Title: Jogging Through Holographic Massive Gravity

Date: Aug 24, 2016 11:55 AM

URL: http://pirsa.org/16080044

Abstract: We present some recent developments in the framework of holographic (Lorentz violating) massive gravity.
We rigorously define the most generic isotropic setup in 3+1 dimensions and we study in detail its phenomenology.
We describe the electric and the viscoelastic responses of the system and we comment on the fate of the KSS viscosity bound in absence of translational symmetry. We conclude with some discussion hints and comments for the future.

# Jogging through holographic massive gravity


Matteo Baggioli

Universitat Autonoma de Barcelona → University of Crete


arXiv:1510.09089

arXiv:1601.03384


With O.Pujolas, L. Alberte, A.Khmelnitsky

Universitat Autònoma de Barcelona


Perimeter Institute for Theoretical Physics

LOW ENERGY CHALLENGES FOR HIGH ENERGY PHYSICISTS II

August 2016

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

# WHY?

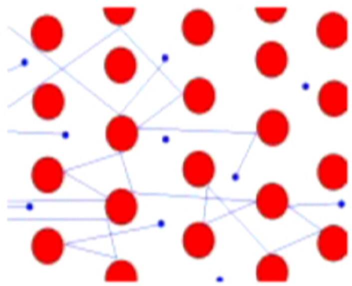
**Translational invariance**

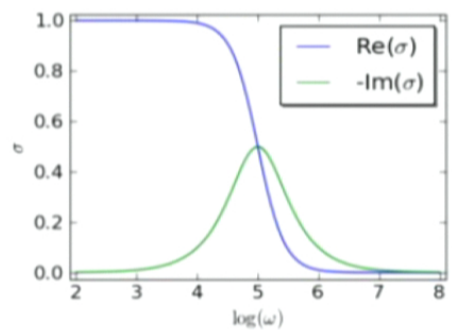
**Momentum can't dissipate**

**Infinite DC quantities**

**Real Materials are different:**

- **Lattice**
- **Disorder**
- **Impurities**






$$\frac{d}{dt}\,p(t) = q\,E - \frac{p(t)}{\tau}$$

$$\sigma_{DC} = \frac{n\,q^2\,\tau}{m}$$

**!!!!**

arXiv:1301.0537


arXiv:1306.5792

" Holographic Drude Model" and beyond ...

Diffeomorphism invariance
( General Relativity) $\longrightarrow \partial_\mu T^{\mu\nu} = 0$

(LV)
MASSIVE
GRAVITY $\longrightarrow \partial_i T^{ij} = -\frac{1}{\tau} T^{tj} \neq 0 \quad \tau \sim \frac{1}{m_G^2}$

Lorentz Invariance

↓

dRGT

NO Lorentz Invariance

# MASKED MASSIVE GRAVITY

**Stueckelberg trick :** $MG \longrightarrow GR + \mathcal{L}_\phi$

$$S = \int d^4x \sqrt{-g} \left[ \frac{1}{2} \left( R + \frac{6}{L^2} \right) - \frac{L^2}{4} F_{\mu\nu} F^{\mu\nu} + \mathcal{L}_\phi \right]$$

**Stueckelberg fields :** $\hat{\phi}^A = x^\mu \delta_\mu^A \qquad \mathcal{I}^{IJ} \equiv g^{\mu\nu} \partial_\mu \phi^I \partial_\nu \phi^J$

arXiv:1311.5157

arXiv:1411.1003

$$X \equiv \frac{1}{2} \mathrm{tr}[\mathcal{I}^{IJ}] \qquad Z \equiv \det[\mathcal{I}^{IJ}]$$

**MOST GENERIC ACTION (in 3+1)**

$$S_\phi \equiv \int d^4x \sqrt{-g}\, \mathcal{L}_\phi = - \int d^4x \sqrt{-g}\, V(X, Z)$$

# SOLIDS VS FLUIDS

$$\phi^I \mapsto \psi^I = O^I_J \phi^J + c^I \ .$$

$$\phi^I \mapsto \psi^I(\phi^J) \, , \qquad \det\left[\frac{\partial \psi^I}{\partial \phi^J}\right] = 1 \, .$$

