Aspects of cosmic acceleration
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SUMMARY

In the last several decades our understanding of cosmology has evolved enormously. We now have a phenomenologically self-consistent model, known as the *Cosmological Standard Model* or *ΛCDM*, which is able to fit the huge amount of observational data with only a few free parameters. Modern cosmological research is now largely driven by the studies exploring the possible extensions of, and alternatives to, this standard picture. This is motivated, first of all, by a few theoretical puzzles in the Cosmological Standard Model. Indeed, while we can effectively describe the observational data, we are still lacking a consistent theoretical picture of the so-called dark sector, namely *dark energy*, which drives the present-day *cosmic acceleration*, and *dark matter*, which is responsible for the *Large Scale Structure* formation of the universe.

However, even if we dismiss these important puzzles, considering them to be too complicated to be tackled with our current knowledge, the study of alternative cosmological models is important given the fact that the quality of cosmological data is progressively evolving forward. This will give us a chance to test many of our current theoretical ideas and to find new directions to move forward. An informative example is the study of gravity. Cosmological observations are able to teach us a lot about the underlying theory of gravity and we might be able to find deviations from the General Theory of Relativity at cosmological scales. Therefore, while being largely motivated as an explanation of cosmic acceleration, such investigations of alternative gravity theories at cosmological scales can also be considered independently from the problem of cosmic acceleration.

With this big picture in mind, the topic of the present thesis is the investigation of phenomena beyond the cosmological standard model in various regimes of interest. Below we briefly summarize the content of the dissertation.

- Chapter 1 sets the stage for the entire thesis. In this chapter we introduce the main concepts of modern cosmology. We present a very short review of cosmological perturbation theory and discuss the essential observations. We also give short introductions to the topics of dynamical dark energy/quintessence, modifications of gravity and screening mechanisms.

- Chapter 2 is dedicated to a study of a new class of inflationary models known as cosmological *α-attractors*. We promote these models towards a unified framework describing both inflation and dark energy. We construct and study several phenomenologically rich models which are compatible with current observations. In the simplest models, with vanishing cosmological constant Λ, one has the tensor to scalar ratio $r = \frac{12\alpha}{N^2}$, with N being the number of e-folds till the end of inflation, and the asymptotic equation of state of dark energy $w = -1 + \frac{2}{9\alpha}$. For example, for a theoretically interesting model given by $\alpha = 7/3$ one finds $r \sim 10^{-2}$ and the asymptotic equation of state is $w \sim -0.9$. Future observations, including large-scale structure surveys as well as Cosmic Microwave Background B-mode polarization experiments will test these, as well as more general models presented here. We also discuss the gravitational reheating in models of quintessential inflation and argue that its investigation may be interesting from the point of view of inflationary cosmology. Such models require a much greater number of e-folds, and therefore predict a spectral index n_s that can exceed the value in more conventional models of inflationary α-attractors by about 0.006. This suggests a way to distinguish the conventional inflationary models from the models of quintessential inflation, even if the latter predict $w = -1$. This chapter is based on Ref. [64].

- The topic of Chapter 3 is the theory of massive bigravity, where one has two dynamical tensor degrees of freedom. We consider an interesting extension where both of the metrics are coupled to the matter sector, which is known as the *doubly-coupled bigravity*. The main aim of this chapter is the study of gravitational-wave propagation in this theory. We demonstrate that the bounds on the speed of gravitational waves imposed by the recent detection of gravitational waves emitted by a pair of merging neutron stars and their electromagnetic counterpart, events GW170817 and GRB170817A, strongly limit the viable solution space of the doubly-coupled models. We have shown that these bounds either force the two metrics to be proportional at the background level or the models to become singly-coupled (i.e. only one of the metrics to be coupled to the matter sector). The mentioned proportional background solutions are particularly interesting. Indeed, it is shown that they provide stable cosmological solutions with phenomenologies equivalent to that of ΛCDM at the background level and at the level of linear perturbations. The nonlinearities, on the other hand, are expected to show deviations from ΛCDM. This chapter is based on Ref. [65].

- In Chapter 4 we study the first cosmological implications of a novel massive gravity theory, recently proposed by Chamseddine and Mukhanov, known as the *mimetic theory of massive gravity*. This is a theory of ghost-free massive gravity, which additionally contains a so-called *mimetic dark matter* component. In an echo of other modified gravity theories, there are self-accelerating solutions which contain a ghost instability. In the ghost-free region of parameter space, the effect of the graviton mass on the cosmic expansion history amounts to an effective negative cosmological constant, a radiation component, and a negative curvature term. This allows us to place constraints on the model parameters—particularly the graviton mass—by insisting that the effective radiation and curvature terms be within observational bounds. The late-time acceleration must be accounted for by a separate positive cosmological constant or other dark energy sector. We impose further constraints at the level of perturbations by demanding linear stability. We comment on the possibility of distinguishing this theory from ΛCDM with current and future large-scale structure surveys. This chapter is based on Ref. [66].

- The final Chapter 5 is dedicated to the study of the effects of screening mechanisms in modified gravity on the dynamics of the spherical collapse of dark matter. In particular, we investigate the splashback scale in *symmetron modified gravity.* The splashback radius $r_{\rm sp}$ has been identified in cosmological N-body simulations as an important scale associated with gravitational collapse and the phase-space distribution of recently accreted material. We employ a semi-analytical approach, namely the self-similar spherical collapse framework, to study the spherical collapse of dark matter haloes in symmetron gravity. We provide, for the first time, insights into how the phenomenology of splashback is affected by modified gravity. The symmetron is a scalar-tensor theory which exhibits a screening mechanism whereby higher-density regions are screened from the effects of a fifth force. In this model, we find that, as over-densities grow over cosmic time, the inner region becomes heavily screened. In particular, we identify a sector of the parameter space for which material currently sitting at the splashback radius $r_{\rm sp}$, during its collapse has followed the formation of this screened region. As a result, we find that for this part of the parameter space the splashback radius is maximally affected by the symmetron force and we predict changes in $r_{\rm sp}$ up to around 10% compared to its General Relativity value. Because this margin is within the precision of present splashback experiments, we expect this feature to soon provide constraints for symmetron gravity on previously unexplored scales. This chapter is based on Ref. [67].