Title: PSI 2018/2019 - Cosmology Review - Lecture 15

Date: Jan 25, 2019 09:00 AM

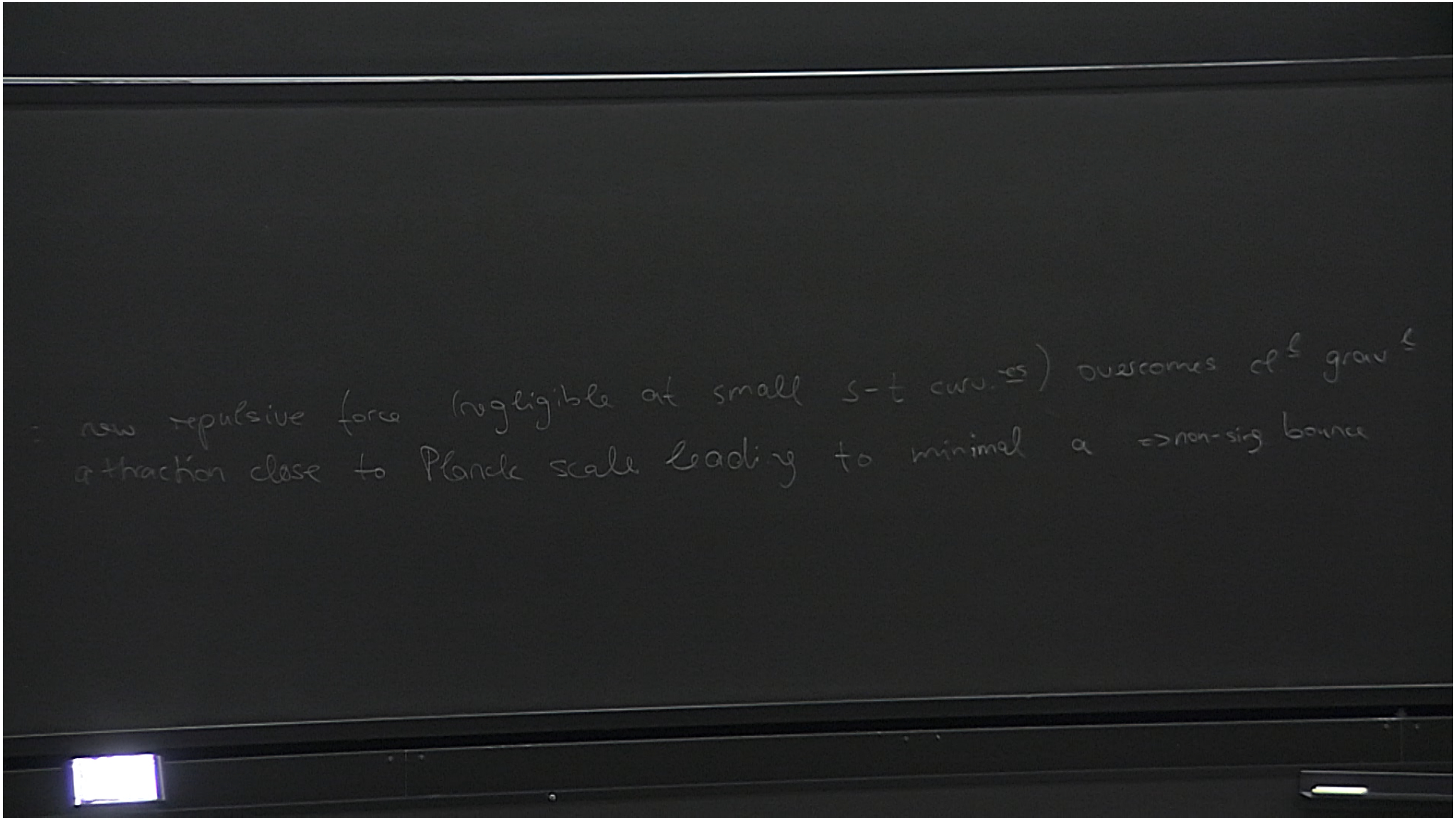
URL: http://pirsa.org/19010016

Abstract:

to resolve sing. ⇊ { exotic matter
modify gravity
qu. departure from GR

QC based:

- LQC based on LQG [Ashtekar, Singh et al.]


