The NS-NS Branes of Non-relativistic String Theory

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work in progress with
Eric Bergshoeff, Johannes Lahnsteiner, Luca Romano and Jan Rosseel, Tonnis ter Veldhuis

Motivation

Non-relativistic gravity (in the bulk)

Gomis, Ooguri (2000); Danielsson, Guijosa, Kruczenski (2000)

Gomis, Gomis, Kamimura (2005)

Bagchi, Gopakumar (2009)

Non-relativistic String Theory

NR strings couple to a curved spacetime, a Kalb Ramond two form and dilaton.

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- String Newton-Cartan (SNC) theory

Gomis, Gomis, Kamimura; Andringa, Bergshoeff, Gomis, de Roo; Bergshoeff, Gomis, Yan

- Torsional Newton-Cartan (TNC) theory

Harmark, Hartong, Obers

hear talk by Natale Zinnato

Classically these two approaches converge to the same theory in the presence of Kalb-Ramond field and assuming the longitudinal spatial isometry.

Harmark, Hartong, Menculini, Obers, Oling

NR Particle

$$\hat{A} = (0, A') : \begin{cases} 0 & \text{is longitudinal to worldline} \\ A' & \text{is transverse to worldline} \end{cases}$$

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NC background fields

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$$\mu = (0, \ldots, D-1), A' = (1, \ldots, D-1),$$

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$$H_{\mu\nu} \rightarrow H_{\mu\nu} + 2\tau_{(\mu} C_{\nu)}\,, \quad B_\mu \rightarrow B_\mu + C_\mu\,.$$

?

$$\partial_{[\mu} \tau_{\nu]} = 0$$

NR string sigma model

$$S_{\text{Pol.}} = -\frac{T}{2}\int d^2\sigma\left[\sqrt{-h}\,h^{\alpha\beta}\,\partial_\alpha x^\mu\partial_\beta x^\nu H_{\mu\nu} + \varepsilon^{\alpha\beta}\left(\lambda\, e_\alpha\tau_\mu + \bar{\lambda}\,\bar{e}_\alpha\bar{\tau}_\mu\right)\partial_\beta x^\mu\right]$$

$$-\frac{T}{2}\int d^2\sigma\,\varepsilon^{\alpha\beta}\partial_\alpha x^\mu\partial_\beta x^\nu B_{\mu\nu}$$

$$\begin{aligned}\delta\tau_\mu{}^A &= 0\,,\\ \delta E_\mu{}^{A'} &= -\lambda_A{}^{A'}\tau_\mu{}^A\,,\\ \delta m_\mu{}^A &= D_\mu(\omega)\lambda^A + \lambda^A{}_{A'}E_\mu{}^{A'} + \sigma^A{}_B\tau_\mu{}^B\,.\end{aligned}$$

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\end{aligned}$$

$$D_{[\mu}(\omega)\tau_{\nu]}{}^A = 0 \rightarrow \varepsilon_C{}^{(A}\tau_{[\mu}{}^{B)}\partial_\nu \tau_{\rho]}{}^C = 0\,.$$

Stückelberg Symmetries

$$H_{\mu\nu} \to H'_{\mu\nu} = H_{\mu\nu} - (C_\mu{}^A \tau_\nu^B + C_\nu{}^A \tau_\mu{}^B)\eta_{AB} ,$$

$$B_{\mu\nu} \to B'_{\mu\nu} = B_{\mu\nu} + (C_\mu{}^A \tau_\nu^B - C_\nu{}^A \tau_\mu{}^B)\varepsilon_{AB}$$

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$$S_{\text{SNG}} = -\frac{T}{2}\int d^2\sigma \, \left[\sqrt{-\tau}\tau^{\alpha\beta}\partial_\alpha x^\mu \partial_\beta x^\nu E_\mu{}^{A'} E_\nu{}^{B'} \delta_{A'B'} + \varepsilon^{\alpha\beta}\partial_\alpha x^\mu \partial_\beta x^\nu \mathscr{B}_{\mu\nu}\right]$$

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galilean boost?

