# Higher-form symmetry, chiral magnetohydrodynamics (MHD) & holography

Based on: Upcoming work in collaboration with Dr. Nabil Iqbal and Dr. Ruth Gregory

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# Chiral MHD Plasma

- Finite temperature physics of a chiral MHD plasma: System with an axial $U(1)_A$ current $j_A$ that is afflicted by an Adler-Bell-Jackiw (ABJ) anomaly, where the corresponding vector $U(1)_V$ current $j_V$ has been coupled to dynamical electromagnetism.

- Motivation: Crucial to understanding systems with anomaly-induced effects such as,
  - Quark-gluon plasma
  - Dirac and Weyl semi-metals
  - Electro-Weak plasma in primordial Universe after the Big Bang

- Computation of the rate of anomalous $U(1)$ processes, e.g. the dissociation rate $\Gamma_A$ of the chiral charge density $j_A^0$ is crucial to the investigation of above systems.

# The Model

- There have been previous work in this direction where it has been found that $\Gamma_A \sim b^2$ (where $b =$ magnetic field). Few modern references are,
  - arXiv:1711.08450: Chiral MHD study by treating the anomaly coefficient $k$ perturbatively (for small $k$).
  - arXiv:1707.09967: Lattice simulations to obtain $\Gamma_A$ and found $10$ orders of magnitude discrepancy in the pre-factor with theoretical hydrodynamic predictions.
- Weakly-coupled physics: Lagrangian describing a massless Dirac fermion $\psi$ coupled to dynamical electromagnetism with photon $a$ (with $f = da$),

$$S[a,\psi] = \int d^4x \left( -\frac{1}{4e^2} f^2 + \overline{\psi} \left( \gamma^\mu \partial_\mu - i\gamma^\mu a_\mu \psi \right) \right) \qquad \text{...(1)}$$

- We shall construct and study a holographic model possessing the symmetries of the above action $S[a,\psi]$.

# 1-form global symmetry in E & M

- Global symmetry: $U(1)^{(1)}$ 1-form symmetry associated with the conservation of magnetic flux (Bianchi Identity)

$$\partial_\mu J^{\mu\nu} = 0, \qquad J^{\mu\nu} := \frac{1}{2}\,\epsilon^{\mu\nu\rho\sigma} f_{\rho\sigma} \qquad \ldots(2)$$

