Cosmological Aspects of Long-Lived Charged Massive Particles

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Tomo Takahashi
Department of Physics, Saga University

Collaborator: Kazunori Kohri (KEK)

Long-Lived Charged Massive Particles (CHAMP)

- Long-lived charged massive particles (CHAMP) can exist in some extension of the standard model.

- From experiments of deep sea water, such massive charged particles are severely constrained if they are stable.

- However, CHAMPs can be unstable, then they can constitute a dominant component (or some fraction) of non-relativistic matter in the early Universe.

- CHAMP would affect various cosmological aspects.

Cosmological effects of CHAMP

- BBN (Catalyzed BBN)

- BBN (particle decay)

- CMB spectrum (particle decay)

⋮

- Large scale structure

Evolution of the bound state

- ● CHAMPs can form the bound-state with light nuclei (p ,He4)

$$\frac{dn_{(^4\mathrm{He}X^-)}}{dt} = -3Hn_{(^4\mathrm{He}X^-)} - \Gamma_X n_{(^4\mathrm{He}X^-)}$$

$$+\langle\sigma_{\mathrm{bnd},^4\mathrm{He}}v\rangle\left[(n_{^4\mathrm{He}} - n_{(^4\mathrm{He}X^-)})n_{X^-} - \left(\frac{m_{^4\mathrm{He}}m_X T}{2\pi m_{(^4\mathrm{He}X^-)}}\right)^{3/2} e^{-E_{b^4\mathrm{He}}/T} n_{(^4\mathrm{He}X^-)}\right]$$

$$+\langle\sigma_{\mathrm{ex}}v\rangle(n_{^4\mathrm{He}} - n_{(^4\mathrm{He}X^-)})n_{(pX^-)} \qquad \to (^4\mathrm{He}X^-)$$

