N=3 higher spin holography and Higgs phenomenon

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Based on collaborations with

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1. INTRODUCTION

Higher spin gauge theory

- Higher spin gauge theory
  - A totally symmetric rank-*s* field

    $$\varphi_{\mu_1 \ldots \mu_s} \sim \varphi_{\mu_1 \ldots \mu_s} + \partial_{(\mu_1} \xi_{\mu_2 \ldots \mu_s)}$$

  - Natural extension of electromagnetism (*s*=1) and gravity (*s*=2)
  - Vasiliev theory is famous as a non-trivial theory on AdS
- Applications
  - Tensionless limit of superstring theory
    - Superstring theory includes massive higher spin states, and the tensionless limit should be related to higher spin gauge theory
  - Simplified version of AdS/CFT correspondence
    - More tractable AdS/CFT correspondence can be constructed than using superstring theory

AdS_4/CFT_3

- Klebanov-Polyakov proposal ’02

4d Vasiliev theory ⟷ 3d O(*N*) vector model

- – Correlation functions [Giombi-Yin ’09-’10]
  - CFT correlators are reproduced from Vasiliev theory w/ GKP-W relation
- – Role of higher spin symmetry [Maldacena-Zhiboedov ’11-’12]
  - Higher spin symmetry is mostly enough to fix the correlators
- – ABJ triality [Chang-Minwalla-Sharma-Yin ’12]
  - 4d extended Vasiliev theory ⬄ 3d ABJ theory ⬄ Superstrings on AdS_4xCP^3
  - Concrete relations between superstrings and higher spin fields via AdS/CFT

AdS_3/CFT_2

- Gaberdiel-Gopakumar proposal ’10

3d Vasiliev theory ⟷ 2d large *N* minimal model

  - More tractable than AdS_4/CFT_3
    - 3d higher spin gauge theory is topological
    - 2d conformal symmetry is enhanced to be infinite dimensional

- Extensions
  - Supersymmetry [CHR,Candu,Gaberdiel,Beccaria,Groher ’12-’13]
  - AdS_3 version of ABJ triality [Gaberdiel-Gopakumar,CHR ’13-’15]
    - 3d extended Vasiliev theory ⇔ 2d coset model ⇔ Superstrings on AdS_3 x M^7
    - Higgs phenomenon of higher spin fields [HR, CH ’15, Gaberdiel-Peng-Zadeh ’15]

Plan of the talk

1. Introduction
2. Higher spin gauge theory
3. AdS_4/CFT_3: ABJ triality
4. AdS_3/CFT_2: Our conjecture
5. Conclusion

2. HIGHER SPIN GAUGE THEORY

Free theory for higher spin fields

- Higher spin gauge symmetry

$$\delta\varphi_{\mu_1\dots\mu_s}=\partial_{(\mu_1}\xi_{\mu_2\dots\mu_s)},\ \ \varphi^{\lambda\sigma}_{\lambda\sigma\mu_5\dots\mu_s}=0,\ \ \xi^{\lambda}_{\lambda\mu_3\dots\mu_s}=0$$

- Equations of motion [Fronsdal '78]

$$\mathcal{F}_{\mu_1\dots\mu_s}\equiv\Box\,\varphi_{\mu_1\dots\mu_s}-\partial_{(\mu_1|}\partial^{\lambda}\varphi_{|\mu_2\dots\mu_s)\lambda}+\partial_{(\mu_1}\partial_{\mu_2}\varphi_{\mu_3\dots\mu_s)\lambda}{}^{\lambda}=0$$

$$\left(\begin{aligned}&\partial^{\mu}F_{\mu\nu}=\partial^{\mu}\partial_{\mu}A_{\nu}-\partial_{\nu}\partial\cdot A=0\ (\text{spin }1)\\&R_{\mu\nu}=\Box\,h_{\mu\nu}-\partial_{\mu}\partial\cdot h_{\nu}-\partial_{\nu}\partial\cdot h_{\mu}+\partial_{\mu}\partial_{\nu}h_{\lambda}{}^{\lambda}=0\ (\text{spin }2)\end{aligned}\right)$$

