Anti-branes in the blackfold approach

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based on work (1812.01067, 1904.13283)
with **J. Armas, N. Nguyen, N.A. Obers, T. Van Riet**

De Sitter constructions in string theory
IPhT CEA/Saclay, December 9, 2019

Context and motivation for blackfolds

In String Theory the fundamental objects are strings and branes

We use them to:

- embed local QFTs
- to generate gravity

D-branes for example…

At weak coupling:

Open String Field Theory

UV

too complex,

hardly used

Dirac-Born-Infeld effective action

for long-wavelength modes

Main tools

Yang-Mills gauge theory

IR

…Tseytlin… ~1988

The DBI action

$$S = -T_p \int d^{p+1}\sigma \sqrt{-\det\left(\gamma_{ab} + F_{ab}\right)} \;+ \dots$$

is derived in open string theory as an effective theory of long-wavelength deformations around a homogeneous state *(planar branes in flat space)*

(Bosonic) modes:

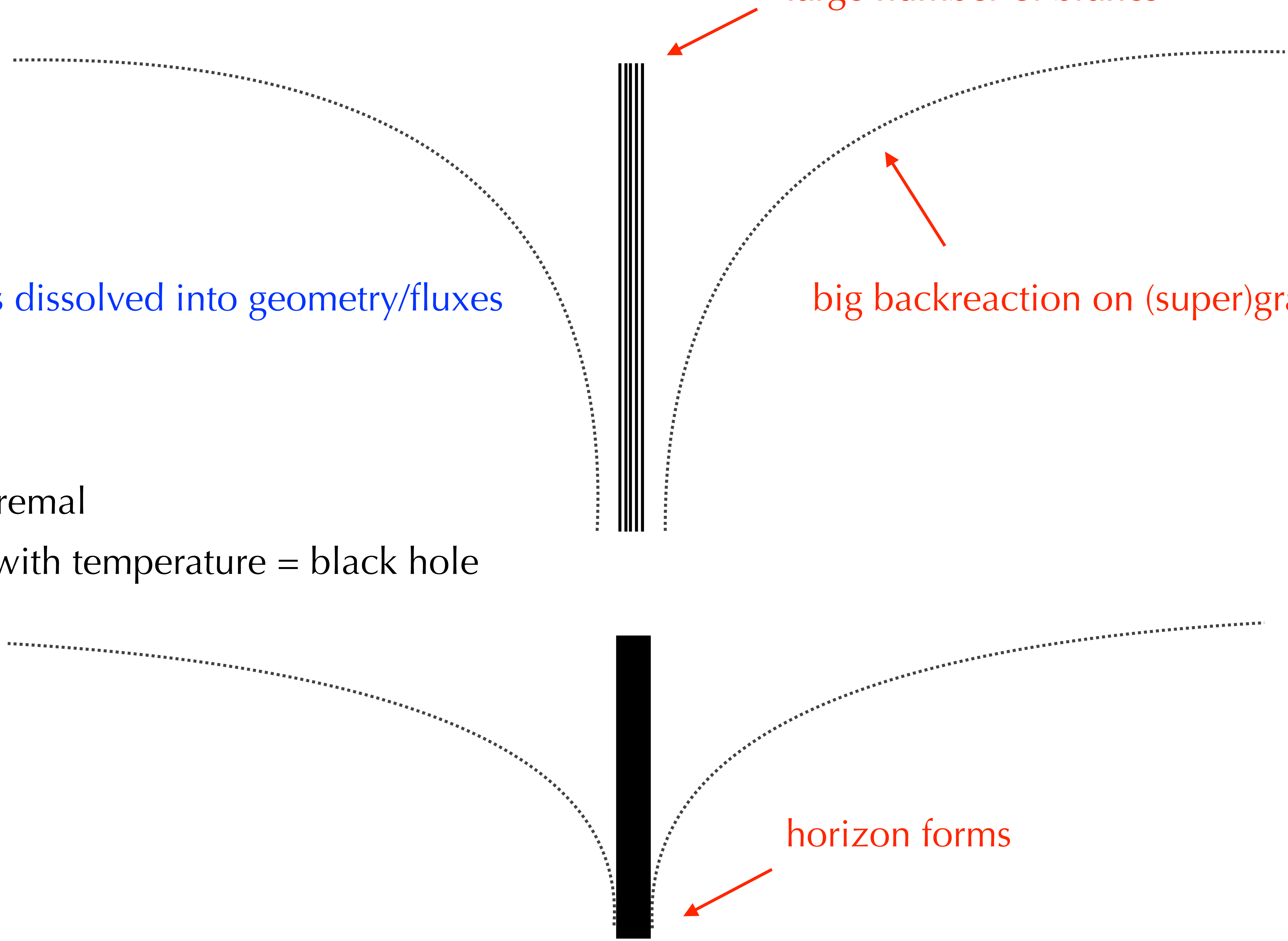
- transverse scalars $X^\mu \longrightarrow \gamma_{ab} = g_{\mu\nu}\partial_a X^\mu \partial_b X^\nu$
- gauge field $A_a \longrightarrow F_{ab} = \partial_a A_b - \partial_b A_a$

Strictly valid for arbitrarily high $F_{ab},\ \partial_a X^\mu$ but only small derivatives.

Yet, we are not afraid to extrapolate…

At strong coupling (on the branes)

large number of branes



Branes dissolved into geometry/fluxes

big backreaction on (super)gravity

extremal

or with temperature = black hole

horizon forms

Q: What is the strong-coupling version of the long-wavelength brane fluctuations (our main open string tool)?

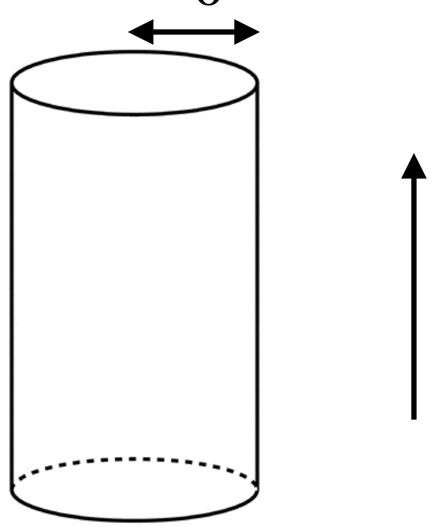
A: A theory of long-wavelength deformations of (black) p-brane solutions in (super)gravity **(BLACKFOLDS)**

Exact supergravity solutions are like the full open string field theory: complicated, limited, not always illuminating…

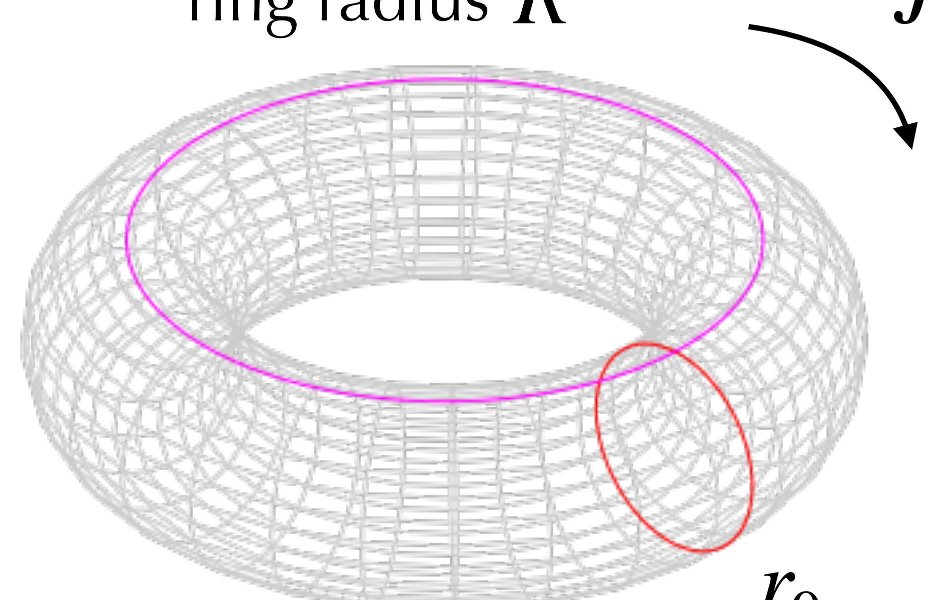
SUGRA long-wavelength theory is versatile, does well under extrapolations and captures a plethora of non-linear brane dynamics…

