



# STRINGS

99

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SUMMARY

D. GROSS

# STRINGS '99

1968

1970

NAL

UNITARIZATION OF DRM

⋮

1985

Argonne

{ ANOMALY CANCELLATION  
HETEROTIC STRING  
C-Y Compactification

⋮

1995

USC

Dualities  
↓  
M-theory

1996

UCSB

M(atrix) Th.

1997

UA

↓  
ADS/CFT

1998

UCSB

1999

AEI

↓  
NON COM. GEO.

2000

U Mich

2000 1/2

TATA

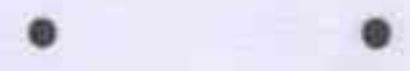
2002

U Cambridge

?



*"It's all string theory to me."*



# HANNIBAL

by Thomas Harris

Sequel to

The Silence of the Lambs

" LATE IN THE NOVEL Lecter sits in  
AN ARMCHAIR DOING MATHEMATICAL CALCULATIONS

'The PAGES ARE FILLED WITH THE SYMBOLS  
OF BOTH ASTROPHYSICS AND PARTICLE  
PHYSICS. THERE ARE REPEATED EFFORTS  
WITH THE SYMBOLS OF STRING THEORY.

THE FEW MATHEMATICIANS WHO COULD FOLLOW  
HIM MIGHT SAY HIS EQUATIONS BEGIN  
BRILLIANTLY AND THEN DECLINE, DOOMED  
BY WISHFUL THINKING.'

.... BRING ON THE NOISY LAMBS, THEN. THEY  
MIGHT AS WELL BE ROARING."

BOOK REVIEW in NYTIMES 6/10/99

# TESTS + APPLICATIONS OF ADS/CFT

- Ren. Group Flows Gubser, Warner
- Instanton MATCHING Green, Okers, Staudacher
- $\langle O^{(L)} O^{(R)} \rangle + \mathcal{T}^{\text{ABSOAB}}$  Klebanov
- Black Holes de Wit, Hawking, Horowitz, Peet
- Anomalies Theisen.
- Wilson Loops Ooguri, Sonnenschein
- $AdS_2$  Maldacena • D1-D5 Dijkgraaf, Maldacena
- NON SUSY/BPS SCENARIOS
- NON BPS D branes Sen, Schwarz, Gates, Horava
- Type 0 theories Klebanov, Blumenhagen, Sagnotti
- Tachyon Condensates Kachru
- BRANE WORLDS Antoniadis, Bachas, Ibanez, Ovrut, Verlinde
- QUANTIZATION Kallosh, Berkowitz
- BRANBIOLOGY Douglas, Mayr, Townsend, Karch
- Little String Theory Aharony
- DLCQ / SUSYM Polchinski
- HOLOGRAPHY Bousso, Gibbons
- MATRIX MODEL Hoppe, Yoneya
- NON-commutative GAUGE THEORY Seiberg, Witten  
Maldacena

# Instantons + AdS/CFT

Green,

Dorey  
Hollowood  
Khoze  
Morrison  
Vandoren

Use IIB STRING THEORY + SL(2, Z) + SUSY

$$\mathcal{L}_{\text{eff}} \sim e^{-2\phi} R + \alpha'^2 e^{-\frac{\phi}{2}} R^4 F_1^{(10,0)}(\tau, \bar{\tau}) + \dots$$

$$\langle \Lambda^{16} \rangle \sim F_{16}(\tau, \bar{\tau}) \int_{\text{AdS}_5 \times S^5} d^{10} X \dots$$

dilatino

$$c_1 q^{-1} + c_2 q^2 + \dots \quad q = e^{2\pi i \gamma} \quad \gamma = \frac{4\pi i}{g^2} + \frac{\theta}{2\pi}$$

## GAUGE THEORY

INSTANTON Moduli Space  $\sim \int d^4 X \frac{d\rho}{\rho^5} \int d^{8N-16} \gamma^i e^{-\sum_{A,B} (\gamma_A \cdot \gamma_B)}$

