AdS_4 BLACK HOLES FROM M-THEORY

Inward bound - Conference on black holes and emergent spacetime, August 18th

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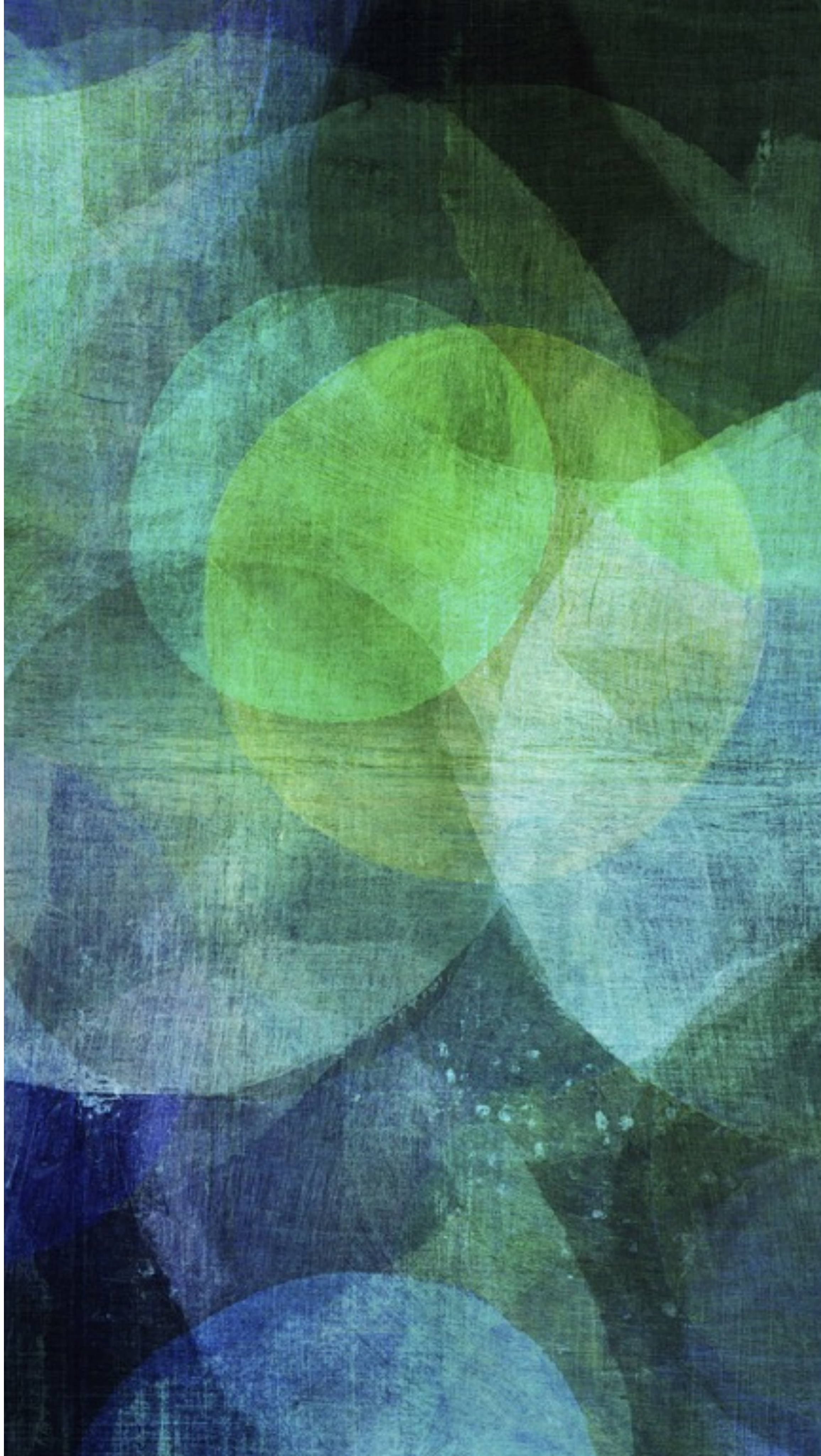
work in progress with R. Monten



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

Class of AdS black holes have comprehensive description of these features!

