U(1) mixing and F-theory GUTs

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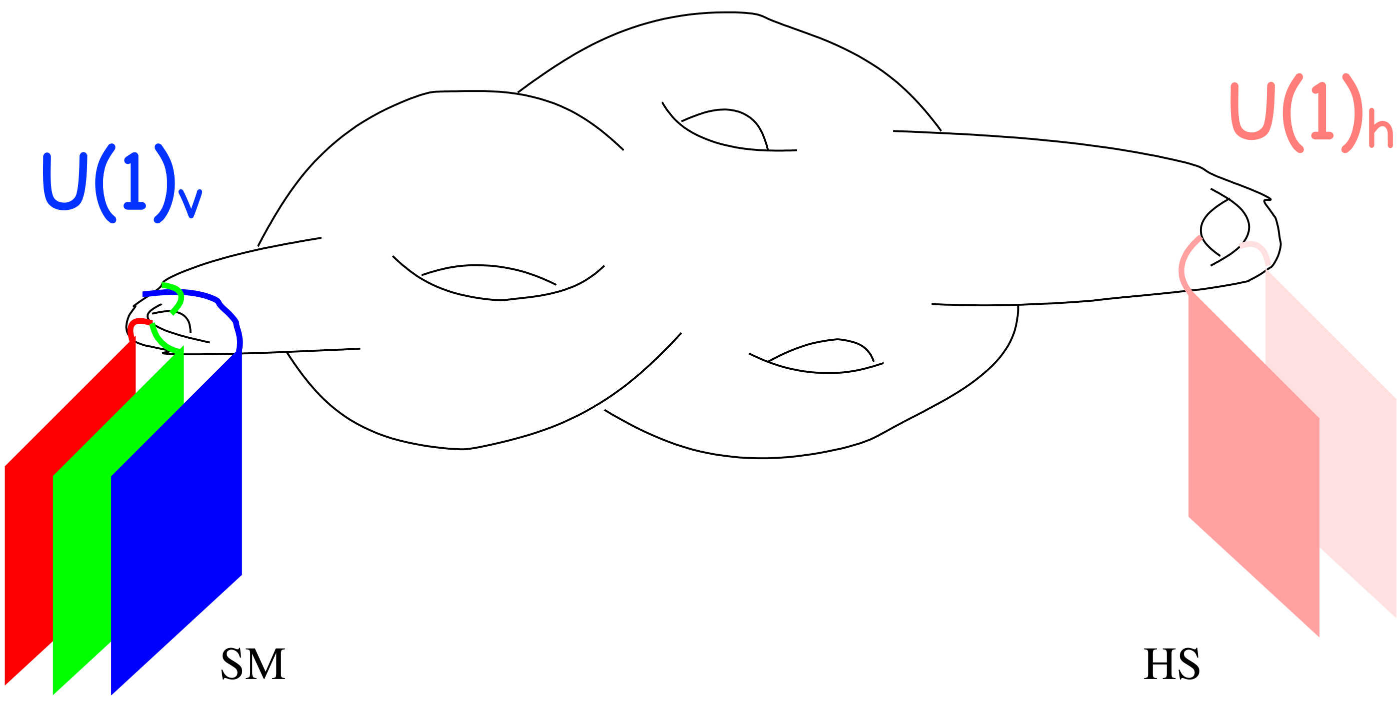
Based on:

F.M., Regalado, Zoccarato

[1406.2729]

Motivation

- Typical type II scenario
  - Open string U(1) from visible gauge sector
  - Extra U(1) from hidden gauge sector



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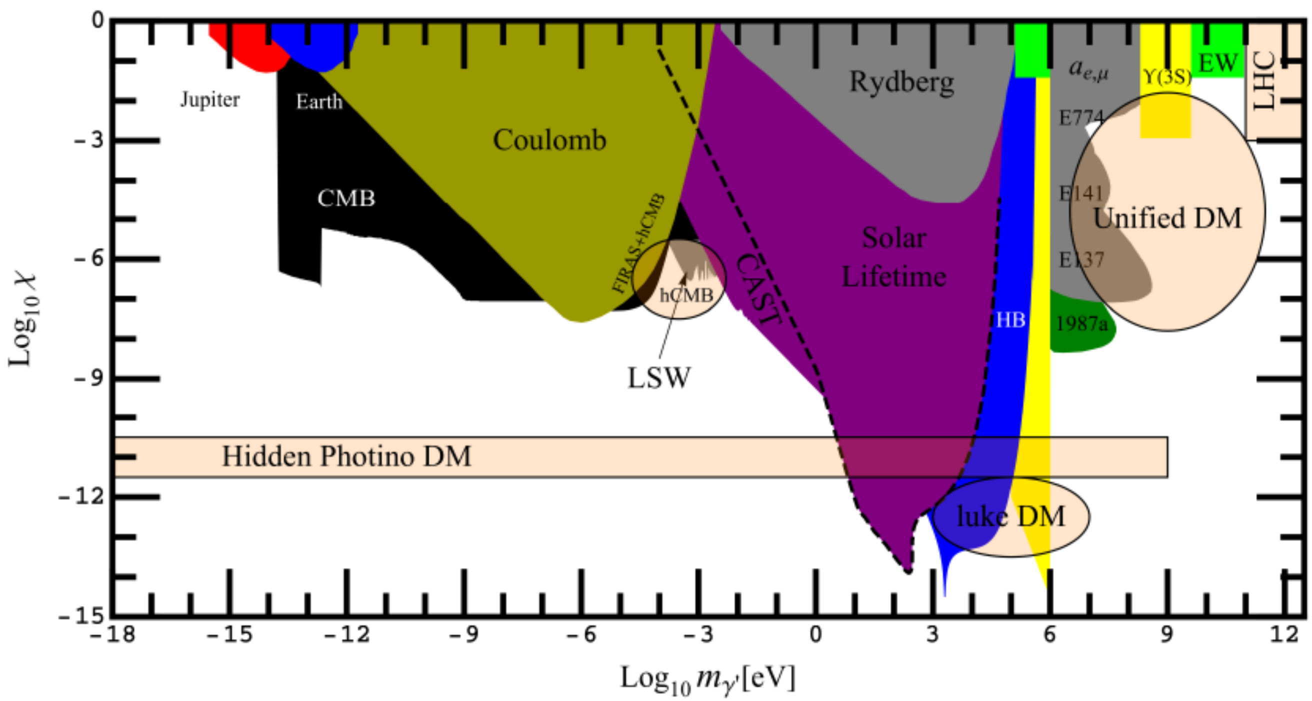
  - Extra U(1) from hidden gauge sector, compatible with experiment as massless or very light hidden gauge symmetries

$$\mathcal{L}_{4d} \supset -\frac{1}{4}\sum_{i=v,h} F^{(i)}_{\mu\nu}F^{(i)\,\mu\nu} + \frac{1}{2}\chi_{vh}F^{(v)}_{\mu\nu}F^{(h)\,\mu\nu} + \frac{1}{2}m^2_{\gamma'}A^{(h)}_\mu A^{(h)\,\mu}$$



taken from Jaeckel and Ringwald '10

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  - Natural scenario: massless hidden U(1) with charged light matter

non-trivial kinetic mixing χ_{vh} $\Longrightarrow$ Milli-charged scenario

Holdom '86

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non-trivial kinetic mixing χ_{vh} $\Longrightarrow$ Milli-charged scenario

Holdom '86

  - Open-open U(1) mixing arises at one loop

Abel [2], Cicoli, Goodsell [4], Jaeckel [4], Khoze [2], Redondo, Ringwald [5] '06-11