$$(pX^-) +^4\mathrm{He} \to (^4\mathrm{He}X^-) + p$$

charge exchange reaction

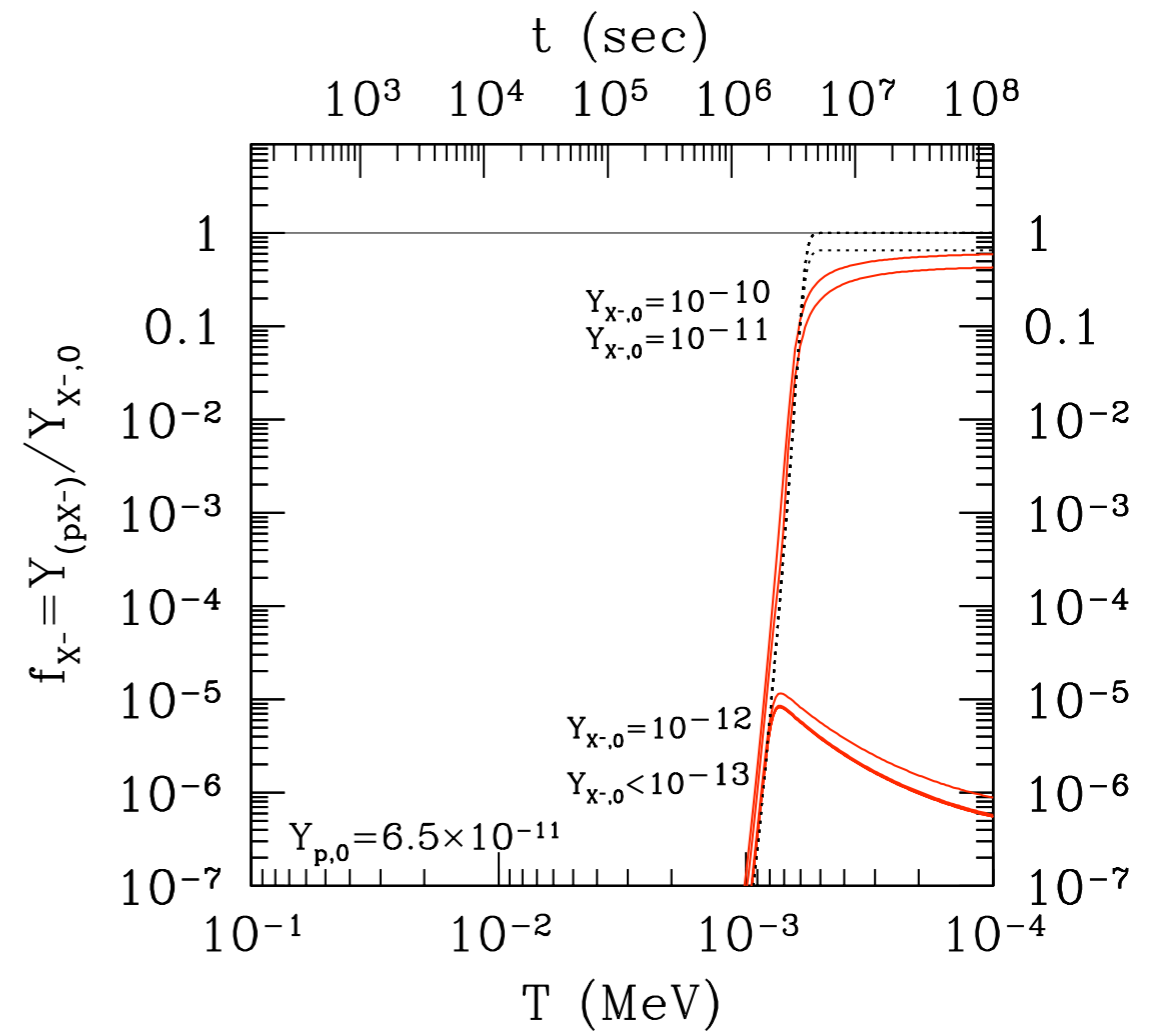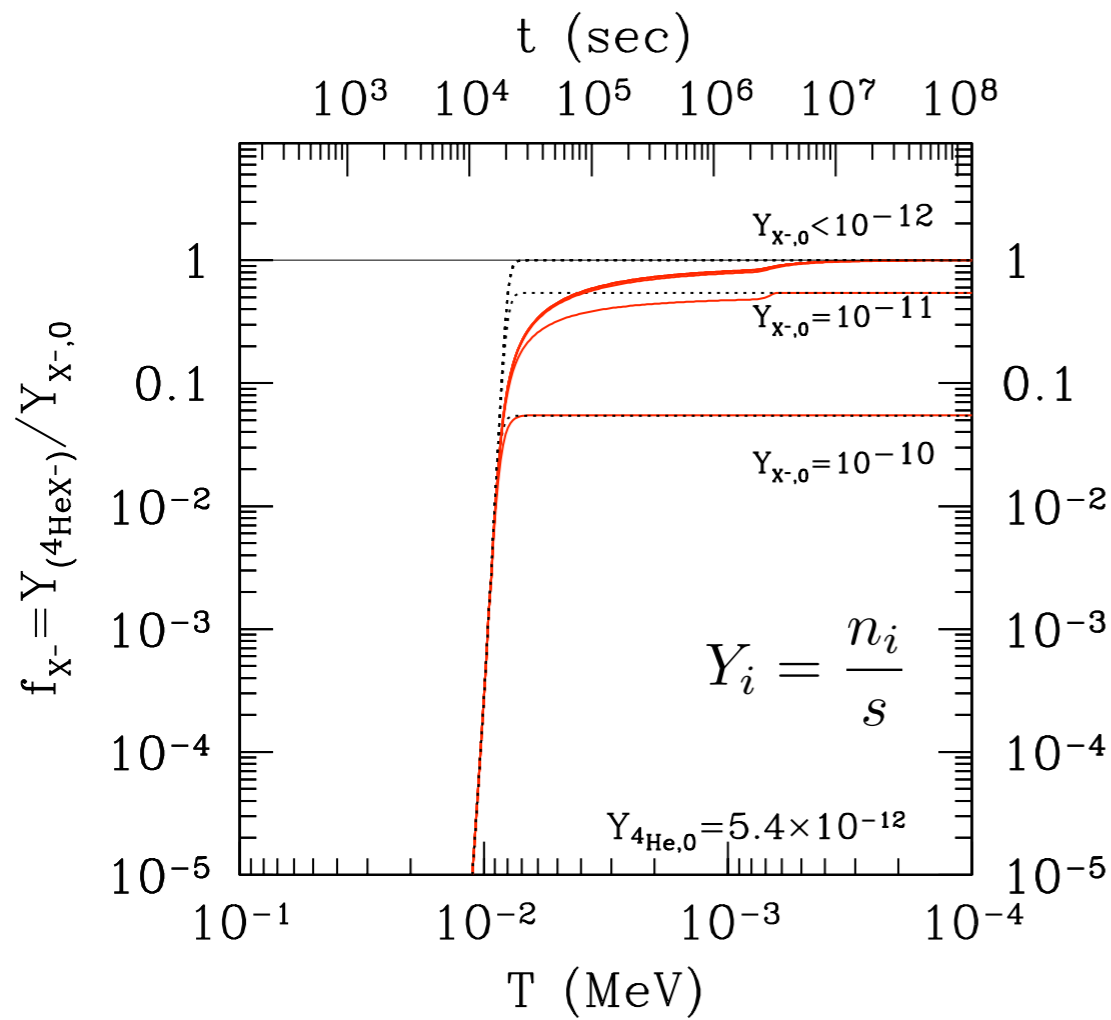$$\frac{dn_{(pX^-)}}{dt} = -3Hn_{(pX^-)} - \Gamma_X n_{(pX^-)}$$

$$+\langle\sigma_{\mathrm{bnd},p}v\rangle\left[(n_p - n_{(pX^-)})n_{X^-} - \left(\frac{m_p m_X T}{2\pi m_{(pX^-)}}\right)^{3/2} e^{-E_{bp}/T} n_{(pX^-)}\right]$$

$$-\langle\sigma_{\mathrm{ex}}v\rangle(n_{^4\mathrm{He}} - n_{(^4\mathrm{He}X^-)})n_{(pX^-)} \qquad \to (pX^-)$$

$$(pX^-) +^4\mathrm{He} \to (^4\mathrm{He}X^-) + p$$

charge exchange reaction

Evolution of the bound state

$$Y_{X^-,0} \simeq 4 \times 10^{-12} \, \Omega_{\mathrm{DM}} h^2 \left(\frac{10^3 \, \mathrm{GeV}}{m_{X^-}} \right)$$

