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6 Conclusions

The research performed in the last four years during my PhD has been focused on several aspects of the early universe, but they all have one aspect in common: the effect of additional heavy sectors on the inflationary dynamics. Together with my collaborators, we have explored theoretical and phenomenological aspects of the embedding of inflation in more complete theories, where the presence of heavy degrees of freedom may leave detectable traces in the data. Besides, it is reasonable to contemplate the possibility of having the inflaton coupled to another sector, such as the Standard Model, or a heavy supersymmetric sector, which might be modifying the basic predictions and leaving hints of its presence.

It is common in the literature to assume that very heavy degrees of freedom can be integrated out without further consequences. Fortunately, the effect of these heavy fields is often negligible and the naive effective theory is justified. However, this is not always the case, and it is important to provide a robust theoretical framework which accounts for this effect. Moreover, in some cases a graceful realisation of inflation can be completely ruined by the presence of instabilities in the additional sector that we might just have forgotten about.

In chapter 2 we have computed the change in the CMB power spectrum and primordial bispectrum due to a transient reduction in the speed of sound, and we have seen that even reductions in the speed of sound as mild as a few percent are potentially detectable by current experiments. If the hints of anomalies seen in the CMB were confirmed by future data releases, it is important to understand if they have a primordial origin, and we have taken a step towards this goal. An essential point of the analysis performed in chapter 2 is that the fits to the data are consistently interpreted by an underlying theory. That is, rather than a blind search, we have searched in the region of parameters where the theory and its predictions are reliable. This was analysed in full detail in chapter 3 from different points of view: we checked several methods and approximations, we double-checked with different Boltzmann codes, and in this process we provided simpler methods to calculate the observational signatures given by effective theories of single-field inflation. This makes a difference with respect to other searches where more significant fits were found, however the underlying physical description breaks down in that regime, and then is practically equivalent to a blind search. On top of that, our predictions go beyond the power spectrum, and have a clearly correlated signal in the bispectrum. This means that if this physical mechanism is able to predict both signatures in good agreement with data, the significance of those predictions increases considerably.

In chapter 4 we considered the effects of an additional supersymmetric sector on supergravity realisations of inflation. We know that if supergravity is to provide an accurate framework for inflation, supersymmetry must be broken by some sector. We analysed the possibility that the inflaton itself is responsible for the breaking of supersymmetry. Naturally, for inflation to be realised, all the other fields must remain stable, and the experimental bounds on isocurvature modes and non-gaussianity constrain their masses and couplings. Since the masses of the supersymmetry preserving fields change during inflation, this imposes constraints on the inflationary regimes and on the parent supergravity. Once these constraints are satisfied, in addition we must face the usual problems of inflation with two fields, which have been explained in the previous chapters. Even more, in supergravity we need to deal with the η problem, and we have showed that in the context of sGoldstino inflation the only option is to fine-tune small field trajectories.

A generalisation from many different perspectives has been given in chapter 5. First of all, we considered the effect of an additional supersymmetric sector with an arbitrarily large number of fields, which allows us to describe it with statistical techniques. We also extended the analysis to more general Kähler functions and found physical scenarios in which those types of couplings naturally arise. More importantly, in previous studies the projection of the mass matrix along the sGoldstino direction was used to derive bounds that constrain inflation. Here we derived complementary bounds by projecting the mass matrix along the supersymmetric directions and imposing stability on the supersymmetric sector. These bounds not only contain the geometry of the field manifold, but also involve the statistical properties of the fermion mass spectrum.

On the other hand, we also stepped aside from the inflationary dynamics in chapter 5 and looked for the existence of stable de Sitter vacua, which supposedly describe the current vacuum in which we live, or alternatively, a hypothetical pre-inflationary stage. We have provided an explanation for an apparent contradiction regarding the stability of uplifted de Sitter vacua in Large

Volume Scenarios. While the uplifting of supersymmetric anti-de Sitter minima to stable de Sitter vacua happens with an exponentially suppressed probability (unless a large mass hierarchy is imposed), uplifting supersymmetric anti-de Sitter maxima results into stable de Sitter vacua with probability exponentially close to one. Moreover, the latter field configurations correspond to minima of the gravitino mass and are stable for arbitrarily large values of the uplifting. In this way, we have seen again that the presence of an additional supersymmetric sector has important consequences in the supergravity description, and we have derived complementary constraints for inflation and the existence of stable de Sitter vacua to those presented in chapter 4 and elsewhere in the literature.

I hope that the results presented in this thesis clarify the role of heavy fields in inflationary cosmology, and that they emphasise the importance of considering their presence in order to provide more consistent, accurate, and complete descriptions and predictions derived from our inflationary models. Future experiments will indeed be sensitive to the interactions of the inflaton with other sectors, and I will keep doing my best to develop new techniques and insights that might help in their detection.