Local supersymmetry and non-relativistic limits of M-theory

Chris Blair (IFT UAM-CSIC)

SUSY24, IFT UAM-CSIC, 13/06/2024

Based on:

arXiv:2104.07579 with A. D. Gallegos, N. Zinnato

Work in progress with E. Bergshoeff, J. Lahnsteiner, J. Rosseel

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Three lies about supersymmetry

Absorbed during my Masters many supermoons ago

Don't take this slide too seriously...

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2. SUSY will surely be discovered at the LHC

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3. 11-dimensional supergravity is unique

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Today I will only discuss number 3 (explicitly) and 1 (implicitly)

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11-d SUGRA is the unique max SUGRA in max dimension

'Unique' assumes Lorentz invariance

$$S = \int d^{11}x\sqrt{-G}\left(R - \frac{1}{48}F^2\right) - \frac{1}{6}C \wedge F \wedge F + \text{fermionic}$$

$F_4 = dC_3$ $\qquad$ Ψ_μ

$$\delta G_{\mu\nu} \sim \bar{\epsilon}\gamma_{(\mu}\Psi_{\nu)}$$
$$\delta C_{\mu\nu\rho} \sim \bar{\epsilon}\gamma_{[\mu\nu}\Psi_{\rho]}$$
$$\delta\Psi_\mu \sim D_\mu\epsilon + (F\cdot\gamma)_\mu\epsilon$$

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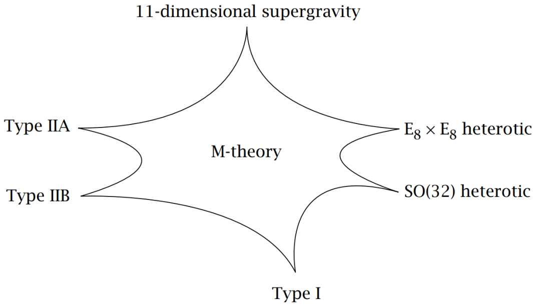
11-d SUGRA: low energy limit of M-theory

Other limits?

Decoupling limits: focus on simpler sub-sectors. Can encode surprising amounts of info e.g. AdS/CFT, Matrix Theory

Examples: **non-relativistic limits**



Non-relativistic decoupling limits

Can be taken for particles, strings and branes

0) Point particles

$$S = -mc \int \mathrm{d}\tau \sqrt{-\eta_{\mu\nu}\dot{x}^\mu \dot{x}^\nu} + qc \int \mathrm{d}\tau A_\mu \dot{x}^\mu$$

$$\mathrm{d}s^2 = -c^2 \mathrm{d}t^2 + \delta_{ab}\mathrm{d}x^a \mathrm{d}x^b$$

Special case: BPS $m = q$, $A_\mu = (c, 0, 0, 0)$

$\longrightarrow$ cancels rest mass divergence

$$S \longrightarrow \frac{1}{2} m \int \mathrm{d}t\, \dot{x}^a \dot{x}^b$$

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Two generalisations:

- extended objects
  in string/M-theory [Gomis, Ooguri; Danielsson, Guijosa, Kruczenski 2000]
- curved backgrounds $\mathrm{d}s^2 = (-c^2\tau_\mu\tau_\nu + \delta_{ab}e^a{}_\mu e^b{}_\nu)\mathrm{d}x^\mu\mathrm{d}x^\nu$, $A_\mu = c\tau_\mu + a_\mu$
  unifying modern perspective [CB, Lahnsteiner, Obers, Yan 2023 + WIP]

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2) Membranes

$$S = -T\int d^3\sigma\sqrt{-\det G} + T\int C_3$$

$$ds^2 = (c^2\eta_{AB}\tau^A{}_\mu\tau^B{}_\nu + c^{-1}\delta_{ab}e^a{}_\mu e^b{}_\nu)dx^\mu dx^\nu$$

$$C_{\mu\nu\rho} = -c^3\epsilon_{ABC}\tau^A{}_\mu\tau^B{}_\nu\tau^C{}_\rho + c_{\mu\nu\rho}$$

$$A = 0, 1, 2 \qquad a = 3, \ldots, 10$$

Units: s.t. $T \sim 1/\ell_p^3$ fixed, c dimensionless parameter

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Taking the membrane decoupling limit in SUGRA

This leads to a non-relativistic SUGRA theory

Limit of bosons

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Bosonic symmetries

Vielbein $E^{\hat{a}}{}_\mu = (c\tau^A{}_\mu, c^{-1/2}e^a{}_\mu)$

$$\Lambda^{\hat{a}}{}_{\hat{b}} = (\Lambda^A{}_B, \quad \Lambda^a{}_b, \quad c^{-3/2}\lambda^a{}_A)$$

