Applied Gauge/Gravity Duality in Particle and Condensed Matter Physics

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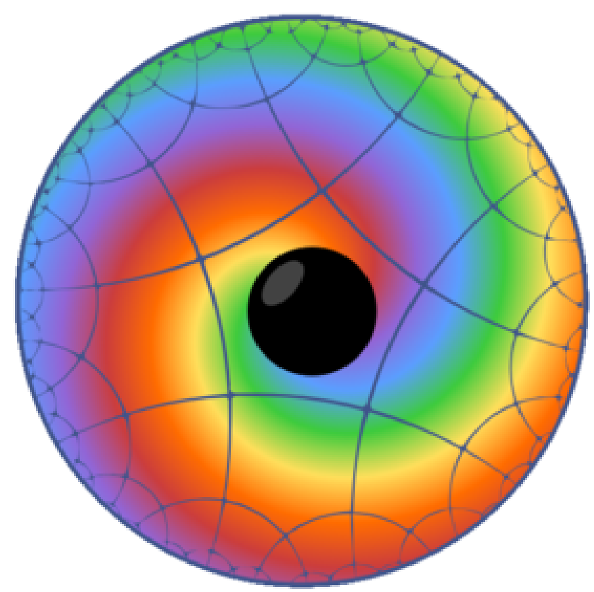
HEP 2019



Outline

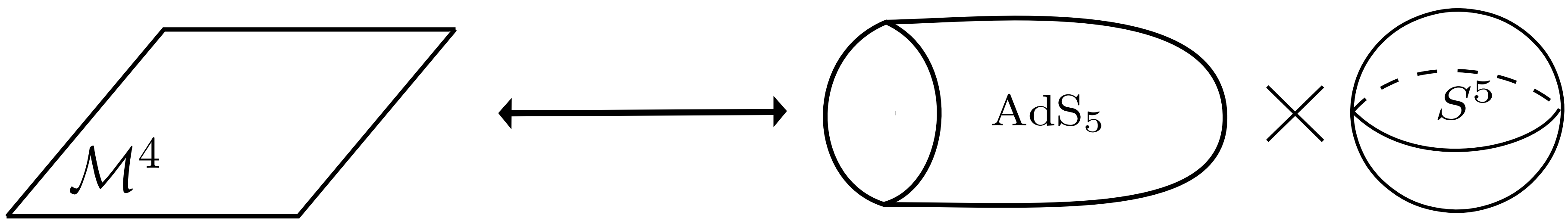
- Crash course in gauge/gravity

- Gauge/gravity and QCD
  - Meson spectrum
  - Jet quenching

- Gauge/gravity and CMT
  - Weyl semimetals
  - Hydrodynamics

The gauge/gravity duality

(Maldacena ‘97, Witten ‘98)



