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Sequestering in models of F-term uplifting

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In collaboration with

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Plan of this talk

I. Introduction

Nonperturbative moduli stabilization & uplifting

II. 5D orbifold model

Dynamically sequestered F-term uplifting

III. Summary

I. Introduction

Nonperturbative moduli stabilization & uplifting

A systematic way for constructing
Minkowski (dS) minimum with low scale ~~SUSY~~
in 4D effective SUGRA

KKLT scenario with $\overline{\text{D3}}$

S : dilaton

T : size moduli $\quad h^{1,1}$

U : shape moduli $\quad h^{2,1}$

KKLT scenario with $\overline{\text{D3}}$

Giddings, Kachru & Polchinski, PRD66 (2002)

$$G_3 = F_3 + S H_3$$

Gukov, Vafa & Witten, NPB584 (2000)

$$W_{flux}(S, U) = \int_{CY} G_3 \wedge \Omega$$

$\langle S \rangle$: ~~dilaton~~

T : size moduli $h^{1,1}$

$\langle U \rangle$: ~~shape moduli~~ $h^{2,1}$

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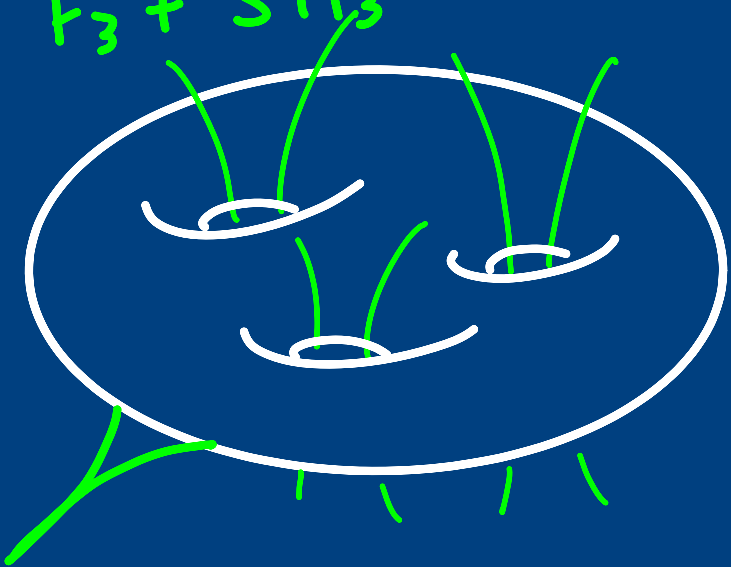

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$\langle S \rangle$: ~~dilaton~~

T : size moduli $h^{1,1}$

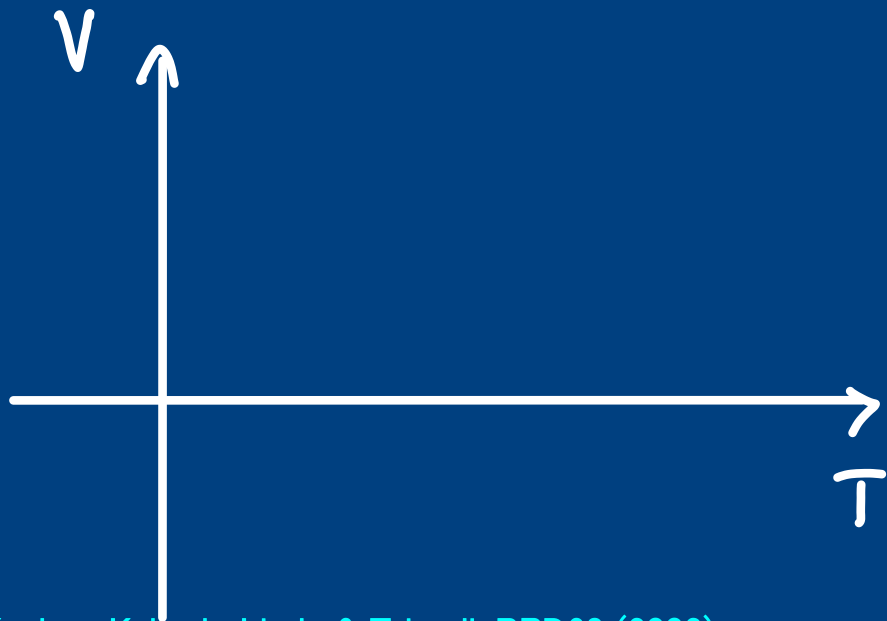
$\langle U \rangle$: ~~shape moduli~~ $h^{2,1}$

$$\begin{cases} K_0 = -3 \ln (T + \bar{T}) \\ W_0 = c \end{cases}$$

$a \sim 4\pi^2$

$c \equiv \langle W_{flux} \rangle$

$M_{Pl} = 1$



Kachru, Kallosh, Linde & Trivedi, PRD68 (2003)