An example: black rings in pure Einstein gravity

- In 2001 Emparan & Reall discovered an exact spinning black ring solution in 5d GR: horizon topology $S^2 \times S^1$
- All attempts to find analytic black ring solutions in d>5 have failed!
- **Blackfold approach: do it like the DBI…**



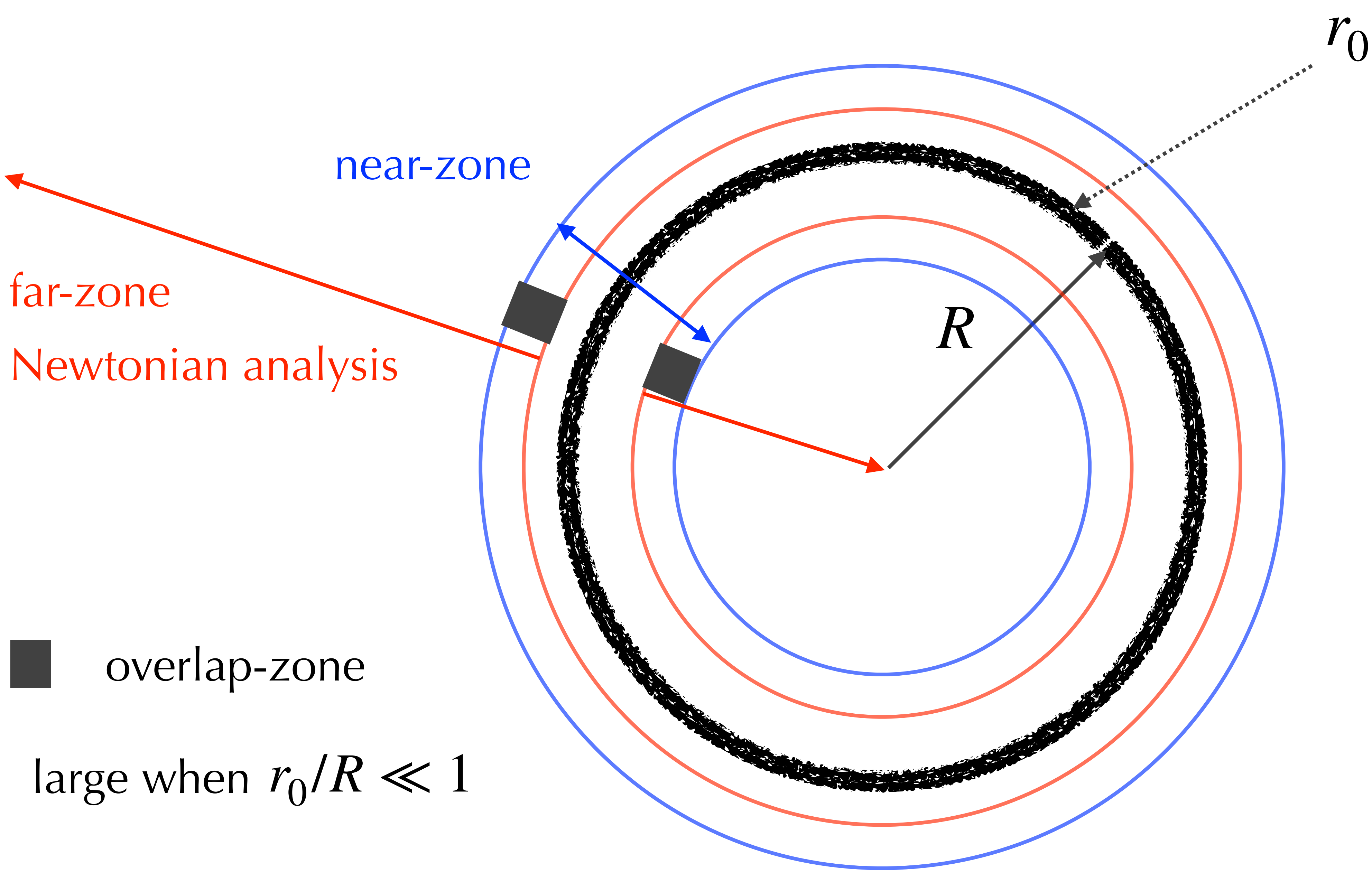
horizon $S^2 \times \mathbb{R}$



horizon $S^2 \times S^1$

Matched asymptotic expansion

Regime: thin black ring $r_0/R \ll 1$, ultra spinning regime



In the near-zone the metric is a deformation of the boosted black string with slowly varying parameters

$$ds^2_{(\text{short})} = \left(\gamma_{ab}(\sigma) + \frac{r_0^n(\sigma)}{r^n} u_a(\sigma) u_b(\sigma)\right) d\sigma^a d\sigma^b + \frac{dr^2}{1 - \frac{r_0^n(\sigma)}{r^n}} + r^2 d\Omega^2_{n+1} + \dots .$$

$\gamma_{ab} = \eta_{\mu\nu} \partial_a X^\mu \partial_b X^\nu$ induced metric on 1+1-dimensional ring worldvolume

u^a worldvolume velocities expressing the boost/angular momentum

The matched asymptotic expansion yields a solution with regular horizon if and only if one satisfies a set of effective equations in (1+1)-spacetime dimensions

Emparan-Harmark-VN-Obers-Rodriguez 2007

Leading order effective theory on a string worldvolume

extrinsic curvature tensor

$$\nabla_a T^{ab} = 0 \ , \quad K_{ab}{}^{\rho} T^{ab} = 0 \ , \quad a, b = 0,1$$

black ring: critical boost

$$T^{ab} = (\varepsilon + P) u^a u^b + P \gamma^{ab}$$

$$T_{zz} = 0 \ \Rightarrow \ R = \frac{n+2}{\sqrt{n+1}} \frac{J}{M}$$

$$n = D - 4 \qquad \varepsilon = \frac{\Omega_{n+1}}{16\pi G}(n+1) r_0^n \ , \quad P = -\frac{1}{n+1}\varepsilon$$

Perfect fluid dynamics on dynamical string worldvolume!

(equation of state fixed by thermodynamics of black string)

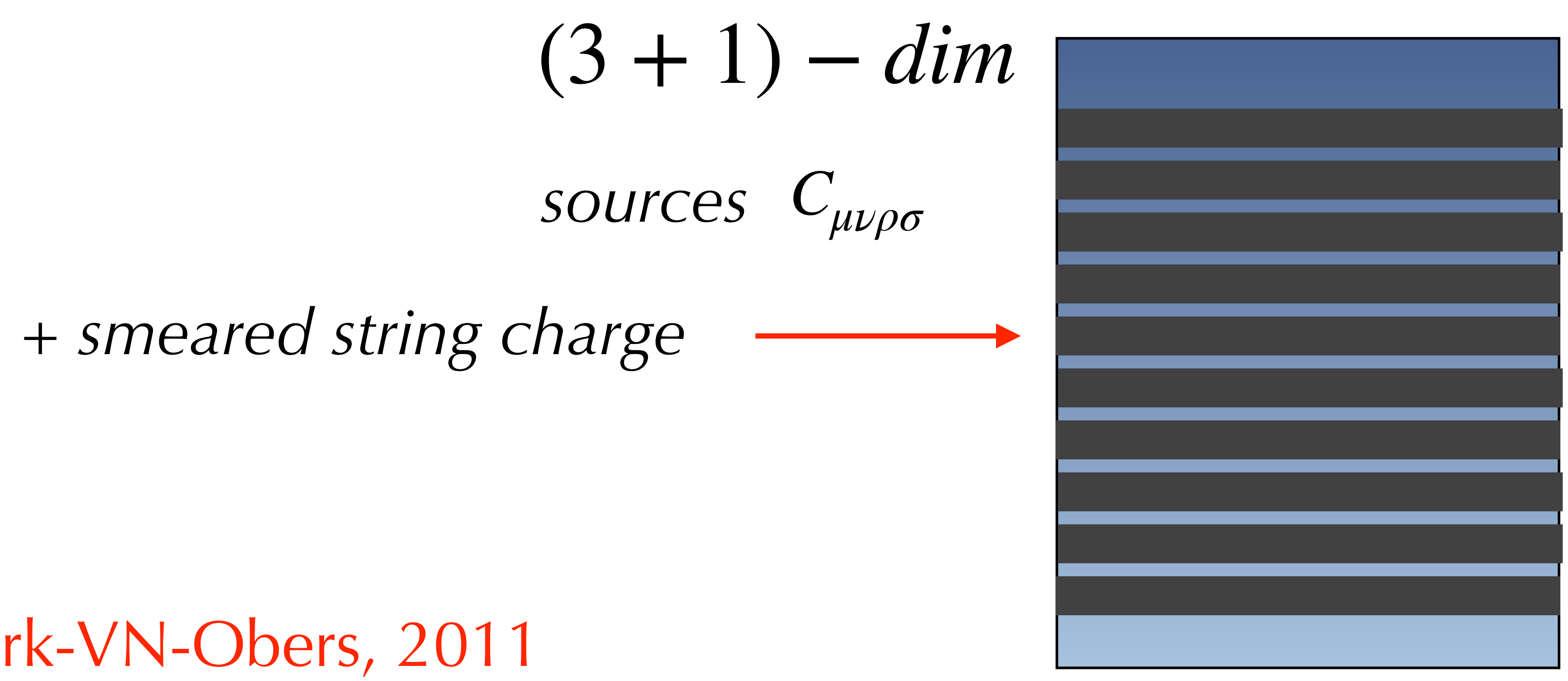
Key points:

- This relation is generic: the long-wavelength dynamics of black branes is hydrodynamics **(fluids on dynamical hypersurfaces)**

- Leading-order hydro determines thermodynamics of 1st-order deformed gravity solution.
  Conjecture: solution of fluid eqs guarantees regular black hole solution (proven at leading order for Einstein gravity by Emparan-Camps 2012)

- Higher-order derivative corrections of fluid dynamics from higher order matched asymptotic expansions

- Can add (higher-form) charges, analyse charged black holes
  → anisotropic higher-form hydrodynamics



Emparan-Harmark-VN-Obers, 2011

- In curved backgrounds: fluid interacts with curvature, fluxes
  forced blackfolds

Armas-Gath-VN-Obers-Pedersen, 2016

- **Extremal blackfolds**

  In supergravity/string theory the leading order hydro is the abelian DBI!

  (SUGRA-DBI correspondence derived, no SUSY required!!)

  Abelian open string gauge fields are recovered from SUGRA

VN, 2015

Grignani-Harmark-Marini-Orselli, 2016

- The leading-order expansions are surprisingly accurate!

from Camps-Emparan-Haddad, 2010

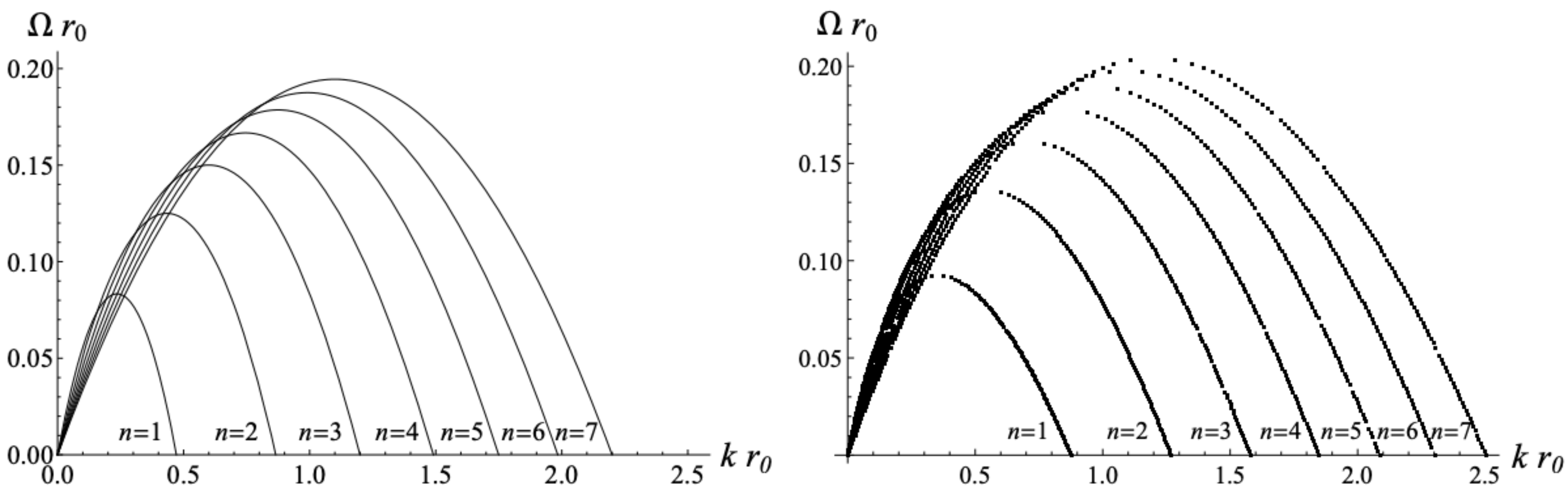


Figure 1: Left: dispersion relation $\Omega(k)$, eq. (1.5), for unstable sound waves in the effective black brane fluid (normalized relative to the thickness r_0). Right: $\Omega(k)$ for the unstable Gregory-Laflamme mode for black branes (numerical data courtesy of P. Figueras). For black p-branes in D spacetime dimensions, the curves depend only on $n = D - p - 3$.

from Armas-Parisini, 2019

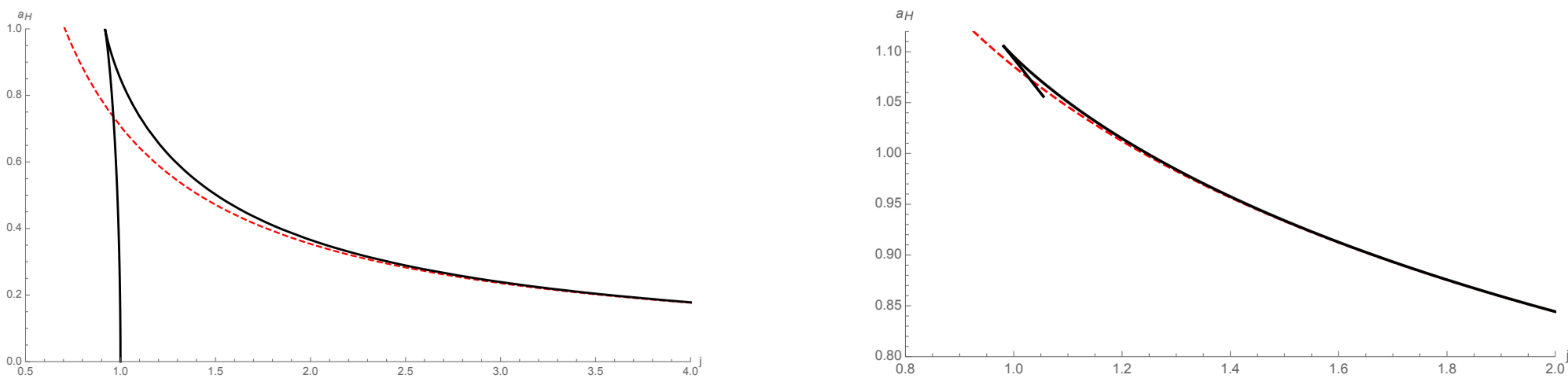


Figure 1: On the left we show the reduced area $a_{\rm H}$ as a function of the reduced angular momentum j for $D = 5$ where the black line is the exact curve of the black ring solution [27] and the dashed red curve is the blackfold approximation up to first order in derivatives [28]. On the right we show the behaviour of the same quantities for black rings in $D = 7$ where the black line is the numerical solution of [29] and the dashed red line the blackfold approximation up to second order in derivatives [30].