$$\mathcal{Z}_{\mathrm{QFT}}[J] = e^{iS_{\mathrm{G}}[J]}$$

Global symmetries ⟷ Gauge symmetries

- For finite temperature QFTs, the dual geometry contains a black hole

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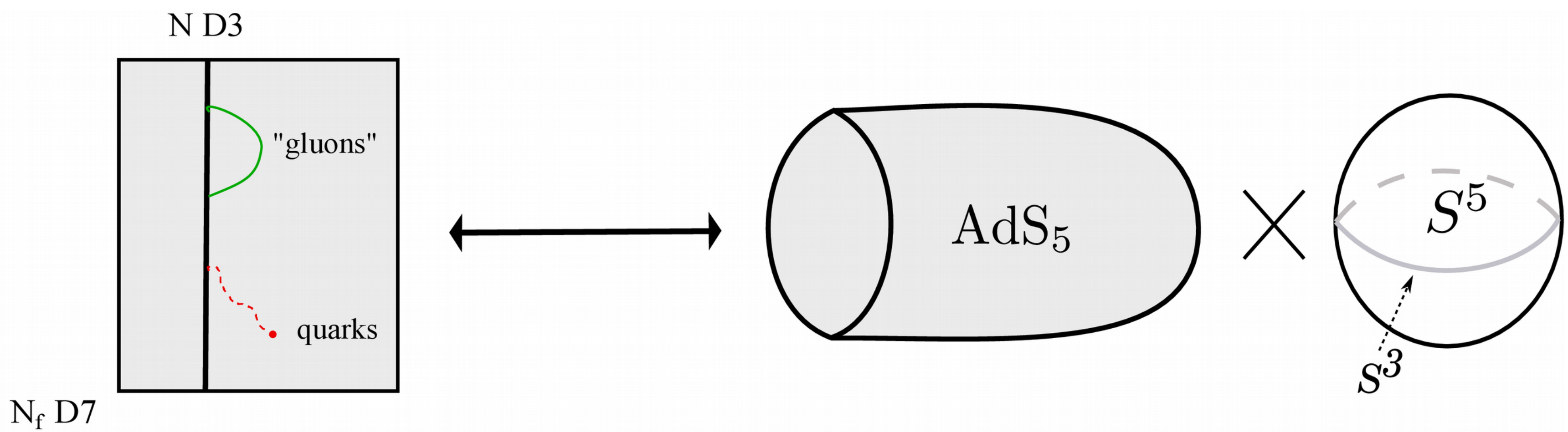
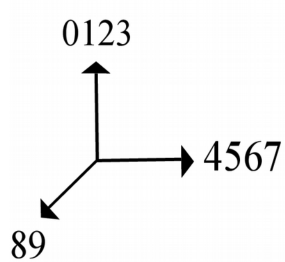
Meson spectrum

(Erdmenger, Evans, Kirsch, Threlfall ‘07)

