Cosmological concordance model with particle creation

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Prague, 2012

Vacuum energy in the expanding space-time

$$T_{\mu\nu} = \Lambda g_{\mu\nu}$$

$$\Lambda \approx H^4$$

(free fields, de Sitter space-time)

$$E \approx H$$

$$V \approx 1/H^3$$

Davies, Fulling, Parker, Ford,
Starobinsky... (70's)

Carneiro and Tavakol, PRD **80**, 043528 (2009).
Carneiro and Tavakol, GRG **41**, 2287 (2009).

QCD condensate

$$\Lambda \approx m^3 H \quad \Rightarrow \quad \begin{cases} \Lambda \approx m^6 \\ H \approx m^3 \end{cases} \qquad (\Lambda \approx 3H^2)$$

$$E \approx H$$

$$V \approx 1/m^3$$

Schützhold, PRL **89**, 081302 (2002).
Klinkhamer and Volovik, PRD **79**, 063527 (2009).
Urban and Zhitnitsky, PLB 688, 9 (2010).
Ohta, PLB 695, 41 (2011).

Dark Matter production

$$3H^2 = \rho_T$$
$$\dot{\rho}_T + 3H(\rho_T + p_T) = 0$$

By using

$$\rho_T = \rho_m + \Lambda \qquad p_T = p_m - \Lambda$$

we have

$$\dot{\rho}_m + 3H(\rho_m + p_m) = -\dot{\Lambda}$$

$$\Lambda = 2\Gamma H \Rightarrow \qquad \dot{\rho}_m + 3H(\rho_m + p_m) = \Gamma\rho_m$$

$$(\Gamma \approx m^3)$$

Dark matter production

$$p_m = 0 \Rightarrow \qquad \frac{1}{a^3}\frac{d}{dt}(a^3 n) = \Gamma n \qquad \text{(Boltzmann eq.)}$$

$$\Lambda = 2\Gamma H \Rightarrow \qquad \Gamma = \frac{3}{2}\left(1 - \Omega_M\right)H$$

