Title: Spinflation

Date: Apr 08, 2008 02:00 PM

URL: http://pirsa.org/08040004

Abstract: TBA

Spinflation

Ivonne Zavala

IPPP, Durham

Based on: JHEP04(2007)026 and JCAP02(2008)010

In collaboration with:

Easson, Gregory, Tasinato and Mota

Motivation

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- String theory: mathematical theory that needs experimental tests.
- Can string theory provide a fundamental origin for the inflaton field?

D-Brane Inflation

- Open string inflation: brane position is the inflaton.

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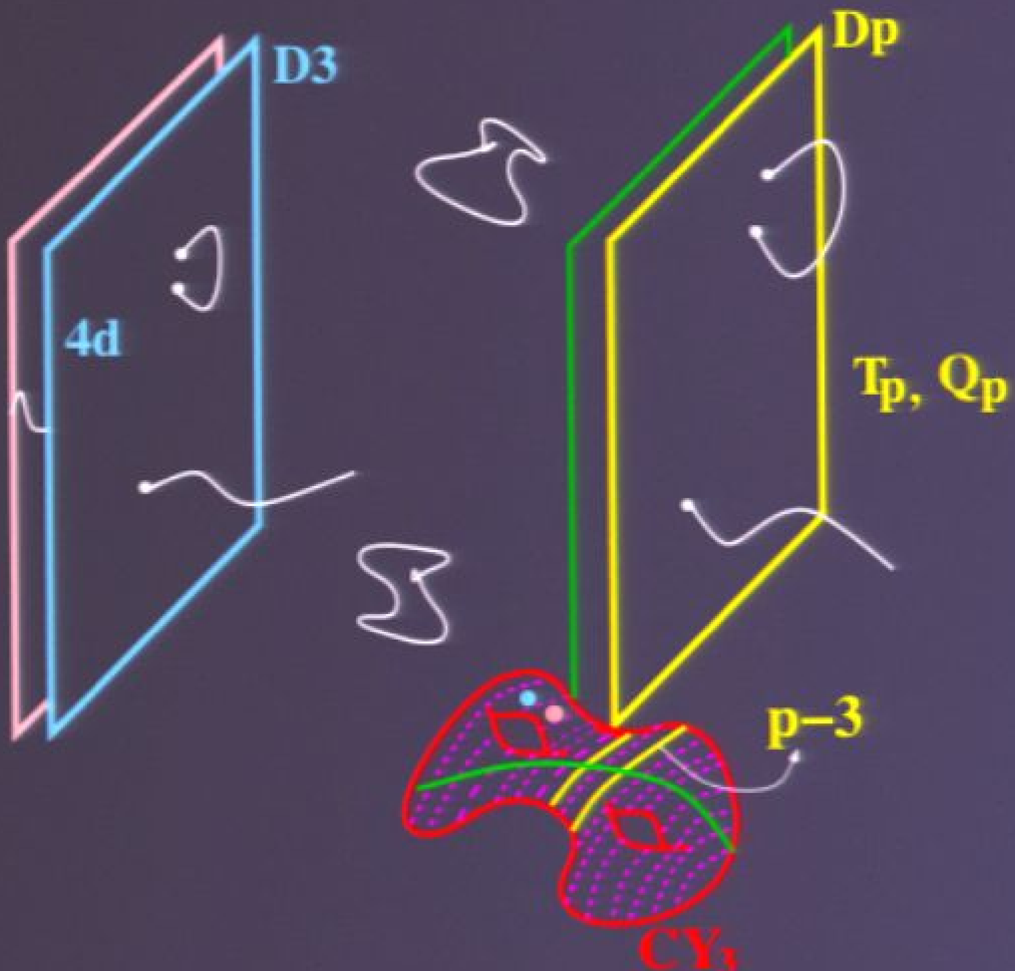

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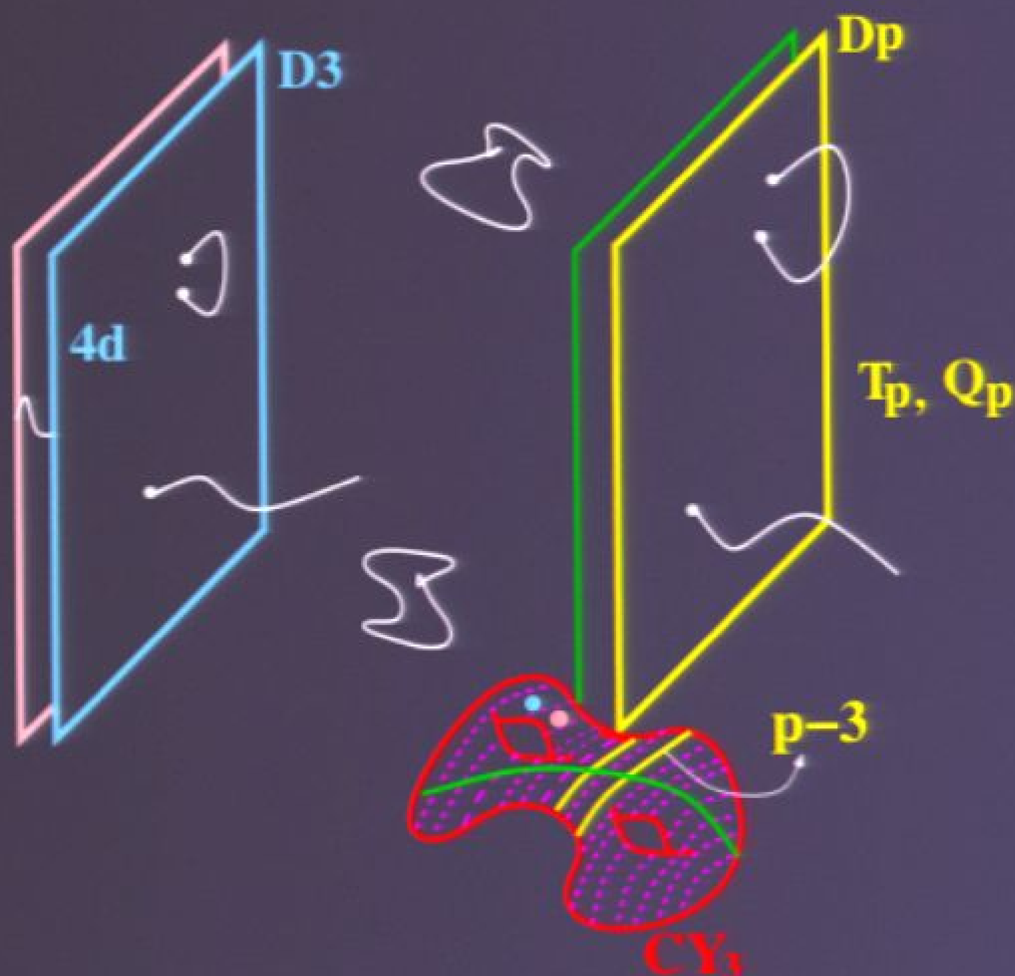

CY compactification
(un warped)

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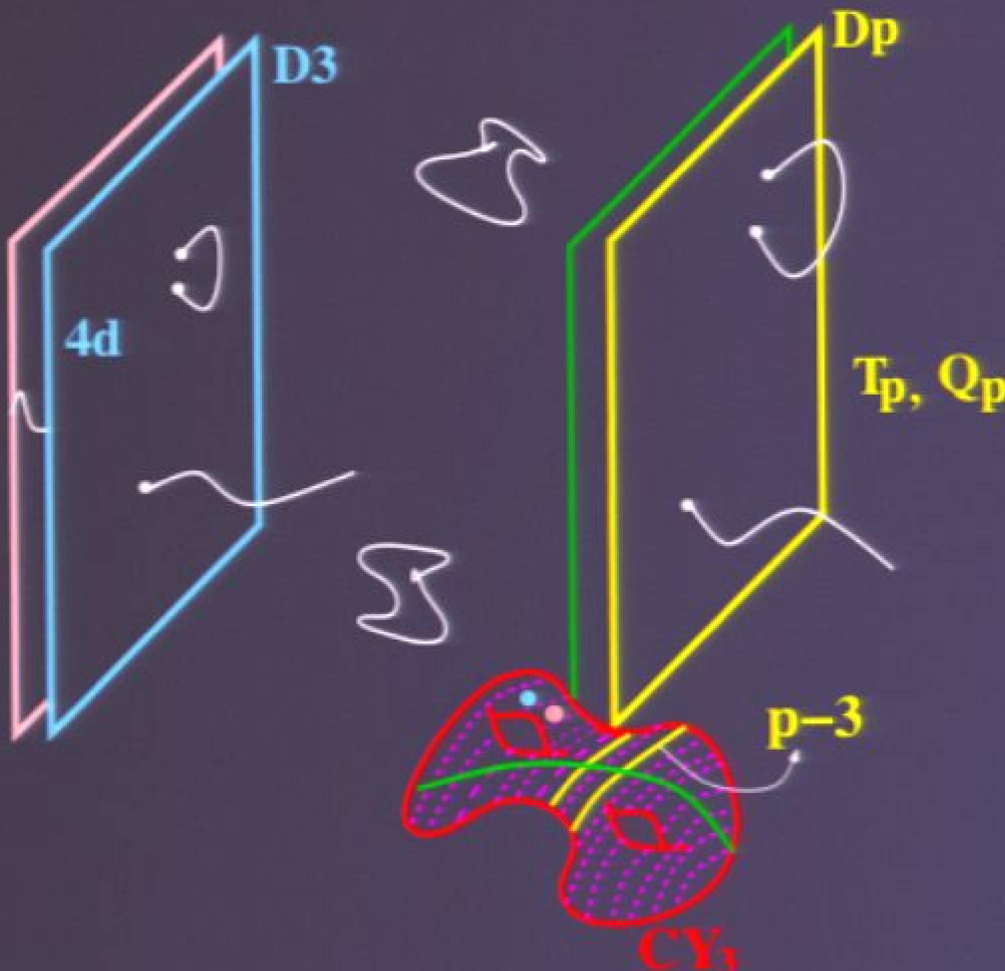

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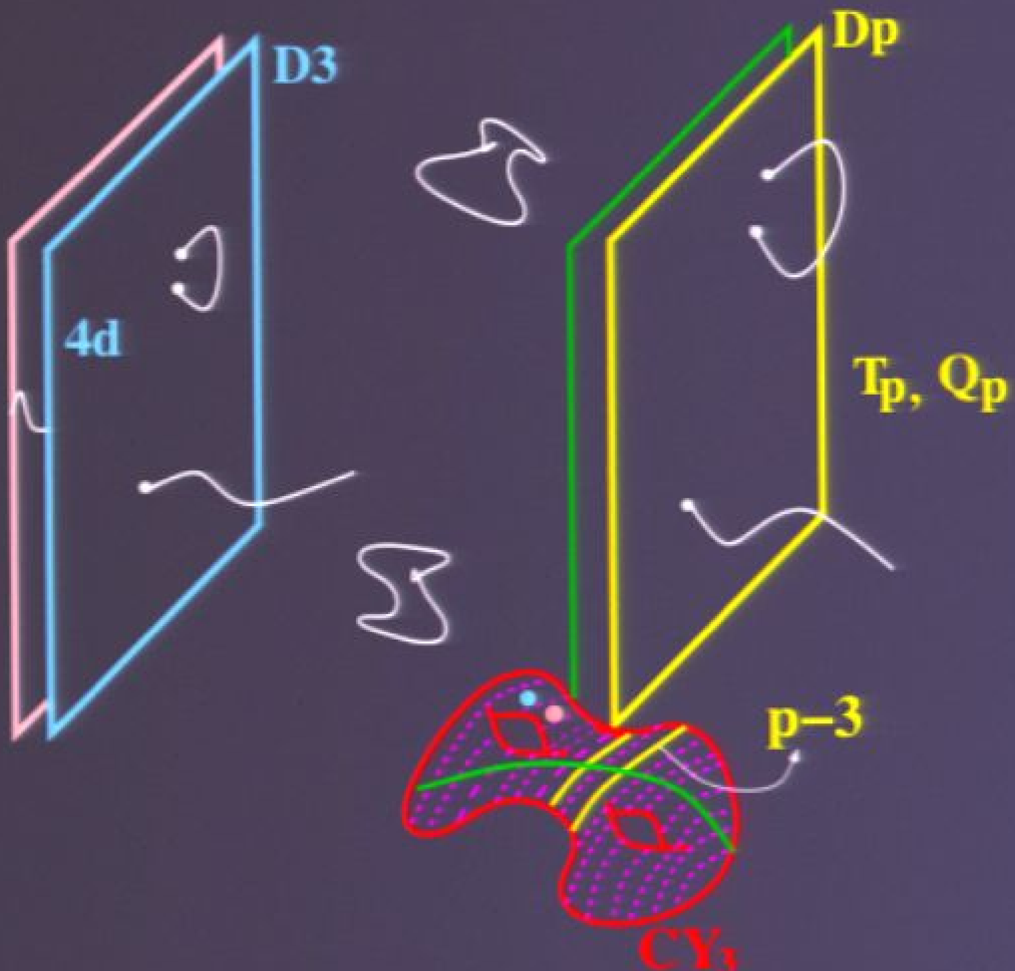

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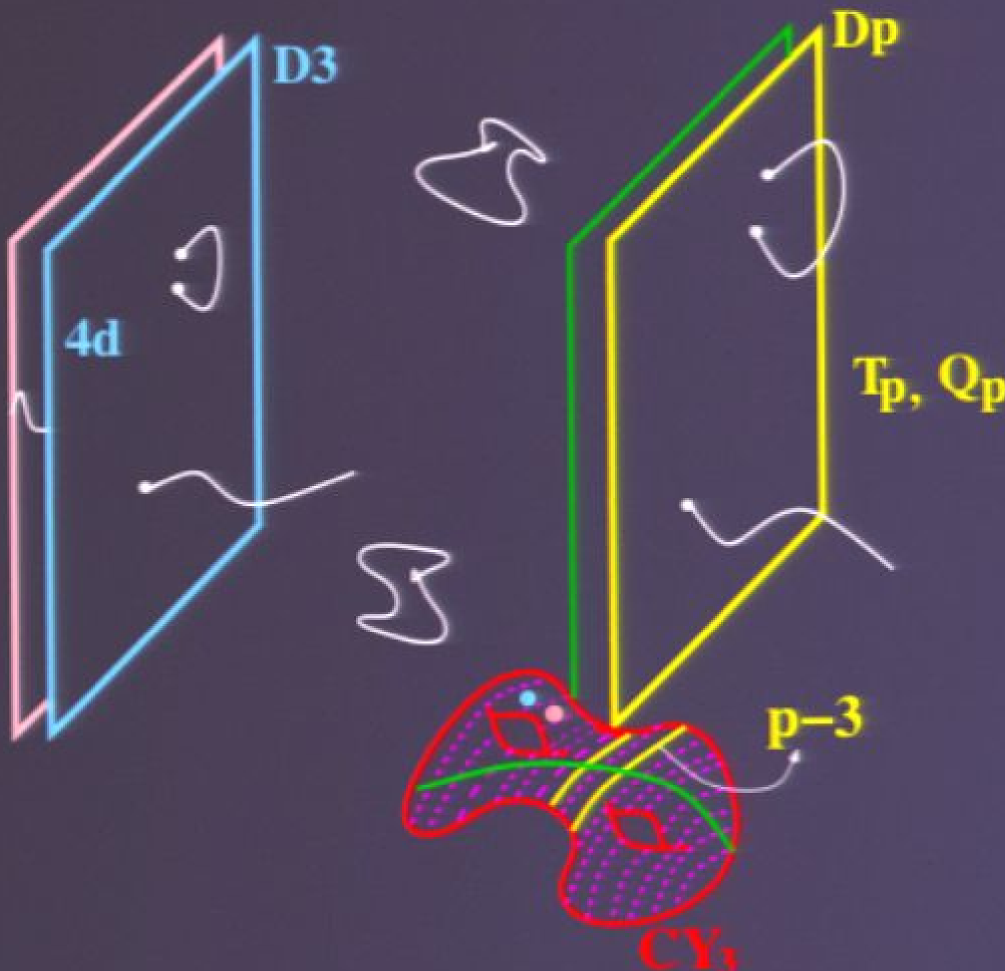

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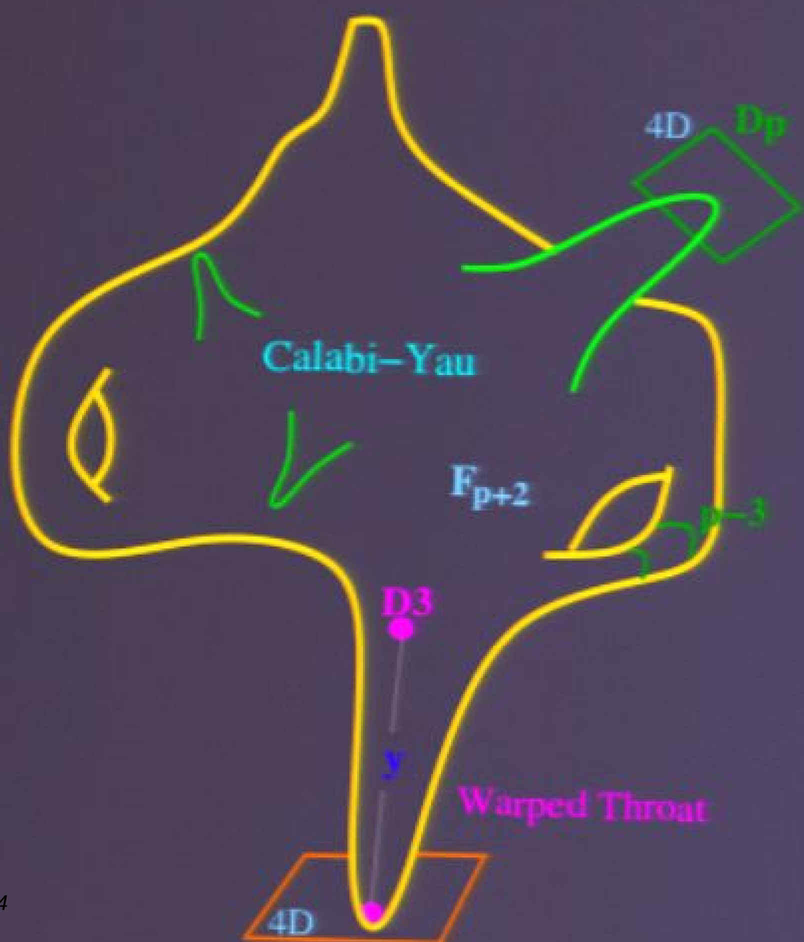

Warped CY
compactification (+ fluxes)

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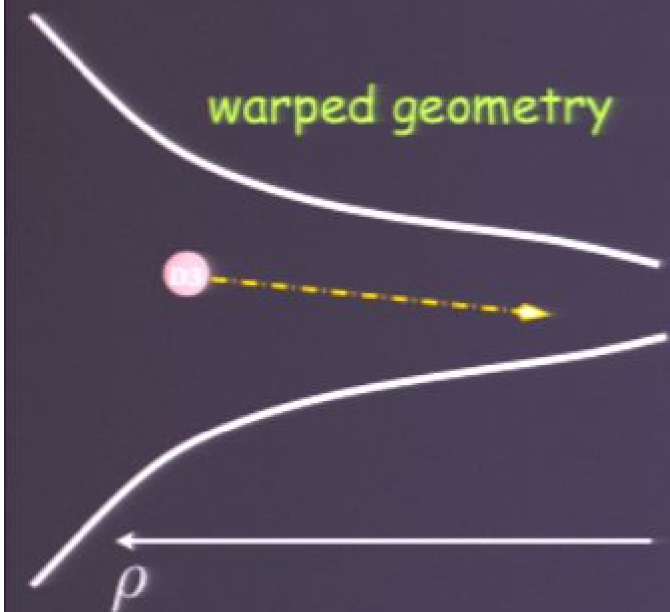
DBI scenario

[Silverstein-Tong]



- Consider the dynamics of a probe D3-brane moving along radial direction in a warped geometry with F5 flux: AdS5 x S5

$$ds_{10}^2 = h^{-1/2}(\rho)\,dx_\mu dx^\mu + h^{1/2}(\rho)\,ds_6^2$$

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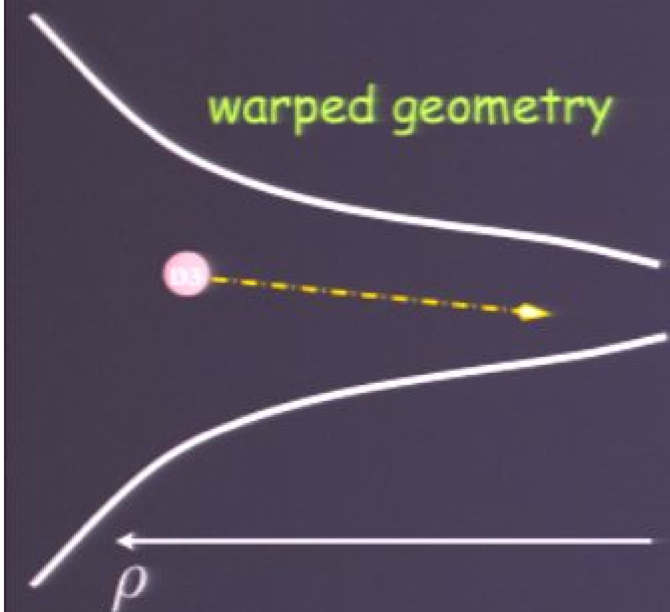

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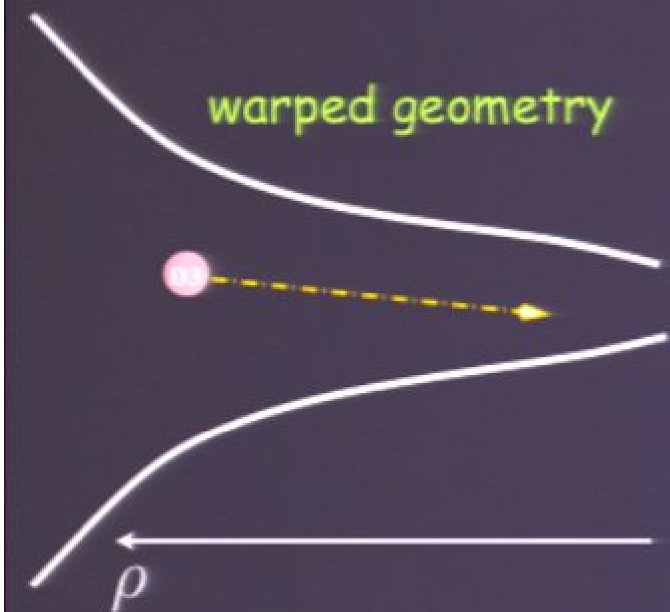

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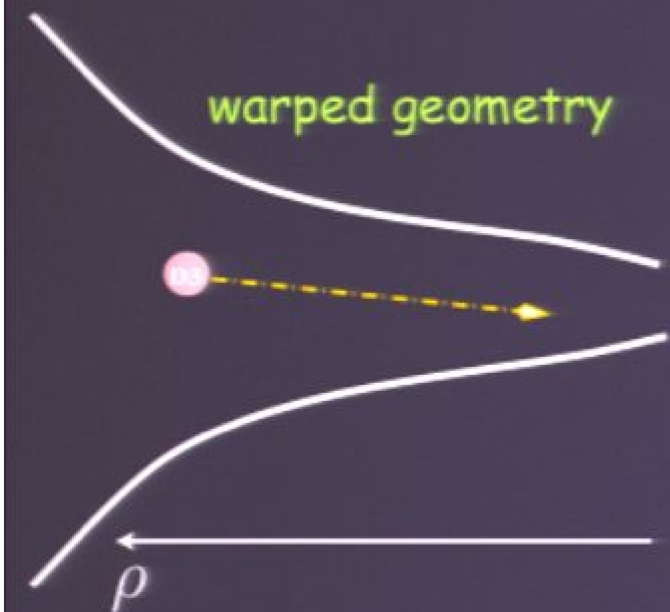

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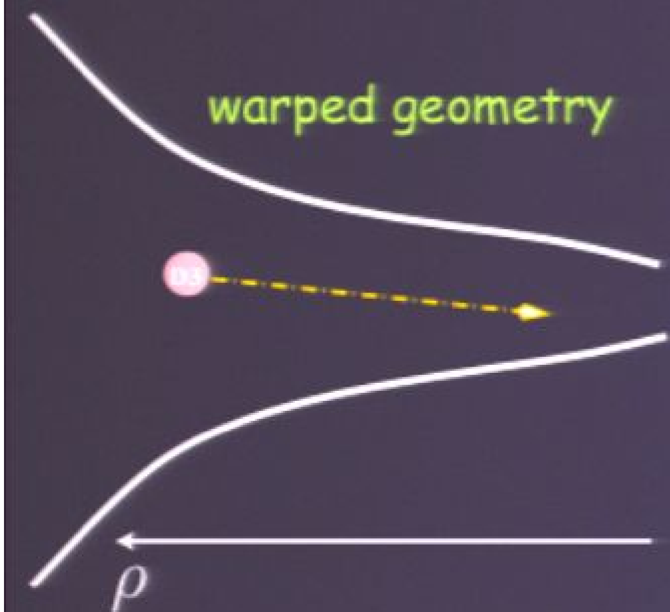

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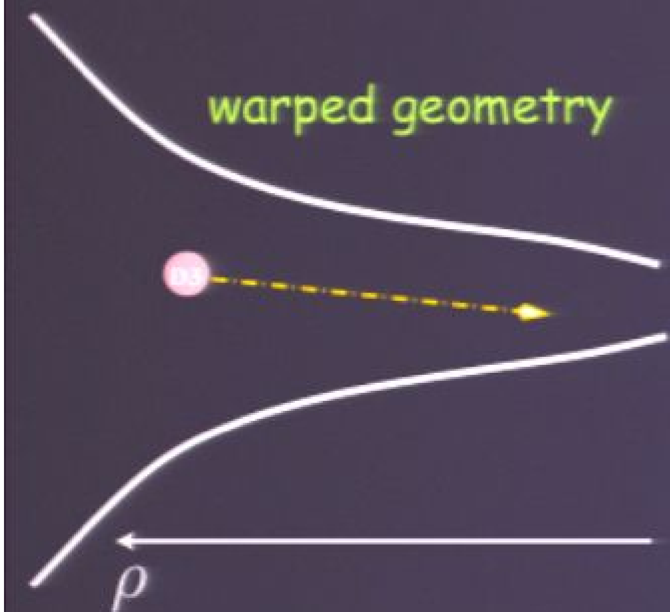

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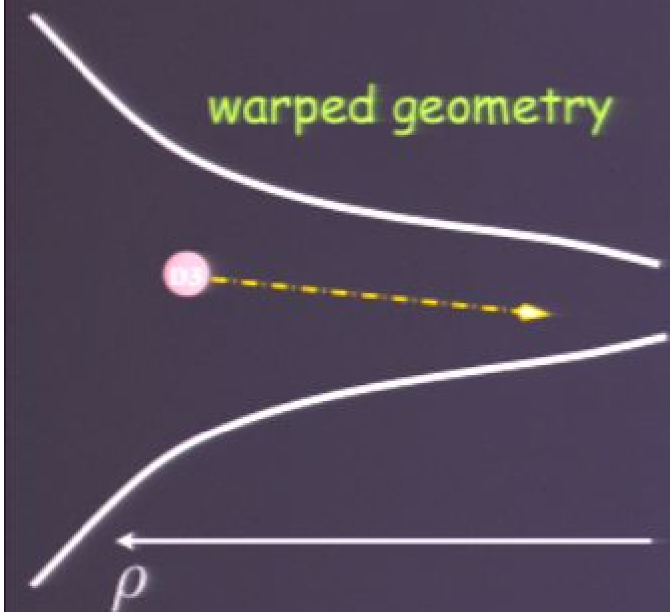

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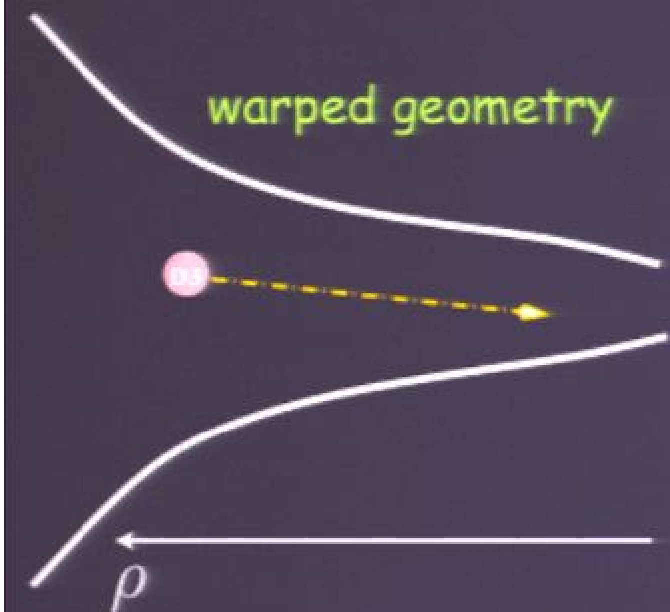

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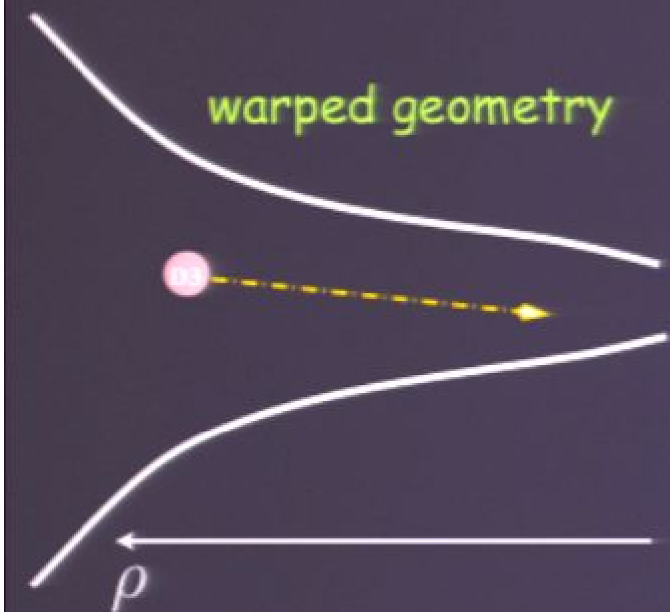

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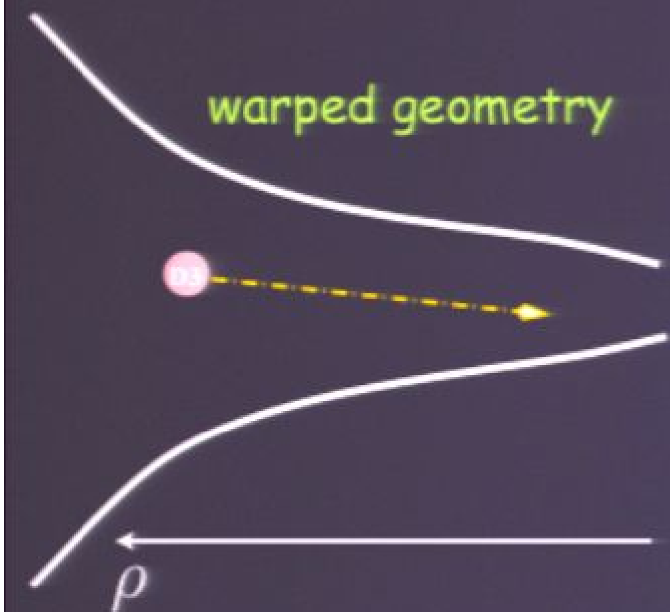

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$$v^2 = g_{\rho\rho}\dot{\rho}^2 \qquad \Longrightarrow \qquad hv^2 < 1$$

Brane trajectories (q=1, branes)

- Conserved energy

$$E = \frac{(\gamma - 1)}{h}; \qquad \gamma \equiv \frac{1}{\sqrt{1 - hv^2}} \qquad (v^2 = g_{\rho\rho}\dot{\rho}^2)$$

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Simple trajectories: brane moves from infinity towards the horizon at .

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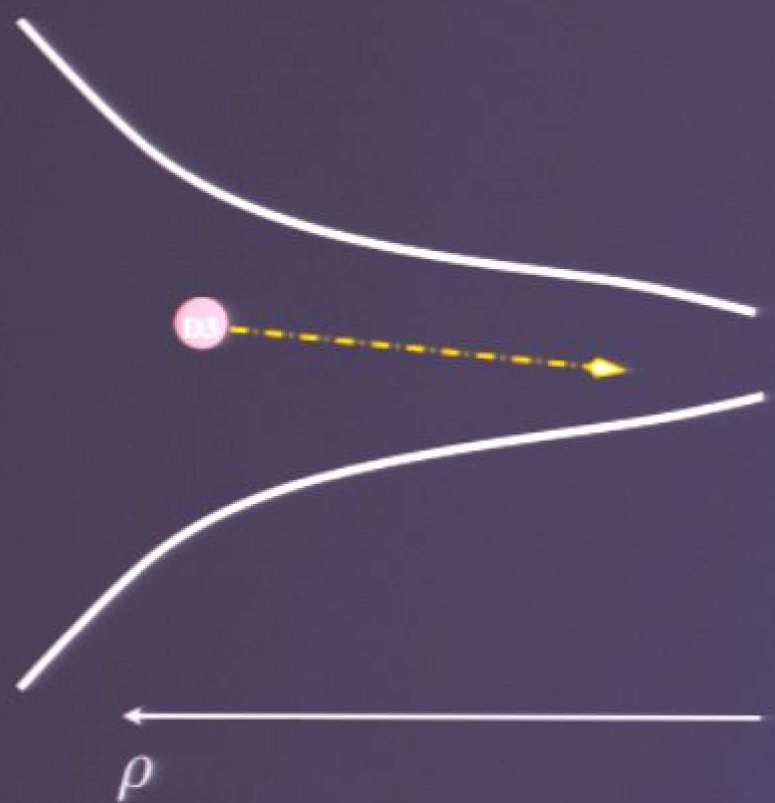

Coupling to gravity: DBI Inflation

- Consider 4D effective action:

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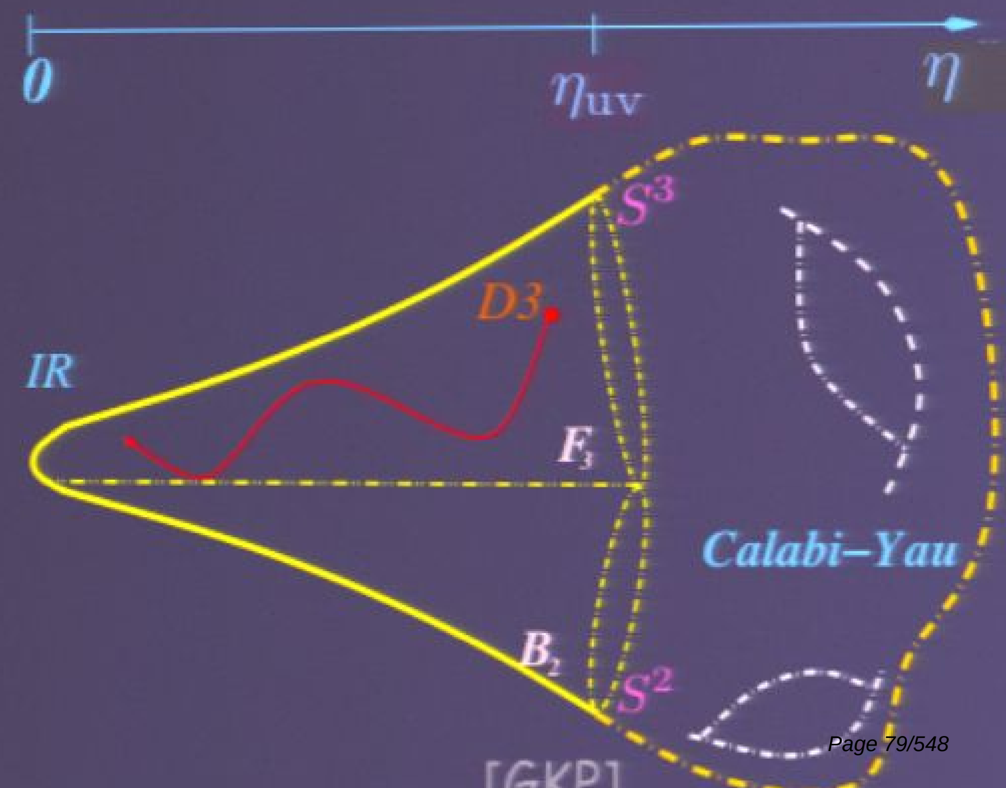
Type IIB solution with F_3, H_3, F_5 internal fluxes

$$ds_{10}^2 = h^{-1/2}(\eta)\, dx_\mu dx^\mu + h^{1/2}(\eta) ds_6^2$$



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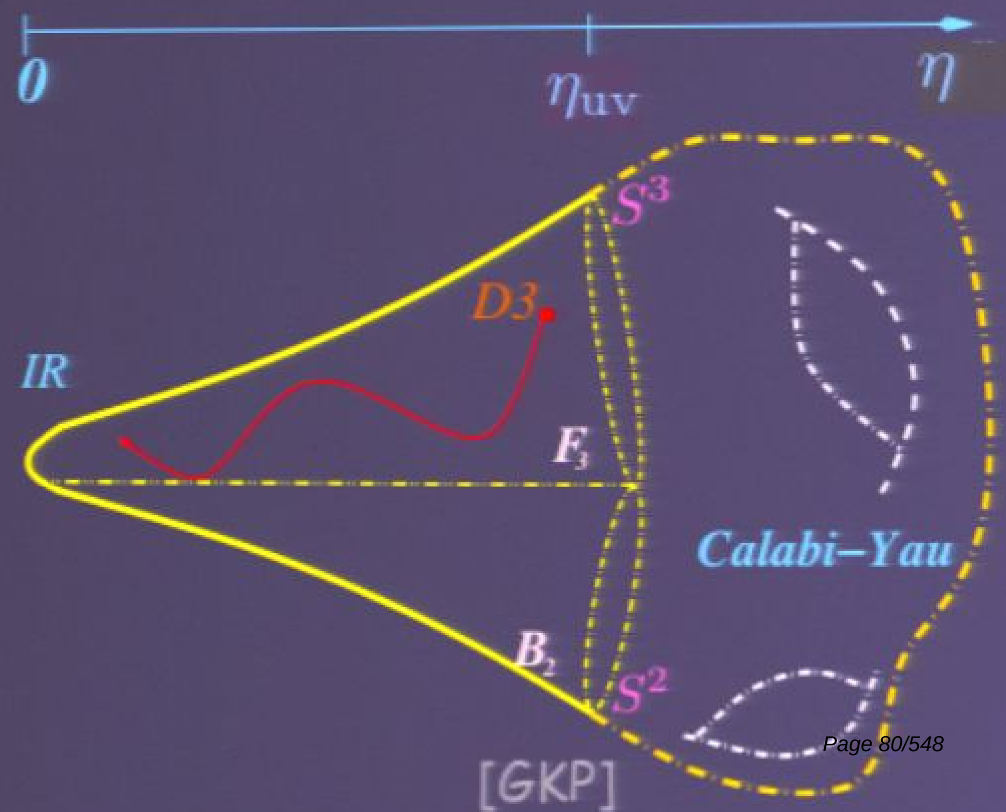

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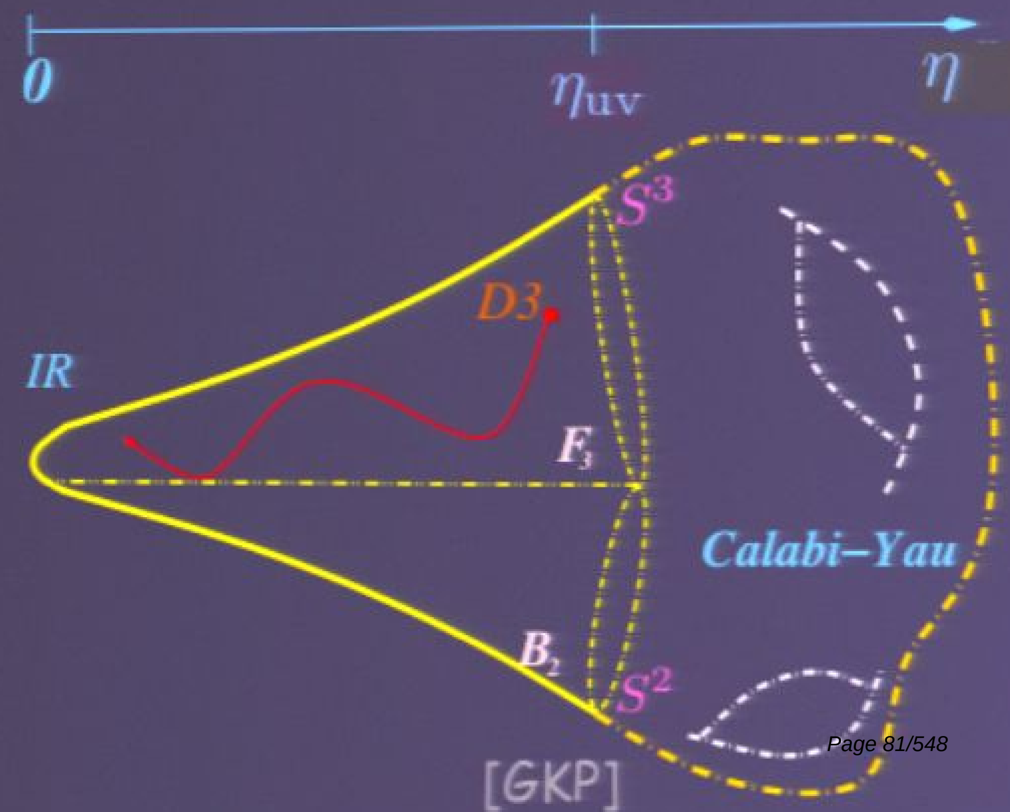

