Twisted BPS decoupling limits and AdS/CFT

Troels Harmark, Center of Gravity
Niels Bohr Institute

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THE CENTER OF GRAVITY

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Talk primarily based on the work:

"Twisted BPS decoupling limits and AdS/CFT", TH, *to appear soon*

Related recent or forthcoming work:

- "Gravitational solitons and non-relativistic string theory", 2501.10178 (JHEP), TH, Lahnsteiner, Obers
- "Finite scalar field theory with SU(1,1) spacetime symmetry from near-BPS limits of N=4 SYM", 2605.24085, Auzzi, Baiguera, Guo, TH, Nardelli
- "Non-Lorentzian geometry in the AdS/CFT correspondence", *to appear soon*, Baiguera, TH, Lei, Maskalaniec, Yan
- "Landscape of U-dual BPS decoupling limits", *to appear soon*, de Boer, Dijkgraaf, TH, Obers, Yan

Collaborators on related works:

Roberto Auzzi, Stefano Baiguera, Jan de Boer, Robbert Dijkgraaf, Lihan Guo, Jelle Hartong, Kristján Kristjánsson, Johannes Lahnsteiner, Yang Lei, David Maskalaniec, Lorenzo Menculini, Giuseppe Nardelli, Niels Obers, Gerben Oling, Marta Orselli, Nico Wintergerst, Ziqi Yan

Plan for talk:

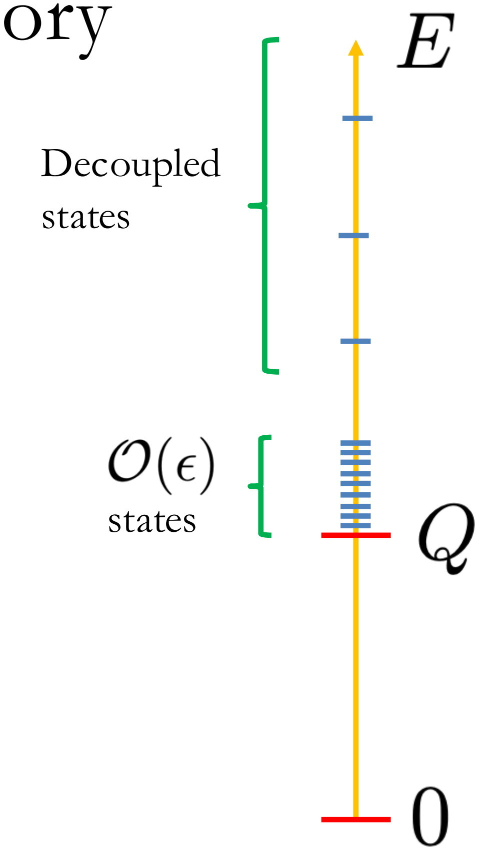
Motivation: BPS decoupling limits
Strings in weakly coupled N=4 SYM

DLCQ revisited
Twisted BPS decoupling limit
All limits of $AdS_5 \times S^5$
Twisted limit of non-abelian DBI

Outlook

Motivation:
BPS decoupling limits

BPS decoupling limits in string/M-theory



BPS bound: $E \geq Q$

Limit keeps finite: $E_{\text{new}} = \dfrac{E - Q}{\epsilon}$

Surviving states: $E = Q + \mathcal{O}(\epsilon)$

- Dynamics simplify
- New symmetries can appear
- Non-perturbative physics more accessible

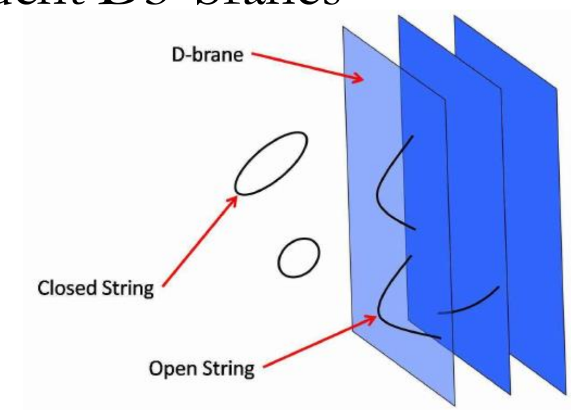
Example:

Maldacena limit = BPS decoupling limit for coincident D3-branes

Open and closed string DOFs decouple

New symmetries: PSU(2,2|4)

Holographic duality: AdS/CFT correspondence



U-duality relates BPS decoupling limits

Using T- and S-duality we can reach other ½ BPS configurations

$$\mathrm{D3} \xleftrightarrow{\text{T-duality}} \mathrm{Dp}$$

$$\mathrm{D0} \xleftrightarrow{\text{S-duality}} \mathrm{DLCQ}$$

$$\mathrm{D1} \xleftrightarrow{\text{S-duality}} \mathrm{F1} \xleftrightarrow{\text{T-duality}} \mathrm{DLCQ}$$

More holographic dualities (BFSS, IMSY,…)

