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Strongly Coupled Cosmologies

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Abstract

Models including an energy transfer from CDM to DE were widely considered in the literature, namely to allow DE a significant high–z density. Strongly Coupled cosmologies assume a much larger coupling between DE and CDM, together with an uncoupled warm DM component, the role of CDM being mostly restricted to radiative eras. This allows us to preserve small scale fluctuations even if the warm particle is quite light, $O(100$ eV). Linear theory shows full agreement between these cosmologies and ΛCDM on supergalactic scales; e.g., CMB spectra are identical. Simultaneously, simulations show that they ease problems related to the properties of MW satellites and cores in dwarfs. While opening new perspectives on early black hole formation and possibly leading towards unificating DE and inflationary fields, **the critical prediction of SC cosmologies is a sterile neutrino or gravitino of mass ~ 100 eV.**

1. Introduction

We discuss a new family of models, starting from their features in the radiative eras. In such epochs, they are chacterized by two extra components, in top of the *usual* radiative ones: a scalar field Φ and a *peculiar* CDM (Cold Dark Matter) component, with energy densities and pressures ρ_Φ & ρ_c and p_ϕ & p_c, respectively. As we assume $\rho_\Phi \simeq p_\Phi \simeq \dot\Phi^2/2a^2$ and being $p_c \simeq 0$, it should be $\rho_\Phi \propto a^{-6}$, $\rho_c \propto a^{-3}$. It is not so, because the models assume an energy flow from CDM to the field, due to a Yukawa–like interaction Lagrangian

$$\mathcal{L}_I = -\mu f(\Phi/m)\bar\psi\psi \; , \tag{1}$$

ψ being the CDM spinor field. If

$$f = \exp(-\Phi/m) \tag{2}$$

with $m = m_p/b$, there exists a solution with

$$\rho_c \propto f(\Phi/m)a^{-3} \tag{3}$$

$$\Phi = m \ln(\tau/\tau_r) \tag{4}$$

being an attractor for the system made by the equations of motions of Φ and ψ (m_p: the Planck mass, τ_r: a generic reference conformal time). Eqs. (3) and (4) imply that $\rho_c \propto \rho_\Phi \propto a^{-4}$, so that CDM and the field dilute at the same rate of the radiative components. On the attractor, the constant early state parameters Ω_c and Ω_Φ (CDM and Φ, respectively) shall then read

$$\Omega_c = 1/(2\beta^2) \; , \quad \Omega_\Phi = 1/(4\beta^2) \tag{5}$$

with

$$\beta^2 = (3/16\pi)b^2 \; . \tag{6}$$

What happens is that the flow of energy from CDM to the field fastens (slows down) the dilution of CDM (Φ); accordingly, the scale factor exponents change: for the former component from -3 to -4, for the latter one from -6 to -4 . The notable point is that this behavior occurs along an attractor: if starting from generic initial conditions, with Ω_Φ and/or Ω_c different from eq. (5), the e.o.m. rebuild the conditions (5), also suitably synchronizing the rates of energy transfer and cosmic expansion. For a detailed proof, see Paper A [1], wherefrom Figure 1 is taken.

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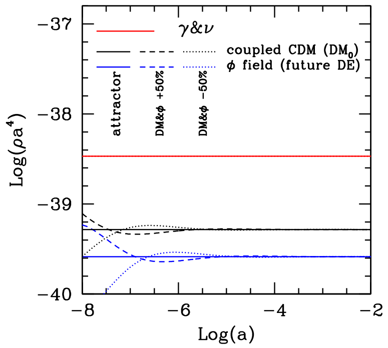

Figure 1: Starting from generic initial conditions, the attractor is soon recovered: both ρ_c and Φ were initially "wrong" or, equivalently, the rate of expansion was "wrong". Here $\beta = 2.8$, so that the overall density of CDM and Φ is smaller than half extra ν species.

