Charged Nariai black holes on the dark bubble

Vincent Van Hemelryck

Based on 2405.13679 with Ulf Danielsson

UPPSALA UNIVERSITET

String Phenomenology 2024 — Padova

The dark bubble scenario

[Banerjee, Danielsson, Dibitetto, Giri, Schillo, 2018]

Alternative to string compactifications:
dS and accelerated expansion challenging

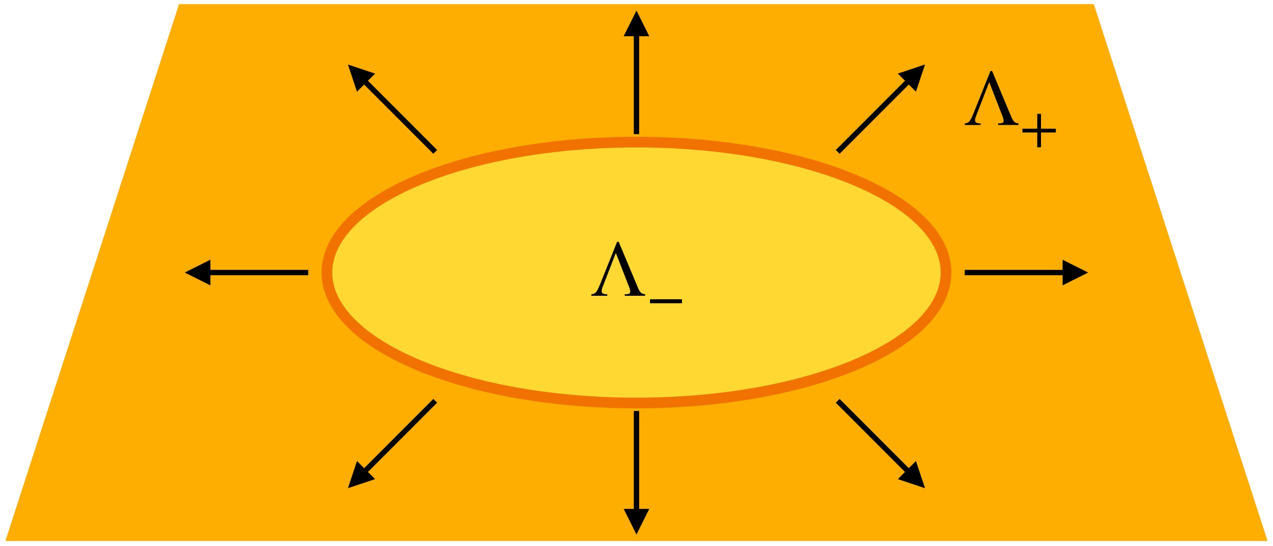
Braneworld model

Unstable AdS_5

Non-perturbative decay: brane nucleation

Codimension-one braneworld different from Randall-Sundrum

Accelerated FLRW cosmology on the bubble wall



$$\Lambda_- < \Lambda_+$$

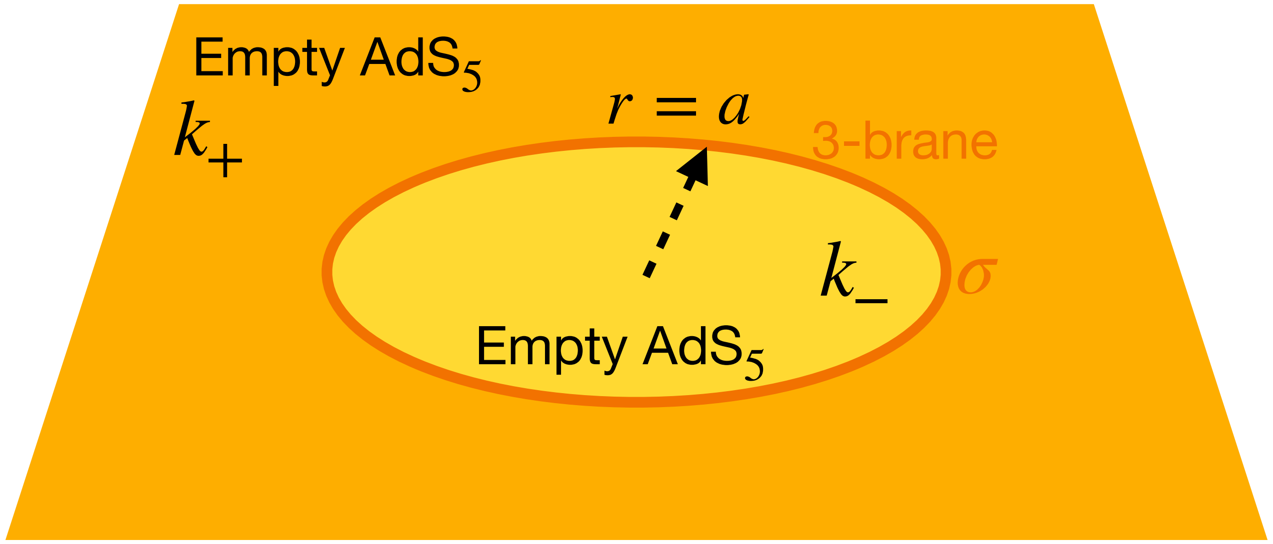
Dynamics of the bubble

Junction conditions

[Banerjee, Danielsson, Dibitetto, Giri, Schillo, 2018]

[Israel, 1966]

$$h^-_{mn} = h^+_{mn}$$



$$\Lambda_\pm = -4k_\pm^2$$

$$k_\pm = 1/L_{\mathrm{AdS},\pm}$$

$$k_+ \lesssim k_-$$

$$k_\pm / M_{\mathrm{Pl},5} \gg 1$$

$$\Delta K_{mn} - h_{mn}\Delta K = -M_{\mathrm{Pl},5}^{-3} S_{mn}$$

