# Hunting for new physics in the primordial Universe

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# Summary

*Where do we come from?*

The quest for the origin of everything has puzzled all the curious minds since our ancestors looked up the starry sky in wonder.

*What is the fundamental law of nature?*

To get a complete answer, from philosophers in ancient Greece to theoretical physicists today, numerous brilliant thinkers have stepped on "the greatest adventure that the human mind has ever begun"[1].

Excitingly, the modern advances of primordial cosmology are building the link between these two most fascinating questions in the history of human civilization. In the current understanding, our Universe originated from a small patch with a hot and dense state 13.8 billion years ago. From the recent developments of fundamental physics, we further speculate that the cosmic expansion was exponentially rapid within the first fraction of a second after the Big Bang. This theoretical proposal, called cosmic inflation, provides a successful description for the earliest stage of the Universe. Meanwhile, during this inflation stage quantum fluctuations can become the initial seeds of cosmic inhomogeneities, which later evolve into galaxies, clusters and large scale structures. Thus it is remarkable that through today's astronomical observations, we can trace the imprints in primordial inhomogeneities left by physics processes during inflation. As a result, primordial cosmology has become an exciting research area for theoretical physicists, where one can hunt for the fundamental laws of physics that govern the earliest moment in our Universe.

Motivated by the big picture above, this thesis is dedicated to exploring the theories of the primordial Universe and their connections with astro-

[1]Quoted from Richard Feynman, *The Feynman Lectures on Physics, Volume III.*

nomical observations.

The first part of the thesis focuses on so-called inflationary curved field spaces. To understand how inflation happens, typically we require a driver called the inflaton field, and it may move in a multi-dimensional field space which in general is curved. Thus the geometry of this internal space can be seen as one particular example of new physics effects during inflation.

In Chapter 2, we investigate a class of inflation models called $\alpha$-attractors. Here the magic of the hyperbolic field space is demonstrated explicitly in the two-field extension of these models. With its effects, the model predictions of single field $\alpha$-attractors are almost unaffected, even when the multi-field effects become significant. This work complements the previous single-field analysis of $\alpha$-attractor models, and also highlights the role of the hyperbolic geometry of the field space.

Chapter 3 proposes another class of cosmological models called "shift-symmetric orbital inflation", where the inflaton circles along an "angular" direction in a general field space. Again the multi-field effects are significant in these models, but in the end we still find single-field like predictions. This work corresponds to a less explored regime in multi-field inflation where the extra field is light but significantly coupled to the inflaton.

While most of the previous analysis of the internal spaces are relying on specific models, Chapter 4 is dedicated to a more general question: what are the model-independent observational signatures of these inflationary curved field spaces? Here I try to answer this question using the non-Gaussian phenomenology of massive fields during inflation, and find the fingerprints of these internal spaces which can be tested in future observations.

The second part of the thesis studies the phenomenology of one very important observable – primordial non-Gaussianity, which captures the deviation from the Gaussian statistics of primordial inhomogeneities. These signals are worth searching for, as a wealth of early-time information is believed to be encoded in the cosmological triangle patterns.

Chapter 5 revisits the non-Gaussianities generated in non-attractor inflation. This class of models are well known to violate Maldacena's consistency relation in the framework of single-field inflation, which has received much attention and investigation. Through careful calculation, we explicitly show what happens to this famous counter-example when realistic and complete models of non-attractor inflation are considered.

Chapter 6 studies the non-Gaussian phenomenology of an alternative to inflation – matter bounce cosmology. We begin with a generalized single-field setup. The non-Gaussian signals generated here can be used to distinguish this alternative scenario from inflation. Moreover, we propose a no-go theorem which rules out many alternative models with the current observational constraints.

**What's next?** This thesis aims to push the frontier of the primordial cosmology. Needless to say, this is a research area under fast development: many interesting theoretical ideas are emerging; and upcoming observational experiments may tell us more about the earliest stage of the Universe. To further explore the new physics effects in the primordial era, the following topics are worthy of deep consideration in the coming years.

- *Internal symmetries* usually play an important role in the fundamental realizations of inflation, and they may also be closely related to the effective field theory, the geometry of the field space and new phenomenology. To hunt for signatures of underlying symmetries during inflation, it is interesting to perform more systematic investigations.
- *Scattering amplitudes* research provides new perspectives and powerful tools in the modern study of quantum field theory. One may wonder whether similar approaches can be applied for bootstrapping correlators in cosmology. While some pioneering studies have appeared recently, this is a brand new area with many open opportunities.
- *Large scale structure surveys* are expected to produce massive amounts of data for cosmology in the near future. Theorists are needed to gain better understanding of the new observational windows for non-Gaussianities and other primordial signals, and also get prepared for possible new discoveries.

Just as it goes[2]:

*The way ahead is a long, long one, oh!*
*I will seek the Truth high and low.*

[2]Qu Yuan (c. 340–278 BC), *The Lament*.