All limits are U-dual to DLCQ

Worldvolume theories of the branes couple to non-Lorentzian geometry after limit

Blair, Lahnsteiner, Obers & Yan '23, '24

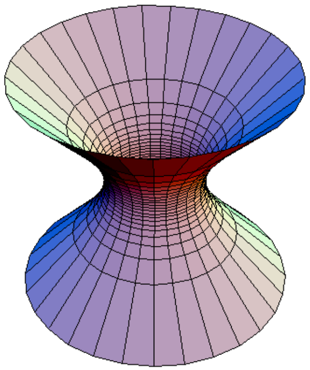
Gomis & Yan '23

¼ BPS intersecting brane limits U-dual to second DLCQ

Less SUSY → several DLCQs

de Boer, Dijkgraaf, TH, Obers, Yan (to appear)

Are all BPS decoupling limits U-dual to DLCQ's?



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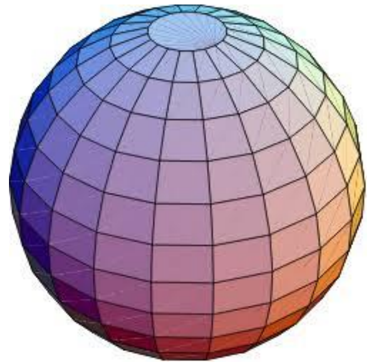


AdS_5 x S^5 background (global patch)

Global symmetry: PSU(2,2|4)

Cartan charges:

E, S_1, S_2 in SU(2,2) sym. of AdS_5

J_1, J_2, J_3 in SU(4) sym. of S^5

Example of BPS bound: $E \geq J_1 + J_2$

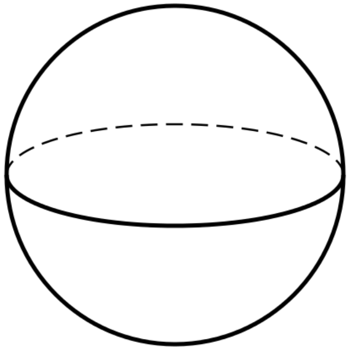
Is the associated BPS decoupling limit a DLCQ?

Motivation:

Strings in weakly coupled N=4 SYM

BPS decoupling limits of N=4 SYM

N=4 SYM with gauge group SU(N) on R x S^3



Global symmetry: PSU(2,2|4)

Cartan charges:
E, S_1, S_2 in SU(2,2) conformal sym.
J_1, J_2, J_3 in SU(4) R-symmetry

Example of BPS bound: $E \geq J_1 + J_2$

What is a natural BPS decoupling limit?

BPS decoupling limits of N=4 SYM

Weakly coupled N=4 SYM → 't Hooft coupling $\lambda \ll 1$

$$E = E_0 + \lambda E_1 + \mathcal{O}(\lambda^2)$$

Bare energy

One-loop contribution

BPS decoupling limits of N=4 SYM

Weakly coupled N=4 SYM → 't Hooft coupling $\lambda \ll 1$

$$E = E_0 + \lambda E_1 + \mathcal{O}(\lambda^2)$$

Bare energy

One-loop contribution

BPS decoupling limit for $E = J_1 + J_2$:

TH, Kristjánsson & Orselli '07 '08
TH & Orselli '06 '14

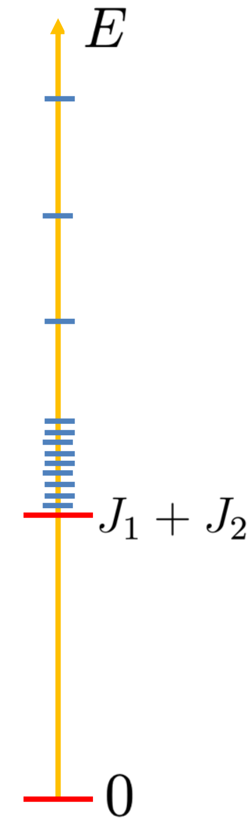
$$E_{\text{limit}} = \frac{E - J_1 - J_2}{\lambda} \quad \text{fixed as} \quad \lambda \to 0$$

Known as "Spin Matrix theory" limit

TH & Orselli '14

Zooms in on states with: $E = J_1 + J_2 + \mathcal{O}(\lambda)$

Effective dynamics in limit: $E_{\text{limit}} = E_1 \Big|_{E_0 = J_1 + J_2}$



BPS decoupling limits of N=4 SYM

In planar limit $N=\infty$ $E_{\text{limit}} = E_1\Big|_{E_0=J_1+J_2}$ corresponds to the Heisenberg $XXX_{1/2}$ spin chain Hamiltonian

Minahan & Zarembo '02

In semi-classical long wave-length limit E_{limit} described by Landau-Lifshitz sigma-model:

Fradkin book '91
Kruczenski '03

$$S = \frac{w}{4\pi}\int d^2\sigma\left(\cos\theta\,\dot{\phi} - \frac{1}{4w^2}\left(\theta'^2 + \sin^2\theta\,\phi'^2\right)\right)$$

(Dot is time-derivative, prime is derivative along string, $w = J_1 + J_2$)

Strings with a non-relativistic worldsheet and target space R x S^2 are part of weakly coupled N=4 SYM!

