Cosmology and particle physics in the type IIA landscape

CERN TH institute on String Phenomenology

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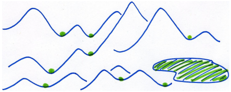
Outline

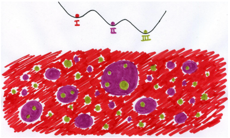
1. Landscape
2. Particle physics
3. Cosmology

1. The String Landscape



- Many apparent "vacua"
- IIB flux compactifications: $\sim 10^{600} \subset \infty$ discrete set
- Possibly dominated by "NG" vacua

Populated by eternal inflation $\Rightarrow$ "Metaverse"



- CC > 0: quantum dynamics not understood
- Semi-classical picture $\Rightarrow$ eternal inflation
- "Explains" CC $\sim 10^{-120}$

Landscape/Swampland problem for predictive phenomenology:

What range of EFT's arise in allowed (metastable) string vacua?

Possibility A: "Anything goes"

Perhaps virtually any variation on standard model below 100 TeV can be realized in string theory (change masses, couplings, matter content, extensions, . . .)

— Predictivity difficult, maybe impossible in practice

— Progress requires real dynamics, measure etc.

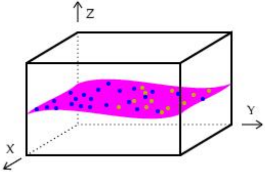
Possibility B: "Low Energy Constraints

Perhaps not all low-E field theories allowed from ST

— May give constraints, (*e.g.* 3/19 of SM parameters)

Important to distinguish A (anything goes) from B (constraints).

To demonstrate B, Need correlations/constraints common to all corners of the theory



If look for, but don't find such constraints, A looks more likely.

$\Rightarrow$ Finding something $\sim$ SM in string theory does not solve problems (though suggests string theory not completely wrong)

If A, does not lead to predictions

If B, need to understand which parameters are constrained.

This talk: 1) IIA IBM models (A?) 2) IIA cosmology (B?)

2. Particle physics

Following the philosophy just espoused,

Want to find constraints on allowed models.

Claim: So far no strong evidence from model building for B.

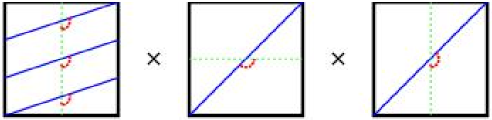
Example: gauge group and matter content

Consistency with A follows if in any corner of string theory, parameters of interest are unconstrained.

Case study: Intersecting Brane Models (IBMs) in IIA

Intersecting Brane Models in IIA

Well known, simple models [reviewed in Lüst talk]



$T^6/Z_2 \times Z_2$ orientifold well studied, $\Rightarrow$ SM gauge group, 3 gens.
[Blumenhagen/Körs/Lüst(/Görlich/Ott), Ibáñez/Marchesano/Rabadan, Aldazabal/Franco/Ibáñez/Rabadan/Uranga, Cvetic/Shiu/Uranga, Cvetic/Li/Liu, Cremades/Ibanez/Marchesano, Kumar/Wells, March./Shiu]

Systematically studied:

Blumenhagen/Gmeiner/Honecker/Lüst/Weigand

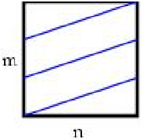
— Extensive computer search, statistics

Douglas/Taylor

— Analytic proof of finiteness, classification, statistics

IBM on $T^6/Z_2 \times Z_2$

Winding numbers on each torus



Tadpoles: $P = n_1 n_2 n_3, Q = -n_1 m_2 m_3, R = -m_1 n_2 m_3, S = -m_1 m_2 n_3$

Cancellation: $\sum_a P_a = \sum_a Q_a = \sum_a R_a = \sum_a S_a = 8$

SUSY conditions (when $P, Q, R, S > 0$):

$$\frac{1}{P} + \frac{j}{Q} + \frac{k}{R} + \frac{l}{S} = 0, \qquad P + \frac{1}{j}Q + \frac{1}{k}R + \frac{1}{l}S > 0\,.$$

3 kinds of branes (up to S_4 symmetry):

a: $- + + +$, **b**: $+ + 0\ 0$, **c**: $+ 0\ 0\ 0$

moduli + **a** branes (negative tadpoles) make problem tricky.