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$$f_{D7} = T$$

$$\begin{cases} K_0 = -3 \ln (T + \bar{T}) \\ W_0 = c - A e^{-aT} \end{cases}$$

$a \sim 4\pi^2$

$c \equiv \langle W_{flux} \rangle$

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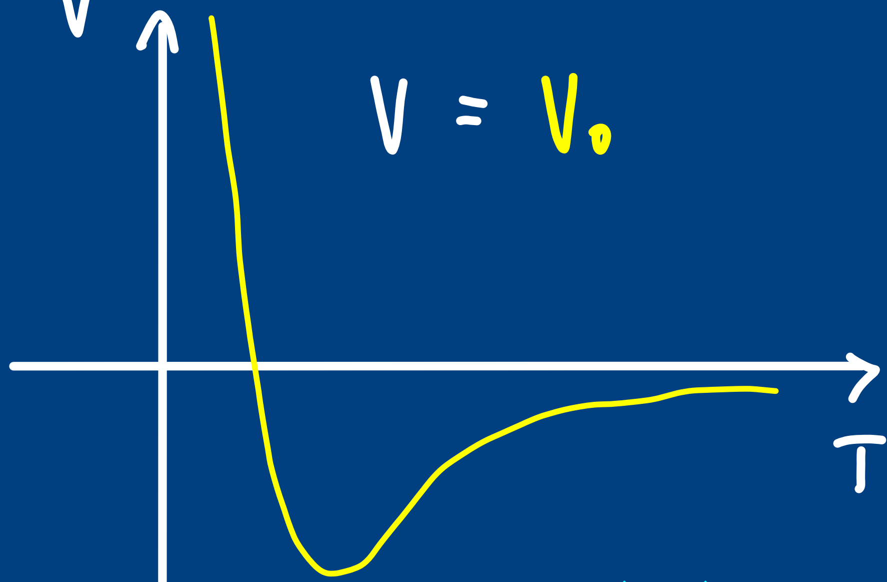

$V = V_0$

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KKLT scenario with $\overline{D3}$

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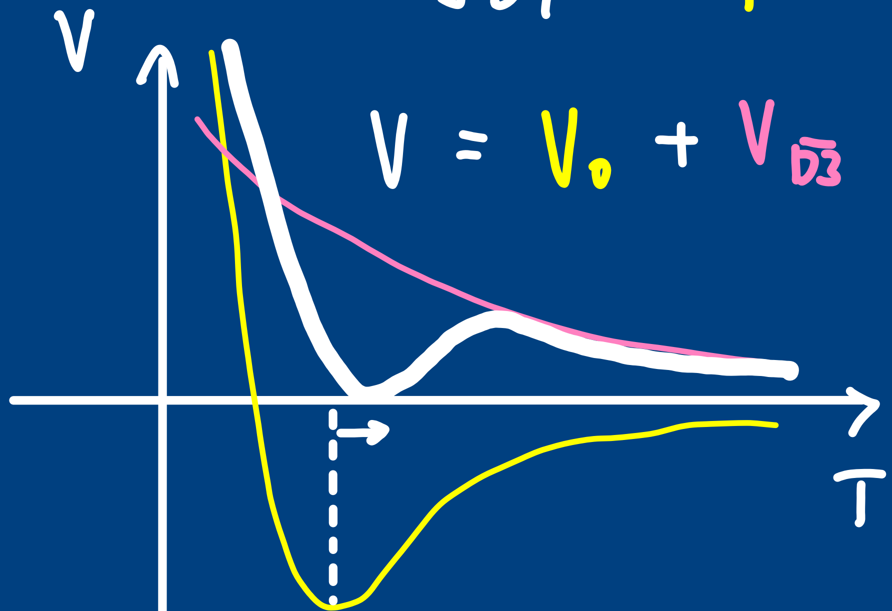

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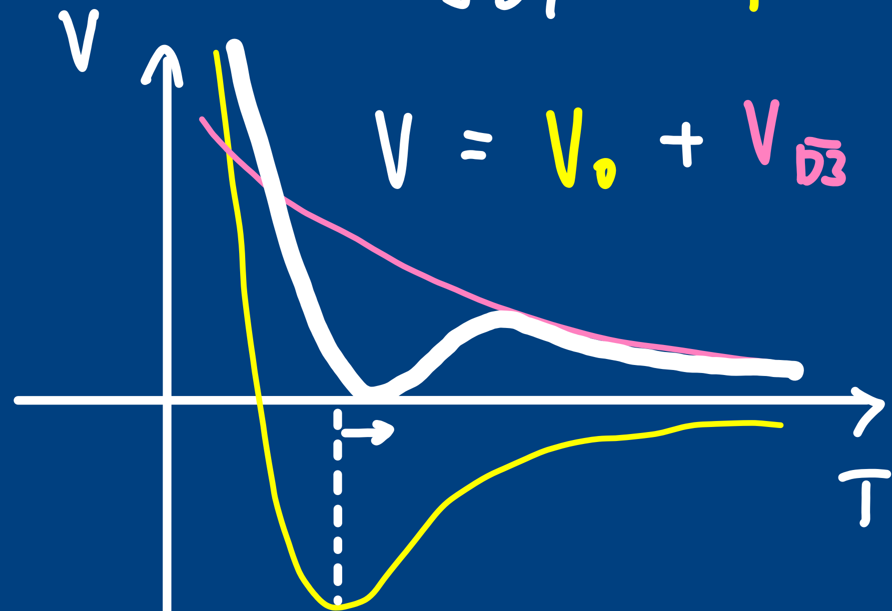