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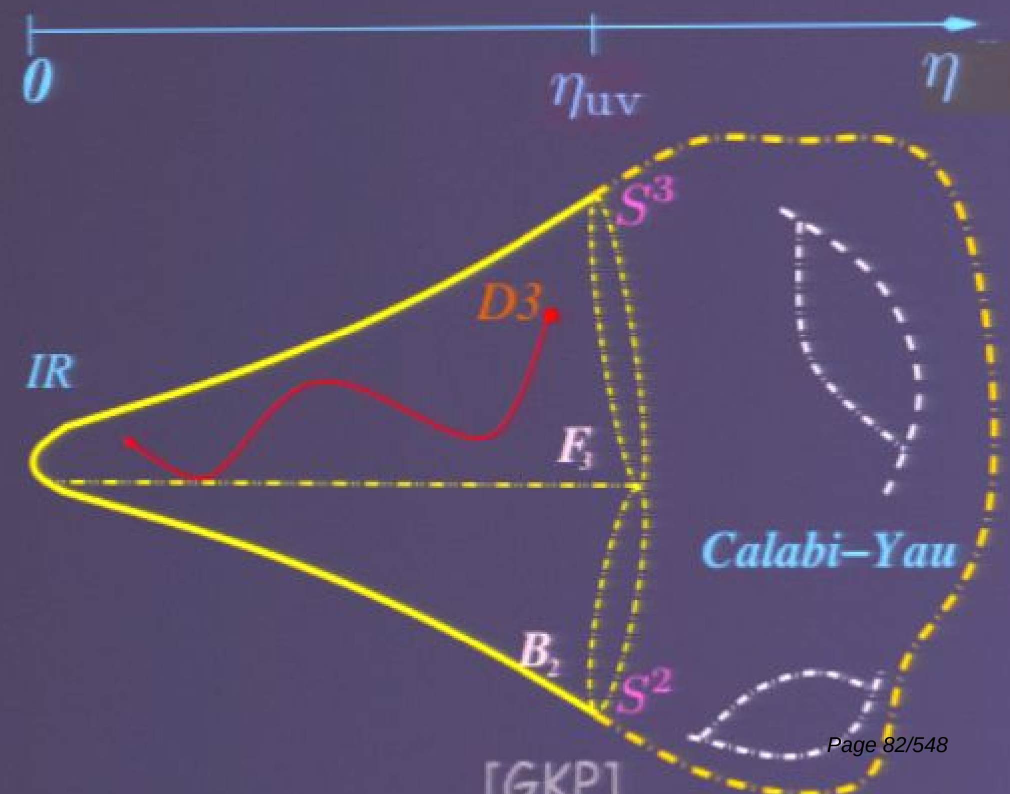

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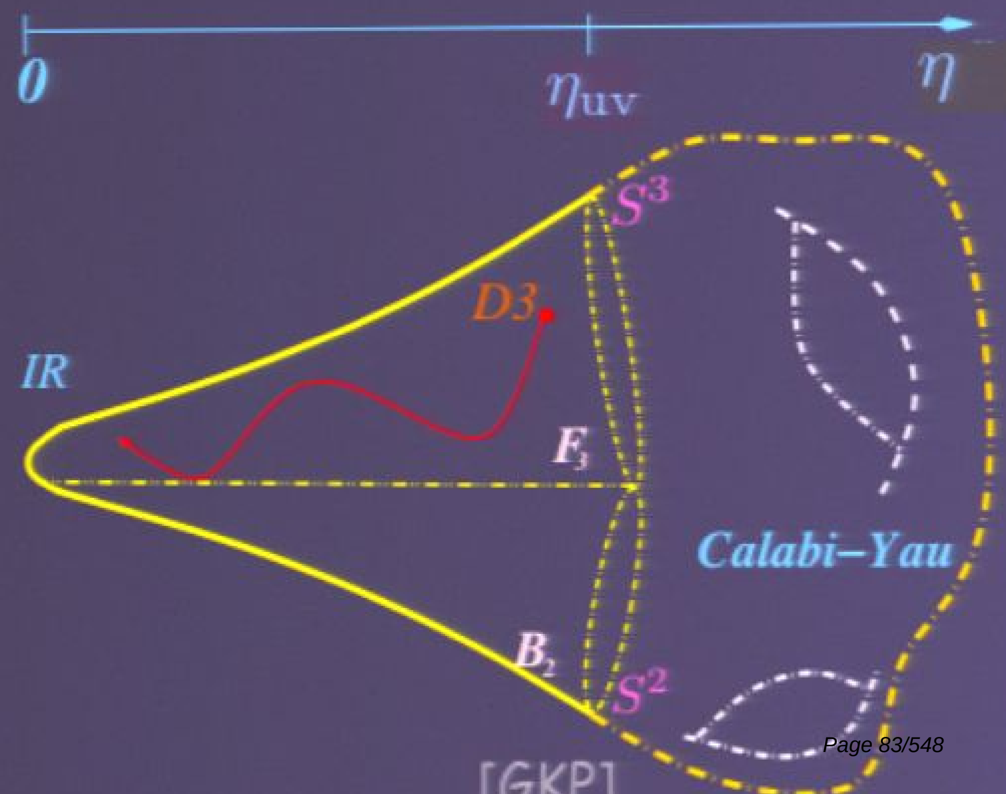

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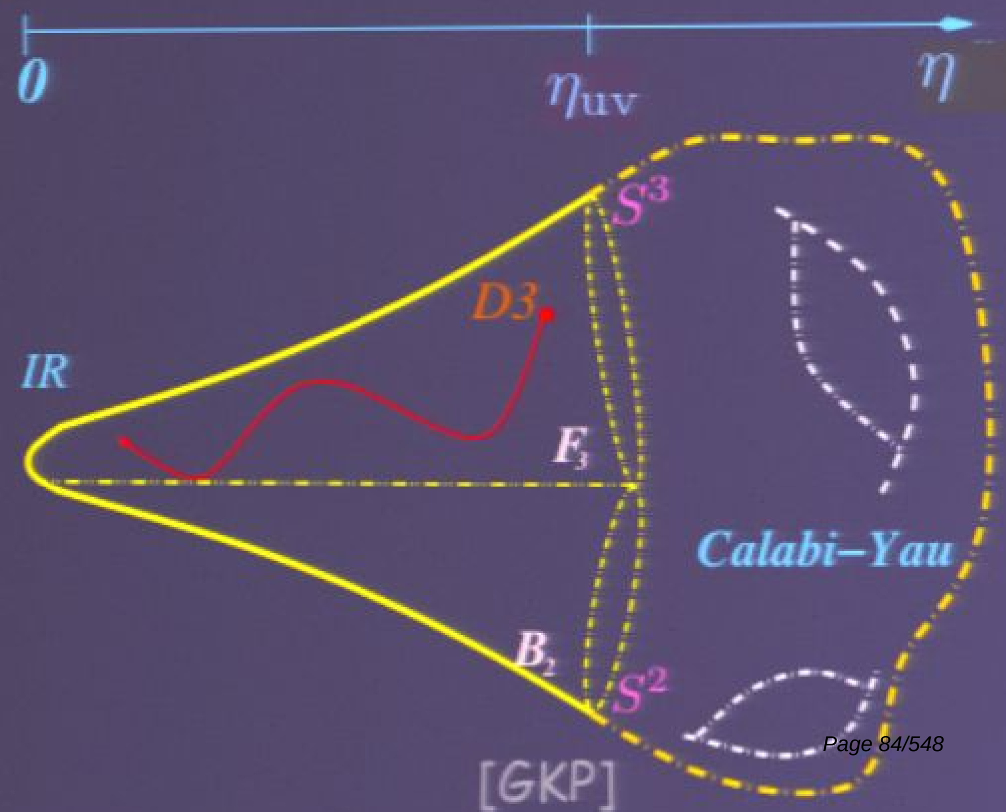

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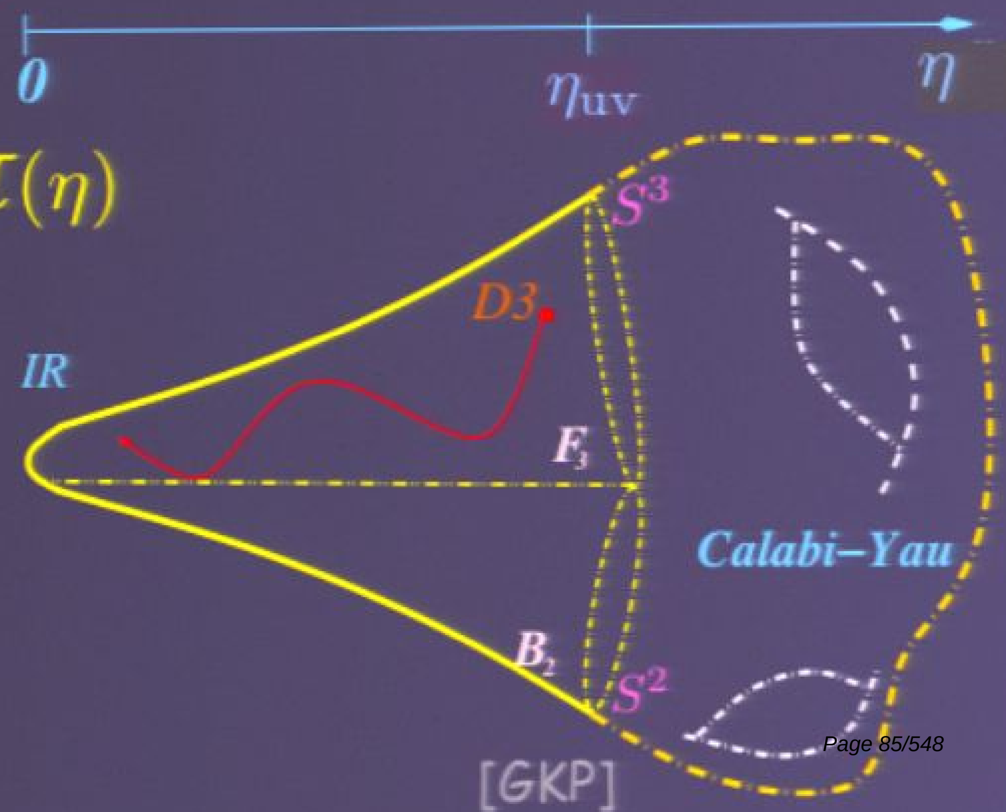

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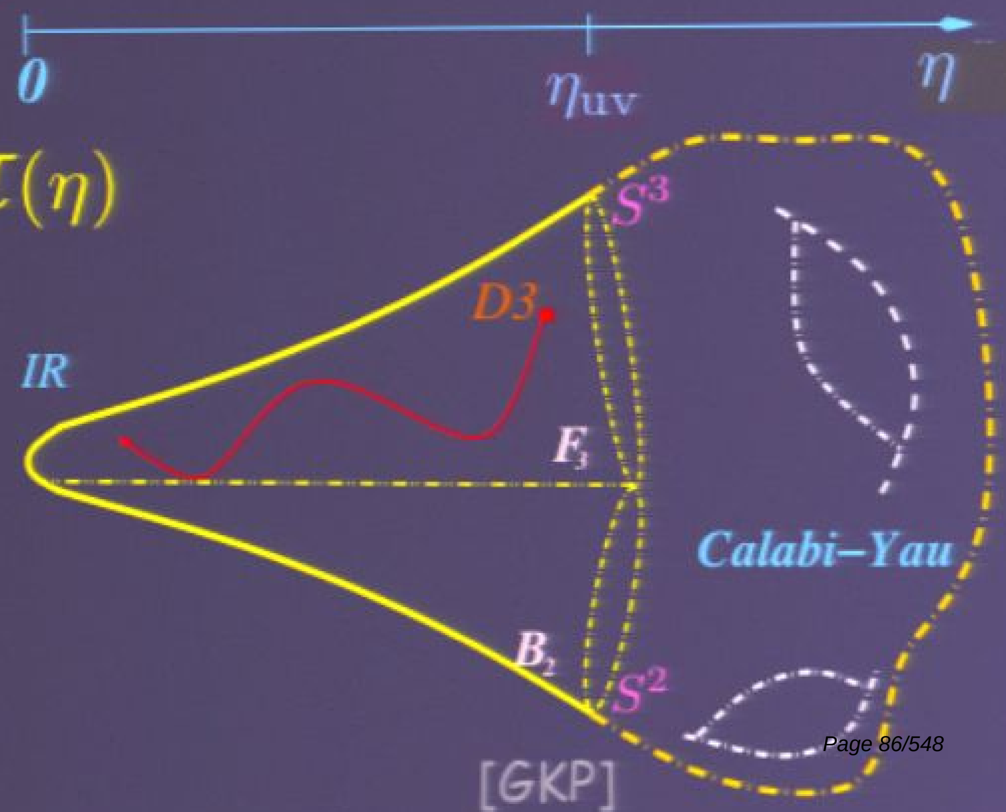

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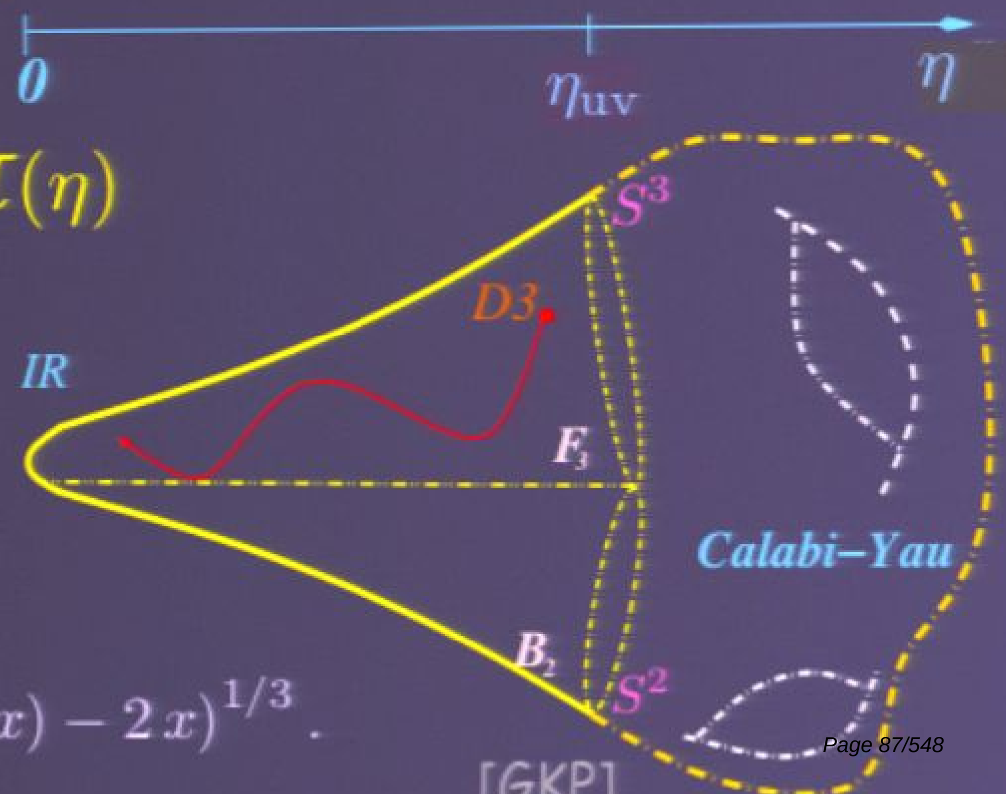

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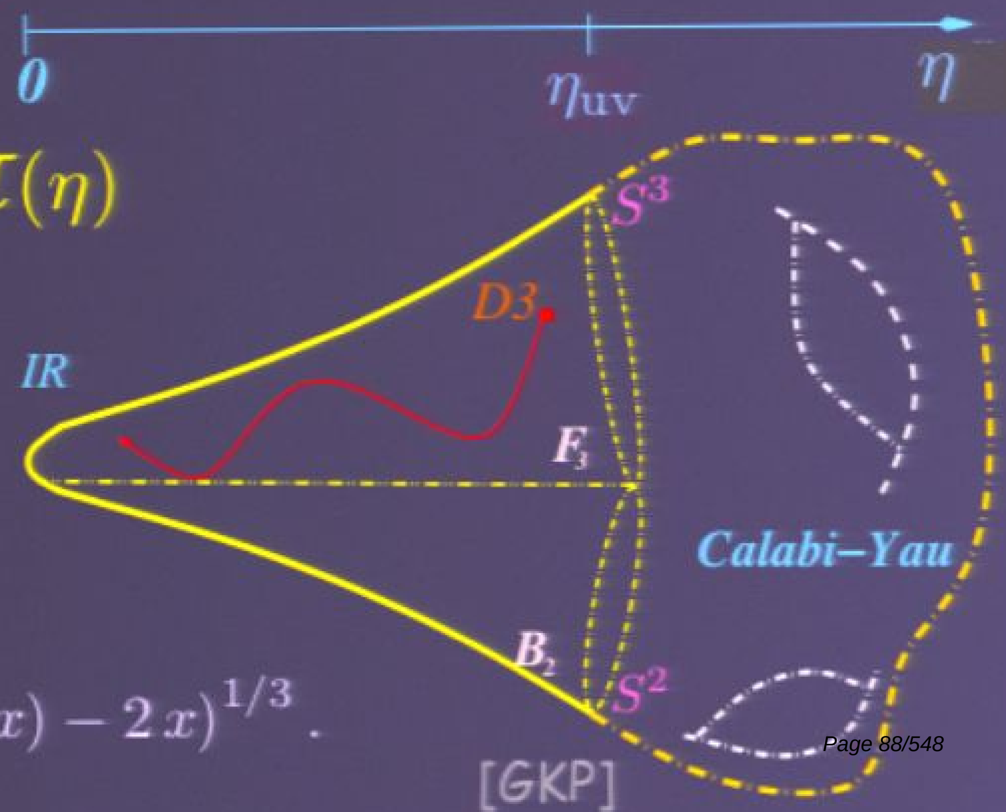

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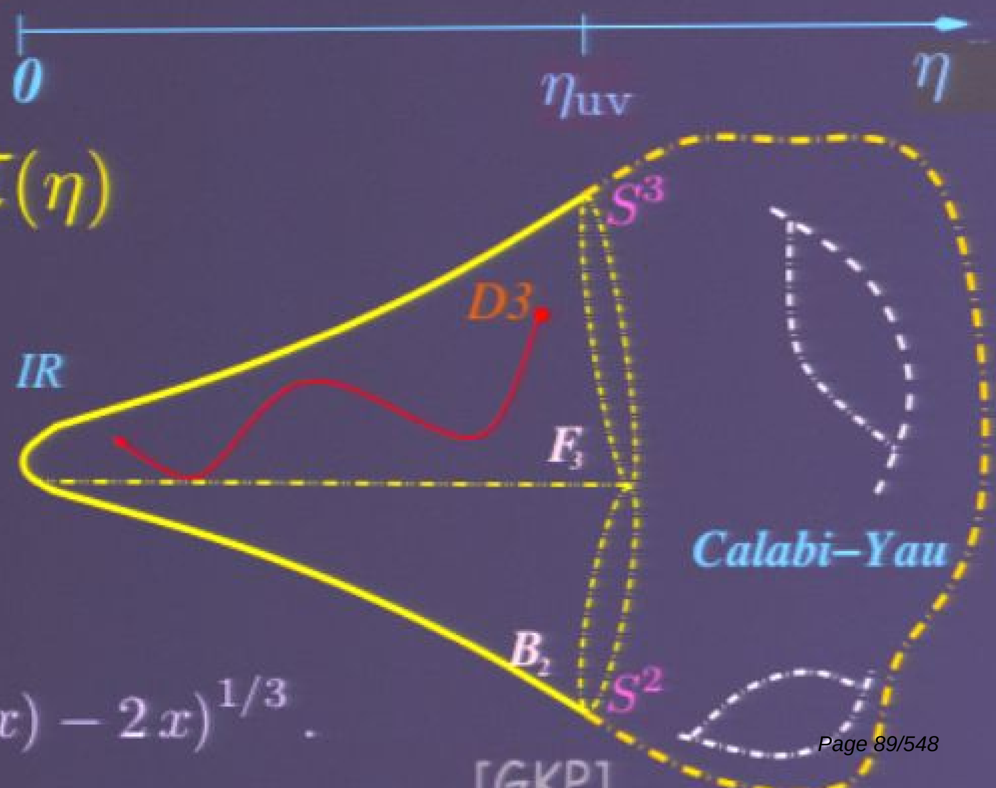

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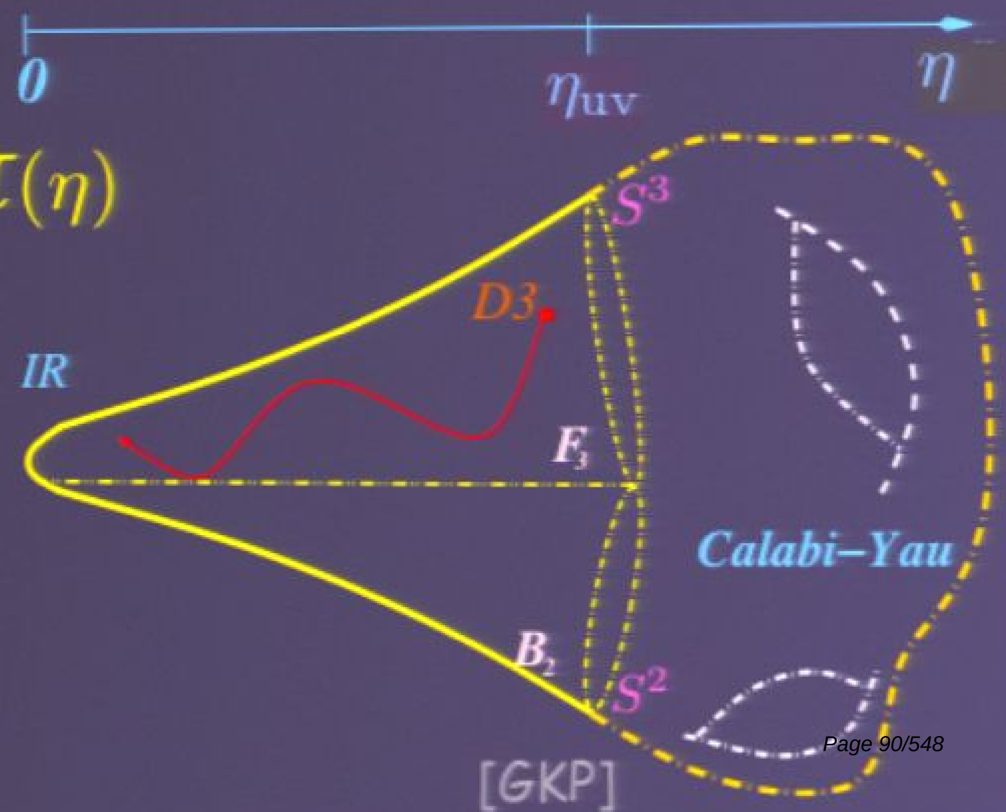

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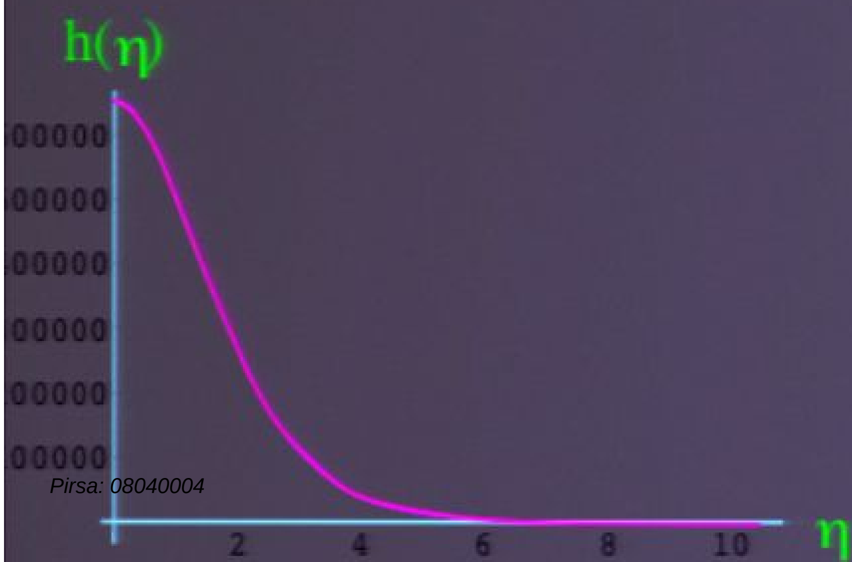

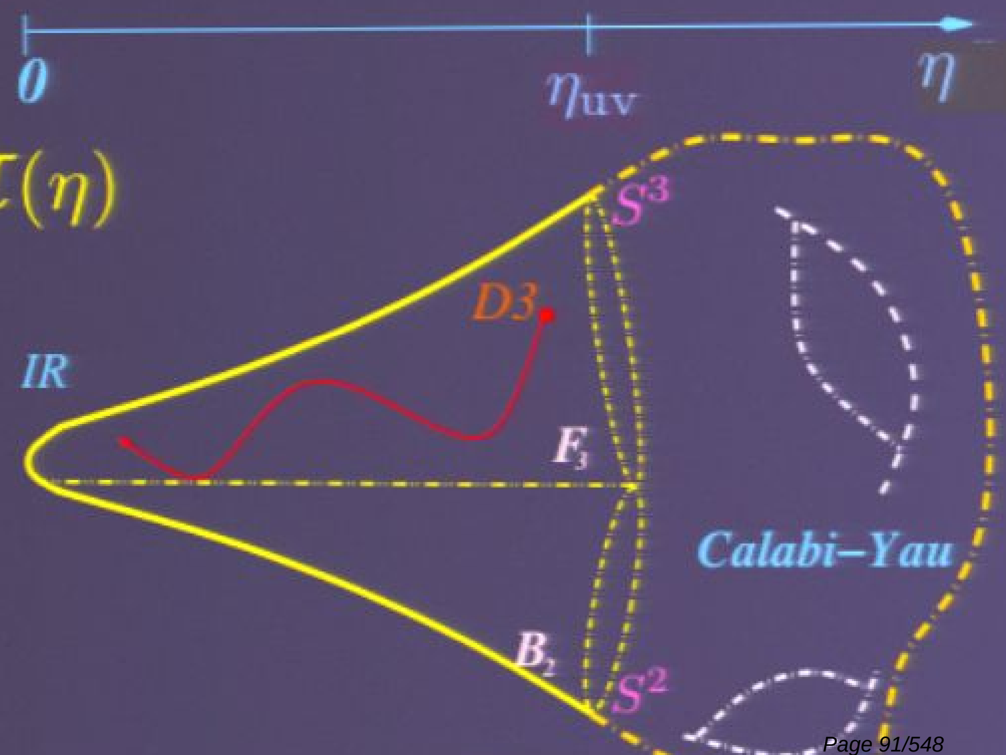

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Brane trajectories (q=1, $y^r = \theta$)

- Conserved quantities

$$E = \frac{(\gamma - 1)}{h} \; ; \qquad l_\theta = g_{\theta\theta}\, \dot\theta\, \gamma$$

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$$E = \frac{(\gamma - 1)}{h} \, ; \qquad l_\theta = g_{\theta\theta} \, \dot{\theta} \, \gamma$$

$$\gamma = \frac{1}{\sqrt{1 - hv^2}} = \sqrt{\frac{1 + h \, \ell^2(\eta)}{1 - h \, g_{\eta\eta} \dot{\eta}^2}} \, ; \qquad \ell^2(\eta) = g^{rs} l_r l_s$$

- Brane trajectories described by equation of motion:

$$\dot{\eta}^2 = \frac{g^{\eta\eta} \, \left[E(h \, E + 2) - \ell^2(\eta) \right]}{(h \, E + 1)^2}$$

=> open as well as closed trajectories

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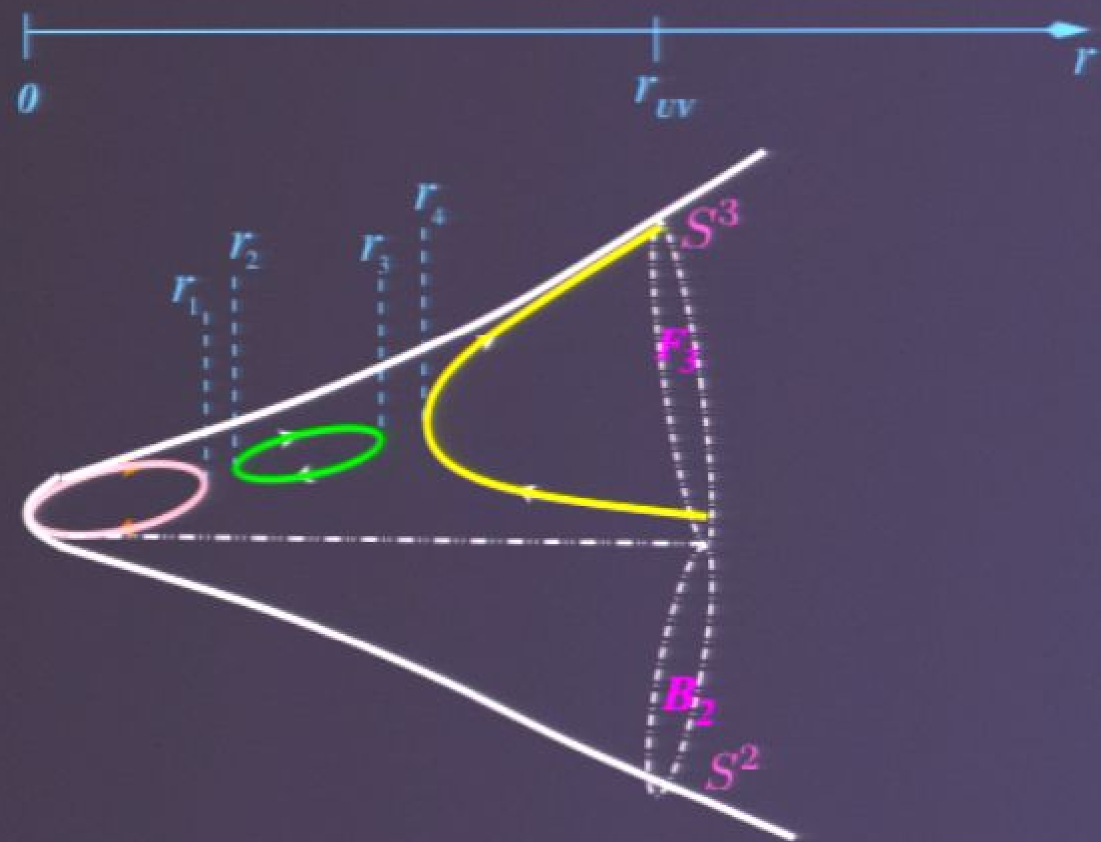
Brane trajectories in Klebanov-Strassler



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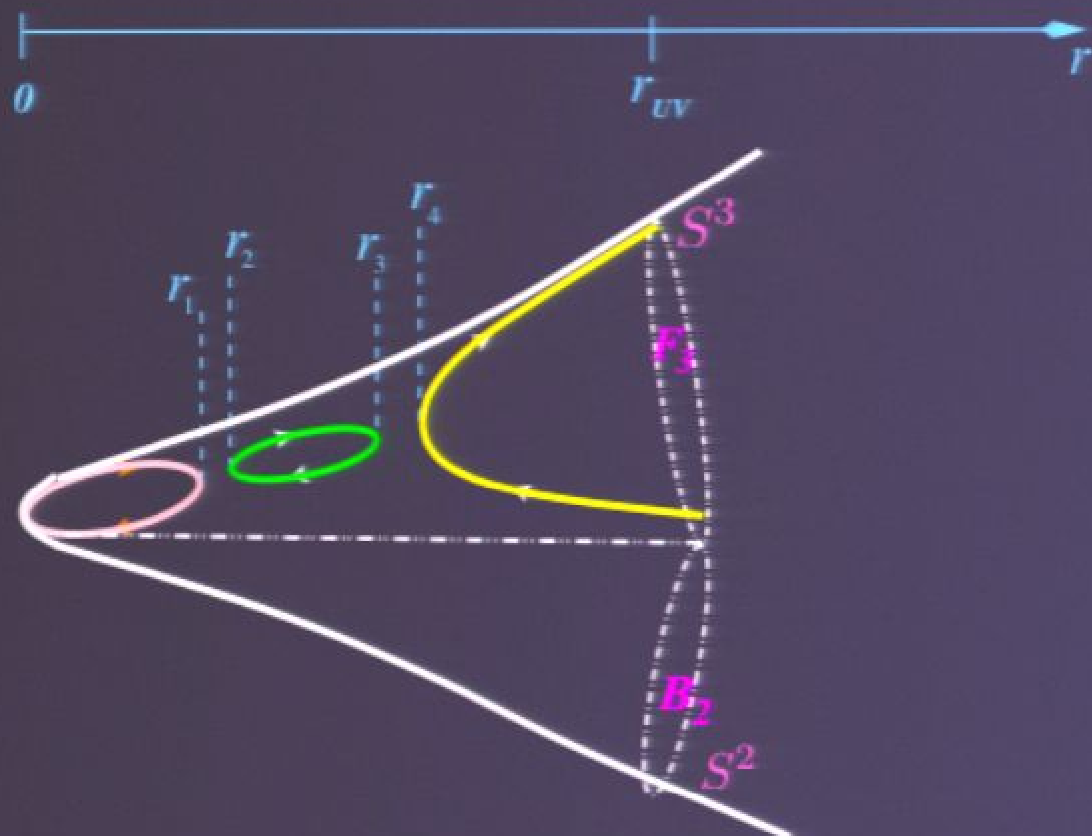

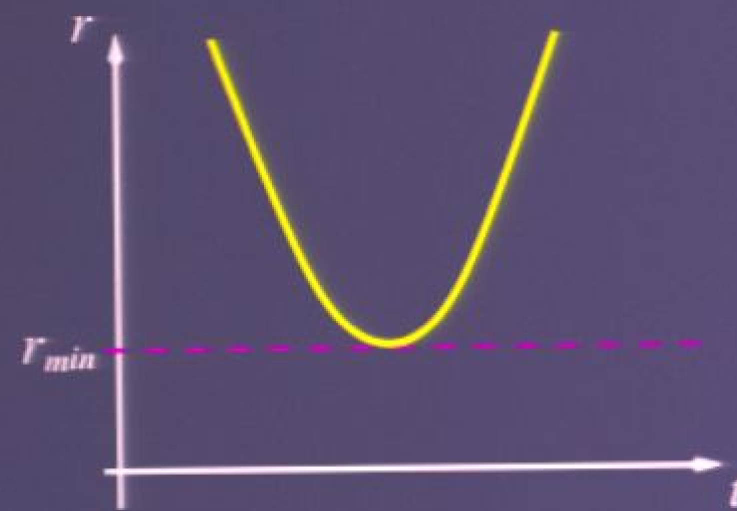

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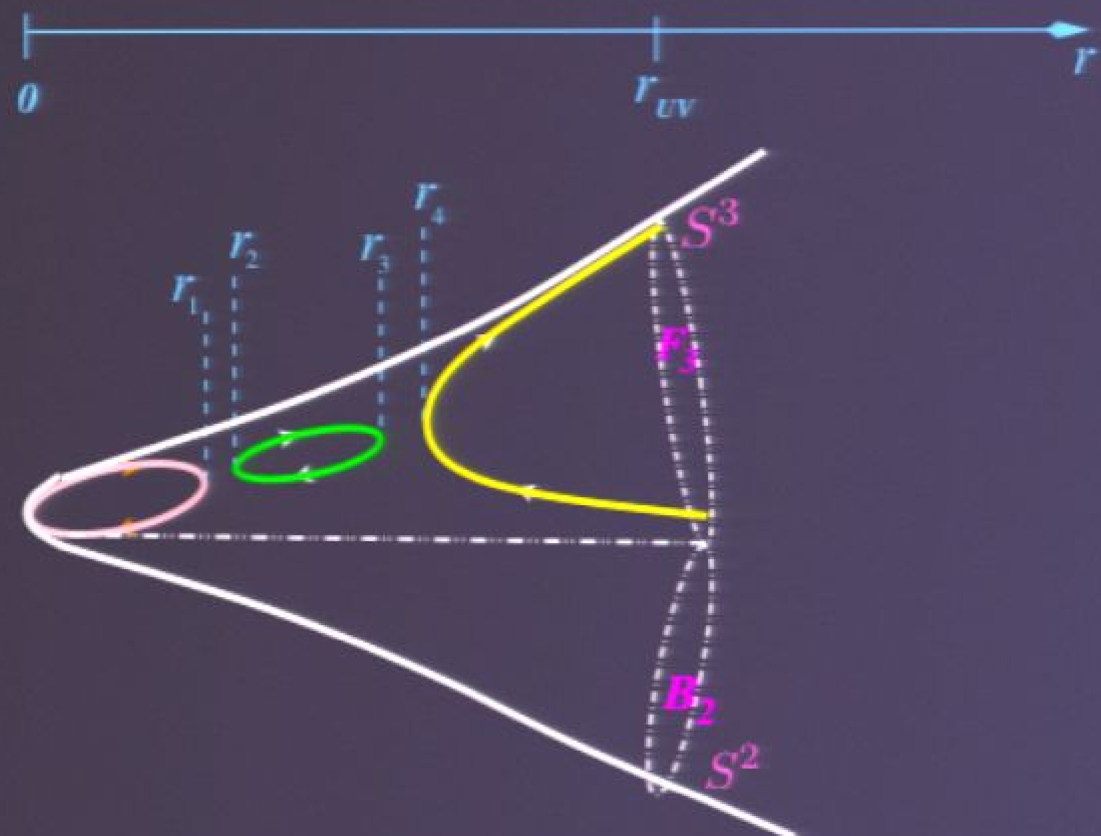

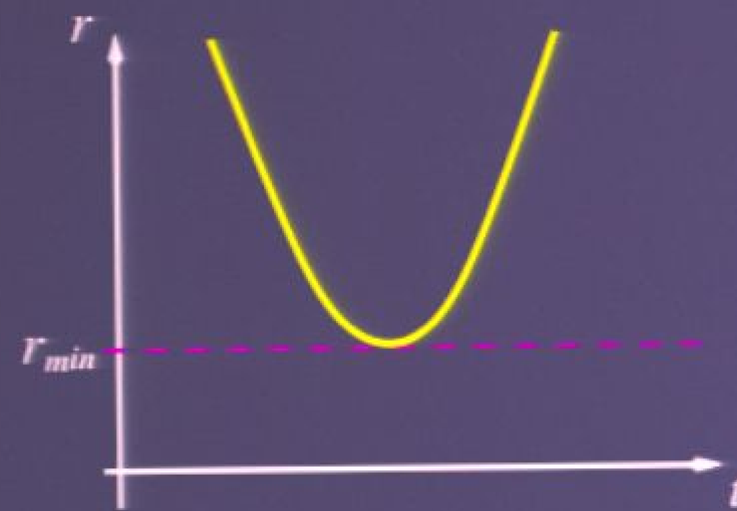

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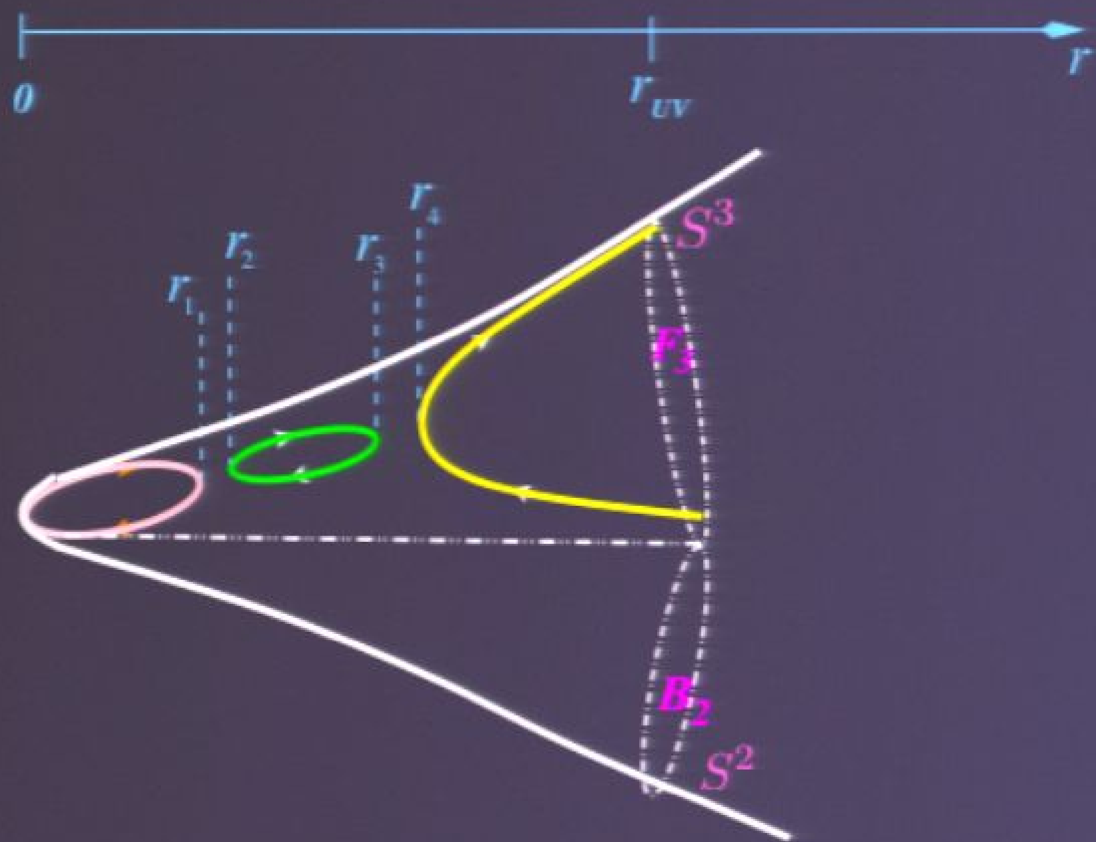

