>Panorama B

>Fluxes and applications

Plan

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- Flux compactifications

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- Moduli stabilization

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- Supersymmetry breaking

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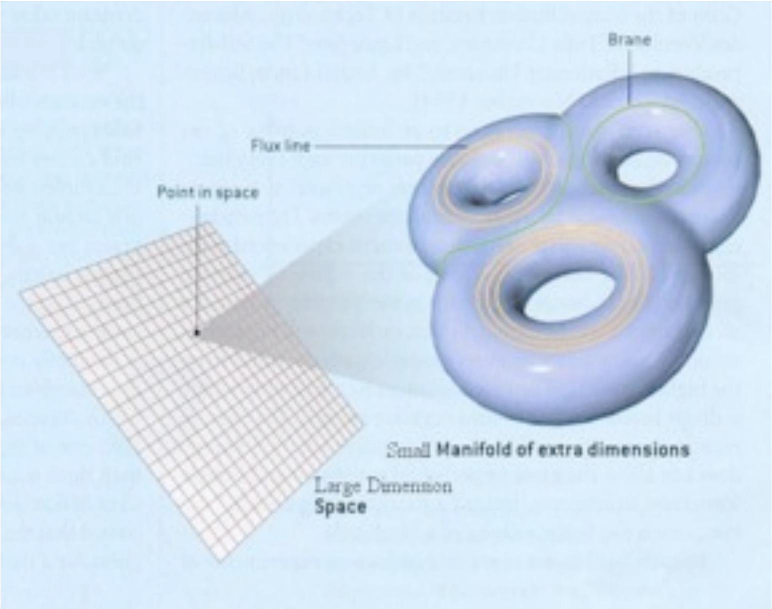
- Inflation

Moduli stabilization

- Massless moduli mediate 5th forces. Unobserved
- Cosmological problems unless massive enough
- Need mechanisms for moduli stabilization



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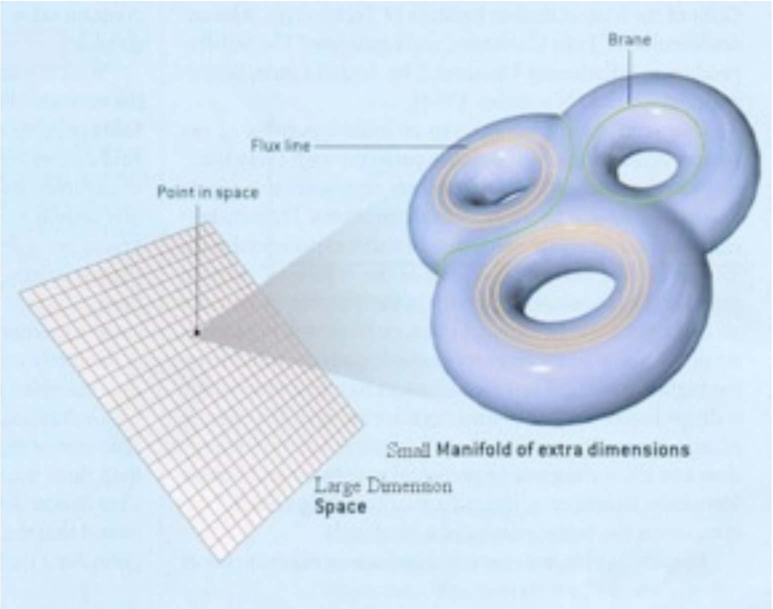
Focus on flux compactifications



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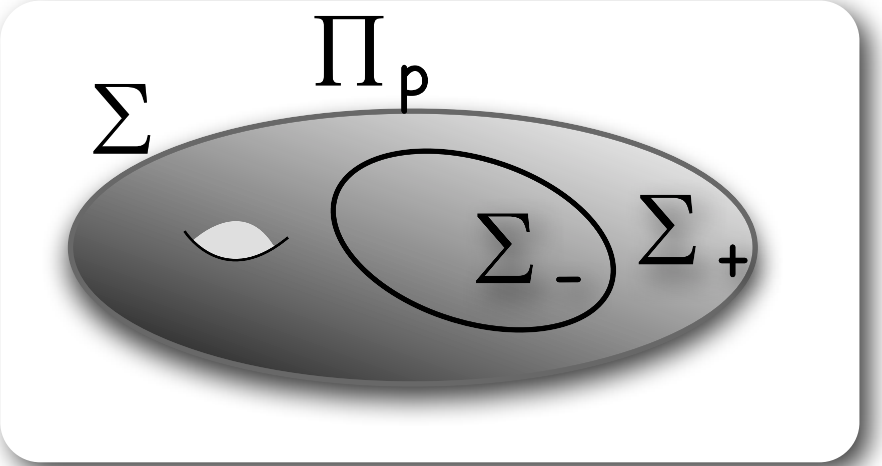
- Flux quantization



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  Vacua need not be Minkowski, but also AdS (or dS??)

  Focus on M_4, or in $(A)dS_4$ with hierarchycal length scales

Type IIB with 3-form fluxes

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Specify integrals, and local sources, satisfying RR tapole condition

$$Q_{\rm flux} + Q_{\rm D3} + Q_{\rm O3} = 0$$

Type IIB with 3-form fluxes

- Flux "tension" and charge

$$\mathcal{L}_G = -\frac{1}{24\kappa_{10}{}^2}\int_{\mathbf{X}_6} d^6y\, g^{\frac{1}{2}}\,\frac{(G_3)_{mnp}\,(\bar{G}_3)^{mnp}}{\mathrm{Im}\,\tau} = -\frac{1}{8\kappa_{10}{}^2}\int_{\mathbf{X}_6} d^6y\,\frac{G_3\wedge *_6\bar{G}_3}{\mathrm{Im}\,\tau}$$

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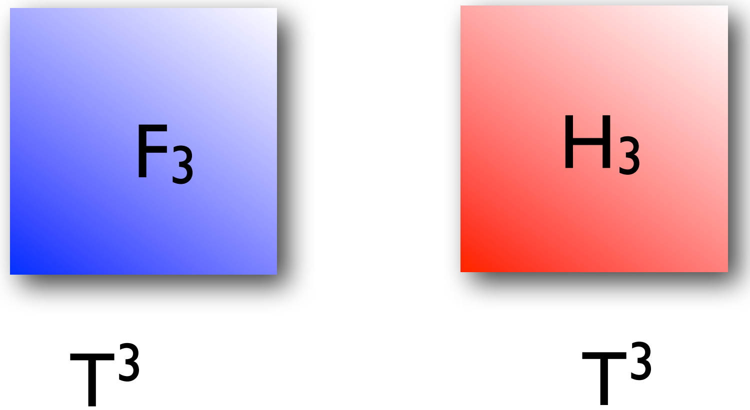

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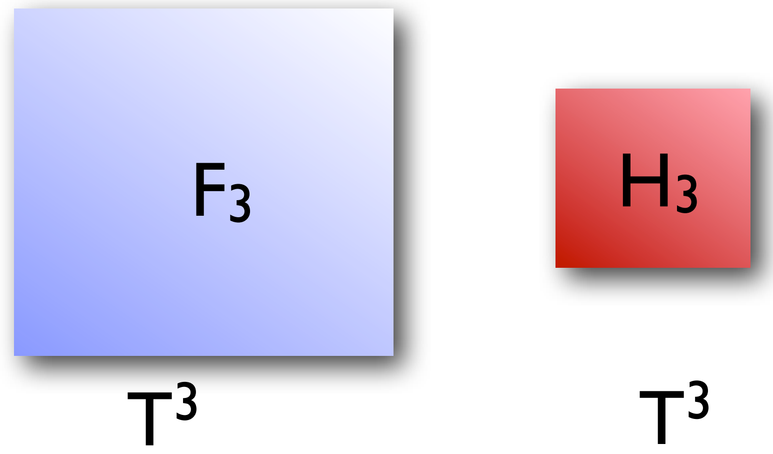

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- Underlying CY makes life easy ⇒ Many explicit models

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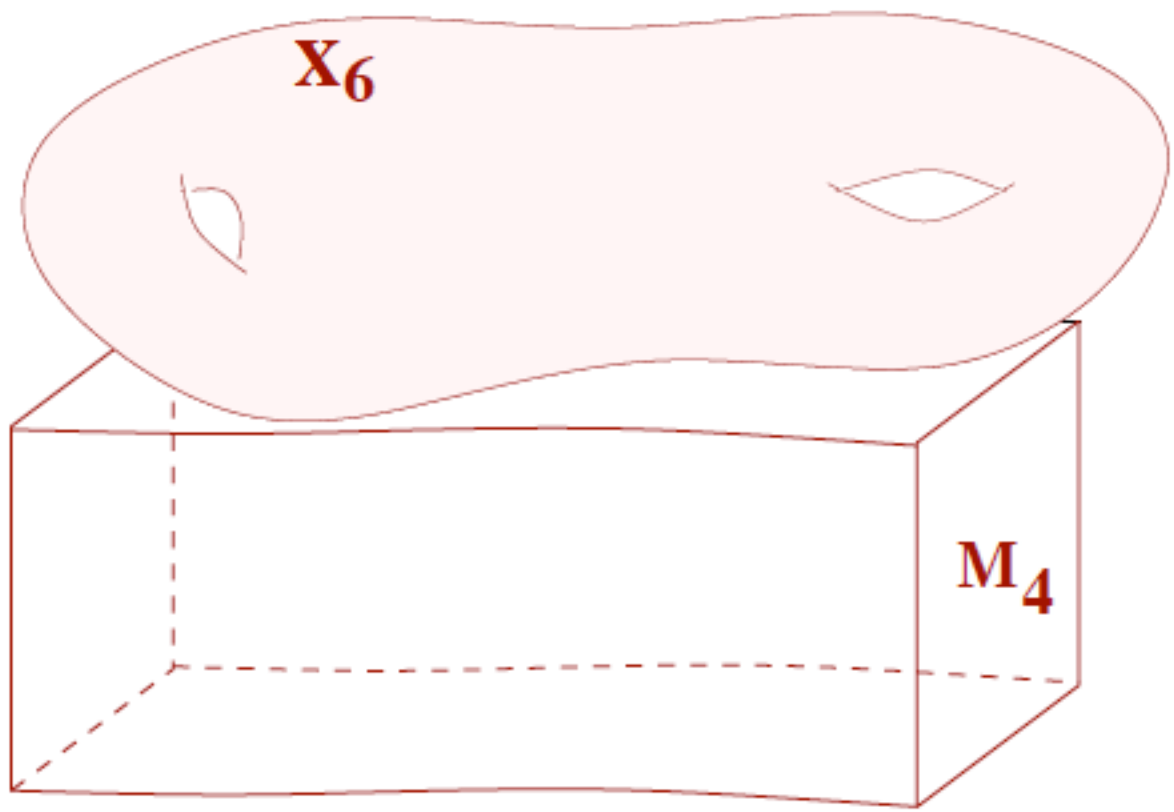

