Chiral Magnetic Effect in holographic models

Flavio Porri

Firenze - 11/07/2017

Based on work in collaboration w/ **Francesco Bigazzi, Aldo Cotrone**

In a few words…

- The aim is to compute anomalous transport coefficients in a strongly coupled system such as the Quark Gluon Plasma.
  - We employ gauge/gravity correspondence to map a strongly coupled system to a weakly coupled gravitational system;
  - We exploit holographic tools to extract transport coefficients from the weakly coupled gravity picture.

QGP = Quark Gluon Plasma

Plan

(I) The Chiral Magnetic Effect

(II) Quark Gluon Plasma

(III) Holography

(IV) Summary & Outlook

CME = Chiral Magnetic Effect

Chiral Magnetic Effect

What is it?

CME :

Generation of *non-dissipative* electric current
induced by chirality imbalance
in external magnetic field.

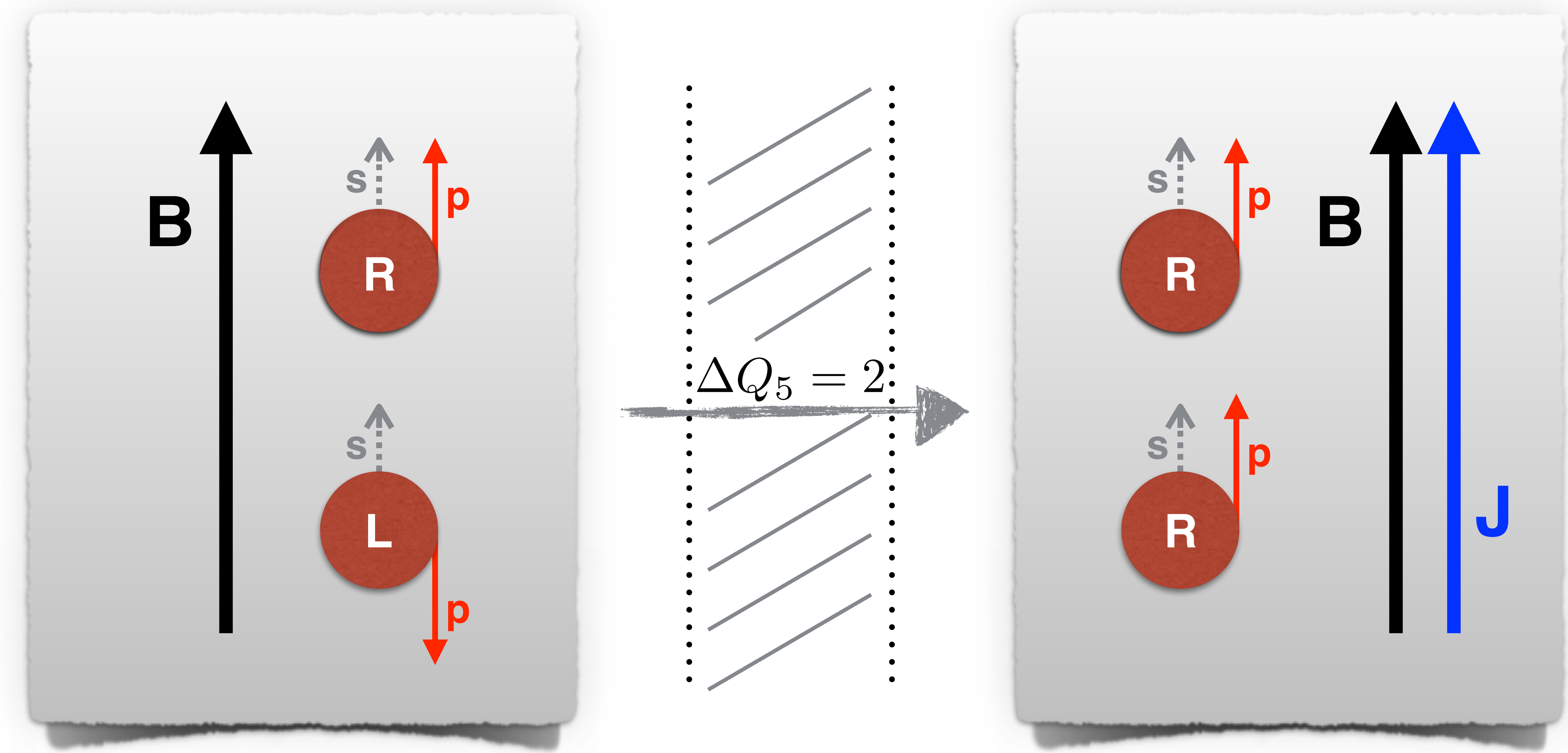
$$\vec{J}_e = \sigma_{\rm CME}\,\vec{B}$$

[Fukushima, Kharzeev, Warringa '08]

and why is that interesting?

