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THE SCIENCE ENABLED BY THE MAUNAKEA SPECTROSCOPIC EXPLORER

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Abstract. With its unique wide-field, multi-object, and dedicated spectroscopic capabilities, the Maunakea Spectroscopic Explorer (MSE) is a powerful facility to shed light on the faint Universe. Built around an upgrade of the Canada-France Hawaii Telescope (CFHT) to a 11.25-meter telescope with a dedicated ~ 1.5 deg^2, 4,000-fiber wide-field spectrograph that covers the optical and near-infrared wavelengths at resolutions between 2,500 and 40,000, the MSE is the essential follow-up complement to the current and next generations of multi-wavelength imaging surveys, such as the LSST, Gaia, Euclid, eROSITA, SKA, and WFIRST, and is an ideal feeder facility for the extremely large telescopes that are currently being built (E-ELT, GMT, and TMT). The science enabled by the MSE is vast and would have an impact on almost all aspects of astronomy research.

Keywords: astronomical observatories, Maunakea, multi-object spectroscopy, survey, large telescope, CFHT

1 Introduction

Following in the foot steps of dedicated spectroscopic facilities like the multiple iterations of the transformative Sloan Digital Sky Surveys (e.g., Blanton et al. 2017), the MSE is the realization of the long-held ambition of the international astronomy community for highly multiplexed, large aperture, optical and near-infrared spectroscopy on a dedicated facility. In this era of all-sky panoptic surveys (Pan-STARRS1, Gaia, soon Euclid, eROSITA or SKA), such a facility is the most glaringly obvious and important missing capability in the international portfolio of astronomical facilities. MSE is built around an upgrade of the CFHT to an 11.25-meter telescope and a dedicated set of heavily multiplexed spectrographs that are envisioned to be running for at least a decade on large spectroscopic surveys. The breadth of the science enabled by such a facility is vast and would impact all fields of astronomy, from the detailed characterization of exoplanet hosts to the next generation of cosmological surveys, via the ultimate Galactic archaeology survey and the definitive Gaia follow-up.

This quick overview of the science envisioned with MSE is developed in much greater details in "A concise overview of the Maunakea Spectroscopic Explorer" (McConnachie et al. 2016b) and in "The detailed science case for the Maunakea Spectroscopic Explorer" (McConnachie et al. 2016a), which have both been developed through contributions of the large MSE Science Team under the guidance of the MSE Project Scientist, Alan McConnachie.

2 MSE capabilities

The system architecture of MSE and its major sub-systems are presented in Figure 1 and its envisioned capabilities are summarized in Figure 2. Compared to operating or planned facilities, MSE is unique in its:

1. *Survey speed and sensitivity:* its étendue is more than twice that of its closest 8-meter competitor (149 vs. 66 m^{2}deg^2 for Subaru/PFS) while the excellent Maunakea site ensures efficient observations of the faintest objects.

