Inflated Branes,

D Balls, and other

Deformities

in nonAdS/nonCFT Duality

w/ Polchinski 3/00

w/ Klebanov in prep.

Klebanov + Tseytlin 3/00

the Strings 2000 Freak Show.

String Theory on Various Backgrounds = Field Theories

$\mathcal{N} = 1^*$ ($\mathcal{N}=4$ YM $\longrightarrow$ $\mathcal{N}=1$ (0) YM)

- See Branes Balloon before your Very Eyes!
- Exclaim at Quarks confined by Abelian Instanton Strings
- Imagine Domain Walls built from Baryons, all imprisoned by Neveu-Schwarz Branes!
- Watch fractional Instantons resum into Wrapped String Worldsheets!

Physics of gauge theory intricately realized in IIB string.

Conifold w/ Fractional Branes: Dual to Field Theory with infinite # of Colors
cf. Witten

Klebanov-Tseytlin soln. dual to Seiberg Duality Cascade.

- Fear the Naked Singularity Below!
- See it Resolved by Creature so Misshapen you Can't Look Away!

$\mathcal{N} = 1^*$ SU(N)

$$W = \mathrm{tr}\,[\Phi_1, \Phi_2]\,\Phi_3 + m \sum_i \Phi_i^2 \longrightarrow [\Phi_i, \Phi_j] \propto m\,\Phi_k\,\epsilon_{ijk}$$

so $\Phi_i \propto$ Any $N \times N$ SU(2) rep.

Vafa-Witten

$\sim e^{\sqrt{N}}$ isolated solns.

$\Phi_i = 0$ SU(N) unbroken $\mathcal{N}=1$ Y.M.

N vacua

CONFINING

OBLIQUE CONF.

