# *Decay of False Vacua via Impurities in String Theories*

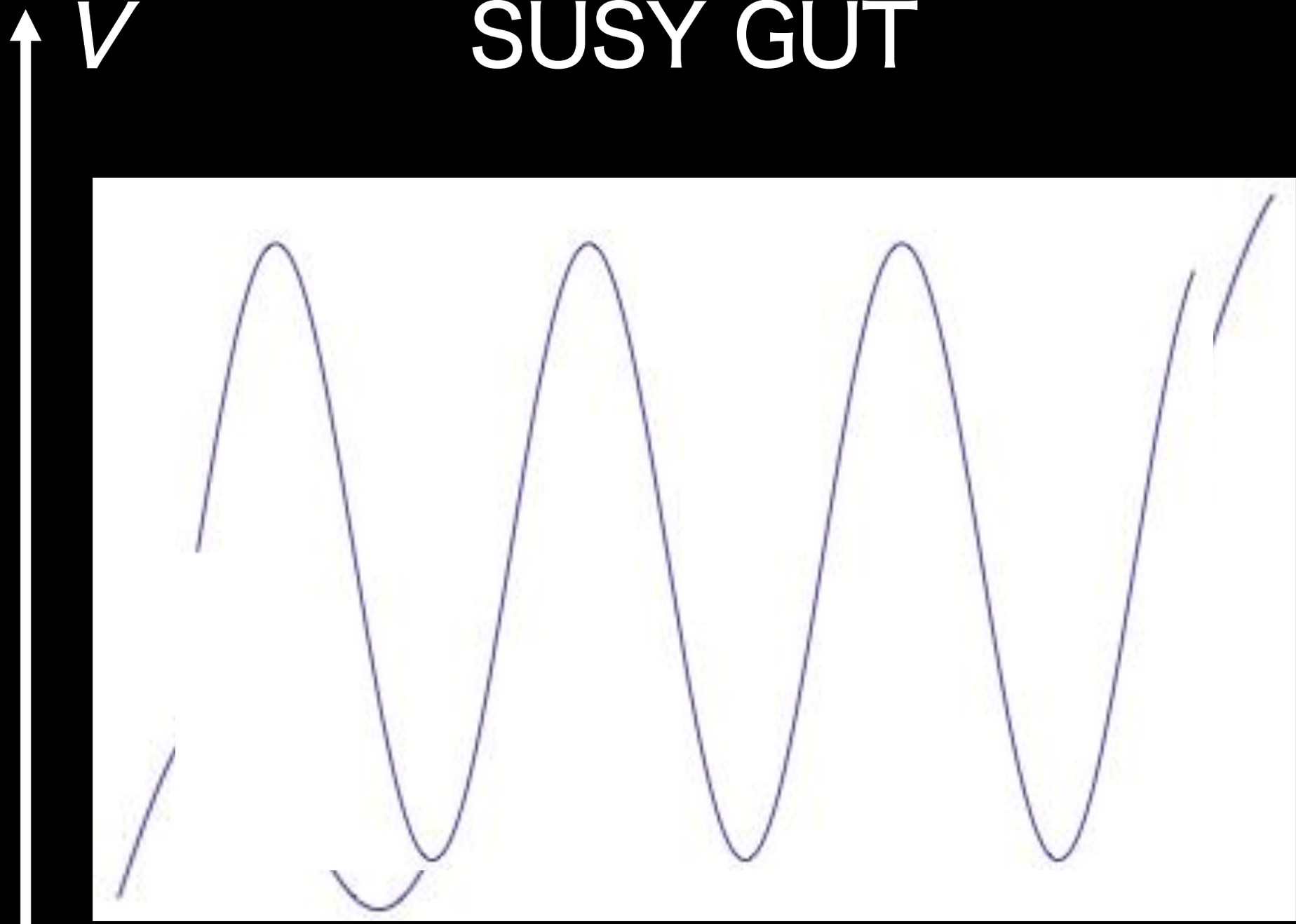
*Yutaka Ookouchi (Kyushu U.)*

*Y. Nakai, YO, N. Tanahashi '18*

*T. Hiramatsu, M. Eto, K. Kamada, T. Kobayashi, YO, '14*

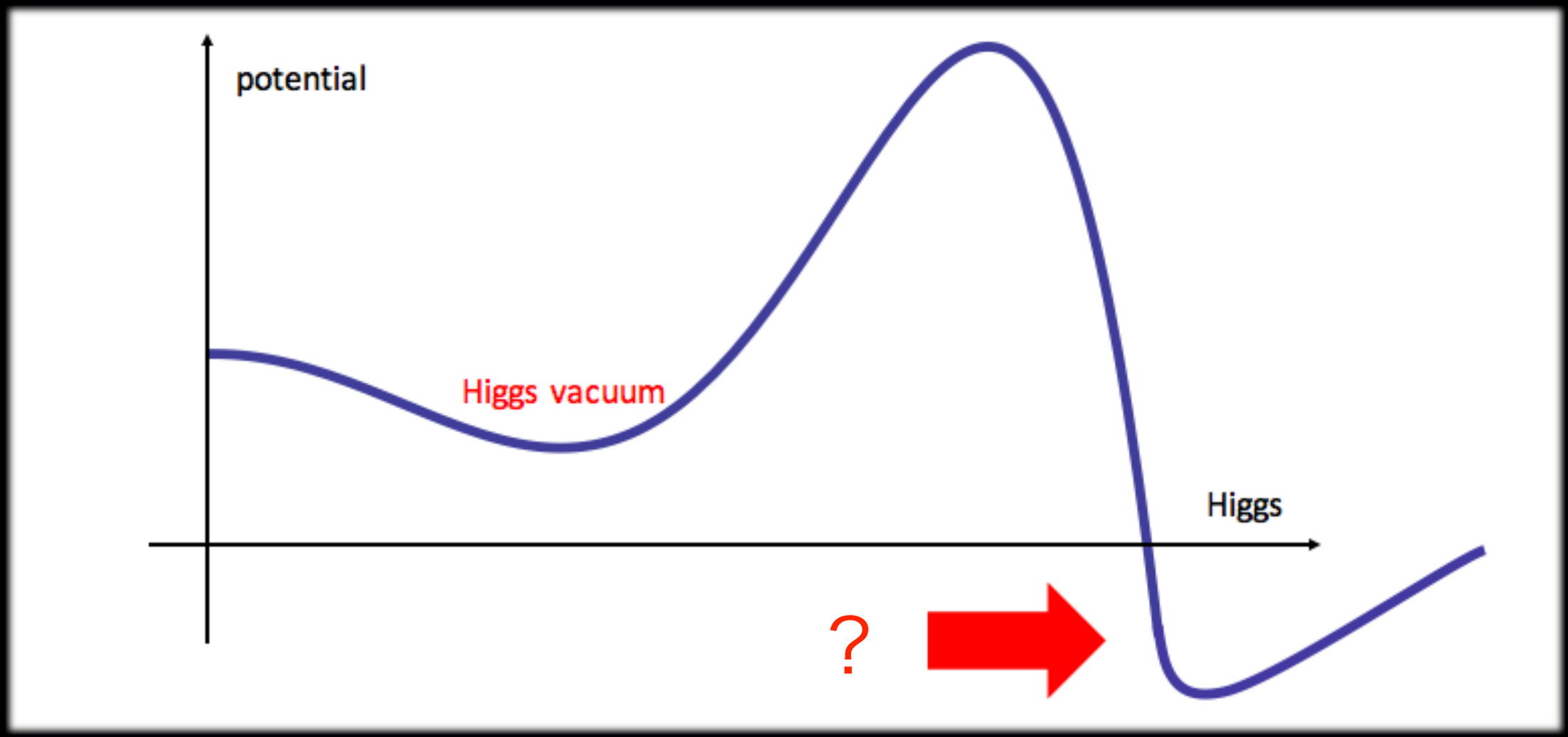
*M. Eto, Y. Hamada, K. Kamada, T. Kobayashi, K. Ohashi, YO, '13*

# SUSY GUT




$SU(3) \times SU(2) \times U(1)$ $SU(4) \times U(1)$

# Higgs Vacuum



# Field theory analysis

Original Idea:

P. J. Steinhardt,`81 and Y. Hosotani `83

# Simple Toy model

Eto, Hamada, Kamada, Kobayashi, Ohashi, YO, '13

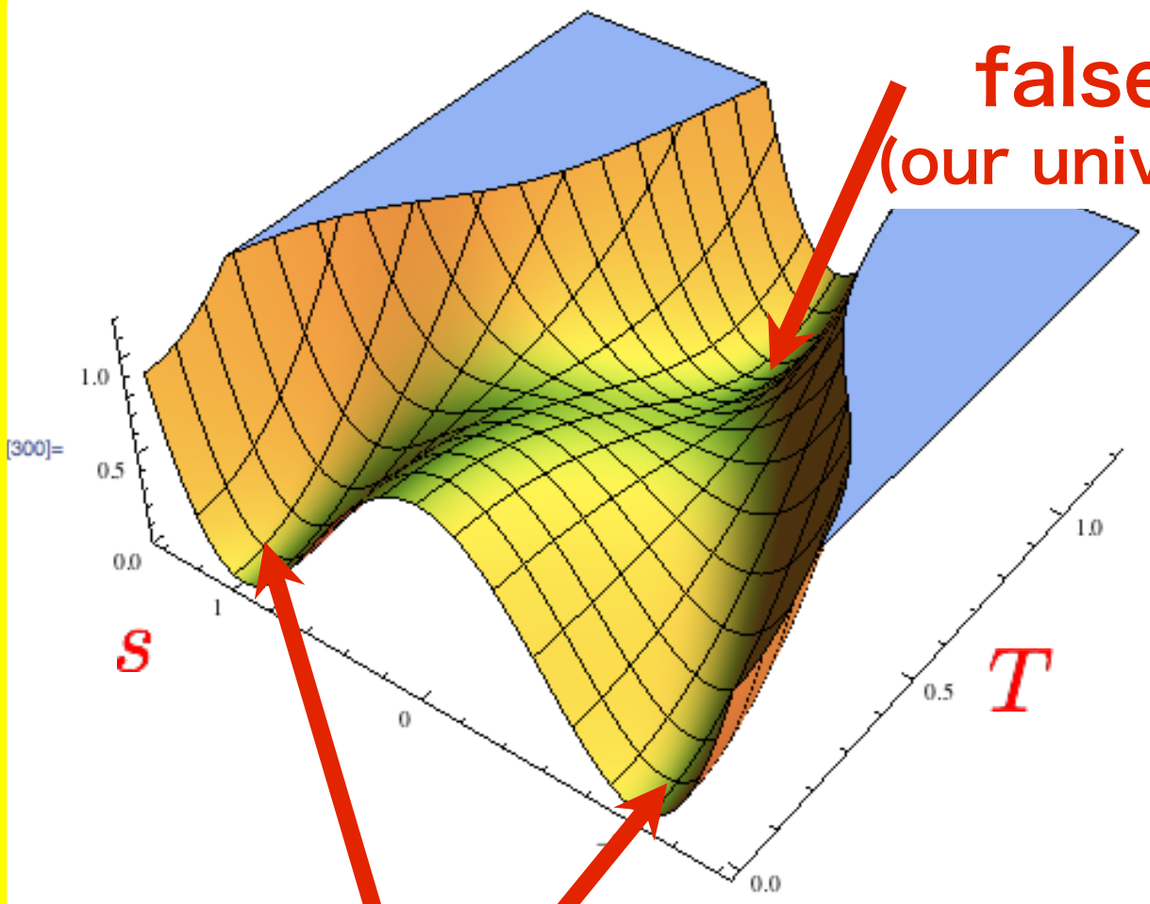
$$\mathcal{L} = \mu^4 \left[ \frac{1}{\mathcal{V}(T)} \left| \tilde{\partial}_\mu T \right|^2 + \epsilon^2 \left| \tilde{\partial}_\mu s \right|^2 - \mathcal{V}(T) |s^2 - 1|^2 - \frac{4}{\epsilon^2} |T|^2 |s|^2 \right] .$$