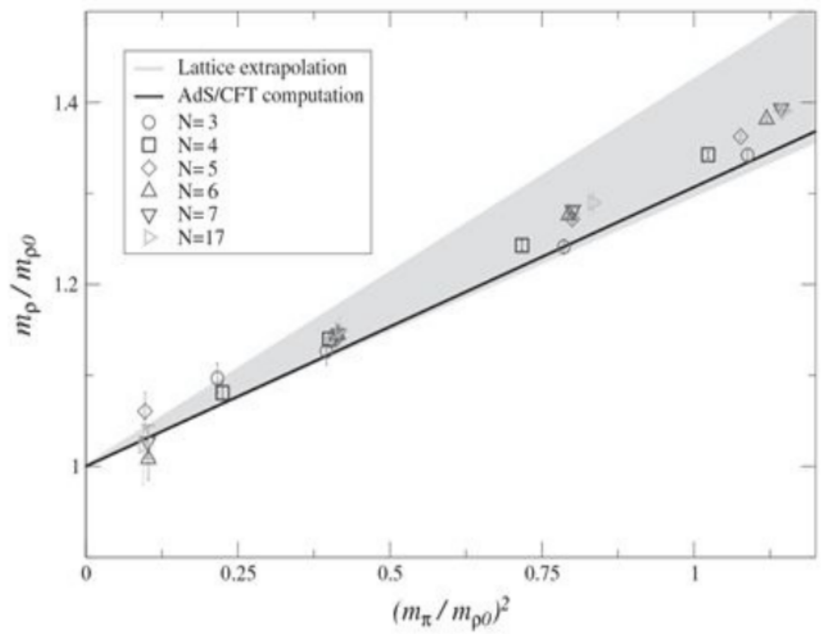




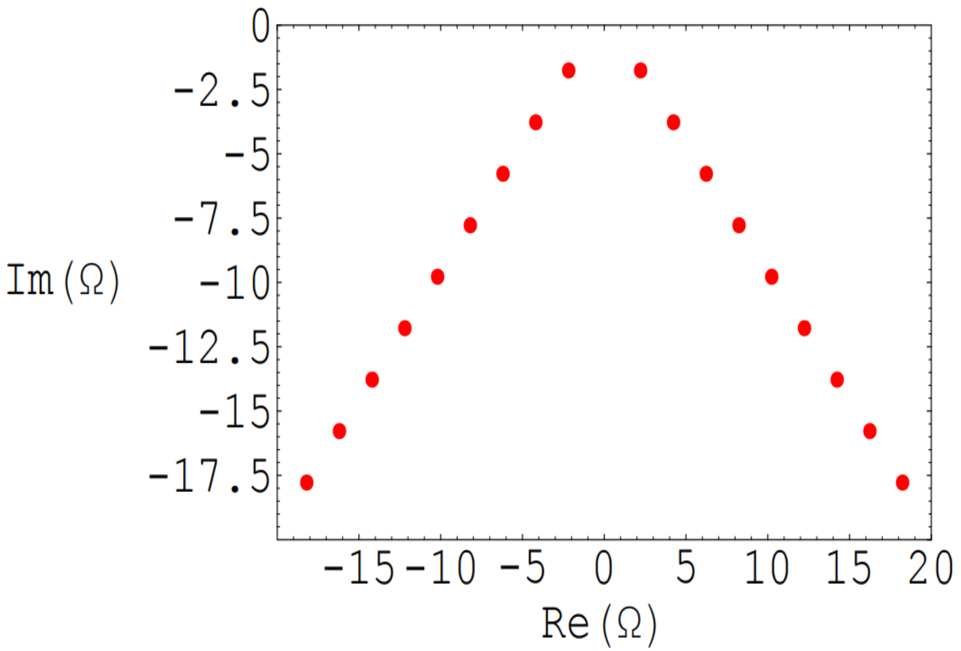
	0	1	2	3	4	5	6	7	8	9
D3	X	X	X	X						
D7	X	X	X	X	X	X	X	X		

Meson spectrum

(Erdmenger, Evans, Kirsch, Threlfall '07)



Comparison with lattice data. T=0



Finite-T quasi-normal modes

- Agreement with lattice-theory results
- Captures the finite-T decoherence of mesons into the plasma

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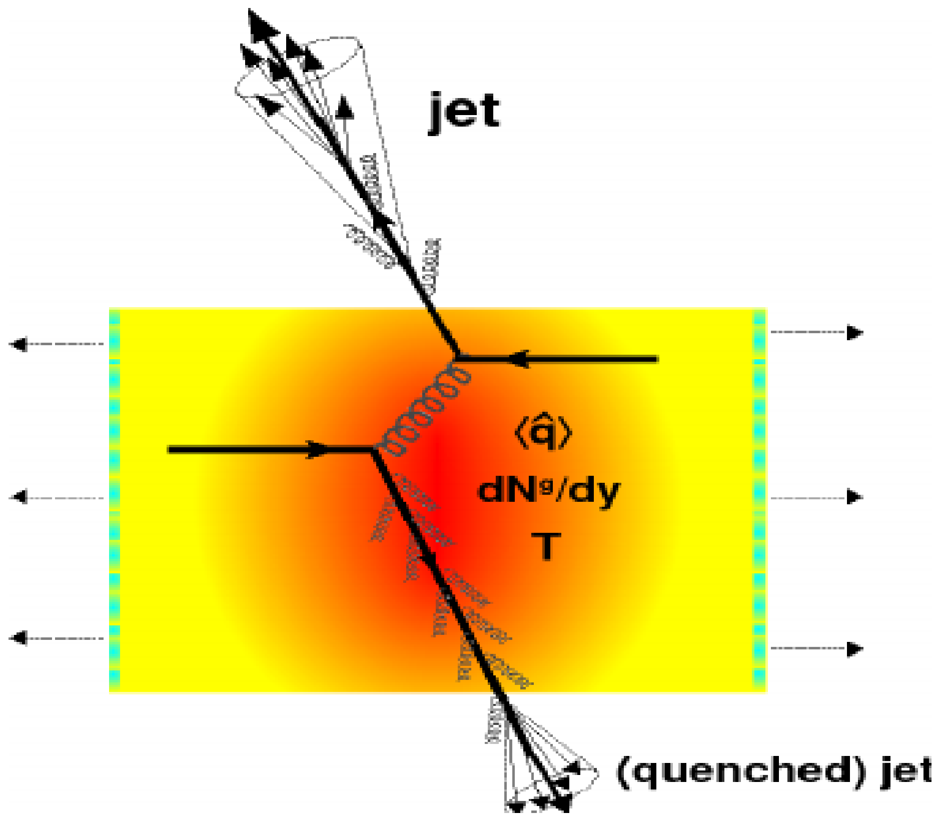
Jet quenching

