*SF2A 2018*
*P. Di Matteo, F. Billebaud, F. Herpin, N. Lagarde, J.-B. Marquette, A. Robin, O. Venot (eds)*

# MAUNAKEA SPECTROSCOPIC EXPLORER: LARGE SPECTROSCOPIC SURVEYS OF FAINT GALAXIES

L. Tresse[*1]

**Abstract.** The Maunakea Spectroscopic Explorer (MSE) is a proposed major modernisation of the 3.6-m Canada-France-Hawaii Telescope into a 11.25-m aperture, 1.52 square degree field of view telescope. MSE will be a fully dedicated facility to carry out multi-object spectroscopy surveys. MSE will provide a spectral resolution performance of $R \sim 2\,500 - 40\,000$ across the wavelength range of $0.36 - 1.8$ $mu$m. On behalf of the MSE team, I outline the current status of the project and the science cases for large spectroscopic surveys of faint galaxies.

Keywords: Astrophysics - Instrumentation and Methods for Astrophysics; Astrophysics - Astrophysics of Galaxies

## 1 Introduction

The Maunakea Spectroscopic Explorer (MSE) is aimed at acquiring thousands and millions of spectra thanks its high multiplex capabilities, that is 4332 spectra per exposure with all spectral resolution available at any time, and an on-target observing efficiency greater than 80 percent. Being a dedicated facility, MSE will collect datasets equivalent to an entire SDSS Legacy Survey[*] every eight weeks. The project aims at uncovering the composition and dynamics of the faint Universe. While the scope of such dedicated facilities may change over the years, the strategic importance of MSE is a key link in the future era of larger, but with small sq. arcmin size field of view, telescopes (24.5-m Giant Magellan Telescope GMT, 30-m -Thirty Meter Telescope TMT, 39.3-m Extremely Large Telescope ELT) and multi-wavelength photometric and imaging surveys. The Canada France Hawaii Telescope (CFHT)[†] observatory has many advantages: an excellent natural site seeing (0.4 arcsec median seeing at $0.5\mu$m), a long history of successful operations, an equatorial location with three quarters entire sky observable. The CFHT will undergo a major renovation with a new calotte enclosure, but in reusing the current building, including piers, and the same ground footprint (see Fig. 1). The resulting MSE will house a telescope altazimuth mount with a 11.25-m segmented primary mirror and a wide field corrector including an Atmospheric Dispersion Corrector to create a 1.5 sq. deg. field of view at prime focus. In mid-2018, the present organisation consists of a Management Group with representatives of Canada, France, Hawaii, Australia, China and India, which contributed engineering and technical design effort during the conceptual design phase, a Project Office (Project Manager: Kei Szeto, Project Advisor: Rick Murowinski, Project Scientist: Alan McConnachie, Project Engineer: Alexis Hill and Systems Scientist: Nicolas Flagey) and a Science Advisory Group (SAG) (representatives of France: N. Martin, Observatoire de Strasbourg and from 2018 L. Tresse, CRAL).

## 2 MSE current status

Year 2017 has undergone ten different subsystem Conceptual Design Reviews (coDR) for eight different subsystems, early 2018 the System-level coDR, they have been wrap up in the Conceptual Design Phase conducted

[*]on behalf of the Maunakea Spectroscopic Explorer team, see the MSE web site at `http://mse.cfht.hawaii.edu/`

[1] Univ Lyon, Univ Lyon1, Ens de Lyon, CNRS, Centre de Recherche Astrophysique de Lyon UMR5574, F-69230 St-Genis-Laval
[*]`https://www.sdss.org/surveys/`
[†]`http://www.cfht.hawaii.edu/`


**Fig. 1. Left:** View of the present CFHT. **Middle:** View of the studied MSE with a 10 percent larger than the CFHT modern calotte enclosure. **Right:** MSE Conceptual System Design Configuration Overview.

by the MSE partners. French teams have worked on the Low/Moderate Resolution Spectrograph (CRAL) with a coDR led in Lyon on 15th June 2017, the Prime Focus Hexapod System and the entire top-end assembly of the telescope, and the overall Systems Engineering (GEPI) during the Conceptual Design. The project should move into the Preliminary Design Phase (PDP) to last for 2-yrs with the signature of a non-binding Statement of Understanding to the end of the PDP. The Management Group will then be transformed into a Collaborative Board. The PDP is estimated to cost USD20-25M, with more than half identified in the current partnership, active research is currently ongoing to establish the full funding of the PDP. The Final Design Phase would occur in 2021-2023, prior construction 2023-2026. The full science operation would start from 2016 onwards. The post PDP is linked to the Master Lease for long term continuation of astronomy on Maunakea beyond 2021, and of course MSE partnership must agree to fund and initiate the construction/operations phase. Current costing of MSE based in coDR studies is USD370M about (2018 economics).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 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 ★ | | | |
| Spectrophotometic accuracy | < 3 % relative | | < 3 % relative | N/A | | | |