mass dim

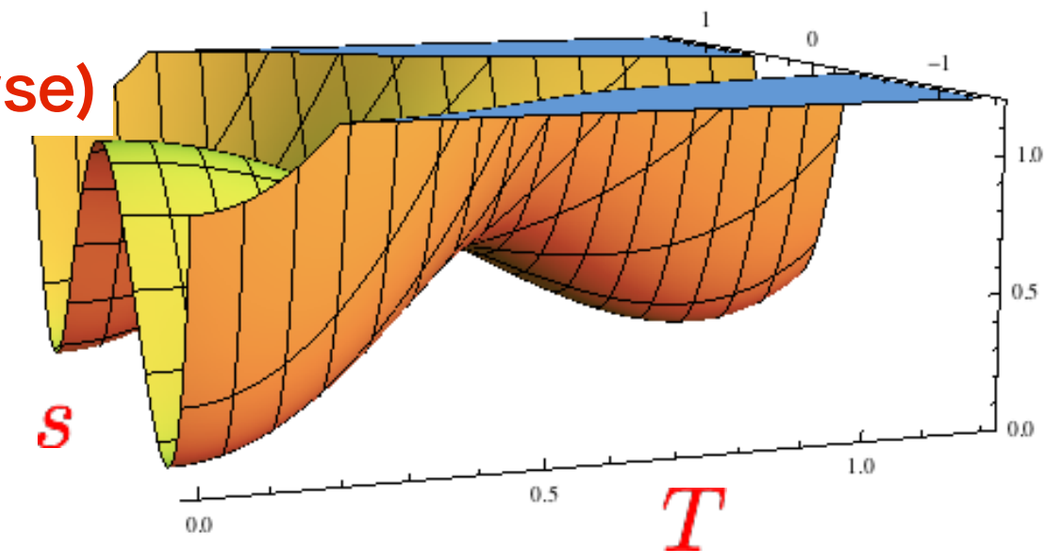
$$\mathcal{V}(T) \equiv 1 - \frac{|T|^2}{2\lambda} + \frac{|T|^4}{4\lambda}.$$

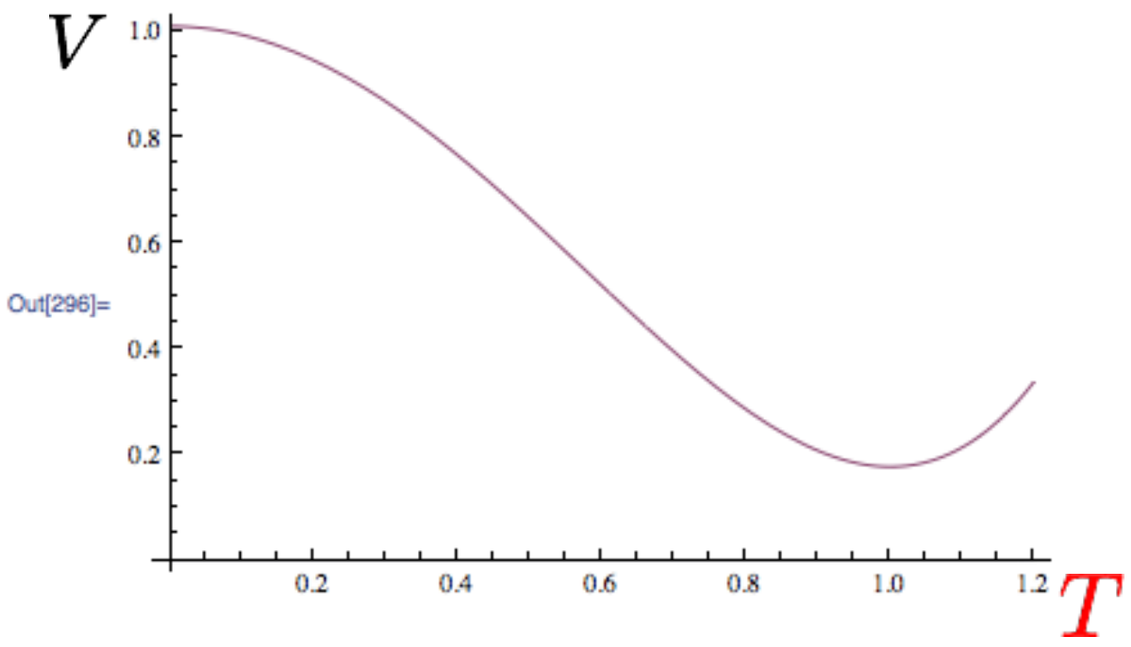
- 2 dim-less fields $T,\ s$
- 2 dim-less parameters $\lambda,\ \epsilon$

# Landscape of vacua




$\epsilon = 1,\ \lambda = 3/10$



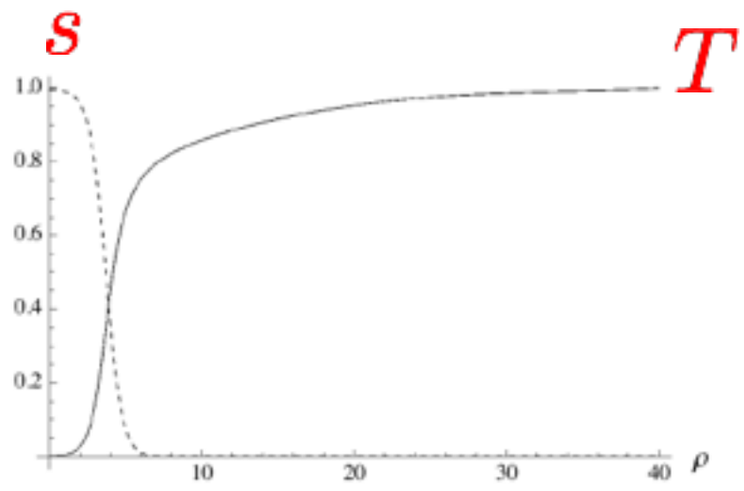
# Cosmic R-string (R-tube) solution

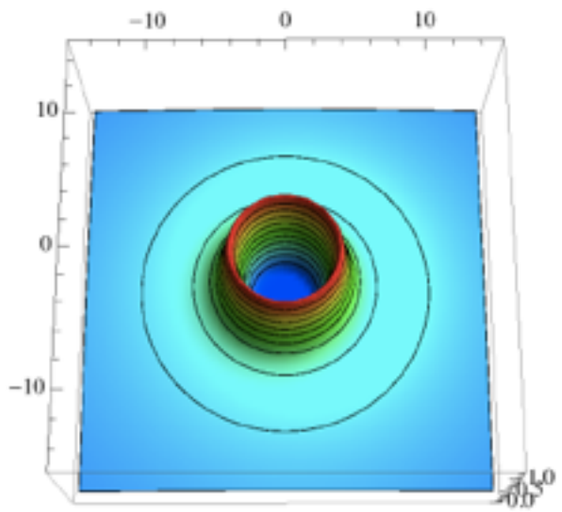
$$T = f(\rho)e^{in\theta}, \quad s = \gamma\, h(\rho),$$