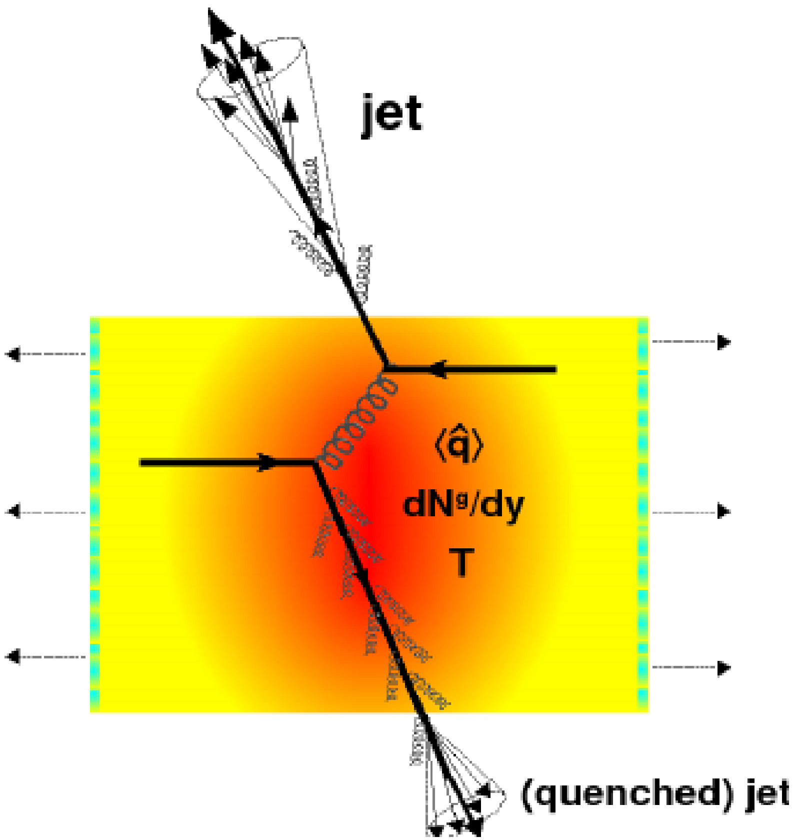
(Qin, Wang ‘15, Jet collaboration ‘13)



From d’Enterria, Betz ‘09

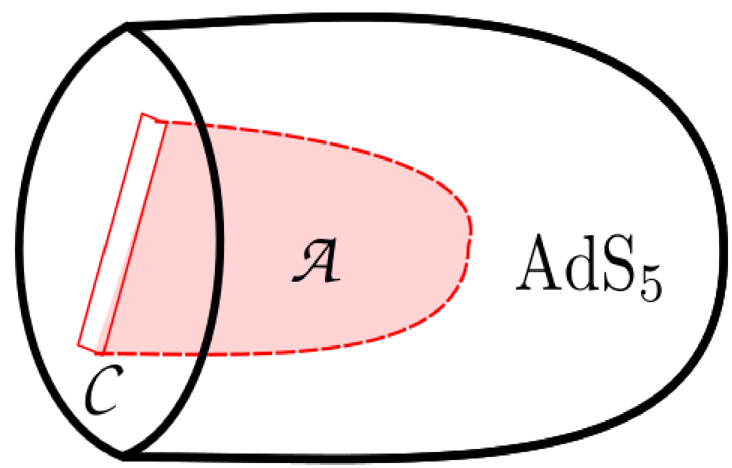
Jet quenching

(Qin, Wang '15, Jet collaboration '13)



From d'Enterria, Betz '09

$$\hat{q} = \frac{d\langle \Delta p_{\mathrm{T}}^2 \rangle}{dL} \qquad \langle W(\mathcal{C}) \rangle = e^{-\hat{q}\frac{L^- L^2}{8\sqrt{2}}}$$



Jet quenching

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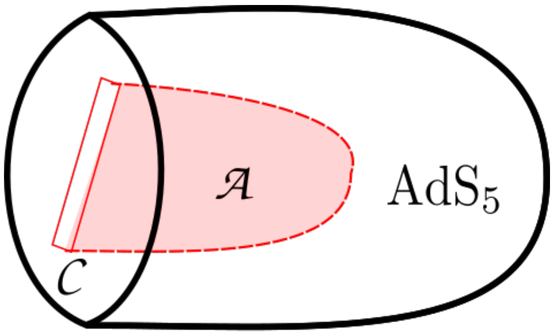