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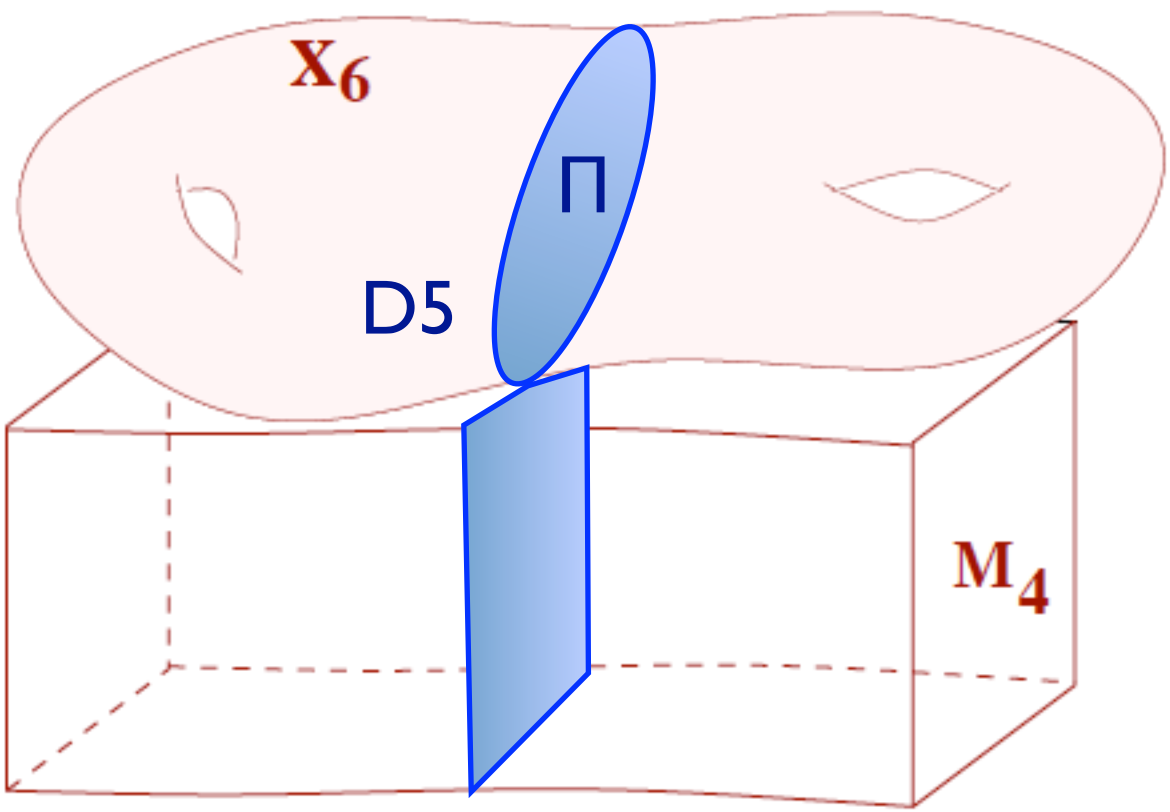

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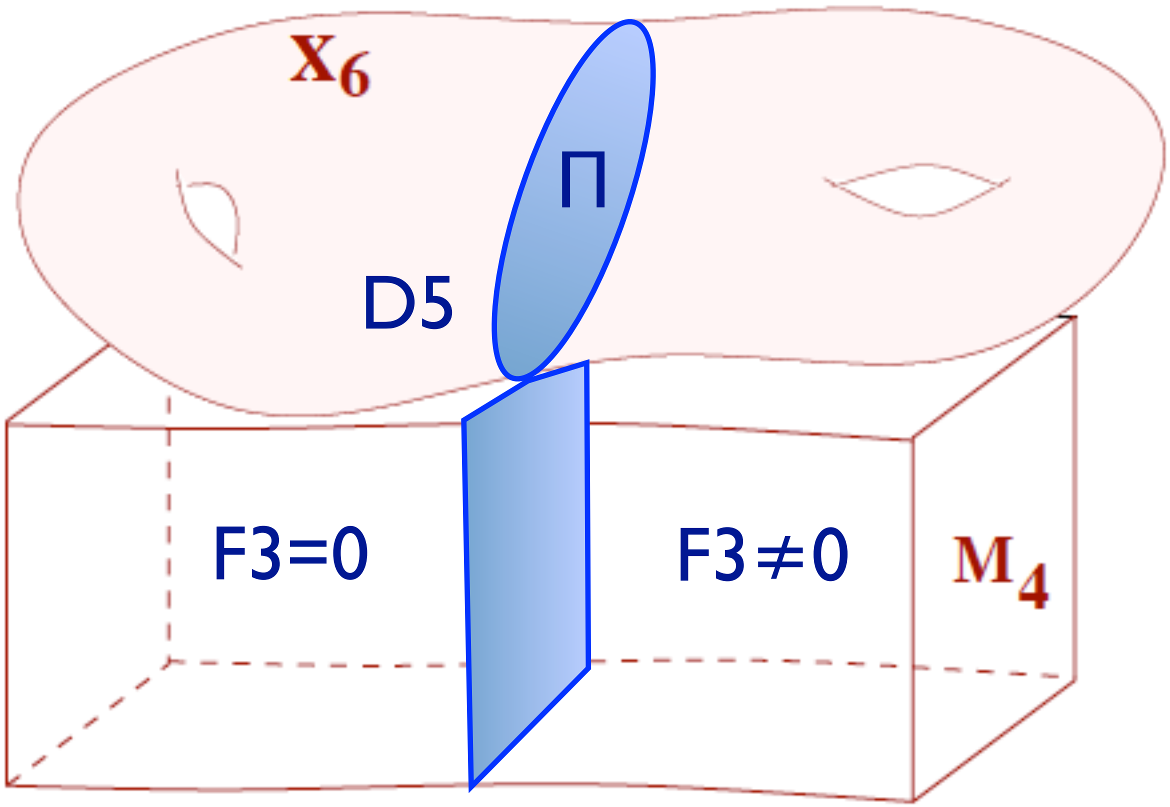

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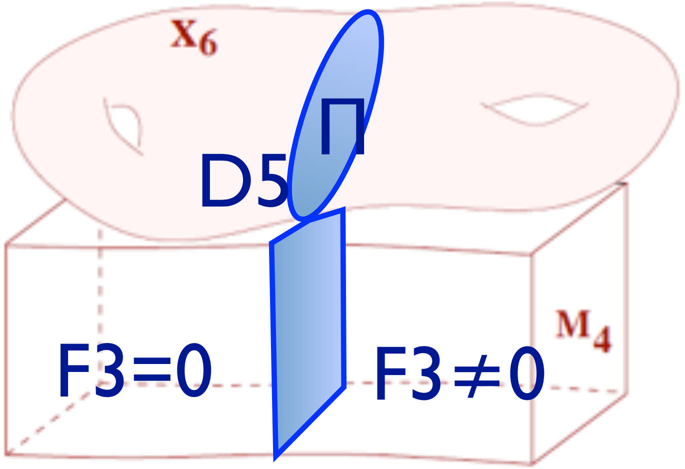

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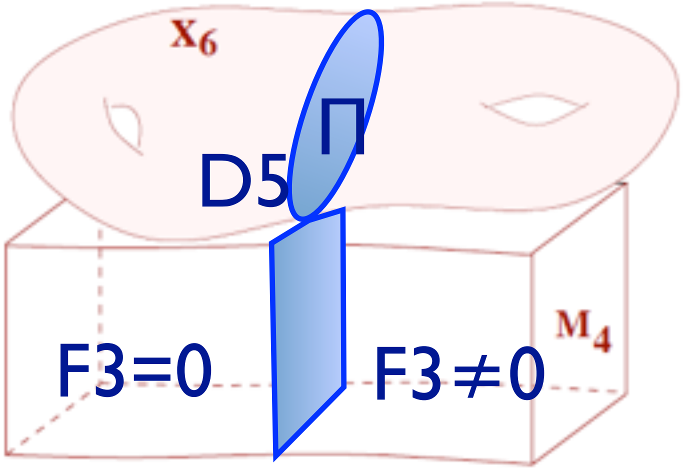
D5 is magnetic source for C2

$$dF_3 = \delta_3(\Pi) \wedge \delta_0(x^3)\, dx^3 ,$$



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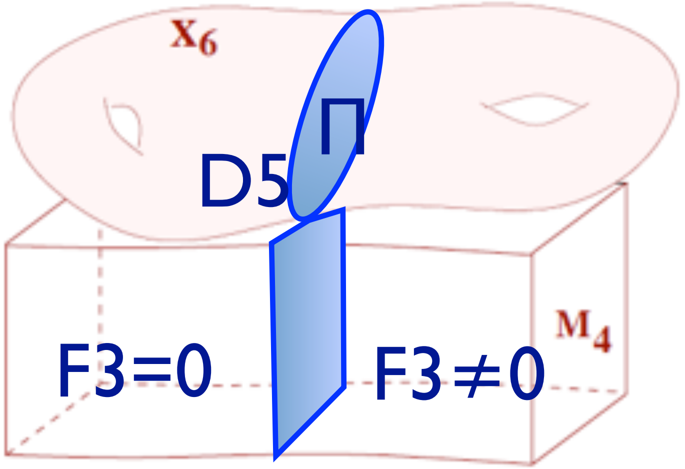

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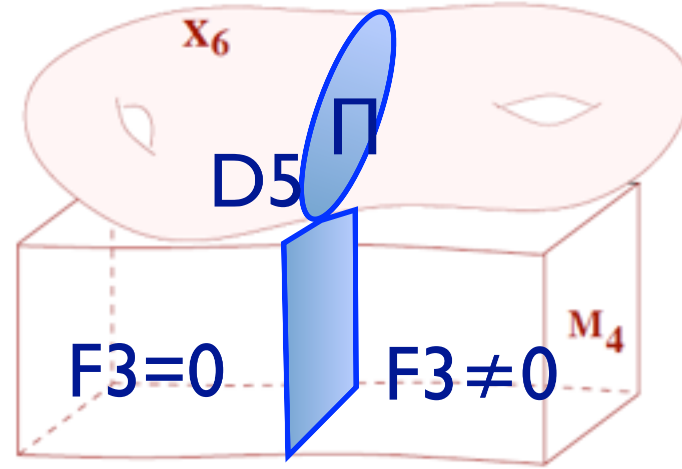

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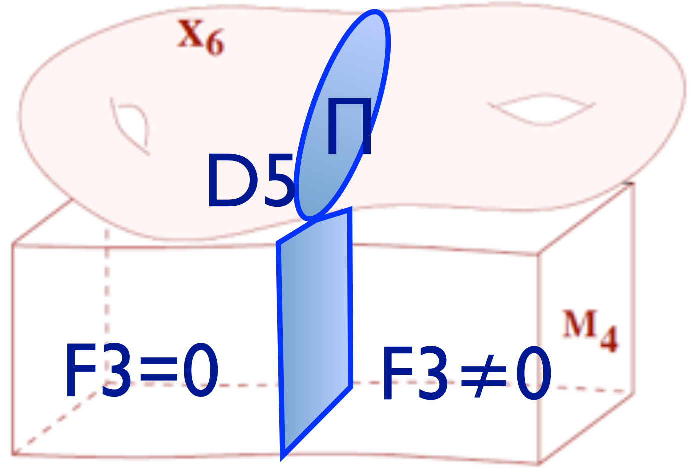

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For general F3, H3 fluxes

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SUSY: G3 is (2,1) $D_\rho W \sim \int_X G_3 \wedge \Omega$ $G_3|_{(0,3)} = 0$

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Vacuum: G4 is SD

Susy: G4 is (2,2)

Towards the SM

- MSSM from magnetized D7s

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Susy
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Non-susy

$$G_3 = 2\,(d\bar{z}_1 dz_2 dz_3 + dz_1 d\bar{z}_2 dz_3 + dz_1 dz_2 d\bar{z}_3 + d\bar{z}_1 d\bar{z}_2 d\bar{z}_3)$$

Stabilizes e.g. at $\tau_1 = \tau_2 = \tau_3 = \tau = i$

Full moduli stabilization & deSitter

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- Corrections

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Generalized fluxes

- Above set of fluxes is not really the most general
- Geometric, non-geometric, U-dual fluxes
- Superpotentials depending on all moduli

