Dimers and orientifolds

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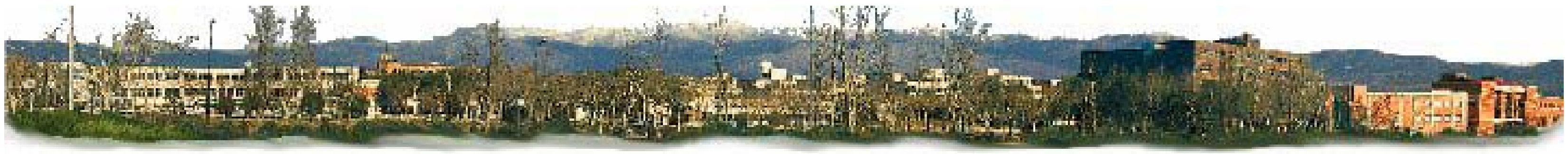
In collaboration with
S. Franco, A. Hanany, D. Krefl, J. Park, D. Vegh, to appear

Strings 2007



Motivation

- Branes at singus:

  - Model building [Aldazabal et al; Berenstein et al; Verlinde et al]
  - Interesting strong dynamics effects: Confinement; Susy breaking with runaway or metastable vacua; ... [Klebanov, Strassler; Bertolini et al; Berenstein et al; Franco et al]
  - Generalizations of gauge/gravity [Klebanov, Strassler]
  - Local models of CY compactification

- Introduction of orientifold quotients is a natural generalization, with similar expected applications

  Present techniques (orbifolding, partial resolution, T-duality) are rudimentary

- Clear need for new tools to systematically construct and classify orientifolds of D-branes at singularities

Dimer diagrams

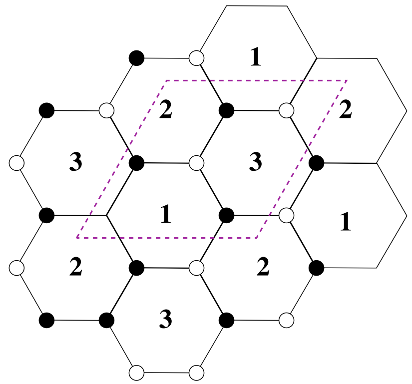
- Similar problem for theories w/o orientifolds is now solved

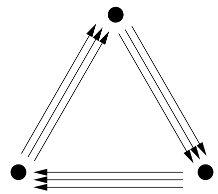
Dimer diagrams encode the information on the gauge theory on D3-branes and on the geometry of the (toric) singularities

[Hanany, Kennaway; Franco, Hanany, Kennaway, Vegh, Wecht]

- Periodic (bipartite) tilings of the plane

Gauge group as faces, matter as edges, couplings as nodes, ...





Web diagram of geometry from zig-zag paths

[Hanany, Vegh; He, Feng, Kennaway, Vafa]

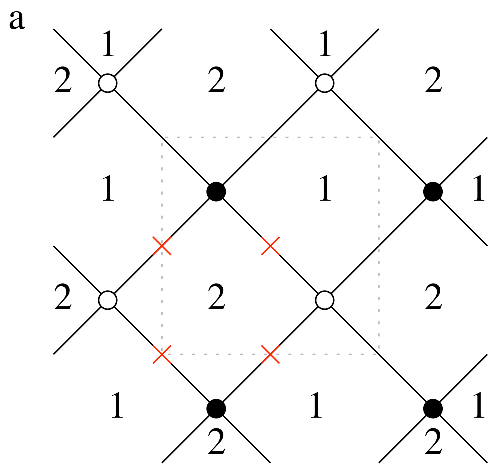
- Extremely insightful for gauge theories (and their gravity duals)