TH, Kristjánsson & Orselli '08

Corresponds to regime:

$$E - J_1 - J_2 \ll \lambda \ll 1\ , \quad J_1 + J_2 \gg 1\ , \quad N \gg 1$$

How do these NR strings arise in dual string theory?

DLCQ limit revisited

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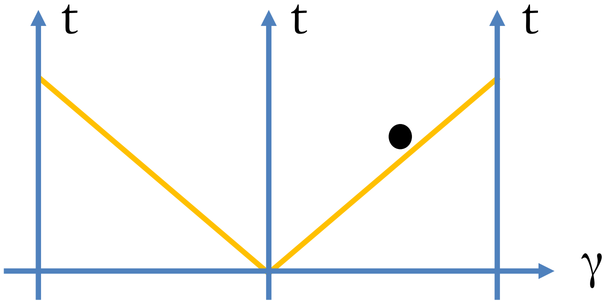


γ: Circle direction

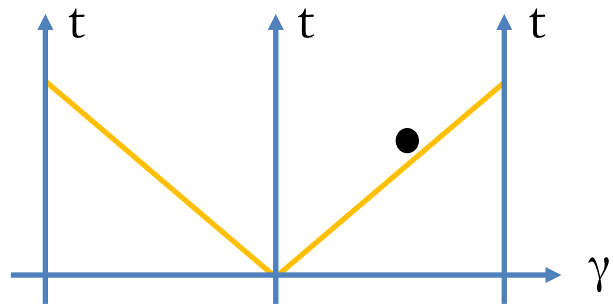
KK-mode on S^1 in type IIA/B string theory

$$ds^2 = R^2(-dt^2 + d\gamma^2) + dx^i dx^i$$

KK-mode: $p_\gamma = w > 0$

BPS bound: $E \geq w \longleftrightarrow \text{speed} \leq 1$

DLCQ limit revisited



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How to approach BPS? $\epsilon \to 0$ with $t = \frac{T}{\epsilon^2}\,,\quad \gamma = \hat{\gamma} + \frac{T}{\epsilon^2}$

Zooms in close to null worldline, speed ≈ 1

Demand finite string spectrum for a string probe: $R = \epsilon$

$$ds^2 = 2d\hat{\gamma}dT + \epsilon^2 d\hat{\gamma}^2 + dx^i dx^i$$

$\epsilon \to 0$: Compact null direction → Discrete light cone quantization (DLCQ)

Can one make sense of geometry in the $\epsilon \to 0$ limit?

DLCQ limit revisited

T-duality resolves the geometry in the limit

$$\text{KK-mode} \xleftrightarrow{\text{T-duality}} \text{F1 (winding mode)}$$

T-dual background:

$$ds^2 = \frac{1}{\epsilon^2}(-dT^2 + dv^2) + dx^i dx^i \ , \quad B = -\frac{1}{\epsilon^2} dT \wedge dv$$

$\epsilon \rightarrow 0$ limit is **non-relativistic string theory** limit

Gomis & Ooguri '00
Danielsson, Guijosa
& Kruczenski '00
(and several later papers)

BPS and near-BPS fluctuations live
in non-Lorentzian geometry

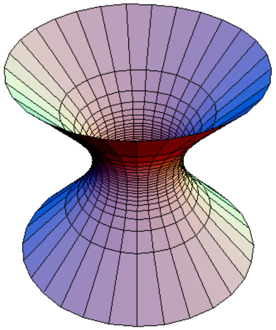
TH, Hartong & Obers '17
Bergshoeff, Gomis & Yan '18
(and several later papers)

Same for U-dual limits

Blair, Lahnsteiner, Obers & Yan '23, '24
Gomis & Yan '23

Twisted BPS decoupling limit

AdS_5 x S^5 background (global patch):



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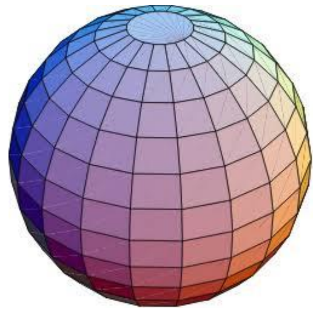

PSU(2,2|4)

Cartan charges:
E , S_1 , S_2 for AdS_5
J_1 , J_2 , J_3 for S^5

Consider BPS bound: $E \geq J_1 + J_2$

We saw a BPS limit in N=4 SYM associated with this bound
What is the dual limit? A DLCQ limit?