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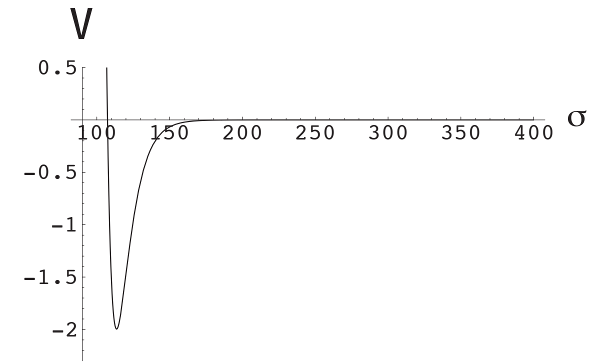
- Use non-perturbative effects from D3-brane instantons

[Kachru, Kallosh, Linde, Trivedi]

One-modulus toy model

$$W = W_{0,\mathrm{flux}} + A(z_0)e^{-T}$$

Susy AdS vacua with stabilized moduli



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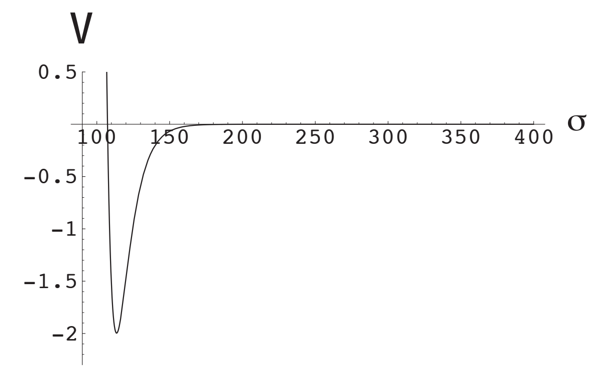

- Must tune W_0 t<< 1 to achieve controlable regime

Can be relaxed in other scenarios (Large Volume Stabilization)

Full moduli stabilization & deSitter

- Use non-perturbative effects from D3-brane instantons

[Kachru, Kallosh, Linde, Trivedi]

One-modulus toy model

$$W = W_{0,\mathrm{flux}} + A(z_0)e^{-T}$$

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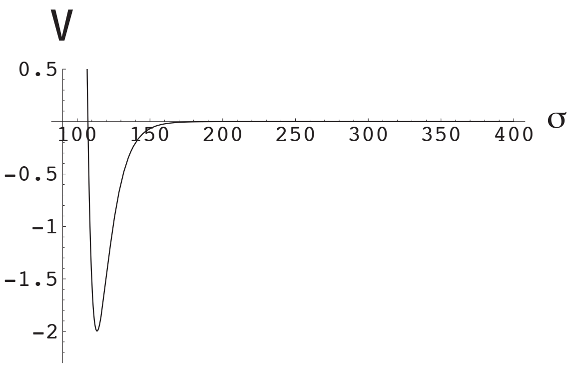

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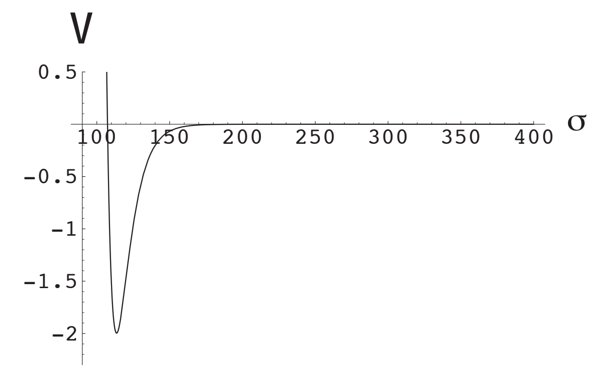

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- Generalization: D3-instantons for each independent Kahler modulus?

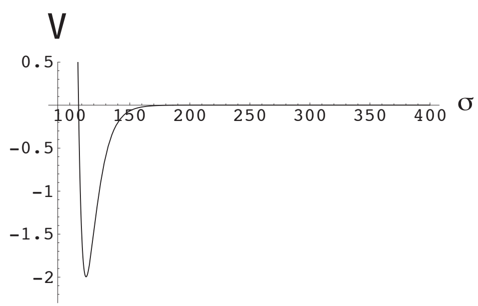
- Clash with SM arising from D7's

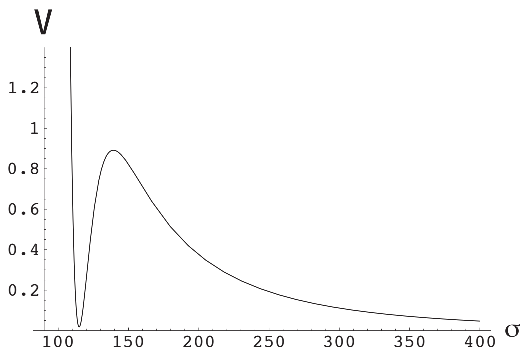
  Intersections of instanton with D7's lead to supos involving SM fields

$$W = e^{-T} \rightarrow W = e^{-T}\Phi_1 \ldots \Phi_n$$

Full moduli stabilization & deSitter

- Proposal to add sources of extra tension for uplifting to deSitter





- Anti D3-branes

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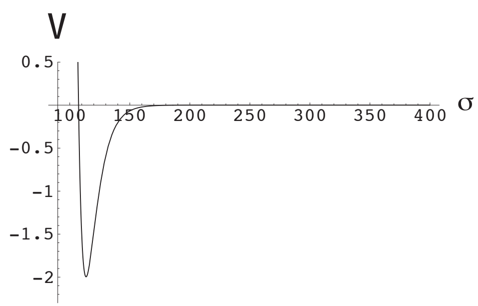

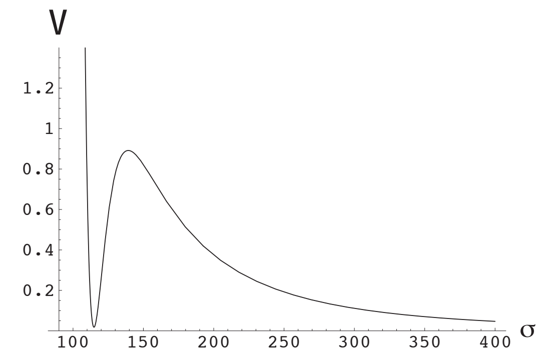

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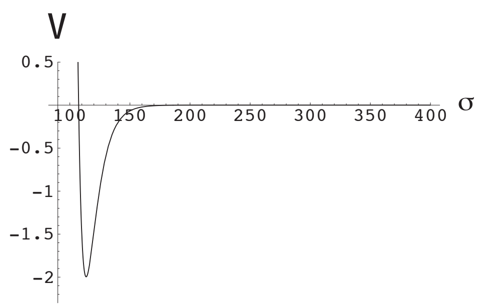

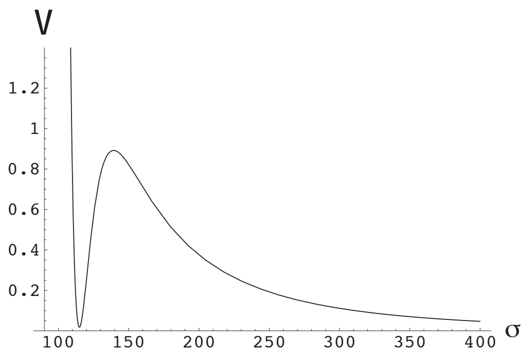

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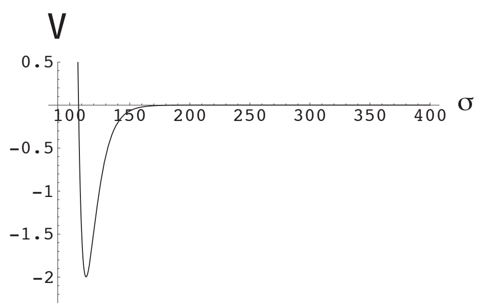

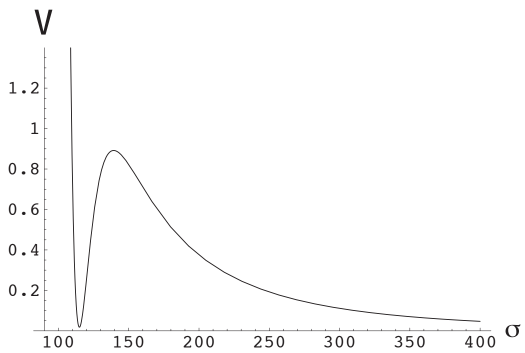

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Generalized fluxes

- Flux compactifications in type IIA involve even and odd forms

⇒ Talk both to Kahler and complex structure moduli!

What about mirror symmetry?

- Using T-duality in local T^3 fibration, H_3 turns e.g. into geometric twist

⇒ Geometric fluxes

- Compactification on non-CY geometries, possibly 4d N=1

SU(3) holonomy → SU(3) structure

⇒ Generalized complex geometry, mirror symmetry, ...

- Painful lack of explicit compact examples

Generalized fluxes

- Generalized geometric and non-geometric fluxes from T-duality

Regard T^3 as T^2 (trivially) fibered over S^1

H_3 is monodromy $b \to b+1$ for $b=\int_{T2} B$

Particular SL(2,Z) monodromy on $T=A_{T2}+ib$

One T-duality along T2 gives $\tau \to \tau+1$ in SL(2,Z) of τ

⇒ Geometric twisting, geometric flux

One S1 non-trivially fibered over two directions $\omega^a{}_{bc}$

Two T-dualities give non-geometric SL(2,Z) monodromy on T

⇒ Non-geometric twisting, non-geometric flux $Q^{ab}{}_c$

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- Generalized geometry. Double (&exceptional) field theory, ...

Flux landscape

- The general picture is compelling enough

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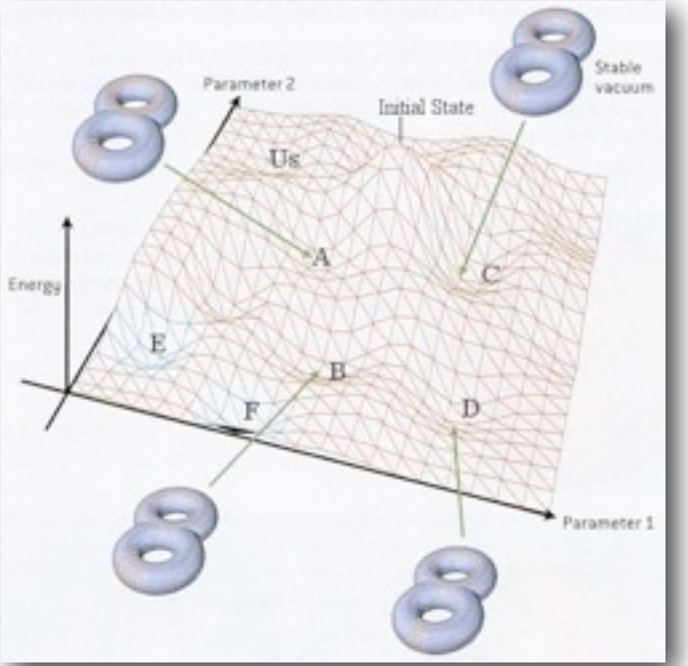

