

# Non-perturbative interactions from fluxes

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# Motivations

- Semirealistic string models:

- ✓ N=1 string compactification:  
(chiral matter from brane intersections)

- ✓ Moduli stabilization:  
(Fluxes and D-brane instantons)

- ✓ SUSY breaking: F-terms, fluxes, hidden sectors, etc.

- D-brane instantons + fluxes

(Blumenhagen, Cvetic, Weigand, Ibanez, Uranga)

- ✓ New chiral couplings:

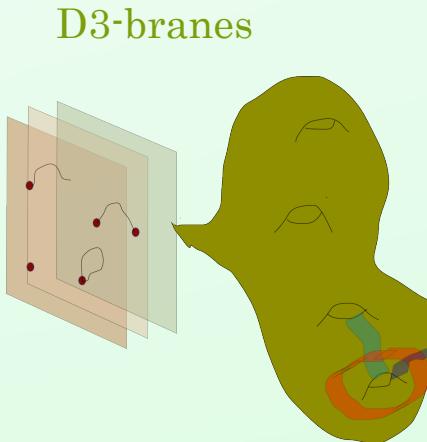
Majorana masses, Yukawa couplings, etc

$$e^{-\frac{8\pi^2 k V_p}{g^2}} + 2\pi i k \theta_p$$

new scales

- ✓ Flux induced couplings:  $W_{\text{inst}}(G_3, T, \tau)$

?



$$R^{1,3} \times CY$$

# Outline

- **The model:** D3-branes on  $\mathbb{C}^3/\mathbb{Z}_2 \times \mathbb{Z}_2$  + 3-form fluxes
- ✓ **SQCD:** gauge group  $U(N_c) + N_f$  flavours
- **D(-1)-instantons:** gauge vs stringy instantons:
  - ✓ Instanton moduli space: D3D(-1) open strings
  - ✓ Instanton action RR/NSNS: Open/closed string amplitudes
- **Non-perturbative potentials:** gauge & stringy instantons:
  - ✓ F-terms: gauge and exotic superpotentials, BW mult fermionic couplings  
(Garcia-Etxebarria, Marchesano, Uranga)
- **Conclusions:**

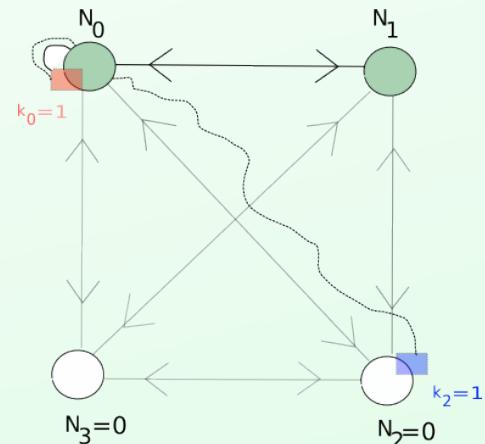
# D3-branes on $\mathbb{C}^3/\mathbb{Z}_2 \times \mathbb{Z}_2$

- D3-brane gauge theory :

✓ Gauge group:  $U(N_0) \times U(N_1)$        $V = \begin{pmatrix} V_0 & 0 \\ 0 & V_1 \end{pmatrix}$

✓ Matter:  $N_0 \bar{N}_1 + \bar{N}_0 N_1$        $\Phi = \begin{pmatrix} 0 & Q \\ \tilde{Q} & 0 \end{pmatrix}$

⇒ SQCD:  $N_c = N_0$      $N_f = N_1$



- D(-1) instantons :

✓ gauge instantons:  $k_0 = 1$        $e^{-\frac{8\pi^2 k}{g^2} + 2\pi i k \theta}$

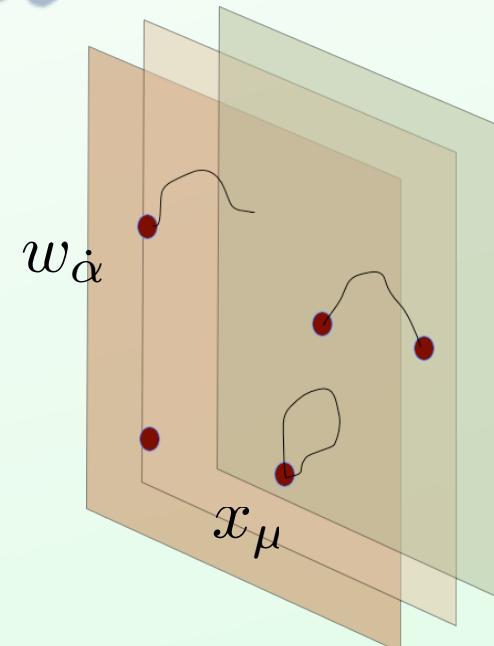
✓ stringy instantons:  $k_2 = 1$        $e^{-\frac{8\pi^2 k V_p}{g^2} + 2\pi i k \theta_p}$