- Another way to attain non-dissipative electronic transport. Alternative to superconductivity based on *spontaneous* symmetry breaking.
- Macroscopic manifestation of the quantum anomaly in relativistic theories of chiral fermions (massless Weyl fermions).
- Provides an indirect way to test CP-violation in QCD.

Massless fermions in external magnetic field



$$\vec{J}_e = \sigma_{\mathrm{CME}}\, \vec{B}$$

$$\sigma_{\mathrm{CME}} \propto Q_5 = (n_R - n_L)$$

…*classically* the chiral charge Q_5 is conserved…

The chiral anomaly links the change in chiral charge to a topological index

$$\Delta Q_5 = \frac{N_f\, g^2}{16\pi^2} \int \mathrm{d}^4x\, \epsilon_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma}$$

A chiral imbalance can be generated by gauge field configurations which are topologically nontrivial:

QED

$$\frac{\Delta Q_5}{V\,\Delta t} \sim e^2\, \vec{E} \cdot \vec{B}$$

Relevant e.g. for cond. mat. systems:
Dirac semi-metal, Weyl semi-metal

QCD

$$\Delta Q_5 = 2\, N_f\, n$$

Where 'n' is the instanton number, receives contribution also from sphalerons.

Instanton contribution is exponentially suppressed. Sphalerons contributes when T is high enough (QGP).

The chiral anomaly links the change in chiral charge to a topological index

$$\Delta Q_5 = \frac{N_f\, g^2}{16\pi^2} \int \mathrm{d}^4x\, \epsilon_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma}$$

A chiral imbalance can be generated by gauge field configurations which are topologically nontrivial:

QCD

$$\Delta Q_5 = 2\, N_f\, n$$

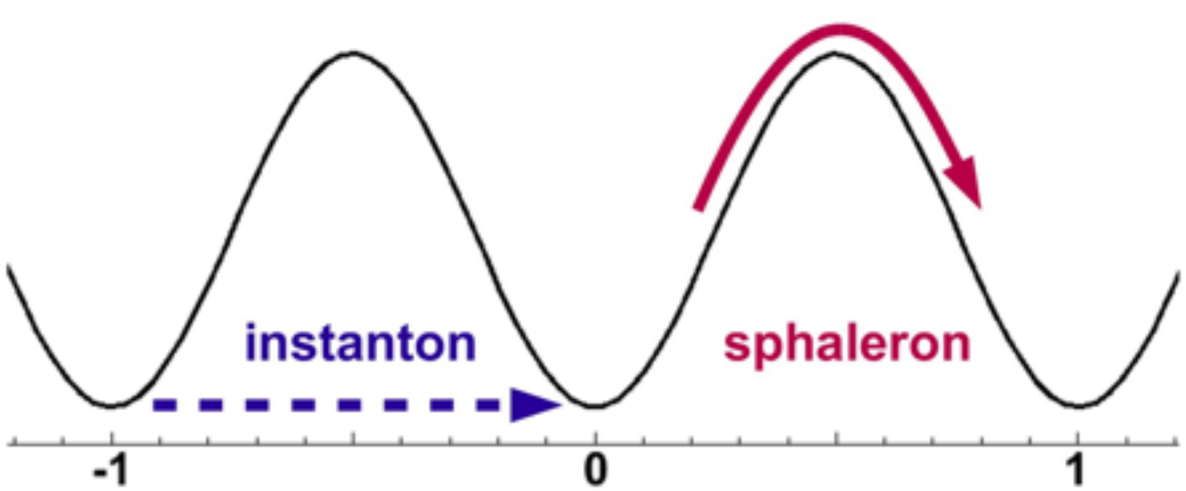
Where 'n' is the instanton number, receives contribution also from sphalerons.

Instanton contribution is exponentially suppressed. Sphalerons contributes when T is high enough (QGP).

