Alternative large N_c baryons and holography

Carlos Hoyos

C. H., A. Karch, 0904.0008

University of Washington
Seattle

Large N @ Swansea
July 7, 2009

INTRODUCTION

Classic large N_c limits of QCD

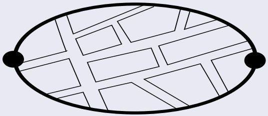
't Hooft; Veneziano '79

How to take the limit

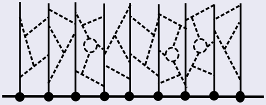
- $SU(3) \to SU(N_c)$, $N_c \to \infty$
- Fundamental Flavors $q^i \to q^i$

Hadrons

Mesons $\overline{q}_i q_i$: string picture



Baryons $\epsilon_{i_1 \cdots i_{N_c}} q^{i_1} \cdots q^{i_{N_c}}$: solitons

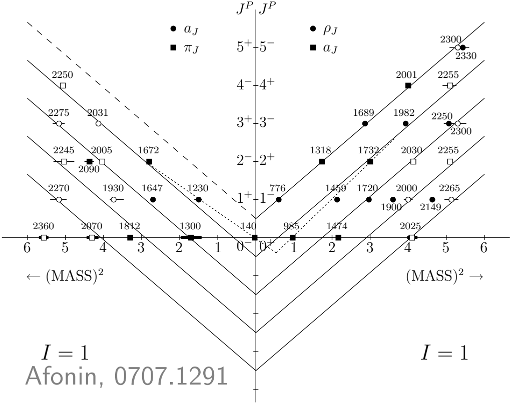


Pomarol

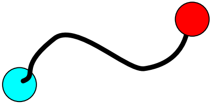
$\alpha' \simeq 1 \text{ GeV}^{-2}$

$$J = \alpha_0 + \alpha' M^2$$

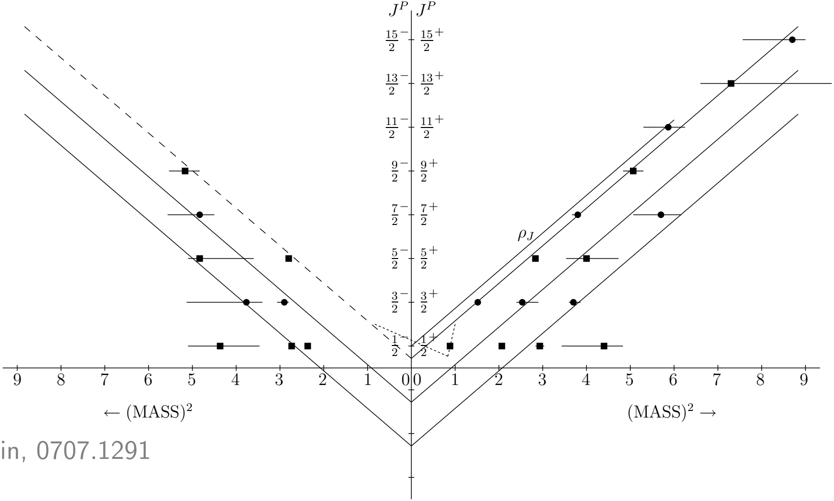
$$\mathcal{M} = \overline{q_i} q^i$$



Afonin, 0707.1291

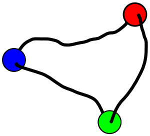


Baryons and Regge trajectories

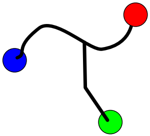


Afonin, 0707.1291

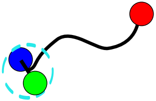
What is a baryon in QCD?



