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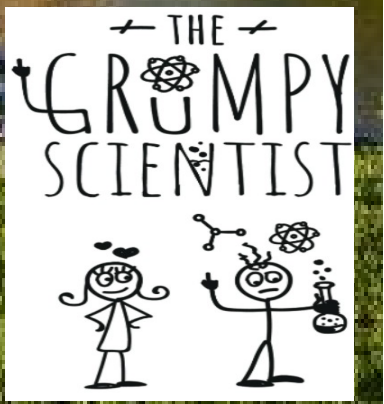
GAUGE-GRAVITY
JUST ADD HONEY !!!

UNIVERSITY
OF CRETE

Matteo Baggioli

UOC & Crete Center for Theoretical Physics



THE GANG

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(Iceland University)

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(UB Barcelona)

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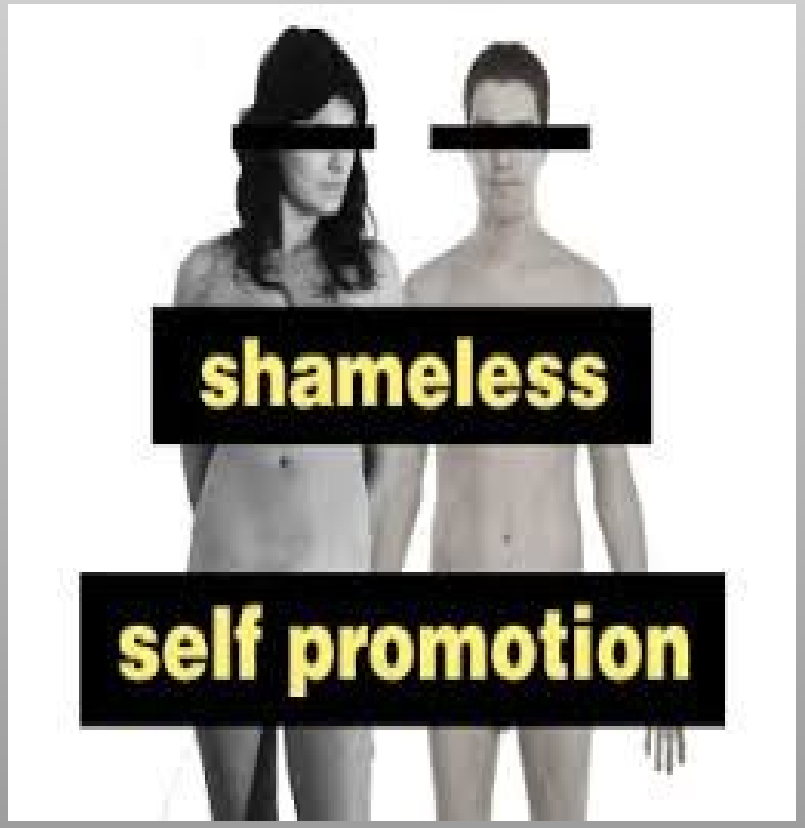
REFERENCES



Holographic Phonons

Elasticity bounds from Effective Field Theory

Solidity of liquids:
How Holography knows it

+

See also Alex's talk

+

EXTEND GAUGE/GRAVITY TO SOLID AND VISCOELASTIC MATERIALS

+ ARE REALLY FLUIDS AND SOLIDS SO DIFFERENT … ?

$$S = \int d^4x \sqrt{g} \left[R - 2\Lambda - m^2 V(X, Z) \right]$$

HOLOGRAPHIC (LV) MASSIVE GRAVITY

$$X \equiv \frac{1}{2} Tr[\mathcal{I}^{IJ}], \quad Z \equiv det[\mathcal{I}^{IJ}]$$

$$\mathcal{I}^{IJ} \equiv \partial_\mu \phi^I \partial^\mu \phi^J \qquad \phi^I = O^I_J x^J$$

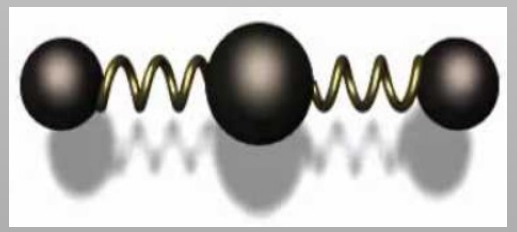
Gravity dual of translational breaking systems