**SOLIDS : V(X,Z)** non zero vectorial and tensorial masses

**FLUIDS : V(Z)** non zero vectorial mass but zero tensorial one

# ELECTRIC RESPONSE

$$\sigma(\omega) = \frac{-iG^R_{J_x J_x}(\omega)}{\omega}$$

**"vectorial" masses**

$$\mathcal{L}^V_\phi = \frac{1}{2}\left(2\,m_1^2(r)\,h^{ti}\,h^{ti} + m_7^2(r)\,h^{ri}\,h^{ri} + m_8^2(r)\,h^{ri}\,h^{ti}\right)$$

**Stability** ⟶ $m_7^2 + 2\,m_1^2 = 0\,, \qquad m_8^2 = 0\,.$ ⟶ $m_V^2(r)$

$$\sigma_{DC} = 1 + \frac{\mu^2}{m_V^2(r_h)}$$

**The radial dependence of the graviton mass Controls the phenomenological properties (T dependence) Of the relaxation time ------> DC conductivity !**

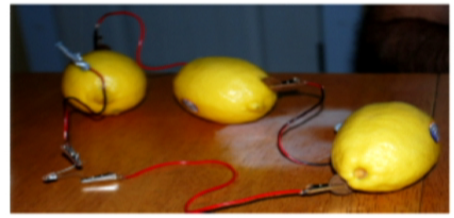
$$m_V^2(r) \sim c_1\,V_X(X,Z) + c_2\,V_Z(X,Z)$$

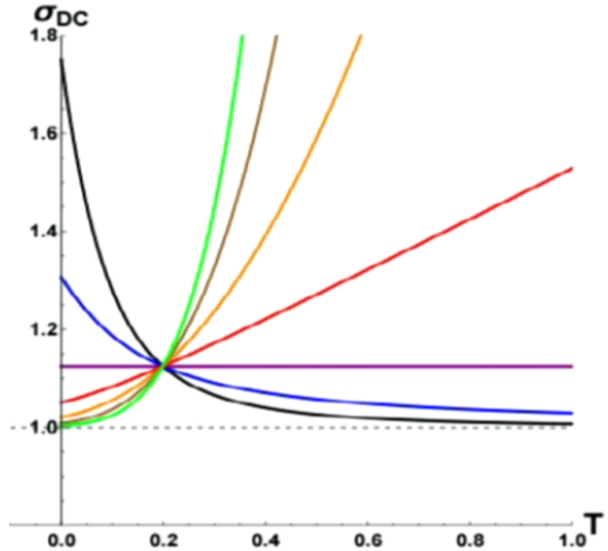
$$m_V^2(r) \sim r^\nu$$

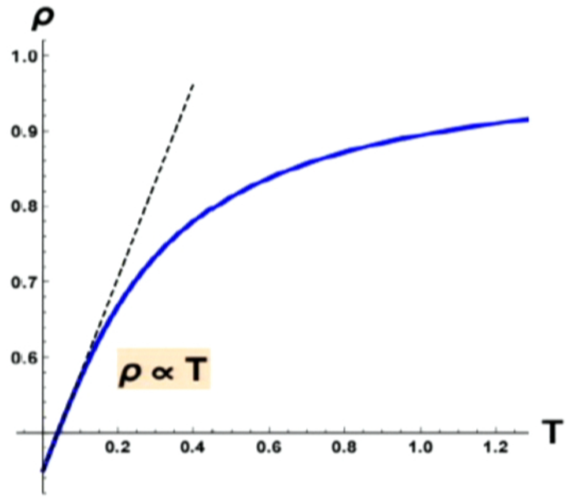
**Non zero in both fluid and solid cases!**

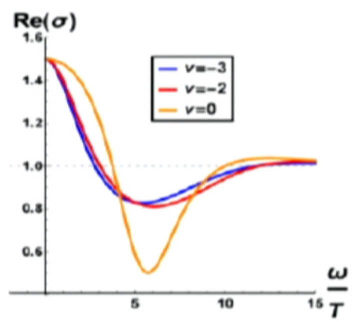
$$V(X) = X^n\,, \qquad n = \frac{4+\nu}{2}$$

