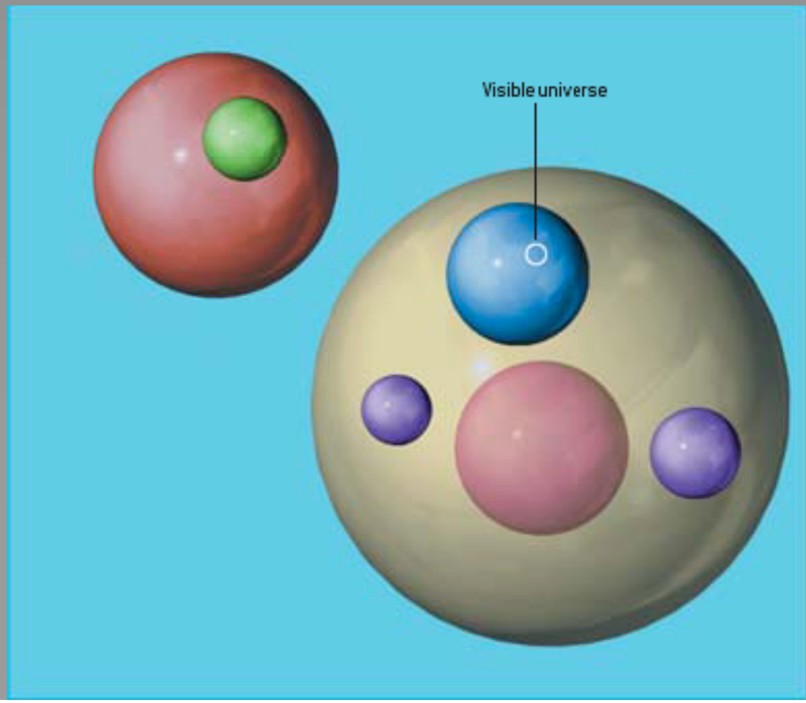


Quantum decay
(tunnel efect)

Multiverse and Eternal Inflation







Interesting But…

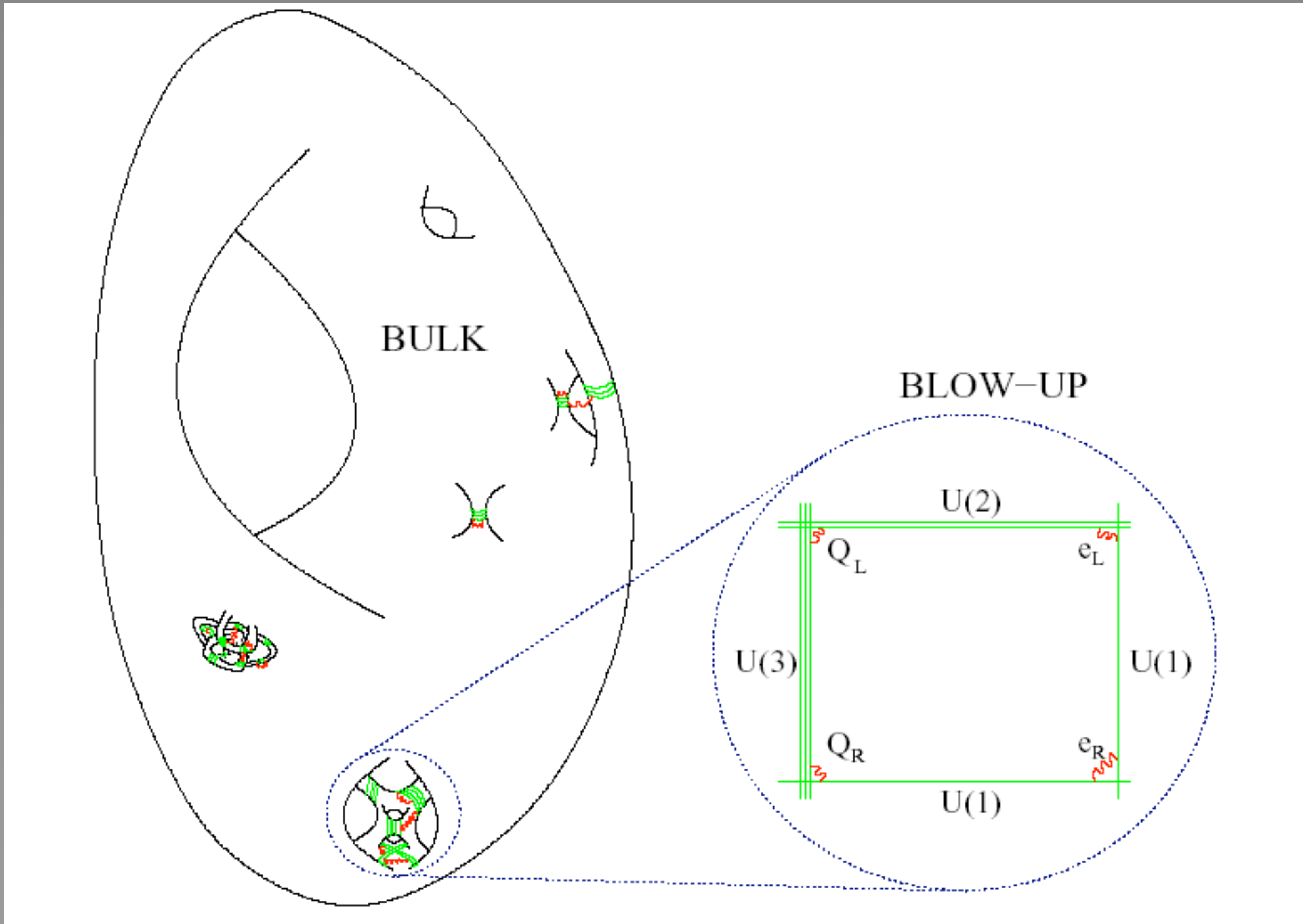
- This is NOT the slow-roll inflation that we are after.

- Where are we in the landscape?

Modular Model Building

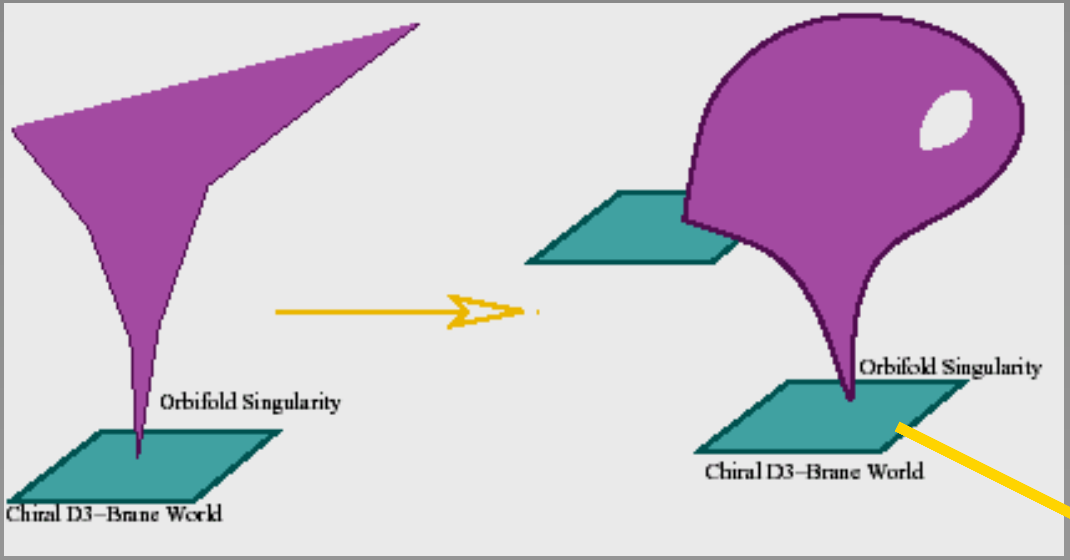
(Bottom up approach)

