TIMELIKE T-DUALITY, BRANES AND DE SITTER SPACE

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9807???

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STRINGS 98

$\mathbb{R}^m \times T^{n,1}$

LORENTZIAN TORUS (FLAT)
n SPACE, 1 TIME.

SOLUTION OF STRING + M-THEORIES

CLOSED TIMELIKE CURVE

CONSIDER BOUNDARIES OF MODULI SPACE

STRINGS ON TIMELIKE S^1 [MOORE]

T-DUALITY $R \to \frac{1}{R}$

SYMMETRY OF BOSONIC + HETEROTIC STRINGS

STRANGE FEATURES;
SWAPS p^0 WITH TIME WINDING No

$(p^0, \underset{\sim}{p}) \to (0, \underset{\sim}{p})$ TACHYONIC

(IF NO WINDING NOS. ORIGINALLY)

DIM REDUCTION ON $T^{n,1} \to$ EUCLIDEAN THEORY IN $\mathbb{R}^m$

- IIA, IIB T-DUAL ON SPACELIKE S^1
- CHECK: REDUCTION OF IIA, IIB SUGRA'S GIVE SAME 8+1 SUGRA
- BUT REDUCTION ON TIMELIKE S^1 OF IIA,B GIVE DIFFERENT SUGRAS

[CREMMER, LAVRINENKO, LU, POPE, STELLE, TRAN]

$\Rightarrow$ IIA,B NOT T-DUAL ON TIMELIKE S^1

- DEFINE 9+1 STRING THEORIES

$$\left.\begin{array}{l} \text{IIA}^* \\ \text{IIB}^* \end{array}\right\} \begin{array}{c} \text{TIMELIKE T-DUAL OF} \\ R \to 0 \text{ LIMIT OF IIA,B} \\ \text{ON TIMELIKE } S^1\text{, RADIUS } R \end{array} \left\{\begin{array}{l} \text{IIB} \\ \text{IIA} \end{array}\right.$$

$\mathrm{II}B^* = \lim_{R\to 0}$ OF $\mathrm{II}A$ ON TIMELIKE S

$= \lim_{R_1, R_2 \to 0}$ OF M ON LORENTZIAN TORUS T^{1}

SCALAR COSET $SL(2;\mathbb{R})/SO(1,1)$

RR SCALAR HAS <u>WRONG SIGN</u> KINETIC TERM

$\delta^{ij} \to \eta^{ij} = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$ $\qquad H^i_{\mu\nu\rho} = \partial_{[\mu} B^i_{\nu\rho]} + \ldots$

$L \sim \eta_{ij} H^i_{\mu\nu\rho} H^{j\,\mu\nu\rho} + i\eta_{ij} \bar{\psi}^i_\mu \Gamma^{\mu\nu\rho} \nabla_\nu \psi^j_\rho + \ldots$

<u>TWISTED</u> SUPERSYMMETRY:

$\{Q^i, Q^j\} = \not{P}\, \eta^{ij} \qquad i,j = 1,2$

Q^1, Q^2: SAME CHIRALITY IN $\mathrm{II}B^*$

OPPOSITE CHIRALITY IN $\mathrm{II}A^*$

II A, B* SUGRA:

$$\int d^{10}x \sqrt{-g}\left(e^{-2\Phi}\left(R + 4(\nabla\Phi)^2 - H^2\right) + \sum_n |dC_n|^2 + \cdots\right)$$

'WRONG' SIGN

RR n-FORM

$C_n \to i C_n$ IN BOSONIC ACTION

II A, B* STRING :— ACT ON II A, B STRING WITH

i^{F_L} ← LEFT-HANDED FERMION NO.

Dp - BRANES OF TYPE II $\xrightarrow[\text{T-DUALITY}]{\text{TIMELIKE}}$

Ep - BRANES OF TYPE II*

NEUMANN $x^1, \dots, x^p$

DIRICHLET $y^{p+1}, \dots, y^9, t$

p - DIMENSIONAL EUCLIDEAN PLANE AT FIXED $\underset{\sim}{y}, t$

D0 - BRANE : PARTICLE WORLD-LINE

E1 - BRANE : TACHYON WORLD-LINE

SUPERGRAVITY SOLUTION:

$$ds^2 = H^{-\frac{1}{2}} d\underset{\sim}{x}^2 + H^{\frac{1}{2}} \left(d\underset{\sim}{y}^2 - dt^2 \right)$$

$H(\underset{\sim}{y}, t)$ HARMONIC FUNCTION

WORLD-VOLUME THEORY

N EP-BRANES:— U(N) SUPER Y.M.
IN p EUCLIDEAN DIMS, 16 SUSY'S
FROM 9+1 SUPER Y.M. ON $T^{9-p,1}$
$SO(9-p,1)$ R-SYMMETRY

SCALAR FROM A_0 HAS KINETIC TERM OF 'WRONG' SIGN, 'GHOST.'
TRUNCATED THEORY HAS GHOST, BUT IF KALUZA-KLEIN TOWERS ARE KEPT, HIGHER DIMENSIONAL GAUGE INVARIANCE CAN BE USED TO ELIMINATE A_0.

