Black Holes in F-theory

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1509.00455

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To appear

Strominger-Vafa ’96

IIB D1-D5

$AdS_3 \times S^3 \times T^4/K3$

(4,4)

MSW ’97

M-theory M5

$AdS_3 \times S^2 \times CY_3$

(0,4)

Are all Black Holes Black Strings in disguise ?

- No! Consider M2 wrapping a curve C in $X=CY_3$. This gives rise to a spinning black hole in D=5 described by topological string on X [Katz, Klemm, Vafa '99].

- However, for elliptically fibered CY_3, there is a black string! Dualize M2 in M-theory to D3 in F-theory.

From M to F

- M-theory on X = IIB-theory on $B_4 \times S^1$

$$T^2 \rightarrow X$$
$$\downarrow$$
$$B_4$$

- M2 on $[nT^2]$ U C = D3 on $C \times S^1$, momentum n.

HMVV ’15

F-theory D3

$AdS_3 \times S^3 \times CY_3$

(0,4)

D3 wrapping Riemann Surface

D3 on curve $C=\Sigma_g$

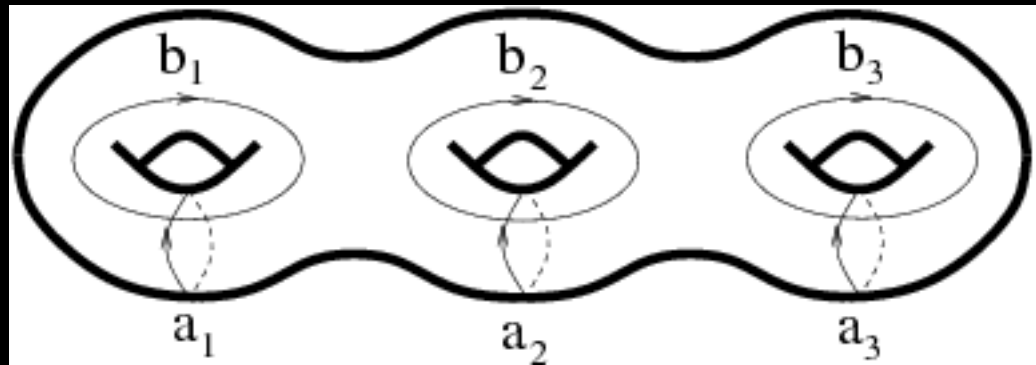
(0,4) & $SU(2)_L$ with $k_L=g$

Spinning Black Holes

$SU(2)_L$ currents

$$J_L^{ij} = \sum_{a,b=1}^{2g} \psi_a^i \psi_b^j \Omega^{ab}$$

i = 1,2



Central charges [Vafa '97]

$$c_L = 6g + 12c_1(B).C$$

$$c_R = 6g + 6c_1(B).C$$

$$2g(C)-2 = C.C - c_1(B).C = Q^i Q^j \eta_{ij} - Q^i c_i$$

Example: P^2

- Base P^2, and consider a $g=0$ P^1 curve in P^2.
- $c_L = 36$ and $c_R = 18 = 3/2 \times 12$
- No left moving fermions
- $36 = 4_{CM} + 4_{P2} + 28_{T28}$ Left movers
- $12 = 4_{CM} + 4_{P2} + 4_{T4}$ Right movers

New Duality

IIB on $AdS_3 \times S^3 \times B_4$

=

$$c_{L,}k_L \, (0,4)_{c_R=6k_R}$$

Cardy regime

$$S = 2\pi\sqrt{\frac{c_L}{6}\left(n - \frac{J_L^2}{4k_L}\right)}$$

$$L_0 > \frac{J_L^2}{4k_L} \Leftrightarrow \textit{cosmic censor}$$

Macroscopics - Sugra

F-theory on $X = CY_3 \longrightarrow B_4$ gives D=6 (1,0) sugra with

$$n_T = h^{1,1}(B_4) - 1$$

$$n_V = h^{1,1}(X) - h^{1,1}(B_4) - 1$$

$$n_H = h^{2,1}(X) + 1$$

For $B_4 = P^2$ this gives pure simple sugra in D=6 (ignoring the hypers). Metric and Self dual *H*.