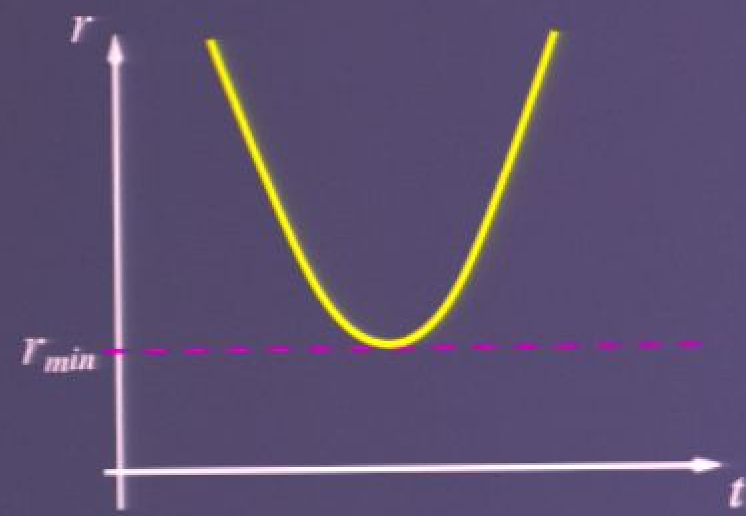

bouncing branes

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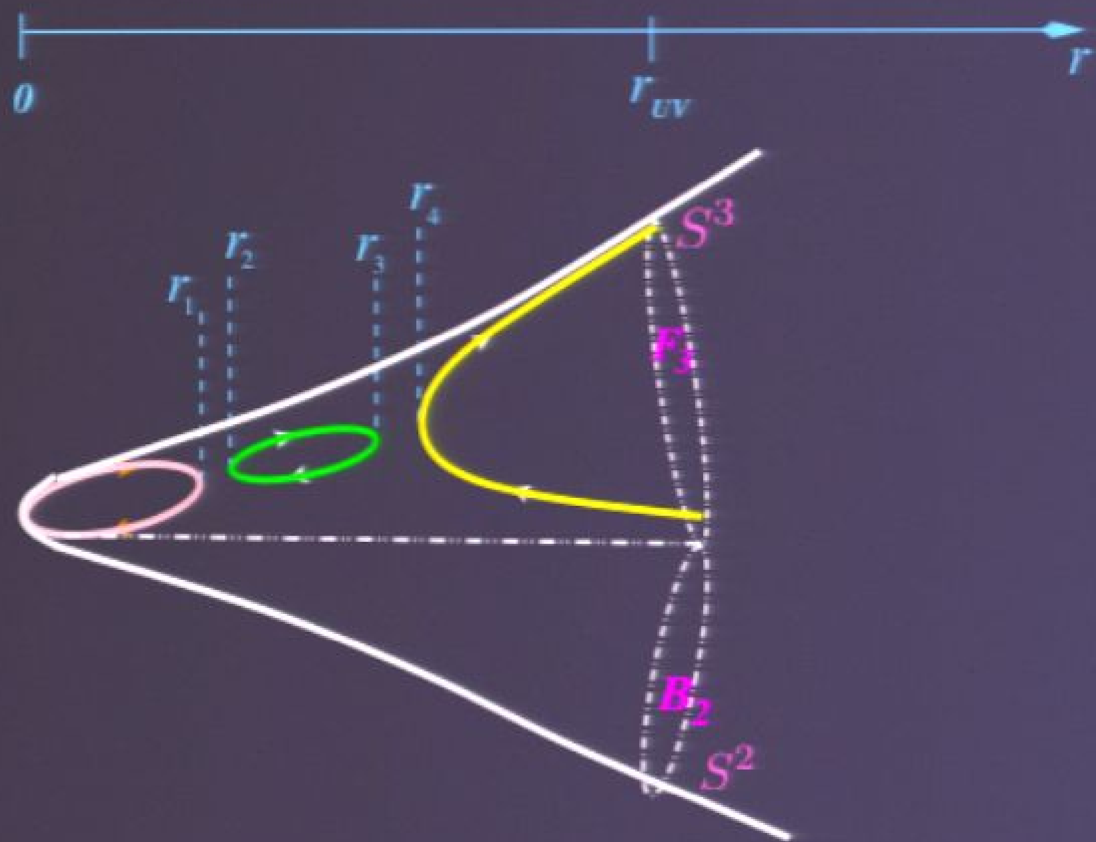
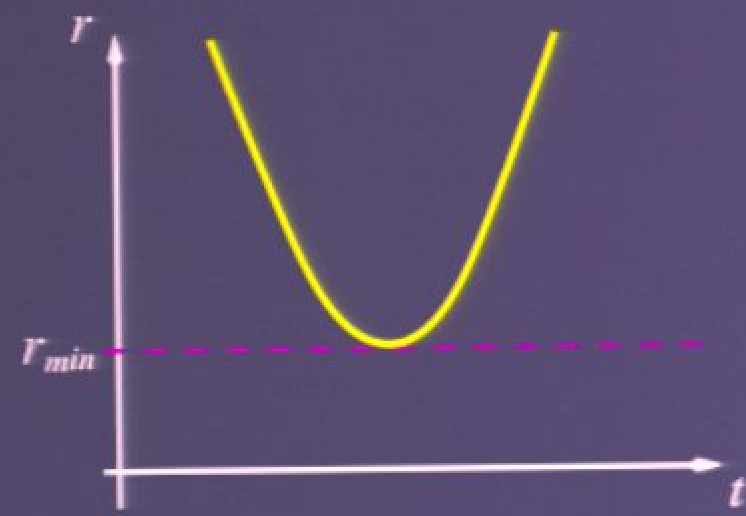
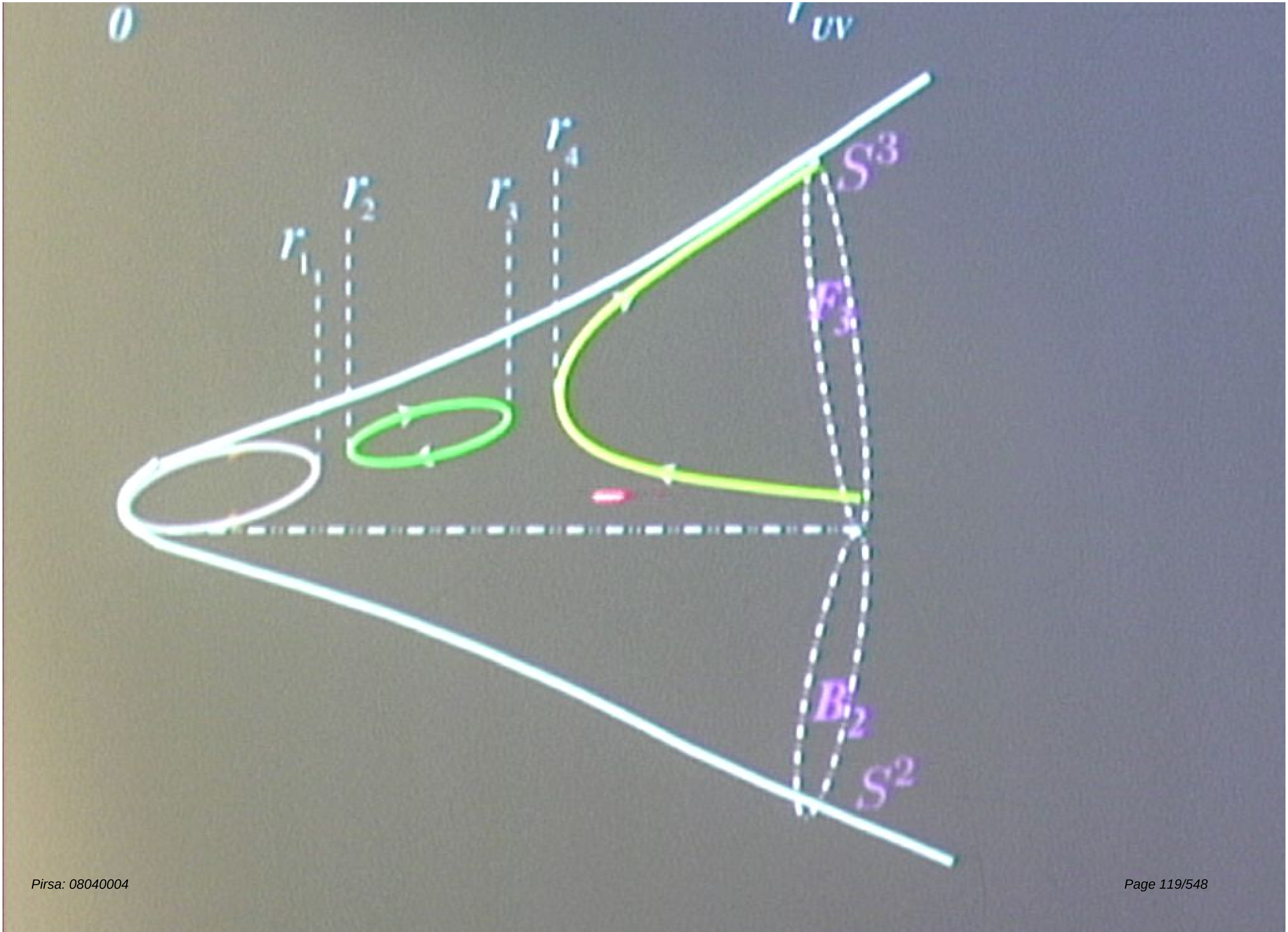




bouncing branes

cyclic branes


0
r_{UV}
r_4
r_2
r_3
r_1
S^3
F_3
B_2
S^2

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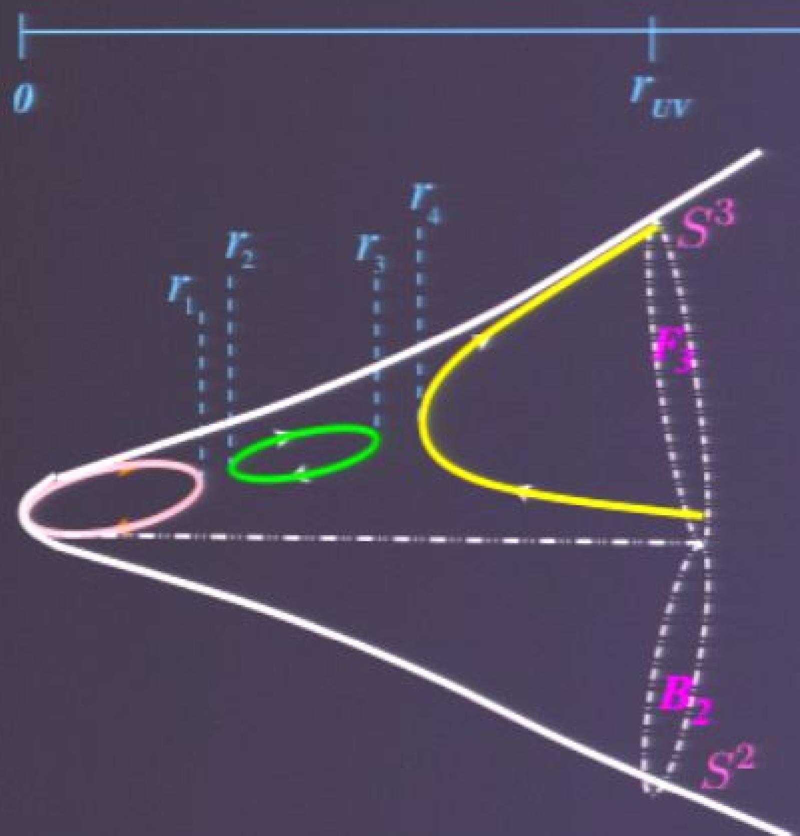

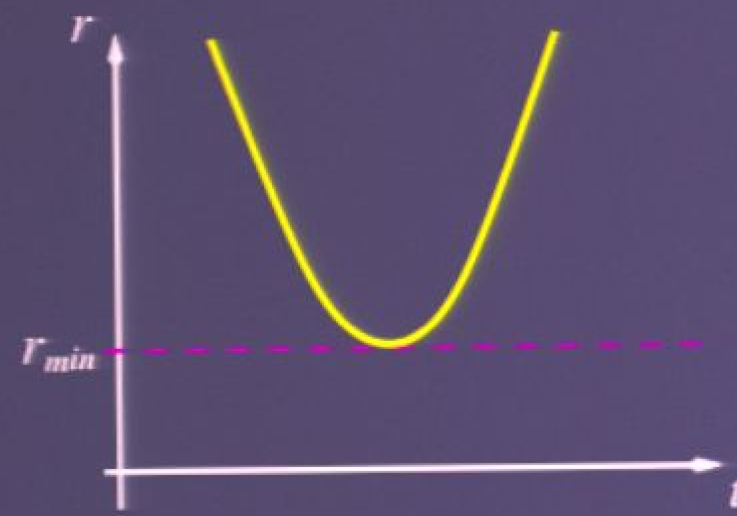

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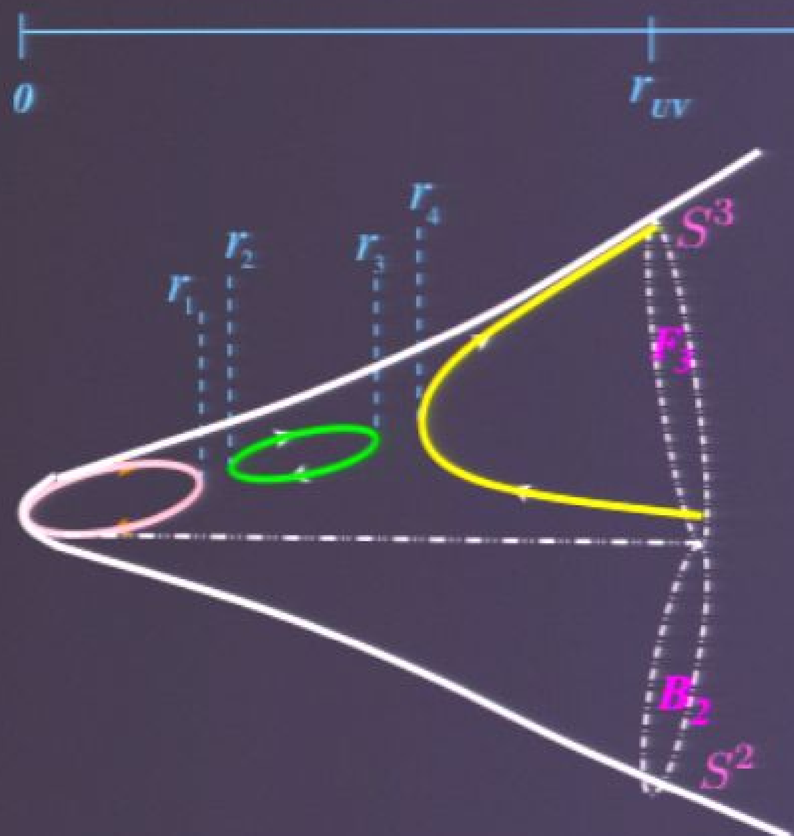

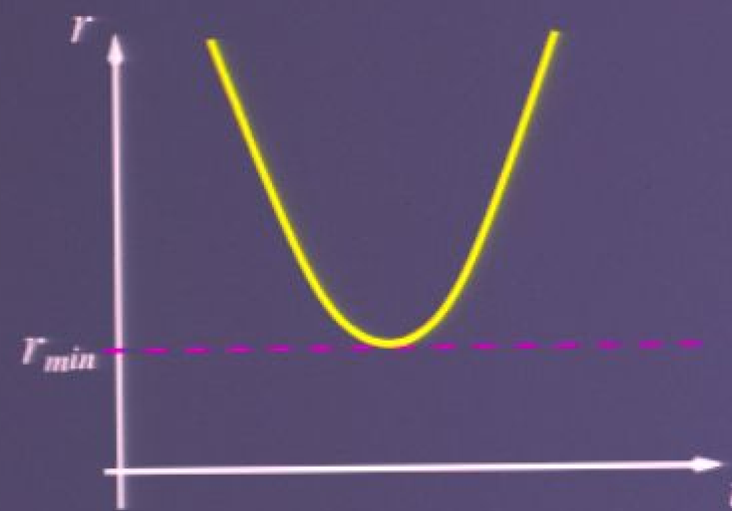

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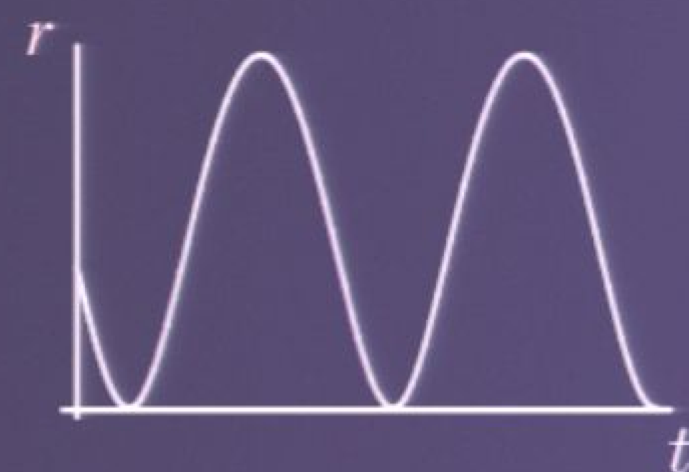

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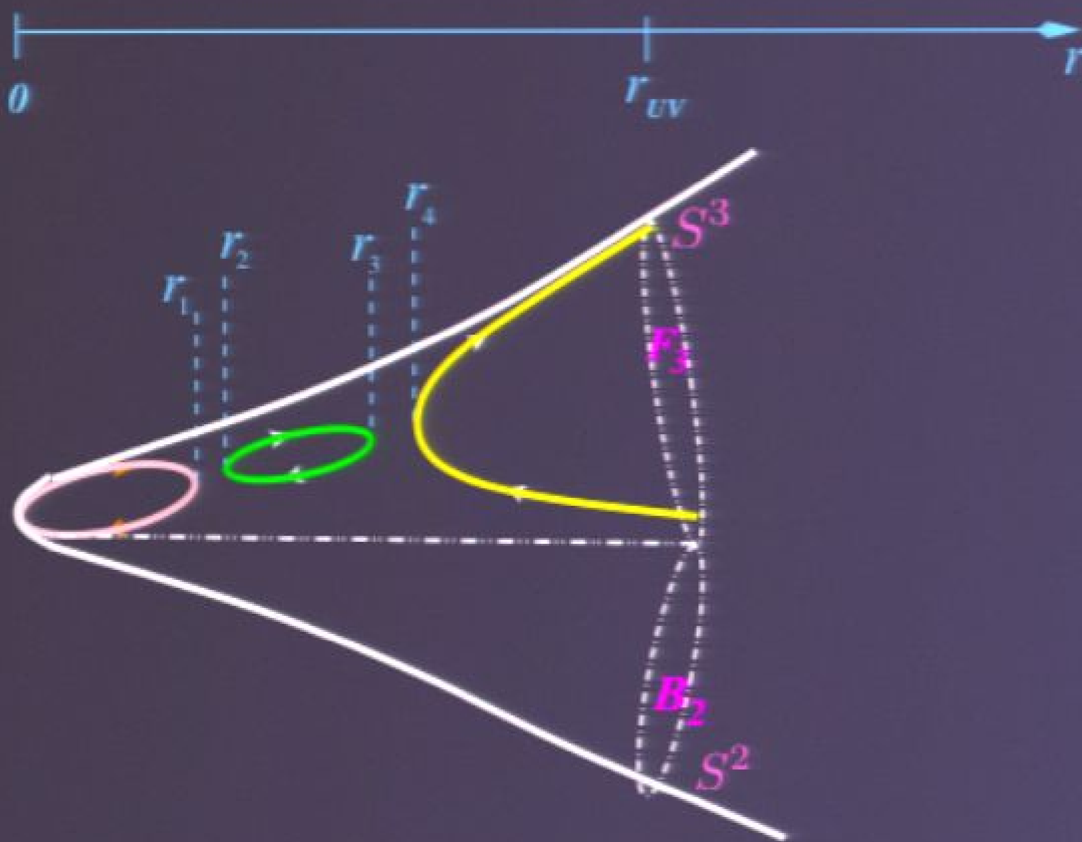

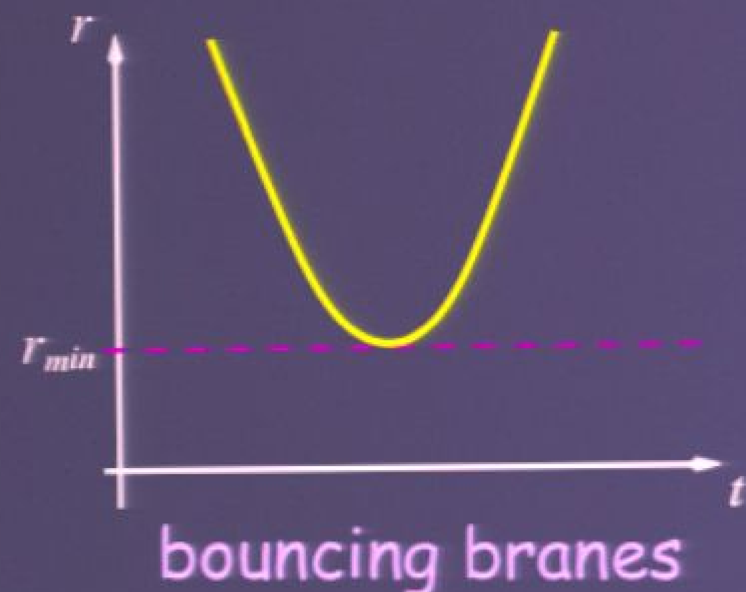

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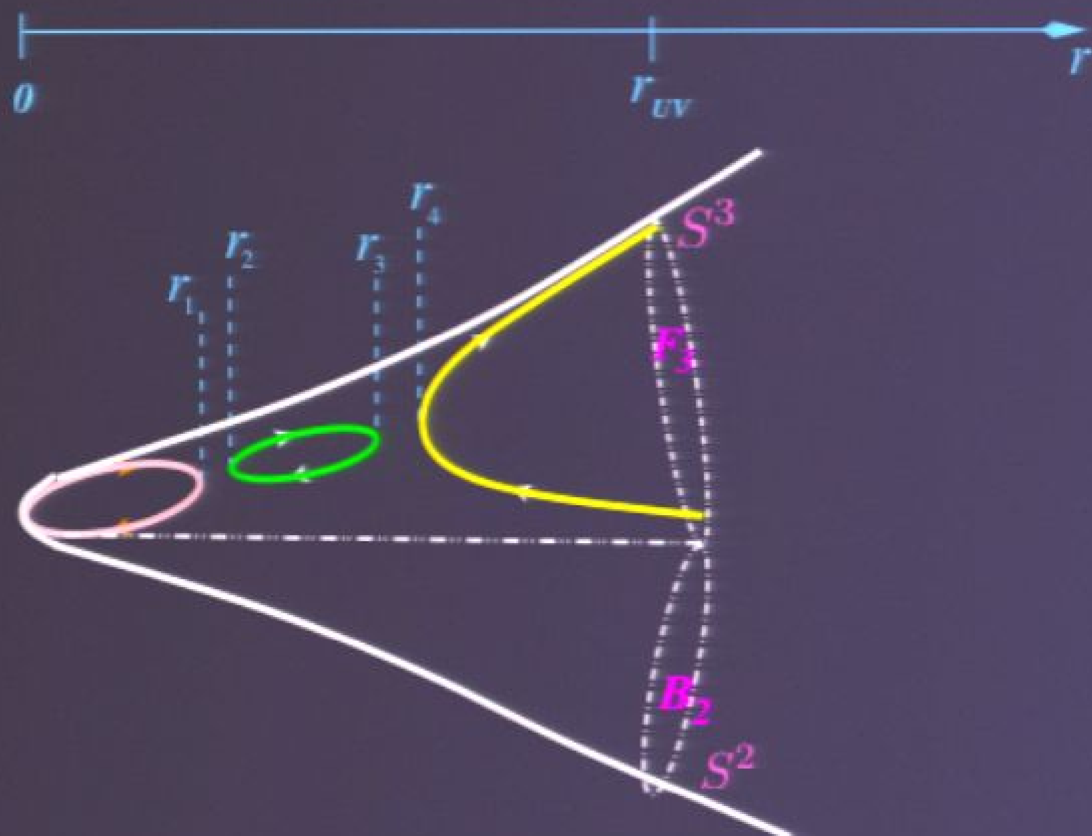

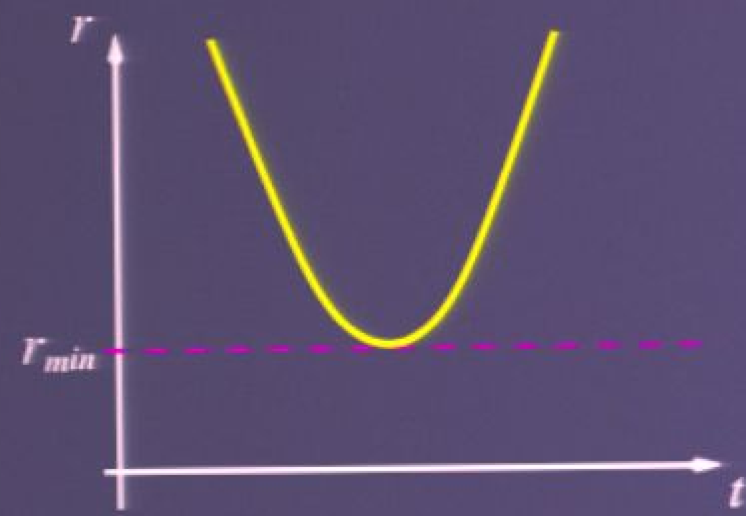

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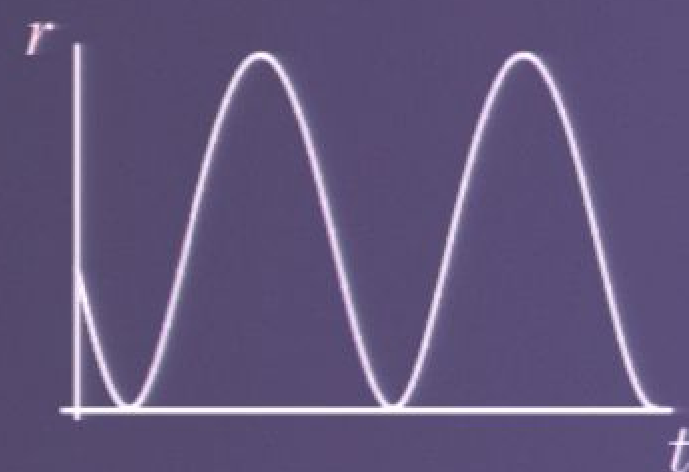

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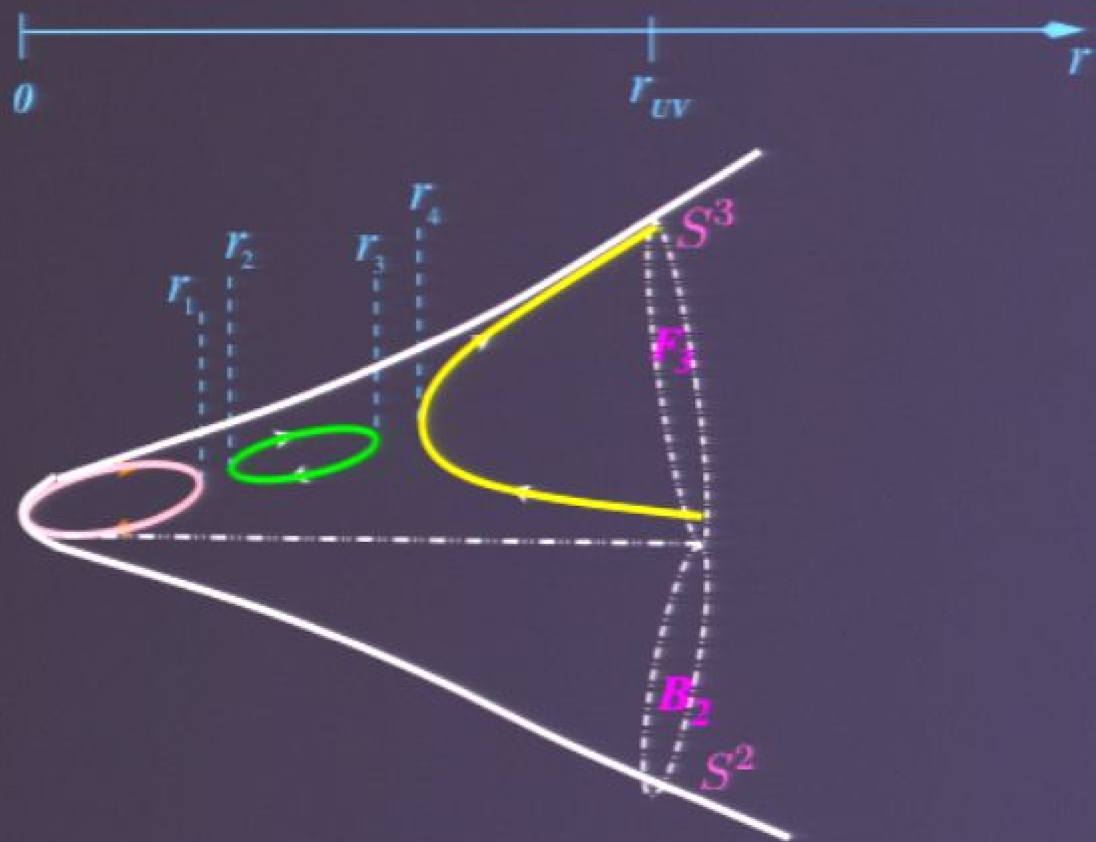

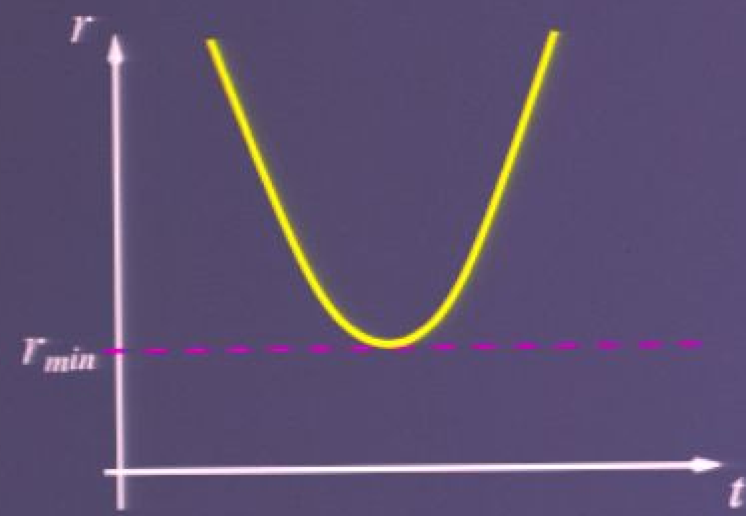

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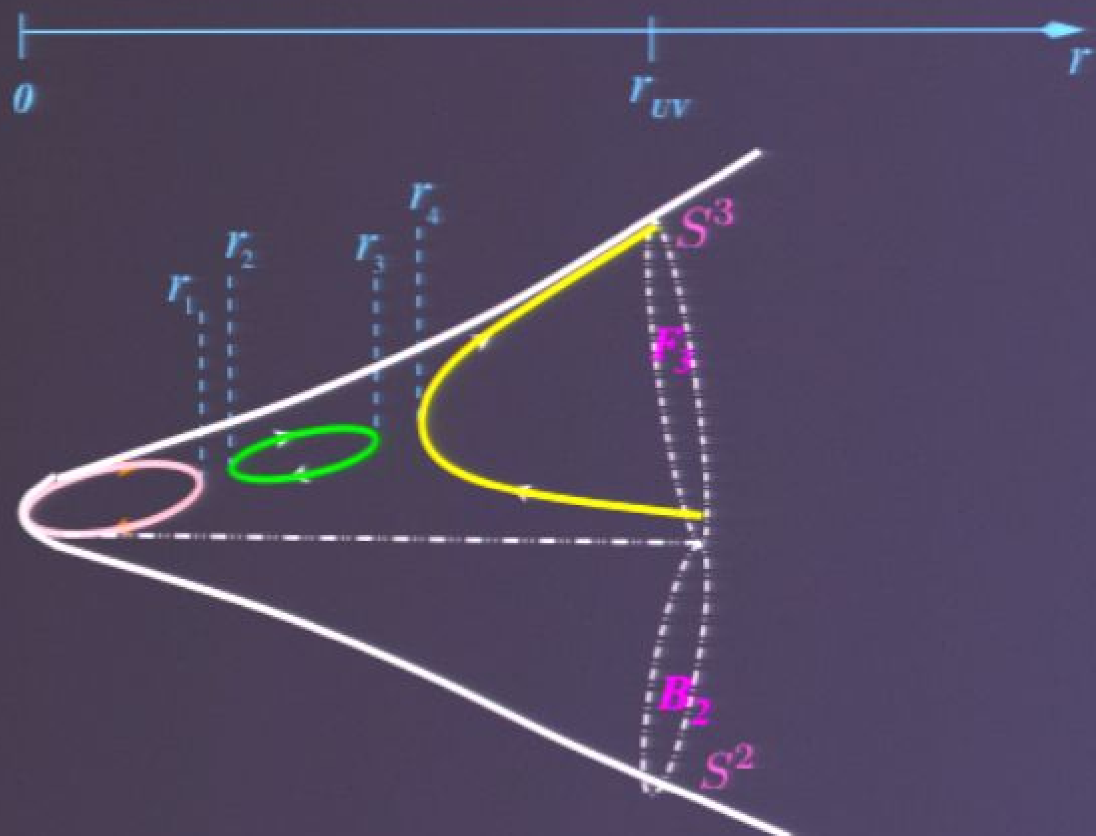

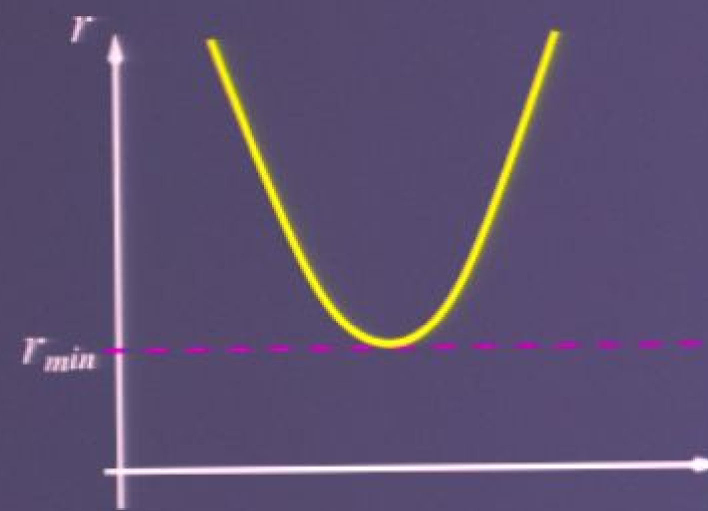

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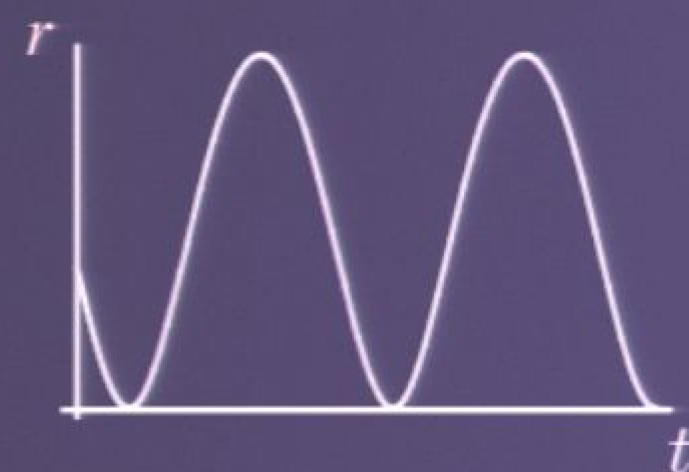

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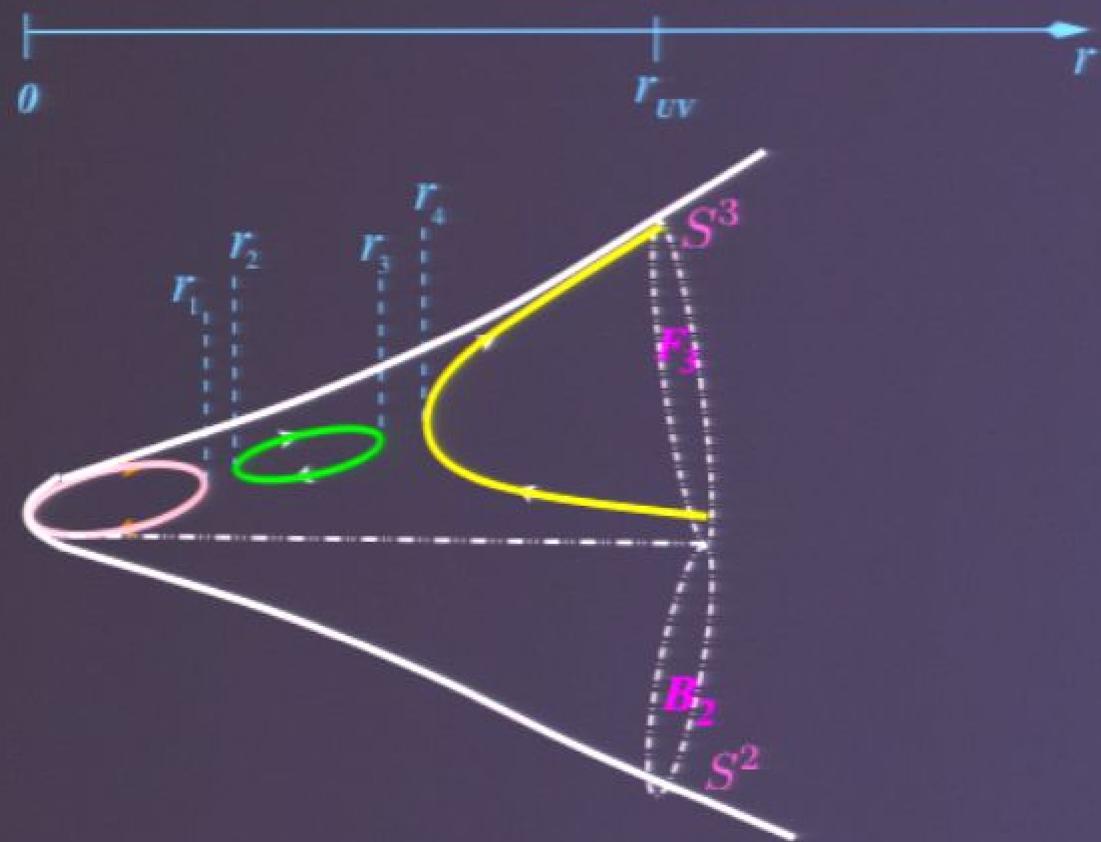

