NASSP Masters Project 2026

1. Level of the project:
Masters

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7. Project title:
Squeezed Bispectrum Correlations of MeerKLASS HI with DES Galaxies and Shear

8. Description of project:
HI intensity mapping with MeerKAT and weak/galaxy lensing from optical surveys probe the same underlying large-scale structure with complementary systematics. The MeerKAT Large Area Synoptic Survey (MeerKLASS) produces deep single-dish HI intensity maps over hundreds of deg^2, reaching the HI-dominated regime in L-band auto-power. The Dark Energy Survey (DES) has delivered high-quality galaxy clustering and cosmic shear catalogues over ~5000 deg^2 with well-characterised photometric redshifts and systematics. A cross-correlation between MeerKLASS and DES is thus a natural next step, and is directly aligned with SKA-LSST science.

To date, most 21 cm-optical cross-correlations have been in configuration or angular space, and primarily with spectroscopic tracers or with the Ly-α forest. On the lensing side, squeezed bispectrum-type estimators have been developed and applied to cross-correlate small-scale tracers with CMB lensing. However, a fully three-dimensional P(kperp,kpar) measurement of HI intensity maps cross-correlated with an optical survey like DES (using a realistic single-dish) pipeline has not yet been demonstrated.

Objective:

The objective is to build a unified analysis that does for MeerKLASS×DES what CHIME recently built for CHIME×Planck: to measure a squeezed-limit integrated bispectrum (IB). In this project we will use MeerKAT L-band (and UHF band when available) intensity maps and DES galaxy/shear maps instead of CHIME HI maps and CMB lensing maps.

Methodology:

The project is computational and data-driven. The student will start from the calibrated MeerKLASS single dish L-band data, processed with the standard KATcali + self-calibration pipeline, as in the recent MeerKLASS L-band deep field work. The student will select a clean MeerKLASS sub-band overlapping DES (e.g. z = 0.35-0.6) based on existing RFI and noise characterisation and construct 3D calibrated T_sky(theta, nu) cubes with known thermal noise and time-stamp derived weights, perform blind frequency-space PCA (or SVD) foreground cleaning, removing N_fg smooth modes, to obtain a foreground-cleaned cube T_clean(theta, nu) that contains HI signal plus thermal noise and residual low-level systematics. To quantify signal loss and extra variance from the cleaning, we will follow the CHIME and MeerKLASS deep-field strategy, i.e., construct transfer functions T_HI(kperp, kpar) by comparing power spectra before and after cleaning, and estimate their scatter across mocks. These transfer functions will be used both to reconstruct the true power spectrum and to build a covariance that includes cosmic variance, thermal noise and cleaning-induced uncertainty.

From the DES public releases, the student will construct matched optical tracers in the MeerKLASS overlap region, select a well-understood DES galaxy sample (e.g. mag-limited or red-sequence) with robust photometric redshifts and systematics weights (seeing, depth, extinction) and define several broad tomographic bins in z_phot (e.g. 3-4 bins spanning 0.3 < z < 0.6), and derive N_g(z_bin) using DES redshift-calibration methods. This will allow the student to build galaxy overdensity maps delta_g(theta; z_bin) on the same angular pixelisation and sky mask as the MeerKLASS cubes.

The next step will be to compute the local small-scale HI power spectrum in 3D voxels that span the survey volume, and then construct the squeezed limit integrated bispectrum in 3D by cross-correlating this position-dependent power spectrum with the large-scale DES tracer field. This tells us how the small-scale 3D HI power responds to the presence of a large-scale shear or galaxy mode. This is directly related to the response of the small-scale power spectrum to long-wavelength density or potential fluctuations, as in Chiang et al. (2014) and its CHIME implementation, but now with full radial information retained.

Expected Outcome:

By the end of the project, the student will have implemented a squeezed limit integrated bispectrum estimator using MeerKLASS HI intensity cubes and tomographic DES galaxy/shear fields. The pipeline will deliver: (i) a first measurement (or upper limits) of the HI-shear/galaxy integrated bispectrum, interpreted as the response of small-scale H I power to large-scale DES modes and (ii) a simulation-validated framework that can be ported directly to future MeerKAT/SKA × DES/LSST analyses.

Requirements:

Students should have an Honours-level background in cosmology, including familiarity with basic statistics. Strong proficiency in Python is essential, and experience with handling survey data is desirable but can be developed during the project. The student must be comfortable working with real, imperfect radio and optical data and running computational simulations.