In global coordinates, junction conditions = Friedmann equations

$$M_{\mathrm{Pl},4}^2 = \frac{1}{2}\left(\frac{1}{k_+} - \frac{1}{k_-}\right) M_{\mathrm{Pl},5}^3, \qquad M_{\mathrm{Pl},4}^2 \Lambda_4 = 3M_{\mathrm{Pl},5}^3 (k_- - k_+) - \sigma$$

Gravity is stronger in lower dimensional theory ↔ compactifications

Small, positive induced c.c. when $\sigma \lesssim 3M_{\mathrm{Pl},5}^3 (k_- - k_+)$

Some remarks

Physics studied on the brane includes

- (Massive) particles as hanging strings on the brane [Banerjee, Danielsson, Giri, 2020-21]
- Gravitational waves [Danielsson, Panizo, Tielemans, 2022]
- Electromagnetic waves [Basile, Danielsson, Giri, Panizo, 2023]
- …

Some remarks

Physics studied on the brane includes

- (Massive) particles as hanging strings on the brane [Banerjee, Danielsson, Giri, 2020-21]
- Gravitational waves [Danielsson, Panizo, Tielemans, 2022]
- Electromagnetic waves [Basile, Danielsson, Giri, Panizo, 2023]
- …

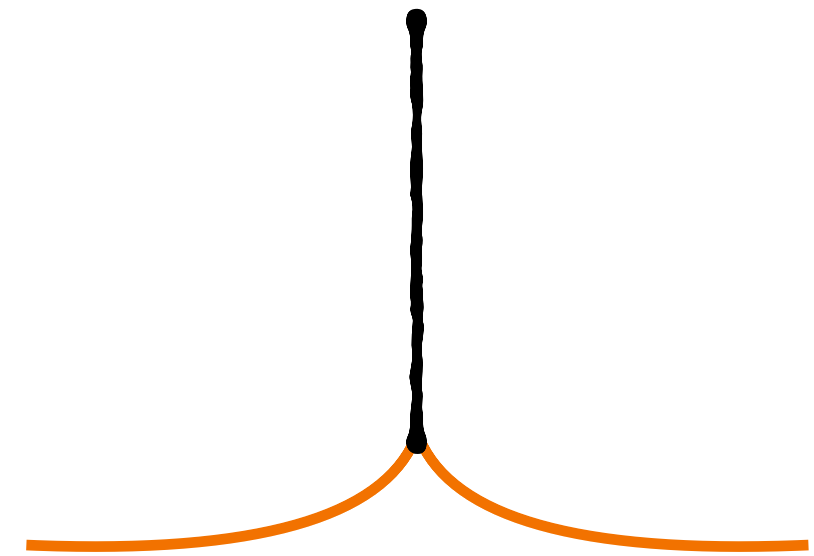
What about black holes?

