Three Dimensional Black Holes with Fluxes

Domenico Orlando

Centre de Physique Théorique de l'École Polytechnique Palaiseau - France

in collaboration with Israel, Kounnas, Petropoulos Detournay, Petropoulos, Spindel

Domenico Orlando Three Dimensional Black Holes with Fluxes

• • = • • = •

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	ne				

- Techniques and General Background
- Asymmetric Deformations
- The 3d Black String
- 4 3d Black String with Fluxes
- 5 Spectra
- 6 Conclusions

何トイヨトイヨト

= nar

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	e				

1 Techniques and General Background

- 2 Asymmetric Deformations
- 3 The 3D Black String
- 4 3D Black String with Fluxes
- 5 Spectra
- 6 Conclusions

• • = • • = •

1

14/		A.A. A. A. A.			
0000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Wess-Zumino-Witten Models

WZW action on a group G

Action:

$$S_k(g) = rac{k}{2\pi} \int_{\Sigma} \langle g^{-1} \partial g, g^{-1} \bar{\partial} g \rangle + rac{k}{12\pi} \int_B \operatorname{Tr} \omega^3$$

where $g \in G$, $\partial B = \Sigma$ and $\omega = g^{-1} dg$.

Invariant under:

 $g(\xi) \to \Omega(z)g(\xi)\bar{\Omega}^{-1}(\bar{z})$

The manifold has $G \times G$ symmetry.

Conserved currents J and J
 generating the affine
 ²g_k
 algebra

3

General	Asy	mmetric	Deformations	٦	he :	Id Black String	Fluxes	Spectra	Conclusions
00000	00	00		C	po _		000000	00	0
3.4.7	-		A 4 7 * 4 *			1 A A			

Wess-Zumino-Witten Models

WZW action on a group G

Action:

$$S_k(g) = rac{k}{2\pi} \int_{\Sigma} \langle g^{-1} \partial g, g^{-1} \bar{\partial} g \rangle + rac{k}{12\pi} \int_B \operatorname{Tr} \omega^3$$

where $g \in G$, $\partial B = \Sigma$ and $\omega = g^{-1} dg$.

Invariant under:

$$g(\xi) \to \Omega(z)g(\xi)\bar{\Omega}^{-1}(\bar{z})$$

The manifold has $G \times G$ symmetry.

Conserved currents J and J
 generating the affine ĝ_k algebra

= nar

ヘロト 人間 ト イヨト イヨト

General	Asy	mmetric	Deformations	٦	he :	Id Black String	Fluxes	Spectra	Conclusions
00000	00	00		C	po _		000000	00	0
3.4.7	-		A 4 7 * 4 *			1 A A			

Wess-Zumino-Witten Models

WZW action on a group G

Action:

$$S_k(g) = \frac{k}{2\pi} \int_{\Sigma} \langle g^{-1} \partial g, g^{-1} \bar{\partial} g \rangle + \frac{k}{12\pi} \int_B \operatorname{Tr} \omega^3$$

where $g \in G$, $\partial B = \Sigma$ and $\omega = g^{-1} dg$.

Invariant under:

$$g(\xi) \to \Omega(z)g(\xi)\bar{\Omega}^{-1}(\bar{z})$$

The manifold has $G \times G$ symmetry.

• Conserved currents J and \overline{J} generating the affine \hat{g}_k algebra

く 伺 ト く ヨ ト く ヨ トー

= nar



- Gauge away an anomaly-free subgroup $H \subset G$
- Promote H to a local symmetry
- Integrate out the gauge fields

Geometry

- G/H coset under the adjoint action
 - $\mathbb{C}/\{g\sim n(h^{-1})g\sigma(h)|h\in h()\}$
- Non-constant: curvature
- Presence of a dilaton
- enoiteenenal a' corrections



- Gauge away an anomaly-free subgroup $H \subset G$
- Promote *H* to a local symmetry
- Integrate out the gauge fields

Seometry • G/H coset under the adjoint action $G/\{g \sim e_i(h^{-1})ge_i(h)|h \in H\}$ • Hon-constant curvature • Presence of a dilaton • In general al corrections

イロト イボト イヨト イヨト

Gaugeo	d Wess-Zumino	-Witten Mod	lels		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- Gauge away an anomaly-free subgroup $H \subset G$
- Promote *H* to a local symmetry
- Integrate out the gauge fields

Geometry

G/H coset under the adjoint action

$G/\{g \sim \epsilon_{\mathbb{I}}(h^{-1})g\epsilon_{\mathbb{I}}(h)|h \in H\}$

- Non-constant curvature
- Presence of a dilaton
- In general « corrections

Gaugeo	d Wess-Zuming	o-Witten Mo	dels		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- Gauge away an anomaly-free subgroup $H \subset G$
- Promote H to a local symmetry
- Integrate out the gauge fields

Geometry

• G/H coset under the adjoint action

$$G / \{g \sim \epsilon_{\mathsf{l}}(h^{-1})g\epsilon_{\mathsf{r}}(h)|h \in H\}$$

- Non-constant curvature
- Presence of a dilaton
- In general α' corrections

3

Gaugeo	d Wess-Zuming	o-Witten Mo	dels		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- Gauge away an anomaly-free subgroup $H \subset G$
- Promote H to a local symmetry
- Integrate out the gauge fields

Geometry

• G/H coset under the adjoint action

$$G / \{g \sim \epsilon_{\mathsf{l}}(h^{-1})g\epsilon_{\mathsf{r}}(h) | h \in H\}$$

Non-constant curvature

- Presence of a dilaton
- In general α' corrections

(日本) (日本) (日本)

3

Gaugeo	d Wess-Zuming	o-Witten Mo	dels		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- Gauge away an anomaly-free subgroup $H \subset G$
- Promote H to a local symmetry
- Integrate out the gauge fields

Geometry

• G/H coset under the adjoint action

$$G / \{g \sim \epsilon_{\mathsf{l}}(h^{-1})g\epsilon_{\mathsf{r}}(h) | h \in H\}$$

- Non-constant curvature
- Presence of a dilaton
- In general α' corrections

(日本) (日本) (日本)

3

Gaugeo	d Wess-Zuming	o-Witten Mo	dels		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- Gauge away an anomaly-free subgroup $H \subset G$
- Promote H to a local symmetry
- Integrate out the gauge fields

Geometry

• G/H coset under the adjoint action

$$G / \{g \sim \epsilon_{\mathsf{l}}(h^{-1})g\epsilon_{\mathsf{r}}(h) | h \in H\}$$

- Non-constant curvature
- Presence of a dilaton
- In general α' corrections

3

く得た くまた くまた

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0
What's	s there in het	ween?			

