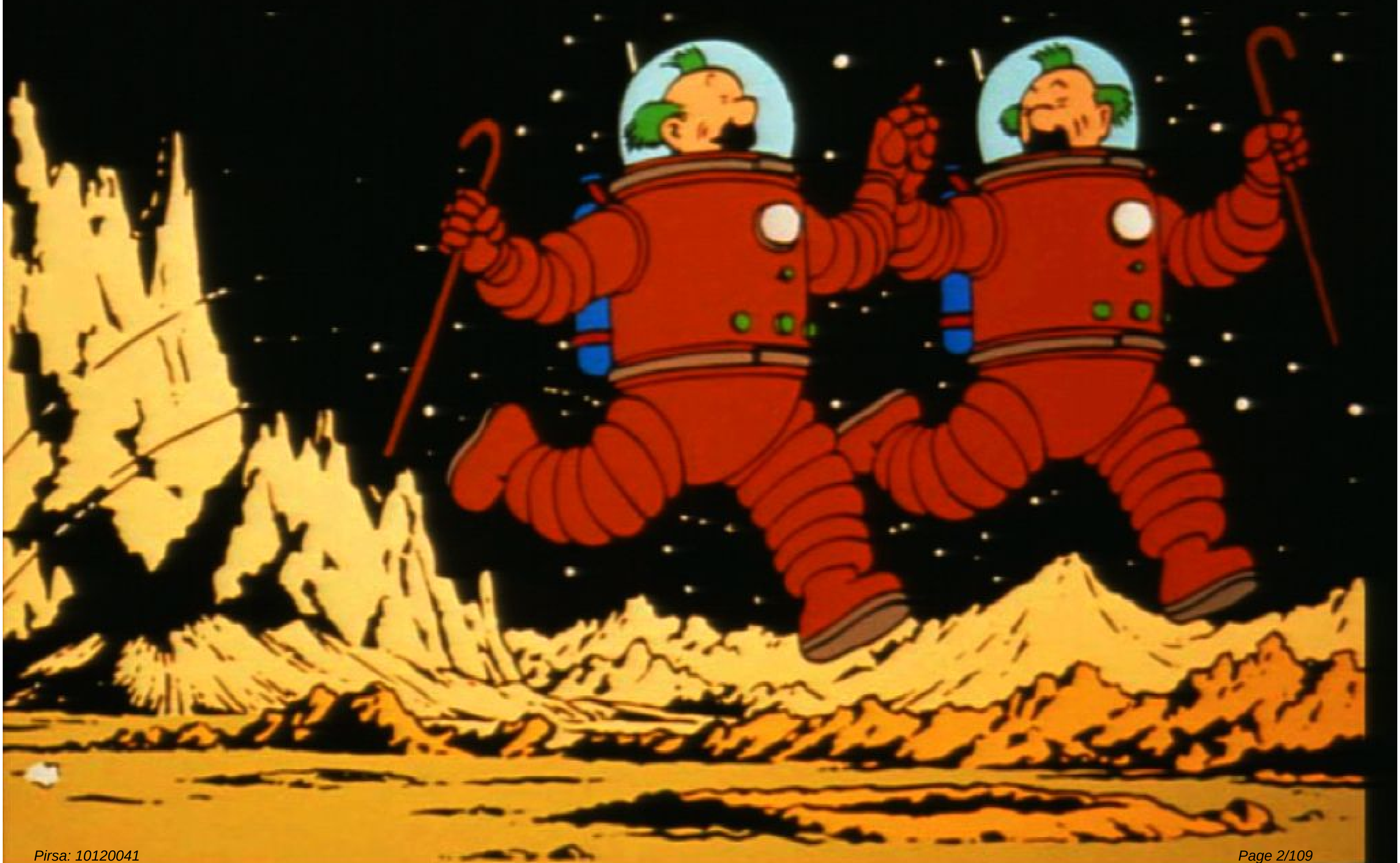
Title: The Fastest Decay in the Landscape

Date: Dec 09, 2010 01:00 PM

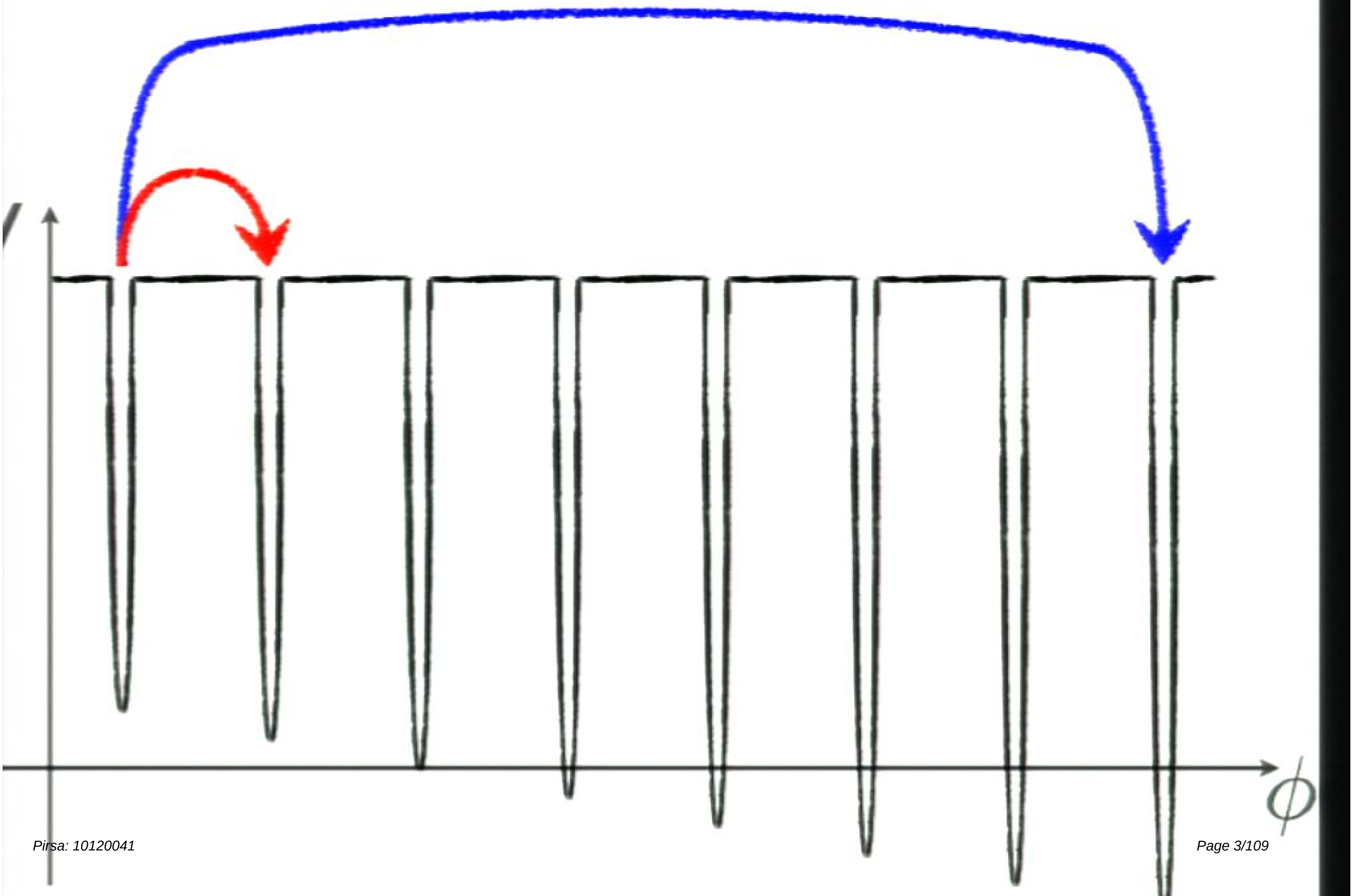
URL: http://pirsa.org/10120041

Abstract: Theories with extra dimensions naturally give rise to a large landscape of vacua stabilized by flux. I will show that the fastest decay is a giant leap to a wildly distant minimum, in which many different fluxes discharge at once. Indeed, the fastest decay is frequently the giantest leap of all, where all the fluxes discharge at once, which destabilizes the extra dimensions and begets a bubble of nothing. Finally, I will discuss how these giant leaps are mediated by the nucleation of "monkey branes" that wrap the extra dimensions.

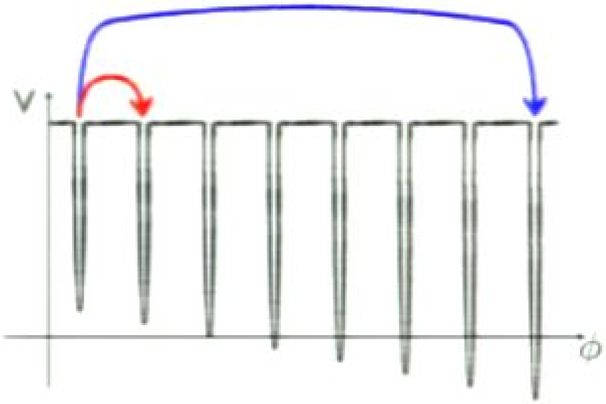
The Fastest Decay in the Landscape



d on work with Adam Brown


V
ϕ

This potential gives small steps

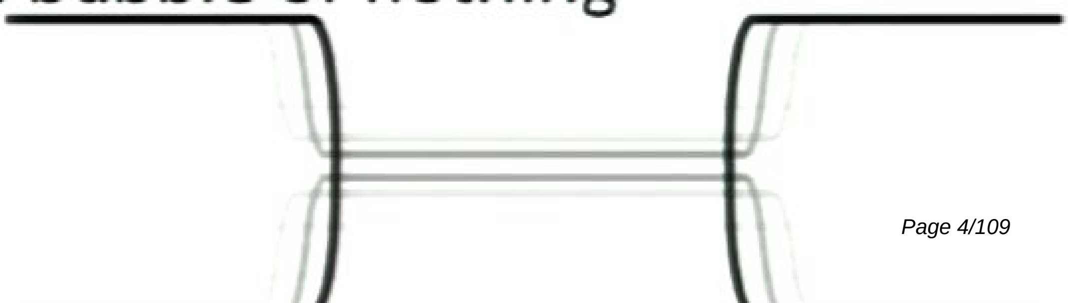


Flux compactifications with many fluxes give giant leaps

Monkey branes

Adding back-reaction

The giantest leap of all is a bubble of nothing



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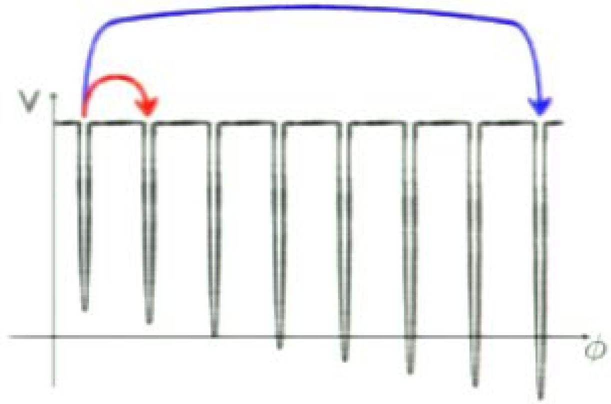
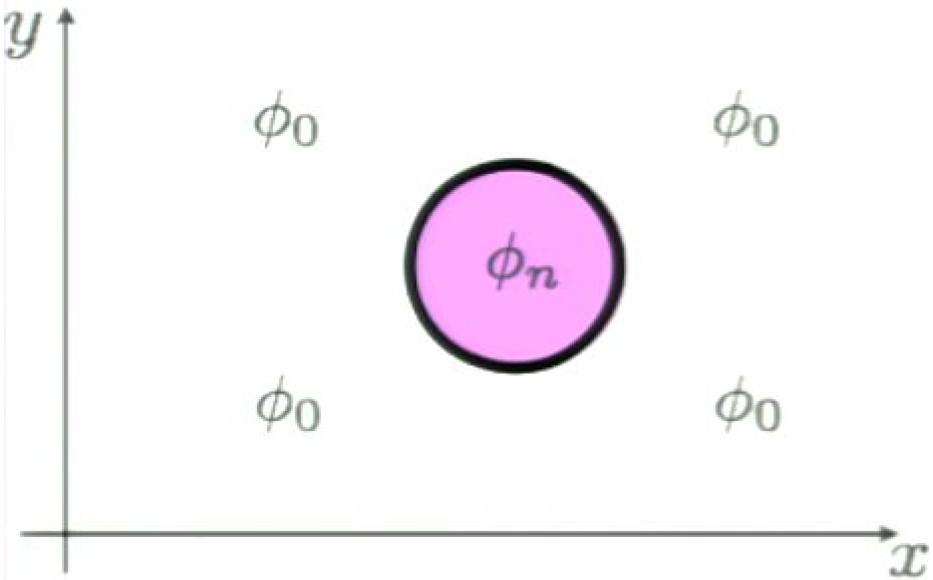
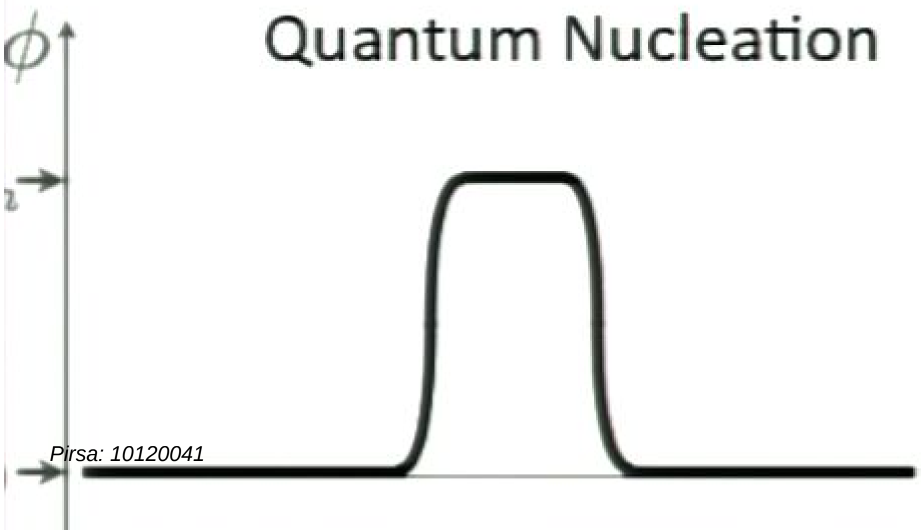




Quantum Nucleation



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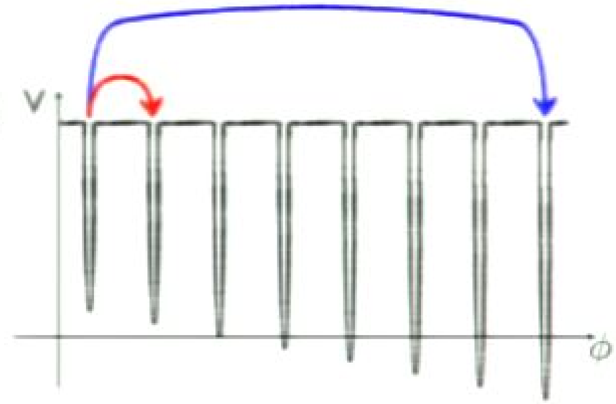

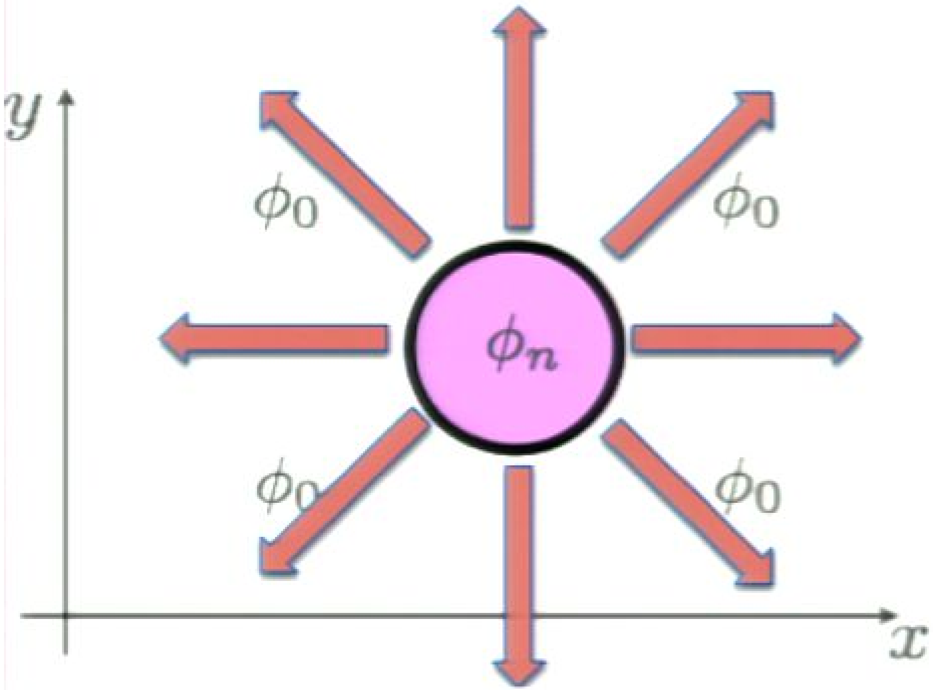

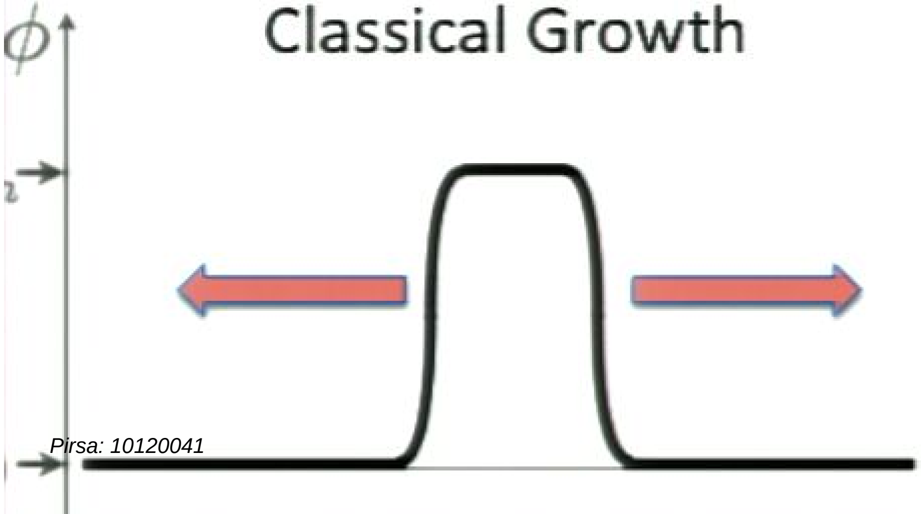

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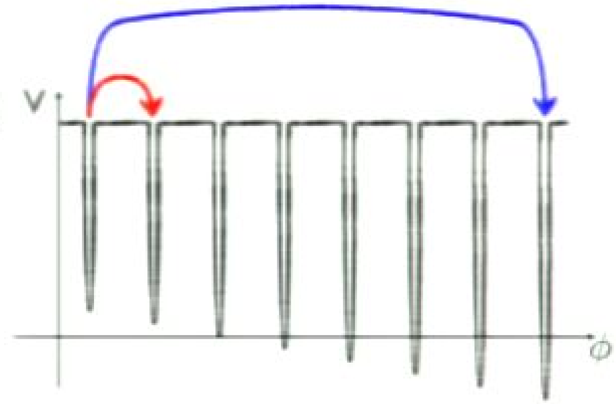
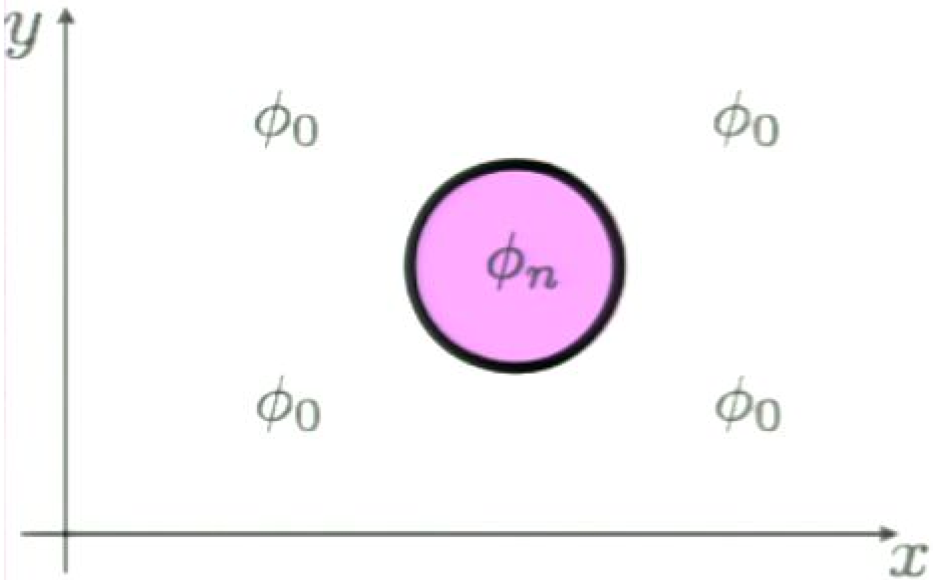
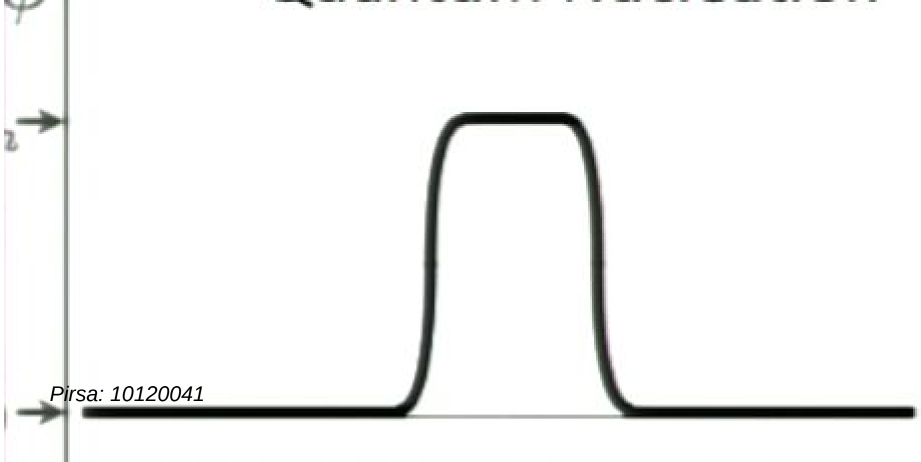




- thin wall
- flat spacetime

Quantum Nucleation



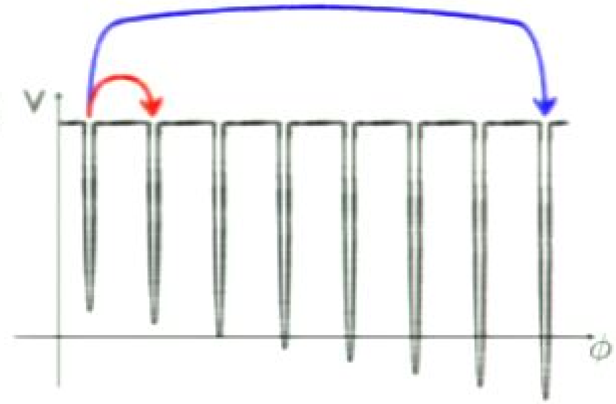
$$\Gamma_n \sim \exp[-\frac{\#}{\hbar}\frac{\sigma_n^4}{\epsilon_n^3}]$$

Coleman (1977)

$$\sigma_n \equiv \int_{\phi_0}^{\phi_n} d\phi \sqrt{2[V(\phi) - V(\phi_0)]}$$

$$\epsilon_n \equiv V(\phi_0) - V(\phi_n)$$

This potential gives small steps

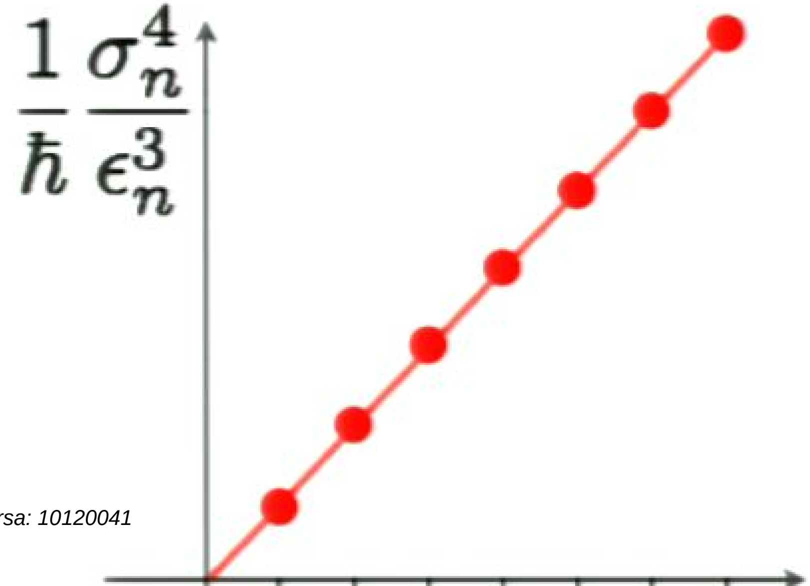


$$\sigma_n = n\sigma_1$$

$$\epsilon_n = n\epsilon_1$$

$$\frac{\sigma_n^4}{\epsilon_n^3} = n\frac{\sigma_1^4}{\epsilon_1^3}$$

- thin wall
- flat spacetime



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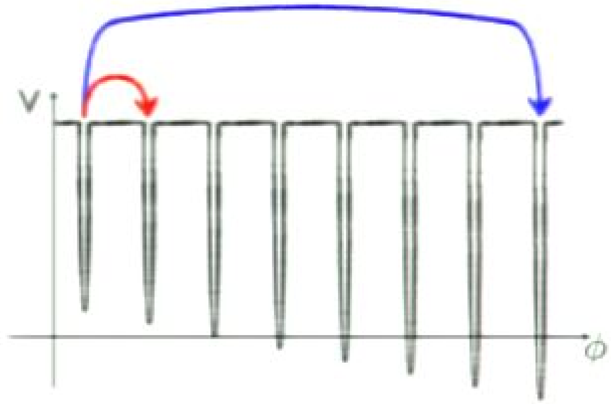

Flux compactifications with many fluxes give giant leaps

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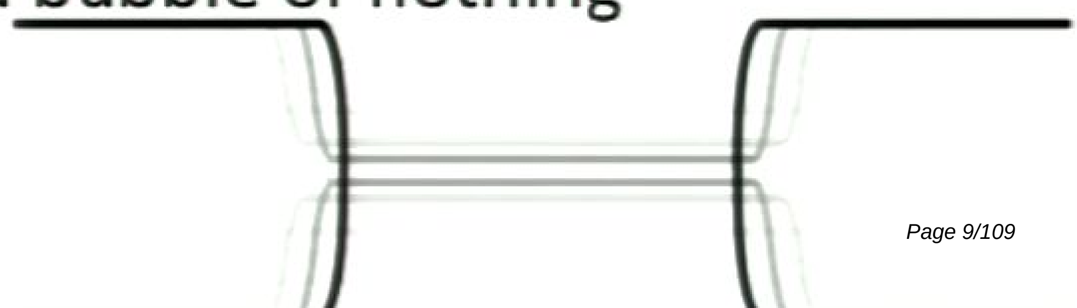


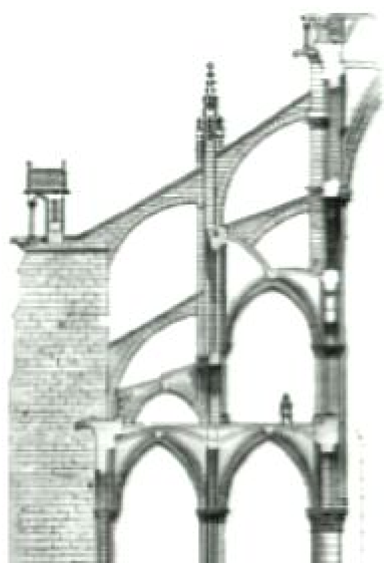
Flux Landscapes

Extra dimensions and fluxes give rise to a landscape

Flux shifts cosmological constant

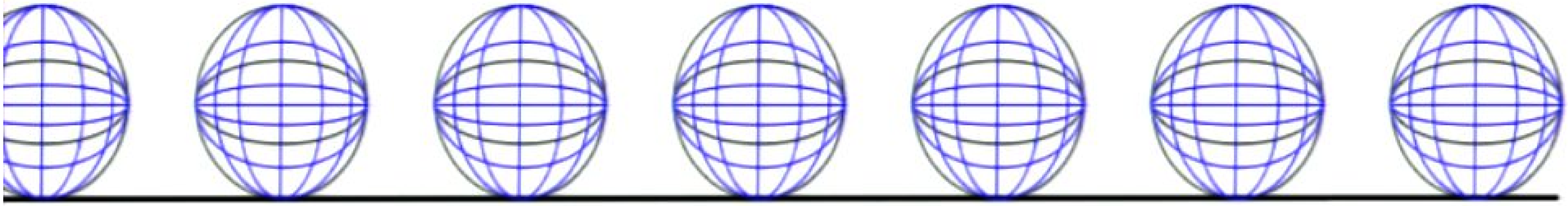
$$\Lambda_{\text{eff}} = \Lambda_0 + \frac{1}{2}F^2$$