BPS string in 6D

BPS solution of 6D theory is the black string with near horizon geometry [BMPV '96]

$$AdS_3 \times S^3$$

and charge/flux

$$4\pi Q = \int_{S^3} H$$

F-theory on $CY_3 \times S^1$

- Compactify to 5D: sugra + 1 VM
- Mass of black hole

$$M^3 = 1/2\, Q^2 n \approx 1/6\, c_L\, n$$

$$c_L = 3Q^2 + \ldots$$

5D Spinning BPS BH

- Large charges:

$$S = 2\pi\sqrt{M^3 - J^2}$$

- Subleading in charges: Gravitational anomaly matches with $B \wedge \mathrm{tr}\,[R \wedge R]$:

$$c_L - c_R = 6c_1(B).C$$

[Dabholkar, Gomes, Murthy, Sen '10][Bonetti & Grimm '11]

Elliptic genus

- $Z_C(\tau,z) = Z_C^F(\tau,z) + Z_C^P(\tau,z)$: Meromorphic Jacobi form of weight 0 and index $k=g-1$.

  [Dabholkar, Murthy, Zagier '12]
- Z_C^F: Mock Jacobi (single centered)
- Z_C^P: Polar part: contains states with $J^2 > M^3$ with exponential growth

$$\exp(2\pi\sqrt{2c_1(B)\cdot C\, n})$$

Example: $B=P^2$

$$Z_d = \frac{N_d(\tau, z)}{\eta^{36d}(\tau)\prod_{s=1}^{d}\varphi_{-2,1}(\tau, sz)}$$

$$polar\ growth : c_L = 36d$$

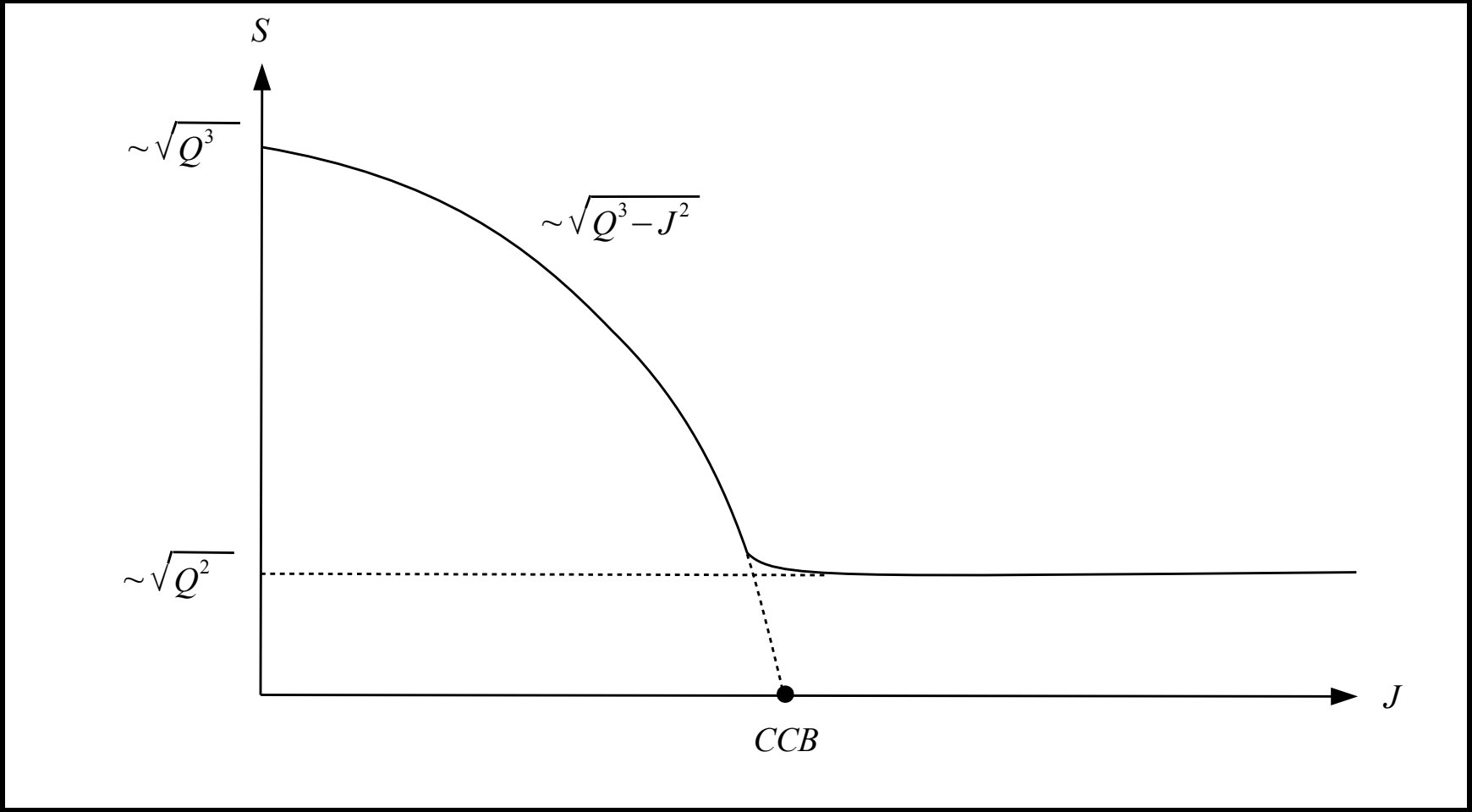
$2g-2=d^2-3d$ and N_d a weak Jacobi form [Huang, Katz, Klemm '15]