Gmeiner, Honecker [3], Ripka, Staessens '09-12

CFT computation

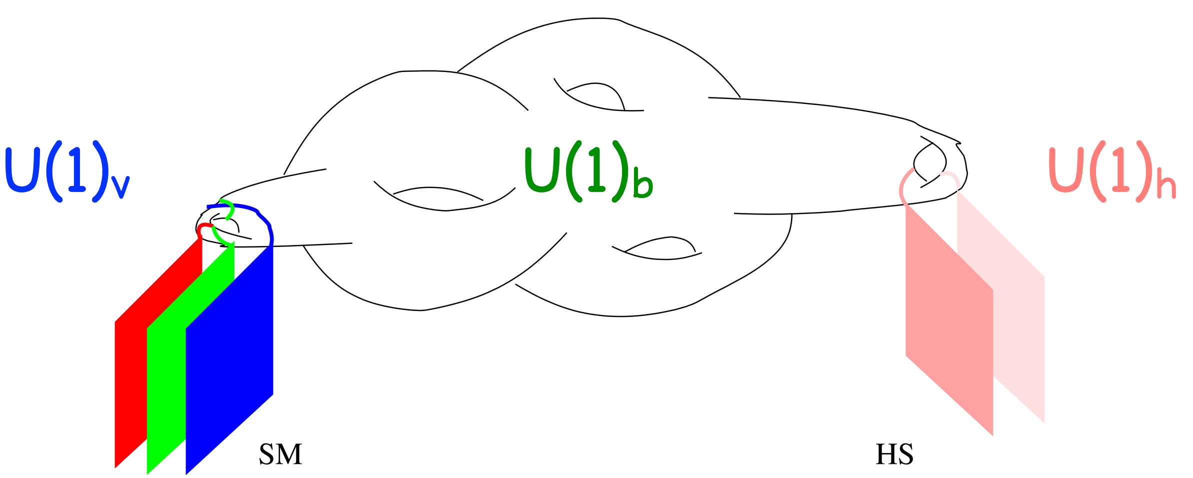
Williams, Burgess, Maharana, Quevedo '11

Bullimore, Conlon, Witowski '10

Shiu, Soler, Ye '13

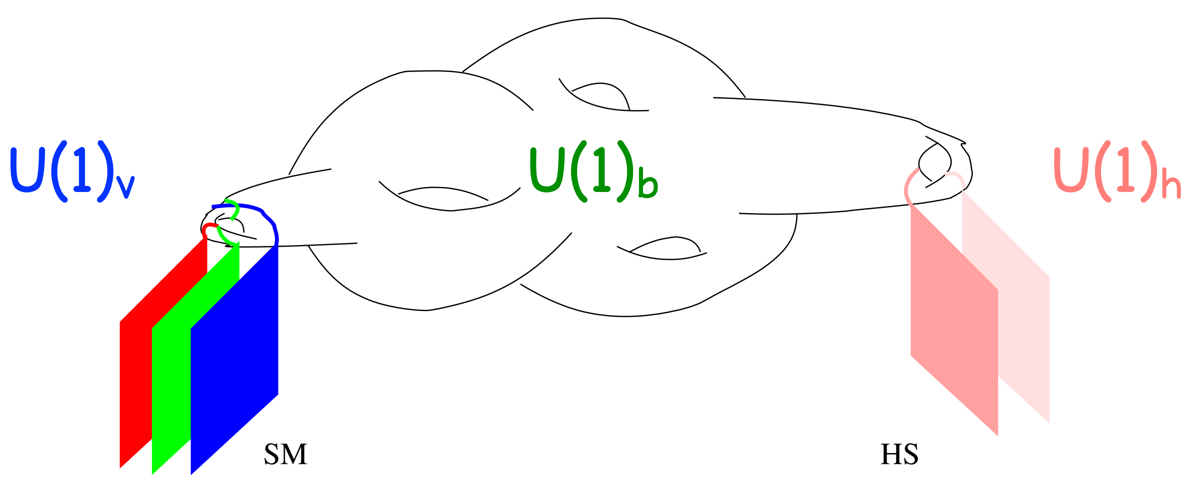
Motivation

- Typical type II scenario
  - Open string U(1) from visible gauge sector
  - Extra U(1) from hidden gauge sector, compatible with experiment as massless or very light hidden gauge symmetries
  - Natural scenario: massless hidden U(1) with charged light matter
  - Also natural to consider a massless hidden U(1) arising from the closed string sector of the compactification



Motivation

- Closed string U(1)'s in type II
  - Arise from dimensional reduction of RR potential: $C_p = A_1 \wedge \omega_{p-1}$
  - Mix with open string U(1)'s at tree level
  - Do not have any light state charged under them



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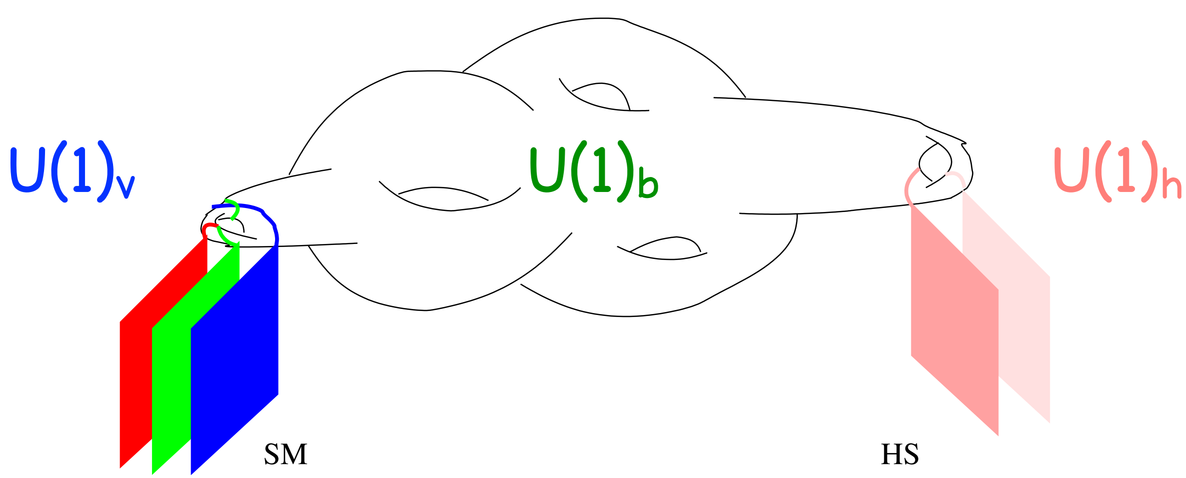
But then, why bother?



Reason I: Millicharges

- U(1)$_b$ can mix with U(1)$_v$ and U(1)$_h$ at the same time

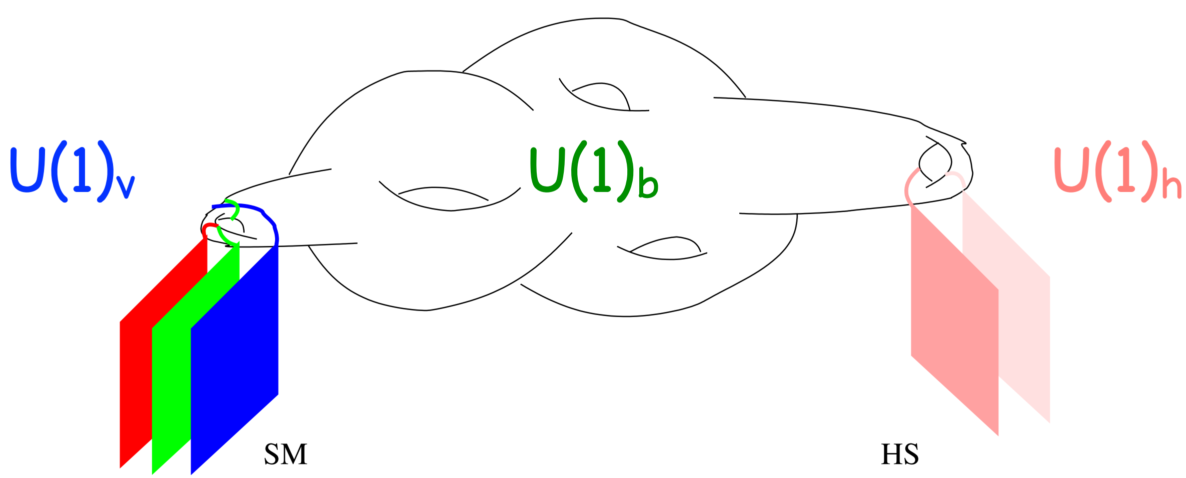
$$\mathcal{L}_{4d} \supset -\frac{1}{4}\sum_{i=v,h,b} F^{(i)}_{\mu\nu}F^{(i)\,\mu\nu} + \frac{1}{2}\left(\chi_{vb}F^{(v)}_{\mu\nu}F^{(b)\,\mu\nu} + \chi_{hb}F^{(h)}_{\mu\nu}F^{(b)\,\mu\nu}\right)$$