$\Phi_i \propto J_i^{(N)}$

SU(N) broken

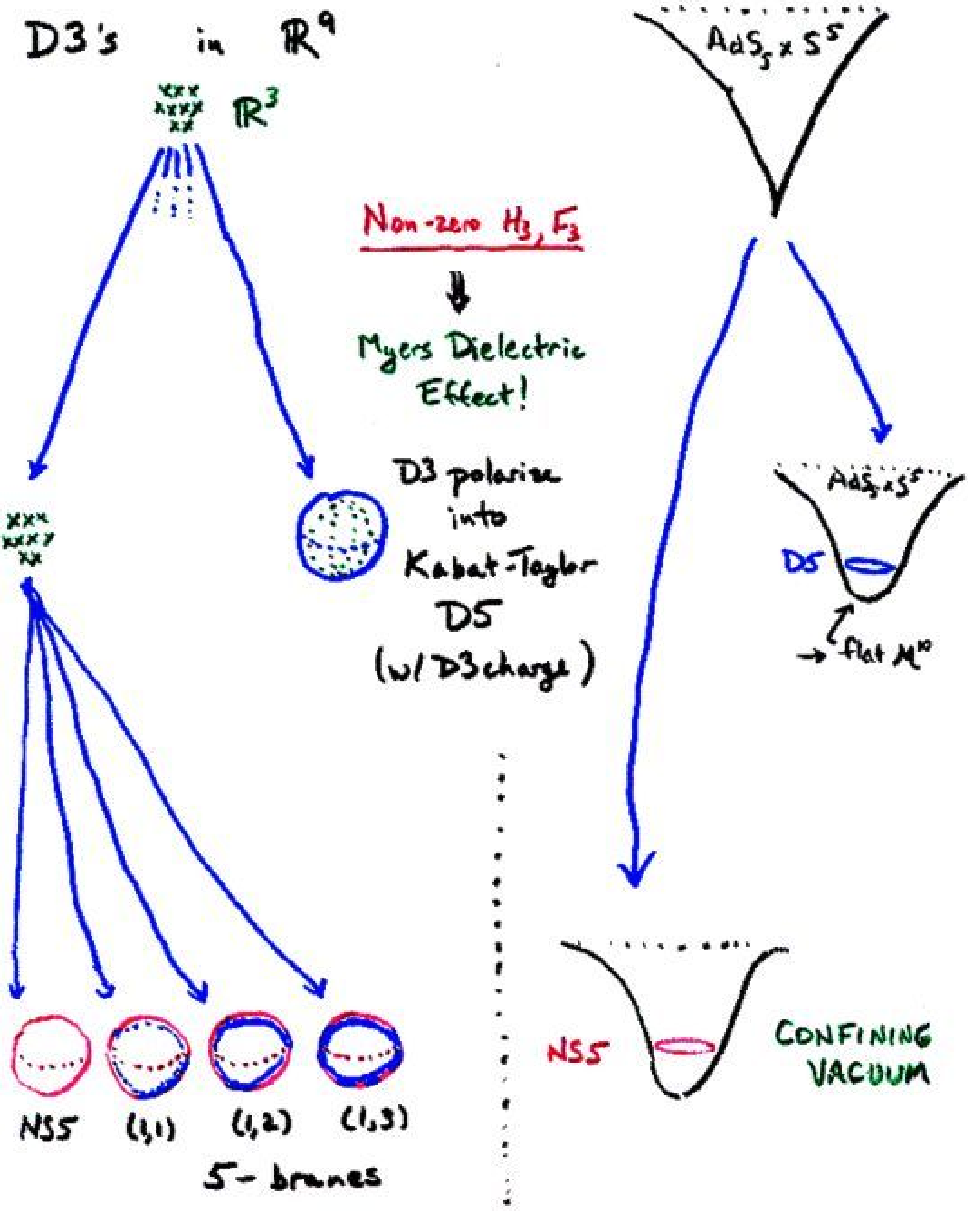
HIGGS

S Duality

Vafa-Witten ; Donagi-Witten

$$\begin{tikzcd} & & H \arrow[dll, "\tau \to -1/\tau"'] \\ C \arrow[r] & O_1 \arrow[r] & O_2 \end{tikzcd}$$

$\tau \to \tau + 1$



D3's in $\mathbb{R}^9$
$\mathbb{R}^3$
Non-zero H_3, F_3
Myers Dielectric Effect!
D3 polarize into Kabat-Taylor D5 (w/ D3 charge)
NS5
(1,1)
(1,2)
(1,3)
5-branes
$AdS_5 \times S^5$
$AdS_5 \times S^5$
D5
flat M^{10}
NS5
CONFINING VACUUM

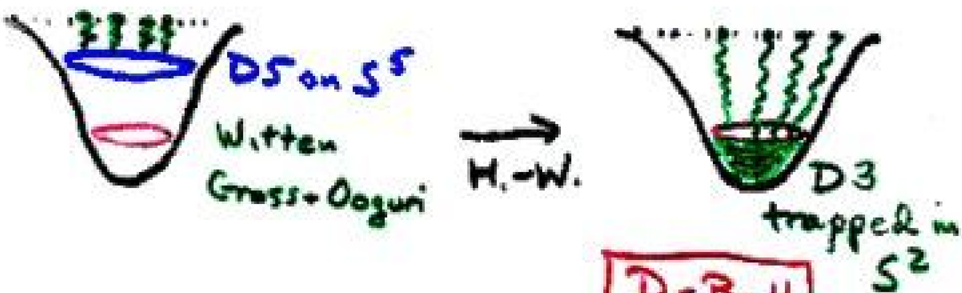
Some Gauge Theory Physics

Confinement

Flux Tube is F1 — NS5/D3 bd. state
[Instanton of N.C. theory on NS5]

Screening

Baryon Vertex:
(joins N heavy quarks)



$\boxed{\text{D-Ball}}$

Domain Wall

- Dissolve Baryon in Domain Wall.
- Build Domain Wall from N.C. Array of Baryons.

⋮

Fractional Instantons
(give $\langle\lambda\lambda\rangle$ in $N=1$)

$\xrightarrow[\text{Dorey + Kumar}]{\text{Resum}}$

String
Worldsheet
Instantons

Gaugino Condensate Breaking $\mathbb{Z}_{2N} \to \mathbb{Z}_2$?

~~slope~~.

Mixes with,
Smaller than scalar
condensate.

✓

Accidental Symmetry,
present only for $m \to \infty$.