Flux stabilizes extra dimensions



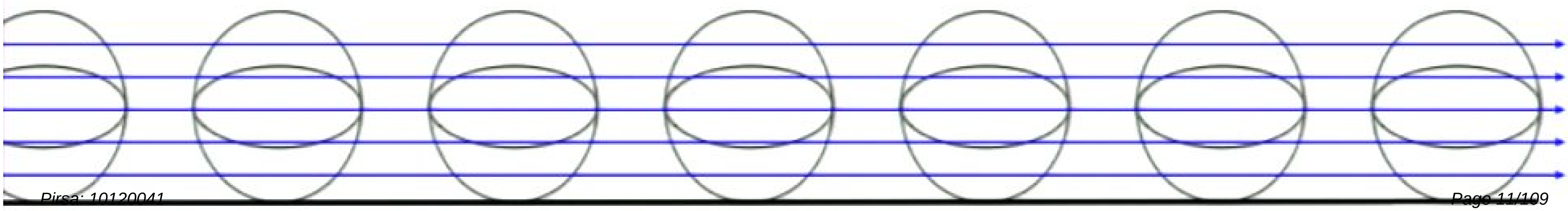
onsider flux tunneling in 1+1+2 dimensions

space time sphere



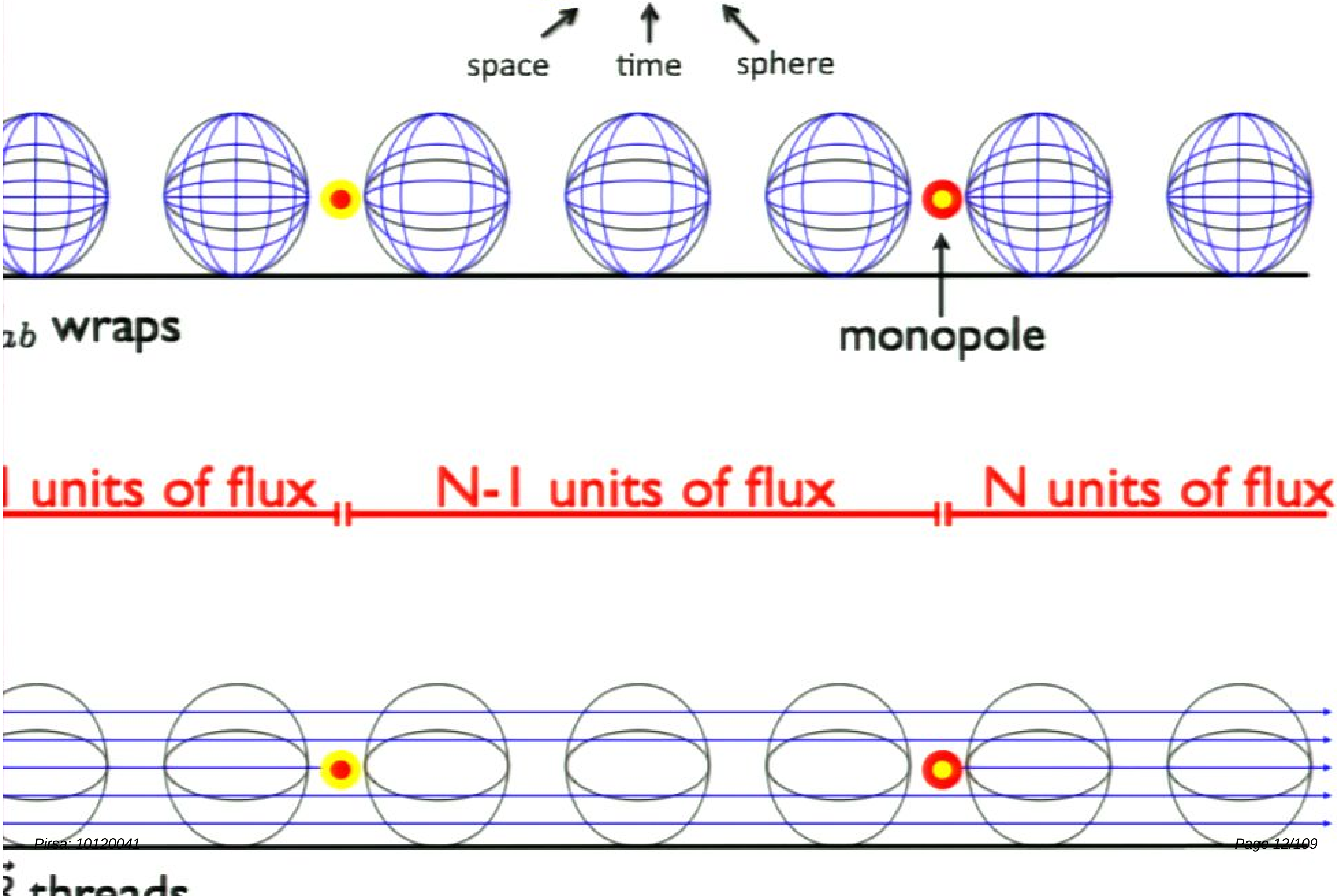
ab wraps

l units of flux N units of flux N units of flux



threads

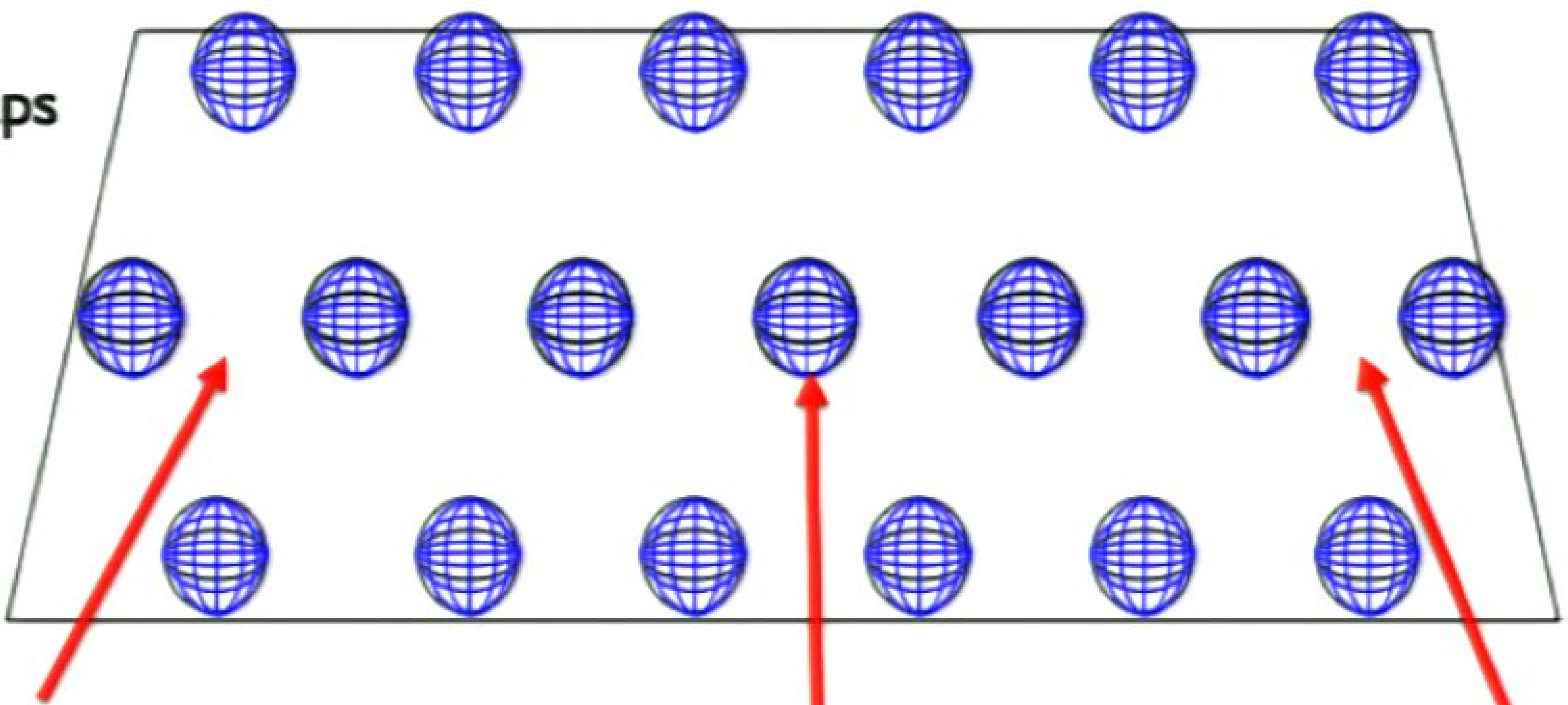
onsider flux tunneling in 1+1+2 dimensions



onsider flux tunneling in 3+1+2 dimensions

space time sphere

, wraps



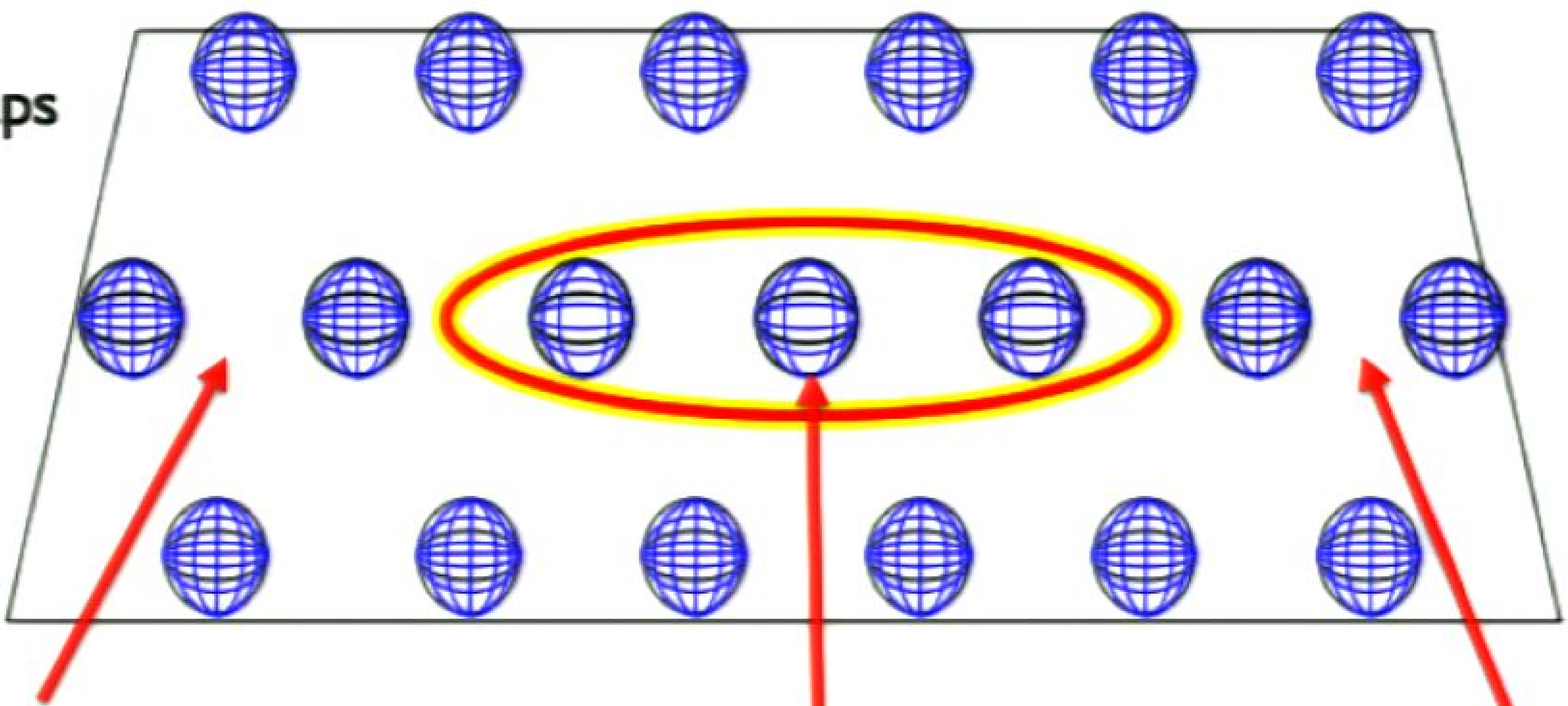
N units of flux N units of flux N units of flux

onsider flux tunneling in 3+1+2 dimensions

space time sphere

Nucleate an extremal black 2-branes

, wraps



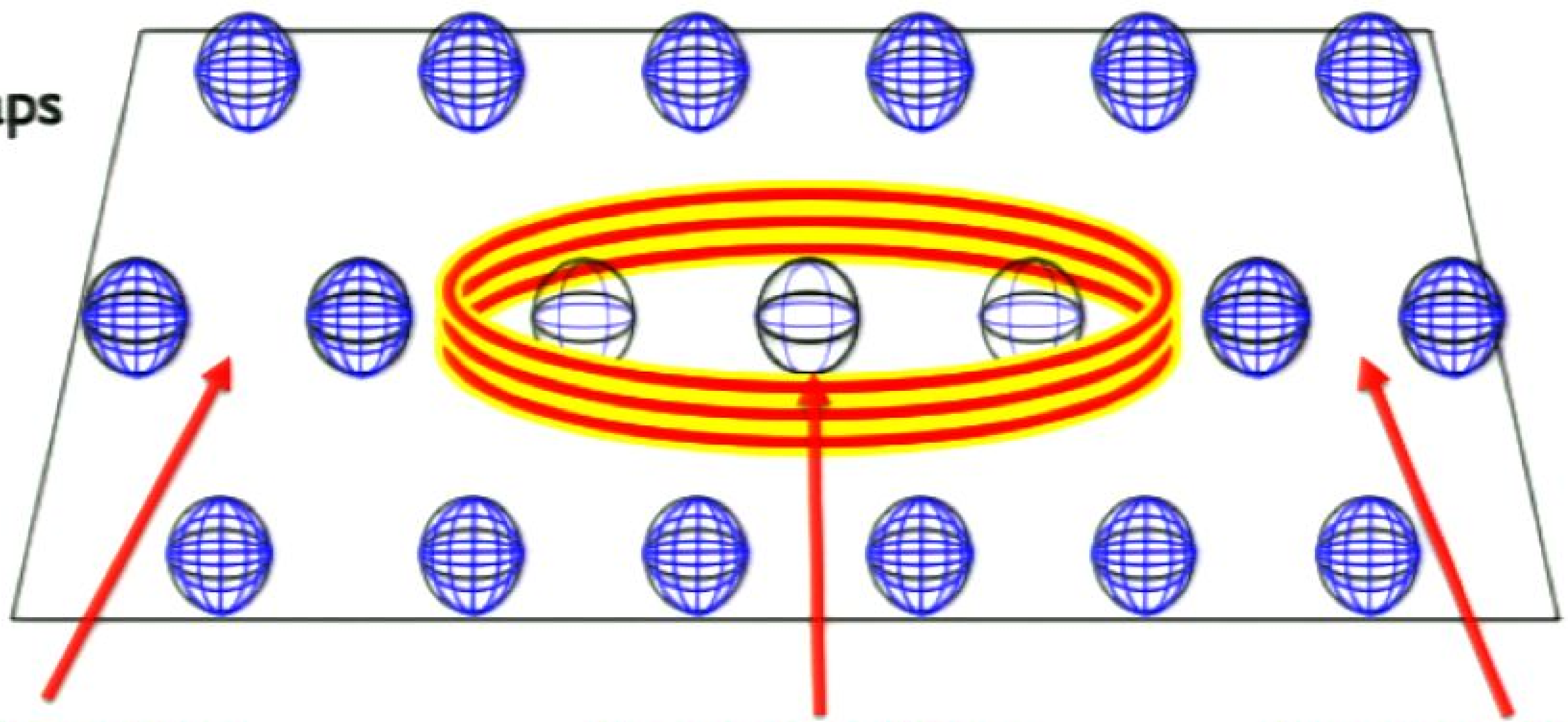
onsider flux tunneling in 3+1+2 dimensions

iant Leaps?

space time sphere

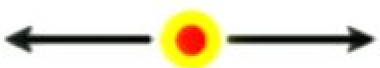
Nucleate a stack of n 2-branes

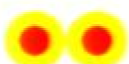
, wraps



What’s the tension of the brane?

as light as possible, given its charge

$\frac{GM^2}{r}$  $\frac{Q^2}{r}$

 $M = Q$

What's the tension of the brane?

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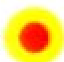
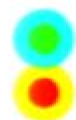
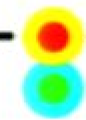
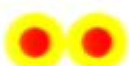
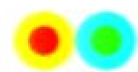
$$\frac{GM^2}{r} \longleftarrow$$  $$\longrightarrow \frac{Q^2}{r}$$



$$\frac{GM^2}{r} \longleftarrow$$  $$\longrightarrow \frac{Q_1^2}{r} + \frac{Q_2^2}{r}$$

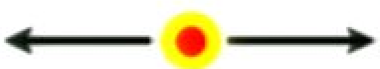
 $M = Q$

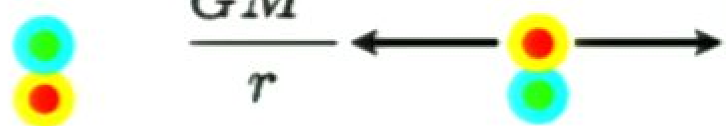
 $M = \sqrt{Q_1^2 + Q_2^2}$

What's the tension of the brane?

as light as possible, given its charge

$$\frac{GM^2}{r} \longleftarrow \longrightarrow \frac{Q^2}{r}$$





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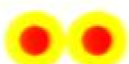

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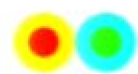

$$M = \sqrt{Q_1^2 + Q_2^2}$$

$$T \sim \left(\sum_{i=1}^{\mathfrak{N}} g_i^2 n_i^2 \right)^{1/2}$$

Large landscape: many different types of fluxes

$$F^2 = \sum_{i=1}^{\mathfrak{N}} g_i^2 N_i^2 \qquad\qquad T \sim \left(\sum_{i=1}^{\mathfrak{N}} g_i^2 n_i^2 \right)^{1/2}$$

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Two decay directions:

MONOFLUX decay

MULTIFLUX decay

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Two decay directions:

MONOFLUX decay

I. $T_n \sim n$

MULTIFLUX decay

I. $T_n \sim \sqrt{n}$

Large landscape: many different types of fluxes

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Two decay directions:

MONOFLUX decay

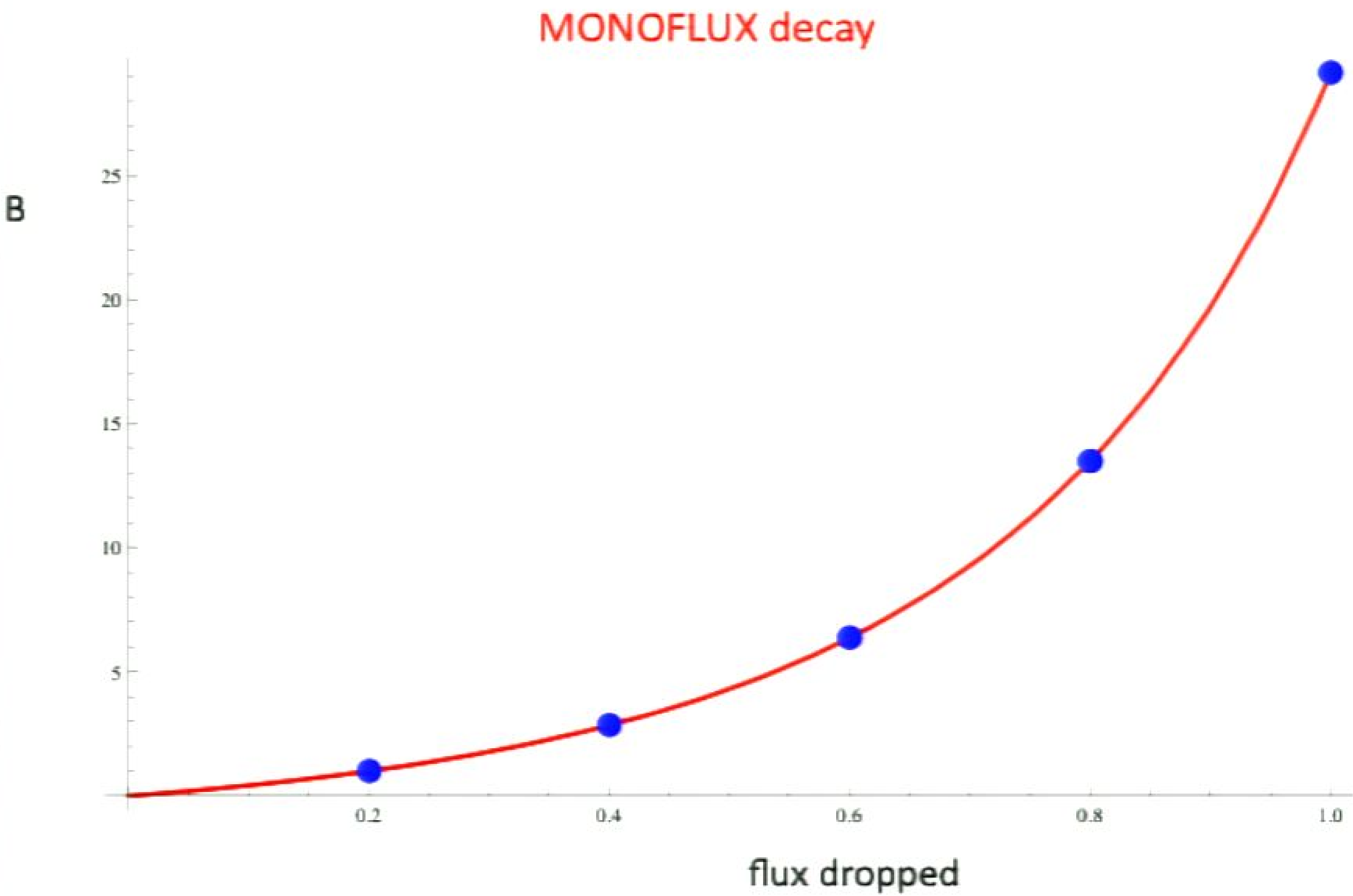
I. $T_n \sim n$

II. $\Delta(F^2) \sim (2N - n)n$

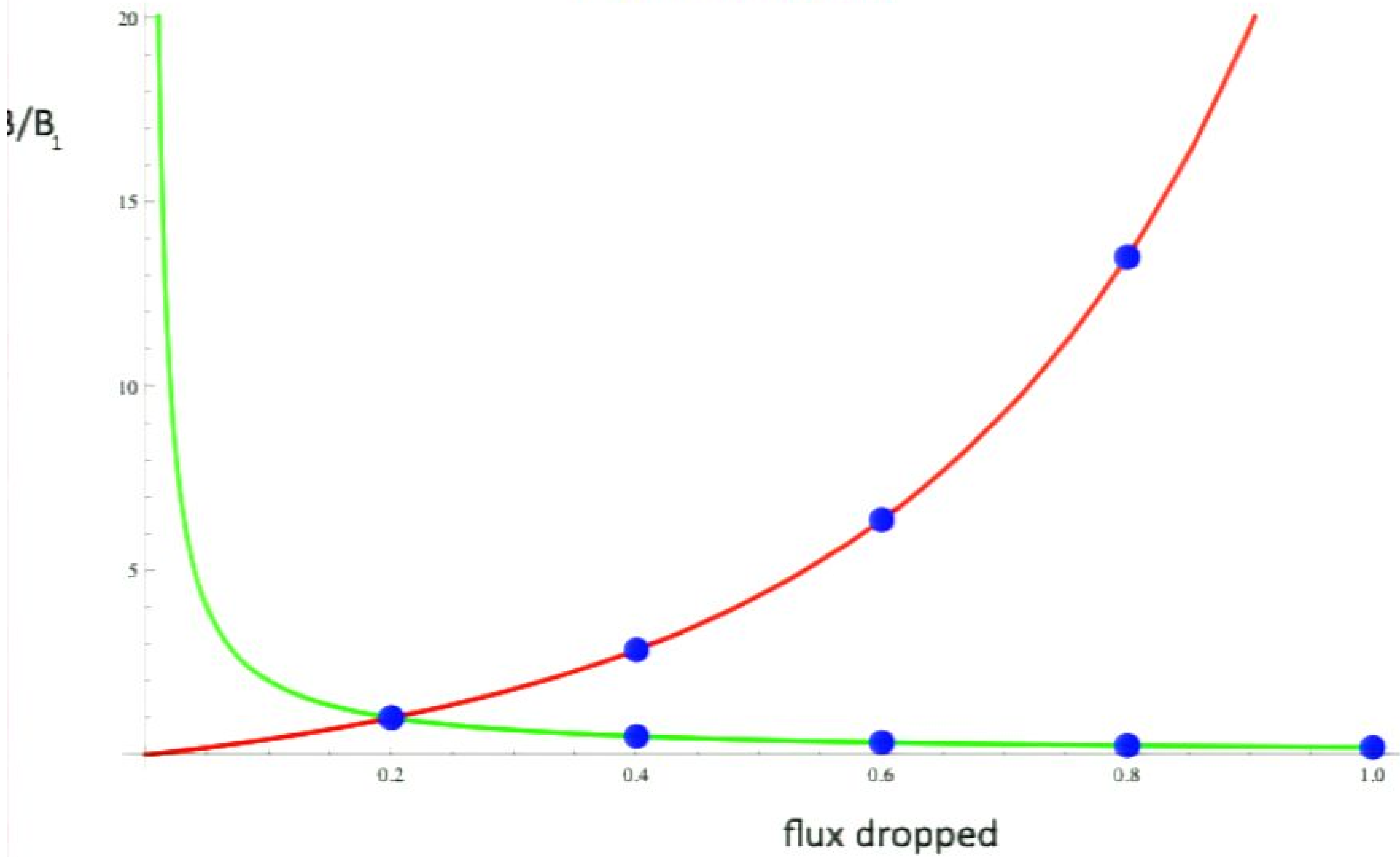
MULTIFLUX decay

I. $T_n \sim \sqrt{n}$

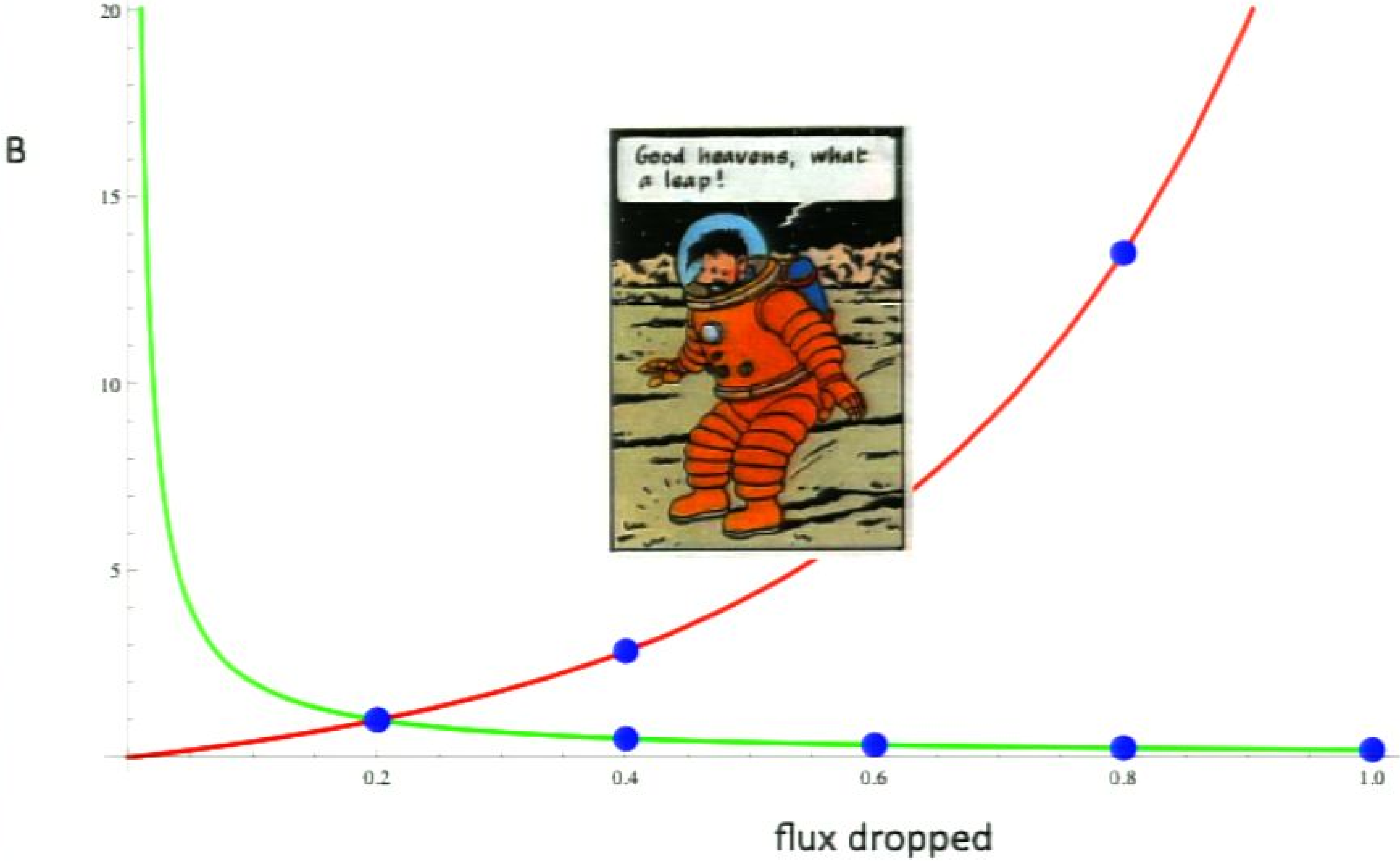
II. $\Delta(F^2) \sim n$


MONOFLUX decay
B
25
20
15
10
5
0.2
0.4
0.6
0.8
1.0
flux dropped

MULTIFLUX decay



MULTIFLUX decay



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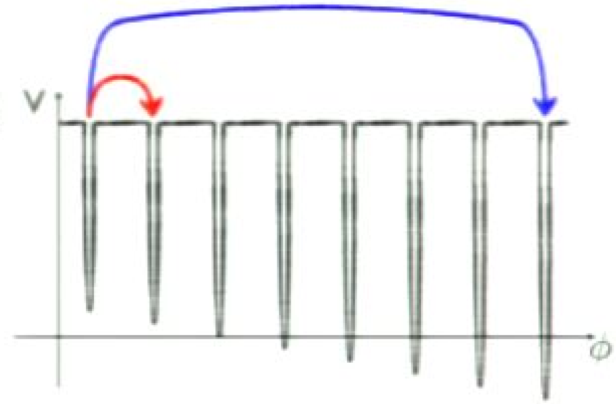

Flux compactifications with many fluxes give giant leaps

Monkey branes

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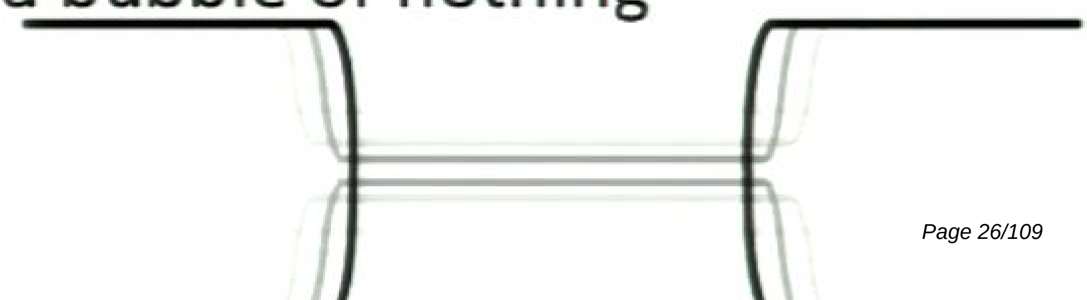
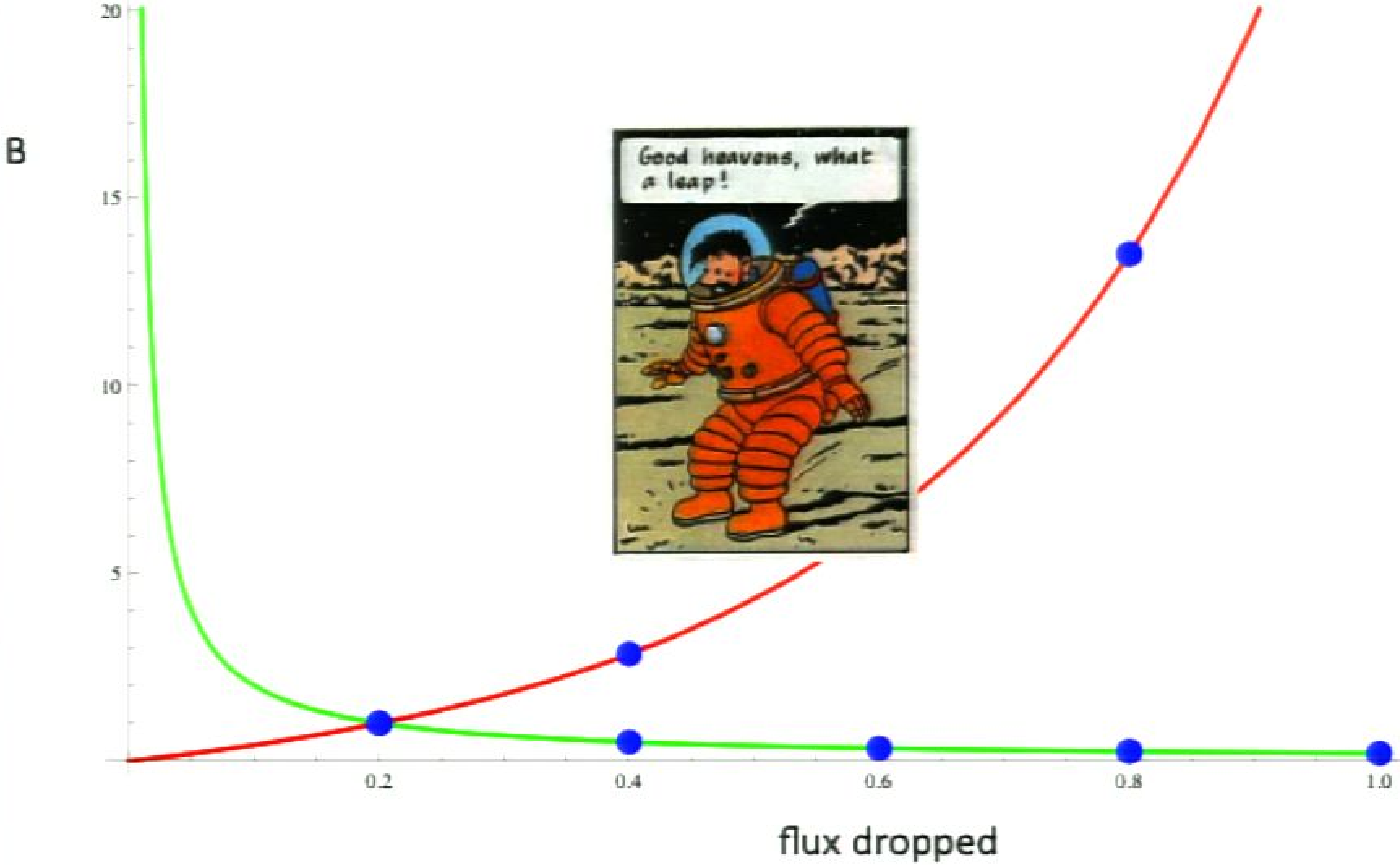
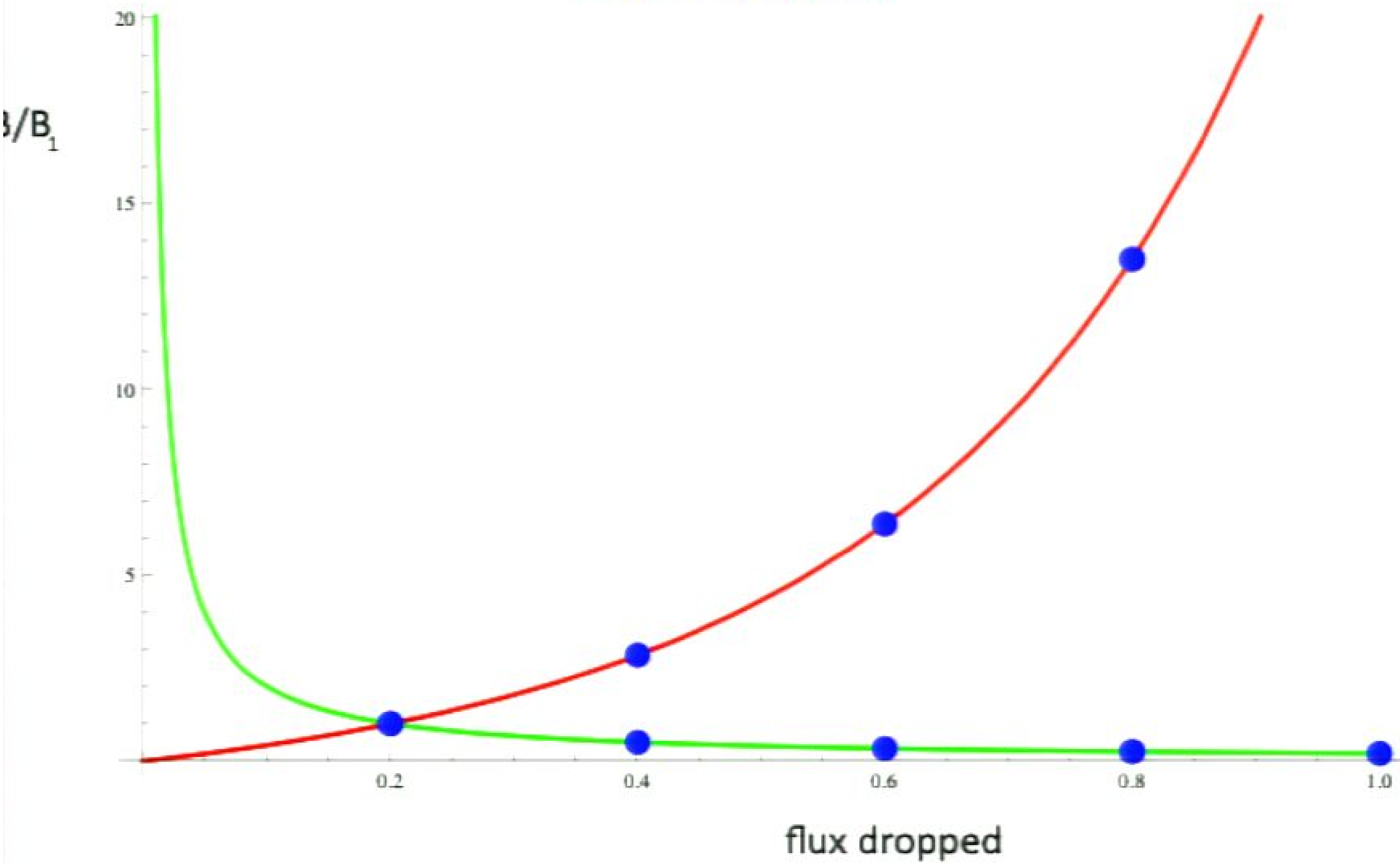
The giantest leap of all is a bubble of nothing