7D black ring from numerics

Dias-Santos-Way, 2014

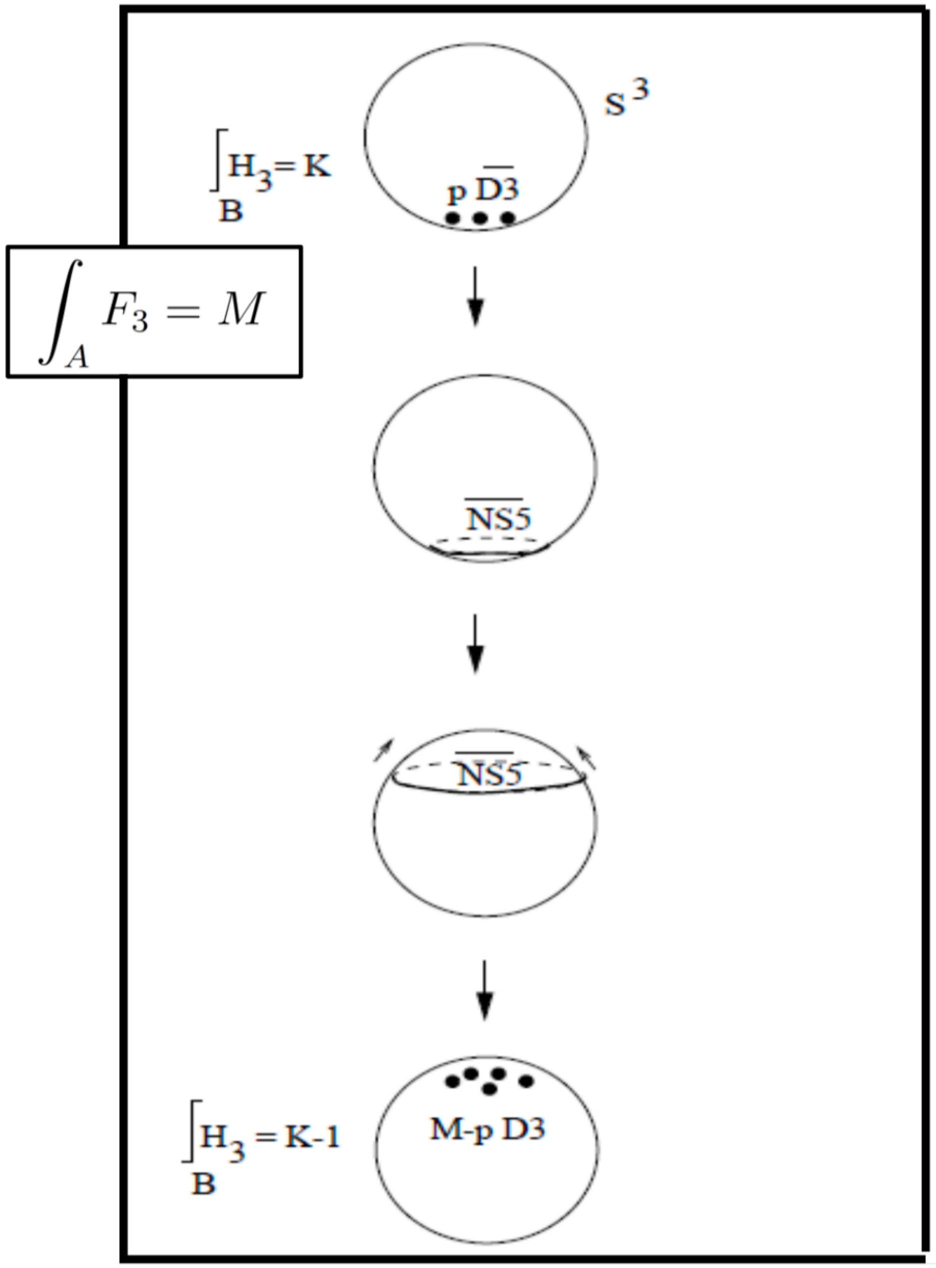
SUSY breaking BLACKFOLDS

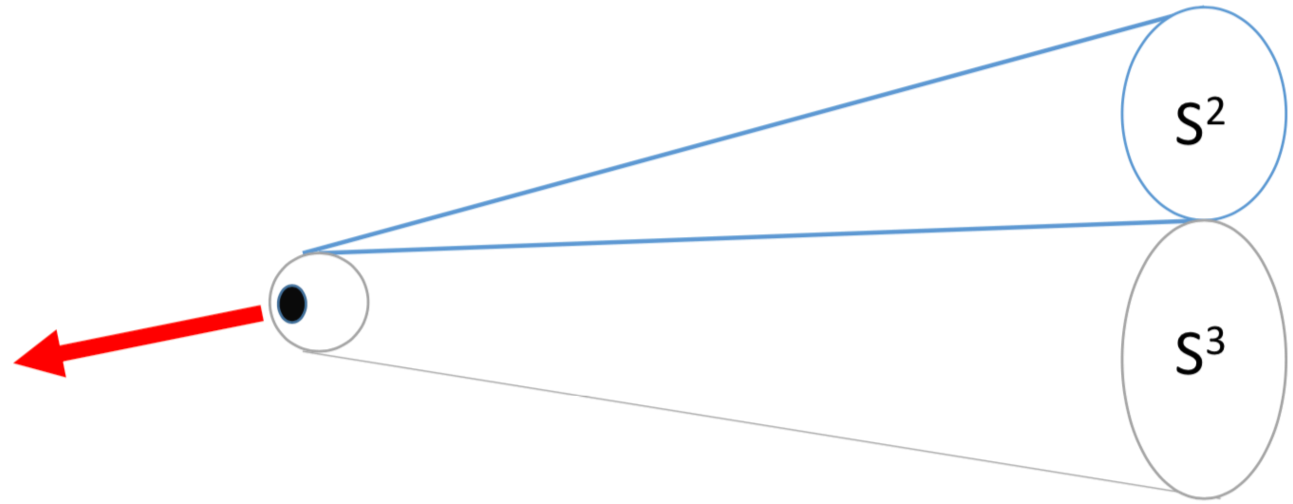
the KPV state in supergravity

Phys.Rev.Lett. 122 (2019) no.18, 181601, arXiv:1812.01067

J. Armas, N. Nguyen, VN, N.A. Obers, T. Van Riet

Kachru, Pearson, Verlinde (KPV) 2001



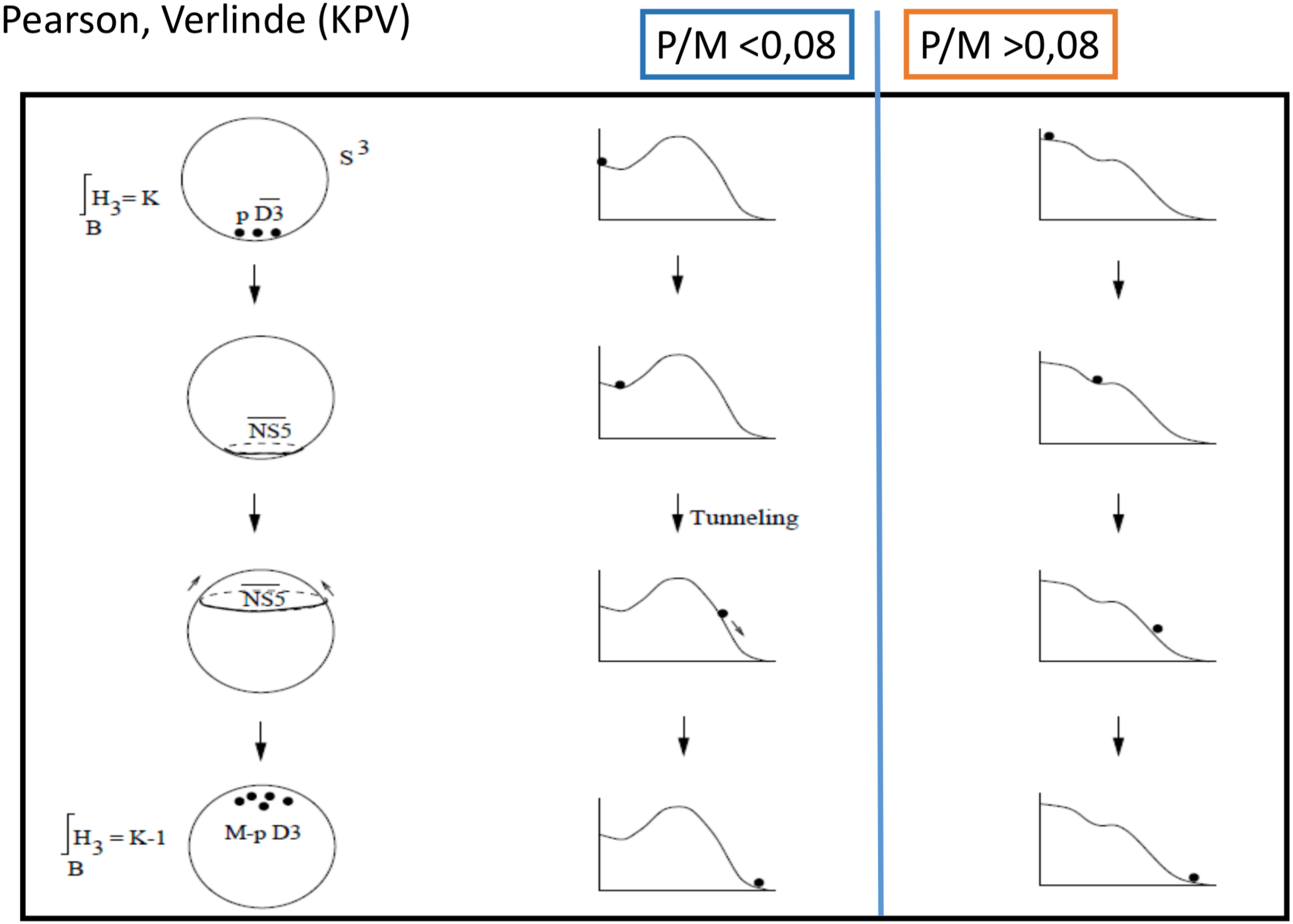


Holographic dual to dynamical SUSY breaking in the Klebanov Strassler gauge theory