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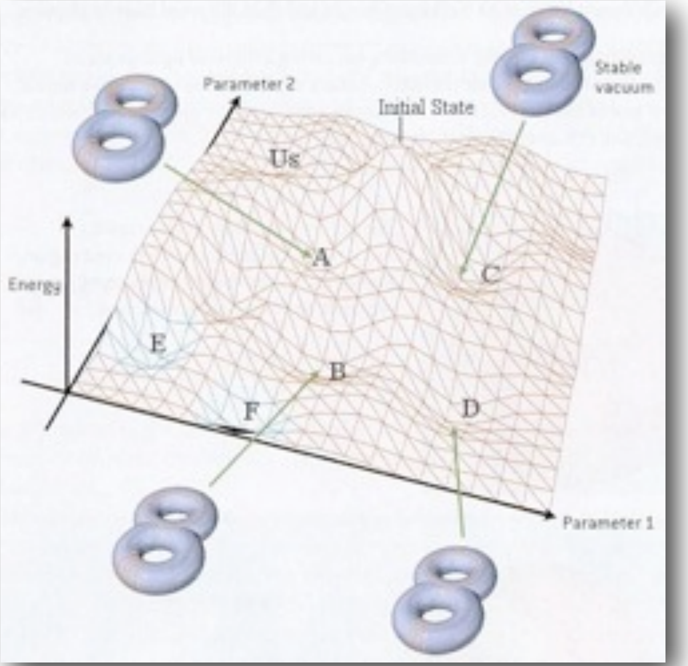
Internal data determine 4d physics

symmetries, spectrum, couplings



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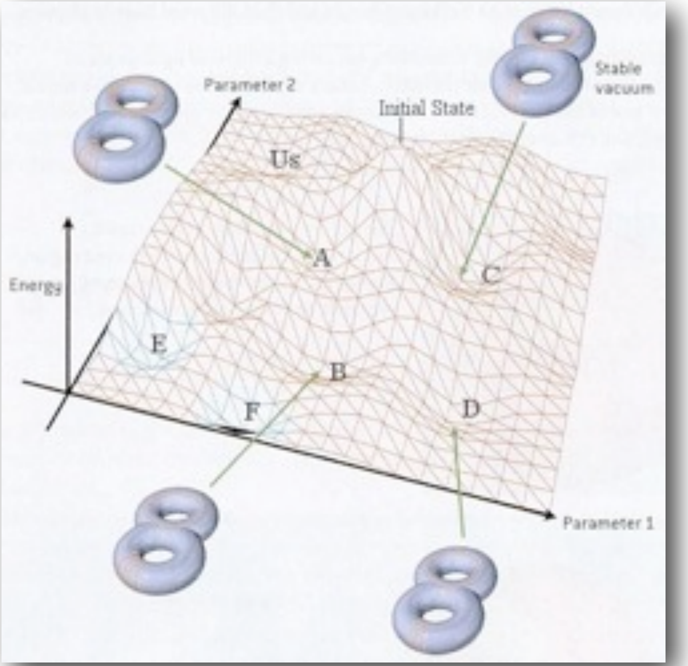

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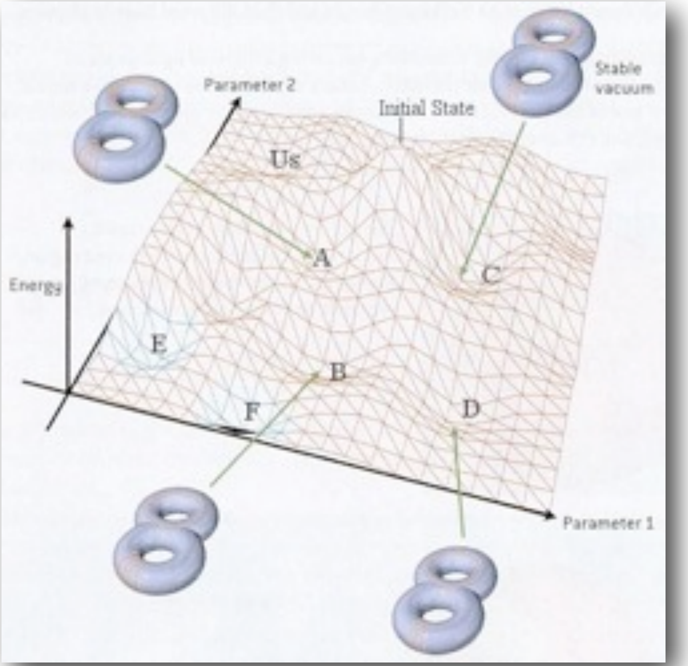

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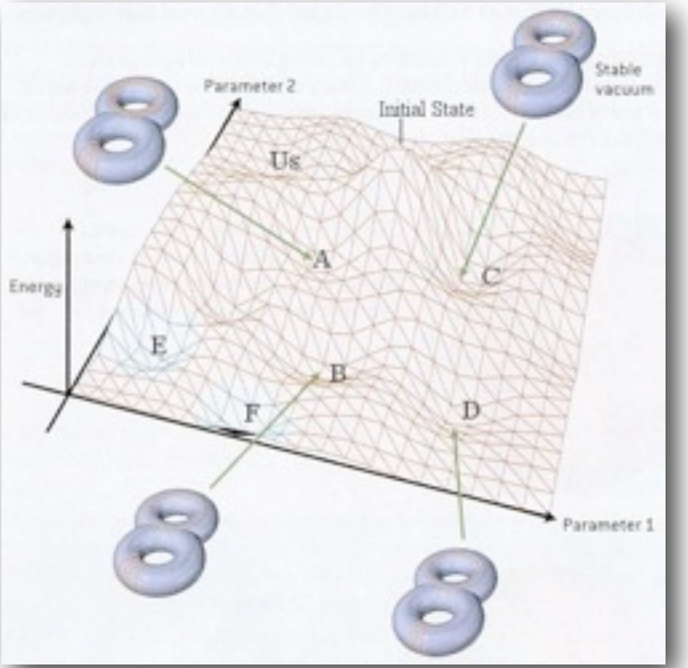

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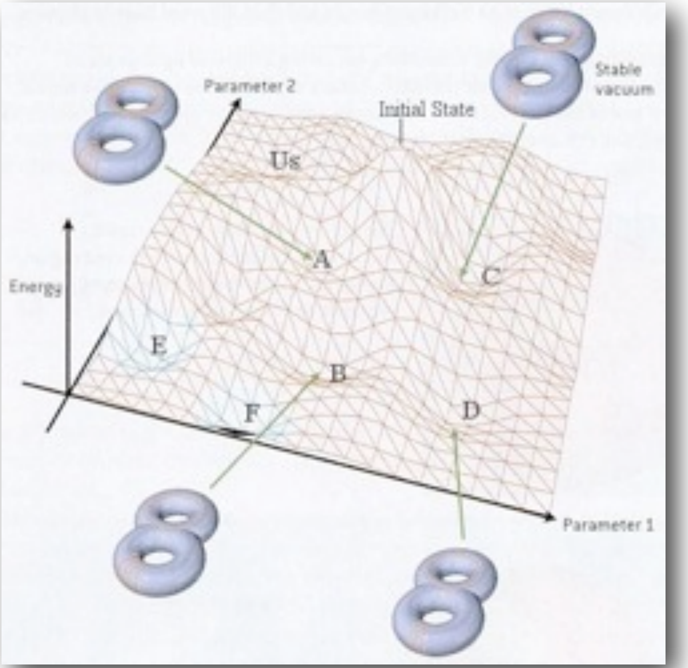

Flux landscape, part of full string landscape

Various estimates by flux counting

Revision of "naturalness": cosmological constant, hierarchy,...

Landscape of viewpoints

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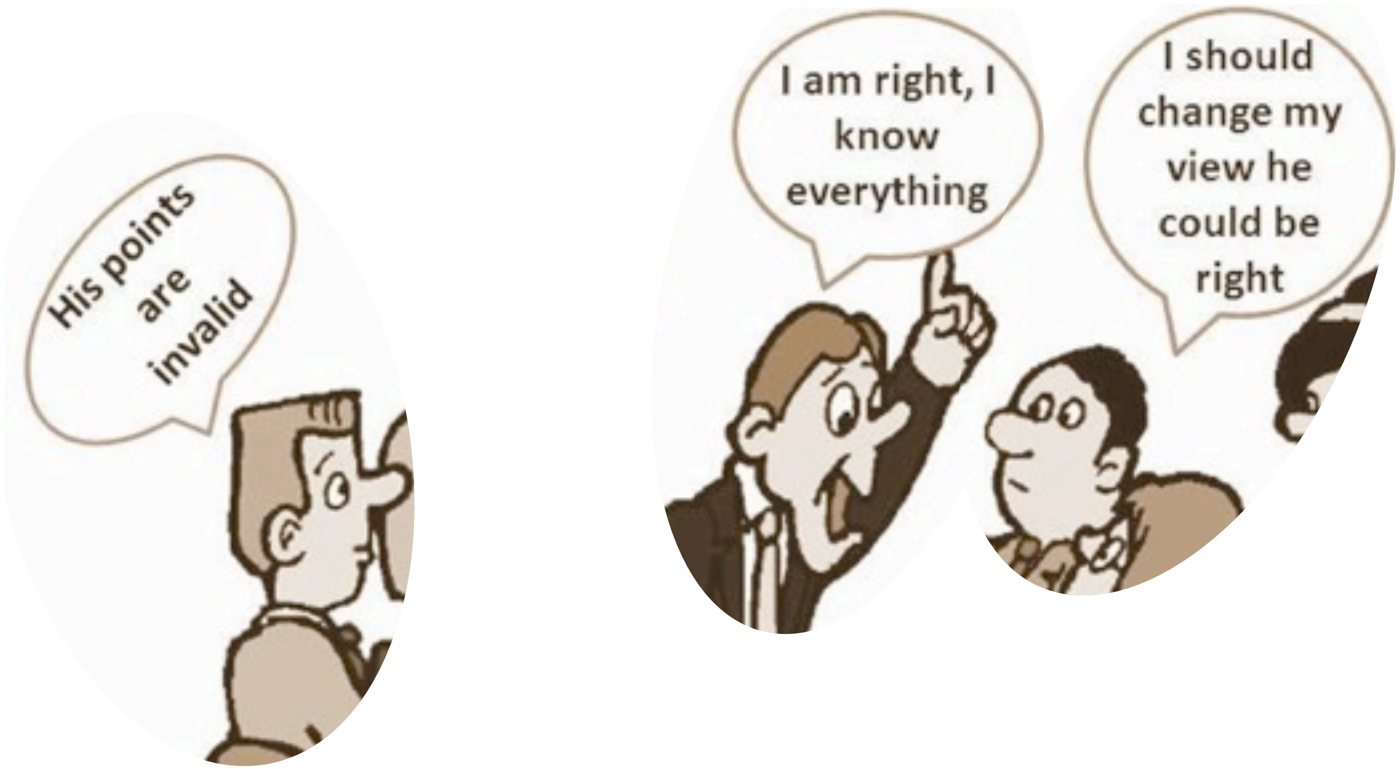

