ADS$_4$ BLACK HOLES FROM M-THEORY

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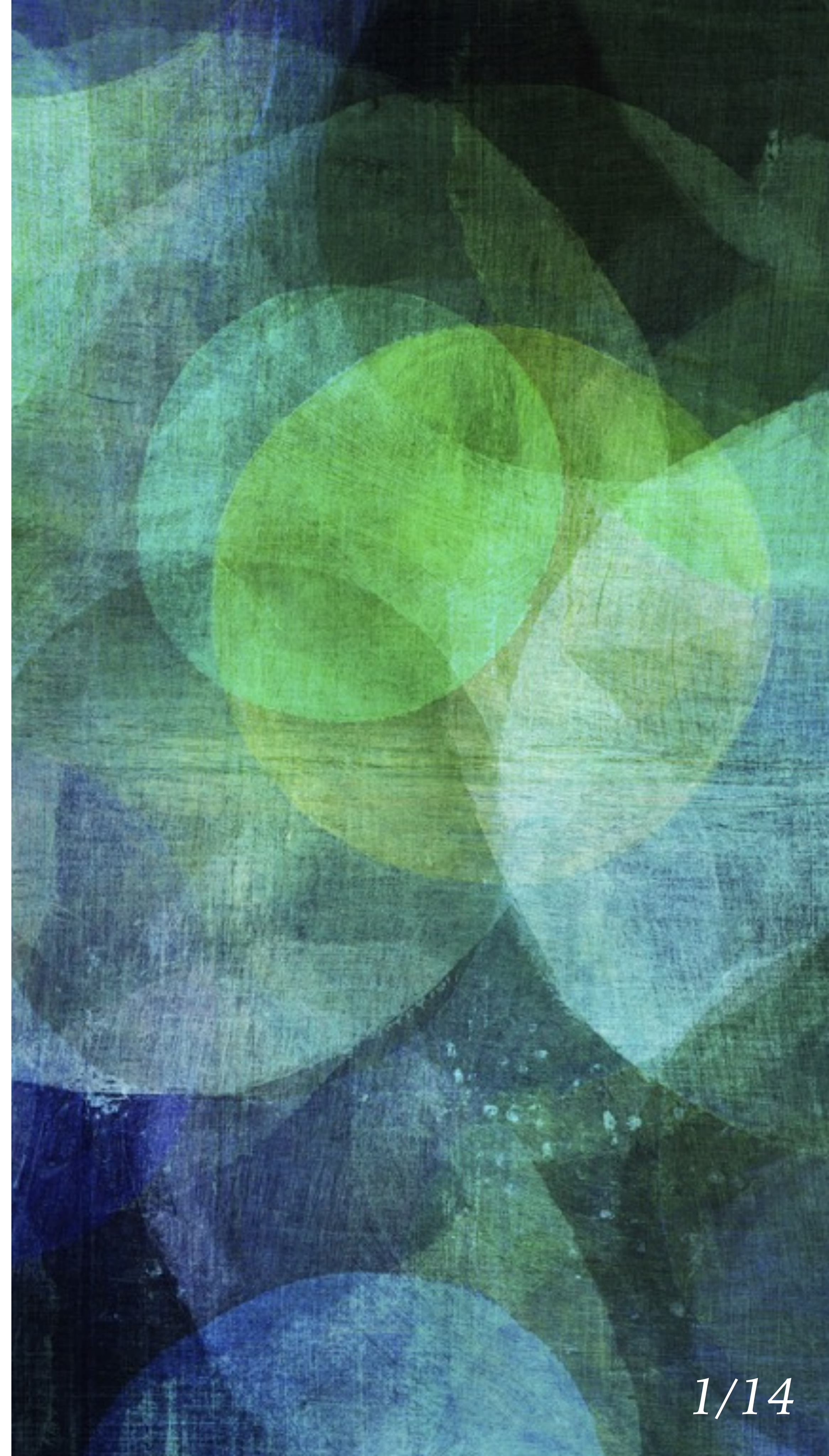
1216.02399 with R. Monten, and work in progress



INTRO AND MOTIVATION

- Black holes = thermodynamic ensembles
- Entropy explained in terms of microstates from string theory
- AdS black holes have a rich thermodynamics and are used to model phase transitions on the field theory side

Focus on black holes with embedding in M-theory: exact AdS/CFT dual.