Black holes on the bubble?

Strings attached on brane bend the brane

→ manifested as particles backreacting with BH geometry

[Banerjee, Danielsson, Giri, 2020]

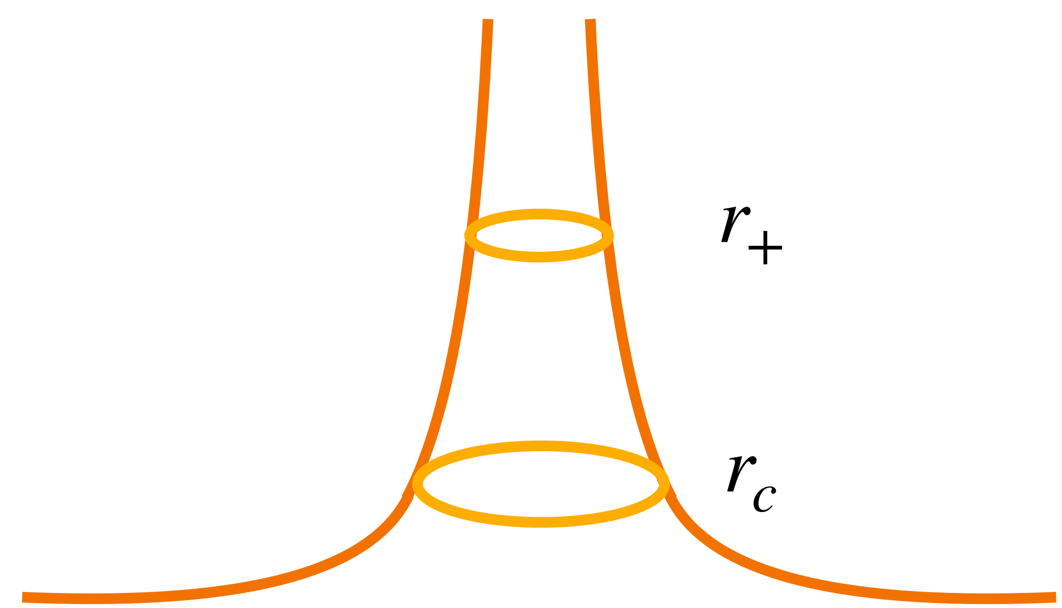


But these are no large black holes

What about large BHs?
→ more extreme bending, “thick strings”

“Take the textbook pictures of BHs seriously”

Goal: RN-dS as induced geometry



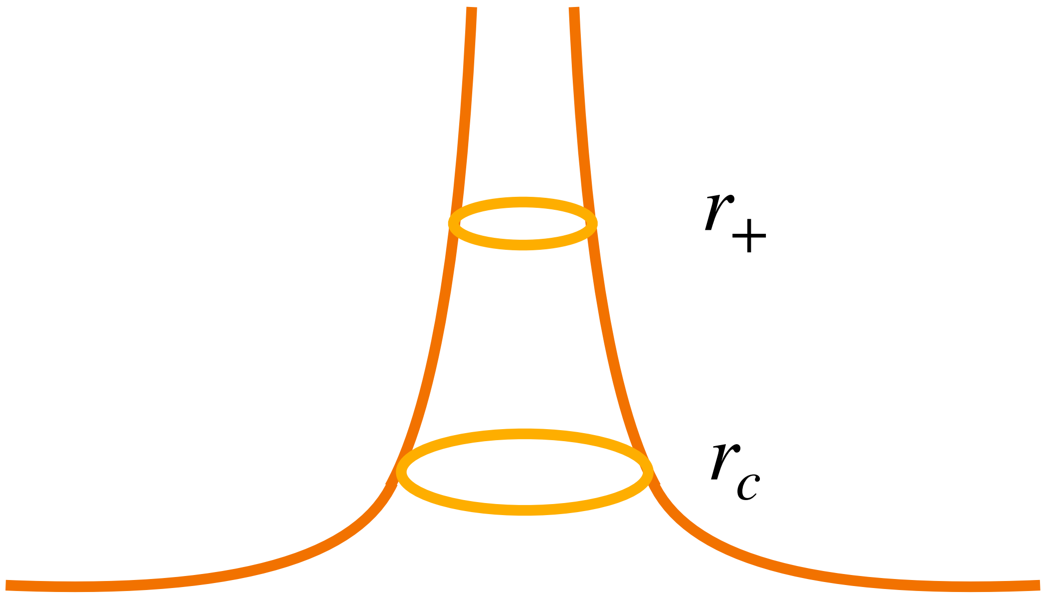
Black holes on the bubble?

