Since holographists began their journey to conquer the real world ten years ago, many interesting results were discovered by studying various gravitational systems.

Starting from eta/s, one often finds holographic systems exhibit similar behavior with real life systems.

For AdS/QGP, this is often enough for one to argue that N=4 SYM is close enough to QCD and then proceed to make predictions for the real-life QGP.

(At least some of) these predictions are actively being tested at RHIC and LHC.

While as far as I know so far there have been no definite confirmation of any of the predictions, they did expand the horizon of theorists, and provide important new observables for experimentalists.

In this sense AdS/QGP is highly successful and relevant.

For AdS/CMT, repeating the same story line is much harder.

Again similarities with real life systems were found, which are encouraging and exciting.

But we still need to argue lessons/features from N=4 SYM, ABJM and their relatives are relevant for electronic systems.

Here merely “similarities” are often not enough to make predictions, not to mention to solve real-life problems.

After the initial excitement about “similarities”, to remain relevant is not easy. Here I believe there is no short-cut. One has to study real CM systems, talk to experimentalists, and become a de facto CM physicist.

Other than simulating specific CM systems, which is definitely important, it is perhaps relatively easier, and potentially much more rewarding to extract general dynamical mechanisms or theoretical structures from gravity.

Had string theory and AdS/CFT been discovered in 60's rather than 90's, string theorists might have discovered confinement first.

Conceivably there might be many more treasures hidden in gravity to be discovered.
(e.g. Shamit's discussion)

I will now very briefly mention two issues which I believe insights from holography has the potential to revolutionize our treatment of quantum matter.

# Systems without quasiparticles

Most challenging problem in modern CM.

Gauge/gravity duality: such systems are treated with ease for systems it can treat, which are rather limited.

Question: can we extract from gauge/gravity duality a systematic field theoretical method for treating SWOQ like what Boltzmann's kinetic theory did for systems with quasi-particles?

# Renormalization group

Current formulation of Wilsonian RG:

- Evolution of Euclidean effective action

- Hamiltonian approach: evolution of wave functions and Hamiltonian (lattice, numerics)

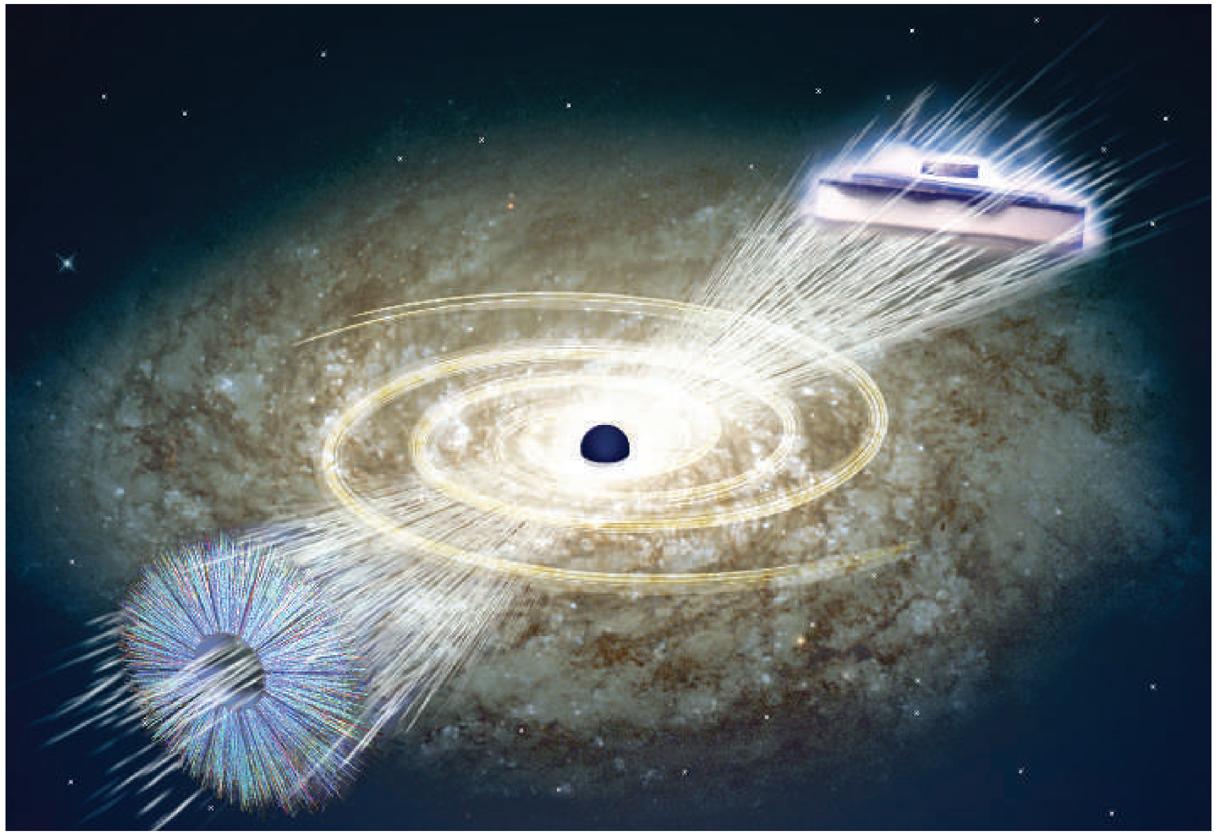
Crucial for dealing with many-body physics, but neither is perfect.