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$$\begin{cases} K_0 = -3 \ln (T + \bar{T}) \\ W_0 = c - A e^{-aT} \end{cases}$$

$a \sim 4\pi^2$

$$m_{3/2} \simeq c \equiv 10^{-14}$$

$c \equiv \langle W_{flux} \rangle$

$M_{Pl} = 1$

$$m_T \simeq a \, m_{3/2}$$

$$F^T \simeq \frac{m_{3/2}}{\ln (M_{Pl}/m_{3/2})} \sim \frac{m_{3/2}}{4\pi^2}$$

Choi, Falkowski, Nilles & Olechowski, NPB718 (2005)

F-term uplifting

Saltman & Silverstein, JHEP0411 (2004)
Lebedev, Nilles & Ratz, PLB636 (2006)
Gomez-Reino & Scrucca, JHEP0605 (2006)
Dudas, Papineau & Pokorski, JHEP0702 (2007),
Higaki, Kobayashi, Omura & H.A., PRD75 (2007), ...

$$V = V_0 + V_{\overline{D3}}$$

Explicit ~~SUSY~~

$$\begin{cases} K_0 = -3 \ln (T + \bar{T}) \\ W_0 = c - A e^{-aT} \end{cases}$$

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Higaki, Kobayashi, Omura & H.A., PRD75 (2007), ...

$$V = V_0 + \cancel{V_{DB}}$$

Explicit ~~SUSY~~ $\longrightarrow$ Dynamical ~~SUSY~~ (DSB)

$$\begin{cases} K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})\,|X|^2 \\ \\ W_0 = c - Ae^{-aT} + f(T)\,X \end{cases}$$

Polonyi

F-term uplifting

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$$V = V_0 + \cancel{V_{D\bar{3}}}$$

Explicit ~~SUSY~~ → Dynamical ~~SUSY~~ (DSB)

$$\begin{cases} K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})\,|X|^2 - \dfrac{1}{4\pi^2 m^2}|X|^4 \quad \leftarrow \text{integrate} \\ W_0 = c - Ae^{-aT} + f(T)\,X + \begin{pmatrix}\text{heavy modes} \\ \text{with mass } m\end{pmatrix} \end{cases}$$

Polonyi, O'R, ISS, ...

F-term uplifting

Saltman & Silverstein, JHEP0411 (2004)
Lebedev, Nilles & Ratz, PLB636 (2006)
Gomez-Reino & Scrucca, JHEP0605 (2006)
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Higaki, Kobayashi, Omura & H.A., PRD75 (2007), ...

$$V = V_0 + \cancel{V_{\overline{D3}}}$$

Explicit ~~SUSY~~ $\longrightarrow$ Dynamical ~~SUSY~~ (DSB)

$$\begin{cases} K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})|X|^2 \\ \qquad - \dfrac{1}{4\pi^2 m^2}|X|^4 \\ W_0 = c - Ae^{-aT} + f(T)X + \begin{pmatrix}\text{heavy modes} \\ \text{with mass } m\end{pmatrix} \end{cases}$$

integrate

Polonyi, O'R, ISS, ...

For $\partial_T^n f \ll 1$, $\langle X\rangle \sim m^2 \ll 1$, $F^X \sim f \approx c \sim m_{3/2}$ $M_{Pl}=1$

$$\boxed{\begin{array}{c}\text{DSB sector } X \text{ can play a role of } \overline{D3} \text{ in KKLT} \\ V_{min} \sim -|V_{moduli}| + |V_{DSB}| \approx 0\end{array}}$$

Issues of flavor in models of F-term uplifting

F-term uplifting provides a systematic way for constructing realistic vacua i.e. Minkowski (dS) min. with low scale ~~SUSY~~

Next task Concrete realization of

$\boxed{\text{Visible (MSSM) sector}}$

$\boxed{\text{Hidden (DSB) sector}}$

Issues of flavor in models of F-term uplifting

F-term uplifting provides a systematic way for constructing realistic vacua i.e. Minkowski (dS) min. with low scale ~~SUSY~~

Next task Concrete realization of

$\boxed{\text{Visible (MSSM) sector}}$ (Matter content
Gauge, Yukawa couplings
Soft ~~SUSY~~ terms, ...

$F^X, F^T \neq 0$

$\boxed{\text{Hidden (DSB) sector}}$ Polonyi, O'R, ISS, ...