The chiral anomaly links the change in chiral charge to a topological index

$$\Delta Q_5 = \frac{N_f\, g^2}{16\pi^2} \int \mathrm{d}^4x\, \epsilon_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma}$$

A chiral imbalance can be generated by gauge field configurations which are topologically nontrivial:



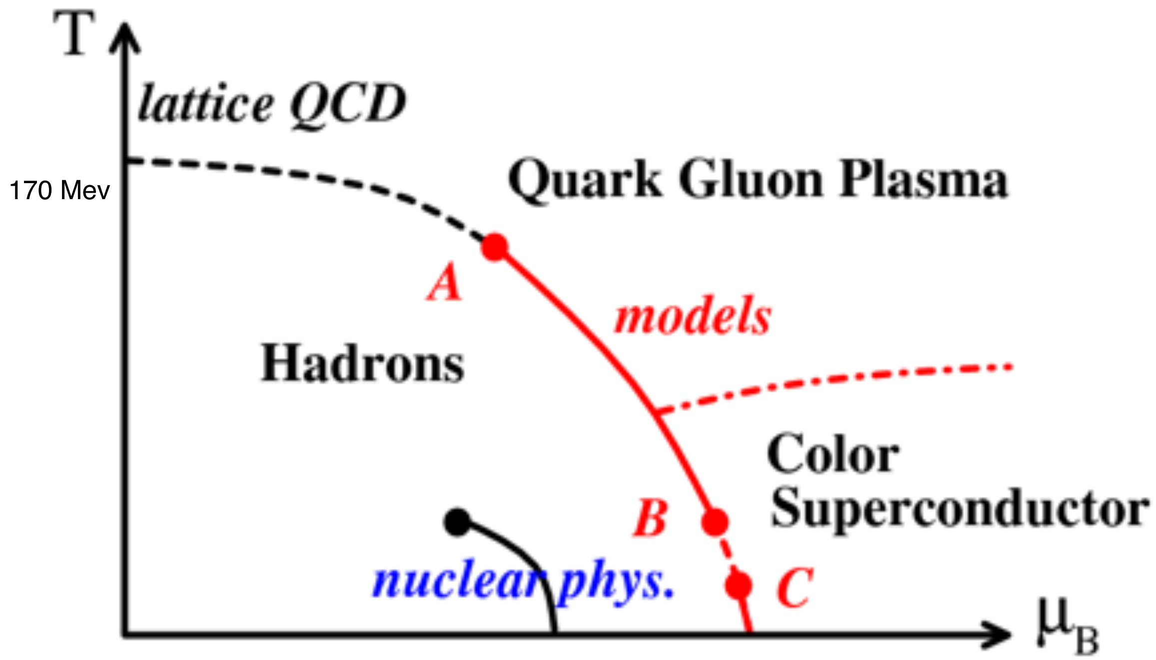
QCD

$$\Delta Q_5 = 2\, N_f\, n$$

Where 'n' is the instanton number, receives contribution also from sphalerons.