Focus on black holes with embedding in M-theory: exact holographic dual

$\mathcal{N}$=2 **gauged supergravity** in 4 dimensions

- scalar potential allows for susy AdS vacua and BPS black hole solutions
- first order equations and solution generating techniques from ungauged
- presence of matter, in particular scalar fields, is a prerequisite for the existence of certain solutions
- BPS multi center black hole studied in (ungauged) $\mathcal{N}$=**2**

OUTLINE OF THE TALK

- Brief overview of AdS4 black holes as solutions of Fayet-Iliopoulos (FI) gauged supergravity and their main features
    - Microstate counting
    - Thermodynamics and phase transitions
- Black hole bound states and holographic vitrification
- New thermal solution M111 model
- Probe analysis and discussion

SIMPLE EXAMPLE: U(1)-FI GAUGED SUPERGRAVITY

Gauging: potential for the scalars and electric charges for fermions

$$S = \int d^4x\sqrt{-g}\Big[\frac{1}{2}R - g_{i\bar{\jmath}}\partial_\mu z^i\partial^\mu\bar{z}^{\bar{\jmath}} + I_{\Lambda\Sigma}F^\Lambda_{\mu\nu}F^{\mu\nu,\Sigma}$$

$$+\frac{1}{2}R_{\Lambda\Sigma}\epsilon^{\mu\nu\rho\sigma}F^\Lambda_{\mu\nu}F^\Sigma_{\rho\sigma} - g^2V(\xi_{\Lambda,}z,\bar{z})\Big]$$

1/4 BPS static black holes by Cacciatori and Klemm `09

- nontrivial scalar profile and magnetic
- reduced amount of supersymmetry: previous Duff and Liu '99 electric 1/2 BPS are naked singularities

$$F = -2i\sqrt{X_0 X_1^3}, \quad n_V = 1:$$

$$ds^2 = -e^{\mathcal{K}}\left(gr + \frac{c}{gr}\right)^2 dt^2 + \frac{e^{-\mathcal{K}} dr^2}{\left(gr + \frac{c}{2gr}\right)^2} + e^{-\mathcal{K}} r^2 d\Omega^2$$

$$z = \frac{\xi_0}{\xi_1}\frac{3r + 3\xi_1 b_1}{r - 4\xi_1 b_1} \qquad F^{\Lambda}_{tr} = 0\,, \qquad F^{\Lambda}_{\theta\phi} = \frac{p^{\Lambda}}{2}\sin\theta$$

$$c = 1 - \frac{32(g\xi_1 b_1)^2}{3} \qquad p^1 = \pm\frac{2}{g\xi_1}\left(\frac{3}{8} - \frac{8(g\xi_1 b_1)^2}{3}\right) \qquad g\xi_{\Lambda}p^{\Lambda} = -1$$

- Solution exist with different topology of the event horizon
- Dyonic solutions as well! NH geometry is function of the gauging parameters and the black hole em charges Dall'Agata and Gnecchi, Hristov and Vandoren '10, Halmagyi '14

Solution is very peculiar to 4d: no static spherical BPS black holes in 5d.

ENTROPY MATCHING

Solutions can be embedded in M-theory compactified on AdS4$\times$ S^7 and will have field theory duals in the class of ABJM models.