  - Removing the χ's by a change of basis induces a hypercharge on matter charged under U(1)$_h$

$$\delta^{\rm eff}_{vh} = \frac{\chi_{vb}\chi_{hb}}{\sqrt{1-\chi^2_{vb}-\chi^2_{hb}}}$$

compared to

$$\delta^{\rm one-loop}_{vh} = \frac{\chi_{vh}}{\sqrt{1-\chi^2_{vh}}}$$



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- Rel. position indep.

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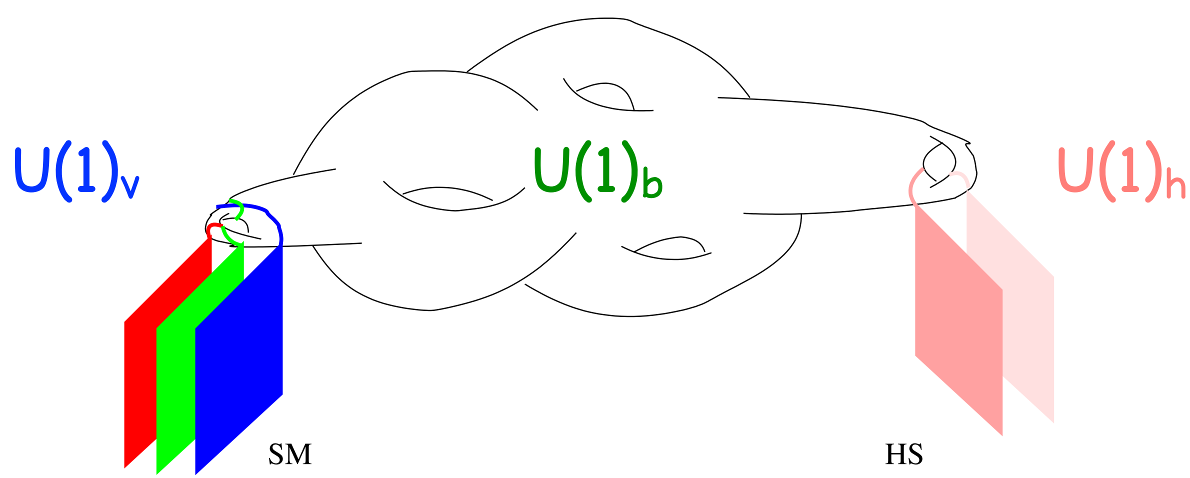

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- Rel. position dep.

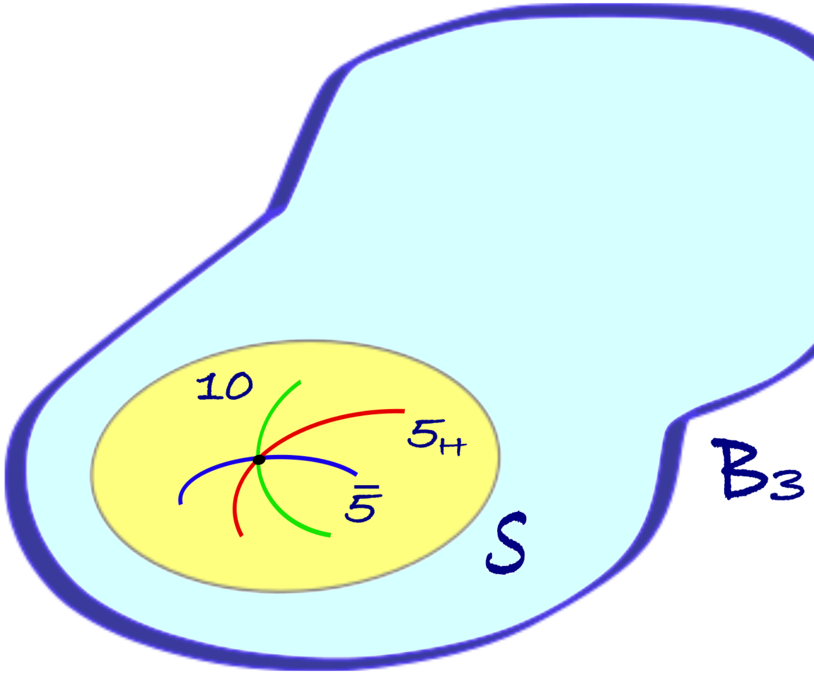
↓

Both contributions could be comparable

Reason II: Unification

- If $U(1)_v = U(1)_Y \subset SU(5)$ or G_{GUT}, then mixing with $U(1)_b$ changes the GUT relations

$$g_1^{\text{measured}} = \frac{g_1^{\text{GUT}}}{\sqrt{1-\chi_{vb}^2}}$$



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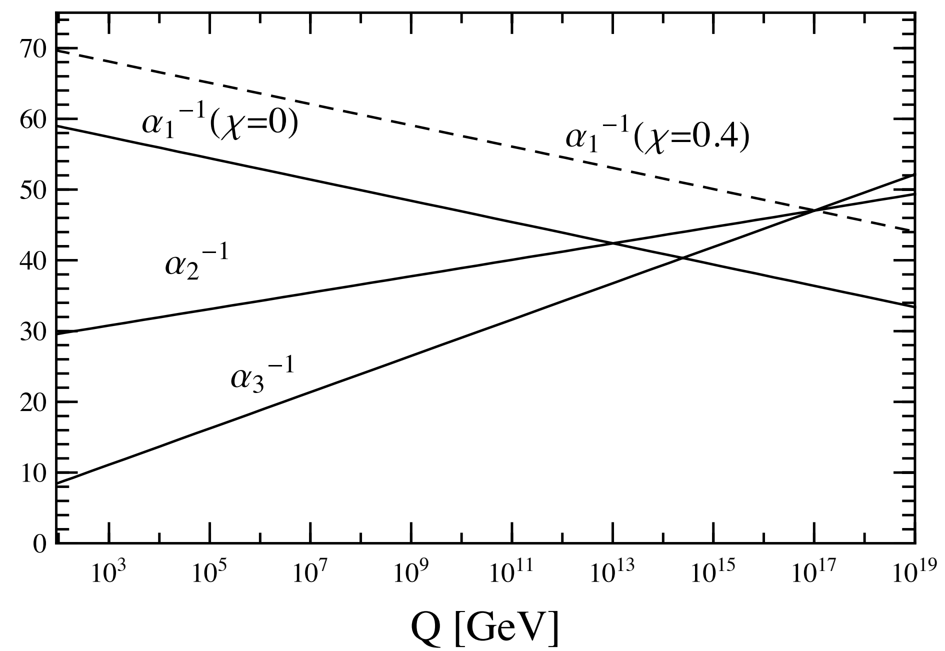
Redondo '08