$k=1$

POSITION in  $R^4$

↑ scale = radial in  $\text{AdS}_5$

↑ fermionic 'zero modes'

$$X_{AB} = \frac{1}{N} \epsilon^{ABCD} \sum_{i=1}^{N-2} \gamma_{iA}^\alpha \gamma_{iB}^\alpha$$

$A, B = 1 \dots 4$

$$\int_{\text{AdS}_5} \times \int d^4 X d^{8N-16} \gamma^i e^{-N|X|^2 + \epsilon^{ABCD} X_{AB} (\gamma_A \cdot \gamma_B)}$$

$$= \int d^4 X \frac{d\rho}{\rho^4} \int d^{5-1} X \int dx (|X|^N e^{-N X^2} \xrightarrow{N \rightarrow \infty} \delta(X-1))$$

FINITE  $N = 1/g_s \Rightarrow$  LOOKS LIKE  $\text{AdS}_5 \times S^5 \times I$ ! 11 DIM

# Black Holes

CORRECTIONS TO AREA COUNTING LAW

DEWIT

For IIA on CY 3 folds, ...

SUGRA calculation using: susy enhancement  
HIGHER DERIV. TERMS R<sup>4</sup>  
WALD'S CORRECTION

IT WORKS  $S_{\text{MICRO}} \approx S_{\text{MACRO}}$ .

Rotating Black Holes in AdS

HAWKING

KERR

✓

RN

?

{ AdS<sub>5</sub>  
susym

NO PHASE TRANSITION

(But see Cvetič + Gibbons!)

BOSE-EINSTEIN  
CONDENSATION ?

QUASI-NORMAL Modes

HOROWITZ

$$\frac{\text{Im} \omega}{r_+} = 2.66$$

← Schw. radius

lowest freq.

of ringing black holes

$$\approx e^{2.67 \cdot \gamma}$$

UNSTABLE MODE OF  
CRITICAL BH in d=4

P BRANE HAIR

PBET

wee branes have no hair (p. 1)

