

# Islands in the Randall-Sundrum model

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Based on 2006.04851 + WIP  
with Chen, Myers, Neuenfeld, Sandor

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# Outline

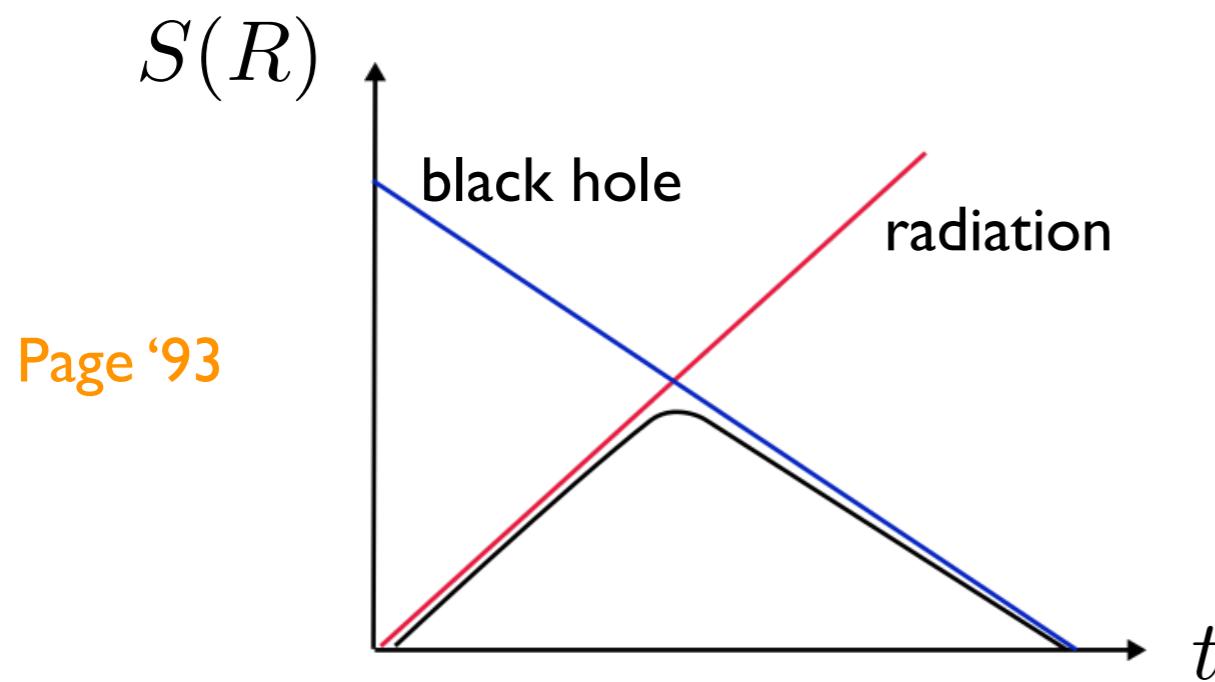
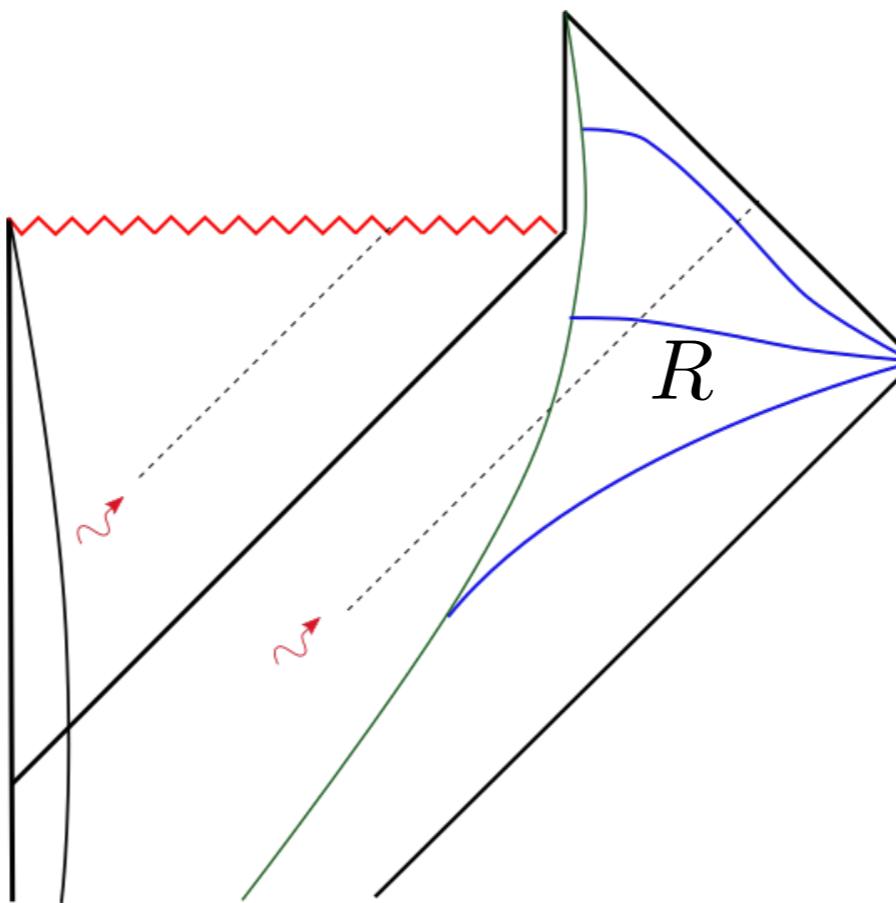
Information paradox & recent progress

