DARK ENERGY CONDENSATION

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Concordance Model

30% Dark Matter, w=0, clusterized

70% Dark Energy, w<0, smooth

two separate and non-interacting fluids

IS THIS THE ONLY POSSIBILITY?

DE-DM INTERACTION

ANDERSON, CARROLL
BELLIDO, CASAS, QUIROS
AMENDOLA ET AL.
COMELLI, M.P., RIOTTO
KHOURY, WELTMAN
GUBSER, PEEBLES
BRAX, VAN DE BRUCK, DAVIS
...

[baryophobic, growth of DM perturbations,..]

UNIFIED DARK MATTER

BILIC, TUPPER, VIOLLIER
BENTO, BERTOLAMI, SEN
....

[perturbations...]

DE-DM INTERACTION + Z_2 SYMMETRY:

$$M \to M(\phi^2) = M_0 f(\phi^2/\mu^2)$$

$$V(\phi) \to V(\phi^2)$$

$\phi \to -\phi$, *M mass of DM, <u>baryons</u>, neutrinos, ...*

natural implementation in scalar-tensor theories:

$$S_M\left[g_{\mu\nu}, \psi\right] \to S_M\left[f(\phi^2/\mu^2)^2 g_{\mu\nu}, \psi\right]$$

energy density: $\rho(\phi) = \rho_M(\phi) + \rho_\phi(\phi)$

$$\rho_M(\phi) = f(\phi^2/\mu^2)\, M_0\, n$$

$$\rho_\phi(\phi) = \frac{1}{2}\dot{\phi}^2 + V(\phi^2/\mu^2)$$

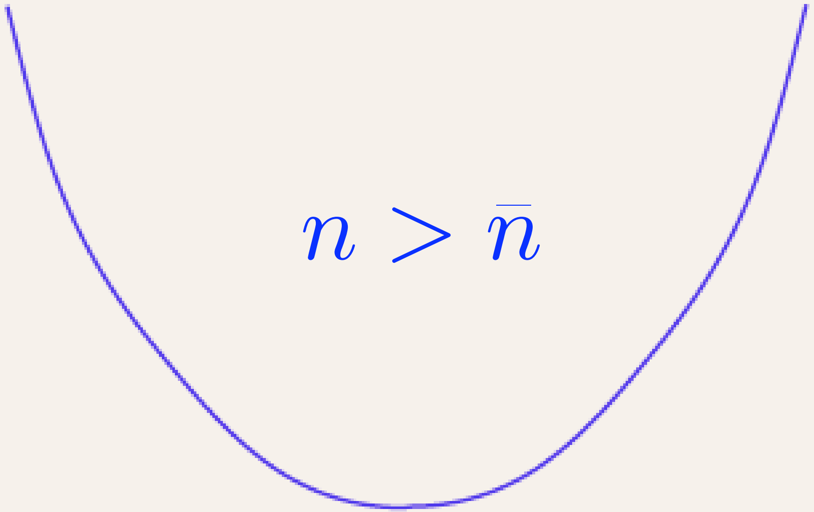
scalar mass in $\phi = 0$:

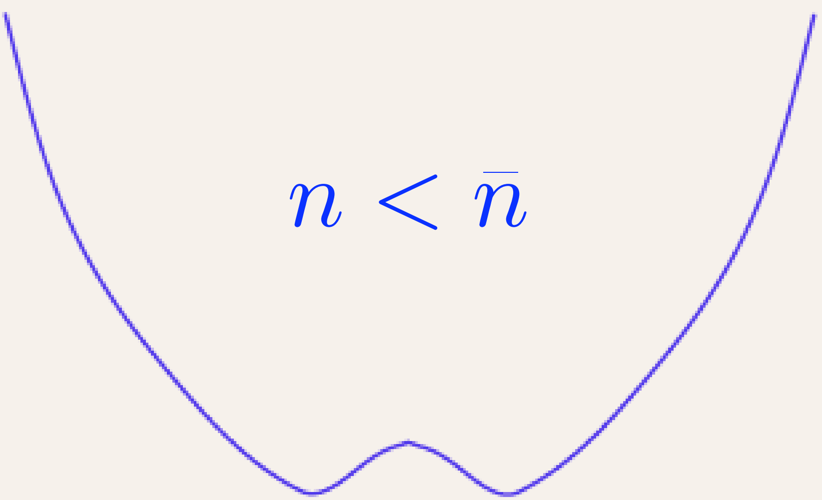
$$m_\phi^2(0) = \frac{2}{\mu^2}\left[V'(0) + f'(0) m\, n\right] = -\frac{2V'(0)}{\mu^2}\left[\frac{n}{\overline{n}} - 1\right]$$

$$\overline{n} \equiv -\frac{V'(0)}{m f'(0)}\,, \qquad (\cdots)' \equiv \frac{d(\cdots)}{d(\phi^2/\mu^2)}$$

phase transition for $n = \bar{n}$

Two Phases





High density: $\phi^2 = 0$

$$\rho_M = f(0) M_0 n \sim a^{-3}$$

$$\rho_\phi = V(0) \sim \text{const.}$$

(~LCDM !)

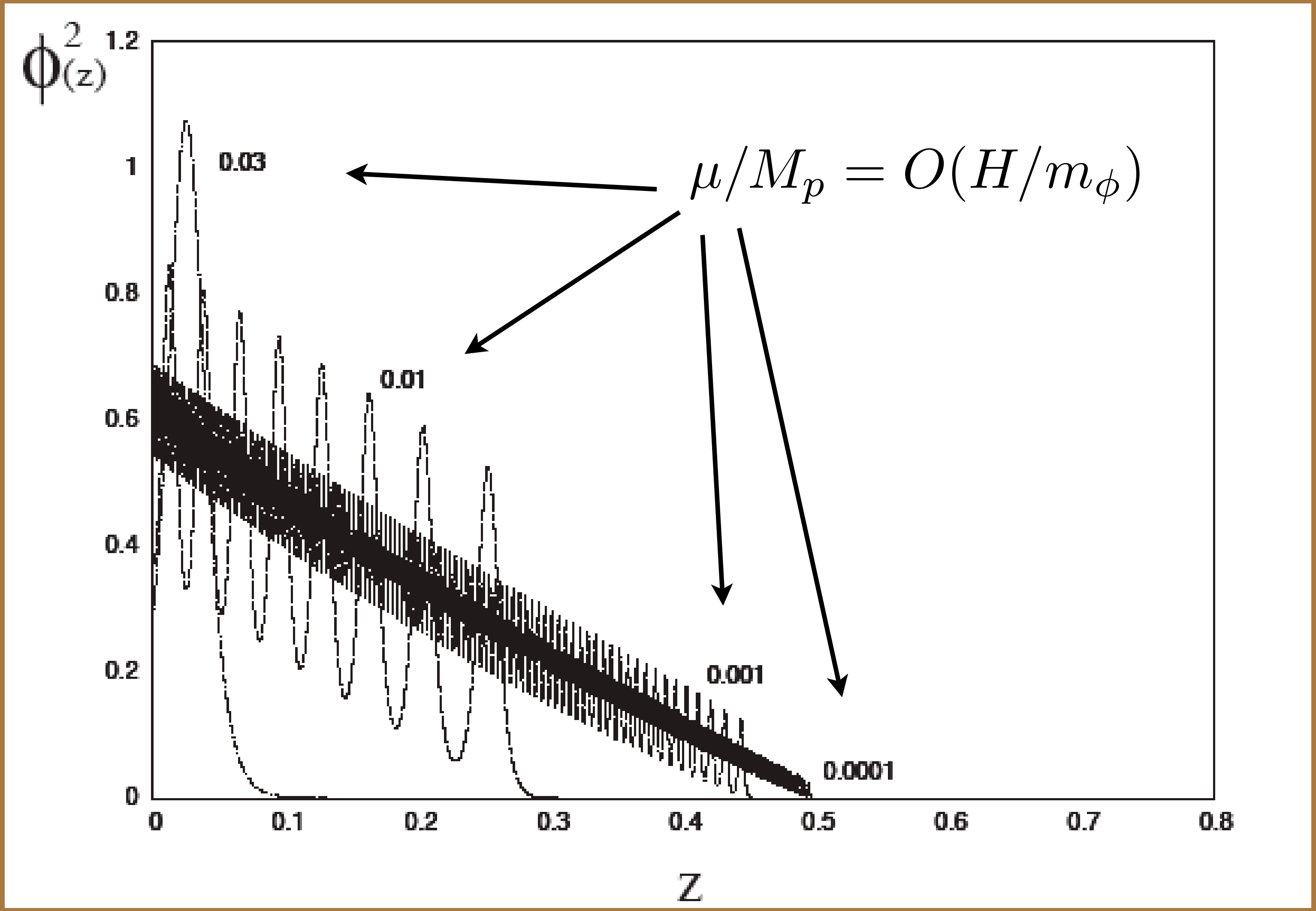
Low density: $\phi^2 = \phi^2(n) \neq 0$

