1 Summary

MSE will be the world's foremost astronomical tool for studying the early history of star formation, chemical enrichment and hierarchical merging in the Milky Way and Local Group galaxies ($d \lesssim 1$ Mpc). Such investigations will naturally focus on acquiring high-resolution optical spectra for large samples of stars. Here, I briefly describe how similar studies — covering much larger volumes — may be possible using integrated-light spectroscopy of dense stellar systems (i.e., globular clusters, ultra-compact dwarfs and galactic nuclei) out to distances of ~ 30 Mpc. Such investigations will, however, be challenging as they require relatively high-S/N spectra for faint sources ($g_{\rm lim} \simeq 20 - 24$). Increased telescope collecting area would greatly benefit such programmes, and I recommend the feasibility of increasing MSE's primary mirror to 11–12m be carefully explored. Finally, I highlight a second possible upgrade to the MSE point design that would cement its place as the definitive tool for Galactic Archaeology (GA) studies in the Local Group and beyond: the addition of a near-IR channel in its high-resolution mode.

2 Galactic Archaeology Using Dense Stellar Systems: Beyond the Local Group

One of the key science drivers for the MSE facility is GA of the Milky Way and its neighbouring galaxies. This field of research has made remarkable progress since 2000, when SDSS began operations. New and ongoing surveys like HERMES/GALAH and APOGEE are expected to make important contributions to this field on short and intermediate timescales.

When MSE begins operations in the next decade, it will quickly become the world's preeminent telescope for GA in the Milky Way and Local Group, thanks to its high multiplexing, wide field of view, large collecting area, and high ($\mathcal{R} = 20\,000$) spectral resolution. Nevertheless, it is worth considering how GA studies currently envisioned for MSE (which will naturally focus on individual stars belonging to the Milky Way or Local Group galaxies) might be extended to a more representative volume of the universe. One particularly exciting possibility is through high-resolution spectroscopy of low-mass, dense stellar systems such as globular clusters, ultra-compact dwarf galaxies (UCDs) and galactic nuclei (i.e., nuclear star clusters). These dense stellar systems are attractive targets because they are often the brightest identifiable objects in their host galaxies. The discovery of multiple stellar populations in some Galactic globular clusters notwithstanding, globular clusters (and perhaps some UCDs) in external galaxies are probably the closest approximations in Nature to *simple stellar populations*, which greatly simplifies the interpretation of their integrated-light spectra. Furthermore, both imaging surveys and theoretical models have advanced to the point where it is possible to efficiently select high-probability targets (e.g., Lee *et al.* 2010; Durrell *et al.* 2014; Muñoz *et al.* 2014) for spectroscopy and compare their observed properties to the predictions of cosmological models (Kravtsov & Gnedin 2005; Moore *et al.* 2006; Gnedin *et al.* 2014; Pfeffer *et al.* 2014). The identification of vast numbers of targets will be even more straightforward in the era of LSST, Euclid and WFIRST.

Pioneering work in this area has focused entirely on abundance measurements for globular clusters associated with the Milky Way or Local Group galaxies (e.g., Colucci *et al.* 2009, 2014; Sakari et al. al. 2014). The very rich globular cluster systems belonging to more distant galaxies — including those in the Virgo cluster at $d \simeq 16.5$ Mpc — are the obvious next targets, as this would allow GA studies for important galaxy types that are not represented in the Local Group — most notably massive red-sequence galaxies. UCDs and galactic nuclei are equally attractive targets since the uncertain relationship between these various type of stellar systems remains hotly debated: i.e., some models suggest that UCDs are the tidally stripped remains of nucleated dwarf galaxies, while a leading theory for the formation of nuclear star clusters in low-mass galaxies involves globular clusters infall due to dynamical friction (see, e.g., Turner *et al.* 2012). The recent exciting discovery of a supermassive black hole in a UCD belonging to the Virgo cluster may lend support to the tidal stripping scenario (Seth *et al.* 2014).

