Stringy Instanton Superpotentials With(out) Orientifolds

Christoffer Petersson

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MPI Workshop 2007

Talk based on:

- *"Superpotentials from Stringy Instantons without Orientifolds"*
  `arXiv:0711.1837 [hep-th]`
  Christoffer Petersson.
- *"Stingy Instantons at Orbifold Singularities"*
  `arXiv:0704.0262 [hep-th]`
  Riccardo Argurio, Matteo Bertolini, Gabriele Ferretti,
  Alberto Lerda, Christoffer Petersson.

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- Stringy Instanton: on a cycle where no space-filling D branes are wrapped. [Ganor][Blumenhagen, Cvetic, Weigand] [Ibanez, Uranga] [Cvetic, Richter,Weigand] [Abel ,Goodsell] [Florea, Kachru, McGreevy,Saulina] [Bianchi,Kiritsis]
  Problem with neutral fermionic zero modes! Remedy:
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  - Background flux [Blumenhagen, Cvetic,Richter,Weigand] [Bergshoeff,Kallosh,Kashani-Poor,Sorokin,Tomasiello] [Martucci,Rosseel,Bleeken,Van Proeyen]
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  - ED brane wrapping a cycle upon which a single space-filling D branes have also been wrapped [Aganagic,Beem ,Kachru] [Garcia-Etxebarria,Uranga][Petersson]

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$\mathbf{Z}_2 \times \mathbf{Z}_2$ orbifold of the $k = 1$ Instanton Sector of $\mathcal{N}$=4 SYM

- The Charged Sector

  $4N_3\ \omega_{\dot\alpha}$ and $\overline{\omega}_{\dot\alpha}$

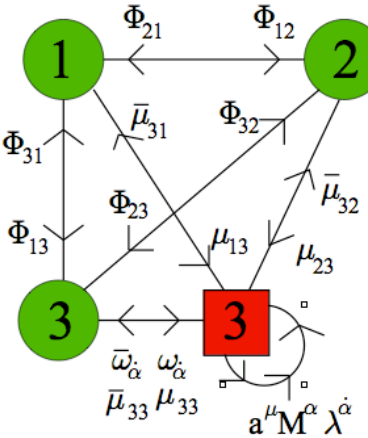
  $2N_3\ \mu_{33}, \overline{\mu}_{33}$

  $2N_1\ \mu_{13}, \overline{\mu}_{31}$

  $2N_2\ \mu_{23}\ \overline{\mu}_{32}$

- The Neutral Sector

  $a^\mu\ , M^\alpha, \lambda^{\dot\alpha}$



We will work in type IIB with fractional D3 branes with rank assignment $(N_1,N_2,N_3,0)$ and fractional D(-1) instanton rank assignment (0,0,1,0)

Instanton Moduli Space Integral

The moduli space integral is given by [Blumenhagen, Cvetic, Weigand]

$$S_W = \mathcal{C} \int d\{a, M, \lambda, D, \omega, \overline{\omega}, \mu, \overline{\mu}\} e^{-S_1 - S_2} \quad .$$

The moduli action for a single fractional instanton, in the ADHM limit, is [Atiyah,Drinfeld,Hitchin,Manin][Dorey,Hollowood,Khoze,Mattis][Billo,Frau,Pesando,Fucito,Lerda,Liccardo]

$$S_1 = i\left(\overline{\mu}_{33}\omega_{\dot{\alpha}} + \overline{\omega}_{\dot{\alpha}}\mu_{33}\right)\lambda^{\dot{\alpha}} - iD^c\left(\overline{\omega}^{\dot{\alpha}}(\tau^c)_{\dot{\alpha}}^{\dot{\beta}}\omega_{\dot{\beta}}\right)$$