de Sitter ➡ $\Gamma = \frac{3}{2}H$

The solution

$$a(t) = C\left[\exp(\Gamma t) - 1\right]^{2/3}$$

$$H = H_0\left[1 - \Omega_m + \Omega_m(1+z)^{3/2}\right]$$

For $t \to \infty$, we obtain

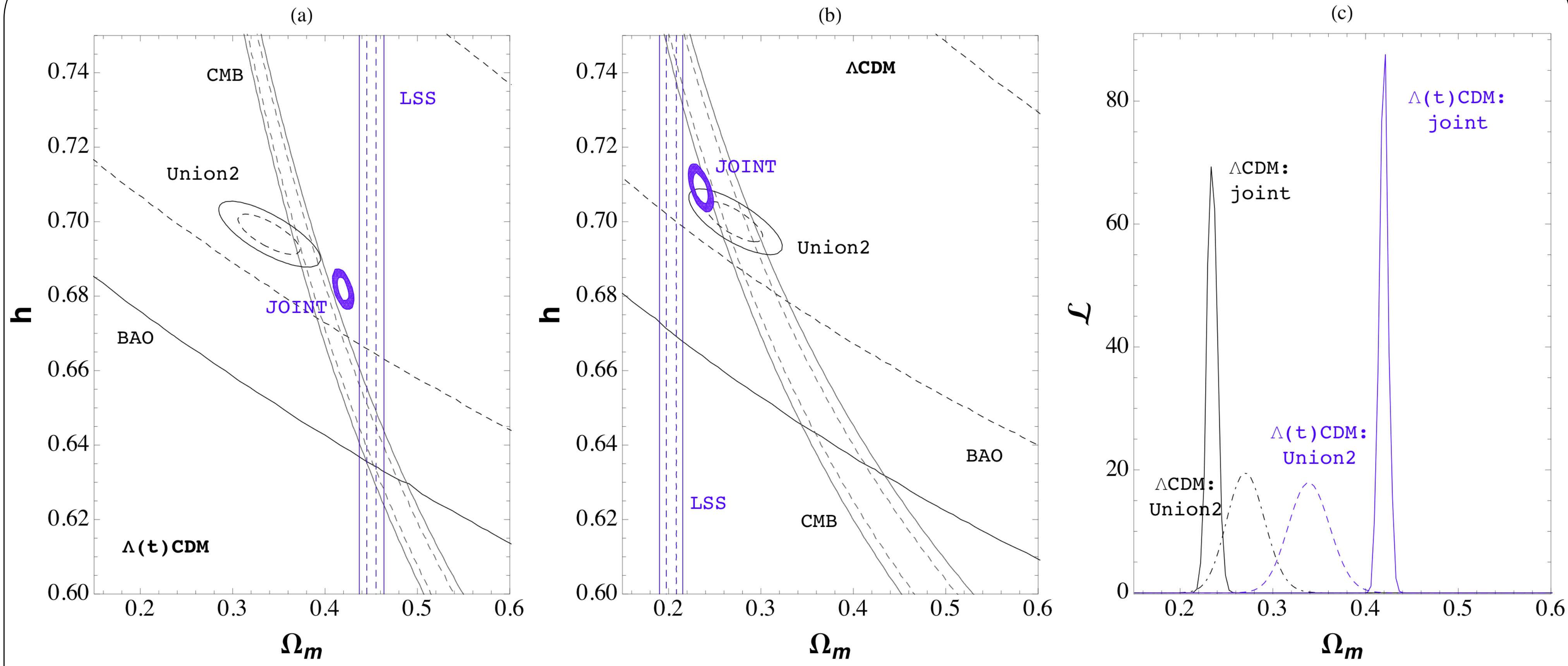
$$a(t) = C\exp(2\Gamma t/3)$$

For $\sigma t << 1$, we have

$$a(t) = C(\sigma t/2)^{2/3}$$

$$\rho_m = 3H_0^2\Omega_m^2(1+z)^3$$

Borges and Carneiro, GRG **37**, 1385 (2005).



