

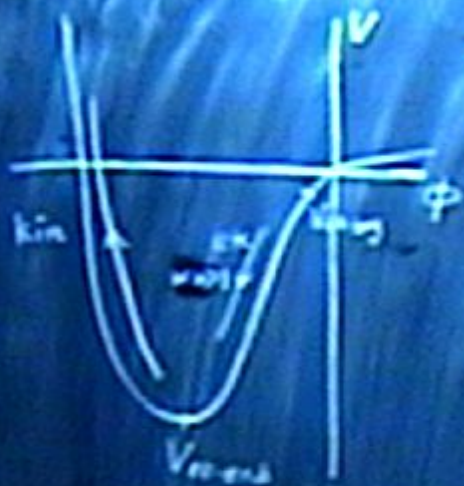
Title: Curvature and Anisotropy Near a Nonsingular Bounce

Date: Jul 14, 2011 05:00 PM

URL: <http://pirsa.org/11070022>

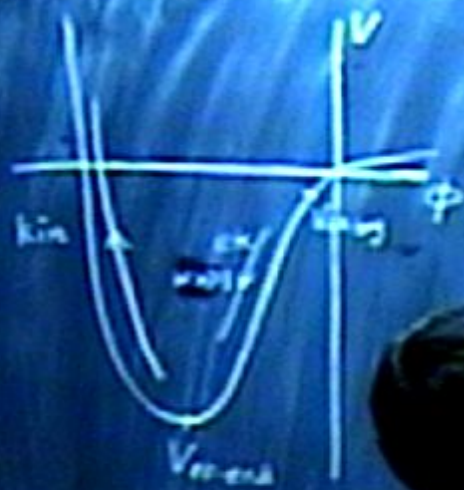
Abstract: Problematic growths of curvature and anisotropy are found in nonsingular bouncing cosmologies that include both an ekpyrotic phase and a bouncing phase. Classically, initial curvature and anisotropy that are suppressed during the ekpyrotic phase will grow back exponentially during the nonsingular bouncing phase. Besides, curvature perturbations and anisotropy are generated by quantum fluctuations during the ekpyrotic phase. In the bouncing phase, an adiabatic curvature perturbation grows to dominate and gives rise to a blue spectrum that spoils the scale-invariance. Meanwhile, a scalar shear perturbation grows nonlinear and creates an overwhelming anisotropy that disrupts the nonsingular bounce altogether.