[Danielsson, VVH, 2024]

Consider Nariai-limit

$r_+ \rightarrow \leftarrow r_c$

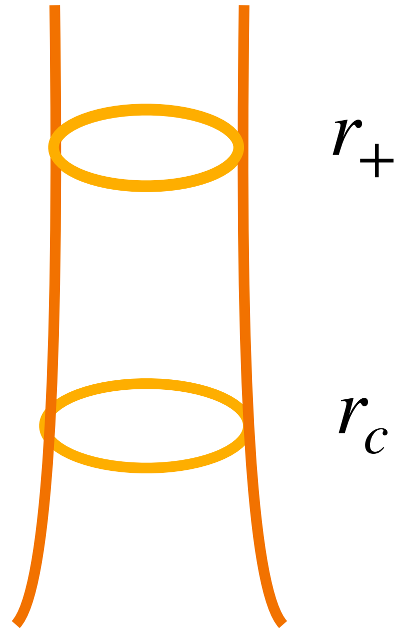
Two horizons become indistinguishable



Geometry becomes $\mathrm{dS}_2 \times S^2$

In the brane embedding, local geometry becomes cylindrical

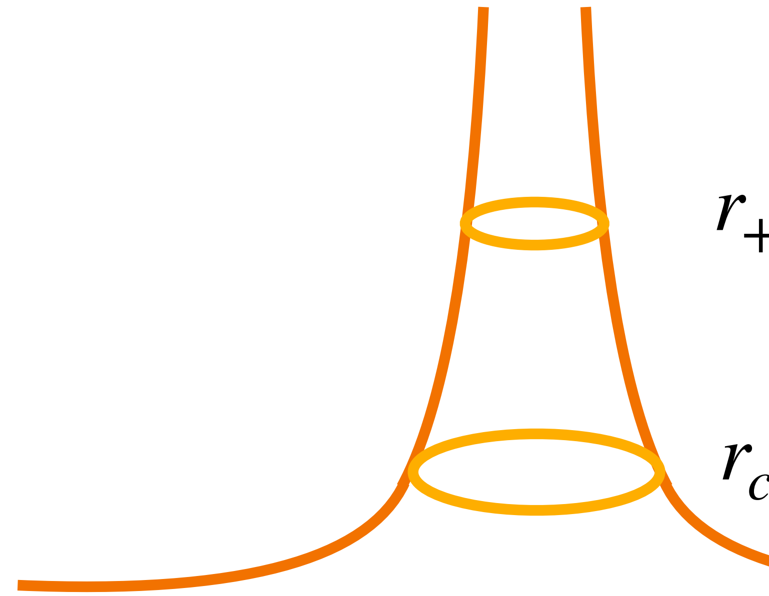
$\rightarrow$ Cylindrical embedding necessary



Black holes on the bubble?

[Danielsson, VVH, 2024]