: new repulsive force (negligible at small s-t curv.-es) overcomes cl.s grav.-t
attraction close to Planck scale leading to minimal a => non-sing bounce

to resolve sing ↓ { exotic matter
modify gravity
qu. departure from GR

QC based:

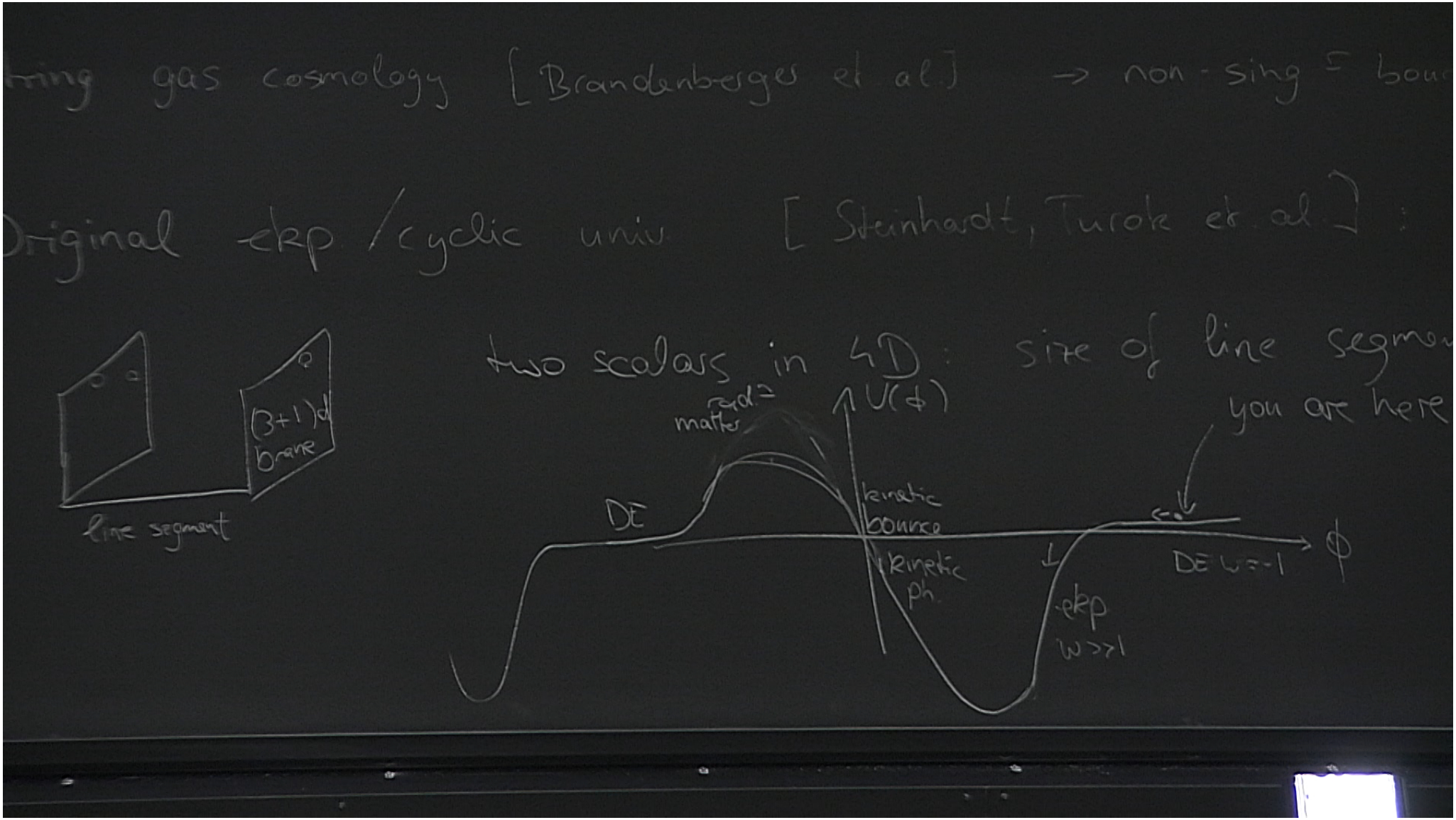
- LQC based on LQG [Ashtekar, Singh et al] : new repul
attraction