These objects provide a good playground for the study of these two distinct, but interconnected aspects via holography.

$\mathcal{N}$=2 **gauged supergravity** in 4 dimensions is characterized by the presence of a scalar potential, allowing for susy AdS vacua and BPS black holes.

Example: **1/4 BPS static AdS black holes** Cacciatori and Klemm `09

- magnetic solutions, AdS2 x S2 near horizon geometry (T=0)
- no asymptotically flat counterpart
- static solution only in 4d. No static BPS black hole in 5d (Gutowski,Reall '04 have angular momentum)

Solutions embedded in M-theory on AdS4$\times$ S^7 and have field theory duals in the ABJM class Aharony, Bergman, Jafferis, Maldacena '08.

Benini, Hristov, Zaffaroni '15: use susy localization on S^2 x S^1 with one unit of magnetic flux on S^2. Computation of the twisted index which, at the critical point, reproduces the macroscopic BH entropy.

THERMAL BLACK HOLES

Solutions can moreover be generalized to non- BPS and thermal ones.

For sufficiently low charge, a phase transition arises between small and large black holes Hristov, CT, Vandoren '13. Similarity with the liquid-gas van der Waals system, Chamblin, Emparan, Johnson, Myers '99.

This talk:

Look for composite configurations in AdS spacetime: dual to ***holographic glass*** Anninos, Anous, Barandes, Denef, Gaasbeek, Peeters '11-'13

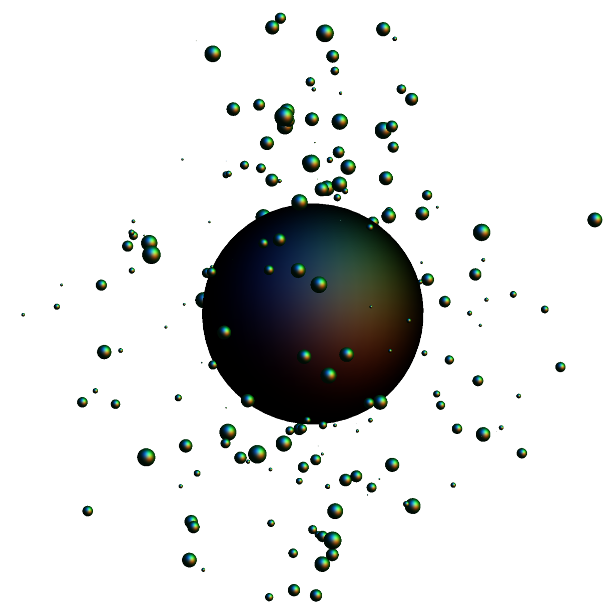
Glass is a peculiar state of matter: disordered like a liquid, rigid like a solid (supercooled liquid). Glass phase transition comes with a dramatic increase of viscosity, and is poorly understood. Glasses are metastable systems, exhibit aging behaviour and have an extremely rugged free energy landscape.

BLACK HOLE BOUND STATES

Disordered geometry, fragmented horizon arises upon cooling: vitrification

High T:

unique single center black hole = liquid



Low T:

zoo of multi center black holes = glass

Gravitational configuration is that of multi center AdS black holes.

Multi black hole geometries exist in flat spacetime Majumdar, Papapetrou '47, Denef '00. However in AdS spacetime are yet to be discovered (attempts in this direction in Chimento, Klemm '13 and Horowitz, Iqbal, Santos '14)

Probe analysis:

Stable and metastable probes exist in the background of a thermal dyonic AdS black hole with scalar profile (neutral scalars) Anninos, Anous, Denef, Peeters '13

In the AdS_4 compactification dual to ABJM theory, one linear combination of the gauge fields is Higgsed, thus massive Aharony, Bergman, Jafferis, Maldacena '08. Aim: study probe stability in a more general black hole background - charged scalars and massive vector field.