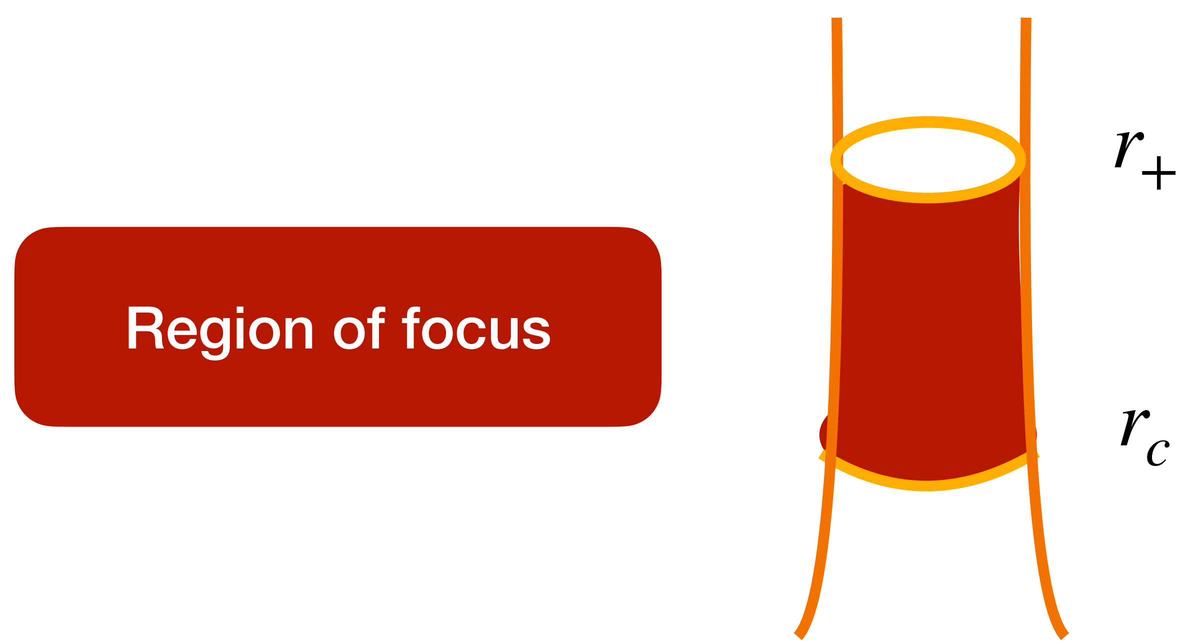
Consider Nariai-limit



$r_+ \rightarrow \leftarrow r_c$

Two horizons become indistinguishable

Geometry becomes $\mathrm{dS}_2 \times S^2$

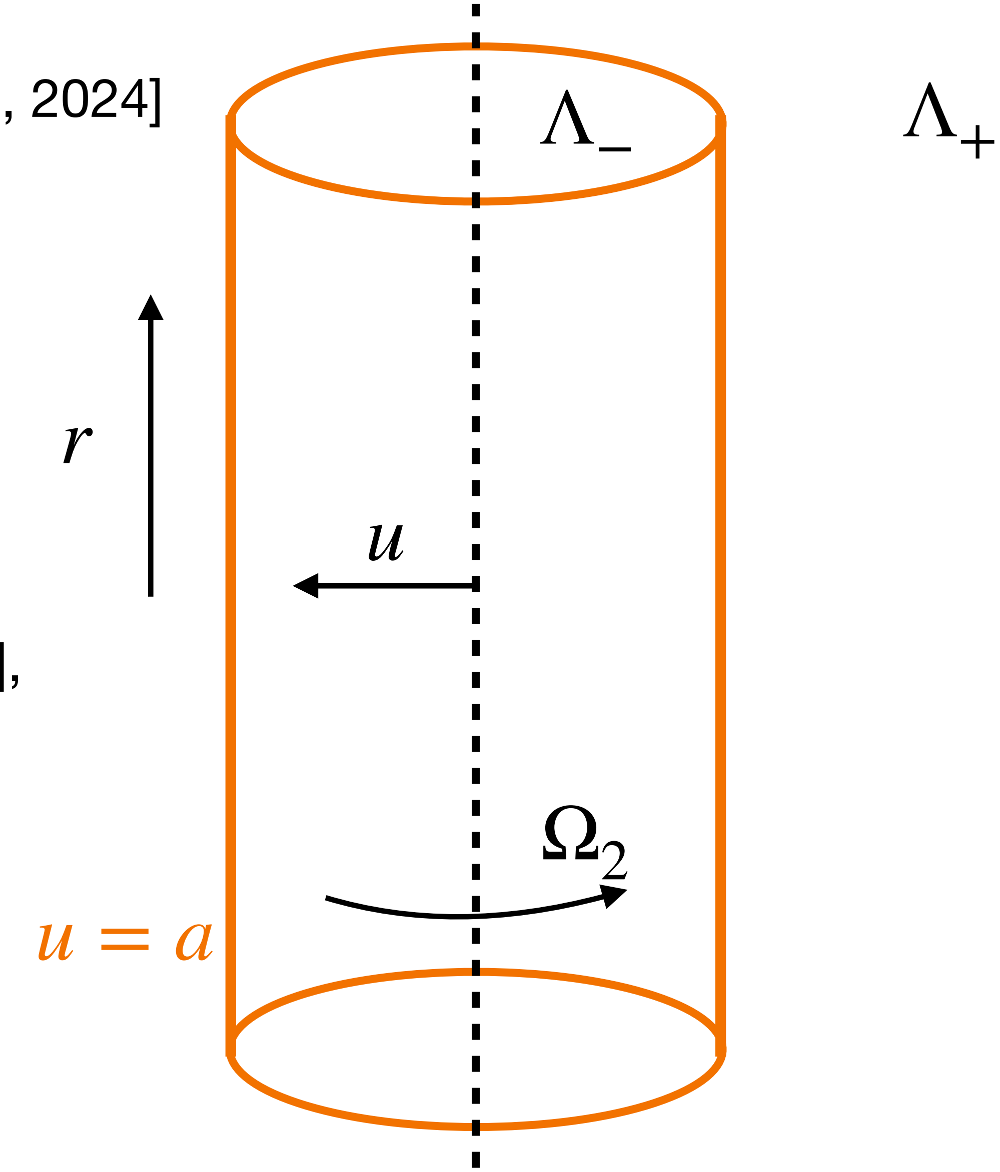


In the brane embedding, local geometry becomes cylindrical

$\rightarrow$ Cylindrical embedding necessary

Nariai geometry from black strings

[Danielsson, VVH, 2024]