● Most Negative CHAMPs are captured by He4 to form $(^4\mathrm{He}X^-)$

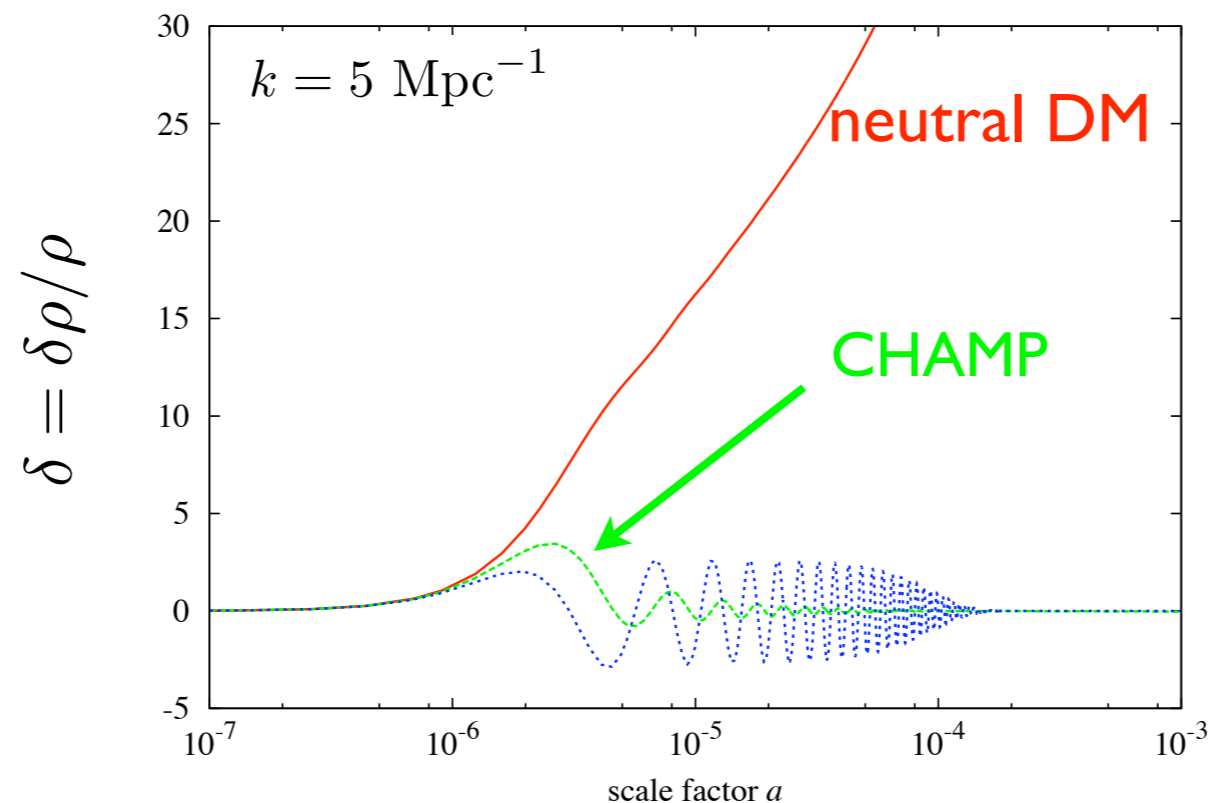# Effects of CHAMP on large scale structure
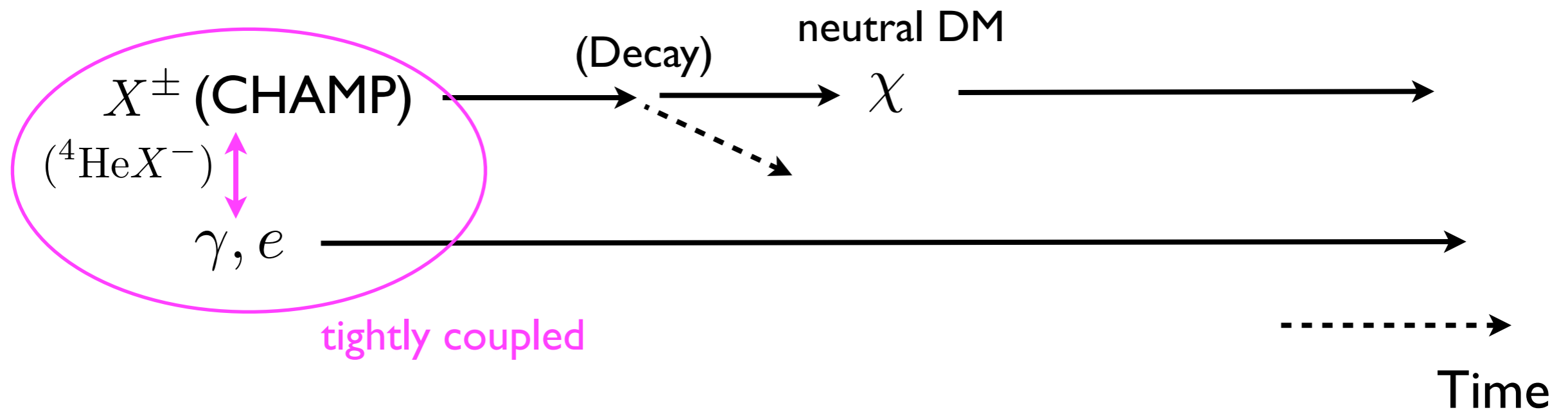
- Charged particles are tightly coupled to bayron-photon fluid.