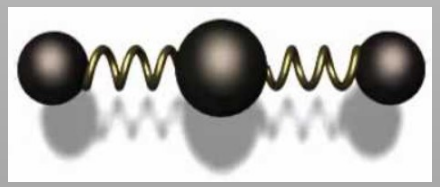
Radially dependent graviton mass

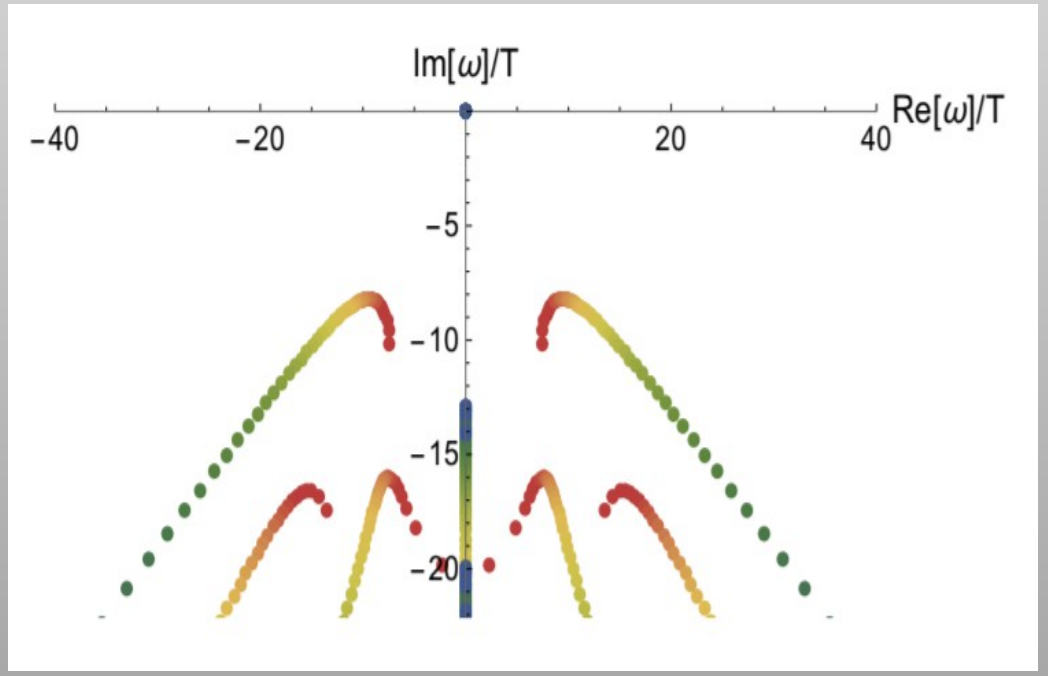
FIND THE PHONON

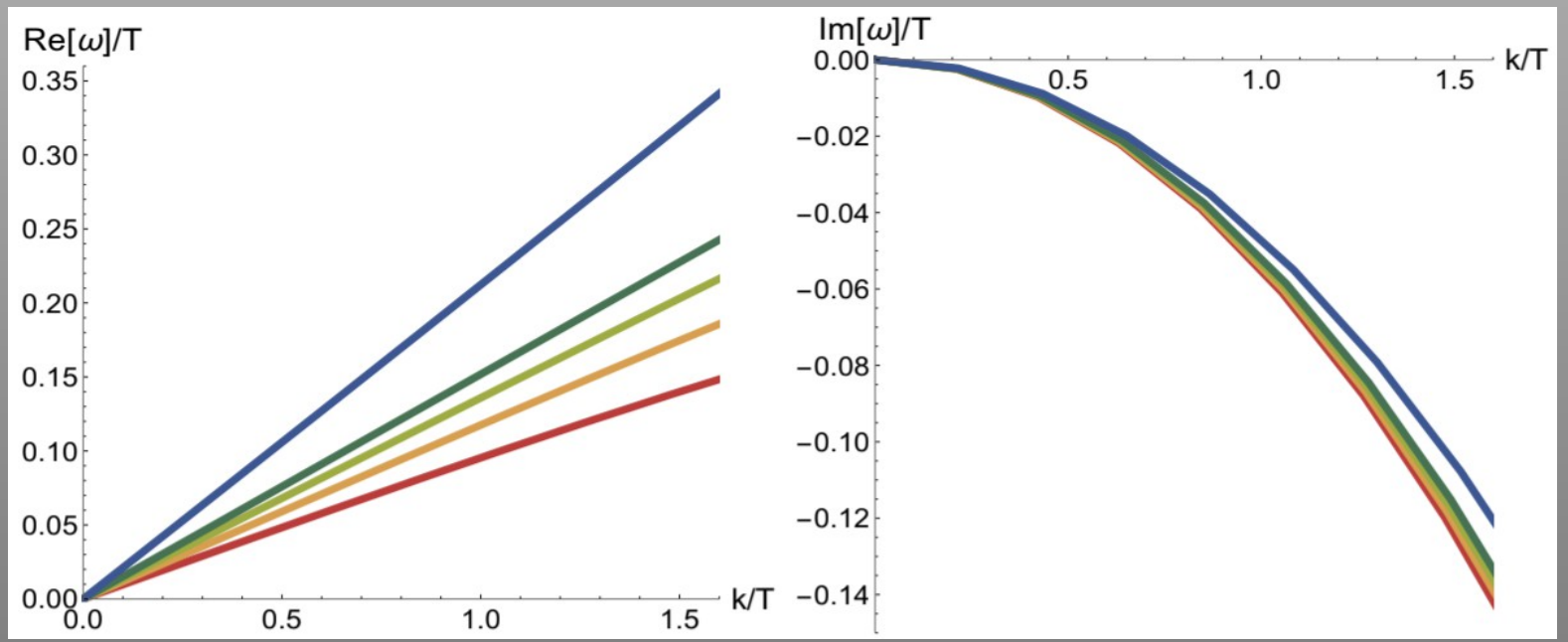
MASSLESS PHONONS

$$\omega = c_T\, k - i\, D\, k^2$$

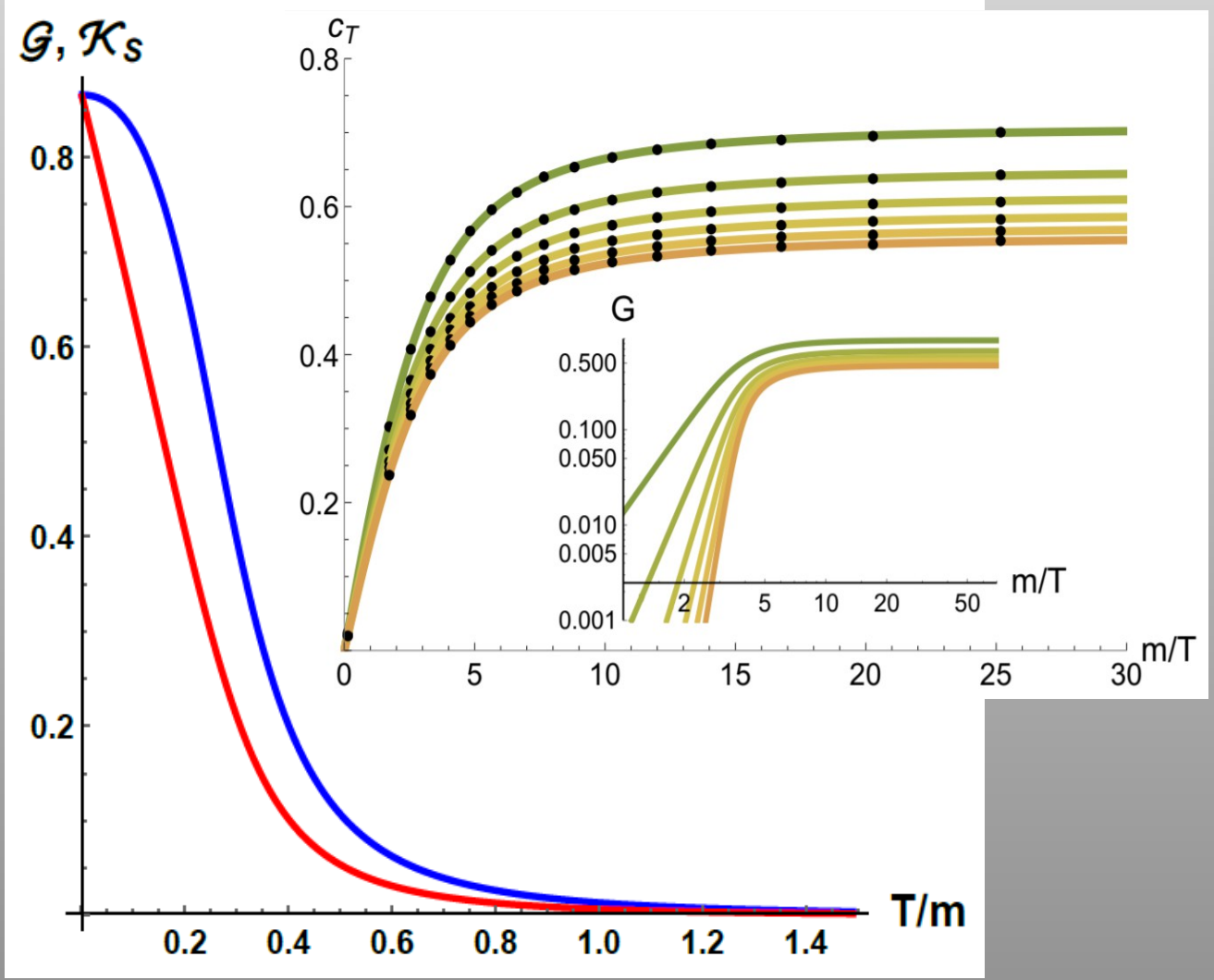








LINEAR (VISCO)-ELASTICITY



$$c_T^2 = \frac{\mathcal{G}}{\chi_{PP}},$$

Explicitely checked !!

$$c_L^2 = \frac{\mathcal{K}_S + \mathcal{G}}{\chi_{PP}}$$

TO DO !

But already non trivial checks

(conformal constraint)

$$G \propto \lim_{\omega \to 0} Re\, \mathcal{G}^R_{T_{ij}T_{ij}}$$

$$K = \frac{3\epsilon - 2\left(sT + \mu\rho\right)}{4}$$

HOLOGRAPHIC

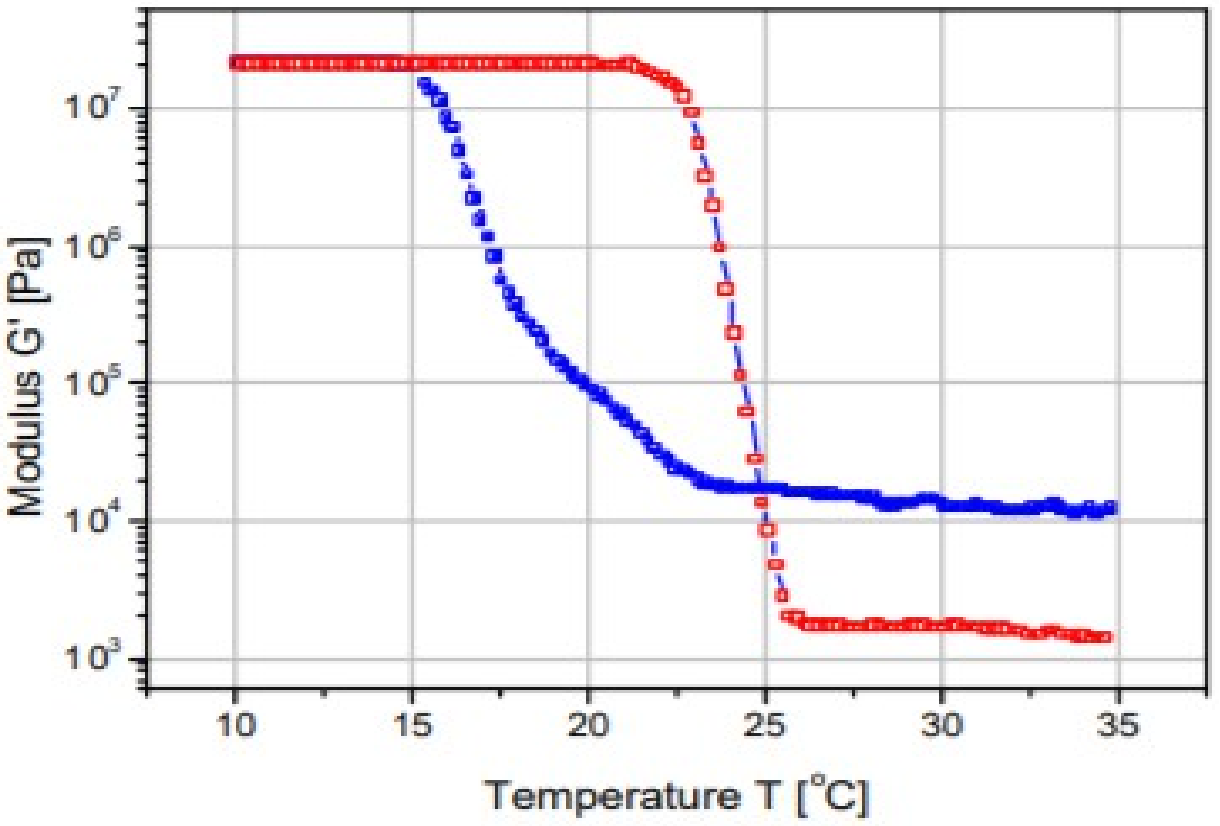
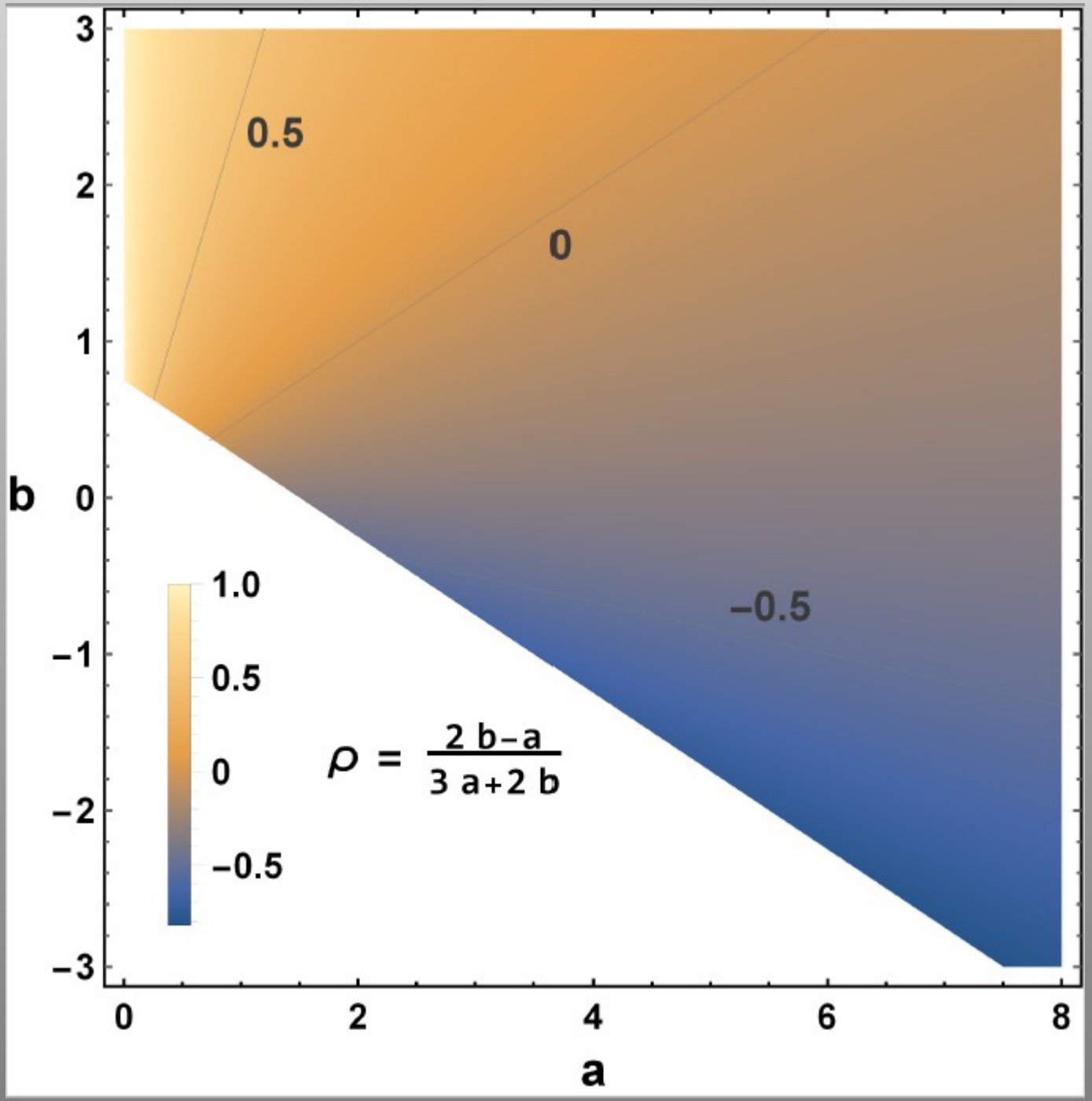