5d background becomes a "magnetic" black string background in AdS_5

[Bernamonti, Caldarelli, Klemm, Olea, Sieg, 2007], [Mann, Radu, Stelea, 2006], …

Glue such two backgrounds together

NSNS action

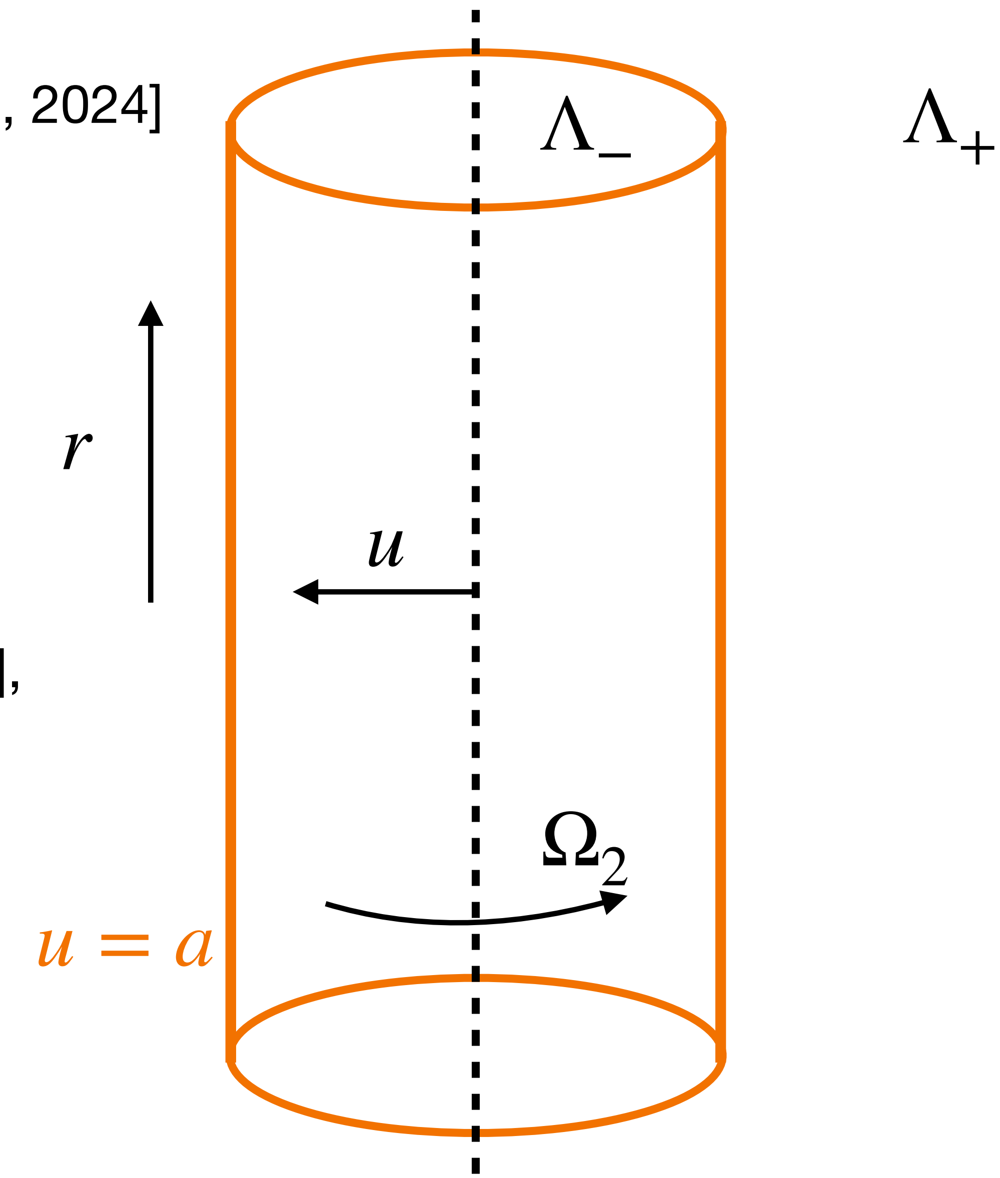
$$S_5 = \frac{1}{2\kappa_5^2}\int \mathrm{d}x^5\sqrt{-g_5}\left(R_5 + 12k^2 - \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}\mathrm{e}^{-(\phi-\phi_0)}\,|\,H_3\,|^2\right)$$