CURVATURE & DISCONTINUITY IN APPROXIMATE NONSINGULAR BUSINESS

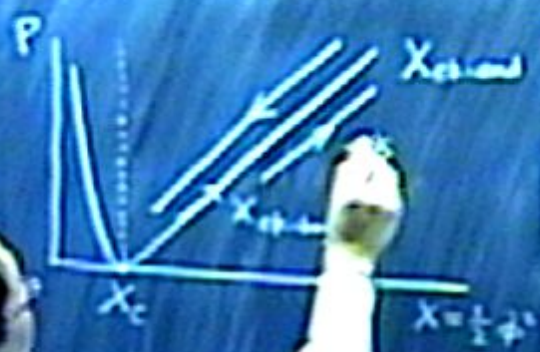


$$I = P(k) - V(\phi)$$

Curvature & dissipation in asymptotically non-singular business



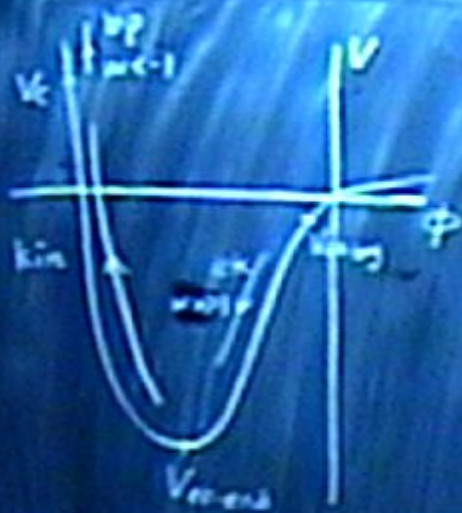
$$I = P(\kappa) - V(\phi)$$



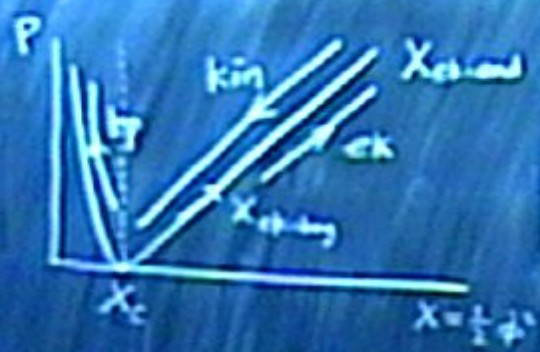
$$\dot{H} = -\frac{1}{2}\phi^2$$



CURVATURE & ANISOTROPY IN ALGEBRAIC NONSINGULAR SURFACES

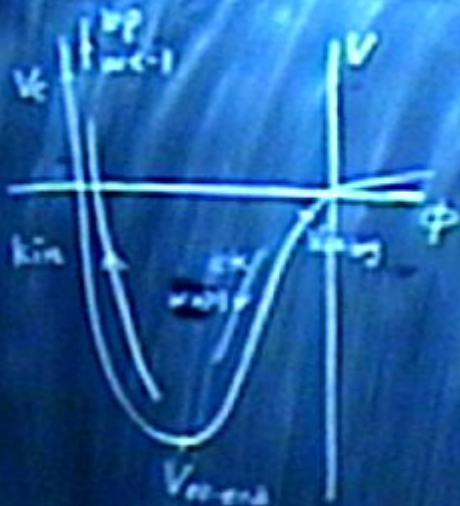


$$I = P(x) - V(\phi)$$

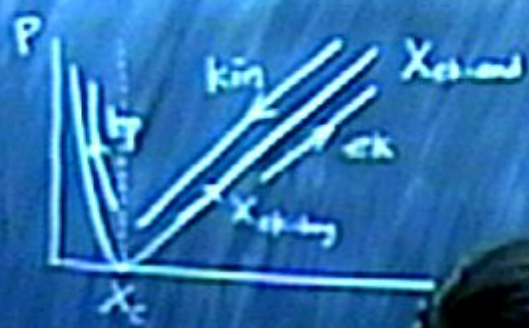


$$\dot{H} = -x P_x > 0$$

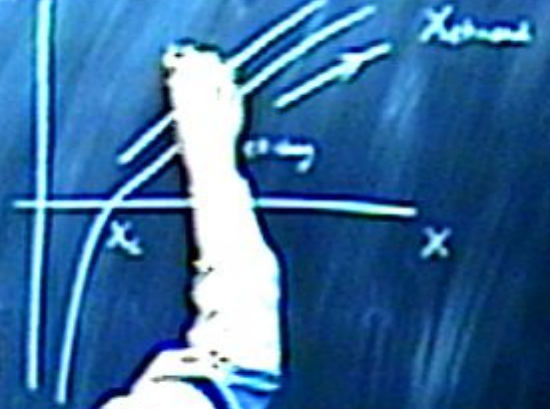
Curvature & dissipation in asymptotic nonsingular business