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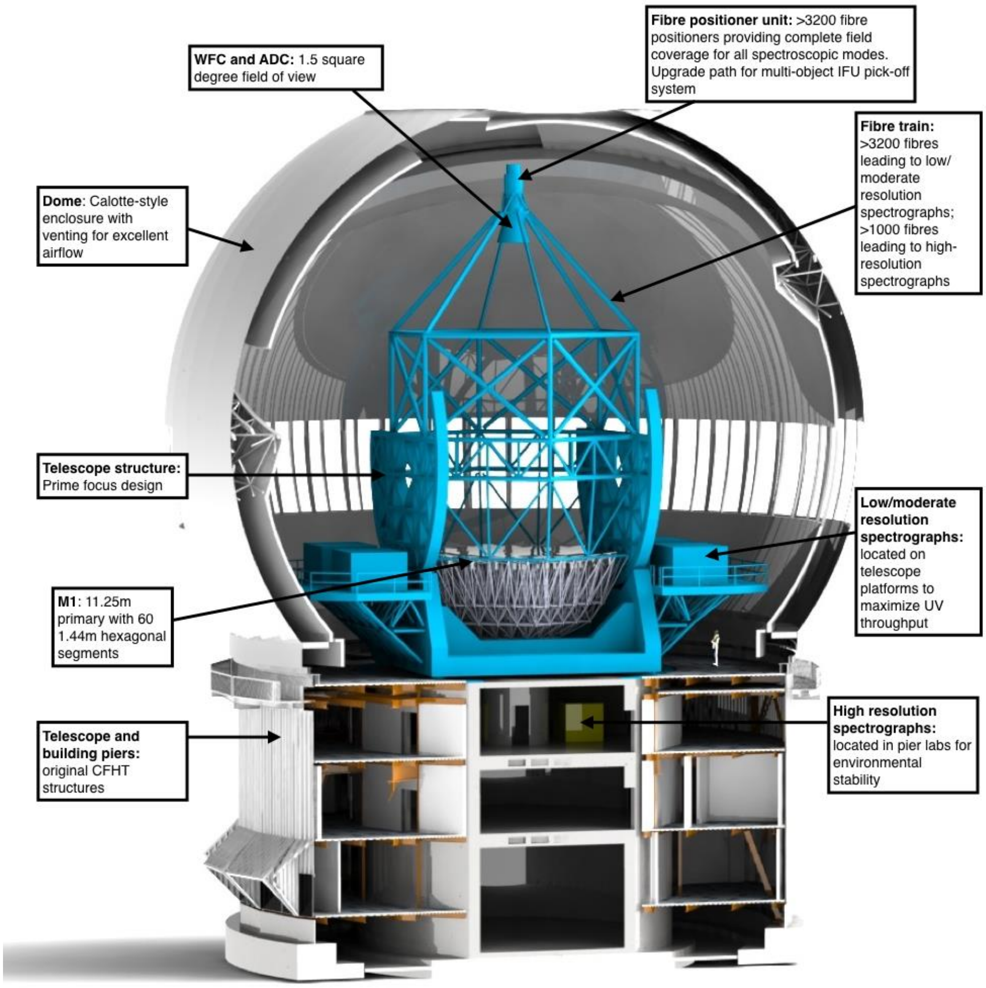

Fig. 1. Cut-away of the MSE revealing the system architecture and major sub-systems. Credit: McConnachie et al. (2016b).

2. *Dedicated operations:* the MSE's specialized capabilities enable a vast range of new science. In particular, they enable very long surveys of millions of target stars or galaxies and allow for time-domain programs with multiple cadences that are difficult to schedule at other facilities.

3. *Spectral performance:* the extensive wavelength coverage of the MSE from the UV (0.36 μm) to the H-band (1.8 μm) uniquely enables the same tracers to be used to study galaxy and black-hole growth at all redshifts to beyond cosmic noon. More locally, the very high resolution mode of MSE (R=40,000) opens the realm of chemical tagging and detailed Galactic archaeology across the full luminosity range of Gaia targets.

3 MSE science

As mentioned above, the science enabled by the MSE is described in great detail in McConnachie et al. (2016a). These proceedings only aim at a succinct summary of the vast amount of new science such a facility would open for investigation.

	Low		Moderate	High			IFU
Accessible sky	30000 square degrees (airmass<1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.5						
Etendue = FoV x π (M1 / 2)²	149						
Modes	Low		Moderate	High			IFU
Wavelength range	0.36 - 1.8 μm		0.36 - 0.95 μm	0.36 - 0.95 μm ♯			IFU capable; anticipated second generation capability
	0.36 - 0.95 μm	J, H bands		0.36 - 0.45 μm	0.45 - 0.60 μm	0.60 - 0.95 μm	
Spectral resolutions	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	>3200		>3200	>1000			
Spectral windows	Full		≈Half	$\lambda_c/30$	$\lambda_c/30$	$\lambda_c/15$	
Sensitivity	m=24 *		m=23.5 *	m=20.0 ♮			
Velocity precision	20 km/s ♪		9 km/s ♪	< 100 m/s ★			
Spectrophotometric accuracy	< 3 % relative		< 3 % relative	N/A			

♯ Dichoric positions are approximate
* SNR/resolution element = 2
♮ SNR/resolution element = 10
♪ SNR/resolution element = 5
★ SNR/resolution element = 30

Fig. 2. Summary of major science capabilities of the MSE. Credit: McConnachie et al. (2016b).

