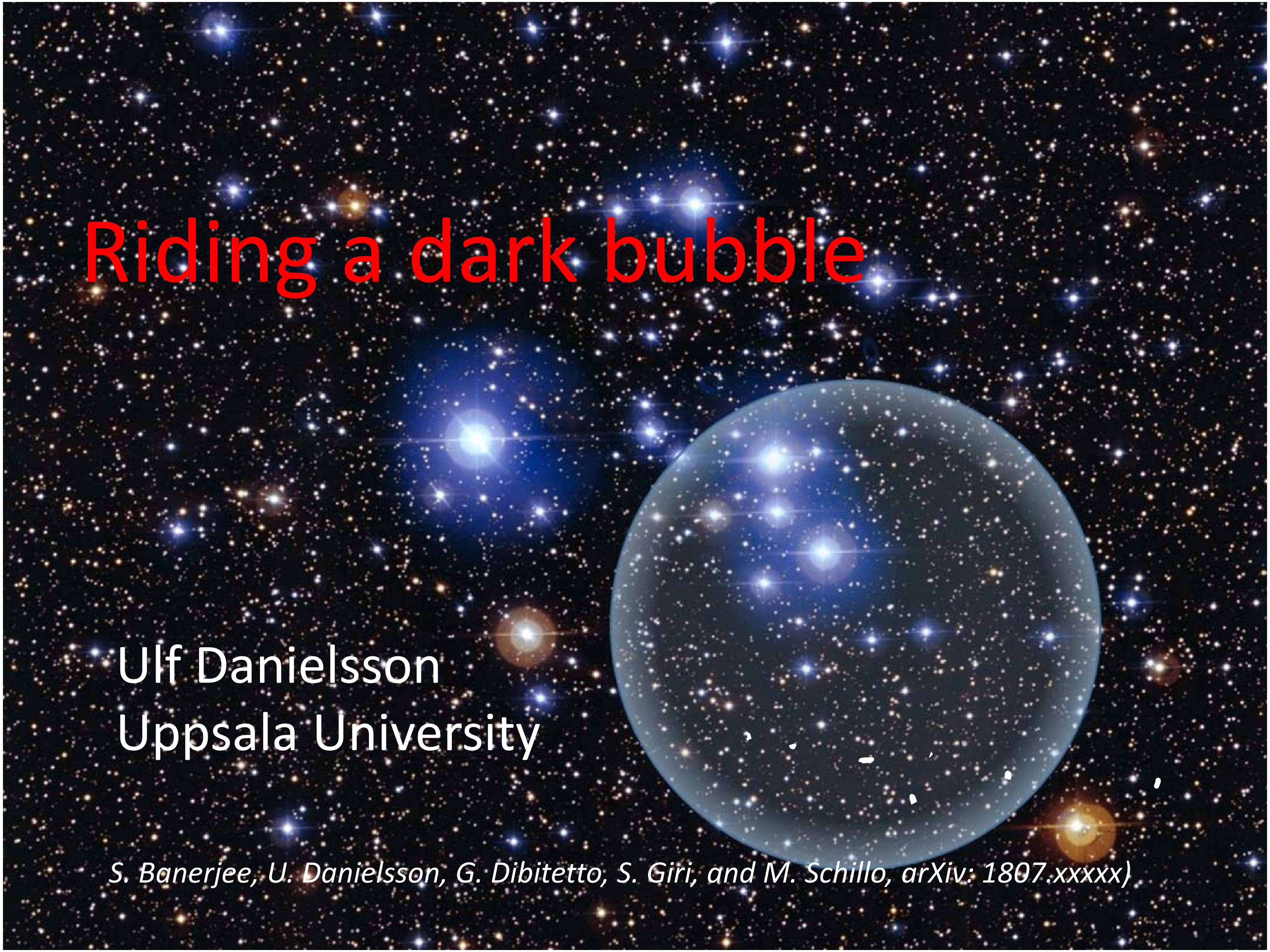


Riding a dark bubble

Ulf Danielsson
Uppsala University

S. Banerjee, U. Danielsson, G. Dibitetto, S. Giri, and M. Schillo, arXiv: 1807.xxxxx)

Background

Hints since many years back that metastable dS is in the swampland, see U. D., Thomas v. Riet 1804.01120 and talk by Thomas.(*)

These unexpected conspiracy makes string theory really interesting... What does it mean? What about cosmology?

*) Also: R. Blumenhagen 1804.10504

Classical, geometric SUGR:

No dS unless O6/F_0 ⇒ tachyonic dS

KKLT:

dS from uplifting and nonperturbative effects?

⇒ instabilities

(Talk by Thomas)

Recently, it was suggested in

G. Obied, H. Ooguri, L. Spodyneiko, C. Vafa, 1806.08362

that $V < c\,|\nabla V|$. This would kill even

$\overset{\nwarrow}{}$ positive

the tachyonic dS. But do they have to be killed?