Expect they also encode the possible orientifold quotients

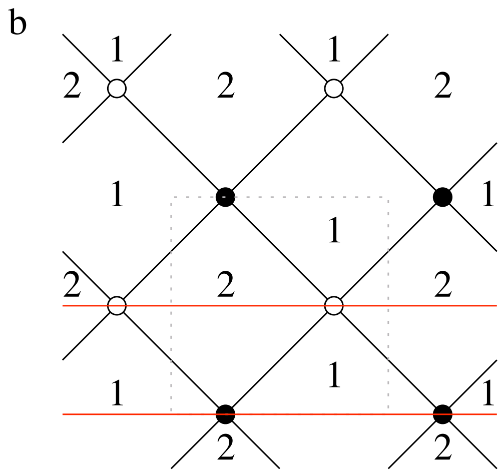
Orientifolding dimer diagrams

- Orientifold as quotient by a symmetry of the system
  - Look for symmetries of the dimer diagram
- Two kinds of orientifolds

Fixed points



Fixed lines



Different orientifold models from different choices of signs

For case (a), overall constraint on number of +/- orientifold points

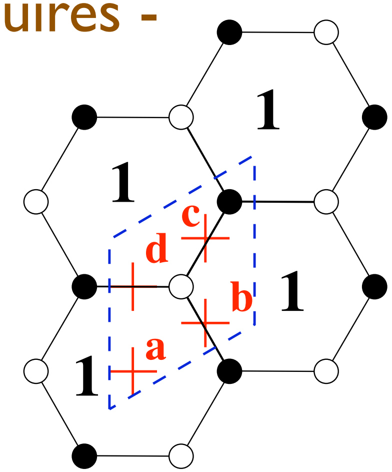
Orientifolds with fixed points

Rules consistent with all known examples and with partial resolution

- Assign charges to orientifold points
- O^+ resp. O^- on face project down to SO resp. Sp factor
- O^+ resp. O^- on edge project down to  resp. 

Susy constraint: product of charges is $(-1)^k$ in dimer of 2k nodes

Ex: C^3 requires -



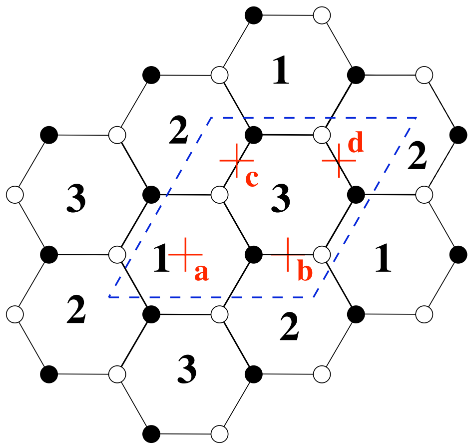
(+---) ⇒ SO(n) with 3  ⇒ O3

(+++-) ⇒SO(n) with 2 + ⇒ O7

(++++) ⇒ SO(n) with 3  ⇒ No!

Some examples

Orientifolds of C^3/Z_3



(+---) ⇒ SO(n)x U(m) $3\ [\ (\Box, \overline{\Box})\ + \begin{smallmatrix}\Box\\\Box\end{smallmatrix}\ ]$

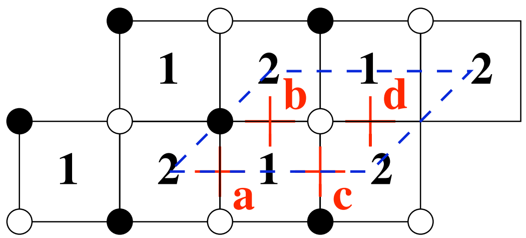
[Angelantonj, Pradisi, Bianchi, Sagnotti, Stanev]

(+++-) ⇒ SO(n) x U(m) $3\ (\Box, \overline{\Box}) + 2\ \Box\Box + \begin{smallmatrix}\Box\\\Box\end{smallmatrix}$

[Not in literature, but easy to construct]

(similarly Sp theories by overall sign flip)

Orientifolds of conifold



(+++-) ⇒ U(n) $\overline{\Box\Box} + 2\ \Box\Box + \overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}$