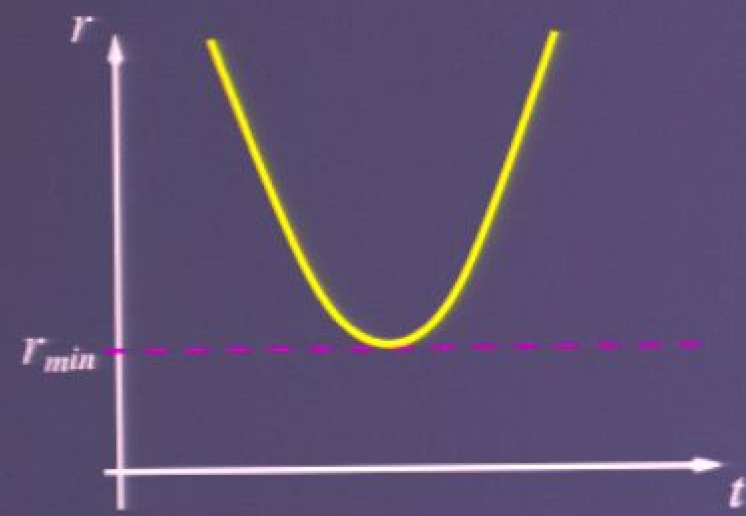

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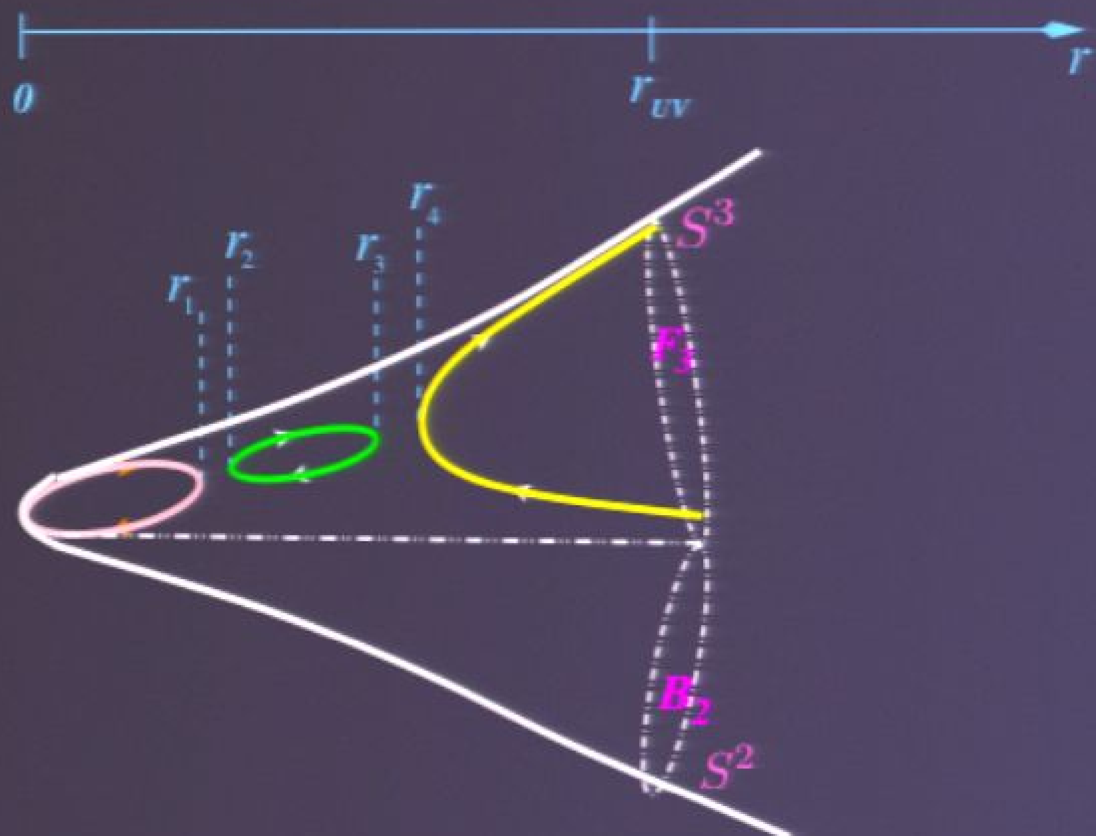

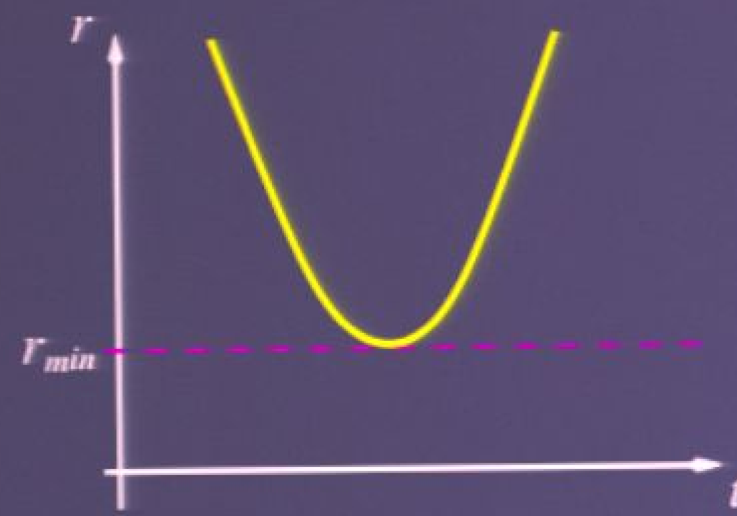

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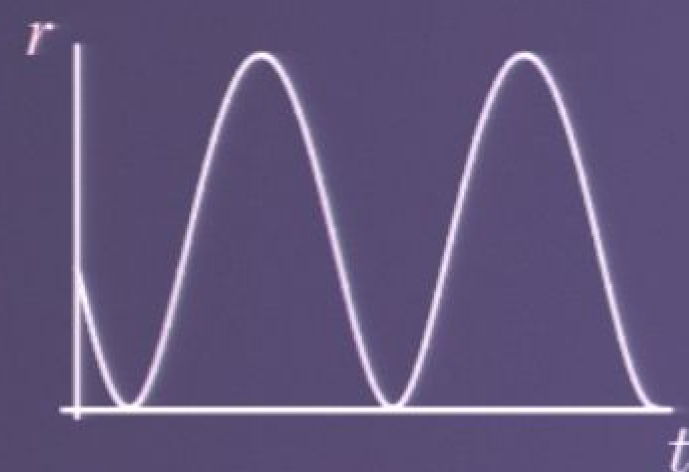

cyclic branes

Mirage Cosmology

$$ds_4^2 = -d\tau^2 + a^2(\tau)dx_i dx^i \,,$$

$$\boxed{H_{ind}^2 = \left(\frac{h'}{4\,h^{3/4}}\right)^2 g^{\eta\eta}\left[E\,(h\,E + 2q) - \ell^2(\eta)\right]}$$

[$\ell = 0$, Kachru-McAllister '02]

where $a(\tau) = h^{-1/4}(\tau)$ and $H_{ind} = \frac{1}{a}\frac{d\,a}{d\eta}\frac{d\,\eta}{d\tau}$

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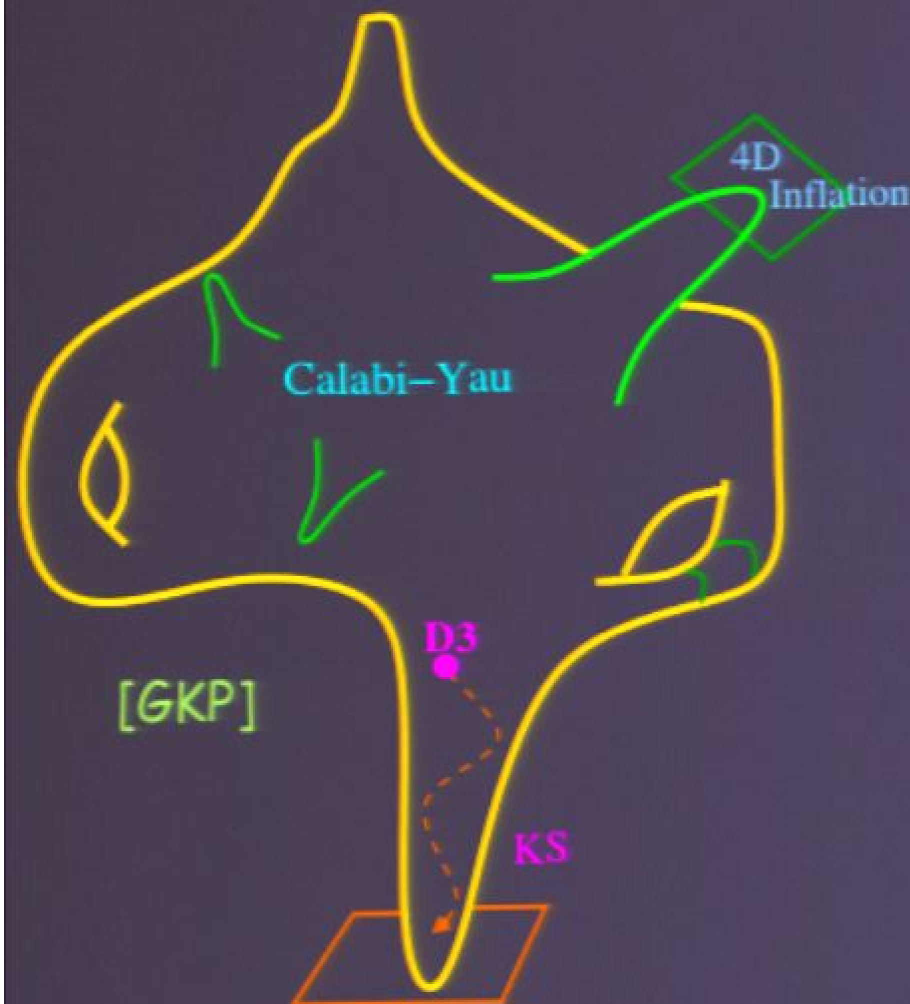
- Mirage bouncing and cyclic universes

Effective 4D approach: DBI Cosmology



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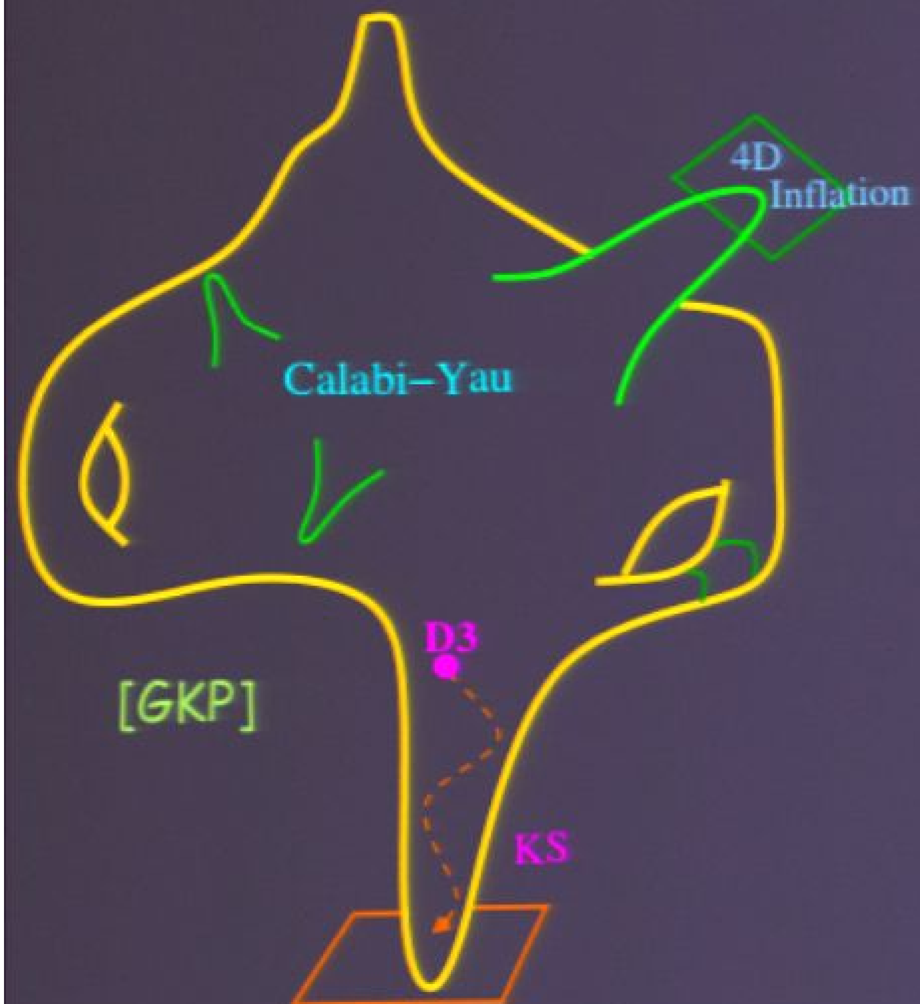

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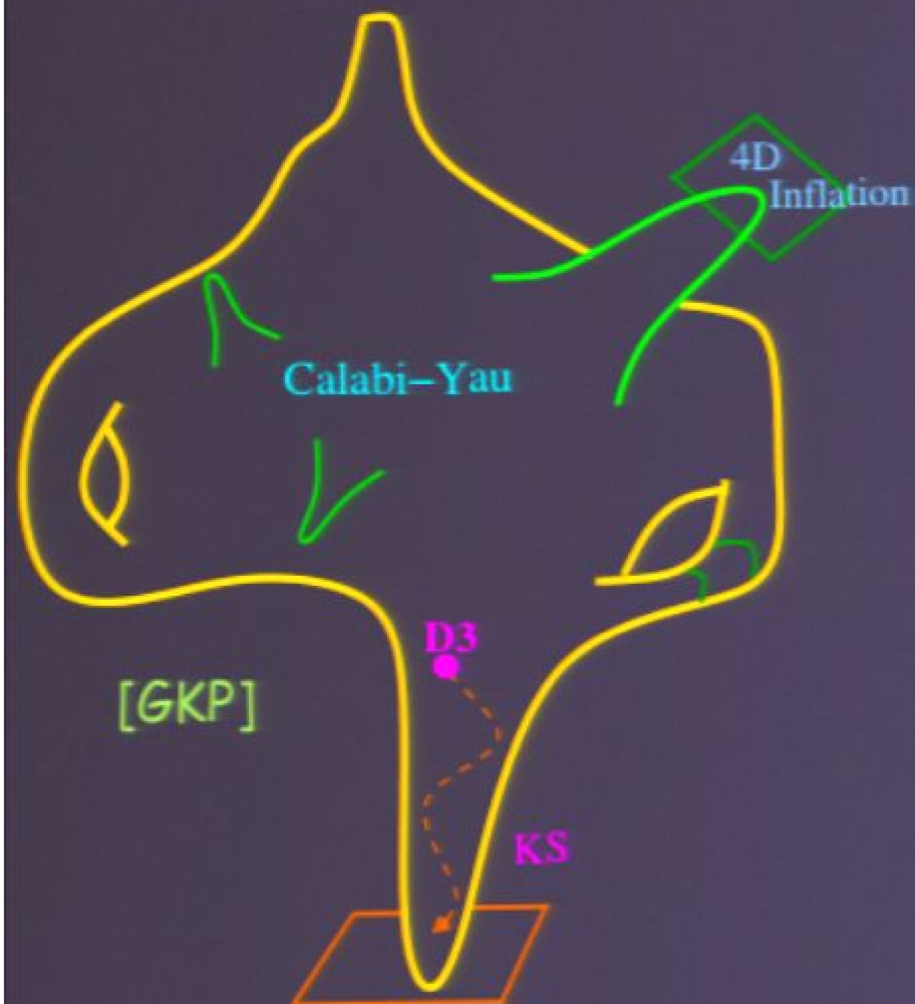

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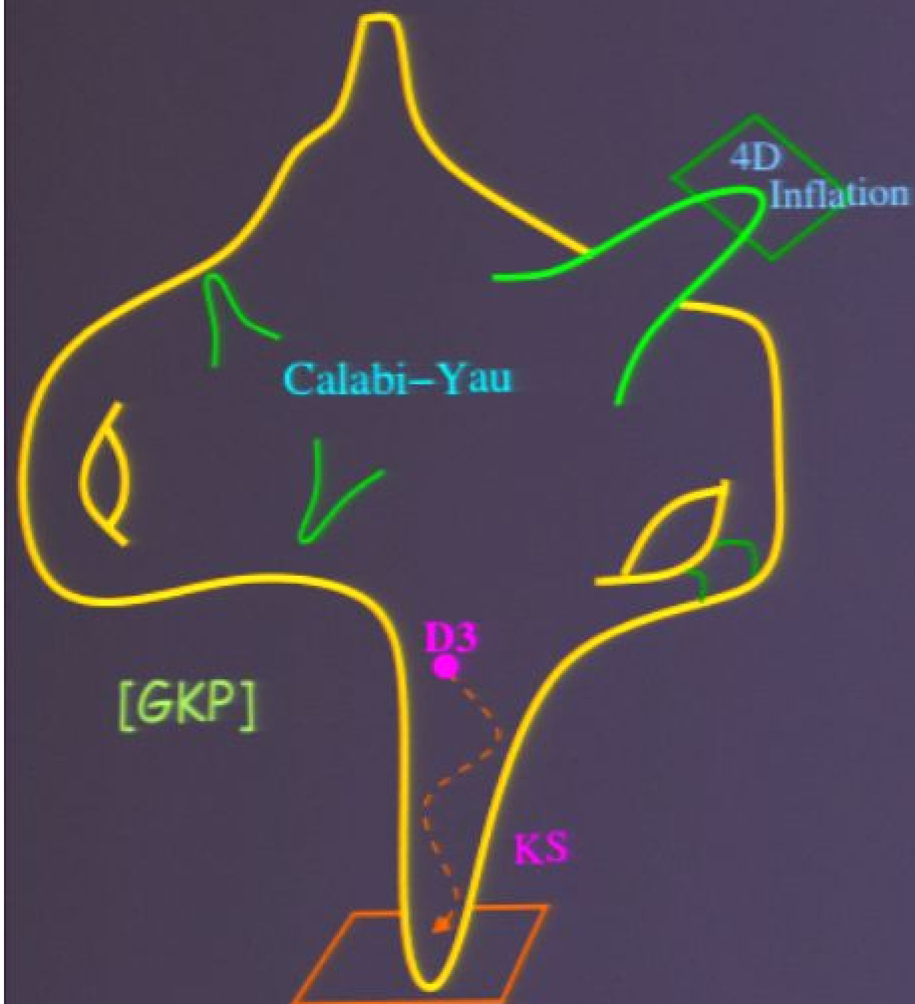

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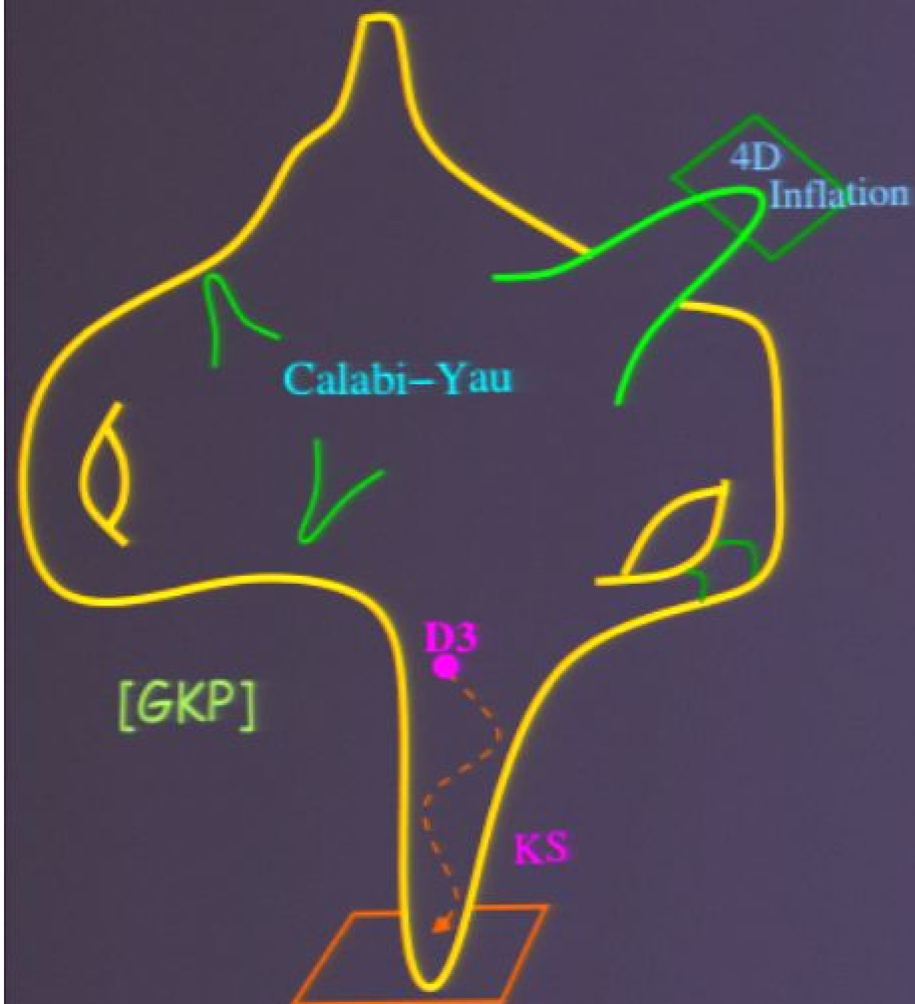

- Couple the system to gravity to study inflationary trajectories.

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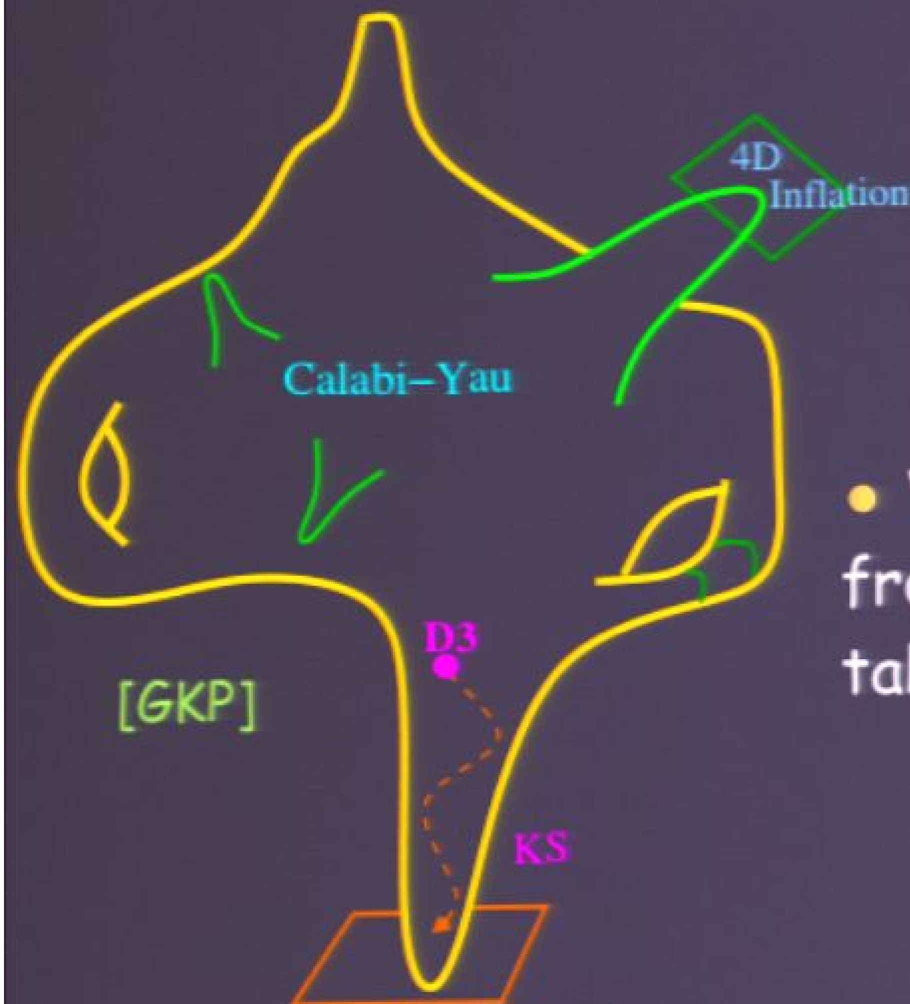

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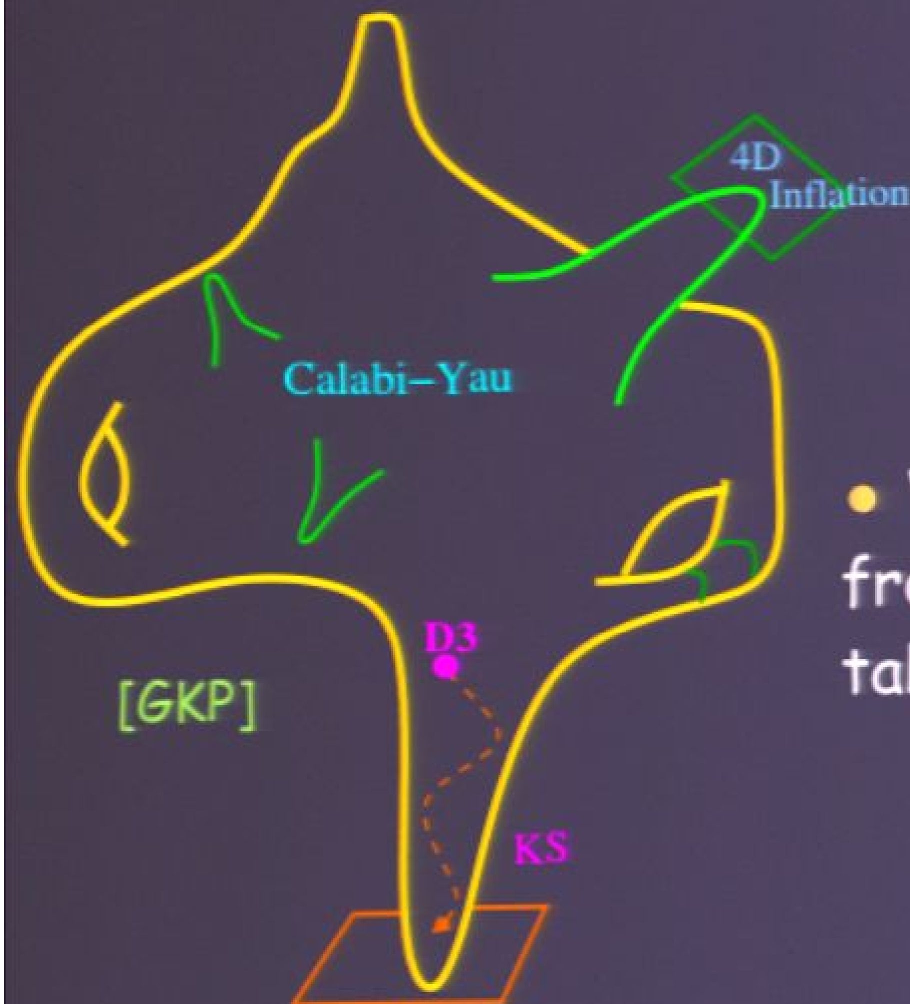

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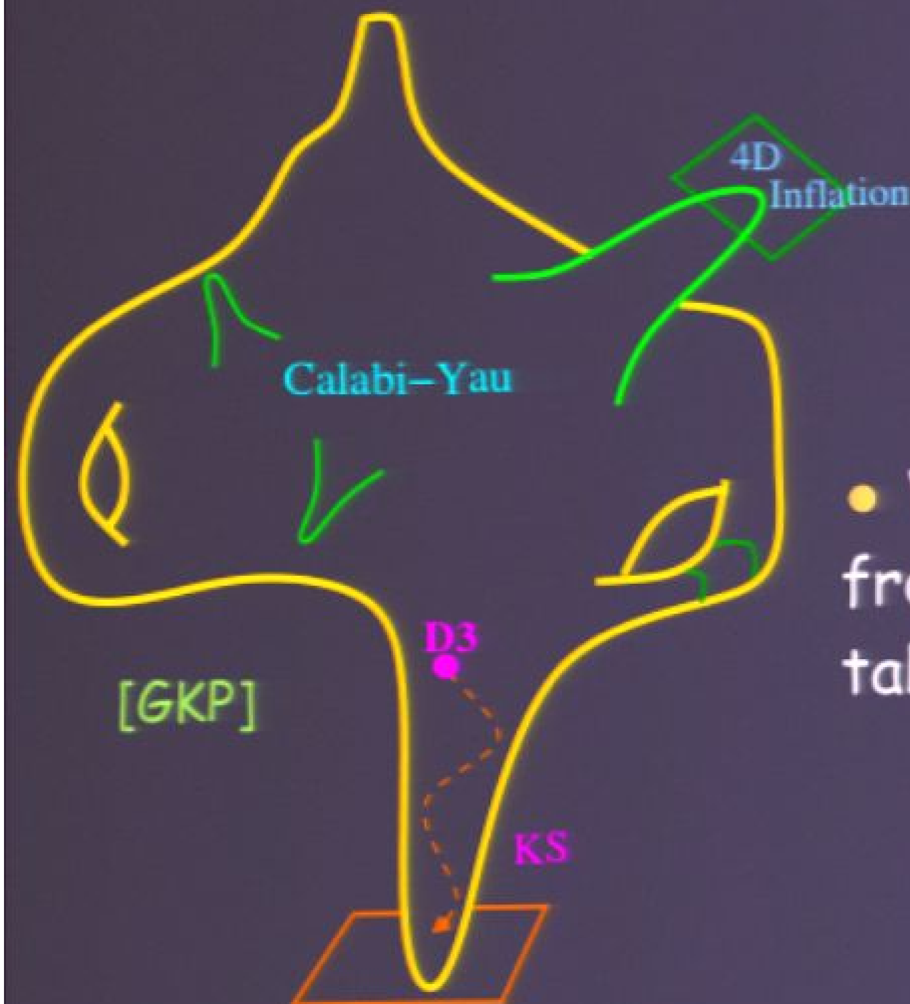

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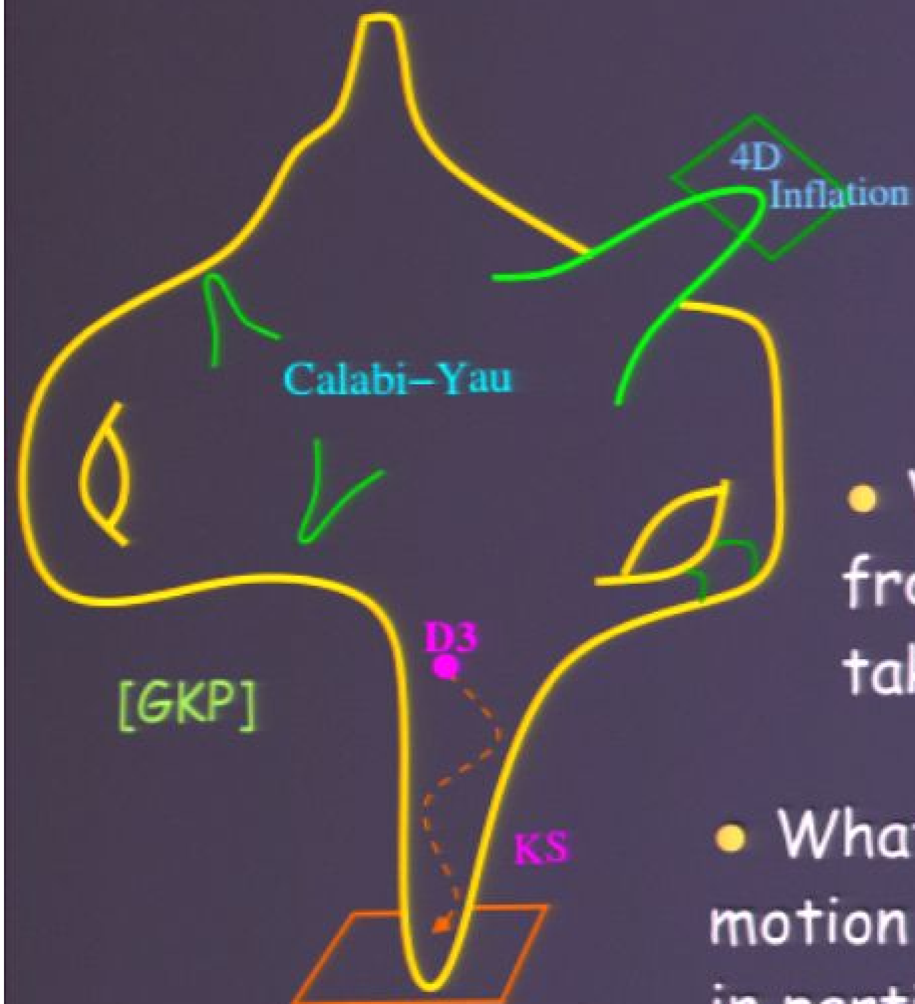

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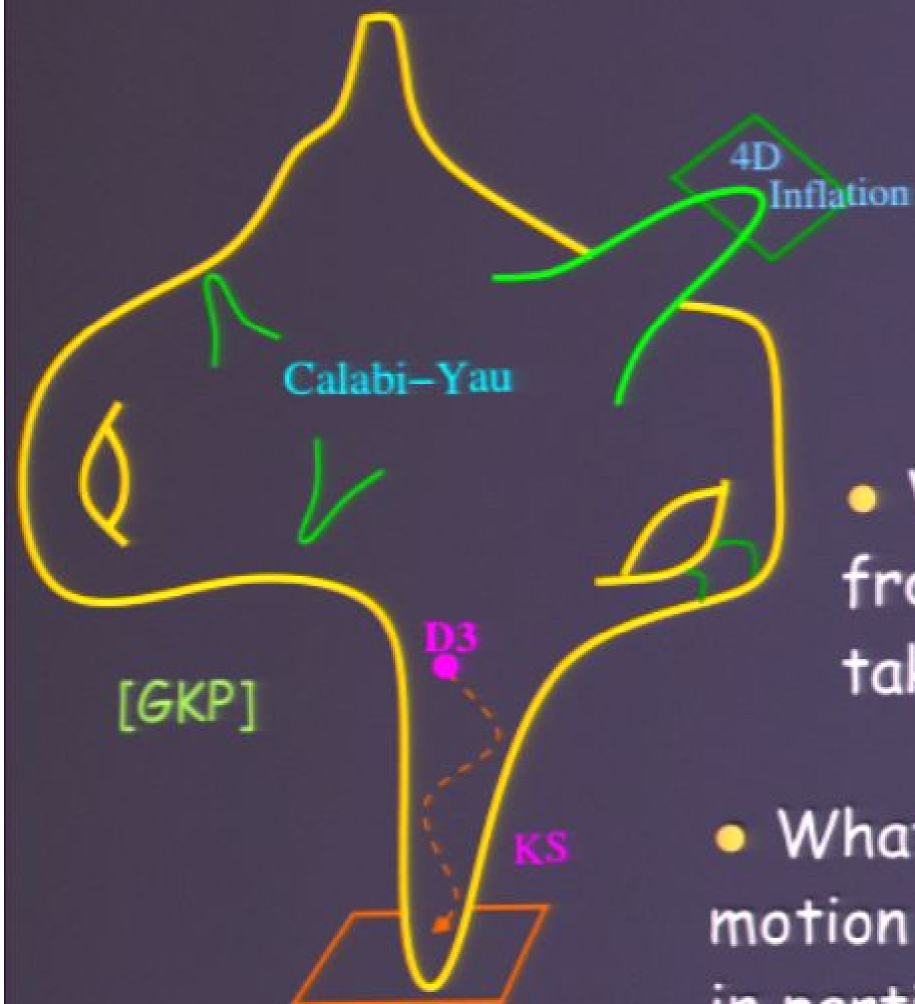

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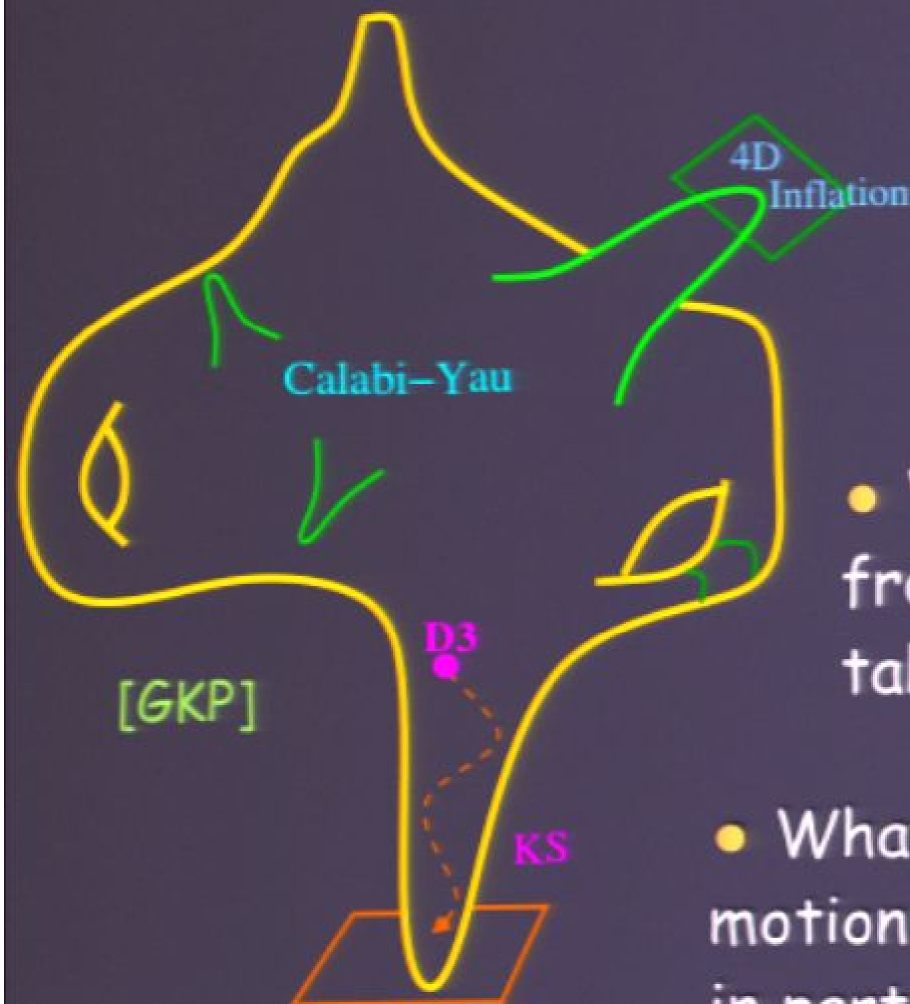

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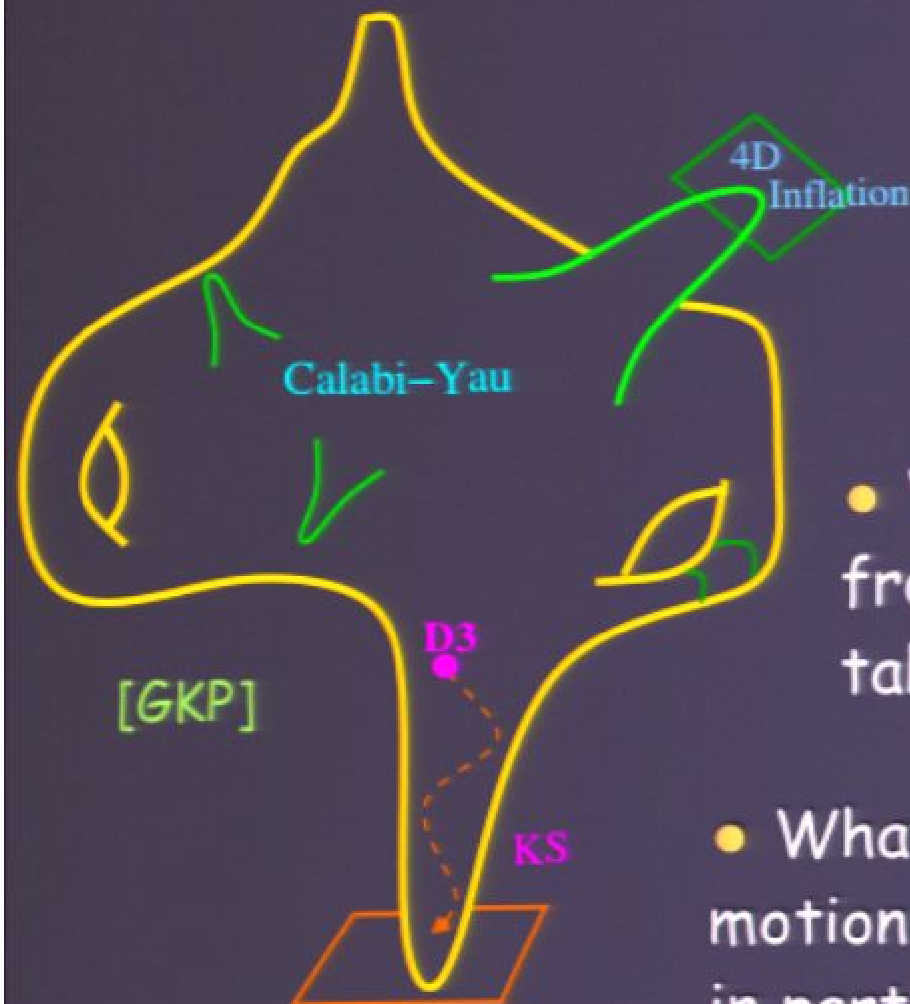