J. Blåbäck, U.D., G. Dibitetto, 1316.8366

$\Rightarrow$ only a couple of e-foldings

*) D. Andriot, 1806.10999

Alternative condition:

Strengthening hates horizons:

$$\left|\frac{\nabla V}{V}\right|^2 + \left|\frac{\nabla^2 V}{V}\right|^2 \gtrsim 1$$

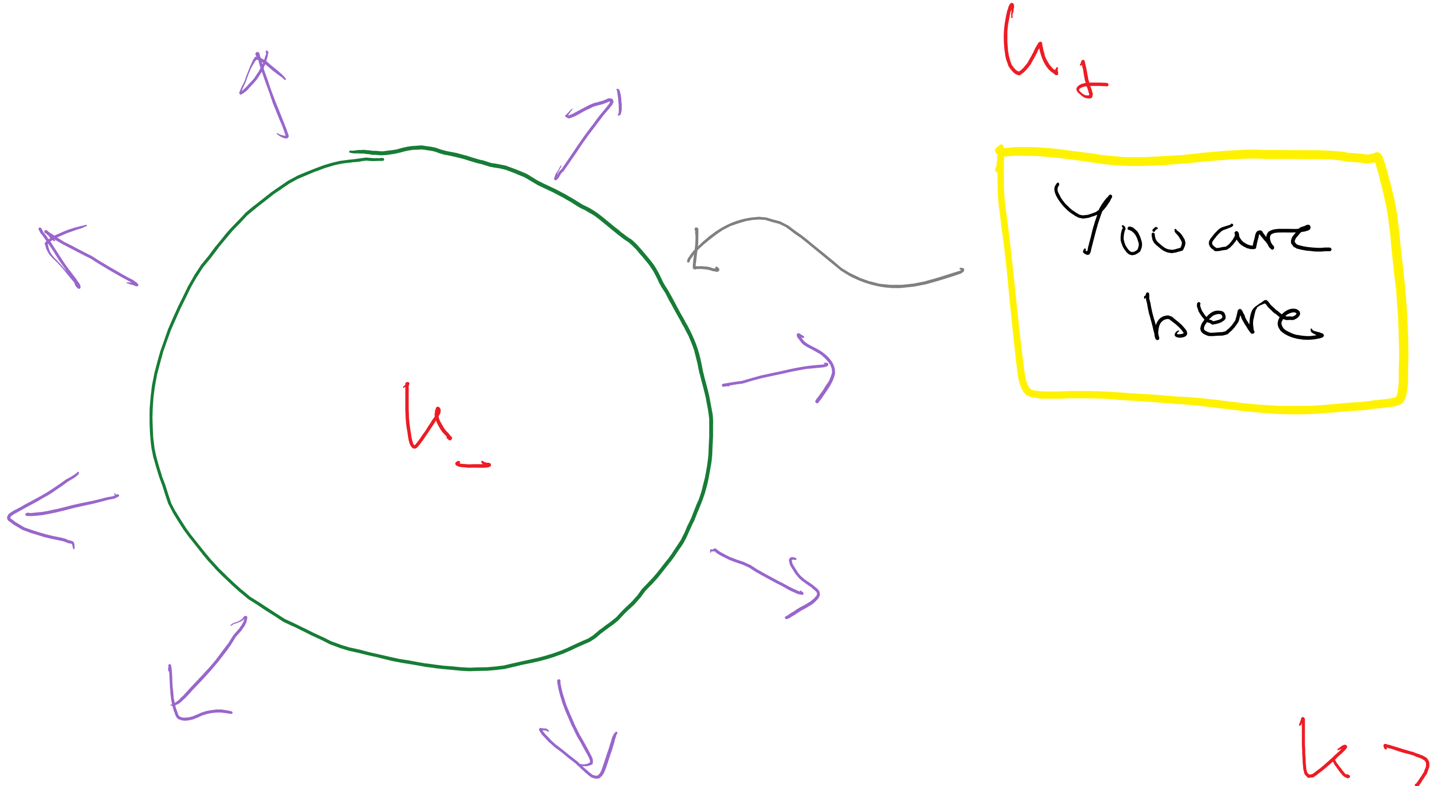
Is there a way out?

Problem finding dS as fundamental time independent vacuum...

Simple observation: our universe is not time independent!

Make the problematic instability into a virtue!

The main idea



$k_- > k_+$

$$ds^2 = (1 + k_\pm^2 r^2)\, dt^2 - \frac{dr^2}{1 + k_\pm^2 r^2} - r^2 d^2\Omega_3$$

Outline

Cosmology

Local physics

Strings realization

If you only care about cosmology...

