Towards the (2,0) Theory

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M(otivation)

More than 20 years since the 6D (2,0) theory was proposed as the low-energy effective theory for multiple M5 branes [Witten '95; Strominger '95]

$\Rightarrow$ Still trying to understand it!

Progress very slow due to lack of known Lagrangian description

But over the years glimpses have emerged using blends of ideas and techniques

What we know (symmetries)

- $\exists$ a SCA in 6D with $(2,0)$ susy: $D(4,2) \simeq \mathfrak{osp}(8^*|4)$ [Kac '77; Nahm '78]
- This SCA allows for a local stress tensor
- A 6D (2,0) SCFT can have no marginal deformations [Córdova, Dumitrescu, Intriligator '16]
  $\Rightarrow$ isolated SCFTs
- Simplest example is the free-tensor multiplet, but refer to (2,0) as the interacting theory

What we know (string theory)

- These (2,0) SCFTs have associated A, D, E Lie algebras [Witten '95]
- When compactified on an S^1_R they reduce to 5D super Yang–Mills with $\mathcal{N} = 2$ (MSYM)
- At a generic point on their moduli space they reduce to copies of the free-tensor multiplet
- At large N the A_{N-1} theories have a holographic dual in terms of 11D sugra on $\mathrm{AdS}_7 \times S^4$ [Maldacena '97]

What we know (abelian theory)

For abelian theory the susy xmfs and eom's are known. It includes 5 scalars, fermions plus a self-dual 2-form:

$$\mathrm{d}B = H \qquad \text{and} \qquad H = *H$$

For abelian theory we have a gerbe structure

$$B \to B + \mathrm{d}\Lambda$$

⇒ still not possible to write a Lorentz-invariant Lagrangian

$$\int H \wedge *H = 0$$

What we know (abelian theory)

Note: $\exists$ indirect ways of attacking the abelian problem

- ◇ Sacrificing manifest 6D Lorentz invariance
  [Aganagic, Park, Popescu, Schwarz '97]
- ◇ Introducing auxiliary scalar field (PST action)
  [Pasti, Sorokin, Tonin '97; Bandos et al. '97]
- ◇ Holographic action principle for selfdual fields in $(4l+2)$D
  [Belov, Moore '06]

What we don't know

What about the interacting theory? Lagrangian?

- $\Rightarrow$ Lattice?
- $\Rightarrow$ Weak-coupling description via introduction of additional parameter? (e.g. ABJM for M2 branes)

But it's worse: The interacting theory would require nonabelian gerbes with selfdual connection $\Rightarrow$??

$\Rightarrow$ No known Lagrangian, set of generalised susy xfms or eom's [Bekaert, Henneaux, Sevrin '00]

Reductions

However:

- ◇ 6 = 5+1: $\mathcal{N} = 2$ 5D SYM with any gauge group
  [Douglas '11; Tachikawa '11]
- ◇ 6 = 4+2: $\mathcal{N} = 2$ 4D theories, Seiberg-Witten curves,...
  [Witten '97; Gaiotto '09; Gaiotto, Moore, Neitzke '09; Alday, Gaiotto, Tachikawa '10; . . .]
- ◇ 6 = 3+3: Hitchin systems, $\mathcal{N} = 2$ 3D theories,...
  [Gaiotto, Moore, Neitzke '09; Dimofte, Gaiotto, Gukov '11; . . .]
- ◇ 6 = 2+4: 2D (0,2) theories labelled by 4 manifolds,...
  [Gadde, Gukov, Putrov '13; . . .]

Lines of Attack

The 6D (2,0) SCFT is special:

- ◇ CFT with maximal susy in maximal number of dimensions
- ◇ Connections to lower-dimensional QFTs
- ◇ Describes interacting M5 branes

How to approach it?

⇒ Through its connections to lower dimensions

⇒ As an abstract SCFT in 6D

- ◇ Connection to $\mathcal{W}_{\mathrm{ADE}}$ algebras
  [Beem, Rastelli, Van rees '14]
- ◇ Superconformal bootstrap for (2,0) theories
  [Beem, Lemos, Rastelli, Van rees '15]

Relation to 5D SYM

Remind some facts about 5D MSYM at this stage:

- Has a dimensional coupling constant $[g^2_{YM}] = M^{-1}$
- Power-counting non-renormalisable
  $\Rightarrow$ new d.o.f. should appear at some scale
- Nahm's classification of SCFT's in various dimensions says that UV-fixed point theory cannot be 5D.
- Natural to identify this with 6D (2,0) CFT.
  $\Rightarrow$ fits nicely with string theory intuition [Seiberg '98]

From string theory the relation between D4- and M5-brane theories given by compactification on $S^1_{R_6}$.