- Action

$$S=\tfrac{1}{2}\int d^Dx\,\varphi^{\mu_1\dots\mu_s}\left(\mathcal{F}_{\mu_1\dots\mu_s}-\tfrac{1}{2}\eta_{(\mu_1\mu_2}\mathcal{F}_{\mu_3\dots\mu_s)\lambda}{}^{\lambda}\right)$$

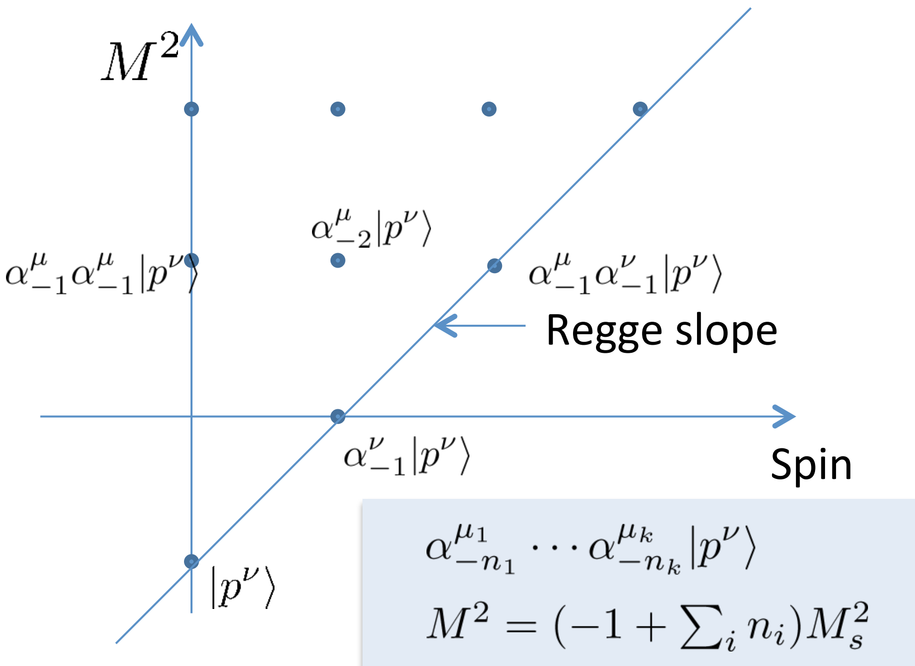
  – Uniquely fixed by the gauge transformation

Interacting theory

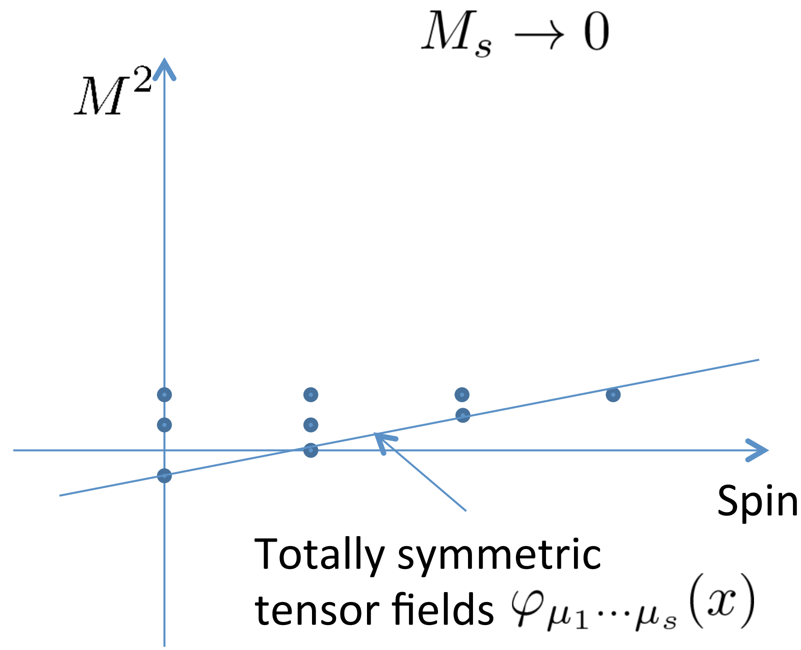
- Difficulty
  - Free theory of higher spin fields is not so difficult
  - No-go theorems [e.g., Weinberg '64] forbid non-trivially interacting higher spin gauge theory (with some assumptions)
- Non-trivial theories
  - Vasiliev theory
    - Defined on AdS space with all higher spins ($s = 2,3,\ldots,\infty$)
    - Only equations of motion are known
  - Higher spin AdS_3 gravity
    - Topological theory (Chern-Simons descriptions)