$$\rho_M \not\propto a^{-3}$$

$$\rho_\phi \not\propto \text{const.}$$

$$\left(\frac{\rho_M}{\rho_\phi} = \text{const if both exp. or p.l.} \right)$$

following a moving minimum...



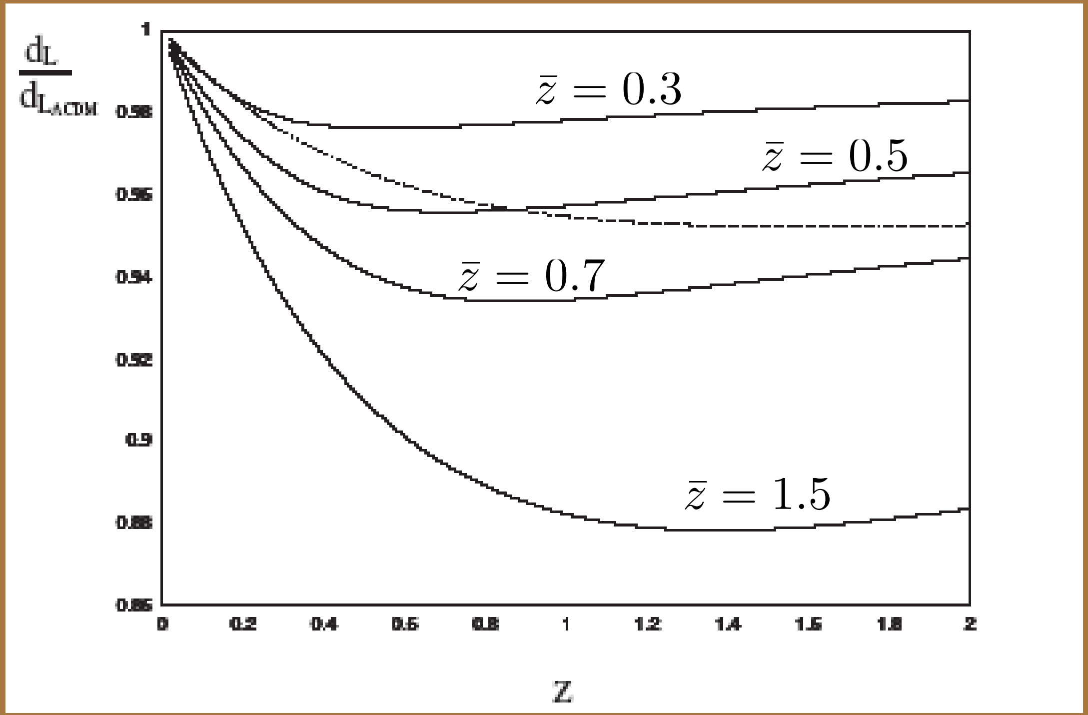
When did it happen?

