Title: A Bouncing Universe approach to Fine Tuning

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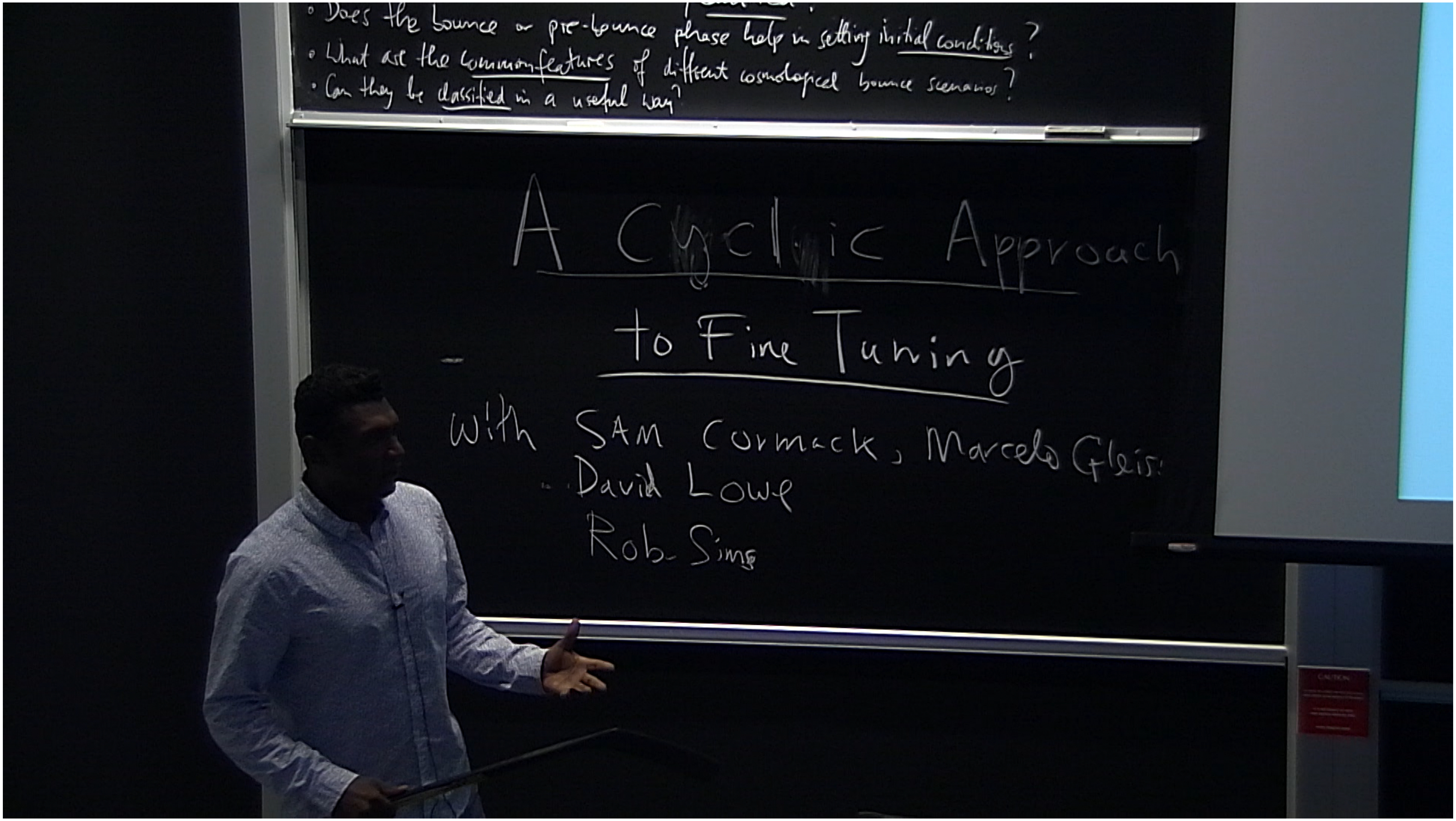
URL: http://pirsa.org/17060103

Abstract:



• Does the bounce or pre-bounce phase help in setting initial conditions?
• What are the common features of different cosmological bounce scenarios?
• Can they be classified in a useful way?
A Cyclic Approach
to Fine Tuning
with SAM Cormack, Marcelo Gleis
David Lowe
Rob Sims