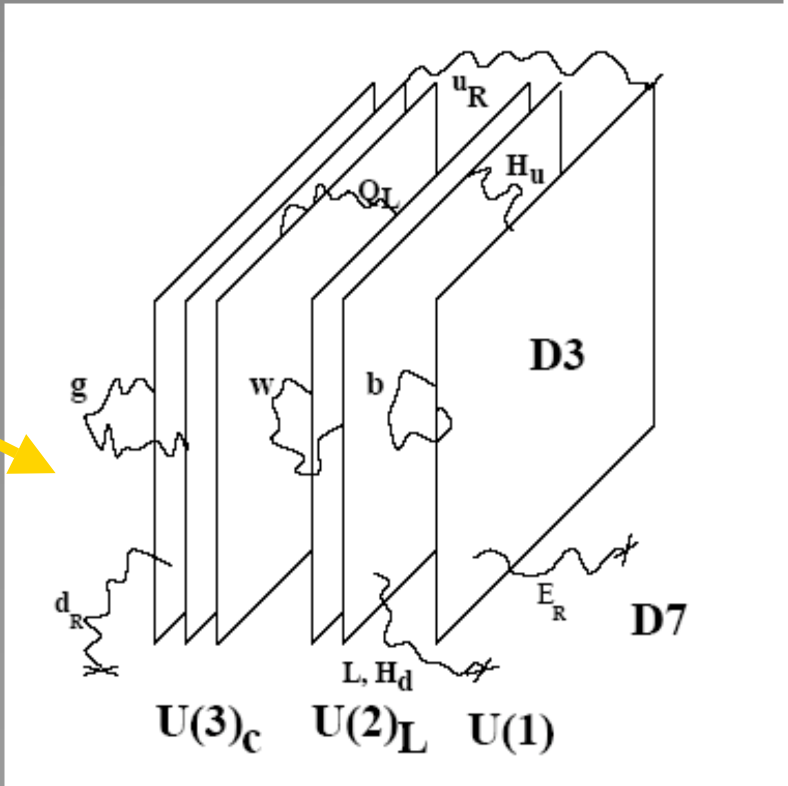
The Standard Model in the CY



Realistic Models

AIQU, CG-MQU,
H. Verlinde et al.





Bottom-up Approach

Aldazabal,Ibanez, FQ, Uranga 2000

Verlinde,Wijnholt 2006

Local (brane) Properties

- Gauge group
- Chiral spectrum
- Yukawa couplings
- Gauge unification
- Proton stability
- Baryogenesis
- Reheating

Global (bulk) Properties

- Moduli Stabilisation
- SUSY Breaking
- Soft terms
- Cosmological constant
- Inflation

PHENOMENOLOGY

(From Strings to LHC)

(LARGE Volume models)

Standard Model on D7 Branes

- Solve hierarchy problem $M_{string} = 10^{11}$ GeV!

$$m_s \sim \frac{M_P}{\sqrt{\mathcal{V}}}, \qquad m_{3/2} \sim \frac{M_P}{\mathcal{V}} W_0.$$

- $W_0 \sim 1$ (no fine tuning)

- Kahler potential for *chiral* matter computed

Conlon, Cremades, FQ (2006)

Chiral Matter on D7 Branes
Soft SUSY Breaking terms

$$m_{soft} = \frac{m_{3/2}}{\ln(M_P/m_{3/2})}.$$

$$\begin{aligned} M_i &= \frac{F^s}{2\tau_s}, \\ m_\alpha &= \sqrt{\lambda} M_i, \\ A_{\alpha\beta\gamma} &= -3\lambda M_i, \\ B &= -(\lambda+1) M_i. \end{aligned}$$

Simplest case
$\lambda = 1/3$

- Universality!
- No extra CP violation!
- $M_i = m_{3/2} / \log(Mp/m_{3/2})$
- String scale 10^{11} GeV
- Solves hierarchy problem!

Stringy source of universality
(approximate)

$$\Psi \Longleftrightarrow \text{Kähler moduli},$$

$$\chi \Longleftrightarrow \text{Complex structure moduli}.$$

$$\Phi = \Psi_{\text{susy-breaking}} \oplus \chi_{\text{flavour}}.$$

CP Violation

$$\phi_A = \{\arg\left(\frac{A_{\alpha\beta\gamma}}{Y_{\alpha\beta\gamma}}\right)\},\ \phi_B = \{\arg B\},\ \phi_C = \{\arg(M_a)\}.$$

Physical phases $\phi = \{\phi_A - \phi_C, \phi_B - \phi_C\}$ vanish !

Also: Anomaly mediation suppressed !!!

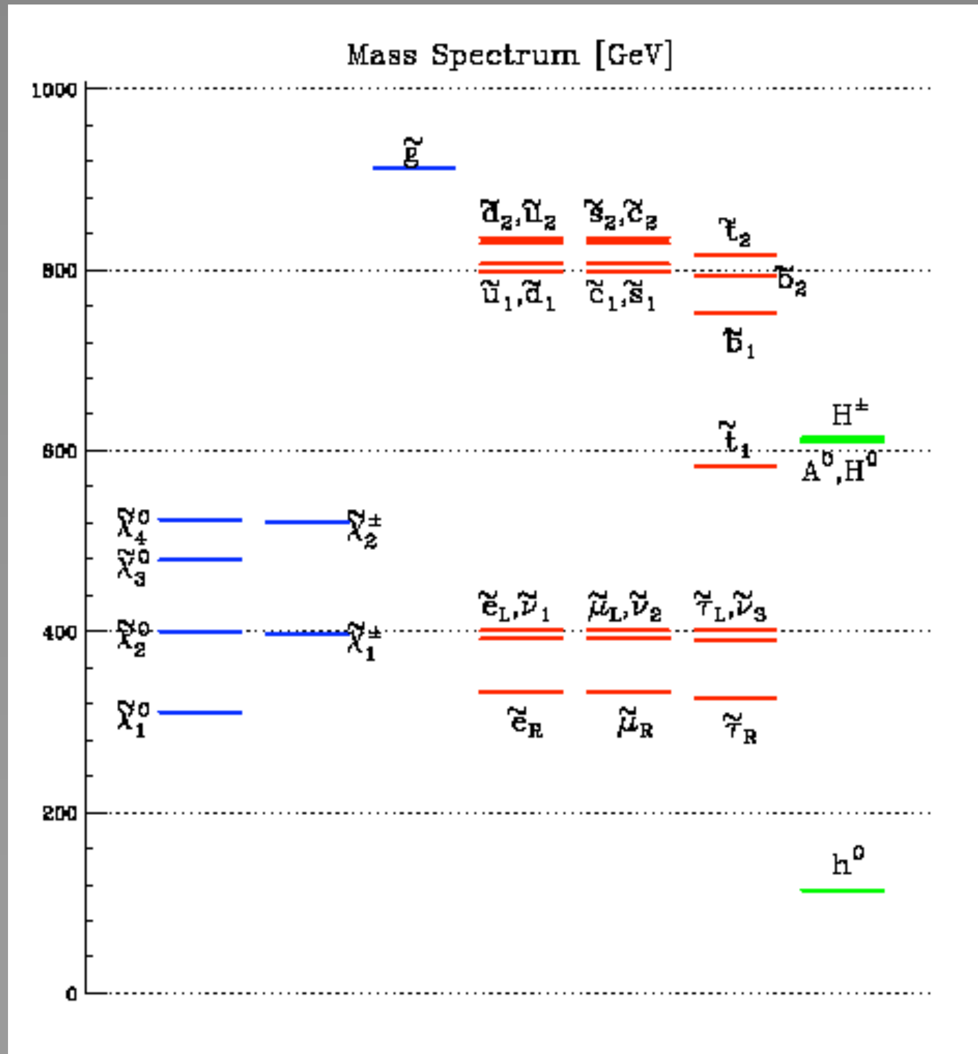
From Strings to LHC data

CKSAQ 0705.3460[hep-ph],

- Stabilise Moduli
- SUSY broken with hierarchy
- "Realistic" Observable sector
- Soft SUSY Breaking terms@Ms
- RG-Running of Soft terms to TeV (softsusy)
- Event Generators (PYTHIA-Herwig)
- Detector Simulators (PGS, GEANT) 10^{-1} fb
- Data Analysis and reconstruction (Root) 100^{-1} fb
- Estimate overall uncertainty

