（ 続紙 １ ）

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論文題目	Non-minimal coupling in the context of multi-field inflation		

（論文内容の要旨）

Jonathan White's thesis is on multi-field inflation models that contain a non-minimal coupling between the Ricci scalar and potentially all of the multiple fields. There are essentially three main parts to Jonathan's thesis:

In the first part Jonathan starts by reviewing the need for inflation, the key distinctions between single and multi-field models of inflation and the different possible formulations of models with non-minimal coupling. As well as reviewing how models with non-minimal coupling might be expected to arise, he also reviews explicitly three currently popular models, namely R^2 inflation, Higgs inflation and models recently proposed by Kallosh and Linde.

In the second part of his thesis Jonathan turns to the formulation dependence of multi-field inflation models with non-minimal coupling. It is well known that models with non-minimal coupling can be re-cast in the form of Einstein gravity via a conformal transformation of the metric. The original "frame" and that after the rescaling of the metric are referred to as the Jordan and Einstein frames, respectively, and there is a long-standing debate as to the level of equivalence between results obtained in the two frames. Jonathan focuses on the difference between the curvature perturbations associated with the Jordan and Einstein frames, as these quantities are very closely linked to the temperature fluctuations of the CMB.

At linear order, as a result of the isocurvature modes inherent to multi-field models of inflation, he starts by showing that the two quantities and their evolutions do not necessarily coincide, meaning that the interpretation of the generation of the primordial curvature perturbation may be very different in the two frames. In particular, he shows that the conservation of one of the curvature perturbations, which would usually indicate that an adiabatic limit has been reached, does not necessarily imply the conservation of the other. The fact that the two curvature perturbations are in general not equal is an indication that they cannot be directly observable, as predictions for any observable quantity should be frame-independent. This result is particularly important if one considers the possibility that isocurvature modes persist until the epoch of recombination and beyond.

After confirming the consistency of the δN formalism in the class of models under consideration, Jonathan then uses the δN formalism to compare the Jordan and Einstein frame curvature perturbations at non-linear order. In doing so, perhaps one of his key findings is the importance of taking into account the difference in definition of the initial flat hypersurfaces as defined in the two frames. Subsequently, the field perturbations on these hypersurfaces, which are used in the δN expansions, are also different, and it is only the flat-gauge perturbations in the Einstein frame for which correlation functions are known. Expressing the Jordan frame flat-gauge field perturbations in terms of those in the Einstein frame he is able to determine the correlation functions of the curvature perturbation in the Jordan frame. The second important difference that he notes is the fact that in the Jordan frame it is the time coordinate N that remains unperturbed, whereas in the Einstein frame it is Ñ. He shows that it is only by taking both of these differences into account that one can confirm the equality of the two curvature perturbations when an adiabatic limit is reached. By studying some specific example models, he then shows explicitly that the curvature perturbations in the Jordan and Einstein frames and their statistical properties can indeed differ substantially, including their non-Gaussianities.

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The final part of Jonathan’s thesis considers the reheating process in the same class of inflation models. Taking a bottom-up approach he assumes that there are no direct interaction terms between the inflaton sector and the Standard Model. As such, reheating of the universe takes place via gravitationally suppressed dimension-5 interaction terms, with the decay rates of the inflatons depending on the masses of the decay products. Since all masses of the Standard Model particles are acquired from the Higgs field expectation value, he argues that the rate of gravitational particle production can be spatially modulated by the stochastic value of the Higgs condensate generated during inflation. He then goes on to show that observational constraints on the curvature perturbation generated from this Higgs isocurvature mode can be used to set a lower bound on the inflaton mass during the reheating phase.

（論文審査の結果の要旨）

本博士論文でホワイト君は、非極小相互作用理論における宇宙の初期揺らぎについて詳細に調べ、これまで議論されてきたいくつかの未解決問題を解決することで、そのような理論からの観測的なシグナルを検証するための基礎を構築した。非極小相互作用理論とは、重力とスカラー場の相互作用がアインシュタイン重力の場合と異なっており、そのため通常のアインシュタイン重力とは異なる現象がおこりうる理論であり、宇宙初期のインフレーションの物理的な起源となっている可能性が指摘されていた。そして、最近の観測データは非極小相互作用理論を支持している。特に、物質の相互作用の統一理論の有力候補であるストリング理論が、そのような非極小相互作用理論を示唆することはよく知られており、本論文は今後の観測の進展次第ではストリング理論の観測的検証につながる可能性を秘めている重要な成果である。

より具体的には、ホワイト君は、宇宙の初期揺らぎを調べる上で本質的に重要な物理量である曲率揺らぎの性質を詳細に調べた。非極小相互作用理論においてはアインシュタインフレームとジョルダンフレームと呼ばれる２種類の系を記述の仕方があるが、それぞれで定義された曲率ゆらぎが本質的に異なる物理量であることを示し、それらの相互関係を明確に与えた。この二つのフレームで定義された曲率ゆらぎの違いを考慮することは、非極小相互作用理論において初期揺らぎに関する観測的予言をする際に非常に重要となる。

また、本論文において、ホワイト君は上記の考察に基づいて初期揺らぎの非線形発展を解いた。非線形発展から生じる揺らぎの非ガウス性は、今後の観測技術の進展の中で、インフレーションモデルに迫る上で重要になると期待される観測量である。この研究の結果、実際に二つのフレームで定義された曲率ゆらぎの違いを考慮することが観測的な予言の際に重要になる場合があることが具体的に示された。

以上より、本論文は非極小相互作用理論という宇宙論的に重要な理論の基礎についての理解を大きく進めたものと言える。よって、本論文は博士（理学）の学位論文として価値あるものと認める。また、平成２６年１月１７日、論文内容とそれに関連した事項について試問を行った結果、合格と認めた。

なお、本論文は、京都大学学位規程第１４条第２項に該当するものと判断し、公表に際しては、無期限で当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公表可能日：　2014　年　　3　月　　1　日以降