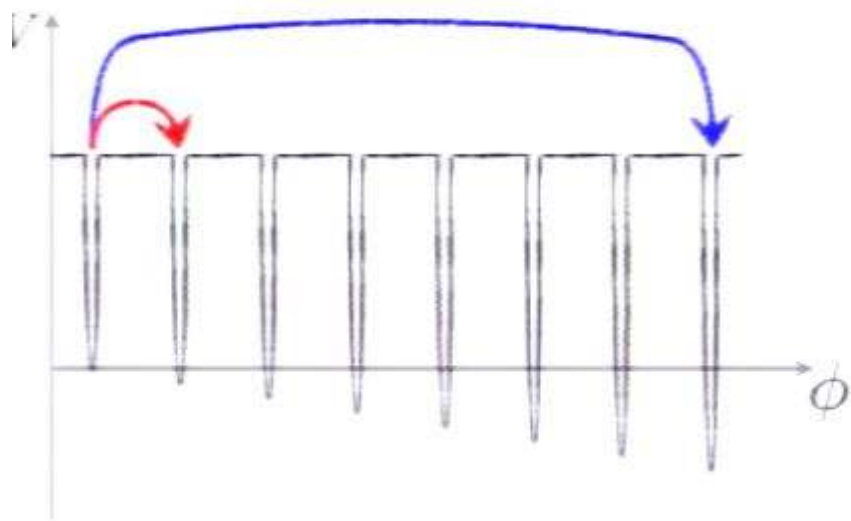


Title: Bubbles of nothing and the big bang

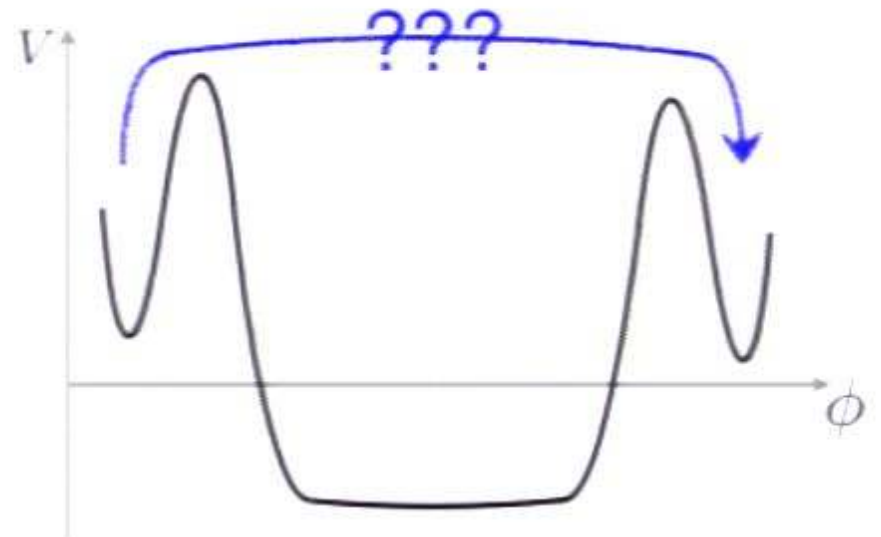
Date: Jun 21, 2011 11:50 AM

URL: <http://pirsa.org/11060047>

Abstract: TBA



what's the fastest decay?

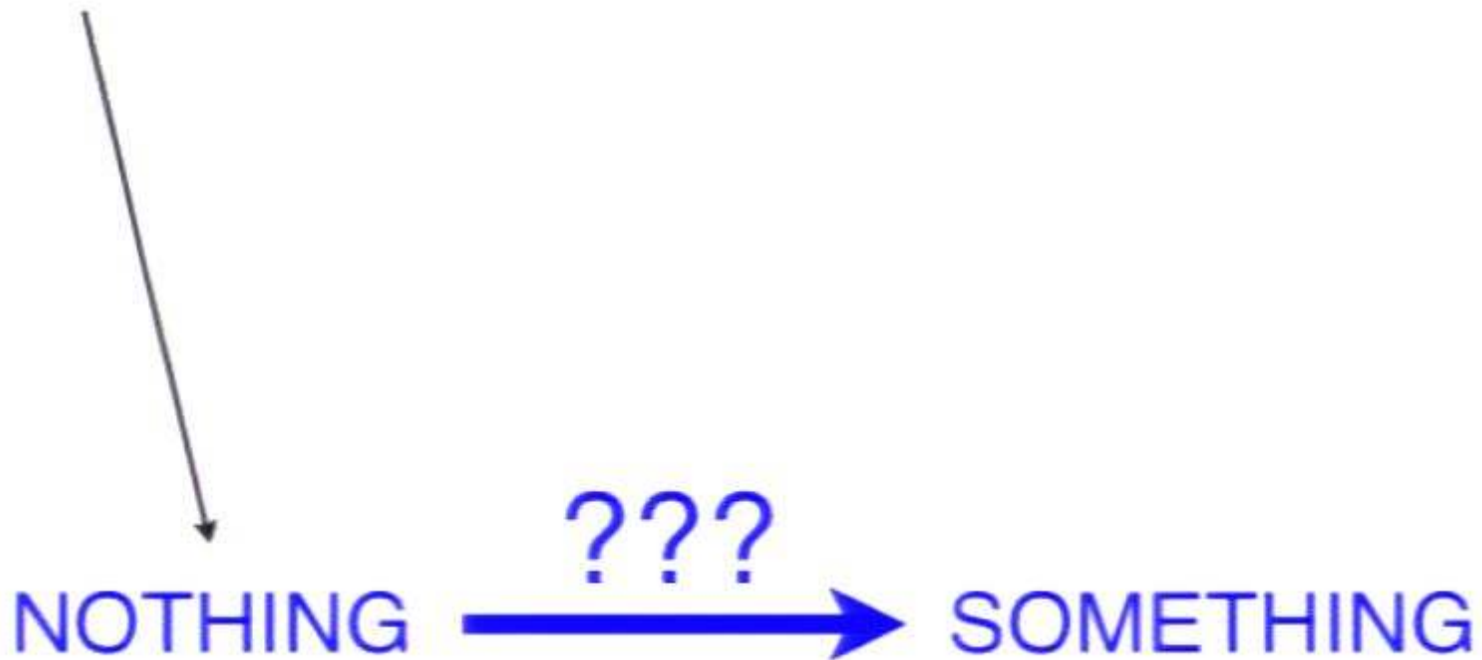


can you get everywhere?

NOTHING $\xrightarrow{???}$ SOMETHING

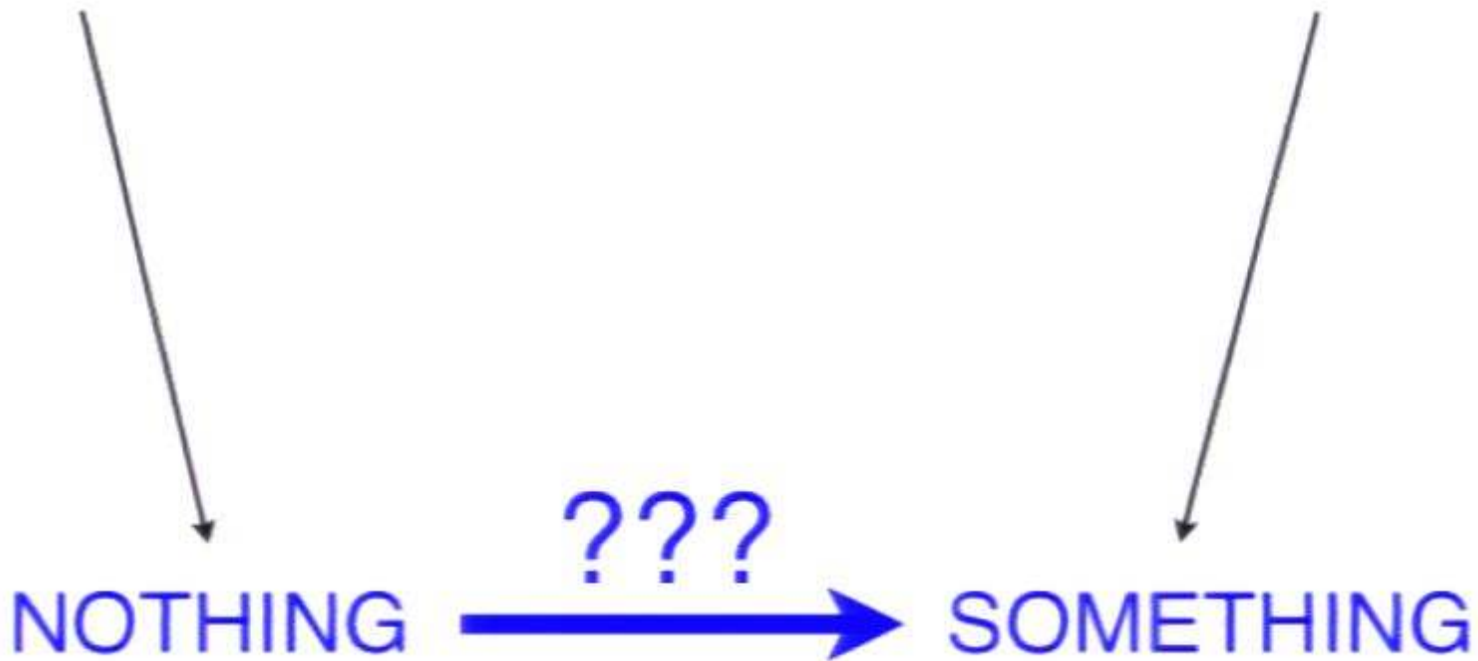
can you make a Universe from nothing?

NOT empty spacetime
literally nothing
no space
no time



NOT empty spacetime
literally nothing
no space
no time

an open Universe
a la Hawking-Turok



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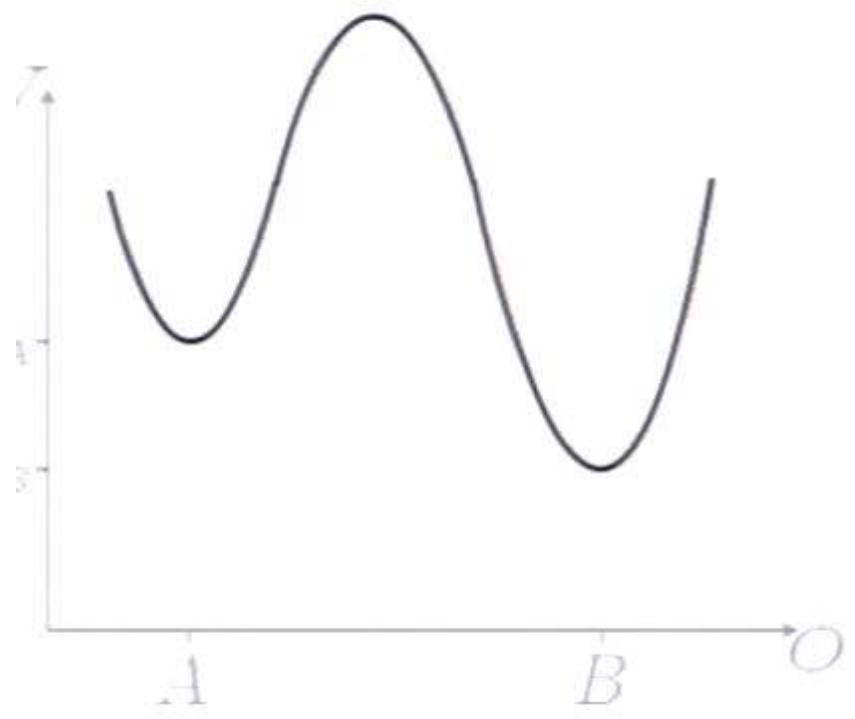
an open Universe
a la Hawking-Turok

NOTHING  SOMETHING

can you make a Universe from nothing?

no

Tunneling in flat spacetime



NOT empty spacetime
literally nothing
no space
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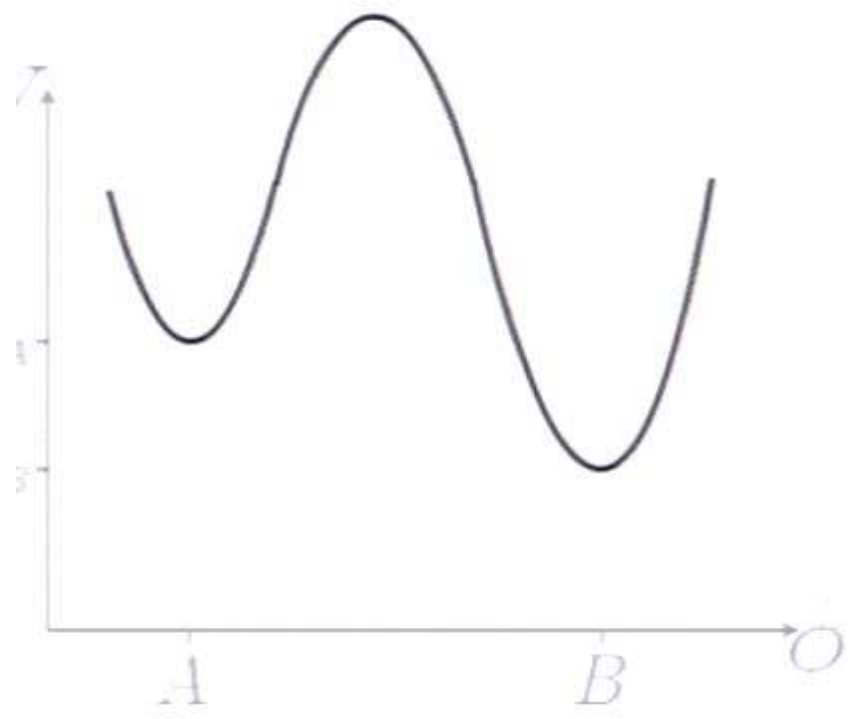
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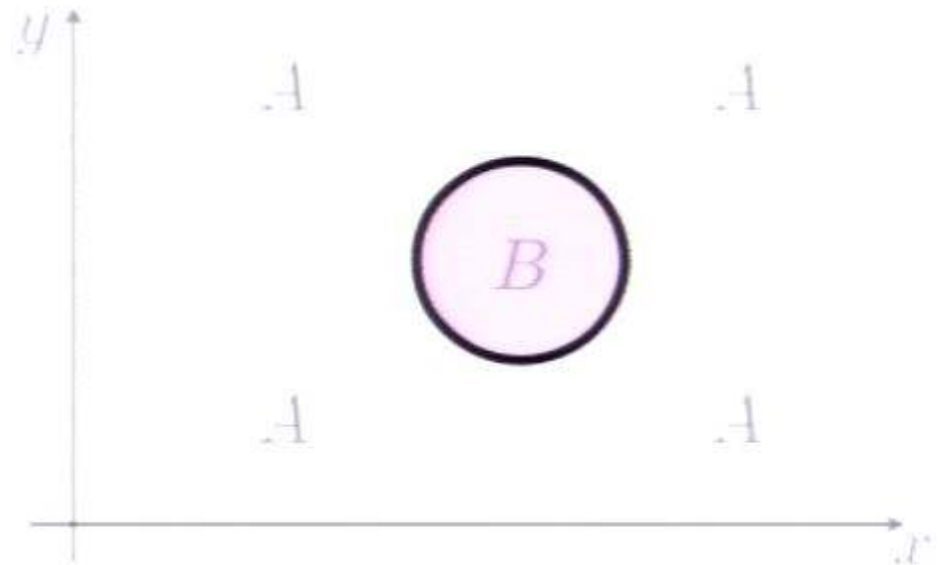
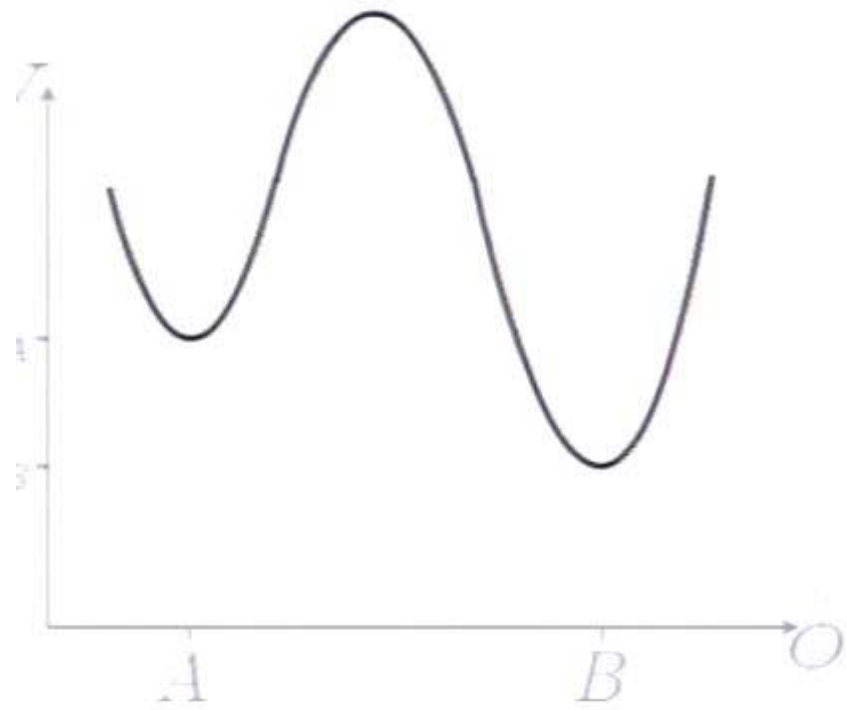
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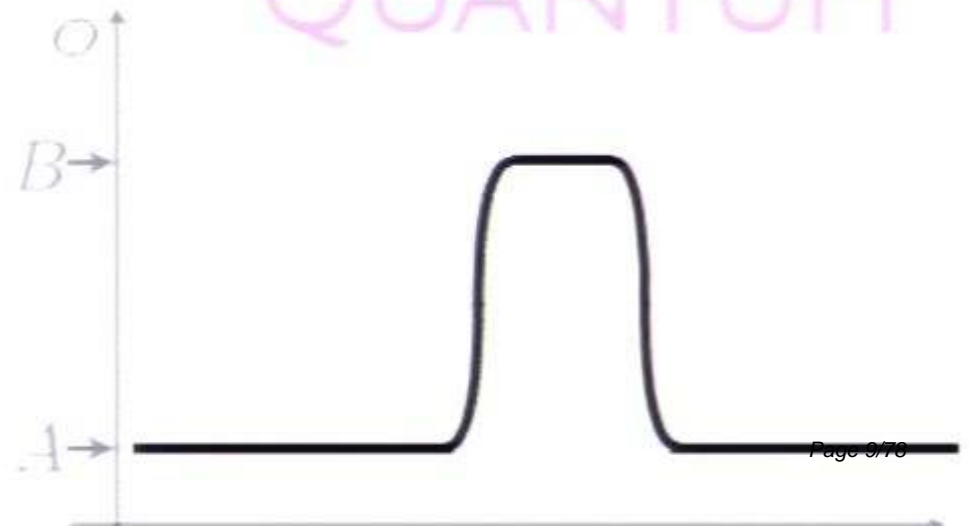
Tunneling in flat spacetime



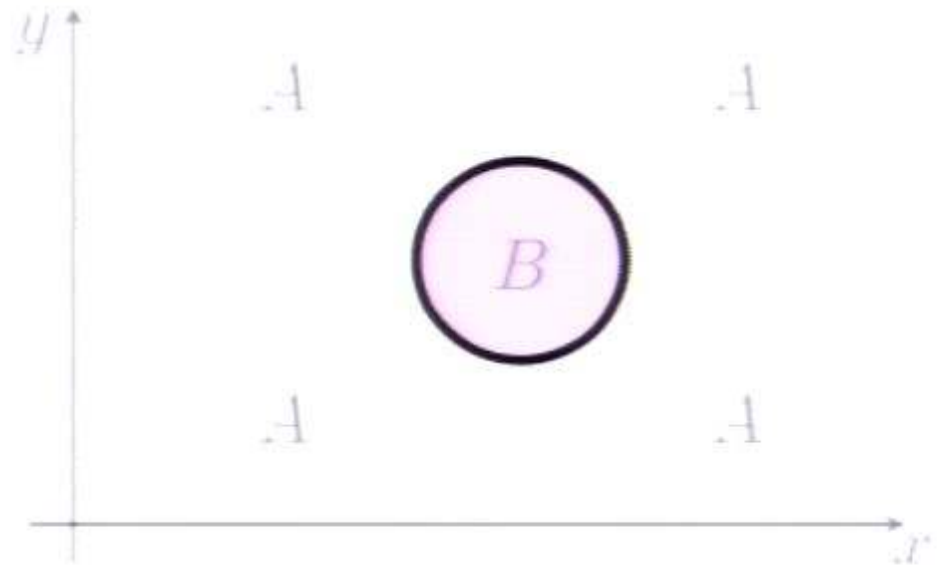
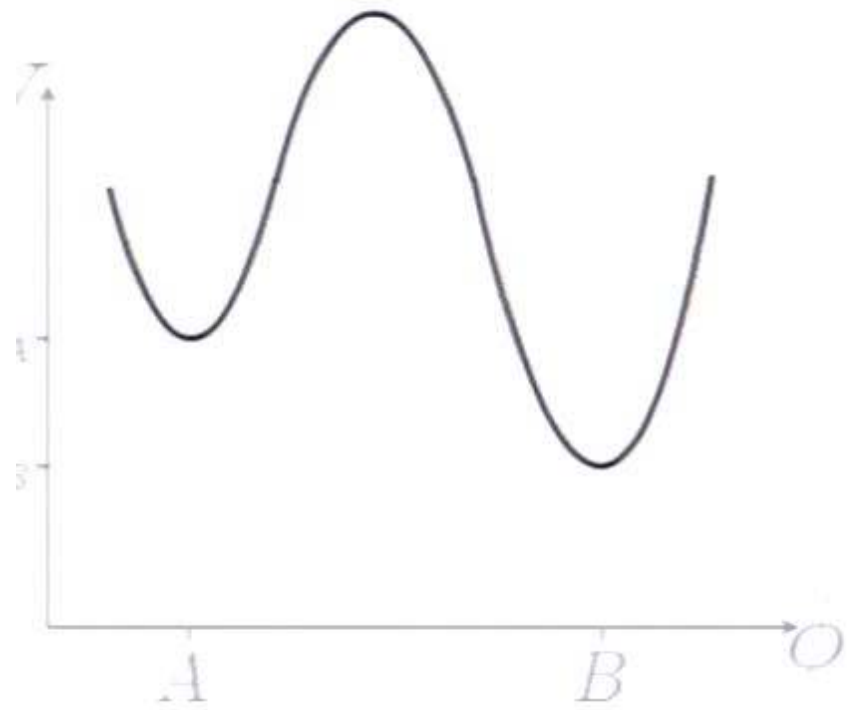
Tunneling in flat spacetime