Issues of flavor in models of F-term uplifting

F-term uplifting provides a systematic way for constructing realistic vacua i.e. Minkowski (dS) min. with low scale SUSY

<u>Next task</u> Concrete realization of

Visible (MSSM) sector

(Matter content
Gauge, Yukawa couplings
Soft SUSY terms, ...

Sequestering (to avoid SUSY flavor problem)

$F^X, F^T \neq 0$

Hidden (DSB) sector

Polonyi, O'R, ISS, ...

→ Simplified model with SUSY, extra dim. ...

II. 5D orbifold model

Dynamically sequestered F-term uplifting

F-term uplifting in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2

$X = $ (DSB sector)

$Q^I = \begin{pmatrix} Q^i, U^i, D^i, \\ L^i, E^i, H_u, H_d \end{pmatrix}$

$\Big\}$ Bulk hyper $\mathcal{H}^I = (H^I, \cancel{H_c^I})$

F-term uplifting in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2

$X = (\text{DSB sector})$

$Q^I = \left(Q^i, U^i, D^i, L^i, E^i, H_u, H_d\right)$

} Bulk hyper $\mathcal{H}^I = (H^I, \cancel{H_c^I})$

$$K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})|X|^2 + Z_{I\bar{I}}(T,\bar{T},|X|^2)|Q^I|^2 + \cdots$$

$$W_0 = c - Ae^{-aT} + fX + \lambda_{IJK}Q^IQ^JQ^K + \cdots$$

F-term uplifting in 5D orbifold model

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Bulk hyper $\mathcal{H}^I = (H^I, \cancel{H^I_c})$

$$K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})|X|^2 + Z_{I\bar{I}}(T,\bar{T},|X|^2)|Q^I|^2 + \cdots$$

superpotential at fixed points

$$W_0 = \underbrace{c - Ae^{-aT}}_{} + fX + \lambda_{IJK} Q^I Q^J Q^K + \cdots$$

NP effects from $\left(\begin{array}{l} \text{fixed points} \\ \text{bulk} \end{array} \right.$

Luty & Sundrum, PRD62 (2000), PRD64 (2001), PRD65(2002), PRD67 (2003)

F-term uplifting in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2

$$\left.\begin{array}{l} X = (\text{DSB sector}) \\ Q^I = \begin{pmatrix} Q^i, U^i, D^i, \\ L^i, E^i, H_u, H_d \end{pmatrix} \end{array}\right\} \text{Bulk hyper } \mathcal{H}^I = (H^I, \cancel{H_c^I})$$

superpotential at fixed points

$$K_0 = -3\ln(T+\bar{T}) + Z_{X\bar{X}}(T,\bar{T})\,|X|^2 + Z_{I\bar{I}}(T,\bar{T},|X|^2)\,|Q^I|^2 + \cdots$$

Calculable !

$$W_0 = c - Ae^{-aT} + fX + \lambda_{IJK}Q^IQ^JQ^K + \cdots$$

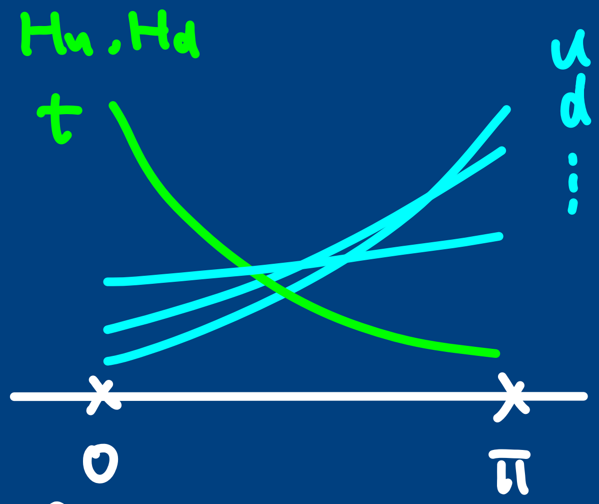
NP effects from (fixed points
bulk

Luty & Sundrum, PRD62 (2000), PRD64 (2001), PRD65(2002), PRD67 (2003)

Yukawa hierarchy in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2

Gherghetta & Pomarol, NPB586 (2000)



$\uparrow$

$\lambda_{IJK} \simeq 1 \quad ({}^\forall I, J, K)$

$$\mathcal{H}^I \sim e^{-c_I y} Q^I + \cdots \qquad \text{E.O.M}$$

$c_I \sim$ U(1) charge for graviphoton

$$Z_{I\bar{J}} = e^{\frac{1}{3}K_0} \frac{1 - |e^{-c_I T}|^2}{c_I} \delta_{I\bar{J}}$$

$$\to T + \bar{T} \quad (c_I \to 0)$$

$$y_{IJK} \sim \lambda_{IJK} \left(e^{K_0} Z_{I\bar{I}} Z_{J\bar{J}} Z_{K\bar{K}} \right)^{\frac{1}{2}}$$