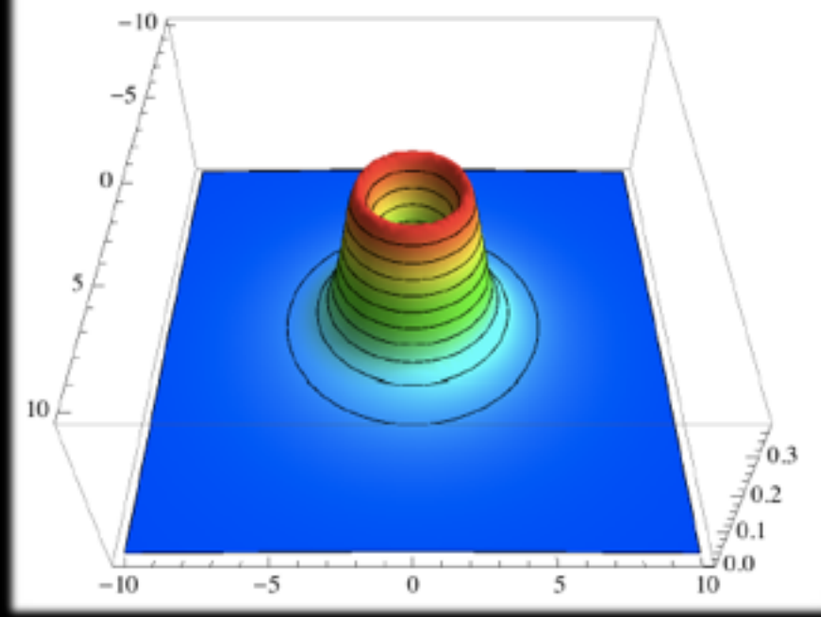
winding number

two vacua

$$\epsilon = 1, \quad \lambda = 27/100$$



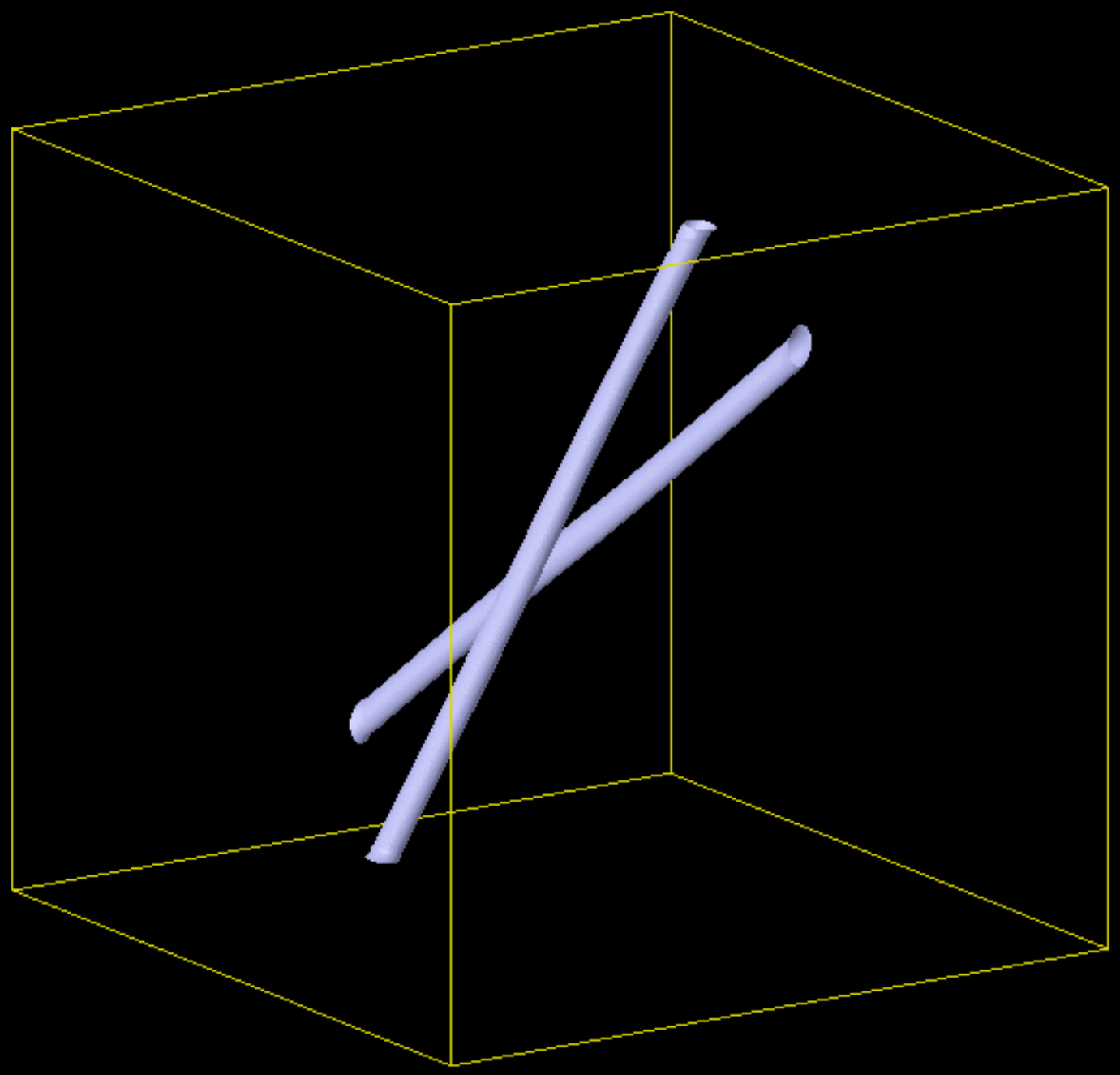



# String collision

# Numerical simulation

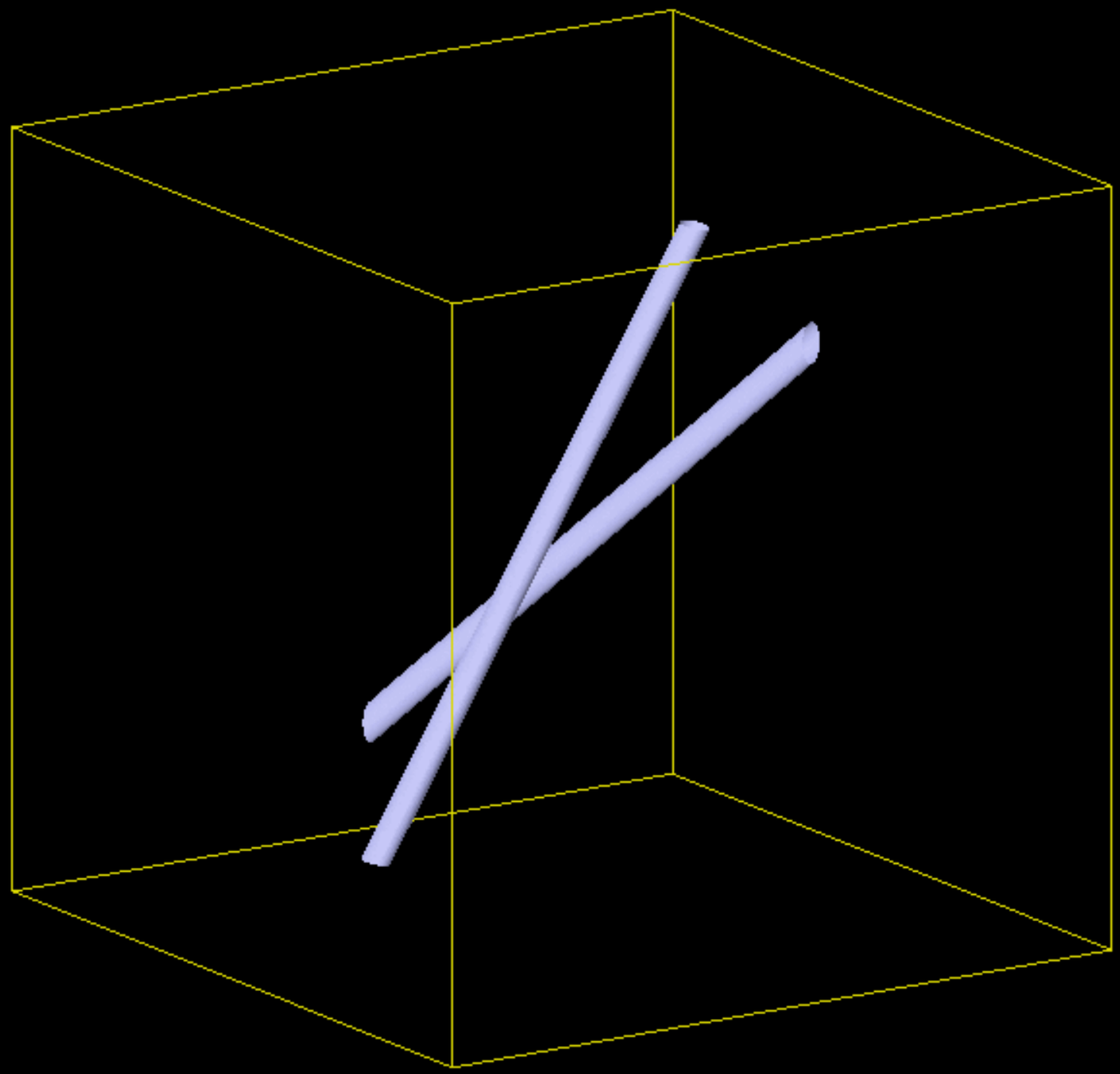
# String(n=1)/String(n=1) collision
# 60% speed of light

Hiramatsu, Eto, Kamada, Kobayashi, YO, '14

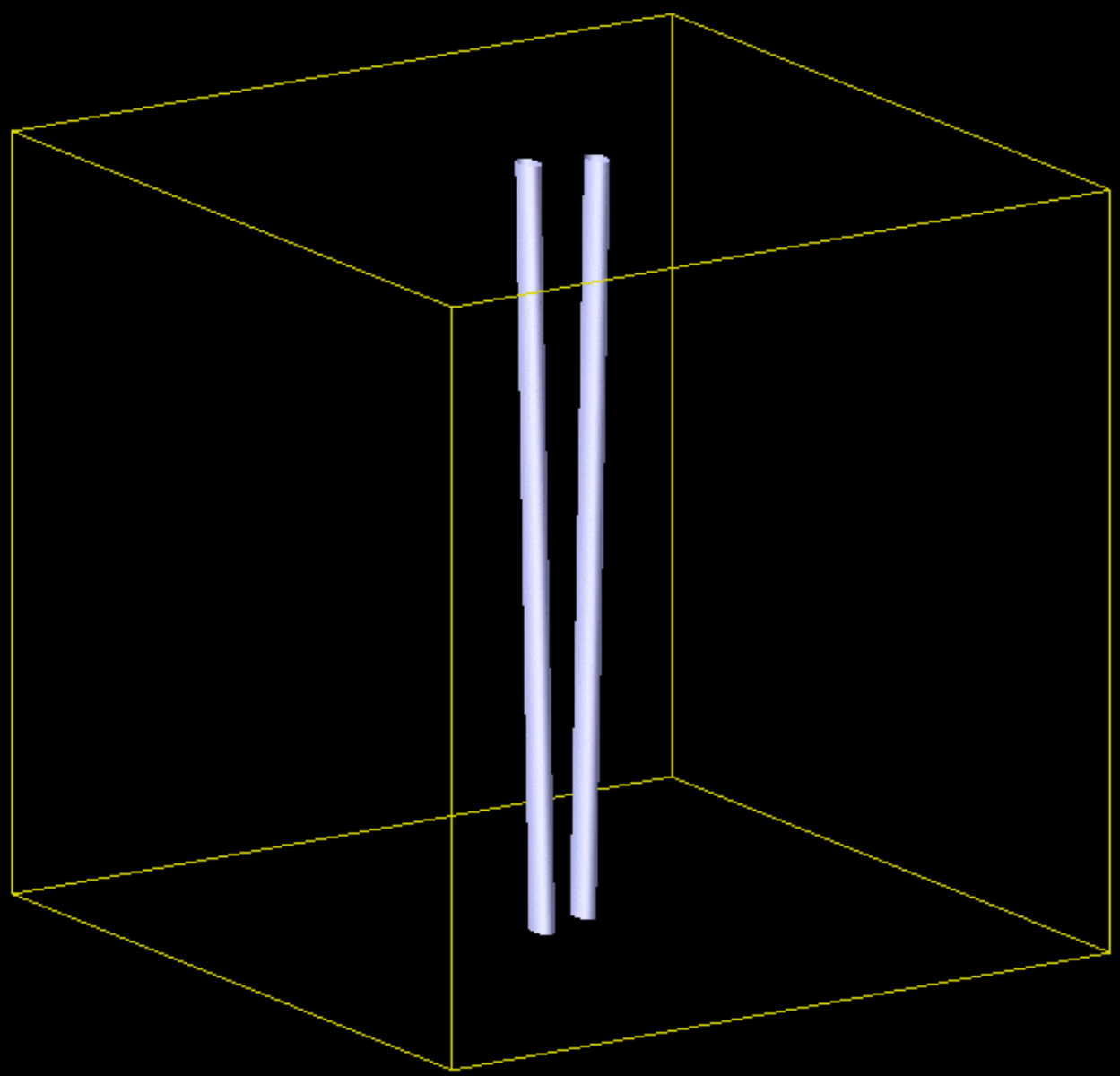


# String(n=1)/String(n=1) collision
# 80% speed of light, large angle

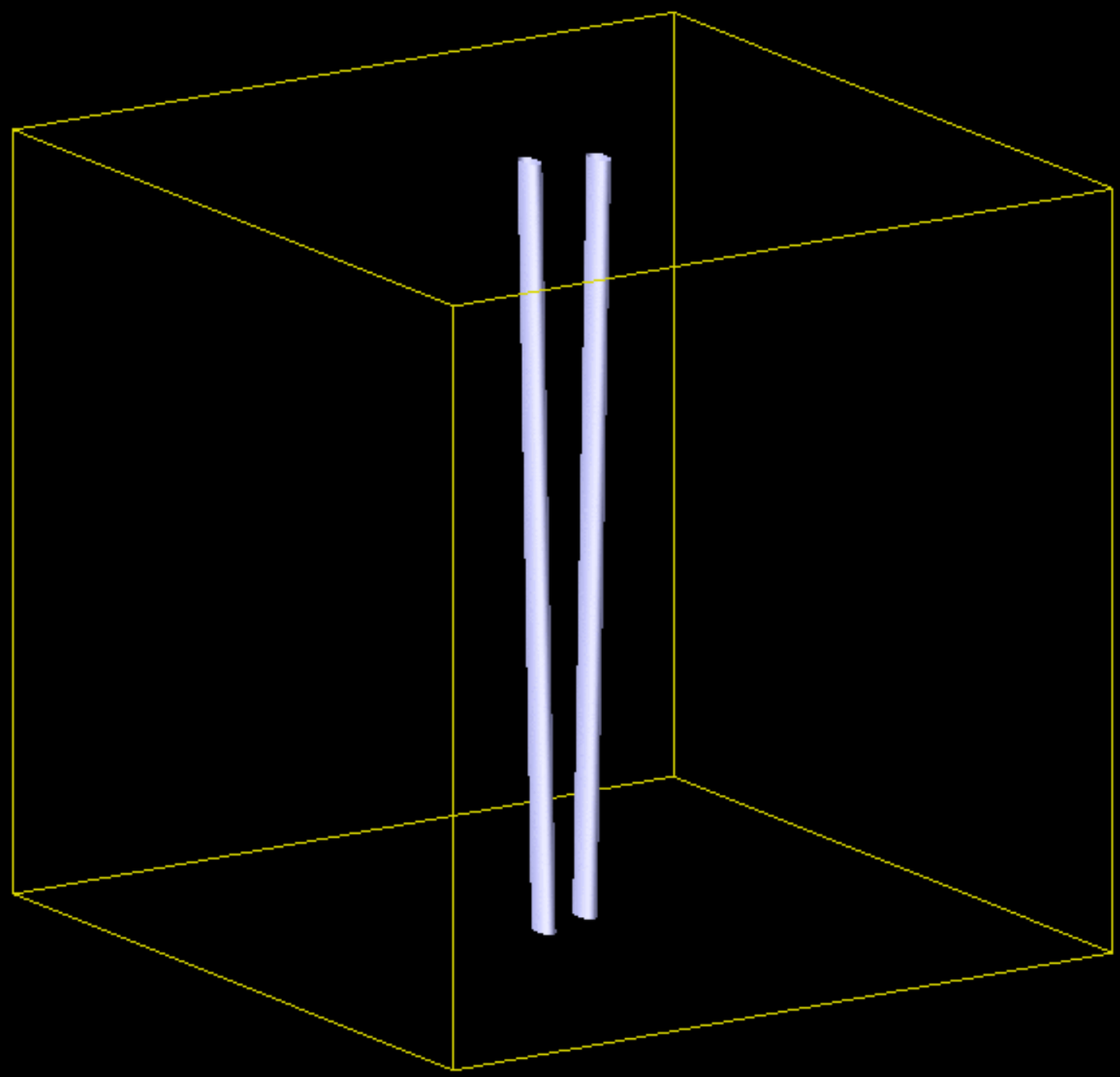
Hiramatsu, Eto, Kamada, Kobayashi, YO, '14



