

String Theory  
without  
Gravity

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Strings '00

Ann Arbor

"s-Duality and Noncommutative  
Gauge Theory"

Gopakumar, Maldacena, Minwalla & AS

" $\mathcal{N}=2$  Theory in Diverse Dimensions"

Gopakumar, Minwalla, Seiberg & AS

Also

Seiberg, Susskind & Toumbas  
hep-th/0005015

Bergshoeff, Berman, van der Schaar  
& Sundell, hep-th/0006112

# Outline

1) What is non commutative  
field/string theory?

2) Why is it interesting?

3)  $S(3+1 \text{ NCYM}) = 3+1 \text{ NCOS}$

Noncommutative  
N=4 Yang Mills

Noncommutative  
Open Superstrings

4) Decoupling closed strings/gravity  
from NCOS

5)  $D+1 \text{ NCOS}$

6)  $5+1 \text{ } \mathcal{N} \text{ Theory}$   
"OM."

7) The  $\mathcal{N}$  Web

4  
What is NC

Field/String Theory?

Replace the usual product  
of two functions

$$f \cdot g(x) = f(x)g(x)$$

with

$$f * g(x) = e^{i\Theta^{ab} \partial_a \partial'_b} f(x)g(x') \Big|_{x=x'}$$

$$\Theta^{ab} = -\Theta^{ba} = \text{constant}$$

For  $f, g$  slowly-varying

$$f * g = f \cdot g + i\Theta^{ab} \partial_a f \partial_b g + \dots$$

\* product is non-local on

scale set by  $\Theta$ . Note

$$[x^a, x^b] \equiv x^a * x^b - x^b * x^a = i\Theta^{ab}$$



NC scalar field theory:

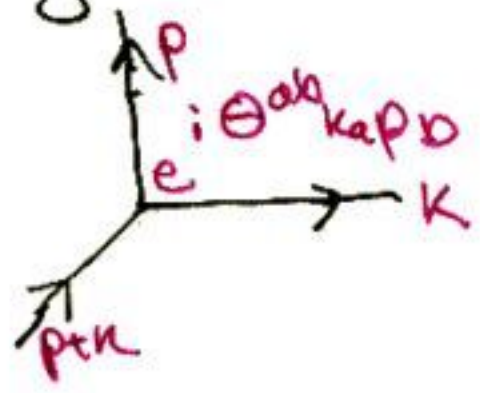
$$\int d^n x (\partial\phi\partial\phi + \phi^3)$$

→  $\int d^n x (\partial\phi * \partial\phi + \phi * \phi * \phi)$   
P drops out