SM



Could explain deviations from unification in SM

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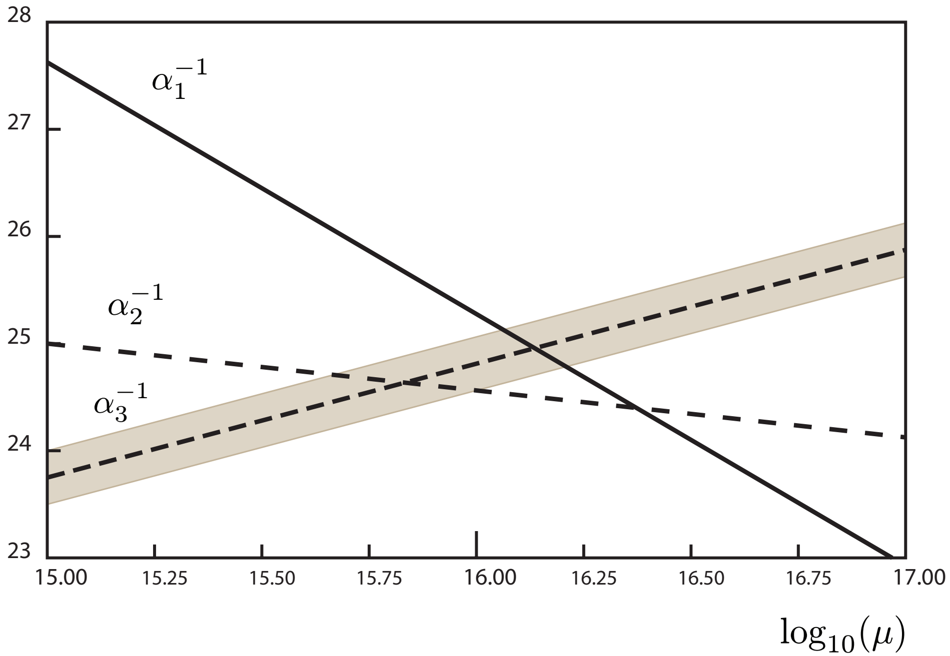
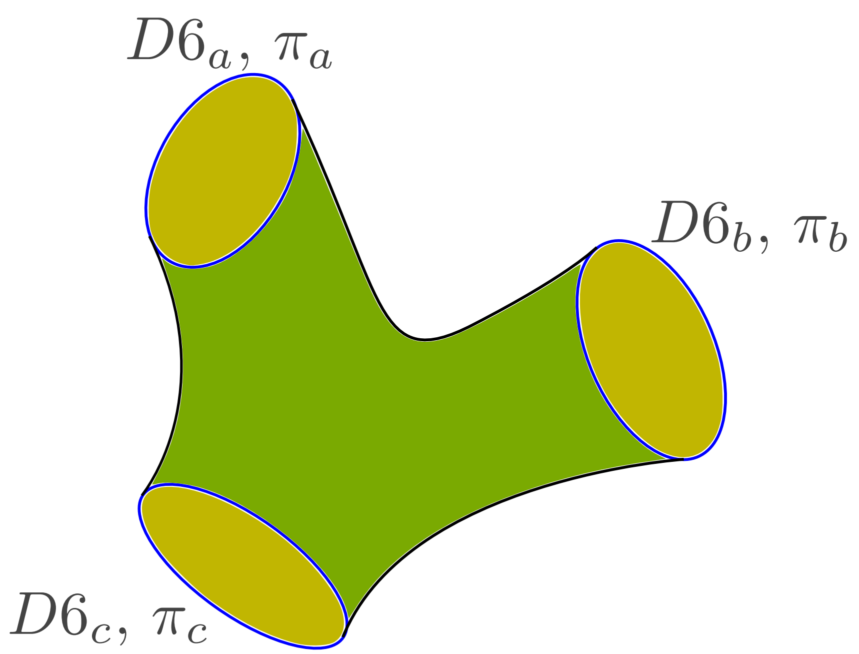
MSSM



Gives further corrections to $U(1)_Y$ coupling constant in F-theory GUTs

see also Hebecker's talk

Computing Open-Closed U(1) mixing



Mixing from DBI

- Mixing between open and closed string U(1)'s can already be seen at the level of the DBI action

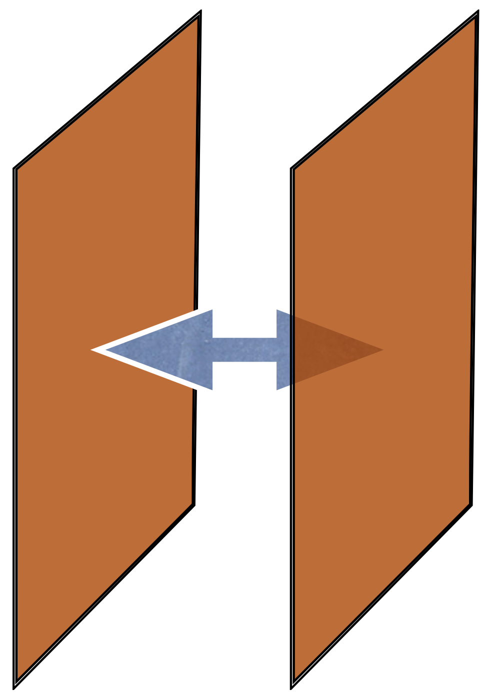
Jockers & Louis '04

Grimm & Lopes '11

Kerstan & Weigand '11

  - Simple setup: separating two D-branes

Cámara, Ibáñez, F.M. '11



$\pi_a \sim \pi_b \sim \pi$

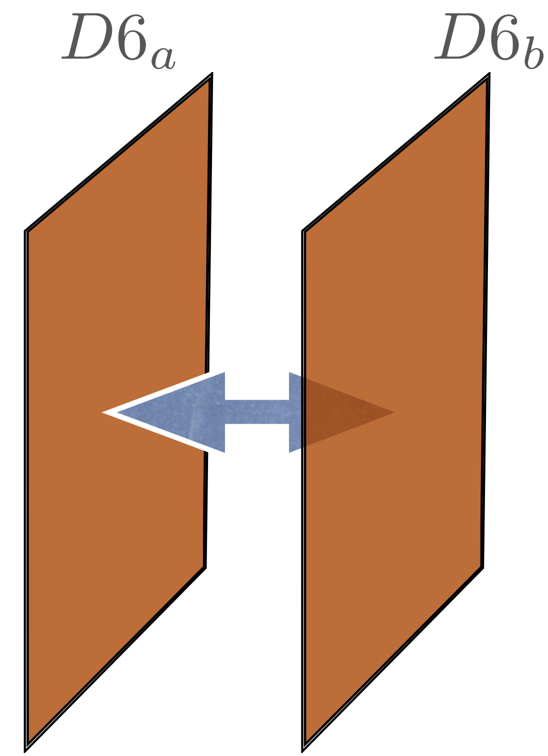
Adjoint Higgsing

$$SU(2) \stackrel{\phi}{\rightarrow} U(1)$$

$$U(1) = \frac{1}{2}[U(1)_a - U(1)_b]$$

mixing depends on the vev of ϕ and some topological conditions

Mixing from DBI



$\pi_a \sim \pi_b \sim \pi$

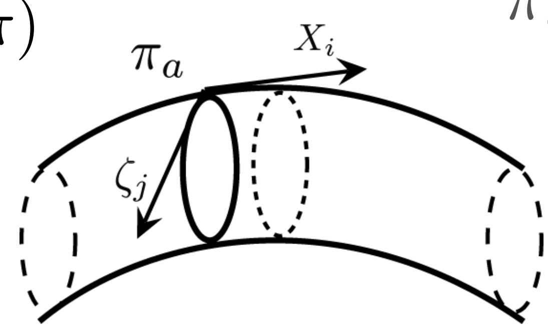
- Type IIA with Higgsed D6-branes
  - Closed string U(1)'s