Radial evolution in AdS appear to incorporate both.

One should be able to extract from gauge/gravity duality a field theoretical RG procedure which combines both. (likely important for treating SWOQ)

# Two developing areas in (possibly "applied") holography

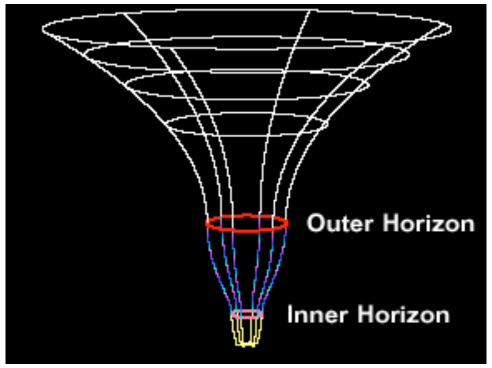
## 1. Our meal ticket has been the black hole.




I think continued systematic study of black branes will pay off in near future.

Lacking a better idea, the most obvious thing to do is find the analogue of the Kerr/Newman classification for planar black branes in AdS.

Work of this general flavor is being pursued along several lines: fluid/gravity, blackfolds, ....




A particularly enticing, and perhaps tractable, question is to find the most general extremal brane (in theories with simple enough matter). This requires extending fluid/gravity for charged systems to T=0 configurations.

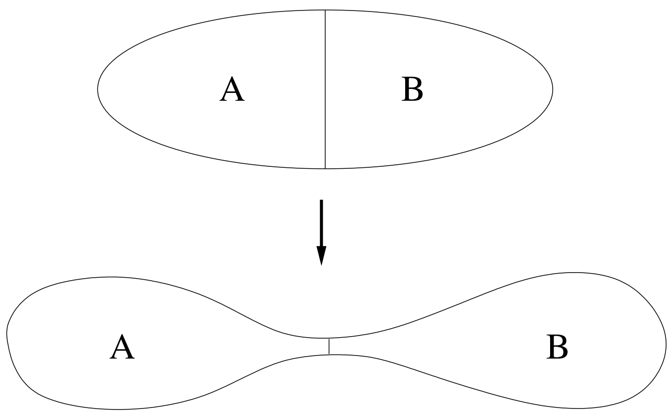
Possible pay offs of a better understanding of this classification, or a full completion of a fluid/gravity correspondence, include:

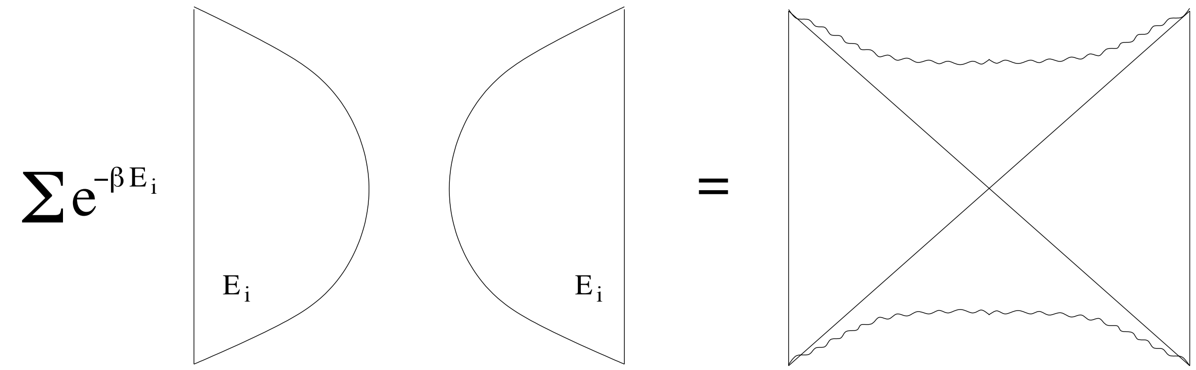
a) possible desingularization of "singular flows" by lifting them to the total space of a higher-dimensional solution