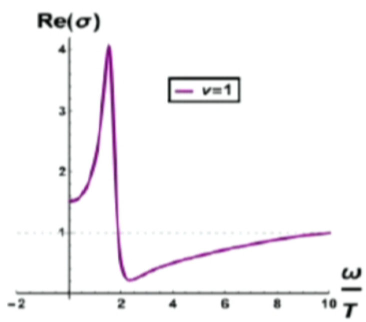
# ELECTRIFYING PHENOMENOLOGY

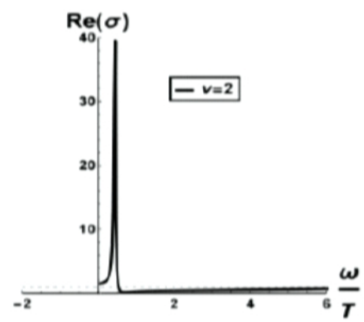




# VISCOELASTIC RESPONSE

**STRAIN TENSOR (SPIN 2)**

$$u_{ij} = \frac{1}{2}\left(\partial_i u_j + \partial_j u_i\right)$$

**STRESS TENSOR**

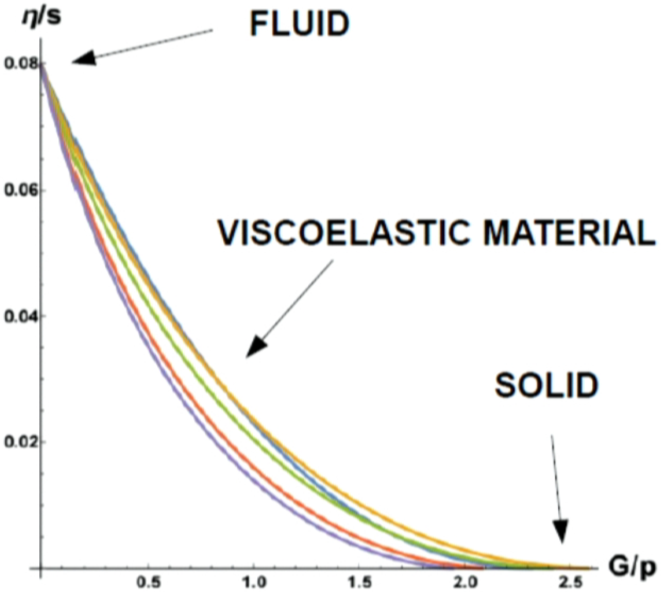
$$T_{ij}^{(T)} = G\, u_{ij}^{(T)} + \eta\, \dot{u}_{ij}^{(T)}$$

dissipationless solids

Fluids

**KUBO FORMULAS:**

$$\eta \equiv \lim_{\omega \to 0} \frac{1}{\omega} \mathrm{Im}\, \mathcal{G}^R_{T_{ij}\, T_{ij}} \qquad G \equiv \lim_{\omega \to 0} \mathrm{Re}\, \mathcal{G}^R_{T_{ij}\, T_{ij}}$$



**"tensorial" mass** $h_x \sim h^{xy}\,, \qquad h_+ \sim h^{xx} - h^{yy}$

$m_T^2(r) \sim V_X(X,Y) \longrightarrow$ **Zero for fluid type**
**Non zero for solid type !**

$$\left[\partial_r^2 + \left(\frac{f'}{f} - \frac{2}{r}\right)\partial_r + \left(\frac{\omega^2}{f^2} - \underline{2\,V_X(r)}\right)\right] h_T = 0$$

- For zero "tensorial mass" (= fluids) we have :