- DONE: *finding BH with massive vectors in $\mathcal{N}$=2 gauged supergravity*
- IN PROGRESS: *use it as the background solution and study of the probe stability*
- FUTURE: *characterize holographic glass*

THE MODEL: M111

Cassani, Koerber, Varela ‘12

M-theory truncation on homogeneous SE7 manifold with one Betti multiplet: gauged $\mathcal{N}$=2 supergravity with hypermultiplets, with fully susy AdS4 vacuum.

$$S = \int d^4x\sqrt{-g}\Big(\frac{R}{2} - g_{i\bar{\jmath}}\partial_\mu z^i \partial^\mu \bar{z}^{\bar{\jmath}} - h_{uv} D_\mu q^u D^\mu q^v + \\ + I_{\Lambda\Sigma} F^{\Lambda}_{\mu\nu} F^{\mu\nu,\Sigma} + \epsilon_{\mu\nu\rho\sigma} R_{\Lambda\Sigma} F^{\mu\nu,\Lambda} F^{\rho\sigma,\Sigma} - V\Big)$$

Gravity, two vector multiplets and universal hypermultiplet. Prepotential $F = -2i\sqrt{X^0 {X^1}^2 X^2}$. Gauging specified by

$$k^a_\Lambda = -\{e_0, 4, 2\} \qquad P^3_\Lambda = \{4 - \frac{1}{2}e^{2\phi}e_0, -2e^{2\phi}, -e^{2\phi}\}$$

$$Dq^u = dq^u + k^u_I A^I$$

Dual is a $\mathcal{N}$=2 Chern-Simons-matter theory studied in Benini, Closset, Cremonesi ’09 and Jafferis ‘09

In this model one of the vectors becomes massive via Higgs mechanism.

BPS black holes found in Petrini, Halmagyi, Zaffaroni '14 (Gauntlett,Donos '12): aim here to generalize to thermal solutions, T>0. Black holes correspond to M2 and M5 branes wrapping non-contractible cycles of the internal manifold

All hyperscalars except one are consistently set to zero. The scalar modes have masses $m^2 = (16, 10, 4, -2, -2)$ corresponding to $\Delta = (6, 5, 4, (2,1), (2,1))$.

The massive vector has $m^2 = 12$ hence $\Delta = 5$.

Fermions are electrically charged: **Dirac-like quantization condition** on the black hole magnetic charges

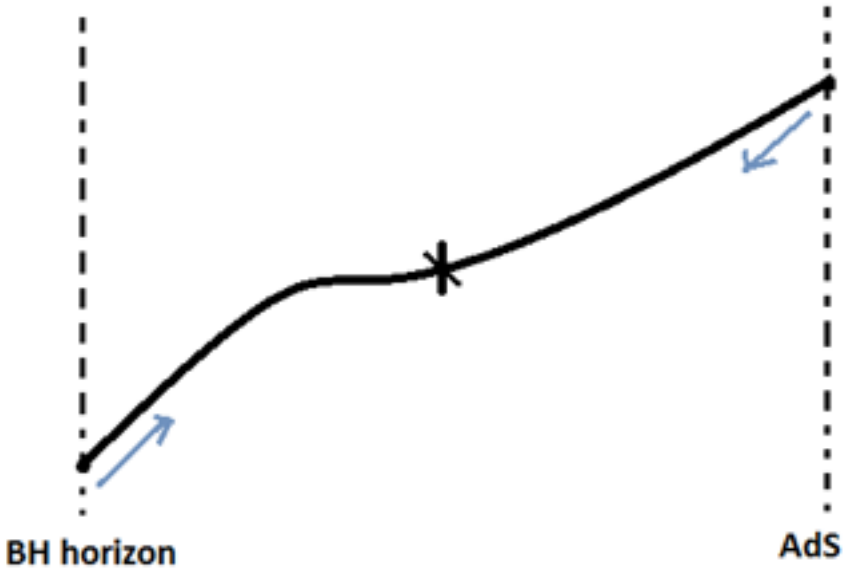
$$P^\Lambda P^3_\Lambda(\bar{u}) \in \mathbb{Z} \qquad\qquad P^\Lambda k^u_\Lambda(\bar{u}) \in \mathbb{Z}$$

Static and spherically symmetric ansatz:

$$ds^2 = -e^{-\beta} h(r) dt^2 + h(r)^{-1} dr^2 + r^2 (d\theta^2 + \sin^2\theta d\varphi^2)$$

$$\phi_I = \phi_I(r) \qquad\qquad A^\Lambda = \tilde{q}^\Lambda(r) dt - P^\Lambda \sin\theta d\phi$$

From Maxwell's equations: $P^\Lambda k_\Lambda^a = 0$. Massive vector is purely electric.

