Author: Hardeman, Sjoerd Reimer
Title: Non-decoupling of heavy scalars in cosmology
Date: 2012-06-08

CHAPTER 6

Conclusions

In studying low energy physics, it is usually assumed that the high energy physics is decoupled and does not affect the low energy physics. Even though gravity is always there, gravitational corrections give rise to Planck suppressed operators, its effetcs are usually assumed to be negligible. This assumption seems reasonable at first sight. The Planck scale is huge compared to any scale that is relevant for almost the complete history of the universe, including the inflationary epoch. Planck suppressed operators will thus be heavily suppressed for all relevant physics.

However, in the research presented in this thesis it is shown that this conclusion is drawn too hastily. As shown in chapter 2, decoupling is non-trivial in supergravity, the only consistent framework to study gravitational effects in field theory. Sectors that do not decouple participate in the dynamics and, therefore, strongly suppressed operators can still have a profound effect by changing the vacuum structure.

In chapter 3 a case study of a supergravity theory is presented, where a vacuum energy expectation value contribution is generated by a gravitational minimally coupled sector that breaks supersymmetry. It is shown that, along with generating this nonzero VEV, the coupling has the effect of changing the stability properties of the extrema of the potential. Local minima will be destabilised for an arbitrary amount of uplifting. Similar in spirit, local maxima — that are stable in Anti-de Sitter due to the Breitenlohner-Freedman bound (eq. 1.53) — can change the sign of its second derivative and become stable after uplifting. Although these vacua seem problematic from a phenomenological point of view, they are very interesting from a conceptual point of view.

Chapters 4 and 5 deal in detail with the case of non-decoupled sectors. Instead of supergravity, the derivation is done in the more general framework of the nonlinear sigma model. In chapter 4 the framework for calculating the properties of a field evolving along a trajectory in field space is introduced. The trajectory is calculated, and it is shown that for general trajectories the adiabatic approximation does not hold. The general equations for the perturbation theory are calculated. Then, the behaviour in the Minkowski limit is studied, and it is shown that the requirement on a Kähler function derived in chapter 2 is indeed the sufficient condition for a sector to decouple.

In chapter 5 this framework is applied to inflation. As the relevant physics is already evident in the minimal extension of a two-field model, this model is presented. It is shown that it is possible, in the case of a large mass hierarchy between the fields, to obtain an effective single-field theory. However, this single field theory is characterised by a speed of sound that is less than the speed of light, with its value determined by the turn rate divided by the mass of the heavy direction. It is shown that this effective field theory agrees, in the large hierarchy limit, with the two-field calculation. The effect of this time dependent speed of sound is that the power spectrum develops a scale dependence, as oscillations in the power spectrum are formed when the speed of sound changes. Furthermore, a reduced speed of sound is known to produce equilateral nongaussianities.

What remains to be studied are non-geodesic trajectories in supergravity. As discussed in chapter 4, basically all supergravity models of the form

$$\begin{aligned} G(H,\bar{H},L,\bar{L}) = {} & f_1(L,\bar{L}) + (H-H_0)^2 f_2(H,\bar{H},L,\bar{L}) \\ & + (\bar{H}-\bar{H}_0)^2 f_3(H,\bar{H},L,\bar{L}) + (H-H_0)(\bar{H}-\bar{H}_0) f_4(H,\bar{H},L,\bar{L}) \end{aligned} \tag{6.1}$$

for arbitrary functions f_1, f_2, f_3 and f_4 can be consistently decoupled along curves of $H = H_0$, where H_0 is an extremum of the H-fields, and thus allow for geodesic trajectory. However, a parameter Δ was introduced, showing that often the evolution of fields is such that fields evolve *not* along minima of the potential. It is exactly this reason that causes the KKLT model to receive large corrections, as calculated in the conclusion of chapter 2: minima in the truncated theory are *not* minima in the full theory. Thus, consistent decoupling fails because using the truncated theory causes one to find the wrong minimum. In chapter 5 it is shown that properly integrating out fields can lead to an effective theory that differs significantly from a theory obtained by naïve truncation. These differences in supergravity language would relate Δ, the deviation from the minimum, and thus β^{-1}, the speed of sound of the effective theory, to the parameter δ of (eq. 2.26), which signifies the difference between the proper calculation of the supergravity minimum and the supergravity minimum that one obtains from an effective theory obtained by truncating the heavy physics.

To conclude, non-decoupling of heavy scalars is a general phenomenon in the physics of evolving vacua. Therefore, one cannot expect heavy physics to be decoupled during the cosmological evolution. Since these effects do not decouple, cosmology — and in particular inflation — is a powerful probe to study these heavy degrees of freedom. It can be expected that these heavy degrees of freedom left signatures in the power spectrum and bispectrum. In this light, the improved measurement of the Planck mission will be very relevant.