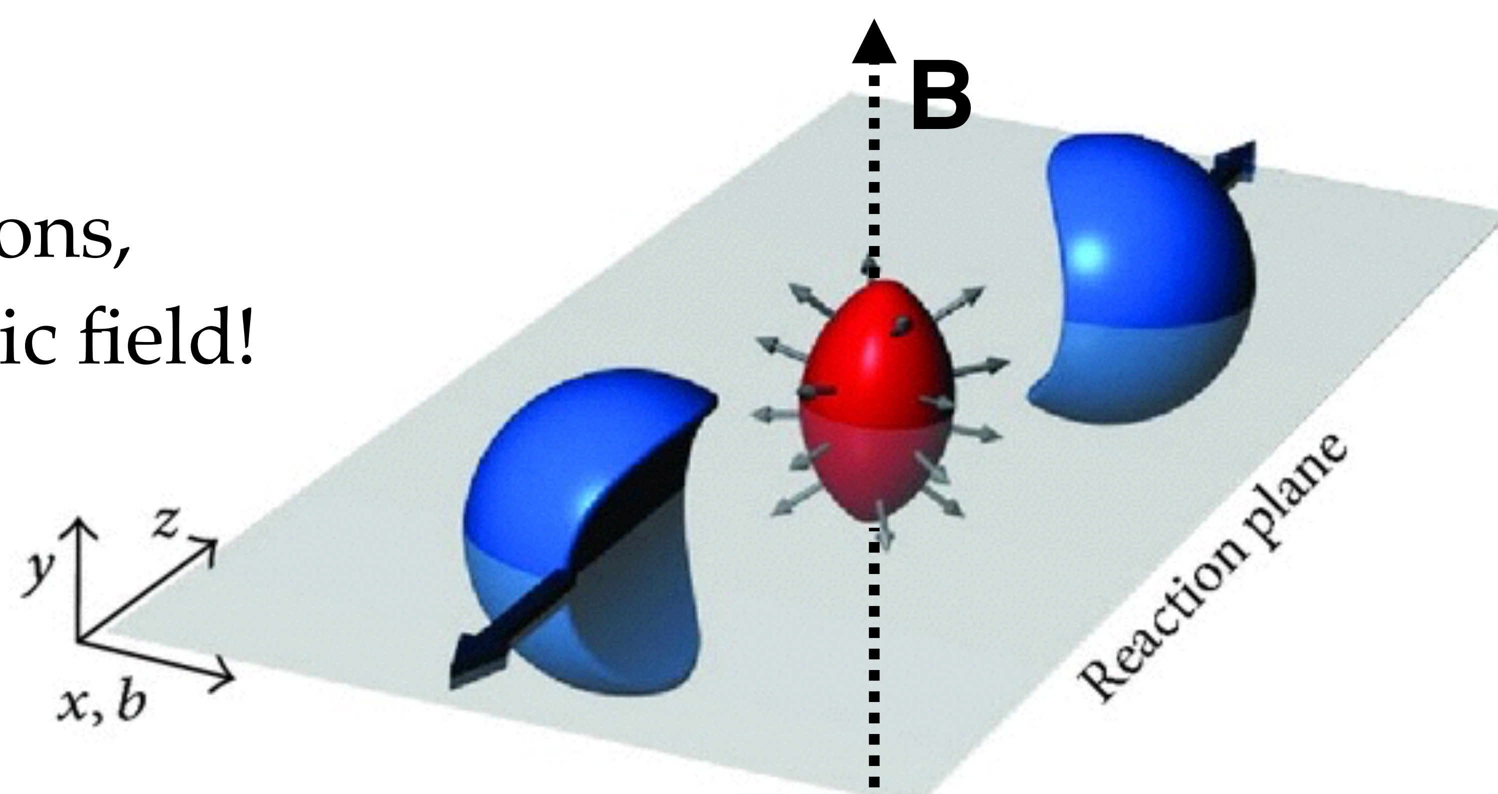
Instanton contribution is exponentially suppressed. Sphalerons contributes when T is high enough (QGP).

Quark Gluon Plasma



- QCD matter at high temperature and finite density;

- Produced in heavy ions collisions, together with a strong magnetic field!



With explicit source for P-breaking cannot be too large in QCD. And this implies that statistically

$$\overline{\Delta Q_5} = 0$$

One needs an observable which is not sensitive to the sign. Here is one: The Chern-Simons diffusion rate

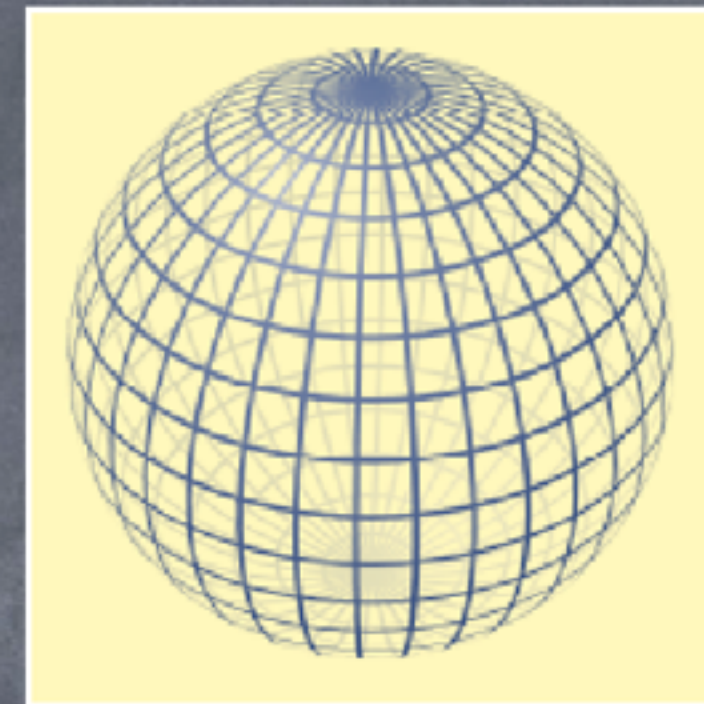
$$\Gamma_{\mathrm{CS}} = \frac{\langle \Delta Q_5^2 \rangle}{V\,\Delta t} = \left(\frac{g^2}{8\pi^2} \right)^2 \int \mathrm{d}^4x \langle O(x)\, O(0) \rangle$$