MULTIFLUX decay



MULTIFLUX decay



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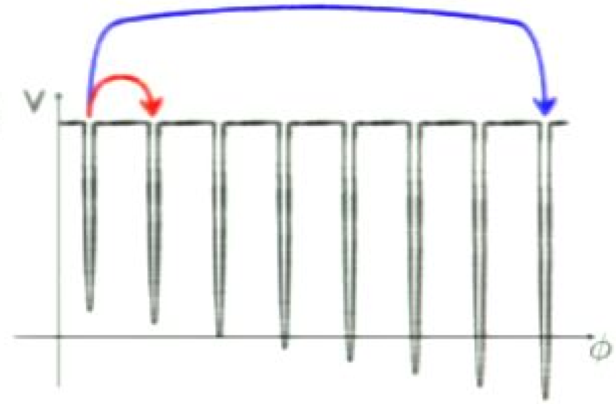

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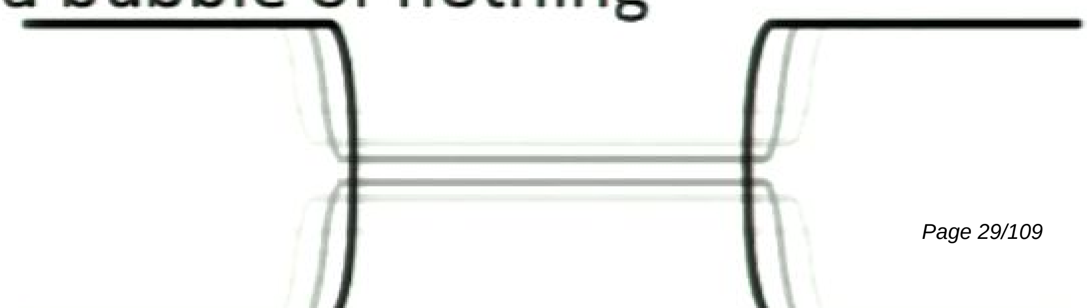

Lifting to Higher Dimensions

A single higher dimensional flux that wraps many distinct cycles in the internal manifold. → Many fluxes

Bousso-Polchinski model

To what extent does the story stay true?

(fix the radion)

$$F^2 = \sum_{i=1}^{\mathfrak{N}} g_i^2 N_i^2 ?$$

$$T \sim \left(\sum_{i=1}^{\mathfrak{N}} g_i^2 n_i^2 \right)^{1/2} ?$$

.ifting to Higher Dimensions

ɿ-form $\mathbf{F}$

flat m-torus T^m

$$\mathbf{F} = \sum_{b=1}^{\mathfrak{N}} F_b \, dw_{i_1} \wedge \cdots \wedge dw_{i_q}$$

F must point ALL legs down the extra dimensions

	t	r	θ	ψ	w_1	$\ldots$	w_q	$\ldots$	w_m
$\mathbf{F}$					x	x	x		
$\star\mathbf{F}$	x	x	x	x				x	x

$$\mathfrak{N} = \binom{m}{q}$$

$$\frac{1}{2}\mathbf{F}^2 \rightarrow \sum_{b=1}^{\mathfrak{N}} F_b^{\,2}$$

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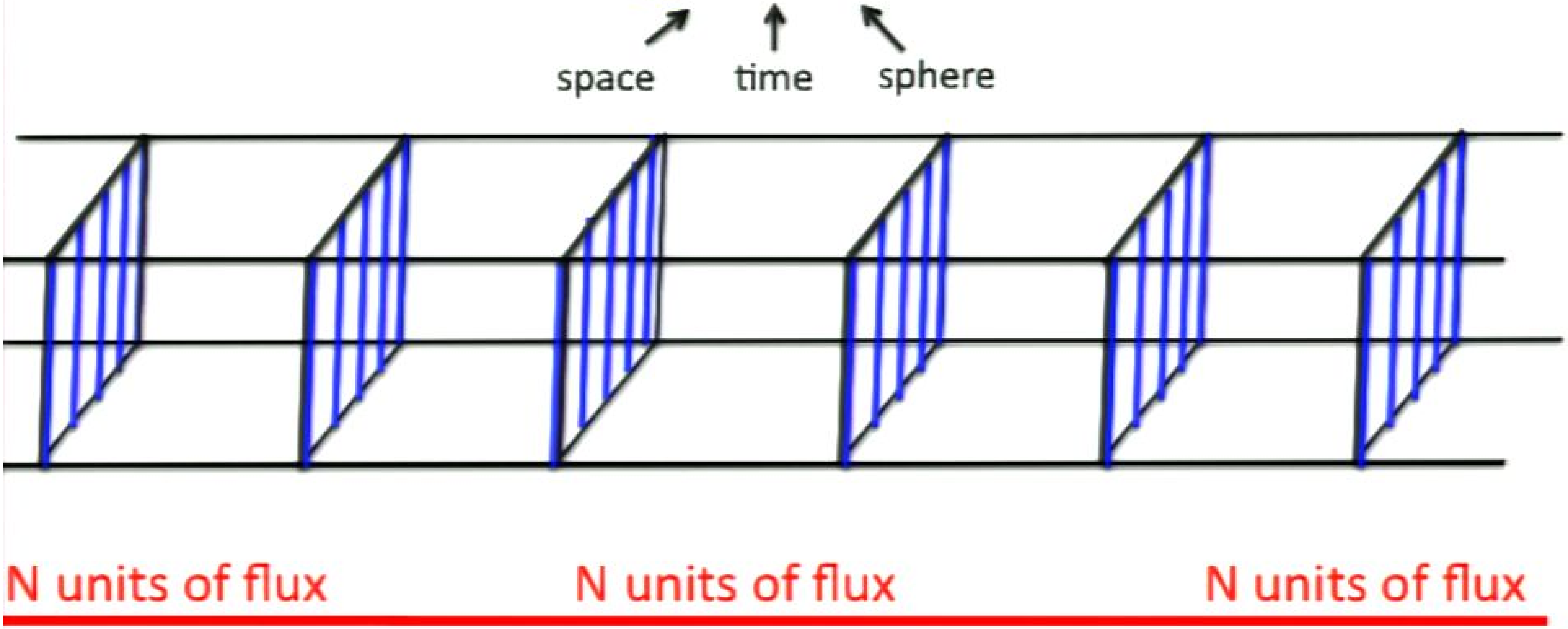

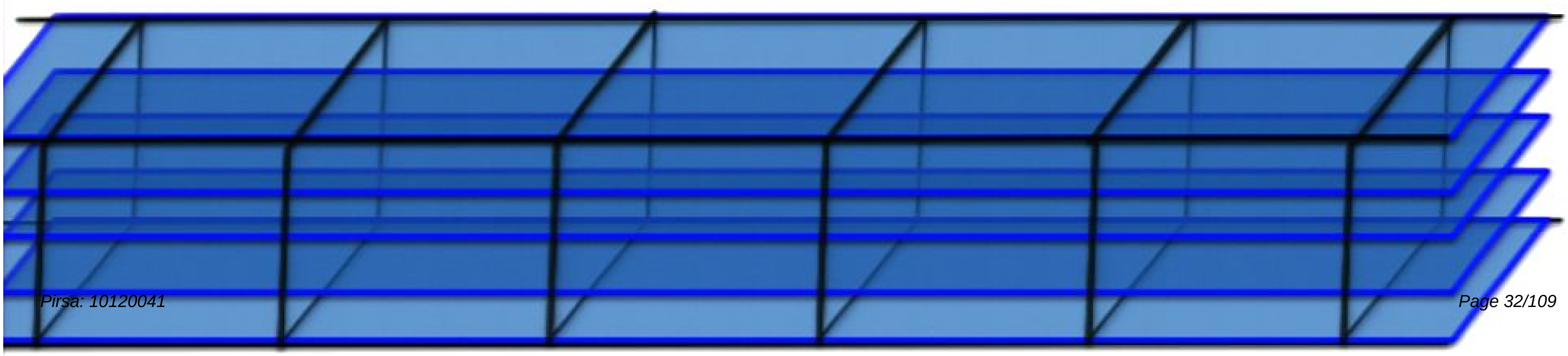

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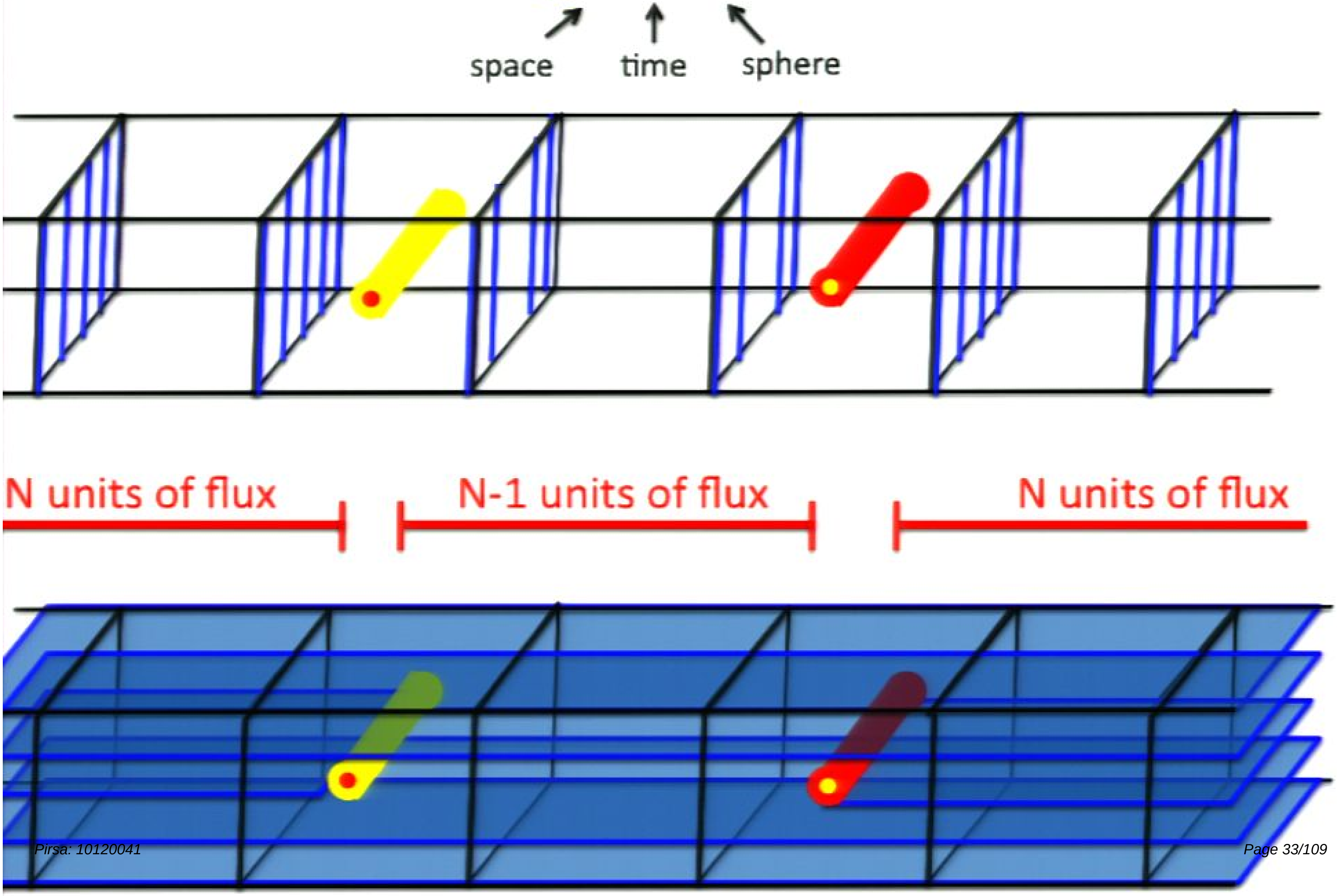

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F must point ALL legs down the extra dimensions

	t	r	θ	ψ	w_1	$\ldots$	w_q	$\ldots$	w_m
$\mathbf{F}$					x	x	x		
$\star\mathbf{F}$	x	x	x	x				x	x
brane	x		x	x				x	x

Brane makes a bubble in the extended directions
wraps the dual cycle

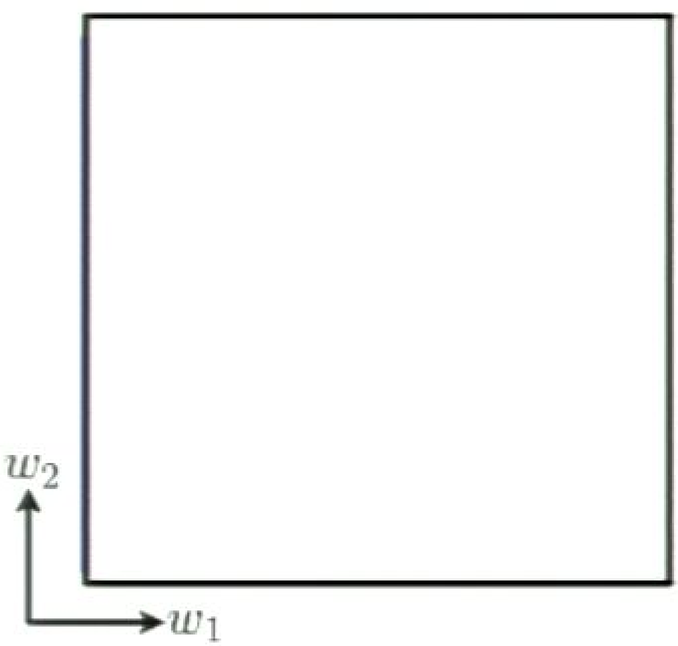
Let's see how this works in some specific cases

Lifting to Higher Dimensions

1-form $\mathbf{F}$

flat 2-torus T^2

$$\mathfrak{N} = \binom{2}{1} = 2$$



Lifting to Higher Dimensions

1-form $\mathbf{F}$

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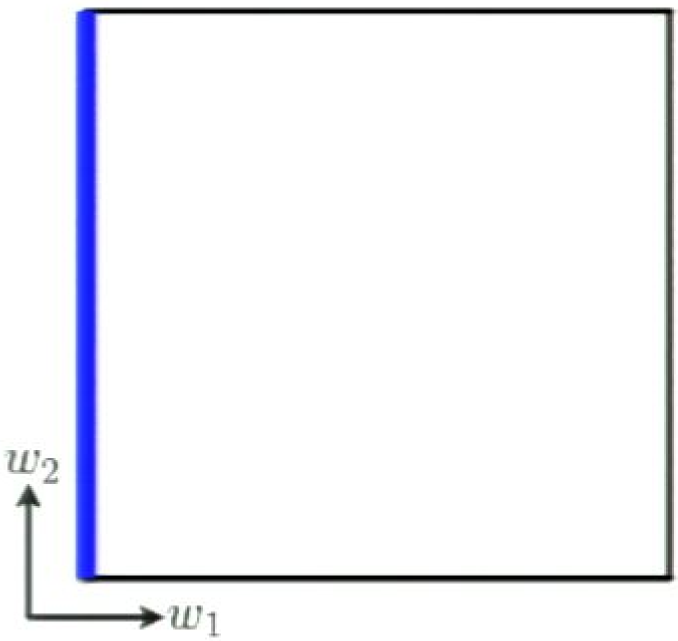


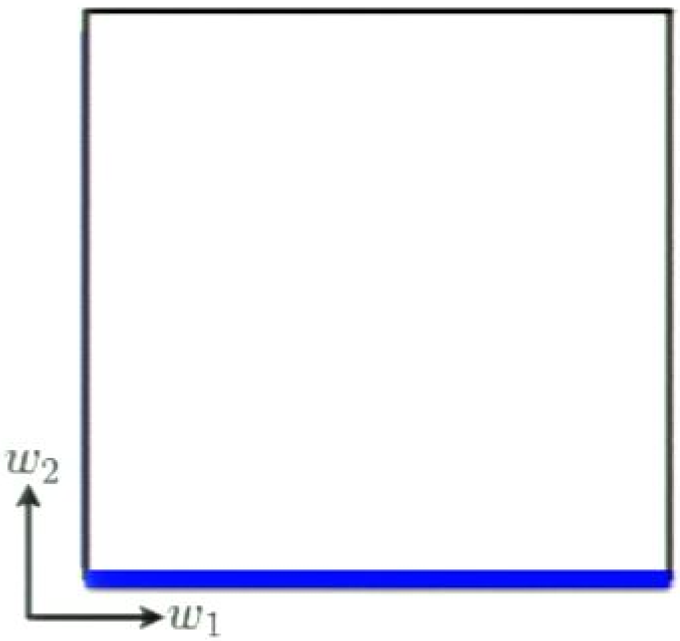
$$\Delta \mathbf{F} = dw_1$$

ifting to Higher Dimensions

1-form $\mathbf{F}$

flat 2-torus T^2

$$\mathfrak{N} = \binom{2}{1} = 2$$



$$\Delta \mathbf{F} = dw_2$$

Lifting to Higher Dimensions

1-form $\mathbf{F}$

flat 2-torus T^2

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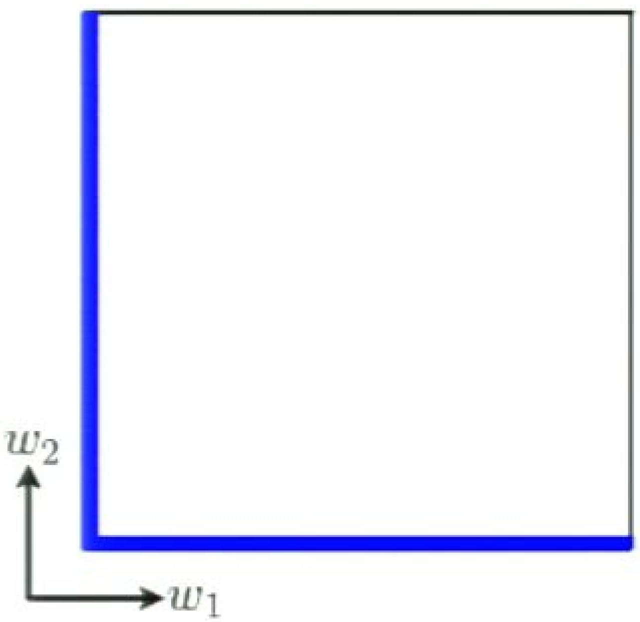

Drop one unit of both $T \sim n$?

Lifting to Higher Dimensions

1-form **F**

flat 2-torus T^2

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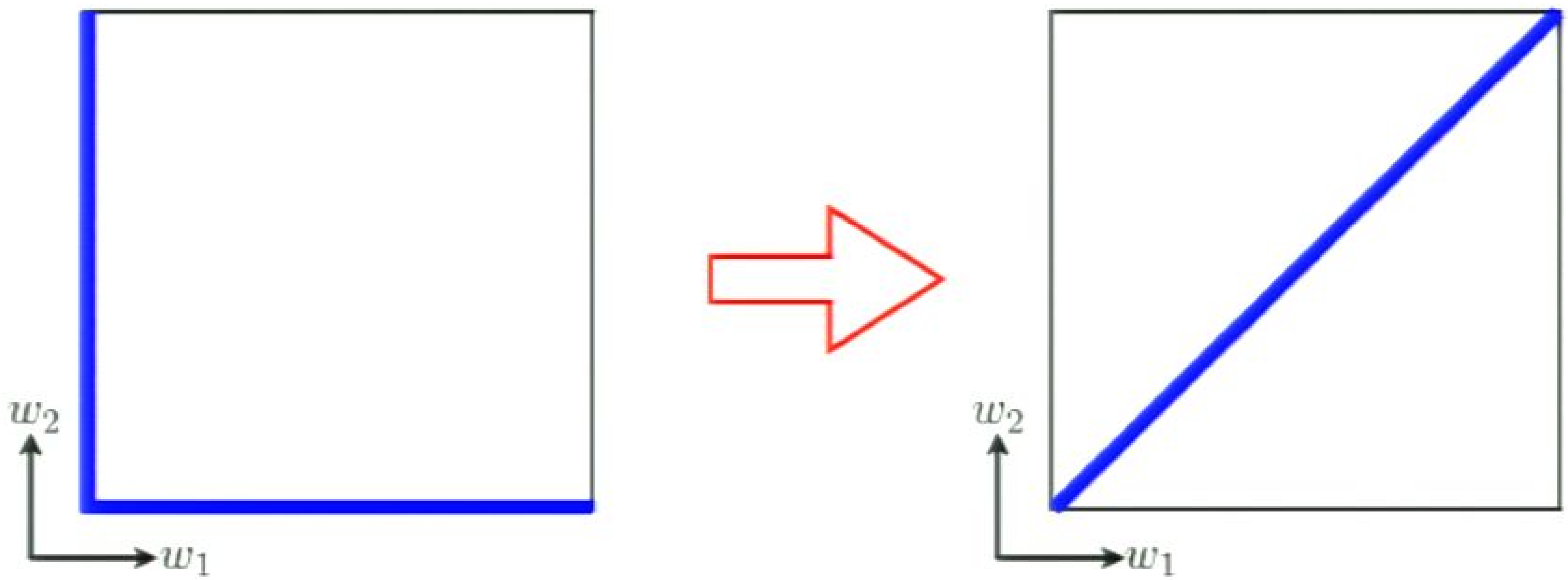

Drop one unit of both $T \sim n$? $T \sim \sqrt{n}$

Lifting to Higher Dimensions

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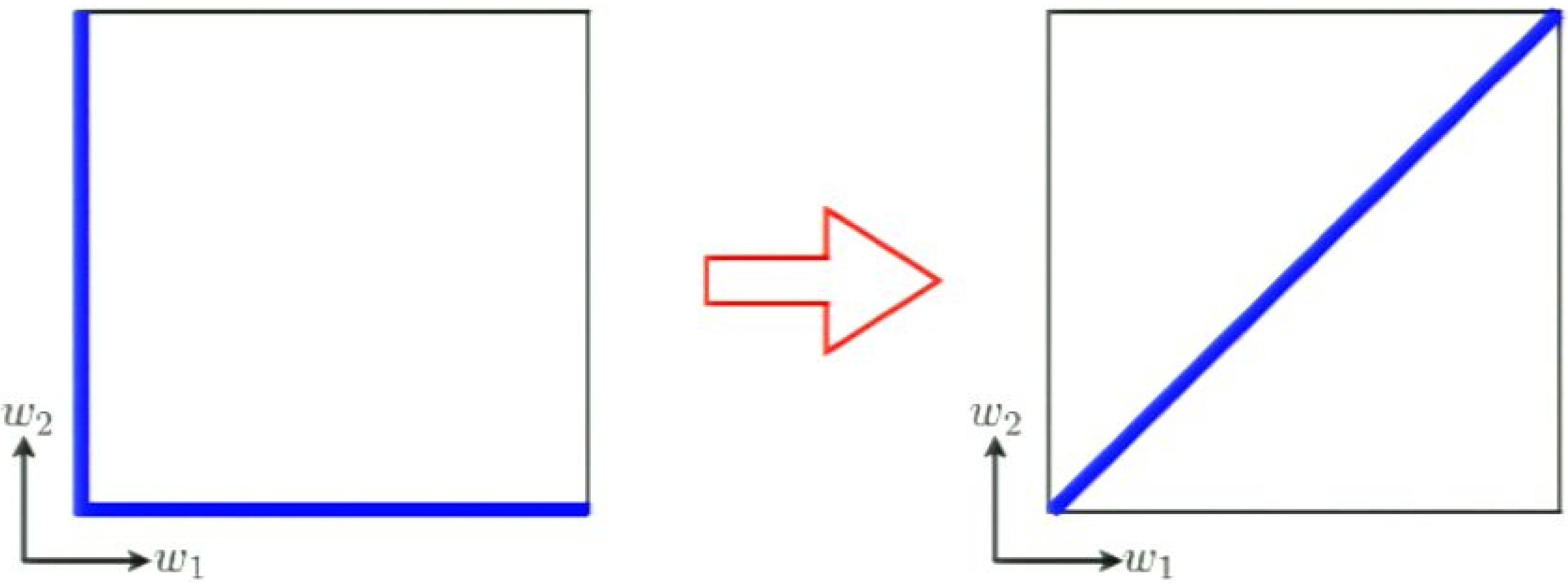


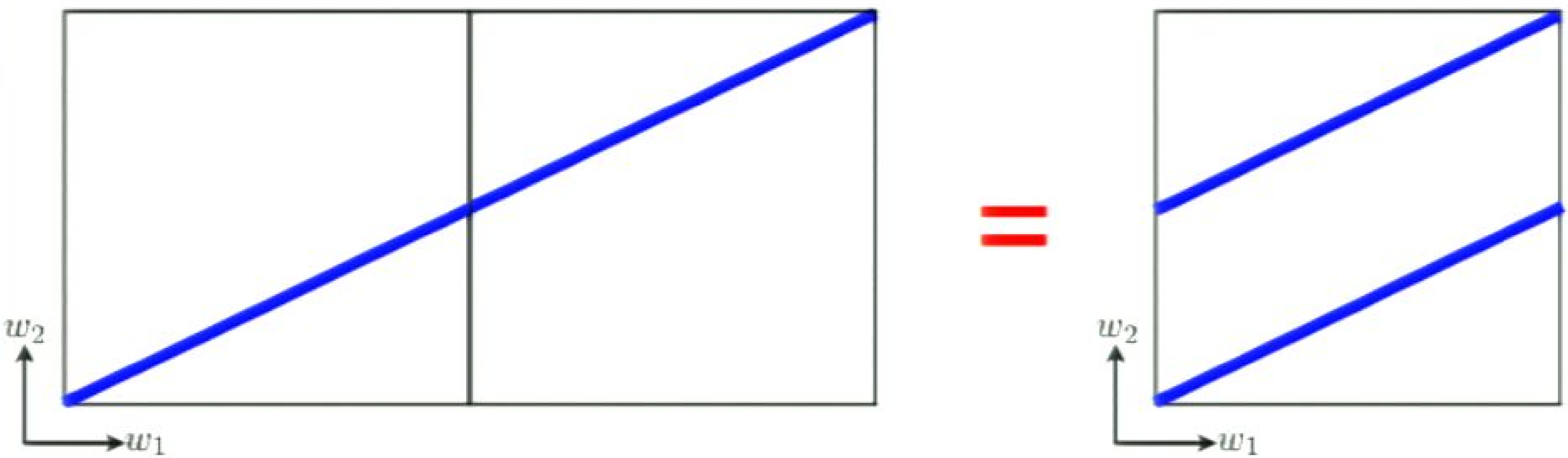
Drop one unit of both ~~$T \sim n$~~ ? $T \sim \sqrt{n}$

Lifting to Higher Dimensions

1-form **F**

flat 2-torus T^2

$$\mathfrak{N} = \binom{2}{1} = 2$$



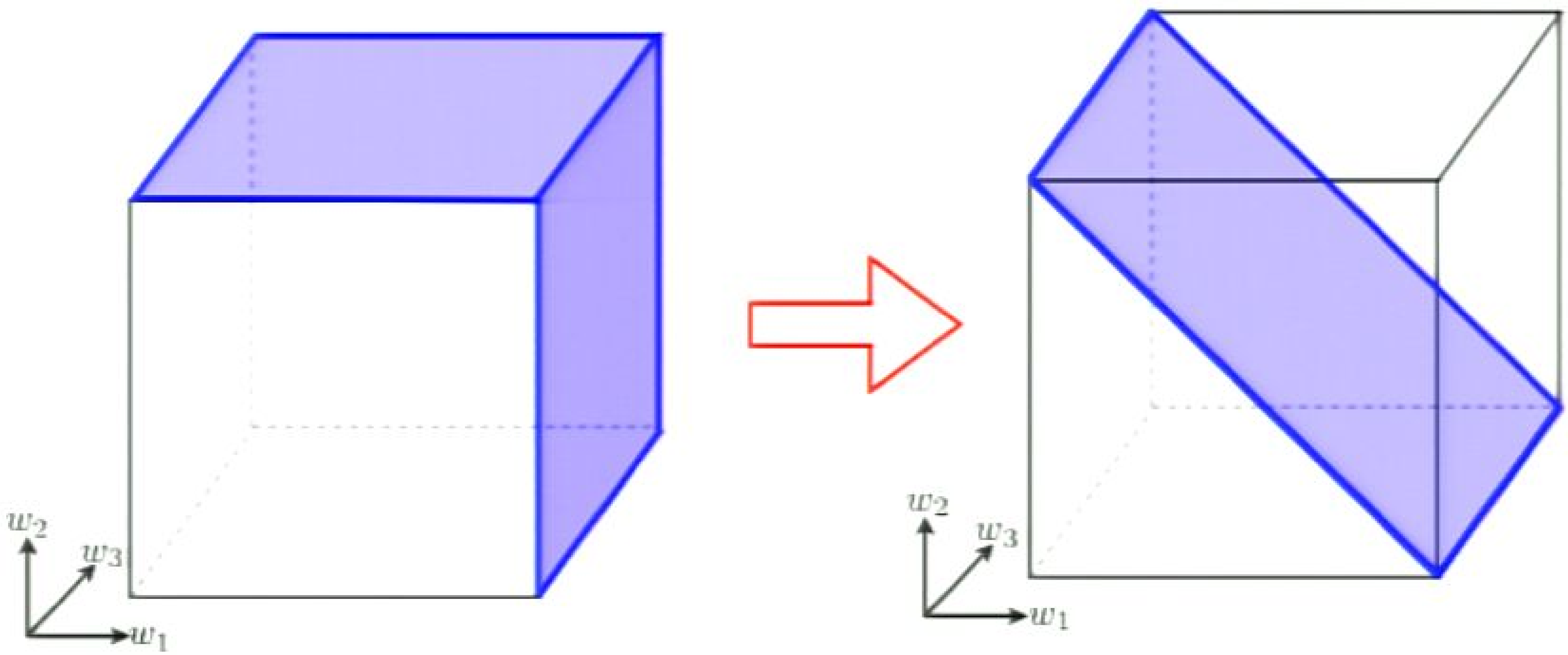
$$T \sim \left(\sum_{i=1}^{\mathfrak{N}} g_i^2 n_i^2 \right)^{1/2} \quad = \quad \text{Pythagoras' Theorem}$$