✗

CONIFOLD : 6-d space with $SU(2) \times SU(2) \times U(1)$

$w^a \in \mathbb{C}^4$, $W_{ij} \equiv w^a \sigma^a_{ij}$: $\det W_{ij} = 0$ Candelas, De la Ossa

$i=1,2$, $j=1,2$

Cone over $T^{1,1}$: topologically $S^2 \times S^3$

	$SU(N+M)$	$\times\ SU(N)$	$\times\ SU(2)$	$\times\ SU(2)$	$\times\ U(1)_R$
$A_{1,2}$	$\square$	$\bar{\square}$	2	1	½
$B_{1,2}$	$\bar{\square}$	$\square$	1	2	½
$A_i B_j$	1	1 + adj	2	2	1

$$W = \mathrm{tr}\,(A_1 B_1 A_2 B_2 - A_1 B_2 A_2 B_1)$$ (cf. Klebanov - Witten)

M=0 : CFT

$\langle A_i \rangle$, $\langle B_j \rangle$ diag $\Rightarrow$ $P_{ij} = A_i B_j$ diag.

$\frac{\partial W}{\partial \Phi_i} = 0 \Rightarrow$ eigenvalues P_{ij} satisfy $\det P_{ij} = 0$!

So we have N D3's moving freely on conifold.

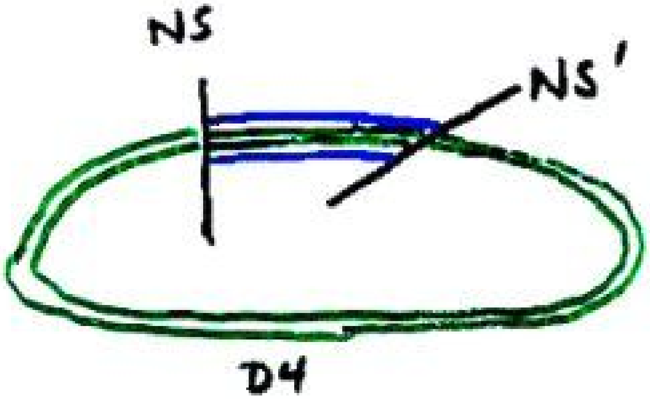
M>0 : $\beta_{N+M} < 0$, $\beta_N > 0$

M ½ D3's are pinned.

Also : $U(1)_R$ anomalous, $\mathbb{Z}_{2M}$ anom. free.

T-dual $\mathrm{II}A$ / M Theory

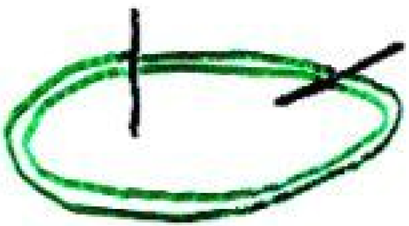
(Elitzur Giveon Kutasov)
Aharony Hanany
Uranga
Dasgupta Mukhi
⋮



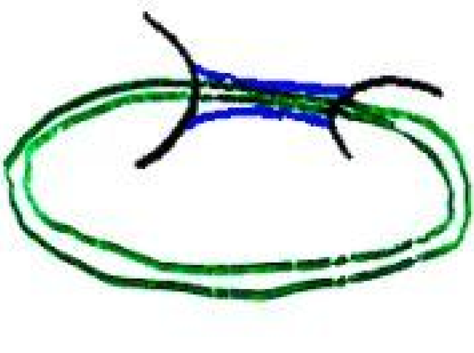
classical

semiclassical

cf. Witten

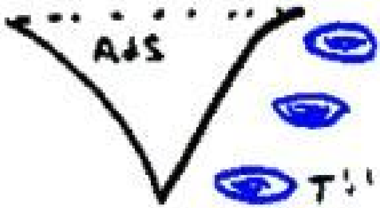


CFT – no bending



Non-CFT – branes bend.