$$\dot{I} = P(x) - V(x)$$



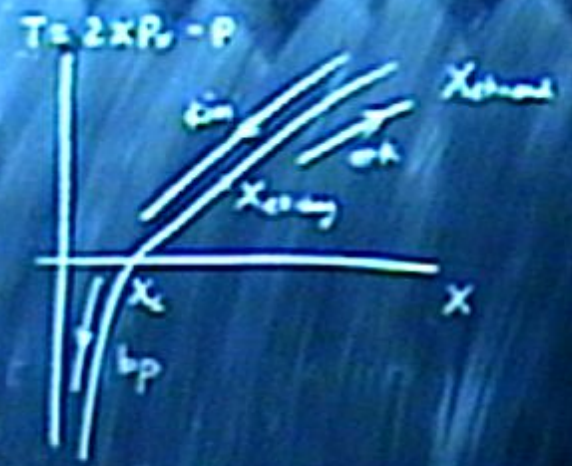
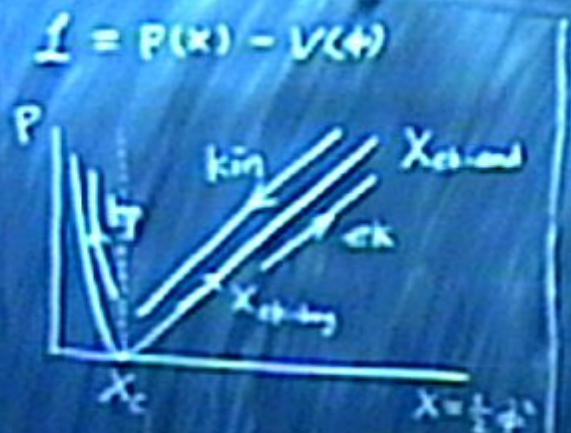
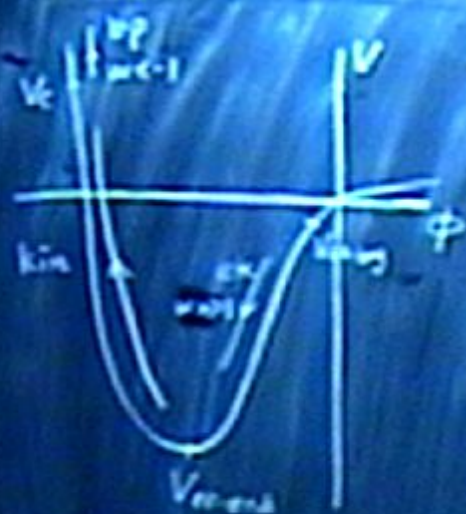
$$T = 2XP_c - P$$



$$\dot{H} = -xP_x > 0$$



Curvature & dissipation in asymptotic nonsingular bounce



$$e^{2V} \frac{X_{c-end}}{X_{c-beg}}$$

$$\dot{H} = -xP_x > 0$$

$$H^2 = \frac{1}{3}(T+V) - \frac{1}{2}\epsilon - \frac{d^2}{dt^2}$$

$$X_c < X_{c-beg} \ll X_{c-end}$$

PROBLEMS

CAUSES

SERIOUSNESS

SOLUTIONS

PROBLEMS

① gravitational instability

CAUSES

$$\frac{P_r}{T_r} = C_i < 0$$

SERIOUSNESS

SOLUTIONS

PROBLEMS

① gravitational instability

CAUSES

$$\frac{P_x}{T_x} = c_i < 0$$

SERIOUSNESS

⚡ ⚡

SOLUTIONS

PROBLEMS

① gravitational instability

CAUSES

$$\frac{P_r}{T_r} = c_i < 0$$

SERIOUSNESS

⚡ ⚡

SOLUTIONS

$k|c| \Delta T \lesssim 1$



PROBLEMS

- ① gravitational instability
- ② classical anisotropy

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

SERIOUSNESS

⚡ ⚡

SOLUTIONS

$$k|c| \Delta T \lesssim 1$$
$$c_s^2 \ll 1$$

$$\dot{T} + 3HT + V\dot{\phi} = 0$$

$$\dot{T} + 3HT + \cancel{V\dot{\Phi}} = 0$$

$$T \propto \frac{1}{a^2}$$

$$\dot{T} + 3HT + \cancel{V\dot{\Phi}} = 0$$

$$T \propto \frac{1}{a^4}$$

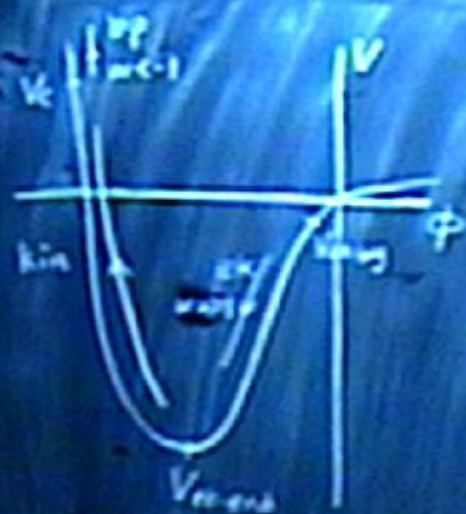
$$\left(\frac{\sigma_{\text{hor-end}}^2}{\sigma_{\text{bp-end}}^2} \right) = \left(\frac{T_{\text{hor-end}}}{T_{\text{bp-end}}} \right)^2$$