# Instanton moduli space

- D3D(-1) on flat space:

$$\begin{array}{ccc}
 \text{open string modes} & \longleftrightarrow & \text{Instanton moduli:} \\
 \text{D(-1)D(-1)} & (x_\mu, \chi_a, D^c, \theta_\alpha^A, \lambda_{\dot{\alpha}} A)_{ij} & \text{positions} \\
 \text{D(-1)D3} & (w_{\dot{\alpha}}, \mu^A)_{iu} & \text{sizes,gauge orientations}
 \end{array}$$

$$\mu = 1,..4 \quad \alpha, \dot{\alpha} = 1, 2 \quad A = 0,..3 \quad c = 1,..3 \quad i = 1,..k \quad u = 1,..N$$



- on  $\mathbb{C}^3/\mathbb{Z}_2 \times \mathbb{Z}_2$

✓ gauge instantons:  $k_0 = 1$   $(x_\mu, D^c, \theta_\alpha^0, \lambda_{\dot{\alpha}0} || w_{\dot{\alpha}u_0}, \mu_{u_0}^0, \mu_{u_1}^1)$

✓ stringy instantons:  $k_2 = 1$   $(x_\mu, D^c, \theta_\alpha^0, \lambda_{\dot{\alpha}0} || \mu_{u_0}^2, \mu_{u_1}^3)$

Only fermions from D3-D(-1) open string modes !

# Instanton action

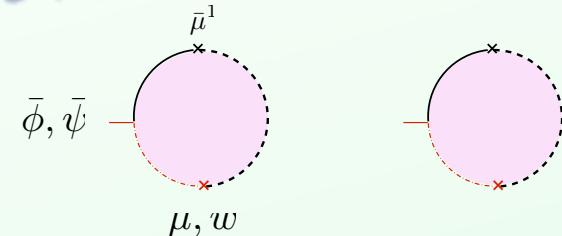
- D(-1)D3-action:

✓ gauge instantons:  $k_0 = 1$

$$S_{\text{D}3/\text{D}(-1)}(\Phi, \bar{\Phi}) = \frac{2\pi^3 \alpha'^2}{g_s} D_c D^c + i D_c (\bar{w}_{\dot{\alpha}} (\tau^c)^{\dot{\alpha}}_{\dot{\beta}} w^{\dot{\beta}}) + i \lambda_{\dot{\alpha}} (\bar{\mu} w^{\dot{\alpha}} + \bar{w}^{\dot{\alpha}} \mu)$$

$$+ \frac{1}{2} \bar{w}_{\dot{\alpha}} (\Phi \bar{\Phi} + \bar{\Phi} \Phi) w^{\dot{\alpha}} + \frac{i}{2} \bar{\mu}^1 \bar{\Phi} \mu - \frac{i}{2} \bar{\mu} \bar{\Phi} \mu^1$$

$$+ i \bar{w}_{\dot{\alpha}} (\bar{D}^{\dot{\alpha}} \bar{\Phi}) \mu^1 - i \bar{\mu}^1 (\bar{D}_{\dot{\alpha}} \bar{\Phi}) w^{\dot{\alpha}} .$$



$$\begin{aligned}\Phi &= \phi(x) + \sqrt{2}\theta\psi(x) + \dots \\ \bar{\Phi} &= \bar{\phi}(x) + \sqrt{2}\bar{\theta}\bar{\psi}(x) + \dots\end{aligned}$$

✓ stringy instantons:  $k_2 = 1$

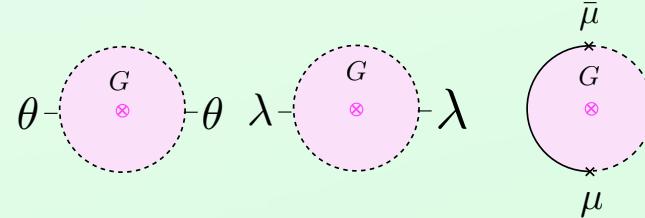
$$\boxed{\bar{\theta}_{\dot{\alpha}} = \frac{\pi}{\sqrt{2}} \alpha' \lambda_{\dot{\alpha}} \approx 0}$$

$$S_{\text{D}3/\text{D}(-1)}(\Phi) = \frac{2\pi^3 \alpha'^2}{g_s} D_c D^c - \frac{i}{2} (\bar{\mu}^3 \Phi \mu^2 - \bar{\mu}^2 \Phi \mu^3) .$$