$M = 0$ Klebanov - Witten



$$ds^2 = ds^2_{AdS_5} + ds^2_{T^{1,1}}$$

$$= h^{-1/2}\, ds^2_{R^4} + h^{1/2}\left(dr^2 + r^2 ds^2_{T^{1,1}}\right)$$

$$h(r) = \frac{4\pi g_s N}{r^4}$$

$M > 0$ Klebanov-Nekrasov, Klebanov-Tseytlin - warped conifold

$$h(r) = \frac{4\pi}{r^4}\left[g_s N + \#(g_s M)^2 \ln r/r_0 + \text{const}\right]$$

$\int_{S^3} F_3 = \# M$ — # ½ D3's const

$\int_{S^2} B_2 = \# g_s M \ln r/r_0$ — $\frac{1}{g^2_{N+M}} = \frac{1}{g^2_N} + \# M \ln r$

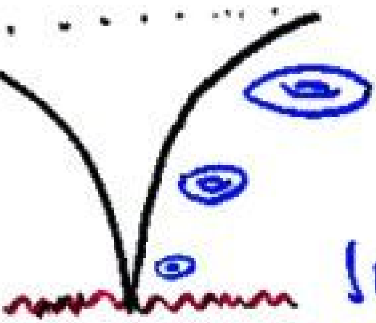
$\phi = \text{constant}$ — $\frac{1}{g^2_{N+M}} + \frac{1}{g^2_N} = \text{const.}$

$\int_{T^{1,1}} F_5 = N - \# M \ln r/r_0$ — # D3's decreases!

What happens when

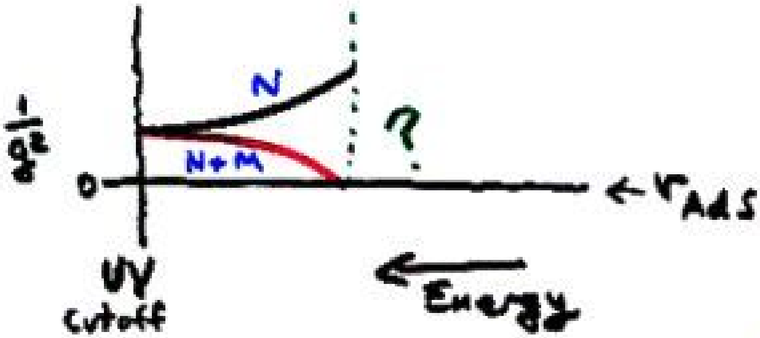
$\int F_5 = 0$?!

(Naked Singularity)



$\int F_3^2 \to \infty$

as S^3_3 shrinks away.



Dualize!

$$SU(N+M) \times SU(N) \longrightarrow SU(2N-(N+M)) = SU(N-M) \times SU(N)$$

	$SU(N+M)$	$SU(N)$			$SU(N-M)$	$SU(N)$
A_i	$\square$	$\bar{\square}$	$\longrightarrow$	a_i	$\square$	$\square$
B_j	$\bar{\square}$	$\square$		b_j	$\bar{\square}$	$\bar{\square}$
	$\uparrow$ 2N flavors			P_{ij}	1	1 + adj

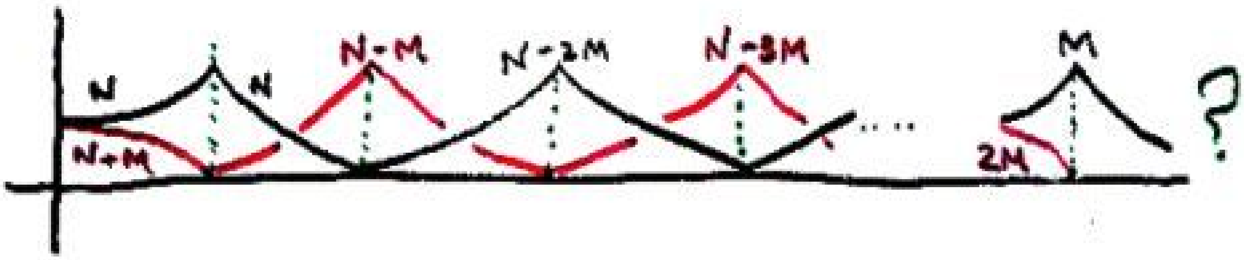
$$W = W_{tree} + W_{Seiberg} = \mathrm{tr}\left(P_{11}P_{22} - P_{12}P_{21}\right) + \mathrm{tr}\, P_{ij} a_i b_j$$

$$\Rightarrow \tilde{W} = \mathrm{tr}(a_1 b_1 a_2 b_2 - a_1 b_2 a_2 b_1)$$

Same as before with $N \to N-M$!!