$$[V = V_0 e^{-\phi^2/\mu^2}\,, \quad M = M_0 e^{b\phi^2/\mu^2}]$$

Constraints:

$$\rho_{tot}(\phi_0) = \frac{3H_0^2}{8\pi G}$$

$$\left.\frac{\rho_M}{\rho_{\rm rad}}\right|_{z_{rec}}$$ + CMB peak positions: agree with WMAP



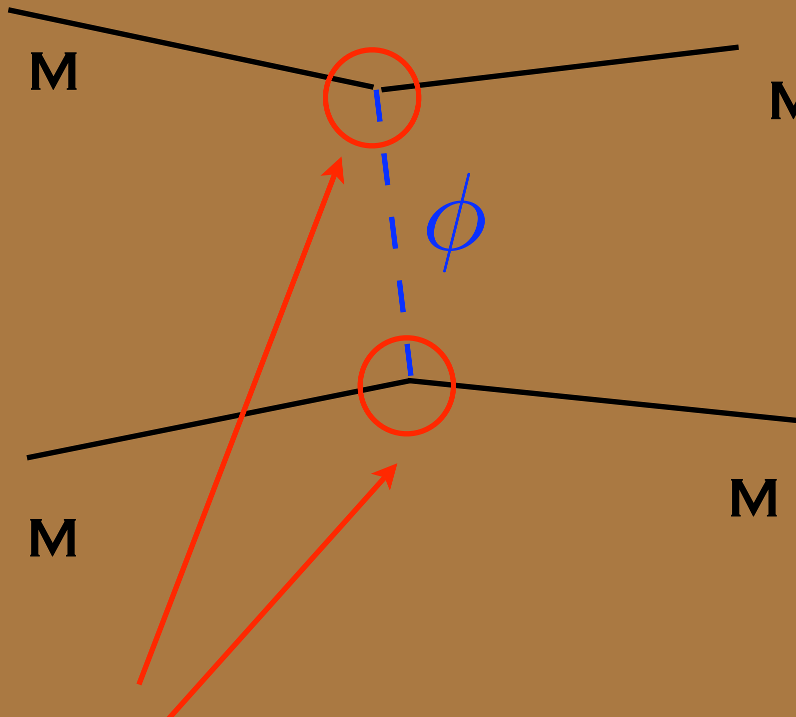
luminosity distance vs. SNeIa

$$\bar{z} \leq 0.51 \qquad (95\% \ c.l.)$$

$$(w_0 \leq -1/2)$$

independent on μ^2

fifth force



$$M\bar{\psi}\psi\frac{\phi}{\mu}$$

$$G \rightarrow G\left(1+\frac{M_p^2}{\mu^2}\right)$$

forbidden by symmetry for $n > \bar{n}$

no scalar force before the transition or inside overdensities!

