Inflation with an SU(3) gauge field

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論 文 内 容 の 要 旨

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専　攻　物理学

論文題目

Inflation with an SU(3) gauge field
(SU(3)ゲージ場を伴うインフレーション)

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There are totally 6 chapters and 2 appendices in this thesis.

Chapter 1 is an introduction. This chapter includes brief overviews of big bang cosmology, inflation theory and anisotropic inflation, the motivation of the study and the outline of the thesis.

The motivation of our study of inflation with an SU(3) gauge field is as follows:

Although statistically isotropic primordial fluctuations are supported in the CMB experiments, anomalies are also shown, though at low statistical significance in the CMB temperature anisotropies. In precision cosmology, we need to study the fine structure of the fluctuation of CMB, e.g., statistical anisotropy. Motivated by the anomaly in observation, many models have been proposed to explain the statistical anisotropy. In the case of statistical anisotropy, one needs to find some mechanism to achieve this. One direction is to find an anisotropic inflation model, so that the primordial fluctuation may have a chance to be statistically anisotropy. One mechanism is found to obtain a stable anisotropic solution, it is achieved by coupling the inflaton and a U(1) gauge field by a nontrivial kinetic function. If the kinetic function satisfies some condition, then the gauge field can survive from the expansion of the universe so that anisotropic inflation occurs. If the gauge field is of SU(2), it will suffer from the non-linear self-coupling of the gauge field itself, which makes it tend to isotropy.

In this thesis, we study the anisotropic behavior of inflation in the presence of an SU(3) gauge field. In the standard model of particle physics, not only U(1) and SU(2) gauge fields but also an SU(3) gauge field plays an important role. In high-energy fundamental theories, there are many non-Abelian gauge fields including SU(3) and other Lie groups. From the viewpoint of group theory, the differences of the structure constant in the SU(3) group may result in a nontrivial phenomenon in the anisotropy of inflation. Therefore, it would be interesting to study the role of a SU(3) gauge field in the early universe in addition to the previous works for the cases of U(1) or SU(2) gauge fields.

In Chapter 2, we first review the standard cosmology and inflation theory. Inflation theory is a theory of the early universe motivated by solving the problems in standard cosmology. Inflation theory can also provide the seed of the cosmic structure generated at a late time through quantum fluctuations in the early universe. In this chapter, we also review how inflation can provide the primordial fluctuations for the CMB anisotropy and large-scale structure.

In Chapter 3, We review anisotropic inflation with U(1) gauge field(s). we first review the mechanism of anisotropic inflation in the case of one U(1) gauge field in this chapter. We then review inflation with two U(1) gauge fields. In this case, the stable solution is a state in which the two electric fields (the derivative of the gauge fields to time) are perpendicular to each other. We then review inflations with N(N > 2) U(1) gauge fields, in these cases, inflations will reach no-hair eventually.

Chapter 4 and Chapter 5 are the parts of our study and Chapter 4 is the main one.

In Chapter 4, we present our study of inflation with an SU(3) gauge field. In §4.1, we first show that in the case of the conventional SU(2) subgroup (the one with Pauli matrices as generators), all the components decay at the non-linear regime (when the gauge field grows to large enough values) eventually and thus universe becomes isotropic eventually. In §4.2 we show for the case of SU(2)⊗U(1) subgroup. In this case, the SU(2) part decays while the U(1) part survives. This is because the generator of the U(1) group commute with those of the SU(2) group thus the U(1) gauge field decouple with the SU(2) gauge field. As a result, when the SU(2) gauge field decays, the U(1) part has a similar solution as the case of the presence of only the U(1) gauge. However, we find small anisotropy generates at the linear regime even the initial condition is isotropic. It is because of the small difference between the growth rates of the SU(2) gauge field and the U(1) gauge field at the linear regime. This is different from the case of three U(1) gauge fields or the case of SU(2) gauge field, both of these two cases would not generate anisotropy if the initial conditions are isotropic. In §4.3, we find the components corresponding to the Cartan generators can survive from the non-linear self-coupling of the gauge field because of the existence of a flat direction. It happens in the space of the SU(2) subgroup in which one generator is a combination of the Cartan generators. Although the survived two gauge components for which the generators are commutative, they align and thus behave as one U(1) gauge field. This is different from the case of two U(1) gauge fields, in which the stable solution is that the velocities of the two gauge fields are perpendicular to each other and have the same magnitude, and thus have smaller anisotropy than that in the case of flat direction. In §4.4 we study the general case of SU(3) gauge field, in the sense that we set the initial velocities of all the components to the same order of magnitude but different values (to avoid all the components pointing to the same direction). We find in this case all the components decay at the non-linear regime thus the universe becomes no-hair eventually.