$$C_3 = A_1^i \wedge \omega_i \qquad \omega_i \in \mathcal{H}_+^{1,1}$$

  - D6-brane moduli

$$\Phi_a = \Phi_a^j \zeta_j \qquad \zeta_j \in \mathcal{H}^1(\pi)$$

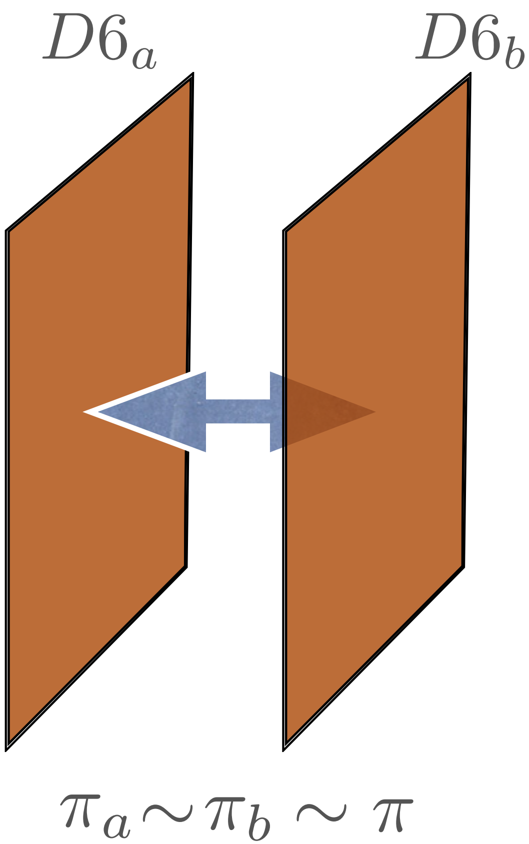
$$\Phi_a^j = \theta_a^j + \lambda_i^j \phi_a^i$$



  - Open-closed mixing

$$f_{i(a-b)} = -\frac{i}{4l_s^3}(\Phi_a^j - \Phi_b^j)\int_\pi \zeta_j \wedge \omega_i$$

Mixing from DBI



- Type IIA with Higgsed D6-branes
  - Open-closed mixing

$$f_{i(a-b)} = -\frac{i}{4l_s^3}(\Phi_a^j - \Phi_b^j)\int_\pi \zeta_j \wedge \omega_i$$

Vanishes whenever

$$\Phi_a^j = \Phi_b^j \to SU(2)$$

or

$$\int_\pi \omega_i \wedge \zeta_j = \int_{\rho_j} \omega_i = 0$$

the 2-cycles ρ_j of π are trivial in ambient space

Mixing from the Witten effect

- DBI dim. reduction only sees D-brane moduli dependence, but typically we aim for models without open string moduli
- More powerful method → use of the Witten effect

Witten '79

Gauge theory that breaks CP → Magnetic monopoles have electric charge

Simplest case: $\theta\, F \wedge F$ → $Q^E = -\frac{\theta}{2\pi}$

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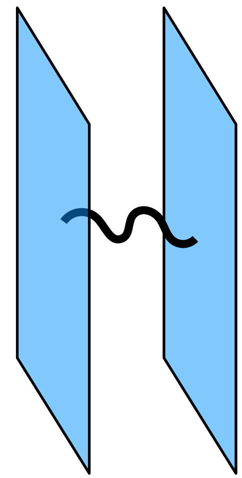
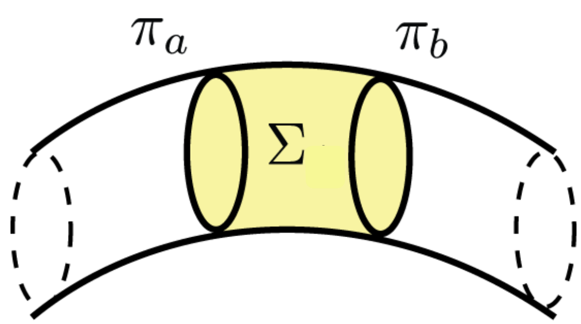
Multiple U(1)'s → $\begin{cases} Q^E_I = n^e_I - \mathrm{Im} f_{IJ}\, n^m_J \\ Q^M_I = n^m_I \end{cases}$

$$S_{4d} \supset -\int_{\mathbb{R}^{1,3}} \mathrm{Re} f_{pq}\, F_p \wedge * F_q + \mathrm{Im} f_{pq}\, F_p \wedge F_q$$

U(1)'s and Monopoles

- Upon adjoint Higgsing SU(2) → U(1) we obtain the following massive states
  - W-bosons (fund. open string)
  - Magnetic monopoles (Dp-brane on p-chain Σ)

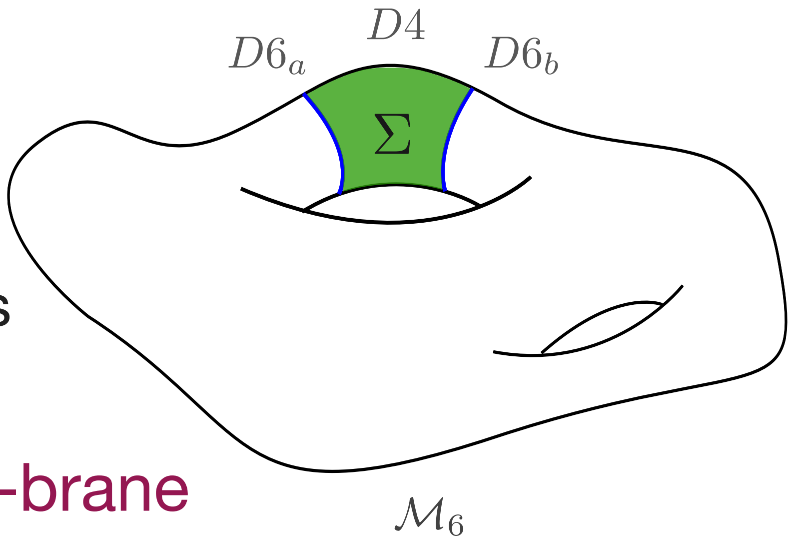




$$\partial\Sigma = \pi_a - \pi_b$$

Monopoles and Mixing

- In our type IIA example these monopoles are D4-branes interpolating between the D6-branes
  - 4-chain Σ interpolates positions
  - Flux F^{D4} on Σ interpolates Wilson lines



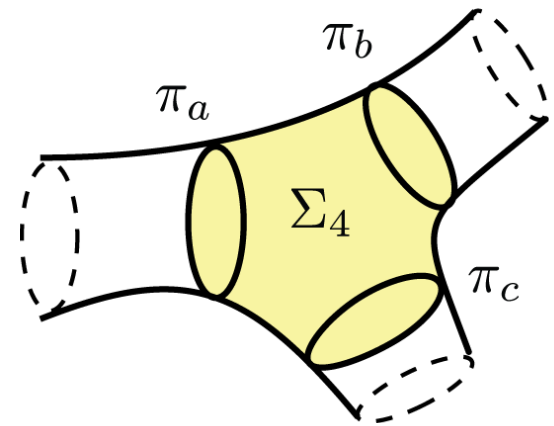
- From dimensional reduction of the D4-brane CS action one can obtain the monopole charges under the closed string U(1), and then obtain the open-closed mixing via the Witten effect

$$f_{i(a-b)} = \frac{1}{2}\int_{\Sigma}(J - i\mathcal{F}^{D4}) \wedge \omega_i$$

Monopoles and Mixing

- This method is general and does not rely on
  - D6-branes having moduli
  - U(1) coming from a Higgsed U(1) [homotopic 3-cycles]
- It can be applied to any open string $U(1)_X$
  - Massless condition

$$\pi_X = \sum_\alpha n_{X\alpha}\pi_\alpha = \partial\Sigma_4 \qquad n_{X\alpha} \in \mathbb{Z}$$



