0. Program Announcements

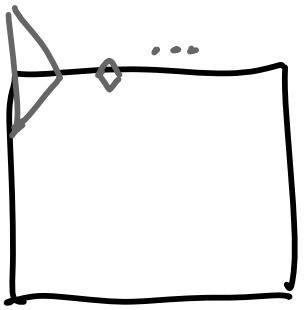
I. New deSitter Solutions

Work in progress with

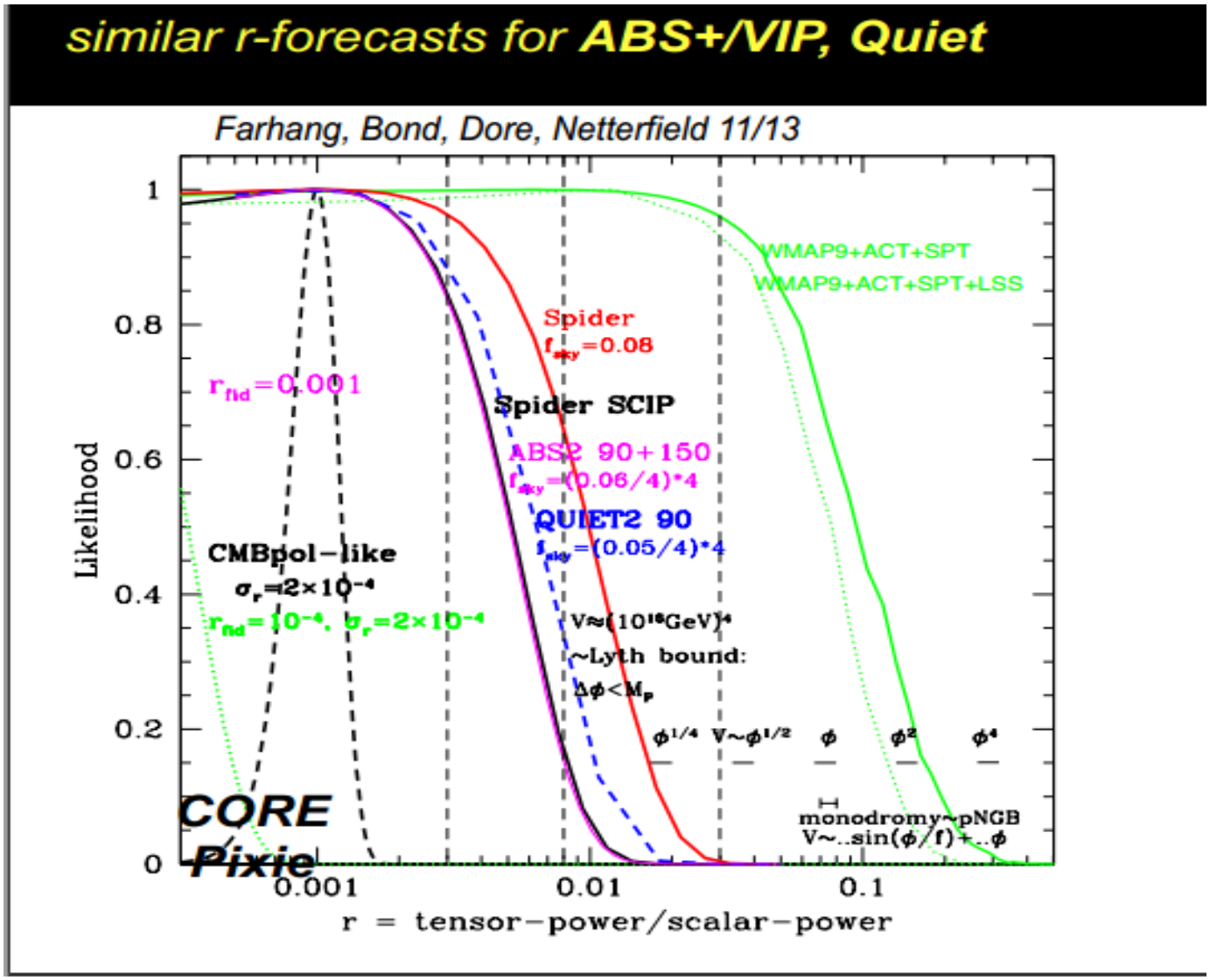
M. Dodelson, X. Dong, G. Torroba

II. General discussion

what is the real mystery of DE?



