Snowmass2021 - Letter of Interest

Cosmological Collider: Precision calculation and probes of new physics

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
□ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
■ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
□ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
■ (TF9) Theory Frontier: Astro-Particle Physics and Cosmology

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Abstract: (maximum 200 words)
Cosmological inflation in the early universe sets the stage for rich dynamics of particle physics at energy scales much above the reach of terrestrial experiments. In the coming decades, much more observational data will further shed light in this era. In particular, the precision in the primordial Non-Gaussianity (NG) measurement will be improved by orders of magnitudes [1]. Among various NG observables, the oscillatory shape in the squeezed limit due to particle production during the inflation is particularly striking. (We will henceforth refer to this oscillatory shape the "signal.") Detecting such a signal at this so-called cosmological collider offers direct evidence of new physics particles and a tool of studying their properties. In order to optimize the sensitivity of such searches, a precise understanding of the size and the shape of the signal is needed. At the same time, such predictions often requires one loop calculation of inflationary correlators and are not available due to its complexity. Our primary goal is to make progress in this direction. We will further explore its implications on new physics scenarios.

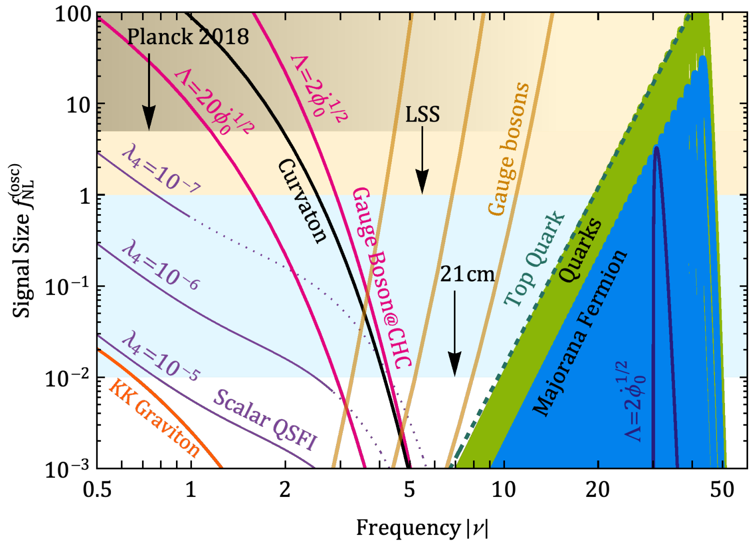

Figure 1: Predictions of cosmological collider signals from various particle models, adapted from [24, 27].

Motivation:

Heavy particles from new physics can be produced on-shell during cosmic inflaton, which can be efficient for particle mass up to (or even higher than) the inflation Hubble scale (up to 10^{14}GeV). It has been emphasized recently that these particles can then impact on spacetime fluctuations and leave unique imprints on their correlations [2–4]. This can be probed by the cosmic microwave background (CMB), the large scale structures (LSS), and the 21cm tomography. Specifically, in the squeezed limit of the 3-point correlation of the curvature fluctuations where the wave number of one mode is much smaller than the other two, the on-shell heavy particles can generate distinct shape dependence. This includes a nonanalytic oscillatory or scaling behavior as a function of momentum ratio, and a particular dependence on the angle between the long mode and the short mode. This gives us the opportunity to search for new physics at an energy scale far beyond the reach of any foreseeable terrestrial experiments. In addition, the shape dependence carries the information about the mass and the spin of the new particles [5–26]

Cosmological Collider Signals

The oscillatory signal in the squeezed bispectrum can be characterized by (1) the (dimensionless) oscillation frequency in the momentum ratio, (2) the angular dependence, and (3) the overall amplitude. (1) and (2) are kinematic manifestation of the mass and the spin of the particles and are quite model independent, while (3) depends on the detailed dynamics of particle production and its coupling to the curvature perturbation. A couple of particle models have been studied that could produce visibly large signals (Fig. 1), but a more general survey will be important, both at the level of EFT and in the model-building.

Many known signals that could be probed in the near future are produced through 1-loop process that explicitly breaks the de Sitter symmetry [24, 27]. The lack of symmetry makes it hard to approach the problem analytically. To compute the signal more reliably, a direct numerical computation is indispensable. The numerical result will be important for (1) confirming the analytical estimates made in literature, (2) providing the link between model parameters and the observation data, (3) setting the starting point of template construction.

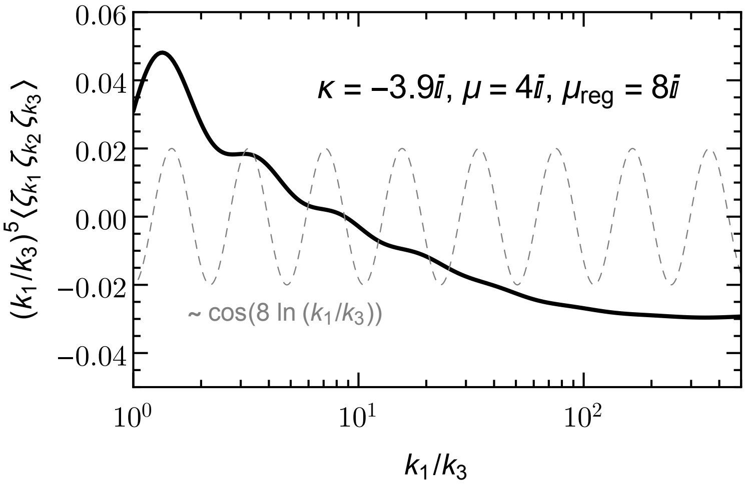

Figure 2: Oscillatory signal (black line) from a pitched 1-loop diagram for complex scalars based on a toy model related to [28]. A sinusoidal (gray dash) curve is included as a guide to the oscillatory pattern.

Objectives:

We will aim at a comprehensive understanding of cosmological collider signals up to the 1-loop level. The major target will be the full numerical computation of relevant 1-loop graphs in inflation background with or without explicit dS symmetry breaking.

We will develop and demonstrate the essential numerical techniques with sample diagrams from known processes involving spin-0, 1/2, and 1 particles, without applying arbitrary simplifications that are used in previous estimations (see e.g. Fig. 2 for the numerical result of a toy model). Along the way, we would also like to investigate a systematic numerical implementation of the regularization and renormalization of the UV divergence in the loop diagrams. We plan to further extend our calculations to 1-loop diagrams with multiple external legs and/or with higher-spin particles running in the loop.

We will also continue the model studies to explore more physical possibilities of producing signals. At the model-independent level, we will try to classify all relevant tree-level and 1-loop level processes in an EFT fashion. This classification will be useful to construct a library of loop functions in inflation background that can be readily computed with better developed numerical tools. The numerical result of these loop functions will be benchmarks for future template construction.

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