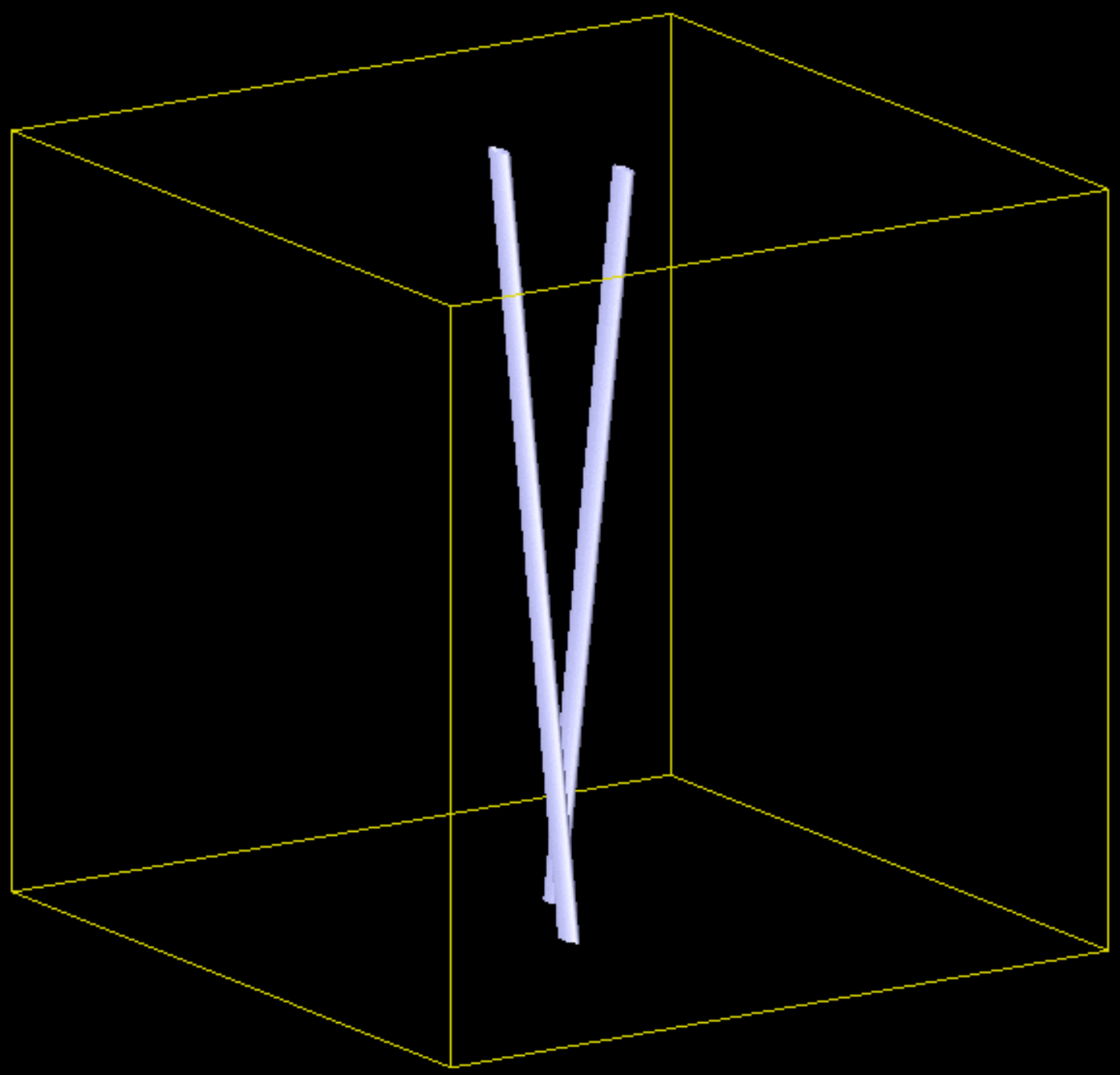
String(n=1) / String(n=1) collision
80% speed of light, small angle