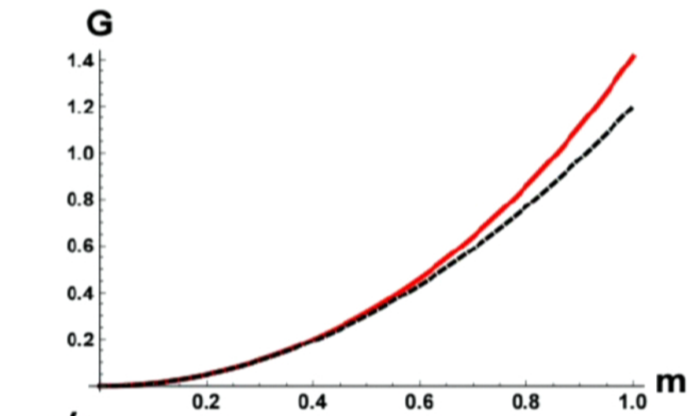
  Rigidity = 0 , $\dfrac{\eta}{s} = \dfrac{1}{4\pi}$

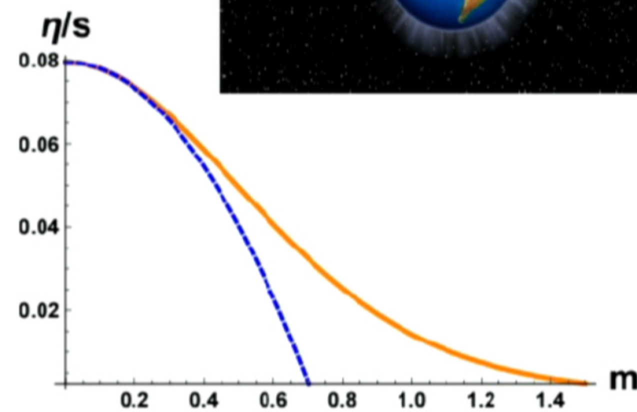
- $c_T^2 \sim m_T^2(r) \longrightarrow$ Solids $\rightarrow$ transverse "bulk"phonons

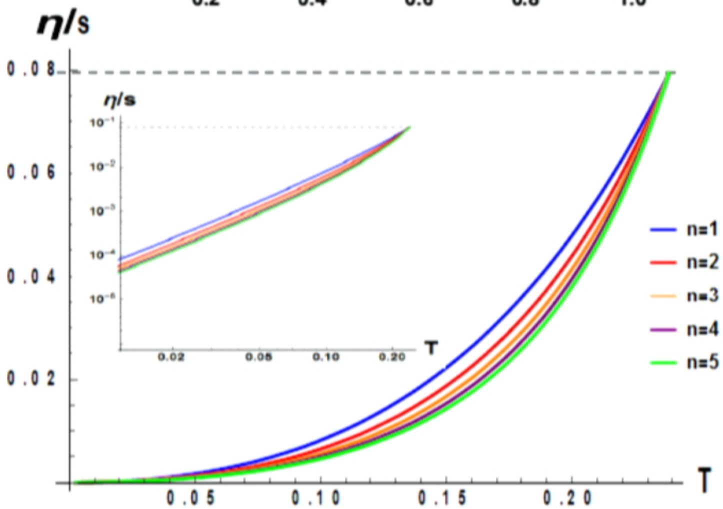
**KSS violation**
**Is Not directly**
**Linked To**
**Mom. Dissipation !!!**

**Increasing the mass (adding some "solid component") the rigidity grows**
**And the KSS ratio drops down!**

# UNIVERSAL BOUNDS ?!




## Generalized bound ?

$$\frac{\eta}{s} \geq \left(\frac{T}{\Delta}\right)^2, \qquad \frac{T}{\Delta} \to 0$$

arXiv:1601.02757

Yes!