In momentum space

$$\phi(k) * \phi(p) = e^{-i\theta^{ab}k_a p_b} \phi(k)\phi(p)$$

so NC ~ phase factors in Feynman diagrams

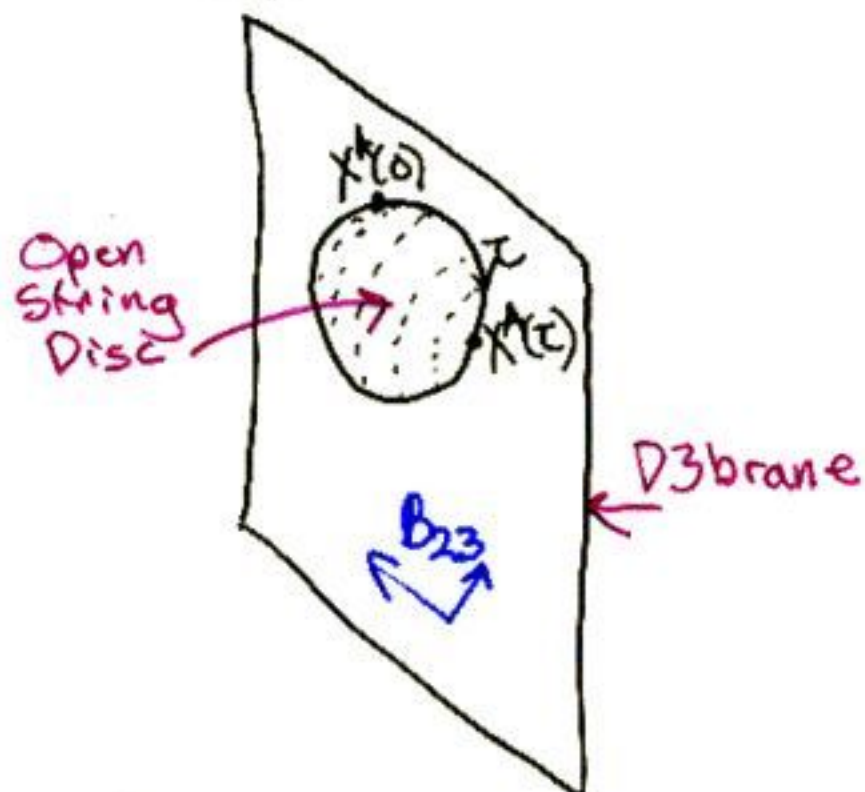


Ditto for NC string theory

# Why is NC field/string theory interesting?

- 1) NCRT is - apparently and surprisingly - a consistent deformation of ordinary QFT.
- 2) NCYM arises in a decoupling limit of string theory. Connes, Douglas & Schwarz
- 3) NCOS and NCYM are part of a little web of dual theories which mirrors the M-web.
- 4) Vexing conceptual issues in string theory - nonlocality & acausality can be studied in a simplified gravity-free setting.

# IIB strings $\rightarrow$ NCYM



Two pt. function

$$x^A(0)x^B(z) = -\alpha' G^{AB} \ln(z)^2 + \frac{i}{2} \Theta^{AB} \epsilon(z)$$

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

Effective open string coupling

$$G_0^2 = g_s \sqrt{\frac{\det(g + 2\pi\alpha' B)}{\det g}}$$

Fradkin & Tseytlin  
Abouelsaoud, Calhan,  
Nappi & Yost

# NCYM limit

Take

$$\alpha' \rightarrow 0$$

holding open string quantities

$$G^{AB}, \Theta^{AB}, G_0$$

fixed. Result has two descriptions

(i)  $N=4$  YM on a noncommutative space.

(ii) A Born-Infeld type YM with nonzero  $F_{23} \sim B_{23}$



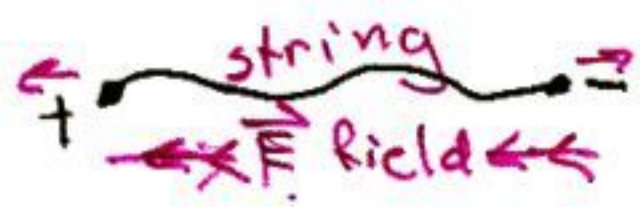
What happens to  $NCYM^q$   
for  $g_{YM} \sim G_0 \rightarrow \infty$ ?

Since  $NCYM$  is embedded in  
 $\mathbb{I}B$  theory, this is determined  
by  $\mathbb{I}B$  S-duality. We find

$$G_0 \rightarrow \frac{1}{G_0}$$

$$B_{23} \sim F_{23} \rightarrow F_{01}$$

But  $F_{01}$  winds up near its  
critical value for which open  
strings are tensionless



In the

$$g' \rightarrow 0$$

decoupling limit

$$T_{\text{eff}} = \frac{1}{2\pi\alpha'_{\text{eff}}} = \frac{1}{\Theta}$$

remains fixed and equal to NC.

Massive string states do not decouple.

S-dual of NC Field Theory  
= String Theory!

The NE parameter  $\theta^{01} = \Theta \epsilon^{01}$   
involves time.

# NCOS limit

More precisely parameterize

$$g_{\mu\nu} = \eta_{\mu\nu} \quad \mu, \nu = 0, 1$$

$$g_{ij} = \frac{\alpha'}{\alpha'_{\text{eff}}} \delta_{ij} \quad \text{transverse}$$

$$2\pi \alpha' \epsilon_0' F_0 = 1 - \frac{\alpha'}{2\alpha'_{\text{eff}}}$$

$$G_0^2 = \sqrt{\frac{\alpha'}{\alpha'_{\text{eff}}}} g_0$$

$$G_{AB} = \frac{\alpha'_{\text{eff}}}{\alpha'} \eta_{AB}$$

$$\Theta^{\mu\nu} = 2\pi \alpha'_{\text{eff}} \epsilon^{\mu\nu}$$

take

$$\alpha' \rightarrow 0$$

$G_0, \alpha'_{\text{eff}}$  fixed.