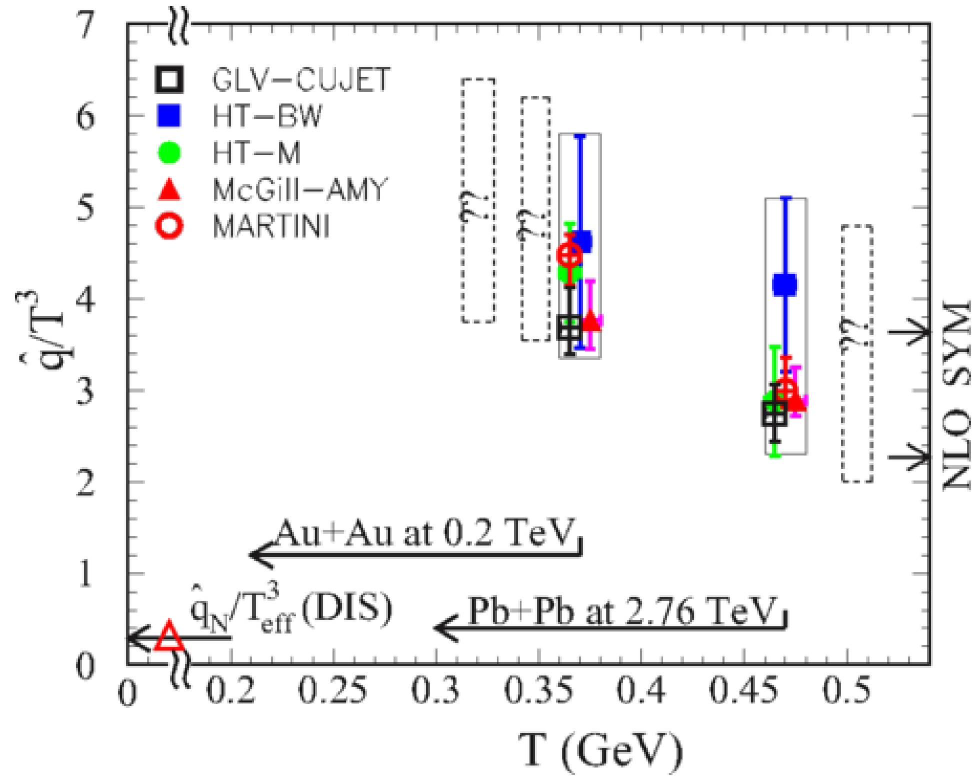

$$\hat{q}^{\rm NLO} \simeq 7.5\sqrt{\lambda}T^3\left(1-\frac{1.97}{\sqrt{\lambda}}\right)$$

