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Primordial non-Gaussianities after *Planck 2015*: An introductory review

Les non-gaussianités primordiales après Planck 2015

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ABSTRACT

Deviations from Gaussian statistics of the cosmological density fluctuations, so-called primordial non-Gaussianities (NG), are one of the most informative fingerprints of the origin of structures in the universe. Indeed, they can probe physics at energy scales inaccessible to laboratory experiments, and are sensitive to the *interactions* of the field(s) that generated the primordial fluctuations, contrary to the Gaussian linear theory. As a result, they can discriminate between inflationary models that are otherwise almost indistinguishable. In this short review, we explain how to compute the non-Gaussian properties in any inflationary scenario. We review the theoretical predictions of several important classes of models. We then describe the ways NG can be probed observationally, and we highlight the recent constraints from the *Planck* mission, as well as their implications. We finally identify well motivated theoretical targets for future experiments and discuss observational prospects.
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RÉSUMÉ

Les déviations à la gaussianité des fluctuations cosmologiques de densité, ou non-gaussianités primordiales, nous fournissent des indices précieux quant à l'origine des grandes structures de l'univers. Elles permettent en effet de sonder la physique à des échelles d'énergie inaccessibles en laboratoire, et sont sensibles aux *interactions* du (ou des) champ(s) à l'origine des fluctuations primordiales, contrairement à la théorie linéaire gaussienne. Elles nous permettent ainsi de différencier des modèles autrement presque indistinguables. Dans cette courte revue, nous expliquons comment calculer les propriétés non gaussiennes des fluctuations générées pendant tout scénario d'inflation. Nous passons en revue les différentes prédictions théoriques de plusieurs grandes classes de modèles. Nous décrivons ensuite la façon dont les non-gaussianités peuvent être contraintes observationnellement et nous soulignons les contraintes récentes apportées par la mission *Planck*, ainsi que leurs implications. Nous discutons enfin les perspectives observationnelles en identifiant des objectifs réalistes et motivés théoriquement.
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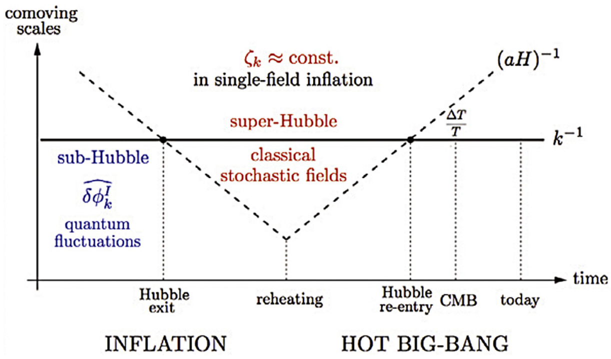

Fig. 1. The inflationary expansion turns sub-Hubble quantum fluctuations into classical super-Hubble perturbations, whose effects we observe in the CMB and the LSS.

1. Introduction

Thanks to unprecedented observational efforts in the last two decades, we now have at hand high quality data of the two main cosmological probes, namely the Cosmic Microwave Background (CMB) anisotropies and the Large Scale Structures (LSS). The picture of the primordial universe that emerges from these data is surprisingly simple: all current observations are consistent with the Λ-Cold Dark Matter model, with initial conditions provided by the simplest inflationary models. The only ingredient of the latter is a single canonical scalar field minimally coupled to gravity and evolving on top of a very flat potential (we call them single-field slow-roll in the following). These scenarios provide a very good fit to the data (see the contribution by Martin, Ringeval and Vennin to this volume) while alternatives to the inflationary paradigm are less compelling (see the contribution by Peter and Lilley). However, despite being phenomenologically successful, these models cannot ultimately be considered as satisfactory, for at least two reasons: they are decoupled from the rest of physics, and they lack an ultraviolet completion.

In particular, as soon as one wants to embed the inflationary paradigm into quantum field theory, it becomes surprisingly challenging to realize slow-roll models in an honest-to-God way [1] (see also the contribution by Silverstein to this volume). One is then led to consider more complicated inflationary models, involving for instance several degrees of freedom, non-canonical actions or features in the potential. While these models can easily be made degenerate with the simplest ones at the leading-order approximation, their complexities often reveal themselves at next-to-leading-order in the form of so-called *primordial non-Gaussianities*: deviations from Gaussian statistics of the primordial density fluctuations. Cosmological data now put stringent bounds on them, constraining inflationary models in a way that would be otherwise impossible. Here we explain how to compute the non-Gaussian properties of inflationary models and we review the associated theoretical predictions in several important classes of models. We mention the ways non-Gaussianities can be probed observationally, as well as the current and expected future constraints. This field of research has been very active in the past decade and we cannot pay entire justice to it in this short introductory review. For complementary details, we refer the interested reader to the reviews [2–12], and to the references to the original literature therein. We use units in which $c = \hbar = M_{\rm Pl} = 1$.

2. Inflation and the origin of the large scale structure of the universe

2.1. From quantum fluctuations to primordial perturbations

Before discussing non-Gaussianities (NG), it is appropriate to remind the reader of some basic facts about the inflationary origin of the large scale structure of the universe, referring her/him to the other contributions in this volume for a more detailed treatment. On cosmological scales, the geometry of the universe can be described at first approximation by a homogeneous and isotropic metric of the (flat) Friedmann–Lemaître–Robertson–Walker (FLRW) form:

$$\overline{{\rm d}s}^2 = -{\rm d}t^2 + a(t)^2 \delta_{ij} {\rm d}x^i {\rm d}x^j \tag{1}$$

where t is the cosmic time, a denotes the scale factor of the universe, and x^i are spatial comoving coordinates. The large scale structure of the universe is then described by small fluctuations above this background, which we label by their fixed 3d Fourier wavevectors $\boldsymbol{k}$ in comoving space. The conceptual problems of the hot Big-Bang model all derive from the increase of the comoving Hubble radius $(aH)^{-1}$, where $H = \dot{a}/a$ denotes the Hubble scale. Inflation solves them by providing an earlier phase in which $(aH)^{-1}$ decreases sufficiently that the observable universe was initially inside the Hubble radius (see Fig. 1 and the contribution by Ellis and Uzan to this volume about the causal structure of inflation). This way, scales of cosmological interest have their physical wavelength $\lambda = \frac{a}{k=|\boldsymbol{k}|}$ less than H^{-1} at the beginning of inflation, exit the Hubble radius during inflation before re-entering it during the Big-Bang era. In this process, unavoidable sub-Hubble quantum fluctuations $\widehat{\delta\phi^I_k}$ of the field(s) driving inflation become classical after Hubble exit [13], manifesting themselves in the Big-Bang

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