BPS state $\longleftrightarrow$ Null worldline in $\mathbb{R} \times S^3 \subset \mathrm{AdS}_5 \times S^5$

BPS state $\longleftrightarrow$ Null worldline in $\mathbb{R} \times S^3 \subset \mathrm{AdS}_5 \times S^5$

Use Hopf fibration of S^3:

S[1]

CP[1]

$$ds^2 = R^2\Big[-dt^2 + (d\gamma + A_i dx^i)^2 + h_{ij}dx^i dx^j\Big]$$

U(1) connection A

Momentum

$p_\gamma = w = J_1 + J_2$

Null worldline: $\gamma = t + \text{const.}\ , \quad dx^i = 0$

BPS state $\longleftrightarrow$ Null worldline in $\mathbb{R} \times S^3 \subset \mathrm{AdS}_5 \times S^5$

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U(1) connection A

Momentum

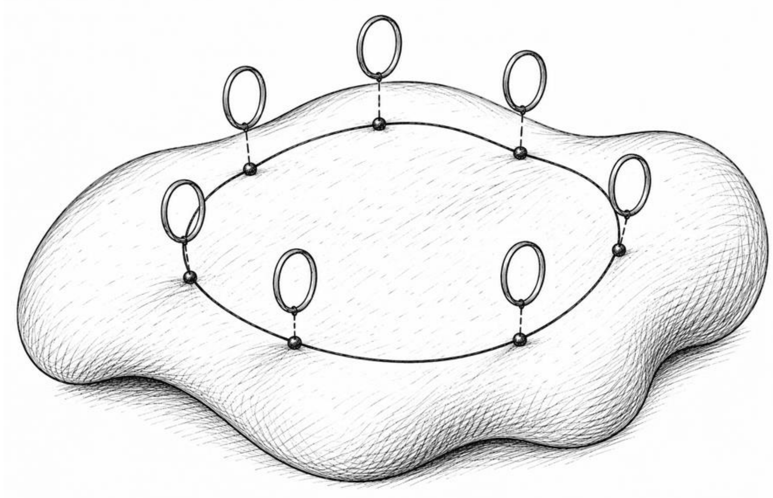
$p_\gamma = w = J_1 + J_2$

Null worldline: $\gamma = t + \text{const.}\ , \quad dx^i = 0$

What prevents us from taking a DLCQ limit?

→ Circle fiber is **twisted** by non-flat U(1) connection A

→ Going in a closed loop in base space: $\Delta\gamma = \oint A$



→ A links scaling of S^1 and CP^1

$$ds^2 = R^2\Big[- dt^2 + (d\gamma + A_i dx^i)^2 + h_{ij}dx^i dx^j \Big]$$

S^1

CP^1

U(1) connection

Momentum

$$p_\gamma = w = J_1 + J_2$$

Close to BPS: $t = \frac{T}{\epsilon^2}\ ,\quad \gamma = \hat{\gamma} + \frac{T}{\epsilon^2} \quad \rightarrow \quad E_T = \frac{E - w}{\epsilon^2}$ and $p_{\hat{\gamma}} = w$

How should R scale compared to ϵ?

S^1 CP^1

$$ds^2 = R^2\Big[-dt^2 + (d\gamma + A_i dx^i)^2 + h_{ij}dx^i dx^j\Big]$$

U(1) connection

Momentum

$$p_\gamma = w = J_1 + J_2$$

Close to BPS: $t = \frac{T}{\epsilon^2}\,,\quad \gamma = \hat{\gamma} + \frac{T}{\epsilon^2}$ $\rightarrow$ $E_T = \frac{E-w}{\epsilon^2}$ and $p_{\hat{\gamma}} = w$

How should R scale compared to ϵ?

→ T-dualize along $\hat{\gamma}$ to winding mode w = $J_1 + J_2$

$$ds^2 = -\frac{R^2}{\epsilon^4}dT^2 + \frac{dv^2}{R^2} + R^2 h_{ij}dx^i dx^j\ ,\quad B = -\left(\frac{dT}{\epsilon^2} + A_i dx^i\right)\wedge dv$$

Untwisted geometry Twist in B-field

Nambu-Goto action: $S = -\frac{1}{2\pi\alpha'}\int d^2\sigma\left(\sqrt{-\det\left(\partial_\alpha X^\mu \partial_\beta X^\nu g_{\mu\nu}\right)} + \frac{1}{2}\epsilon^{\alpha\beta}\partial_\alpha X^\mu \partial_\beta X^\nu B_{\mu\nu}\right)$

$$ds^2 = R^2\Big[-dt^2 + (d\gamma + A_i dx^i)^2 + h_{ij}dx^i dx^j\Big]$$

S^1 — CP^1 — U(1) connection

Momentum
$p_\gamma = w = J_1 + J_2$

Close to BPS: $t = \frac{T}{\epsilon^2}\,,\quad \gamma = \hat{\gamma} + \frac{T}{\epsilon^2}$ → $E_T = \frac{E - w}{\epsilon^2}$ and $p_{\hat{\gamma}} = w$

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Untwisted geometry — Twist in B-field

Nambu-Goto action: $S = \frac{w}{2\pi}\int d^2\sigma\left(-\frac{1}{\epsilon^2}\sqrt{(1-\epsilon^4 h_{00})\left(1+\frac{R^4}{w^2}h_{11}\right)+\frac{\epsilon^4 R^4}{w^2}h_{01}^2} + \frac{1}{\epsilon^2} + A_0\right)$

No divergence + coupling to h_{ij} → $\boxed{R = \sqrt{\epsilon}}$

S^1 CP^1

$$ds^2 = R^2\Big[-dt^2 + (d\gamma + A_i dx^i)^2 + h_{ij}dx^i dx^j\Big]$$

U(1) connection

Momentum

$$p_\gamma = w = J_1 + J_2$$

Close to BPS: $t = \frac{T}{\epsilon^2}\,,\quad \gamma = \hat{\gamma} + \frac{T}{\epsilon^2} \;\rightarrow\; E_T = \frac{E - w}{\epsilon^2}$ and $p_{\hat{\gamma}} = w$

How should R scale compared to ϵ?