Zhang, Hou, Ren ‘13

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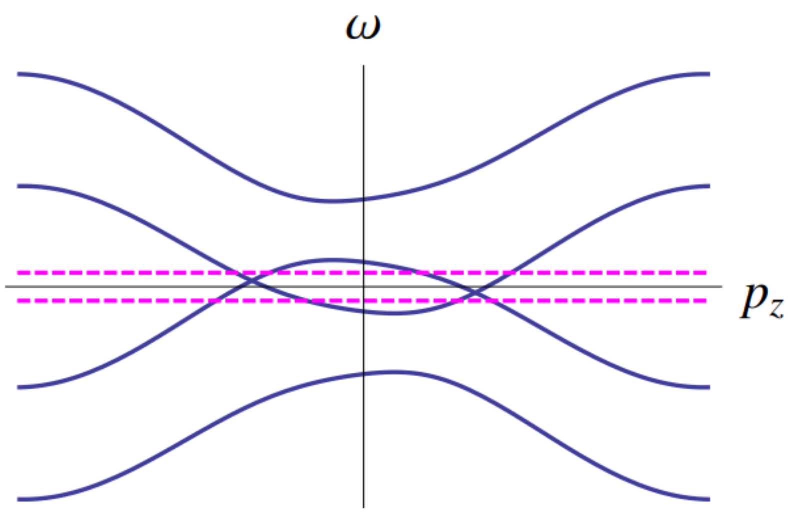
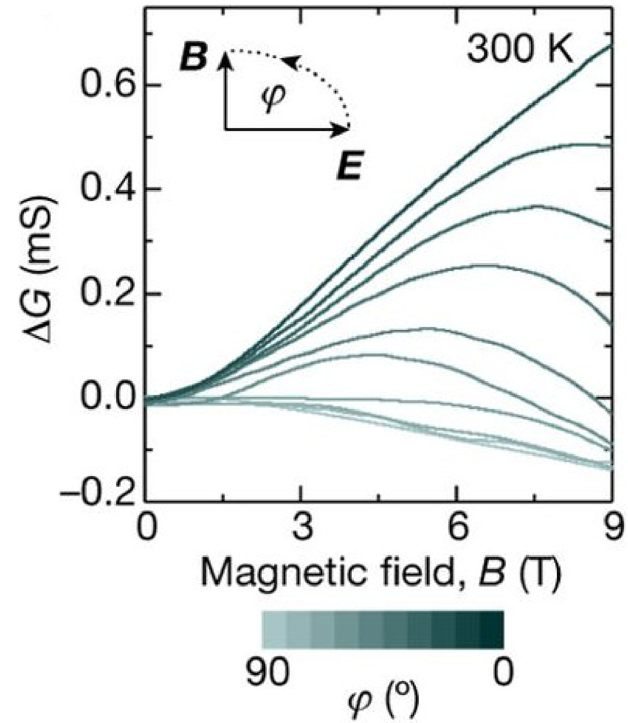
Weyl semimetals

(Landsteiner '16)



$$H_{eff} = \pm v_F(k_0)\vec{\sigma}\cdot(\vec{k}-\vec{k_0})$$



Gooth et. al. '17

- Axial anomaly: $\partial_\mu J^\mu_5 = \frac{1}{48\pi^2}\epsilon^{\mu\nu\rho\sigma}(3F_{\mu\nu}F_{\rho\sigma} + F^5_{\mu\nu}F^5_{\rho\sigma}) \propto 3E\cdot B + E^5\cdot B^5$

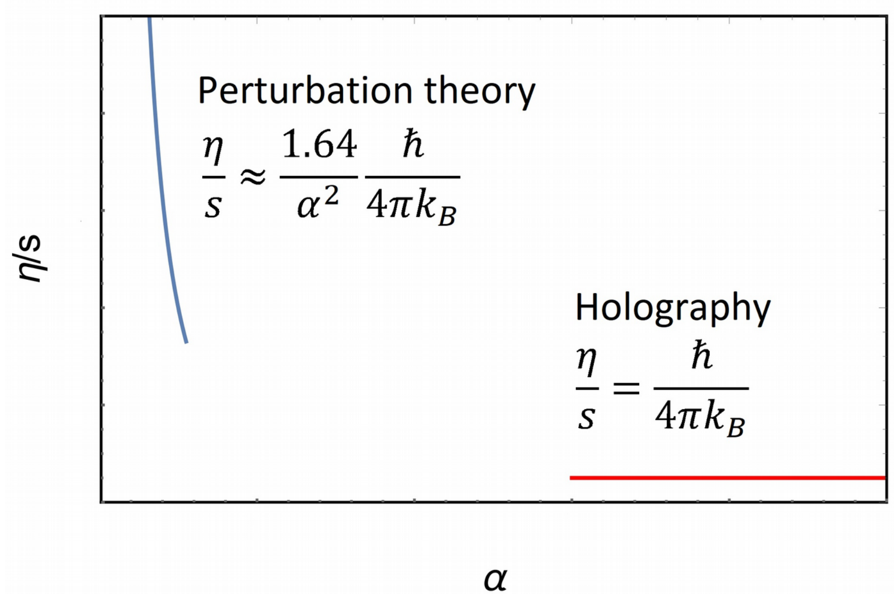
- Axial-torsional anomaly: $\partial_\mu J^\mu_5 = \frac{e}{16\pi^2 l^2}\left(E^a\cdot B_a + \frac{l^2}{l_5^2}E^a_5\cdot B^5_a\right)$ (Ferreiros et. al. '19)

