NASSP Masters Project 2026

1. Level of the project:
Masters

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7. Project title:
Tomographic Cross-Correlations of MALS Radio Cubes with DES Galaxy Surveys

8. Description of project:
Wide-area optical surveys such as the Dark Energy Survey (DES) and deep radio surveys such as the MeerKAT Absorption Line Survey (MALS) provide highly complementary views of the large-scale structure of the Universe. DES delivers accurate optical galaxy positions, photometric redshifts and well-characterised selection functions over thousands of square degrees, while MALS consists of roughly six hundred 1-square degree pointings in the southern sky with excellent continuum sensitivity and uv-coverage. Although the MALS pointings are sparsely and quasi-randomly distributed, they contain rich information in both the visibility and image domains that can be exploited through cross-correlations with overlapping optical galaxy catalogues.

The aim of this project is to treat the MALS data as a set of 3D radio data cubes (in both visibility and image space) on top of which we define radio intensity or source-density fields, and then cross-correlate these fields with DES galaxy overdensity maps in redshift bins. Rather than relying on a single contiguous radio footprint and overdensity maps, we will use estimators that naturally handle disjoint patches and incomplete sky coverage, and that exploit the high-fidelity calibration and noise characterisation of the MALS data. This will provide a robust, first demonstration of radio-optical clustering and tomographic cross-correlations using MALS and DES, and will lay the groundwork for future SKA-LSST cross-correlation studies.

Objective:
The project is organised around three closely linked goals:
(i) **Build calibrated MALS visibility and image cubes for clustering and cross-correlation.**
Using public MALS L-band products and calibration (Deka et. al. 2024, Gupta et. al. 2025), we will construct frequency-resolved visibility cubes and Stokes I image cubes for pointings overlapping DES, enforcing a homogeneous imaging setup (weighting, uv-taper, resolution) and validating beams and noise with standard radio-imaging tests.

(ii) **Define radio tracers and match them to DES tomographic galaxy fields**
From the image cubes, we will construct two radio tracers, a flux-limited, completeness-corrected source catalogue and an intensity-based field with primary beam and noise modelling and project these onto the DES footprint. Matched DES galaxy overdensity maps will be built in several photometric-redshift bins on the same pixelisation and joint mask.

(iii) **Measure and model tomographic MALS×DES cross-correlations with appropriate estimators.**
Treating 1-square degree MALS pointings as disjoint patches, we will measure radio-DES angular cross-correlations with Landy–Szalay or pseudo-$C\ell$ estimators that include the joint window function, and interpret the results with simple SKADS-inspired N(z) and bias models to constrain the effective radio bias and redshift sensitivity of the MALS tracers.

Methodology:
The project is computational and data-driven. The student will first review the theory of angular auto- and cross-correlations (line-of-sight kernels W(z), N(z), bias b(z), Limber approximation) and practical treatments of incomplete sky coverage with configuration-space and pseudo-$C\ell$ estimators, alongside the MALS data-release papers (calibration, completeness, purity) and DES clustering/tomography analyses (galaxy samples, masks, redshift calibration).

Using calibrated MALS visibilities, the student will set up a standard imaging pipeline (e.g. CASA/WSClean) to produce Stokes I image cubes with homogeneous angular and frequency resolution, propagating primary beam, and noise models, and validating the products via flux/astrometry checks and noise statistics. From these, they will build two radio tracers: (i) a source-based tracer, using a source finder to construct flux-limited catalogues with completeness weights and corresponding number-count maps; and (ii) an intensity-based tracer, based on mean-subtracted, primary-beam-corrected continuum intensity maps with bright sources and artefacts masked. Masks will combine MALS primary-beam cuts, noise thresholds and DES imaging coverage.

From DES public catalogues, the student will select a well-characterised galaxy sample with robust photometric redshifts, apply DES systematics and imaging masks, and construct tomographic bins (e.g. 3-5 bins). Within each MALS pointing, DES galaxy overdensity maps will be built on the same pixelisation and mask as the radio maps. For each overlapping patch, the radio-DES cross-correlation will be measured either in configuration space (Landy-Szalay type estimator) or in flat-sky harmonic space (pseudo-$C\ell$ with the joint window function), and combined across pointings by inverse-variance weighting.

Finally, using a Boltzmann or CCL-like code, the student will compute theoretical auto- and cross-spectra based on a SKADS-inspired radio N_r(z), DES N_g(z_bin) and simple bias models, and fit a Gaussian likelihood for the effective radio bias and basic N_r(z) shape parameters, testing robustness against changes in flux cuts, masks, binning and estimator choices.

Requirements:
Students must have a background in cosmology at the Honours level, including familiarity with cosmological large-scale structure and basic statistics. Proficiency in Python is essential, while experience with scientific libraries and basic handling of radio or optical survey data will be very helpful. Comfort working with real, imperfect survey data is important, since the project is data-driven.