- Canonical QG [Dirac, DeWitt, Bergmann] : wave fn of the univ

epulsive force (negligible at small s-t curv. $\leq$) overcomes eff$^{\underline{e}}$ grav $\leq$

on close to Planck scale leading to minimal a $\Rightarrow$ non-sing bounce

w vanishes for vanishing a $\rightarrow$ spontaneously avoid sing^{y} with bounce [Pinto-Neto et al]


ring gas cosmology [Brandenberger et al] → non-sing ≠ bou
Original ekp / cyclic univ [Steinhardt, Turok et al]:
(3+1)d brane
line segment
two scalars in 4D: size of line segm
matter
U(ϕ)
you are here
DE
kinetic bounce
kinetic ph
ekp
w>>1
DE w=-1
ϕ

→ non-sing ⊂ bounce with string gas (at ~ Hagedorn temp

Turok et al.] : sing ⊂ bounce based on heterotic M-Theory

e of line segment, vol. of CY

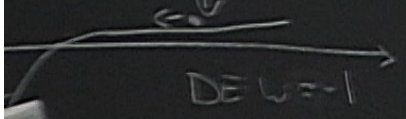
you are here

habitable

- only a small fraction of our uni

but will crunch

the rest will crunch.



with stringy gas (at ~ Hagedorn temp)

string = bounce based on heterotic M-Theory

t, vol. of CY

- only a small fraction of our univ. will make it through the bounce

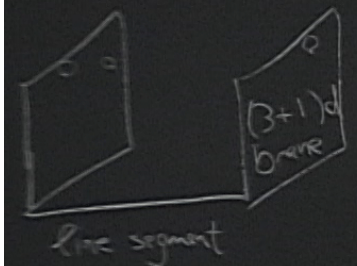


the rest will crunch.

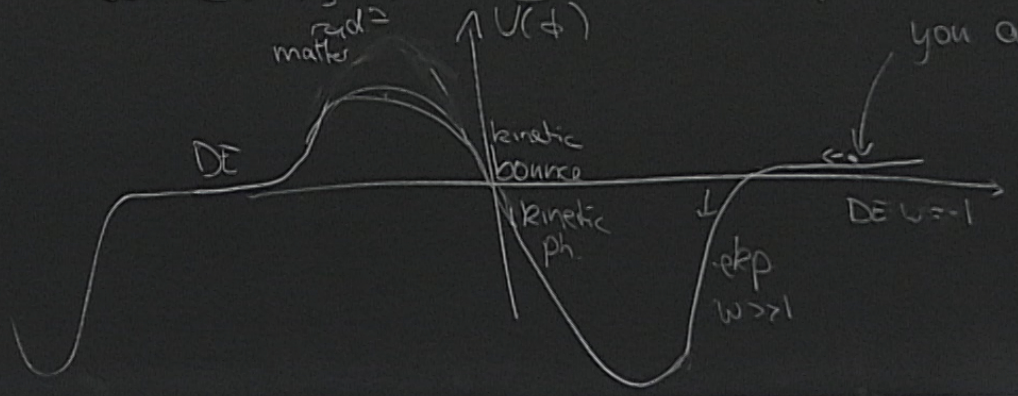
- the huge growth per cycle avoids the build-up of entropy
  ↳ is diluted

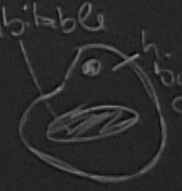
ng gas cosmology [Brandenberger et al.] → non-sing ≠ bounce with stringy

iginal ekp / cyclic univ [Steinhardt, Turok et al.] : sing ≠ bounce



two scalars in 4D : size of line segment, vol. of





- only
the rest
- the huge

Antigravity [Bars et al.] : minimal conformal extension to SM. →

(Generalised) Galileon / Horndeski th. : higher derivatives,

- they can be implemented in SUGRA

Massive gravity [Biswas et al.] : graviton becomes massive → n

minimal conformal extension to SM → brief antigravity ph. at $t \sim 0$

$\mathcal{L}_{SR}$: $H_{\mu\nu}$: higher derivatives, only 2nd order eom.s

ented in SUGRA

Λ = graviton becomes massive → non-sing. $\mathcal{L}_{SR}$

Ghost condensate

$$\mathcal{L} = \sqrt{-g}\left[\frac{R}{2} + K(\phi)X + T(\phi)X^2 - U(\phi)\right]$$

$$X \equiv -\frac{1}{2} g^{\mu\nu}\partial_\mu\phi\,\partial_\nu\phi$$

(ekp. $K=1$, $T=0$, $U=-V_0 e^{-c\phi}$)

eg. $K(\phi) = 1 - \frac{2}{(1+\phi^2)^2}$ $\quad T(\phi) = \frac{T_b}{(1+\phi^2)^2}$