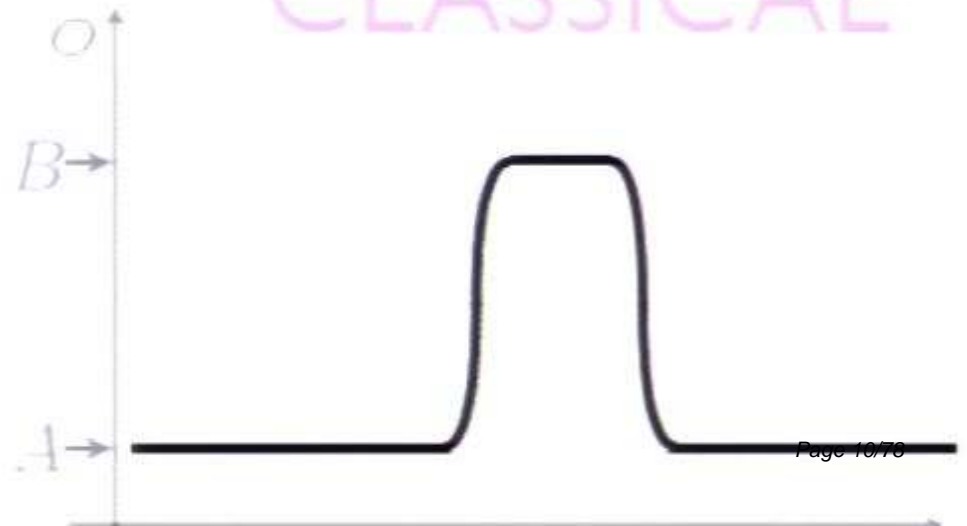
QUANTUM



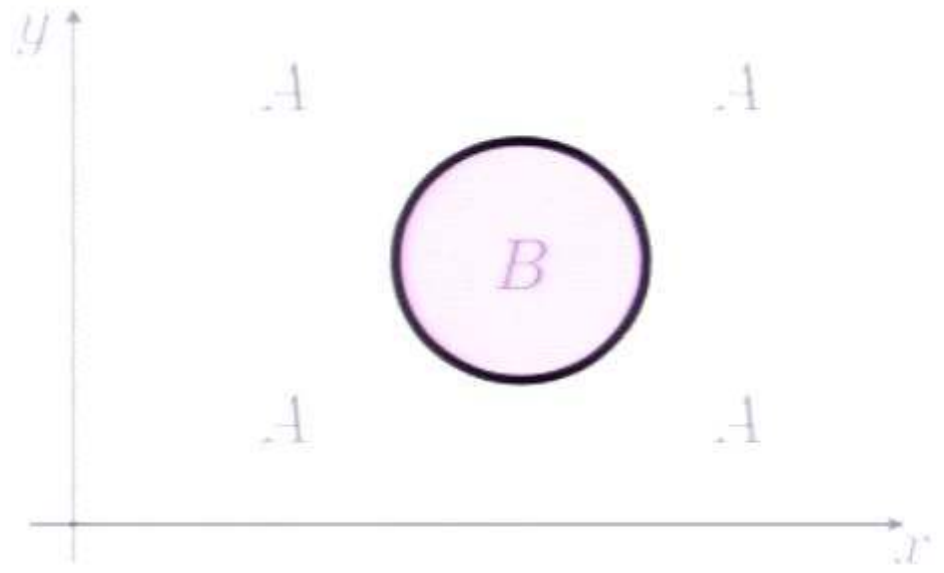
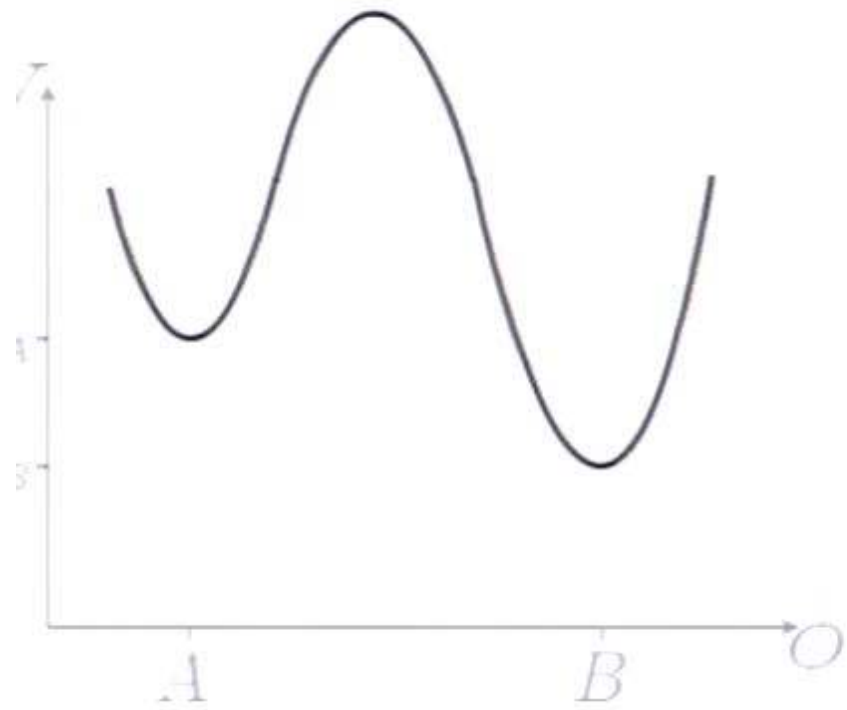
Tunneling in flat spacetime



CLASSICAL



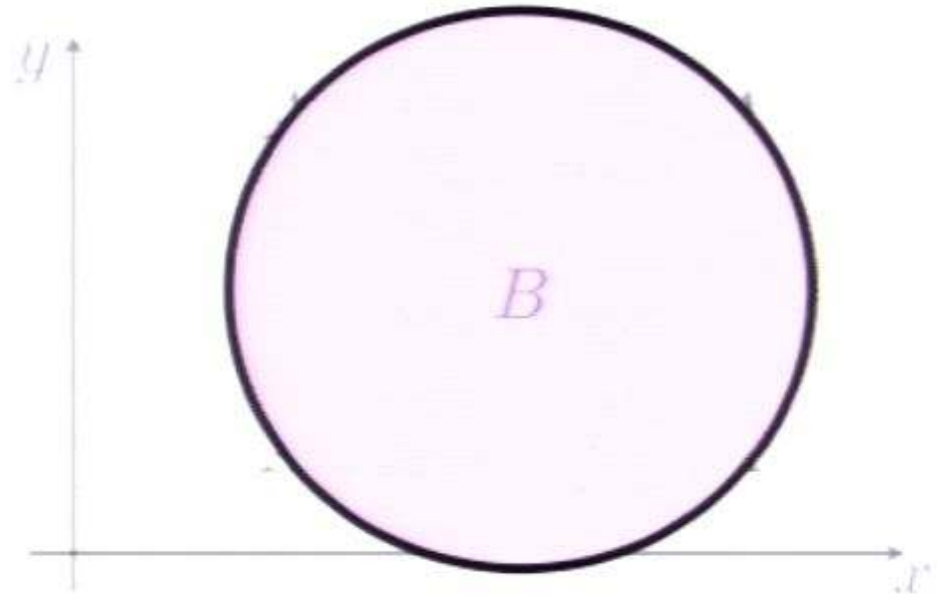
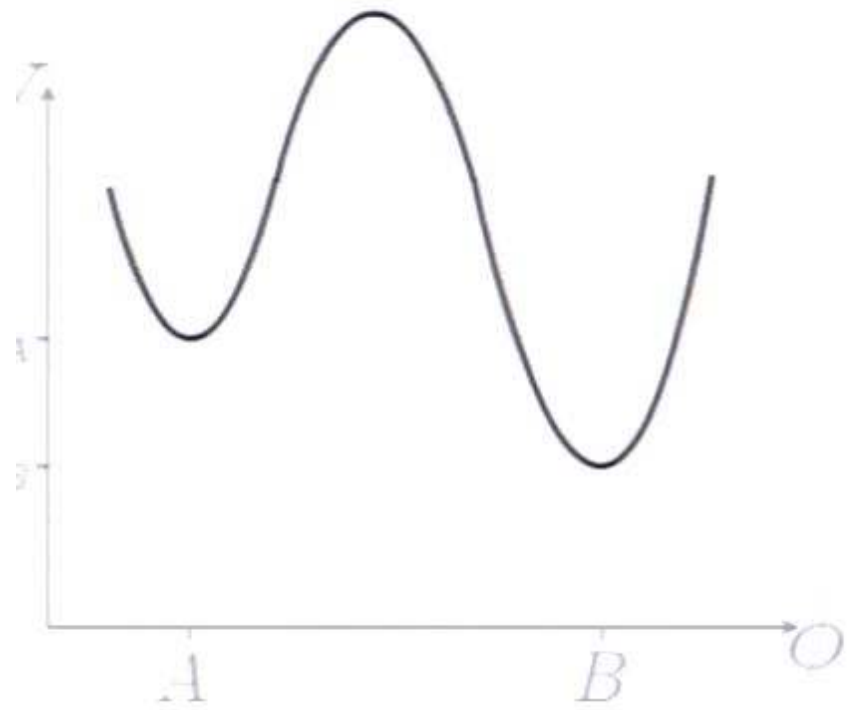
Tunneling in flat spacetime



CLASSICAL



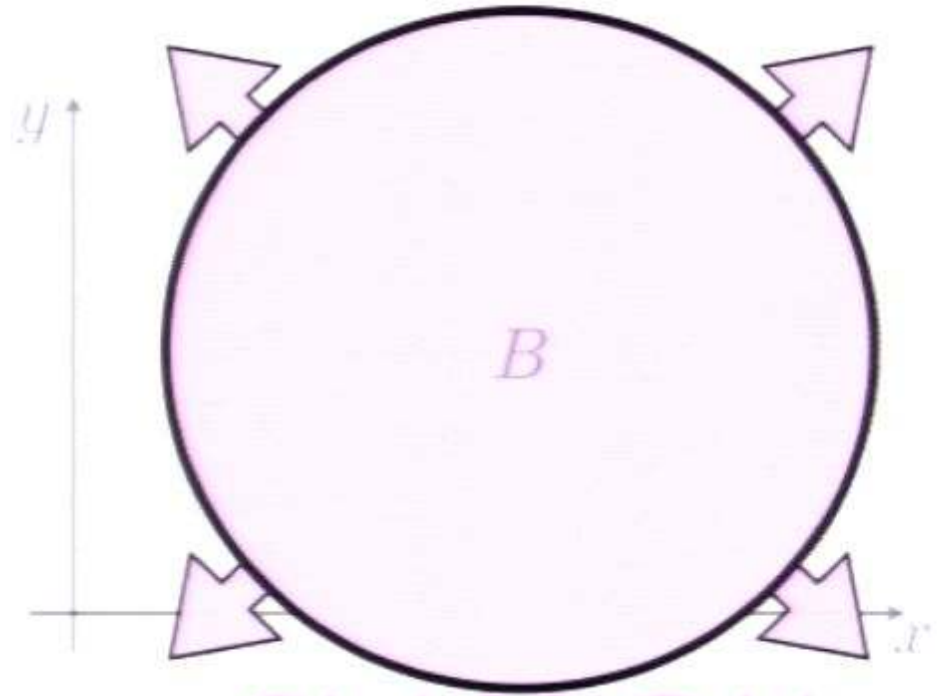
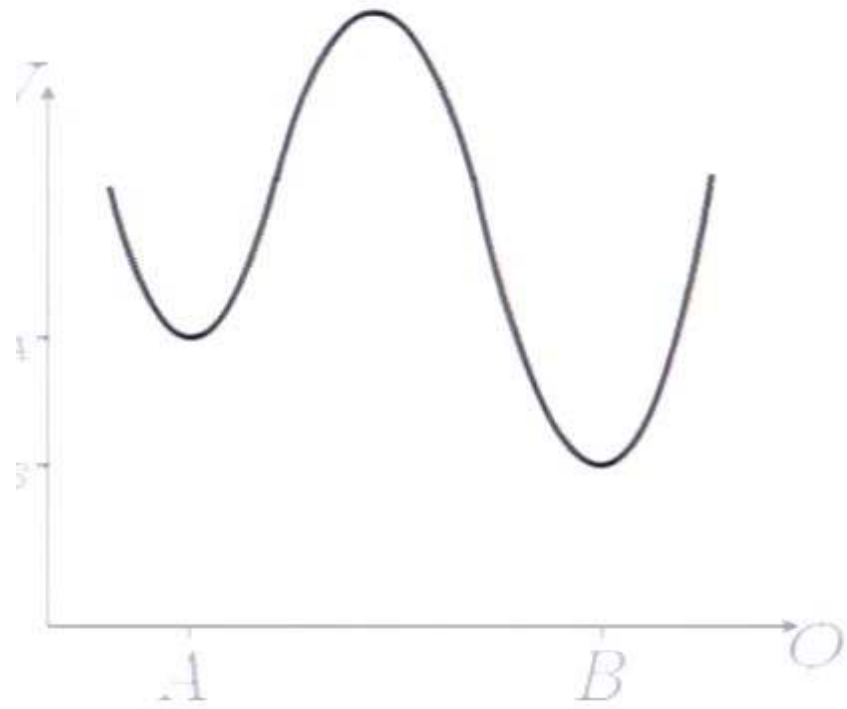
Tunneling in flat spacetime



CLASSICAL



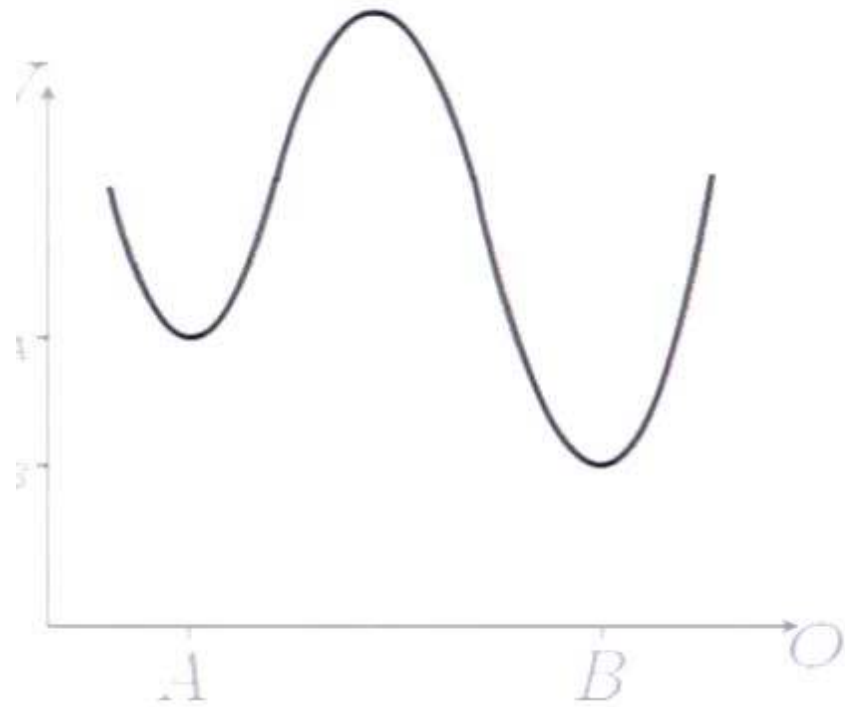
Tunneling in flat spacetime



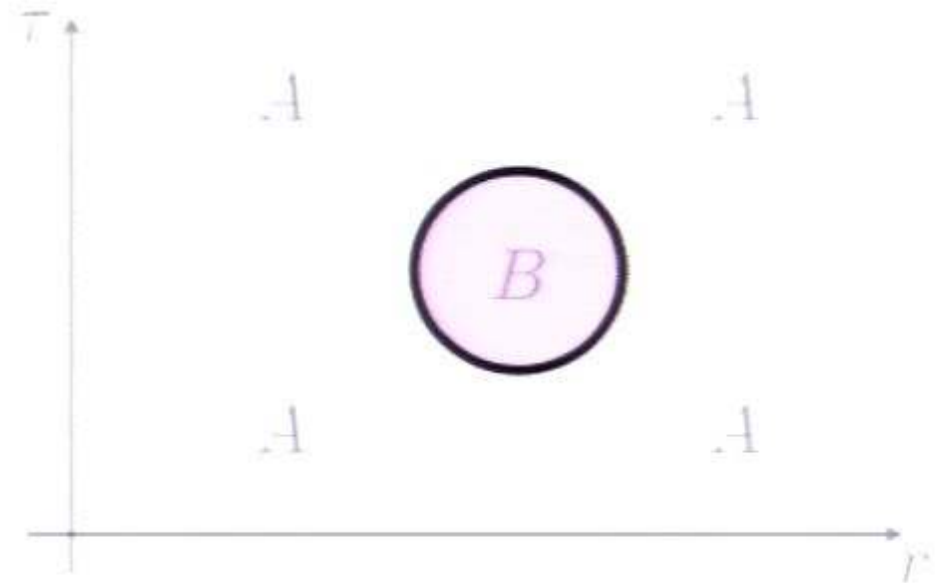
CLASSICAL



Tunneling in flat spacetime



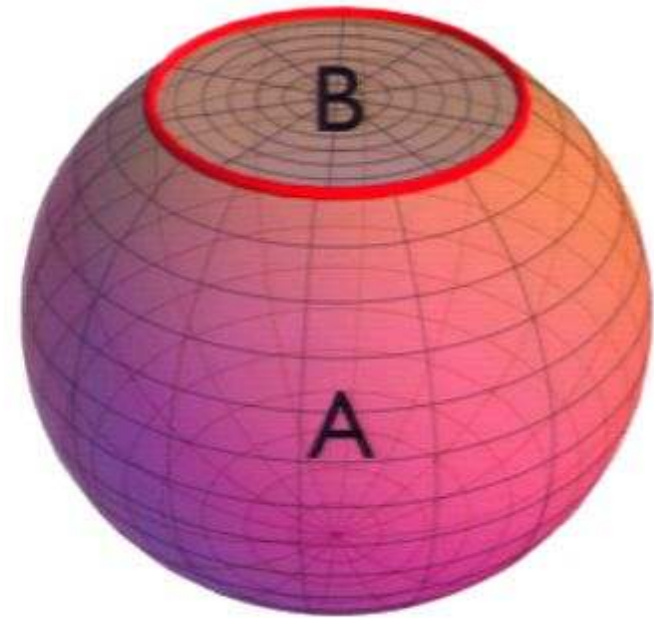
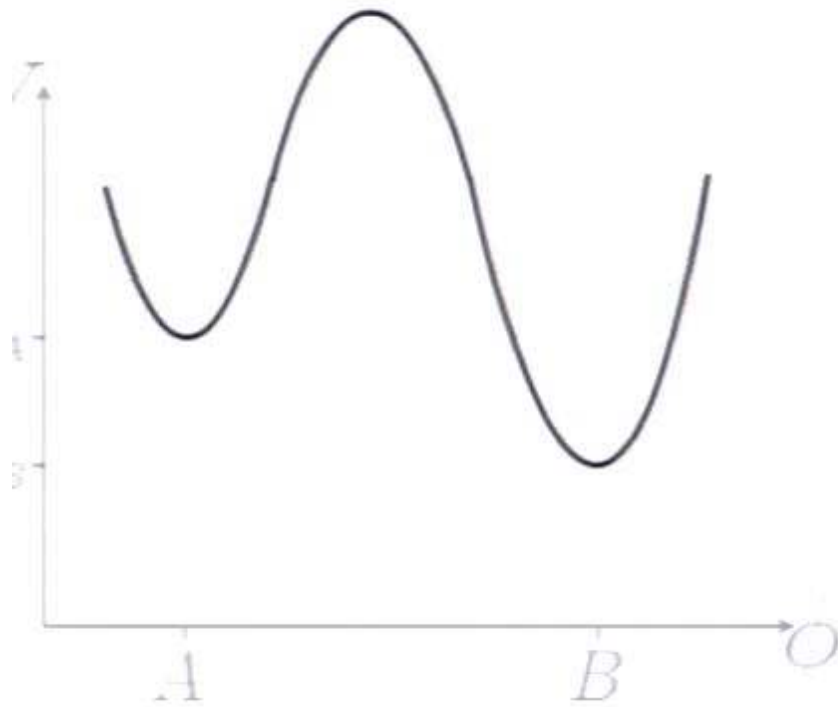
instanton lives on \mathcal{R}^4



$$\Gamma_{A \rightarrow B} = \exp[-S_E(\text{instanton}) + S_E(A)]$$

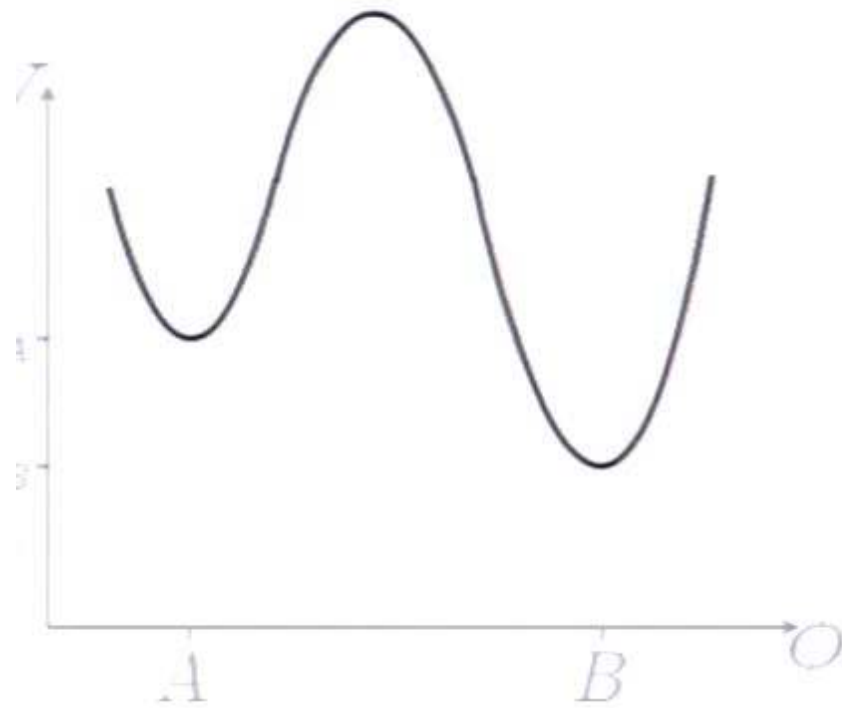
tunneling in dynamical spacetime

instanton lives on S^4

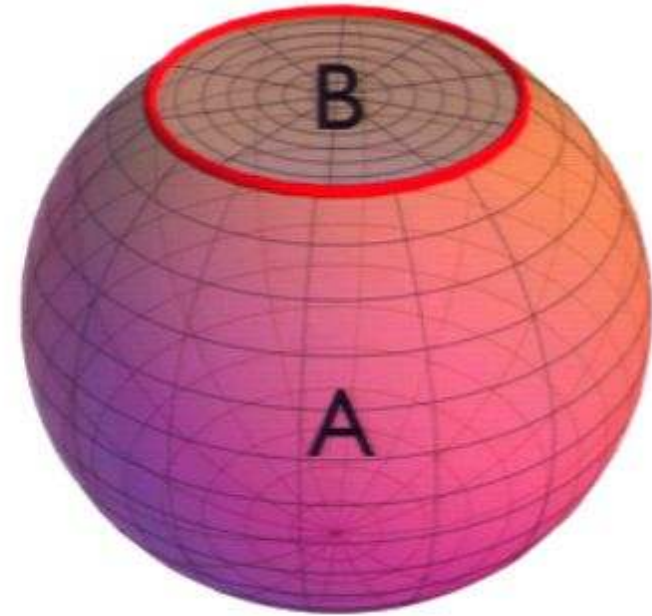


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Tunneling in dynamical spacetime



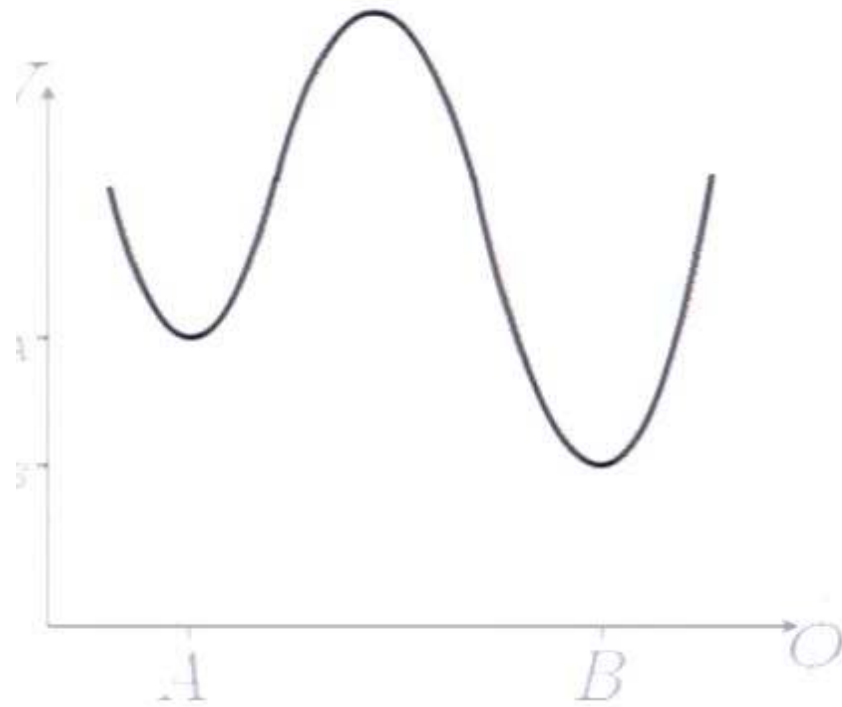
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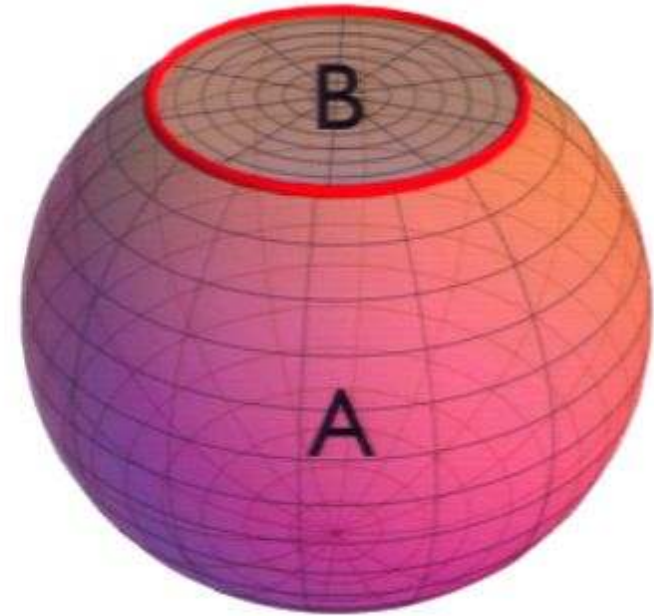
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The SAME instanton governs tunneling in both directions