Lifting to Higher Dimensions

1-form $\mathbf{F}$

flat 3-torus T^3

$$\mathfrak{N} = \binom{3}{1} = 3$$



Still true

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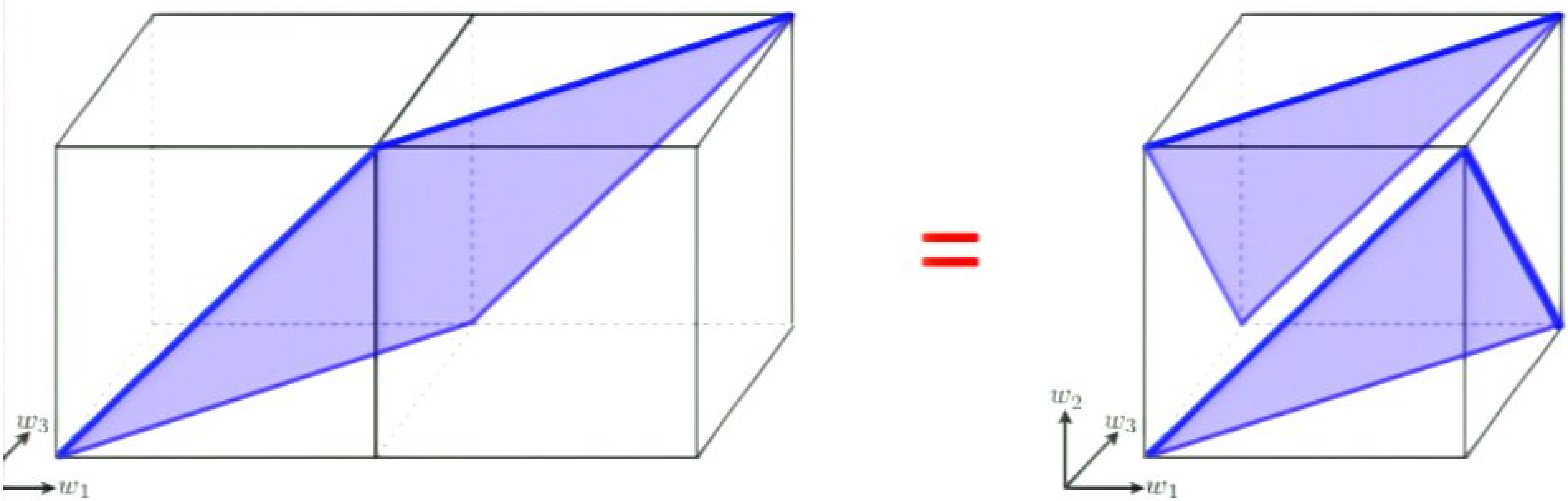

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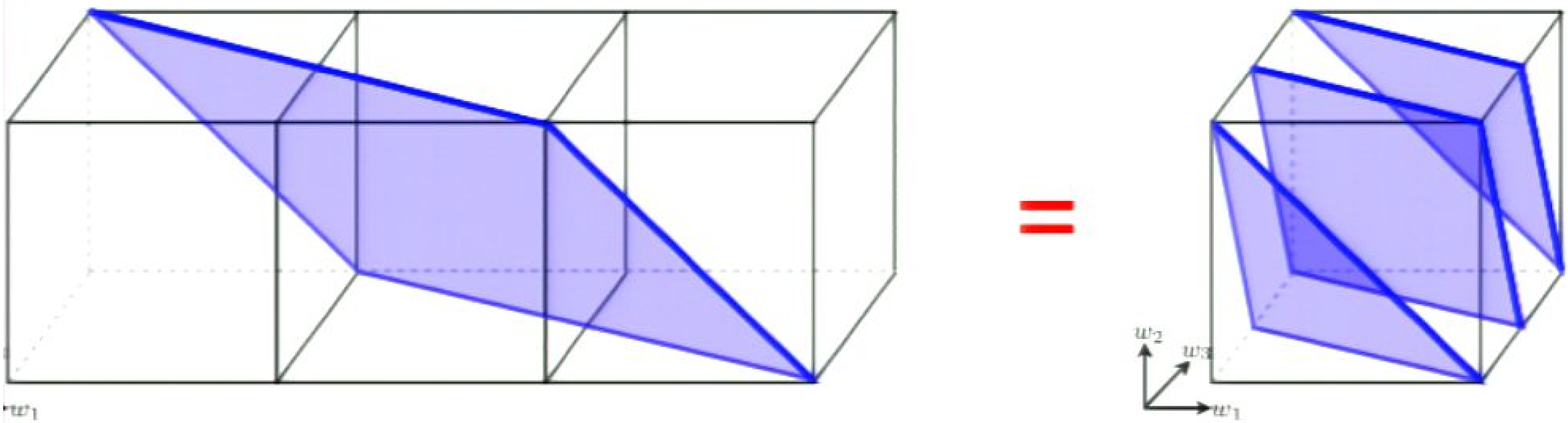

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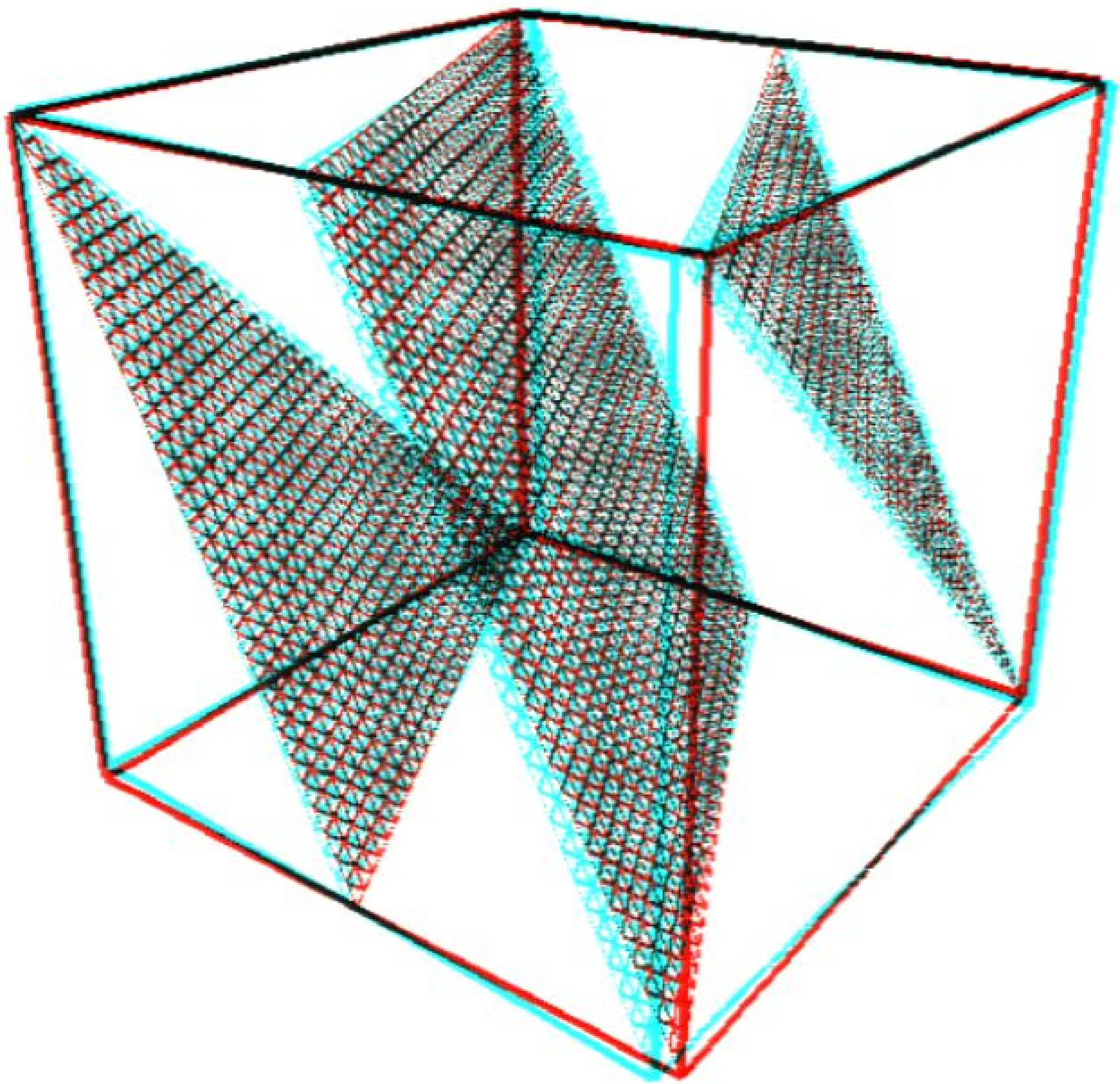

ifting to Higher Dimensions

2-form $\mathbf{F}$

flat 4-torus T^3

$$\mathfrak{N} = \binom{4}{2} = 6$$

$$\Delta\mathbf{F} = dw_1 \wedge dw_2 + dw_3 \wedge dw_4$$

.ifting to Higher Dimensions

2-form $\mathbf{F}$

flat 4-torus T^3

$$\mathfrak{N} = \binom{4}{2} = 6$$

$$\Delta \mathbf{F} = dw_1 \wedge dw_2 + dw_3 \wedge dw_4$$

No longer true!

Requires 2 branes $\quad T \sim n$

Lifting to Higher Dimensions

The general case

$$\mathbf{dF} = \star \mathbf{j}$$

$$\Delta \mathbf{F} = \star g \mathbf{Y}_1 \wedge \cdots \wedge \mathbf{Y}_q$$

This tells us when a single, flat brane can be found.

DECOMPOSABILITY

When it can be, $T \sim \sqrt{n}$

Otherwise worse

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The general case

T is intermediate

$\sim \sqrt{n}$ $\qquad T \sim n$

	w_1	w_2	w_3	w_4
1	x	x		
2	x		x	
3		x	x	
4			x	x
5		x		x
6	x			x

Ideal configuration is CURVED

Lifting to Higher Dimensions

The general case

T is intermediate

$\sim \sqrt{n}$ $\qquad T \sim n$

Clustering

	w_1	w_2	w_3	w_4
1	x	x		
2	x		x	
3		x	x	
4			x	x
5		x		x
6	x			x

Ideal configuration is CURVED

eaks rotation symmetry of landscape

$$\mathbf{F} = dw_1 \wedge dw_2 + dw_2 \wedge dw_3$$

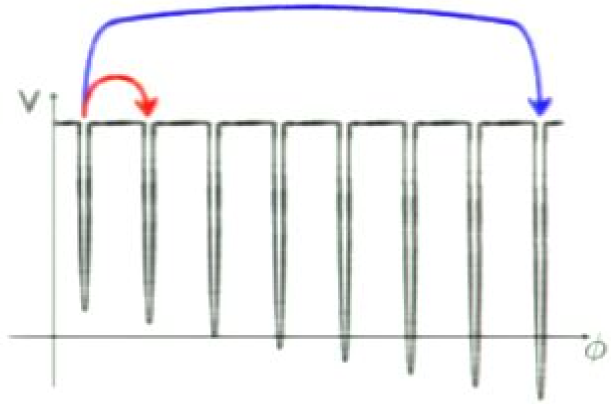
$$\mathbf{F} = dw_1 \wedge dw_2 + dw_3 \wedge dw_4$$

eaks reflection symmetry of landscape

$$= dw_1 \wedge dw_3 + dw_1 \wedge dw_4 + dw_2 \wedge dw_3 + dw_2 \wedge dw_4$$

$$= dw_1 \wedge dw_3 + dw_1 \wedge dw_4 - dw_2 \wedge dw_3 + dw_2 \wedge dw_4$$

This potential gives small steps

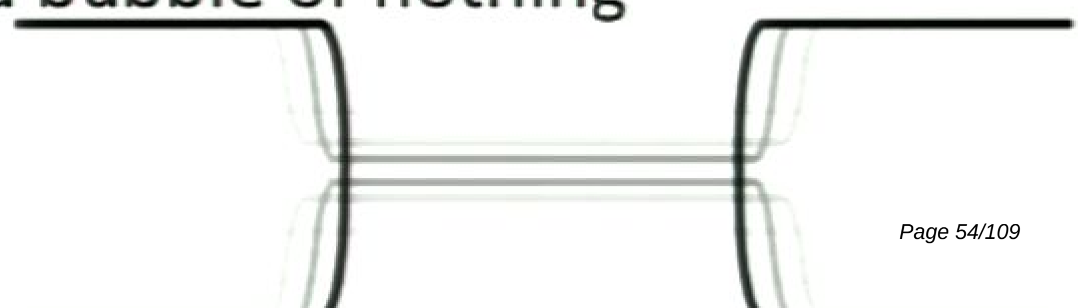


Flux compactifications with many fluxes give giant leaps

Monkey branes

Adding back-reaction

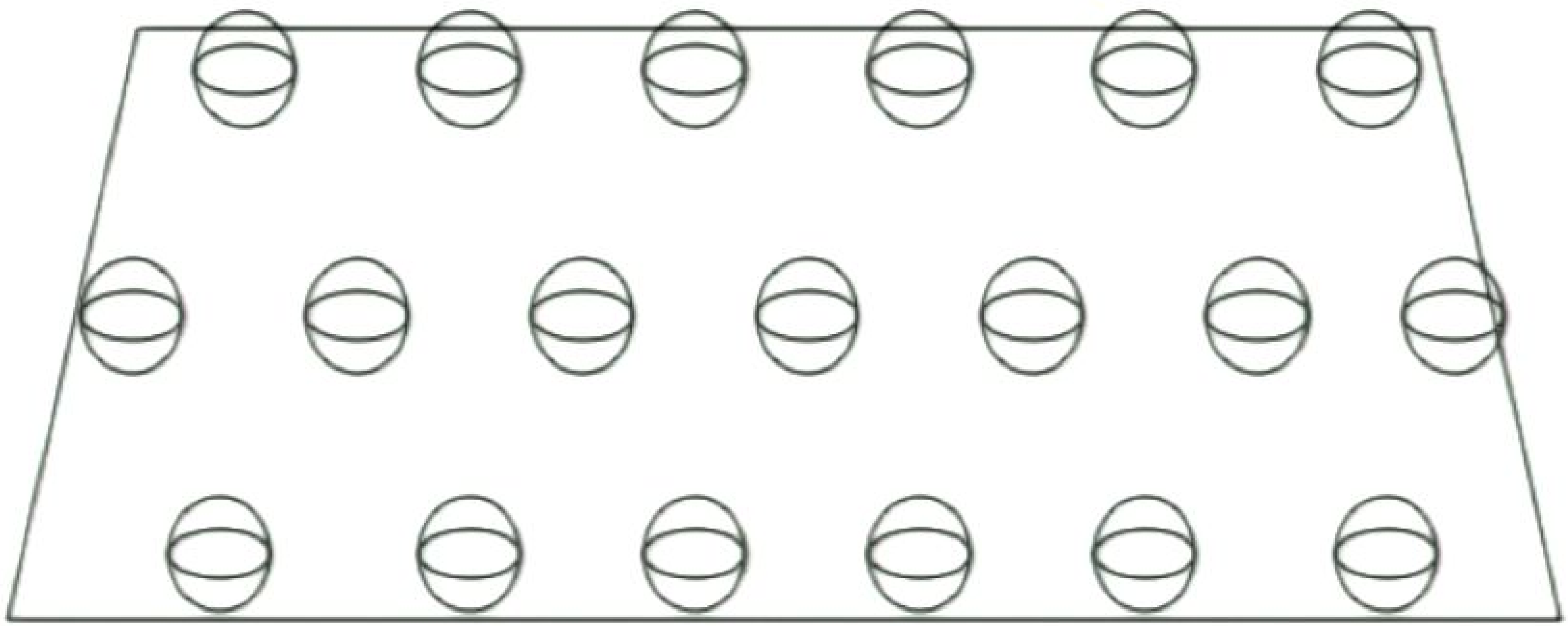
The giantest leap of all is a bubble of nothing



implest possible model with stabilized XDs 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



ree ingredients:

- spatial curvature of 2-spheres
- 2-form F_{ab} flux wrapping 2-spheres

i.e. Maxwell magnetic flux

$$S_{\rm EM} = \int d^6x\,\sqrt{-G}\left(\frac{1}{2}\mathcal{R}^{(6)} - \frac{1}{4}F_{AB}F^{AB} - \Lambda_6\right)$$

Freund Rubin (1980)

ective 4D theory:

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

$\mathfrak{N}$ different two-form fluxes, each with field strength

$$\mathbf{F}_i = \frac{g_i N_i}{4\pi} \sin\theta\, d\theta \wedge d\phi, \qquad F^2 = \sum_{i=1}^{\mathfrak{N}} g_i^2 N_i^2$$

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

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

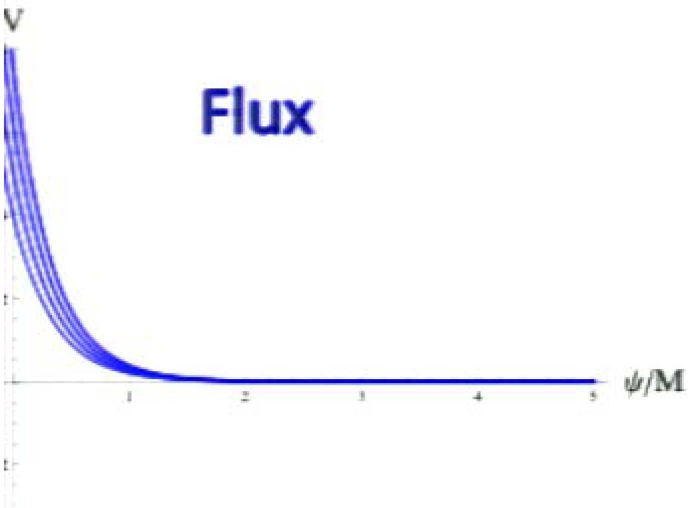
canonically normalized RADION

FLUX 'repulsive'

CURVATURE 'attractive' medium-range

C.C. 'reulsive' long-range

Flux



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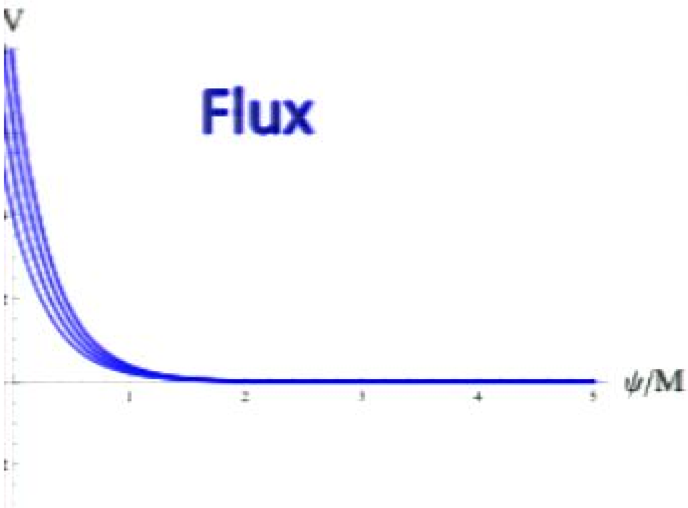

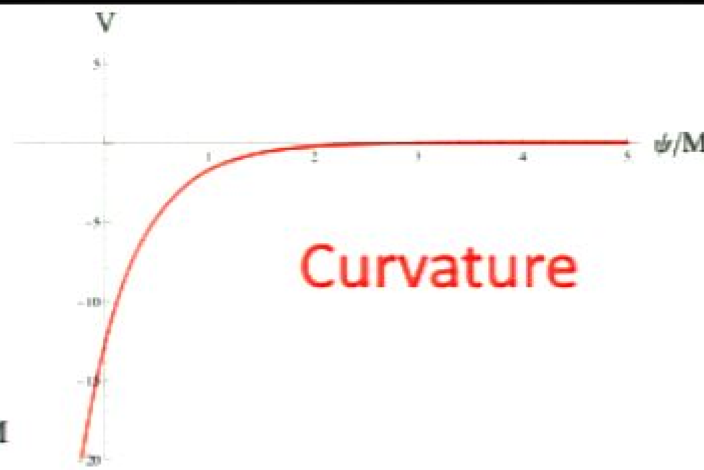

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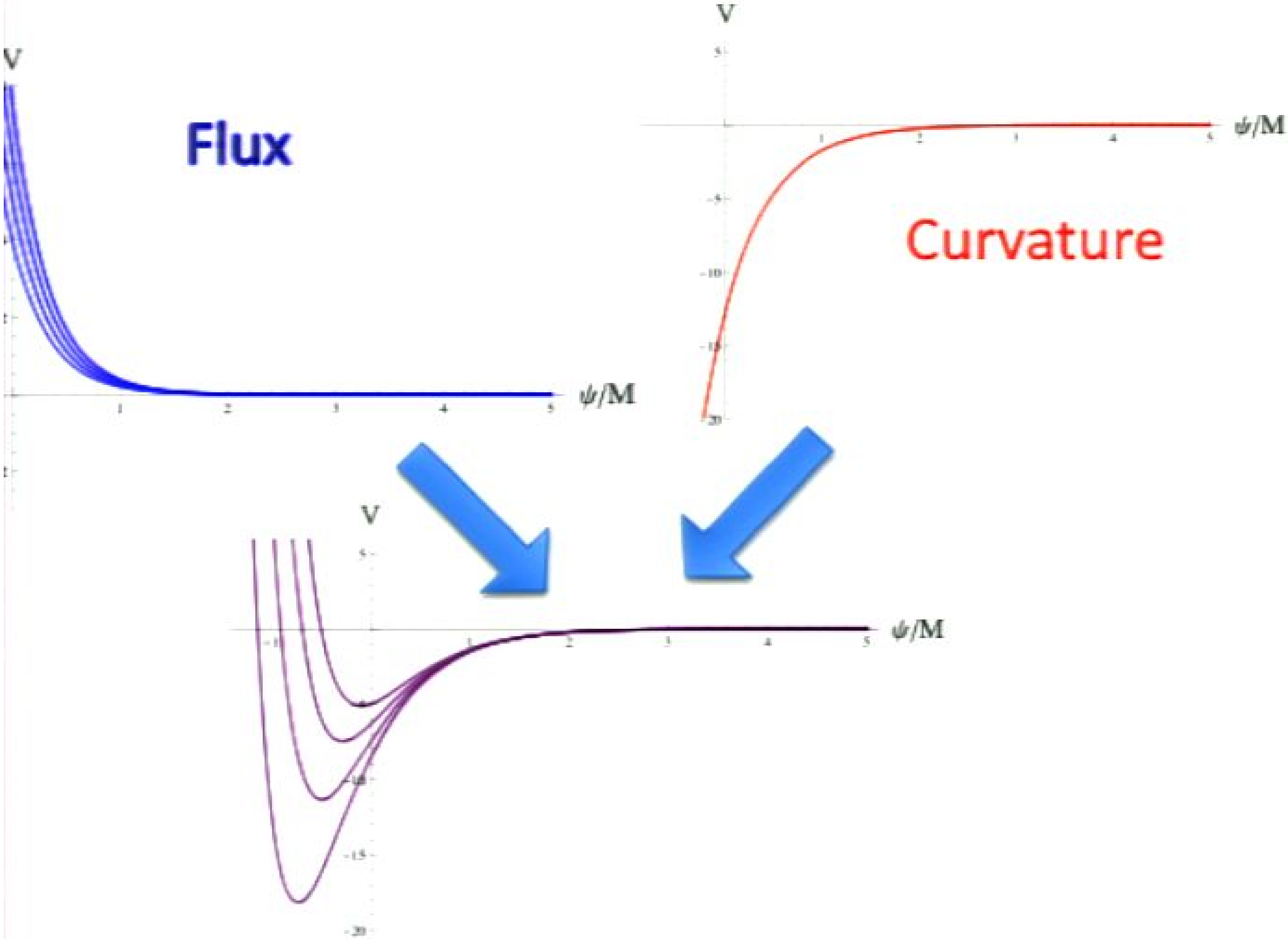

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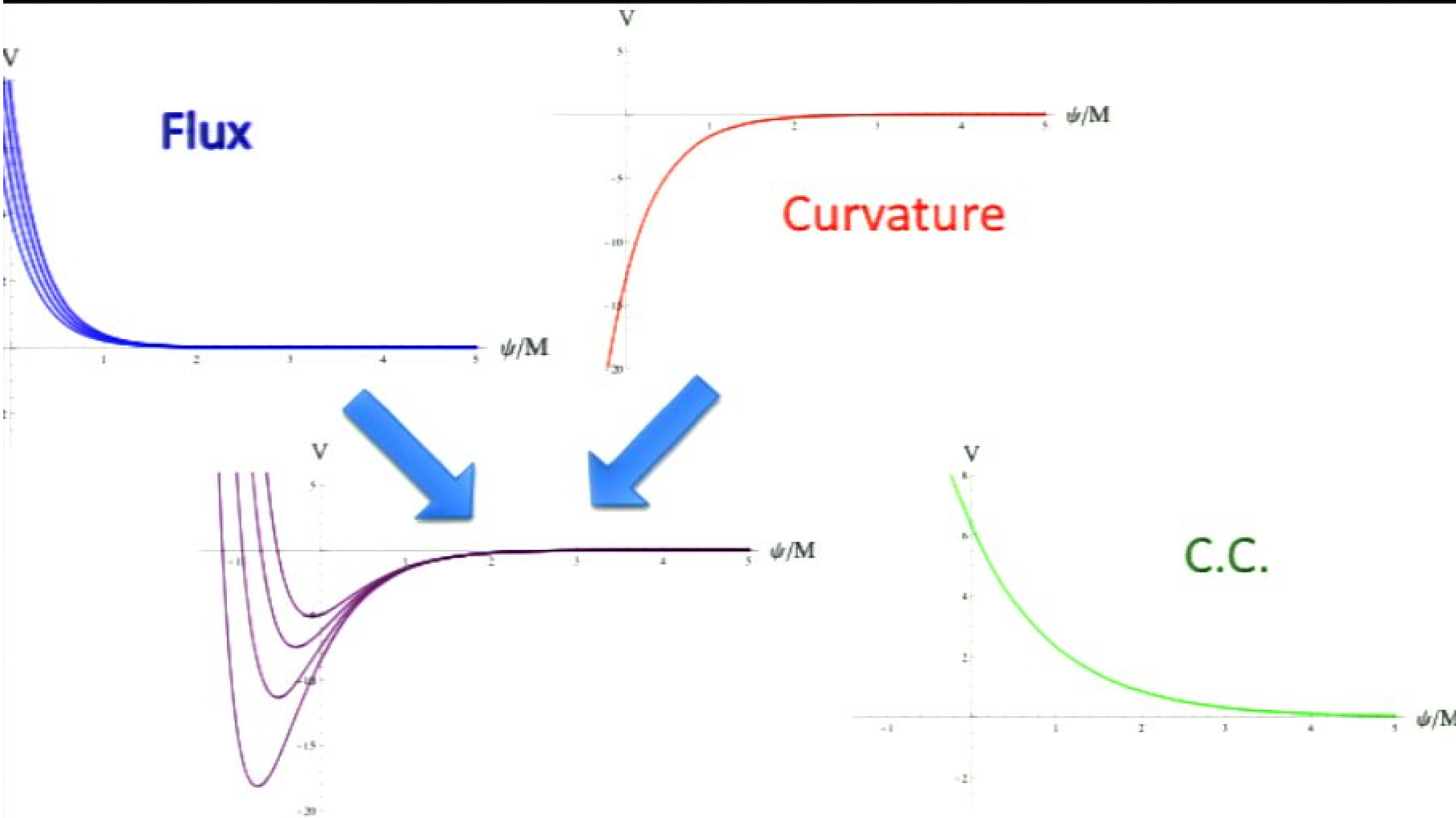

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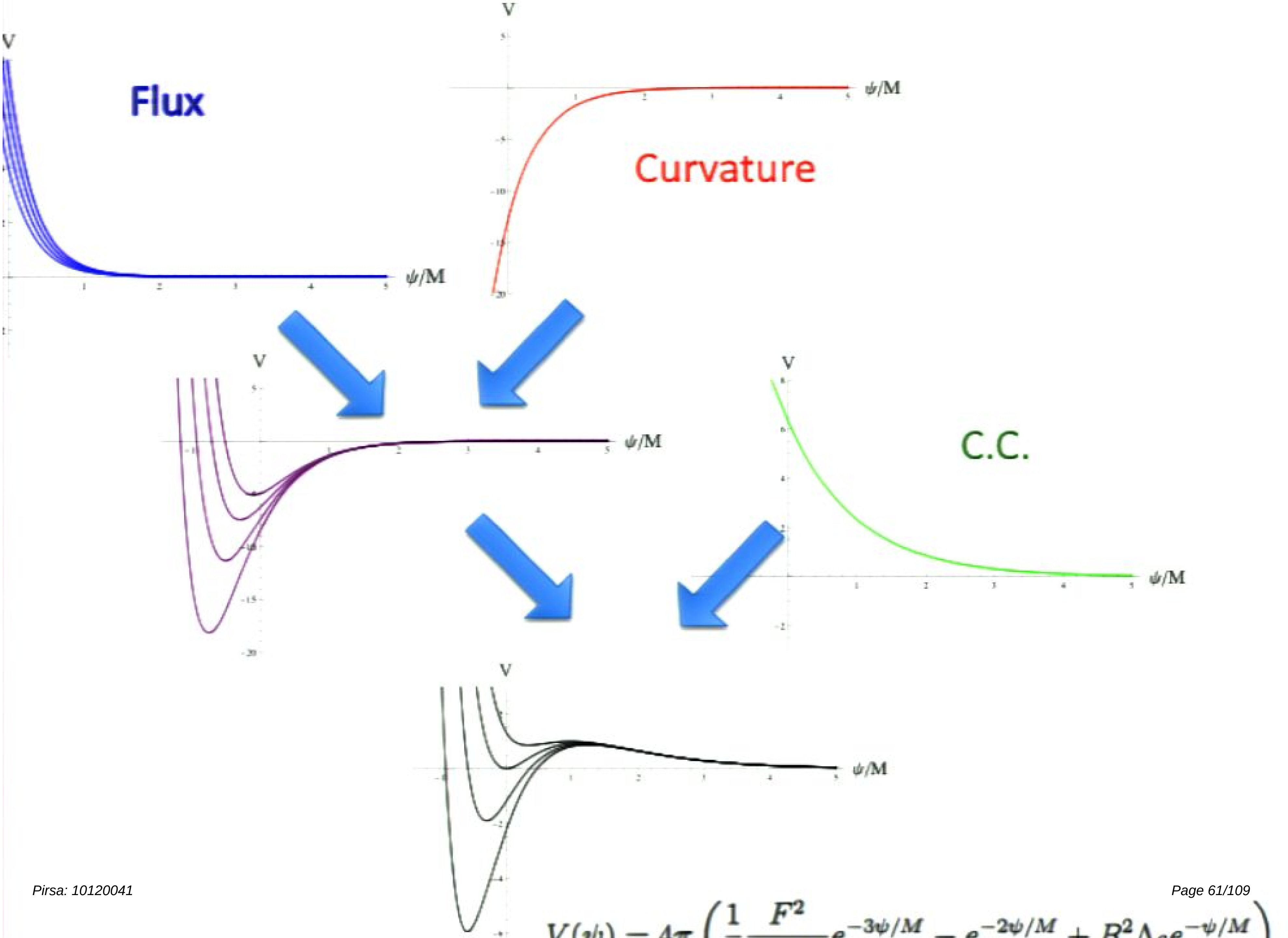