Our model: islands on the brane

Topological black holes

# An old question...

Entropy of  
radiation in time

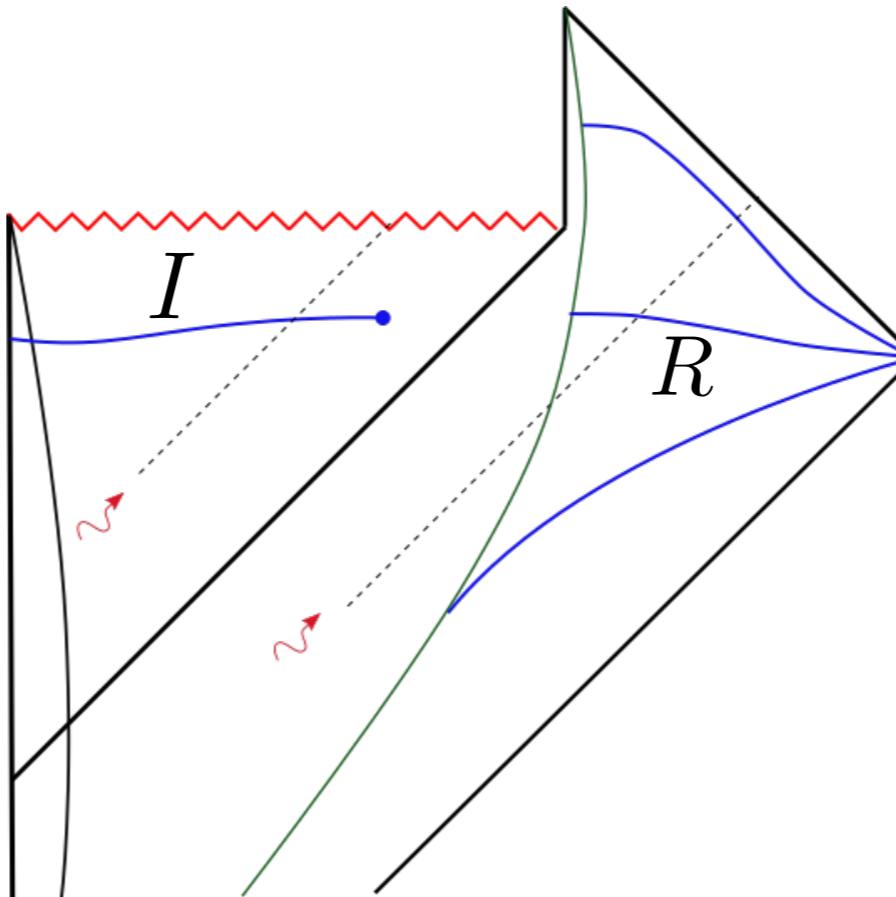


Unitarity  $\rightarrow$  ‘Page curve’

But how?

# A new answer

Page curve from  
semiclassical gravity



Almehiri-Engelhardt-Marolf-Maxfield,  
Pennington,  
Almehiri-Mahajan-Maldacena-Zhao, ...

‘Island’ formula

$$S(R) = \min_I \left[ \text{ext} \left( \frac{A(\partial I)}{4G} + S_{\text{semi-cl}}(R \cup I) \right) \right]$$

Useful if : gravity (BH) + no-gravity (Rad) are entangled

Still a bit mysterious... how can we make it easy ? **2006.04851**

- Islands in a more familiar holographic setup ?
- Natural setting for gravity + no-gravity entangled ?
- Explicit models in 2d → higher dimensions ?