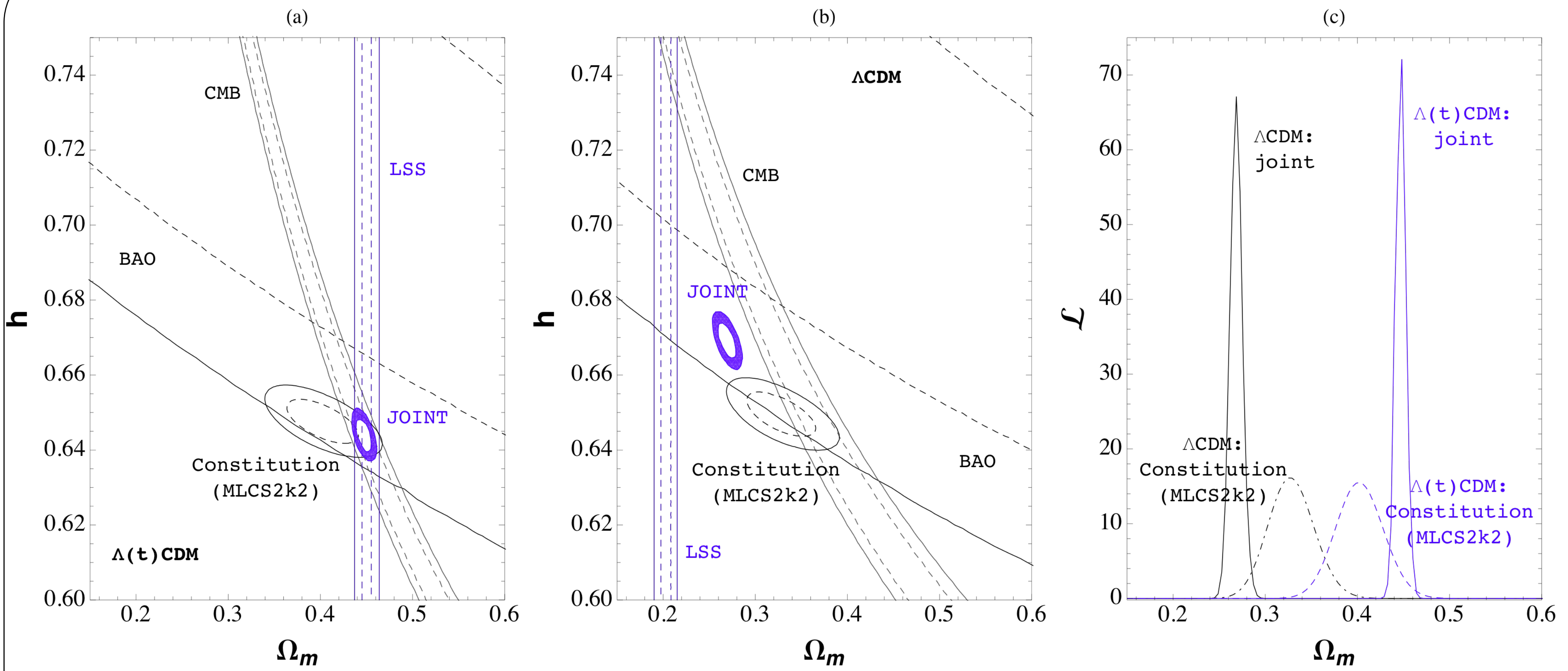
$\chi^2_r = 1.06$

$\Omega_m = 0.42 \pm 0.01$

$\chi^2_r = 1.03$

$\Omega_m = 0.24 \pm 0.01$

Carneiro, Pigozzo, Borges and Alcaniz, PRD **74**, 023532 (2006).