Introduce a current-current deformation

$$S_k(g) + \int \mathrm{d}^2 z \, c_{ik} J^i \tilde{J}^k$$

• Truly marginal deformation if and only if

$$c_{im}c_{jn}f_{ijk} = 0$$
 $c_{mi}c_{nj}\tilde{f}_{ijk}$

- Exact cft for any value of the deformation parameters c_{ij}
- Boundaries for the moduli, corresponding to the gauged model.

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0
What's	s there in het	ween?			

Introduce a current-current deformation

$$S_k(g) + \int \mathrm{d}^2 z \, c_{ik} J^i \tilde{J}^k$$

• Truly marginal deformation if and only if

$$c_{im}c_{jn}f_{ijk}=0$$
 $c_{mi}c_{nj}\tilde{f}_{ijk}=0$

- Exact cft for any value of the deformation parameters c_{ij}
- Boundaries for the moduli, corresponding to the gauged model.

伺 ト イ ヨ ト イ ヨ ト

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0
What's	s there in het	ween?			

Introduce a current-current deformation

$$S_k(g) + \int \mathrm{d}^2 z \, c_{ik} J^i \tilde{J}^k$$

• Truly marginal deformation if and only if

$$c_{im}c_{jn}f_{ijk}=0 \qquad \qquad c_{mi}c_{nj}\tilde{f}_{ijk}=0$$

- Exact cft for any value of the deformation parameters c_{ij}
- Boundaries for the moduli, corresponding to the gauged model.

(4 同) トイヨト イヨト

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra 00	Conclusions O
What's	there in het	ween?			

Introduce a current-current deformation

$$S_k(g) + \int \mathrm{d}^2 z \, c_{ik} J^i \tilde{J}^k$$

• Truly marginal deformation if and only if

$$c_{im}c_{jn}f_{ijk} = 0 \qquad \qquad c_{mi}c_{nj}\tilde{f}_{ijk} = 0$$

- Exact cft for any value of the deformation parameters c_{ij}
- Boundaries for the moduli, corresponding to the gauged model.

伺下 イヨト イヨト

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0
What's	s there in het	ween?			

cft point of view

- $O(d, \overline{d})$ transformation of the charge lattice $\Lambda \subset \mathfrak{h} \times \overline{\mathfrak{h}}$ $D_{\mathfrak{h}, \overline{\mathfrak{h}}} \sim O(d, \overline{d}) / (O(d) \times O(\overline{d}))$.
- Parafermion decomposition. The undeformed wzw model is:

 $\hat{\mathfrak{g}}_k \simeq \left(\hat{\mathfrak{g}}_k / \hat{\mathfrak{h}} \otimes t_{\Lambda_k} \right) / \Gamma_k,$

and the deformed one becomes

 $\hat{\mathfrak{g}}_k(\mathcal{O})\simeq \left(\hat{\mathfrak{g}}_k/\hat{\mathfrak{h}}\otimes t_{\mathcal{O}\Lambda_k}\right)/\Gamma_k,$

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
What's	there in het	ween?			

cft point of view

• $O(d, \overline{d})$ transformation of the charge lattice $\Lambda \subset \mathfrak{h} imes \overline{\mathfrak{h}}$

$$D_{\mathfrak{h},\overline{\mathfrak{h}}} \sim O(d,\overline{d}) / (O(d) \times O(\overline{d})).$$

Parafermion decomposition. The undeformed wzw model is:

$$\hat{\mathfrak{g}}_k \simeq \left(\hat{\mathfrak{g}}_k / \hat{\mathfrak{h}} \otimes t_{\Lambda_k} \right) / \Gamma_k,$$

and the deformed one becomes

$$\hat{\mathfrak{g}}_k(\mathcal{O})\simeq \left(\hat{\mathfrak{g}}_k/\hat{\mathfrak{h}}\otimes t_{\mathcal{O}\Lambda_k}\right)/\Gamma_k,$$

(4 同) トイヨト イヨト



what's there in between

Lagrangian point of view

• Implement the O(d,d) rotation (first order in α')

$$M \to M' = \Omega M \Omega^t, \quad \Phi \to \Phi' = \Phi + \frac{1}{2} \log \left(\frac{\det \hat{g}}{\det \hat{g}'} \right)$$

where M is a $2d \times 2d$ matrix containing g and B.

- Sum of the *G*/*H* parafermion and a deformed *H* with a suitable T-duality.
- Identify the deformed model with the coset

 $\frac{G \times H}{H}$

where H is embedded in both groups.

Sar



What's there in between?

Lagrangian point of view

• Implement the O(d,d) rotation (first order in α')

$$M \to M' = \Omega M \Omega^t$$
, $\Phi \to \Phi' = \Phi + \frac{1}{2} \log \left(\frac{\det \hat{g}}{\det \hat{g}'} \right)$

where *M* is a $2d \times 2d$ matrix containing *g* and *B*.