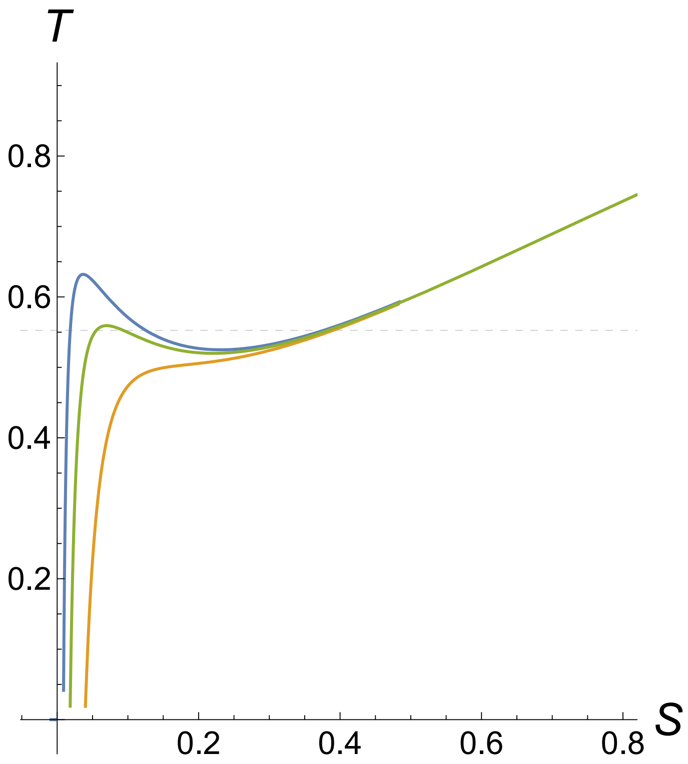
Benini, Hristov, Zaffaroni '15

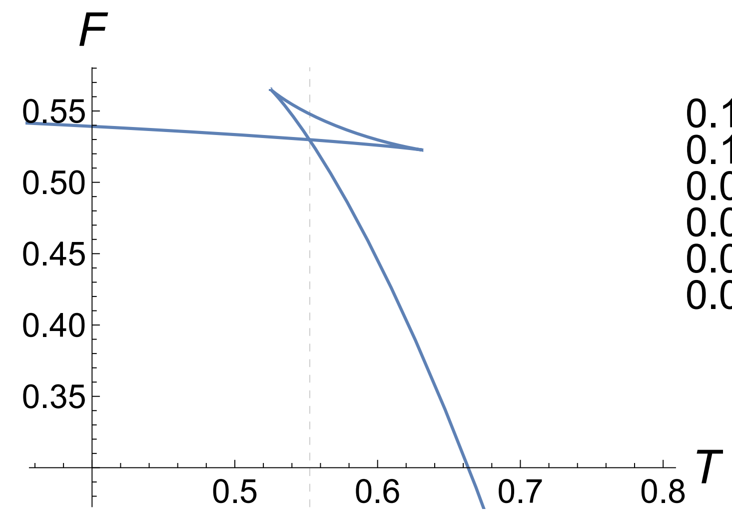
- computed large N limit of the topologically twisted index of ABJM theory, which counts states of the theory compactified on S^2 with magnetic flux
- **at the critical point, it coincides with the macroscopic entropy of the magnetic 1/4 BPS black hole!**

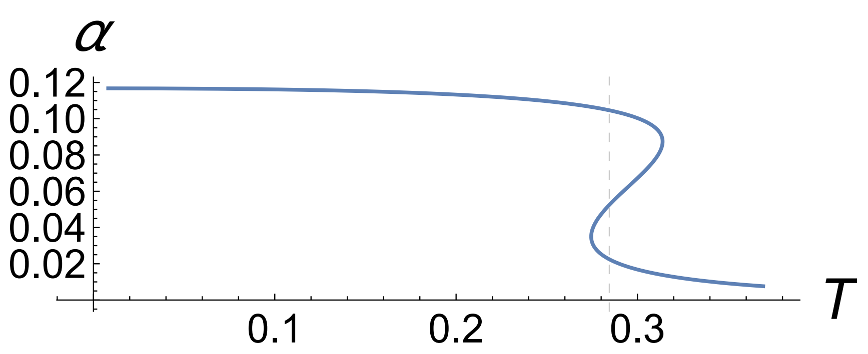
Solutions can furthermore be generalized to non- BPS and thermal ones…