Yukawa hierarchy in 5D orbifold model

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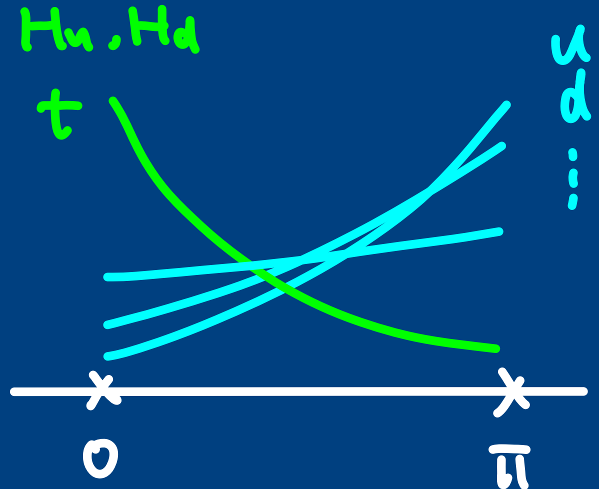


$$Z_{I\bar{J}} = e^{\frac{1}{3}K_0} \frac{1 - |e^{-c_I T}|^2}{c_I} \delta_{I\bar{J}}$$

$$\rightarrow T + \bar{T} \quad (c_I \rightarrow 0)$$

$\lambda_{IJK} \simeq 1 \quad (\forall I, J, K)$

$$y_{IJK} \sim \lambda_{IJK} \left(e^{K_0} Z_{I\bar{I}} Z_{J\bar{J}} Z_{K\bar{K}} \right)^{\frac{1}{2}}$$

$c_q \sim (-3, -2, 2)$

$c_u \sim (-5, -2, 2)$

$c_d \sim (-3, -3, -2)$

$c_{H_u} = c_{H_d} \sim 2$

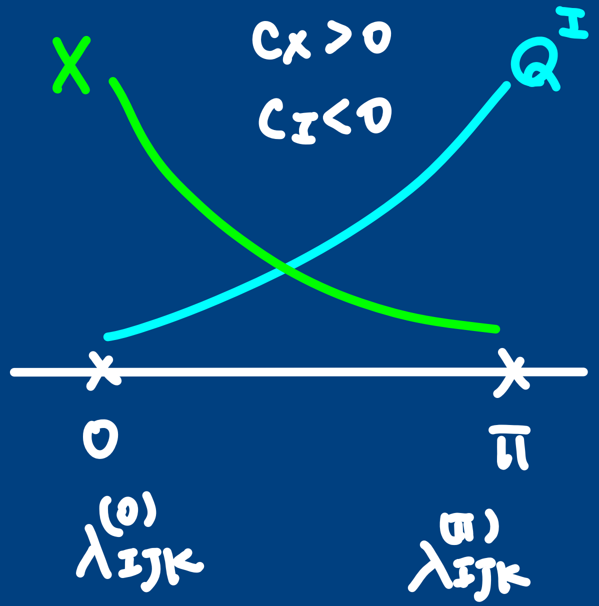
$$y_u \sim \begin{pmatrix} \varepsilon^8 & \varepsilon^5 & \varepsilon^3 \\ \varepsilon^7 & \varepsilon^4 & \varepsilon^2 \\ \varepsilon^5 & \varepsilon^2 & 1 \end{pmatrix}, \quad y_d \sim \begin{pmatrix} \varepsilon^6 & \varepsilon^6 & \varepsilon^5 \\ \varepsilon^5 & \varepsilon^5 & \varepsilon^4 \\ \varepsilon^3 & \varepsilon^3 & \varepsilon^2 \end{pmatrix}$$

Choi, Kim, Kim & Kobayashi, EPJC35 (2004)

Dynamical sequestering in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2

Higaki, Kobayashi, Omura & H.A., JHEP0804 (2008)



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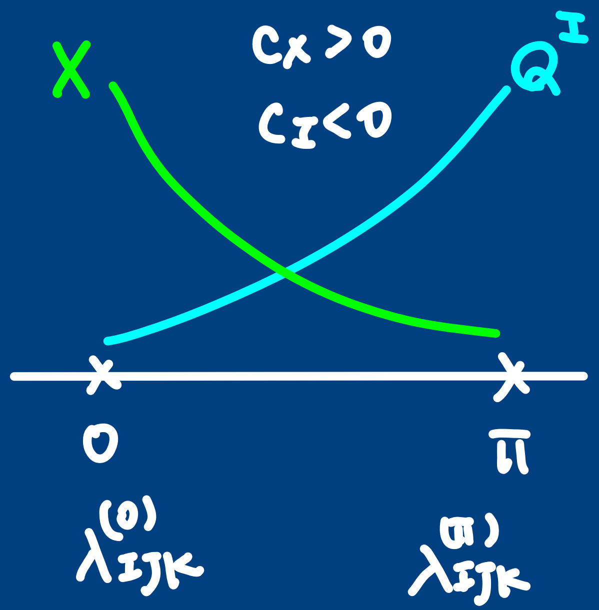