  - Σ_4 is wrapped by the open string monopole

$$f_{iX} = \frac{1}{2}\int_{\Sigma_X} (J - i\mathcal{F}^{D4}) \wedge \omega_i$$

Mixing and M-theory

- The expression

$$f_{iX} = \frac{1}{2}\int_{\Sigma_X} (J - i\mathcal{F}^{D4}) \wedge \omega_i$$

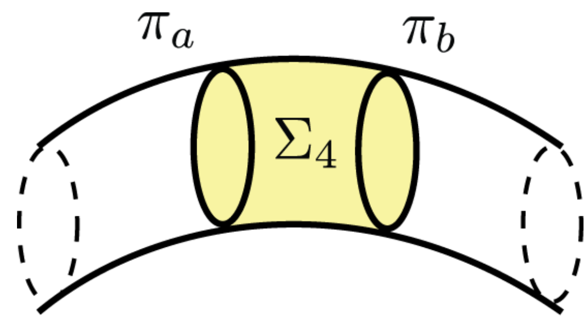
matches previous results motivated by M-theory

Cámara, Ibáñez, F.M. '11

- We can establish the following dictionary:

	U(1)'s	Monopoles
M-theory	$\omega \in \mathcal{H}^{1,1}(\mathcal{M}_7)$	$\Lambda_5 \in H_5(\mathcal{M}_7)$
type IIA	$\omega \in \mathcal{H}^{1,1}_+(\mathcal{M}_6)$ $\pi_X - \pi_X^* = \partial\Sigma_4$	$\pi_4 \in H_4^-(\mathcal{M}_6, \pi_{\mathrm{D6}})$ → $H_4^-(\mathcal{M}_6)$, $\{\Sigma_4\}$ relative homology group

Mixing and Linear Equivalence



- The vanishing kinetic mixing condition

$$\text{Re}\, f_{i(a-b)} = \frac{1}{2}\int_{\Sigma_4} J \wedge \omega_i = 0$$

is similar to asking that the 3-cycles π_a and π_b are linearly equivalent

- Linear equivalence: criterion to compare p-cycles in the same homology class [harmonic forms on (p+1)-chains vanish]

  - Typically used for divisors but can be applied to more general cycles wrapped by BPS D-branes

Hitchin '99

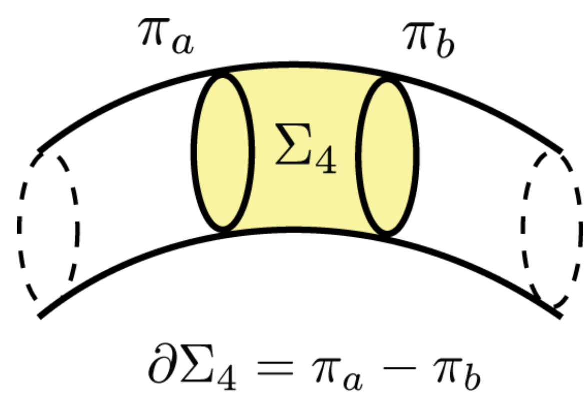
  - Allows to write the kinetic mixing as

$$\text{Re}\, f_{i(a-b)} = \frac{1}{2}\int_{\mathcal{M}_6} J \wedge \omega_i \wedge \varpi_2 \qquad d\varpi_2 = \delta_3(\pi_3^a) - \delta_3(\pi_3^b)$$

Recap of type IIA

- Open-closed U(1) mixing is a holomorphic quantity of the 4d effective theory that can be computed via a chain integral

$$f_{iX} = \frac{1}{2}\int_{\Sigma_X} (J - i\mathcal{F}^{D4}) \wedge \omega_i$$



- The physical meaning of this chain is the internal worldvolume of the open string U(1) monopole

- The mathematical meaning is the measurement of linear equivalence between submanifolds, or generalised version that include D-brane Wilson lines

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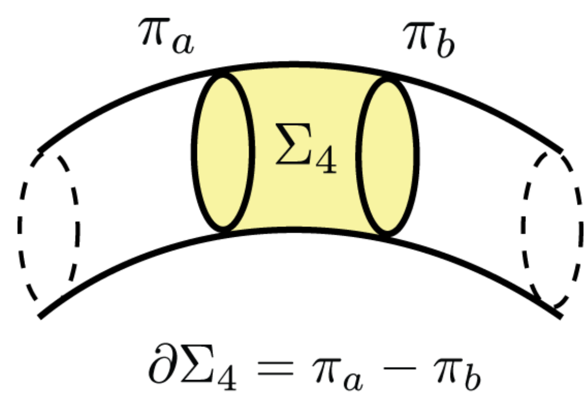


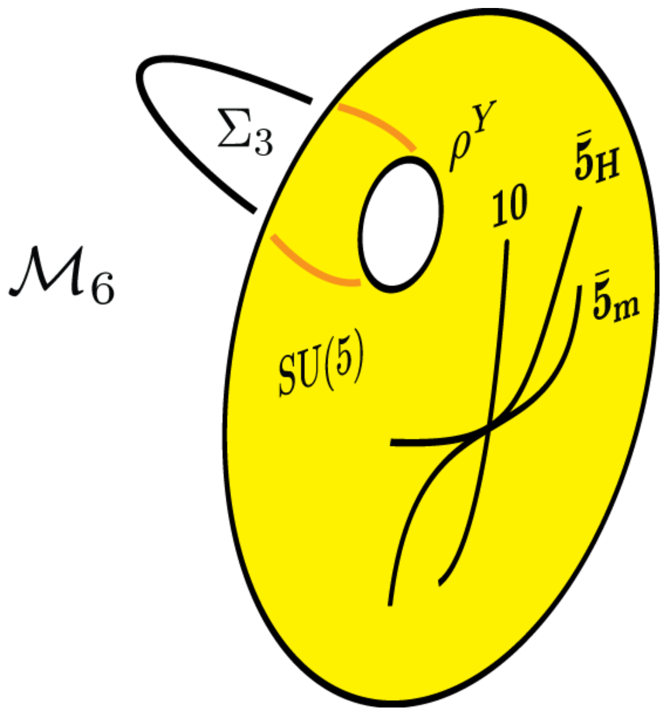
- Another holomorphic quantity computed via a chain integral is the D6-brane superpotential

Martucci '06

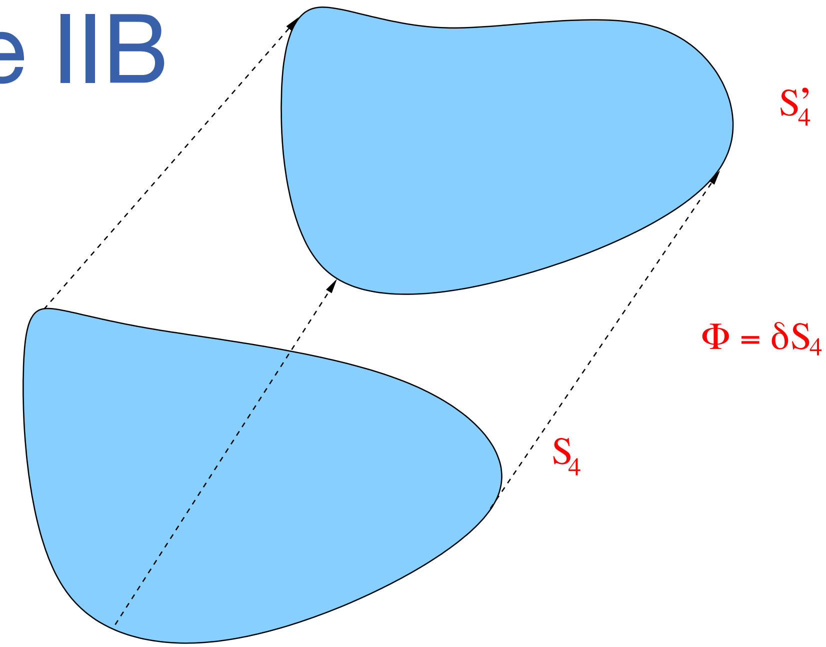
$$W_{\rm D6} \sim \int_{\mathcal{M}_6} (J - i\mathcal{F})^2$$

both quantities related in N=2 (unorientifolded CY geometry)