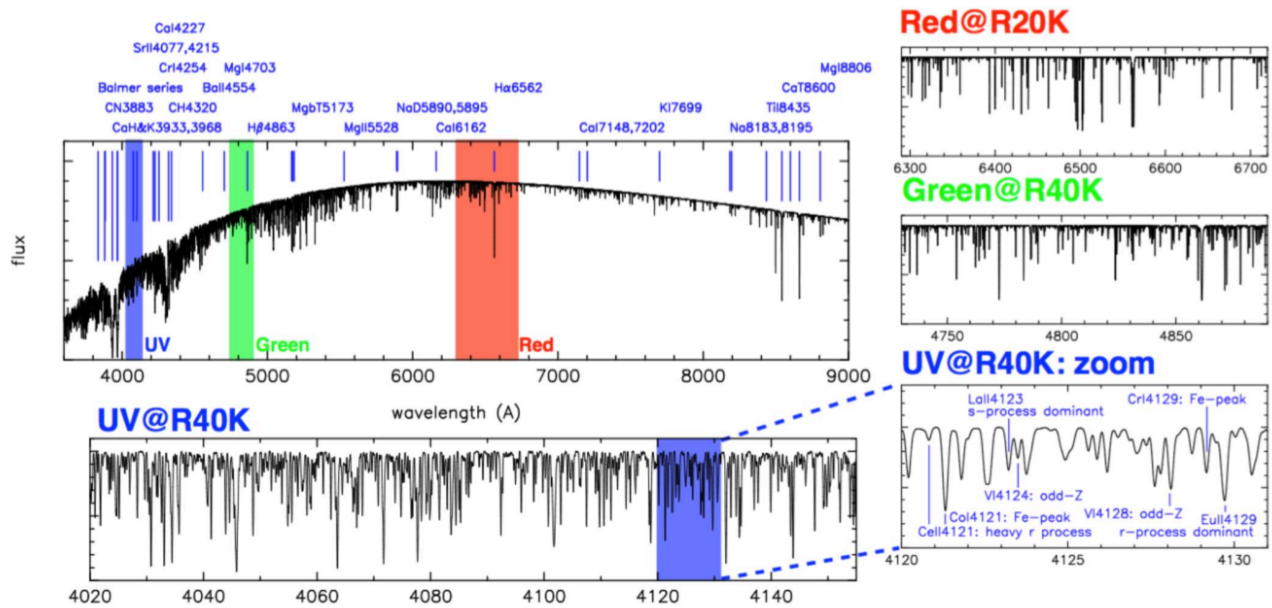

Fig. 3. The main panel shows the relative flux of a synthetic spectrum of a metal-poor red-giant star at the intermediate MSE spectral resolution of $R \sim 6,000$), along with some of the strong-line stellar diagnostics accessible at this resolution. Highlighted regions show the normalized flux in three windows observable with the high resolution mode of MSE. A magnified region of the UV window shows examples of the species that will be identified at high resolution. MSE chemical tagging surveys will identify species sampling a large and diverse set of nucleosynthetic pathways and processes. Credit: McConnachie et al. (2016b).