But states with $J^2 > M^3$ cannot correspond to single centered black holes, since it would violate cosmic censorship.

It could come from orbital spin of the CM of a single center, but that cancels out in the elliptic genus.

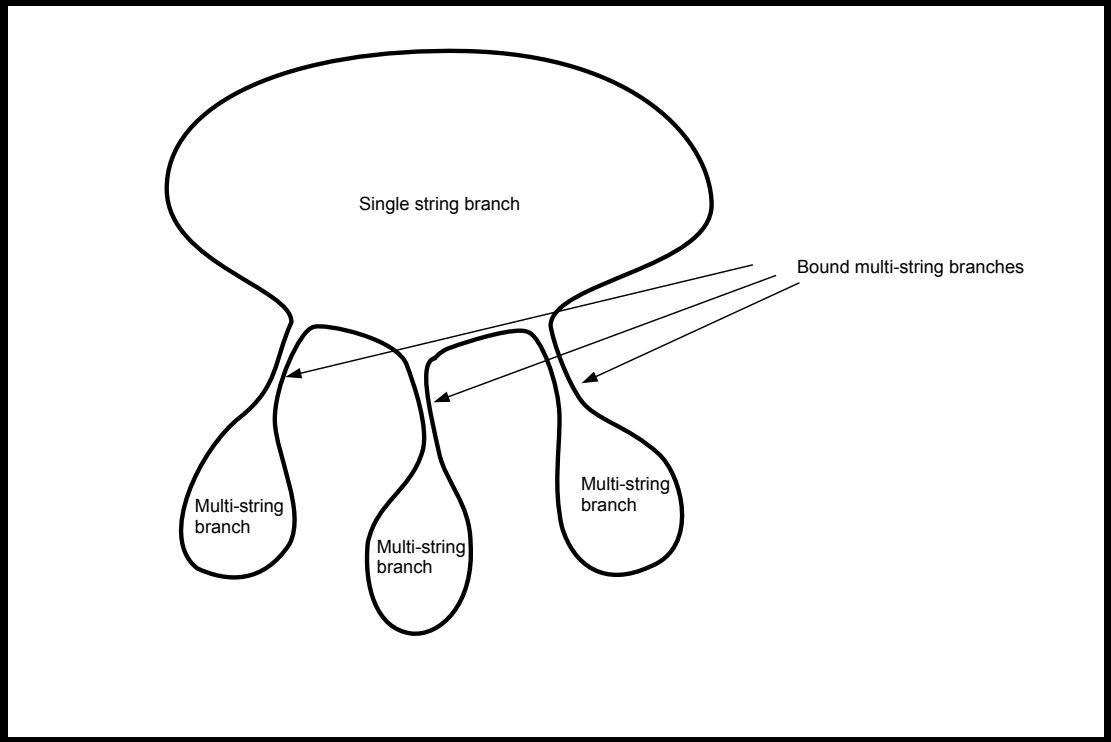
Hence it should correspond to *bound states*.