Figure 9: Melting behavior of chocolate with different types of fat

THE POISSON RATIO

$$V(X,Z) = X^a\, Z^b$$



IN 2D

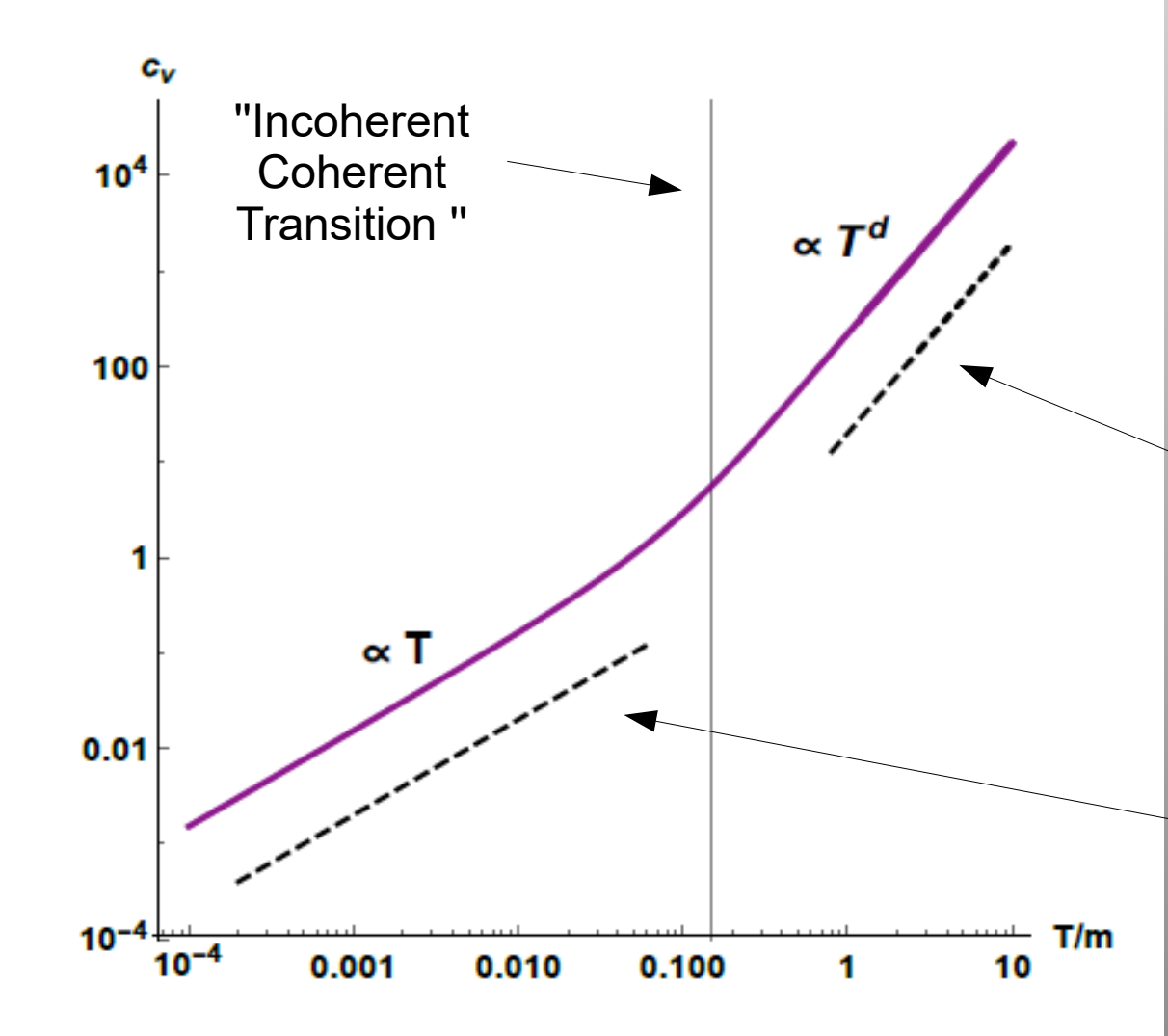
$$\rho = \frac{\mathcal{K} - G}{\mathcal{K} + G}$$

$$-1 < \rho < 1$$

glass like

rubber like

THE HEAT CAPACITY



Crossover at the "Glass transition" !!

Debye theory

Due to "disorder" Predicted using Random matrix theory !

Observed in amorphous solids, glasses and viscoelatic materials!!!

VISCOELASTICITY

NOTE: violation of KSS

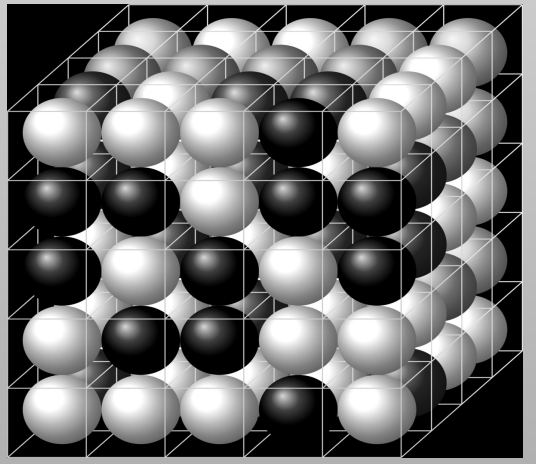
cf. violation in viscoelastic Fermi liquids ?