$\boxed{\text{Caution! } W \text{ \underline{is} renormalized.}}$

cf. Polchinski's talk – related but different.



<u>Comments</u>:

① UV requires $SU(\infty) \times SU(\infty)$.

Strings on this bckd dual to field theory with ∞ colors.

② Question: what is the S-dual $\left(\tau_{IIB} \to -\frac{1}{\tau_{IIB}}\right)$?

③ Low-energy theory is pure $SU(M)$ $\mathcal{N}=1$.

Expect a) $U(1)_R$ anomalous $\to$ $\mathbb{Z}_{2M}$ true at all scales.

b) $\langle \lambda\lambda \rangle$ condenses $\Downarrow$ $\mathbb{Z}_2$, M vacua, see in IR?

$U(1)$ vs. $\mathbb{Z}_{2M}$ hard to see if M large but

$U(1) \cdots \mathbb{Z}_{2M} \longrightarrow \mathbb{Z}_2$ should be visible in IR.

but K-T solution preserves $U(1)$.

cf. Maldacena's talk.

Question: what happens to conifold with M $\frac{1}{2}$ D3's at singularity?

Trick: Add 1 D3 as probe.

$$SU(M+1) \times \text{"}SU(1)\text{"}$$

$A_i \quad \square$

$B_j \quad \bar{\square}$

SU(M+1) with 2 flavors.

$A_i B_j = P_{ij}$ are singlets: position of D3

$$W = W_{tree} + W_{ADS}$$

$$= \lambda \det_{ij} P_{ij} + \# \left(\frac{\Lambda_{M+1}^{3M+1}}{\det_{ij} P_{ij}} \right)^{\frac{1}{M-1}}$$

<u>So</u>

$$\epsilon_{ik}\epsilon_{jl} \frac{\partial W}{\partial P_{ij}} = P_{kl} \left[\lambda + \# \Lambda_{M+1}^{(3M+1)/(M-1)} \left(\det P_{ij} \right)^{-M/(M-1)} \right] = 0$$

$$\Rightarrow \boxed{\det P_{ij} = \left(\lambda^{M-1} \Lambda_{M+1}^{3M+1} \right)^{1/M}}$$

M branches — each of which is a <u>deformed conifold</u>

$$T^{1,1} \sim \underbrace{S^2}_{\text{Shrinks aw}} \times S^3 \longrightarrow S^3 \text{ at tip.}$$

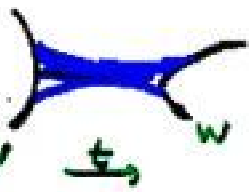
Checks: Preliminary!

① $U(1)_R \to \mathbb{Z}_2$ by the deformation: χSB!

② Confinement:

③ Screening: monopole is $\frac{1}{2}$D1 = D3 on S^2

④ M Theory: $\mathcal{N}=1$ YM



M5 Witten

$$\boxed{\begin{matrix} vw = \Lambda^2 \\ t = v^M \end{matrix}} \longleftarrow \begin{cases} vw = 0 & \text{conifold} \\ vw = \text{const} & \text{deformation} \end{cases}$$

so projects onto def. conifold.

⑤ SUGRA: $\frac{1}{2}$ D3's = D5's on S^2 of $T^{1,1}$

These exert "pressure" on the S^2, make it shrink?

Ansatz: KT solution matches smoothly onto deformed conifold at tip –

Naked singularity of KT resolved through geometry.
unlike P.S. $\mathcal{N}=1^*$

Full solution – Warped Deformed Conifold – not yet constructed.

Comments: Pure 4d $\mathcal{N}=1$ YM is not in SUGRA but many embeddings of $\mathcal{N}=1$ are.

Guess: any embeddings related to conifold (cf. Maldacena + Nuñez) ~~are~~ have singularities resolved, XSB through deformation.

All are in same univ. class but have different massive states.

Duality Wall MJS '95 Similar embeddings of S.M. into theories with ever-growing gauge groups in U.V.

Physically reasonable?