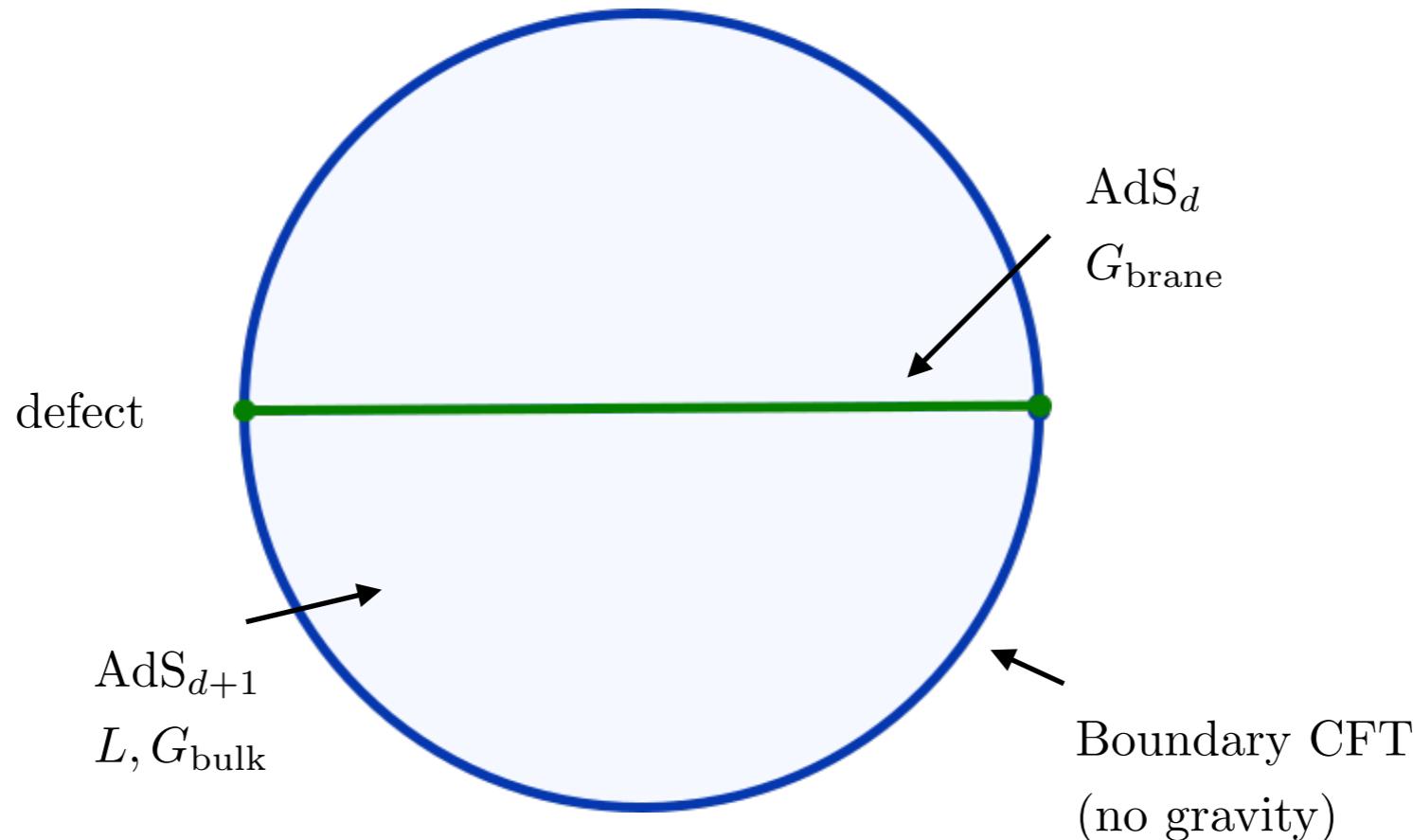
JT gravity

Einstein gravity

# **Islands on the brane**

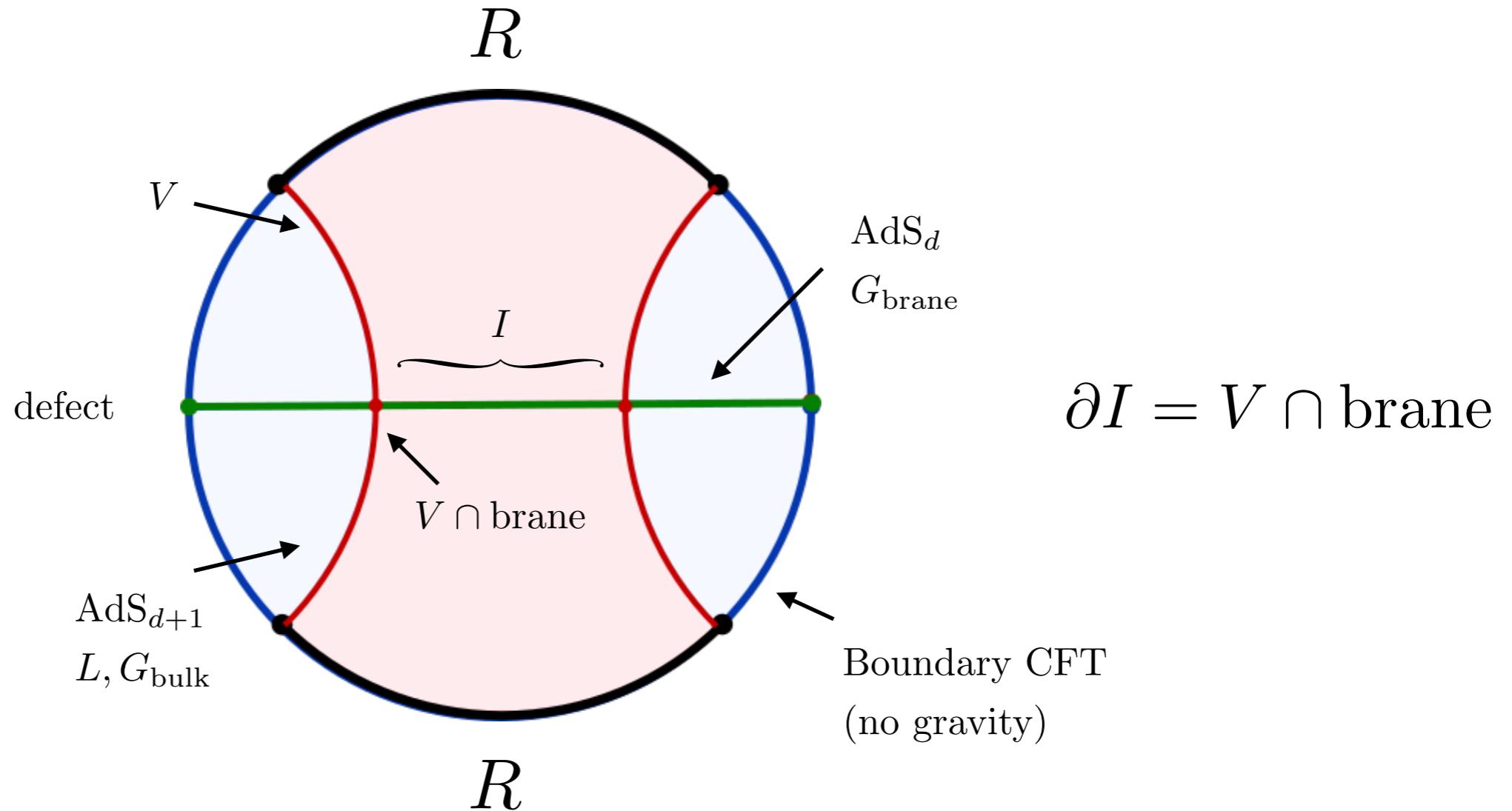
# Our model: islands on the brane

Karch-Randall '00



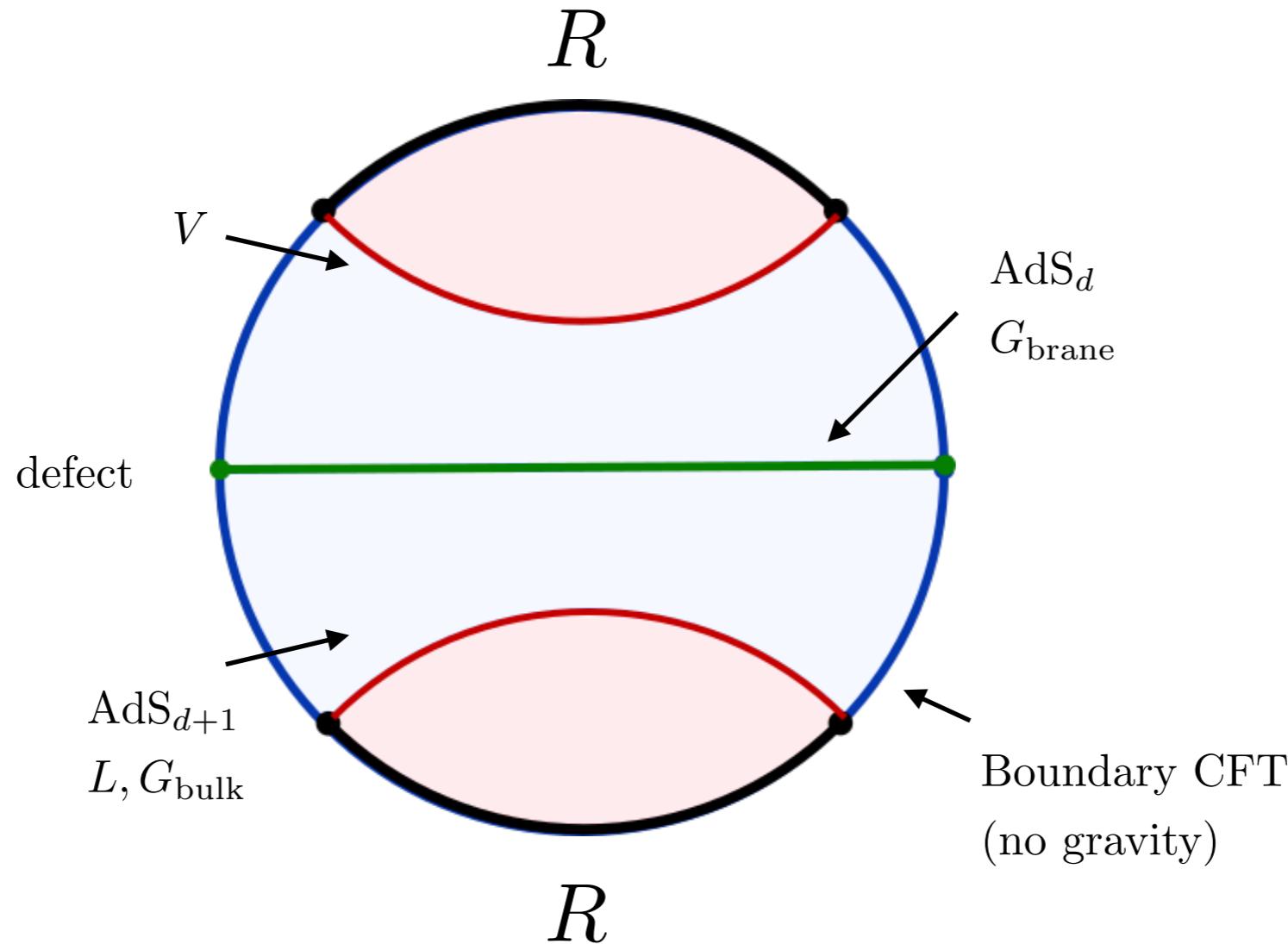
Almehiri-Mahajan-Maldacena-Zhao '19  
Rozali-Sully-Van Raamsdonck-Waddell-Wakeham '19

# Our model: islands on the brane



$$S_{\text{EE}}(R) = \min \left[ \underset{V}{\text{ext}} \left( \frac{A(V)}{4G_{\text{bulk}}} + \frac{A(\partial I)}{4G_{\text{brane}}} \right) \right]$$

# Our model: islands on the brane



$$S_{\text{EE}}(R) = \min \left[ \underset{V}{\text{ext}} \left( \frac{A(V)}{4G_{\text{bulk}}} + \frac{A(\partial I)}{4\cancel{G}_{\text{brane}}} \right) \right]$$

# Bulk picture

$$I = I_{\text{bulk}} + I_{\text{brane}}$$

$$I_{\text{bulk}} = \frac{1}{16\pi G_{\text{bulk}}} \int d^{d+1}x \sqrt{-g} \left( R(g) + \frac{d(d-1)}{L^2} \right)$$

$$I_{\text{brane}} = -T \int d^d x \sqrt{-\tilde{g}} + \frac{1}{16\pi G_{\text{brane}}} \int d^d x \sqrt{\tilde{g}} \tilde{R}(\tilde{g})$$