The String Landscape

- Consider Heterotic String Theory

$$S = \frac{1}{2\alpha'^4}\int d^{10}x\sqrt{-g_{10}}\left(\mathcal{R}_{10} - \frac{1}{2}\partial_A\phi\partial^A\phi - \frac{1}{12}e^{-\phi}\left(H_{ABC} - \frac{\alpha'}{16}e^{\frac{\phi}{2}}\overline{\chi}_{10}\Gamma_{ABC}\chi_{10}\right)^2 - \frac{\alpha'}{4}e^{-\frac{\phi}{2}}\mathrm{tr}(F_{AB}F^{AB}) - \alpha'\mathrm{tr}(\overline{\chi}_{10}\Gamma^A D_A\chi_{10})\right)$$

$$ds^2_{10} = e^{-6\sigma}ds^2_4 + e^{2\sigma}g^0_{mn}dy^m dy^n \qquad \varphi = \frac{\phi}{2} - 6\sigma$$

$$g^2_{YM} \equiv e^{\varphi}$$

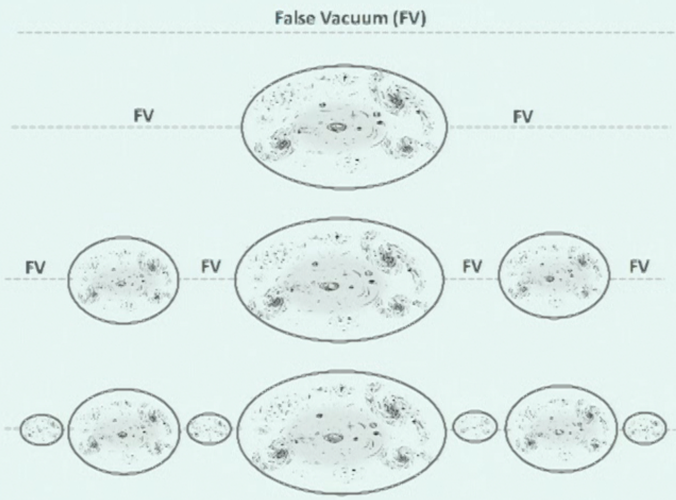
$$S_{4d} = S_{gravity} + S_{gauge} + S_{CY}$$

$$S_{gravity} = \frac{2}{\alpha'}\int d^4x\sqrt{-g_4}\left(\mathcal{R}_4 - \frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - \frac{3}{2}\partial_\mu\rho\partial^\mu\rho\right)$$

$$S_{gauge} = \int d^4x\sqrt{-g_4}\left(-\frac{1}{2g^2_{YM}}\mathrm{tr}(F_{\mu\nu}F^{\mu\nu}) - \frac{2}{g^2_{YM}}\mathrm{tr}(\overline{\lambda}\Gamma^\mu D_\mu\lambda)\right)$$

Inflationary Multiverse

String Landscape + Eternal Inflation

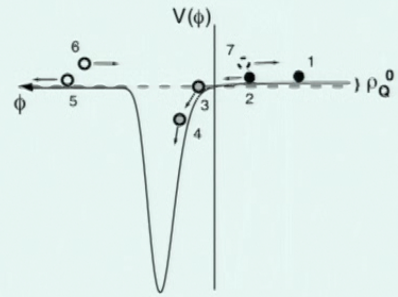


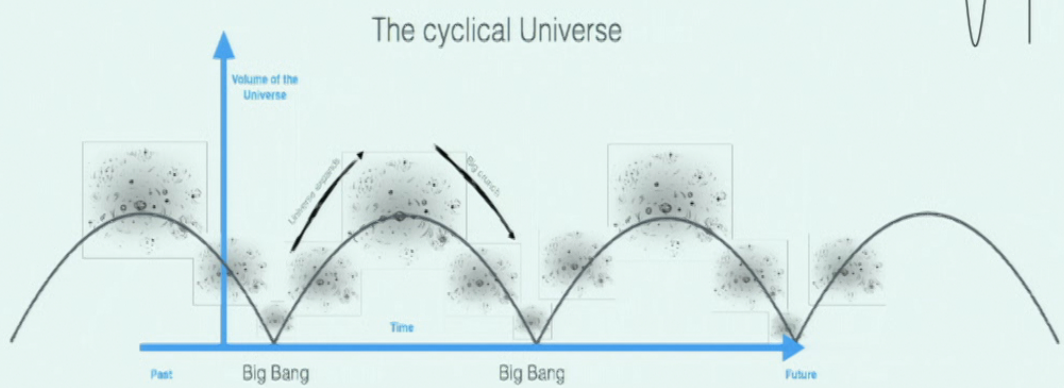
See Brandenberger for critique: CQG 2013

