STRINGS

ON

P-P- WAVES

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OUTLINE

(1) STRINGS ON PP WAVES FROM GAUGE THEORY

D. BERENSTEIN, J.M., H. VASTASE

⋮

(2) WORLD-SHEET DYNAMICS ON P-P WAVES

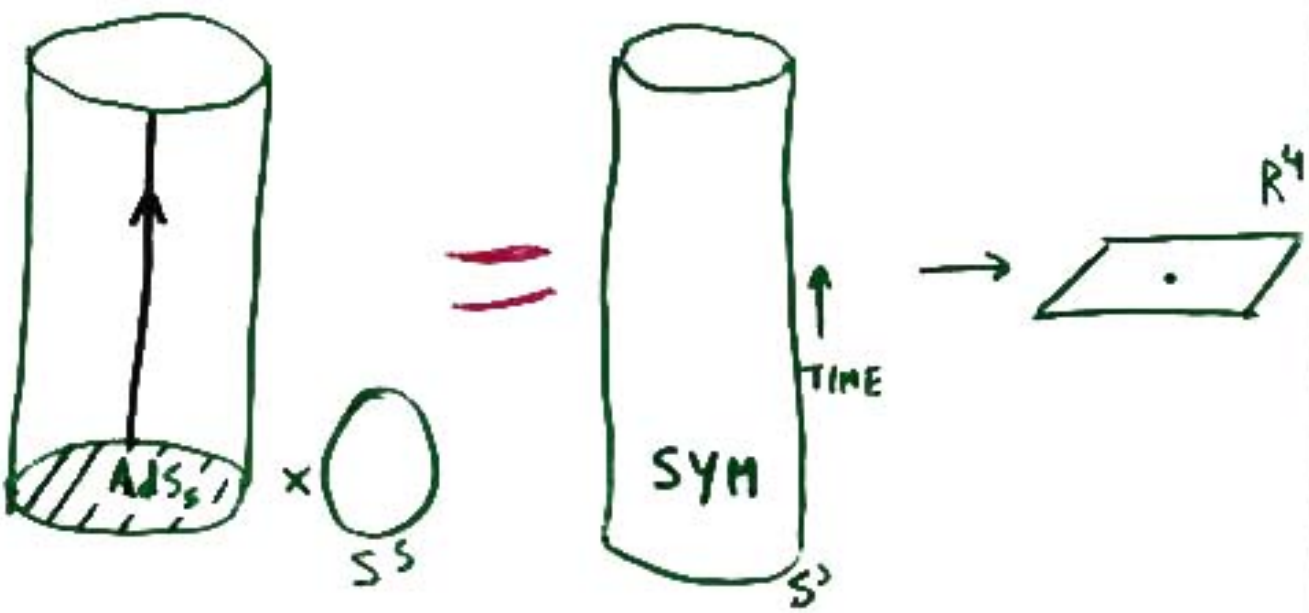
J.M. & L. MAOZ

J.M. & BERKOVITS

IIB STRINGS ON $AdS_5 \times S_5$ = $\mathcal{N}=4$ SUPER-YANG-MILLS ON $S^3 \times \mathbb{R}$

$$R_{AdS} = R_{S^5} = (g_{YM}^2 N)^{1/4}$$

$$\int_{S^5} F_5 = N = \text{NUMBER OF COLORS}$$



STATE S — STATES ON S^3 — OPERATORS ON $\mathbb{R}^4$

ENERGY E — ENERGY E = Δ (CONFORMAL DIMENSION)

PLANE WAVE LIMIT

J = ANGULAR MOMENTUM ON S^5 $= U(1) \subset SO(6)$ R-CHARGE OF THE OPERATOR

$J \to \infty$
$R \to \infty$ $\quad \frac{J}{R^2} \sim \frac{J}{\sqrt{g^2_{YM} N}}$ - FIXED

BLAU FIGUEROA-O'FARRILL HULL PAPADOPOULOS

$AdS_5 \times S_5 \to$ PLANE WAVE

$$ds^2 = -dx^+ dx^- - r^2 (dx^+)^2 + d\vec{r}_8^{\,2}$$

$$-P_- = \frac{J}{R^2}$$

$$-P_+ = \Delta - J$$

STRING SPECTRUM ON PLANE WAVES

- COVARIANTLY CONSTANT NULL KILLING VECTOR $\sim \frac{\partial}{\partial x^-}$

- ACTION SIMPLIFIES IN LIGHT CONE GAUGE

$$x^+ = \tau$$

→ FIX $-P_-$ $(\sim p^+)$

METSAEV

$$S_{l.c.} = \int d\tau \int_0^{|P_-|} d\sigma \; (\partial x)^2 - \mu^2 x^2 + \bar{S}\not{\partial} S + S \not{M} S$$