	A	B	C
m_s	10^{11}	10^{11}	10^{11}
$\tan\beta$	15	10	23
M	580	500	1000
sgnμ	+	+	-
$\tilde{e}_L, \tilde{\mu}_L$	464	401	792
$\tilde{e}_R, \tilde{\mu}_R$	386	333	661
$\tilde{\tau}_L$	463	402	779
$\tilde{\tau}_R$	369	326	618
$\tilde{u}_1, \tilde{c}_1$	924	806	1527
$\tilde{u}_2, \tilde{c}_2$	951	829	1580
$\tilde{t}_1$	679	582	1166
$\tilde{t}_2$	958	815	1448
$\tilde{d}_1, \tilde{s}_1$	915	798	1512
$\tilde{d}_2, \tilde{s}_2$	958	835	1585
$\tilde{b}_1$	859	752	1405
$\tilde{b}_2$	903	792	1455
χ_1^0	364	311	643
χ_2^0	469	400	822
χ_3^0	541	479	862
χ_4^0	587	524	927
$\chi_1^{\pm}$	467	397	821
$\chi_2^{\pm}$	584	521	924
A_0, H_0	679	610	1042
$H^{\pm}$	684	614	1046
$\tilde{g}$	1048	913	1745
$\tilde{\nu}_{1,2}$	456	392	789
$\tilde{\nu}_3$	451	390	771
h	116	114	118
$B(b \to s\gamma)/10^{-4}$	3.3	3.4	4.42
$\delta a_\mu/10^{-10}$	7.9	7.0	-4.3
Ωh^2	0.12	0.01	—

Low energy spectrum

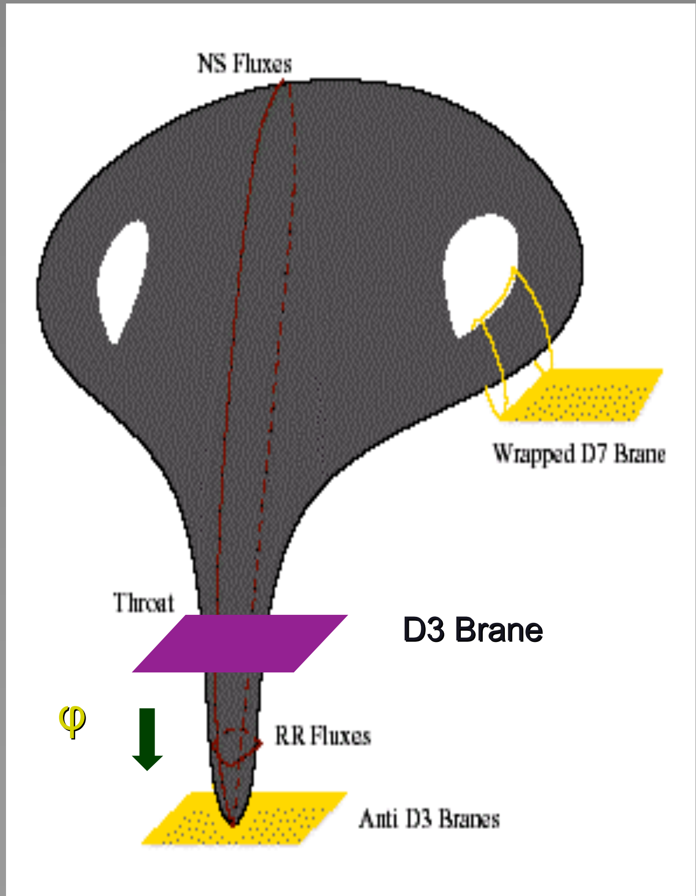


COSMOLOGY

(Inflation, Cosmological moduli problem, etc.)