→ T-dualize along $\hat{\gamma}$ to winding mode $w = J_1 + J_2$

$$ds^2 = -\frac{dT^2}{\epsilon^3} + \frac{dv^2}{\epsilon} + \epsilon\, h_{ij}dx^i dx^j\,,\quad B = -\left(\frac{dT}{\epsilon^2} + A_i dx^i\right)\wedge dv$$

Untwisted geometry

Twist in B-field

Nambu-Goto action: $S = \frac{w}{2\pi}\int d^2\sigma\left(-\frac{1}{\epsilon^2}\sqrt{(1-\epsilon^4 h_{00})\left(1+\frac{R^4}{w^2}h_{11}\right)+\frac{\epsilon^4 R^4}{w^2}h_{01}^2}+\frac{1}{\epsilon^2}+A_0\right)$

No divergence + coupling to h_{ij} → $\boxed{R = \sqrt{\epsilon}}$

Finite Nambu-Goto action in limit:

$$S = \frac{w}{2\pi}\int d^2\sigma\left(A_i\dot{x}^i - \mathcal{H}\right) \ , \quad \mathcal{H}(x,x') = \frac{1}{2w^2}h_{ij}x'^i x'^j$$

Clearly different from NRST action

Limit in original frame:

$$ds^2 = \epsilon\left[2\frac{dT}{\epsilon^2}(d\hat{\gamma} + A_i dx^i) + (d\hat{\gamma} + A_i dx^i)^2 + h_{ij}dx^i dx^j\right]$$

String tension goes to zero

Rescaling energy above BPS

Action previously found in "two-step" limit procedure

Combination gives the same, but made of two "Non-BPS limits"

→ BPS nature, and role of the twist, now clear

TH, Hartong & Obers '17
TH, Hartong, Obers & Yan '18
TH, Hartong, Menculini, Obers & Oling '19
TH, Hartong, Obers & Oling '20
Bidussi, TH, Hartong, Obers & Oling '23

Finite Nambu-Goto action in limit:

$$S = \frac{w}{2\pi}\int d^2\sigma\left(A_i\dot{x}^i - \mathcal{H}\right) \ , \quad \mathcal{H}(x,x') = \frac{1}{2w^2}h_{ij}x'^i x'^j$$

Gives the Landau-Lifshitz model for specific case:

$$S = \frac{w}{4\pi}\int d^2\sigma\left(\cos\theta\,\dot{\phi} - \frac{1}{4w^2}\left(\theta'^2 + \sin^2\theta\,\phi'^2\right)\right)$$

Matches the action in corresponding "Spin Matrix theory" BPS decoupling limit of N=4 SYM

How come this can work?

- Action semi-classical for w $\gg$ 1
- AdS_5 x S^5 is protected background
- Near BPS → quantum fluctuations under control

TH, Kristjánsson & Orselli '08

What about directions outside $\mathbb{R}\times S^3 \subset \mathrm{AdS}_5 \times S^5$?

- Confining potential for those directions proportional to $1/\epsilon^2$

Finite Nambu-Goto action in limit:

$$S = \frac{w}{2\pi}\int d^2\sigma\,\left(A_i \dot{x}^i - \mathcal{H}\right)\ ,\quad \mathcal{H}(x,x') = \frac{1}{2w^2} h_{ij} x'^i x'^j$$

Sigma-model is a phase-space action
→BPS and near-BPS fluctuations live in a symplectic geometry:

TH, Hartong, Obers & Oling '20; Bidussi, TH, Hartong, Obers & Oling '23

Symplectic two-form from connection: $\omega = dA$

Euler-Lagrange: $\omega_{ij}\dot{x}^j = \frac{\partial \mathcal{H}}{\partial x^i} - \left(\frac{\partial \mathcal{H}}{\partial x'^i}\right)'$

$\{x^i(\tau,\sigma), x^j(\tau,\sigma')\} = \Delta^{ij}(\sigma)\delta(\sigma-\sigma')$ with Δ^{ij} inverse of ω_{ij}

For specific case: h_{ij} describes Kähler geometry $\mathbb{CP}^1$
$\omega = dA$ is corresponding symplectic two-form

Fully covariant formulation of target space
→ U(1)-Galilean geometry

TH, Hartong, Obers '17
TH, Hartong, Obers & Oling '20
Bidussi, TH, Hartong, Obers & Oling '23