b) possible prediction of "new phases" of matter

2. Emergence of space-time

One attractive idea that has been widely discussed of late is the notion that space-time may arise from entanglement:



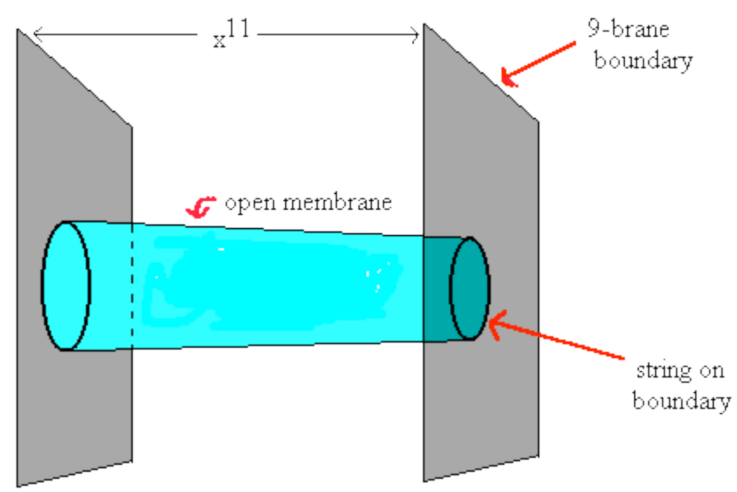




# Something that has been slightly less remarked upon is the analogy between the "tenfold way" of Ludwig et al and Kitaev, and the emergence of d.o.f. in string theory.

| Cartan label | T | C | S | Hamiltonian | $G/H$ (ferm. NL$\sigma$M) |
|---|---|---|---|---|---|
| A (unitary) | 0 | 0 | 0 | $\mathrm{U}(N)$ | $\mathrm{U}(2n)/\mathrm{U}(n)\times\mathrm{U}(n)$ |
| AI (orthogonal) | +1 | 0 | 0 | $\mathrm{U}(N)/\mathrm{O}(N)$ | $\mathrm{Sp}(2n)/\mathrm{Sp}(n)\times\mathrm{Sp}(n)$ |
| AII (symplectic) | −1 | 0 | 0 | $\mathrm{U}(2N)/\mathrm{Sp}(2N)$ | $\mathrm{O}(2n)/\mathrm{O}(n)\times\mathrm{O}(n)$ |
| AIII (ch. unit.) | 0 | 0 | 1 | $\mathrm{U}(N+M)/\mathrm{U}(N)\times\mathrm{U}(M)$ | $\mathrm{U}(n)$ |
| BDI (ch. orth.) | +1 | +1 | 1 | $\mathrm{O}(N+M)/\mathrm{O}(N)\times\mathrm{O}(M)$ | $\mathrm{U}(2n)/\mathrm{Sp}(2n)$ |
| CII (ch. sympl.) | −1 | −1 | 1 | $\mathrm{Sp}(N+M)/\mathrm{Sp}(N)\times\mathrm{Sp}(M)$ | $\mathrm{U}(2n)/\mathrm{O}(2n)$ |
| D (BdG) | 0 | +1 | 0 | $\mathrm{SO}(2N)$ | $\mathrm{O}(2n)/\mathrm{U}(n)$ |
| C (BdG) | 0 | −1 | 0 | $\mathrm{Sp}(2N)$ | $\mathrm{Sp}(2n)/\mathrm{U}(n)$ |
| DIII (BdG) | −1 | +1 | 1 | $\mathrm{SO}(2N)/\mathrm{U}(N)$ | $\mathrm{O}(2n)$ |
| CI (BdG) | +1 | −1 | 1 | $\mathrm{Sp}(2N)/\mathrm{U}(N)$ | $\mathrm{Sp}(2n)$ |

