Six Dimensional $\mathcal{N}$=(2,0) SCFTs on AdS_5xS^1

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Exact Quantum Fields and the Structure of M-theory

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Work in progress with Berkooz and Rey

Motivations

- No need to motivate here the study of the 6d $\mathcal{N}$=(2,0) SCFTs (many talks)…
- Studying supersymmetric theories on various curved spaces has already led to many interesting results, in particular with conserved supersymmetry; $AdS_5 x S^1$ preserves 16 supercharges, like $S^5 x S^1$
- Can embed the $\mathcal{N}$=(2,0) SCFTs on $AdS_5 x S^1$ into string theory and use the AdS/CFT correspondence to study them.
- Will find surprising results…

Review of A_{n-1} 6d $\mathcal{N}=(2,0)$ SCFTs

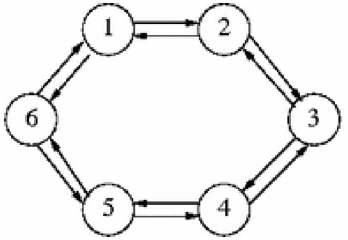
- Will focus on this case for simplicity.
- Arises from n M5-branes, n NS5-branes in type IIA, or a C^2/Z_n singularity in type IIB
- $\mathcal{N}=(2,0)$ tensor multiplet contains 2-form field with self-dual field strength, 5 scalars and fermions.
- Moduli space is $R^{5(n-1)}/S_n$ (ignoring center of mass), low-energy theory has (n-1) tensor multiplets and BPS strings with tensions $|\Phi_i-\Phi_j|$; interacting SCFT at origin.

Compactification on a circle

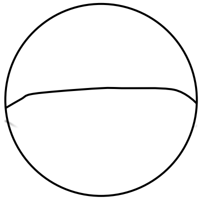
- Leaves same moduli space $R^{5(n-1)}/S_n$
- At energies below $1/R$, get a 5d $\mathcal{N}=2$ SYM theory with gauge group $SU(n)$, $g_{YM}^2 \sim R$; moduli space described by VEVs of adjoint scalar fields. Wrapped BPS strings become BPS W-bosons; SU(n) unbroken at origin.
- In type IIB on C^2/Z_n BPS strings come from D3-branes wrapped on 2-cycles. $3(n-1)$ scalars come from blow-up modes, $2(n-1)$ from B_2 and C_2 integrated on 2-cycles.

Embedding in string theory

- Consider type IIB string theory on $AdS_5 x S^5/Z_n$ = near-horizon limit of K D3-branes on C^2/Z_n. Dual to 4d $\mathcal{N}$=2 $SU(K)^n$ elliptic quiver with bi-fundamental hypermultipets (Kachru-Silverstein)



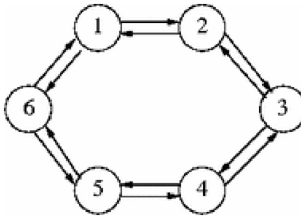
- Locally have C^2/Z_n orbifold living on $AdS_5 x S^1$ in $AdS_5 x S^5/Z_n$



- 4d $\mathcal{N}$=2 theory has n exactly marginal deformations – complex gauge couplings. One maps to type IIB dilaton-axion.

- Other (n-1) to B_2 and C_2 fields on 2-cycles of singularity. Other blow-up modes tachyonic.
- At orbifold point have n equal gauge couplings, non-zero B_2 fields on 2-cycles.
- But can also take B_2 fields to zero – get at low energy 6d $\mathcal{N}=(2,0)$ A_{n-1} SCFT living on $AdS_5 \times S^1$ (coupling to rest of type IIB), with $R_{AdS}=R_S$ and specific boundary conditions
- Near this point "moduli space" (space of SUSY vacua on AdS_5) is C^{n-1}/S_n with A_{n-1} (2,0) SCFT arising at the origin. Subspace of original moduli space (containing fields that remain massless on AdS_5).