# String(n=1)/String(n=1) collision
# 86% speed of light

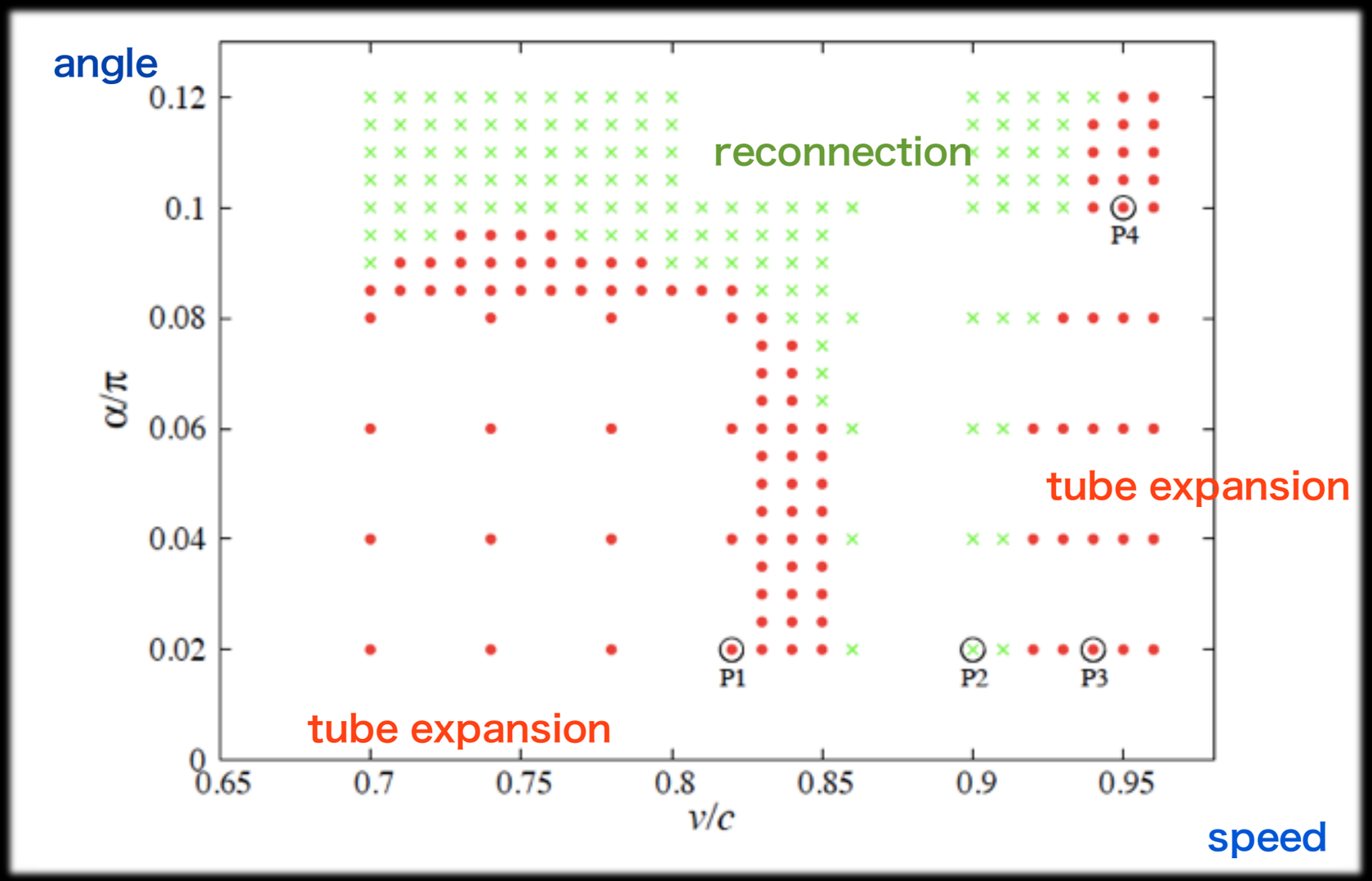


# String(n=1) / String(n=1) collision
# 94% speed of light

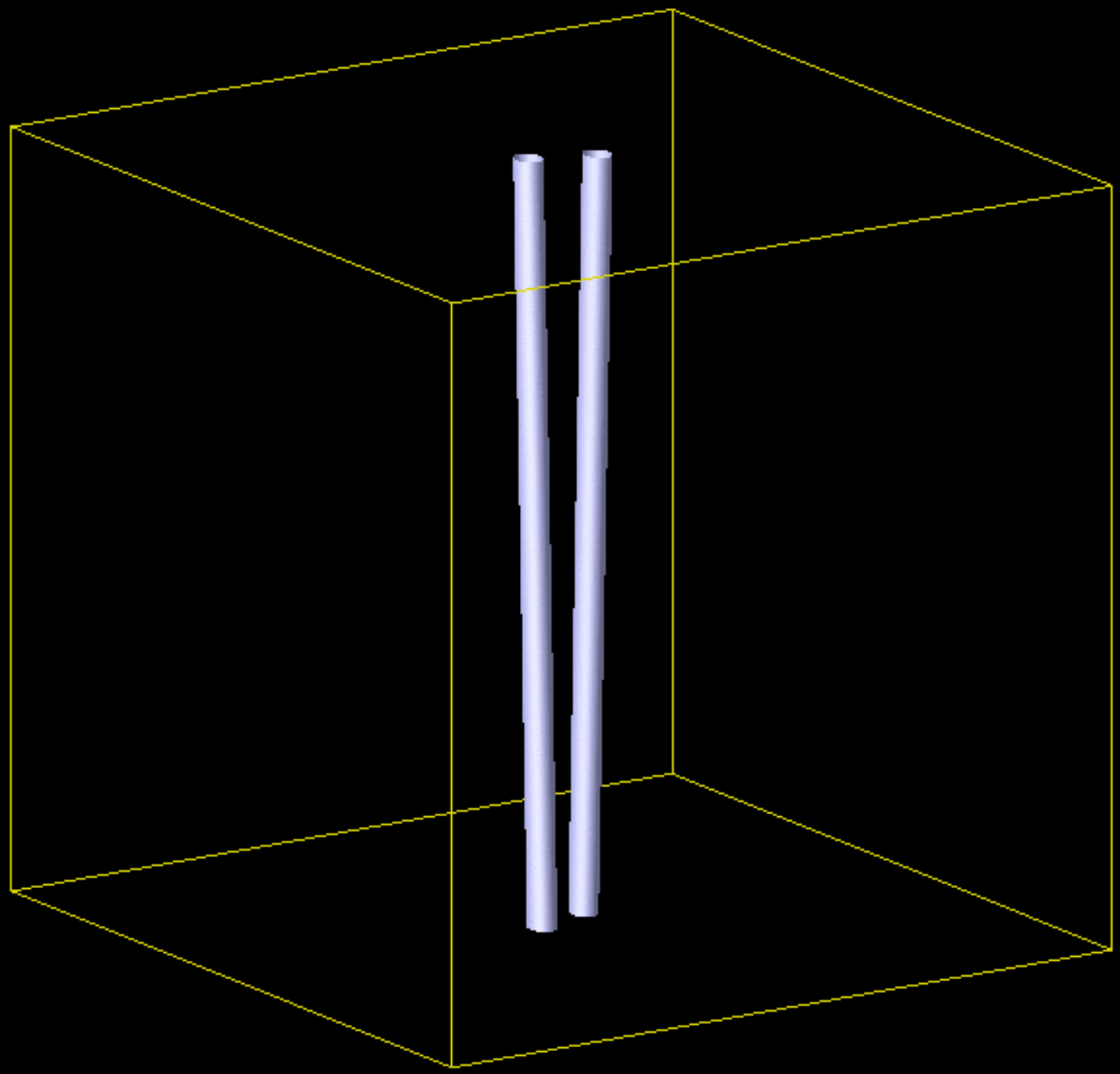


# String/String collision

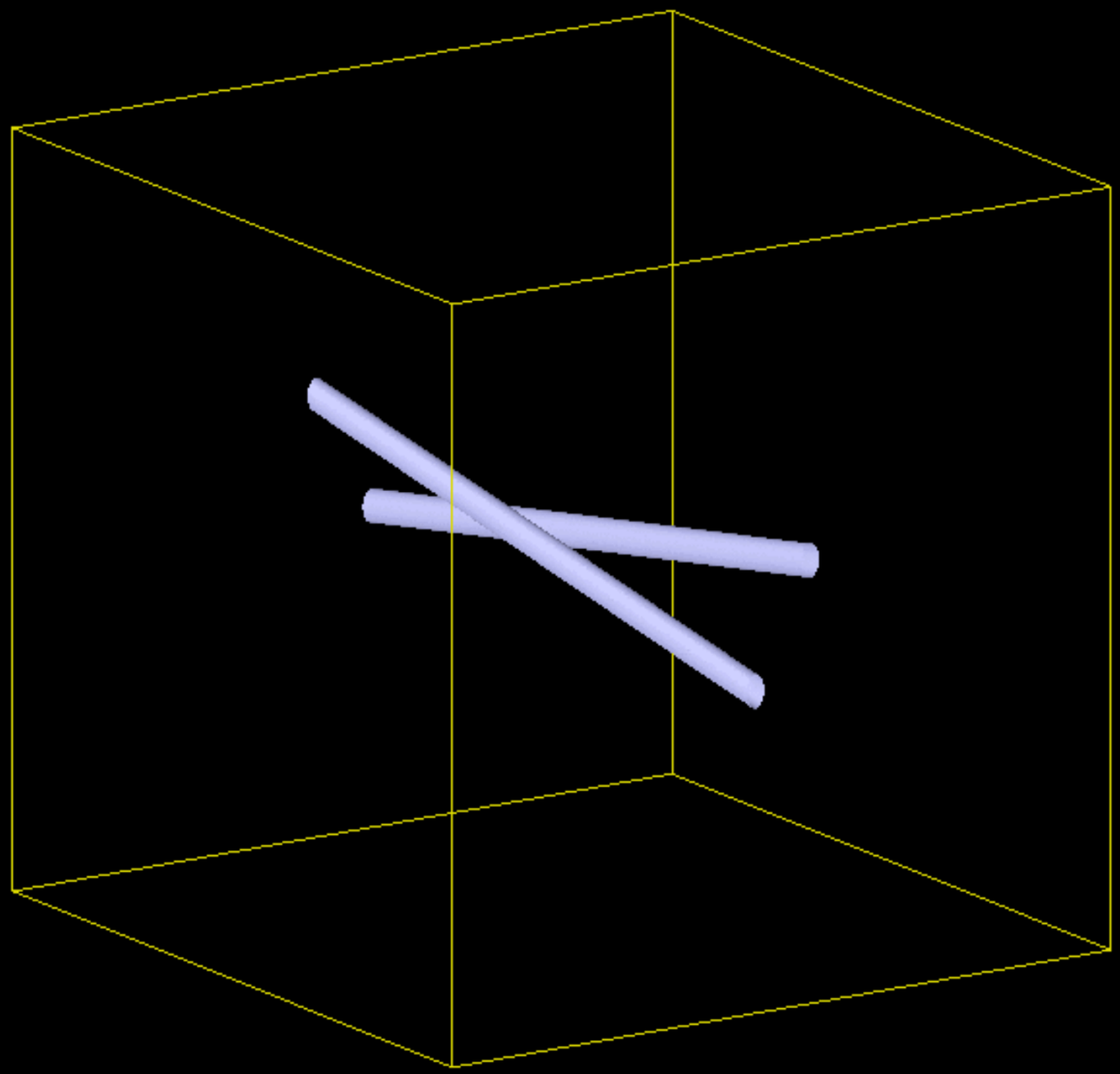
we observed three patterns



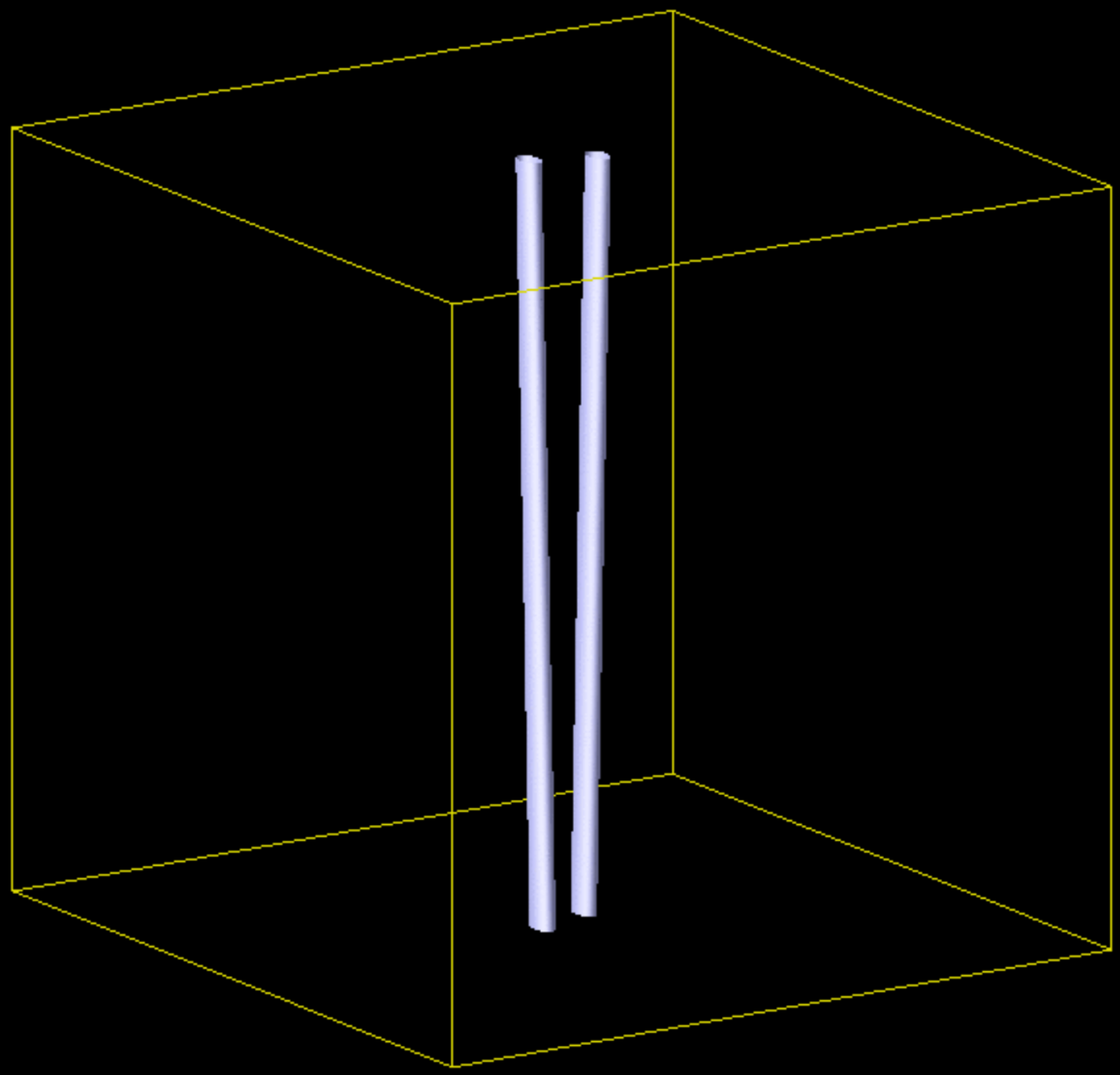
# String(n=1)/Anti-String(n=-1) collision
# 60% speed of light