B Fest: Week 13 (June 26-27)

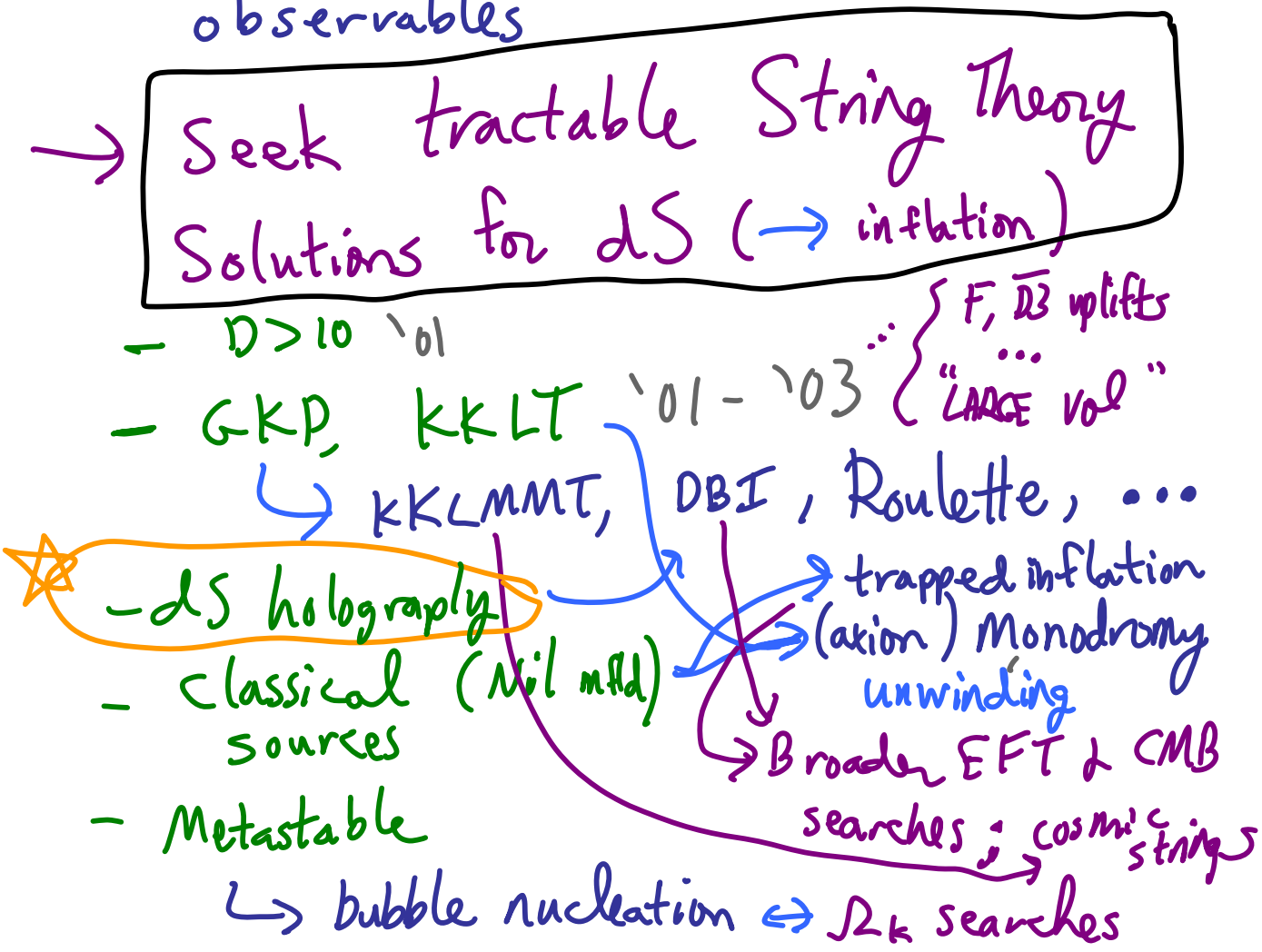


B mode exptal types coming include: Chao-Lin Kuo, John Kovac, Alan Kogut, Adrian Lee, Barth Netterfield, Sarah Church, Clem Pryke, Suzanne Staggs, Seth Hillbrand, Shaul Hanany; Dick, George Efstathiou, Matias,...

BICEP Spider QUIET ABS EBEX Pixie Planck Epic ACT SPTpol ...

Cosmological constant & inflation (ΛCDM)

- raises big questions about framework & initial conditions
- UV-sensitive (to quantum gravity) phenomenological observables



Simple backgrounds ("p-branes", "D-branes" "Freund-Rubin") led to rapid progress in black hole physics, string dualities, and the AdS/CFT correspondence.

The cosmological (dS, FRW) case has been slower in part because of the complication of the solutions

~~Simple~~ de Sitter Solutions

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We present a framework for de Sitter model building in type IIA string theory, illustrated with specific examples. We find metastable dS minima of the potential for moduli obtained from a compactification on a product of two Nil three-manifolds (which have