- Sum of the *G*/*H* parafermion and a deformed *H* with a suitable T-duality.
- Identify the deformed model with the coset

 $\frac{G \times H}{H}$

where H is embedded in both groups.

Domenico Orlando Three Dimensional Black Holes with Fluxes

Sar

General occop Asymmetric Deformations occop The 3d Black String occop Fluxes occop Spectra occop Conclusions occop W/bat's thore in batwoon?

What's there in between?

Lagrangian point of view

• Implement the O(d, d) rotation (first order in α')

$$M \to M' = \Omega M \Omega^t, \quad \Phi \to \Phi' = \Phi + \frac{1}{2} \log \left(\frac{\det \hat{g}}{\det \hat{g}'} \right)$$

where *M* is a $2d \times 2d$ matrix containing *g* and *B*.

- Sum of the G/H parafermion and a deformed H with a suitable T-duality.
- Identify the deformed model with the coset



where H is embedded in both groups.

Sar

General occore Asymmetric Deformations occore The 3d Black String occore Fluxes occore Spectra occore Conclusions occore All back String occore occore occore occore occore occore occore

What's there in between?

Lagrangian point of view

• Implement the O(d,d) rotation (first order in α')

$$M \to M' = \Omega M \Omega^t, \quad \Phi \to \Phi' = \Phi + \frac{1}{2} \log \left(\frac{\det \hat{g}}{\det \hat{g}'} \right)$$

where *M* is a $2d \times 2d$ matrix containing *g* and *B*.

- Sum of the G/H parafermion and a deformed H with a suitable T-duality.
- Identify the deformed model with the coset

$$\frac{G \times H}{H}$$

where H is embedded in both groups.

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	e				



- 3 The 3D Black String
- 4 3D Black String with Fluxes
- 5 Spectra

6 Conclusions

伺をすきをすきた。

1

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_a \mathbf{h}_a \int \, \mathrm{d}z^2 \, J^a(z) \bar{I}_G(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

Highlights

Simple geometric description...

- cfit interpretation.

- Sact all-order solution-

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

- Simple geometric description.
- cit interpretation.
- a Exact all-order solution

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

Highlights

Simple geometric description.

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

Highlights

- Simple geometric description.
- cft interpretation.
- Exact all-order solution.
- The limiting geometry is the coset by left action.

200

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

- Simple geometric description.
- cft interpretation.
- Exact all-order solution.
- The limiting geometry is the coset by left action.

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

- Simple geometric description.
- cft interpretation.
- Exact all-order solution.
- The limiting geometry is the coset by left action.

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

- Simple geometric description.
- cft interpretation.
- Exact all-order solution.
- The limiting geometry is the coset by left action.

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	●000	00	000000	00	0

The Action

$$S = S_{wzw}(G) + \sum_{a} \mathbf{h}_{a} \int dz^{2} J^{a}(z) \overline{I}_{G}(z)$$

- $J(z)^a$ is a holomorphic current in the torus of the G group
- $\bar{I}_G(z)$ is an external right-moving current (in heterotic strings comes from the gauge sector).

- Simple geometric description.
- cft interpretation.
- Exact all-order solution.
- The limiting geometry is the coset by left action.

Asymmetric Deformations						
0000	Al Asymmetric Deform 0 0	ations The 3d Black String 00	Fluxes 000000	oo	o	

The Geometry

Metric of the squashed group

$$\langle \mathrm{d}g, \mathrm{d}g \rangle_{\mathsf{h}} = \sum_{\mu} J_{\mu} \otimes J_{\mu} + \sum_{a} \left(1 - 2\mathsf{h}_{a}^{2} \right) J_{a} \otimes J_{a}$$

Kalb--Ramond field

$$H_{[3]} = \frac{1}{2} f_{mnp} J^m \wedge J^n \wedge J^p - 2 \sum_a h_a^2 f_{anp} J^a \wedge J^n \wedge J^p$$

• a $U(1)^{\operatorname{rank}(G)}$ gauge field:

$$F^a=\sqrt{rac{k}{2k_g}}{
m h}_a f^a_{\ \mu
u}J^\mu\wedge J^
u$$

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0

The Geometry

• Metric of the squashed group

$$\langle dg, dg \rangle_{\mathsf{h}} = \sum_{\mu} J_{\mu} \otimes J_{\mu} + \sum_{a} \left(1 - 2\mathsf{h}_{a}^{2} \right) J_{a} \otimes J_{a}$$

Kalb--Ramond field

$$H_{[3]} = \frac{1}{2} f_{mnp} J^m \wedge J^n \wedge J^p - 2 \sum_a h_a^2 f_{anp} J^a \wedge J^n \wedge J^p,$$

• a $U(1)^{\operatorname{rank}(G)}$ gauge field:

$$F^a = \sqrt{rac{k}{2k_g}} {\sf h}_a f^a{}_{\mu
u} J^\mu \wedge J^
u$$

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0

The Geometry

• Metric of the squashed group

$$\langle dg, dg \rangle_{\mathsf{h}} = \sum_{\mu} J_{\mu} \otimes J_{\mu} + \sum_{a} \left(1 - 2\mathsf{h}_{a}^{2} \right) J_{a} \otimes J_{a}$$

Kalb--Ramond field

$$H_{[3]} = \frac{1}{2} f_{\mathsf{mnp}} J^{\mathsf{m}} \wedge J^{\mathsf{n}} \wedge J^{\mathsf{p}} - 2 \sum_{a} \mathsf{h}_{a}^{2} f_{a\mathsf{np}} J^{a} \wedge J^{\mathsf{n}} \wedge J^{\mathsf{p}},$$