- Locally confined backreaction if :

$$p/M << 1$$

Kachru, Pearson, Verlinde (KPV)



- KPV results obtained with a probe (DBI) computation. NS5 probe action from S-dual of D5 DBI.

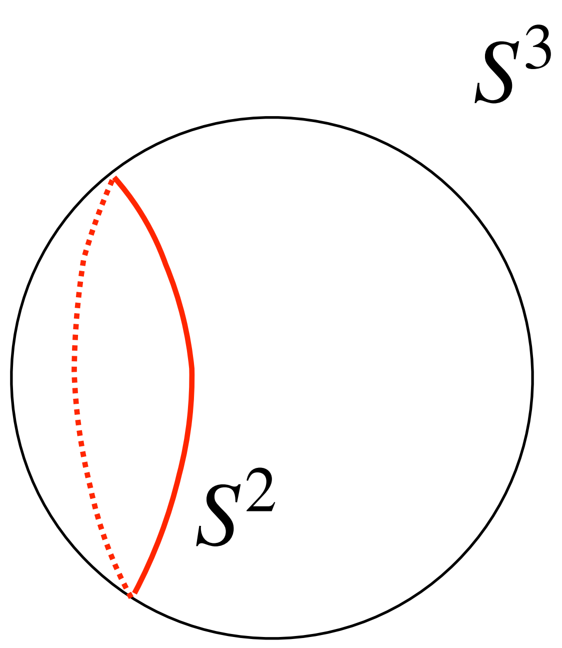
- The backreaction of the anti-brane probes was criticised. All attempted gravity solutions exhibited **unphysical singularities!**

Bena-Grana-Halmagyi, 2009

……

- Ansatz in supergravity described localised 3-branes

  The solution of 5-branes wrapping a 2-sphere was very hard to construct!!



- No-go theorems of **Maldonado-Diaz-VanRiet-Vercnocke** (2015):

- localised extremal 3-brane solutions do not exist

horizon topology

$$\mathbb{R}^3 \times S^5$$

- localised black 3-brane solutions may exist, but require special boundary conditions on the horizon

- wrapped extremal and non-extremal 5-brane solutions are allowed

horizon topology

$$\mathbb{R}^3 \times S^3 \times S^2$$

Running with blackfolds

- Hydro blackfold eqs are necessary conditions

  (determine the thermodynamic features of 1st order perturbative SUGRA solution)

- Full 1st order MAE is not yet available (in progress)

  (would demonstrate that blackfold eqs are also sufficient conditions)

- For the 5-brane solutions of interest we should study long-wavelength deformations of the D3-NS5 bound state

From type IIB SUGRA we obtain for D3-NS5

$$T_{ab} = \mathcal{C}\Big[r_0^2\left(u_a u_b - \frac{1}{2}\gamma_{ab}\right) - r_0^2 \sin^2\theta\, \sinh^2\alpha\, \hat{h}_{ab}$$
$$- r_0^2 \cos^2\theta\, \sinh^2\alpha\, \gamma_{ab}\Big]\ ,$$

$$J_2 = \mathcal{C} r_0^2 \sinh^2\alpha\, \sin\theta\cos\theta\, v\wedge w\ ,$$
$$J_4 = \mathcal{C} r_0^2 \sinh\alpha\cosh\alpha\sin\theta\, *(v\wedge w)\ ,$$
$$\mathrm{j}_6 = \mathcal{C} r_0^2 \sinh\alpha\cosh\alpha\cos\theta\, *1\ ,$$

$$\nabla_a T^{a\mu} = \frac{g_s^{-1}}{6!} H_7^{\mu a_1\cdots a_6}\mathrm{j}_{6a_1\cdots a_6} + \frac{1}{2!}F_3^{\mu a_1 a_2} J_{2a_1a_2}$$
$$+\frac{3}{4!}H_3^{\mu a_1 a_2} C_2^{a_3 a_4} J_{4a_1\cdots a_4}\ ,$$
$$d\star J_2 + H_3\wedge\star J_4 = 0\ ,$$
$$d\star J_4 - \star\mathrm{j}_6\wedge F_3 = 0\ ,\quad d\star\mathrm{j}_6 = 0\ .$$

Extremal solutions: we recover the KPV solution and the effective potential of the S-dual D5 DBI