Mixing in type IIB and F-theory GUTs



Mixing in type IIB



- Type IIB with Higgsed D7-branes

  - Closed string U(1)'s

$$C_4 = A_1^i \wedge \mathrm{Re}\,\gamma_i \qquad \gamma_i \in \mathcal{H}_+^{2,1}$$

  - Two D7-branes in the same homology class of a CY are always linearly equivalent to each other [no harmonic 5-form]

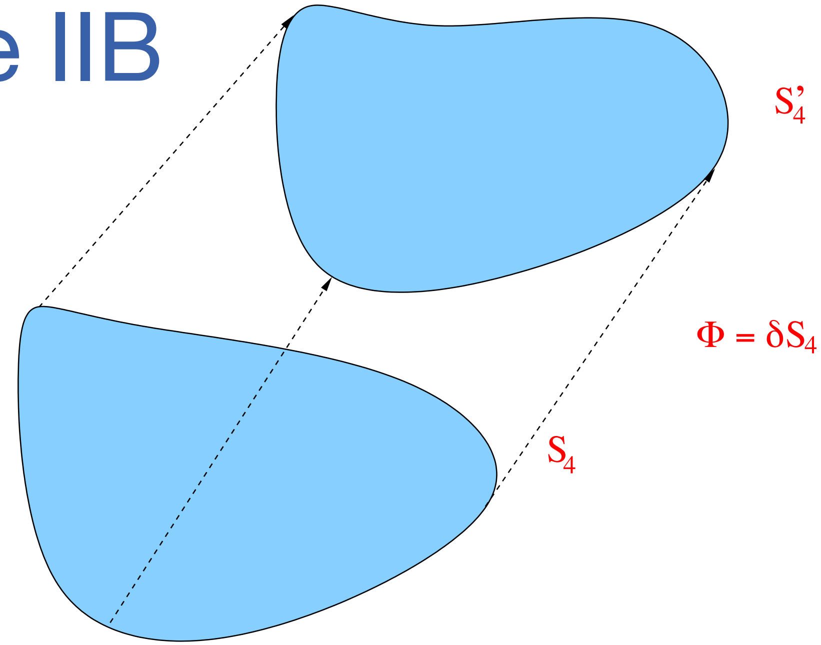
  - However, magnetised D7-branes carry charge of D5-brane, for which linear equivalence is non-trivial

  - Open-closed mixing from DBI analysis with moduli

Jockers & Louis '04

$$f_{i(a-b)} = -\frac{i}{4}(a_a^j - a_b^j)\int_S A_j \wedge \gamma_i - \frac{i}{4}(\Phi_a^m - \Phi_b^m)\int_S \iota_{X_m}\gamma_i \wedge F_2$$

Mixing in type IIB



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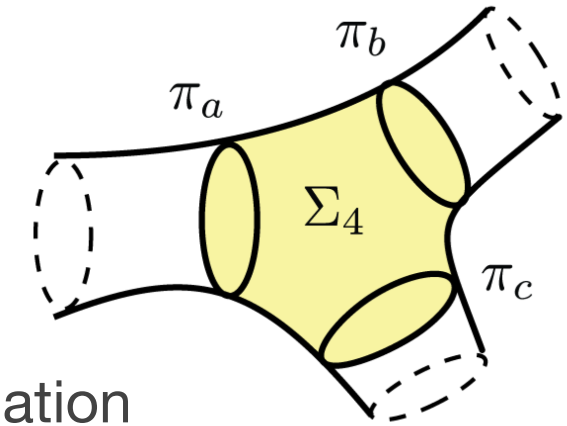
  - However, magnetised D7-branes carry charge of D5-brane, for which linear equivalence is non-trivial
  - Open-closed mixing from Witten effect [D5-brane monopole]

$$f_{i(a-b)} = -\frac{i}{2}\int_\Gamma \gamma_i \wedge \tilde{\mathcal{F}}$$

Mixing in type IIB



- General case
  - Fluxes contribute to the Stückelberg mass. Massless open string U(1) for a linear combination such that all induced D-brane charges also vanish
  - Appropriate framework: generalised homology Monopoles are described by D-brane networks on generalised chains

    Evslin and Martucci ' 07
  - Mixing can still be extracted from the Witten effect on these open string magnetic monopoles

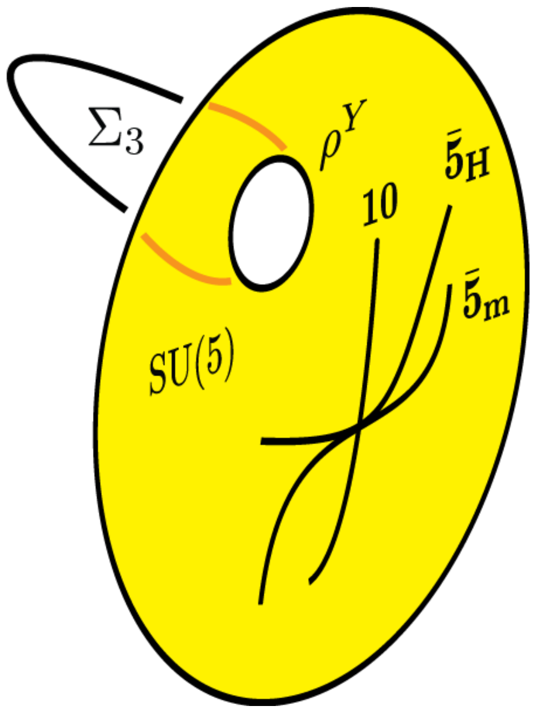
$$f_{iX} = -\frac{i}{2} j_{(\mathfrak{S},\mathfrak{F})_X}(\gamma_i),$$

Hypercharge mixing in F-theory GUTs

- Consider F-theory SU(5) with hypercharge breaking

Buican et al. ' 06
Donagui & Winhkolt '08
Beasley et al. '08

  - Flux F_Y is non-trivial in $H^2(S)$ but trivial in ambient space



Hypercharge mixing in F-theory GUTs

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  - Flux F_Y is non-trivial in $H^2(S)$ but trivial in ambient space
  - Monopole is subtle: genuine D-brane network in a generalised chain

Buican et al. ' 06
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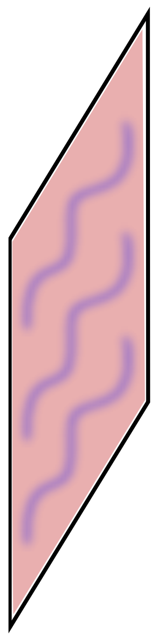
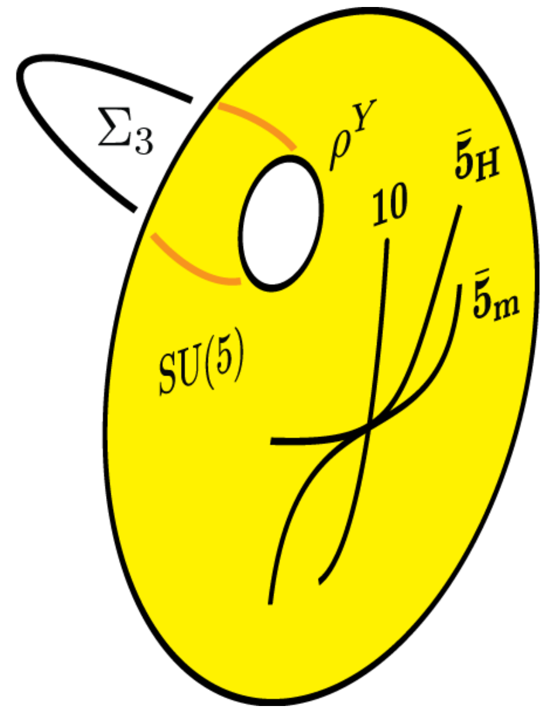


$D7_a$
(S_a, F_a)