Strings ⇔ Higher spin fields

- String spectrum



- Tensionless limit



- Higher spin gauge symmetry may appear at the tensionless limit
- The theory can be examined using the (broken) large symmetry

Towards the Gross's speculation

- Backgrounds
  - Superstring theory may be given by a broken phase of higher spin gauge theory [Gross '88]
  - Recent developments are made by working on AdS space
    - Vasiliev theory as a non-trivial higher spin gauge theory on AdS space
    - AdS/CFT correspondence utilizing the Vasiliev theory
- Concrete proposals
  - Relations between superstrings and higher spin fields via AdS/CFT
    - AdS_4/CFT_3 ➔ ABJ triality [Chang-Minwalla-Sharma-Yin '12]
    - AdS_3/CFT_2 ➔ AdS_3 versions [Gaberdiel-Gopakumar, CHR '13-'15], Higgsing [HR, CH '15, Gaberdiel-Peng-Zadeh '15]

3. ADS$_4$/CFT$_3$: ABJ TRIALITY

Klebanov-Polyakov

- Klebanov-Polyakov conjecture '02

4d Vasiliev theory ⟷ 3d O(N) vector model

- O(N) vector model

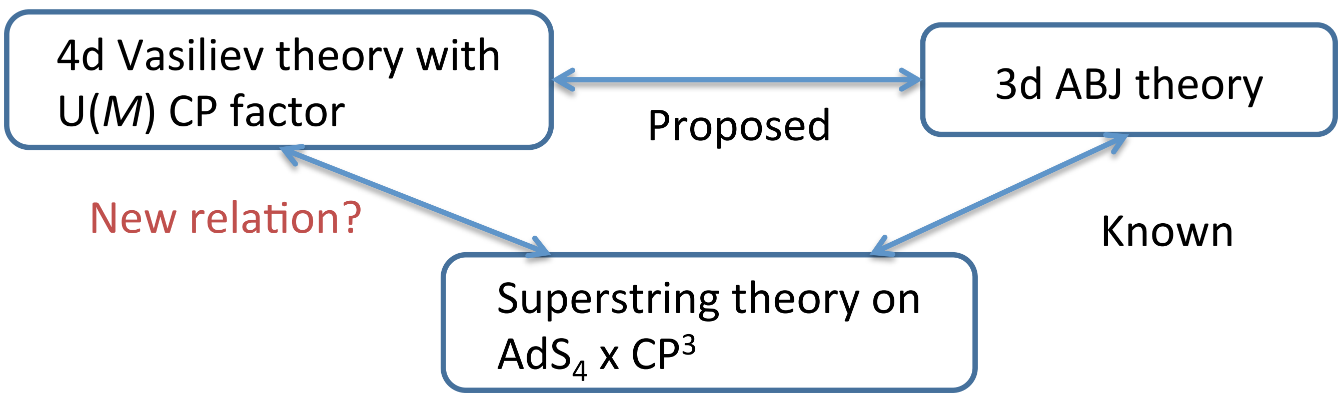
$$S = \sum_{i=1}^{N} \int d^3x \partial^\mu h^i \partial_\mu h^i$$ + O(N) invariant constraint