$$\mathrm{d}s_5^2 = f(u)\left(-\mathrm{d}t^2 + dr^2\right) + u^2\mathrm{d}\Omega_2 + \frac{\mathrm{d}u^2}{w(u)}$$

$$\star_5\, H_3 = q\ \mathrm{vol}_{S^2}$$

Nariai geometry from black strings

[Danielsson, VVH, 2024]



5d background becomes a "magnetic" black string background in AdS_5

[Bernamonti, Caldarelli, Klemm, Olea, Sieg, 2007], [Mann, Radu, Stelea, 2006], ...

Glue such two backgrounds together

NSNS action

$$S_5 = \frac{1}{2\kappa_5^2} \int \mathrm{d}x^5 \sqrt{-g_5} \left(R_5 + 12k^2 - \frac{1}{2}(\partial\phi)^2 - \frac{1}{2} \mathrm{e}^{-(\phi-\phi_0)} |H_3|^2 \right)$$

$$\mathrm{d}s_5^2 = f(u) \left(-\left(1 - k_2^2 r^2\right) \mathrm{d}t^2 + \frac{\mathrm{d}r^2}{1 - k_2^2 r^2} \right) + u^2 \mathrm{d}\Omega_2 + \frac{\mathrm{d}u^2}{w(u)},$$

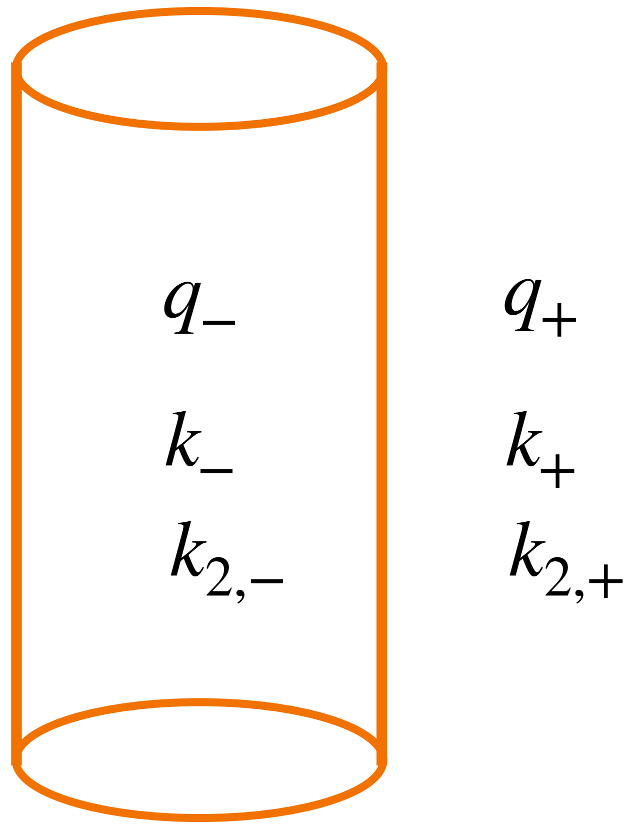
$$\star_5 H_3 = q \, \mathrm{vol}_{S^2}$$