The Israel junction condition:

$$\sigma = \frac{3}{8\pi G_5}\left(\sqrt{k_-^2 + \frac{\varepsilon + \dot{a}^2}{a^2}} - \sqrt{k_+^2 + \frac{\varepsilon + \dot{a}^2}{a^2}}\right)$$

$\varepsilon = -1, 0, +1$ is the curvature

with induced metric on the shell:

$$ds_4^2 = -d\tau^2 + a^2(\tau)\, d^2\Omega_3$$

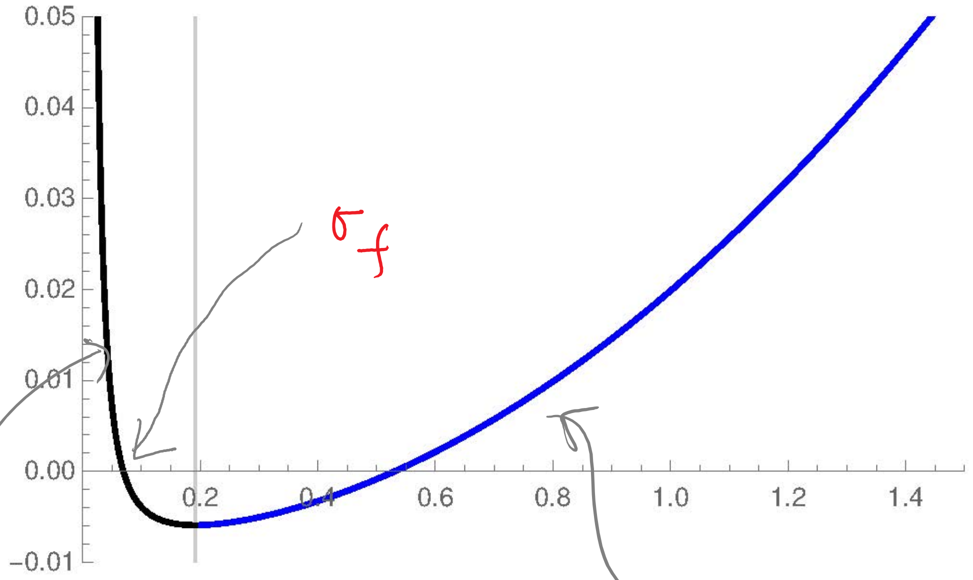
Expand around $\sigma = \sigma_f = \frac{3}{8\pi G_5}(k_- - k_+)$ to get...

$$\boxed{\frac{\dot{a}^2}{a^2} = -\frac{\varepsilon}{a^2} + \frac{8\pi G_4}{3}\Lambda_4}$$

... Friedmann!

where $G_4 = \frac{2k_-k_+}{k_- - k_+} G_5$ and $\Lambda_4 = \sigma_f - \sigma$

Plot $\frac{\varepsilon_+ \dot{a}^2}{a^2} = \frac{8\pi G_4}{3}\Lambda_4$ as a function of general σ ...



σ_f

$\Lambda_4 = \sigma_f - \sigma > 0$

branch with $\sigma = \sqrt{\ } + \sqrt{\ }$

→ inside/inside

in like in RS ...

Radiation: consider AdS-Schwarzschild:

$$1 + u^2 a^2 \longrightarrow 1 + u^2 a^2 - \frac{4G_5 m}{\pi a^2}$$

... which gives:

$$\frac{\dot{a}^2}{a^2} = -\frac{1}{a^2} + \frac{8\pi G_4}{3}\Big(\underbrace{\sigma_f - \sigma}_{\Lambda_4} + \boxed{\frac{4}{\pi}\left(\frac{m_+}{u_+} - \frac{m_-}{u_-}\right)\frac{1}{a^4}}\Big)$$

... like radiation

... just like holography at finite T...

Thermal equilibrium across the shell:

$$T_-^4 \sim \frac{m_- L_-^3}{a^4} = \frac{m_+ L_+^3}{a^4} \sim T_+^4$$

$$\Rightarrow \left(\frac{m_+}{L_+} - \frac{m_-}{L_-}\right)\frac{1}{a^4} \sim \left(\frac{1}{L_+^3} - \frac{1}{L_-^3}\right) T^4 \frac{1}{a^4}$$

$$\boxed{\sim \left(L_+^3 - L_-^3\right) T^4 \frac{1}{a^4}}$$

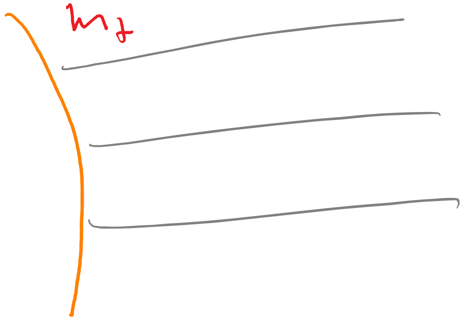
# of degrees of freedom

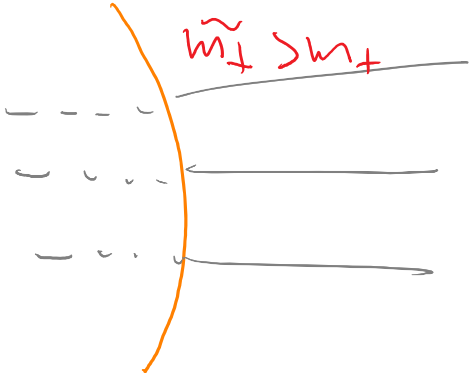
Massive matter!

To get a positive contribution $\sim 1/a^3$ out of

$$\sigma_f - \sigma + \frac{4}{\pi}\left(\frac{m_+}{u_+} - \frac{m_-}{u_-}\right)\frac{1}{a^4}$$

... you need $m_+ \simeq \eta a$. This is achieved through strings extending outwards from the brane. The brane eats strings as it climbs the throat. The strings compensate for the $1/a$ - redshift, or equivalently, loss of potential energy.