$$O = \frac{1}{4} \epsilon_{\mu\nu\rho\sigma} F^{\mu\nu} F^{\rho\sigma}$$

$$\dot{Q}_5 = -c\, Q_5 \, \frac{\Gamma_{\mathrm{CS}}}{T^3}$$

Holography for QGP

=



=

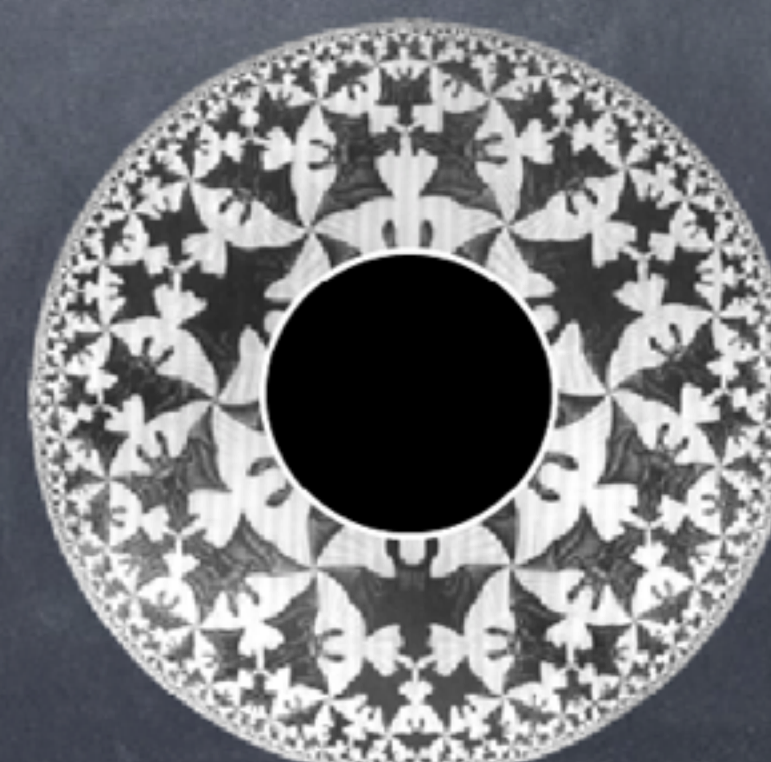


Image: Karl Landsteiner

Holographic approach

- Provides a framework to study strongly coupled systems;
- It is known to give realistic results for transport coefficients such as the shear viscosity;
- Beautifully incorporates anomalies;
- Two possible approaches (to pick the gravity theory): bottom-up or top-down.