$$\dot{T} + 3HT + \cancel{V\dot{\phi}} = 0$$

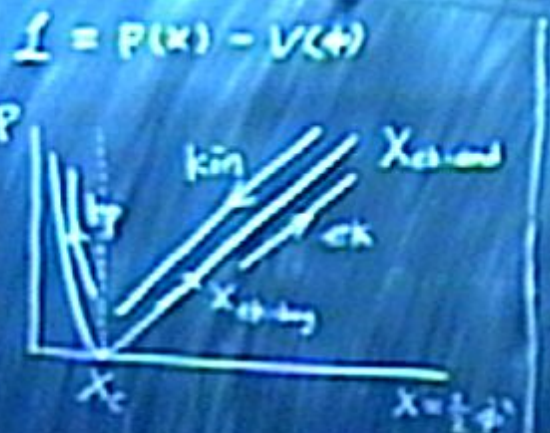
$$T \propto \frac{1}{a^2}$$

$$\left(\frac{\sigma_{\text{hor-end}}^2}{\sigma_{\text{lp-end}}^2} \right) = \left(\frac{T_{\text{hor-end}}}{T_{\text{lp-end}}} \right)^2$$

CURVATURE & ASYMMETRY IN APPROXIMATE NONSINGULAR BOUNCES

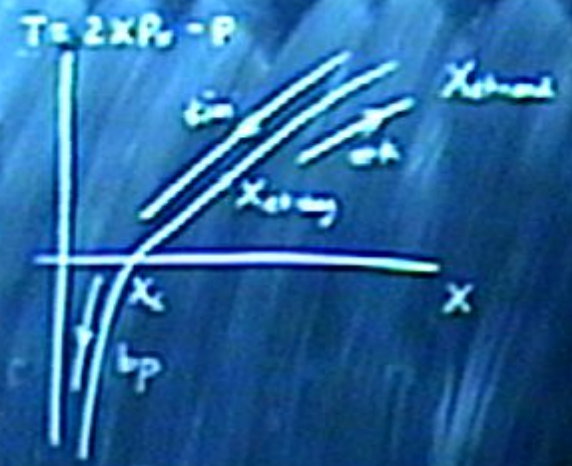


$$e^{2V} = \frac{X_{\text{res-end}}}{X_{\text{res-beg}}}$$



$$\dot{H} = -x P_x > 0$$

$$H^c = \frac{1}{3}(T+V) - \frac{1}{2} \frac{1}{x^2} - \frac{1}{2} \frac{1}{x^2}$$



$$X_c < X_{\text{res-beg}} \ll X_{\text{res-end}}$$

$$\dot{T} + 3HT + \cancel{V\dot{\Phi}} = 0$$

$$T \propto \frac{1}{a^2}$$

$$\left(\frac{\sigma_{\text{top-end}}^2}{\sigma_{\text{bottom-end}}^2} \right) = \left(\frac{T_{\text{top-end}}}{T_{\text{bottom-end}}} \right)^2$$

$\sim V_c \sim X_{\text{ext-end}}$

$$\dot{T} + 3HT + \cancel{V} = 0$$

$$T \propto \frac{1}{a^3}$$

$\sim v_c \sim X_{\text{et-end}}$

$$\left(\frac{\sigma_{\text{br-end}}^2}{\sigma_{\text{br-end}}} \right) = \left(\frac{T_{\text{br-end}}}{T_{\text{br-ing}}} \right)^2$$

$$\dot{T} + 3HT + V\dot{\phi} = 0$$

$$T \propto \frac{1}{a^2}$$

$$\left(\frac{\sigma_{\text{hor-end}}^2}{\sigma_{\text{bp-end}}^2} \right) = \left(\frac{T_{\text{hor-end}}}{T_{\text{bp-end}}} \right)^2 \sim \frac{X_{\text{hor-end}}}{X_c} \rightarrow \frac{X_{\text{hor-end}}}{X_{\text{hor-bag}}} = e^{2N}$$

$\sim V_c \sim X_{\text{hor-end}}$
 $\sim X_c \sim X_{\text{hor-end}}$

$$\dot{T} + 3HT + \cancel{V} = 0$$

$$T \propto \frac{1}{a^3}$$

$$\left(\frac{\sigma_{\text{hor-end}}^2}{\sigma_{\text{bp-end}}^2} \right) = \left(\frac{T_{\text{hor-end}}}{T_{\text{bp-end}}} \right) \approx \frac{V_c \sim X_{\text{hor-end}}}{X_c} \rightarrow \frac{X_{\text{hor-end}}}{X_{\text{hor-beg}}} = e^{2N}$$