If you care about local physics...

Consider linear perturbations in 5D-metric

$$\left[-\frac{p^2}{a^2}+\frac{\partial^2}{\partial z^2}-4k^2\right]\chi(p,z)$$

A, Padilla 0410033

spatial 3-momentum to get gravitational potential as a function of r

$$a=e^{kz}$$

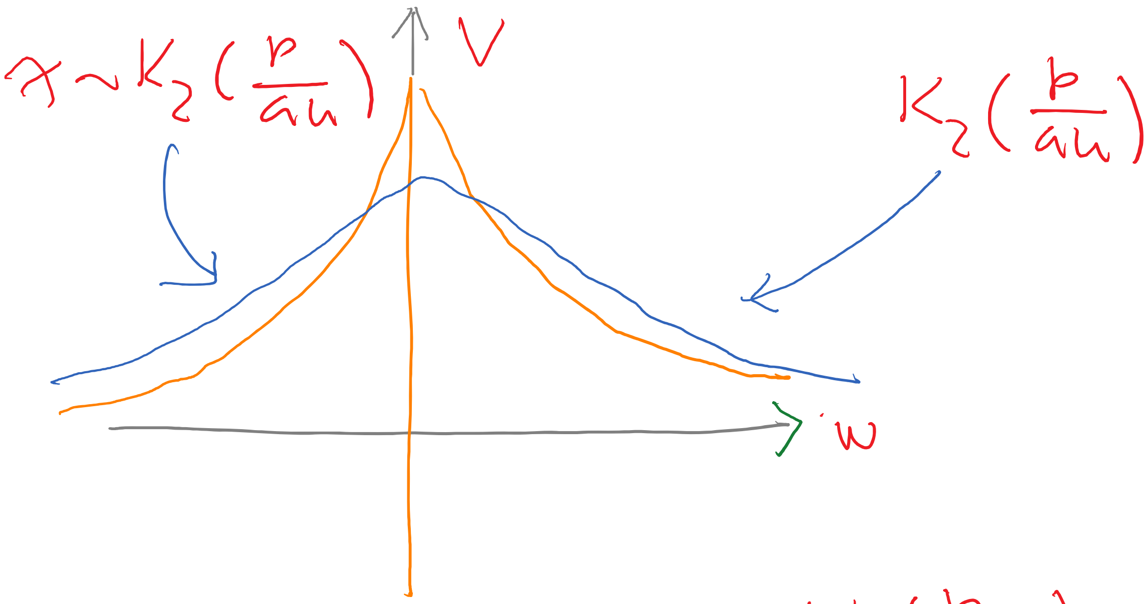
... general solution: $\chi = A\,K_2\left(\frac{p}{ak}\right)+B\,I_2\left(\frac{p}{ak}\right)$

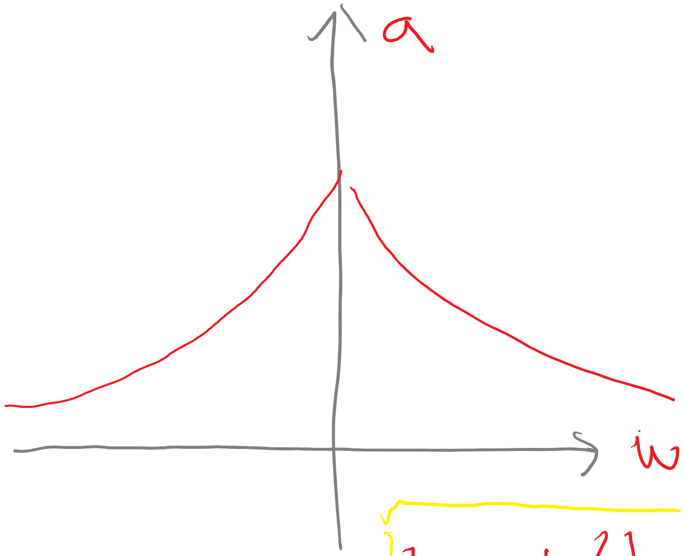
... subject to junction condition:

source

$$\chi_-'-\chi_+'-\frac{5}{3}\chi_b=\Sigma$$

Randall-Sundrum with two insides





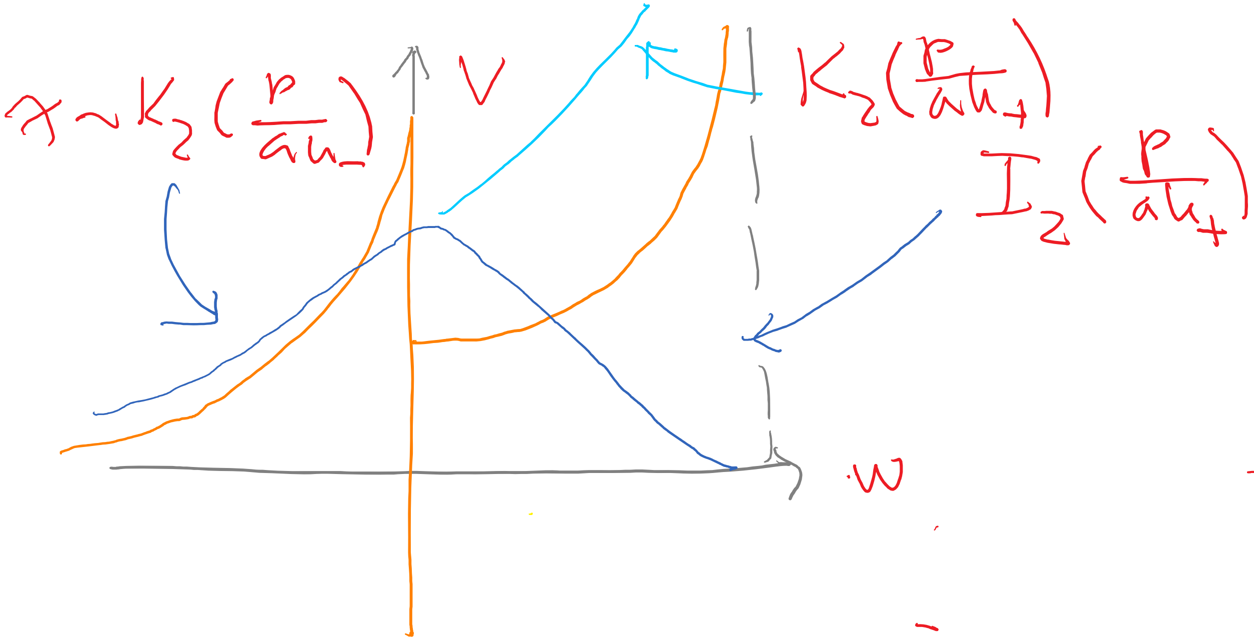
$$\boxed{\begin{array}{l} kw = \pm\left(\frac{1}{a}-1\right) \\ a<1 \end{array}}$$

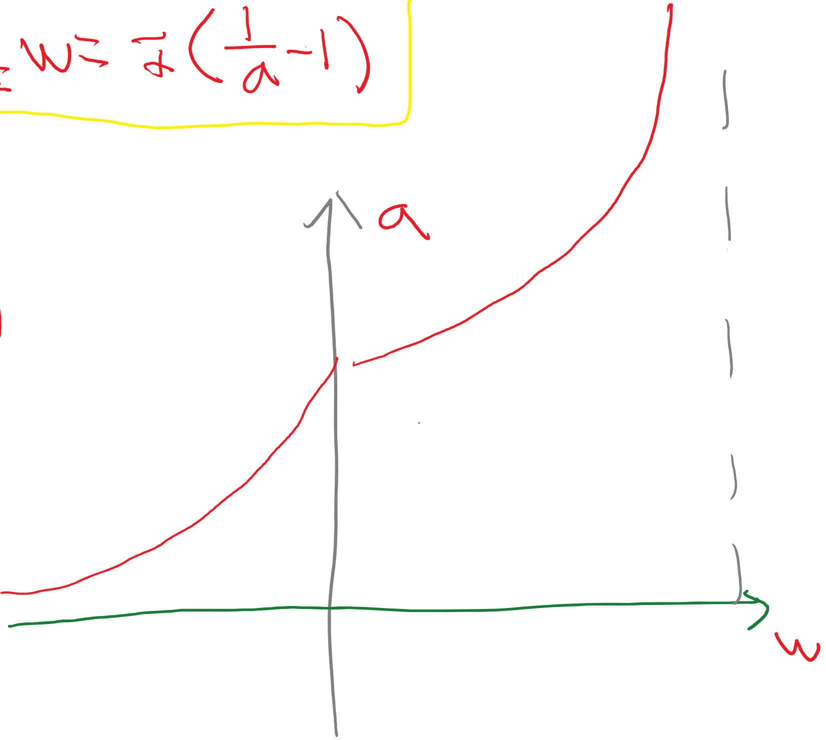
We get:
$$\chi_b \frac{p}{a} \frac{K_1\left(\frac{p}{ka}\right)}{K_2\left(\frac{p}{ka}\right)} = \Sigma$$

$$\Rightarrow \quad \chi \sim \frac{k\Sigma}{\left(\frac{p}{a}\right)^2} \quad \Rightarrow \quad G_4 \sim k$$

An inside and an outside

$$\boxed{u_\pm w = \mp\left(\frac{1}{a} - 1\right)}$$





Keeping K_2 and I_2, to localize on brane $\chi \sim \dfrac{u_- \Sigma'}{\left(\frac{p}{a}\right)^2 + \boxed{u_- u_+}}$

Disaster!