Brane-Antibrane Inflation

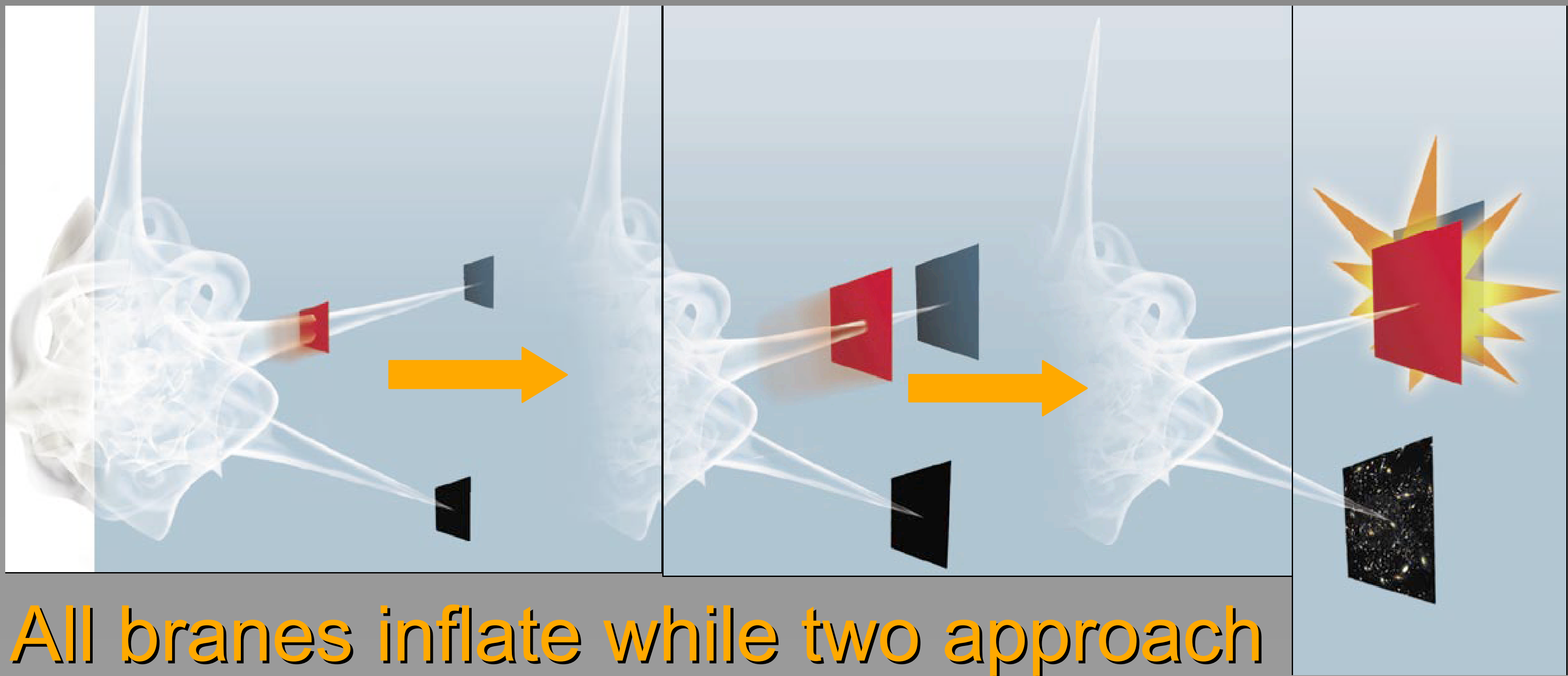
BMNRQZ, DSS



KKLMMT, HKP, KTW, FT, BCSQ

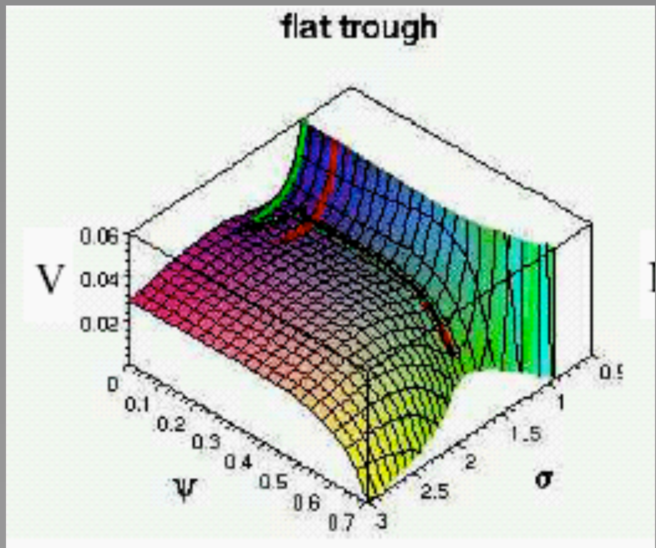
φ inflaton field

BRANE - ANTIBRANE INFLATION



All branes inflate while two approach

Slow-roll (large field) inflation possible.
Need 1/1000 fine tuning of parameters to get 60-efoldings (η-problem)



N~60, δ_H~10^{-5} for

Burgess, Cline, Stoica, FQ

Ms~ 10^{15} GeV

n_s~1.05

n_s<1 (Cline-Stoica)

Needs at least two throats !

Also: D3-D7 on K3xT2

Kallosh et al.

DBI in the sky

Silverstein-Tong, Chen, Tye et al.

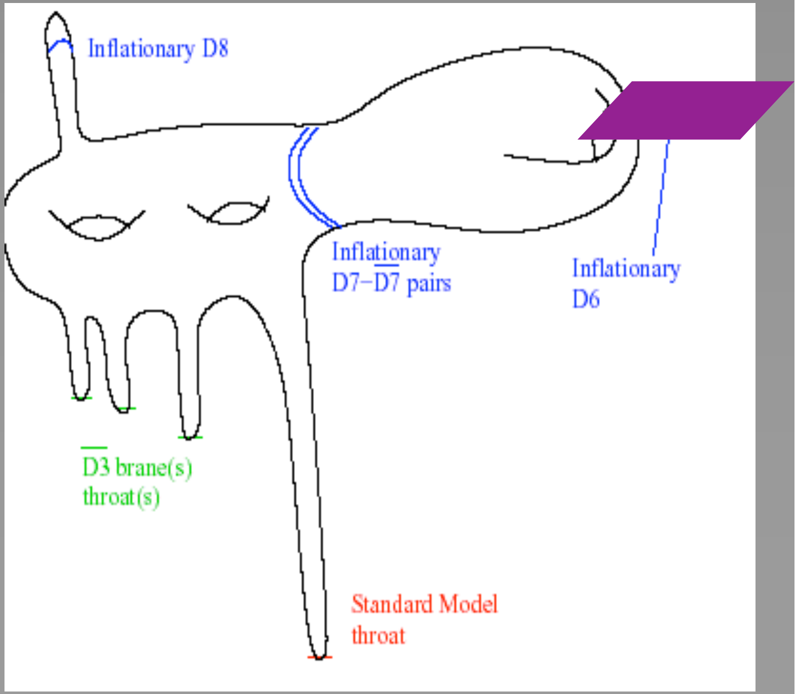
Tachyonic Inflation

Sen, Raeymakers, Cremades-Sinha-FQ

$$S = \int d^4x \sqrt{-g} \left(\frac{M_{pl}^2}{2} R - \mathcal{A} V(T) \sqrt{1 + \mathcal{B} \partial_\mu T \partial^\mu T} \right)$$

$$V(T) = \frac{V_0}{\cosh(\frac{T}{\sqrt{2\alpha'}})}.$$

A,B depend on warping (fluxes) and E&M fields on non-BPS brane. If A,B~1 no slow-roll



$$\epsilon = \frac{M_{pl}^2}{2\mathcal{A}\mathcal{B}} \left(\frac{V'^2}{V^3} \right) \ll 1 \,,$$

$$\eta = \frac{M_{pl}^2}{\mathcal{A}\mathcal{B}} \left[\frac{V''}{V^2} - \frac{1}{2} \left(\frac{V'^2}{V^3} \right) \right] \ll 1 \,.$$

$$\delta_H = \frac{\sqrt{\mathcal{A}^2 \mathcal{B}}}{5\pi\sqrt{3} M_{pl}^3} \frac{V^2}{V'}.$$

AB large → slow-roll

No fine-tuning! But need large fluxes

Racetrack Inflation

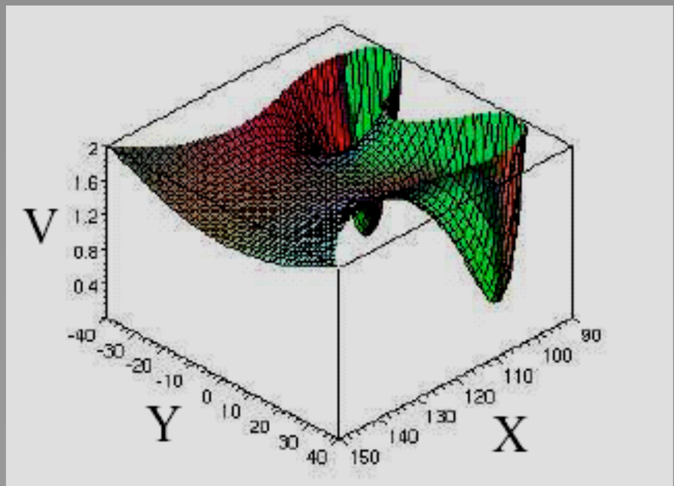
Blanco-Pillado et al.

$$W = W_0 + A\, e^{-aT} + B\, e^{-bT}\,.$$

→ Topological eternal inflation !

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

$$\eta \equiv M_{pl}^2\,\frac{V''}{V} \ll 1\,.$$



Slow roll if 1/1000 fine tuning,

N~60, δ_H~10^{-5} for Ms~10^{15} GeV

n_s ~ 0.95 !!