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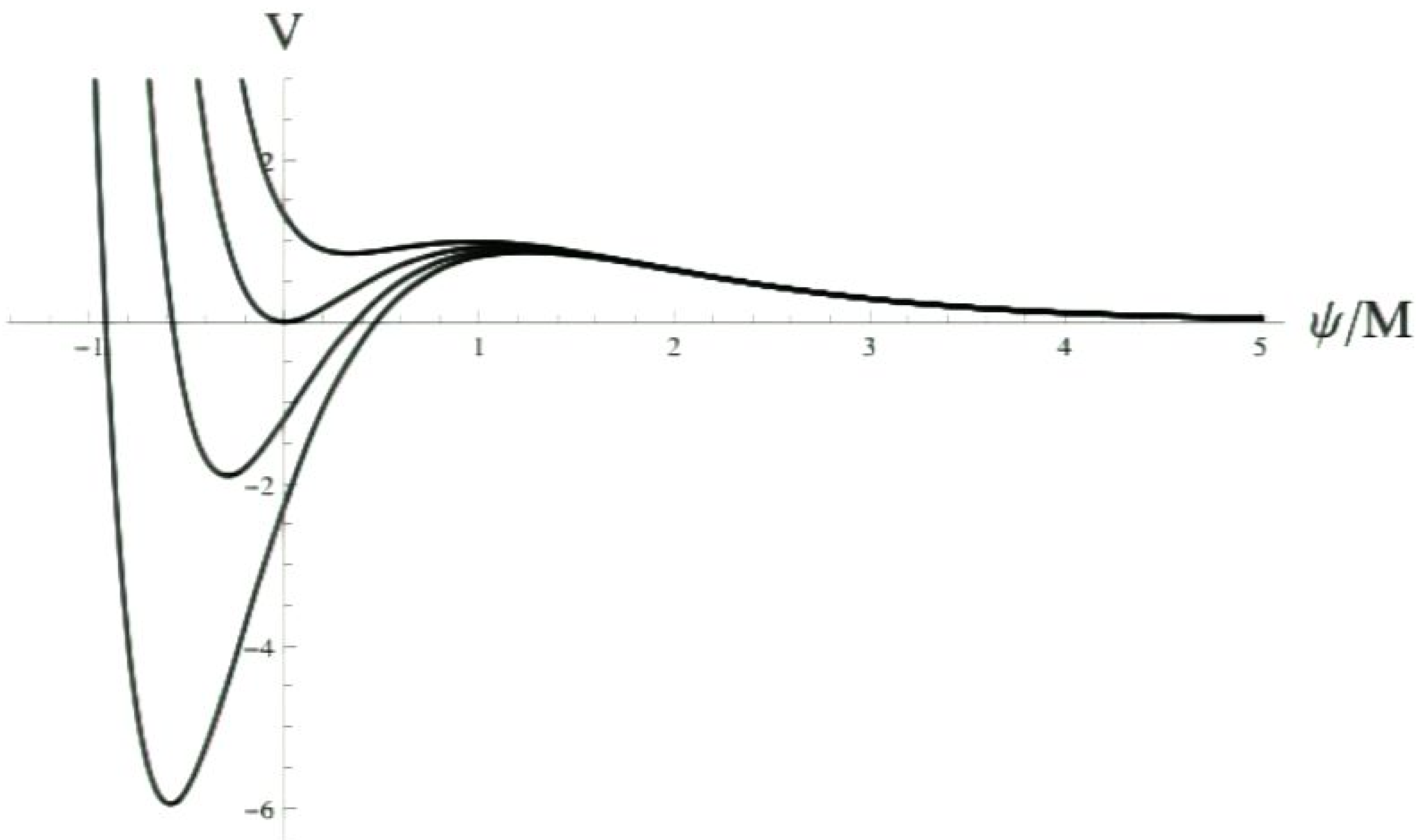
A landscape of (discrete) vacua



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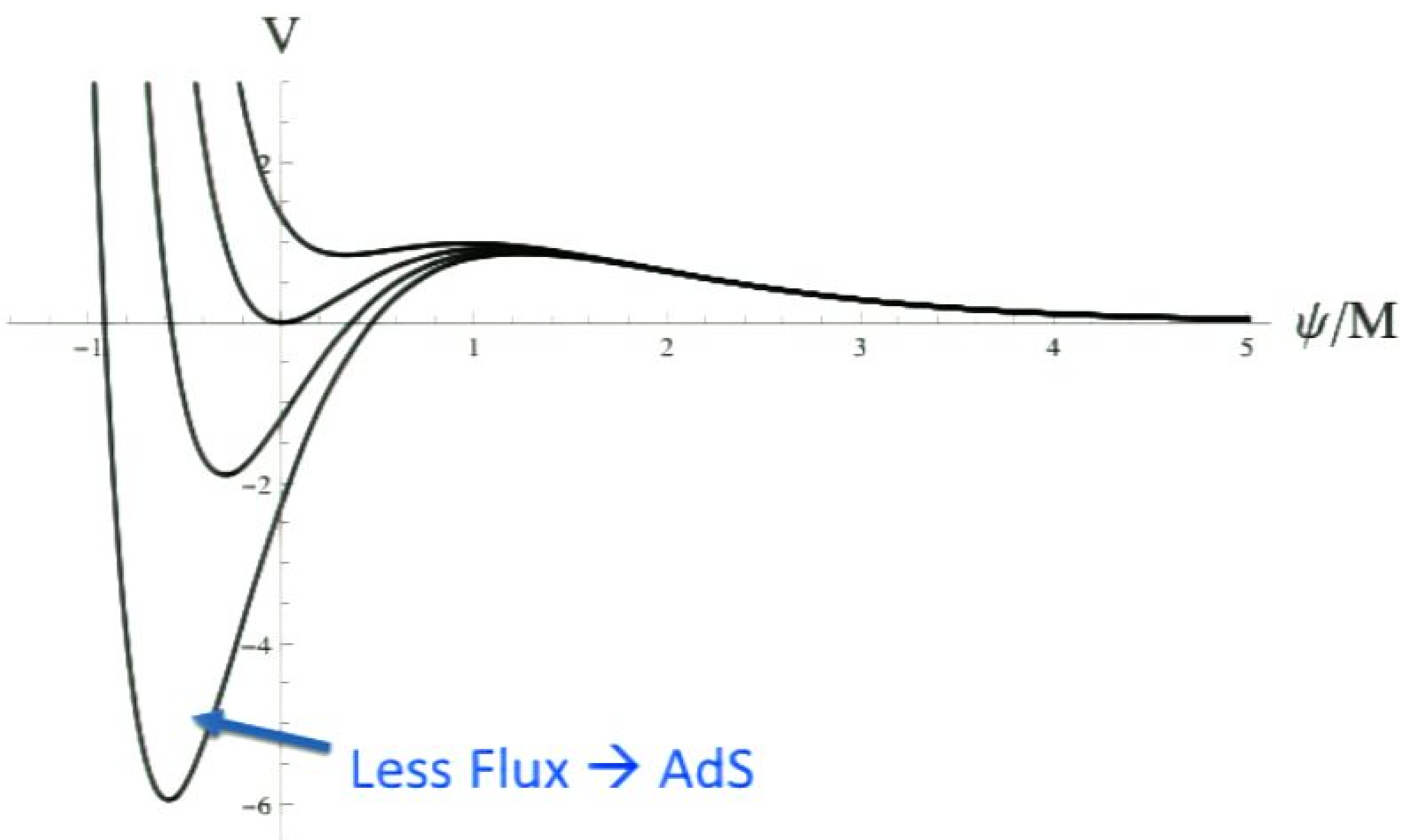
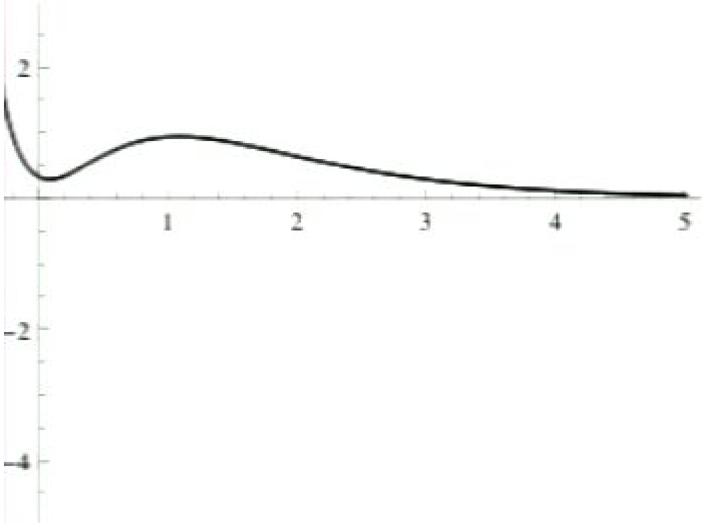
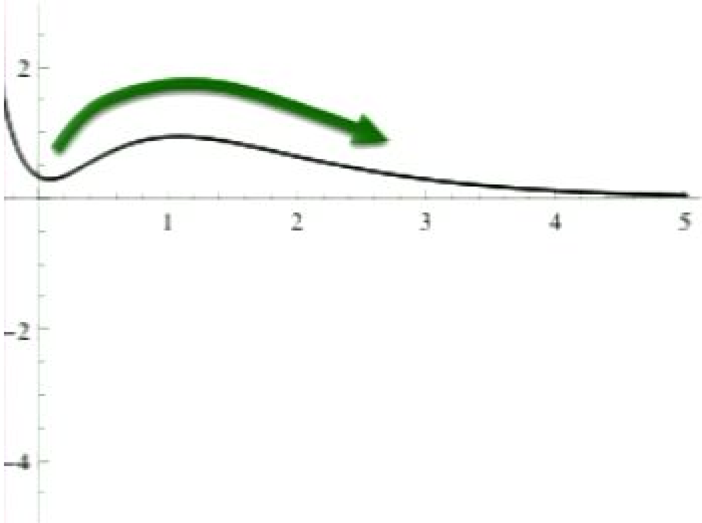
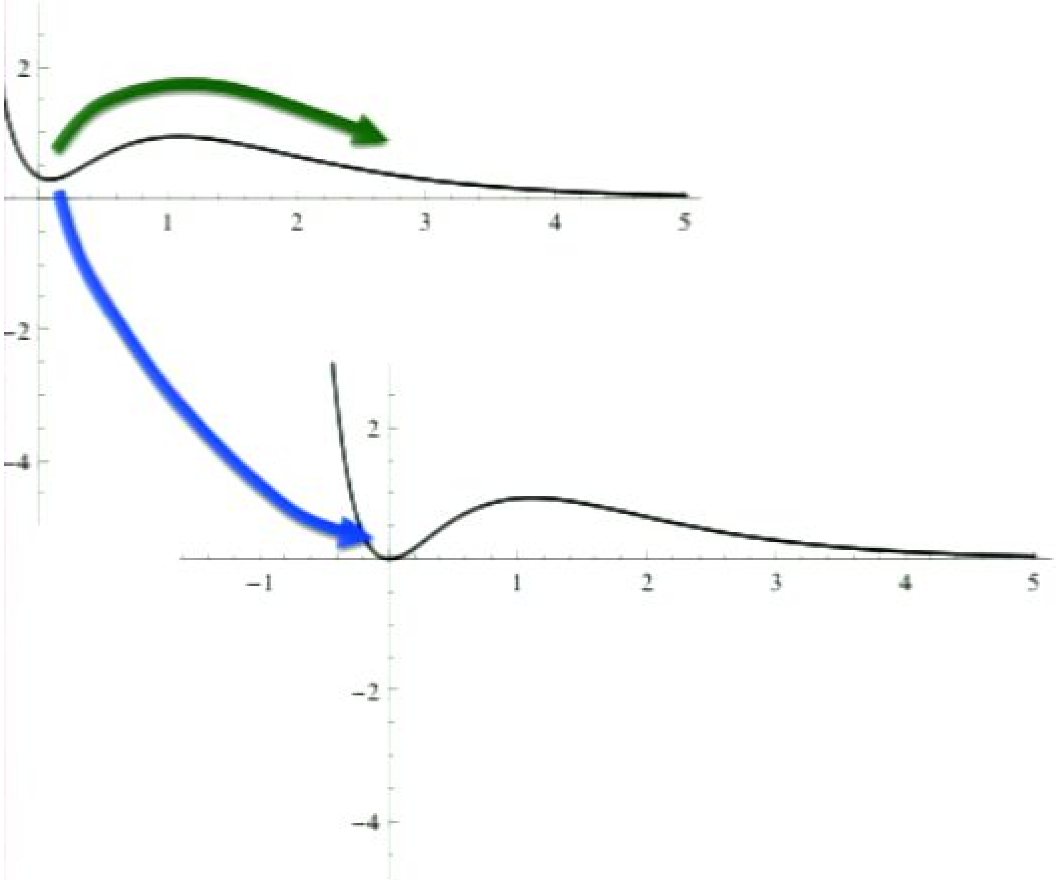




2
−2
−4
1
2
3
4
5

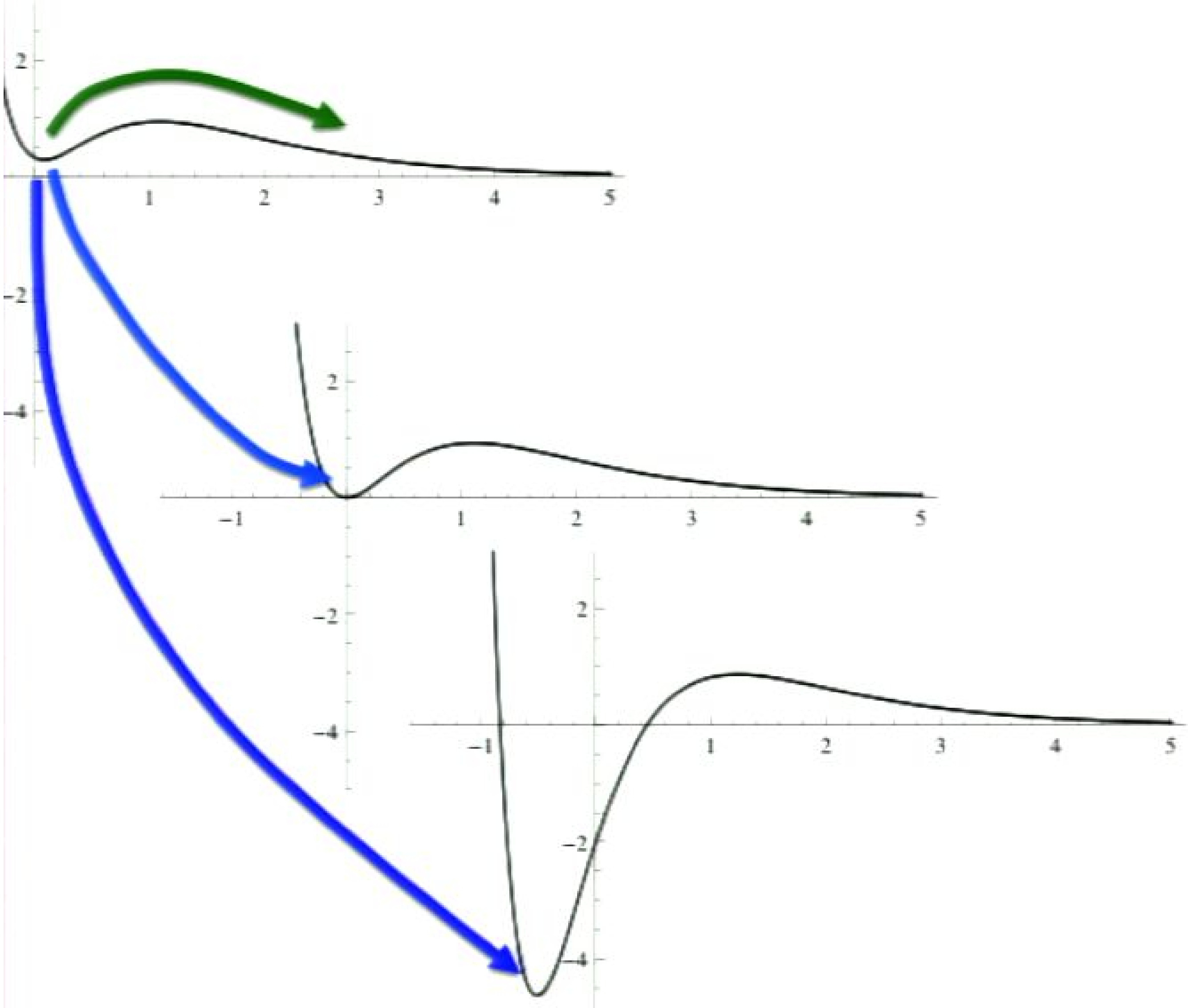
Decompactify





Decompactify

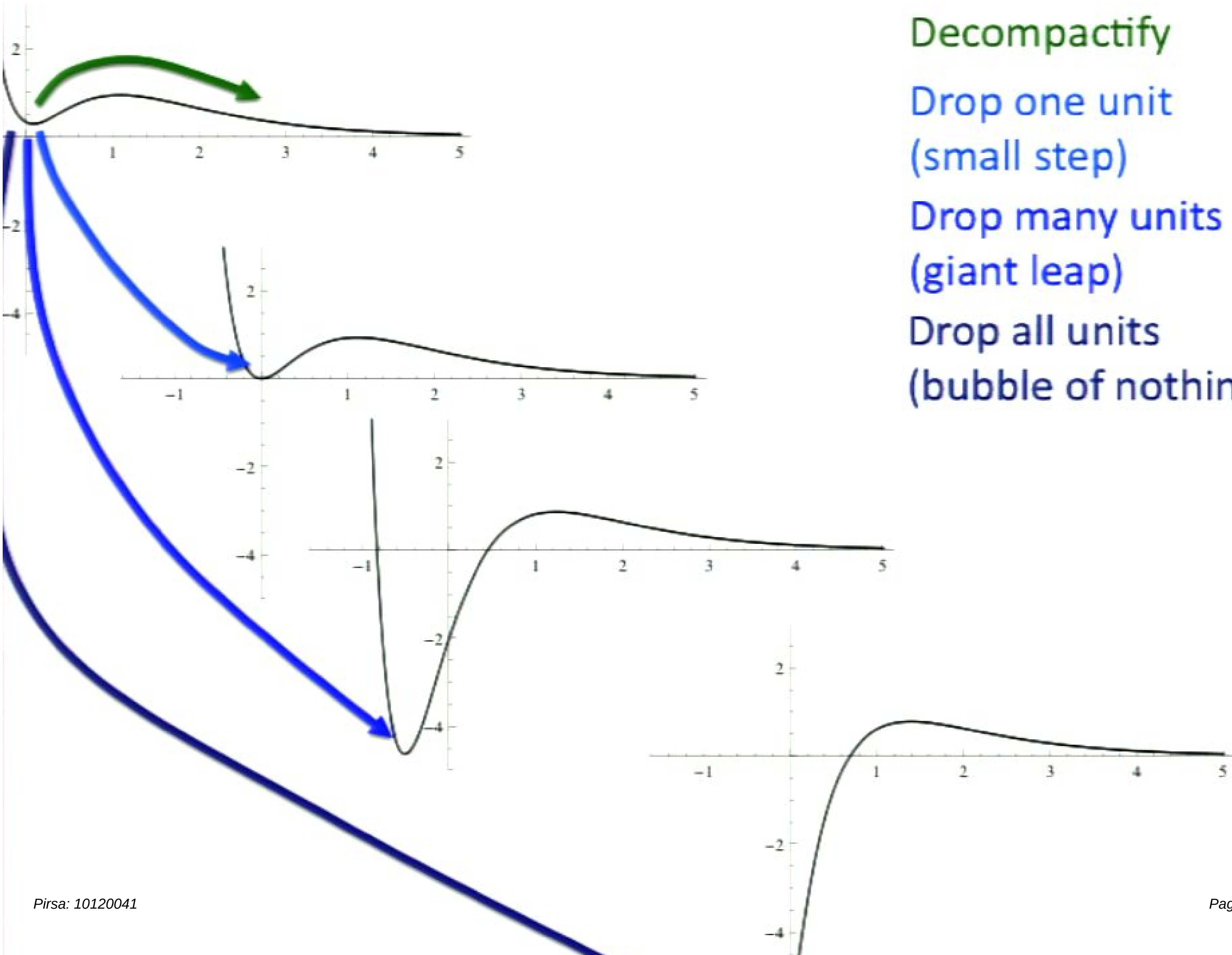
Drop one unit
(small step)



Decompactify

Drop one unit
(small step)

Drop many units
(giant leap)



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Drop one unit
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Drop many units
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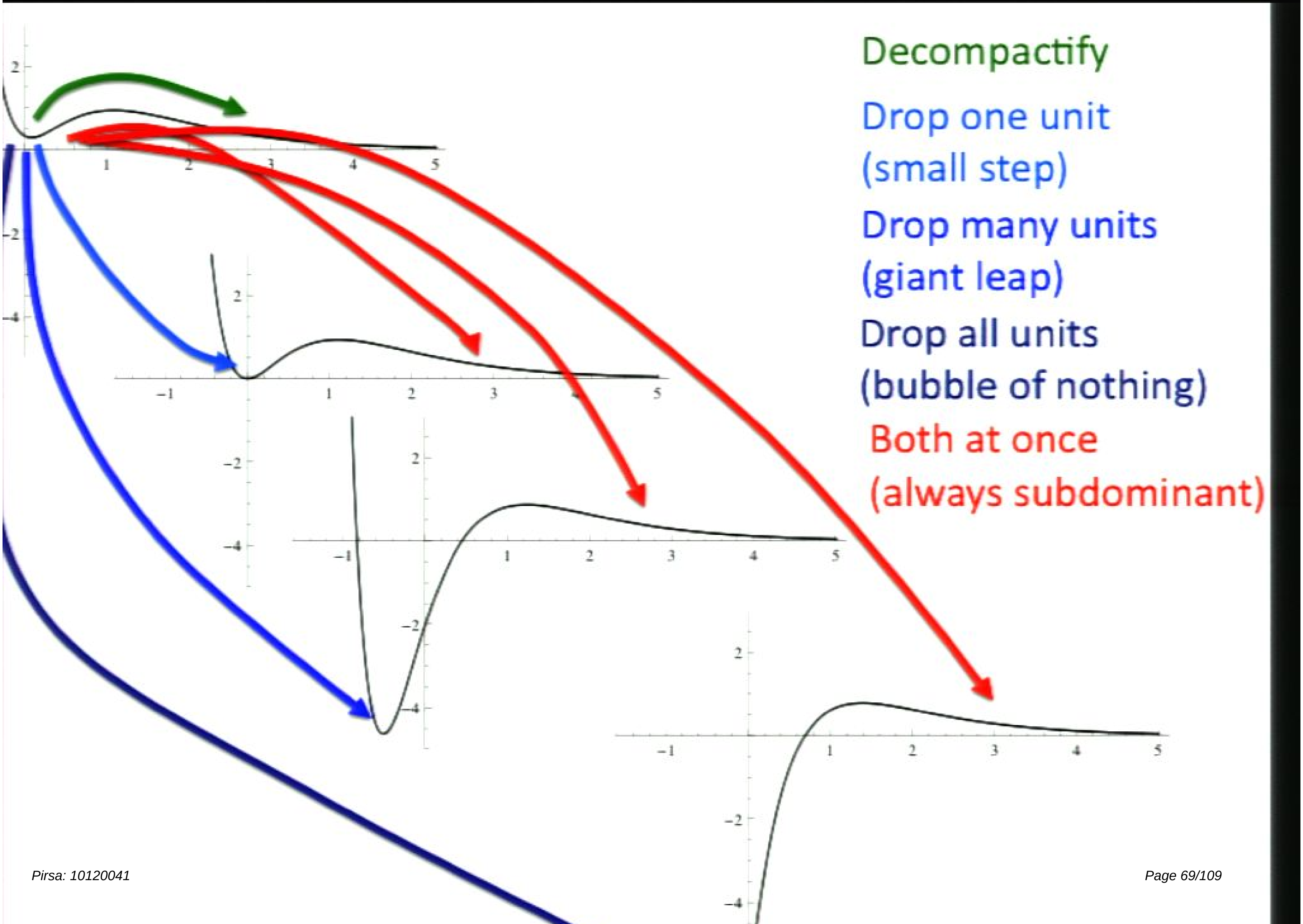
Drop all units
(bubble of nothing)



Decompactify
Drop one unit
(small step)
Drop many units
(giant leap)
Drop all units
(bubble of nothing)
Both at once
(always subdominant)

2 reasons back-reaction helps giant leaps

Radion mediates attractive force

$$S_{\text{brane tension}} = -T \int_{\Sigma} \sqrt{-\gamma}\, d^3\xi \qquad\qquad ds^2 = e^{-\psi(x)/M_4} g_{\mu\nu} dx^\mu dx^\nu + e^{\psi(x)/M_4} R^2 \, d\Omega_2^2$$

$$S_{\text{brane tension}} = -T e^{-3\psi(\xi)/2M_4} \times (\text{surface area})$$

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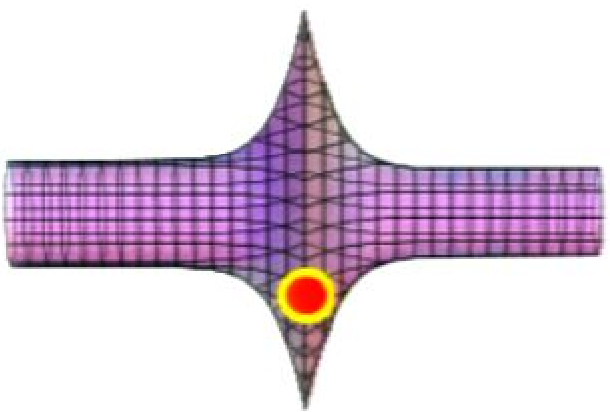

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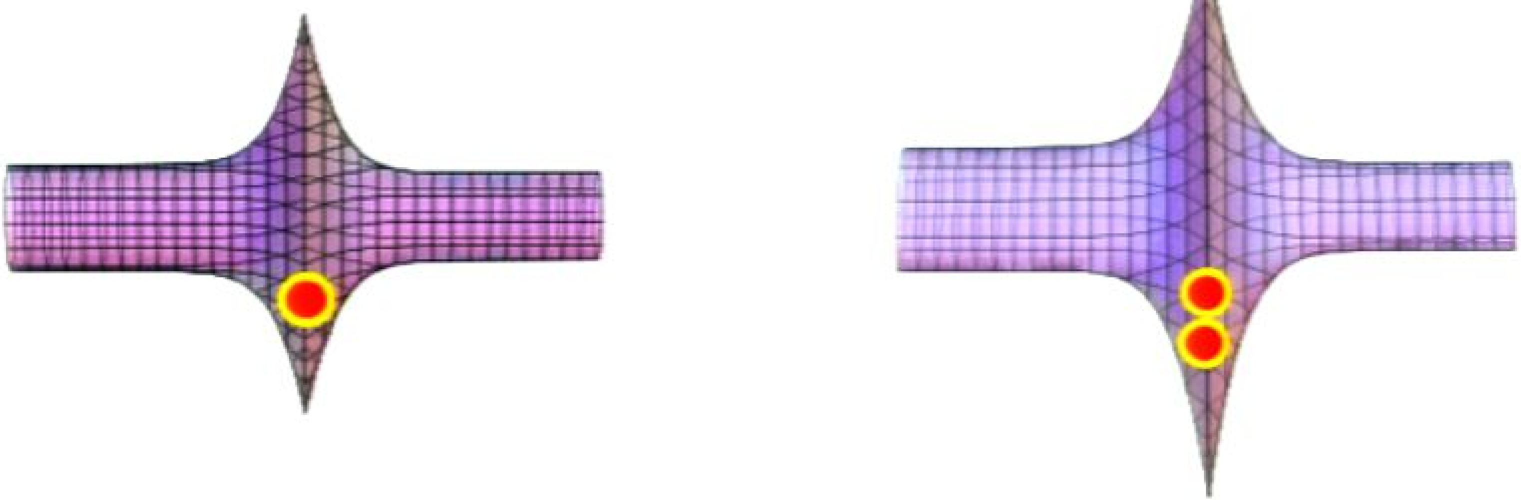
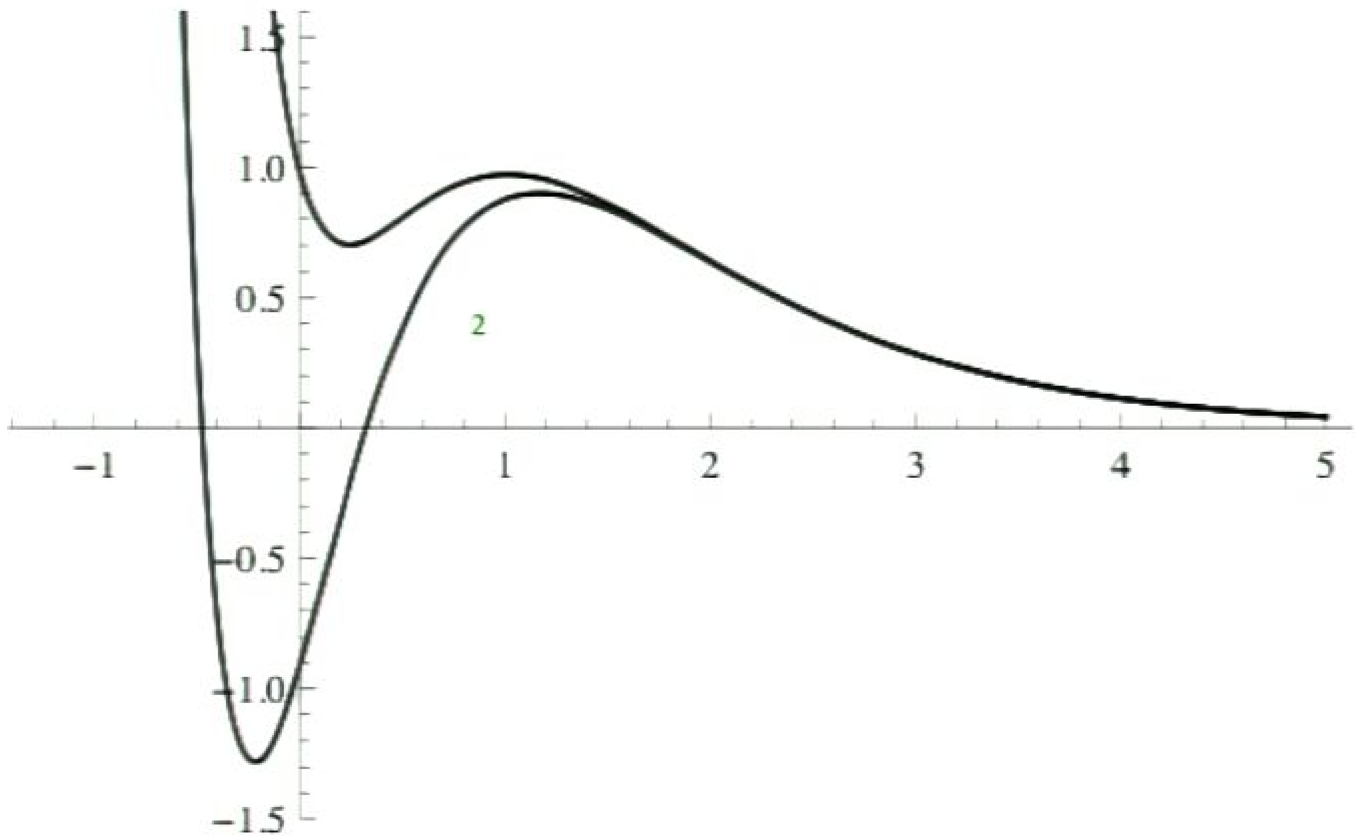


2 reasons back-reaction helps giant leaps

Radion can readjust for extra energy



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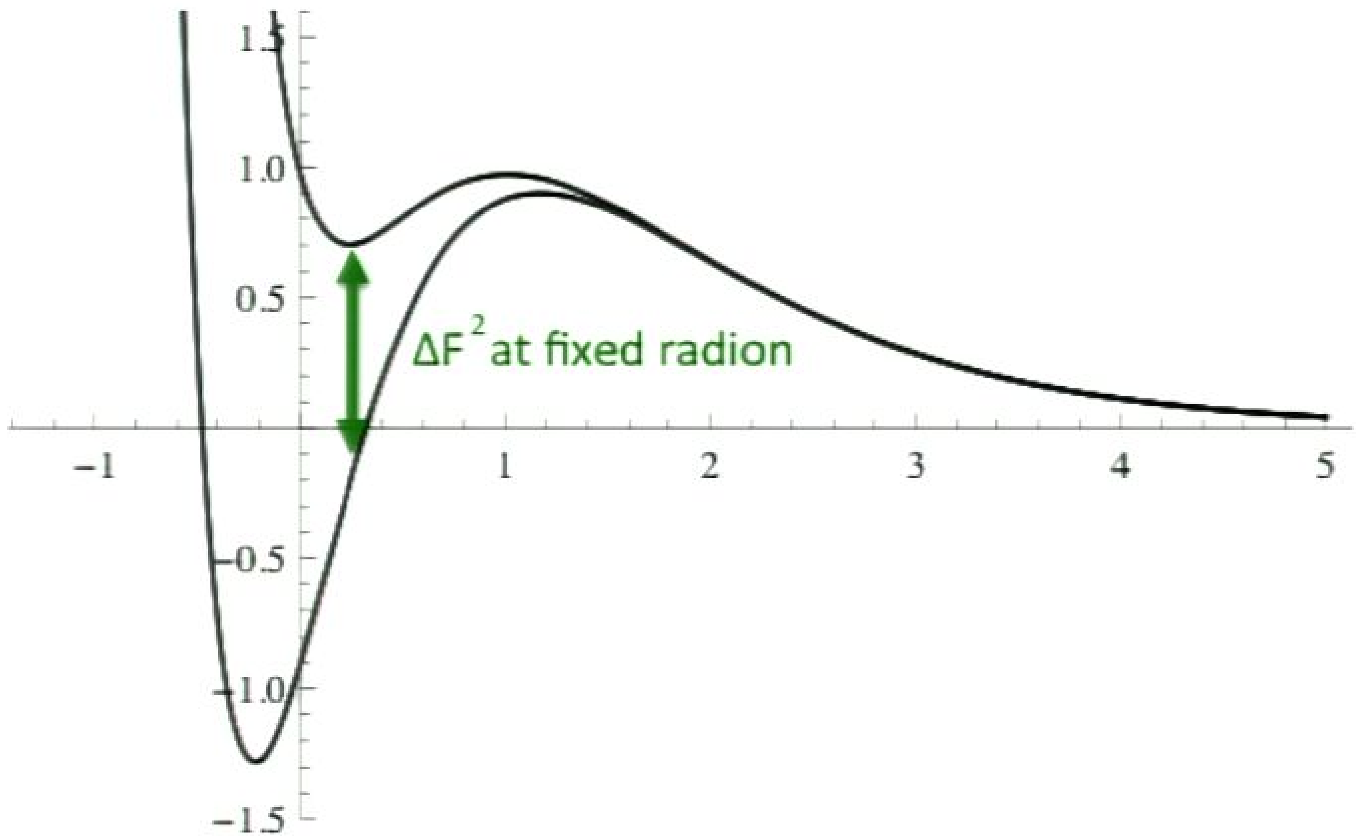