A_0: COLLECTIVE COORD FOR BRANE-TIME

N E4-BRANES →

U(N) SUPER Y.M. IN 4 EUCLIDEAN DIMENSIONS SO(5,1) R-SYMMETRY

SO(4) LORENTZ SYMMETRY

SO(5,1) CONFORMAL SYMMETRY

MUST BE SUPERCONFORMAL GROUP CONTAINING SO(5,1) × SO(5,1):

→ SU*(4/4) 32 FERM. GENS

5-DIM. SUPER DE SITTER GROUP ?

THIS EUCLIDEAN SUPER YANG-MILLS THEORY CAN BE TWISTED → TOPOLOGICAL YM

[ACHARYA, FIGUEROA-O'FARRILL, O'LOUGHLIN, SPENCE
BLAU, THOMPSON]

IIB* HAS SOLUTION

5-DIM DE SITTER dS_5 $\frac{SO(5,1)}{SO(4,1)}$

$\times$ 5-DIM HYPERBOLIC SPACE H^5 $\frac{SO(5,1)}{SO(5)}$

ISOMETRY: $SO(5,1) \times SO(5,1)$

MAXIMALLY SUPERSYMMETRIC: 32 KILLING SPINORS

SUPER de SITTER INVARIANCE $SU^*(4/4)$

E4-BRANE INTERPOLATES BETWEEN

$dS_5 \times H^5$ AND FLAT SPACE

$\Rightarrow$ DUALITY BETWEEN LARGE-N

EUCLIDEAN SUPER Y. M.

AND IIB* STRING IN $dS_5 \times H^5$?

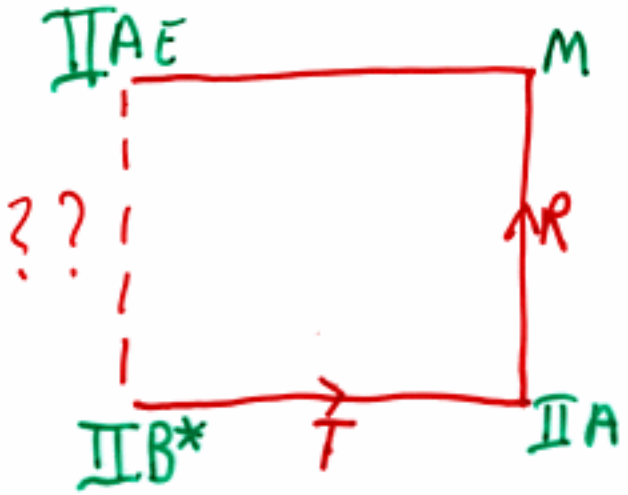
- OTHER 'NEW' THEORIES ?
- STRONG-COUPLING LIMITS OF IIA, IIB*?
- M-THEORY ON TIMELIKE S^1 10+1

→ $\underline{\text{IIA}_E}$ EUCLIDEAN STRING THEORY 10+0

2+1 BRANE → 2+0 BRANE, EUCLID: WORLD SHEET

WHAT IS T-DUAL OF IIA_E? (SPACELIKE S^1)

A EUCLIDEAN IIB ?? OR: IIB*



M ON $T^{1,1}$

TIMELIKE S^1, RAD T
SPACELIKE S^1, RADIUS R

IIB* HAS DIFFERENT SIGNATURE & ALREADY HAS A T-DUAL

$\underline{\text{IIB}^*}$: $L \sim -e^{-2\phi}(dB_2)^2 + (dC_2)^2 + \ldots$

FUND. STRINGS, 1+1 WORLD SHEET $\sim B_2$

E2 BRANES 2+0 W.S. COUPLES TO C_2

STRONG COUPLING: $\phi \to -\phi$, $B_2 \leftrightarrow C_2$

$\to$ $\underline{\text{IIB}' \text{ STRING}}$

$$L \sim e^{-2\phi'}(dB_2')^2 - (dC_2')^2 + \ldots$$

FUND. 2+0 BRANE, COUPLES TO B_2'

D-STRING 1+1 W.S., COUPLES TO C_2'

PERTURBATIVE IIB': 'EUCLIDEAN' STRINGS

T-DUAL OF IIAE $\longrightarrow$ IIB'