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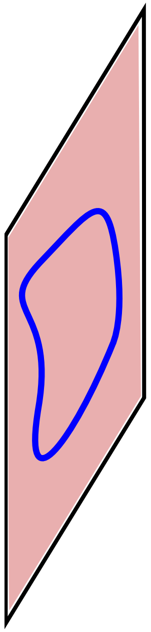
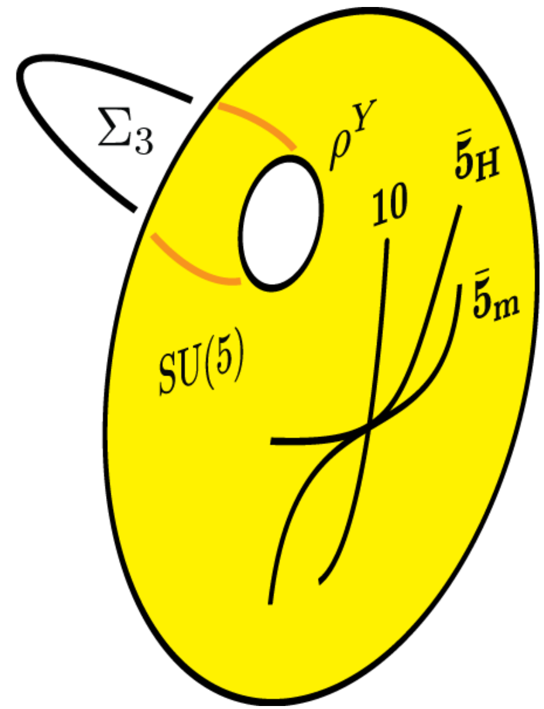


$D7_a + D5_a$

$$f_{iY} = -\frac{i}{2}\int_{S_a} \gamma_i \wedge A_{\Pi_a}$$

$$dA_a = F_a - \delta(\Pi_a)$$



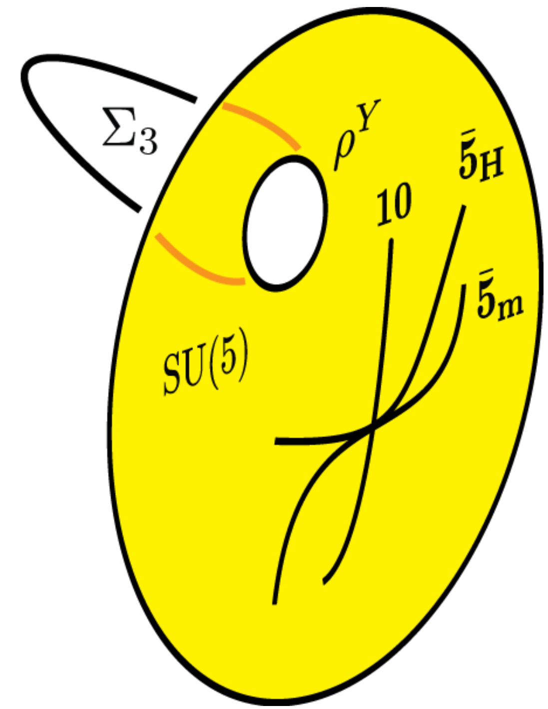
Hypercharge mixing in F-theory GUTs

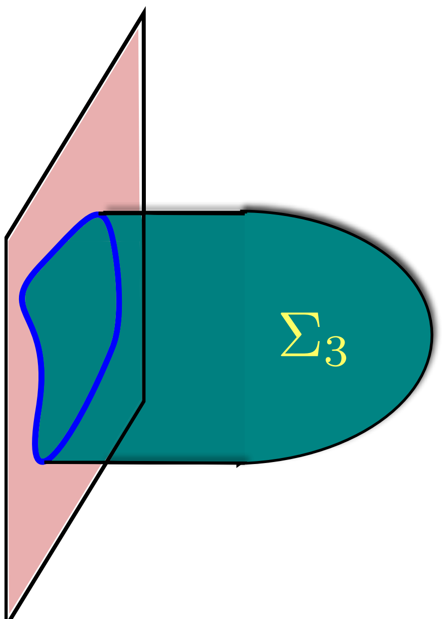
- Consider F-theory SU(5) with hypercharge breaking

Buican et al. ' 06
Donagui & Winhkolt '08
Beasley et al. '08

  - Flux F_Y is non-trivial in $H^2(S)$ but trivial in ambient space

  - Monopole is subtle: genuine D-brane network in a generalised chain





$$f_{iY} = -\frac{i}{2}\left[\int_{S_a} \gamma_i \wedge A_{\Pi_a} + \int_{\Sigma_3} \gamma_i\right]$$

$$dA_a = F_a - \delta(\Pi_a)$$

Conclusions

- Open-closed U(1) kinetic mixing is phenomenologically relevant as a source of millicharged particles and inducing corrections to gauge coupling unification
- In general it can be computed via a chain integral. Physical meaning: U(1) magnetic monopoles and Witten effect
- Mathematical meaning: linear equivalence of submanifolds and generalised version for D-branes (generalised geometry)
- Particularly interesting case: F-theory GUT hypercharge mixing with bulk U(1)'s. Monopole is subtle and so is the expression for the mixing

The String Theory Universe

& 20th European Workshop on String Theory
2nd COST MP1210 Meeting

22–26 September 2014
Philosophicum, JGU Mainz

www.strings2014.uni-mainz.de

The conference is dedicated to all aspects of superstring, supergravity and supersymmetric theories and is embedded in the MITP programme **String Theory and its Applications**.

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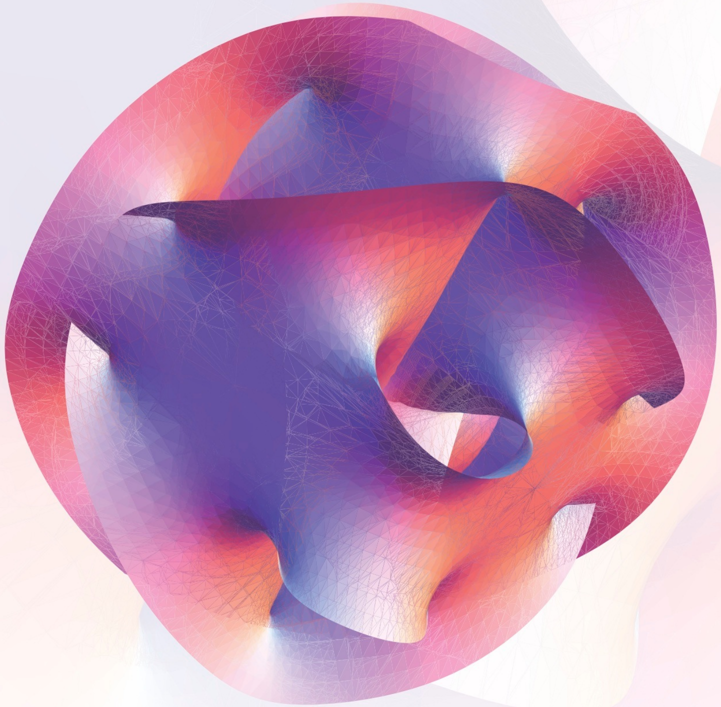

Overview Talks

Paul Chesler | Harvard
Fernando Marchesano | Madrid
Dario Martelli | London
Tadashi Takayanagi | Kyoto
Ivonne Zavala | Groningen

Special Interest Talks

Lutz Köpke | Mainz
IceCube Neutrino Observatory

Ana Achúcarro | Leiden
Strings and the Cosmic Microwave Background

MITP Public Lecture

Dieter Lüst | Munich
Strings im Multiversum
Mainzer Wissenschaftsmarkt
Saturday, 13 September 2014 at 6pm.

Working Groups

Gauge/Gravity Duality
String Phenomenology
Cosmology and Quantum Gravity

mitp Mainz Institute for Theoretical Physics