Cyclic Cosmologies

Addresses a host of cosmological problems (including CC problem)

Steinhardt, Truck (Science '02)





Cyclic Bounces

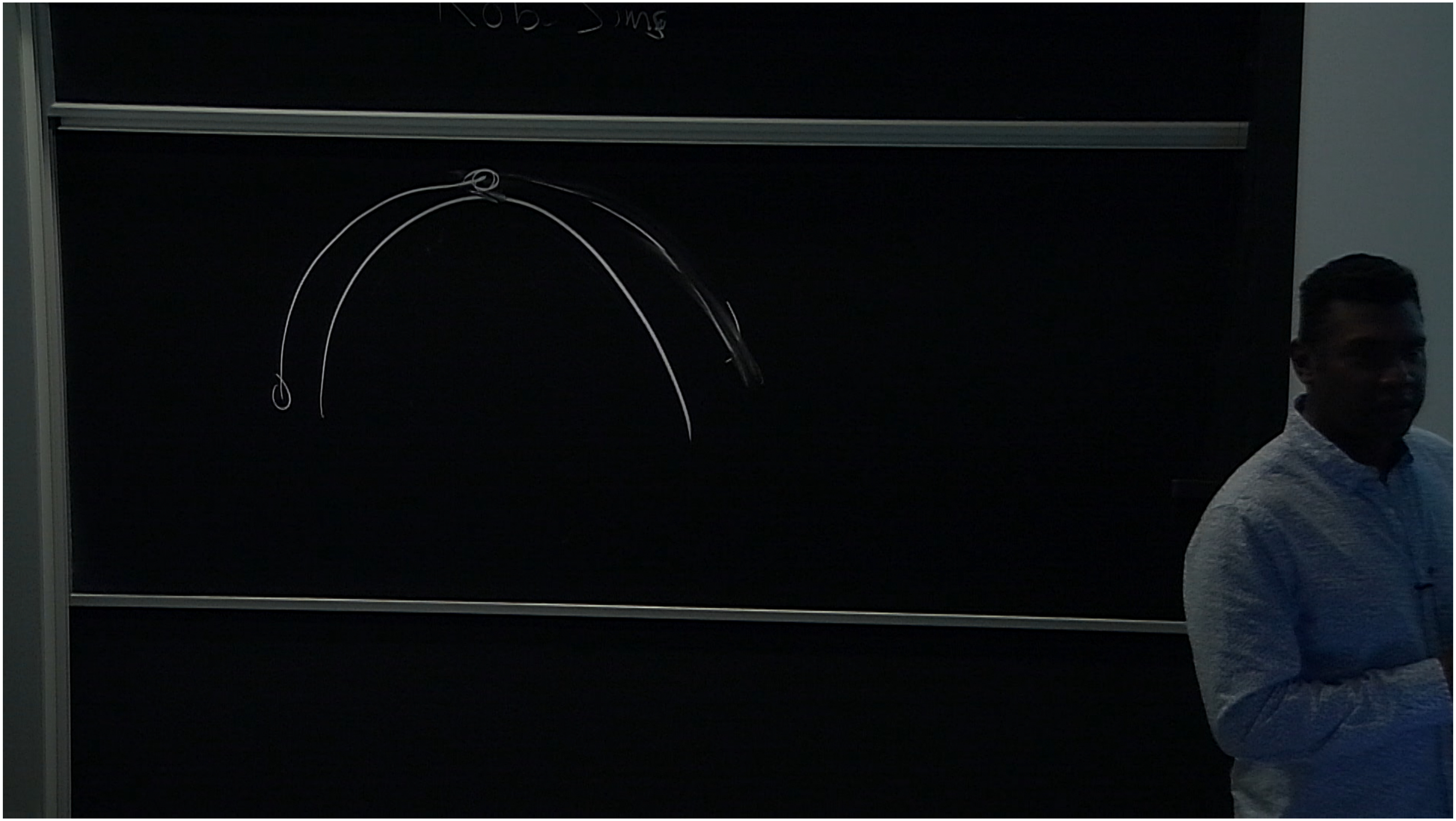
Promote all gauge sector couplings to a moduli field.