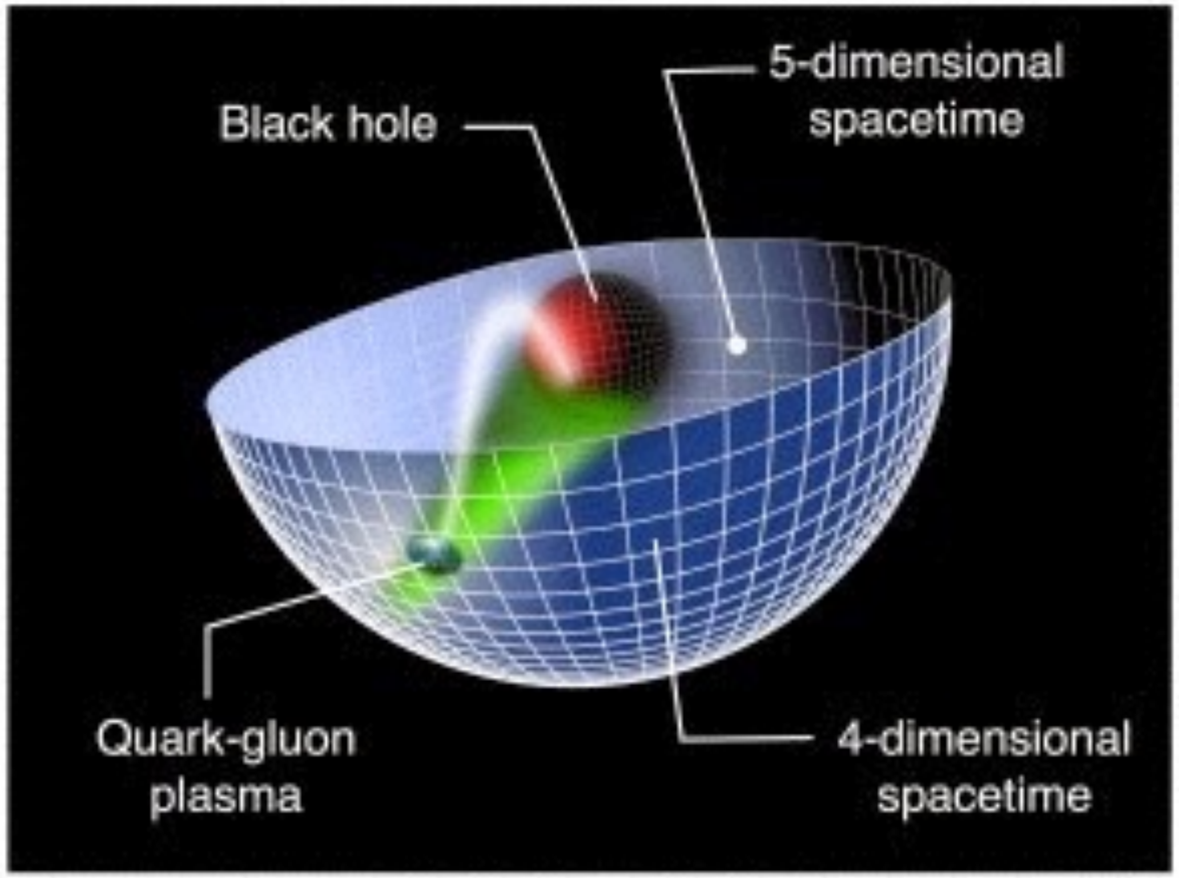


Image: SLAC National Accelerator

Dictionary

- Gravity background = state in the dual QFT;
- Black hole temperature = QGP temperature;
- Topological operator = pseudo-scalar (axion) field in the bulk;
- Anomalous current = massive bulk vector.

Holographic correlators in a nut shell

- The boundary value of a bulk field is identified with the source for the dual operator.

$$\Phi_0(x) = \Phi(z = z_b, x) = J(x)$$

$$\langle O\, O \rangle = \frac{\delta^2 Z}{\delta J^2} \longleftrightarrow \langle O\, O \rangle = \frac{\delta^2 S_{\text{on-shell}}}{\delta \Phi_0^2}$$

$$O = \epsilon_{\mu\nu\rho\sigma} F^{A\mu\nu} F_A^{\rho\sigma}$$

Bottom-up vs Top-down

We know holography works well for N=4 SU(Nc) SYM.
A supersymmetric, conformal version of QCD.

- Bottom-up: Assume holography works for any gravity theory; Build an effective gravitational action which mimics known features of QCD; Extract predictions.

- Top-down: Start from N=4 SYM set-up (string theory on a stack of flat D3-branes); Add modifications to the brane construction and try to reach more realistic theories (break supersymmetry and conformality, add fundamental flavors…)

In our case: placed the D3s on a curve background + added N_f D7-branes. It corresponds to some N=1 SYM coupled to N_f fundamental flavors. (It also breaks conformal symmetry!)

Summary & Outlook

- The aim is to compute anomalous transport coefficients of the strongly coupled Quark Gluon Plasma.

  - We employ gauge/gravity correspondence to map a strongly coupled system to a weakly coupled gravitational system;

  - We use holography to extract transport coefficients from the weakly coupled gravity picture.

Future prospects

- Anomalous transport in QGP is sensitive to the CP-violating sector of QCD.

- Effect of the flavor dynamics still to be understood in top-down holography.

- New intriguing bounds from holography $\frac{\Gamma_{\rm CS}}{s\,T\,g_{YM}^2} \sim \frac{\eta}{s} \geq \frac{\hbar}{4\pi}$