Holographic zero sound

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AdS/CMT

Holography (AdS/CFT):

Strongly coupled QFTs $\Leftrightarrow$ Weakly coupled gravity theories

Playground for strongly coupled physics without a quasiparticle description

No quantitative predictions, but one can try to identify universal qualitative phenomena

Sound in hydrodynamics

System near equilibrium

Conserved quantities:

$$\partial_\mu \langle T^{\mu\nu} \rangle = 0$$

Expand in gradients $\frac{\partial}{\partial t}, \frac{\partial}{\partial x^i}$

Sound in hydrodynamics

$$\partial_t \left\langle T^{tt} \right\rangle + \partial_i \left\langle T^{ti} \right\rangle = 0$$
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Near equilibrium:

$\left\langle T^{tt} \right\rangle \approx \varepsilon + \delta\varepsilon$, $\left\langle T^{ij} \right\rangle \approx \delta^{ij}(P + \delta P)$, $\delta P \approx (\partial P / \partial \varepsilon)\, \delta\varepsilon$.

$$\left(\partial_t^2 - \frac{\partial P}{\partial \varepsilon} \partial_i \partial^i \right) \delta\varepsilon = 0$$

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Wave equation!

$$\omega = \pm v_s k, \qquad v_s^2 = \frac{\partial P}{\partial \varepsilon}$$

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Wave equation!

$$\omega = \pm v_s k - i\Gamma k^2 + \mathcal{O}(k^3), \qquad v_s^2 = \frac{\partial P}{\partial \varepsilon}$$

Fermi liquids

System of fermions: adiabatically turn on repulsive interactions

Landau theory: effective description, quasiparticles

Fermi liquids in nature:

- Helium-3
- Electron sea in metals

Reference point for non-Fermi liquids (strange metals)

“Zero sound” excitations

Zero sound in Fermi liquids

$\delta n_{\mathbf{p}}(t, \mathbf{x})$ quasiparticles per unit momentum $\mathbf{p}$

Boltzmann equation:

$$\frac{\partial \delta n_{\mathbf{p}}}{\partial t} + \mathbf{v}_{\mathbf{p}} \cdot \nabla \delta n_{\mathbf{p}} + \text{interactions} = \text{collisions}$$

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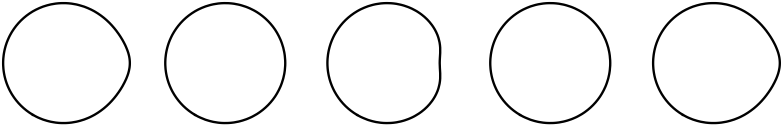
Low temperature: neglect collisions

Solution: "zero sound"

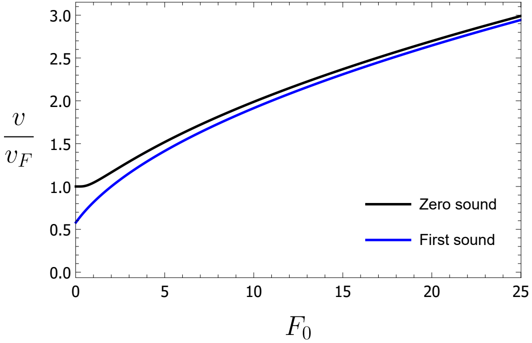
$$\omega = \pm v k - i\Gamma k^2 + \mathcal{O}(k^3)$$

Non-isotropic deformation of Fermi surface



Properties of zero sound

Speed $v \geq$ speed of sound v_s



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Quasiparticle scattering rate: $\nu \sim \dfrac{\pi^2 T^2 + \omega^2}{\mu(1 - e^{-\omega/T})}$

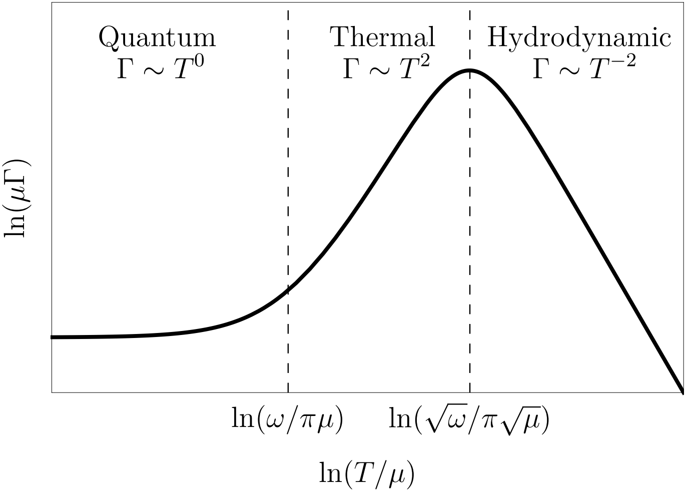
Dial up temperature, attenuation:

- Quantum collisionless, $T \ll \omega$, $\Gamma \sim T^0$
- Thermal collisionless, $T^2/\mu \ll \omega \ll T$, $\Gamma \sim T^2$

Hydrodynamic sound, $\omega \ll T^2/\mu, \Gamma \sim T^{-2}$

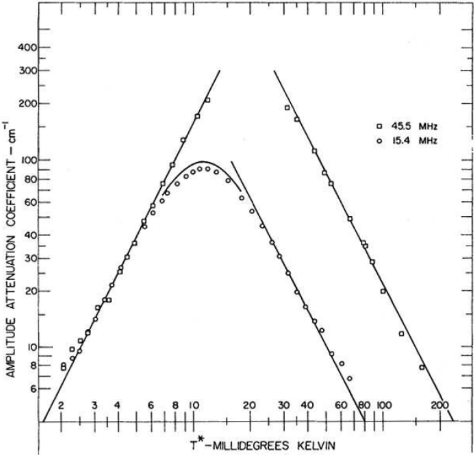
Zero sound $\rightarrow$ hydrodynamic sound as temperature increases

(Zero) sound attenuation



(Zero) sound attenuation

Zero sound attenuation in Helium-3



[Abel, Anderson, Wheatley, Phys. Rev. Lett. 17 (Jul, 1966) 74-78]

Holographic zero sound

Holographic models with bulk gauge field. Dual field theory:

- $U(1)$ global symmetry
- Non-zero chemical potential μ, charge density $\langle J_t \rangle$

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Spectrum of collective excitations includes low-temperature longitudinal modes with sound-like dispersion

$$\omega = \pm vk - i\Gamma k^2 + \mathcal{O}(k^3)$$

"Holographic zero sound" (HZS)

[Karch, Son, Starinets, 0806.3796; Davison, Starinets, 1109.6343; Edalati, Jottar, Leigh, 1005.4075; Davison, Kaplis, 1111.0660]

Poles in two-point functions of $T_{\mu\nu}$ and J_μ

Model

Spacetime filling brane with back-reaction

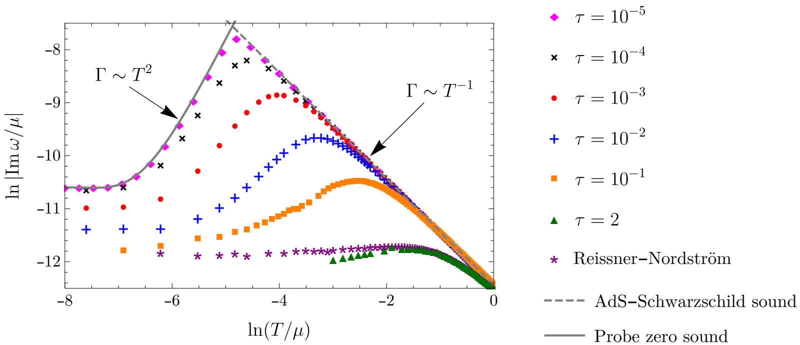
$$S = \frac{1}{16\pi G_N} \int \mathrm{d}^4x \sqrt{-\det g} \left(R + \frac{d(d-1)}{L_0^2} \right) \\ - T_D \int \mathrm{d}^4x \sqrt{-\det(g + \alpha F)}$$

Admits charged black brane solutions:
(2+1)-dimensional boundary CFT at T and μ

Earlier models appear as limits

HZS attenuation

$$\tilde{\alpha} = 1,\ k/\mu = 0.01, \tau = 8\pi G_N L^2 T_D$$



Qualitative resemblance to zero sound in Fermi liquids

Temperature scaling quantitatively different (closer for small τ)

Maximum shrinks with increasing τ

Summary and outlook

Holographic models exhibit a holographic zero sound mode

Qualitative similarities to zero sound in Fermi liquids

How generic is this mode?

- Is it universal in holographic models?
- If not, what controls its appearance?

Outside of holography, do low temperature sound modes exist in non-Fermi liquids?

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Thank you!