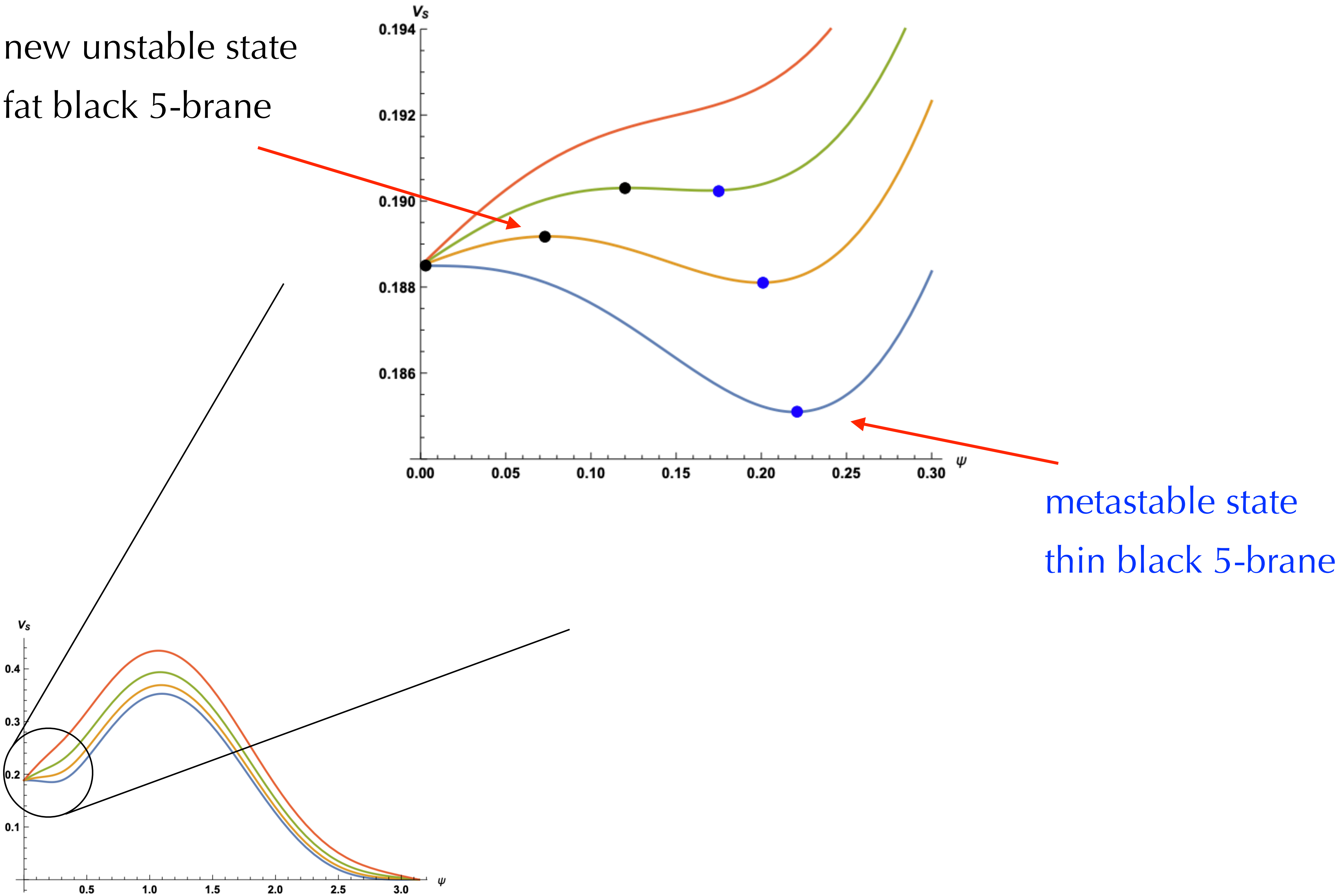
META-STABLE

HEAT UP

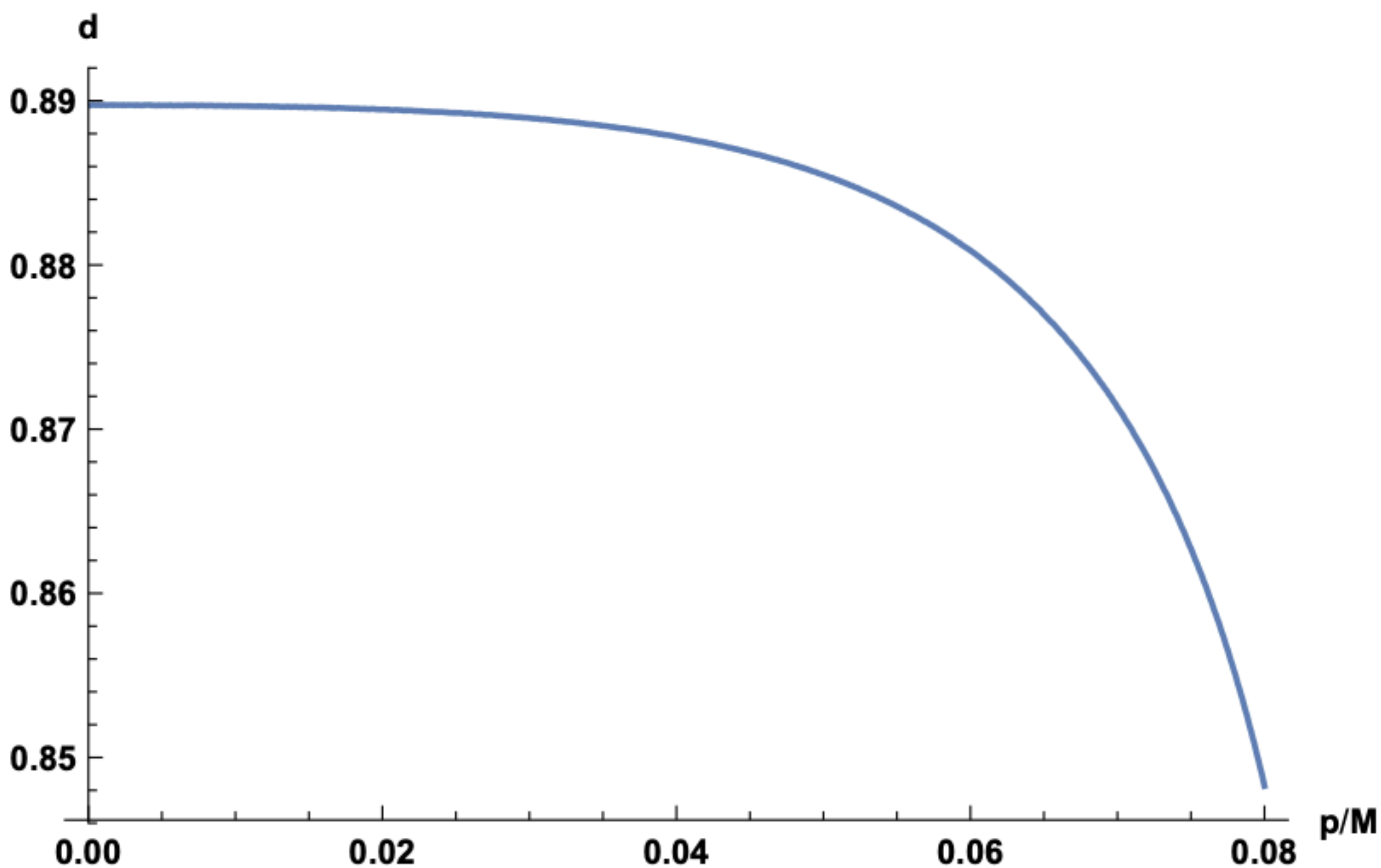
UNSTABLE

At finite-T a transition is expected, but how it happens is unclear without computation

Fixed anti-brane charge



Ratio $d \sim \frac{r_{black-hole}}{R_{S^2}}$ at the transition point is essentially independent of the anti-brane charge



SUSY breaking BLACKFOLDS

anti-M2 branes in CGLP

(Cvetic-Gibbons-Lu-Pope ’00)

JHEP 1908 (2019) 128, arXiv:1904.13283

J. Armas, N. Nguyen, VN, N.A. Obers

- Studied in the probe approximation by **Klebanov-Pufu '10**

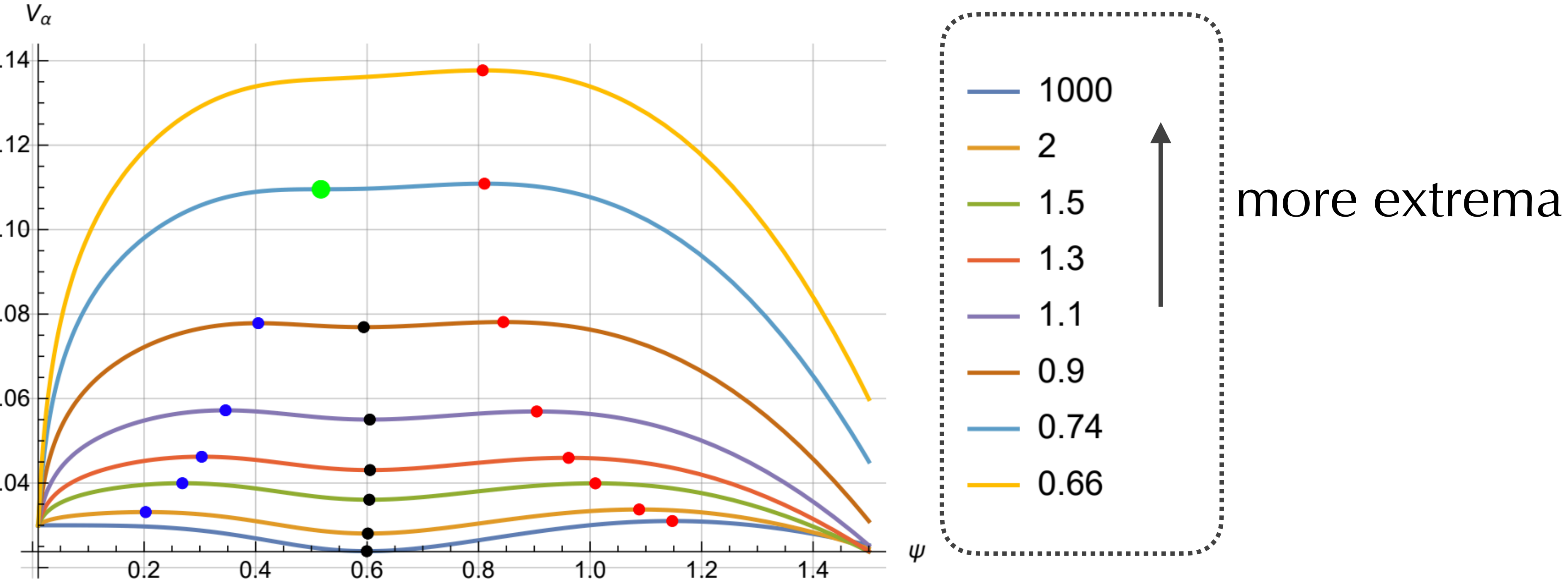
- Metastable state for $p/\tilde{M} \lesssim 0.054$