Hydrodynamics

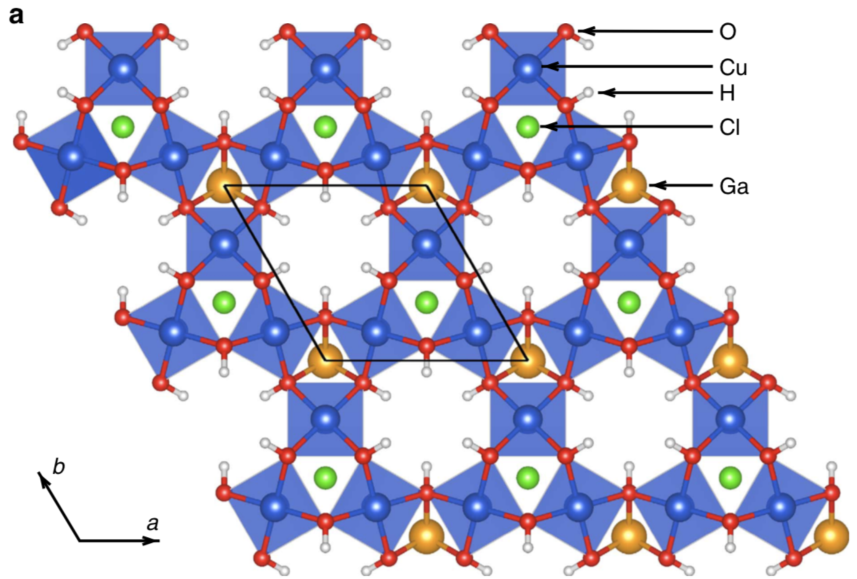
(Hubeny, Minwalla, Rangamani '11)

- Black holes naturally behave as fluids ⟶ Dual QFT behaves as a fluid
- Gauge/gravity = method to derive hydrodynamics
- Extends the Israel-Stewart formalism
- Can calculate all the transport coefficients, anomalous or not
- Alternative to kinetic theory approach at strong coupling
- Gives access to the thermalization process

Hydrodynamics & CMT

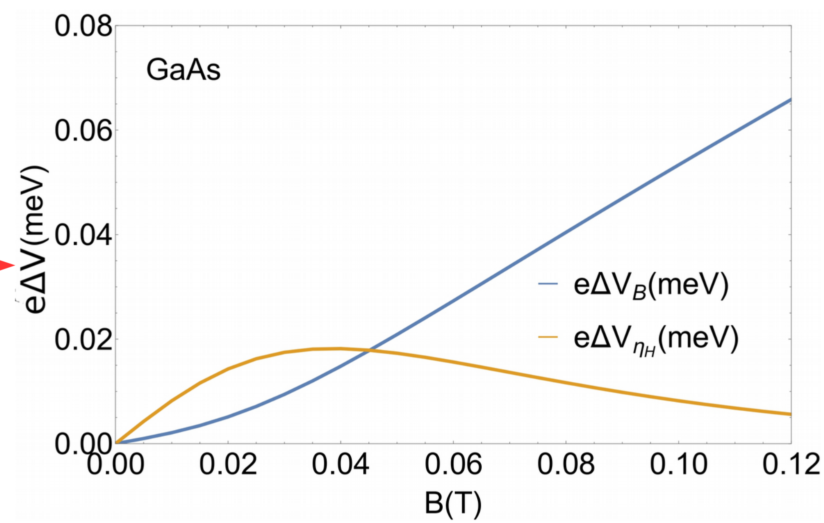


Erdmenger, I. M., Meyer, Rodríguez-Fernández '18



Di Sante, Erdmenger, I. M., Meyer, Rodríguez-Fernández, Thomale, Van Loon, Wehling (in preparation)

$$T^{\mu\nu} = \epsilon u^\mu u^\nu + P\Delta^{\mu\nu} - \eta\sigma^{\mu\nu} - \eta_{\rm H}\tilde{\sigma}^{\mu\nu}$$



Erdmenger, Hankiewicz, I.M., Meyer, Rodríguez-Fernández, Tutschku arXiv: 1905.NNNNN

Conclusions

1) CMT systems have exotic phenomenological properties

2) Gauge/gravity provides an effective calculation tool at any temperature

3) Combining both can lead to lessons that carry over to BSM physics and quantum gravity.

4) Experimental verification possible through tabletop experiments

Thank you!