- Theory has 16 conserved supercharges.
- 4d $\mathcal{N}$=2 SCFT has a global symmetry $SU(2)_R x U(1)_R x U(1)^n$. The $U(1)^n$ is the flavor symmetry of the n bi-fundamental hypermultiplets. The lowest dimension operators charged under relative U(1)'s in $U(1)^n$ are di-baryons, with a classical dimension ~ K.



- In string theory : D3-branes wrapped around the (n-1) 2-cycles and the S^1 (in S^5/Z_n).
- A factor of $SU(2)_R x U(1)_R x U(1)$ is realized geometrically through isometries of S^5/Z_n. (SU(2) for n=2)

Naïve expectation

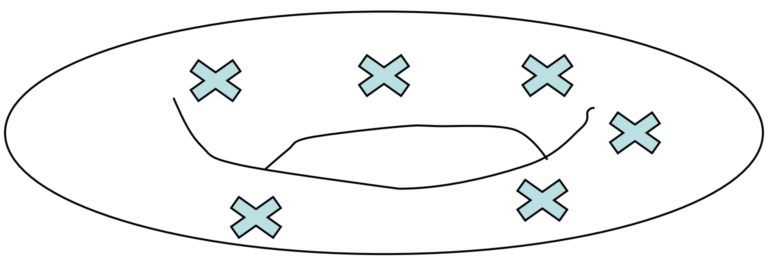
- Far from singular point get (n-1) tensor multiplets on $AdS_5 x S^1 \rightarrow U(1)^{n-1}$ gauge theory on $AdS_5 \rightarrow U(1)^{n-1}$ global symmetry of 4d $\mathcal{N}=2$ SCFT (out of $U(1)^n$ acting on hypers; overall U(1) is geometrical).
- When we go to singular point expect $\mathcal{N}=(2,0)$ theory on S^1 to give an SU(n) gauge theory on AdS_5. Not obvious since strongly coupled ($R_{AdS}=R_S$). Would mean global symmetry of 4d $\mathcal{N}=2$ SCFT enhanced to SU(n).

Failure of naïve expectation

- But can show that global symmetries in 4d $\mathcal{N}$=2 SCFTs cannot be enhanced as a function of exactly marginal deformations (unlike in 4d $\mathcal{N}$=1), except at free points.
- Current multiplet of 4d $\mathcal{N}$=2 cannot continuously become a long multiplet, except when have also conserved higher spin currents (as in free theories).
- Naïve expectation fails; note that W-bosons = wrapped D3-branes are not BPS. (Strings)
- What does happen in 4d $\mathcal{N}$=2 SCFT ?

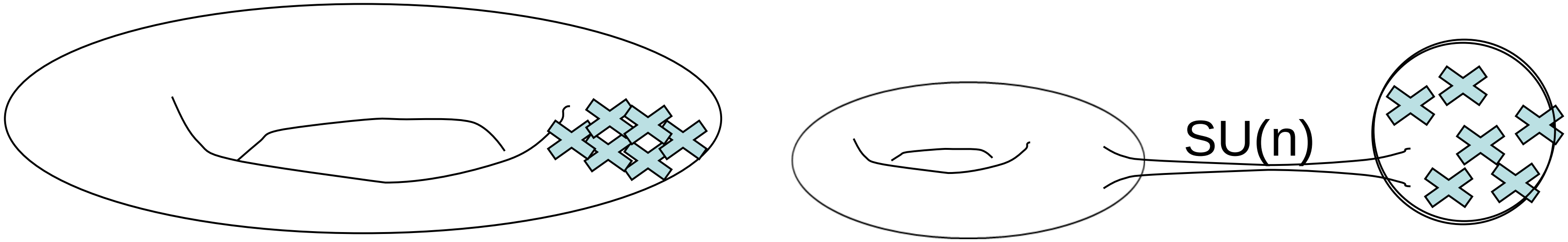
Singular limit in 4d $\mathcal{N}$=2 SCFT

- Space of couplings of $SU(K)^n$ quiver is moduli space of n marked points on a torus (Witten, based on brane construction). In modern language (Gaiotto et al) = A_{K-1} 6d (2,0) theory ($K \neq n$) on a torus with n minimal (U(1)) punctures. Has a weakly coupled $SU(K)^n$ limit.