Twisted BPS decoupling limits of $AdS_5 \times S^5$

General BPS bound in AdS_5 x S^5: $$E \geq \sum_{i=1}^{p} S_i + \sum_{j=1}^{q+1} J_j$$

S_i : Angular mom. on AdS_5
J_j : Angular mom. on S^5

DOFs near BPS live in subspace $\mathrm{AdS}_{2p+1} \times S^{2q+1} \subset \mathrm{AdS}_5 \times S^5$

After twisted BPS decoupling limit:

$$S = \frac{w}{2\pi} \int d^2\sigma \left(m_i \dot{x}^i - \mathcal{H} \right) \ , \quad \mathcal{H}(x, x') = \frac{1}{2w^2} h_{ij} x'^i x'^j$$

Two-step approach:
TH, Hartong, Obers & Oling '20

$$\omega = dm \ , \quad m = \tilde{A}^{(p)} + A^{(q)} \ , \quad \text{Base space} = \mathbb{CH}^p \times \mathbb{CP}^q$$

From fibration of AdS_{2p+1}

From fibration of S^{2q+1}

General BPS bound in AdS_5 x S^5: $E \geq \sum_{i=1}^{p} S_i + \sum_{j=1}^{q+1} J_j$

S_i : Angular mom. on AdS_5
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After twisted BPS decoupling limit:

$$S = \frac{w}{2\pi} \int d^2\sigma \left(m_i \dot{x}^i - \mathcal{H} \right) \ , \quad \mathcal{H}(x, x') = \frac{1}{2w^2} h_{ij} x'^i x'^j$$

Two-step approach:
TH, Hartong, Obers & Oling '20

$$\omega = dm \ , \quad m = \tilde{A}^{(p)} + A^{(q)} \ , \quad \text{Base space} = \mathbb{C}\mathrm{H}^p \times \mathbb{C}\mathrm{P}^q$$

Dual to Spin Matrix limit: $\lambda \to 0 \ \ \text{with} \ \ \dfrac{E - \sum_{i=1}^{p} S_i - \sum_{j=1}^{q+1} J_j}{\lambda} = \text{fixed}$

TH, Kristjánsson & Orselli '07; TH & Orselli '14; TH & Wintergerst '19;
Baiguera, TH & Wintergerst '20; Baiguera, TH, Lei & Wintergerst '21; Baiguera, TH & Lei '22, '23

Perfect match of sigma-models in limits

TH, Kristjánsson & Orselli '08; TH, Hartong & Obers '17;
TH, Hartong, Obers & Yan '18; TH, Hartong, Obers & Oling '20

Special case:

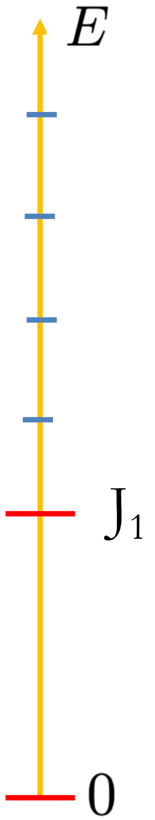
BMN case: BPS bound $E \geq J_1$

Null worldline in $\mathbb{R} \times S^1 \subset \mathrm{AdS}_5 \times S^5$

→ No twist, but also no transverse directions

→ Only ½ BPS states survive limit due to energy gap

A degenerate case



Twisted BPS decoupling limits of D-branes

BPS state: $E = \sum_{i=1}^{q+1} J_i$ D3-branes wrap S^3 in AdS_5

After T-duality along S^1 fiber: D4-brane in type IIA

Twisted BPS decoupling limit of non-abelian DBI gives:

$$S = \int dt\, \mathrm{STr}\left(w\, A_i^{(q)} \dot{x}^i - \frac{w^2}{16\pi^2 N} h_{ij}\, [x^j, x^k]\, h_{kl}\, [x^l, x^i] \right)$$

→ D-branes probe same symplectic geometry as the string

→ But now matrix valued!

Alternative formulation: $H = \frac{1}{2} \sum_i \mathrm{tr}(y_i^2) - \frac{1}{32\pi^2 N} \sum_{i<j} \mathrm{tr}([y_i, y_j]^2)\ ,\quad \sum_{k=1}^{q+1} [y_{2k-1}, y_{2k}] = 0$

Phase space: $y_{2k-1} = X_k\ ,\quad y_{2k} = P_k \quad \text{for} \quad k = 1, .., q+1$ Generalizes TH '16