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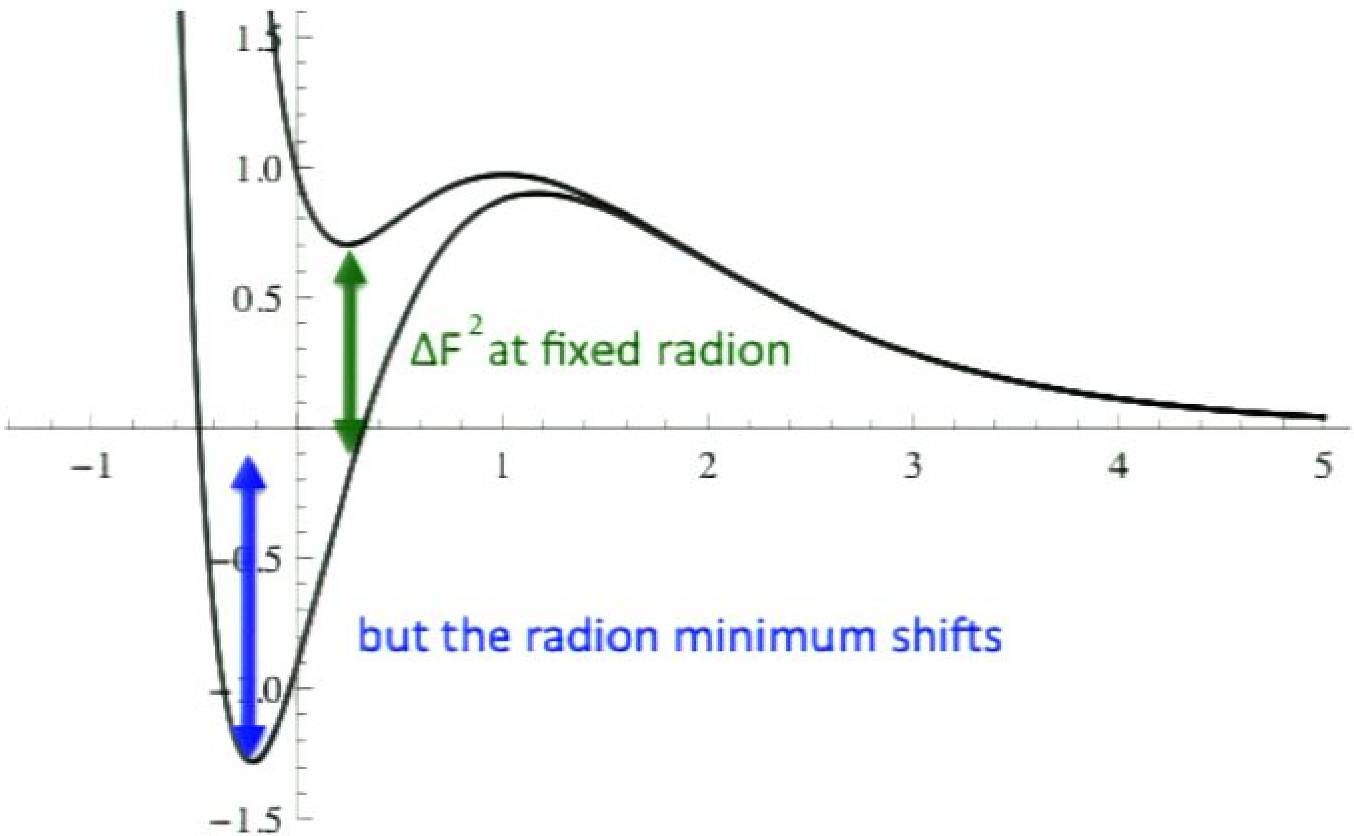

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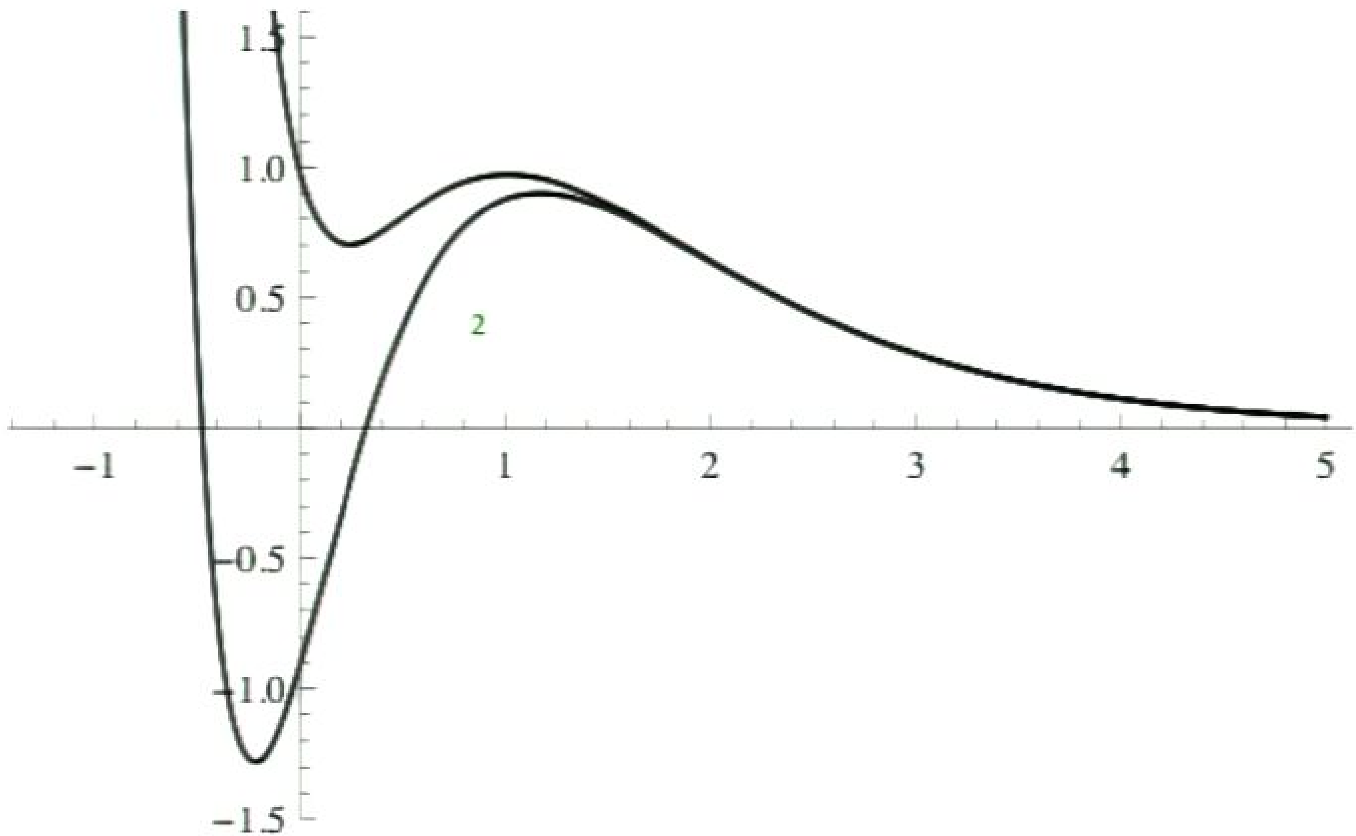

1 reason it hurts giant leaps:

Thick wall means less region in the true vacuum

2 reasons back-reaction helps giant leaps

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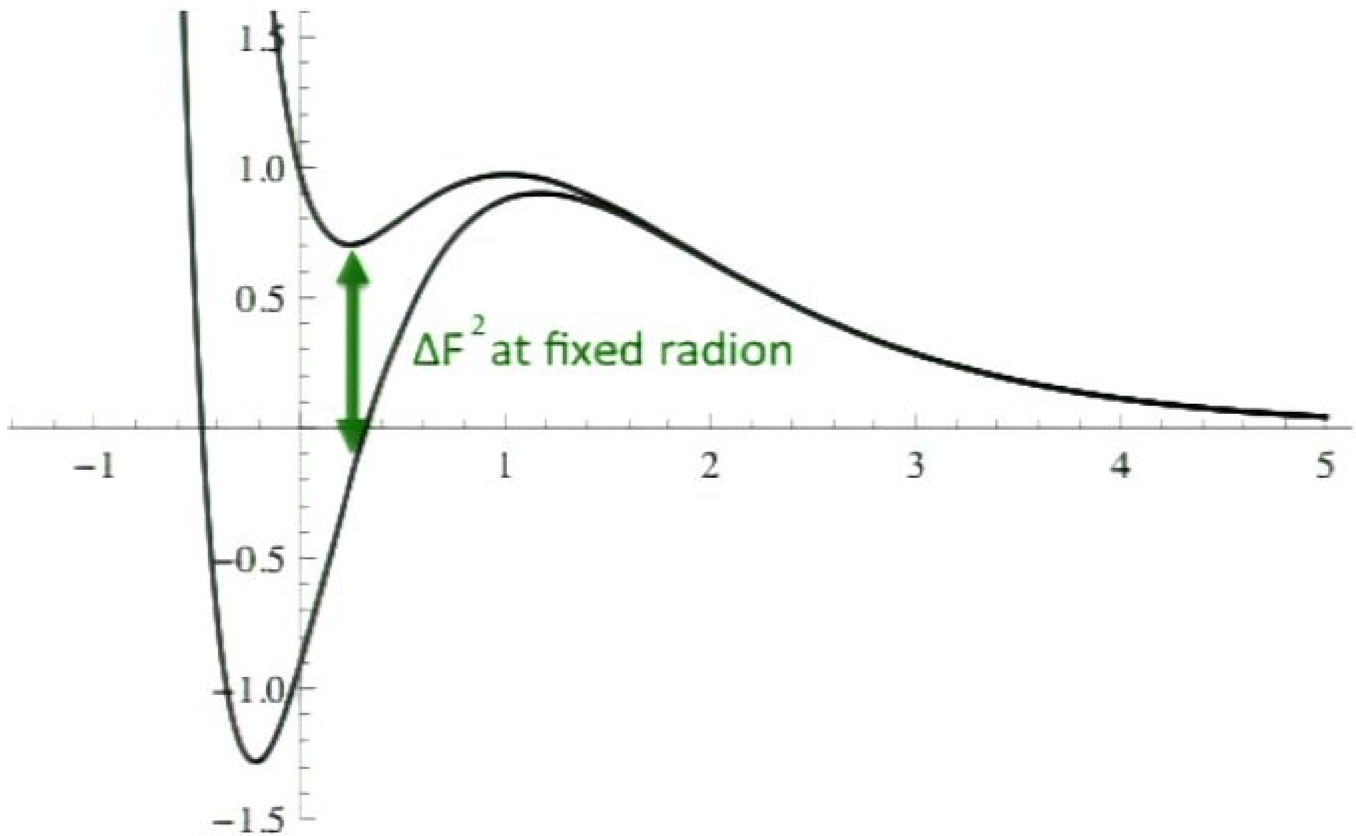

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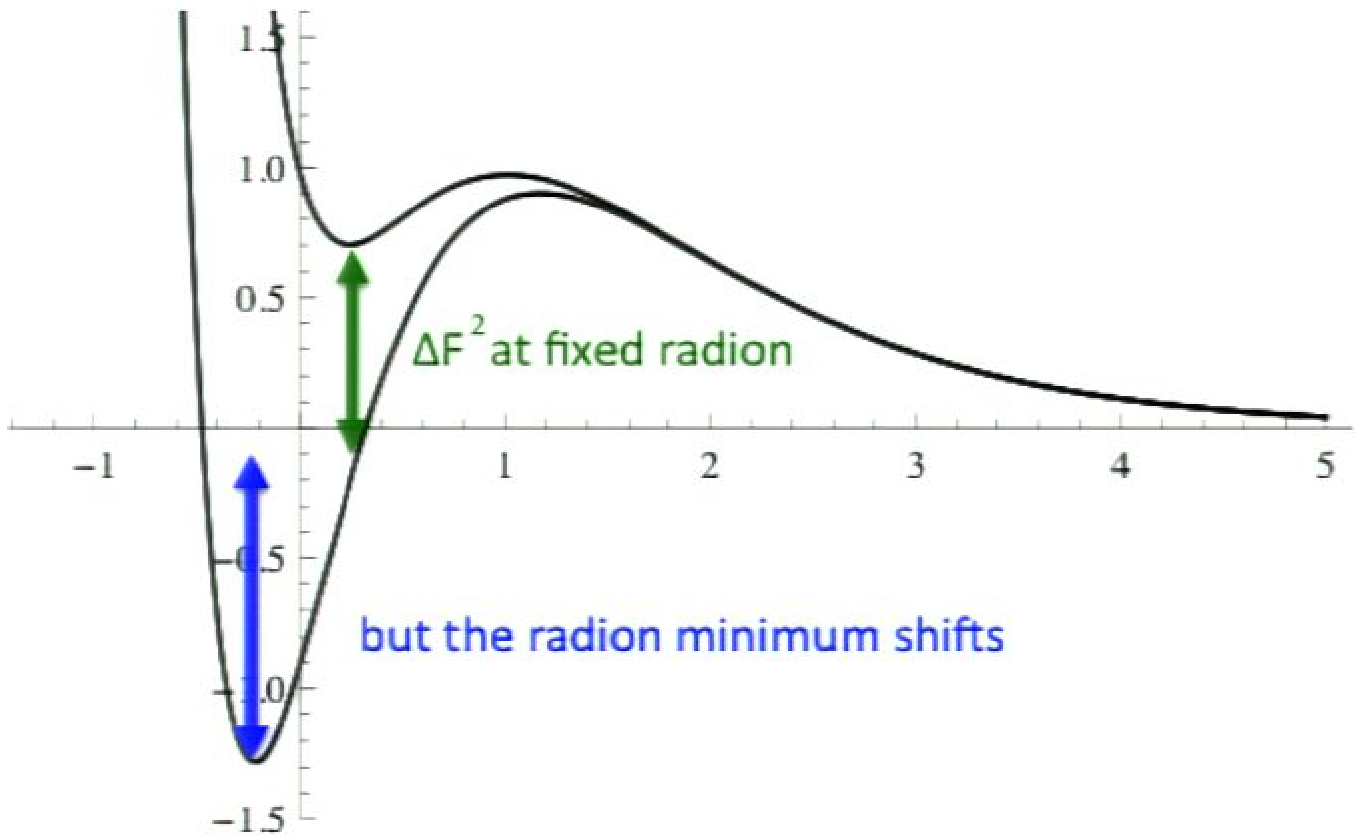

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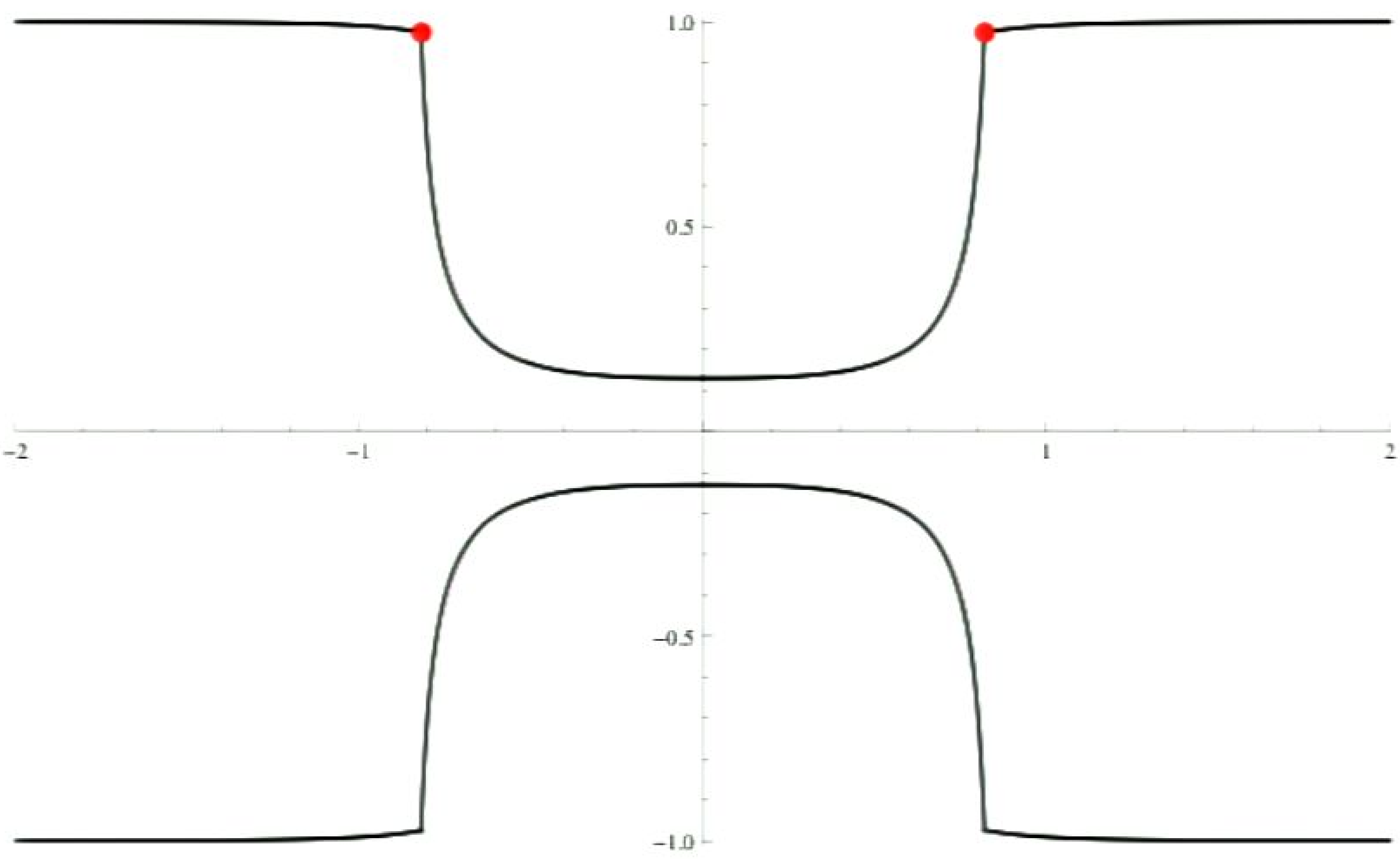
Sample instanton profile



Let's look at two extreme examples

$$F^2 = \sum_{i=1}^{\mathfrak{N}} g_i^2 N_i^2$$

$$T = \frac{2}{\sqrt{3}} \left(\sum_{i=1}^{\mathfrak{N}} g_i^2 n_i^2 \right)^{\frac{1}{2}}$$

MONOFLUX

A single type of flux and many units of it

$$\mathfrak{N} = 1 \quad N \gg 1 \quad F^2 = g^2 N^2$$

MULTIFLUX

Many different types of flux, each with a single unit

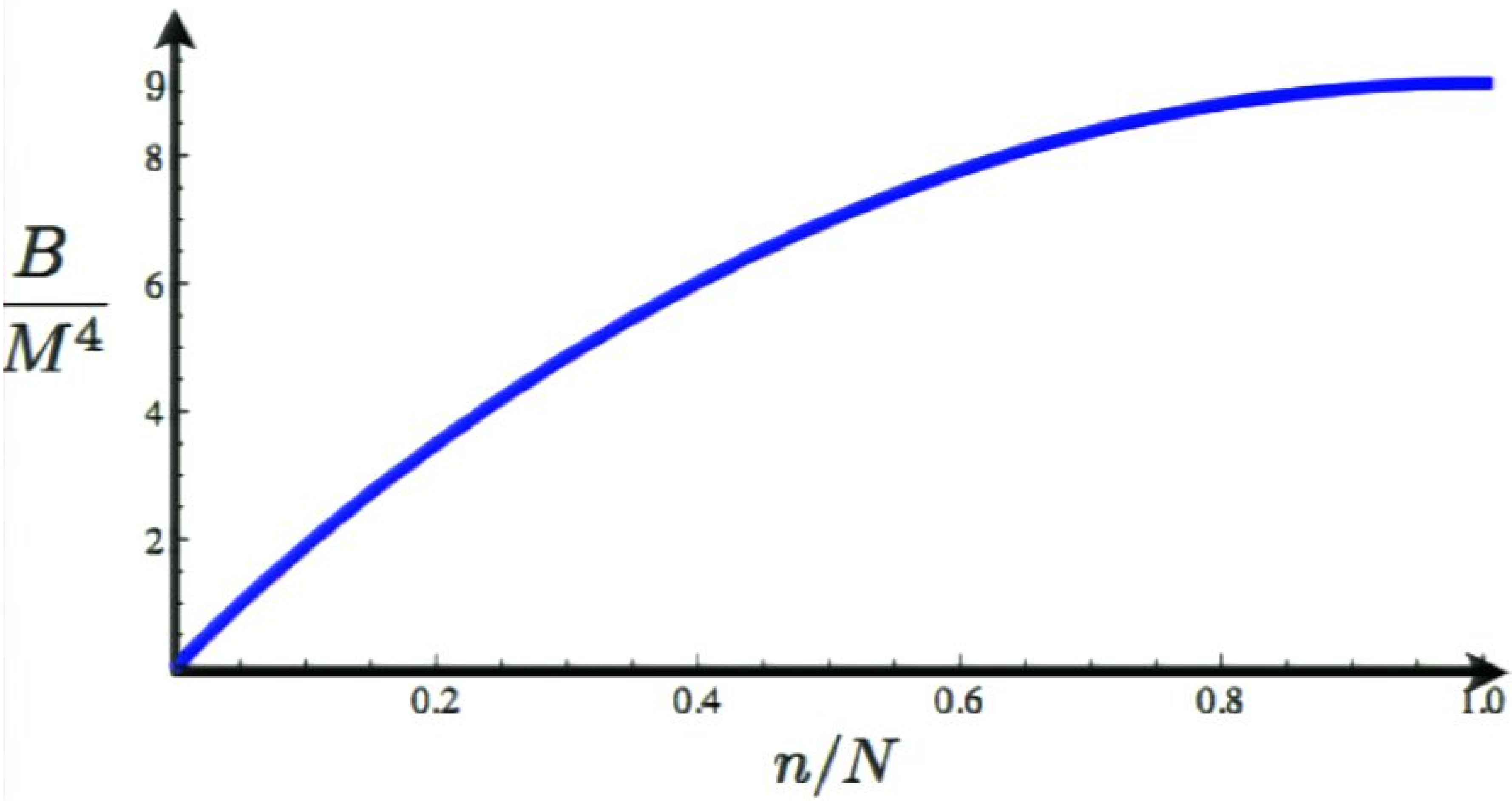
$$\mathfrak{N} \gg 1 \quad N_i = 1 \qquad F^2 = g^2 \mathfrak{N}$$

Decay Rates

$$\Gamma \sim e^{-B/\hbar}, \qquad B = S_E(\text{instanton}) - S_E(\text{false vacuum})$$

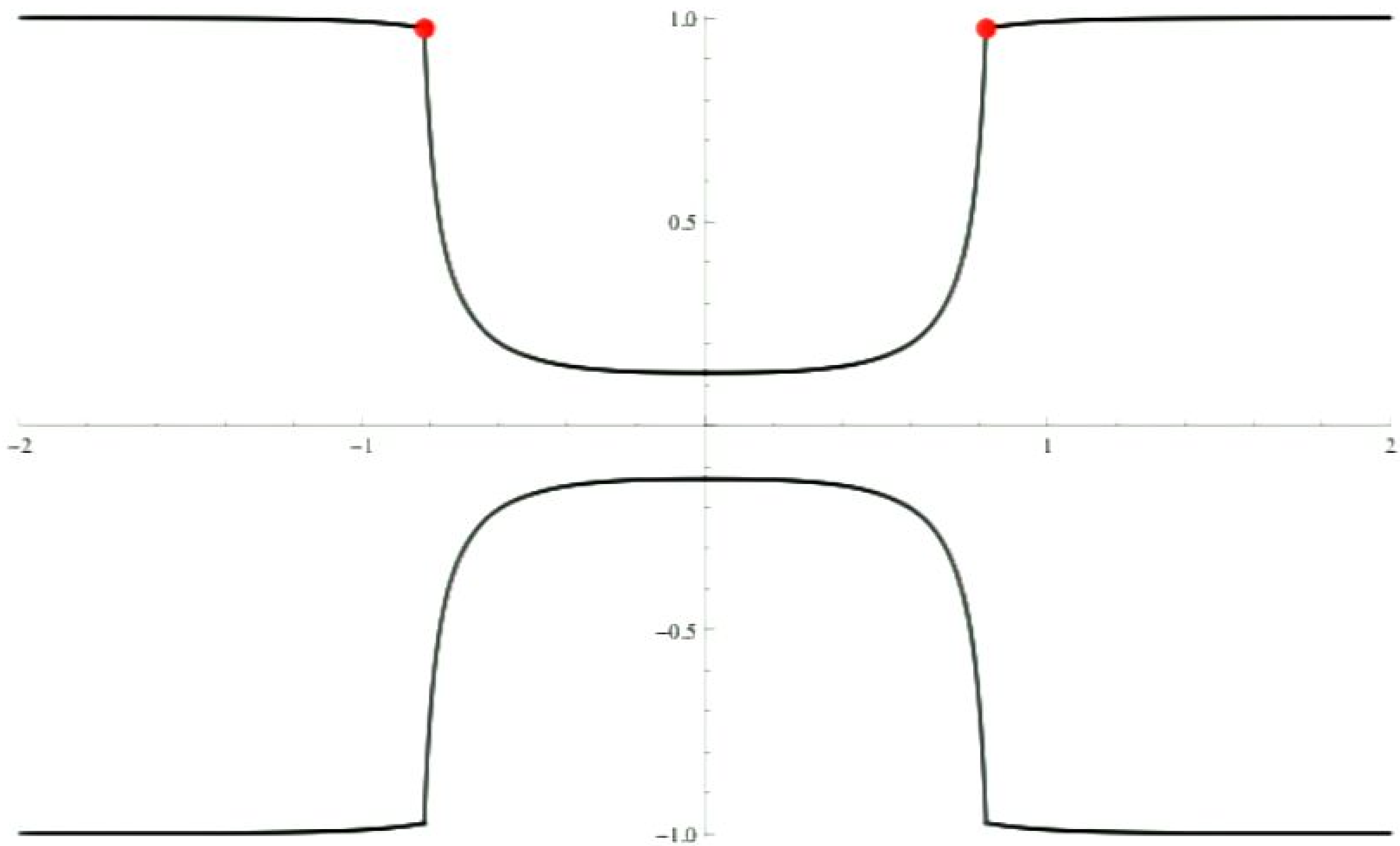
MONOFLUX

From V=0



SMALL STEPS WIN

Sample instanton profile



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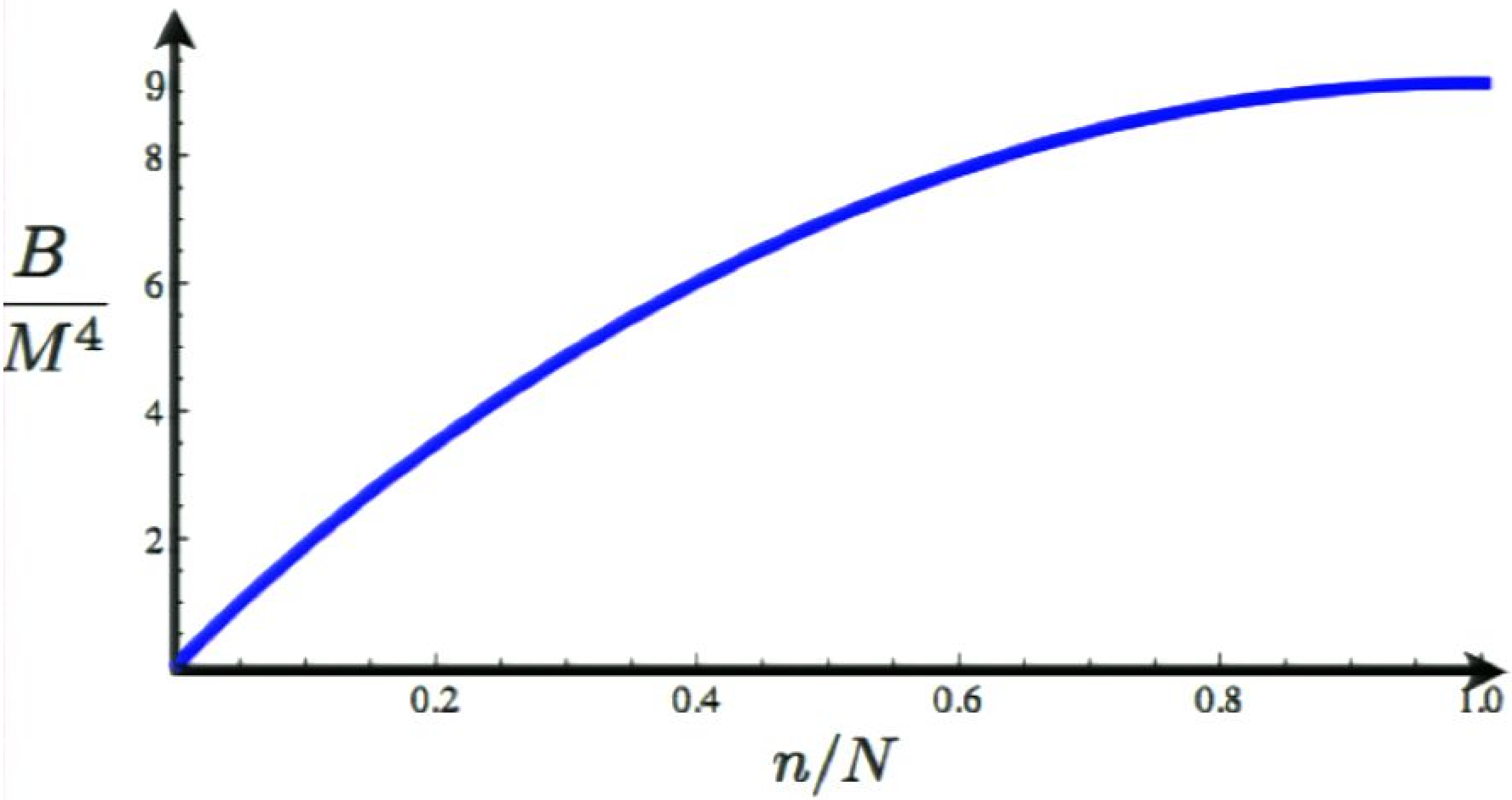
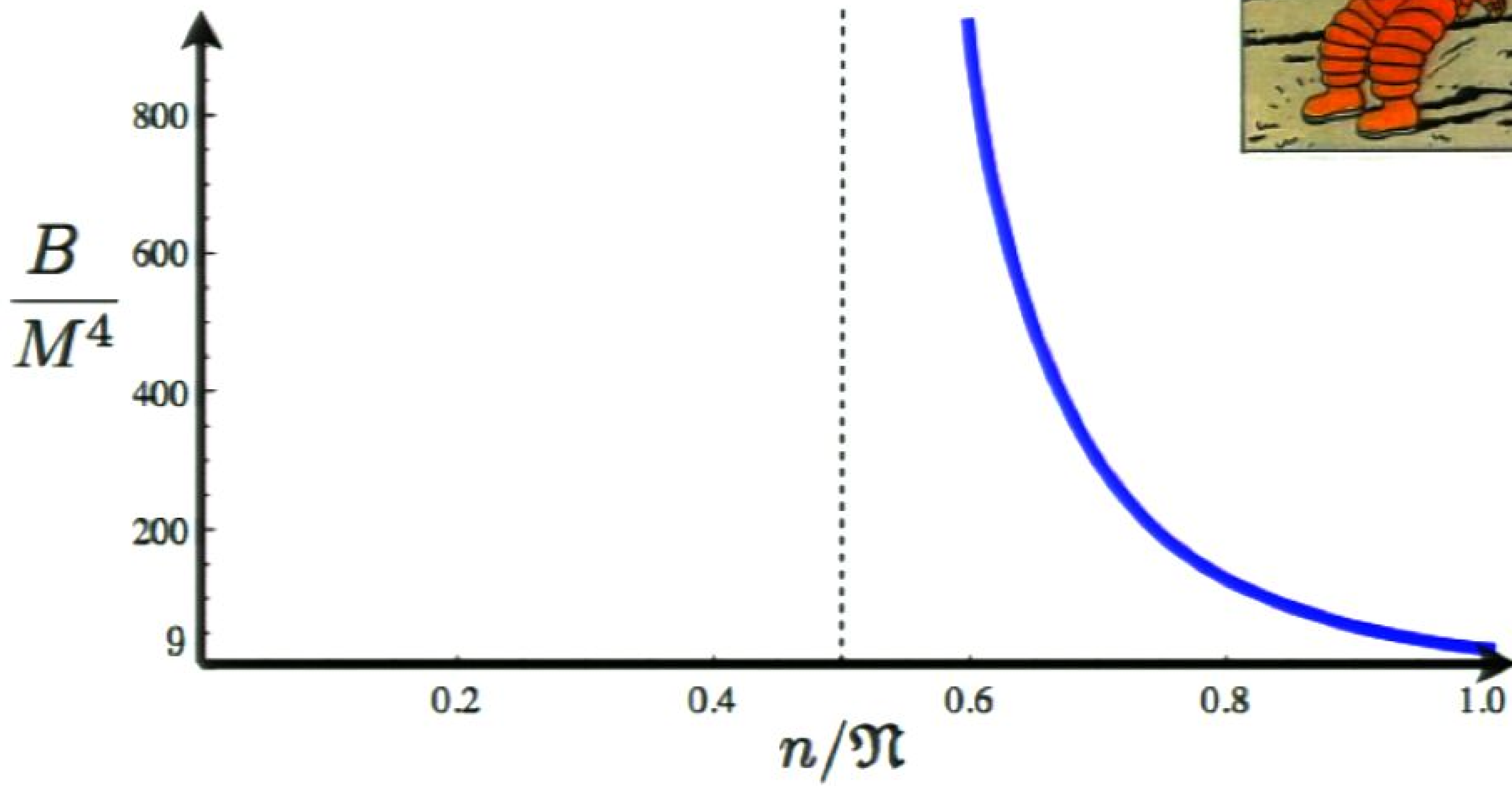