PROBLEMS

- ① gravitational instability
- ② classical anisotropy

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

$$\left(\frac{a_{\text{horiz}}}{a_{\text{horiz}}}\right)^{-6} > e^{-2N}$$

SERIOUSNESS

☹ ☹

☹ ☹ ☹

SOLUTIONS

$$k|c| \sigma T \lesssim 1$$
$$c_s^2 \ll 1$$

PROBLEMS

- ① gravitational instability
- ② classical entropy

CAUSES

$$\frac{P_{\text{tr}}}{T_{\text{tr}}} = c_s^2 < 0$$

$$\left(\frac{\Delta_{\text{grav}}}{\Delta_{\text{entropy}}}\right)^{-6} \gg e^{-2N}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$k|c| \omega t \lesssim 1$
 $c_s^2 \gg 1$

DE before EK

PROBLEMS

- ① gravitational instability
- ② classical anisotropy

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

$$\left(\frac{a_{\text{pert}}}{a_{\text{bg}}}\right)^{-6} > e^{-2N}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$k|c| aT \lesssim 1$
 $c_s^2 \ll 1$

DE before EK

PROBLEMS

- ① gravitational instability
- ② classical anisotropy

CAUSES

$$\frac{P_x}{T_x} = c_i^2 < 0$$

$$\left(\frac{a_{\text{horiz}}}{a_{\text{eq}}}\right)^{-6} > e^{-2N}$$

SERIOUSNESS

✘ ✘

✘ ✘ ✘

SOLUTIONS

$$k|c| aT \lesssim 1$$

$$c_i^2 \ll 1$$

DE before EK

$$\sigma_{\text{ek-bag}}^2 \lesssim X_c$$

PROBLEMS

- ① gravitational instability
- ② classical anisotropy
- ③ blue s

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

$$\left(\frac{a_{\text{horiz}}}{a_{\text{horiz}}}\right)^{-6} > e^{-2N}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$$k|c| aT \lesssim 1$$

$$c_s^2 \ll 1$$

DE before EK

$$\sigma_{\text{ek-horiz}}^2 \lesssim X_c$$

PROBLEMS

- ① gravitational instability
- ② classical anisotropy
- ③ blue spectrum of curr. pert
- ④ anisotropy for shear pert

CAUSES

$$\frac{P_{\text{tr}}}{T_{\text{tr}}} = c_s^2 < 0$$

$$\left(\frac{A_{\text{tr.ang}}}{A_{\text{tr.ang}}}\right)^{-6} \rightarrow e^{-2N}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$$k|c| \sigma_T \lesssim 1$$

$$c_s^2 \ll 1$$

DE before EK

$$\sigma_{\text{ek.ang}}^2 \lesssim X_c$$

PROBLEMS

- ① gravitational instability
- ② classical anisotropy
- ③ blue spectrum of curr. pert
- ④ anisotropis for shear pert

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

$$\left(\frac{A_{\text{cur. pert}}}{A_{\text{isotropy}}}\right)^{-6} > e^{-2N}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$$k|c| aT \lesssim 1$$
$$c_s^2 \propto 1$$