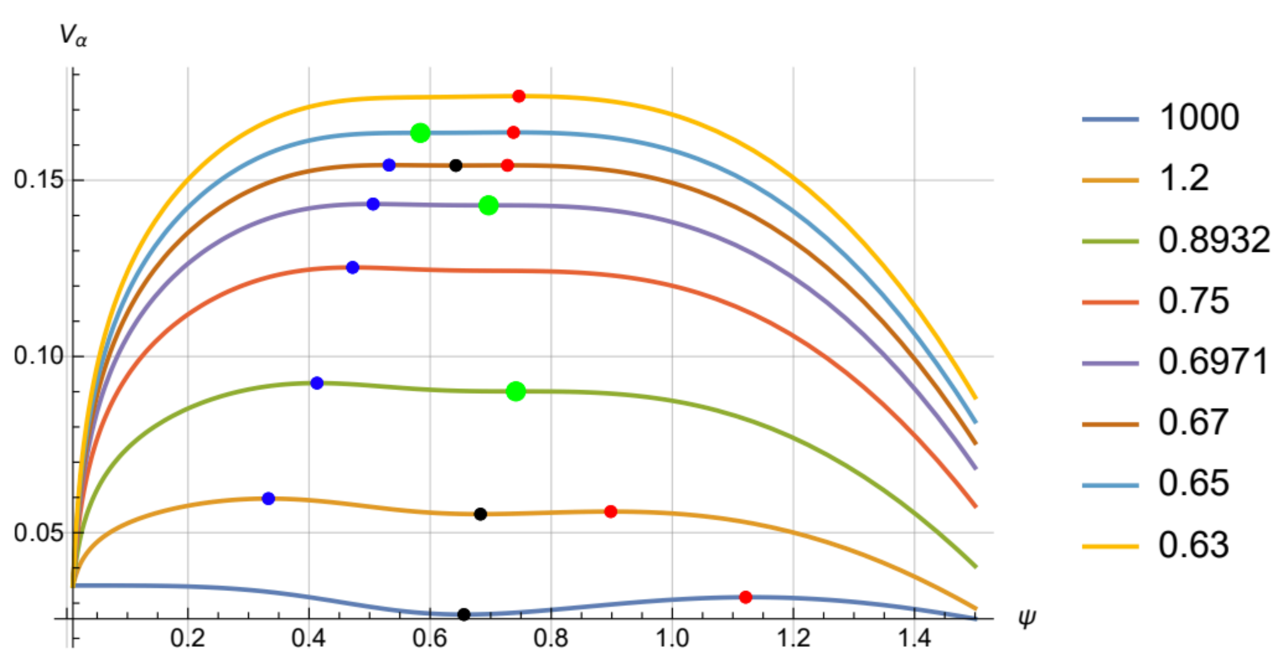
- Blackfolds recover at T=0 the KP potential and the KP metastable state

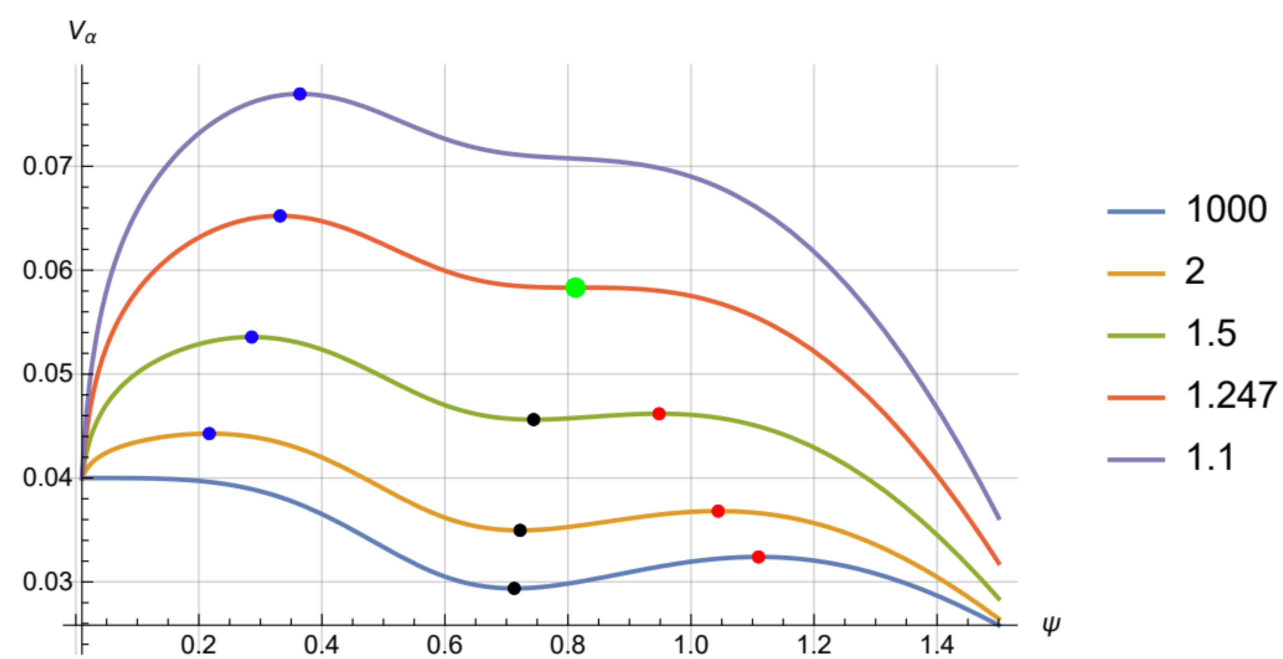
- Blackfolds reveal an intricate structure of finite-T transitions