- Inside the horizon, CHAMPs participate in the acoustic oscillation, which suppresses the growth of fluctuations of champ.

Effects of CHAMP on large scale structure

■ Evolution of density fluctuations

(For the scale which enters the horizon before the decay)

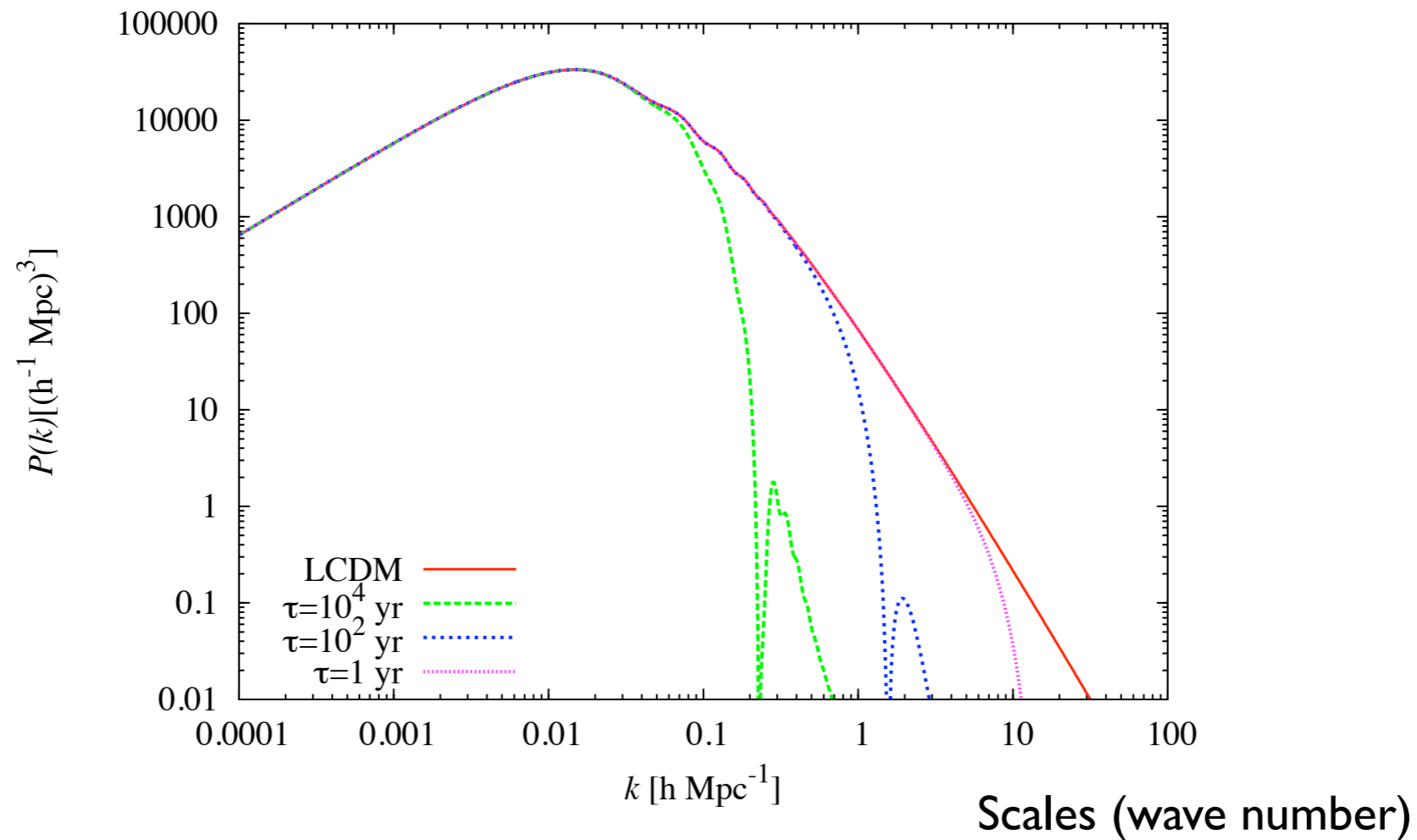

- Density fluctuations for the scale which has already in the horizon before the decay cannot grow (participate in acoustic ocs.)

