NASSP Masters Project 2026

1. Level of the project:
Masters

2. Name of primary supervisor:
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3. Institution of supervisor:
University of KwaZulu-Natal

4. Name of co-supervisor:
Prof. Kavilan Moodley

5. Institution of co-supervisor:
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7. Project title:

Probing the primordial non-Gaussianity of the universe using the squeezed limit HI-ISW cross-bispectrum with HIRAX and Planck surveys.

8. Description of project:
Cosmic inflation is considered one of the pillars of the ΛCDM cosmological model. While the general paradigm of inflation strongly supports the idea that fluctuations follow a Gaussian distribution, some studies suggest that primordial mass density fluctuations during an inflationary era may be non-Gaussian. Primordial non-Gaussianity (PNG) represents deviations from Gaussian statistics in the initial conditions of cosmological perturbations and serves as a powerful discriminator among viable models of cosmic inflation. The 3-point statistic correlation vanishes for linear Gaussian fields and is thus a sensitive probe of non-linearities and non-Gaussianities in the cosmic density field. Hence, the bispectrum is the lowest-order summary statistic sensitive to the shape of structures generated by gravitational instability and is a natural probe of the non-Gaussianity of primordial fluctuations. Among the various density fields that can be used in the bispectrum estimator, we will focus on neutral hydrogen (HI) intensity mapping and integrated Sachs-Wolfe (ISW) secondary anisotropy in the cosmic microwave background, as their combination provides complementary sensitivity to the large-scale gravitational potential and, hence, to the underlying matter distribution.

Objective and Methodology:

This project has multiple motivations. First, the student will model an estimator for 3-point statistics of the HI-ISW observables, utilising a position-dependent power-spectrum formalism. Then the student will study the detection of this signal by calculating the signal-to-noise ratio (SNR) and leveraging the synergy between HIRAX and Planck surveys. Second, the student will estimate the constraints on primordial non-Gaussianity from the integrated bispectrum of 21 cm-21cm-ISW, using a Fisher matrix analysis. The integrated cross-bispectrum, which combines two 21 cm fields with an ISW fluctuation, represents a higher-order statistical measure that quantifies three-point correlation functions. This integrated quantity maintains its capability to constrain primordial cosmological parameters, particularly the local-type non-Gaussianity parameter f_NL.

Expected Outcome:
By the end of the project, students will be familiar with primordial non-Gaussianity and inflationary signatures, 21 cm intensity mapping techniques, cosmic microwave background and secondary anisotropies, high-order statistics, large-scale structure, multi-probe cosmology, and cross-correlation techniques. Students will write the code for the pipeline analysis, enabling the addition of more parameter constraints in future work. Students will master the theoretical forecast formalism using the Fisher matrix approach and the use of Boltzmann solvers, such as CAMB and CLASS.

9. Requirements:

Basic knowledge of cosmology and general relativity. Strong background in mathematical and statistical methods. Strong programming skills in Python.