Relativistic T-duality

$$\hat{S}_{Rel} \sim T \int d^2\sigma \left[\sqrt{-h} h^{\alpha\beta} \partial_\alpha x^\mu \partial_\beta x^\nu \hat{G}_{\mu\nu}(x) + \varepsilon^{\alpha\beta} \partial_\alpha x^\mu \partial_\beta x^\nu \hat{B}_{\mu\nu}(x) \right]$$

Assume an isometry v with $\mu = (v, i)$

Buscher's T-duality rules are given by Buscher; Roček, Verlinde

$$\tilde{G}_{vv} = \frac{1}{\hat{G}_{vv}}, \qquad \tilde{B}_{vi} = \frac{\hat{G}_{vi}}{\hat{G}_{vv}},$$

$$\tilde{G}_{vi} = \frac{\hat{B}_{vi}}{\hat{G}_{vv}}, \qquad \tilde{B}_{ij} = \hat{B}_{ij} + \frac{\hat{B}_{vi}\hat{G}_{vj} - \hat{B}_{vj}\hat{G}_{vi}}{\hat{G}_{vv}}$$

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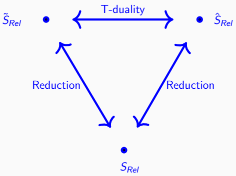
$10D$



$9D$

T-Duality in Non-relativistic String Theory

For the purpose of our discussion, we distinguish two distinct T-duality rules:

Gomis, Ouguri, Gomis; Gomis, Kamimura

Bergshoeff, Gomis, Yan; Bergshoeff, Rosseel, S, Yan

- Longitudinal Spatial T-duality
- Transverse T-duality

NR T-duality

- The transverse T-dual of a non-relativistic string theory gives a non-relativistic string theory in a T-dual background like in relativistic T-duality.

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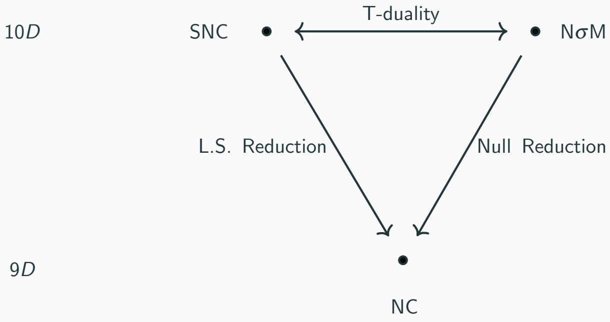
$10D$ SNC • ←T-duality→ • SNC'

- Along a longitudinal spatial direction, T-duality maps nonrelativistic string theory on a SNC background to relativistic string theory on a Lorentzian geometry with a null isometry direction and $\partial_{[i}\tilde{G}_{j]v} = \partial_{[i}\tilde{B}_{j]v} = 0$.


10D
SNC
T-duality
NσM
L.S. Reduction
Null Reduction
9D
NC

Solutions

Solutions that satisfy $\tilde{G}_{vv} = \partial_{[i}\tilde{G}_{j]v} = \partial_{[i}\tilde{B}_{j]v} = 0$ are

- pp-wave solution

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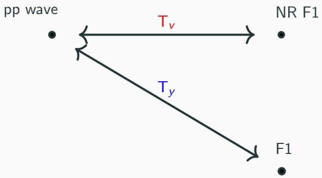
- pp-wave solution
- NS5-brane solution
- KK monopole