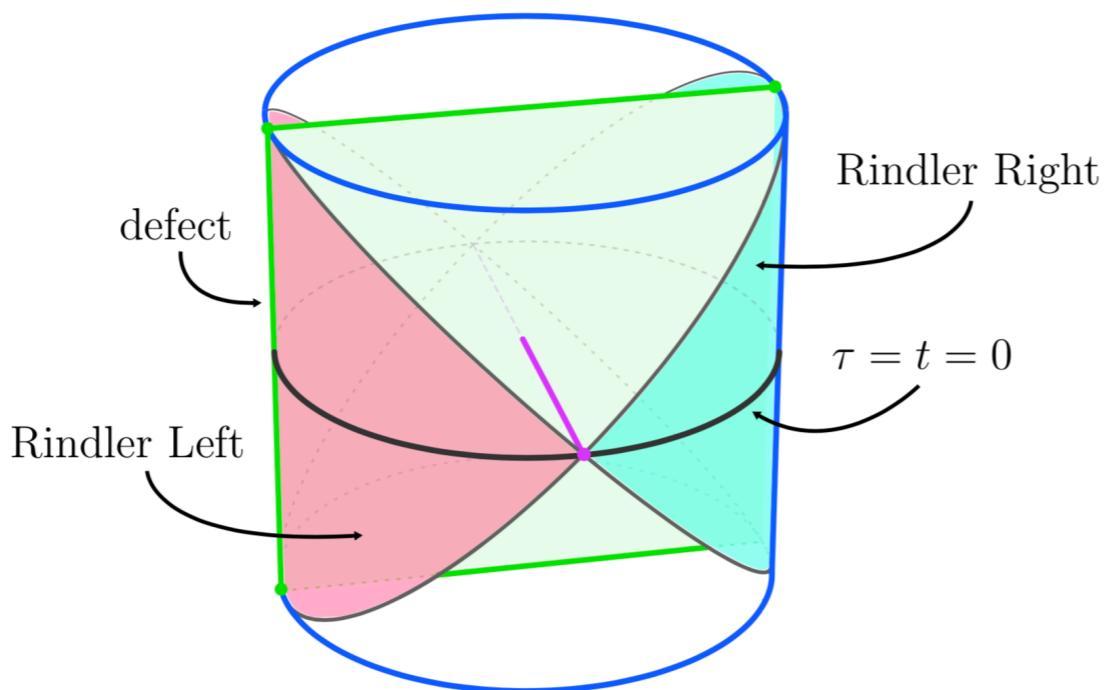
Theory on the brane  $\rightarrow$  Einstein gravity regime

Two contributions combine in replica to give the island formula!

How to get a Page curve?

# Topological black hole and Page curve

# Topological black hole

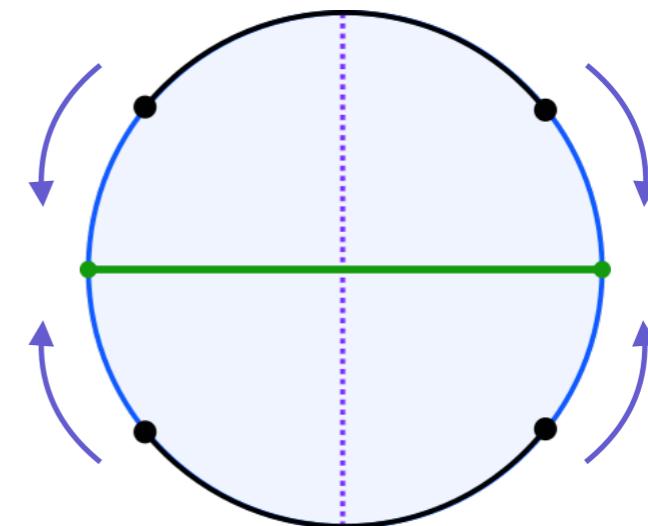
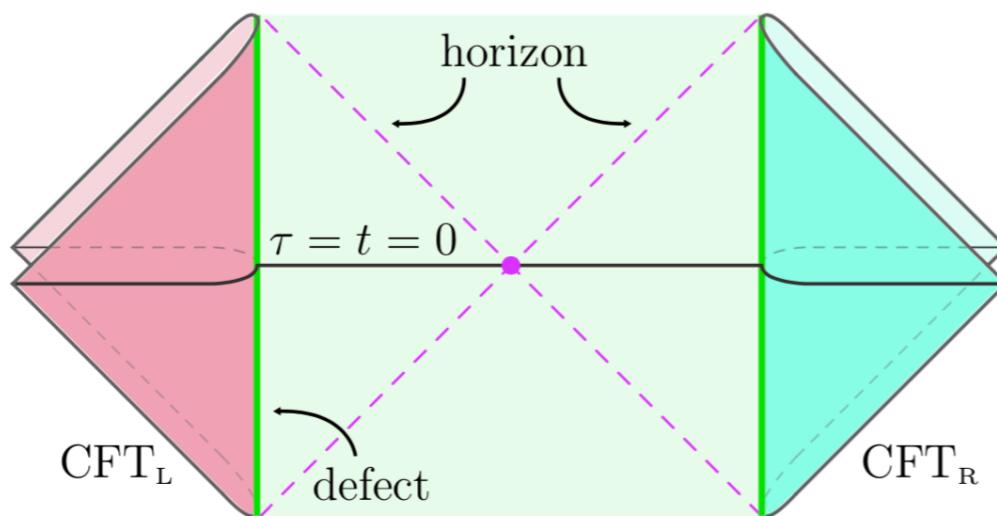