Open string quantities

remain finite. This definition is independent of its S-dual relation to NCYM.

The NCOS theory is just open string theory on D-branes with phases

$$S = \frac{1}{G_0^2} (A \circ A + A *_\theta A *_\theta A)$$

$$A(p) *_\theta A(k) = e^{-i \theta^{ab} p_a k_b} A *_w A$$

where  $\theta = \alpha' e F$ , and

$*_w$  is Witten's NC<sub>open</sub> string field theory product.



## What about the closed string sector?

Asymptotic closed strings far from the brane are massive and decouple for  $\alpha' \rightarrow 0$ , but light "near-horizon" closed strings might remain. However a detailed analysis of nonplanar



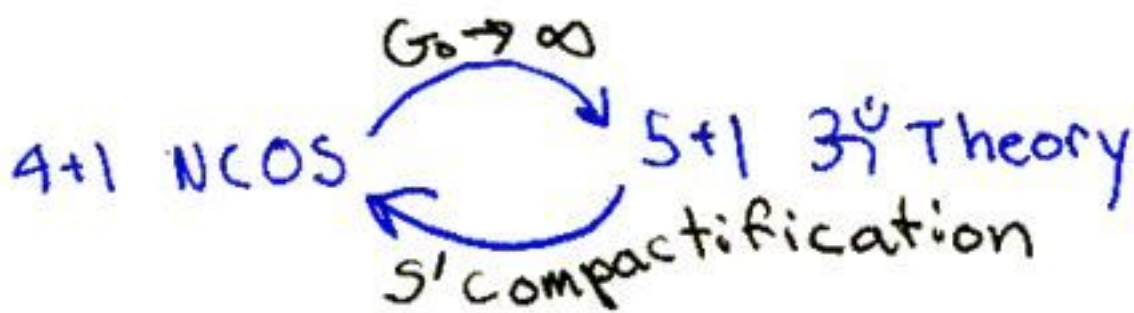
diagrams  $\rightarrow$  phase factors cancel on-shell closed string poles.

This works for  $d \leq 5+1$ .

NCOS theories in  $d \leq 6$   
are apparently perturbatively  
consistent open string  
theories without physical  
closed strings or gravity.

What is strongly coupled NCOS in other dimensions?

Several interesting cases. Discuss



3D is the Sanskrit character for  $\mathcal{O}M$ , which stands for Open Membrane, or "That which captures the underlying nature of reality".

# Critical Open Membranes

An M2 can end on an M5, just as a string can end on a D-brane  
Townsend AS



Action

$$S \sim M_p^3 \cdot \text{Volume} + \int_{M2} A$$

At a critical value of the 3-form field strength  $A$ , M2s are tensionless!



# The 5+1 3<sup>U</sup> Limit

Define

$$g_{\mu\nu} = M_{pl}^2 \quad \mu, \nu = 0, 1, 2$$

$$g_{ij} = \frac{2M_{eff}^3}{M_{pl}^3} \delta_{ij} \quad i, j = 3, 4, 5$$

$$A_{012} = M_{pl}^3 \left[ \frac{2M_{pl}^3 - M_{eff}^3}{2M_{pl}^3 + M_{eff}^3} \right]$$