$$S = \int d^4x \sqrt{-g} \left[\frac{R}{16\pi G} - \frac{1}{2} \left[\epsilon \partial_\mu \psi \partial^\mu \psi + 2V(\psi) \right] + S_{gf} \right]$$

with

$$S_{gf} = -\frac{1}{4} \sum_i \frac{1}{(g^i_{YM})^2} F^i_{\mu\nu} F^{\mu\nu i},$$

$$V(\psi) = -\Lambda^4 (1 + \cos(\psi/f))$$



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E.O.M

$$\Psi'' = -2\mathcal{H}\Psi' + \frac{a^2\beta}{\tilde{f}}\sin(\Psi/\tilde{f});$$

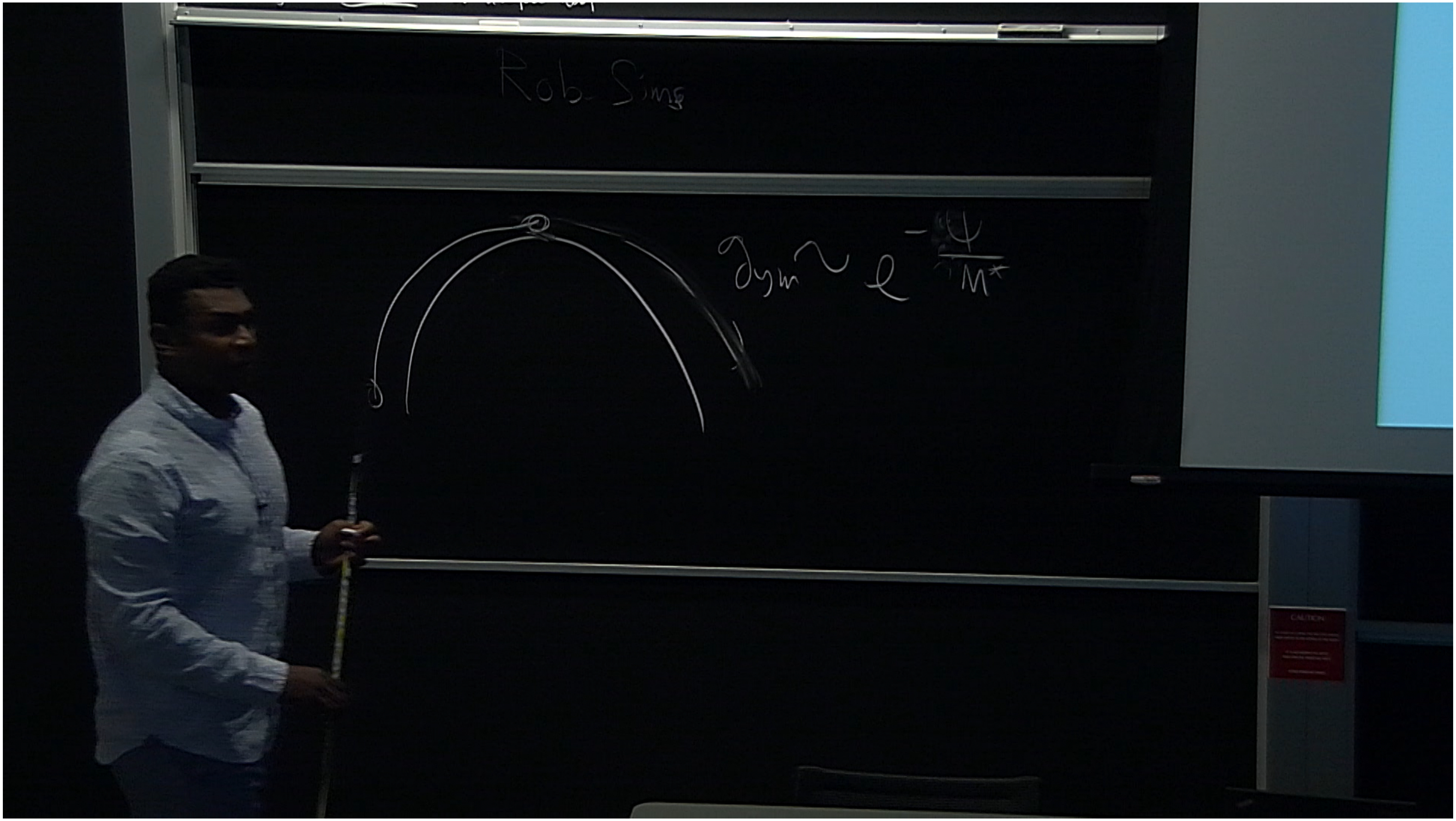
$$a'' = \frac{a'^2}{a} - \frac{1}{3a} + \frac{a\Psi'^2}{3} - \frac{a^3\beta}{3}(1+\cos(\Psi/\tilde{f}))$$