Two-quark interactions $\mathcal{B} = \epsilon_{ijk} q^i q^j q^k$



Baryon vertex $\mathcal{B} = \epsilon_{ijk} q^i q^j q^k$



Baryon formed by a quark-diquark state
$\mathcal{B} = \epsilon_{ijk} q^i q^j Q^k$

Other large N_c limits of QCD

Corrigan and Ramond '79; Armoni,Shifman and Veneziano '03

How to take the limit

- $SU(3) \to SU(N_c)$, $N_c \to \infty$
- Fundamental Flavors $\Psi_{[ij]} = \frac{1}{2}\epsilon_{ijk} q^k \to \Psi_{[ij]}$; $N_{AS} \leq 5$
- More flavors: q^i
- Chiral version Ryttov,Sannino '05

Hadrons

- 'Light' mesons: $\overline{q_i} q^i$, $\overline{\Psi}^{[ij]} \Psi_{[ij]}$
- 'Heavy baryons': $\epsilon_{i_1 \cdots i_{N_c}} q^{i_1} \cdots q^{i_{N_c}}$
- 'Heavy' mesons: $\epsilon_{i_1 i_2 \cdots i_{N_c-2} i_{N_c-1} i_{N_c}} \overline{\Psi}^{[i_1 i_2]} \ldots \overline{\Psi}^{[i_{N_c-2} i_{N_c-1}]} q^{i_{N_c}}$
- 'Light' baryons: $\Psi_{[ij]} q^i q^j$

Planar equivalence and Regge trajectories

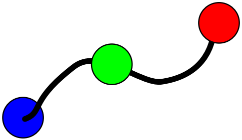
Armoni and Patella, 0901.4508

- Supersymmetric theory:

$$\overline{q_i} e^{i\int A} q^j \to \overline{q_i} \int dx \; e^{i\int^x A} \lambda^i_j(x) e^{i\int_x A} q^j + \mathcal{O}(1/R)$$

- Equivalence: $\lambda^i_j \to \Psi_{[ij]}$
- Quarks joined by fermionic/unoriented string

$$\overline{q_i} e^{i\int A} q^j \to q_i \int dx \; e^{i\int^x A} \Psi_{[ij]}(x) e^{i\int_x A} q^j + \mathcal{O}(1/R)$$



Holography

- Natural framework for large N_c gauge theories at strong coupling
- Mesons appear as fluctuations of probe branes in the geometry
- Usual baryons appear as heavy objects: D-branes

How are light baryons realized?

HOLOGRAPHIC MODEL

Field theory

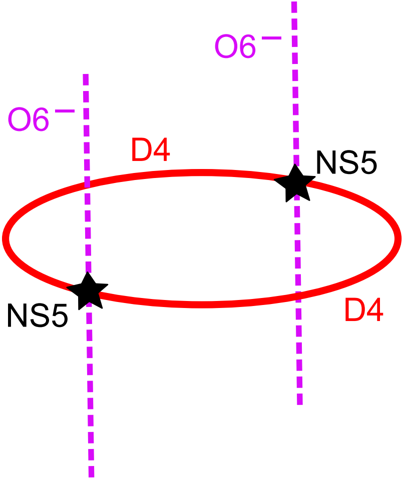
- $\mathcal{N}=4$ $SU(N_c)$ SYM + $\mathcal{N}=2$ hypermultiplets Q, $\widetilde{Q}$
- Global symmetries: $SU(2)_L \times SU(2)_R \times U(1)_R \times U(N_f)$

fields	$SU(N_c) \times U(N_f)$	$(j_R, j_L)_R$
$\mathcal{Q}$	$(\mathbf{1}, \mathbf{1})$	$(1/2, 0)_1$
Φ_1, Φ_2	$(\mathbf{N_c^2} - \mathbf{1}, \mathbf{1})$	$(1/2, 1/2)_0$
Φ_3	$(\mathbf{N_c^2} - \mathbf{1}, \mathbf{1})$	$(0, 0)_{\pm 2}$
Q	$(\overline{\mathbf{N}}_\mathbf{c}, \mathbf{N_f})$	$(1/2, 0)_0$
$\widetilde{Q}$	$(\mathbf{N_c}, \overline{\mathbf{N}}_\mathbf{f})$	$(1/2, 0)_0$