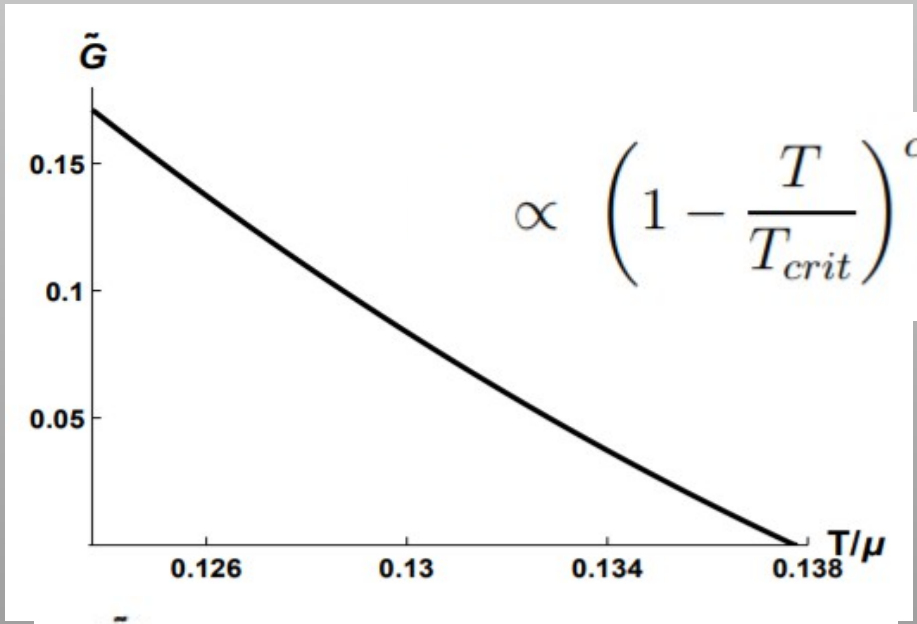
arXiv:1801.08627

$$T_{ij} = G\,u_{ij} + \eta\,\dot{u}_{ij} + \ldots$$

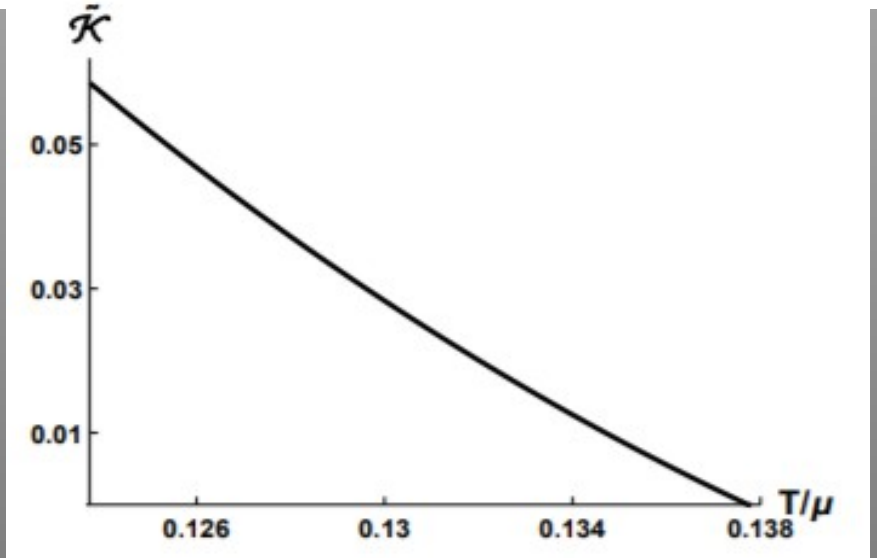
A slightly different case

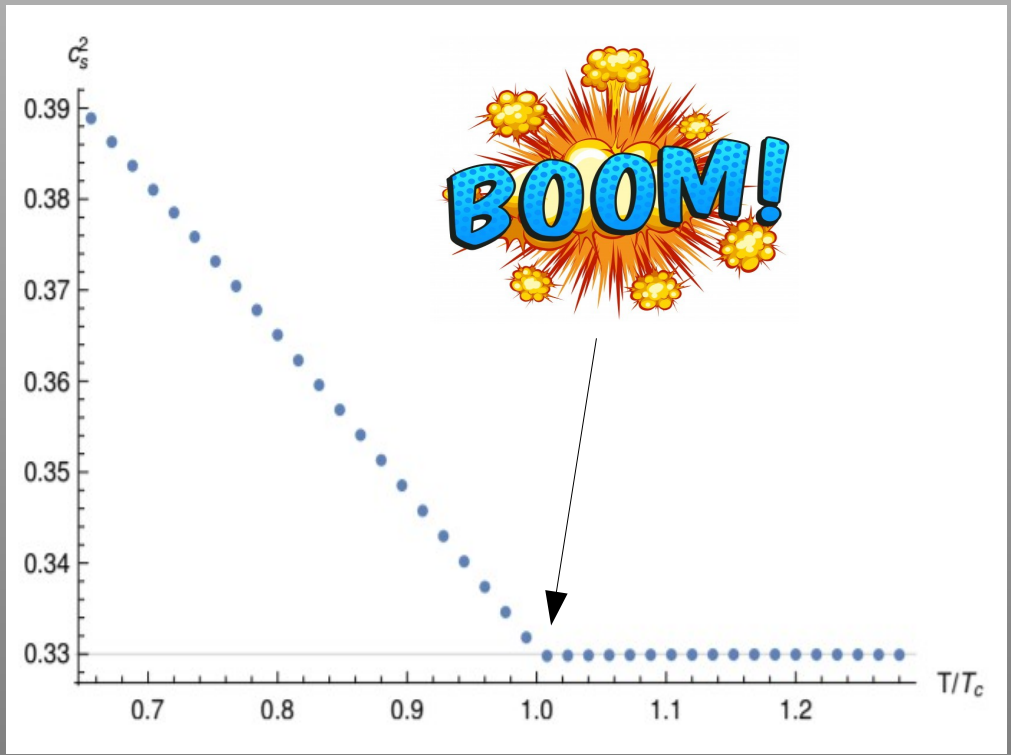
SPONTANEOUS SYMMETRY BREAKING OF TRANSLATIONS





$$\propto \left(1 - \frac{T}{T_{crit}}\right)^{\alpha_{\mathcal{K}}}, \qquad \alpha_{\mathcal{K}} = 1$$



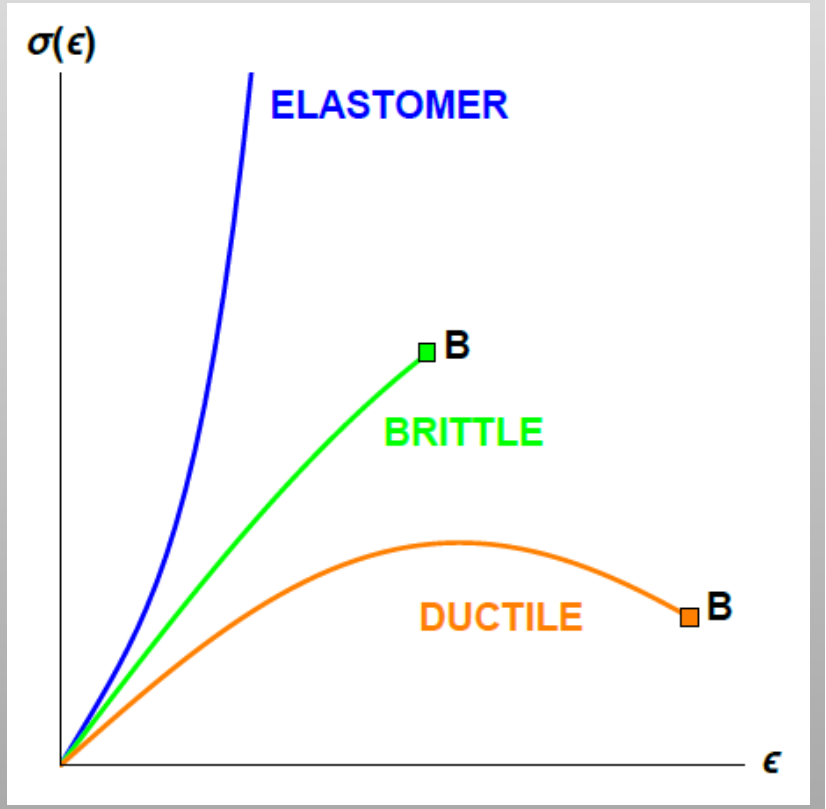


NONLINEARITIES

EFT + Holography

$$\sigma(\varepsilon) = \underbrace{\mathcal{G}\,\epsilon}_{linear} + \mathcal{G}^{(2)}\,\epsilon^2 + \dots$$

$$\Sigma(\kappa) = \underbrace{\mathcal{K}\,\kappa}_{linear} + \mathcal{K}^{(2)}\,\kappa^2 + \dots$$



$$\vec{\phi} = \begin{pmatrix} \phi^x \\ \phi^y \end{pmatrix} = \mathfrak{I}\,\vec{x} = \frac{\kappa}{2} \begin{pmatrix} \sqrt{1+\frac{\varepsilon^2}{4}} & \varepsilon/2 \\ \varepsilon/2 & \sqrt{1+\frac{\varepsilon^2}{4}} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

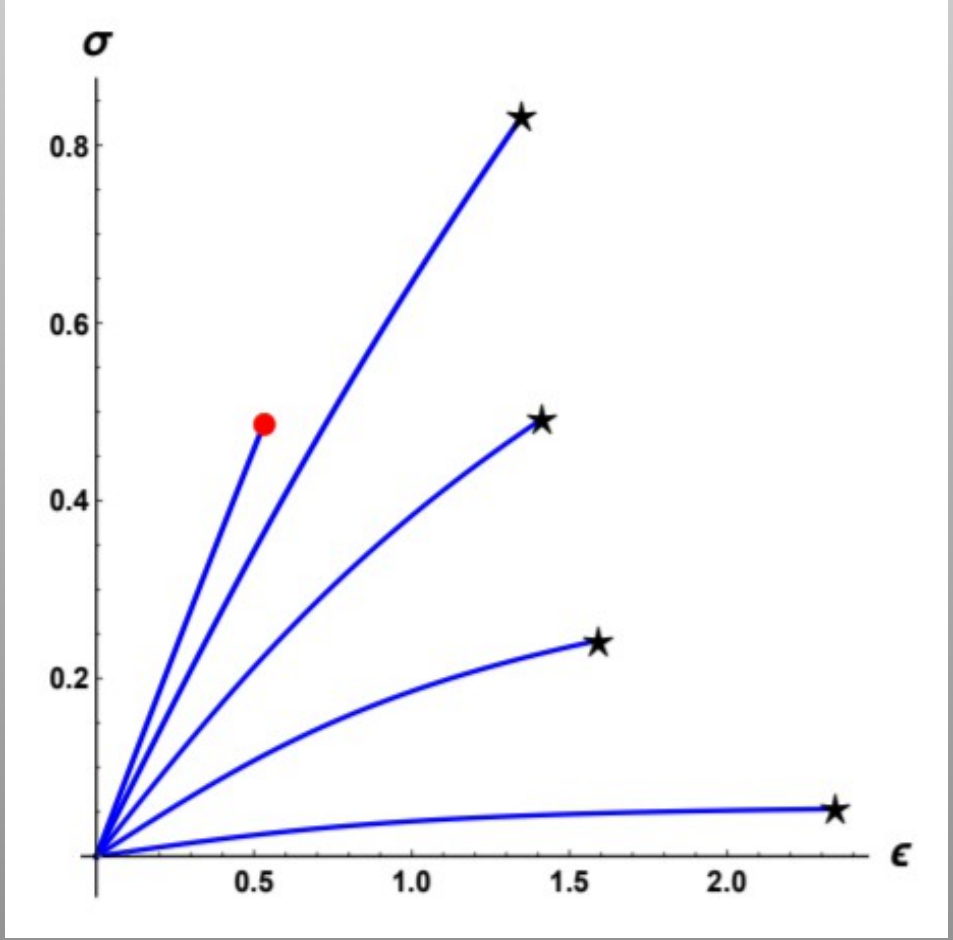
- **PURE SHEAR STRAIN** $\quad \partial_{\{x}\phi_{y\}} = \varepsilon\,, \quad \det\mathfrak{I} = 1 \;\; (\kappa = 2)$