$$\mathcal{H}^2 = -\frac{\Psi'^2}{6} - \frac{a^2\beta}{3}\left(1+\cos(\Psi/\tilde{f})\right) + \frac{1}{3a^2} - \frac{KM_p^2}{\rho_{r0}}$$

when field is minimized we get exact solution :

$$\Psi' = \frac{\sqrt{\lambda}}{a^2};$$

$$a^2(\eta) = \frac{1}{6}\left[1+\sqrt{1-6\lambda}\sin(\eta+\eta_0)\right]$$


Rob Sims

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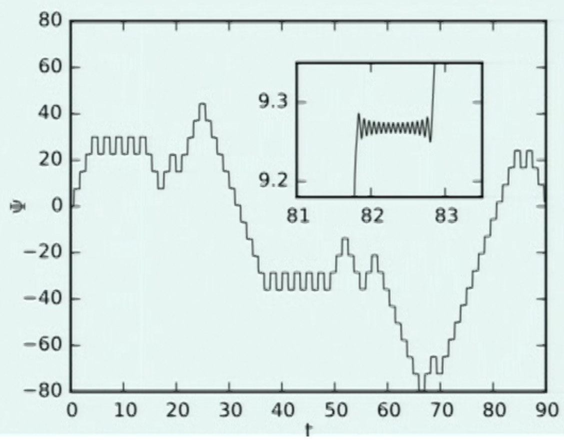
Evolution of Coupling Constants

1. Ψ remains approximately constant during the expansion and contraction phases.
2. Ψ changes relatively quickly during the bounce phase.
3. The change in Ψ can change sign from bounce to bounce in a pseudo-random way.

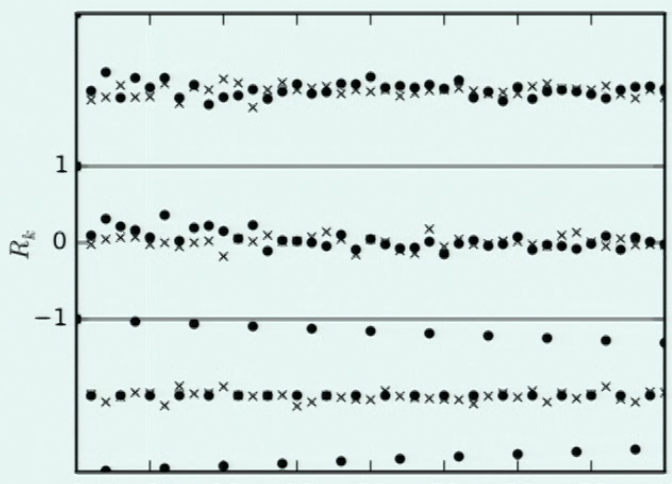


Behavior of Coupling

$$\Delta_i = \Psi_{i+1} - \Psi_i,$$

and define the autocorrelation of the differences as

$$R_k = \frac{\sum_{i=1}^{N-k} \Delta_i \Delta_{i+k}}{\sum_{i=1}^{N} \Delta_i^2}.$$



Observational Consistency

$$\frac{\Delta g_{YM}}{g_{YM}} \sim \Delta\Psi = \frac{\Delta\psi}{M_p}$$

Since the parameter f sets the variation of ψ away from the bounce, the fractional variation of g_{YM} will be of the order f/M_p.