Ghost condensate

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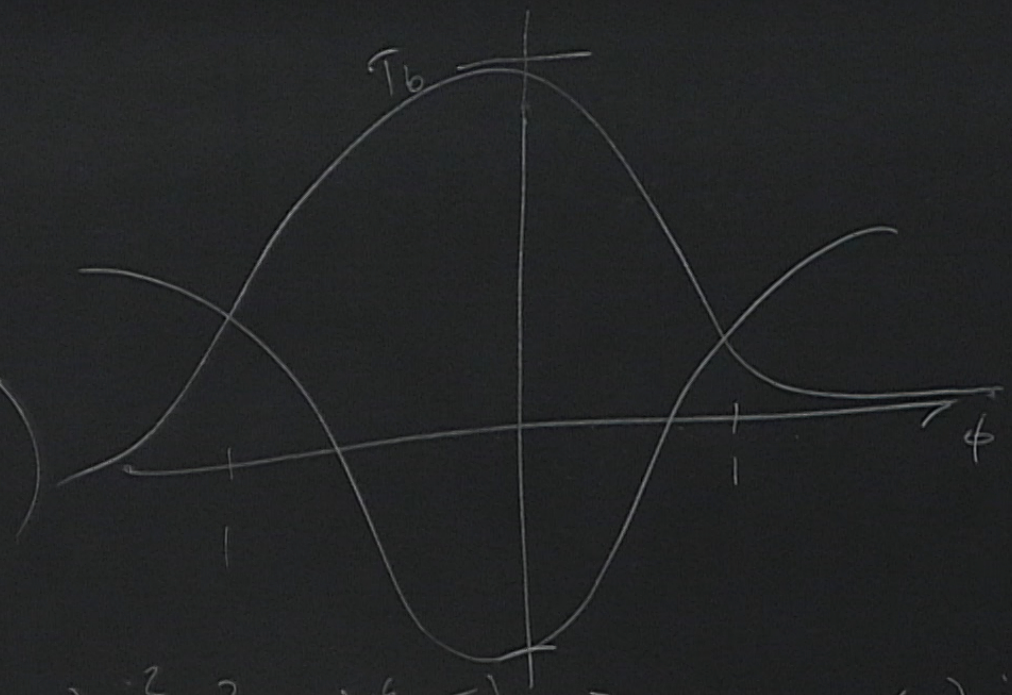
(exp. $K=1$, $T=0$, $U=-V_0 e^{-c\phi}$)

eg. $K(\phi) = 1 - \frac{2}{(1+\phi^2)^2}$ $\quad T(\phi) = \frac{T_b}{(1+\phi^2)^2}$ en dims $\rho = \frac{1}{2}K(\phi)\dot{\phi}^2 +$

$$T_{\mu\nu} = -\frac{2}{\sqrt{-g}}\frac{\delta \mathcal{L}}{\delta g^{\mu\nu}} \qquad T^0_{\ 0} = -\rho \qquad T^i_{\ i} = P$$

$(\phi)]$

$T=0,\ V=-V_0 e^{-c\phi}$



en dims $\rho = \frac{1}{2}K(\phi)\dot{\phi}^2 + \frac{3}{4}T(\phi)\dot{\phi}^4 - V(\phi)$

