New Massive Gravity in Three Dimensions

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based on a collaboration with Olaf Hohm and Paul Townsend,

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Outline

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1. Introduction
2. Gravity in Three Dimensions

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3. The CGMG Model

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except if you are in three dimensions .....

A Useful Analogy: Spin 1

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  - $m_+ = 0:$ massive topological spin 1

Deser, Jackiw, Templeton (1982)

Higher-derivative Maxwell

$$\left(m_+\,\delta_\mu{}^\nu + \epsilon_\mu{}^{\tau\nu}\partial_\tau\right)A_\nu = 0 \quad \stackrel{m_+\to 0}{\Longrightarrow} \quad A_\mu \;\to\; F_\mu \equiv \epsilon_\mu{}^{\nu\rho}\,\partial_\nu A_\rho$$

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- $A_\mu \quad \to \quad F_\mu \qquad \Rightarrow \qquad \left(\Box + m^2\right)F_\mu = 0$
- $\mathcal{L} \;\sim\; m^2\,\epsilon^{\mu\nu\rho}A_\mu\partial_\nu A_\rho \;+\; \epsilon^{\mu\nu\rho}F_\mu\partial_\nu F_\rho$: high.-deriv. Maxwell

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Pure Gravity

$$\mathcal{L}_{\rm pure} \;\sim\; h^{\mu\nu}\mathcal{G}_{\mu\nu}(h)\,, \qquad\qquad \mathcal{G}_{\mu\nu}(h) = \tfrac{1}{2}\epsilon_{(\mu}{}^{\eta\rho}\,\epsilon_{\nu)}{}^{\tau\sigma}\partial_\eta\partial_\tau\, h_{\rho\sigma}$$

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$$\mathcal{G}_{\mu\nu}(h) = 0 \qquad \Rightarrow \qquad h_{\mu\nu} = \partial_\mu a_\nu + \partial_\nu a_\mu \; : \quad \text{no dynamics}$$

Pauli-Fierz

- $\mathcal{L}_{\rm PF} \;\sim\; h^{\mu\nu}\mathcal{G}_{\mu\nu}(h) - \frac{1}{2}m^2\left(h^{\mu\nu}h_{\mu\nu} - h^2\right)$

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- $S_{\rm TMG}[g] = \frac{1}{\kappa^2}\int\, d^3x\left\{-\sqrt{-g}\,R + \frac{1}{\mu}\mathcal{L}_{\rm LCS}\right\}$ with

$$\mathcal{L}_{\rm LCS} = \frac{1}{2}\left[\Gamma^\alpha_{\mu\beta}\partial_\nu\Gamma^\beta_{\rho\alpha} + \frac{2}{3}\Gamma^\alpha_{\mu\gamma}\Gamma^\gamma_{\nu\beta}\Gamma^\beta_{\rho\alpha}\right]$$

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- $S_{\rm NMG}[g] = \frac{1}{\kappa^2}\int d^3x\,\sqrt{-g}\left[-R + \frac{1}{m^2}K\right]$ with

$$K = R_{\mu\nu}R^{\mu\nu} - \tfrac{3}{8}R^2$$

Hohm, Townsend + E.B. (2009)

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- CGMG : massive gravitons ($m_\pm$), BTZ black holes and new non-BTZ black holes

Question

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CTMG: either gravitons or BTZ black holes have positive energy.

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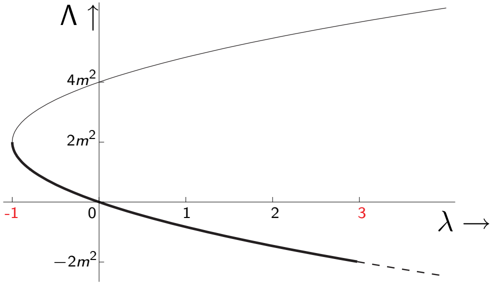

CNMG with $\sigma = -1\,,\ m^2 > 0$

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$$c_L = \frac{3\ell}{2G_3}\left(\sigma + \frac{1}{\mu\ell} + \frac{1}{2\ell^2 m^2}\right), \qquad c_R = \frac{3\ell}{2G_3}\left(\sigma - \frac{1}{\mu\ell} + \frac{1}{2\ell^2 m^2}\right)$$

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- Relation to Hořava-Lifshitz Gravity with $z = 4$?