Relativistic Solutions vs Non-relativistic Solutions I

PP-wave solution

$$
\begin{aligned}
ds^2_{\mathrm{pp}} &= 2du\, dv + K\, du^2 + dz^2_{(8)}\,,\\
\hat{B} &= 0\,,\\
e^{\hat{\Phi}} &= g_s\,.
\end{aligned}
$$



$$F = 1 + \frac{K(z_{(8)})}{2}, \quad v + u \propto y$$

Relativistic Solutions vs Non-relativistic Solutions I

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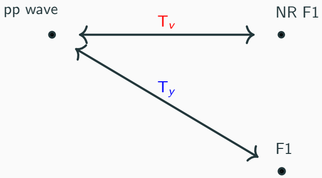
NR fundamental string solution

$$\tau_\mu{}^A = \delta_\mu{}^A\,, \qquad E_\mu{}^{A'} = \delta_\mu{}^{A'}\,,$$

$$\mathscr{B}_{\underline{01}} = K(z_{(8)})\,, \qquad e^{\Phi} = g_s\,.$$



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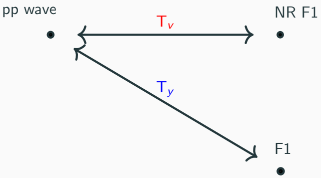

Fundamental String solution F1

$$
\begin{aligned}
ds^2_{\mathrm{F1}} &= F^{-1}(-dt^2 + {\color{blue}dy^2}) + dz^2_{(8)}\,,\\
\tilde{B}_{01} &= (1 - F^{-1})\,,\\
e^{\tilde{\Phi}} &= g_s\, F^{-1/2}\,,
\end{aligned}
$$

$$
{\color{red}F = 1 + \frac{K(z_{(8)})}{2}\,, \quad v + u \propto y}
$$

Relativistic Solutions

NS5 brane solution

$$ds^2_{\mathrm{NS5}} = -dt^2 + dy^2 + dy^2_{(4)} + F\, dz^2_{(4)}\,,$$

$$(d\tilde{B})_{mnp} = \frac{1}{6}\varepsilon_{mnp}{}^{r}\partial_r F\,, \qquad \mathrm{e}^{\tilde{\Phi}} = g_s\, F^{1/2}\,,$$

Relativistic Solutions

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KK monopole

$$ds^2_{\mathrm{KK5}} = -\,dt^2 + dy^2 + dy^2_{(4)} + F\,dz^2_{(3)} + F^{-1}\left(dz + A_m(z_{(3)})dz^m_{(3)}\right)^2\,,$$

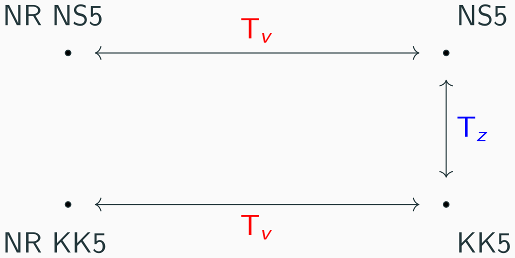
$$\text{with} \quad \partial_{[m}A_{n]} = \varepsilon_{mnp}\partial^p F\,.$$

$t + y \propto v$

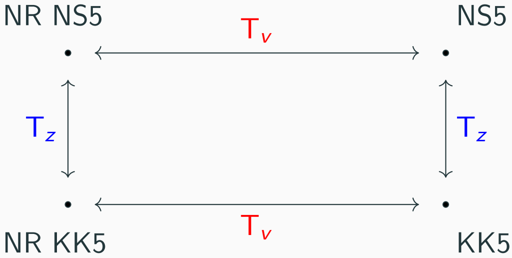
$\partial_{[i}\tilde{G}_{j]v} = \partial_{[i}\tilde{B}_{j]v} = 0$

Relativistic vs Non-relativistic Solutions II

Relativistic vs Non-relativistic Solutions II



Relativistic vs Non-relativistic Solutions II



Outlook

- Supersymmetric version of this theory, do NR solutions saturate BPS bound? *work in progress*

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  hear talk by Ziqi Yan

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  hear talk by Ziqi Yan
- Does intersecting brane give a higher dimensional viewpoint to some black holes in four and five dimensions as in relativistic case? Strong non-relativistic gravity?

Thank you!