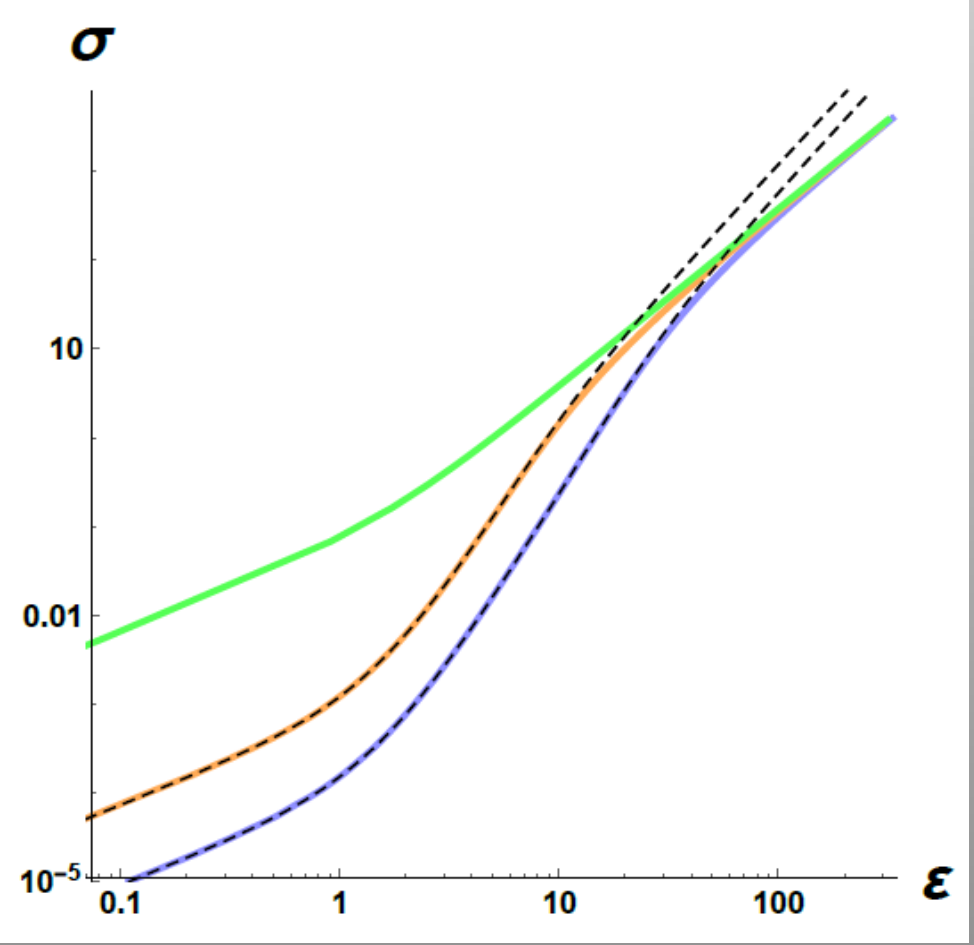
- **PURE COMPRESSION (BULK STRAIN)** $\quad \varepsilon = 0\,, \quad \partial\cdot\phi = \kappa$

Results

Both from EFT and HOLOGRAPHY

Predictions ?? YES !!





- **Scalings (measurable?)** **Bounds (observable?)**
- **Correlations**

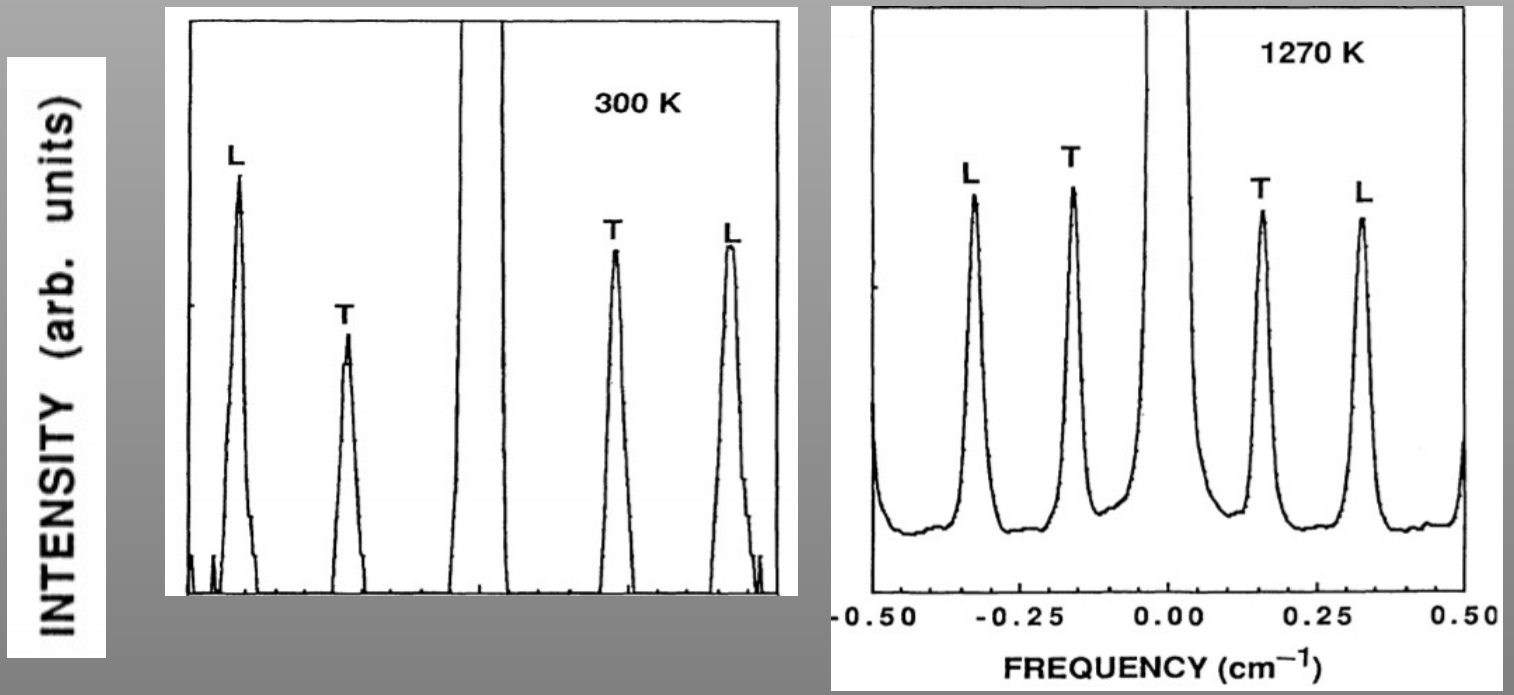
ARE LIQUIDS AND SOLIDS REALLY DIFFERENT ?

NOT IF

$$\omega > \omega_F \equiv \frac{1}{\tau}$$

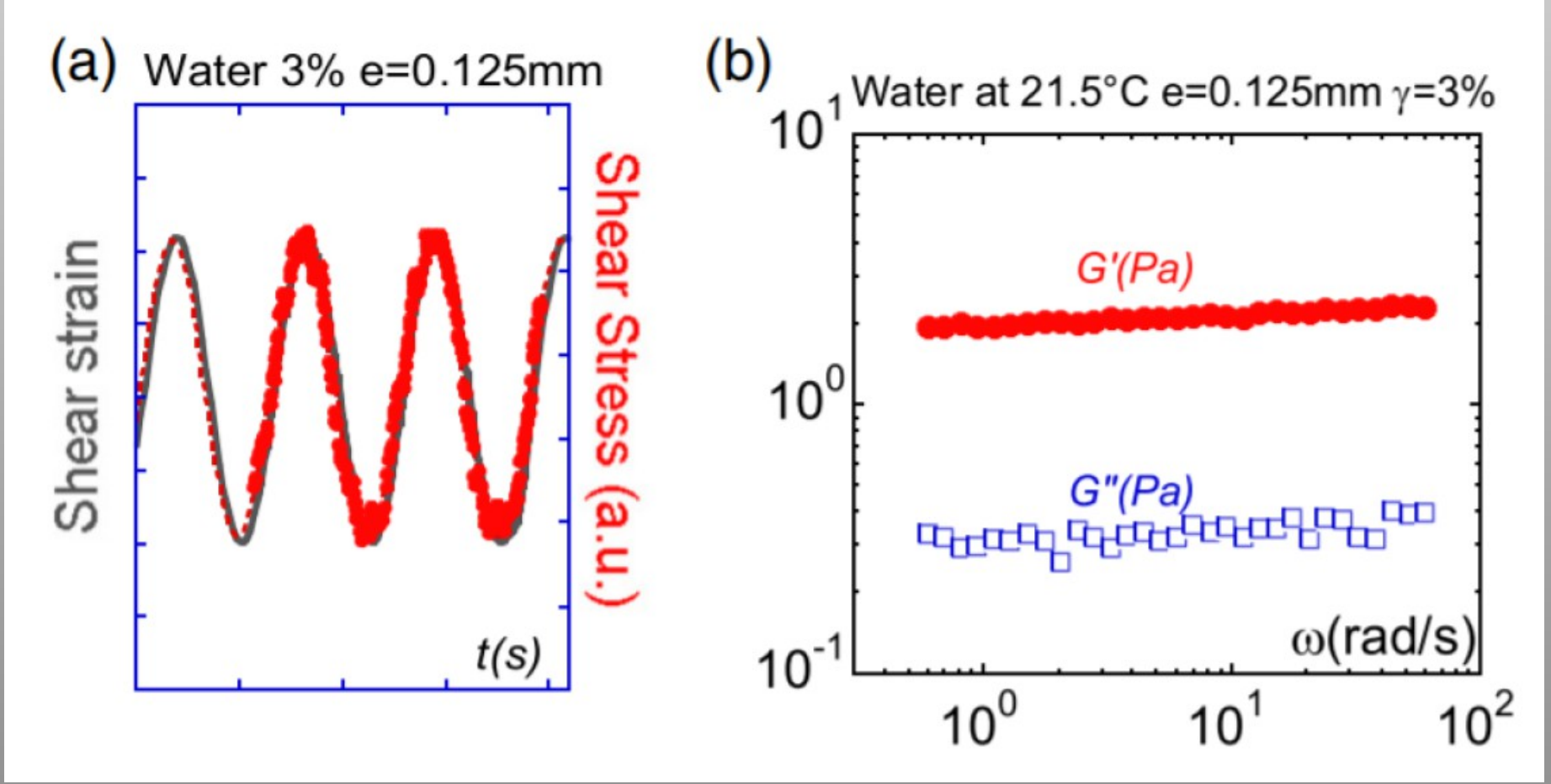
Proved in several experiments !!