and the interactions between the charged sector and the chiral superfields,

$$\begin{aligned} S_2 \quad = \quad & \frac{1}{2}\overline{\omega}_{33\dot{\alpha}}\{\Phi\overline{\Phi}\}\omega_{33}^{\dot{\alpha}} \\ & + \frac{i}{2}\overline{\mu}_{31}\overline{\Phi}_{13}\mu_{33} - \frac{i}{2}\overline{\mu}_{33}\overline{\Phi}_{31}\mu_{13} + \frac{i}{2}\overline{\mu}_{32}\overline{\Phi}_{23}\mu_{33} - \frac{i}{2}\overline{\mu}_{33}\overline{\Phi}_{32}\mu_{23} \\ & - \frac{i}{2}\overline{\mu}_{32}\Phi_{21}\mu_{13} + \frac{i}{2}\overline{\mu}_{31}\Phi_{12}\mu_{23} \end{aligned}$$

where $\{\Phi\overline{\Phi}\} = \Phi_{31}\overline{\Phi}_{13} + \overline{\Phi}_{31}\Phi_{13} + \Phi_{32}\overline{\Phi}_{23} + \overline{\Phi}_{32}\Phi_{23}$.

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The Prefactor

The scaling dimension of the moduli fields are given by

$$\begin{aligned}[a^\mu] &= [\omega_{\dot\alpha}] = [\overline{\omega}_{\dot\alpha}] = M_s^{-1}\ ,\ [D^c] = M_s^2 \\ \left[M^\alpha\right] &= [\mu] = [\overline{\mu}] = M_s^{-1/2}\ ,\ [\lambda^{\dot\alpha}] = M_s^{3/2}\ .\end{aligned}$$

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Note that β_3 can also be obtained from [Billo,Frau,Pesando,Di Vecchia,Lerda,Marotta]

$$< \mathbf{1} >^{\mathcal{A}}_{\mathrm{D}(-1)_3\mathrm{D}3} = -\left(3N_3 - N_1 - N_2\right) \ln\left(\frac{\mu}{M_s}\right) = -\beta_3 \ln\left(\frac{\mu}{M_s}\right)$$

By also including the vacuum disk amplitude of the fractional instanton we get [Polchinski]

$$\mathcal{C} = M_s^{\beta_3}\ e^{-\frac{8\pi^2}{g_3^2(M_s)}} = \Lambda^{3N_3 - N_1 - N_2}\ .$$

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Dimensional Analysis

$$S_W = \int d^4x d^2\theta \; W_{\text{np}} \quad , \text{ where } x^\mu = a^\mu \quad \text{and} \quad \theta^\alpha = M^\alpha$$

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- ADS case: For $N_1 + N_2 = N_3 - 1$ where $N_f = N_1 + N_2$ and $N_c = N_3$, [Affleck,Dine,Seiberg][Akerblom,Blumenhagen,Lust,Plauschinn,Schmidt-Sommerfeld]

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Consider the D3 brane content $(N_1, N_2, 0, 0)$ and D-instanton content $(0, 0, 1, 0)$. [Argurio,Bertolini, Ferretti, Lerda ,Petersson]

$$S_1 = 0 \quad , \quad S_2 = \frac{i}{2}\,\bar{\mu}_{31}\Phi_{12}\mu_{23} - \frac{i}{2}\,\bar{\mu}_{32}\Phi_{21}\mu_{13}$$

$$W \propto \int d\{\lambda, D, \mu, \bar{\mu}\}\, e^{-S_2} \equiv 0$$

Let us introduce an O3 plane such that the gauge groups are $USp(N)$ and the neutral sector is projected in the following way,

$$a_\mu = (a_\mu)^T \quad , M^\alpha = (M^\alpha)^T \quad , \quad \lambda_{\dot\alpha} = -(\lambda_{\dot\alpha})^T \quad \text{projected out!}$$

$$\Rightarrow W \sim \delta_{N_f, N_c} \det(\Phi)$$

Stabilizes the theory which already has ADS superpotential from a $(1, 0, 0, 0)$ fractional gauge instanton.