✓ flux couplings:

$$\begin{cases} \bar{G} = 2e^\phi G_{(0,3)} \sim W_{\text{flux}} \\ G = 2e^\phi G_{(3,0)} \sim (D_\tau W_{\text{flux}})^* \end{cases}$$

$$S^{\text{flux}} = \frac{2\pi i}{g_s} \left[ G \theta^\alpha \theta_\alpha - \frac{(\pi \alpha')^2}{2} \bar{G} \lambda_{\dot{\alpha}} \lambda^{\dot{\alpha}} \right] + \frac{i}{2} G \bar{\mu} \mu ,$$



# Instanton integral

- Effective interactions:

$$S_{\text{eff}} = M_s^{k_A \beta_A} e^{2\pi i k_A \tau_A} \int d\mathfrak{M} e^{-S_{D3D(-1)} - S_{\text{flux}}}$$

✓ F-terms:

$$S_{\text{eff}} = \int d^4x d^2\theta W_{\text{inst}}(x, \theta)$$

- General form:

$$W_{\text{inst}}(x, \theta) = \Phi^m \bar{\Phi}^n (\bar{D}_{\dot{\alpha}} \bar{\Phi} \bar{D}^{\dot{\alpha}} \bar{\Phi})^p \Big|_{\bar{\theta}=0} \quad \left\{ \begin{array}{l} \bullet \quad n=p=0 \text{ Affleck, Dine, Seiberg superpotential} \\ \bullet \quad p=-n \text{ Beasley-Witten multifermions} \end{array} \right.$$

- $U(1)^3 \in SO(6)$  R-symmetries :  $Q(d\mathfrak{M}) = Q(S_{\text{eff}})$

→ determines m,n,p

!

# Effective interactions

- ADS, BW F-terms:

$$W_{\text{inst}} = \mathcal{C} \Lambda^{2N_0+1-p} \left. \frac{(\bar{D}_{\dot{\alpha}} \bar{\Phi} \bar{D}^{\dot{\alpha}} \bar{\Phi})^p}{\bar{\Phi}^p \Phi^{p+2N_0-2}} \right|_{\bar{\theta}=0} \quad N_1 = N_0 - 1 + p \quad p = 0, 1, ..$$

- Flux-induced couplings:

$$W_{\text{inst}} = \mathcal{C} G \Lambda^{2N_0+2-p} \left. \frac{(\bar{D}_{\dot{\alpha}} \bar{\Phi} \bar{D}^{\dot{\alpha}} \bar{\Phi})^p}{\bar{\Phi}^{p+2} \Phi^{2N_0+p-2}} \right|_{\bar{\theta}=0} \quad N_1 = N_0 - 2 + p \quad p = 1, ..$$

$$W_{\text{inst}} = \mathcal{C} \bar{G} \Lambda^{2N_0-p} \left. \frac{(\bar{D}_{\dot{\alpha}} \bar{\Phi} \bar{D}^{\dot{\alpha}} \bar{\Phi})^p}{\bar{\Phi}^{p-3} \Phi^{2N_0+p-3}} \right|_{\bar{\theta}=0} \quad N_1 = N_0 + p \quad p = 0, 1, ..$$

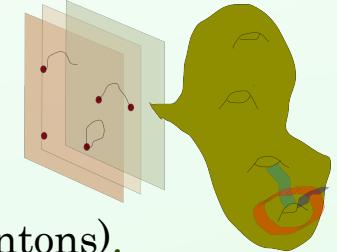
$$W_{\text{inst}} = \mathcal{C} \bar{G} M_s^{2-2N_0} e^{2\pi i \tau_2} \Phi^{2N_0} \quad N_1 = N_0 \quad \xleftarrow{\text{stringy instantons}}$$

gauge instantons

# Conclusions

- Flux induced non-perturbative interactions: gauge & stringy instantons

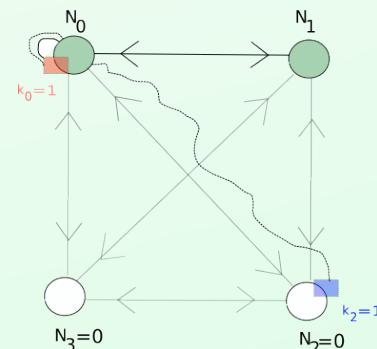
✓ Superpotentials, multi-fermionic interactions, etc.



✓ Exotic superpotentials for U(N) gauge theories (U(1)-stringy instantons).

- Moduli stabilization:  $N_f = N_c$

✓ Kahler moduli stabilization :  $e^{-\frac{8\pi^2 k V_p}{g^2} + 2\pi i k \theta_p}$



- Susy breaking:

✓ Soft symmetry breaking :  $G_{(3,0)} \sim (D_\tau W_{\text{flux}})^* \sim m_{\frac{1}{2}}$   $N_f = N_c - 1$

✓ Instanton mediated breaking :  $G_{(0,3)} \sim W_{\text{flux}} \sim m_{\frac{3}{2}}$   $N_f = N_c$