- Supersymmetric projection $\mathbf{Z}_2 \subset SU(2)_L$
- Φ_1, Φ_2 $\longrightarrow$ antisymmetric

D-brane setup

Park and Uranga, hep-th/9808161



- $2N_c$ D4 branes
- N_f D6s on top of $O6^-$
- $N_f \ll N_c$ (quenched)
- Projection made in T-dual ($D3+D7/O7+\mathbf{Z}_2$)

Field theory from D-branes

	0	1	2	3	4	5	6	7	8	9
$D3$	X	X	X	X	·	·	·	·	·	·
$O7/D7$	X	X	X	X	·	·	X	X	X	X
$\mathbf{Z}_2$	X	X	X	X	X	X	·	·	·	·

Chan-Paton factors

- Orbifold projection $X \to \pm\gamma_p X \gamma_p^{-1}$

$$\gamma_3 = \begin{pmatrix} iI_{N_c} & \\ & -iI_{N_c} \end{pmatrix}, \quad \gamma_7 = \begin{pmatrix} iI_{N_f} & \\ & -iI_{N_f} \end{pmatrix},$$

- Orientifold projection $X \to \pm\omega_p X^T \omega_p^{-1}$

$$\omega_3 = \begin{pmatrix} & I_{N_c} \\ -I_{N_c} & \end{pmatrix}, \quad \omega_7 = \begin{pmatrix} & I_{N_f} \\ I_{N_f} & \end{pmatrix},$$

Orientifold projection

- D3 brane fields

$$\begin{array}{lr} A_{0123} & \text{Adjoint } SU(N_c) \\ X_{45} & \text{Adjoint } SU(N_c) \\ X_{67},\ X_{89} & \text{Antisymmetric } SU(N_c) \end{array}$$

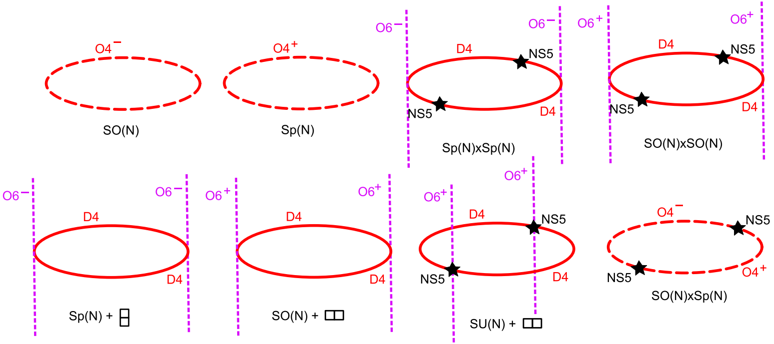
- D3/D7 spectrum

$$H^A \quad (\mathbf{N_c}, \overline{\mathbf{N_f}})$$

- D7 brane fields ($A_{0123}, X_{45} \leftrightarrow A_{6789}$ parity odd)

$$\begin{array}{lr} A_{0123} & \text{Adjoint } SU(N_f) \\ X_{45} & \text{Adjoint } SU(N_f) \\ A_{6789} & \text{Antisymmetric } SU(N_f) \end{array}$$

Other examples



BPS Spectrum: field theory

BPS hypermultiplet $j_L = \ell/2$, n

- Lowest component: $\Delta = 2j_R + R/2$
- Bosonic degrees of freedom $8(\ell + 1)$

- Bosons:

Δ	$(j_R, j_L)_R$	#
$\ell + 2$	$\left(\frac{\ell}{2} + 1, \frac{\ell}{2}\right)_0$	2
$\ell + 3$	$\left(\frac{\ell}{2}, \frac{\ell}{2}\right)_{\pm 2} \oplus \left(\frac{\ell}{2}, \frac{\ell}{2}\right)_0$	$1 \oplus 2$
$\ell + 4$	$\left(\frac{\ell}{2} - 1, \frac{\ell}{2}\right)_0$	2