String(n=1)/Anti-String(n=-1) collision
80% speed of light, large angle

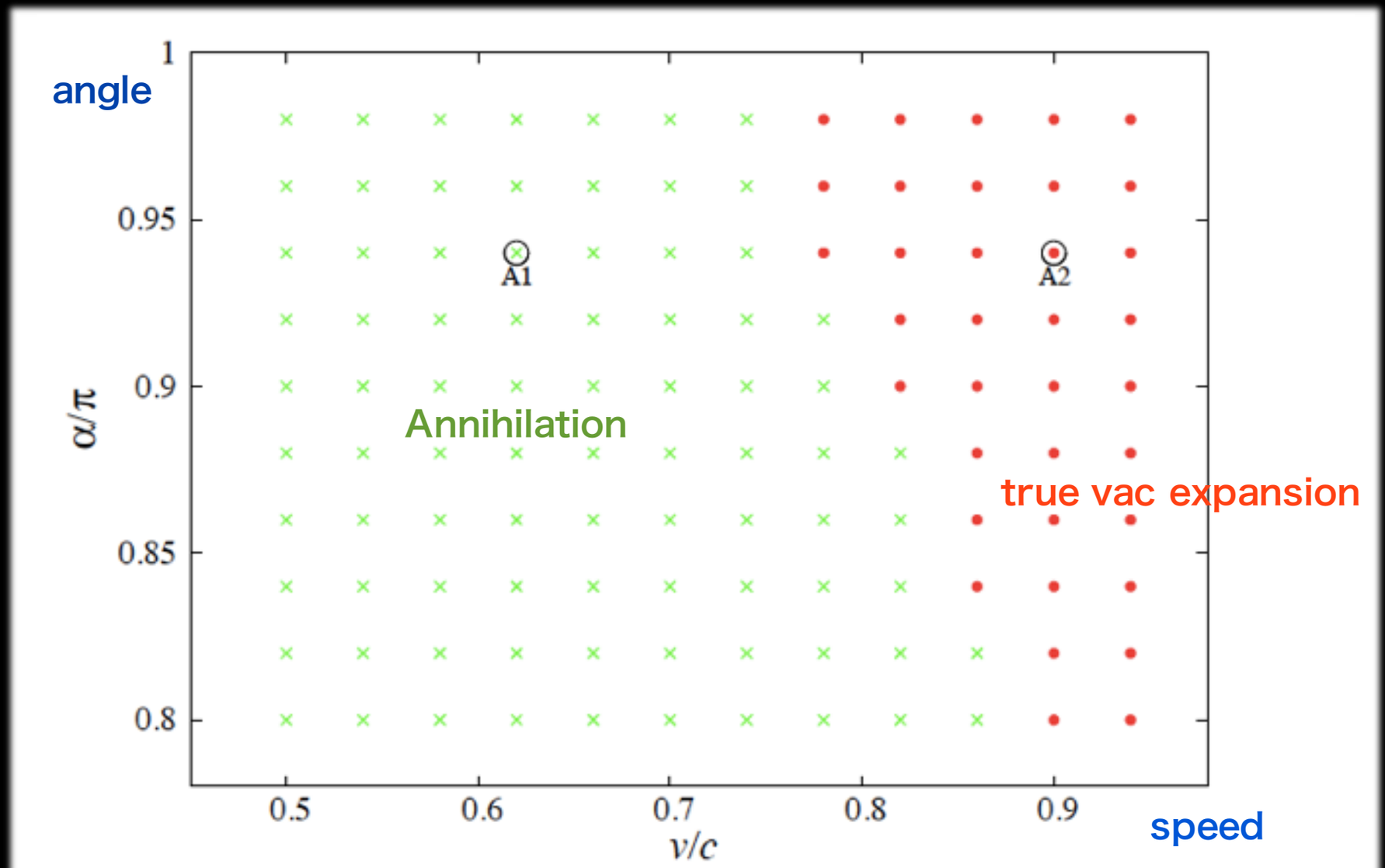


String(n=1) / Anti-String(n=-1) collision
80% speed of light, small angle



# String/Anti-string collision

we observed two patterns



# Application to String Theory

Type IIB String Theory
compactified on Calabi-Yau manifold

# Set up of geometry

M. Aganagic, C. Beem, J. Seo and C. Vafa, Nucl. Phys. B 789, 382 (2008)

Kasai, YO 16

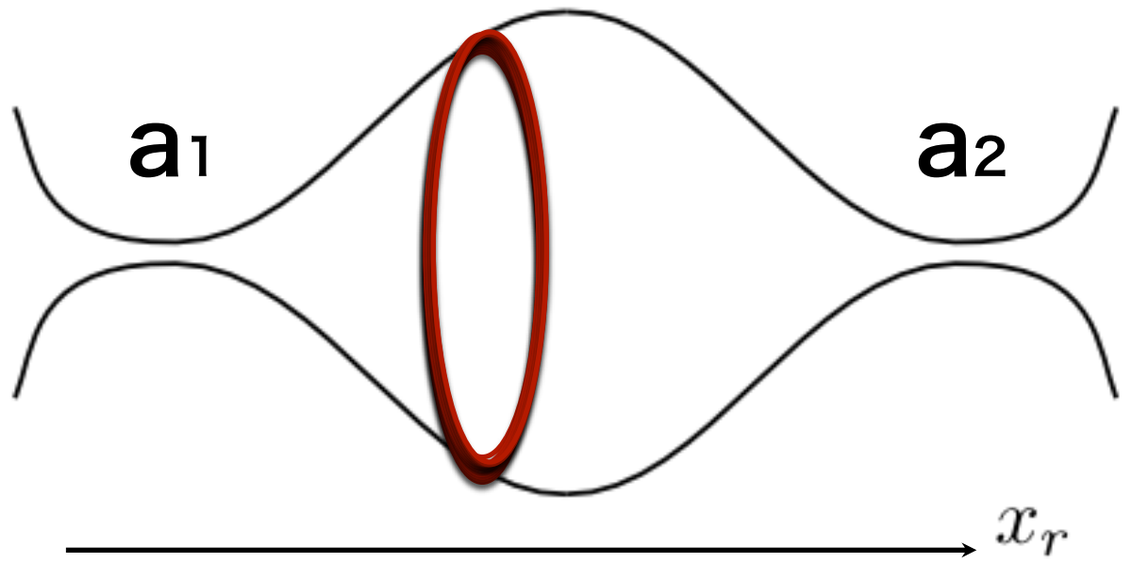
Use the Calabi-Yau manifold

$$W'(x)^2 + y^2 + z^2 + w^2 = 0 \qquad W'(x) = g(x - a_1)(x - a_2).$$

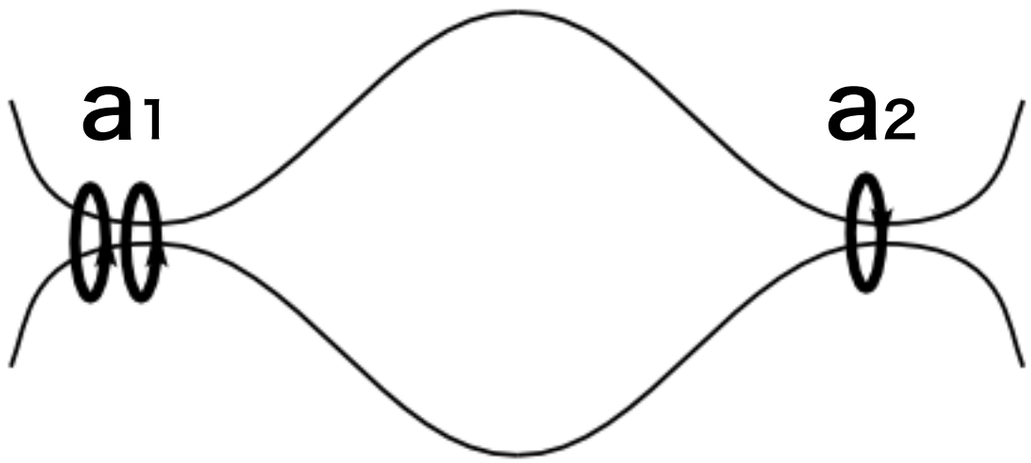
Important 3-dim sub-manifold

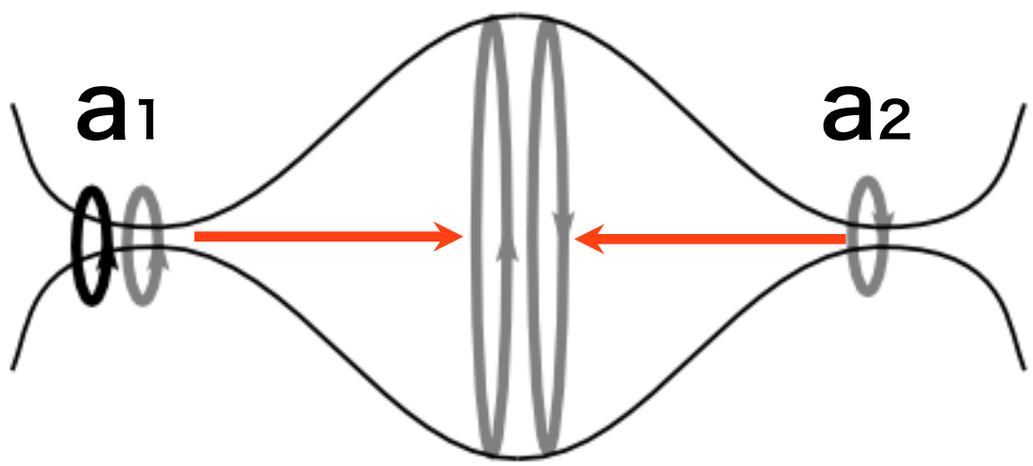
$$y_i^2 + z_i^2 + w_i^2 = g^2(x_r - a_1)^2(x_r - a_2)^2$$

**3-cycle=set of $S^2$**



# True and false vacua




false vacuum

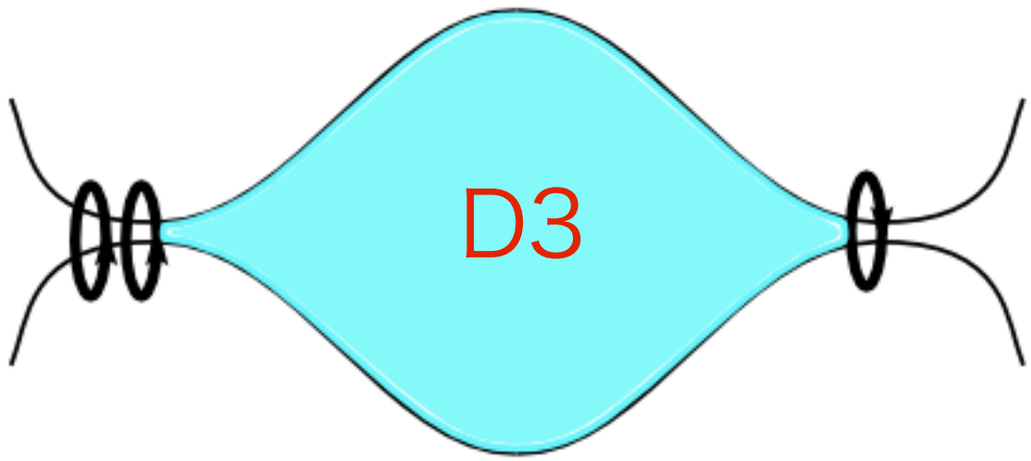
Wrapping n D5 branes at $a_1$

Wrapping n anti-D5 branes at $a_2$

true vacuum

→ D5/anti-D5 annihilation

# Add D3 brane as an impurity




D3 plays a role of monopole

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| D3 | ○ | × | × | × | ○ | ○ | ○ | × | × | × |
| DW | ○ | △ | △ | △ | ○ | ○ | ○ | × | × | × |

# Bound state of D3/DWD5

bound state energy

$$E_{D5/D3} = \sqrt{(T_{D5} 4\pi R^2 V_3)^2 + (n_{D3} T_{D3} V_3)^2}.$$


total energy of system

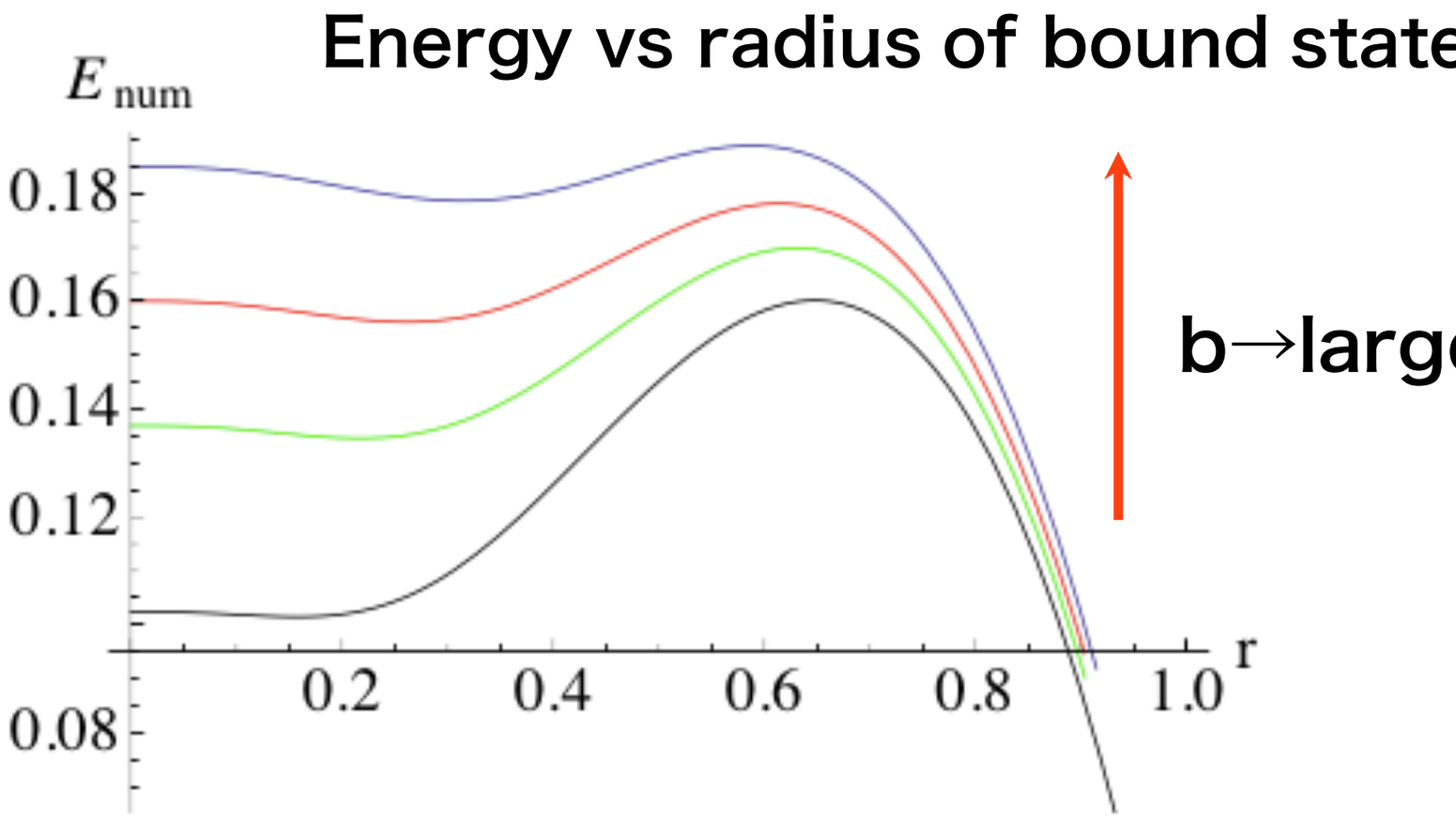
$$E_{\text{total}} = \sqrt{(T_{D5} 4\pi R^2 V_3)^2 + (n_{D3} T_{D3} V_3)^2} - \frac{4\pi}{3} \Delta V R^3 + \text{const},$$

dimensionless parameters

winding number of monopole

$$r = \frac{\Delta V}{3 T_{DW}} R, \qquad b^4 = \left(\frac{\Delta V}{3 T_{DW}}\right)^4 \left(\frac{T_{D3} n_{D3}}{4\pi T_{D5}}\right)^2.$$