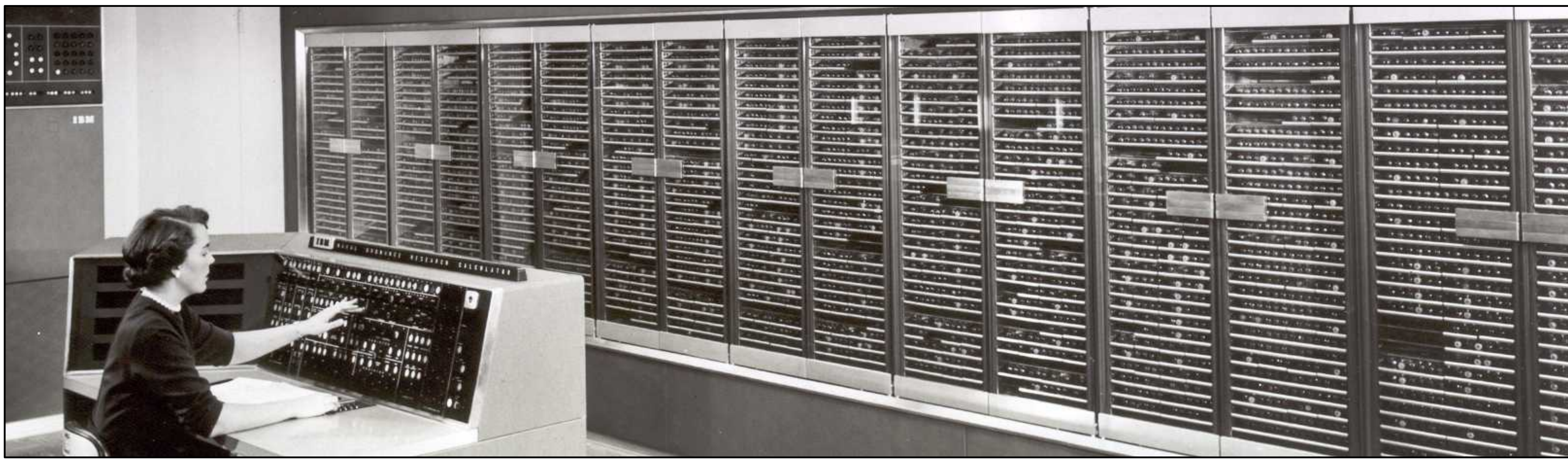
Their essential insight is that gapless degrees of freedom (edge modes) arise at the interface of two different types of "nothing" (insulators).

The K-theory classification they employ feels similar to that of D-branes.

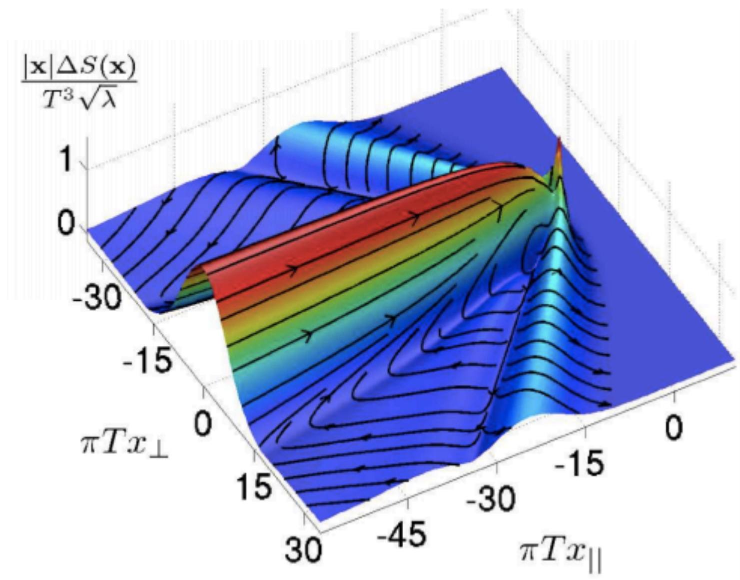



More mysterious is a possible interpretation of the E8 walls of M-theory as such an interface. In the analogy, macroscopic gravity is one of the "nothing" phases; what are the others?