Take

$$M_{pl} \rightarrow \infty$$

in order to decouple gravity,  
while holding the effective  
tension

$$T_{eff} \sim M_{eff}^3$$

Fixed  $\Rightarrow$  decoupled theory of  
light open membranes

# 5+1 $3\bar{0}$ $\leftrightarrow$ M analogy

Perturbative  
String  
Theory

Theory w/o  
Dimensionless  
coupling

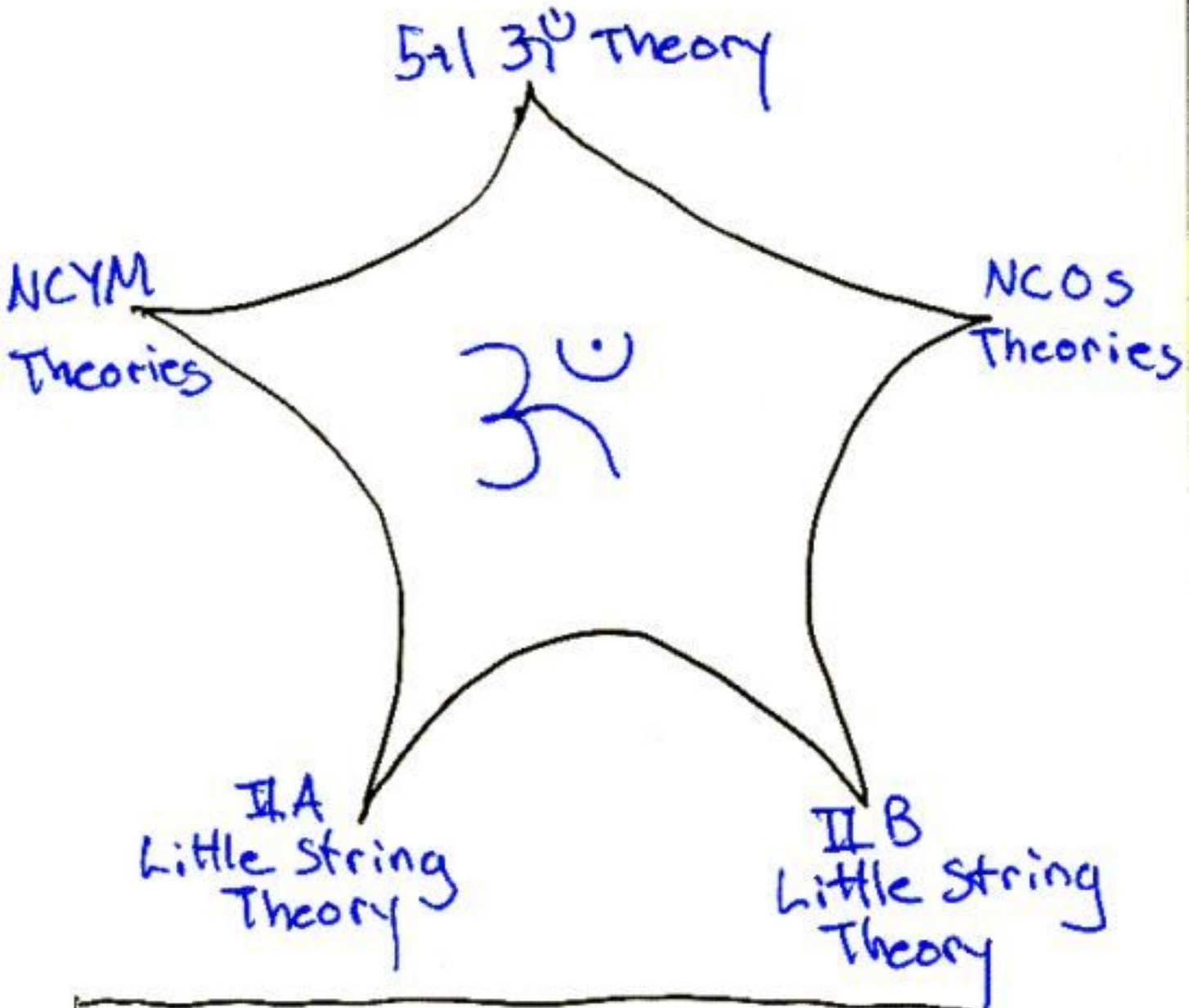


critical field  
scaling limit



Both 5+1  $3\bar{0}$  and M are the strong coupling limits of perturbatively well-defined string theories.

# The 3<sup>0</sup> Web



3<sup>0</sup> : "That which captures the underlying nature of reality"  
 Mandukya Upanishad c. 700 B.C. <sup>M theory</sup>

To Be  
Continued



## A millennial problem

Compute the statistical entropy of de Sitter space.

The quest to compute and understand black hole entropy has led to deep insights on the nature of gravity, field theory and string theory. Our failure to compute the superficially similar de Sitter entropy indicates a major gap in our understanding. I expect that filling this gap will lead to deep and surprising new insights on the nature of the universe as a whole.