THERMAL BLACK HOLES

- For sufficiently low charge, a phase transition arises between small and large black holes Hristov, CT, Vandoren ’13. Previous studies of stability in Cvetic, Gubser ‘99







Similarity with the liquid-gas van der Waals system, as noticed in Chamblin, Emparan, Johnson, Myers ’99 (*see the black hole chemistry talk*)

Thermal BH useful also for *holographic vitrification*

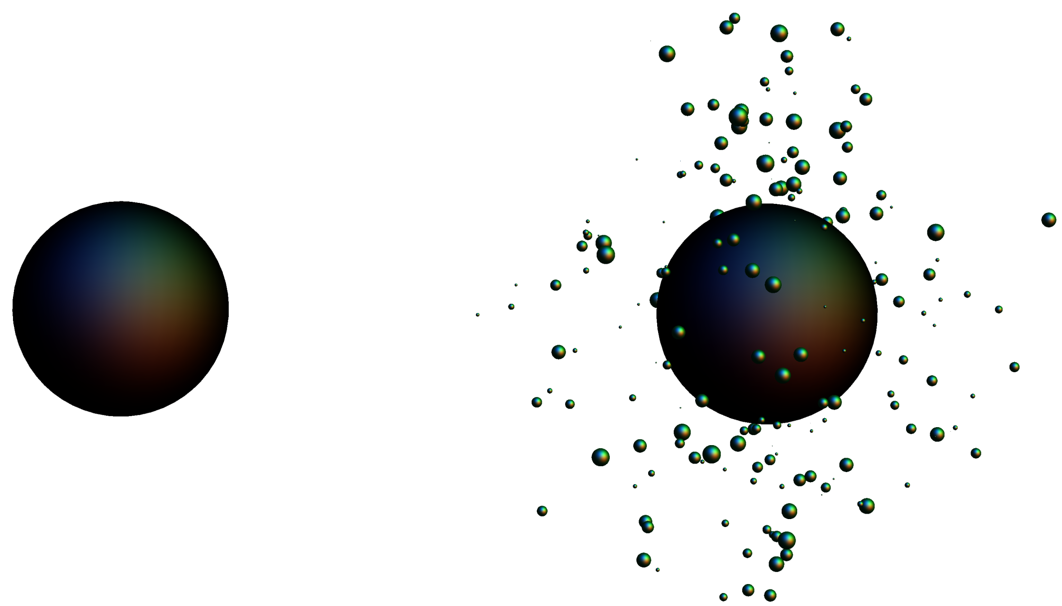
BLACK HOLE BOUND STATES

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

Glass: supercooled liquid. Liquid-glass phase transition is poorly understood

Holographic models can capture dynamical features not present in other models.

High T



Low T

Disordered geometry, fragmented horizon arises upon cooling: vitrification

Stable ad metastable probes exist in the background of a thermal dyonic AdS black hole of $\mathcal{N}$=2 FI-gauged supergravity, with scalar profile Anninos, Anous, Denef, Peeters '13

Exponentially slow relaxation: qualitative features of glass

- Backreaction? DIFFICULT. Multi center AdS black holes yet to be discovered (while they exist in flat space Majumdar, Papapetrou '47, Denef '99)
- In generic AdS_4 compactifications dual to ABJM theories, one linear combination of the gauge fields is Higgsed, thus massive

Aim: study probe stability in a more general black hole background - charged scalars and massive vector field. BPS solutions found in Petrini, Halmagyi, Zaffaroni '14

THE MODEL: M111

Cassani, Koerber, Varela '12

- M-theory truncation on homogeneous SE7 manifold with one Betti multiplet. Has $\mathcal{N}$=2 AdS4 vacuum.

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

Prepotential $F = -2i\sqrt{X^0 {X^1}^2 X^2}$. Gravity, two vector multiplets and universal hypermultiplet. 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 field theory was studied in Benini, Closset, Cremonesi '09, Jafferis '09

- ➤ one of the vectors becomes massive via Higgs mechanism.

BPS black holes found in Petrini, Halmagyi, Zaffaroni '14: aim here to generalize to thermal solutions.