3.1 Exoplanets and stellar astrophysics

MSE will provide spectroscopic characterization at high resolution and high SNR of the faint end of the PLATO target distribution ($g \sim 16$), to allow for statistical analysis of the properties of planet-hosting stars as a function of stellar and chemical parameters. With high velocity accuracy and stability, MSE time domain spectroscopic programs will allow for highly complete, statistical studies of the prevalence of stellar multiplicity into the regime of hot Jupiters for this and other samples and also directly measure binary fractions away from the Solar neighborhood. MSE will also investigate links between the interstellar medium and the stellar formation history and follow up rare objects and LSST transients.

3.2 Chemical tagging in the outer Galaxy: the definitive Gaia follow-up

MSE will have an unmatched capability for chemical tagging experiments. Recent work in this field has started to reveal the dimensionality of chemical space and has shown the potential for chemistry to be used in addition to, or instead of, phase space, to reveal the stellar associations that represent the remnants of the building blocks of the Galaxy. MSE will push these techniques forward and will focus on understanding the outer components of the Galaxy — the halo, thick disk and outer disk — where dynamical times are long and whose chemistry is inaccessible from 4-m class facilities. These components will be decomposed into their constituent star formation events by measuring abundances of chemical species that trace a large number of nucleosynthetic pathways. This includes rare species and heavy elements at blue wavelengths (Figure 3). *MSE is the only facility capable of high resolution studies of stars across the full luminosity range of Gaia targets.*

3.3 The Dark Matter Observatory

MSE is the ultimate facility for probing the dynamics of dark matter over all spatial scales. For Milky Way dwarf galaxies, MSE will obtain complete samples of tens of thousands of member stars to very large radius and with multiple epochs to remove binary stars. Such analyses will allow the internal dark matter profile of the systems to be derived with high accuracy. In the Galactic halo, high precision radial velocity mapping of stellar streams will reveal the extent of their heating through interactions with dark sub-halos and place strong limits on the mass function of dark sub-halos around an L* galaxy. On cluster scales, MSE will use galaxies, planetary nebulae and globular clusters as dynamical tracers to provide a fully consistent portrait of dark-matter halos across the mass function.

3.4 The connection between galaxies and the large scale structure of the Universe

Within the ΛCDM paradigm, it is fundamental to understand how galaxies evolve and grow relative to the dark matter structure in which they are embedded. This requires mapping the distribution of stellar populations and supermassive black holes to the dark matter halos and filamentary structures that dominate the mass density of the Universe, and to do so over all mass and spatial scales. MSE will provide a breakthrough in extragalactic astronomy by linking the formation and evolution of galaxies to the surrounding large-scale structure, across the full range of relevant spatial scales (from kpc to Mpc). A local galaxy survey with MSE out to 100 Mpc could sample our neighborhood down to the lowest detectable masses of $3 \times 10^5\,\mathrm{M}_\odot$ allowing for a complete census of mass in the local Universe. A deep near infrared selected spectroscopic survey will be able to measure velocity dispersion masses for systems analogous to the Milky Way, M31, or M33 to $z = 1$, providing a direct measurement of dark matter assembly for $> 10^{12}\,\mathrm{M}_\odot$ halos over half the age of the Universe. MSE will follow galaxy evolution across the peak in star-formation and merger activity, and trace the transition from merger-dominated spheroid formation to the growth of disks.

4 Conclusions

With the breadth of the science it enables combined to its capability as a follow-up machine for the upcoming large surveys of the sky, MSE will enable transformational science in areas as diverse as exoplanetary host characterization; stellar monitoring campaigns; tomographic mapping of the interstellar and intergalactic media; the in-situ chemical tagging of the distant Galaxy; connecting galaxies to the large scale structure of the Universe; measuring the mass functions of cold dark matter sub-halos in galaxy and cluster-scale hosts; reverberation mapping of supermassive black holes in quasars. MSE is the largest ground based optical and near infrared telescope in its class, and it will occupy a unique and critical role in the emerging network of astronomical facilities active in the 2020s and beyond.

This contribution builds heavily on the work of the MSE Science Team and the MSE Project Office.

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