- State counting

	Bulk fields	Higher spin currents
Vector-like model	One higher spin field $\varphi_{\mu_1 \cdots \mu_s}$	$\sum_{i=1}^{N} h^i \partial_{(\mu_1} \cdots \partial_{\mu_s)} h^i$
Matrix-like model	Many string states with fixed total spin $\alpha_{-n_1}^{\mu_1} \cdots \alpha_{-n_k}^{\mu_k} \vert p\rangle$	$\mathrm{tr}[\nabla^{m_1} X \nabla^{m_2} X \cdots \nabla^{m_j} X]$

ABJ triality

- Klebanov-Polyakov proposal '02
  - 4d Vasiliev theory ⇔ 3d O(N) vector model
- ABJ triality [Chang-Minwalla-Sharma-Yin '12]
  - HS side: 4d Vasiliev theory with U(M) Chan-Paton factor
  - CFT side: 3d U(N)$_k$ x U(M)$_{-k}$ Chern-Simons-Matter theory (ABJ theory)
  - String side: Superstring theory on AdS$_4$ x CP^3



Adding CP factor

- 3d ABJ theory
  - Bi-fundamentals under U(N) x U(M) gauge symmetry

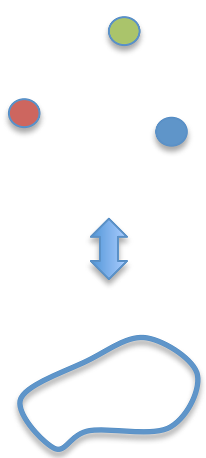
$$A_i^{\alpha}, B_{\beta}^{j} \ (i, j = 1, 2, \ldots, N, \ \alpha, \beta = 1, 2, \ldots, M)$$

- Higher spin region: $M << N$
  - ‘t Hooft parameter is stronger for U(N) than U(M)

U(N) invariant currents — Higher spin fields

$$[J_{\mu_1 \ldots \mu_s}]^{\alpha}{}_{\beta} = A_i^{\alpha} \partial_{(\mu_1} \cdots \partial_{\mu_s)} B_{\beta}^{i} \quad \Longleftrightarrow \quad [\varphi_{\mu_1 \ldots \mu_s}]^{\alpha}{}_{\beta}$$

- String region: $M \approx N >> 1$
  - $\mathrm{tr}[ABAB \cdots AB]$ ⇔ strings
  - Single-string state ⇔ Multi-particle state of higher spin fields



4. ADS$_3$/CFT$_2$: OUR CONJECTURE

Gaberdiel-Gopakumar

- Gaberdiel-Gopakumar conjecture ’10

3d Vasiliev theory ⟺ 2d W_N minimal model

- 3d Vasiliev theory [Prokushkin-Vasiliev ’98]
  - Massless sector: Gauge fields with spin $s = 2,3,\ldots,\infty$
  - Massive sector: Complex scalar fields with mass $M^2 = -1 + \lambda^2$
- Minimal model w.r.t. W_N algebra
  - Coset description: $(\mathrm{su}(N)_k \oplus \mathrm{su}(N)_1)\,/\mathrm{su}(N)_{k+1}$
  - ’t Hooft limit: $k, N \to \infty, \ \lambda = N/(N+k)$: finite
- Evidence
  - Symmetry, partition function, correlation functions,…

Lower dimensional triality

- Gaberdiel-Gopakumar proposal '10
  - 3d Vasiliev theory ⇔ 2d W_N minimal model
- Extension [CHR '13] (c.f. [Gaberdiel-Gopakumar '13] for *M*=2)
  - HS side: 3d Vasiliev theory with U(*M*) CP factor
  - CFT side: 2d coset-type model at 't Hooft limit $$\frac{\mathrm{su}(N+M)_k \oplus \mathrm{so}(2NM)_1}{\mathrm{su}(N)_{k+M} \oplus \mathrm{u}(1)}$$
- Related superstring theory
  - *N*=4 holography [Gaberdiel-Gopakumar '13-'15]
    - *N*=4 SUSY ➔ Superstrings on $AdS_3 \times M^7$ ($M^7 = S^3 \times S^3 \times S^1$ or $S^3 \times T^4$)
    - U(2) CP factor ➔ String bit picture is obscure
  - Holography with U(*M*) CP factor [CHR '14, HR '15]
    - *N*=3 SUSY at *k*=*N*+*M* ➔ M^7 = SO(5)/SO(3) (or SU(3)/U(1))??
    - BPS spectrum is shown to agree (cf. [Argurio-Giveon-Shomer '00])

