# A (Brief) Review of "Little String Theories"

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# Outline

- Definition and simple properties.
- Motivations.
- Useful constructions using DLCQ and holography.
- Behavior at finite energy density/temperature.
- Future directions.

# Definitions

- The simplest definition of "little string theories" (LSTs) is the $g_s \to 0$ limit of k overlapping NS5-branes in type IIA (N=(2,0)) or IIB (N=(1,1)) string theory. This gives a non-trivial non-gravitational d=6 theory, with a scale $M_s$ inherited from the underlying string theory, and no other parameters (no coupling constant).
(Seiberg; Berkooz, Rozali, Seiberg)
- Equivalent definitions :

* (2,0) : (I) M5-branes with transverse circle,
$R \to 0, M_p \to \infty, RM_p^3 = M_s^2 = const.$
(II) IIB on ALE singularities, $g_s \to 0.$
ADE classification.

* (1,1) : (I) D5-branes with $g_s \to \infty.$
(II) IIA on ALE singularities, $g_s \to 0.$

# Simple Properties

- Classification of theories with 16 supercharges : (2,0) and (1,1) SUSY, ADE (many more theories with 8 supercharges).
- Low energy limit is SYM with $g_{YM}^2 = 1/M_s^2$ for (1,1) SUSY, non-trivial SCFT for (2,0).
- Moduli space is $\mathbf{R}^{4r}/W$ for (1,1) SUSY, $(\mathbf{R}^4 \times S^1)^r/W$ for (2,0) SUSY.
- T-duality symmetry, $R \leftrightarrow 1/M_s^2 R$, (2,0) is interchanged with (1,1). Indication of non-locality, no unique energy-momentum tensor after compactification.
- BPS strings with tension $T = M_s^2$ (at origin of moduli space). The (2,0) LST has no other BPS states before compactification, the (1,1) LST has also low-energy gluons.

# Motivations

- Non-trivial non-gravitational six dimensional theories. Related to many other interesting theories by compactification.
- "Stringy" theories without gravity (T-duality, Hagedorn spectrum). Intermediate theories between local field theory and string theory.
- Toy models for studying DLCQ.
- Interesting examples of holography and non-locality.
- Applications for M(atrix) theory, brane constructions, ...

# Useful Constructions : I. DLCQ

- DLCQ descriptions of LSTs may be derived directly (as in Seiberg's derivation of M(atrix) theory), or from M(atrix) theory with 5-branes. For all LSTs we find a 1+1 dimensional N=(4,4) SCFT compactified on a circle of radius $\Sigma = 1/M_s^2 R$.
- (2,0) P_=N/R : sigma model on moduli space of N instantons of the appropriate (ADE type) group. Equivalently (for $A_{k-1}$), it is the IR theory of the Higgs branch of U(N) SQCD with k hypermultiplets. The space is singular (for example, for $A_1$ it contains an $\mathbf{R}^4/\mathbf{Z}_2$ singularity with zero theta angle), but the sigma model on it seems to make sense in the DLCQ context.

(OA, Berkooz, Kachru, Seiberg, Silverstein; Witten)

- (1,1) $P_- \equiv N/R$ (with longitudinal Wilson line) : IR theory of the Coulomb branch of appropriate ADE-type quiver gauge theory. For example, for $A_{k-1}$, the $U(N)^k$ SQCD theory with bifundamental hypermultiplets. (Sethi; Ganor, Sethi)

- The DLCQ construction gives an explicit non-perturbative definition of LSTs, enabling (in principle) computations of all their states and correlation functions. However, in practice such computations are very complicated, since the relevant theories are far from trivial even before taking the large N limit. As usual in DLCQ, it is difficult to study other points in the moduli space or compactifications, both of which lead to much more complicated theories.