➡ "Damping" of matter power spectrum on small scales

"Damping" of Matter Power Spectrum

[Sigurdson, Kamionkowski 2004]

■ Matter Power spectrum

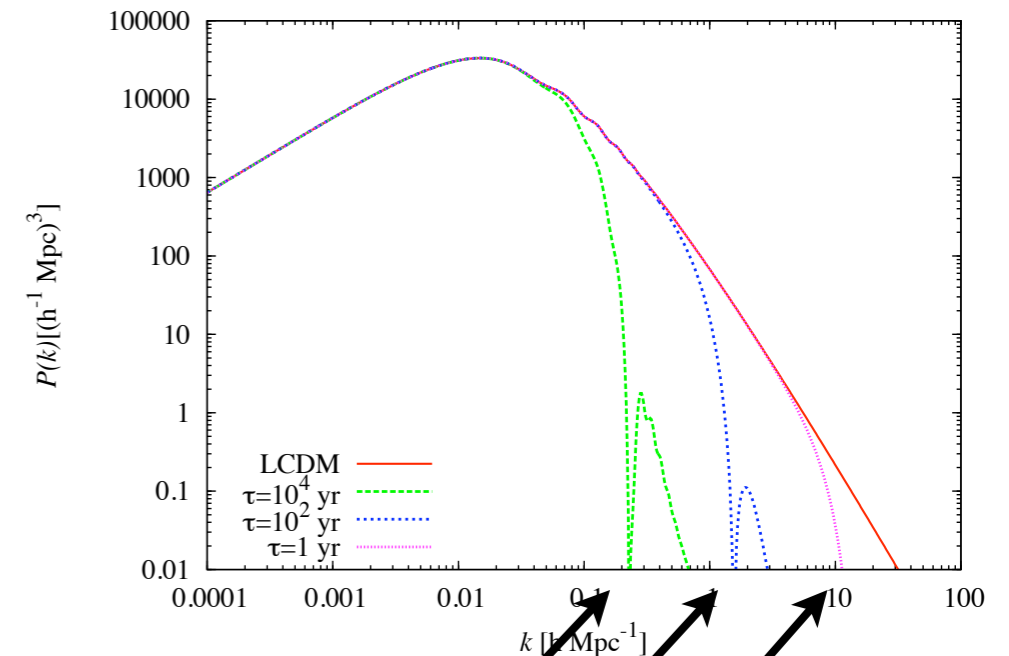- Power on smaller scales is suppressed due to "acoustic damping"

- Fluctuations of the scale which enters the horizon **before** the decay

  ➤ Acoustic oscillation

- Fluctuations of the scale which enters the horizon **after** the decay
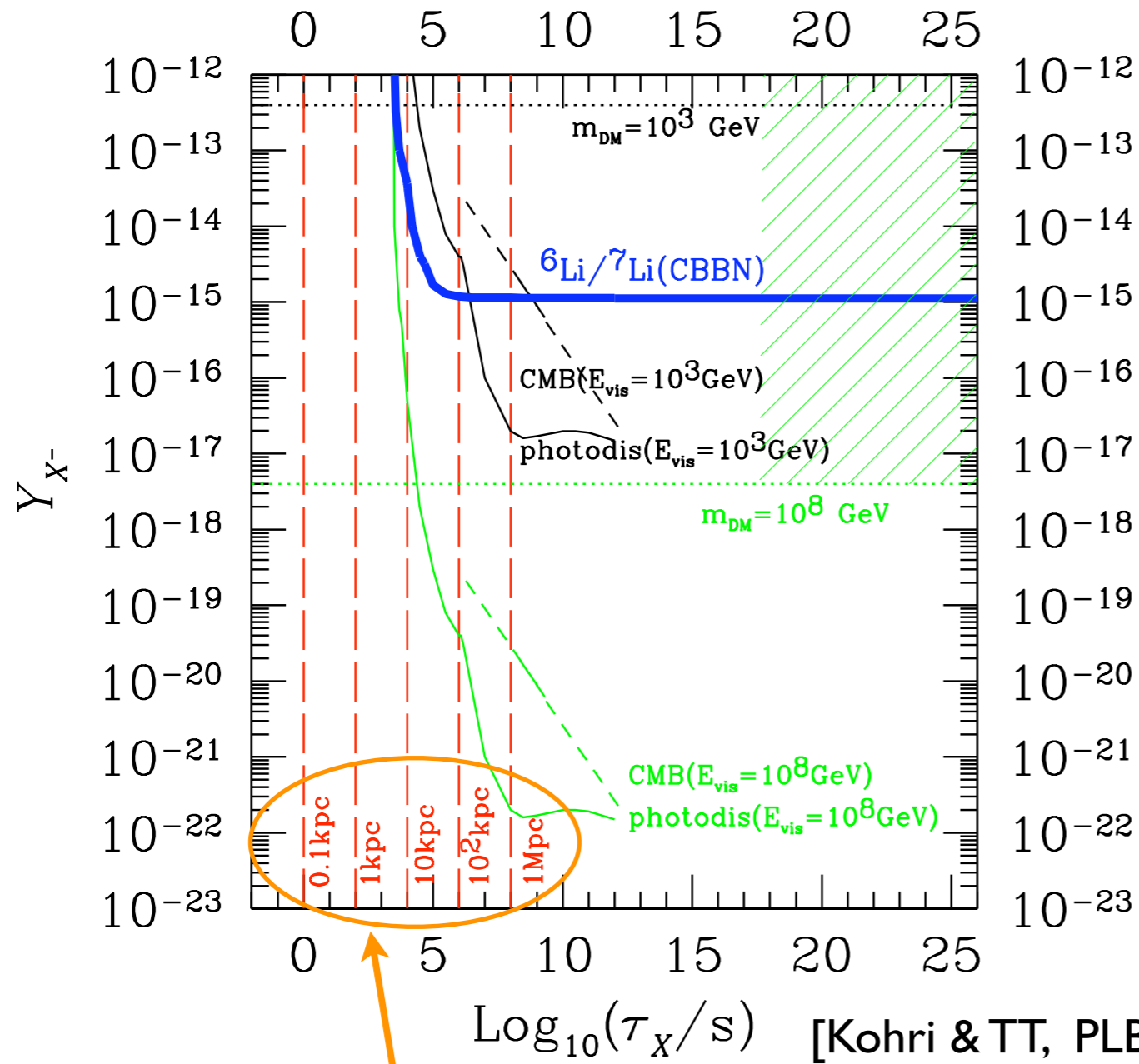
  ➤ Same as the neutral DM case (no damping)