Also for W_0=0 if add matter

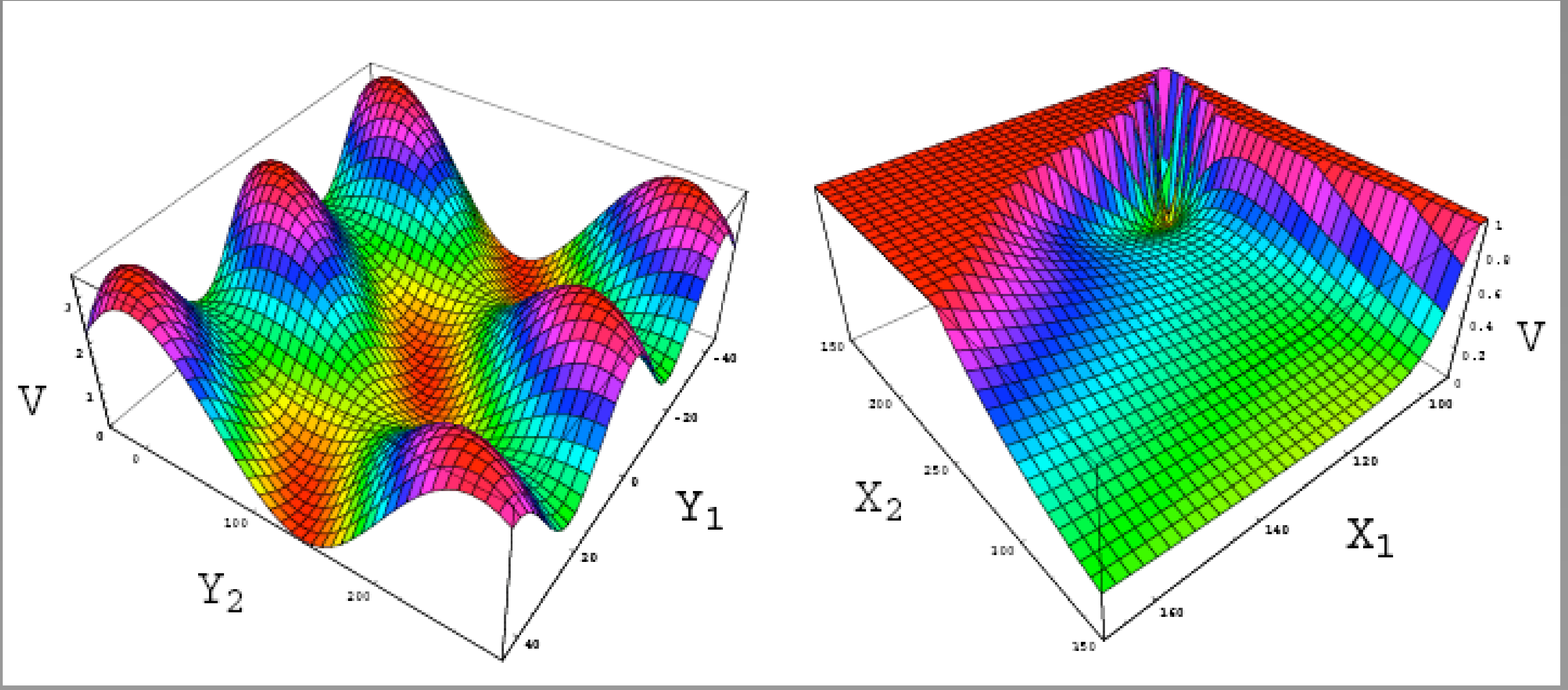
Lalak, Ross, Sarkar

Better Racetrack Inflation

Blanco-Pillado et al.

$$W = W_0 + A\,e^{-a\tau_1} + B\,e^{-b\tau_2}$$

Douglas et al.



Explicitly derived model

Similar physics

Kähler Moduli Inflation

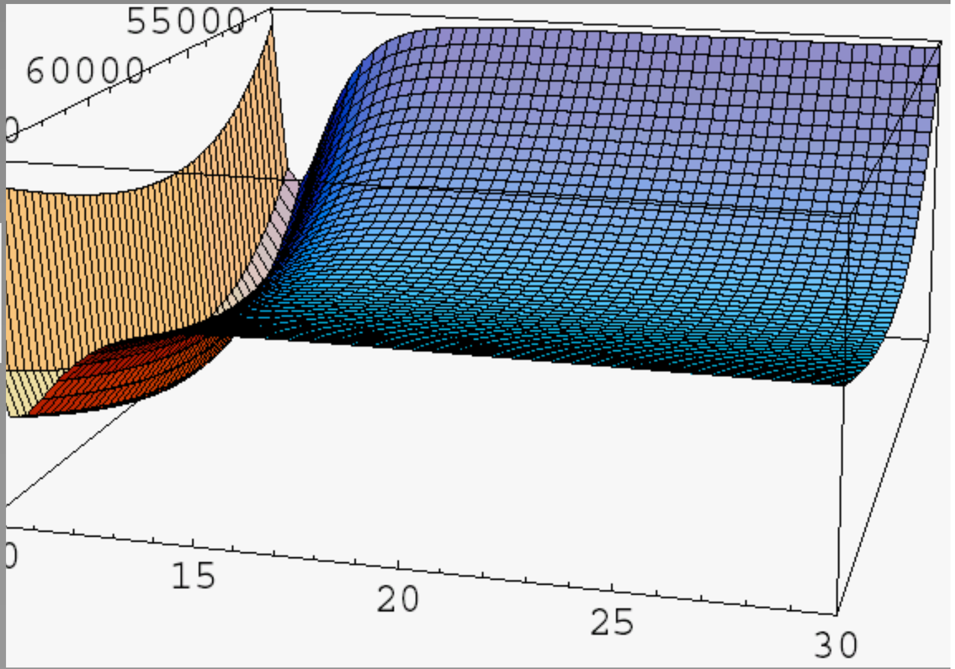
Conlon-FQ

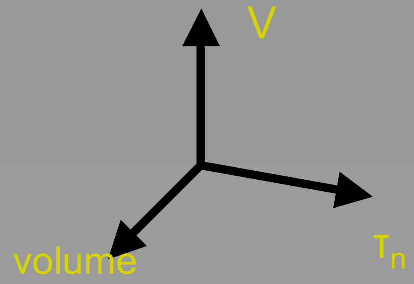
Bond-Kofman-Prokushkin

Calabi-Yau:

$h_{21} > h_{11} > 2$

$$V = \sum_i \frac{8(a_i A_i)^2 \sqrt{\tau_i}}{3\mathcal{V}\lambda_i \alpha} e^{-2a_i\tau_i} - \sum_i 4\frac{a_i A_i}{\mathcal{V}^2} W_0 \tau_i e^{-a_i\tau_i} + \frac{3\xi W_0^2}{4\mathcal{V}^3}.$$





Small field inflation

No fine-tuning!!

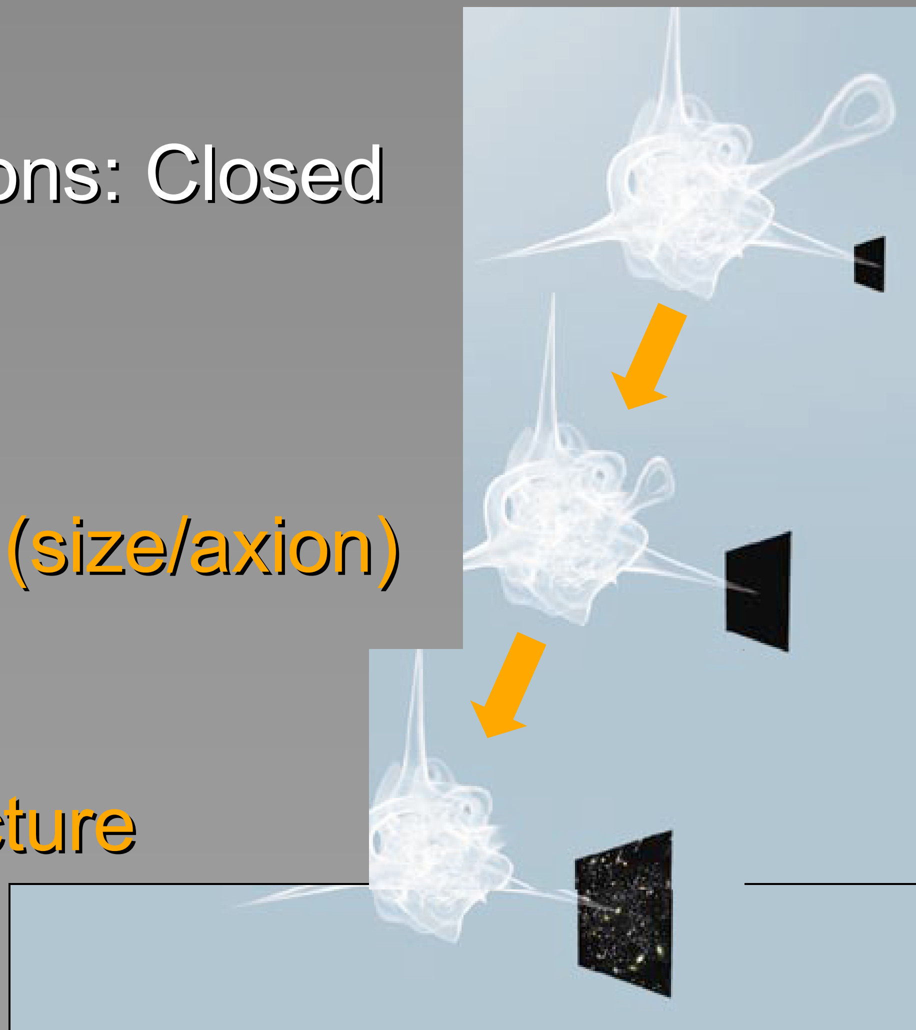
$0.960 < n < 0.967$

GUT scale Ms?, Loops?

