Snowmass2021 - Letter of Interest

Cosmology with the MaunaKea Spectroscopic Explorer

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
☐ (Other) *[Please specify frontier/topical group]*

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Collaboration : MaunaKea Spectroscopic Explorer (MSE)

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Abstract: (maximum 200 words)

The MaunaKea Spectroscopic Explorer (MSE) High-z Cosmology Survey will probe a large volume of the Universe with a galaxy density sufficient to explore inflation by measuring the local non-Gaussianity parameter $f_{\rm NL}$ to a precision $\sigma(f_{\rm NL}) = 1.8$. Combining the MSE High-z Cosmology Survey data with data from a next generation CMB stage 4 experiment and existing DESI data will provide the first 5σ confirmation of the neutrino mass hierarchy from astronomical observations. In addition, Baryonic Acoustic Oscillations observed within the sample will measure the distance-redshift relationship in six bins $1.6 < z < 4.0$, each with an accuracy of $\sim 0.6\%$. The simultaneous measurements of Redshift Space Distortions constrain the amplitude of density fluctuations, at a level ranging from 1.9% to 3.6%. The proposed survey covers 10,000 deg^2, measuring redshifts for Emission Line Galaxies $1.6 < z < 2.4$, Lyman Break Galaxies $2.4 < z < 4.0$, and quasars $2.1 < z < 3.5$, and will take 100 nights per year for a 5-year MSE program.

This document summarizes the science case related to cosmology studies with the MaunaKea Spectroscopic Explorer (MSE) found in MSE Cosmology Working Group et al. (2019). MSE is a highly-multiplexed (4332 fibers), wide FOV (1.5 sq deg), large aperture (11.25 m in diameter), optical/NIR (360nm to 1300nm) facility for obtaining spectroscopy with a resolution $R \sim 2500 - 4000$. MSE is designed as a multi-purpose facility allowing a range of science: details of the non-cosmology focused studies can be found in MSE Science Team et al. (2019).

The MSE High-z Cosmology Survey is designed to probe a large volume of the Universe with a galaxy density sufficient to measure the extremely-large-scale density fluctuations required to explore primordial non-Gaussianity and therefore inflation. We expect a measurement of the level of non-Gaussianity as parameterized by the local parameter $f_{\rm NL}$ to a precision $\sigma(f_{\rm NL}) = 1.8$ using the large-scale power spectrum, and a factor ~ 1.5 improvement on this bringing in information from the bispectrum (Karagiannis et al., 2018). Combining the MSE High-z Cosmology Survey data with data from a next generation CMB stage 4 experiment and existing DESI data will provide the first 5σ confirmation[1] of the neutrino mass hierarchy from astronomical observations. Only combining the data from the MSE High-z Cosmology Survey together with Planck provides a 4σ neutrino mass measurement.

Baryon Acoustic Oscillations (BAO) observed within the sample will provide measurements of the distance-redshift relationship in six different redshift bins between $z = 1.6$ and 4.0, each with an accuracy of $\sim 0.6\%$. These high-redshift measurements will provide a probe of the Dark Matter dominated era and test models of Modified Gravity and exotic models where Dark Energy properties vary at high redshift. The simultaneous measurements of Redshift Space Distortions (RSD) at redshifts where Dark Energy has not yet become important directly constrain the amplitude of the fluctuations parameterized by σ_8, at a level ranging from 1.9% to 3.6% for the same redshift bins. The MSE High-z Cosmology Survey will be a powerful resource for other cosmological measurements and tests with significant legacy value. Examples of possible studies include those made using the bispectrum or from identifying clusters of galaxies or voids. Cross-correlation with CMB data will be particularly exciting: the MSE High-z Cosmology Survey will include coverage over $2 < z < 3$, which corresponds to the peak of the CMB lensing effectiveness (Planck Collaboration et al., 2018).

In addition to the High-z survey, MSE could also be used to perform a deep survey for LSST photometric redshift training pointed observations of galaxy clusters to $z = 1$, and an IFU-based peculiar velocity survey. More details of these cases can be found in MSE Cosmology Working Group et al. (2019).