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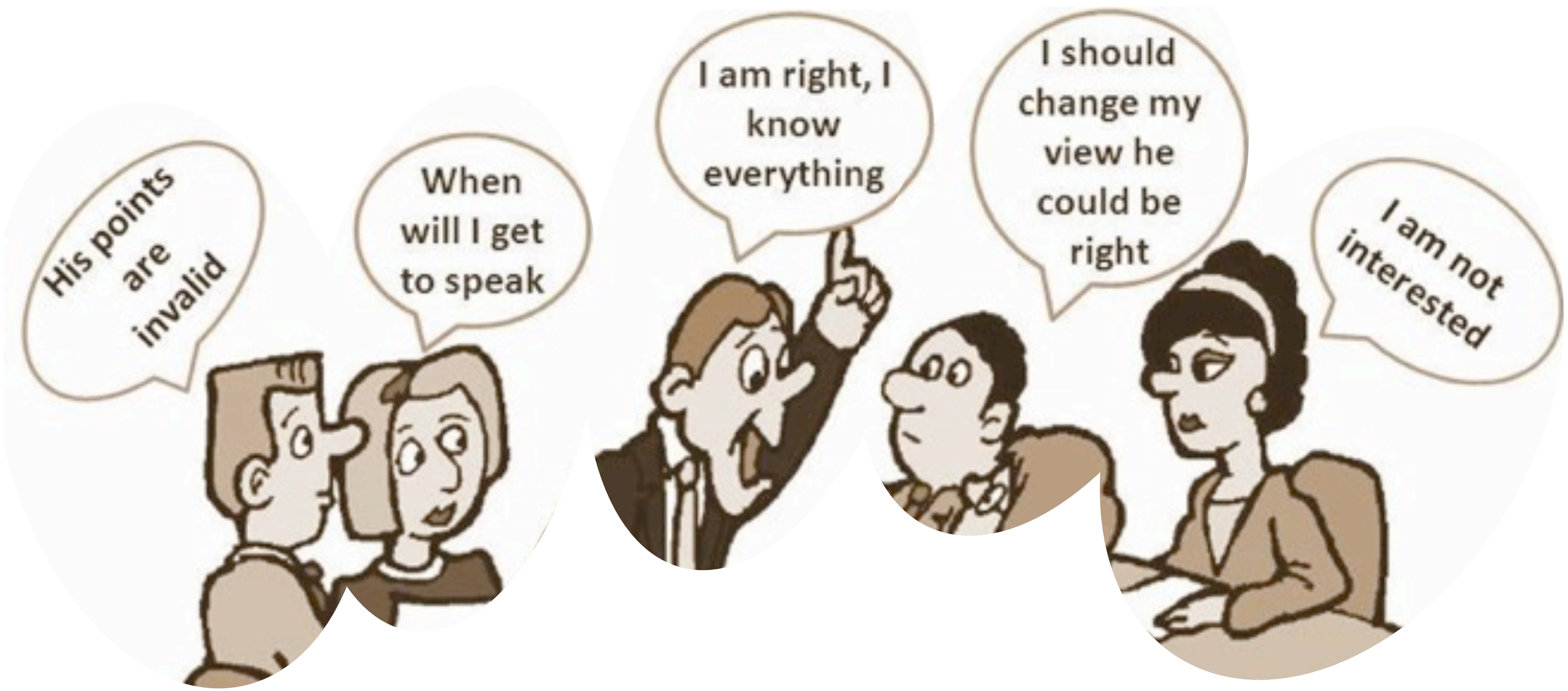

Landscape of viewpoints

Yeah, but...

Yeah, but...

What about some real Physics?

Landscape of viewpoints

What about some real Physics?

Keep rocking

After all, we are dealing with a theory
which is much more clever than any of us

Fluxes and D-branes

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- Focus on inter-relations between (field strength) fluxes and D-branes

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- Efects at several levels

  - Topological: Freed-Witten consistency conditions

  - (Susy) Open string moduli stabilization

  - Susy breaking

Freed-Witten consistency conditions

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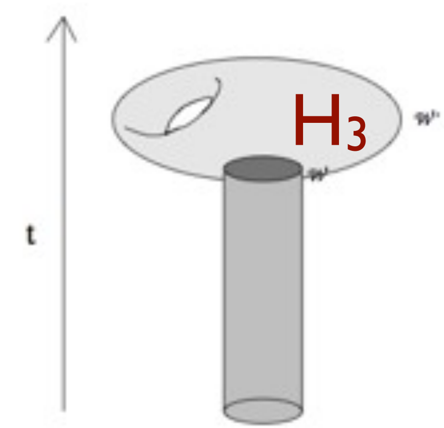
Take D6-brane on 3-cycle with non-trivial H_3

$$\int_{\mathrm{D6}} H_3 \wedge \tilde{A}_4$$



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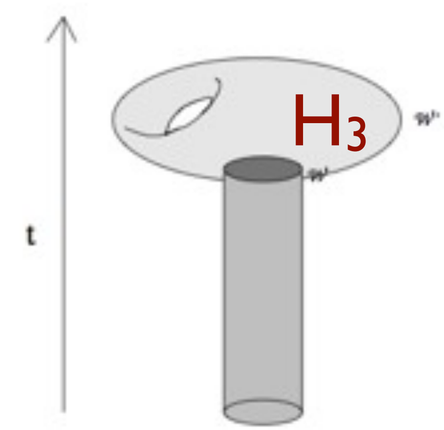

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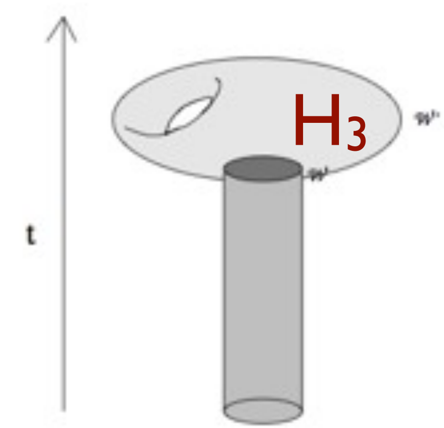

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- Analogous statements for RR fluxes

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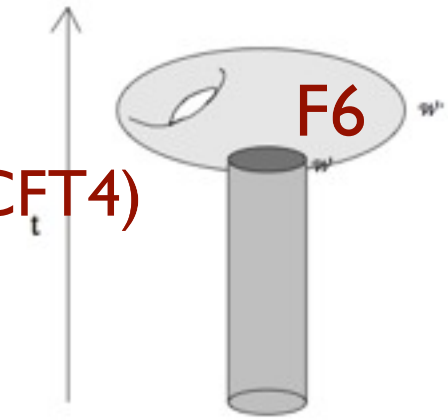

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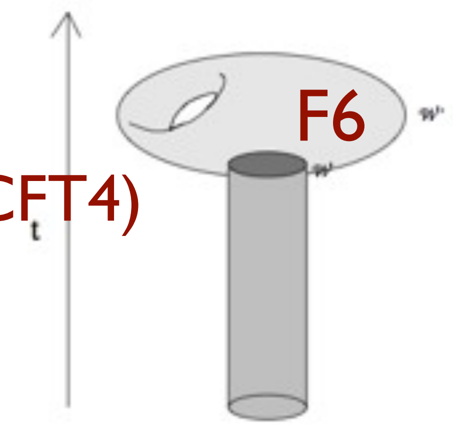

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Junction: D6 on X6. Emits k F1's (Zk strings)

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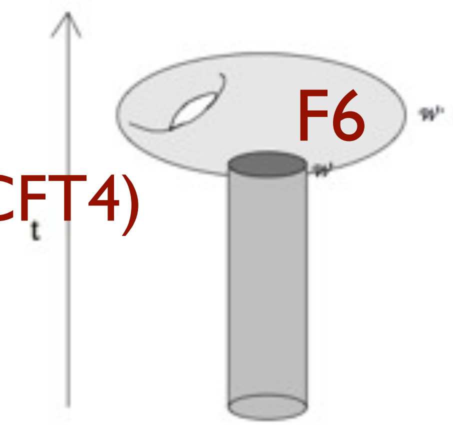

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- Can also do Zk domain walls. See later

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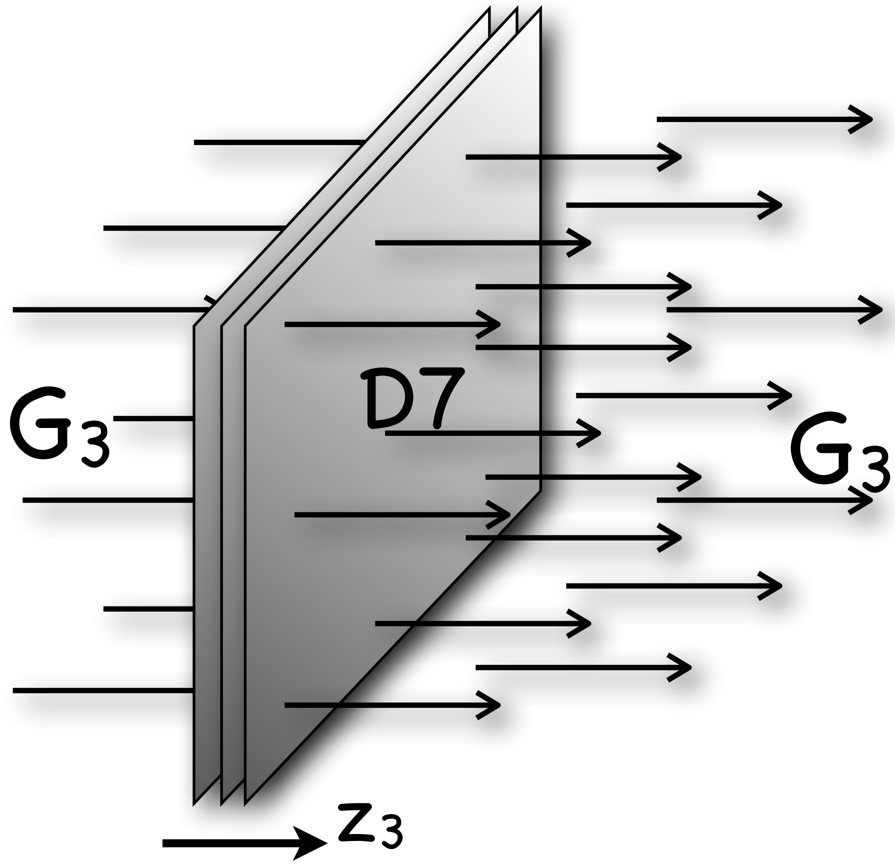
- An appealing scenario: Susy MSSM D-brane sector and non-susy flux



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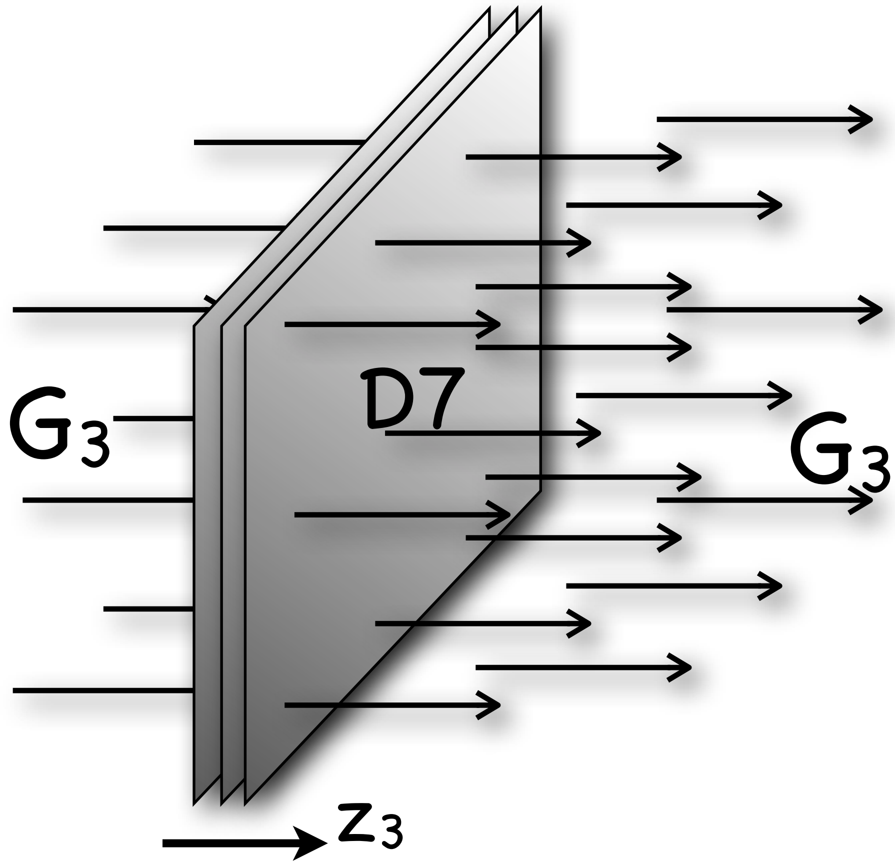

