Static supersymmetric black holes in AdS_4 with spherical symmetry

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References

- S. Cacciatori and D. Klemm, 0911.4926:

➔ Considered arbitrary static BPS spacetimes: very general, non-spherical horizons, complicated BPS equations !

- G. Dall'Agata and A. Gnecchi, 1012.3756

➔ Considered also dyonic solutions (see later)

- H. Looyestijn, K. Hristov, S.V., 1005.3650

Intro & Motivation

1) BPS Black Holes in flat spacetime:

- Entropy, area law
- Microscopics, stringy realization, D-branes
- Wall crossing phenomena; instantons and hypermultiplets

2) Black Holes in AdS spacetime:

- AdS_4 / CFT_3 and applications in CMT (& QCD)
- Main interest in non-BPS black holes, finite temperature. Here: study of BPS black holes!

Static AdS$_4$ black holes

Static, spherically symmetric spacetimes (+,-,-,-)

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

- AdS$_4$: $U^2(r) = 1 + g^2 r^2$; $h(r) = r$ $(\Lambda = -3g^2)$
- RN-AdS$_4$:

$$U^2(r) = 1 - \frac{2M}{r} + \frac{Q^2 + P^2}{r^2} + g^2 r^2 \ ; \ h(r) = r$$

Static AdS$_4$ black holes

- Einstein + Maxwell + cosmological constant

$$L = \sqrt{-g}\left(R(g) - F_{\mu\nu}F^{\mu\nu} - \Lambda\right)$$

- Minimally gauged N=2 D=4 supergravity
- BPS conditions (Romans '92):

$$class \quad 1) \qquad M = Q,\, P = 0 \Rightarrow U^2 = (1 - \frac{Q}{r})^2 + g^2 r^2$$

➔ No horizons, naked singularity at $r = 0$. Solution is ½ BPS.

Static AdS$_4$ black holes

- "Exotic"- BPS solution (Romans, '92) :

$$class\ \ 2): M = Q\ ;\ \ P = \frac{1}{2g} \Rightarrow U^2(r) = (gr + \frac{1}{2gr})^2 + \frac{Q^2}{r^2}$$

➔ Solution is ¼ BPS, again no horizon, naked singularity at $r = 0$. There is no flat spacetime limit $g \to 0$.

HOW TO RESOLVE THE NAKED SINGULARITY ???

WE WILL FIND MODELS: $Q = 0 \quad U^2(r) \sim (gr + \frac{c}{2gr})^2\ ;\ c < 0$

HORIZON LOCATED AT $r_H = \sqrt{\frac{-c}{2g^2}}$

Ingredients

- Add extra vector multiplets in N=2 D=4 sugra, specified by prepotential. Non-constant scalars.
- Abelian gaugings and non-trivial scalar potential for the scalars.
- Simplest setting: Fayet-Iliopoulos terms (gauging R-symmetry), no hypermultiplets. [See also Cacciatori and Klemm, ‘09]
- The scalar potential must allow for N=2 AdS_4 vacua at infinity. This requires certain prepotentials +gaugings.

FI-Gauged supergravity

- N=2 D=4 Lagrangian (ungauged part) $z^\Lambda = X^\Lambda / X^0$

$$L = R(g) + K_{i\bar{j}} \partial z^{\bar{i}} \partial z^j + I_{\Lambda\Sigma}(z) F^\Lambda F^\Sigma + R_{\Lambda\Sigma}(z) \varepsilon^{\mu\nu\rho\sigma} F^\Lambda_{\mu\nu} F^\Sigma_{\rho\sigma}$$

- Add scalar potential

$$V = g^2 (K^{i\bar{j}} f_i^\Lambda f_{\bar{j}}^\Sigma - 3\bar{L}^\Lambda L^\Sigma) \xi_\Lambda \xi_\Sigma \quad L^\Lambda \equiv e^K X^\Lambda \quad f_i^\Lambda \equiv e^{K/2} D_i X^\Lambda$$

- FI terms charge the gravitinos

$$\nabla_\mu \psi_{\nu A} = \partial_\mu \psi_{\nu A} + \ldots + \frac{i}{2} g \xi_\Lambda A_\mu^\Lambda \sigma_A^{3B} \psi_{\mu B} \;\; ; \; A, B = 1,2 \; ; \; e_\Lambda \equiv g \xi_\Lambda$$

Quantization condition

- Since the FI-terms determine the electric charges of the gravitinos, one expects a quantization condition in the presence of magnetic charges

$$2e_\Lambda p^\Lambda = n \quad ; \quad n \in \mathbb{Z}$$

- In a theory which is electromagnetically gauged, one expects (see later)

$$2(e_\Lambda p^\Lambda - m^\Sigma q_\Sigma) = n \quad ; \quad n \in \mathbb{Z}$$

BPS Black Hole Ansatz

- We only look for magnetically charged solutions:

$$A_\varphi^\Lambda = -p^\Lambda \cos\theta \;\; ; \;\; q_\Lambda = 0$$

- Ansatz for Killing spinors (breaking to ¼ BPS):

$$\varepsilon_A = \varepsilon_{AB}\gamma^0\varepsilon^B \;\; ; \;\; \varepsilon_A = \pm\sigma^3_{AB}\gamma^1\varepsilon^B$$