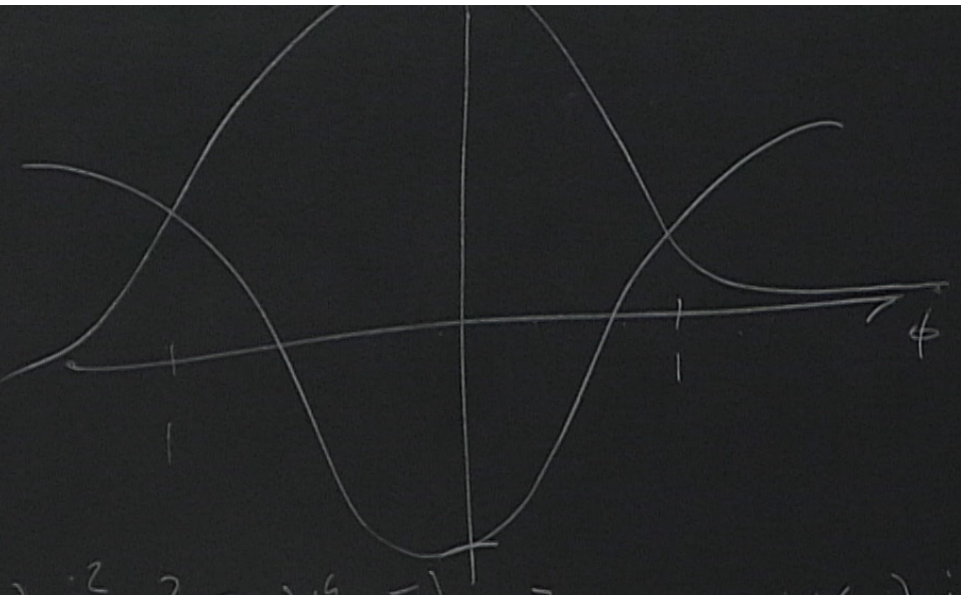
pression $p = \frac{1}{2}K(\phi)\dot{\phi}^2 + \frac{1}{4}T(\phi)\dot{\phi}^4 - V(\phi)$

$\rho + p = K(\phi)\dot{\phi}^2 + T(\phi)\dot{\phi}^4$

$\rho + p|_{\phi=0} = -\dot{\phi}^2 + T_b\dot{\phi}^4$

$-U(\phi)]$

$c=1,\ T=0,\ U=-V_0 e^{-c\phi}$)



$\left.\begin{aligned} \text{en dims}\quad \rho &= \tfrac{1}{2}K(\phi)\dot\phi^2 + \tfrac{3}{4}T(\phi)\dot\phi^4 - V(\phi) \\ \text{pressure}\quad p &= \tfrac{1}{2}K(\phi)\dot\phi^2 + \tfrac{1}{4}T(\phi)\dot\phi^4 - V(\phi) \end{aligned}\right\} \rho + p = K(\phi)\dot\phi^2 + T(\phi)\dot\phi^4$

$\rho + p\big|_{\phi=0} = -\dot\phi^2 + T_0\dot\phi^4$

$\dot\phi^2 < \frac{1}{T_0}$ for ~~NEC~~

$$\phi = \bar{\phi}(t) + \delta\phi(t)$$

$$\delta\mathcal{L}^{(2)} \supset \int d^4x \sqrt{-g} \left(\frac{1}{2} K(\phi) (\delta\dot{\phi})^2 + \frac{1}{4} T(\phi) (\dot{\bar{\phi}} + \delta\dot{\phi})^4 \right)$$

$$\delta\mathcal{L}^{(2)}\big|_{\phi=0} \supset \int d^4x \sqrt{-g} \, (\delta\dot{\phi})^2 \left[-\frac{1}{2} + \frac{3}{2} T_b \dot{\bar{\phi}}^2 \right]$$

need $\dot{\bar{\phi}}^2 > \frac{1}{3T_b}$ to avoid ghosts

$$\to \frac{1}{3\Gamma_b} < \dot{\phi}^2\Big|_{\phi=0} < \frac{1}{\Gamma_b}$$

$$\Gamma(\phi)\left(\dot{\bar{\phi}} + \delta\dot{\phi}\right)^4\Big)$$

$$\dot{\bar{\phi}}^2\Big]$$

$\frac{1}{\Gamma_b}$ to avoid ghosts

$\phi = \bar{\phi}(t) + \delta\phi(t)$

$\rightarrow \frac{1}{3\bar{T}_b} < \dot{\phi}$

$$\delta\mathcal{L}^{(2)} \supset \int d^4x \sqrt{-g} \left(\frac{1}{2} K(\phi) (\delta\dot{\phi})^2 + \frac{1}{4} \bar{T}(\phi) (\dot{\bar{\phi}} + \delta\dot{\phi})^4 \right)$$