negative scalar curvature) combined with orientifolds, branes, fractional Chern-Simons forms, and fluxes. As a discrete quantum number is taken large, the curvature, field strengths, inverse ...

Alternate title

%%Complicated de Sitter Solutions

h/t G. Shiu

Aharony, Danielsson, Dong, de Wolfe, Flauger, Gwanie, Hertzberg

Hom, Paban, Shiu, Taylor, Tegmark, Torroba, Wrase

...

String theory $\longrightarrow$

potential with structure

$$V(\Phi, \sigma; \dots) \rightsquigarrow$$

Φ: dilaton; σ: size; other sizes, axions, brane positions...

$$\sum_i \hat{V}_i e^{\breve{\beta}_i \Phi + \breve{\gamma}_i \sigma} + \sum_l \sigma_l e^{\breve{\gamma}_i \Phi_i} \frac{\delta(w - w_l)}{\sqrt{g_{mn}}}$$

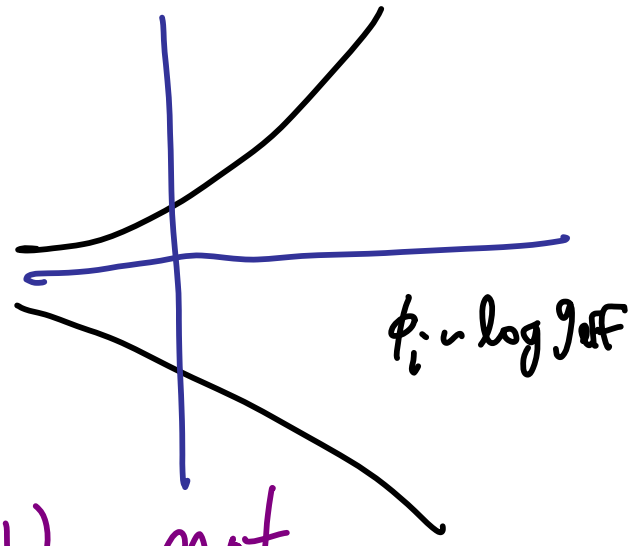
bulk; localized defects

$\gamma_i, \beta_i \sim \mathcal{O}(1/M_p)$

+ warping effects (cf constraints)

+ quantum, non-perturbative

$$\sum_i \hat{V}_i e^{\beta_i \frac{\phi_{ic}}{M_p}}$$



- Here $\beta_i \sim O(1)$, not suitable for slow roll

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e.g. IIB compactified from $\tilde{D} = 10 \to D = 5$ on 5-sphere