High-frequency longitudinal and transverse dynamics in water



THAT'S IT ?? NO !

Experiments by Noirez's group in Paris



LIQUIDS SUPPORT PROPAGATING SHEAR WAVES ALSO AT LOW FREQUENCIES !!!

LIQUIDS BEHAVE LIKE ELASTIC SOLIDS ALSO AT LOW FREQUENCY !!!

And now ?????

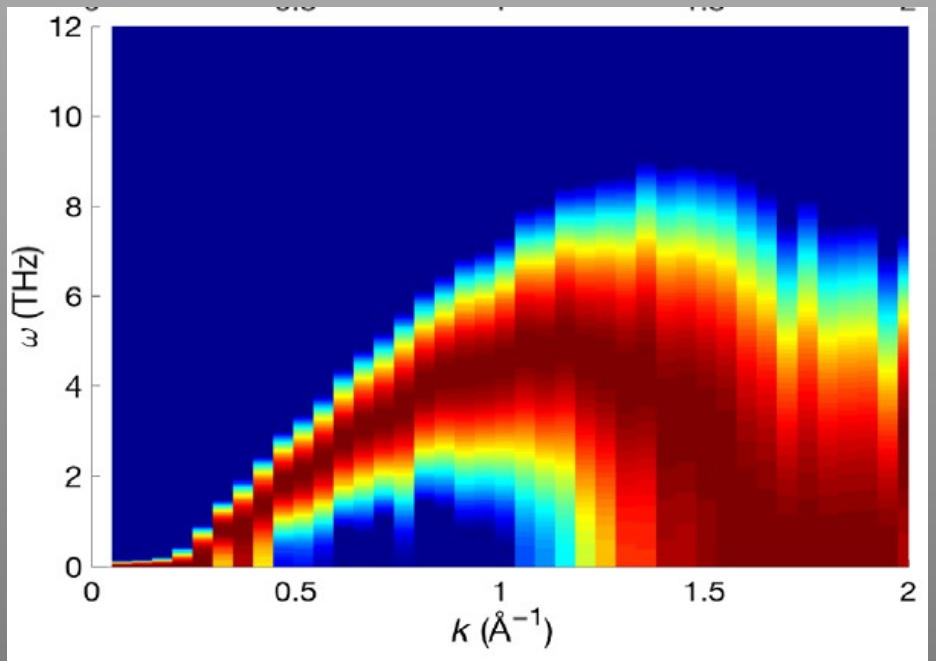
A possible explanation !

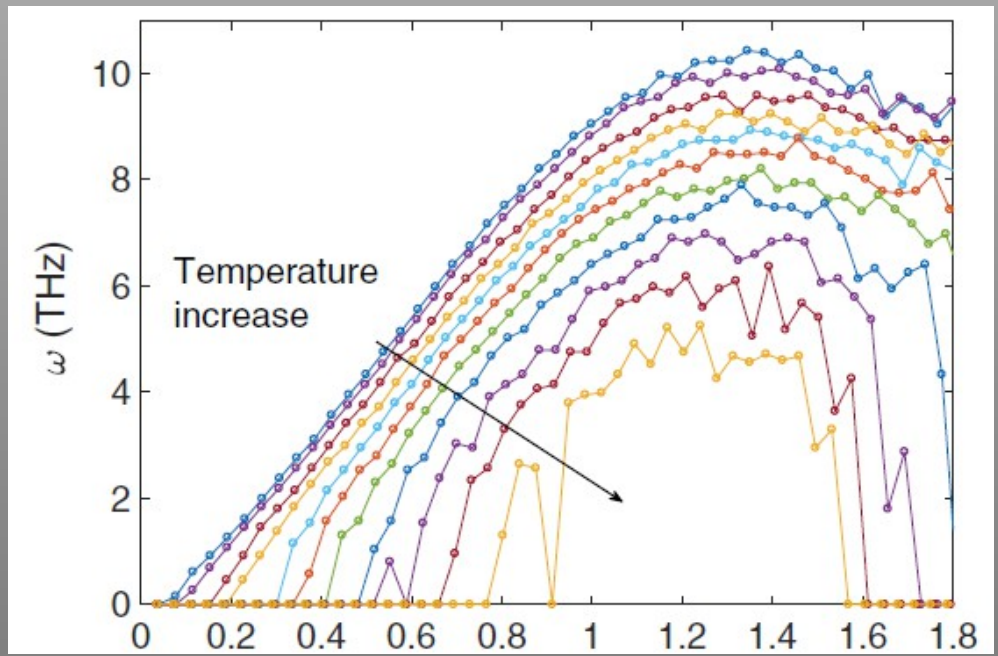
arXiv:1512.06592 arXiv:1706.00836

The presence of a k-gap in the shear collective modes !!
It can be proven using Frenkel reduction and Maxwell interpolation
And starting from Navier Stokes equation !!