$\mathrm{SO}(1,10) \to \mathrm{SO}(1,2) \quad \mathrm{SO}(8) \quad$ boosts

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Limit of fermions

$$\Psi_\mu = c^{1/2}\psi_{-\mu} + c^{-1}\psi_{+\mu}$$

$$\gamma_{012}\psi_{\pm\mu} = \pm\psi_{\pm\mu}$$

c.f. non-rel string limit and $\mathcal{N} = 1$ SUGRA in 10d

[Bergshoeff et al 2021]

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Fermionic symmetries

SUSY $\epsilon = c^{1/2}\epsilon_- + c^{-1}\epsilon_+$

Expanding SUSY must lead to emergent symmetries and constraints

Use the power expansion

$$S = c^3 S_3 + c^0 S_0 + c^{-3} S_{-3} + \dots$$

$$\delta = c^3 \delta_3 + c^0 \delta_0 + c^{-3} \delta_{-3} + \dots$$

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$$\Longrightarrow$$

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Divergent action: $S_3 \sim -\int f^{(-)}_{abcd} f^{(-)abcd}$

$$f_4 = dc_3, f_{abcd} = e^\mu{}_a \ldots f_{\mu\nu\rho\sigma}$$

$$f^{(\pm)}{}_{abcd} = \pm\frac{1}{4!}\epsilon_{abcd}{}^{efgh} f^{(\pm)}_{efgh}$$

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Auxiliary field λ_{abcd} removes S_3

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Upshot:

$\delta_3 S_0 = 0 \Rightarrow$ emergent fermionic symmetry of S_0

$\delta_0 S_0 = -\delta_3 S_{-3} \Rightarrow S_0$ invariance needs $\delta_3 \equiv 0 \Rightarrow$ constraints

Constraints beget constraints

Max SUSY or half-max SUSY?

$\delta_3(\text{bosons}) = 0$ $\delta_3(\text{fermions}) \neq 0$

$\epsilon_+ \times T_{ab}{}^{A}$
$\epsilon_- \times T_a{}^{\{AB\}}, f_{Aabc}, f^{(+)}_{abcd}$

$T_{\mu\nu}{}^{A} = 2\partial_{[\mu}\tau^{A}{}_{\nu]}$
torsion

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Option 1: Half-maximal SUSY $\epsilon_+ \neq 0, \epsilon_- = 0$

$T_{ab}{}^A = 0 \xrightarrow{\delta_0} f_{abcd} = 0$

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Option 1: Half-maximal SUSY $\quad \epsilon_+ \neq 0,\ \epsilon_- = 0$

$$T_{ab}{}^A = 0 \xrightarrow{\delta_0} f_{abcd} = 0$$

Option 2: Maximal SUSY $\quad \epsilon_\pm \neq 0$

$$T_{ab}{}^A, T_a{}^{\{AB\}}, f_{Aabc}, f^{(+)}_{abcd} = 0 \xrightarrow{\delta_0} \text{fermionic curvatures} \xrightarrow{\delta_0} \text{bosonic curvatures} \xrightarrow{\delta_0} \dots$$
$$\partial\tau \xrightarrow{\delta_0} \partial\psi_\pm \xrightarrow{\delta_0} \partial^2\tau \xrightarrow{\delta_0} \partial^2\psi_\pm \xrightarrow{\delta_0} \partial^3\tau \xrightarrow{\delta_0} \dots\ ???$$

A maximally SUSY solution exists

It may be easier to find solutions than the theory itself...

	0	1	2	3	4	5	6	7	8	9	10
Non-rel membrane limit	×	×	×	–	–	–	–	–	–	–	–
M2 solution	×	–	–	×	×	–	–	–	–	–	–

Holographically dual to non-rel limit of a 3d SCFT (ABJM) [Lambert-Smith 2024]

$\tau^0 = \mathcal{H}^{-1/3}\mathrm{d}x^0 \quad \tau^\alpha = \mathcal{H}^{1/6}\mathrm{d}x^\alpha$

$\alpha = 1, 2$

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$c_{034} = \mathcal{H}^{-1} \quad \lambda_{abcd} = 0$

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$$= ((x^1)^2 + (x^2)^2)^{-3} \text{ for M2 near horizon}$$

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All physical curvatures zero $\longrightarrow$ all (possible) constraints obeyed

$\exists$ Killing spinor solution with 32 independent parameters using both SUSY and emergent fermionic shift symmetry

Non-relativistic supersymmetry in 11 dimensions is a complicated beast

Despite many constraints, it seems that it is a non-trivial theory

Membrane non-relativistic limit:

half-maximal SUSY $\leftrightarrow$ simple constraints

maximal SUSY $\leftrightarrow$ complicated constraints

... but $\exists$ (surprisingly) non-trivial interesting solution

$\longrightarrow$ dimensional reduction and type II maximal SUGRA?

$\longrightarrow$ new novel holographic dualities?

$\longrightarrow$ this limit is U-dual to M-theory on a null circle $\longrightarrow$ Matrix Theory

Five-brane non-relativistic limit:

further non-uniqueness of non-relativistic 11-d SUGRA

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Thanks for listening!