Damping scale:

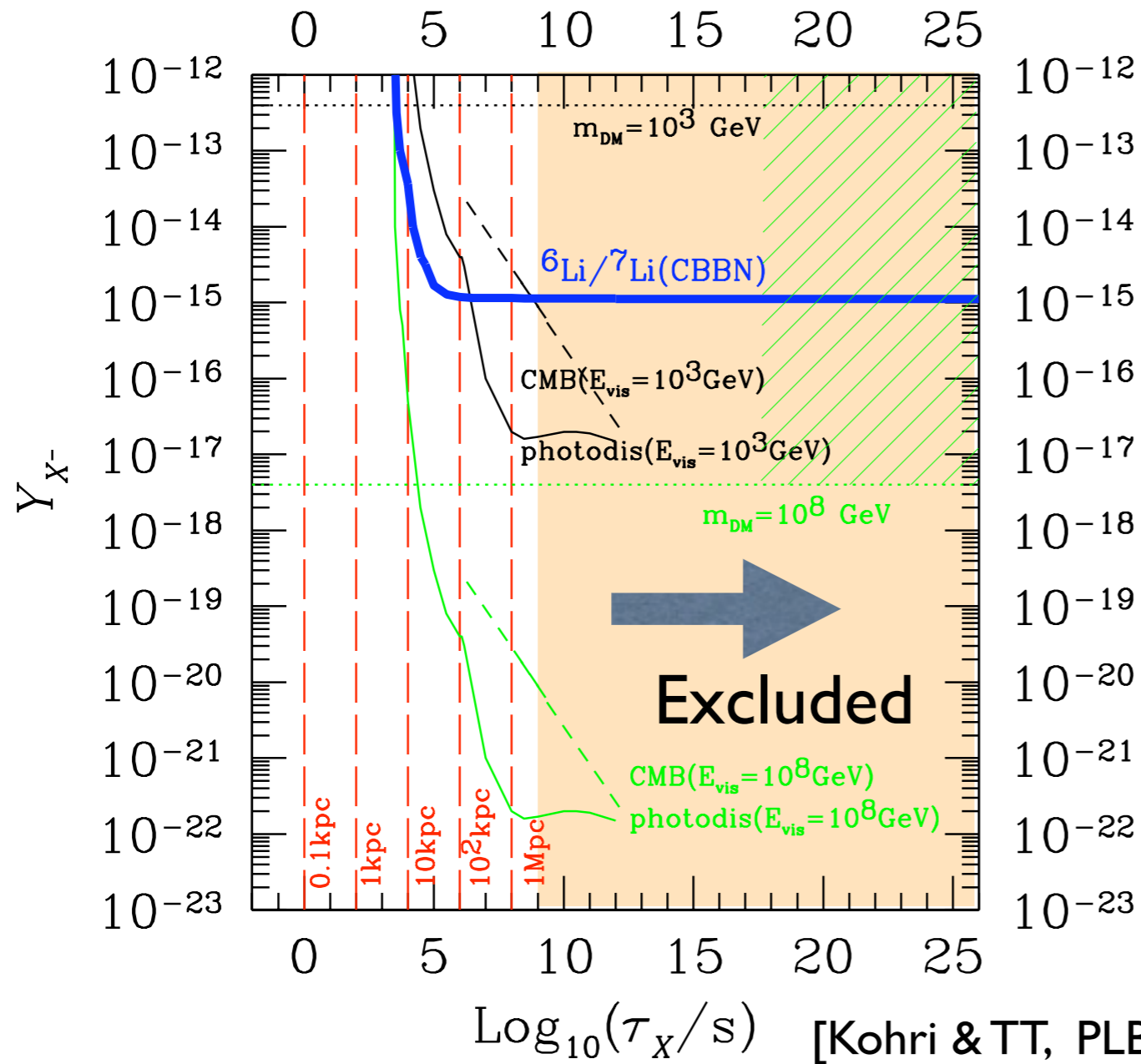$$k_X \equiv aH|_{t=\tau_X} \quad \longrightarrow \quad k_X \simeq 10^4 \sqrt{\frac{\sec}{\tau_X}} \, \mathrm{Mpc}^{-1}.$$