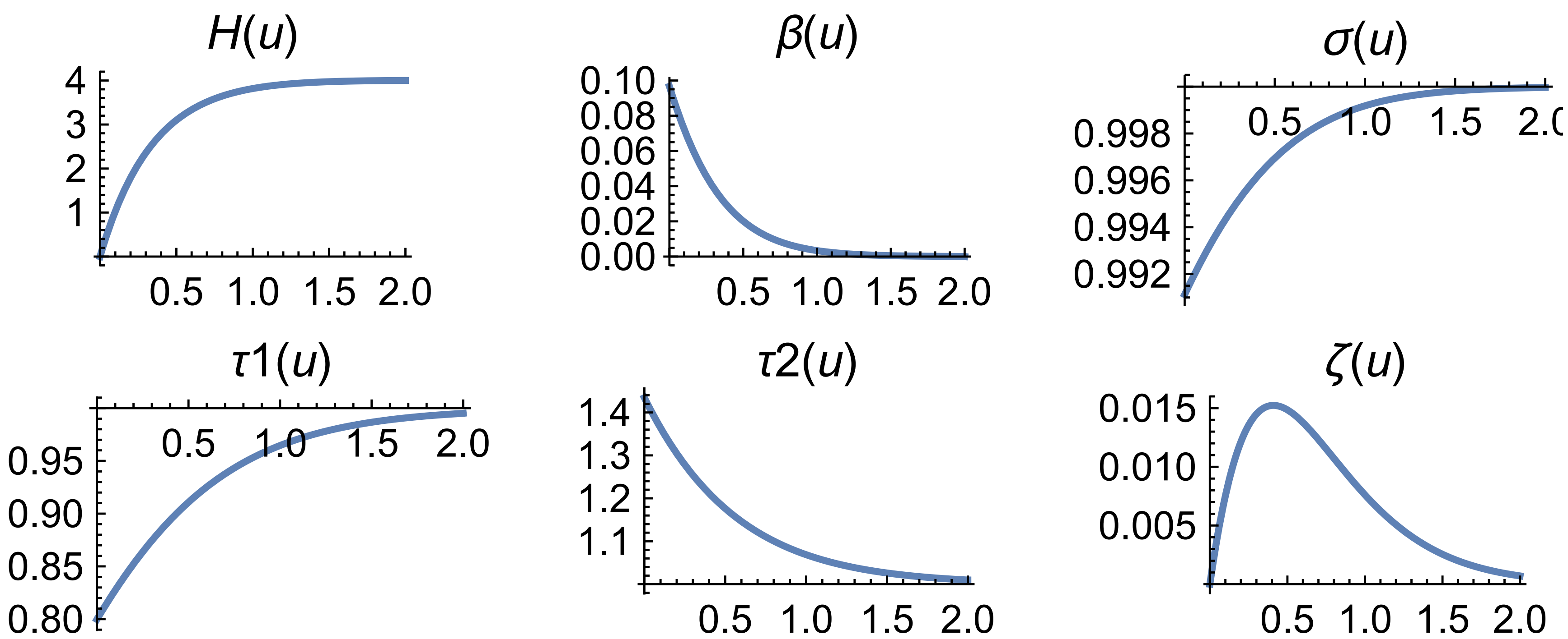


Expansion in series at the black hole horizon and at infinity. Demand to match in between!