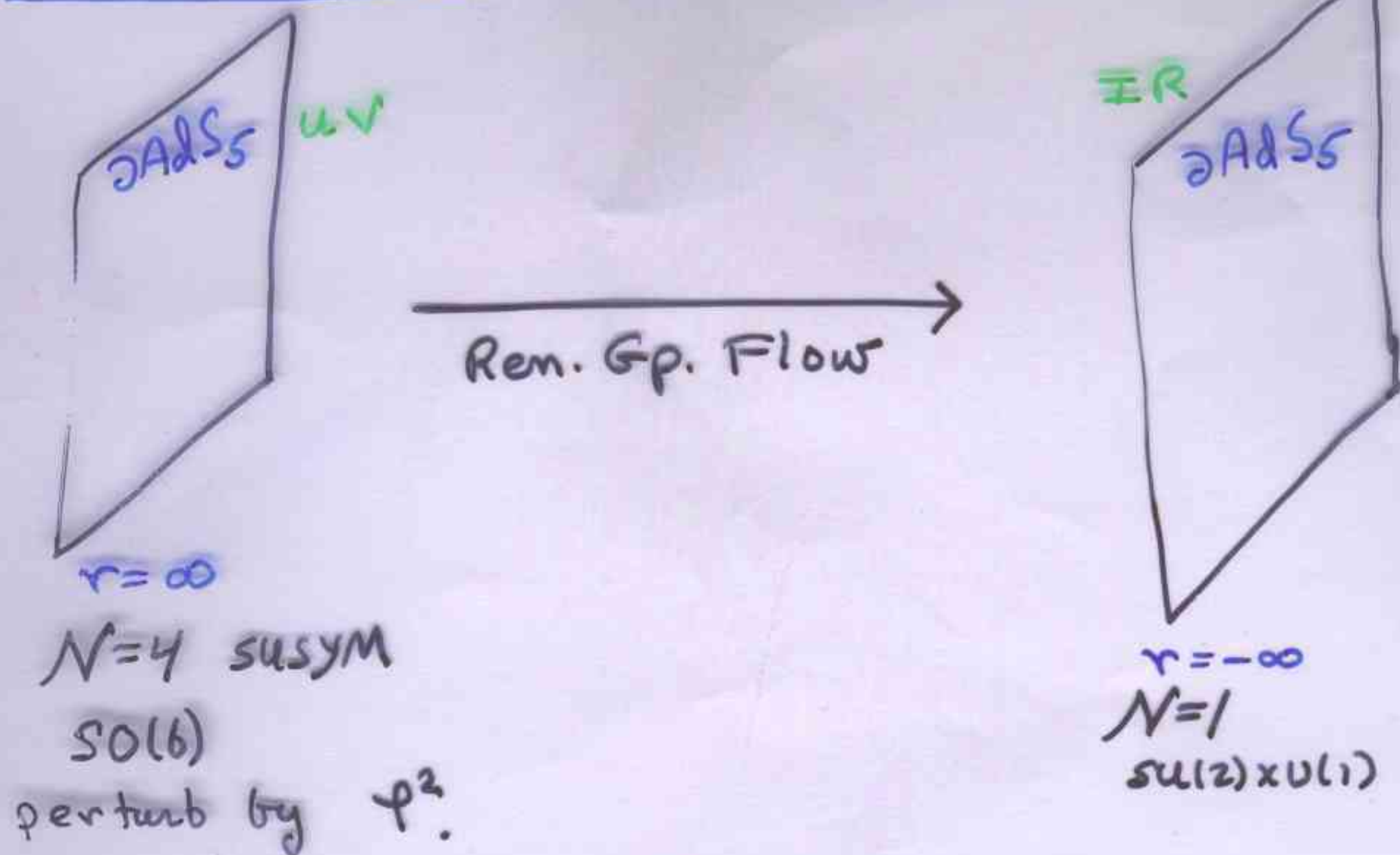


delocalize for small p.



# Ren. Group Flows

Talks of Gubser, Warner.



c theorem for:  $C = \frac{1}{A'(s)^3}$

$$ds^2 = dr^2 + e^{2A(s)} (dx_\mu^2)$$

- c theorem  $A'' > 0$   $C \downarrow$  ALONG FLOW

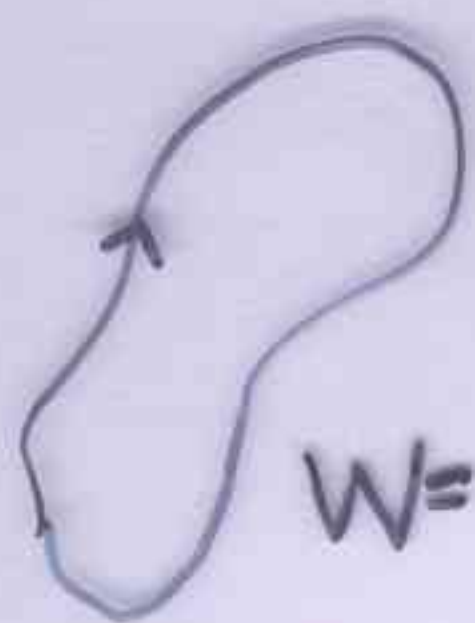
$$\frac{C_{IR}}{C_{UV}} = \frac{27}{32}$$

AT FIXED PT.  $\langle T^\mu_\mu \rangle \propto C$

- GRADIENT FLOW =  $N=1$  SUSY PRESERVING FLOW.

MANY other interesting { sick healthy } FLOWS.

# Wilson Loops



$$W = \text{Tr} e^{i \oint (\dot{x} \cdot A + \dot{y} \phi + \dots) ds}$$

Ooguri

BPS:  $\dot{x}^2 = \dot{y}^2$


FINITE

CALCULABLE FOR  $g^2 N \gg$

HOW TO CALCULATE FOR  $\dot{x}^2 \neq \dot{y}^2$ ? Loop  $\mathcal{E}g$ ?