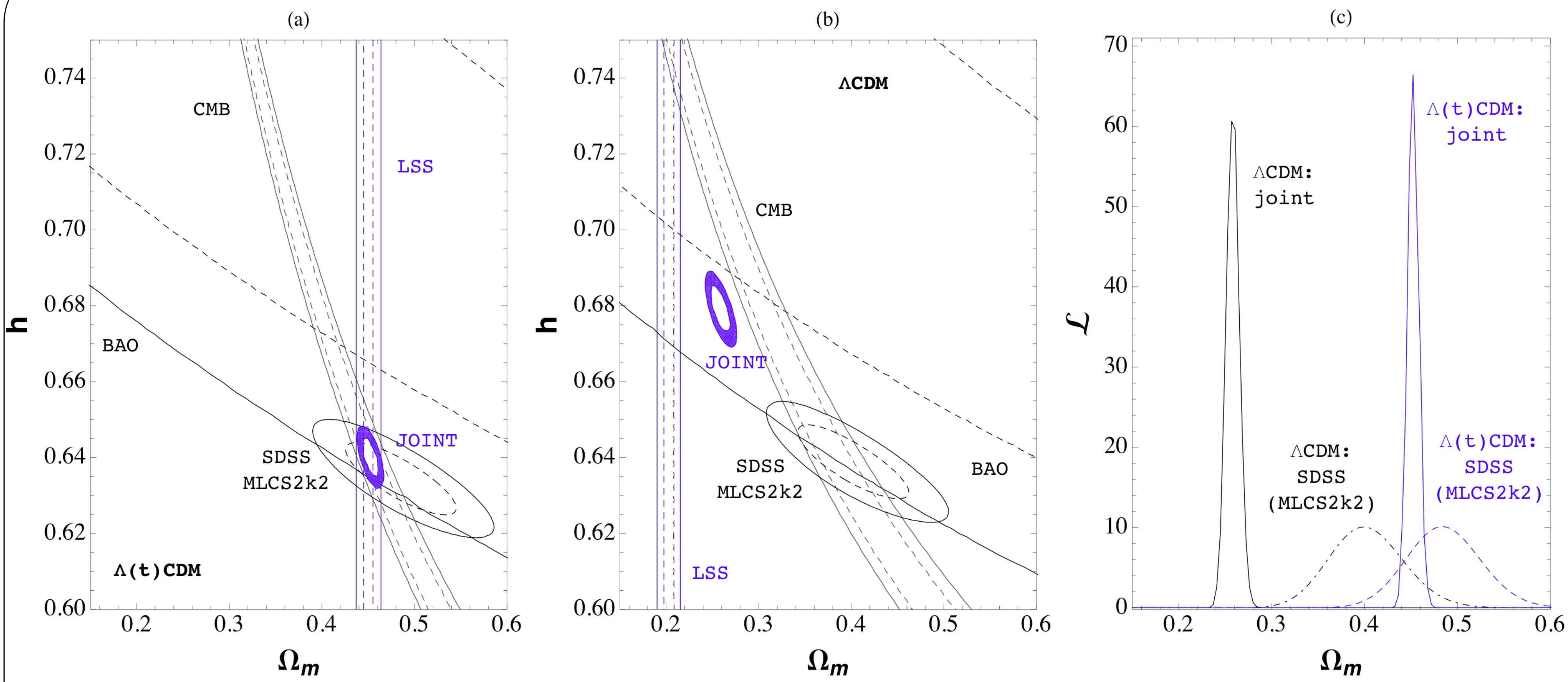
$\chi_r^2 = 1.06$

$\Omega_m = 0.45 \pm 0.01$

$\chi_r^2 = 1.38$

$\Omega_m = 0.27 \pm 0.01$

Carneiro, Dantas, Pigozzo and Alcaniz, PRD 77, 083504 (2008).



$$\chi_r^2 = 0.84$$
$$\Omega_m = 0.45 \pm 0.01$$

$$\chi_r^2 = 1.23$$
$$\Omega_m = 0.26 \pm 0.01$$

Pigozzo, Dantas, Carneiro and Alcaniz, JCAP **1108**, 022 (2011).