The requirements for detailed abundance measurements depend strongly on the exact science question: i.e., there is no single choice of spectral resolution, wavelength region, or S/N ratio that satisfies the requirements for all elements or processes. However, S/N values of $\simeq$ 30-80 are typical for many important elements when operating at a resolution of $\mathcal{R} \simeq 20\,000$. Since the targets in this case are rather faint ($g_{\rm lim} = 20 - 24$ depending on distance and intrinsic luminosity), the required exposures are expected to be long (hours, or tens of hours).

3 Possible Upgrades to the MSE Point Design Specifications

Here we consider two possible changes to the MSE "point design" that would benefit studies of this sort.

3.1 Increased Primary Mirror Aperture

In 2012, the MSE science team concluded that the facility's primary mirror must have a *minimum* effective diameter of 10m to address the key scientific questions expected in the coming decade. To meet this requirement, a segmented mirror design was adopted based on considerations of weight, cost, and the unavailability of monolithic mirrors of this size. To further enhance cost effectiveness, the MSE point design utilized 60 hexagonal mirror segments, measuring 1.45m (corner to corner) with an associated system of edge sensors, actuators and segment support assemblies. These choice were driven, in part, by the desire to build upon the large investments in design, development and infrastructure for E-ELT and TMT mirror systems.

Needless to say, virtually all science cases considered in the MSE scientific feasibility report would benefit from an increased telescope aperture. Moreover, a larger aperture would make it possible to carry out some ambitious programmes that might otherwise be considered overly challenging or time consuming, as may be the case for the extragalactic GA studies described above. Thus, one possible upgrade to the MSE point design that needs careful consideration is the addition of extra mirror segments. For instance, 12 segments added to the MSE primary mirror point design would increase the collecting area of the telescope by 20%, bringing the effective diameter of MSE to 11.2m. The would provide a collecting area almost double that of the 8.2m Subaru telescope and fully 7.5 times larger than that of ESO's proposed 4MOST facility, definitively separating MSE from all other planned or proposed spectroscopic facilities.

In short, it is recommended that an engineering study investigating the feasibility (including the associated risk and cost) of increasing MSE's primary mirror to a diameter of $\sim$ 11–12m. In particular, such a study should determine the largest primary mirror that is possible given the telescope pier capacity and enclosure support requirements.

3.2 High-Resolution Spectroscopy: Extension to the Near IR

After a careful consideration of diverse science cases in the fields of the ISM, stellar astrophysics (including exoplanets), Galactic structure and Local Group galaxies, the MSE science team recommended that MSE's high-resolution mode have a minimum spectral resolution of $\mathcal{R} \simeq 20\,000$ and cover (at least) two broad and adjustable windows in the optical (370–1000 nm) spectral region.

Inspired by the early success of the APOGEE survey (Anders *et al.* 2014), an extension of MSE's high-resolution spectrograph system into the near-IR region should be given serious consideration. While implementing such a capability would unavoidably entail some increase in complexity and cost, there are scientifically compelling reasons to explore this possibility. Firstly, extinction in the near-IR region is dramatically reduced compared to the visible (i.e., $A_H = A_V/6$) making it possible to probe highly reddened regions (such as in the Galactic disk and bar/bulge, or in the heavily extincted regions of nearby late-type galaxies). Secondly, the near-IR region is highly sensitive to evolved stellar populations, including RGB, AGB and red clump stars. Combining spectral diagnostics measured simultaneously in the blue, red and near-IR regions thus makes it possible to probe the star formation and chemical enrichment histories of complex stellar populations in a level of detail that would not be possible from a single region alone. And, finally, as demonstrated by APOGEE for the H band, the near-IR region is rich is important molecular lines (e.g., OH, CN, CO) and includes numerous atomic lines of α, "iron peak" and "odd-Z" elements.

4 References

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