MODULI INFLATION

Candidate Inflatons: Closed string modes

- Kahler Moduli (size/axion)
- Complex structure moduli?



Open Questions

- Inflation possible but not generic (fine tuning)
- Initial conditions/Singularity,…
- Non tensor perturbations (r=s/t<<<1)?

Baumann, McCalister

- Tension phenomenology vs cosmology

Gravitino mass 1 TeV/Gravitino mass >> 1 TeV ??

Ross, Sarkar

Kallosh-Linde

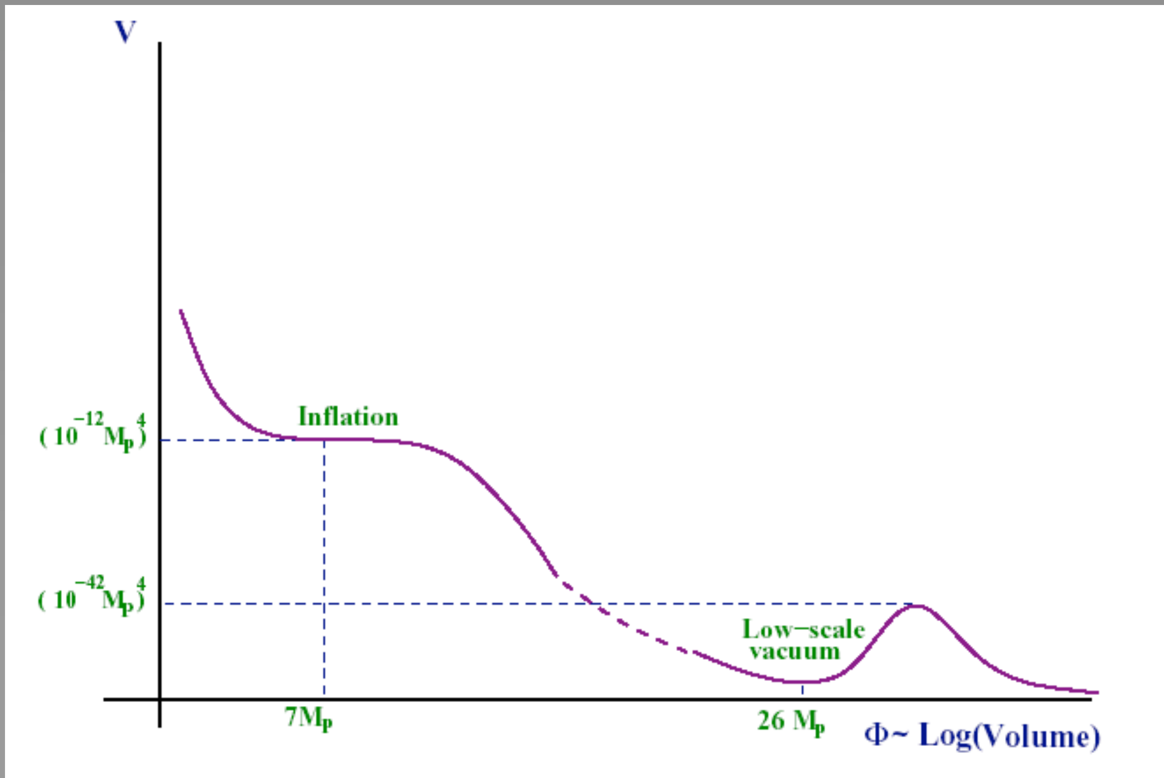
(string scale 10 11 GeV/ string scale ~ GUT scale)

Possible ways out

- Low scale inflation?

German, Ross, Sarkar, …

- Runaway before reheating?



Conlon et al.

After Inflation

Physics of Moduli Fields

- Dilaton and Complex Structure

  Moduli masses:

$$m_{3/2} \sim \frac{M_P}{\mathcal{V}}, \qquad m_s \sim \frac{M_P}{\sqrt{\mathcal{V}}}.$$

- Small (heavy) Kahler moduli

$$m_{\tau_s} \sim \frac{M_P \ln(M_P/m_{3/2})}{\mathcal{V}}.$$

- Large (light) Kahler modulus

$$m_{\tau_b} \sim \frac{M_P}{\mathcal{V}^{3/2}} \sim M_P \left(\frac{m_{3/2}}{M_P}\right)^{3/2}.$$

Physical Fields

$$\delta\tau_b = \left(\sqrt{6}\langle\tau_b\rangle^{1/4}\langle\tau_s\rangle^{3/4}(1-2\epsilon)\right)\frac{\Phi}{\sqrt{2}} + \left(\sqrt{\frac{4}{3}}\langle\tau_b\rangle\right)\frac{\chi}{\sqrt{2}} \sim \mathcal{O}\left(\mathcal{V}^{1/6}\right)\Phi + \mathcal{O}\left(\mathcal{V}^{2/3}\right)\chi$$

$$\delta\tau_s = \left(\frac{2\sqrt{6}}{3}\langle\tau_b\rangle^{3/4}\langle\tau_s\rangle^{1/4}\right)\frac{\Phi}{\sqrt{2}} + \left(\frac{\sqrt{3}}{a_s}(1-2\epsilon)\right)\frac{\chi}{\sqrt{2}} \sim \mathcal{O}\left(\mathcal{V}^{1/2}\right)\Phi + \mathcal{O}(1)\,\chi \quad (3.7)$$

Decay Rates

$$\lambda_{\chi\gamma\gamma} = \frac{\sqrt{6}}{2M_P\ln\left(M_P/m_{3/2}\right)},$$

$$\lambda_{\Phi\gamma\gamma} \sim \left(\frac{2}{\sqrt{3}}\frac{\langle\tau_b\rangle^{3/4}}{\langle\tau_s\rangle^{3/4}M_P}\right) \sim \frac{\sqrt{\mathcal{V}}}{M_P} \sim \frac{1}{m_s}.$$

$$\delta\mathcal{L}_{\Phi ee} \sim \frac{\sqrt{\mathcal{V}}\chi}{M_P}m_e\bar{e}e \sim \frac{\chi}{m_s}m_e\bar{e}e.$$

$$\delta\mathcal{L}_{\chi ee} \sim \left(1+\frac{1}{a\langle\tau_s\rangle}\right)\frac{1}{\sqrt{6}}\frac{\chi}{M_P}m_e\bar{e}e.$$

	Light modulus χ	Heavy Modulus Φ
Mass	$\sim m_{3/2}\left(\frac{m_{3/2}}{M_P}\right)^{\frac{1}{2}} \sim 2\text{MeV}$	$2\, m_{3/2}\ln(M_p/M_{3/2}) \sim 1200\text{TeV}$
Matter Couplings	M_P^{-1}	m_s^{-1}
Decay Modes		
$\gamma\gamma$	$\text{Br} \sim 0.025, \quad \tau \sim 6.5\times 10^{25}\text{s}$	$\tau \sim 10^{-17}\text{s}$
e^+e^-	$\text{Br} \sim 0.975, \quad \tau \sim 1.7\times 10^{24}\text{s}$	$\tau \sim 10^{-17}\text{s}$
$\psi_{3/2}\psi_{3/2}$	inaccessible	$\text{Br} \sim 10^{-30}, \quad \tau \sim 10^{-2}\text{s}$

Other Cosmological Implications

J.Conlon, FQ

- Cosmological moduli problem

DCQR, BKN

U,S: trapped at their minimum

T: except for volume, heavy ad decay fast ! (No CMP nor gravitino overproduction)

Volume: (mass MeV) CMP

- Observational implications of light volume modulus?