• a $U(1)^{\operatorname{rank}(G)}$ gauge field:

$$F^a = \sqrt{rac{k}{2k_g}} {\sf h}_a f^a{}_{\mu
u} J^\mu \wedge J^
u$$

200

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000	0000	00	000000	00	0

The Geometry

• Metric of the squashed group

$$\langle dg, dg \rangle_{\mathsf{h}} = \sum_{\mu} J_{\mu} \otimes J_{\mu} + \sum_{a} \left(1 - 2\mathsf{h}_{a}^{2} \right) J_{a} \otimes J_{a}$$

Kalb--Ramond field

$$H_{[3]} = \frac{1}{2} f_{\mathsf{mnp}} J^{\mathsf{m}} \wedge J^{\mathsf{n}} \wedge J^{\mathsf{p}} - 2 \sum_{a} \mathsf{h}_{a}^{2} f_{a\mathsf{np}} J^{a} \wedge J^{\mathsf{n}} \wedge J^{\mathsf{p}},$$

• a $U(1)^{\operatorname{rank}(G)}$ gauge field:

$$F^a = \sqrt{rac{k}{2k_g}} \mathbf{h}_a f^a_{\ \mu
u} J^\mu \wedge J^
u$$
A	Defense	•			
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- Just metric and U(1)^{rank(G)} electric/magnetic field.

A	Defense	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- ullet Just metric and $U(1)^{\mathrm{rank}(G)}$ electric/magnetic field.

A	Defense	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- ullet Just metric and $U(1)^{\mathrm{rank}(G)}$ electric/magnetic field.

伺 ト イ ヨ ト イ ヨ ト

A	Defense	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1			
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- Just metric and $U(1)^{\mathrm{rank}(G)}$ electric/magnetic field.

伺下 イヨト イヨト

00000	0000	00	000000	00	0
A					

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- Just metric and $U(1)^{\operatorname{rank}(G)}$ electric/magnetic field.

伺下 イヨト イヨト

00000	0000	00	000000	00	0
A					

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No *B* field.

ullet Just metric and $U(1)^{\mathrm{rank}(G)}$ electric/magnetic field.

何トイヨトイヨト

00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.

• Just metric and $U(1)^{\operatorname{rank}(G)}$ electric/magnetic field.

何トイヨトイヨト

00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Limit case

- Limit value for the deformation parameter $h = 1/\sqrt{2}$
- rank(G) directions decompactify
- Metric of the left action coset G/H
- Most simple case: $AdS_2 \times S^2$
- Flag spaces
- Asymmetric coset (mathematically)
- Kähler geometry. No B field.
- Just metric and $U(1)^{rank(G)}$ electric/magnetic field.

く 同 ト く ヨ ト く ヨ ト 一

There	are	more	things	in	heaven	and	earth	
00000	0000		00			000000	00	0
General	Asymme	tric Deformati	ons The	3d Blac	ck String	Fluxes	Spectra	Conclusions

- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's c-theorem
 - Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Technon condensation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

Compact groups: Zamolodchikov's c-theorem
 Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's *c*-theorem
- Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's c-theorem
- Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation

There	are	more	things	in	heaven	and	earth	
00000	0000		00			000000	00	0
General	Asymme	tric Deformati	ons The	3d Bla	ck String	Fluxes	Spectra	Conclusions

- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's *c*-theorem
- Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's *c*-theorem
- Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation
- Pair creation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's *c*-theorem
- Degrees of freedom decrease with the flow

Physically

- Relaxation of the original unstable vacuum
- Tachyon condensation

Pair creation



- Current-current deformations are in general the only truly marginal ones.
- Other operators are possible. At best marginally relevant or almost relevant.

Renormalization Group flow

- Compact groups: Zamolodchikov's *c*-theorem
- Degrees of freedom decrease with the flow

- Relaxation of the original unstable vacuum
- Tachyon condensation
- Pair creation

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	e				

- 1 Techniques and General Background
- 2 Asymmetric Deformations
- The 3d Black String
- 4 3D Black String with Fluxes
- 5 Spectra
- 6 Conclusions

伺をすきをすきた。

Э

Horne	and Horowitz'	Black S	tring		
00000	0000	•0	000000	00	0
General	Asymmetric Deformations	The 3d Black Stri	ng Fluxes	Spectra	Conclusions

- Witten's $SL(2,\mathbb{R})/U(1)$ two-dimensional black hole
- Generalization to three dimensions as an axial SL(2, R) × R/R gauging (Horowitz and Horne)
 Low energy fields:

$$ds^{2} = -\left(1 - \frac{M}{r}\right) dt^{2} + \left(1 - \frac{Q^{2}}{Mr}\right) dx^{2} + \frac{dr^{2}}{\left(1 - \frac{M}{r}\right)\left(1 - \frac{Q^{2}}{Mr}\right) 8r^{2}}$$
$$H = \frac{Q}{r^{2}} dt \wedge dx \wedge dr$$
$$\Phi = \log r$$

• *M* is the mass, *Q* the charge (with respect to the Kalb--Ramond field)

3

Sac



 \bullet Witten's $\mathit{SL}(2,\mathbb{R})/\mathit{U}(1)$ two-dimensional black hole

Generalization to three dimensions as an axial SL(2, R) × R/R gauging (Horowitz and Horne)
 Low energy fields:

$$ds^{2} = -\left(1 - \frac{M}{r}\right) dt^{2} + \left(1 - \frac{Q^{2}}{Mr}\right) dx^{2} + \frac{dr^{2}}{\left(1 - \frac{M}{r}\right) \left(1 - \frac{Q^{2}}{Mr}\right) 8r^{2}}$$
$$H = \frac{Q}{r^{2}} dt \wedge dx \wedge dr$$
$$\Phi = \log r$$

• *M* is the mass, *Q* the charge (with respect to the Kalb--Ramond field)

Sar



- Witten's $SL(2,\mathbb{R})/U(1)$ two-dimensional black hole
- Generalization to three dimensions as an axial $SL(2, \mathbb{R}) \times \mathbb{R}/\mathbb{R}$ gauging (Horowitz and Horne)