Glue two backgrounds together

DBI of D3-brane

$$S_{\text{brane}} = -\sigma \int \mathrm{d}x^4 \sqrt{-\det(h_{mn} + \tau\mathcal{F}_{mn})} \text{ with } \tau\mathcal{F} = \tau F + B$$

$$\mathrm{d} \star_5 H \propto \star_4 \mathcal{F} \wedge \delta(u-a)\mathrm{d}u$$



+ other parameters

Functions $f_\pm(u)$ and $w_\pm(u)$ not known analytically, double expansion required in $\frac{k_{2\pm}^2}{k_\pm^2}$ and $\frac{1}{(k_\pm u)^2}$

Solving junction conditions

$f_\pm(a)$
$w_\pm(a)$

$$\left(K^+_{mn} - K^-_{mn}\right) - h_{mn}(K^+ - K^-) = -\kappa_5^2 S_{mn}$$

Einstein equations for Nariai background!

$$-\frac{1}{a^2} = -\frac{Q^2}{a^4} - \Lambda_4$$

$$-k_2^2 = +\frac{Q^2}{a^4} - \Lambda_4$$

Λ_4 and Q functions of σ, $k_\pm$, $q_\pm$, $c_{r\pm}$

Solving junction conditions

$f_\pm(a)$
$w_\pm(a)$

$$\left(K^+_{mn} - K^-_{mn}\right) - h_{mn}(K^+ - K^-) = -\kappa_5^2 S_{mn}$$

$$S = \int \sqrt{-g_4}\left(R_4 - 2\Lambda_4 - \frac{1}{2}|F|^2\right)$$

$$\mathrm{d}s_4^2 = -(1 - k_2^2 r^2)\mathrm{d}t^2 + \frac{\mathrm{d}r^2}{1 - k_2^2 r^2} + a^2 \mathrm{d}\Omega_2$$

$$F = \frac{2Q}{a^2}$$

Einstein equations for Nariai background!

$$-\frac{1}{a^2} = -\frac{Q^2}{a^4} - \Lambda_4$$

$$-k_2^2 = +\frac{Q^2}{a^4} - \Lambda_4$$

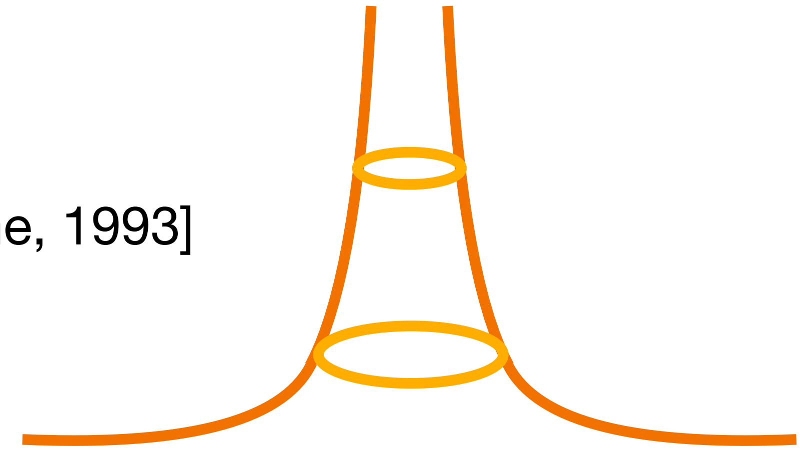
Λ_4 and Q functions of σ, $k_\pm$, $q_\pm$, $c_{r\pm}$

Conclusions

- Charged Nariai geometry ($\mathrm{dS}_2 \times S^2$) on the dark bubble
- Glueing modified magnetic black string solutions together
- Junction conditions $\rightarrow$ 4d Nariai Einstein equations
- $\alpha_{\mathrm{EM}} = \frac{3}{2} g_s$ from energy conservation as in [Danielsson, Panizo, 2023] from string embedding

Future directions:

- Instability analysis from 4d and 5d   à la [Gregory, Laflamme, 1993]
- Going beyond Nariai limit



Thank you!