Luscher term

Sonnenschein


$$W = e^{-T(\sqrt{\lambda} f(L) + \frac{c}{L})}$$

↑  
QUANTUM FLUCTUATIONS  
OF STRING  $\sigma$ .

ARE THEY FINITE?

# NON SUSY SCENARIOS

STABLE NON BPS STATES

KINKS OF unstable  $D_p \bar{D}_p$  vacua.

Sen

Schwarz  $D7, 8$

Gaiendi Boundary states

Horava.

stable NON BPS in IIA on  $T^4/I_4$



phase transitions

I

D2 branes on non susy cycle

II

pair of D2 on susy cycle.

## Type 0 STRINGS

NON CHIRAL GSO PROJECTION

Klebanov

Blumenhagen

Sagnotti



$U(N) \times U(N)$   
Form  $(N, \bar{N}) + (\bar{N}, N)$

conf.  $N \rightarrow \infty$

$II_B$  orbifold

on  $AdS_5$

Tachyon appears in twisted sector

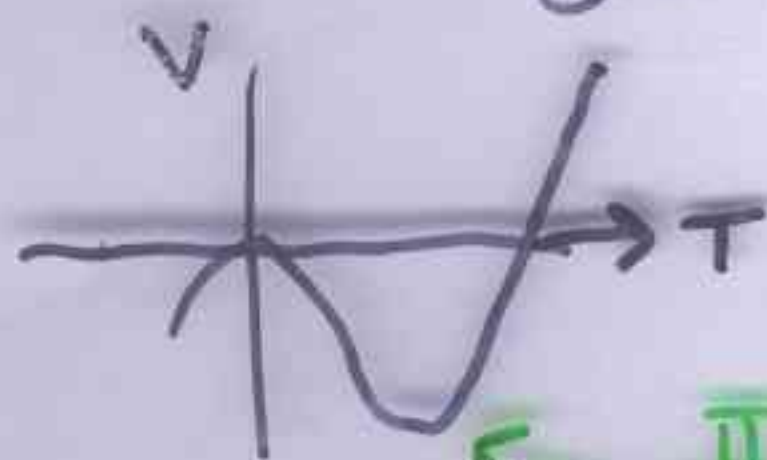
for  $\lambda = g^2 N \gg$

But  $\Delta = 4 + \frac{\lambda^2}{8\pi^2}$  real for  $\lambda \ll$

$\Rightarrow$  SINGULARITY in  $\lambda$  EXPANSION.

TACHYON CONDENSATES

Kachru



$\leftarrow II_B$  on orbifolds

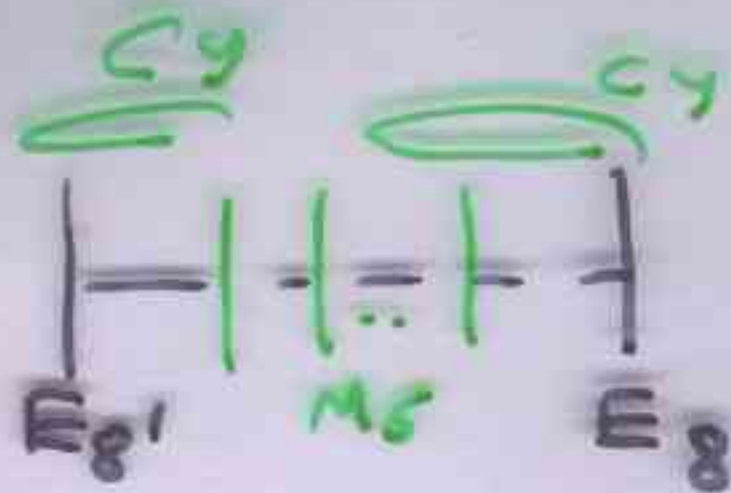
$\Lambda_{tree} = 0$

Ren. group Flows

$\rightarrow$  subcritical theory?