Entropy (fixed Q)

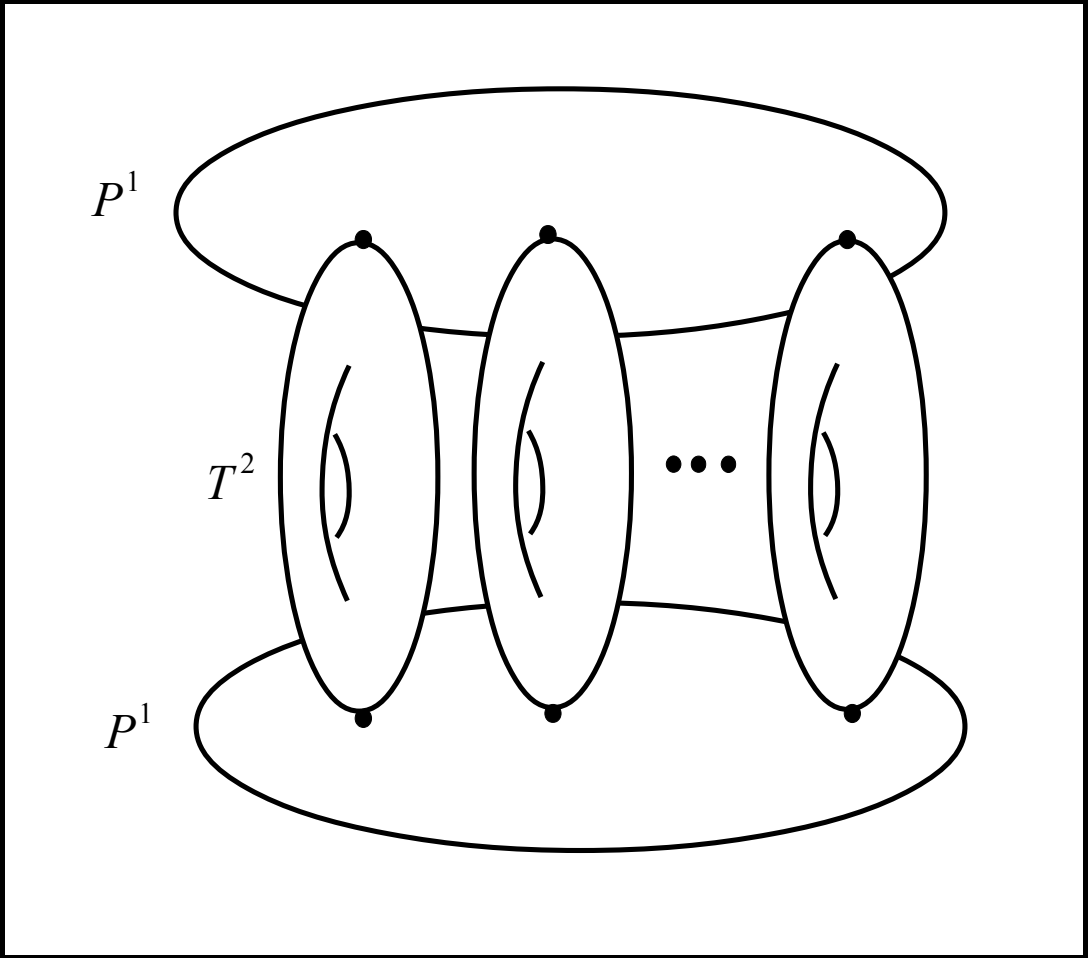


Multi-string branches

Elliptic genus contains contributions from different CFT branches



M-theory picture of bound states



Macroscopics ?

What is the gravity interpretation of this

$$S \approx Q$$

entropic phase (instead of $S \approx Q^{3/2}$) ?

They must be bound states of black holes, bounded by KK momentum…

But we actually don't know of any BH bound states in 5d sugra...nobody ever did this...