# Bound state of D3/DWD5

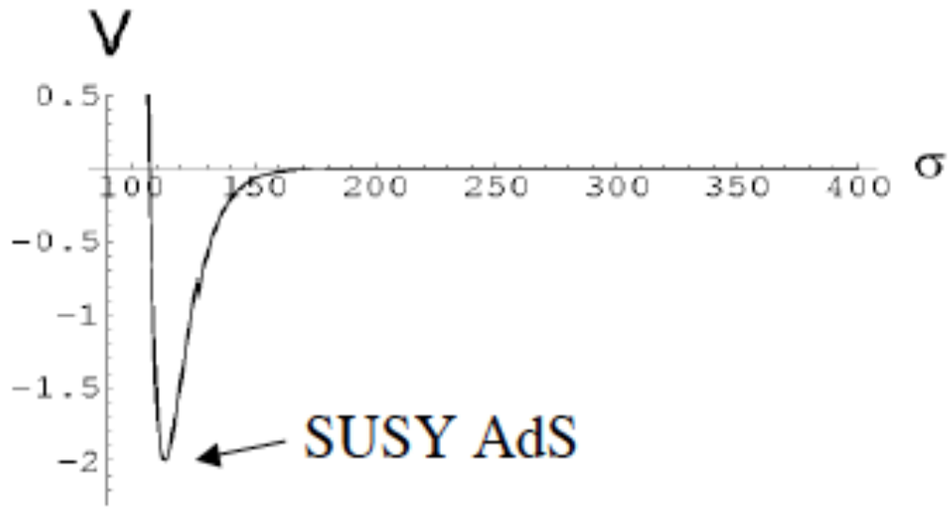


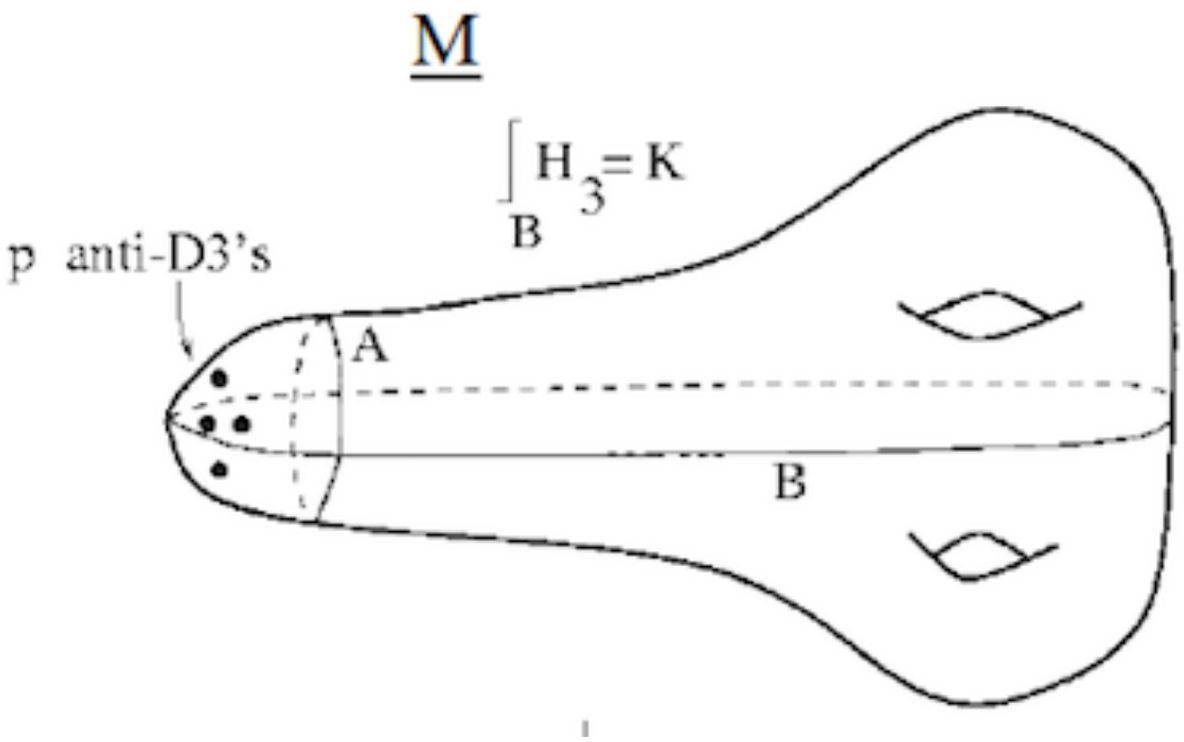

When b is large, the bubble is unstable

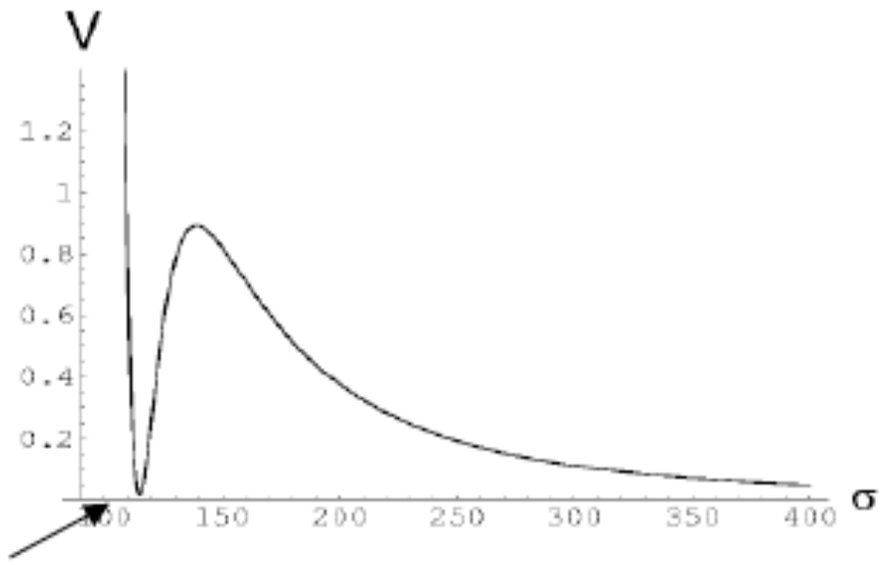
$$b > \frac{\sqrt{2}}{3} \qquad \text{(unstable).}$$ → bubble expand without bound

# KKLT model

- ✔ compact Calabi-Yau
- ✔ stabilized moduli
- ✔ up-lifted by anti-D3 branes

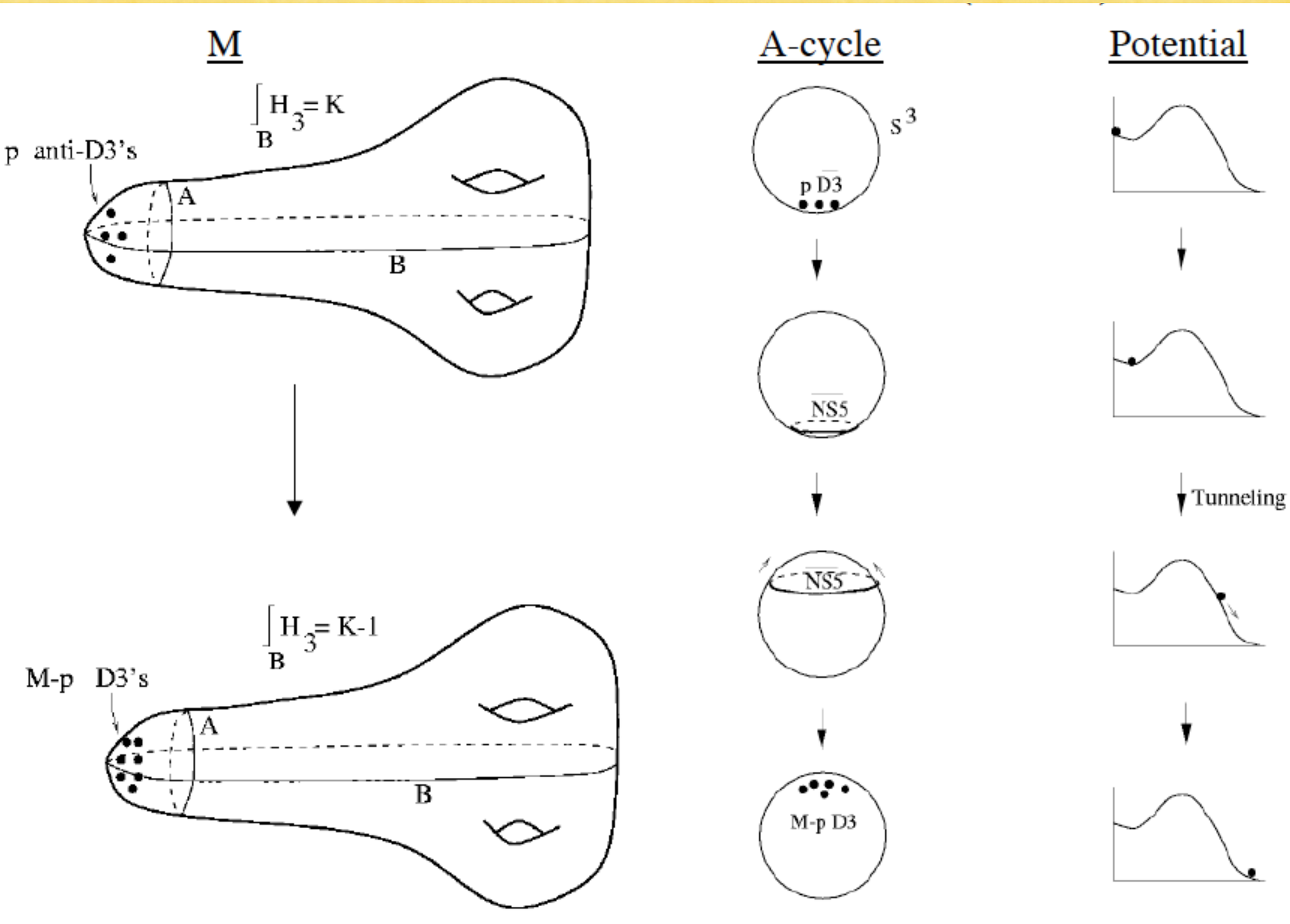



small positive cosmological constant

# KKLT model


M
A-cycle
Potential
p anti-D3's
$\int_B H_3 = K$
A
B
$S^3$
p D3
NS5
NS5
M-p D3
Tunneling
M-p D3's
$\int_B H_3 = K-1$
A
B