Higher order terms in K can be derived by off-shell dimensional reduction

Sakamura & H.A., PRD75 (2007)

$$Z_{I\bar{J}} = e^{\frac{1}{3}K_0}\,\frac{1-\left|e^{-c_I T}\right|^2}{c_I}\,\delta_{I\bar{J}} + \frac{1}{3}\,e^{\frac{1}{3}K_0}\,\frac{1-\left|e^{-(c_I+c_X)T}\right|^2}{c_I+c_X}\,|X|^2\,\delta_{I\bar{J}}$$

Dynamical sequestering in 5D orbifold model

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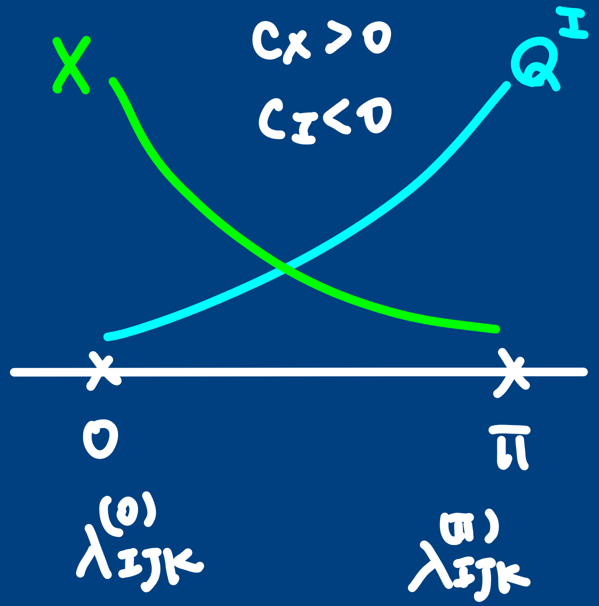

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Sakamura & H.A., PRD75 (2007)

$$m_I^2 \simeq \frac{c_I^2}{1-\epsilon_I^2}\left(\frac{\epsilon_I^2}{1-\epsilon_I^2}|F^T|^2 - \frac{1}{3}\,\frac{\epsilon_I^2-\epsilon_X^2}{c_I(c_X-c_I)}|F^X|^2 \right)$$

$\boxed{\text{Scalar mass}}$

$$\epsilon_I = e^{-|c_I|T}$$

$$\epsilon_X = e^{-c_X T}$$

Dynamical sequestering in 5D orbifold model

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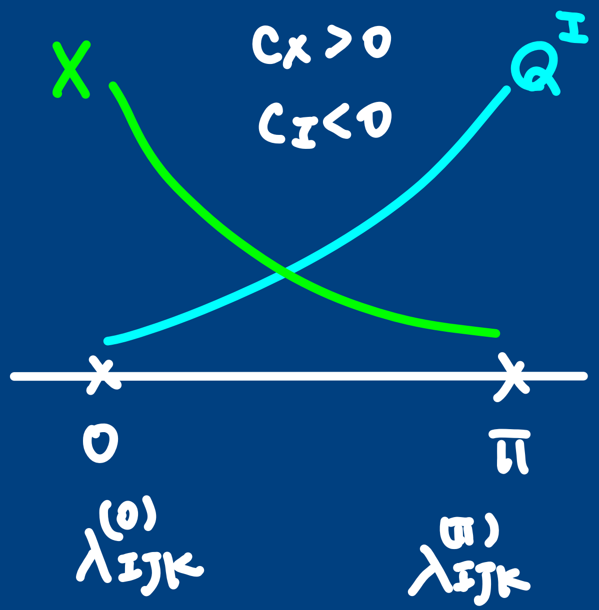

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Same factor

$$m_I^2 \simeq \frac{c_I^2}{1-\epsilon_I^2}\left(\frac{\epsilon_I^2}{1-\epsilon_I^2}|F^T|^2 - \frac{1}{3}\frac{\epsilon_I^2-\epsilon_X^2}{c_I(c_X-c_I)}|F^X|^2\right)$$