SMALL STEPS WIN

Decay Rates

MULTIFLUX

From V=0



GIANT LEAPS WIN

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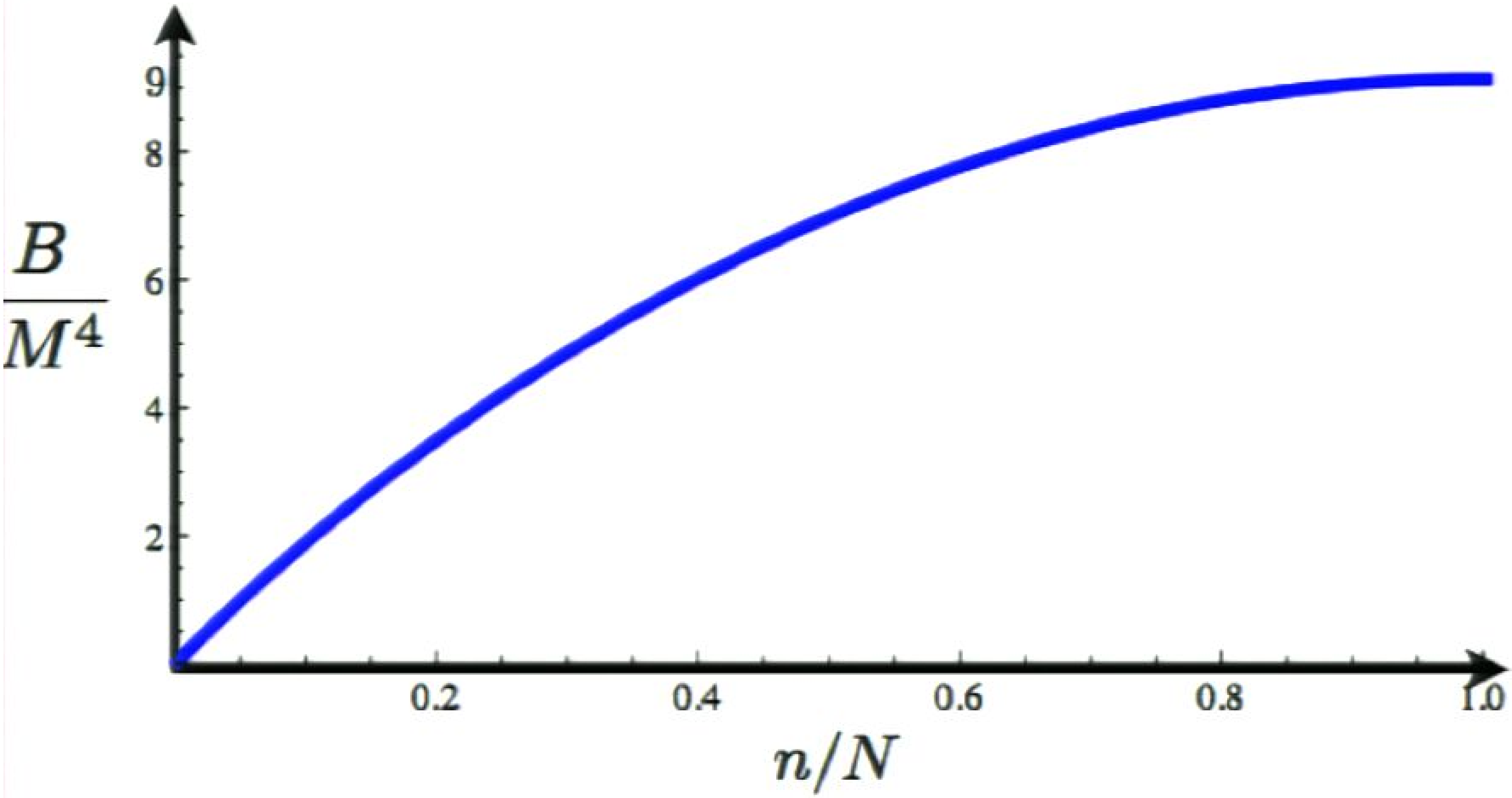
MONOFLUX

From V=0

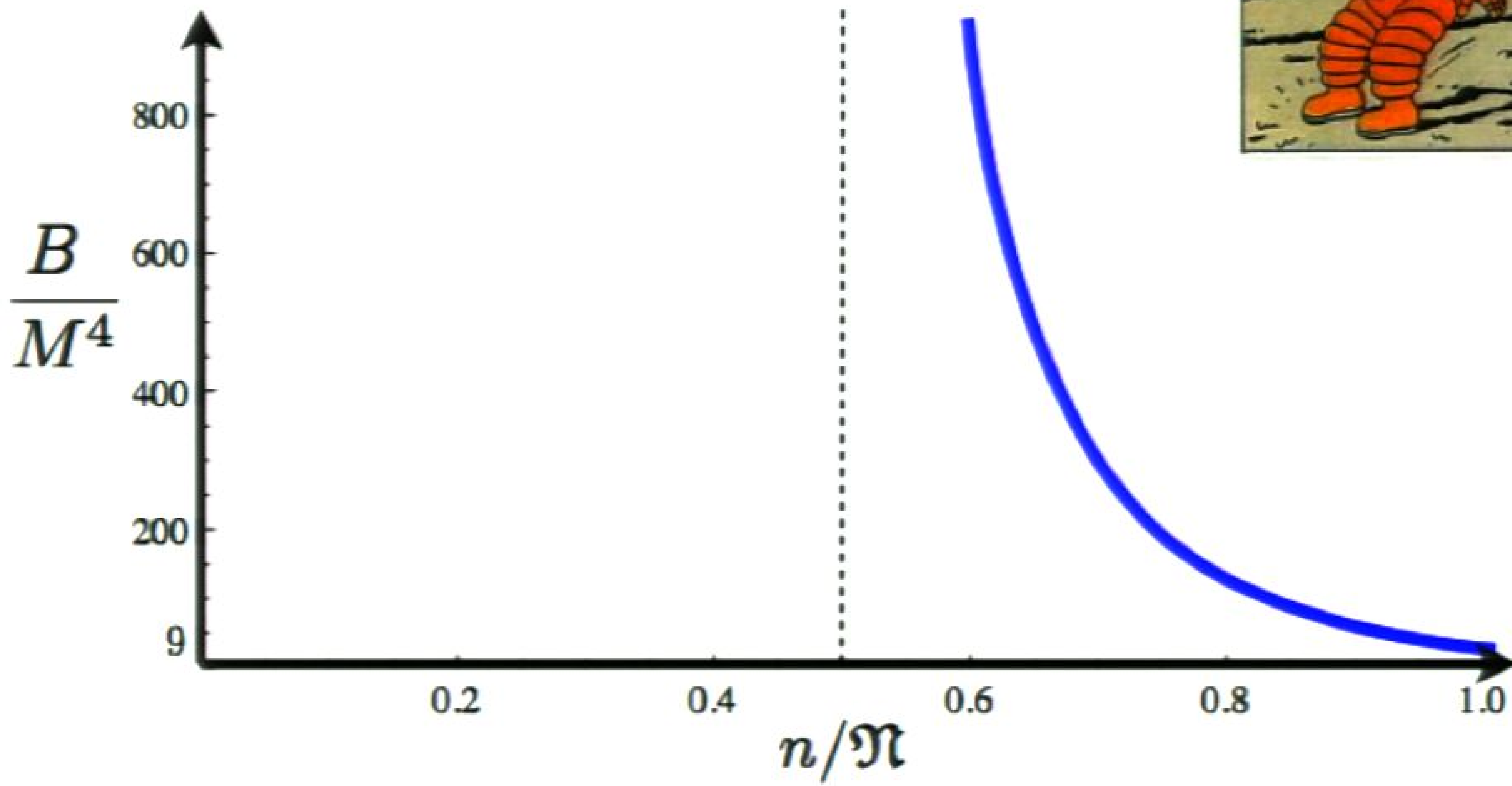


SMALL STEPS WIN

Decay Rates

MULTIFLUX

From V=0

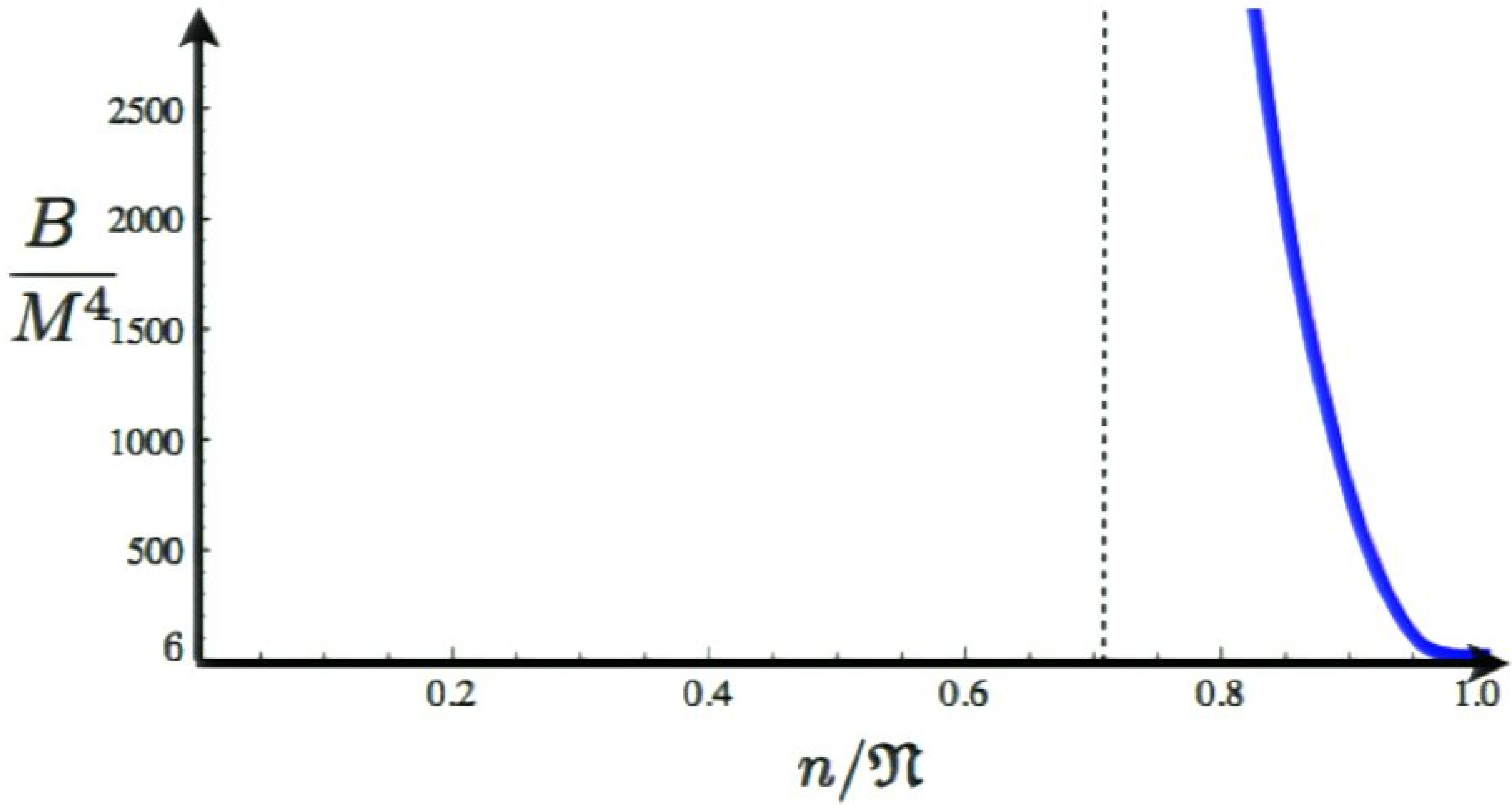


GIANT LEAPS WIN

Decay Rates

MULTIFLUX

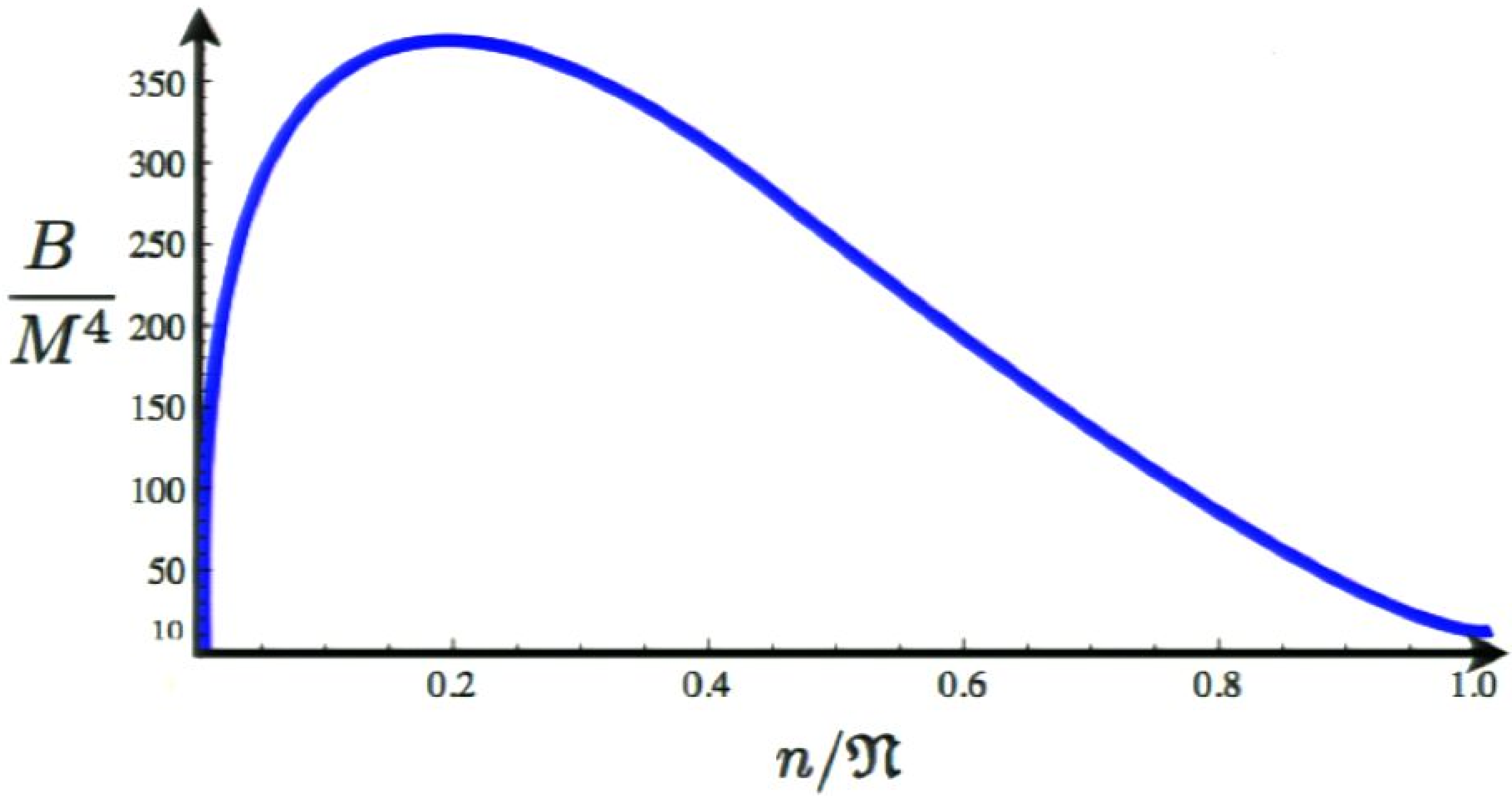
From V<0



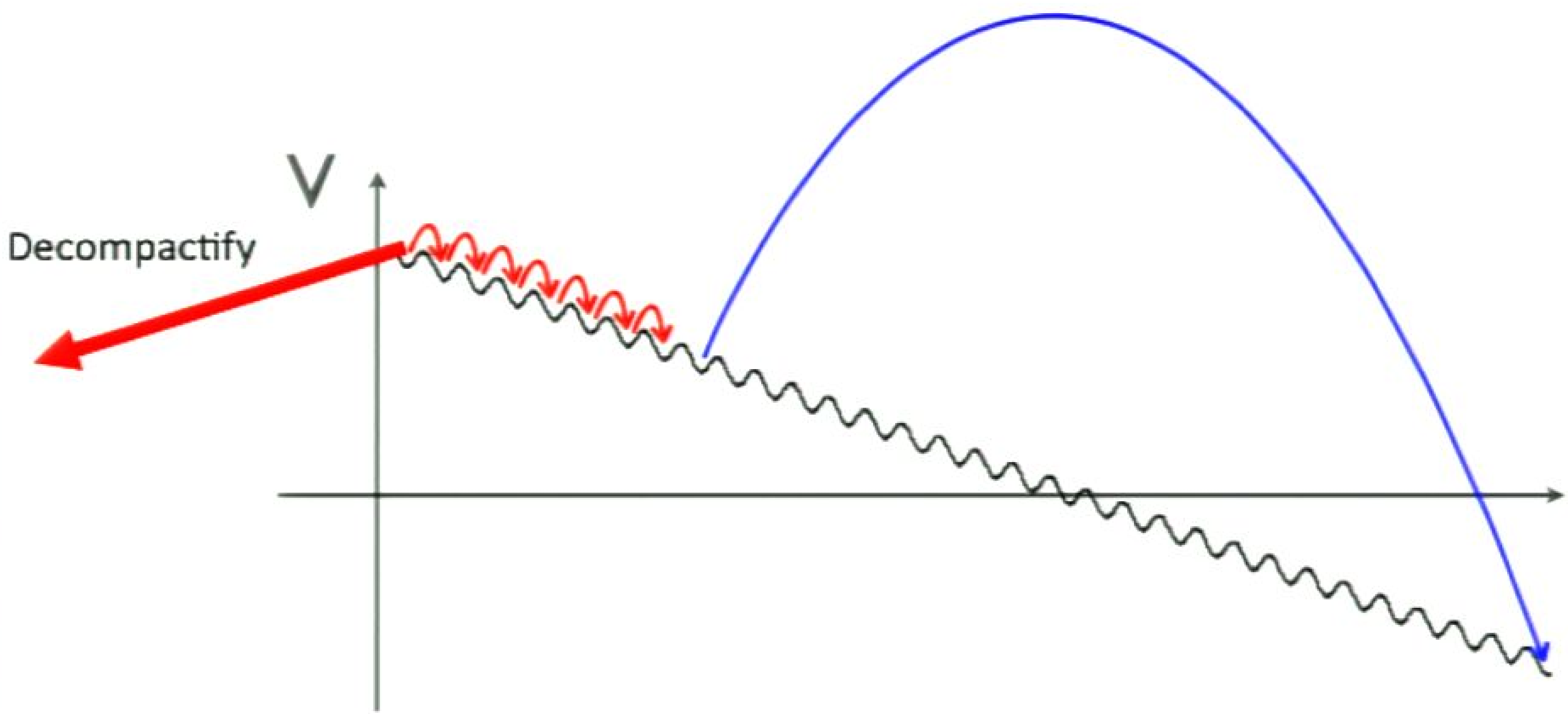
GIANT LEAPS WIN

Decay Rates

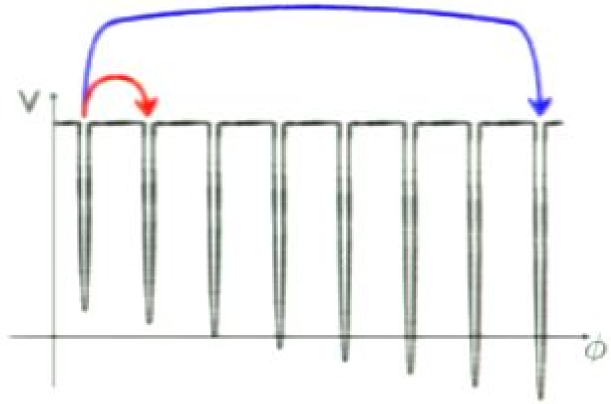
MULTIFLUX   From V>0



GIANT LEAPS MAY WIN


V
Decompactify

This potential gives small steps



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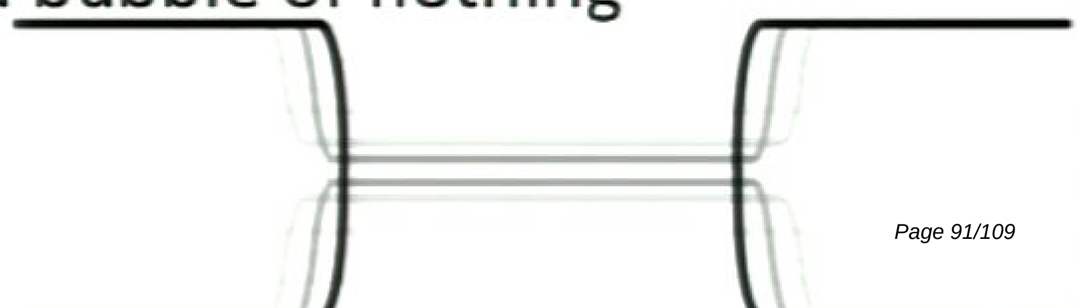
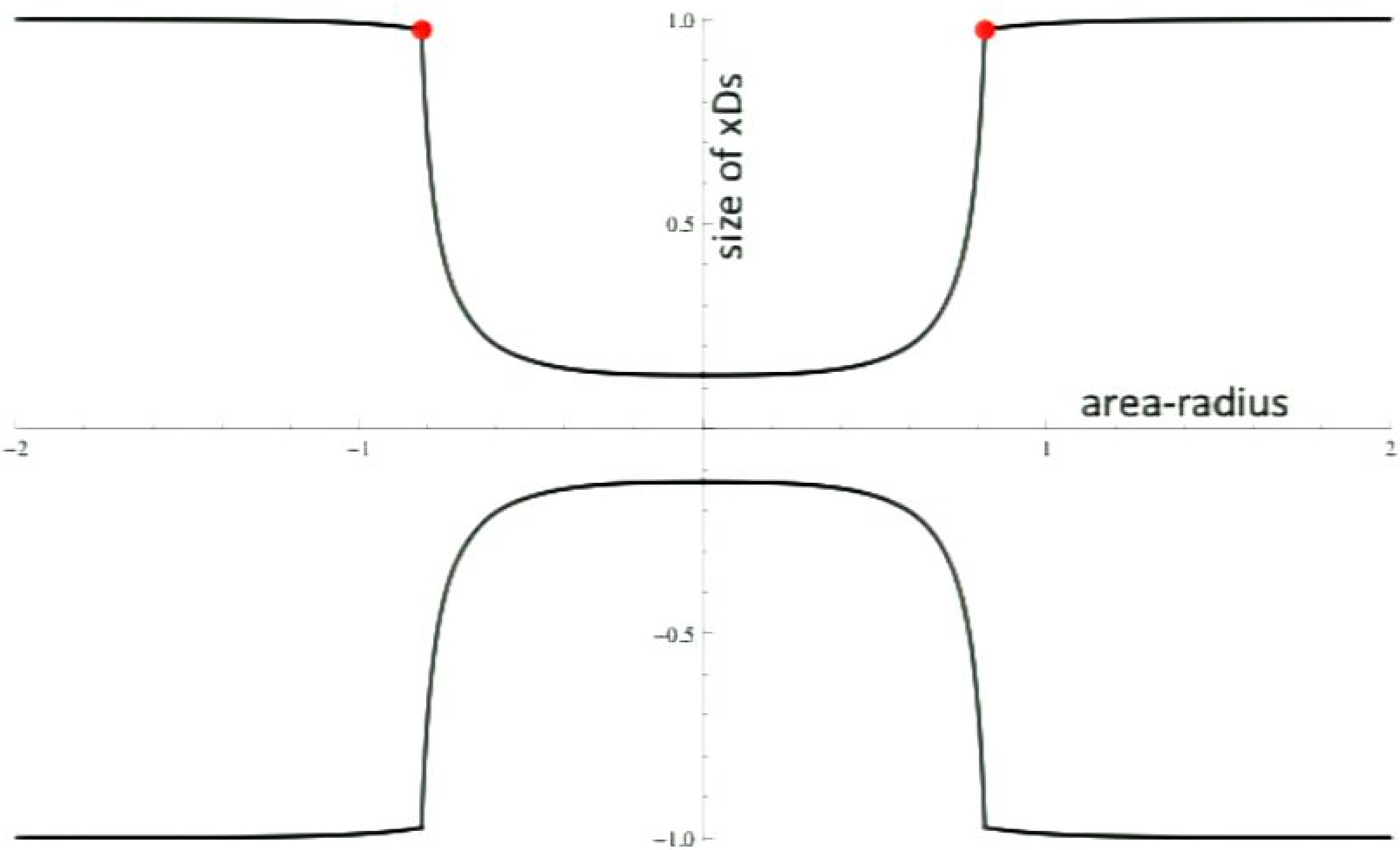
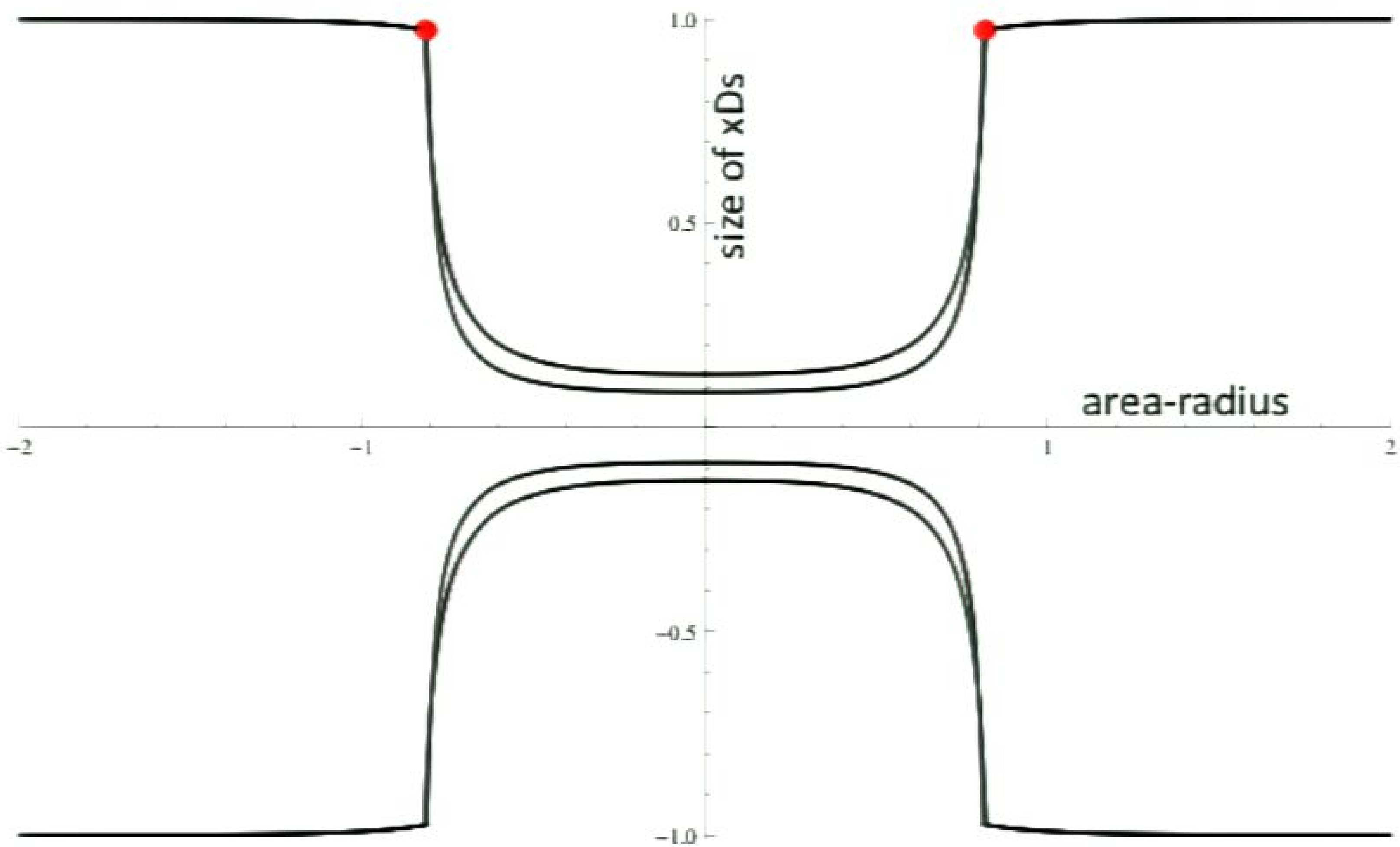