Hence there are at first three distinct gauge theories at play: $\Uparrow$

- ◇ 5D SYM, as an effective theory up to some cutoff scale
- ◇ Its UV completion including some new d.o.f.
- ◇ The 6D UV fixed-point (2,0) CFT

By dimensional analysis one can relate:

$$g_{YM}^2 \sim R_6$$

From string theory the relation between D4- and M5-brane theories given by compactification on $S^1_{R_6}$.

Hence there are at first three distinct gauge theories at play: $\Downarrow$

- The 6D (2,0) CFT
- Its compactification on S^1 keeping all KK modes
- Its KK reduction leaving only 5D MSYM theory

By dimensional analysis one can relate:

$$g_{YM}^2 \sim R_6$$

But: 5D SYM has topological $U(1)$ conserved current

$$*J = \frac{1}{8\pi^2}\mathrm{tr}(F \wedge F)$$

$\Rightarrow$ $\exists$ states that carry instanton charge k

Instanton-soliton BPS states with mass

$$M \propto \frac{k}{g_{YM}^2} \propto \frac{k}{R_6}$$

Interpretation of k as S^1 momentum of compactified 6D theory.
[Rozali '97; Berkooz, Rozali, Seiberg '97]

$\Rightarrow$ Even in Yang-Mills limit this tower of states knows about M-theory direction; at least in the BPS sector

Proposal

All KK modes of (2,0) on S^1 included in 5D SYM. No new d.o.f. need to be added in the UV:

(2,0) CFT on S^1 keeping all KK modes

$$\Updownarrow$$

5D SYM including all states carrying instanton charge

$\Rightarrow$ Strong coupling limit of SYM defines the (2,0) theory

$\Rightarrow$ Implications for renormalisability and finiteness of 5D MSYM

[Douglas ’11; Lambert, CP, Schmidt-Sommerfeld ’11]

Evidence

Matching of simple $\frac{1}{2}$- and $\frac{1}{4}$-BPS states between two theories in the tensor branch

Significant progress due to susy localisation

- ◇ The superconformal index of a theory on $\mathbb{R}^6$ counts operators in certain short multiplets of the SCA
- ◇ Via the operator-state map, it can be mapped to a path integral on $S^5 \times S^1$
- ◇ Could the partition function of 5D MSYM on S^5 give back the 6D index?
- ◇ Yes: Calculation uses localisation. Agrees with AdS/CFT [Källén, Zabzine '12; Kim^2 '12; ...]

Well-definedness of 5D MSYM

For highly susy theories superspace predicts the first counterterms being generated at high orders in perturbation theory: 6-loops for 5D MSYM.

Modern techniques allow the direct evaluation of the coefficients for these counterterms. Finiteness of 5D SYM would imply that:

a) Either: all of these coefficients are zero and the theory is perturbatively finite
b) Or: the instanton-solitons play a crucial role and cancel the UV divergences

First sharp prediction of a) in the evaluation of $\mathrm{tr} D^2 F^4$ coefficient. It turns out to be nonzero [Douglas '11; Bern, Carrasco, Dixon, Douglas, von Hippel, Johansson '12]

$\Rightarrow$ a) is out

Implementing b) also difficult and unusual: soliton-antisoliton loops?

In general, soliton pair production is expected to be suppressed by

$$e^{-R_S/R_C}$$

[Banks '12; CP, Royston '14]

But: in 5D SYM solitons are instantons and $R_S = \rho$ is a modulus

$\Rightarrow$ When $\rho \sim R_C$ the suppression argument breaks down...

$\Rightarrow$ Introduce these quantum states in by hand...?

Note: The calculation of the 5D MSYM could still make sense even if b) is not realised. Localisation only sensitive to a protected subsector

$\Rightarrow$ Classification of susy, Lorentz and R-symmetry preserving irrelevant operators...? [Chang, Lin, Wang, Yin '14 & '15]

Summary

- ◇ Revisited general aspects of (2,0) SCFT in 6D
- ◇ Status of the relation to 5D MSYM
- ◇ Also: Deconstruction proposal for $(2,0)_{\mathsf{A}_{k-1}}$ theories...
- ◇ Also: DLCQ approach to (2,0)...
- ◇ Also: 3-algebra approach to (2,0)...

⇒ Goal: Creatively combine all of the above along with chiral algebra and bootstrap approaches