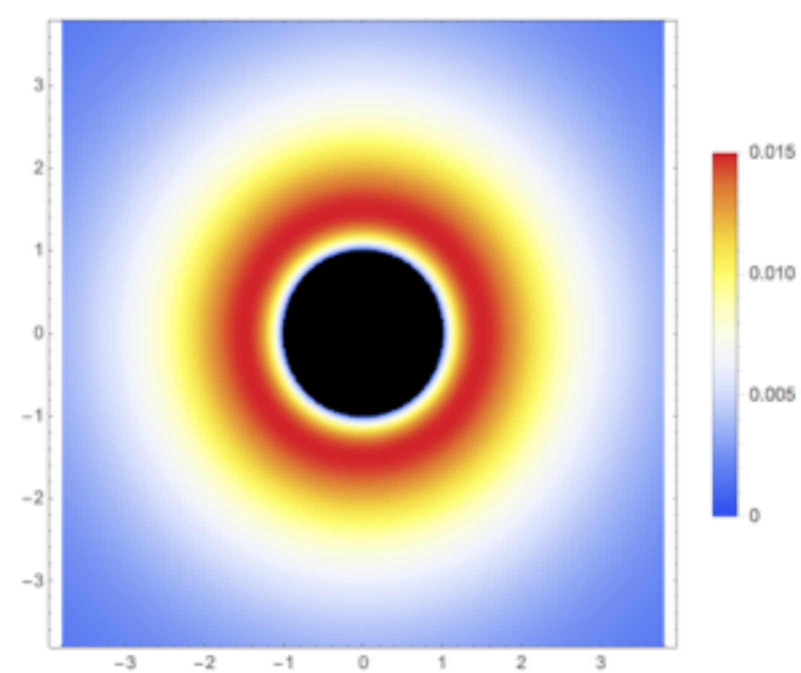
In total we have 14 first order ODEs

Solution is specified by 7 free parameters: $Q_\Lambda, P^\Lambda, r_h, \sigma_1, \eta_1$

Example of electric BH with massive vector and nontrivial scalar profile:



Black hole is surrounded by a massive vector "atmosphere", which hovers outside the black hole horizon



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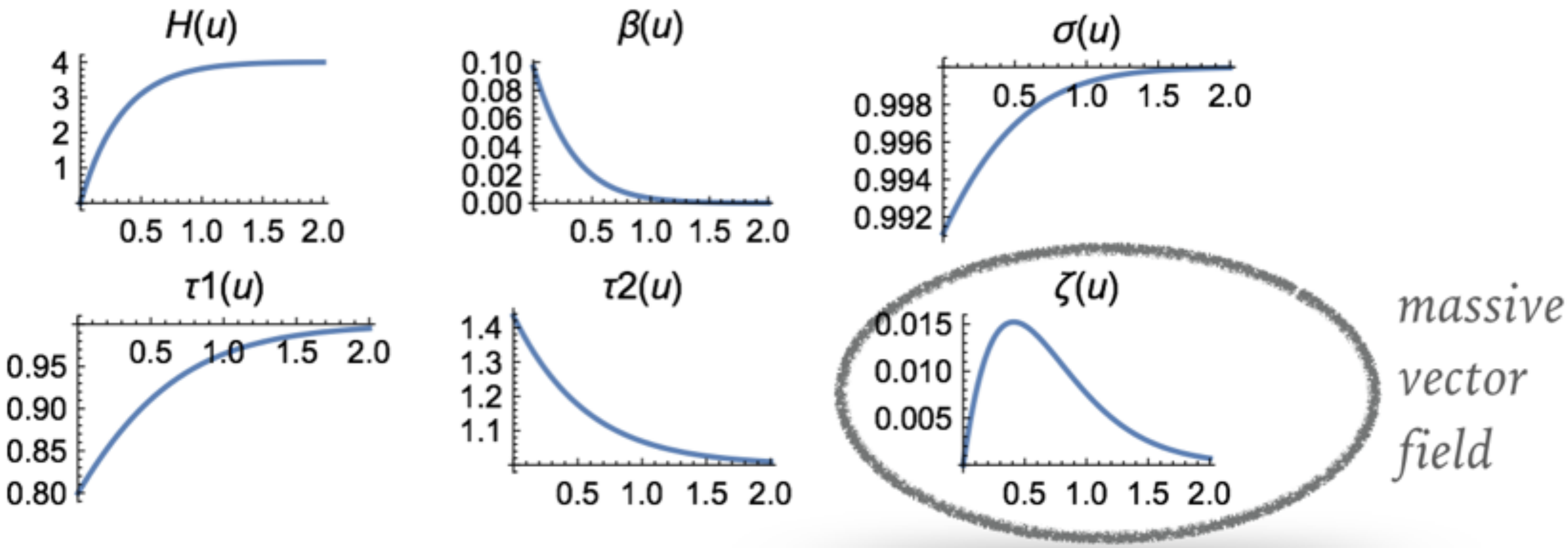
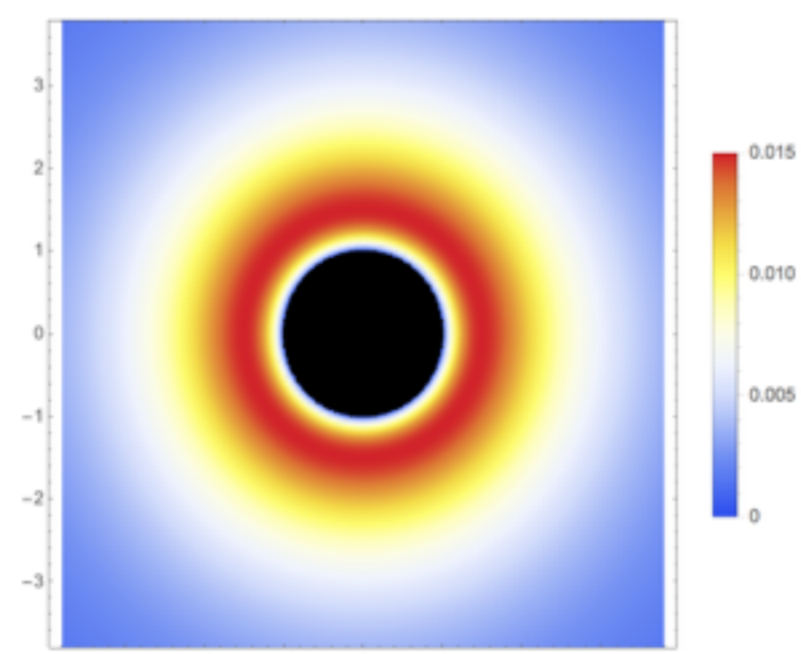