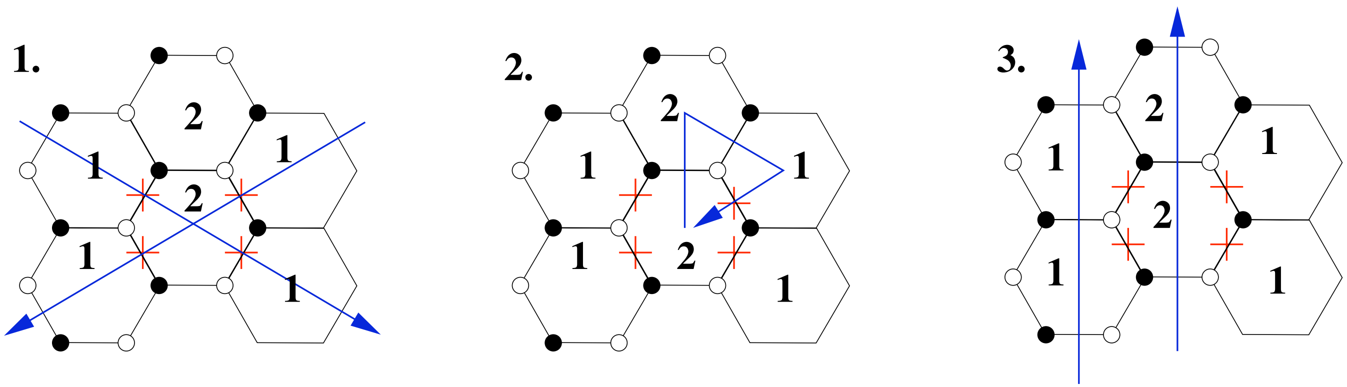
(+---) ⇒ U(n) $\overline{\Box\Box} + 2\ \begin{smallmatrix}\Box\\\Box\end{smallmatrix} + \overline{\begin{smallmatrix}\Box\\\Box\end{smallmatrix}}$

[Park, Rabadan, AU]

A long list of known and new orientifold models ....

Geometric action

- Need to characterize the action $\Omega R(-)^{F_L}$ for each model
- Regard gauge invariant mesonic operators as coordinates
  Closed paths on the dimer
- Read out orientifold action on mesons from dimer
  - 1. At each passage through an $O^{+/-}$, picks a +/- sign
  - 2. Hom. trivial paths pick a (-) sign per enclosed node
  - 3. Path mapped to image, pick (-) per node/O^- in strip

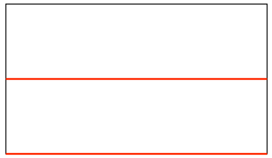


- Consistent with all known models

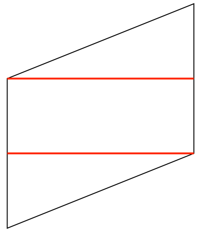
Orientifolds with fixed lines

Rules consistent with all known examples and with partial resolution

- Assign charges to orientifold lines consistently with unit cell structure



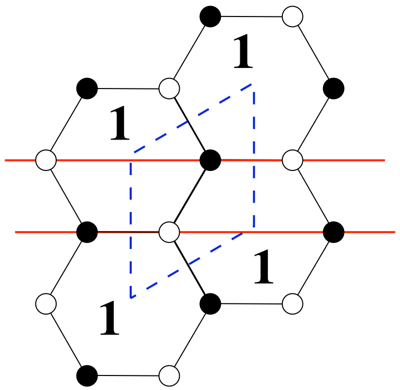
vs.