Negative

$\boxed{\text{Scalar mass}}$

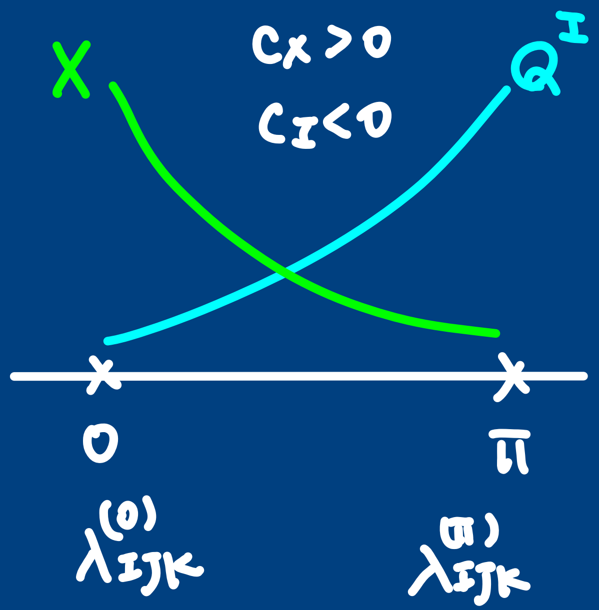
$\epsilon_I = e^{-|c_I|T}$

$\epsilon_X = e^{-c_X T}$

- ☆ Modulus mediation ≤ direct mediation.
- ☆ Direct mediation yields tachyonic contribution.
- ☆ $\epsilon_I^2,\ \epsilon_X \ll \frac{1}{4\pi^2}$ ⟶ Anomaly mediation

Dynamical sequestering in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2 Higaki, Kobayashi, Omura & H.A., JHEP0804 (2008)



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Sakamura & H.A., PRD75 (2007)

$\boxed{\text{A-term}}$

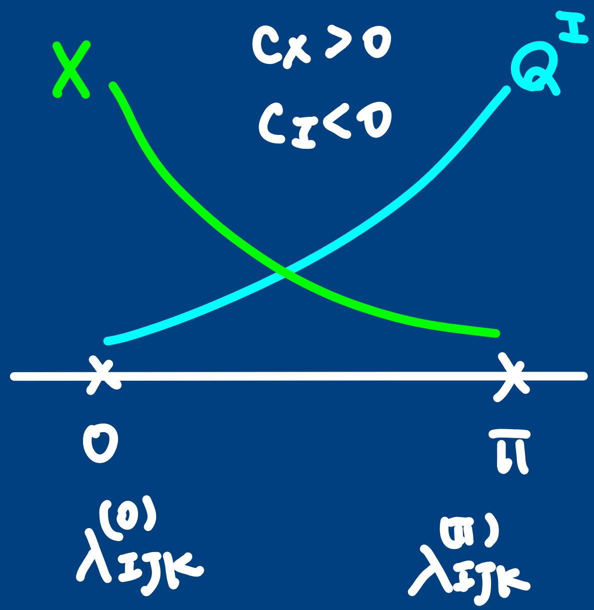
$$\epsilon_I = e^{-|c_I|T}$$

$$\epsilon_X = e^{-c_X T}$$

$$A_{IJK} \simeq -\left\{ \left(\frac{c_I}{1-\epsilon_I^2} + (I \leftrightarrow J) + (I \leftrightarrow K) \right) - \frac{(c_I + c_J + c_K)\,\lambda^{(\pi)}_{IJK}}{\lambda^{(0)}_{IJK}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK}} \right\} F^T + \frac{\lambda^{(0)}_{IJK,X}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK,X}\epsilon_X}{\lambda^{(0)}_{IJK}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK}} F^X$$

Dynamical sequestering in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2 Higaki, Kobayashi, Omura & H.A., JHEP0804 (2008)



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Sakamura & H.A., PRD75 (2007)

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$$+ \frac{\lambda^{(0)}_{IJK,X}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK,X}\epsilon_X}{\lambda^{(0)}_{IJK}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK}} F^X$$

$\lambda^{(\pi)}_{IJK} \neq 0$ ϵ_I^2 ←

A-term

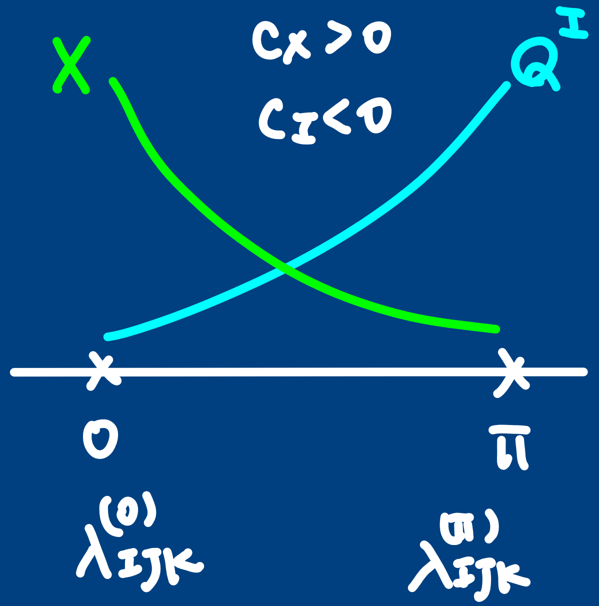
$$\epsilon_I = e^{-|c_I|T}$$

$$\epsilon_X = e^{-c_X T}$$

☆ $\epsilon_I^2,\ \epsilon_X \ll \frac{1}{4\pi^2} \xrightarrow{\lambda^{(\pi)}_{IJK} \neq 0}$ Anomaly mediation