$$\omega = \sqrt{c^2 k^2 - \frac{1}{\tau^2}}$$

$$k > k_{gap} \equiv \frac{1}{c\tau}$$



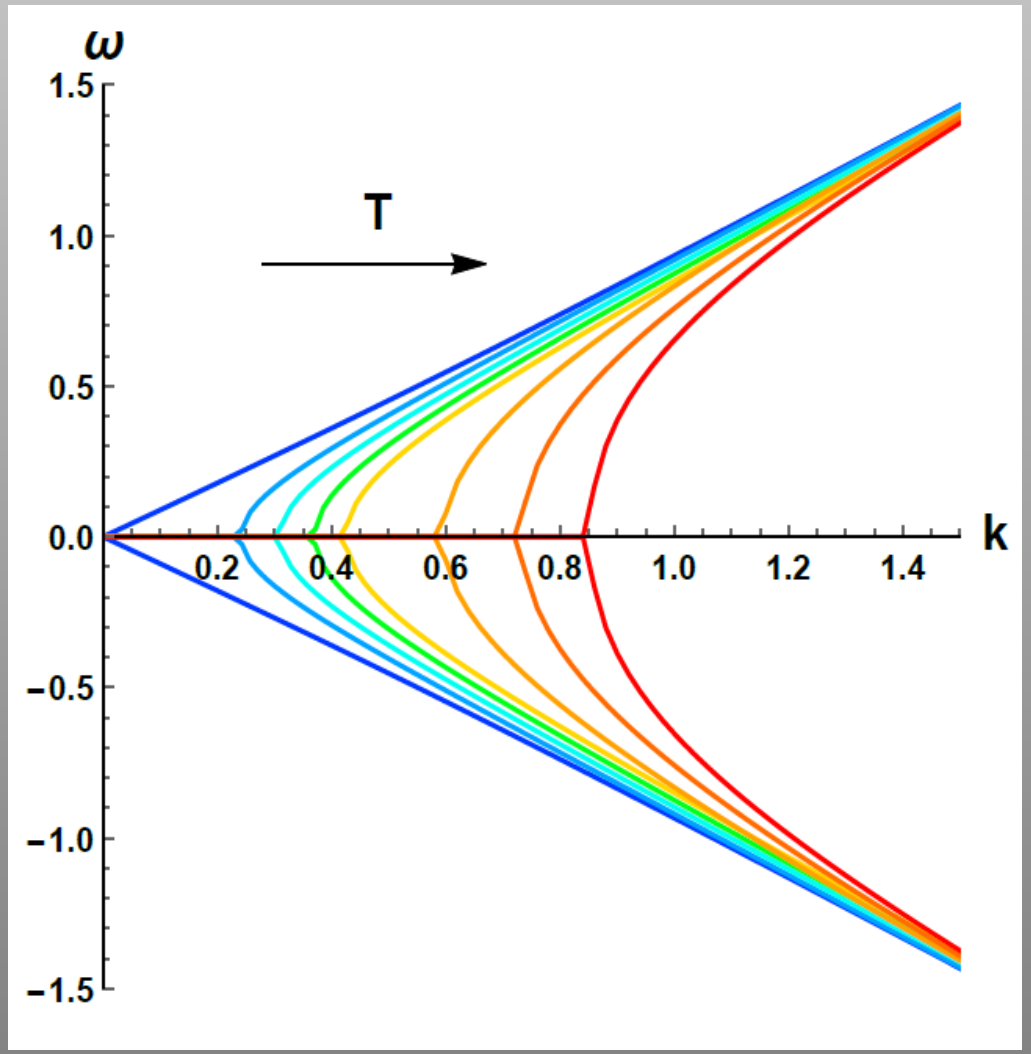


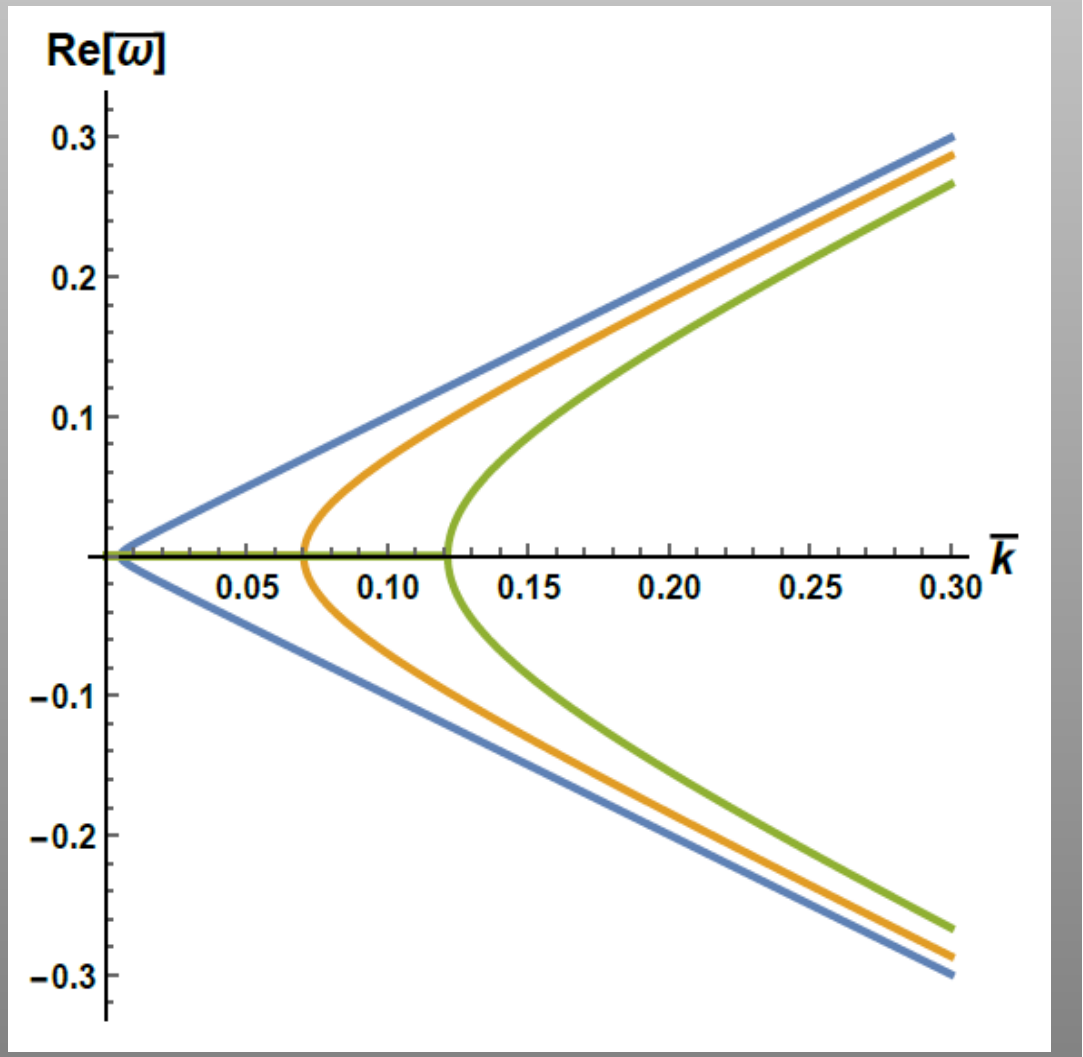
Holography knows it !

Two different models show
A k-gap moving as it should !!

