Quintessence From a Decaying Dark Matter

Houri Ziaeepour
Mullard Space Science Laboratory,
Holmbury St. Mary, Dorking, Surrey RH5 6NT, UK.
Email: hz@mssl.ucl.ac.uk

Abstract

It is a known fact that a quintessence model with \( w_q < -1 \) fits the publicly available Super Nova (SN) type Ia data better than a model with cosmological constant or \( w_q > -1 \). Two types of models have this property: Scalar fields with unconventional kinetic term and models with cosmological constant and a slowly decaying Cold Dark Matter (CDM). In this work we investigate the possibility of replacing the cosmological constant in the latter models with gradual condensation of a scalar field produced during the decay of the CDM and present some preliminary results. The advantage of this class of models to the ordinary quintessence is that the evolution of the dark energy and CDM are correlated and cosmological coincidence problem is solved or at least reduced to the fine tuning of the coupling between decaying CDM and quintessence field i.e the Hierarchy problem. Here we show that for part of the parameter space these models are consistent with present estimation of cosmological parameters.

1 Motivations and Model

The mystery of the Dark Energy / Cosmological Constant persists despite great efforts of particle physicists and cosmologists to find a convincing solution. Since the famous article by S. Weinberg, it is well known that candidate models should not only explain the smallness of the Cosmological Constant, if it is somehow related to Quantum Gravity, but also what is called the coincidence problem i.e. why does Dark Energy become dominant quite late in the history of the Universe? Models inspired by String Theory like 4-form gauge models can describe the smallness of the Dark Energy but not the coincidence problem. Anthropic models explain the latter problem but it is very difficult to find a natural and convincing particle physics model for them. The same problem somehow exists for the alternative to a Cosmological Constant i.e. for Quintessence Models. Even if tracker solutions make the model not very sensitive to the initial conditions, some fine tuning of the slope of the potential is necessary. It is also an open question if both inflation and quintessence behavior can be explained by the same field and if not, what is their relation and which type of particle physics can provide both of them specially in a natural way. Here we suggest an alternative to a primordial quintessence field. There are at least two motivations for the existence of a Decaying Dark Matter (DDM). If R-parity in SUSY models is not strictly conserved, the LSP which is one of the best candidates of DM can decay to Standard Model particles. Violation of this symmetry is one of the many ways for providing neutrinos with very small mass and large mixing angle. Another motivation is the search for sources of Ultra High Energy Cosmic Rays (UHECRs). In this case, DDM must be composed of ultra heavy particles with \( M_{dm} \sim 10^{22} - 10^{25} eV \). In a recent work we have shown that the lifetime of UHDM (Ultra Heavy Dark Matter) can be relatively short, i.e. \( \tau \sim 10 - 100 \tau_0 \) where \( \tau_0 \) is the age of the Universe \[\text{astro-ph/0001137}\]. If a very small fraction of the mass of primary DDM particles changes to a scalar field with proper self interaction potential, the gradual condensation of this field at late time behaves like a quintessential matter. The advantage of this model to others is that late time yield of this type of energy and its correlation with the amount of Dark Matter comes up naturally and the dominance of one with respect to the other at each epoch is automatically explained.

In the present work we only study the plausibility of this model. We postpone a more detailed study to elsewhere. The natural choice of cosmological parameters for this model is an initial \( \rho_{dm}(t_0) \approx \rho_c(t_0) - \rho_{hot}(t_0) \) where \( t_0 \) is an early time in the history of the Universe. For the result presented here we consider it to be the time of decoupling of CMB photons; \( \rho_{hot} = \rho_\gamma + \rho_\nu \). The remnants of the decay else than
quintessence field mainly consist of very energetic particles which will contribute to the yield of Hot Dark Matter. There is strict constraint on the amount of the latter from cosmological observations and the model must be consistent with observations. However, one should not forget that massive particles like proton/antiproton and even electrons become colder with the expansion of the Universe and at some point they are not any more considered as hot. In fact it can be shown that the whole effect on the equation of state of the Universe is the reduction of the effective $w_q$ of the Cosmological Constant or a quintessence matter.

We summarize our preliminary results in two following figures. The first figure shows $\chi^2$ of the fit of Quintessence Models on the publicly available Super-Novae Ia data. Models with $w_q < -1$ fit the data better than $w_q \geq -1$.

The second figure shows the evolution of density of various types of matter from decoupling of CMB photons to today for a typical selection of parameters. In one hand it shows that it is possible to obtain the present “equivalent” value of cosmological parameters without fine tuning of the suggested model. Another conclusion is that the appearance of cosmological parameters as measured in the local Universe is very recent i.e. the measurement of cosmological parameters at high redshift permits to distinguish between this model and other quintessence models.

2 Discussion and Perspectives

It is evident that the model presented here can not be believed before investigating many issues. The first and one of the most important ones is the condensation of the scalar field. One should determine the mass and the form of the potential and find the region of the parameter space that in a natural way can lead to a late condensation. The other issue is that the value of $w_q$ for this type of matter can not be constant. This can affect the evolution of halos, star formation rate, ionization of IGM etc. and can be used to verify the model.
Figure 2: Evolution of Total, CDM, Hot and Quintessence matter density with redshift (magenta curves). It corresponds to a flat cosmology with $\tau_{dm} = 1.2\tau_0$ where $\tau_0$ is the age of the Universe, $w_q = -0.9$ and $f = 10^{-4}$ where $f$ is the fraction in energy of the mass of DDM that condensates as a quintessence field. For each density the corresponding quantity for a “Standard Cosmological” model with $\Omega_{dm} = 0.3$ and $\Omega_\Lambda = 0.7$ with only CMB photons and primordial neutrinos as Hot Matter is shown (green curves).