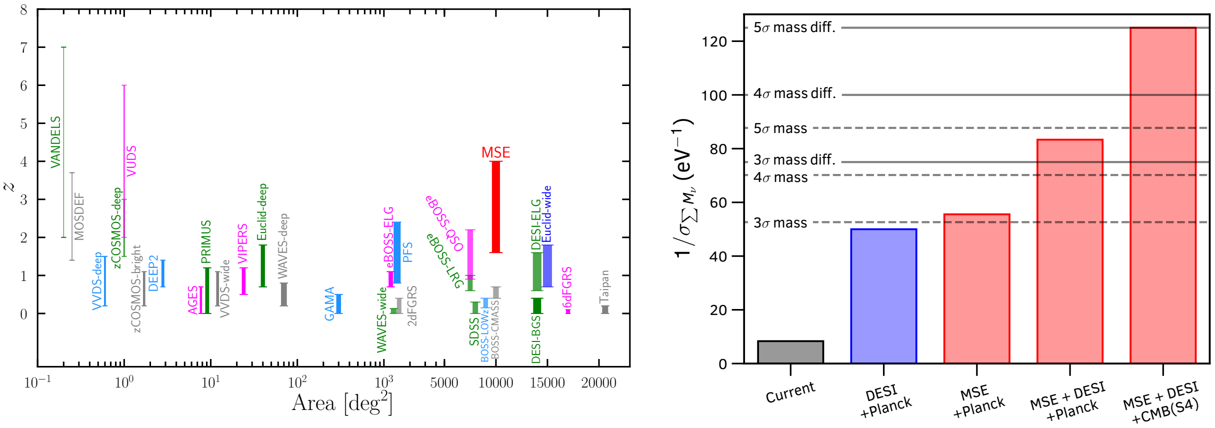

Figure 1: (*left*) Recent galaxy redshift surveys as a function of their area and redshift range, compared with the proposed MSE survey. The thickness of each bar is proportional to the total number of galaxies. Notice the transition from logarithmic to linear scale on x-axis at 5000 deg^2. (*right*) A summary of the neutrino mass constraints achievable with the MSE compared to other surveys. The dashed and solid horizontal lines show the requirements for 3, 4 and 5σ constraints on the sum of neutrino masses (either hierarchy) and on the mass difference between hierarchies respectively.

The proposed survey covers 10,000 deg^2, measuring redshifts for Emission Line Galaxies (ELGs) with 1.6 <

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[1] assuming neutrino masses are distributed in the normal hierarchy and $\sum m_\nu = 0.057$ eV

$z < 2.4$, Lyman Break Galaxies (LBGs) with $2.4 < z < 4.0$, and quasars $2.1 < z < 3.5$. The ELGs and LBGs will be used as direct tracers of the underlying density field, while the Lyman-α (Lyα) forests in the quasar spectra will be used to probe structure along their lines of sight. Exposures of duration 1,800 sec will guarantee a redshift determination efficiency of 90% for ELGs and at least 50% for LBGs. Each exposure covers 1.52 deg^2 and we expect to pack the observations onto the sky to cover the maximum area possible without gaps, such that each exposure provides approximately 1.25 deg^2 of extra coverage. Thus the survey will be comprised of 8,000 pointings, and will take 4,000 hours on target in total. As we will only use Dark-Time observations, the survey will need to be spread over a number of years, for example taking ~100 nights per year over 5 years, interspersed with other programs. The left panel of Fig. 1 shows how the proposed MSE survey compares to other current and planned galaxy redshift surveys.