- O^+ resp. O^- on face project down to SO resp. Sp factor
- O^+ resp. O^- on edge project down to $\square\square$ resp. $\begin{smallmatrix}\square\\\square\end{smallmatrix}$

No constraint on orientifold line charges

Ex: C^3

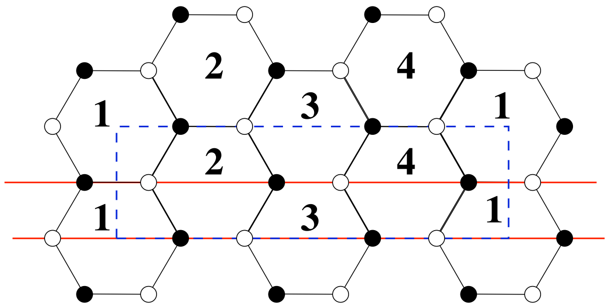


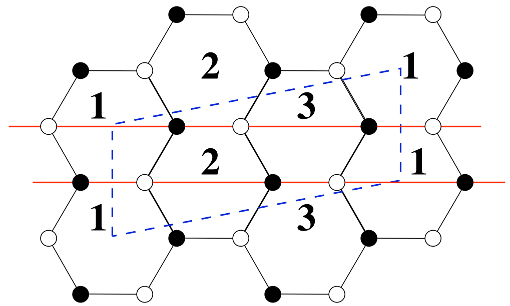
+ $\Rightarrow$SO(n) with 2 $\square\square$ + $\begin{smallmatrix}\square\\\square\end{smallmatrix}$ $\Rightarrow$ O7'

Similar set of rules to obtain geometric action

Some examples

Orientifolds of $C^2/Z_N \times C$





$(+-) \Rightarrow SO_1 \times Sp_2 \times SO_3 \times Sp_4$

$(\square_i, \square_{i+1}) + \yng(1,1)_1 + \yng(2)_2 + \yng(1,1)_3 + \yng(2)_4$

[AU]

No analog of (+-)

$(--) \Rightarrow Sp_1 \times Sp_2 \times Sp_3 \times Sp_4$

$(\square_i, \square_{i+1}) + \yng(1,1)_1 + \yng(1,1)_2 + \yng(1,1)_3 + \yng(1,1)_4$

$(--) \Rightarrow Sp_1 \times Sp_2 \times Sp_3$

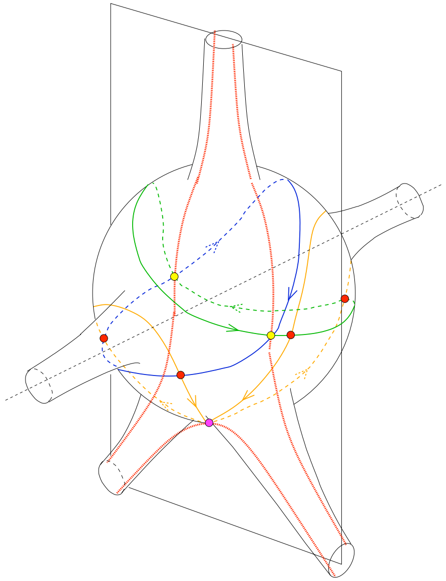
$(\square_i, \square_{i+1}) + \yng(1,1)_1 + \yng(1,1)_2 + \yng(1,1)_3$

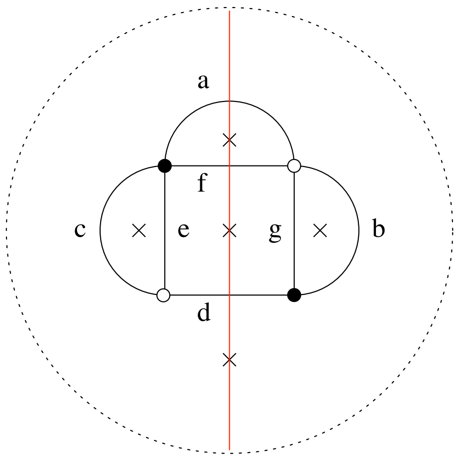
[Feng, Karch, He, AU]

A long list of known and new orientifold models ....