- Singular limit involves n punctures coming together – (n-1) couplings go to infinity.

Singular limit in 4d $\mathcal{N}$=2 SCFT

- 

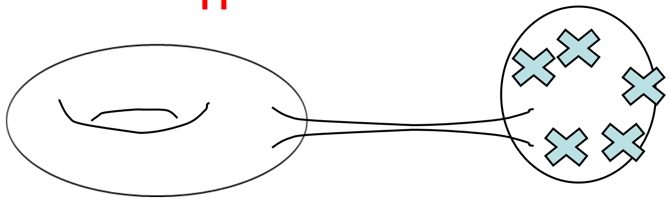
- Studied already (local on Riemann surface). In this limit develop a weakly coupled SU(n) gauge theory, with $g_{SU(n)}$ going to zero at singular point ! It is coupled to two different 4d $\mathcal{N}$=2 SCFTs with an SU(n) global symmetry : A_{K-1} on a torus with a single SU(n) puncture ($Q_{K,n}$) and a sphere with one SU(n) puncture and n U(1) punctures (P_n).

Singular limit in 4d $\mathcal{N}$=2 SCFT

- The new SU(n) is strong-weak dual to original $SU(K)^n$; similar to Argyres-Seiberg where SU(2) arises at strong coupling in 4d $\mathcal{N}$=2 SU(3) theory with N_f=6.
- Implies that 4d $\mathcal{N}$=2 SCFT has at singular point infinite number of conserved high-spin currents (instead of naïve expectation – new global SU(n)). These should somehow map to $\mathcal{N}$=(2,0) theory on $AdS_5 x S^1$.
- Does this theory develop massless high-spin fields ? Strange but not impossible on AdS_5.

Simpler interpretation

- Higher spins seem inevitable, but actually we propose a simpler picture. The new 4d SU(n) and the P_n theory can live on the boundary of AdS_5; can have 4d $\mathcal{N}=2$ theories living there. The 4d SU(n) gauge theory couples to both $Q_{K,n}$ and P_n, and has a vanishing beta function.



- Identify the bulk theory with the $Q_{K,n}$ theory. The 4d SU(n) gauge theory must couple to 5d SU(n) gauge fields on AdS_5, helping to cancel its beta function.

Simpler interpretation

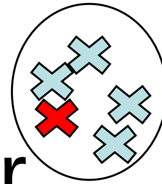
- This picture is related by extra AdS/CFT (for $SU(n) \times P_n$) to picture with high-spin fields in the bulk, but seems much simpler.
- Have SU(n) in AdS_5 but no global symmetry. Usually say unique boundary condition for G gauge fields on AdS_5 !? When have global symmetry G can always gauge it = couple to 4d G gauge fields on boundary. When bulk theory is weakly coupled, get large (R_{AdS}/g_G^2) contribution to beta function of G, inconsistent with conformal symmetry.

Simpler interpretation

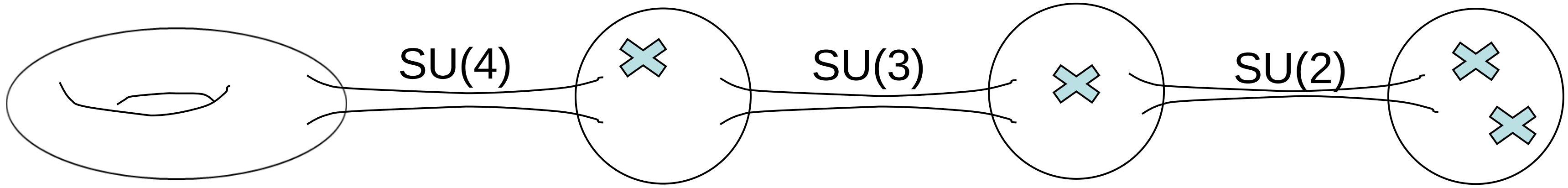
- In our case we know contribution to beta function. Implies bulk 5d SU(n) is strongly coupled at R_{AdS}. Thus, no contradiction with semi-classical analysis of allowed boundary conditions.
- Note that this 5d SU(n) is different from the naïve one we expected; not broken when we go on the moduli space (exactly marginal deformations described by changing couplings of SU(n) and P_n on boundary; $U(1)^{n-1}$ acts on boundary P_n theory).