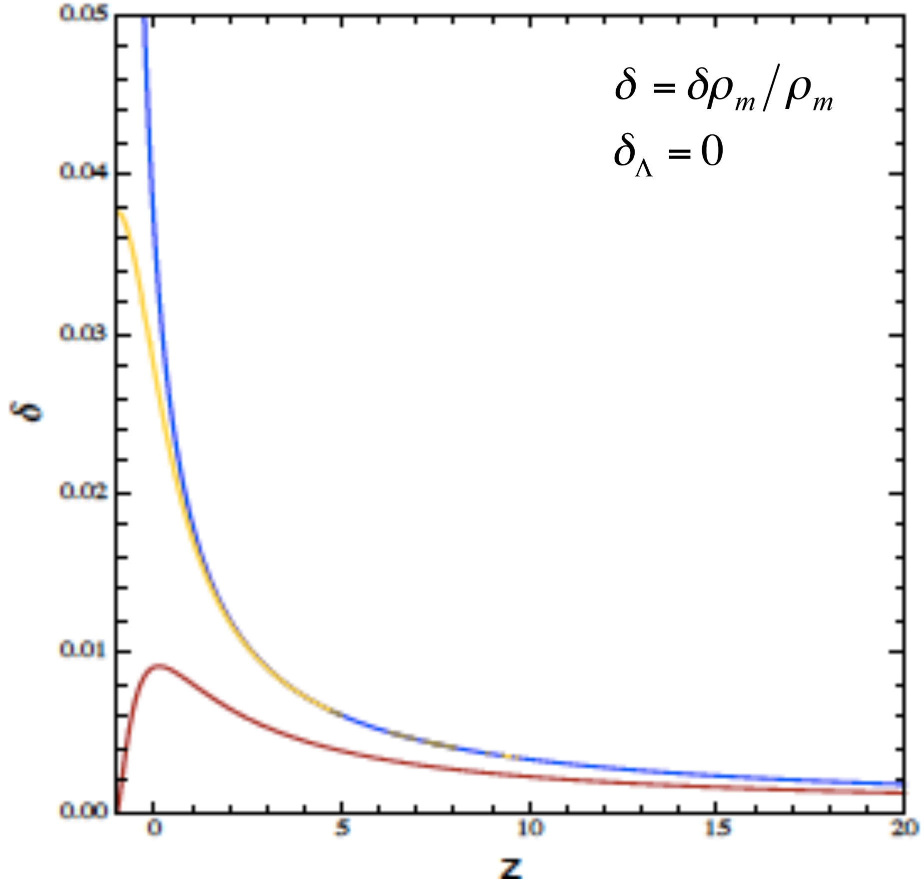
Universe age

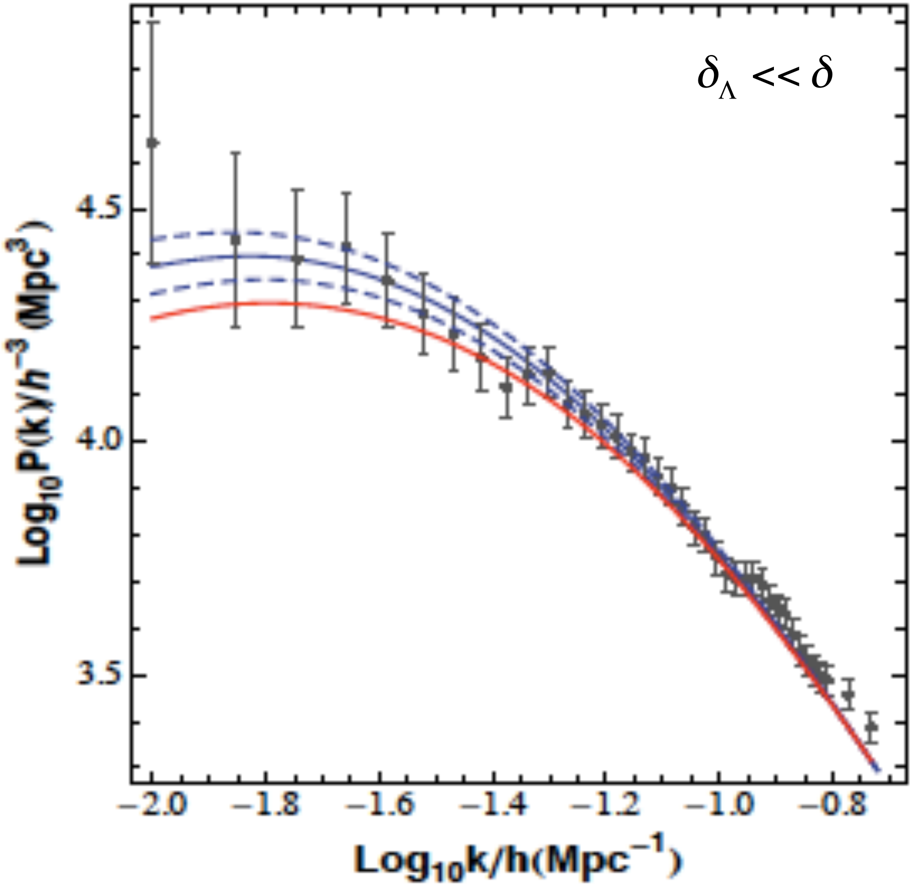
$$H_0 t_0 = \frac{2\ln\Omega_m}{3(\Omega_m - 1)} \approx 0.97$$