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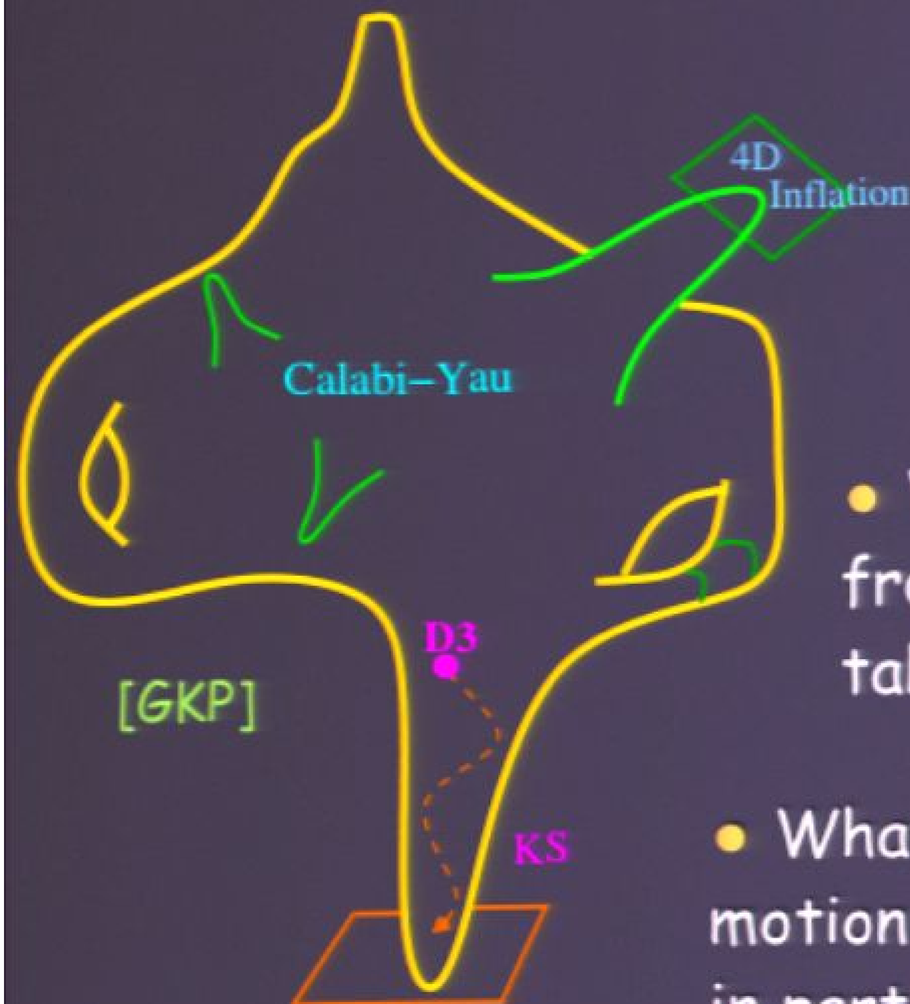

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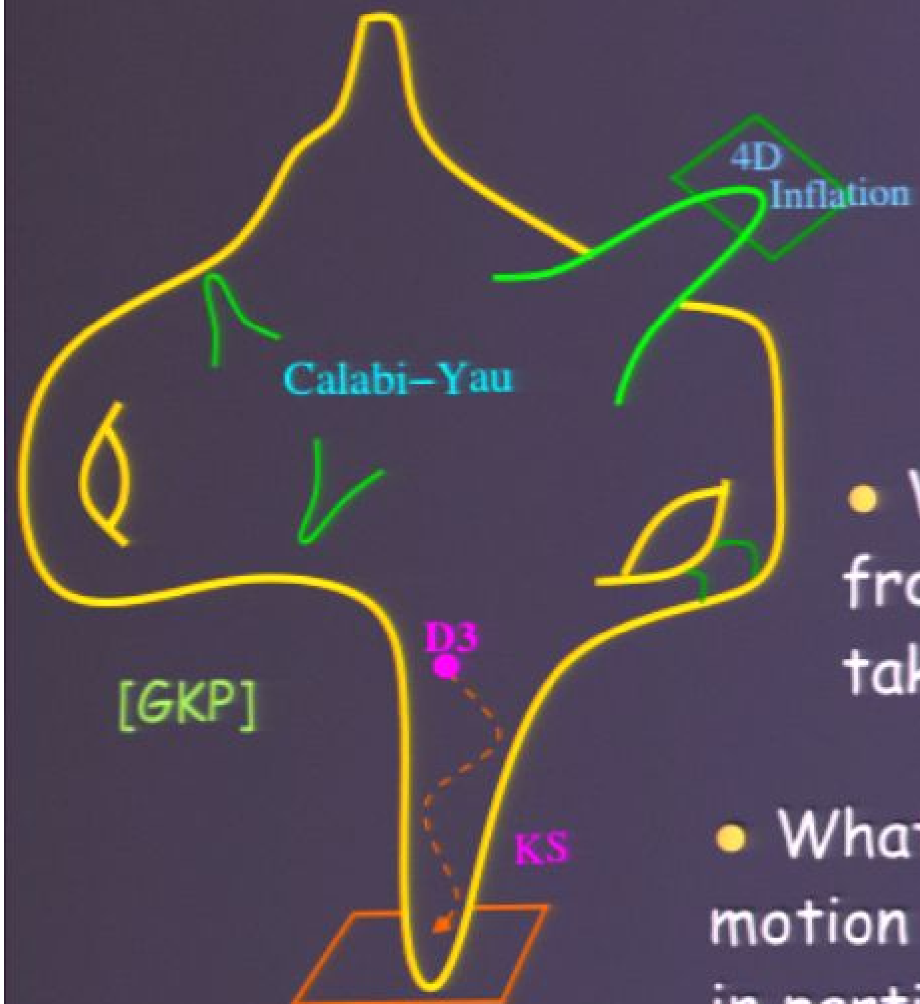

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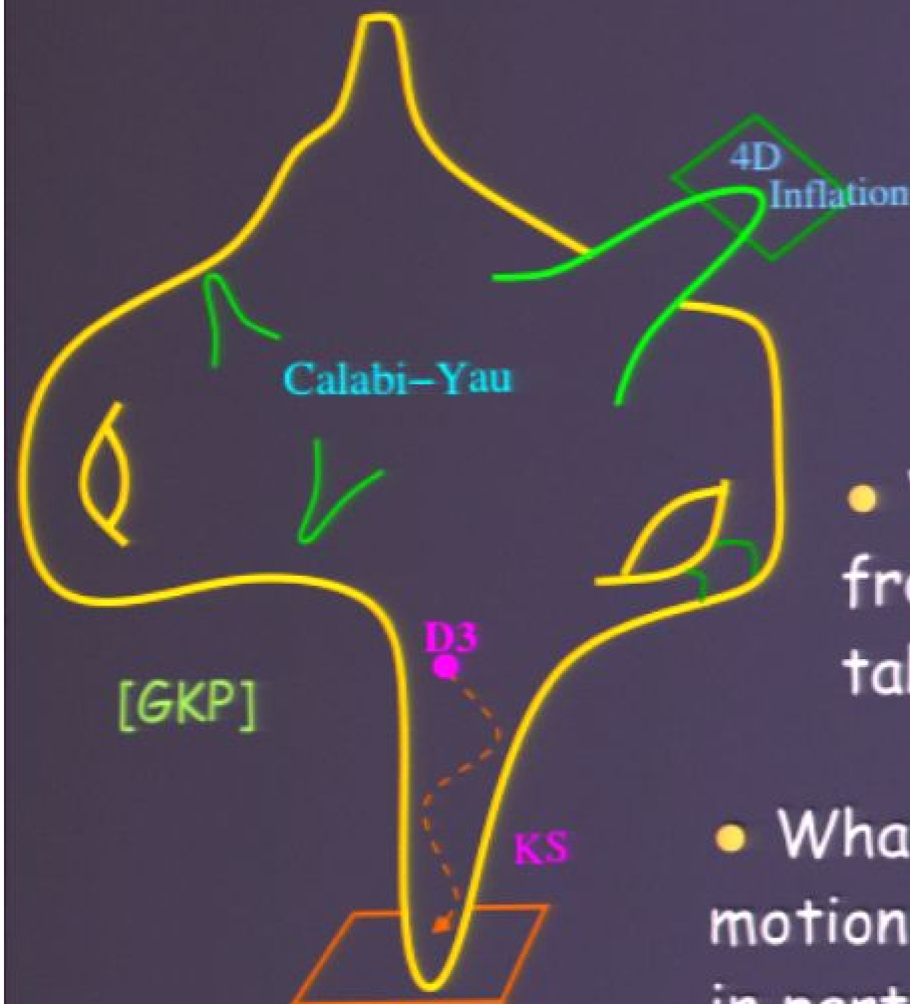
Effective 4D approach: DBI Cosmology



- Couple the system to gravity to study inflationary trajectories. [Quevedo, Gibbons, Silverstein-Tong].
- What happens to brane trajectories from 4D point of view (backreaction is taken into account)?
- What is the effect of brane angular motion (spin) on 4D cosmological expansion, in particular on acceleration ?
- Can the angular motion relax the constraints on DBI Inflation

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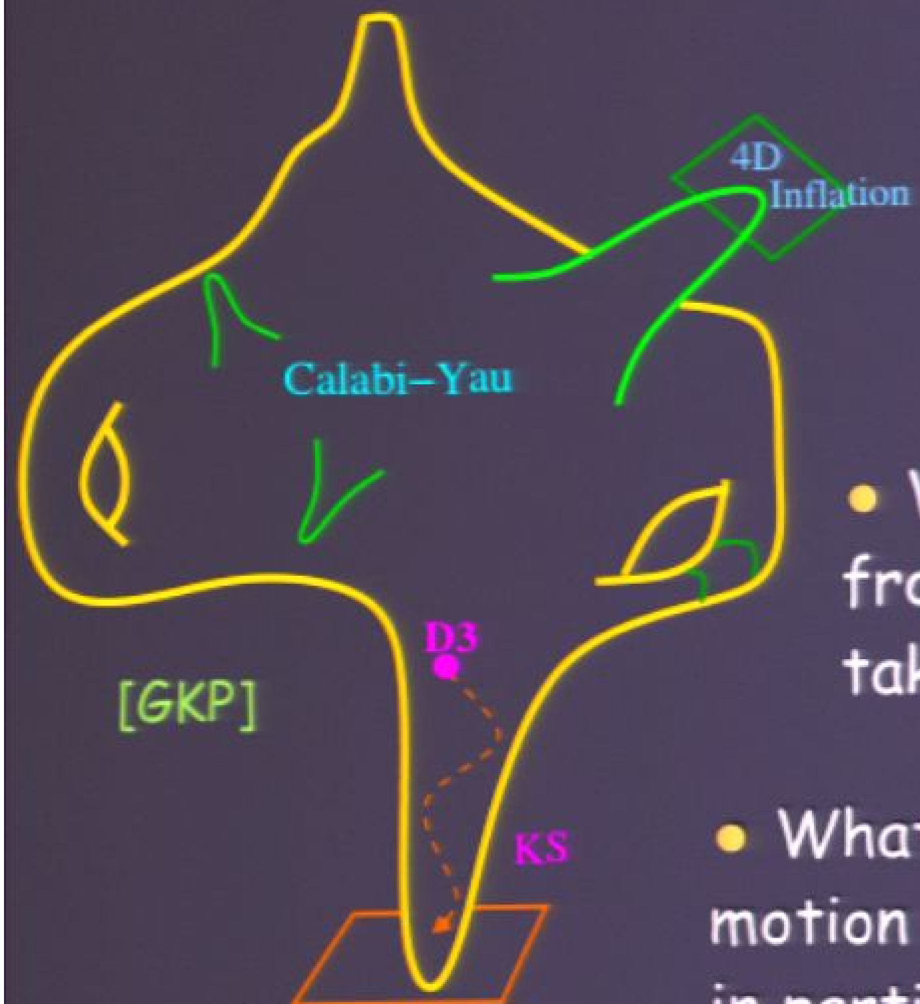

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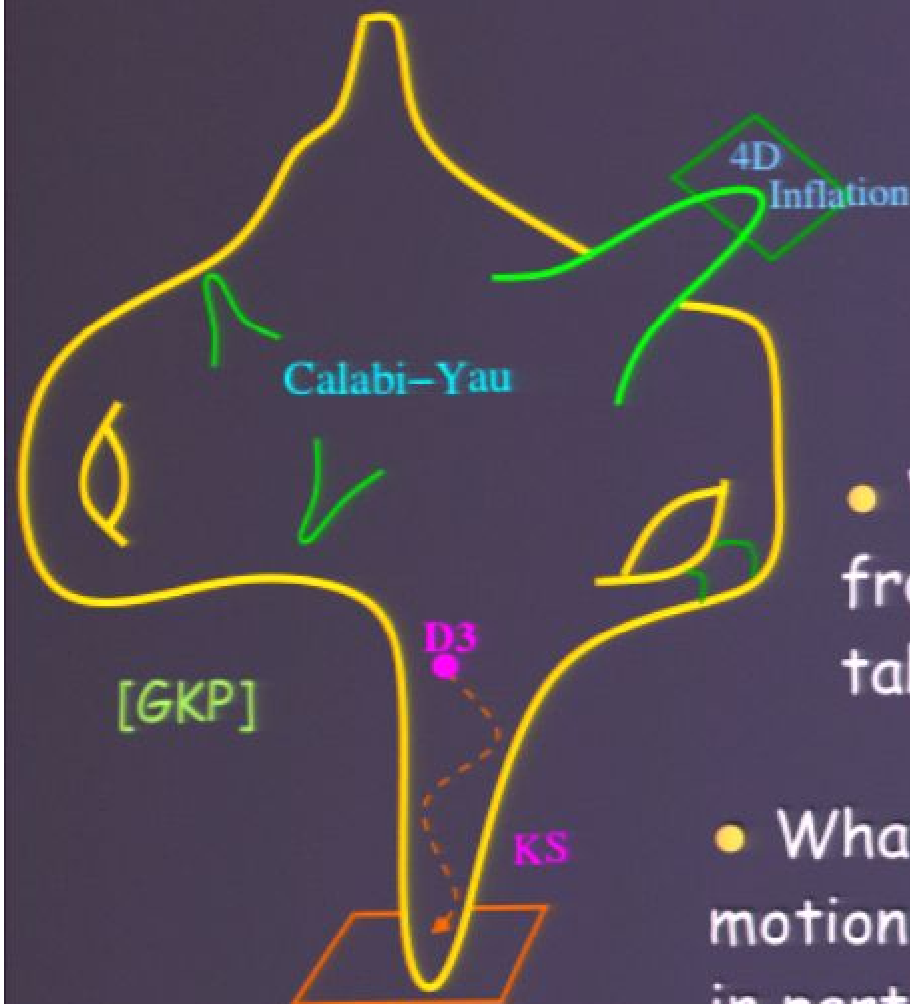

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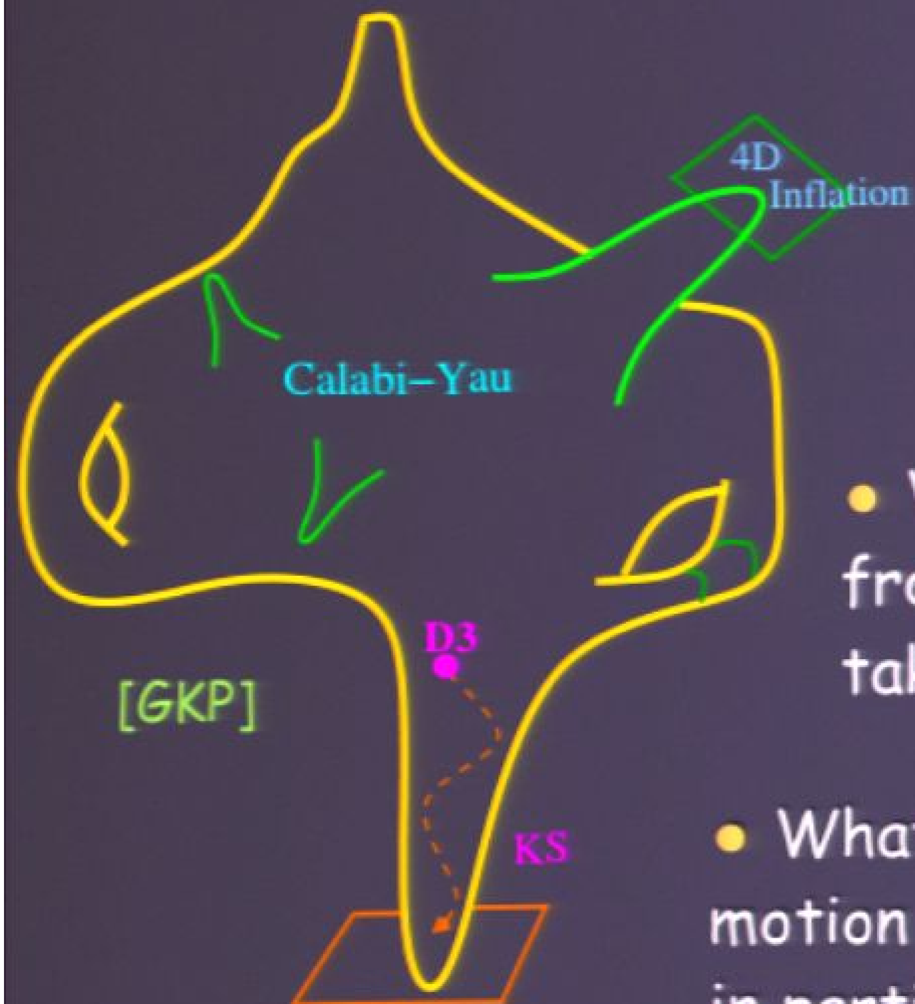

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Multifield DBI Inflation

$$S_4 = \frac{M_{Pl}^2}{2}\int d^4x\sqrt{-g}\,R$$

$$-\,g_s^{-1}\int d^4x\sqrt{-g}\left[h^{-1}\sqrt{1-h\,g_{mn}\dot{\phi}^m\dot{\phi}^n}-q\,h^{-1}+V(\phi^m)\right]$$

$$M_{Pl}^2 = V_6/\kappa_{10}^2 \qquad \kappa_{10}^2 = \frac{(2\pi)^7}{2}g_s^2\alpha'^4$$

Four dimensional metric is of FRW form:

$$ds_4^2 = -dt^2 + a^2(t)\,dx_i dx^i$$

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Brane trajectory
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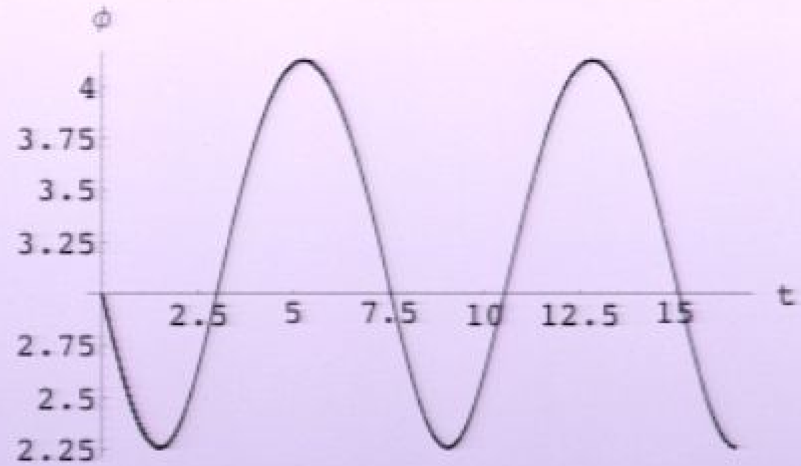

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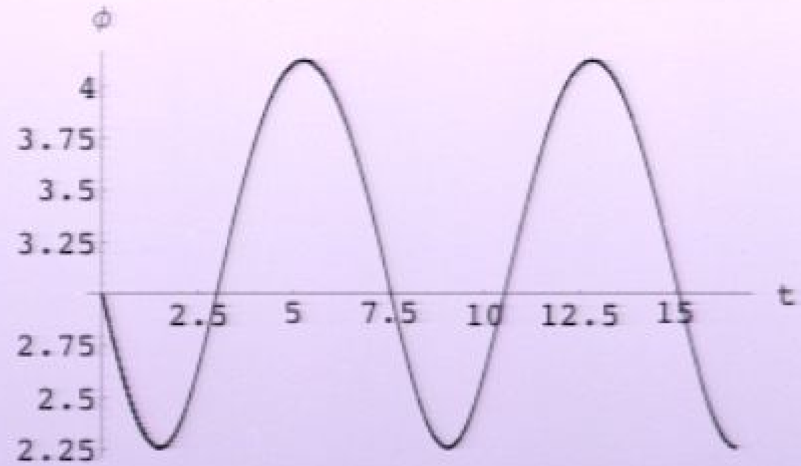
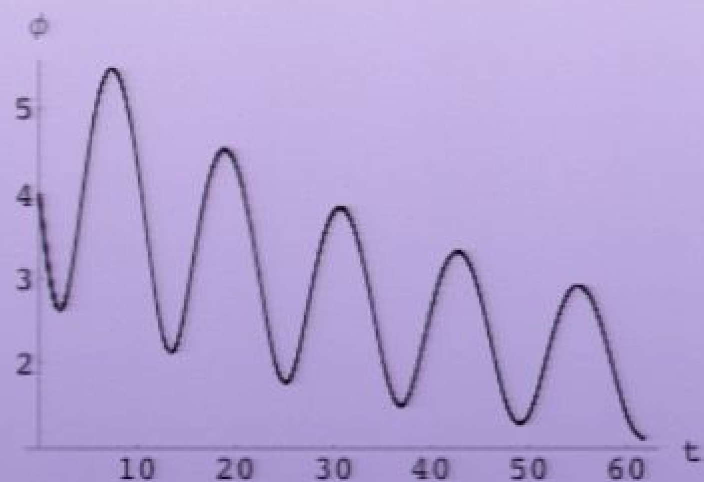


Brane position and scale factor with gravity switched on .



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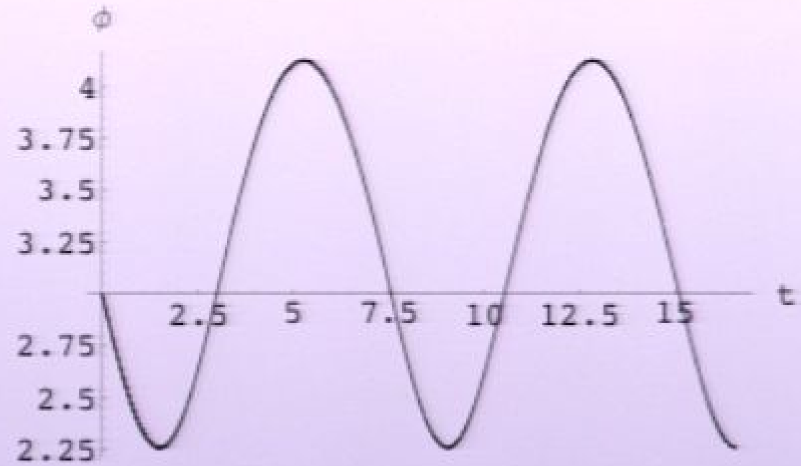

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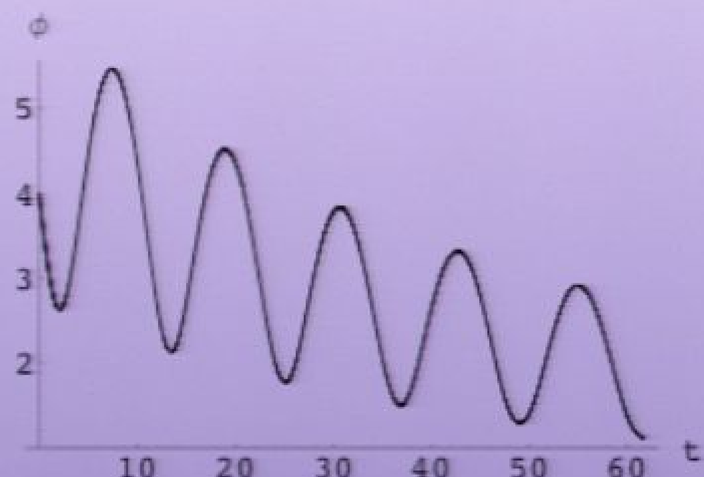

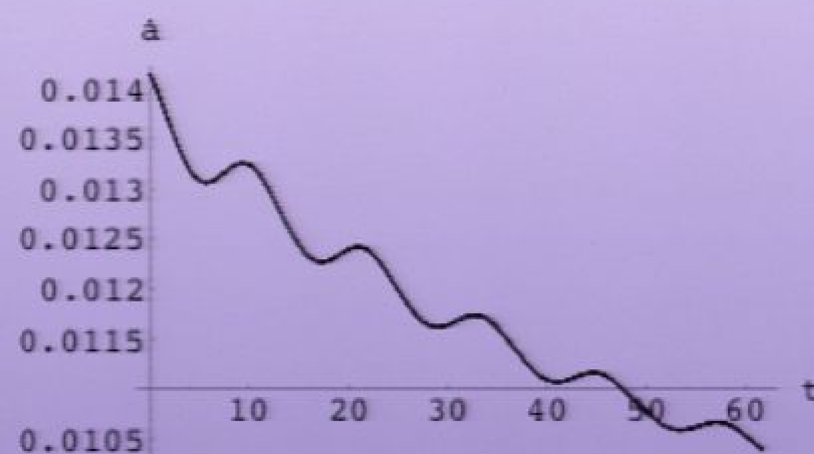

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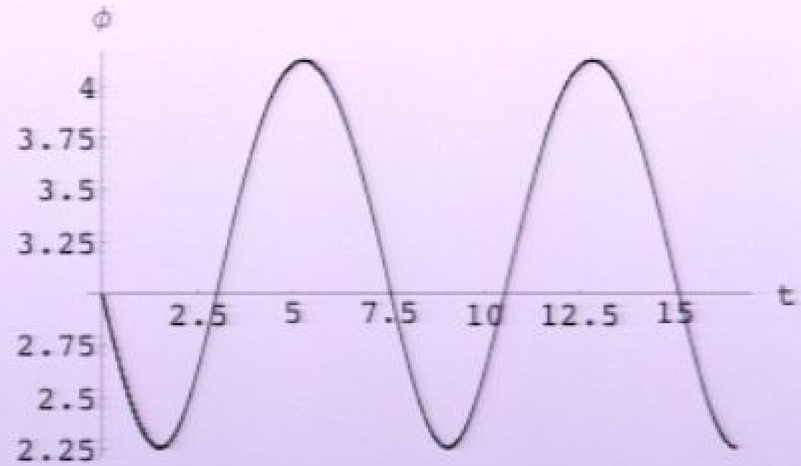

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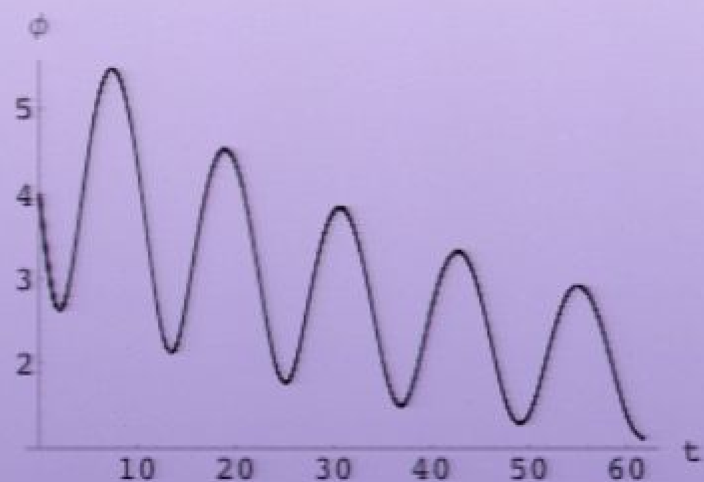

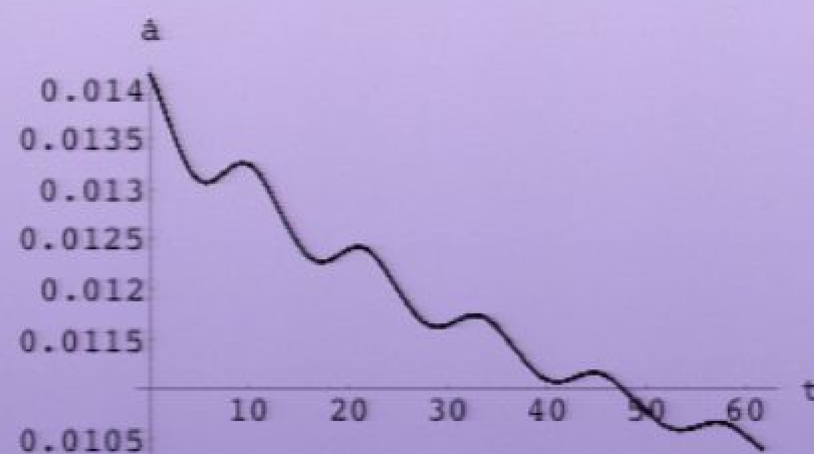

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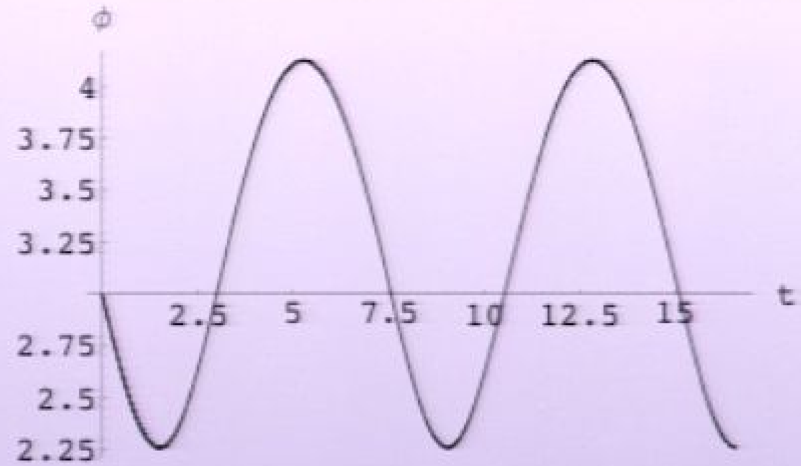

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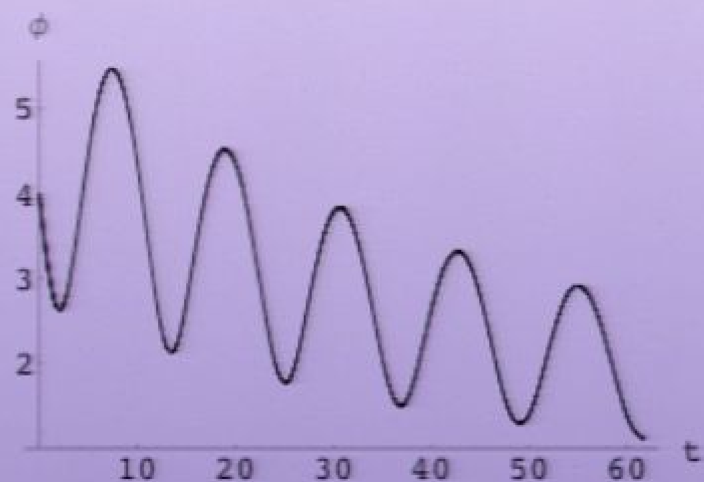

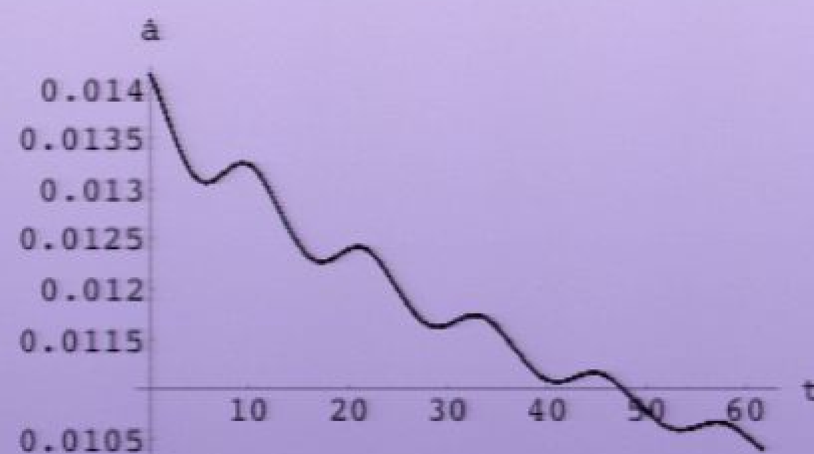

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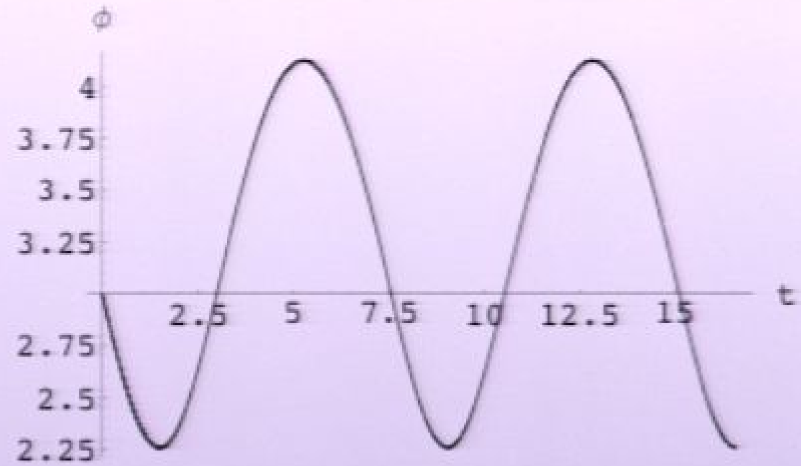

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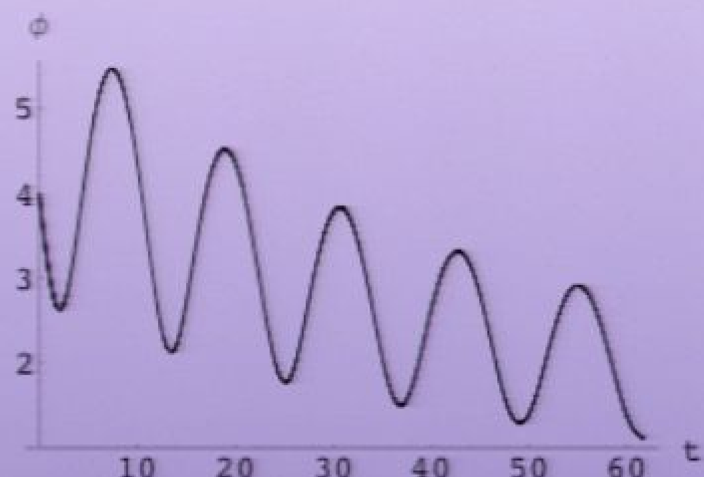

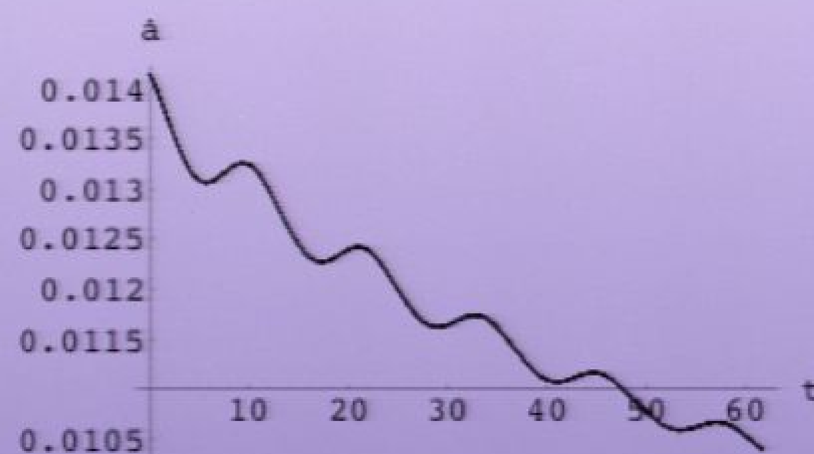

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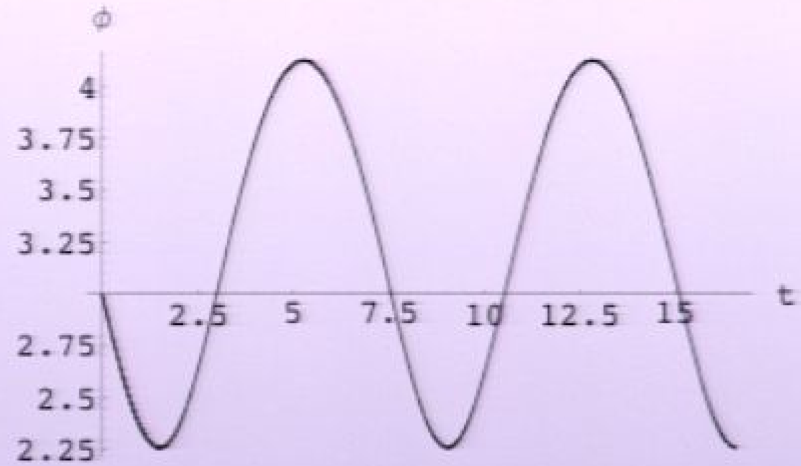

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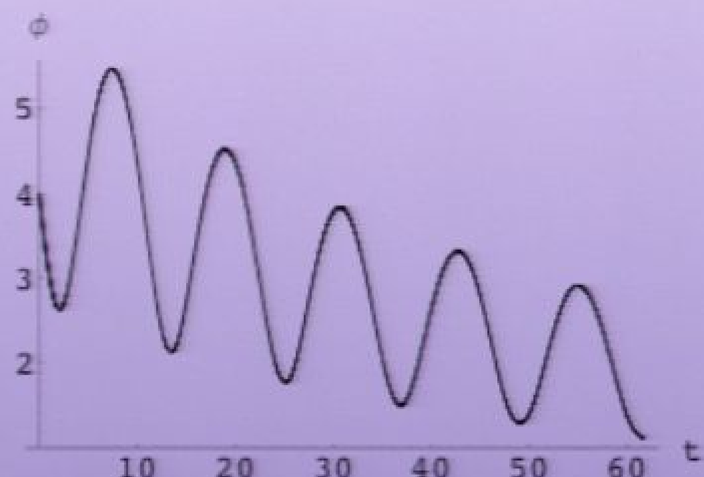

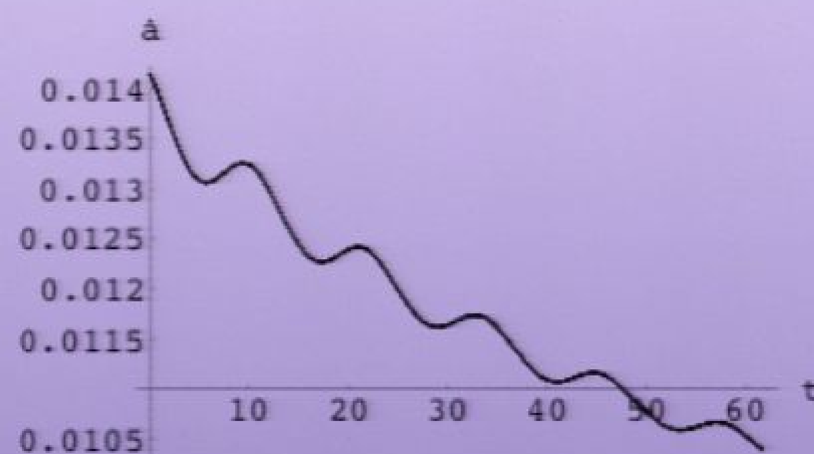

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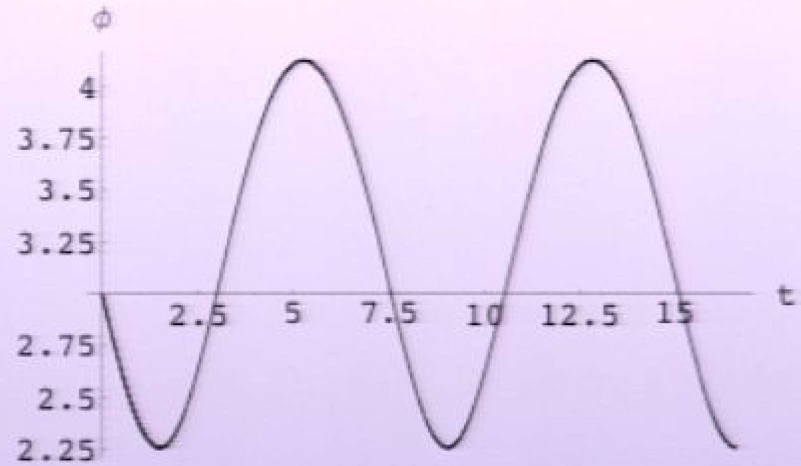