Constraint on CHAMP

(Density of CHAMPs is fixed to give the present DM density if they are stable in this figure.)

[Kohri & TT, PLB, 0909.4601]

Damping scales of matter power spectrum

Constraint on CHAMP

[Kohri & TT, PLB, 0909.4601]
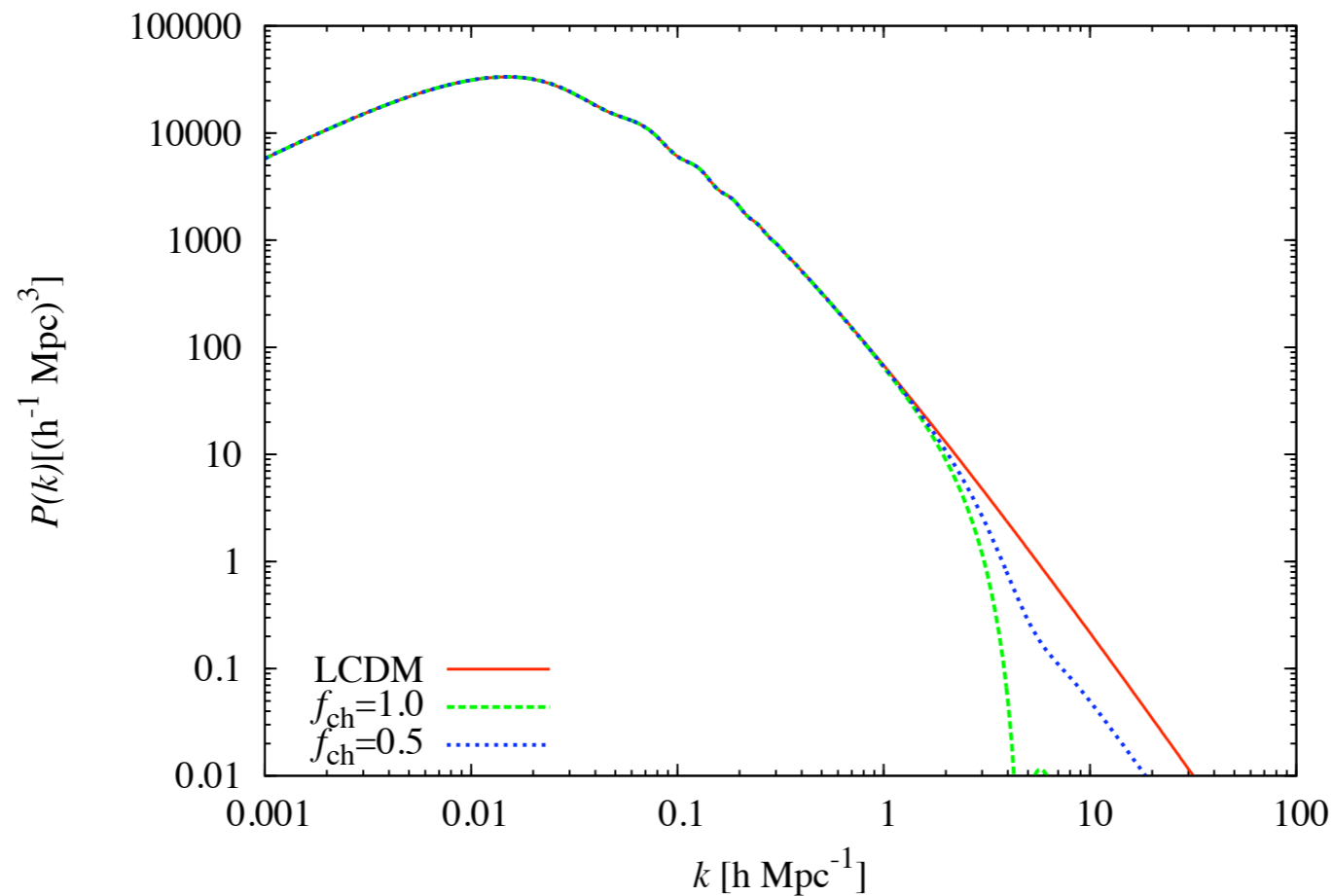
(Future observations of QSO-galaxy strong lens system can probe ~ O(1) kpc)   [Hisano, Inoue, TT 2006]

- Smaller scale structure is observed, a severer constraint on the lifetime would be obtained.