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

**Fig. 2.** MSE capabilities as defined by the Science Reference Observations.

| | 8 - 12 m class facilities | | | | | | |
|---|---|---|---|---|---|---|---|
| | VLT / MOONS | | Subaru / PFS | | MSE | | |
| *Dedicated facility* | No | | No | | Yes | | |
| *Aperture (M1 in m)* | 8.2 | | 8.2 | | 11.25 | | |
| *Field of View (sq. deg)* | 0.14 | | 1.25 | | 1.52 | | |
| *Etendue* | 7.4 | | 66 | | 151 | | |
| *Multiplexing* | 1000 | | 2394 | | 4329 | | |
| *Etendue x Multiplexing* | 7400 *( = 0.01 )* | | 158004 *( = 0.24 )* | | 653679 *( = 1.00 )* | | |
| *Observing fraction* | < 1 ? | | 0.2 (first 5 years) 0.2 - 0.5 afterwards ? | | 1 | | |
| *Spectral resolution (approx)* | 4000 | 18000 | 3000 | 5000 | 3000 | 6500 | 40000 |
| *Wavelength coverage (um)* | 0.65 - 1.80 | windows | 0.38 - 1.26 | 0.71 - 0.89 | 0.36 - 1.8 | 0.36 - 0.95 50% | windows |
| *IFU* | No | | No | | Second generation | | |

**Fig. 3.** MSE in comparison to other planned multi-object spectrographs on 8-m class telescopes.

## 3 Science cases and MSE capabilities

Through 2015-2016, a Science Reference Observations have gathered science programs that are high profile, transformative in their field, and which are uniquely possible with MSE. They are presented in *The Detailed Science Case for the Maunakea Spectroscopic Explorer: the Composition and Dynamics of the Faint Universe* by McConnachie et al. (2016a) along with *A concise overview of the Maunakea Spectroscopic Explorer* by McConnachie et al. (2016b). It has led to a matrix of science requirements in terms of spectral resolution, focal plane input, sensitivity, calibration and operations both for resolved stellar sources and extragalactic sources, and to the MSE capabilities shown in Fig. 2. Figure 3 compares MSE to other multi-object spectrographs that have similar sensitivities to MSE within the 8-10 m class telescopes. For instance, the tendue $(FOV \times \pi \times (M1/2)^2)$ of MSE is 20 and 2 times larger than MOONS/VLT and PFS/Subaru, respectively, and the wavelength coverage is unmatched by any other wide-field, spectroscopic facility in any aperture class. In 2019, the creation of a Design Reference Survey for MSE will start, with a scientific team increased by a factor three (about 300 members) with new potential partners. Nine Science Working Groups are updating Science Cases to publish them early 2019 (Solar system science, Exoplanets & stellar astrophysics, Chemical nucleosynthesis, Milky Way & resolved stellar population, Galaxy formation and evolution, Active Galactic Nuclei & supermassive black holes, Astrophysical tests of dark matter, Cosmology, Time domain astronomy and the transient Universe).