It should be noted that there is no flat direction in the potential for the conventional SU(2) gauge field. This gives rise to an interesting inflationary scenario with an SU(3) gauge field, which cannot be realized in the conventional SU(2) case. On the contrary, in a realistic universe, it is reasonable to expect that all the components of the SU(3) gauge field have nonvanishing initial velocities of the same order of magnitude. We found that the generated anisotropy eventually decays due to the nonlinear self-couplings of the gauge field. In this sense, the cosmic no-hair conjecture holds. However, the transient anisotropy should exist practically on the large scales and its effect would be imprinted on the cosmic microwave background and the large-scale structure.

In Chapter 5 we extend the analysis of flat direction to inflation with an SU(N)(N > 3) gauge field. From group theory, we know that each root vector corresponds to an SU(2) algebra in which one of the generators is a combination of Cartan generators and the coefficients are the components of the root vector. In our case, for each simple root with two non-zero components, there is a flat direction in some subspace of the corresponding SU(2) gauge field, similar to the situation in the SU(3). The gauge components corresponding to the Cartan generators can survive from the non-linear self-coupling because of the existence of a flat direction. This flat direction results in anisotropy same as the case of only one U(1) gauge field. Thus, the conventional SU(2) gauge field has a specialty among general non-Abelian gauge fields in inflation.

Chapter 6 is the conclusion and discussion.

Appendix A is the group theory which this thesis may use.
Appendix B is the analysis of configurations of SU(3) gauge field in the axially symmetric Bianchi type I spacetime.

（別紙１）　論文審査の結果の要旨

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論文題目	Inflation with an SU(3) gauge field 「SU(3)ゲージ場を伴うインフレーション」		
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要　　旨

本論文の要旨は以下のとおりである。

本論文の骨子は、第１章で研究の背景、第２章でインフレーションの基礎、第３章でU(1)非等方インフレーション、第４章で SU(3)ゲージ場を伴うインフレーション、第５章で SU(N)ゲージ場への拡張、第６章でまとめと展望、となっている。

第１章では導入として、インフレーション理論の現状と SU(3)ゲージ場を伴うインフレーション研究の動機が明確に記述されている。
第２章は、ビッグバン宇宙論を記述するフリードマン方程式の導出に始まり、インフレーション理論の簡潔なレヴューがまとめられている。また、インフレーション理論の予言と宇宙背景放射観測との比較がなされている。
第３章では、U(1)ゲージ場の場合に、非等方インフレーションの解説がなされている。

非等方インフレーションは SU(2)ゲージ場にまではすでに拡張がなされていた。最近、SU(2)ゲージ場の Chern-Simons 項がある場合のインフレーション理論の研究が盛んになっている。一般に、ゲージ群の回数が１と２以上では定性的に性質が異なる可能性があり、SU(3)ゲージ場の研究は必須であると考えられていた。しかし、SU(3)以上の高いランクを持ったゲージ群に関する研究は、その解析が複雑なため、なされていなかった。

第４章では、SU(3)ゲージ場を伴うインフレーションモデルの解析がなされており、本論文の中心的な部分となっている。この解析によって、SU(2)ゲージ場の場合とは異なり、SU(3)ゲージ場では有効ポテンシャルに平坦な方向が存在することが発見された。これは観測量に統計的な非等方性が残り得ることを意味し、非常に重要な知見を与えている。
第５章では、さらにランクを大きくしていった場合にも有効ポテンシャルに平坦な方向が存在することを示している。
第６章では、まとめと展望が述べられている。
付録には、有用な数学的な事項がまとめられている。

ゲージ場を伴うインフレーション宇宙論は標準理論を超えた素粒子モデルの情報を運ぶ可能性があり、将来の観測の進展を考えるとその研究の重要性は高い。SU(N)ゲージ場を伴うインフレーション研究への新たな道を拓いた本研究は今後評価を高めていくと予想できる。

本研究は、SU(3)ゲージ場を伴うインフレーション宇宙を解析したものであり，ゲージ場のある場合のインフレーション研究の重要な知見を得たものとして価値ある研究の集積であると認める。

よって，学位申請者の Pengyuan Gao 氏は，博士（理学）の学位を得る資格があると認める。

- 特記事項　なし
- 特許登録数　０件
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