$\uparrow$ g_{++} METRIC

$\uparrow$ RR FIELDS

- QUANTIZE

$$H_{l.c.} = -P_+ = \sum_{n=-\infty}^{\infty} N_n \sqrt{\mu^2 + \frac{m^2}{(\alpha' P_-)^2}}$$

$$\Delta - J = \sum_{n=-\infty}^{\infty} N_n (\Delta - J)_n \quad ; (\Delta - J)_n = \sqrt{1 + \frac{g^2 N n^2}{J^2}}$$

YANG MILLS OPERATORS

$$Z = \phi^1 + i\phi^2 \qquad ; \quad J = J_{12}$$

$$Tr[Z^J] \longleftrightarrow |0\, P_-\rangle_{s.c.}$$

$$\sum_l Tr[Z^l W Z^{J-l}] \leftrightarrow (\alpha_0^\nu)^\dagger |0, P_-\rangle_{s.c.}$$

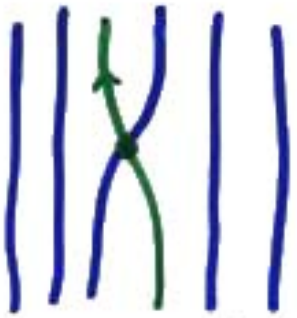
$$\sum_l Tr[\cdots Z^l W Z^{J-l}] e^{\frac{2\pi i m l}{J}} \leftrightarrow -(\alpha_m^\nu)^\dagger |0, P\rangle_{s.c.}$$

$$\sum_{l_1 \cdots l_n} Tr[Z^{l_1} W \cdots\cdots] e^{\frac{2\pi i \sum m_i l_i}{J}} \leftrightarrow \prod_i (\alpha_{m_i}^{\cdot})^\dagger |0 P\rangle$$

$P_6 = \sum m_i = 0$ ENSURED BY CYCLICITY OF THE TRACE

$\Delta - J \sim 1$ FREE Y.M.

INTERACTIONS →



$$\Delta - J = 1 + \frac{1}{2}\frac{g^2 N m^2}{J^2}$$ 1-LOOP

SANTAMBROGIO & ZANON

$$\Delta - J = \sqrt{1 + \frac{g^2 N m^2}{J^2}}$$ ALL LOOPS

↑

IF LARGE → FLAT SPACE LIMIT

. STRING OF Z 's → DEFINE A LATTICE

→ OTHER EXCITATIONS MOVE ALONG IT

$J \to \infty$ ≈ CONTINUUM LIMIT

. Z 's ≈ STRING BITS

. PRECISE MATCH IN THE SPECTRUM.

WORLDSHEET DYNAMICS ON INTERESTING P-P-WAVES

. STUDY BACKGROUNDS WITH RR FIELDS OF THE p-p WAVE FORM

$$ds^2 = -dx^+ dx^- + g_{++}(y)(dx^+)^2 + dy^2$$

$$F_5 = dx^+ \wedge \varphi_4$$

. CONSIDER NON-CONSTANT 4-FORMS.

↔ GET <u>INTERACTING</u> THEORIES IN LIGHT CONE GAUGE

• THEORIES WITH (2,2) SUSY ON THE WORLDSHEET IN LIGHTCONE GAUGE

$$S_{L.C.} = \int dt \int_0^{|P^-|} dx \int d^4\theta \sum_{i=1}^{4} \phi_i \bar{\phi}_i + \int d^2\theta\, W(\phi) + c.c.$$

$W(\phi)$: ARBITRARY SUPERPOTENTIAL

WE CAN FIND A GRAVITY BACKGROUND GIVING THIS:

$$\mathcal{P}_4 = \partial_i \partial_j W \times (1,3)\text{-FORMS} \quad + c.c.$$

$$\mathcal{P}_4 = \partial_i \partial_j W\, \gamma^{jk}\, \epsilon_{k_1 \ldots k_4}\, dz^i dz^{k_1} \ldots dz^{k_4}$$

$$g_{++} = |\partial W|^2$$

<u>SUSY</u>: GENERIC W → ONLY 4-SUPERTIME SUSY

$$\{Q_+, Q_+\} \sim -P_+ = H_{L.C.}$$

- <u>NO</u> $\{Q_-, Q_-\} \sim P_-$ SUSY ✗

(THESE SUSY IMPLIES WE HAVE FREE FERMIONS ON THE W.S.)

ARE THESE SOLUTIONS?