Gamma rays, e^+-e^-

Solution of CMP?

Thermal Inflation

Lyth+Stewart (1995)

$$V = V_0 + (T^2 - m_\sigma^2)\,\sigma^2 + \cdots$$

$$\langle \sigma \rangle \equiv M_* \gg m_\sigma .$$

$$m_\sigma \sim 1 \text{ TeV and } M_* \sim 10^{11} \text{ GeV}$$

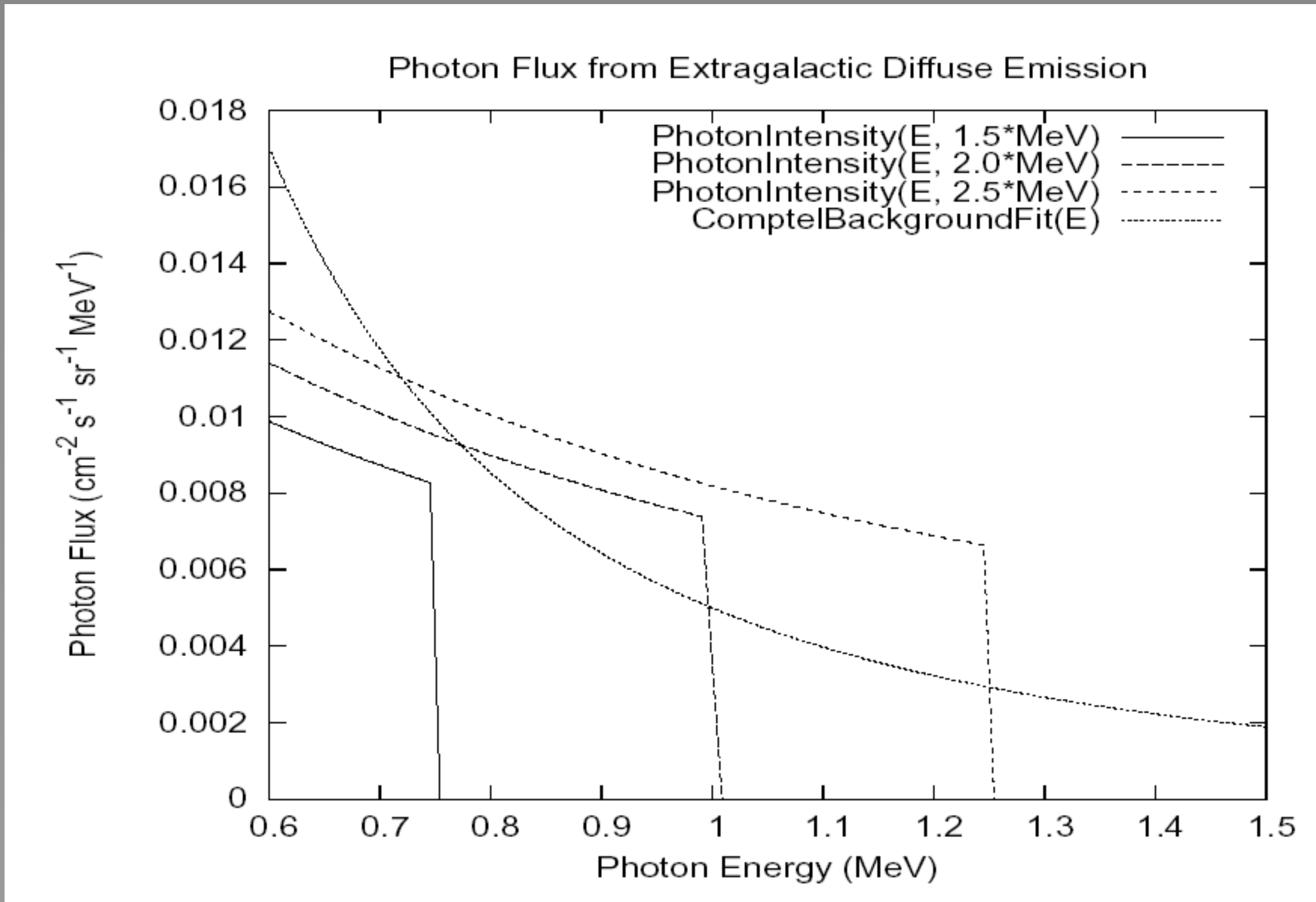
Number of e-folds

$$N \sim \log\left(V_0^{1/4}/T_c\right) \sim \log\left(M_*/m_\sigma\right)^{1/2}$$

N~10 dilutes moduli

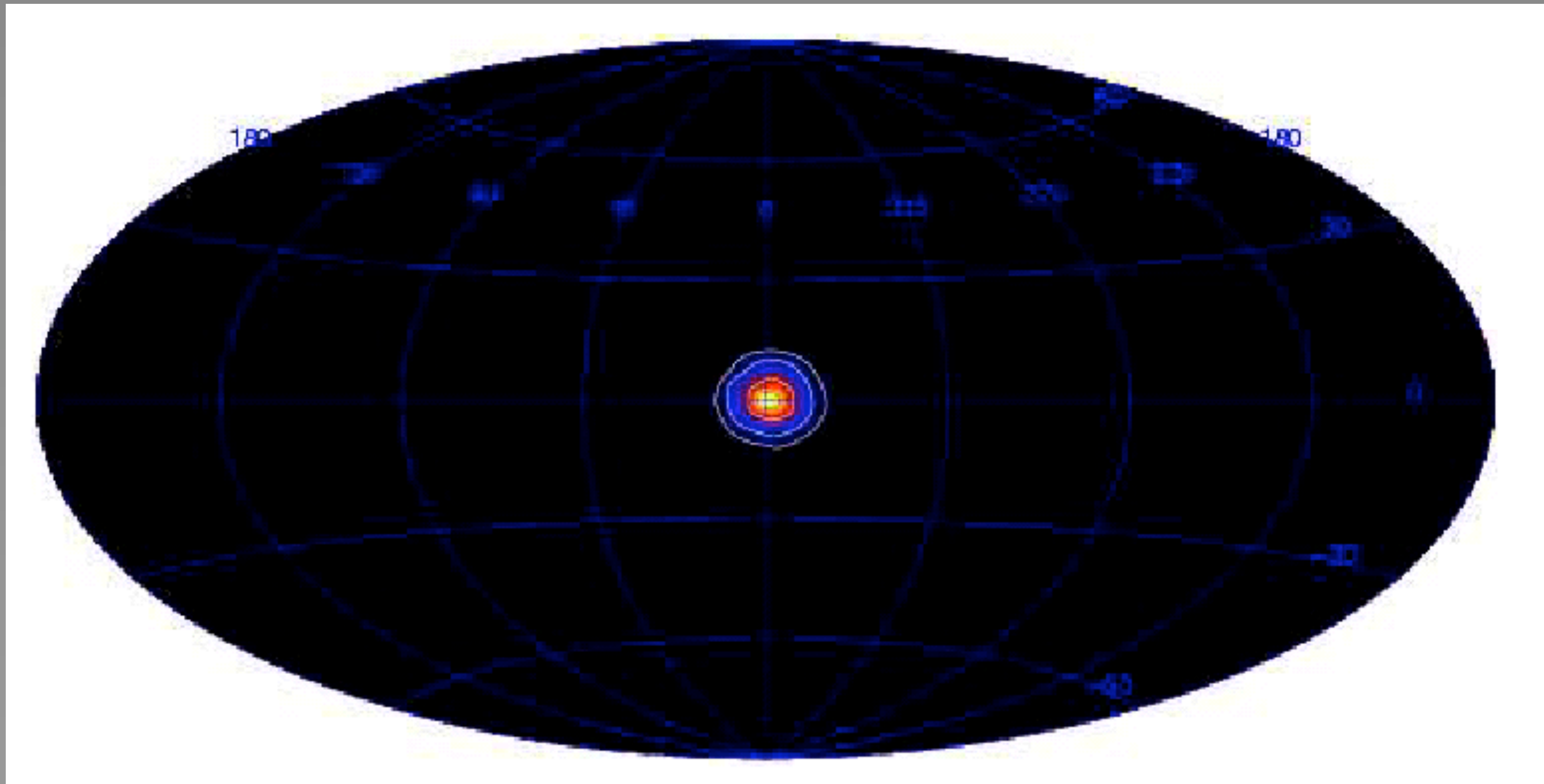
Late time implications:

Diffuse Gamma Ray Background

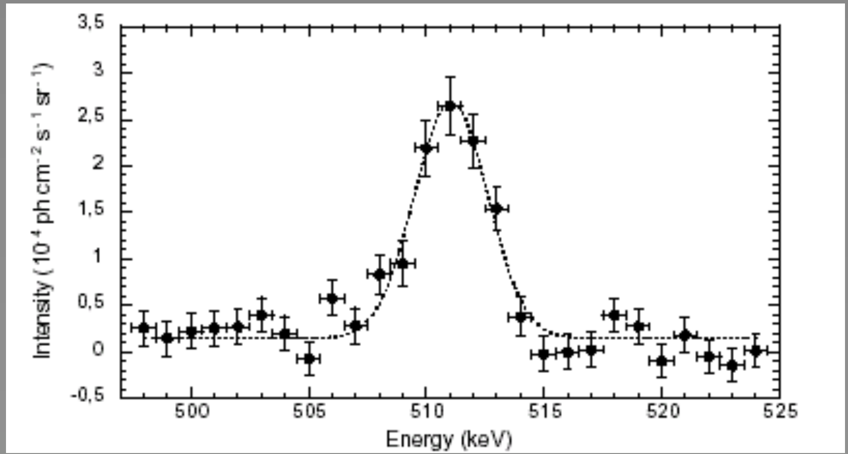


$$\frac{\Omega_\chi}{\Omega_m} \lesssim \left(\frac{1\mathrm{MeV}}{m_\chi}\right)^{3.5}.$$

The 511 keV Line



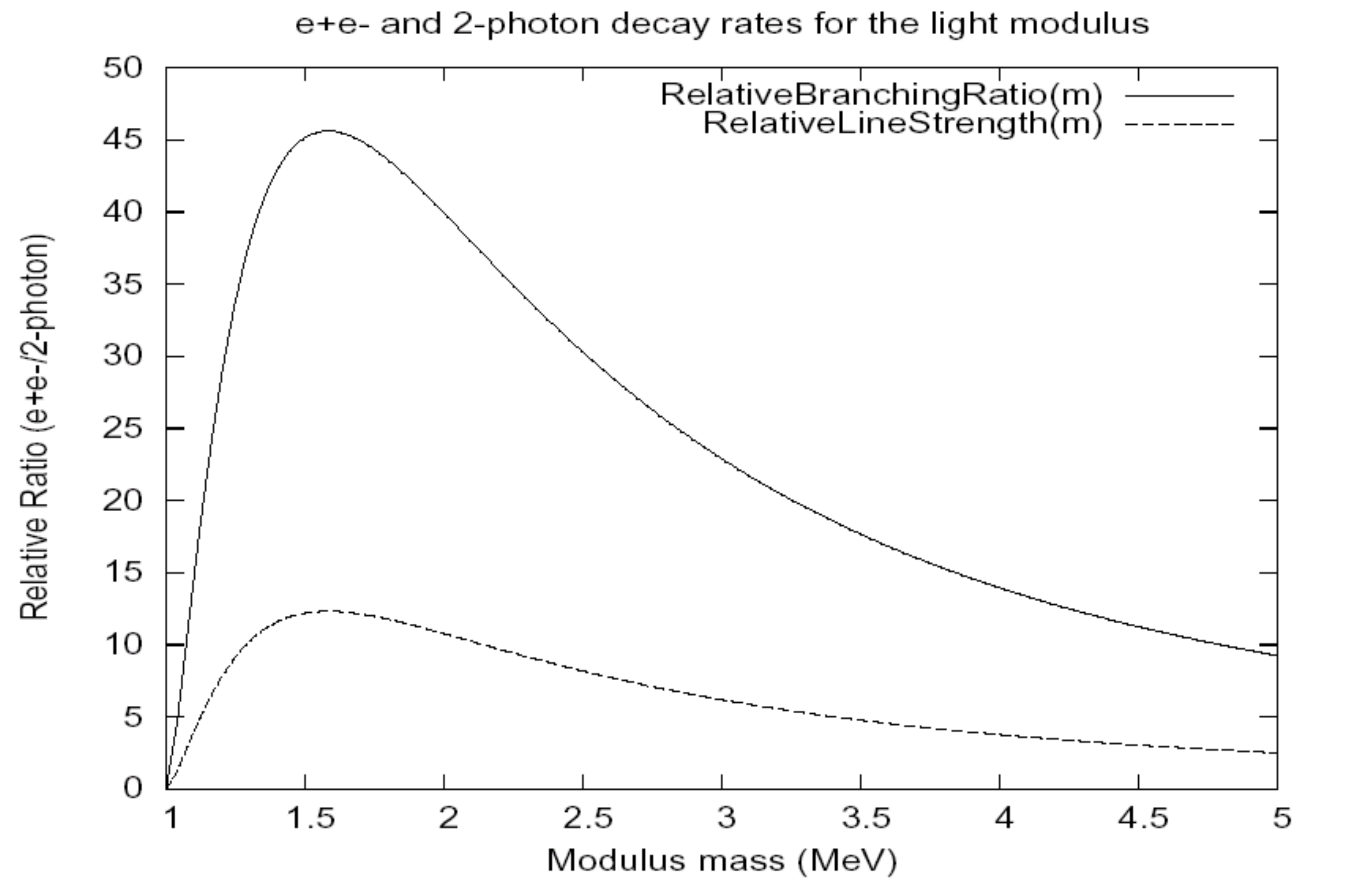
INTEGRAL/ SPI 511 keV line



Light Modulus χ: Dark matter?

Mass 1MeV, coupling to electrons dominant

511 keV from volume modulus decay? (prediction!)



$$\frac{\Omega_\chi}{\Omega_{dm}} \lesssim 10^{-3} \left(\frac{2\mathrm{MeV}}{m_\chi}\right)^2 .$$

Intensity $\sim 8 \times 10^{-5} \mathrm{photons\ cm^{-2} s^{-1}}$

INTEGRAL $\lesssim 5 \times 10^{-5} \mathrm{photons\ cm^{-2} s^{-1}}$

CONCLUSIONS

- Exciting times for string cosmology/phenomenology!
- Soft terms calculable ➡ rich phenomenology
- Distinctive moduli cosmology
- Concrete models of inflation **(closed vs open string inflaton)**
- Model independent signatures: **cosmic strings, no tensor modes, light modulus (CMP, 511 keV? Prediction!)**
- Many open questions

  M_{GUT} vs 10^{11} GeV scales?

  Fully realistic model?...
- Alternatives to inflation?