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Growth of perturbations in dark energy cosmologies

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In the framework of the spherical collapse model, we study the non-linear growth of cosmic structures in the minimally and non-minimally coupled quintessence cosmologies. In non-minimally coupled quintessence models there is a non-minimally coupling between the scalar field and the Ricci scalar. We first investigate the background Hubble expansion in these models and then follow the models in perturbation levels. We see that the equation of state of dark energy in the case of non-minimally quintessence model can enter the phantom regime of expansion ($w_{de} < -1$) while in the minimally coupled quintessence models the equation of state is remaining in quintessence regimes $w_{de} > -1$. On of the most important features of non-minimally coupled quintessence models is that the gravitational coupling G is no longer constant and varies with cosmic time.
However, for a minimally quintessence models the gravitational coupling is constant, as defined in GR limit as G_N. Regarding to non-minimally quintessence models, the definition of gravitational coupling G is basically different if we assume the perturbations of scalar fields or not. Notice that the perturbations of scalar fields can be assumed due to non-minimally coupling between scalar fields and Ricci scalar. We show that the scalar field perturbations have a significant impact on the evolution of gravitational coupling G. Since we have two different relations for effective gravitational coupling G_{eff} according to the fact that the scalar field is clustered or not, we expect to see a different evolution for the growth of matter perturbations in the case of clustered non-minimally quintessence models compare to homogeneous quintessence models. We also compare the evolution of matter perturbations in both clustered and homogeneous non-minimally quintessence models with that of in minimally quintessence models in which the gravitational coupling G is constant.

In linear regime of the growth of matter perturbations, we show that the quintessence term causes the decrements of the growth of structures at low redshifts ($z < 1$). On the other hand at high redshifts ($z > 1$) In particular, we will see that the growth factor of matter perturbations in non-minimally coupled quintessence models with positive (negative) coupling parameter is lower (higher) than that obtained in minimally coupled quintessence Universe. Moreover, the perturbations of scalar fields causes that the growth factor is decreasing compare to homogeneous cases.

In non-linear regime for the evolution of matter perturbations, we will show that the spherical collapse parameters δ_c and Δ_{vir} are strongly affected by perturbation of scalar field and moreover these quantities have different evolution for minimally, clustered non-minimally and homogeneous non-minimally quintessence models.
Notice that the linear overdensity parameter δ_c is a crucial parameter in Press Schechter formalism to calculate the abundance of virialized halos. Also the size of virialized halos can be obtained by using the virial overdensity Δ_{vir}.
As an important result, we show that in all quintessence models, minimally or non-minimally coupled, the quantities δ_c and Δ_{vir} reach to 1.686 and 178, respectively. This result indicates that the early matter dominated Universe should be recovered in quintessence cosmological models, as expected.
We finally investigate the number count of massive halos for minimally and non-minimally coupled quintessence models. In prior case, the model gives an excess of
virialized halos with respect to the concordance ΛCDM model. While in the later case we show that the number of halos is higher (lower) that that of obtained in concordance ΛCDM scenario when the coupling parameter between scalar field and gravity is negative (positive).

Summary

In the standard model of cosmology, the accelerated expansion of the Universe is interpreted by taking the cosmological constant term into account. However, it is still unclear the true origin of this observational fact. Hence it is interesting to explore some alternatives models to the simplest scenario, in particular by considering a more general framework where scalar field models are responsible for the accelerated expansion of the Universe. When these models are directly coupled to the gravity they dubbed non-minimally quintessence models otherwise they are called minimally quintessence models. In non-minimally quintessence models the Newtonian gravitational constant is no longer constant and varies with cosmic time. In this work, by working in the framework of spherical collapse model, we show the effects of scalar field perturbation on the growth factor of cosmic structures and also the parameters of spherical collapse model. We also calculate the influence of scalar field perturbations on the mass function and number count of massive halos in the context of Press-Schechter formalism.

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