Supersymmetrizing Massive Gravity

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Outline

- Motivation
- Forming matter action
- Coupling to Supergravity
- Main results
- Summary

MOTIVATION

- Forming massive gravity via Higgs mechanism (by Chamseddine and Mukhanov)
- Four scalar fields with global Lorentz symmetry coupled to gravity
- Scalar fields taking a vacuum expectation value breaking diffeomorphism invariance spontaneously
- Result massive graviton

[A. Chamseddine and V. Mukhanov, Journal of High Energy Physics, 08, (2010), 11.]

- $\longrightarrow$ Generalize this to the supersymmetric case

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FOUR CHIRAL SUPERFIELDS

- Consider four $N = 1$ chiral superfields with global Lorentz symmetry

$$\overline{D}_{\dot{\alpha}}\Phi^{A}\left(x,\theta,\overline{\theta}\right)=0$$

- Given by

$$\Phi_A = \varphi_A + i(\theta\sigma^{\mu}\bar{\theta})\partial_{\mu}\varphi_A - \frac{1}{4}\theta\theta\bar{\theta}\bar{\theta}\partial_{\mu}\partial^{\mu}\varphi_A + \sqrt{2}\theta\psi_A - \frac{i}{\sqrt{2}}\theta\theta\left(\partial_{\mu}\psi_A\sigma^{\mu}\bar{\theta}\right) + \theta\theta F_A$$

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BASIC FIELD

- In bosonic case: $H_{AB} = g^{\mu\nu}\partial_\mu\phi_A\partial_\nu\phi_B$
- Our case: Define H_{ABC} as the basic field

$$H_{ABC} = D^\alpha\Phi_A(\sigma_B)_{\alpha\dot{\alpha}}\bar{D}^{\dot{\alpha}}\Phi^*_C = D\Phi_A\sigma_B\bar{D}\Phi^*_C \quad (1)$$

- Work instead with $\overline{H}_{ABC} = H_{ABC} - Dx_A\sigma_B\bar{D}x^*_C$ to avoid including higher order terms

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FORMING OUR ACTION

- Using this $\overline{H}_{ABC}$ construct D-type terms to form the matter multiplets ($\overline{H}_{ABC}\overline{H}_{BCA}$,..)
- Couple to the Supergravity Lagrangian using the rules of tensor calculus.

$$L_{S.G} = -\frac{e}{2\kappa^2} R(e, w) - \frac{e}{3} |u|^2 + \frac{e}{3} A_\mu A^\mu - \frac{1}{2} \bar{\phi}_\mu R^\mu \qquad (2)$$

- Lagrangian field content:
  - spin-2 field, $e_{a\mu}$
  - spin-3/2 field, ϕ_μ
  - auxiliary fields u, A_μ

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COUPLING VETOR MULTIPLET TO SUPERGRAVITY

- Vector multiplet

$$V = (C, \xi, M, V_\mu, \lambda, D) \tag{3}$$

- D-type multiplet action formula

$$\begin{aligned} e^{-1}L_D = {} & D + \frac{i\kappa}{2}\bar{\phi}_\mu \gamma^5 \gamma^\mu \lambda - \frac{\kappa}{3}(uM^* + u^* M) + \frac{i\kappa^2}{8}\epsilon^{\mu\nu\rho\sigma}\bar{\phi}_\mu \gamma_\nu \phi_\rho \bar{\xi}\phi_\sigma \\ & + \frac{2}{3}\kappa V_\mu \left(A^\mu + \frac{3}{8} i e^{-1}\epsilon^{\mu\rho\sigma\tau}\bar{\phi}_\rho \gamma_\tau \phi_\sigma\right) - i\frac{\kappa}{3}e^{-1}\bar{\xi}\gamma_5 \gamma_\mu R^\mu \\ & - \frac{2}{3}\kappa^2 C e^{-1} L_{S.G.} + e^{-1}L_{S.G.} \end{aligned} \tag{4}$$

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WHAT WE WANT?

- Expanding the fields around the vacuum solution

$$\varphi^A = x^A + \chi^A, \qquad e^\mu_A = \delta^\mu_A + \bar{e}^\mu_A, \tag{5}$$

- An action with the following required conditions
  - A Fierz-Pauli term for the vierbeins ($\bar{e}^\mu_A \bar{e}^A_\mu - \bar{e}^2$)
  - No linear vierbein term
  - Maxwell form for the χ_A fields

$$l\left(\partial_\mu \chi_A \partial^\mu \chi^{A*} - \partial_A \chi^A \partial_B \chi^{B*}\right) \tag{6}$$

    where l is a constant
  - Ghost free: no terms like

$$\partial_\mu \chi_A \partial^\mu \chi^A, \quad \text{or} \quad \partial_A \chi^A \partial_B \chi^B \tag{7}$$

  - Massive gravitinos

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MATTER ACTION

- First four conditions well satisfied with three D-type terms:
  - $\bar{H}_{ABC}\bar{H}_{BCA}$
  - $\bar{H}_{ABB}\bar{H}_{CCA}$
  - $\bar{H}_{AB}\bar{H}^{*}_{AB}$ where $H_{AB} = D\Phi_A D\Phi_B$
- Gravitino massive by adding two F-type terms and coupling them to supergravity:
  - $\bar{D}^2\left(D\Phi_A\sigma^{AB}D\Phi_B\right)$
  - $\bar{D}^2\left(D\Phi_A D\Phi^A \bar{D}\Phi^{*}_{B}\bar{D}\Phi^{B*}\right)$

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COUPLING CHIRAL MULTIPLET TO SUPERGRAVITY

- Chiral multiplet (F-type)

$$F = (z, X_L, h) \tag{8}$$

  - Complex scalar field z
  - Left-handed Weyl spinors X_L
  - Complex auxiliary field h
- Action formula

$$e^{-1} L_F = h + \kappa u z + \kappa \bar{\phi}_\mu \gamma^\mu \chi + i\kappa^2 \bar{\phi}_\mu \gamma^{\mu\nu} \phi_{vR} z + h.c. \tag{9}$$

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- Scalar components of the chiral multiplets φ_A acquired a vacuum expectation value
- $\rightarrow$ Diffeomorphism invariance and local supersymmetry broken spontaneously

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- Global Lorentz index A identified with the space-time Lorentz index
  - Scalar fields $\chi_A \to$ vectors
  - Chiral spinors $\psi_A \to$ spin-$3/2$ Rarita-Schwinger fields
- Spectrum of the model in the broken phase:
  - A massive spin-2 field
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  - A massive vector

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DEGREES OF FREEDOM: BEFORE COUPLING

- Counting degrees of freedom: supergravity coupled to a $N = 1$ supersymmetry model similar to the Wess-Zumino model
- Before the coupling, supergravity contains
  - one massless spin-2 graviton (two bosonic dof)
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- $N = 1$ supersymmetry model:
  - Four spin-0 particles, φ^A, with only six degrees of freedom (3 times 2) since φ^0 decouples due to Fierz-Pauli choice
  - Six fermionic degrees of freedom forming a multiplet
- Overall eight fermionic degrees of freedom and eight bosonic degrees of freedom

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- Constructed a supersymmetric theory of massive gravity
- Coupled a pure Supergravity multiplet to a matter multiplet
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- Before diffeomorphism breaking:
  spin-$1/2$ and not spin-$3/2$ $\rightarrow$ two gravitinos with different masses
- ϕ_μ: genuine gravitino
- ψ_A: identified with a gravitino after the breaking

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