linear perturbations

$$\phi + \delta\varphi \qquad\qquad n + \delta n$$

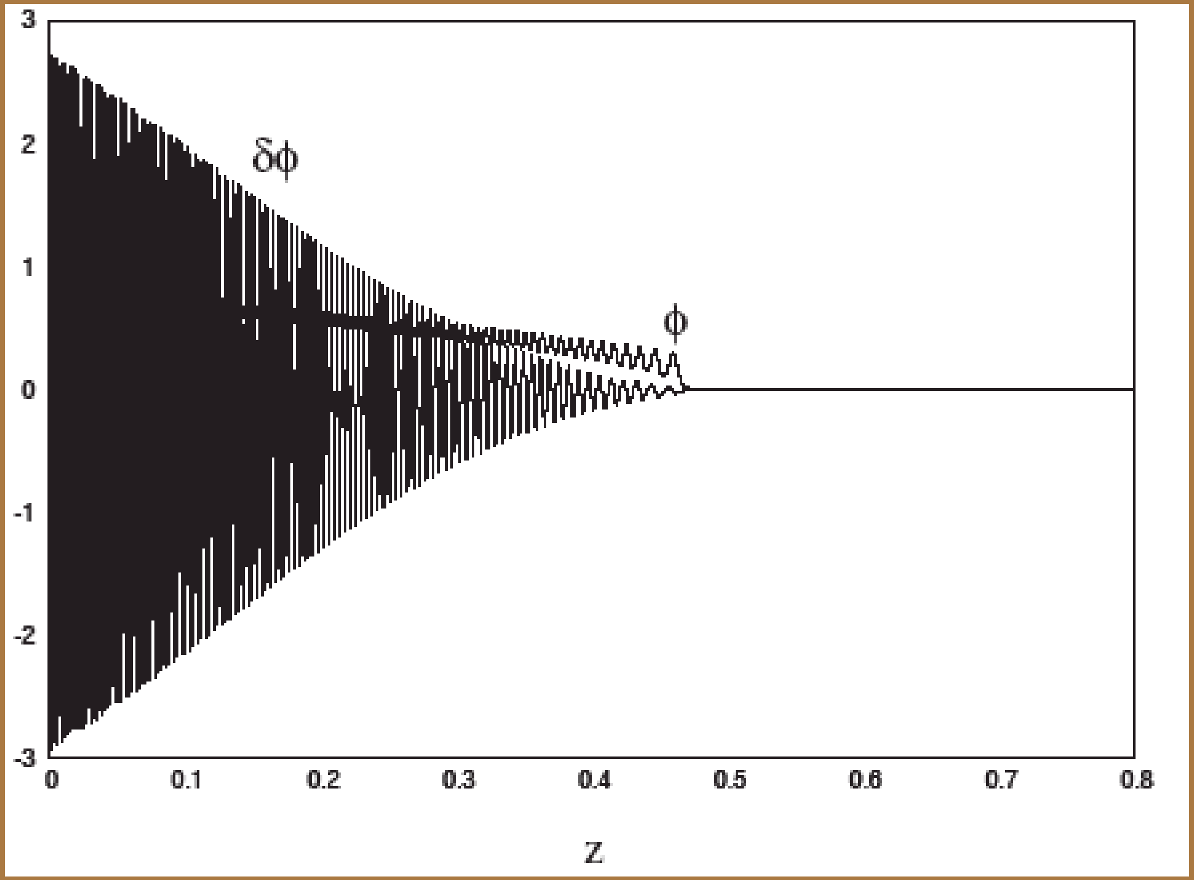
1) deviations from geodesics equation

$$\dot{\theta} + \left(\frac{\dot{a}}{a} + 2b \frac{\phi \dot{\phi}}{\mu^2} \right) \theta = 2bk^2 \frac{\phi \delta\varphi}{\mu^2} \qquad (\theta \equiv i k^i v_i)$$