Dynamical sequestering in 5D orbifold model

Ex. 5D SUGRA on S^1/Z_2 Higaki, Kobayashi, Omura & H.A., JHEP0804 (2008)



Higher order terms in K can be derived by off-shell dimensional reduction

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$$A_{IJK} \simeq -\left\{ \left(\frac{c_I}{1-\epsilon_I^2} + (I \leftrightarrow J) + (I \leftrightarrow K) \right) - \frac{(c_I + c_J + c_K)\,\lambda^{(\pi)}_{IJK}}{\lambda^{(0)}_{IJK}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK}} \right\} F^T$$

$\lambda^{(\pi)}_{IJK} \neq 0$ $\quad \epsilon_I^2$

$\lambda^{(\pi)}_{IJK} = 0$ $\quad c_I + c_J + c_K$

$$+ \frac{\lambda^{(0)}_{IJK,X}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK,X}\epsilon_X}{\lambda^{(0)}_{IJK}\epsilon_I\epsilon_J\epsilon_K + \lambda^{(\pi)}_{IJK}} F^X$$

$\boxed{\text{A-term}}$

$$\epsilon_I = e^{-|c_I|T}$$

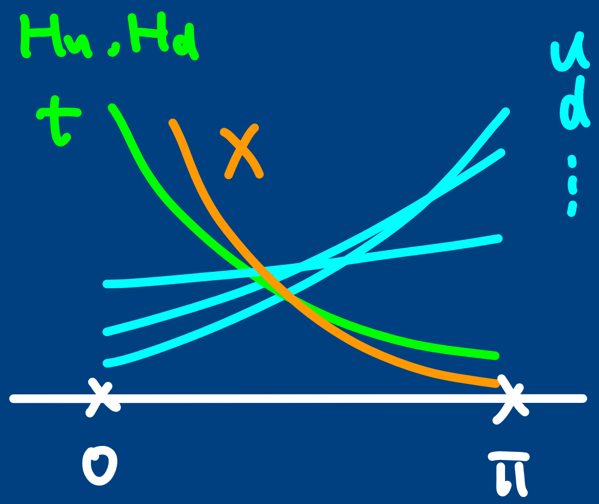
$$\epsilon_X = e^{-c_X T}$$

★ $\epsilon_I^2,\ \epsilon_X \ll \dfrac{1}{4\pi^2}$

$\xrightarrow{\lambda^{(\pi)}_{IJK} \neq 0}$ Anomaly mediation

$\xrightarrow{\lambda^{(\pi)}_{IJK},\ \lambda^{(0,\pi)}_{IJK,X} = 0}$ Modulus mediation

Yukawa hierarchy v.s. sequestering in 5D

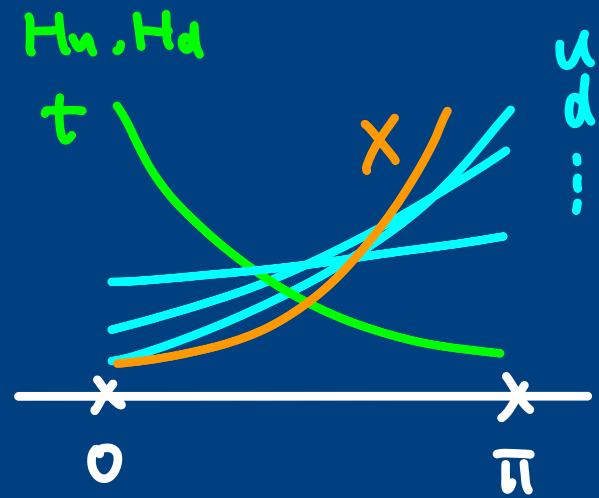


$$|m^2_{\tilde{t}, H_u H_d}| \gg |M_a^2| \geq |m^2_{\rm others}|$$

at M_{GUT}

$g_Y \lessgtr 0$ sfermions become tachyonic by RGE at M_Z.

or



For $I = u, d, \cdots$

$$|m_I^2| \gg |M_a^2|$$

$m_I^2 < 0$ at M_{GUT}

$\rightarrow$ 〃 at M_Z

Either Yukawa hierarchy or sequestering by wavefunc. localization $\longrightarrow$

- Multi moduli (Y. Sakamura's talk)
- 6D SUGRA

Ⅲ. Summary

Sequestering in models of F-term uplifting

F-term uplifting provides a systematic way for constructing realistic vacua i.e. ~~SUSY~~ Minkowski (dS) min.

<u>Flavor issues</u>

☆ Some implications from a simple 5D model.

- Dynamical sequestering by wave func. localization
- Either Yukawa hierarchy or sequestering

  Fixed point dynamics, more than single ED (modulus)?

☆ Still challenging issue in supergravity/string models

- Extension to magnetized D-brane models

Cremades, Ibanez & Marchesano, JHEP0405 (2004)

END