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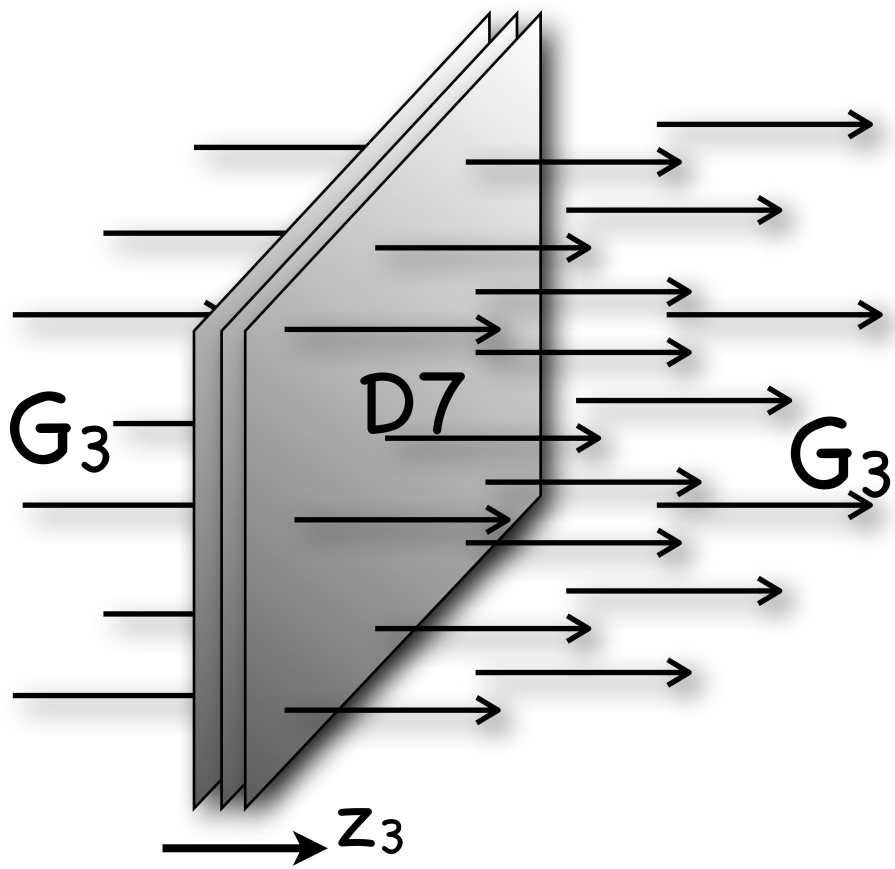
Explicitly computable using D-brane world-volume action in general supergravity background, or using 4d effective theory approach



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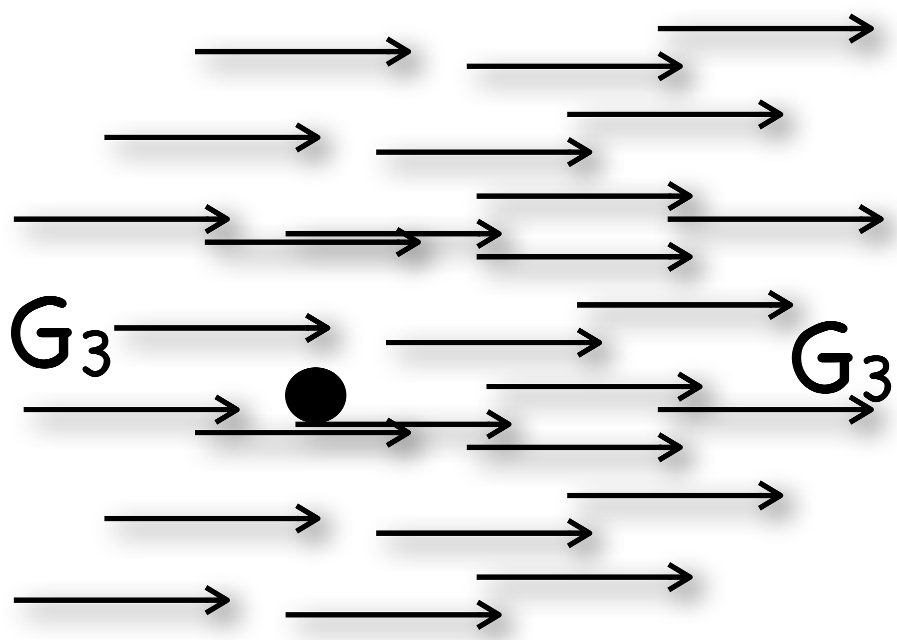

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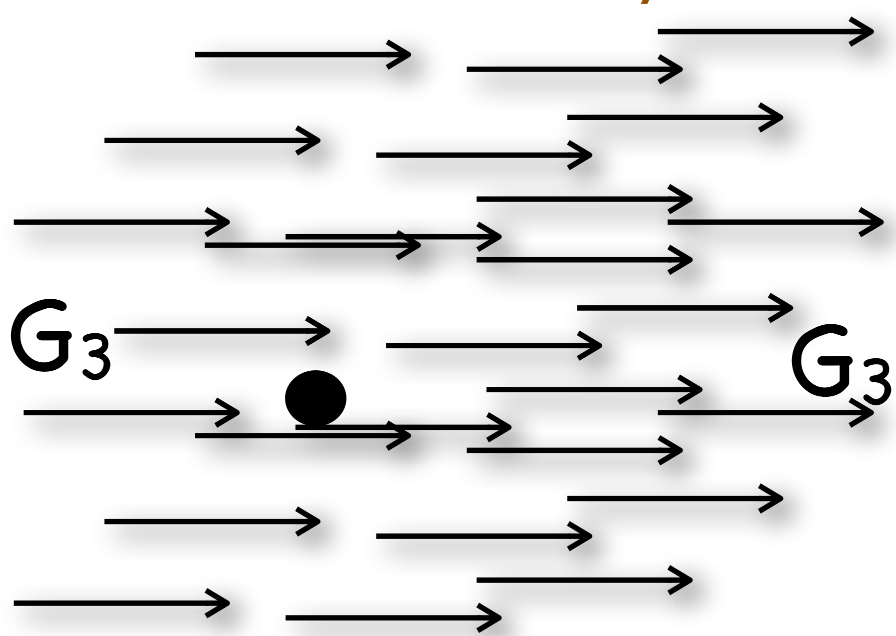

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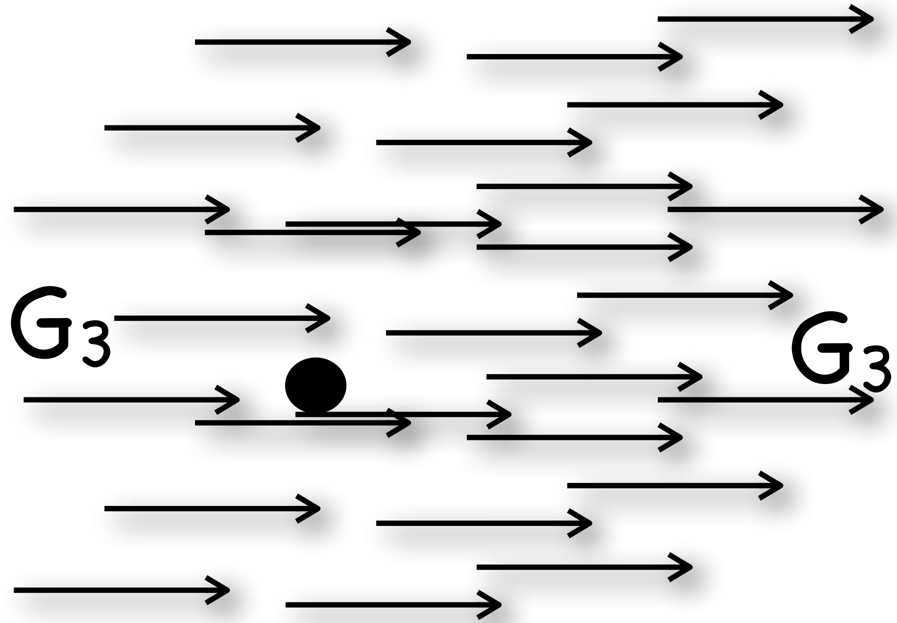

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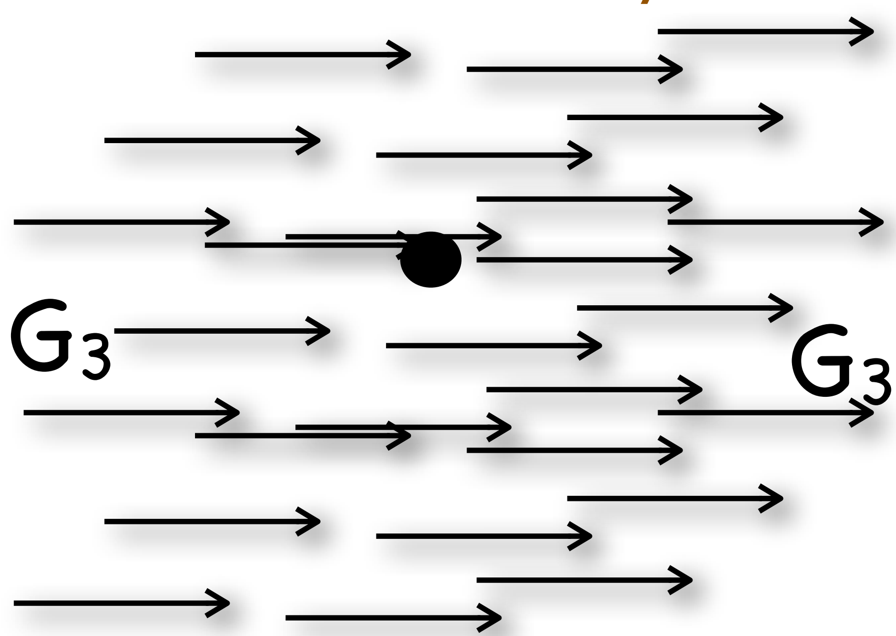