$\int d^{10}x \sqrt{-G_{(10)}}\, R \to V_R : \beta_R = 4\sqrt{\frac{2}{15}}$

$\int d^{10}x \sqrt{-G_{(10)}}\, |F_5|^2 \to V_{F^2} : \beta_{F5} = 2\sqrt{\frac{10}{3}}$

"O3-planes" $\to \sigma_{O3} : \alpha_{O3} = \sqrt{\frac{10}{3}}$

Bottom-up Warmup :

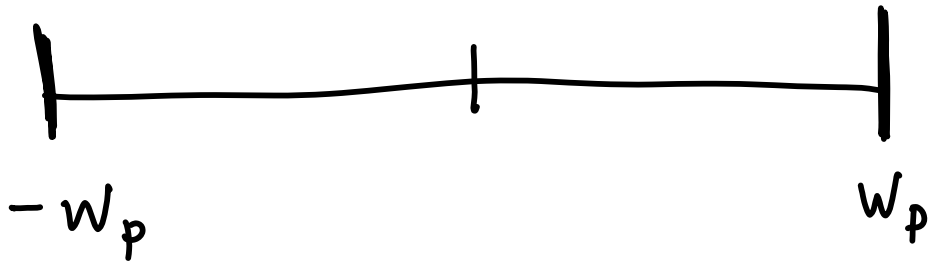
Consider $D = 5$ theory with potential that is simply

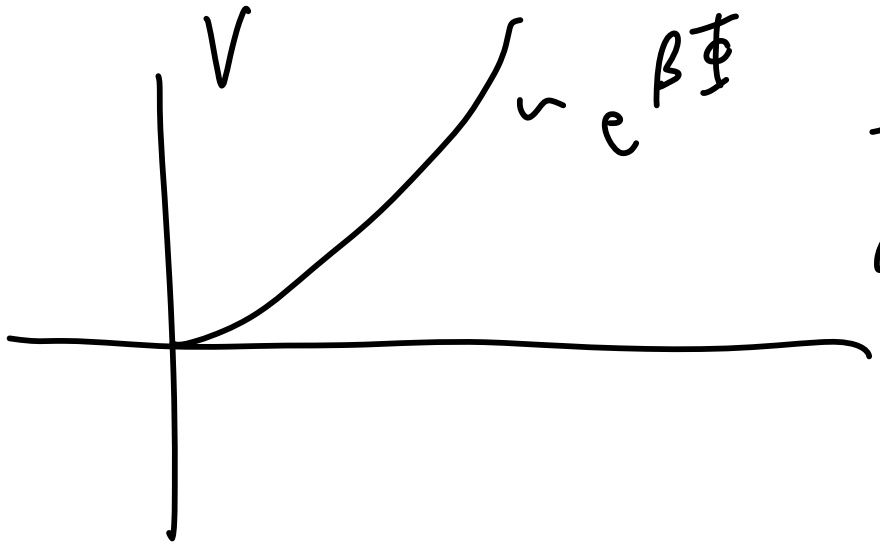
$$V = \hat{V} e^{\beta \phi}$$

plus a localized source (cf "orientifold plane")

$$\sigma = -\hat{\sigma} e^{\gamma \phi} [\delta(w - w_p) + \delta(w + w_p)]$$

$(\hat{\sigma} > 0)$





tadpole in $D=5$

Reduce to $d=4$ along one direction

$$ds^2 = a(w)^2 ds^2_{dS_4} + dw^2$$

$$\phi = \phi(w)$$

cf Randall-Sundrum Kaloper ... Chamblin/Reall ...