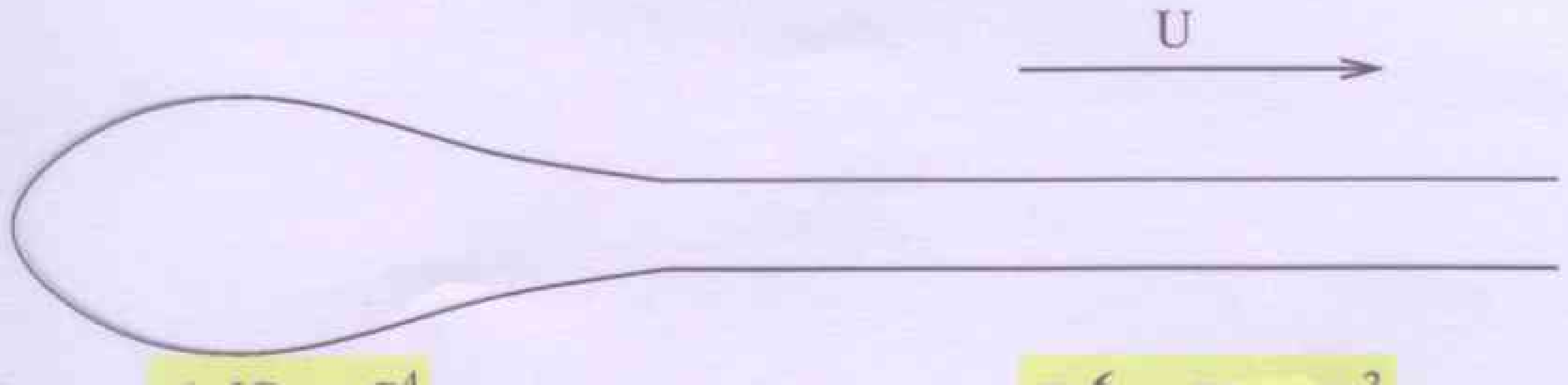
# Useful Constructions : II. Holography

- The holographic description of LSTs is derivable, as in the AdS/CFT correspondence (Maldacena), by taking the near-horizon limit of the relevant 5-branes. This description is useful mainly in the (2,0) case, since the (1,1) case leads to singular backgrounds (as for generic D-branes).
- The $A_{k-1}$ (2,0) LSTs are holographically dual to M theory compactified on the space

$$l_p^{-2} ds^2 = H^{-1/3} dx_6^2 + H^{2/3}(dx_{11}^2 + dU^2 + U^2 d\Omega_3^2),$$

$$H = \sum_{j=-\infty}^{\infty} \frac{\pi k}{(U^2 + (x_{11} - 2\pi j M_s^2)^2)^{3/2}},$$

with k units of 4-form flux on $S^3 \times S^1$.




$AdS_7 \times S^4$ $\qquad$ $\mathbf{R}^6 \times \mathbf{R} \times S^3$

- This manifold smoothly interpolates between $AdS_7 \times S^4$ (for small U) and an $\mathbf{R}^6 \times \mathbf{R} \times S^3$ linear dilaton ("throat") background of string theory (for large U).
  (OA, Berkooz, Kutasov, Seiberg; Maldacena, Strominger; Itzhaki, Maldacena, Sonnenschein, Yankielowicz; Boonstra, Skenderis, Townsend)
- The holographic description is useful for :

* Using supergravity to compute the low-energy states and correlation functions (Minwalla, Seiberg), for large k and low energies where supergravity is applicable. This describes the 't Hooft limit of the LST (where $M_s^2/k$ is kept constant). The LST correlators are related to the S-matrix.

* Seeing a continuous (naively seven dimensional) spectrum above $M \sim M_s/\sqrt{k}$.

* Identifying LST operators using the "throat" string theory; nice relation between ADE classifications of SU(2) modular invariants and of LSTs. ...

# Behavior at Finite Energy Density/Temperature

- The holographic description allows the computation of the equation of state at finite temperature/energy density, via the dual black hole configuration. We find

  $E = T_H S; \quad T_H = M_s / \sqrt{6k},$

  for $A_{k-1}$, independently of the volume. The derivation is reliable for large k and large energy densities (much above $M_s^6$).
- Exponential density of states at high energies, like free string theory. Generic high-energy state is a single long string?
- General arguments suggest non-locality at the Hagedorn scale $T_H$ (e.g. no Fourier transform for correlation functions) (Peet, Polchinski; OA, Banks); note that this scale is different from the naïve string scale $M_s$, related to T-duality.

- The DLCQ analysis naively gives the same equation of state, but a careful analysis is required to find the density of states whose energy scales as $E \sim 1/N$ in the large $N$ limit. At least in the (1,1) case there seem to be "long string" states with the correct behavior, similar to those of type IIA string theory (work in progress).
- Unlike standard string theory, here $T_H$ seems to be a limiting temperature; there is no clear sign of a phase transition.
- The equation of state for intermediate energy scales, between the field theory behavior and the Hagedorn behavior (for instance, for high energies in the 't Hooft limit), is still unclear.

# Future Directions

- High energy behavior : is the theory an "asymptotically free" string theory? If so, is there a simpler construction of the theory? If not, what is it?
- Intermediate energy behavior : can compute correlation functions from supergravity (in the 't Hooft limit), what does the theory behave like in this regime?
- The holographic behavior implies many interesting results in the DLCQ descriptions, like the continuous spectrum of states; these states should be found in the corresponding 1+1 dimensional field theories (work in progress).
- Compactifications.