The mirror picture

- Mirror geometry is a Riemann surface Σ (times C*) fibration
  [Hori, Vafa]
- Mirror D6-branes on special lagrangian cycles ⇒ 1-cycles on Σ
  Intersection numbers reproduce matter
  Disk instantons reproduce superpotential
  [He, Feng, Kennaway, Vafa]
- Orientifolds are O6's fixed under antiholomorphic involution





- Roughly: Signs in dimer are signs of O6-branches

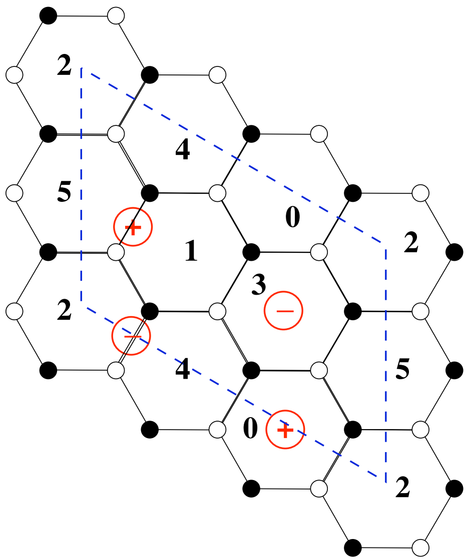
Application I: Dynamical Susy Breaking

- Susy breaking (with runaway) already in early models

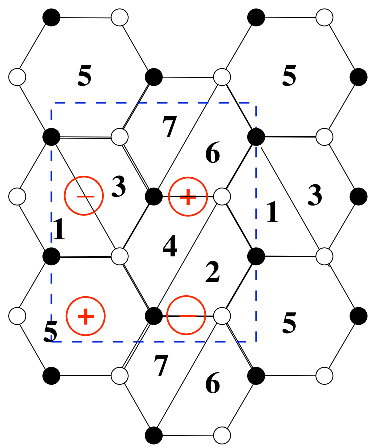
  U(5) with $3(10+\overline{5})$ [Lykken, Poppitz, Trivedi '98]

- Construct SU(5) with just $10+\overline{5}$, which has DSB vacuum [Affleck, Dine, Seiberg]

Ex: Z6'



Ex: PdP4



- Simple to construct, and to generalize ...

- Proposals based on orientifolding quivers: [Wijnholt; Antebi, Volansky]

  Not quite correct in the detail...

Application II: D-brane instantons

- 4d Gauge theory operators from D-brane instantons

  Intersections between instanton and 4d branes lead to fermion zero modes, saturated by insertion of 4d operator

  [Ganor; Florea, Kachru, McGreevy, Saulina; Blumenhagen, Cvetic, Weigand; Ibanez, AU; ...]

- Generating W requires two uncharged fermion zero modes

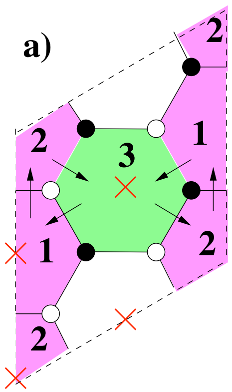
  Orientifolds needed to remove extra N=2 zero modes

  [Bianchi et al; Argurio et al; Ibanez, Schellekens, AU]

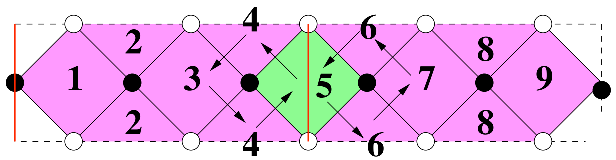
- Easy to construct D-brane instantons contributing to W for systems of branes at singularities

E.g.

a)



b)



[Argurio, Bertolini, Ferretti, Lerda, Petersson]

[Argurio, Bertolini, Franco, Kachru]

Conclusions

- Provided tools to classify orientifolds of toric singus
  - Reproduce all known orientifolds (plus many more)
  - Rules consistent with partial resolution

- Described several interesting applications
  - Dynamical Susy Breaking
  - D-brane instantons

- Open directions
  - Systematic study of new families of theories
  - Improve understanding of mirror side