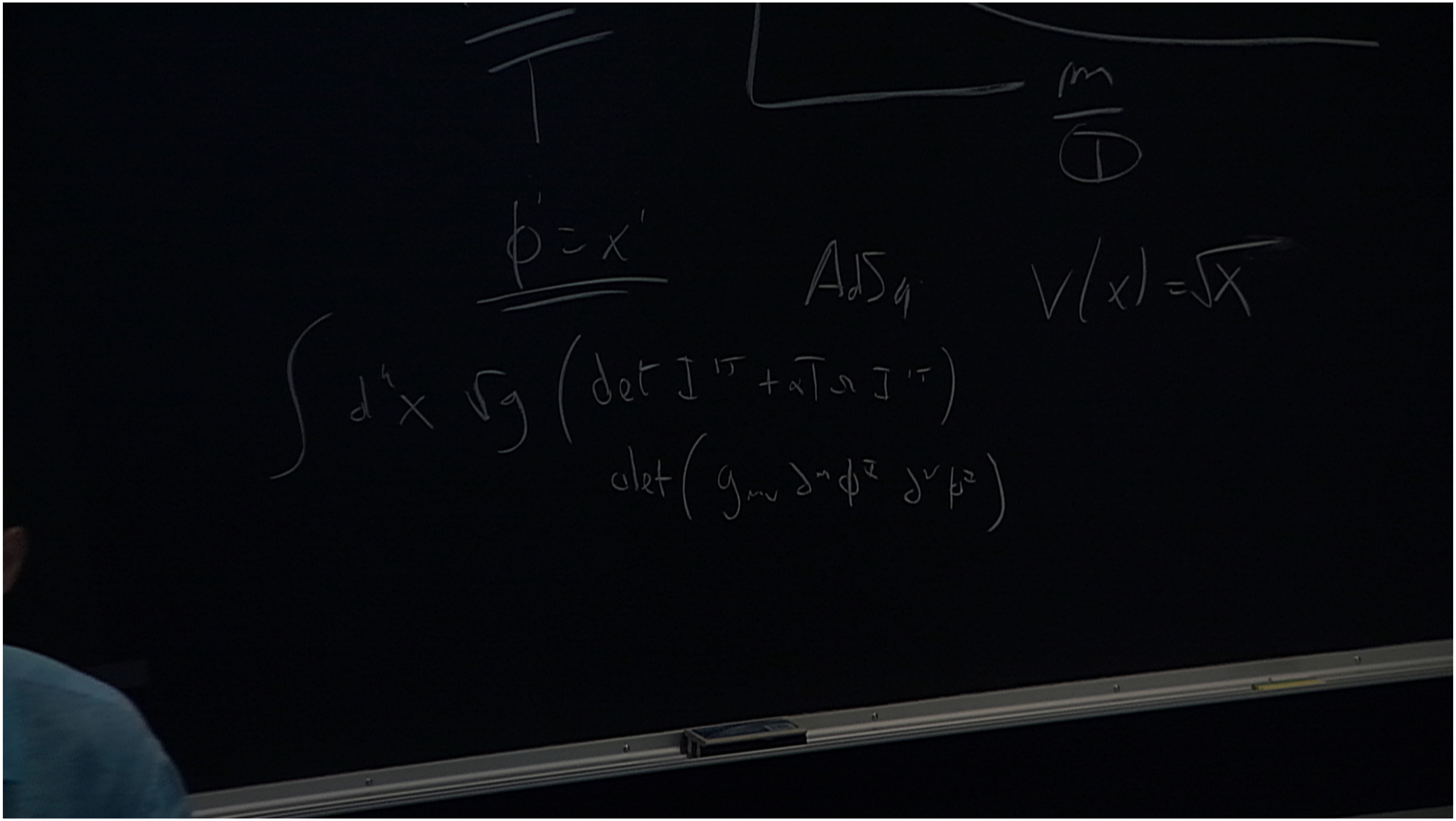
$$4\pi\,\frac{\eta}{s} + \mathcal{C}\,\frac{G}{p} \leq 1$$

MAYBE

# to do list:


- What Massive Gravity is really mimicking ?
- Can we link MG with explicitely disordered models ? “mean field disorder” ?
- Can MG encode phonon physics and elasticity ? Holographic solids ??
- Holographic EFTs for Condensed Matter ?
- Which is the fate of universal bounds and scalings ?
- Can we find correlations or predict something ?


THANK YOU !!!
THANKS FOR NOT FALLING ASLEEP
DURING THIS PRESENTATION


φ' = x'
AdS4
V(x) = √X
∫ d⁴x √g (det I + α Tr I)
det(g ∂φ ∂φ)