THE MATTER POWER SPECTRUM AS A TOOL TO
DISCRIMINATE DARK MATTER-DARK ENERGY
INTERACTIONS

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The coincidence problem of late cosmic acceleration gets significantly alleviated when a suitable interaction between matter and dark energy, either of phantom type or not, enters the picture. We show that a class of models featuring this interaction fares rather well when contrasted with the anisotropies of the CMBR and the matter power spectrum. The latter test is very sensible to the interaction and may be used to discriminate between different models.

Keywords: Cosmology, Cosmic microwave background, Matter power spectrum

1. Introduction

In order to account for the current stage of cosmic accelerated expansion many dark energy candidates have been invoked up to now. By far, the simplest one is the cosmological constant. However, while models based on it seem to fare rather well when confronted with the observational data they face two severe difficulties on the theoretical side: (i) its measured value is about 120 orders of magnitude lower than the one predicted by QFT, and (ii) the “coincidence problem”, namely, why are the densities of matter and dark energy of precisely the same order today. This is why dynamic dark energy models, not based on the zero-point energy of vacuum, have been proposed in the recent years.

There is a particular class of models in which the dark energy interacts with the dark matter (assumed non-relativistic) so that neither of them conserve separately.¹ Here, we consider a specific model within this class with the interesting feature that it evades the first difficulty (the dark energy no longer relies on the quantum vacuum) and considerable alleviates the second one.² In this model the balance equations for the cold dark matter and dark energy are \( \dot{\rho}_c + 3H\rho_c = Q \), and \( \dot{\rho}_x + 3H(1+w_x)\rho_x = -Q \), respectively, with \( Q = 3Hc^2(\rho_c + \rho_x) \), where \( c^2 \) is a dimensionless, constant parameter that measures the strength of the interaction.
Thus, the ratio, $\rho_c/\rho_x$, between the aforesaid energy densities is found to evolve from a constant, but unstable value, at early times to a lower, constant and stable value at late times\(^2\) -see also Fig. 2 of\(^3\).

The target of short Communication is to use the cosmic microwave background radiation (CMBR) and large scale structure to constrain this model (for full accounts, see Refs.\(^3\) and,\(^4\) respectively). As we shall see, the latter can be used as a tool to discriminate between interacting and non-interacting models as well as to discriminate between different interactions. The SNIa data practically do not constrain the model as the $c^2$ shows large degeneracy -see Fig. 3 of\(^3\).

2. Constraints from the CMBR

Upon exploring the whole parameter space and using the the first year data provided by the WMAP satellite we found that the parameters of the model fall into the following ranges:\(^3\) $\Omega_x = 0.43 \pm 0.12$, $\Omega_b = 0.08 \pm 0.01$, $n_s = 0.98 \pm 0.02$, $H_0 = 56 \pm 4$ km/s/Mpc. As for the equation of state parameter of the dark energy only an upper bound can be set, $w_x \leq -0.86$, while the preferred value of $c^2$ is $5 \times 10^{-3}$ but it still exhibits degeneration. The Bayesian Information Criteria\(^5\) allows to show that this extra parameter fits the data better than models with no interaction. After combining the WMAP and the SNIa data of Riess \textit{et al.}, $\Omega_x$ goes up to 0.68 and $c^2$ increases to $6.3 \times 10^{-3}$.

3. Constraints from the matter power spectrum

For the sake of comparison, we assume that in interacting and non-interacting models density perturbations have the same amplitude when they come within the horizon. For non-interacting models, this prescription leads to the Harrison-Zeldovich power spectrum, $P(k) \sim k^{-n}$ with $n_s = 1$ on large scales. During the matter epoch, if density perturbations and the background energy density evolve as $\delta_c \sim a^{p/2}$ and $\rho_c \sim a^{-\alpha}$, respectively, we have that $P(k) \sim k^{-3+2p/(\alpha-2)}$. During the matter-dominated era, $p \approx 2(\alpha - 2) + 0.6c^2$ and the slope of the scale-invariant spectrum is $n_s = 1$ with a very weak dependence on the interaction.

The slope of the matter power spectrum on scales $k \geq k_{eq}$ is determined by the growth rate of subhorizon sized matter perturbations during radiation domination. If a mode that crosses the horizon before matter-radiation equality grows as $\delta_c \sim \tau^{q/2}$ during the radiation dominated era, then the amplitude of the power spectrum today would be $P(k) = P(k_{eq})(k_{eq}/k)^{-3+q}$. For cold dark matter models, dark matter perturbations experience only logarithm growth, so models with less growth will have less power at small scales as do, for instance, mixed dark matter models\(^7\) which contain a significant fraction of massive neutrinos. Figs. 2(a) and 2(b) of Ref.\(^4\) depicts the power spectrum for different interacting models and mixed dark matter models, respectively. With increasing $c^2$ or $m_\nu$, the matter power spectrum exhibits larger oscillations as a consequence to the increased ratio of baryons to dark matter. Figs. 2(c) and 2(d), of the same reference, show that the slope of $P(k)$ decreases
with increasing $c^2$ and $m_{\nu}$. In both cases the behavior is rather similar. Therefore, observations of large scale structure that constrain the neutrino mass also serve to set constraints on the strength of the dark matter-dark energy interaction during the radiation-dominated era and discriminate interacting from non-interacting models. Further, there is an important difference between interacting and mixed models. In the former the maximum of $P(k)$ shifts to the left for increasing $c^2$, in the latter the maximum does not shifts by increasing the neutrino mass. This can be understood as follows. At larger $c^2$, the dark matter density becomes smaller at any given redshift and the matter-radiation equality is delayed. This does not occur with massive neutrinos where the matter-radiation equality takes place always at the same redshift.

Since the interaction affects the slope of $P(k)$, we resorted to the 2dFRGS data\(^8\) to constrain $c^2$. We used a Monte Carlo Markov chain to run the CMBFAST code, adapted to solve the interacting model. We ran the chain for $10^5$ models, that were sufficient to reach convergence. Fig. 4 of Ref.\(^4\) depicts the joint confidence contours at the 68%, 95%, and 99% level for pairs of parameters after marginalizing over the rest. The $1\sigma$ confidence levels and upper limits for the model parameters resulted to be: $c^2 \leq 3 \times 10^{-3}$, $\Omega_c h^2 = 0.1 \pm 0.02$, $H_0 = 83^{+6}_{-10}$ km/s/Mpc. The data are very insensitive to $w_x$ and baryon fraction. It is only fair to say that quintessence non-interacting models are also compatible with the 2dFGRS data at $1\sigma$ level.

4. Concluding remarks

In summary, (i) the interacting dark matter-dark energy model of Ref.\(^2\) significantly alleviates the coincidence problem and is consistent with the observational data, $c^2 < 10^{-2}$ at 99% confidence level. (ii) $k_{eq}$ is sensitive to the $c^2$ value and decreases with increasing $c^2$. (iii) The slope of the matter power spectrum is also affected by the interaction -the stronger the interaction, the more negative the slope. This may be of help to determine $c^2$.

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