Low energy fields:

$$ds^{2} = -\left(1 - \frac{M}{r}\right) dt^{2} + \left(1 - \frac{Q^{2}}{Mr}\right) dx^{2} + \frac{dr^{2}}{\left(1 - \frac{M}{r}\right) \left(1 - \frac{Q^{2}}{Mr}\right) 8r}$$
$$H = \frac{Q}{r^{2}} dt \wedge dx \wedge dr$$

 $\Phi = \log r$

• *M* is the mass, *Q* the charge (with respect to the Kalb--Ramond field)

Sar

< 注 > < 注 >

< 17 ▶



- Witten's $SL(2,\mathbb{R})/U(1)$ two-dimensional black hole
- Generalization to three dimensions as an axial $SL(2,\mathbb{R}) \times \mathbb{R}/\mathbb{R}$ gauging (Horowitz and Horne)
- Low energy fields:

$$ds^{2} = -\left(1 - \frac{M}{r}\right) dt^{2} + \left(1 - \frac{Q^{2}}{Mr}\right) dx^{2} + \frac{dr^{2}}{\left(1 - \frac{M}{r}\right) \left(1 - \frac{Q^{2}}{Mr}\right) 8r^{2}}$$
$$H = \frac{Q}{r^{2}} dt \wedge dx \wedge dr$$
$$\Phi = \log r$$

• *M* is the mass, *Q* the charge (with respect to the Kalb--Ramond field)

Horne	and Horowitz'	Black Strin	าฮ		
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- . For $p \gg 1$ the black string is the $f_0 f_0$ deformation. For $p \ll 1$ there is an analytic continuation and we go to $f_0 f_0$
 - $\mu = 1$ is a singular point (in moduli space) and
 - corresponds to the plan deformation.

・ロト ・四ト ・ヨト・



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\overline{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- . For $p \gg 1$ the black string is the $f_0 f_2$ deformation. For $p \ll 1$ there is an analytic continuation and we go to $f_0 f_2$.
 - p = 1 is a singular point (in moduli space) and

イロト イポト イヨト イヨト



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model

• Only the combination $\mu = Q/M$ is physical.

In detail

For μ > 1 the black string is the f₂/₂ deformation
 For μ < 1 there is an analytic continuation and we go to f₂/₃.
 μ = 1 is a singular point (in moduli space) and

イロト イポト イヨト イヨト



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

For p > 1 the black string is the J₂J₂ deformation
 For p < 1 there is an analytic continuation and we go to J₀J₃
 p = 1 is a singular point (in moduli space) and corresponds to the T¹T¹ deformation.

• □ ▶ • @ ▶ • E ▶ • E ▶



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- For $\mu > 1$ the black string is the $J_2 \overline{J}_2$ deformation
- For $\mu < 1$ there is an analytic continuation and we go to $J_3 \bar{J}_3$
- $\mu = 1$ is a singular point (in moduli space) and corresponds to the $J^+\bar{J}^+$ deformation.



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- For $\mu > 1$ the black string is the $J_2 \overline{J}_2$ deformation
- For $\mu < 1$ there is an analytic continuation and we go to $J_3 \bar{J}_3$
- $\mu = 1$ is a singular point (in moduli space) and corresponds to the $J^+\bar{J}^+$ deformation.



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- For $\mu > 1$ the black string is the $J_2 \overline{J}_2$ deformation
- \bullet For $\mu < 1$ there is an analytic continuation and we go to $J_3 \bar{J}_3$
- $\mu = 1$ is a singular point (in moduli space) and corresponds to the $J^+ \overline{J}^+$ deformation.



- The axial gauging is one of the ways to read the effect of a current-current deformation.
- The black-string is a $J\bar{J}$ deformation of the $SL(2,\mathbb{R})$ wzw model
- Only the combination $\mu = Q/M$ is physical.

In detail

- For $\mu > 1$ the black string is the $J_2 \overline{J}_2$ deformation
- \bullet For $\mu < 1$ there is an analytic continuation and we go to $J_3 \bar{J}_3$
- $\mu = 1$ is a singular point (in moduli space) and corresponds to the $J^+\bar{J}^+$ deformation.

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra 00	Conclusions O
Outlin	e				

- 1 Techniques and General Background
- 2 Asymmetric Deformations
- 3 The 3D Black String
- 4 3d Black String with Fluxes

5 Spectra

6 Conclusions

伺をすきをすきた。

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes •00000	Spectra 00	Conclusions O
More	defomations				

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int dz^2 J \bar{J} + \mathbf{h} \int dz^2 J \bar{I}$$

Nothing new under the sun

- For SU(2)

- \sim For $SL(2, \mathbb{R})$ with J_3 deformation.
- Here black string with electric flux. Two true

parameters (mass and charge).

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes ●00000	Spectra 00	Conclusions O
More of	defomations				

- After the $J\bar{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \mathrm{d}z^2 J \bar{J} + \mathbf{h} \int \mathrm{d}z^2 J \bar{I}$$

Nothing new under the sun

◦ For SU(2)

- For SL(2, IR) with f₃ deformation.
- Here black string with electric flux. Two trues

parameters (mass and charge).

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes •00000	Spectra 00	Conclusions O
More of	defomations				

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \, \mathrm{d} z^2 \, J \bar{J} + \mathsf{h} \int \, \mathrm{d} z^2 \, J \bar{I}$$

Nothing new under the sun

- For SU(2)
- For SL(2, R) with I₃ deformation.
- Here black string with electric flux. Two tri

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes ●00000	Spectra 00	Conclusions O
More of	defomations				

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \, \mathrm{d} z^2 \, J \bar{J} + \mathbf{h} \int \, \mathrm{d} z^2 \, J \bar{I}$$

Nothing new under the sun

- For *SU*(2)
- For $SL(2,\mathbb{R})$ with J_3 deformation.
- Here black string with electric flux. Two true parameters (mass and charge).