DE before EK

$$\sigma_{\text{ek. bag}}^2 \lesssim X_c$$

PROBLEMS

① gravitational instability

② classical anisotropy

blue spectrum

curr pert

anisotrop's

shear pert

CAUSES

$$\frac{P_{\text{tr}}}{T_{\text{tr}}} = c_s^2 < 0$$

$$\left(\frac{a_{\text{post-bag}}}{a_{\text{pre-bag}}}\right)^6 > e^{2N}$$

$$\left(\frac{R^{\text{min}}}{R^{\text{max}}}\right) > e^{N-2N_s}$$

SERIOUSNESS

☹ ☹

☹ ☹ ☹

SOLUTIONS

$$k|c| \sigma T \lesssim 1$$

$$c_s^2 \propto 1$$

DE before EK

$$\sigma_{\text{ek-bag}}^2 \leq X_c$$

PROBLEMS

① gravitational instability

② classical anisotropy

CAUSES

$$\frac{P_{\text{tr}}}{T_{\text{tr}}} = c_s^2 < 0$$

$$\left(\frac{a_{\text{pert}}}{a_{\text{bg}}} \right)^{-6} > e^{-2N}$$

$$\left(\frac{R^{\text{min}}}{R^{\text{max}}} \right) > e^{N-2N_0}$$

SERIOUSNESS

⚡ ⚡

⚡ ⚡ ⚡

SOLUTIONS

$$k|c| aT \lesssim 1$$

$$c_s^2 \gg 1$$

DE before EK

$$\sigma_{\text{ek-bag}}^2 \lesssim X_c$$



PROBLEMS

① gravitational instability

② classical anisotropy

③ blue spectrum of curr. pert

④ anisotropies from shear pert

CAUSES

$$\frac{P_{\text{irr}}}{T_{\text{irr}}} = c_s^2 < 0$$

$$\left(\frac{a_{\text{sp-ord}}}{a_{\text{ek-bag}}} \right)^{-6} > e^{2N}$$

$$\left(\frac{R_{\text{radh}}}{R_{\text{min}}} \right) > e^{N-2N_s}$$

$$\left(\frac{\sigma_{\text{sp-ord}}^2}{\sigma_{\text{ek-ord}}^2} \right) > e^{4N}$$

SERIOUSNESS

☹ ☹

☹ ☹ ☹

☹ ☹ ☹ ☹

SOLUTIONS

$k|c| \sigma T \lesssim 1$

$c_s^2 \propto 1$

DE before EK

$\sigma_{\text{ek-bag}}^2 \lesssim X_c$

PROBLEMS

① gravitational instability

② classical anisotropy

③ blue spectrum of curv. pert

④ anisotropy for shear pert

CAUSES

$$\frac{P_{\text{irr}}}{T_{\text{irr}}} = c_s^2 < 0$$

$$\left(\frac{A_{\text{irr, end}}}{A_{\text{irr, beg}}} \right)^{-6} > e^{2N}$$

$$\left(\frac{R_{\text{max}}}{R_{\text{min}}} \right) > e^{N-2N_s}$$

$$\left(\frac{\sigma_{\text{irr, end}}^2}{\sigma_{\text{irr, beg}}^2} \right) > e^{4N}$$

SERIOUSNESS

✖ ✖

✖ ✖ ✖

✖ ✖ ✖ ✖

✖ ✖ ✖ ✖ ✖

SOLUTIONS

$k|c| \sigma T \lesssim 1$

$c_s^2 \propto 1$

DE before EK

$\sigma_{\text{ek, beg}}^2 \leq X_c$

PROBLEMS

① gravitational instability

② classical anisotropy

③ blue spectrum of curr. pert

④ anisotrop for shear pert

CAUSES

$$\frac{P_{\text{irr}}}{T_{\text{irr}}} = c_s^2 < 0$$

$$\left(\frac{a_{\text{irr.ond}}}{a_{\text{irr.leg}}} \right)^{-6} > e^{2N}$$

$$\left(\frac{R_{\text{irr.ond}}}{R_{\text{irr.leg}}} \right) > e^{N-2N_s}$$

$$\left(\frac{\sigma_{\text{irr.ond}}^2}{\sigma_{\text{irr.leg}}^2} \right) > e^{4N}$$

SERIOUSNESS

✘ ✘

✘ ✘ ✘

✘ ✘ ✘ ✘

✘ ✘ ✘ ✘ ✘

SOLUTIONS

$$k|c| aT \lesssim 1$$

$$c_s^2 \propto 1$$

DE before EK

$$\sigma_{\text{ek.leg}}^2 \leq X_c$$

PROBLEMS

① gravitational instability

② classical anisotropy

③ blue spectrum of curr pert

④ anisotropy = shear pert

CAUSES

$$\frac{P_{\text{irr}}}{T_{\text{irr}}} = c_s^2 < 0$$

$$\left(\frac{a_{\text{sp-ord}}}{a_{\text{is-ord}}} \right)^6 > e^{2N}$$

$$\left(\frac{R^{\text{radh}}}{R^{\text{is-ord}}} \right) > e^{N-2N_s}$$

$$\left(\frac{\sigma_{\text{sp-ord}}^2}{\sigma_{\text{ek-ord}}^2} \right) > e^{4N}$$