Observations by Webb et al. suggest fine structure may have varied by

$$\frac{\Delta\alpha}{\alpha} = -0.72 \pm 0.18 \times 10^{-5}$$

Constrains coupling to be $f/M_p \sim 10^{-5}$

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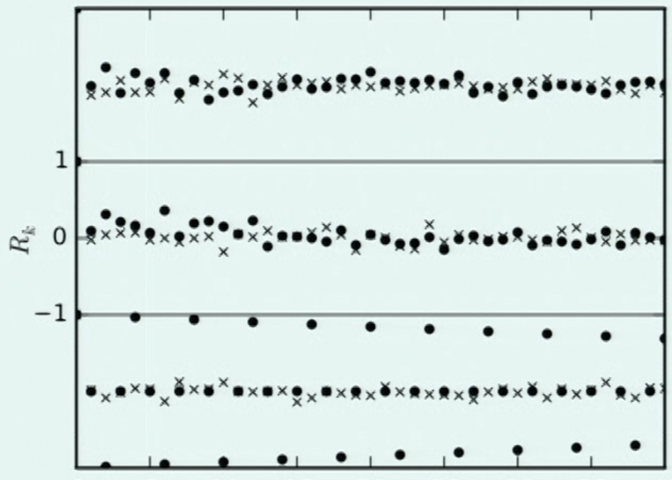
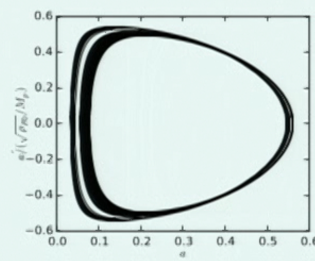
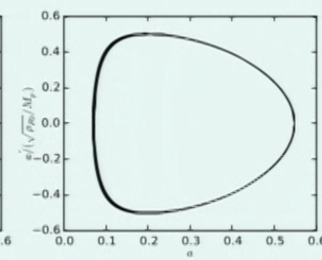


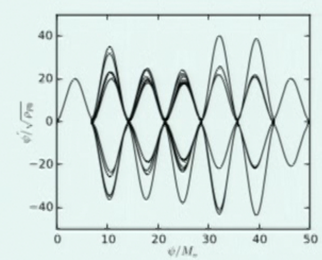
Stability Analysis



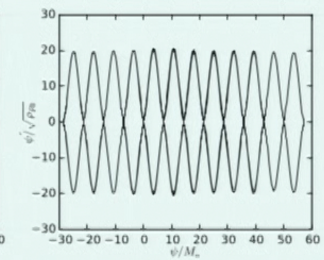
(a) Phase portrait showing limit cycle for $f = 10^{-2} M_p$



(b) Phase portrait showing limit cycle for $f = 10^{-3} M_p$



(c) Phase portrait for ghost field,



(d) Phase portrait for ghost field,

Peturbations

$$\psi \mapsto \psi(\eta) + \chi(\eta, \mathbf{x})$$

$$ds^2 = a^2(\eta)\left(-(1+2\phi)\,d\eta^2 + (1-2\theta)\,\gamma_{ij}dx^i dx^j\right)$$

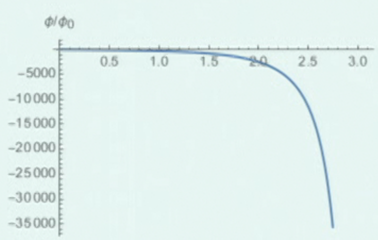
$$\nabla^2\phi - 3\mathcal{H}\phi' - 3\phi\left(\mathcal{H}^2 - \mathcal{K}\right) = \frac{1}{2M_p^2}\left(\phi\left(\psi'\right)^2 - \psi'\chi' + a^2\frac{\partial V}{\partial\psi}\chi\right)$$