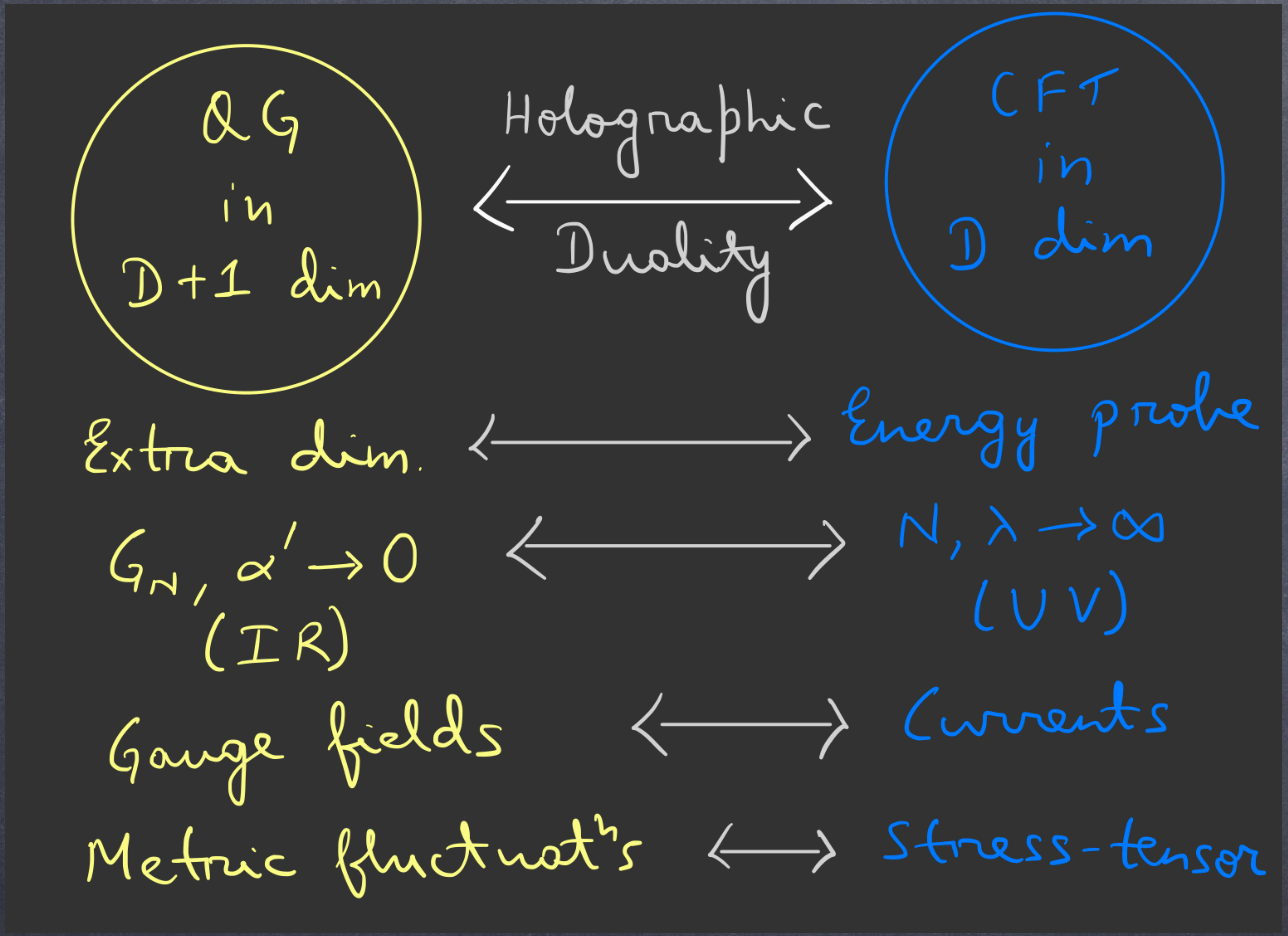
- Gauge symmetry: $U(1)^{(0)}_A$ 0-form symmetry associated with vector phase rotations of the $\psi$ field, $\psi \to e^{i\alpha}\psi$.
- Classically, ∃ global $U(1)^{(0)}_A$ 0-form symmetry associated with $\psi \to e^{i\alpha\gamma^5}\psi$; but at QM level is broken by the ABJ anomaly:

$$\partial_\mu j^\mu_A = k\,\epsilon^{\mu\nu\rho\sigma} f_{\mu\nu} f_{\rho\sigma} \qquad \ldots(3)$$

- Eq.(3) can also be written as,

$$\partial_\mu j^\mu_A = \tilde{k}\,\epsilon_{\mu\nu\rho\sigma} J^{\mu\nu} J^{\rho\sigma} \qquad \ldots(4)$$