$p/\tilde{M} = 0.03$

- fat unstable
- thin unstable
- metastable
- merger



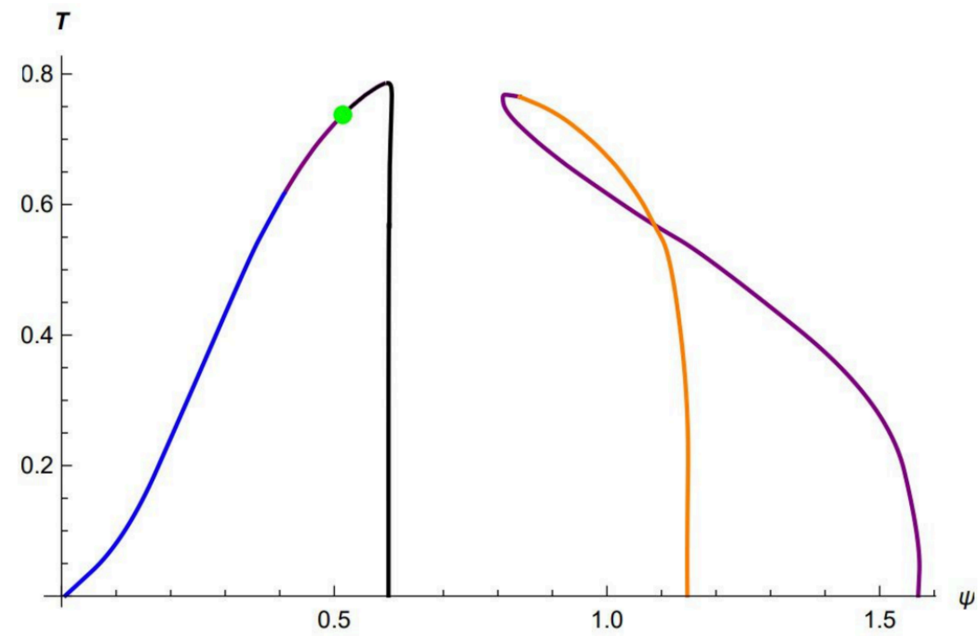




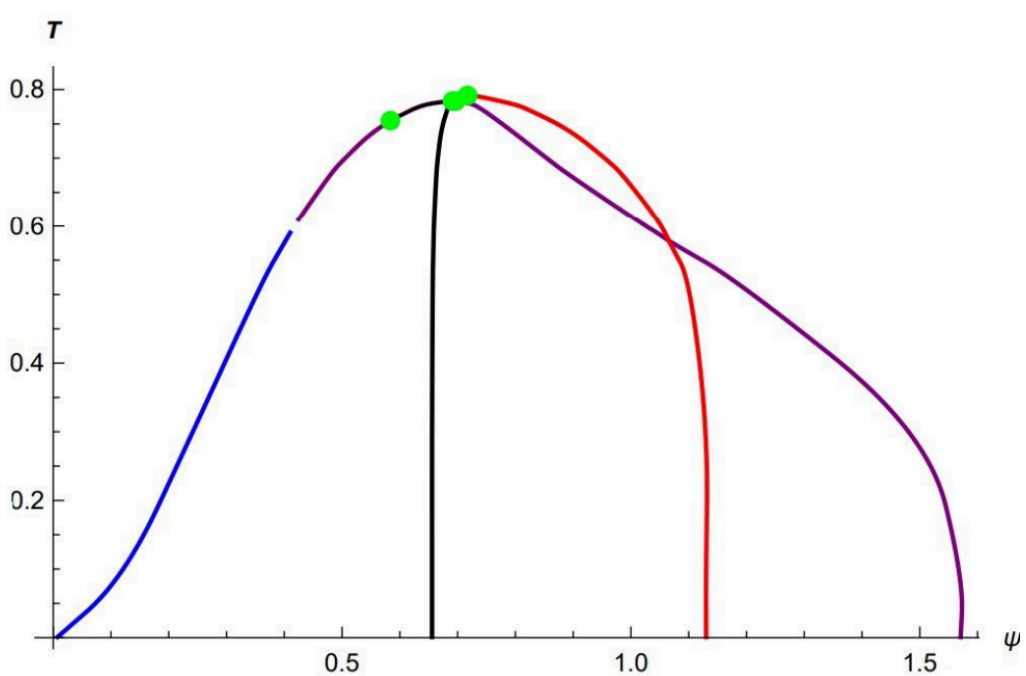
$p/\tilde{M} = 0.035$

$p/\tilde{M} = 0.04$

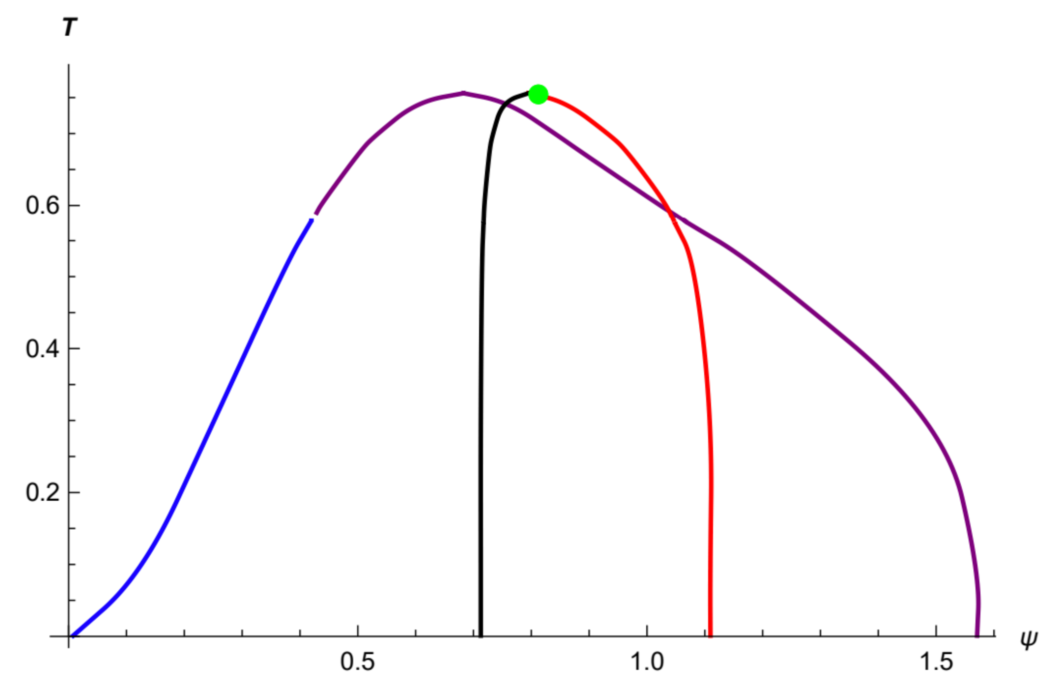
Same information as we vary the temperature



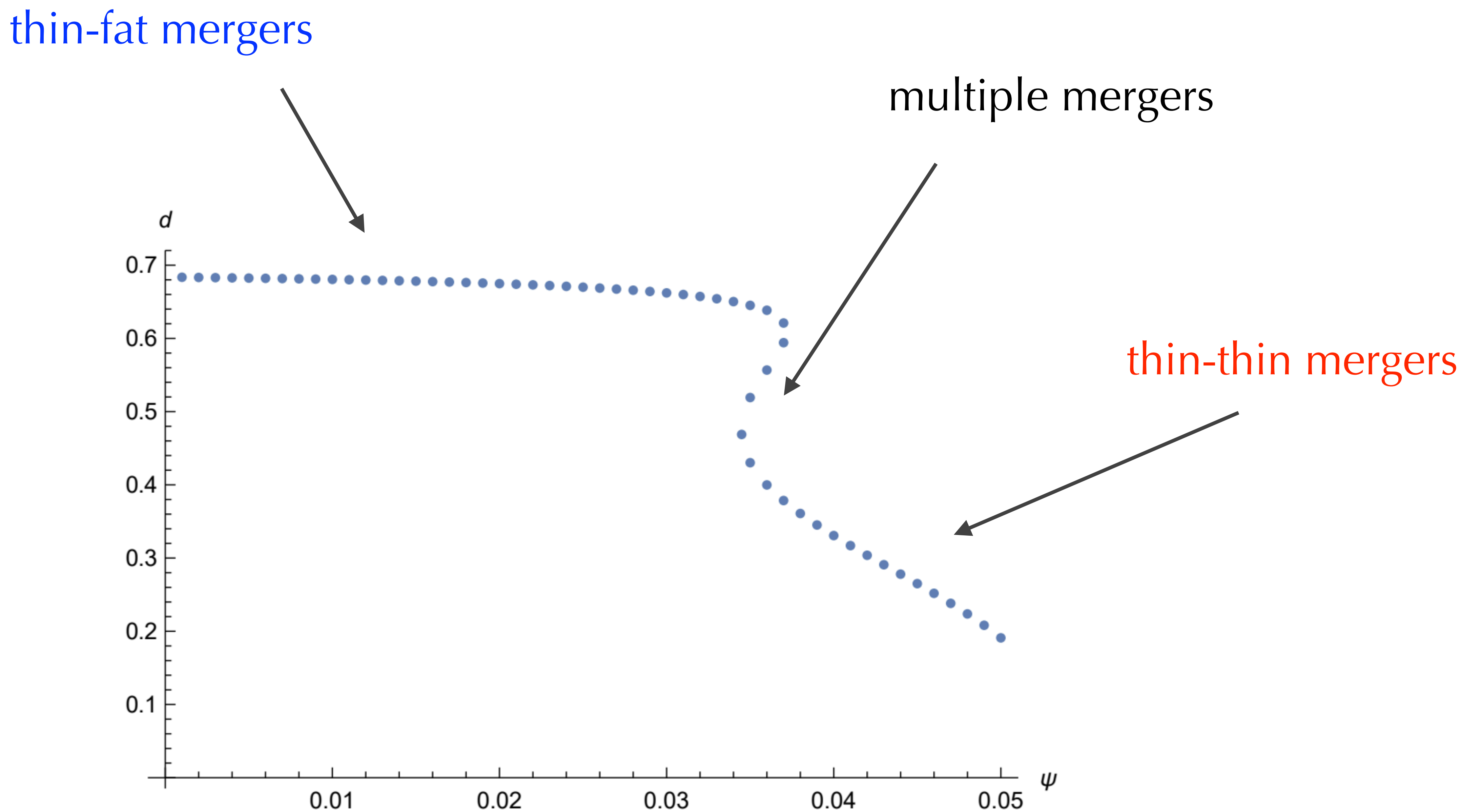
$$p/\tilde{M} = 0.03$$



$$p/\tilde{M} = 0.035$$



$$p/\tilde{M} = 0.04$$



fatness ratio d at the merger point of the metastable state

Questions

- Explicit construction of 1st order MAEs
  (more general: systematic MAEs in SUGRA-string/M-theory?
  SUSY: a theory of G-structure deformations?) VN '14

- Stability Bena-Grana-Kuperstein-Massai '14,…
  (Nguyen upcoming paper)

- Distill quantitative lessons in AdS/CFT