Tunneling in dynamical spacetime



instanton lives on S^4

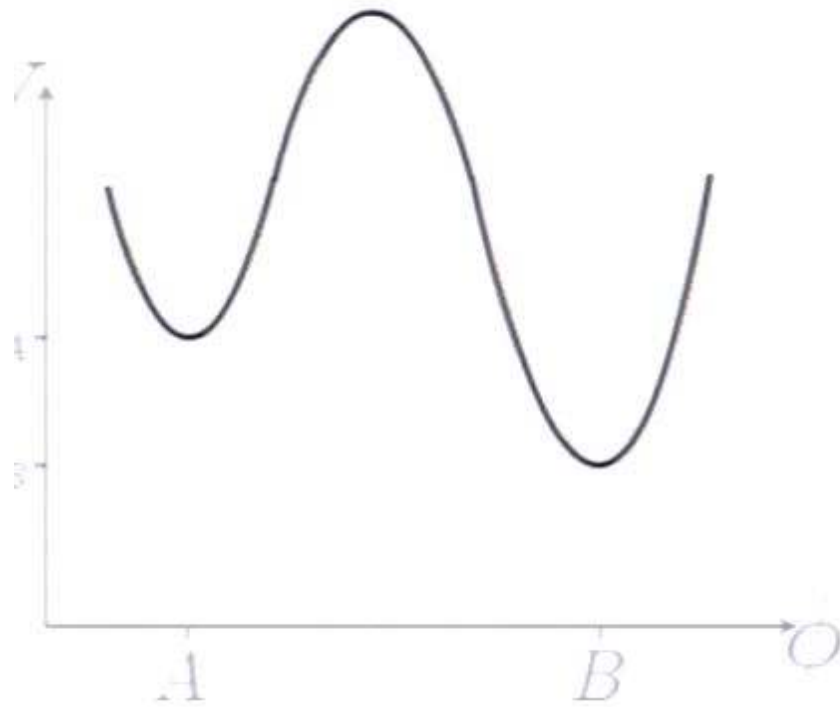


$$\Gamma_{A \rightarrow B} = \exp[-S_E(\text{instanton}) + S_E(A)]$$

The SAME instanton governs tunneling in both directions

$$\Gamma_{B \rightarrow A} = \exp[-S_E(\text{instanton}) + S_E(B)]$$

Tunneling in dynamical spacetime



$$S_E(\text{instanton}) = \text{finite}$$

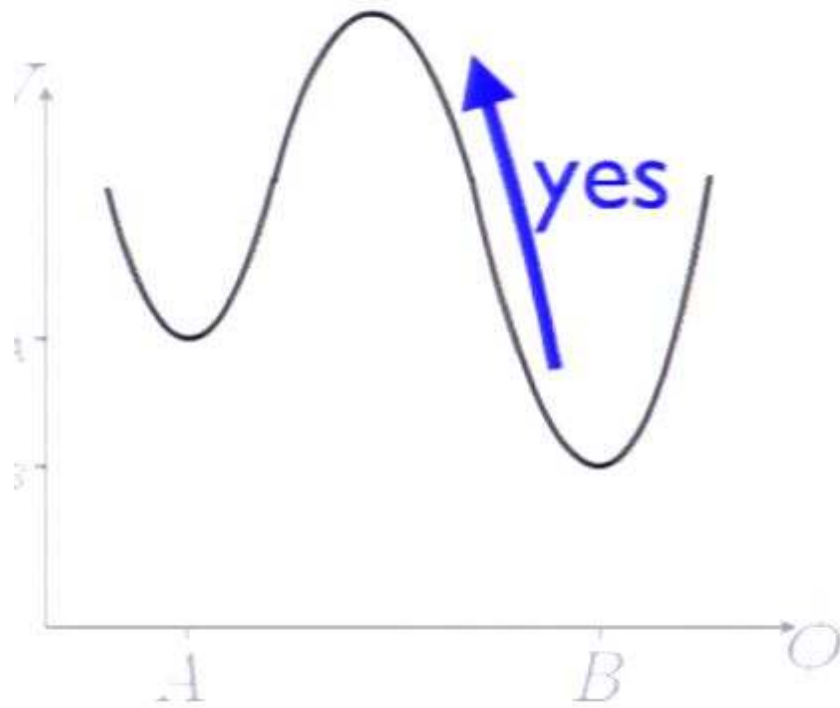
$$S_E(\text{de Sitter}) = -\frac{24\pi^2 M_{\text{Pl}}^4}{V}$$

$$\Gamma_{A \rightarrow B} = \exp[-S_E(\text{instanton}) + S_E(A)]$$

The SAME instanton governs tunneling in both directions

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Tunneling in dynamical spacetime



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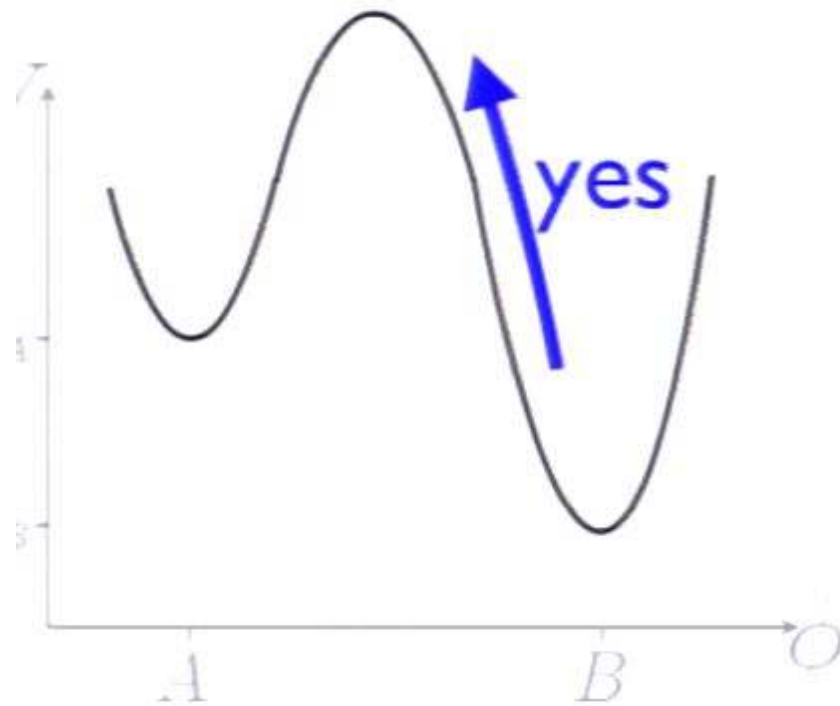
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Tunneling in dynamical spacetime



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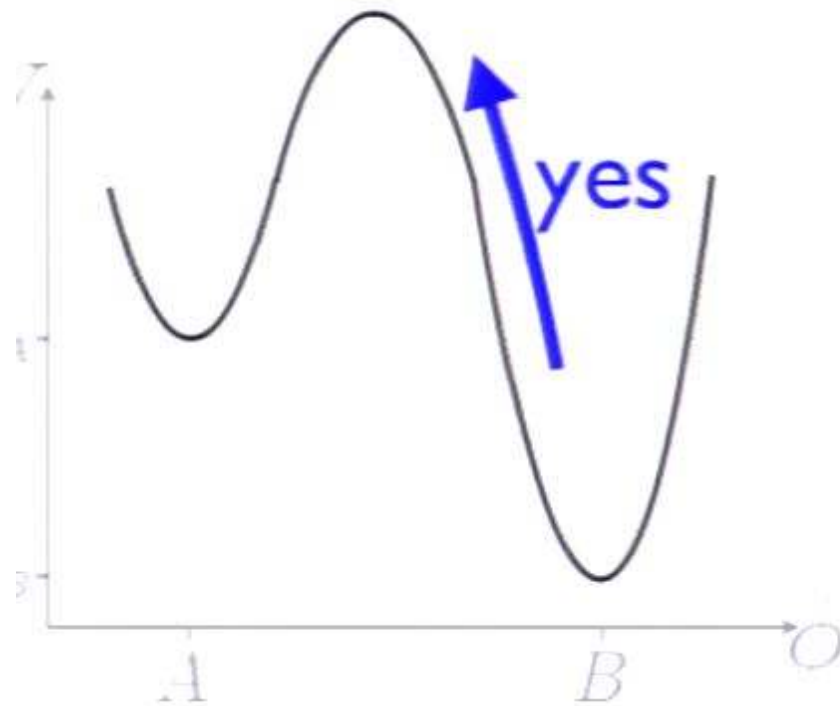
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Tunneling in dynamical spacetime



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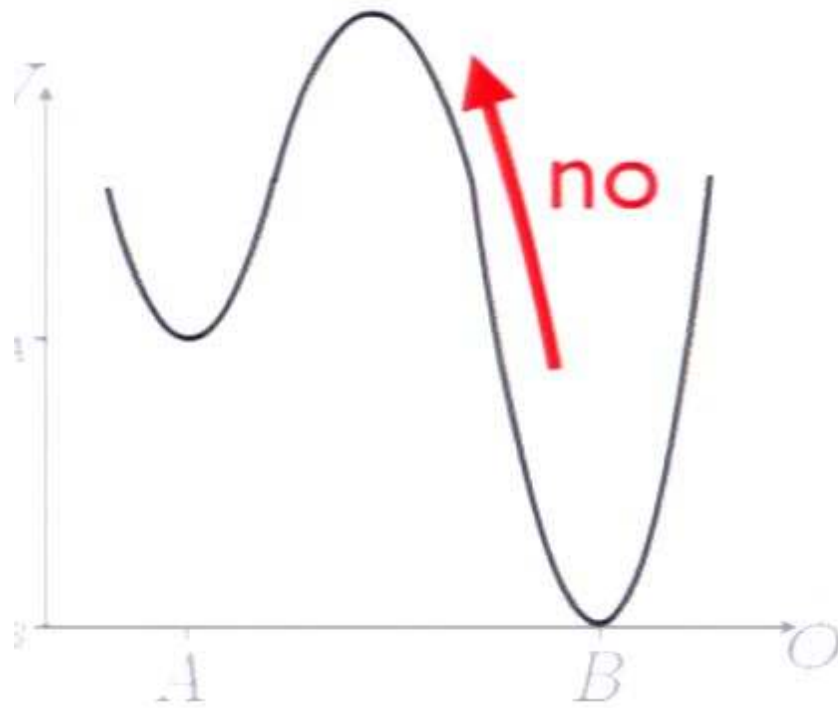
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Tunneling in dynamical spacetime



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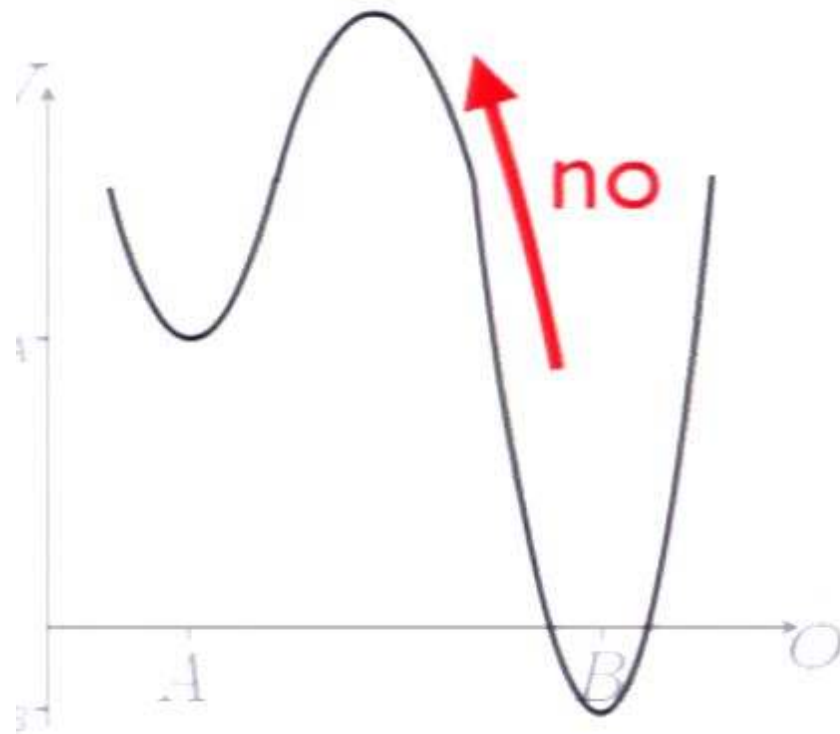
$$S_E(\text{Minkowski}) = -\infty$$

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Tunneling in dynamical spacetime



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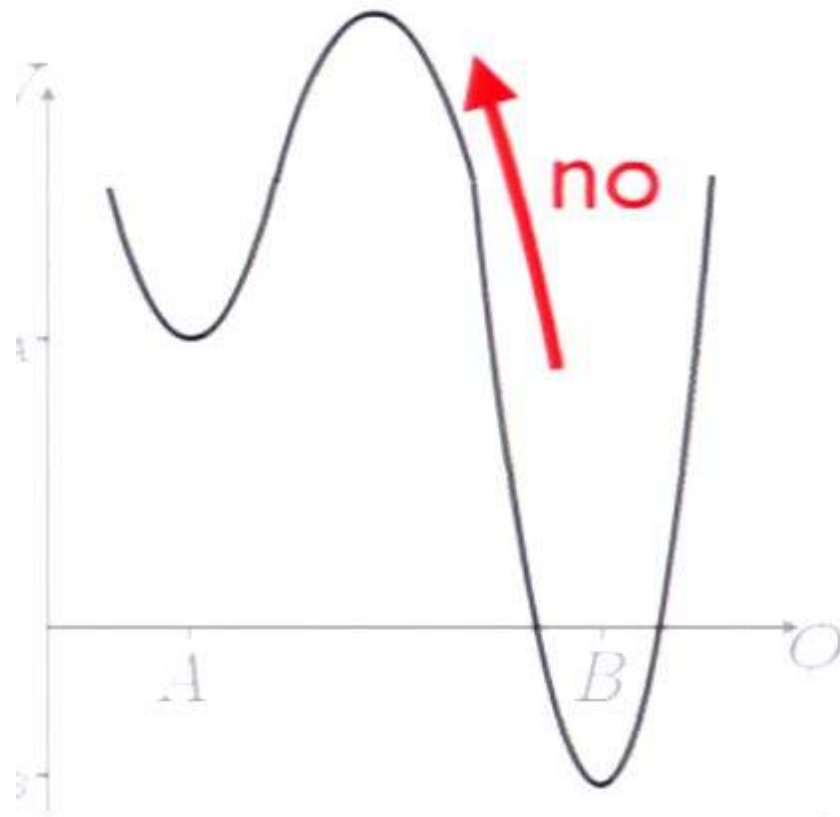
$$S_E(\text{AdS}) = -\infty$$

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Tunneling in dynamical spacetime



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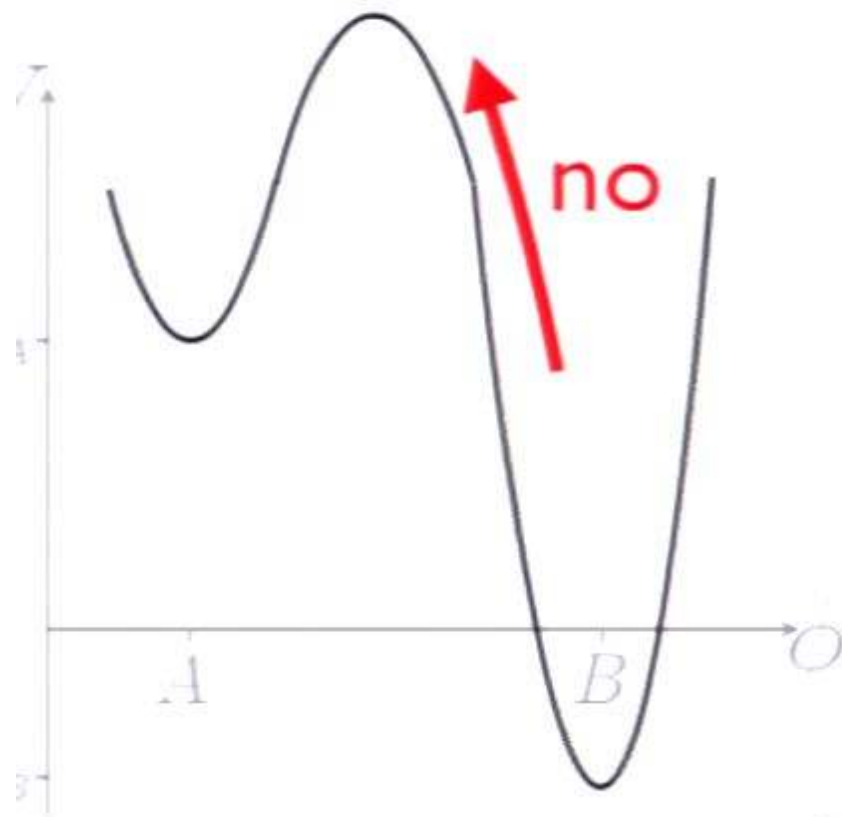
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The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

Uptunneling is impossible from Minkowski or AdS

p-tunneling from Minkowski?

homogenously?

no (infinite volume)

inhomogenously?

no (null-energy condition)

(infalling 'normal' surface becomes 'anti-trapped')

Penrose
Guth & Farhi

The SAME instanton governs tunneling in both directions

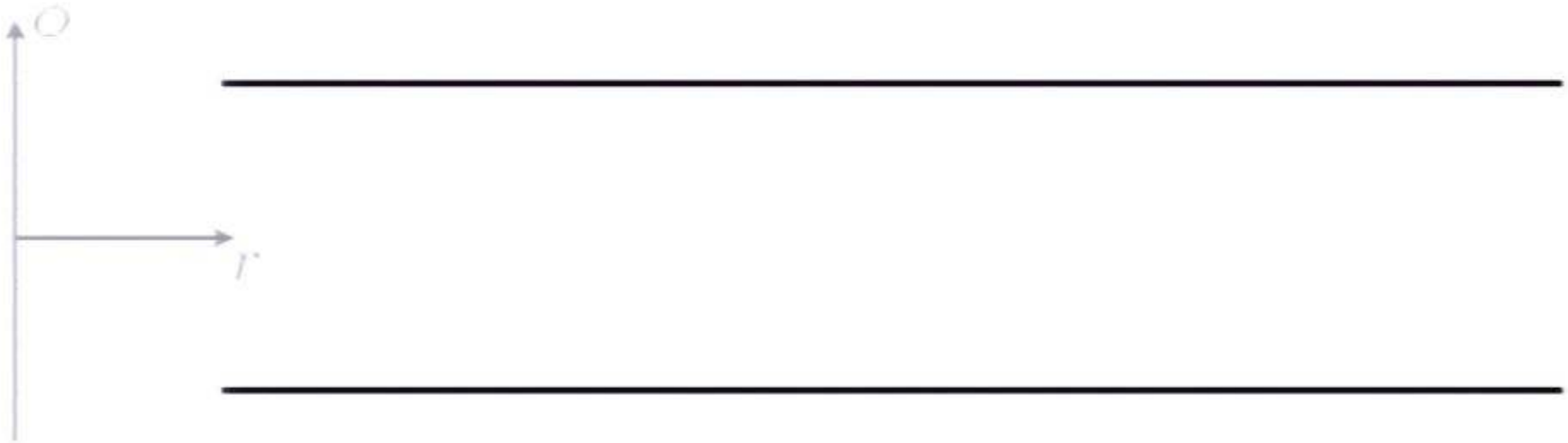
Uptunneling is possible from de Sitter

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The SAME instanton governs tunneling in both directions

bubble of nothing

3+1+1 dim
unstabilized
Minkowski

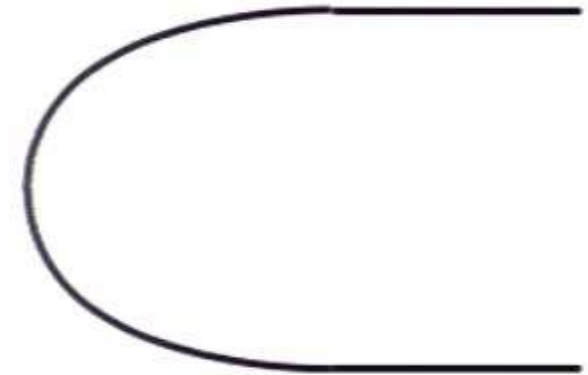
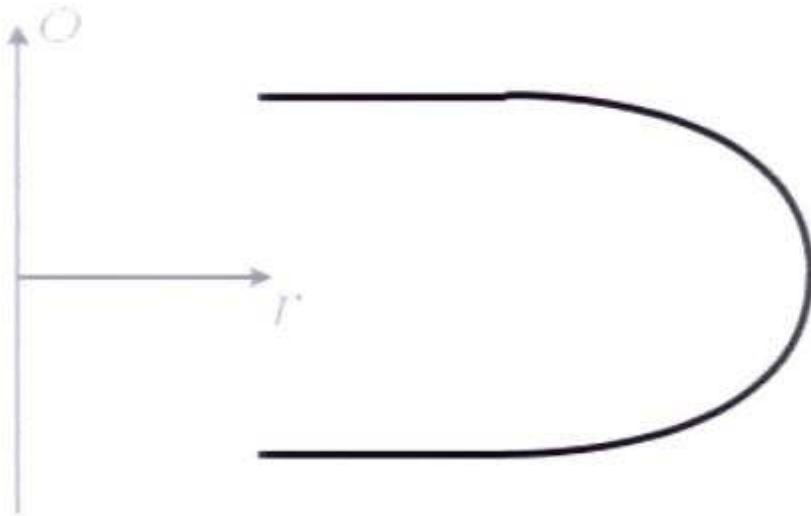


$$ds^2 = dr^2 + r^2 d\Omega_2^2 + d\phi^2$$

The SAME instanton governs tunneling in both directions

bubble of nothing

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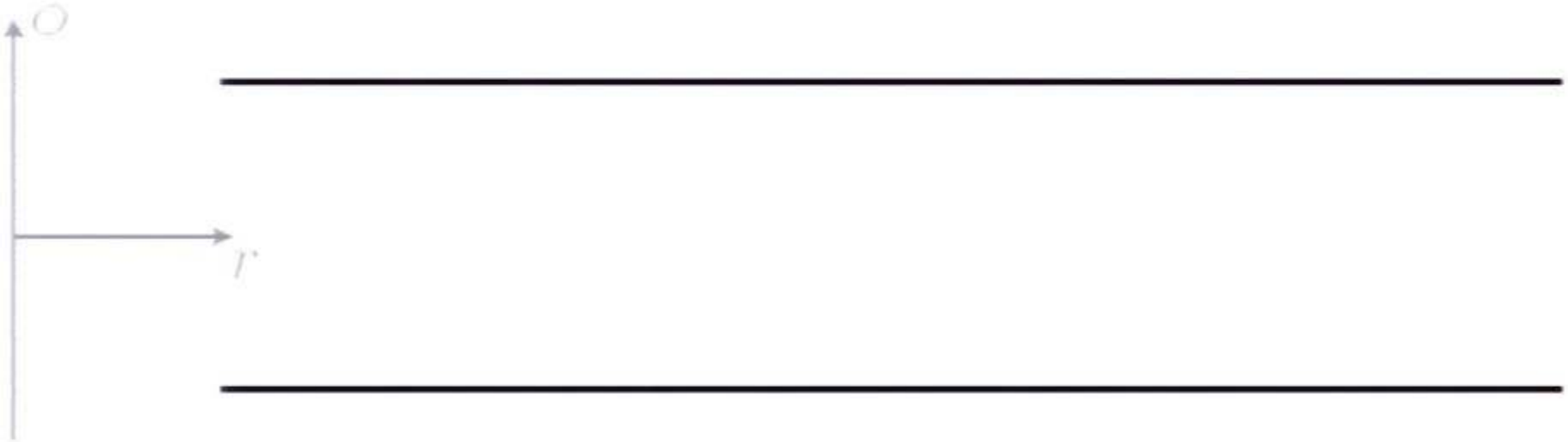


$$ds^2 = \frac{dr^2}{1 - 1/r^2} + r^2 d\Omega_2^2 + \left(1 - \frac{1}{r^2}\right) d\phi^2$$