$$\mathcal{H}\phi + \phi' = -\frac{1}{2M_p^2}\psi'\chi$$

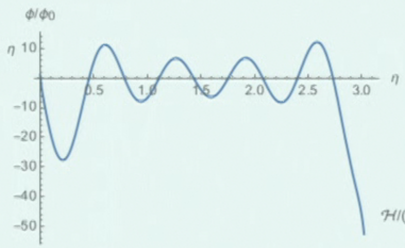
$$\phi'' + 3\mathcal{H}\phi' + \left(2\mathcal{H}' + \mathcal{H}^2 - \mathcal{K}\right)\phi = \frac{1}{2M_p^2}\left(\phi\left(\psi'\right) - \psi'\chi' - a^2\frac{\partial V}{\partial\psi}\chi\right)$$

$$\phi_k'' + 6\mathcal{H}\phi_k' + \left(k^2 + 2\mathcal{H}' + 4\mathcal{H}^2 - 4\mathcal{K}\right)\phi_k = 0.$$

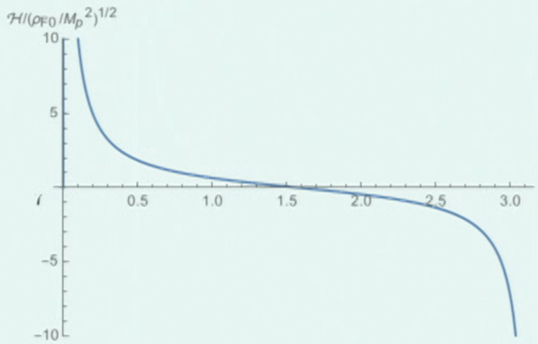
$$\chi_k'' + 2\mathcal{H}\chi_k' + \left(k^2 + \frac{2}{M_p^2}\psi'^2\right)\chi_k = -4\mathcal{H}\psi'\phi_k.$$

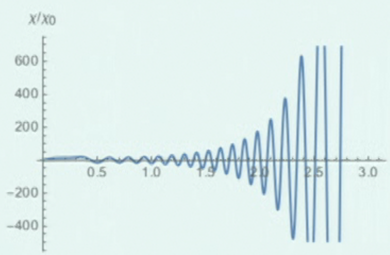


(c) $k = \sqrt{\rho_{F0}}/M_p$



(d) $k = 10\sqrt{\rho_{F0}}/M_p$





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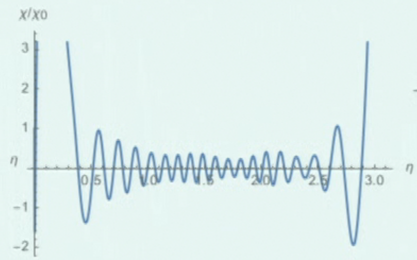


(b) $k = 10\sqrt{\rho_{F0}}/M_p$

note: amplitudes of perts are relative to their initial amplitudes at bounce.

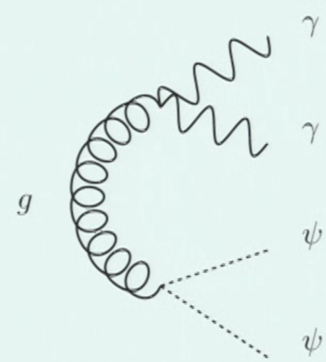
$$k \gtrsim 10\sqrt{\rho_{F0}}/M_p$$

Perts that enter horizon early are stable throughout expansio
and contraction

$$k \lesssim 10\sqrt{\rho_{F0}}/M_{p:}$$

Perts that enter horizon later are unstable throughout expansion and contraction

Quantum Stability



(a) Graviton mediated vacuum decay

(b) Direct coupling vacuum decay

These could be alleviated by Ghost Condensate (Arkani-Hamed et al.)

$$S = \int d^3x dt \left[\frac{1}{2} M^4 \dot{\phi}^2 - \frac{1}{2} \tilde{M} (\nabla^2 \phi)^2 - \frac{M^4}{2c} \dot{\phi} (\nabla \phi)^2 + \frac{M^4}{8c^2} (\nabla \phi)^4 + ... \right]$$

Conclusion

- Cyclic Bouncing Cosmologies can be useful for addressing fine tuning of gauge couplings of standard model.
- The toy theory presently relies on ghost moduli fields which are randomized during bounce.
- Couplings get stabilized due to Hubble friction.
- Stability analysis showed that system is classically stable.
- Currently investigating issue of quantum stability.
- A more realistic setting may be Ekpyrotic which uses $w>1$ eos.