# BRANE Worlds

STRONGLY COUPLED  
HETEROTIC **ORUT**



D(9-n) BRANE



$n$  bulk dimensions



other 'worlds'

**ANTONIADES**  
**BACHAS**  
**IBANES**

SM

CONCEIVABLE

$R_T \sim \text{mm} \quad n=2$   
 $\sim \text{fm} \quad n=6$   
 $M_s \sim 1-10 \text{ TeV}$

EXCITING!

STIMULATES NEW TESTS OF GRAVITY!

But:

COUPLING CONSTANT UNIFICATION  
PROTON DECAY, . . . . .  
" NATURALNESS & STABILITY.

## WARPED COMPACTIFICATIONS

**Verlinde**



5D Einstein Equations  
= 4D Ren Gp Equations.

MIGHT explain why  $\Lambda \sim$  small at UV

→ small in IR.

# NON COMMUTATIVE GAUGE THEORY

Witten, Seiberg

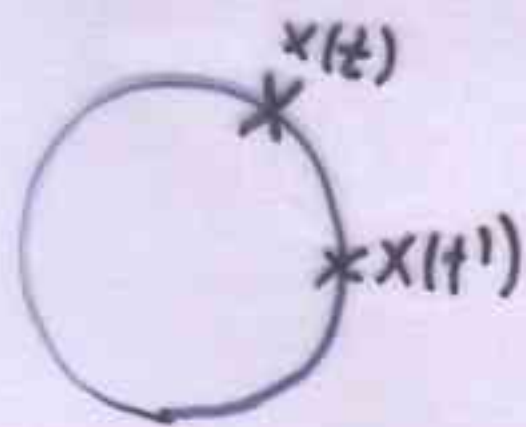
[Conne, Douglas, Schwarz]

DP



$B \neq 0$

Open string Theory  
in constant  $B$ :



$$[x^i, x^j] = 2\theta^{ij}$$

$$B \gg \quad :F(x_t): :g(x_0): = :e^{\theta^{ij} \partial_{x_t^i} \partial_{x_0^j}} f(x_t) g(x_0):$$

$$\equiv :F(x_t) * g(x):$$

$$G^{ij} = \left( \frac{1}{g + 2\pi\alpha' B} \right)^{ij}$$

$$\theta^{ij} = 2\pi\alpha' \left( \frac{1}{g + 2\pi\alpha' B} \right)^{ij}$$

LIMIT:

$$\alpha' \sim \sqrt{\epsilon}$$

$$g_{11} \sim \epsilon$$

$$g_{+} \sim 1$$

$$B \neq 0$$

$$\epsilon \rightarrow 0$$

$$\mathcal{L}_{\text{eff}} = \frac{1}{g_s} \sqrt{G} G^{ij} F^{il} \text{Tr} \hat{F}_{ij} * \hat{F}_{kl}$$

COMPLETE DESCRIPTION  
OF STRING THEORY IN THIS  
REGIME.

EQUV. TO STANDARD YM BY

$$\hat{A}_i = A_i - \frac{1}{4} \theta^{kl} (A_k \partial_l A_i + F_{li}) + \dots$$

NEW MARGINAL DEFORMATION OF YM.

MANY APPLICATIONS ...

COMPACTIFICATION on small  $T_2$

Conne, Douglas, Schwarz

Resolution of Instanton Moduli Space

NEKRASOV, SCHWARZ

# MISSING Talks

- Tests of AdS/CFT beyond  $N=\infty$

$\frac{1}{N^2}$   
chiral  
anomaly

- Calculations in GAUGE THEORY  $g^2 N \gg 1$   
String Theory  $\alpha' \gg 1$   
in AdS

- SPACE TIME DESCRIPTION OF  
BLACK HOLE FORMATION  
AND EVAPORATION

- DUAL, Holographic DESCRIPTION  
OF FLAT SPACE

- Dual, Holographic DESCRIPTION  
OF COSMOLOGY

- A NON PERTURBATIVE  
BACKGROUND INDEPENDENT  
FORMULATION OF

? Theory

WHEN WILL  
STRING THEORY

LIVE UP TO ITS  
PROMISES ?

IN THE  
NEXT  
MILLENNIUM