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$$m^2 \sim |G_{(0,3)}|^2$$

$$M \sim G_{(0,3)}$$

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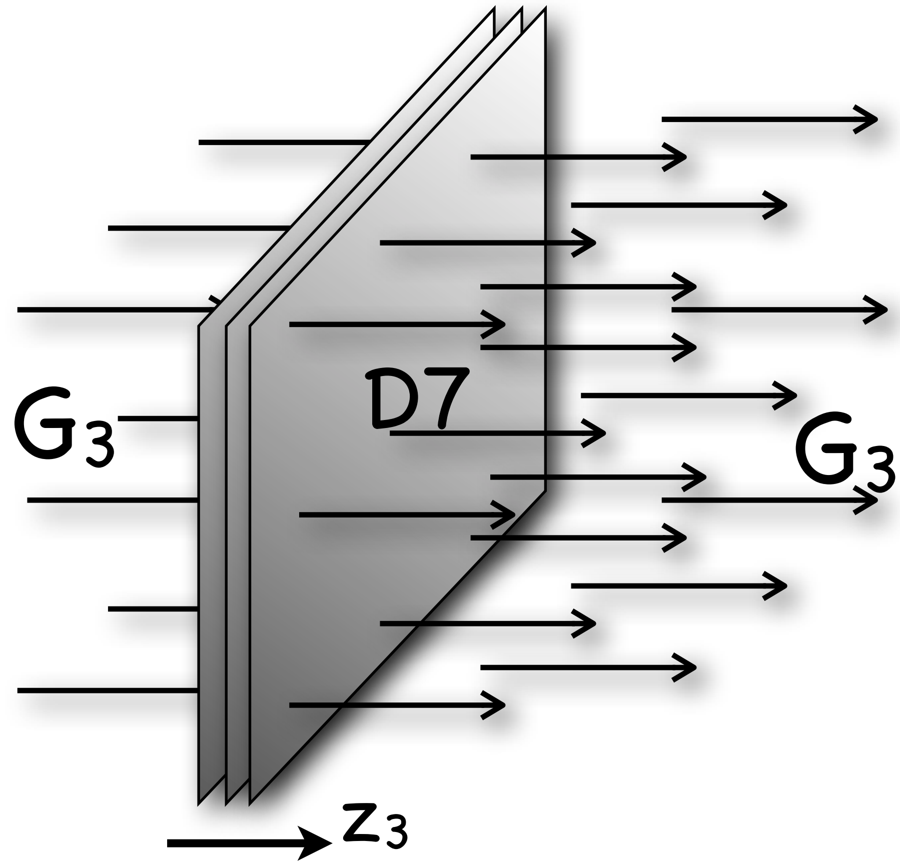

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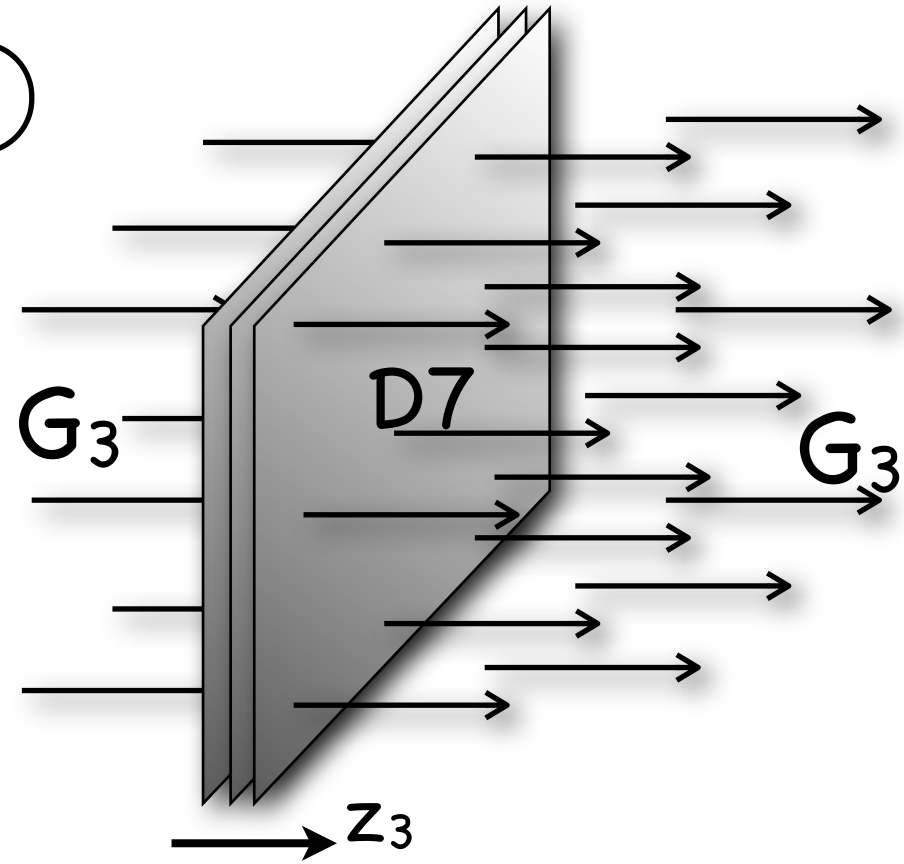

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- Can recover both D3 and D7 results from effective theory

  Flux components are vevs for moduli auxiliary fields: spurions

$$D_\tau W \sim \int_X \overline{G}_3 \wedge \Omega \qquad D_{z_i} W \sim \int_X G_3 \wedge \chi_{(2,1),i} \quad D_\rho W \sim \int_X G_3 \wedge \Omega$$

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LowE Susy: TeV soft terms from $M_c \sim 10^{11}\mathrm{GeV}$

~~LowE Susy~~: Choose $M_c \sim 10^{14}\mathrm{GeV}$ then $M_{SUSY} \sim 10^{10}\mathrm{GeV}$

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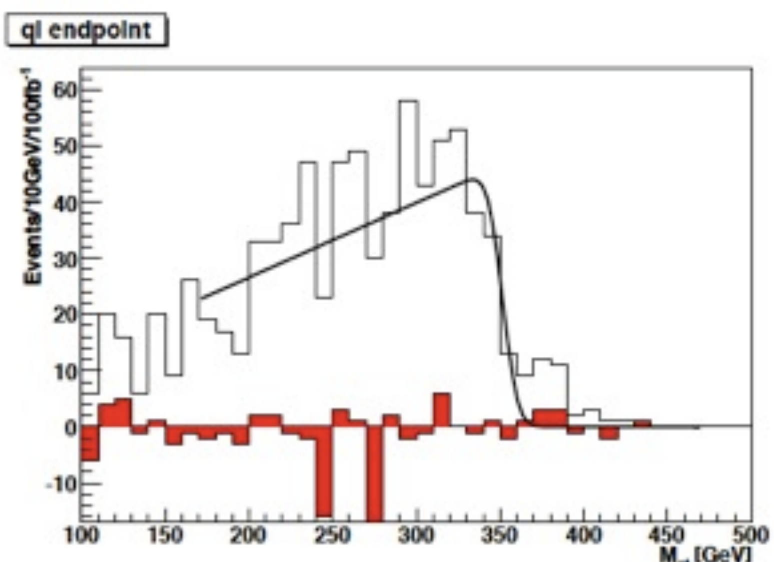
- Scales $M_{SUSY} \sim f \frac{\alpha'}{R^3} \sim f \frac{M_c^2}{M_p}$ f: possible local suppression

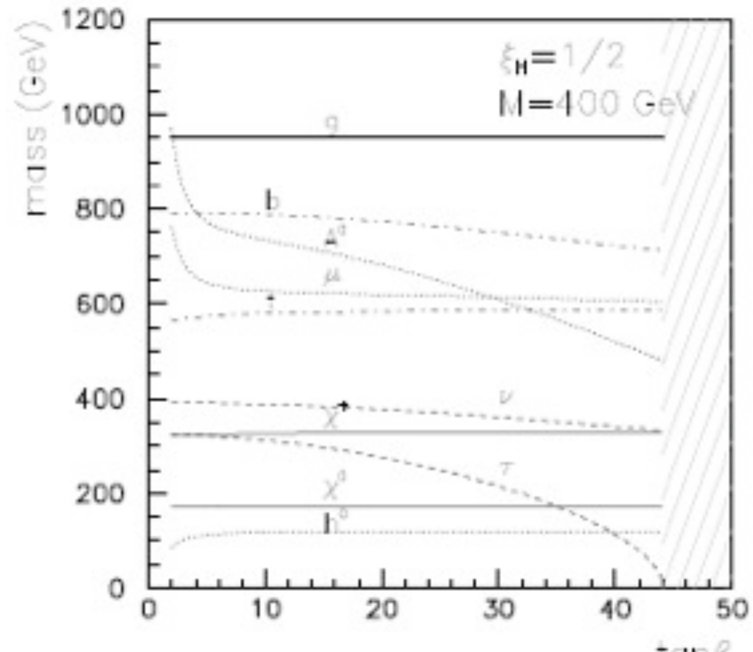
LowE Susy: TeV soft terms from $M_c \sim 10^{11}\mathrm{GeV}$

~~LowE Susy:~~ Choose $M_c \sim 10^{14}\mathrm{GeV}$ then $M_{SUSY} \sim 10^{10}\mathrm{GeV}$

- Can get to make plots



Ex: spectrum reconstruction from edges
Conlon, Kom, Suruliz, Allanach, Quevedo '07

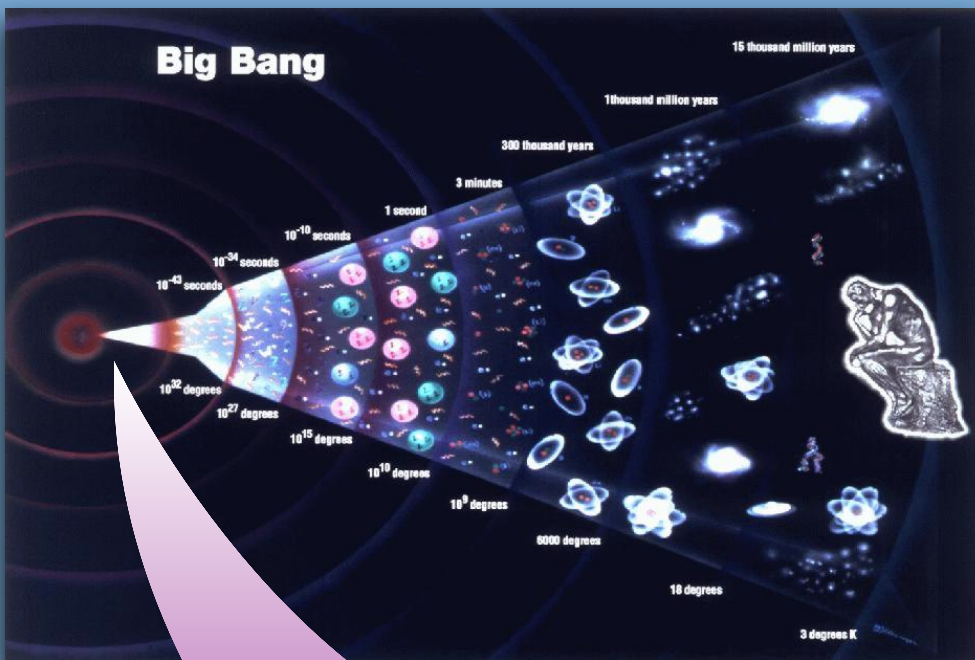


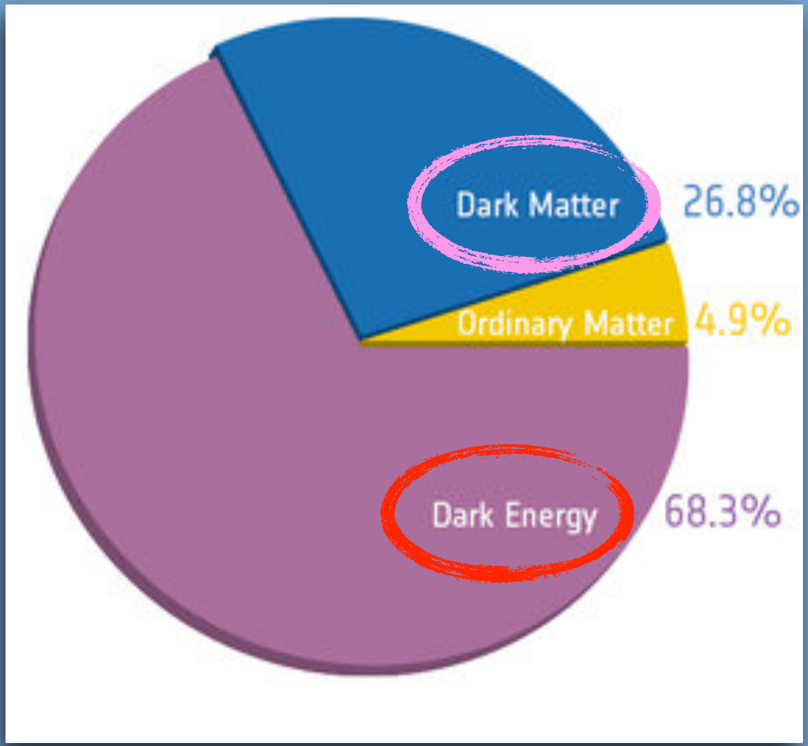
Ex: MSSM parameters Aparicio, Cerdeno, Ibañez '08