Attractor equations

- BPS conditions imply attractor flow equations:

$$U\partial_r z^i = K^{i\bar{j}} \bar{f}_{\bar{j}}^{\Lambda} \left(\frac{2I_{\Lambda\Sigma}p^{\Sigma}}{h^2} \mp g\xi_{\Lambda}\right)$$

$$\partial_r U = -L^{\Lambda}\left(\frac{2I_{\Lambda\Sigma}p^{\Sigma}}{h^2} \mp g\xi_{\Lambda}\right)$$

$$\frac{U}{h}\partial_r h = L^{\Lambda}\left(\frac{2I_{\Lambda\Sigma}p^{\Sigma}}{h^2} \pm g\xi_{\Lambda}\right)$$

together with the quantization condition for n=1 (!!)

$$2g\xi_{\Lambda}p^{\Lambda} = \mp 1$$

Example I

- Simplest case: 1 vector multiplet. Prepotential

$$F = -2i\sqrt{X^0 (X^1)^3}$$

- Look for solution of the form (ansatz)

$$U(r) = e^{K/2}(gr + \frac{c}{2gr}) \quad ; \quad h(r) = re^{-K/2}$$

$$\mathrm{Re}(X^\Lambda) = H^\Lambda \quad ; \quad \mathrm{Re}(F_\Lambda) = 0 \quad ; \quad H^\Lambda = \alpha^\Lambda + \frac{\beta^\Lambda}{r}$$

Example I

- Solution parametrized by 7 parameters (c, 2 constants in each harmonic function, 2 magnetic charges)
- The BPS equations relate most of these parameters to the FI terms, and one ends up with only three parameters, e.g.

$$\beta^1 \ \ \& \ \ \xi_\Lambda \quad ; \Lambda = 0,1$$

- For instance, $$c = 1 - \frac{32}{3}(g\xi_1\beta^1)^2$$

Example I

- Horizon is located at (computed from g_{tt}=0)

$$r_H = \sqrt{\frac{16}{3}(\xi_1\beta^1)^2 - \frac{1}{2g^2}}$$

- Singularities at (where g_{tt} diverges)

$$r_s = \pm 4\xi_1\beta^1, \quad r_s = \mp\frac{4}{3}\xi_1\beta^1$$

- Black holes require $r_H > r_S \Rightarrow \ c < -\frac{1}{2}$

Example I

- Entropy can be computed explicitly, and is function of gravitino and black hole charges,

$$S = S(e_\Lambda, p^\Lambda)\ ;\ \ e_\Lambda \equiv g\xi_\Lambda$$

- Near horizon geometry is $AdS_2 x S^2$, but with unequal radii:

$$R_{S^2} > \sqrt{2} R_{AdS_2}$$

M-theory embedding

- The solution can first be embedded in D=4 N=8 sugra (1/16 BPS), by truncation, and then be lifted to D=11 [Duff and Liu, Cvetic et al.,'99],

$$D=11\ sugra\ on\ S^7 \Leftrightarrow SO(8)\ gauged\ \ N=8\ sugra\ D=4$$

$$\Updownarrow$$

$$truncation\ \ to\ U(1)^4\ \ N=2\ \ D=4$$

- Prepotential and FI-terms:

$$F=-2i\sqrt{X^0X^1X^2X^3}\ \ ;\ \ \xi_\Lambda=1\ \forall\Lambda=0,1,2,3$$

M-theory embedding

- Microscopic description in terms of M2-branes.
- In D=4, there are no electric charges, hence M2 branes are not spinning
- The D=4 magnetic charges lift to NUT-like charges. This implies that Kaluza-Klein monopoles are present
- Bound state of M2 and KK ? (More research needed)

Dyonic AdS_4 BH

- Trick: electromagnetic rotation of the purely magnetic black holes. [see also Dall'Agata and Gnecchi]
- Technology: magnetic gaugings in N=2 D=4 sugra [D'Auria et al., de Wit et al.]
- In our case: gravitinos get both electric and magnetic charges, which are mutually local. Dirac quantization condition:

$$2(e_\Lambda p^\Lambda - m^\Sigma q_\Sigma) = n \quad ; \quad n \in \mathbb{Z}$$

Dyonic AdS_4 BH

- Solution has both electric and magnetic (dual) field strengths

$$F^{\Lambda}_{\theta\varphi} = \frac{p^{\Lambda}}{2}\sin\theta \quad ; \quad G_{\Sigma,\theta\varphi} = \frac{q_{\Sigma}}{2}\sin\theta$$

- BPS solutions (ansatz) in terms of harmonic functions:

$$\mathrm{Re}(X^{\Lambda}) = H^{\Lambda} \quad ; \quad \mathrm{Re}(F_{\Sigma}) = H_{\Sigma}$$

Example II

- Consider prepotential (truncated STU model)

$$F = \frac{(X^1)^3}{X^0}$$

- This is the dual prepotential of Example I, related by a particular symplectic rotation.
- Gauging with one electric and one magnetic gauge field. Gravitino charges (e_0, m^1). This is needed to get an AdS_4 vacuum at infinity.
- Black hole is also dyonic: $2(e_0 p^0 - m^1 q_1) = \pm 1$

Conclusions

- Initiated study of BPS black holes in gauged N=2 D=4 sugra.
- New BPS AdS black holes exist and avoid naked singularities ! Magnetic and dyonic.
- Found attractor flow equations.
- M-theory embedding: microscopic description?
- Generalizations to non-BPS, non-extremal ?