論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Cosmological Applications of Disformal Transformations
著者(和文)	Chibana De Castro Fabio
Author(English)	Fabio Chibana De Castro
出典(和文)	学位:博士(理学), 学位授与機関:東京工業大学, 報告番号:甲第11568号, 授与年月日:2020年9月25日, 学位の種別:課程博士, 審査員:山口 昌英,伊藤 克司,慈道 大介,今村 洋介,須山 輝明
Citation(English)	Degree:Doctor (Science), Conferring organization: Tokyo Institute of Technology, Report number:甲第11568号, Conferred date:2020/9/25, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Physics 系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Science)
学生氏名： Student's Name	Fabio Chibana de Castro	指導教員（主）： Academic Supervisor(main)	Prof. Masahide Yamaguchi
		指導教員（副）： Academic Supervisor(sub)	

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Scalar-tensor theories present itself as a suitable candidate to replace GR, since it is the simplest extension of Einstein's gravity. The next generation of astronomical and cosmological surveys will allow us to further investigate the space of possible theories and find a robust replacement for General Relativity. A useful tool in the study of scalar-tensor theories is the disformal transformation. A natural generalization of the conformal transformation, introducing derivative coupling, the disformal transformation allows the investigation of existing theories as well as the construction of new models.

In this work, we study disformal transformations in two contexts: the relationship between cosmological observables defined in disformally related frames, and how a disformal coupling between dark matter and dark energy affects the growth of the structure in our Universe.

To study the invariance of cosmology under disformal transformations, we first define the Jordan and Einstein frames. In the former, the scalar field couples non-minimally to gravity and minimally to matter whereas in the latter it couples minimally to gravity but universally to matter. Due to the new force mediated by the scalar field, Newton's “constant” is no longer constant. Since the effective gravitational constant is a dimensionful quantity, it is not disformal invariant. Furthermore, the disformal transformation introduces post-Newtonian corrections, such that the Newtonian limit is the same as in the conformal case. The redshift, being a dimensionless quantity, does not change, but the relationship between the redshift and scalar factor does. Hence, it is possible to have an accelerated expansion in one frame but not in the other. As a result, concepts like the redshift drift and the solution to the horizon problem are frame-dependent. Also, we show that cosmological distances are frame-dependent, although the distance-duality relation is still robust. Now, contrary to the conformal case, the photon distribution function, and consequently the Boltzmann equation, also changes under disformal transformations. Nevertheless, the shape of the black-body CMB spectrum is frame-independent. We also investigate the concept of adiabaticity and show that, in general, it is frame-dependent. Nevertheless, for purely disformal transformations, the adiabaticity condition can be satisfied if the matter fluid behaves as a Chaplygin gas.

Another issue tackled in this work is how the cosmological evolution changes when the dark matter fluid and the dark energy scalar field are disformally coupled to each other. In the Einstein frame action, instead of a universal coupling to all species, couples only to the dark matter particle. Since the interaction modifies the continuity equation for dark matter, the relationship between the galaxies' peculiar velocities and the growth of the dark matter field is modified. The peculiar velocity is especially relevant when comparing the observed galaxy power spectrum with the theoretical matter distribution, due to the Kaiser effect. Hence, the interaction between dark matter and the scalar field motivates the introduction of the modified Kaiser formula. Since the galaxy power spectrum gives information about the effective matter growth rate, redshift space distortions are no longer able to measure the actual matter growth. Nevertheless, with the analysis of data spanning multiple redshifts, or combining observations targeting different physical phenomena (such as weak lensing), it is possible to separate the growth of structure from the effects of the coupling. We study concrete cosmological examples, dubbed models I, II, and III. The conformal Model I corresponds to the familiar coupled quintessence scenario. Due to the coupling at the background level, it does not admit tracker solutions, which motivates the introduction of model II. We propose the conformal model II in an attempt to preserve the tracker behavior of the DE scalar field. Independently of initial conditions, the field "tracks" the evolution of dominant component in the universe, which can alleviate the coincidence problem. The last possibility we study is the disformal model III. By design, there is no interaction at the background level such that the background evolution is the same as in the standard quintessence scenario.

In all three models, the interaction enhances the matter clustering, and the growth rate is larger than in uncoupled cosmologies. However, while in conformal models I and II the effect of the interaction term on the effective growth rate increases the redshift-space distortion, in model III the disformal coupling has the opposite effect. It counterbalances the growth, suppressing the distortion. For that reason, a large dataset, combining different probes, is necessary to constraint the disformal coupling.

To get some insights about the predicted constraining power of future experiments on interacting cosmologies, we perform a Fisher matrix analysis. For our choices of fiducial cosmologies, future surveys could, in principle, probe the interaction within 1σ in both conformal cases. Unfortunately, the predict constraint on the disformal model III is not tight enough, signaling the necessity of a combined analysis.