We observe the ELGs with a density adequate for BAO measurements, $nP(k = 0.1\text{h.Mpc}^{-1}) = 1$, or 600 deg^{-2} targets. Requiring a redshift efficiency of order 90% for ELGs with $r < 24$, leads to an exposure time of 1800s. In addition this exposure time allows us to observe the Lyα forest in QSOs with $r < 24$ or even $r < 24.5$, with a SNR per resolution element of the order of 2-3 in the forest, which is optimal for studies of the cross-correlation between the HI absorption and the positions of the other tracers. Assuming the quasar luminosity function of Palanque-Delabrouille et al. (2013) we can expect there to be 150 to 170 deg^{-2} quasars with $z > 2.1$. The rest of the fibres will be filled with LBGs at the level of approximately 1400 deg^{-2} targets. As the exposure time of 1800s is driven by getting a high redshift efficiency for the ELGs, we expect for the LBGs a lower redshift efficiency at the order of 50%. As a result the LBG density is not optimized for BAO measurements but it is still sufficient for the measurement of the primordial non-Gaussianity. Note that the combination of all three samples together with the sky fibres, fits within the budget for our survey set at 2600 fibres/deg^2, with a small amount of margin remaining. Detailed predictions for the targeting and redshift measurement efficiencies are provided in MSE Cosmology Working Group et al. (2019).

Given the uncertainties in targeting, we adopt rounded numbers for our baseline predictions, assuming a 10,000 deg^2 survey consisting of two samples:

- ELG sample: $1.6 < z < 2.4$, 5.4M galaxies (with a 540 deg^{-2} density corresponding to 600 deg^{-2} targets)
- LBG sample: $2.4 < z < 4$, 7.0M galaxies (with a 700 deg^{-2} density corresponding to 1400 deg^{-2} targets)

For both ELGs and LBGs, we assume a large-scale structure bias $b(z) = G(0)/G(z)$, where G is the linear growth rate of overdensities in the matter; empirically, the overall clustering of luminous galaxies on linear scales changes little with redshift, even as the underlying dark matter overdensities change greatly in amplitude. We anticipate being able to measure the galaxy power spectrum across a range of scales between $k_{\rm min} = 2\pi/V^{1/3}$ and $k_{\rm max} = 0.2h/\text{Mpc}$ where V is the comoving volume of the Universe covered by our proposed survey; We choose our value of $k_{\rm max}$ based on what is achievable with our current state-of-the-art theoretical modelling although, in the era of MSE it is likely we will be able to model even further into the non-linear regime. Combining with *Planck* constraints on the standard ΛCDM parameters, we obtain an error on the sum of neutrino masses of 0.018 eV. This is better than any other current or planned survey and would enable a 3σ constraint on the sum of neutrino masses in either hierarchy. Additionally combining with the highly complementary DESI survey and a ‘Stage 4’ CMB experiment will lead to the first 5σ confirmation of the neutrino mass hierarchy, a fundamental measurement for particle physics (see the right panel of Fig. 1).

The unique $1/k^2$ dependence of the galaxy bias introduced by primordial non-Gaussianity also means that the lower values of k that can be reliably measured (i.e., the larger the cosmological ‘baseline’ available to us), the stronger constraints we can obtain. The fact that a cosmology survey with MSE will allow us to probe higher redshifts and larger cosmological volumes than other surveys is a strength that will result in superior constraints. Under the same assumptions defined above for our neutrino mass constraints, we find that MSE ELGs can constrain primordial non-Gaussianity of the local form to a precision $\sigma(f_{\rm NL}) = 4.1$. MSE LBGs at higher redshifts can reach a tighter constraining precision of $\sigma(f_{\rm NL}) = 2.0$. The individual QSOs that give rise to our proposed Lyα forest sample can also be used as tracers of the density field and reach a precision of $\sigma(f_{\rm NL}) = 5.7$, which itself is already at the level of current CMB constraints. Overall, the combination of MSE ELGs and LBGs will provide a constraint on primordial non-Gaussianity (the local ansatz) to a precision $\sigma(f_{\rm NL}) = 1.8$. This will be further improved by including the QSOs measured in the same volume. In addition, measurements of $f_{\rm NL}$ have been shown to be greatly improved by the use of multiple overlapping tracers of the same density field with different galaxy bias (Seljak, 2009), and by including constraints from the bispectrum (Karagiannis et al., 2018).

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