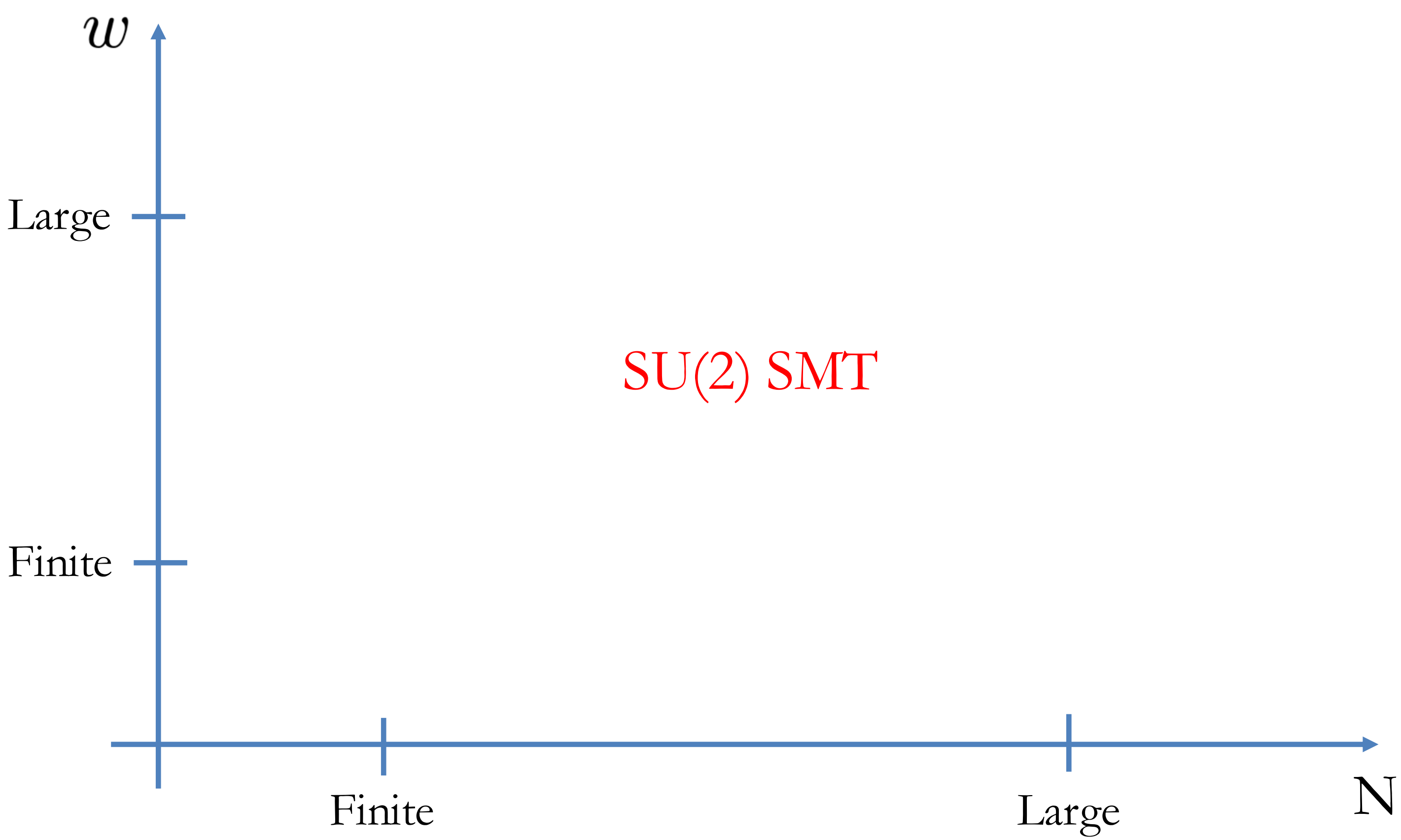
Matches N=4 SYM in same limit for finite N TH & Orselli '14; TH '16

Outlook

Can one “derive” holography in a twisted limit?