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes •00000	Spectra 00	Conclusions O
More of	defomations				

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \, \mathrm{d} z^2 \, J \bar{J} + \mathbf{h} \int \, \mathrm{d} z^2 \, J \bar{I}$$

Nothing new under the sun

- For *SU*(2)
- For $SL(2,\mathbb{R})$ with J_3 deformation.
- Here black string with electric flux. Two true parameters (mass and charge).

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes •00000	Spectra 00	Conclusions O
More of	defomations				

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \, \mathrm{d} z^2 \, J \bar{J} + \mathbf{h} \int \, \mathrm{d} z^2 \, J \bar{I}$$

Nothing new under the sun

- For *SU*(2)
- For $SL(2,\mathbb{R})$ with J_3 deformation.

• Here black string with electric flux. Two true parameters (mass and charge).
General 00000	Asymmetric Deformations	The 3d Black String	Fluxes •00000	Spectra 00	Conclusions O
More of	defomations				

Double Deformations

- After the $J\overline{J}$ deformation, the $SL(2,\mathbb{R}) \times SL(2,\mathbb{R})$ isometry is broken to $U(1) \times U(1)$
- Room for another asymmetric deformation

$$\delta S = \delta \kappa \int \, \mathrm{d} z^2 \, J \bar{J} + \mathbf{h} \int \, \mathrm{d} z^2 \, J \bar{I}$$

Nothing new under the sun

- For *SU*(2)
- For $SL(2, \mathbb{R})$ with J_3 deformation.
- Here black string with electric flux. Two true parameters (mass and charge).

Electri	ic Black Branc				
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Electric Black Brane

Local coordinates

$$\begin{split} \frac{1}{k} ds^2 &= -dt^2 + \cos^2 t \frac{\left(\kappa^2 - 2h^2\right)\cos^2 t + \kappa^4 \sin^2 t}{\Delta_{\kappa}(t)^2} d\psi^2 + \\ &- 4h^2 \frac{\cos^2 t \sin^2 t}{\Delta_{\kappa}(t)^2} d\psi \, d\varphi + \sin^2 t \frac{\cos^2 t + \left(\kappa^2 - 2h^2\right)\sin^2 t}{\Delta_{\kappa}(t)^2} d\varphi^2 \\ \frac{1}{k} B &= \frac{\kappa^2 - 2h^2}{\kappa^2} \frac{\cos^2 t}{\Delta_{\kappa}(t)} d\varphi \wedge d\psi \\ F &= 2h \sqrt{\frac{2k}{k_g}} \frac{\sin\left(2t\right)}{\Delta_{\kappa}(t)^2} \left(\kappa^2 d\psi \wedge dt + dt \wedge d\varphi\right) \\ e^{-\Phi} &= \frac{\sqrt{\kappa^2 - 2h^2}}{\Delta_{\kappa}(t)} \end{split}$$

where $\Delta_{\kappa}(t) = \cos^2 t + \kappa^2 \sin^2 t$

DQA

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 00●000	Spectra 00	Conclusions O
Coordi	inates, coordir	nates			

Some technical stuff

define

$$\kappa^2 = \frac{\lambda}{\lambda + 1}$$
$$r = \lambda + \cos \beta$$

curvature

$$\mathcal{R} = 2\frac{2r\left(1+2\lambda\right)-7\lambda\left(1+\lambda\right)-2h^{2}\left(1+\lambda\right)^{2}}{r^{2}}$$

AdS₃ doesn't appear any more (λ → ∞)
 Constant-length Killing vector k = (1 + λ) ∂_ψ + λ∂_φ:

$||k||^{2} = \lambda (1 + \lambda) - 2h^{2} (1 + \lambda)^{2} = \omega^{2}$

Caradi	the second s				
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Some technical stuff

define

$$\kappa^2 = \frac{\lambda}{\lambda + 1}$$
$$r = \lambda + \cos \beta$$

curvature

$$\mathcal{R} = 2\frac{2r\left(1+2\lambda\right)-7\lambda\left(1+\lambda\right)-2h^{2}\left(1+\lambda\right)^{2}}{r^{2}}$$

AdS₃ doesn't appear any more (λ → ∞)
Constant-length Killing vector k = (1 + λ) ∂_ψ + λ∂_φ:

$||k||^{2} = \lambda (1 + \lambda) - 2h^{2} (1 + \lambda)^{2} = \omega^{2}$

-					
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Some technical stuff

define

$$\kappa^2 = \frac{\lambda}{\lambda + 1}$$
$$r = \lambda + \cos \beta$$

curvature

$$\mathcal{R} = 2\frac{2r\left(1+2\lambda\right)-7\lambda\left(1+\lambda\right)-2\mathsf{h}^{2}\left(1+\lambda\right)^{2}}{r^{2}}.$$

AdS₃ doesn't appear any more (λ → ∞)
 Constant-length Killing vector k = (1 + λ) ∂_ψ + λ∂_φ:

$$||k||^{2} = \lambda (1 + \lambda) - 2h^{2} (1 + \lambda)^{2} = \omega^{2}$$

-					
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Some technical stuff

define

$$\kappa^2 = \frac{\lambda}{\lambda + 1}$$
$$r = \lambda + \cos \beta$$

curvature

$$\mathcal{R} = 2\frac{2r\left(1+2\lambda\right)-7\lambda\left(1+\lambda\right)-2\mathsf{h}^{2}\left(1+\lambda\right)^{2}}{r^{2}}$$