The SAME instanton governs tunneling in both directions

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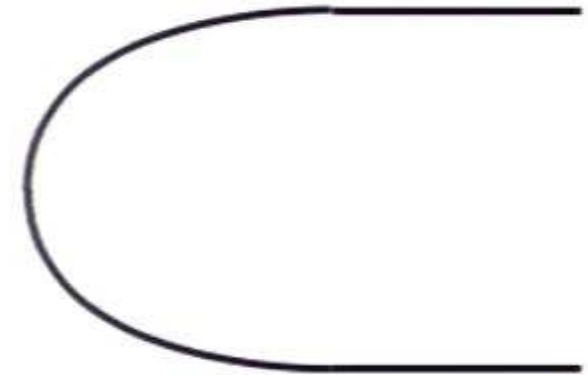
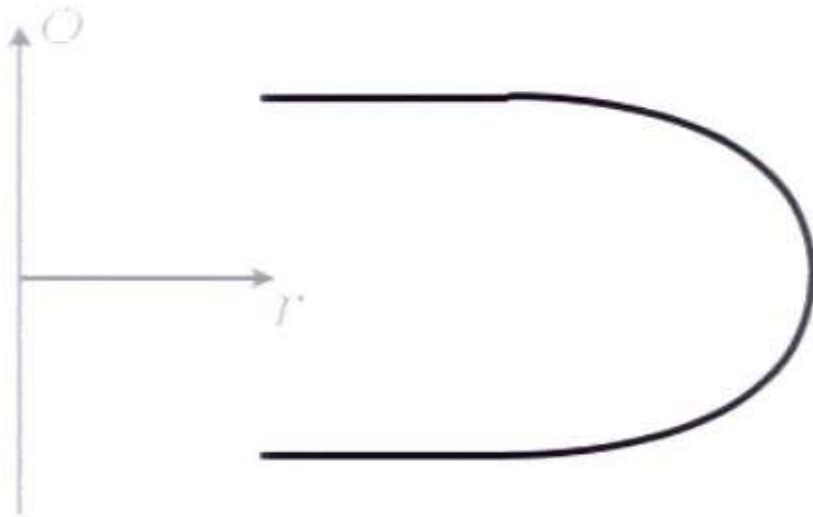


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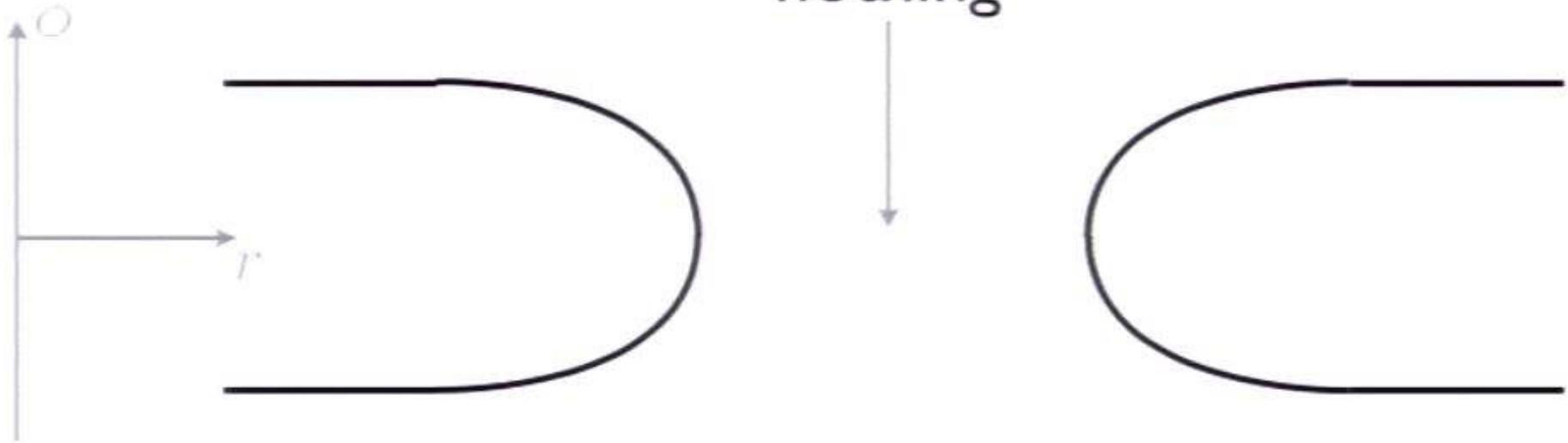


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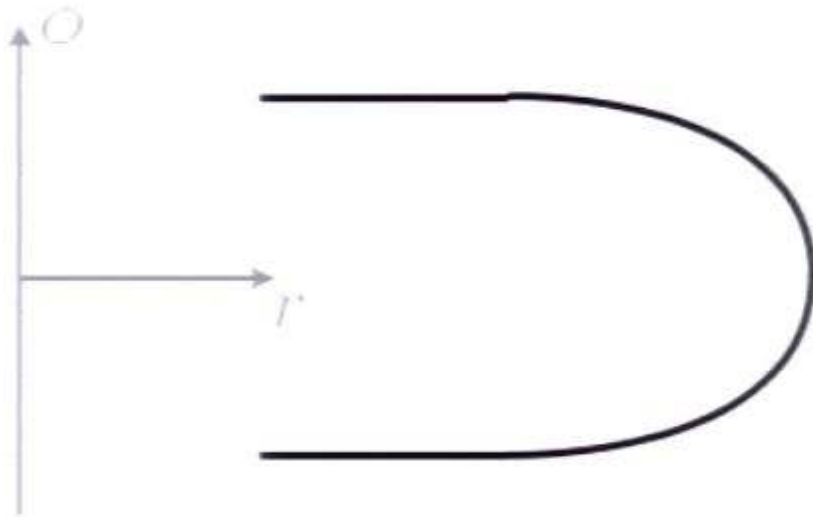


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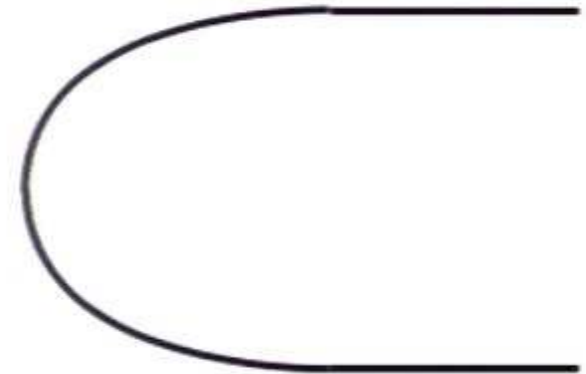
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nothing



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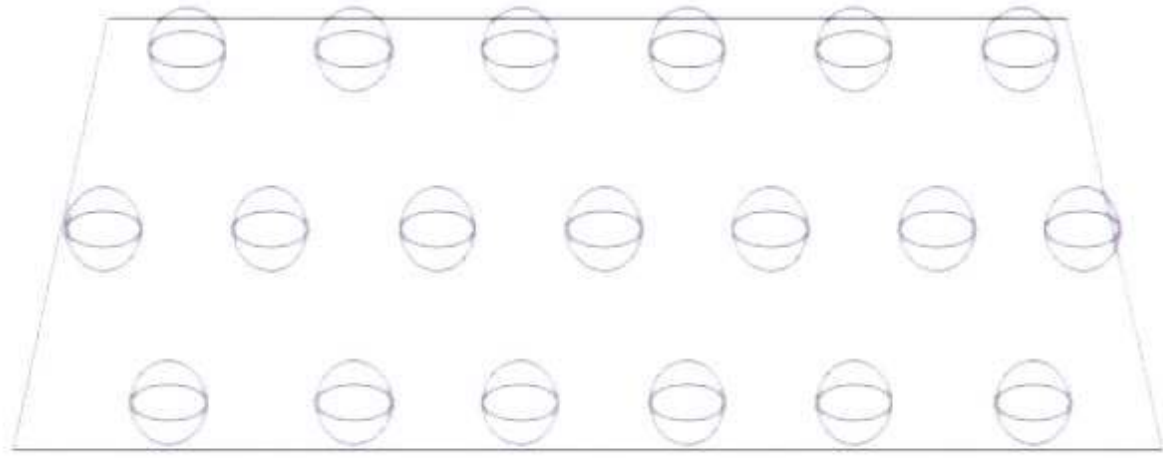
The SAME instanton governs tunneling in both directions

Simplest possible model with **stabilized XD**s that supports **Minkowski and de Sitter** 4D slices is **6D Einstein-Maxwell**

$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu + R^2 d\Omega_2^2$$

4D dS, Min, or AdS

2D sphere

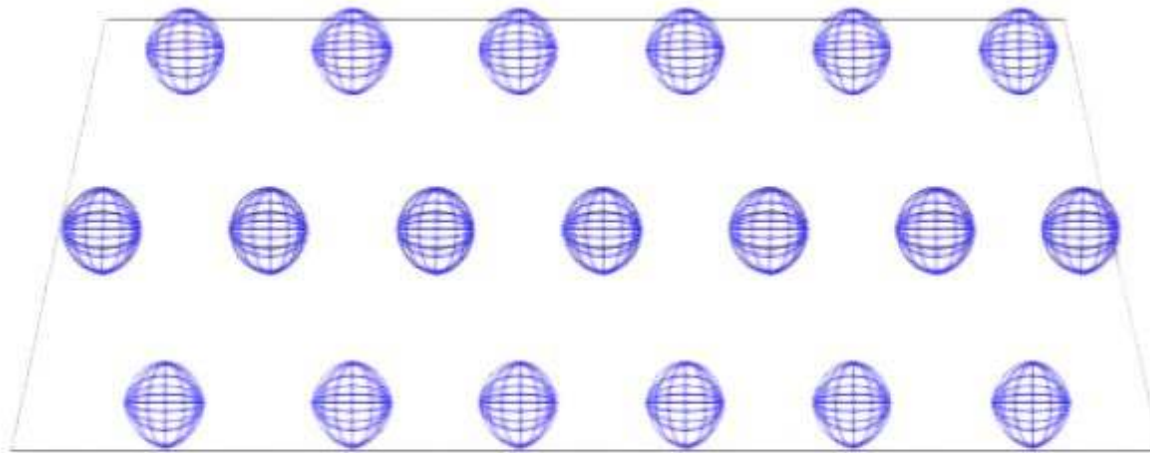


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4D dS, Min, or AdS

2D sphere



Three ingredients:

- spatial **curvature** of 2-spheres
- 2-form F_{ab} **flux** wrapping 2-spheres
- 6D **cosmo-constant**

i.e. Maxwell
magnetic flux

$$S = \int d^6x \sqrt{-\tilde{g}} \left(\frac{1}{2} \tilde{R}^{(6)} - \frac{1}{4} F_{MN} F^{MN} - \Lambda_6 \right)$$

Freund, Rubin (1980)

Einstein
Maxwell
c.c.

Effective 4D theory:

$$ds^2 = e^{-\psi(x)/M_4} g_{\mu\nu} dx^\mu dx^\nu + e^{\psi(x)/M_4} R^2 d\Omega_2^2$$



$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} M_4^2 R^{(4)} - \frac{1}{2} \partial_\mu \psi \partial^\mu \psi - V_4(\psi) \right)$$

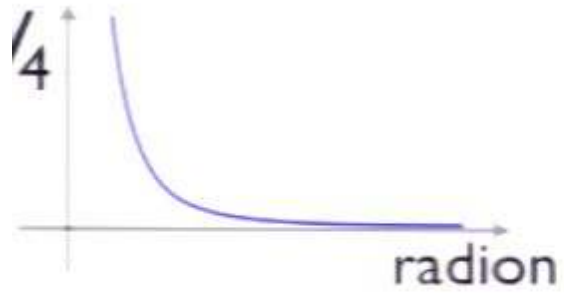
$$V_4(\psi) = 4\pi \left(\frac{\frac{1}{2} F^2}{16\pi^2 M_4^2} e^{-3\psi/M_4} - e^{-2\psi/M_4} + R^2 \Lambda_6 e^{-\psi/M_4} \right)$$

canonically normalized RADION
FLUX
CURVATURE
C.C.

‘repulsive’ short range
‘attractive’ medium range
‘repulsive’ long range

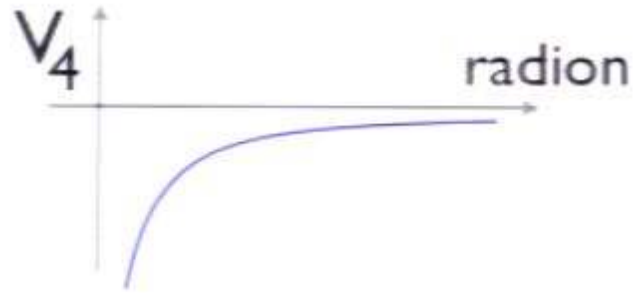
flux

short-range, repulsive



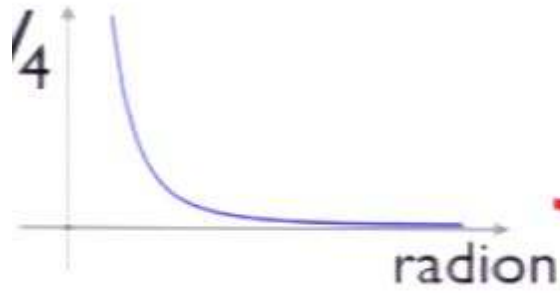
curvature

medium-range, attractive



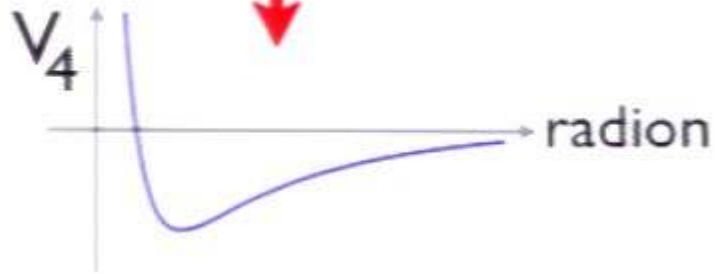
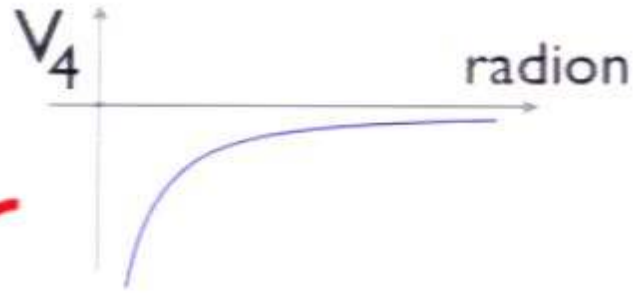
flux

short-range, repulsive



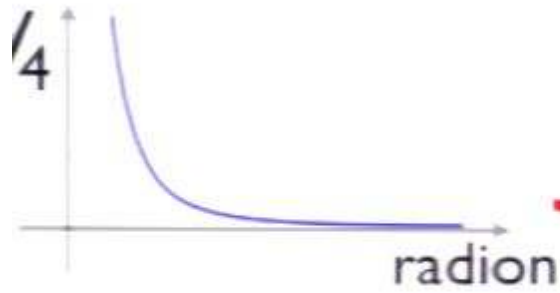
curvature

medium-range, attractive



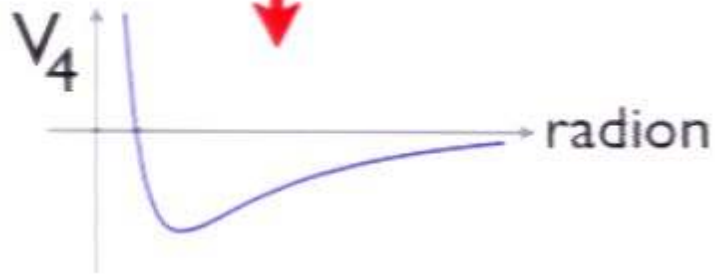
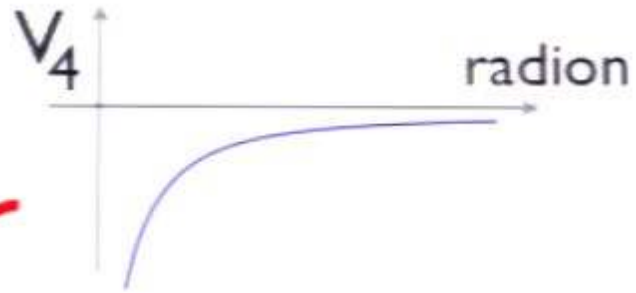
flux

short-range, repulsive

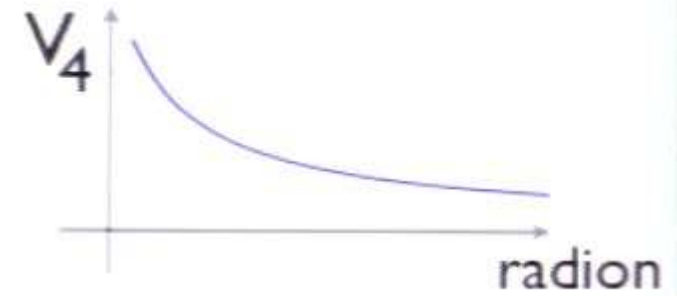


curvature

medium-range, attractive

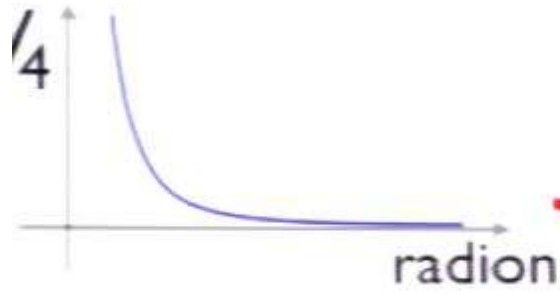


6D +ve c.c.
long-range, repulsive



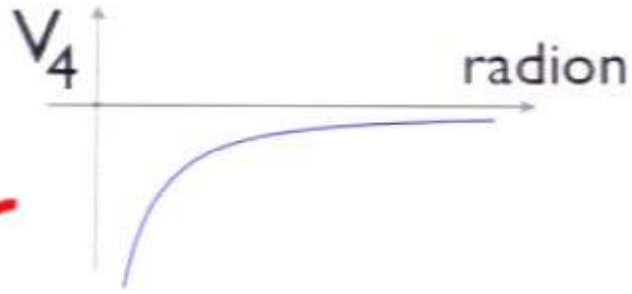
flux

short-range, repulsive

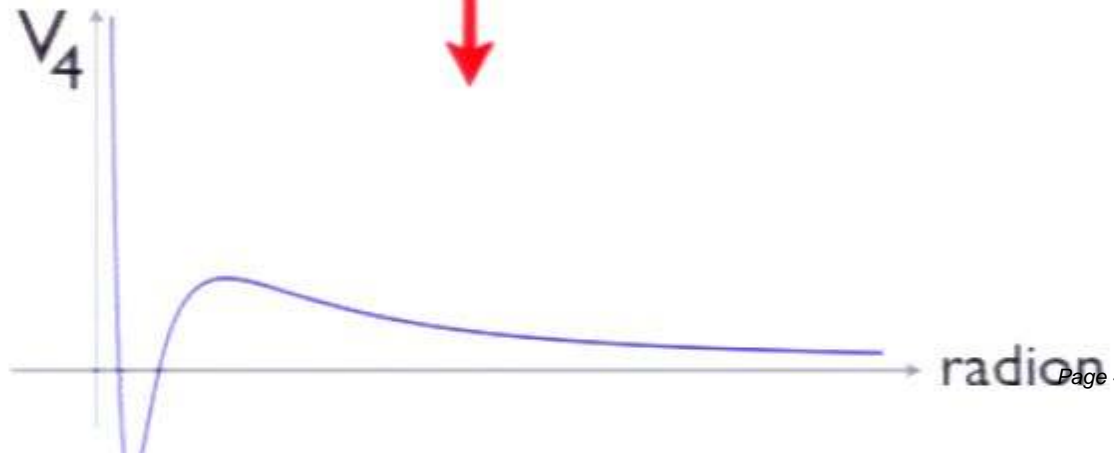
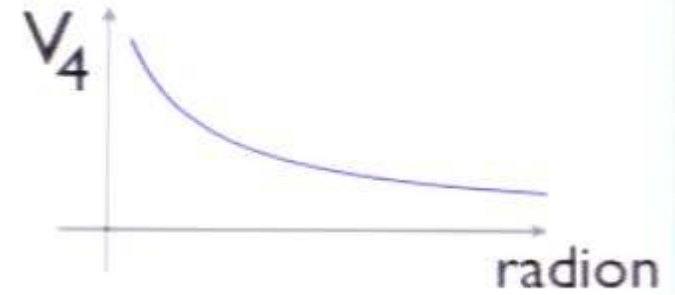
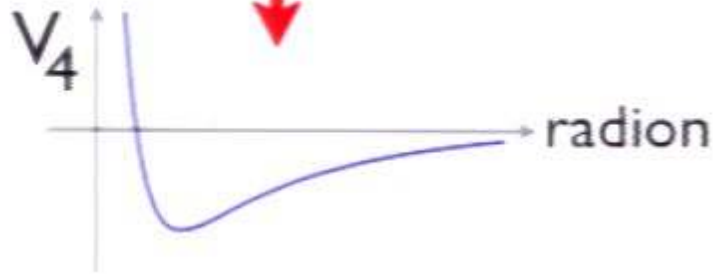


curvature

medium-range, attractive

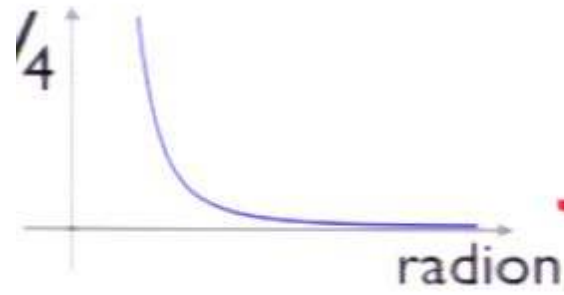


6D +ve c.c.
long-range, repulsive



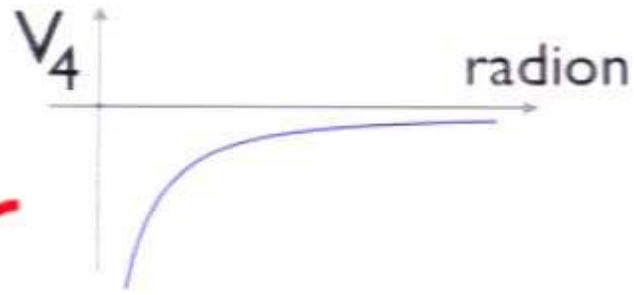
flux

short-range, repulsive

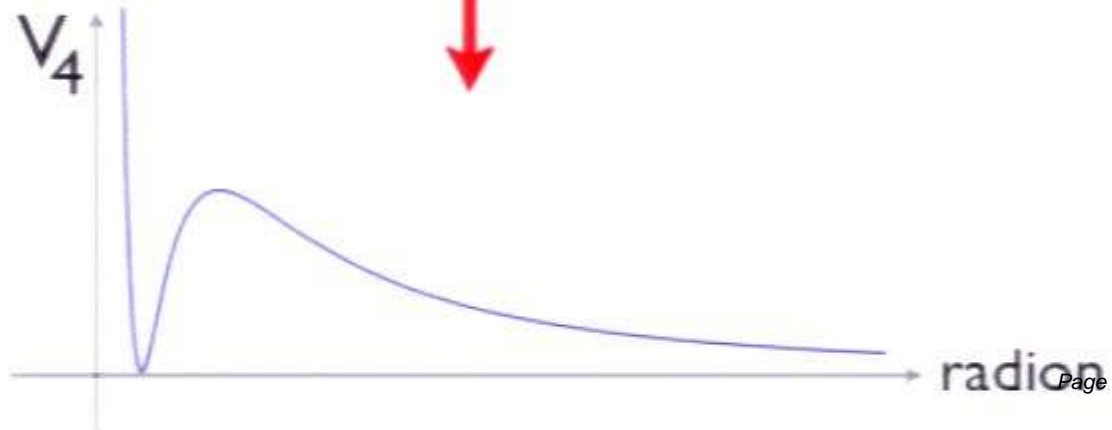
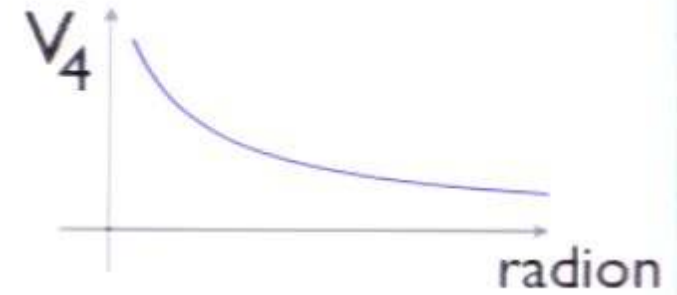
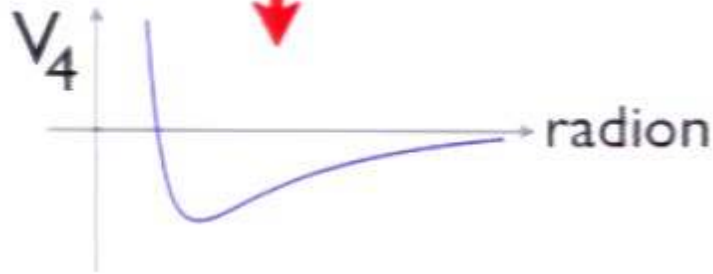