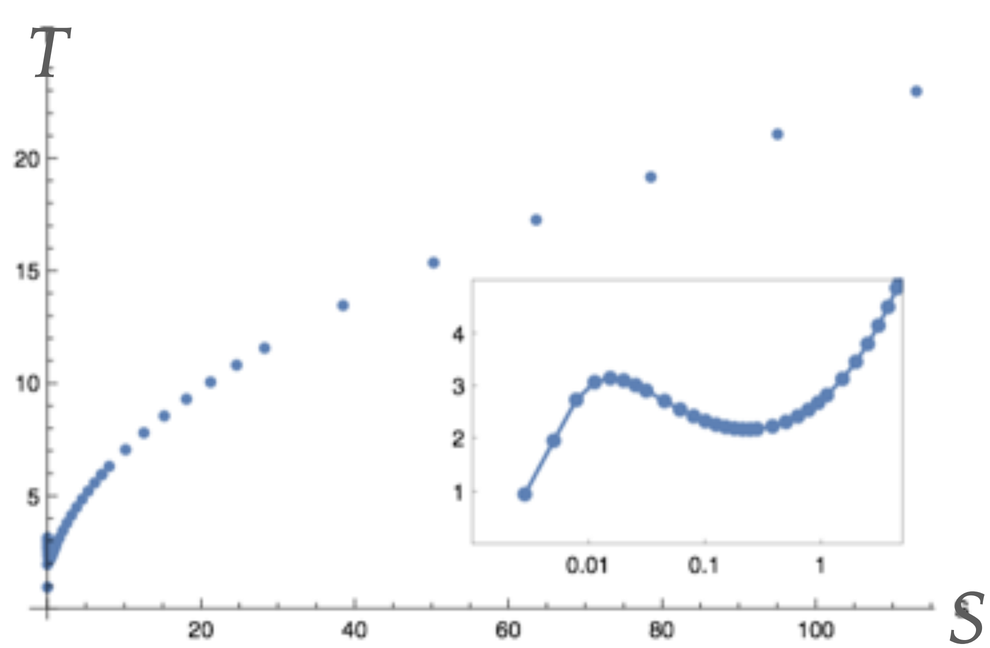


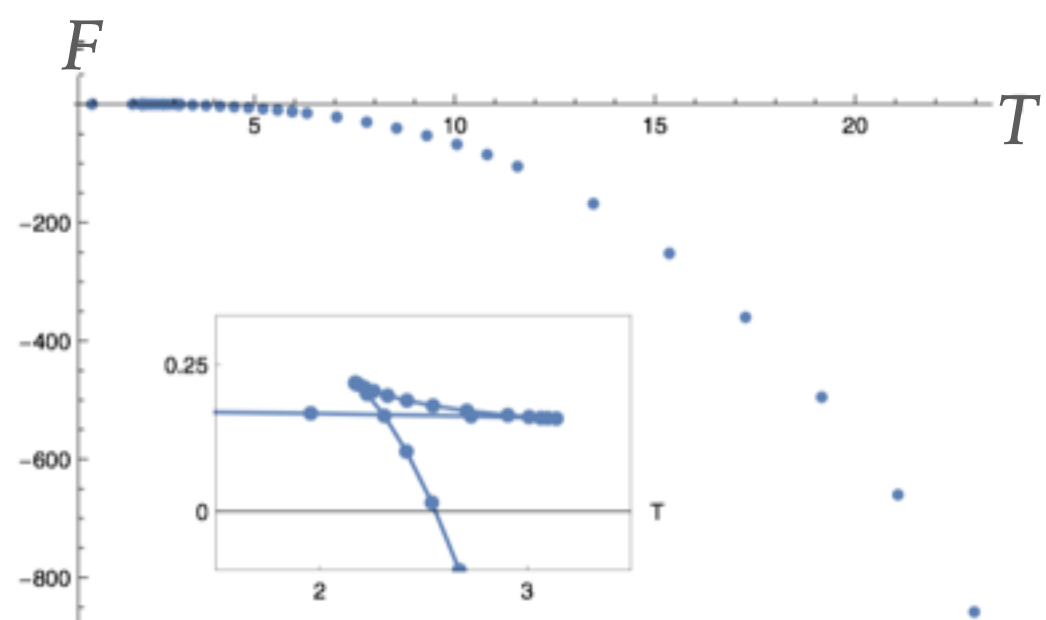
Black hole is surrounded by a massive vector "atmosphere", which hovers outside the black hole horizon

We verified that the first law is satisfied by the solutions, confirming the accuracy of the numerics.