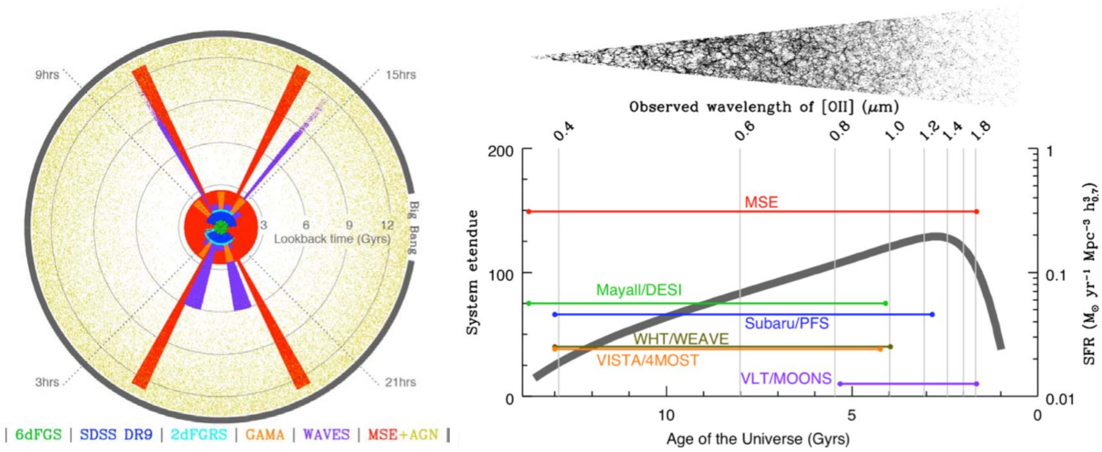


**Fig. 4. Left:** Illustrative survey of MSE with cones truncated at redshift at which $L^*$ galaxies are no longer visible **Right:** Cosmic star formation rate versus lookback time. Horizontal lines indicate the observed wavelength of [OII]3727Å. Figures extracted from McConnachie et al. (2016a)

## 4 MSE and large spectroscopic surveys of faint galaxies

One of the Science Reference Observations, detailed in McConnachie et al. (2016a), aims at linking galaxies to the large scale structure of the Universe, in studying galaxies and their environments in the nearby Universe, the baryonic content and dark matter distribution of the nearest massive clusters, the multi-scale clustering and halo occupation function, and the chemical evolution of galaxies and active galactic nuclei. The non-linear growth of stellar mass is decoupled from the dark matter growth, see e.g. Behroozi, Wechsler & Conroy (2013). Thus we need to address relationship between halo mass and its baryonic content: what is the abundance and structure of dark matter halos, especially at low-mass scales? what is the interplay of star formation, quenching, roles of environment and feedback? Such studies require deep spectroscopic surveys. A low/moderate spectrograph sensitive to 1.8 $\mu$m will enable to reach beyond cosmic noon ($z \sim 2$) with the observed [OII]3727Å emission line. At $z \sim 1.5$ MSE will observe all key optical features, at $z \sim 2.5$ it simultaneously links Lyman-$\alpha$ and UV-absorption lines with optical emission lines , and up to $z \sim 3$ it retains the ability to observe [OII]3727Å and Ca H&K spectral features. These surveys will probe galaxy evolution over all redshifts through the peak of star formation and galaxy assembly in the Universe, trace the transition from merger-dominated spheroid formation to the growth of disks, span relevant spatial scales (from Kpc to Mpc), i.e. including non-linear regime and enable a local galaxy survey out to 100 Mpc down to lowest masses $3.10^5$ $M_\odot$. To acquire a SDSS-like survey at the peak of the star formation history of the Universe requires a 5-7 yr program, which is only feasible with a dedicated facility. For instance, 8 survey cubes (50 Mpc/h)$^3$ observed at a 100% completeness level, will probe the build-up of large scale structure, stellar mass, halo occupation and star formation out to a redshift of $z \sim 3$, access to the direct dark matter assembly for $10^{12}$ $M_\odot$ halos out to $z = 1$ and trace the most massive halos out to $z \sim 5$.

## 5 Conclusion

As noted in the MSE brochure, MSE will be a powerful, efficient and reliable survey machine providing ultraviolet to near-infrared spectroscopy for the plethora of faint objects detected in next generation imaging surveys. MSE will provide targets for follow-up with small field of view, AO-assisted ELTs, and it will be complementary to other MOS on 4-10m telescopes. MSE is an essential follow-up facility to current and next generations of multi-wavelength imaging surveys, including LSST, Gaia, Euclid, WFIRST, PLATO, and the SKA, and is designed to complement and go beyond the science goals of other planned and current spectroscopic capabilities like VISTA/4MOST, WHT/WEAVE, AAT/HERMES and Subaru/PFS. It is an ideal feeder facility for ELT, TMT and GMT, and provides the missing link between wide field imaging and small field precision astronomy. MSE is optimized for high throughput, high signal-to-noise observations of the faintest sources in the Universe with high quality calibration and stability being ensured through the dedicated operational mode of the observatory. By the end of 2018, the complete detailed project will be published in the Maunakea Spectroscopic Explorer 2018 book (Hill, Flagey, McConnachie & Szeto 2018). MSE is a unique combination of capabilities not currently available anywhere in the world.

LT acknowledges the available contributions from the MSE science and technical teams.

## References

Behroozi, P. S.; Wechsler, & R. H.; Conroy, C. 2013, ApJ, 770, 57

McConnachie, A., et al. 2016a, arXiv:1606.00043

McConnachie, A., et al. 2016b, arXiv:1606.00060

Hill, A., Flagey, N., McConnachie, A. & Szeto, K. 2018, Maunakea Spectroscopic Explorer 2018 book, ISBN 9781732873100, LCCN 2018961660