O-planes $T_{loc} \sim -\hat{\sigma} e^{\alpha\phi} [\delta(w-w_p) + \delta(w+w_p)]$

$\Rightarrow$ boundary conditions

Equations (radial version of Friedmann eqn's) ($k_s = 1$ here)

$$\frac{1}{2}(D-1)(D-2)\,\frac{a'^2-1}{a^2} = \frac{1}{2}\phi'^2 - V(\phi)$$

$$\phi'' + (D-1)\,\frac{a'}{a}\,\phi' - V'(\phi) = 0$$

3 integration constants + w_p parameter

- $a'(-w_p) = -\dfrac{a\,\sigma(\phi)}{2(D-2)}$
- $\phi'(-w_p) = \dfrac{1}{2}\,\sigma'(\phi)$ $\quad w = -w_p$
- $a'(0) = 0 = \phi'(0)$

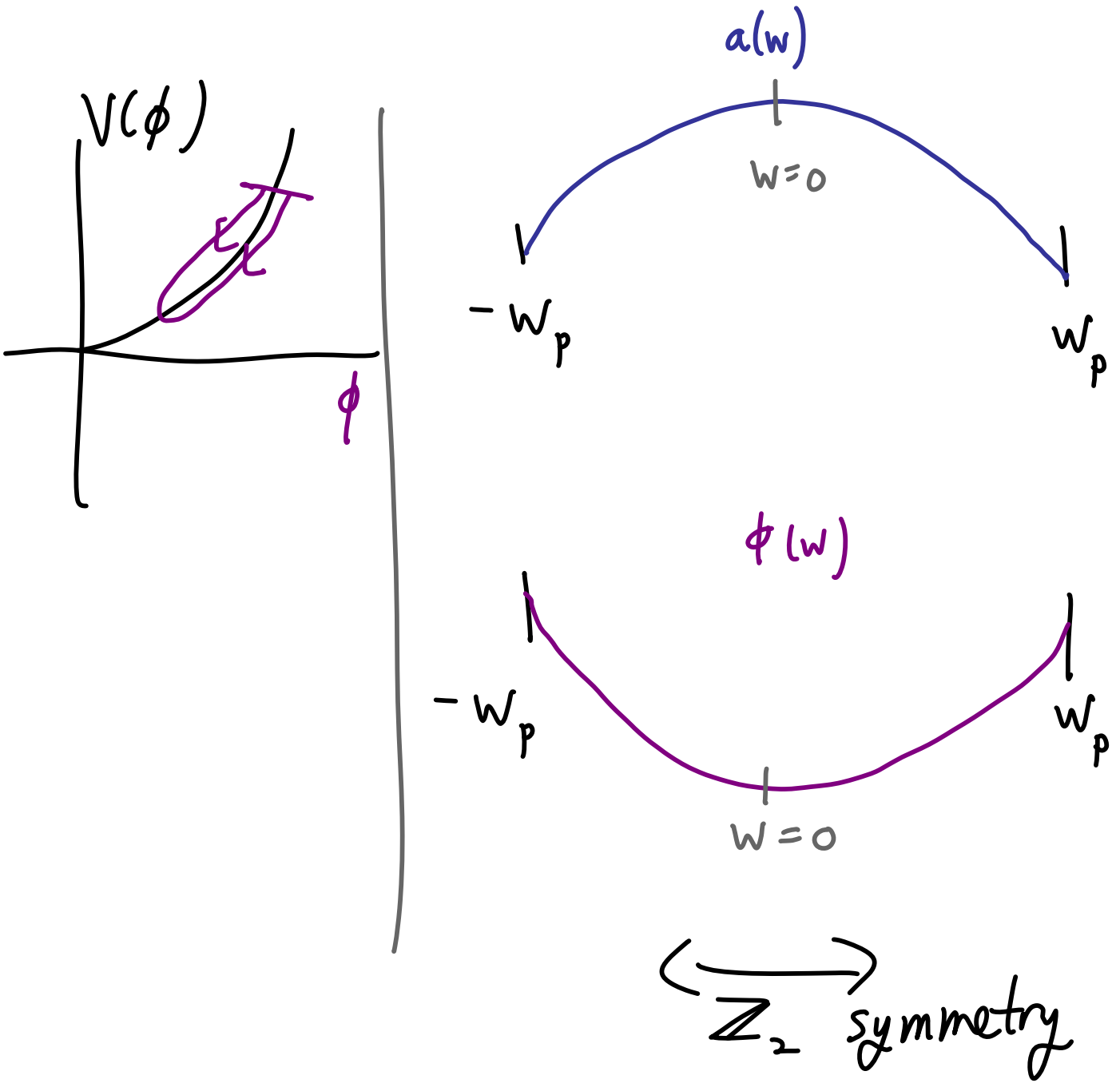
- Find numerical solutions ✓

- Analytically can show α, β are restricted : without additional structure (e.g. brane at $w=0$)