Keeping K_2 on both sides gives:

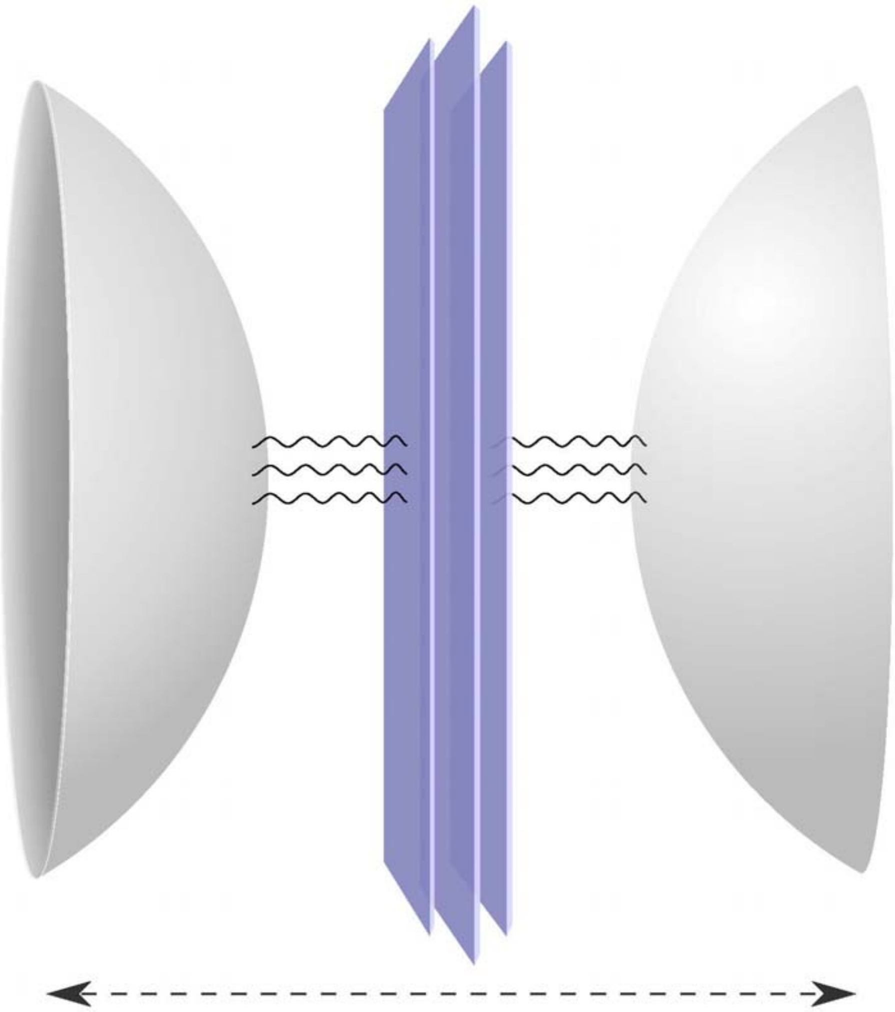
$$\chi \sim -\frac{2 u_- u_+}{u_- - u_+} \frac{\Sigma'}{\left(\frac{p}{a}\right)^2} = -G_4 \frac{\Sigma'}{\left(\frac{p}{a}\right)^2}$$

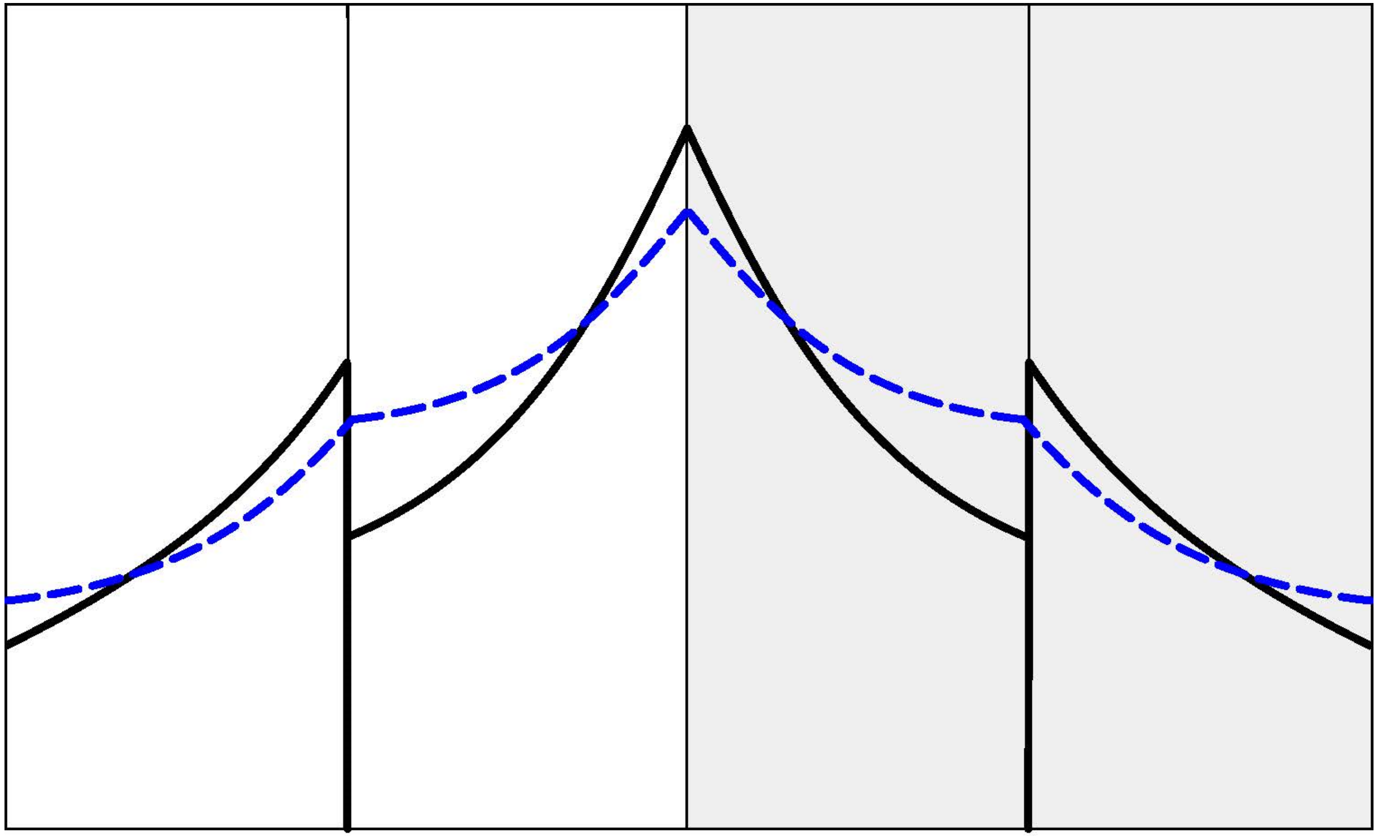
This is in perfect agreement with Friedmann'