Cosmological Standard Model

(ΛCDM, "concordance model")

Flash back





inflation
cf. Shiu's
lectures

Fluxes, 3-forms and axion monodromy

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  continuous symmetry broken by non-pert effects to a discrete periodicity

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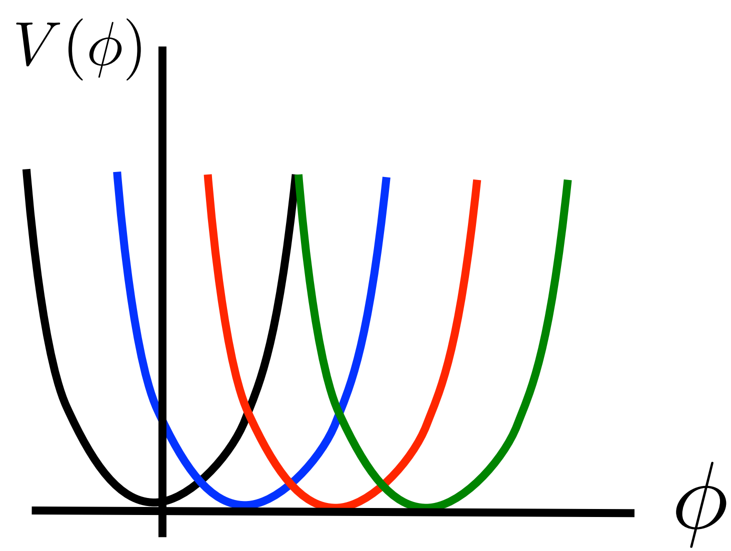
- String theory axions have sub-Planckian decay constant

Axion monodromy:
Potential is periodic but multivalued



Field theory analogue:
theta dependent vacuum energy
in large N pure gluodynamics Witten

Discrete Zn gauge symmetries

Flash back

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  Zn particles, Zn strings, ...

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- There are Zn gauge symmetries associated to 4d domain walls

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  Zn symmetry of a 3-form that eats up a 2-form

$$\frac{1}{2}|F_4|^2 + |db_2 - n\, c_3|^2$$

Gauge invariance

$$c_3 \to c_3 + d\Lambda_2 \quad ; \quad b_2 \to b_2 + n\Lambda_2$$

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- Dualizing b2 to an axion, get Kaloper-Sorbo description of axion monodromy models.

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- Can consider other Zn charged objects in 4d

Lagrangian for 3-form eating up a 2-form

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Can arise in D-brane & flux models

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- Structure is automatic in flux compactifications

After all, fluxes produce the stabilization of axions in moduli!!

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Integrating over fluxed CY with $\phi = \int_{\Sigma_2} B_2 \; , \quad M = \int_{\Pi_p} F_p$

Change in axion induces extra flux

$$\Delta\phi \to \Delta \int_{\Sigma_2 \times \Pi_p} \tilde{F}_{p+2} = \phi M$$

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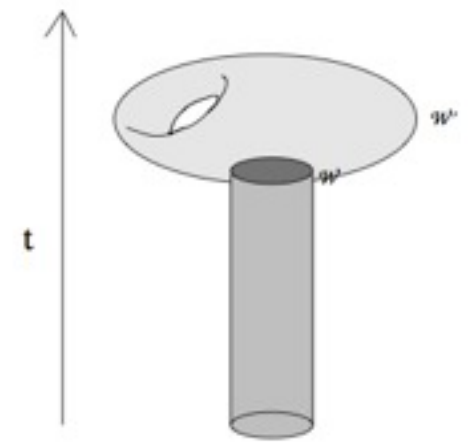
- Monodromy

  Multiple branches connected by domain walls changing (p+2)-form flux. They are D(6-p) on (4-p)-cycle

Fluxes, 3-forms and axion monodromy

- Many other realizations



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$$F_4 = \int_B F_7 \quad ; \quad \int_A H_3 = n$$

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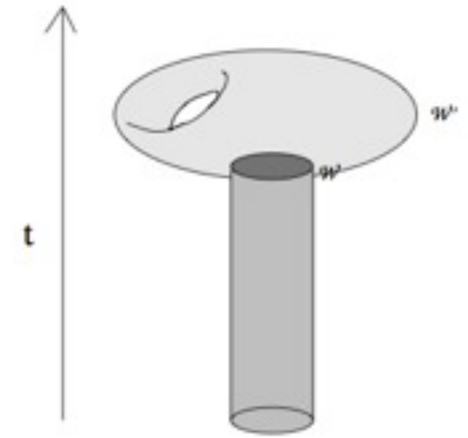

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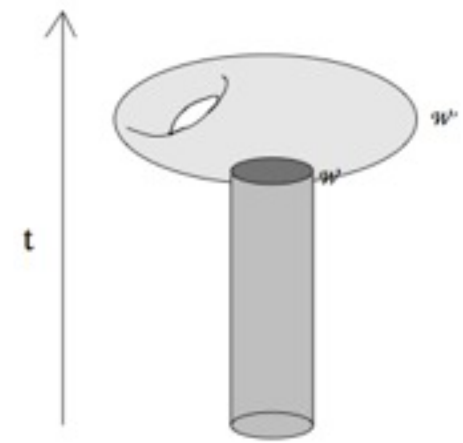

10d IIB axion has a monodromy. Origin of energetic cost?

GVW supo $\quad W = \int_{X_6} (F_3 - \tau \overline{H}_3) \wedge \Omega$

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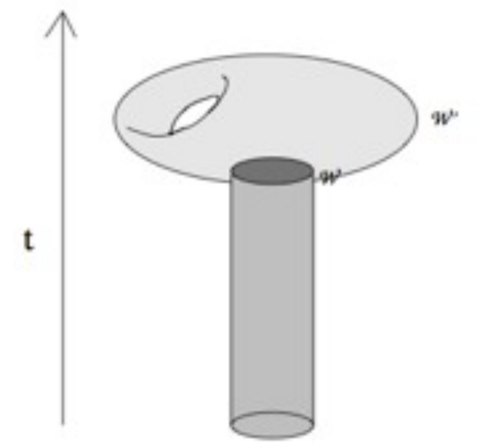

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Period of C0 changes n units of F3 flux on A

4d Domain Wall is D5 on B

4d instanton is D(-1) (cosine modulation)

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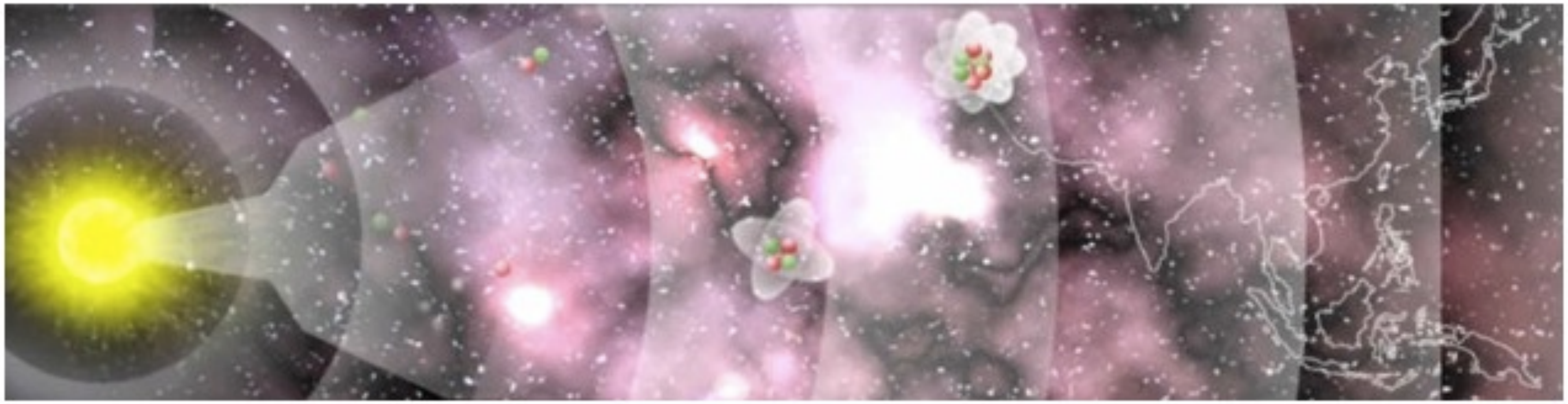
- Expect continuous progress and new results
  and useful input from LHC & cosmo

To all organizers & hosts & participats of

The 10th Asian Winter School on Strings, Particles and Cosmology



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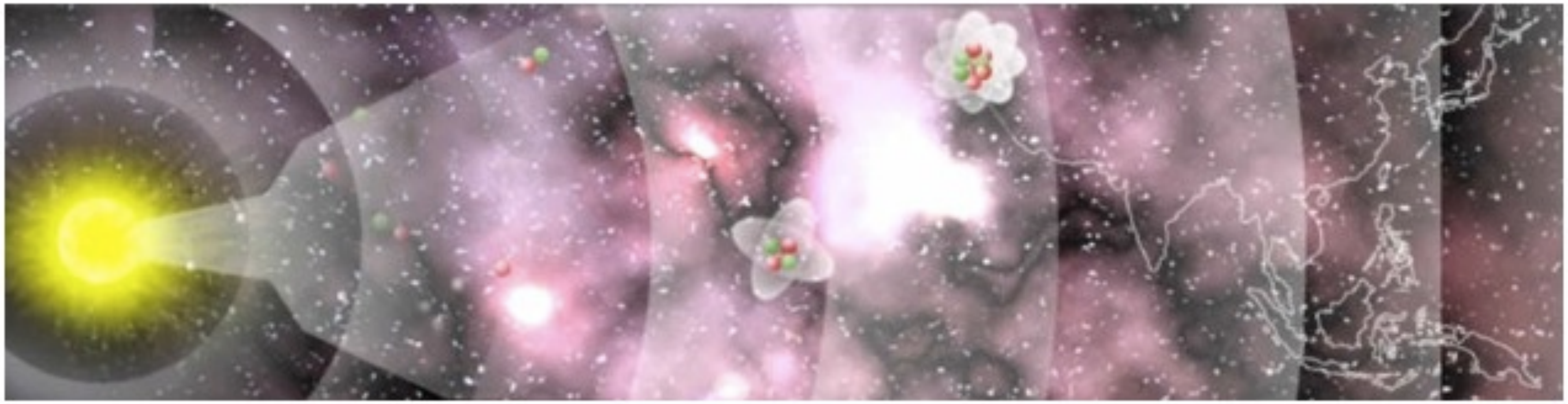

ありがとう

Arigato * Thank You