Moduli space of (2,0) on $AdS_5 x S^1$

- At origin of "moduli space" coupling constant of 4d SU(n) goes to zero – infinitely far away (in natural Zamolodchikov metric).
- Moreover, origin of "moduli space" is not just a point but an (n-2)-dimensional space – space of moduli of P_n theory = a sphere with (n+1) marked points. Big change…

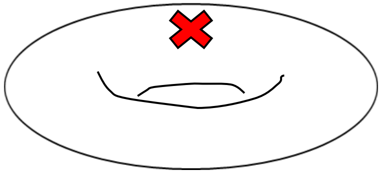


- The P_n theory has a region in its parameter space where it becomes a weakly coupled 4d SU(n-1)xSU(n-2)x…xSU(2) theory with bi-fundamental hypers + 1+n fundamentals.



- Note all beta functions in this chain vanish. $Q_{K,n}$ contributes to beta function of SU(n) like (n+1) fundamental hypers.
- In this region it is easy to compute how many d.o.f. we are adding on the boundary (say in sense of conformal anomalies) : $O(n^3)$. Amusing since bulk 6d (2,0) theory also has $O(n^3)$ d.o.f. But no clear relation – for instance, 6d d.o.f. and 4d d.o.f. lead to a different density of states as a function of temperature / energy.

- This is all for the specific boundary condition that we get from type IIB. Can also take a "standard" boundary condition for 5d SU(n) gauge fields, and then the (2,0) theory is part of the gravitational dual to the $Q_{K,n}$ theory (which has an SU(n) global symmetry). In this case the (2,0) theory has no "moduli space". Does this make sense in full type IIB string theory ?



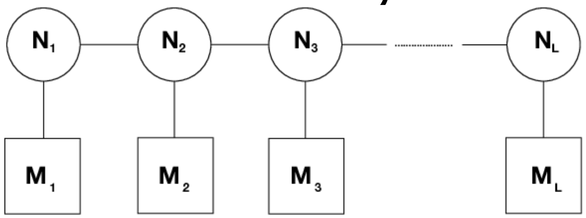
- Interesting to study other boundary conditions and other values of R_{AdS}/R_S; generally no string theory embedding.

A decoupling limit

- Used type IIB to study A_{n-1} $\mathcal{N}$=(2,0) theory on AdS_5xS^1, but, as in flat space, can also decouple it from rest of type IIB. Need to take $M_s \rightarrow \infty$, keeping n, g_s, R_{AdS}, tensions of wrapped D3-branes fixed (0). Bulk theory becomes free, (2,0) remains interacting.
- In $SU(K)^n$ SCFT take $K \rightarrow \infty$ with couplings as above. Limit of 4d $\mathcal{N}$=2 SCFT contains a sector dual to $\mathcal{N}$=(2,0) theory on AdS_5xS^1. Not a SCFT. No local correlators. General : any branes or singularities on AdS_pxM.

Universality of construction

- We embedded the A_{n-1} (2,0) theory on $AdS_5 \times S^1$ in string theory in a specific way. But it also appears in many other places. For instance, linear 4d $\mathcal{N}$=2 quiver SCFTs, arising from D4-branes intersecting and ending on D6-branes and n NS5-branes, have type IIA string theory duals including n NS5-branes wrapping $AdS_5 \times S^1$. So they also include the same A_{n-1} (2,0) theory on $AdS_5 \times S^1$ (and a corresponding decoupling limit).



Universality of construction

- The corresponding 4d $\mathcal{N}=2$ theories come from taking some A_{K-1} (2,0) theory on a different Riemann surface, but again with n minimal punctures. Again the limit where we get at low energies the A_{n-1} (2,0) theory involves bringing the n minimal punctures together. We get a weakly coupled SU(n) theory, coupled to P_n and to some other theory - can repeat the previous discussion.
- A_{n-1} on $AdS_5 x S^1$ (with same b.c.) a universal sector in the large K limit of all these CFTs.