- ARE OK AT ONE LOOP IN α'
  (SINCE THEY ARE SUGRA SOLUTIONS)

- ONE CAN USE BERKOVITS' $SU(4) \ltimes U(4)$
  INVARIANT FORMALISM TO SHOW
  THAT IT IS A SOLUTION (IN PROGRESS)

GENERALITIES

. R-G FLOW ON THE WORLDSHEET

→ BOOSTS IN +- DIRECTIONS

SPACETIME	WORLDSHEET
SMALL $\|P_-\|$	U.V.
u	
FLAT SPACE	FREE CFT
SMALL RR FIELDS	
LARGE $\|P_-\|$	I.R.
HIGH CURVATURE (HIGH TIDAL FORCES)	GENERICALLY WE HAVE A MASS GAP

MASSIVE PARTICLES MOVING ALONG THE STRING

INTEGRABLE MODELS

Example:

. $\mathcal{N}=2$ SINE GORDON MODEL

$$\mathcal{L} = \int d^4\theta\, \phi\bar{\phi} + \int d^2\theta \sim \cos\beta\phi + \text{c.c.}$$

$$\phi|_{\theta=\bar{\theta}=0} = \varphi + i\rho$$

$$|dW|^2 \sim \cosh 2\beta\rho - \cos 2\beta\varphi$$

$$\varphi \sim \varphi + \frac{2\pi}{\beta}$$

. PARTICLE SPECTRUM

$$M_m = 2M_s \sin\left(\frac{m\beta^2}{16}\right)$$

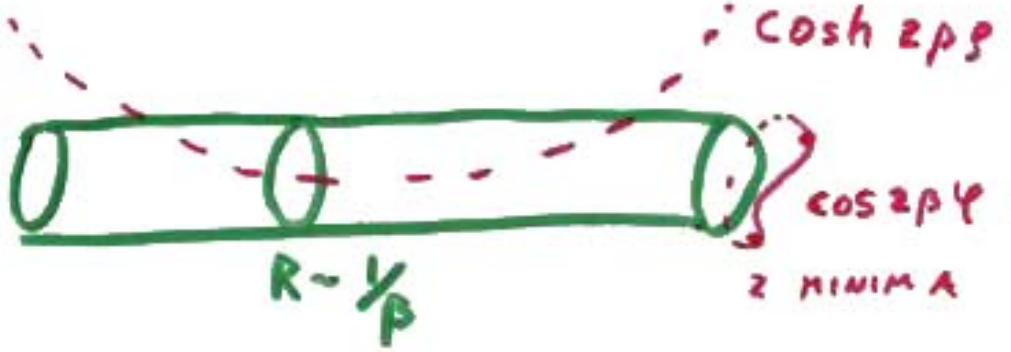
$$m = 1 \ldots N \qquad N = \left[\frac{8\pi}{\beta^2}\right]$$

. LARGE $|\beta|$ → VERY BIG WORLDSHEET

→ CAN USE ∞ SPACE PARTICLE SPECTRUM AND S-MATRIX

. SMALL β → SEMICLASSICAL LIMIT

~ SLOWLY VARYING AB FIELDS



. LARGE β → STRONGLY QUANTUM S.G.

ONLY THE SOLITONS SURVIVE IN THE SPECTRUM.

→ "T-DUALITY" - MIRROR SYMMETRY

→ SAUSAGE MODEL

. FENDLEY - INTRILIGATOR

. HORI KAPUSTIN

$\beta = \infty$

→ ROUND $CP^1 \sim S^2$

. SMALL P_- → LARGE CP^1

. STRINGS WITH SMALL $|P_-|$ SEE A LARGE TRANSVERSE SPACE

. STRINGS WITH LARGE $|P_-|$ → SEE SMALL SPACE.

. WHAT IS THE STRING BACKGROUND THAT GIVES RISE TO THE CP^1 MODEL IN LIGHT CONE GAUGE ?

• MASS SCALE OF THE LIGHT CONE THEORY

$$m^2 \sim \partial_\alpha X^+ \partial_\alpha X^+$$

• TERMS LIKE

$$m^2 F(x) \rightarrow \partial_\alpha X^+ \partial_\alpha X^+ F(x)$$

$$\Rightarrow F(x) = g_{++}(x)$$

. IN CP^1

$$\mathcal{L}_{eff} \sim \log(E^2/m^2)\left(\partial\theta^2 + \sin^2\theta(\partial\gamma)^2\right)$$

$$\downarrow$$

$$\log(E^2/(\partial x^+)^2)\left[\partial^2\theta + \sin^2\theta(\partial\gamma)^2\right]$$

→ LOOKS LIKE HIGHER STRING MODES ARE EXCITED

SUMMARY

- WE FOUND A CLASS OF BACKGROUNDS WHICH ARE OF THE PP-WAVE FORM
- THEY LEAD TO INTERACTING MASSIVE THEORIES IN LIGHT CONE GAUGE
- MASSIVE MIRROR SYMMETRY → LEADS TO SURPRISING BACKGROUNDS