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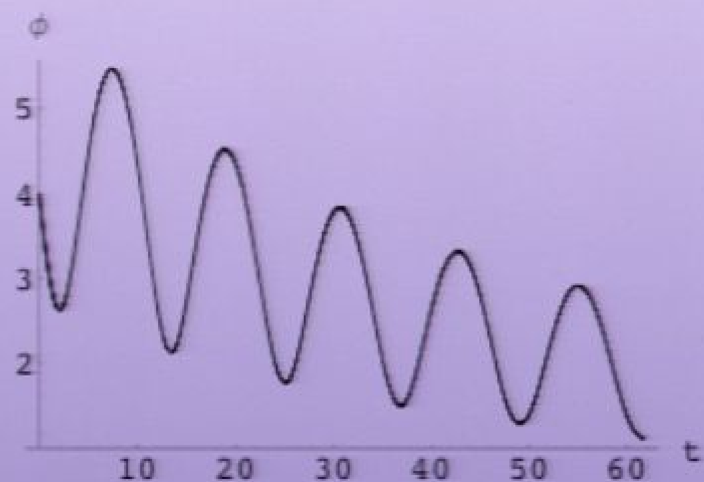

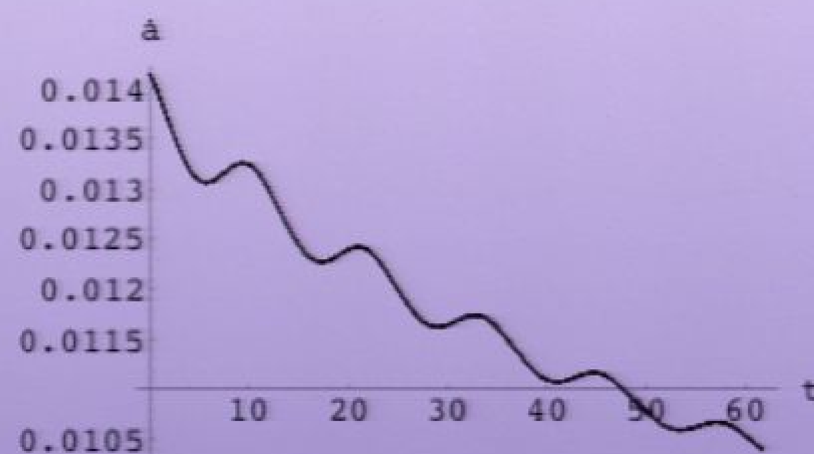

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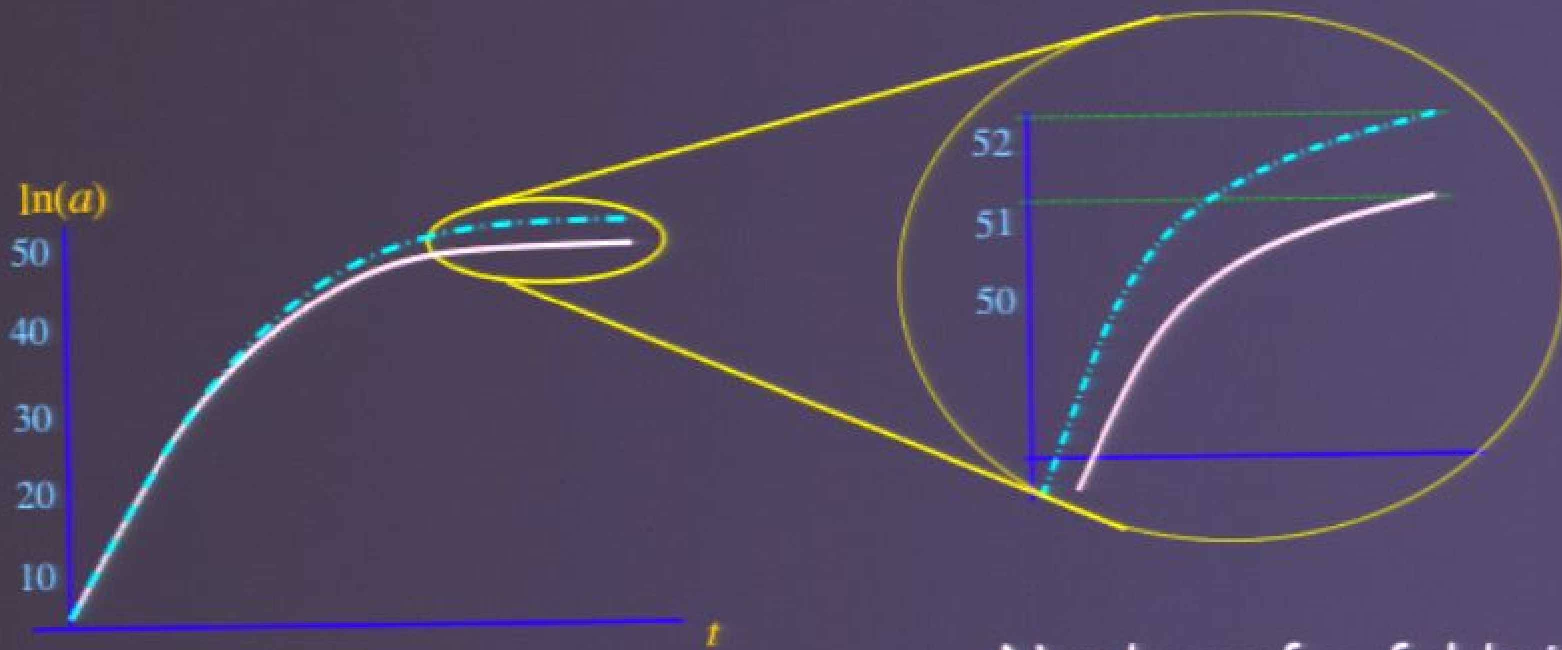

Number of e-folds increases by few units with angular momentum

Inflation $\Rightarrow mg_s M$ large

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=> End of inflation (γ becomes small): reheating through oscillations around tip

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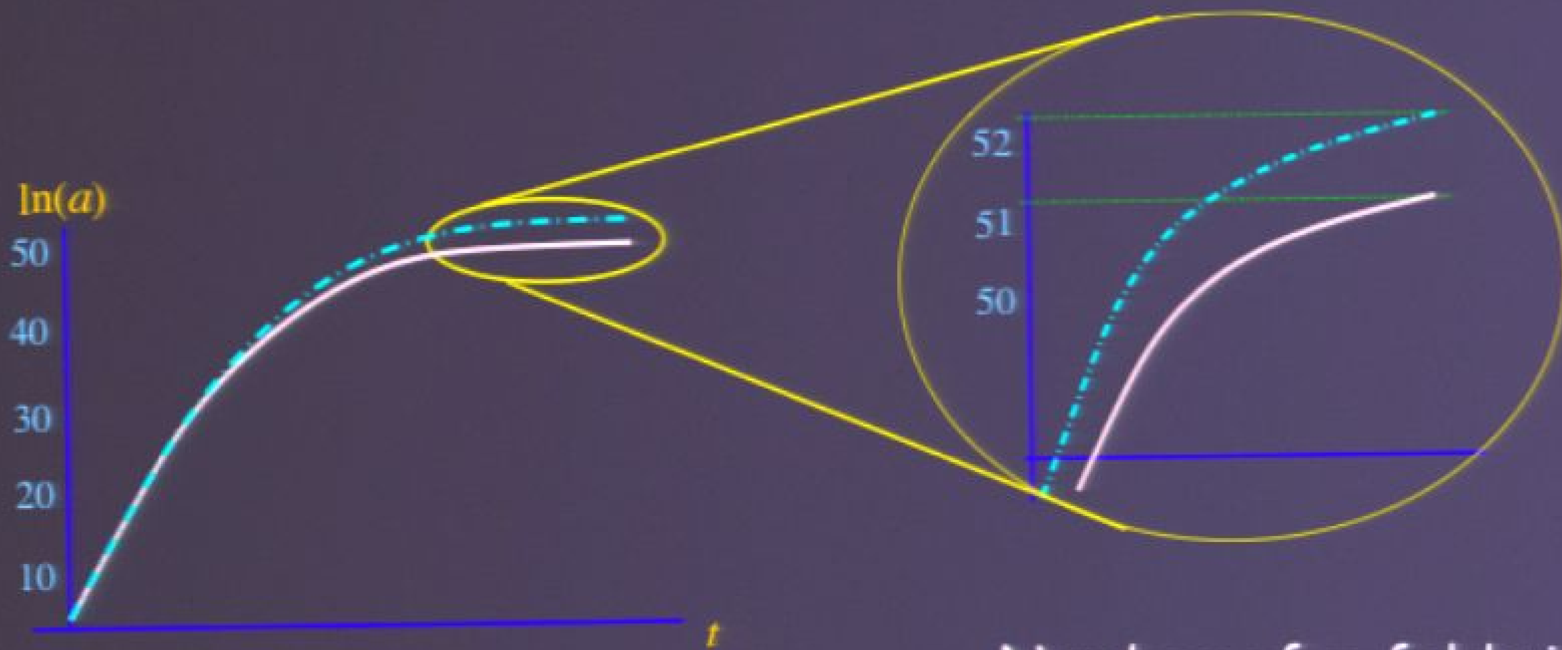

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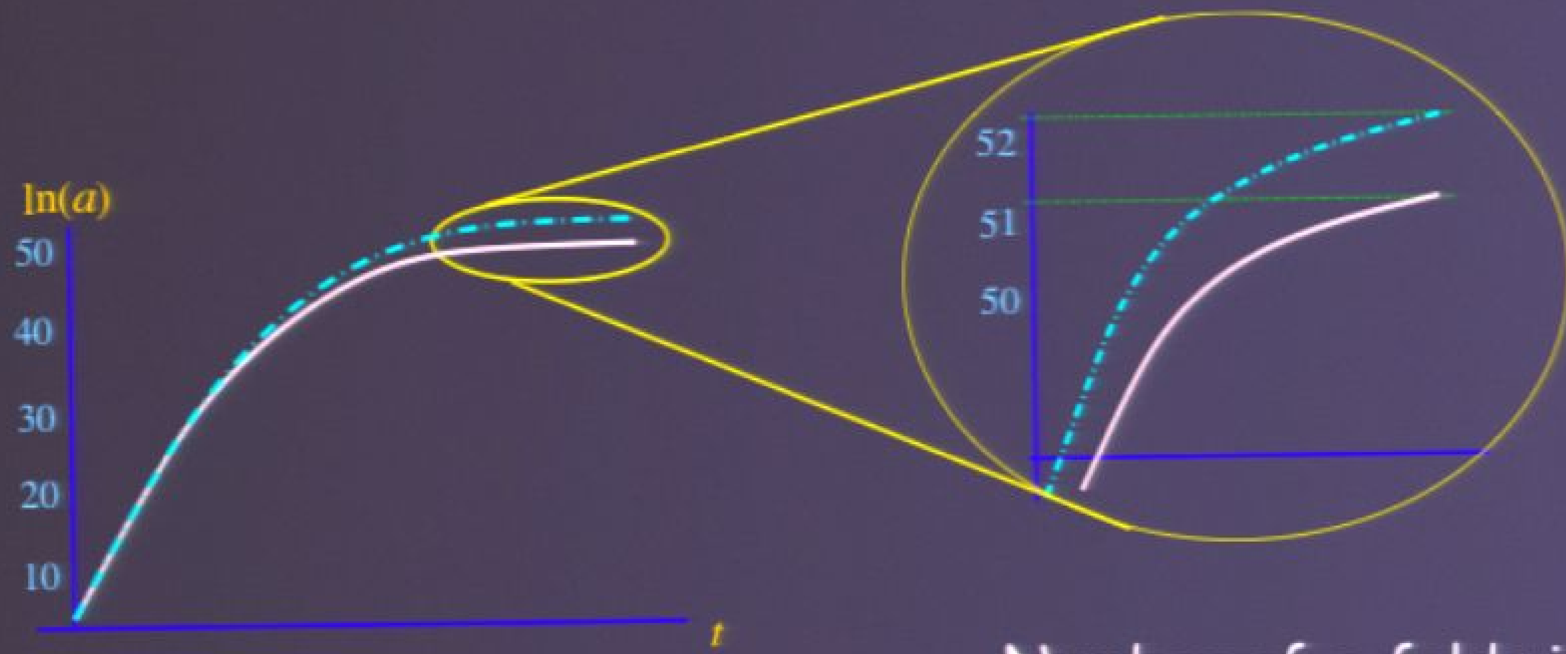

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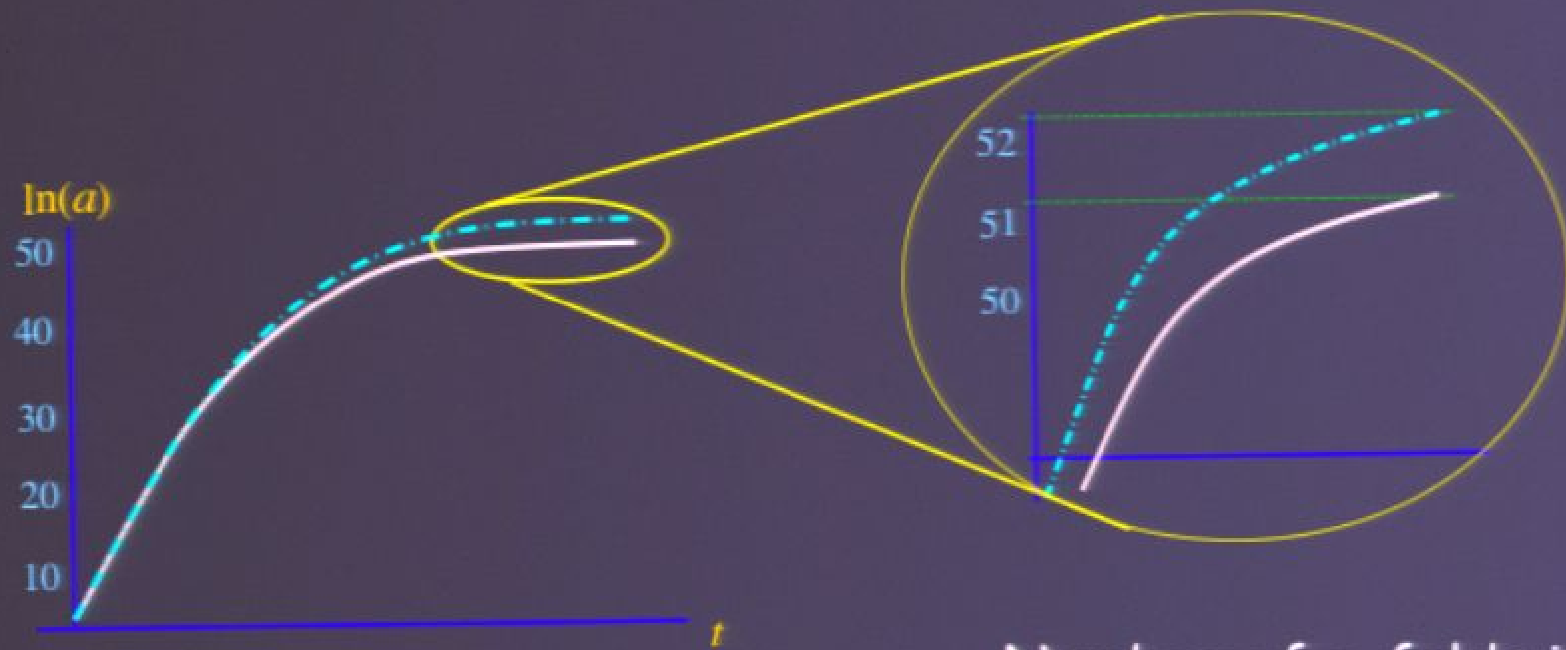

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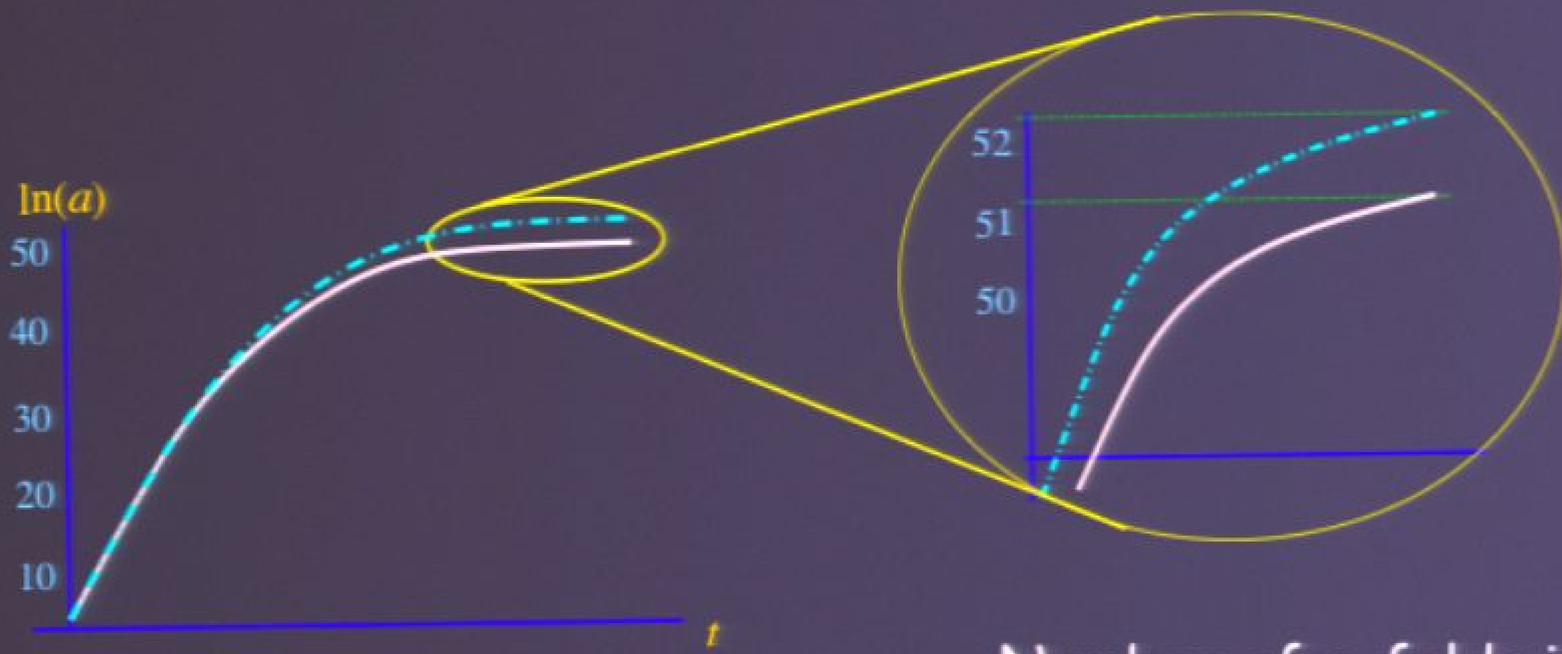

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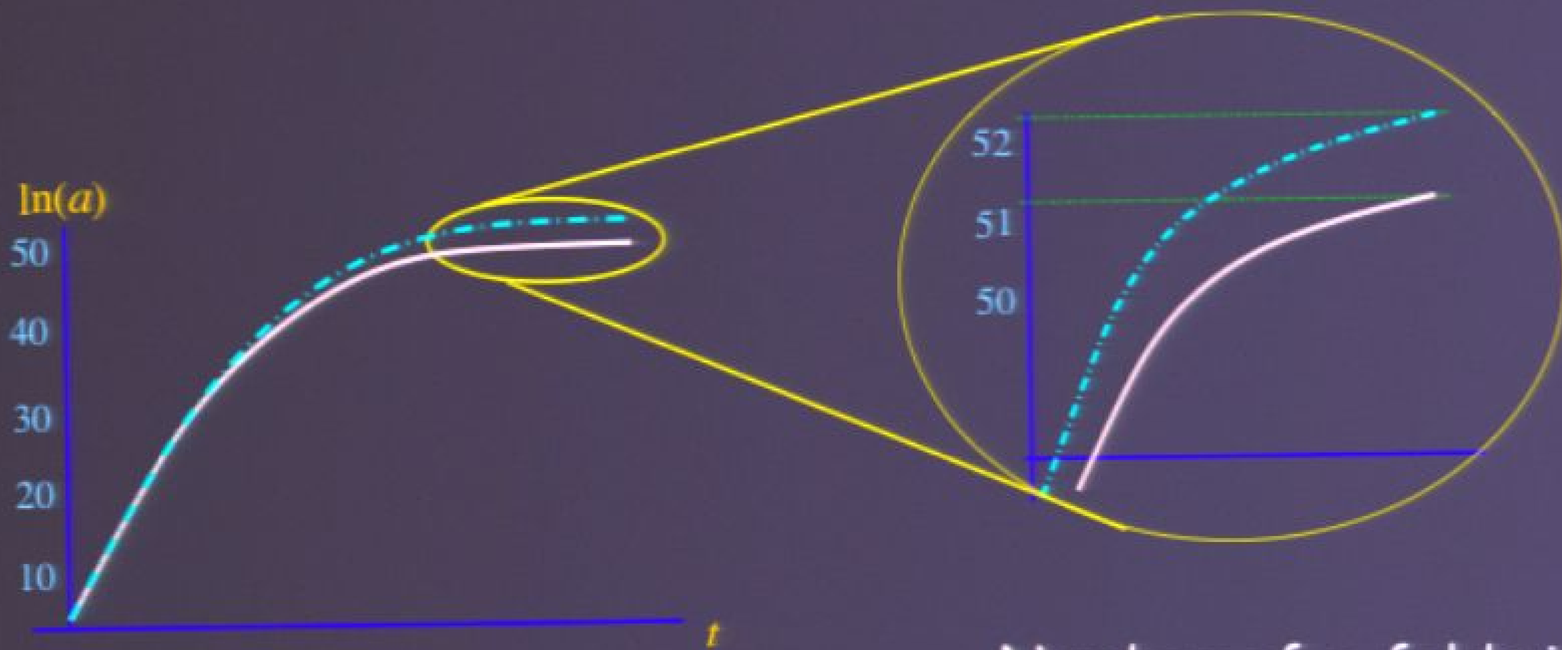

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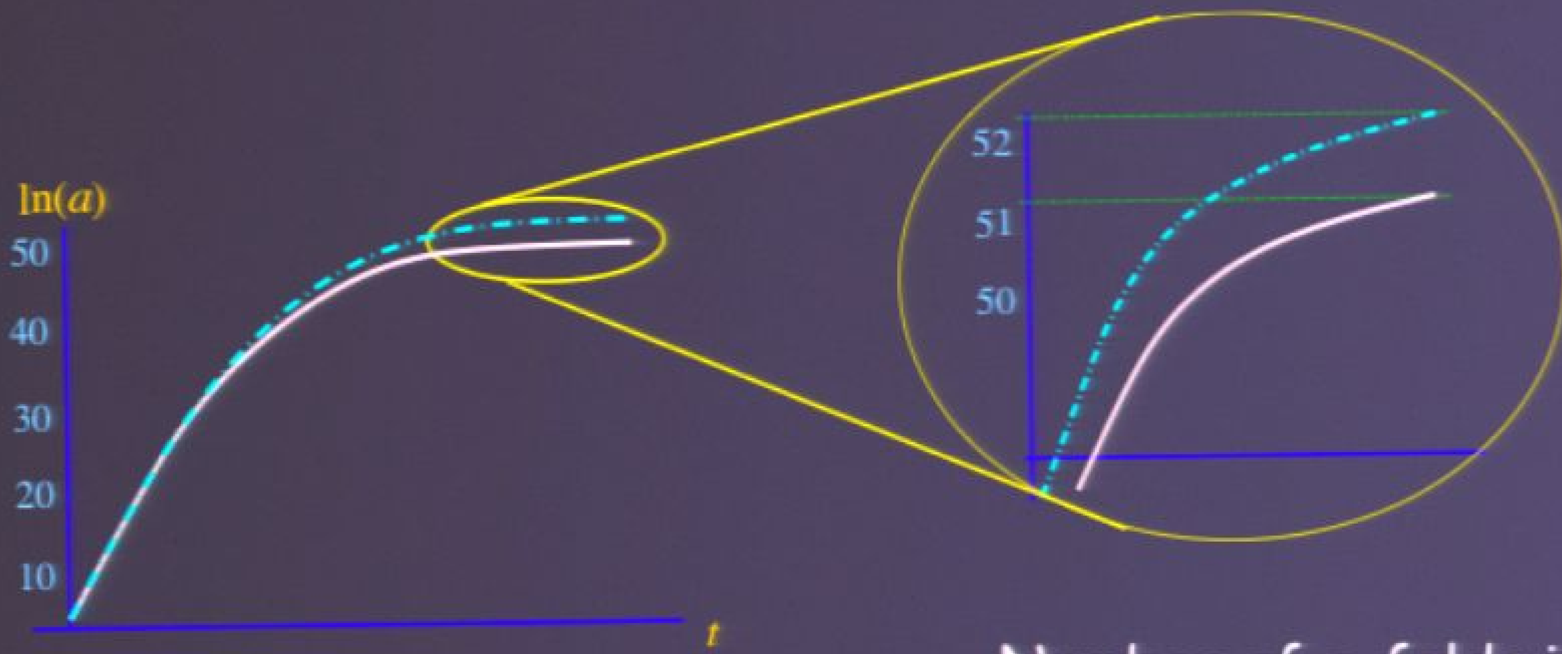

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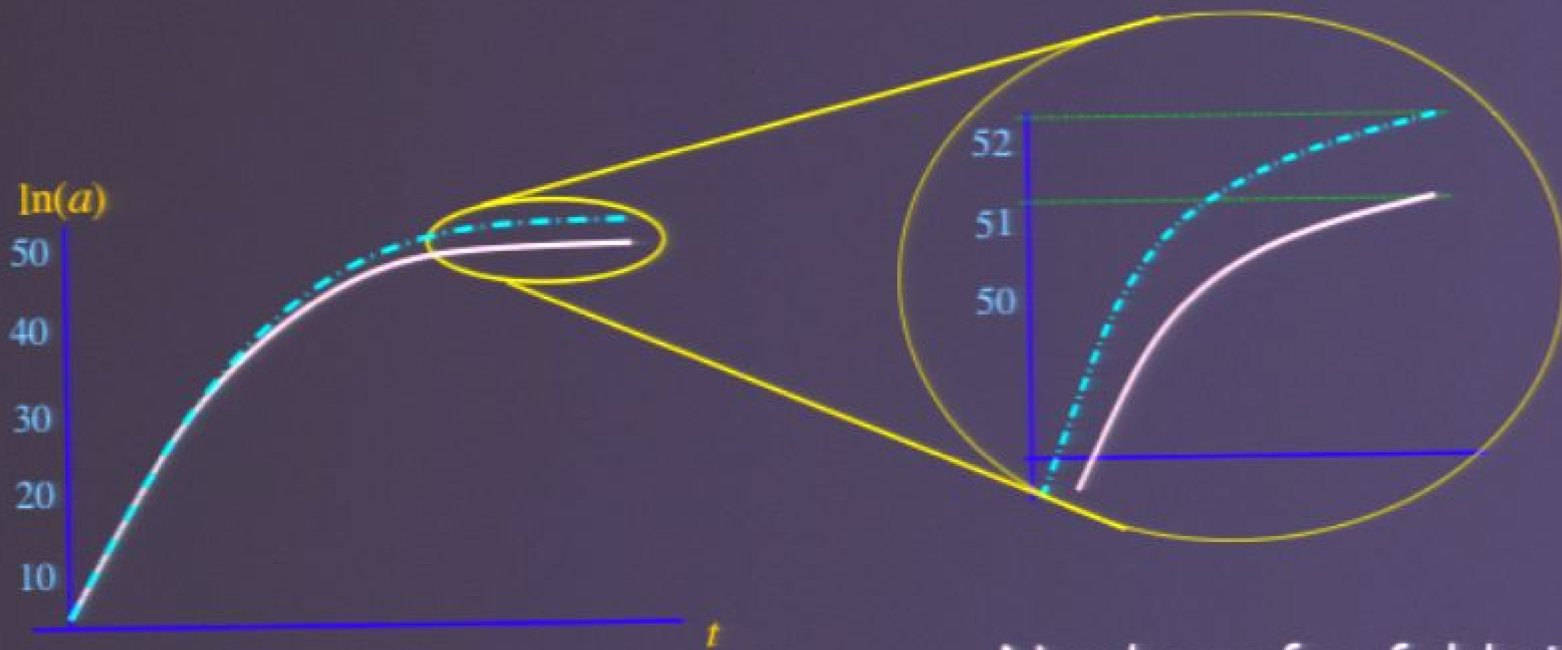

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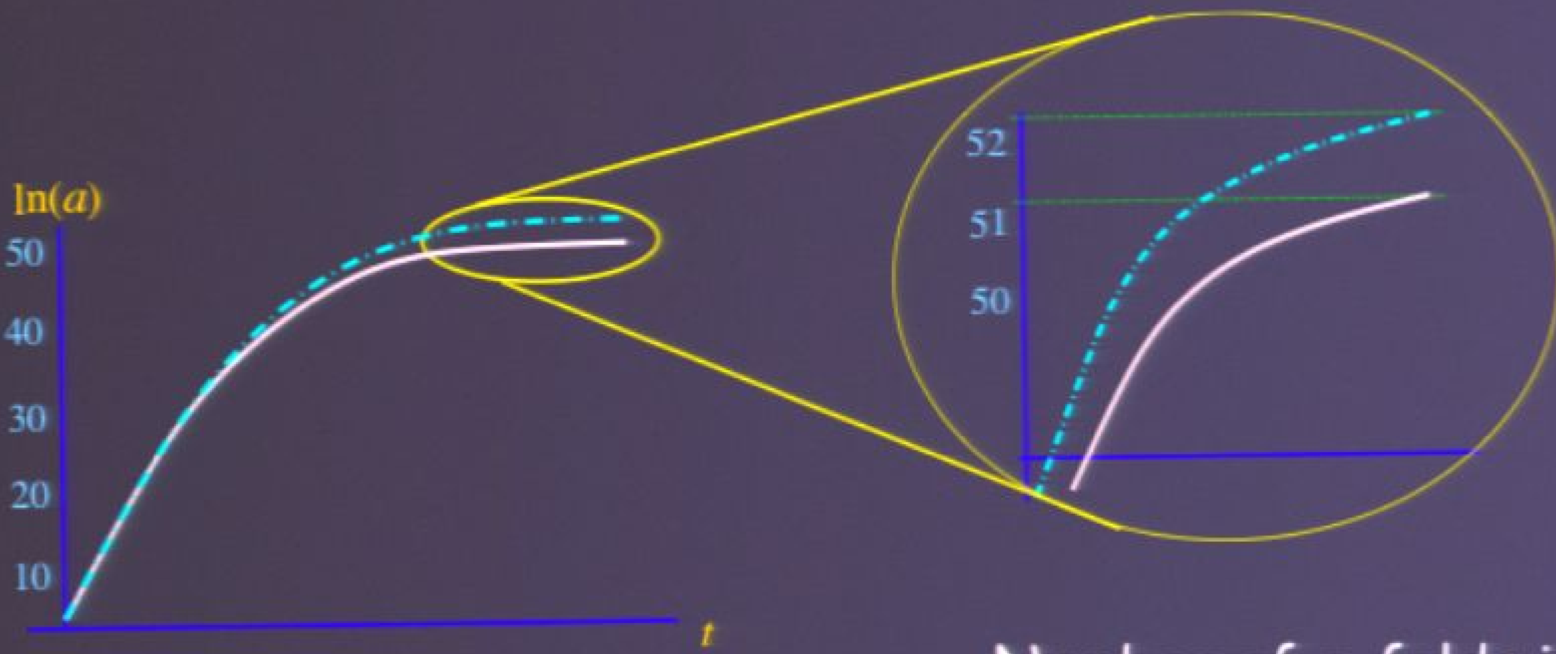

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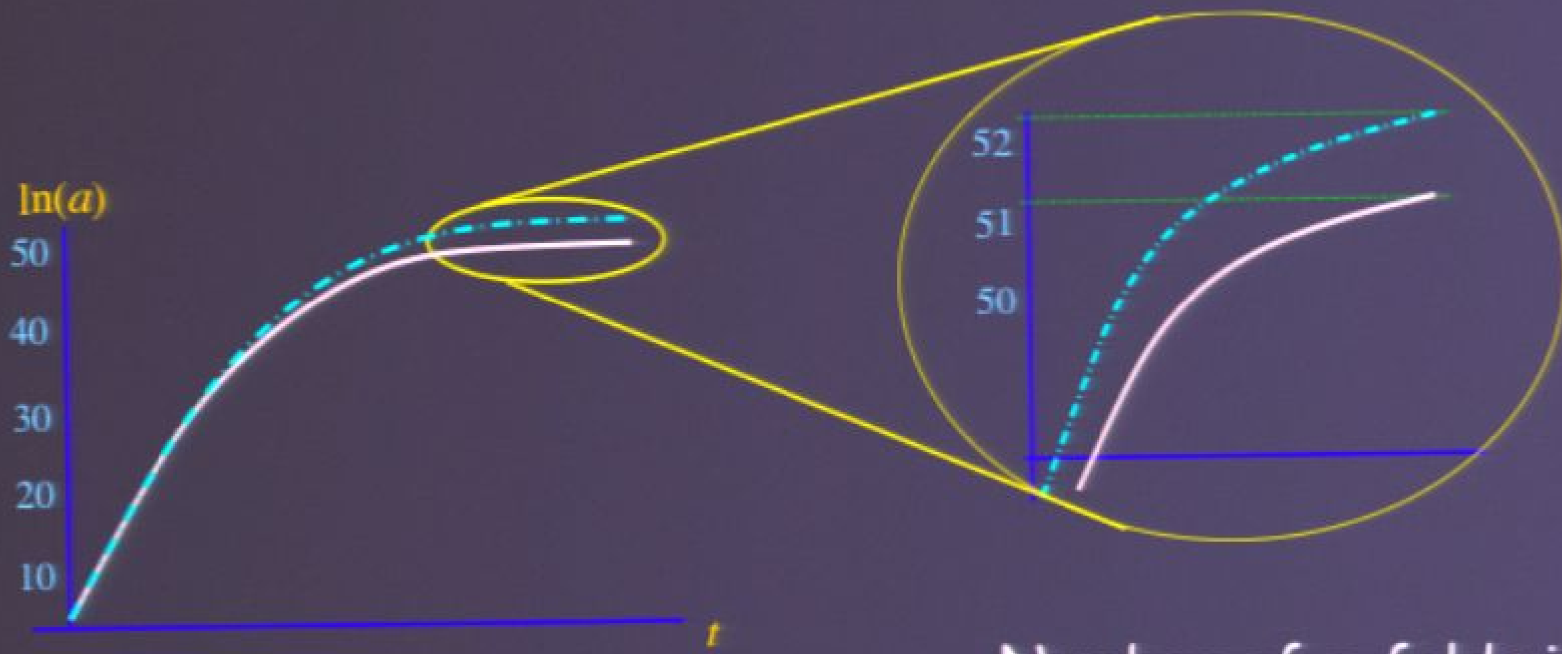

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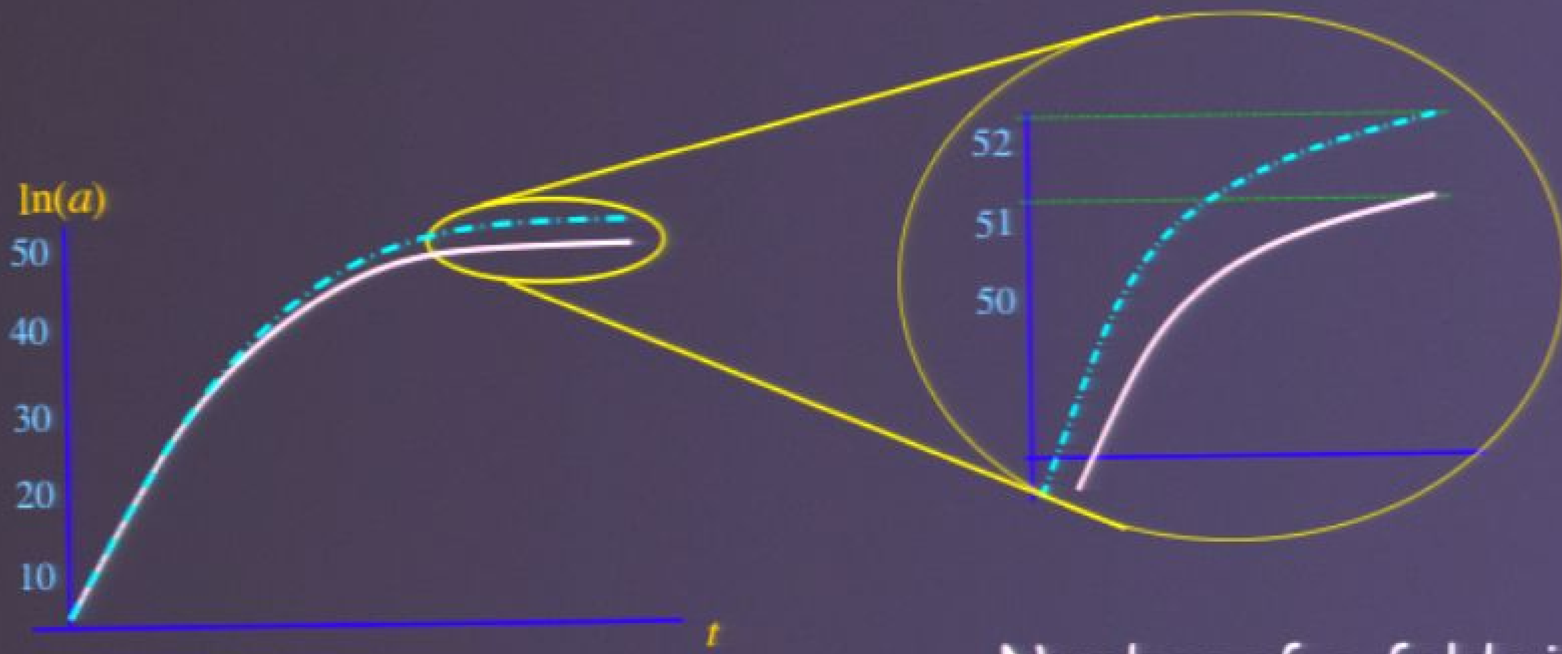

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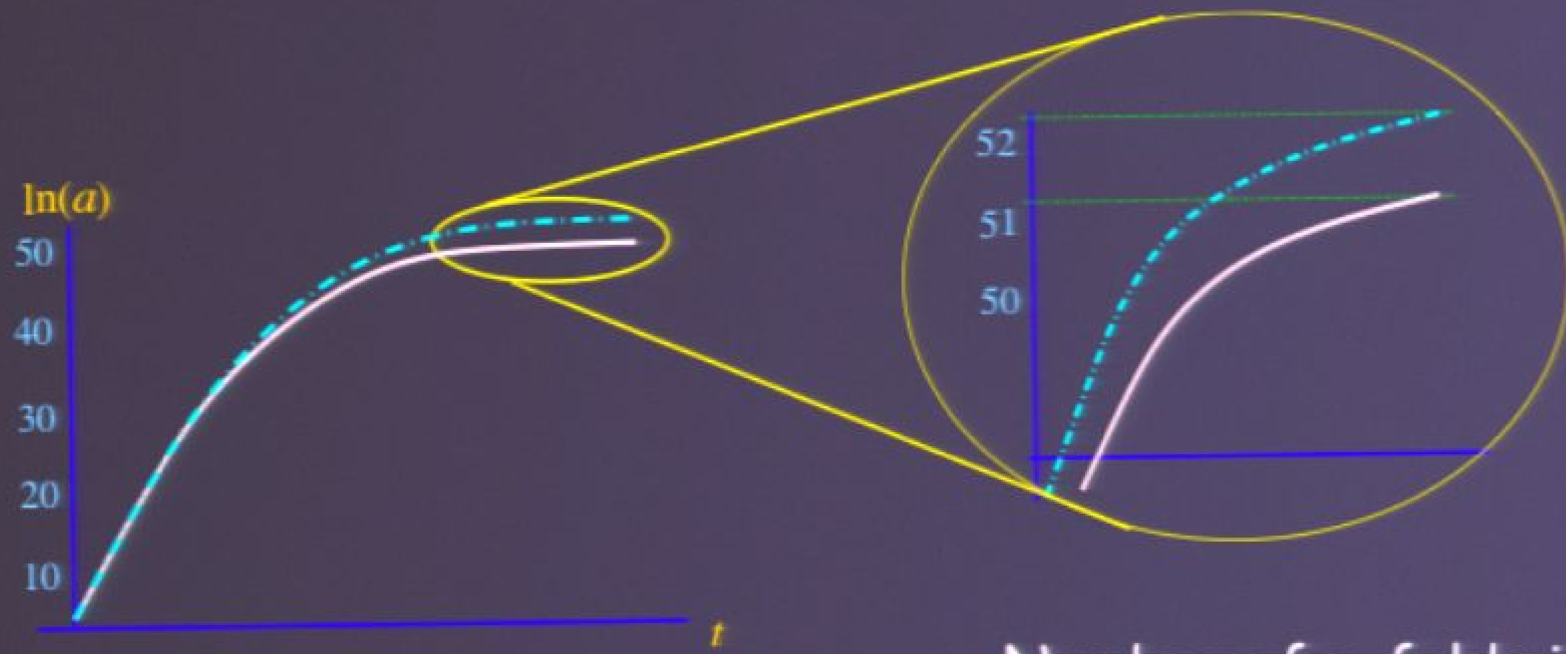