Persistent source along stretched string

Sign from $\sigma_f = \sigma + \frac{4}{n}\underbrace{\left(h_+ m_+(a) - h_- m_-(a)\right)}_{>0 \text{ for stretched string.}}\frac{1}{a^4}$

Note that both calculations come from the same junction condition





Strings realization

Let us consider IIB on $AdS_5 \times M_5$. We focus on two different vacua;

SUSY with $M_5 = S^5$, flux F_5,

~~SUSY~~ with M_5 = squashed S^5, flux F_5, G_3

← Romans

fibration over $\mathbb{CP}_2$

$F_3 + \tau H_3$

Consider decay where SUSY nucleates within ~~SUSY~~ ...

Following, e.g., Gunaydin, Romans, Warner NPB272, 598 (1986)
Pilch, Warner 0002192

we have the superpotential

$$W = \frac{1}{4\rho^2}\left(\cosh 2\chi\,(\rho^6-2) - (3\rho^6+2)\right)$$

with potential

$$V = g^2\left(\frac{1}{8}\left|\frac{\partial W}{\partial \chi}\right|^2 + \frac{1}{48}\left|\rho\frac{\partial W}{\partial \rho}\right|^2 - \frac{1}{3}|W|^2\right)$$

SUSY at $\rho = 1,\ \chi = 0$

~~SUSY~~ at $\rho = 1,\ \chi = \frac{1}{2}\operatorname{arccosh} 2$

……

This gives: $V_{\cancel{susy}} < V_{susy} < 0$

in 5d we make sure that we have the same F_5 in the two vacua we get: $V_{susy} < V_{\cancel{susy}} < 0$

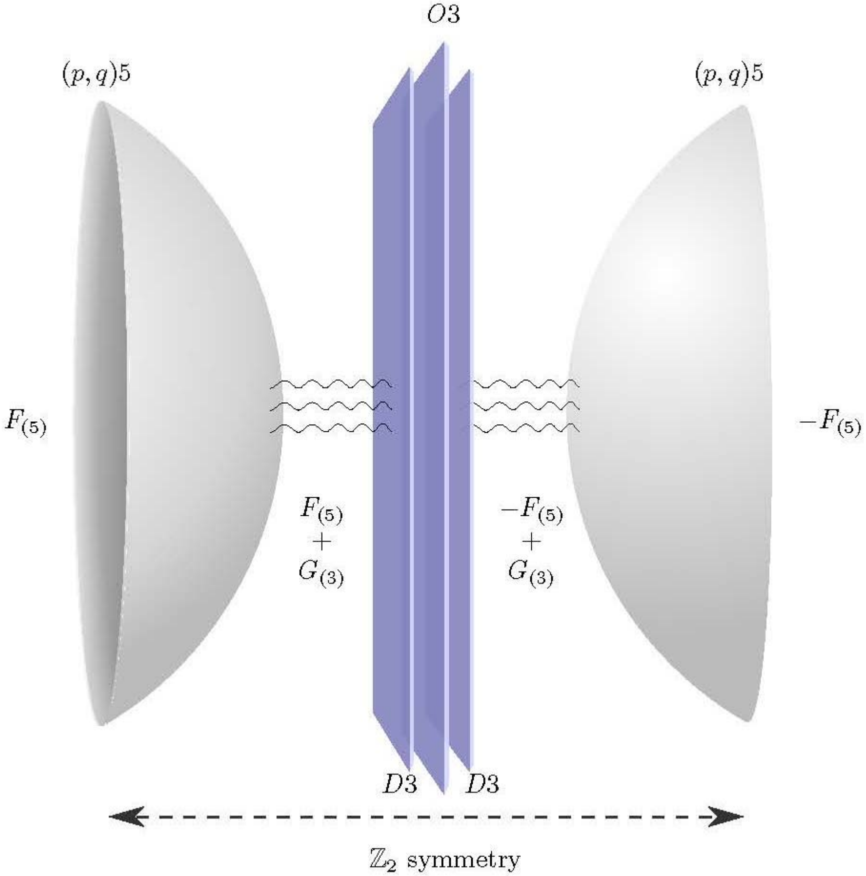
To separate the two vacua we need fundamental NS5/D5-brane (wrapped) sourcing change in flux and W.