2) large fluctuations after the transition

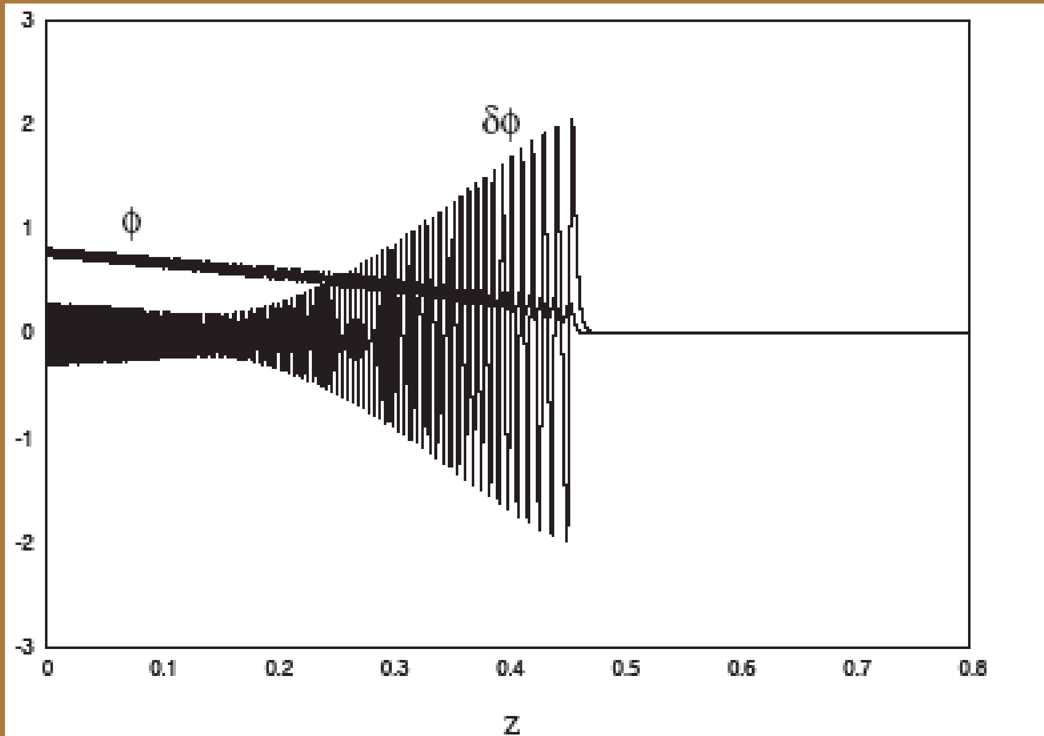
$$\delta\varphi \simeq - \left(2 \log \frac{\bar{n}}{n} \right)^{-1} \frac{\delta n}{n} \phi \qquad (H < k/a < m_\phi)$$

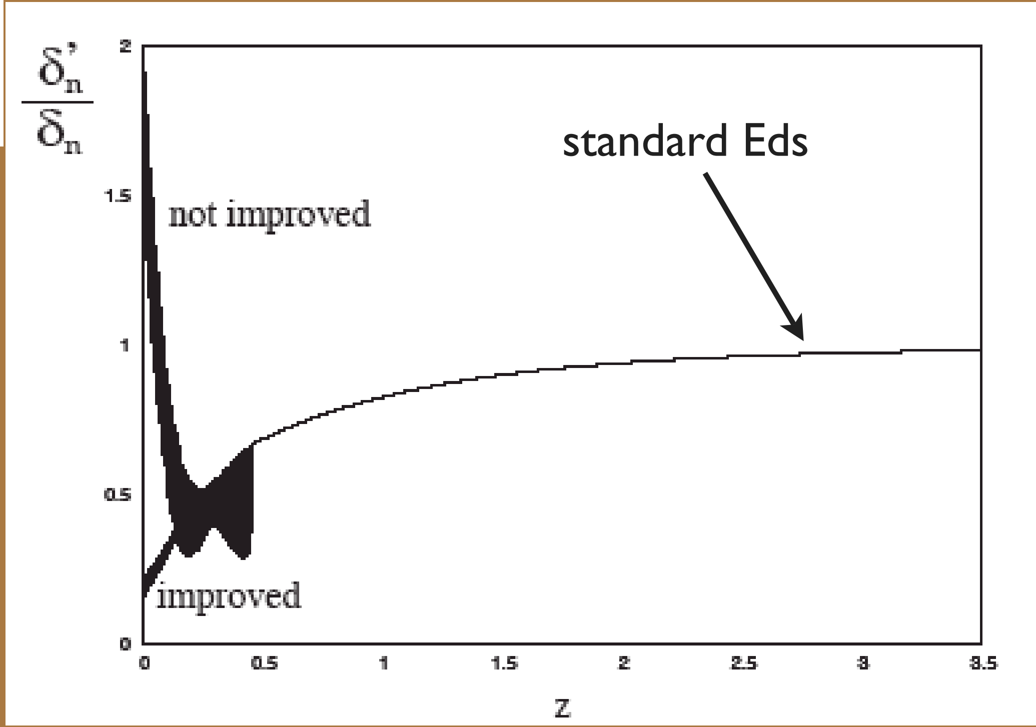
linear disaster!