AdS-Rindler coords

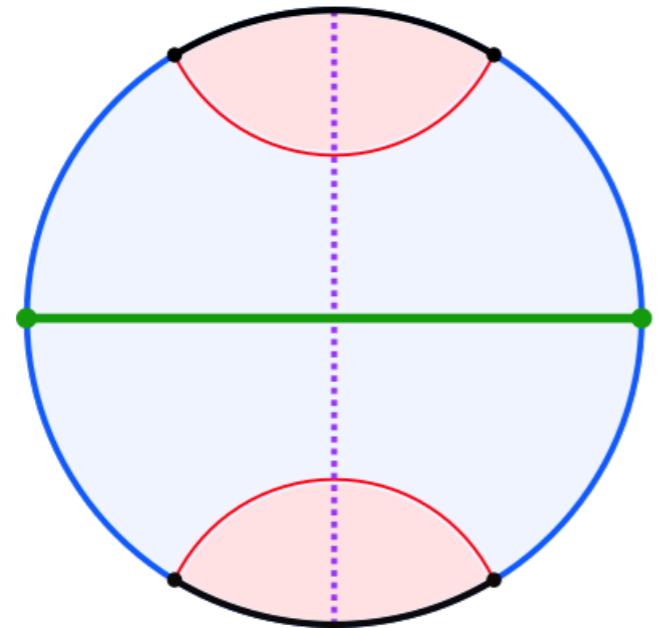
Evolution in Rindler time

Brane perspective

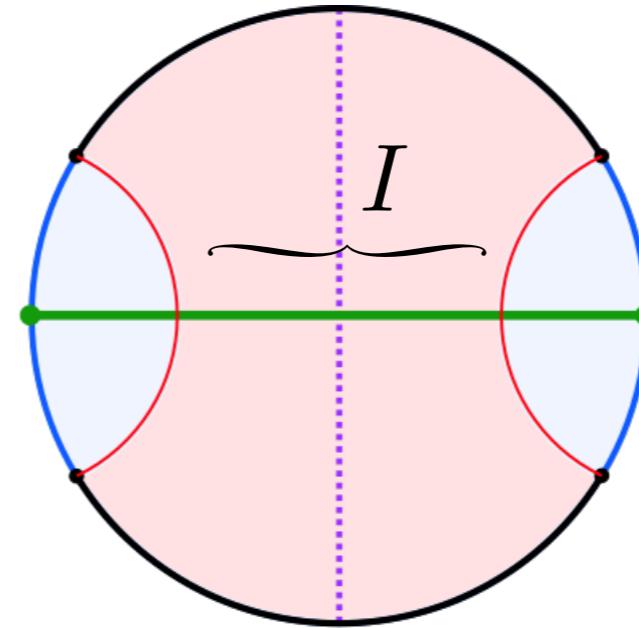
Time evolution  
(top view)



Early time



Late time



Island

RT surface transition!  $\rightarrow$  Hawking-Page

Headrick '10

Provides Page curve in arbitrary dimensions

## Summary

Islands become more intuitive with Randall-Sundrum

Simple example of topological black hole

Many questions

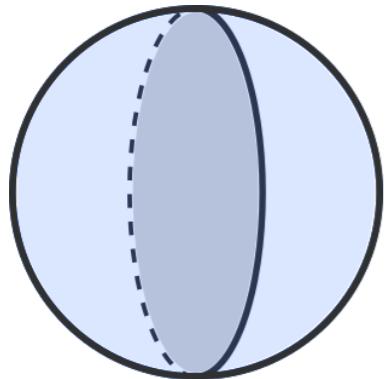
Realistic black holes?

How is the information encoded?!

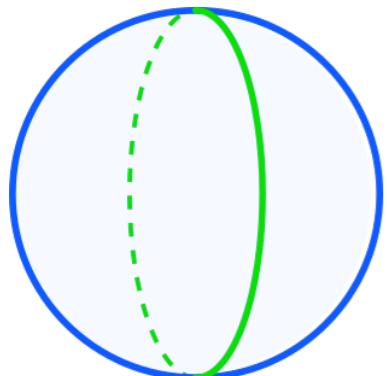
Thank you!