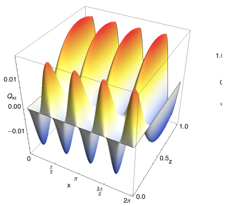
# To make progress…



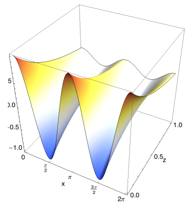
# Non-Equilibrium

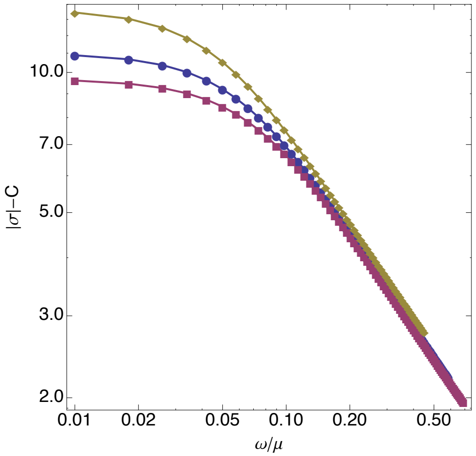


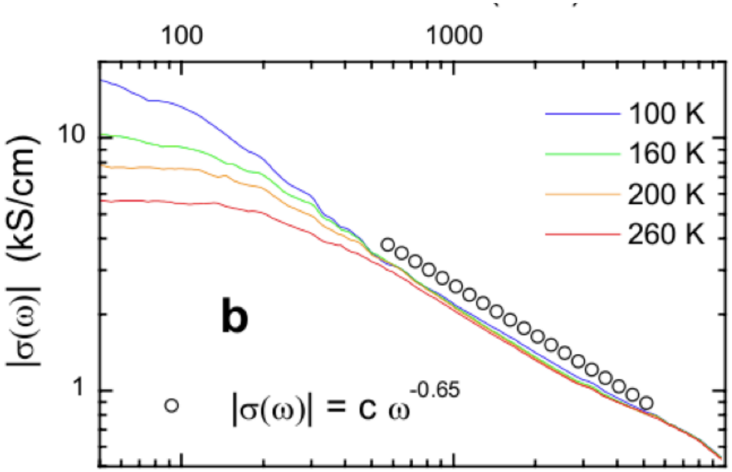

Chesler and Yaffe



# Lattices



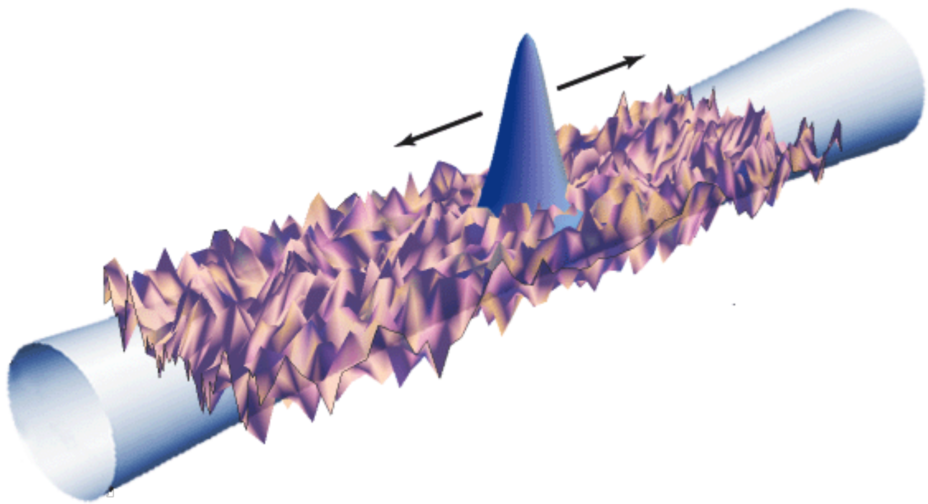



$$|\sigma(\omega)| \sim \frac{1}{\omega^{2/3}}$$

with Gary Horowitz and Jorge Santos

# Disorder



# AdS/CFT “applications”

So far (Heavy Ions)

- Transport ($\eta/s$, but also conductivities etc.)

- Connection to Hydrodynamics

- Energy Loss

- Thermalization

- Fluctuations

♠ General (Rapid) time evolution+scattering?