Mixed scenario (neutral DM + CHAMP)

- In some models, neutral DM and CHAMPs coexist.

- Parametrize the fraction of champ as: $f_{\mathrm{ch}} = \dfrac{n_{\mathrm{ch}}}{n_\chi}$ $\left(\dfrac{\Delta m}{m} \ll 1 \right)$

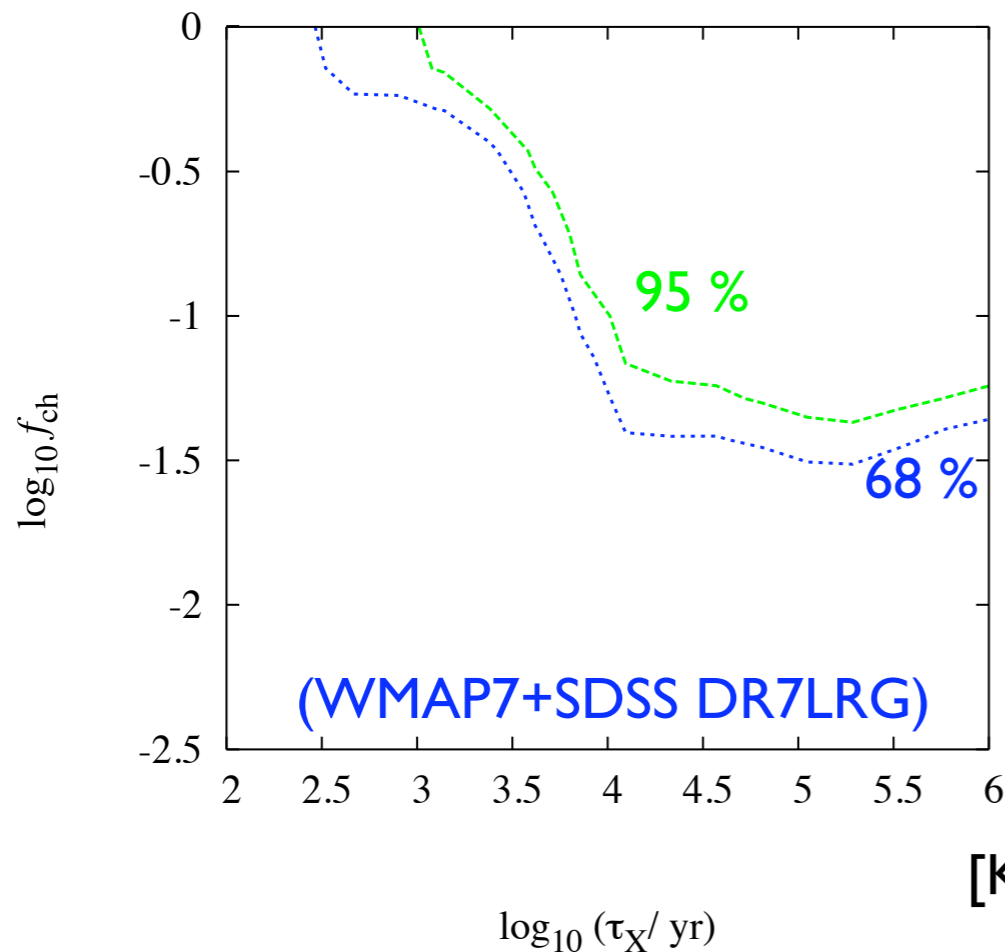- Smaller fraction of CHAMP suppresses the matter power less.

Mixed scenario (neutral DM + CHAMP)

- In some models, neutral DM and CHAMPs coexist.

- Parametrize the fraction of champ as: $f_{\rm ch} = \dfrac{n_{\rm ch}}{n_\chi}$ $\left(\frac{\Delta m}{m} \ll 1 \right)$

■ **Constraint on the fraction and the life time of CHAMP**

95 %

68 %

(WMAP7+SDSS DR7LRG)

$\log_{10} f_{\rm ch}$

$\log_{10} (\tau_{\rm X}/\,{\rm yr})$

➡ Some fraction would be allowed even if CHAMPs are relatively long-lived (from LSS).

Summary

- (Most) negative CHAMPs are captured by He4.

- CHAMPs significantly affect density fluctuations.

- If CHAMPs are (very) long-lived, the structure of the Universe is "suppressed" on smaller scales.

- If further smaller scale structure is observed, a severer constraint on CHAMP lifetime is obtained.

- Mixed scenario (neutral DM+CHAMPs) can also be constrained by cosmological data.