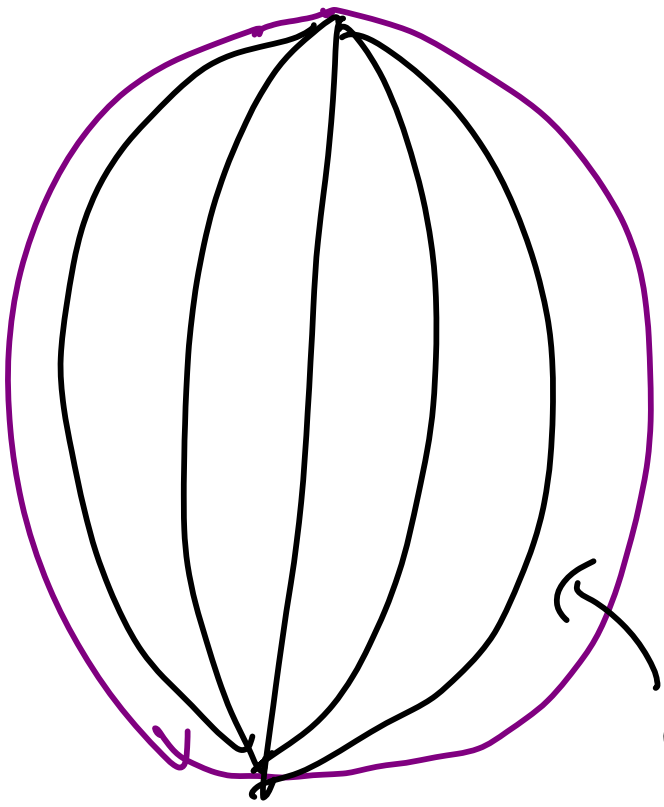
$$\alpha^2 \geq \frac{D-1}{D-2} \qquad \beta \leq \frac{2\alpha}{D-1}$$

is a no-go region

- Analytic sol'ns for special potentials
(e.g. continuation of FRW/FRW)



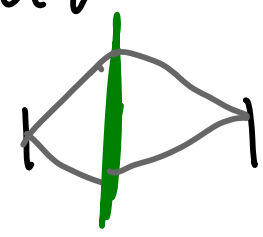
☆ Non singular dS_4 Solution



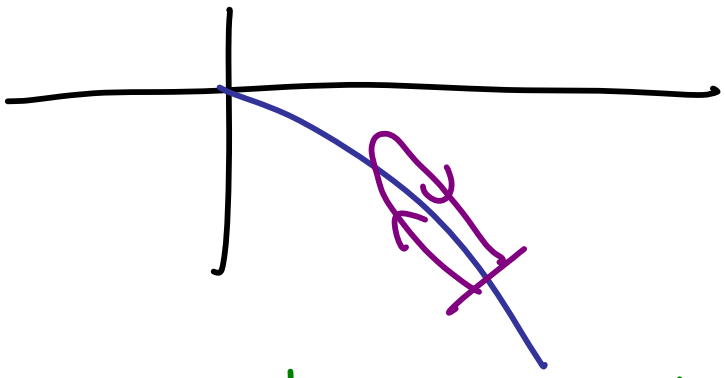
$$ds^2_D = dw^2 + a(w)^2 ds^2_{d=D-1}$$

$D = 5$, $d = 4$

- Similar analysis with "UV brane" $\sigma_{br} \propto e^{\alpha_{br}\phi}$



For intuition (if it helps), this is analogous to ($w \leftrightarrow$ time) to field rolling in time on $V < 0$ with negative curvature spatial slices



(This would have bang/crunch singularities, but in our case the Orientifolds cut off the interval at $\pm w_p$, excising singularities.)