All hyperscalars except one will be 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 $\Delta = 5$

Gravitini, gaugini and hyperscalars are electrically charged: **Dirac-like quantization condition** on the black hole magnetic charges

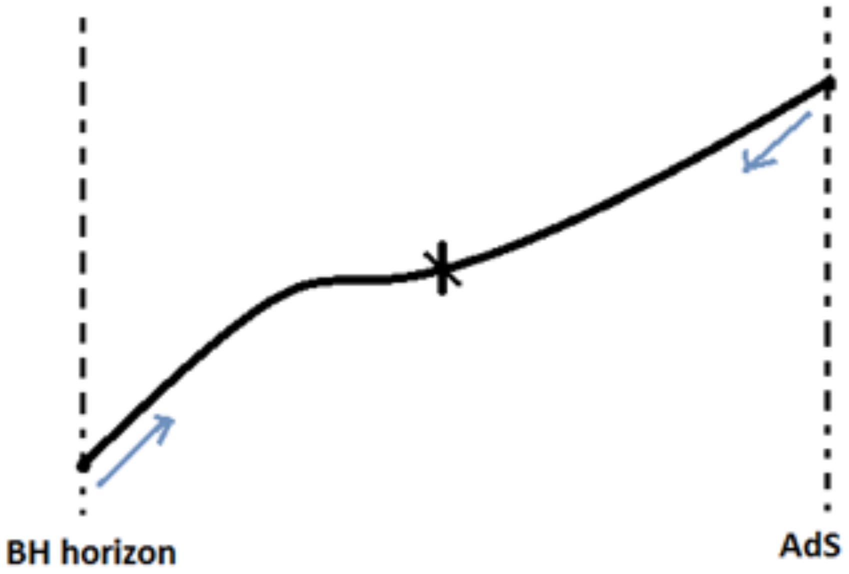
$$P^\Lambda P^3_\Lambda(\bar{u}) \in \mathbb{Z} \qquad\qquad P^\Lambda k^u_\Lambda(\bar{u}) \in \mathbb{Z}$$

Static and spherically symmetric ansatz:

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

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

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

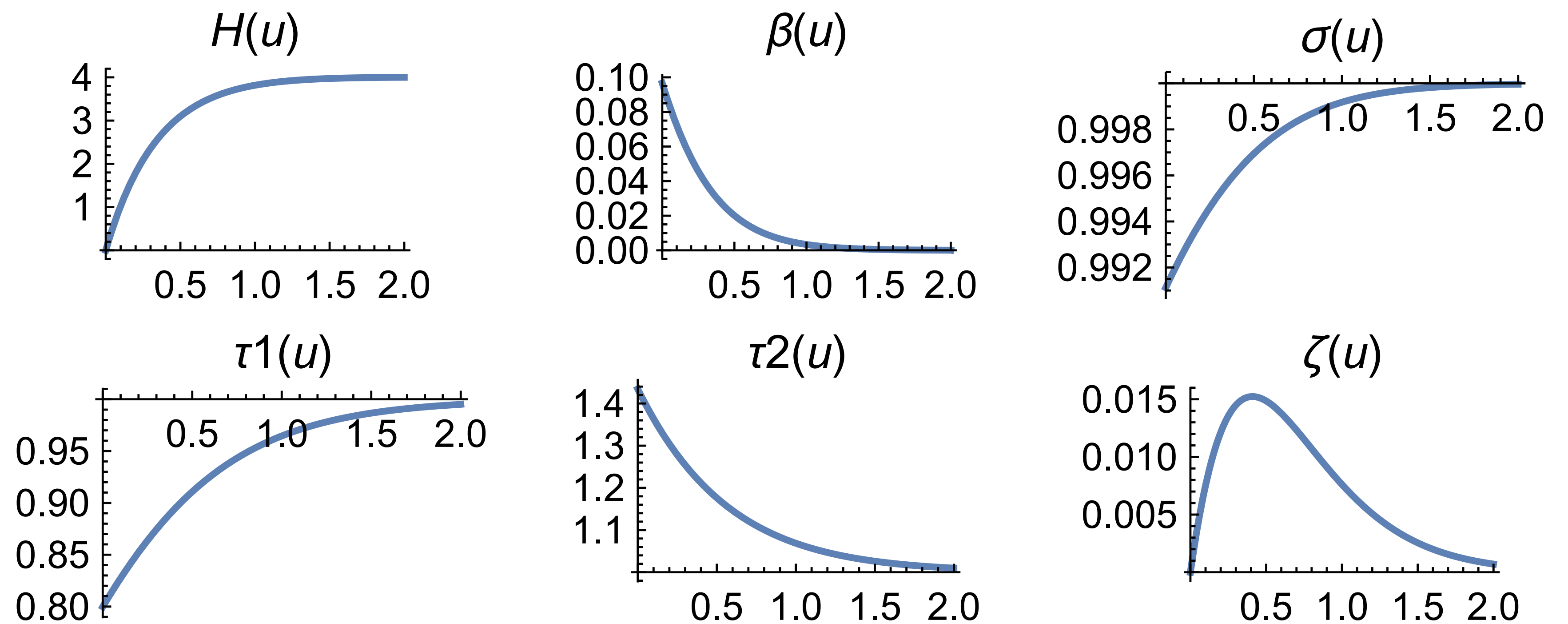


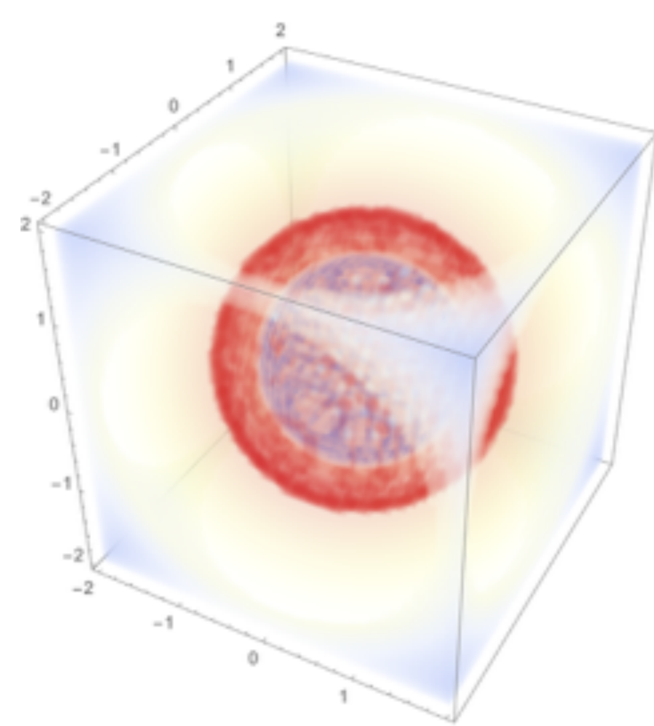
Expansion in series at the black hole horizon and at infinity. Demand to match in between!