Minimal tension estimated from:

$$\sigma_{BPS} = \Delta W = \left(\frac{n}{N_5}\right)^{7/3}\left(6 - \frac{7}{2^{2/3}}\right)$$

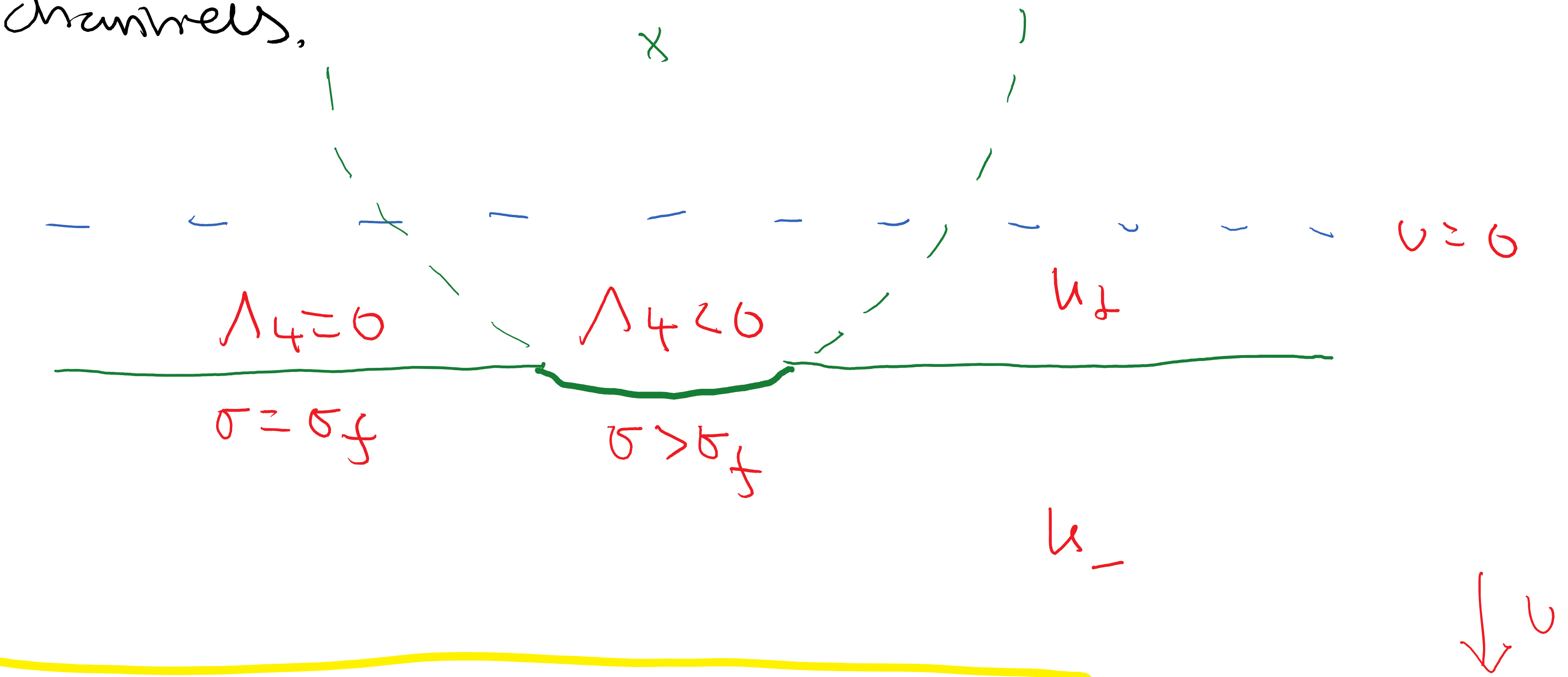
in while $$\sigma_f = \left(\frac{n}{N_5}\right)^{7/3}\left(6 - \frac{9}{2^{7/6}}\right)$$

$$\sigma_{BPS} < \sigma_f \Rightarrow \boxed{\text{Decay} \Rightarrow \text{positive cc braneworld}}$$


$O3$
$(p,q)5$
$(p,q)5$
$F_{(5)}$
$-F_{(5)}$
$F_{(5)} + G_{(3)}$
$-F_{(5)} + G_{(3)}$
$D3$
$D3$
$\mathbb{Z}_2$ symmetry

Conclusions

Effective 4D dS without disastrous decay channels. ✓



A. Padilla,
R. Gregory
0107108

$$\boxed{E>0 \Rightarrow \text{bubble cannot nucleate}}$$

Strong realization, even though Λ_4 not small, ✓

To do: find new landscape with small Λ_4 and realistic particle physics.