- Fermions:

Δ	$(j_R, j_L)_R$	#
$\ell + 5/2$	$\left(\frac{\ell+1}{2}, \frac{\ell}{2}\right)_{\pm 1}$	2
$\ell + 7/2$	$\left(\frac{\ell-1}{2}, \frac{\ell}{2}\right)_{\pm 1}$	2

BPS Spectrum: gravity dual

$$AdS_5 \times \mathbf{RP}^5 + \text{O7/D7 on } \mathbf{RP}^3 \subset \mathbf{RP}^5$$

D7 brane fluctuations

- Isometry $\mathbf{RP}^3$: $SO(4)/\mathbf{Z}_2 \simeq SU(2)_L/\mathbf{Z}_2 \times SU(2)_R$
- Rotation on plane transverse to D7: $U(1)_R$
- Supersymmetries: $(j_R, j_L)_R = (1/2, 0)_1$

D7 KK modes on $\mathbf{S}^3 \subset \mathbf{S}^5$: A, Φ, Ψ enter in hypermultiplets with $j_L = \ell/2$

Δ	mode
$\ell + 2$	$A_-^{\ell+1}$
$\ell + 5/2$	Ψ_-^{ℓ}
$\ell + 3$	Φ^{ℓ}, A^{ℓ}
$\ell + 7/2$	$\Psi_+^{\ell-1}$
$\ell + 4$	$A_+^{\ell-1}$

Kruczenski, Mateos, Myers and Winters, hep-th/0304032; Kirsch hep-th/0607205

Projection of the bosonic BPS spectrum

Parity odd modes $\ell = 2k+1$ ($j_L = k+1/2$) are projected to the antisymmetric rep. of $SU(N_f)$

$$\Phi^{2k+1} \to -(\Phi^{2k+1})^T \quad , \quad A^{2k+1} \to -(A^{2k+1})^T \quad , \quad A_\pm^{2k+2} \to -(A_\pm^{2k+2})^T \, .$$

Example

$$\mathcal{B}^{ab} = Q_i^a \Phi_1^{[ij]} Q_j^b$$

- $\mathcal{B}$ ($\Delta = 3$, $R = 0$) is the lowest component of a $j_L = 1/2$ multiplet
- Symmetric in flavor $\Rightarrow$ antisymmetric in $SU(2)_R \Rightarrow j_R = 1/2$
- Antisymmetric in flavor $\Rightarrow$ symmetric in $SU(2)_R \Rightarrow j_R = 3/2$
- BPS condition $\Delta = 2j_R + R/2 \Rightarrow$ antisymmetric in flavor

Full spectrum

- Massless string excitations - BPS operators: $\sim m_q/\sqrt{\lambda}$ (e.g. $\mathcal{B}^{[ab]}$)
- Small string excitations - non-BPS operators: $\sim m_q/\lambda^{1/4}$ (e.g. $\mathcal{B}^{(ab)}$)
- Large classical strings - semiclassical regime: $\sim m_q$
- D3 on $\mathbf{RP}^3$ - Pfaffian operators/heavy mesons: $\sim N_c m_q/\sqrt{\lambda}$
- D5 on $\mathbf{RP}^5$ - Baryon operator: $\sim N_c m_q$

Meson-baryon degeneracy

- Mesons and baryons lie on parallel 'Regge trajectories' (defined by ℓ)
- Degenerate in the semiclassical limit $\sim m_q/\sqrt{\lambda}$ or $\sim m_q/\lambda^{1/4} \ll m_q$.
- $SO(5)$ symmetry: mass $\sim n + \ell \Rightarrow$ accidental degeneracy

Conclusions

- Alternative baryons and mesons have a common description in bulk
- In the semiclassical limit mesons and baryons are degenerate
- The results do not depend on the AdS_5 part of the geometry
- In a confining theory, a similar construction will lead to equal Regge slopes