

NASSP Masters Project 2026

1. Level of the project:

Masters

2. Name of primary supervisor:

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4. Name of co-supervisor:

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7. Project title:

Probing the evolution of the stellar-to-neutral hydrogen ratio using halo-based power spectra with HIRAX and LSST

8. Description of project:

In the standard cosmological paradigm, structure formation is related to the evolution of dark matter density fluctuations, which eventually collapse into halos. These halos host galaxies and baryonic gas, whose distribution between stars and neutral hydrogen gas is regulated by various processes, such as gas cooling, star formation, and feedback. The distribution of the total baryonic density into stars and neutral hydrogen gas is quantified by the stellar fraction, $f_{\text{star}}(z) = \rho_{\text{star}}(z)/\rho_{\text{b}}(z)$, and the neutral hydrogen fraction, $f_{\text{HI}}(z) = \rho_{\text{HI}}(z)/\rho_{\text{b}}(z)$, where $\rho_{\text{star}}(z)$ and $\rho_{\text{HI}}(z)$ are the total density of stars and neutral hydrogen, respectively. $\rho_{\text{b}}(z)$ is the total density of baryonic matter. The ratio of $f_{\text{star}}(z)$ and $f_{\text{HI}}(z)$ is quantified as $R(z) = f_{\text{star}}(z)/f_{\text{HI}}(z)$. Since both the distribution of galaxies and HI gas are biased tracers of the matter distribution, they are used as proxies to infer the distribution of the total density of matter in dark matter halos. The power spectra of these tracers provide a potential tool to investigate these quantities using appropriate halo occupation distribution models. We will use the specifications of the HIRAX and LSST surveys, respectively, for HI and galaxy samples.

Objective:

This project aims to constrain the redshift evolution of the stellar-to-neutral-hydrogen fraction in galaxies based on the measurements of the galaxy and HI auto and cross power spectra. The

ratio between the stellar fraction and the neutral hydrogen fraction traces how efficiently baryonic matter is converted from cold gas into stars within dark matter halos. By connecting galaxy evolution parameters to clustering observables, we intend to determine how accurately future surveys can measure the stellar fraction, the neutral hydrogen fraction, and their ratio as functions of redshift.

Methodology:

We will relate galaxy evolution parameters to observable clustering statistics through a combination of theoretical modeling and statistical forecasting. The connection between baryonic matter and dark matter halos is described using the halo model, where halos are characterized by a mass function $n(M,z)$ and a halo bias $b_h(M,z)$. The stellar and neutral hydrogen masses within halos are modeled through simple scaling relations with halo mass, $M_{\text{star}}(M, z) = f_{\text{star}}(M, z) \times M$ and $M_{\text{HI}}(M, z) = f_{\text{HI}}(M, z) \times M$, where f_{star} and f_{HI} represent the stellar and HI fractions. These relations determine the effective clustering biases of galaxies and neutral hydrogen through halo-mass-weighted averages of the halo bias. The resulting biases in turn enter the observable power spectra of galaxies and HI. To quantify the sensitivity of clustering measurements to the baryonic parameters, we implement a Fisher matrix F_{ij} based on the galaxies and HI spectra. Inverting this matrix yields the parameter covariance and the forecasted uncertainties on $f_{\text{star}}/f_{\text{HI}}$, thereby providing quantitative predictions for how well future large-scale structure surveys can constrain the baryonic content of galaxies across cosmic time.

Expected Outcomes:

The student will become familiar with clustering and its summary statistics, such as 2-point correlation functions, and will be able to compute them theoretically and numerically. The student will understand the properties of halo occupation distribution models. The student will demonstrate how to constrain parameters using the Fisher forecast method. The student will develop the code for the pipeline analysis, enabling the addition of more parameter constraints in future work.

Requirements:

The student must have good programming skills in Python, and a basic knowledge of cosmology.