Universality of construction

- A special case of this is the 4d $\mathcal{N}=2$ SU(K) gauge theory with $N_f=2K$, obtained from K D4-branes intersecting two NS5-branes and ending on 2K D6-branes. Here n=2 so gravitational dual is highly curved, especially near the NS5-branes and the D6-branes.
- But can still claim that the A_1 (2,0) SCFT on $AdS_5 \times S^1$ with boundary conditions that couple it to SU(2) + a doublet hypermultiplet, is a decoupled sector in the large K strong coupling limit of this SCFT.

Generalization to LSTs

- In our discussion we did not use the fact that the (2,0) theory was conformal – can use same methods for non-conformal theories. In particular, can study "little string theories" (LSTs) arising from the decoupling limit of n NS5-branes, or a C^2/Z_n singularity, in type II, with $g_s \to 0$ and the string scale M_s fixed.
- We can obtain the (2,0) LST on $AdS_5 x S^1$ from the same starting point of type IIB on $AdS_5 x S^5/Z_n$, by $K \to \infty$ with $g_s K$ fixed ($M_s R_{AdS}$ fixed). Similar but extra BPS string.

Summary

- Argued that A_{n-1} (2,0) theories on $AdS_5 x S^1$ with $R_{AdS}=R_S$ and specific boundary conditions are different from expected – "moduli space" is singular near origin, have SU(n) gauge fields on AdS_5 but different from naive ones arising in flat space.

- This theory appears as a decoupled sector in the large K, strong coupling limit of many 4d $\mathcal{N}=2$ quiver SCFTs.

Further questions

- What can we compute ? In 4d $\mathcal{N}$=2 SCFT can compute many things using localization, and in particular correlation functions of some Wilson/'t Hooft lines on S^4. These map to BPS strings in (2,0), so it should be possible to compute their tension as a function of the couplings of SU(n) and P_n, and some of their correlation functions.
- Are "boundary correlators" (computable in principle) enough to characterize A_{n-1} (2,0) theory on $AdS_5 x S^1$?

Further questions

- What other boundary conditions are allowed? Can we have SU(n) global symmetry and supersymmetry for any R_{AdS}/R_S ? For specific values of R_{AdS}/R_S can we couple to 4d $\mathcal{N}$=2 SU(n) gauge fields+matter on the boundary ? Can we embed these in string/M theory ?
- Can we compute partition function on AdS_5xS^1 by some localization method ? BPS states related to part of index of 4d $\mathcal{N}$=2 SCFTs. (Work in progress Bae+Rey)

Further questions

- Can we relate the SU(n) we found to the SU(n) appearing on $R^5 x S^1$ (perhaps by taking R_{AdS}/R_S large) ?
- Far on moduli space, have a description with $U(1)^{n-1}$ and "moduli" coming from the bulk; near the origin, have a description where they come from the boundary. What is relation between them ? AdS/CFT ? Strong-weak duality (similar to Gaiotto-Witten) ?
- Gravity dual for (2,0) theory on $AdS_5 x S^1$?
- Any relation to infinite chiral algebras? AGT?

Further questions

- Many possible generalizations…
- Other D_n and E_n $\mathcal{N}=(2,0)$ theories on $AdS_5 x S^1$ can be similarly studied using type IIB on $AdS_5 x S^5/\Gamma$, where Γ is the appropriate ADE-subgroup of SU(2)
- Similar methods should be useful for studying various $\mathcal{N}=(2,0)$ theories on $AdS_4 x S^2$ and $AdS_3 x S^3$, 6d $\mathcal{N}=(1,0)$ theories on $AdS_5 x S^1$ and other manifolds, 5d theories on $AdS_4 x S^1$, 4d $\mathcal{N}=4$ SYM on $AdS_3 x S^1$, etc.

Further questions

- Which sets of punctures coming together on a Riemann surface correspond to (2,0) theories on $AdS_5 x S^1$? What happens otherwise ? What happens if you bring together punctures and handles on the Riemann surface ?
- When is there a LST-like limit, with another BPS string ? Seems to arise when bringing punctures together + a 1-cycle in Riemann surface becoming small. New (2,0) LSTs ?