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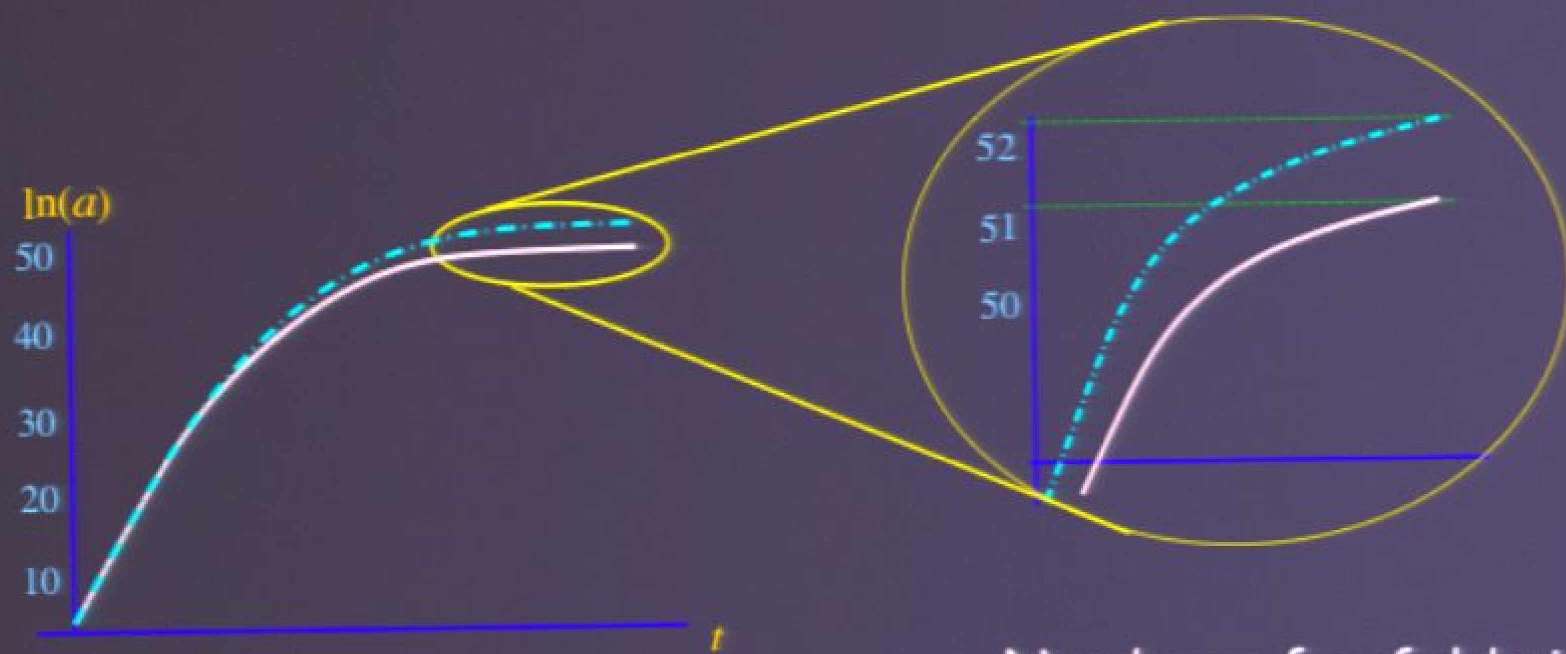

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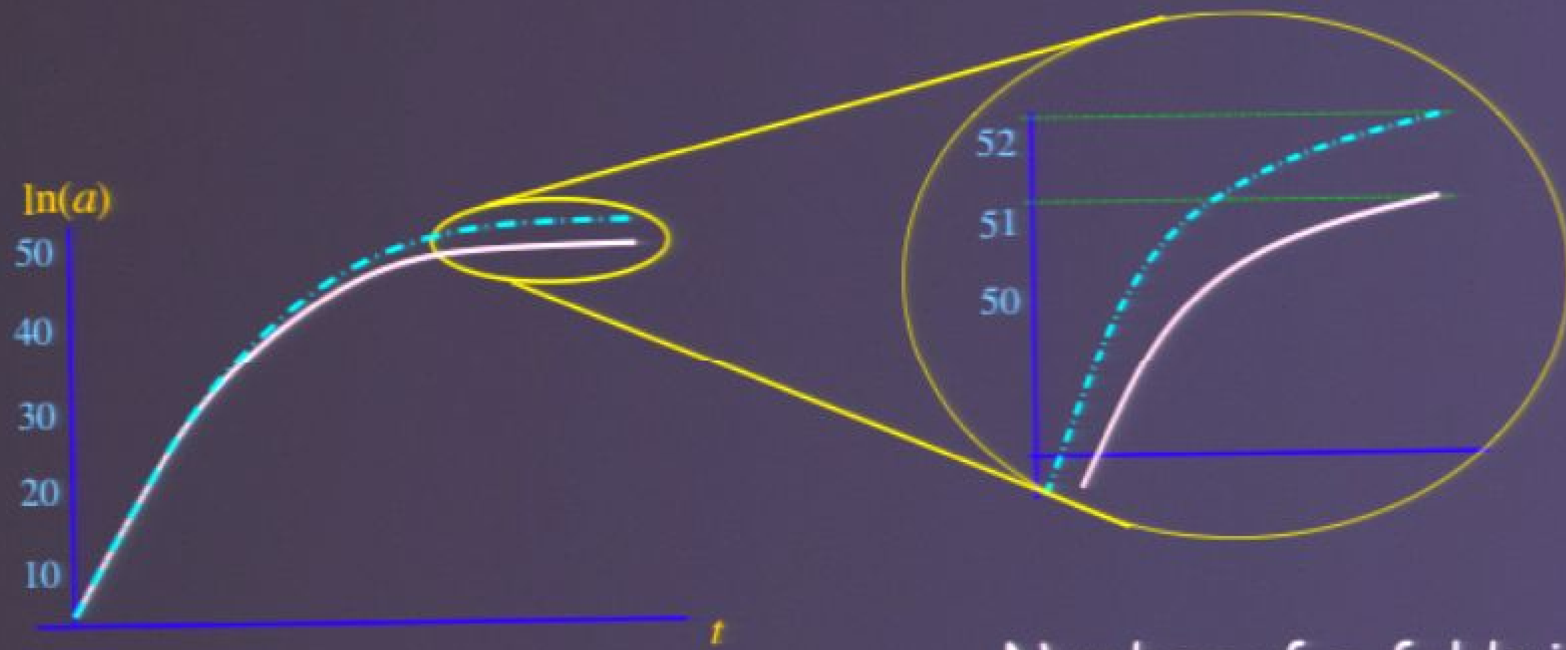

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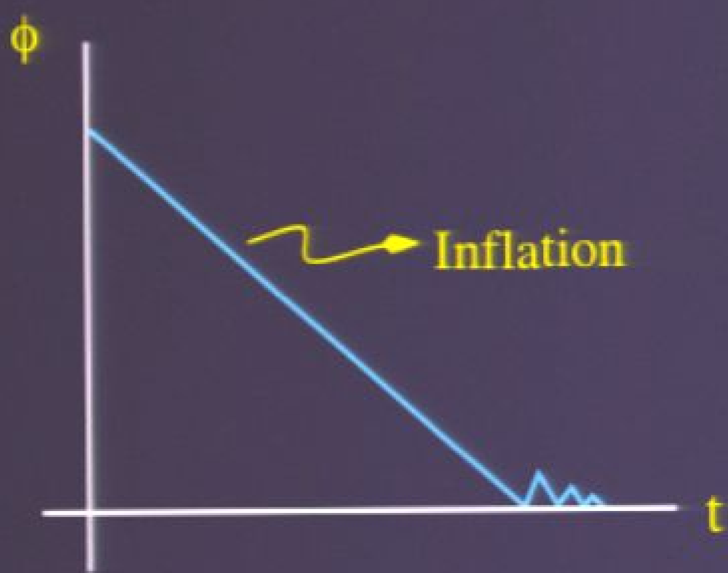

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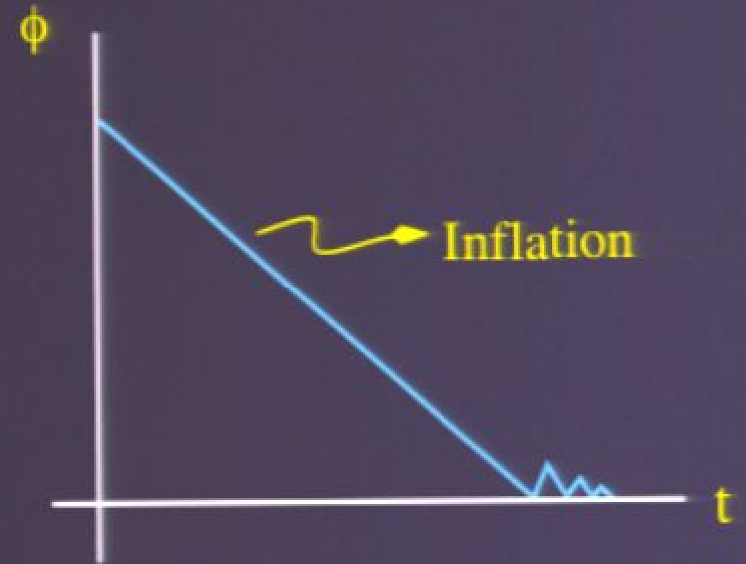

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Accelerating Solutions: Spinflation

Brane trajectory

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Consistency bounds

- Backreaction:
  - ✓ acceleration of the brane has to be small in string units (validity of DBI action).
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$$\Longrightarrow \qquad \boxed{\gamma - 1 \ll g_s^{-1} R^4 \ell_s^{-4} = g_s M^2}$$

- UV scale:
  - ✓ Total 6D volume > throat volume

$$\Longrightarrow \qquad \boxed{g_s M < \left(\frac{4}{\eta_{UV}}\right)^{3/2} \frac{\ell_s}{\epsilon^{2/3}} \sqrt{3} g_s \pi^2 \frac{M_{pl}}{M_s}}$$

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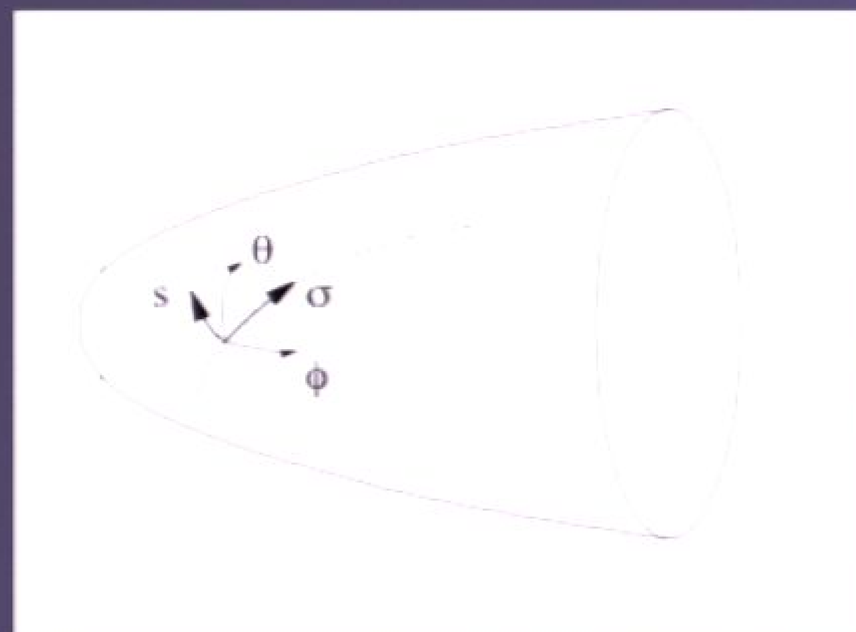

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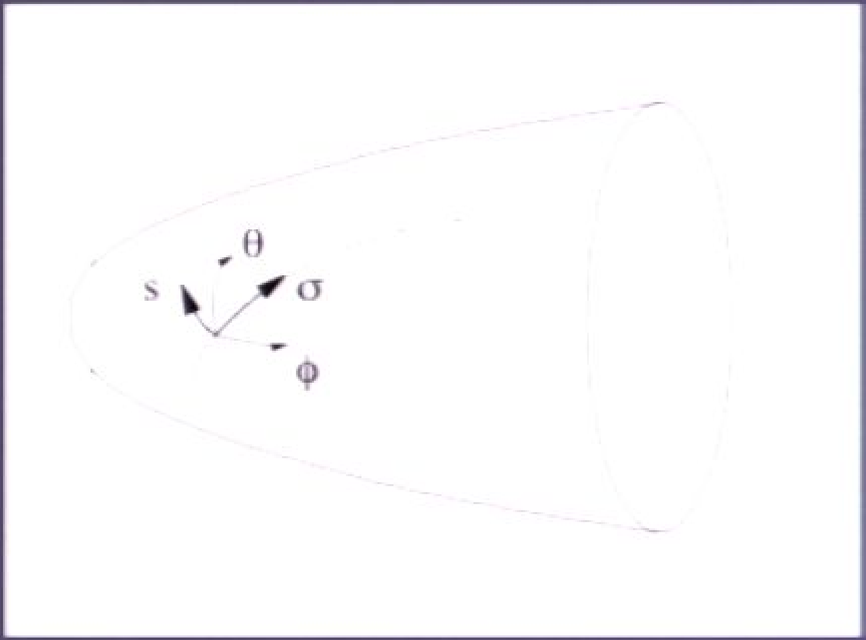

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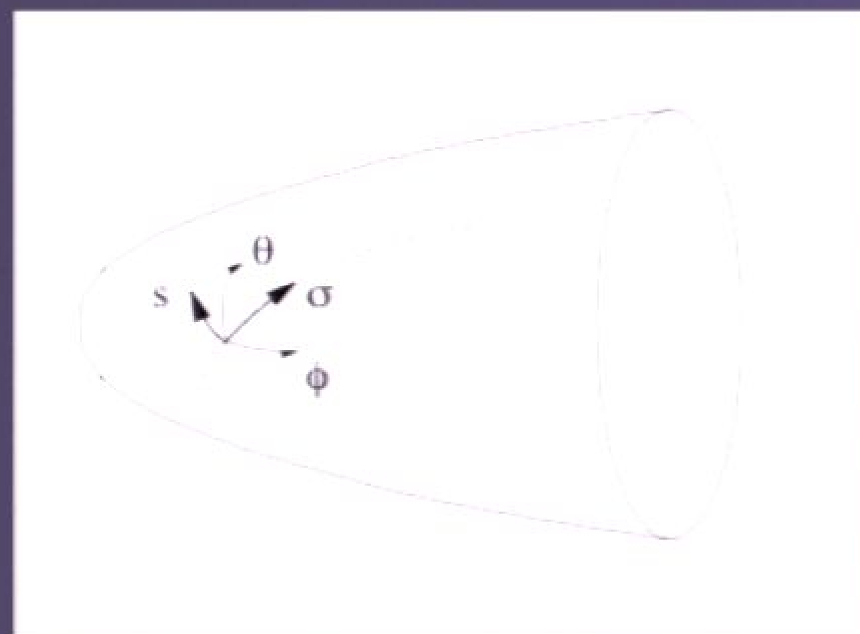

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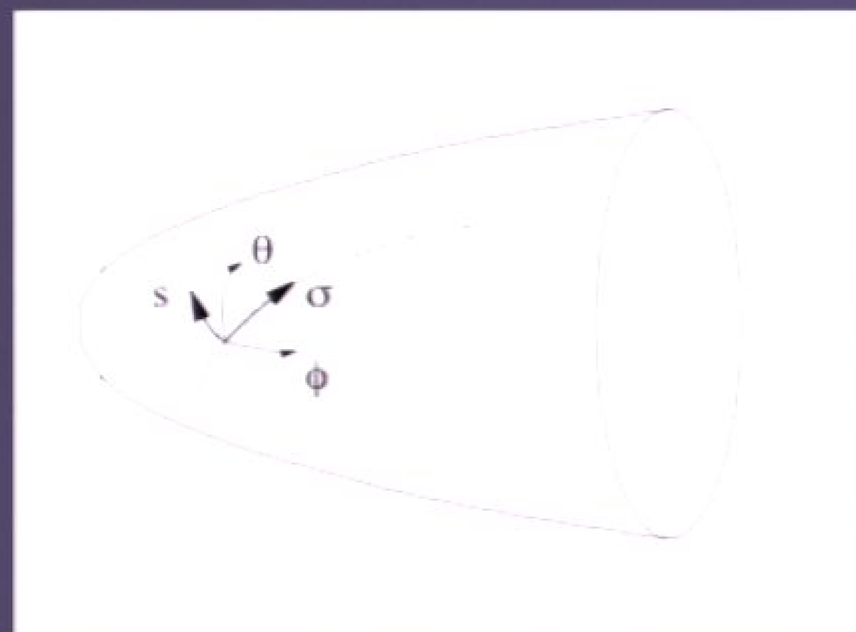

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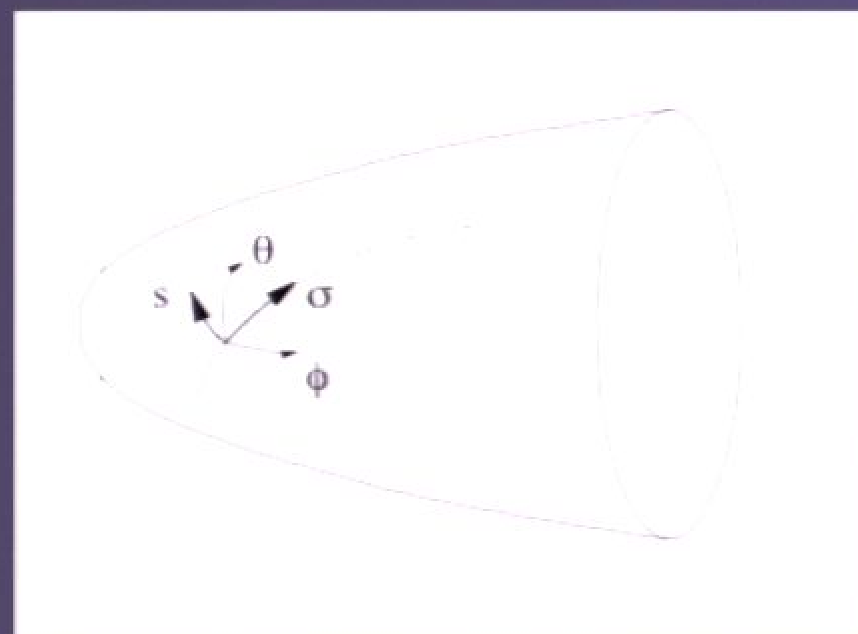

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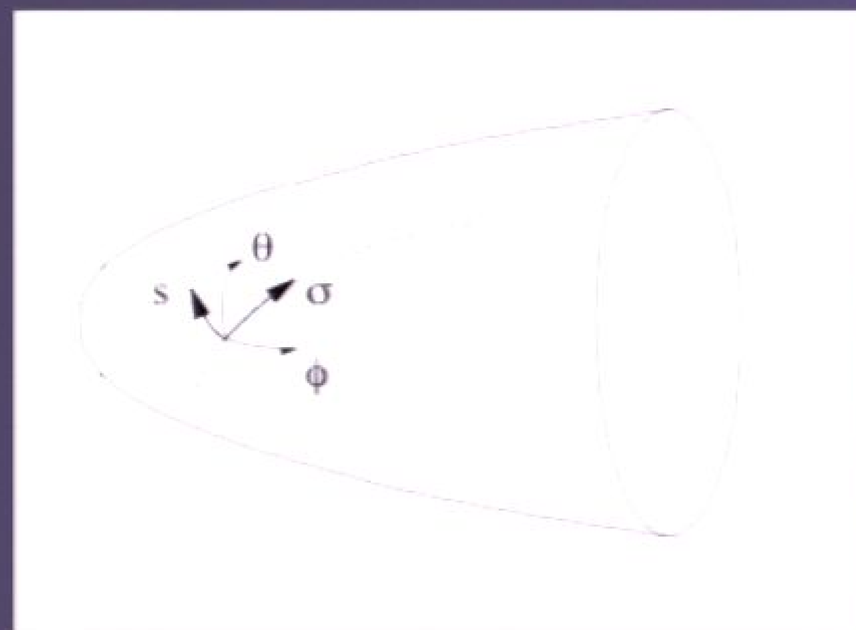

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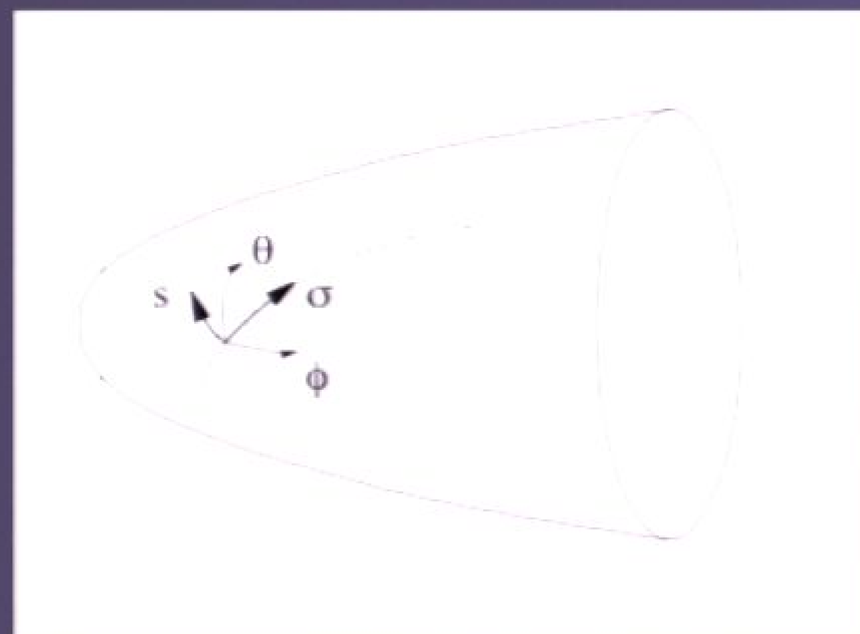

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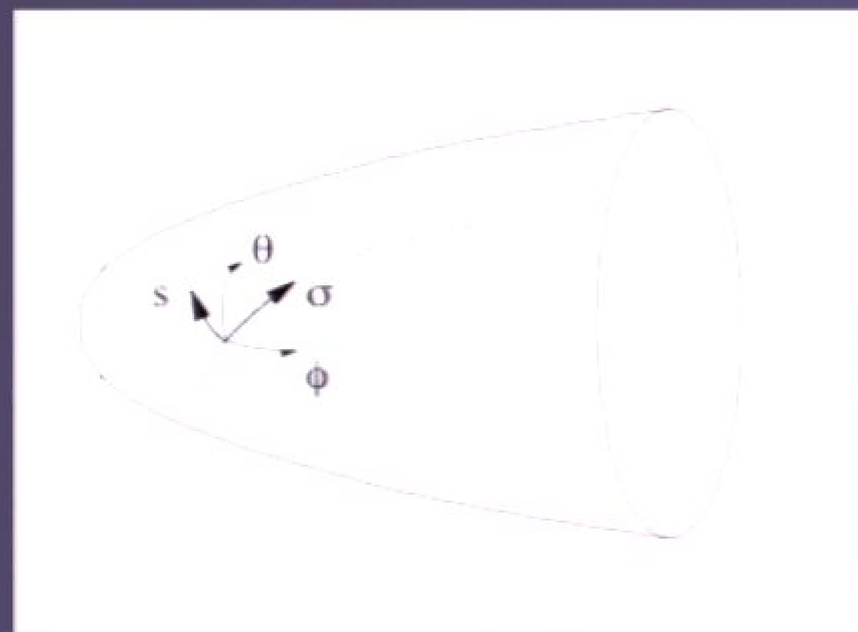

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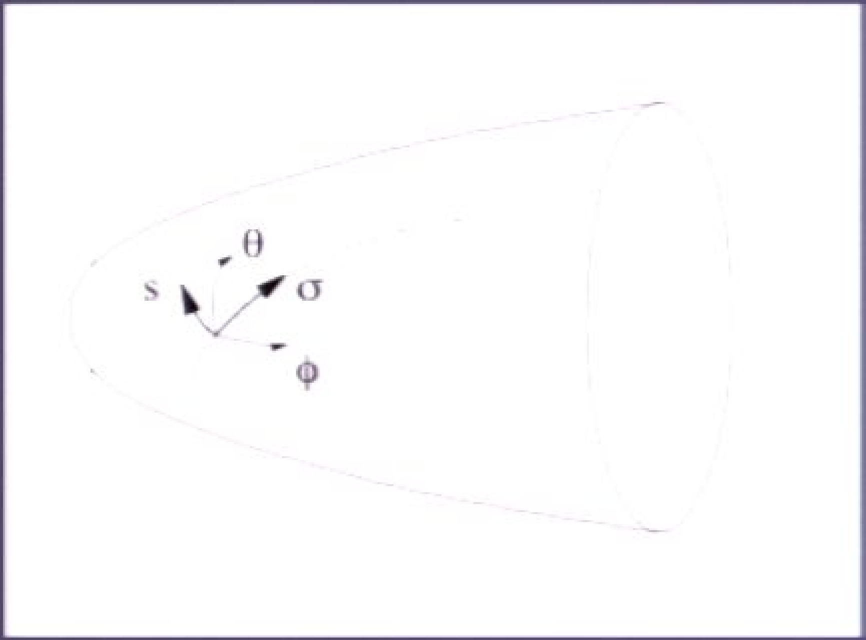

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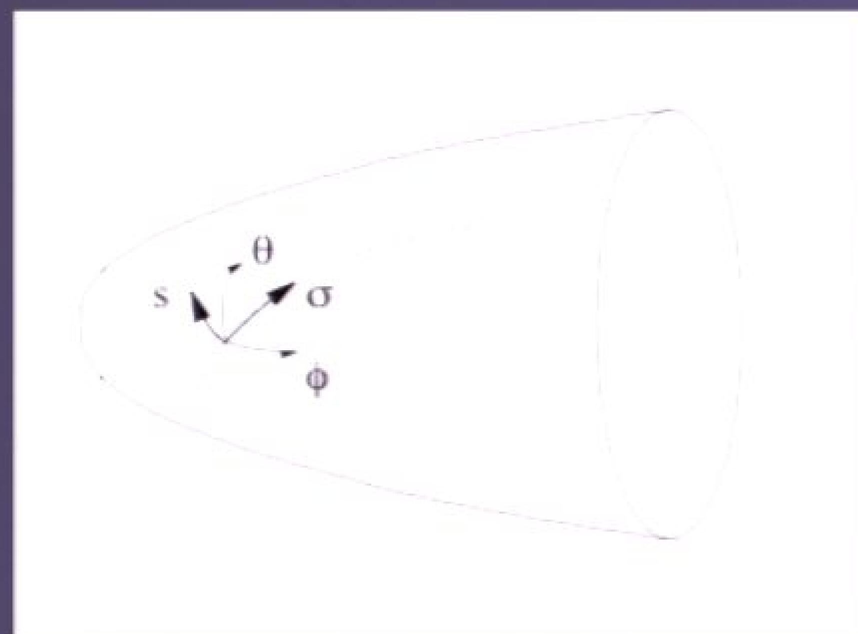

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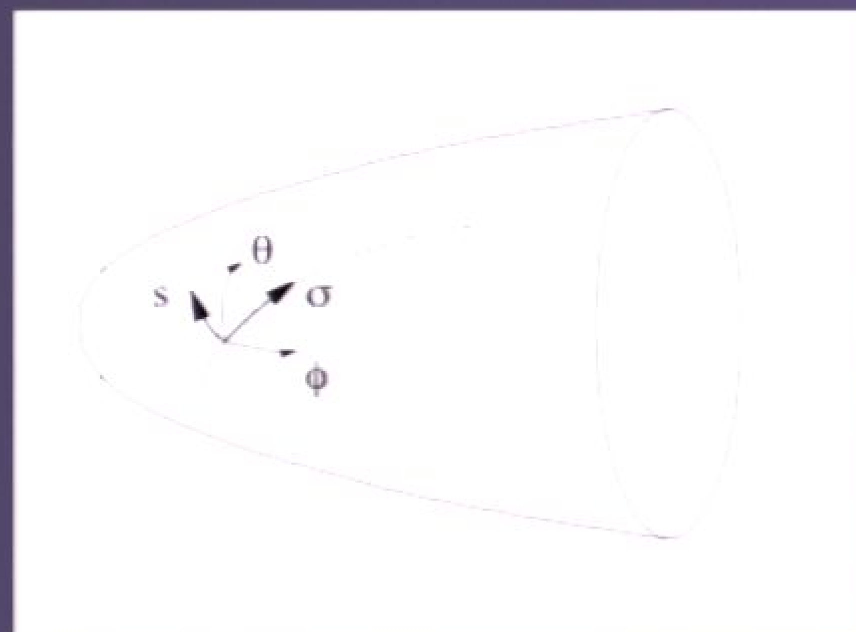

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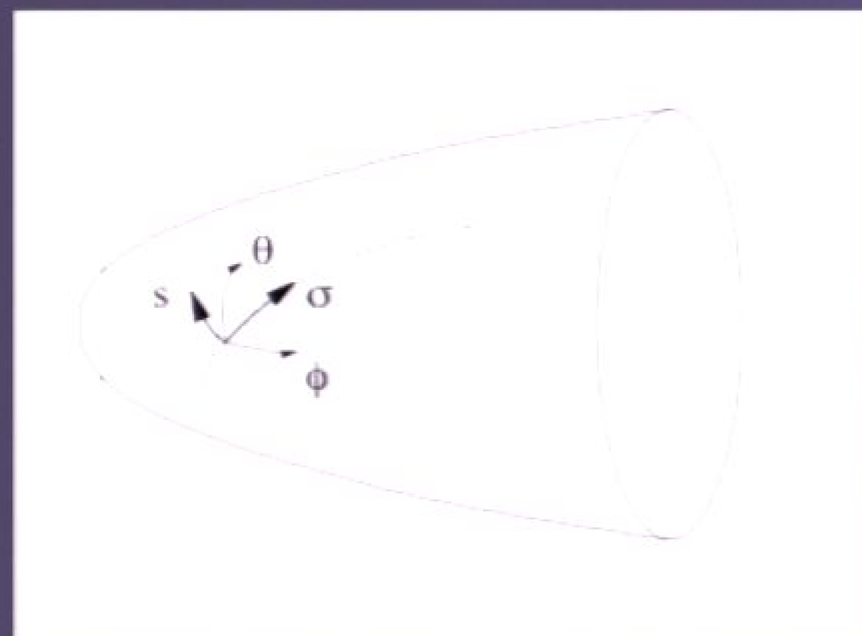

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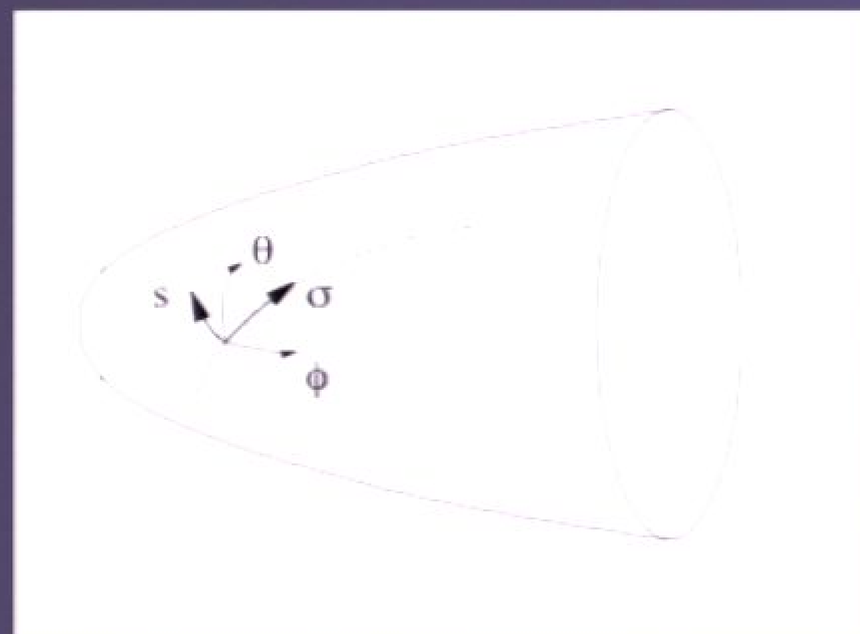

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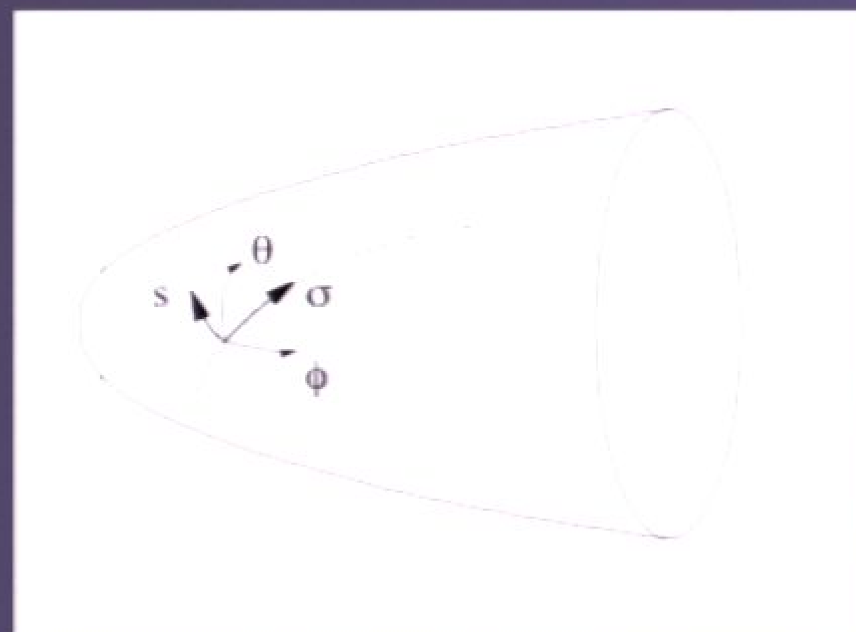

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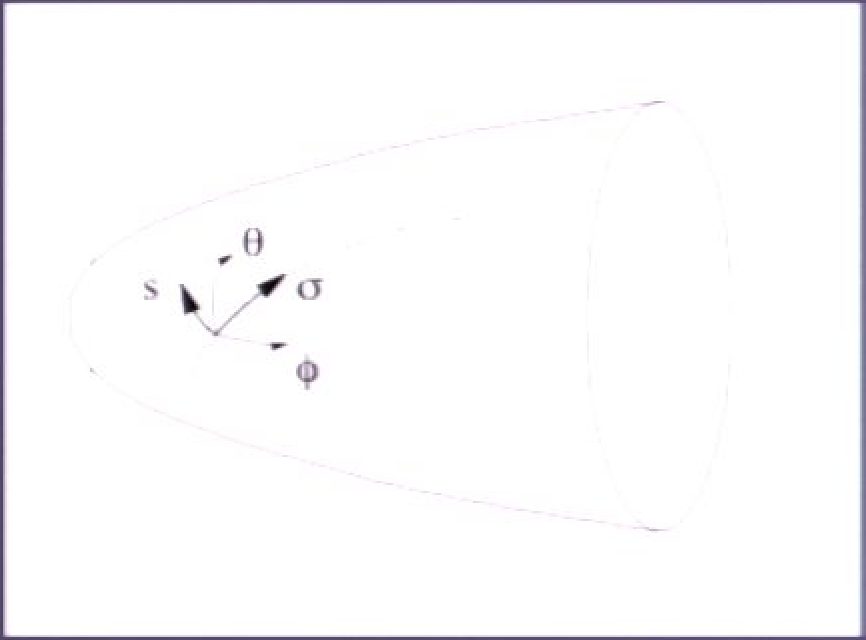

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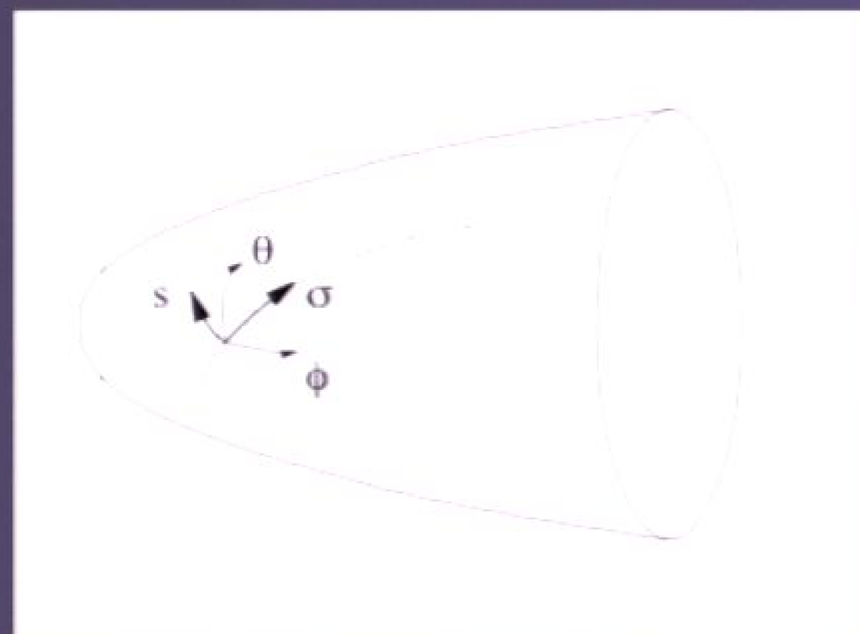

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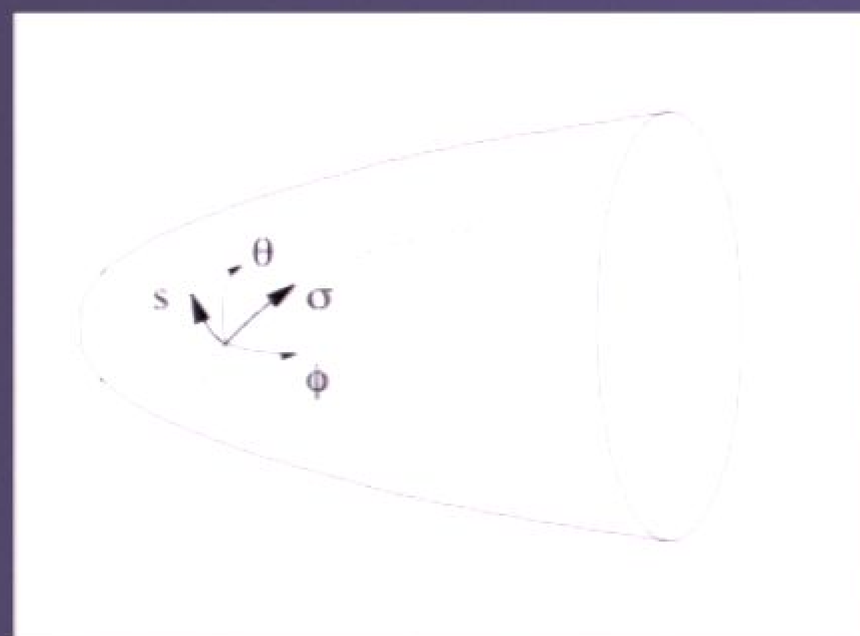