$$dM = TdS + \phi^{\Lambda} dQ_{\Lambda} - \chi_{\Lambda} dP^{\Lambda}$$

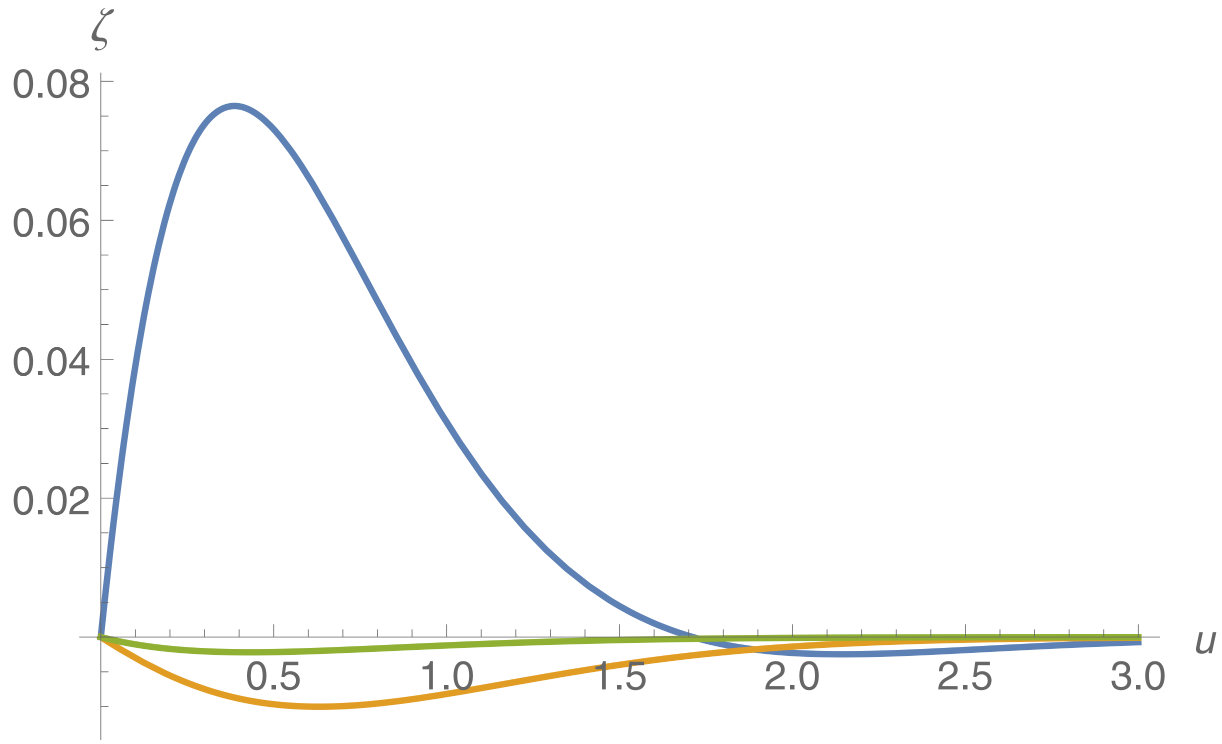
Computing free energy via holographic renormalization and study thermodynamics in the canonical ensemble. E.g. purely electric solution:





First order phase transition for Q< Qc $\simeq$ 0.17

The derivative of F has a discontinuity. First order phase transition between small and large black holes, similar to that found for RN AdS black holes Chamblin, Emparan, Johnson, Myers, ’99.

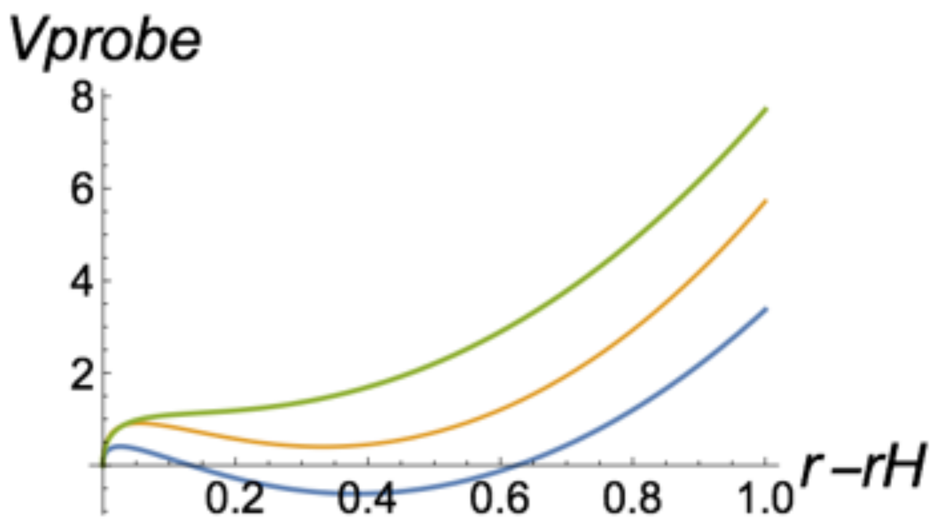


Radial profile for the massive vector field for small black holes, medium and large ones

The process involves two phases where the condensate is never vanishing, massive vector field is always switched on. No restoring of the broken symmetry for a finite temperature, as opposed to the holographic superconductor of Hartnoll, Herzog, Horowitz '08

Solutions found (stable branch) will be used as background for the probe analysis. Action for the probe: Anninos, Anous, Denef, Peeters '13

$$S = -\int m\ ds + \int (A^\Lambda Q_\Lambda - B_\Lambda P^\Lambda) d^4x \qquad m = |\mathcal{Z}(z, \mathcal{Q})| = |< \mathcal{Q}, \mathcal{V} >|$$



Vprobe is zero at the black hole horizon.

Unstable, stable and metastable probes

- Expectation: at high temperatures the single-center horizon will be thermodynamically favored (liquid phase), probe will enter the black hole
- Compare with the previous case of uncharged scalar. Effect of the interaction probes - condensate

CONCLUSIONS AND OUTLOOK

FI-gauged supergravity: analytic solutions, amenable to micro state counting

- BPS solution exist with nonzero entropy for models M^{111} and Q^{111}: microstates?

Solutions with hypermultiplets: equations more involved, but solutions can be found and they present interesting thermodynamics features

- Probe action, chart the parameter space of probe charges looking for stable and metastable probes
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THANKS FOR ATTENTION!