M-theory S-Matrix from 6d CFT

Shai M. Chester
Princeton University

Based on arXiv:1805.00892 with E. Perlmutter
M-theory S-Matrix

- M-theory is a quantum theory of interacting supergravitons in 11d with no dimensionless coupling.

- Graviton S-matrix in small momentum ($\ell_{11} \ll 1$) expansion:

\[
\mathcal{A}(s, t, u) = \ell_{11}^9 \mathcal{A}_R(s, t, u) + \sum_{m=0}^{\infty} \ell_{11}^{15+2m} \mathcal{A}_{D^2mR^4}(s, t, u) + \text{Loops}
\]

- Protected terms from type IIA string theory + duality [Green, Tseytlin]:
  \[
  \mathcal{A}_{R^4} = \mathcal{A}_R \frac{stu}{3 \cdot 2^7}, \quad \mathcal{A}_{D^2R^4} = \mathcal{A}_{D^4R^4} = 0, \quad \mathcal{A}_{D^6R^4} = \mathcal{A}_R \frac{(stu)^2}{15 \cdot 2^{15}}.
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- Goal: Find all tree level terms $\mathcal{A}_{D^{2m}R^4}$ for $m > 3$ using AdS/CFT.
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M-theory contains two non-perturbative dynamical objects: M2 branes and M5 branes.

We study \((2, 0)\) \(A_{N-1}\) 6d SCFT that describes stack of \(N\) M5 branes, and is dual at large \(N\) to M-theory on \(AdS_7 \times S^4\).

We compute:

\[
G_k(U, V) = x_{12}^{2k} x_{34}^{2k} \left\langle \mathcal{O}_k \mathcal{O}_k \mathcal{O}_k \mathcal{O}_k \right\rangle
\]

of \(k\)-th lowest dimension half-BPS operators in CFT\(_6\) in large \(N\) expansion.

\(U \equiv \frac{x_{12}^2 x_{34}^2}{x_{13}^2 x_{24}^2}\), \(V \equiv \frac{x_{14}^2 x_{23}^2}{x_{13}^2 x_{24}^2}\) are conformal cross ratios.

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We use Mellin transform \( G_k(U, V) \rightarrow M_k(s, t, u) \) [Mack, Penedones], where \( s, t, u \) are like Mandelstam variables in Mellin space.

For \( N \) large, let \( M_{\text{tree}}^k(s, t, u) \equiv \sum_{p=1}^{\infty} M^{(p)}_k(s, t, u) \), where \( p \) is degree in \( s, t, u \rightarrow \infty \), and \( M^{(p)}_k \) fixed in terms of CFT\(_6\) data by:

1. Crossing symmetry.
2. Superconformal Ward identities [Dolan, Gallot, Sokatchev; Rastelli, Zhou].
3. Poles in \( s, t, u \) correspond to dimensions of operators in \( \mathcal{O}_k \times \mathcal{O}_k \), for tree level only allow poles for half-BPS operators.

Flat space limit of \( M^{(p)}_k(s, t, u) \) gives \( 2p \) derivative contribution to \( \mathcal{A}|_{7d}(s, t, u) \) [Penedones], e.g. \( M^{(1)}_k \rightarrow \mathcal{A}_R|_{7d} \).
Tree Level Half-BPS Four Point functions: Constraints

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- \( M^{(1)}_k \) fixed by central charge \( \frac{1}{c_T} \approx N^{-3} \) \cite{Rastelli, Zhou} \( \Rightarrow A_R|_{7d} \) is proportional to gravitational coupling \( \kappa^2 \approx N^{-3} \) as expected.

- No \( M^{(p)}_k \) for \( p = 2, 3 \) \( \Rightarrow \) no \( A_{R^2}|_{7d} \) or \( A_{R^3}|_{7d} \) \cite{SMC, Perlmutter}.

- \( M^{(p)}_k \) for \( 4 \leq p < 10 \), which gives \( A_{D^{2p-8}R^4}|_{7d} \) in flat space limit, fixed by small set of CFT\(_6\) OPE coefficients \cite{SMC, Perlmutter}.

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- \( M^{(4)}_k \) fixed by half-BPS OPE coefficient \( \lambda_{\text{BPS}}^2 \) \cite{SMC, Perlmutter} that can be computed exactly \cite{Beem, Rastelli, van Rees}.

  - Flat space limit of \( M^{(4)}_k \) correctly reproduces the known \( A_{R^4}|_{7d} \)!
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Conclusion

Results:

- Tree level $D^{2m}R^4$ contributions to 11d M-theory S-matrix for $m < 6$ in terms of CFT$_6$ data.

- Known half-BPS CFT$_6$ data precisely reproduces $R^4$ contribution.

Future Directions:

- Derive loop Mellin amplitudes $\Rightarrow$ loop 11d S-matrix terms.

- 6d numerical bootstrap [Beem, Lemos, Rastelli, van Rees] to fix CFT$_6$ data $\Rightarrow$ 11d S-matrix coefficients.

- Apply method to AdS$_{d+1}$/CFT$_d$ for other $d$.

  - See Silviu Pufu’s talk tomorrow for $d = 3$ case [SCM, Pufu, Yin].

See my poster for more details!