1.0
size of xDs
0.5
area-radius
−2
−1
1
2
−0.5
−1.0



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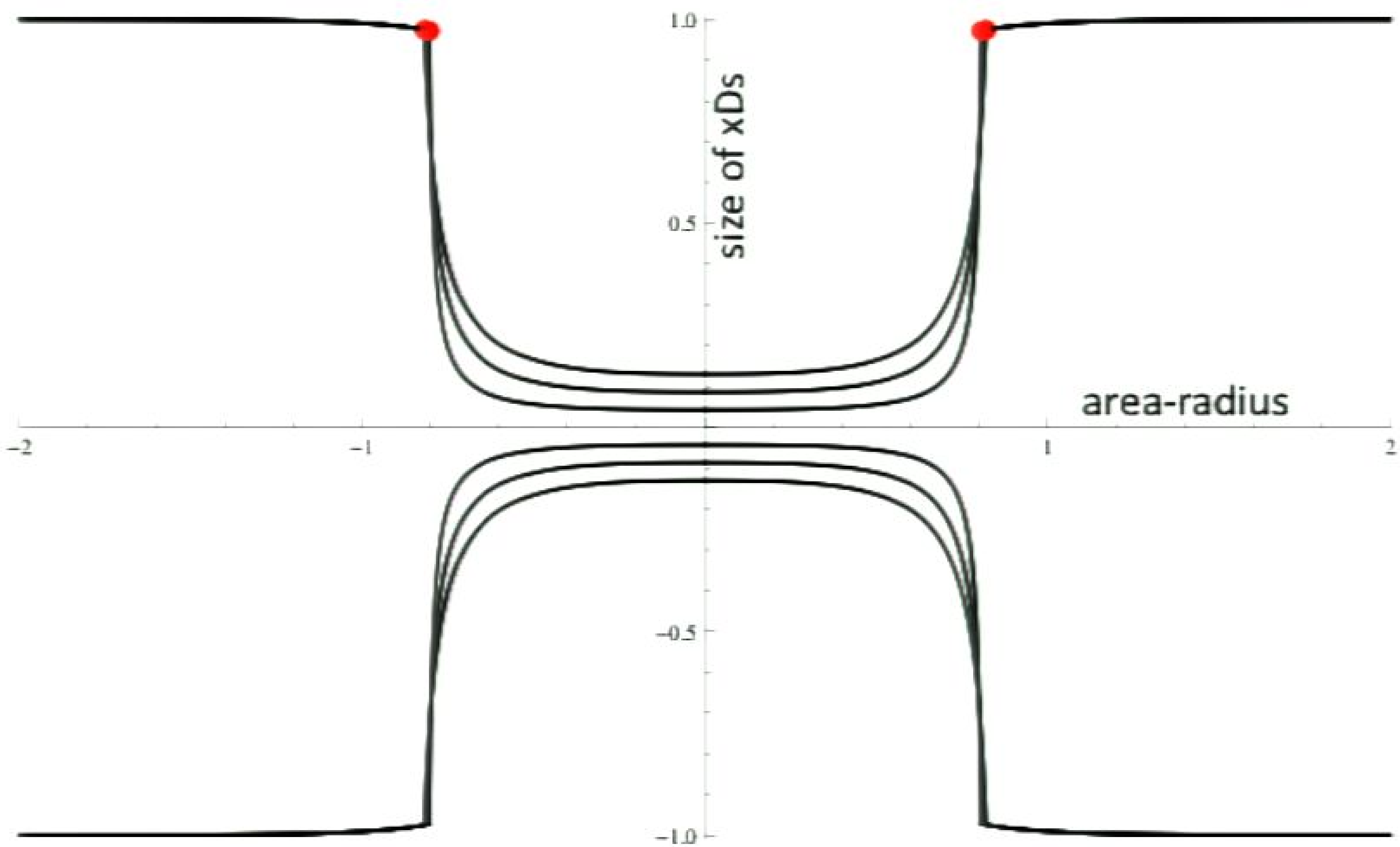

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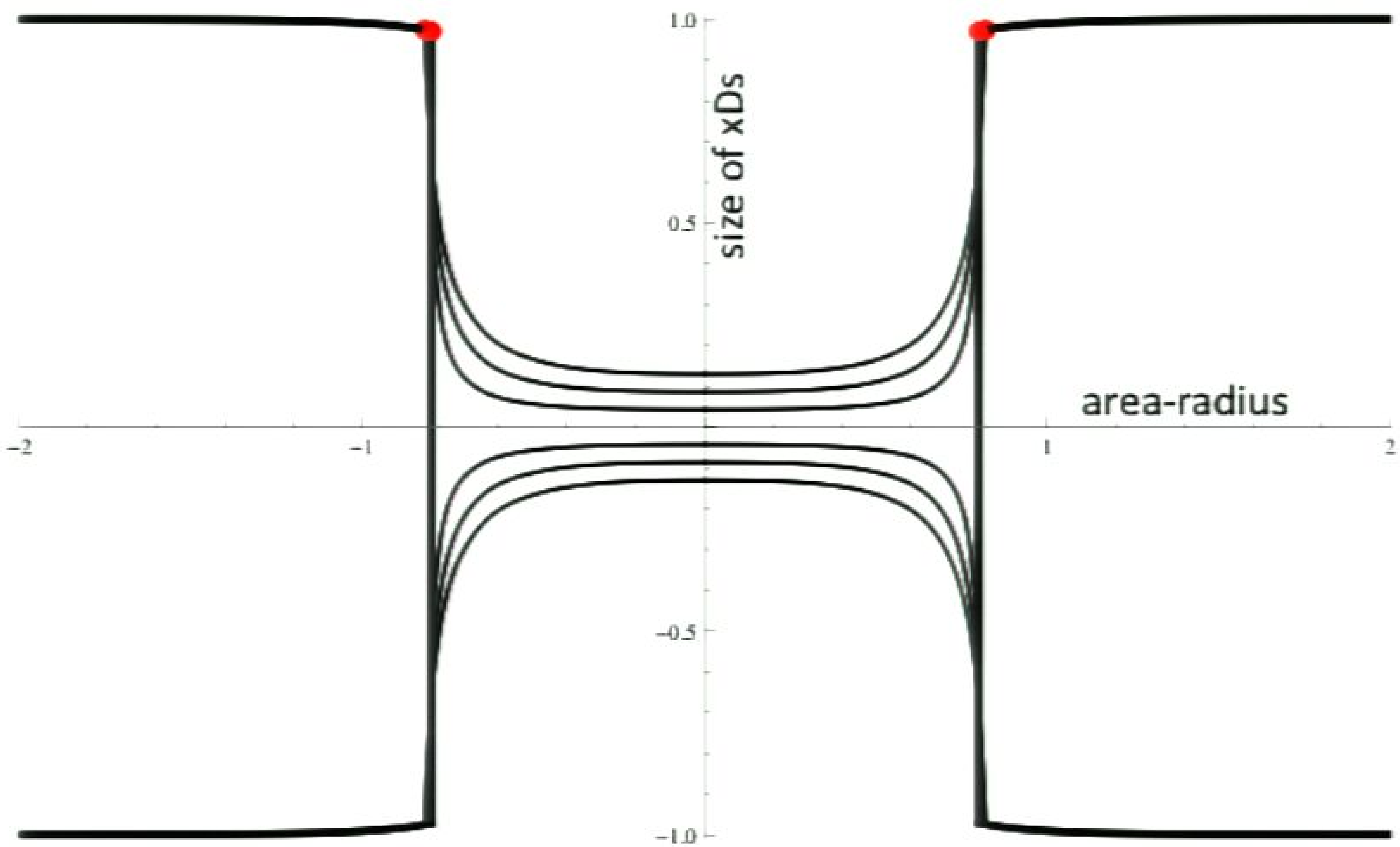
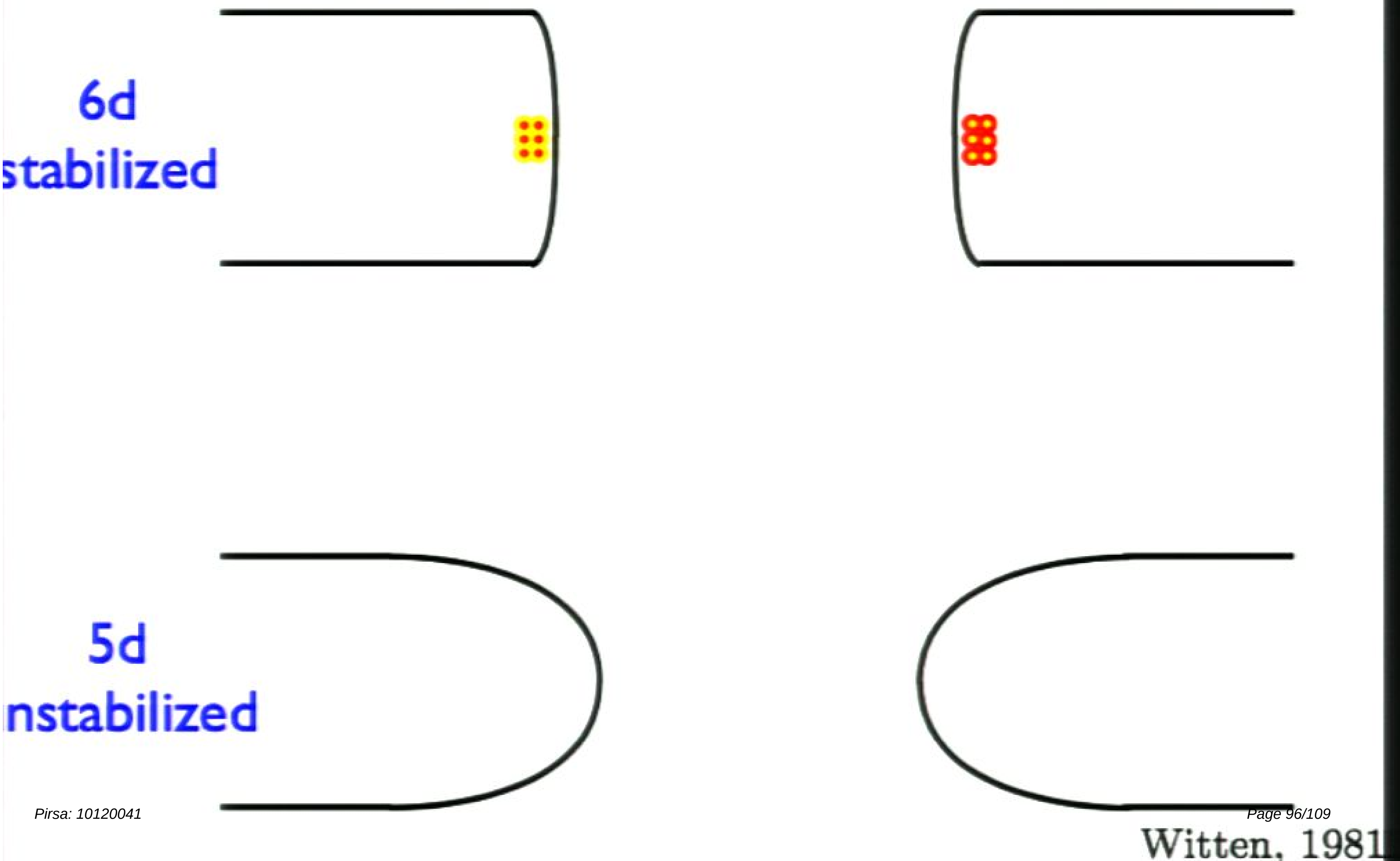
−2
−1
1
2
−0.5
−1.0



1.0
0.5
size of xDs
area-radius
−2
−1
1
2
−0.5
−1.0

ubble of Nothing

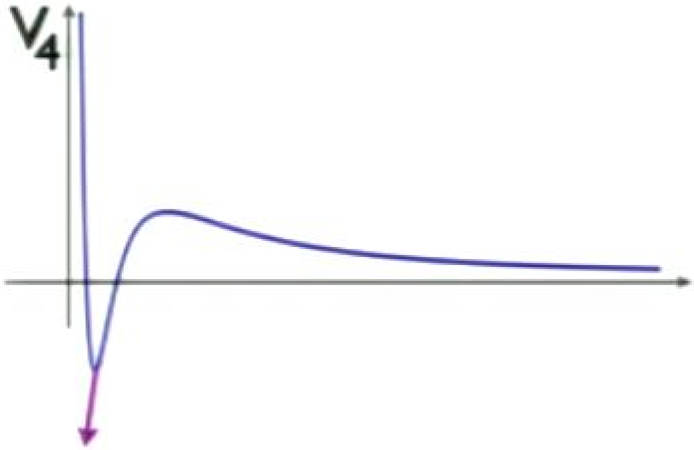


In the limit that ALL flux discharged:

I. Extra dimensions shrink to zero size

II. What about the 3-volume of a slice through the bubble?

like an infinitely thin pancake?



negative V

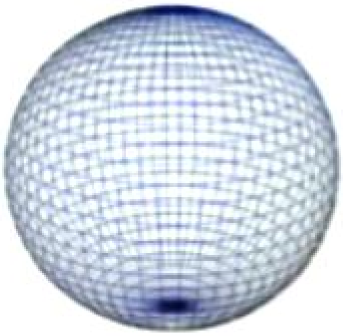
↓

negative curvature

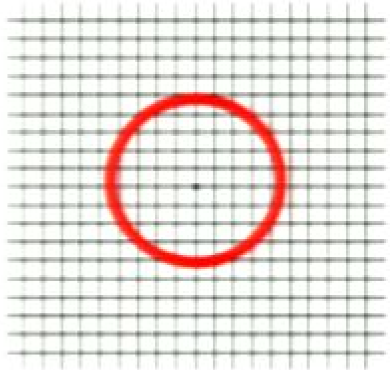
(AdS)

11. What about the 3-volume of a slice through the bubble?

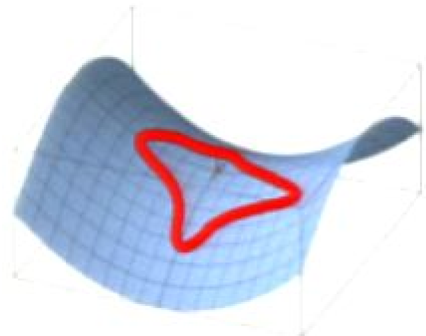
like an infinitely thin pancake?



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

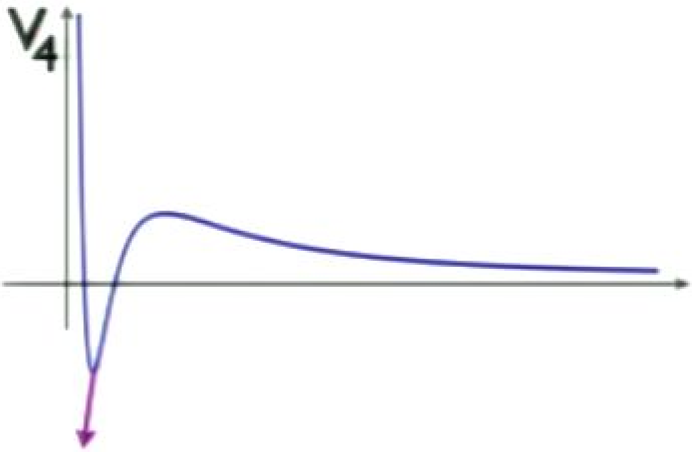


$\text{Area} = \pi r^2$



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

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



negative V

↓

negative curvature

(AdS)

II. What about the 3-volume of a slice through the bubble?

like an infinitely thin pancake?

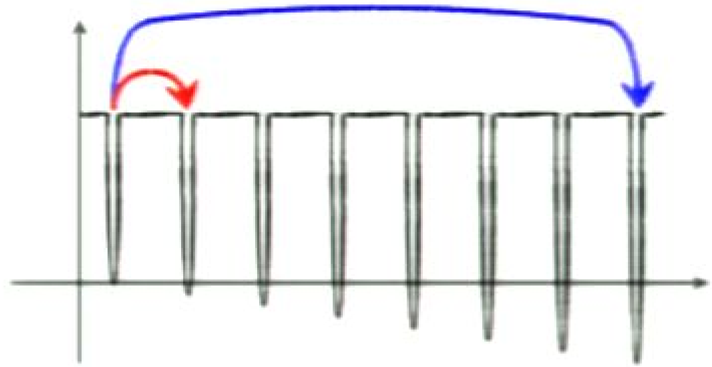
$$\text{Volume} \sim \text{Area} \times l_{curv}$$

$$l_{\mathrm{curv}} \to 0$$

11. What about the 3-volume of a slice through the bubble?

like an infinitely thin pancake?

This potential gives small steps



Flux compactifications with many fluxes give giant leaps
Monkey branes

Back-reaction on the compactification

The giantest leap of all is a bubble of nothing

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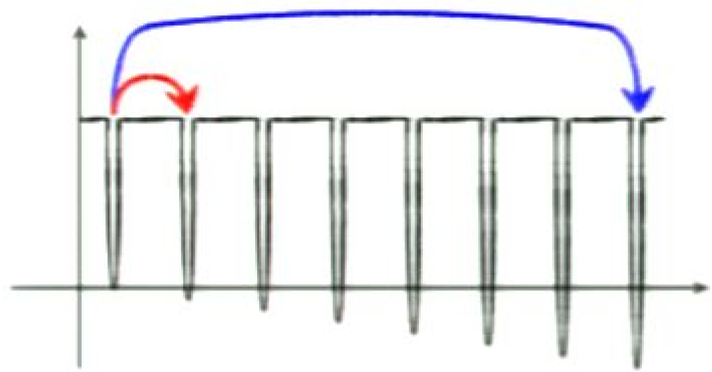

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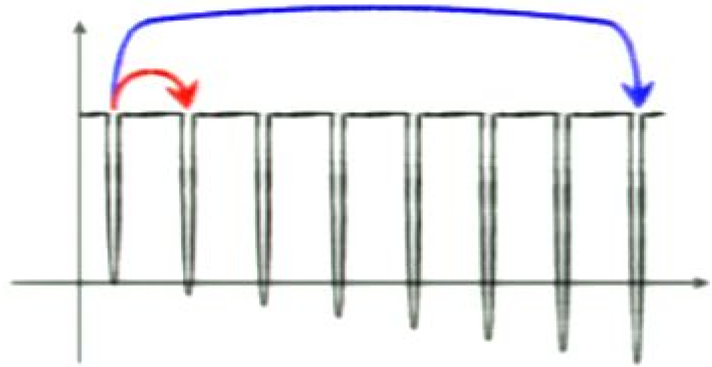


Flux compactifications with many fluxes give giant leaps

Monkey branes

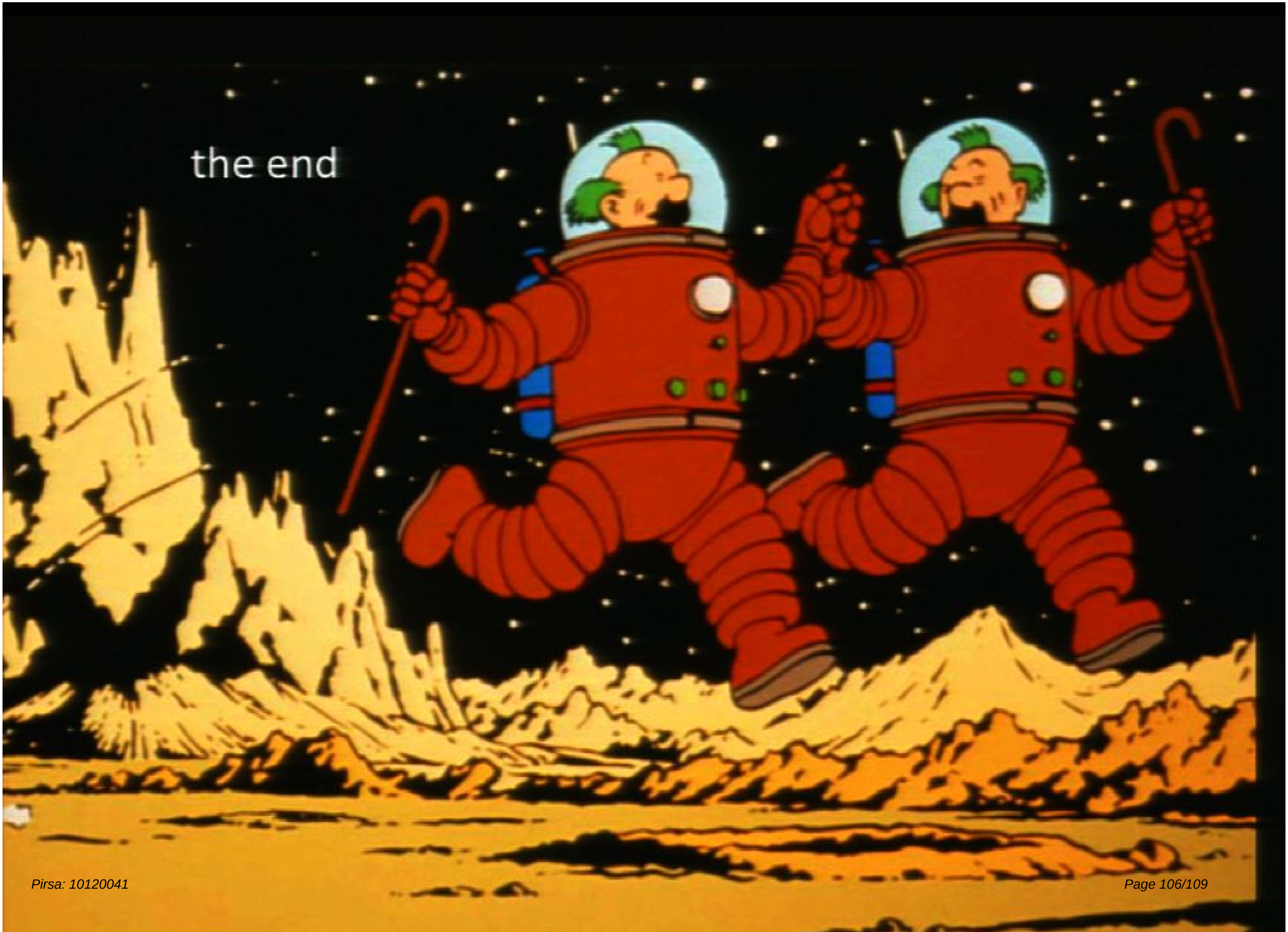
Back-reaction on the compactification

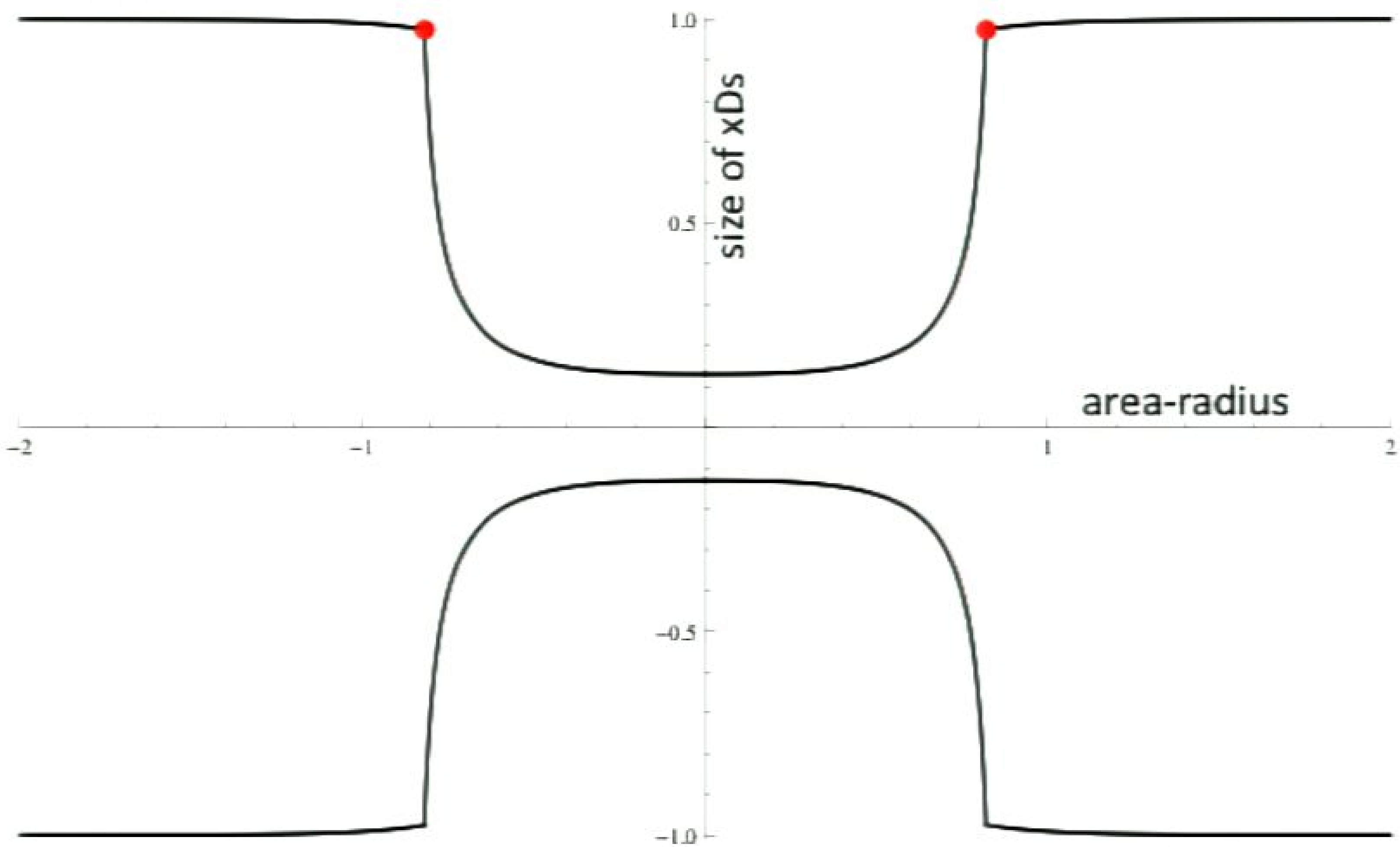
The giantest leap of all is a bubble of nothing

Summary

- Giant leaps beat small steps in landscapes
- The bubble of nothing can be the fastest decay
- It is realized smoothly as the limit of flux tunneling
- When the many fluxes come from higher dimensional model, still expect enhancement. Richer behavior.

- If we live in a multiflux landscape, then we draw two conclusions. We got here by an exponentially subdominant decay, and we will leave here by a bubble of nothing.


the end

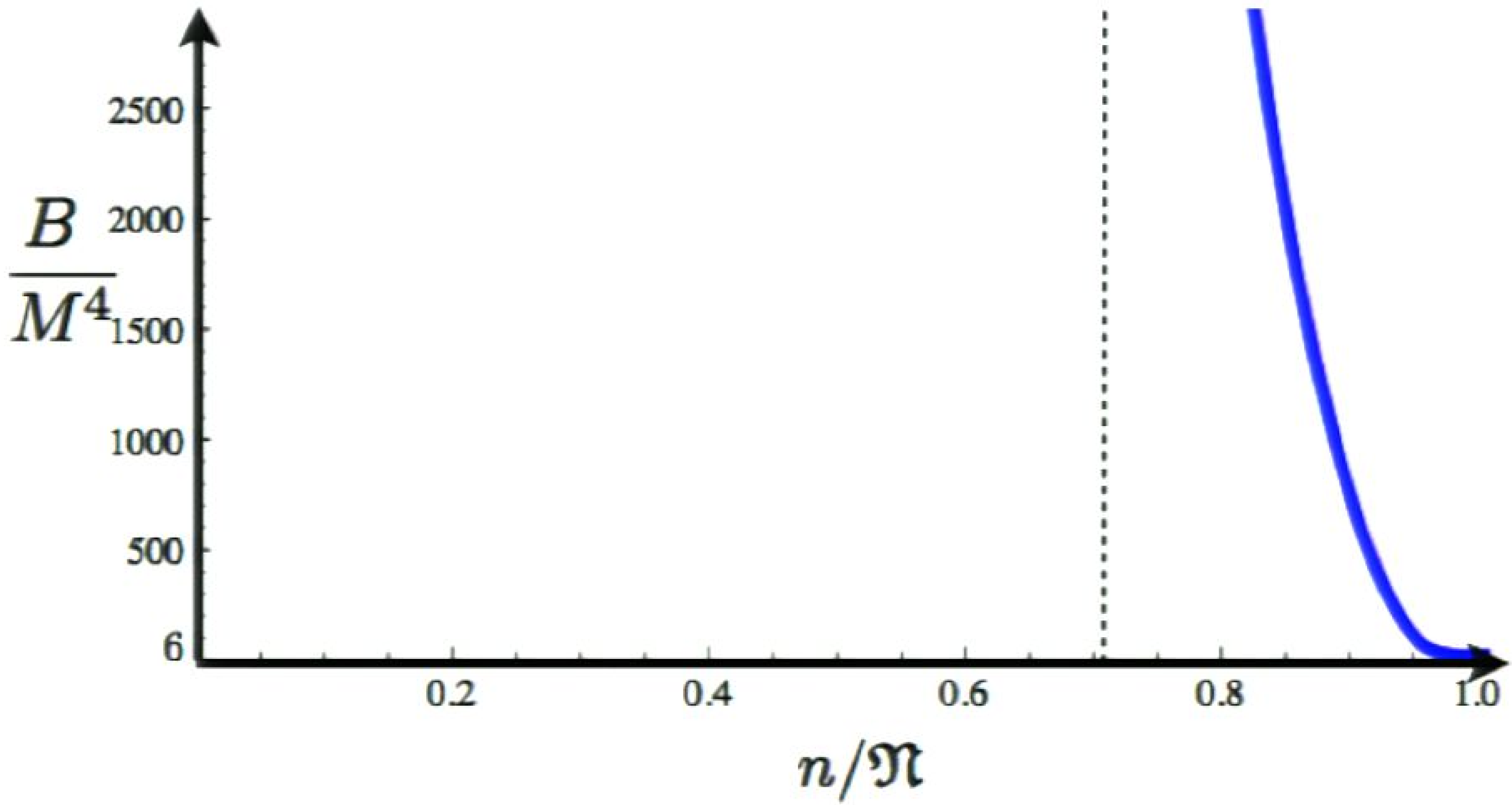


1.0
0.5
size of xDs
area-radius
−2
−1
1
2
−0.5
−1.0

Decay Rates

MULTIFLUX

From V<0



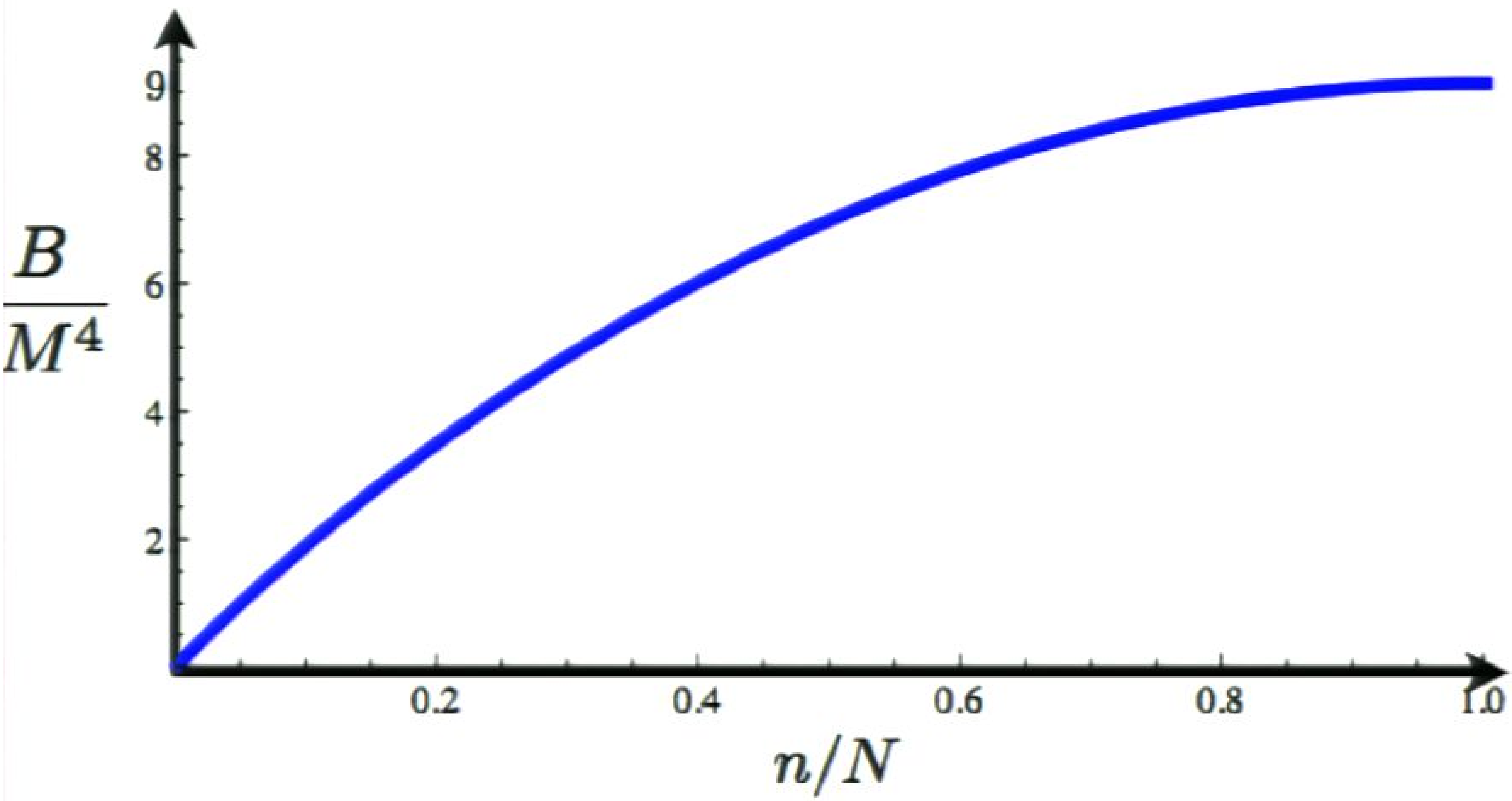
GIANT LEAPS WIN

$$\Gamma \sim e^{-B/\hbar}, \qquad B = S_E(\text{instanton}) - S_E(\text{false vacuum})$$

Decay Rates

MONOFLUX

From V=0



SMALL STEPS WIN