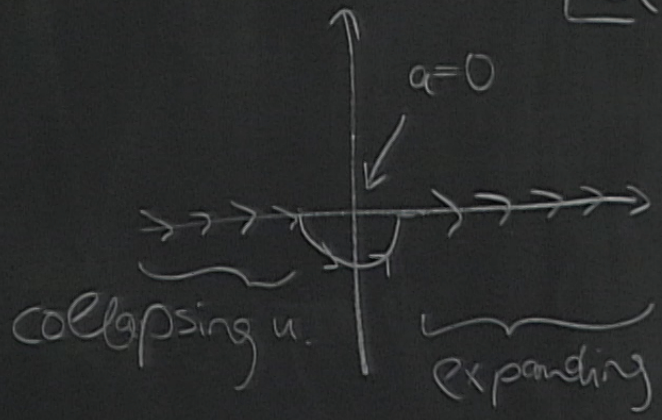
$$\delta\mathcal{L}^{(2)}\big|_{\phi=0} \supset \int d^4x \sqrt{-g} \, (\delta\dot{\phi})^2 \underbrace{\left[-\frac{1}{2} + \frac{3}{2} \bar{T}_b \dot{\bar{\phi}}^2 \right]}$$

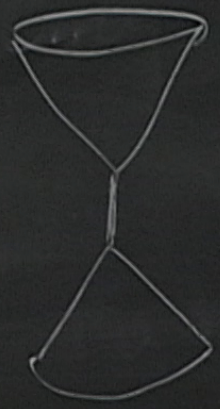
need $\dot{\bar{\phi}}^2 > \frac{1}{3\bar{T}_b}$ to avoid ghosts

- long wavelength fluct^{ns} propagate unharmed through the bounce [Koehn et. al]

→ avoid $a = 0$ in the complex plane

$\mathbb{C}a$

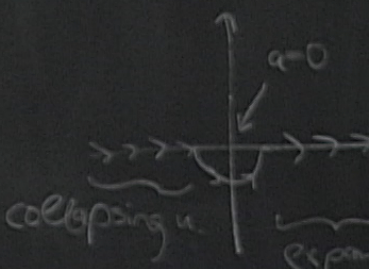




Perfect Bounce [Gielen, Turok]

extend QC in a minimal way

- extend a to -ve & complex values → avoid a = 0
  (-ve: cl.; complex: qu.)
- b.c.s at $a \to \pm\infty$



the complex plane

simplest ex. flat FRW filled w/ rad =



Perfect Bounce [Gielen, Turok]

$$S_{EH} = \frac{1}{16\pi G}\int d^4x \sqrt{-\tilde{g}}\,\tilde{R}[\tilde{g}] \qquad \tilde{g}_{\mu\nu} = g_{\mu\nu}\phi^2 \left(\frac{}{}\right.$$

Stückelberg trick: introduce sc field + add $\frac{1}{2}$ symmetry

$$\rightarrow S = \int d^4x \sqrt{-g}\left(\frac{1}{2}(\partial\phi)^2 + \frac{\phi^2}{12}R[g]\right) \qquad \rightarrow g \rightarrow \Omega^2 g\,,\ \phi \rightarrow \left(\right.$$

$$a \sim \underbrace{g_r^{-1/2} (-g)^{-1/8}}_{+ve} \phi$$

$\left(\frac{3}{4}\pi G\right)$

so no extra def s

$\Rightarrow \Omega' \phi$ leaves S inv. $\Rightarrow$ Weyl inv

$a \sim \underbrace{g_r^{-1/2} (-g)^{-1/8}}_{+ve} \phi$

$\hat{H}|\Psi\rangle = 0 \Rightarrow \left(-\frac{d^2}{da^2} + \frac{c}{a^2} + m^2\right)\chi = 0$

def ?

inv. $\frac{1}{3}$ $\Rightarrow$ Weyl inv $\frac{e}{}$

$a \sim \underbrace{\rho_c \, (-g)^{-1/2}}_{+ve}{}^{-1/8} \, \phi$

$\langle d\underline{I} \rangle = 0 \Rightarrow \left(-\frac{d^2}{da^2} + \frac{\overset{\downarrow}{c}}{a^2} + m^2 \right) \chi = 0$

def ?

inv. $\overset{t}{=}$ $\Rightarrow$ Weyl inv $\overset{e}{=}$

$$a \sim \underbrace{\beta_c \, (-g)^{-1/2}}_{+ve}{}^{-1/3} \, \phi$$

$$(-\partial^2 - \underbrace{c}_{\downarrow})\chi = 0 \quad \Rightarrow \quad \left(-\frac{d^2}{da^2} + \frac{c}{a^2} + m^2\right)\chi = 0$$

$$\chi^{(\pm)} \sim e^{\mp i m a} \qquad \text{both at } a \to \begin{cases} +\infty \\ -\infty \end{cases}$$

$\Rightarrow$ Weyl inv