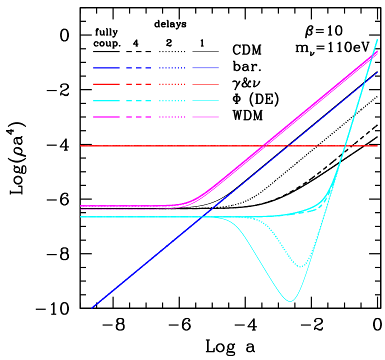

Figure 2: Background evolution. WDM derelativisation breaks the former conformal invariance, allowed by CDM–Φ coupling. Different curves yield models where coupling either persists down to $z = 0$ or fades earlier (see text). The w (field state parameter) shift, from +1 to -1 is tuned to account for a present DE density parameter $\Omega_d = 0.7$.

These models are then characterized by three phases: (B) before (the radiative eras); (D) during (them); (A) after (matter–radiation equality).

The stages (D) and (A) were treated both in [1] and in a further Paper B [2], focused on fluctuation evolution, finding that, from the above attractor, the models naturally evolve towards a picture consistent with today's Universe. Besides of baryons this requires a WDM (Warm Dark Matter) component (see, e.g., [3]).

More in detail: Present epoch DM (Dark Matter) is mostly warm, Φ has turned into quintessential DE (Dark Energy), while CDM has an almost negligible density, although playing a basic ancillary role. In Figure 2 we show the background evolution in some spatially flat models with $\Omega_d = 0.7$, $\Omega_b = 0.045$, $h = 0.685$, in agreement with Planck results. Model dynamics is somehow reminiscent of the coupled DE option, studied by many authors [4]. Here, however, coupling plays its key role through radiative eras. Switching it off (or letting $m \to \infty$) after WDM derelativized, could even ease the fit with data. Besides of a coupling persistent down to $z = 0$, we therefore consider the cases of β fading exponentially at $z = 10^{-D} z_{der}$ (here we assume WDM to be a sterile ν with a former thermal distribution; the redshift z_{der} is when $m_\nu = T_\nu$; the exponent D is dubbed *delay*).

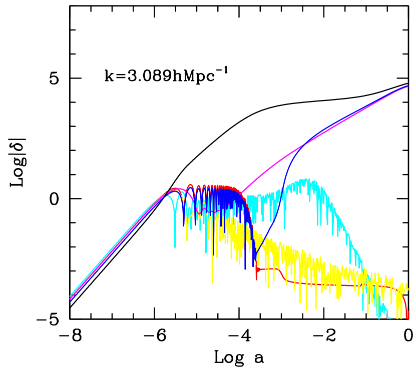

Figure 3: Linear fluctuation evolution in a model with $D = 2$. The wave number considered corresponds to a scale of $8\,h^{-1}$Mpc. Colors as in Figure 2. The scale in ordinate is arbitrary (but see text).

2. Fluctuation evolution

In Paper B it is widely discussed how the public program CMBFAST (or, similarly, CAMB) is to be modified to follow fluctuation evolution in these models. Changes involve also out–of–horizon initial conditions.

A notable feature of these models is that there is no cut in the transfer function of WDM. The point is that, in the non–relativistic regime, the presence of a CDM–Φ coupling yields an increase of the effective self–gravity of CDM, as though

$$G \to G^* = G(1 + 4\beta^2/3) \tag{7}$$

(see [5]). The interaction of CDM with other components is set by G, the G–shift concerning just CDM–CDM gravity. When fluctuations reach the horizon, the CDM density parameter is $O(\beta^{-2})$. However, as its self interaction is boosted by a factor $O(\beta^2)$, it evolves as though $\Omega_c \sim 2/3$, indipendently of β.

The other, velocity dependent, changes in CDM dynamics, not discussed here, do not modify the fact that the growth of CDM fluctuations is never dominated by the baryon–radiation plasma. Accordingly, while baryons and radiation yield sound waves, and collisionless components suffer free streaming, the CDM fluctuations δ_c suffer no *Meszaros*'s effect and steadily grow.