- Explicit numerical solutions

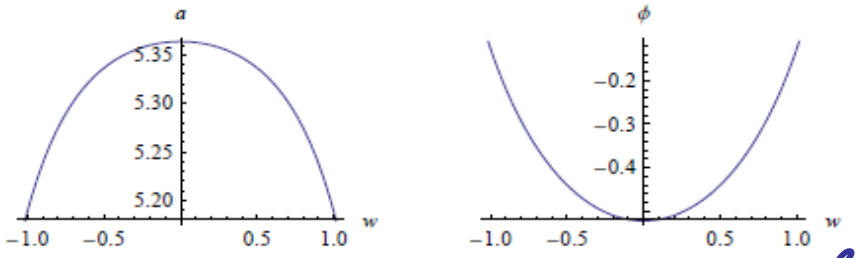


Figure 1: $V(\phi) = e^{3\phi}, \quad \sigma(\phi) = -e^{3\phi}.$ $\alpha = \beta = 3$

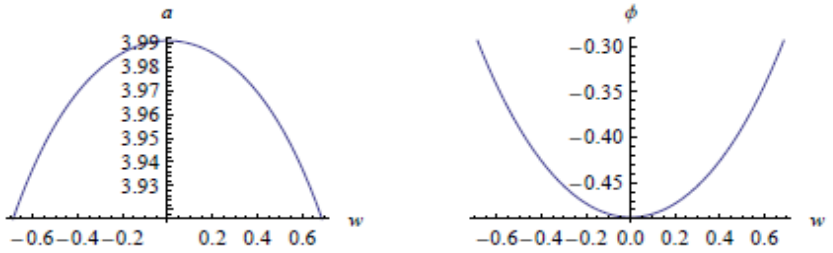


Figure 2: $V(\phi) = e^{2\phi}, \quad \sigma(\phi) = -e^{3\phi}.$ $\alpha = 3, \beta = 2$

- $d = D-1$ naive (smeared) effective potential would <u>not</u> give sol'ns

- Some no-go regions in γ, β but easy to avoid

- Similar solutions w/ UV brane

Top Down examples

$\beta \phi_{canonical}$

- $D > 10$ $V \propto (D-10)\, e$

$$\beta = \frac{2}{\sqrt{D-2}} \qquad \alpha = \frac{D}{2\sqrt{D-2}}$$

(orientifold $(D-2)$-plane)

- IIB $\overset{\smile}{D} = 10 \longrightarrow D = 5$ on $S^5/\mathbb{Z}_k$

V_{flux}, σ_{03}, σ_{7B}

$$\beta = 2\sqrt{\frac{16}{3}}, \quad \gamma_{03} = \sqrt{\frac{10}{3}}, \quad \alpha_{7B} = 2\sqrt{\frac{2}{15}}$$

(All depend only on $\phi_1 = \sqrt{\frac{5}{6}} \log \frac{g_5}{R^4}$)

etc (expect a zoo!)

Control Parametrics & Warping

IIB example : naive d=4 potential:

$$V^{(4d)}_{Naive} \sim \left(\frac{g_s^2}{\ell R^5/k}\right)^2 \Bigg\{ -\frac{1}{R^2 g_s^2}\cdot\frac{R^5\ell}{k} - \frac{1}{g_s} \qquad (O3)$$

$$+ \frac{N_f R^4}{g_s^2 k} + \frac{N_c^2 k}{R^5}\ell \Bigg\}$$

$(>B)$ $\qquad$ (F_5^2)

Does give good estimate of parametrics $\frac{R^4}{g_s} \sim \frac{k}{N_f}$, $\frac{R}{\ell} \sim N_c^2 N_f$