Example: The BPS bound $E \geq w = J_1 + J_2$

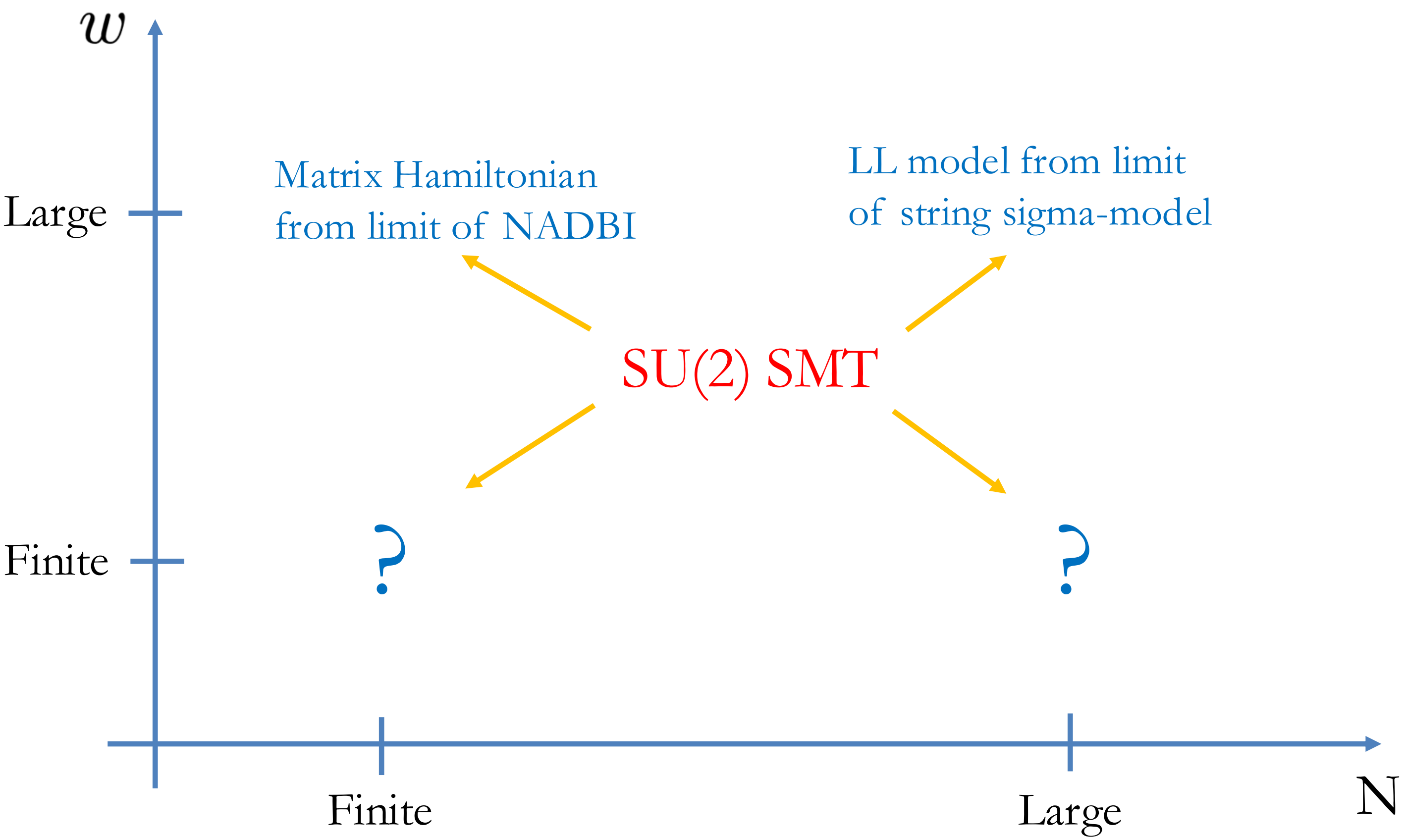
Limit of N=4 SYM: SU(2) Spin Matrix theory (SMT) for any w & N



Can one "derive" holography in a twisted limit?

Example: The BPS bound $E \geq w = J_1 + J_2$

Limit of type IIB string theory on $AdS_5 \times S^5$



Non-Lorentzian geometry in AdS_5/CFT_4 correspondence

Can probes see non-Lorentzian geometry?

"Non-Lorentzian geometry in the AdS/CFT correspondence", Baiguera, TH, Lei, Maskalaniec, Yan (to appear)

U-duality orbit of twisted BPS decoupling limit ?

Use U-duality transformations to find D-brane (and other brane) versions of limit → New geometries / holographic correspondences

Limits for other curved space-times

$AdS_4 \times CP^3$, $AdS_3 \times S^3$, etc.

Black hole from Spin Matrix theory

Can I obtain black hole dynamics in strong coupling regime ?

THANK YOU!

U-duality orbit of twisted BPS decoupling limit

Use U-duality transformations to find D-brane (and other brane) versions of limit → New geometries / holographic correspondences

For DLCQ: Itzhaki, Maldacena, Sonnenschein & Yankielowicz '98
Blair, Lahnsteiner, Obers & Yan '23, '24;
"Landscape of U-dual BPS decoupling limits", de Boer, Dijkgraaf, TH, Obers, Yan (to appear soon)

Relation between DLCQ and twisted limits:

Explored in upcoming work

"Non-Lorentzian geometry in the AdS/CFT correspondence", Baiguera, TH, Lei, Maskalaniec, Yan (to appear soon)

Better understanding of Spin Matrix theory

QFT formulation? Non-Lorentzian CFT? Strong coupling limit?

TH & Wintergerst '19; Baiguera, TH & Wintergerst '20;
Baiguera, TH, Lei & Wintergerst '21; Baiguera, TH & Lei '22, '23
Baiguera, TH, Lei & Yan '25
2605.24085 by Auzzi, Baiguera, Guo, TH, Nardelli

Sigma-model for finite momentum/winding w in limit of $AdS_5 \times S^5$:
Can one match gauge and string theory sides in the quantum string regime?
This would constitute a proof of AdS/CFT in this BPS limit

Splitting/joining of strings:
Perturbative / non-perturbative description?
Can one connect the stringy regime to finite N?
→ On the SYM side, these come from the same theory: Spin Matrix theory

Matrix-valued symplectic geometry for D-branes on $AdS_5 \times S^5$:
Open string description? Non-abelian action?

Limits for other curved space-times:
$AdS_4 \times CP^3$, $AdS_3 \times S^3$, etc.

Twisted BPS decoupling limit for black holes?
BPS black hole in $AdS_5 \times S^5$