SERIOUSNESS

✘ ✘

✘ ✘ ✘

✘ ✘ ✘ ✘

✘ ✘ ✘ ✘ ✘

SOLUTIONS

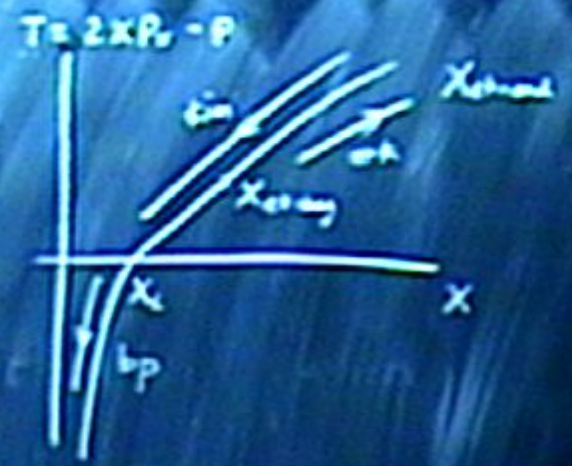
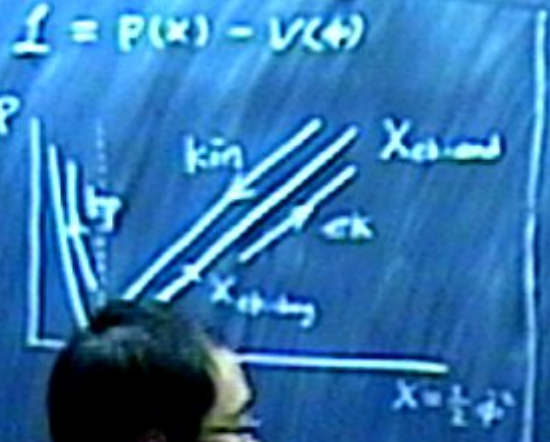
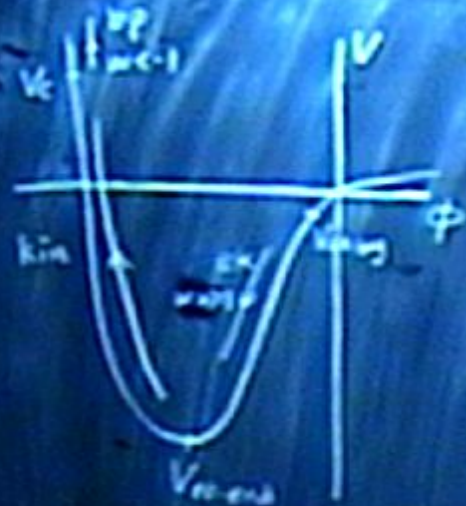
$$k|c| aT \lesssim 1$$

$$c_s^2 \ll 1$$

DE before EK

$$\sigma_{\text{ek-ord}}^2 \leq X_c$$

Curvature & asymmetry in asymmetric nonsingular business



$$e^{2V} = \frac{X_{eq-end}}{X_{c-beg}}$$

$$P_x > 0$$

$$(T=V) - \frac{1}{2} \frac{P}{P_x} \rightarrow \frac{P}{2P_x}$$

$$X_c < X_{eq-beg} \ll X_{c-end}$$



PROBLEMS

- ① gravitational instability
- ② classical anisotropy
- ③ blue spectrum of curv. pert
- ④ anisotropy from shear

CAUSES

$$\frac{P_x}{T_x} = c_s^2 < 0$$

$$\left(\frac{\Delta_{\text{curv}}}{\Delta_{\text{long}}}\right)^{-6} > e^{2N}$$

$$> e^{N-2N_s}$$

$$> e^{4N}$$

SERIOUSNESS

⚡⚡

⚡⚡⚡

⚡⚡⚡⚡

⚡⚡⚡⚡⚡

SOLUTIONS

$$k|c| \Delta T \lesssim 1$$

$$c_s^2 \ll 1$$

DE before EK

$$\sigma_{\text{ek-long}}^2 \leq X_c$$

$$X_c \ll X_{\text{ek-end}}$$