Marginal deformation & Higgsing

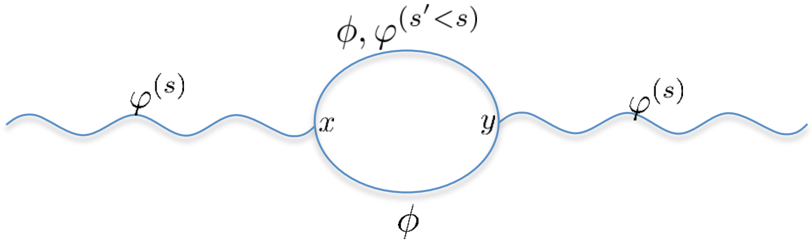
[HR '15]

- Turn on string tension

Superstring theory	CFT	Higher spin gauge theory
Tensionless limit	2d $\mathcal{N}$=3 coset model	3d $\mathcal{N}$=3 Vasiliev theory
Turning on string tension	Double-trace type deformations	Change of boundary conditions for bulk fields

[Witten '01]

- Higgs mass of spin s fields from one loop effects



  – Non-standard boundary conditions for ϕ induces non-trivial mass term
    - For a massive graviton [Porrati '01, Duff-Liu-Sati '02, Kiritsis '06, Aharony-Clark-Karch '06]
    - For higher spin fields on AdS_4 [Girardello-Porrati-Zaffaroni '02]

CFT methods

- Higgs phenomenon from CFT
  - Conserved current ⇔ Higher spin fields are massless

    $$\partial \cdot J^{(s)} = 0$$

  - Non-conserved current ⇔ Higher spin fields are massive

    $$\partial \cdot J^{(s)} = \alpha \mathcal{O}^{(s-1)}$$

- Higgs mass from scaling dimension
  - Scaling dimension can be computed by

    $$\begin{aligned} |\partial \cdot J^{(s)}|^2 &\propto (\Delta - s - d + 2)\langle J^{(s)} | J^{(s)} \rangle \\ &= |\alpha \mathcal{O}^{(s-1)}|^2 = \alpha^2 \langle \mathcal{O}^{(s-1)} | \mathcal{O}^{(s-1)} \rangle \end{aligned}$$

  - Dictionary for AdS_{d+1}/CFT_d

$$M^2_{(s)} = \Delta(\Delta - d) - (d + s - 2)(s - 2)$$

Our results

- The masses of spin *s* fields
  - Leading in $1/N$ (or $1/c$) but all order in f^2 [HR, CH '15]

$$\begin{cases} M_{(s)}^2 = 0 & (\mathrm{so}(3)_R \text{ singlet}) \\ M_{(s)}^2 = \frac{12(s-1)}{c} \frac{f^2}{(1+f^2)^2} & (\mathrm{so}(3)_R \text{ triplet}) \end{cases}$$

- Comments

$$\left(c = \tfrac{3}{2} M N = \tfrac{3}{2G_N}\right)$$

  - $M^2 = 0$
    - Similar results were obtained at the leading order of f in [Gaberdiel-jin-Li '13]
    - Probably masses are generated at the higher order of M/N except for s=2
  - $M^2 \propto s$-1
    - Superstrings with pure NSNS-flux?? (M/N-corrections should be checked)
    - $M^2 \approx s \log(s)$ ⇔ superstrings with pure RR-flux [Gaberdiel-Peng-Zadeh '15]