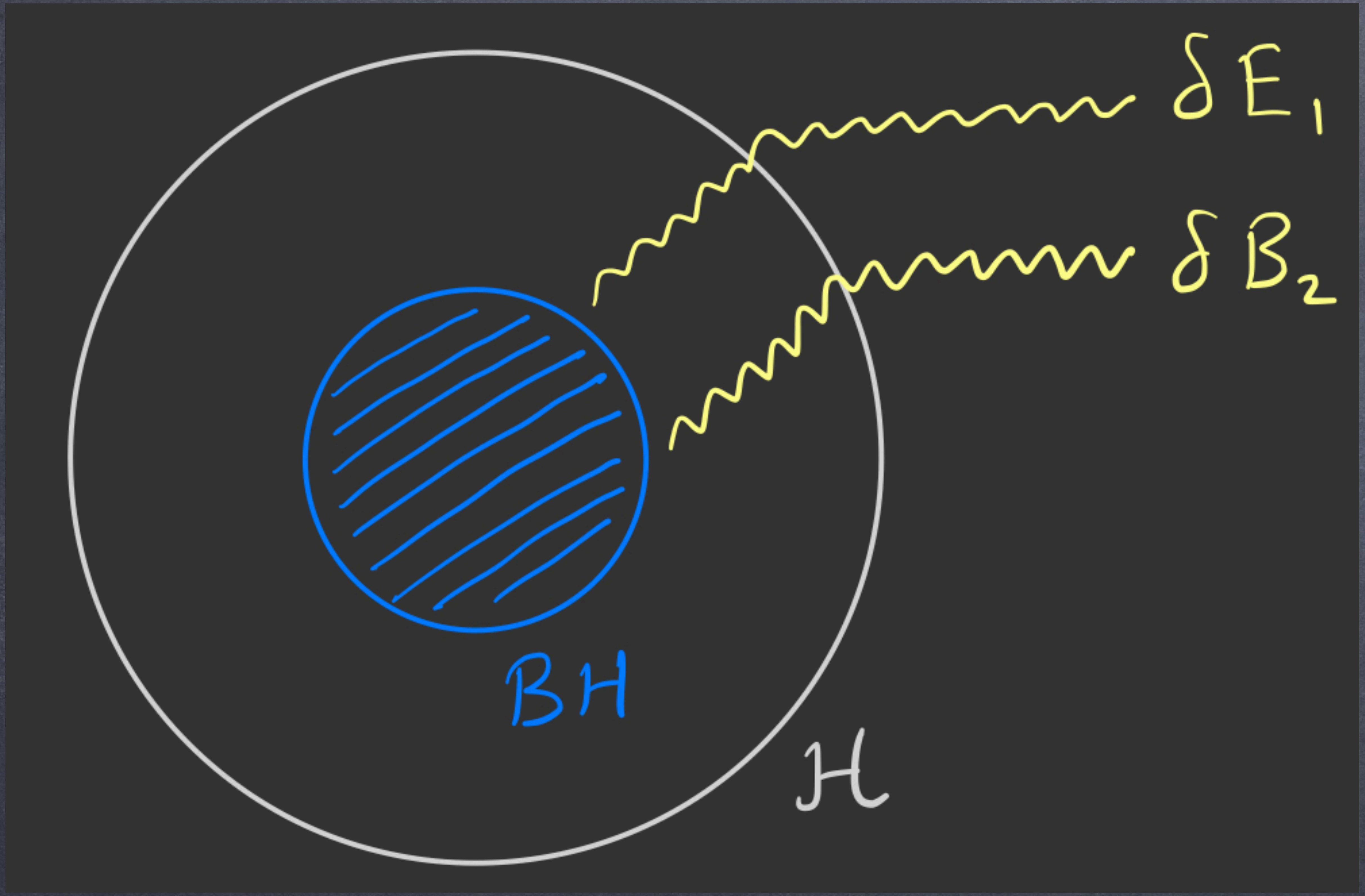
# Holography




$$E_1 \leftrightarrow j^\mu_A$$
$$B_2 \leftrightarrow J^{\mu\nu}$$

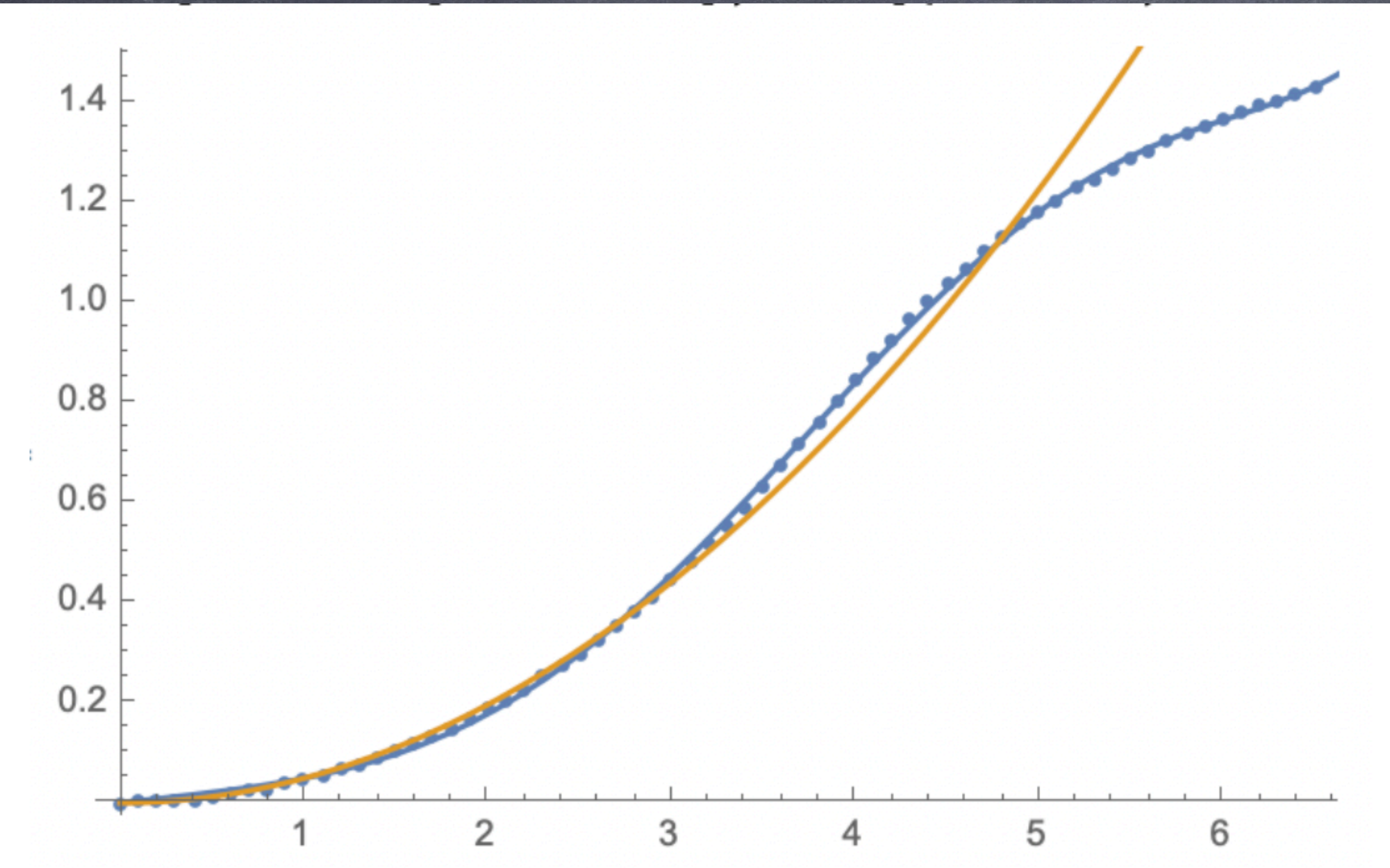
$$S_5 = \int_{\mathcal{M}^5} \left|dE_1\right|^2 + \left|dB_2\right|^2 + \tilde{k}\, E_1 \wedge \star dB_2 \wedge \star dB_2 + \cdots \qquad \ldots(5)$$

# Further steps




- We study the bulk model in a $AdS_5 - Schwarzschild$ background.
- Next we move on to find the background magnetic field solution of (5) and study fluctuations of $\delta E_1$ and $\delta B_2$ in this background.
- We numerically solve for these fluctuations (by solving their EoMs) and then compute the lowest Quasi Normal Mode (QNM) from these solutions.

# Results




- This QNM $\Gamma_A(b)$ goes as (for a small neighbourhood around $b = 0$),

$$\boxed{\Gamma_A(b) \sim b^2} \quad \ldots(6)$$

- This is in agreement with previous literature.
- However, the nice quadratic behaviour of $\Gamma_A(b)$ stops as $b >> 0$.

Thank You for listening..