curvature

medium-range, attractive

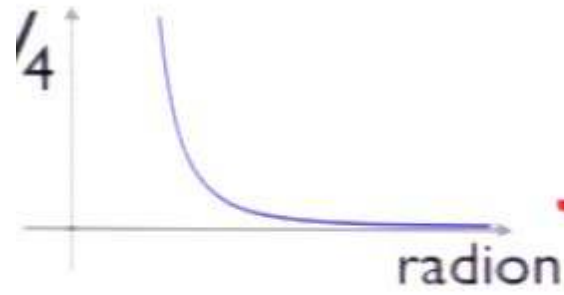


6D +ve c.c.
long-range, repulsive



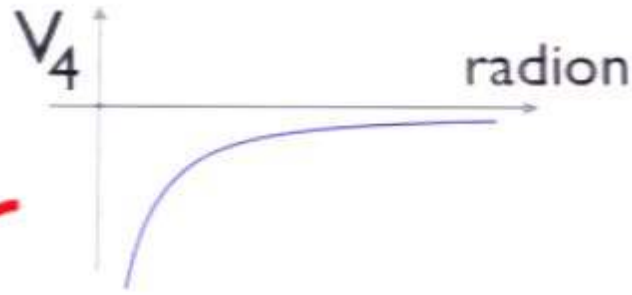
flux

short-range, repulsive



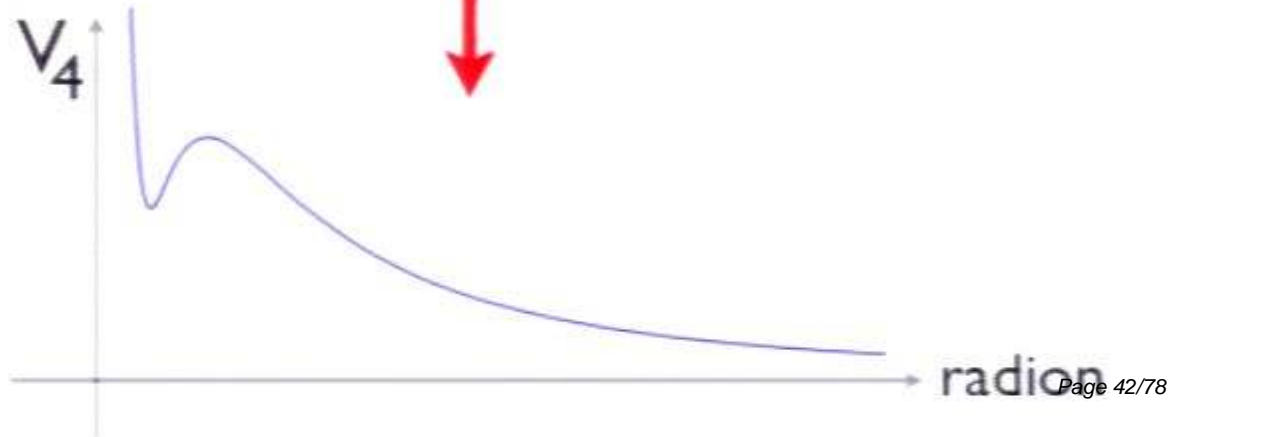
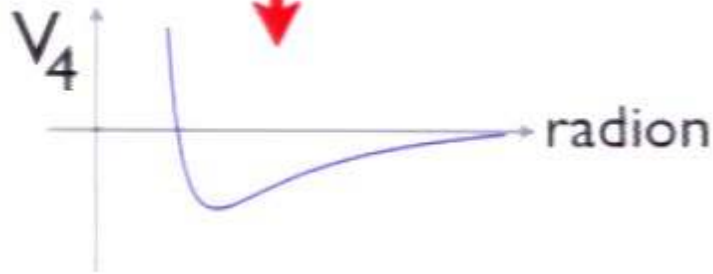
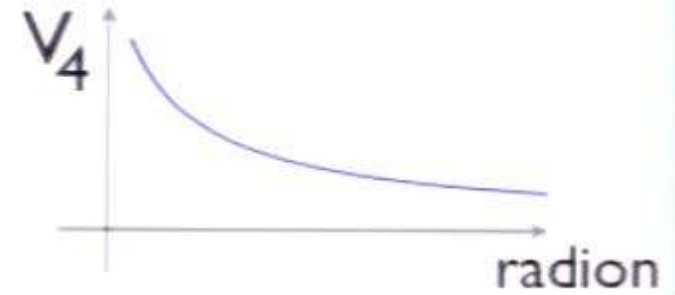
curvature

medium-range, attractive



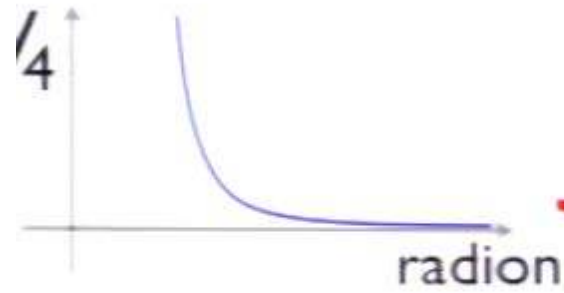
6D +ve c.c.

long-range, repulsive



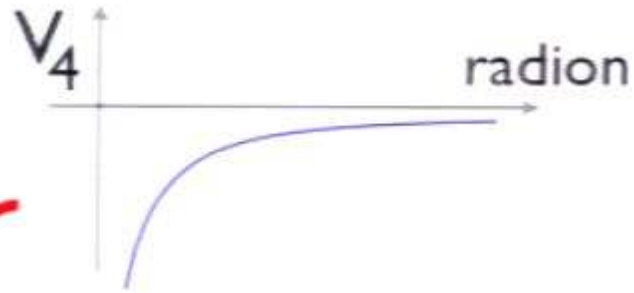
flux

short-range, repulsive

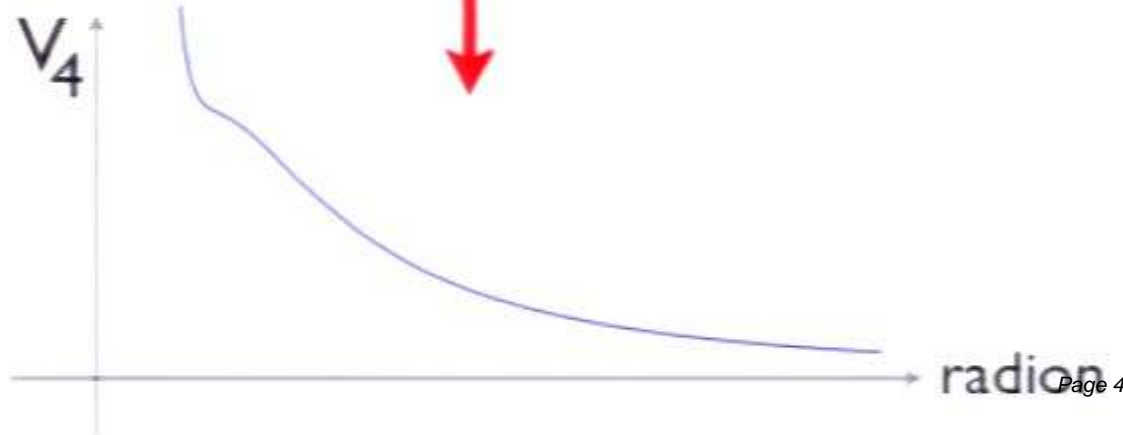
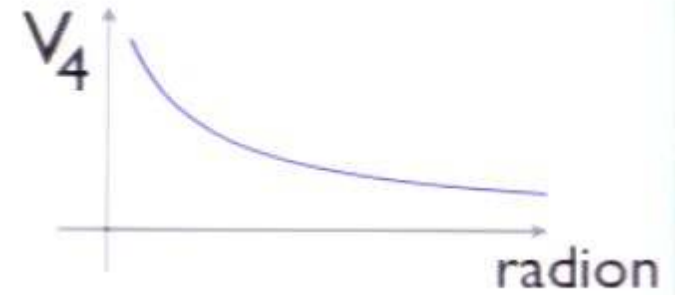
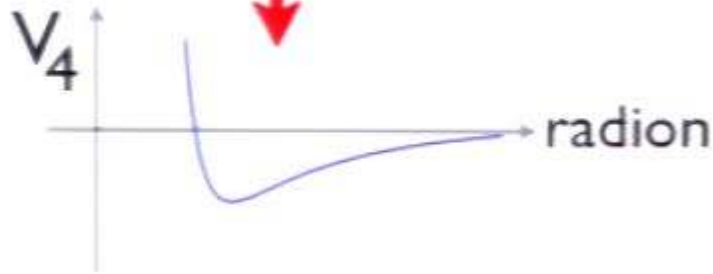


curvature

medium-range, attractive

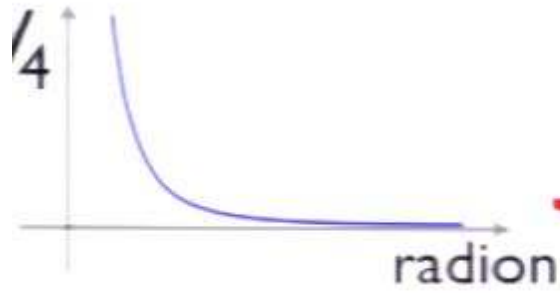


6D +ve c.c.
long-range, repulsive



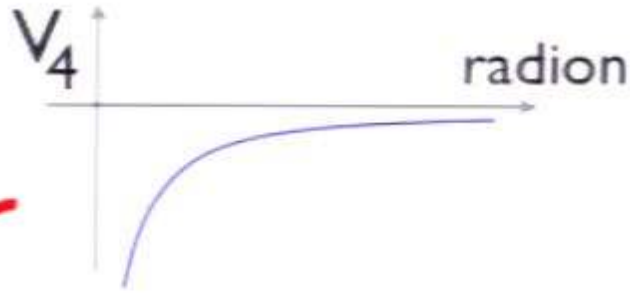
flux

short-range, repulsive

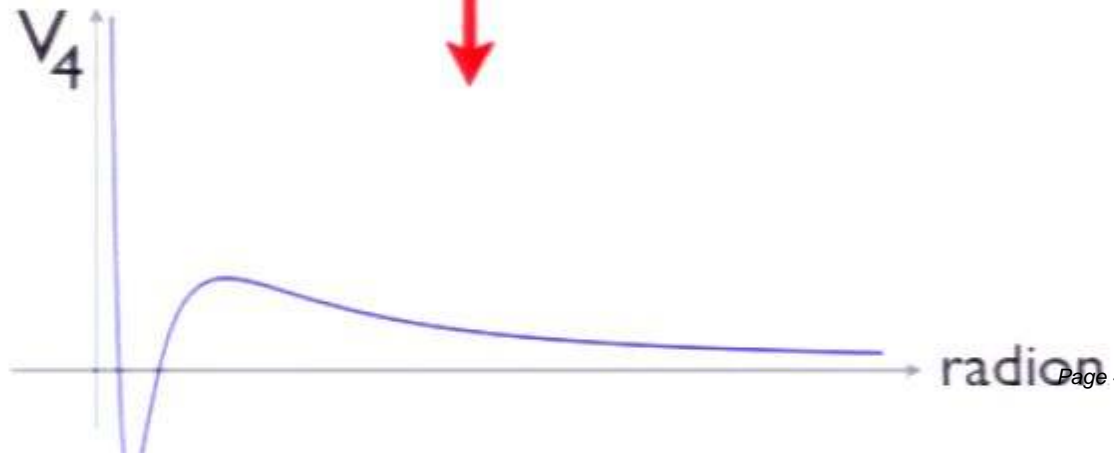
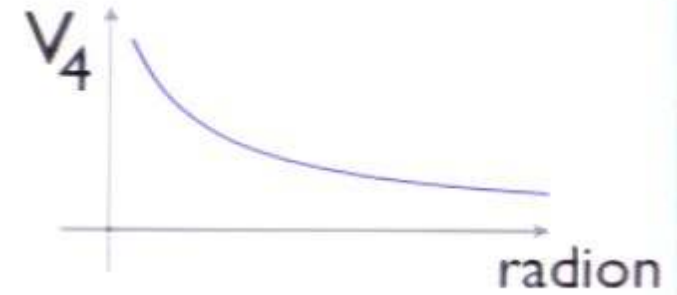
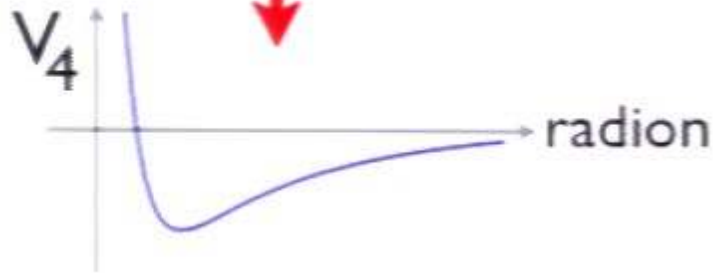


curvature

medium-range, attractive

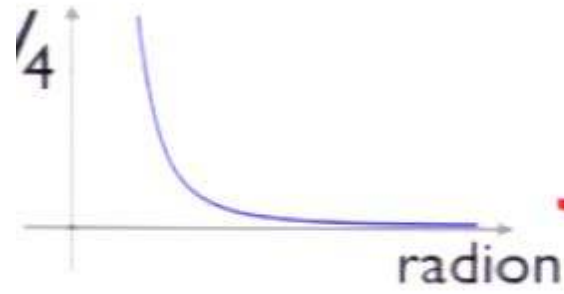


6D +ve c.c.
long-range, repulsive



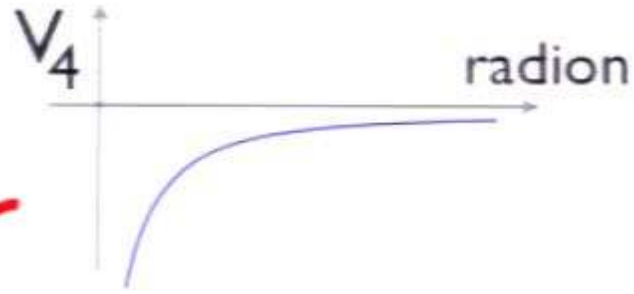
flux

short-range, repulsive

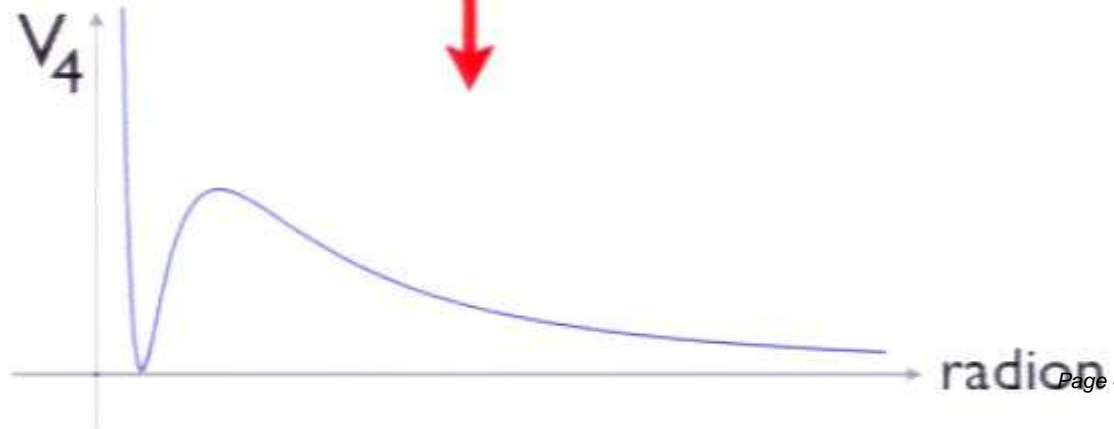
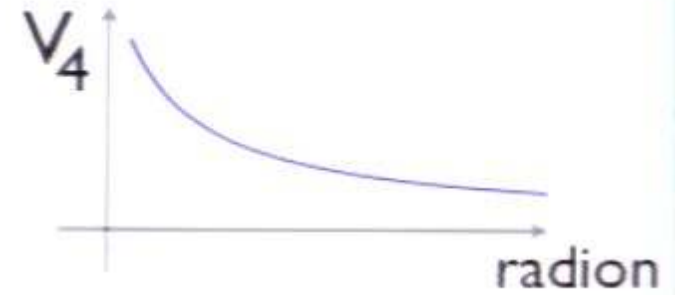
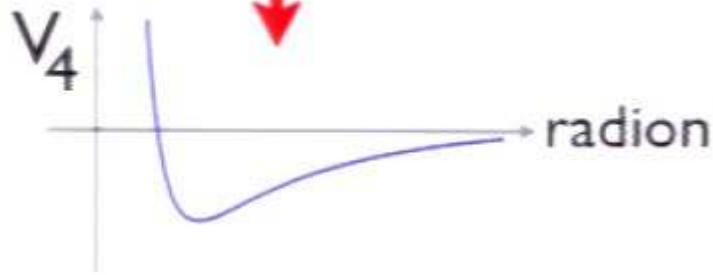


curvature

medium-range, attractive

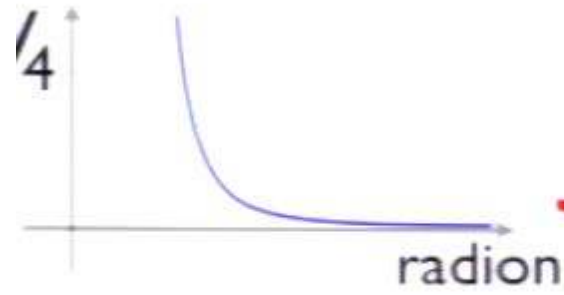


6D +ve c.c.
long-range, repulsive



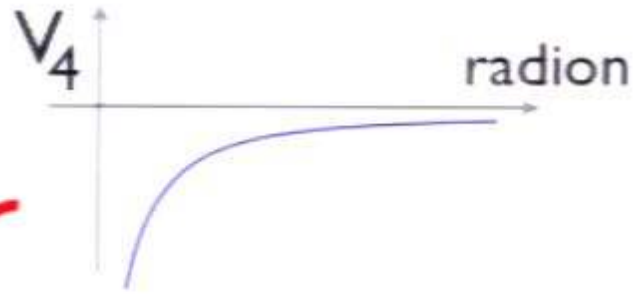
flux

short-range, repulsive

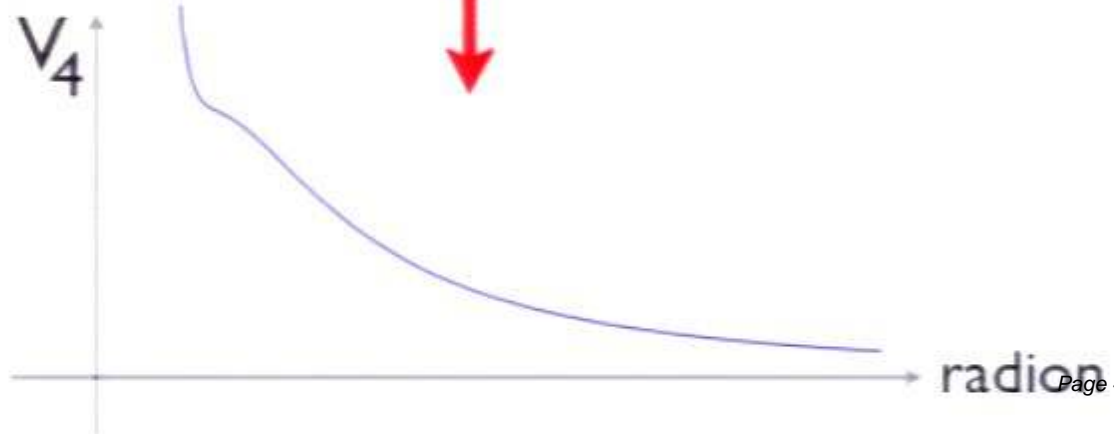
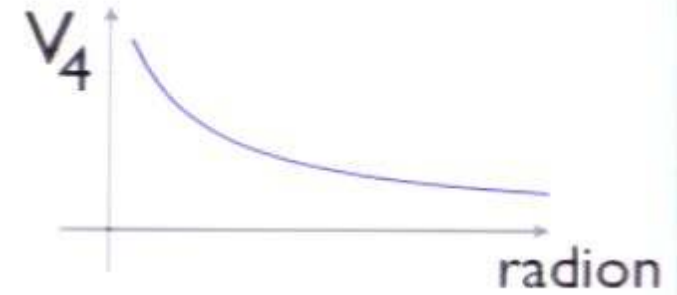
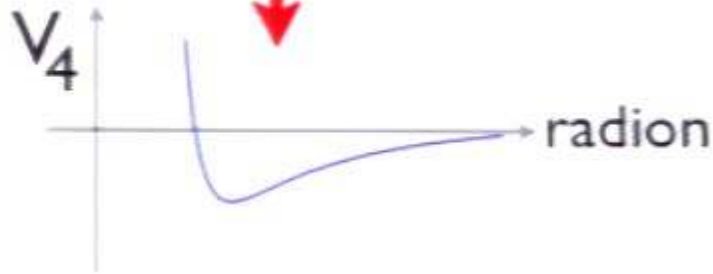