$$t_0 \approx 13.5 Gyr \qquad\qquad (h = 0.7)$$

Transition redshift

$$z_T = \left(\frac{2}{\Omega_m} - 2\right)^{\frac{2}{3}} - 1 \approx 0.81$$





The matter power spectrum

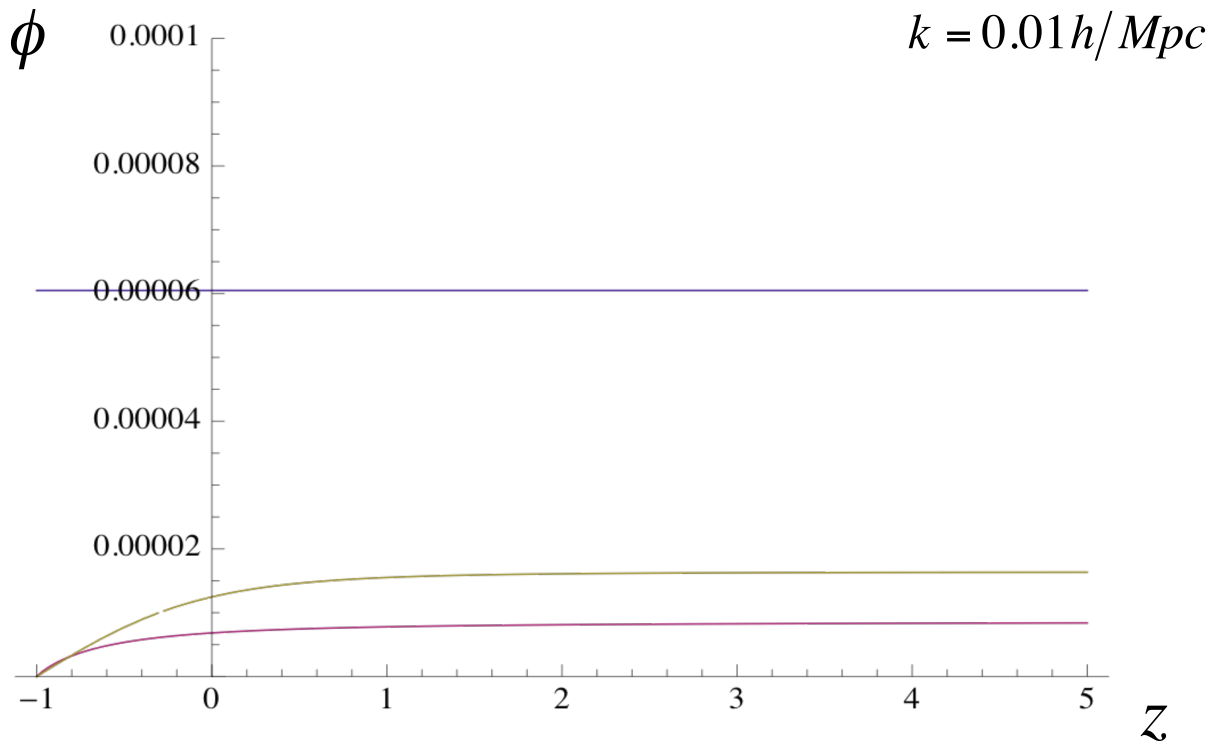
$$\ddot{\delta} + \left(2H + \frac{\psi}{\rho_m}\right)\dot{\delta} - \left[\frac{\rho_m}{2} - 2H\frac{\psi}{\rho_m} - \frac{d}{dt}\left(\frac{\psi}{\rho_m}\right)\right]\delta = 0$$

$$\psi = -\dot{\Lambda}$$

(Waga, 1994)

Borges, Carneiro, Fabris and Pigozzo, PRD **77**, 043513 (2008).

Zimdahl, Borges, Carneiro, Fabris and Hipolito-Ricaldi, JCAP **1104**, 028 (2011).



The gravitational potential and the ISW effect

$$k^2\phi = \rho_m a^2 \delta/2$$

Alcaniz, Borges, Carneiro, Fabris, Pigozzo, Zimdahl, arXiv:1201.5919.

Conclusions

- QCD condensate
- Matter creation

- Background tests
- Density perturbations
- CMB and Integrated Sachs-Wolf effect

- Cosmological constant problem
- Cosmic coincidence