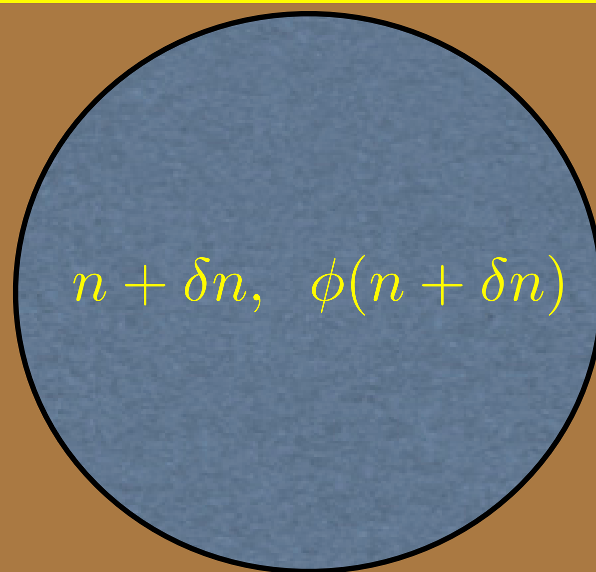
linear theory does not feel symmetry restoration inside overdensities: when $n + \delta n > \bar{n}$, $\phi \to 0$ and the scalar force shuts off