• AdS_3 doesn't appear any more $(\lambda \rightarrow \infty)$

• Constant-length Killing vector $k = (1 + \lambda) \partial_{\psi} + \lambda \partial_{\phi}$:

$$||k||^{2} = \lambda (1 + \lambda) - 2h^{2} (1 + \lambda)^{2} = \omega^{2}$$

-					
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Some technical stuff

define

$$\kappa^2 = \frac{\lambda}{\lambda + 1}$$
$$r = \lambda + \cos \beta$$

curvature

$$\mathcal{R} = 2\frac{2r\left(1+2\lambda\right)-7\lambda\left(1+\lambda\right)-2\mathsf{h}^{2}\left(1+\lambda\right)^{2}}{r^{2}}.$$

- AdS_3 doesn't appear any more $(\lambda \rightarrow \infty)$
- Constant-length Killing vector $k = (1 + \lambda) \partial_{\psi} + \lambda \partial_{\phi}$:

$$\left\|k\right\|^{2} = \lambda \left(1 + \lambda\right) - 2\mathbf{h}^{2} \left(1 + \lambda\right)^{2} = \omega^{2}$$

Coord	linatos coor	dinator			
00000	0000	00	000000	00	0
General	Asymmetric Deformation	s The 3d Black String	Fluxes	Spectra	Conclusions

The metric

• Using the Killing vector and continuing on r:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dt^{2} + 2\frac{\omega}{r} dx dt + \omega dx^{2} + \frac{1}{4(r-\lambda)(r-\lambda-1)} dr^{2}$$

- Singular in $r = 0, \lambda, \lambda + 1$
- Volume form $\sqrt{\omega}/(2r) dt \wedge dx \wedge dr$
- Eddington-Finkelstein coordinates:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dT^{2} + 2\frac{\omega}{r} dX dT + \omega dX^{2} - \frac{1}{r} dT$$

Coord	inator	coording	ator				
00000	0000		00		000000	00	0
General	Asymmetric D	Deformations	The 3d Black S	String	Fluxes	Spectra	Conclusions

The metric

• Using the Killing vector and continuing on r:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dt^{2} + 2\frac{\omega}{r} dx dt + \omega dx^{2} + \frac{1}{4(r-\lambda)(r-\lambda-1)} dr^{2}$$

- Singular in $r = 0, \lambda, \lambda + 1$
- Volume form $\sqrt{\omega}/(2r)\,\mathrm{d}t\wedge\,\mathrm{d}x\wedge\,\mathrm{d}r$

Eddington-Finkelstein coordinates:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dT^{2} + 2\frac{\omega}{r} dX dT + \omega dX^{2} - \frac{1}{r} dT dr$$

Coord	inator	coordin	ator				
00000	0000		00	00	00000	00	0
General	Asymmetric I	Deformations	The 3d Black Stri	ing Fl i	uxes	Spectra	Conclusions

The metric

• Using the Killing vector and continuing on r:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dt^{2} + 2\frac{\omega}{r} dx dt + \omega dx^{2} + \frac{1}{4(r-\lambda)(r-\lambda-1)} dr^{2}$$

- Singular in $r = 0, \lambda, \lambda + 1$
- Volume form $\sqrt{\omega}/(2r) \, \mathrm{d}t \wedge \, \mathrm{d}x \wedge \, \mathrm{d}r$

Eddington-Finkelstein coordinates:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dT^{2} + 2\frac{\omega}{r} dX dT + \omega dX^{2} - \frac{1}{r} dT dr$$

Coord	inator	coordin	ator				
00000	0000		00	00	00000	00	0
General	Asymmetric I	Deformations	The 3d Black Stri	ing Fl i	uxes	Spectra	Conclusions

The metric

• Using the Killing vector and continuing on r:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dt^{2} + 2\frac{\omega}{r} dx dt + \omega dx^{2} + \frac{1}{4(r-\lambda)(r-\lambda-1)} dr^{2}$$

- Singular in $r = 0, \lambda, \lambda + 1$
- Volume form $\sqrt{\omega}/(2r) \, \mathrm{d}t \wedge \, \mathrm{d}x \wedge \, \mathrm{d}r$
- Eddington-Finkelstein coordinates:

$$ds^{2} = \left(-1 + \frac{1+2\lambda}{r} - \frac{\lambda(1+\lambda) - \omega}{r^{2}}\right) dT^{2} + 2\frac{\omega}{r} dX dT + \omega dX^{2} - \frac{1}{r} dT dr$$

D	and the second second				
00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Penrose diagram



۹	Two horizons in $r = \lambda$	λ
	and $r = \lambda + 1$	
•	Time-like singularity	in
	r = 0	

0000 0000	0	00	00000	00	0

Other fields

$$F = \pm \frac{\sqrt{2}h(1+\lambda)}{r^2\sqrt{k_g}} dt \wedge dr$$
$$H = \mp \frac{\omega}{r^2} dt \wedge dx \wedge dr$$
$$\Phi = \Phi_* - \frac{1}{2}\log r$$

- Asymptotically is flat space with linear dilaton
- Choose Killing vectors at infinity that preserve the dilaton

00000	0000	00	000000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Other fields

$$F = \pm \frac{\sqrt{2}h(1+\lambda)}{r^2\sqrt{k_g}} dt \wedge dr$$
$$H = \mp \frac{\omega}{r^2} dt \wedge dx \wedge dr$$
$$\Phi = \Phi_* - \frac{1}{2}\log r$$

- Asymptotically is flat space with linear dilaton
- Choose Killing vectors at infinity that preserve the dilaton
- Density of mass and momentum

00000	0000	00	00000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Other fields

$$F = \pm \frac{\sqrt{2}h(1+\lambda)}{r^2\sqrt{k_g}} dt \wedge dr$$
$$H = \mp \frac{\omega}{r^2} dt \wedge dx \wedge dr$$
$$\Phi = \Phi_* - \frac{1}{2}\log r$$

- Asymptotically is flat space with linear dilaton
- Choose Killing vectors at infinity that preserve the dilaton
- Density of mass and momentum