curvature

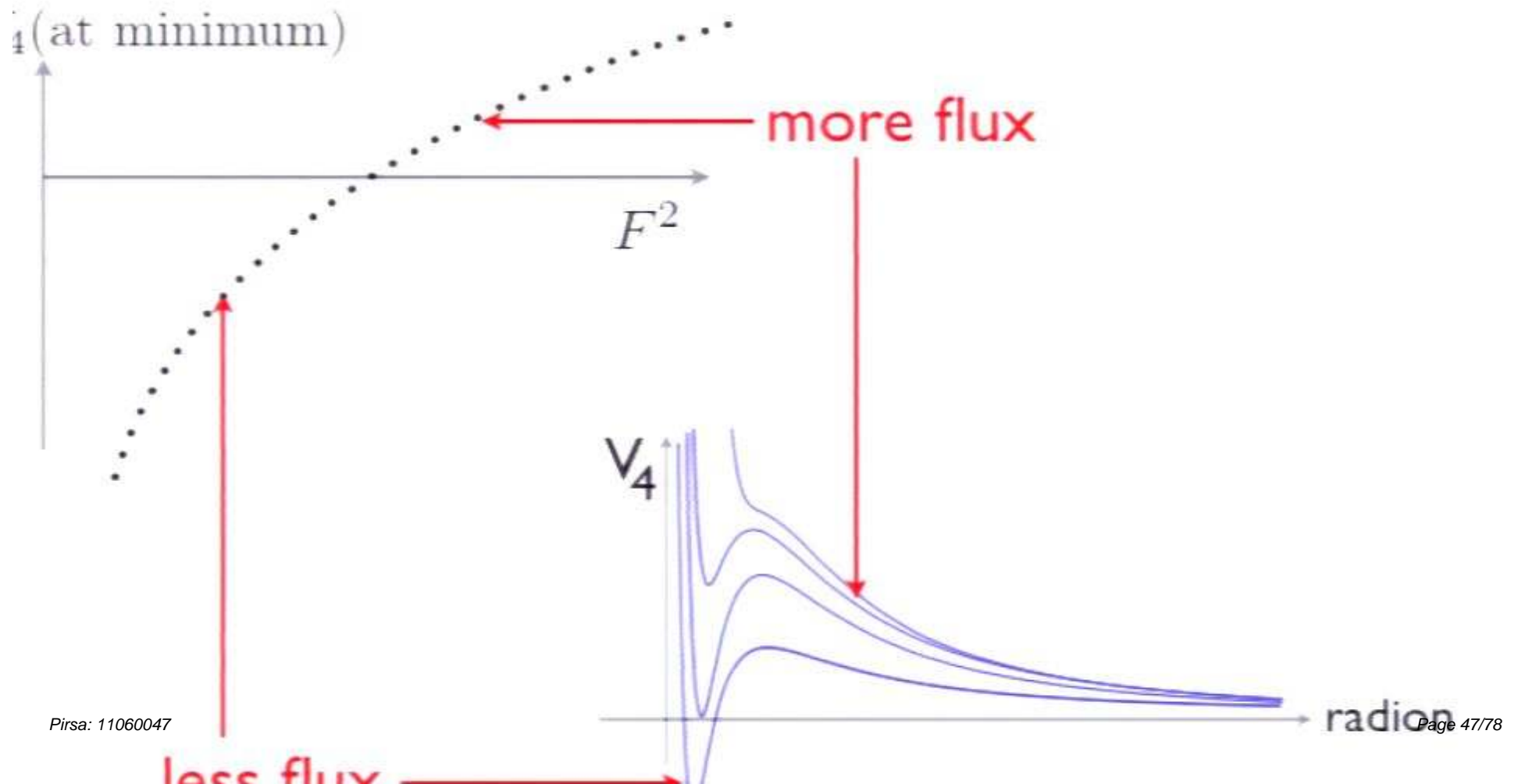
medium-range, attractive



6D +ve c.c.
long-range, repulsive

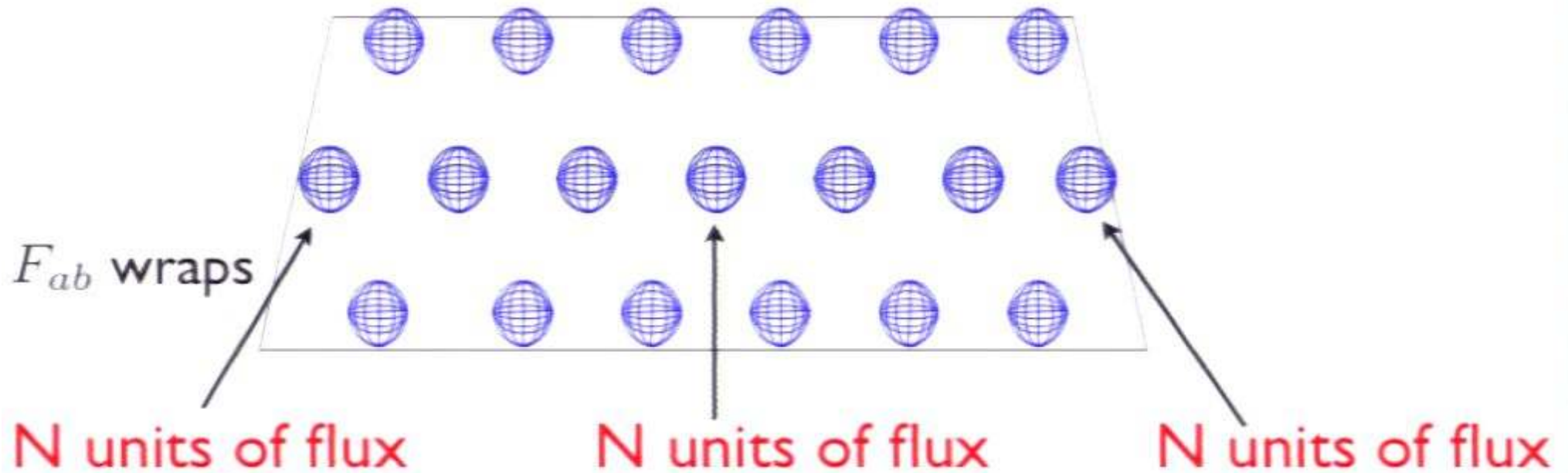


a landscape of (discrete) flux vacua

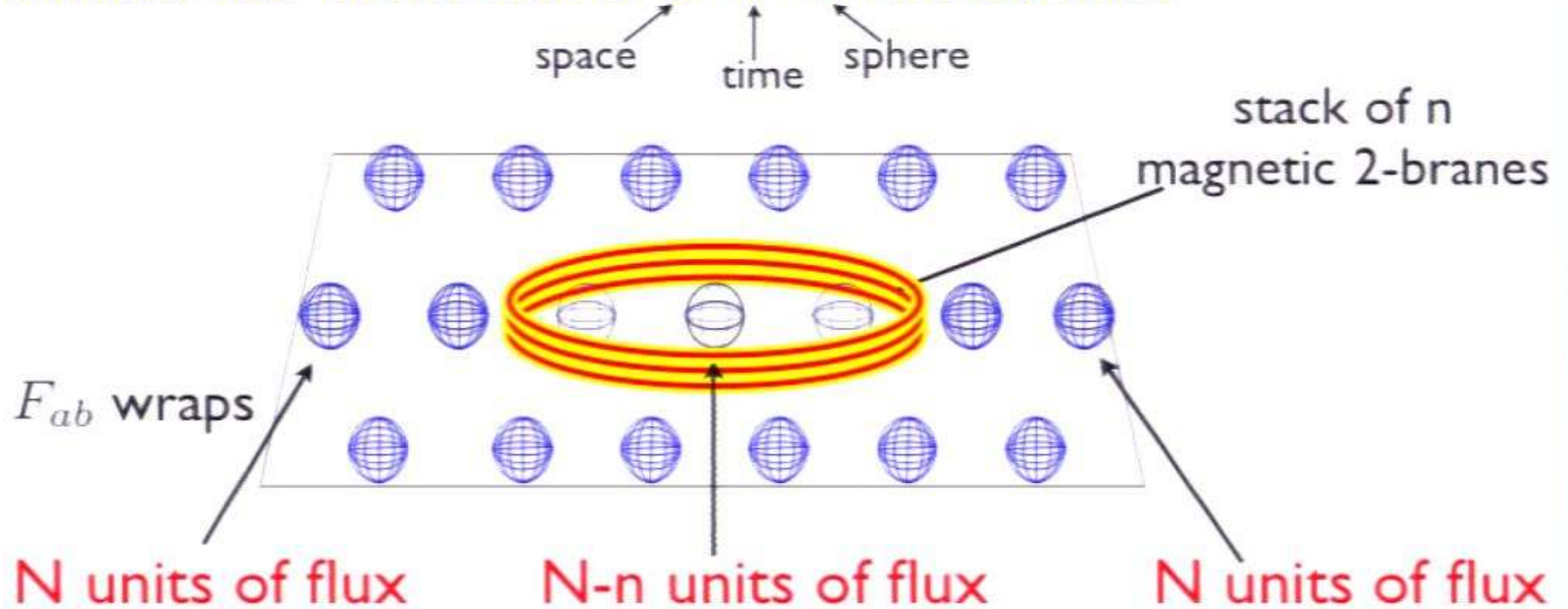


Consider the transition in $3+1+2$ dimensions

space time sphere



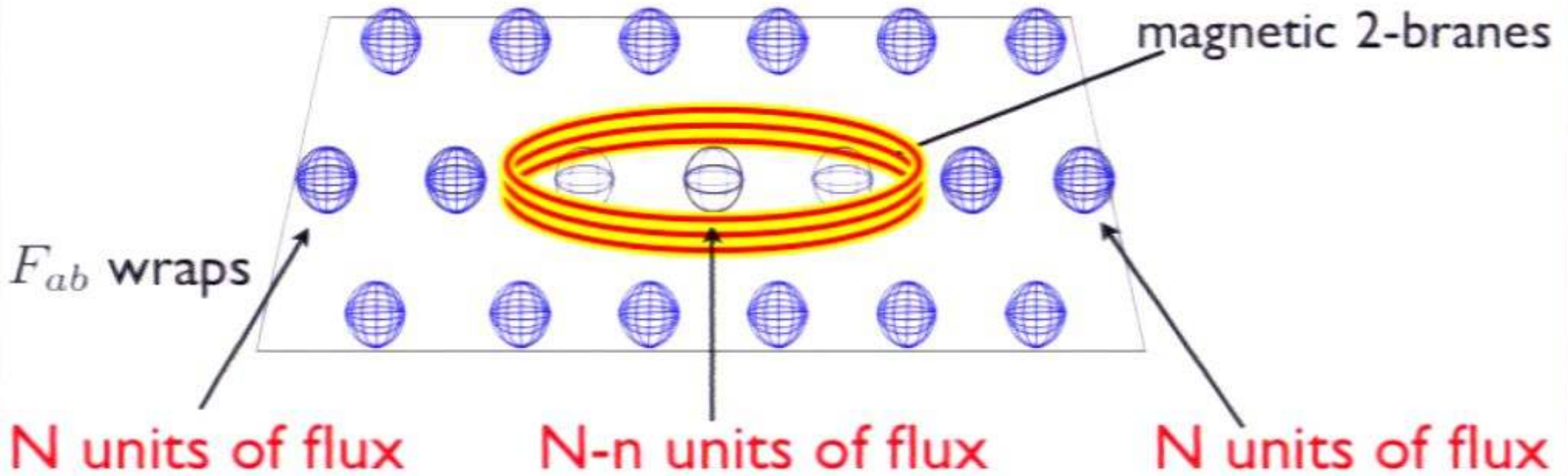
Consider the transition in $3+1+2$ dimensions



Consider the transition in $3+1+2$ dimensions

space time sphere

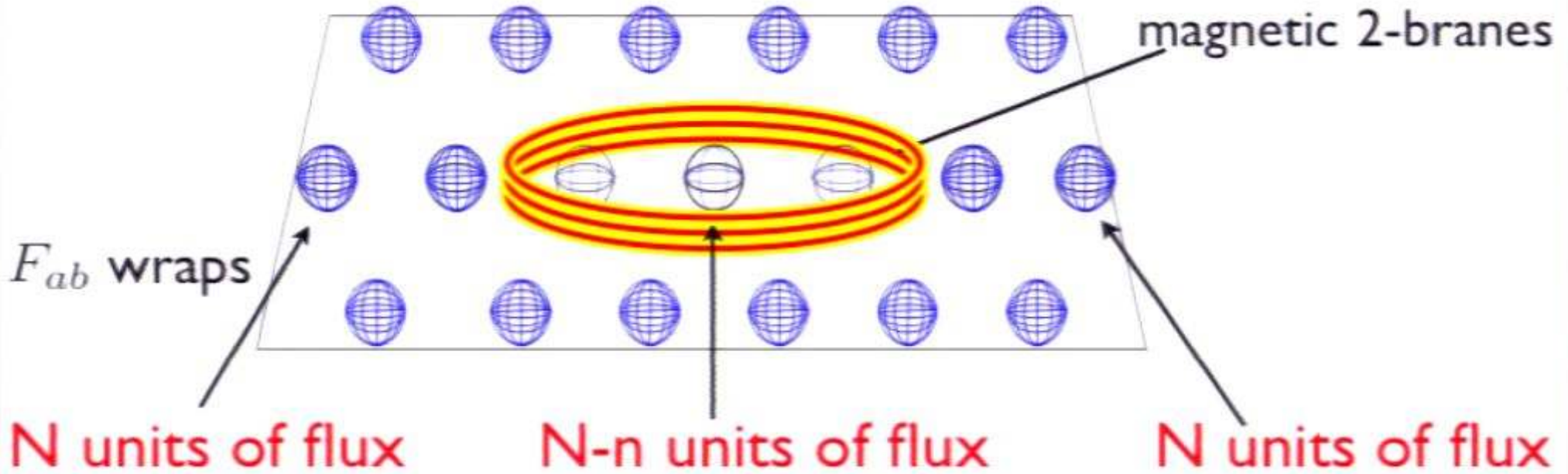
stack of n
magnetic 2-branes



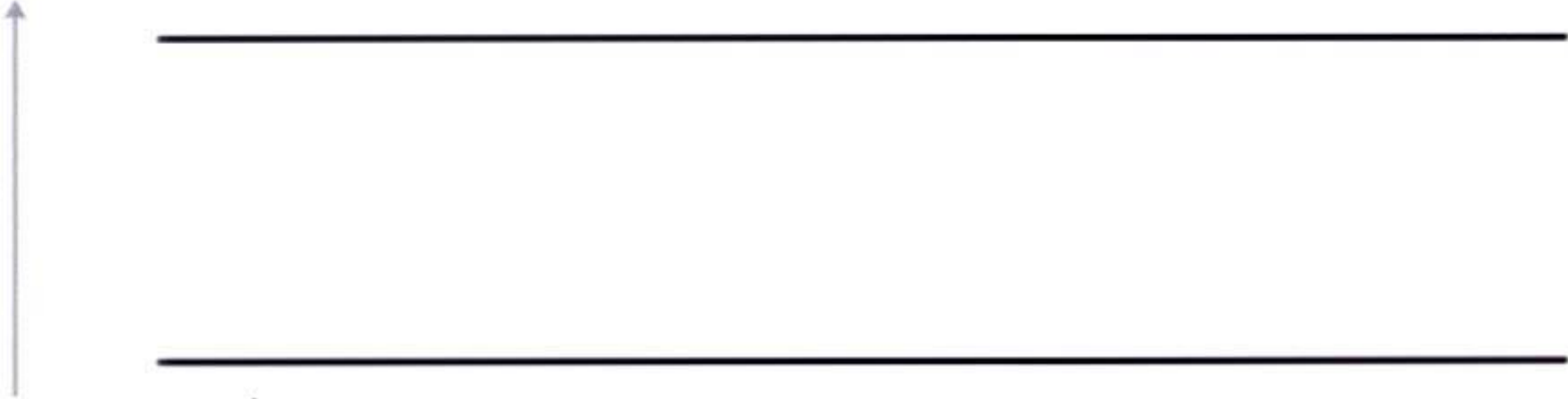
Consider the transition in $3+1+2$ dimensions