Work in progress (w. Crichigno and Porri)

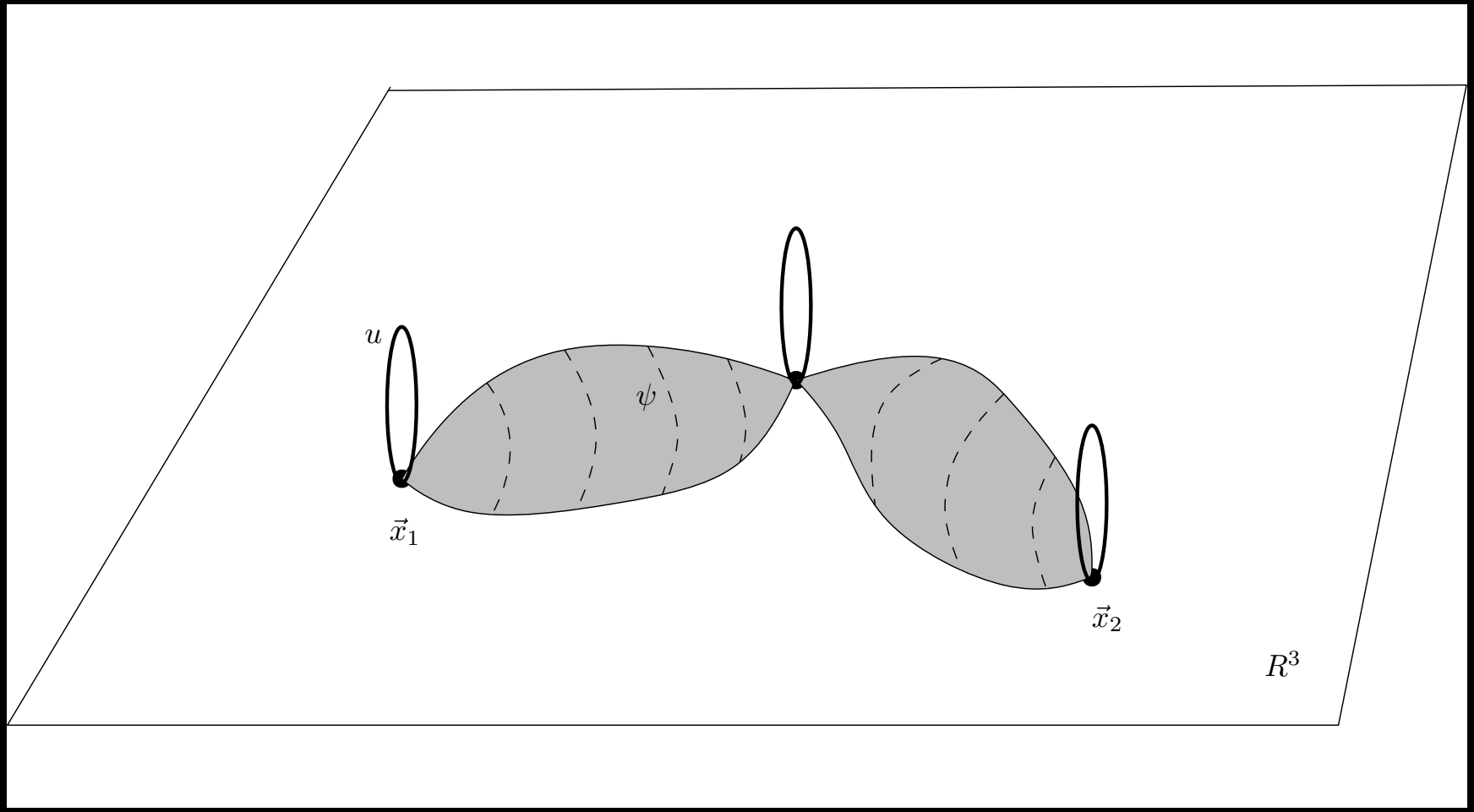
- Take $B=P^2$. Can we find sugra bound states?
- In 6d this amounts to finding BPS multicentered black strings in minimal (1,0) sugra.
- BPS solutions have been classified by Gutowski, Martelli, Reall ’03 in terms of harmonic functions.
- Find if they bind after KK and are regular.

Work in progress (w. Crichigno and Porri)

Metrics and Harmonic functions

$$ds_6^2 = -2H^{-1}(du+\beta)\left(dv+\omega-\frac{F}{2}(du+\beta)\right)+Hds^2_{HK_4}$$

Work in progress (w. Crichigno and Porri)



Concluding Statement

- F-theory has been an active field of research for string pheno and SCFT's.

- F-theory is also a great area to study black hole physics and quantum gravity.