# 3 equivalent perspectives

Almehiri-Mahajan-  
Maldacena-Zhao '19

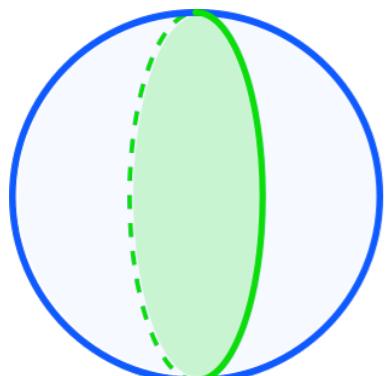


Bulk: AdS<sub>d</sub> brane embedded in AdS<sub>d+1</sub>



Boundary: hol CFT<sub>d</sub> coupled to defect

Integrate out bulk and brane



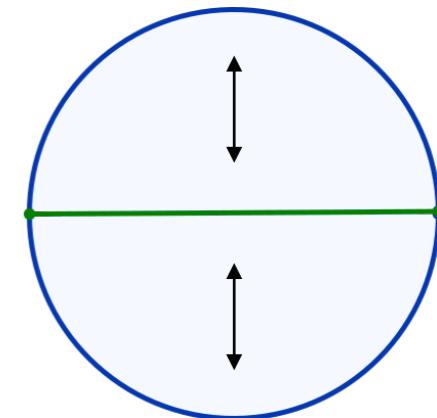
Brane: holCFT<sub>d</sub> + holCFT<sub>d</sub> on AdS<sub>d</sub>

Integrate out bulk, not brane

Effective description (RS)

# Brane gravity

Integrate out on-shell bulk action up to brane



$$I_{\text{eff}} = \frac{1}{16\pi G_{\text{eff}}} \int d^d x \sqrt{\tilde{g}} \left[ \tilde{R}(\tilde{g}) + \frac{(d-1)(d-2)}{\ell_{\text{eff}}^2} + L^2 \left( \tilde{R}^2 + \dots \right) \right]$$

Einstein gravity

$$\tilde{R} \sim \frac{1}{\ell_{\text{eff}}^2} \quad \left( \frac{L}{\ell_{\text{eff}}} \right)^2 \ll 1$$

easy!

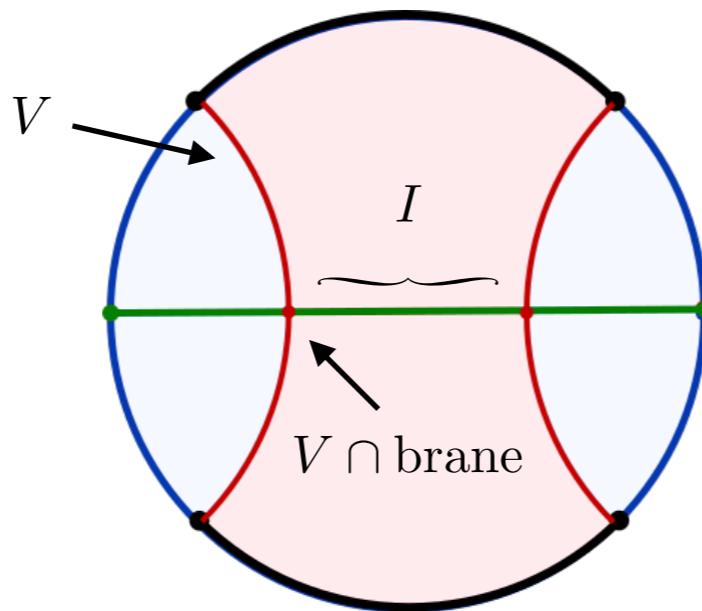
$$\frac{1}{G_{\text{eff}}} = \frac{2L}{(d-2)G_{\text{bulk}}} + \frac{1}{G_{\text{brane}}}$$

# Gravity path integral

Island formula arises from ‘replica wormholes’

In the brane model:

$$Z \approx e^{-(I_{\text{bulk}} + I_{\text{brane}})} \longrightarrow S = \frac{A(V)}{4G_{\text{bulk}}} + \frac{A(V \cap \text{brane})}{4G_{\text{brane}}}$$



Interesting even without black holes !

2006.04851

What if... ?

$$G_{\text{bulk}} > 0 \quad , \quad G_{\text{brane}} < 0 \quad , \quad G_{\text{eff}} > 0$$

Multiple minima

$$\frac{A(V \cap \text{brane})}{4G_{\text{brane}}} + \frac{A(V)}{4G_{\text{bulk}}}$$

Islands as ‘Bubbles’ ?