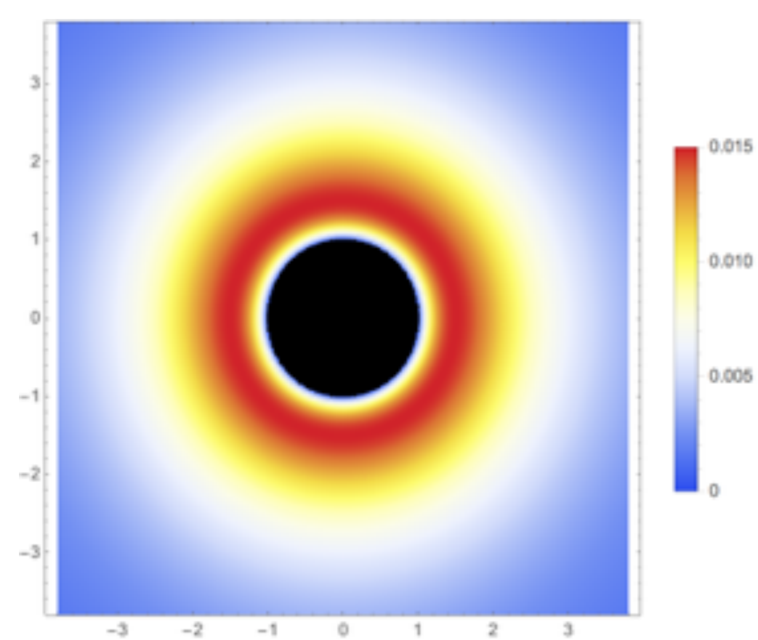
In total we have 14 first order ODEs

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:







Composite system, bound state:

Massive vector seen as an object hovering outside the black hole horizon

We verified that the first law of thermodynamics (keeping fixed $\sigma_1 = \eta_1 = 0$)

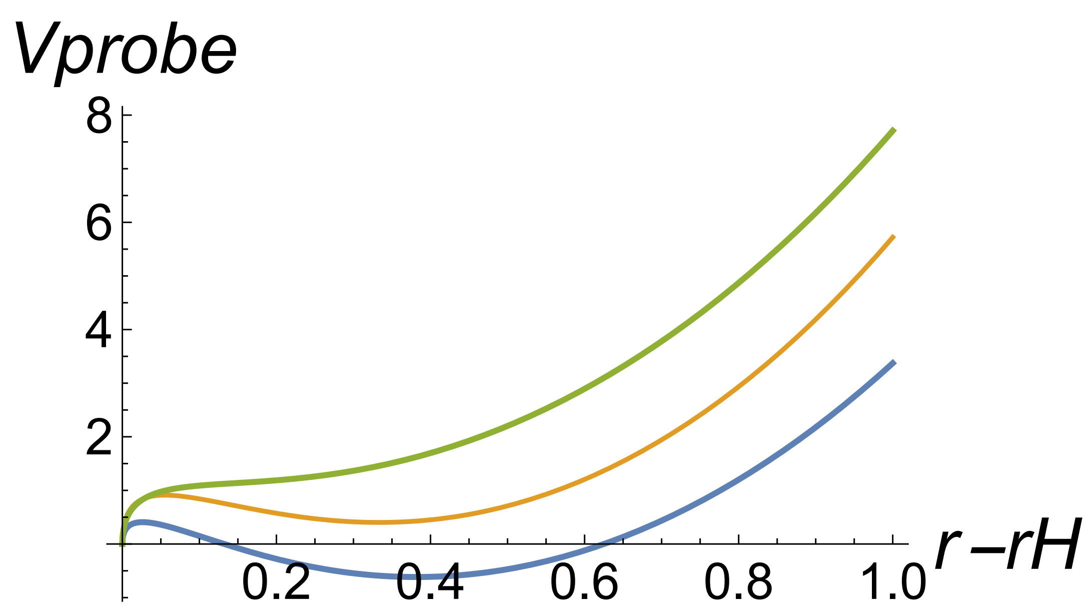
$$\delta M = T\delta S + \phi^\Lambda \delta Q_\Lambda - \chi_\Lambda \delta P^\Lambda$$

is satisfied by the solutions and this confirms accuracy of our numerical computations

- *variational principle and on shell action the background, via holographic renormalization*
- *background thermodynamics. We are able to find small - medium- large black holes. Phase transitions?*

Action for the probe: $$S = -\int m\ ds + \int (A^\Lambda Q_\Lambda - B_\Lambda P^\Lambda) d^4x$$

$$m = |\mathcal{Z}(z, \mathcal{Q})| = | < \mathcal{Q}, \mathcal{V} > |$$



- charting the parameter space of the probe charges
- Expectation: at high temperatures the probe will melt into the black hole
- compare with the previous case of uncharged scalar $\rightarrow$ effect of the interaction probes - condensate

THANKS FOR ATTENTION!