space time sphere

stack of n
magnetic 2-branes



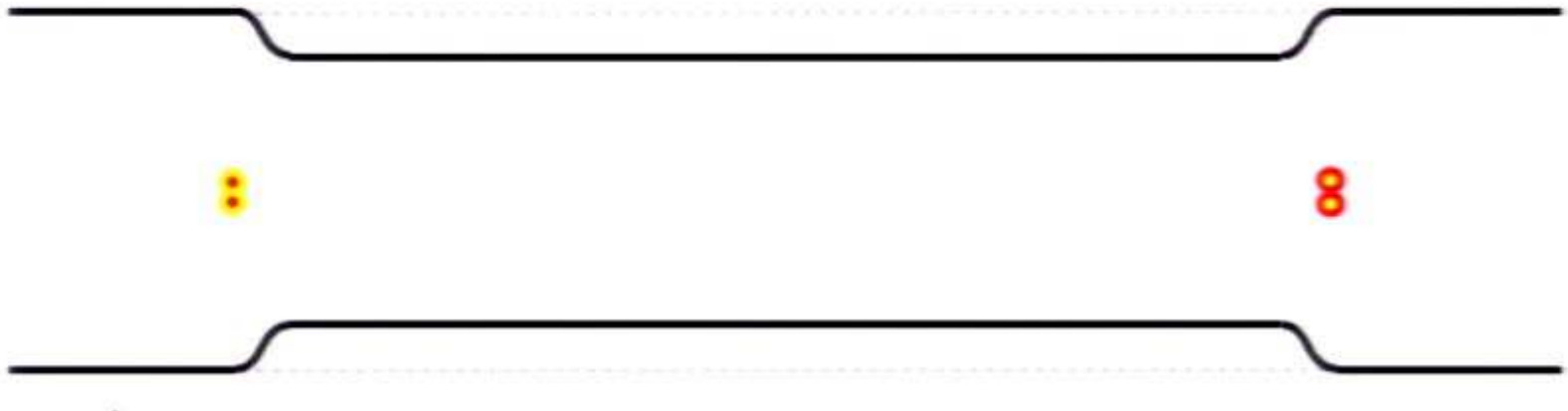
extra
dimensions



N units of flux

N units of flux

extra
dimensions

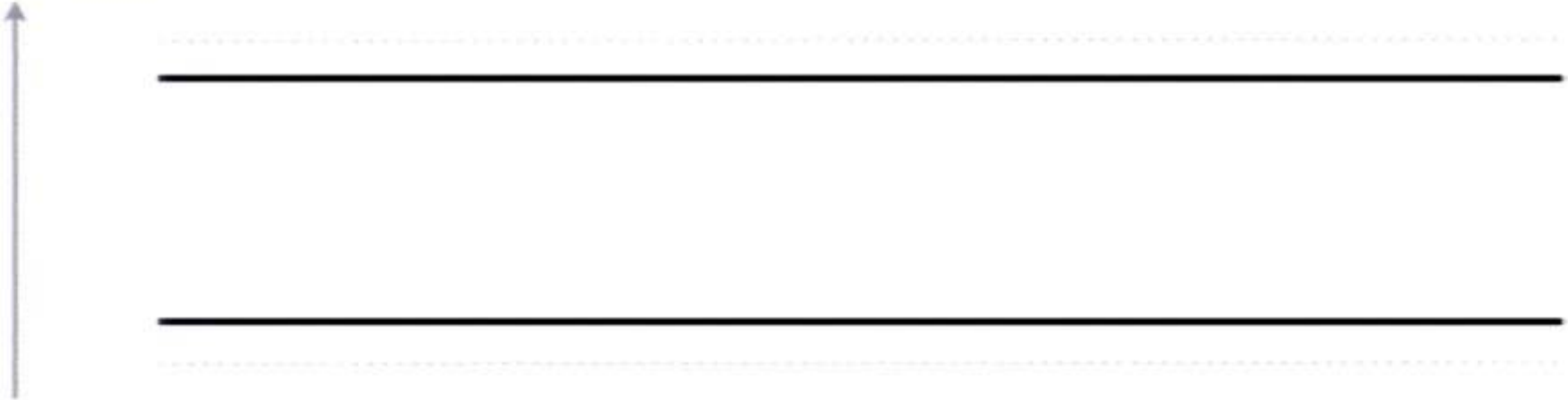


N units of flux

N-20 units of flux

N units of flux

extra
dimensions

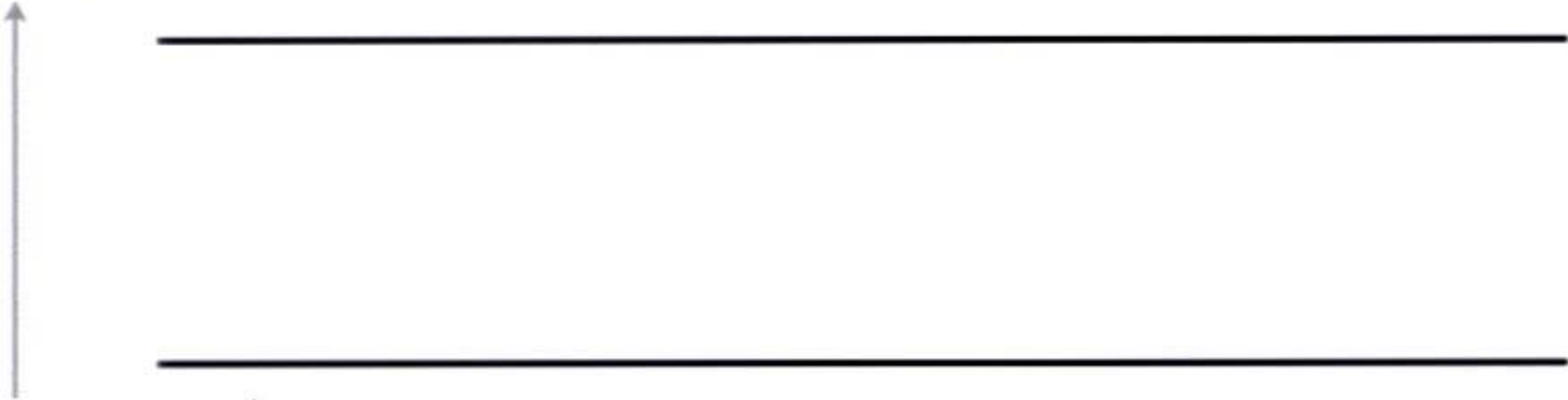


N units of flux

N-20 units of flux

N units of flux

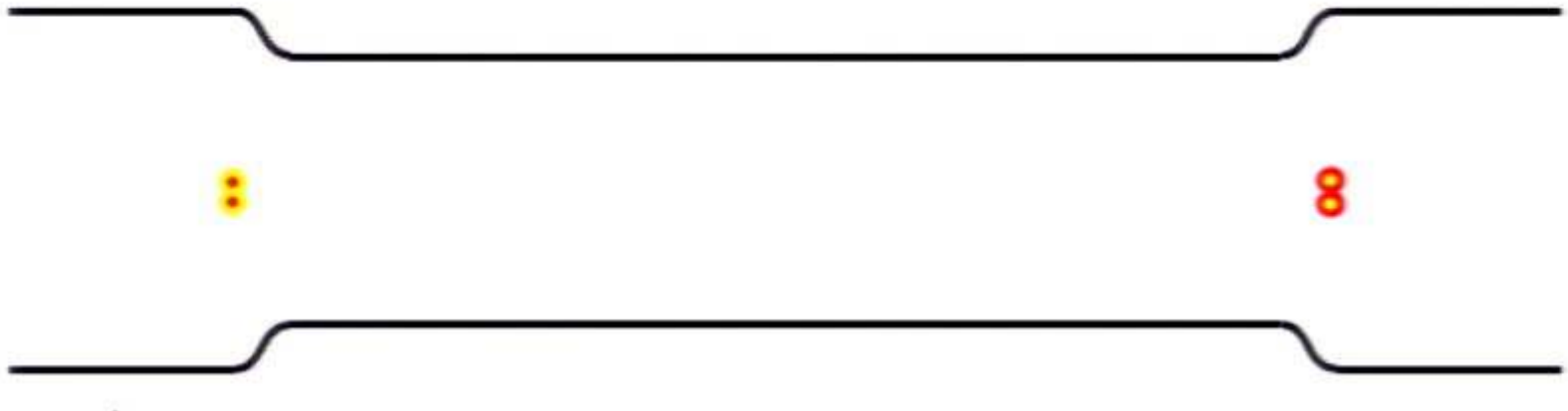
extra
dimensions



N units of flux

N units of flux

extra
dimensions

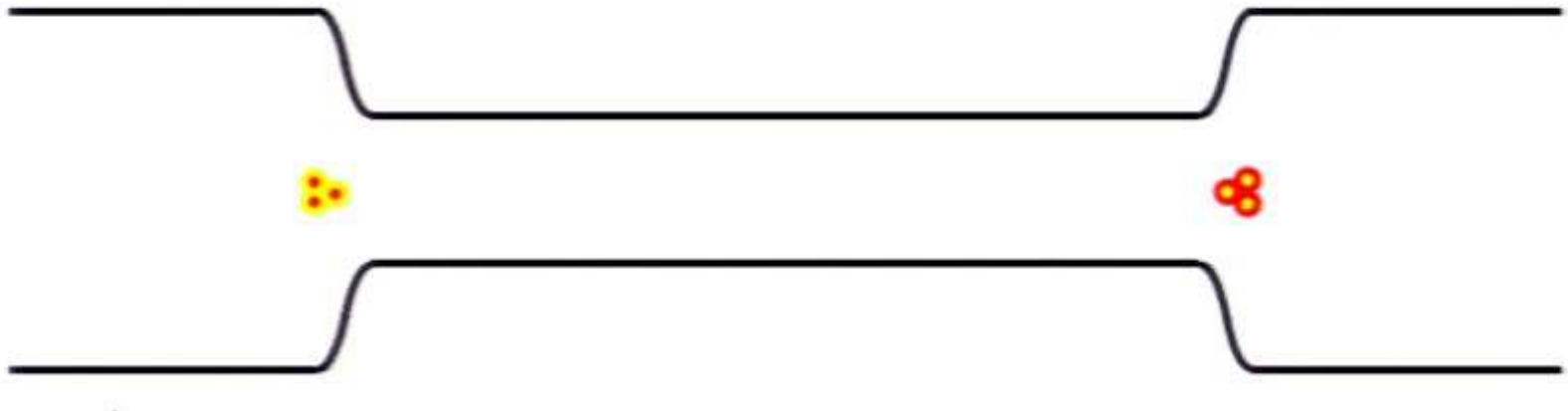


N units of flux

N-20 units of flux

N units of flux

extra
dimensions

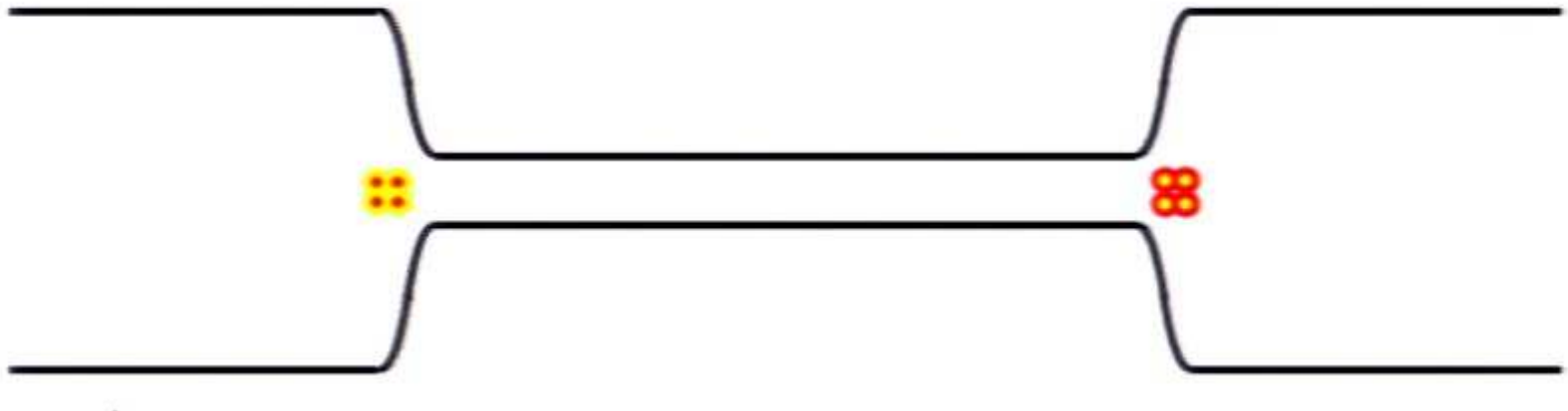


N units of flux

N-30 units of flux

N units of flux

extra
dimensions

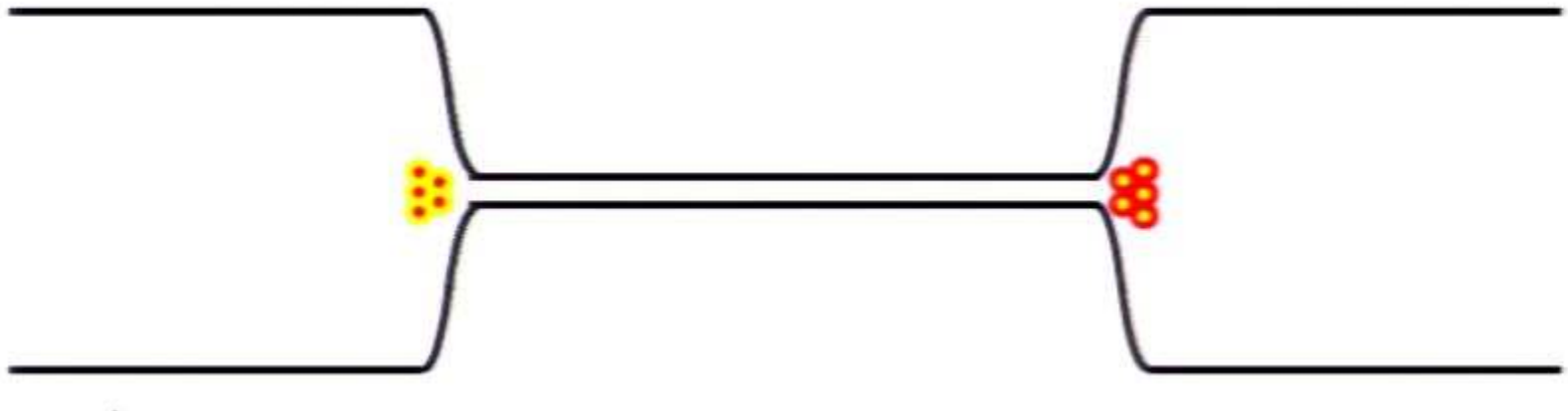


N units of flux

N-40 units of flux

N units of flux

extra
dimensions

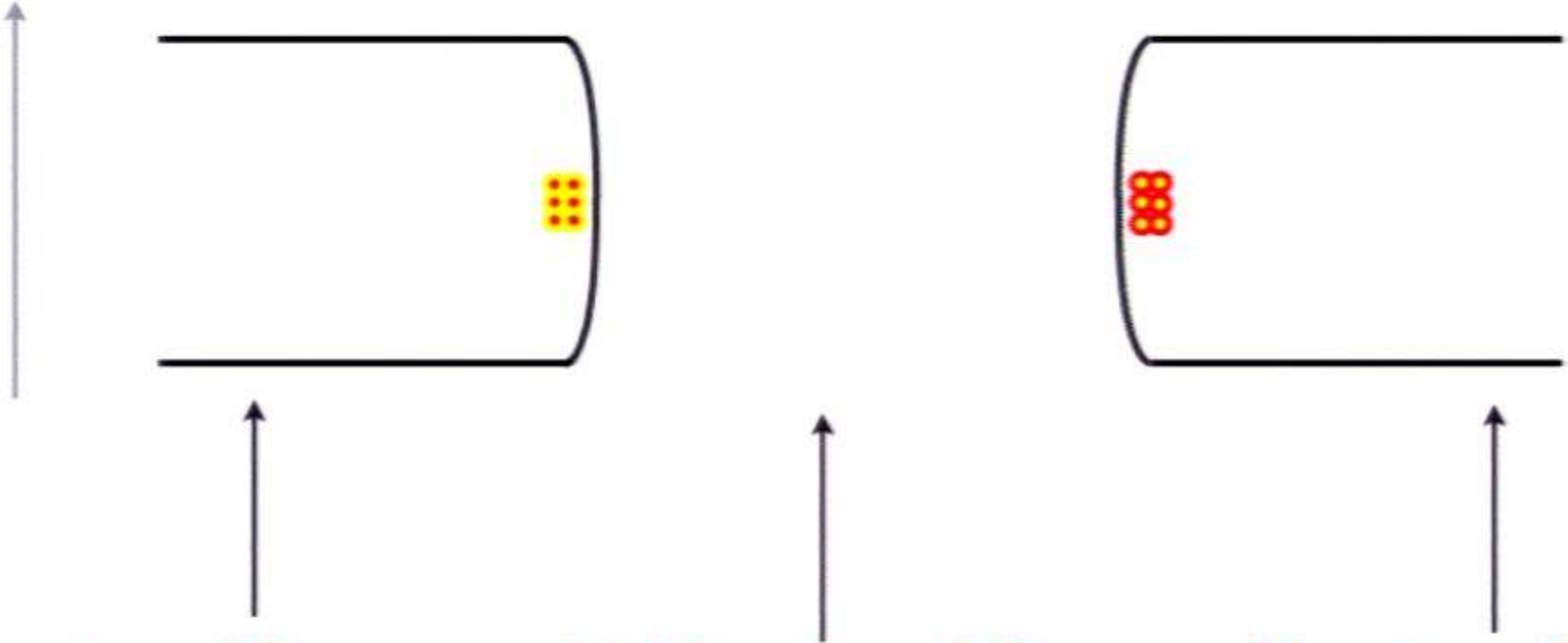


N units of flux

$N-50$ units of flux

N units of flux

extra
dimensions



N units of flux

N-N units of flux

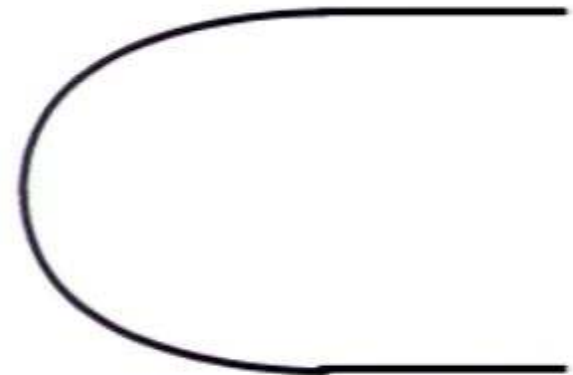
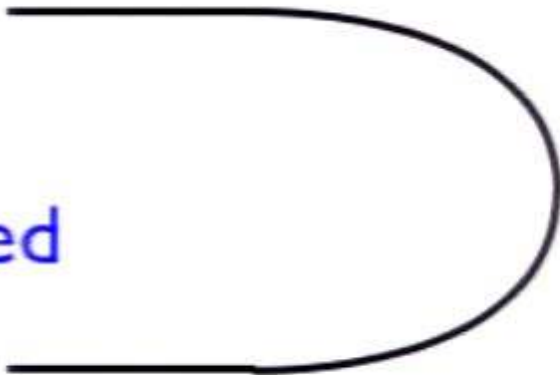
N units of flux

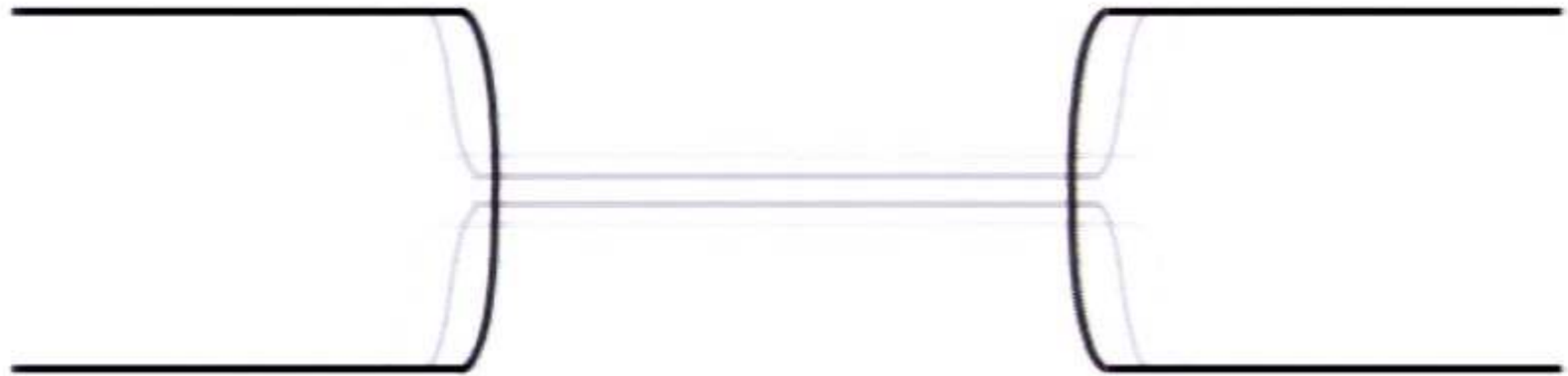
“bubble of nothing”

6d
stabilized



5d
unstabilized

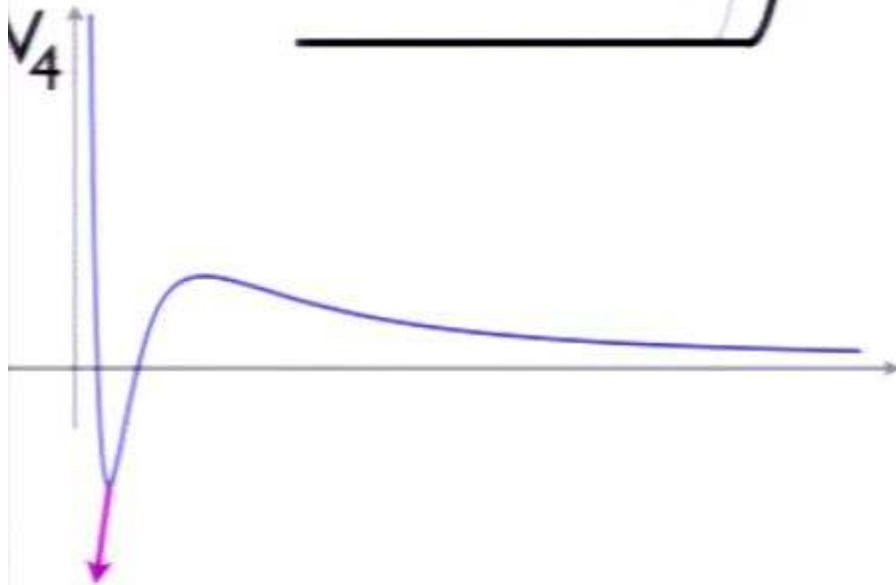
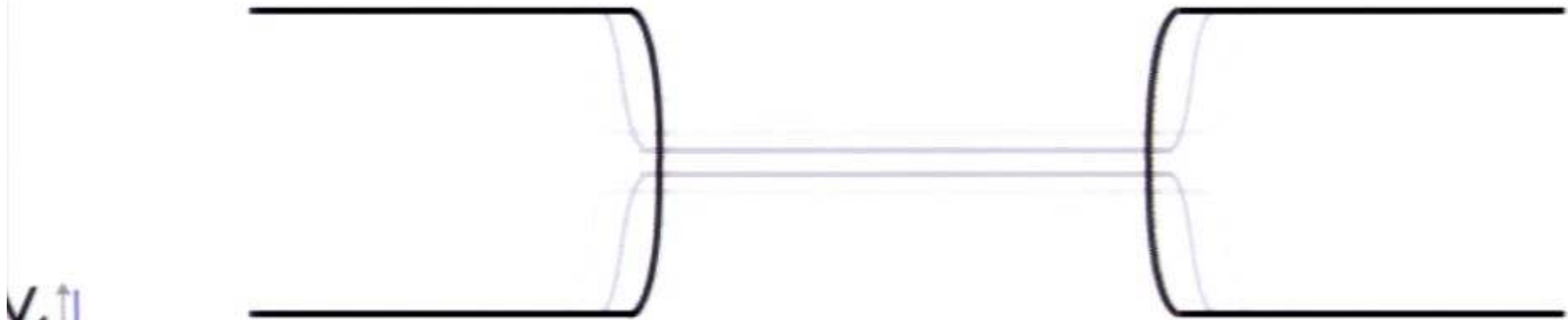




in the limit that **ALL** flux discharged:

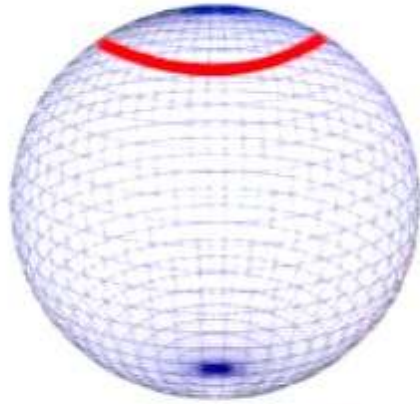
1. Extra dimensions shrink to zero size

1. What about the **3-volume** of a slice through the bubble?
like an infinitely thin pancake?

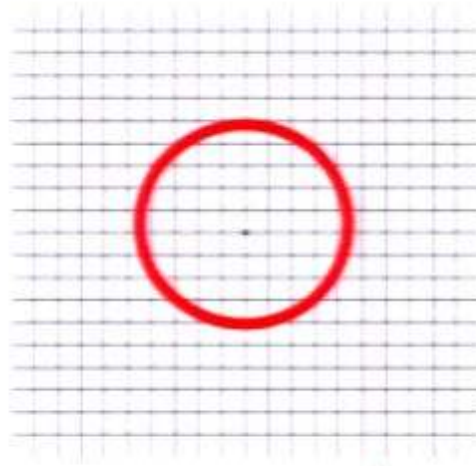


negative V
↓
negative curvature
(AdS)

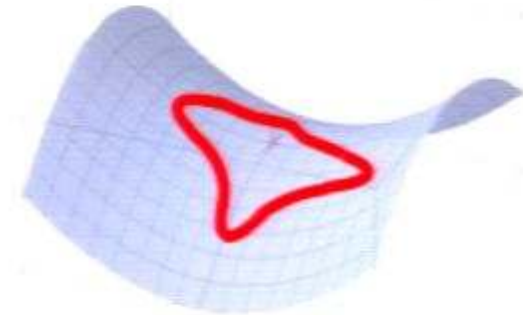
1. What about the **3-volume** of a slice through the bubble?
like an infinitely thin pancake?



$$\text{Area} > \pi r^2$$

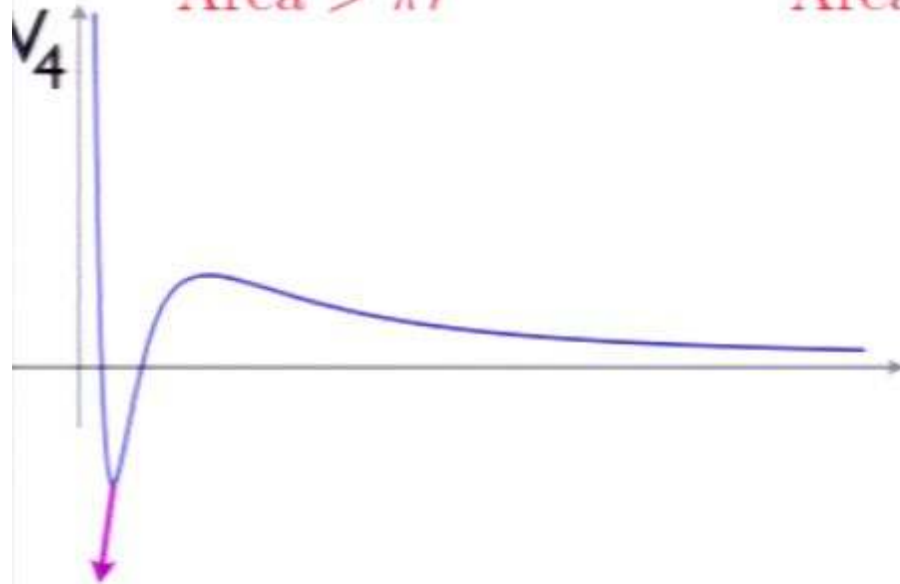


$$\text{Area} = \pi r^2$$



$$\text{Area} < \pi r^2$$

$$\text{Area} \sim r l_{\text{curv}}$$



negative V



negative curvature
(AdS)

1. What about the **3-volume** of a slice through the bubble?
like an infinitely thin pancake?

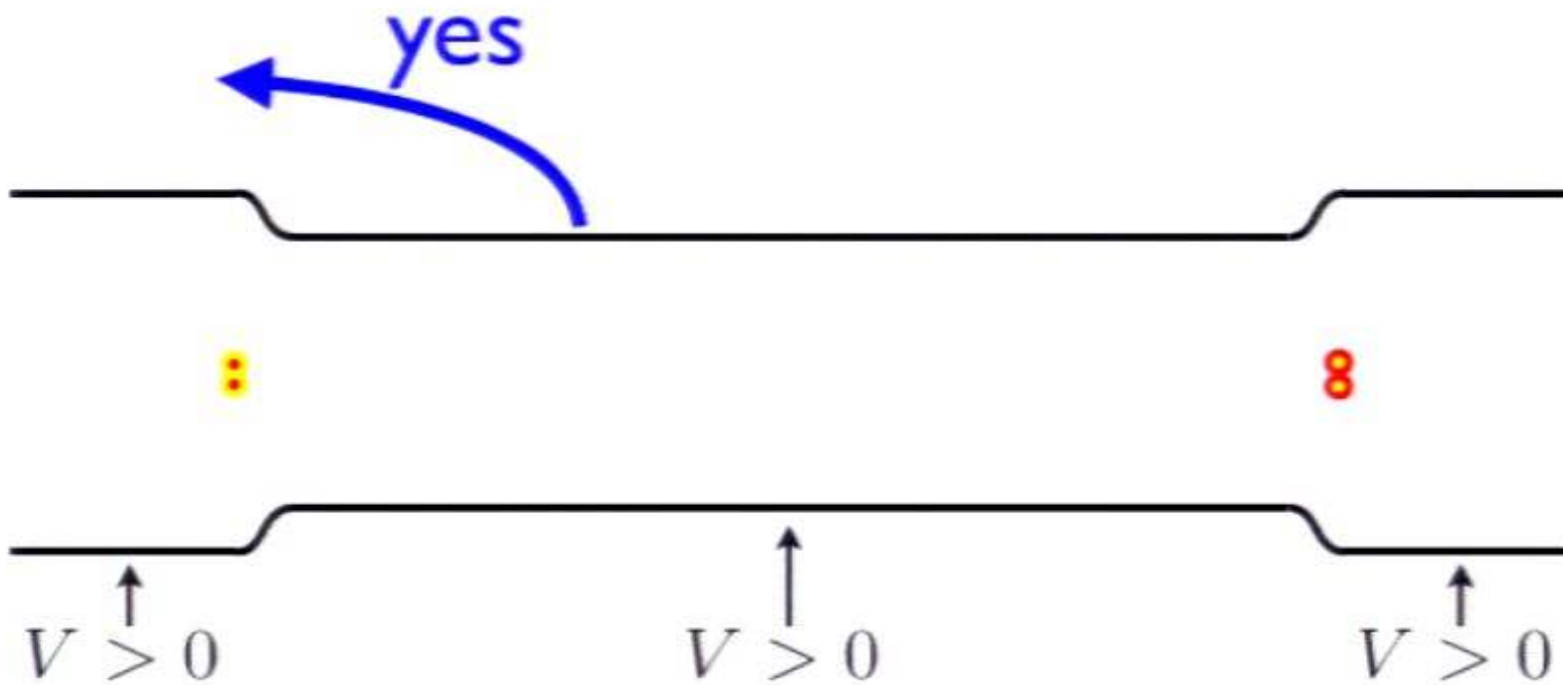
'Nothing' is AdS space (in the limit as $l_{\text{AdS}} \rightarrow 0$)

The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

Uptunneling is **impossible** from Minkowski or AdS

'Nothing' is AdS space (in the limit as $l_{\text{max}} \rightarrow 0$)

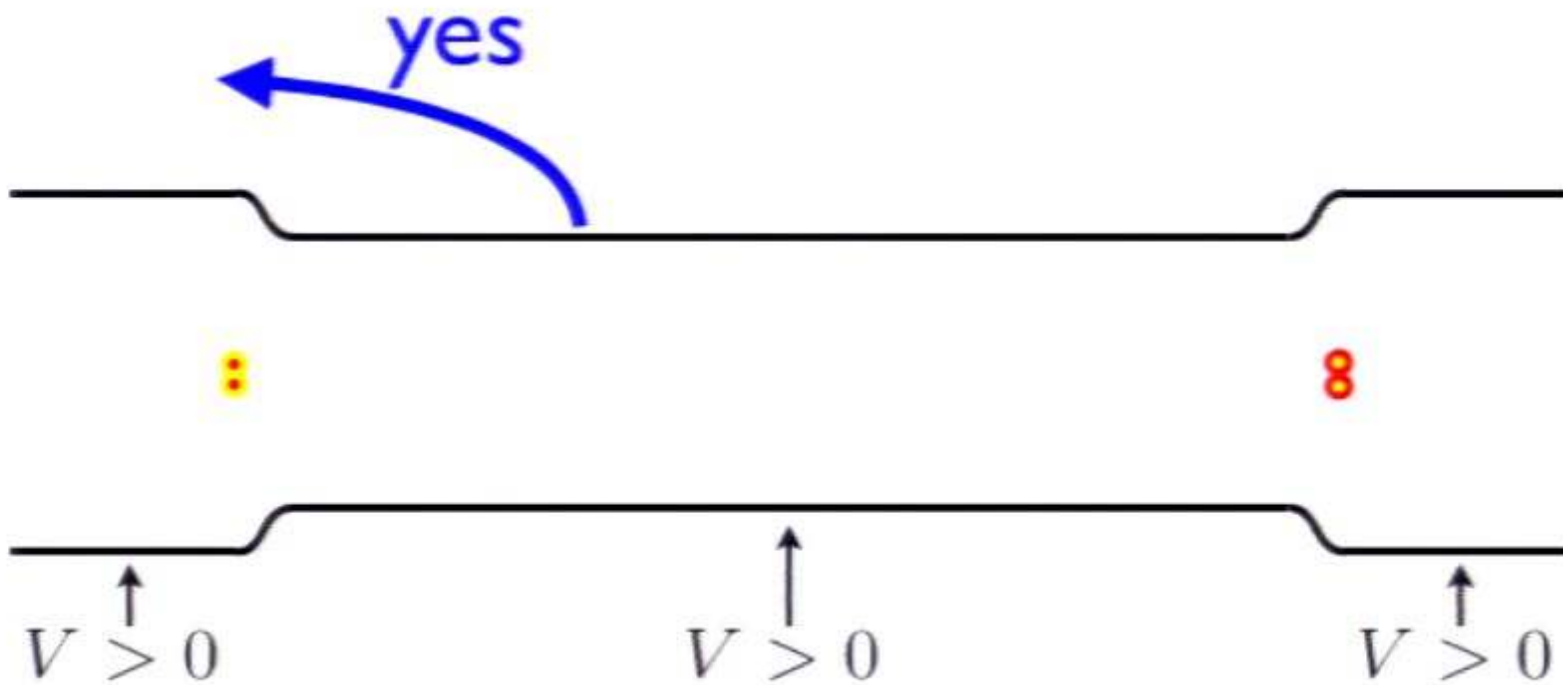


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'Nothing' is AdS space (in the limit as $l_{\text{AdS}} \rightarrow 0$)