# KKLT model

We take non-compact limit for estimation of the decay rate

$$\frac{1}{G_{10}}\int d^{10}x(\cdots) \simeq \frac{V_6}{G_{10}}\int d^4x$$

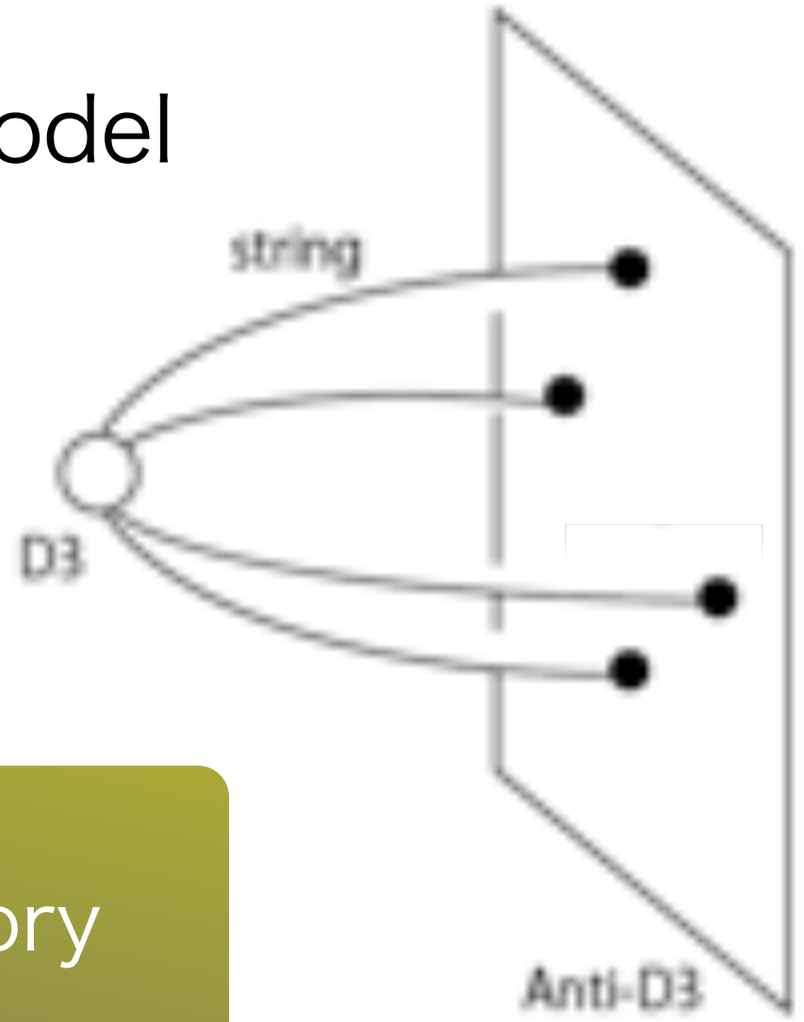
$$V_6 \to \infty$$

gravity effect is negligible

# Dyon as an impurity

Let us apply our idea to the KKLT model

In this model, a dyon can be a seed for catalytic decay




Nakai, YO, Tanahashi : arXiv 1808.10235

## Universal Lagrangian of $Z_p$ gauge theory

$$p \int_{4D} B_2 \wedge F_2 \qquad F_2 = dA$$

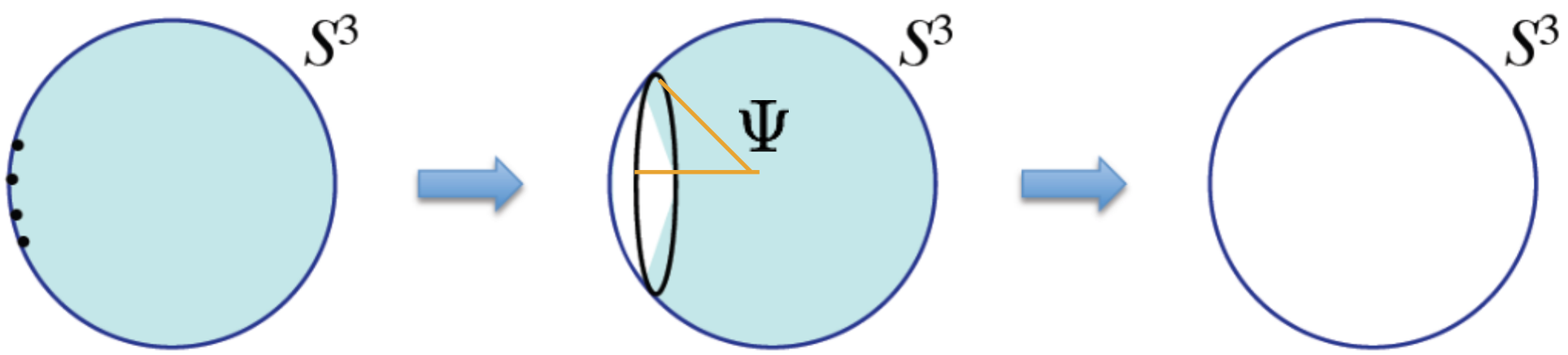
[ Banks-Seiberg `10 ]

# Action of the NS-five brane

$$S = -\frac{T_{NS}}{g_s^2}\int d^6\xi\sqrt{-\det\left(g_{ab} - 2\pi g_s\alpha'\widetilde{\mathcal{F}}\right)} - T_{NS}\int B_6 \ .$$

$$\widetilde{\mathcal{L}}_D = \ -\sqrt{V_2(\Psi)^2(\tilde{r}^4 + \mathcal{B}^2) + \mathcal{D}^2}\sqrt{1 - \dot{\Psi}^2 + \Psi'^2} + \frac{\tilde{r}^2}{\pi}\left(\Psi - \frac{1}{2}\sin 2\Psi\right)$$

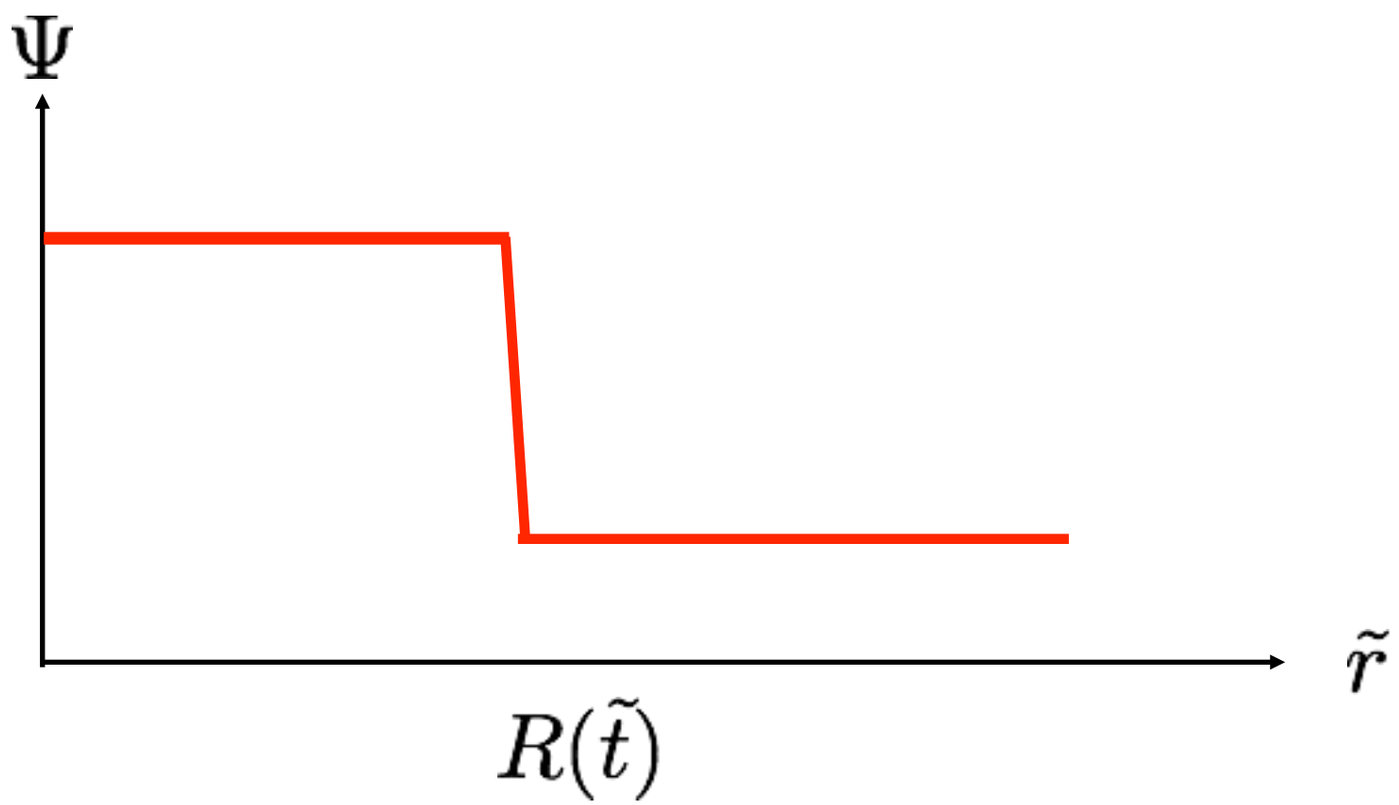
$$V_2(\Psi) = \frac{1}{\pi}\sqrt{b_0^4\sin^4\Psi + \left(\frac{\pi p}{M} - \left(\Psi - \frac{1}{2}\sin 2\Psi\right)\right)^2} \ .$$



# Life-time of KKLT vacuum

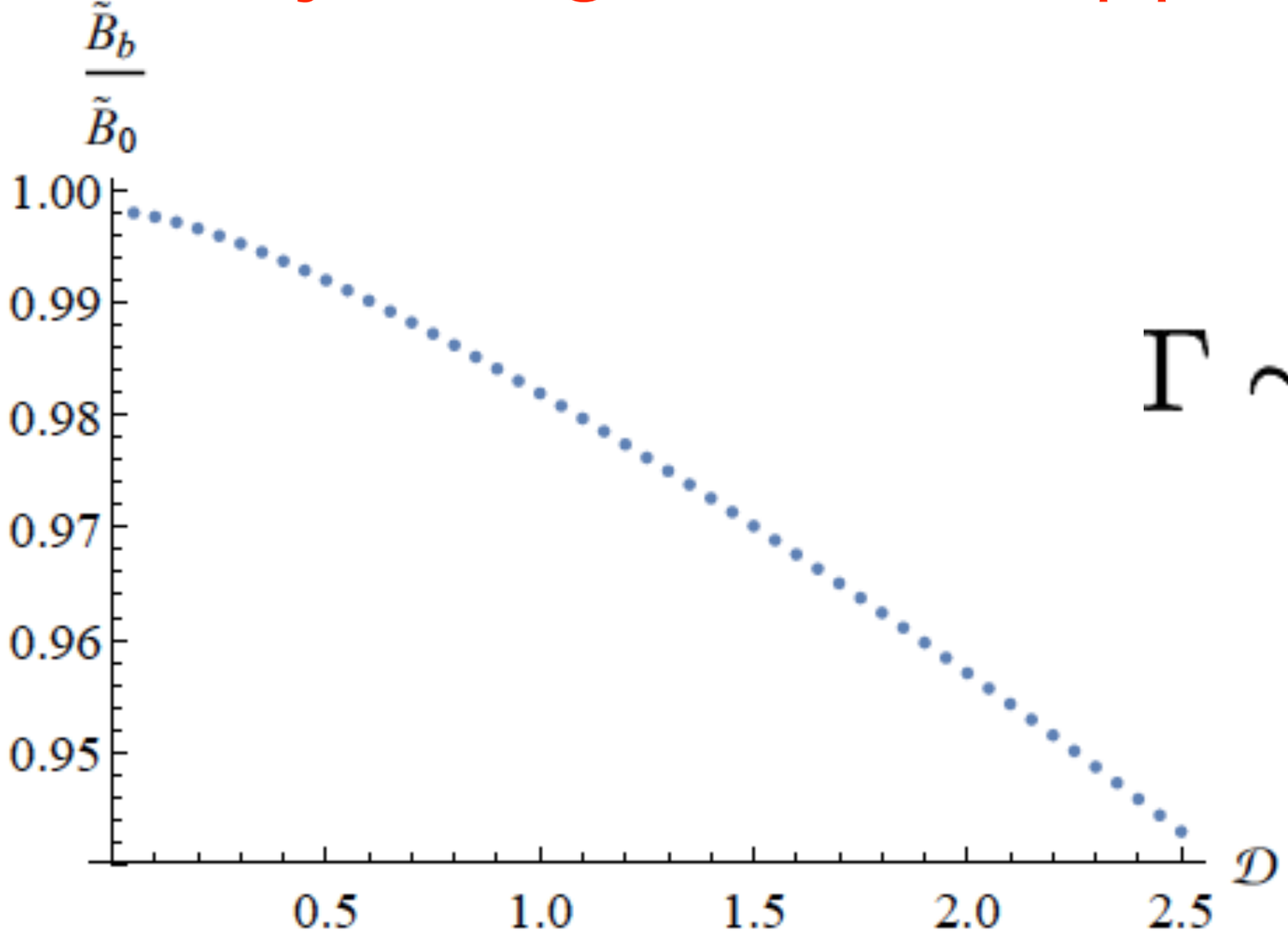
by using thin-wall approximation

$$\Psi = (\Psi_{\max} - \Psi_{\min}) \left[1 - \theta\big(\tilde{r} - R(\tilde{t})\big)\right] + \Psi_{\min} \ .$$



# Life-time of KKLT vacuum

by using thin-wall approximation




$$\Gamma \sim \exp\left(-\tilde{B}_b\right)$$

$$\tilde{B}_0 > \tilde{B}_b$$

Life-time is drastically shorter!

# *Summary*

Claim 1) Vacuum instability by catalysis plays crucial role in string landscape

Claim 2) In estimating the life-time of vacuum, the shape of the potential is not enough

Claim 3) Bubble can be a giant monopole

Claim 4) Topology of a bubble is not necessarily sphere

Claim 5) KKLT de Sitter vacuum may be unstable