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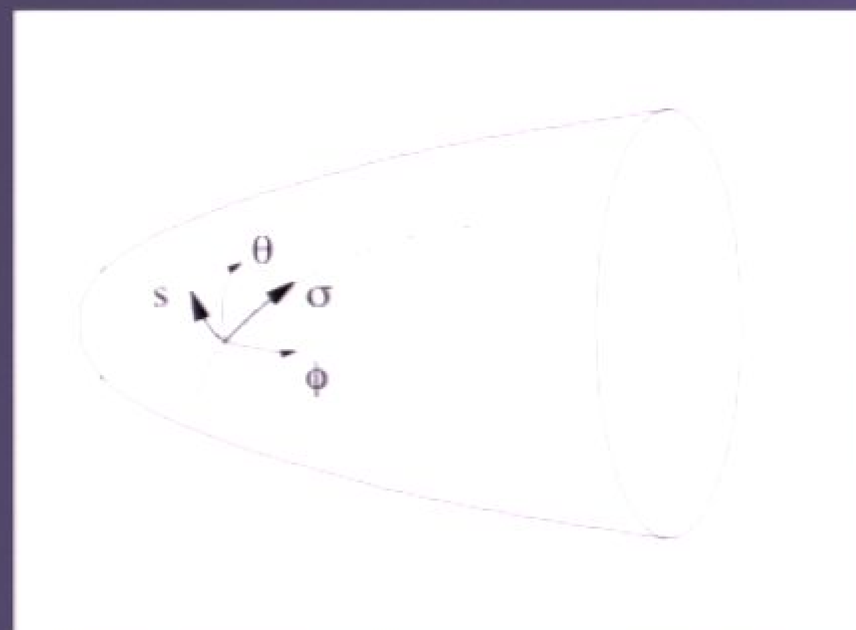

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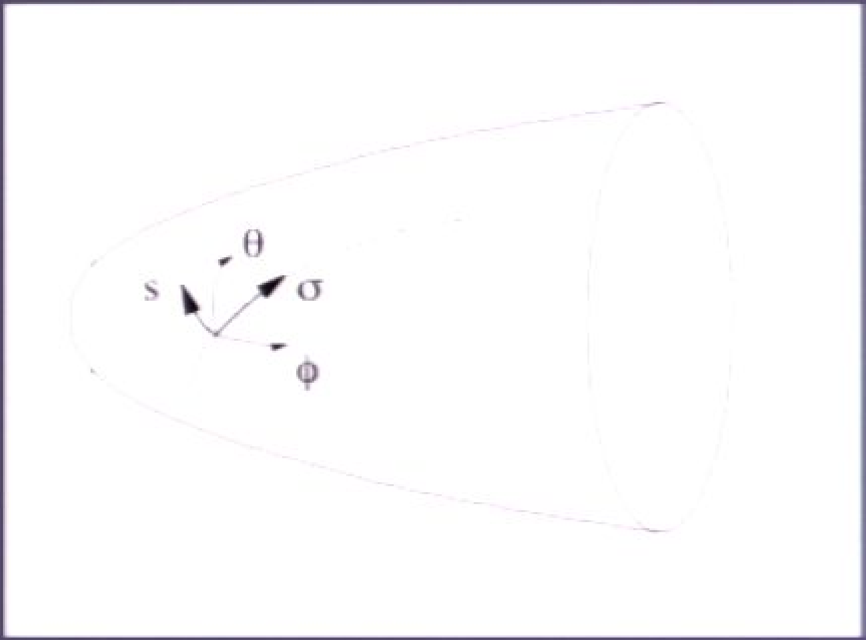

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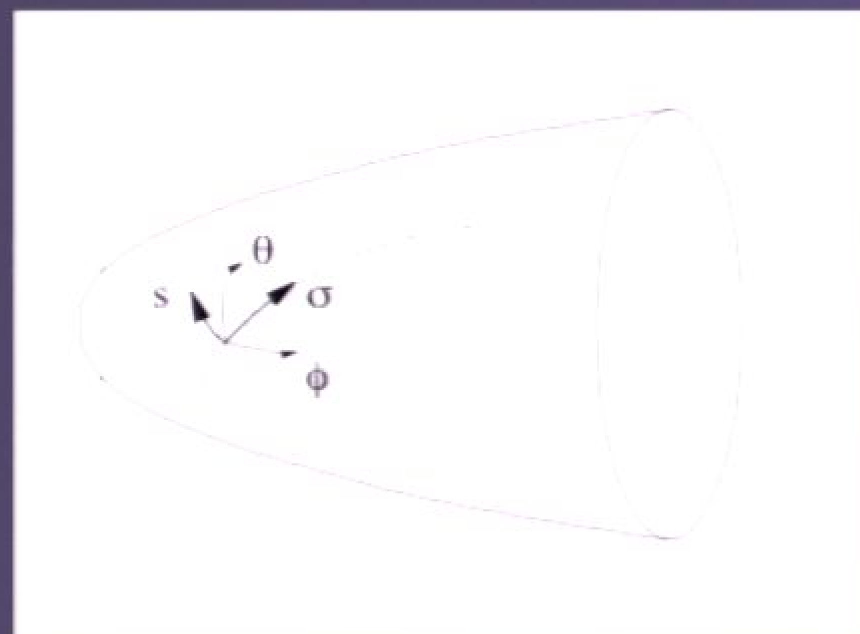

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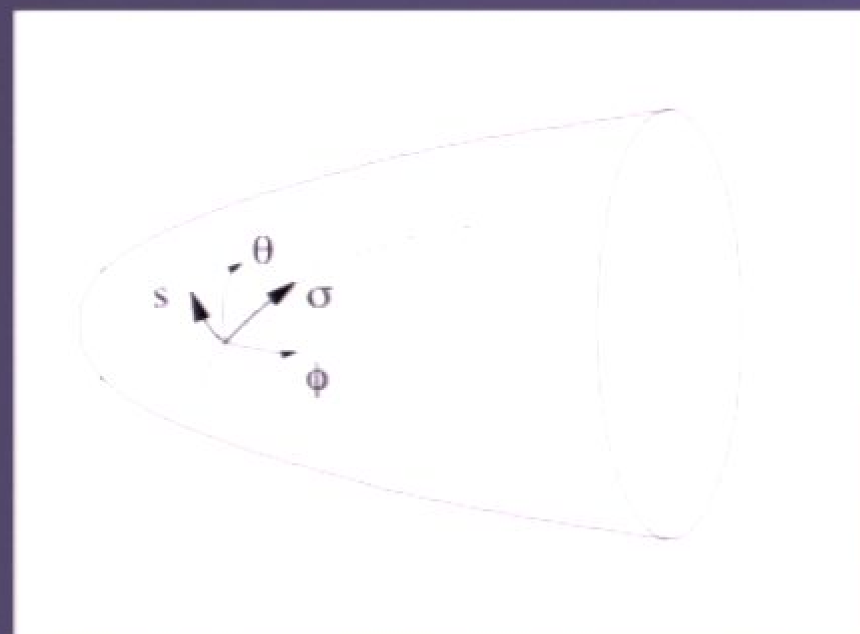

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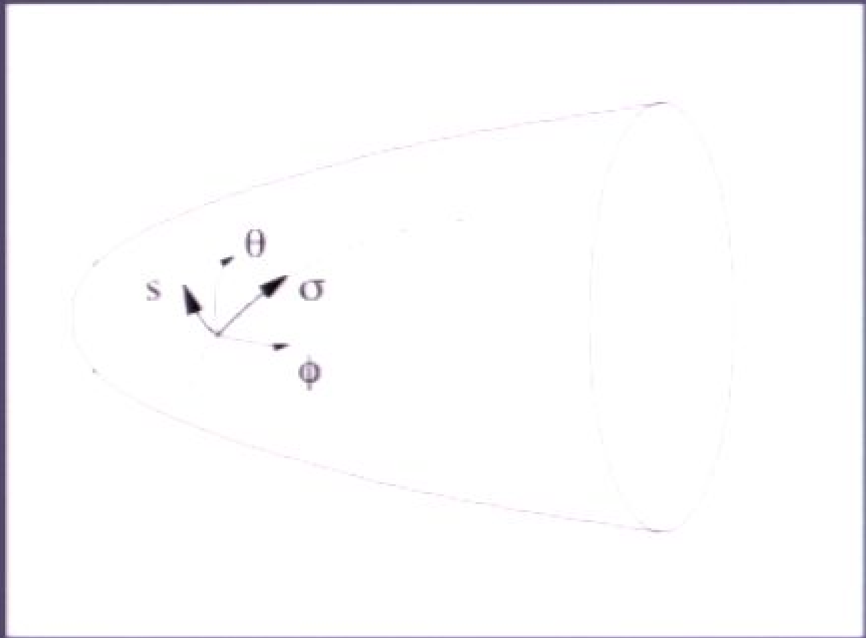

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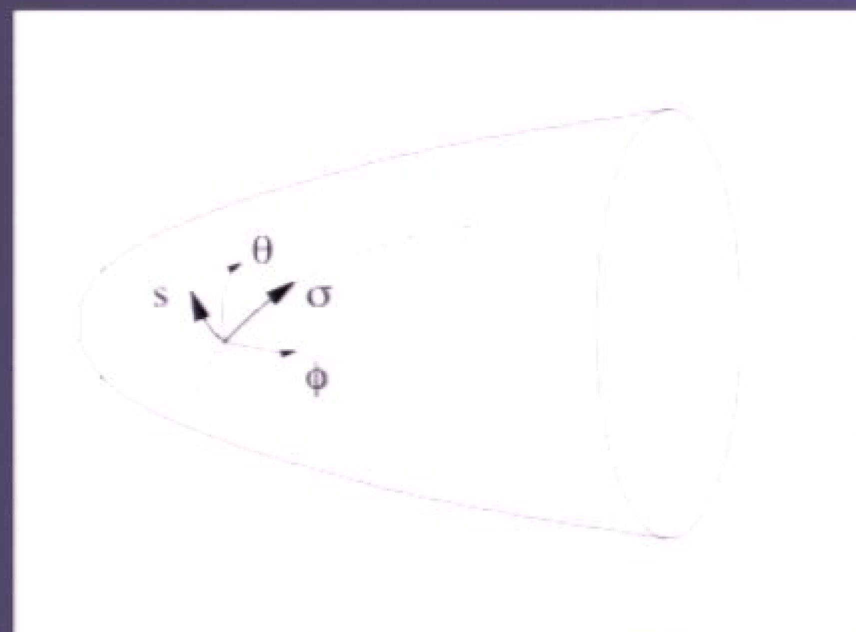

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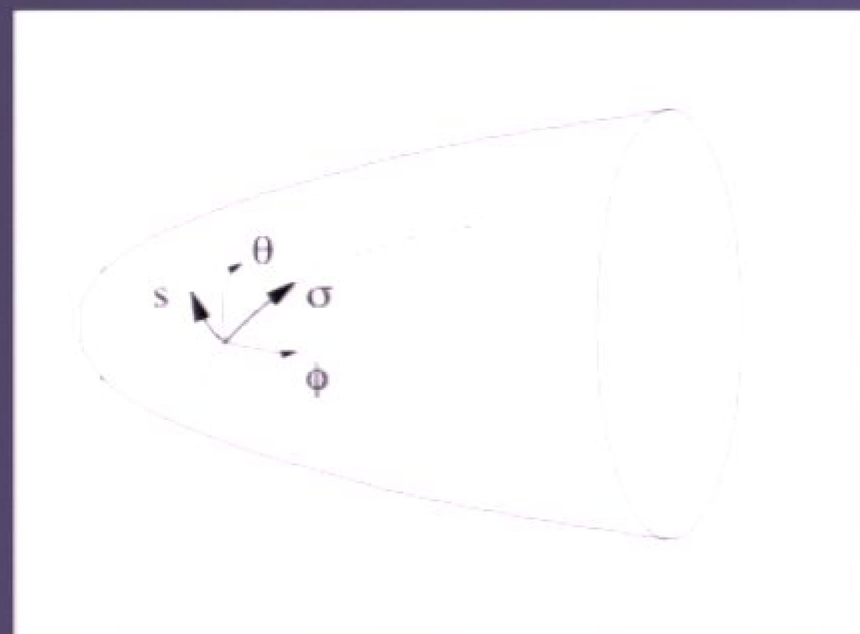

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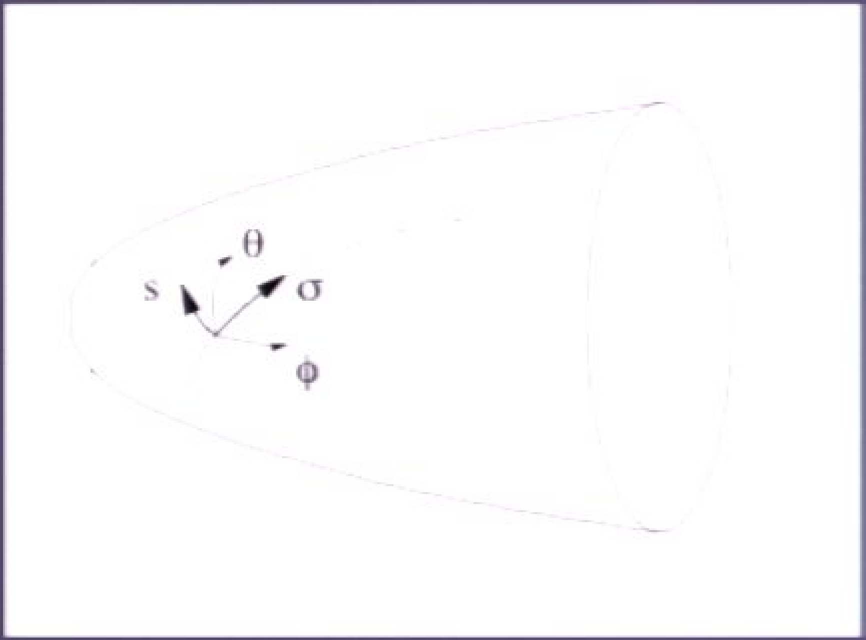

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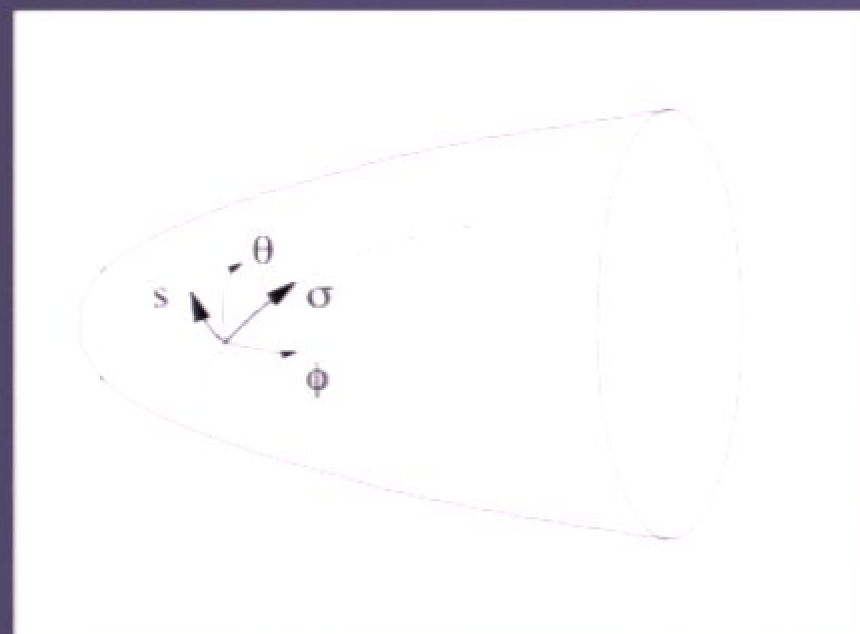

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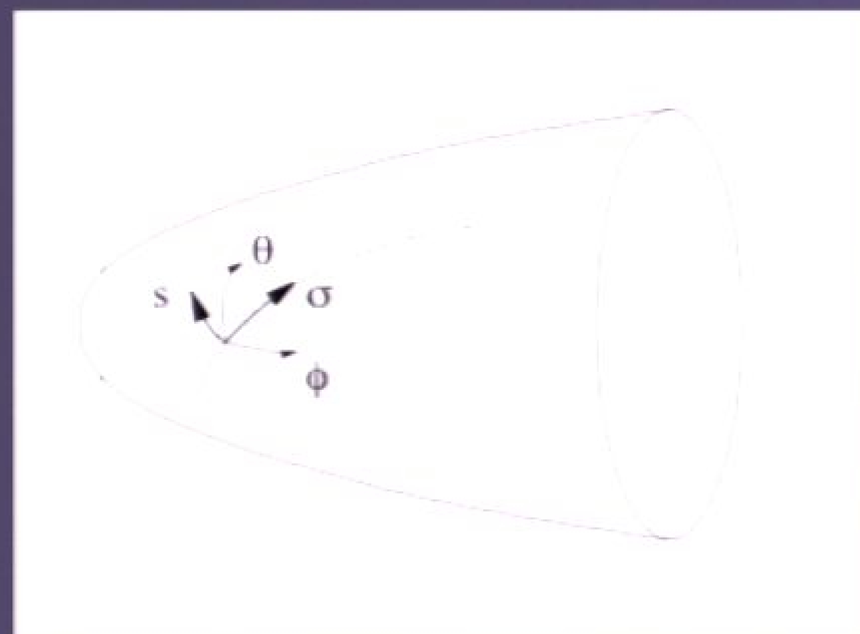

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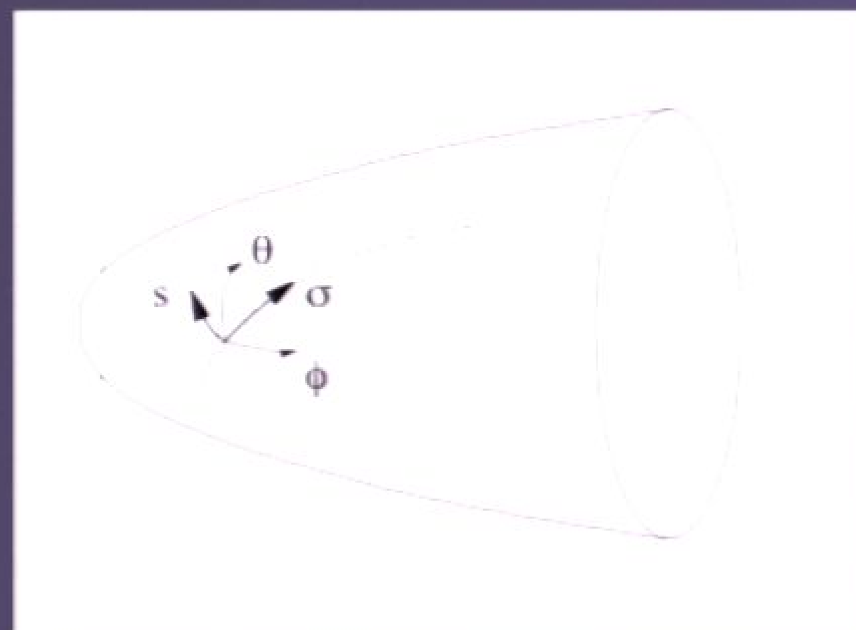

Perturbations in Spinflation

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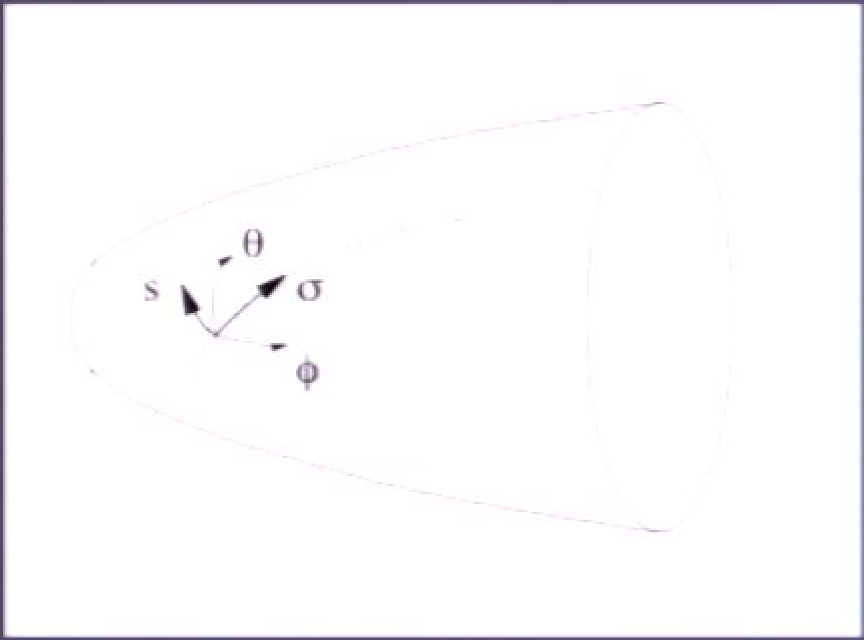

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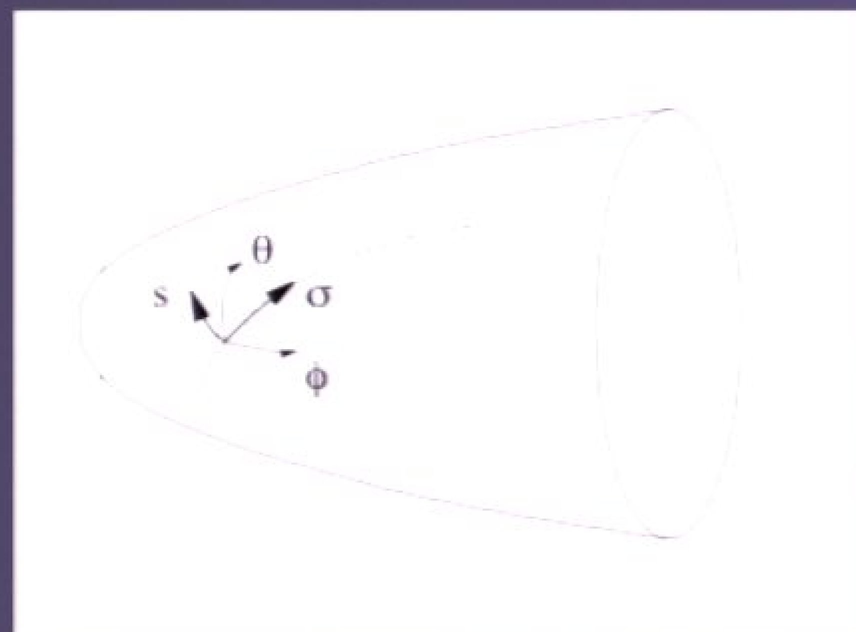

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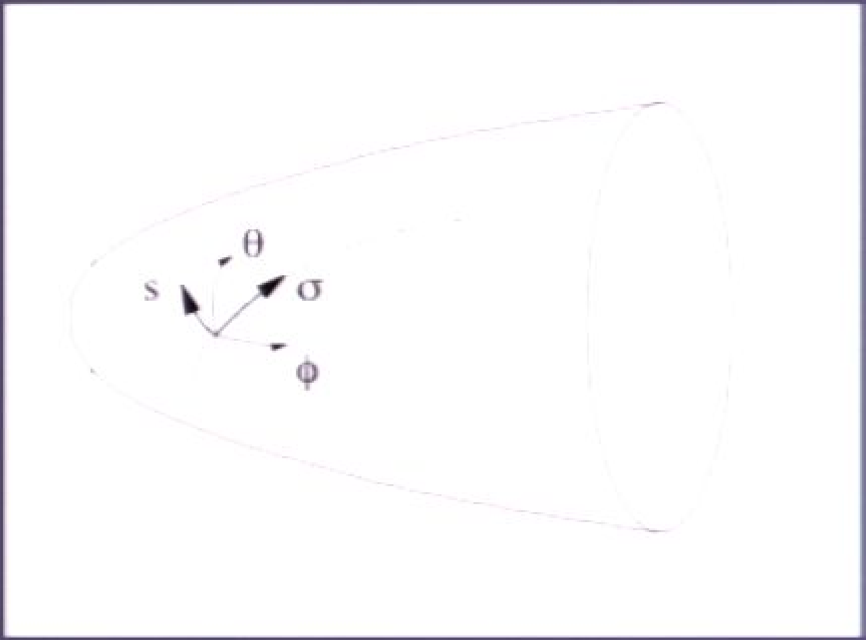

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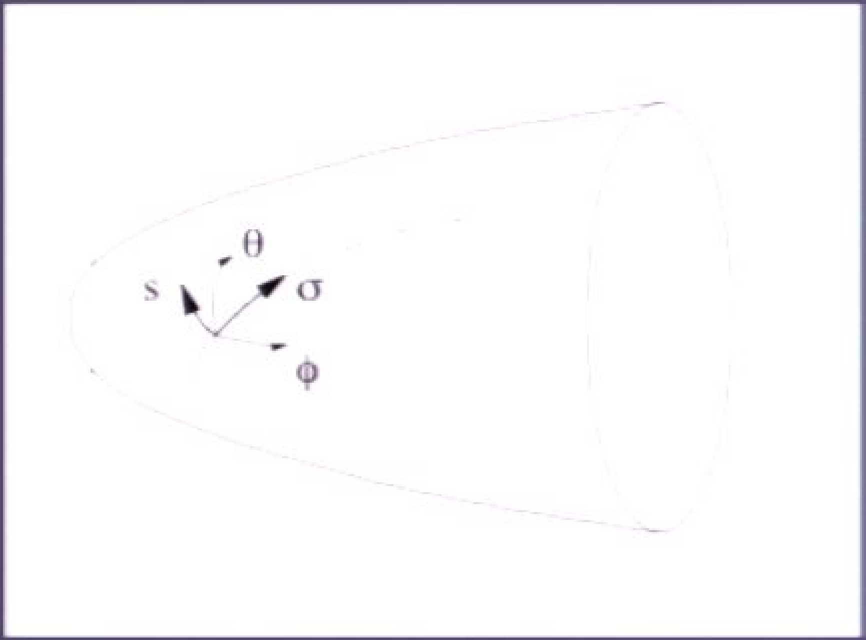

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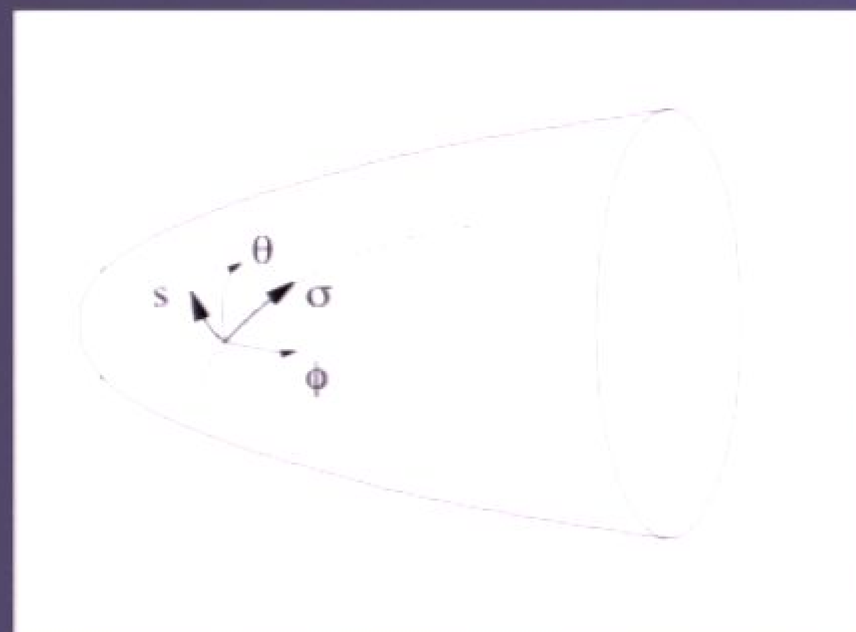

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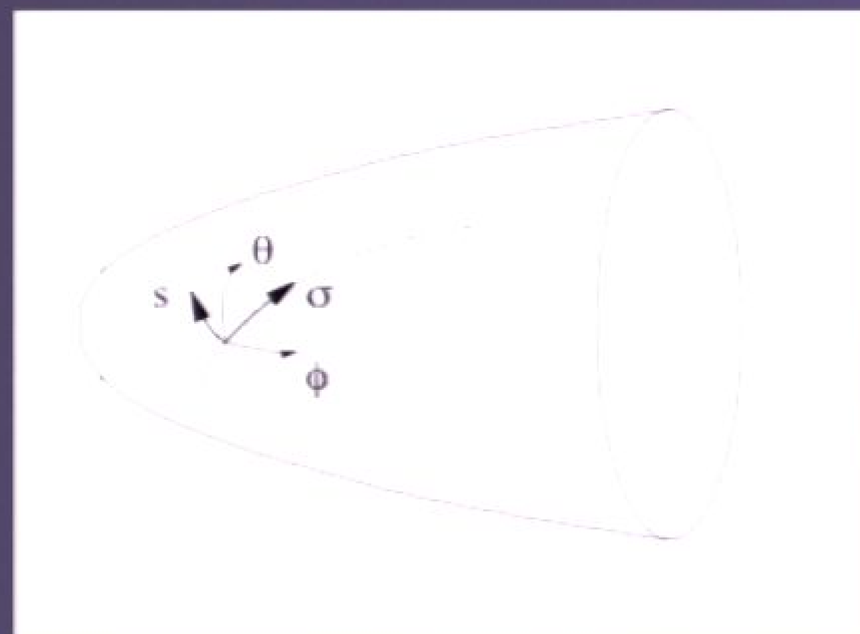

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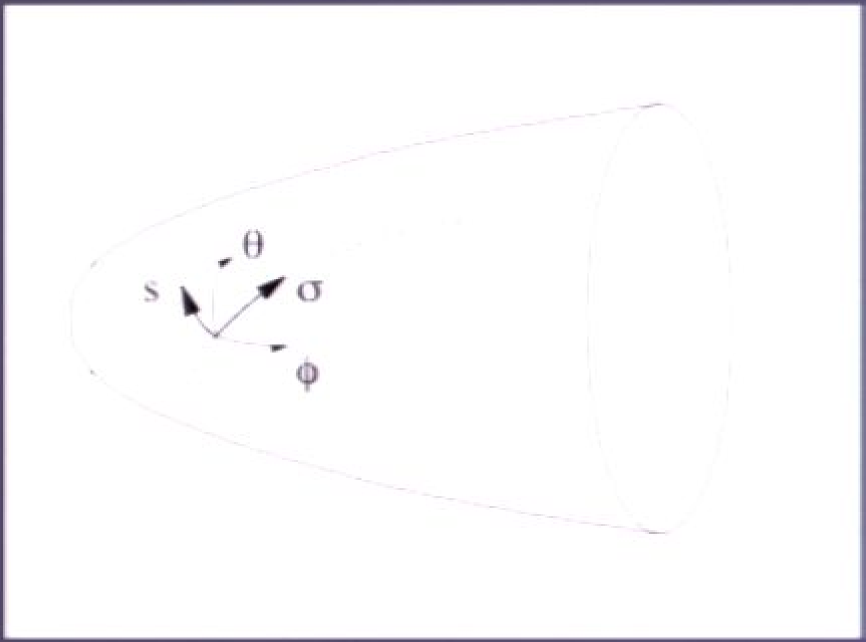

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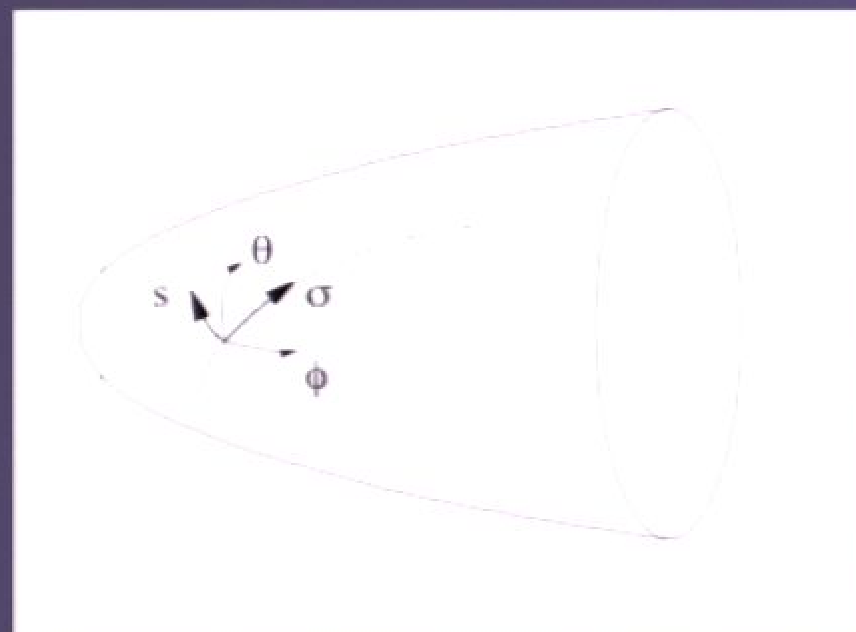

Perturbations in Spinflation

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★ Since the brane moves along different directions, various fields can contribute to the evolution of the perturbations

★ One can extract some general features, without explicitly solving the equations:

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✓ Curvature and entropy perturbations evolve at different speeds.
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General features

★ Since the brane moves along different directions, various fields can contribute to the evolution of the perturbations

★ One can extract some general features, without explicitly solving the equations:

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$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\ \tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\ddot{\delta\sigma}_\Phi + \left(3H + 3\frac{\dot\gamma}{\gamma}\right)\dot{\delta\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot\sigma c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot P - c_S^2\dot E\right)\frac{\delta s}{\dot\sigma}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot\sigma H^2 c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot H}{H} - \frac{\ddot\sigma}{\dot\sigma}\right)\frac{a^3(E+P)}{\dot\sigma H^2 c_S^2}\right]^{\cdot}$$

$$\delta\ddot s + \left(3H + \frac{\dot\gamma}{\gamma}\right)\delta\dot s + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot\sigma\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot P - c_S^2\dot E\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot\sigma}{\dot\sigma} - \frac{\dot\alpha}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot\sigma}{f}\right) + \dot\sigma\left(\frac{\dot\alpha}{\dot\sigma} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\,\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \dfrac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\dfrac{\dot{H}}{H} - \dfrac{\ddot{\sigma}}{\dot{\sigma}}\right)\dfrac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\,\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\dfrac{\ddot{\sigma}}{\dot{\sigma}} - \dfrac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\dfrac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\dfrac{\dot{\alpha}}{\dot{\sigma}} - \dfrac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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Perturbations in Spinflation

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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Perturbations in Spinflation

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Perturbations in Spinflation

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Perturbations in Spinflation

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Perturbations in Spinflation

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Perturbations in Spinflation

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Perturbations in Spinflation

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Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

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$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation
General features

★ Since the brane moves along different directions, various fields can contribute to the evolution of the perturbations

★ One can extract some general features, without explicitly solving the equations:

✓ The entropy perturbation evolves independently of the curvature perturbation at large scales. Yet (at large scales $k^2/a^2 \ll 1$) entropy perturbation seeds curvature one.

✓ Curvature and entropy perturbations evolve at different speeds.
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Perturbations in Spinflation
General features

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$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]^{\cdot}$$

$$c_S^2 = \gamma^{-2}$$

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Perturbations in Spinflation
General features

★ Since the brane moves along different directions, various fields can contribute to the evolution of the perturbations

★ One can extract some general features, without explicitly solving the equations:

✓ The entropy perturbation evolves independently of the curvature perturbation at large scales. Yet (at large scales $k^2/a^2 \ll 1$) entropy perturbation seeds curvature one.

✓ Curvature and entropy perturbations evolve at different speeds.
Curvature perturbations move with a speed $c_S^2 = \gamma^{-2} \ll 1$.
Entropy perturbations move at speed of light.
Different perturbations cross the horizon at different times.

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

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$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $\quad U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\ \tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $\quad U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot\gamma}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot\sigma c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{H c_S^2}\left(\dot P - c_S^2\dot E\right)\frac{\delta s}{\dot\sigma}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot\sigma H^2 c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot H}{H} - \frac{\ddot\sigma}{\dot\sigma}\right)\frac{a^3(E+P)}{\dot\sigma H^2 c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot\gamma}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot\sigma\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot P - c_S^2\dot E\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot\sigma}{\dot\sigma} - \frac{\dot\alpha}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot\sigma}{f}\right) + \dot\sigma\left(\frac{\dot\alpha}{\dot\sigma} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\;\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \dfrac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\dfrac{\dot{H}}{H} - \dfrac{\ddot{\sigma}}{\dot{\sigma}}\right)\dfrac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\dfrac{\ddot{\sigma}}{\dot{\sigma}} - \dfrac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\dfrac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\dfrac{\dot{\alpha}}{\dot{\sigma}} - \dfrac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \dfrac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\dfrac{\dot{H}}{H} - \dfrac{\ddot{\sigma}}{\dot{\sigma}}\right)\dfrac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\dfrac{\ddot{\sigma}}{\dot{\sigma}} - \dfrac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\dfrac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\dfrac{\dot{\alpha}}{\dot{\sigma}} - \dfrac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\dot{\sigma}c_S^2}{a^3(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\tan\alpha H}{a(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$

$c_S^2 = \gamma^{-2}$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\,\cos\alpha}{f\,\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\ddot{\delta\sigma}_\Phi + \left(3H + 3\frac{\dot\gamma}{\gamma}\right)\dot{\delta\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot\sigma c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot P - c_S^2\dot E\right)\frac{\delta s}{\dot\sigma}\right]^{\cdot}$$

where $$U_{\sigma_\Phi} \equiv \frac{\dot\sigma H^2 c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot H}{H} - \frac{\ddot\sigma}{\dot\sigma}\right)\frac{a^3(E+P)}{\dot\sigma H^2 c_S^2}\right]^{\cdot}$$

$$\delta\ddot s + \left(3H + \frac{\dot\gamma}{\gamma}\right)\delta\dot s + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot\sigma\ \tan\alpha\,H}{a\,(E+P)^2}\left(\dot P - c_S^2\dot E\right)\xi$$

where $$U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot\sigma}{\dot\sigma} - \frac{\dot\alpha}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot\sigma}{f}\right) + \dot\sigma\left(\frac{\dot\alpha}{\dot\sigma} - \frac{f'\cos\alpha}{f\tan\alpha}\right)\right]$$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2 c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot\gamma}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\,\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot\sigma c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{H c_S^2}\left(\dot P - c_S^2\dot E\right)\frac{\delta s}{\dot\sigma}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \dfrac{\dot\sigma H^2 c_S^2}{a^3\,(E+P)}\left[\left(\dfrac{\dot H}{H} - \dfrac{\ddot\sigma}{\dot\sigma}\right)\dfrac{a^3(E+P)}{\dot\sigma H^2 c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot\gamma}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\,\frac{\dot\sigma\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot P - c_S^2\dot E\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\dfrac{\ddot\sigma}{\dot\sigma} - \dfrac{\dot\alpha}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\dfrac{f'\,\dot\sigma}{f}\right) + \dot\sigma\left(\dfrac{\dot\alpha}{\dot\sigma} - \dfrac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$

Perturbations in Spinflation

$$\delta\ddot{\sigma}_\Phi + \left(3H + 3\frac{\dot{\gamma}}{\gamma}\right)\delta\dot{\sigma}_\Phi + \left(U_{\sigma_\Phi} + c_s^2\frac{k^2}{a^2}\right)\delta\sigma_\Phi = -\left(\frac{H\,\dot{\sigma}c_S^2}{a^3\,(E+P)}\right)\left[\frac{a^3\tan\alpha}{Hc_S^2}\left(\dot{P} - c_S^2\dot{E}\right)\frac{\delta s}{\dot{\sigma}}\right]^{\cdot}$$

where $U_{\sigma_\Phi} \equiv \frac{\dot{\sigma}H^2c_S^2}{a^3\,(E+P)}\left[\left(\frac{\dot{H}}{H} - \frac{\ddot{\sigma}}{\dot{\sigma}}\right)\frac{a^3(E+P)}{\dot{\sigma}H^2c_S^2}\right]^{\cdot}$

$$\delta\ddot{s} + \left(3H + \frac{\dot{\gamma}}{\gamma}\right)\delta\dot{s} + \left(U_s + \frac{k^2}{a^2}\right)\delta s = -\frac{k^2}{a^2}\frac{\dot{\sigma}\,\tan\alpha\,H}{a\,(E+P)^2}\left(\dot{P} - c_S^2\dot{E}\right)\xi$$

where $U_s = \tan\alpha\left[3H\tan\alpha\left(\frac{\ddot{\sigma}}{\dot{\sigma}} - \frac{\dot{\alpha}}{\tan\alpha} + 3Hc_S^2 - \cos\alpha\frac{f'\,\dot{\sigma}}{f}\right) + \dot{\sigma}\left(\frac{\dot{\alpha}}{\dot{\sigma}} - \frac{f'\cos\alpha}{f\,\tan\alpha}\right)\right]$

$$c_S^2 = \gamma^{-2}$$