5. CONCLUSION

Summary

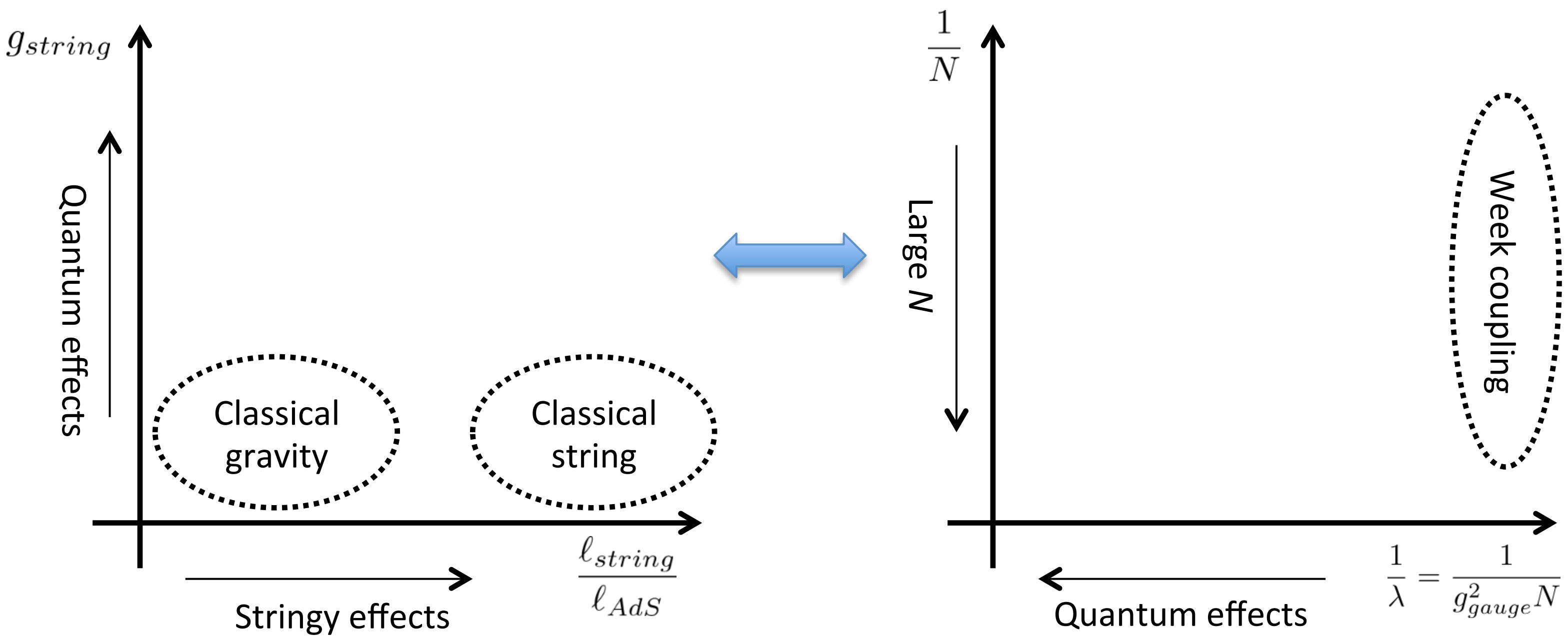
- Three trialities among higher spin fields, strings and CFT

	CFT ⇔ Strings	HS⇔ Strings	Tractability
ABJ triality (AdS_4)	○	○	△
N=4 triality (AdS_3)	○	△	○
N=3 triality (AdS_3)	△	○	○

- Higgs masses from the symmetry breaking
  - Compare to string spectrum
    - *M*/*N*-corrections should be computed
    - Understand AdS_3/CFT_2 with *N*=3 SUSY
  - Generalize to the ABJ triality
    - The methods for 3d CFTs have been developed

The map of AdS/CFT

- Superstrings on AdS_5xS^5
- 4d U(N) gauge theory



- Tensionless limit of string theory (higher spin gauge theory) can be dual to a perturbative region of gauge theory
- Higher spin gauge theory is easier to solve than string theory