EUCLIDEAN WORLD-SHEET, INSTEAD OF TARGET SPACE

T-DUALITY: $X(\sigma,\tau) \longrightarrow \tilde{X}(\sigma,\tau)$

$$\partial_\alpha X = \epsilon_\alpha{}^\beta \partial_\beta \tilde{X}$$

$$(\partial_\alpha X)(\partial^\alpha X) = \eta (\partial_\alpha \tilde{X})(\partial^\alpha \tilde{X})$$

LORENTZIAN W.S.: $\eta = 1$, $X, \tilde{X}$ SAME SIG

EUCLIDEAN W.S. $\eta = -1$, $X, \tilde{X}$ DIFF. SIG

FOR EUC. W.S., T-DUALITY CHANGES SIGNATURE

IIAE ON SPACELIKE S^1, RADIUS R

$\equiv$ IIB′ ON TIMELIKE S^1, RADIUS $1/R$

IIB′ STRONG COUPLING DUAL OF IIB* IN 9+1 IIAE IN 10+0

SPACELIKE T-DUALITY: IIB'_{9+1}

$\longrightarrow$ SIGNATURE 8+2 ??

STRONG COUPLING LIMIT OF IIA*

- IIA* SUGRA CAN'T BE OBTAINED FROM 11-D SUGRA
- CAN BE OBTAINED FROM 9+2

$$L \sim R + (dC_3)^2 + C_3 \wedge dC_3 \wedge dC_3$$

'WRONG' SIGN

THIS IS <u>ONLY</u> 11-D FIELD THEORY GIVING IIA* ON REDUCTION

- INFINITE TOWER OF E1-BRANES OR TACHYONS BECOME MASSLESS AS $g_s \to \infty$, KK TOWER FOR DECOMPACTIFYING EXTRA TIME

M* THEORY IN 9+2 DIMS

M-THEORY ON $T^{2,1}$ $(T^3, (++-))$
IN LIMIT IN WHICH $T^{2,1}$
SHRINKS TO ZERO SIZE
$\rightarrow$ M* IN 9+2

ON TIMELIKE S^1 : IIA* IN 9+1
ON SPACELIKE S^1 : IIA_{8+2} IN 8+2

$g_{\mu\nu}$, $C_{\mu\nu\rho}$, ψ_μ PSEUDO-MAJORANA
9+2 SUPERGRAVITY THEORY

M^*_{9+2} ON SHRINKING $T^{3,0}$

$\rightarrow$ M' THEORY IN 6+5 DIMS

D = 11 M-THEORIES

10+1, 9+2, 6+5 (1+10, 2+9, 5+6)

D = 10 IIA THEORIES

10+0, 9+1, $9+1^*$, 8+2, 6+4, 5+5, $5+5^*$

D = 10 IIB THEORIES

9+1, $9+1^*$, (9+1′), 7+3, 5+5, $5+5^*$ (5+5′)

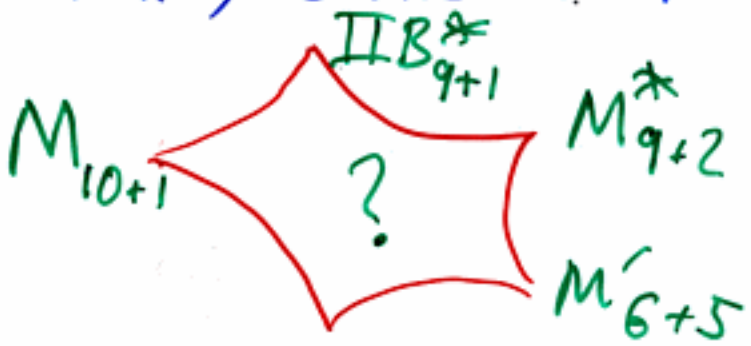
D = 12 F-THEORIES

11+1, 10+2, 9+3, 7+5, 6+6

$\rightarrow$ ZERO-SLOPE OR LOW 'ENERGY' LIMITS GIVES CORRESPONDING SUPERGRAVITY THEORIES.

CONCLUSIONS

- DUALITY CAN CHANGE SPACE-TIME SIGNATURE, SIGNS OF KINETIC TERMS...



ALL 'CORNERS' OF MODULI SPACE

- DIFFERENT REAL FORMS OF 'COMPLEX' THY
- DE SITTER SPACES AND BRANES OF VARIOUS SIGNATURES [CMH + KHURI]
  D-BRANES, E-BRANES etc
- NEW SUPERGRAVITIES
- THEORIES HAVE SOLUTIONS $\mathbb{R}^{p+q}$
  TIMELIKE COMPACTIFICATIONS USED TO LINK THEM