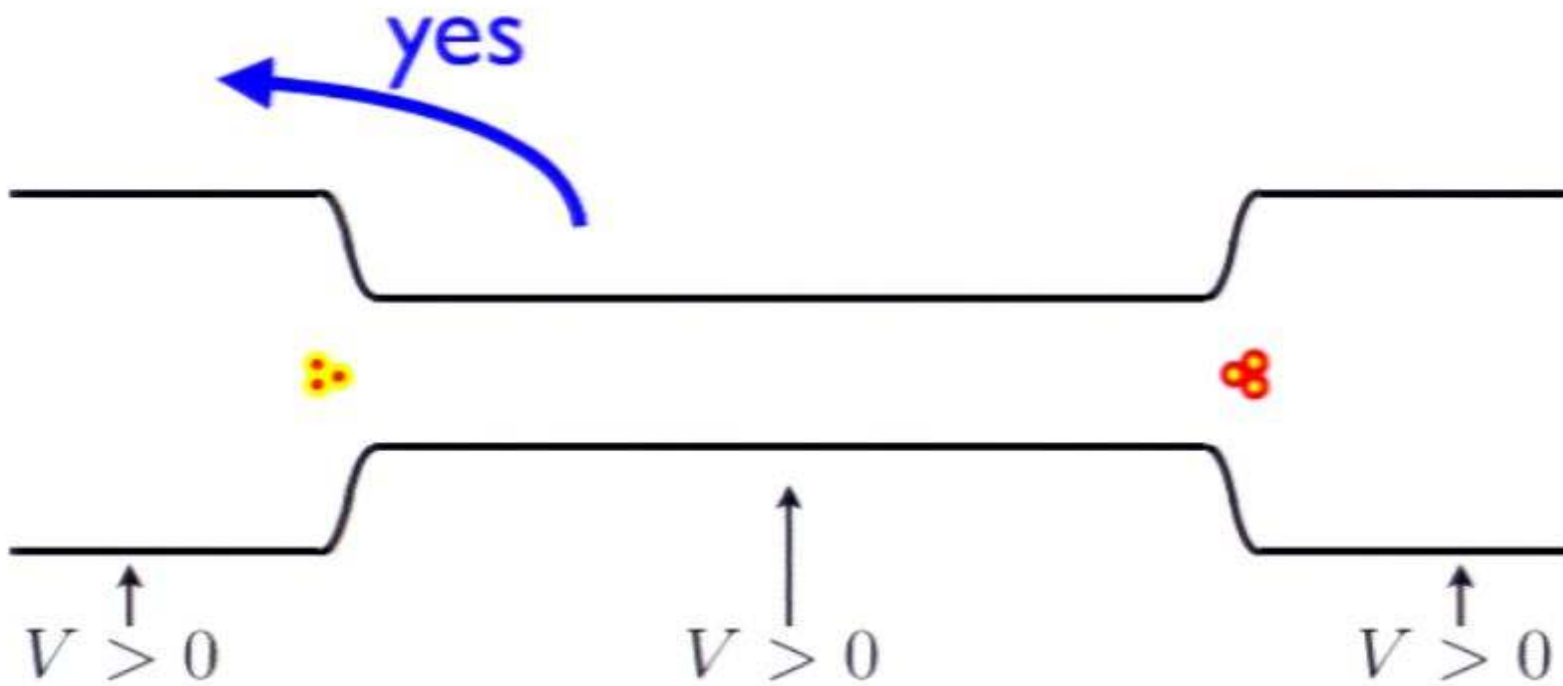


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Uptunneling is impossible from Minkowski or AdS

'Nothing' is AdS space (in the limit as $l_{\text{Planck}} \rightarrow 0$)

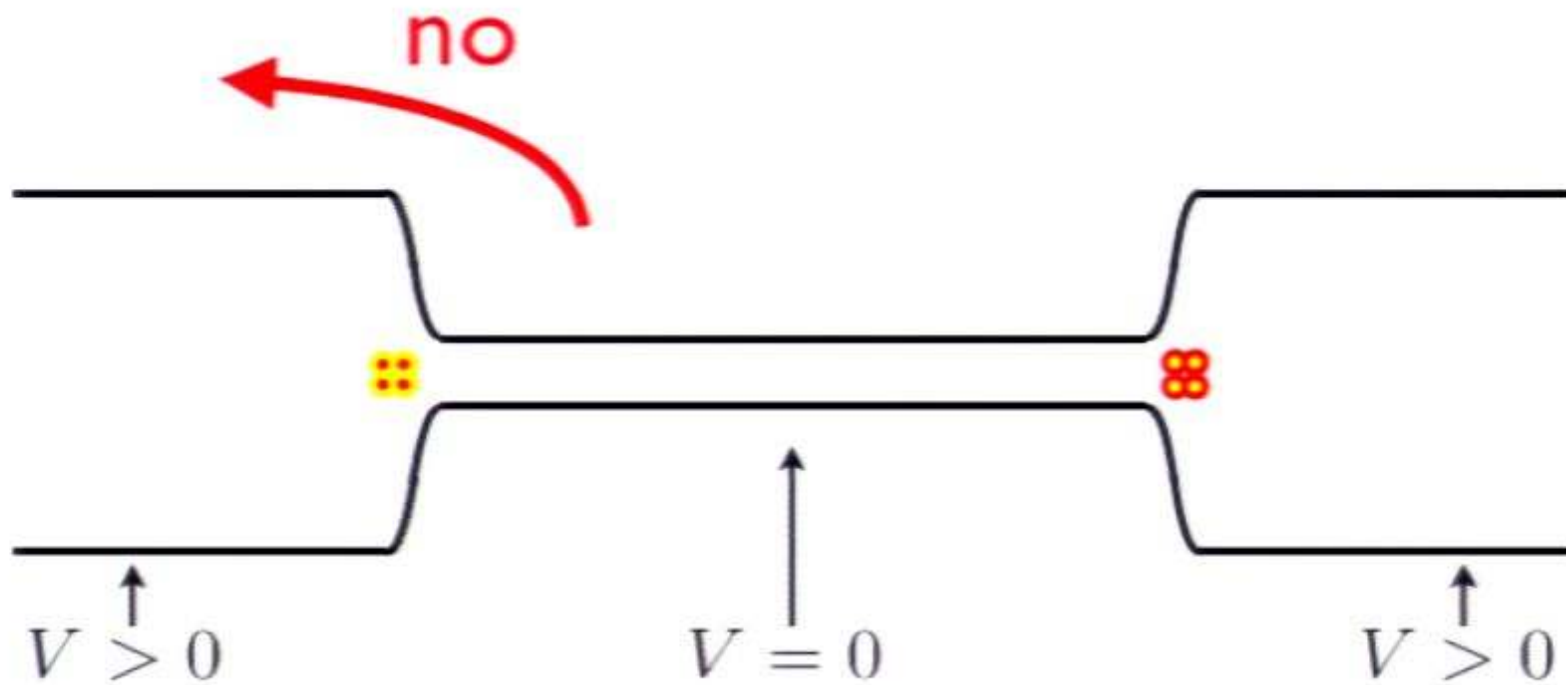


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'Nothing' is AdS space (in the limit as $l_{\text{AdS}} \rightarrow 0$)

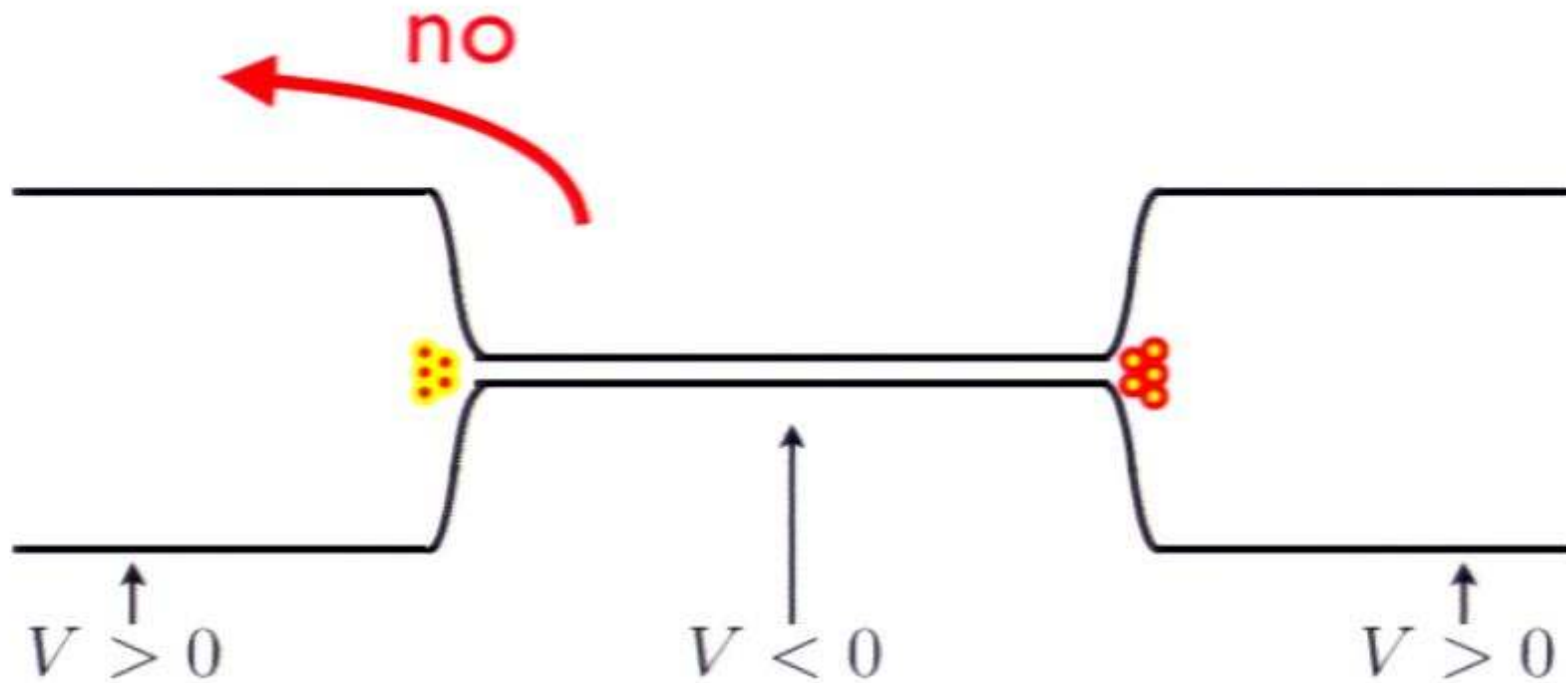


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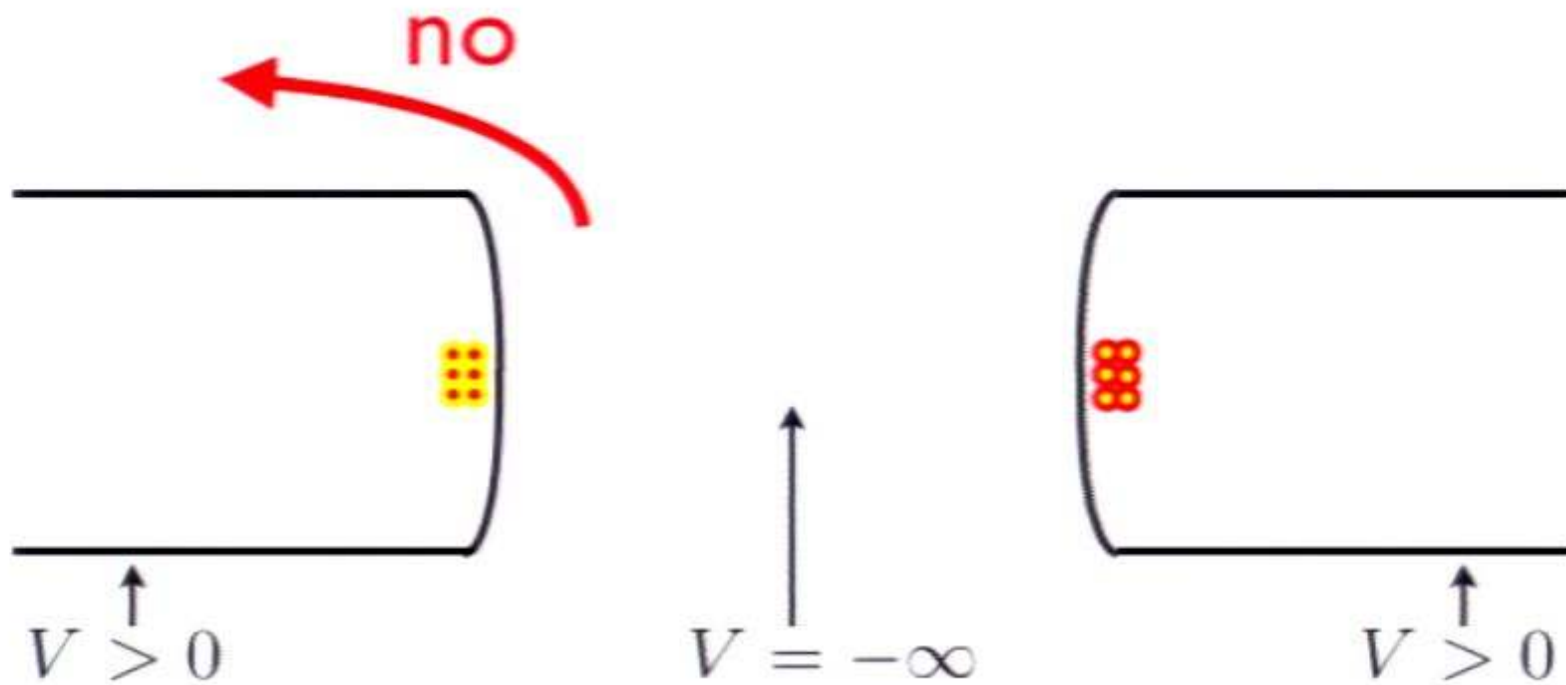


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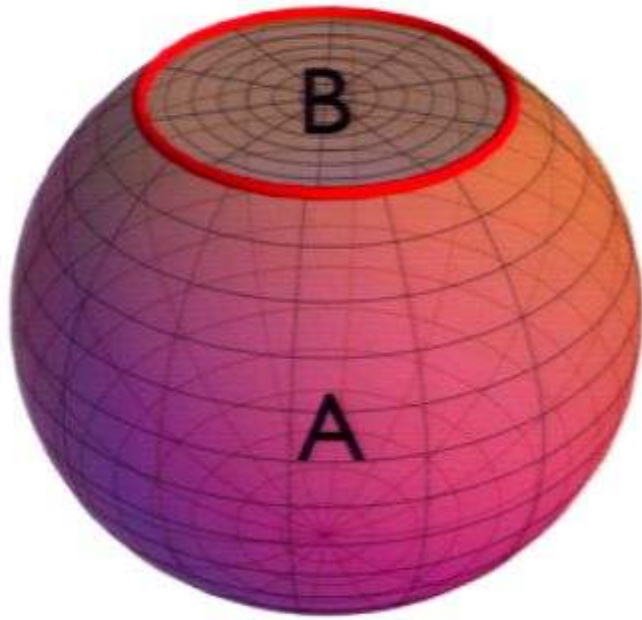


The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

Uptunneling is **impossible** from Minkowski or AdS

'Nothing' is AdS space (in the limit as $l_{\text{AdS}} \rightarrow 0$)



$$S_E(\text{instanton}) = \text{finite}$$

$$S_E(\text{de Sitter}) = -\frac{24\pi^2 M_{\text{Pl}}^4}{V}$$

$$S_E(\text{Minkowski}) = -\infty$$

$$S_E(\text{AdS}) = -\infty$$

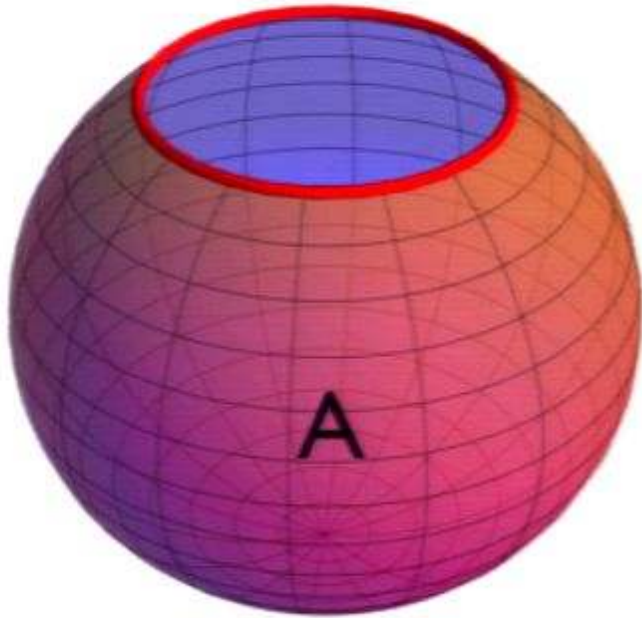
$$\Gamma_{B \rightarrow A} = \exp[-S_E(\text{instanton}) + S_E(B)]$$

The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

Uptunneling is **impossible** from Minkowski or AdS

'Nothing' is AdS space (in the limit as $\ell_{\text{AdS}} \rightarrow 0$)



$$S_E(\text{instanton}) = \text{finite}$$

$$S_E(\text{de Sitter}) = -\frac{24\pi^2 M_{\text{Pl}}^4}{V}$$

$$S_E(\text{Minkowski}) = -\infty$$

$$S_E(\text{AdS}) = -\infty$$

$$S_E(\text{nothing}) = -\infty$$

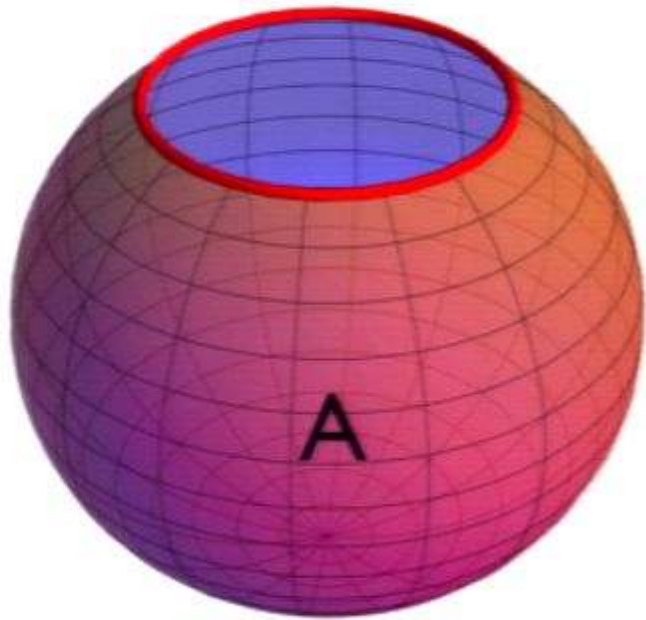
$$\Gamma_{\text{nothing} \rightarrow A} = \exp[-S_E(\text{instanton}) + S_E(\text{nothing})] = 0$$

The SAME instanton governs tunneling in both directions

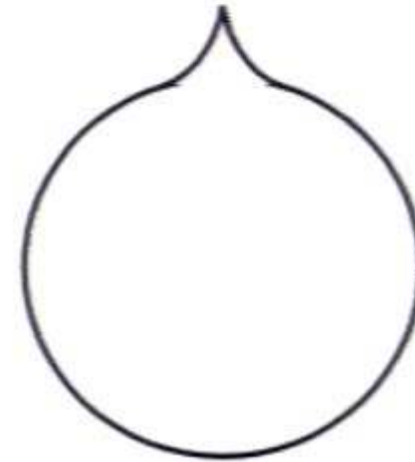
Uptunneling is possible from de Sitter

Uptunneling is **impossible** from Minkowski or AdS

'Nothing' is AdS space (in the limit as $\ell_{\text{cosm}} \rightarrow 0$)



4D
Einstein
Frame



Smooth 6D metric

Singular 4D metric



Bubble of nothing instanton = Hawking-Turok instanton

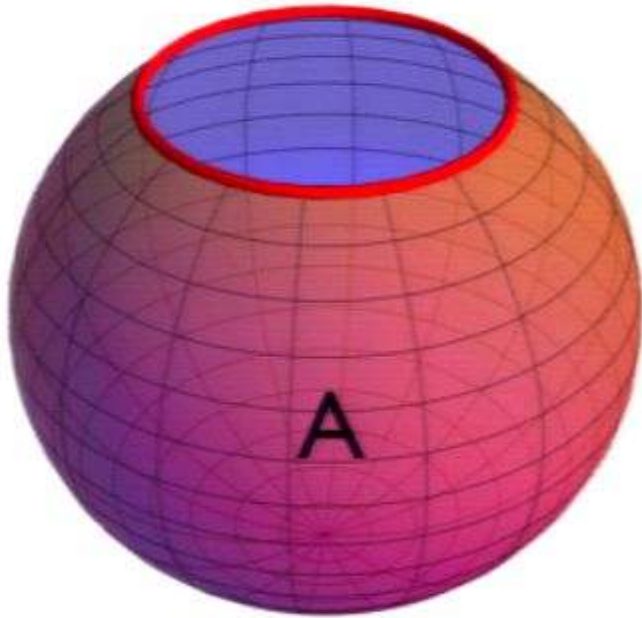
NOT empty spacetime
literally nothing
no space
no time

an open Universe
a la Hawking-Turok

NOTHING  SOMETHING

can you make a Universe from nothing?

no



$$S_E(\text{instanton}) = \text{finite}$$

$$S_E(\text{de Sitter}) = -\frac{24\pi^2 M_{\text{Pl}}^4}{V}$$

$$S_E(\text{Minkowski}) = -\infty$$

$$S_E(\text{AdS}) = -\infty$$

$$S_E(\text{nothing}) = -\infty$$

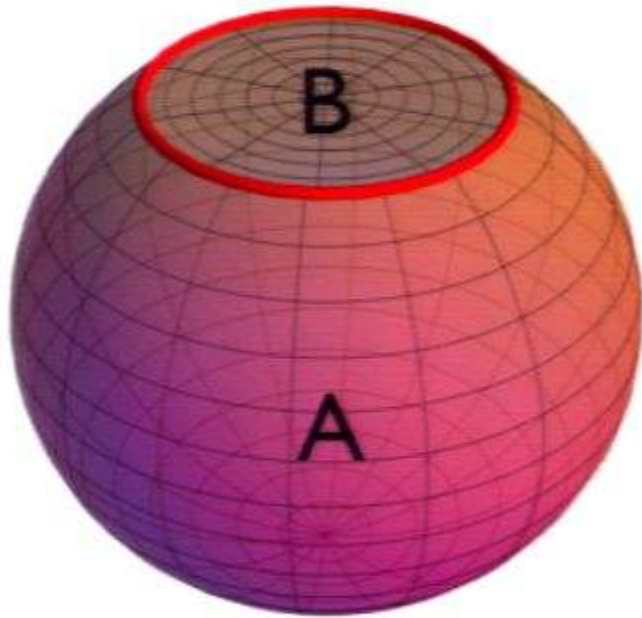
$$\Gamma_{\text{nothing} \rightarrow A} = \exp[-S_E(\text{instanton}) + S_E(\text{nothing})] = 0$$

The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

Uptunneling is **impossible** from Minkowski or AdS

'Nothing' is AdS space (in the limit as $\ell_{\text{max}} \rightarrow 0$)



$$S_E(\text{instanton}) = \text{finite}$$

$$S_E(\text{de Sitter}) = -\frac{24\pi^2 M_{\text{Pl}}^4}{V}$$

$$S_E(\text{Minkowski}) = -\infty$$

$$S_E(\text{AdS}) = -\infty$$

$$\Gamma_{B \rightarrow A} = \exp[-S_E(\text{instanton}) + S_E(B)]$$

The SAME instanton governs tunneling in both directions

Uptunneling is possible from de Sitter

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'Nothing' is AdS space (in the limit as $\ell_{\text{AdS}} \rightarrow 0$)