$\rightarrow V_{QR}/V \sim \frac{1}{N_c^2 N_f}$ corrections small

Redshift space distortions

So far, took $V_{D=5}(\phi)$ with a tadpole, and used radial evolution $\phi(w)$ & warping $a(w)$ with nonsingular b.c. to obtain $d=4$ de Sitter solution

$\Rightarrow$ at least new saddle points, next checking if $\delta\phi$, $\delta g_{\mu\nu}$ are stable at 2nd order (Radion ✓)

★ Tool: $V_{eff}[\delta\phi, \delta g_{\mu\nu}]\Big|_{\text{sol'n of constraints}}$ with strong warping Douglas '10, Giddings ..

Perturbation Analysis

$$ds_D^2 = a(z)^2\left(e^{2\delta A(z,x)}dz^2 + e^{-\frac{2}{d-2}\delta A(z,x)}\tilde{g}_{\mu\nu}dx^\mu dx^\nu\right)$$

$$\phi \to \phi + \delta\phi(z,x)$$

- Constraints reduce it to 1 radion mode $c(x)$ $\quad \delta A(x,z) = \frac{c(x)}{a(z)^{D-3}}$

  plus $\delta\phi(x,z)$

- $m^2_{c(x)} = \left(\frac{1}{\int dz\, a^{3-d}}\right)\int dz\, a^{3-d}\left(2(d-1) + (d-2)(d-4)\left[\frac{a'}{a}\right]^2\right)$

  > 0 ✓

- still working out $\delta\phi(x,w)$

Douglas '10 Warping helps (screens negative sources)

$$V_{eff}\, G_N^2 = \frac{-\frac{3}{2}}{\sum_i \frac{1}{\lambda_i} \left| \int \sqrt{g}\, u_i \right|^2}$$

where λ_i are energy eigenvalues & u_i normalized wavefunctions for the analogue Schrodinger problem

$$\lambda_i u_i = -\partial_w^2 u_i + \overbrace{\left[-V[\phi(w)] - \phi'^2(w) - \sigma_{loc}\right]}^{U_{Q.M.}(w)} u_i$$

In our case, $U(w)$ is a double well potential. $\delta\phi$, $\delta g_{\mu\nu}$ affect $\{\lambda_i, u_i\}$ (low-lying levels dominate)

in progress

Summary

- $V \sim e^{\beta\phi}$ tadpoles + O-planes

  $\rightarrow dS_d$ solutions

  (fewer ingredients, more explicit about internal fields)

- Quadratic stability in progress

  $m^2_{c(x)} > 0$, need $m^2_{All} > -H^2 \cdot \epsilon$

- holographic description in progress.

  2 stages: $D \rightarrow D\text{-}1 \rightarrow D\text{-}2$

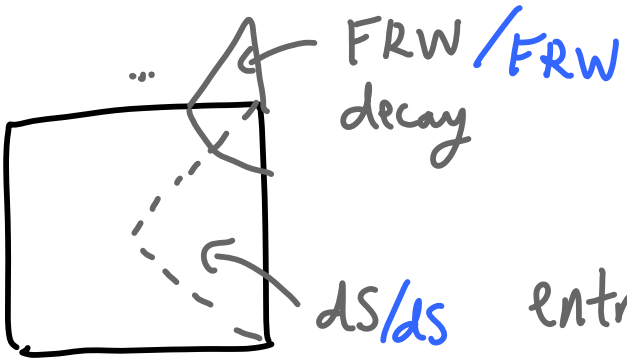
  $U(N_c)^k$

  + IR 03

  UV 7B

Discussion

What is the framework?



entropy $S_{GH} = \frac{A}{4G_N}$

observer-dependent horizons

causal patch = warped compactification

$$ds_d^2 = dw + \sin^2 w \, ds^2_{dS_{d-1}}$$

$M_p^{(d-1)}$ & S finite in dS but $\to \infty$ in FRW.

Does this help with initial conditions "problem"? Is it a problem?

(In AdS/CFT no preferred state.)