[Akerblom,Blumenhagen,Lust,Plauschinn,Schmidt-Sommerfeld]

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Stabilizes the theory which already has ADS superpotential from a $(1, 0, 0, 0)$ fractional gauge instanton.

[Akerblom,Blumenhagen,Lust,Plauschinn,Schmidt-Sommerfeld]

Consider the D3 brane content $(N_1, N_2, 0, 0)$ and D-instanton content $(0, 0, 1, 0)$. [Argurio,Bertolini, Ferretti, Lerda ,Petersson]

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Stringy Instanton Superpotentials with Orientifolds

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From the two fermionic δ-functions we obtain,

$$\left(\overline{\mu}_{33}\omega_{\dot{1}} + \overline{\omega}_{\dot{1}}\mu_{33}\right)\left(\overline{\mu}_{33}\omega_{\dot{2}} + \overline{\omega}_{\dot{2}}\mu_{33}\right) = \overline{\mu}_{33}\left(\omega_{\dot{1}}\overline{\omega}_{\dot{2}} - \overline{\omega}_{\dot{1}}\omega_{\dot{2}}\right)\mu_{33}$$

and the following constraint

$$N_1 = N_2 \ .$$

The integration over these remaining fermions brings down determinants of Φ_{21} and Φ_{12} and we arrive at the following result,

$$W^{\mathrm{s}}_{\mathrm{np}} \quad = \quad \Lambda_s^{3-2N}\,\det[\Phi_{21}]\,\det[\Phi_{12}] \times \mathcal{I} \qquad \text{for } N_1 = N_2 = N$$

where the remaining task is to evaluate the following bosonic integral,

$$\mathcal{I} = \int d^2\omega_{\dot{\alpha}} d^2\overline{\omega}_{\dot{\alpha}}\left(\omega_{\dot{1}}\overline{\omega}_{\dot{2}} - \omega_{\dot{2}}\overline{\omega}_{\dot{1}}\right)\,\delta^3_{\mathrm{B}}\left(\overline{\omega}^{\dot{\alpha}}(\tau^c)_{\dot{\alpha}}^{\dot{\beta}}\omega_{\dot{\beta}}\right)\,e^{-\frac{1}{2}\overline{\omega}_{\dot{1}}\{\Phi\overline{\Phi}\}\omega_{\dot{2}}+\frac{1}{2}\overline{\omega}_{\dot{2}}\{\Phi\overline{\Phi}\}\omega_{\dot{1}}} \ .$$

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Bosonic Integral

$$\delta^3_{\mathrm{B}}\left(\overline{\omega}^{\dot{\alpha}}(\tau^c)_{\dot{\alpha}}^{\ \dot{\beta}}\omega_{\dot{\beta}}\right) = \int \frac{dp^1}{2\pi} e^{ip^1(-\omega_{\dot{1}}\overline{\omega}_{\dot{1}}+\omega_{\dot{2}}\overline{\omega}_{\dot{2}})} \int \frac{dp^2}{2\pi} e^{p^2(\omega_{\dot{1}}\overline{\omega}_{\dot{1}}+\omega_{\dot{2}}\overline{\omega}_{\dot{2}})} \int \frac{dp^3}{2\pi} e^{ip^3(\omega_{\dot{1}}\overline{\omega}_{\dot{2}}+\omega_{\dot{2}}\overline{\omega}_{\dot{1}})}$$

and

$$\mathcal{I} = \int \frac{d^3p}{(2\pi)^3} d^2\omega d^2\overline{\omega}\left(-\frac{\partial}{\partial M_1} + \frac{\partial}{\partial M_4}\right)\exp\left(-\begin{bmatrix} \omega_{\dot{1}} & \omega_{\dot{2}} \end{bmatrix}\begin{bmatrix} M_1 & M_2 \\ M_3 & M_4 \end{bmatrix}\begin{bmatrix} \overline{\omega}_{\dot{2}} \\ \overline{\omega}_{\dot{1}} \end{bmatrix}\right)$$