00000	0000	00	00000	00	0
General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions

Other fields

$$F = \pm \frac{\sqrt{2}h(1+\lambda)}{r^2\sqrt{k_g}} dt \wedge dr$$
$$H = \mp \frac{\omega}{r^2} dt \wedge dx \wedge dr$$
$$\Phi = \Phi_* - \frac{1}{2}\log r$$

- Asymptotically is flat space with linear dilaton
- Choose Killing vectors at infinity that preserve the dilaton
- Density of mass and momentum

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	e				

- 1 Techniques and General Background
- 2 Asymmetric Deformations
- 3 The 3D Black String
- 4 3D Black String with Fluxes

5 Spectra

6 Conclusions

く得た くまた くまた

3

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra ●○	Conclusions O
Spect	rum				

- The costruction is motivated by the underlying CFT
- The deformation is a O(2,2) rotation on the abelian subgroup
- Weights for these lattices are:

$$L_0 = \frac{1}{k} \left(\mu + n + \frac{a}{2} \right)^2,$$

$$\bar{L}_0 = \frac{\bar{\mu}^2}{k+2} + \frac{1}{k_g} \left(\bar{n} + \frac{\bar{a}}{2} \right)^2,$$

Deformation driven the operator

$$\mathcal{O} = \kappa^2 \frac{\left(J^2 + \iota \psi_1 \psi_3\right)}{\sqrt{k}} \frac{\bar{J}^2}{\sqrt{k+2}} + \mathsf{h} \frac{\left(J^2 + \iota \psi_1 \psi_3\right)}{\sqrt{k}} \frac{\bar{I}}{\sqrt{k}}$$

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra • O	Conclusions O
Spectr	rum				

- The costruction is motivated by the underlying CFT
- The deformation is a O(2,2) rotation on the abelian subgroup
- Weights for these lattices are:

$$L_{0} = \frac{1}{k} \left(\mu + n + \frac{a}{2} \right)^{2},$$

$$\bar{L}_{0} = \frac{\bar{\mu}^{2}}{k+2} + \frac{1}{k_{g}} \left(\bar{n} + \frac{\bar{a}}{2} \right)^{2},$$

• Deformation driven the operator

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra • O	Conclusions O
Spect	rum				

- The costruction is motivated by the underlying CFT
- The deformation is a O(2,2) rotation on the abelian subgroup
- Weights for these lattices are:

$$L_{0} = \frac{1}{k} \left(\mu + n + \frac{a}{2} \right)^{2},$$

$$\bar{L}_{0} = \frac{\bar{\mu}^{2}}{k+2} + \frac{1}{k_{g}} \left(\bar{n} + \frac{\bar{a}}{2} \right)^{2},$$

Deformation driven the operator

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra ••	Conclusions O
Spectr	rum				

- The costruction is motivated by the underlying CFT
- The deformation is a O(2,2) rotation on the abelian subgroup
- Weights for these lattices are:

$$L_{0} = \frac{1}{k} \left(\mu + n + \frac{a}{2} \right)^{2},$$

$$\bar{L}_{0} = \frac{\bar{\mu}^{2}}{k+2} + \frac{1}{k_{g}} \left(\bar{n} + \frac{\bar{a}}{2} \right)^{2},$$

Deformation driven the operator

$$\mathcal{O} = \kappa^2 \frac{\left(J^2 + \iota \psi_1 \psi_3\right)}{\sqrt{k}} \frac{\overline{J}^2}{\sqrt{k+2}} + \mathsf{h} \frac{\left(J^2 + \iota \psi_1 \psi_3\right)}{\sqrt{k}} \frac{\overline{I}}{\sqrt{k_g}}.$$

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000		00	000000	O	O
Spectr	rum				

Deformed Weights

• Rotation in the anti-holomorphic + boost

$$L_0^{\mathsf{dd}} = \left\{ \frac{1}{\sqrt{k}} \left(\mu + n + \frac{a}{2} \right) \cosh x + \left(\frac{\bar{\mu}}{\sqrt{k+2}} \cos \alpha + \frac{1}{\sqrt{k_g}} \left(\bar{n} + \frac{\bar{a}}{2} \right) \sin \alpha \right) \sinh x \right\}^2,$$

$$\bar{L}_0^{\mathsf{dd}} = \left\{ \left(\frac{\bar{\mu}}{\sqrt{k+2}} \cos \alpha + \frac{1}{\sqrt{k_g}} \left(\bar{n} + \frac{\bar{a}}{2} \right) \sin \alpha \right) \cosh x + \frac{1}{\sqrt{k}} \left(\mu + n + \frac{a}{2} \right) \sinh x \right\}^2$$

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra 00	Conclusions O
Outlin	ne				

- 1) Techniques and General Background
- 2 Asymmetric Deformations
- 3 The 3D Black String
- 4 3D Black String with Fluxes
- 5 Spectra
- 6 Conclusions

3

General	Asymmetric Deformations	The 3d Black String	Fluxes	Spectra	Conclusions
00000		00	000000	00	•
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

イロト イポト イヨト イヨト

1

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

イロト イポト イヨト イヨト

Э

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation.
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

ヘロト 人間 ト イヨト イヨト

Э

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

・ロト ・ 聞 ト ・ 臣 ト ・ 臣 ト

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

 \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

伺 ト イ ヨ ト イ ヨ ト

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

伺 ト イ ヨ ト イ ヨ ト

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.

伺とくヨとくヨと

General 00000	Asymmetric Deformations	The 3d Black String	Fluxes 000000	Spectra	Conclusions •
What	did we see?				

- Current-current deformations
- Asymmetric deformations
- Exact CFT backgrounds with nice geometric properties.

Black String

- Interpretation as a current-current deformation
- Double deformation
- Electric Fields
- Geometric structure
- Spectrum of primary operators.