Results of hep-th/0606109 [Douglas/Taylor]

- Analytic proof of finite solution set
- Polynomial algorithm for finding models with fixed G
- Polynomial scaling estimates for $\mathcal{N}(G)$

  — SU(N) factor $\sim 1/N^{\nu}$ of models, $\nu \sim 1-3$

  e.g. $SU(3) \times SU(2) \times U(1) \sim 1/100\mathcal{N}_{\rm total}$
- roughly uniform, independent distribution of generation number g

$\Rightarrow$ Gauge group, # generations $\sim$ randomly, independently distributed

Results compatible with BGHLW

IBM's: recent results [w/V. Rosenhaus, to appear]

- Found all **a** combinations ($\sim 10^5$)

- Can compute all models w/any fixed gauge group (poly. time)

- U(N) $\times$ U(2) $\times$ U(2)) models computed, $\mathcal{N}_{N22} \sim 1/N$

$[\mathcal{N}_{422} = 528K, \mathcal{N}_{522} = 362K, \mathcal{N}_{622} = 300K, \mathcal{N}_{722} = 270K, \mathcal{N}_{822} = 265K,]$

Conclusion: for G, gen. numbers, looks like A: "anything goes"

Conclusion supported by recent work on other orbifolds ($\mathbf{Z}_6$, $\mathbf{Z}_6'$)

[Gmeiner/Lüst/Stein, (Gmeiner/Honecker)^2]

Challenge, find constraints on low-E theory valid across landscape

3. Cosmology

Can we find simple cosmological constraints (B)?

Consider slow-roll inflation in IIA [Hertzberg/Kachru/Taylor/Tegmark]

— Many Calabi-Yau's → low E 4D physics

— Many flux combinations (exp. many ∞ families)

— Vast field space

Might figure: somewhere tuning → many e-folds of inflation

But no: with "standard stuff" (H, RR fluxes, D6-branes, O6-planes)

$$\epsilon \geq \frac{27}{13} \quad \text{if} \quad V > 0$$

Outline of no-go result: start with 10D action

$$S = \frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{-g}\,e^{-2\phi}\Big(R+4(\partial_\mu\phi)^2-\frac{1}{2}|H_3|^2-e^{2\phi}\sum_p|F_p|^2\Big)$$
$$-\mu_6\int_{\rm D6} d^7\xi\sqrt{-g}\,e^{-\phi}+2\mu_6\int_{\rm O6} d^7\xi\sqrt{-g}\,e^{-\phi}$$

KK reduce (use *e.g.* Grimm-Louis), consider dependence on

$$\rho\equiv({\rm Vol})^{\frac{1}{3}},\quad \tau\equiv e^{-\phi}\sqrt{\rm Vol}.$$

Look at 2D slices (fix all other moduli) Slow roll parameter satisfies

$$\epsilon\geq\frac{1}{8\pi G}\left[\left(\frac{\partial\ln V}{\partial\hat\rho}\right)^2+\left(\frac{\partial\ln V}{\partial\hat\tau}\right)^2\right]\geq\frac{27}{13}$$

($\hat\rho,\hat\tau$ have canonical KE, $\sim\ln\rho,\ln\tau$)

Outline of Proof:

$$|F_p|^2 \propto \rho^{-p} \text{ in string frame}$$

$\rightarrow$ Einstein frame ($g^E = (8\pi G \tau^2/\kappa_{10}^2) g^4$)

$$H_3 \rightarrow \rho^{-3}\tau^{-3} \quad F_p \rightarrow \rho^{3-p}\tau^{-4} \quad D6 \rightarrow \tau^{-3} \quad O6 \rightarrow -\tau^{-3}$$

$$V = \frac{A_3(\phi_i)}{\rho^3\tau^2} + \sum_p \frac{A_p(\phi_i)}{\rho^{p-3}\tau^4} + \frac{A_{D6}(\phi_i)}{\tau^3} - \frac{A_{O6}(\phi_i)}{\tau^3}$$

$$\Rightarrow -\rho\frac{\partial V}{\partial \rho} - 3\tau\frac{\partial V}{\partial \tau} = 9V + \sum_p p\, V_p \geq 9V$$

$$\Rightarrow \left| \left(\frac{\partial \ln V}{\partial \ln \rho}\right) + 3\left(\frac{\partial \ln V}{\partial \ln \tau}\right) \right| \geq 9$$

$$\Rightarrow \epsilon \geq \frac{1}{8\pi G}\left[\left(\frac{\partial \ln V}{\partial \hat{\rho}}\right)^2 + \left(\frac{\partial \ln V}{\partial \hat{\tau}}\right)^2\right] \geq \frac{27}{13}$$

Conclusion: no slow roll inflation in standard IIA IBM etc. models

- Possible ways around no-go theorem:

— Geometric fluxes ($\rho^{-1}\tau^{-2} \to 7V$)
[Silverstein, Silverstein/Westphal,
Caviezel/Koerber/Körs/Lüst/Tsimpis/Zagermann]

— Non-geometric fluxes ($\rho^{1,3}\tau^{-2} \to 5V, 3V$)

— NS-NS 5-branes ($\rho^{-2}\tau^{-2} \to 8V$)

Trouble: most of these take us out of regime of control.

Note: slow-roll also difficult in IIB
[Baumann/Dymarsky/Klebanov/McAllister(/Steinhardt), etc.]

Conclusions

- String landscape can give (A) Anything or (B) constraints.
- IBM's in IIA give Anything for gauge group, generations
- Large class of IIA models give (B) Constraints on cosmology
- Challenge: find landscape constraints on low-E particle physics
  — May want to combine study of cosmology + particle physics