where $M_1 = -ip^3 - \frac{1}{2}\{\Phi\overline{\Phi}\}$, $M_2 = ip^1 - p^2$, $M_3 = -ip^1 - p^2$ and $M_4 = -ip^3 + \frac{1}{2}\{\Phi\overline{\Phi}\}$. Performing the Gaussian integrals, we obtain

$$\int d^3p\left(-\frac{\partial}{\partial M_1} + \frac{\partial}{\partial M_4}\right)\frac{1}{M_1M_4 - M_3M_2} = \int d^3p \frac{\{\Phi\overline{\Phi}\}}{\left[p^2 + \frac{1}{4}\{\Phi\overline{\Phi}\}^2\right]^2}$$

where we have inserted back the expressions for the M's, and $p^2 = \sum_{i=1}^3 (p_i)^2$. If we now change to spherical coordinates ($\int d^3p = 4\pi \int dp\, p^2$), rescale $\tilde{p} = \frac{2p}{\{\Phi\overline{\Phi}\}}$ and use the fact that $\int_0^\infty d\tilde{p} \frac{\tilde{p}^2}{[\tilde{p}^2+1]^2} = \frac{\pi}{4}$, we can conclude that:

The bosonic integral $\mathcal{I}$ only results in an irrelevant numerical factor which can be absorbed in the prefactor Λ_s.

The final result of the moduli space integral has the structure of a baryonic mass term,

$$W^{\mathrm{s}}_{\mathrm{np}} = \Lambda_s^{3-2N}\, \mathcal{B}\tilde{\mathcal{B}}$$

for $N_1 = N_2 = N$ and where $\mathcal{B} = \det[\Phi_{21}]$, $\tilde{\mathcal{B}} = \det[\Phi_{12}]$.

- We have generated a holomorphic superpotential term without using the D-term constraints for the matter fields.
- It has been shown in related configurations where orientifolds were used that such a term will have dramatic effects on the gauge dynamics and, for example, give rise to dynamical supersymmetry breaking [Argurio,Bertolini,Franco,Kachru][Aharony,Kachru.Silverstein][Buican,Malyshev,Verlinde] [Aganagic,Beem ,Kachru] [Garcia-Etxebarria,Uranga]

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Implications for the Gauge Dynamics

We have generated a non-perturbative superpotential term for a SU(N)×SU(N) gauge theory with an additional global U(1) factor which has an instanton associated to it.

$N_f = N_c + 1$ SQCD case [Seiberg] where the gauge group is SU(N) and we consider only the part the flavor group which is SU($N+1$), broken down to SU(N)×U(1) by

$$W_{\text{tree}} = \Phi^f_{23}\Phi_{31c}\Phi^c_{12f} - \Phi^f_{21c}\Phi^c_{13}\Phi_{32f} \qquad c = 1, ..., N \text{ and } f = 1, ..., N$$

There is also a non-perturbative superpotential term

$$W_{\text{np}} = \Lambda^{-2N+1}\left(\mathcal{M}^i_j\mathcal{B}_i\tilde{\mathcal{B}}^j - \det[\mathcal{M}^i_j]\right) \qquad i, j = 1, ..., N+1$$

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Summary

- We have show that it is possible to derive non-perturbative superpotential terms from stringy instantons by considering one additional cycle which is wrapped by a single space-filling D brane together with an instanton ED brane, without introducing orientifold planes.
- By evaluating the moduli space integral for the $\mathbb{Z}_2 \times \mathbb{Z}_2$ orbifold background we found a holomorphic superpotential term with the structure of a baryonic mass term.
- We believe that this result is quite general and should be applicable to many D brane systems in backgrounds with more general (non-)compact Calabi-Yau manifolds. We regard this computation as a example of how such a stringy instanton effect could arise, and have important effects, in more realistic theories.

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