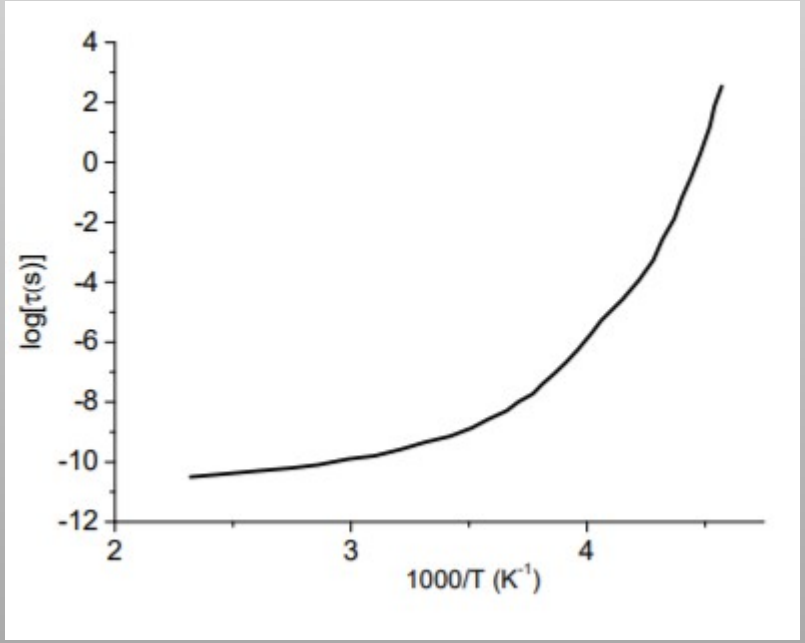
arXiv:1311.5157

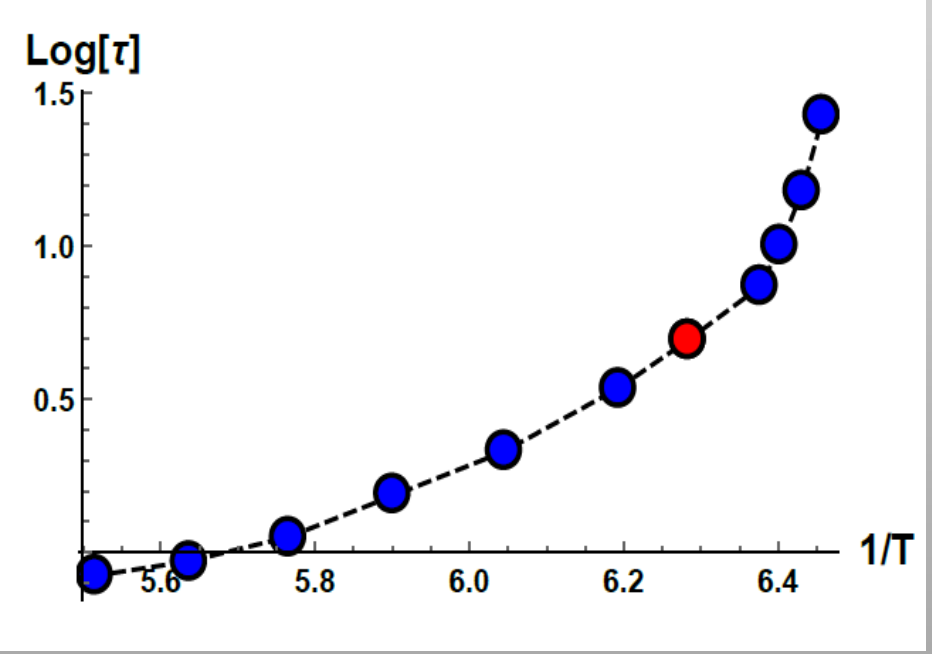
arXiv:1801.03199

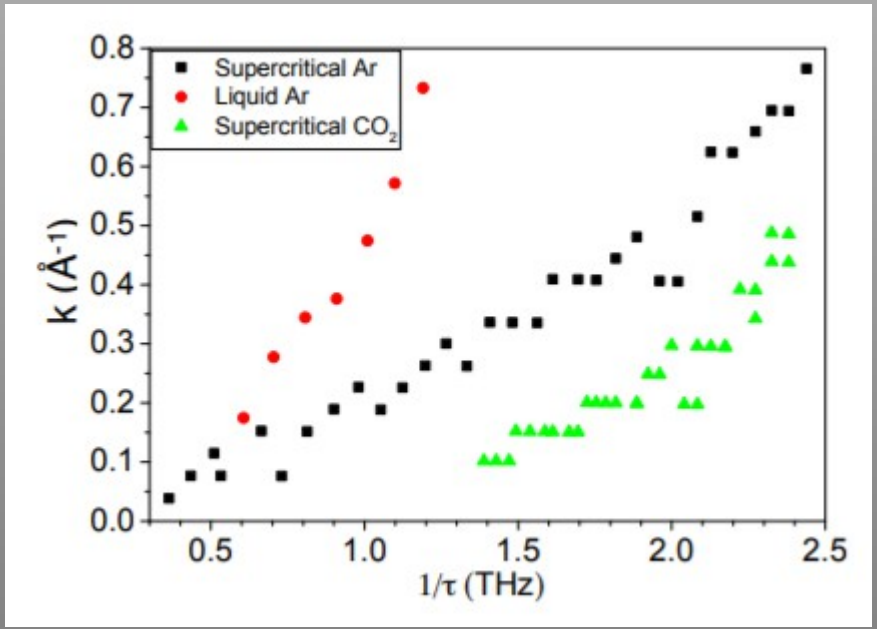


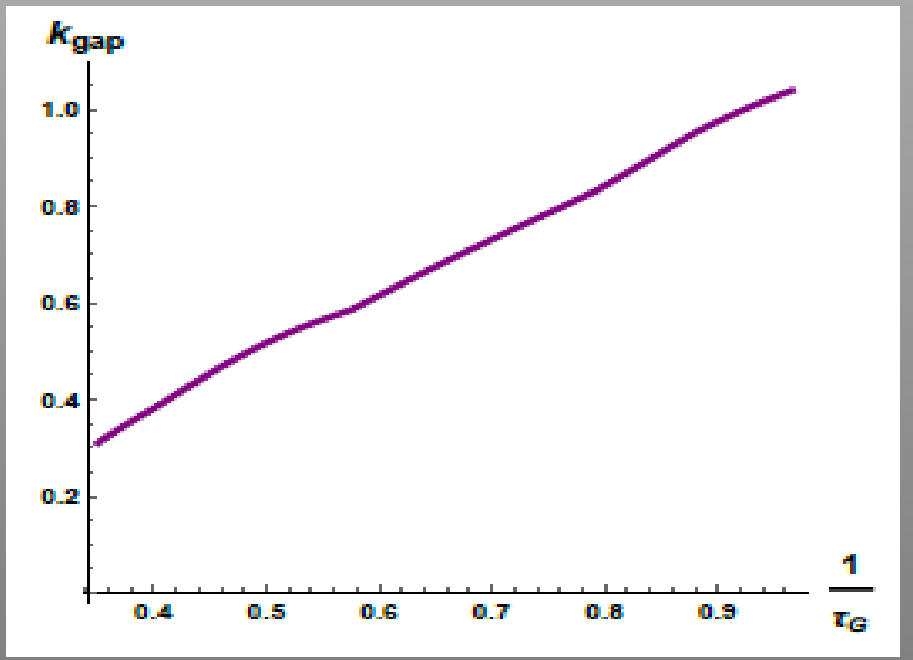


Even more ...


log[τ(s)]
1000/T (K^{-1})


Log[τ]
1/T

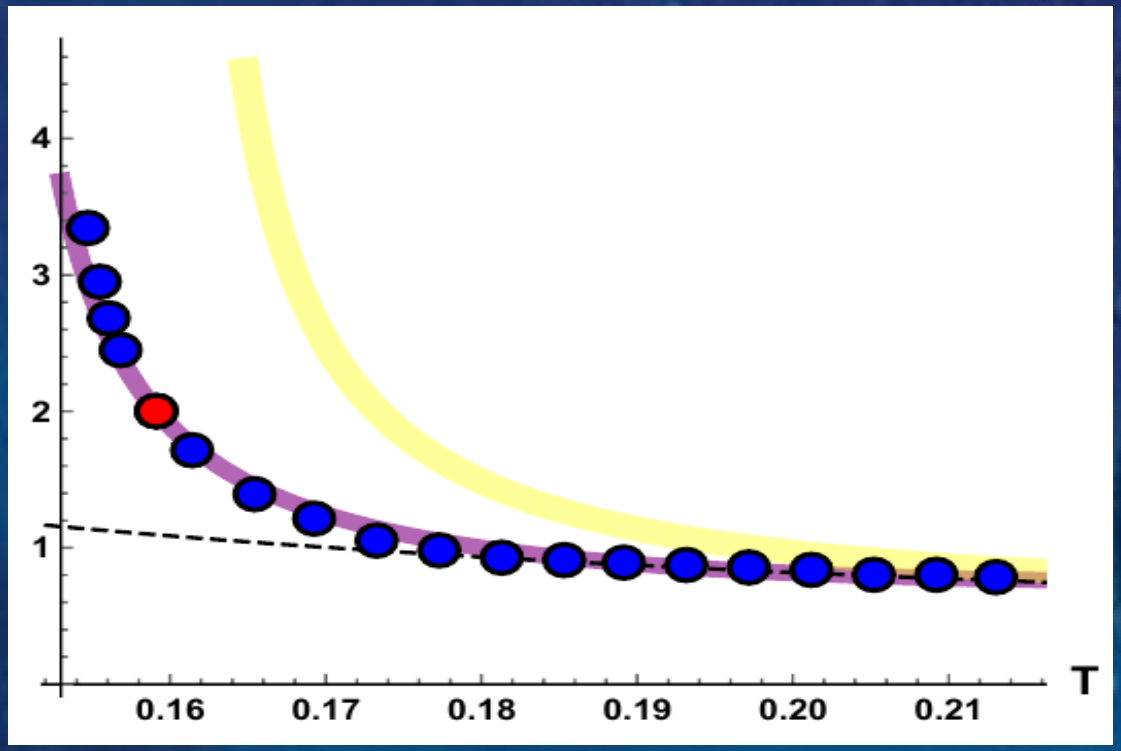

Supercritical Ar
Liquid Ar
Supercritical CO$_2$
k (Å^{-1})
1/τ (THz)

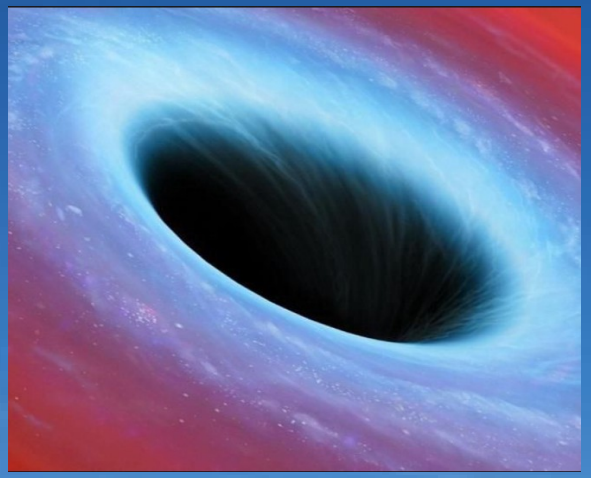

k_{gap}
$\frac{1}{\tau_G}$

$$\tau_G = \frac{D}{c^2 - D\Gamma}$$

"THERE ARE NO ACCIDENTS."

- Master Oogway





+

Do we really understand fluids and solids ?
Are they really different?

TO THINK LIST

Holographic piezoelectricity

Phase transitions and instabilities
Using Borel methods

Dissipation in EFT

Thermoelasticity

Fracton-elasticity duality

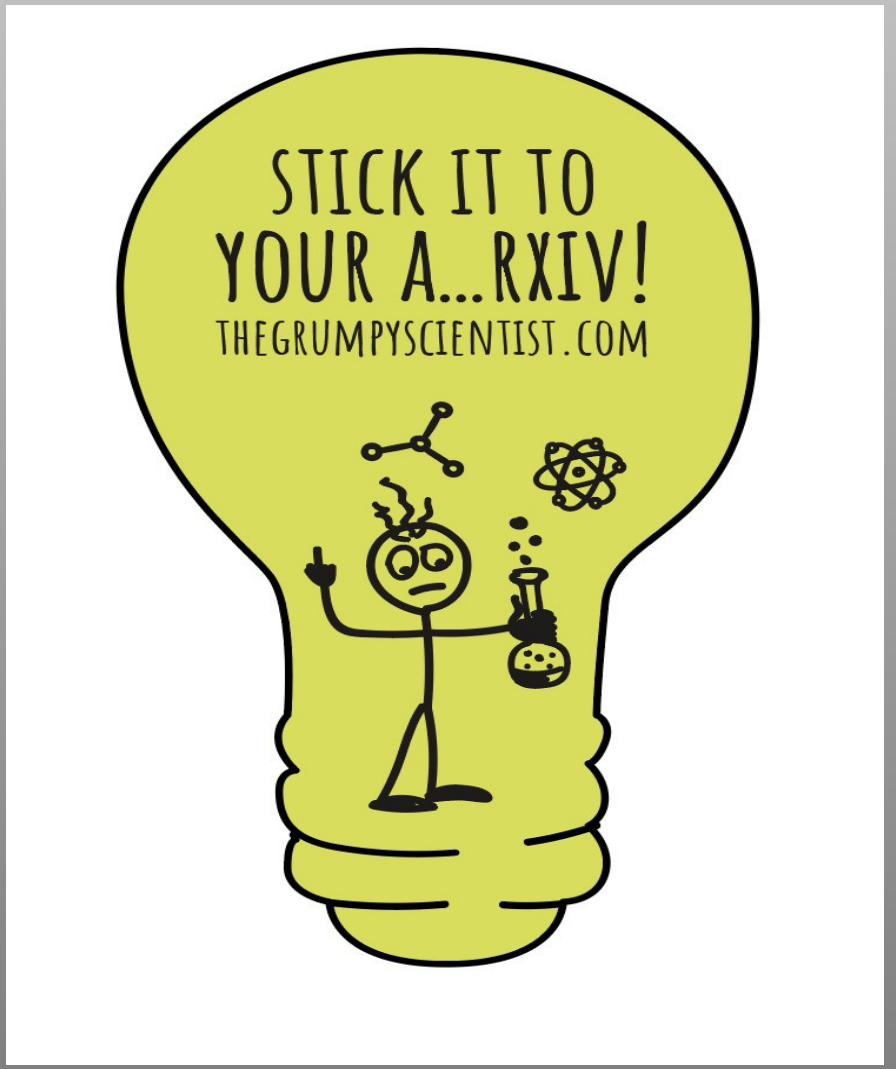
Crystal diffusion

Finite time response and glassy behaviours (creep,...)

Solid-gravity correspondence

thegrumpyscientist

STAY GRUMPY, STAY SCIENTIST



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