Improved linear perturbation theory: $\phi(n) \rightarrow \phi(n + \delta n)$



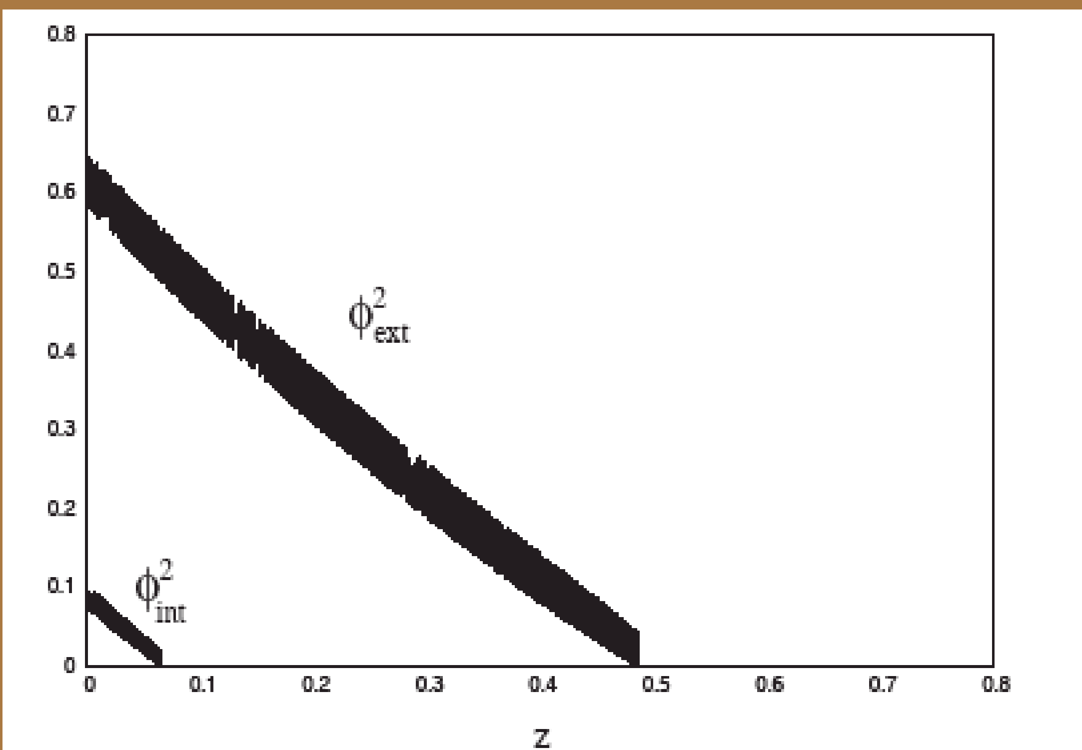


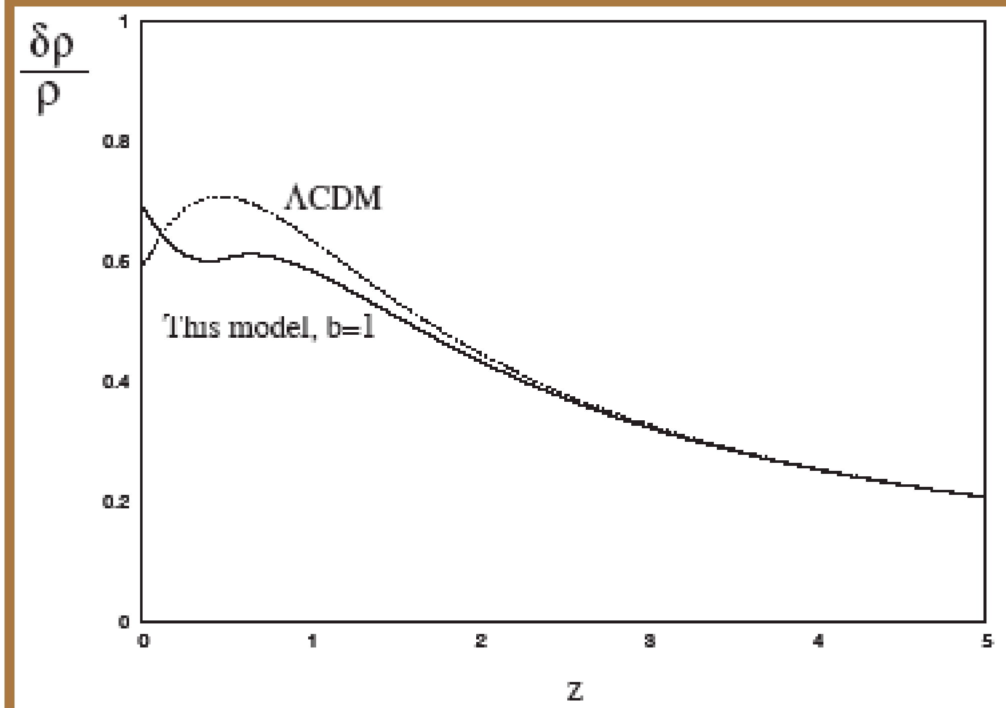
going more non-linear: spherical collapse



$n, \;\; \phi(n)$

assuming $R > m_\phi^{-1}$





no transition inside objects with $\delta\rho/\rho > 1$!

Conclusions

1) The cosmological background today might be quite different from LCDM
($\rho_M/\rho_\phi = const\,,\, w = -1/2\,,$ ...)

2) Z_2 provides a way to avoid the `fifth force' problems of quintessence, to grow DM perturbations correctly, and to achieve independence on the initial conditions

3) the model is potentially distinguishable from LCDM (signature from the transition), but more work needed to compare to observations

4) same scheme may be interesting also for non-DM particles (ex. mass varying neutrinos) and non-DE fields